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Verification of wave forecasts: DMI-WAM nov-dec 2001

Jacob Woge Nielsen
Jacob Berg Jørgensen
Jun She

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Jacob Woge Nielsen, Jacob Berg Jørgensen, Jun She
e-mails: jw@dmi.dk, jbj@dmi.dk, js@dmi.dk

The Danish Meteorological Institute, Copenhagen, Denmark

Contents

1 Introduction

We analyse the quality of wave forecasts produced by *DMI-WAM*: DMI's operational set-up of the 3rd generation wave model *WAM Cycle4*. The two-month study period spans November 1st-December 31st 2001. Wave observations are collected from a number of sources, and each station is analysed separately.

The significant wave height H_s is the primary parameter of interest, but other wave parameters (wave period, direction, swell parameters) are examined where the data material is adequate.

We calculate standard error measures both as a function of forecast range (1-48 hours) and of wave height. Grand averages are calculated as mean values over all stations, and over all ranges. Averages are also calculated for a number of separate geographical regions.

All model results are forecasts. This means that errors in the parameters do not necessarily imply errors of the model, but may reflect errors in the meteorological forcing data and initial conditions.

DMI has produced short-range operational wave forecasts since 1999. A pre-operational validation study was carried out in 1999 [5], and a combined wave-wind validation in 2000 [4] for a 14 month hindcast period. This report marks the beginning of routine monitoring of the wave forecast quality.

Ch. 2 briefly describes the DMI wave model set-up, ch. 3 gives an overview of the data material, and ch. 4 outlines the statistical error measures used to describe the forecast quality. Ch. 5 presents and discusses results for the two-month period (tables and plots). Ch. 6 concludes the work. Comprehensive results for each station are put into the Appendix. References (indicated by [ ]), and lists of figures/tables are found at the end of the report.

2 DMI-WAM

DMI has run an operational wave forecasting service for Danish waters since 1999, using the 3rd generation wave model *WAM Cycle4* forced by DMI's numerical weather prediction model *HIRLAM*. Since the first release, the geographical model domain has been widely expanded, to include a large part of the Northern Atlantic, and the Mediterranean. The 2001 model setup is described in detail below.

2.1 Physical model

WAM Cycle4 solves the spectral wave equation

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

where $F(f, \theta; \vec{x}, t)$ is spectral wave energy density, depending on wave frequency, wave direction, position and time; $c(f, \theta)$ is the 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; S_{bf} is interaction with the sea bed through friction and wave refraction. The present DMI-WAM still lacks current data (S_{cu}=0) and information about sea ice.

A comprehensive description of WAM Cycle4 may be found in [3],[1].

2.2 Model setup

DMI provides wave forecasts in three geographical domains as shown below:

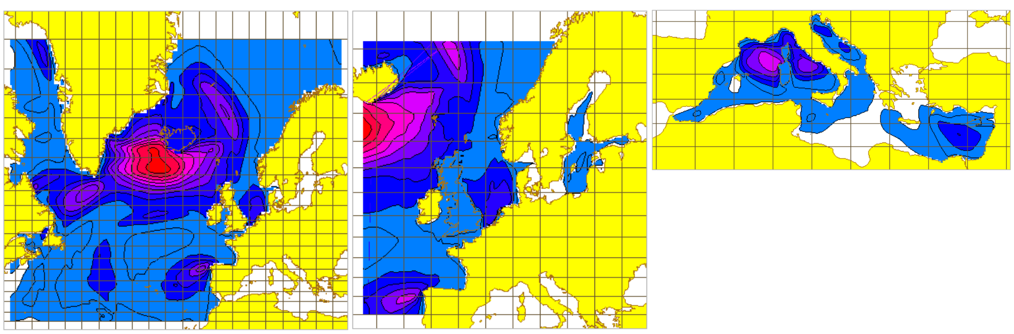

Figure 1. DMI wave models. North Atlantic, North Sea-Baltic, and Mediterranean model

The model open boundaries are chosen as follows. The coarse grid North Atlantic model uses the JONSWAP wind-sea spectrum (see [2],[1]). The fine grid North Sea - Baltic model is nested into the North Atlantic model, and uses spatially interpolated wave spectra calculated by that model. The Mediterranean is treated as a closed basin, assuming no wave energy exchange with the Atlantic or the Black Sea. Please refer to Table 1 for a model setup summary.

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

Model	North Atlantic	North Sea - Baltic	Mediterranean
Space res.	30’ by 30’	10’ by 10’	10’ by 10’
Time step	4 min	4 min	2 min
Frequencies	25	25	25
Direction res.	15^o	15^o	15^o
Forcing model(s)	Hirlam G	Hirlam E	Hirlam E+G
- resolution of	0.45^o	0.15^o	$0.15^o/0.45^o$
Longitudes	69^oW-30^oE	20^oW-30^oE	6^oW-46^oE
Latitudes	30^oN-75^oN	36^oN-68^oN	30.5^oN-46^oN
Open boundaries	JONSWAP	Nested	Closed basin
Forecast range	1-54 h	1-54 h	1-54 h
Output time step	1 h	1 h	1 h
Schedule	4x daily	4x daily	4x daily

Table 1. DMI-WAM set-up. The forecast range was increased from 48h to 54h during the study period.

2.3 Weather models

The forcing models are the DMI limited area numerical weather prediction models Hirlam-E and Hirlam-G. Both are currently being used in the DMI weather forecasting service. The G model has larger area coverage than the E model, but in return has lower spatial resolution (50km vs. 16km). The forcing field consists of the wind vector at 10m height, interpolated linearly in time and space to match the wave model grids.

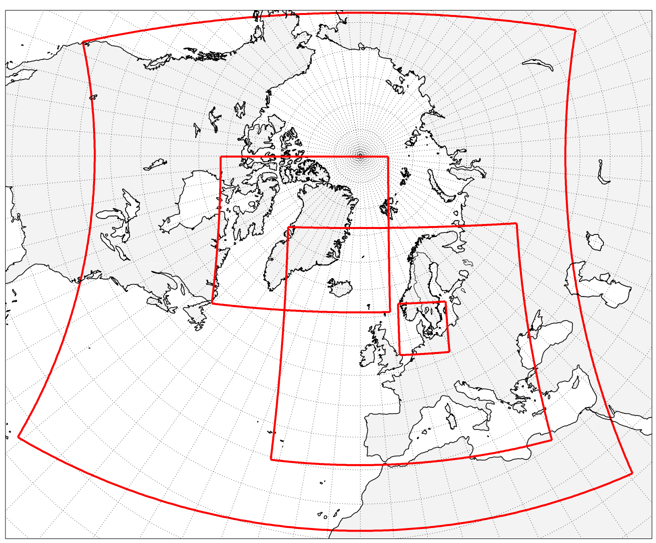

Figure 2. DMI Hirlam. The outermost box is the G model, the box covering most of Europe is the E model.

3 Wave data

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

3.1 Forecasts

Wave parameters output from DMI-WAM are shown in Table 2.

	DMI-WAM output
H_s	Significant wave height
H_{sw}	Height of swell
T_{02}	Mean wave period
T_p	Dominant wave period
T_{sw}	Swell mean period
θ_w	Mean wave direction
θ_{sw}	Swell direction

Table 2. DMI-WAM wave parameters

The forecasts are stored as hourly maps in model resolution. Time series for each station, analysis, and parameter, are extracted using the closest model grid point. A total of 244 forecasts were produced during the two-month study period. The forecast data coverage is almost 100%.

A note on the accuracy of the dominant wave period T_p. While other wave parameters are obtained by integrating the wave energy spectrum, T_p is just the discretized model frequency (inverse) containing the highest energy. T_p can only take one of 25 distinct values. In cases with two competing wave energy maxima (wind sea and swell), T_p may flip between the two, as first one, then the other has the highest energy. This means that T_p is not a smooth function of time or space.

3.2 Observations

Wave data is obtained from a number of sources, as indicated in table 3. Table 4 shows the number of stations for each wave parameter, and for each of 8 geographical domains, plus the overall data coverage. SMHI, KDI and NCMR data is kindly provided by each agency in question. NDBC data is retrieved via the GTS. Station numbers and positions are shown on the maps below. Only stations that record regularly were considered suitable for verification; this resulted in a total of 28 stations. The full station list and time series plots are found in the Appendix.

	Wave Data providers
NDBC	National Data Buoy Center (UK)
SMHI	Swedish Meteorological Institute
KDI	Danish Coastal Authorities
NCMR	National Center for Marine Research (Greece)

Table 3. Wave data providers.

The normal sampling rate is 1 hour, with an overall H_s data coverage of 72%. At Danish West Coast and Mediterranean stations the sampling rate is 3 hours, leading to app. two-thirds missing data. Considering 3 hour sampling as 100% coverage at these stations, the H_s data coverage is 84%. Figure 4 shows the 1 hour H_s data coverage at all stations.

A very few stations report maximum wave height H_{max} or mean wave direction θ_w. These are not verified in the present report.

The measuring accuracy varies from station to station, as may be seen from the station plots in the Appendix. A few buoys use 0.5m wave height accuracy, most 0.1m or 0.01m. T_{02} is recorded with 0.01s accuracy, while T_p accuracy is 1s at most stations. Statistics on the observed wave parameters are shown in the appendix.

Parameter	H_s	T_{02}	T_p	θ_w	H_{sw}	T_{sw}	θ_{sw}	H_{max}
Atlantic	8	-	8	-	-	-	-	-
Br. Channel	4	-	1	-	-	-	-	-
Irish Sea	2	-	4	-	-	-	-	-
Scotland	1	-	2	-	-	-	-	-
North Sea	5	-	4	-	-	-	-	-
Danish West Coast	4	4	4	-	-	-	-	-
Baltic Sea	3	3	-	-	-	-	-	3
Mediterranean	1	1	1	1	-	-	-	-
Total	28	8	24	1	-	-	-	3
Coverage	84%	96%	87%	-	-	-	-	-

Table 4. Number of wave stations in each domain, and for each wave parameter.

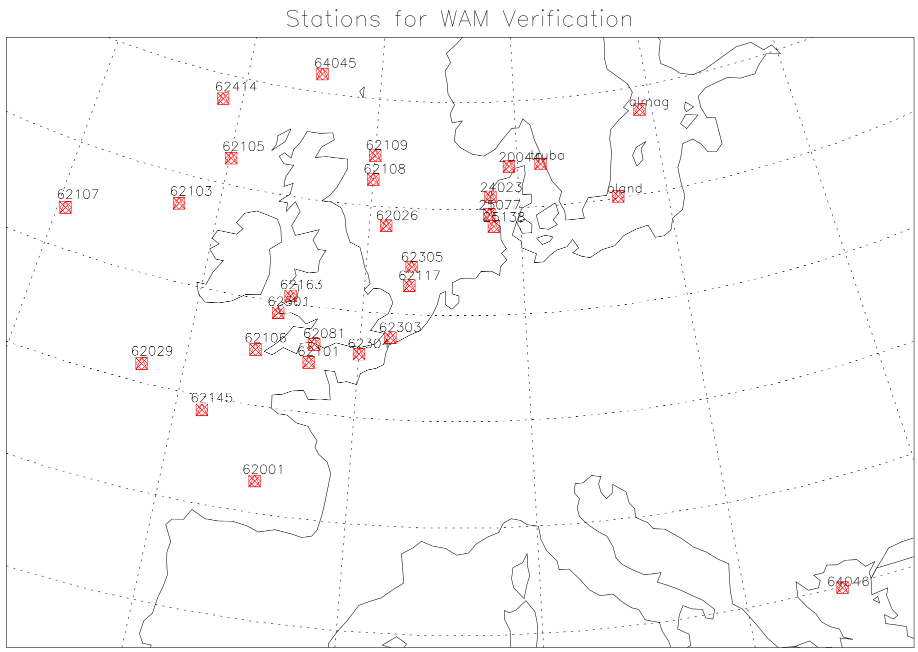

Figure 3. Wave recorder locations.

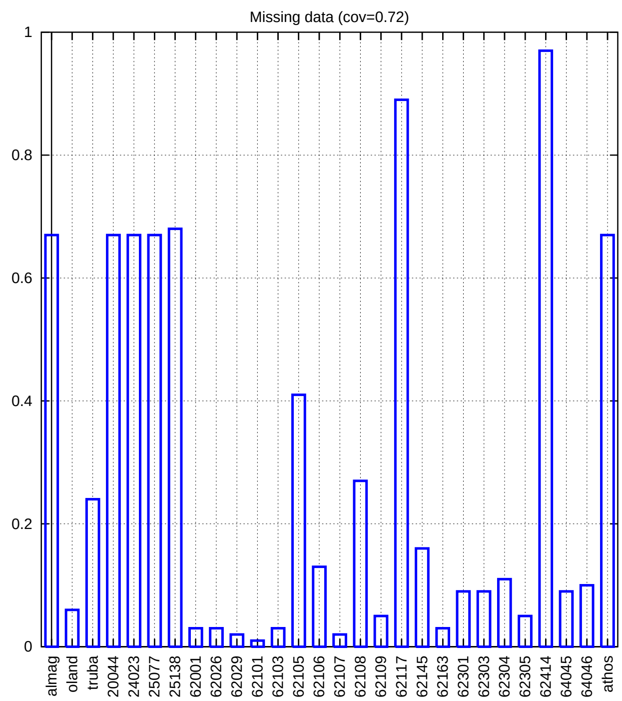

Figure 4. Missing data. Significant wave height. Stations 20044, 24023, 25077, 25138 and athos only sample every 3rd hour.

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 residual matrix reads (brackets indicate a dependency)

$residual(station, analysis, range)$

with the number of stations depending on the parameter in question (see Table 4), analysis every 6 hours, and forecasts ranging from 1-48 hours in 1 hour steps. By averaging the residual over all analyses, we get the model bias or mean error:

$bias(station, range)$

Further linear 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 using the residual squared. The range- and station-dependency ($rms1, rms2$), and the grand average (RMS), is calculated in the same way as for the bias values.

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.

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

It should be noted that the very high wave bin are sparsely populated. Averaging over all stations gives the full model error dependency on wave height, calculated both as an absolute value and as a relative error in %.
The scatter index si 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. This only makes sense for positive definite variables.

$si = \frac{rms}{<obs>}$

Correlation coefficients are *cc* calculated using forecast pseudo time series, established by concatenating all 1-6 hour forecasts, then all 7-12 hour forecasts and so on. This gives coefficients valid for each of the 6 hour ranges blocks 1-6, 7-12, .. , 43-48 hours:

$cc(station, block)$

As before, range- and station-dependent values ($cc1, cc2$), and a grand average (CC), are calculated.

5 Results

This section describes the nov-dec 2001 wave verification results for significant wave height, mean wave period, and dominant wave period. Swell and directional parameters are not observed at any fixed location (with one exception) and maximum wave height is not calculated by the wave model.

Below, we discuss grand averages and regional averages. Detailed results for each station are found in the Appendix the end of the report.

5.1 Significant wave height

Table 5 shows bias and relative bias, rms error, scatter index and correlation coefficient, averaged over the full forecast range. The total number of data points used to produce the statistics is 327936. The error estimates are sorted out on 8 geographical regions.

Parameter Region	#st	bias cm	rms cm	si %	cc %	bias %
Atlantic	8	-20	57	18	91	-6
Scotland	1	-49	76	18	93	-12
Br. Channel	4	30	52	52	86	29
Irish Sea	2	-4	36	26	92	-4
North Sea	5	1	52	23	92	0
Danish West Coast	4	11	42	28	89	6
Baltic Sea	3	17	53	49	83	16
Meditter.	1	-14	50	32	92	-9
All Waters	28	0	52	30	90	4

Table 5. Significant wave height results

The wave model has zero or insignificant bias on average and an rms error of 0.52 m. Scatter index is low (0.30) and correlation coefficient high (0.90 for the 1-6 hour range, see Fig. 5). There is a large regional spread. Waves are underestimated on average in the Atlantic, in particular at the station north of the Shetland Isles, and at the station in the Aegean Sea. Conversely, waves are overestimated in the British Channel, in the Baltic and at the Danish West Coast. The scatter index is well below an acceptance level of 0.4 in most regions, with the Baltic and the British Channel as exceptions (Fig 5).

The error dependency on forecast range and on wave height is shown in Fig. 6 for the full model system.

The model bias does not depend on forecast range, while the rms error increases slowly, from 0.45m at short range to 0.60m at 48h range. The rms error is significant already at analysis time since the model is initialised without any use of the observed sea state.

There is a strong dependency on wave height. Small waves (below 2m) are overestimated, while high waves (in excess of 3m) are underestimated. This negative bias, and the rms error, both increase with increasing wave height. Very small waves (below 0.5m) are overestimated by about 75%, and since most of the waves are small, this leads to the rather misleading result of no average wave bias.

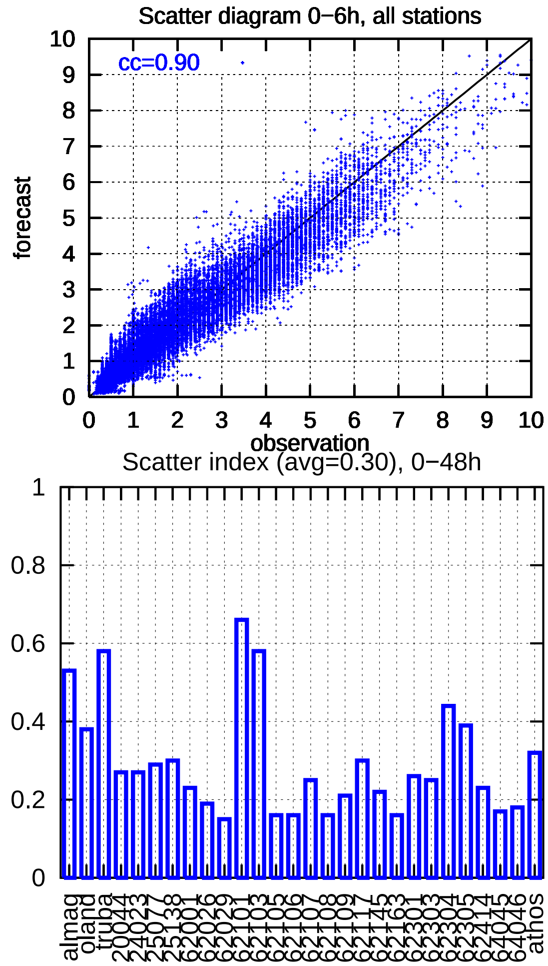

Figure 5. Upper panel: short range (1-6h) scatter diagram, lower panel: scatter index

Results for each single station is shown in the Appendix. Please refer to Table 8 and Fig. 3 for station numbers and locations.

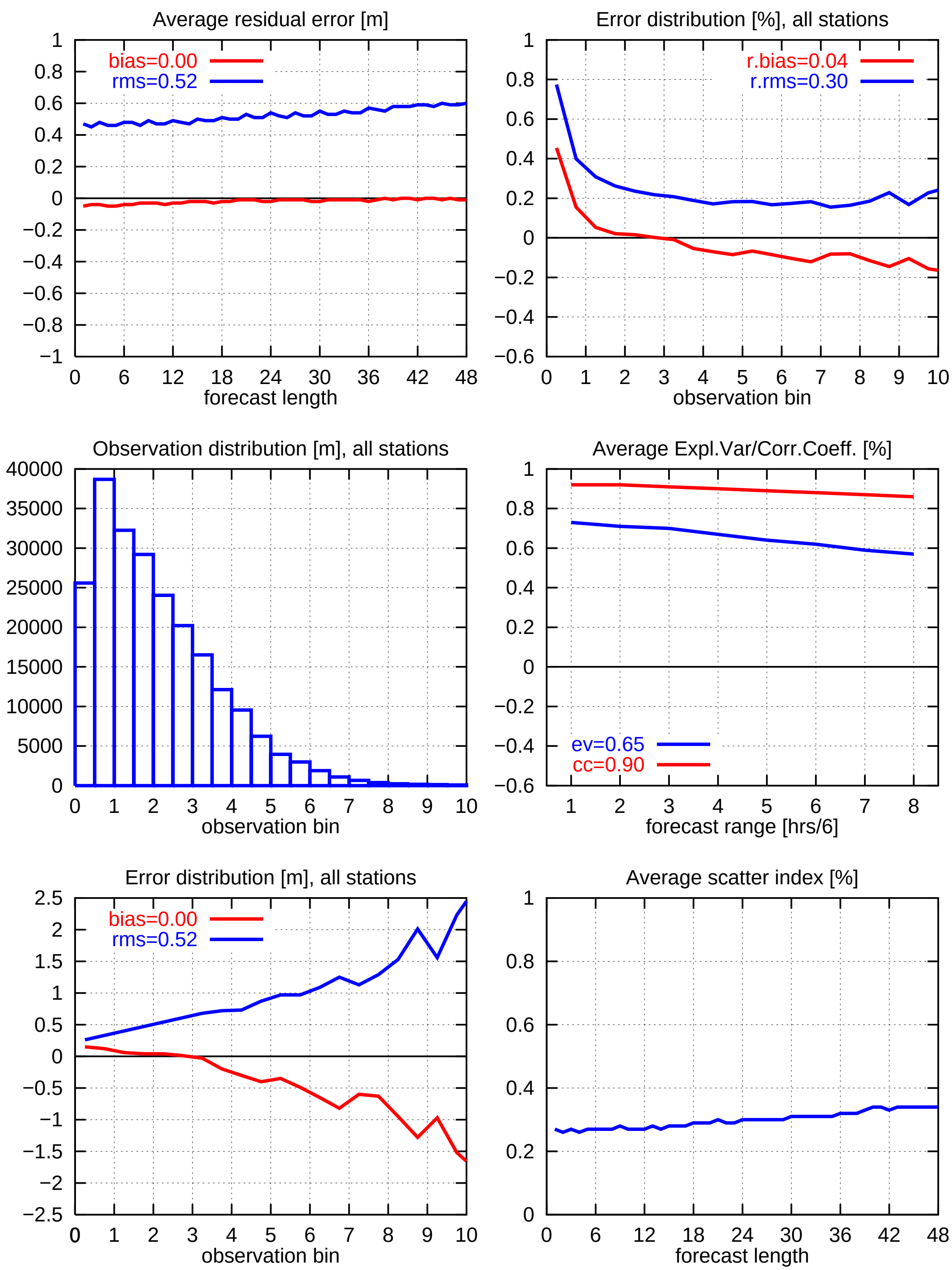

Figure 6. All stations: significant wave height

5.2 Mean wave period

The mean wave period T_{02} is only measured at 8 stations. Grand averages are shown in Table 6, and a short-range scatter diagram in Fig. 7.

Parameter Region	#st	bias sec.	rms sec.	si %	cc %	bias %
Danish West Coast	4	2.08	2.33	51	66	46
Baltic Sea	3	0.65	0.98	24	72	16
Meditter.	1	0.65	0.95	22	84	15
All Waters	8	1.37	1.65	37	70	31

Table 6. Mean wave period results

At the Danish West Coast stations T_{02} is grossly overestimated. The reason for this is yet unresolved. At the stations in the Baltic and the Mediterranean T_{02} is slightly overestimated, with a positive bias of 0.65s or 15%. The scatter index is well below the acceptancy level of 0.4. Data sheets for these stations are presented in the Appendix.

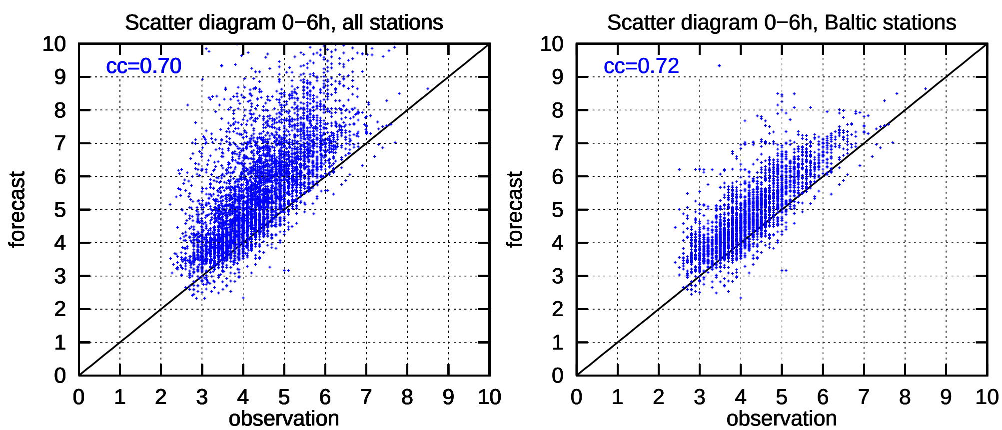

Figure 7. Mean wave period, 1-6h range. Left panel: all stations, right panel: Baltic stations

5.3 Dominant wave period

The dominant (or *peak*) wave period T_p is recorded at the 20 NDBC stations. Grand averages are shown in Table 7, short-range scatter diagrams in Fig. 8.
T_p shows very bad verification results for a number of reasons:

- a low recording accuracy of 1 sec
- a corresponding low forecast accuracy
- time series that flick between a high and a low period peak

The latter reason is the worst. Even when the wave spectrum is rather well predicted, we may get a very large T_p error in situations with a two-peaked spectrum (swell and wind sea).

Parameter Region	#st	bias sec.	rms sec.	si %	cc %	bias %
Atlantic	8	2.74	3.37	43	60	35
Scotland	1	2.89	3.22	39	68	35
Br. Channel	4	0.25	2.67	48	42	11
Irish Sea	2	2.45	3.97	78	28	49
North Sea	4	2.87	3.81	65	39	49
Danish West Coast	4	0.90	3.11	44	34	13
Meditter.	1	-0.25	1.20	21	75	-4
All Waters	24	1.90	3.24	50	47	29

Table 7. Dominant wave period results

Only the single Aegean Sea station in the Mediterranean has a good score, with a small negative bias of -0.25s (-4%) and a scatter index of 0.21. This station is the only one where swell is most often not present, as Baltic stations do not record T_p.

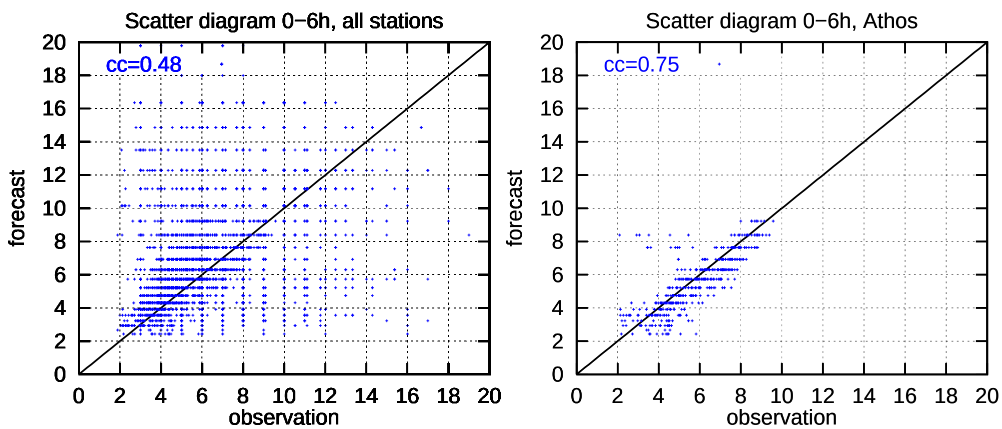

Figure 8. Dominant wave period, 1-6h range. Left panel: all stations, right panel: Athos

6 Conclusion

DMI wave forecasts from nov-dec 2001 are verified, using wave data from 28 buoys.

Main conclusions are:

- The significant wave height H_s gives reasonable results
- Other wave parameters are either not recorded or have some data problem
- The forecast quality decreases slowly with increasing forecast range
- There is a large regional spread in forecast quality
- There is a strong error dependency on wave height

The *significant wave height* is recorded at all stations. The error distribution is examined in terms of forecast range, as a function of observed wave height, and for separate geographical regions.

The bias is zero on average. There is a large geographical spread, and a strong dependency on wave height. Low waves (below 3m) are overpredicted, while high waves (in excess of 3m) are underpredicted. The relative error increases with wave height; waves of 10m height have an average negative bias of 17%.

The average rms error is 0.52m, increasing slowly with forecast range. There is a large regional spread. High waves ($>$3m) have a rather constant relative rms error of roughly 20%.

An average scatter index SI=0.30 is acceptable, with just a few stations having si$>$0.4 (sometimes used as an acceptance level) due to low recording accuracy. The average correlation coefficient CC=0.90.

Two types of wave period are recorded; the mean wave period and the dominant (peak) wave period. *Dominant wave period* predictions are not good. This is 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. Only the Meditteranean station shows good results, with a bias of -0.25s and a scatter index of 0.21.

The *mean wave period* is recorded at 8 locations, half of which have a data interpretation problem. At the remaining 4 stations the model overestimates the mean wave period by 0.65s or 15% on average, with a scatter index of 0.24 and a correlation coefficient of 0.75.

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

Only a single station records wave direction; this is not verified.

Future reports are planned on a three-monthly basis.

7 Appendix

This Appendix contains a 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), arranged sequentially according to the station table.

7.1 Station table

Station ID	Agency	Region	lat.	lon.	parameters
almag	SMHI	Baltic	59.15N	19.13E	H_s, H_{max}, T_{02}
oland	SMHI	Baltic	56.07N	16.68E	H_s, H_{max}, T_{02}
truba	SMHI	Baltic	57.60N	11.63E	H_s, H_{max}, T_{02}
20044	KDI	D. West Coast	57.58N	9.41E	H_s, T_{02}, T_p
24023	KDI	D. West Coast	56.47N	8.06E	H_s, T_{02}, T_p
25077	KDI	D. West Coast	55.81N	7.94E	H_s, T_{02}, T_p
25138	KDI	D. West Coast	55.35N	8.23E	H_s, T_{02}, T_p
62001	NDBC	Atlantic	45.20N	5.00W	H_s, T_p
62026	NDBC	North Sea	55.30N	1.10E	H_s, T_p
62029	NDBC	Atlantic	48.70N	12.40W	H_s, T_p
62101	NDBC	B.Channel	50.60N	2.70W	H_s, T_p
62103	NDBC	B.Channel	49.90N	2.90W	H_s, T_p
62105	NDBC	Atlantic	54.90N	12.60W	H_s, T_p
62106	NDBC	Atlantic	57.00N	9.90W	H_s, T_p
62107	NDBC	Atlantic	50.10N	6.10W	H_s, T_p
62108	NDBC	Atlantic	53.50N	19.50W	H_s, T_p
62109	NDBC	North Sea	57.00N	0.00	H_s, T_p
62117	NDBC	North Sea	57.90N	0.00	H_s, T_p
62145	NDBC	North Sea	53.10N	2.80E	H_s, T_p
62163	NDBC	Atlantic	47.50N	8.50W	H_s, T_p
62301	NDBC	Irish Sea	52.30N	4.50W	H_s, T_p
62303	NDBC	Irish Sea	51.60N	5.10W	H_s, T_p
62304	NDBC	B.Channel	51.10N	1.80E	H_s, T_p
62305	NDBC	B.Channel	50.40N	0.00	H_s, T_p
62414	NDBC	North Sea	53.80N	2.90E	H_s
64045	NDBC	Atlantic	59.10N	11.40W	H_s, T_p
64046	NDBC	Scotland	60.70N	4.50W	H_s, T_p
athos	NCMR	Mediterr.	39.96N	24.72E	$H_s, T_{02}, T_p, \theta_w$

Table 8. Wave stations. Station name/number, driving agency, position, and wave parameters. SMHI=Swedish Meteorological Institute, NDBC=National Data Buoy Center (UK), NCMR=National Center for MArine Research (Greece), KDI=Coastal Authorities (Denmark). H_s=significant wave height, H_{max}=maximum wave height, T_{02}=mean wave period, T_p=peak or dominant wave period, θ_w=mean wave direction.

7.2 Observed wave statistics

Station	mean	stdev	min	max
almag	1.09	0.94	0.21	5.44
oland	1.32	0.67	0.19	5.13
truba	0.90	0.62	0.13	4.12
20044	1.52	0.84	0.19	4.18
24023	1.69	0.84	0.32	4.39
25077	1.66	0.86	0.25	5.09
25138	1.20	0.75	0.18	3.59
62001	2.61	1.04	0.80	6.90
62026	2.32	1.29	0.50	7.30
62029	3.05	1.08	1.10	6.90
62101	0.84	0.50	0.00	3.50
62103	1.24	0.60	0.30	3.40
62105	3.70	1.39	1.30	9.40
62106	3.79	1.57	0.90	10.90
62107	2.06	0.97	0.70	6.40
62108	3.77	1.27	1.60	9.30
62109	2.57	1.32	0.10	6.90
62117	2.39	1.20	0.40	5.30
62145	1.76	1.06	0.30	6.10
62163	2.75	1.01	1.00	6.70
62301	1.20	0.74	0.00	4.00
62303	1.58	0.98	0.20	6.30
62304	0.86	0.57	0.20	3.70
62305	1.09	0.79	0.10	4.60
62414	2.16	0.98	0.60	4.00
64045	4.10	1.61	1.10	12.30
64046	4.18	1.63	1.10	10.70
athos	1.59	1.18	0.11	5.56

Table 9. Observed wave height

Station	mean	stdev	min	max
almag	3.93	0.74	2.70	6.10
oland	4.61	0.90	2.60	8.50
truba	3.91	0.75	2.40	7.00
20044	4.37	0.83	2.47	6.56
24023	5.01	0.86	2.84	7.69
25077	4.82	0.89	2.61	7.69
25138	4.10	0.91	2.22	6.90
athos	4.32	1.09	2.47	7.28

Table 10. Observed mean wave period

Station	mean	stdev	min	max
oland	4.61	0.90	2.60	8.50
20044	6.64	2.30	2.27	15.38
24023	8.49	2.56	2.78	16.67
25077	7.81	2.40	2.78	15.38
25138	6.19	2.28	1.89	13.33
62001	7.23	1.48	5.00	12.00
62026	6.20	1.34	3.00	10.00
62029	7.51	1.17	5.00	13.00
62101	3.96	0.89	2.00	7.00
62103	7.75	1.64	5.00	18.00
62105	8.09	1.24	6.00	12.00
62106	7.99	1.25	4.00	13.00
62107	8.72	1.44	6.00	14.00
62108	8.01	1.04	6.00	12.00
62109	6.58	1.34	4.00	16.00
62117	5.81	1.23	3.00	9.00
62145	4.93	1.02	3.00	7.00
62163	7.23	1.36	5.00	12.00
62301	4.40	1.13	3.00	9.00
62303	6.56	1.43	4.00	19.00
62304	6.28	0.77	3.00	9.00
62305	7.44	1.94	3.00	26.00
64045	8.20	1.17	4.00	13.00
64046	8.34	1.15	6.00	13.00
athos	5.73	1.68	2.10	9.57

Table 11. Observed dominant wave period

7.3 Wave forecast statistics

Parameter Station	bias cm	rms cm	si %	cc %	bias %
almag	9	57	53	79	8
oland	15	50	38	85	12
truba	26	52	58	85	29
20044	1	41	27	88	1
24023	17	46	27	89	10
25077	26	47	29	90	15
25138	-1	36	30	87	-1
62001	-40	59	23	91	-15
62026	-4	44	19	94	-2
62029	-20	46	15	93	-7
62101	39	55	66	84	46
62103	57	72	58	87	46
62105	-22	60	16	92	-6
62106	-22	61	16	94	-6
62107	20	52	25	88	10
62108	-25	62	16	90	-7
62109	-8	54	21	91	-3
62117	39	73	30	89	16
62145	-6	39	22	93	-3
62163	-22	44	16	92	-8
62301	-11	31	26	92	-9
62303	3	40	25	91	2
62304	5	38	44	81	6
62305	20	42	39	90	19
62414	-15	49	23	93	-7
64045	-30	71	17	92	-7
64046	-49	76	18	93	-12
athos	-14	50	32	92	-9

Table 12. Predicted significant wave height

Parameter Station	bias s	rms s	si %	cc %	bias %
almag	0.67	1.14	29	62	17
oland	0.55	0.81	17	83	12
truba	0.73	1.01	26	71	19
20044	1.56	1.78	41	72	36
24023	2.16	2.26	47	69	43
25077	2.18	2.40	50	66	45
25138	2.42	2.77	68	55	59
athos	0.65	0.95	22	84	15

Table 13. Predicted mean wave period

Parameter Station	bias s	rms s	si %	cc %	bias %
20044	0.26	2.72	41	33	4
24023	0.36	2.70	32	45	4
25077	0.97	3.27	42	29	12
25138	2.00	3.76	61	29	32
62001	2.94	3.92	54	51	41
62026	2.40	3.38	55	57	39
62029	3.41	3.91	52	55	45
62101	2.88	3.95	100	39	73
62103	0.56	2.46	32	45	7
62105	3.03	3.49	43	65	38
62106	3.21	3.62	45	58	40
62107	0.75	2.13	24	64	9
62108	2.73	3.05	38	57	34
62109	2.82	3.90	59	36	43
62117	4.12	4.91	84	21	71
62145	2.12	3.05	62	44	43
62163	2.85	3.55	49	61	39
62301	3.09	4.57	104	24	70
62303	1.81	3.38	51	32	28
62304	-0.97	1.53	24	50	-15
62305	-1.46	2.75	37	34	-20
64045	2.96	3.32	40	66	36
64046	2.89	3.22	39	68	35
athos	-0.25	1.20	21	75	-4

Table 14. Predicted dominant wave period

7.4 Significant wave height station plots

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

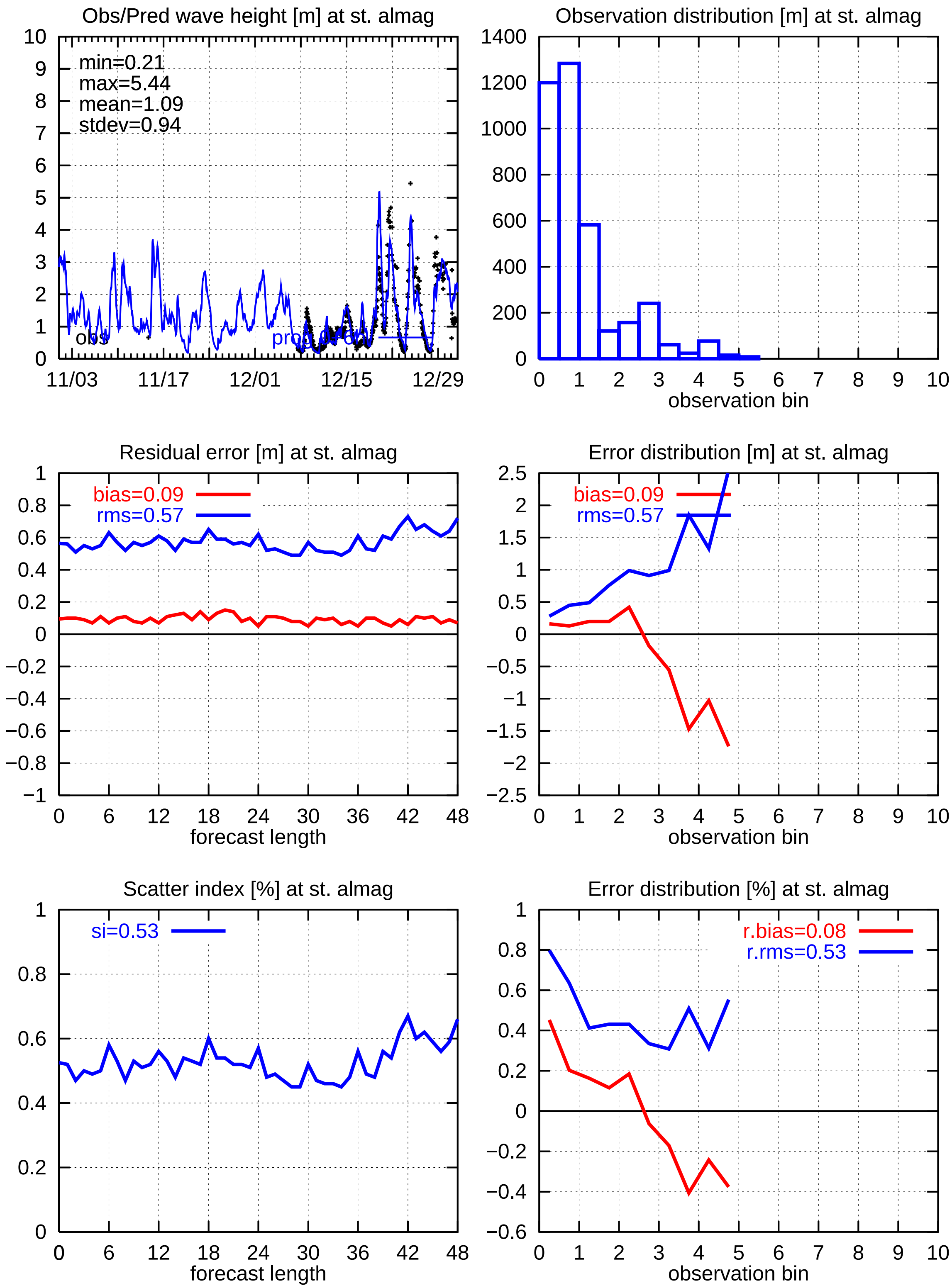

Figure 9. st. Almagrundet: significant wave height

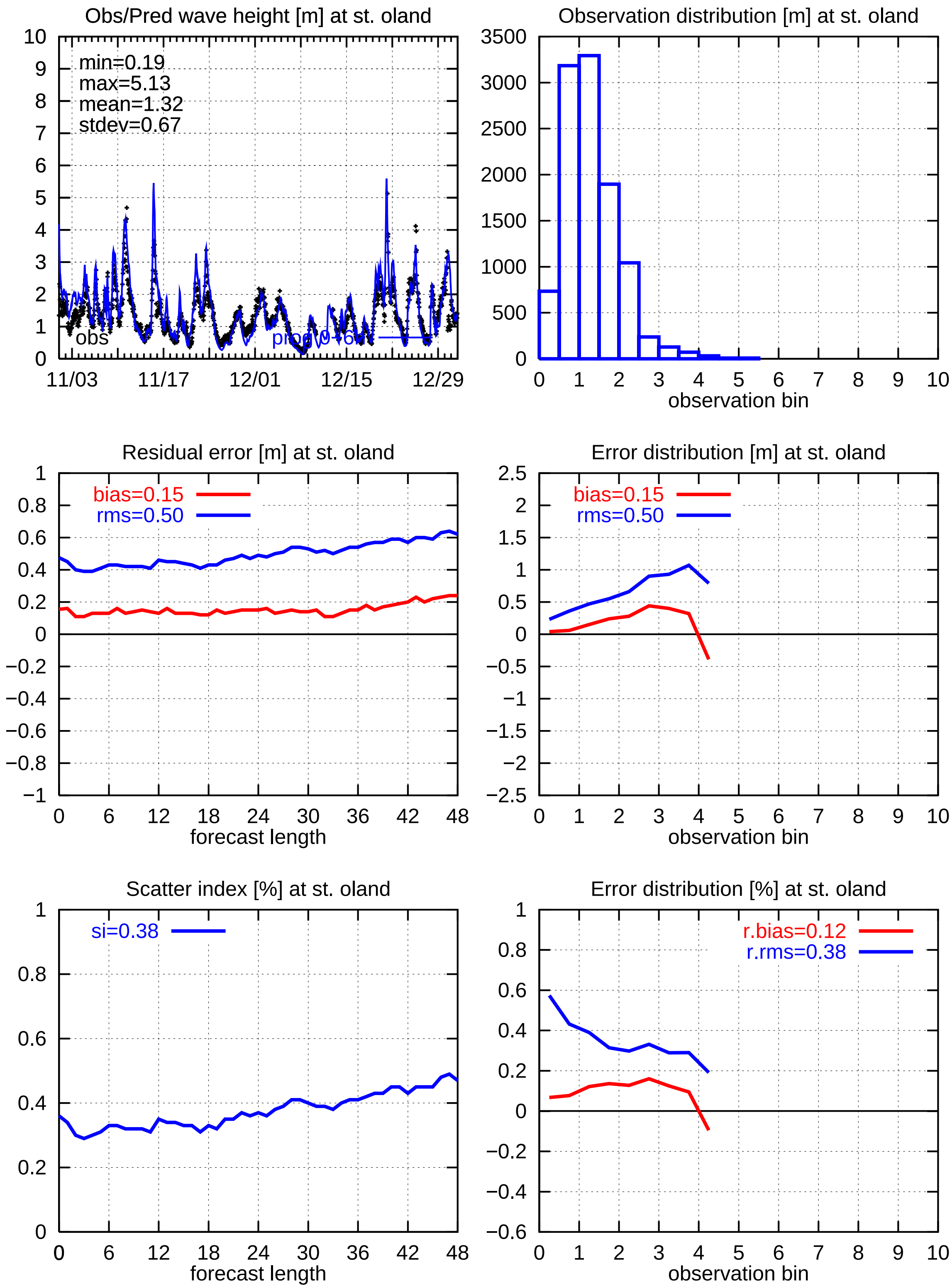

Figure 10. st. Øland: significant wave height

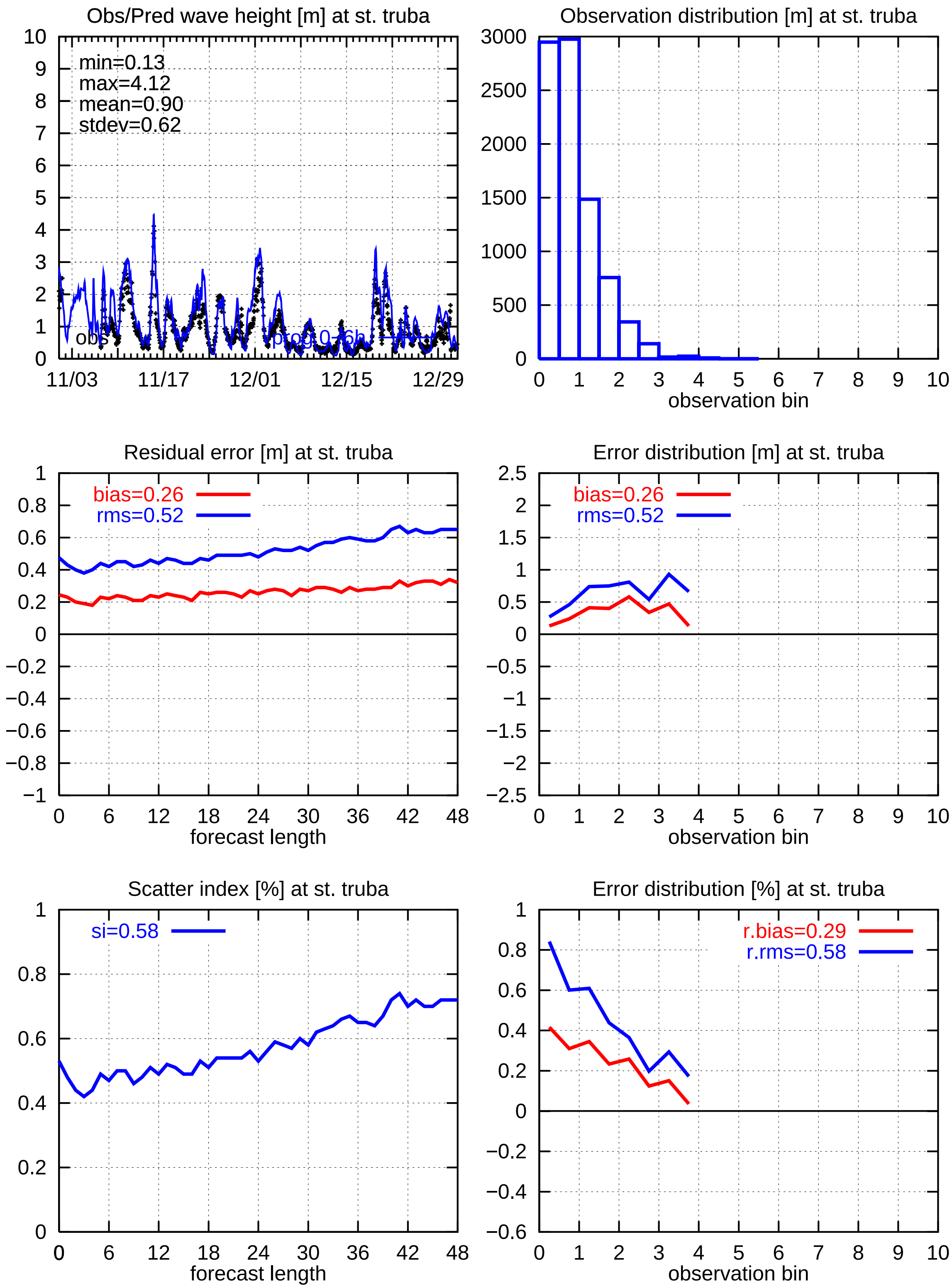

Figure 11. st. Trubaduren: significant wave height

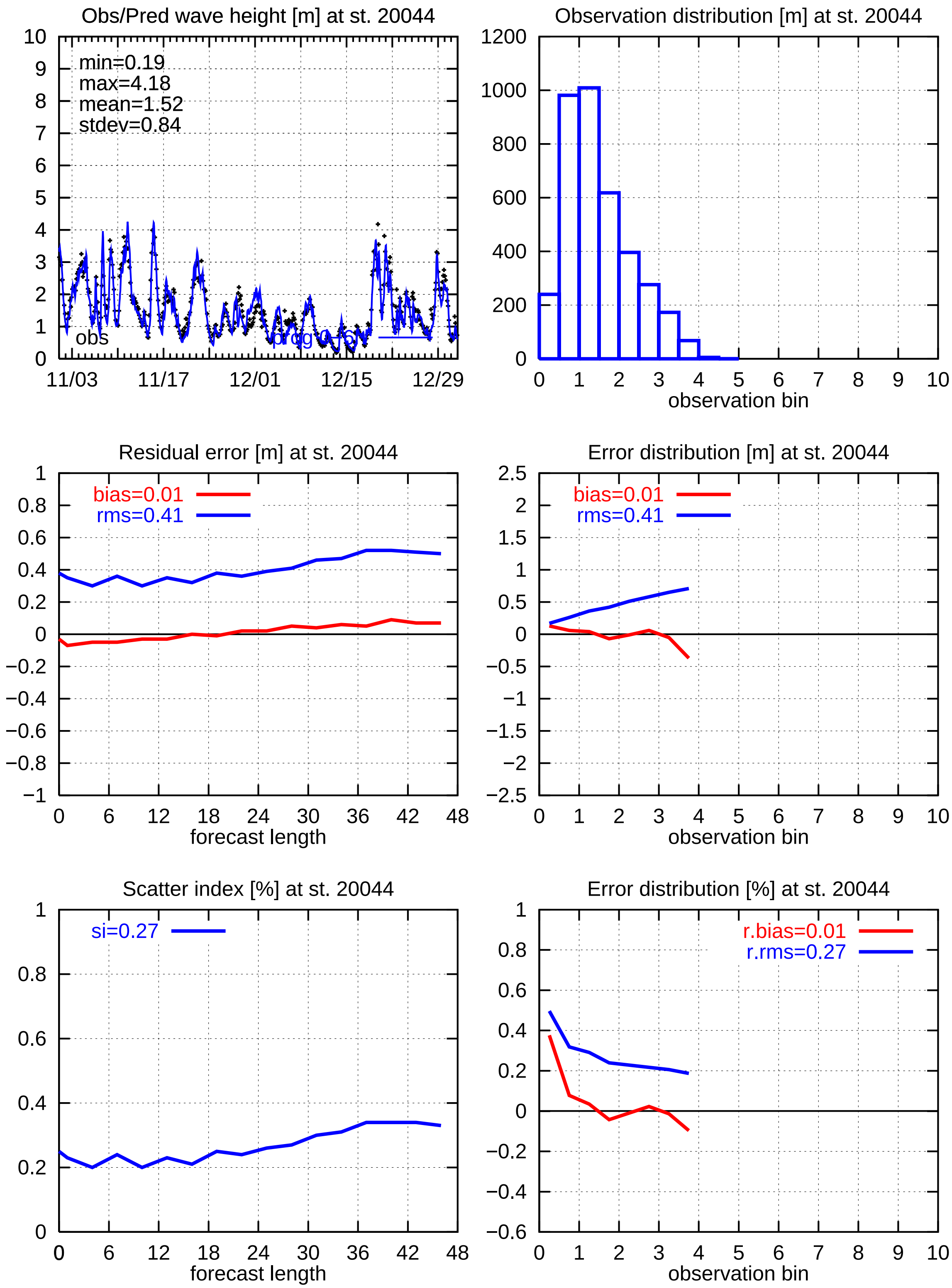

Figure 12. st. 20044: significant wave height

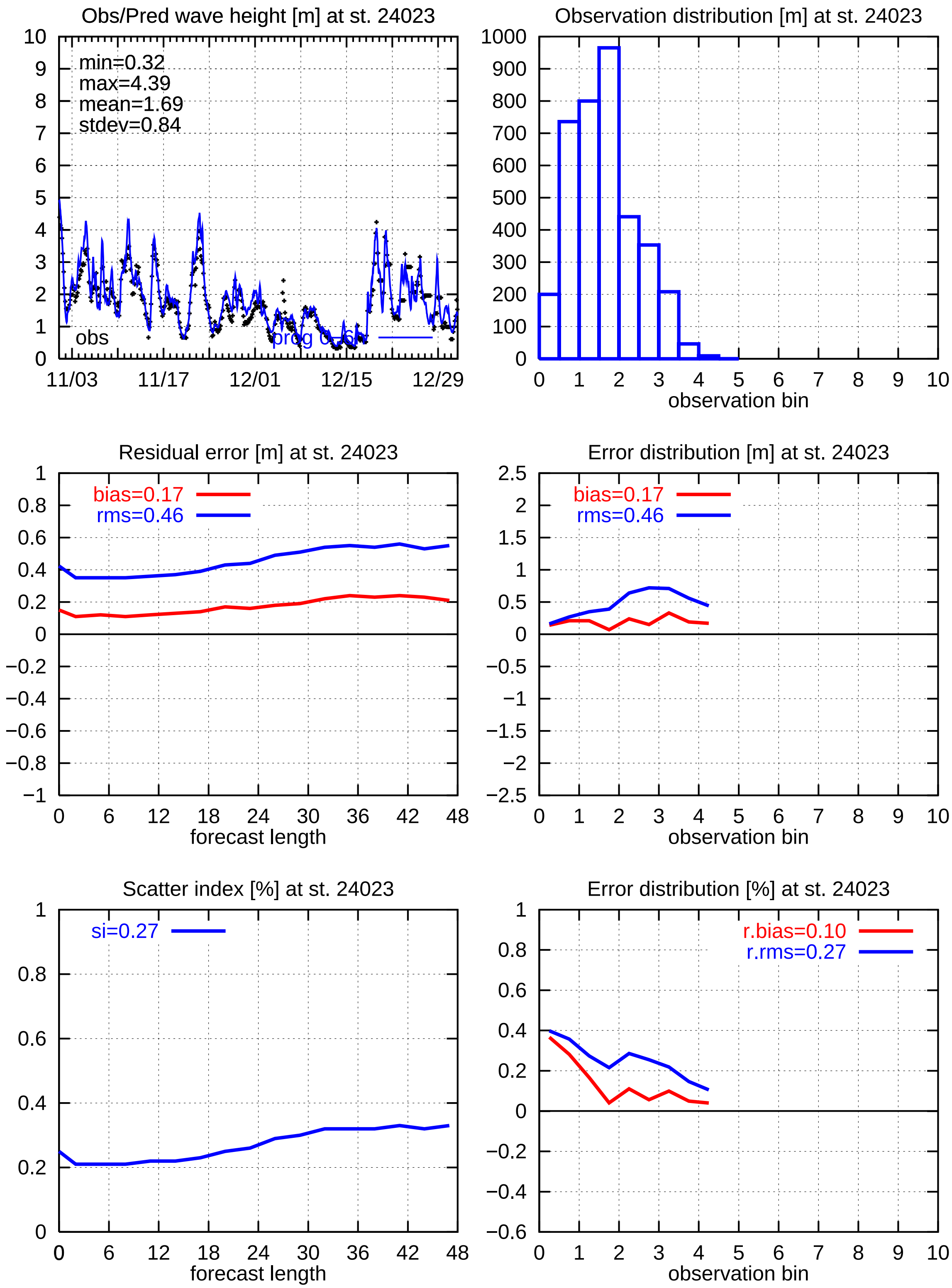

Figure 13. st. 24023: significant wave height

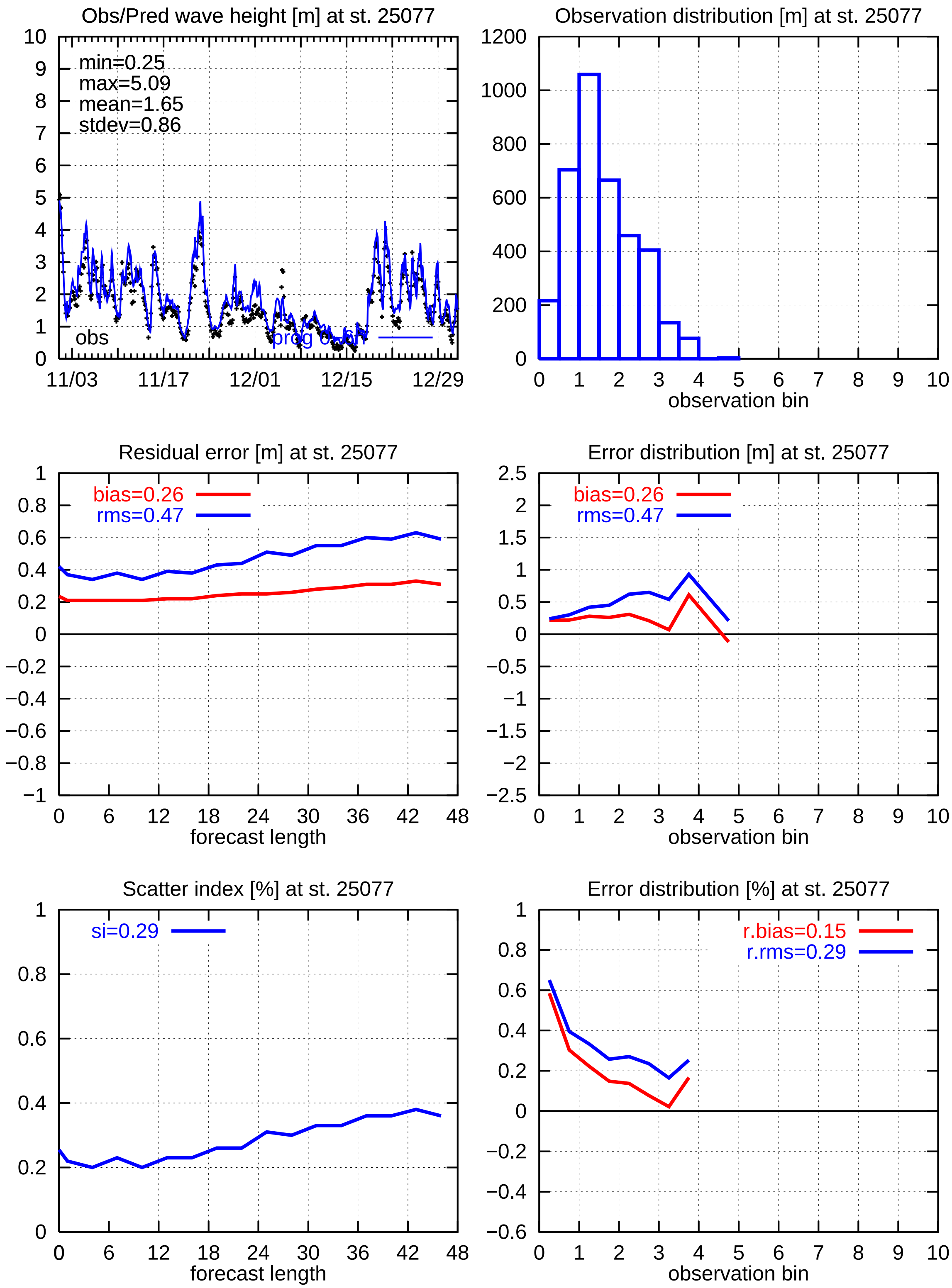

Figure 14. st. 25077: significant wave height

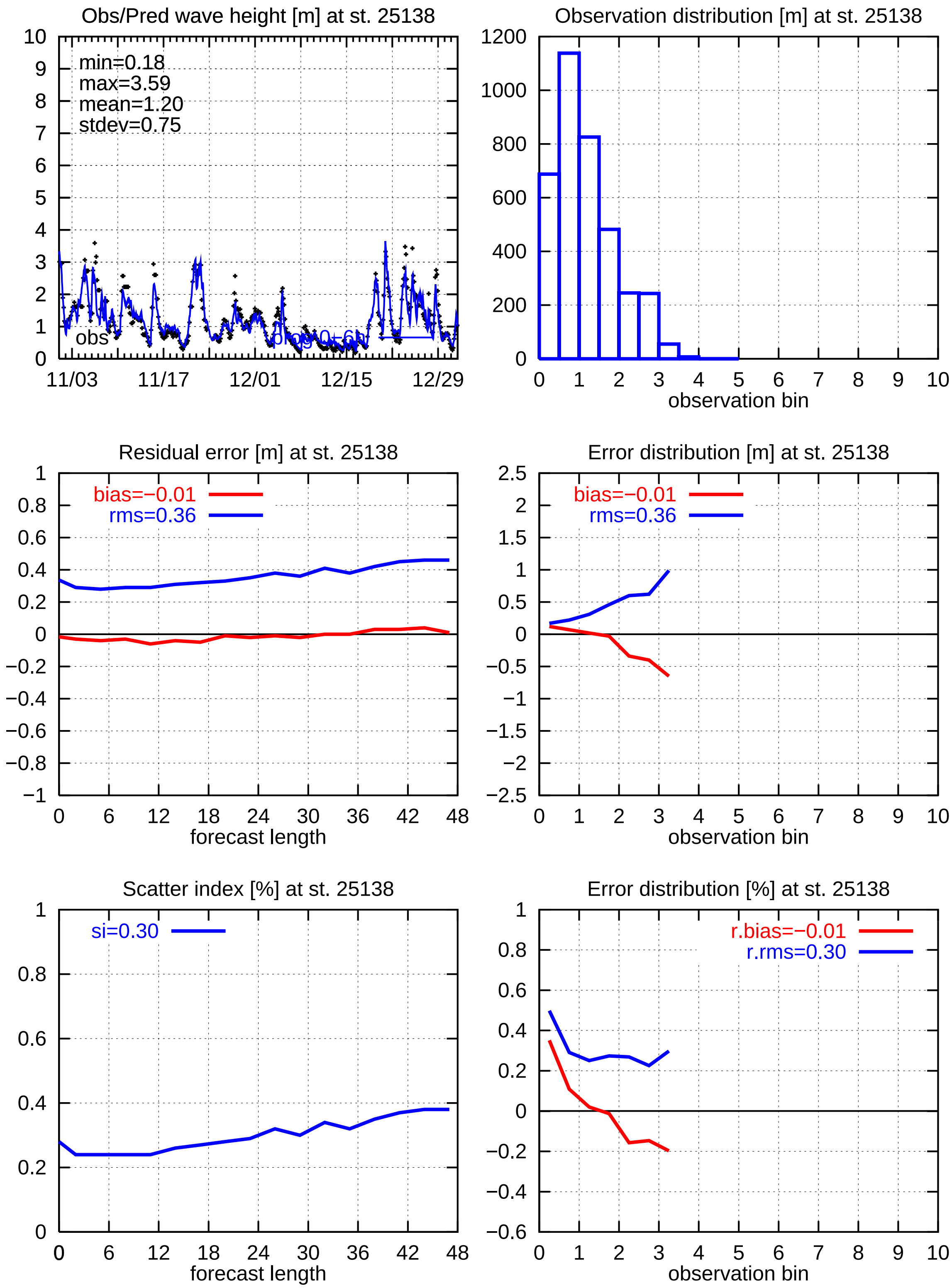

Figure 15. st. 25138: significant wave height

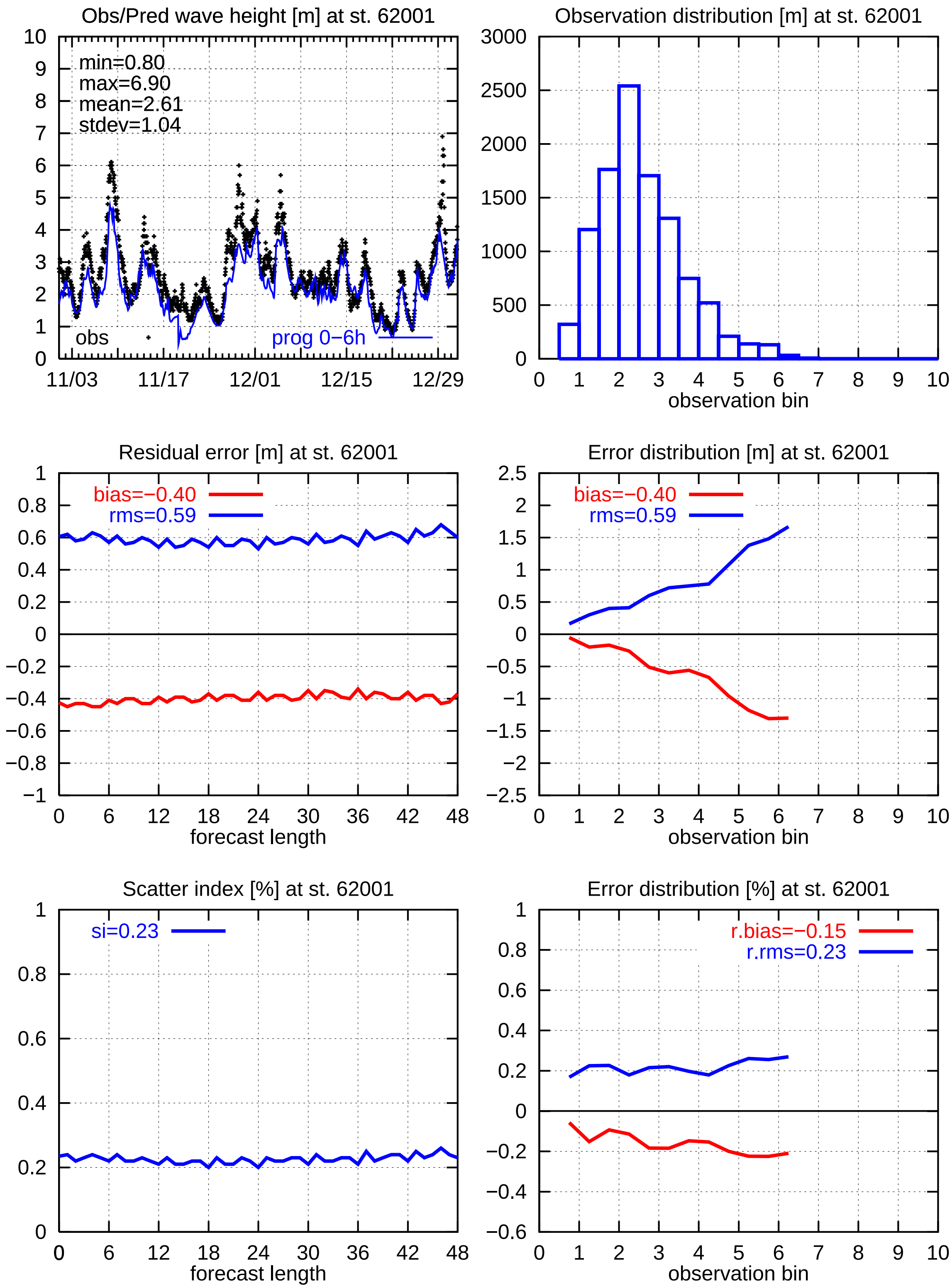

Figure 16. st. 62001: significant wave height

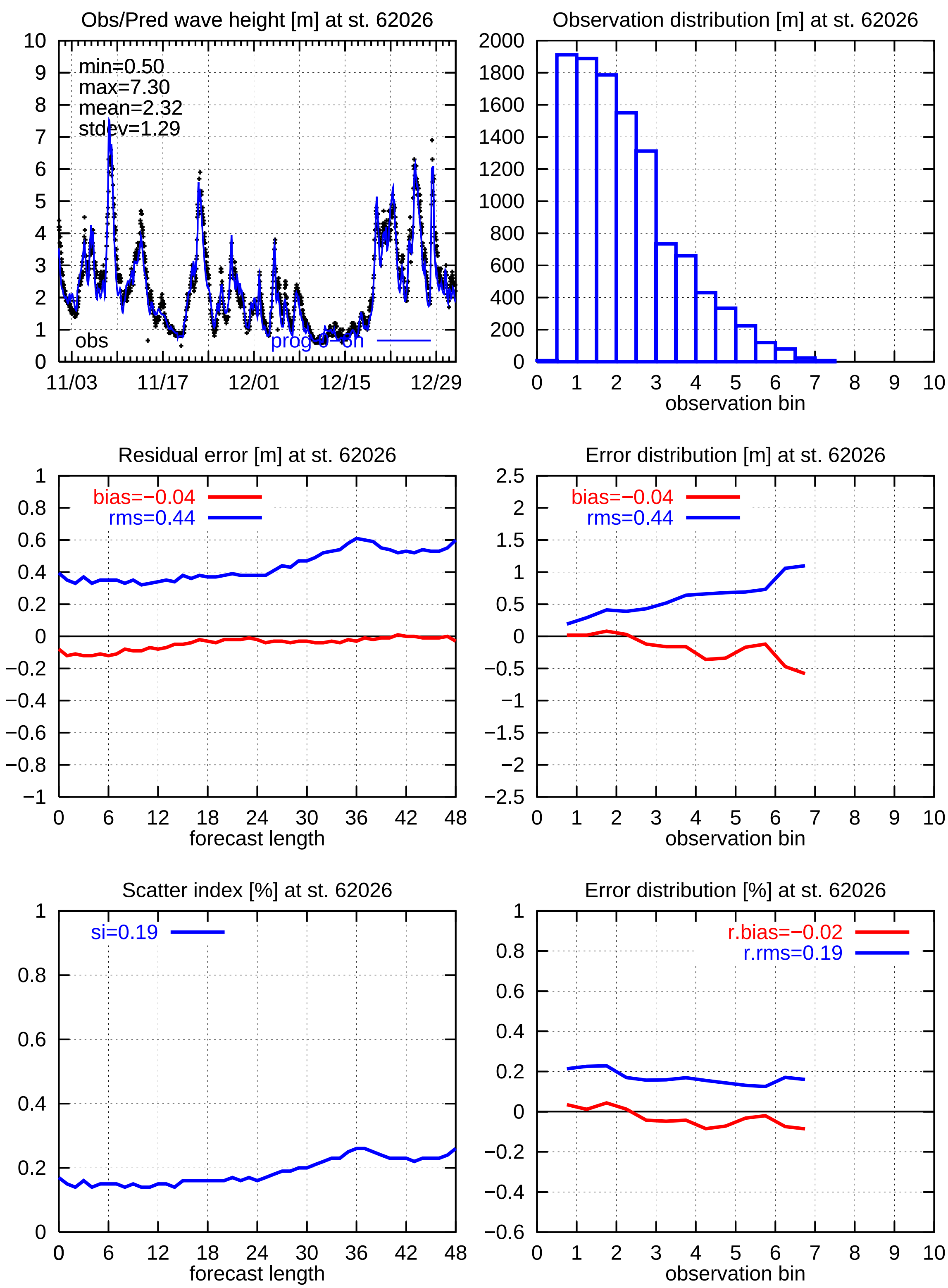

Figure 17. st. 62026: significant wave height

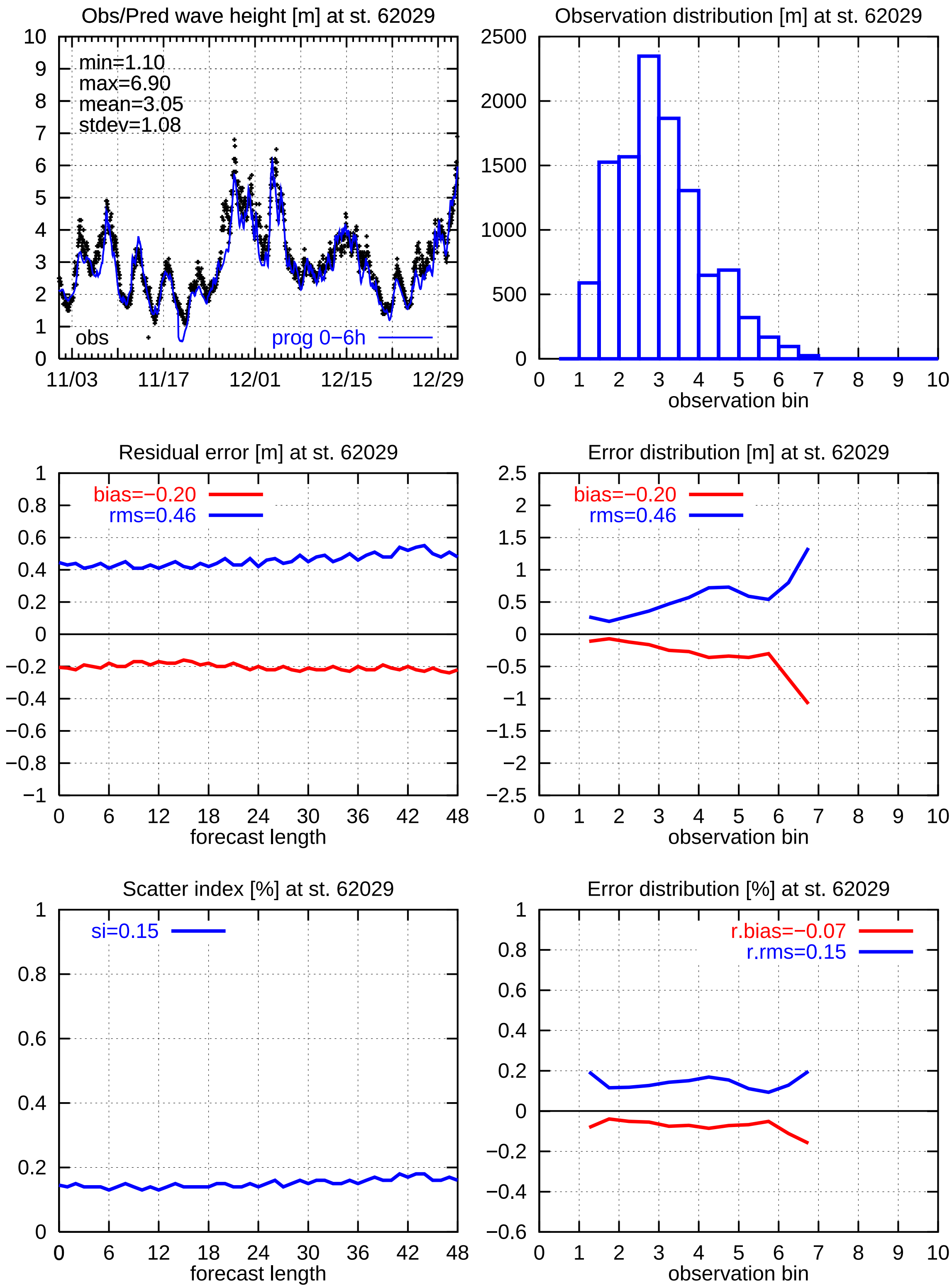

Figure 18. st. 62029: significant wave height

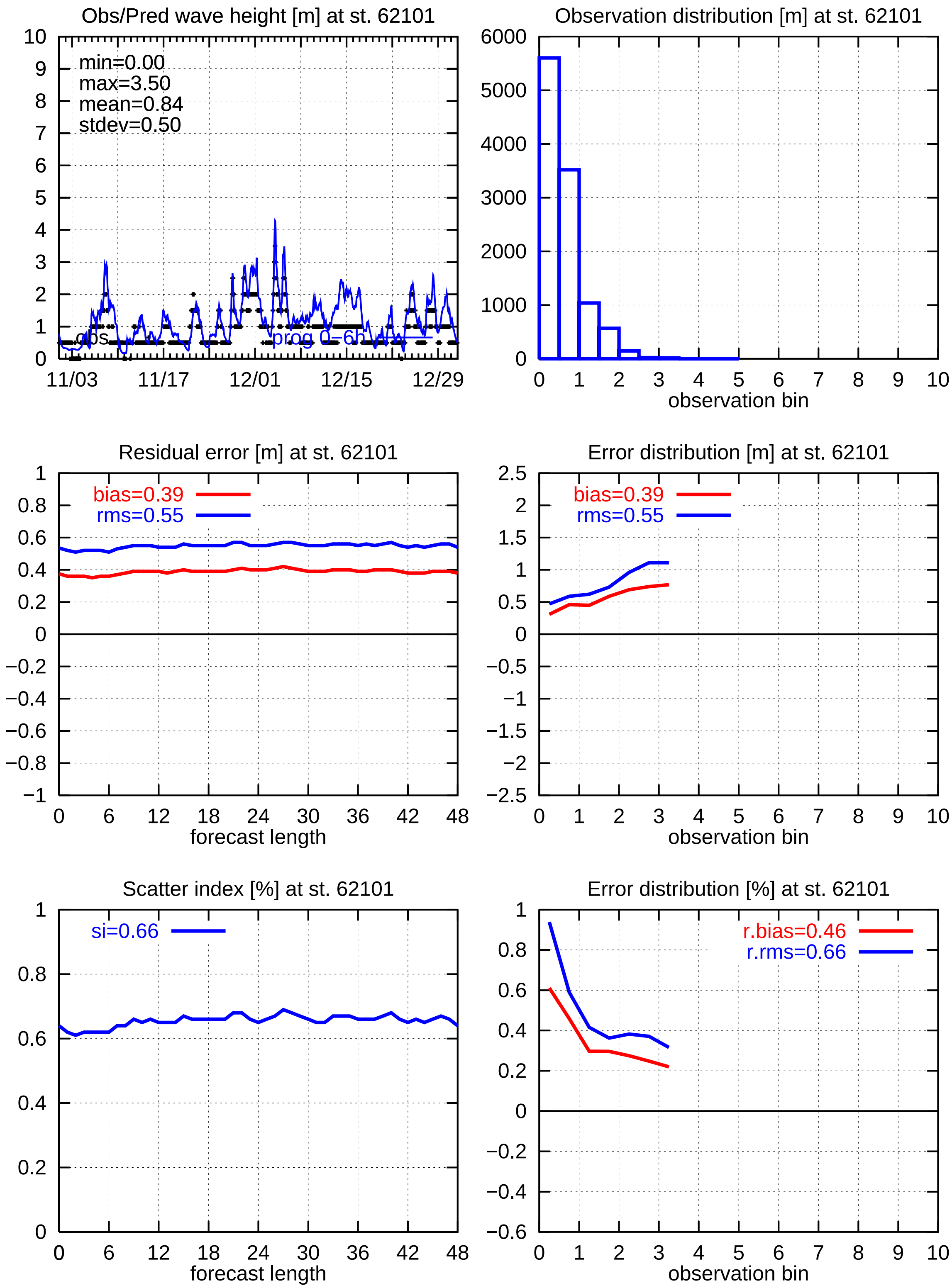

Figure 19. st. 62101: significant wave height

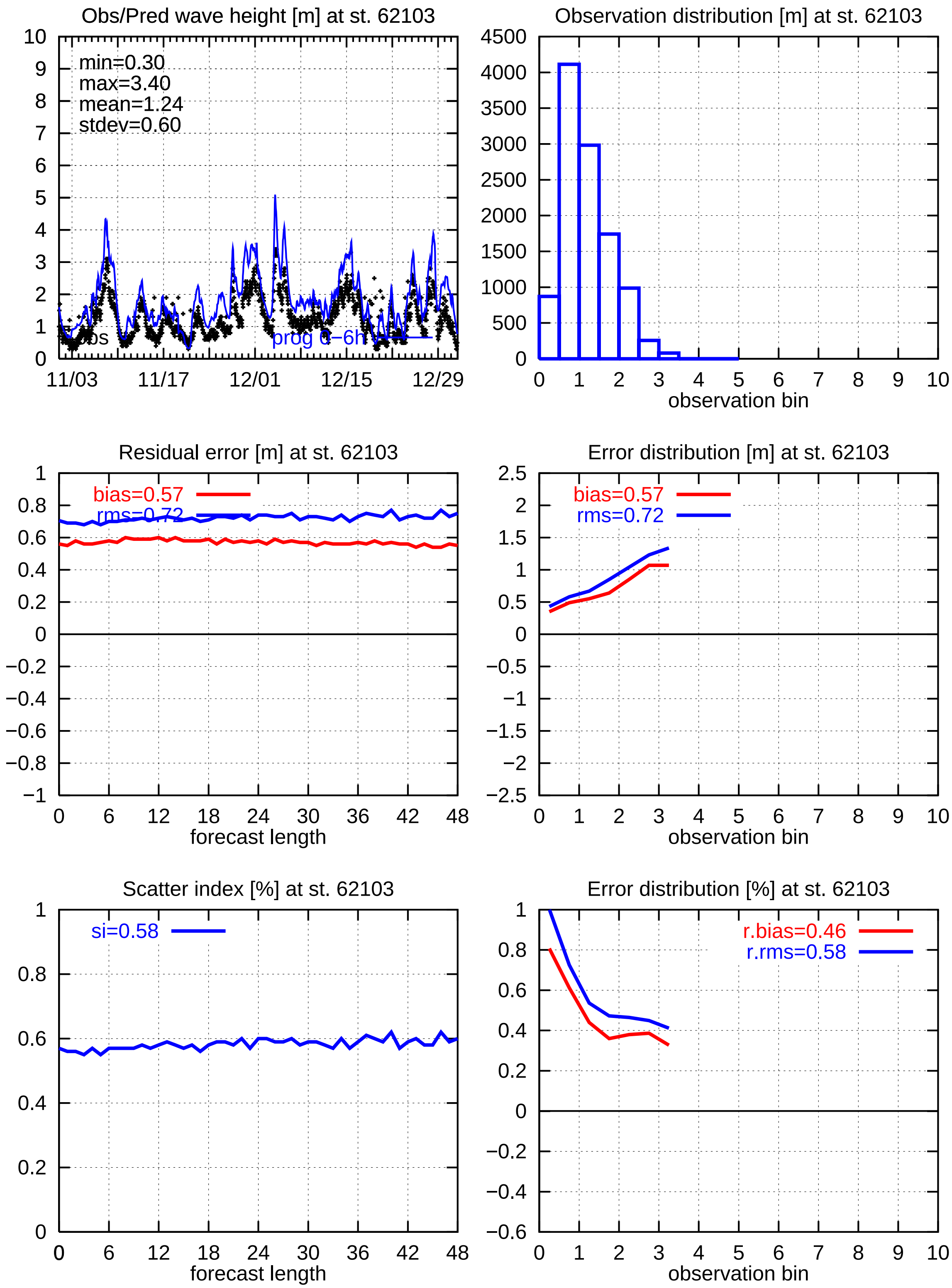

Figure 20. st. 62103: significant wave height

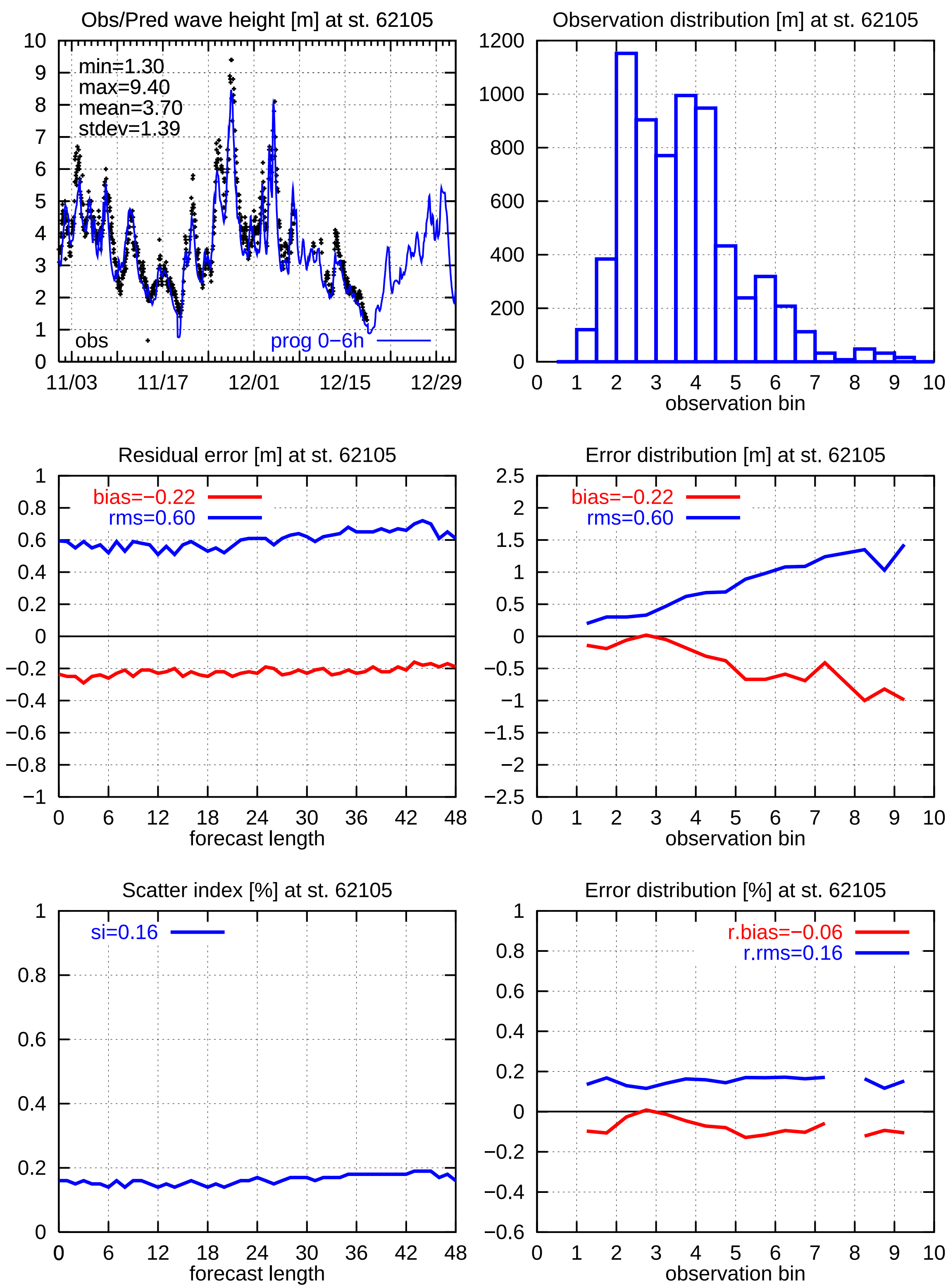

Figure 21. st. 62105: significant wave height

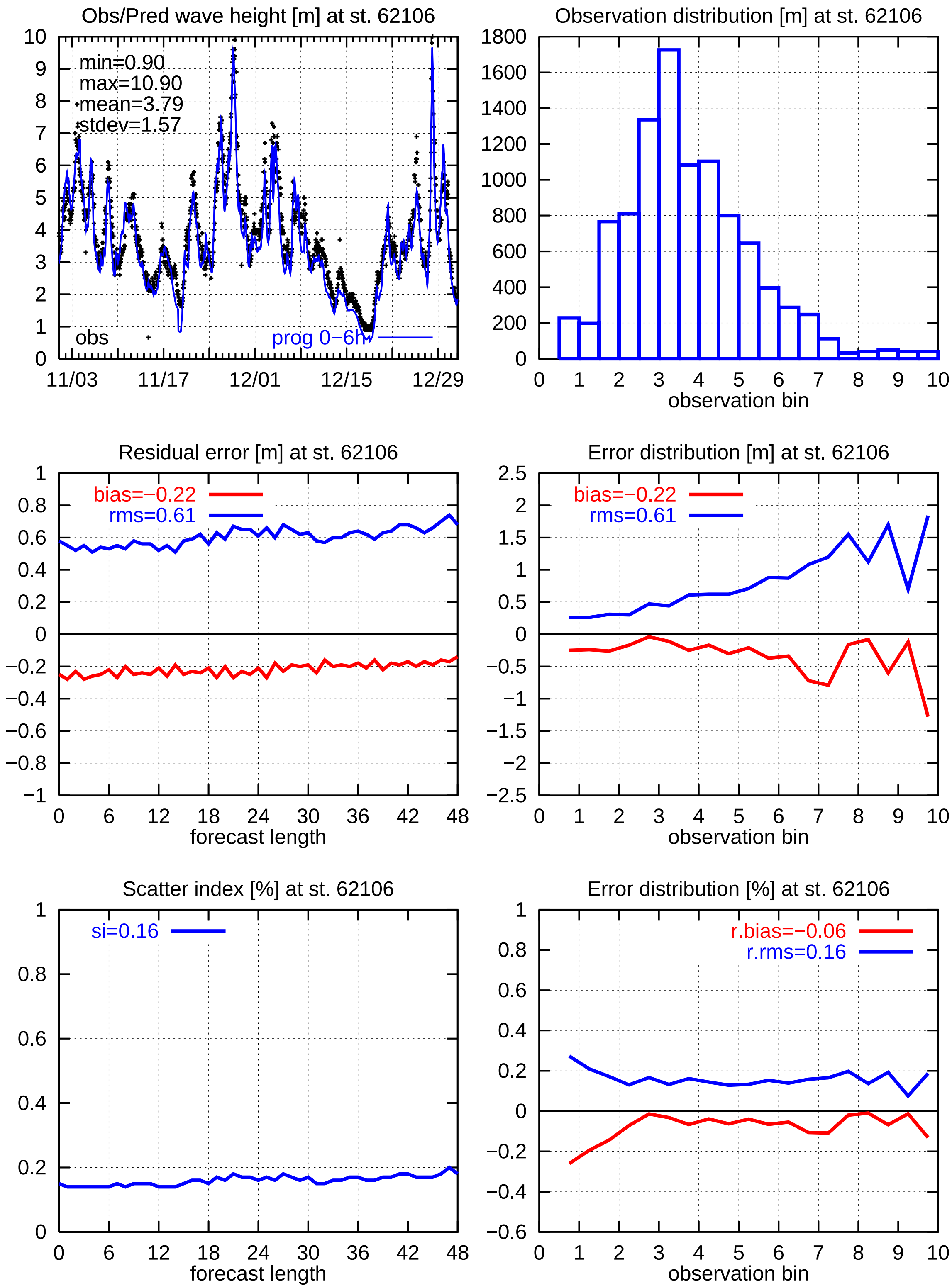

Figure 22. st. 62106: significant wave height

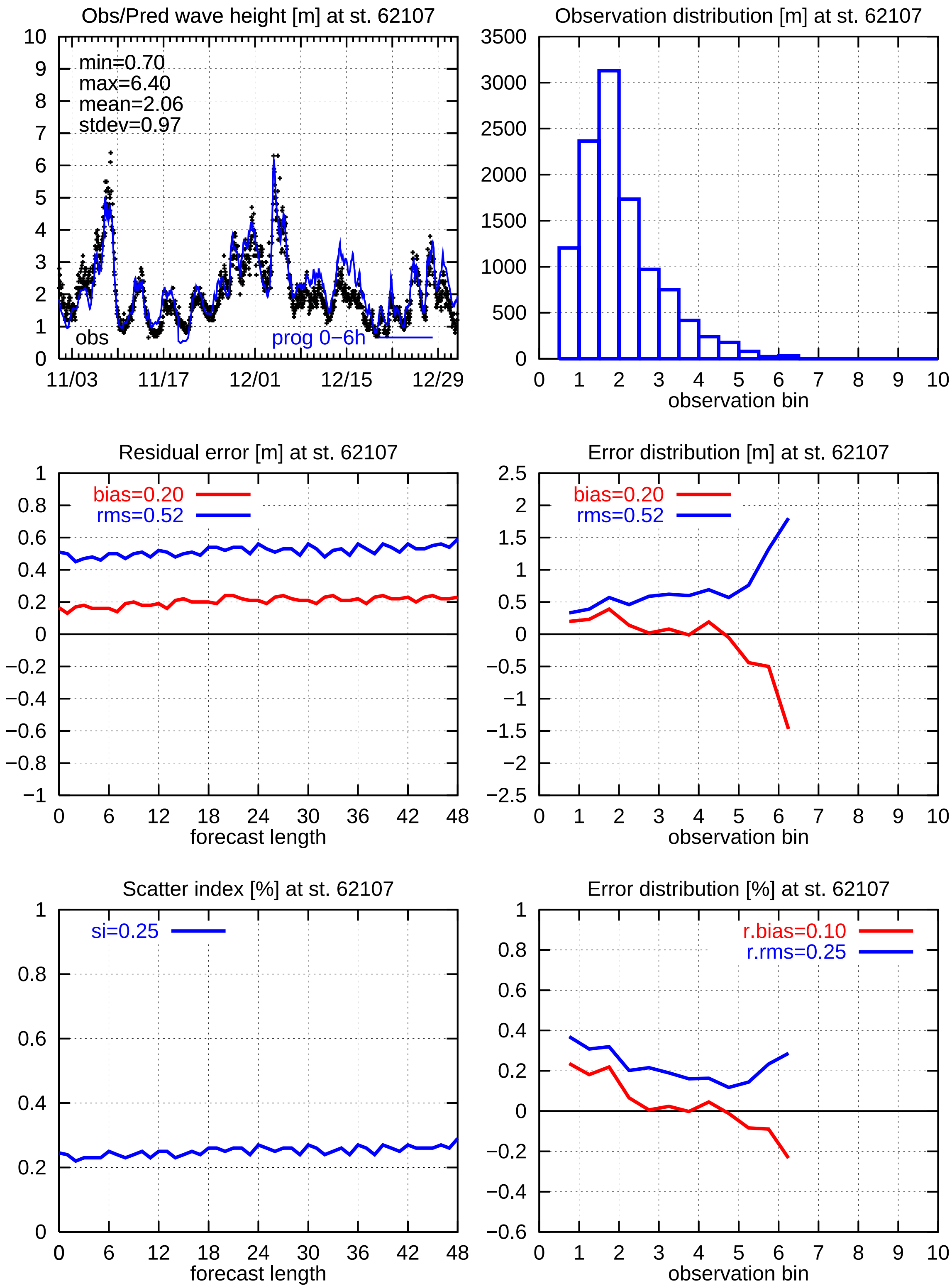

Figure 23. st. 62107: significant wave height

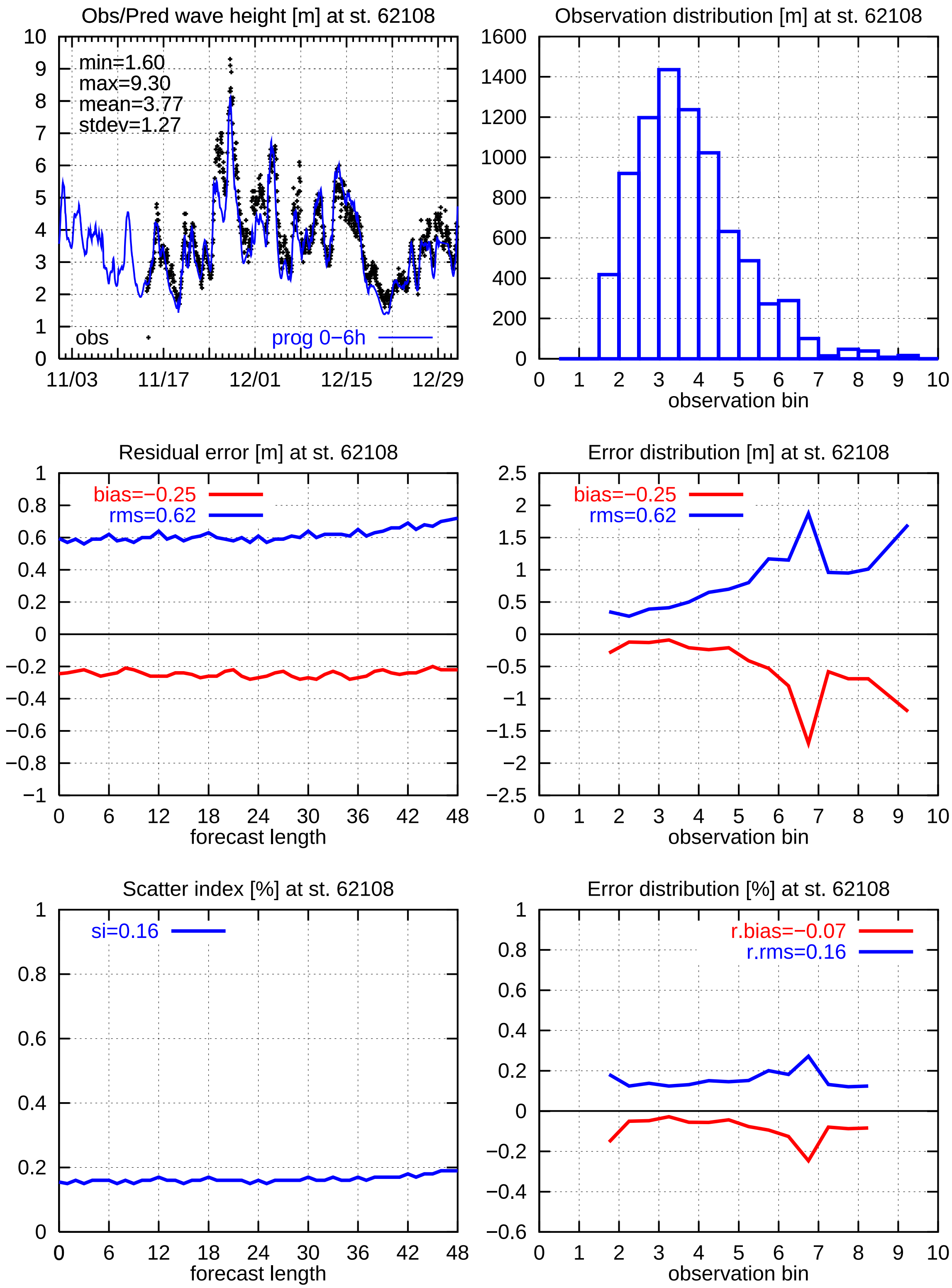

Figure 24. st. 62108: significant wave height

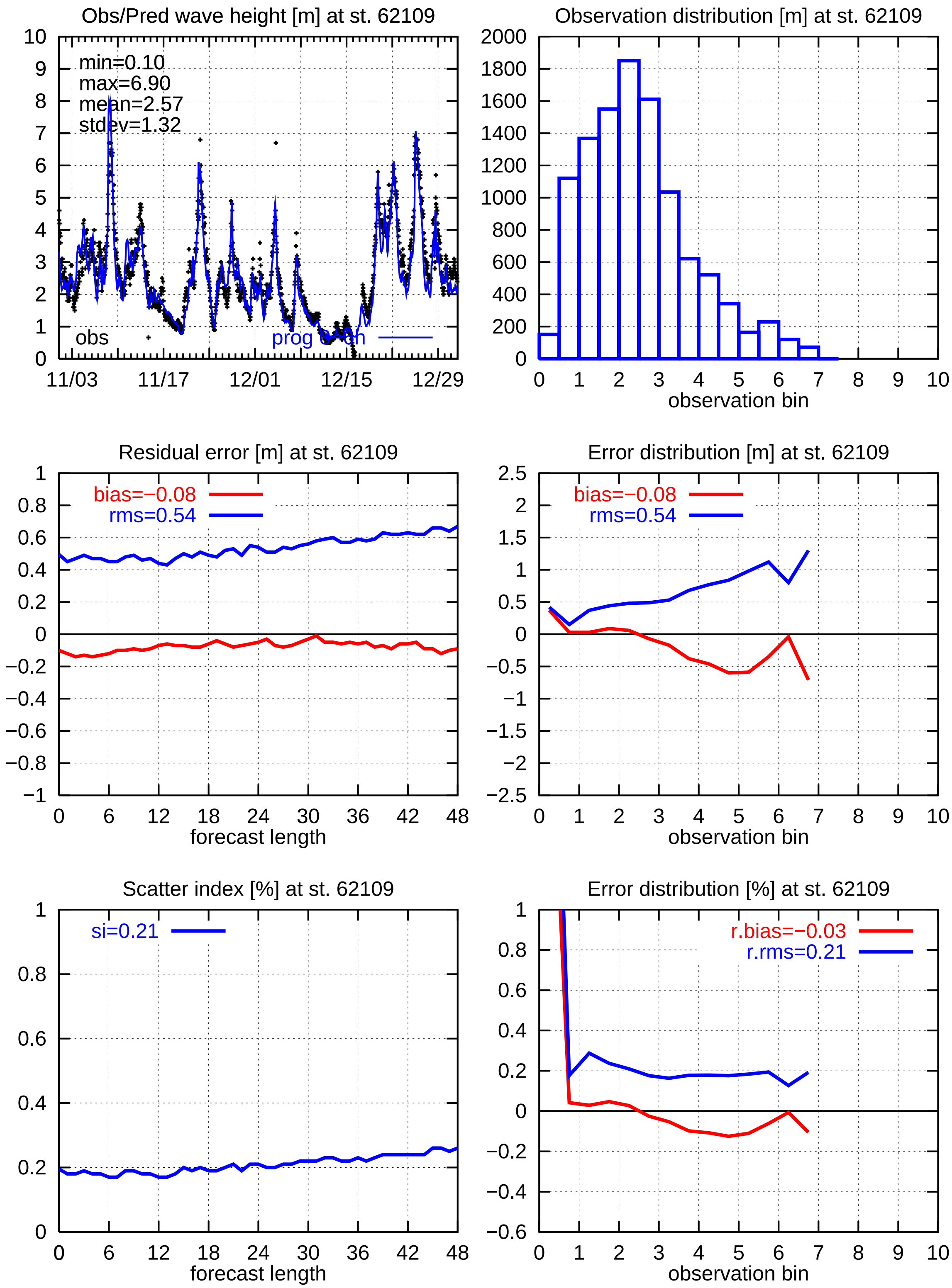

Figure 25. st. 62109: significant wave height

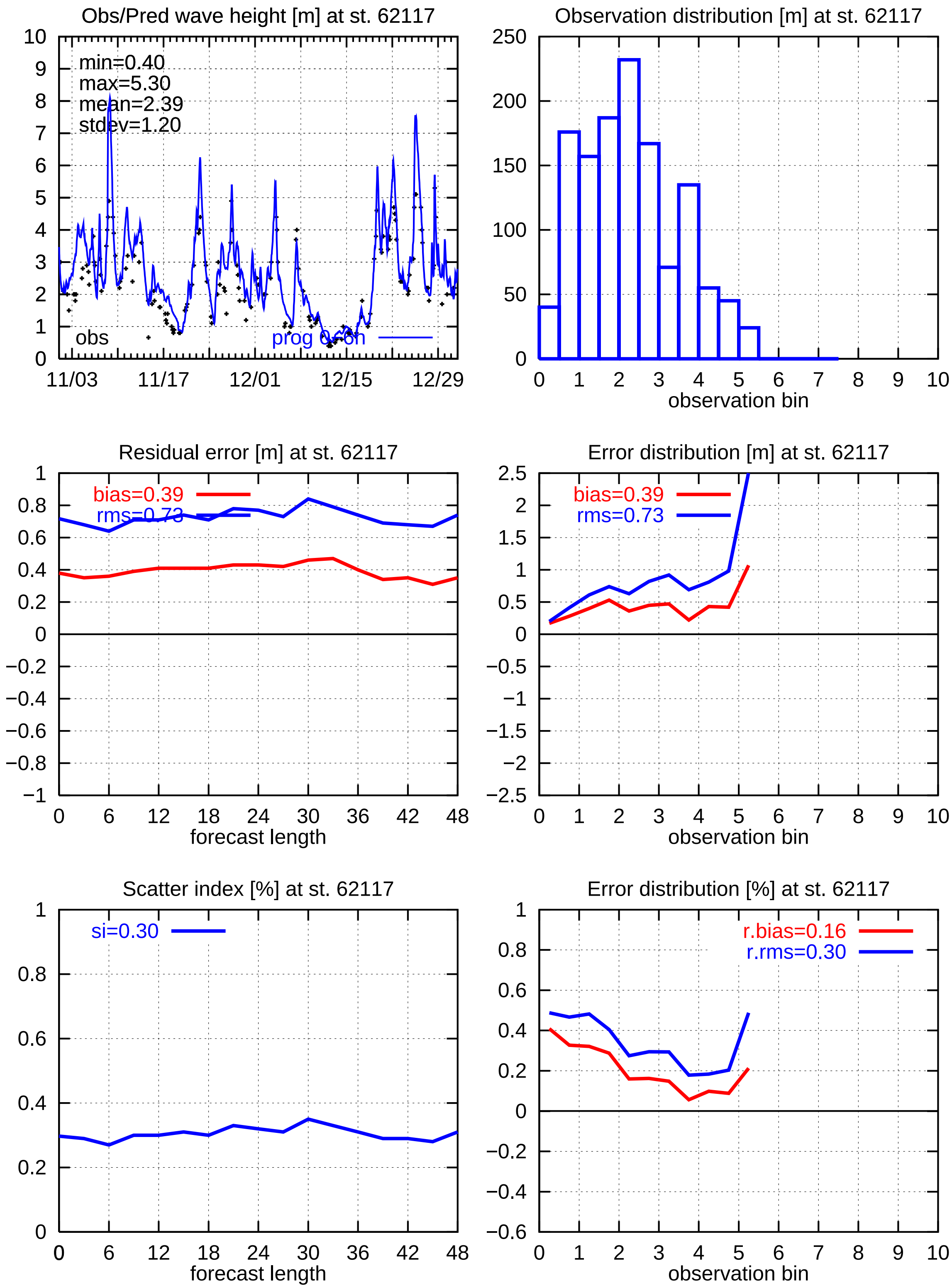

Figure 26. st. 62117: significant wave height

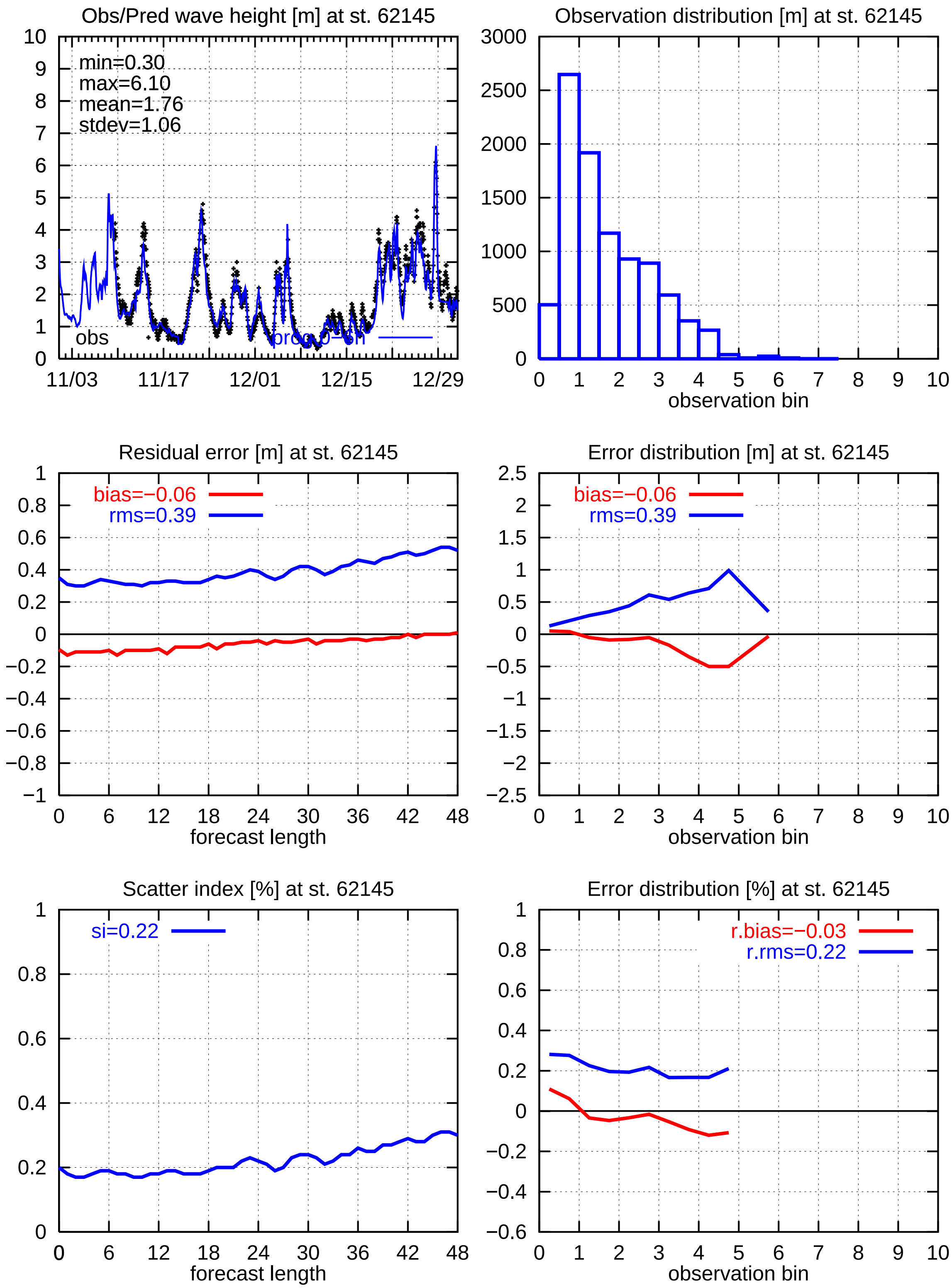

Figure 27. st. 62145: significant wave height

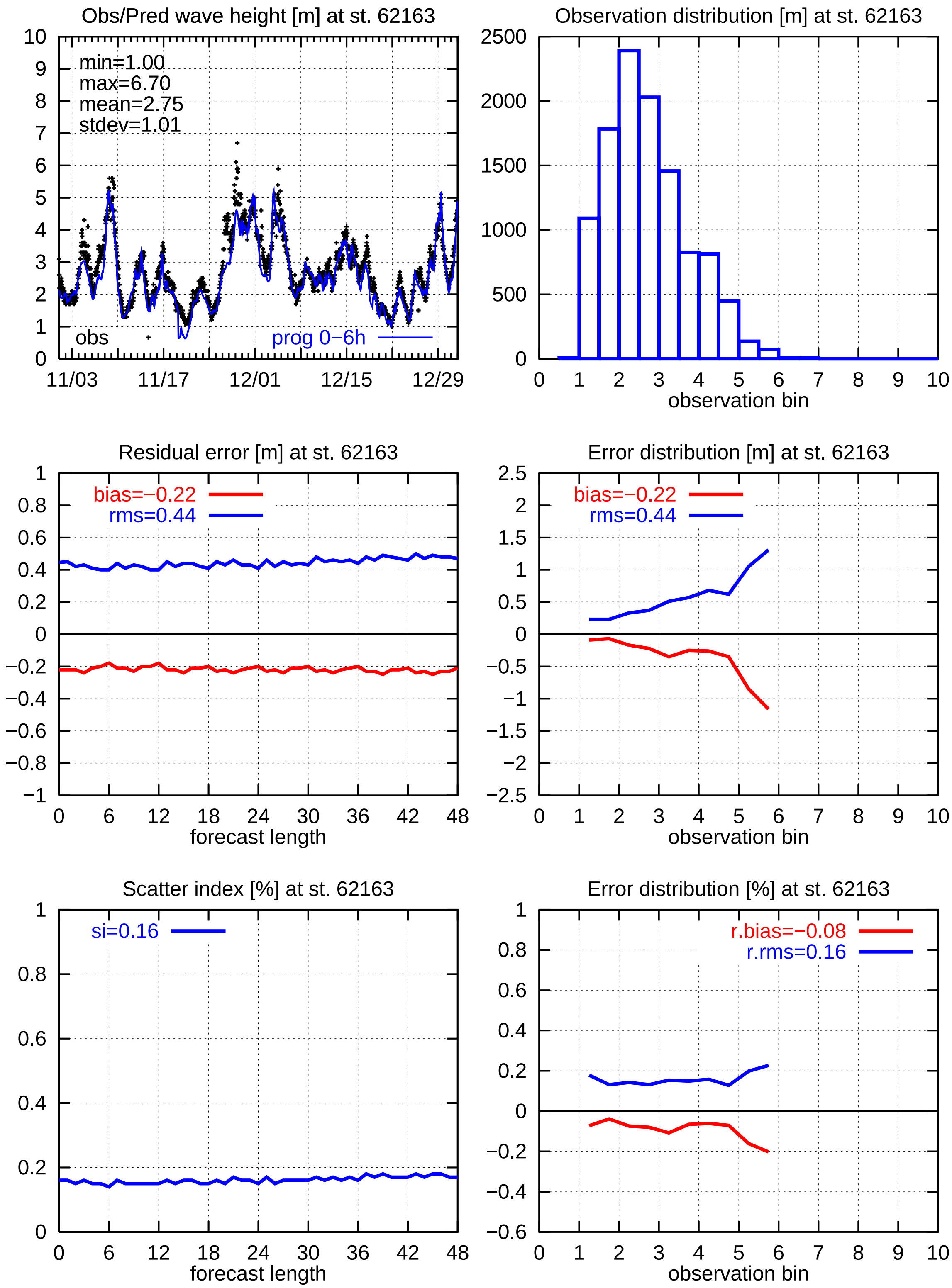

Figure 28. st. 62163: significant wave height

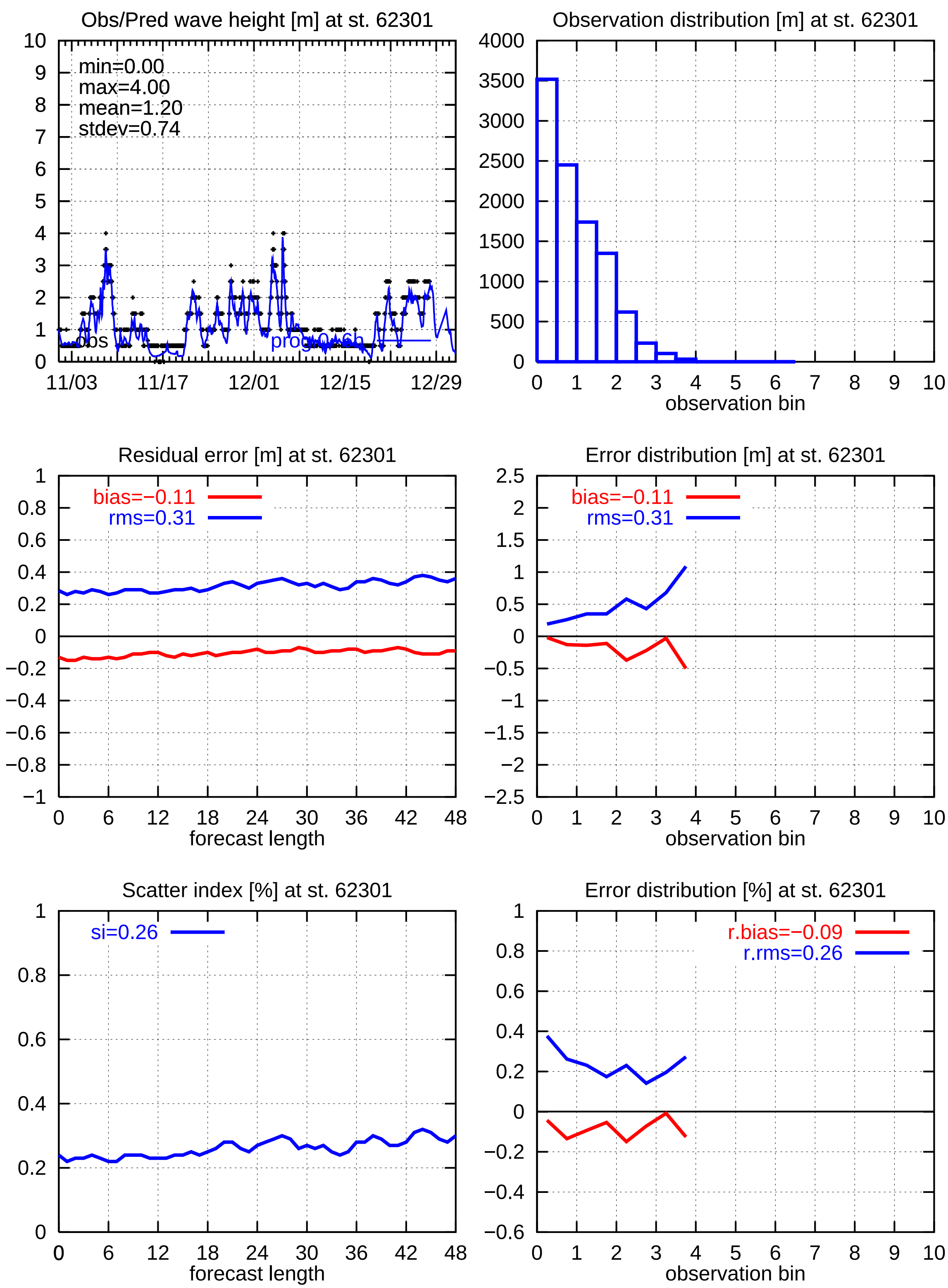

Figure 29. st. 62301: significant wave height

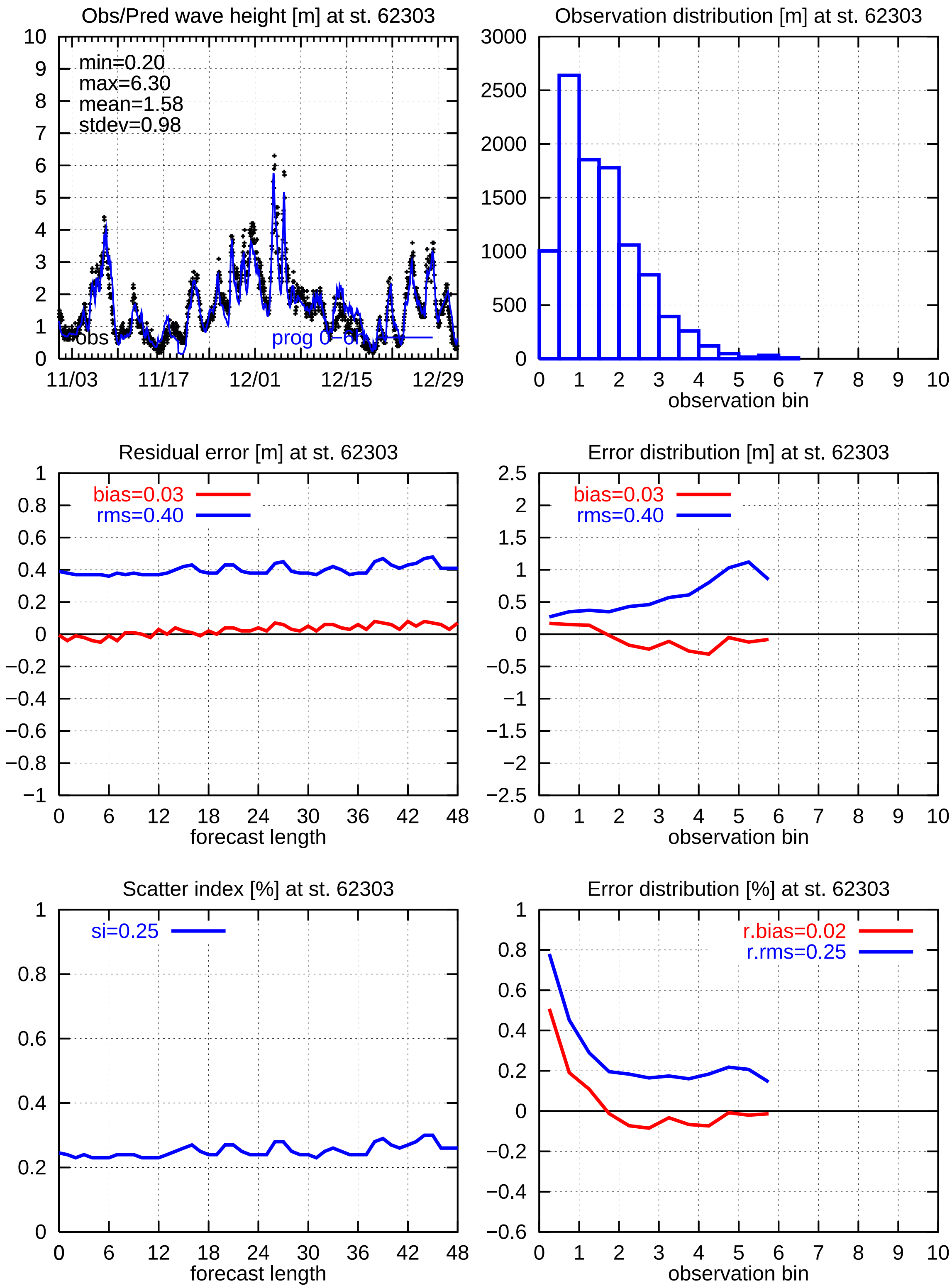

Figure 30. st. 62303: significant wave height

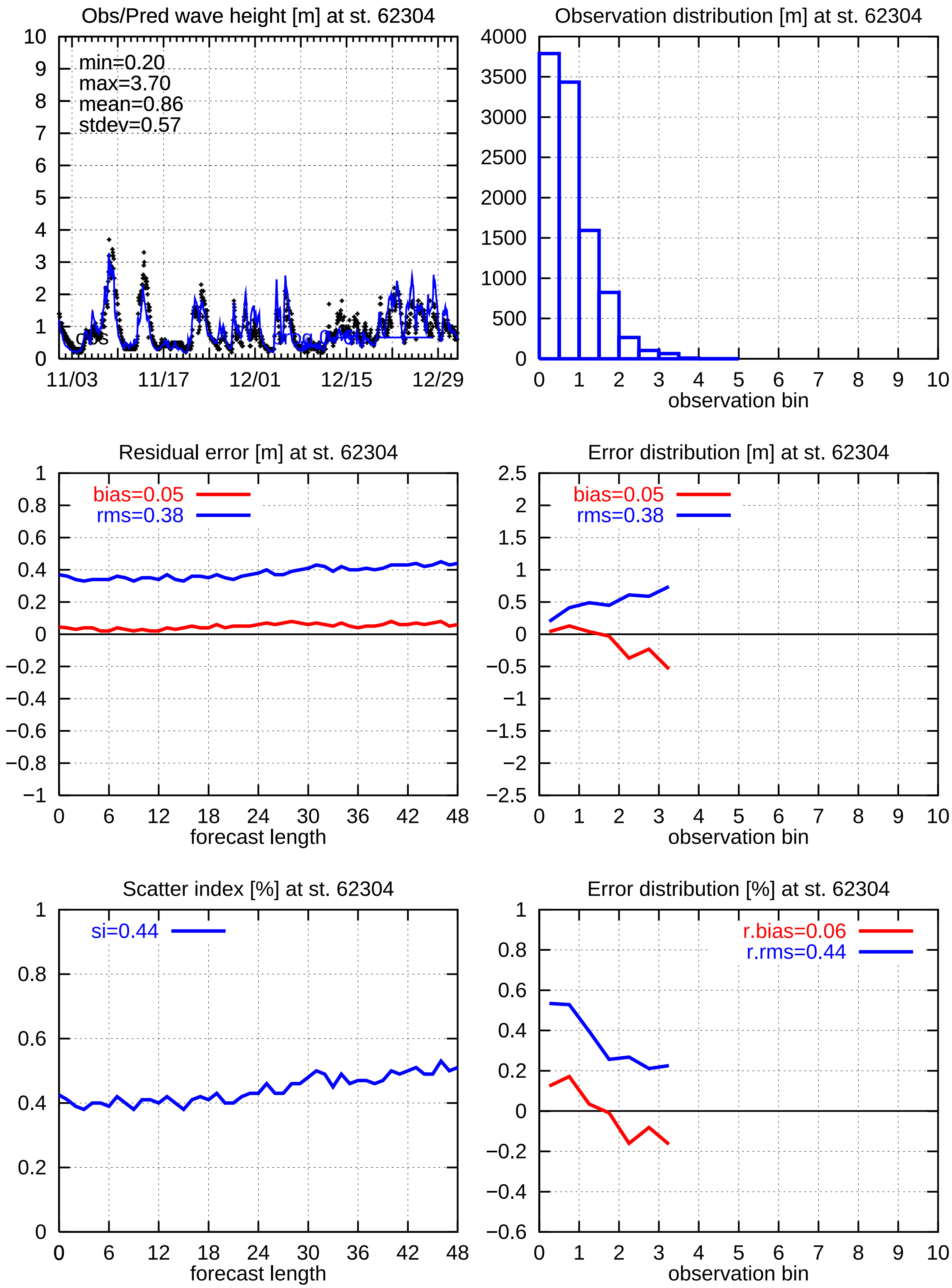

Figure 31. st. 62304: significant wave height

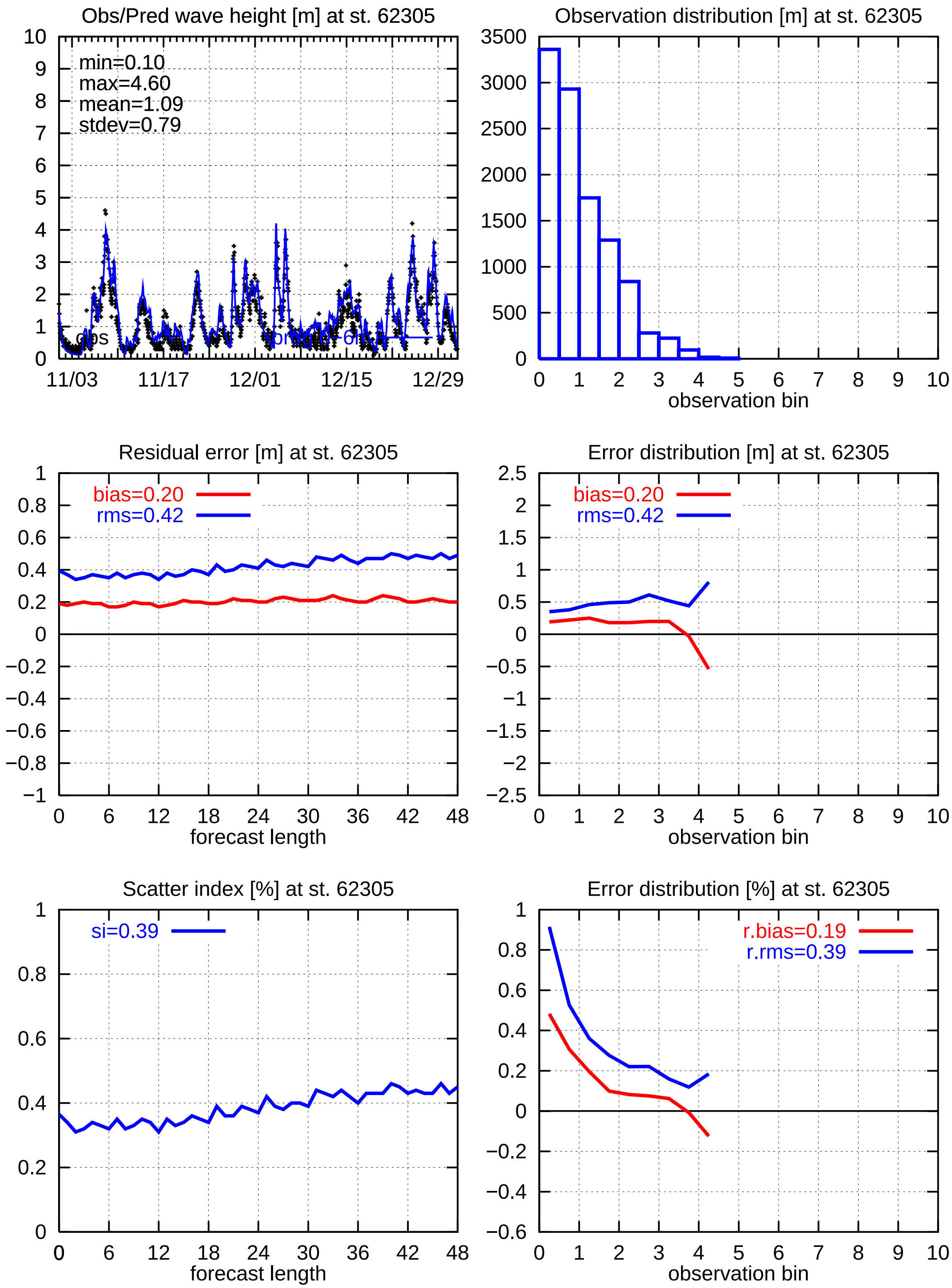

Figure 32. st. 62305: significant wave height

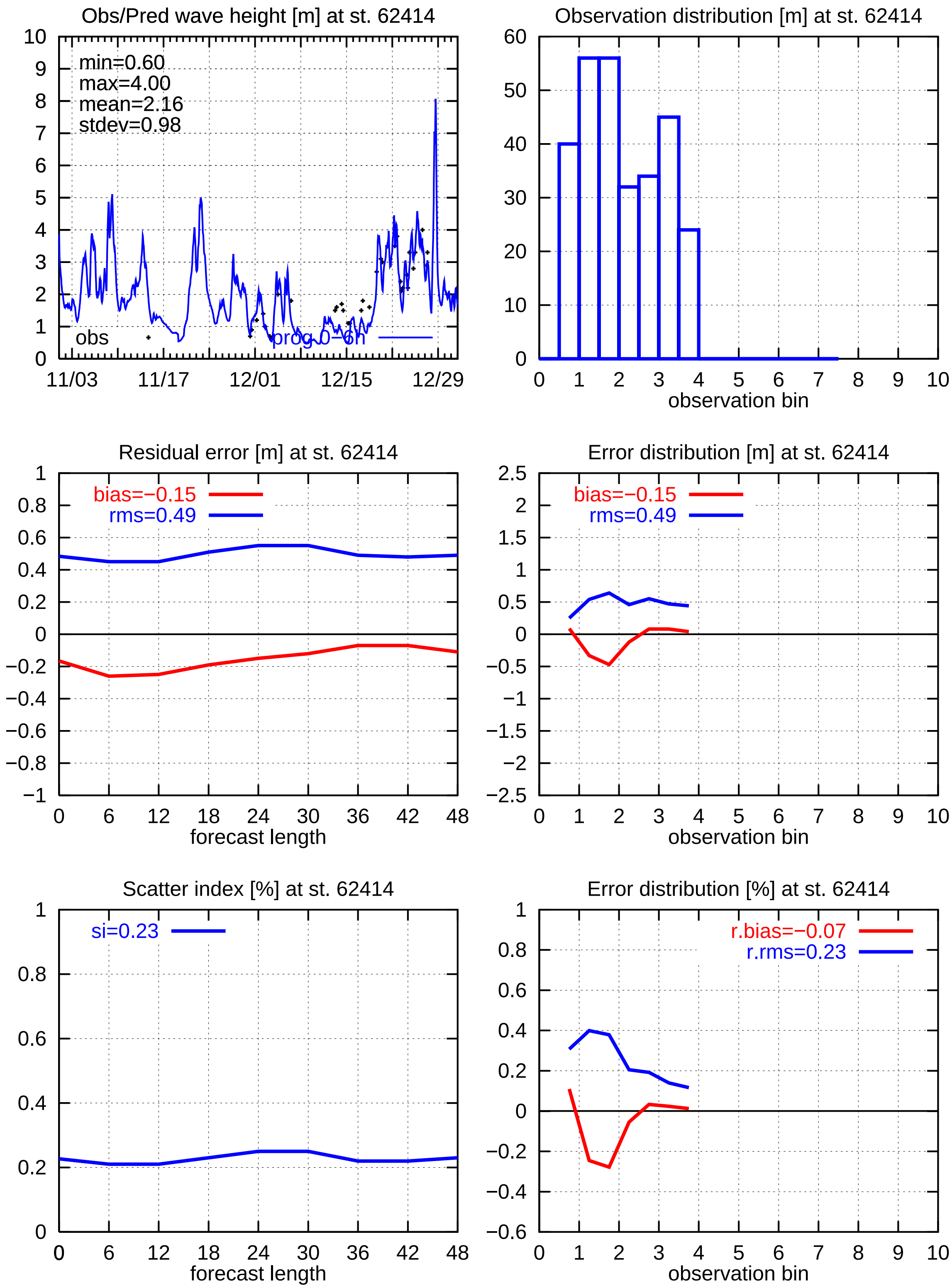

Figure 33. st. 62414: significant wave height

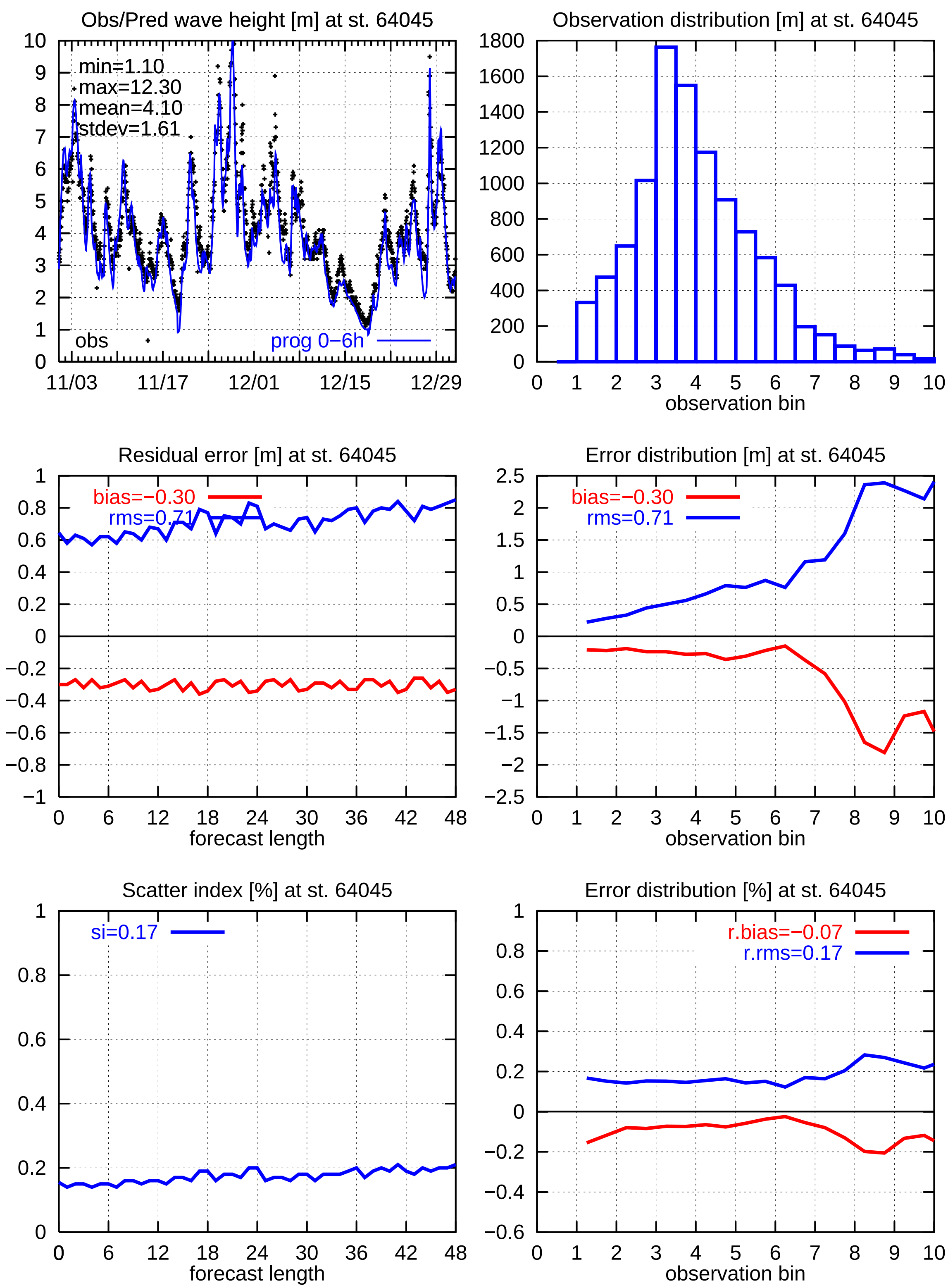

Figure 34. st. 64045: significant wave height

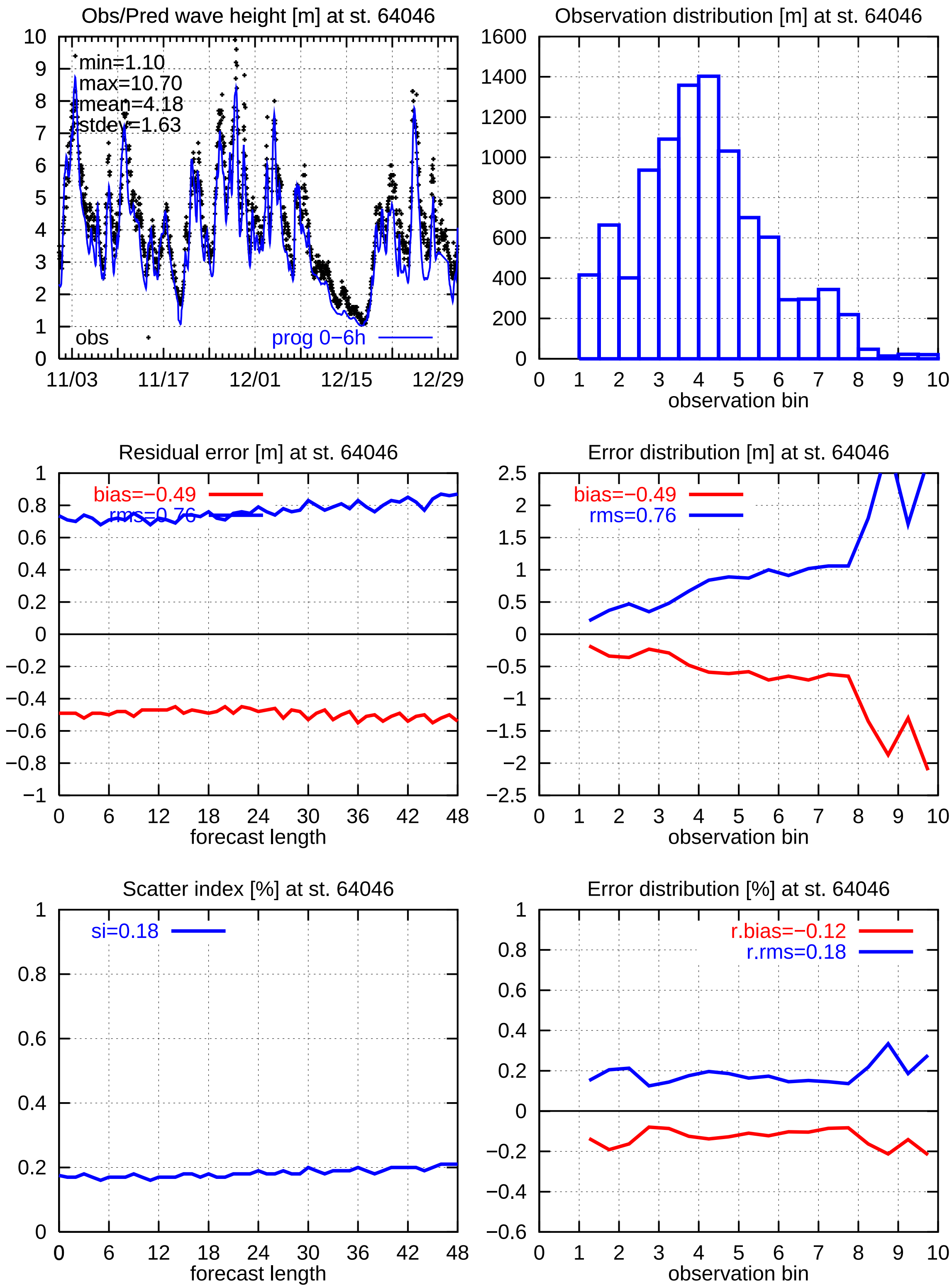

Figure 35. st. 64046: significant wave height

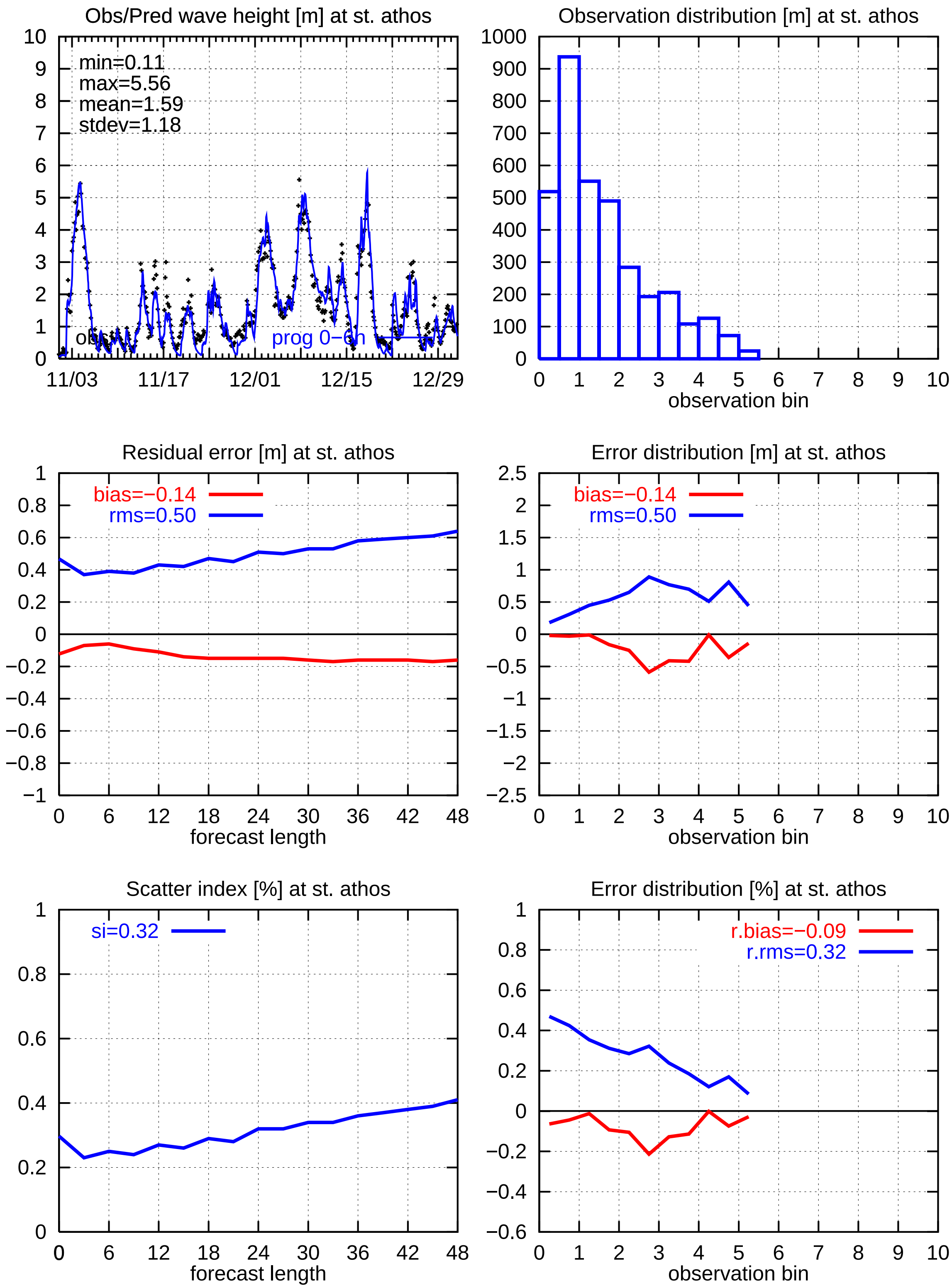

Figure 36. st. Athos: significant wave height

7.5 Mean wave period station plots

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

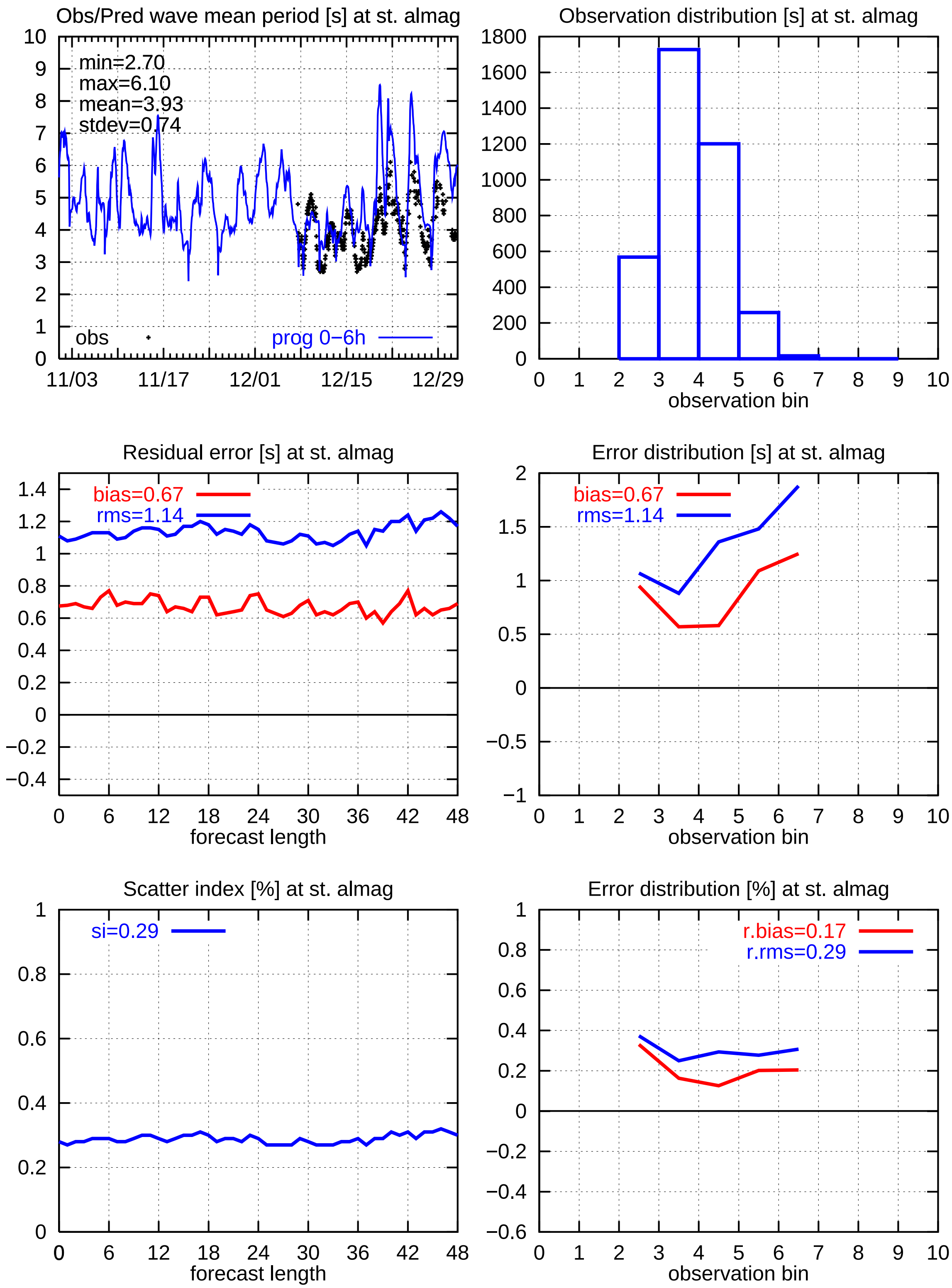

Figure 37. st. Almagrundet: mean wave period

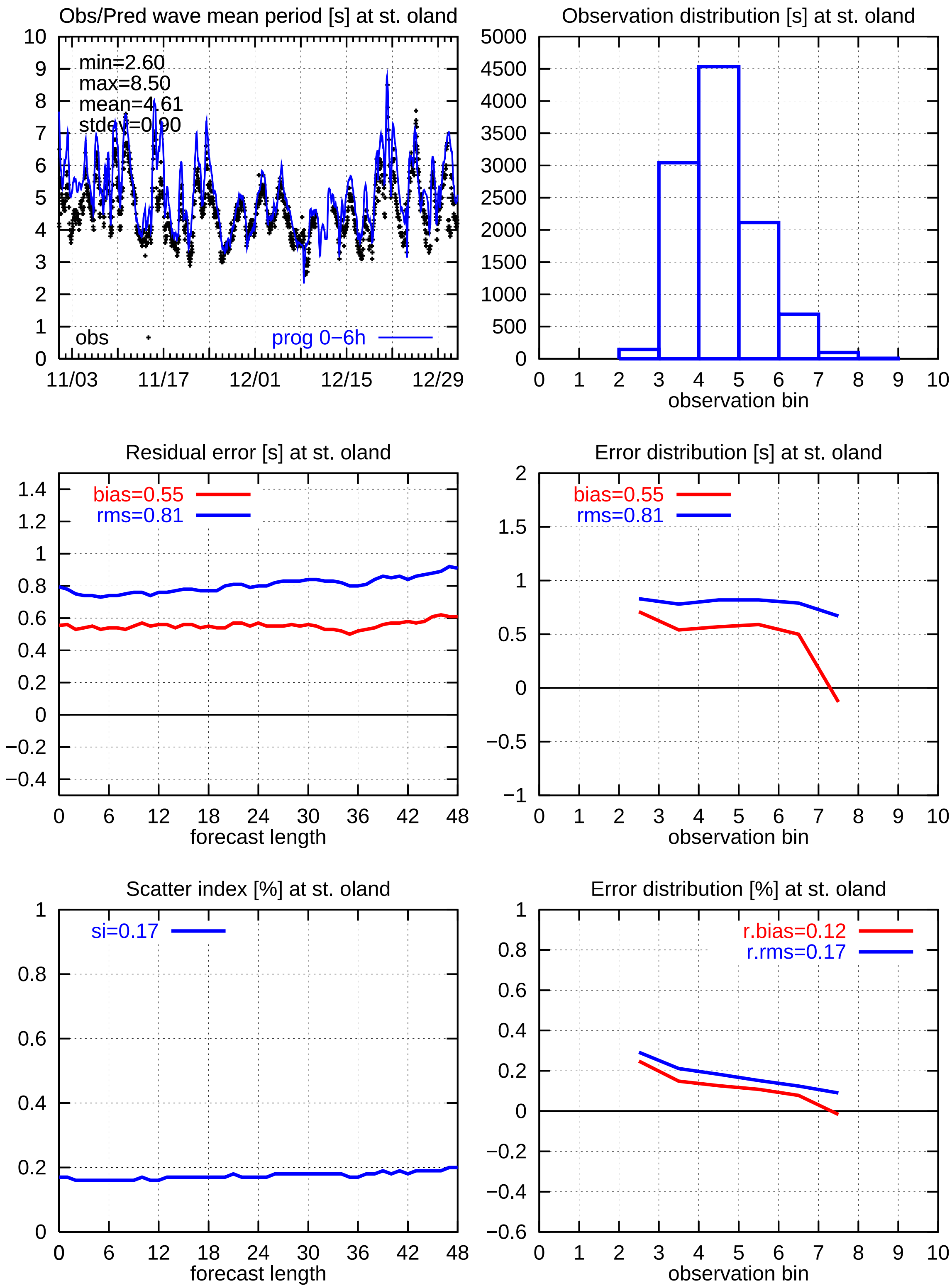

Figure 38. st. Øland: mean wave period

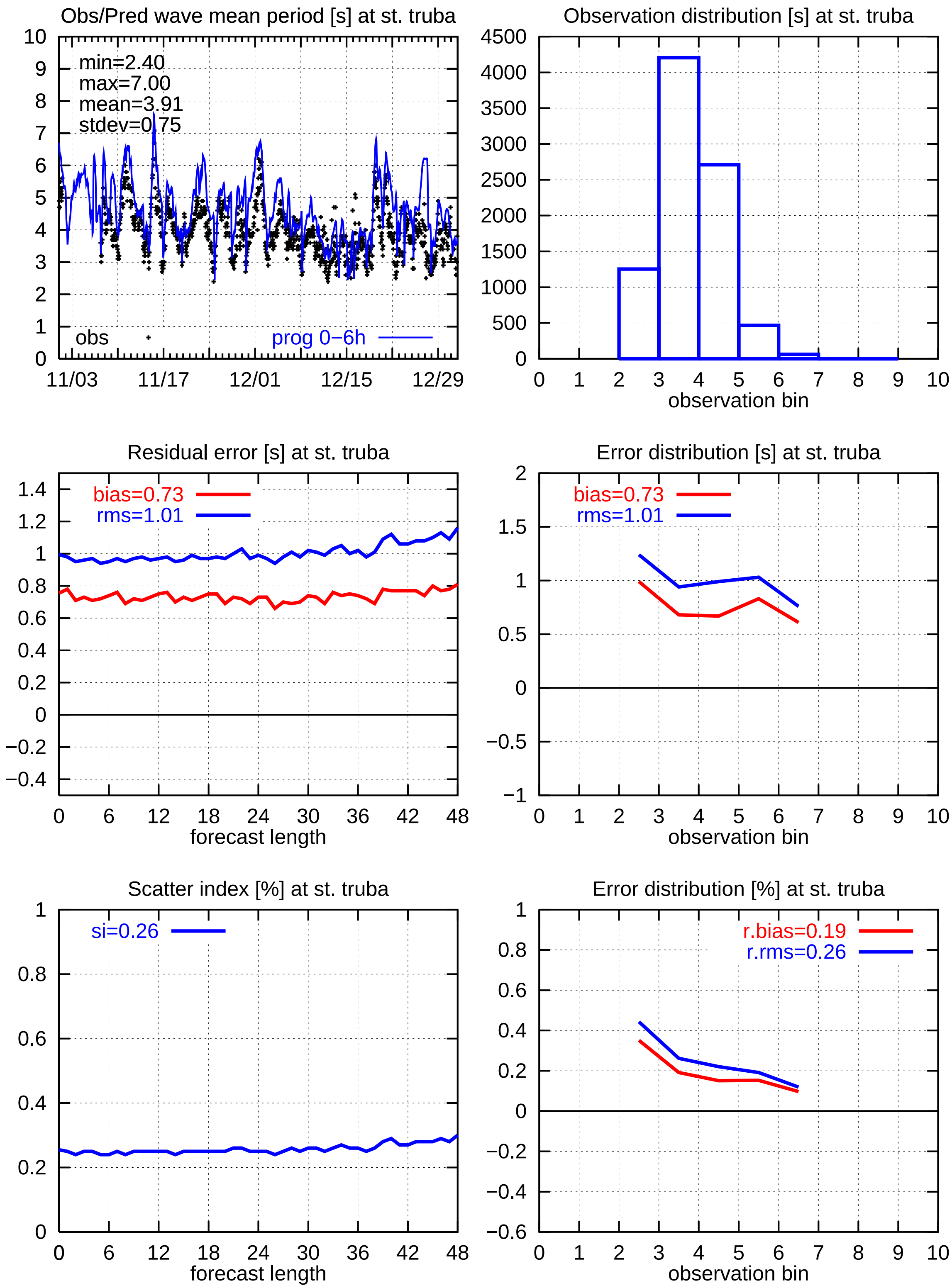

Figure 39. st. Trubaduren: mean wave period

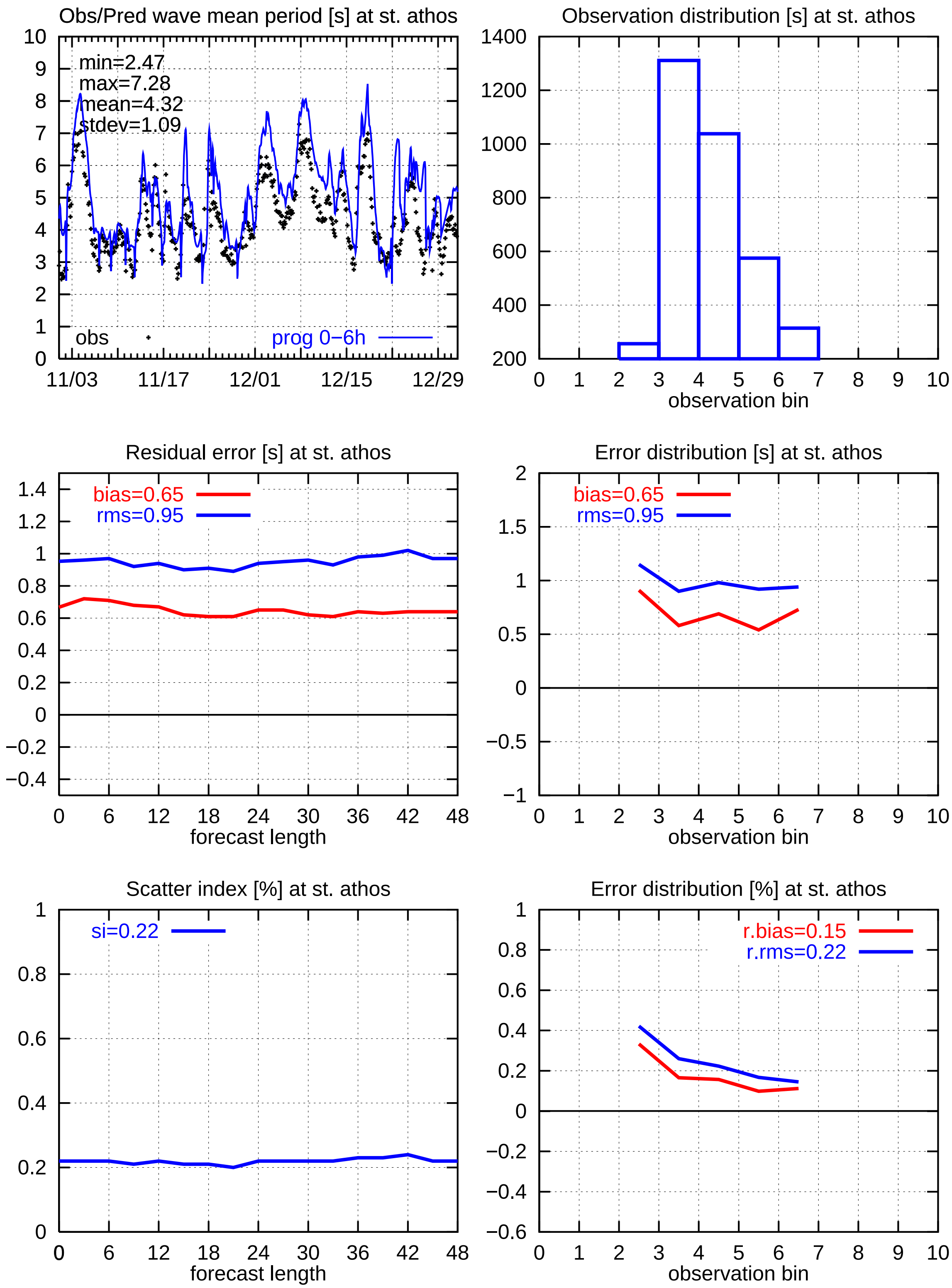

Figure 40. st. Athos: mean wave period

7.6 Dominant wave period station plots

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

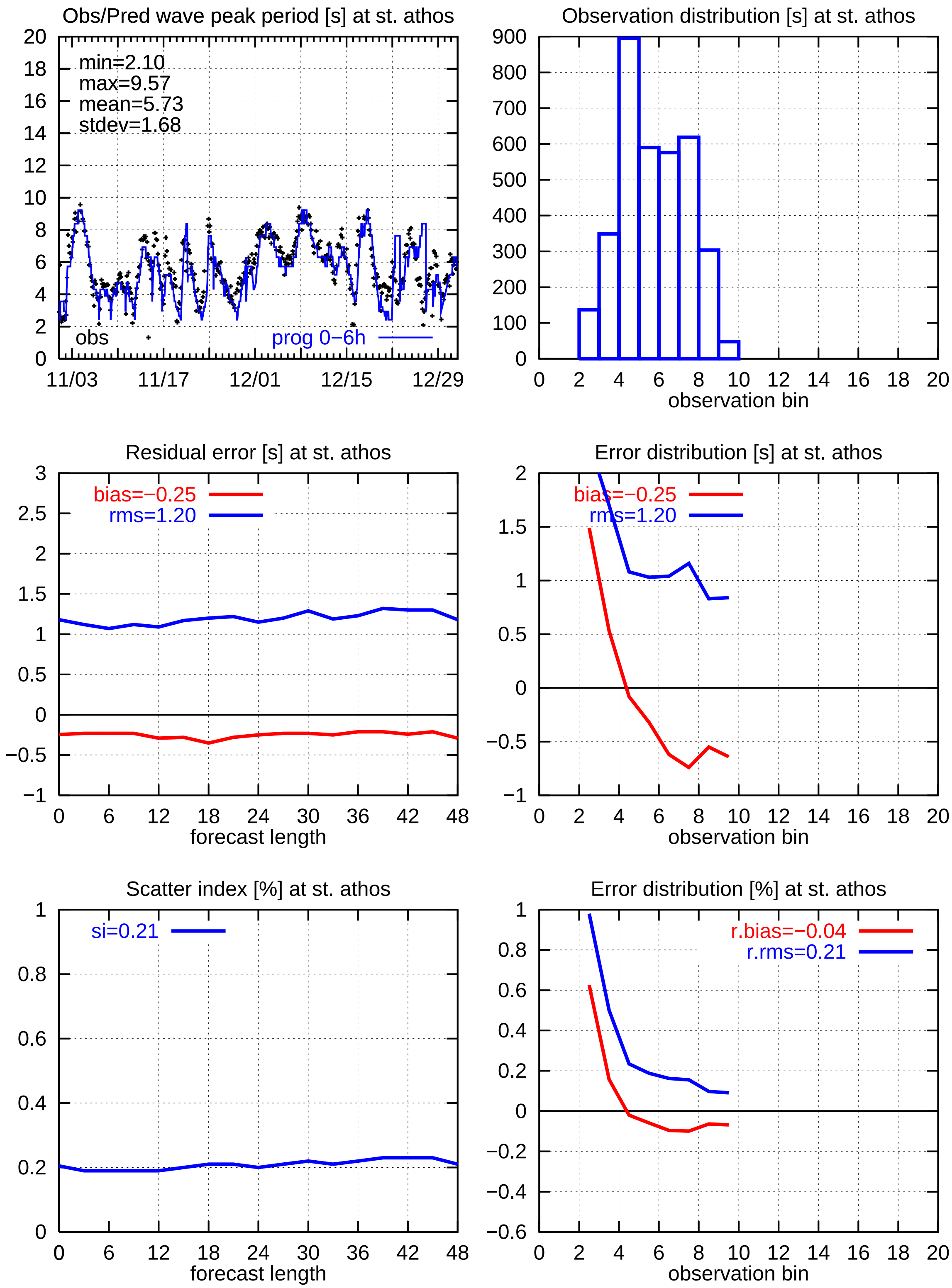

Figure 41. st. Athos: dominant wave period

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[1] G. Komen et al. *Dynamics and Modelling of Ocean Waves*. Cambridge University Press, 1994.

[2] The SWAMP group. *Ocean Wave Modelling*. Plenum Press, New York, 1985.

[3] H. Günther, S. Hasselmann, and P. Janssen. Wamodel cycle4 (revised version). Technical Report 4, Deutches Klimarechnenzentrum, 1992.

[4] J. She. Hirlam-wam quality assessment on winds and waves in the North Sea. Scientific Report 00-27, Danish Meteorological Institute, 2000. Copenhagen, Denmark.

[5] J. She and J.W. Nielsen. Operational wave forecasts in Baltic and North Sea. Scientific Report 99-07, Danish Meteorological Institute, 1999. Copenhagen, Denmark.

List of Tables

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