

Report on Field Measurements Petten Sea Defence

Storm Season 2003–2004



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1 Introduction

1.1 General

Wave and wave run-up measurements have been made at the Petten Sea Defence in the Netherlands since 1994. The *Rijkswaterstaat* Directorate North Holland (Information Service Water) makes these measurements under the authority of the *Rijkswaterstaat* National Institute for Coastal and Marine Management (RIKZ).

A range of equipment is used for various measurements. Buoys, pressure sensors, radar equipment and water level staffs, for example, measure vertical water level deviations while, among other instruments, a wave run-up staff and video cameras measure wave run-up against the dike.

Although these measurements up to the end of season 2000–2001 were filed, they were not documented. An analysis and detailed description of the measurements made during the two most recent storm seasons 2001–2002 and 2002–2003 are given in storm season reports [Hordijk, February 2003 and July 2003]. The present report describes the field measurements made during storm season 2003–2004.

1.2 Background

Primary water defences protect the Netherlands against flooding by the North Sea, the major rivers and the inland seas. The Dutch Water Defence Act [*Wet op de Waterkering*] stipulates that these water defences are tested every five years to determine if they guarantee the required safety level. The defences are tested against the Hydraulic Boundary Conditions [*Hydraulische Randvoorwaarden – HR*], which lay down normative water levels and waves. The RIKZ is responsible for the knowledge, calculation equipment and calculations used for defining the Hydraulic Boundary Conditions applicable to salt waters.

There are insufficient measurements available of waves close inshore to estimate the normative waves immediately off the dikes. An alternative approach to formulating Hydraulic Boundary Conditions is to use wave measurements which have been made at five different deep water stations since approx. 25 years. On the basis of the available measurements the normative deep water wave conditions are estimated. A numerical wave model, such as spectral wave model SWAN, then translates these scaled conditions into normative conditions immediately off the dike, which in fact are the basis for the wave boundary conditions applicable to our defences.

It goes without saying that a reliable wave model is required for formulating reliable wave boundary conditions. Especially measurements in shallow water – immediately off the dike – are necessary for verifying the current wave models. Verification of wave model SWAN takes place off the straight Dutch coast on the basis of, among other data, storm measurements at the Petten site.

1.3 Objectives

The main objectives of the Petten survey are to follow wave propagation from deep water through the surf zone to the dike, and to measure wave run-up against the dike. This information is then used to quantify the reliability of a wave model, eg SWAN, and of wave run-up modelling with respect to the straight Dutch coastline.

The objective of writing this storm season report is to gain an understanding of the measurements made, and to describe the data in a way that makes them transferable.

1.4 Organisation

The measurements made on the Petten field site are part of a joint research programme by the RIKZ and the Road & Hydraulic Engineering Division [DWW]. The primary objective of the RIKZ is “to provide applied recommendations on the basis of knowledge acquired”. This knowledge is for use by all departments of the Netherlands Ministry of Transport, Public Works and Water Management and – subject to the Boundary Conditions – by relevant external partners. From an internal point of view, the RIKZ programme is part of the SBW Field Measurements [SBW-Veldmetingen] project, which in turn falls under the project “Strength and Stress on Water Defences” [Sterkte en Belasting op Waterkeringen, SBW] and aims to provide valid measurements for the testing and improvement of models applied to determine the Hydraulic Boundary Conditions.

The Rijkswaterstaat Measurement Information Service Water of Directorate North Holland makes the measurements at and carries out maintenance of the field site.

1.5 Other projects

The Petten part of the SBW Field Measurements project has links with the following projects: *HR-B&O*, *HR-2006*, *Dijkbekleding*, *Nautilus* and *CLASH*. The *HR-B&O* project comprises management and maintenance of models and model results used for calculating Hydraulic Boundary Conditions. Boundary Conditions for safety testing applicable to the coastline defences are generated under the *HR-2006* project, and are published in reference book *Hydraulische Randvoorwaarden 2006 voor het toetsen van primaire waterkeringen*, on testing primary defences. The *Dijkbekleding* project advises the Project Office Sea Defences [Projectbureau Zeeweringen] with respect to wave conditions to be

used for developing dike revetment required for strengthening the dikes along the rivers *Westerschelde* and the *Oosterschelde*. The *Nautilus* project aims to advise in the fields of, for example, piloting and storm surge forecasts. CLASH is an EU project, which among other objectives, researches the effect of long waves on wave run-up and wave overtopping.

1.6 Report outline

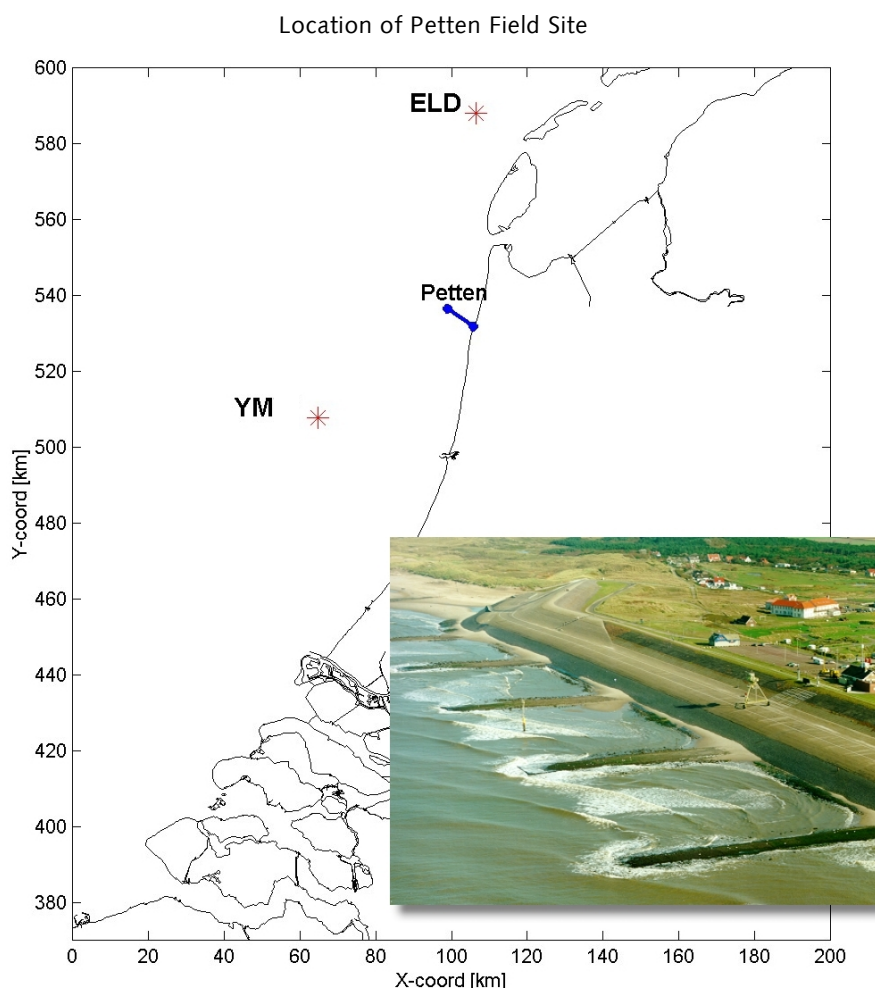
To begin with, chapter 2 describes the Petten field site by giving an outline of the field site set-up, followed by descriptions of the equipment applied, management and maintenance, and data collection. Chapter 3 discusses processing and storage of measuring results. The reliability of validated measuring results and the reliability of measuring results is discussed in chapter 4. Chapter 5 first presents the wind characteristics, wave characteristics and results from morphological measurements, after which interesting storm periods are selected on the basis of measured wind speeds and water levels. These selected storm seasons are described in detail in chapters 6 and 7. To conclude, chapter 8 briefly gives the report's conclusions and recommendations.

2 Description of Petten Field Site

2.1 Location

The field site is located off the coast of the province of North Holland near the town of Petten, where the Petten Sea Defence (figure 2.1) gives local shelter to the coastline. Determination of the height of the sea dike is based on a safety level with a chance of exceedence of 1/10,000 per annum, and measures 12.75 metres above Dutch vertical reference level *NAP*. Over the years the adjacent dune areas have retreated, so that in comparison with the coastline the Petten Sea Defence extends slightly out into sea.

Figure 2.1 Location of Petten field site



2.2 Equipment

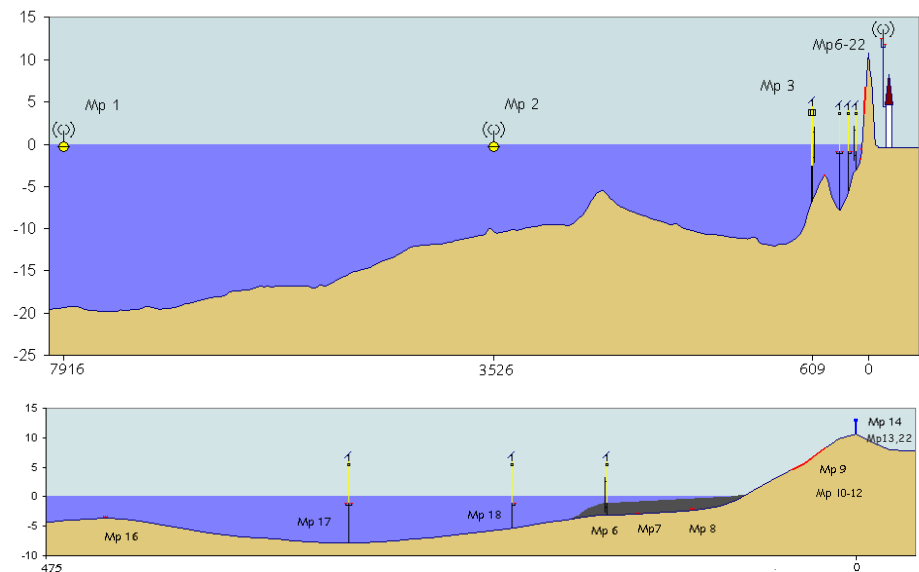
2.2.1 Field site set-up

To gain an understanding of wave propagation from deep waters to the coastline, on-site measurements are taken at various distances from the dike at measuring points within or near section 20,830 of the *Rijkswaterstaat* annual coastal sounding programme. Wave run-up measurements are furthermore taken along the dike slope for use by the Road & Hydraulic Engineering Division.

Figure 2.2 below shows the locations of all measuring points in a cross shore profile corresponding with the measuring section. To avoid confusion, an enlarged graph of the relevant area shows the positions immediately offshore.

Some of the factors in selecting the measuring equipment are the location, the variables to be measured and the instruments available. The measuring points (MPs), the variables to be measured, the types of instrument and the collection frequencies are listed in tables 2.1 and 2.2 below.

Figure 2.2 Petten field site
(distance and height
in metres)



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Table 2.1 Measuring points and equipment at Petten field site

Measuring point	Sensor/instrument	Dist. to ref. pt. ¹ [m]	X coord RD [m]	Y coord RD [m]	Z [NAP +/- m]	Location
MP 13	Anemometer (131), wind vane (132) Barometer (133)	-35	105798 105798	531673 531673	0.00 0.00	<i>Dijk te Kijk</i> ²
MP 22	Barometer (221)	-35	105798	531673	0.00	<i>Dijk te Kijk</i>
MP 14	Video camera 1 (141)	-0.2	105769	531693	17.3	Crest of dike
MP 19	Video cameras 2, 3 (191, 192)	1.1	105759	531677	16.6	Crest of dike
MP 12	Pressure sensor (121)	12.7	105749	531683	9.28	Dike's upper slope
MP 11	Pressure sensor (111)	18.2	105744	531685	7.23	Dike's upper slope
MP 9	Wave run-up staff (091)	19.4 (centre)	105743	531686	6.92 (centre)	Dike's upper slope
MP 10	Pressure sensor (101)	25.6	105738	531689	5.70	Dike's lower slope
MP 8	Pressure sensor (081)	55.7	105720	531719	0.55	Dike's lower slope
MP 7	Pressure sensor (071) Pressure sensor (072)	75.4 75.4	105703 105703	531730 531730	0.23 -0.29	Groyne post Groyne post
MP 6	Capacitance wire (061) Pressure sensor (062) Radar level meter (063) Anemometer (064) Wind vane (065) Water level staff (066) ASM-IV (067)	 122.9 122.7 122 122 122 122.7	105663 105663 105663 105663 105663 105663 105661	531752 531752 531752 531752 531752 531752 531715	-0.38 -0.92 9.01 12.58 12.58 -0.93	} } } Breaker } bar post } } }
MP 18	Pressure sensor (181)	170.5	105617	531771	-1.20	Sea bed
MP 17	Pressure sensors (171, 175) Current meters (172, 173, 174)	276.7 276.7	105522 105522	531817 531817	-3.13 -3.13	Sea bed Sea bed
MP 16	Pressure sensors (161, 162)	436.6	105377	531886	-2.50	Sea bed
MP 3	Water level staff (031) Digital level meter (032) Radar level meters (033/034)	609 609 609	105234 105234 105234	531985 531985 531985	-3.00 0.00 11.32	Post Post Post
MP 2	Directional waverider (021)	3526	102896	533802		Petten <i>Polder</i>
MP 1	Directional waverider (011)	7916	99003	535832		NAP -20m

¹ The distance to the reference point is defined in relation to section 20,830 with zero coordinates

x = 105767, y = 531690 (corresponding with approx. the crest of the dike) and direction (nautical) 297,9 degrees

² Information centre "*Dijk te Kijk*" ("Sea Dike on Show")

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Table 2.2 Equipment and collection frequency

Measuring point	Sensor/instrument	Measuring variable [unit]	Data collection frequency (Hz)
MP 13	Anemometer (131)	Wind direction [°]	1/60
	Wind vane (132)	Wind speed [metre per second]	1/60
	Barometer (133)	Atmospheric pressure [mbar]	1/60
MP 22	Barometer (221)	Atmospheric pressure [mbar]	1/60
MP 14	Video camera 1 (141)	Measuring section and surf zone	25 images per second
MP 19	Video cameras 2,3 (191,192)	Wave run-up (eg in grid)	25 images per second
MP 12	Pressure sensor (121)	Water pressure [mbar]	4.00
MP 11	Pressure sensor (111)	Water pressure [mbar]	4.00
MP 9	Wave run-up staff (091)	Wave run-up [m]	10.00
MP 10	Pressure sensor (101)	Water pressure [mbar]	4.00
MP 8	Pressure sensor (081)	Water pressure [mbar]	4.00
MP 7	Pressure sensors (071, 072)	Water pressure [mbar]	4.00
MP 6	Capacitance wire (061)	Surface deviation [m]	4.00
	Pressure sensor (062)	Water pressure [mbar]	4.00
	Radar level meter (063)	Surface deviation [m]	2.56
	Anemometer (064)	Wind speed [metre per second]	1-min. mean
	Wind vane (065)	Wind direction [°]	1-min. mean
	Water level staff (066)	Water level [NAP +/-m]	2.56
	ASM-IV (067)	Bottom topography [NAP +/-m]	3 samples per hour
MP 18	Pressure sensor (181)	Water pressure [mbar]	4.00
MP 17	Pressure sensors (171, 175)	Water pressure [mbar] en	4.00/1.00
	Current meters (172, 173, 174)	Flow velocity [m/s]	1.00
MP 16	Pressure sensors (161,162)	Water pressure [mbar]	4.00
MP 3	Water level staff (031)	Water level [NAP +/-m]	2.56
	Digital level meter (032)	Water level [NAP +/-m]	0.10
	Radar level meter (033/034)	Surface deviation [m]	2.56 per 10-min. mean
MP 2	Directional Waverider (021)	Surface deviation [m] and wave direction [°]	1.28
MP 1	Directional Waverider (011)	Surface deviation [m] and wave direction [°]	1.28

2.2.2 Equipment changes compared with previous season

A number of equipment changes were made for storm season 2003–2004:

- Water level staffs were mounted at MPs 3 and 6.
- A barometer was installed at MP 13.
- Pressure sensor 163 at MP 16 broke down during a storm in the previous season and was removed before storm season 2003–2004.
- Until the end of the previous storm season, all pressure sensors apart from sensor 175 at MP 17, were equipped with automatic atmospheric pressure compensators. Analysis of the measuring data demonstrates, however, that the signals of the pressure compensated sensors show unacceptable deviations, which increased as the instruments were submerged for longer periods of time. Before storm season 2003–2004 the decision was therefore made that all pressure sensors apart from sensor 162 at MP 16 were to be adjusted to avoid automatic compensation for atmospheric pressure changes. Instead of automatic compensation, the pressure signals were compensated during the data processing stage, for which the reliable atmospheric pressure measurements at MPs 13 and 22 were used.

2.2.3 Operation of equipment

This subparagraph briefly describes the operation of the instruments used on the field site, in the following order:

- Directional waverider
- Digital level meter (DLM)
- Pressure sensor
- Radar level meter
- Current meter
- Wave run-up staff
- Video camera
- Wind vane/anemometer
- Barometer
- Capacitance wire
- Water level staff
- ASMIV sea bed staff

Please refer to appendix A for photographs of all above-mentioned measuring instruments. Photograph 9 gives an overview of the measuring set-up immediately off the dike.

Directional waverider (see photograph 1 in appendix A)

The directional waverider is a buoy supplied by Datawell and has a diameter of 0.9 metre. The instrument contains equipment for measuring vertical accelerations, horizontal positions, pitch, roll and heave. The buoy is furthermore equipped with two permanent accelerometers, a compass and a direction gauge. The data collected are transmitted to shore by means of telemetric links. The directional waverider enables short wave registration including wave direction. At approx. 8 km offshore, MP 1 is defined as the field site's offshore

reference point, and MP 2 is located over a sand ridge on the Petten *polder* (figure 2.2).

Digital Level Meter (DLM)

The digital level meter consists of a vertical tube with an opening below the minimum water level. The opening's flow resistance functions as a high frequency filter. High frequencies, ie wind waves, do not penetrate into the tube. A float measures the water level within the tube and a metal wire connects it to a pulley, while a counterbalance ensures continuous wire tension. The pulley's rotations show the course of water level deviations.

Pressure sensor (see photographs 2 and 6 in appendix A)

The pressure sensor measures the total hydrostatic pressure (atmospheric pressure, upper water layer and any current pressure). The pressure sensors on the Petten field site are installed to define wave spectrum (MPs 6, 7, 8, 16, 17 and 18) and to determine the layer thickness of run-up waves against the dike (MPs 8, 10, 11 and 12). An additional number of pressure sensors (sensors 161, 171 and 062) were positioned at equal distances in the surf zone to measure long wave reflection.

Radar Level Meter (see photograph 4 in appendix A)

The water surface, ie water levels and wave heights, is measured at approx. *NAP* +10 metres by the radar level meters supplied by Enraf.

Current meter (see photograph 5 in appendix A)

Instantaneous flow velocity is measured in three directions by an Aquadopp current meter (172–174). The results are used in particular to determine the extent of longer wave reflection.

Wave run-up staff (see photograph 3 in appendix A)

The wave run-up staff (091) used for measuring wave run-up against the dike, was supplied by Etrometa. Operation of this instrument, which consists of a series of electrodes at equal distances of 0.05 metre, relies on the principle of electronic conductivity. The wave run-up staff, which is 12 metres long, is placed in the dike revetment and registers the wave run-up height against the slope.

Video camera (see photographs 7 and 8 in appendix A)

Whenever wave run-up is expected to occur, videos are recorded (191 and 192) to obtain a two-dimensional picture of the wave conditions between the two groynes and of wave run-up against the dike. A grid was painted on the dike for easy illustration of wave run-up.

Wind vane/anemometer

Throughout the storm season, the wind speeds and their wind directions are measured non-stop at two locations: in the surf zone at approx. *NAP* +10 metres (064 and 065), and at the landward side of the dike also at a height of approx. 10 metres (131 and 132).

Barometer

Both at the field site's Visitor Information Centre "*Dijk te Kijk*" ("Sea Dike on Show") and at MP 13, pressure sensors (221) measure the atmospheric pressure non-stop during the storm season.

Capacitance wire (see photograph 10 in appendix A)

The principle of the capacitance wire is that of measuring the capacity of two wires stretched closely along each other. An increase in water level along these wires results in a capacity decrease, which allows charting of the surface deviations, for example as a result of water level deviations and waves.

Water level staff

The water level staff is mounted on a post injected into the sea bed, and consists of four sections with a total length of 12 metres. The water level staff works according to the principle of electronic conductivity and applies a series of electrodes at equal distances of 0.05 metre.

ASMIV sea bed staff (see photographs 11 and 12 in appendix A)

From November 2002 the bottom topography near MP 6 has been measured by means of an ASMIV sea bed staff supplied by the German company ARGUS. This instrument consists of 192 optic sensors cast in a metal rod at equal distances of 1 centimetre, and measures its surrounding turbidity non-stop. The measuring results show a clear distinction between the sea bed layer and the water layer above. The sea bed staff is a stand-alone sensor with 8 MB storage capacity and is programmed by means of an infrared interface. Voltage is supplied by two 9 Volt batteries, which need replacement after 3 months.

2.3 Management and maintenance

The Information Service Water is responsible for keeping the field site operational, which entails preventive and corrective maintenance. Corrective maintenance entails repair or replacement of faulty equipment, while preventive maintenance keeps the equipment in a condition which minimizes the chance of corrective maintenance.

Installation and maintenance of the instrument set-up at the MSW³ post (MP 3) are carried out exclusively by the MSW technical management department. The MP 3 instrument set-up was therefore designed and installed by the RIKZ IT department. The MSW is responsible for the operation of the DLM, but not for the operation of the radar level meter and water level staff, as these instruments are included in the maintenance programme of the MSW post.

³ Monitoring System Water

2.4 Data collection

In 2001 a system was developed on the basis of the Qinsy system, which accepts remote data transfer commands. The measuring data are stored onto two PCs in a locked room at the Petten Visitor Information Centre "*Dijk te Kijk*". In 2002 a network link to Petten was set up for the purpose of daily sensor operation checks. This network is used for making daily copies of the measuring data to IJmuiden where they are burned onto a CD, which in turn is sent to Den Oever for processing. After the data have been processed, both the raw and processed data are burned onto a CD together with a processing report, and are subsequently sent to the RIKZ every month.

3 Data Processing and Storage

3.1 Data processing

The *RIKZ* used to process measuring data with 'ad hoc' software, ie Fortran scripts. In 2002 the *RIKZ* commissioned the development of wave processing software to streamline data processing and improve processing maintenance, which resulted in Waves2002, a programme for daily processing of wave data. Batch version Waves2004 was released recently, and it enables easy processing of longer data periods. In due course it shall replace all ad hoc software used so far. Please refer to the Waves2004 user manual [Dekker et al, 2004] for further details.

Processing of storm season 2003–2004 was carried out by Measurement Information Service of Directorate North Holland. It used both Waves2004 and the above-mentioned ad hoc software, although the Fortran scripts were in fact adapted for their processing methodology to correspond exactly to that of Waves2004. The *RIKZ* carried out a general check of the processing results. The results generated by the ad hoc software were used for the layout of the storm season report.

Validation of the measuring data was carried out by using the raw measuring signal, where spikes, time errors and stagnations were deleted and the data gaps were completed. Validation at parameter level, which checks parameter reliability, was **not** carried out; the same applies to the storms. In other words, a general but no systematic validation was carried out.

3.2 Software settings

The following settings were used for the processing of storm season 2003–2004 in both the ad hoc software and Waves2004:

- Settings for validation process
In the validation process, minor spikes of the data signal were deleted on the basis of the sigma/delta test with coefficient 4. For the stagnation criterion, 6 seconds were set for wave signals and 12 seconds for flow velocity signals. No stagnation criterion was applied for slow signals such as atmospheric pressure, whereas a value of 2 seconds was applied for the interpolation criterion. Please refer to the Waves2004 user manual for further details on these criteria [Dekker et al, 2004].

- Analysis settings

In the ad hoc software, all equipment used for determining wave spectra and parameters was set to have a minimum quality of 90%. The directional correction value was defined at -2. Please refer to the Waves2004 user manual for relevant background information [Dekker et al. 2004]. A 20-minute value was set for the block length, ie the duration of the signal blocks to be analysed. This duration is long enough with respect to signal reliability and short enough to speak of a stationary signal within the block, which is generally the case for block lengths under approx. 30 minutes. In the analysis, the water level measured by the DLM (032) was used as the reference water level.

Please refer to the configuration files for further details on the settings applied. They are available for every working day (see paragraph 3.3).

3.3 Data storage

The raw and processed data, together with their processing reports, are stored at the RIKZ on a network drive. To improve data access by all users for further analyses, the most relevant results are also stored on the CD-ROM enclosed with this report. The results are:

- Day files (validated at signal level):
 - batch files (gm, rr, g2, tm and hm files)
 - gp files (parameters)
 - gs files (spectra referred to as *Hrmeet_sb5*)
 - gd files (directional spectra)
 - cfg files (configuration files) and processing reports
- Storm data:
 - raw data
 - processed data
- Morphological measurements:
 - soundings (ASCII format (X, Y, Z))
 - groyne section measurements (ASCII format (X, Y, Z))

In addition to the above-mentioned files, please find attached a PDF version of this storm season report and a document outlining the various files.

4 Data Availability and Reliability

This chapter begins by describing the availability of the validated measuring data over storm season 2003–2004 and subsequently discusses the reliability of these data.

4.1 Data availability

Appendix B contains bar graphs showing the availability of validated measuring data for every month during storm season 2003–2004 (1 October 2003 to 30 April 2004). Key to the colours is:

- Green:** every day a minimum of 80% of the anticipated values is available after processing
- Yellow:** every day 50% to 80% of the anticipated values is available after processing
- Red:** every day less than 50% of the anticipated values is available after processing
- Black:** nil measuring values available

Since previous storm season, radar signals at MP 3 are collected at two different frequencies (table 2.2), which are both shown in the bar graphs. As instruments 091–121, 141 and 191 are located on the dike and do not produce any output unless there is sufficient wave run-up, they are not included in the bar graphs. Neither is the sea bed staff.

The availability of validated measuring data throughout the storm season is illustrated in figure 4.1 for all measuring instruments, excluding those located on the dike. Some instruments are placed at a height where they stand partially or entirely clear at low water levels, so that obviously no validated measuring data are available for these periods. As this distorts the equipment's performance, the availability of these instruments is shaded in figure 4.1

During storm season 2003–2004, it occurred several times that all signals were simultaneously interrupted. This was generally caused by failing collection equipment and by field site maintenance work. These breakdowns, amounting to 12 days, result in a maximum of 94 percent availability of validated data.

Figure 4.1 shows that for the majority of instruments validated data are available during more than 85 percent of the storm season.

This percentage drops extensively for a number of instruments.

- Radar 033 (58%): Throughout the season the signal of this instrument generated an extensive number of spikes, so that in the validation process a large number of data were rejected.
- Current meter 172–174 (5%): The current meter broke down at the end of the previous storm season and could not be repaired until March 2004. From March this instrument has failed to perform well.
- Pressure sensor 175 (15%): The pressure sensor connected to the current meter was broken down until March 2004. After repairs this instrument performed well during April.
- Pressure sensors 071 and 072 (32% and 45% resp.): These pressure sensors stand clear at low water levels, so that no data could be registered during more than half of the storm season.
- Pressure sensor 081 (29%): The pressure sensor stands clear at low water levels, which is over two-thirds of the storm season, so that no data could be registered over this period.
- Capacitance wire 061 (63%): The wire stands clear at low water levels.
- Water level staff 066 (71%): The staff stands clear at low water levels.

The mean availability of validated data over storm season 2003–2004 is 72%. Correction for instruments standing clear at MPs 6, 7 and 8, provides a mean percentage of 77.

Figure 4.1 Availability of validated data over storm season 2003–2004

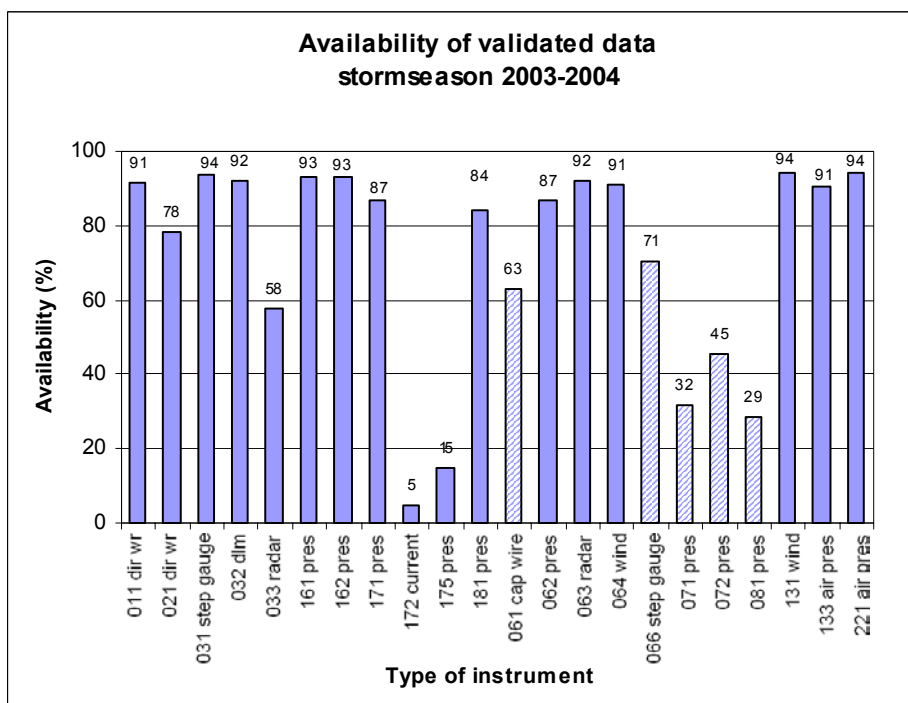
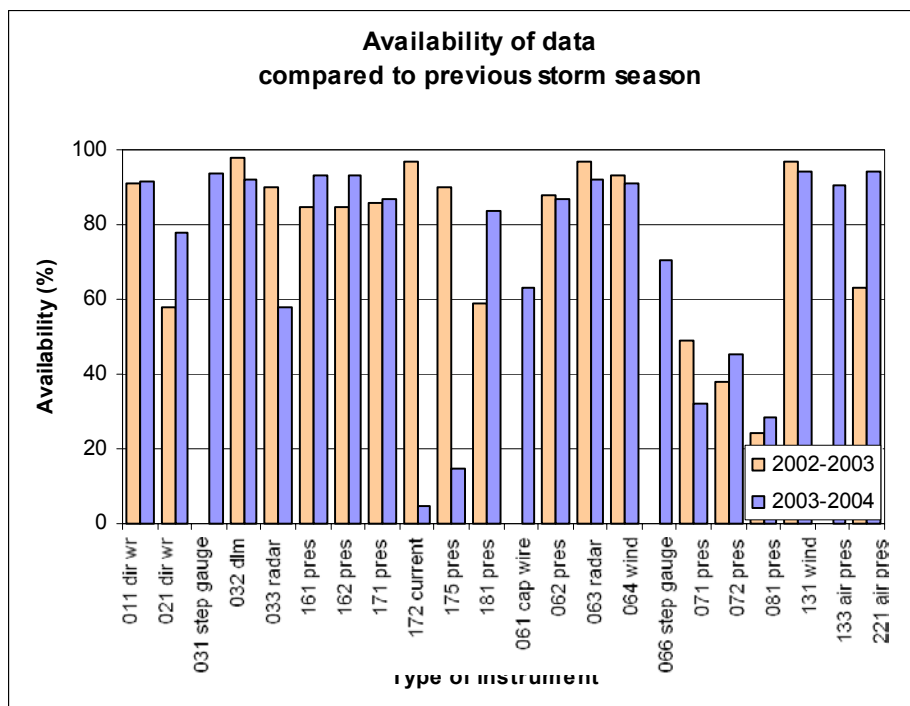


Figure 4.2 compares the availability of the validated data over storm season 2003–2004 with those of previous season 2002–2003, and shows clearly that for the majority of instruments the results of the most recent storm season are similar to those of the previous storm season. Over storm season 2003–2004, however, the performance of instruments 021, 161, 181 and 221 shows a clear improvement, whereas that of instruments 033, 172, 175 and 071 is considerably poorer.

Figure 4.2 Availability of validated data compared with that of previous season



4.2 Data reliability

4.2.1 Reliability of measuring techniques applied

The circumstances in which the measurements were made, such as breaking waves and currents, are the main factor in the reliability of the measuring data. The paragraphs below discuss the reliability of the measuring data in the local Petten circumstances

Directional waverider

The directional waverider is a generally accepted instrument for wave measurements at deeper water. The criterion for using this buoy is the absence of breaking waves in the measuring area. As MPs 1 and 2 on the Petten site meet this criterion, the assumption can be made that the measuring data generated by the wave buoys are reliable – with the exception of wave direction and directional spreading for long waves, ie over 30 seconds.

Digital Level Meter (DLM)

The DLM is a generally accepted instrument for measuring water levels and is applied on a large scale throughout national water level network MSW. The standard deviation for the complete set-up, where the DLM is mounted in a subdued water level tube, is 2.5 centimetres. The DLM located at MP3 is part of the national measuring network (Petten South). The statement can be made that these measuring data are very reliable.

Pressure sensor

The assumption can be made that the pressure sensors provide a virtually precise pressure measurement. There are doubts, however, about the accuracy of the process which translates the measured pressures into water level deviations, because it is not clear how factors such as sensor distance to the water surface, sensor distance to the sea bed, water salinity, flow and sediment transport actually influence this process. The reliability of the final measurement results, ie water level deviations, generated by the pressure sensors has been a topic of discussion for several years. Research into possible distorting influences such as flow, salinity and sediment transport is strongly recommended.

Radar level meter

The Enraf 973 radar level meter at MP3 (033) turned out to have teething problems in 2002 and was therefore evaluated at Measuring Post Noordwijk. The objective was to develop an improved instrument with a clear indication of the measuring performance and the range of application. During this evaluation process it appeared that not all problems could be easily solved. Datawell is currently developing an improved instrument. The radar signal at MP 3 was very poor throughout the most recent storm season. The many spikes resulted in the rejection of a large number of data. In conclusion, its data reliability is not deemed considerable.

The radar level meter at MP 6 is an older type: Enraf 873. In principle this type of radar level meter was approved for measuring waves in deep water, and evaluation took place at Measuring Post Noordwijk as early as 1997/1998. On the Petten site it is applied differently, however, because MP 6 is located in the surf zone. There is no doubt about heavily breaking waves affecting data reliability. Moreover there are software problems resulting in systematically incorrect registration of long waves.

Flow velocity meter

The flow velocity meter is positioned in the surf zone. It is as yet not clear if the current data measured in turbulent circumstances are reliable.

Anemometer/Wind vane

The anemometer and wind vane results can be assumed to be reliable. Comparison of the wind data generated at MP 6 (just off the dike) and MP 13 (behind the dike) shows that there are regularly minor deviations in both the measured wind directions and wind speeds, but these are caused by the dike's geometry. It appears that the most significant deviations occur at wind directions of approx. 180 degrees. The deviations are minor at wind speeds between 220 and 90 degrees.

Barometer

The reliability of the barometer data depends on the instrument's set-up. Wind can for example distort the signal. Generally speaking, however, it can be said that the barometer generates reliable data.

Water level staff

The water level staff consists of a series of electrodes placed at equal distances of 0.05 metre, and works according to the principle of electronic conductivity. The simplicity of the measuring principle allows reliable measurements in the absence of heavy wave breaking. At MP 6, however, heavy wave breaking occurs during storms, and spray can distort the measuring signal and consequently affect data reliability.

ASMIV sea bed staff

The measuring principle of the ASMIV sea bed staff is that of optic measurement of water turbidity. The sea bed can be defined accurately to within a centimetre. Considering the simplicity of the measuring principle and the fact that the measuring results correspond closely with those of simultaneous bottom height measurements, the conclusion was drawn that the ASMIV measuring results are very reliable.

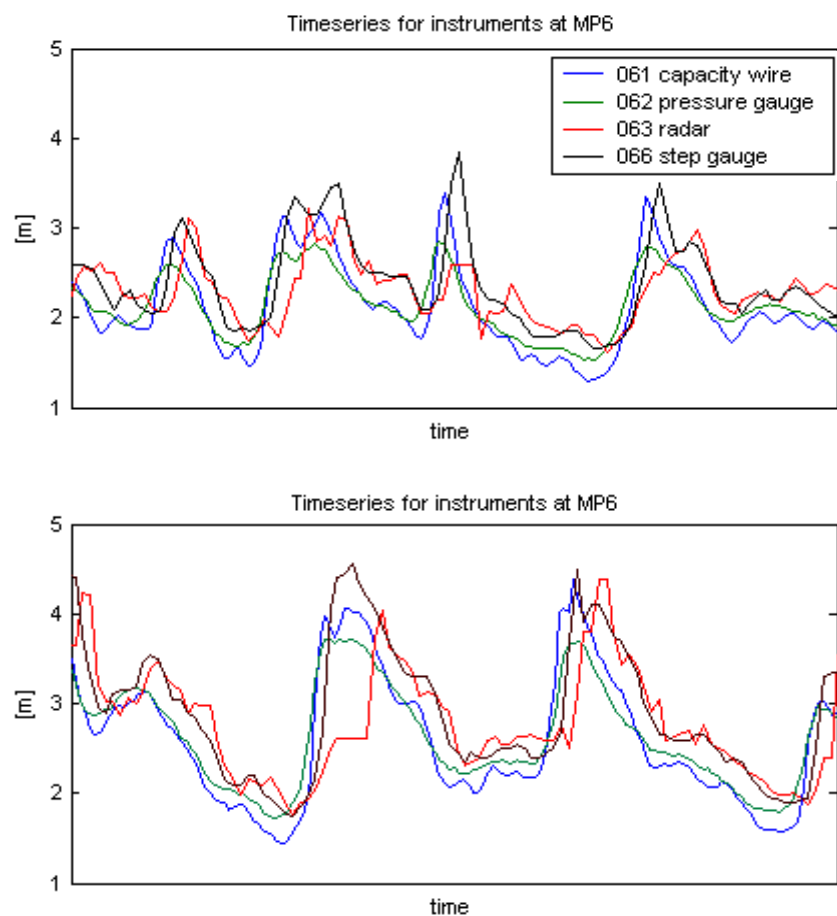
Capacitance wire

The simplicity of the measuring principle allows the statement that the water level deviations measured with this instrument are reliable, provided the wire is sufficiently taut. The problem of a capacitance wire is that it slackens or even breaks in particular in storm conditions. It is essential that very regular maintenance checks are carried out to obtain reliable measurements. The bottom end of the wire is positioned at approx. NAP -0.20 metre, which means that measurements at low water levels are not accurate.

4.2.2 Reliability of surf zone measurements

Several times over the past years, the conclusion was drawn that various measuring instruments applied at MP 6 in the surf zone, generate significantly varying data particularly during storms. Before these measurements can be used for wave model verification, the reliability of the various measuring techniques clearly needs to be quantified. During storm season 2003–2004 measurements were made at MP 6 with four different types of measuring instruments: a capacitance wire, a pressure sensor, a radar level meter and a water level meter. By way of comparison, figure 4.3 shows the signals of these four instruments at two random points in time during a storm in December 2003 (see paragraph 5.4 and chapter 6).

Figure 4.3 Comparison of MP 6 signals



Subparagraph 4.2.1 above briefly discusses the reliability of the measuring techniques applied at MP 6. The following additional remarks are made with respect to figure 4.3.

- An explanation for the minor phase shifts between the different signals can be the positioning of the instruments. As the instruments are not placed at exactly the same position, the 'same' waves are measured at different points in time. Another explanation can be that there are minor deviations in logging by the different instruments (time logging).

- The signals generated by the capacitance wire and the water level staff produce very similar changes. The vertical shift of approx. 0.25 metre is caused by slightly different calibration of the instruments. These instruments seem to generate the most reliable measuring data.
- The water surface deviations measured by the pressure sensor are too minor, but are yet to be corrected by means of a transfer function. This correction does not involve the measuring signal but the spectrum. The signal of the pressure sensor is furthermore smoother than the other signals. The reason is that the sensor is located at a certain depth below the water surface, so that it picks up the effect of smaller waves hardly or not at all.
- The radar seems to miss the peaks of larger waves. The calculated wave heights are therefore rather low (see also table 5.1). The radar signal seems very unreliable. *Note: The long waves which the radar registered incorrectly, are excluded from figure 4.3.*

5 Description of Storm Season 2003–2004

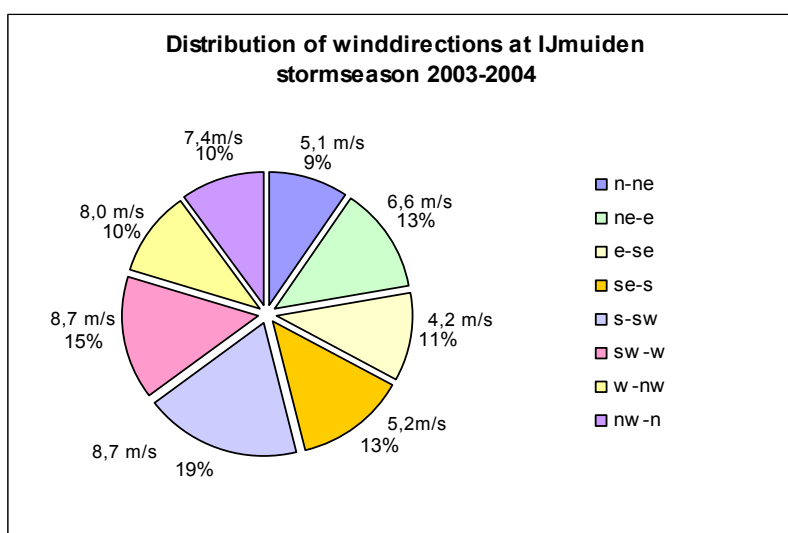
This chapter begins with a description of the wave and wind characteristics during storm season 2003–2004, followed by the morphological measurements. To conclude, the interesting storm periods are selected on the basis of the measured wind speeds and water levels, which are discussed in detail in chapters 6 and 7.

5.1 Wind characteristics

The wind directions and wind speeds are measured on the field site at MP 6 (just off the dike) and MP 13 (behind the crest of the dike). A comparison of measuring values generated by these instruments shows that a slight difference in both wind speeds and wind directions is measured regularly. As indicated in chapter 4, this is caused by the wind adjusting over the Petten Sea Defence.

Considering the fact that the Petten Sea Defence affects the wind over MPs 6 and 13, and moreover that the wind is not measured at exactly at the standard height of 10 metres, the ensuing data are not used for determining the wind characteristics over storm season 2003–2004. The hour-mean data measured at IJmuiden on behalf of the Royal Dutch Meteorological Institute (KNMI) were used instead, as these data were in fact registered at the standard height of 10 metres. The distribution of wind directions is given in figure 5.1, together with the mean wind speeds over storm season 2003–2004.

Figure 5.1 IJmuiden wind characteristics



5.2 Wave characteristics

Directional waveriders (011 and 021), pressure sensors (062, 071, 072, 081, 161, 162, 171, 175 and 181), radar level meters (033 and 063), water level staffs (031 and 066) and a capacitance wire (061) on the field site measure the vertical water level deviations caused by the wind. Wave processing software was used to calculate wave parameters and spectra for the above-mentioned instruments over all 20-minute blocks for which validated data are available. Table 5.1 lists the statistical characteristics of the following wave parameters:

- wave height H_{m0}
- wave period T_{m-10} (0,03 – 0,50 Hz)
- wave period T_{m02} (0,03 – 0,50 Hz)
- peak period T_{pb}

Please refer to appendix C for a graphic representation of the frequency curves for wave height H_{m0} and wave period T_{m-10} (figures C.1 and C.2.). As the frequency curves were calculated over a relatively short period of time, ie 7 months, the curves have small kinks. The dataset is in fact too small to allow statistical extrapolation. The remark is furthermore made that the distribution of T_{m-10} is not related to that of H_{m0} , so that the highest waves do not coincide with the highest periods. The higher periods are generally measured if there is swell from the north, originating from an old storm field present in the wave field. These waves are characterized by a relatively small wave height.

The following remarks are made with respect to table 5.1:

- The table clearly shows that wave height decreases towards the coastline (in the table from left to right).
- Period T_{m-10} does not decrease towards the dike, but in fact increases! This increase is the result of wave generating.
- T_{m02} is much less susceptible of the increase in low frequency energy and remains virtually constant towards the dike.
- A number of extremely high and unrealistic values were measured for peak period T_{pb} . This period measure is strongly affected by the noise on the spectrum, ie random peaks, and contrary to T_{m-10} it is not a stable parameter.
- During storm the radar level meter (033) and the water level staff (031) at MP 3 registered significantly different wave heights of more than one metre (values 0.1 % and 1 % in table 5.1). An explanation is that there was poor reception of the radar signal during the storm, so that a large number of storm data were rejected in the validation process.
- Given the fact that software problems cause systematic errors in long wave registration by the radar at MP 6, the periods are relatively high. Wave height H_{m0} is seriously underestimated because the radar does not pick up any wave peaks. Wave heights registered by the pressure sensor also seem slightly low.

.....
Table 5.1 Wave characteristics over storm season 2003–2004

		Measuring instrument														
		011	021	031	033	161	162	171	181	061	062	063	066	071	072	081
Availability (%)		91%	78%	94%	58%	93%	93%	87%	84%	63%	87%	92%	71%	32%	45%	29%
H_{m0} [m]	mean	1.24	1.15	1.09	0.94	0.90	0.86	0.78	0.70	0.76	0.59	0.54	0.72	0.64	0.61	0.54
	0.1%	5.60	5.05	4.65	3.25	3.55	3.35	2.60	2.50	2.30	2.00	1.80	2.35	1.90	1.90	1.80
	1%	4.45	4.00	3.95	2.80	2.95	2.75	2.15	2.05	2.00	1.50	1.40	2.00	1.60	1.50	1.50
	5%	3.10	2.95	2.85	2.20	2.25	2.15	1.75	1.50	1.50	1.20	1.15	1.50	1.15	1.15	1.20
	10%	2.50	2.30	2.20	1.90	1.80	1.75	1.50	1.30	1.35	1.05	1.05	1.30	1.05	1.05	1.05
T_{m-10} [sec]	mean	5.7	5.7	5.8	5.9	6.7	6.7	6.7	6.6	6.6	6.4	6.6	6.1	6.8	6.6	8.5
	0.1%	11.7	11.9	11.6	12.1	12.3	12.2	10.4	11.3	13.0	12.5	13.2	11.3	10.3	10.3	13.7
	1%	9.8	9.8	9.6	9.7	10.2	10.2	9.5	10.3	10.5	10.5	11.9	9.9	9.7	9.7	12.1
	5%	8.3	8.4	8.5	8.6	9.0	9.0	8.8	9.2	9.2	9.1	10.1	8.7	8.9	8.7	11.1
	10%	7.4	7.5	7.8	7.8	8.4	8.4	8.3	8.5	8.6	8.3	8.9	8.0	8.3	8.1	10.4
T_{m02} [sec]	mean	4.5	4.5	4.5	4.5	5.4	5.4	5.6	4.6	4.4	4.2	4.2	4.0	4.8	4.6	5.5
	0.1%	8.4	8.2	8.0	8.3	8.9	9.0	8.1	7.3	6.8	6.6	7.8	6.8	7.5	7.1	7.7
	1%	7.4	7.4	6.9	7.2	7.8	7.9	7.5	6.6	5.9	5.9	6.9	5.6	6.8	6.3	7.1
	5%	6.5	6.3	6.1	6.2	6.9	6.9	6.9	5.9	5.4	5.4	5.8	5.0	5.8	5.6	6.5
	10%	5.9	5.9	5.6	5.7	6.5	6.4	6.6	5.5	5.1	5.1	5.3	4.7	5.5	5.2	6.3
T_{pb} [sec]	mean	6.3	6.4	6.9	6.8	7.5	7.5	7.3	8.1	8.4	8.4	8.6	8.3	8.4	8.5	9.4
	0.1%	16.3	16.3	16.2	16.5	16.4	16.4	16.7	16.9	22.7	18.9	19.8	17.3	13.8	15.0	17.9
	1%	13.4	13.7	13.1	13.7	13.7	13.7	13.1	14.1	16.0	15.9	16.4	15.4	13.1	14.0	16.5
	5%	10.4	10.8	11.3	11.1	11.7	11.6	11.3	12.6	13.5	13.8	14.3	13.7	12.3	13.0	14.6
	10%	9.2	9.5	10.4	10.3	10.8	10.8	10.5	11.8	12.3	12.7	12.9	12.7	12.0	12.4	13.4

Due to insufficient validated data for pressure sensor 175, this sensor is not included in the above table.

5.3 Morphological measurements

5.3.1 Types of measurement

Currents and waves cause sediment transport which in turn leads to constant changing of the cross-shore profile at the Petten Sea Defence. As the cross-shore profile has a direct effect on wave height, it is essential to monitor not only the waves but also the bottom topography changes. During storm season 2003–2004, the sea bed was mapped several times by means of soundings and groyne section measurements. These random registrations do give information on the general sea bed behaviour during the storm season, but not on the erosion depth during storms. To map the maximum erosion depth, which defines the maximum wave height, during storm season 2003–2004 the sea bed level near MP 6 was also measured non-stop with an ASMIV sea bed staff.

5.3.2 Soundings

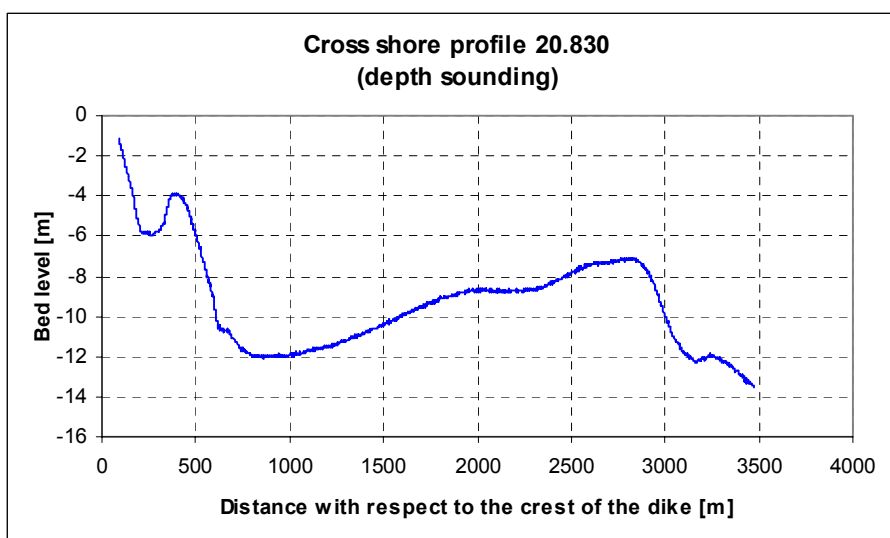
The soundings were carried out for 9 Jarkus sections over 5 groyne sections, being Jarkus section 20,830, corresponding with the measuring section, and for 4 sections north and 4 sections south of the measuring section.

The soundings were carried out on the following dates:

- 4 September 2003
- 6 November 2003
- 4 December 2003
- 13 February 2004
- 29 March 2004

The sea bed profile off the Petten Sea Defence as for Jarkus section 20,830, corresponding with the measuring section, is given in figure 5.2. All sounding data are available digitally in ASCII format (see paragraph 3.3).

Figure 5.2 Cross-shore profile in measuring section (Jarkus section 20,830)



5.3.3 Groyne section measurements

The groyne section measurements were carried out for 7 parallel sections between the groynes north and south of the measuring section. By using 'WESP', the sea bed topography was registered to 100–150 metres seaward of the crest of the dike. The groyne section measurements were carried out on the following dates:

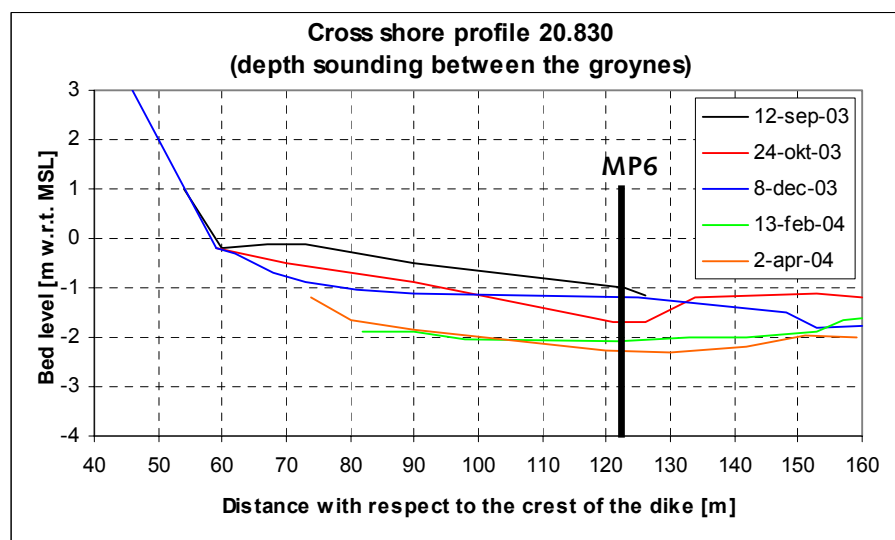
- 12 September 2003
- 24 October 2003
- 8 December 2003
- 13 February 2004
- 2 April 2004

Figure 5.3 shows the results for the central section, ie section 20,830, corresponding with the measuring section. The registration on 12 September 2003 shows a typical summer profile with a large quantity of sand off the toe of the dike. It furthermore clearly shows that during the storm season there was considerable sea bed erosion along the full section.

The level changes need to be considered not just as a single section in two dimensions but interpolated over all 7 sections in three dimensions to get a picture of and to understand the topography changes within a groyne section.

The data required for 3D processing, being the results from the 7 sections 20,785, 20,800, 20,815, 20,830, 20,845, 20,860 and 20,875, are digitally available in ASCII format (X, Y, Z) (see paragraph 4.5.4).

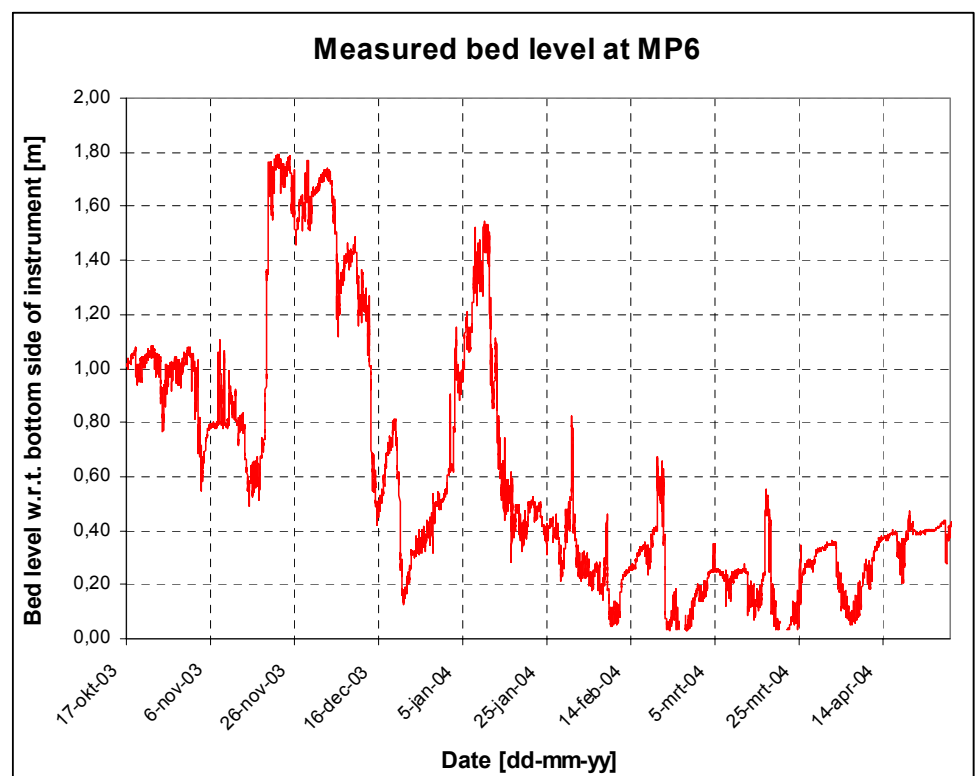
Figure 5.3 Groyne section measurements Jarkus section 20,830



5.3.4 ASMIV sea bed staff

The measuring principle of the ASMIV sea bed staff is that of measurement of surrounding water turbidity by optic sensors. The sensors register 100% turbidity in the solid sea bed, which enables very accurate measuring signals of the sea bed topography. Figure 5.4 gives the levels near MP 6 (see figure 5.3) as measured by the sea bed staff from 17 October 2003 to 31 April 2004. This figure clearly shows that the sea bed levels near MP 6 varied strongly during storm season 2003–2004. There was so much sand accretion mid November and at the end of January, that over a short period of time the sea bed level near MP 6 increased by approx. one metre. Sand nourishments carried out at both ends of the solid sea defence could be the cause. An initial brief analysis shows that the periods during which the sea bed level dropped significantly often coincided with periods of strong wind or storm, with Force 7 on the Beaufort Scale as a minimum. On 14 and 15 December 2003 the sea bed level dropped sharply by approx. one metre during a northwesterly storm with maximum wind speeds of 18 metres per second. A similar drop in sea bed level was measured on 13 and 14 January 2004 during a westerly storm with wind speeds up to 16 metres per second.

Figure 5.4 ASMIV results near MP 6



During the most recent storm season it was demonstrated that the bed level near MP 6 is subject to major changes. To determine the effect of erosion on the waves just off the dike, however, it does not suffice to make measurements at one single location. A more detailed analysis,

where the ASMIV data are linked to spatial information, ie soundings and groyne section measurements, is therefore strongly recommended.

5.4 Storm period selection

Measured storms are hindcast to be able to define the SWAN wave model reliability for storm conditions. On the basis of a comparison of model results and measuring data, a statement can be made on the model's reliability. The storm measurements carried out on the Petten site can be used for verification of wave model SWAN with respect to the straight Dutch coastline. If during a storm the water level increases to such an extent that wave run-up occurs regularly against the upper slope of the Petten Sea Defence, storm measurements on the Petten site can furthermore be used for verification of wave run-up formulations.

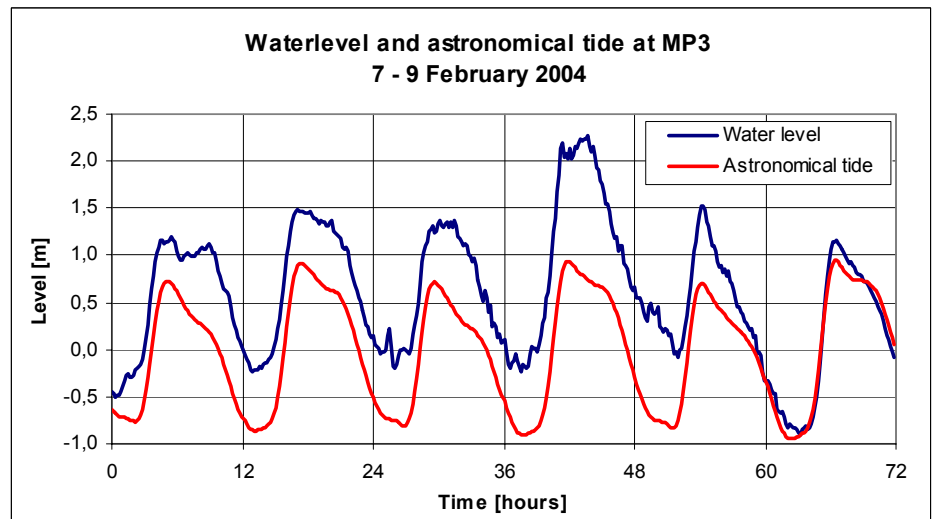
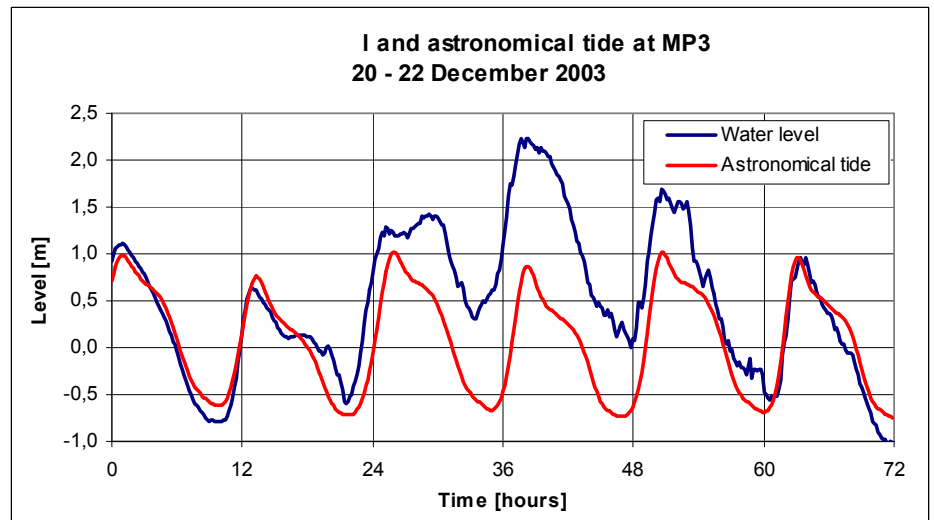
The first criterion used for determining the interesting storm periods for, for example, hindcasting with wave model SWAN and wave run-up analyses, was the wind speed measured, ie exceeding 15 metres per second or approx. Force 7 on the Beaufort Scale. Use was made of the wind measurements carried out near IJmuiden on behalf of the KNMI. The periods in which wind speed exceeded 15 metres per second during several hours, are:

- 6–8 October 2003
- 3 November 2003
- 14–15 December 2003
- 20–22 December 2003
- 26–27 December 2003
- 13–14 January 2004
- 16–17 January 2004
- 31 January–4 February 2004
- 7–9 February 2004
- 20–23 March 2004

Not only the wind speeds but also the simultaneous water levels need to be checked to determine whether or not these storm periods are interesting enough for further analyses such as hindcasting and wave run-up analyses. As the local water depth in shallow water is a contributing factor in the maximum wave height, higher water levels allow higher waves. Higher water levels moreover provide an increased chance of wave run-up against the upper slope of the Petten Sea Defence.

The above-mentioned water levels for these storm periods are illustrated in appendix D, which shows that during two storm periods, ie 20–22 December 2003 and 7–9 February 2004, the water level deviations were well over *NAP* +2.0 metres (figure 5.5). These two storm periods are very interesting for further analysis and are therefore discussed in more detail in chapter 6.

Figure 5.5 Water level and astronomical tide
20–22 Dec 2003 and
7–9 Feb 2004



6 Description of Storm Period 20–22 December 2003

Two interesting storm periods were selected in chapter 5 on the basis of measured wind speeds and water levels: 20–22 December 2003 and 7–9 February 2004. This chapter describes storm period 20–22 December 2003, and includes a discussion of the general storm conditions, measured wind, water level, waves and wave run-up. Low frequency wave generating is also briefly discussed.

6.1 Storm conditions

On 20 December a very active low pressure area developed in the interface between mild air present over southern Europe and cold air which flowed along the east side of a high pressure area over Greenland towards the south (figure 6.1). On 21 December this depression moved across the North Sea to Denmark, which caused a westerly to northwesterly storm. In the eastern area of the West Frisian Islands the wind occasionally increased to Force 10 on the Beaufort Scale, while at the western coast Force 8 was amply measured.

6.2 Wind measurements

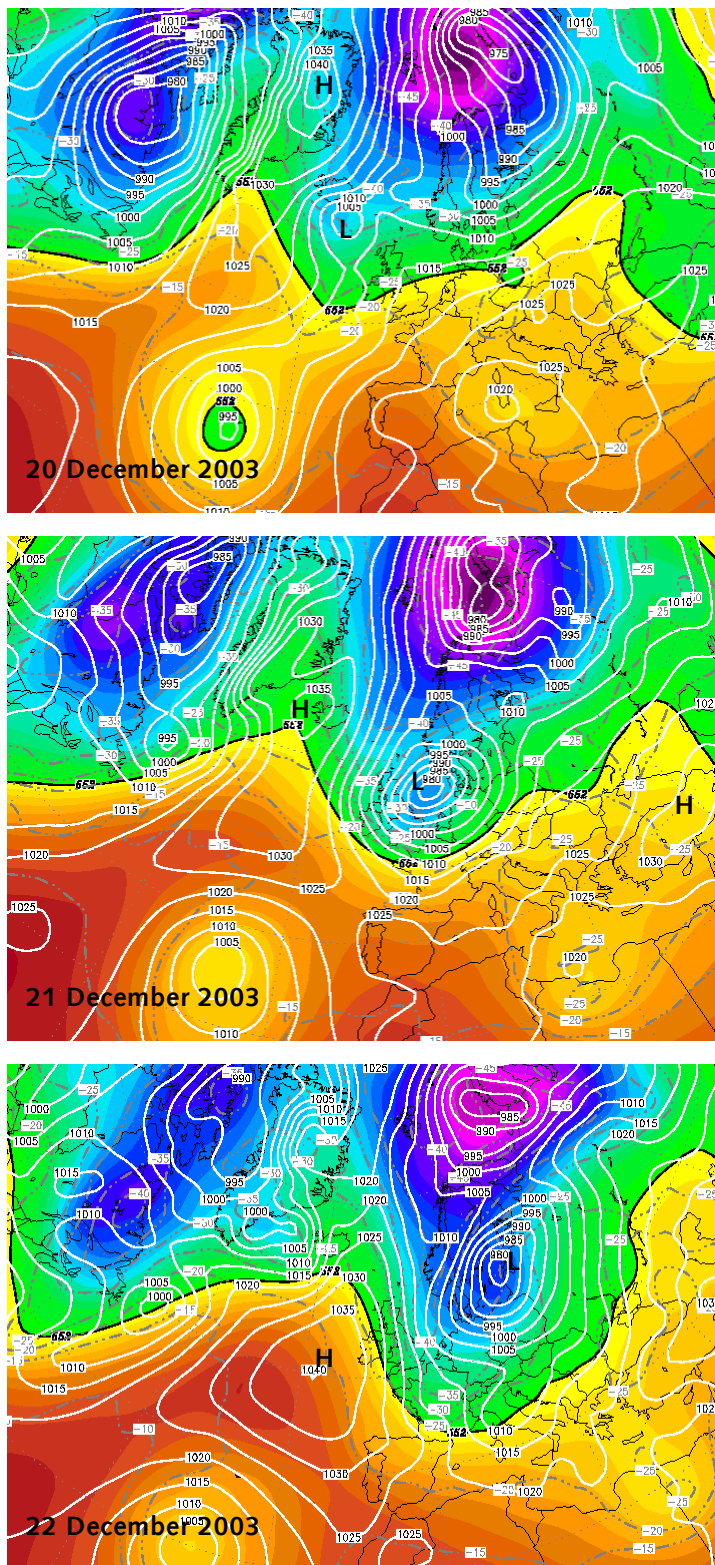
The wind direction and wind speed were measured on the Petten site at MP 6 off the dike and at MP 13 behind the crest of the dike. The 10-minute mean results, together with the hour mean values measured near IJmuiden on behalf of the *KNMI*, are illustrated in appendix E (figure E.1). This appendix shows that during the storm period of 20–22 December 2003 the wind veered from south to north with strongly fluctuating wind speeds. Near Petten as well as IJmuiden wind speeds exceeding 20 metres per second, also referred to as Force 8, were measured at the peak of the storm.

6.3 Water level measurements

Water levels measured by the digital level meter at MP 3 (Petten South⁴) as well as the astronomical tide are illustrated in figure 5.5 above. This figure shows that during the second high tide on 21 December a maximum water level of *NAP* +2.24 metres was measured. At that point in time the wind driven set-up measured approx. 1.5 metres.

⁴ Measuring point 3 is part of the Monitoring System Water (MSW), which refers to it as “measuring point Petten South”.

Figure 6.1: Atmospheric pressure 20–22 December 2003 [Source: Wetterzentrale Karlsruhe]



6.4 Wave Measurements

Waves are measured on the Petten site by waveriders, pressure sensors, radar level meters, water level staffs and a capacitance wire. In processing the measuring data, 20-minute energy density spectra and wave parameters are calculated for all instruments for which validated data are available.

Energy density spectra

The development of the energy density spectrum during the storm period is illustrated for MP 1 in appendix E.2. The points in time for which the spectra are given, were selected on the basis of the following measured wind speeds and water level deviations:

- 20 December 12:00 hrs: immediately before the storm broke
- 21 December 06:00 hrs: first high tide during the storm
- 21 December 14:00 hrs: maximum water level and peak of the storm
- 22 December 03:00 hrs: first high tide after peak of the storm

Appendix E.2 clearly shows that during the storm the spectrum peak shifts towards the low frequency end of the spectrum. After the peak of the storm it shifts back towards the higher frequencies. The observation is made that narrow peaks characterize the MP 1 spectra. This generally occurs in the case of persistent westerly to northwesterly winds during a storm.

The spectra for the various measuring points are given in appendix E.3 to illustrate the spectrum shift towards the coastline before the peak of the storm, ie 21 December 14:00 hours. The standardized spectra are furthermore given together to illustrate the spectral shape variances towards the coastline. The appendix shows that between MPs 3 and 17 in particular, energy shifts towards higher frequencies, which is the result of wave breaking on and behind the breaker bar near MP 3. Contrary to most other storms over the previous years, wave breaking caused much energy dissipation especially in this area during storm period 20–22 December. The hypothesis is that during this storm the significantly higher wave periods caused particular wave breaking further offshore. Visual observations from the dike during the storm confirm this hypothesis.

Appendix E.3 furthermore shows that near MP 6 in shallow water off the dike, energy is redistributed to lower frequencies. This is most likely caused by long wave generating resulting from wave breaking.

Wave parameters

To be able to study wave height and wave period variances during the storm period, appendix E.4 presents graphs with the variances in wave parameters H_{m0} , T_{m02} and T_{m-10} for waveriders 011 and 021, for water level staffs 031 and 066, and for pressure sensors 161, 171 and 071. The first figure clearly shows that on the first day and over a short period of time, wave height near MP 1 increases strongly to nearly 4

metres. This strong increase in wave height is caused by the sharp increase in wind speed to over 20 metres per second. The highest waves were measured at high tide in the early afternoon of 21 December, when wave height H_{m0} varied between 2 metres off the dike and nearly 7 metres near MP 1.

The second figure of appendix E.4 shows that wave period T_{m-10} , which is susceptible of low frequency energy, ie long waves, increases to a maximum of approx. 11 seconds at MP 1. Another clear illustration is that after the peak of the storm T_{m-10} decreases only very gradually, which can be explained by the fact that there is still an extensive amount of low frequency energy present in the area after the storm. As by contrast wave period T_{m02} is more susceptible of high frequency energy, ie short waves, this wave period does decrease quickly after the peak of the storm (see third figure in appendix E.4).

6.5 Wave run-up measurements

Run-up against the upper slope of the dike is measured by, among other instruments, a run-up staff placed in the dike revetment. The bottom end of this staff, which is 12 metres long, lies at *NAP* +5.70 metres. On 21 December 2003 run-up was measured between 12:45 hours and 18:00 hours, where it exceeded the levels *NAP* +6 metres, *NAP* +7 metres and *NAP* +8 metres during 527 seconds, 51 seconds and 12 seconds respectively. The highest run-up was *NAP* +8.91 metres, and is illustrated in appendix E.5, including an enlarged part of the highest run-up.

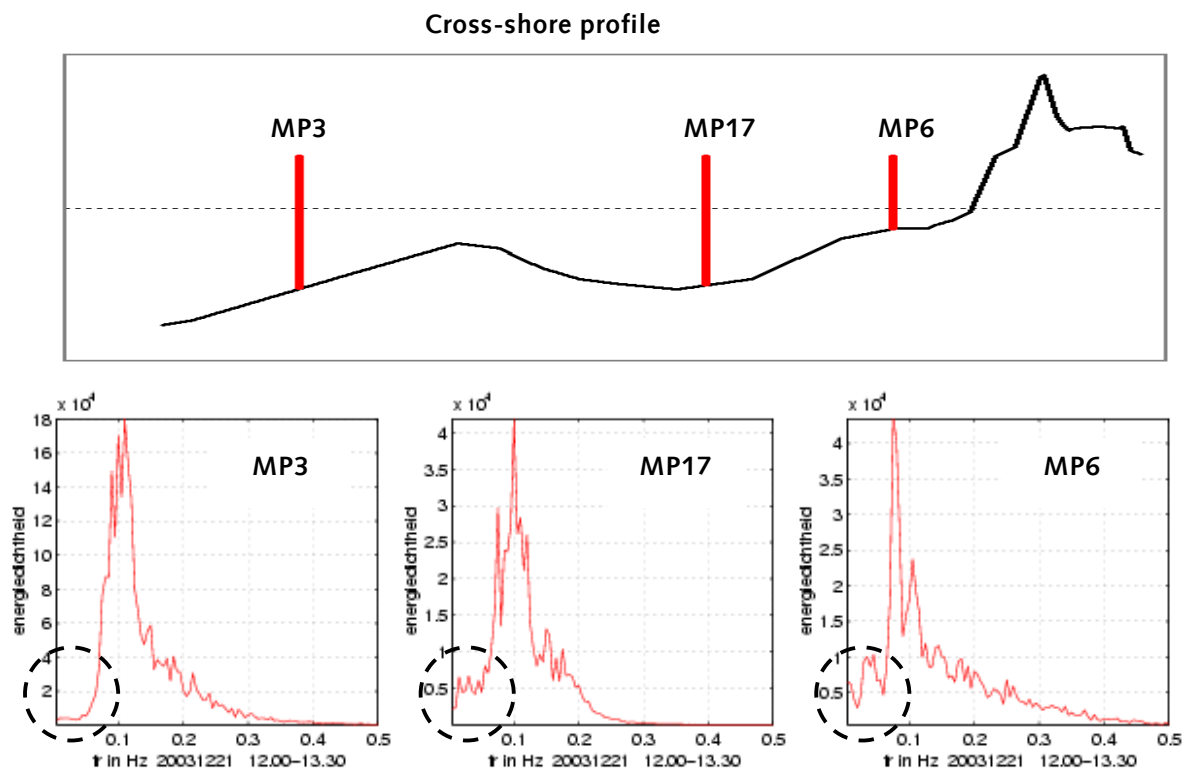
6.6 Low-frequency waves

On the Petten field site, low frequency waves are most often measured during storm, where a distinction can be made between two types of long waves: low frequency waves originating from an earlier storm field elsewhere, also referred to as swell, and low frequency waves generated locally. This local generating is caused by the interaction between shorter waves and wave breaking in shallow water. The low frequency waves generated locally, with T_{m-10} exceeding 75 seconds, do not run up against the dike but cause a temporary water surface elevation, which enables shorter waves to run up higher against the dike.

To get an impression of the quantity of low frequency energy generated locally during the storm of 20–22 December, wave spectra are calculated for the peak of the storm⁵. For MPs 3, 17 and 6 they are given in figure 6.2. It shows that there was some, although minimal, increase in low frequency energy between MPs 3 and 17 and between MPs 17 and 6. These results correspond with earlier results from a similar analysis of a comparable storm on 27 October 2002.

⁵ The high frequency energy and the extremely low frequency energy were filtered out for the calculation of the wave spectra required. Contrary to the 0.03–0.5 Hz spectra resulting from standard processing, these 'filtered' spectra do include the generated low frequency energy.

Figure 6.2: Spectra (including low frequency energy) calculated for instruments 031, 171 and 066.



7 Description of Storm Period 7-9 February 2004

Two interesting storm periods were selected in chapter 5, on the basis of measured wind speeds and water levels: 20–22 December 2003 and 7–9 February 2004. The former period was discussed in chapter 6, whereas the present chapter describes storm period 7–9 February 2003 and discusses its general storm conditions, measured wind, water level, waves and wave run-up.

7.1 Storm conditions

In the night of 7 to 8 February, a front which was linked to a minor depression, moved from the North Sea to Denmark (figure 7.1). The main cause of the resulting westerly storm was the major difference in atmospheric pressure which built up between this low pressure area and a high pressure area quickly building up west of the British Isles. The storm with strong gusts of wind occurred on the south side of the front moving from west to east across the Netherlands. After the wind speeds slightly subsided, they increased all along the western coast in the evening of 8 February, which caused a northwesterly storm with Force 8 to 9 on the Beaufort Scale.

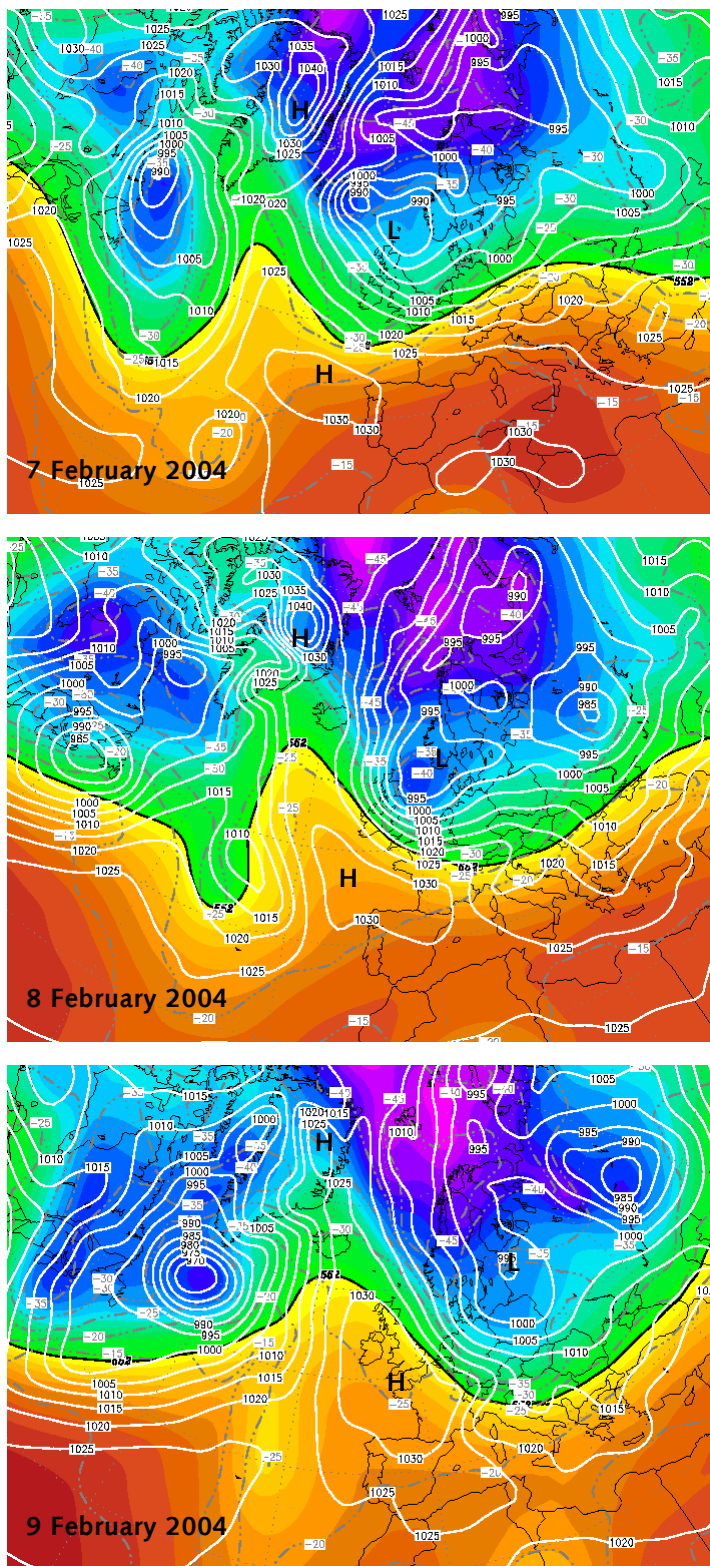
7.2 Wind measurements

On the Petten site, wind direction and wind speed are measured at MP 6 off the dike and at MP 13 behind the crest of the dike. The 10-minute mean results, together with the hour mean values measured near IJmuiden on behalf of the *KNMI*, are illustrated in appendix F (figure F.1). This appendix shows that during the storm period of 7–9 February 2004 the wind gradually veered from southwest to northwest. Near Petten as well as IJmuiden wind speeds exceeding 20 metres per second, also referred to as Force 8 on the Beaufort Sale, were measured at the peak of the storm.

7.3 Water level measurements

The water level measured with the digital level meter at MP 3 (Petten South) and the astronomical tide are given in figure 5.5 above. This figure clearly shows that virtually throughout the storm period there was significant wind driven set-up of the water level. During the high tide in the early evening of 8 February, a maximum water level of *NAP* +2.25 metres was measured. At that point in time, the wind driven set-up was approximately 1.5 metres.

Figure 7.1: Atmospheric pressure 7–9 February 2004 [Source: Wetterzentrale Karlsruhe]



7.4 Wave measurements

Waves are measured on the Petten site by means of waveriders, pressure sensors, radar level meters, water level staffs and a capacitance wire. In processing the measuring data, 20-minute energy density spectra and wave parameters are calculated for all instruments for which validated data are available.

Energy density spectra

The development of the energy density spectrum during the storm period for MP 1 is illustrated in appendix F.2. The points in time for which the spectra are given were selected on the basis of the following measured wind speeds and water level deviations:

- 8 February 06:00 hrs: high tide before peak of the storm
- 8 February 20:00 hrs: maximum water level and peak of the storm
- 9 February 06:00 hrs: first high tide after peak of the storm

Appendix F.2 shows that narrow peaks characterize the spectra for MP 1 on 8 February just as they do for the storm in December 2003. For the February storm the observation can be made as well that during the storm period the peak shifts to the left-hand side of the spectrum.

To be able to study the spectrum shift towards the coastline, appendix F.3 gives the spectra for various measuring points before the peak of the storm, ie 8 February 20:00 hours. The standardized spectra are furthermore given together to illustrate the spectral shape changes towards the coastline. It is clear that the spectrum peak drops towards the coastline and at the same time energy is redistributed to higher frequencies.

Wave parameters

Appendix F.4 illustrates the changes in wave parameters H_{m0} , T_{m02} and T_{m-10} for waveriders 011 and 021, water level staffs 031 and 066, and pressure sensors 161, 171 and 071, to enable study of wave height and wave period during the storm period. Small sections of signal are unavailable for pressure sensor 071 at MP 7 immediately off the dike. As explained in chapter 4, this is because the pressure sensor stands clear at low water levels.

Wave height changes measured by the three outer measuring locations are very similar to the changes in wind speed (see appendix F.1), whereas the wave height changes registered at the other measuring locations, ie in shallower water, generally correspond with the water level deviations. During the peak of the storm on 8 February, wave height H_{m0} is approx. 6 metres at the outermost measuring location and approx. 2 metres immediately off the Petten Sea Defence at MP 7. Wave periods T_{m02} and T_{m-10} show similar changes during the storm period, but vary approx. 2 seconds.

Wave period T_{m-10} , which is susceptible of low frequency energy, ie long waves, increases during the storm to a maximum of 9 to 10

seconds at all measuring locations, whereas period T_{m02} increases to a maximum of 8 seconds at the outer measuring locations.

7.5 Wave run-up measurements

Wave run-up against the upper slope of the dike is measured by, among other instruments, a run-up staff placed in the dike revetment. The bottom end of this staff, which is 12 metres long, lies at *NAP* +5.70 metres. On 8 February 2004, run-up was measured between 17:00 hours and 22:30 hours. As the top end of the staff, from approx. *NAP* +6.80 metres, malfunctioned, not all higher run-up was registered. The run-up measured is illustrated in appendix F.5

8 General Conclusions and Recommendations

This chapter draws the general conclusions and makes a number of recommendations

Data availability

The average availability of validated data concerning storm season 2003–2004, is 72%. Correcting the instruments at MPs 6, 7 and 8 for the periods that the instruments stand clear above the water level, lifts the average percentage to 77. Compared to storm season 2002–2003, the performance of instruments 021, 161, 162, 181 and 221 clearly improved during the most recent storm season, but the performance of instruments 033, 172, 175 and 071 was considerably poorer.

Recommendation

It is recommended that an understanding be gained of the failure mechanisms and their chances of occurrence. The ensuing results can then be used for efficient improvement of the field site's robustness.

Reliability of surf zone measurements

Several times during the past years, the conclusion was drawn that various measuring instruments, when applied at MP 6 in the surf zone, generate significantly varying data and in particular during storms. Over the past season, measurements were made at MP 6 with four different instruments: a pressure sensor, a radar level meter, a capacitance wire and a water level staff. A comparison of the measuring results of a storm in December showed that the signals generated by the water level staff and the capacitance wire were very similar. These instruments seem to generate the most reliable measuring results.

Recommendation

To be able to quantify the reliability of surf zone measurements, it is recommended that research be carried out into the reliability of the different measuring techniques in the surf zone.

Changes in sea bed topography

During storm season 2003–2004, the sea bed topography at MP 6 was measured non-stop with an ASMIV sea bed staff to chart the maximum erosion depth, which determines the maximum wave height. The results show that the sea bed near MP 6 is subject to major changes, and that there is severe erosion particularly during storms.

Recommendation

Measurements made at one single location are not sufficient for determining the effect of sea bed changes on waves in front off the dike. A more detailed analysis, where the ASMIV results are linked to spatial information such as soundings and groyne section measurements, is therefore recommended.

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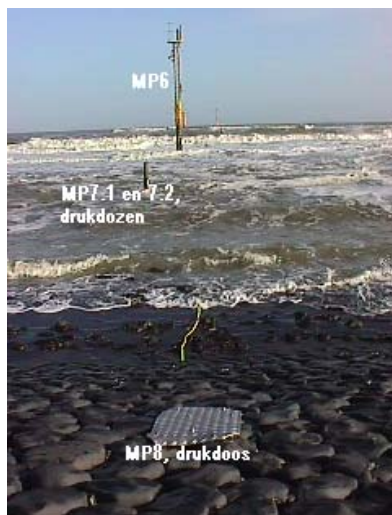
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Photograph 1 MP1 en 2
directional
wave rider



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Photograph 2 MPs 6, 7 and 8
pressure sensors



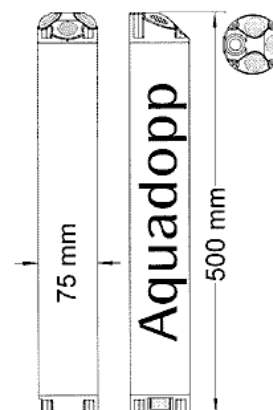
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Photograph 3 MP 9 run-up staff
with to its left
pressure sensor
MP 11



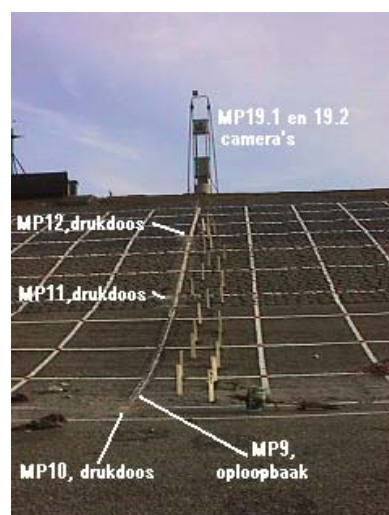
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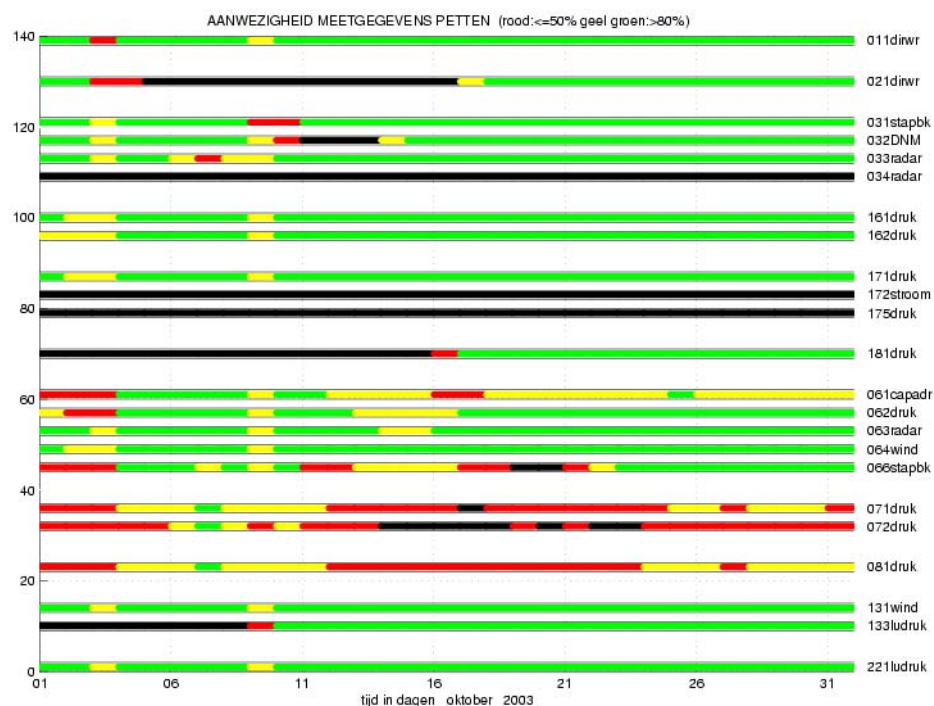


Figure B.2 Availability of data over November 2003

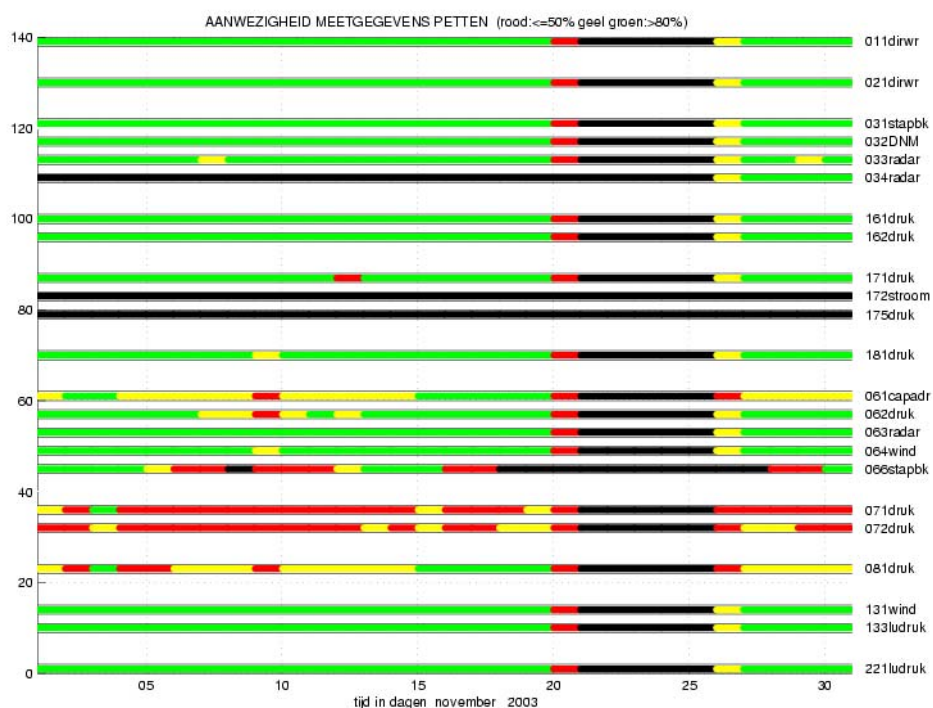


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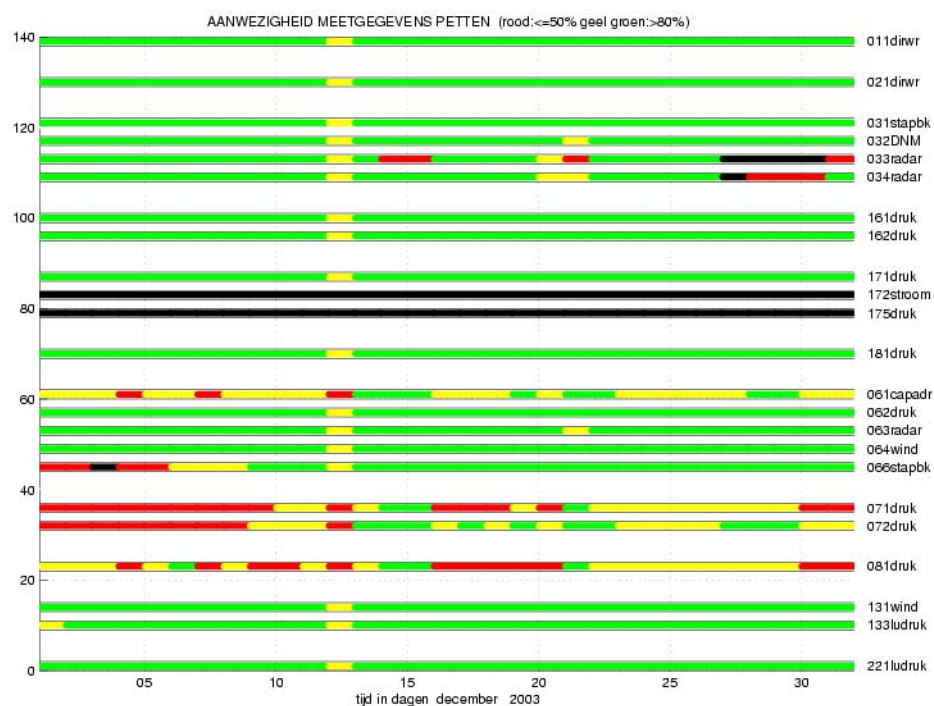


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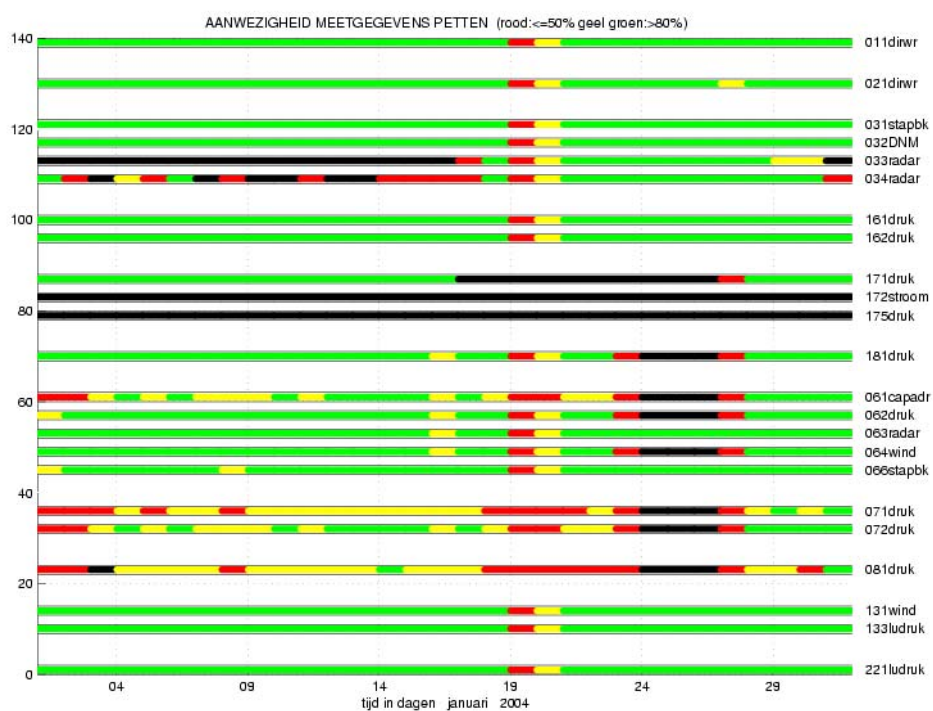


Figure B.5 Availability of data over February 2004

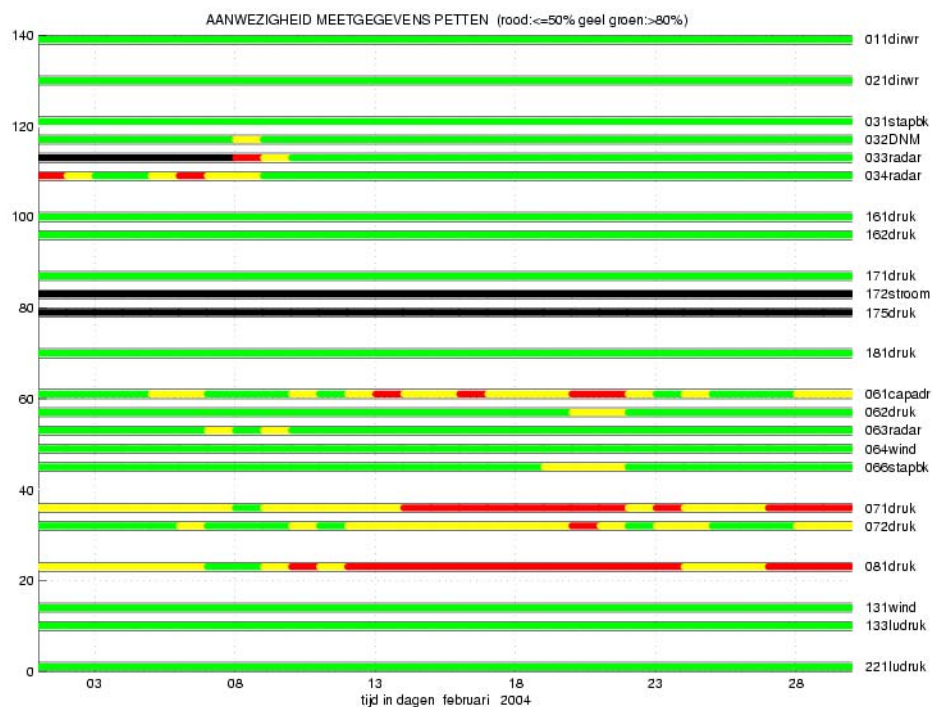


Figure B.6 Availability of data over March 2004

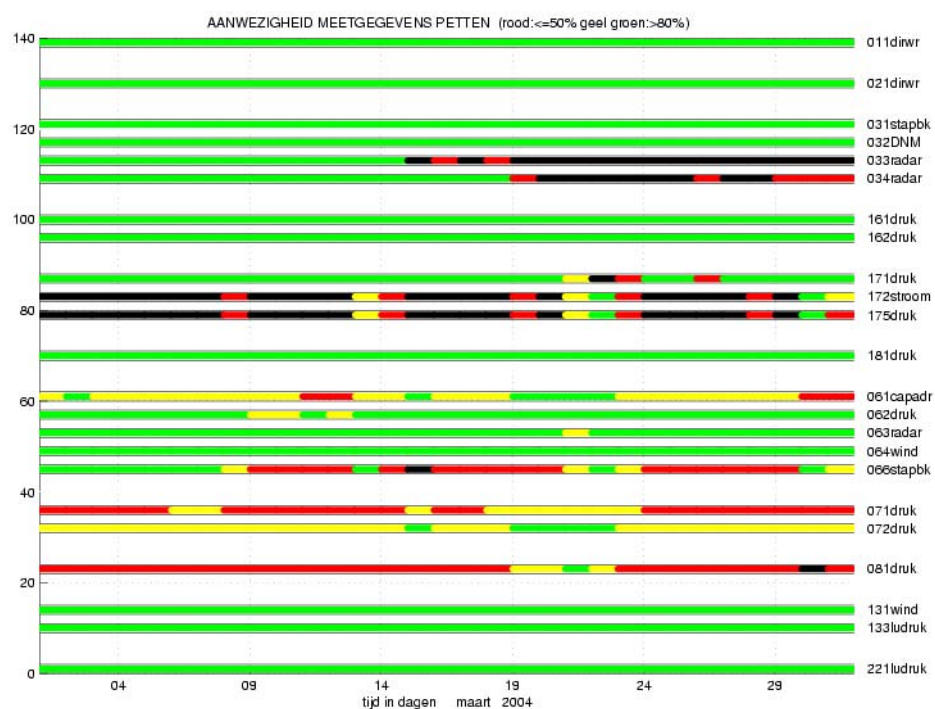
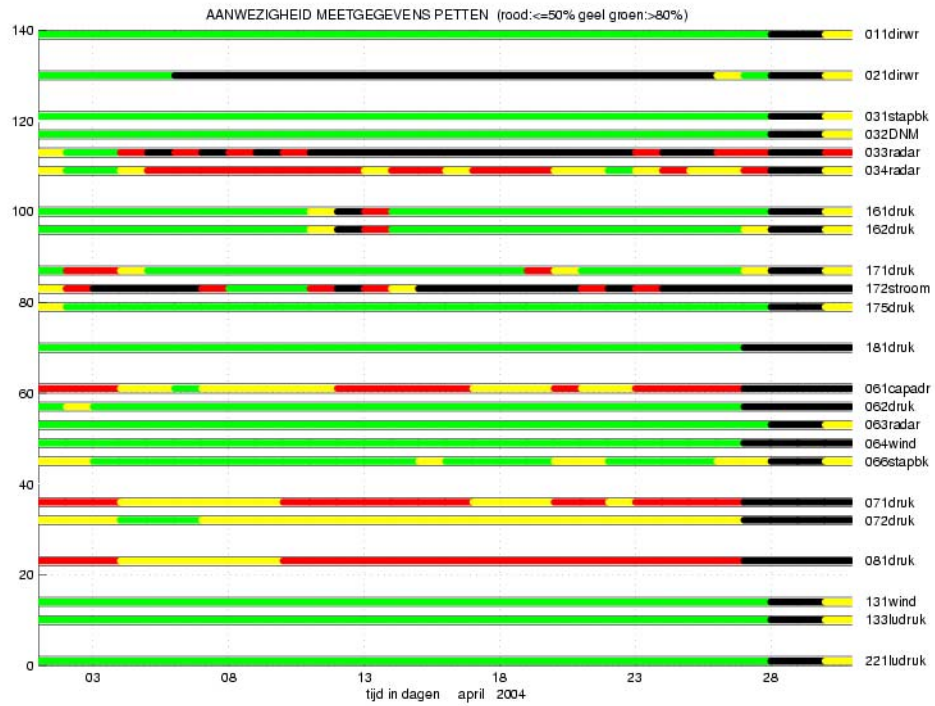


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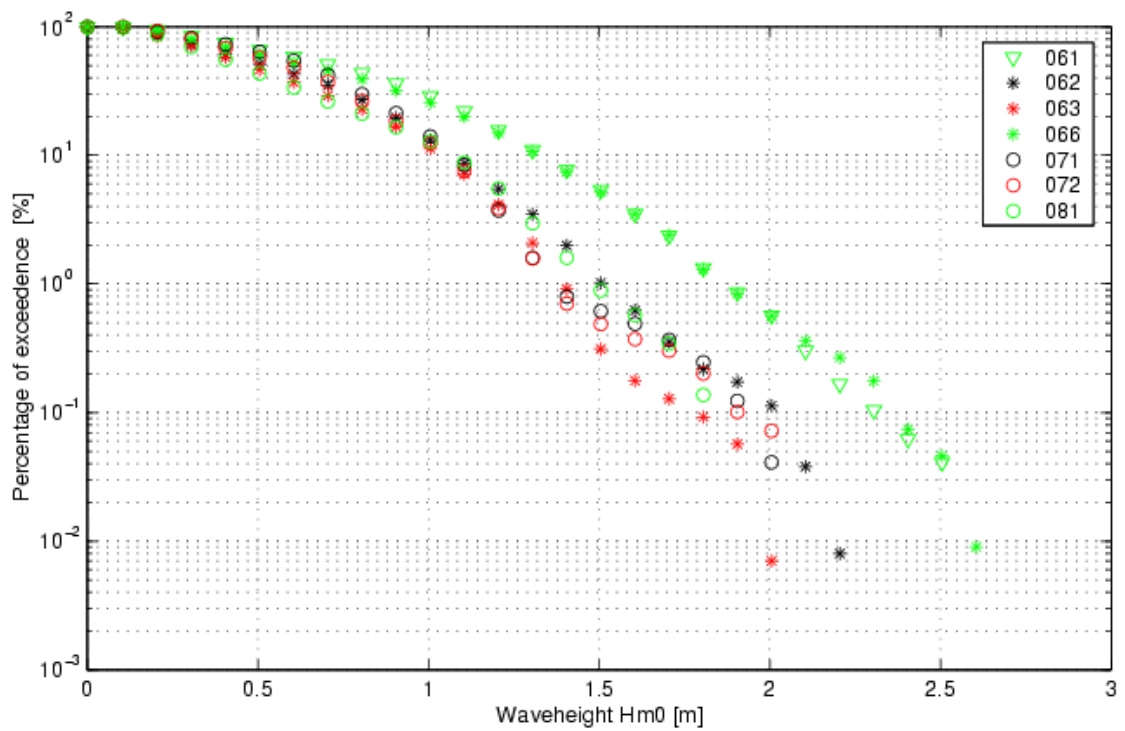
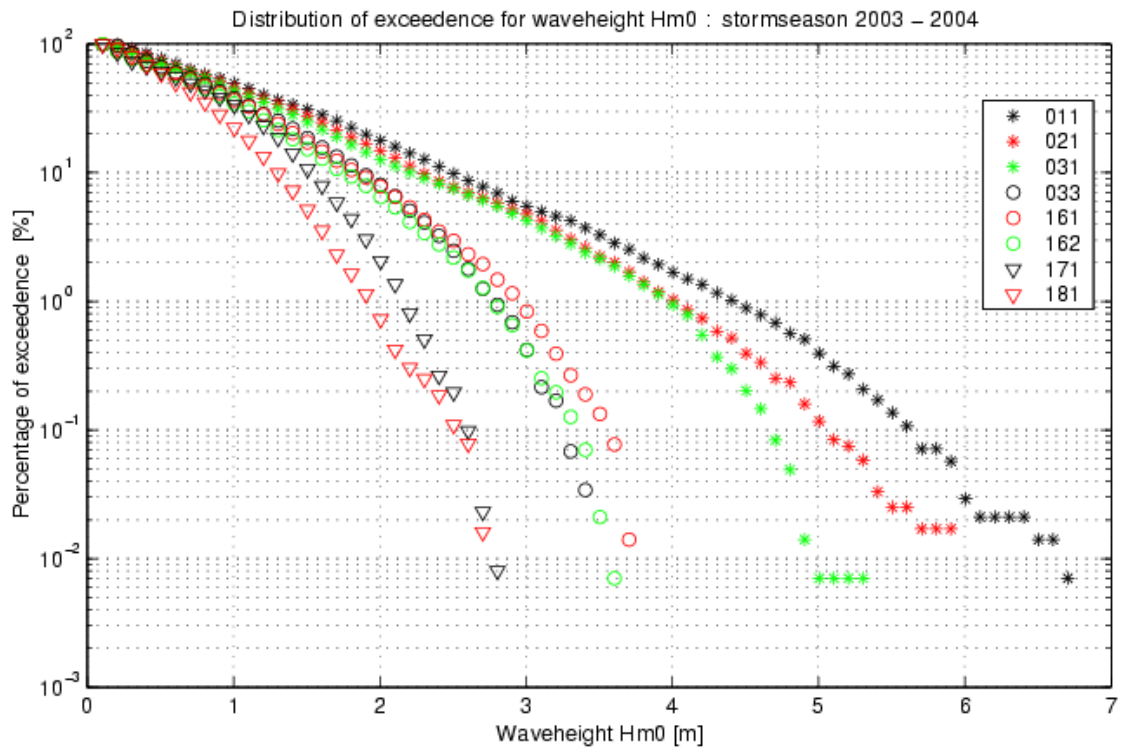
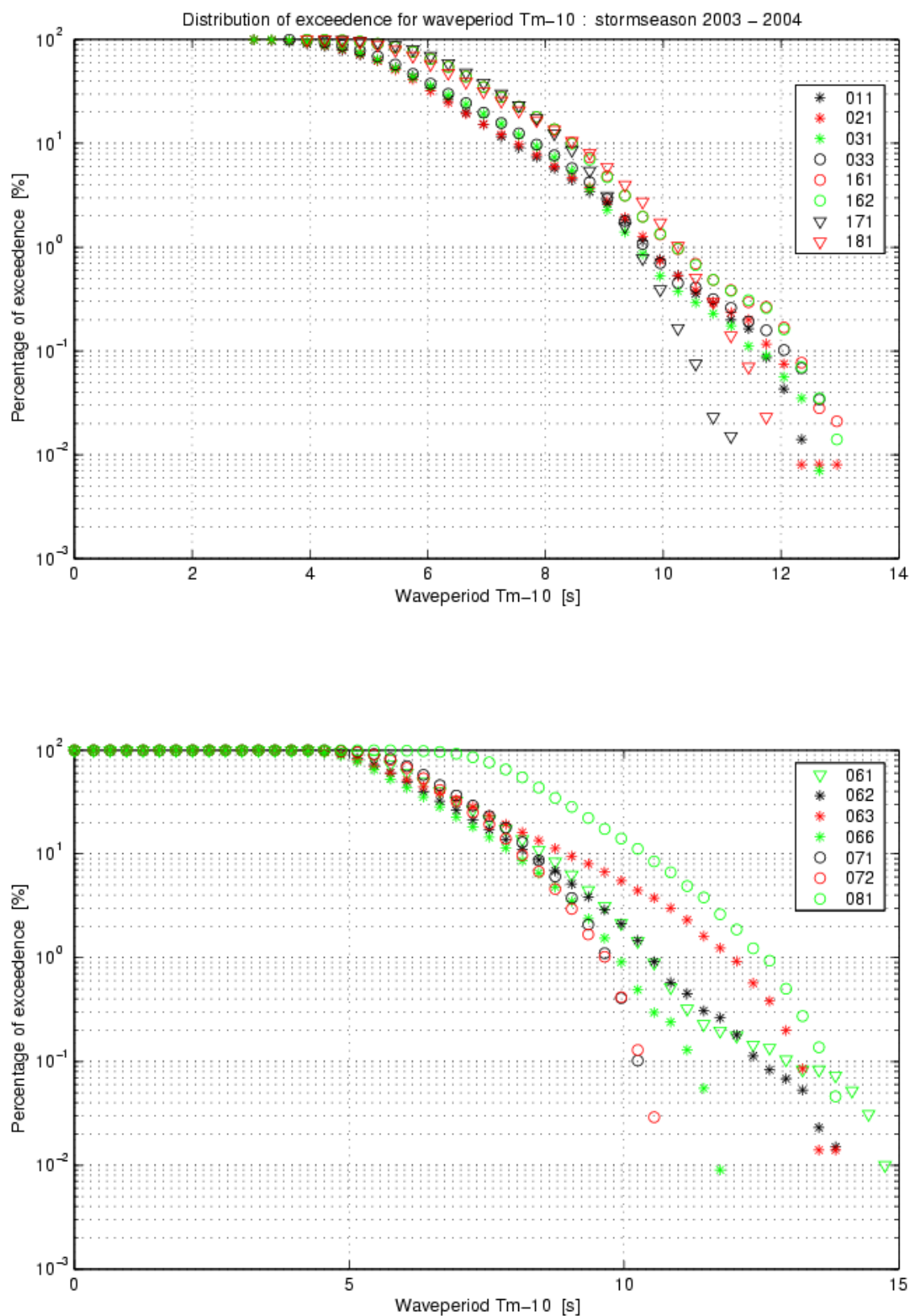
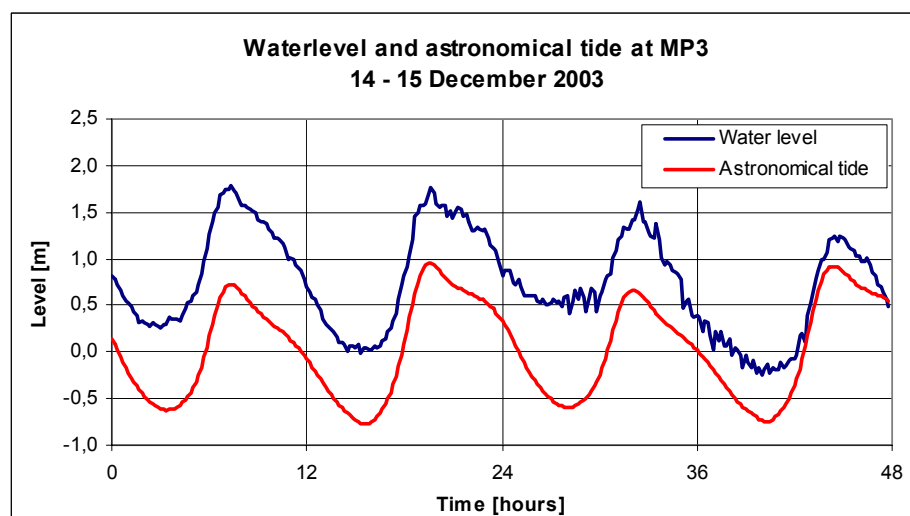
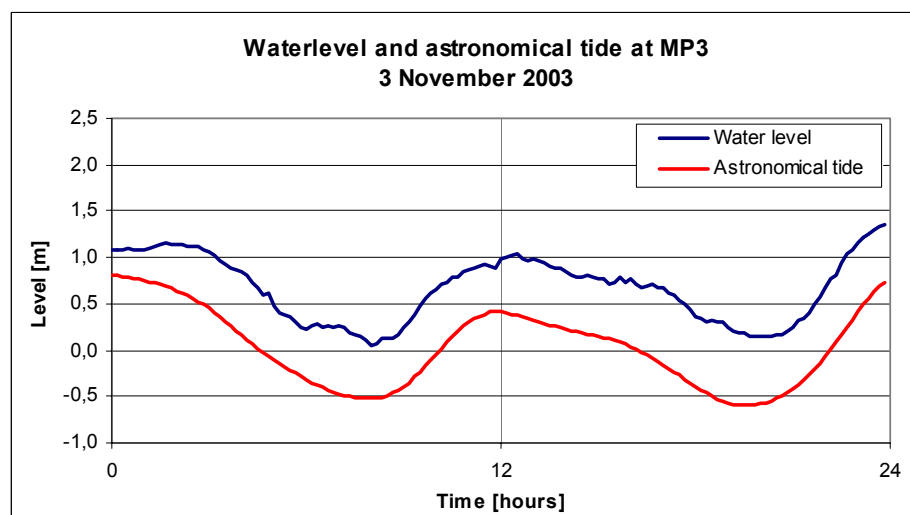
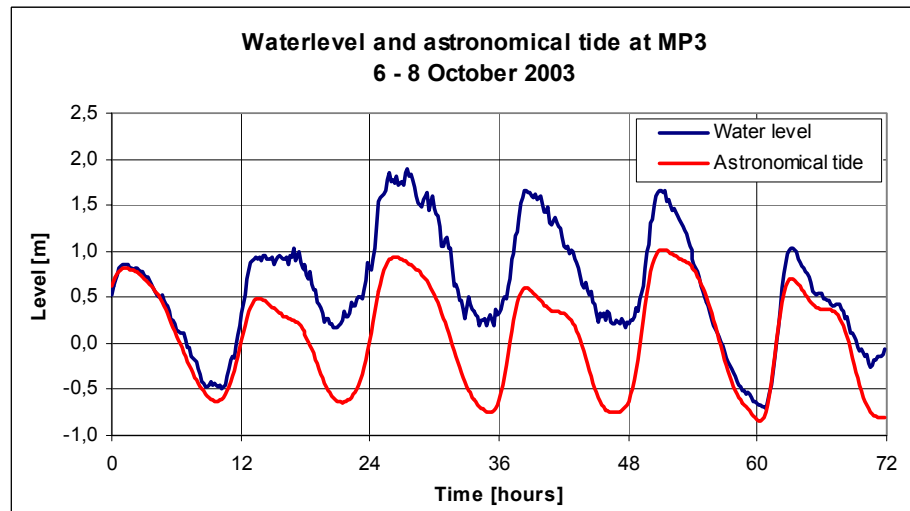


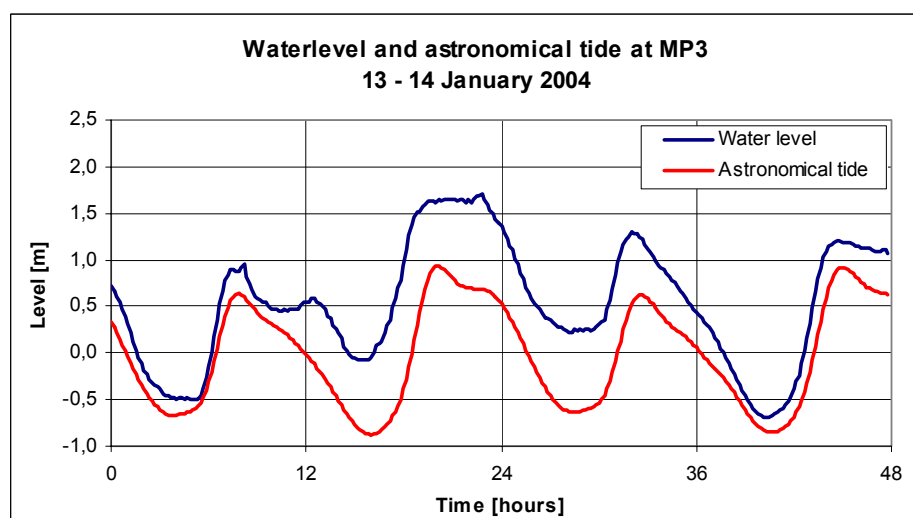
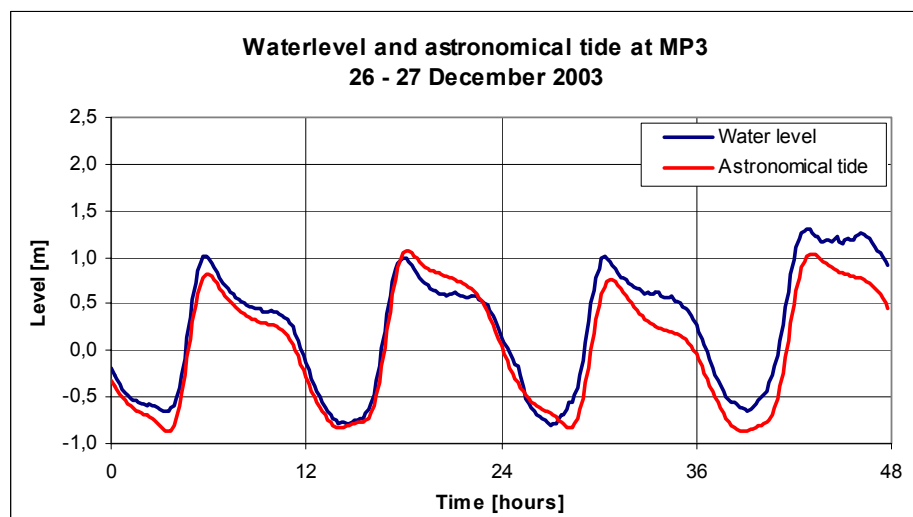
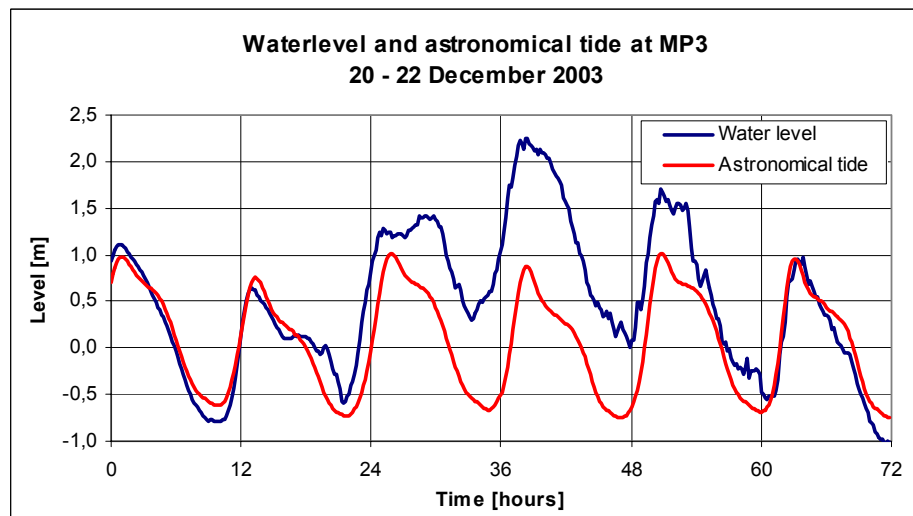
Figure C.2 Frequency curves T_m-10

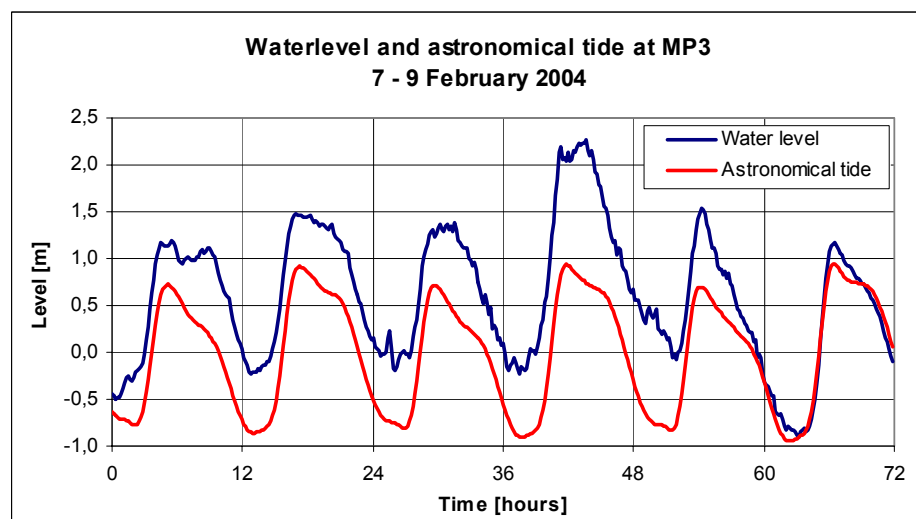
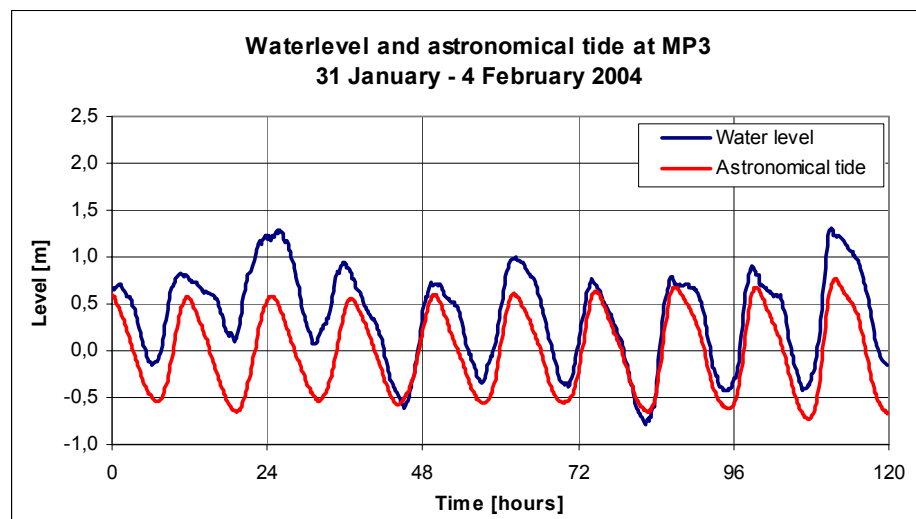
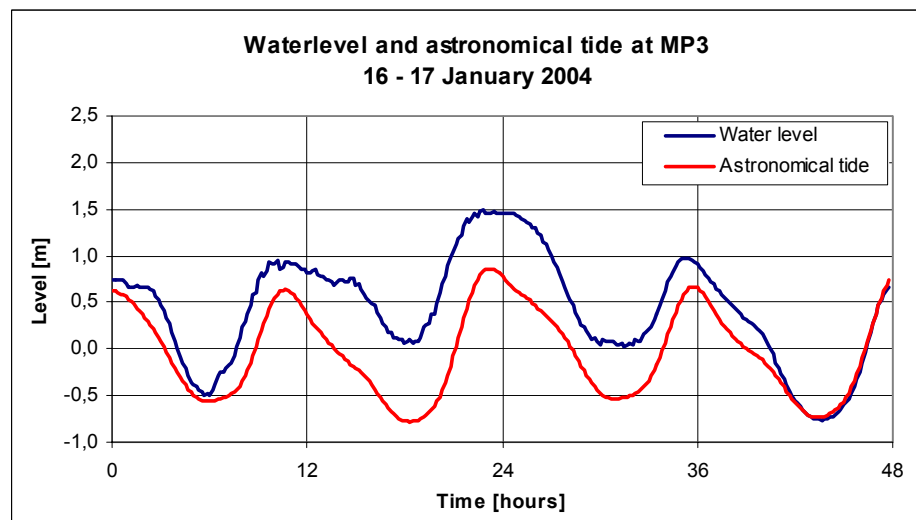


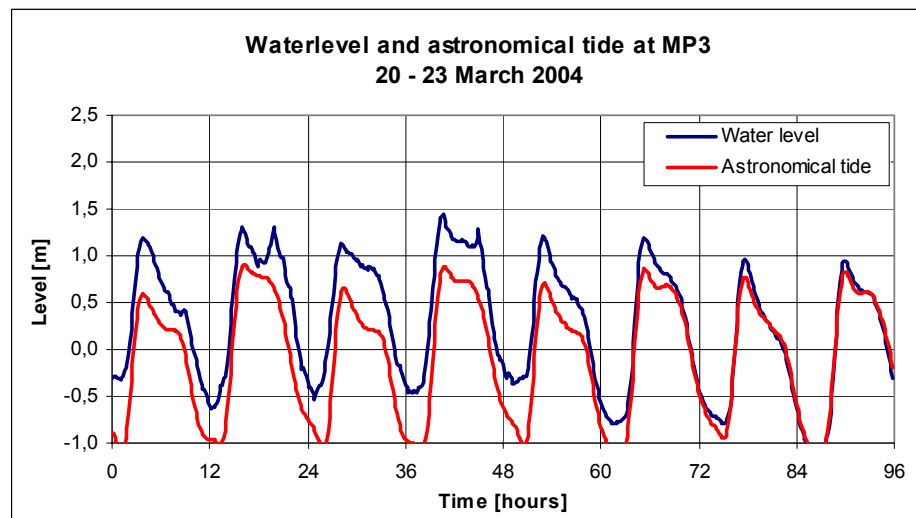
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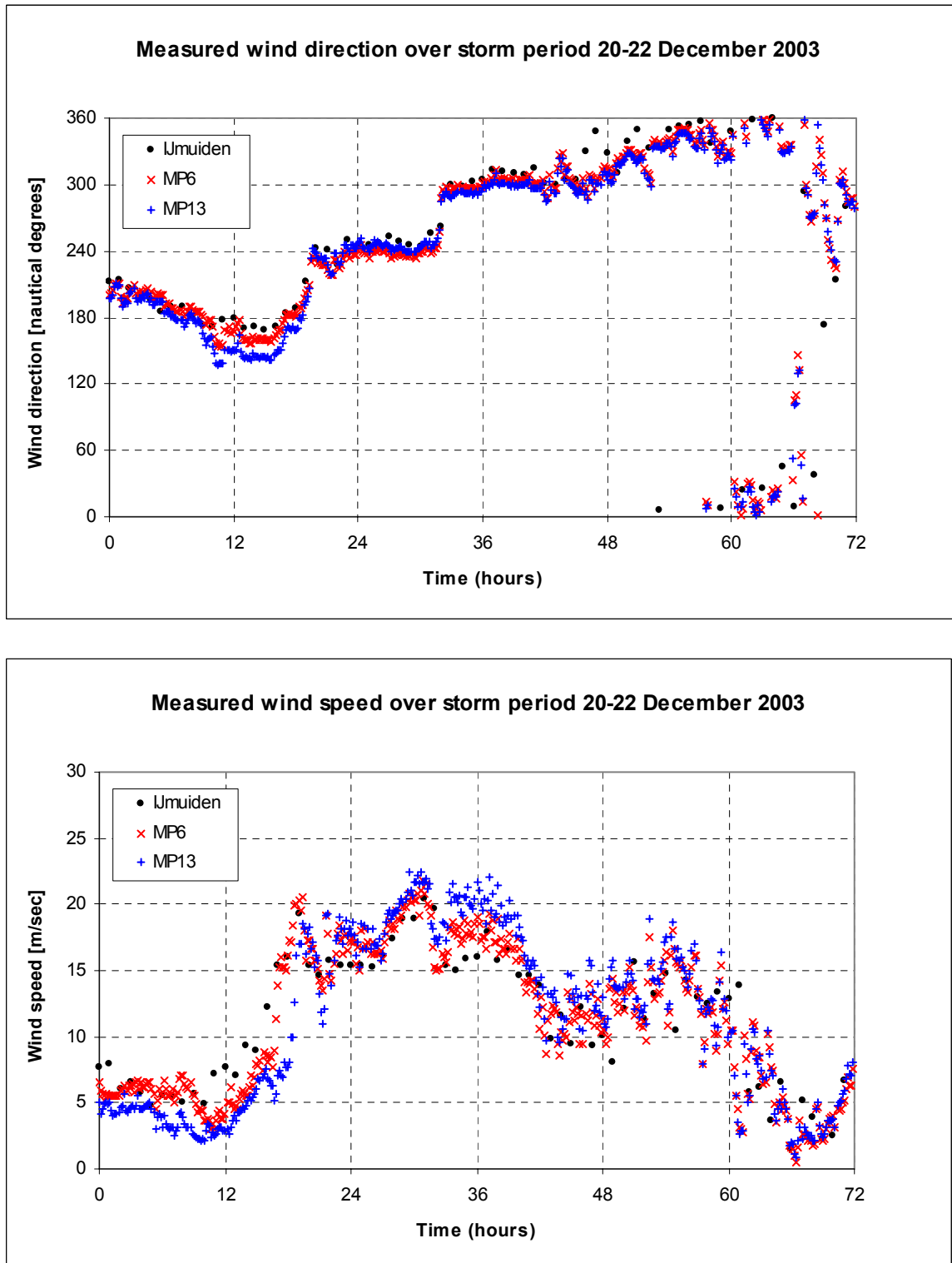


Figure E.2 Wave spectra for MP 1

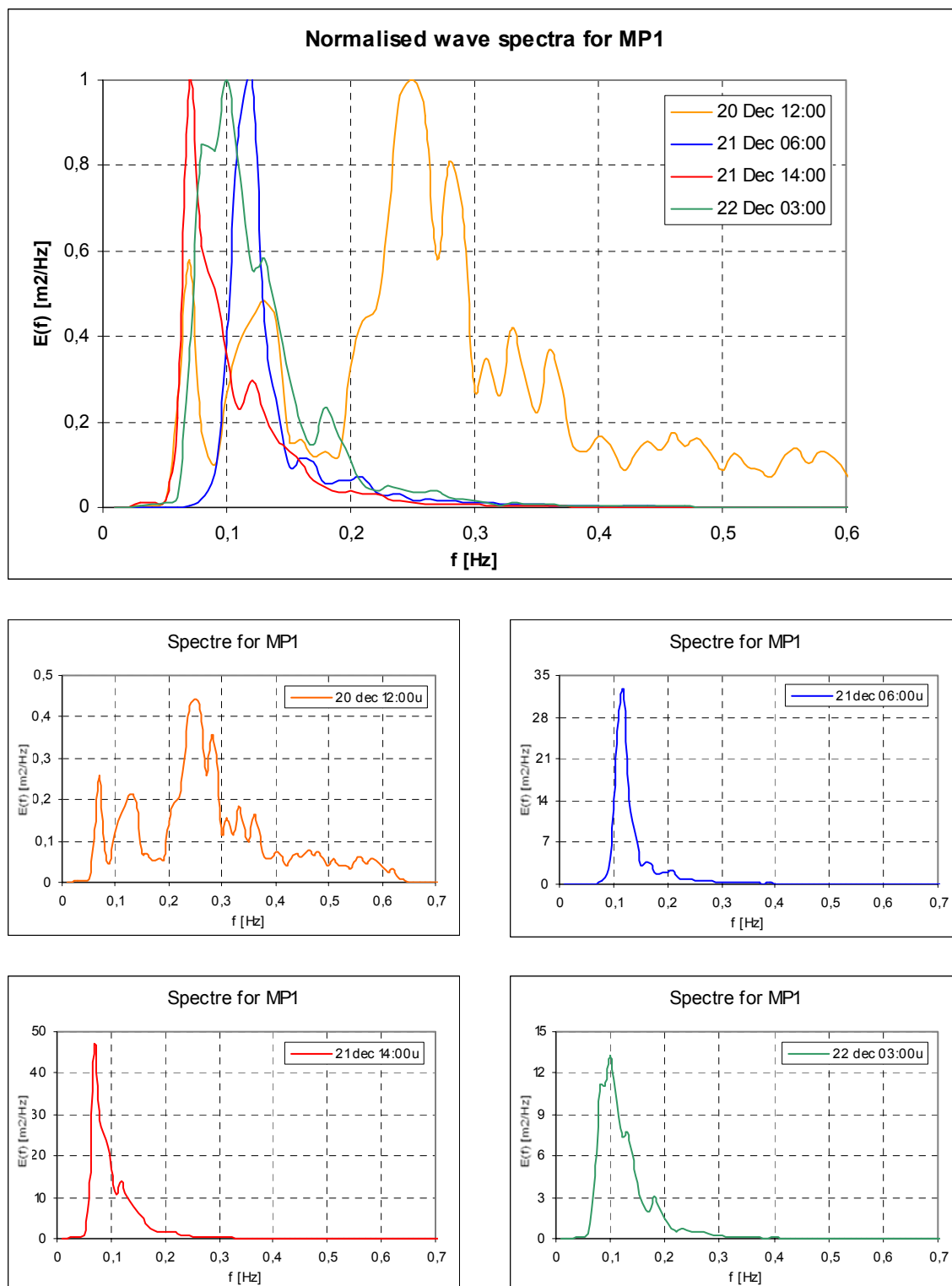
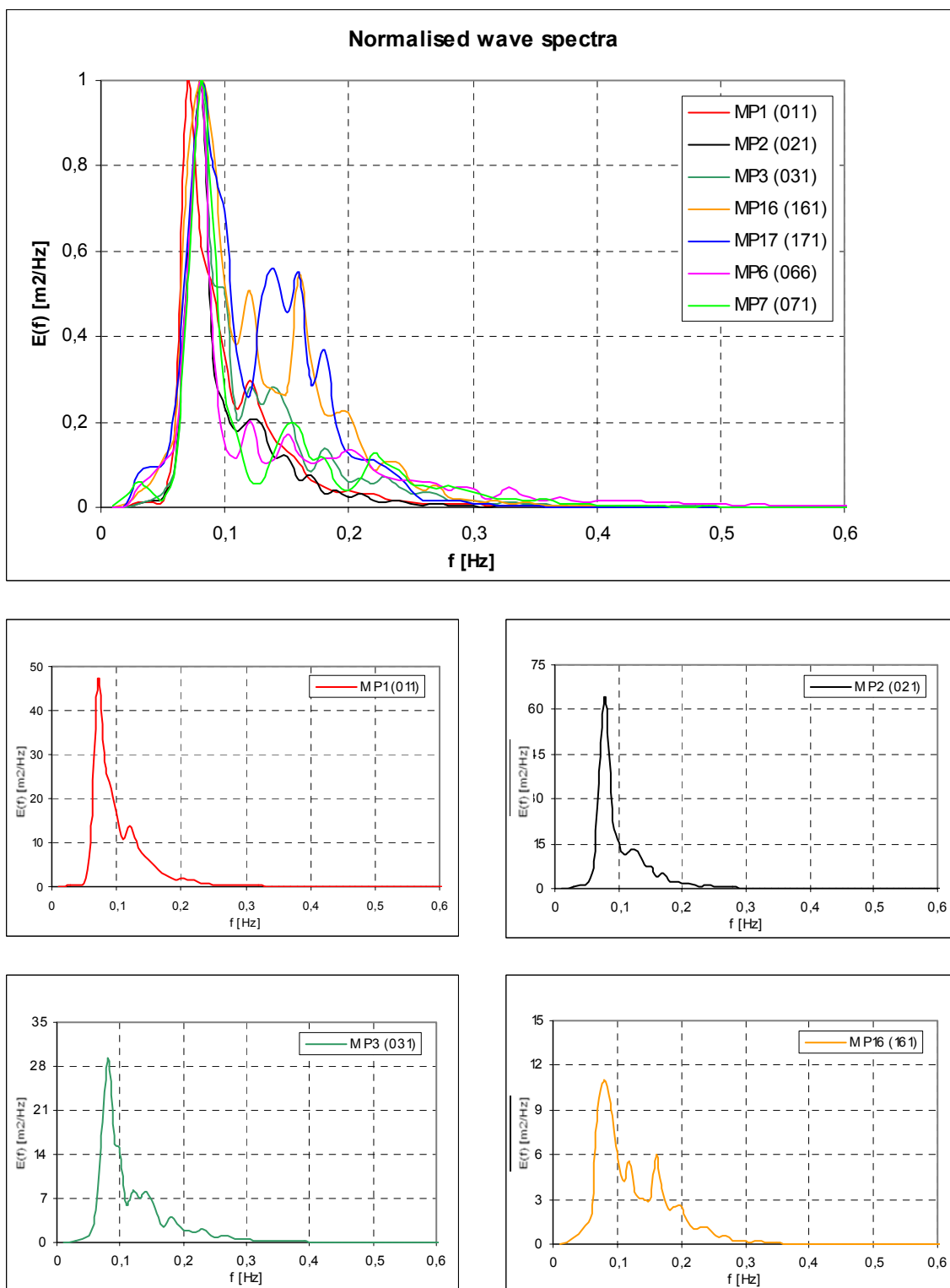


Figure E.3 Wave spectra for the peak of the storm (21 December 2 am)



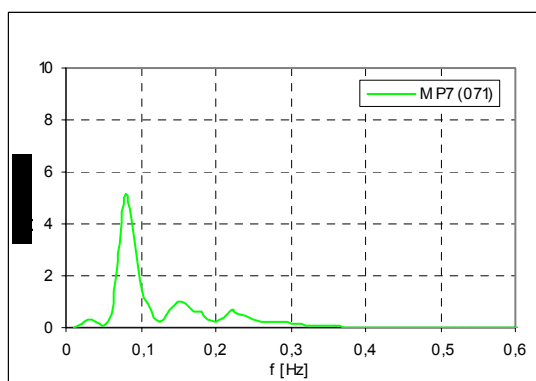
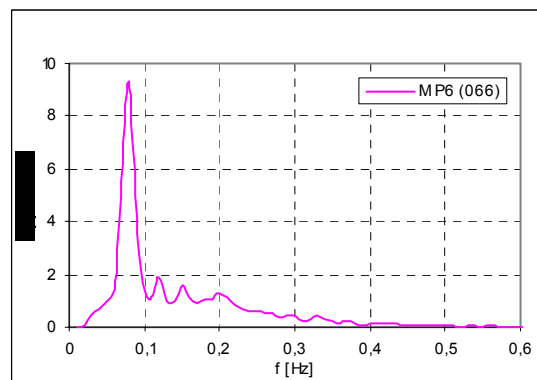
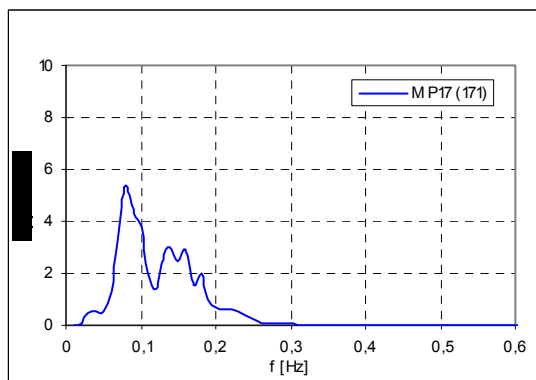
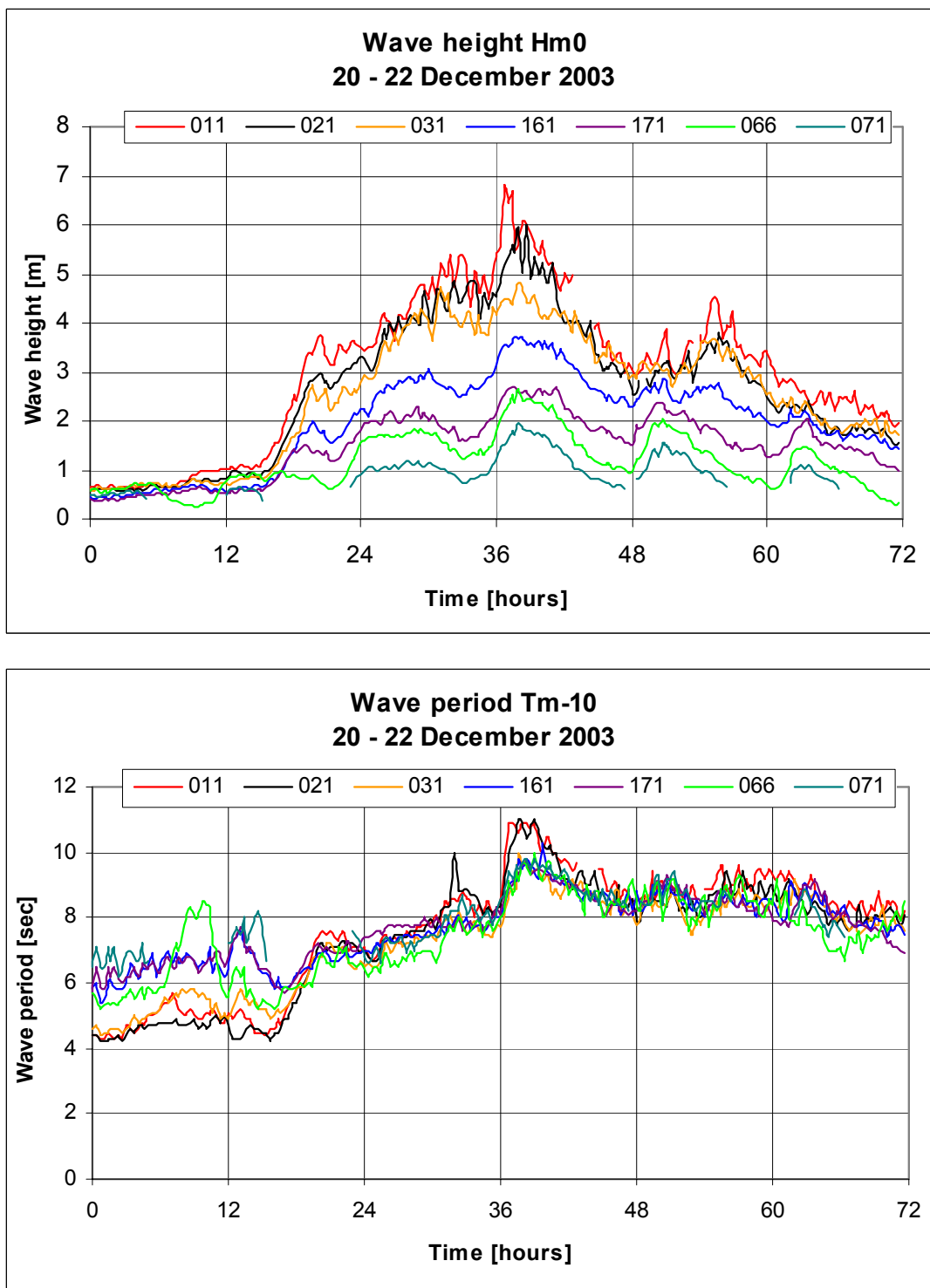


Figure E.4 Wave parameters H_{m0} , T_{m-10} and T_{m02}



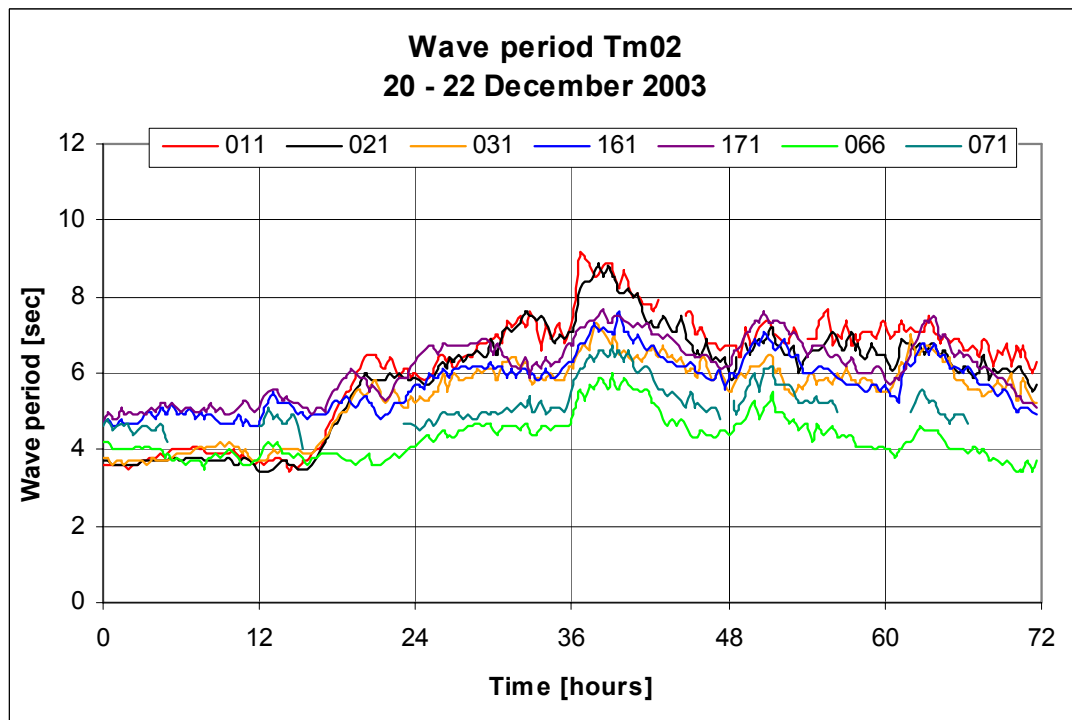
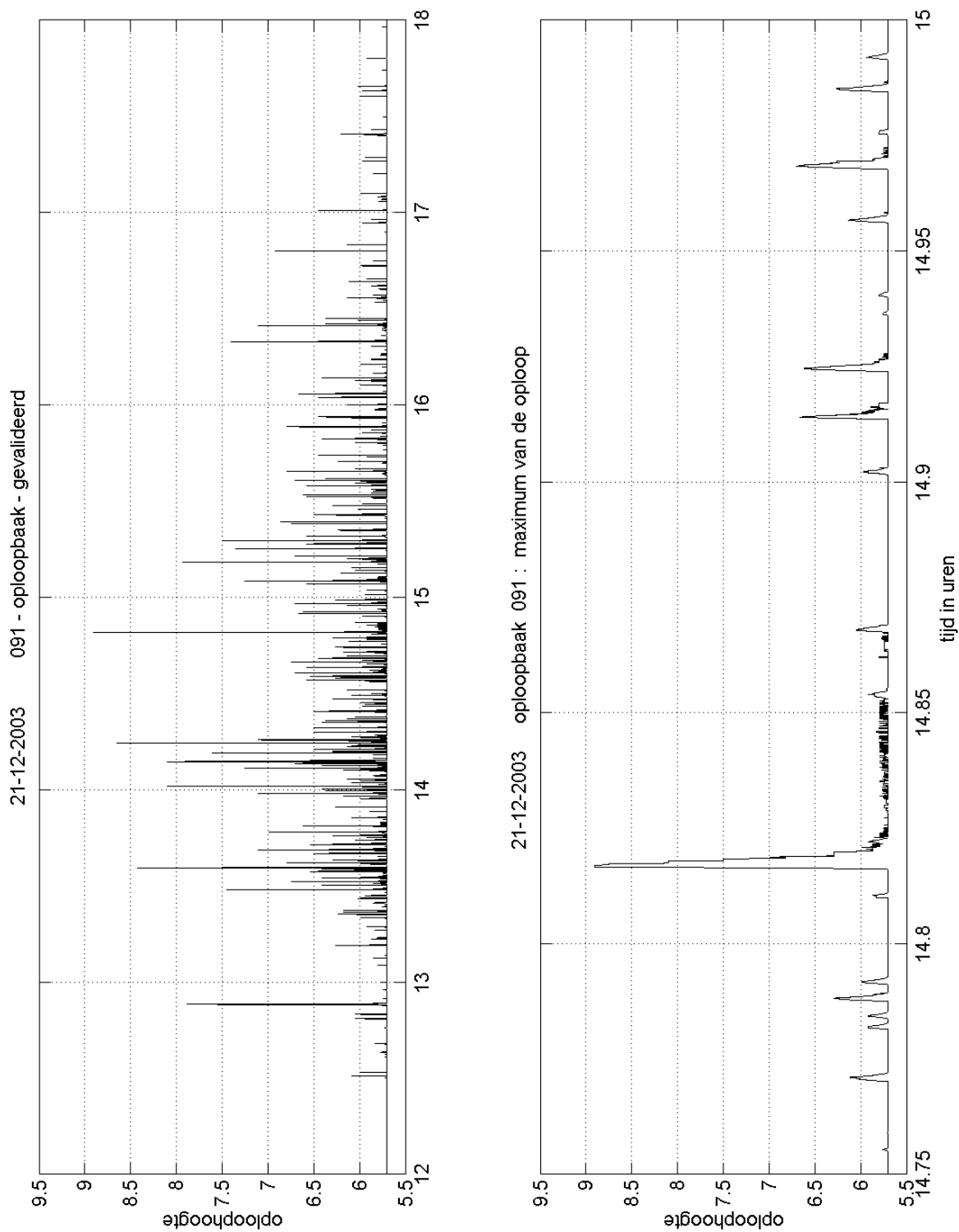


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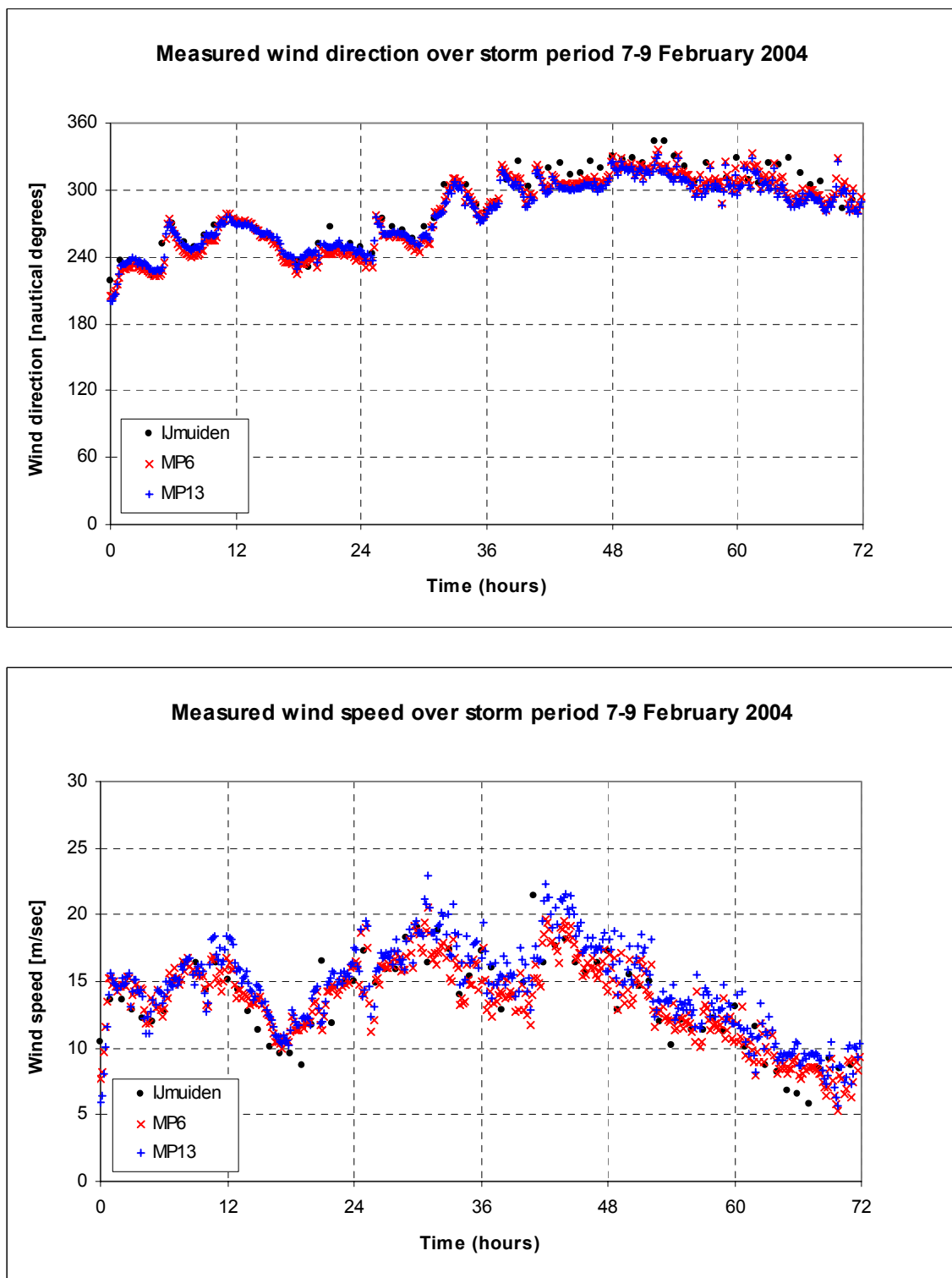


Figure F.2 Wave spectra for MP1

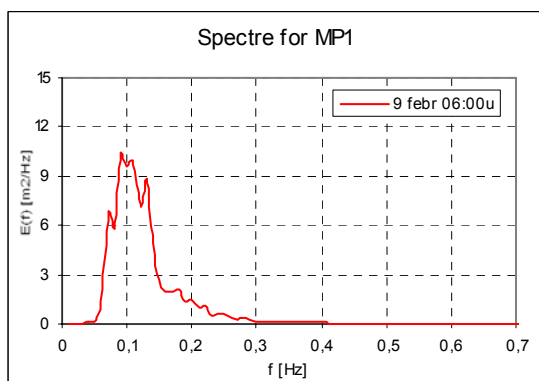
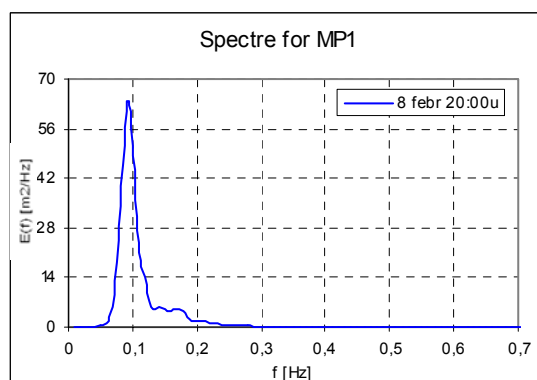
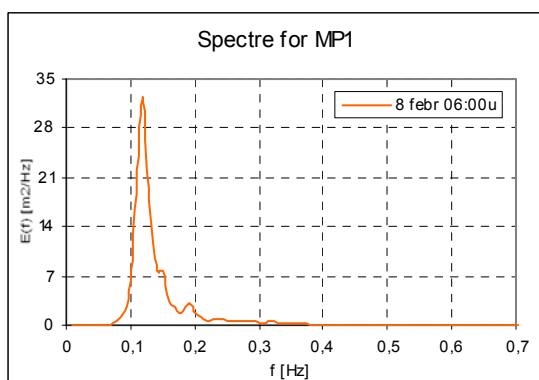
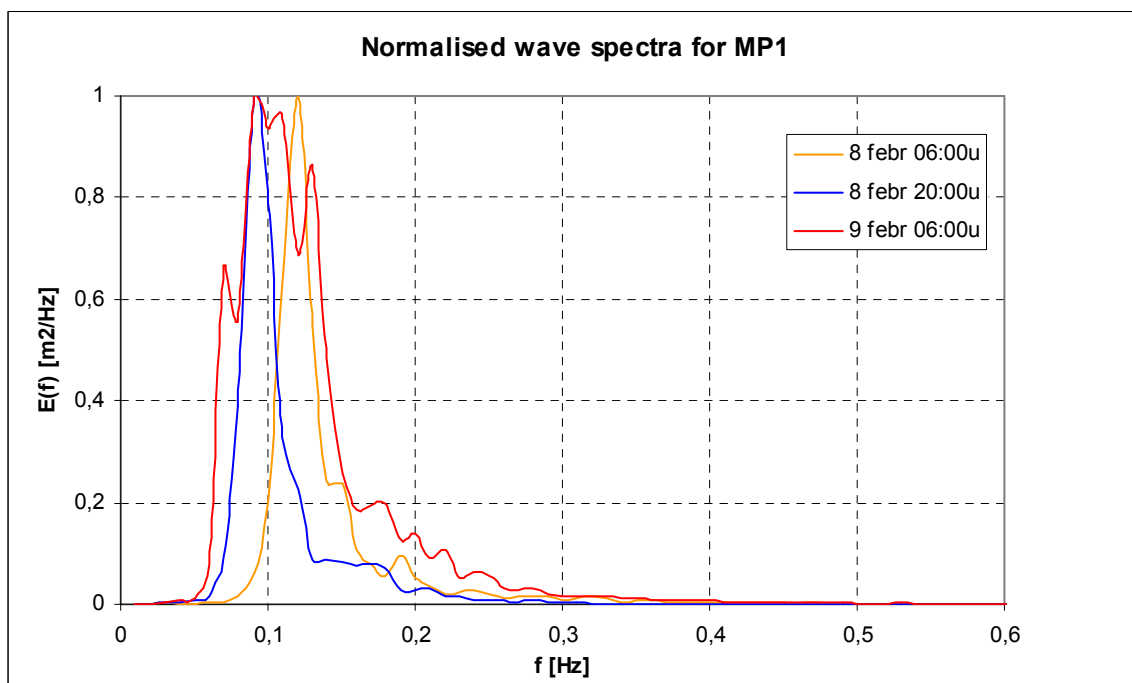
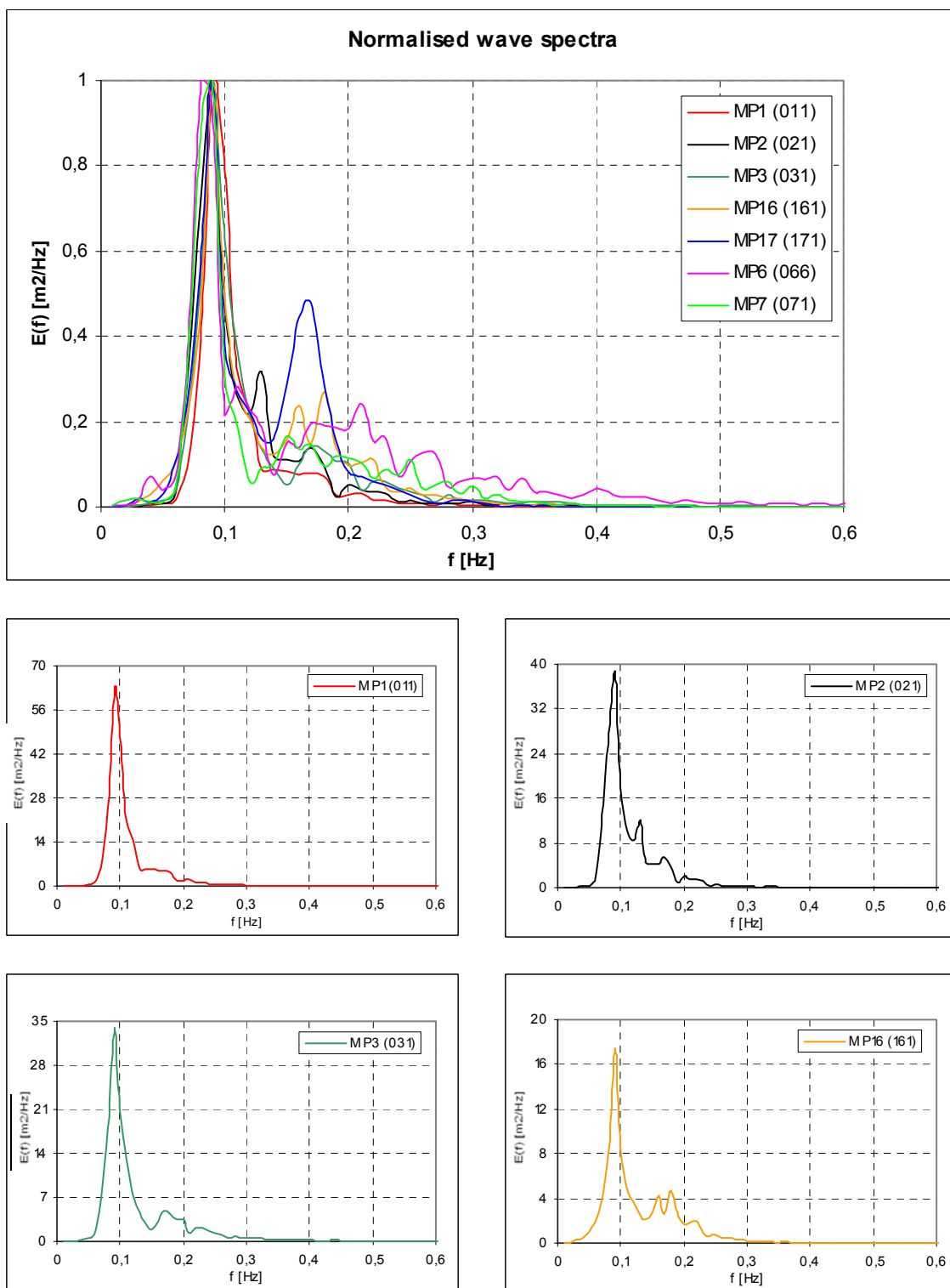
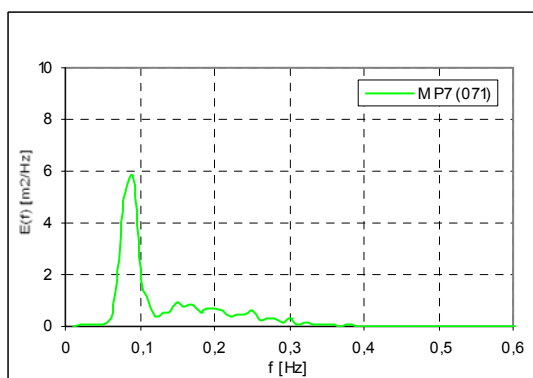
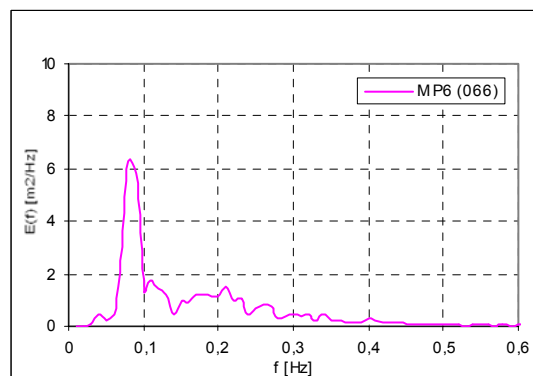
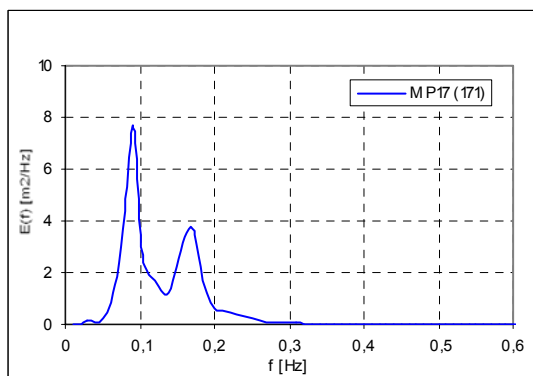
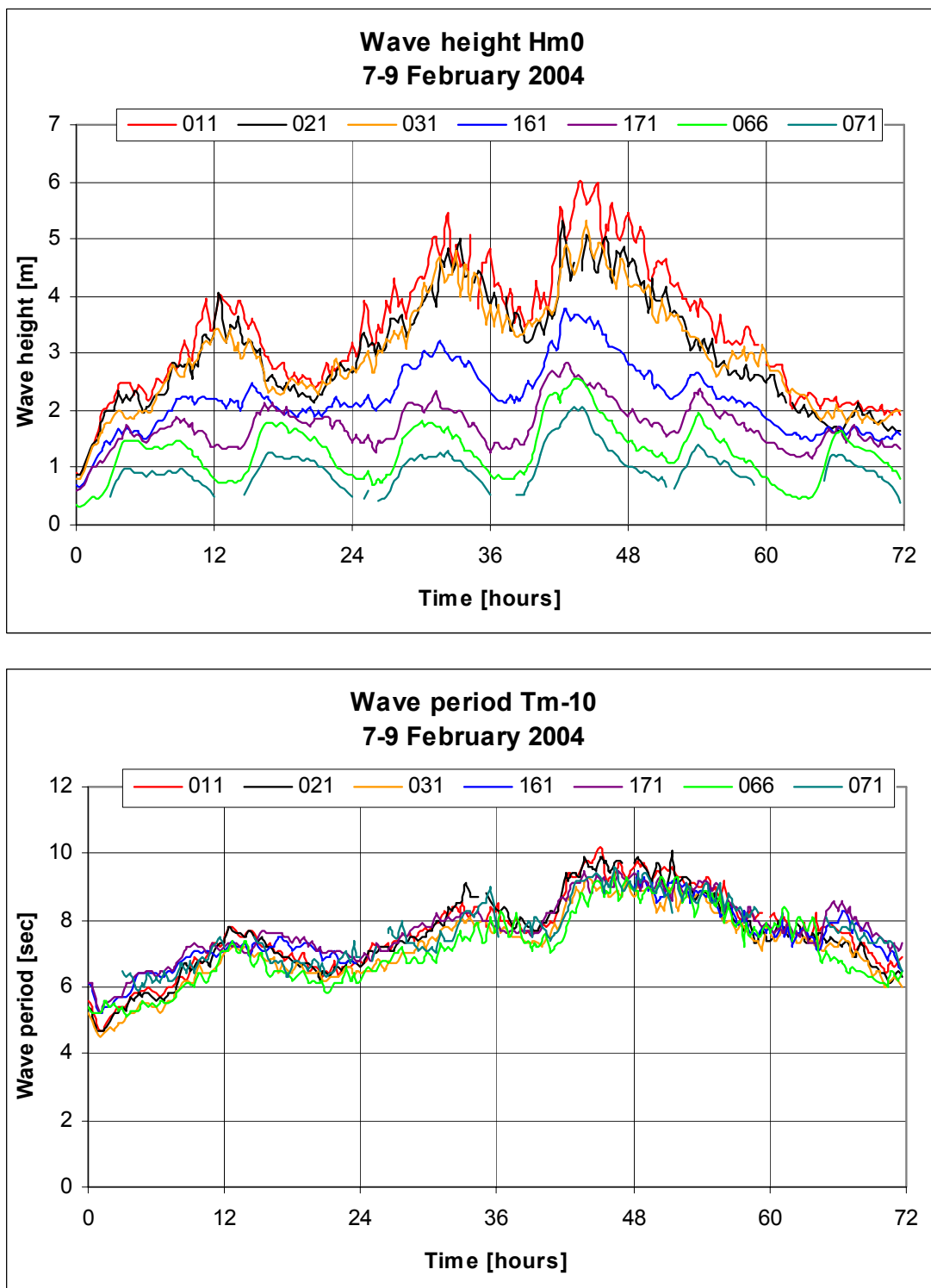


Figure F.3 Wave spectra for the peak of the storm (8 February 8 am)





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Figure F.4 Wave parameters H_{m0} , T_{m-10} and T_{m02}



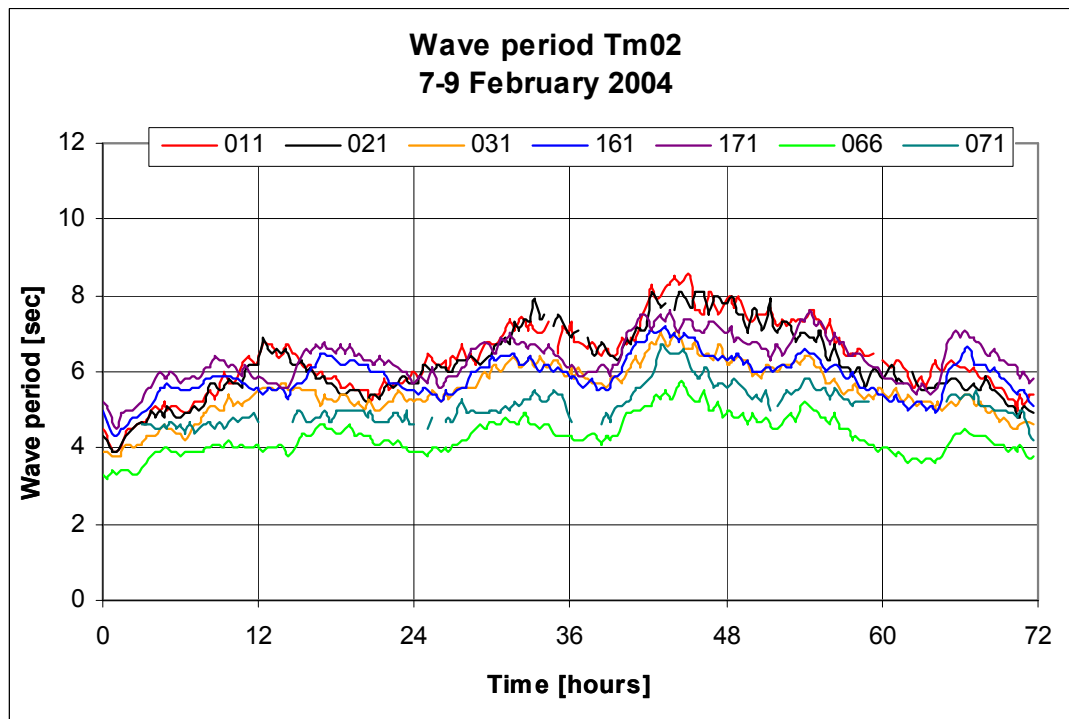
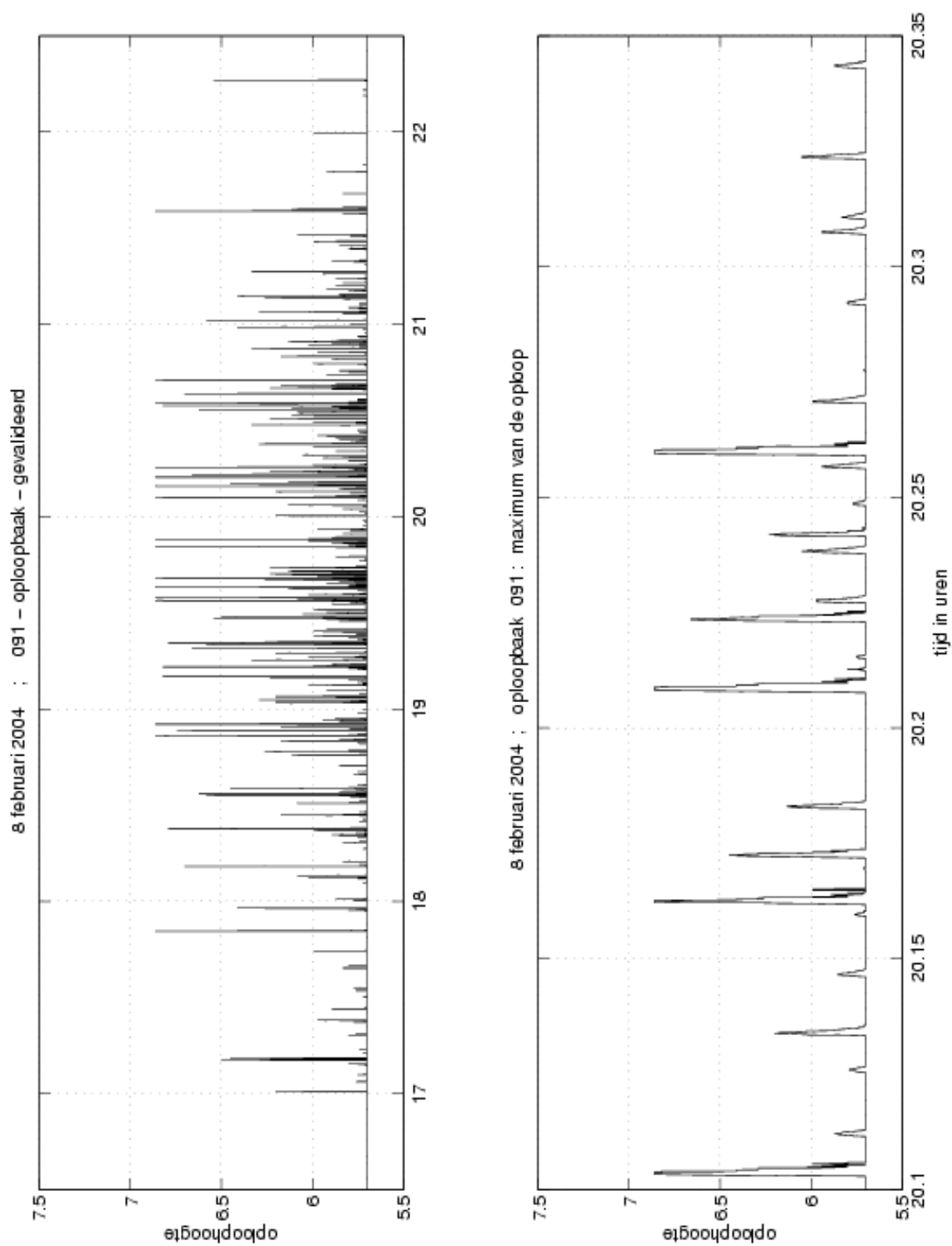


Figure F.5 Wave run-up



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