Prepared for:

Rijkswaterstaat IJsselmeergebied

Wave measurement Lake Taihu, China

Data report 2006

Report

September 2007

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$H_{1/3}$	Significant wave height, determined as the mean of the highest 1/3 part of the waves
$H_{1/10}$	Mean of the highest 1/10 part of the waves
$H_{1/50}$	Mean of the highest 1/50 part of the waves
H_{m0}	Spectral significant wave height, determined from the zeroth moment from the energy spectrum, according to $H_{m0} = 4\sqrt{m_0}$
H_{mean}	Mean wave height in a measurement series
H_{max}	Maximum wave height in a measurement series
H_s	Significant wave height
m_n	nth spectral moment, defined as $m_n = \int f^n E(f)\,df$
σ_H	Standard deviation of the wave height, defined as $\sigma_H = \sqrt{\frac{\sum_i^N (H_i - H_{mean})^2}{N-1}}$ with N is the number of waves
σ_T	Standard deviation of the wave period, defined as $\sigma_T = \sqrt{\frac{\sum_i^N (T_i - T_z)^2}{N-1}}$ with N is the number of waves
$T_{1/3}$	Mean of the highest 1/3 part of the wave periods
$T_{H1/3}$	Mean of the wave periods, belonging to the waves that will be formed by $H_{1/3}$
T_{Hmax}	Wave period of the maximum wave height H_{max}
T_{m-10}	Spectral mean wave period, determined from the zeroth and first negative moment of the energy spectrum according to $T_{m-10} = m_{-1} / m_0$
T_{m01}	Wave period corresponding to the mean frequency of the wave spectrum, determined from the zeroth and first moment of the energy spectrum according to $T_{m01} = m_0 / m_1$
T_{m02}	Wave period corresponding to the quadratic mean frequency of the wave spectrum, determined from the zeroth and second moment of the energy spectrum according to $T_{m02} = \sqrt{m_0 / m_2}$
T_{max}	Maximum wave period in a measurement series
T_p	Peak period of the energy spectrum
T_z	Mean wave period in a measurement series

1 Introduction

1.1 General

RWS IJsselmeergebied (RWS IJG) is executing wave measurements in the framework of the project 'Veiligheidsnormering dijken' (Safety Standards for Dikes). The aim of the wave measurement program is to collect wind and wave data to validate the existing wave models and formulas. Therefore measuring poles were installed on the IJsselmeer and Slotermeer (Lake IJssel, Lake Sloten; The Netherlands). The wave data obtained at the IJsselmeer will be used to get better understanding in the wave climatology on the IJsselmeer, to validate models like SWAN and to make online wave data available for navigation. The wave measuring pole at the Slotermeer is mainly applied to get better insight into the wave growth limits at shallow water. RWS RIZA coordinates the analysis of the measurements on the IJsselmeer and Slotermeer.

Within the framework of the wave measuring program, Rijkswaterstaat and the Taihu Basin Authority (TBA) in China started to collaborate. Three measuring stations will be installed on the large and shallow Lake Taihu to measure wind, water level and waves. The aim of the measurements is comparable to the objective of the wave-recorder pile at the Slotermeer, namely to get better understanding in the formulation of the wave growth limit on shallow lakes with a flat bottom. The dimensions of Lake Taihu are comparable to the dimensions of the Markermeer and IJsselmeer together. An advantage of the location is the relatively large fetch, the limited water depth and the possibility that very high wind speeds occur (possible influence of typhoons).

Since May 2006 one measurement station is operational (measurement station Gonghu); the two others will be operational during 2007. The measurement program at Lake Taihu will be continued at least to the end of 2008.

RWS IJG has commissioned WL | Delft Hydraulics to prepare a brief data report on the measurements in 2006. A more extensive analysis of the data may be carried out in a later stage when data from the other measuring stations are also available.

1.2 Aim of the present report

The aim of the present project is to collect and analyse the available wave and wind data, identify sources of errors and predefine a validation plan. In this study we limit ourselves to the measurements in 2006 at one location (Gonghu).

1.3 Approach

The scope of work of the present study consisted of the following tasks:

- Analysis of available measured data
  - Global analysis of data return, quality and range of conditions
  - Detailed analysis of selected storm periods
- Reconnaissance of errors and plan for validation
- Preparation of a report.

The global analysis of the measured data was carried out based on files with processed data on a 10 minute interval as produced by the measuring system (STAT-files). To obtain an impression of the reliability of these data, a few basic checks were carried out on these data, such as a comparison with previous records.

Based on the results of the global analysis two periods have been selected for detailed processing using the original time-traces from the instruments. The wave data for these periods have been analysed in blocks of 20 minutes. For each of these blocks a number of characteristic wave parameters have been determined. Graphs of selected parameters are used to describe the conditions during the selected storm periods.

Based on discussions with experts on wave measurements and data processing and using the experience gained by processing the first months of data, possible sources of errors in the data have been identified. The way these can affect the results and possible checks that can be included in a more thorough validation are presented.

After a brief description of the measurement site in the Chapter 2, the following chapters give some more details on the methodology and results for three tasks mentioned above: Chapter 3 presents the global analysis, Chapter 4 the detailed analysis of the selected periods and Chapter 5 possible errors and suggestions for validation. In Chapter 6 the accuracy of H_{m0} in the STAT-files and the occurrence of the wave growth limit have been discussed. Chapter 7 summarizes the conclusions and gives some recommendations.

This report has been prepared by Johan Dekker and Carline Bos, who also carried out the analysis of the data using Matlab routines. The discussions with Marcel Bottema (Rijkswaterstaat, RIZA) and Bas Blok were very valuable for our understanding of the operation of the measuring system and some specific details regarding the Log_aLevel.

2 Description measurement locations

2.1 Wave measuring network

The Taihu wave measuring network (Taihu WMN) consists of three measuring stations (see Figure 1):

- Gonghu, in a north-easterly lobe of Lake Taihu
- Dapukou; near the western shore of Lake Taihu;
- Pingtaishan, in the centre of Lake Taihu.

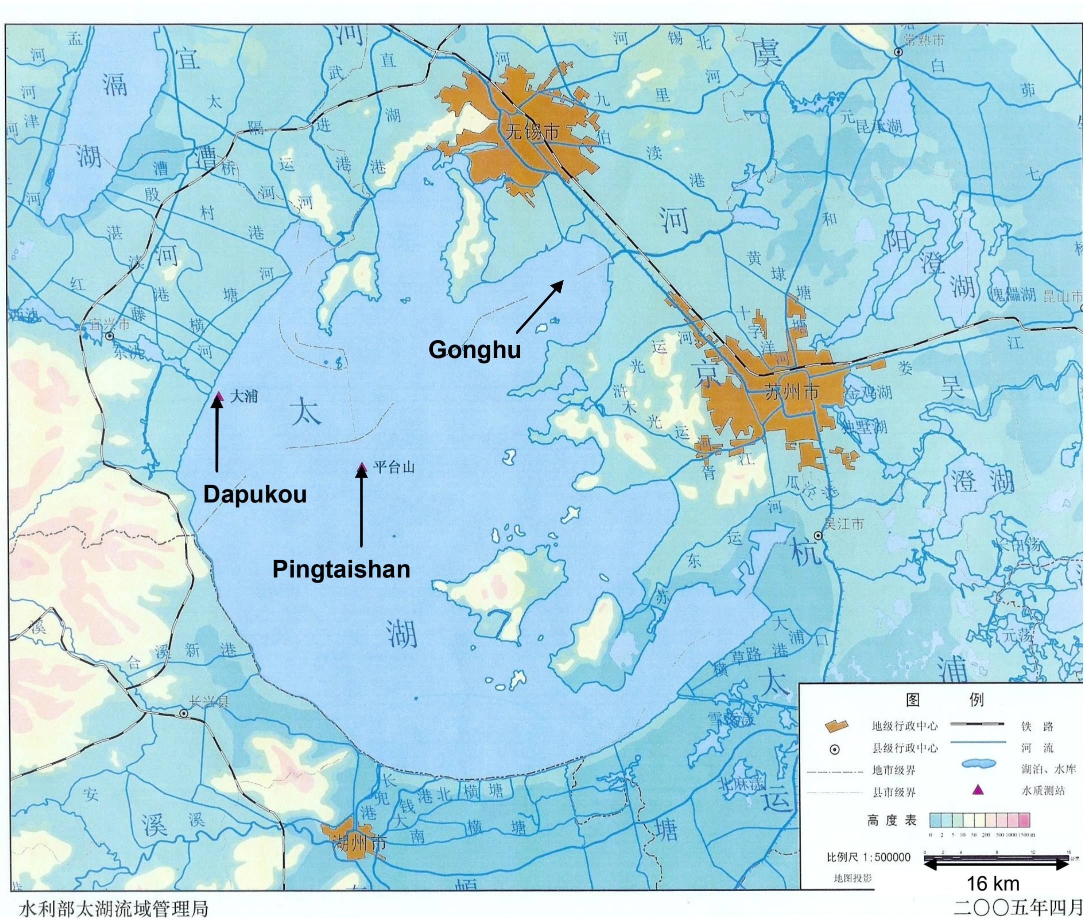


Figure 1 Overview of Lake Taihu with the locations of the three stations

The instrumentation at Gonghu was installed in May 2006 on an existing station for measuring of water quality parameters (see Figure 2). In 2006 the stations Dapukou and Pingtaishan (see Figure 3) were under construction – expected to be operational in March 2007 – so that no data were available yet for these stations. Therefore this report presents only data for Gonghu.

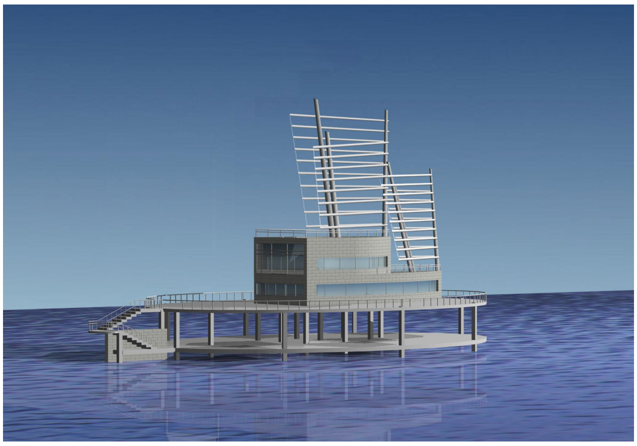


Figure 2 Gonghu measuring station (photo Rijkswaterstaat)

Figure 3 Artist impression of Dapukou / Pingtaishan measuring stations

The location of the stations is given in Table 1. The coordinates for Gonghu are taken from the Taihu WMN Manual (RWS, 2006). The location of the two other stations will be available after installation in 2007.

Station	Latitude	Longitude
Gonghu	31°26'11.8"N	120°24'4.0"E
Dapukou	to be installed in 2007	
Pingtaishan	to be installed in 2007	

Table 1 Locations of the measuring stations

2.2 Instrumentation

The set-up of measuring equipment for the stations is in principal similar. At all three stations, instruments are installed to measure the following principal parameters directly:

- wind speed
- wind direction
- mean water level
- water level fluctuations, from which the wave height is derived

Further some auxiliary instruments are installed to measure the temperature in the datalogger and the voltage of the battery to obtain information on the status of the equipment. The various instruments that are used to measure the above mentioned parameters are given in Table 2.

Parameter	**Supplier**	**Type**
Wind speed	Mierij meteo	Anemometer model 018
Wind direction	Mierij meteo	Wind vane model 508
Water level (mean value)	Druck	Pressure sensor
Water level-fluctuations/wave height	General Acoustics	Log_aLevel
Air temperature (in datalogger)	Campbell	Temperature sensor
Battery voltage	Campbell	Voltage sensor

Table 2 Measuring instruments at the stations

At the Gonghu station the wind meter is connected to the existing sail shaped steel structure. The anemometer is mounted at 23.12 m +MSL, the wind vane at 22.62 m +MSL. The pressure sensor is placed in a PVC-tube and fixed to one of the concrete piles of the platform. The sensor is located at 0.61 m +MSL. The Log_aLevel is connected to a steel beam and fixed on the South-South-westerly side of the main platform level. The end of the beam reaches 1.0 m outside of the concrete platform. The instrument is fixed at a height of 6.90 m +MSL. Considering the position of the station in the lake, the waves from relevant directions (Southeast to West) are not affected by the platform.

According to the TWN Manual (RWS, 2004) the local bottom level is about 1.1 m +MSL. The mean water level at Gonghu during the considered period is 3.25 m +MSL (minimum 2.8 m +MSL, maximum 3.7 m +MSL and 3.1 m +MSL during installation on 9 May 2006).

Considering the height of the anemometer at Gonghu and the mean water level, the measured wind speed is the wind speed at approximately 20 m above the surface. A correction will be required to obtain the wind speed at 10 m above the surface that is commonly used as input in wave hindcast models.

Figure 4 Instruments installed at Gonghu: anemometer and wind vane (left); pressure gauge (centre) and Log_aLevel (right; source photos: RWS, 2006)

2.3 Data acquisition

Data acquisition is carried out using a Campbell CR1000 datalogger. A 'datalogger program' defines the way at which the connected instruments are scanned and data are stored on the datalogger. Further a few additional parameters are calculated. The logger program uses two separate scan intervals. The scan frequency for the acoustic Log_aLevel instrument measuring the water level fluctuations is 4 Hz. The scan rate for all other sensors like the wind-direction-sensor, pressure sensor, battery and temperature-sensor is 1 Hz.

Each wind speed and –direction sample is stored in the 'Wind' DataTable. This file contains therefore data at an interval of 1 second.

Each sample from the Log_aLevel sensor is stored in the data logger's memory. Therefore, the output rate to the 'DataTable' where the water level fluctuations are stored is also 4 Hz. As these data are used to derive the wave parameters, the 'DataTable' for this instrument is called the 'Waves' DataTable.

Part of the data processing, like computation of the wave height, takes place on-line at the datalogger. The following parameters are calculated on-line at 10-minute intervals (i.e. calculated from a dataset of 600 values):

- mean and maximum wind speed
- mean wind direction
- mean water level (from pressure sensor)
- mean water level (from the Log_aLevel)
- an estimator of the wave height H_{m0} (from Log_aLevel)

These derived parameters - and the two status parameters temperature and battery-voltage - are stored in a separate third DataTable. This 'Stat' DataTable has an output interval of 10 minutes. Note that the wave height H_{m0} calculated on-line is computed using an approximate procedure; the correct procedure is used in the detailed analysis.

On a scheduled 12-hourly basis all measured data in the DataTables is written (appended) for each measuring station into three data-files on the central PC of the Taihu WMN. These files are: STATION_Waves.dat, STATION_Wind.dat and STATION_Stat.dat containing the raw wave data, the raw wind data and the 10-minutes processed data for the relevant STATION.

Creating files for each day

Once per day the above described data-files are automatically split into files per day. Thus the following files are obtained for each day:

- STNyymmddStat.dat, containing the 10-minute averaged statistics; a complete file contains 144 records (6 per hour, 24 hours per day)
- STNyymmddWind.dat, containing the 1 Hz raw data of the anemometer and the wind vane; a complete file contains 86400 records (every second per day)
- STNyymmddWave.dat, containing the 4 Hz raw data from the Log_aLevel; a complete file contains 345600 records (four every second per day)

The station code STN in the above file names is GON for Gonghu. For the stations Dapukou and Pingtaishan these codes will be respectively DAP and PIN.

2.4 Data from the Log_aLevel

Though the Log_aLevel has been tested in a wave flume before it was implemented at the RWS stations in the IJsselmeer (WL, 2005), the first experience in the field showed that under certain conditions (H_{m0} > 0.4-0.5 m) the results were not very reliable (Bottema, 2006). This has lead to modification of the software/settings of the instrument. This has improved the data from the instruments (Bottema, 2007). However, the working principle of the instrument, reflection of a sound beam by the water surface, can lead to unreliable data in the following situations (Bottema, 2007):

- Calm conditions (no wind)
- High wind speeds
- Steep water surface slopes

A more detailed discussion is given of possible errors is given in Section 5.3.

The analysis in this report is based on Log_aLevel data from an instrument with the old software/settings. In the course of 2007 the instrument at Gonghu will be upgraded. A very detailed analysis of the validity based on the present data is therefore not useful. However, the present analysis has been very useful to set-up procedures for the processing of the data and to get insight in the most critical aspects of the processing. In view of the above considerations on the functioning of the instrument at high wind speeds, one of the challenges will be to develop procedures to get as much as possible wave information of reasonable quality from the signals to reach the goal of analysing the wave growth limit in shallow water.

3 Global analysis of available data

3.1 Data return

Figure 5 shows the availability of the measurement data in the STAT-files. The availability of data on the measurement location is indicated per day. Distinction is made between 0%, 25%, 50%, 75% and 100% availability of the data. It can be seen that the data return in these files is fairly good. Periods with missing data are usually short. Only in November data are missing for about 10 days. A summary is given in Table 3.

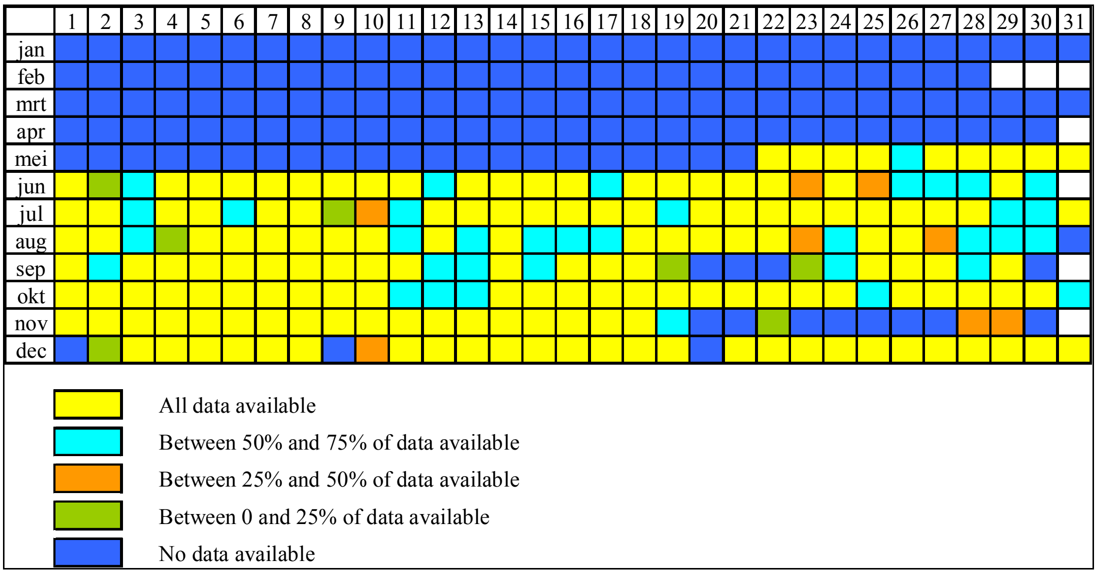


Figure 5 Availability of data in STAT-files at Gonghu in 2006

Month	All data	50%-75%	25%-50%	0%-25%	No data
May	9	1			21
June	20	7	2	1	
July	23	6	1	1	
August	17	10	2	1	1
September	18	6		2	4
October	26	5			
November	18	1	2	1	8
December	26		1	1	3

Table 3 Summary of data return in the STAT-files at Gonghu in 2006

At this stage the data return was further evaluated by checking whether the daily files with the detailed data for wind and waves were available. Figure 6 and Figure 7 show the availability of respectively the WIND and WAVE-files. In Figure 6 it can be seen that occasionally some files are missing. Usually this coincides with missing WAVE-files (see Figure 7) and lacking data in the STAT-files. This is probably due to some failure in the measuring system. In Figure 7 it is however remarkable that the WAVE-files are missing for the entire period from 17 August to 22 September. As the STAT-files provide data on Hs for most of this period, no explanation can be given. Possibly some files have not been transferred from the PC of the Taihu WMN to RDIJ. From the global analysis (see further in this chapter) it appears that no important events occurred during this period of missing WAVE-files. The issue has therefore not further been pursued.

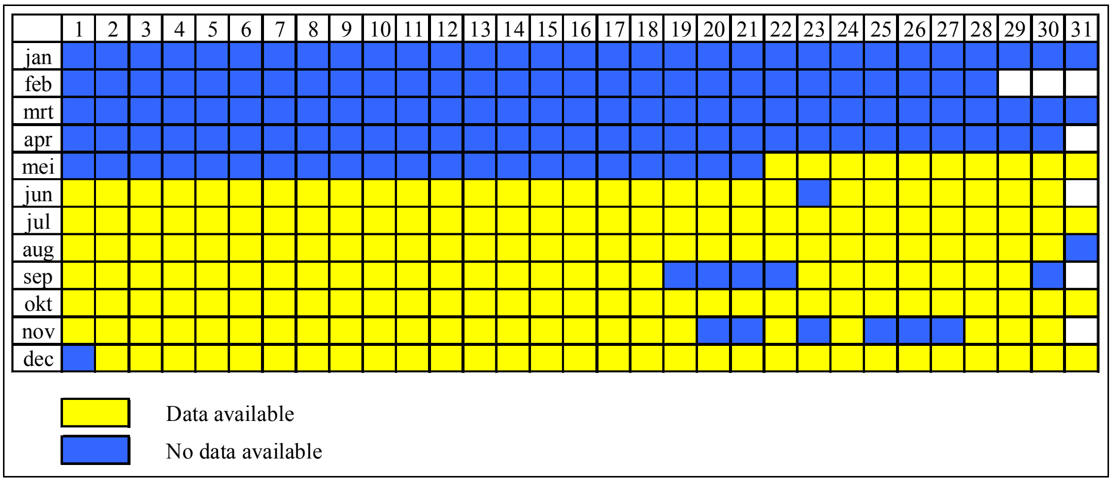


Figure 6 Availability of WIND-files at Gonghu in 2006

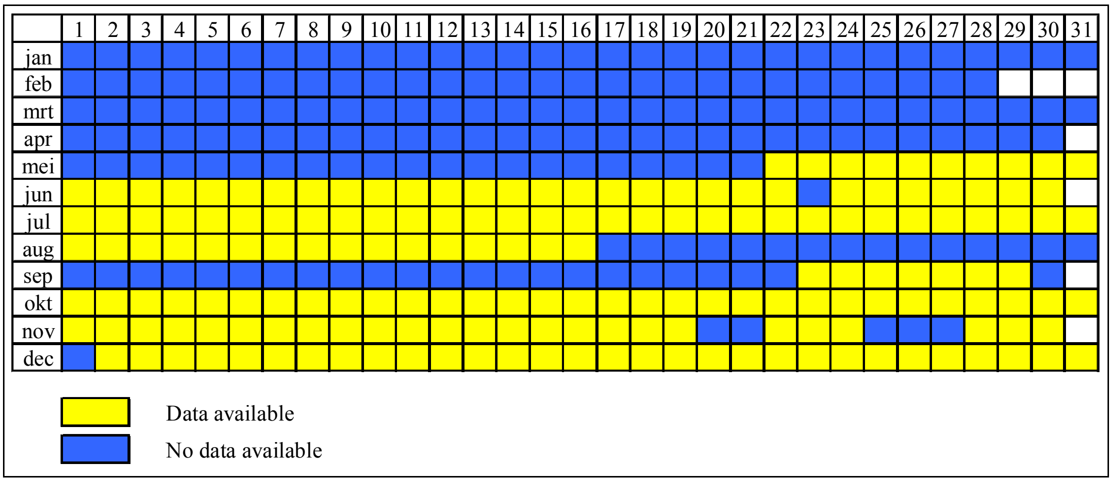


Figure 7 Availability of WAVE-files at Gonghu in 2006

3.2 Processing of STAT-files

For the global analysis of the conditions at Gonghu station during 2006, a dedicated Matlab script was written. This Matlab script reads all available STAT-files and combines the data to a time series of data for the entire year. This time series of data is used for further processing, e.g. to prepare plots of the measured conditions per month.

Initially, plots were prepared of the data as given in the STAT-files. Figure 8 shows an example plot of the data for December 2006. It is obvious from this plot that the data contain erroneous results, mainly in the data (both wave height and water level) from the Log_aLevel. The significant wave heights in the STAT-files contain values up to several metres, which is physically impossible at the site. These errors in the wave height coincide with errors in the water levels from the Log_aLevel. At other moments the water level data from the Log_aLevel are fairly consistent with those from the pressure sensor (WL-L resp. WL-P in second panel of Figure 8), though a small off-set between the two seems to exist.

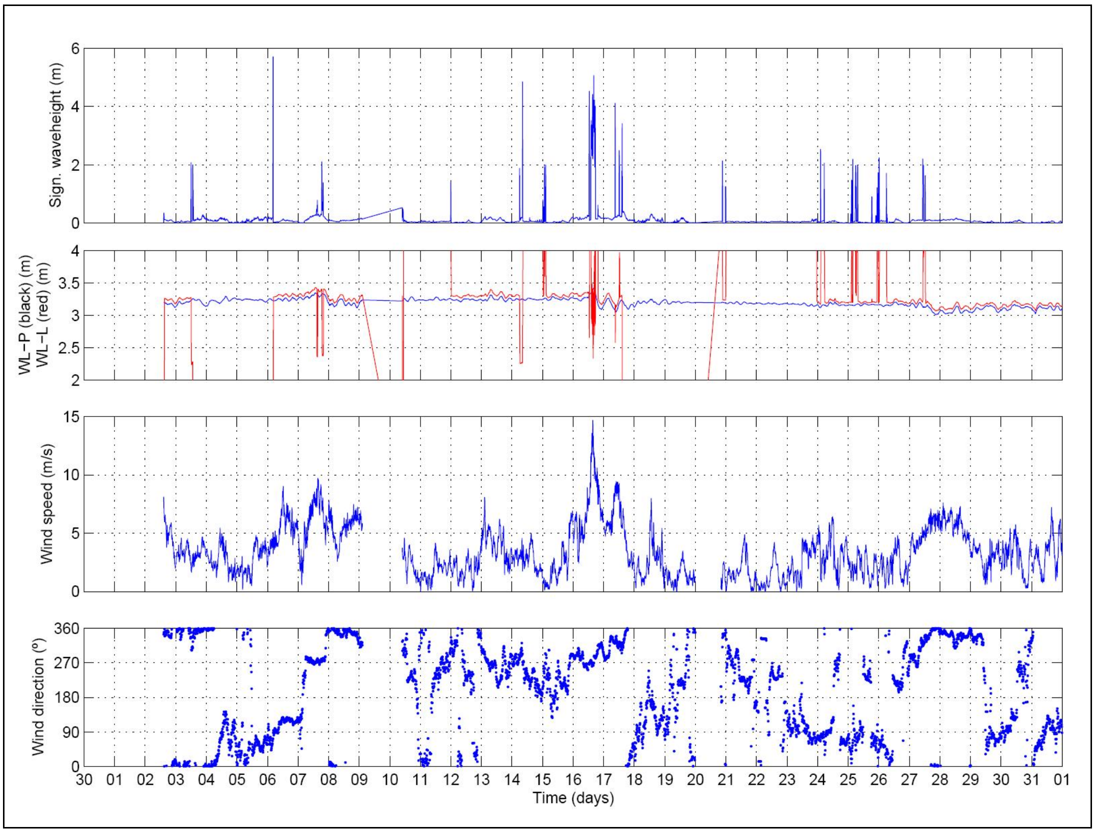


Figure 8 Example plot of data from the STAT-files (December 2006)

Following these initial results a few rough checks were implemented to eliminate these obviously wrong data. For the significant wave heights all values not complying with the following criteria were eliminated.

$$H_{s,i} < 1.6 H_{s,i-1} \ , \qquad (3.1)$$

$$H_{s,i} \leq 0.5\ m \ , \qquad (3.2)$$

where i denotes the record number in the STAT file. For the water level based on the Log_aLevel recorder all values deviating more than 0.5 m from the average over all available data (3.25 m +MSL), were eliminated. Note that these are preliminary criteria that will need to be refined for the data from the upgraded Log_aLevel.

3.3 Conditions during 2006

Plots of the resulting time series from May until December 2006 are shown in Appendix A. Figures A.1 to A.8 show for each month the significant wave height, water level, wind speed and wind direction at Gonghu station. Water levels are shown both from the pressure sensor (in blue) and from the Log_aLevel instrument (in red). Some interesting aspects of the measured data are briefly described below.

Water level

The water level in the lake varies between 2.8 m +MSL and 3.7 m +MSL during the period of the measurements. The mean value is about 3.25 m +MSL. In the records the effect of the wind on the water level can clearly be seen. During periods with strong wind from westerly directions the water level at Gonghu increases with a few decimetres (see e.g. 27 May, 22 June, 26 August, and 16 December). Strong wind from north-easterly direction seems to lead to a lower water level (e.g. 14 July). Considering the location of the station in the north-easterly lobe of the lake this is consistent with the expected response of the lake to wind.

It is interesting to note that there seems to be some seiching in the lake after the fairly sharp drop in the wind speed on 27 May and 17 December: The water level shows some oscillations with a height in the order of a few decimetre and a period in the order of 7 hours on 27 May and 12 hours on 17 December.

It can further be seen that the water level increases gradually during July from about 3.25 m +MSL to about 3.6 m +MSL. In August the level drops again to the mean level. In September similar long-term variations can be seen. Winds are very weak in these periods; the variation in water level may be due to variations in inflow and outflow of the lake.

Finally the Log_aLevel appears to give values that are generally a few centimetres higher than those from the pressure sensor. As discussed in Section 3.2 the results from the Log_aLevel contain also erroneous readings. In the data processing, part of these erroneous data has been removed, which shows up as gaps in the red lines.

Wind speed and direction

The wind speeds are generally very moderate. The graphs show that in some months (e.g. September and October) the wind speeds even rarely exceed values of 5 m/s. In these months the directions are generally from north-easterly directions. Periods in which the wind speeds exceed 10 m/s occur on average only 1-2 times per month. The duration of these events varies considerably. On 14-16 July the wind speed was 10 m/s or more for about two days, whereas on 22 June the wind speed exceeded 10 m/s only for about half an hour, although one of the 10-minute averages was as high as 18.7 m/s.

The range of wind conditions that occurred during the period of the measurements in 2006 is illustrated in the wind rose in Figure 9. Table 4 gives the corresponding joint occurrence values. It can be seen that the highest wind speeds are from south-easterly and westerly directions. Northerly and South-easterly directions are relatively frequent. This may be caused by the monsoon climate.

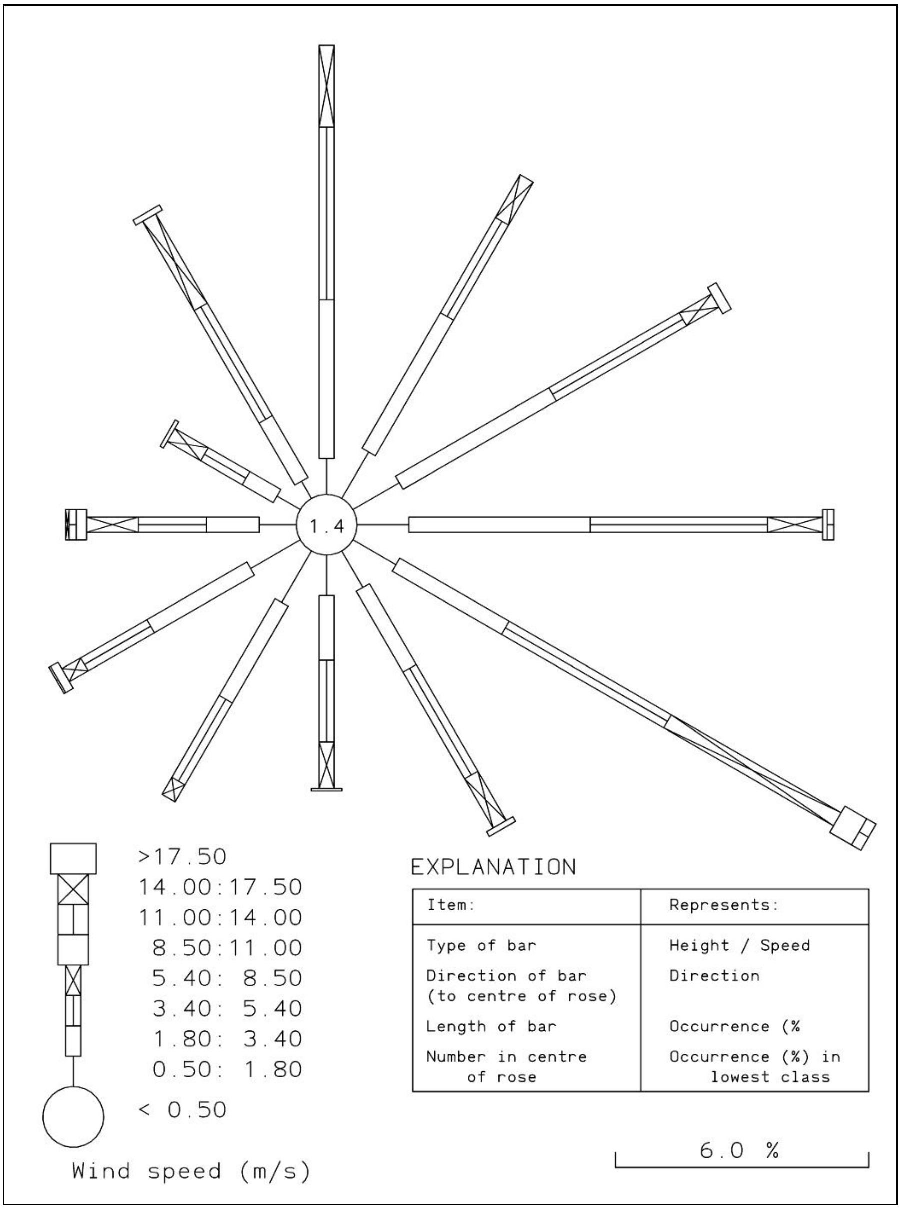


Figure 9 Wind rose for 10-minute average wind measured at Gonghu (22 May – 31 December 2006)

Wind speed (m/s)	Wind direction (°N)												
	0	30	60	90	120	150	180	210	240	270	300	330	All
< 0.50	0.09	0.10	0.10	0.08	0.09	0.09	0.12	0.15	0.19	0.11	0.10	0.13	1.39
0.50 - 1.80	0.85	1.27	1.27	1.23	1.17	1.00	0.96	1.41	1.36	0.88	0.64	0.47	12.50
1.80 - 3.40	3.76	3.71	4.20	4.30	2.99	2.21	1.53	2.65	2.73	1.25	0.85	1.70	31.88
3.40 - 5.40	4.09	2.60	3.56	4.20	4.43	2.92	1.94	2.24	1.81	1.61	1.14	3.08	33.62
5.40 - 8.50	1.94	1.17	0.88	1.31	4.64	1.35	1.10	0.47	0.51	1.23	0.91	2.44	17.96
8.50 -11.00	0.01	0.03	0.23	0.10	0.60	0.13	0.06	0.02	0.21	0.24	0.09	0.14	1.85
11.00 -14.00	0.00	.	0.00	0.16	0.25	0.02	.	.	0.05	0.17	0.02	.	0.68
14.00 -17.50	.	.	.	0.00	0.01	.	.	.	0.01	0.08	.	.	0.11
17.50 -21.00	.	.	.	.	.	.	.	.	0.00	.	.	.	0.00
21.00 -24.50	.	.	.	.	.	.	.	.	.	.	.	.	.
24.50 -28.50	.	.	.	.	.	.	.	.	.	.	.	.	.
28.50 -33.00	.	.	.	.	.	.	.	.	.	.	.	.	.
>33.00	.	.	.	.	.	.	.	.	.	.	.	.	.
Total	10.75	8.89	10.24	11.38	14.20	7.72	5.71	6.94	6.88	5.58	3.75	7.96	100.00

Table 4 Joint occurrence of wind speed and direction at Gonghu (period 22 May – 31 Dec 2006; in %)

The stations Dapukou and Pingtaishan that will be operational in the course of 2007 seem to be well positioned with respect to the South-easterly wind directions.

Wave height

Wave heights are generally low. The significant wave height is mostly below 0.2 m. During stronger winds from southerly to westerly directions the wave heights increase to values up to about H_s = 0.4 m. For wave heights above H_s = 0.4 m or slightly higher the results in the STAT-files appear to be not very reliable in most cases. This is related to the problems with the software/settings of the Log_aLevel and is expected to improve with the new software/settings to be implemented in the course of 2007.

4 Description storm periods

4.1 Introduction

This chapter describes the conditions during two storm periods in 2006 in more detail. These storm periods were selected based on the global analysis of the data in Chapter 3. First a shortlist of interesting events was made by selecting periods of strong wind (wind speed of 12 m/s and higher). Table 5 gives some characteristics of these events, which are described in some more detail below.

Date	Wind speed	Wind direction	Sign. wave height
27 May	17 m/s	270°N	> 0.4 m
22 June	19 m/s	225°N	0.15 m
29 June	13 m/s	290°N	0.2 m
1 July	14 m/s	250°N	0.3 – 0.45 m
15 July	15 m/s	90°N	0.2 – 0.35 m
26 August	15 m/s	240°N	< 0.2 m
16 December	15 m/s	270°N	0.3 – 0.4 m

Table 5 Overview of events with wind speeds over 12 m/s at Gonghu

May 27th 2006
On this day the wind speed increases to about 17 m/s. The wind direction is around 270 N and the wave height increases considerably. Though the wave heights during the storm peak seem to be less reliable, this storm period has been selected for further investigation, hoping the detailed analysis provides useful results around the storm peak.

June 22nd 2006
This day the wind speed increases to about 19 m/s. However the duration is very short, possibly because it is caused by a thunder shower, so that the wave height does not reach very extreme values. This event has not been examined further. Note that this event would not be in the “short list” when the hourly mean wind speed instead of the 10-minute values from the STAT files were used.

June 29th 2006
The wind speeds reaches values just above 13 m/s, but due to the more north-westerly direction and the short duration of the event, the significant wave heights remain below 0.3 m. This event has not further been elaborated.

July 1st 2006
The wind speed reaches values between 10 and 14 m/s for several hours. Wind directions are westerly to south-westerly. As the scope of the project included detailed processing of only two storm periods, this event has not been elaborated. The event could be relevant for detailed processing in a later stage.

July 15th 2006
Around the 15th of July the wind speed is above 10 m/s for about 2 days. However the wind is coming from easterly to south-easterly directions, leading to wave conditions that are mostly below H_s = 0.3 m. Therefore this storm will not be discussed in more detail.

August 26th 2006
At the 26th of August a high narrow peak in the wind speed can be noticed. Though the direction during the peak is from south-westerly direction, the duration is so short that the wave height remains below H_s = 0.2 m. Therefore this period was not selected for further investigation.

December 16th, 2006
On the 16th of December the wind speed is increasing to about 15 m/s. The direction of the wind is about 270°N. However the wave height data is not reliable, it seems that the wave height is increasing in this period. Because this period meets the criteria for a storm period, the 16th of December has been further examined. Accordingly the reliability of the data will then be checked.

In the following sections of this chapter two storm periods will be investigated in more detail. Two of the events with a high wind speed in Table 5 have a very short duration and are probably caused by thunderstorms (22 June, 26 August). Using a (moving) mean hourly wind speed instead of the 10-minutes averages, these two events would not have been in the "shortlist". From the remaining events, the storms of 27 May, 1 July and 16 December are the most interesting ones. As the scope of the project includes detailed analysis of two storms, storm of 1 July has not been included. It could be worthwhile to carry out a detailed analysis on this event in a later stage.

For the two selected events the day before and after the storm have been included in the detailed analysis. Thus the two storm periods considered are from 26 to 28 May 2006 and from 15 to 17 December 2006.

4.2 Processing of WIND and WAVE files

To process the data in the WIND and WAVE-files a number of Matlab scripts were written to carry out the following tasks:

- Read the files and store data in Matlab data files (.mat files)
- Read the Matlab data files, process data and write results for each day to text file (.xtb files)
- Read the ASCII result files and prepare the following plots
  - a plot showing the wind conditions during the entire period
  - plots with selected parameters for each day of the selected period

The scripts are using parts of the Matlab scripts developed for the processing of measurements on the IJsselmeer (Lake IJssel) by Dr Marcel Bottema of RWS/RIZA. Some details of the processing are described below.

Wind

The data in the WIND-files for the selected periods were split into blocks of 20 minutes. The mean wind speed in this interval was calculated by averaging all values in the block. The average wind direction was derived by calculating the vectorial mean value. Though the difference is expected to be small, it is recommended to determine the mean wind speed also by vectorial averaging.

Waves

The data in the WAVE-files for the selected periods were split into blocks of 20 minutes (72 blocks per day). The processing was carried out on the water level registrations of each 20-minute block and included three steps:

- basic quality check on the data
- spectral analysis to obtain a number of characteristic wave parameters in the frequency domain
- time domain analysis to obtain a number of characteristic wave parameters in the time domain

The quality check on the data included a few checks commonly applied on wave data. These include

- detection of gaps in the data; gaps up to 3 values have been repaired by interpolation;
- detection of outliers; data deviating more than 4 times the standard deviation of the signal were deleted (set to NaN, "Not-a-Number").

Experience on the IJsselmeer (Bottema, 2007) has shown that the 4 σ criterion may lead to erroneously deleting correct data. Bottema (2007) therefore suggest to use a criterion based on the standard deviation of the signal and the first derivative. It is recommended to further elaborate the quality control and repair procedure when the data from 2007 will be processed.

Various codes written to a string are indicators for the quality of the record. The following codes are used:

Code	Meaning
9	complete block (after interpolation)
8	gaps of more than 3 values
7	data in block > 4 σ
6	gaps of more than 3 values after deleting data in block > 4 σ
5	data in block with skewness <0 or >1
4	data in block with wave steepness > 0.14 (based on T_{m01})

Table 6 Quality code in WIND and WAVES files

The 20-minutes blocks were subsequently analysed to obtain a number of characteristic wave parameters in the frequency and time domain. The spectral analysis was carried out using Matlab procedures by Dr Ap van Dongeren (WL | Delft Hydraulics) that were already available from earlier projects. This analysis provides the frequency spectrum of the waves and frequency-domain parameters such as the spectral significant wave height H_{m0}, the peak wave period T_p and spectral mean periods T_{m-10}, T_{m01} and T_{m02}.

The time-domain analysis was done using relevant parts of Matlab scripts developed by Dr Marcel Bottema of RWS/RIZA. This analysis provides the exceedance curve of the individual waves and periods in the data block and time-domain parameters such as the significant wave height $H_{1/3}$, the maximum wave height H_{max}, the mean zero-crossing wave period T_z and the time-domain wave periods $T_{1/3}$, $T_{H1/3}$, T_{max} and T_{Hmax}.

All parameters on wind and waves including the quality codes were written in ASCII text files (.xtb files) for each day. Each of these text files contains the parameters, percentile values for wave height and wave period and spectral densities for all 72 blocks in a day. These files can be used for further processing and analysis. Based on the xtb-files figures have been prepared summarizing the 20-minutes block wave conditions. A few of these block files are included in the description of the storm periods. A complete set of ‘block plots’ is provided digitally (pdf-format).

4.3 Storm period 26-28 May 2006

The results of the processing of the WIND and WAVE files for the period 26-28 May 2006 are presented in Appendix B. On the day before the storm the wind is a moderate breeze (8 m/s decreasing to 6 m/s) from Westerly directions (see Fig. B.1). The wind then veers to South-West for a few hours, but when the wind speed increases the direction turns to West again and during the entire period of higher wind speeds the direction is fairly constant from West. Wind speeds reach values of 15 m/s. After the peak of the storm the wind speed drops to a moderate breeze again for a few hours, on 28 May further reducing to a gentle, later a light breeze (around 4, resp. 2 m/s). The direction changes then from West through South to South-East.

Figure B.2 shows that on the first day of the selected period the wave height decreases from about H_{m0} = 0.3m to about H_{m0} = 0.2m due to the reduction of the wind speed. Wave periods similarly from T_{m-10} = 2.25s to T_{m-10} = 2.0s. The water level drops about 0.2 m during the first half of the day, increasing again 0.1m later.

When the wind speed increases to about 10 m/s between 4:00 and 6:00 h on 27 May, the wave height increases to about H_{m0} = 0.3m again. When the wind increases further, the wave height increases as well, but the reliability of the data decreases. During the peak of the storm the significant wave height reaches values around H_{m0} = 0.45m, but most blocks do not provide reliable data. After 15:00 h the wind speed reduces, leading to lower and again reliable wave heights from the Log_aLevel. Within a few hours the significant wave height drops from values around H_{m0} = 0.4m to values of H_{m0} = 0.2m.

During the first part of 28 May the significant wave heights are between H_{m0} = 0.1m and H_{m0} = 0.2m (when wind speeds are 4-6 m/s), but later the wave height decreases and after about 16:00 h - when the wind drops to values around 2 m/s from southerly direction – the wave heights are very low and seem to be less reliable. These conditions are however not of relevance for the purpose of verifying the wave growth limit in shallow water.

Figures B.5 to B.13 show a few characteristic block plots for the period of 26-28 May. All block plots are available in digital format on the CD in the back of the report. Each block plot presents the following data:

- The mean water level and start time of the block,
- The wave signal from the Log_aLevel for the entire period of 20 minutes (in two parts: 0-600s and 600-1200s; upper two graphs),
- Two graphs with the distribution of wave height (left) and period (right) of the individual waves within the 20 minute block in the form of wave height/period exceedance graphs; in the plot for the distribution of the wave heights the drawn line indicates the Rayleigh distribution,
- The wave spectrum,
- Selected characteristic parameters for the 20-minute block.

Table 7 contains some remarks for each of the selected block plots.

Fig.	Block	Comments
B.5	May-26-12	A normal 20-minute block with a wave height of H_{m0} = 0.26 m
B.6	May-27-15	Block with a wave height of H_{m0} = 0.33 m; some low-frequency energy in the wave spectrum
B.7	May-27-18	Good block with a fairly large wave height of H_{m0} = 0.37 m before storm peak
B.8	May-27-21	Block with lot of low-frequency energy due to gap and irregularities (e.g. just after 400s) in the signal
B.9	May-27-36	Fairly good block in period with highest winds. Though the signal shows some irregularities (e.g. just before 200s), the spectrum and the parameters have the right order. It is interesting to note that the distribution of the wave heights deviates from the Rayleigh distribution.
B.10	May-27-38	Block during storm peak for which analysis fails due to many irregularities in the signal. The mean water level is about 0.1 m too low (compare to value in Figure B.9). Parts of the signal seem to be quite normal.
B.11	May-27-43	Block with extreme amount of low-frequency energy due to the irregularities in the signal. The large fluctuations also affect the distribution of the individual waves: the smallest individual wave is about 0.4m due to the erroneous mean water level.
B.12	May-28-31	First fairly good block after the storm peak. Some irregularities (e.g. around 550s), which also shows in the distribution of the wave periods (high maximum wave period)
B.13	May-28-54	Normal block with fairly broad wave spectrum

Table 7 Remarks to block plots presented in Figures B.5 to B.13

4.4 Storm period 15-17 December 2006

The results of the processing of the WIND and WAVE files for the period 15-17 December 2006 are presented in Appendix C. Figure C.1 shows that the wind speed is very low during the first hours of the selected period and from variable directions (roughly between South and West). At the end of the day the wind speed increases and the direction is more stable from West to Northwest directions. Around noon on 16 December (Fig. C.2) the wind speed increases rapidly to reach a maximum close to 14 m/s from West between 15:00 h and 16:00 h. The wind speed then gradually decreases again to about 6 m/s. On 17 December the wind speed increases again to reach a value of about 9 m/s from Northwest direction between 9:00 h and 12:00 h. Subsequently the wind speed reduces again to values around 2 m/s from Northerly to North-easterly directions.

During the very low wind speeds at the start of the selected period the wave heights are too low for adequate detection by the Log_aLevel, leading to erroneous results, also for the water level. After 3:00 h on 15 December the results are more reliable, though the significant wave heights are still very low (H_{m0} = 0.01-0.05m). Only after 15:00 h, when the wind speed increases to about 4 m/s, the significant wave height increases to values above H_{m0} = 0.05m, though values of H_{m0} = 0.1m are only reached when the wind speed increases to about 6 m/s around 21:20 h.

During the peak of the storm on 16 December the data for waves and water level from the Log_aLevel are unfortunately rather unreliable. Some of the records contain rather large "jumps" in the mean value as illustrated in the top panel of . Others show very small amplitudes for a condition where the significant wave height is more than H_{m0} = 0.2m (Figure 10, centre) or a combination of these with other fluctuations in the mean signal (Figure 10. Others show very small amplitudes for a condition where, according to the results of previous blocks, the significant wave height is more than H_{m0} = 0.2m (Figure 10, centre) or a combination of these with other fluctuations in the mean signal (Figure 10, bottom). Note that the bottom panel in Figure 10 is a block just before the peak of this storm.

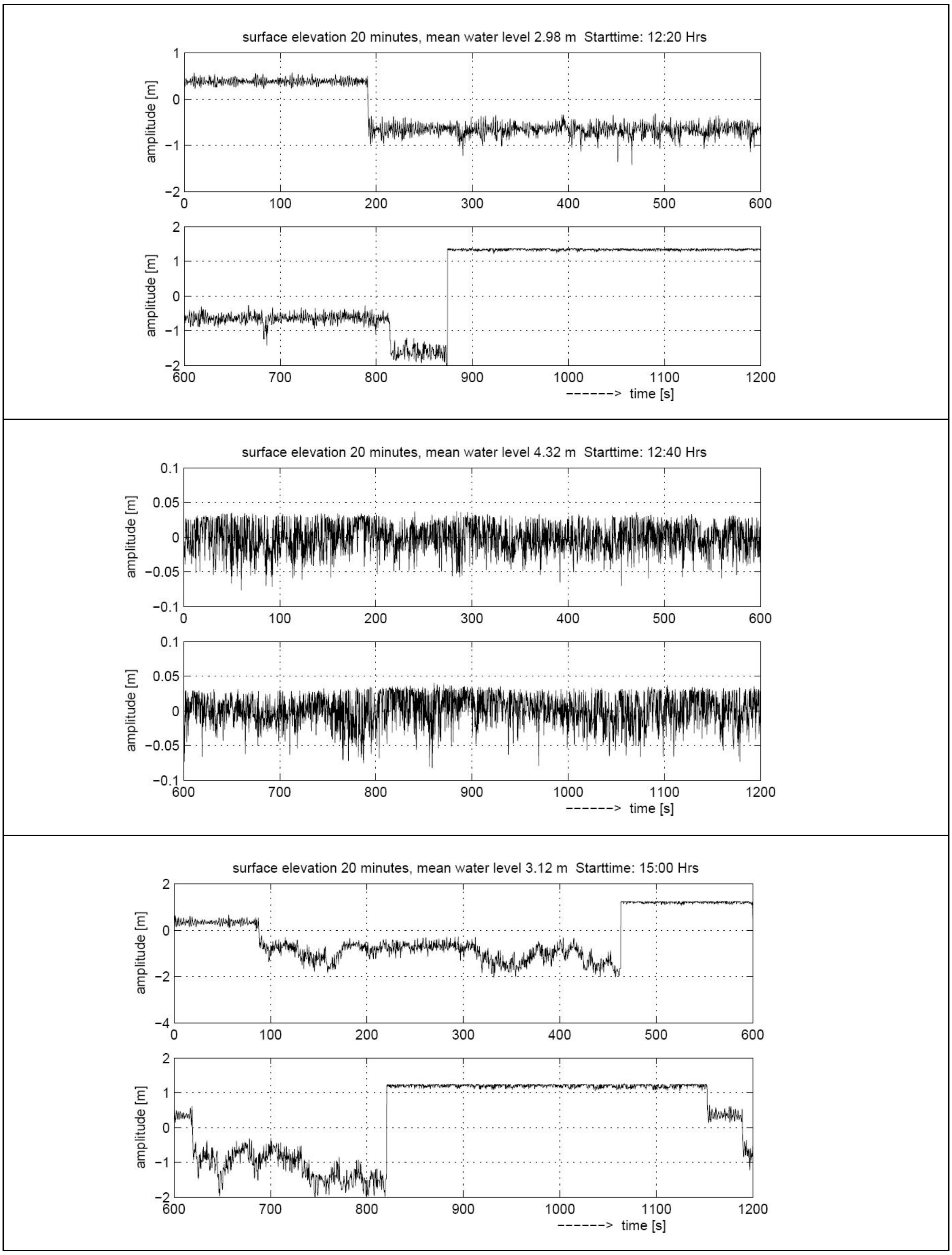


Figure 10 Examples of Log_aLevel records with various sorts of errors: jumps in mean value (top), insignificant signal for waves with H_{m0} > 0.2m (centre) and jumps in combination with long period fluctuations (bottom)

Due to these errors in the time series of the surface elevation both the wave parameters and the mean water level for these blocks are erroneous. The first valid data after the peak of the storm are obtained for 19:00 h on 16 December. Between 19:00 h and 24:00 h the wave heights decrease gradually from H_{m0} = 0.25m to H_{m0} = 0.15m.

On 17 December the wave height increases again and reaches values around H_{m0} = 0.25m during the hours that the wind speed increases to values around 9 m/s. Most of the records after 14:00h on 17 December seem to be unreliable ("jumps" in mean level over 20 minute record, unexpected mean water level around 0.5m -MSL, a lot of energy at low frequencies, etc). Considering the decrease in wind speed and the change in wind direction to North and North-east, we expect that the significant wave heights will be further decreasing to values of H_{m0} = 0.1m and lower. Significant wave heights of H_{m0} = 0.3m and more that are calculated for some records in this period are considered to be wrong (inconsistent with wind speeds, affected by errors in the data files). The reason for these erroneous results is not clear.

Figures C.5 to C.12 show a few characteristic block plots for the period of 15-17 December. All block plots are available in digital format on the CD in the back of the report. Table 8 contains some remarks for each of the selected block points.

Fig.	**Block**	**Comments**
C.5	Dec-15-02	Normal 20-minute block for extremely low wave height H_{m0} = 0.00 m
C.6	Dec-15-04	Erroneous block for low wave height; mean water level wrong (compare Fig. C.5)
C.7	Dec-15-05	Erroneous block; no time-domain analysis because signal contains only one zero up-crossing
C.8	Dec-15-07	Erroneous block, wrong mean water level, strange wave signal very low wave
C.9	Dec-16-25	Normal block for wave height H_{m0} = 0.14 m
C.10	Dec-16-37	Last good block before peak of storm, H_{m0} = 0.24 m
C.11	Dec-16-47	Block at maximum wind speed; mean water level about 1 m too low, very irregular wave signal, only few part where wave signal is around actual mean water level (parts around about 1.0 in signal plots)
C.12	Dec-17-47	Erroneous block after storm; mean water level wrong, wave height does not match wind speed of 6.4 m/s (see also Figure 16)

Table 8 Remarks to block plots presented in Figures C.5 to C.12

5 Reconnaissance of errors and validation plan

5.1 Possible sources of errors

When carrying out field measurements several types of problems may occur. Buoys are "caught" by fishermen, instruments get damaged due to severe weather, data communication fails and so on. Depending on the kind of problem there may be loss of data or the quality of the data is affected. The possible errors that are relevant for the processing and interpretation of the measurement data can be in different links in the chain from the real world to a representative value:

- The conditions at the position of the instrument may not be representative for the actual conditions in a larger area
- The instrument may not accurately measure the conditions or the processing of the measured signal in the instrument can be wrong
- The communication between the data logger and the instrument may fail
- There may be errors in the operation of the data logger
- Communication between the data logger and the PC where data are processed and stored may be disturbed
- The processing of the data (splitting) on the recording PC can introduce errors in the actual data files.

These aspects, the possible consequences, quality checks to verify the data and corrections that can be applied to increase the quality of the data are briefly discussed below.

5.1.1 Representative measuring location

If the site of the measuring station is not well chosen, the wind or wave conditions may not be representative for the conditions in a larger area. This can e.g. occur if a wind meter is for a certain direction in the lee of a large building or high trees. At Gonghu an existing measuring platform has been used, which poses some limitations in the placing of the instruments.

The distance from the Gonghu station to the shore of the lake is a few kilometres in the relevant directions (South-east to West). In Northerly direction the station is closer to shore, but as the fetches are short, these directions are not relevant for the purpose of the measurements. The wind meter at the station Gonghu is mounted about 20 m above the mean water level on the existing sail-shaped frame on top of the small building (see Figure 2). The frame extends some 10 m above the building. This is expected to be sufficiently high to minimise the effect of the building on the platform. The parts of the sail-shaped frame extending above the wind meter may have a small effect on wind speed and direction. It should be noted that for use in wave hindcast models, which commonly require the wind speed at a height of 10 m as input, a reduction of the wind speed will be required to account for the vertical variation of the wind speed. Depending on the adopted formula and surface roughness, this factor is expected to be about 0.90-0.95. The effect of the frame on the measured wind is expected to be small compared to the uncertainty in the correction factor. The measured wind is therefore expected to be well representative for the conditions on that part of the lake.

The Log_aLevel at Gonghu is mounted on the South-Southwest side of the upper platform of the measuring station some 3.8 m above the water surface (not visible Figure 2). In Figure 4 (right panel) it can be seen that the station is surrounded by a fence in the water. If debris is blown against the fence by the wind, this may eventually affect the wave height within the fenced area. It is difficult to judge how much debris may float on the lake during more severe wind conditions and whether this may affect the wave heights. We expect that the effect will be small and will mainly affect the results for small waves. These cases are not relevant for the purpose of the measurements: verifying the wave growth limit in shallow water. It will be difficult to trace this in the data from the wave recorder.

5.1.2 Accuracy of the instrument

Wind

Measuring wind is a standard practice and the instruments are fairly accurate and sufficient for the purpose of acquiring data for the validation of wave hindcasting models. For the wind direction it is important that the instrument is well-aligned with North. Some instruments can show a small inaccuracy around direction 0° (North). This is not the most relevant direction in Lake Taihu.

Waves

The Log_aLevel works on the principle of reflection of an acoustic signal by the water surface. The distance between the instrument and the water surface is derived from the time interval between sending the signal and observing of the reflected signal. Possible sources of errors or inaccuracies in this process are (see also Bottema, 2007):

- The speed of sound is temperature dependent. This is compensated for using the results of a secondary instrument measuring the speed of sound. This secondary instrument is installed on the same side of the Gonghu station as the Log_aLevel (S-SW side). It is therefore not expected that the temperature will lead to inaccuracies.
- The reflection of the acoustic signal may not reach the sensor. This may happen when the water surface has a large slope. Under conditions without wind, smooth water surface without ripples but with some swell waves, the signal can be reflected away from the instrument. This may occur if the tilt of the water level is more than half of the sight angle. This occurs roughly when $H/0.5L > \tan(1.5°)$ which leads to the following criterion

$$\frac{H}{L} > 0.013 \tag{5.1}$$

Conditions without wind are generally less relevant for the purpose of the measurements (assessing the wave growth limit). The effect of the signal being reflected away from the sensor may however also occur under more extreme conditions when the waves have a sharp wave crest with a steep forward face. Due to the roughness of the surface by ripples the critical slope of the water surface will be higher. Bottema (2007, Fig. C.10) shows some examples comparing results from Log_aLevel instruments (with the corrected software/settings) with capacitance probes during storm conditions on the

IJsselmeer. These time traces show a few instances where the Log_aLevel starts to give faulty readings on the slope of a fairly high (and steep) wave.

- The acoustic signal is "blown away" by strong wind and the reflection does not reach the recorder. Based on geometrical considerations, it is estimated that on a perfectly flat and smooth surface this blowing away is expected to occur if the ratio between the wind speed and the speed of sound is somewhere between ¼ and ½ of the sight angle. Assuming that the speed of sound is 340 m/s, the criterion of half the sight angle would mean that the signal gets blown away when the wind speed between the sensor and the surface is about 9 m/s. Considering that the wind speed at 20 m above the surface is about 1.3 times higher that at 2 m above the surface, this would mean that the "blowing away" may lead to problems when the measured wind speed is 11-12 m/s. Due to gustiness the effect may occur at lower wind speeds, but the waves and ripples on the water surface increase the wind speed at which problems may occur. Bottema (2007) concludes that in the wave measurements on the IJsselmeer the large number of outliers in the signal from the Log_aLevel for situations with wind speeds exceeding 12 m/s is most likely due to the "blowing away" of the signal. Experience on the North Sea a couple of years ago was that the instrument worked up to 9 or 10 Beaufort, 21-25m/s (Bas Blok, personal communication). The nature of the wave field on the North Sea is, however, quite different than the wave field on lakes such as IJsselmeer and Lake Taihu.
- The sight angle of the instrument is 3°. With the height of about 3.8 m above the water surface this means that the instrument has a footprint with a diameter of about 0.2 m. Bottema (2007) shows that this leads to underestimation of the wave height by 1-5% and a small overestimation of about 1% of the wave periods. This effect is strongest for conditions with short wave periods. The effect is stronger for low water levels (larger footprint) and smaller at high water levels (smaller footprint).
- Vibrations of the sensor. The manual shows a picture of the location of the Log_aLevel on the platform. The photo shows that the cable between the instrument and the station is hanging freely. Motions of this cable due to wind could cause vibrations in the support of the instrument. This may lead to inaccuracies in the readings of the instrument. If the wind exerts high forces on the cable during an extreme event, this may cause the cable to break, leading to failure of the instrument during extreme wind speeds.
- False reflections by rain or spray. It is unclear how the sensor reacts to rain or spray from the waves. This may show up in the data as a very irregular signal due to false reflections. Bottema (2007) mentions however that "no obvious correlation was found between rainy periods and malfunctioning of the Log_aLevels". This may therefore not be an important issue for the quality of the data, though verification, if possible, is relevant as the intensity of the rain during typhoons may be much larger than on the IJsselmeer.

5.1.3 Communication data logger – instrument

According to our information the Log_aLevel can provide both an analog and a digital output signal. When the digital output signal is used, the communication with the data logger can fail due to a timing error. Bottema (2006) mentions regular patterns of missing samples during a pilot with Log_aLevels on the IJsselmeer. Figure 11 shows that this occurs also in the WAVE files from Gonghu. It can be seen that the basic time step is indeed 0.25 s (4 Hz), but that at more or less regular intervals of about 75 s the time step is 3 or 4 times as long (2 or 3 records missing). The interval between two events with a time step of 1 s is about 600 s. These missing data are repaired in the detailed processing by interpolation, but in this way some of the peaks or troughs from the waves may be underestimated.

The problem of missing records does not occur in the WIND files, as the output signal from the anemometer and wind vane is analog.

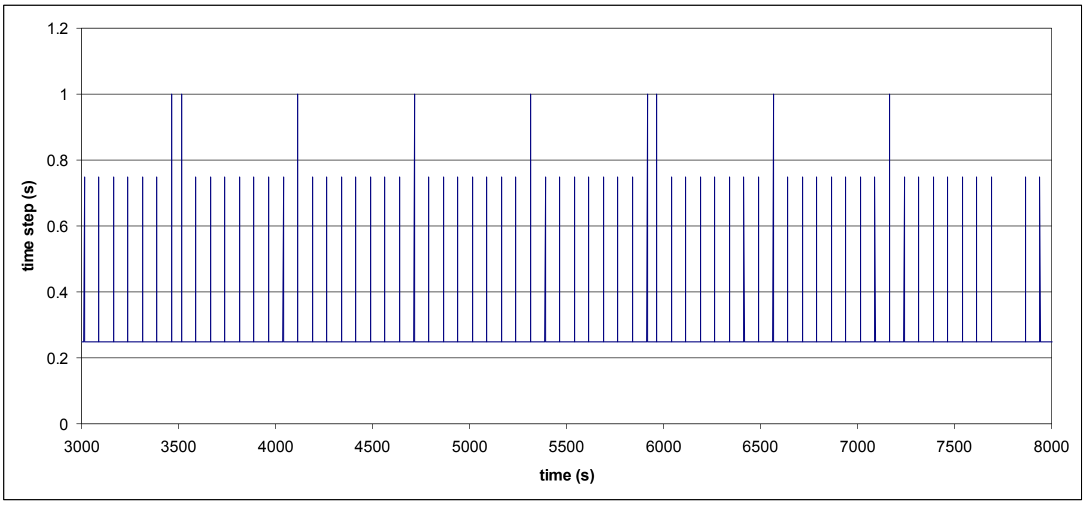


Figure 11 Time step in a WAVE file (GON060523Waves.dat)

5.1.4 Operation of data logger

The operation of the data logger may be hampered. A possible reason may be failure of the power supply (battery low). This may be a reason for the fact that there are a few days that there are no data at all (see Figure 5 to Figure 7).

5.1.5 Communication storage PC – data logger

The data communication between the data logger and the storage PC is controlled using the standard software LoggerNet supplied with the CR1000 data logger by Campbell Scientific. The system is set up in such a way that the PC connects to the data logger automatically twice a day at 02:00:00 and 14:00:00 hours to retrieve the data. The data are stored in three separate data files ##_Waves.dat, ##_Wind.dat and ##_Stat.dat, where ## is the station name (in 2006 only Gonghu).

In the communication between storage PC and data logger the following errors may occur:

- Failure to make connection with the data logger
  This means that no data are retrieved at all. It may be possible to recover this data at the next moment when the PC connects to the datalogger. If this is not possible (e.g. because part of the memory has been overwritten by newer data) it will show up as missing data.
- Transfer of data is disturbed due to a bad connection.
  It is not clear whether this may be a serious issue at Taihu. In principle the logger system detects interrupted data transfer and retries the data transfer after a delay of

several minutes. Because of this, it is not expected that communication problems may lead to distortion of a correctly measured signal. However, the communication between storage PC and data logger is considered to be one of the possible sources for "double" data in one of the wind files (see Section 5.2).

5.1.6 Processing of data into files

The data in the data files for the categories Waves, Wind and Stat are for each of the measuring stations split into so-called "day files" These files are stored in separate subdirectories for each of the three measuring stations. The extraction of all data for one day is carried out by a "splitprogram". The splitprogram is included in the automated process and is executed once per day, for Gonghu at 6:00 AM. This results in three files with files names STNyymmddWaves.dat, STNyymmddWind.dat and STNyymmddStat.dat, where STN is the station code (GON, DAP or PIN) and yymmdd the date. The splitting program may be a possible source for "double" data in one of the wind files (see Section 5.2).

5.2 Observed errors

During the processing and analysis of the data for the present report, a number of errors have been observed in the data. The most remarkable are briefly discussed below.

STAT files

1. The water levels from the Log_aLevel do not always agree with the values from the pressure sensor (see Figure 12). Small differences of a few cm are caused by inaccuracies in the offset (calibration) of the instruments, but this is not the case for the larger differences. In view of the range of the data it seems that the Log_aLevel values are erroneous.

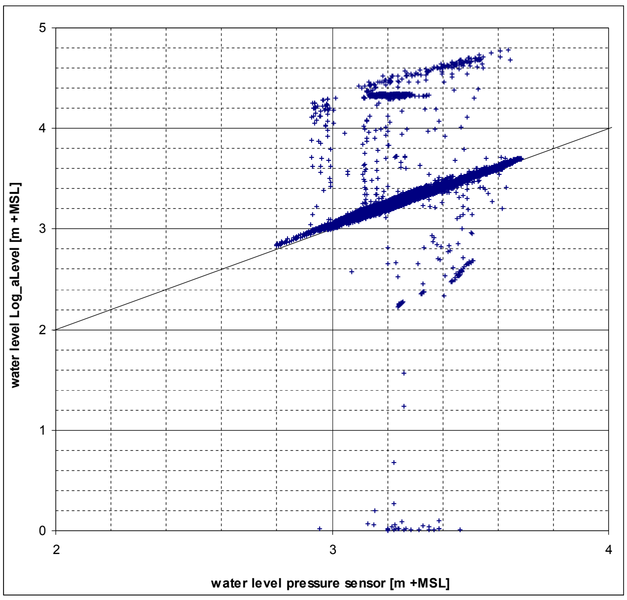


Figure 12 Scatter diagram of water level from the Log_aLevel vs level from the pressure sensor

To get some insight in the conditions during which this occurs, the correlation of these errors with several parameters has been briefly analysed. Figure 13 shows the ratio of the two water levels versus the wind speed, wind direction, wave height and logger temperature. It can be seen that there is no clear correlation with wind speed, direction or logger temperature. A large number of the conditions when the levels differ are for fairly low wave heights (H_{m0} < 0.15 m). For (erroneous) wave heights larger than H_{m0} > 0.5 m the number of errors in the water level is fairly large, but there are also data were the water level from the Log_aLevel is (more or less) correct.

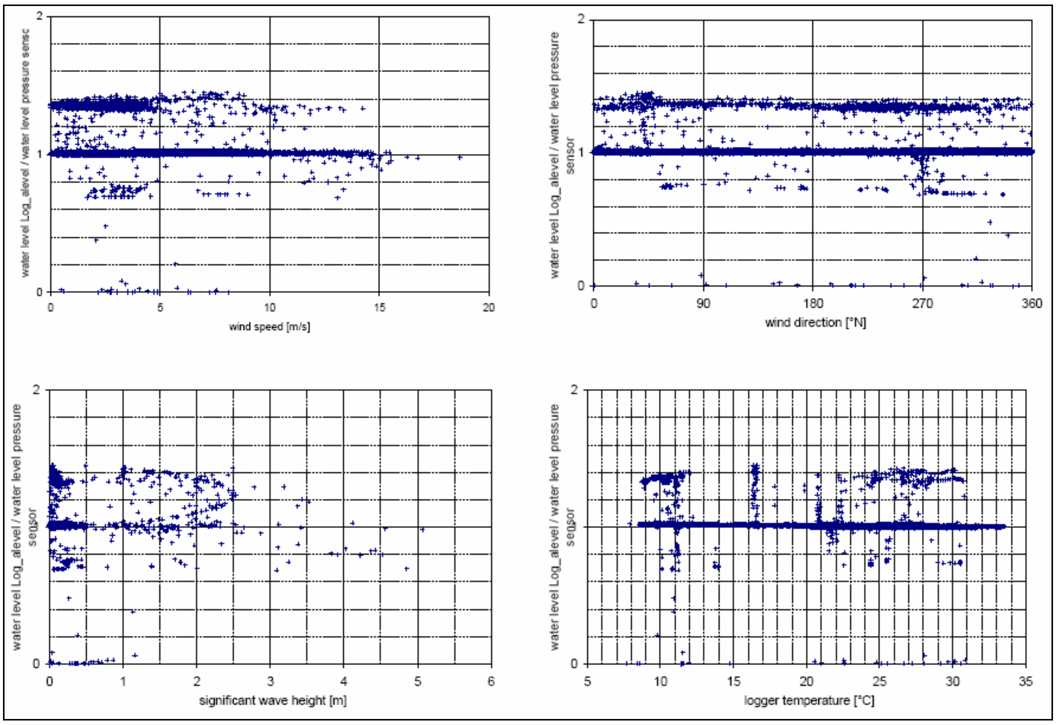


Figure 13 Correlation of error in water level from Log_aLevel with several other parameters from the STAT file

2. The wave height data in the STAT files contain extremely high values. A few rough checks were implemented in the global analysis (see Section 3.2). These may be further refined, e.g. by using a correlation of the wave height with wind speed and direction.

WAVES files

1. The 4 Hz time series have regular gaps of 1 or more records.
2. The time series contains occasionally large "jumps" in the mean level (see Figure 8)
   period 26-28 May: 23 blocks during the peak of the storm
   period 15-17 December: 4 blocks for very low waves (H_{m0}=0.01m), 13 during the peak, 4 at "average" wave heights
3. The time series contains sometimes outliers.

The last two generate in most cases a lot of low-frequency energy in the wave spectrum.

WIND files

1. The 1 Hz time series has occasionally gaps of a few records.

2. At least one of the 6 day files (which are 26-28 May and 15-17 December) included in the detailed processing contained parts with the same time, but different parameter values (GON061217Wind.dat; 48 records from 19:56:40 to 19:57:26). The most likely sources for this error are the communication between the data logger and the storage PC or in the splitprogram.

5.3 Validation plan

Before the results of the wave measurements can reliably be used to verify the wave growth limit in shallow water a thorough validation of the data will be required. The greatest challenge in this respect is probably to obtain reliable results for more extreme conditions. The detailed analysis in the present report shows that for higher wave heights and wind speeds many 20-minutes blocks contain various sorts of errors. The improved software/settings of the instrument seems to have a beneficial effect on the data from the Log_aLevel (Bottema, 2007), but this aspect remains a point of concern which will need to be re-analysed based on data from the improved instrument.

The future validation should consist of a more detailed analysis of the wave measurements (with results from all stations in Lake Taihu) and should include checks on the data in various stages of the processing.

Validation of the WIND and WAVE files

In the detailed analysis one example was found of a file where the time was not monotonously increasing. In the processing of the WIND and WAVE files a check must be included whether the time is increasing. If not, the block must be considered as invalid. If this occurs more often and for the most interesting conditions (high wind speeds and wave heights), it will be necessary to try tracing the origin of this error so that the validity of these blocks can be judged in more detail.

Processing of the WAVE-files

The detailed analysis has shown that some WAVE-files contain blocks with various sorts of errors. In some cases the errors seem to be limited to a few parts of the timeseries. Figure 14 shows an example of such a timeseries and the wave spectrum based on this data. It can be seen that the outliers are reflected by a fairly large amount of low-frequency energy. For highly interesting events (storm peaks), it may be worthwhile to evaluate whether data with a reasonable quality can be derived from such blocks e.g. by applying a high-pass filtering on the wave spectrum or by developing techniques to cut the suspicious parts from the timeseries.

Also for blocks containing large jumps (see e.g. Figure 8, top panel) it may be possible to use certain parts. A possibility may be to use the water level from the pressure sensor and compare that with a moving average of the level from the Log_aLevel. Sections where the difference is large may be removed prior to an analysis of the data. If the remaining part of the block is too short the data must be rejected.

The above mentioned very detailed analysis may involve visual inspection of the timeseries. This is only sensible if the block is expected to be very valuable with respect to the purpose of the measurements: determining the wave growth limit in shallow water.

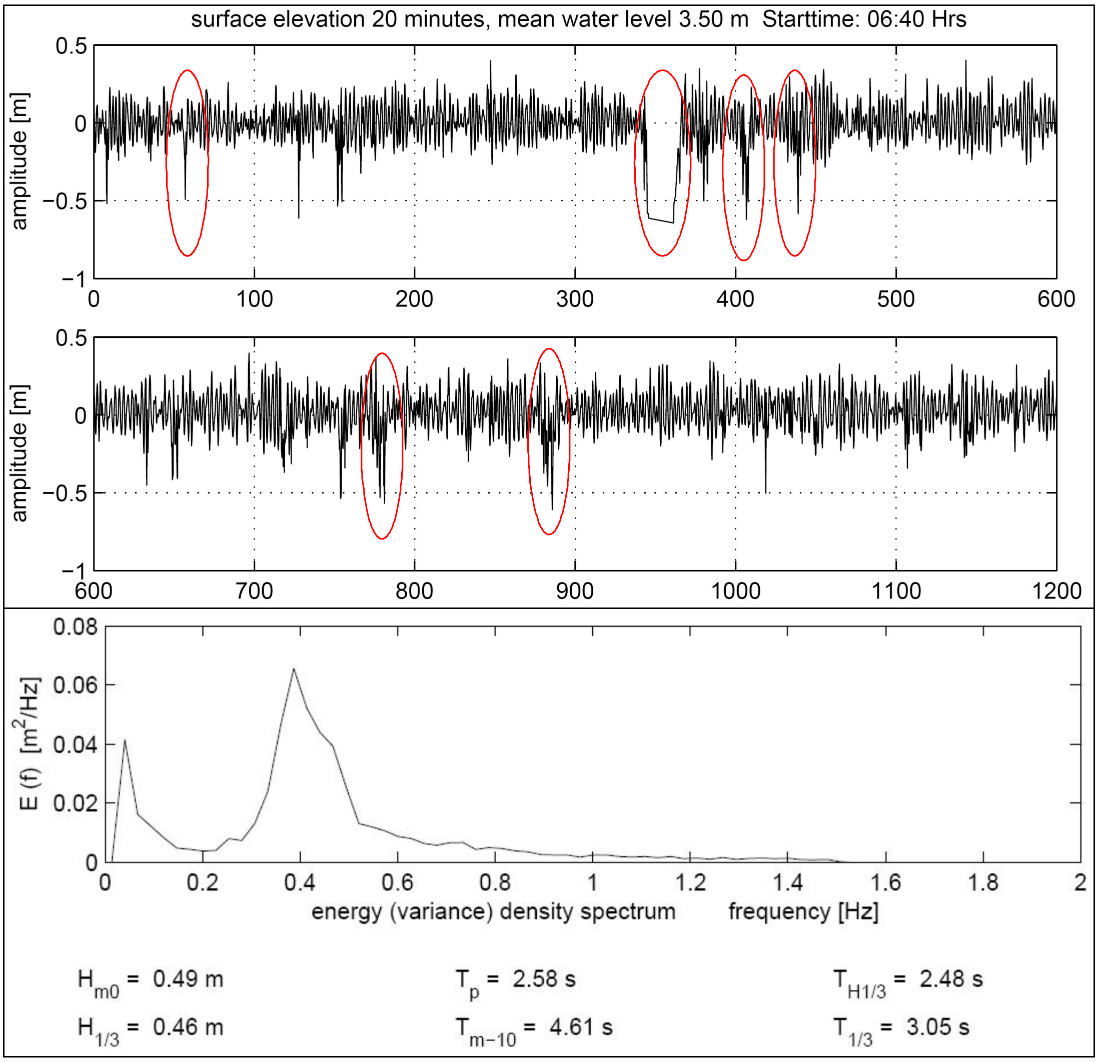


Figure 14 Example of timeseries from Log_aLevel with several outliers (some indicated, top panel) and the wave spectrum based on these data

Validation of wave parameters (xtb-files)

To verify whether the wave parameters derived in the detailed analysis are valid, criteria can be developed based on a number of the parameters calculated in the detailed processing. Graphs presented by Bottema (2006) suggest that the skewness of the time series, the ratios $H_{1/3}/H_{m0}$ and H_{max}/H_{m0} and relations between H_{m0} and characteristic wave periods may be useful to develop suitable criteria. This is confirmed by the scatter diagrams shown in Figure 15. The plots show that the majority of the measurements have values for e.g. the skewness and kurtosis (left panels) that are in the same range, but that the data with erroneous wave heights (roughly above H_{m0}=0.4m) have deviating values. The same applies for the mean and peak wave period T_{m-10} and T_p (right panels).

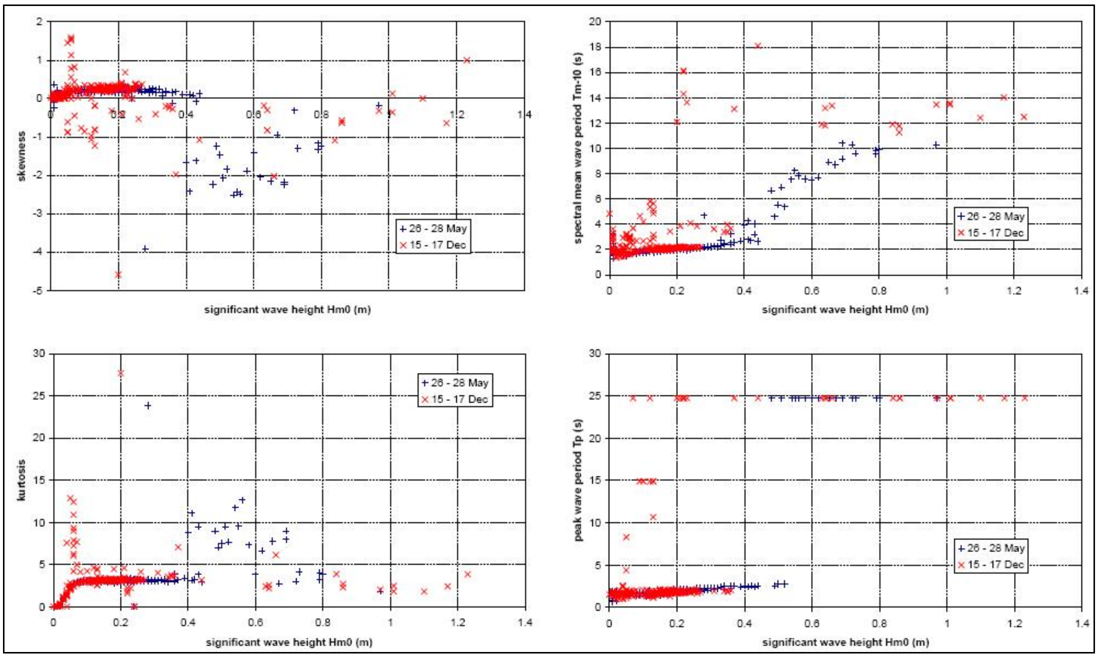


Figure 15 Scatter diagrams of some parameters against the significant wave height Hm0

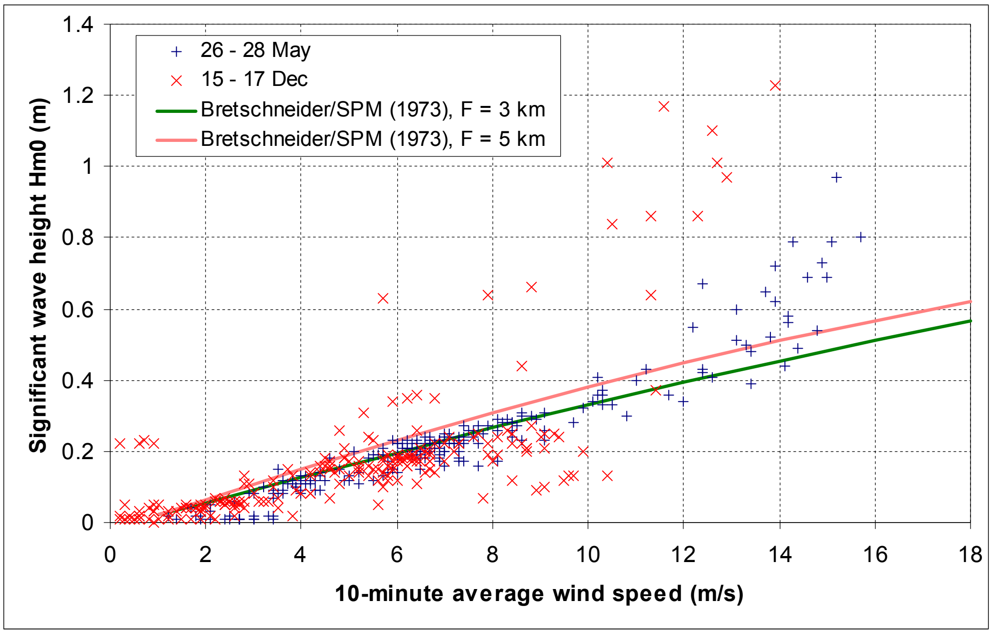
Figure 16 shows an example of data selection based on criteria for the skewness, kurtosis and peak period. The top panel shows the scatter diagram of significant wave height versus wind speed for all data in the two storm periods. The lower panel shows the same for the selected data. In the top panel it can be seen that the correlation between wave height and wind speed is quite good up to a wind speed 10-12 m/s (wave height of about 0.4 m), especially in the period in May. For higher wind speeds the wave height is larger than the correlation for the lower wind speeds suggests. This is confirmed by the comparison with the predictive formula of Bretschneider (CERC, 1973) for a depth of 2.2 m for two different characteristic fetches (note that the actual fetch is varying with the direction).

In the lower panel of Figure 16 only records satisfying the following criteria have been plotted:

- 0 < skewness < 0.5,
- 2 < kurtosis < 4,
- peak period $T_p < 5$ s.

It can be seen that the remaining wave height data show a fairly good correlation with the wind speed and are therefore expected to be reliable data. Further refinement of the criteria for the selected parameters is required. Bottema (2007) mentions that skewness values up to 1.0 and kurtosis up to 4.5 are possible. This refinement and also the development of other criteria as suggested by Bottema (2006) is only useful when the data from the Log_aLevel instruments with improved software/settings are available.

This good correlation of the wave height with the wind speed leads to another criterion for data validation: correlation of the wave height with wind speed. This should be done for a range of wind directions to allow incorporating differences in fetch in various directions. Further analysis can provide criteria for the wave height (especially an upper limit) as function of wind speed and direction.



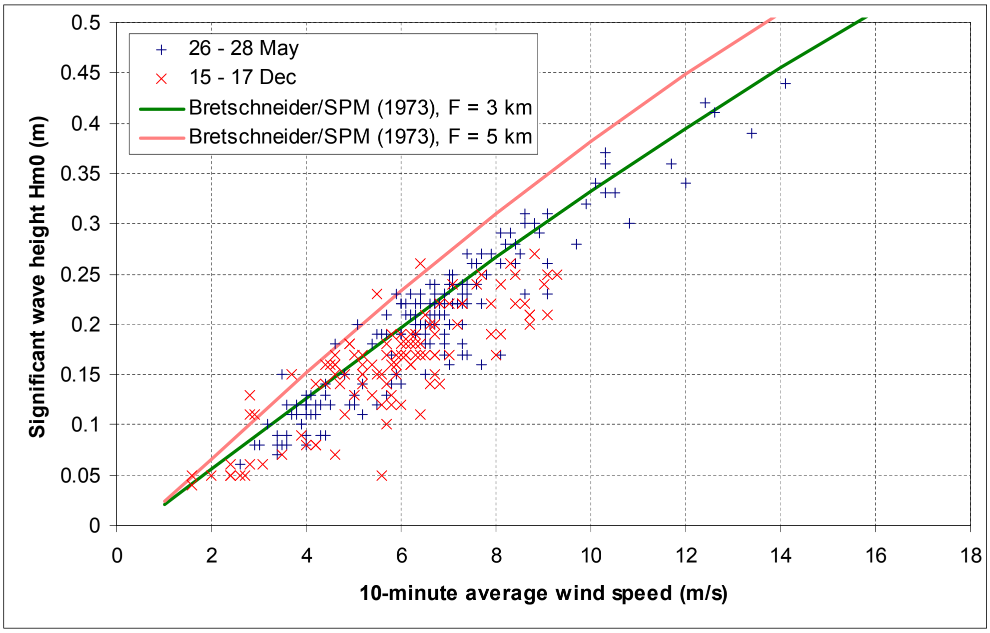


Figure 16 Correlation between 10-minute average wind speed and significant wave height without (top) and with selection of data (bottom) based on criteria for skewness, kurtosis and peak period

Developing criteria based on the above mentioned parameters is best carried out based on results from the instrument with improved software/settings. It may be worthwhile to carry out the detailed analysis not only on a few events selected to verify the growth limit, but on a larger selection of events or on all data. In that way a larger dataset is obtained, which may improve the accuracy of the criteria developed to evaluate the quality of the data.

6 Discussion

6.1 Accuracy of estimate H_{m0} in STAT file

To evaluate the accuracy of the estimation of the wave height in the on-line processing as included in the STAT files, the wave heights H_{m0} from the detailed analysis have been compared with the corresponding values from the STAT files. Figure 17 compares for both analysed storm periods the estimated wave heights H_{m0} from the STAT file with the result from the detailed processing. It can be seen that the estimate in the STAT file is generally reasonably accurate. Only when the data from the Log_aLevel are less reliable due to the mentioned errors in the timeseries, the difference between the two values is fairly large.

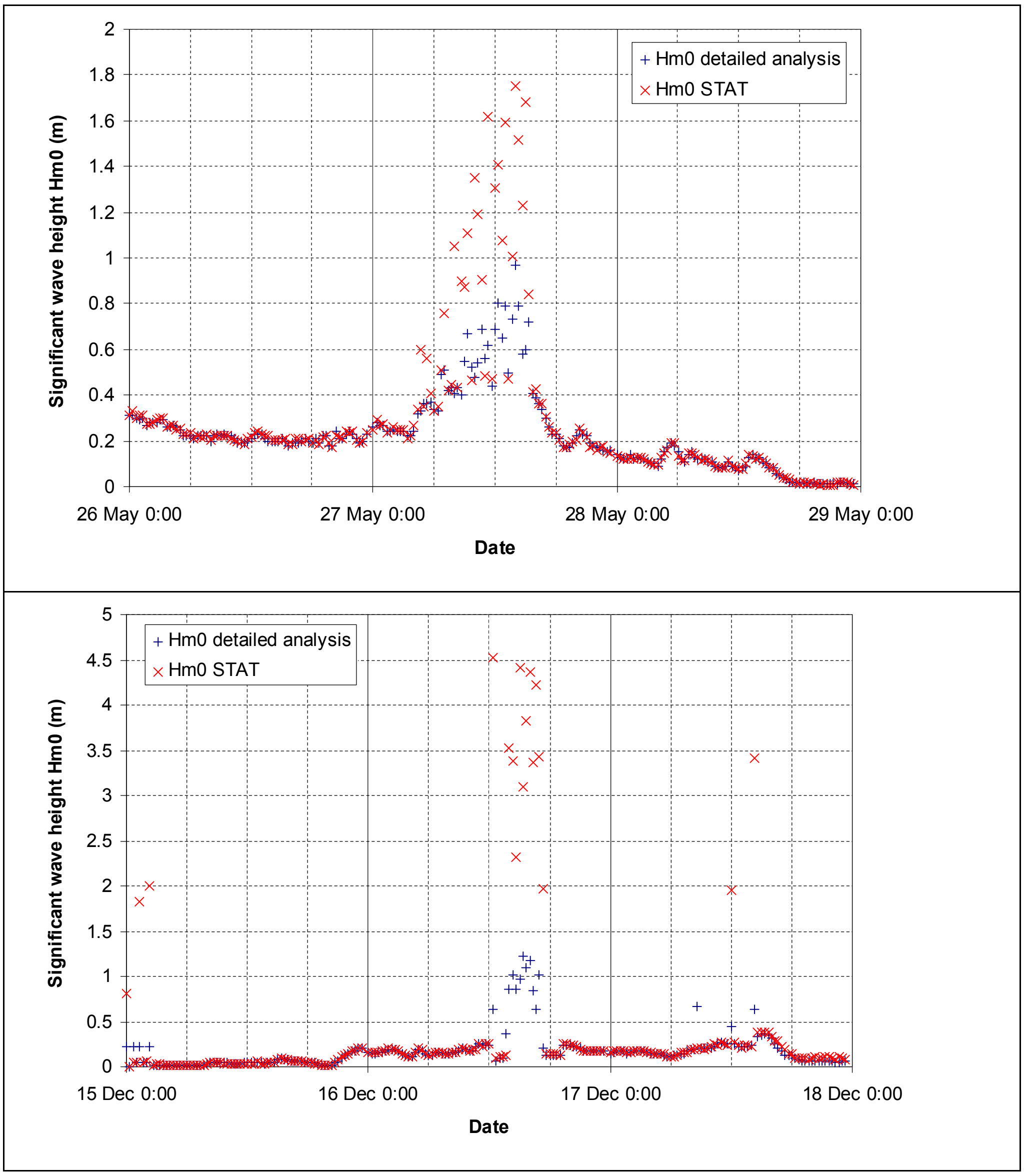


Figure 17 Comparison of wave height H_{m0} from STAT file with result from detailed processing

When only reliable data are selected using the criteria for skewness, kurtosis and peak period as discussed in Section 5.3, the agreement between the estimate in the STAT file and the value calculated in the detailed processing is good (see Figure 18). The estimate in the STAT file is generally a little higher than the value from the detailed processing.

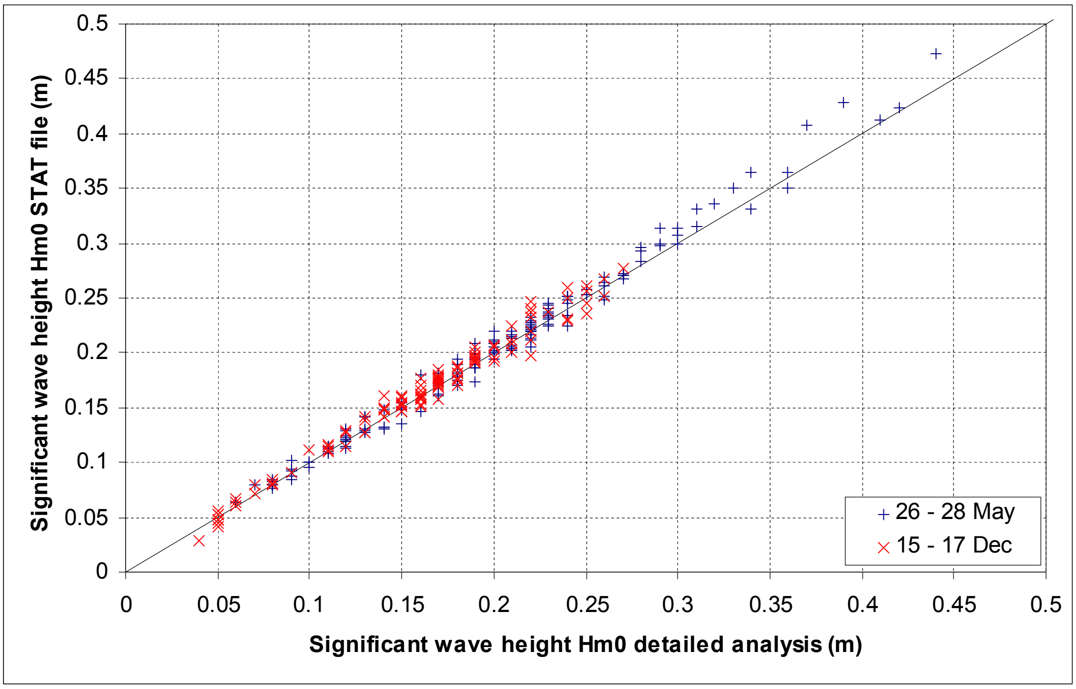


Figure 18 Scatter plot of wave height H_{m0} from STAT file with result from detailed processing for selected reliable data

6.2 The wave growth limit

For the purpose of the measurements it is of interest whether during the period of the observations conditions occurred where the wave growth was affected by the depth. This will occur if the ratio of the wave height over the water depth H_{m0}/d is in the order of 0.3 or more. Considering the depth is about 2.2 m (varies with the water level, may be slightly more due to wind set-up), this means that the wave height should be $H_{m0} = 0.7$ m. As the measured wave heights are less reliable for wave heights higher than $H_{m0} = 0.4$ m or slightly higher, no reliable measurements will be available.

During the considered period (2006) we expect that no conditions have occurred during which the wave height was close to the growth limit. In Figure 16 it can be seen that at Gonghu the representative fetch is about 3-5km. Table 9 shows that for these fetches the wind speed must be in the order of 25 m/s to reach the wave growth limit. Such wind speeds have not occurred during 2006.

	wind speed (m/s)									
fetch (km)	2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0
3	0.07	0.16	0.25	0.33	0.41	0.48	0.55	0.62	0.68	0.73
5	0.09	0.19	0.29	0.38	0.46	0.54	0.61	0.67	0.73	0.78
8	0.10	0.22	0.33	0.42	0.51	0.58	0.65	0.70	0.76	0.81
10	0.11	0.24	0.35	0.44	0.52	0.60	0.66	0.72	0.77	0.82
15	0.12	0.26	0.38	0.47	0.55	0.62	0.68	0.73	0.78	0.83
20	0.13	0.28	0.39	0.49	0.56	0.63	0.69	0.74	0.79	0.83
25	0.13	0.29	0.41	0.50	0.57	0.63	0.69	0.74	0.79	0.83
30	0.14	0.30	0.41	0.50	0.57	0.64	0.69	0.74	0.79	0.83
50	0.15	0.32	0.43	0.51	0.58	0.64	0.70	0.74	0.79	0.83

Table 9 Significant wave height for selected wind speeds and fetch lengths according to Bretschneider (CERC, 1973) for a water depth of 2.2 m

7 Conclusions and recommendations

From the global analysis it is concluded that in general the data return of the measurement campaign is fairly good. The main parameters in the STAT-files are only missing for a few days. Files with the raw signal of the wind are missing for the same few days. However, WAVE files with the raw signal are missing for the same few days, but also for a much longer period in August/September 2006. Fortunately this has no important consequences as the conditions during this periods were very mild (low wind speeds).

Both the global and the detailed analysis have shown that the Log_aLevel regularly contains erroneous data. Unfortunately one of the situations in which this occurs, is under conditions that are the purpose of the measurements: extreme wind speeds for which the wave growth is limited by the depth. Improved software/settings of the instrument that will be installed in 2007 may improve this, but to some extent the problems may be inherent to the measuring principle of the instrument. This will have to be re-analysed with data from the improved instrument.

It is possible that the timeseries in the WAVE files recorded with the improved Log_aLevel still contain the types of errors encountered in this study for conditions with high wind speeds (large “jumps” in the mean level, long-period fluctuation, etc.). In that case, it may be necessary to try to develop procedures that allow using as much as possible of the information contained in the signal to obtain an estimate of reasonable quality of the wave conditions during these extreme events.

The results from analysis show that the period of the measurements in 2006 contains seven events with wind speeds over 12 m/s. Two of these are of very short duration, probably related to thunderstorms, and are not of interest for the investigating the wave growth limit in shallow water. The data from the detailed analysis show that with the present software/settings of the Log_aLevel the wave data above these wind speeds become increasingly unreliable. From the two events for which a detailed analysis has been carried out, the valid data are unfortunately still in the range for which no significant limitation of the wave growth due to the water depth is expected, as the ratio of the wave height over water depth is about $H_{m0}/d = 0.2\text{-}0.25$. A significant effect of the limited depth is expected at higher values of about $H_{m0}/d = 0.3$.

Considering that the stations Dapukou and Pingtaishan to be installed in 2007 are at locations with a longer fetch, especially for South-easterly direction, the data from these stations may prove to be valuable for investigating the wave growth limit as relevant wave conditions may be reached at lower wind speeds. The number of events may also be larger as wind from South-easterly direction occurs more frequently than other directions.

8 References

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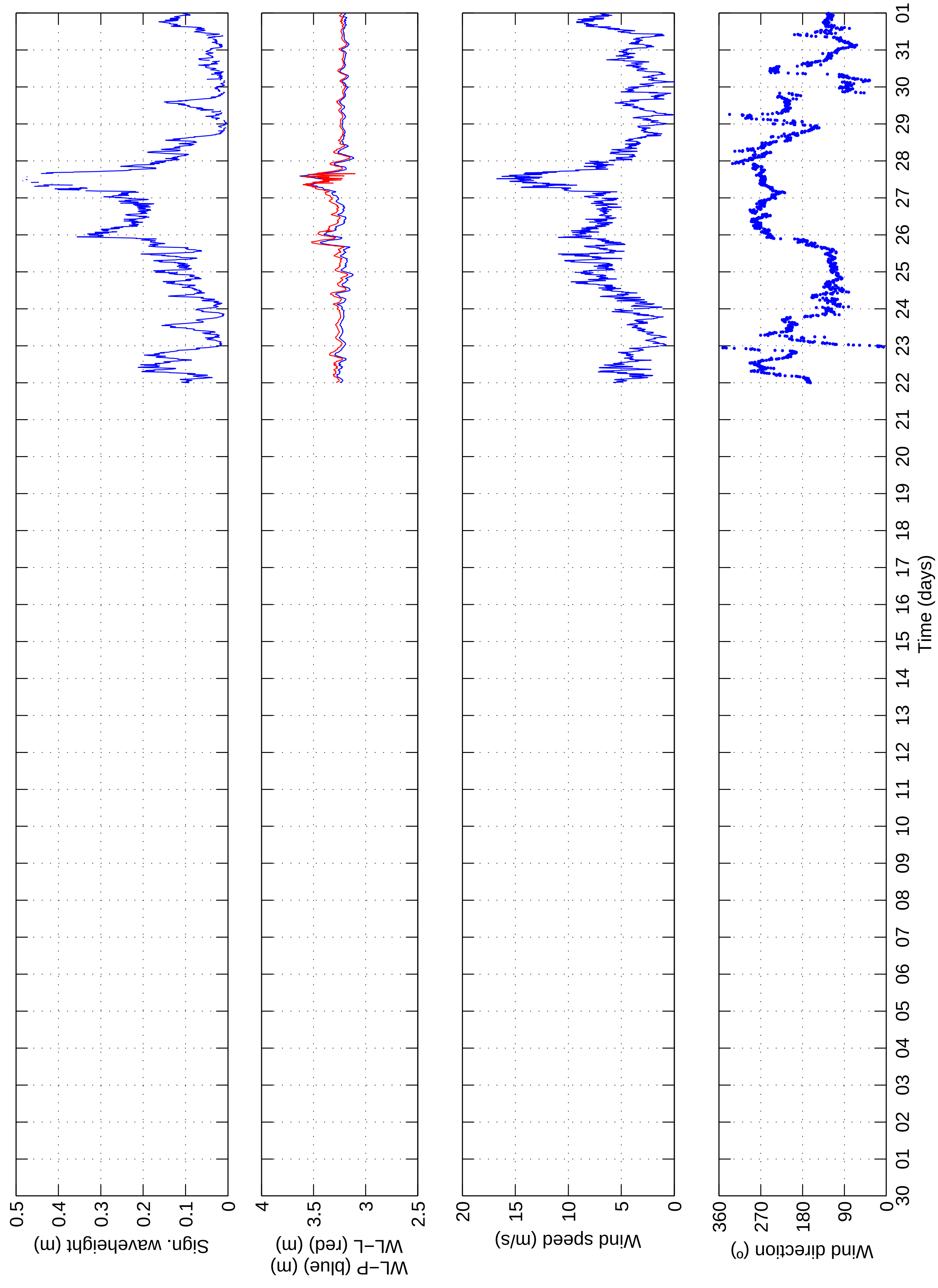
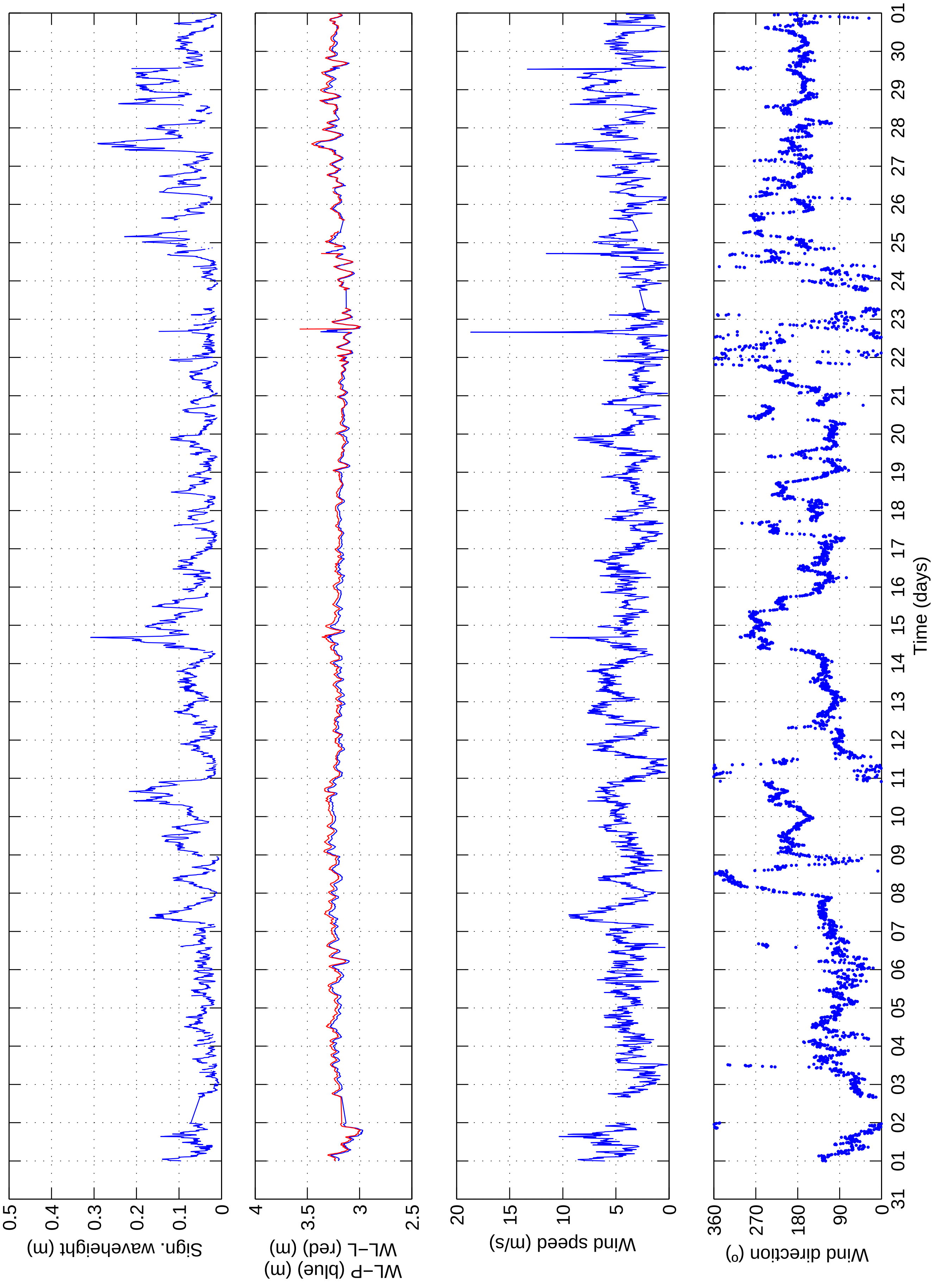
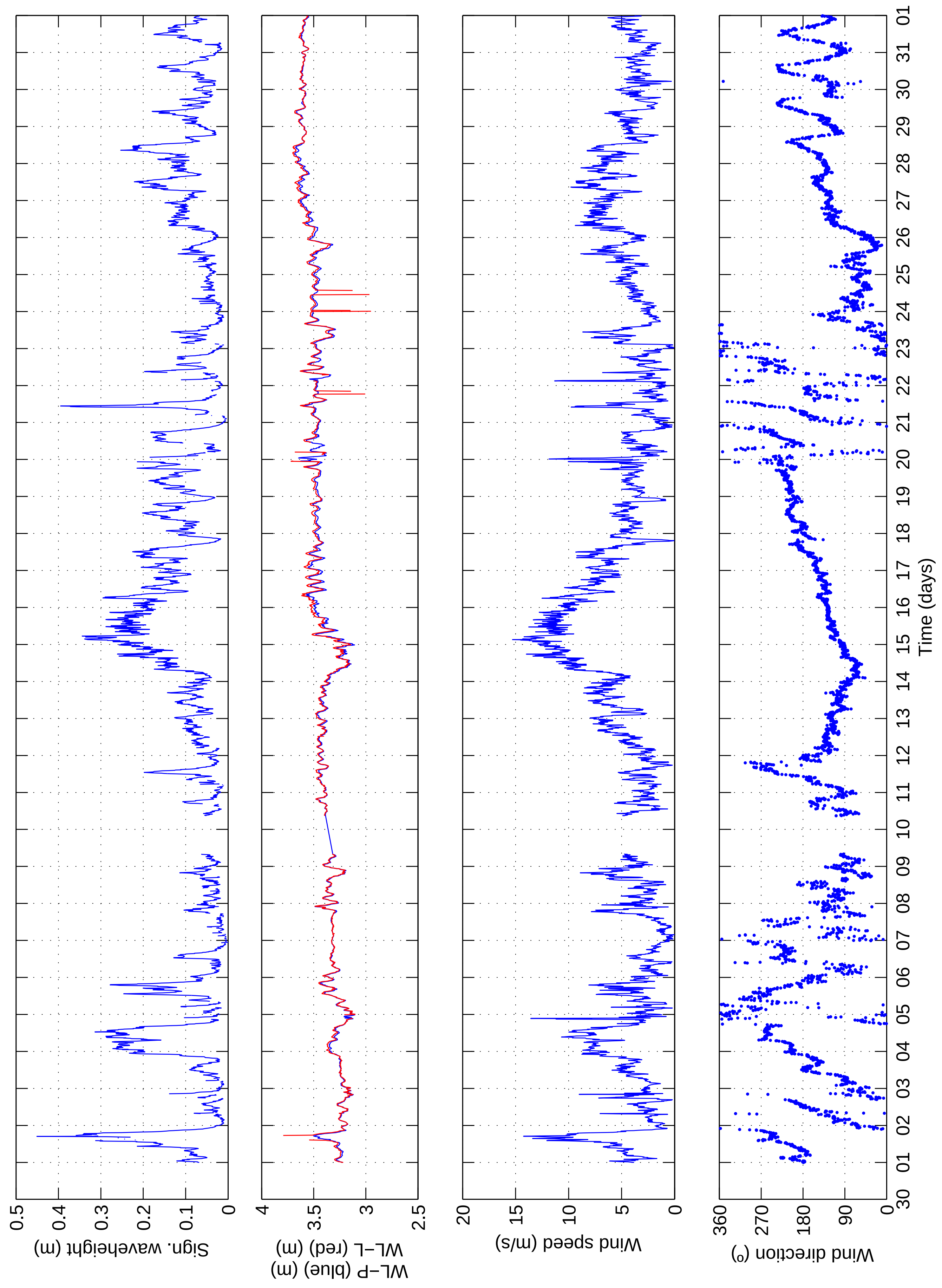
A Plots global analysis



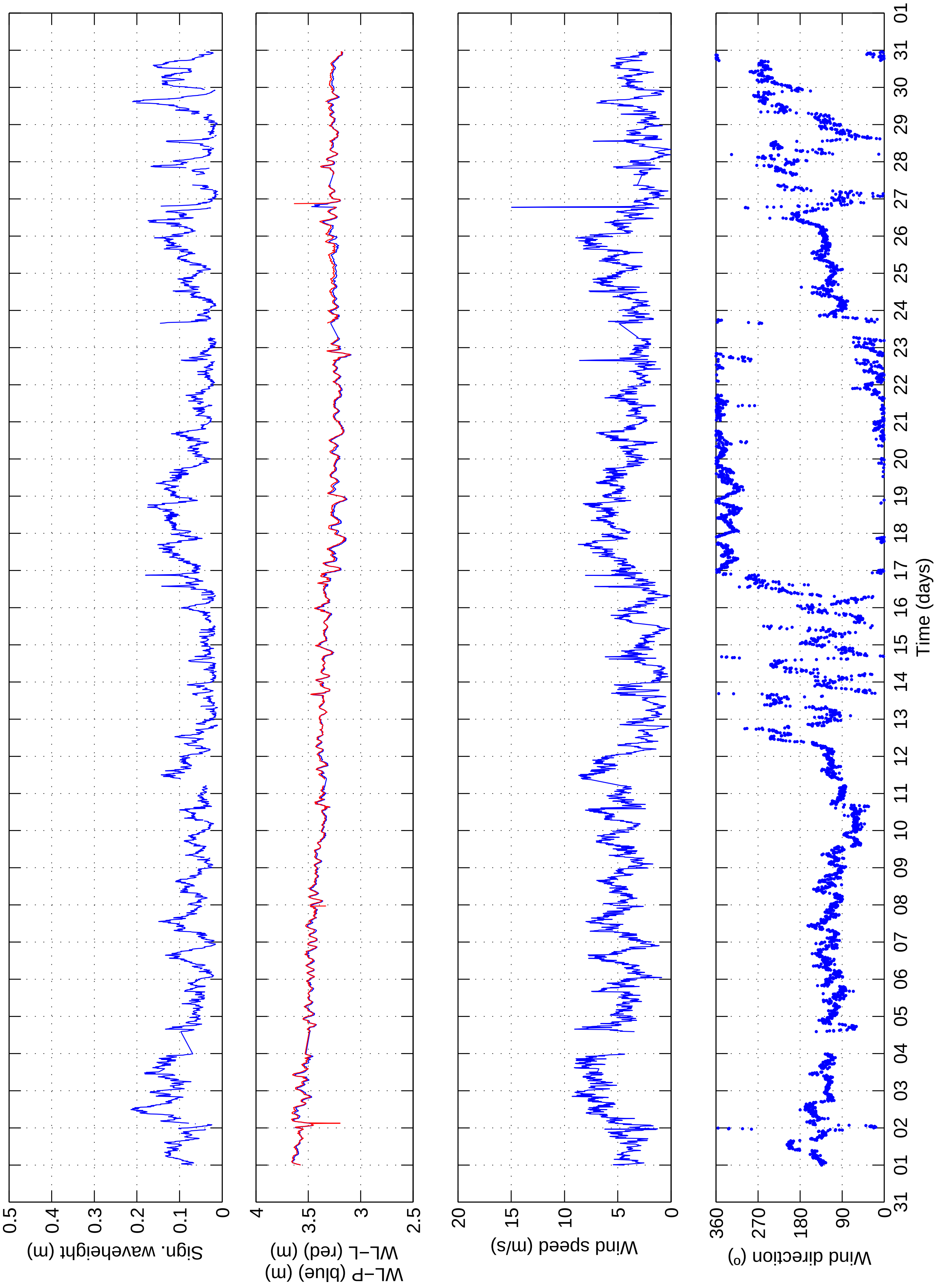
Overview of conditions at Gonghu station during May 2006 based on STAT files	Lake Taihu	
WL | DELFT HYDRAULICS	H4955	Fig. A.1



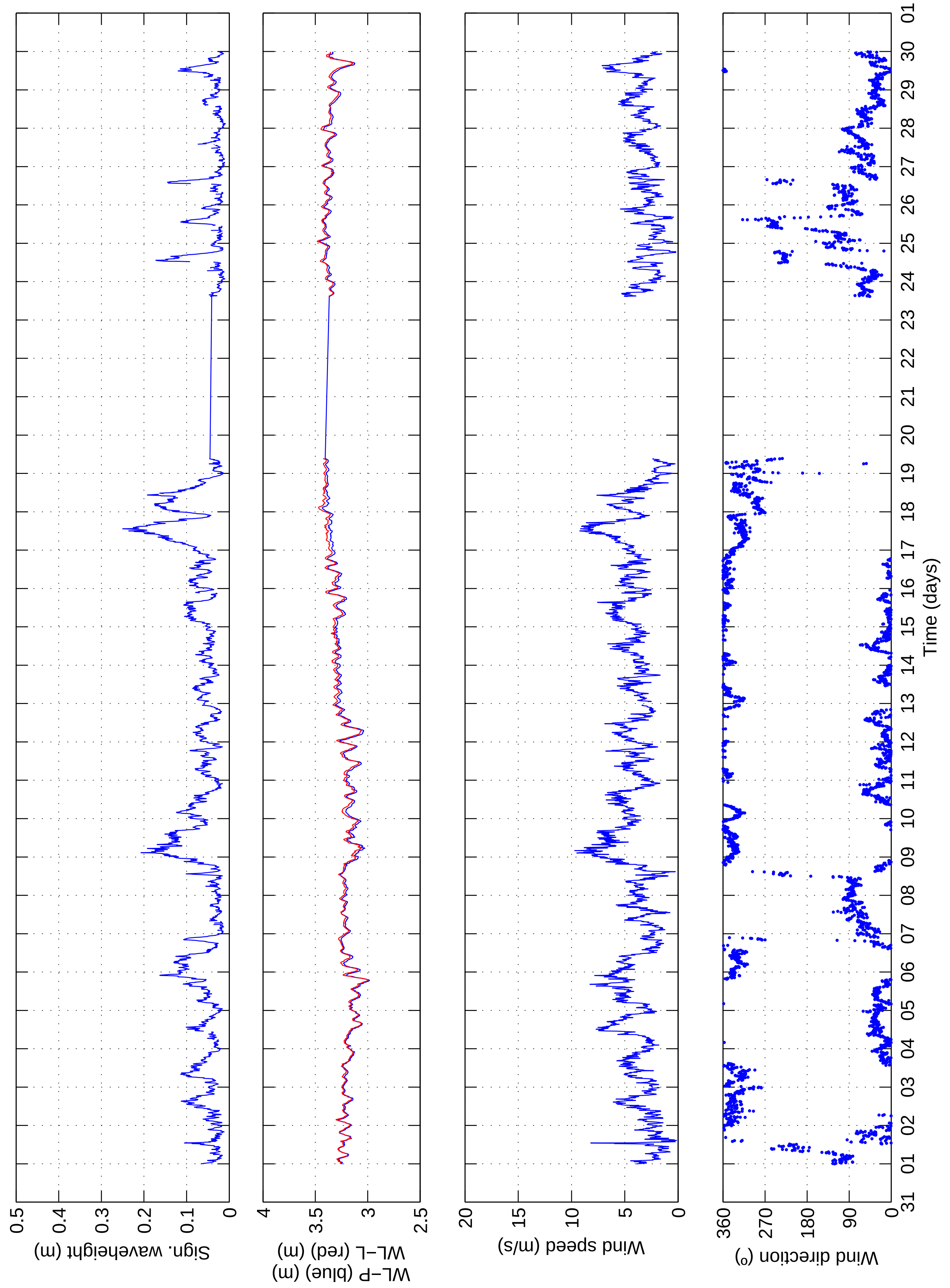
Overview of conditions at Gonghu station during June 2006 based on STAT files	Lake Taihu	
WL | DELFT HYDRAULICS	H4955	Fig. A.2



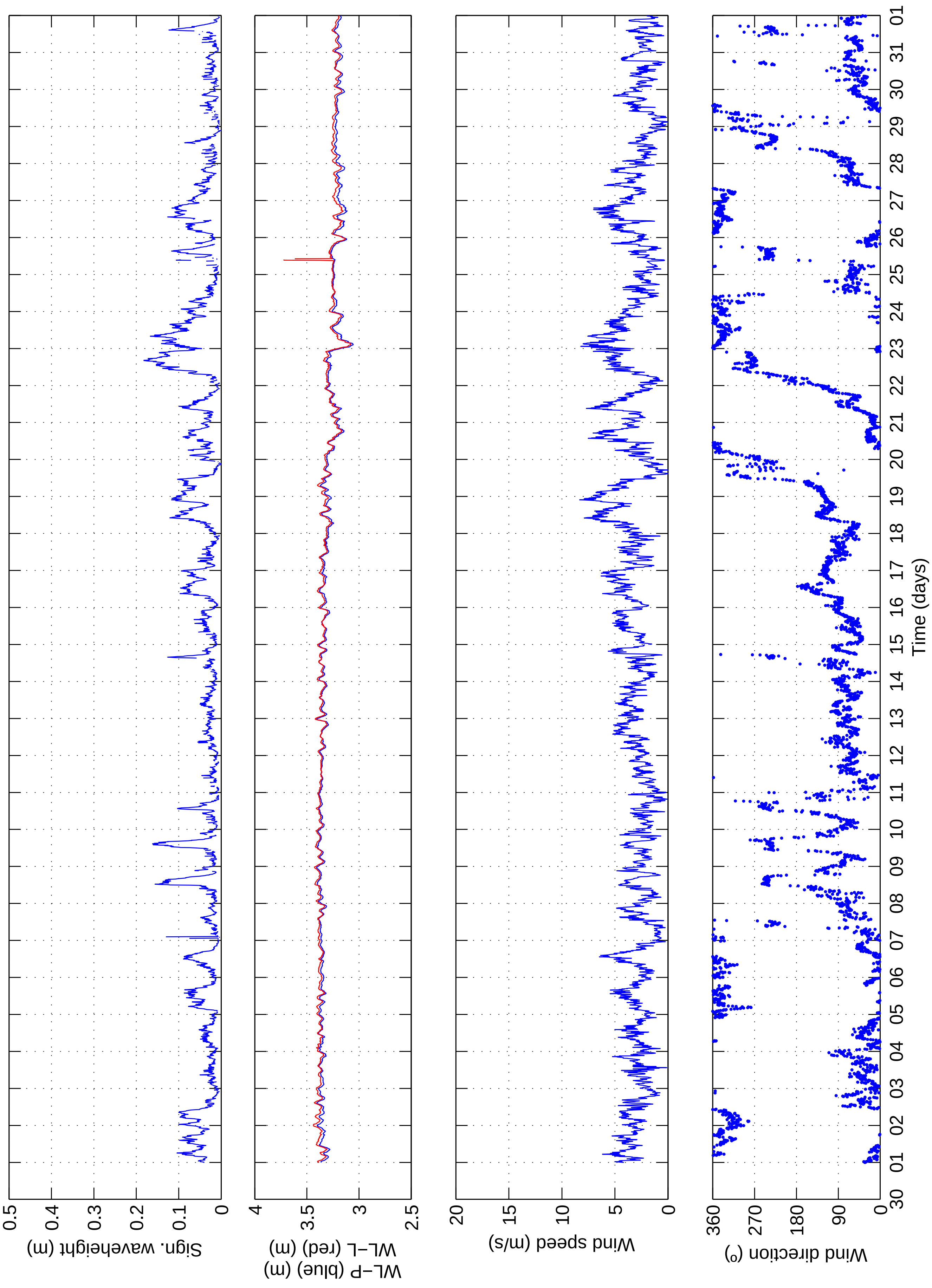
Overview of conditions at Gonghu station during July 2006 based on STAT files	Lake Taihu	
WL | DELFT HYDRAULICS	H4955	Fig. A.3



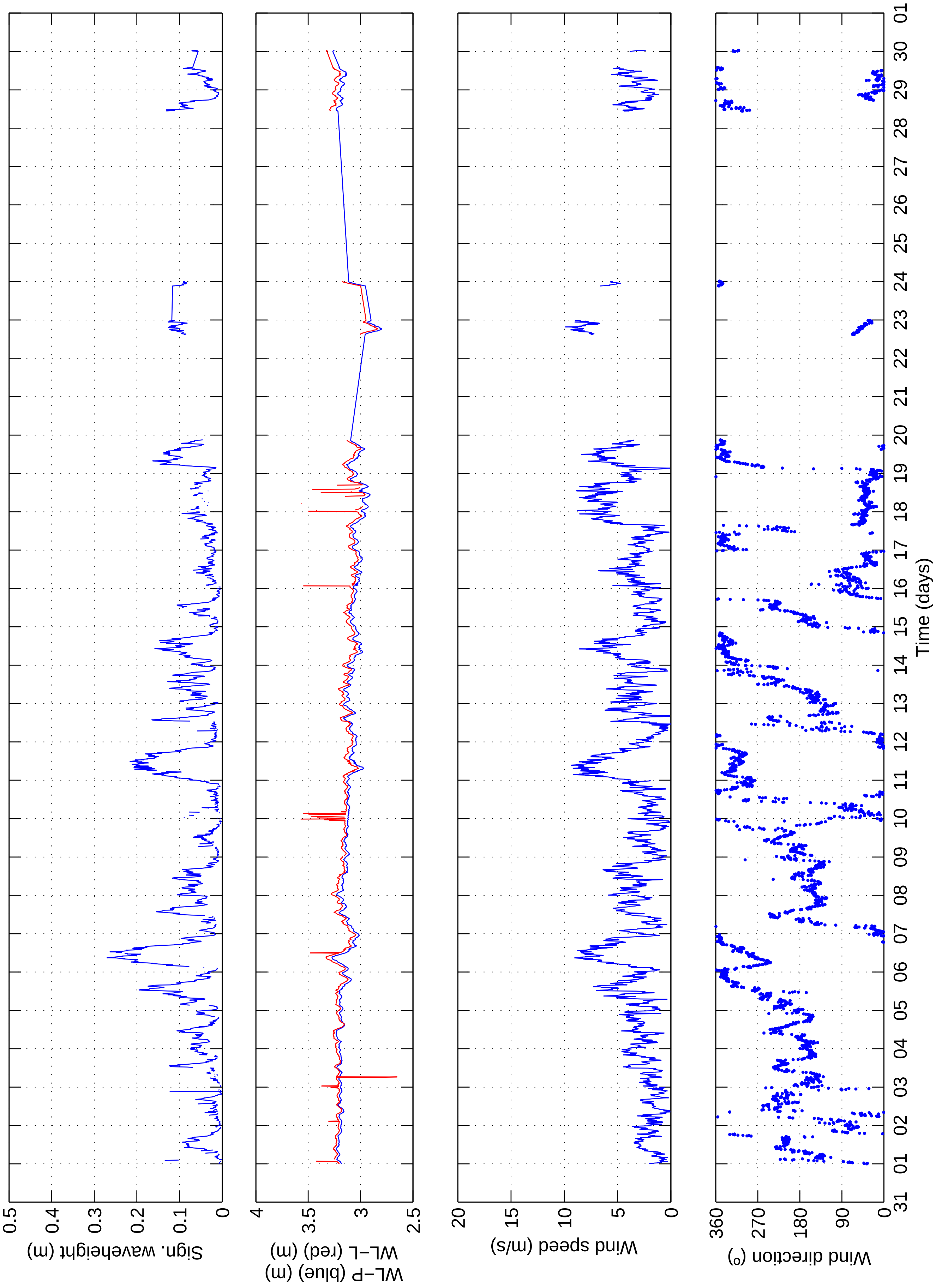
Overview of conditions at Gonghu station during August 2006 based on STAT files	Lake Taihu
WL | DELFT HYDRAULICS	H4955 | Fig. A.4



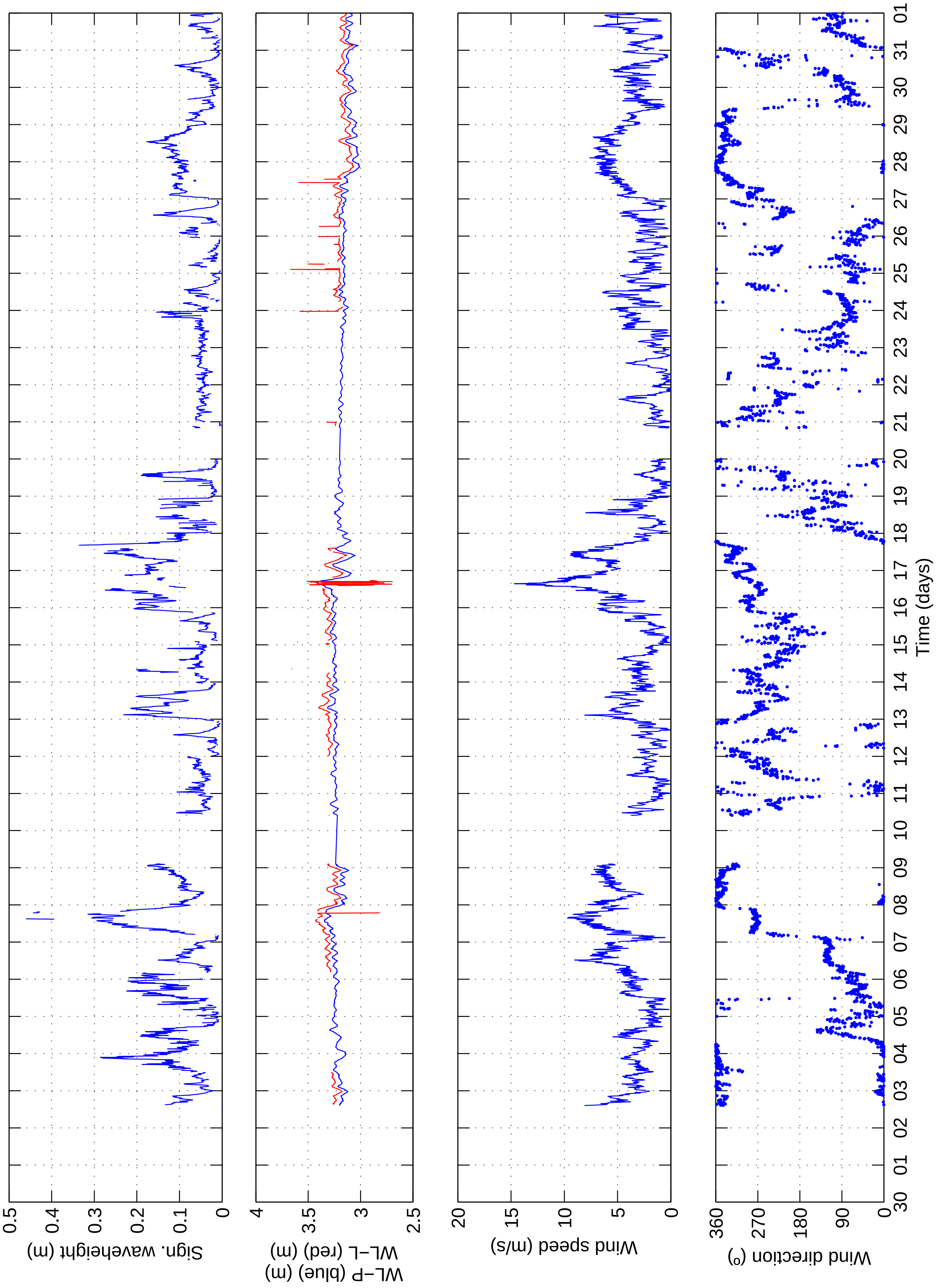
Overview of conditions at Gonghu station during September 2006 based on STAT files	Lake Taihu	
WL | DELFT HYDRAULICS	H4955	Fig. A.5



Overview of conditions at Gonghu station during October 2006 based on STAT files	Lake Taihu	
WL | DELFT HYDRAULICS	H4955	Fig. A.6

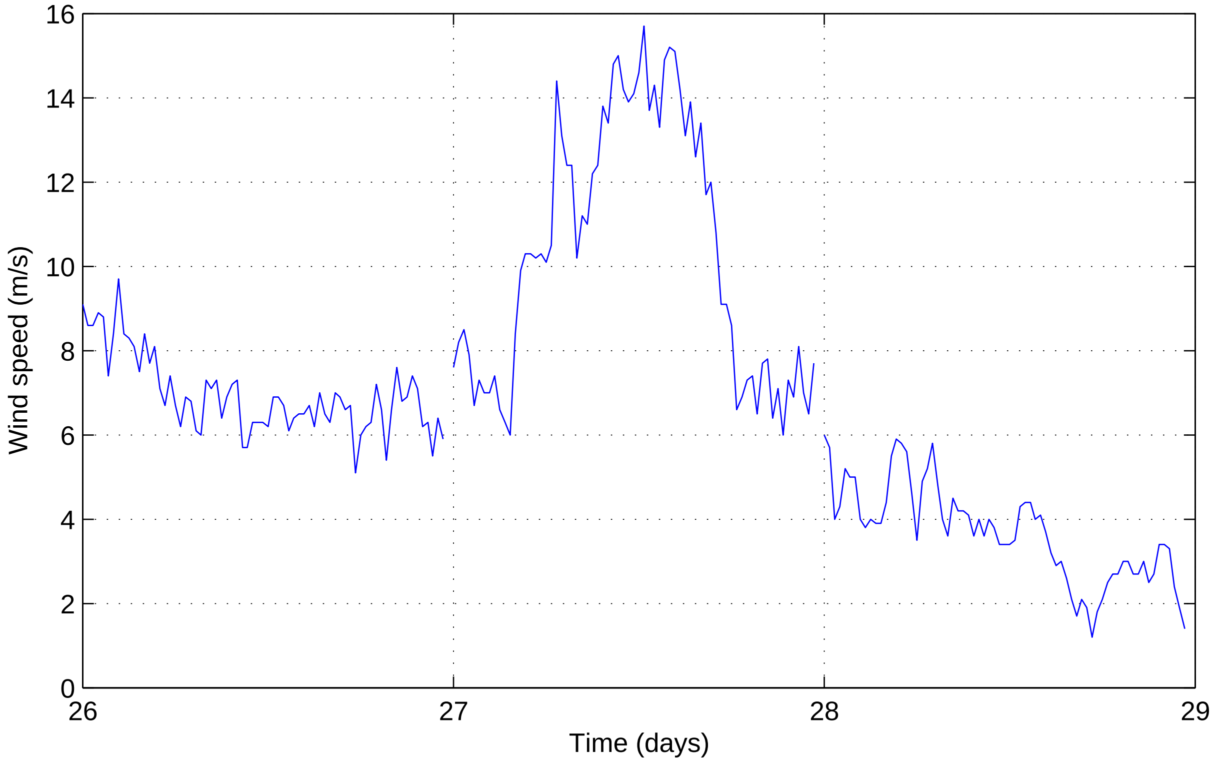


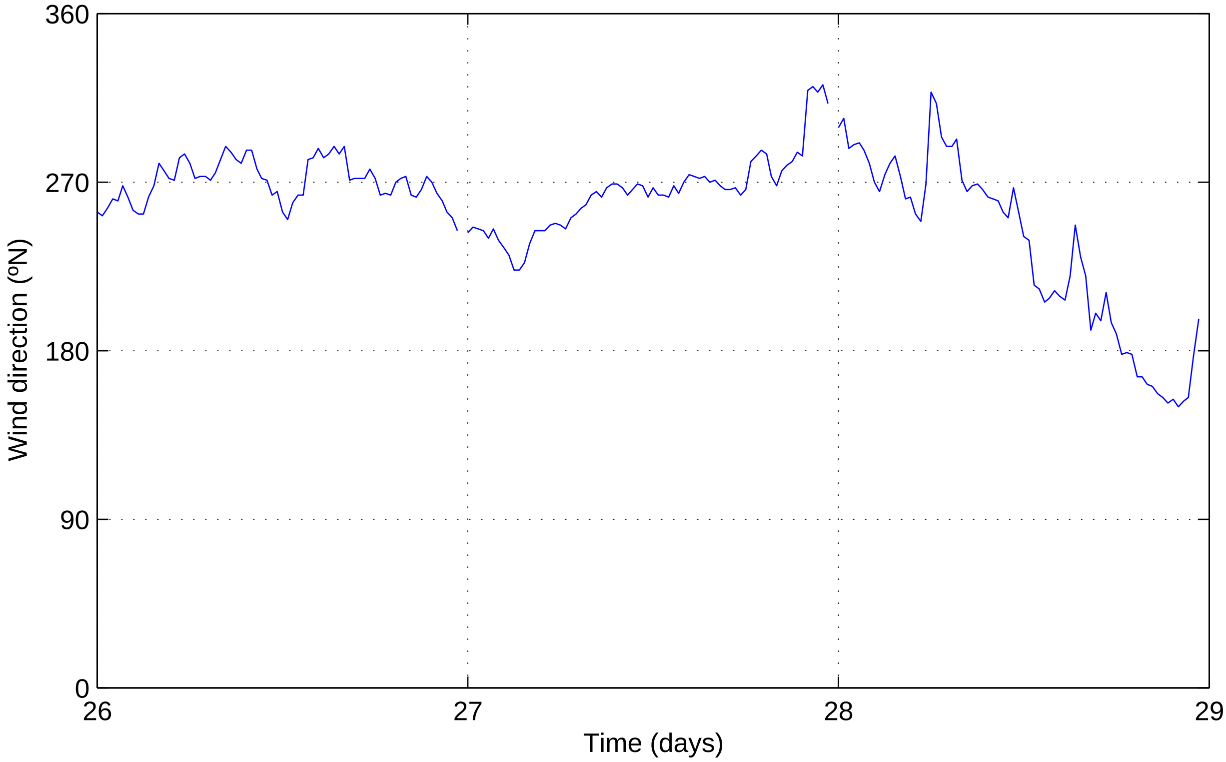
Overview of conditions at Gonghu station during November 2006 based on STAT files	Lake Taihu	
WL | DELFT HYDRAULICS	H4955	Fig. A.7



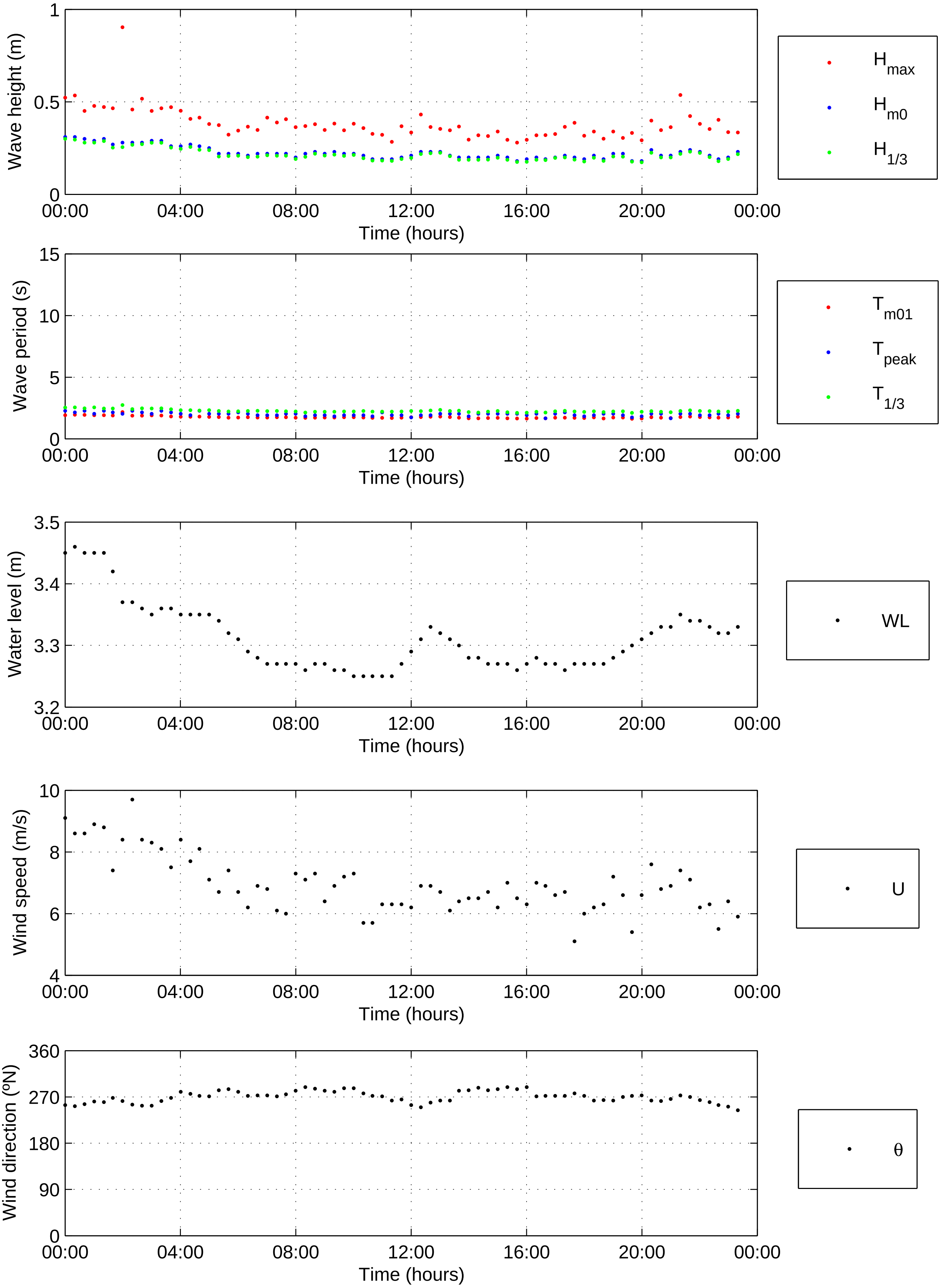
Overview of conditions at Gonghu station during December 2006 based on STAT files	Lake Taihu	
WL | DELFT HYDRAULICS	H4955	Fig. A.8

B Storm period May 2006



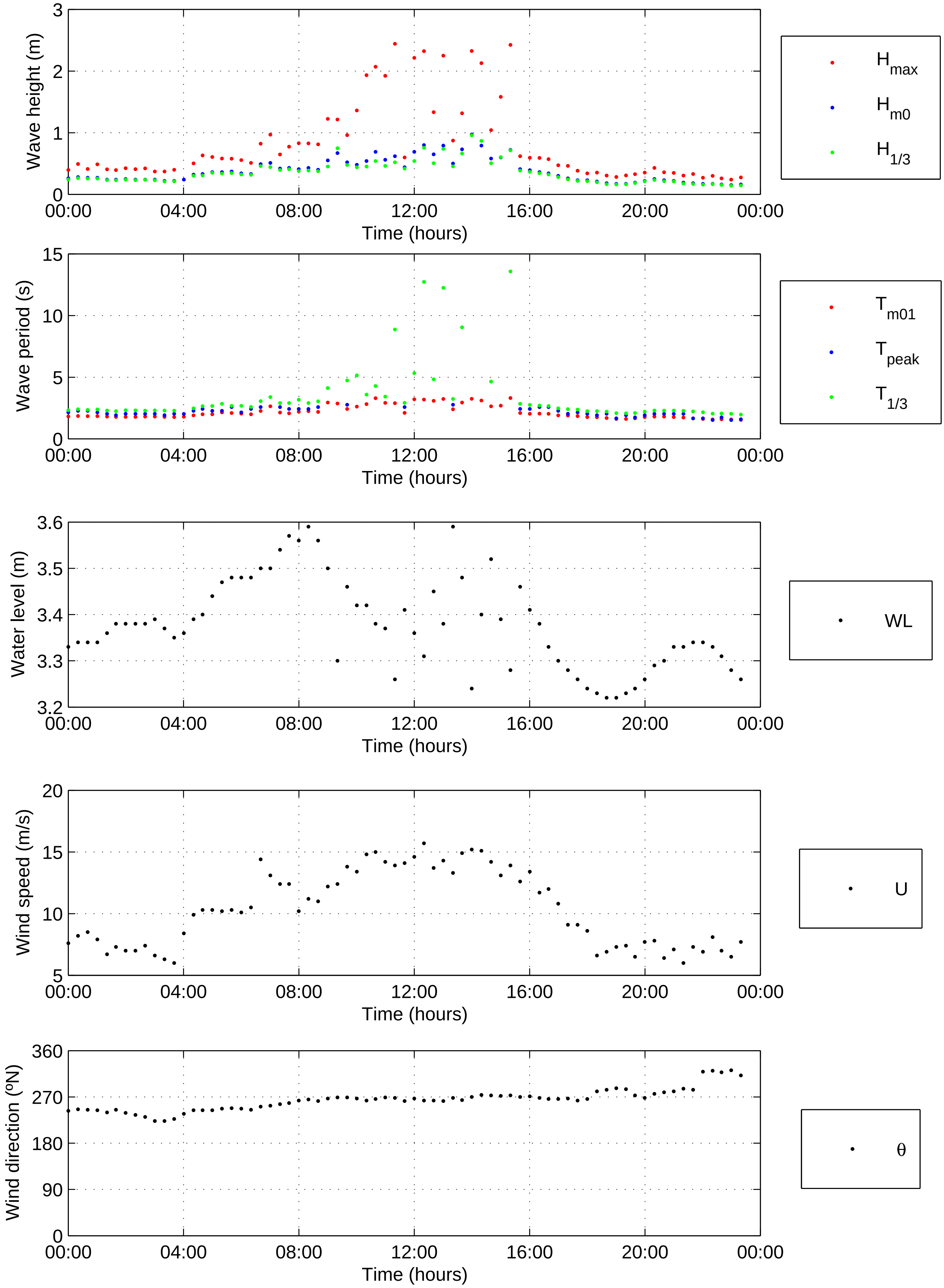


20 minutes mean wind speed and direction at Gonghu Storm period 26 to 28 May 2006	Lake Taihu	
WL | DELFT HYDRAULICS	H4955	Fig. B.1

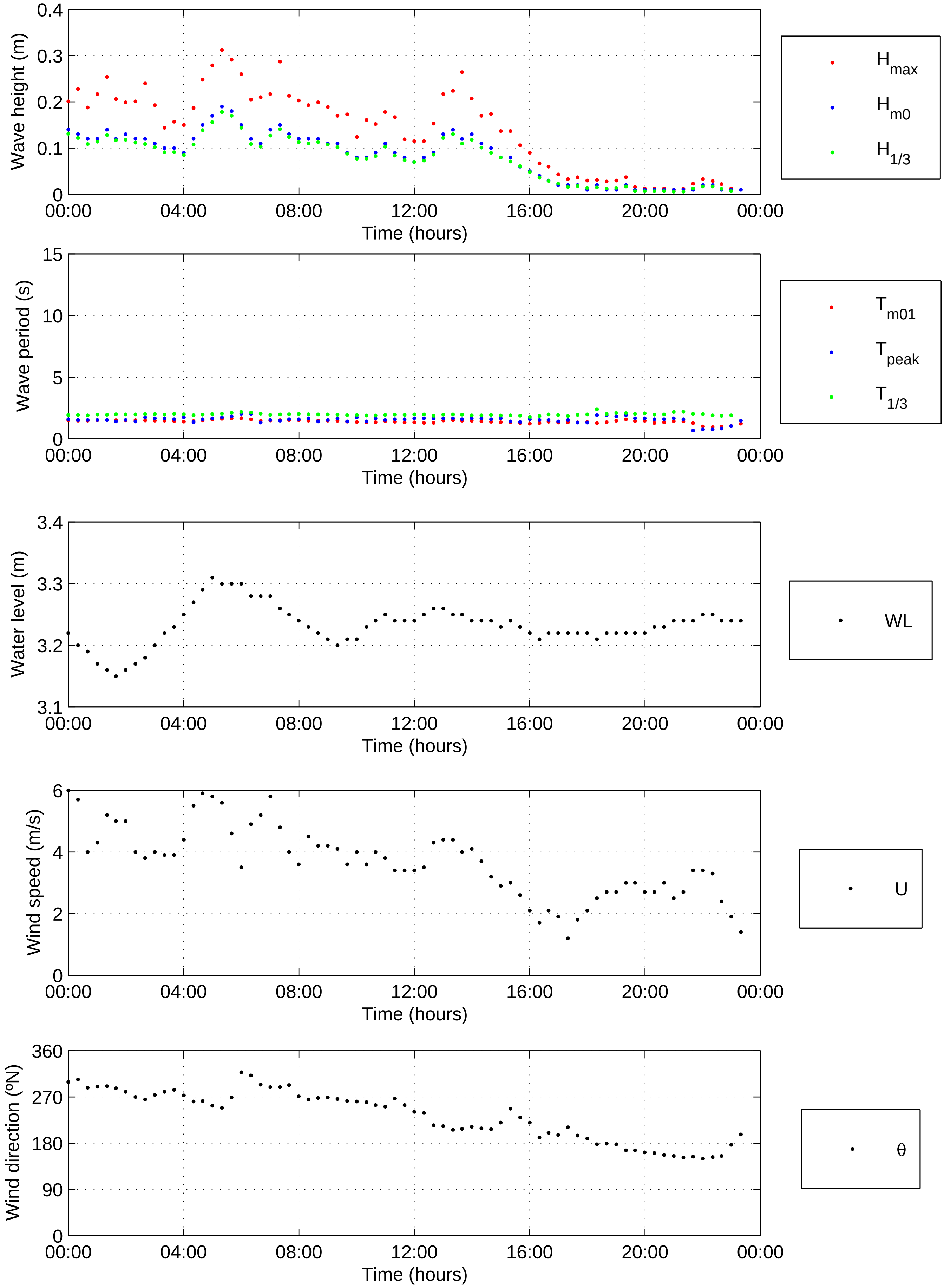


Wave height, wave period, water level and wind at Gonghu
26 May 2006

	Lake Taihu	
WL | DELFT HYDRAULICS	H4955	Fig. B.2

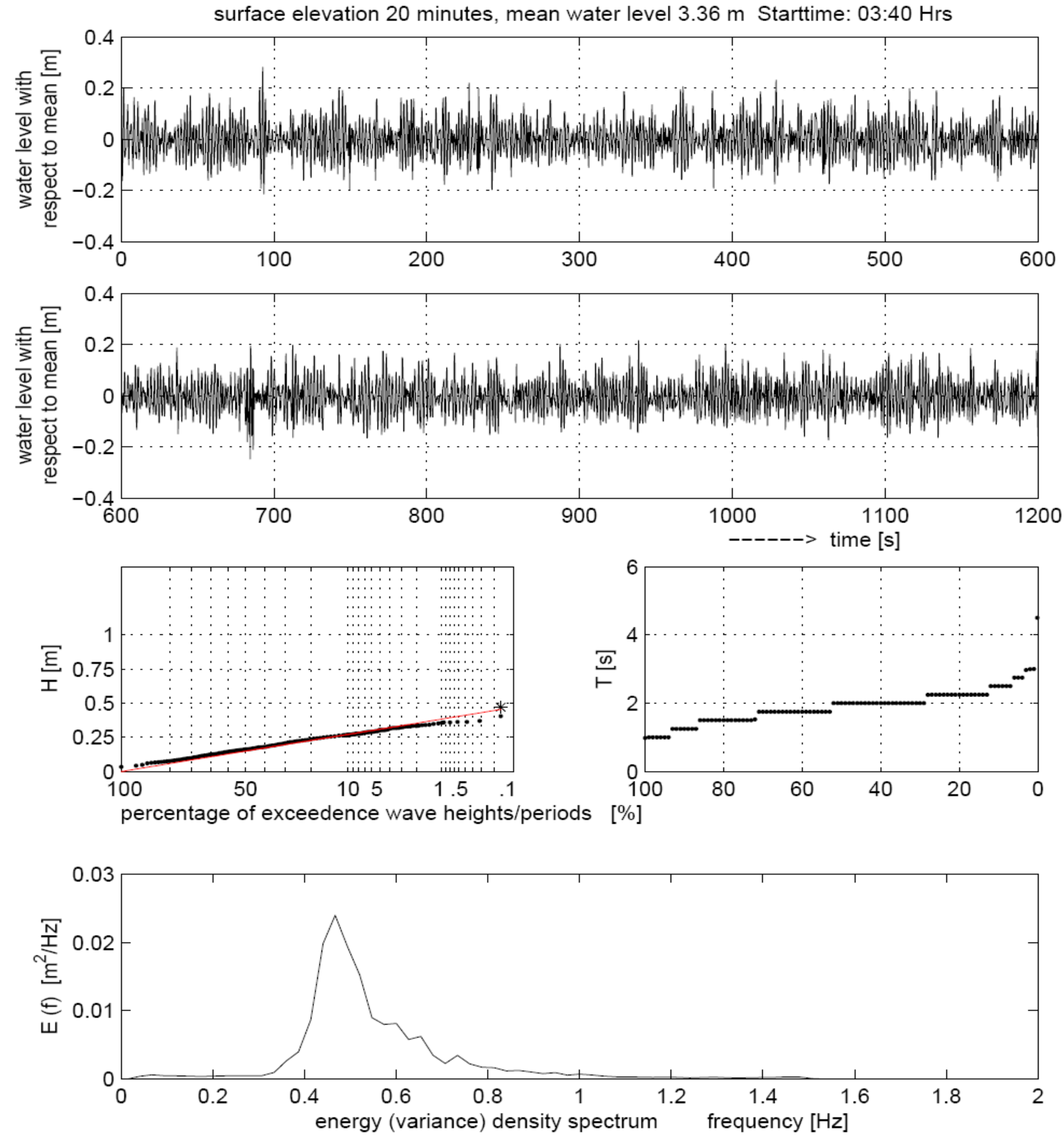


Wave height, wave period, water level and wind at Gonghu 27 May 2006	Lake Taihu	
WL | DELFT HYDRAULICS	H4955	Fig. B.3



Wave height, wave period, water level and wind at Gonghu
28 May 2006

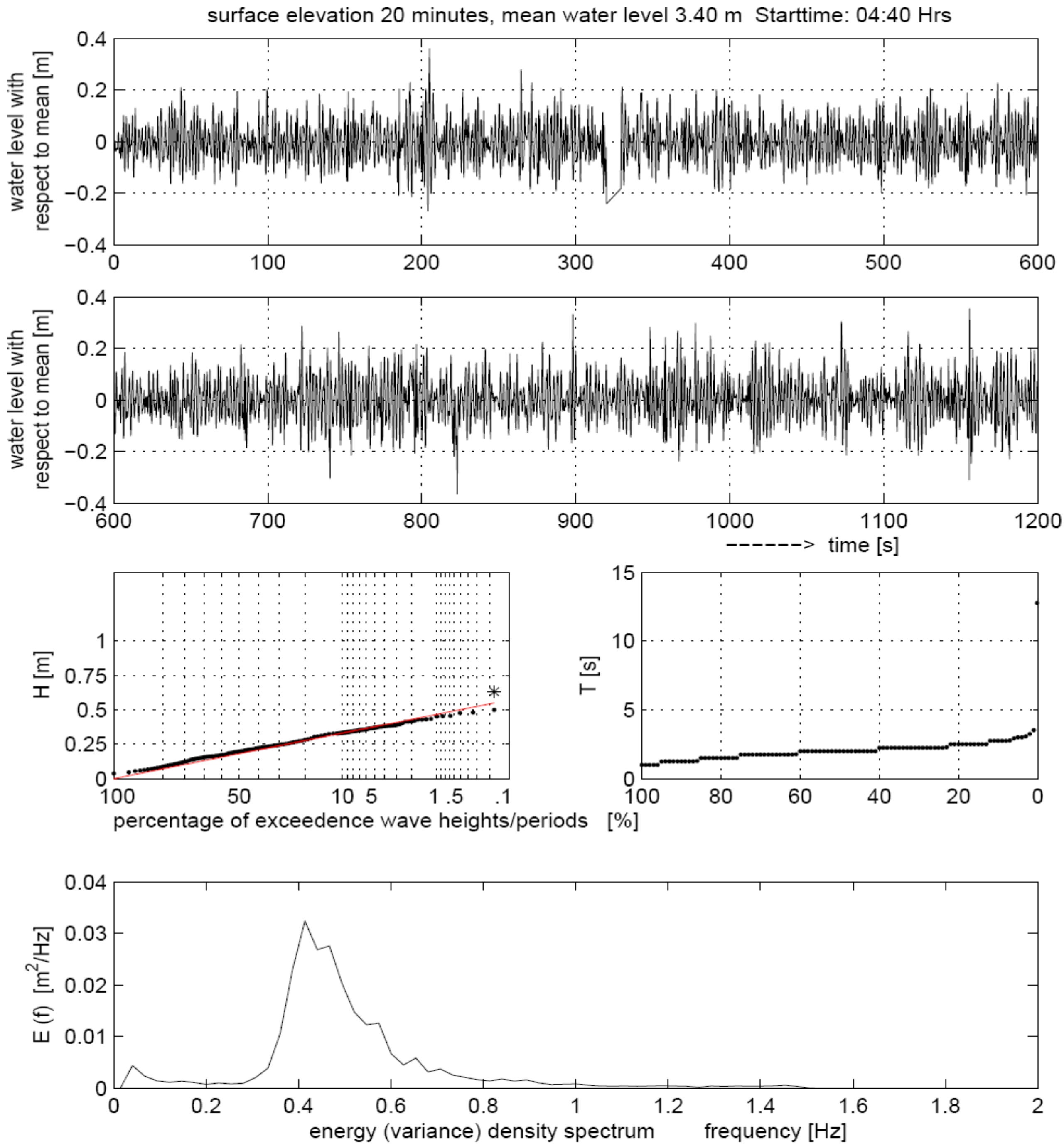
	Lake Taihu	
WL | DELFT HYDRAULICS	H4955	Fig. B.4



H_{m0} = 0.26 m	T_p = 2.14 s	$T_{H1/3}$ = 2.00 s
$H_{1/3}$ = 0.25 m	T_{m-10} = 2.10 s	$T_{1/3}$ = 2.40 s
$H_{1/10}$ = 0.31 m	T_{m01} = 1.82 s	skewness = 0.20
$H_{1/50}$ = 0.37 m	T_{m02} = 1.73 s	kurtosis = 3.02
H_{max} = 0.47 m	T_{Hmax} = 2.00 s	κ = 0.50

Water level, wave spectrum and wave parameters for a block of 20 minutes based on WAVE file (Log_aLevel), 26 May 2006

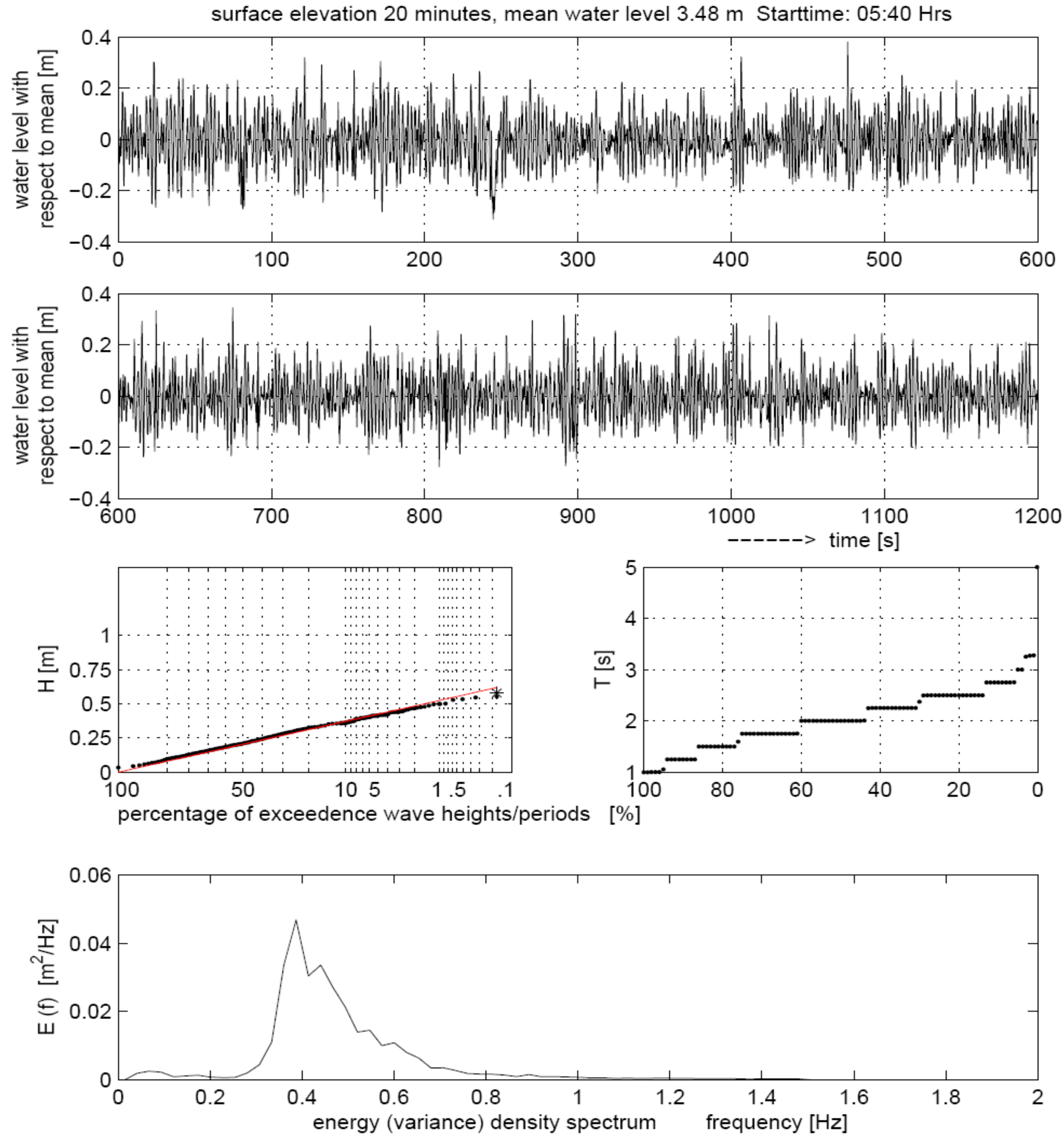
Lake Taihu



H_{m0} = 0.33 m	T_p = 2.42 s	$T_{H1/3}$ = 2.23 s
$H_{1/3}$ = 0.31 m	T_{m-10} = 2.73 s	$T_{1/3}$ = 2.65 s
$H_{1/10}$ = 0.38 m	T_{m01} = 1.99 s	skewness = 0.07
$H_{1/50}$ = 0.47 m	T_{m02} = 1.84 s	kurtosis = 3.23
H_{max} = 0.63 m	T_{Hmax} = 2.25 s	κ = 0.47

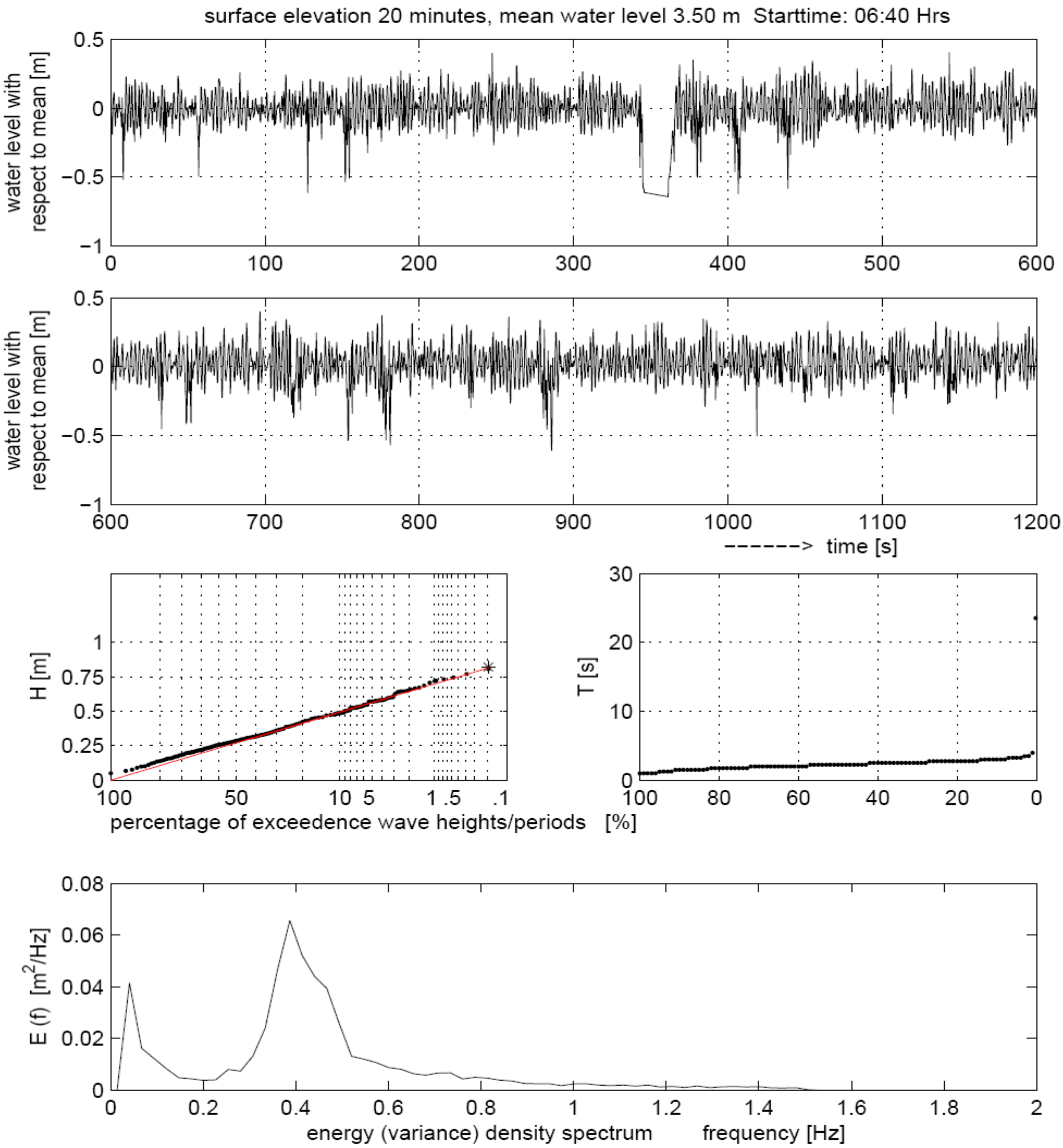
Water level, wave spectrum and wave parameters for a block of 20 minutes based on WAVE file (Log_aLevel), 27 May 2006

Lake Taihu



H_{m0} = 0.37 m	T_p = 2.58 s	$T_{H1/3}$ = 2.25 s
$H_{1/3}$ = 0.35 m	T_{m-10} = 2.56 s	$T_{1/3}$ = 2.67 s
$H_{1/10}$ = 0.43 m	T_{m01} = 2.09 s	skewness = 0.18
$H_{1/50}$ = 0.51 m	T_{m02} = 1.95 s	kurtosis = 3.18
H_{max} = 0.58 m	T_{Hmax} = 2.25 s	κ = 0.46

Water level, wave spectrum and wave parameters for a block of 20 minutes based on WAVE file (Log_aLevel), 27 May 2006	Lake Taihu	
WL | Delft Hydraulics	H4955	Fig. B.7



H_{m0} = 0.49 m

$H_{1/3}$ = 0.46 m

$H_{1/10}$ = 0.59 m

$H_{1/50}$ = 0.73 m

H_{max} = 0.82 m

T_p = 2.58 s

T_{m-10} = 4.61 s

T_{m01} = 2.26 s

T_{m02} = 1.93 s

T_{Hmax} = 2.75 s

$T_{H1/3}$ = 2.48 s

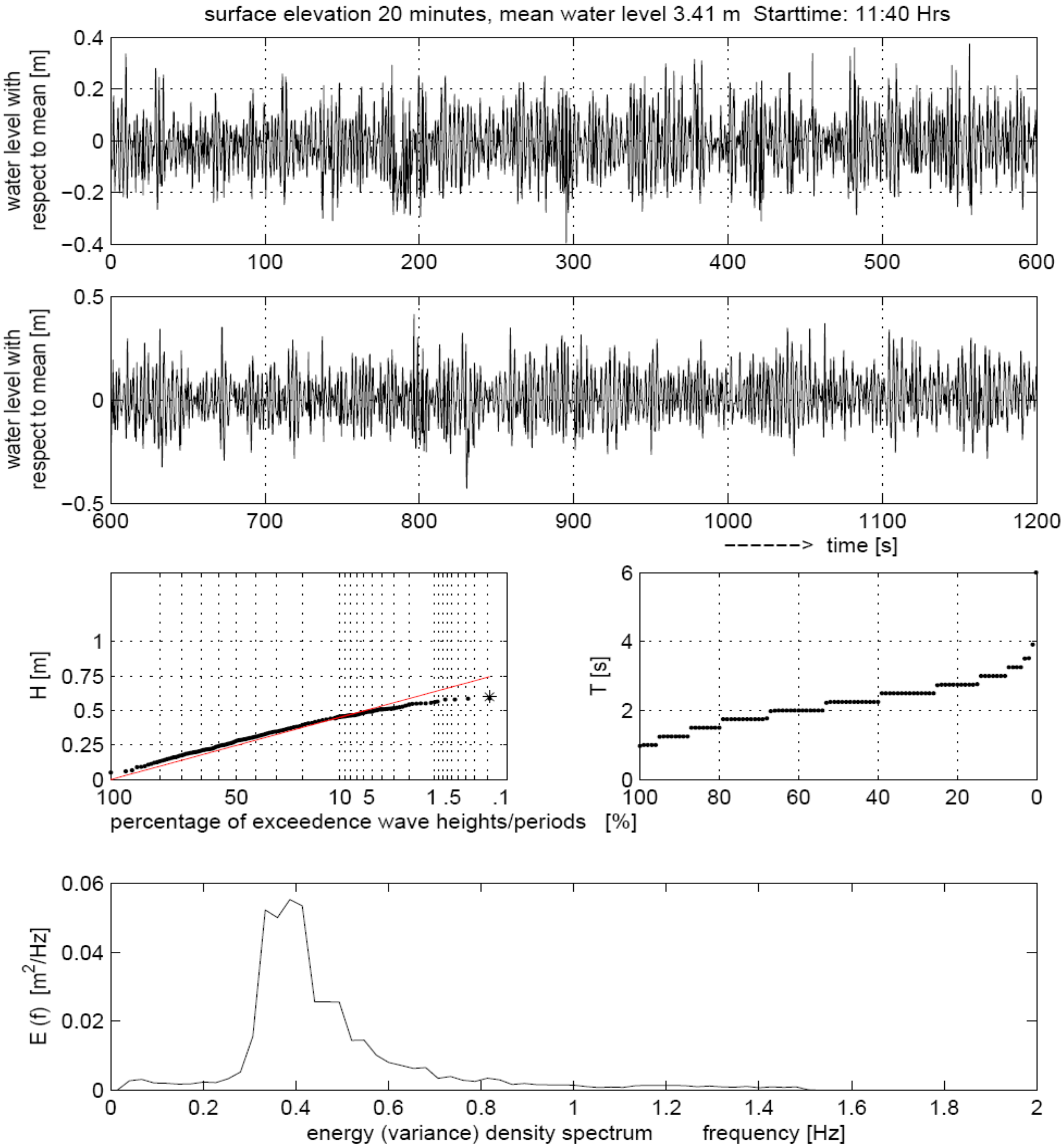
$T_{1/3}$ = 3.05 s

skewness = −1.24

kurtosis = 7.03

κ = 0.33

Water level, wave spectrum and wave parameters for a block of 20 minutes based on WAVE file (Log_aLevel), 27 May 2006	Lake Taihu	
WL | Delft Hydraulics	H4955	Fig. B.8



H_{m0} = 0.44 m

$H_{1/3}$ = 0.42 m

$H_{1/10}$ = 0.50 m

$H_{1/50}$ = 0.57 m

H_{max} = 0.60 m

T_p = 2.58 s

T_{m-10} = 2.65 s

T_{m01} = 2.11 s

T_{m02} = 1.91 s

T_{Hmax} = 1.75 s

$T_{H1/3}$ = 2.31 s

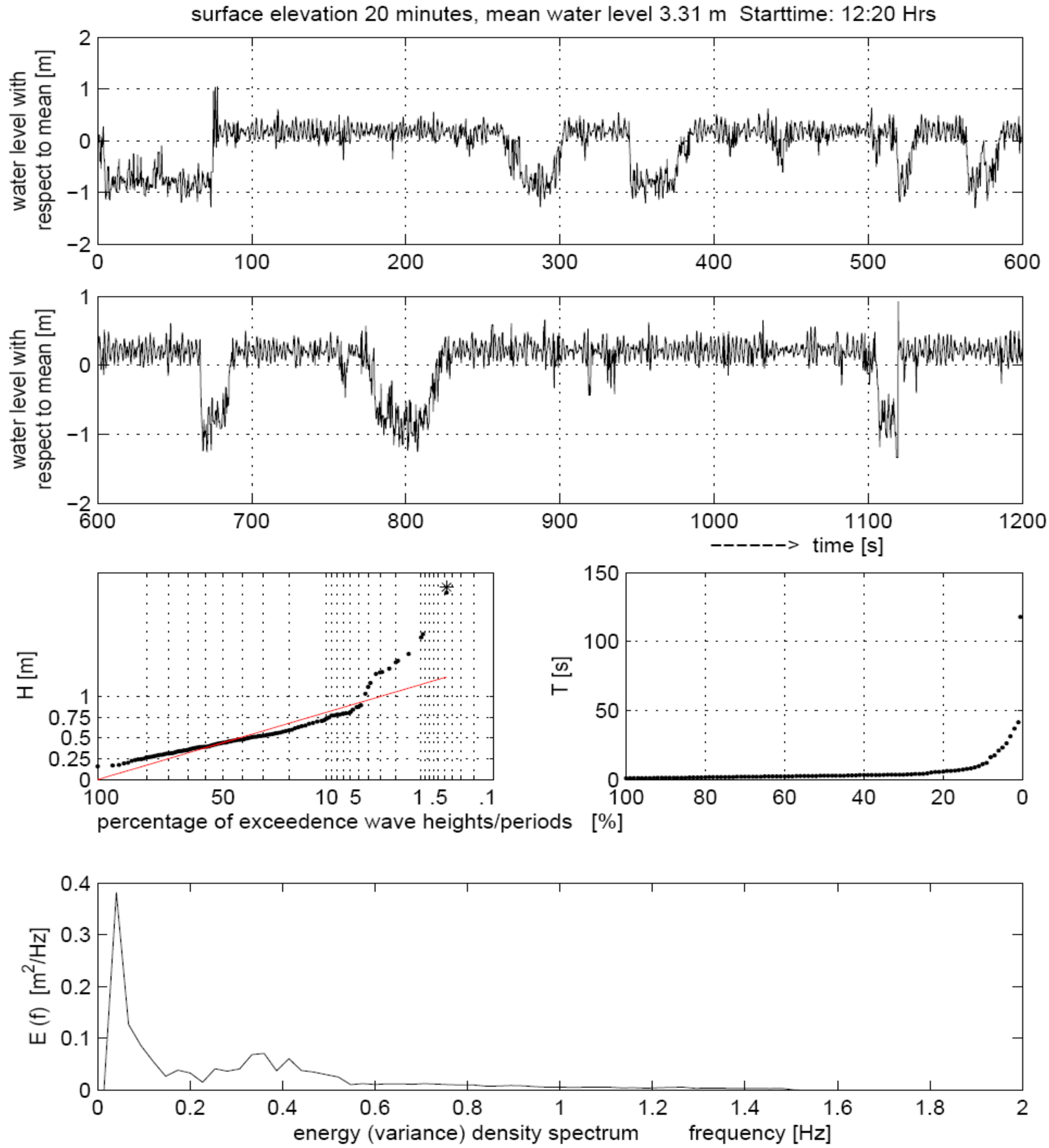
$T_{1/3}$ = 2.92 s

skewness = 0.13

kurtosis = 2.91

κ = 0.46

Water level, wave spectrum and wave parameters for a block of 20 minutes based on WAVE file (Log_aLevel), 27 May 2006	Lake Taihu	
WL | Delft Hydraulics	H4955	Fig. B.9



H_{m0} = 0.80 m

$H_{1/3}$ = 0.76 m

$H_{1/10}$ = 1.16 m

$H_{1/50}$ = 1.96 m

H_{max} = 2.32 m

T_p = 24.74 s

T_{m-10} = 9.95 s

T_{m01} = 3.18 s

T_{m02} = 2.23 s

T_{Hmax} = 117.75 s

$T_{H1/3}$ = 10.57 s

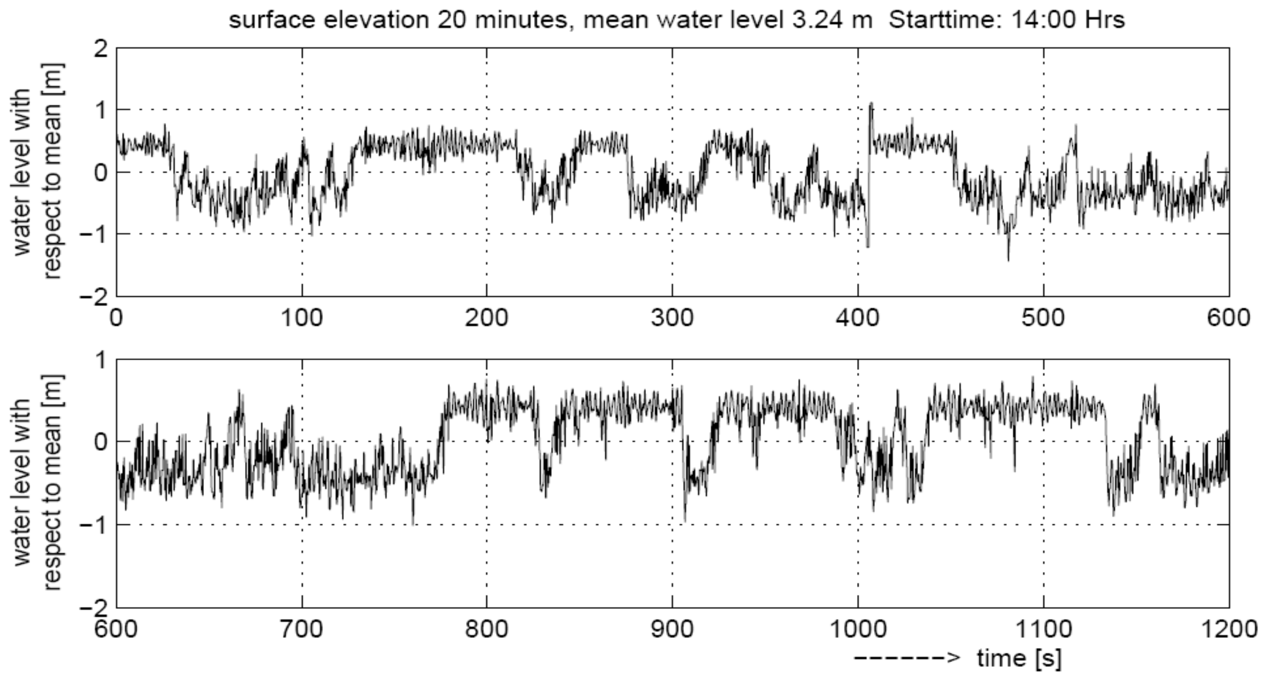
$T_{1/3}$ = 12.73 s

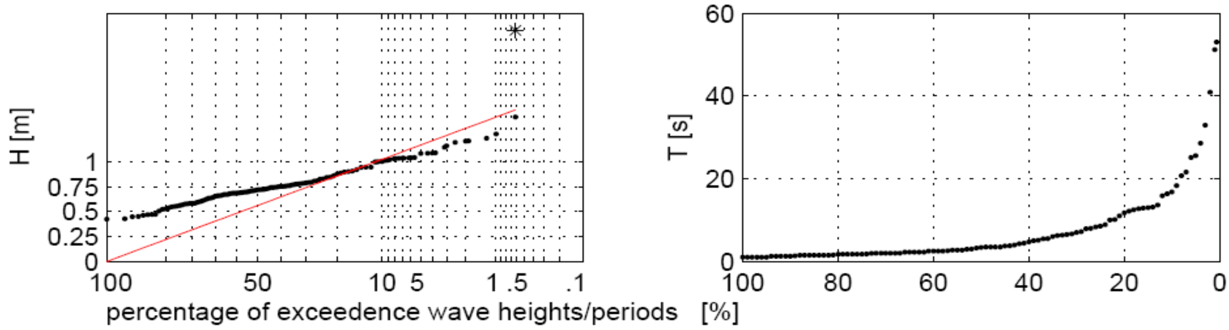
skewness = −1.23

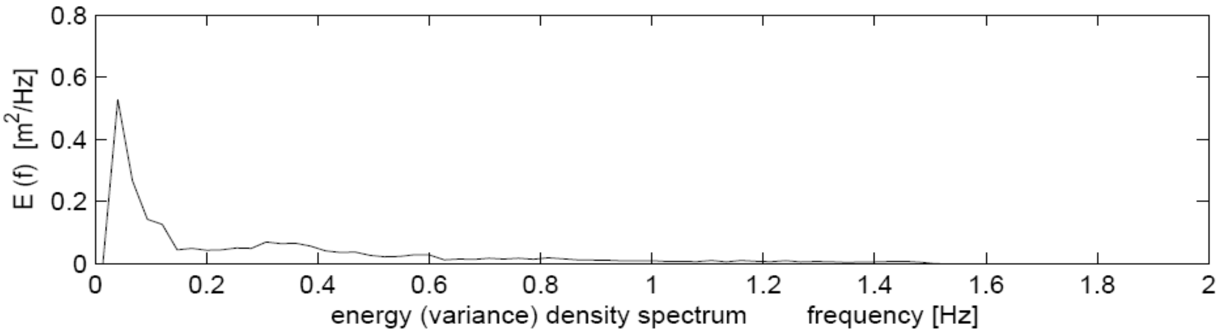
kurtosis = 3.86

κ = 0.34

Water level, wave spectrum and wave parameters for a block of 20 minutes based on WAVE file (Log_aLevel), 27 May 2006	Lake Taihu	
WL | Delft Hydraulics	H4955	Fig. B.10

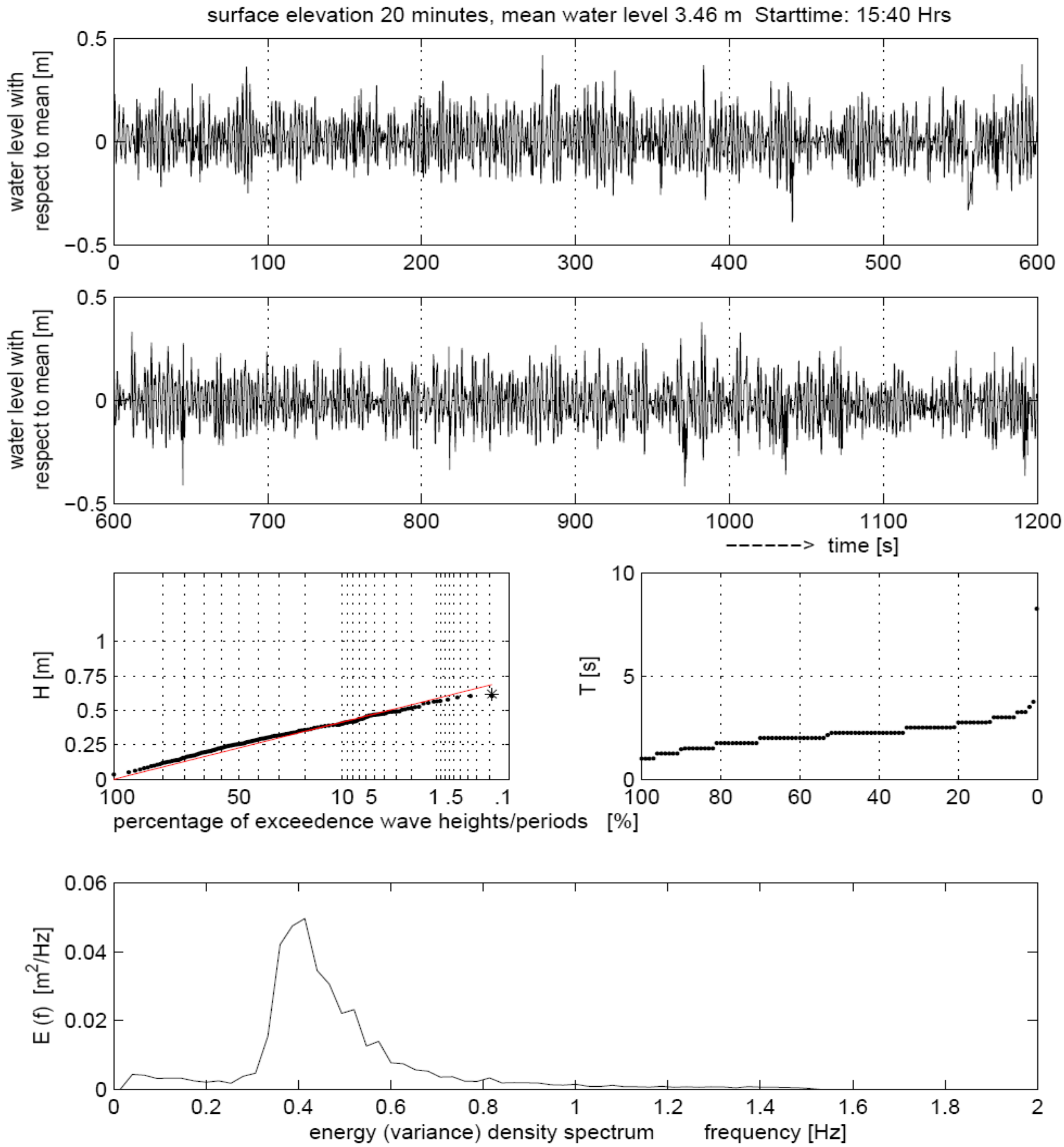






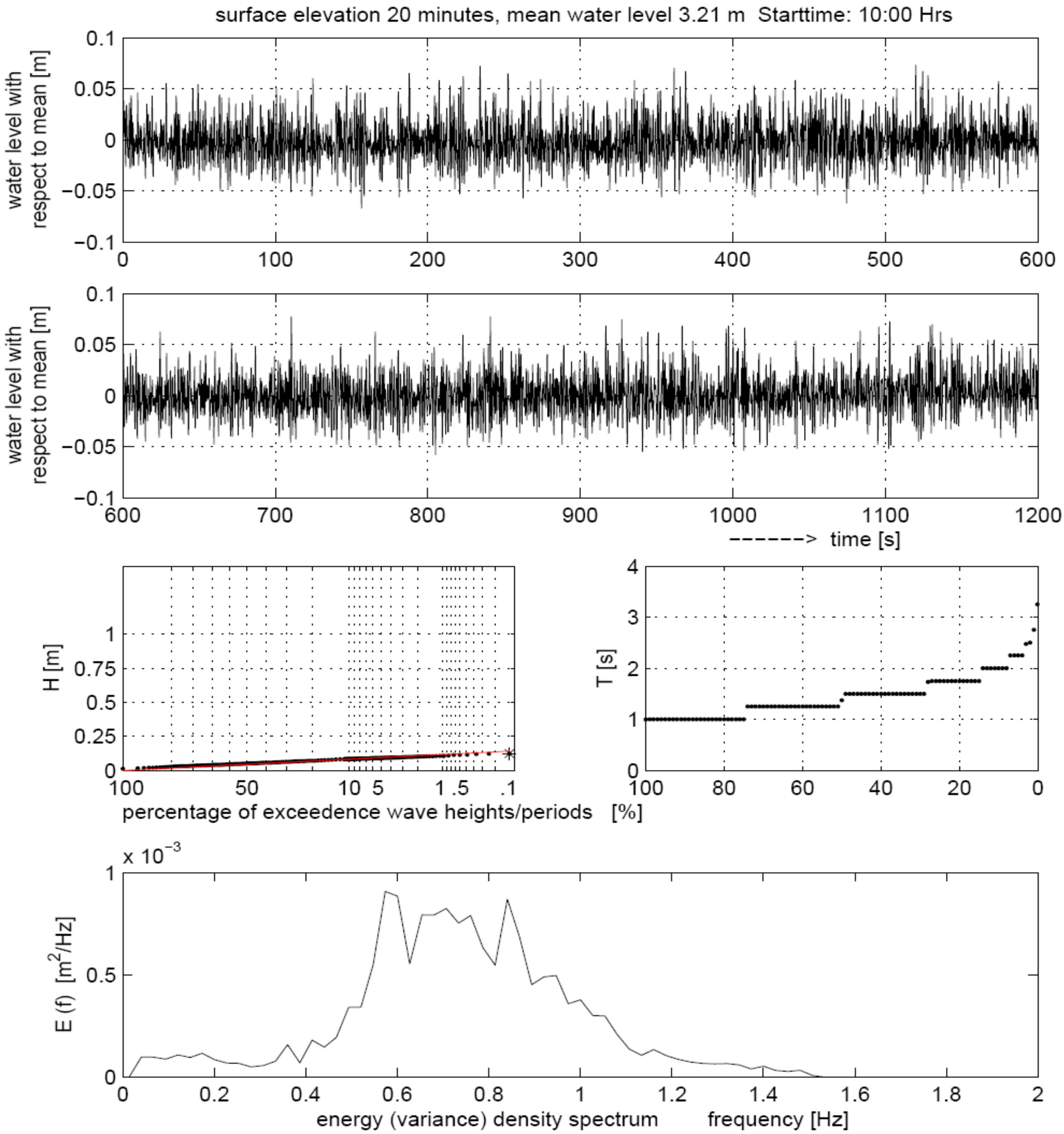
H_{m0} = 0.97 m	T_p = 24.74 s	$T_{H1/3}$ = 13.39 s
$H_{1/3}$ = 0.96 m	T_{m-10} = 10.28 s	$T_{1/3}$ = 16.67 s
$H_{1/10}$ = 1.19 m	T_{m01} = 3.25 s	skewness = −0.18
$H_{1/50}$ = 1.67 m	T_{m02} = 2.19 s	kurtosis = 1.79
H_{max} = 2.32 m	T_{Hmax} = 51.25 s	κ = 0.36

Water level, wave spectrum and wave parameters for a block of 20 minutes based on WAVE file (Log_aLevel), 27 May 2006	Lake Taihu	
WL | Delft Hydraulics	H4955	Fig. B.11



H_{m0} = 0.41 m	T_p = 2.42 s	$T_{H1/3}$ = 2.36 s
$H_{1/3}$ = 0.39 m	T_{m-10} = 2.78 s	$T_{1/3}$ = 2.84 s
$H_{1/10}$ = 0.48 m	T_{m01} = 2.09 s	skewness = 0.11
$H_{1/50}$ = 0.57 m	T_{m02} = 1.91 s	kurtosis = 3.10
H_{max} = 0.62 m	T_{Hmax} = 2.00 s	κ = 0.44

Water level, wave spectrum and wave parameters for a block of 20 minutes based on WAVE file (Log_aLevel), 27 May 2006	Lake Taihu	
WL | Delft Hydraulics	H4955	Fig. B.12



H_{m0} = 0.08 m

$H_{1/3}$ = 0.08 m

$H_{1/10}$ = 0.09 m

$H_{1/50}$ = 0.11 m

H_{max} = 0.12 m

T_p = 1.74 s

T_{m-10} = 1.84 s

T_{m01} = 1.36 s

T_{m02} = 1.28 s

T_{Hmax} = 1.25 s

$T_{H1/3}$ = 1.49 s

$T_{1/3}$ = 1.93 s

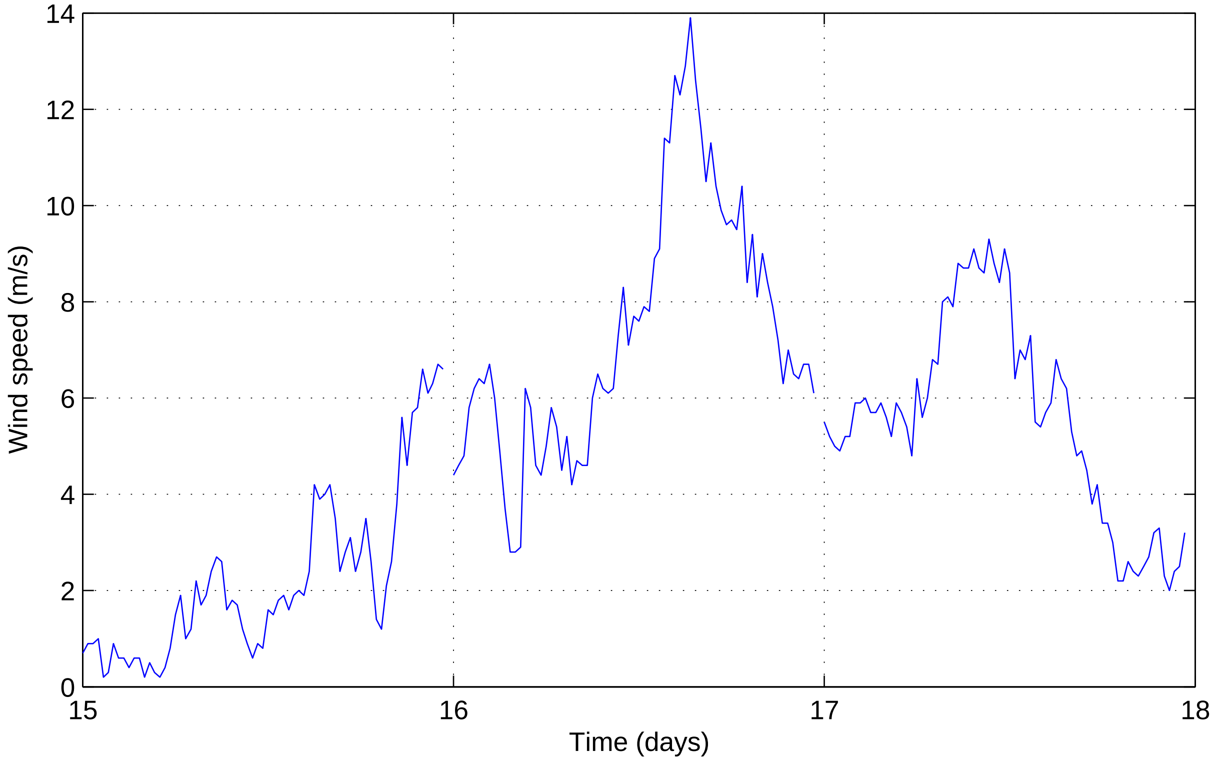
skewness = 0.25

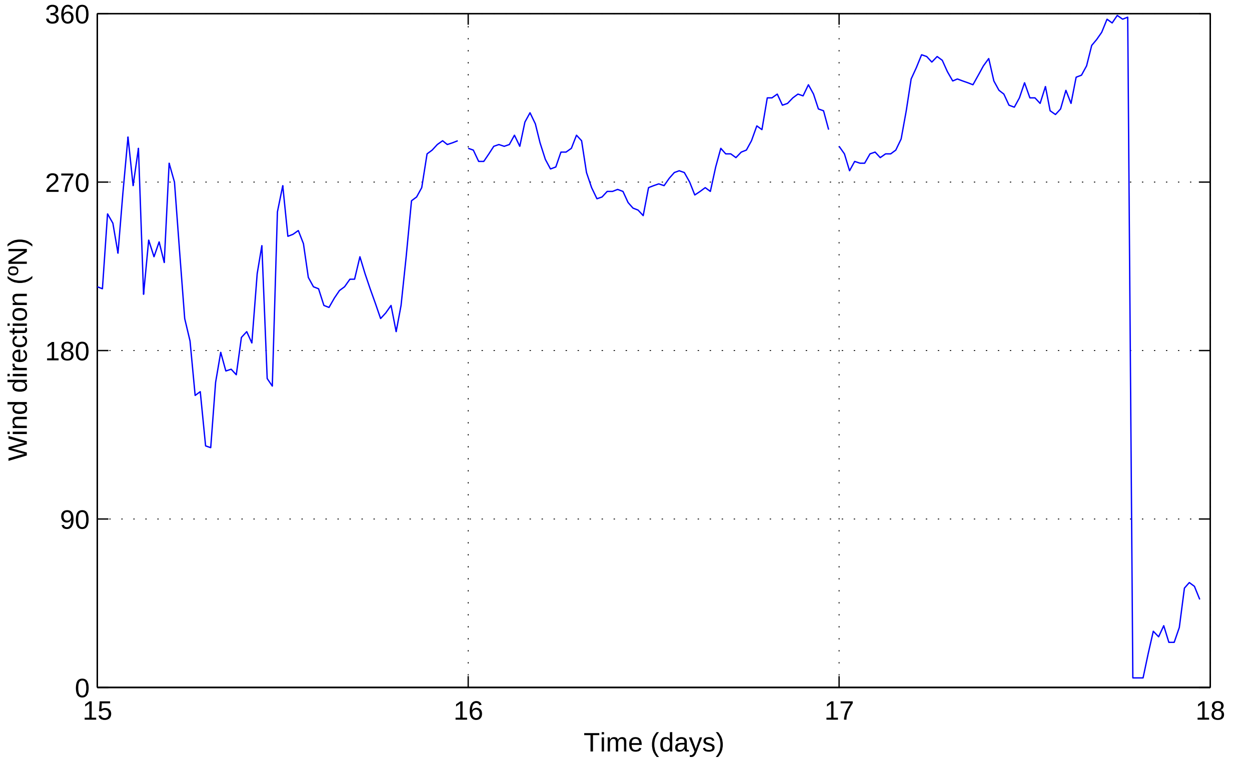
kurtosis = 2.97

κ = 0.27

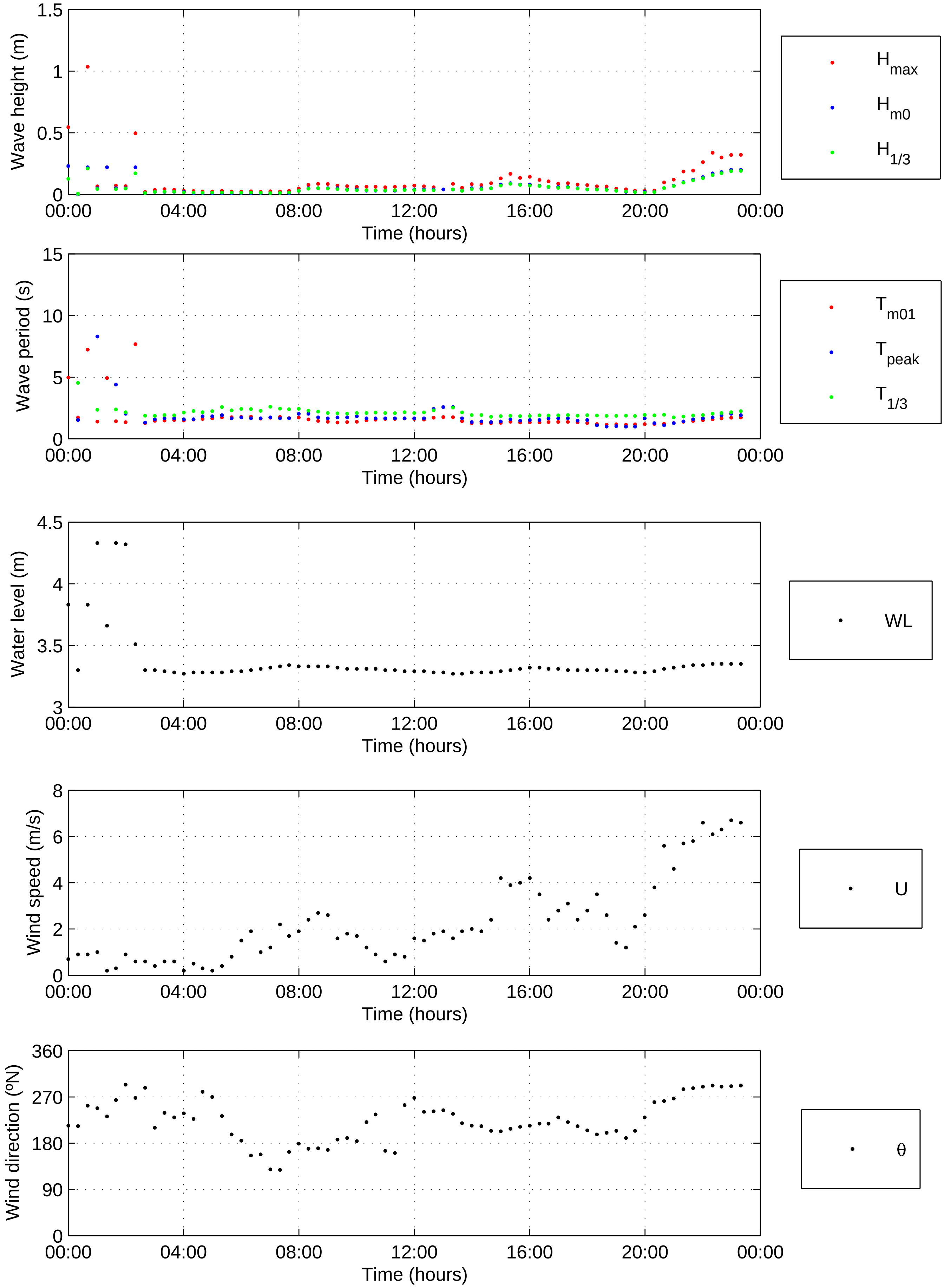
Water level, wave spectrum and wave parameters for a block of 20 minutes based on WAVE file (Log_aLevel), 28 May 2006	Lake Taihu	
WL | Delft Hydraulics	H4955	Fig. B.13

C Storm period December 2006

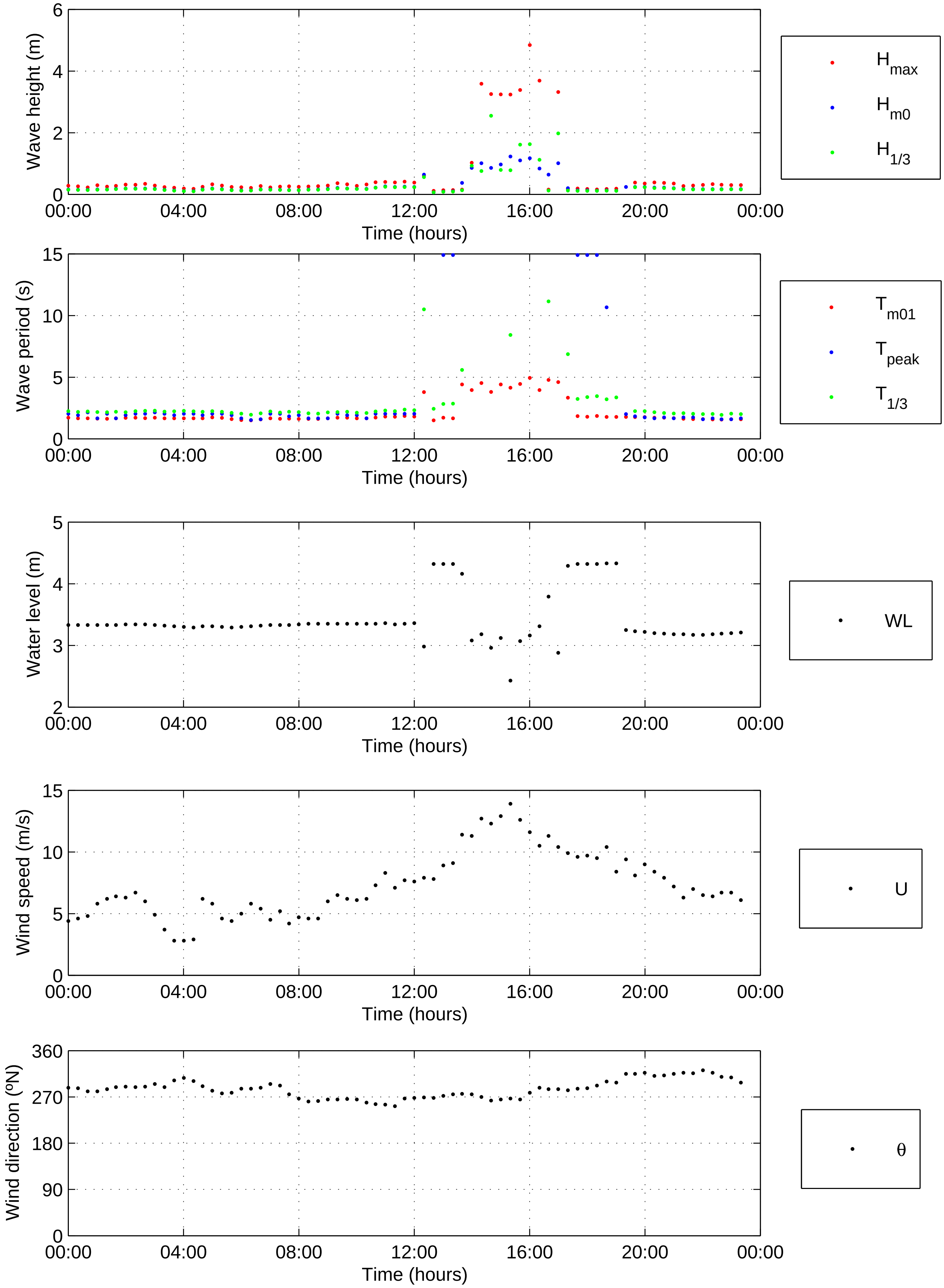




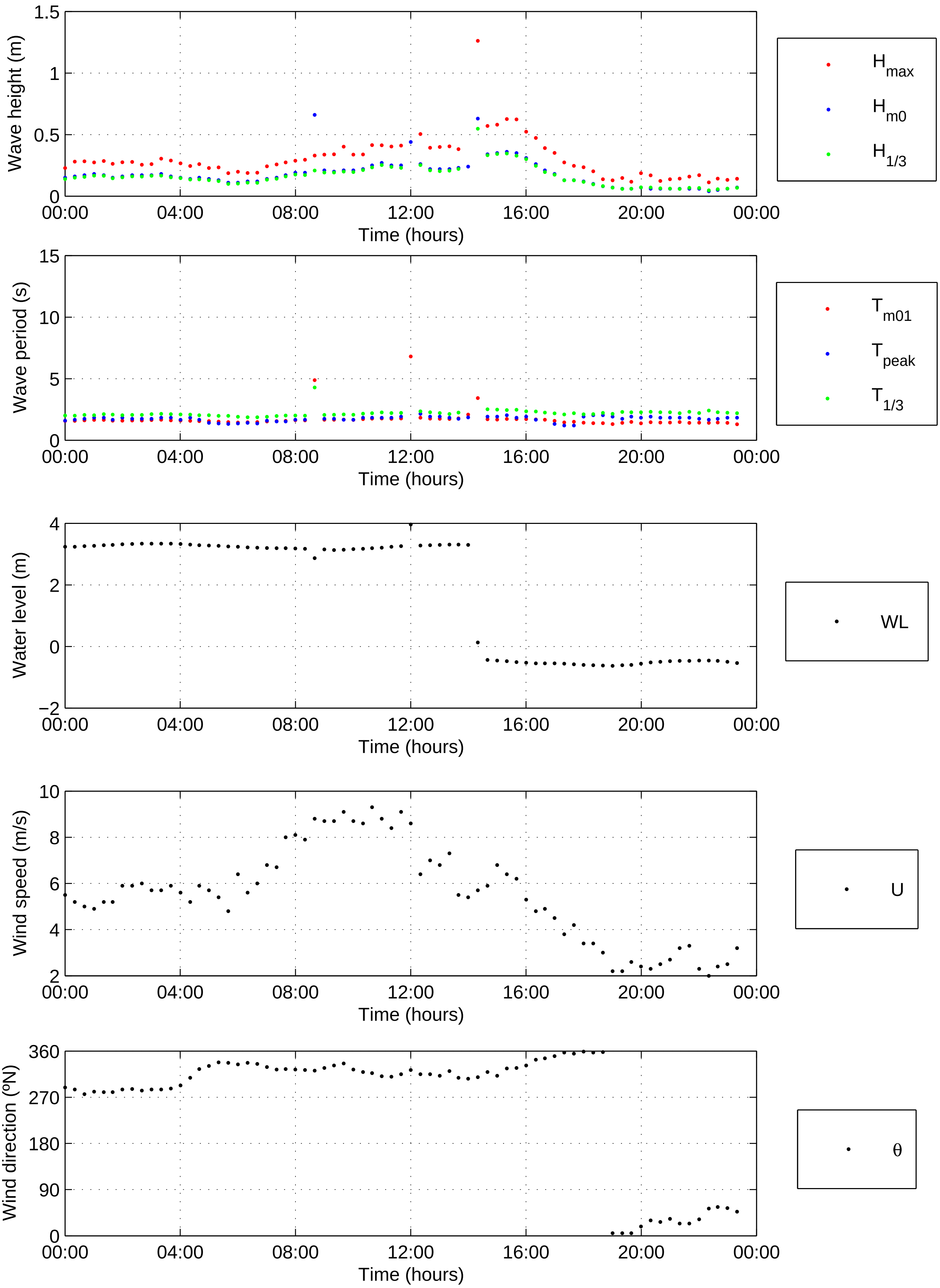
20 minutes mean wind speed and direction at Gonghu Storm period 15 to 17 December 2006	Lake Taihu	
WL | DELFT HYDRAULICS	H4955	Fig. C.1



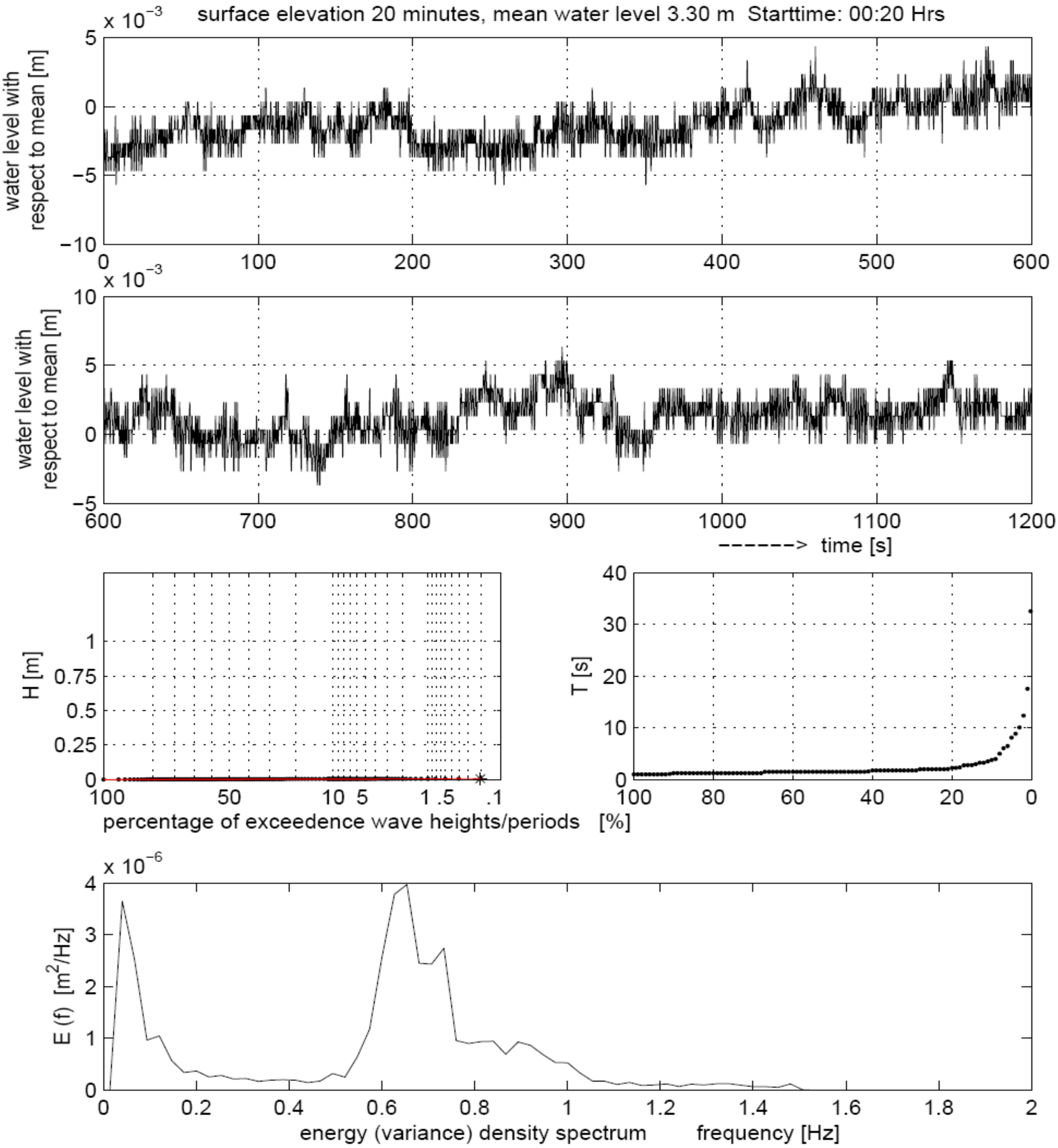
Wave height, wave period, water level and wind at Gonghu 15 December 2006	Lake Taihu	
WL | DELFT HYDRAULICS	H4955	Fig. C.2



Wave height, wave period, water level and wind at Gonghu 16 December 2006	Lake Taihu	
WL | DELFT HYDRAULICS	H4955	Fig. C.3

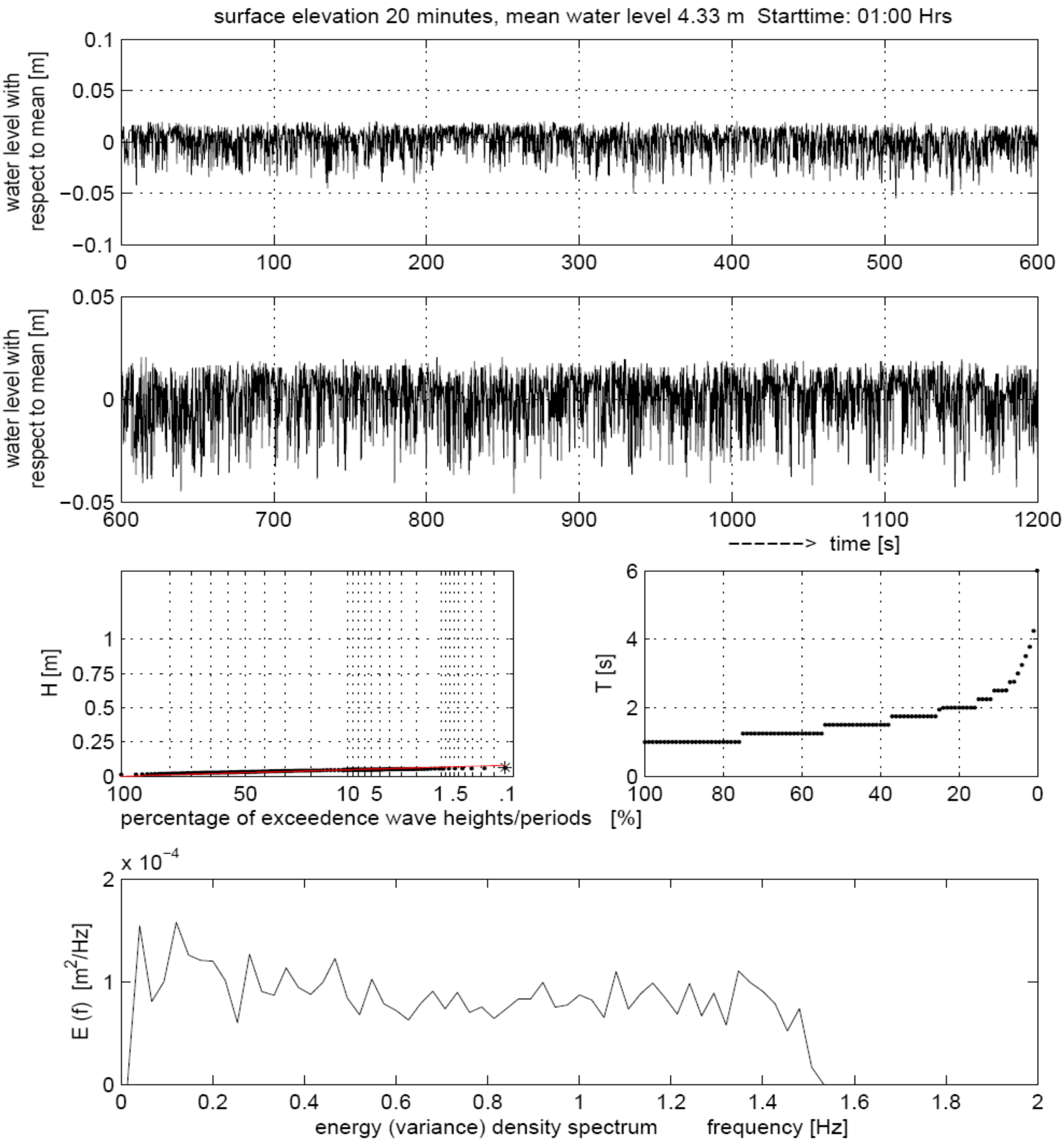


Wave height, wave period, water level and wind at Gonghu 17 December 2006	Lake Taihu	
WL | DELFT HYDRAULICS	H4955	Fig. C.4



H_{m0} = 0.00 m	T_p = 1.53 s	$T_{H1/3}$ = 3.04 s
$H_{1/3}$ = 0.00 m	T_{m-10} = 4.84 s	$T_{1/3}$ = 4.53 s
$H_{1/10}$ = 0.00 m	T_{m01} = 1.73 s	skewness = 0.02
$H_{1/50}$ = 0.01 m	T_{m02} = 1.52 s	kurtosis = 0.00
H_{max} = 0.01 m	T_{Hmax} = 1.50 s	κ = 0.53

Water level, wave spectrum and wave parameters for a block of 20 minutes based on WAVE file (Log_aLevel), 15 Dec 2006	Lake Taihu	
WL | Delft Hydraulics	H4955	Fig. C.5



H_{m0} = 0.05 m

$H_{1/3}$ = 0.04 m

$H_{1/10}$ = 0.05 m

$H_{1/50}$ = 0.06 m

H_{max} = 0.07 m

T_p = 8.30 s

T_{m-10} = 3.23 s

T_{m01} = 1.40 s

T_{m02} = 1.19 s

T_{Hmax} = 2.00 s

$T_{H1/3}$ = 1.85 s

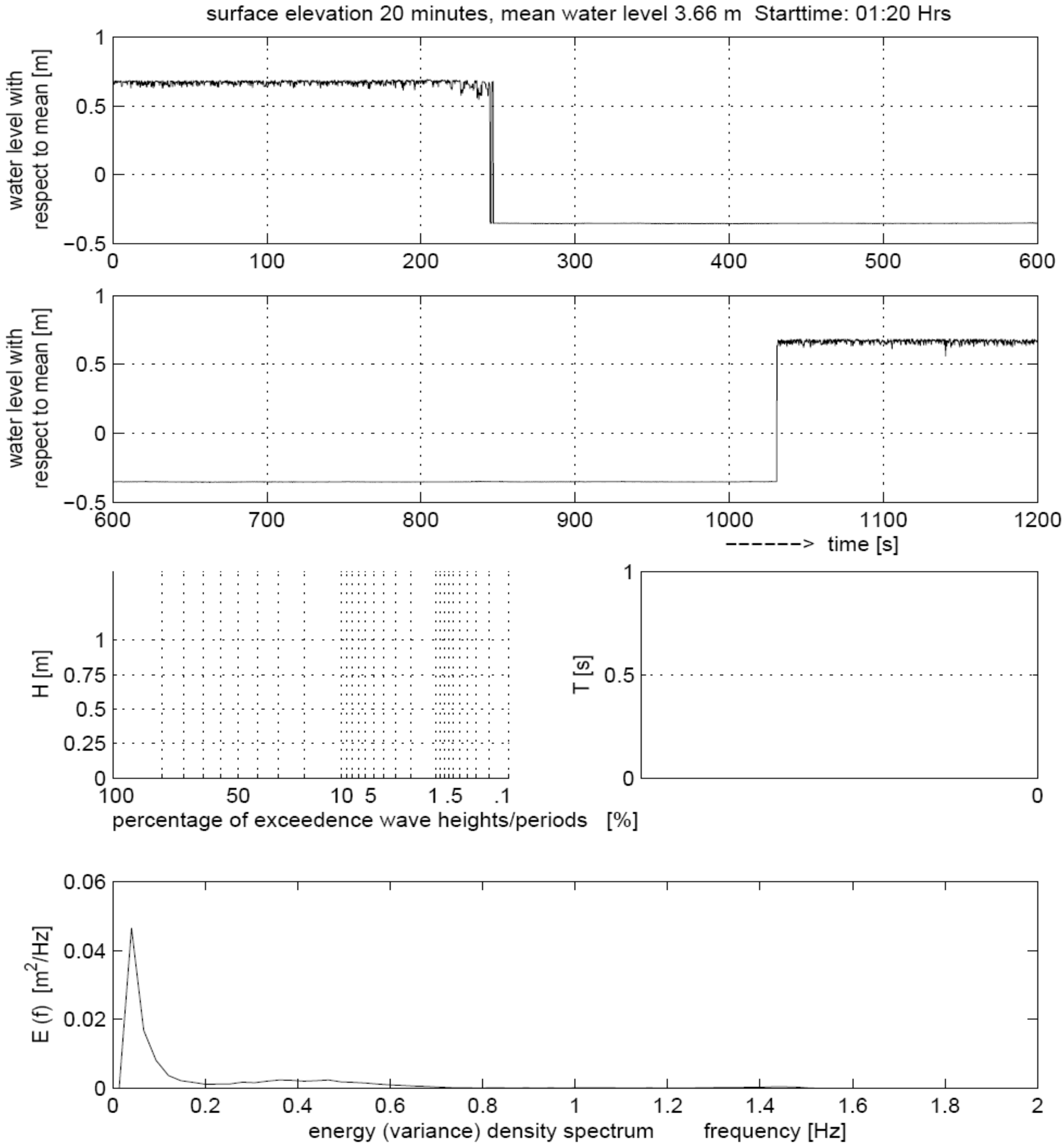
$T_{1/3}$ = 2.36 s

skewness = −0.88

kurtosis = 2.36

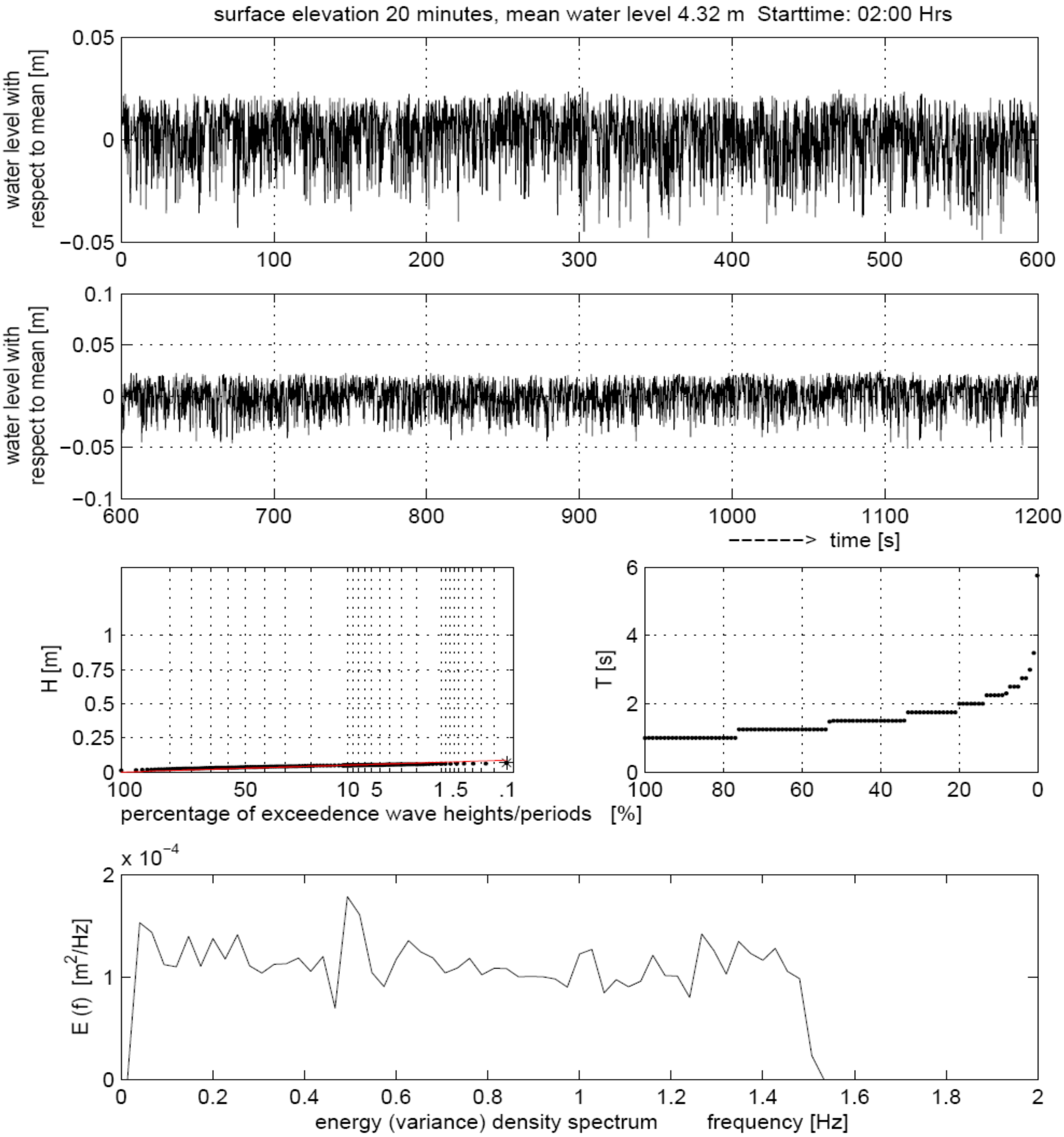
κ = 0.16

Water level, wave spectrum and wave parameters for a block of 20 minutes based on WAVE file (Log_aLevel), 15 Dec 2006	Lake Taihu	
WL | Delft Hydraulics	H4955	Fig. C.6



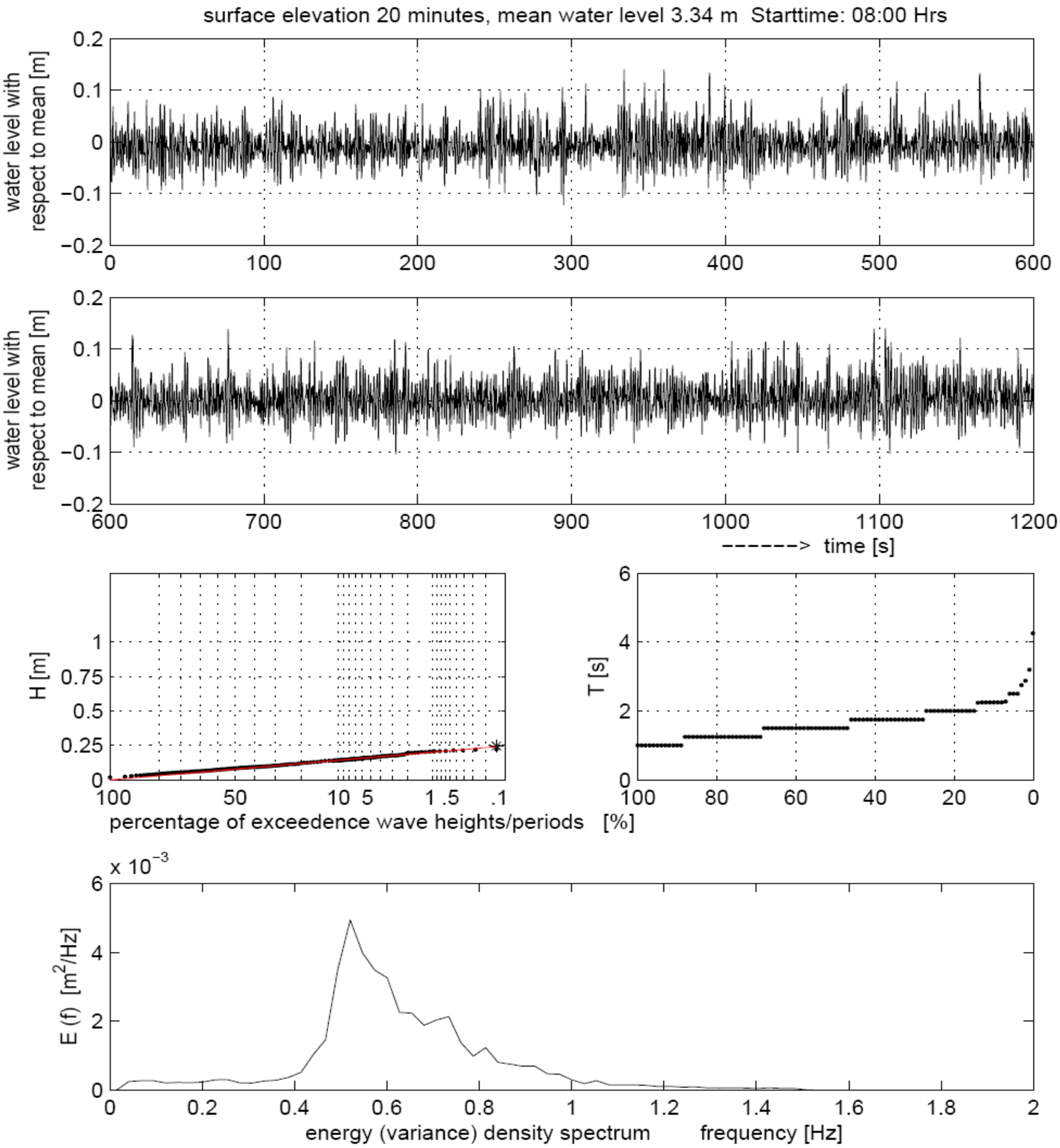
H_{m0} = 0.22 m	T_p = 24.74 s	$T_{H1/3}$ = NaN s
$H_{1/3}$ = NaN m	T_{m-10} = 14.29 s	$T_{1/3}$ = NaN s
$H_{1/10}$ = NaN m	T_{m01} = 4.93 s	skewness = 0.68
$H_{1/50}$ = NaN m	T_{m02} = 2.94 s	kurtosis = 1.57
H_{max} = NaN m	T_{Hmax} = NaN s	κ = 0.60

Water level, wave spectrum and wave parameters for a block of 20 minutes based on WAVE file (Log_aLevel), 15 Dec 2006	Lake Taihu	
WL | Delft Hydraulics	H4955	Fig. C.7



H_{m0} = 0.05 m	T_p = 2.03 s	$T_{H1/3}$ = 1.72 s
$H_{1/3}$ = 0.05 m	T_{m-10} = 2.95 s	$T_{1/3}$ = 2.16 s
$H_{1/10}$ = 0.05 m	T_{m01} = 1.35 s	skewness = −0.61
$H_{1/50}$ = 0.06 m	T_{m02} = 1.16 s	kurtosis = 2.14
H_{max} = 0.07 m	T_{Hmax} = 2.00 s	κ = 0.14

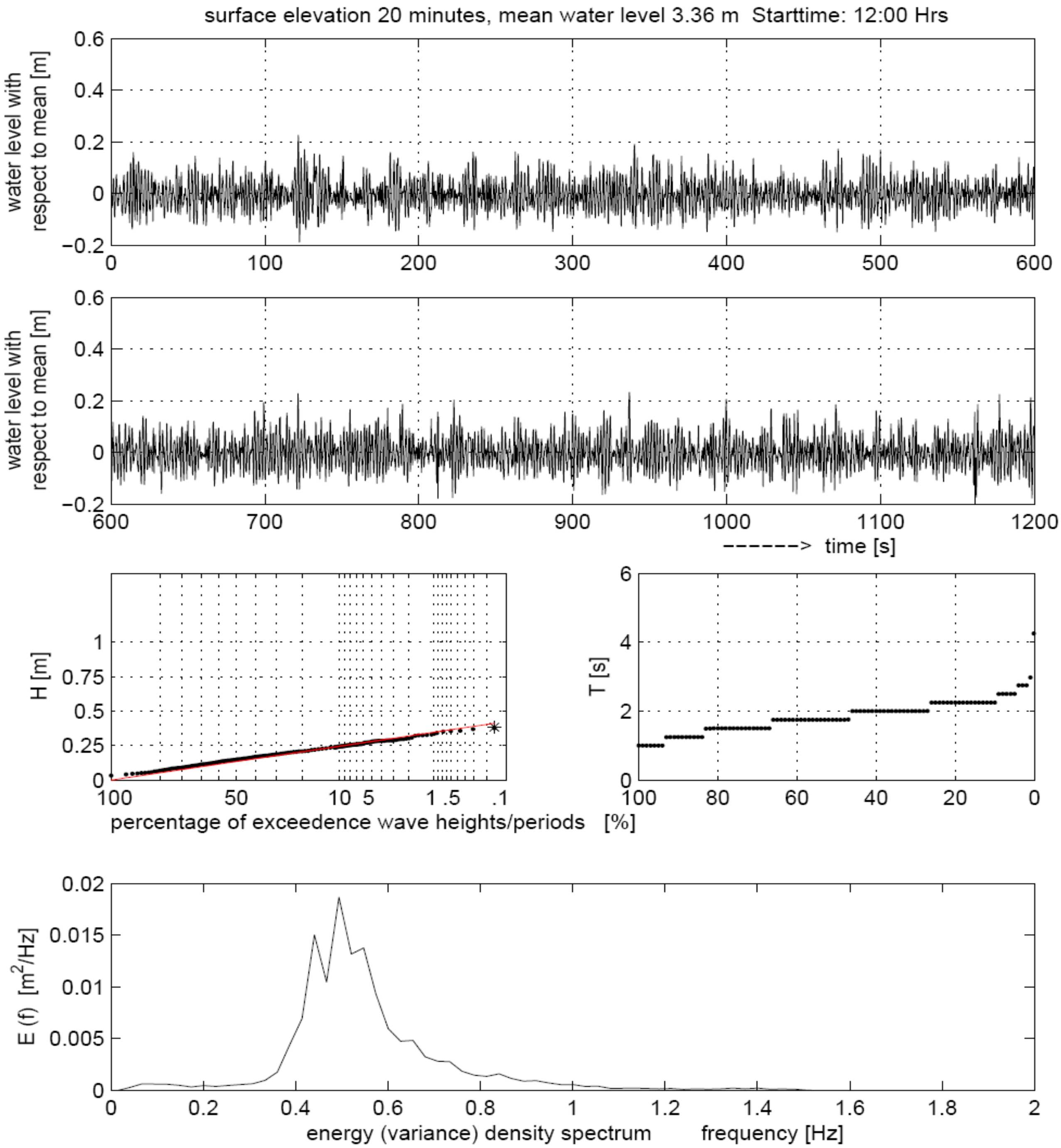
Water level, wave spectrum and wave parameters for a block of 20 minutes based on WAVE file (Log_aLevel), 15 Dec 2006	Lake Taihu	
WL | Delft Hydraulics	H4955	Fig. C.8



H_{m0} = 0.14 m	T_p = 1.92 s	$T_{H1/3}$ = 1.72 s
$H_{1/3}$ = 0.13 m	T_{m-10} = 2.04 s	$T_{1/3}$ = 2.17 s
$H_{1/10}$ = 0.17 m	T_{m01} = 1.61 s	skewness = 0.34
$H_{1/50}$ = 0.21 m	T_{m02} = 1.52 s	kurtosis = 3.39
H_{max} = 0.25 m	T_{Hmax} = 1.50 s	κ = 0.38

Water level, wave spectrum and wave parameters for a block of 20 minutes based on WAVE file (Log_aLevel), 16 Dec 2006

Lake Taihu



H_{m0} = 0.24 m

$H_{1/3}$ = 0.23 m

$H_{1/10}$ = 0.28 m

$H_{1/50}$ = 0.34 m

H_{max} = 0.38 m

T_p = 2.03 s

T_{m-10} = 2.12 s

T_{m01} = 1.81 s

T_{m02} = 1.72 s

T_{Hmax} = 2.25 s

$T_{H1/3}$ = 1.98 s

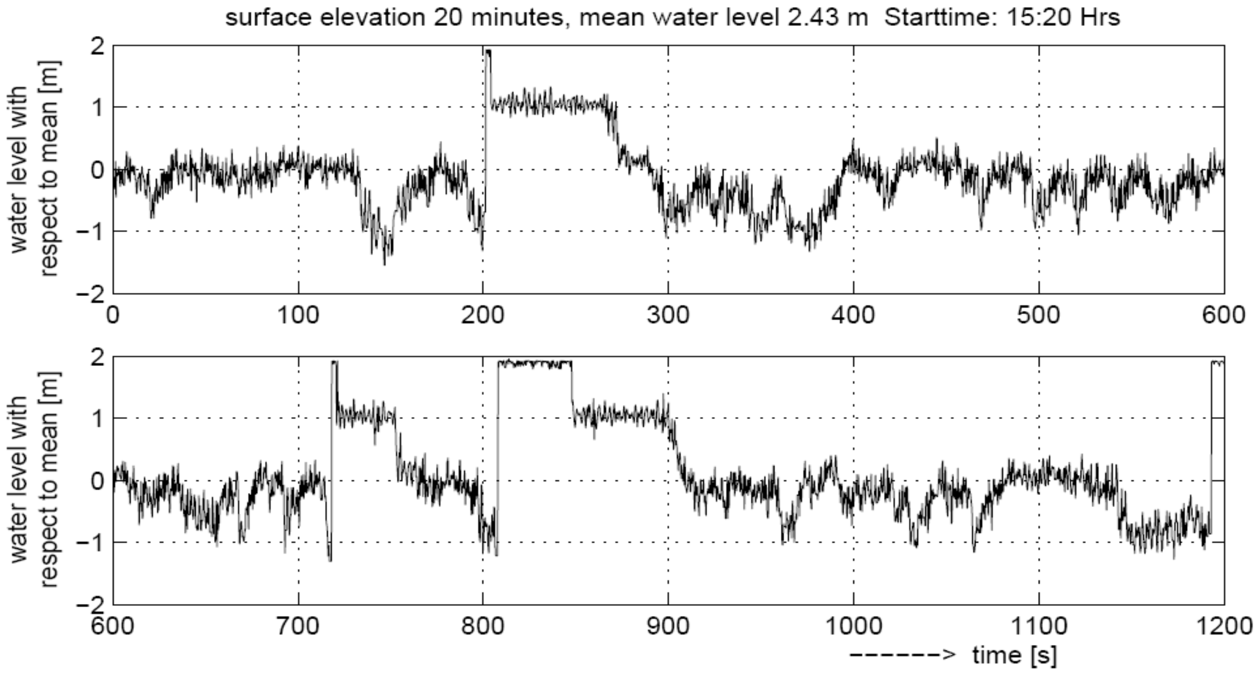
$T_{1/3}$ = 2.33 s

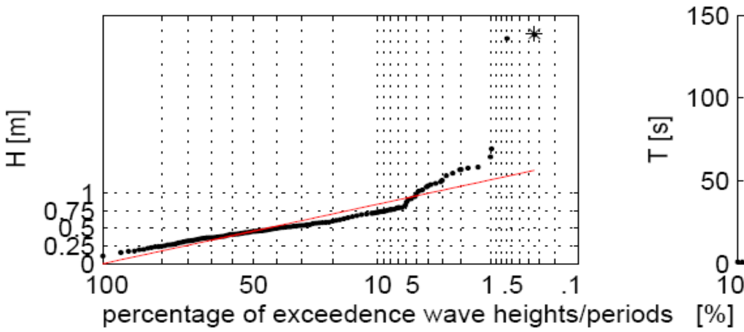
skewness = 0.23

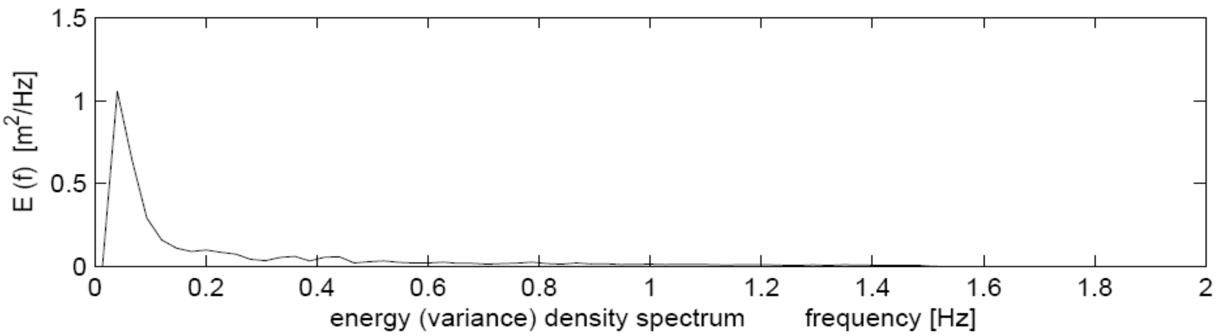
kurtosis = 3.01

κ = 0.48

Water level, wave spectrum and wave parameters for a block of 20 minutes based on WAVE file (Log_aLevel), 16 Dec 2006	Lake Taihu	
WL | Delft Hydraulics	H4955	Fig. C.10

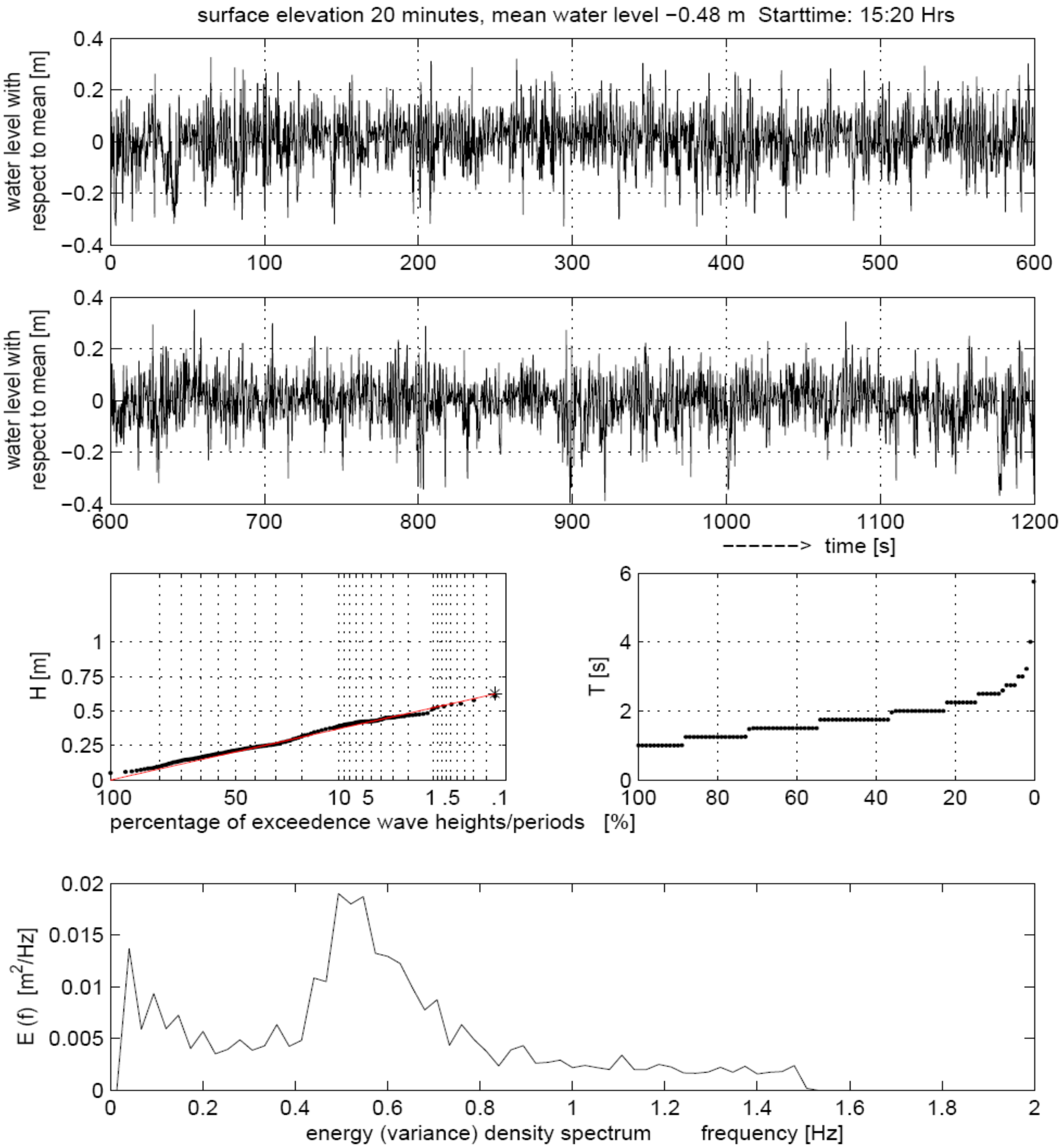






H_{m0} = 1.23 m	T_p = 24.74 s	$T_{H1/3}$ = 7.56 s
$H_{1/3}$ = 0.78 m	T_{m-10} = 12.48 s	$T_{1/3}$ = 8.43 s
$H_{1/10}$ = 1.22 m	T_{m01} = 4.14 s	skewness = 1.00
$H_{1/50}$ = 2.31 m	T_{m02} = 2.52 s	kurtosis = 3.85
H_{max} = 3.24 m	T_{Hmax} = 88.00 s	κ = 0.52

Water level, wave spectrum and wave parameters for a block of 20 minutes based on WAVE file (Log_aLevel), 16 Dec 2006	Lake Taihu	
WL | Delft Hydraulics	H4955	Fig. C.11



H_{m0} = 0.36 m

$H_{1/3}$ = 0.35 m

$H_{1/10}$ = 0.44 m

$H_{1/50}$ = 0.53 m

H_{max} = 0.63 m

T_p = 2.03 s

T_{m-10} = 3.66 s

T_{m01} = 1.73 s

T_{m02} = 1.49 s

T_{Hmax} = 1.75 s

$T_{H1/3}$ = 1.96 s

$T_{1/3}$ = 2.45 s

skewness = −0.27

kurtosis = 3.71

κ = 0.21

Water level, wave spectrum and wave parameters for a block of 20 minutes based on WAVE file (Log_aLevel), 17 Dec 2006	Lake Taihu	
WL | Delft Hydraulics	H4955	Fig. C.12