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Verification of DMI wave forecasts 2nd quarter of 2003

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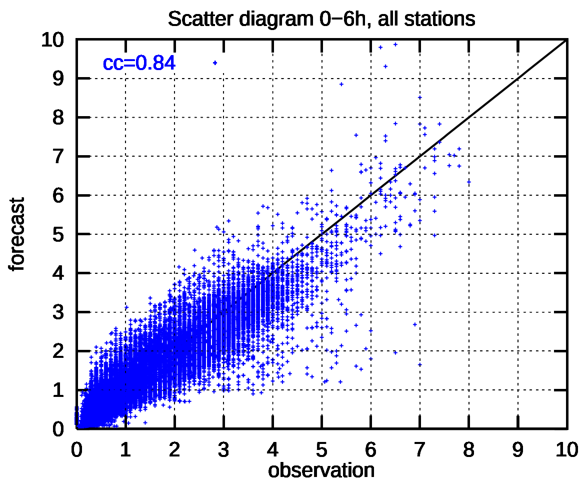

Figure 1. Significant wave height: short range (1-6h) forecasts

Contents

1 Introduction with Key Numbers

We analyse the quality of wave forecasts valid for the 2nd quarter of 2003, produced by *DMI-WAM* - DMI's operational set-up of the 3rd generation wave model *WAM Cycle4*.

Focus is on significant wave height. Other wave parameters (period, direction) are examined where the data material is adequate. No swell data is available.

Standard error measures (bias, rms error, ..) are calculated as a function of forecast range and of wave height. Special statistics are done for the highest waves. Grand averages are calculated as mean values over all stations, over all ranges, and for separate geographical regions.

All model results are forecasts, without any analysed sea state. A forecast error may imply a wave model error, or errors in the wind forecast.

Wave recorder data are retrieved via the GTS (Global Telecommunication System) from the National Data Buoy Center (UK). Additional data have kindly been provided by the Swedish Meteorological Institute, the National Center for Marine Research (Greece), the German Bundesamt für Seeschiffahrt in Hamburg, and the Danish Coastal Authority.

DMI has produced short-range operational wave forecasts since 1999. A pre-operational validation study was carried out in 1999 [11], a combined wave-wind validation study in 2000 [10], and a verification pilot study in 2002 [9]. Previous quarterly reports are found in the reference list.

Outline: A Key Number Table is given below. Ch. 2 describes the DMI wave model set-up, ch. 3 lines out the data material, and in ch. 4 we define the statistical error measures used to describe the forecast quality. Ch. 5 presents and discusses the results. Ch. 6 concludes the work. Comprehensive results for each station are found in the Appendix. References and lists of figures/tables are found at the end of the report.

Key Numbers pertaining to the full model system are shown in Table 1 below. Please refer to Ch. 5 for a detailed explanation and discussion.

Parameter	H_s	T_{02}	T_p	θ_w
bias	-4cm	0.9s	1.3s	3^o
relative bias	3%	26%	21%	
rms error	41cm	1.2s	2.6s	
st.dev				46^o
scatter index	0.36	0.32	0.42	
corr.coeff.	0.84	0.65	0.46	0.84
peak bias	-50cm			
rel. peak bias	-9%			

Table 1. Key numbers

2 DMI-WAM

DMI runs an operational wave forecasting service *DMI-WAM*, using the 3rd generation wave model *WAM Cycle4* forced by DMI's numerical weather prediction model *HIRLAM*.

2.1 Physical model

WAM Cycle4 solves the spectral wave equation

$$\frac{\partial F}{\partial t} + \vec{c} \cdot \vec{\nabla} F = S_{in} + S_{nl} + S_{ds} + S_{cu} + S_{bf}$$

where $F(f, \theta; \vec{x}, t)$ is spectral wave energy density, depending on wave frequency, wave direction, position and time; $c(f, d)$ is the depth-dependent wave group speed; S_{in} is wind energy input; S_{nl} is non-linear wave-wave interaction; S_{ds} is wave energy dissipation through wave breaking (white capping); S_{cu} is wave-current interaction; and S_{bf} is interaction with the sea bed through friction and wave refraction. For further information on WAM Cycle4, please refer to [1], [3].

2.2 Model set-up

DMI-WAM has four geographical domains, including a large part of the North Atlantic, the North Sea and Baltic Sea, the Transition Area (inner Danish waters), and the Mediterranean (cf. Table 2 and Figure 2).

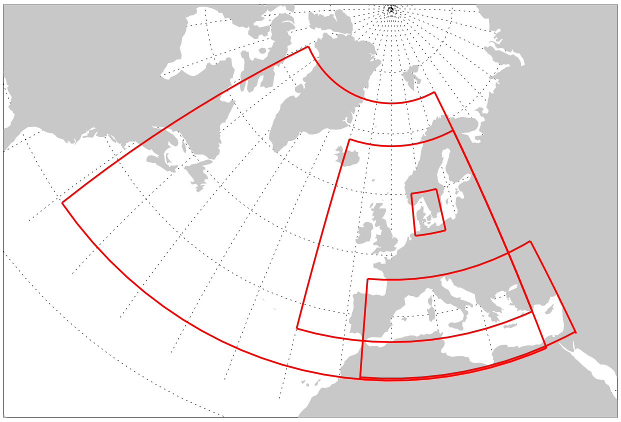

Figure 2. The four DMI wave model domains. From the large scale North Atlantic model, the Baltic and the Mediterranean are excluded. From the regional North Sea - Baltic model (or NW European Shelf model), the Mediterranean is excluded.

The model open boundaries are chosen as follows. The coarse grid North Atlantic model uses the JONSWAP wind-sea spectrum (see [1], [2]). The fine grid North Sea - Baltic model is nested into the North Atlantic model, and uses time/space interpolated boundary wave spectra calculated by that model. In the same way, the Transition Area mode uses boundary wave spectra calculated by the North Sea - Baltic model. The Mediterranean is treated as a closed basin, assuming no wave energy exchange with the Atlantic or the Black Sea.

DMI-WAM runs without current refraction (S_{cu}=0), and sea ice information is also not included.

The wave forecasting system has been coldstarted once and for all using developed sea. Subsequent model runs are initialised using the sea state at analysis time, calculated by the previous run as a 6 hour forecast.

Model	North Atlantic	North Sea - Baltic	Transition Area	Mediterranean
Space resol.	1/2^o	1/6^o	1/30^o	1/6^o
Time step	10 min	4 min	1 min	2 min
Frequencies	25	25	25	25
Direction resol.	30^o	30^o	30^o	30^o
Forcing model(s)	Hirlam G	Hirlam E	Hirlam E	Hirlam E+G
- resolution of	0.45^o	0.15^o	0.15^o	0.15^o/0.45^o
Longitudes	69^{o}W-30^{o}E	20^{o}W-30^{o}E	7^{o}E-16^{o}E	6^{o}W-36^{o}E
Latitudes	30^{o}N-75^{o}N	36^{o}N-68^{o}N	53^{o}N-60^{o}N	30.5^{o}N-46^{o}N
Open boundaries	JONSWAP	Nested	Nested	Closed basin
Forecast range	54 h	54 h	54 h	54h
Output time step	1 h	1 h	1 h	1 h
Schedule	4x daily	4x daily	4x daily	4x daily

Table 2. DMI-WAM set-up. The wave model frequencies range from 0.04177 Hz to 0.41145 Hz in 10% steps. The Mediterranean model patches Hirlam E+G to get maximum resolution.

2.3 Weather model

The forcing models are the DMI limited area numerical weather prediction models Hirlam-E (15 km resolution) and Hirlam-G (45 km resolution). The G model embeds the E model, and both are currently being used in the DMI weather forecasting service. The wind vector at 10m height is interpolated linearly in time and space, from the rotated spherical weather model grids onto the spherical wave model grids.

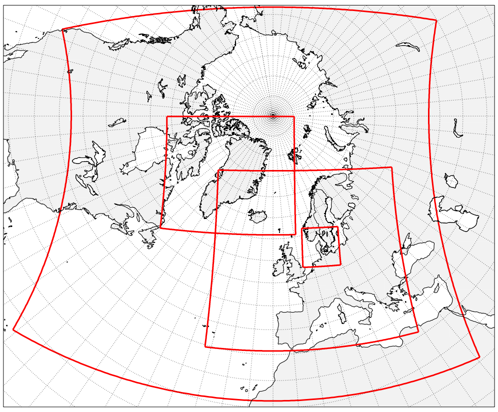

Figure 3. DMI Hirlam. The outermost box is the G model, the box covering most of Europe is the E model.

3 Wave data

The verification data consists of operational DMI-WAM wave forecasts, and wave observations from a number of fixed positions (buoys, platforms).

3.1 Forecasts

All wave forecasts are archived as hourly maps in the model's spatial resolution. Time series for verification stations are sampled using nearest model grid point. This is done for each parameter shown in Table 3. Out of 364 scheduled forecasts, 361 were produced and archived.

	Wave parameter	stations
H_s	Significant wave height	31
H_{sw}	Height of swell	-
T_{02}	Mean wave period	9
T_p	Dominant wave period	26
T_{sw}	Swell mean period	-
θ_w	Mean wave direction	6
θ_{sw}	Swell direction	-

Table 3. DMI-WAM wave parameters, obtained by a suitable integral of the wave energy spectrum. T_p is the discretized model frequency (inverse) containing the highest energy, picked from a set of predefined values. The second column shows the number of validation stations. None of the fixed stations record swell, but some record maximum wave height H_m, which is not calculated by the wave model.

3.2 Observations

A total of 31 wave recorders are pre-selected for verification; station positions are shown in Fig. 4 and comprehensive station information is given in Appendix 7.1. Observed wave statistics are shown in Appendix 7.2.

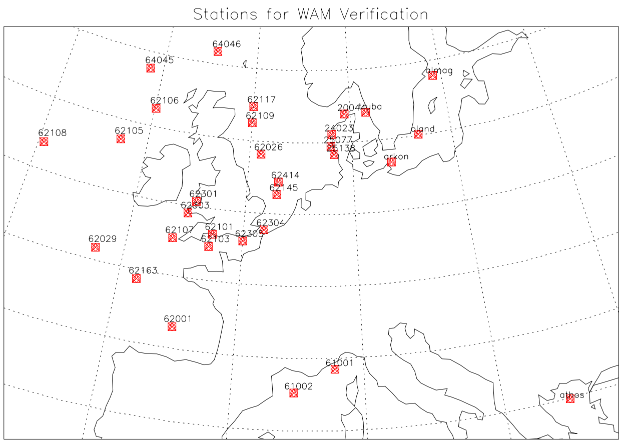

Figure 4. Wave recorder locations.

The sampling rate is ususally 1 hour, but please refer to Appendix 7.1. Sampling accuracy is H_s:0.1m, T_{02}:0.01s, T_p:1s, θ_w:1^o, but it may be higher or lower at single buoys.

The data coverage is 78% (see Fig. 5 for missing data), Obvious data errors have been removed. At one station no data was available during this three-month period.

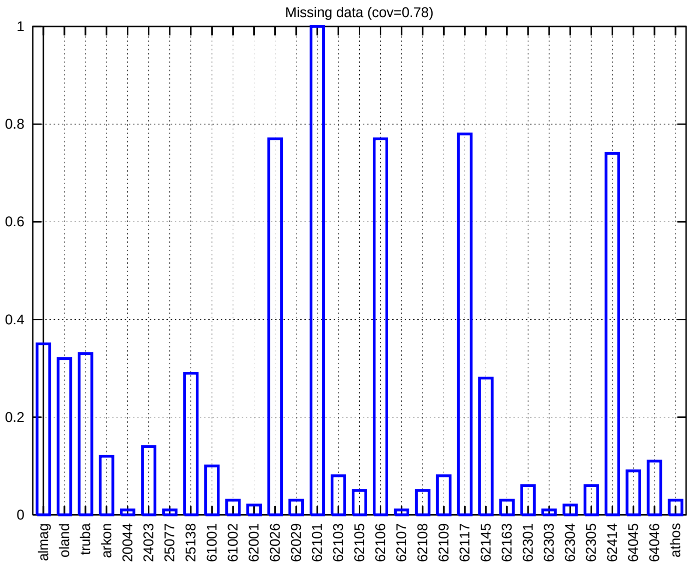

Figure 5. Missing data. St. 20044, 24023, 25077 and 25138 sample every 3 hours, but every hour in storm situations. St. 62117, 62414 and Athos sample every 3 hours. At these stations, the data coverage is based on 3 hour sampling.

4 Error measures

Model errors are calculated using a 3-d residual matrix, built from all available observations and forecasts. With the general formula $residual = forecast - observation$ the matrix reads (brackets indicate a dependency)

$residual(station, analysis, range)$

with the number of stations depending on the parameter in question (cf. Table 3), analysis every 6 hours, and forecasts ranging from 1-54 hours in 1 hour steps. The residual matrix has roughly 0.6*10^6 data points. By averaging the residual over all analyses, we get the model bias or mean error:

$bias(station, range)$

Further averaging gives the bias for each forecast range (averaged over all stations), for each station (averaged over the full forecast range), and as a grand average:

$bias1(range)$
$bias2(station)$
$BIAS$

In the same way, the root mean square error $rms(station, range)$ is calculated and averaged using the residual squared.

For the wave height only, the bias and rms error are also calculated as a function of wave height. The residual is sorted into observation bins 0.5m wide and averaged for each bin.

$bias(station, obsbin)$
$rms(station, obsbin)$

Averaging these parameters over all stations gives the model error dependency on wave height, calculated both as an absolute value and as a relative error in %.

The scatter index $si = \frac{rms}{<obs>}$ is obtained by normalising rms with the observed mean value. si may be used to intercompare rms errors at stations with large differences in wave climate. Averaging is done as above.

Correlation coefficients $cc(station, block)$ are calculated using forecast pseudo time series, established by concatenating forecasts in 6 hour range blocks. This gives coefficients valid for each of the 9 range blocks 1-6, 7-12, .. , 49-54 hours. Range block and station-dependent values ($cc1, cc2$), and a grand average (CC), are calculated.

A special peak bias $pbias(station, block)$ is calculated using the 5 most extreme events at each station, allowing for a forecast phase error of a few hours. Peak biases are calculated both as absolute and relative values.

5 Results

This section describes wave verification results for the 2nd quarter of 2003, for significant wave height (H_s), mean and dominant wave period (T_{02}, T_p), and mean wave direction (θ_w). Swell data was not available. We discuss grand averages and averages for 8 geographical regions, for each wave parameter in turn. Detailed results for each station are found in the Appendix at the end of the report.

5.1 Significant wave height

Table 4 shows bias and relative bias, rms error, scatter index and correlation coefficient, averaged over the full forecast range. Fig. 1 on the front page shows the short range (1-6h) scatter diagram. Results for each single station are shown in Table 13, Appendix 7.3. Data sheets are presented in Appendix 7.4.

Parameter	#st	bias		rms	si	cc
Region		cm	%	cm		
Atlantic	8	−21	−9	53	0.22	0.80
North Sea	5	−3	−2	33	0.27	0.87
Br.Channel	4	35	48	50	0.73	0.78
Irish Sea	2	−21	−15	39	0.32	0.86
Scotland−Faroe	1	−27	−11	46	0.20	0.88
Danish West Coast	4	1	1	29	0.32	0.89
Kattegat−Baltic	4	8	12	34	0.49	0.84
Mediterranean	3	−1	2	37	0.48	0.85
All Waters	31	−4	3	41	0.36	0.84

Table 4. Significant wave height results

There is a small bias and an rms error of 0.41 m. A large positive bias is found only in the British Channel. Scatter index is low (0.36) and correlation coefficient high (0.84). There is some regional spread.

The error dependency on forecast range and on wave height is shown in Fig. 6.

There is a weak dependence on forecast range, with short range forecasts being slightly better than long-range (2-day) forecasts. The rms error is significant already at analysis time since the model is initialised without any use of the observed sea state.

Errors depend strongly on wave height. Small waves have positive bias, while higher waves most often are underestimated. The rms error increases with wave height. The relative rms error is 20-30% except for very small waves.

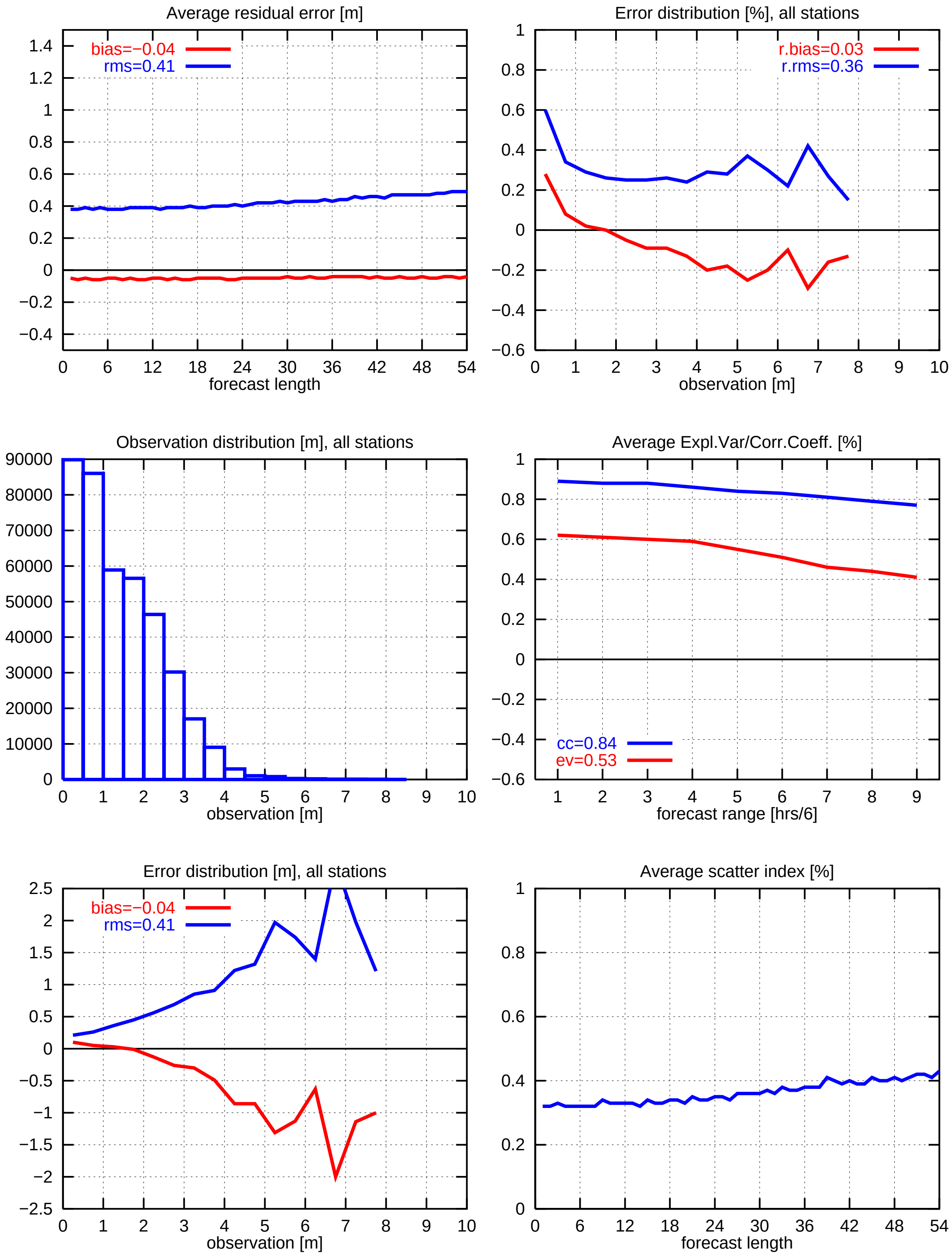

Figure 6. Significant wave height

5.2 Extreme wave height

The error on the highest waves observed is calculated for the 5 highest events at each station, using the forecast error allowing for a few hours' phase displacement. Table 5 below shows range-averaged peak biases. Peak biases for each station are shown in Table 14, Appendix 7.3.

Parameter Region	#st	peak bias cm	peak bias %
Atlantic	8	−104	−18
North Sea	5	−5	0
Br.Channel	4	14	12
Irish Sea	2	−66	−18
Scotland−Faroe	1	−148	−27
Danish West Coast	4	−12	−3
Kattegat−Baltic	4	−48	−8
Mediterranean	3	−57	−14
All Waters	31	−50	−9

Table 5. Extreme wave height results

The highest waves are underestimated. The atlantic station 62107 has a data problem during this period and should possibly have benne left out (see 27). The Shetland station 64045 has a large negative peak bias, but the highest event is overpredicted (see fig. 38). The bias is about -0.4m, increasing beyond the 36 hour forecast (Fig. 7).

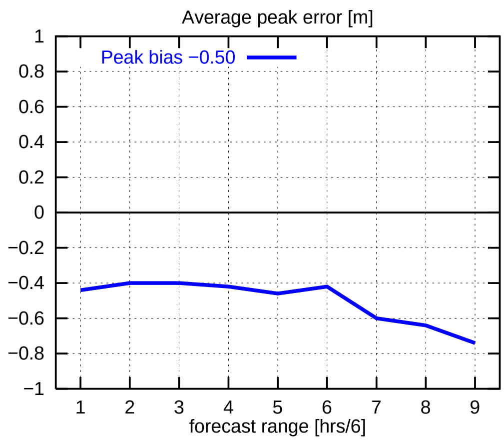

Figure 7. Peak wave height errors.

5.3 Mean wave period

The mean wave period T_{02} is recorded at 9 stations. Grand averages are shown in Table 6, and a short-range scatter diagram in Fig. 8. Results for each station are shown in Table 15, Appendix 7.3. Data sheets are presented in Appendix 7.5.

Parameter Region	#st	bias sec.	 %	rms sec.	si	cc
Danish West Coast	4	1.3	34	1.5	0.40	0.65
Kattegat–Baltic	4	0.6	17	0.8	0.24	0.69
Mediterranean	1	0.9	26	1.1	0.34	0.47
All Waters	9	0.9	26	1.2	0.32	0.65

Table 6. Mean wave period results

At the Danish West Coast stations T_{02} is overestimated by 34%. The reason for this is still unresolved. At other stations T_{02} is slightly overestimated. The scatter index at these stations is below the acceptancy level of 0.4.

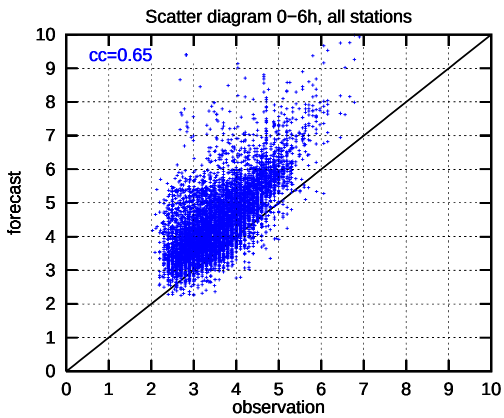

Figure 8. Mean wave period, 1-6h range.

5.4 Dominant wave period

The dominant (or *peak*) wave period T_p is recorded at 26 stations. Grand averages are shown in Table 7, short-range scatter diagrams in Fig. 9. Results for each station are found in Table 16, Appendix 7.3. Data sheets for Mediterranean stations only in Appendix 7.6.

Parameter Region	#st	bias sec.	bias %	rms sec.	si	cc
Atlantic	8	2.3	33	3.1	0.42	0.53
North Sea	4	1.6	35	2.3	0.49	0.54
Br.Channel	4	−0.8	−12	2.3	0.31	0.26
Irish Sea	2	2.4	42	3.3	0.58	0.41
Scotland−Faroe	1	2.4	36	2.9	0.42	0.64
Danish West Coast	4	0.2	4	2.3	0.40	0.43
Mediterranean	3	0.2	5	1.8	0.39	0.34
All Waters	26	1.3	21	2.6	0.42	0.46

Table 7. Dominant wave period results

T_p errors are large, due partly to low recording and forecasting accuracy, and partly to the non-smoothness of the series, with T_p shifting abruptly between a high and a low period peak. Even when the wave spectrum is rather well predicted, a small error in the shape of the spectrum may lead to very large T_p errors in situations with a two-peaked spectrum (swell and wind sea).

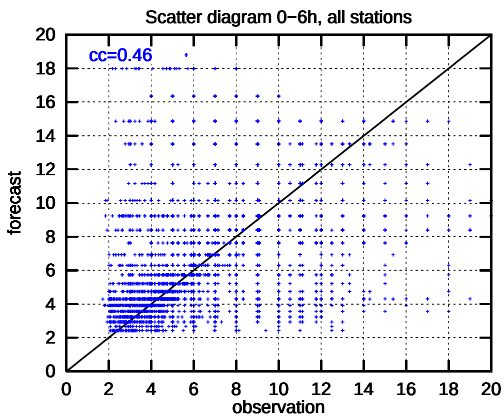

Figure 9. Dominant wave period, 1-6h range.

5.5 Mean wave direction

The mean wave direction θ_w is recorded at 6 stations. The results are presented in Table 8 and the scatter diagram in Fig. 10. Results for each station is found in Table 17, Appendix 7.3. Data sheets are not shown.

Parameter Region	#st	bias deg.	std deg.	cc
Danish West Coast	4	0	43	0.82
Kattegat–Baltic	1	11	51	0.91
Mediterranean	1	6	55	0.86
All Waters	6	3	46	0.84

Table 8. Mean wave direction results

The mean wave direction predictions fit the observations well, with no bias, some scatter, and a high correlation coefficient.

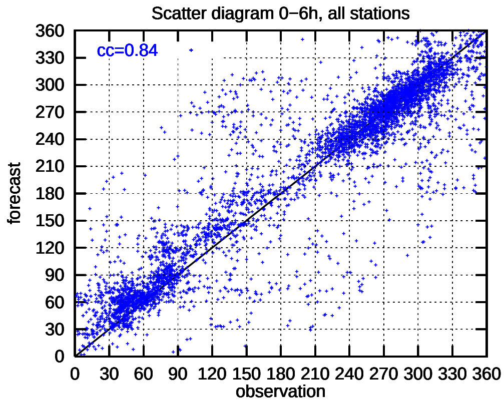

Figure 10. Mean wave direction, 1-6h range.

6 Conclusion

DMI wave forecasts valid for the 2nd quarter of 2003 are verified, using wave data from 31 buoys. Two buoys have not provided data in this period.

Main conclusions are:

- Significant wave height H_s and mean wave direction θ_w are usually well predicted
- We have some problems predicting wave period T_{02} and T_p
- There is a large regional spread in forecast quality
- The H_s error depends on wave height; very high waves are slightly underestimated
- The forecast quality decreases a little with increasing forecast range

The *significant wave height* is recorded at 30 stations. The average bias is small, independent of forecast range, There is some geographical spread, and a pronounced dependency on wave height. Small waves are overpredicted, while high waves are underestimated by up to 30%. The average rms error is 0.41m, increasing gradually with forecast range. For medium-sized and large waves the rms error is roughly 25%. The average scatter index SI=0.36. A few have si$>$0.4 (sometimes used as an acceptance level), partly due to low recording accuracy and small average wave height. The observation-forecast correlation is high, 0.84 on average.

The highest waves are underestimated by almost 10% (-0.5m on average). The forecasts get worse beyond 36 hours' range.

The *mean wave period* is recorded at 9 stations. 4 of these have a data interpretation problem. At the remaining 4 stations the model overestimates the mean wave period by 0.5-1.0s.

Dominant wave period is recorded at 26 stations, The predictions are not good. Bias and rms errors range up to several seconds. This could be a data problem; a well predicted wave spectrum does not guarantee a correct dominant wave period in situations with two spectral maxima. Also, most stations sample only with 1s accuracy and so does the model; this in itself leads to large error measures.

Mean wave direction is recorded at 6 stations. The predictions have no bias, a standard deviation of 40-50^o, and a high correlation coefficient.

Swell parameters are not recorded at any of the fixed positions. A few record *maximum wave height* but this is not predicted by the wave model.

7 Appendix

This Appendix contains a wave recorder station table (below), observation statistics tables, forecast statistics tables, and a plot sheet for each station and each parameter ($H_s, T_{02}, T_p, \theta_w$), arranged sequentially according to the station table.

7.1 Wave recorders

Station ID	Agency	Region	lat.	lon.	δt	parameters
almag	SMHI	Baltic	59.15N	19.13E	1h	H_s, H_m, T_{02}
oland	SMHI	Baltic	56.07N	16.68E	1h	H_s, H_m, T_{02}
truba	SMHI	Baltic	57.60N	11.63E	1h	H_s, H_m, T_{02}
arkona	BSH	Baltic	54.72N	13.74E	1h	$H_s, H_m, T_{02}, \theta_w$
20044	KDI	D. West Coast	57.58N	9.41E	3h*	$H_s, H_m, T_{02}, T_p, \theta_w$
24023	KDI	D. West Coast	56.47N	8.06E	3h*	$H_s, H_m, T_{02}, T_p, \theta_w$
25077	KDI	D. West Coast	55.81N	7.94E	3h*	$H_s, H_m, T_{02}, T_p, \theta_w$
25138	KDI	D. West Coast	55.35N	8.23E	3h*	$H_s, H_m, T_{02}, T_p, \theta_w$
61001	NDBC	Mediterranean	43.4N	7.8W	1h	H_s, T_p
61002	NDBC	Mediterranean	42.1N	4.7W	1h	H_s, T_p
62001	NDBC	Atlantic	45.2N	5.0W	1h	H_s, T_p
62026	NDBC	North Sea	55.3N	1.1E	1h	H_s, T_p
62029	NDBC	Atlantic	48.7N	12.4W	1h	H_s, T_p
62101	NDBC	B.Channel	50.6N	2.7W	1h	H_s, T_p
62103	NDBC	B.Channel	49.9N	2.9W	1h	H_s, T_p
62105	NDBC	Atlantic	54.9N	12.6W	1h	H_s, T_p
62106	NDBC	Atlantic	57.0N	9.9W	1h	H_s, T_p
62107	NDBC	Atlantic	50.1N	6.1W	1h	H_s, T_p
62108	NDBC	Atlantic	53.5N	19.5W	1h	H_s, T_p
62109	NDBC	North Sea	57.0N	0.0	1h	H_s, T_p
62117	NDBC	North Sea	57.9N	0.0	3h	H_s, T_p
62145	NDBC	North Sea	53.1N	2.8E	1h	H_s, T_p
62163	NDBC	Atlantic	47.5N	8.5W	1h	H_s, T_p
62301	NDBC	Irish Sea	52.3N	4.5W	1h	H_s, T_p
62303	NDBC	Irish Sea	51.6N	5.1W	1h	H_s, T_p
62304	NDBC	B.Channel	51.1N	1.8E	1h	H_s, T_p
62305	NDBC	B.Channel	50.4N	0.0	1h	H_s, T_p
62414	NDBC	North Sea	53.8N	2.9E	3h	H_s
64045	NDBC	Atlantic	59.1N	11.4W	1h	H_s, T_p
64046	NDBC	Scotland	60.7N	4.5W	1h	H_s, T_p
athos	NCMR	Mediterranean	39.96N	24.72E	3h	$H_s, T_{02}, T_p, \theta_w$

Table 9. Wave stations. Station name/number, driving agency, position, and wave parameters. SMHI=Swedish Meteorological Institute, BSH=Bundesamt für Seeschiffahrt in Hamburg, KDI=Coastal Authorities (Denmark), NDBC=National Data Buoy Center (UK), NCMR=National Center for Marine Research (Greece). H_s=significant wave height, H_m=maximum wave height, T_{02}=mean wave period, T_p=peak or dominant wave period, θ_w=mean wave direction. δt is the sampling rate in hours. * = 1h sampling during stormy conditions.

7.2 Observed wave statistics

Station	min	mean	max	stdev
almag	0.1	0.8	5.4	0.7
oland	0.1	0.6	2.5	0.4
truba	0.1	0.6	2.2	0.4
arkon	0.1	0.7	2.7	0.5
20044	0.1	0.9	3.3	0.6
24023	0.2	1.0	3.8	0.6
25077	0.1	0.9	3.9	0.6
25138	0.1	0.8	3.1	0.5
61001	0.2	0.8	3.7	0.6
61002	0.2	1.2	6.3	1.0
62001	0.8	2.0	4.2	0.7
62026	0.4	1.2	3.2	0.6
62029	0.9	2.5	5.1	0.7
62101	-	-	-	-
62103	0.2	0.9	5.3	0.5
62105	0.8	2.6	7.7	0.9
62106	1.5	2.7	7.3	1.0
62107	0.4	2.0	7.0	0.9
62108	1.0	2.9	7.1	0.8
62109	0.4	1.5	5.1	0.7
62117	0.4	1.4	4.0	0.7
62145	0.2	1.0	4.0	0.6
62163	0.9	2.2	5.6	0.7
62301	0.0	0.9	2.5	0.5
62303	0.3	1.5	4.3	0.7
62304	0.1	0.5	2.8	0.3
62305	0.1	0.7	5.4	0.5
62414	0.2	1.0	4.1	0.6
64045	1.0	2.5	8.0	1.0
64046	1.0	2.3	7.0	0.8
athos	0.0	0.5	3.3	0.5

Table 10. Observed wave height.

Station	min	mean	max	stdev
almag	2.5	3.7	5.4	0.6
oland	2.4	3.6	5.7	0.6
truba	2.2	3.6	5.7	0.6
arkon	2.1	3.2	5.3	0.6
20044	2.2	3.6	6.1	0.7
24023	2.3	4.0	6.8	0.8
25077	2.3	4.0	6.9	0.8
25138	2.0	3.5	5.6	0.7
athos	2.3	3.3	5.9	0.6

Table 11. Observed mean wave period

Station	min	mean	max	stdev
20044	1.9	5.4	12.5	1.9
24023	1.7	6.7	15.4	2.6
25077	1.9	6.3	15.4	2.5
25138	1.8	5.0	15.4	2.2
61001	3.0	5.0	14.0	1.2
61002	3.0	5.2	22.0	1.6
62001	5.0	7.1	12.0	1.2
62026	4.0	4.7	7.0	0.7
62029	5.0	7.1	11.0	0.9
62101	-	-	-	-
62103	6.0	8.2	17.0	1.5
62105	5.0	7.0	10.0	0.9
62106	5.0	7.6	11.0	1.2
62107	6.0	9.6	26.0	2.4
62108	5.0	7.2	10.0	1.0
62109	4.0	5.3	9.0	1.0
62117	3.0	4.7	8.0	1.1
62145	3.0	4.3	8.0	0.9
62163	5.0	6.9	11.0	1.0
62301	3.0	5.2	10.0	1.3
62303	4.0	6.4	11.0	1.1
62304	4.0	6.0	9.0	0.7
62305	5.0	8.2	19.0	1.7
64045	5.0	7.0	11.0	1.0
64046	5.0	6.8	11.0	1.0
athos	2.0	4.1	9.4	1.2

Table 12. Observed dominant wave period

7.3 Wave forecast statistics

Parameter	bias		rms	si	cc
Station	cm	%	cm		
almag	16	21	51	0.65	0.78
oland	13	21	30	0.47	0.88
truba	2	3	28	0.44	0.82
arkon	3	4	28	0.41	0.88
20044	3	4	30	0.35	0.86
24023	−1	−1	34	0.33	0.89
25077	6	6	24	0.26	0.93
25138	−4	−5	27	0.34	0.88
61001	−1	−1	35	0.45	0.85
61002	−11	−9	43	0.35	0.91
62001	−18	−9	43	0.22	0.83
62026	−13	−11	31	0.26	0.89
62029	−24	−9	49	0.19	0.83
62101	-	-	-	-	-
62103	54	58	66	0.70	0.81
62105	−13	−5	43	0.17	0.88
62106	−32	−12	54	0.20	0.78
62107	−18	−9	76	0.37	0.64
62108	−30	−10	63	0.22	0.74
62109	−17	−12	38	0.26	0.86
62117	3	2	41	0.29	0.81
62145	6	6	27	0.27	0.89
62163	−15	−7	43	0.19	0.86
62301	−3	−4	28	0.32	0.83
62303	−39	−25	50	0.33	0.89
62304	26	54	43	0.88	0.74
62305	23	34	42	0.62	0.79
62414	5	5	29	0.28	0.89
64045	−19	−7	53	0.21	0.85
64046	−27	−11	46	0.20	0.88
athos	8	16	34	0.64	0.78

Table 13. Predicted significant wave height

Parameter	Obs	peak	
Station	m	m	%
almag	4.4	−2.2	−46
oland	2.1	0.6	27
truba	2.0	−0.0	−1
arkon	2.5	−0.2	−9
20044	2.9	−0.2	−7
24023	2.8	0.2	11
25077	3.4	−0.2	−8
25138	2.4	−0.2	−8
61001	3.3	0.0	1
61002	5.4	−1.0	−18
62001	4.0	−0.1	−3
62026	2.5	−0.1	−4
62029	4.7	−0.9	−19
62101	-	-	-
62103	3.0	0.5	26
62105	6.0	−0.1	−1
62106	5.3	−0.8	−17
62107	6.4	−3.5	−54
62108	5.8	−1.3	−23
62109	3.9	0.1	2
62117	1.6	−0.1	−5
62145	3.3	−0.4	−13
62163	4.6	−0.8	−16
62301	2.5	−0.2	−9
62303	3.9	−1.1	−28
62304	2.2	0.2	11
62305	3.1	−0.3	−2
62414	1.3	0.2	20
64045	6.9	−0.8	−12
64046	5.7	−1.5	−27
athos	2.7	−0.7	−24

Table 14. Average of top 5 wave events (peaks) and corresponding mean peak error (peak bias)

Parameter Station	bias sec	 %	rms sec	si	cc
almag	0.7	18	0.9	0.25	0.70
oland	0.4	12	0.6	0.18	0.81
truba	0.5	14	0.8	0.23	0.52
arkon	0.8	24	1.0	0.30	0.73
20044	1.1	30	1.3	0.36	0.73
24023	1.6	41	1.9	0.47	0.59
25077	1.2	30	1.4	0.36	0.74
25138	1.2	34	1.5	0.43	0.54
athos	0.9	26	1.1	0.34	0.47

Table 15. Predicted mean wave period

Parameter Station	bias sec	 %	rms sec	si	cc
20044	0.1	1	2.0	0.36	0.41
24023	0.3	4	2.2	0.33	0.55
25077	0.1	2	2.7	0.43	0.37
25138	0.5	10	2.5	0.49	0.41
61001	0.1	2	1.6	0.31	0.31
61002	0.2	4	1.6	0.31	0.49
62001	2.8	39	3.3	0.47	0.45
62026	1.1	23	1.5	0.32	0.58
62029	2.5	36	2.9	0.41	0.56
62101	-	-	-	-	-
62103	0.8	9	2.0	0.25	0.37
62105	2.5	36	3.0	0.42	0.62
62106	3.4	45	4.0	0.52	0.55
62107	−0.2	−2	2.6	0.27	0.27
62108	2.3	33	2.7	0.38	0.64
62109	1.4	27	2.3	0.43	0.57
62117	2.5	52	3.2	0.68	0.40
62145	1.6	37	2.2	0.52	0.60
62163	2.8	40	3.2	0.46	0.49
62301	2.7	51	3.6	0.69	0.42
62303	2.1	33	3.0	0.46	0.41
62304	−1.1	−18	1.6	0.27	0.30
62305	−2.2	−26	3.2	0.40	0.11
64045	2.5	35	2.8	0.40	0.66
64046	2.4	36	2.9	0.42	0.64
athos	0.4	9	2.2	0.54	0.23

Table 16. Predicted dominant wave period

Parameter Station	bias deg	std deg	cc
arkon	11	51	0.91
20044	−2	50	0.90
24023	−2	29	0.80
25077	−4	40	0.78
25138	8	51	0.79
athos	6	55	0.86

Table 17. Predicted mean wave direction

7.4 Significant wave height

The following pages show significant wave height error statistics for each station.

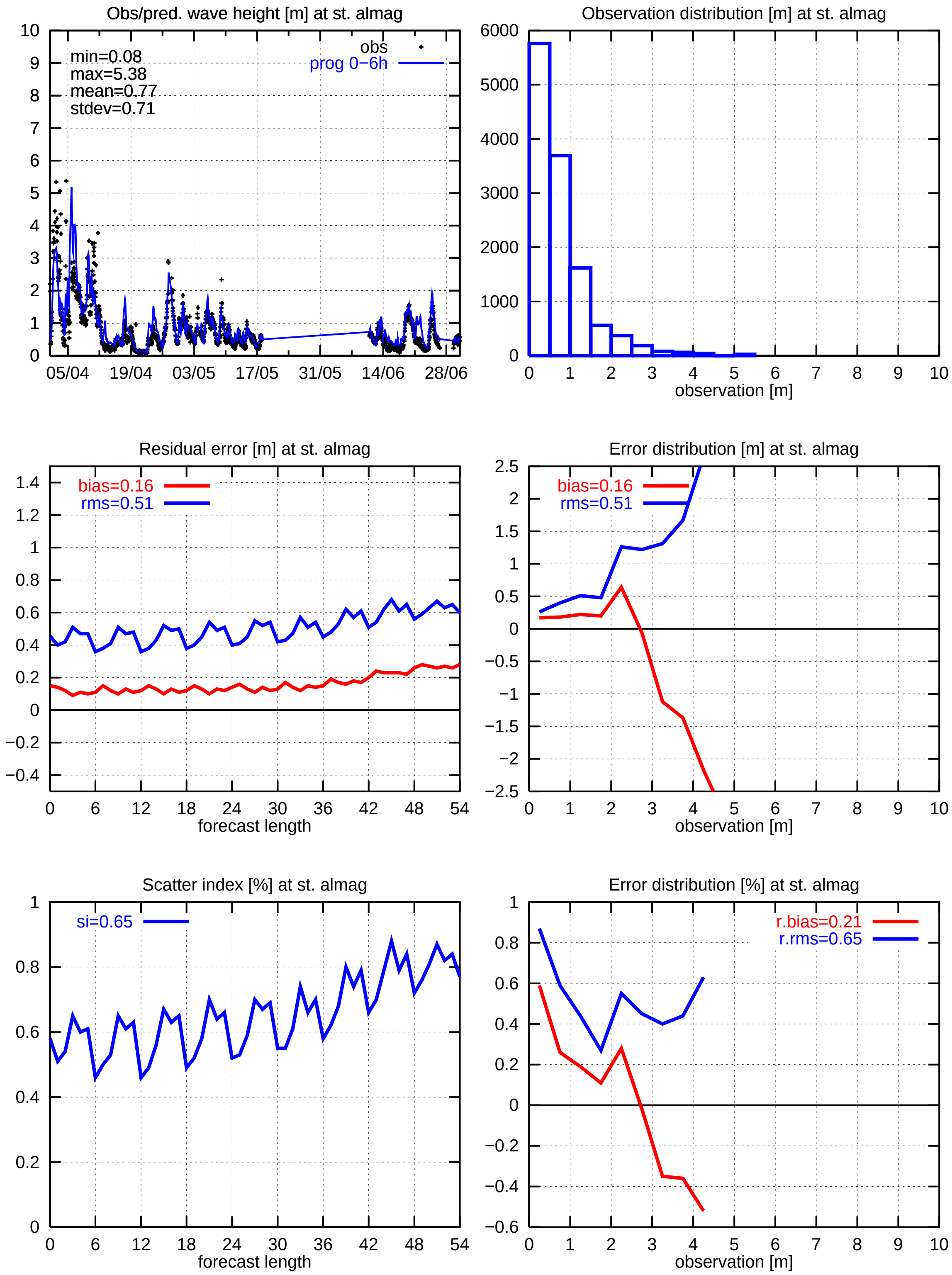

Figure 11. Significant wave height: Almagrundet

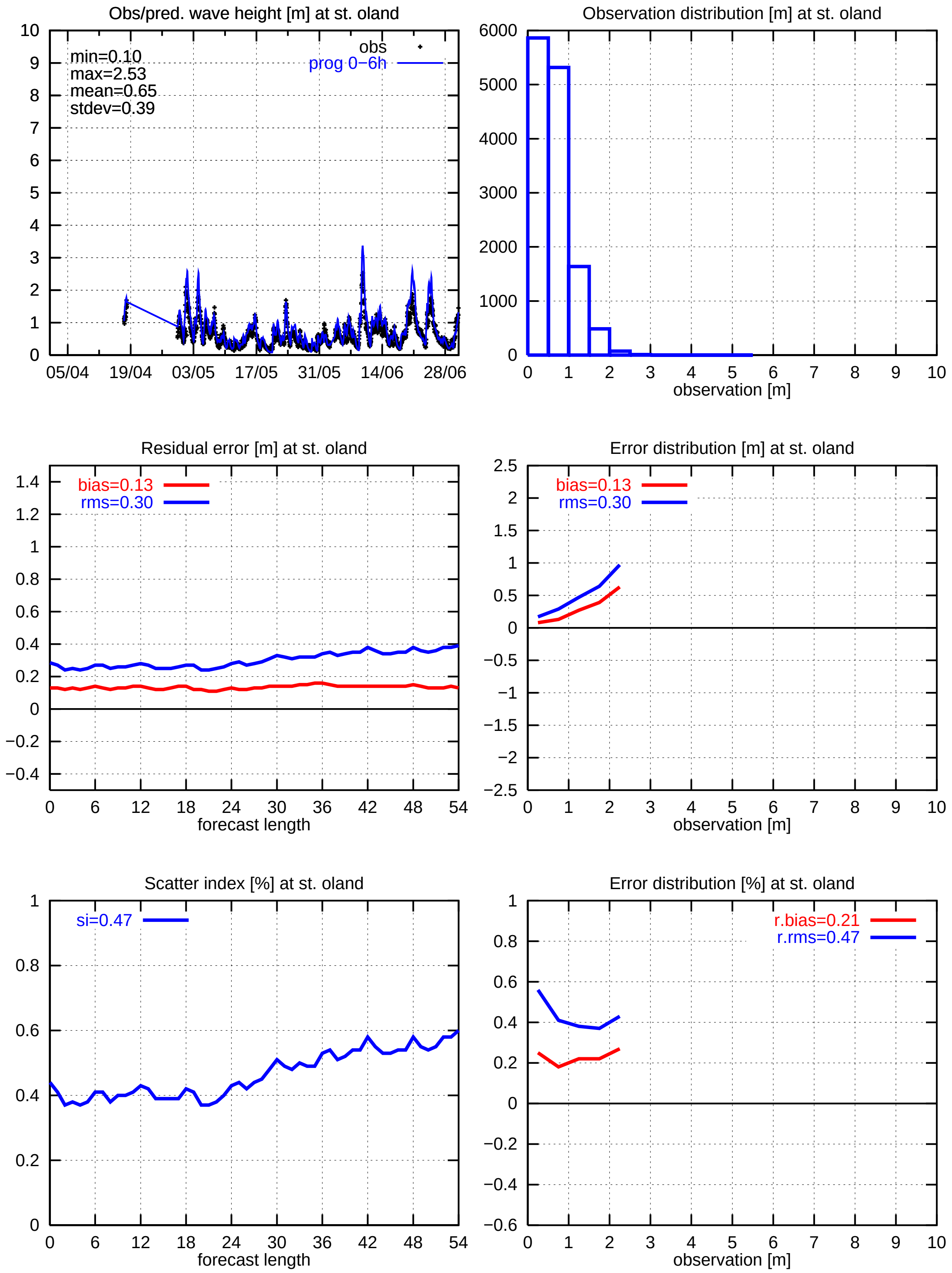

Figure 12. Significant wave height: Øland

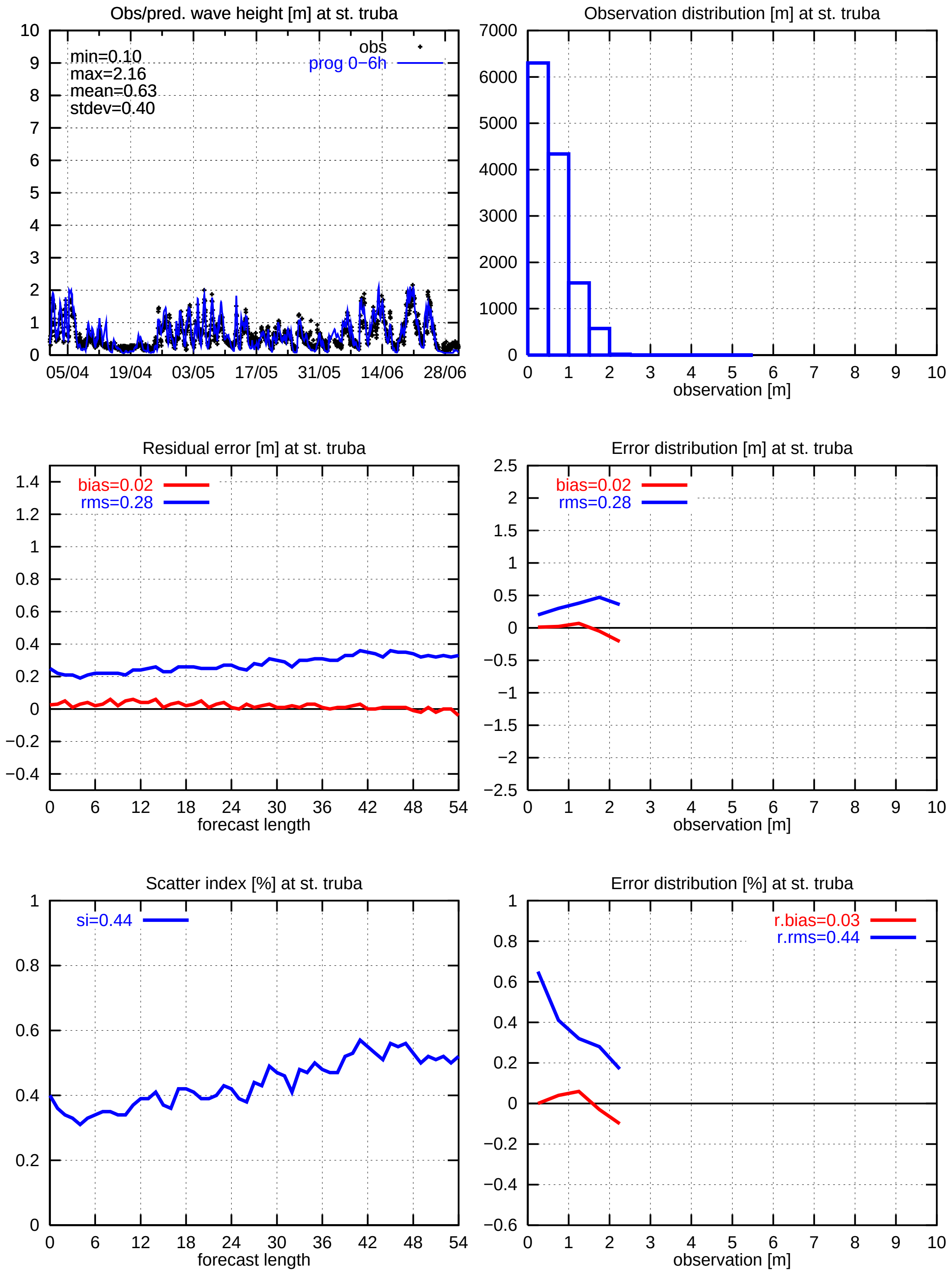

Figure 13. Significant wave height: Trubaduren

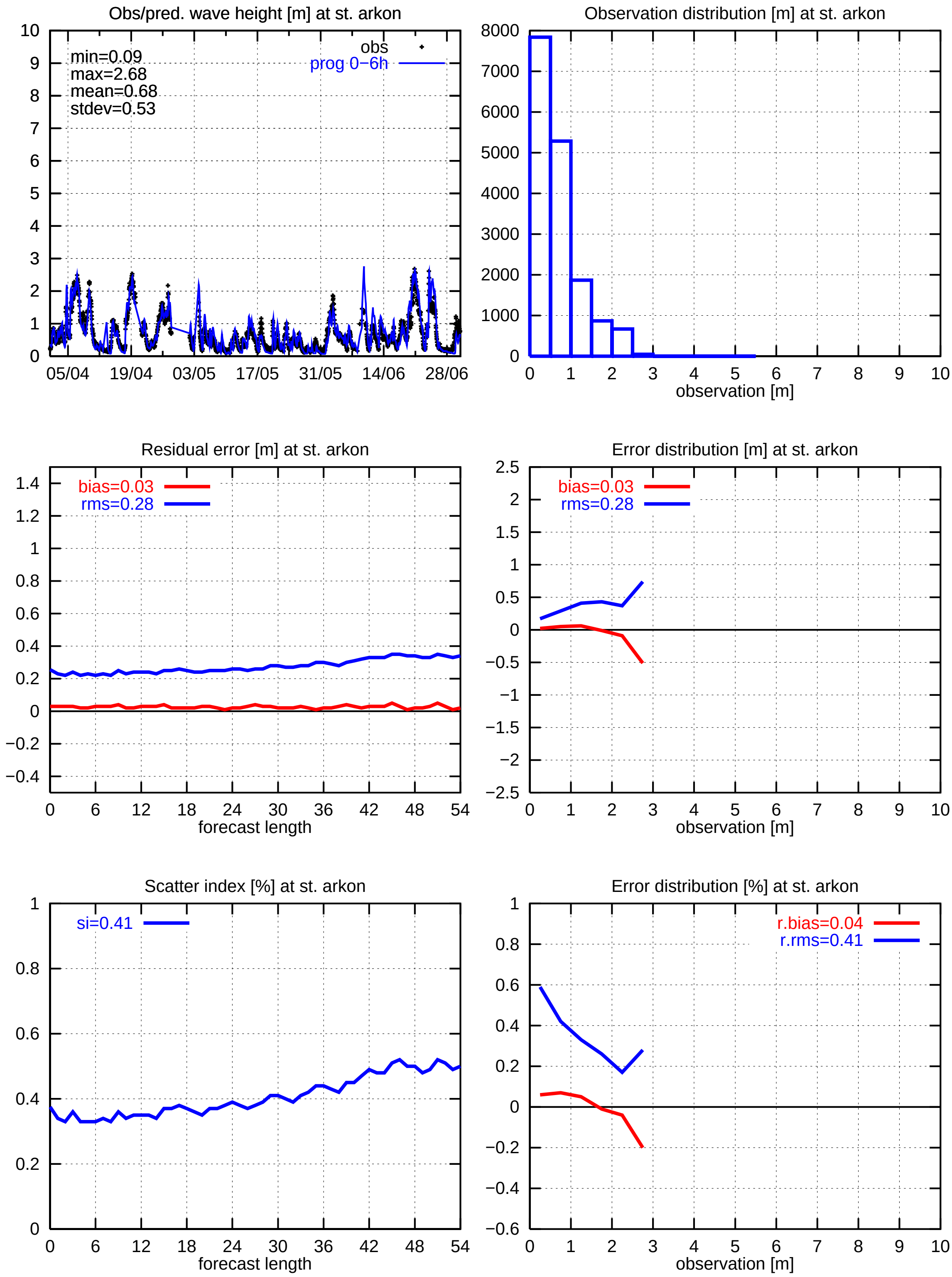

Figure 14. Significant wave height: Arkona

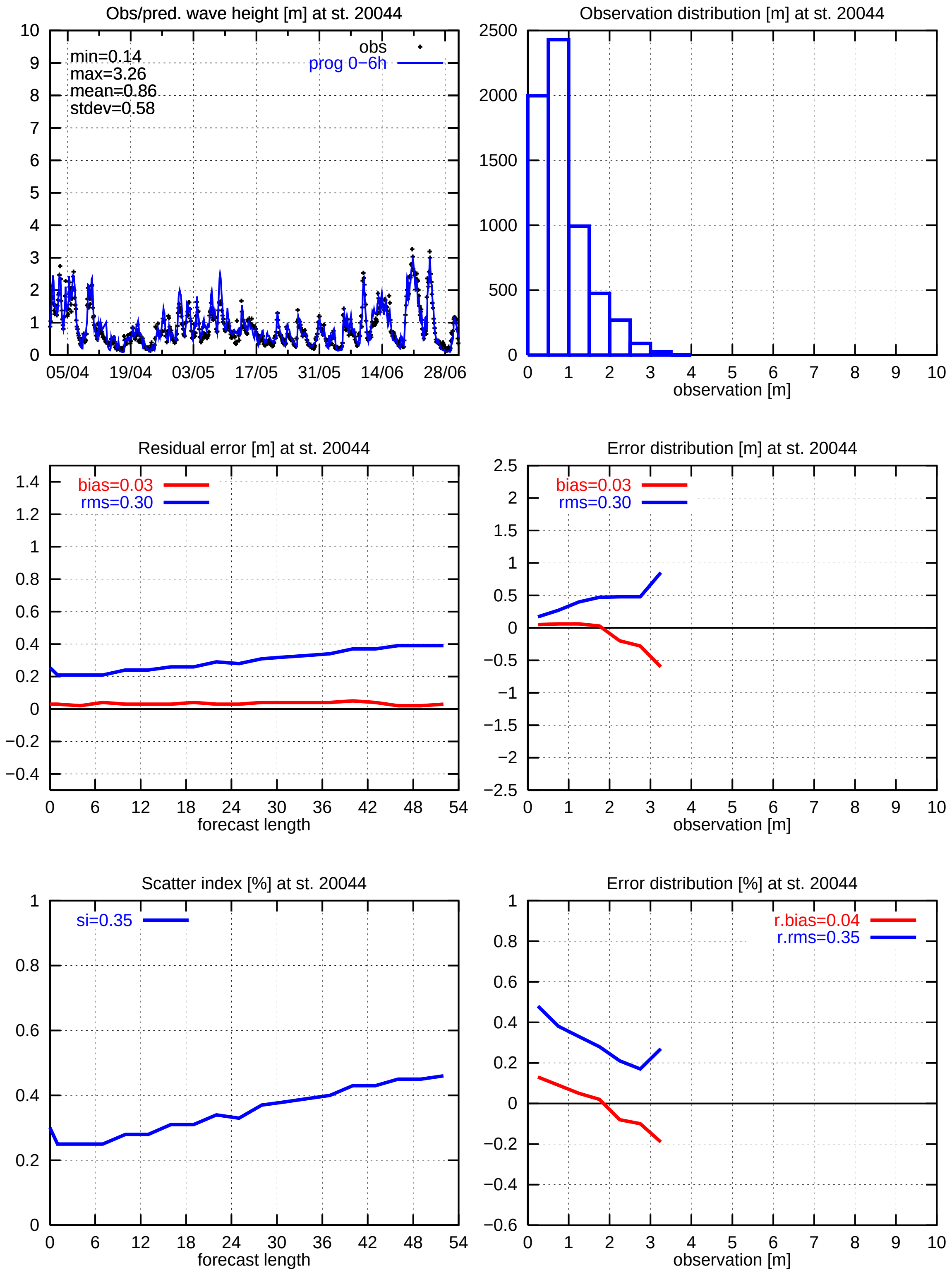

Figure 15. Significant wave height: 20044. The zig-zag curves are caused by irregular 3h sampling.

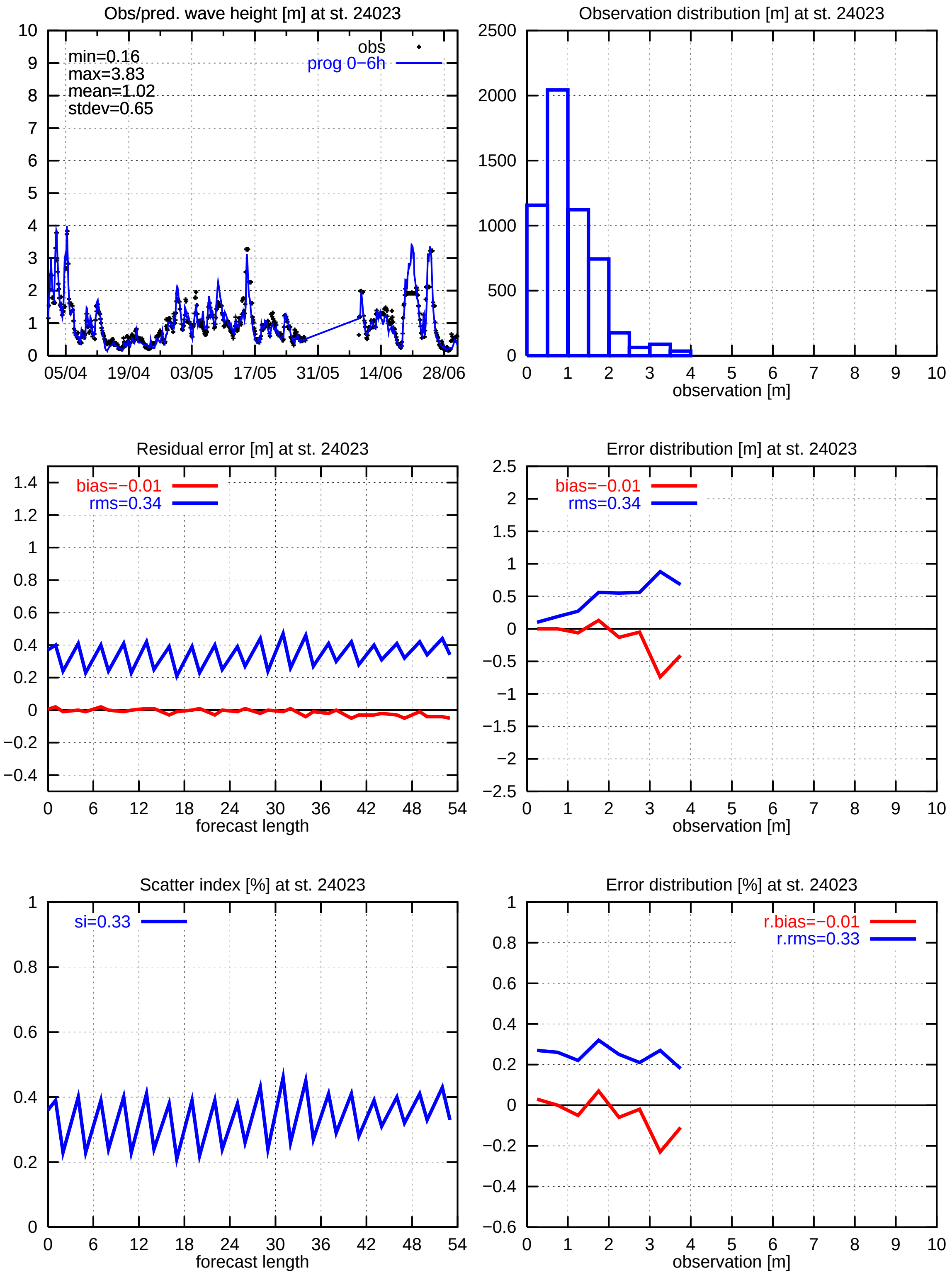

Figure 16. Significant wave height: 24023. The zig-zag curves are caused by irregular 3h sampling.

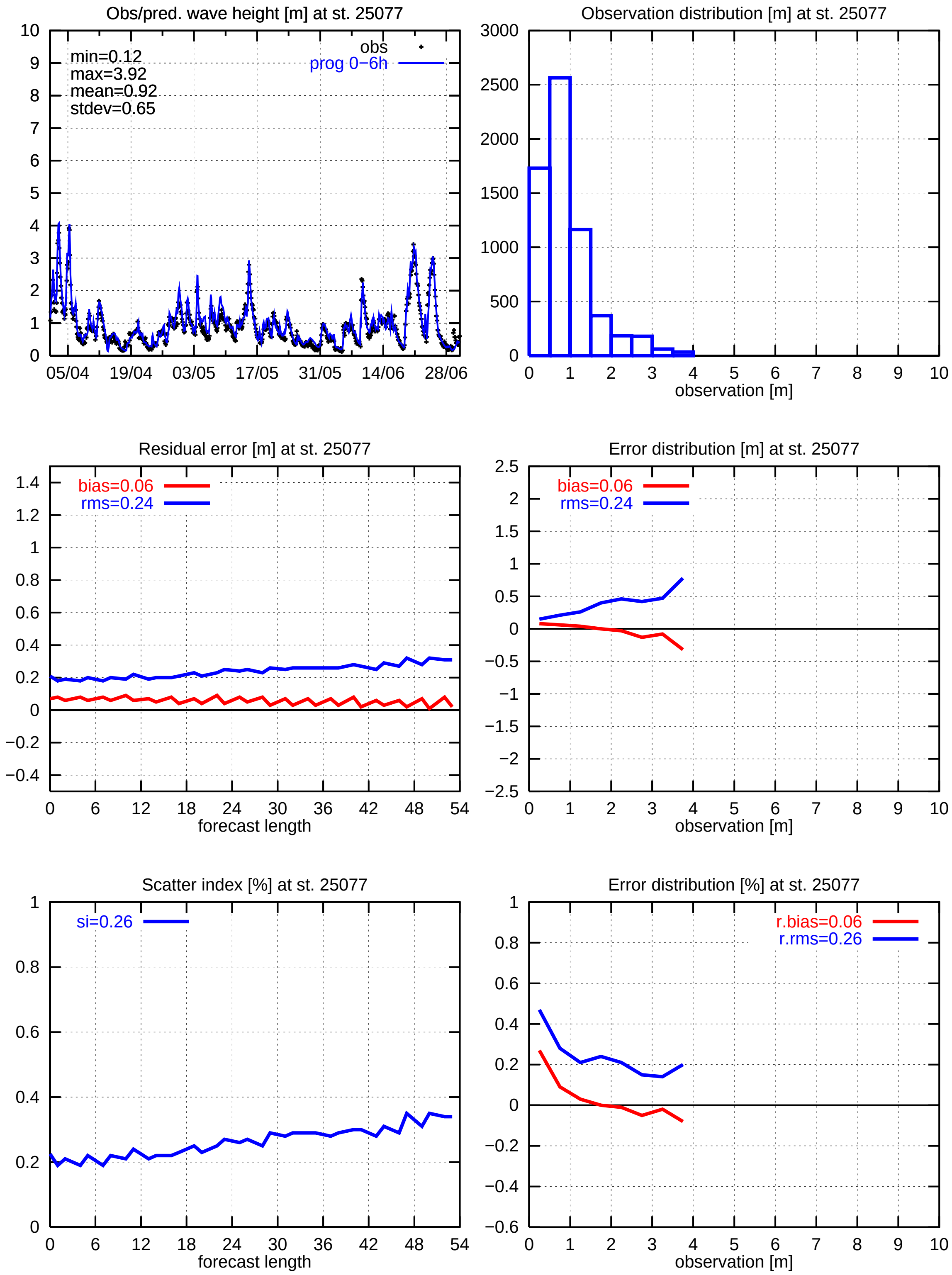

Figure 17. Significant wave height: 25077. The zig-zag curves are caused by irregular 3h sampling.

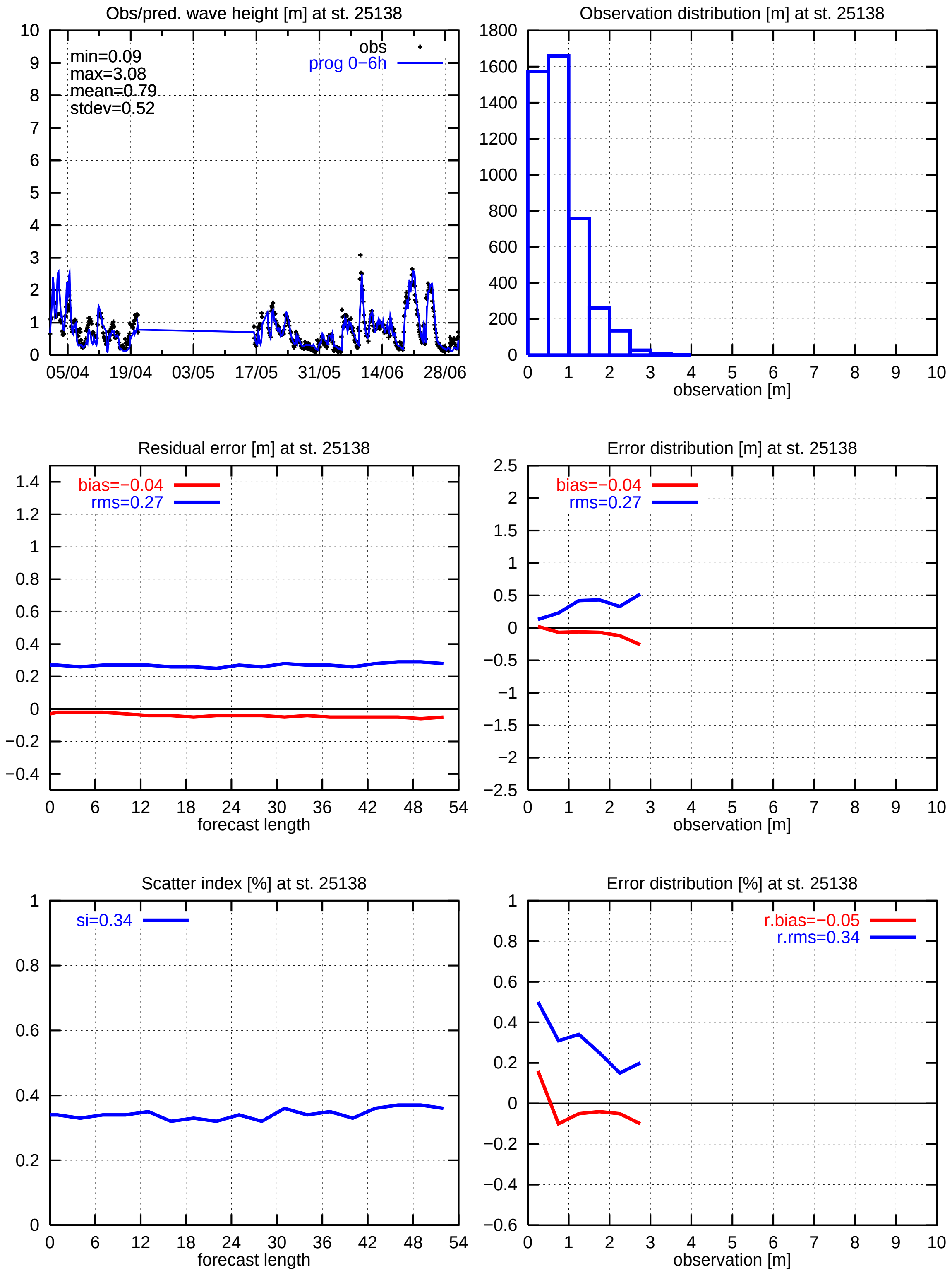

Figure 18. Significant wave height: 25138. The zig-zag curves are caused by irregular 3h sampling.

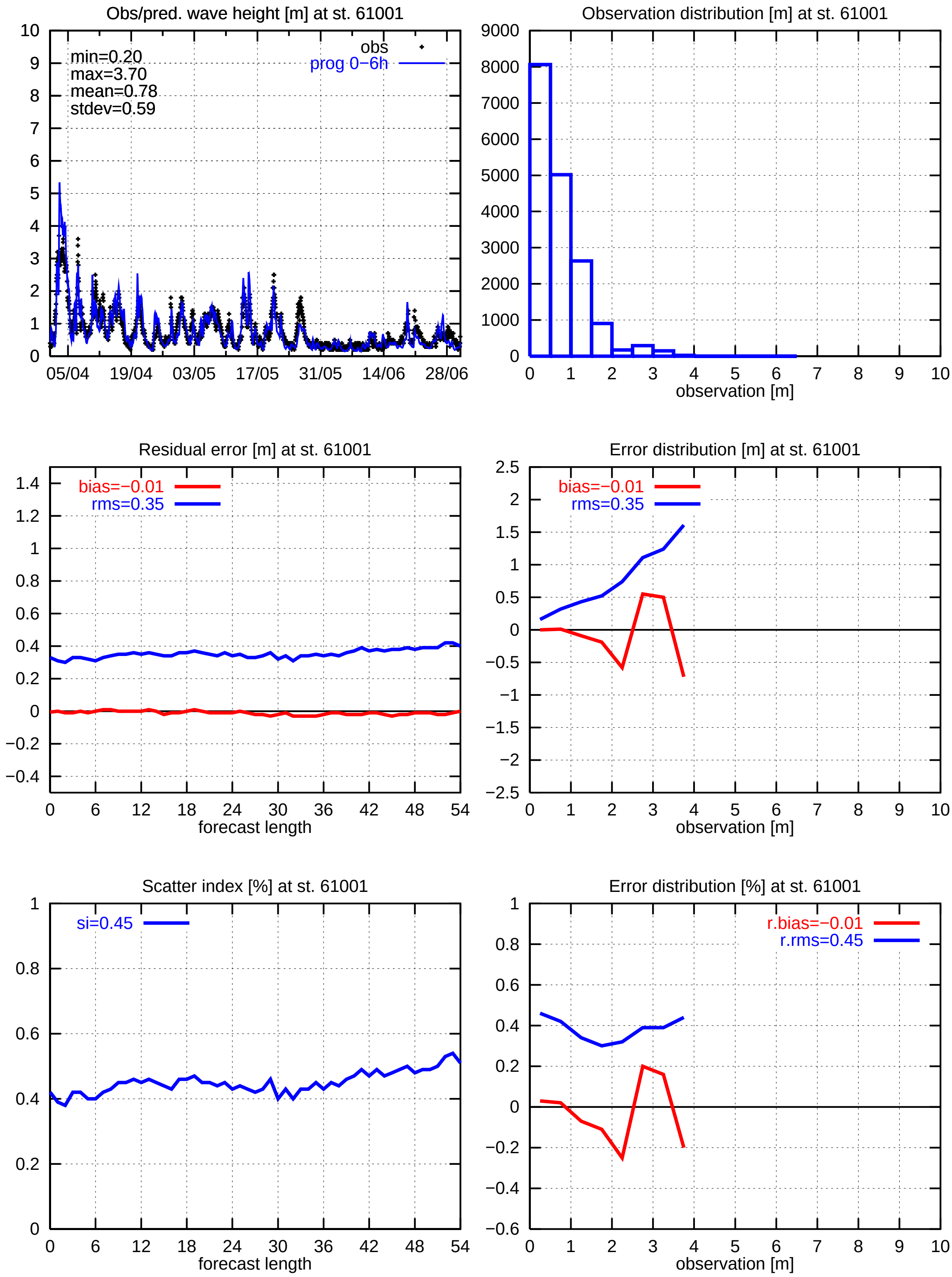

Figure 19. Significant wave height: 61001

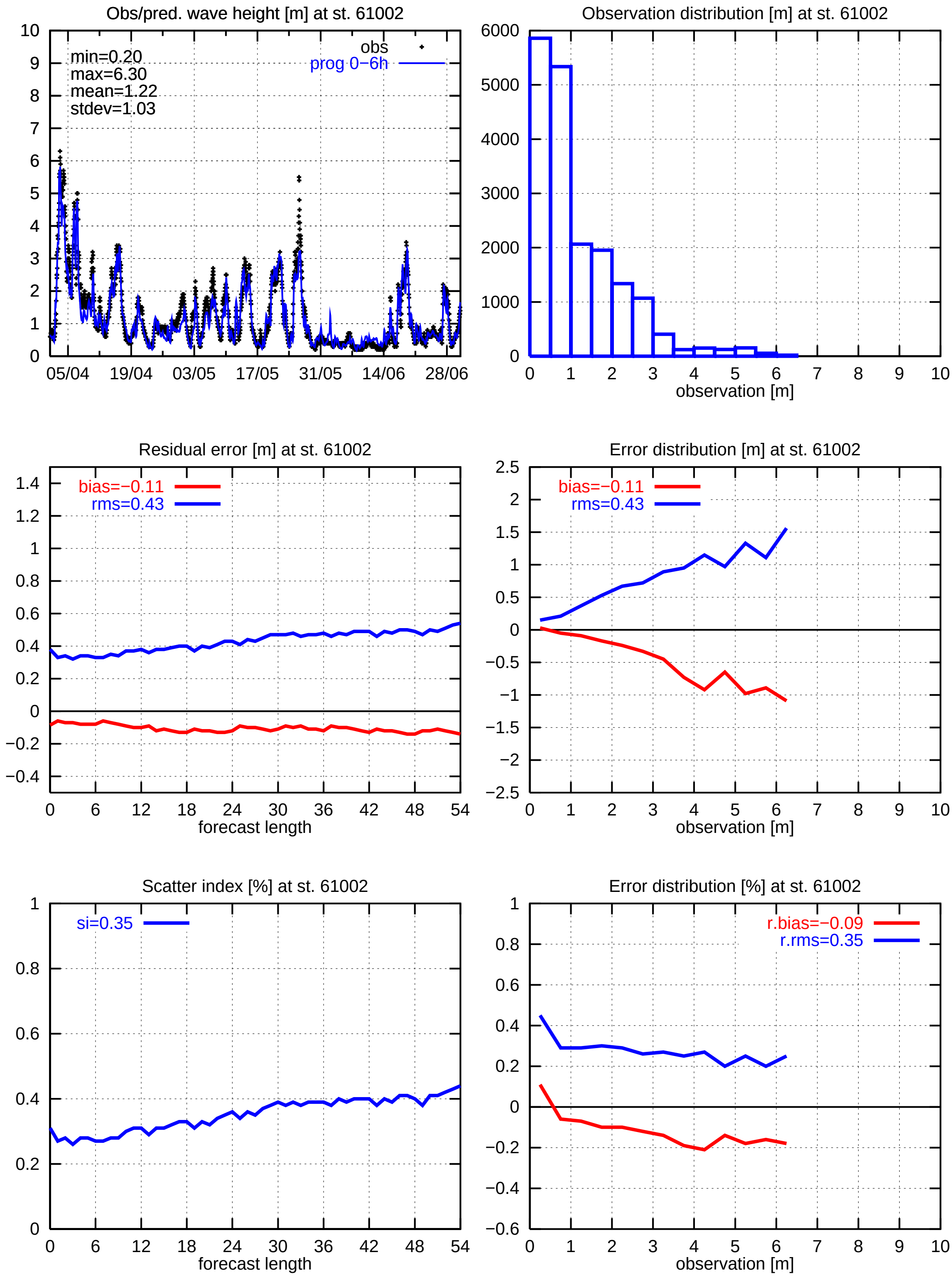

Figure 20. Significant wave height: 61002

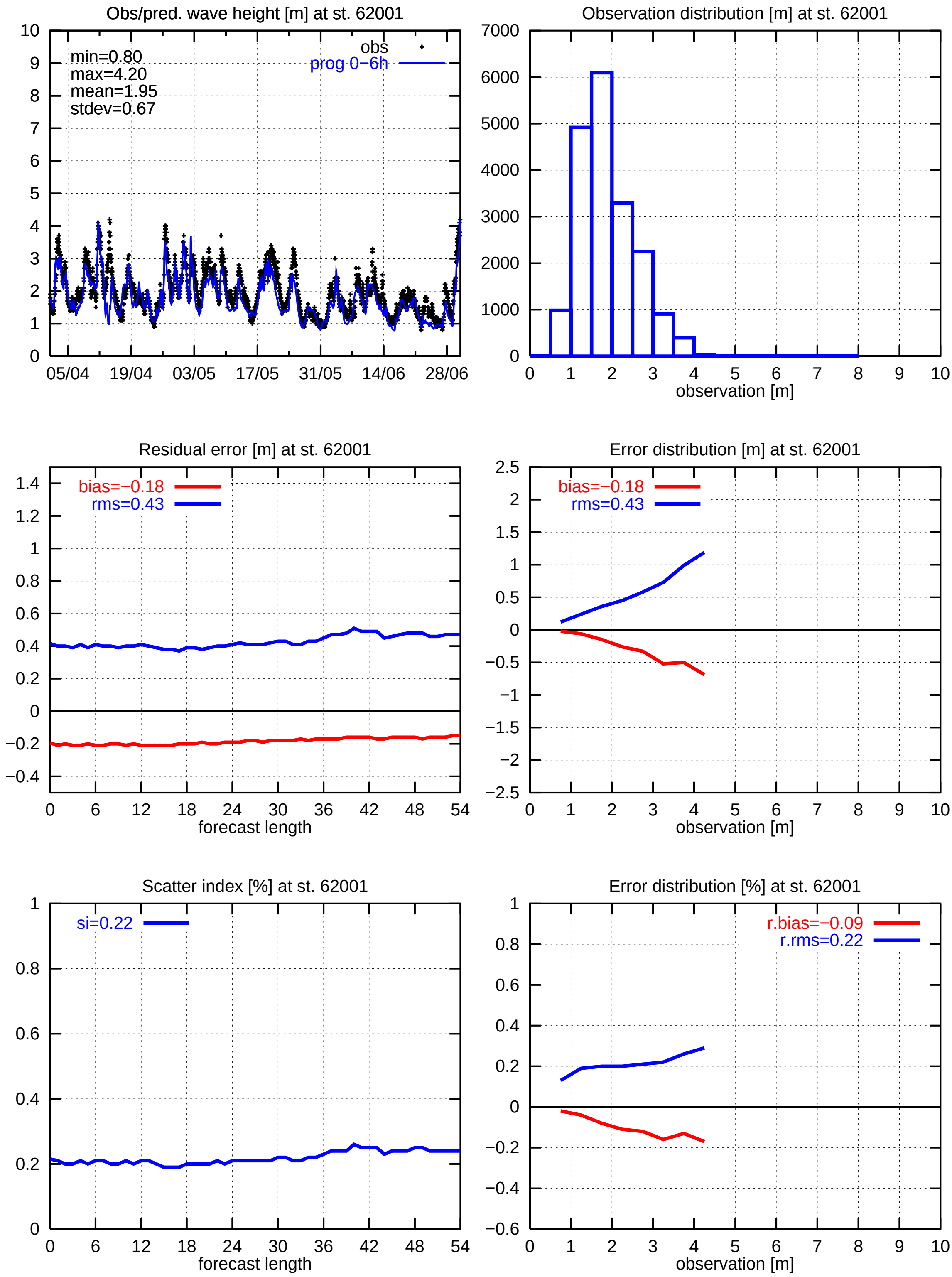

Figure 21. Significant wave height: 62001

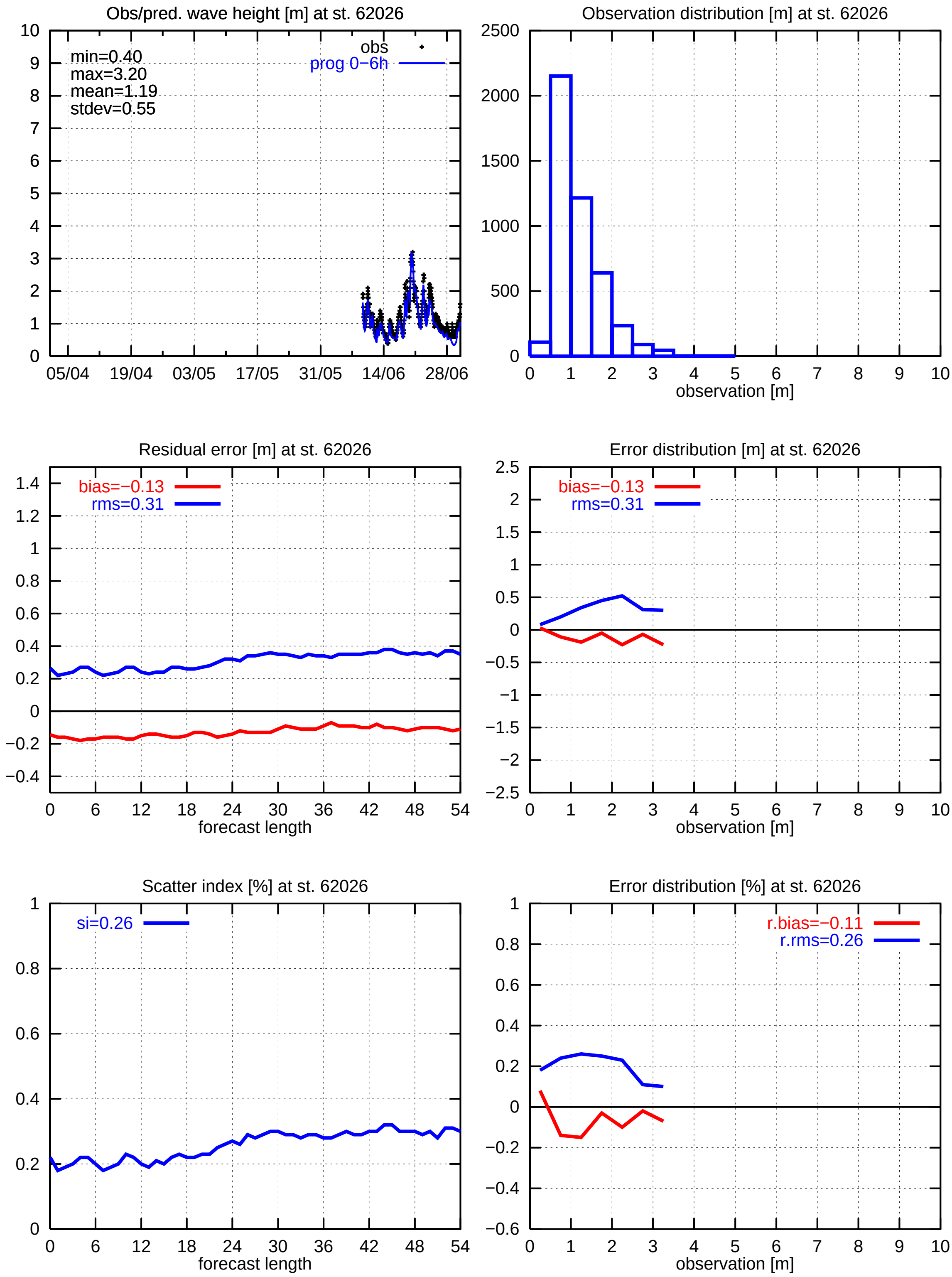

Figure 22. Significant wave height: 62026

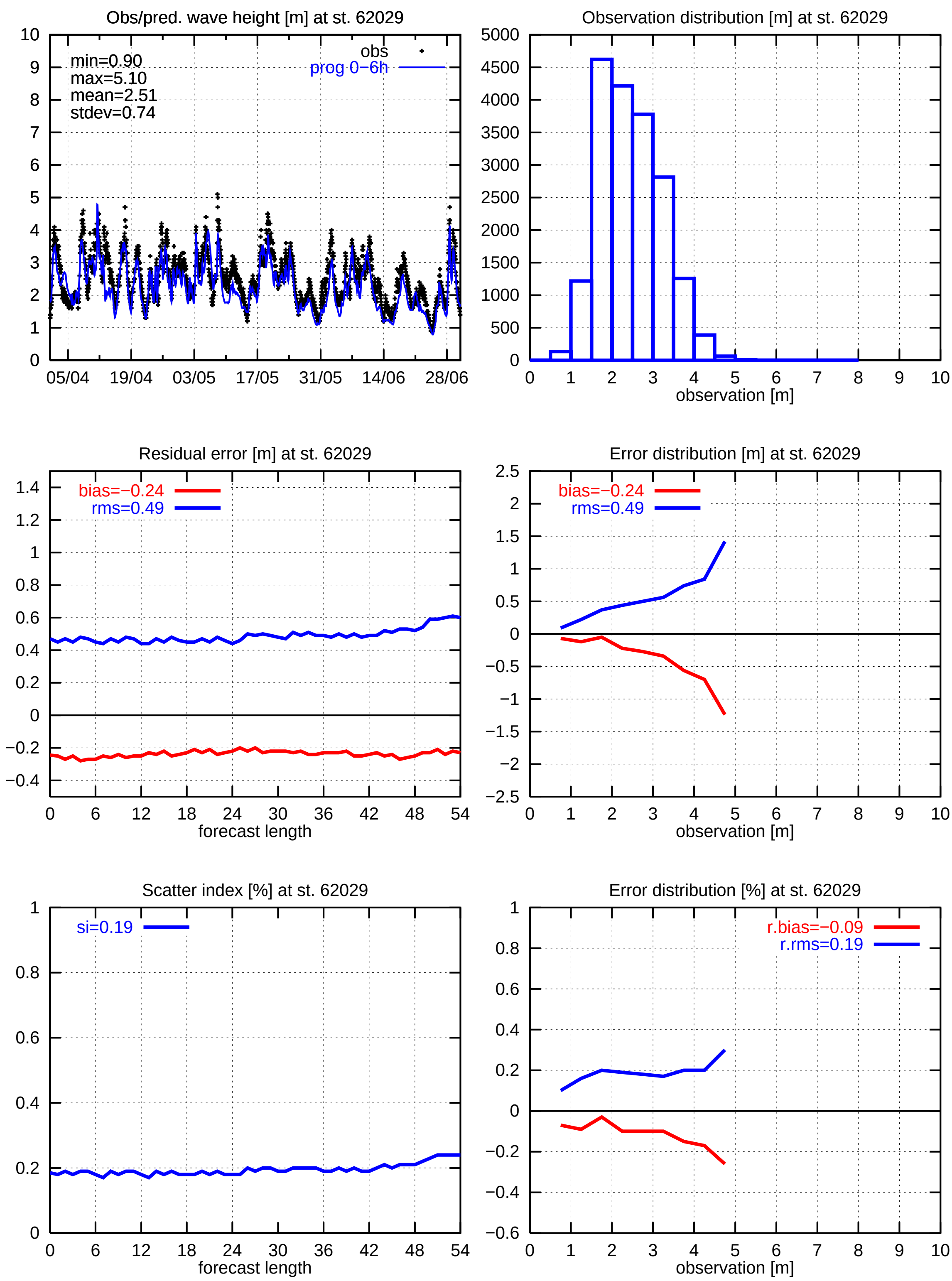

Figure 23. Significant wave height: 62029

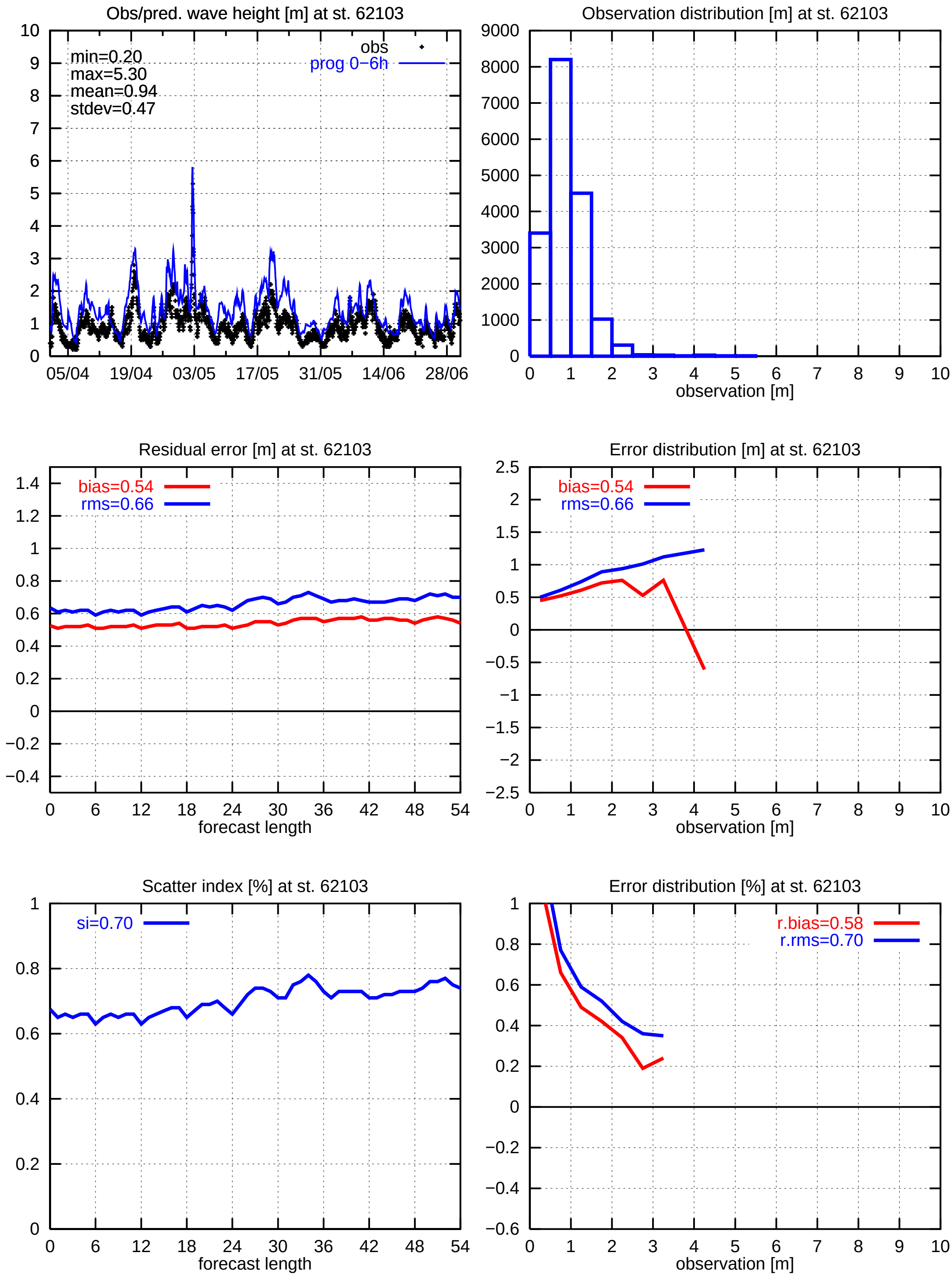

Figure 24. Significant wave height: 62103

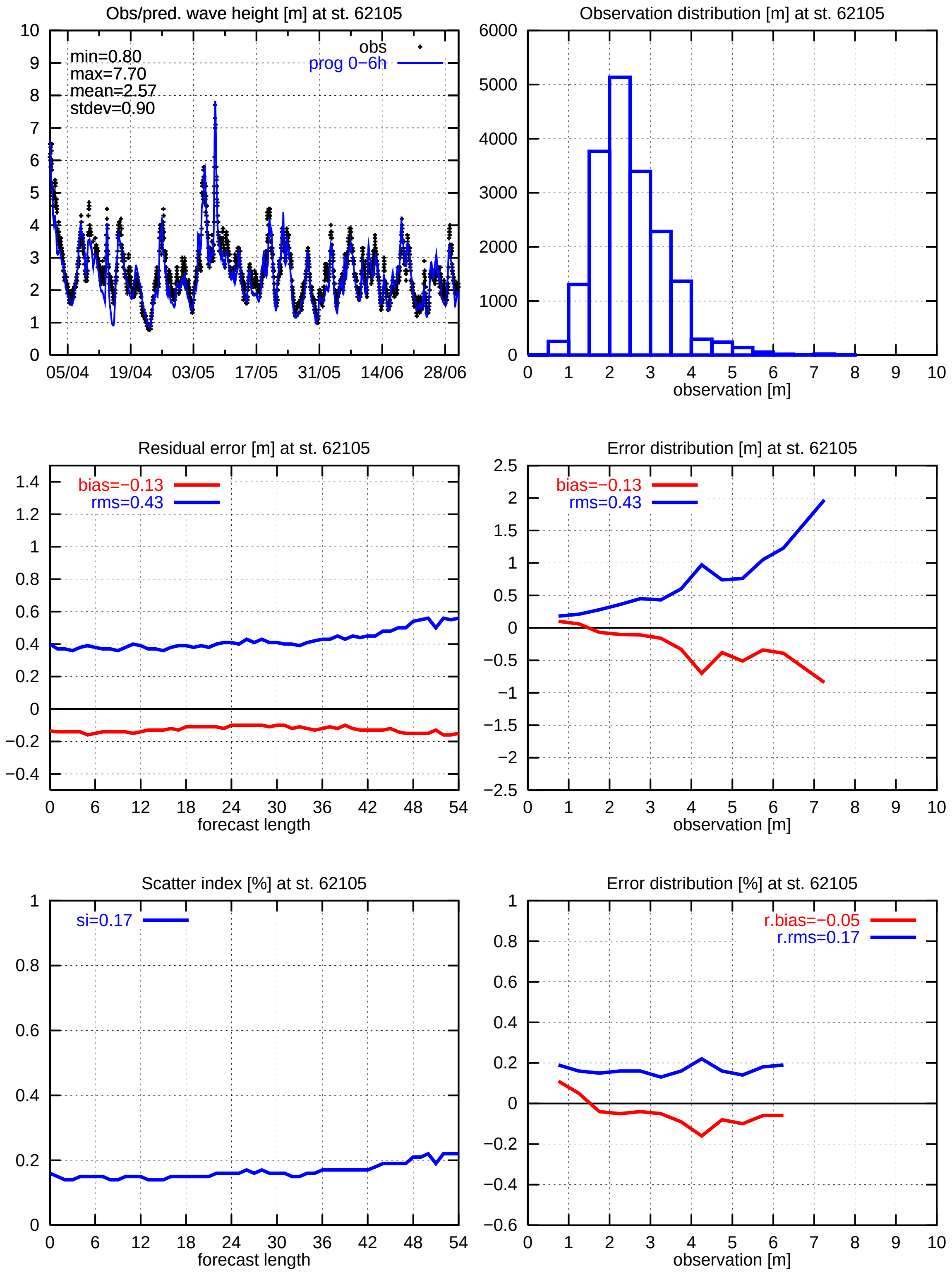

Figure 25. Significant wave height: 62105.

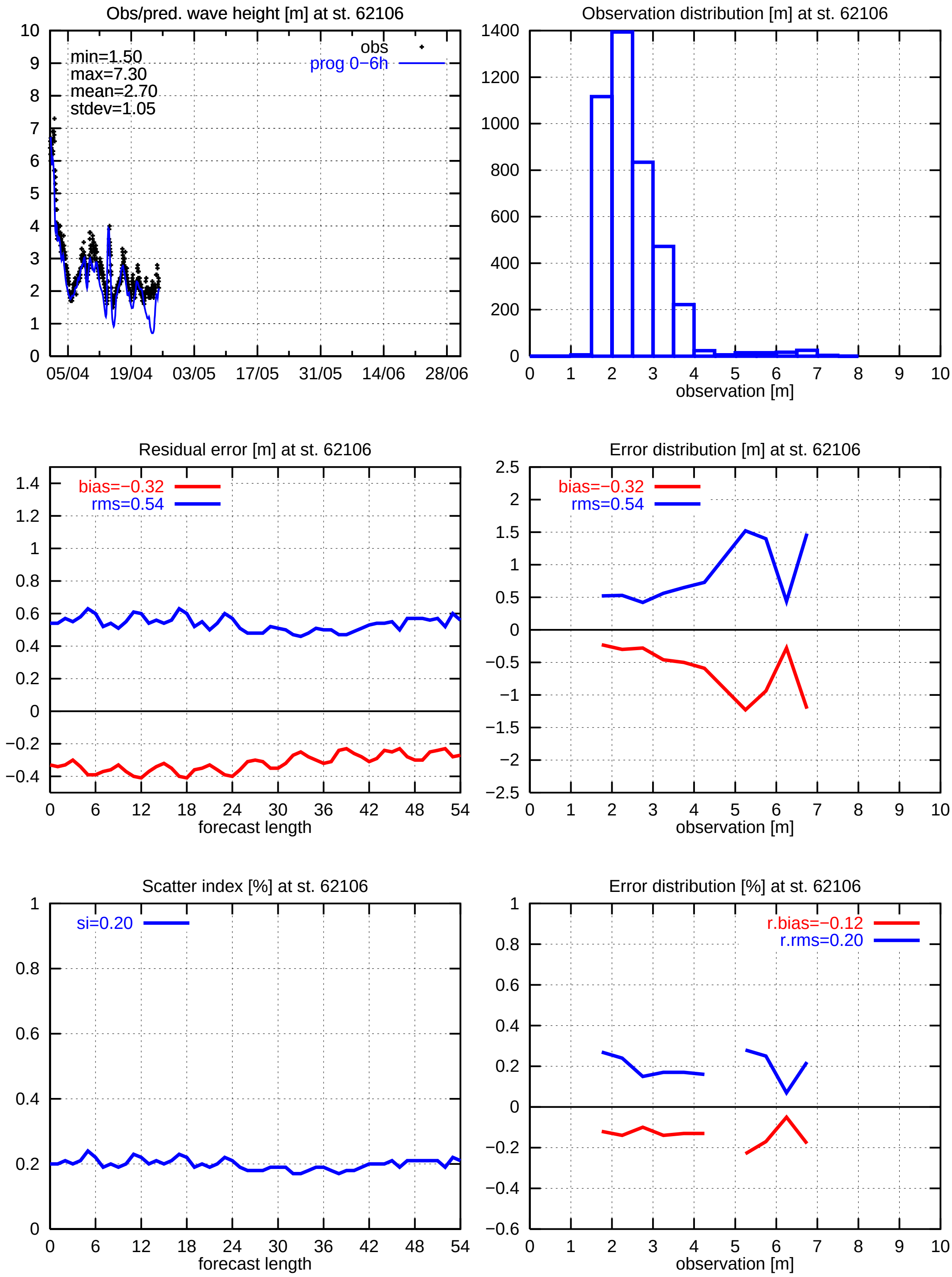

Figure 26. Significant wave height: 62106.

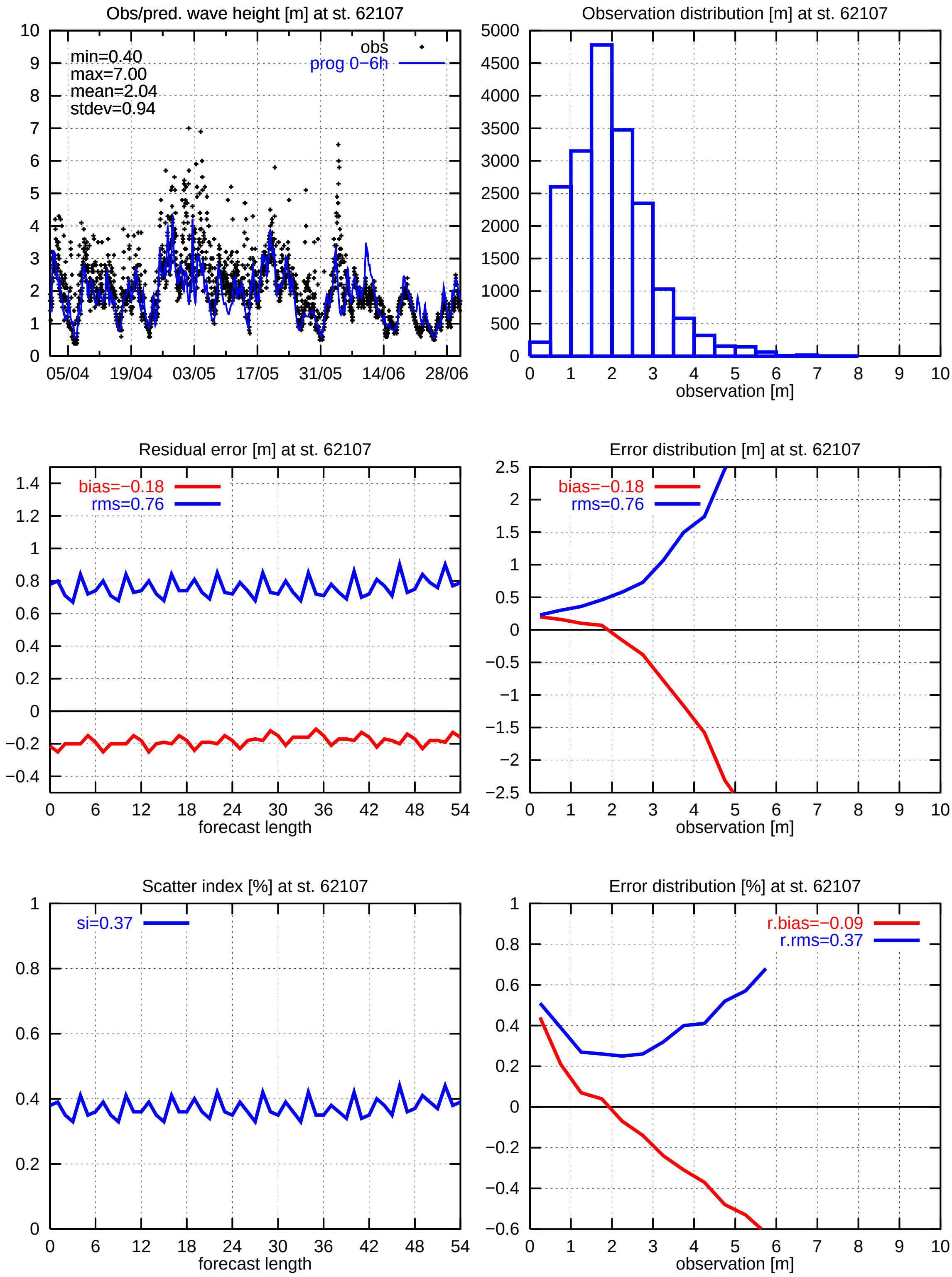

Figure 27. Significant wave height: 62107

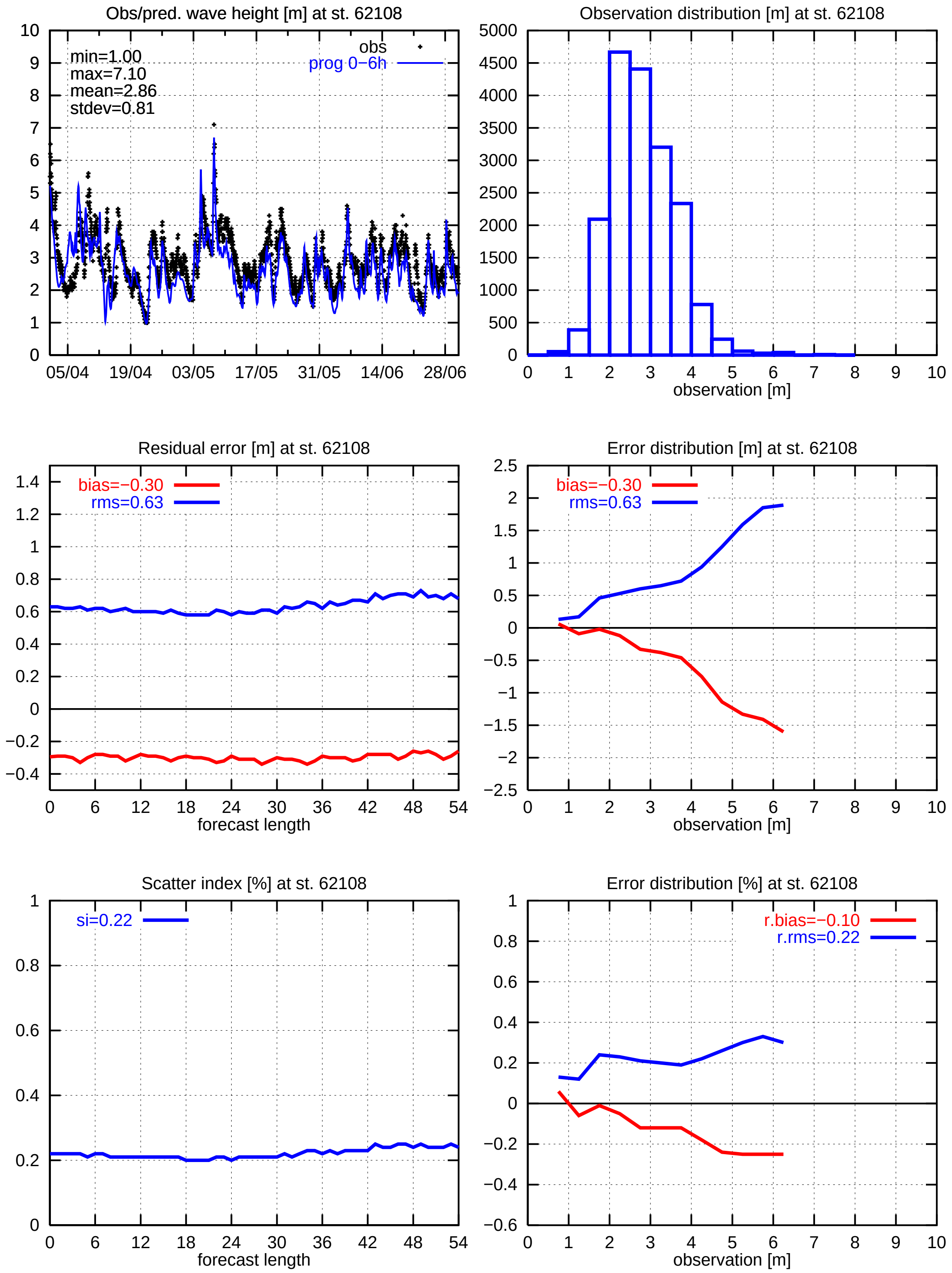

Figure 28. Significant wave height: 62108

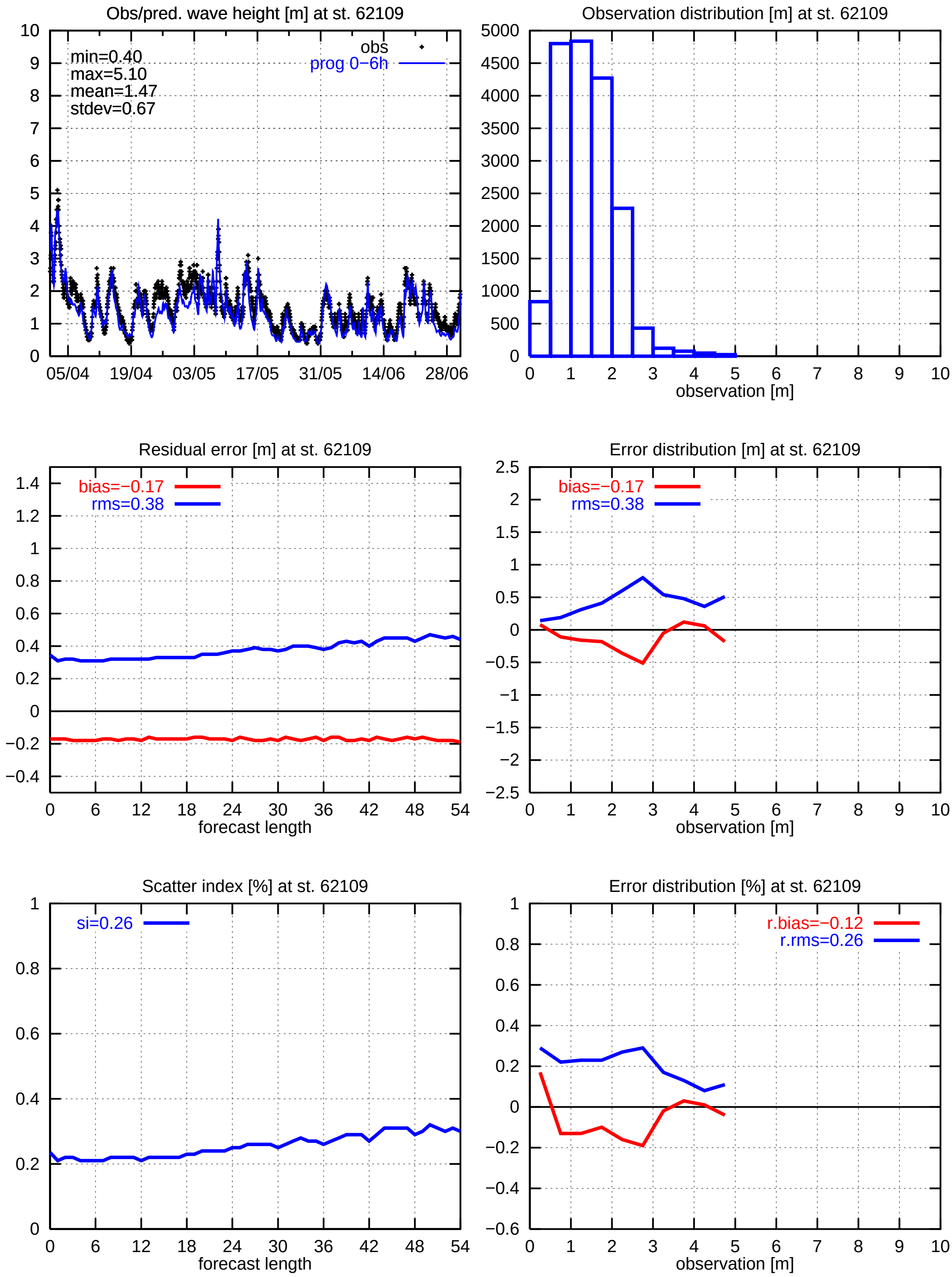

Figure 29. Significant wave height: 62109

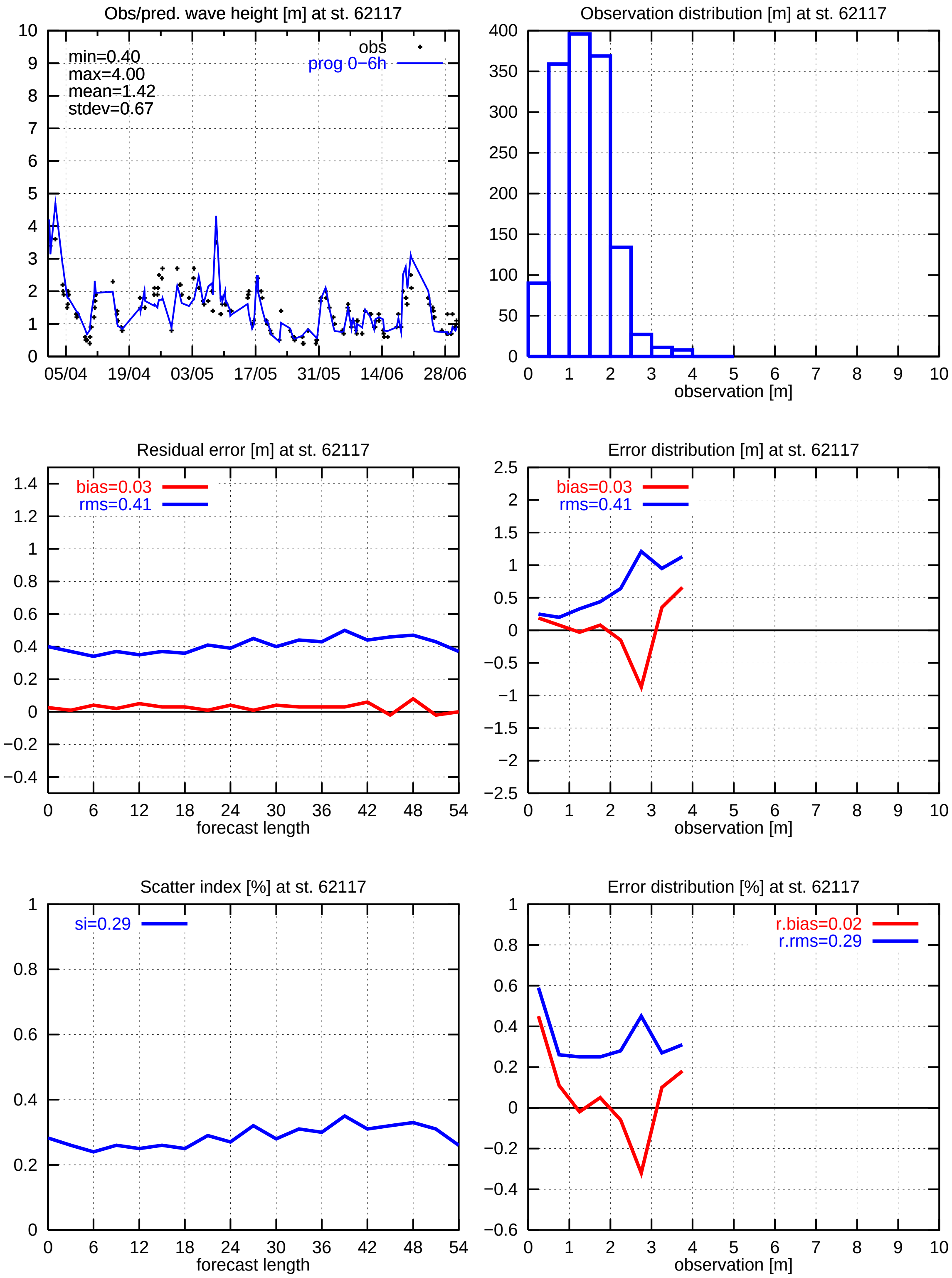

Figure 30. Significant wave height: 62117.

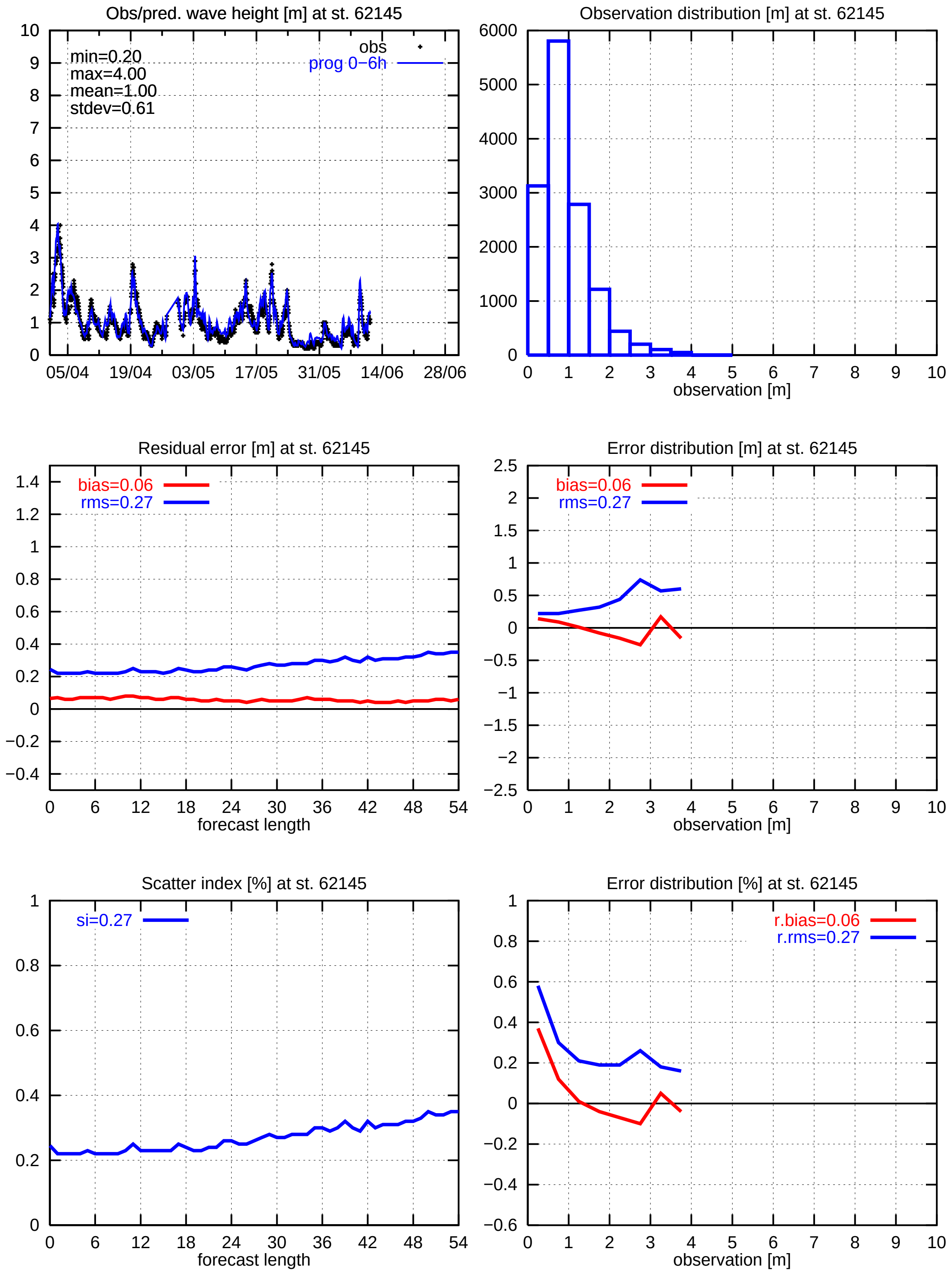

Figure 31. Significant wave height: 62145

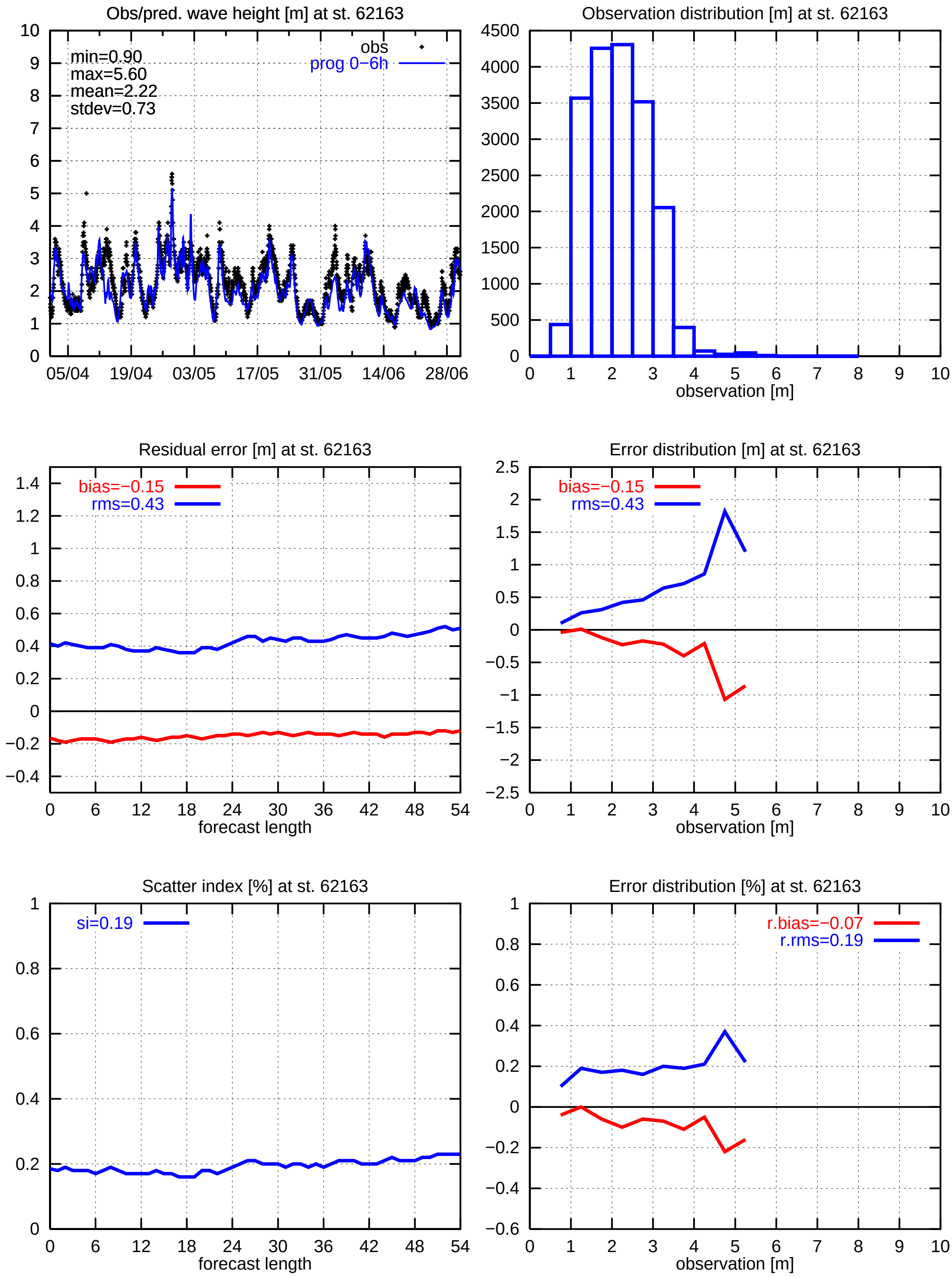

Figure 32. Significant wave height: 62163

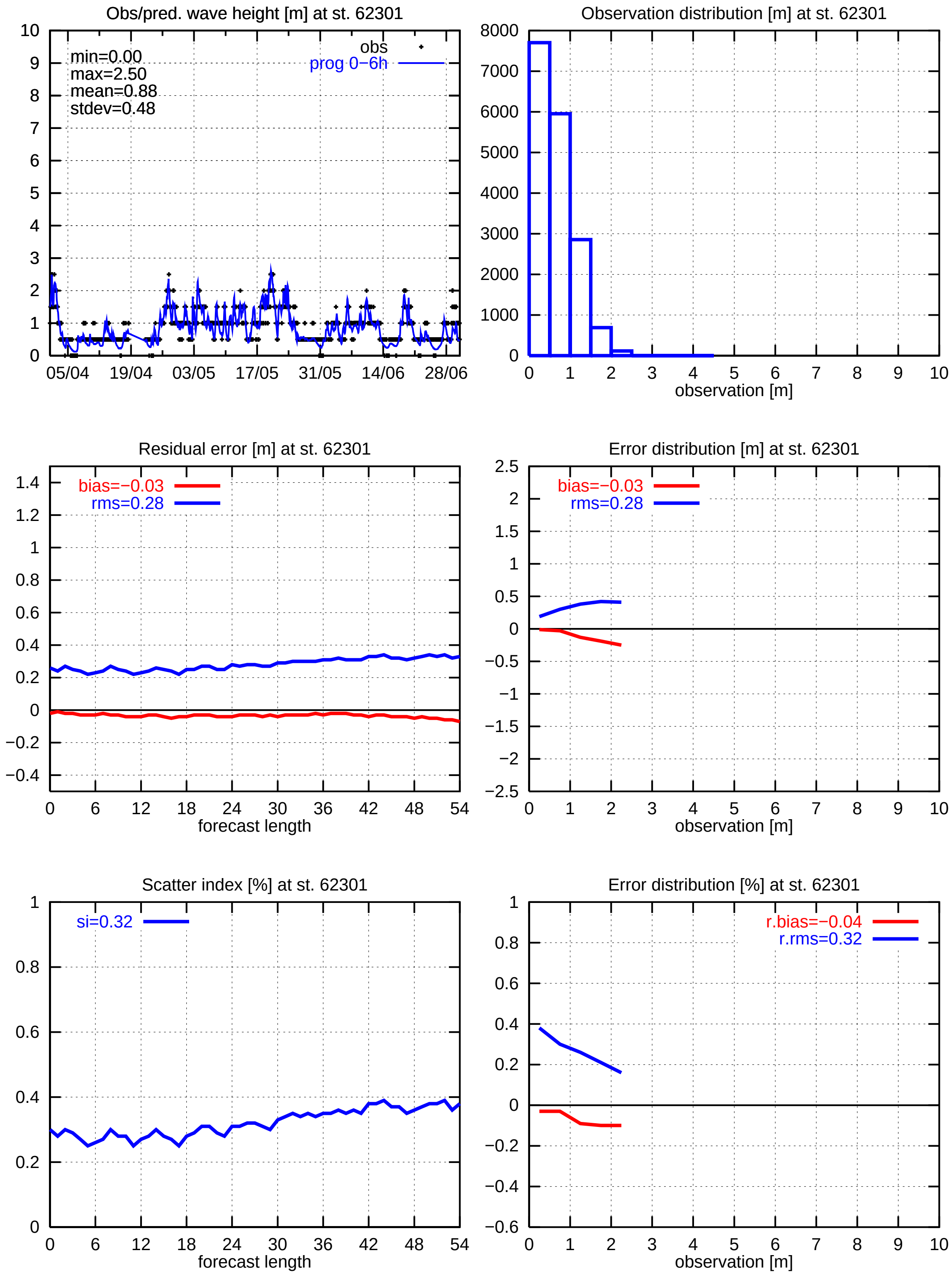

Figure 33. Significant wave height: 62301. The sampling accuracy is 0.5m

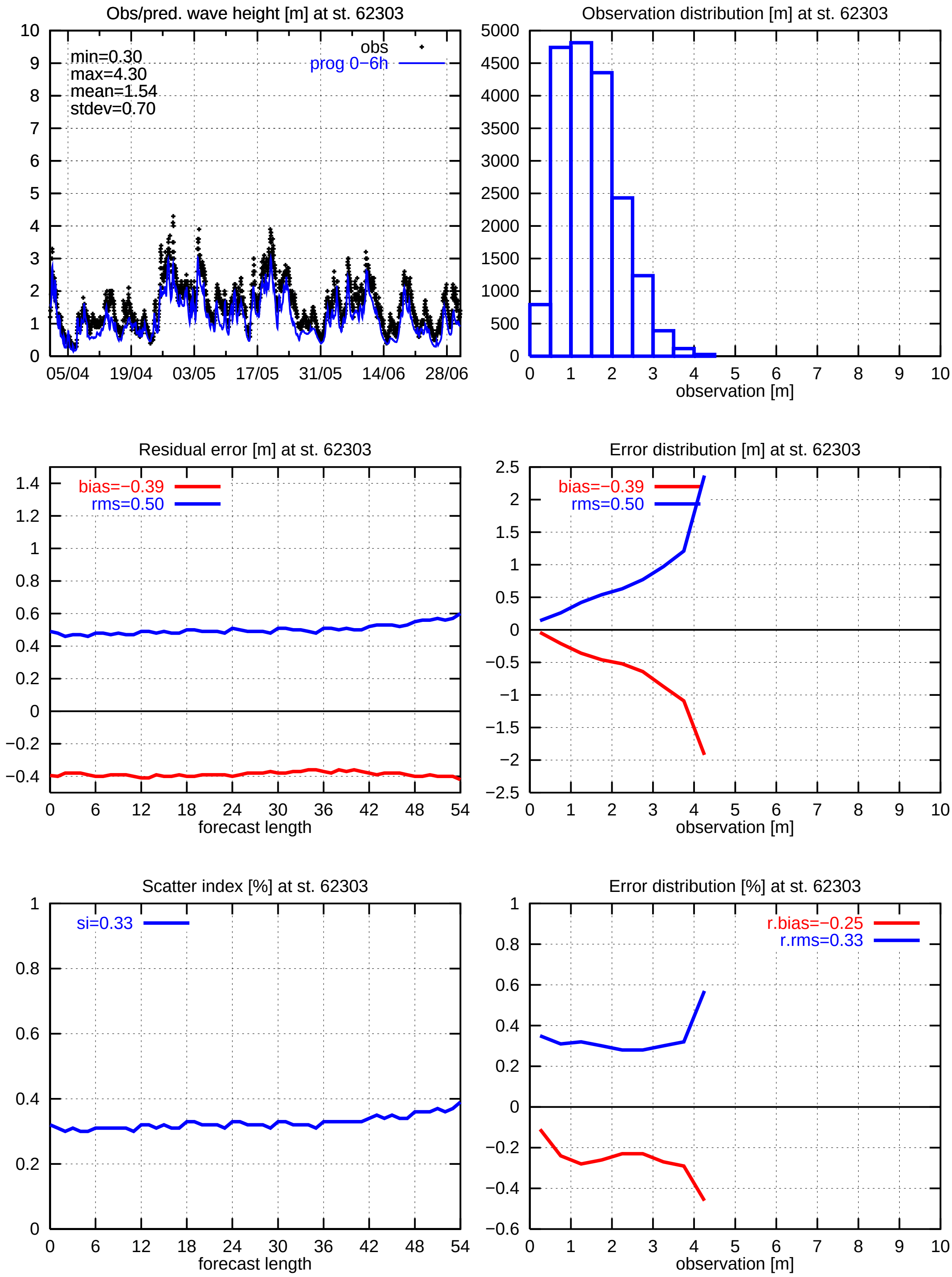

Figure 34. Significant wave height: 62303

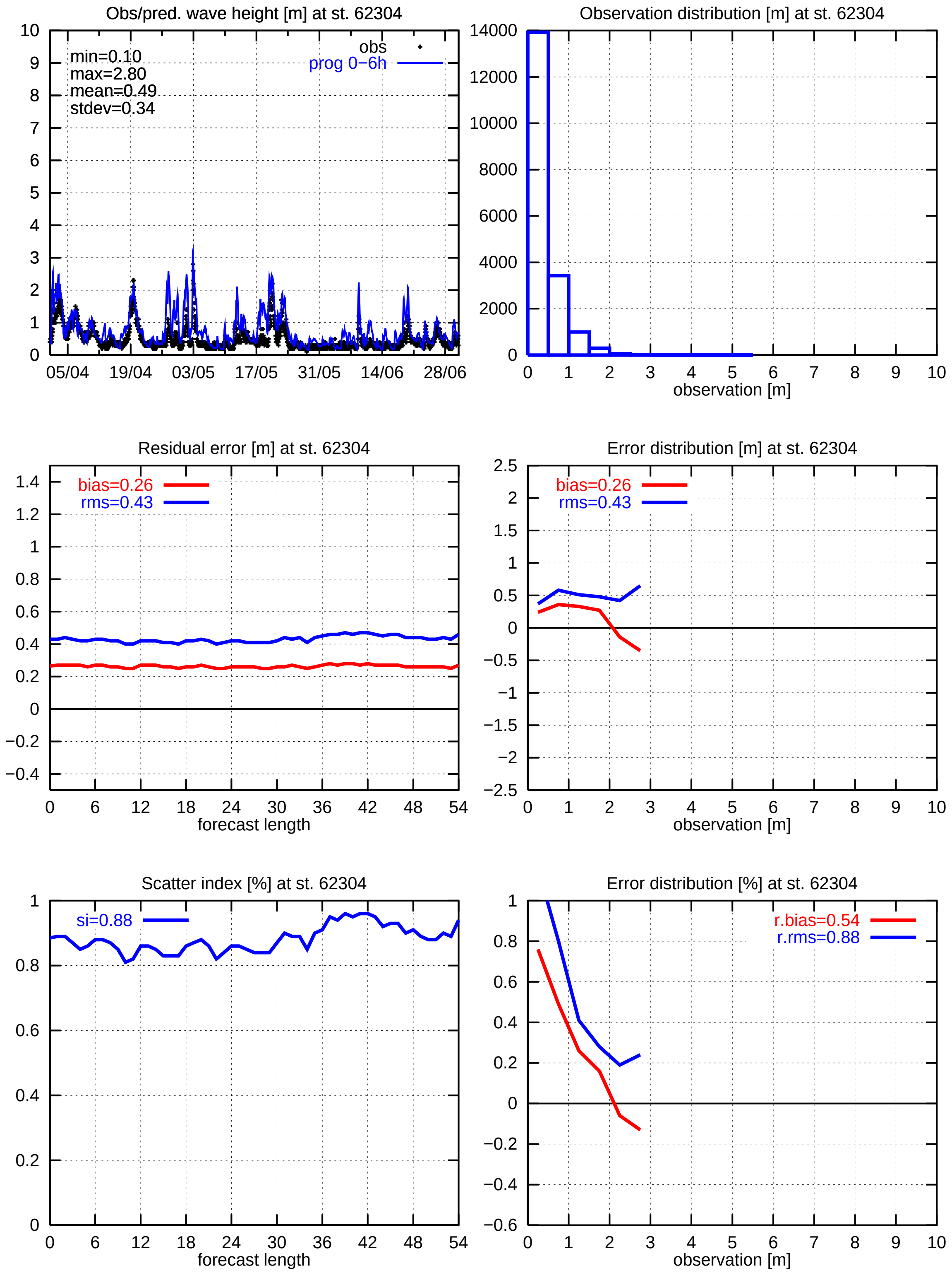

Figure 35. Significant wave height: 62304

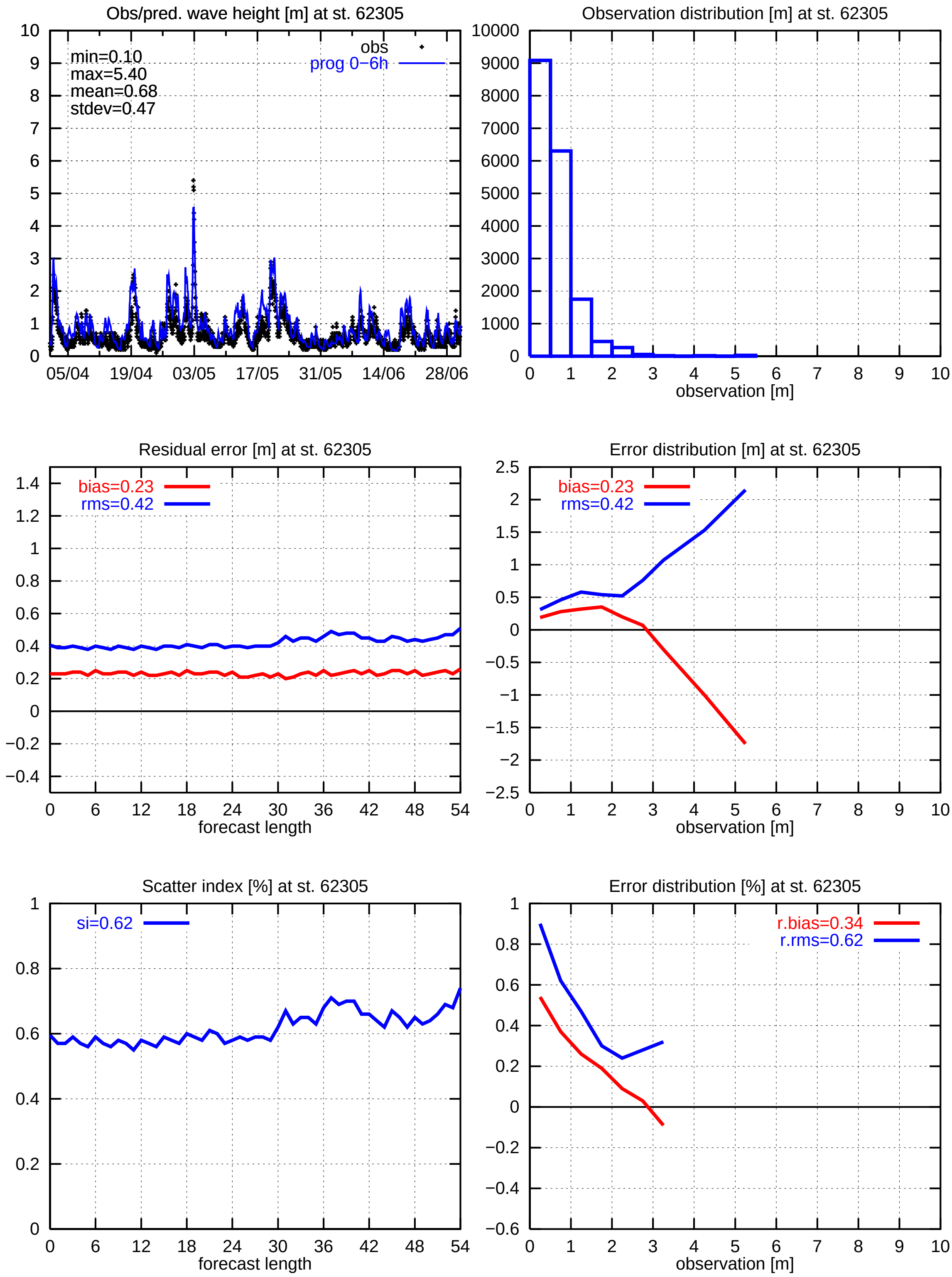

Figure 36. Significant wave height: 62305

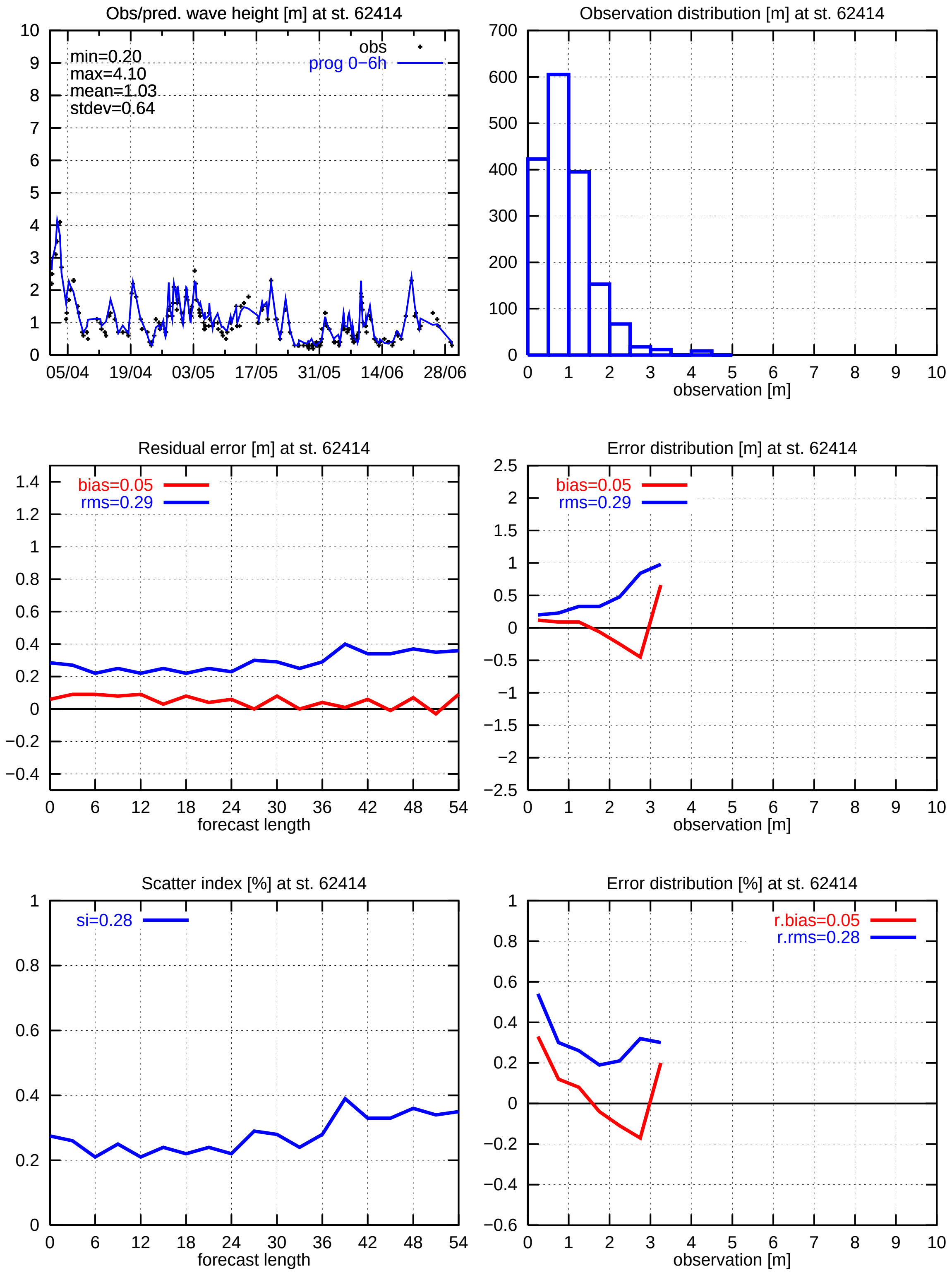

Figure 37. Significant wave height: 62414. The zig-zag curves are caused by irregular 3h sampling.

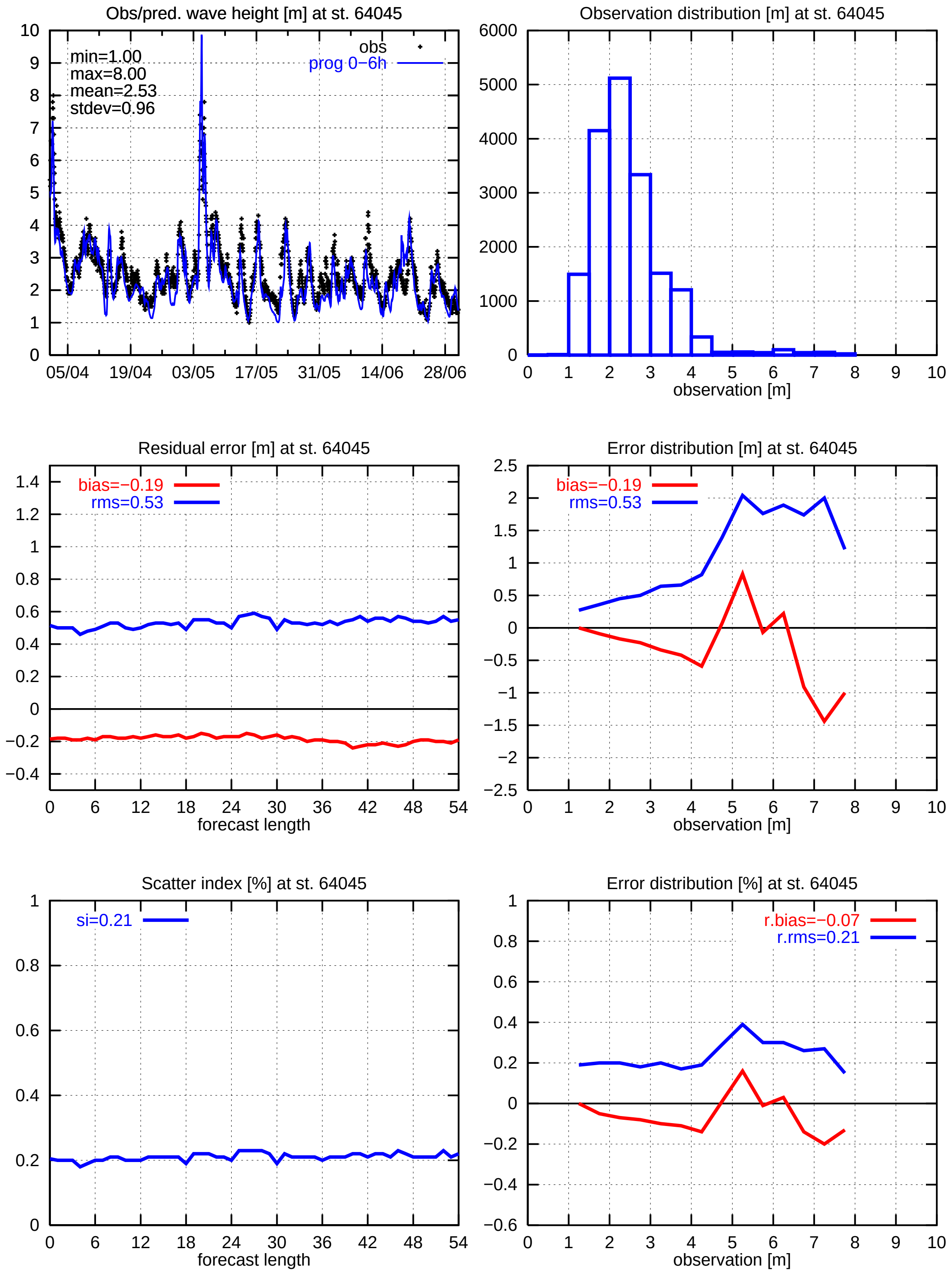

Figure 38. Significant wave height: 64045.

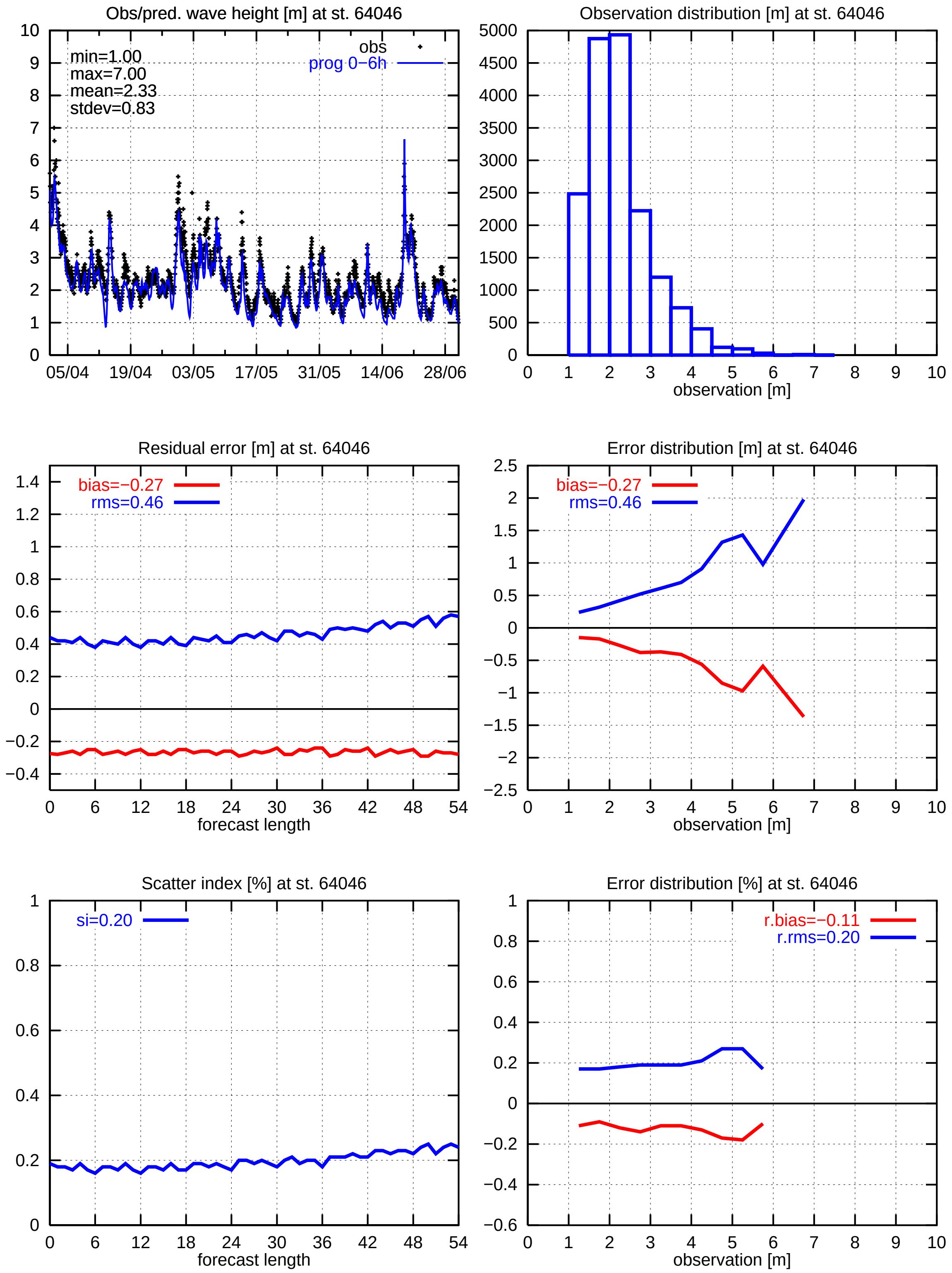

Figure 39. Significant wave height: 64046

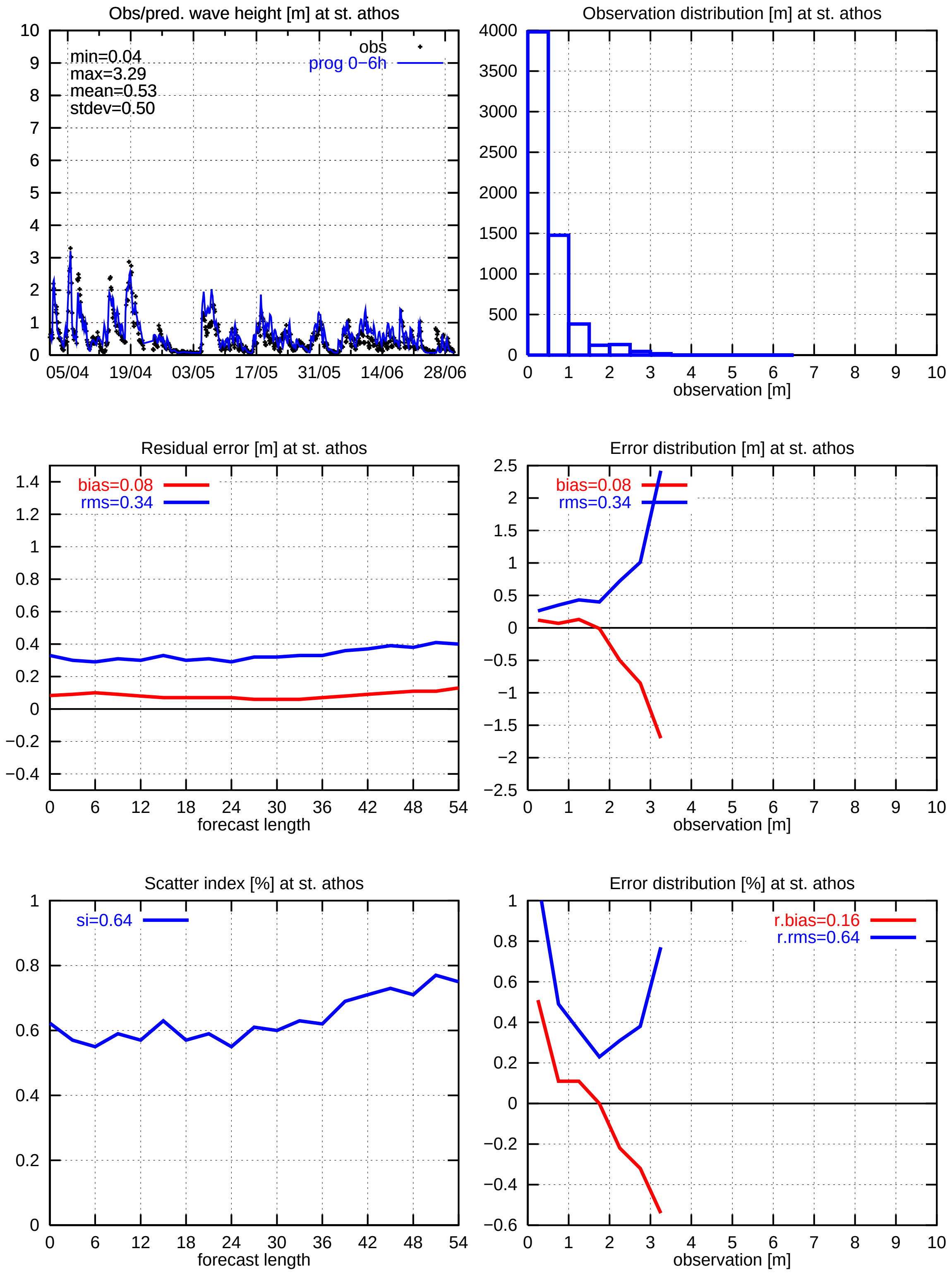

Figure 40. Significant wave height: Athos

7.5 Mean wave period

The following pages show mean wave period error statistics for each station. Only stations with reasonable statistics are included.

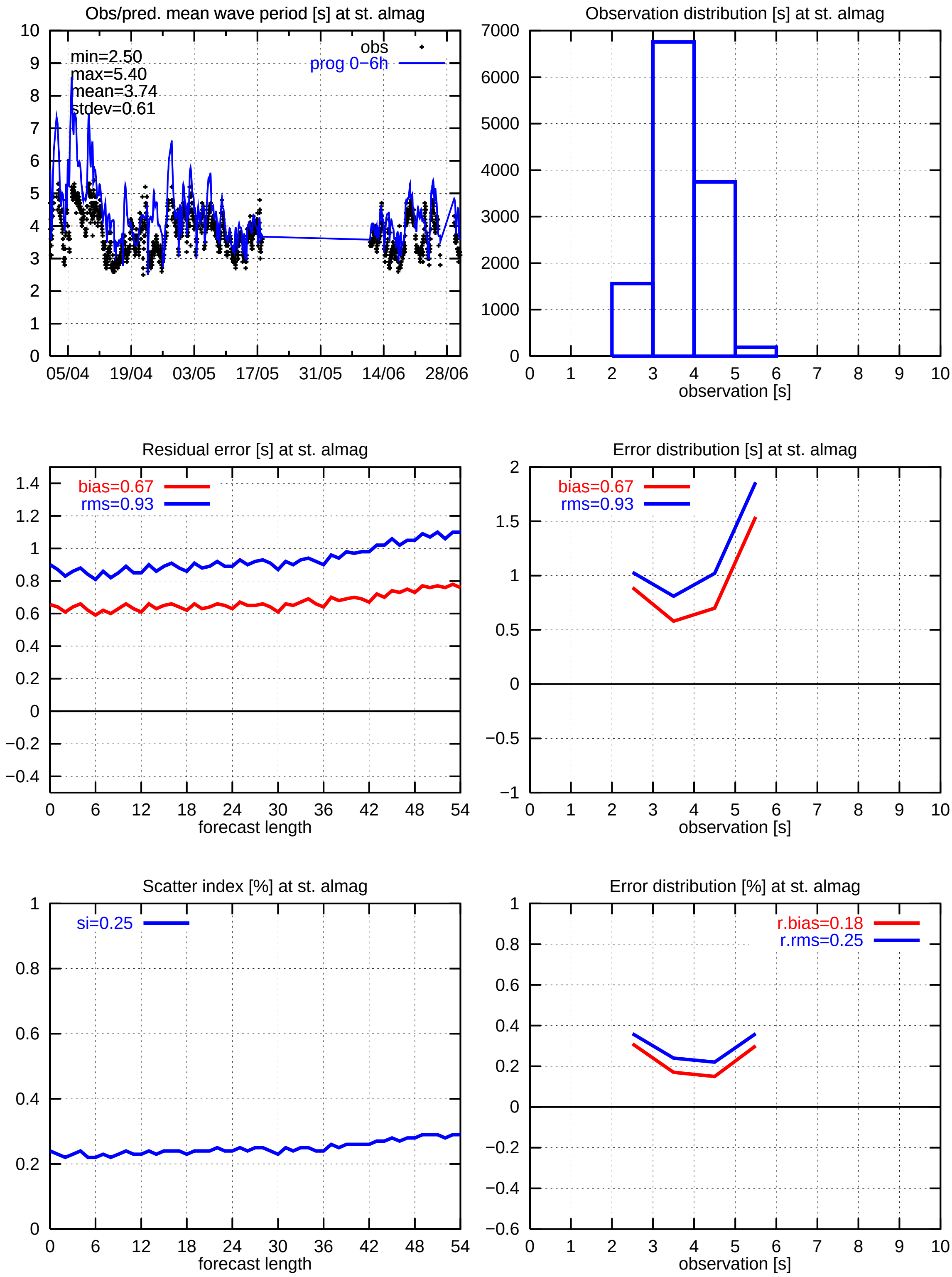

Figure 41. Mean wave period: Almagrundet

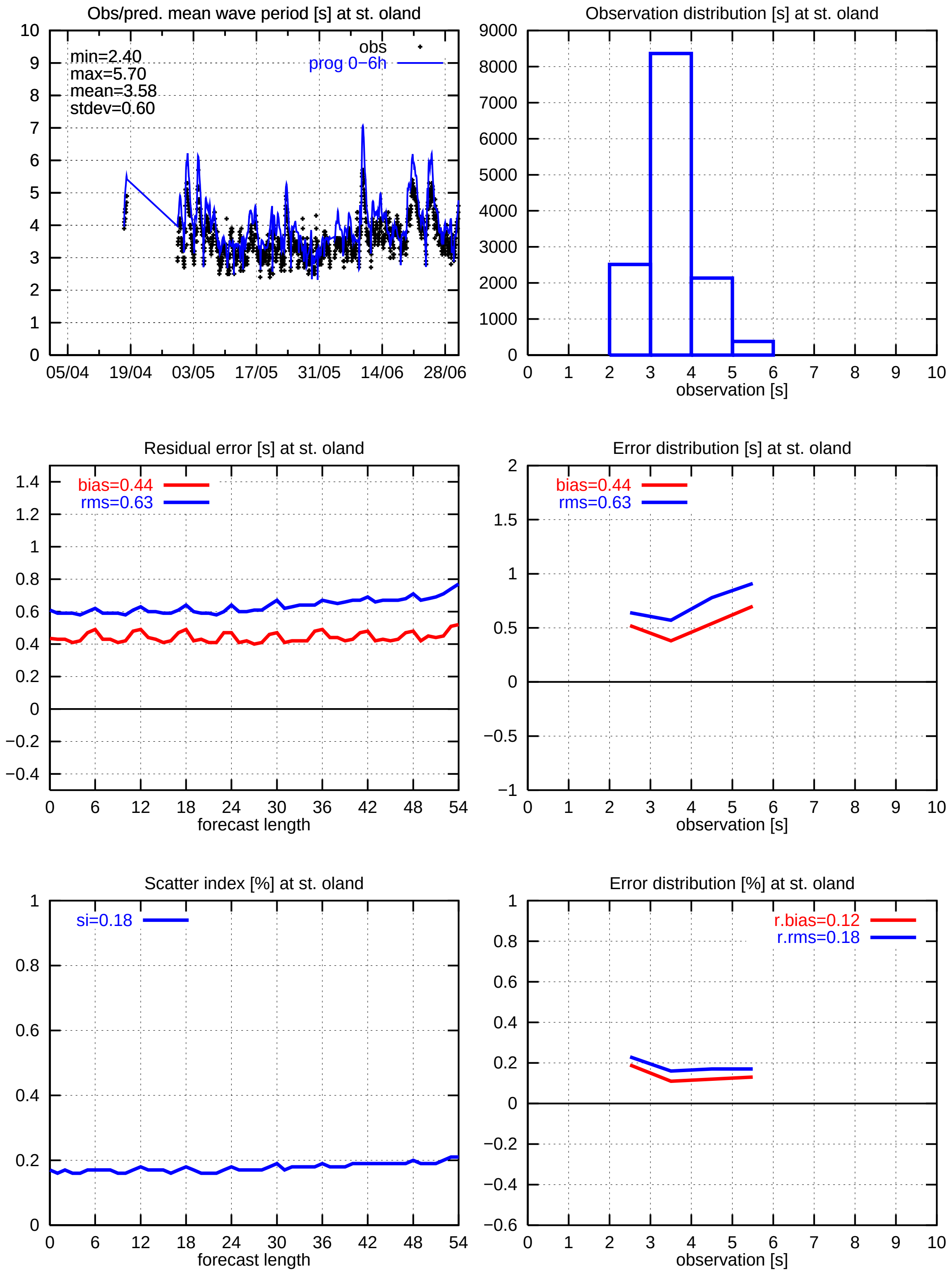

Figure 42. Mean wave period: Øland

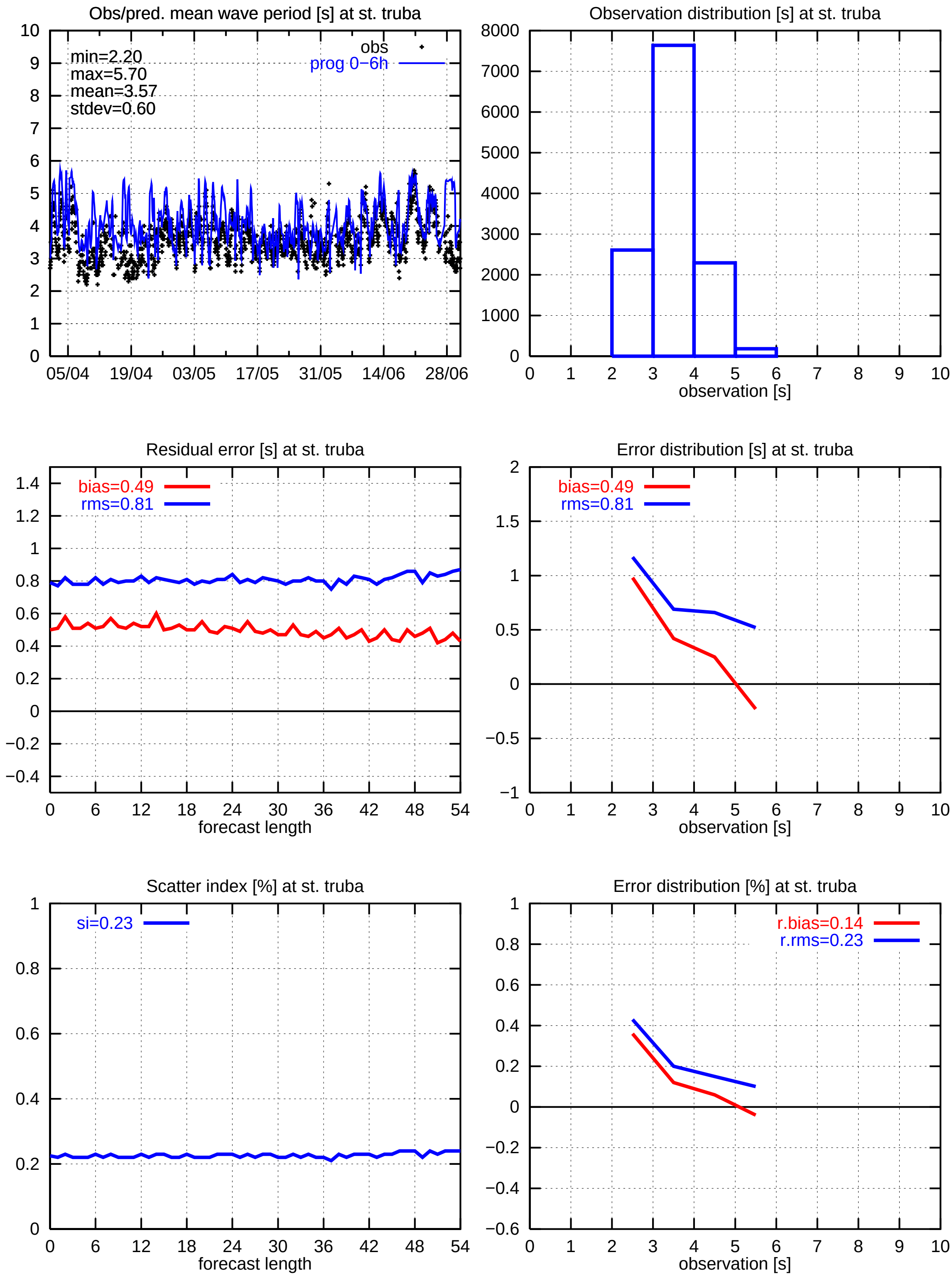

Figure 43. Mean wave period: Trubaduren

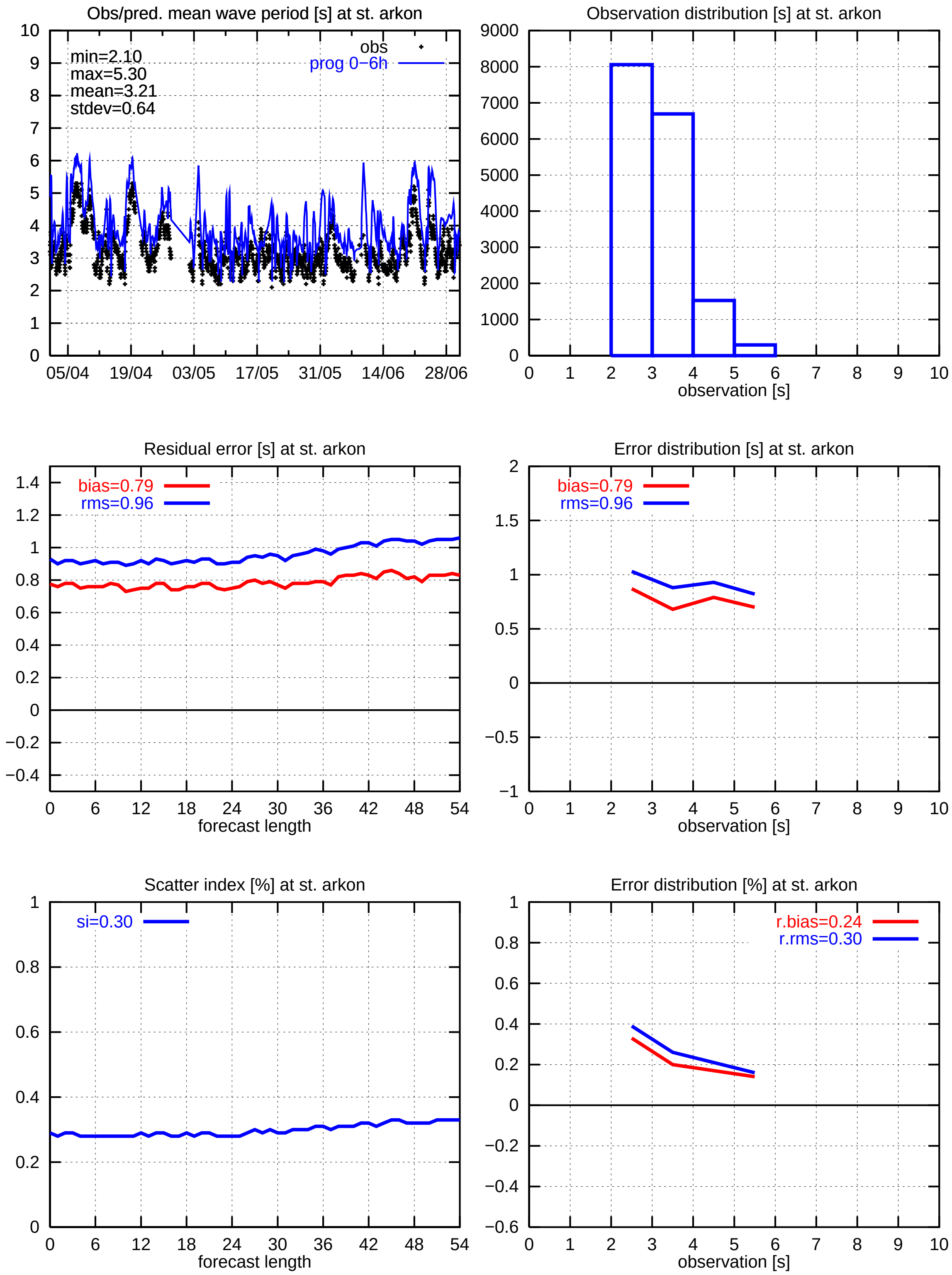

Figure 44. Mean wave period: Arkona

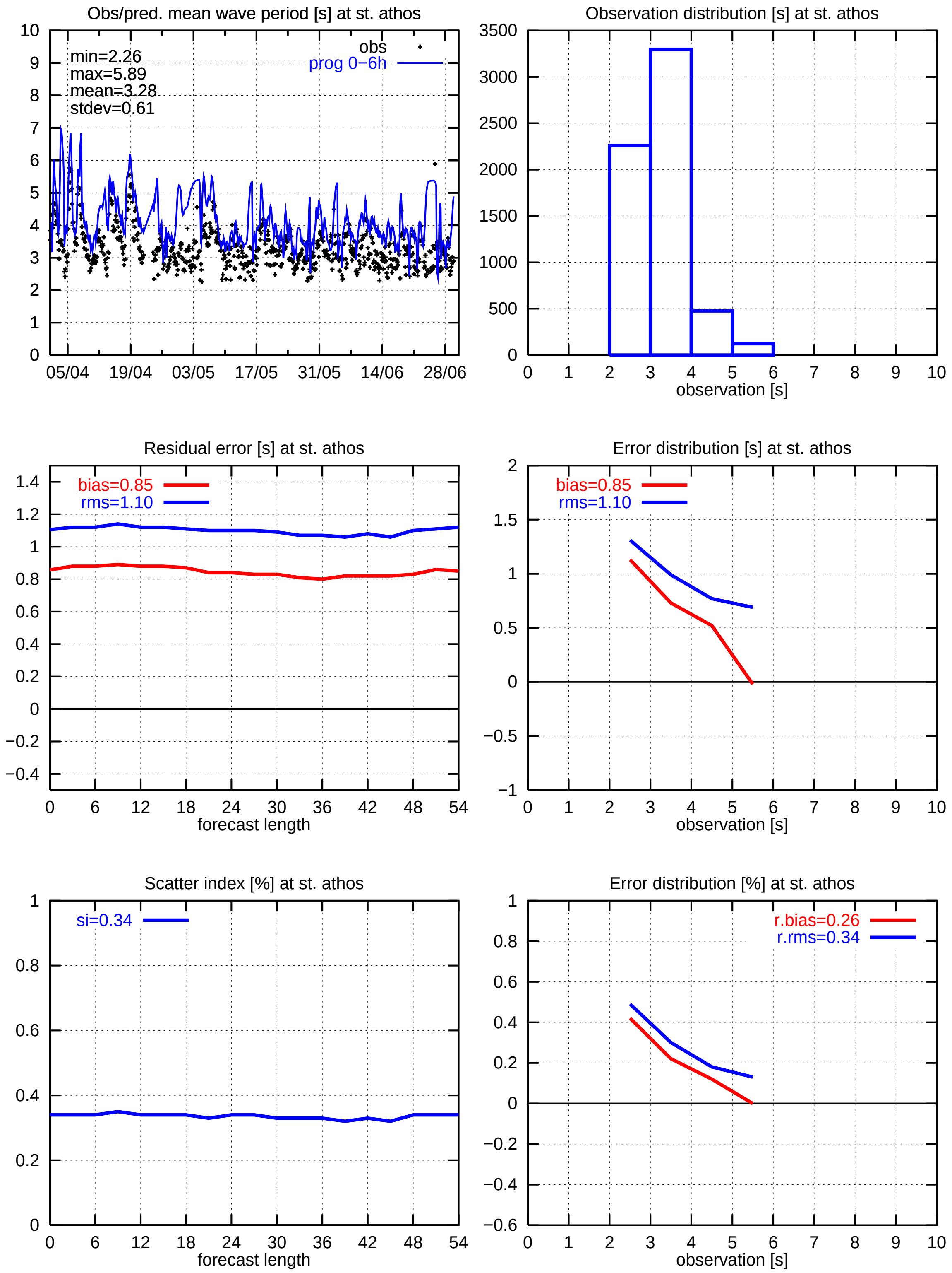

Figure 45. Mean wave period: Athos

7.6 Dominant wave period

The following pages show dominant wave period error statistics for each station. Only stations with reasonable statistics are included.

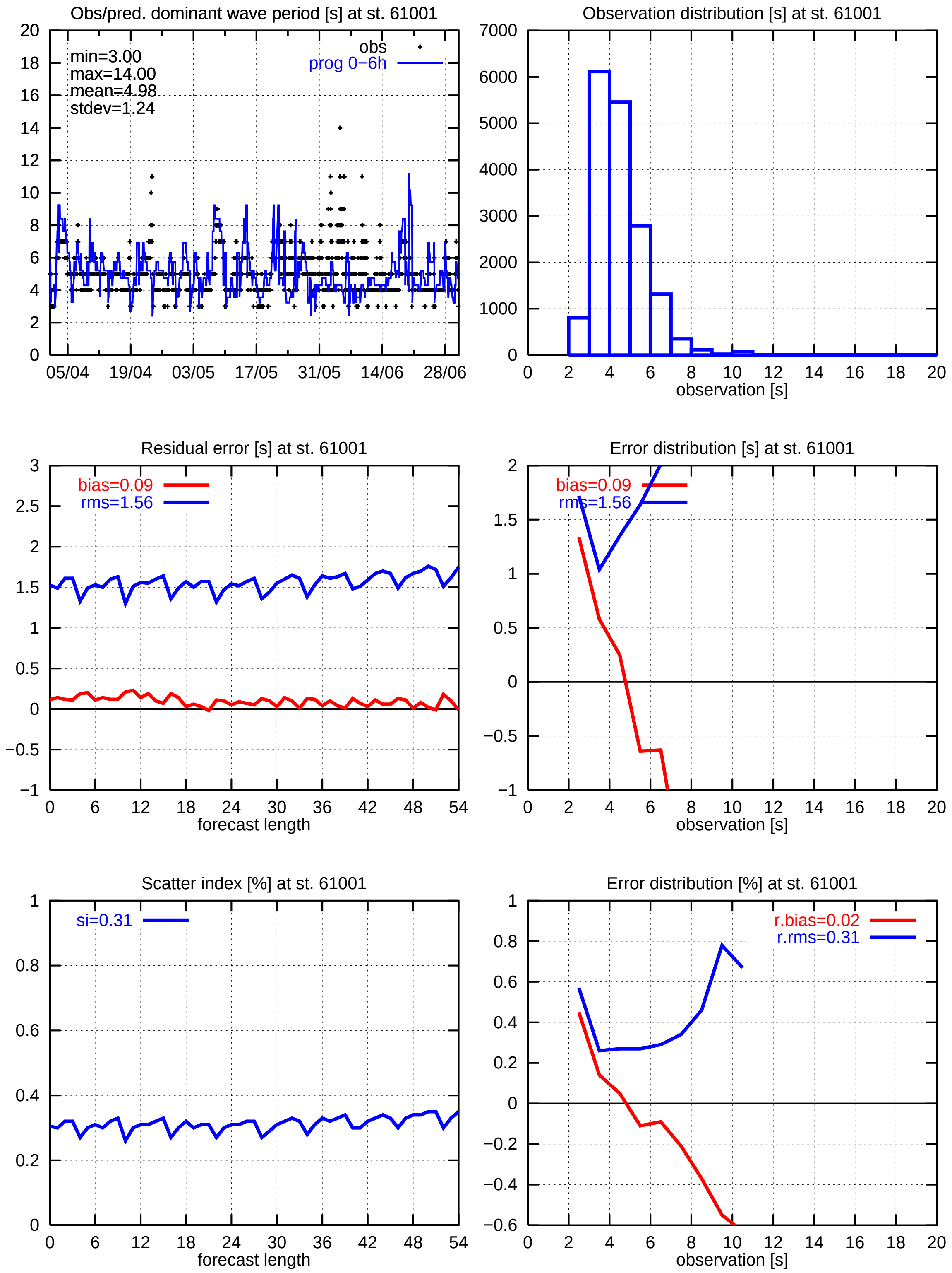

Figure 46. Dominant wave period: 61001

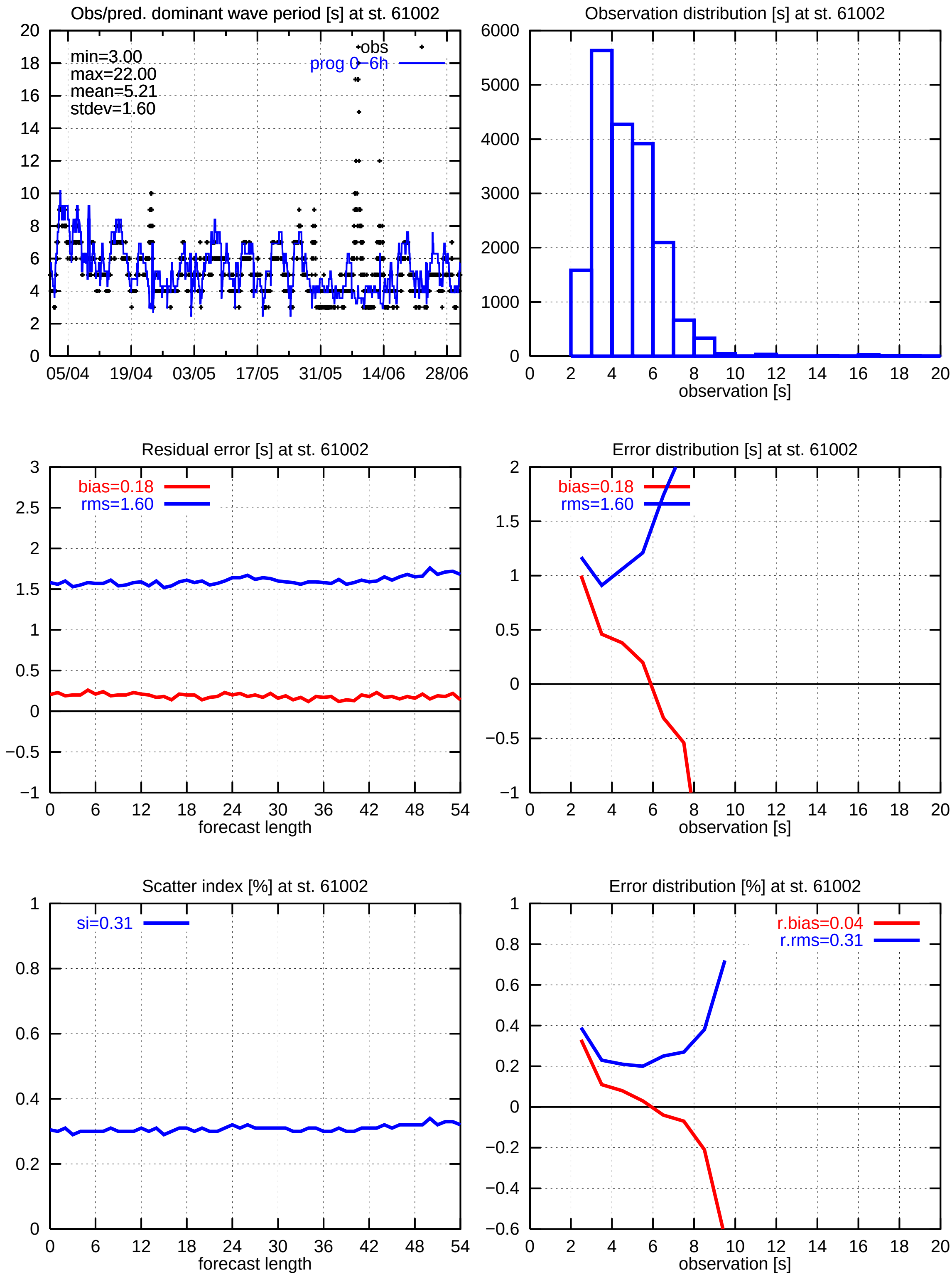

Figure 47. Dominant wave period: 61002

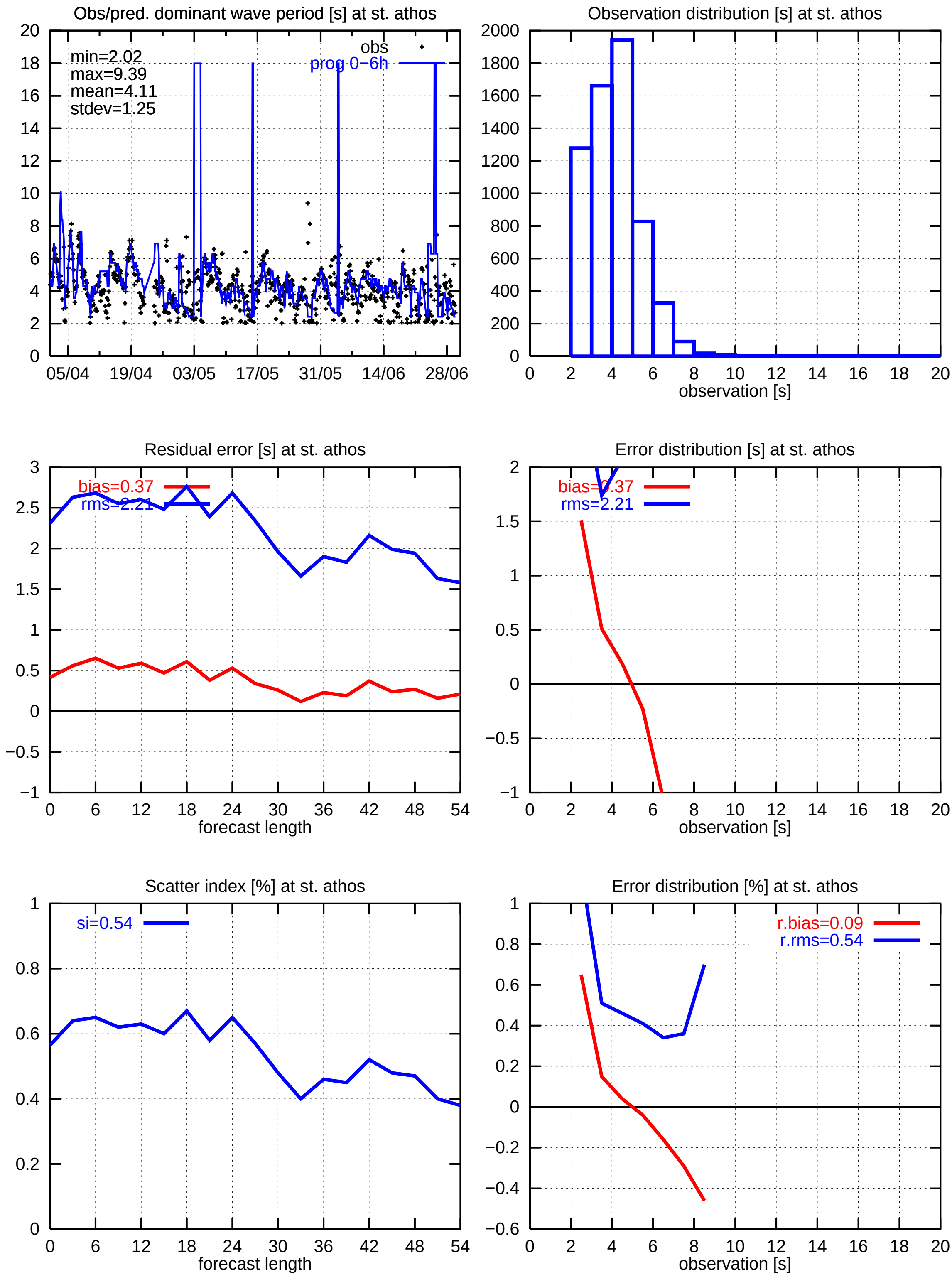

Figure 48. Dominant wave period: Athos

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List of Tables

List of Figures