ATTACHMENT N: OCEANWEATHER EXTREME WAVE STUDY

Wave Extreme Storm Study for Cook Inlet: Kenai, Alaska

Submitted to

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1. INTRODUCTION

This report details a database of wave hindcasts in a certain class of Cook Inlet, Alaska storms, in aid of the redesign of a revetment that protects land on the north side of and near the entrance to the Kenai River, Cook Inlet. The redesign requires specification of 50-year return period extremes. The total design profile requires the generation of winds, waves, water level variations (from the semi-diurnal tidal range, and wind/pressure forcing surge effects), and temporal varying ice field covering Cook Inlet. The engineering need is being satisfied through a series of linked-studies, beginning with a survey and assembly of historical metocean data in the area of interest, followed by reconstruction of wind fields for a population of the highest ranked storms of the relevant type, use of the wind fields to drive a proven third-generation (3G) basin and regional scale numerical spectral wave prediction model that considers not only sea states generated within Cook Inlet but also wave energy propagated into the Inlet from the contiguous North Pacific Ocean and that ultimately provides boundary conditions to a local hyperfine wave model (STWAVE) that provides the data needed for the coastal engineering associated with the revetment design. This report does not include STWAVE or storm surge modeling, which will be carried out by separate parties.

The metocean data assembly and wind field analysis phases of the study were carried out by Oceanweather in 2009. The storm type of interest has been identified to be the transient episodes of strongly inlet rectified and accelerated southwesterly flows. Thirty such events have been identified within the period 1970-2007 and the wind fields produced are available for the wave hindcast.

2. WAVE MODEL SETUP

UNIWAVE Model

Overview

OWI’s standard UNIWAVE high-resolution full spectral wave hindcast model was used for all wave hindcasts. UNIWAVE incorporates deep water and shallow processes and the option to use either OWI’s highly calibrated first generation source term physics (ODGP2) or third generation (3G) physics (OWI3G). OWI3G was developed in the early 1990s under sponsorship of Environment Canada and for a time the model served as the operational wave forecast model of the Canadian Meteorological Center, and was known as CSOWM.

Computational details on the OWI's 3rd generation physics can be found in Khandekar *et al.* (1994) and Forristall and Greenwood (1998). OWI3G follows rather faithfully the formulation of the first 3G spectral wave model, WAM (WAMDI, 1988) with a few notable exceptions as noted below. In general, 3G models solve the action balance equation for the time rate change of directional wave spectra

$$\frac{DN(\vec{x},t,f,\theta)}{Dt} = \sum_i S_i$$

where $N(\vec{x},t,f,\theta)$ is the wave action and equal to $E(\vec{x},t,f,\theta)/\omega$ where E is the directional wave spectrum in frequency (f) and direction (θ), and ω is the radial frequency. S_i represents the source sink mechanisms:

$$\sum_i S_i = S_{in} + S_{nl} + S_{ds} + S_{w-b} + S_b$$

and S_{in} is the atmospheric input S_{nl} is the nonlinear wave-wave interaction, S_{ds} is dissipation due to high frequency wave breaking, S_b is the bottom dissipation and S_{w-b} is the sink mechanism for depth limited wave breaking (depth-limited breaking is not included in OWI3G).

The action balance equation is solved by what is called the "fractional-step" method; that is, solution of the action balance equation is split into the advective and source-sink parts and solved in alternative steps. The advective effect operated only on the spatial distribution in action density, or the second term on the right hand side of the equation below:

$$\frac{DN(\vec{x},t,f,\theta)}{Dt} = \left\{ \frac{\partial}{\partial t} + \vec{c}_g \cdot \frac{\partial}{\partial \vec{x}} \right\} N(\vec{x},t,f,\theta)$$

where $\vec{c}_g$ is the group speed of each spectral wave component defined for each frequency by the depth-dependent linear dispersion relationship:

$$\omega^2 = g\kappa \tanh(\kappa h)$$

and ω is the radial frequency (ω=2πf), h is the water depth and κ is the wave number (κ=2π/L, where L is the wavelength defined at frequency f, and dependent on the water depth).

The advection scheme in OWI3G is described briefly below. Once the spectra are updated for propagation over the fixed grid, the source term integration is computed or ∂N/∂t.

The Spectral Resolution

Direction: 24 bands. Band 1 is centered 7.5° clockwise from true north; the width of each band is 15°

Frequency: Band 1 is centered on 0.039 hz; the bands increase in geometric progression (ratio = 1.10064) to band 23, .32157 hz. This binning is negligibly coarser than used WAMDI (ratio = 1.100) and no coarser than that used in typical 15 frequency binning of ODGP.

Propagation Scheme

The downstream interpolation scheme described by Greenwood et al. (1985) is used throughout. Propagation over a time step at a grid point is implemented within the alternate growth-propagation cycle in the model integration by forming linear combinations of spectral variances at neighboring points. The weights used are extracted from a pre-computed table of propagation coefficients, which vary by latitude only in deep water, and are specific to each grid point in shallow water. The table of interpolation coefficients is calculated based upon great circle wave ray paths in deep water; in shallow water the weights are calculated following a ray tracing study through a digital bathymetry resolved on the wave model grid and thereby include the effects of refraction and shoaling.

The limiting water depth for shallow propagation and growth processes is taken according to the conventional definition:

$kd > \pi$, where $k = .006123\ m^{-1}$ for the .039 Hz frequency bin.

Spectral Growth/Dissipation Algorithms

The spectral growth algorithm used in OWI3G follows closely that of WAM. Also, the individual source terms follows the theoretical forms used in WAM but with different numerics and code and with the following modifications. First, a linear excitation source term is added to atmospheric input terms, S_{in}, taken as a downscaled variant of the term used in OWI's 1G ODGP model (see e.g. Khandakar et al., 1994 for a description of the 1G model source terms). This allows the sea to grow from a flat calm initial condition in OWI3G, unlike all cycles of WAM which require an artificial warm start from a prescribed initial spectrum. The exponential input term is the empirical form of Snyder et al. (1981) with a slightly rescaled coefficient, in which S_{in} is taken as a linear function of friction velocity U_*. However, unlike WAM in which U_* is computed from the 10 meter wind speed U_{10} following the drag law of Wu (1982), in OWI3G, a different drag law is used that was developed in the model tuning stage. That drag law follows Wu closely up to about 20 m/sec then becomes asymptotic to a constant at wind speeds above 30 m/s. It appears that OWI3G was the first wave model to incorporate a saturation surface drag formulation. That is, rather than retain the usual unlimited linear increase of the drag coefficient with increasing wind speed; OWI3G capped the drag coefficient at a value of 2.2×10^{-3} which is reached at a wind speed of 29.5 m/s. Recent estimates of the 10-m surface marine drag coefficient in extreme winds in the field (Powell et al., 2003) and in a wind-tunnel/wave-tank set up (Donelan et al., 2005) tend to support the notion of saturation of the drag coefficient at high wind speeds.

The non-linear term is approximated by the standard Discrete Interaction Approximation (DIA) except that in OWI's model a second quartet of interactions is included as described by Forristall and Greenwood (1998). As in WAM, the non-linear transfer for waves in shallow water are described by the deep water transfer multiplied by a scaling factor which is a function of wave number and water depth (see Hasselman and Hasselman, 1985).

The dissipation source term, S_{ds} is also taken from WAM except that the dependence on frequency is cubic rather than quadratic.

OWI3G was developed based upon tuning runs against the fetch-limited growth benchmark for 20 m/s wind speeds under constant winds used to tune WAM, and trial hindcasts of a well-documented moderate extratropical cyclone (SWADE IOP-1, see Cardone et al., 1995) and two intense Gulf of Mexico hurricanes (Camille, 1969; Frederick, 1979). The bottom friction source term is a simple quadratic law with a specified tunable friction factor. The friction factor adopted in the North Sea version of WAM (NEDWAM) is .076, which is exactly twice the value originally proposed for WAM, which was based upon studies of pure swell attenuation in the North Sea JONSWAP experiment. In GOMOS we have used the smaller JONSWAP friction coefficient since it appears to provide more nearly unbiased wave predictions in shallow water.

An interesting comparison of the performance of OWI's first generation (1G) model and OWI3G in an extratropical setting is given by Khandekar, et al. (1994) a comparison of the performance of OWI1G, OWI3G and the latest cycle of WAM (WAM-4) in extreme storms is given in Cardone et al. (1996). Much more extensive validations of OWI's 3G wave model in long-term hindcast studies are given recently by Swail and Cox (2000) and Cox and Swail (2001) and Swail et al.(2006).

Kenai7km

The Kenai7km mesh is a 3G application of the UNIWAVE model on a latitude-longitude grid of .0625 degree in latitude by 0.125 degree in longitude (Figure 1). The model grid covers the domain of 55.3125-61.8125N and 201.250-211E and has 1,982 active grid points. Bathymetry for the grid was obtained from the Alaska Ocean Observing System (AOOS) Digital Elevation Model (DEM) version 1.03 which provides a netCDF archive with nominal spacing of 1km. The DEM datum is not specified, but source documentation indicates that the data was primarily based on electronic navigation charts. A comparison of DEM data in the Kenai area against Chart 16662 shows good agreement and it was assumed that the data represent a mean lower low water reference. DEM data were not modified for use in the Kenai7km model. A model minimum depth of 3 meters was applied at all locations. All simulations were made assuming zero-ice with all wave points active in the model.

Boundary spectra along the exposed southern boundary of the model were provided from the Global Reanalysis of Ocean Waves Fine Northeast Pacific (GROWFine:NEPAC) model which is an hourly archive of wave spectra from a 35 km Northeast Pacific hindcast. The GROWFine: NEPAC also includes pickup from a global archive, so all northern and southern hemisphere swells reaching the Kenai7km wave grid are represented. Details on the GROWFine: NEPAC hindcast are found in the *GROWFINE: NEPAC Project Description* document which has been delivered with the hindcast.

Kenai/KenaiMTR

Nested within the Kenai7km grid are the Kenai and KenaiMTR grids. Both grids apply the UNIWAVE model on a latitude-longitude grid of .0125 degree in latitude by 0.025 degree in longitude (Figure 2/3). The model grids cover the domain of 60-61.25N and 207-209E and have 2,860 active grid points. Bathymetry for the grids was also obtained from the AOOS DEM, with the Kenai model applying the unmodified depths and KenaiMTR (Mean Tidal Range) applies an additional 5.38 meters added to all depths to represent the mean tidal range as obtained from chart 16662. A model minimum depth of 3 meters was applied at all locations. Results from both Kenai and KenaiMTR model grid are provided, but only the KenaiMTR results are applied to derive the 50-year wave conditions. All simulations were made assuming zero-ice with all wave points active in the model.

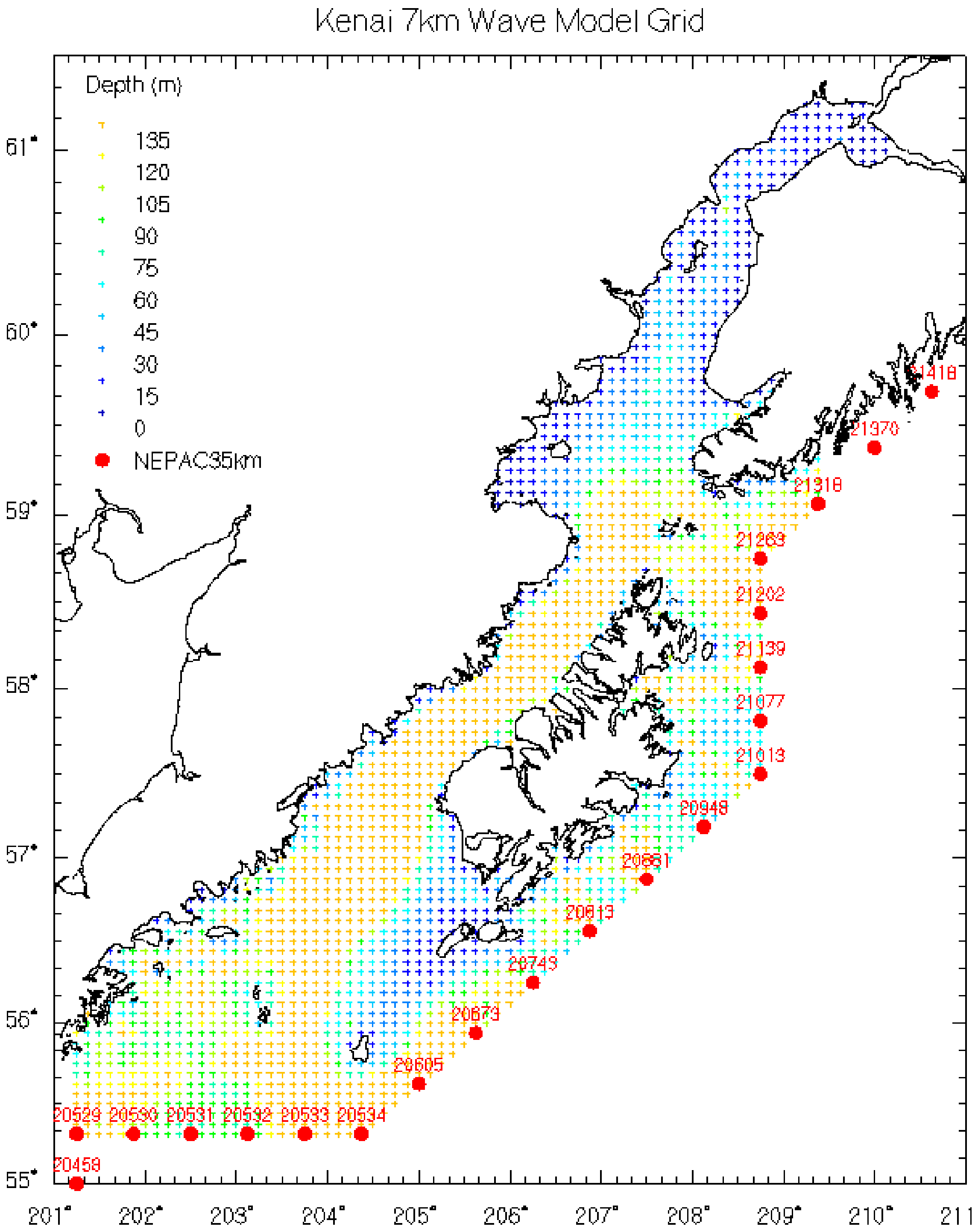


Figure 1 Kenai7km wave model grid with GROWFine:NEPAC spectral boundary locations

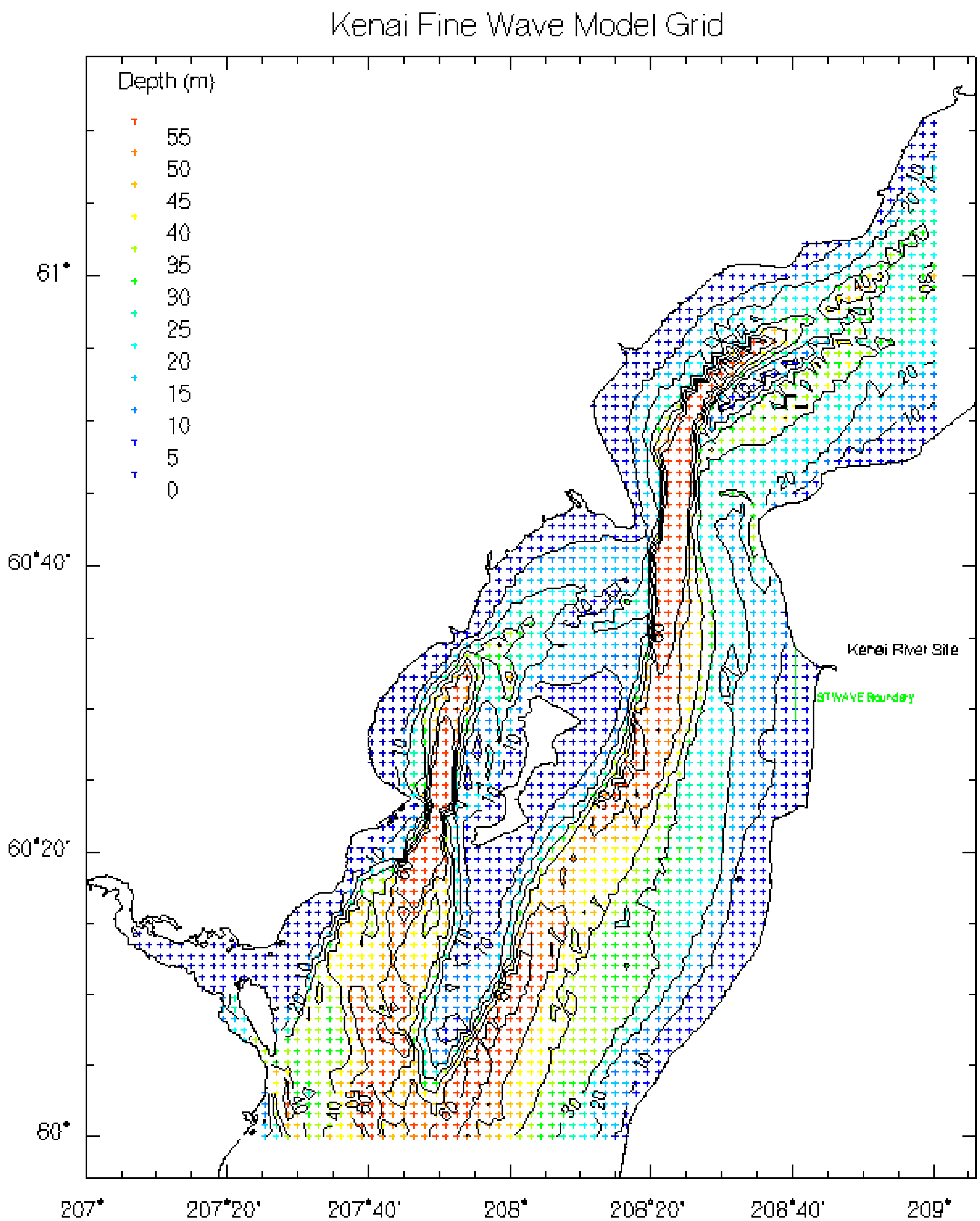


Figure 2. Kenai wave model grid applying unmodified AOOS DEM bathymetry

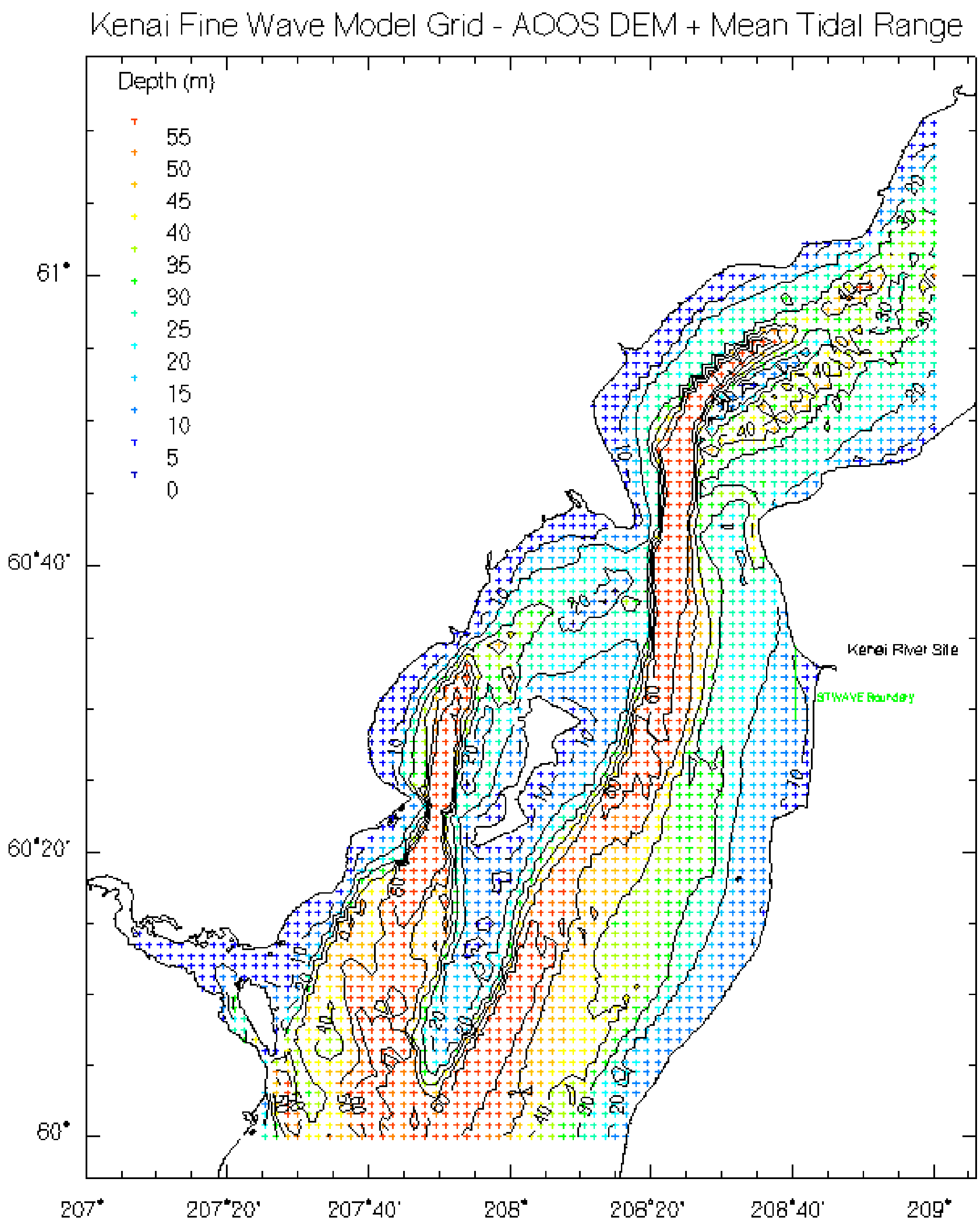


Figure 3 KenaiMTR wave model grid applying unmodified AOOS DEM bathymetry plus the mean tidal range at Kenai

CONTINUOUS HINDCAST VERIFICATION

Of the many NDBC (National Data Buoy Center) buoys deployed in the eastern North Pacific, the only buoy situated within Cook Inlet is buoy 46106 (59°45'36" N 152°5'24" W) and it has been deployed only since 2007. Also of interest is buoy 46077 (57°55'12" N 154°15'15" W) which is located in the Shelikof Strait and is more exposed to North Pacific swells. Unfortunately, no high ranked storms analyzed by Oceanweather were selected from 2007 or 2008. Thus, the need for continuous hindcasting during 2007/2008 was tasked to search for swell events and establish the model swell performance.

Complicating the validation procedure was the lack of good local wind fields. In the storm hindcast study, winds within Cook Inlet were subject to individual storm analysis. In the continuous hindcast, GROWFine:NEPAC winds were applied which do not include very localized effects. To properly evaluate the swell performance, statistical comparisons were restricted to time periods were the measured peak spectral period is 10 seconds or greater to remove contamination due to local events. Figure 4 shows a monthly timeseries of measurements and hindcast winds and waves during January 2008. Waves with measured periods >= 10 seconds are highlighted in blue. All 10+ second events are extracted for the two buoys over the 2007-2008 period are shown in Figure 5 as a scatter plot with summary statistics. Most of the events selected are from buoy 46077 which is more exposed to Northeast Pacific swells. Overall, there was zero wave bias and a RMS error of 40 cm in the significant wave height comparisons.

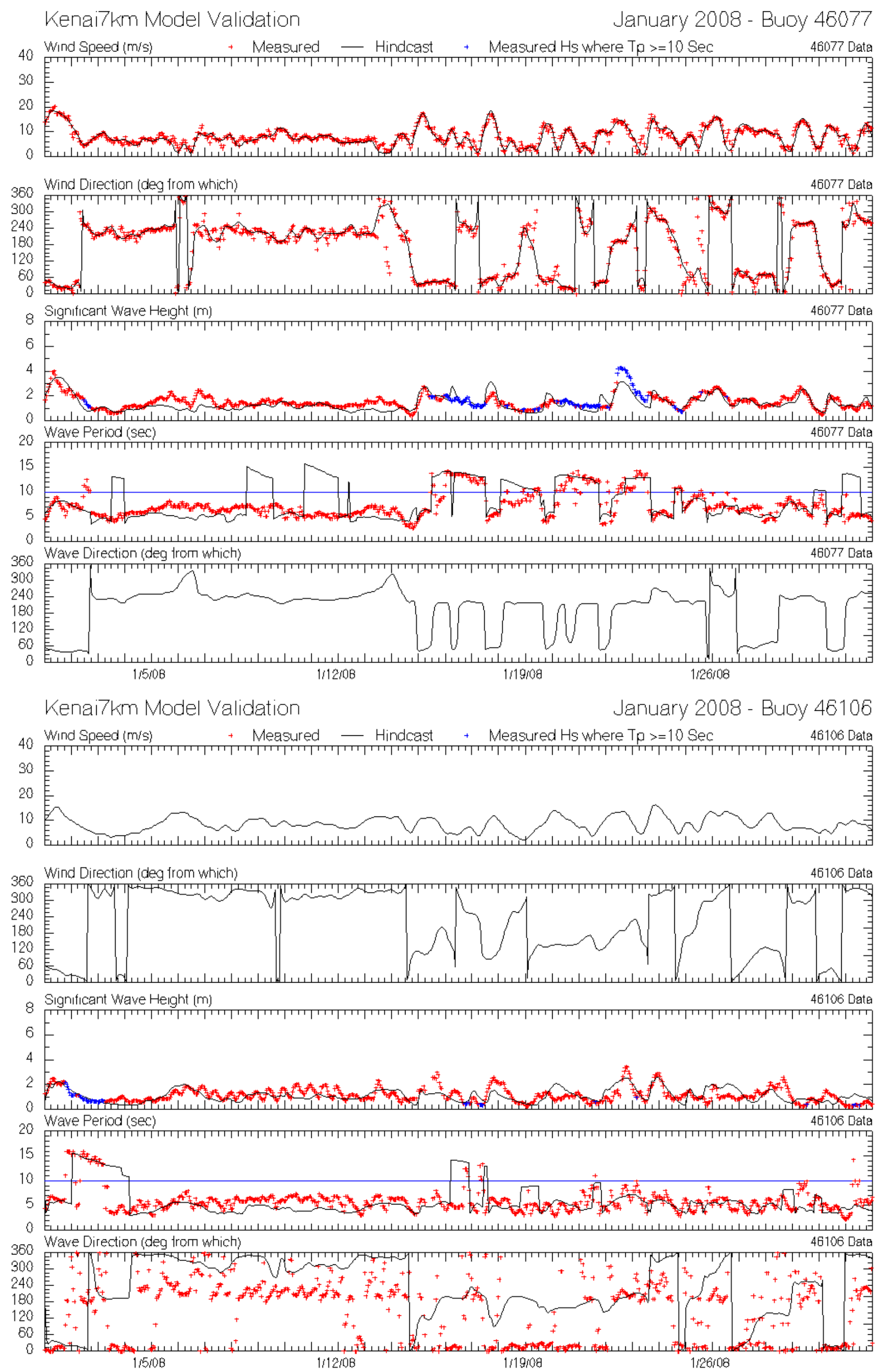
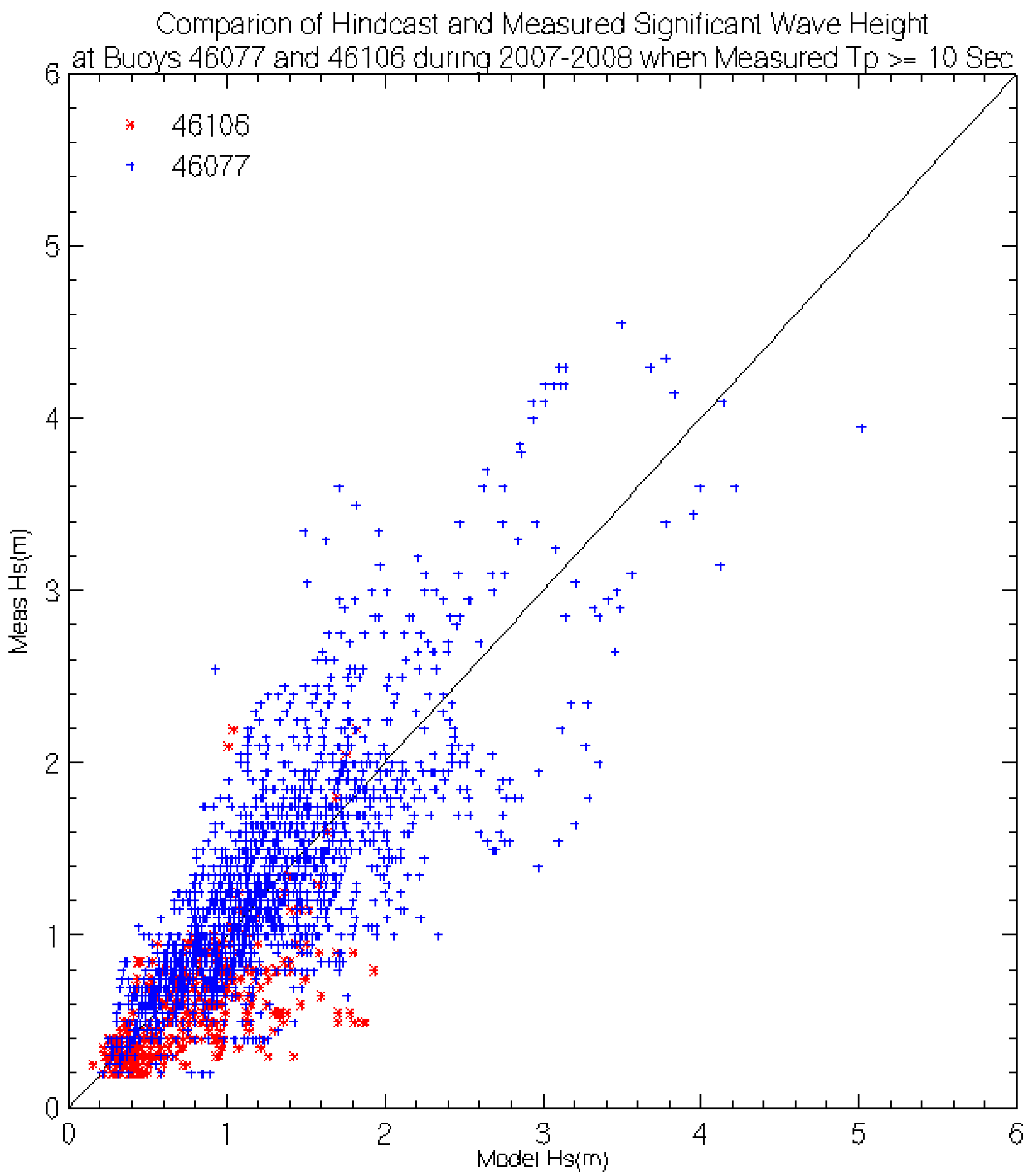


Figure 4. Monthly timeseries plots of winds and waves at buoys 46077 (top) and 46106 (bottom) during January 2008.



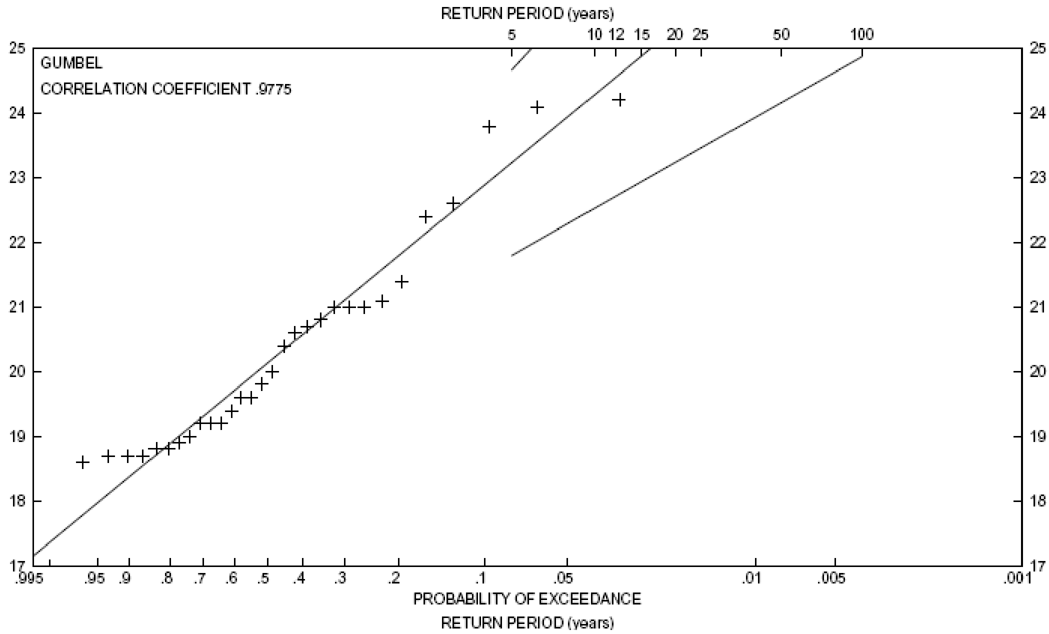
	Station	Grid Point	Number of Pts	Mean Meas	Mean Hind	Diff (H-M)	RMS Error	Stnd Dev	Scat Index	Ratio	Corr Coeff
Wind Spd. (m/s)	Combined	0	1589	6.03	6.76	0.73	2.76	2.66	0.44	0.57	0.69
Wind Dir. (deg)	Combined	0	1589	129.97	216.74	5.37	N/A	46.04	0.13	N/A	N/A
Sig Wave Ht (m)	Combined	0	2151	1.19	1.19	0.00	0.40	0.40	0.34	0.50	0.81
Wave Period (s)	Combined	0	2151	11.48	9.99	-1.49	3.77	3.46	0.30	0.45	0.27
Wave Dir (deg)	Combined	0	349	199.85	170.97	-34.67	N/A	83.50	0.23	N/A	N/A

Figure 5. Scatter plot of significant wave heights when measured peak wave period was >= 10 seconds with summary statistics

50-YEAR CONDITIONS BASED ON NIKISKI

A task requested in the original proposal was to test constant winds through various wind directions to determine the most energetic wind direction for wind-sea extremes. In order to run a series of winds that were consistent with the desired 50-year conditions it was proposed to run a series of eight wind directions using the 50-year return period wind speed as determined by an analysis of measured wind peaks at National Ocean Station 9455750 (NKTA2) at Nikiski, Alaska (60°41'0" N 151°23'54" W). This measurement station provides a 13 year record of measured winds at a coastal location just north of Kenai. It was determined during the previous wind study to be the best dataset for local winds.

Data for Nikiski were obtained from the National Ocean Service and were adjusted for height, stability and directional roughness (see wind report for details) to obtain a 13 year record (Sept-1996 to Sept 2008) of wind speeds and wind directions. Some manual editing was performed to remove spurious spikes in the dataset, but overall the data was very clean. A peak over threshold analysis applying Gumbel distribution (see Appendix for Gumbel definition) on the top 30 wind peaks was performed for the omni-directional, and eight wind directional sectors. Figure 6 shows an example of the omni directional fit and extremes using the Gumbel distribution resulting in an omni-directional 50-year wind speed of 26.3 m/s. This procedure was repeated for eight directional bins, based on measured wind direction, and extremes are summaried in Table 1.



Onmi Directional Extremes at Nikiski
Top 30 storms
24.20, 24.10, 23.80, 22.60, 22.40, 21.40, 21.10, 21.00, 21.00, 21.00, 20.80, 20.70, 20.60, 20.40, 20.00,
19.80, 19.60, 19.60, 19.40, 19.20, 19.20, 19.20, 19.00, 18.90, 18.80, 18.80, 18.70, 18.70, 18.70, 18.60,

Period	Prob.	Gumbel	lcl	ucl
5.	0.0800	23.23	21.80	24.67
10.	0.0400	24.28	22.52	26.03
12.	0.0333	24.55	22.71	26.39
15.	0.0267	24.88	22.94	26.82
20.	0.0200	25.31	23.24	27.38
25.	0.0160	25.64	23.46	27.82
50.	0.0080	26.66	24.17	29.16
100.	0.0040	27.68	24.87	30.49

Figure 6. Gumbel fit to Nikiski wind speeds

Table 1 50-year wind speed extremes at Nikiski by wind direction

Sector	Wind Direction (deg, from which)	50-year Wind Speed (m/s)
NNE	22.5°	26.1
ENE	67.5°	19.4
ESE	112.5°	21.4
SSE	157.5°	25.0
SSW	202.5°	26.5
WSW	247.5°	24.6
WNW	292.5°	19.0
NNW	337.5°	22.9

Each storm period applied a sector direction/50-year wind speed held constant over a 48-hour period. The Kenai7km model was run with no spectral boundary conditions, while the Kenai and KenaiMTR grids used the corresponding Kenai7km boundary conditions. Figure 7 shows the contours of maximum winds and waves resulting from each of the hindcasts for the SSW (South-Southwest) run. Maximum plots of all sector runs for each model are contained in the Appendix.

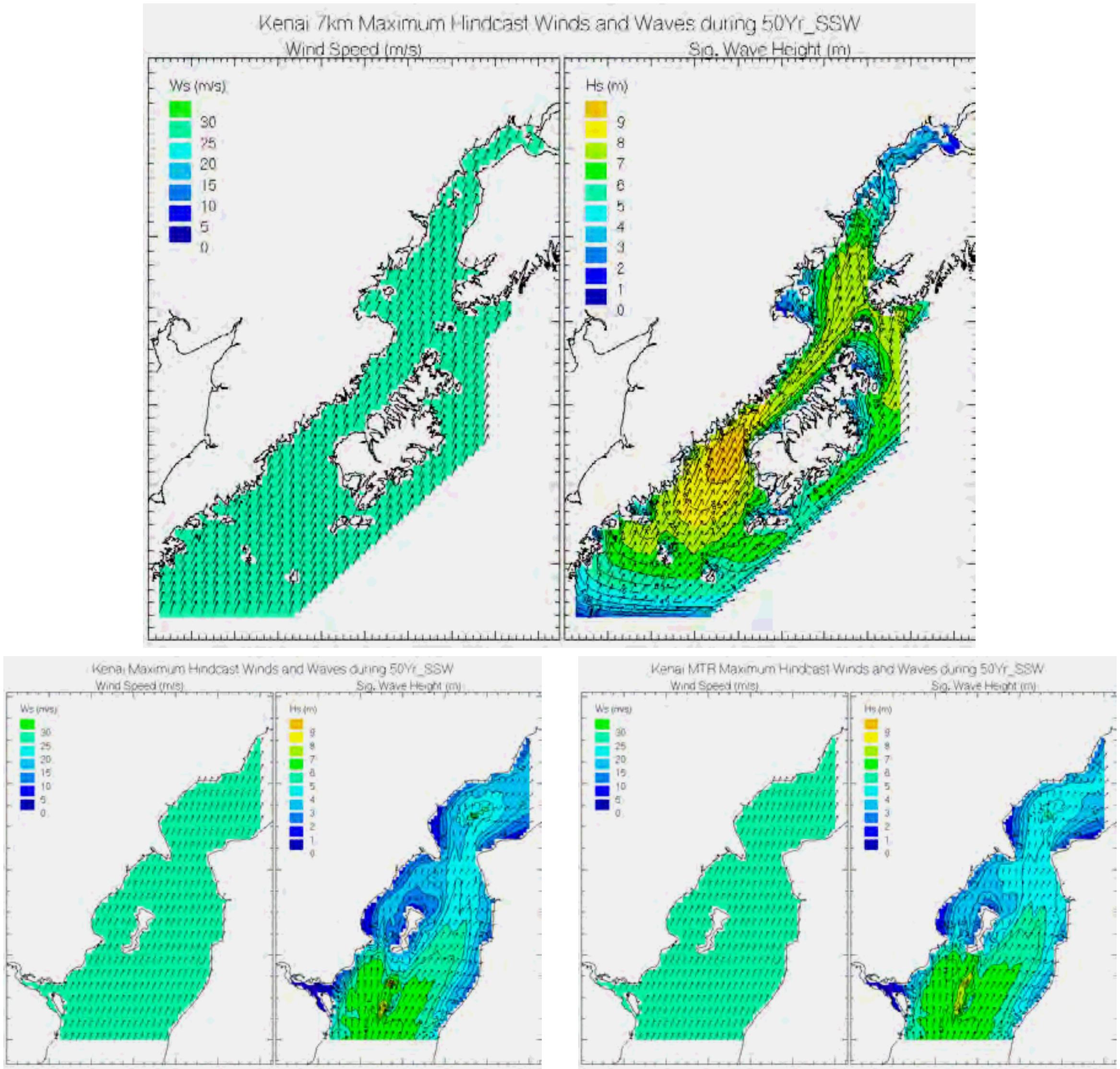


Figure 7 Maximum winds (m/s, left) and waves (m, right) for the SSW constant test on the Kenai7km (top), Kenai (bottom left) and KenaiMTR (bottom right) grids

STORM PRODUCTION AN D EXTREMES

Storm Production

In the previous wind study, a series of 30 storm events were hindcast to represent the most intense wave generation candidates (Table 2). Boundary spectra from the GROWFINE: NEPAC model were extracted for each storm period and applied along the boundary of the Kenai7km model grid. Each storm period was run with an additional 36 hours spin-up to the start times indicated in Table 2, this spin-up period was removed from all archived timeseries. All three model grids: Kenai7km, Kenai and KenaiMTR were run for all storms and wave fields archived on the Kenai and KenaiMTR at 15-minute timestep for all active grid points. All simulations were made assuming zero-ice with all wave points active in the model. Maximum wind and wave conditions during the 19730310 storm are shown in Figure 8. Plots of all storm maximum conditions are detailed in the Appendix.

Table 2. Storm periods from wind study

Storm ID	Start (CYMDH)	End (CYMDH)
19730310	1973030900	1973031112
19740303	1974030118	1974030412
19750126	1975012512	1975012718
19751021	1975102000	1975102206
19760130	1976012900	1976013112
19780820	1978081812	1978082112
19800207	1980020518	1980020806
19850228	1985022606	1985022812
19870222	1987022012	1987022300
19900827	1990082506	1990082800
19920515	1992051312	1992051606
19930921	1993092000	1993092200
19960925	1996092406	1996092700
19971229	1997122718	1997123006
19980817	1998081418	1998081806

19991223	1999122118	1999122406
20000128	2000012612	2000012900
20010228	2001022518	2001030100
20010404	2001040306	2001040512
20010502	2001042912	2001050218
20020213	2002021100	2002021318
20020501	2002042918	2002050200
20020927	2002092512	2002092800
20021008	2002100606	2002100818
20030105	2003010312	2003010606
20030727	2003072600	2003072818
20050924	2005092218	2005092600
20051019	2005101618	2005101906
20051124	2005112206	2005112418
20060818	2006081612	2006082018

Extremes

Timeseries from the KenaiMTR storm runs for grid point number 1780 located at 60.5375N 208.7000E at water depth of 7.08 meters were extracted for computing a 50-year return period significant wave height. Figure 9 shows the resulting Gumbel fit to the 30 hindcast significant wave heights which results in a 50-year return period of 3.1 meters at the grid point location. Interestingly, this result is within 10% of the significant wave height hindcast (2.9 meters at GP 1780) in the SSW test run which applied the steady-state Nikiski 50-year wind speed. The 50-year wave period associated with respect to wave height extreme (7.9 seconds) from storms is found from regressions of the form TP = C0* HS** C1 (TP in seconds, HS in meters). The wind speed 50-year return period (23.7 m/s) is obtained by the Gumbel peaks over threshold fit to the wind peaks in the 30 storms. All derived extremes at grid point 1780 as shown in Table 3.

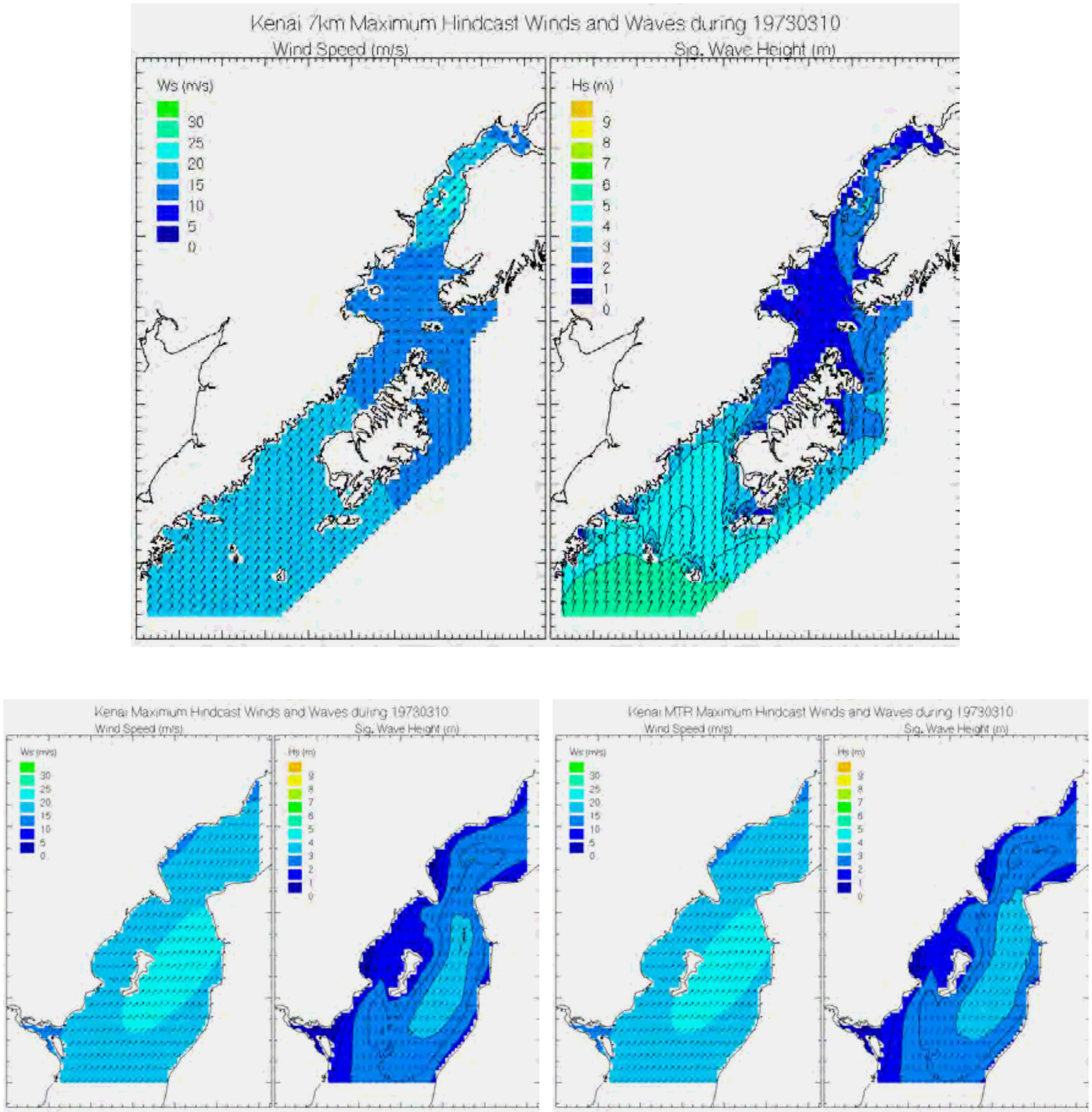
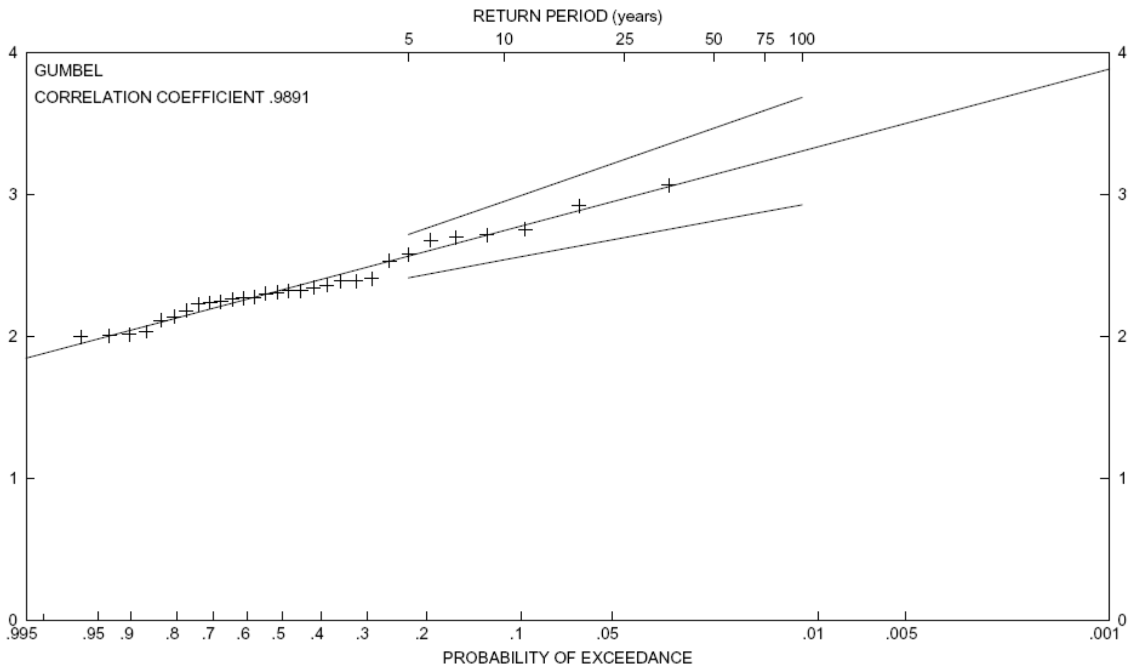


Figure 8. Maximum winds (m/s, left) and waves (m. right) for the 19730310 storm event on the Kenai7km (top), Kenai (bottom left) and KenaiMTR (bottom, right) grids.

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Onmi Directional Sig. Wave Height at GP1780 (KenaiMTR)
Max 3.069 * 0.5 = 1.5345; 30 storms
3.07, 2.92, 2.76, 2.71, 2.70, 2.68, 2.58, 2.53, 2.41, 2.39, 2.39, 2.36, 2.35, 2.33, 2.33,
2.31, 2.30, 2.28, 2.27, 2.27, 2.25, 2.24, 2.23, 2.18, 2.14, 2.12, 2.03, 2.01, 2.01, 2.00,

Period   Prob.  Gumbel   lcl    ucl
     0. 0.0000   0.00   0.00   0.00
     5. 0.2267   2.57   2.41   2.72
    10. 0.1133   2.75   2.54   2.95
    25. 0.0453   2.97   2.70   3.25
    50. 0.0227   3.14   2.81   3.47
    75. 0.0151   3.24   2.88   3.60
   100. 0.0113   3.31   2.93   3.69
```

Figure 9 Gumbel distribution fit to the peak sig. wave heights hindcast at GP 1780 from the KenaiMTR hindcast

Table 3 50-Year return period extremes at GP 1780 based on KenaiMTR storm runs

Variable	**50-Year Return Period**
Significant Wave Height (m)	3.1
Associated Wave Period (s)	7.9
Wind Speed (m/s)	23.7

DELIVERABLES

All hindcast deliverables are contained on a single DVD volume, including a copy of this report in PDF format.

Data-Sources-Grids

The Data-Sources-Grids directory contains much of the source data tapped for this study. Complete buoy data files obtained from the National Ocean Data Center in F291 format are contained in two zip files for NOAA buoys 46077 and 46016. See http://www.nodc.noaa.gov/General/NODC-Archive/f291.html for information on the F291 format. Source data for the Nikiski site was obtained from the National Ocean Service in METO.NOS format, see http://tidesandcurrents.noaa.gov/data_menu.shtml?stn=9455760 Nikiski, AK&type=Meteorological+Observations for information. Decoded measurements in a comma-delimited file (with hand edits for data spikes) are contained in the NTKA2-ED.csv file. Variables/units are given in the file header. Source bathymetry from AOOS (www.aoos.org) are provided in the AOOSbathymetricDEMv1.03.nc. This file is in netCDF format and contains header information as to its contents.

Grid files for the Kenai and KenaiMTR models are give both as ascii files and graphically as GIF images. Grid ascii files contain model lat and long (I,J), grid point number (kpt, 0=land), latitudes and longitudes (alat, along), landsea indicator (zang, 0=land, 360=water) as well as depth (meters, decimal and nearest integer).

Buoy-Verif

The Buoy-Verif directory contains comma-delimited CSV files and GIF images which contain the evaluations of the 2007-2008 continuous hindcasts against buoys 46077 and 46106. Periods where the measured peak period are >= 10 seconds are highlighted in blue in the GIF images. All CSV files contain modeled/measurement headers with units. Dates are provided in Julian format which is in the same definition as Microsoft Excel.

Wave-Hindcasts

The Wave-Hindcast directory contains plots, timeseries and spectra for all the storm runs (30 events plus 8 constant wind runs) for both the Kenai and KenaiMTR model grids. Each storm is in a unique directory and each contains a Plots, PtSort, and Spectra directory. The Plots contain the maximum wind/wave plots for each run. The PtSort directory contains the complete archive of winds and waves at each model grid point for the Kenai and KenaiMTR hindcasts. All dates are UTC and Julian dates in Microsoft Excel format. Definitions of the standard OWI wind and wave fields are shown in the Appendix. Timestep for all output is every 15-minute. Wave spectra were archived at 27 locations (see Table 4 and Figure 10) offshore of Kenai for use in follow-on STWAVE modeling. Each file contains the variances in each 23 frequency by 24 direction bands applied in the UNIWAVE model. Format description of the wave spectra may be found in the Appendix.

Wind-Study

This directory contains the complete wind study report and output previously delivered. This directory has not been modified from the original delivery and it contained here for convenience.

Table 4 Wave Spectra Archive Locations

Grid Point Number	Latitude (deg)	Longitude (deg)
1588	60.4750	208.6500
1589	60.4750	208.6750
1590	60.4750	208.7000
1623	60.4874	208.6500
1624	60.4875	208.6750
1625	60.4875	208.7000
1660	60.5000	208.6500
1661	60.5000	208.6750
1662	60.5000	208.7000
1669	60.5125	208.6500
1700	60.5125	208.6750
1701	60.5125	208.7000
1739	60.5250	208.6500
1740	60.5250	208.6750
1741	60.5250	208.7000
1778	60.5375	208.6500
1779	60.5375	208.6750
1780	60.5375	208.7000
1816	60.5500	208.6500
1817	60.5500	208.6750
1818	60.5500	208.7000
1854	60.5625	208.6500
1855	60.5625	208.6750
1888	60.5750	208.6500
1920	60.5875	208.6500
1950	60.6000	208.6500
1980	60.6125	208.6500

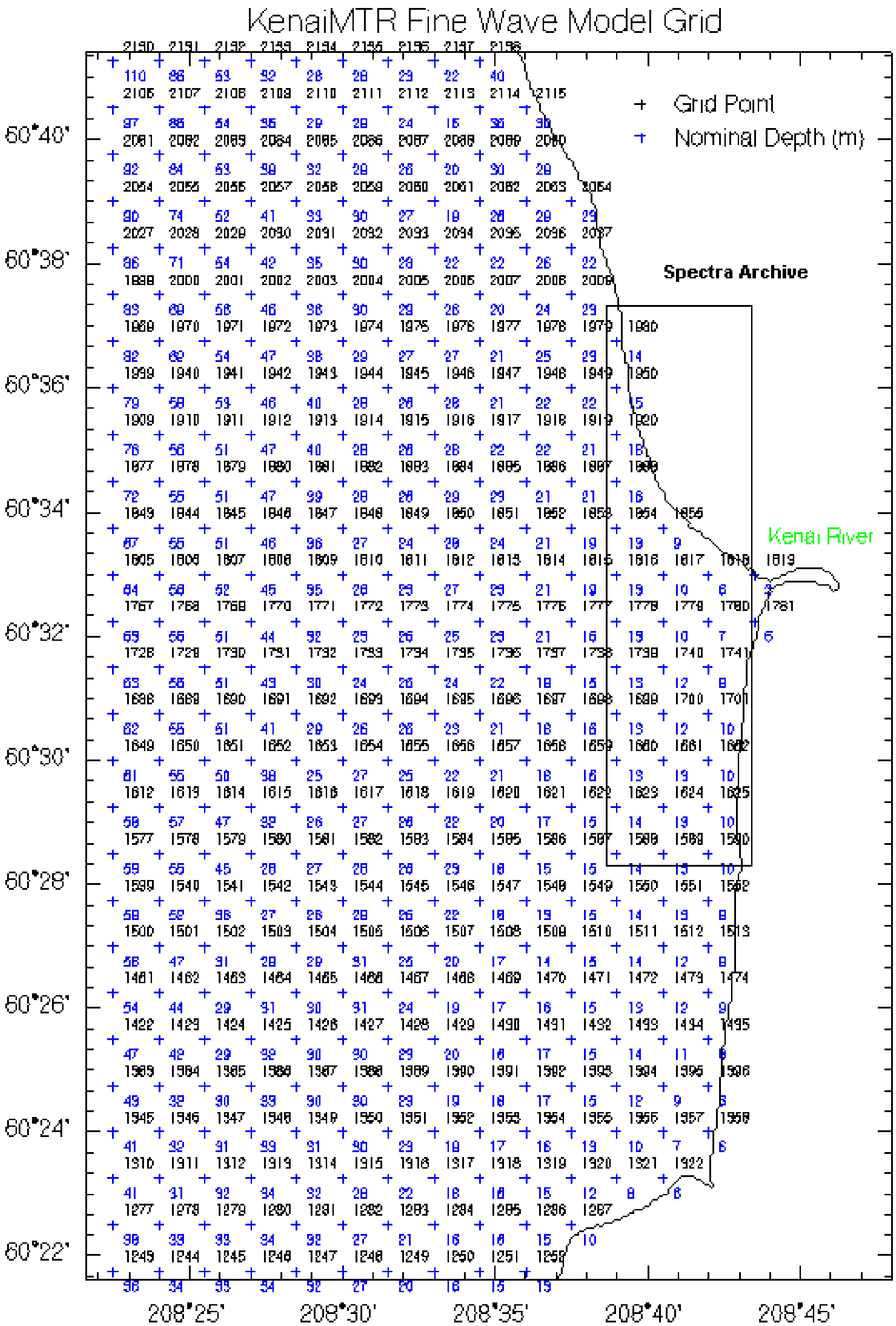


Figure 10 Wave spectra archive locations

REFERENCES

Cardone, V. J., H. C. Graber, R. E. Jensen, S. Hasselmann, M. J. Caruso. ***In search of the true surface wind field in SWADE IOP-1: Ocean wave modelling perspective***. The Global Atmosphere and Ocean System, 3, 107-150.

Cardone, V. J., R. E. Jensen, D. T. Resio, V. R. Swail and A. T. Cox. ***Evaluation of contemporary ocean wave models in rare extreme events: Halloween storm of October, 1991; Storm of the century of March, 1993.*** J. of Atmos. And Ocean. Tech., 13, 198-230.

Cox, A. T. and V. R. Swail. A Global Wave Hindcast over the Period 1958-1997: Validation and Climate Assessment. JGR (Oceans), Vol. 106, No. C2, pp. 2313-2329, February 2001.

Donelan, M.A., B. K. Haus, N. Reul, W. J. Plant, M. Stiassnie, H. C. Graber, O.B. Brown and E.S. Saltzman, 2004. On the limiting aerodynamic roughness of the ocean in very strong winds. Geophys. Res. Lttrs., Vol. 31, L18306

Forristall, G.Z. and J. A. Greenwood, 1998. Directional spreading of measured and hindcasted wave spectra. Proc. 5th International Workshop on Wave Hindcasting and Forecasting, Melbourne, FL, January 26-30, 1998

Greenwood, J.A., V.J. Cardone and L. M. Lawson, 1985. Intercomparison test version of the SAIL wave model. Oean Wave Modelling, the SWAMPO Group, Plenum Press, 221-233.

Hasselmann, S and Hasselmann, K.,1981. A symmetrical method of computing the non-linear transfer in a gravity wave spectrum. Hamb. Geophys. Einzelschriften, Reihe A: Wiss. Abhand, 52, 138pp.

Khandekar, M. L., R. Lalbeharry and V. J. Cardone. 1994. The performance of the Canadian spectral ocean wave model (CSOWM) during the Grand Banks ERS-1 SAR wave spectra validation experiment. Atmosphere-Oceans, 32, 31-60.

Powell, M.D., P.J. Vickery and T.A. Reinhold, Reduced drag coefficient for high wind speeds in tropical cyclones (2003), *Nature*, **422**, 279-283.

Snyder, R.L., Dobson, F.W., Elliott, J.AS., and Long, R.L. (1981). Array measurements of atmospheric pressure fluctuations above surface gravity waves. J. Fluid Mech., 102, 1-59

Swail, V. R. and A. T. Cox. On the use of NCEP/NCAR Reanalysis Surface Marine Wind Fields for a Long Term North Atlantic Wave Hindcast J. Atmo. Tech. Vol. 17, No. 4, pp. 532-545, 2000.

Swail, V.R., V.J. Cardone, M. Ferguson, D.J. Gummer, E.L. Harris, E.A. Orelup and A.T. Cox, 2006 ***The MSC50 Wind and Wave Reanalysis***. 9th International Wind and Wave Workshop, September 25-29, 2006, Victoria, B.C.

WAMDIG, (1988). The WAM model – a third generation ocean wave prediction model. J. Phys. Oceanogr., 18, 1775-1810.

Wu, J., 1982. Wind-stress coefficients over the sea surface from breeze to hurricane. J. Geophys. Res., 87, 9704-9706.

APPENDIX A OWI Wind and Wave Fields Definitions

Date in YYYYMM format (UTC)
Date in DDHHMM format (UTC)
Date in Julian format (MS-Excel definition)

WD Wind Direction:
From which the wind is blowing, clockwise from true north in degrees (meteorological convention).

WS Wind Speed:
1-hour average of the effective neutral wind at a height of 10 meters, units in meters/second.

ETOT Total Variance of Total Spectrum:
The sum of the variance components of the hindcast spectrum, over the 552 bins of the 3G wave model, in
meters squared.

TP Peak Spectral Period of Total Spectrum:
Peak period is the reciprocal of peak frequency, in seconds. Peak frequency is computed by taking the spectral density in each frequency bin, and fitting a parabola to the highest density and one neighbor on each side. If highest density is in the .32157 Hz bin, the peak period reported is the peak period of a Pierson-Moskowitz spectrum having the same total variance as the hindcast spectrum.

VMD Vector Mean Direction of Total Spectrum:
To which waves are traveling, clockwise from north in degrees
(oceanographic convention).

$$\text{VMD} = \tan^{-1}\frac{\int_0^{2\pi}\int_0^{\infty}\sin\theta E(f,\theta)\,df\,d\theta}{\int_0^{2\pi}\int_0^{\infty}\cos\theta E(f,\theta)\,df\,d\theta}$$

Explanation of sea/swell computation:
The sum of the variance components of the hindcast spectrum, over the 552 bins of the 3G model, in meters
squared. To partition sea (primary) and swell (secondary) we compute a P-M (Pierson-Moskowitz) spectrum, with a cos^3 spreading, from the adopted wind speed and direction. For each of the 552 bins, the lesser of the hindcast variance component and P-M variance component is thrown into the sea partition; the excess, if any, of hindcast over P-M is thrown into the swell partition.

ETTSEA Total Variance of Primary Partition "Sea"
TPSEA Peak Spectral Period of Primary Partition:
VMDSEA Vector Mean Direction of Primary Partition:

ETTSW Total Variance of Secondary Partition: "Swell"
TPSW Peak Spectral Period of Secondary Partition:
VMDSW Vector Mean Direction of Secondary Partition:

MO1 First Spectral Moment of Total Spectrum:

Following Haring and Heideman (OTC 3230, 1978) the first and second moments contain powers of $\omega = 2\pi f$; thus:

$$M_1 = \sum\sum 2\pi f dS$$
$$M_2 = \sum\sum (2\pi f)^2 dS$$

where dS is a variance component and the double sum extend over
552 bins.

MO2 Second Spectral Moment of Total Spectrum:

HS Significant Wave Height:
4.000 times the square root of the total variance, in meters.

Dominant Direction: Following Haring and Heideman, the dominant direction ψ is the solution of the equations

$$A\cos 2\psi = \sum\sum \cos 2\theta\pi dS$$
$$A\sin 2\psi = \sum\sum \sin 2\theta\pi dS$$

The angle ψ is determined only to within 180 degrees. Haring and Heideman choose from the pair (ψ, ψ+180) the value closer to the peak direction.

Angular Spreading Function: The angular spreading function (Gumbel, Greenwood & Durand) is the mean value, over the 552 bins, of cos(θ -VMD), weighted by the variance component in each bin. If the angular spectrum is uniformly distributed over 360 degrees, this statistic is zero if uniformly distributed over 180 degrees, $2/\pi$ if all variance is concentrated at the VMD, 1. For the use of this statistic in fitting an exponential distribution to the angular spectrum, see Pearson & Hartley, Biometrika Tables for statisticians, 2:123 ff.
Angular spreading (ANGSPR) is related to $\cos^n(\theta)$ spreading as follows:
n = (2*ANGSPR)/(1-ANGSPR)

In-Line Variance Ratio: called directional spreading by Haring and Heideman, p 1542. Computed as:

$$Rat = \frac{\sum\sum \cos^2(\theta - \psi) ds}{\sum\sum dS}$$

If spectral variance is uniformly distributed over the entire compass, or over a semicircle, Rat = 0.5; if variance is confined to one angular band, or to two band 180 degrees apart, Rat = 1.00 . According to Haring and Heideman, cos^2 spreading corresponds to Rat = 0.75 .

APPENDIX B: Wave Spectra Format

Description of Two-Dimensional Hindcast Spectrum Table

The first line of each spectrum gives date, grid point number, latitude, longitude, water depth, wind speed, wind direction (measured from which) and significant wave height. The next line gives the nominal frequencies of each frequency bin. Directional bands are identified at the left. The 552 element array contains the variance components (NOT spectral densities) for 23 frequencies and 24 directions. The 24 directional bins, each 15 degrees wide, are numbered clockwise from north; the first bin, with a nominal direction 7.5 degrees, extends from 0 to 15 degrees.

Frequency bins are spaced in geometric progression (to facilitate the computation of interactions); the nominal frequency is the geometric mean of the two ends. The frequency ratio is .75**(-1./3.), i.e. 1.100642416; this ratio was chosen in preference to the 1.1000 of official WAM to simplify interaction formulas. The first 22 bins are straightforward; the last requires explanation (continued below table).

	nom. freq	left end	right end	bandwidth
1	0.0390000	0.0371742	0.0409155	0.0037413
2	0.0429251	0.0409155	0.0450333	0.0041178
3	0.0472451	0.0450333	0.0495656	0.0045323
4	0.0520000	0.0495656	0.0545540	0.0049884
5	0.0572334	0.0545540	0.0600444	0.0054904
6	0.0629935	0.0600444	0.0660874	0.0060430
7	0.0693333	0.0660874	0.0727386	0.0066512
8	0.0763112	0.0727386	0.0800592	0.0073206
9	0.0839914	0.0800592	0.0881166	0.0080574
10	0.0924444	0.0881166	0.0969849	0.0088683
11	0.1017483	0.0969849	0.1067457	0.0097608
12	0.1119885	0.1067457	0.1174888	0.0107431
13	0.1232593	0.1174888	0.1293131	0.0118244
14	0.1356644	0.1293132	0.1423275	0.0130144
15	0.1493180	0.1423275	0.1566517	0.0143242
16	0.1643457	0.1566517	0.1724175	0.0157658
17	0.1808858	0.1724175	0.1897700	0.0173525
18	0.1990906	0.1897700	0.2088690	0.0190989
19	0.2191276	0.2088690	0.2298900	0.0210211
20	0.2411811	0.2298900	0.2530267	0.0231367
21	0.2654541	0.2530267	0.2784919	0.0254652
22	0.2921701	0.2784919	0.3065200	0.0280281
23	0.3215748	0.3065200	2.5274134	

The 23rd frequency band is an integrated band comprising what would be bins 23 through 44 (continuing the geometric progression) of a fully discrete bin system. To model the cascade of wave energy from high to low frequencies endorsed by non-linear interactions, we compute interactions involving bins out to 44. This requires a parametric assumption about the spectral density between 0.30652 and 2.52741 Hz; and the customary assumption is that density is proportional to omega**(-x), where x is a disposable parameter. We are using x = 4.5 for the following reasons:

(1) There are quasi-physical arguments supporting the exponents 4 & 5. The exponent 5 is germane to a Pierson-Moskowitz spectrum.

(2) A crude energy balance computation in the tail, with wind input scaled as omega**2 and interactions scaled as omega**11, shows that 4.5 is the only exponent capable of yielding an equilibrium spectrum in the tail.

To compute a "density" at 0.32157 Hz, we compute what fraction of the integrated band belongs to the bin from 0.30652 to 0.33737 Hz. Sparing a few details, the result is:

```
dens = (variance component)*rbw
```

where rbw (dimensions seconds) is a function of the exponent as follows:

```
 x      rbw
4.0   8.11849
4.5   9.24794
5.0  10.32933
```

Anspec is the variance summed over frequency per direction bin.
Fspec is the variance summed over direction per frequency.
Dens is the frequency spectrum represented as density in units of m^2Hz.

```
Sample Table:
196301.240600.  gp  1121.  lat  34.00  long   31.00  depth 2590.89   10.95 m/s from 273.97 deg; hsig =  3.37
frequency 0.0390 0.0429 0.0472 0.0520 0.0572 0.0630 0.0693 0.0763 0.0840 0.0924 0.1017 0.1120 0.1233 0.1357 0.1493 0.1643 0.1809 0.1991 0.2191 0.2412 0.2655 0.2922 0.3216   anspec
 direction

    7.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0001 0.0001 0.0001 0.0001 0.0002 0.0002 0.0002 0.0002 0.0009   0.0020
   22.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0001 0.0002 0.0003 0.0004 0.0005 0.0006 0.0006 0.0006 0.0006 0.0005 0.0016   0.0059
   37.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0001 0.0002 0.0004 0.0006 0.0011 0.0014 0.0015 0.0014 0.0014 0.0012 0.0011 0.0009 0.0025   0.0137
   52.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0001 0.0003 0.0006 0.0012 0.0021 0.0030 0.0032 0.0031 0.0028 0.0024 0.0020 0.0016 0.0012 0.0031   0.0268
   67.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0002 0.0005 0.0010 0.0018 0.0034 0.0054 0.0061 0.0056 0.0049 0.0041 0.0032 0.0025 0.0018 0.0013 0.0034   0.0454
   82.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0001 0.0003 0.0008 0.0018 0.0031 0.0051 0.0086 0.0098 0.0087 0.0075 0.0061 0.0048 0.0036 0.0026 0.0019 0.0014 0.0035   0.0695
   97.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0002 0.0010 0.0028 0.0056 0.0087 0.0130 0.0148 0.0128 0.0104 0.0083 0.0064 0.0047 0.0035 0.0025 0.0019 0.0014 0.0035   0.1015
  112.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0001 0.0005 0.0024 0.0068 0.0129 0.0188 0.0223 0.0185 0.0144 0.0107 0.0079 0.0058 0.0044 0.0032 0.0024 0.0018 0.0013 0.0035   0.1376
  127.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0004 0.0024 0.0072 0.0147 0.0231 0.0242 0.0178 0.0127 0.0091 0.0066 0.0050 0.0039 0.0029 0.0022 0.0017 0.0012 0.0033   0.1385
  142.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0001 0.0005 0.0023 0.0072 0.0148 0.0175 0.0127 0.0089 0.0066 0.0051 0.0040 0.0032 0.0025 0.0019 0.0015 0.0011 0.0029   0.0930
  157.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0002 0.0008 0.0025 0.0050 0.0072 0.0068 0.0053 0.0043 0.0036 0.0030 0.0025 0.0020 0.0015 0.0012 0.0009 0.0024   0.0493
  172.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0001 0.0003 0.0006 0.0009 0.0013 0.0015 0.0018 0.0020 0.0020 0.0019 0.0016 0.0013 0.0011 0.0009 0.0006 0.0018   0.0197
  187.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0001 0.0001 0.0001 0.0002 0.0003 0.0004 0.0005 0.0007 0.0007 0.0007 0.0006 0.0005 0.0004 0.0012   0.0064
  202.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0001 0.0001 0.0001 0.0001 0.0001 0.0002 0.0002 0.0001 0.0006   0.0016
  217.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0001   0.0003
  232.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000   0.0000
  247.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000   0.0000
  262.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000   0.0000
  277.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000   0.0000
  292.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000   0.0000
  307.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000   0.0000
  322.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000   0.0000
  337.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000   0.0001
  352.50   0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0003   0.0005
fspec      0.0000 0.0000 0.0000 0.0000 0.0000 0.0002 0.0013 0.0069 0.0213 0.0460 0.0760 0.0934 0.0859 0.0744 0.0627 0.0525 0.0433 0.0350 0.0276 0.0216 0.0167 0.0125 0.0345   0.7118
dens         0.00   0.00   0.00   0.00   0.00   0.03   0.20   0.94   2.64   5.18   7.78   8.70   7.27   5.72   4.38   3.33   2.50   1.83   1.31   0.93   0.66   0.45   0.32
```

Each table can be read with the following FORTRAN format statements:

```
    REAL THETA(24), SPEC(23,24), FREQ(23), ANGSPEC(24)
    REAL FSPEC(23), ETOT, DENS(23)
    REAL CYM, DHM, GP, Lat, Long, Depth, WS, WD, HSig

10   format (2f7.0, 4x, f7.0, 5x, f7.2, 6x, f8.2, 7x, 2f8.2,
   & 9x, f7.2, 12x, f6.2)
101  format (9x, 23f7.4)
11   format (f8.2, 2x, 23f7.4, 2x, f7.4)
12   format (10x, 23f7.4, 2x, f7.4)
13   format (10x, 23f7.2)

20   READ (10,10,END=30) CYM, DHM, GP, Lat, Long, Depth, WS, WD, HSig
    READ (10,101) (FREQ(I), I=1,23)
    READ (10,*)
    READ (10,*)
    READ (10,11) (THETA(J), (SPEC(I,J), I=1,23), ANGSPEC(J), J=1,24)
    READ (10,12) (FSPEC(I), I=1,23), ETOT
    READ (10,13) (DENS(I), I=1,23)
    READ (10,*)
    ! [insert processing code here]
    GO TO 20  !read next table
30   CONTINUE  !end of file during read
```

Variable definitions:

CYM - Year and month in the format CCYYMM

DHM - Day, hour and minute (gmt) in the format DDHHmm
GP - Grid point
LAT - Latitude of grid point
LONG - Longitude of grid point
DEPTH - Depth of grid point
WS - Wind speed (m/s) at grid point
WD - Wind direction (from which, clockwise from true north)
HS - Significant wave height (m)
FREQ(I) - Geometric mean of the lower and upper ends of the bandwidth. The frequency bands are given below.
THETA(J) - Mean direction of angular bin, to which waves are traveling, clockwise from true north. The bin extends +/- 7.5 degrees from the center (the value displayed in the table).
SPEC(I,J) - Variance component (not spectral density), in m**2, in frequency band I and angular band J.
ANGSPEC(J)- Variance summed over all frequencies per direction (the right most column).
FSPEC(I) - Variance summed over all directions per frequency (the first footer line).
ETOT - Total variance located at the end of the first footer line.
DENS(I) - Frequency spectrum represented as density in units of m**2 Hz (second footer line).

APPENDIX C: OWI Extremal Analysis Description

Calculation of Return-Period Extremes

The distributional assumptions used are:

1. Gumbel distribution of extremes:

$$Pr\{H \le h\} = \exp\left[-\exp\left(\frac{a_1 - h}{b_1}\right)\right]$$

2. Borgman distributions of extremes, i.e., Gumbel distribution of squared extremes:

$$Pr\{H \le h\} = \exp\left[-\exp\left(\frac{a_2 - h^2}{b_2}\right)\right]$$

3. Galton distribution of height, i.e. normal distribution of log heights:

$$Pr\{H \le h\} = \frac{1}{\sqrt{2\pi}}\int_{\infty}^{x} \exp\left(-\frac{t^2}{2}\right) dt$$, where $$x = \frac{\log h - a_3}{b_3}$$

4. Weibull distribution described in next section

The fitting procedure of Gumbel (1958, pp. 34 - 36) was followed for Gumbel, Borgman and Galton, with plotting positions based in i/(n+1), often called Weibull plotting position. Specifically, let

$$y_i = -\log_e\left[-\log_e\left(\frac{i}{n+1}\right)\right],$$

and define zi as the root of the equation

$$\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{z} \exp\left(\frac{-1}{2t^2}\right) dt = \frac{1}{n+1}.$$

Then the constants a and b are determined from

$$b_1 = \sqrt{\frac{Var(h)}{Var(y_i)}}, a_1 = Av(h) - b_1 Av(y_i)$$

$$b_2 = \sqrt{\frac{Var(h^2)}{Var(y_i)}}, a_2 = Av(h^2) - b_2 Av(y_i)$$

$$b_3 = \sqrt{\frac{Var(\log_e h)}{Var(z_i)}}, a_3 = Av(\log_e h)$$

where Av and Var denote the average and the variance of the operand.

The extrapolations corresponding to a return period of T years are based upon n storms as a complete enumeration of the relevant storm events in Y years.

The cumulative distribution function corresponding to return period T is

$$P_T = 1 - \frac{Y}{nT}.$$

Define zT as the root of

$$\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{z} \exp\left(\frac{-1}{2t^2}\right)dt = P_T.$$

Then the height with return period T is computed as

$$h_{T1} = a_1 - b_1\log_e(-\log_e P_T);$$

$$h_{T2} = \sqrt{a_2 - b_2\log_e(-\log_e P_T)};$$

$$h_{T3} = \exp(a_3 + b_3 z_T).$$

The 90% confidence limits shown on the individual predicted extreme values were computed according to the method of Dick and Darwin (1954) (see also Gumbel, 1958, p. 218). In 90% of extrapolations, the true values of the return period extremes will be between the limits indicated.

Weibull Distribution

The Weibull distribution is a generalization of the exponential distribution, most expediently defined in terms of the exceedance probability:

$Q = \Pr\{X \geq x\} = \exp[-y^{\alpha}]$, where $y = (x - \mu)/\sigma$;

X is the variable to be distributed (for example, wave height);

α is the shape parameter:

for $\alpha = 1$, the distribution is exponential

for $\alpha < 1$, the distribution is long-tailed

for $\alpha > 1$, the distribution is short-tailed

μ is the lower limit of the distribution; $\Pr\{\mathrm{X} < \mu\} = 0$;

σ is a scale parameter such that $\Pr\{\mathrm{X} \geq \mu + \sigma\} = 1/e$

The parameter α is a pure number; μ and σ have the same units as X; whence it follows that y is dimensionless. For some purposes, the probability density, -dQ/dx, is more convenient than Q:

$$-\frac{dQ}{dx} = \frac{Q\alpha}{\sigma} y^{\alpha-1}$$

The fitting method adopted is to take an arbitrary value for μ, and then fit σ and α by the method of maximum likelihood. The value assumed for μ is

$\mathrm{M} = 0.5(H_1 + 0.98H_2)$, where

M is the assumed μ, used in the subsequent computation;

H1 is a value, often taken as a percentage of the largest X reported, such that X-values less than H1 are excluded from extremal analysis.

H2 is the smallest X used in the extremal analysis. Thus $H_2 \geq H_1$.

The method of maximum likelihood finds $\hat{\alpha}, \hat{\beta}$, such that

$\frac{d}{d\alpha}\left[\log\frac{dP}{dx}\right] = 0$ and $\frac{d}{d\beta} = \left[\log\frac{dP}{dx}\right] = 0$ when evaluated at the point ($\hat{\alpha}, \hat{\beta}$);

then the adopted is given by $\sigma = \hat{\beta}^{-1/\hat{\alpha}}$.

Printed and plotted extremes are based on the observation that if X is Weibull distributed, then

$Z = -\log_e[X - \mathrm{M}]$ is Gumbel distributed; specifically,

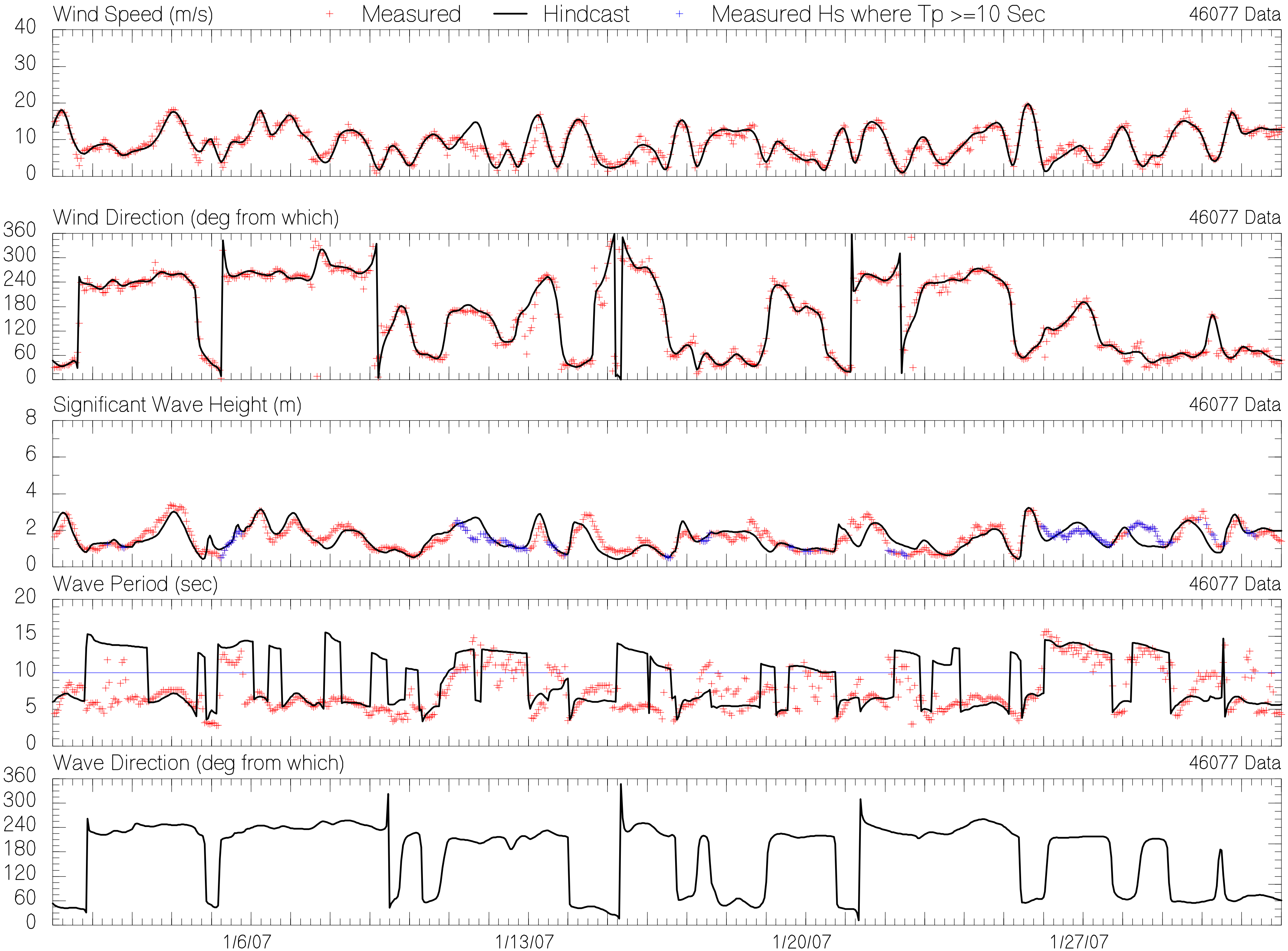
$$Q = \Pr\{Z \leq z\} = \exp\left[-\exp\left(\frac{z - A}{B}\right)\right], A = \sigma, B = \frac{1}{\alpha}.$$

The ordinate and abscissa of a Weibull exceedance plot are respectively log X and log(log Q).

APPENDIX D: Buoy Verification Plots for Continuous and Maximum Plots from Storm Runs

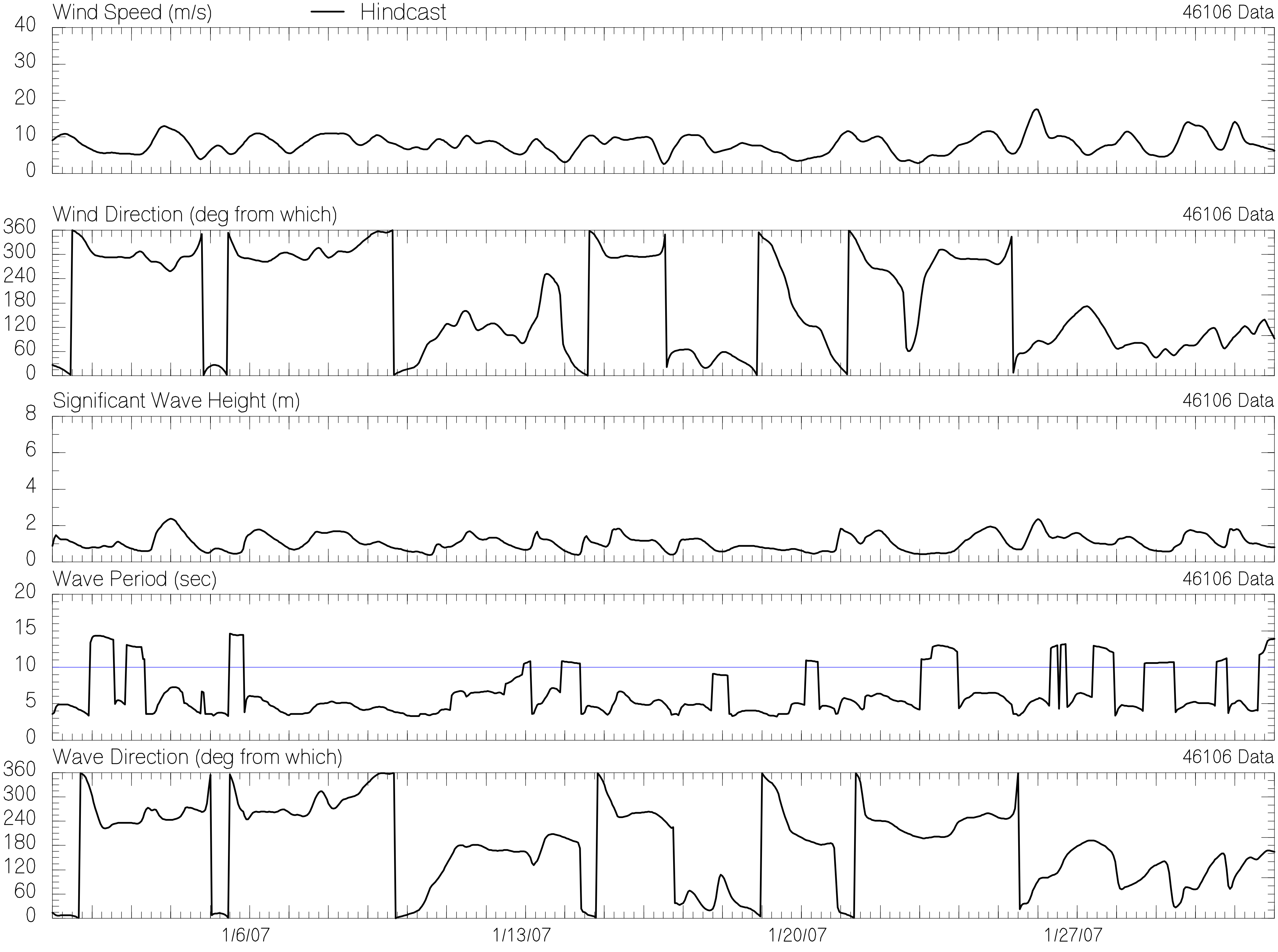
Kenai7km Model Validation

January 2007 - Buoy 46077



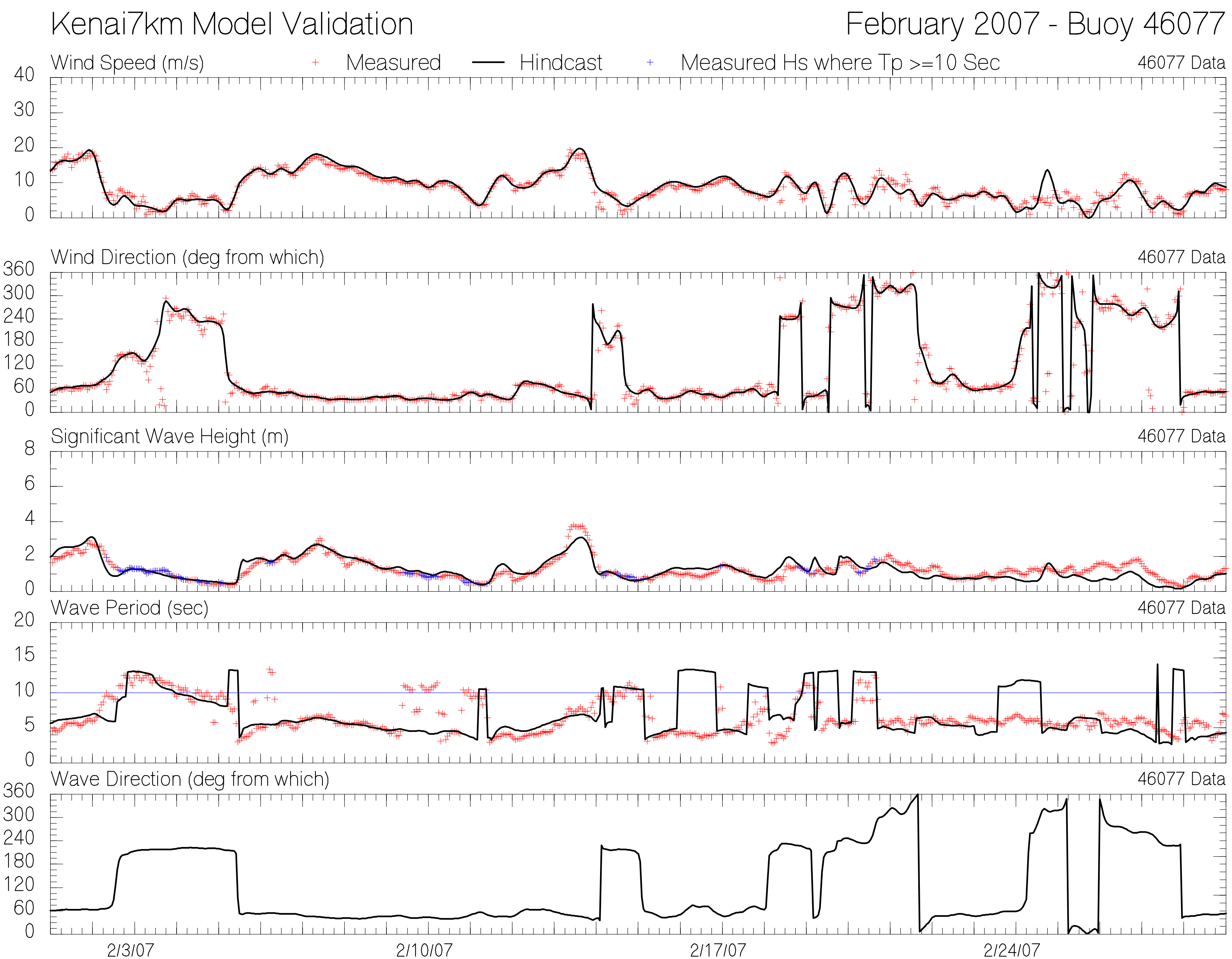
Kenai7km Model Validation

January 2007 - Buoy 46106



Printed from L:\Kenai\QC\Kenai7km\200701\46106.WPG (created on Nov-24-2009 02:55PM)

oceanweather inc.

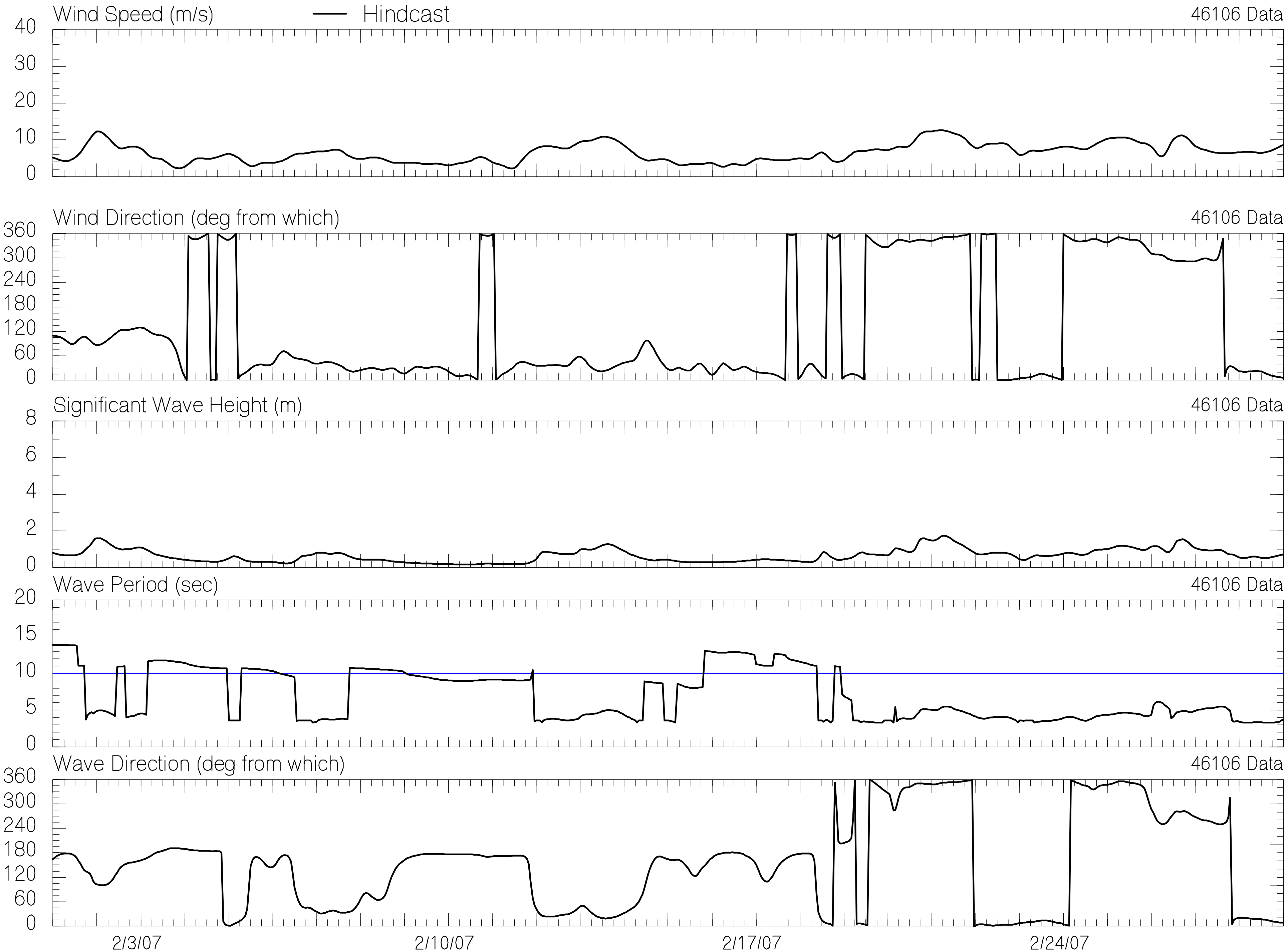


Printed from L:\Kenai\QC\Kenai7km\200702\46077.WPG (created on Nov-24-2009 02:55PM)

oceanweather inc.

Kenai7km Model Validation

February 2007 - Buoy 46106



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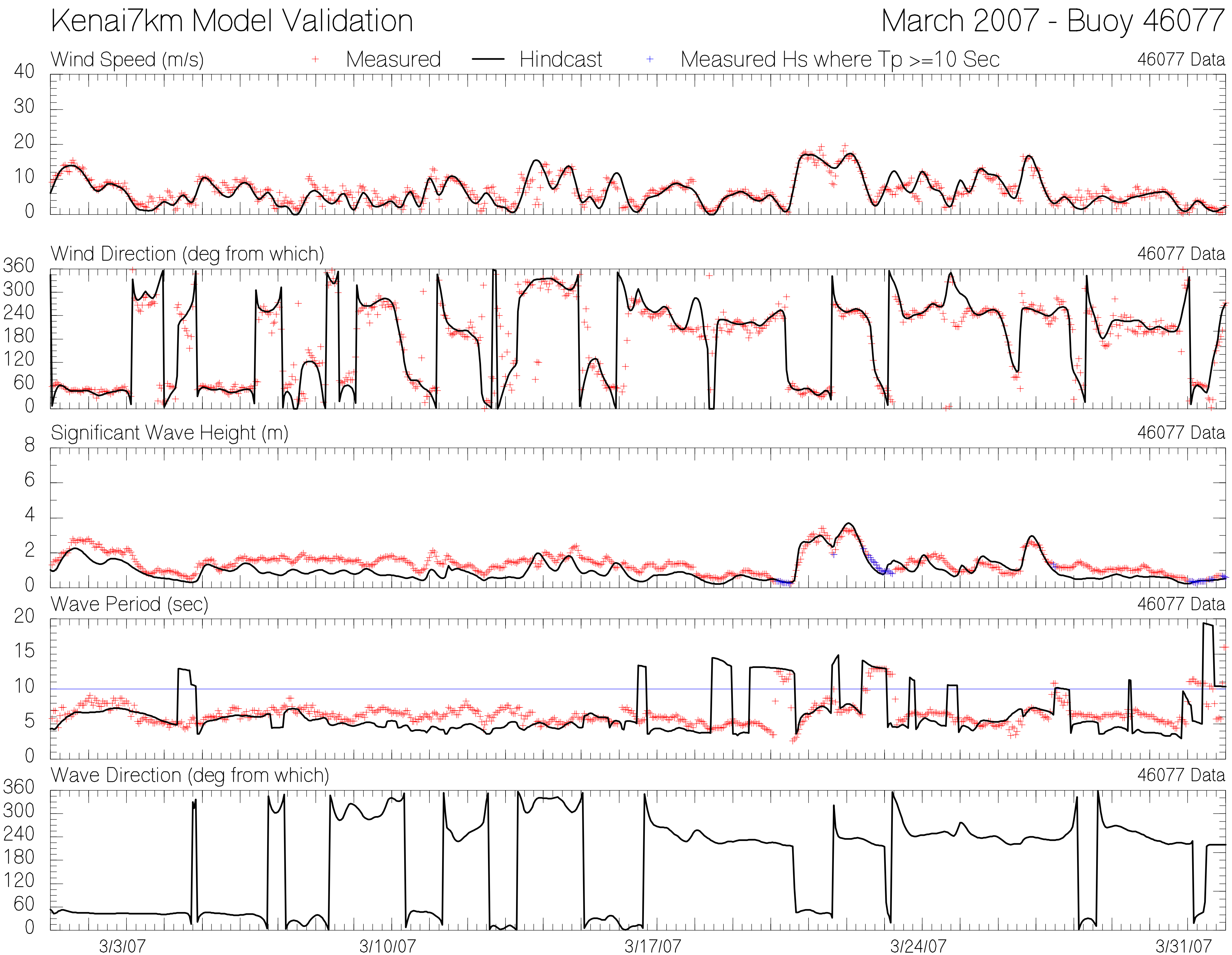
oceanweather inc.

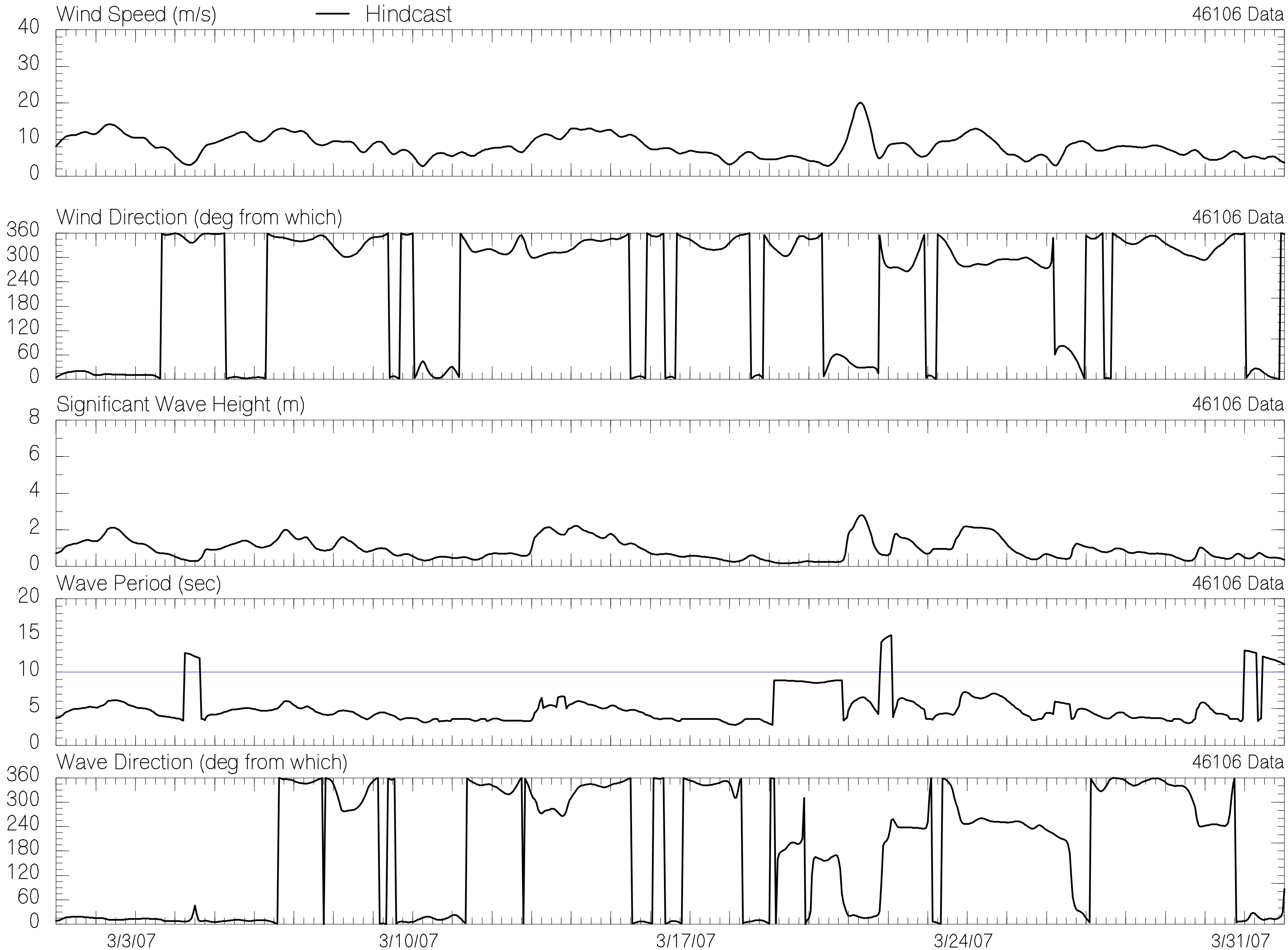


Printed from L:\Kenai\QC\Kenai7km\200703\46077.WPG (created on Nov-24-2009 02:56PM)

oceanweather inc.

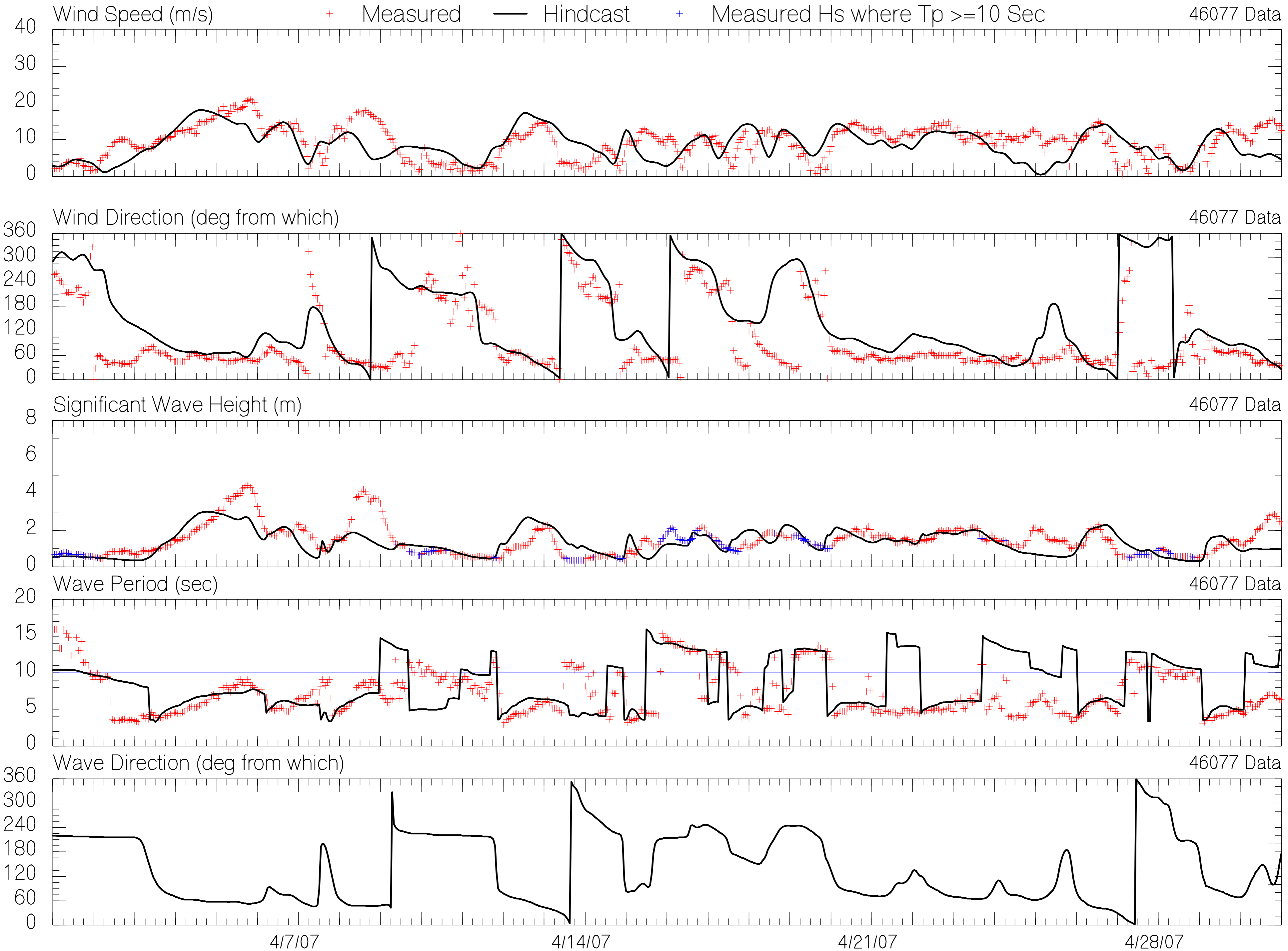
Kenai7km Model Validation

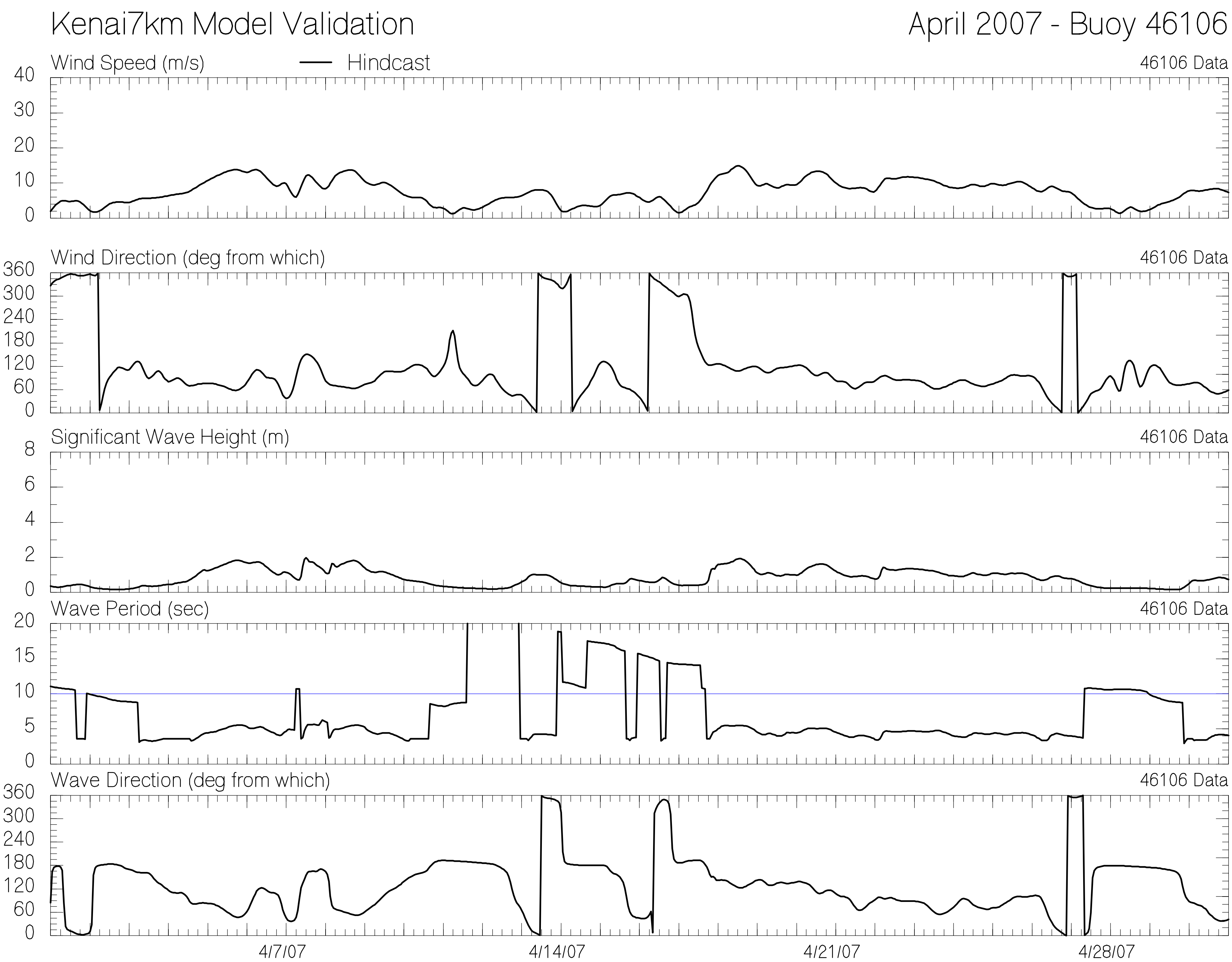
March 2007 - Buoy 46106



Kenai7km Model Validation

April 2007 - Buoy 46077

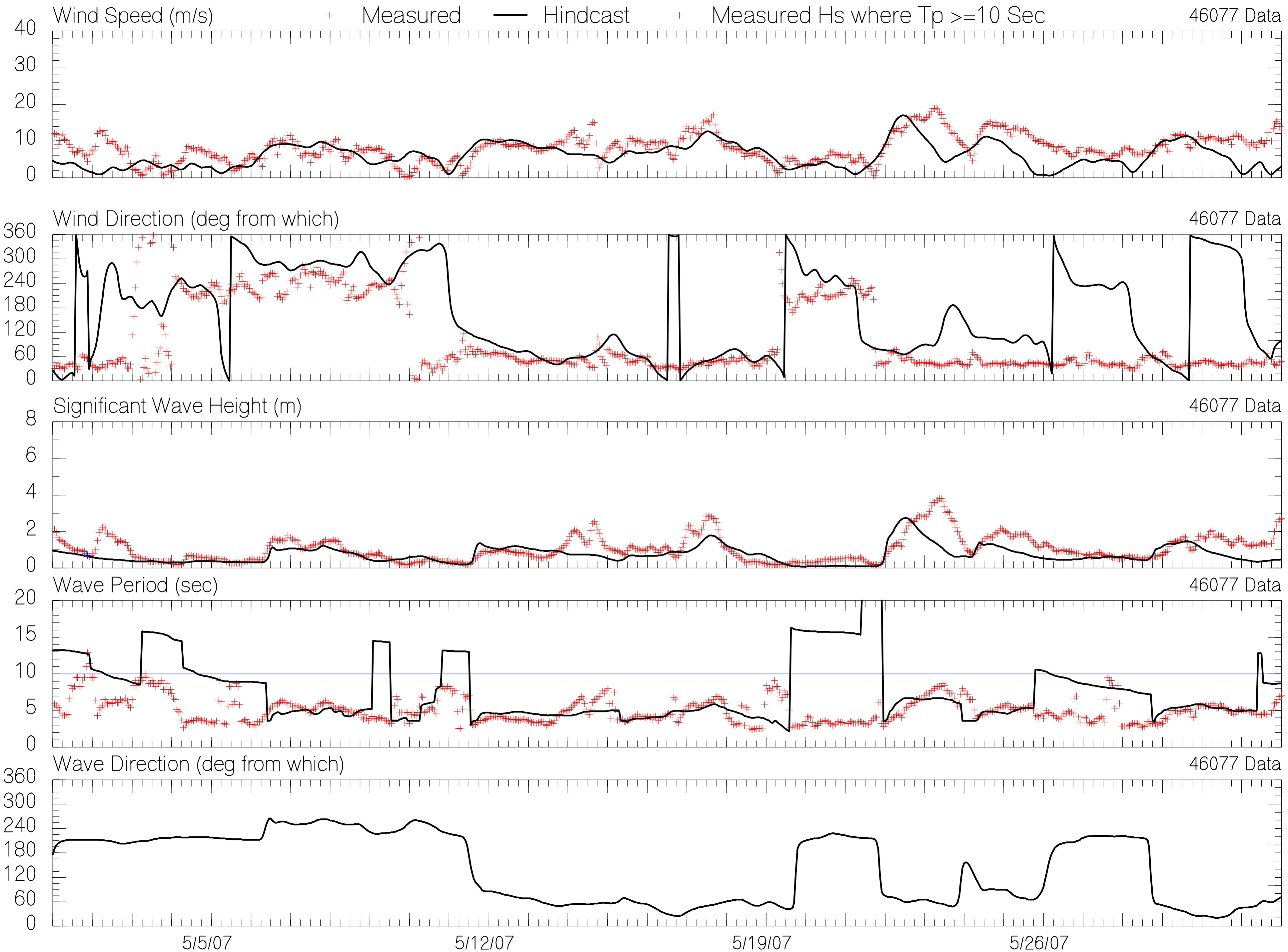




Printed from L:\Kenai\QC\Kenai7km\200704\46106.WPG (created on Nov-24-2009 02:56PM)

oceanweather inc.

Kenai7km Model Validation May 2007 - Buoy 46077

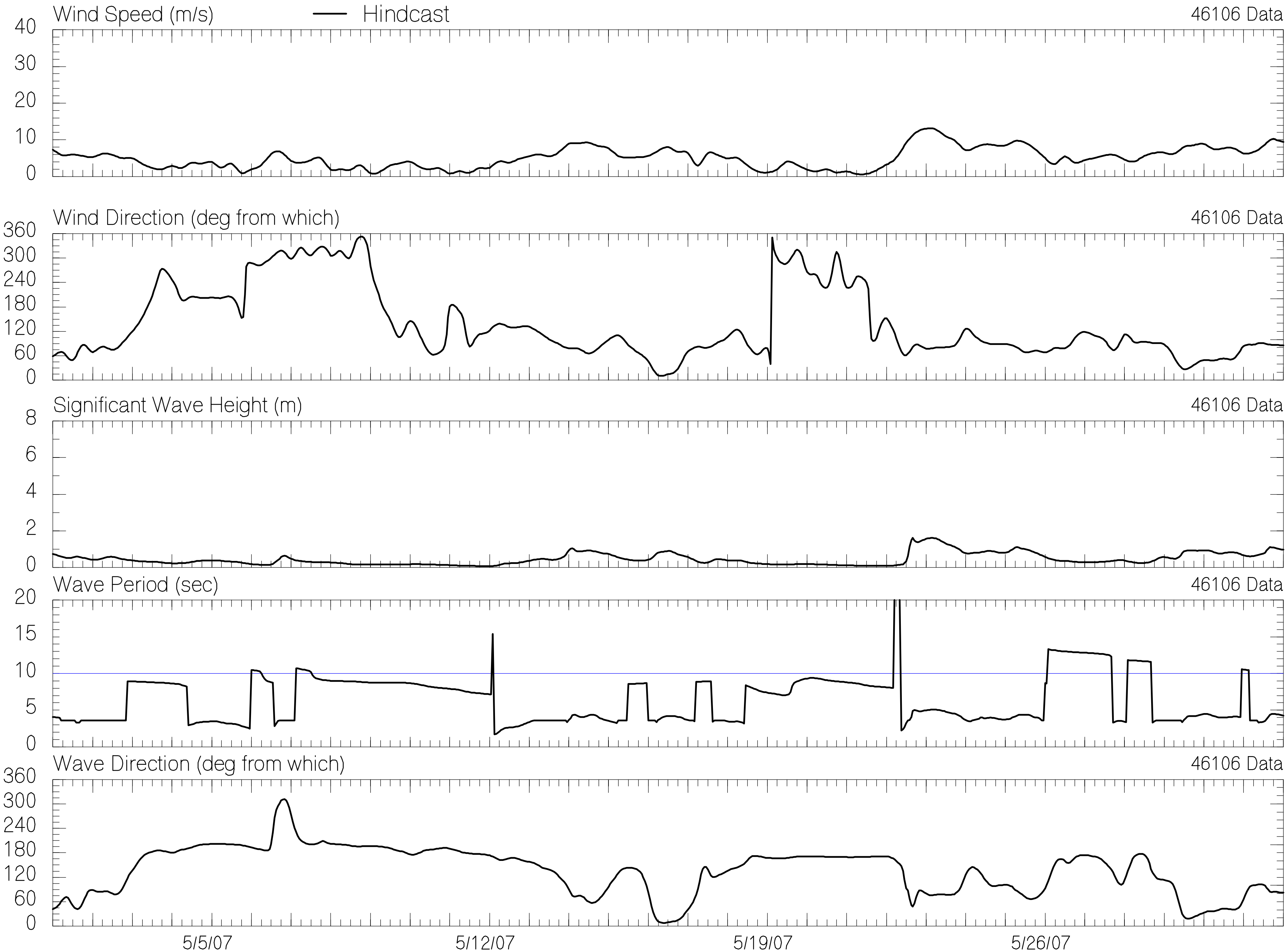


Printed from L:\Kenai\QC\Kenai7km\200705\46077.WPG (created on Nov-24-2009 02:56PM)

oceanweather inc.

Kenai7km Model Validation

May 2007 - Buoy 46106

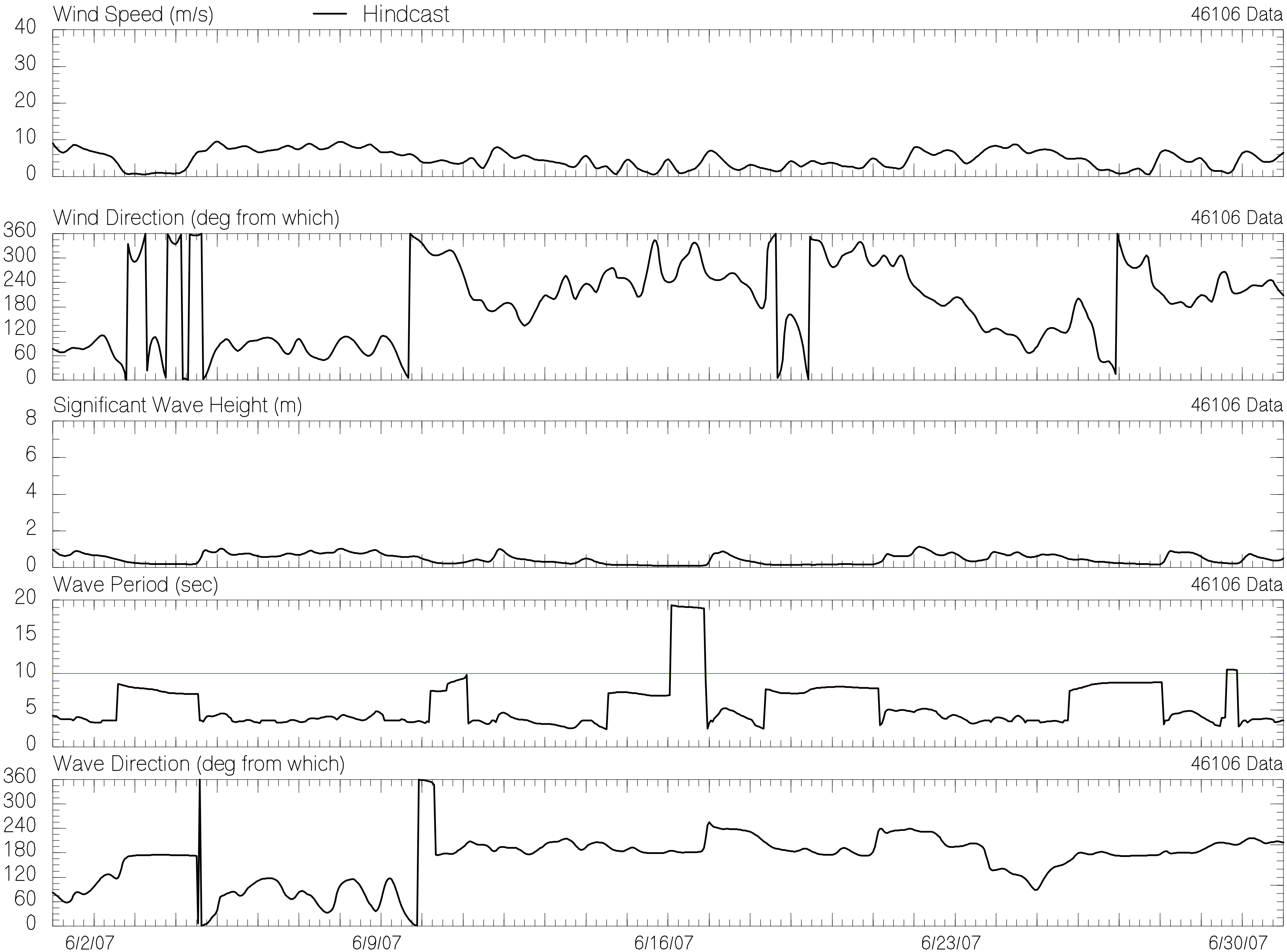


Printed from L:\Kenai\QC\Kenai7km\200706\46077.WPG (created on Nov-24-2009 02:57PM)

oceanweather inc.

Kenai7km Model Validation

June 2007 - Buoy 46106

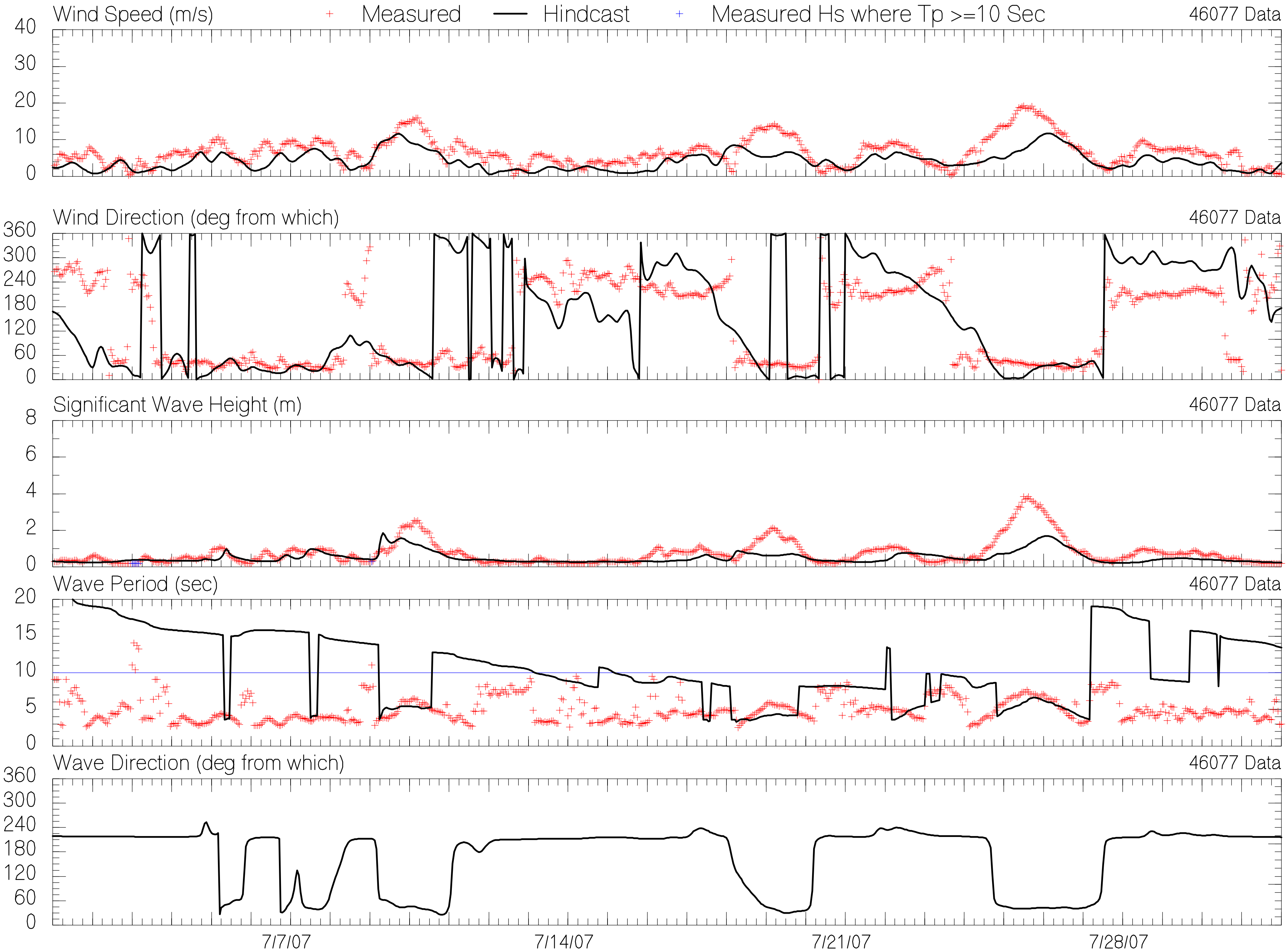


Printed from L:\Kenai\QC\Kenai7km\200706\46106.WPG (created on Nov-24-2009 02:57PM)

oceanweather inc.

Kenai7km Model Validation

July 2007 - Buoy 46077

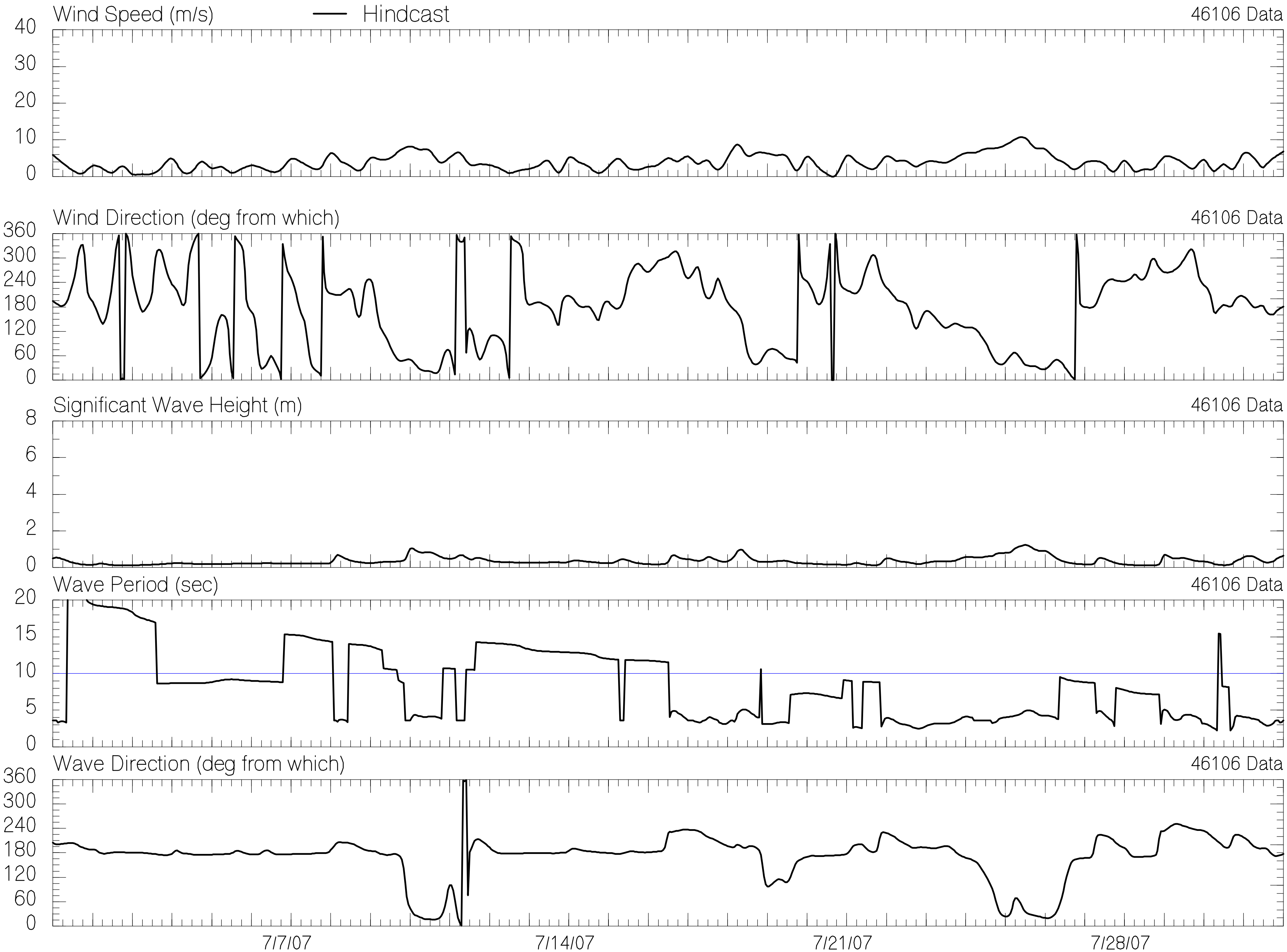


Printed from L:\Kenai\QC\Kenai7km\200707\46077.WPG (created on Nov-24-2009 02:57PM)

oceanweather inc.

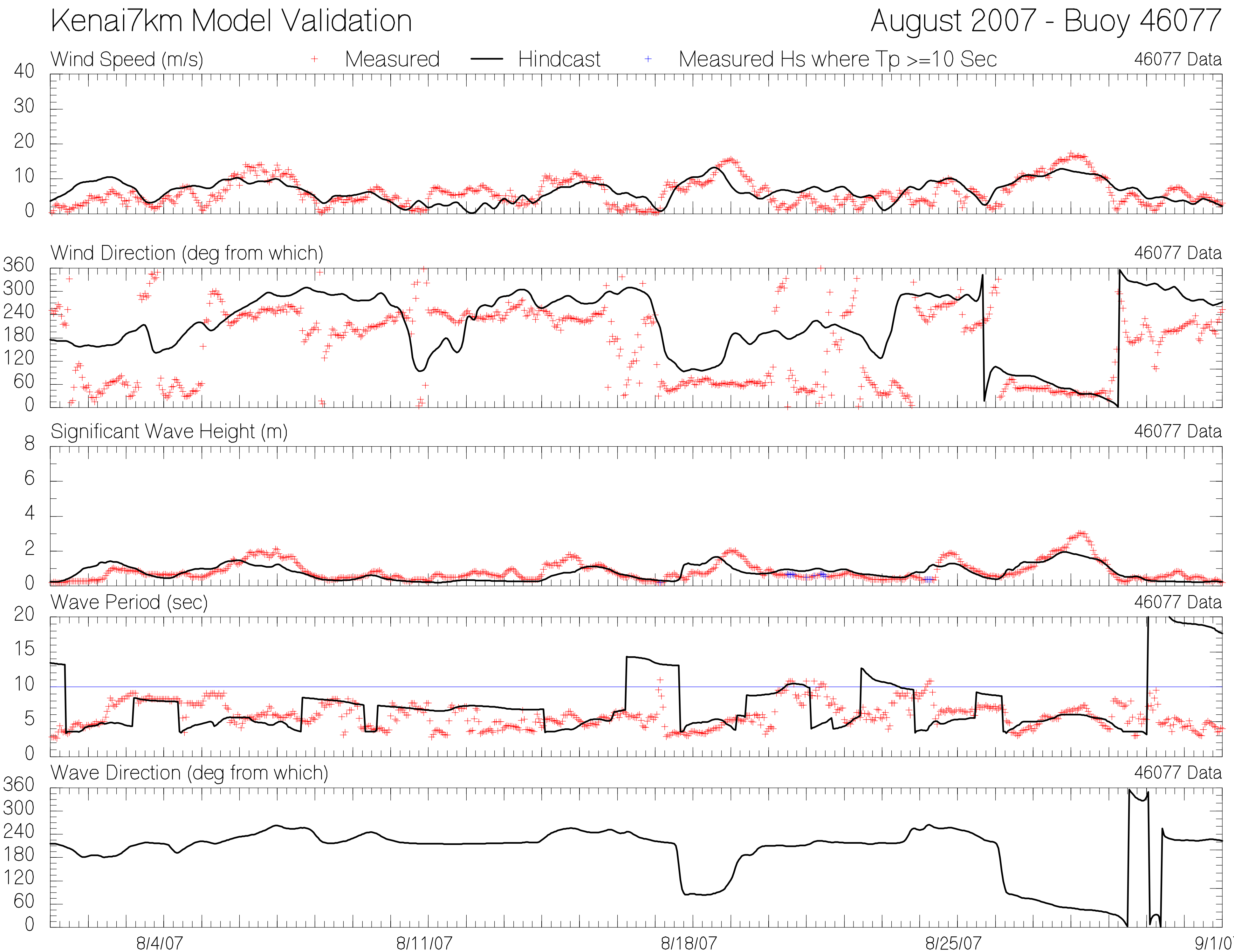
Kenai7km Model Validation

July 2007 - Buoy 46106



Printed from L:\Kenai\QC\Kenai7km\200707\46106.WPG (created on Nov-24-2009 02:57PM)

oceanweather inc.

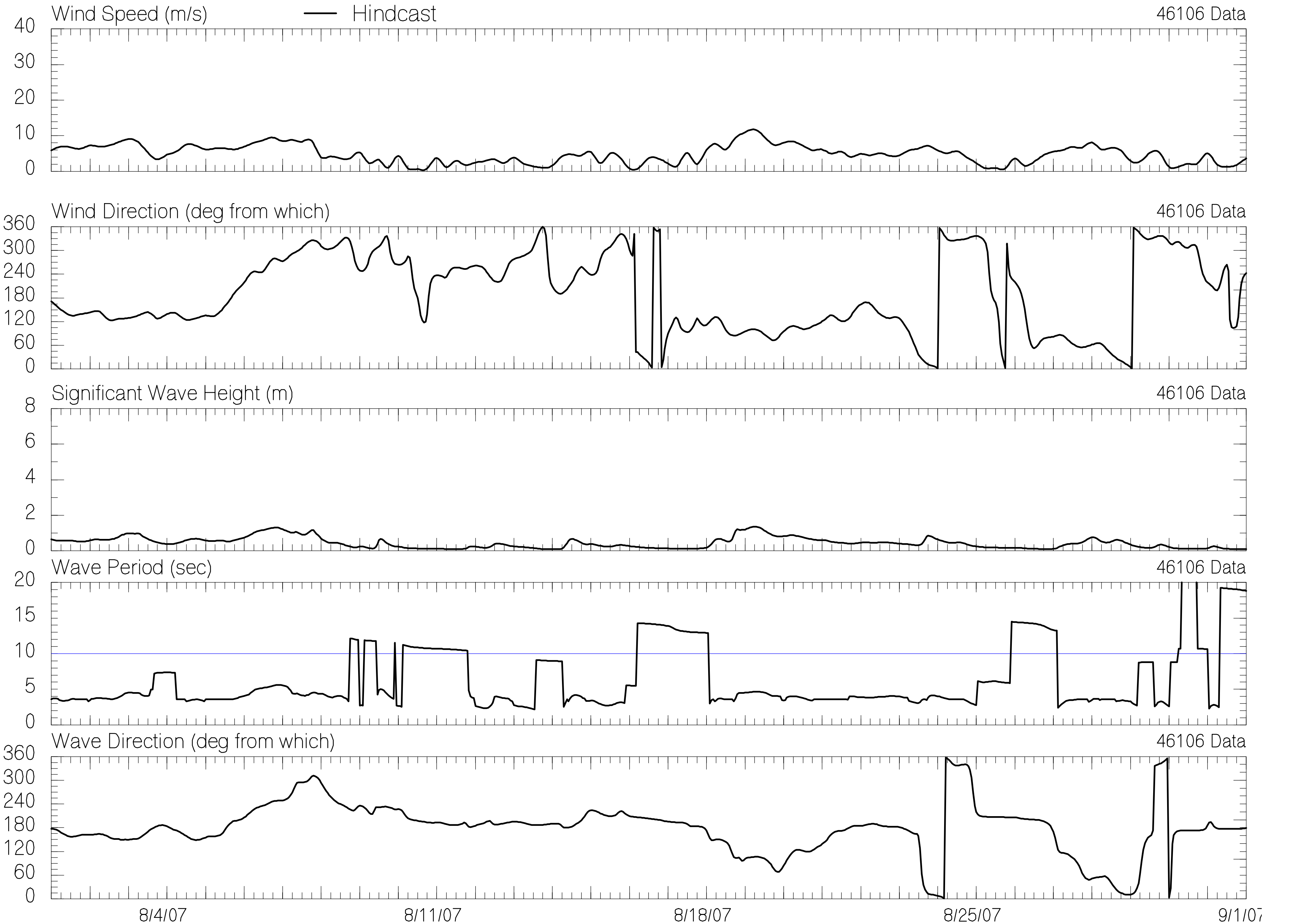


Printed from L:\Kenai\QC\Kenai7km\200708\46077.WPG (created on Nov-24-2009 02:57PM)

oceanweather inc.

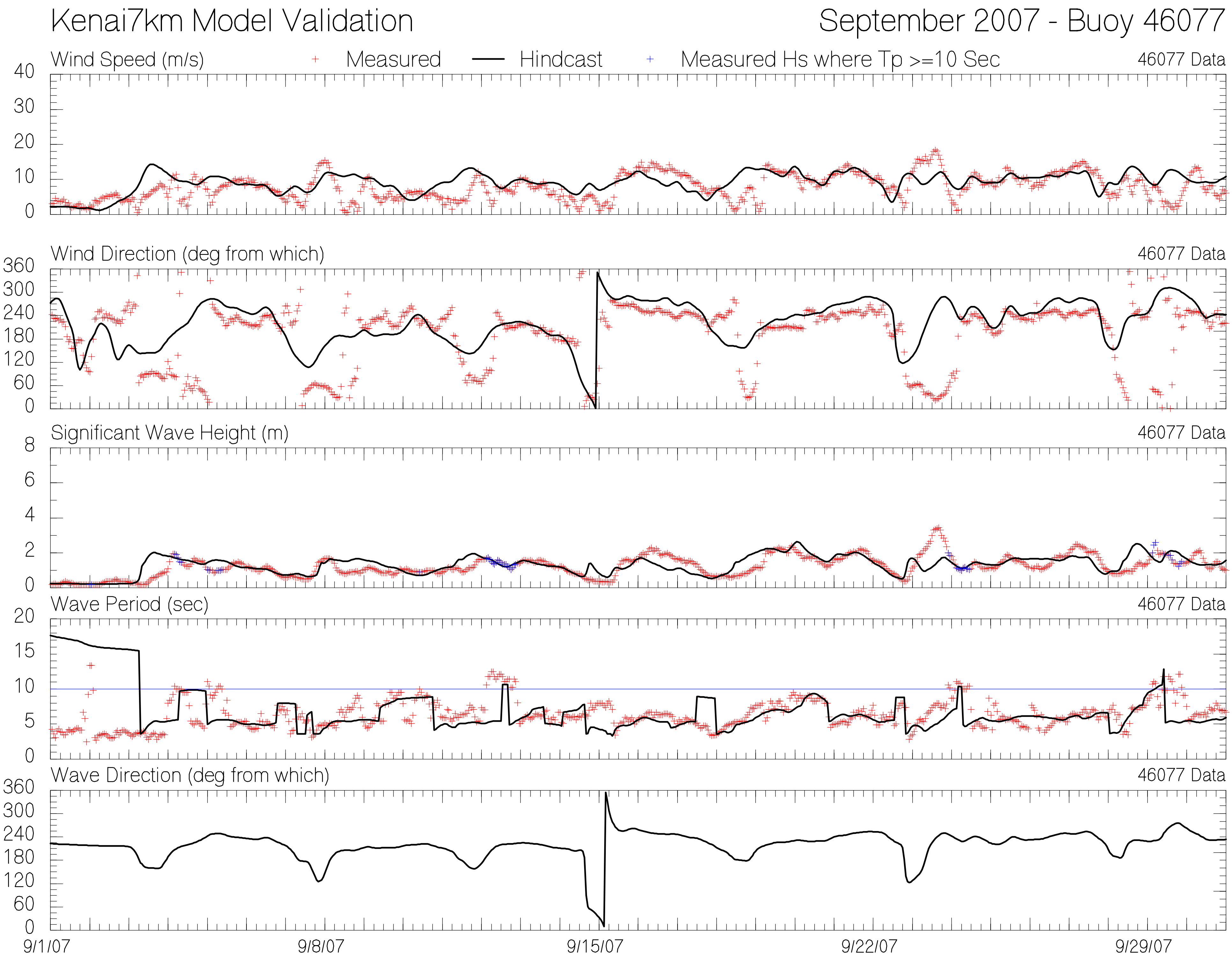
Kenai7km Model Validation

August 2007 - Buoy 46106



Printed from L:\Kenai\QC\Kenai7km\200708\46106.WPG (created on Nov-24-2009 02:58PM)

oceanweather inc.

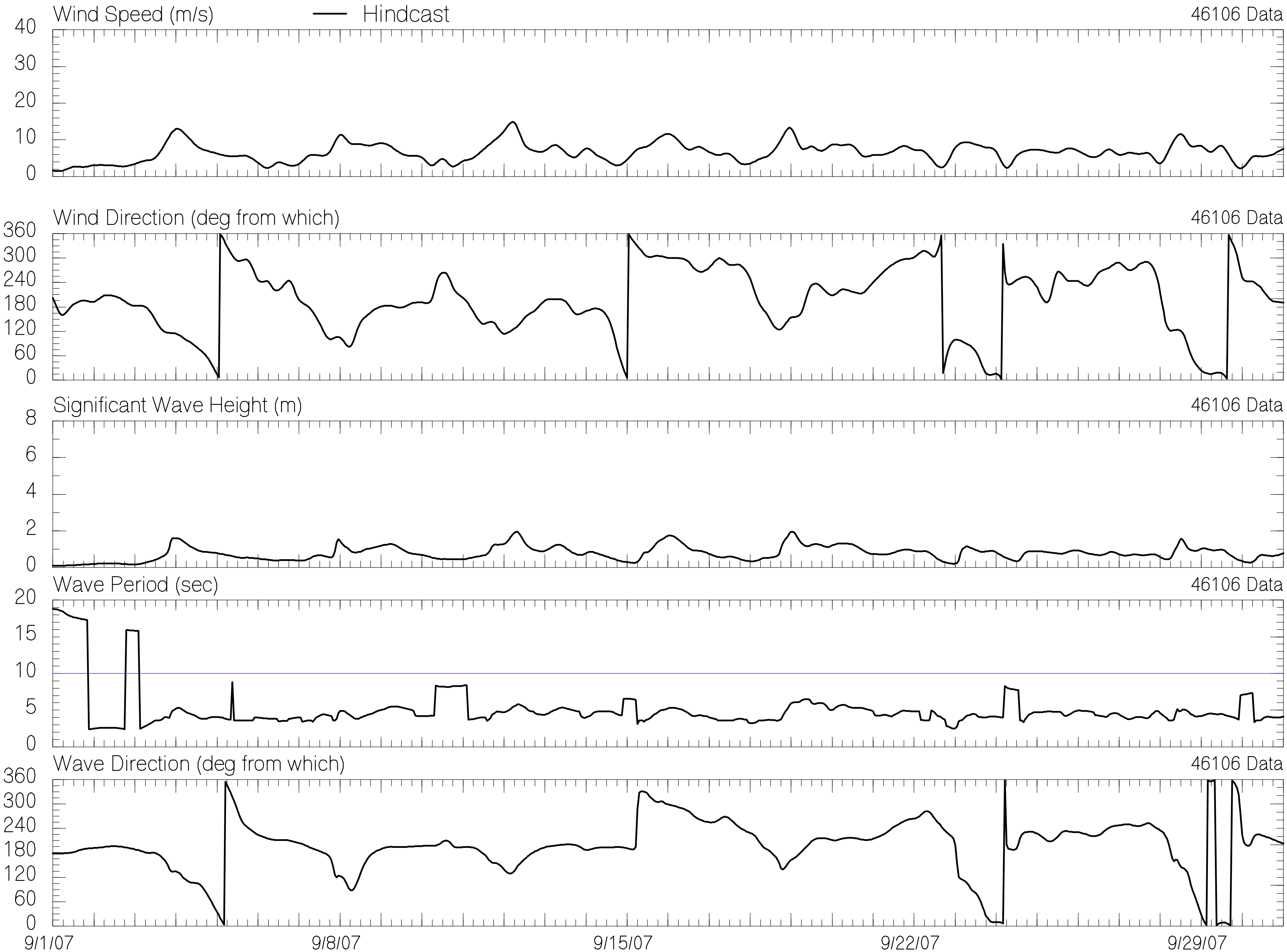


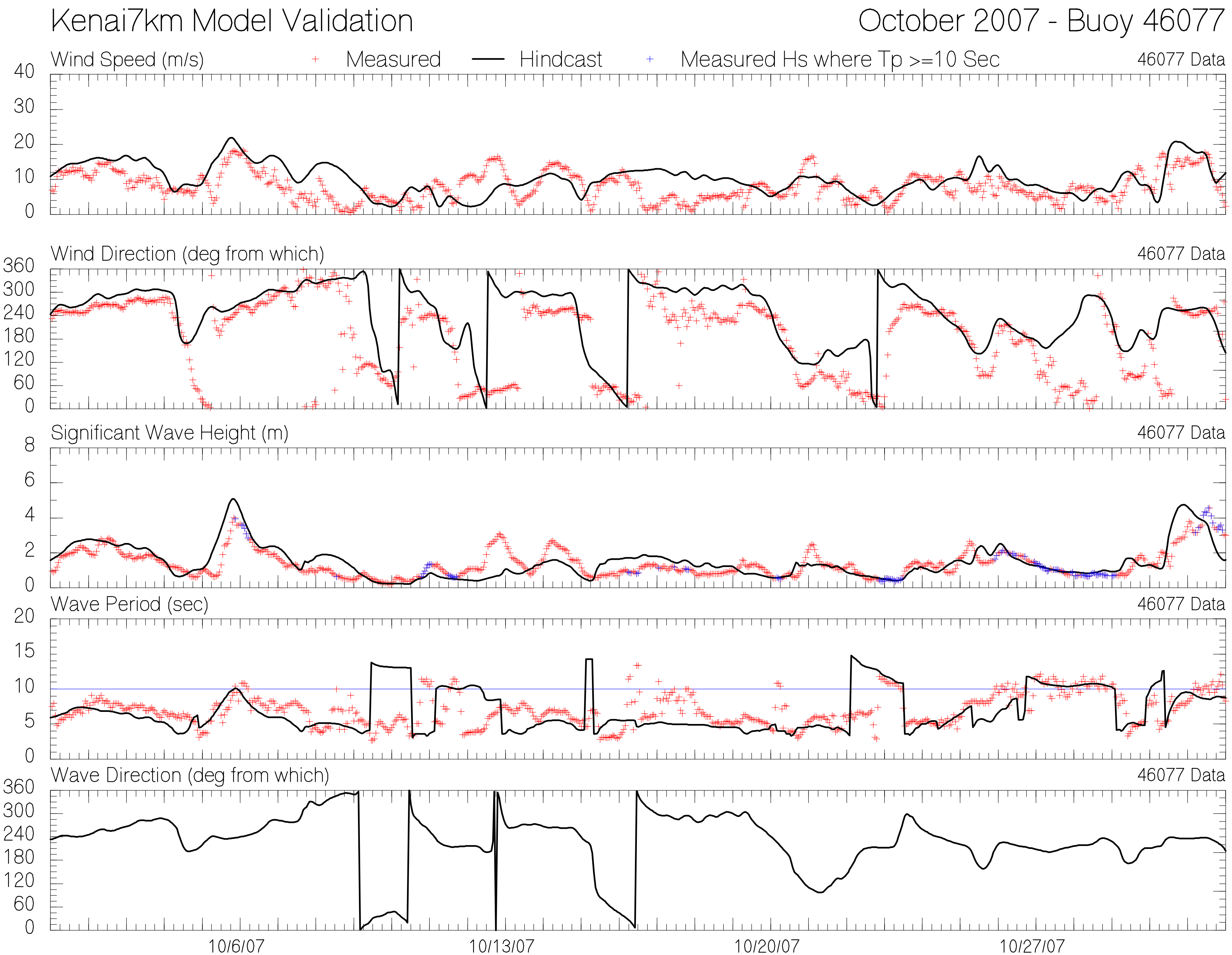
Printed from L:\Kenai\QC\Kenai7km\200709\46077.WPG (created on Nov-24-2009 02:58PM)

oceanweather inc.

Kenai7km Model Validation

September 2007 - Buoy 46106



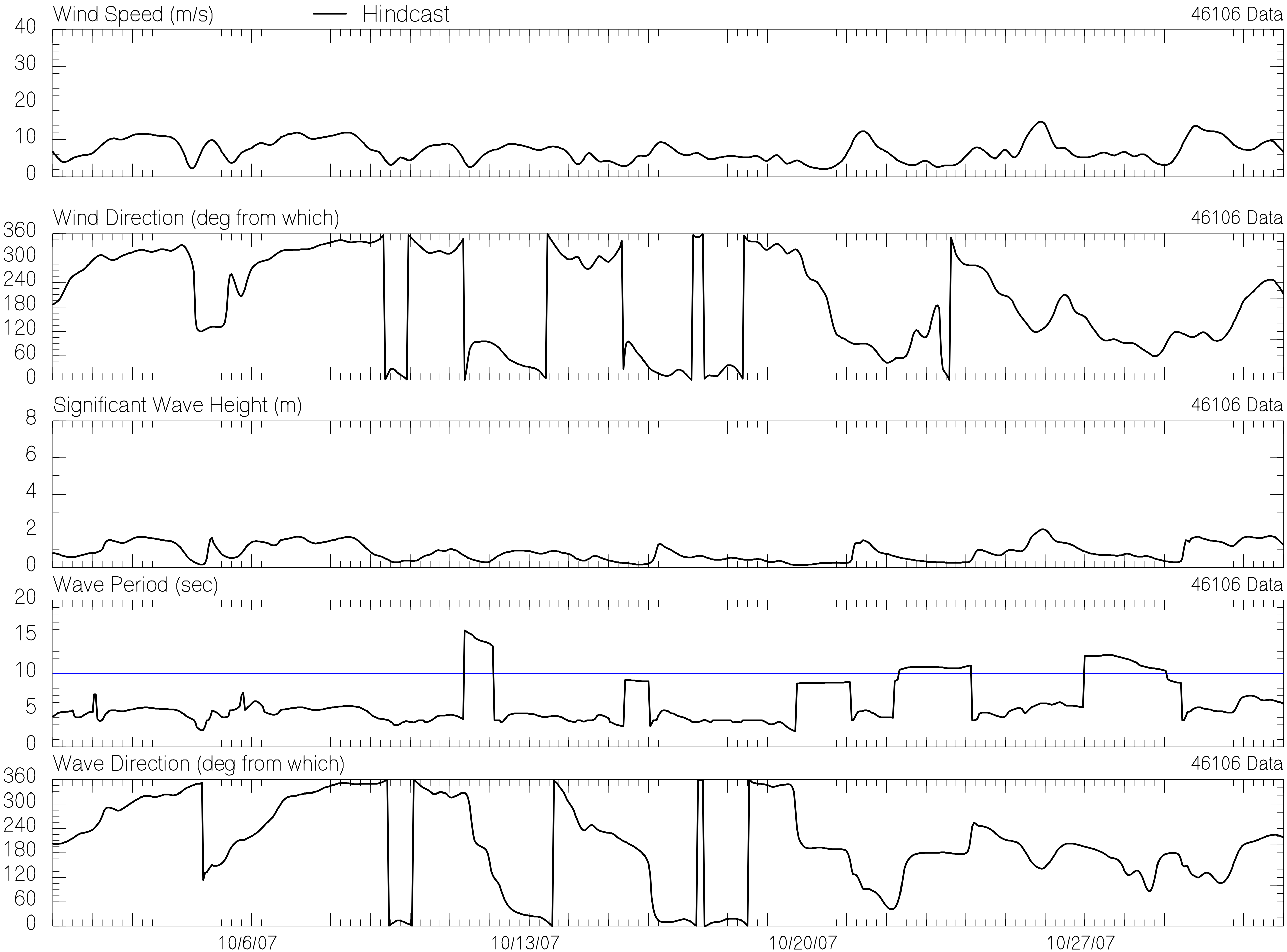


Printed from L:\Kenai\QC\Kenai7km\200710\46077.WPG (created on Nov-24-2009 02:58PM)

oceanweather inc.

Kenai7km Model Validation

October 2007 - Buoy 46106



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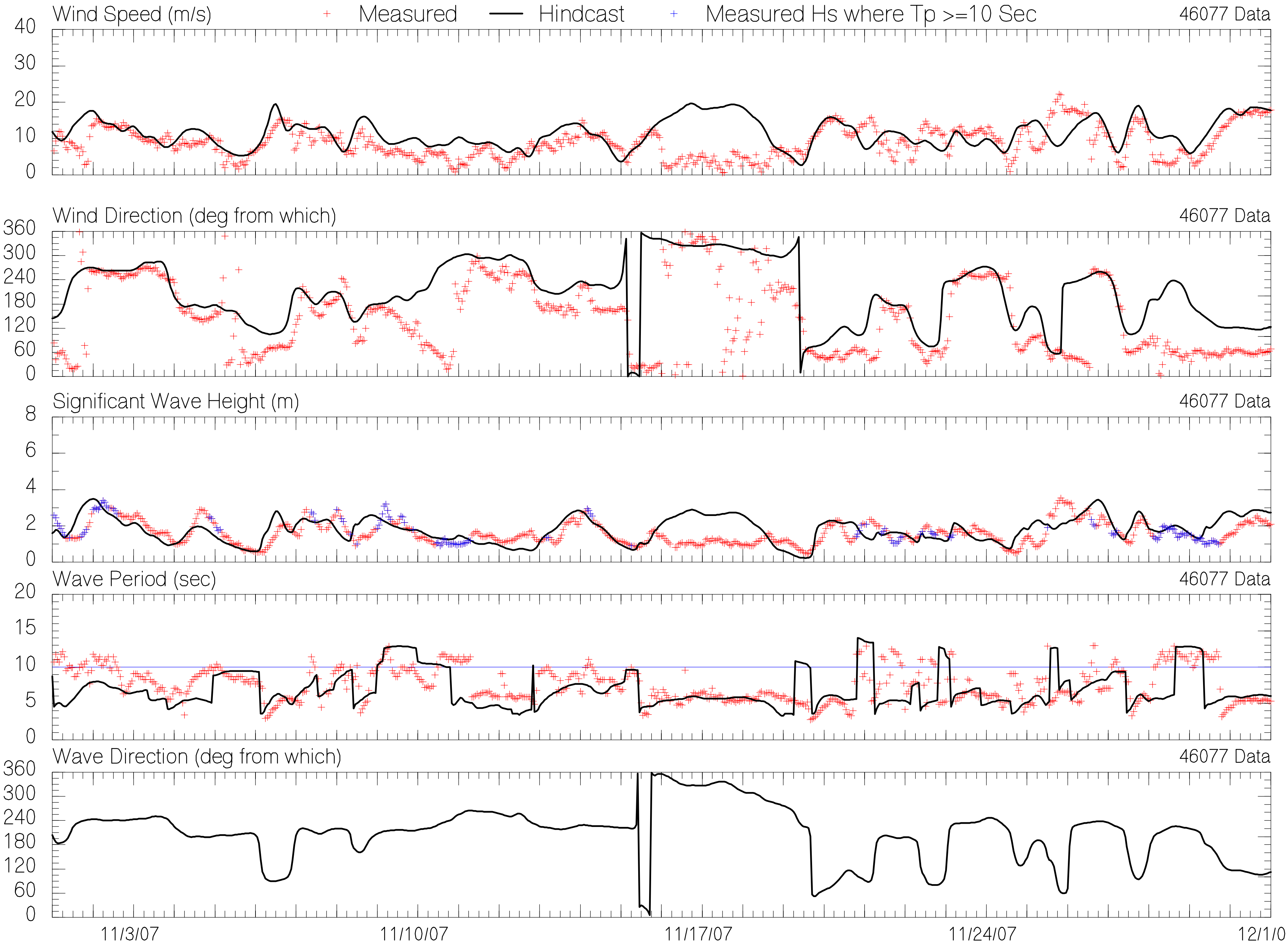
oceanweather inc.

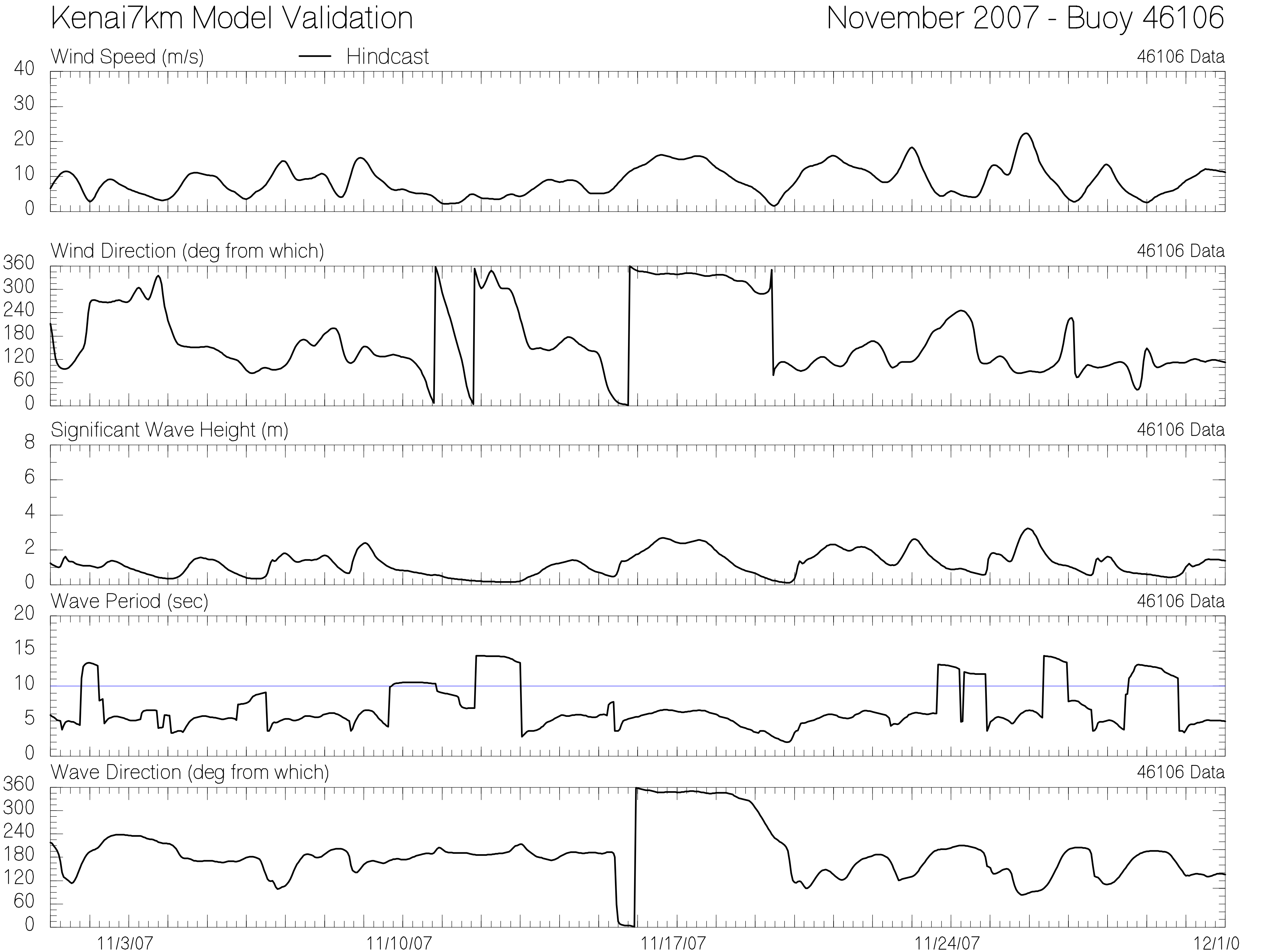
Kenai7km Model Validation

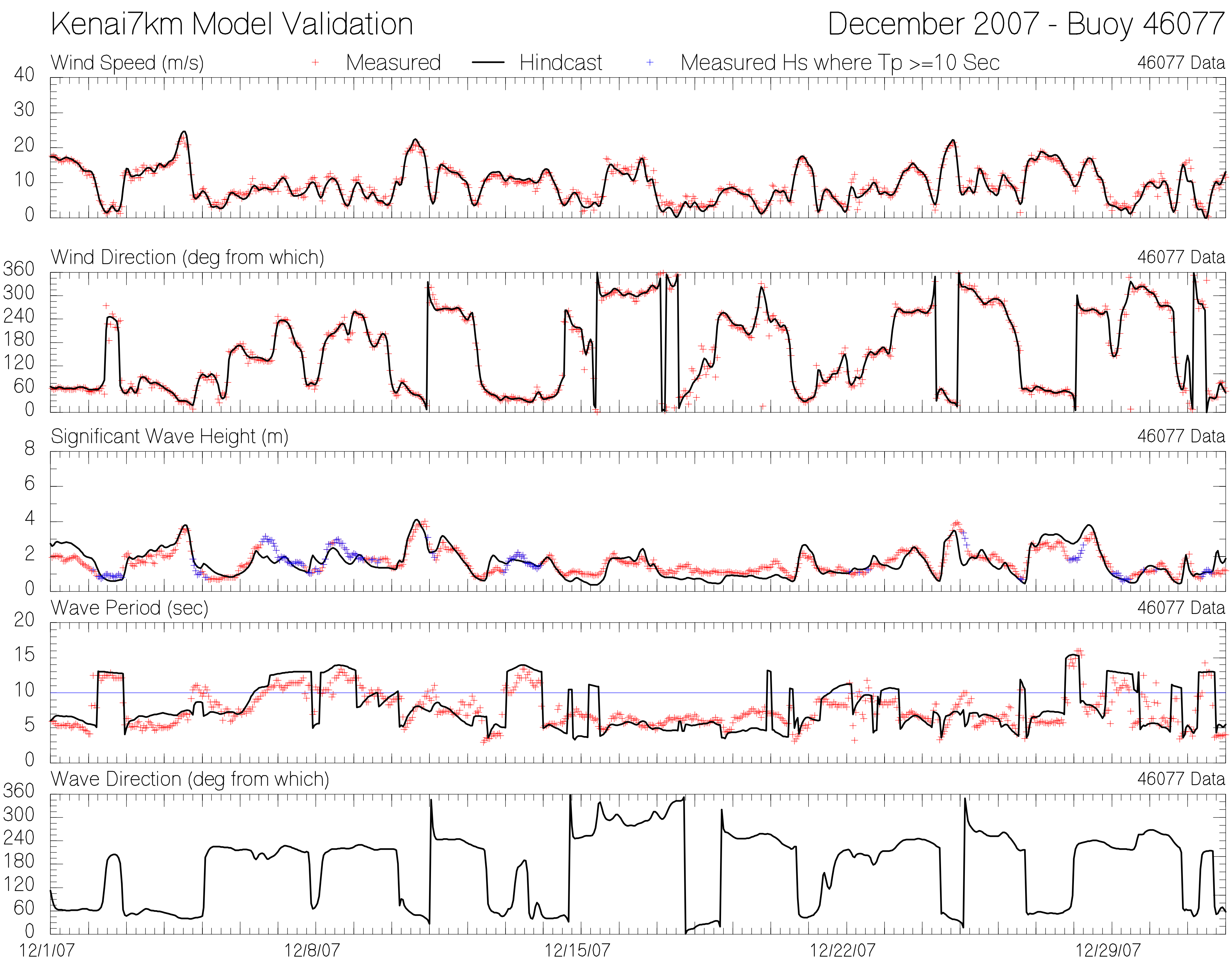
November 2007 - Buoy 46077



Printed from L:\Kenai\QC\Kenai7km\200711\46077.WPG (created on Nov-24-2009 02:58PM)

oceanweather inc.

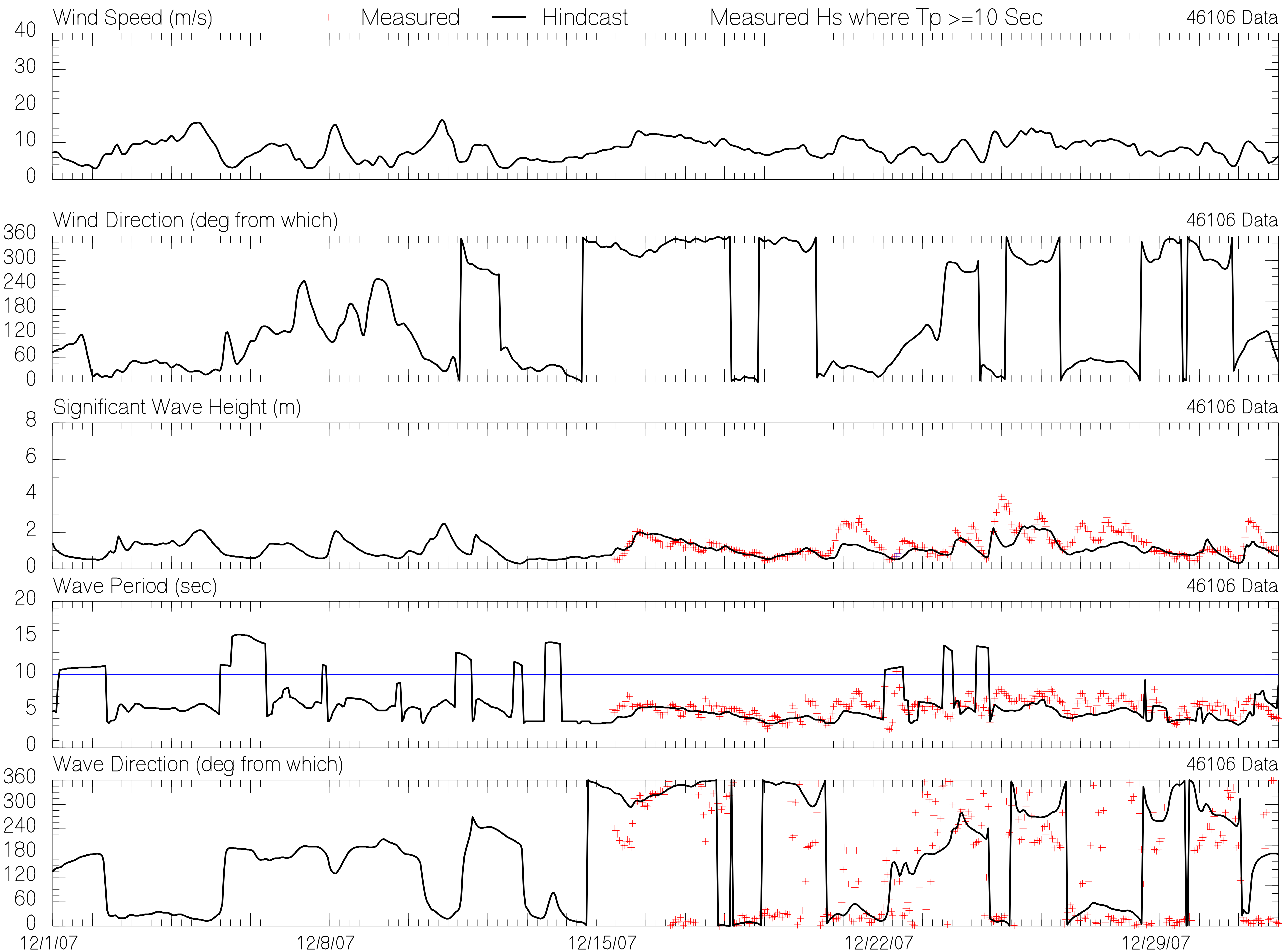

Kenai7km Model Validation
November 2007 - Buoy 46106
Wind Speed (m/s)
Hindcast
46106 Data
40
30
20
10
0
Wind Direction (deg from which)
46106 Data
360
300
240
180
120
60
0
Significant Wave Height (m)
46106 Data
8
6
4
2
0
Wave Period (sec)
46106 Data
20
15
10
5
0
Wave Direction (deg from which)
46106 Data
360
300
240
180
120
60
0
11/3/07
11/10/07
11/17/07
11/24/07
12/1/0
oceanweather inc.

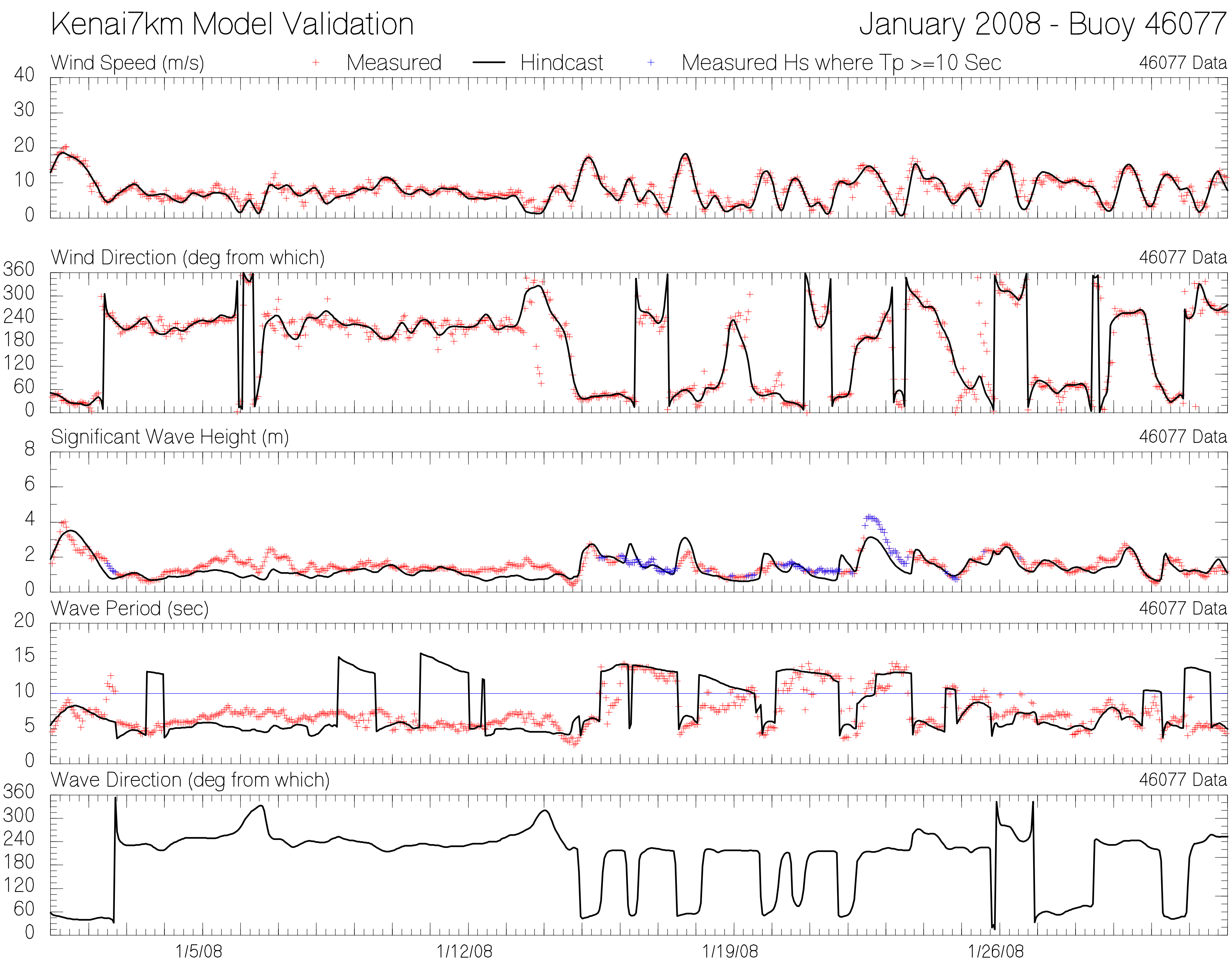


Printed from L:\Kenai\QC\Kenai7km\200712\46077.WPG (created on Nov-24-2009 02:59PM)

oceanweather inc.

Kenai7km Model Validation   December 2007 - Buoy 46106





Printed from L:\Kenai\QC\Kenai7km\200801\46077.WPG (created on Nov-24-2009 02:59PM)

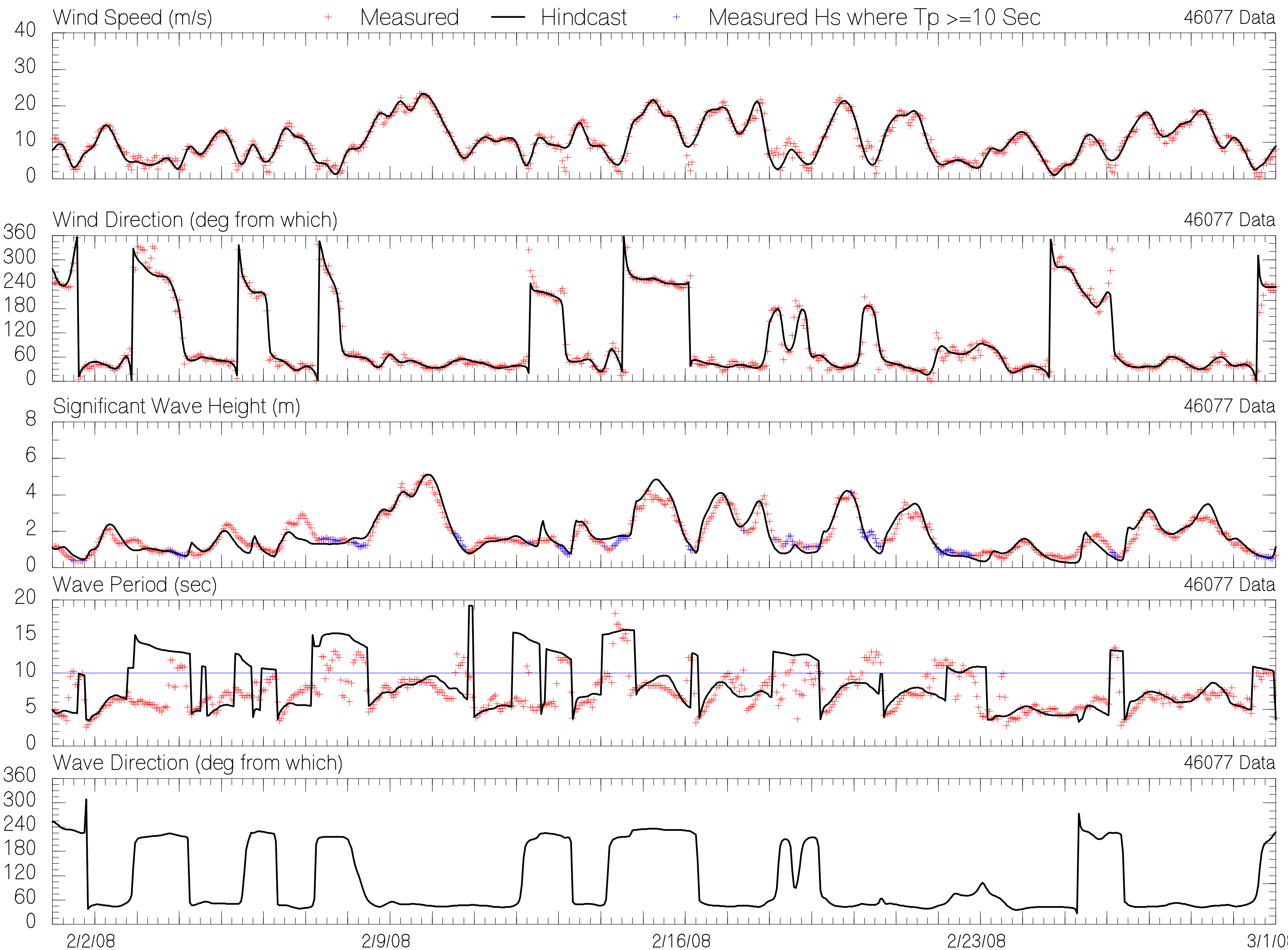
oceanweather inc.

Printed from L:\Kenai\QC\Kenai7km\200801\46106.WPG (created on Nov-24-2009 02:59PM)

oceanweather inc.

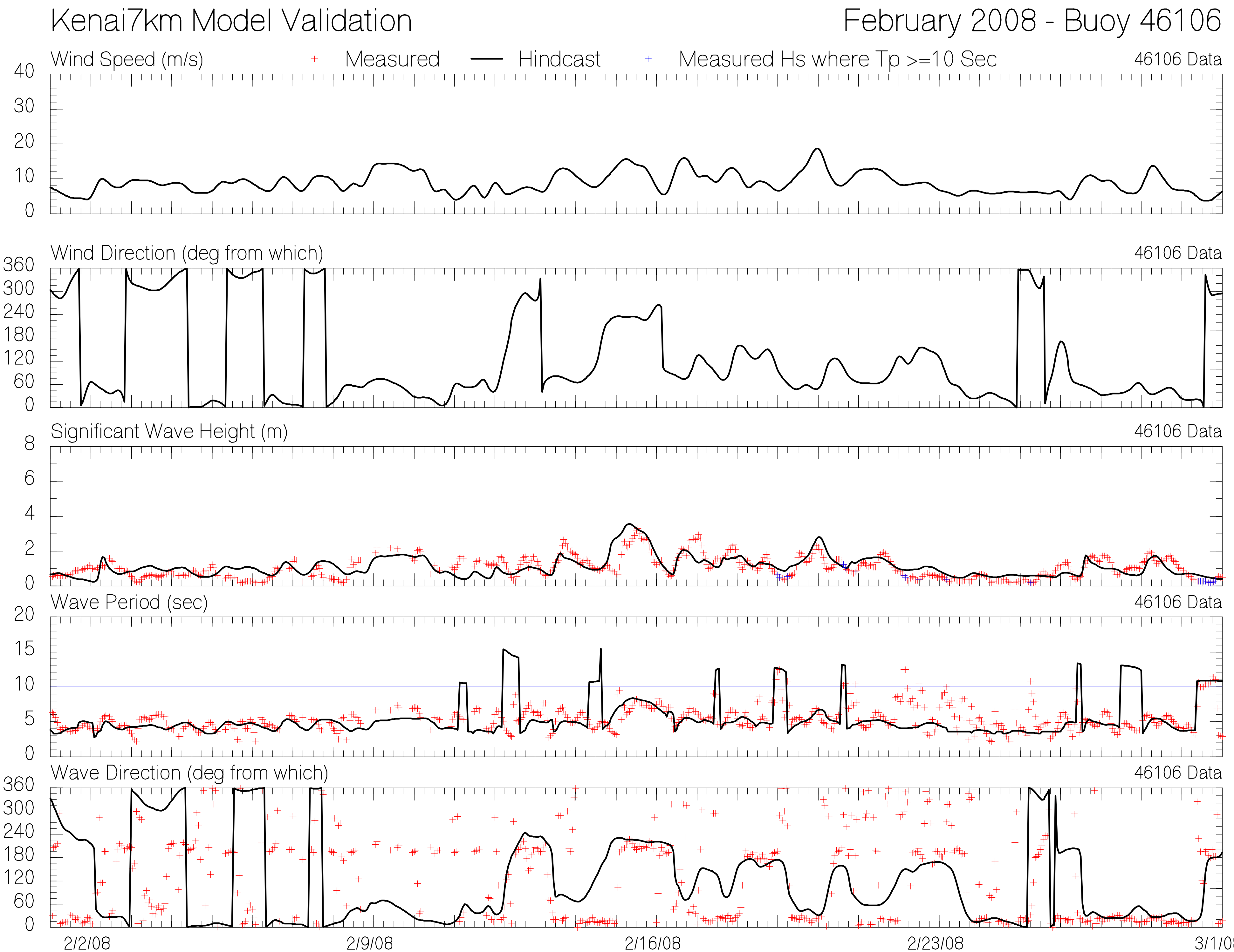
Kenai7km Model Validation

February 2008 - Buoy 46077



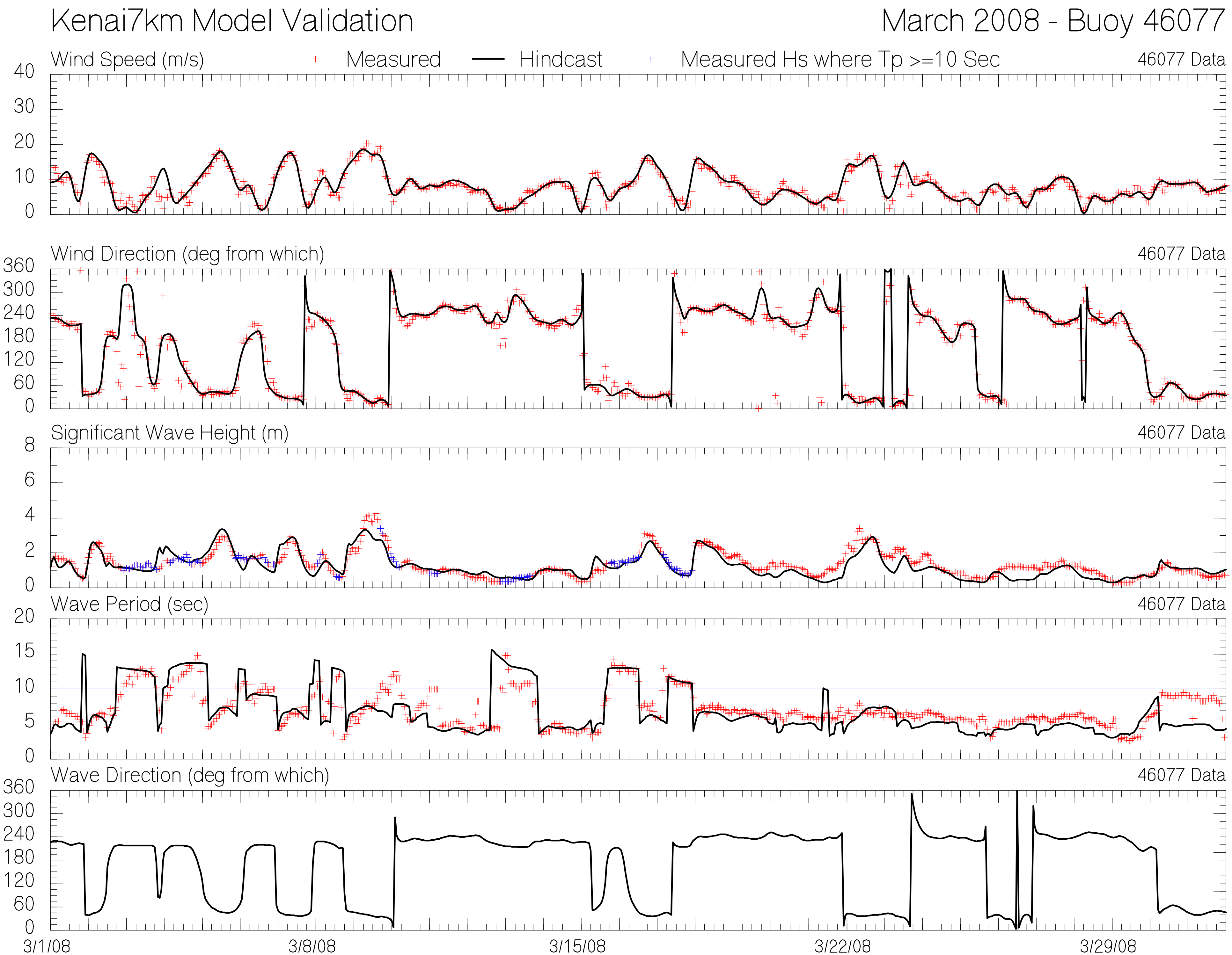
Printed from L:\Kenai\QC\Kenai7km\200802\46077.WPG (created on Nov-24-2009 03:00PM)

oceanweather inc.



Printed from L:\Kenai\QC\Kenai7km\200802\46106.WPG (created on Nov-24-2009 03:00PM)

oceanweather inc.

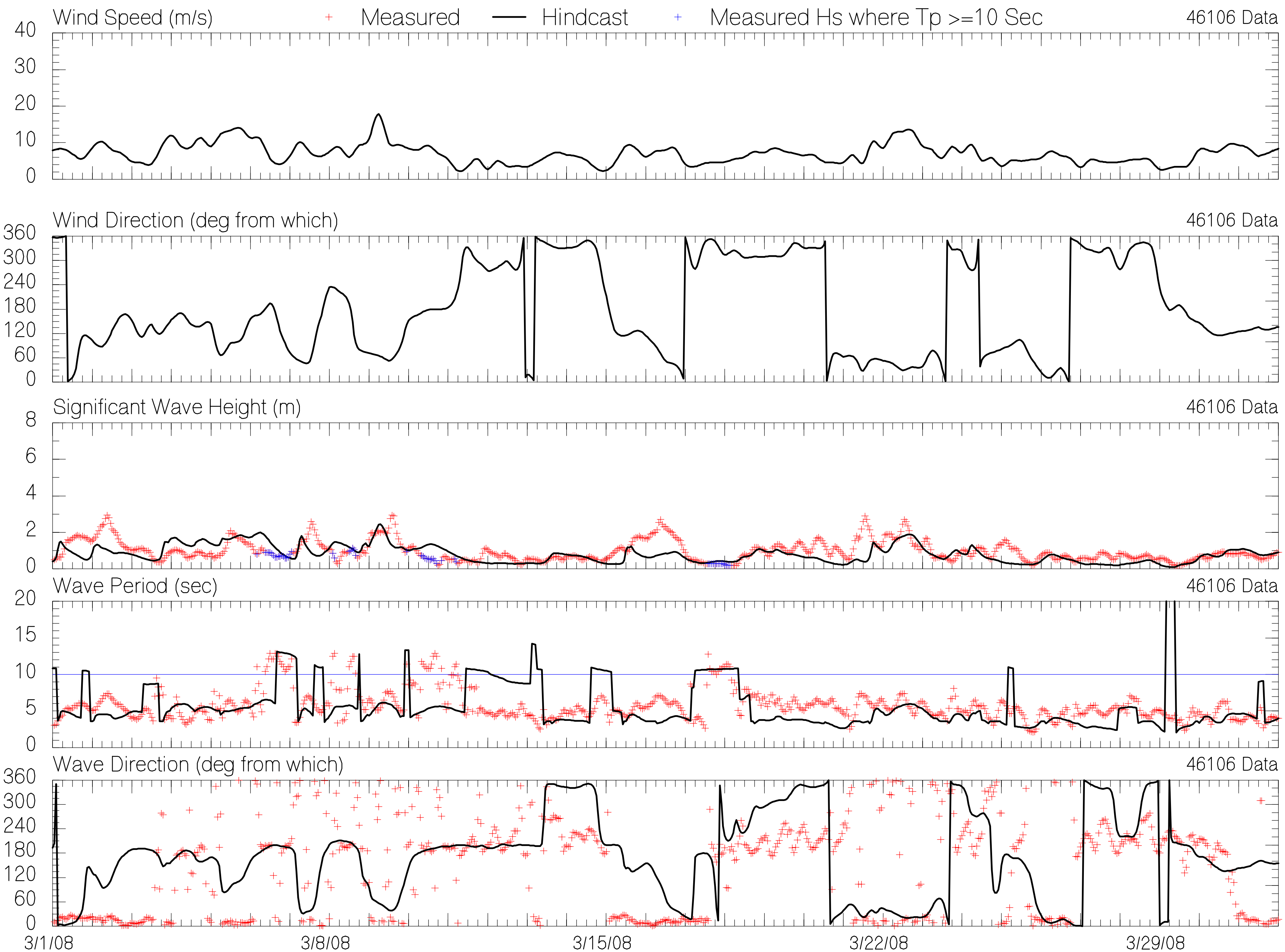


Printed from L:\Kenai\QC\Kenai7km\200803\46077.WPG (created on Nov-24-2009 03:00PM)

oceanweather inc.

Kenai7km Model Validation

March 2008 - Buoy 46106



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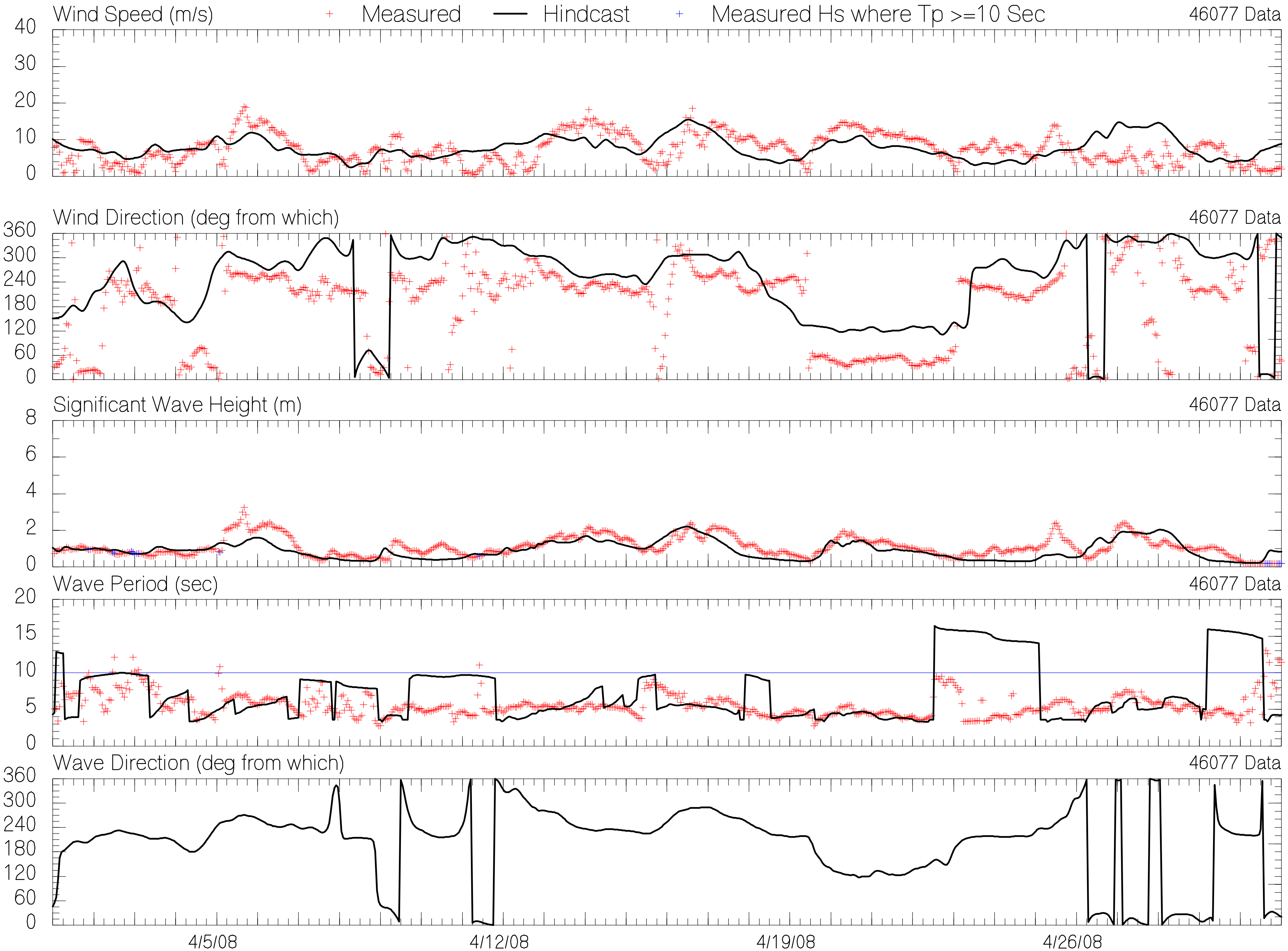
oceanweather inc.

Kenai7km Model Validation

April 2008 - Buoy 46077



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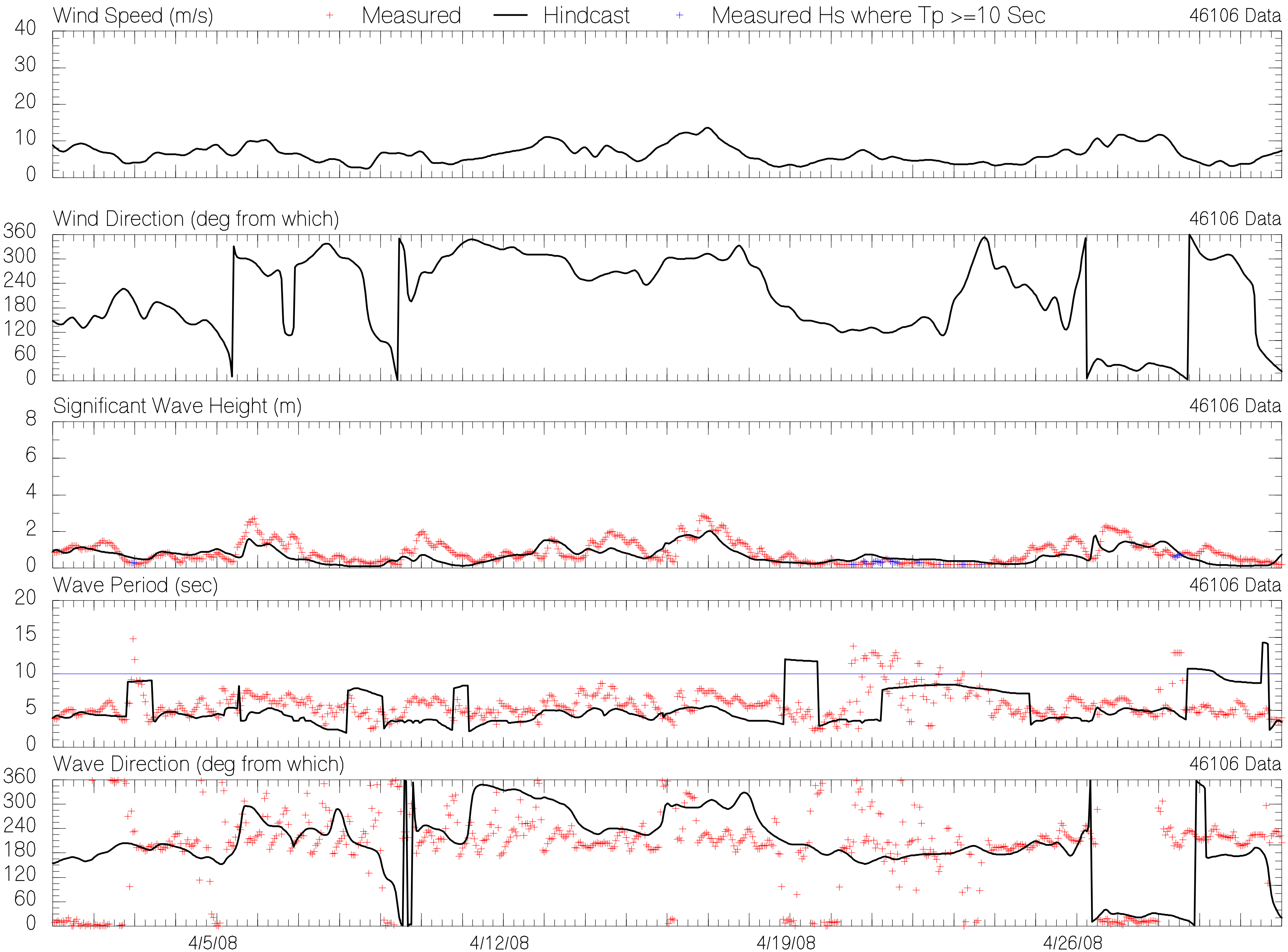
oceanweather inc.

Kenai7km Model Validation

April 2008 - Buoy 46106

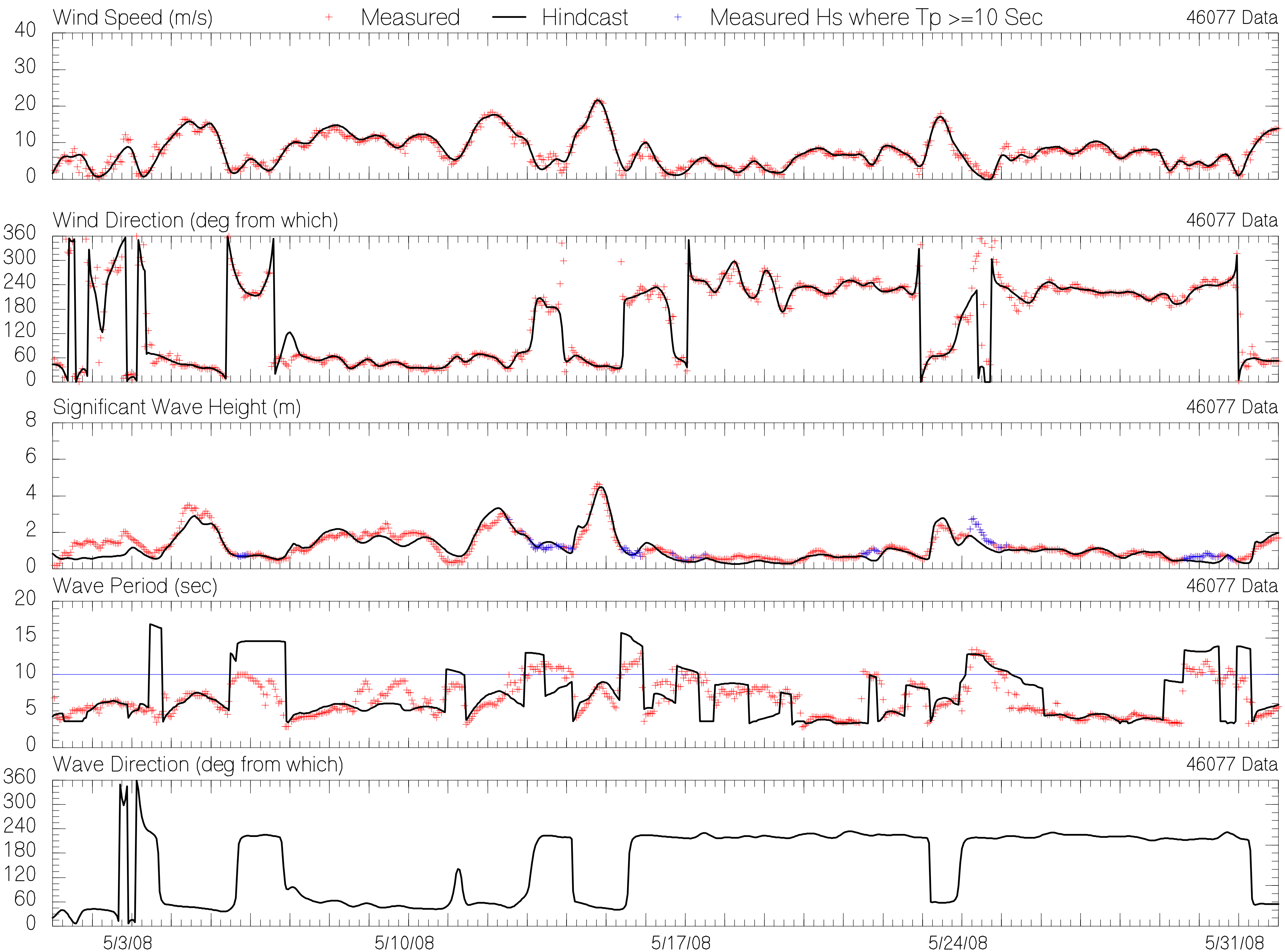


Printed from L:\Kenai\QC\Kenai7km\200804\46106.WPG (created on Nov-24-2009 03:01PM)

oceanweather inc.

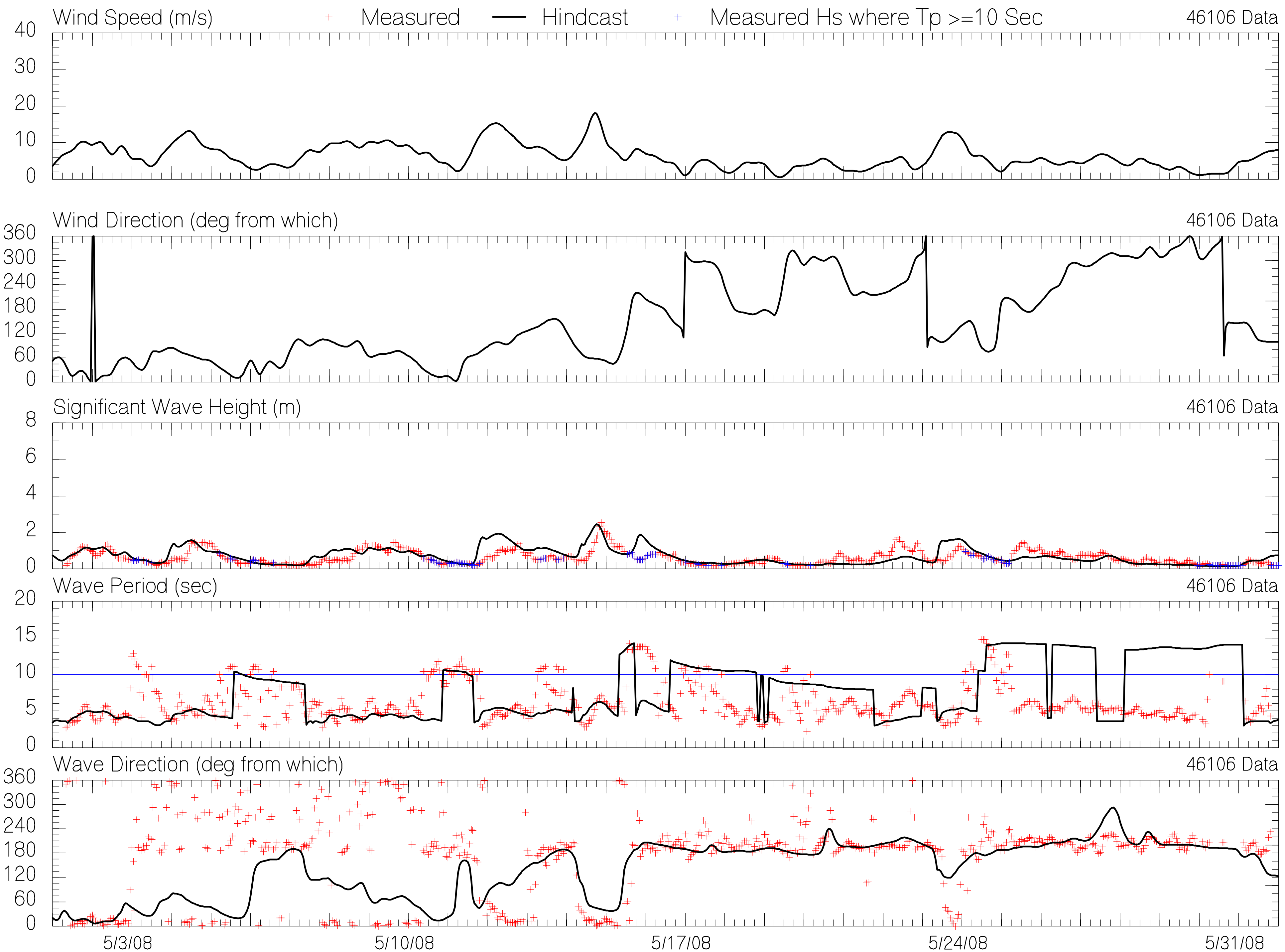
Kenai7km Model Validation

May 2008 - Buoy 46077



Kenai7km Model Validation

May 2008 - Buoy 46106



Printed from L:\Kenai\QC\Kenai7km\200805\46106.WPG (created on Nov-24-2009 03:01PM)

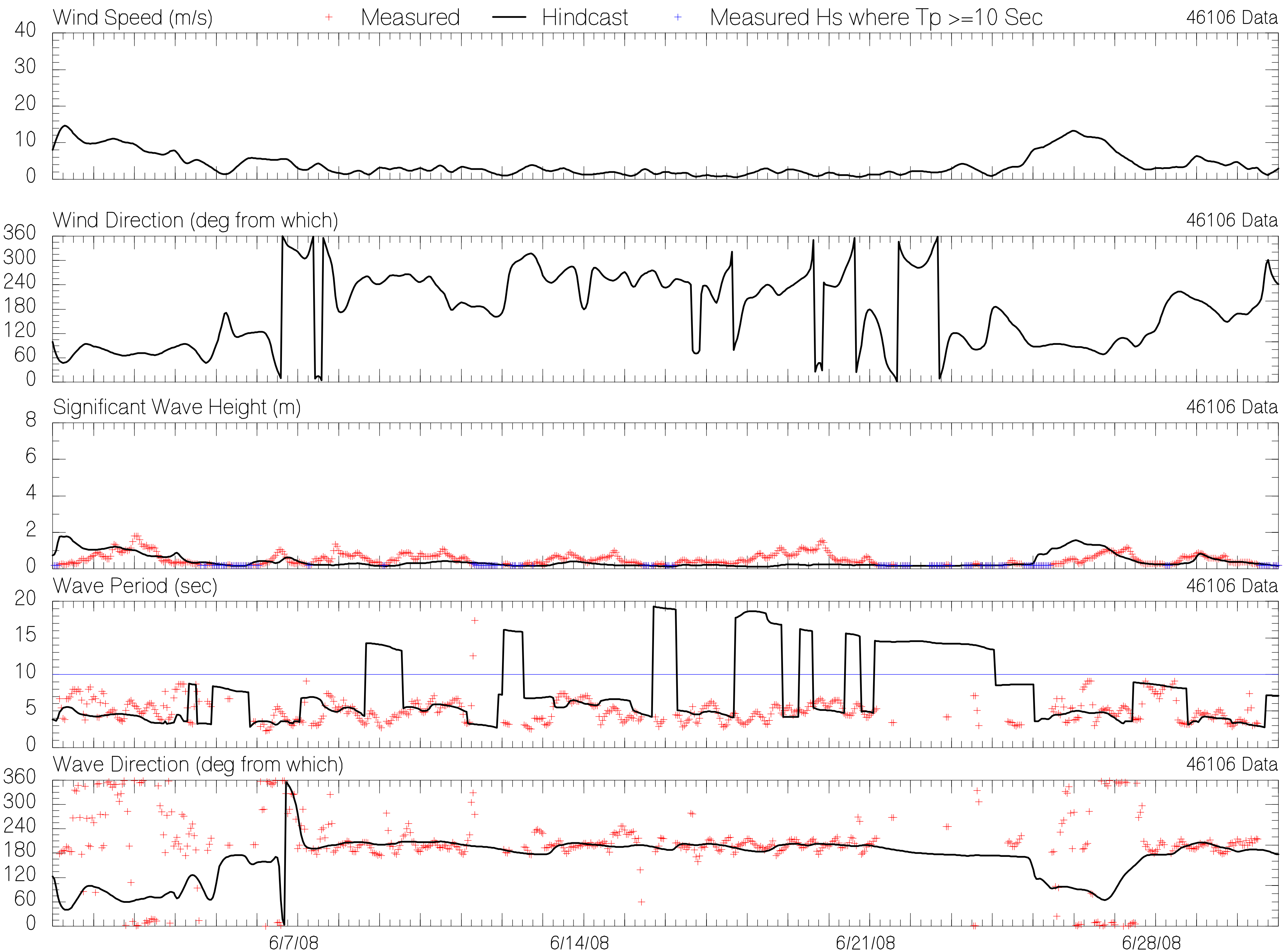
oceanweather inc.

Printed from L:\Kenai\QC\Kenai7km\200806\46077.WPG (created on Nov-24-2009 03:01PM)

oceanweather inc.

Kenai7km Model Validation

June 2008 - Buoy 46106



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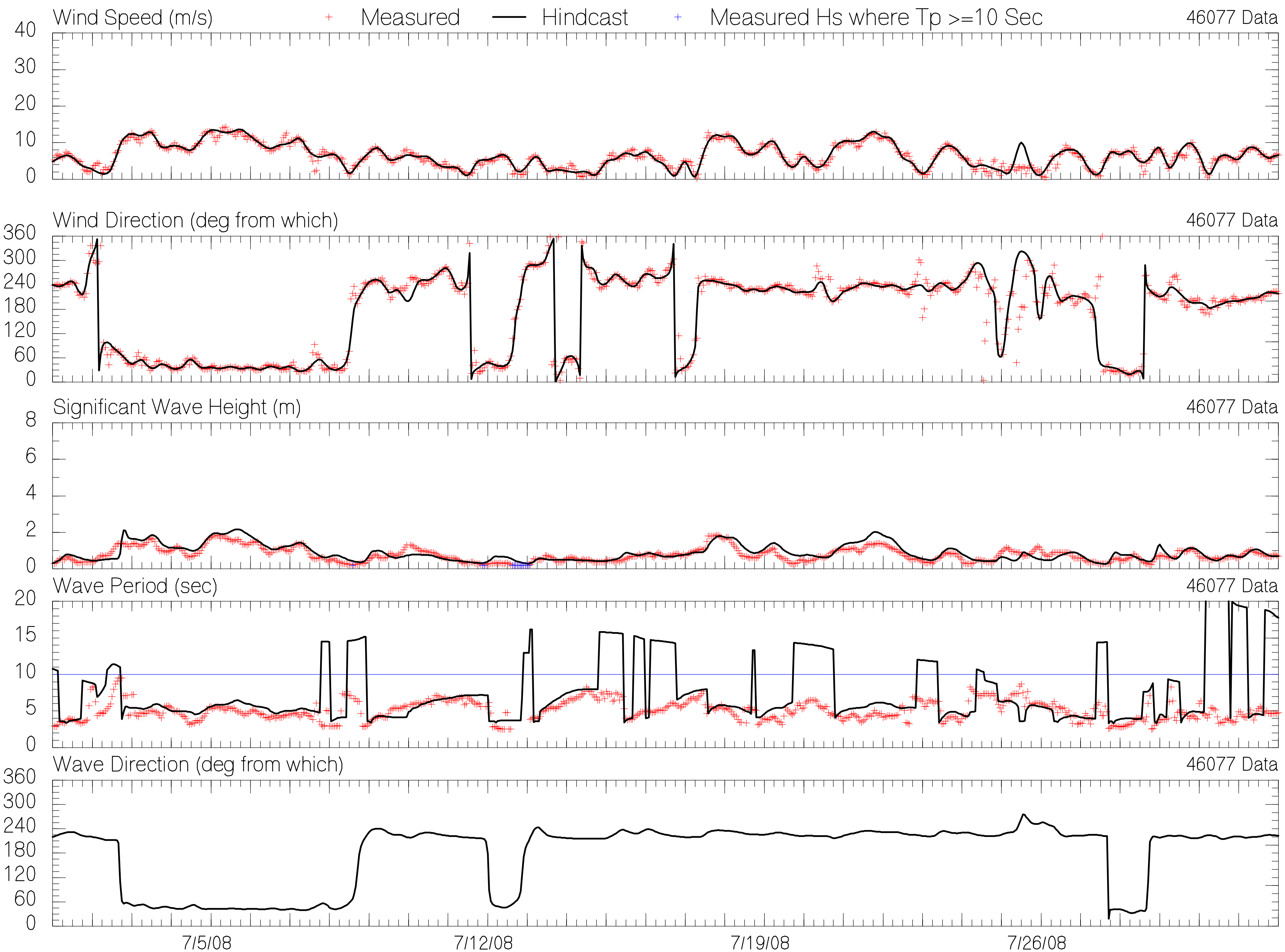
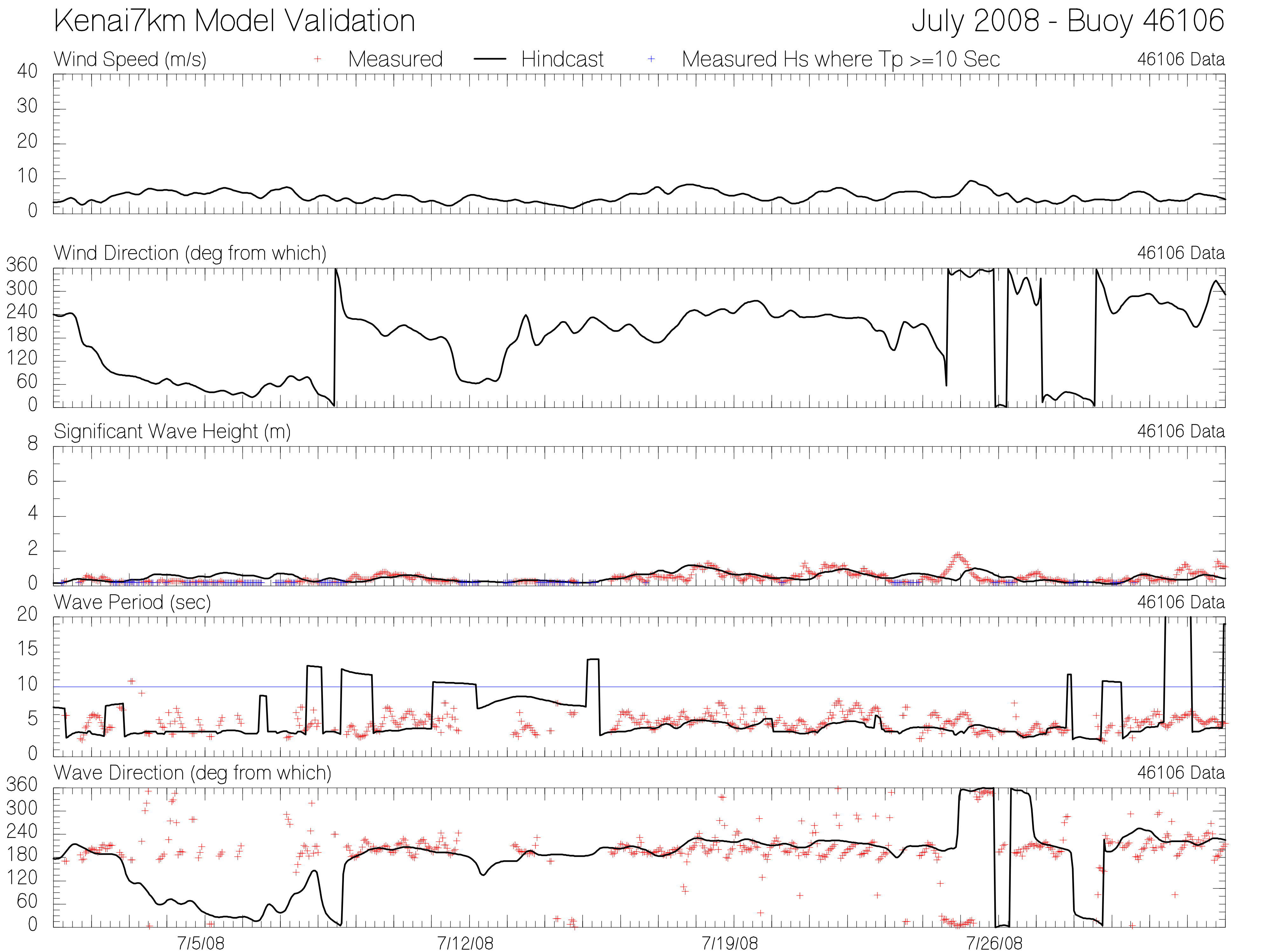
oceanweather inc.

Kenai7km Model Validation

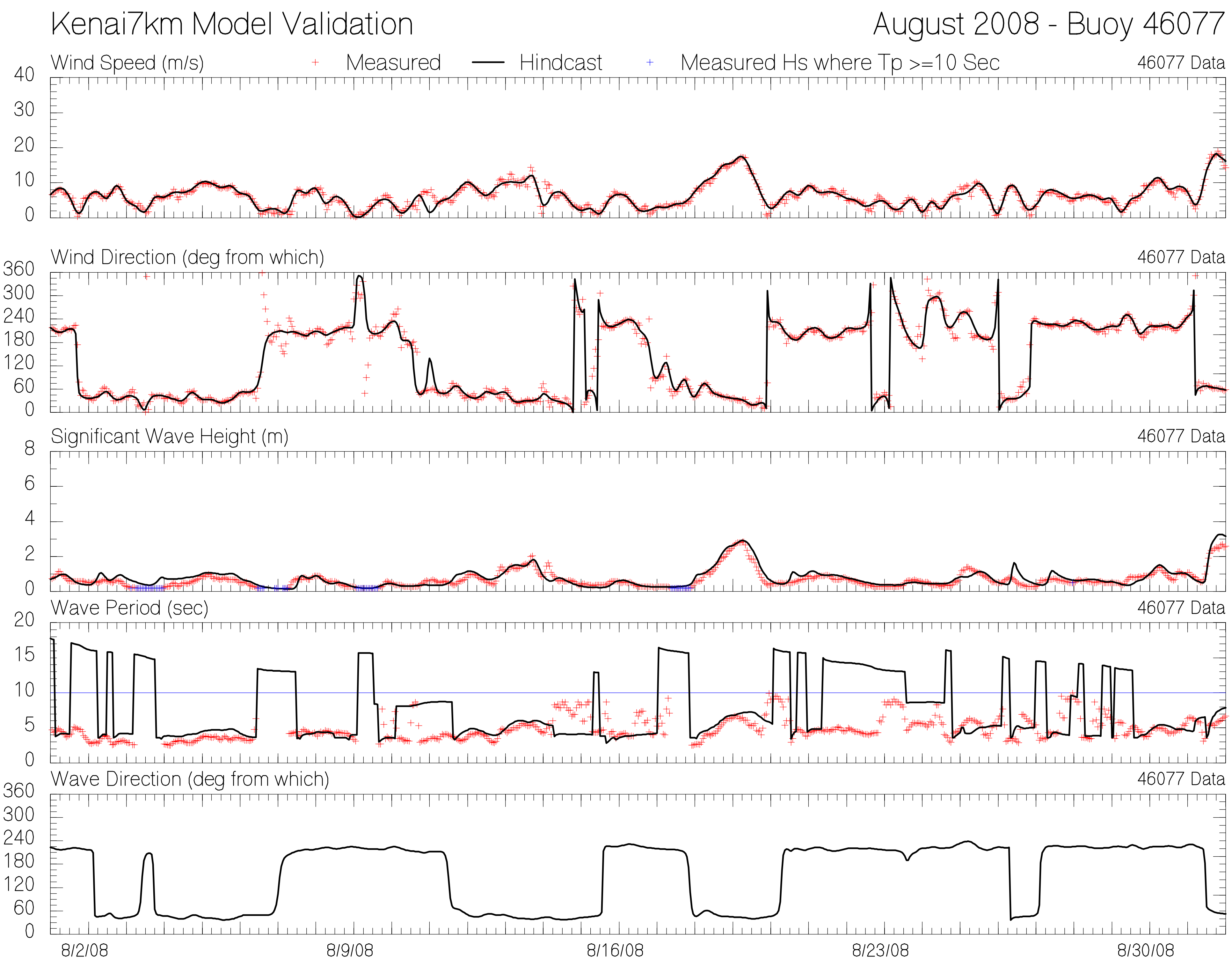
July 2008 - Buoy 46077





Printed from L:\Kenai\QC\Kenai7km\200807\46106.WPG (created on Nov-24-2009 03:02PM)

oceanweather inc.

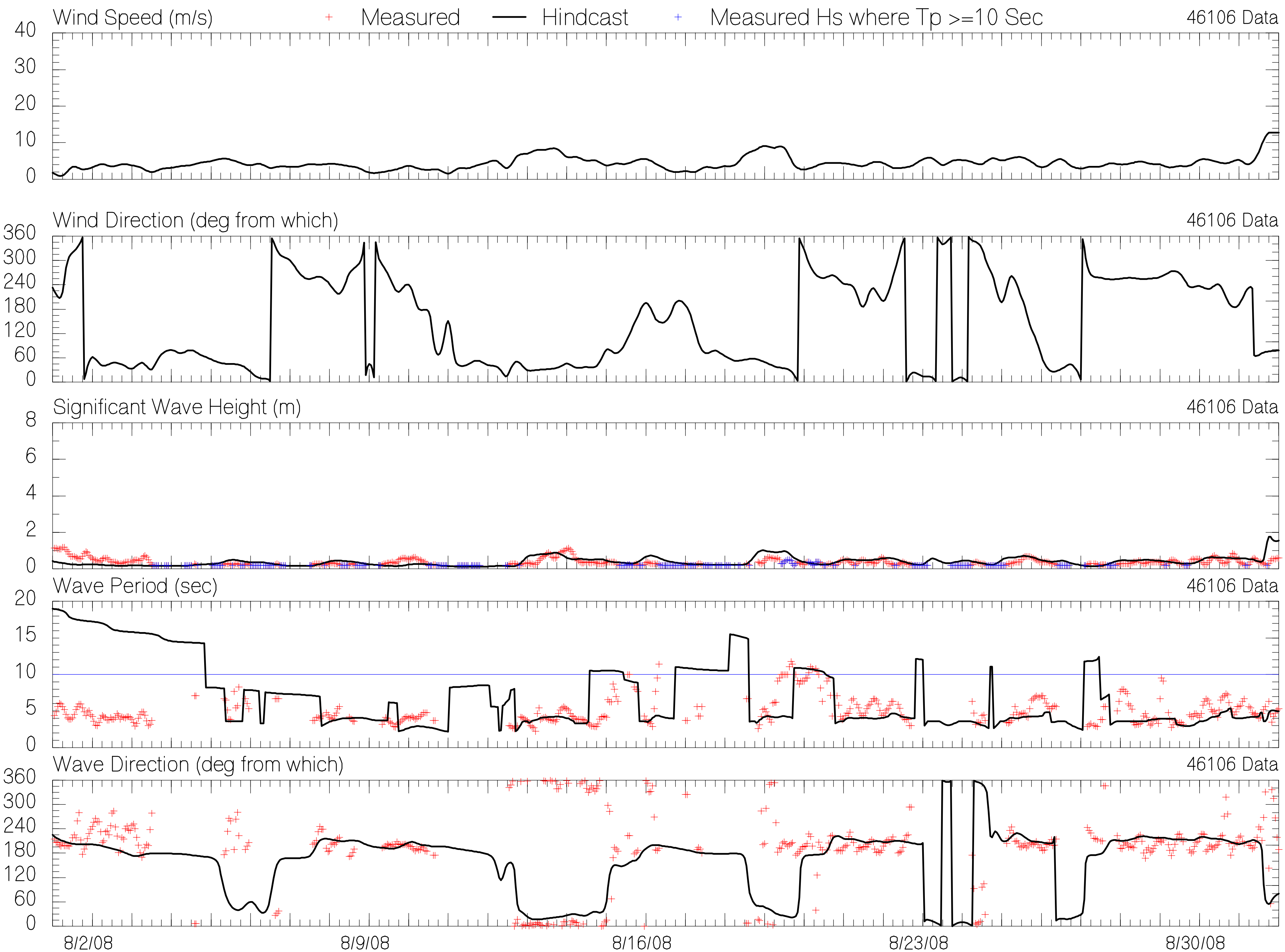


Printed from L:\Kenai\QC\Kenai7km\200808\46077.WPG (created on Nov-24-2009 03:02PM)

oceanweather inc.

Kenai7km Model Validation

August 2008 - Buoy 46106



Printed from L:\Kenai\QC\Kenai7km\200808\46106.WPG (created on Nov-24-2009 03:02PM)

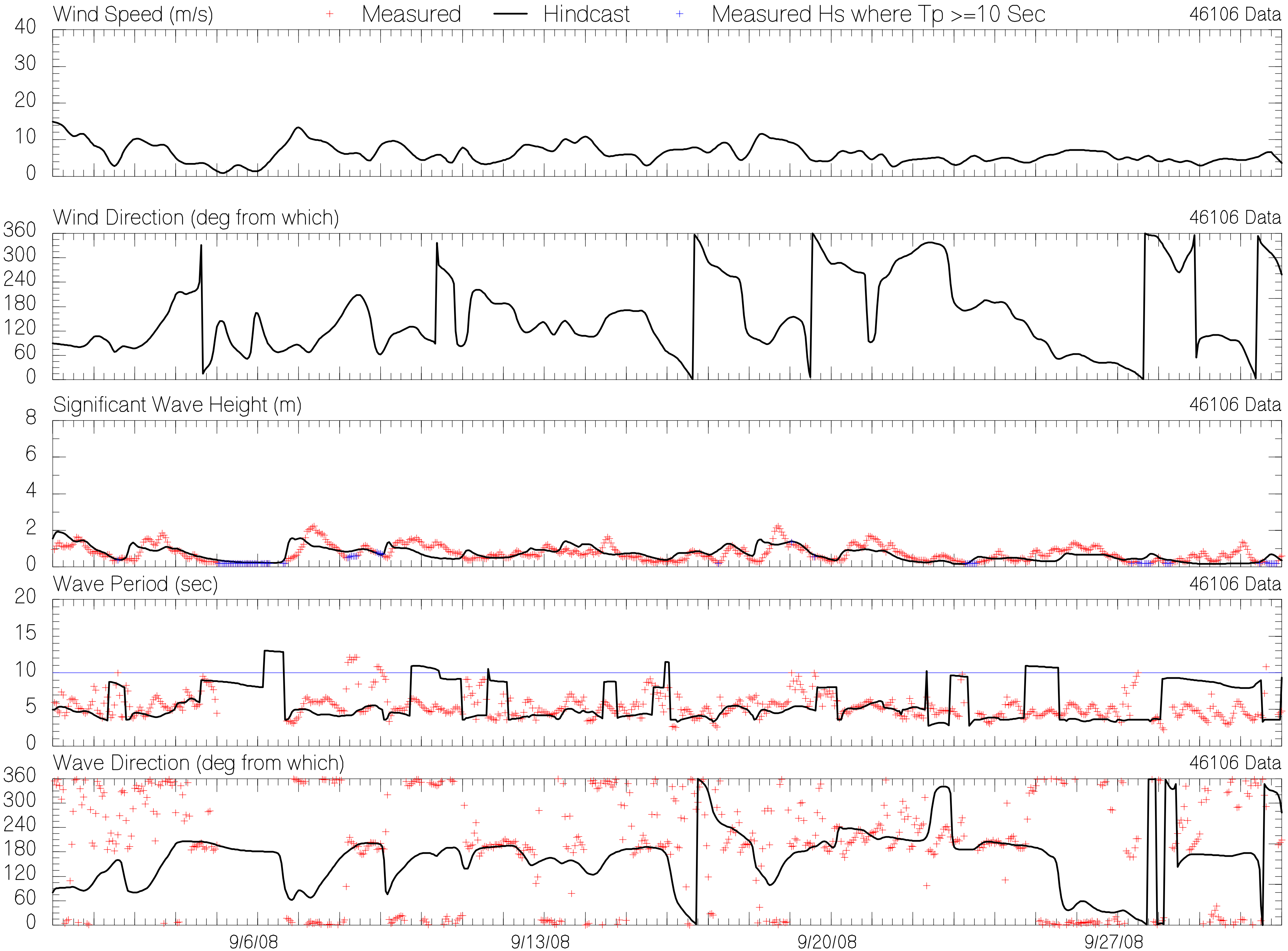
oceanweather inc.

Printed from L:\Kenai\QC\Kenai7km\200809\46077.WPG (created on Nov-24-2009 03:02PM)

oceanweather inc.

Kenai7km Model Validation

September 2008 - Buoy 46106

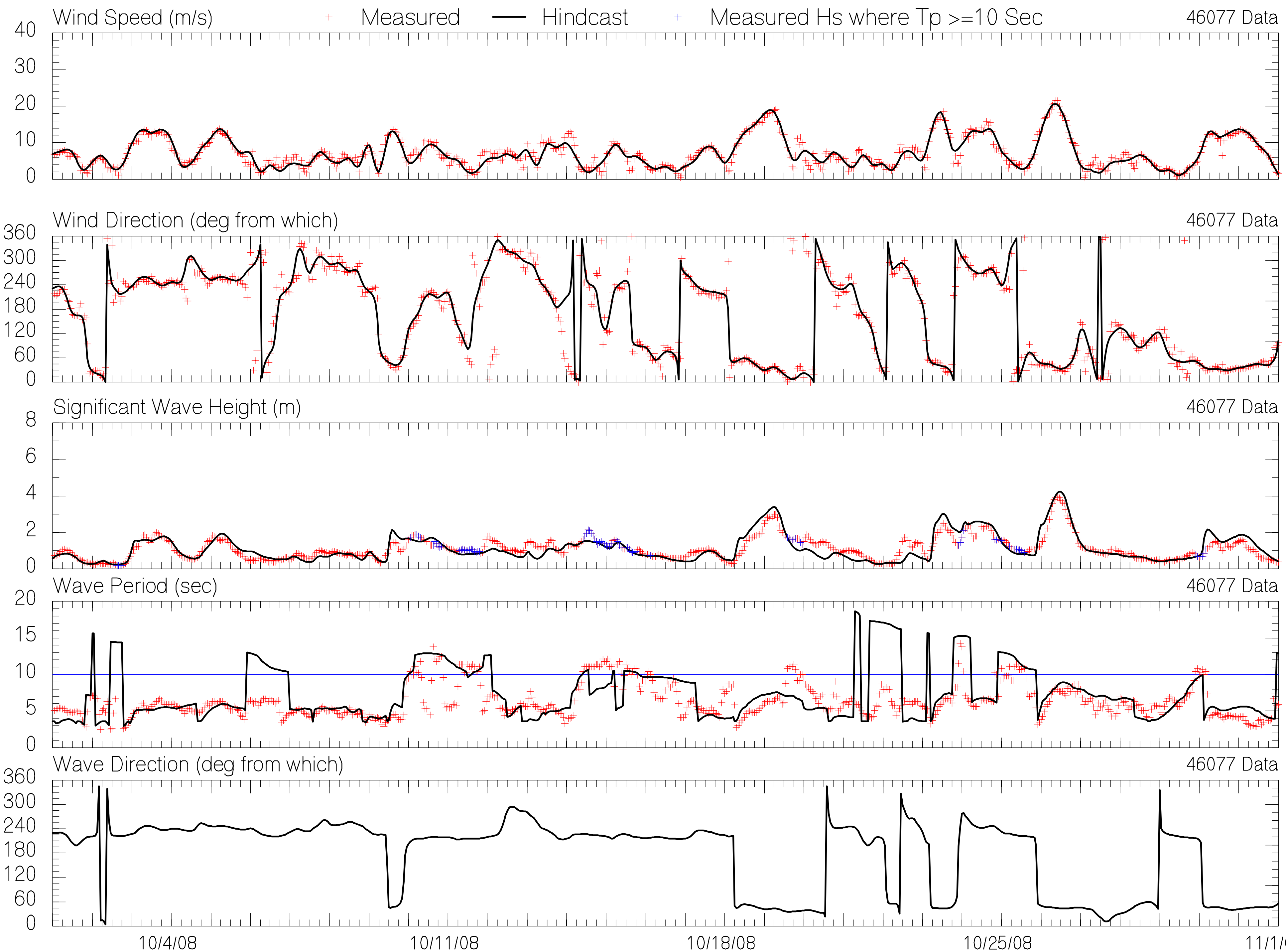


Printed from L:\Kenai\QC\Kenai7km\200809\46106.WPG (created on Nov-24-2009 03:03PM)

oceanweather inc.

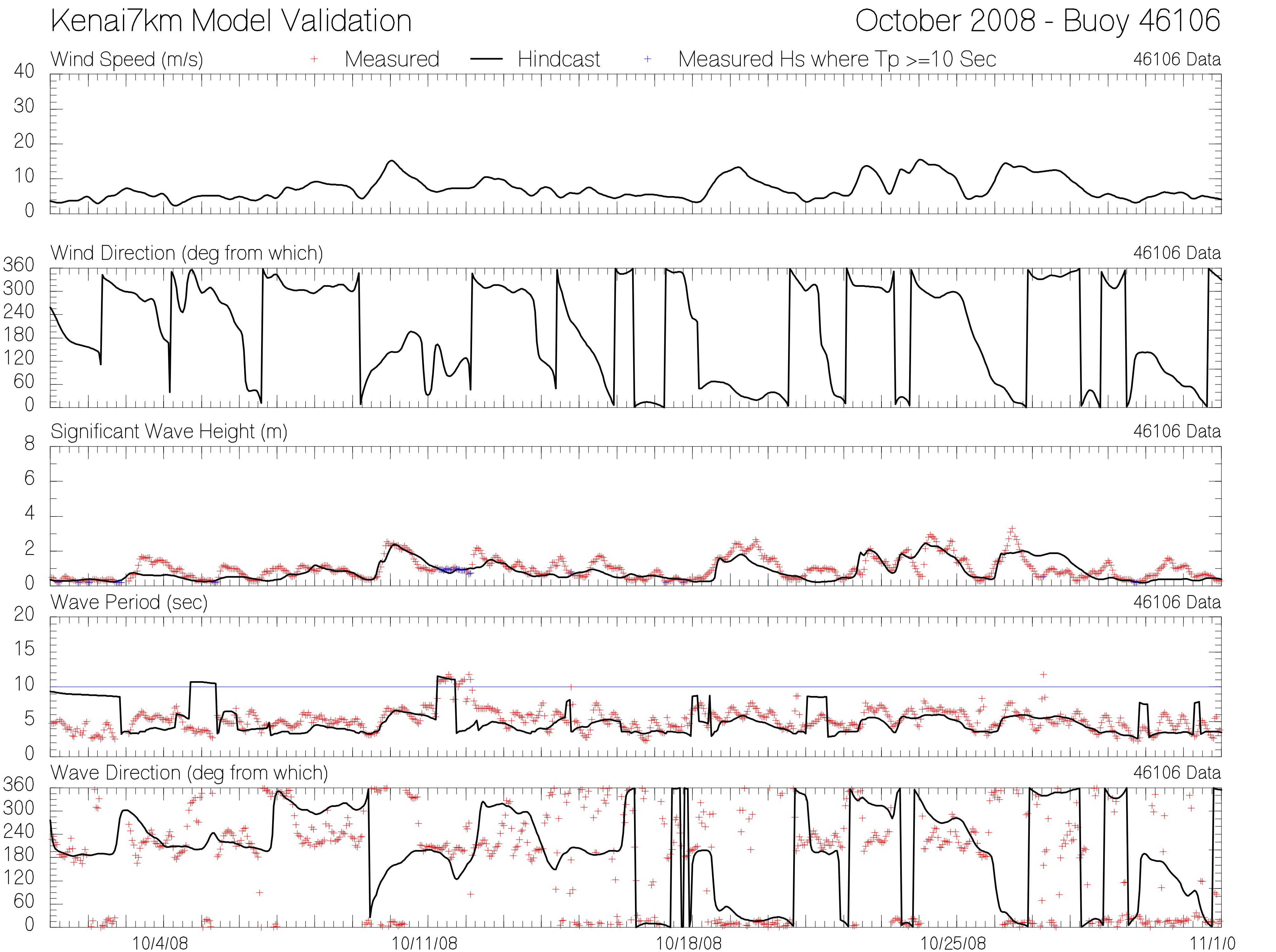
Kenai7km Model Validation

October 2008 - Buoy 46077



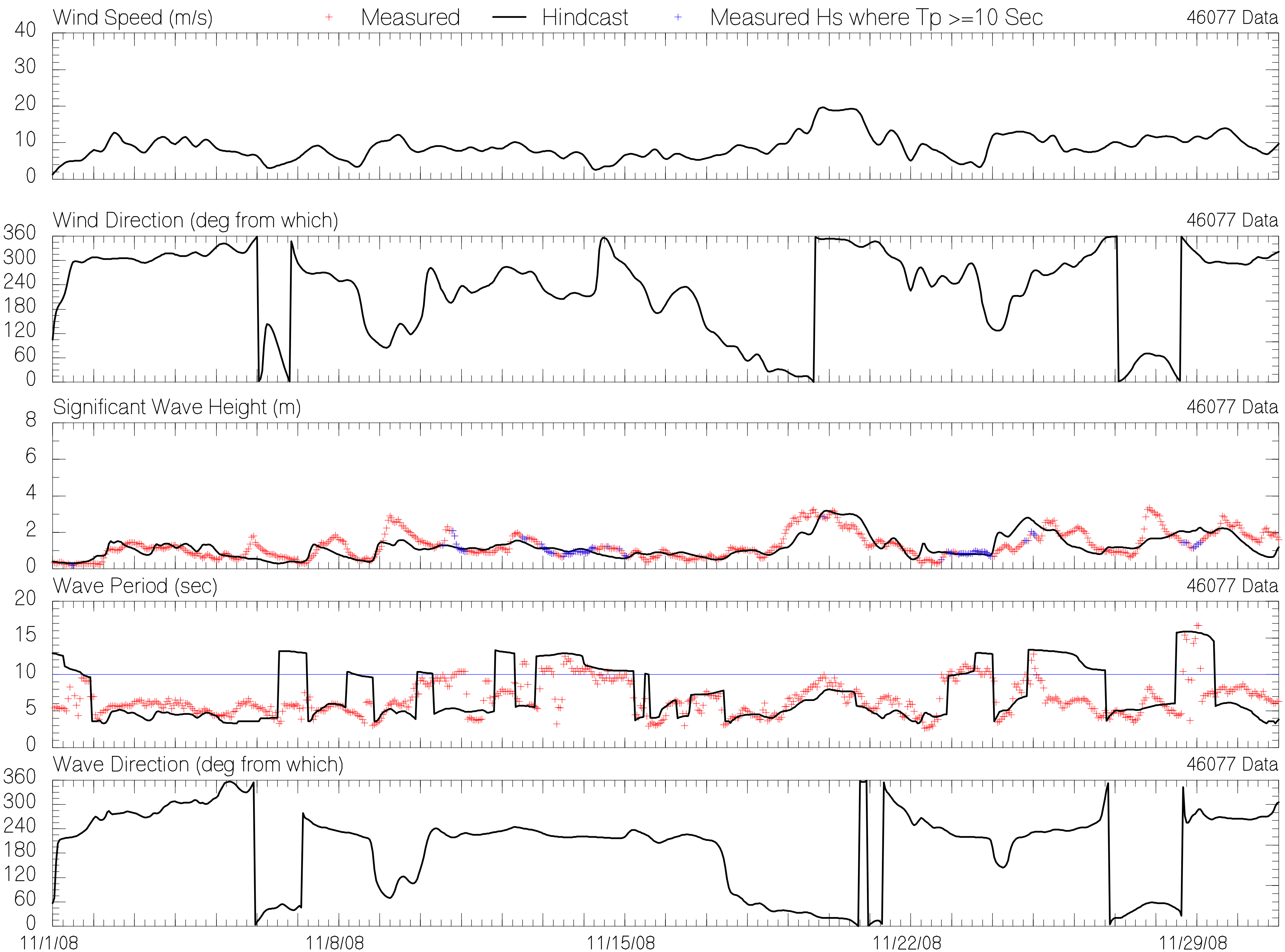
Printed from L:\Kenai\QC\Kenai7km\200810\46077.WPG (created on Nov-24-2009 03:03PM)

oceanweather inc.


Kenai7km Model Validation
October 2008 - Buoy 46106
Wind Speed (m/s)
Measured
Hindcast
Measured Hs where Tp >=10 Sec
46106 Data
40
30
20
10
0
Wind Direction (deg from which)
46106 Data
360
300
240
180
120
60
0
Significant Wave Height (m)
46106 Data
8
6
4
2
0
Wave Period (sec)
46106 Data
20
15
10
5
0
Wave Direction (deg from which)
46106 Data
360
300
240
180
120
60
0
10/4/08
10/11/08
10/18/08
10/25/08
11/1/0

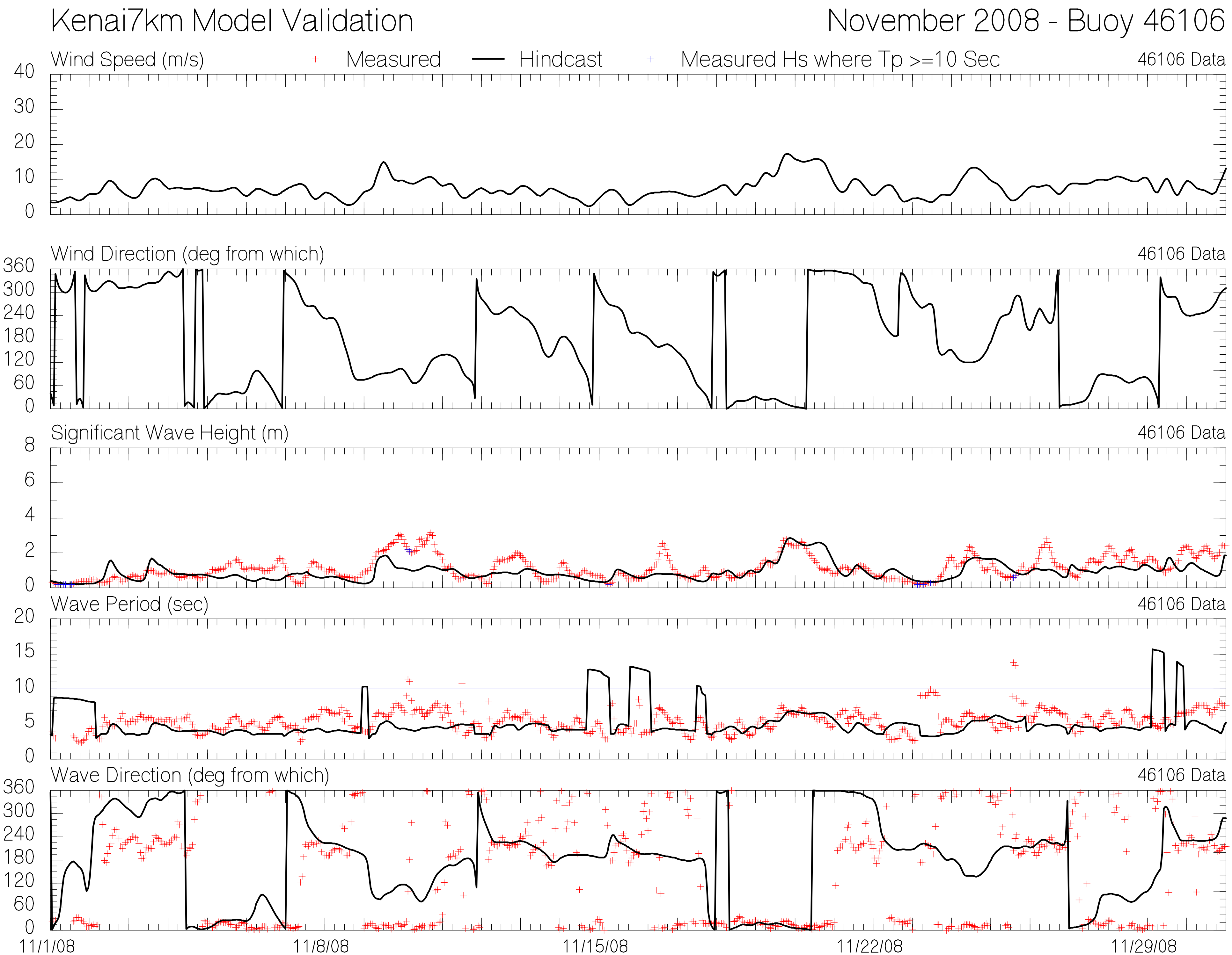
Kenai7km Model Validation

November 2008 - Buoy 46077



Printed from L:\Kenai\QC\Kenai7km\200811\46077.WPG (created on Nov-24-2009 03:03PM)

oceanweather inc.

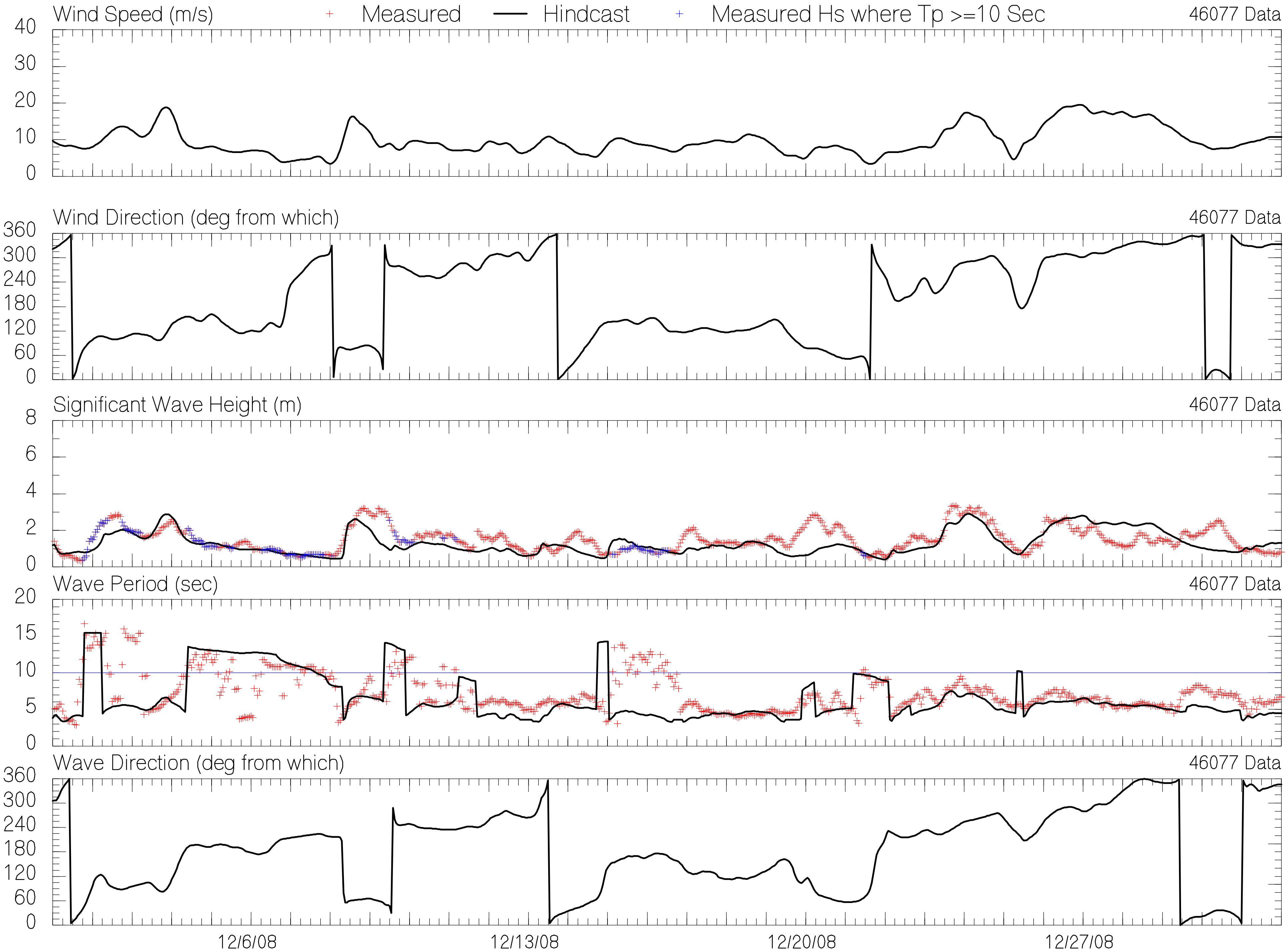


Printed from L:\Kenai\QC\Kenai7km\200811\46106.WPG (created on Nov-24-2009 03:03PM)

oceanweather inc.

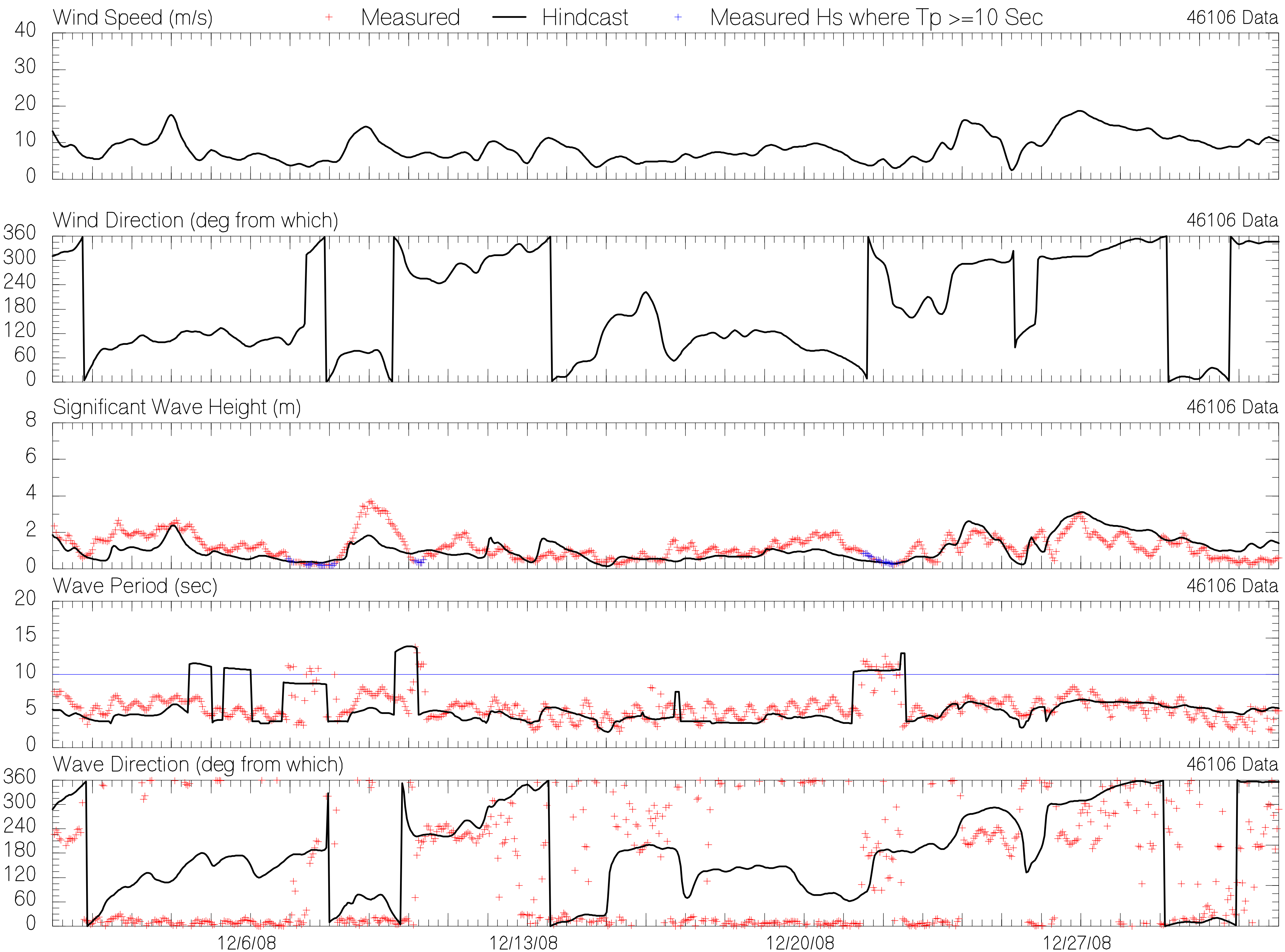
Kenai7km Model Validation

December 2008 - Buoy 46077



Kenai7km Model Validation

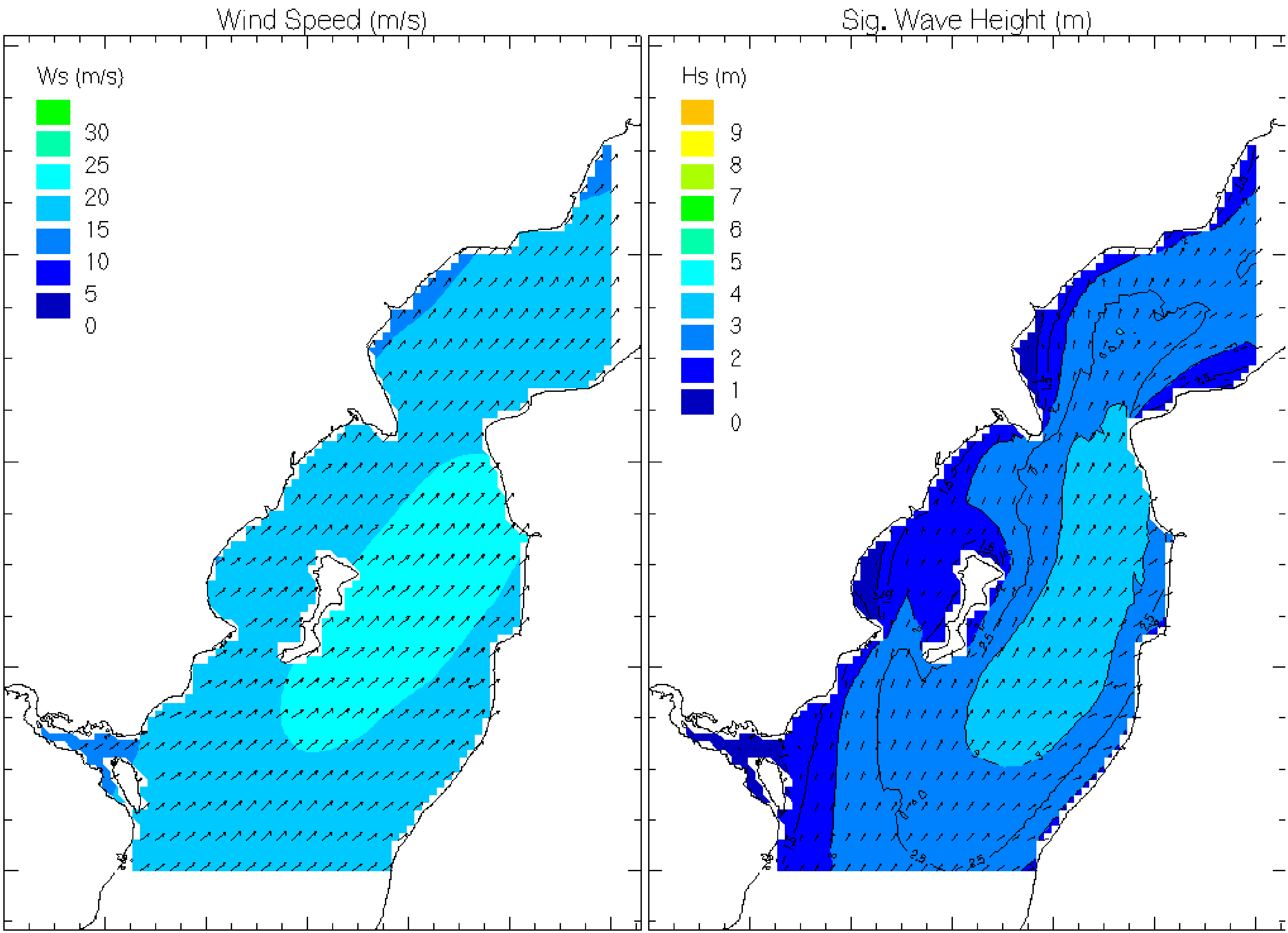
December 2008 - Buoy 46106



Printed from L:\Kenai\QC\Kenai7km\200812\46106.WPG (created on Nov-24-2009 03:04PM)

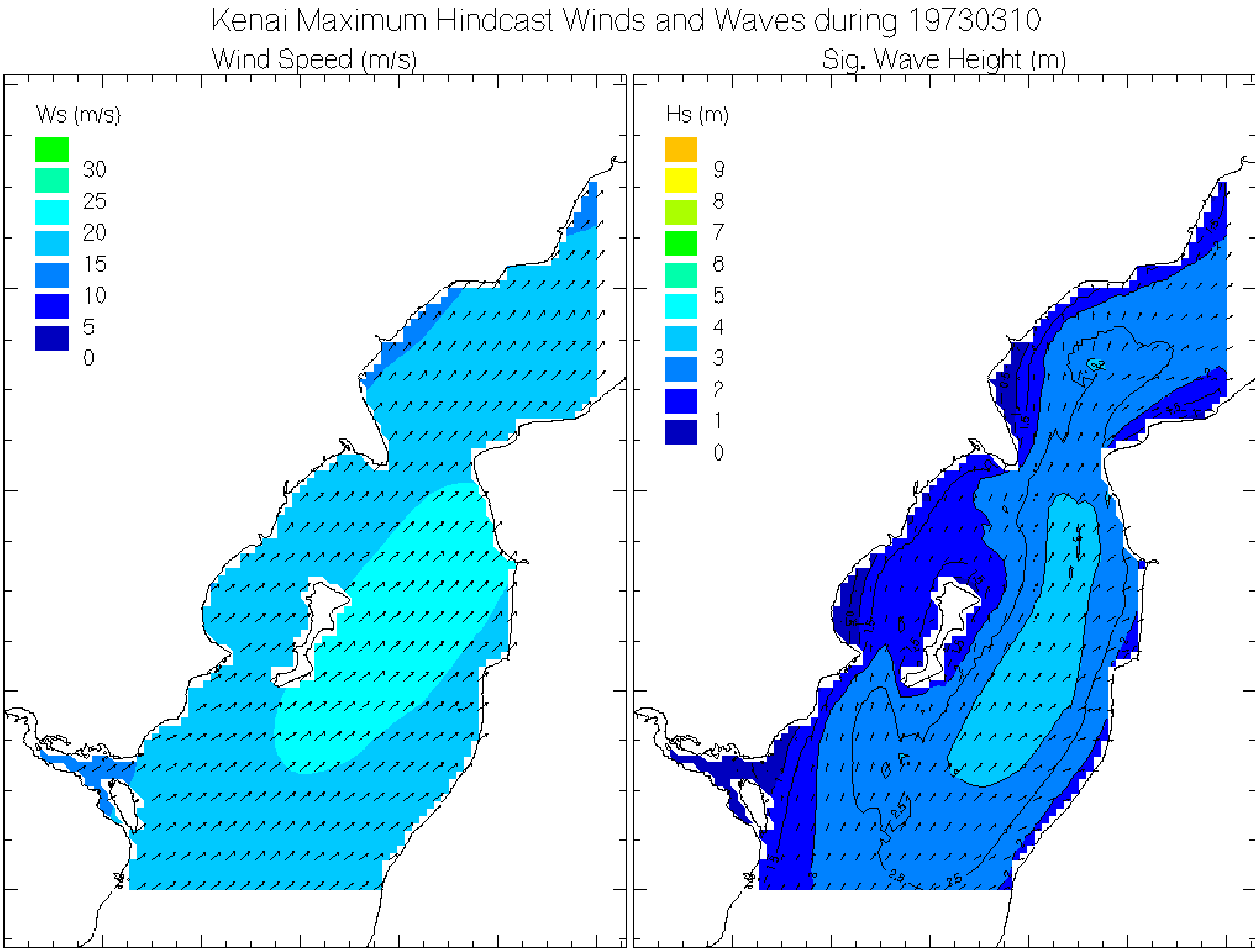
oceanweather inc.

Kenai MTR Maximum Hindcast Winds and Waves during 19730310

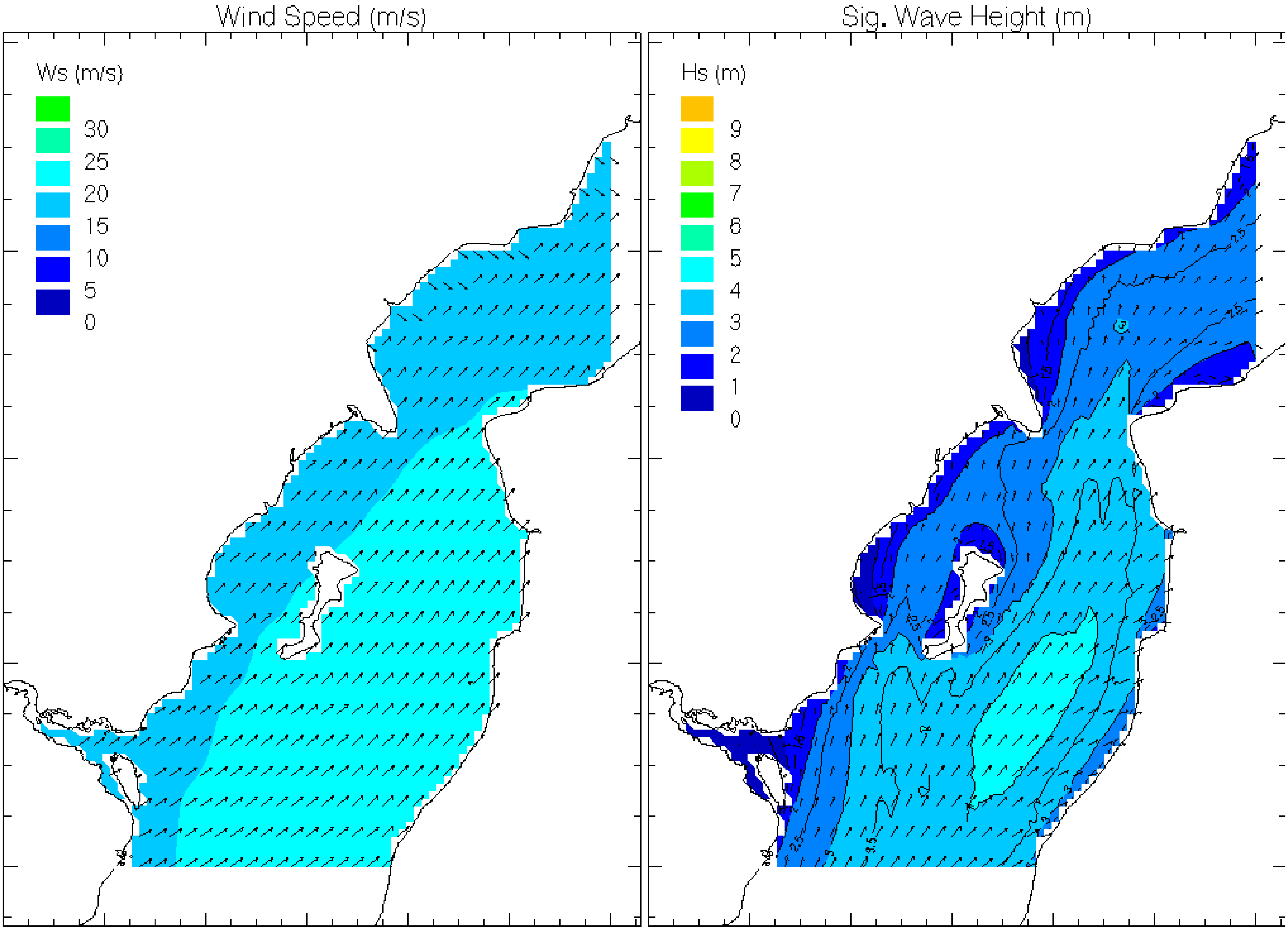


Printed from L:\Kenai\Deliver\Complete\Wave-Hindcasts\19730310\Plots\KenaiMTR_MaxFlds.gif (created on Nov-23-2009 02:45PM)

oceanweather inc.


Kenai Maximum Hindcast Winds and Waves during 19730310
Wind Speed (m/s)
Ws (m/s)
30
25
20
15
10
5
0
Sig. Wave Height (m)
Hs (m)
9
8
7
6
5
4
3
2
1
0

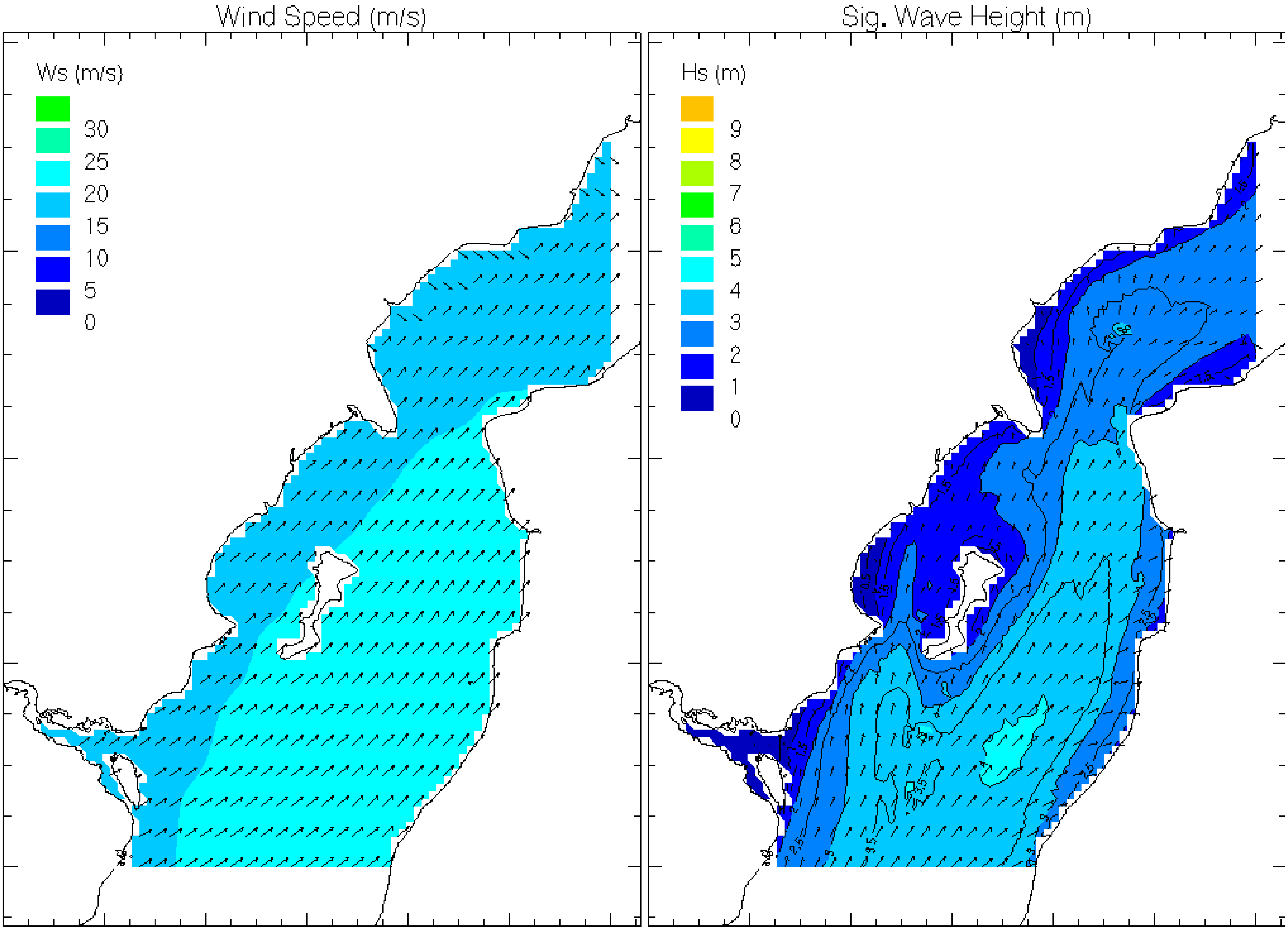
Kenai MTR Maximum Hindcast Winds and Waves during 19740303



Printed from L:\Kenai\Deliver\Complete\Wave-Hindcasts\19740303\Plots\KenaiMTR_MaxFlds.gif (created on Nov-23-2009 02:45PM)

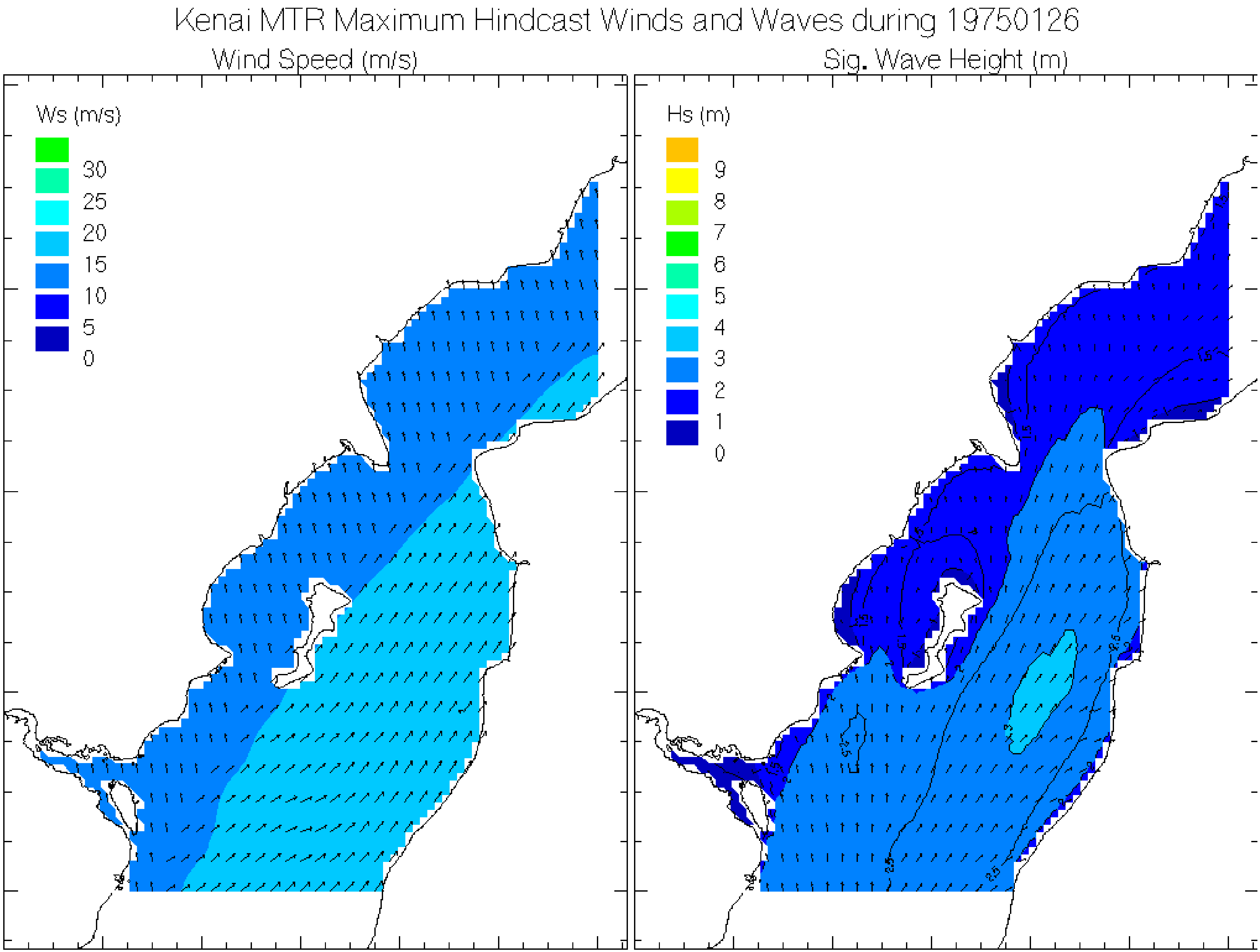
oceanweather inc.

Kenai Maximum Hindcast Winds and Waves during 19740303



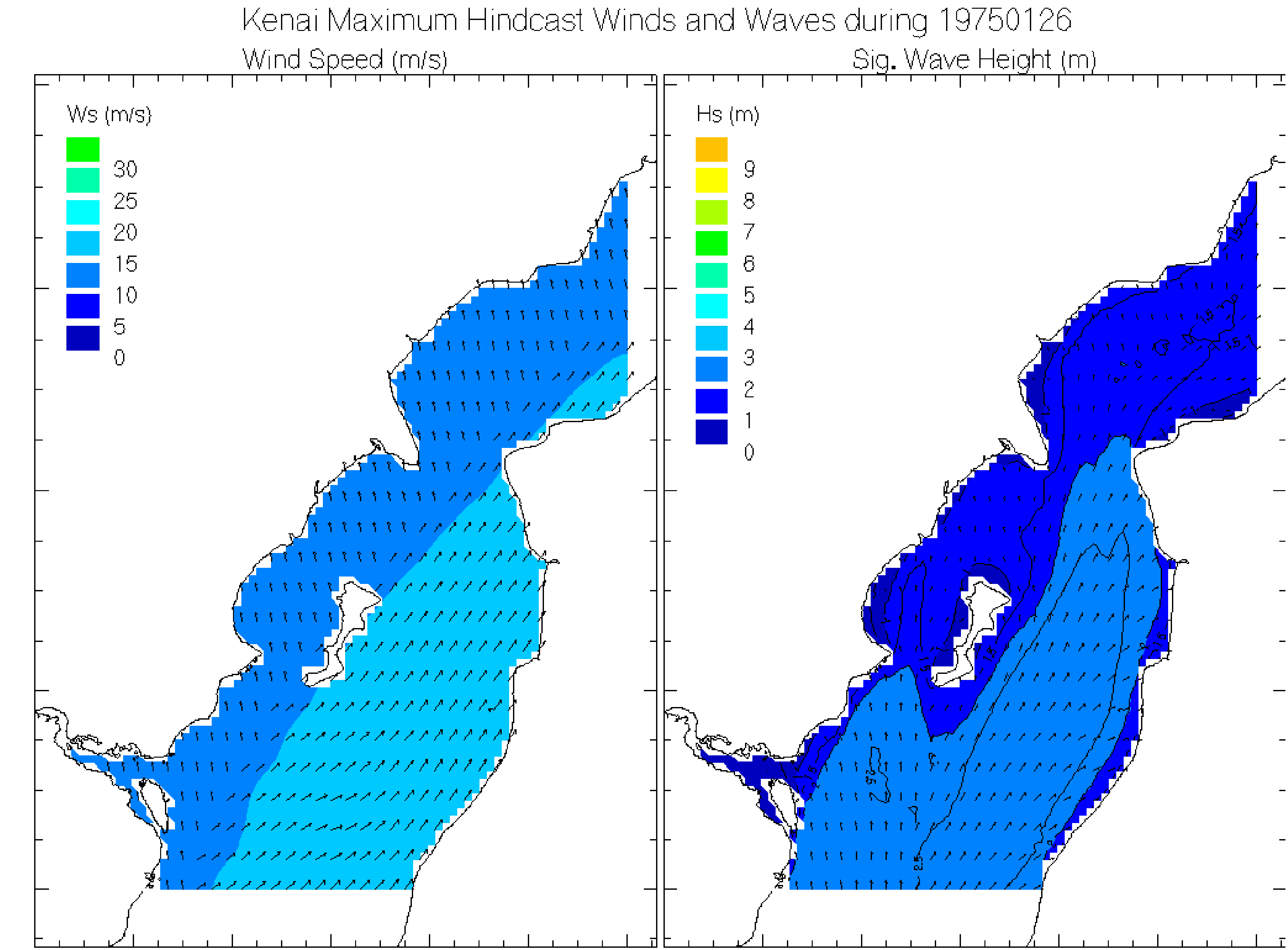
Printed from L:\Kenai\Deliver\Complete\Wave-Hindcasts\19740303\Plots\Kenai_MaxFlds.gif (created on Nov-23-2009 10:48AM)

oceanweather inc.



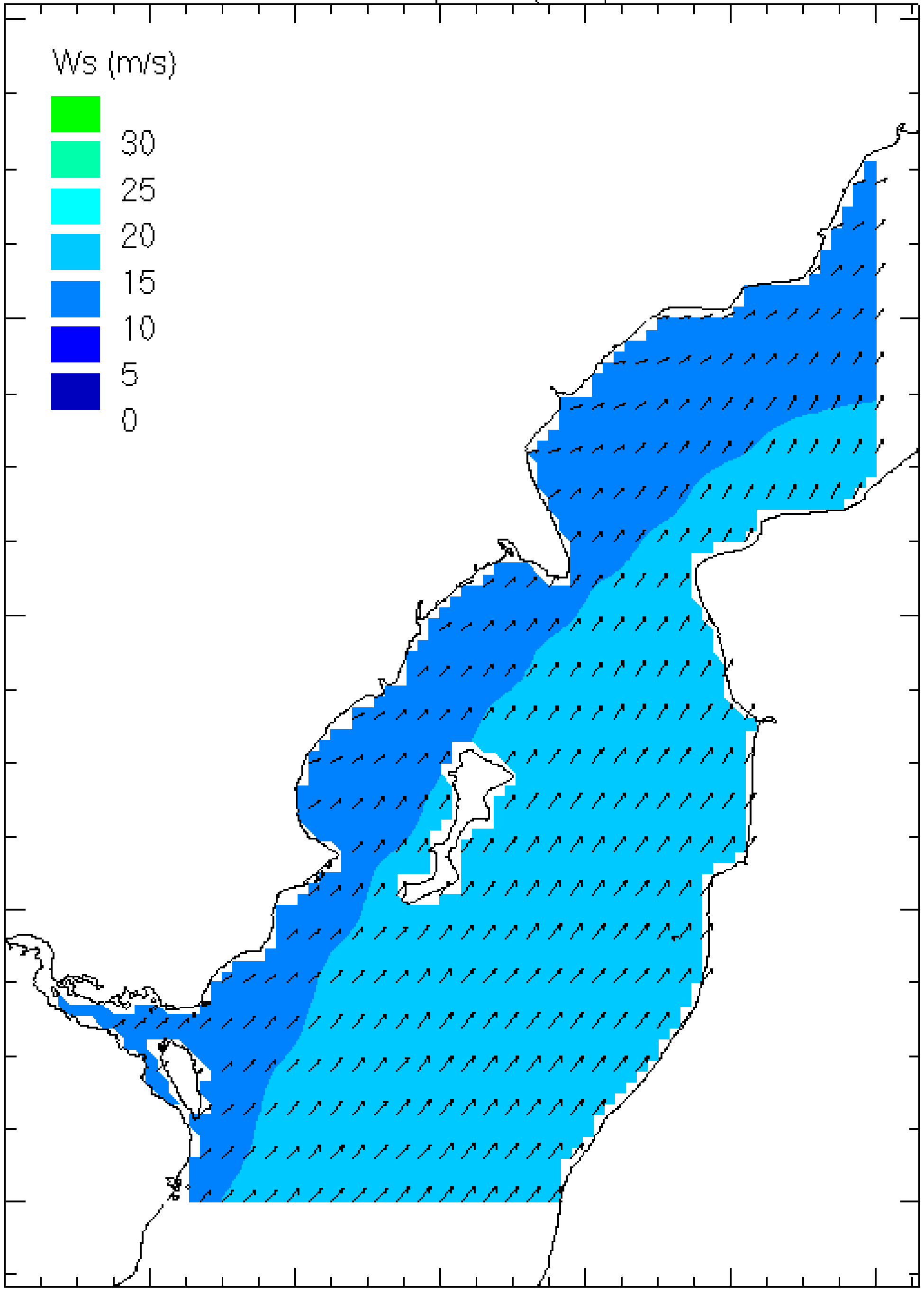
Printed from L:\Kenai\Deliver\Complete\Wave-Hindcasts\19750126\Plots\KenaiMTR_MaxFlds.gif (created on Nov-23-2009 02:45PM)

oceanweather inc.

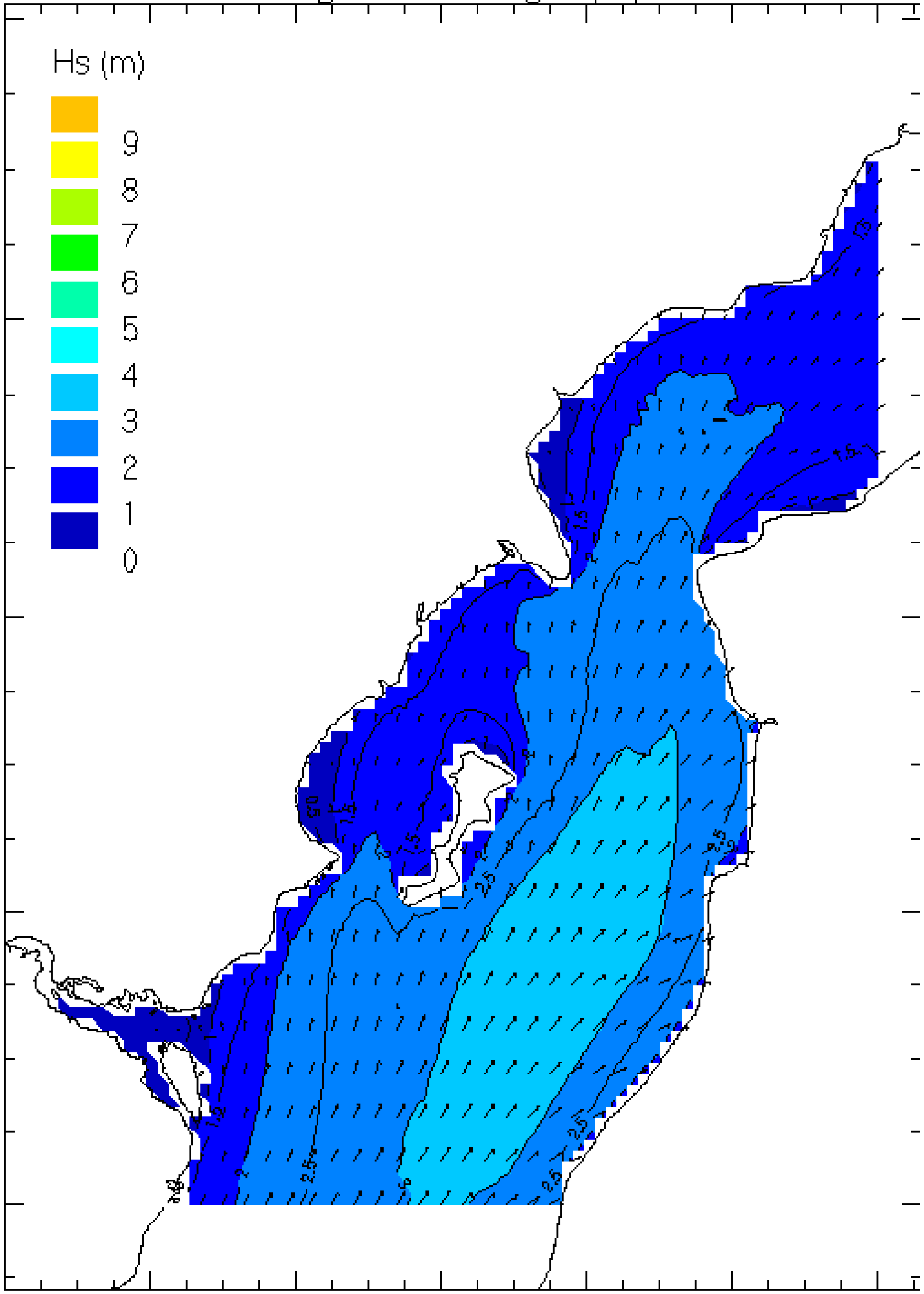

Kenai Maximum Hindcast Winds and Waves during 19750126
Wind Speed (m/s)
Sig. Wave Height (m)
Ws (m/s)
30
25
20
15
10
5
0
Hs (m)
9
8
7
6
5
4
3
2
1
0

Kenai MTR Maximum Hindcast Winds and Waves during 19751021

Wind Speed (m/s)



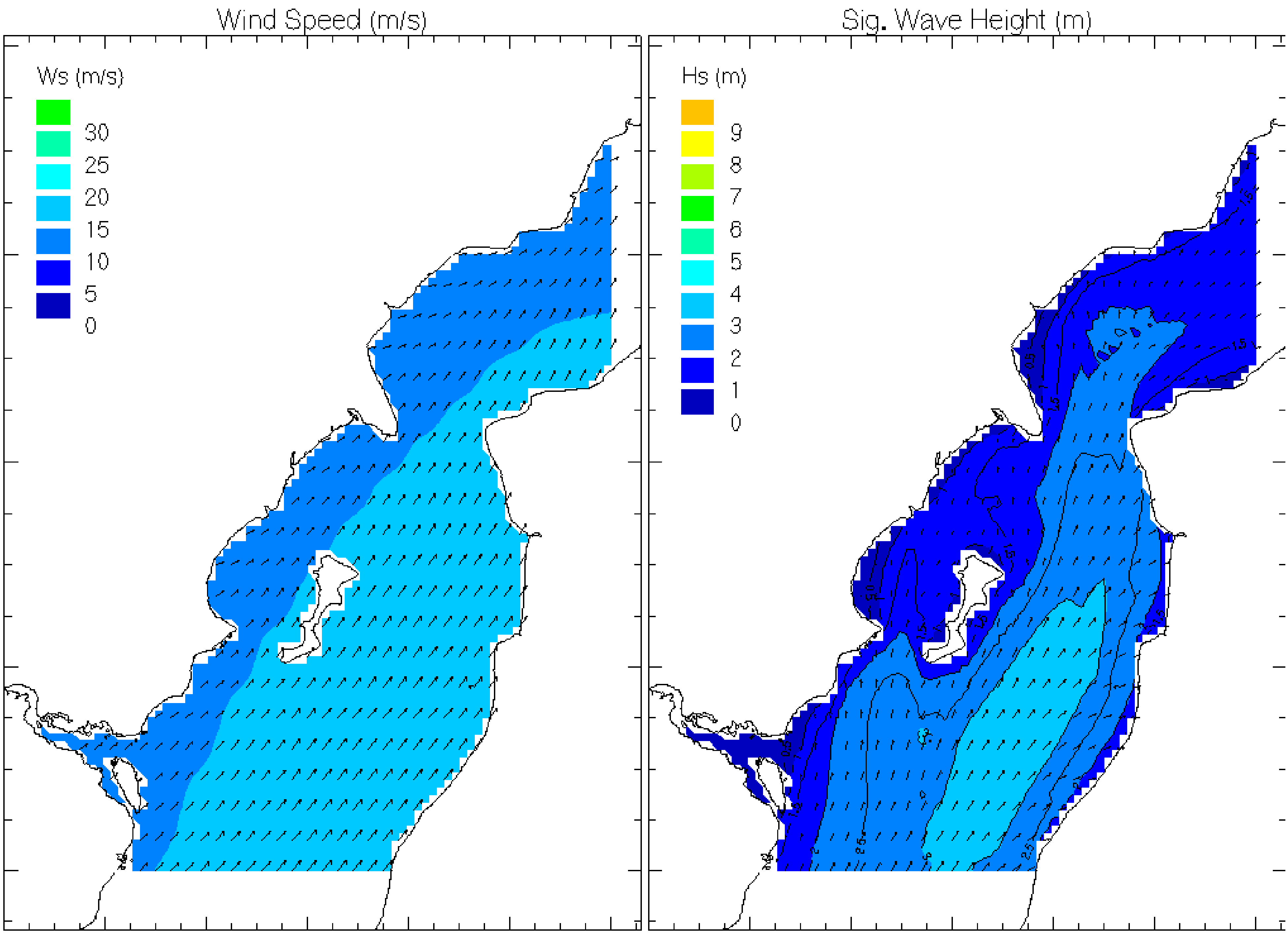
Sig. Wave Height (m)



Printed from L:\Kenai\Deliver\Complete\Wave-Hindcasts\19751021\Plots\KenaiMTR_MaxFlds.gif (created on Nov-23-2009 02:45PM)

oceanweather inc.

Kenai Maximum Hindcast Winds and Waves during 19751021



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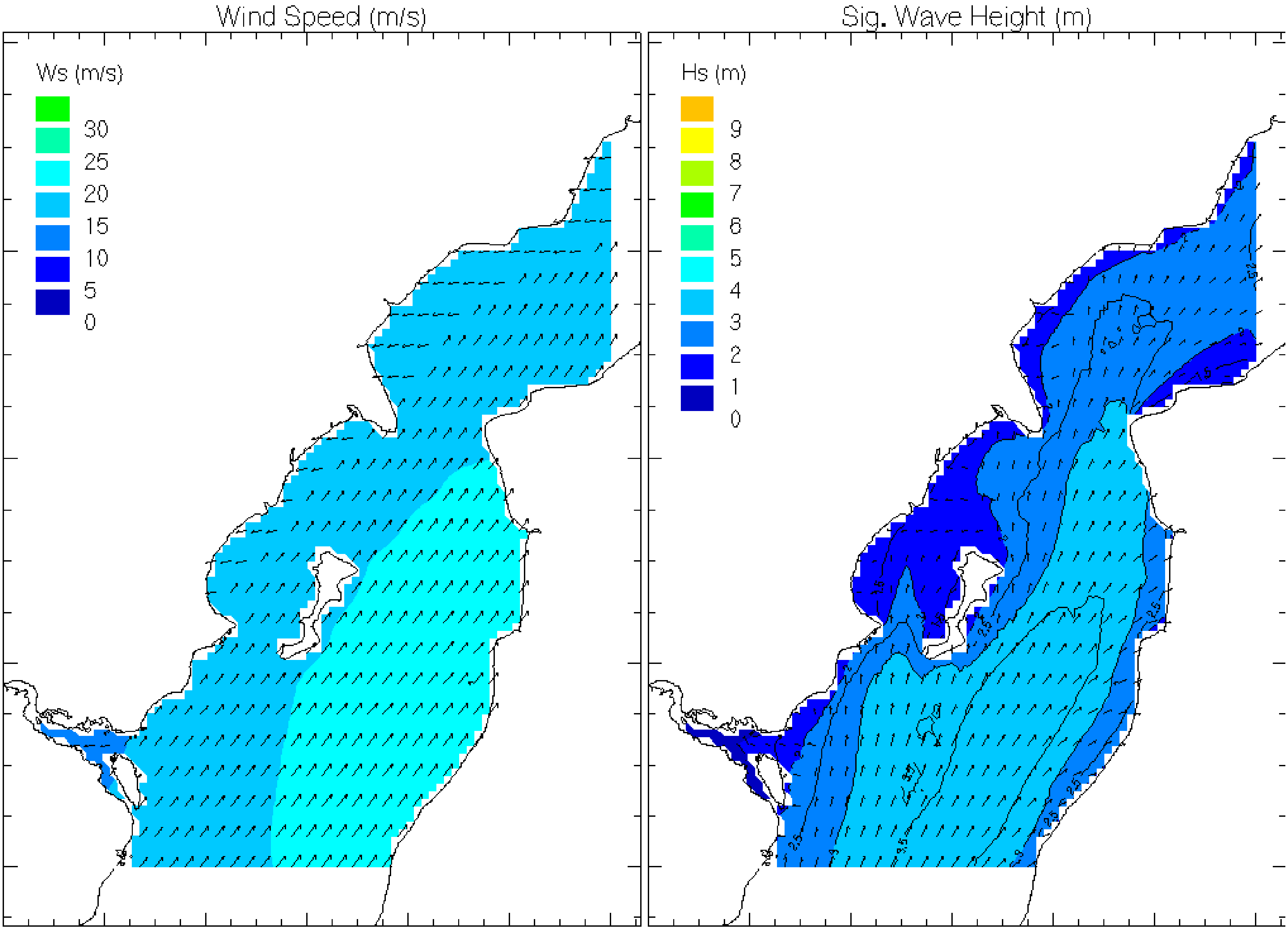
oceanweather inc.

Kenai MTR Maximum Hindcast Winds and Waves during 19760130



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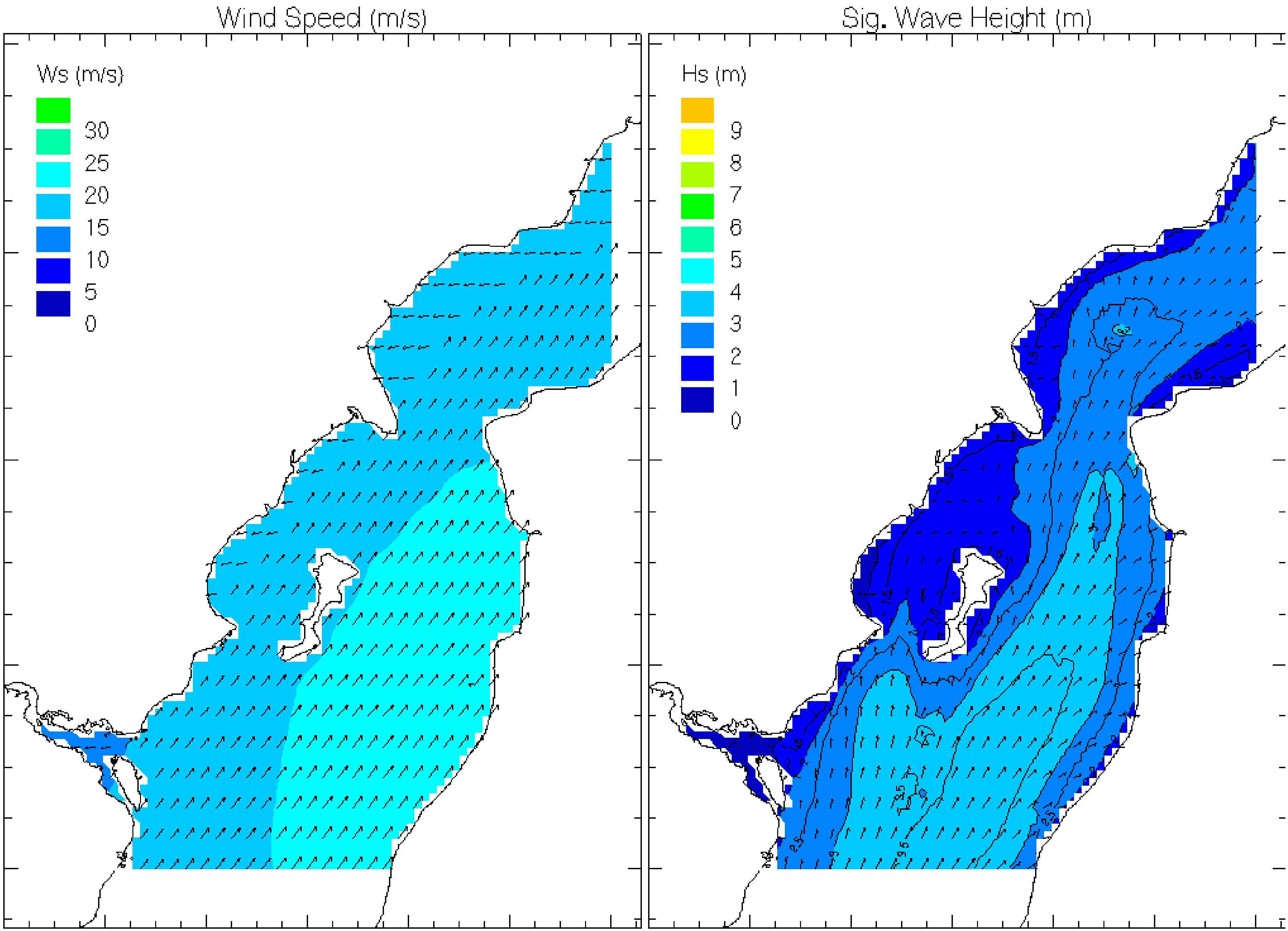
oceanweather inc.

Kenai Maximum Hindcast Winds and Waves during 19760130



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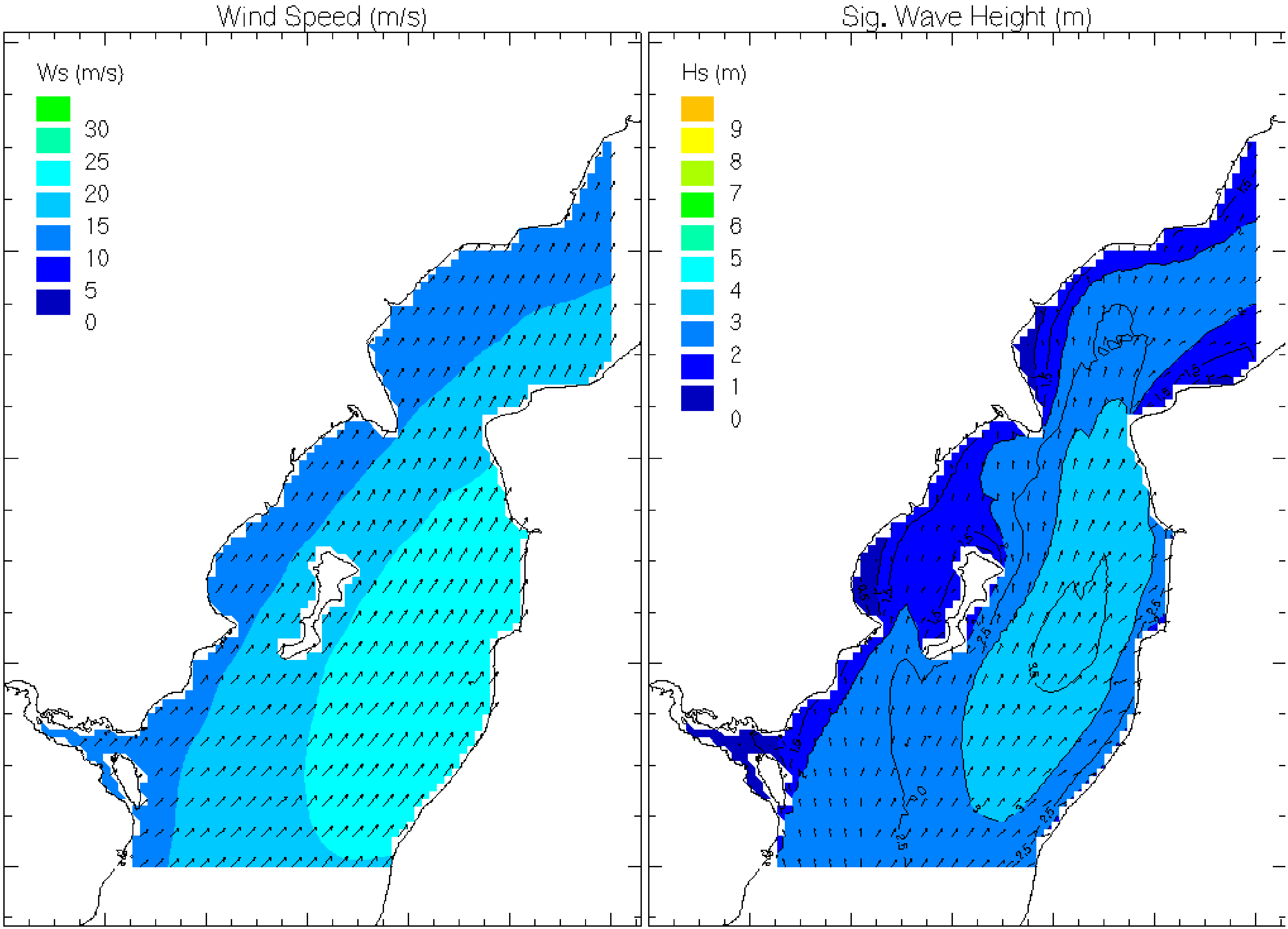
oceanweather inc.

Kenai MTR Maximum Hindcast Winds and Waves during 19780820



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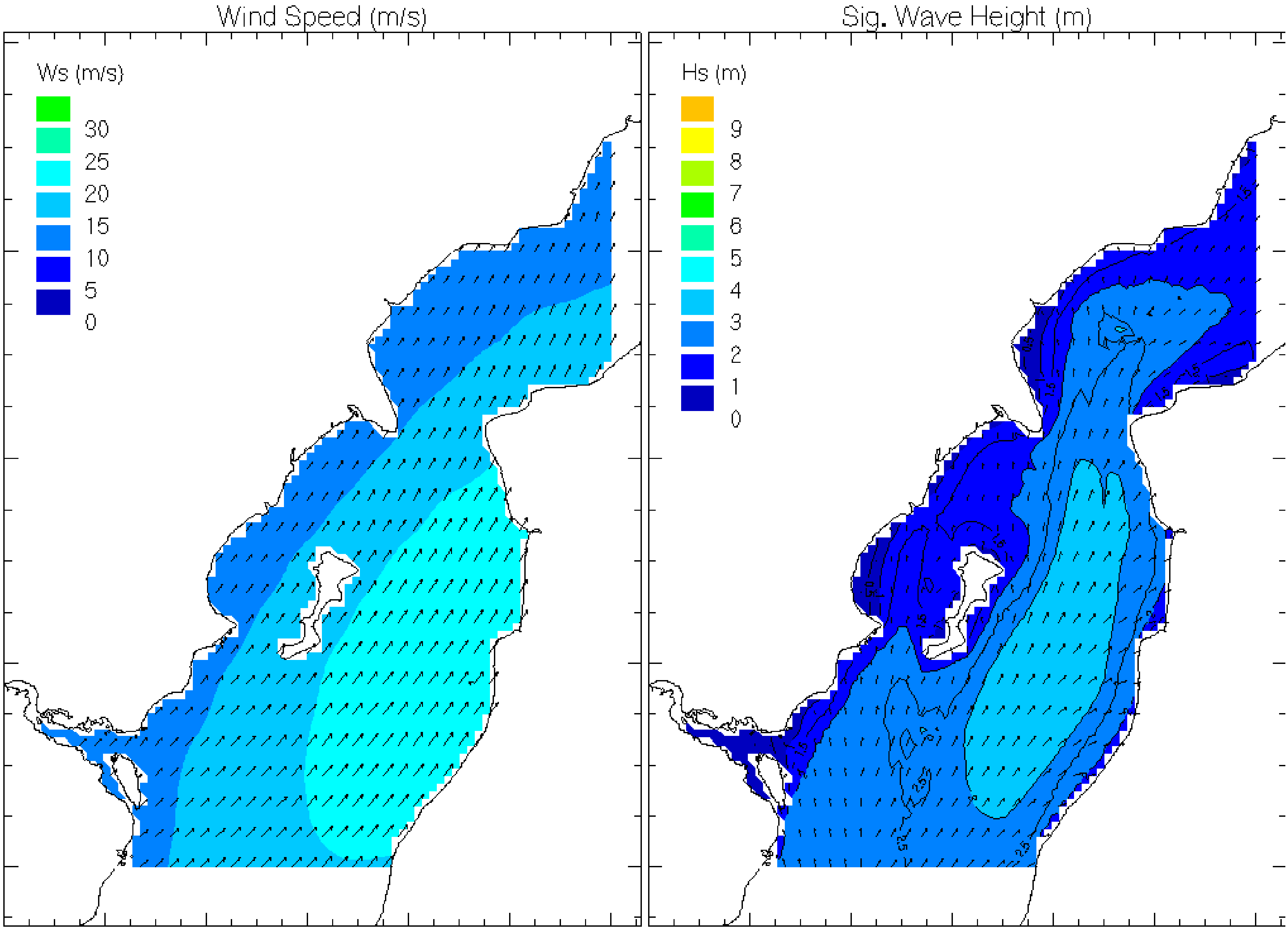
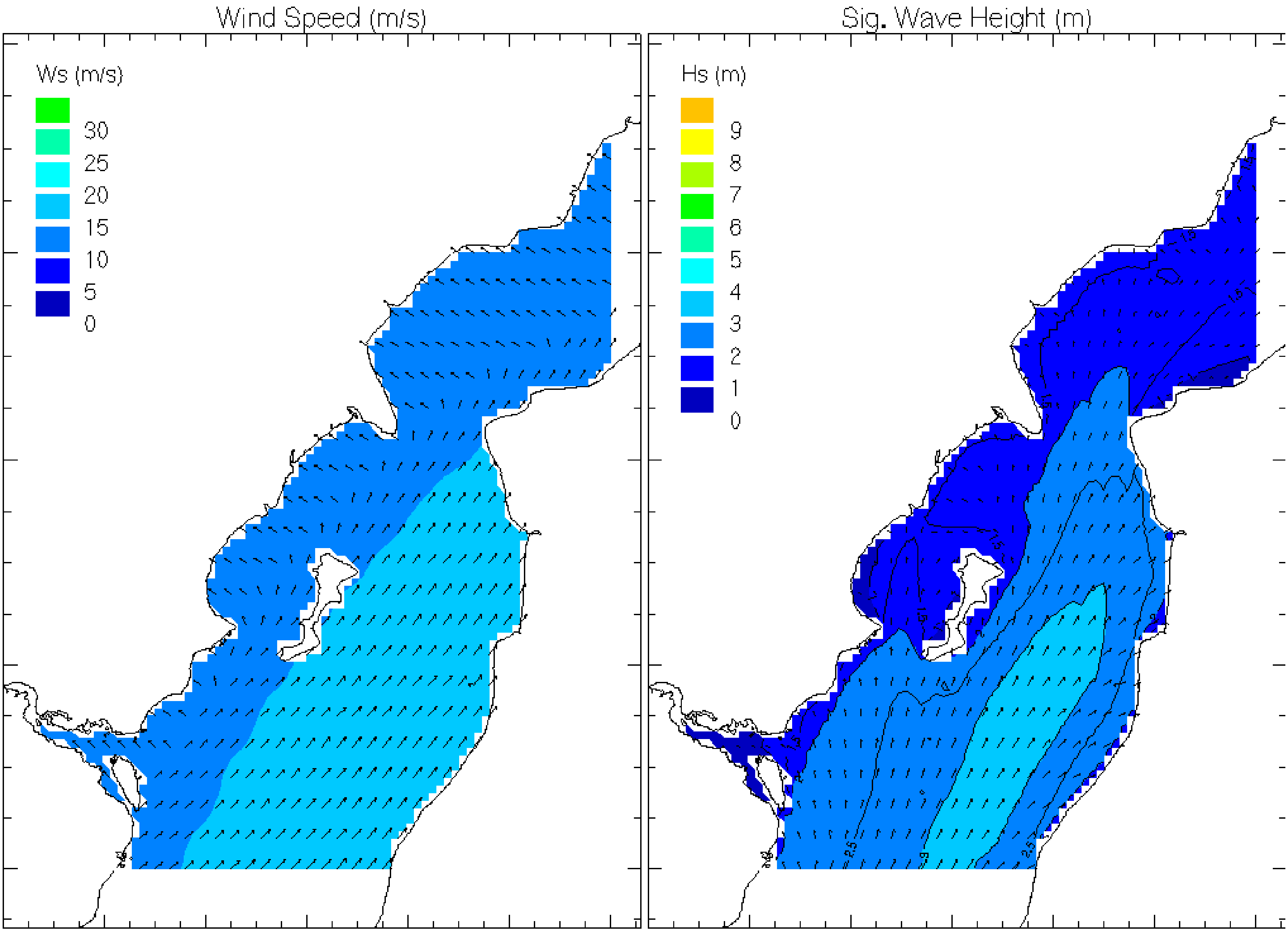
oceanweather inc.

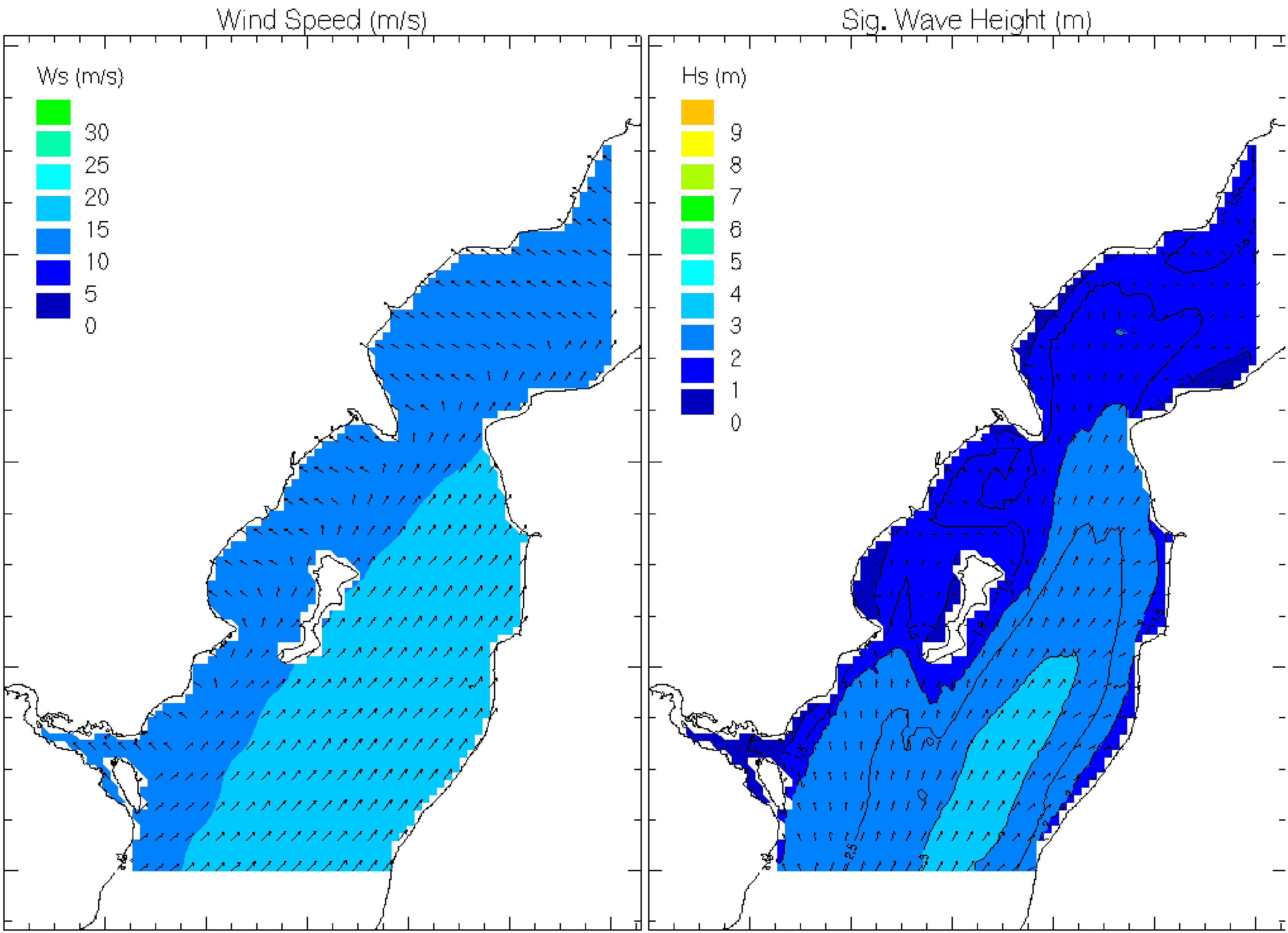
Kenai Maximum Hindcast Winds and Waves during 19780820



Kenai MTR Maximum Hindcast Winds and Waves during 19800207



Kenai Maximum Hindcast Winds and Waves during 19800207



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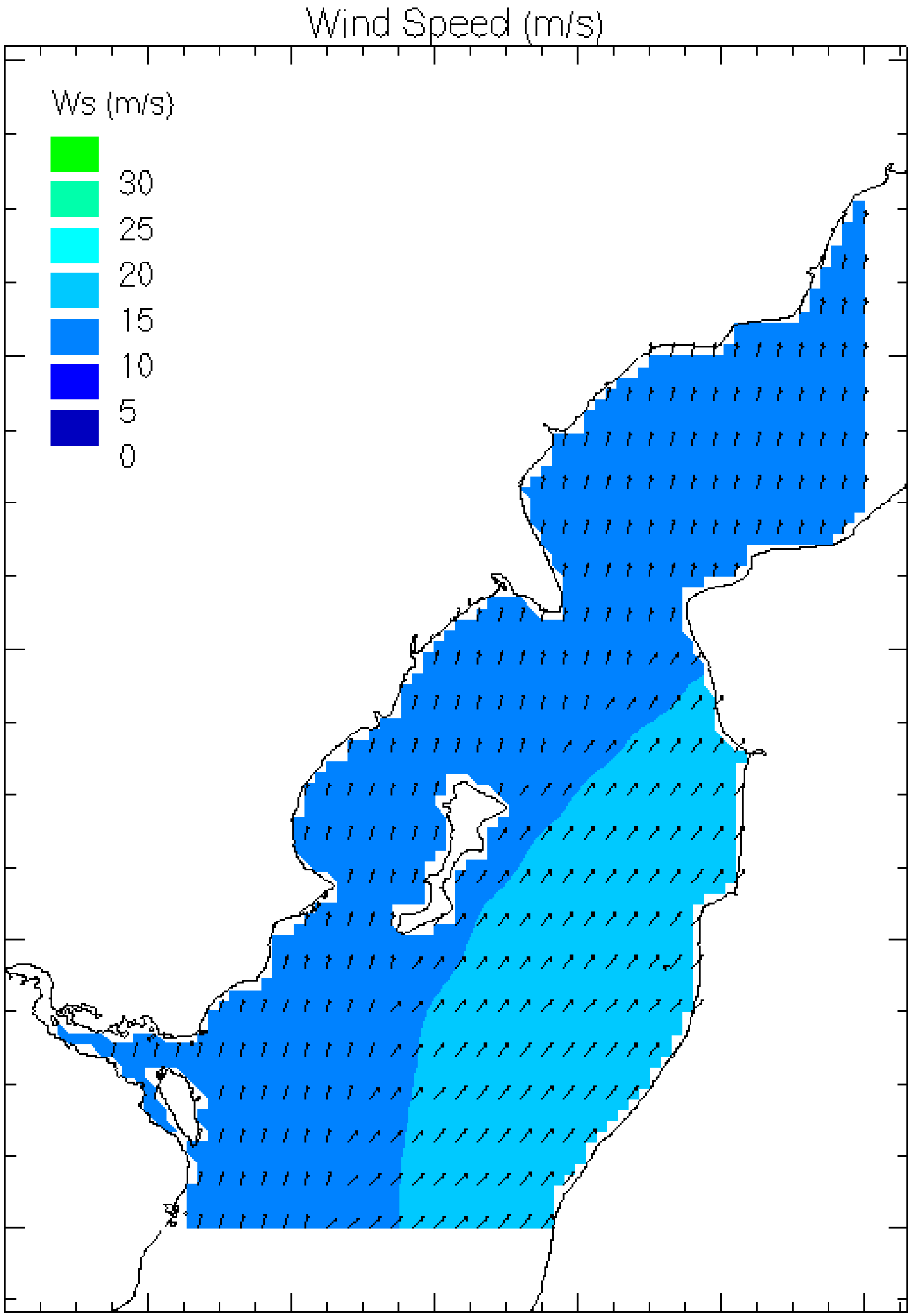
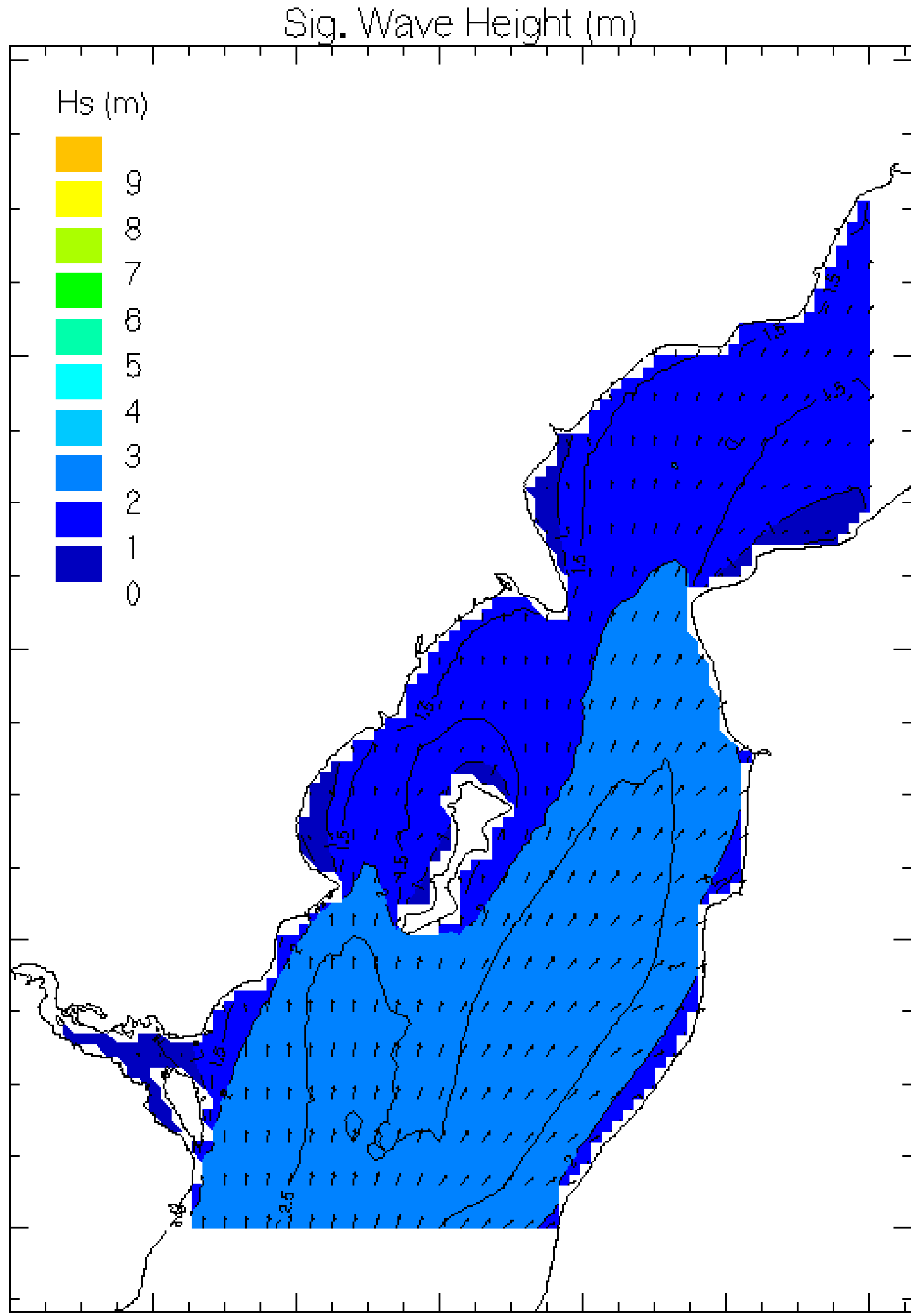
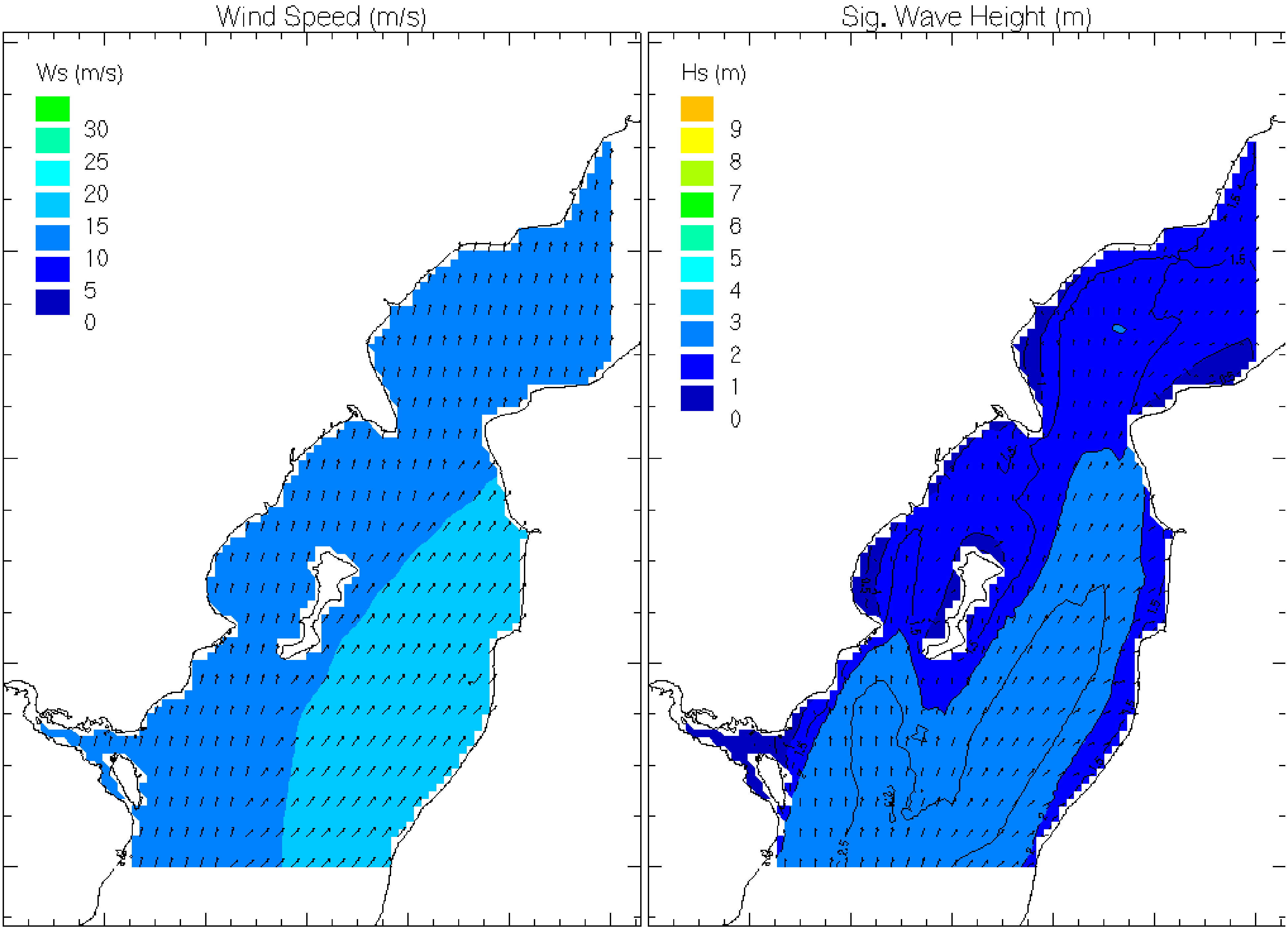
oceanweather inc.

Kenai MTR Maximum Hindcast Winds and Waves during 19850228





Kenai Maximum Hindcast Winds and Waves during 19850228



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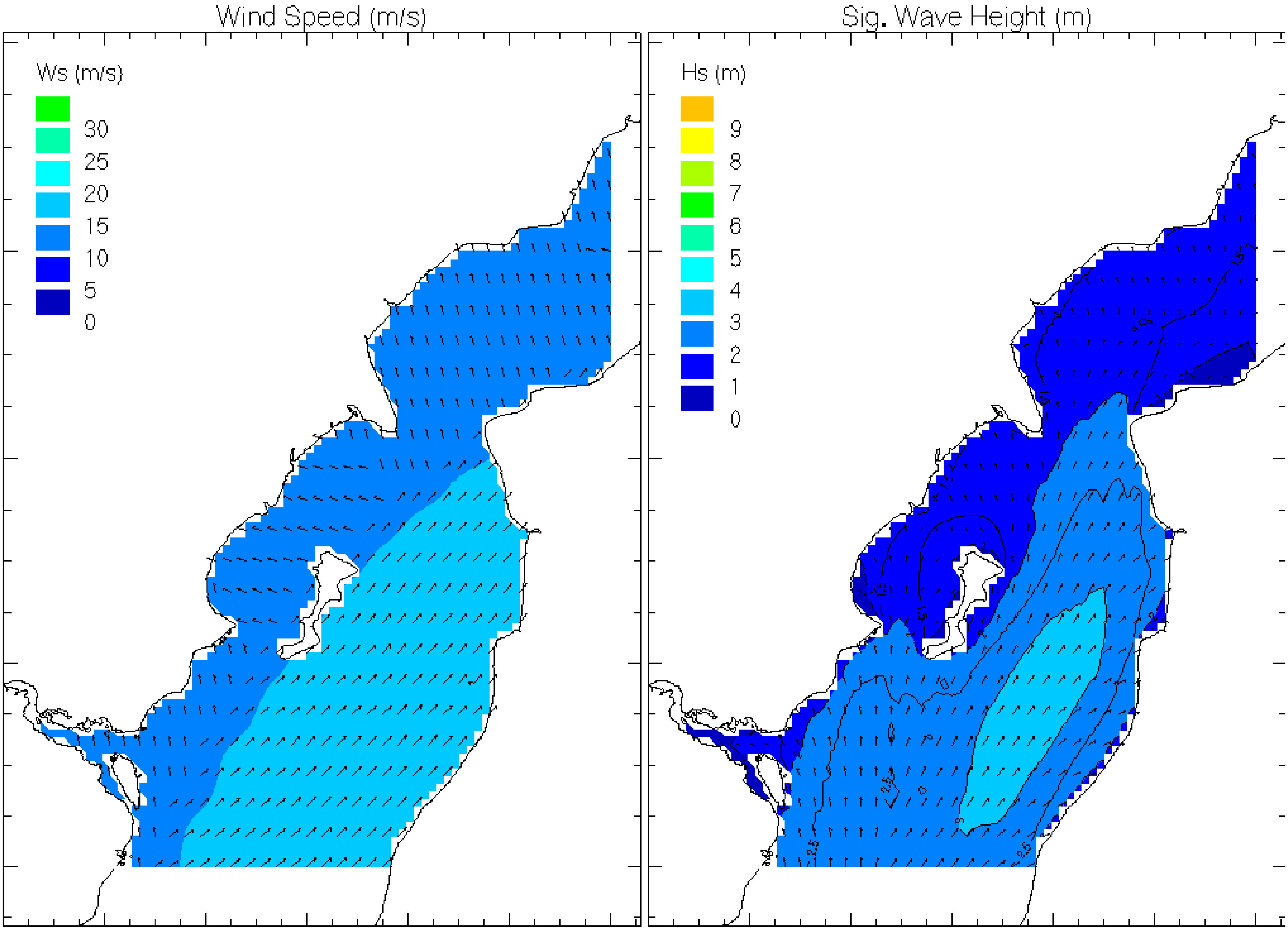
oceanweather inc.

Kenai MTR Maximum Hindcast Winds and Waves during 19870222



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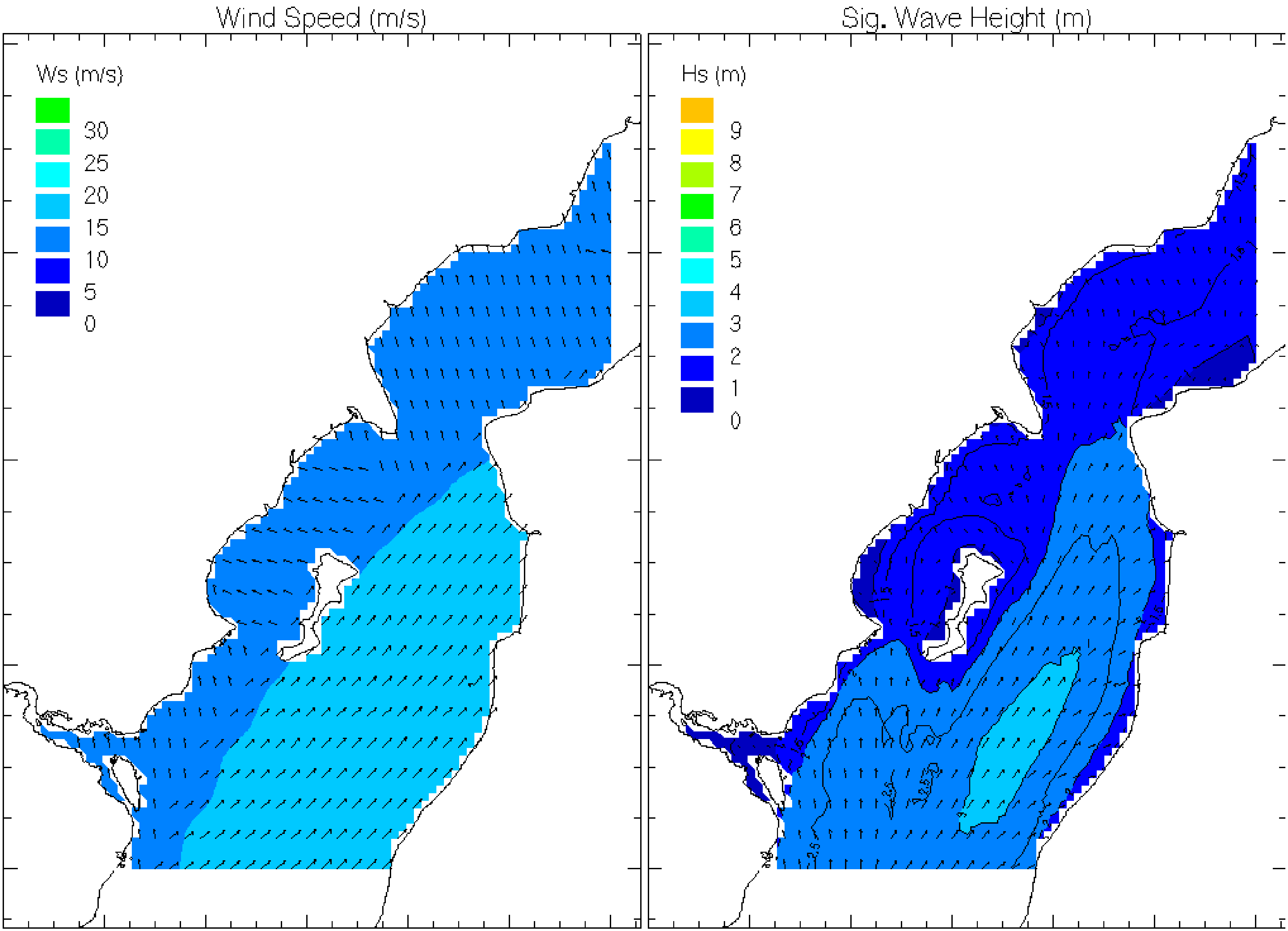
oceanweather inc.

Kenai Maximum Hindcast Winds and Waves during 19870222



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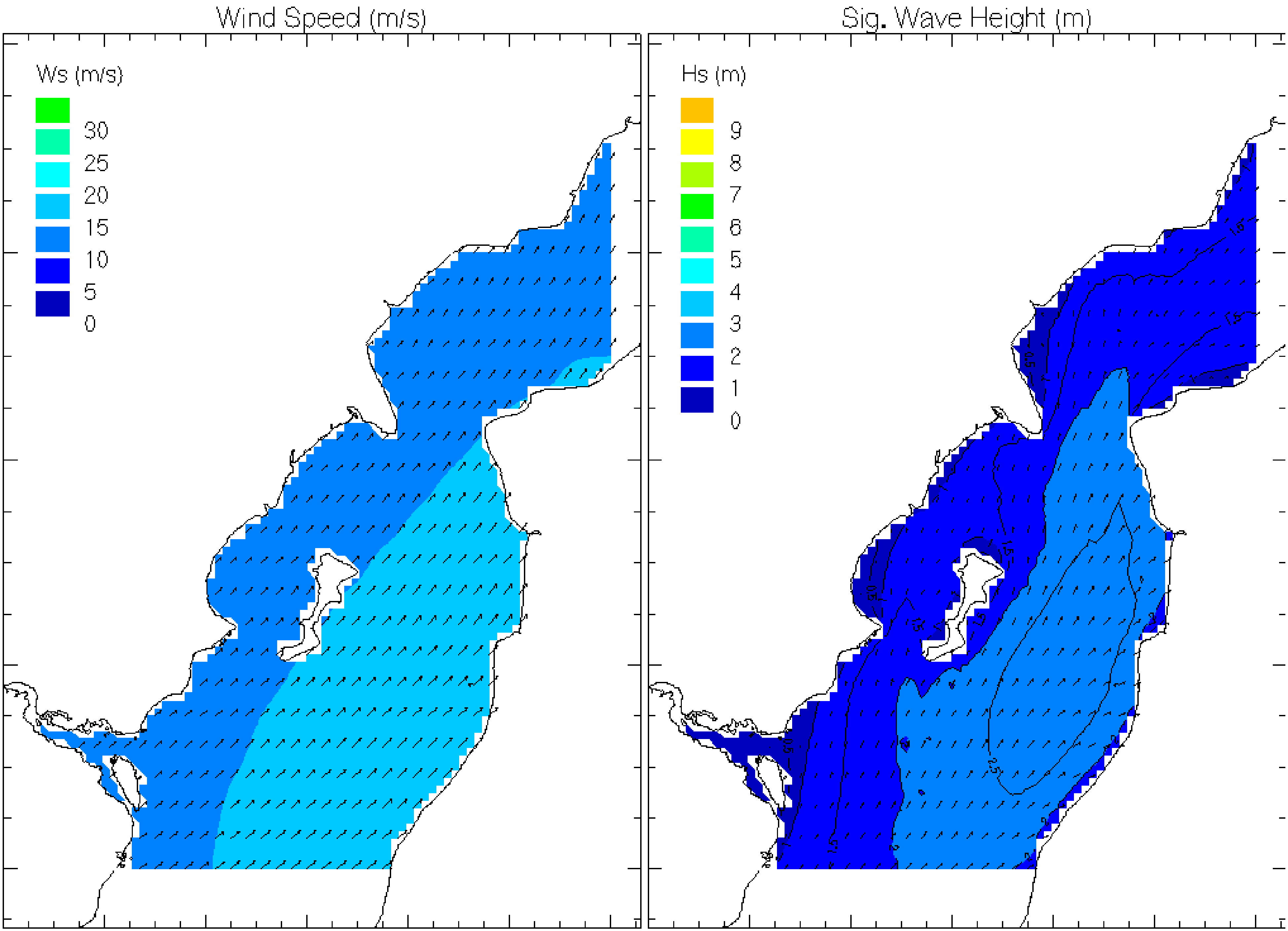
oceanweather inc.

Kenai MTR Maximum Hindcast Winds and Waves during 19900827



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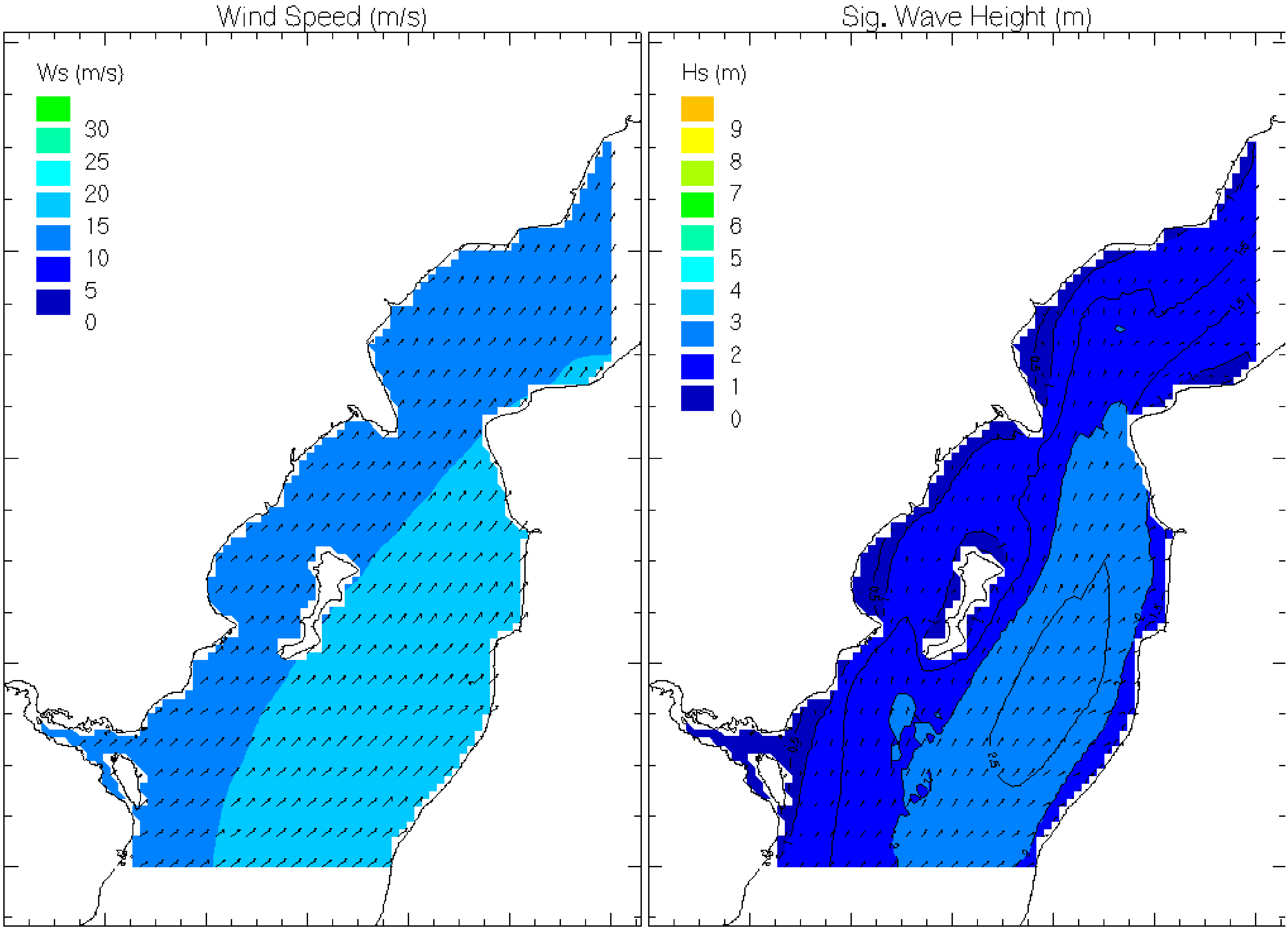
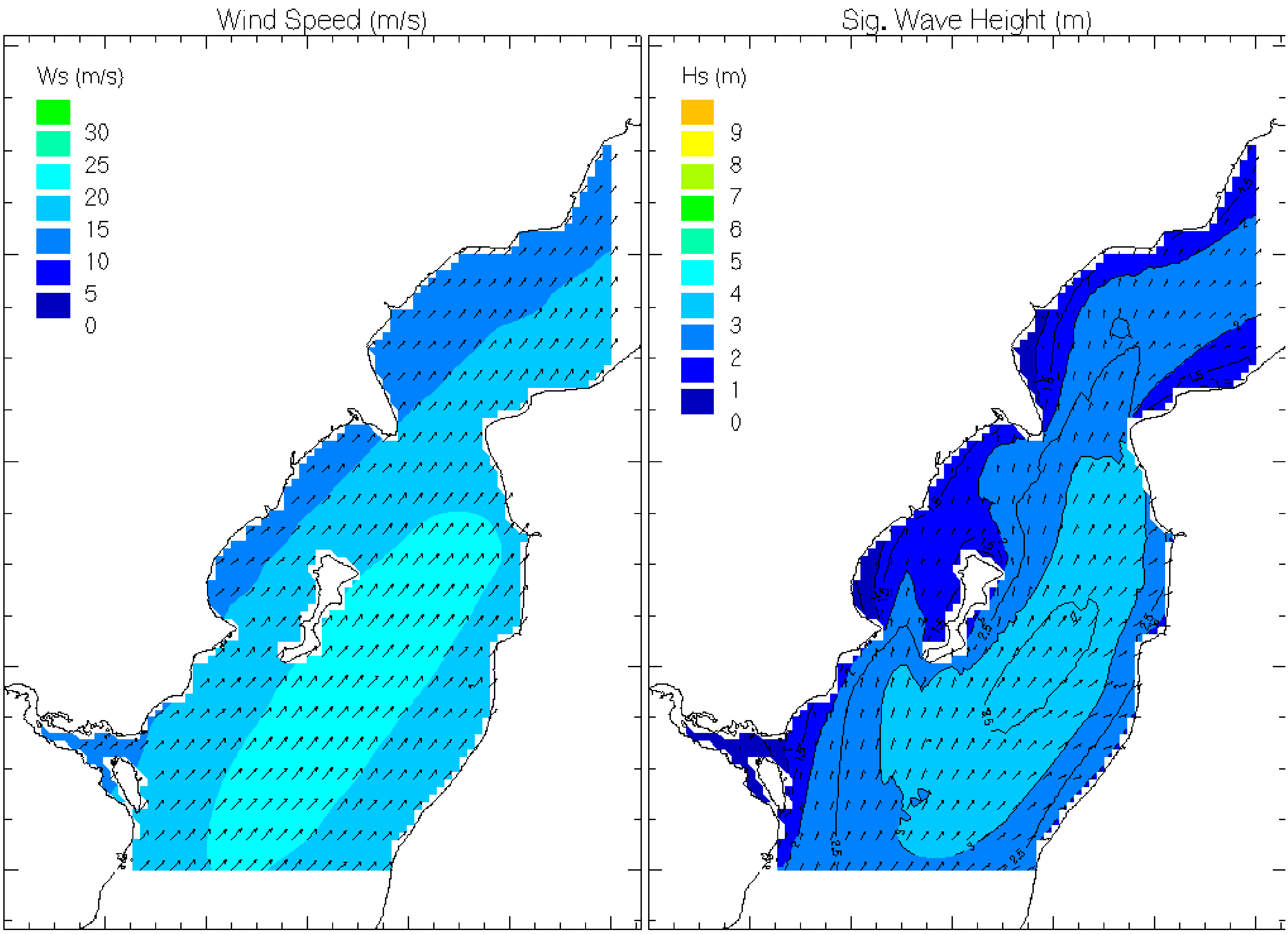
oceanweather inc.

Kenai Maximum Hindcast Winds and Waves during 19900827



Kenai MTR Maximum Hindcast Winds and Waves during 19920515



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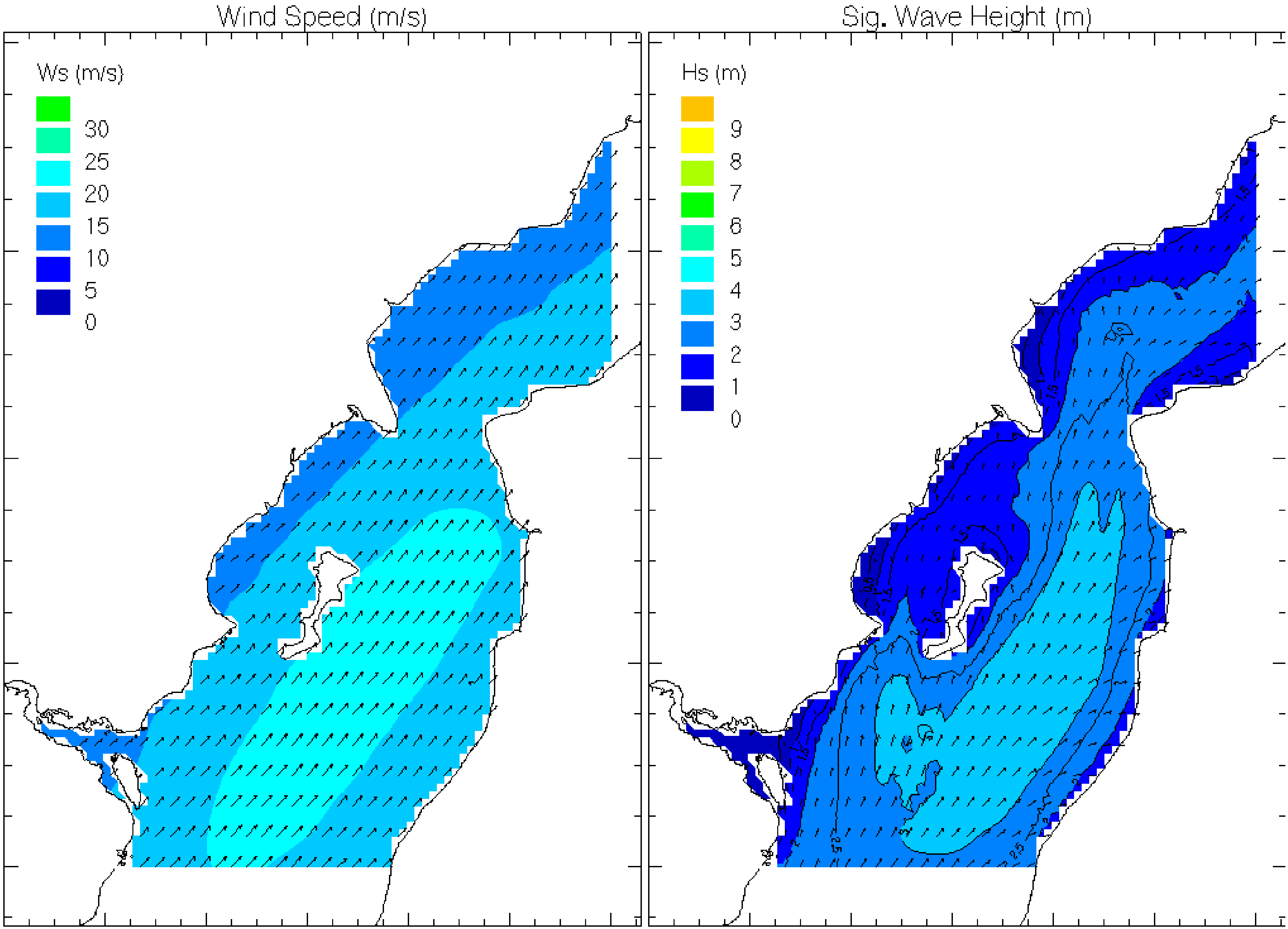
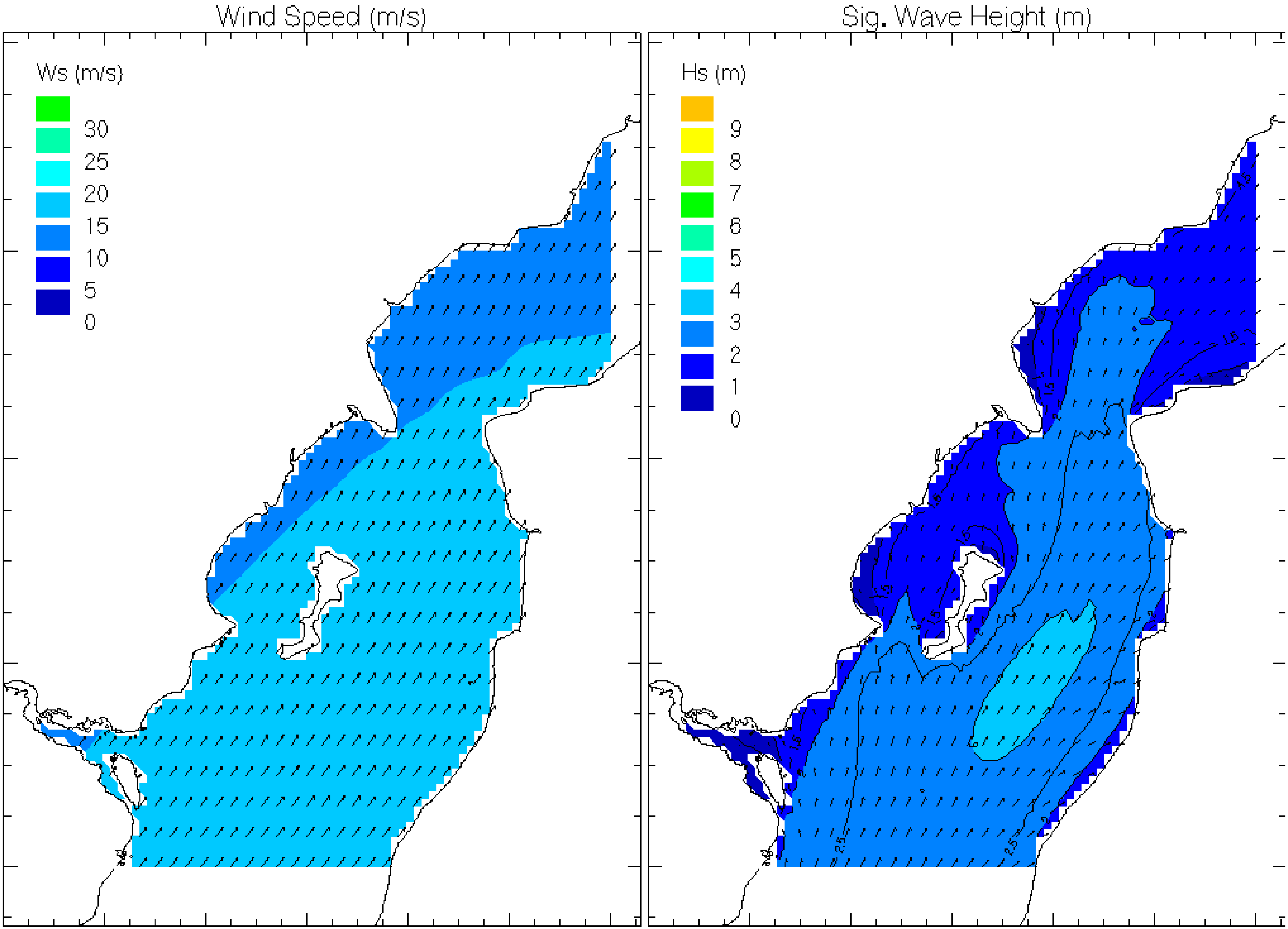
oceanweather inc.

Kenai Maximum Hindcast Winds and Waves during 19920515



Kenai MTR Maximum Hindcast Winds and Waves during 19930921



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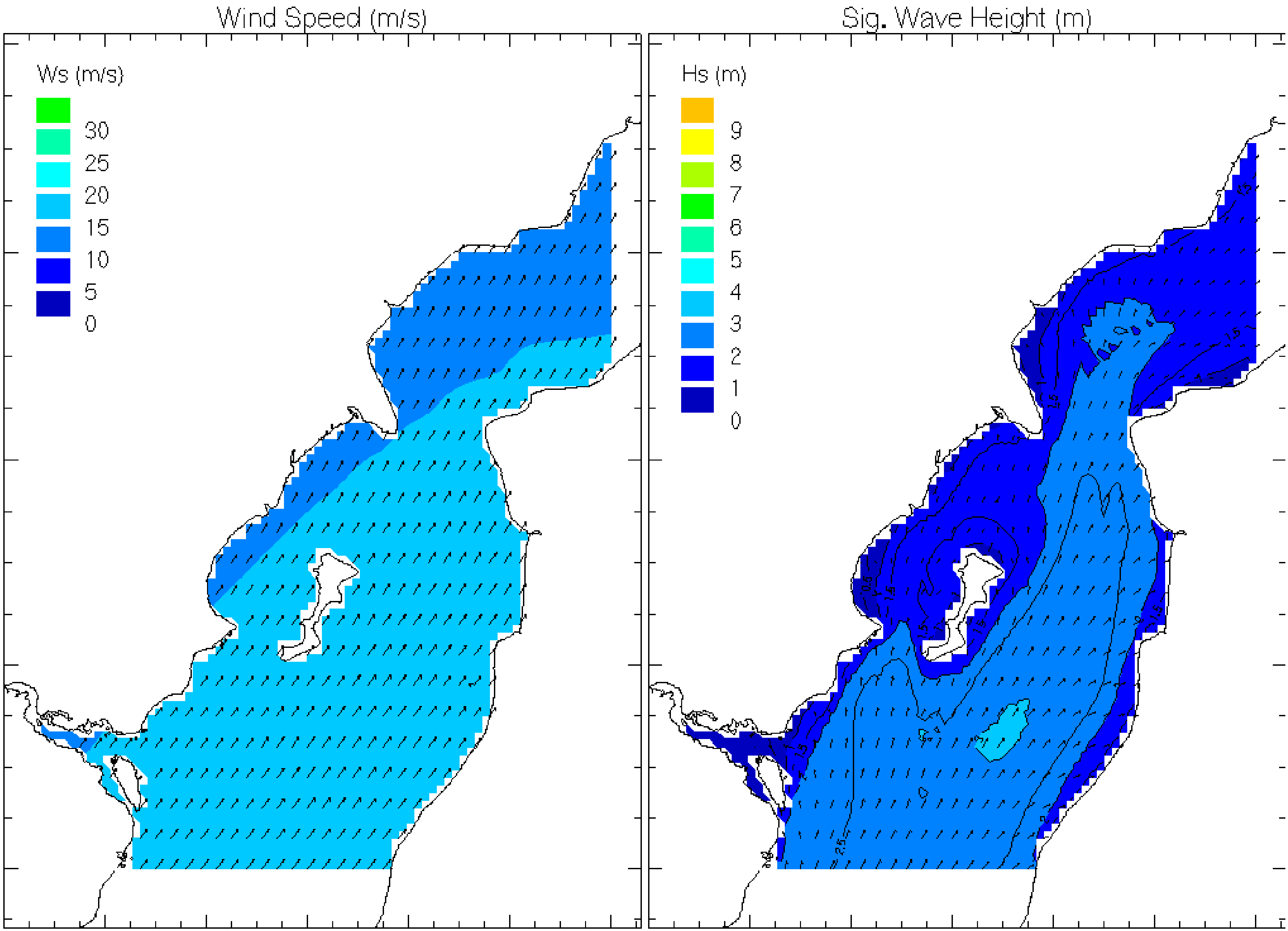
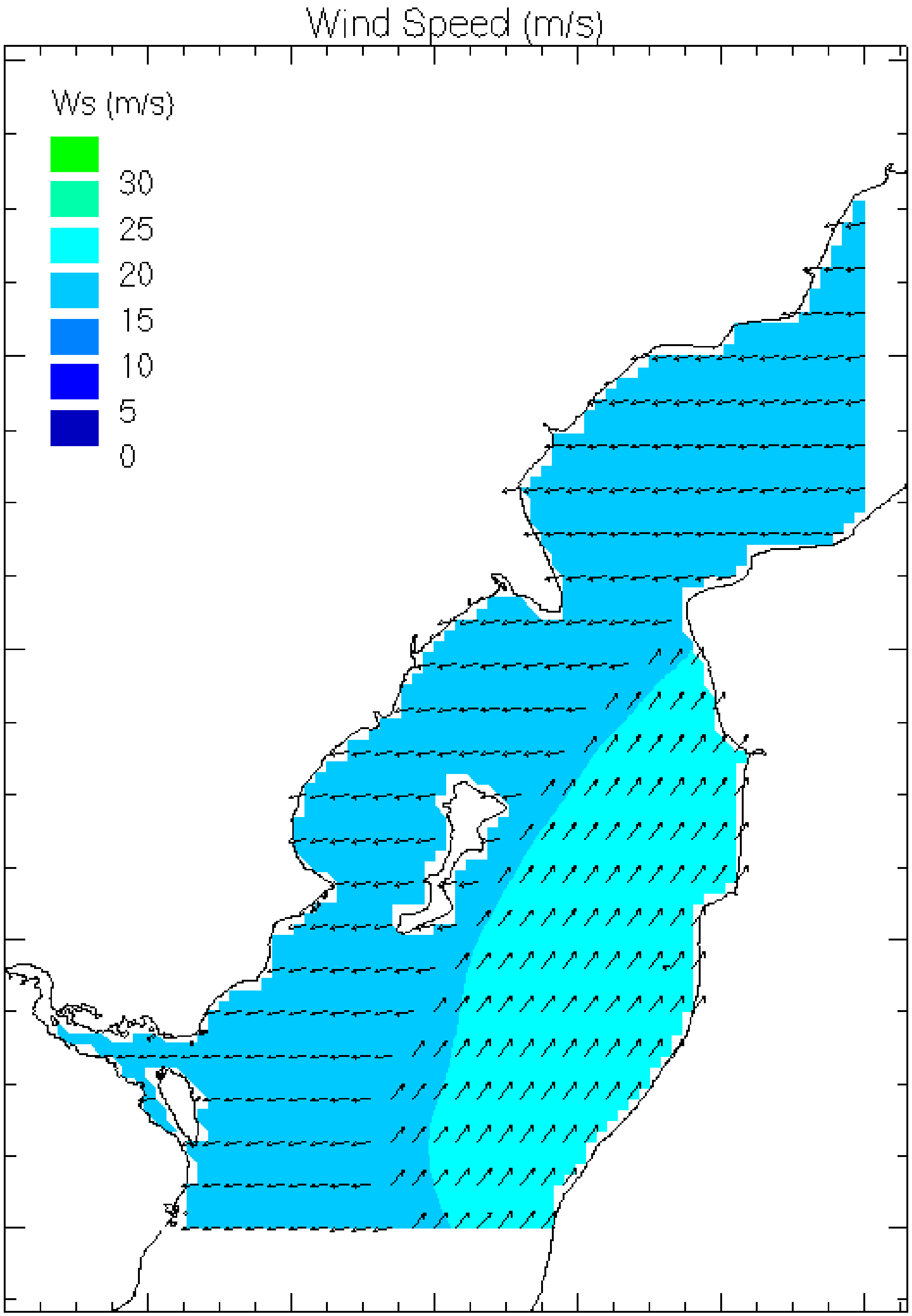
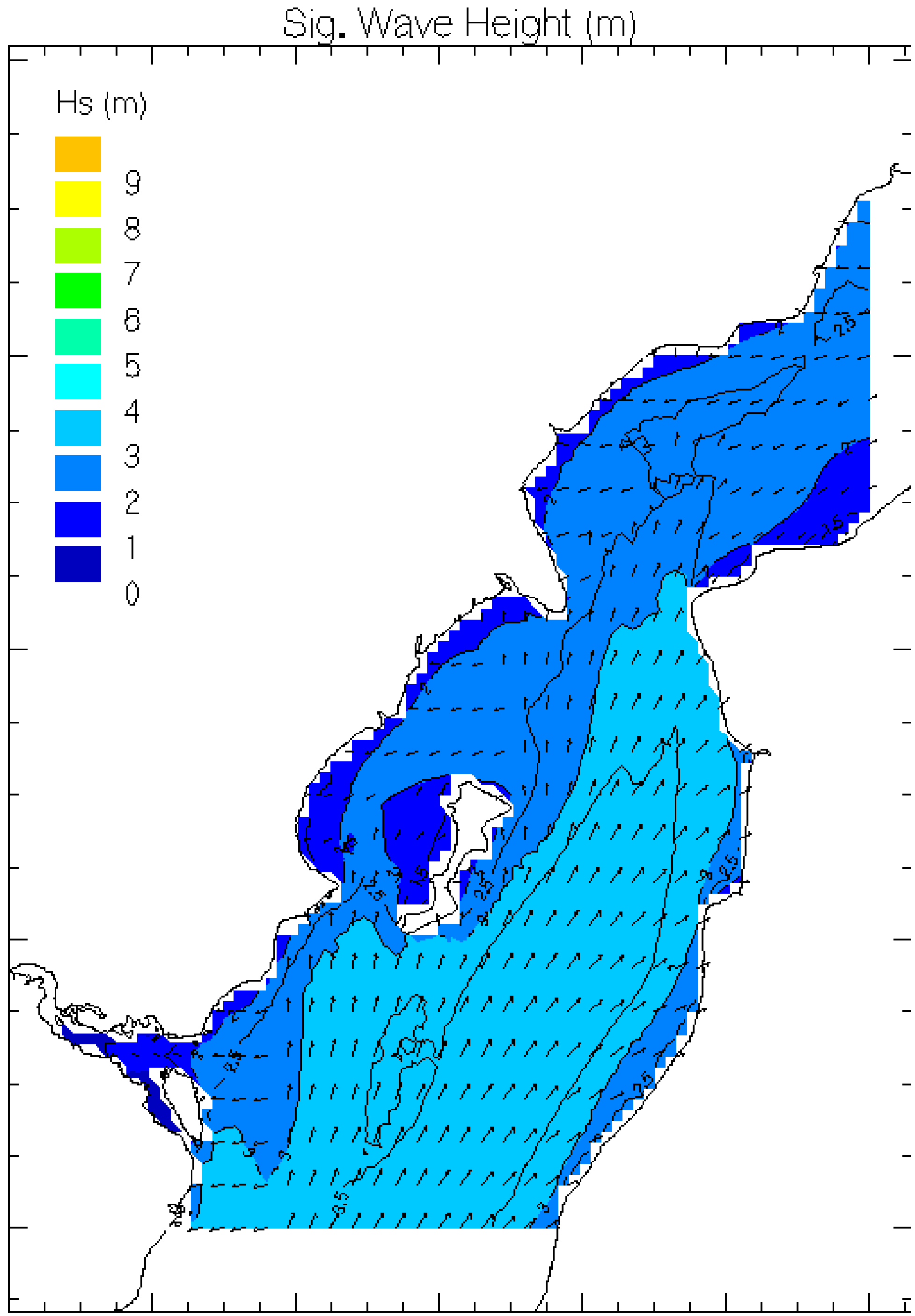
oceanweather inc.

Kenai Maximum Hindcast Winds and Waves during 19930921

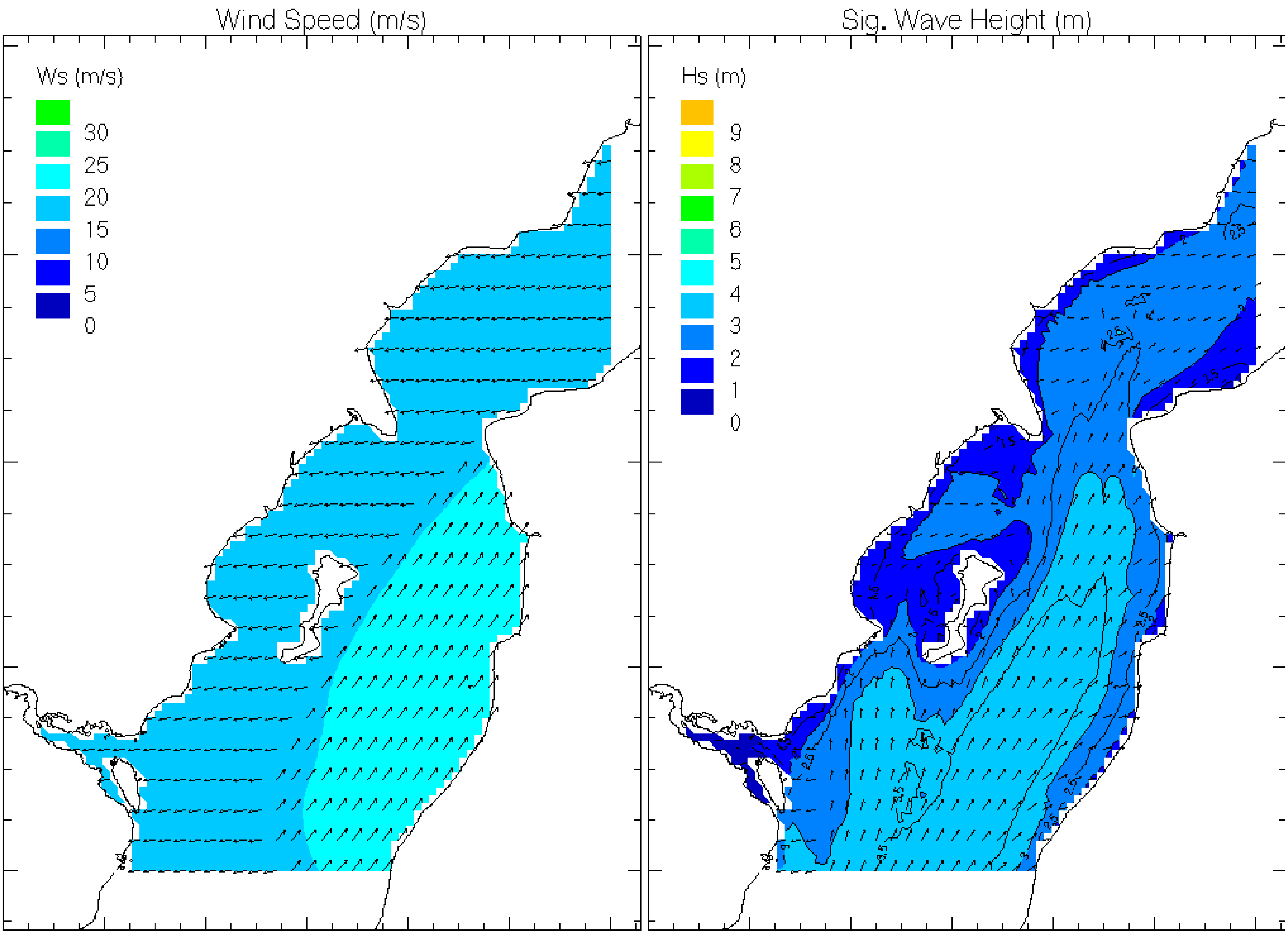


Kenai MTR Maximum Hindcast Winds and Waves during 19960925





Kenai Maximum Hindcast Winds and Waves during 19960925



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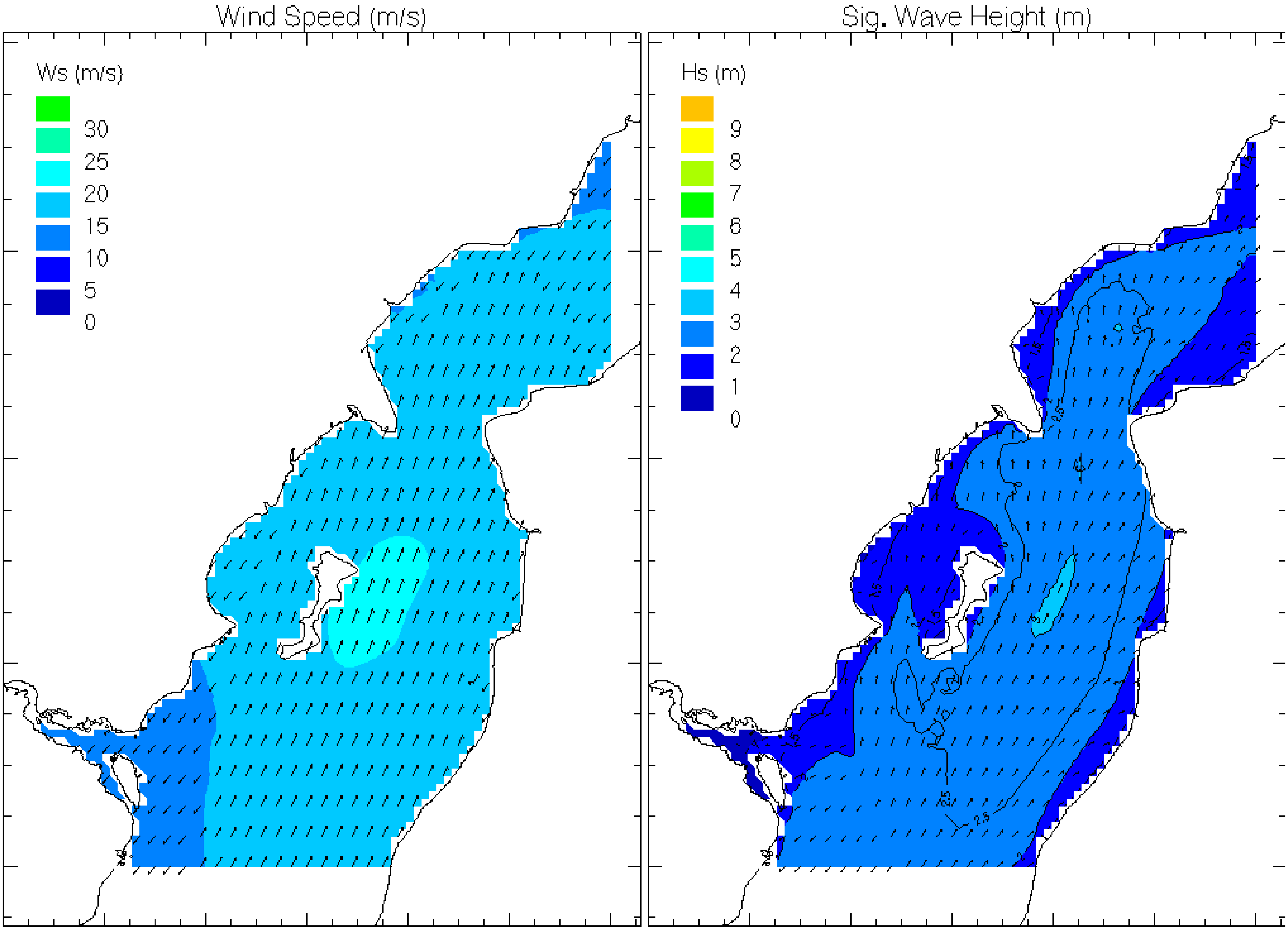
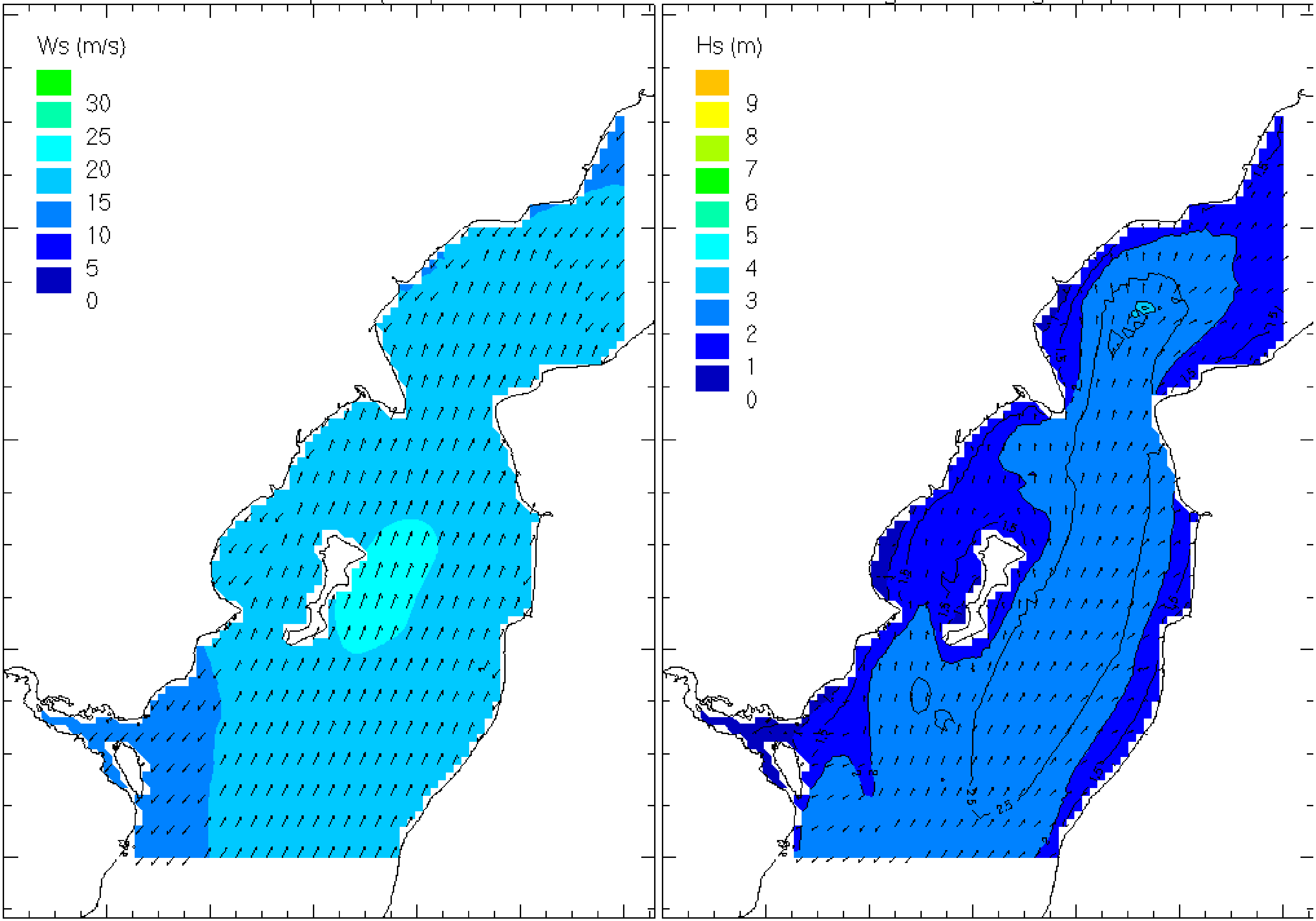
oceanweather inc.

Kenai MTR Maximum Hindcast Winds and Waves during 19971229



Kenai Maximum Hindcast Winds and Waves during 19971229

Wind Speed (m/s) Sig. Wave Height (m)



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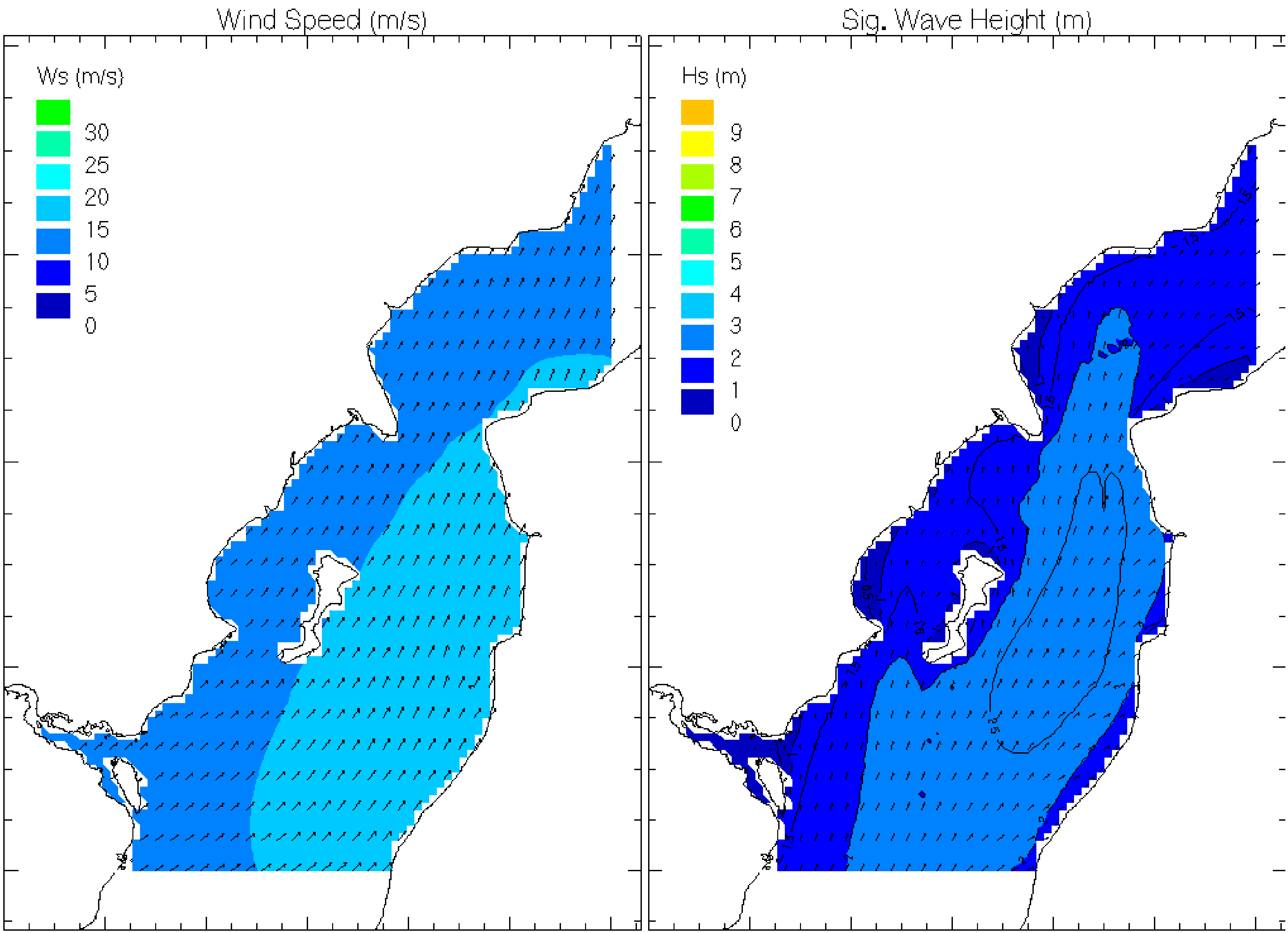
oceanweather inc.

Kenai MTR Maximum Hindcast Winds and Waves during 19980817



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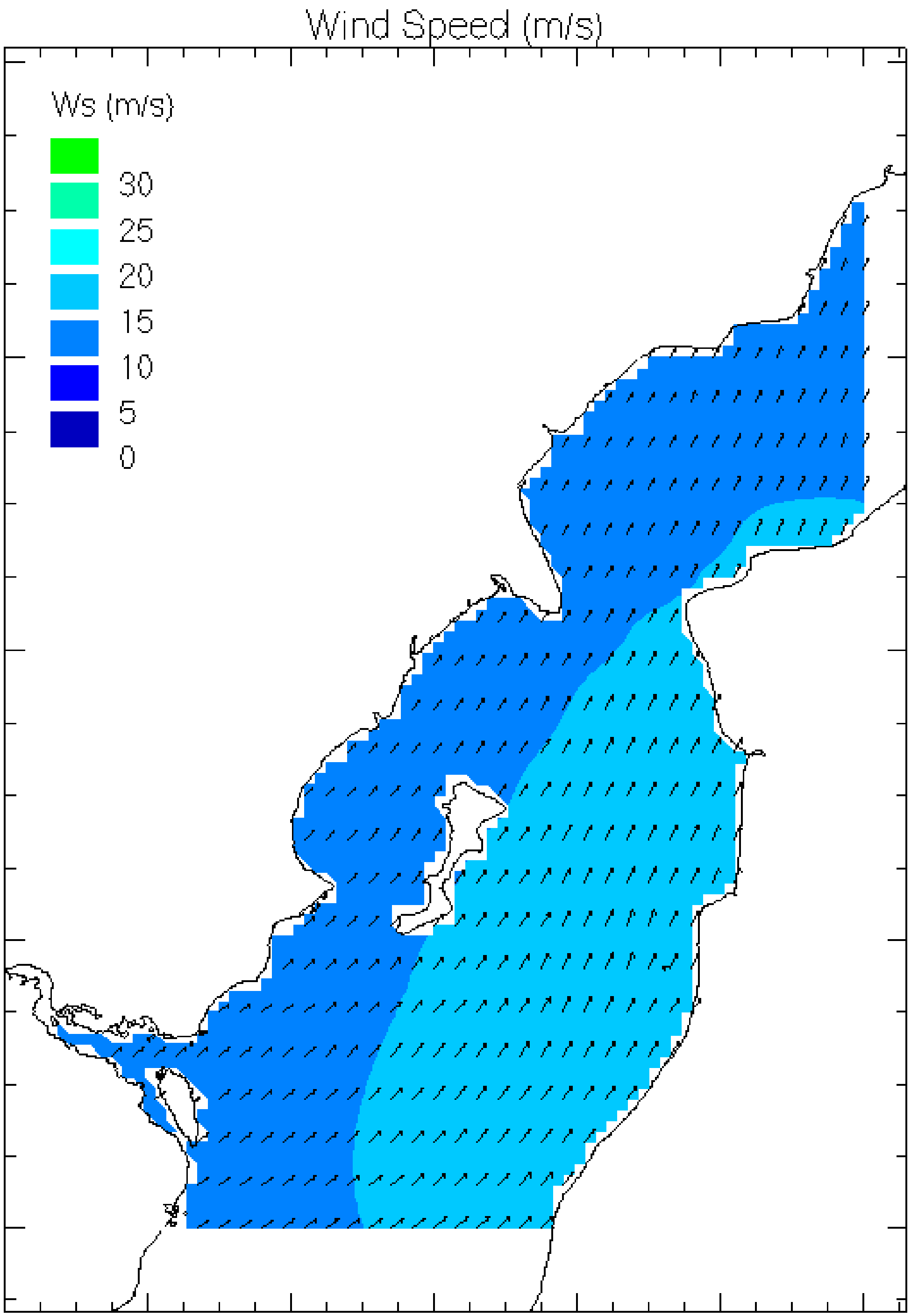
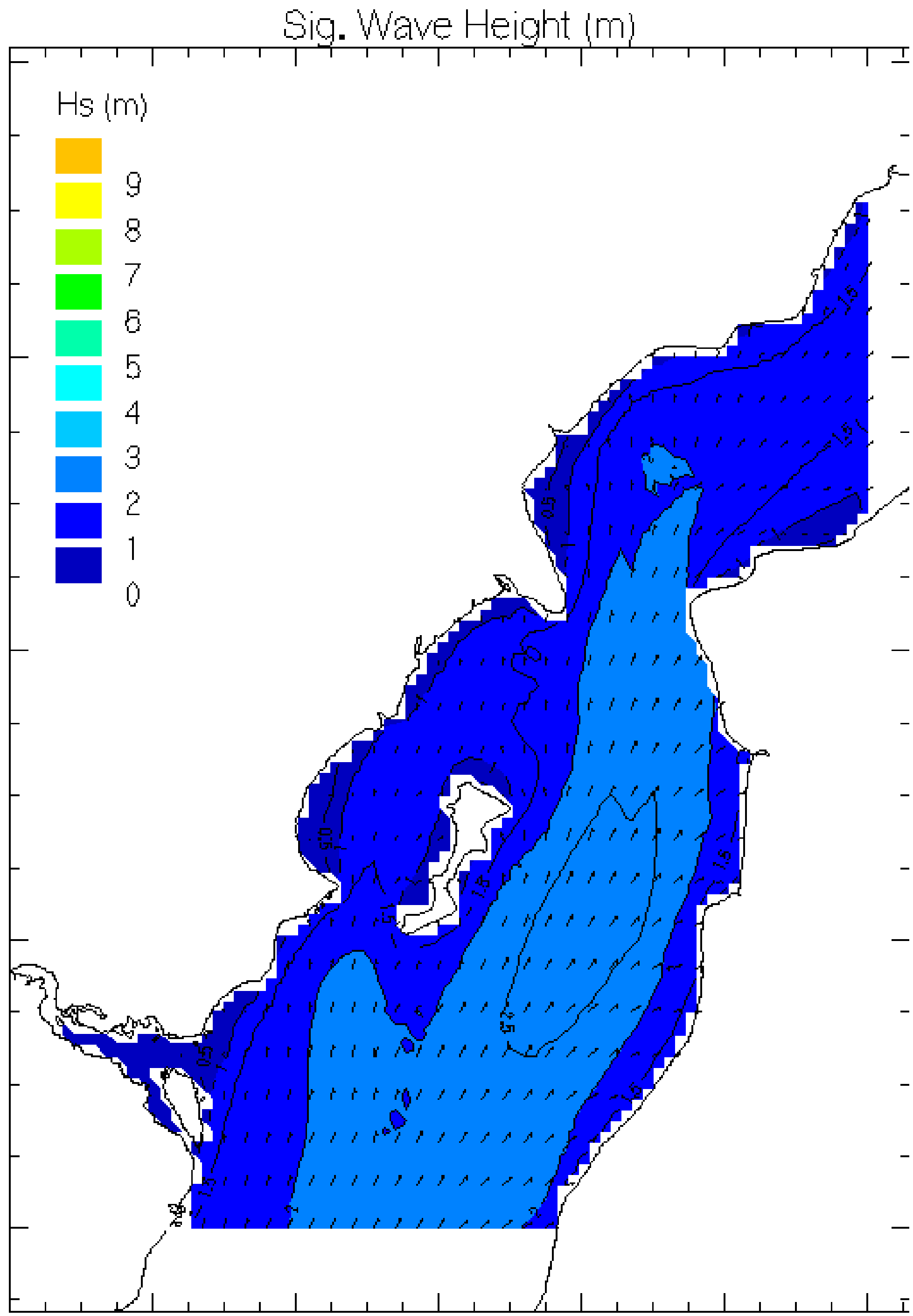
oceanweather inc.

Kenai Maximum Hindcast Winds and Waves during 19980817





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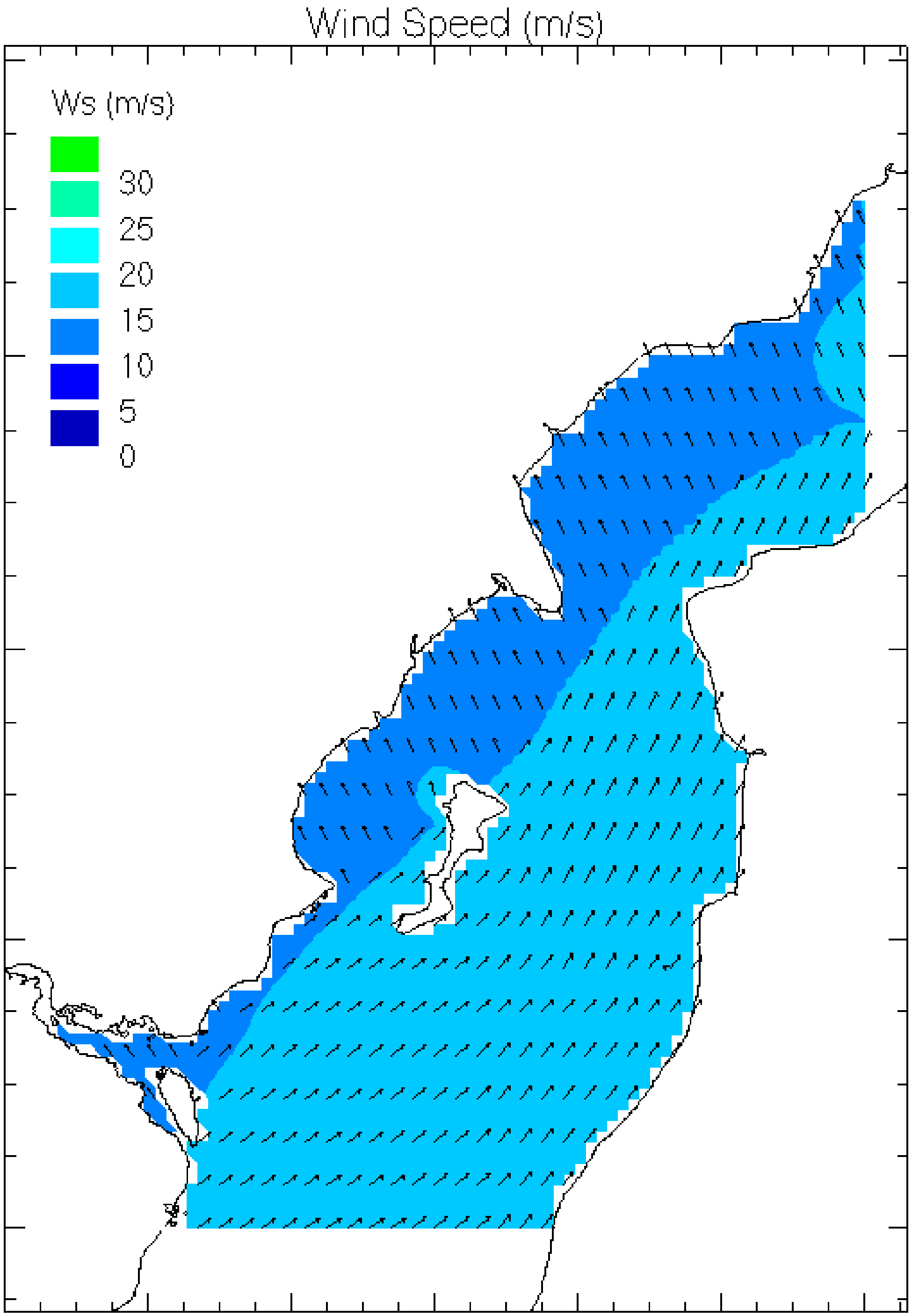
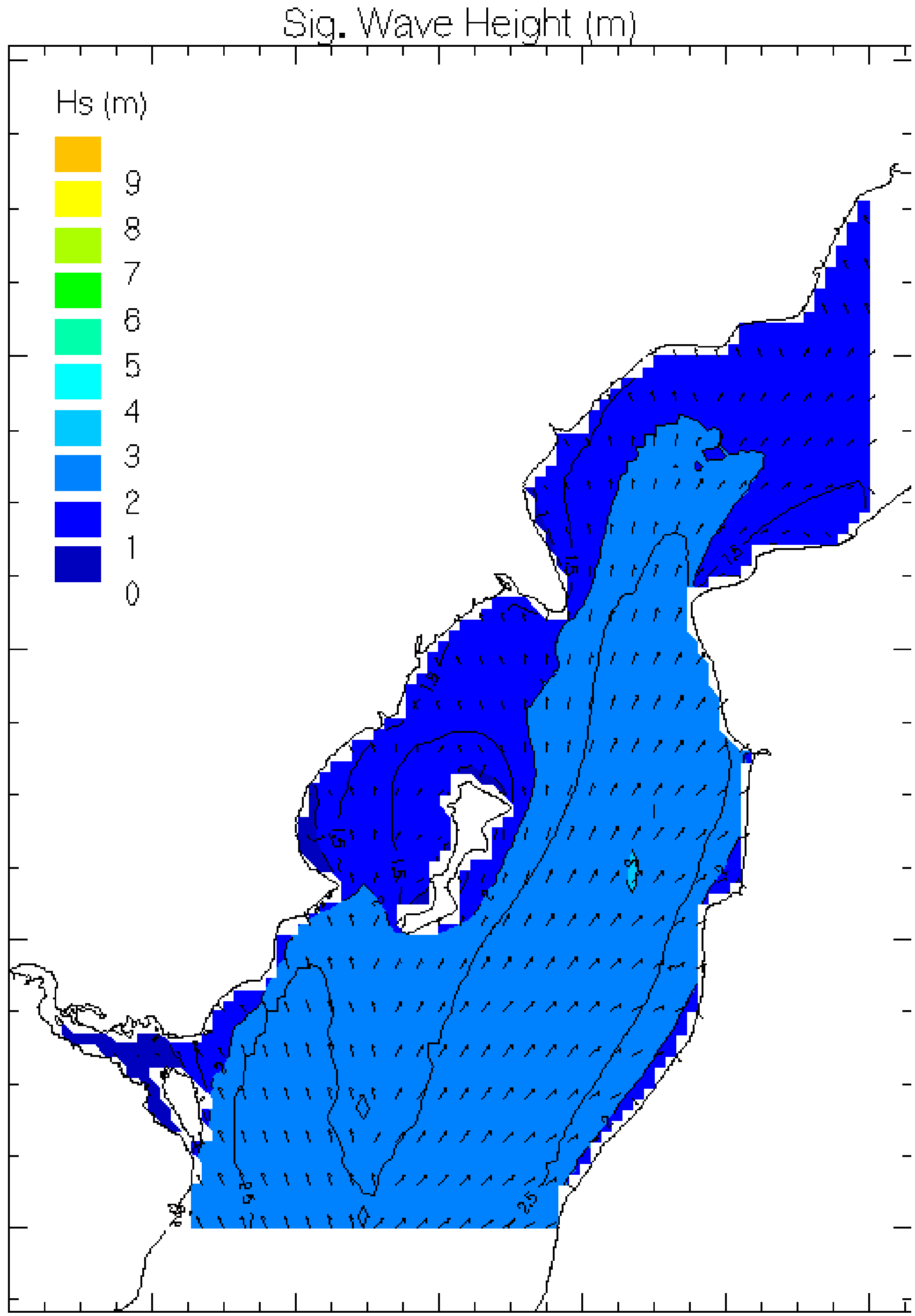
oceanweather inc.

Kenai MTR Maximum Hindcast Winds and Waves during 19991223





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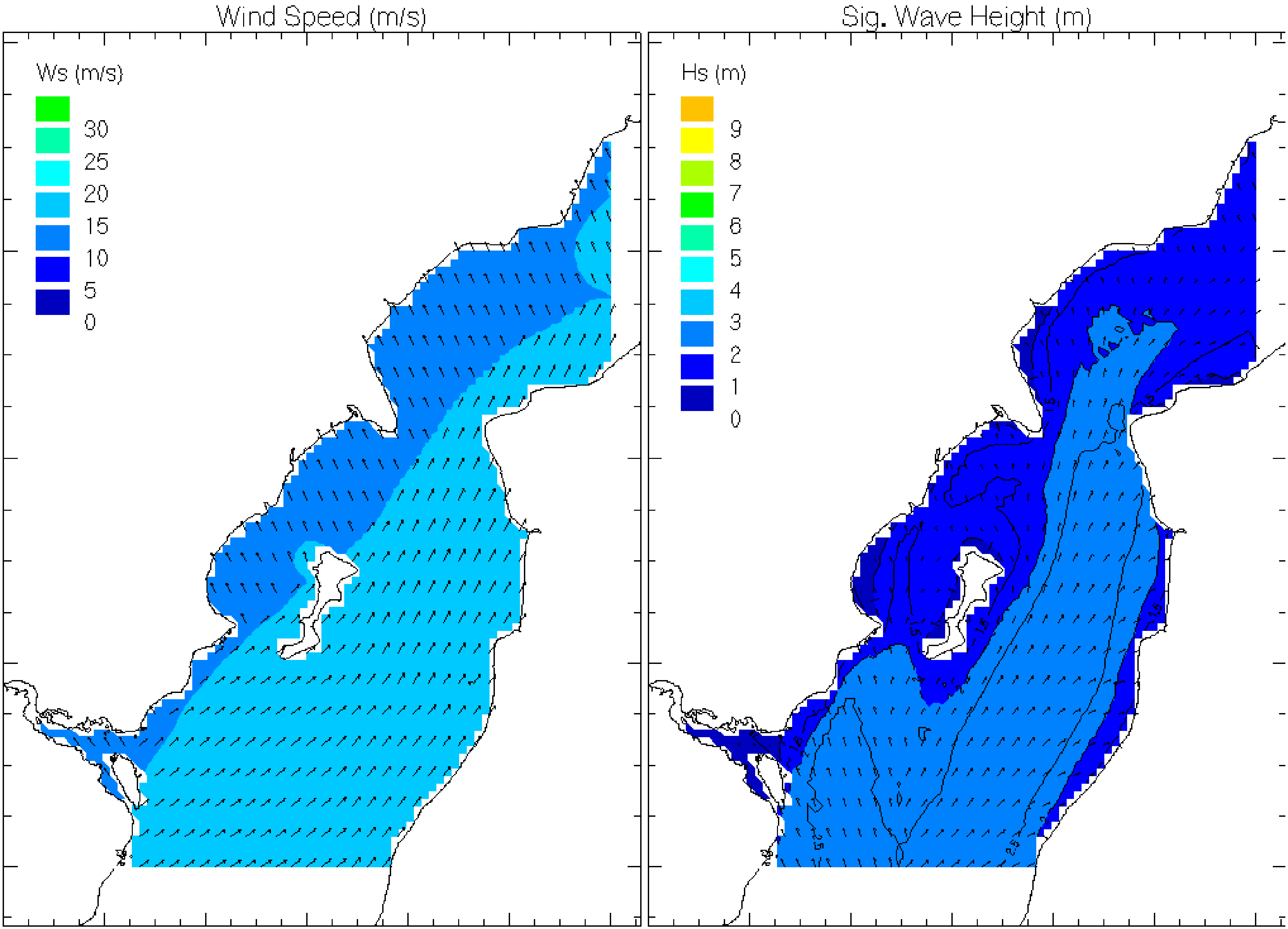
oceanweather inc.

Kenai Maximum Hindcast Winds and Waves during 19991223



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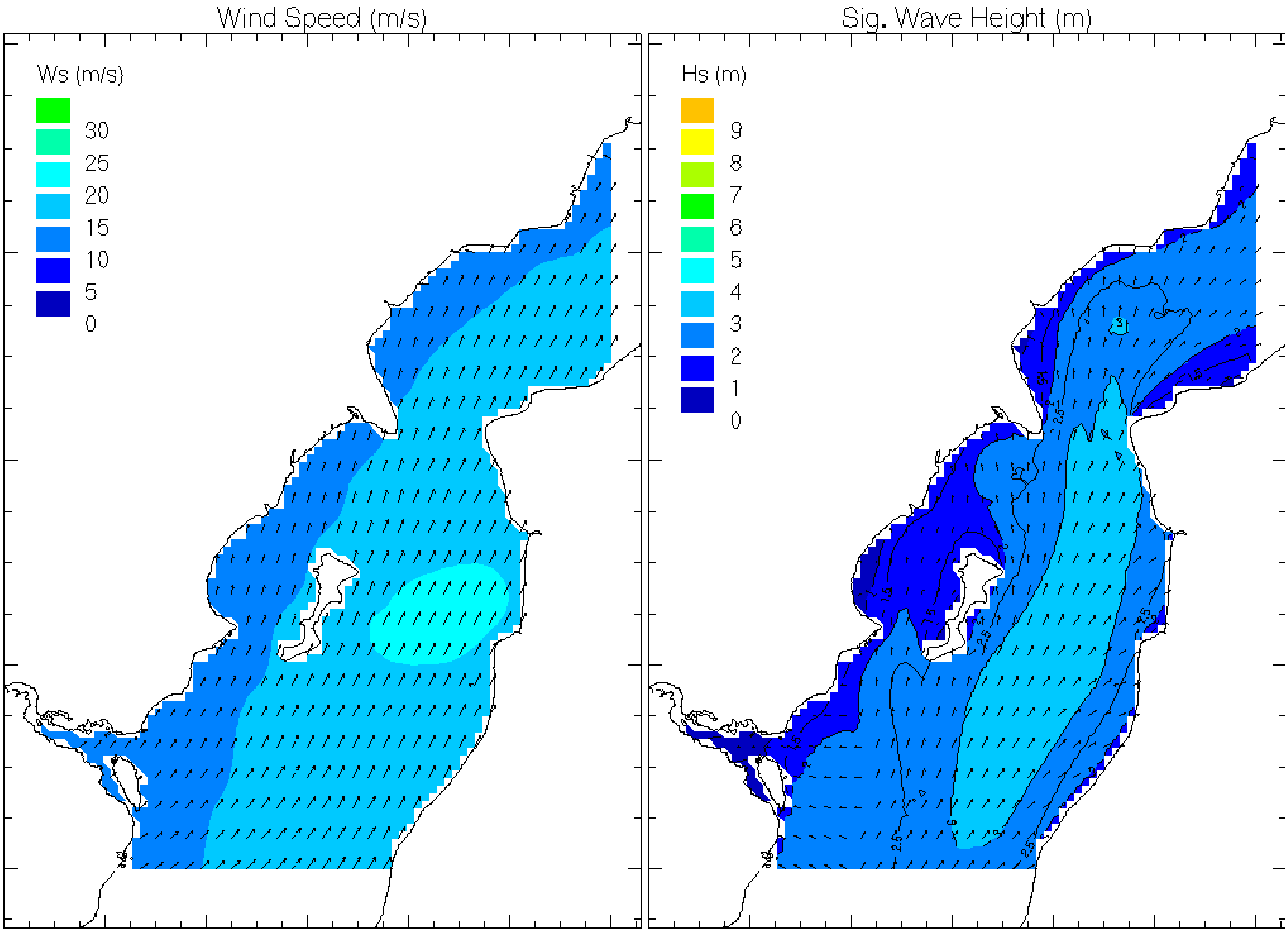
oceanweather inc.

Kenai MTR Maximum Hindcast Winds and Waves during 20000128



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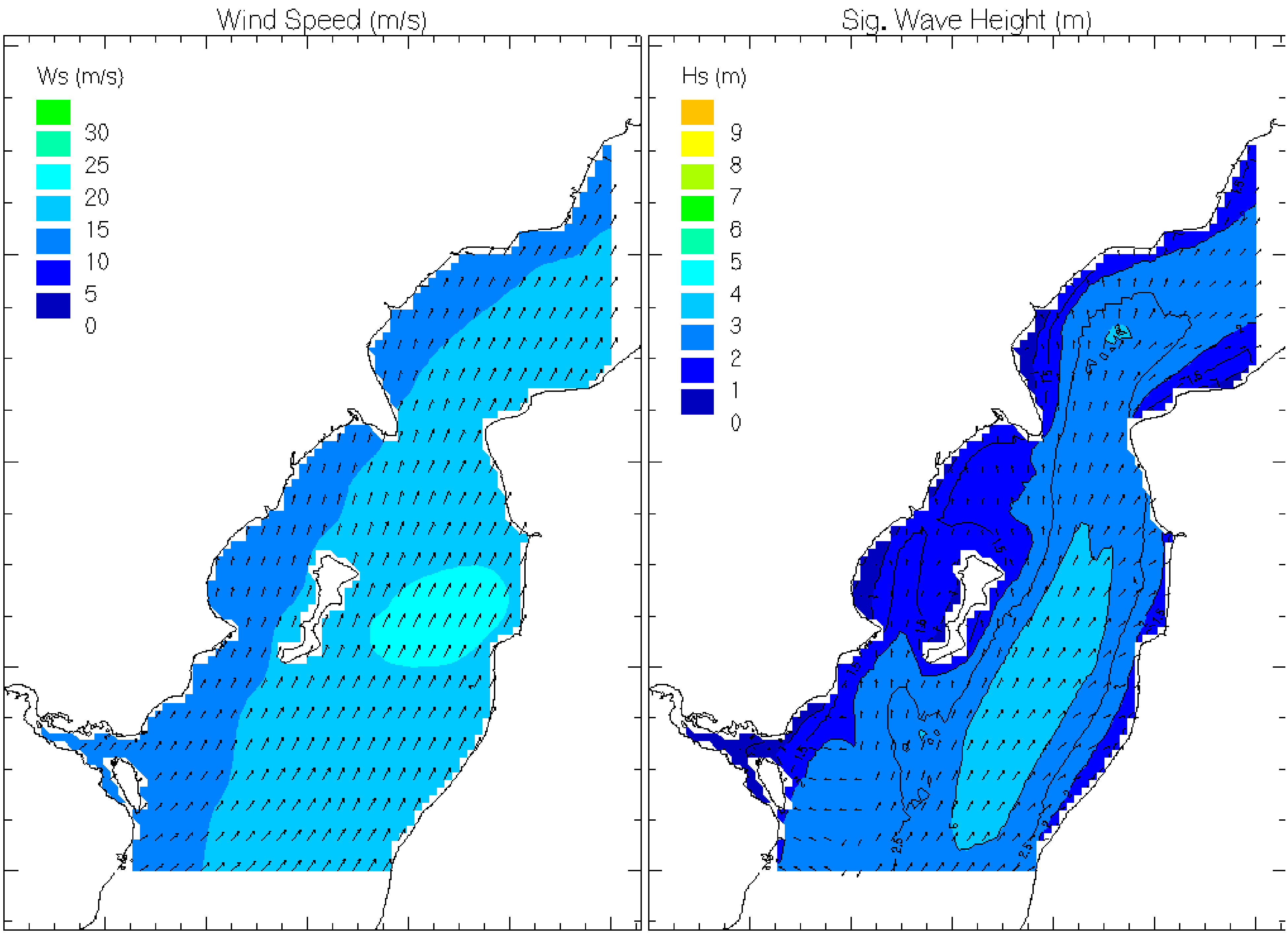
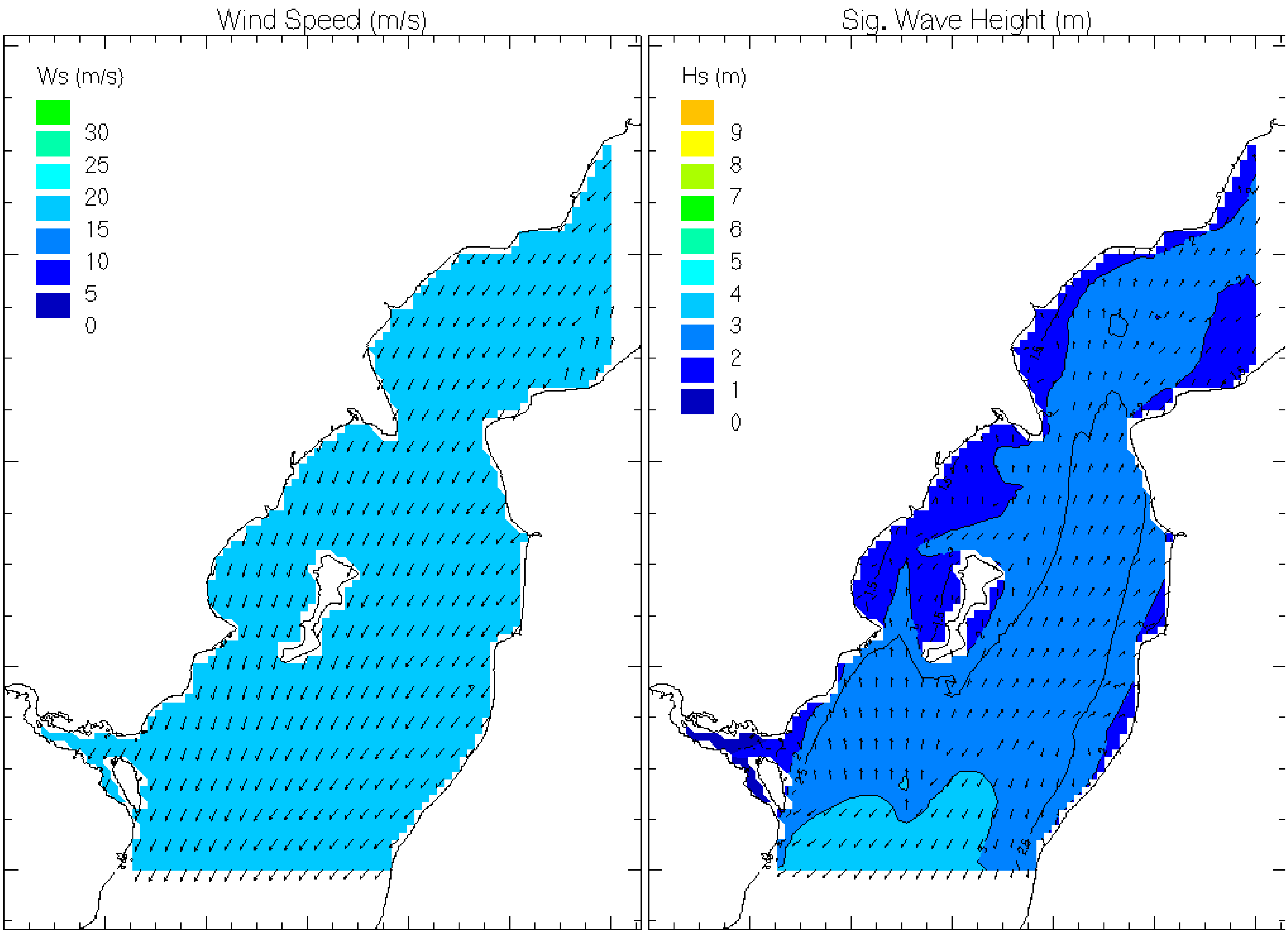
oceanweather inc.

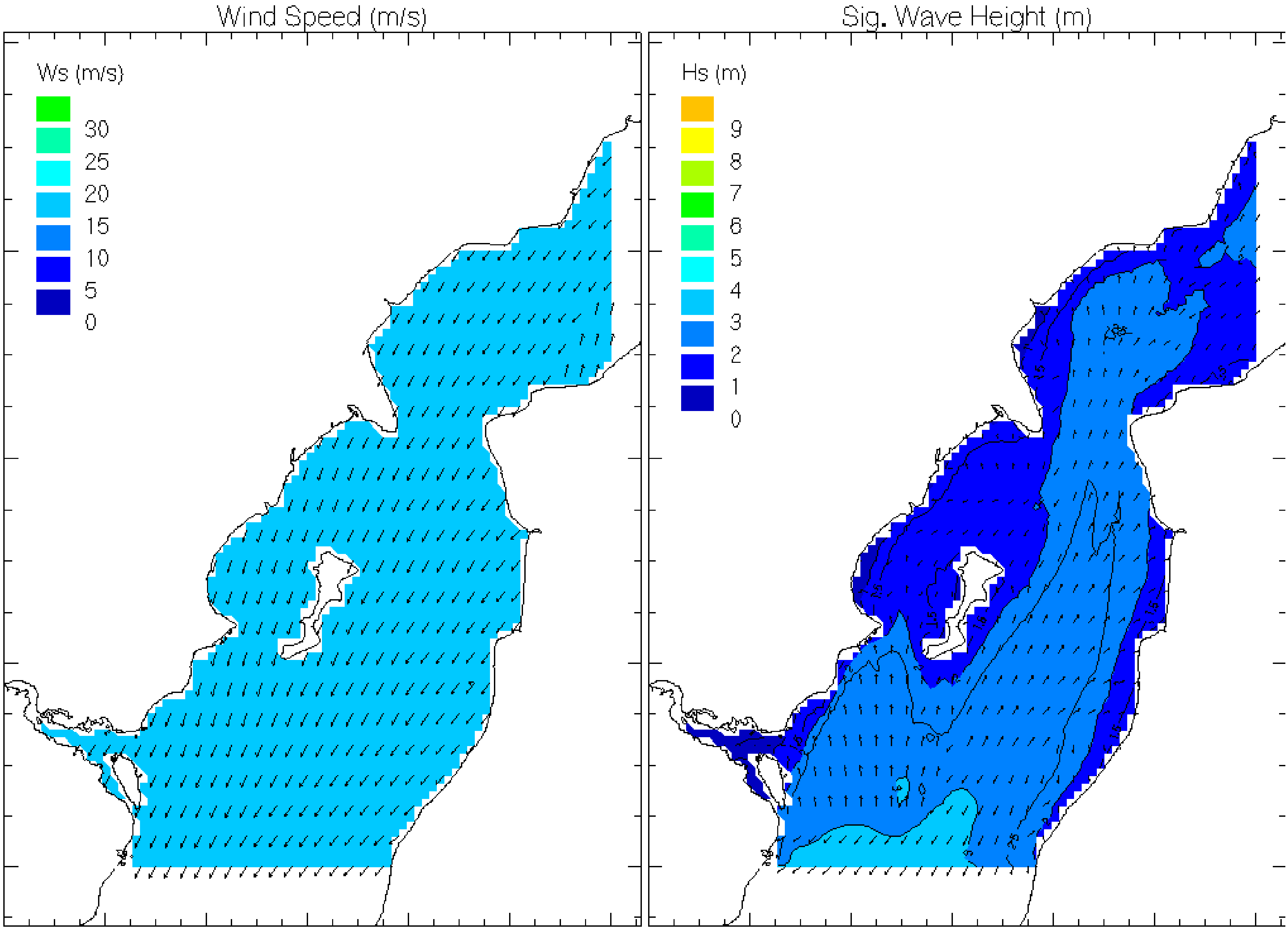
Kenai Maximum Hindcast Winds and Waves during 20000128



Kenai MTR Maximum Hindcast Winds and Waves during 20010228



Kenai Maximum Hindcast Winds and Waves during 20010228



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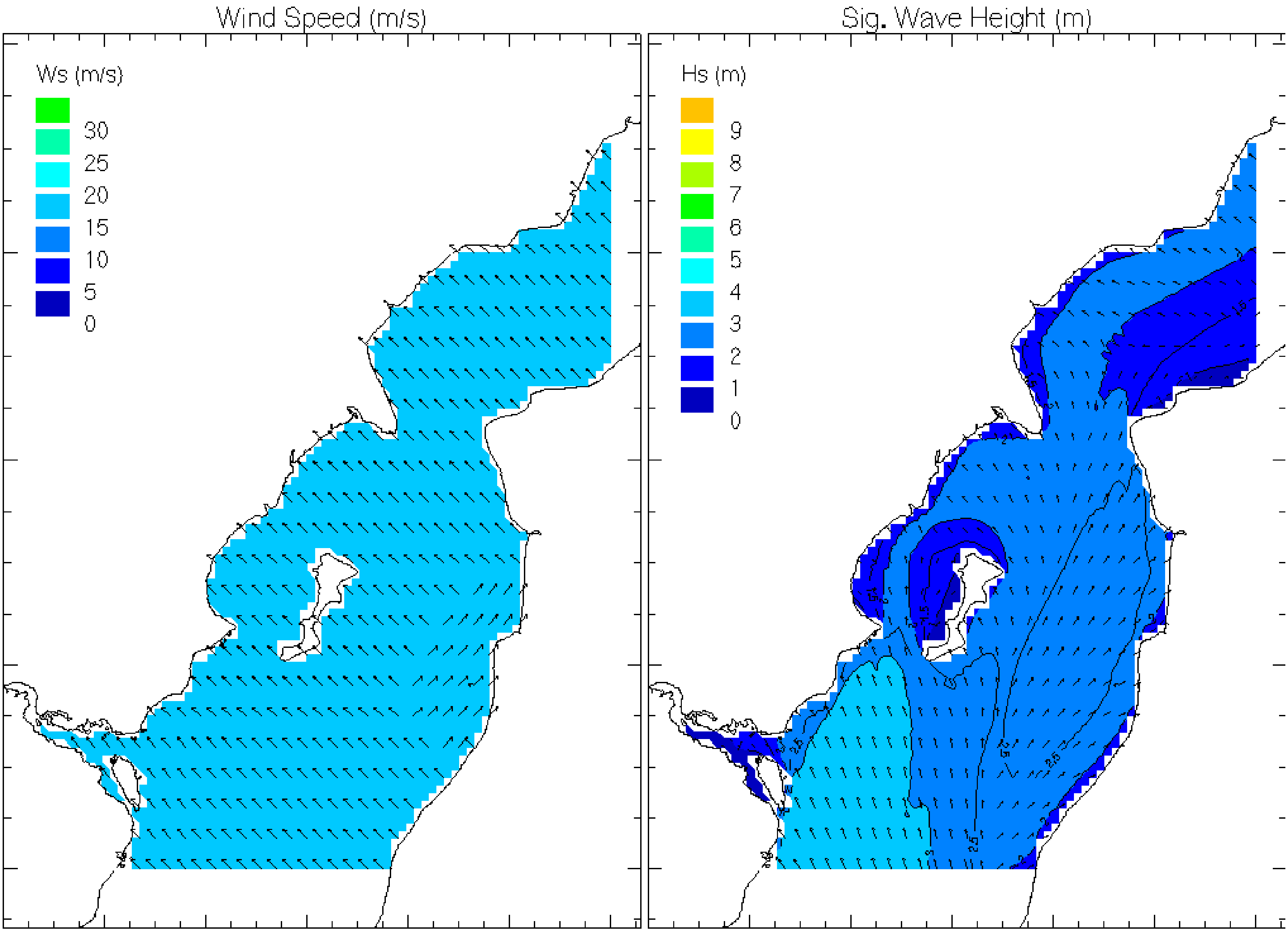
oceanweather inc.

Kenai MTR Maximum Hindcast Winds and Waves during 20010404



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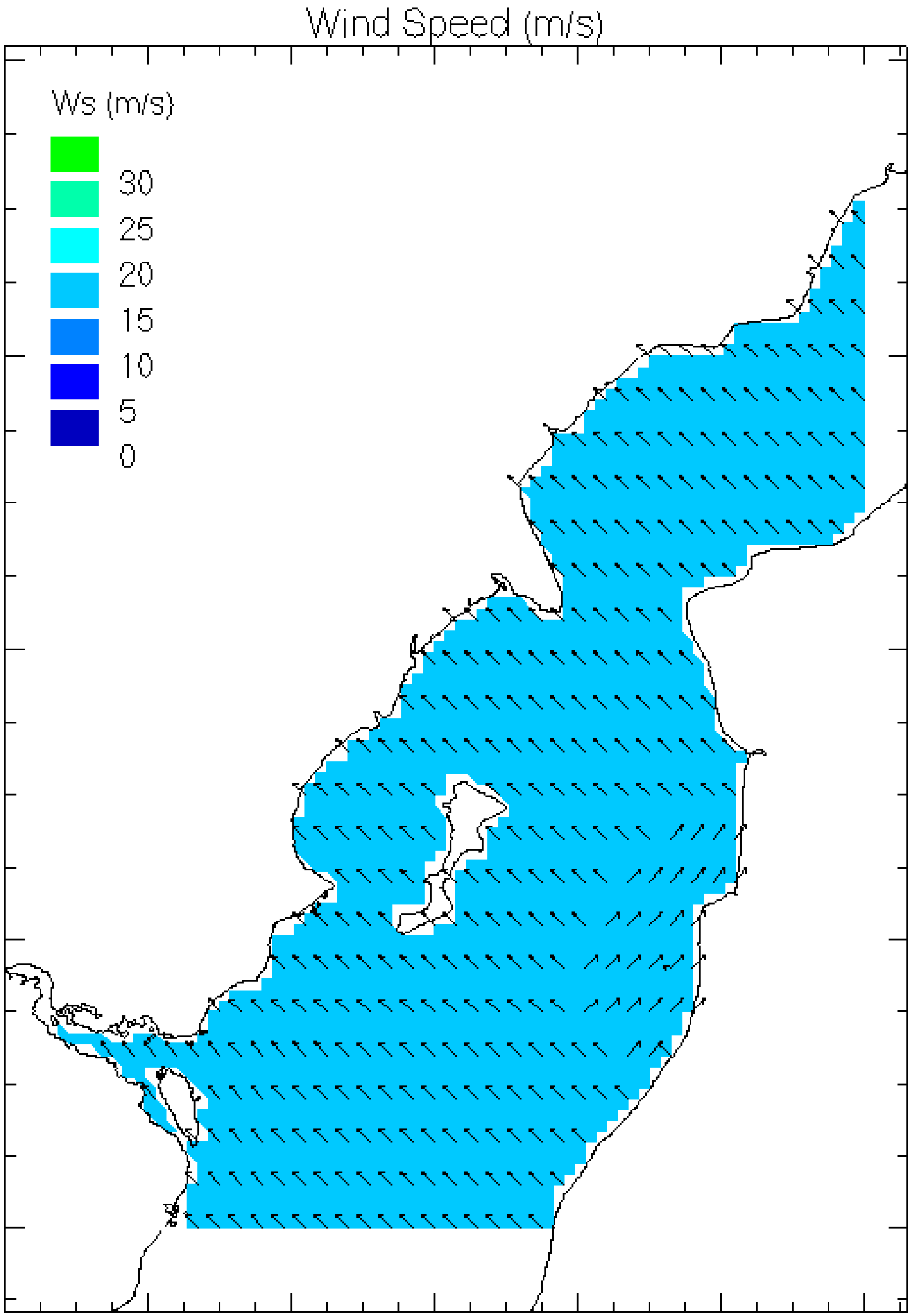
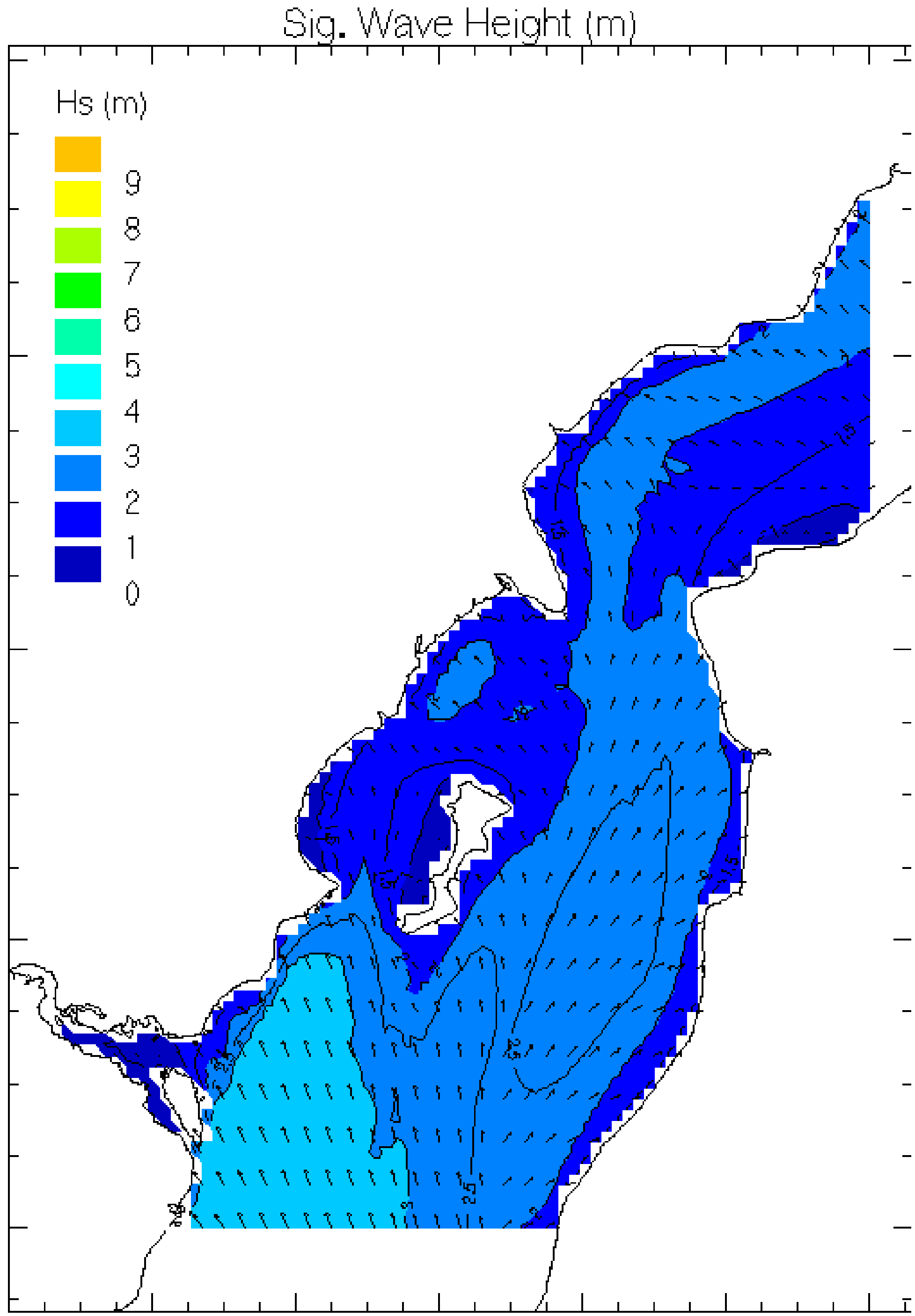
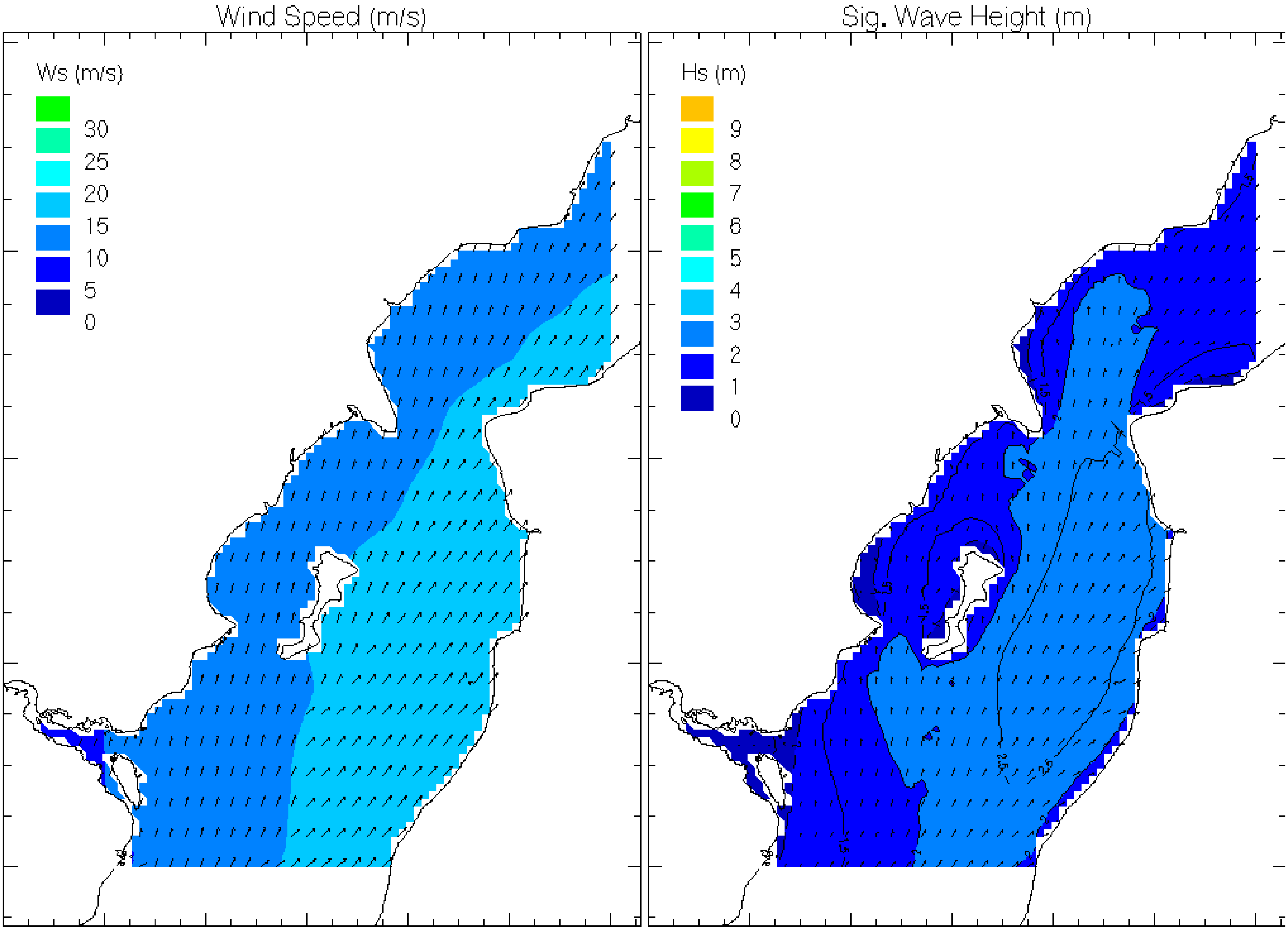
oceanweather inc.

Kenai Maximum Hindcast Winds and Waves during 20010404





Kenai MTR Maximum Hindcast Winds and Waves during 20010502



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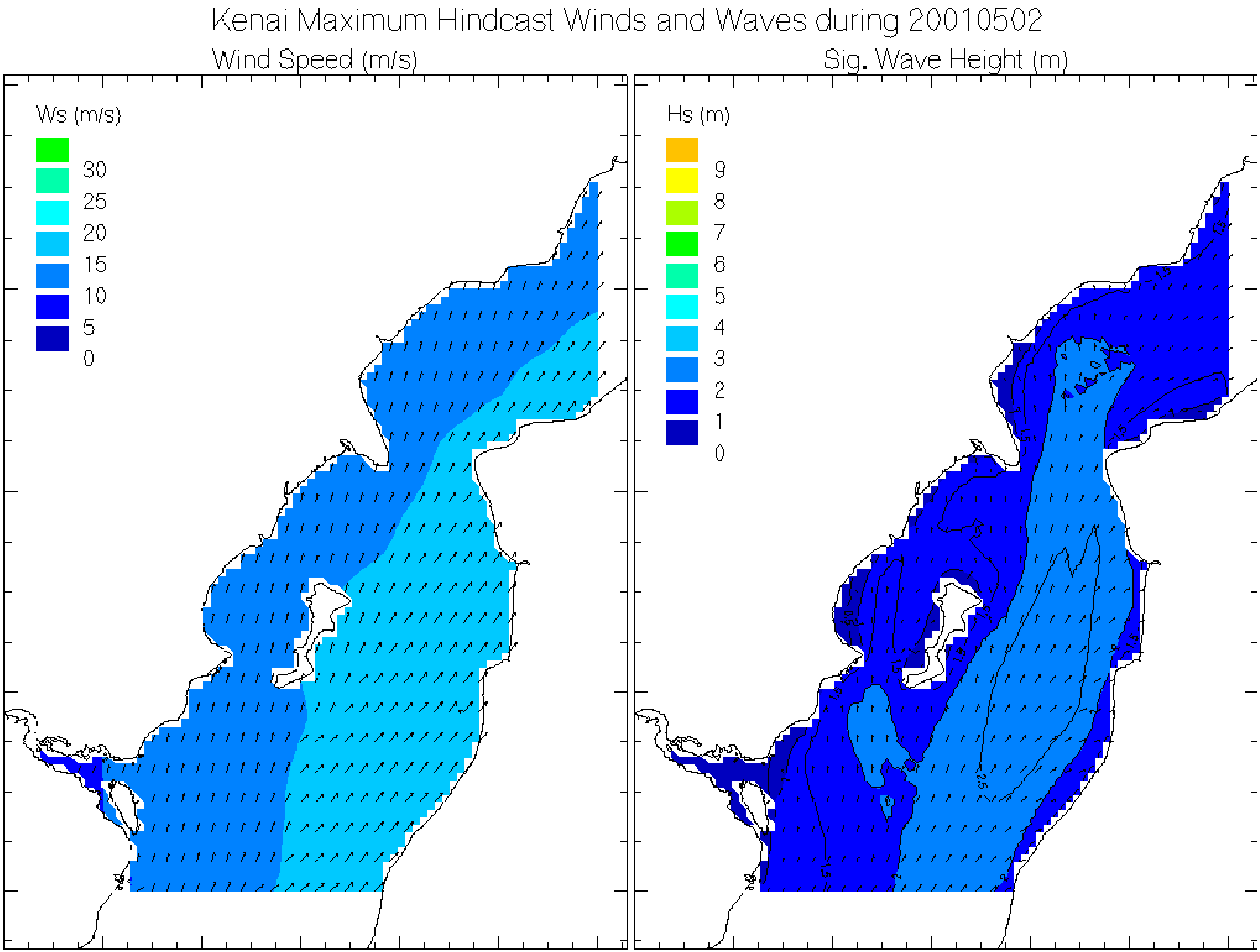
oceanweather inc.



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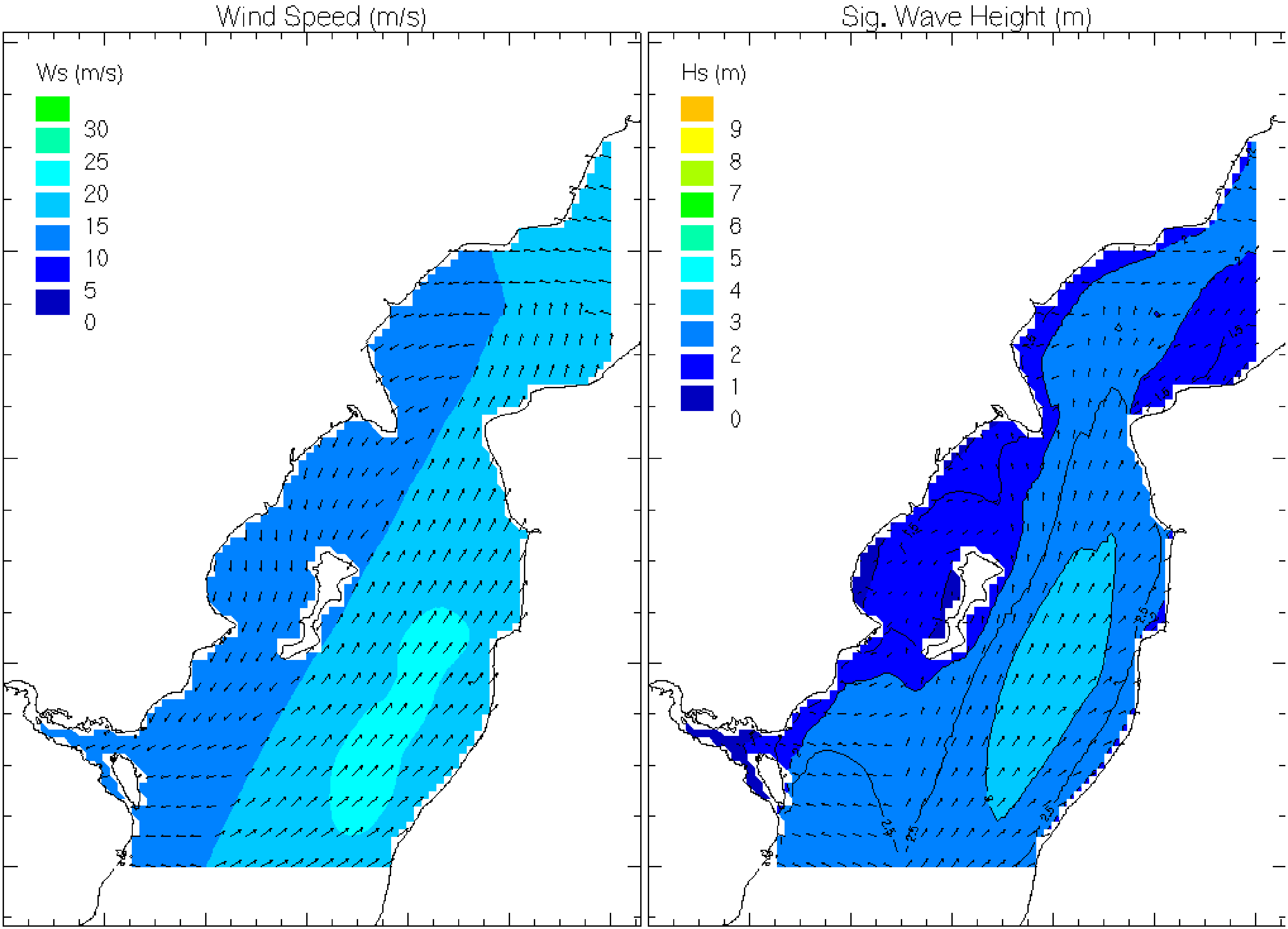
oceanweather inc.

Kenai MTR Maximum Hindcast Winds and Waves during 20020213



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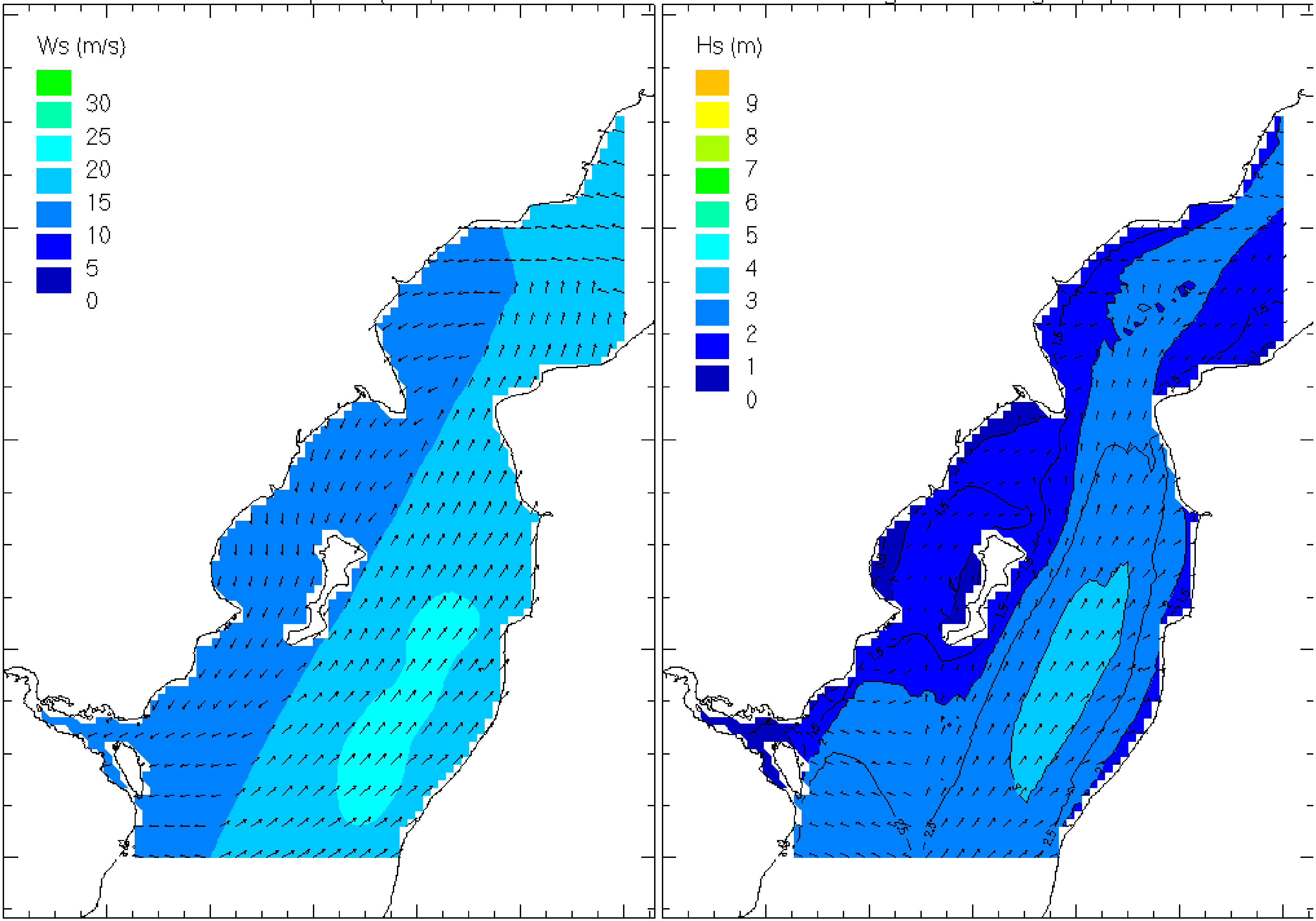
oceanweather inc.

Kenai Maximum Hindcast Winds and Waves during 20020213

Wind Speed (m/s) Sig. Wave Height (m)



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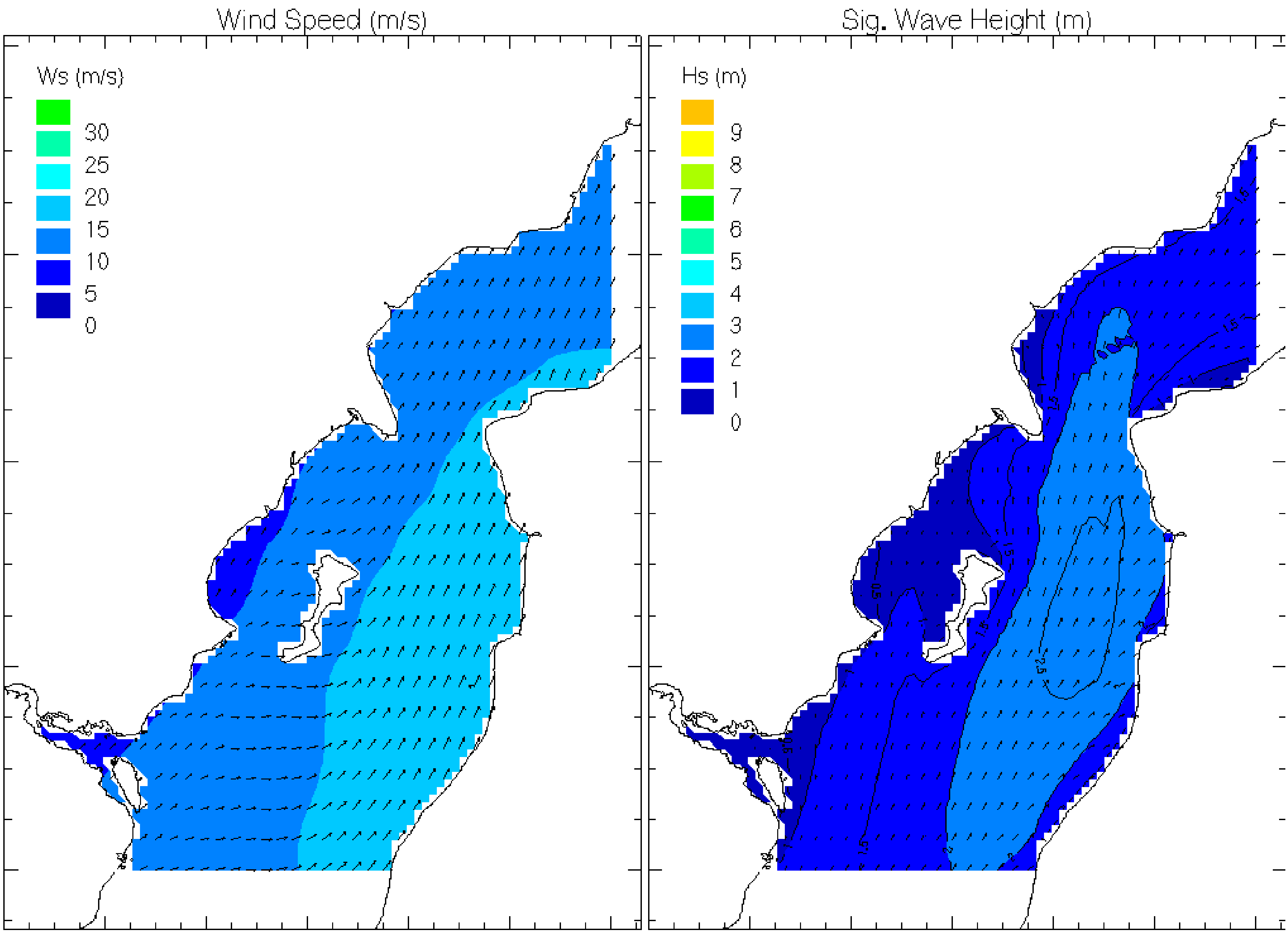
oceanweather inc.

Kenai MTR Maximum Hindcast Winds and Waves during 20020501



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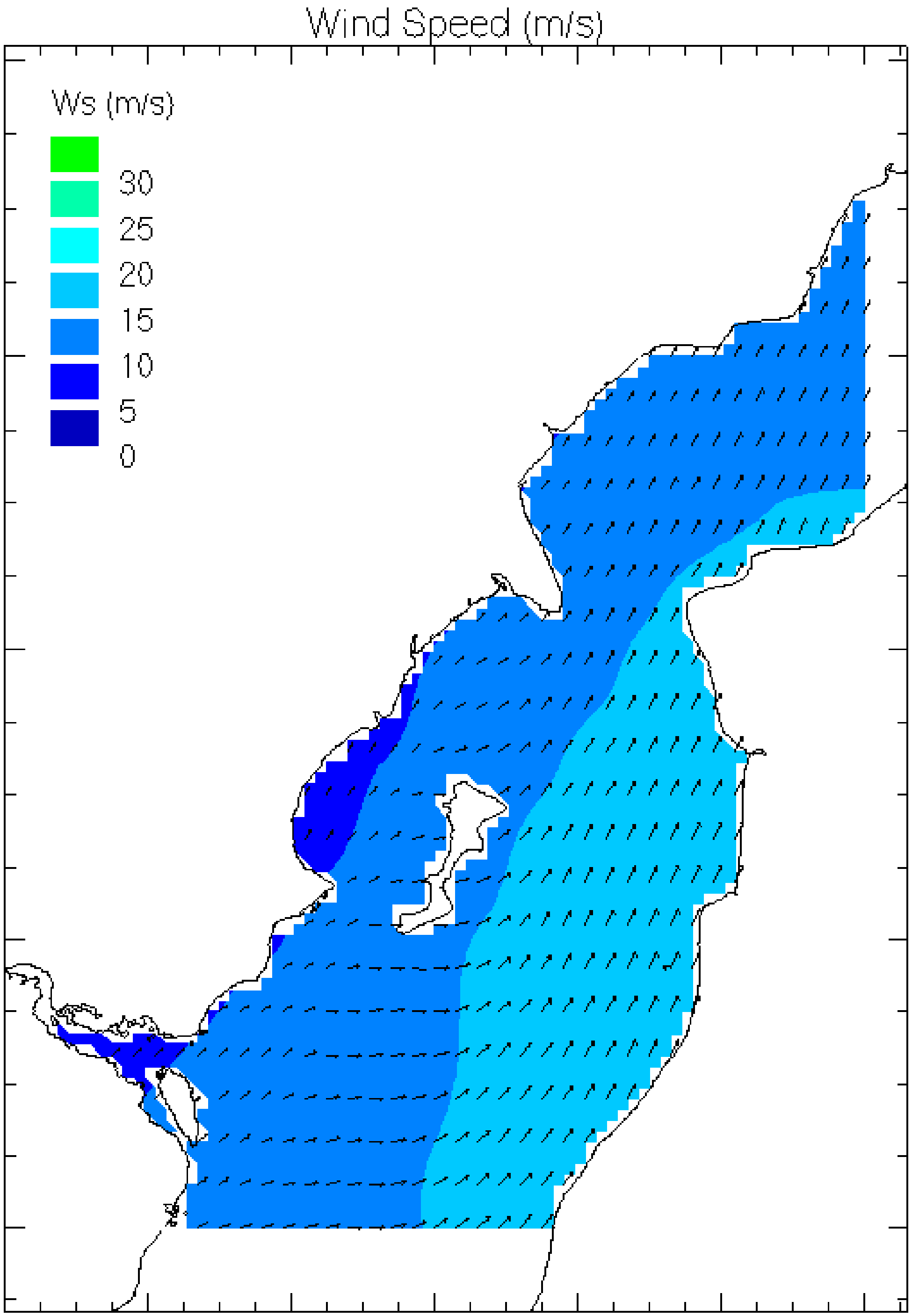
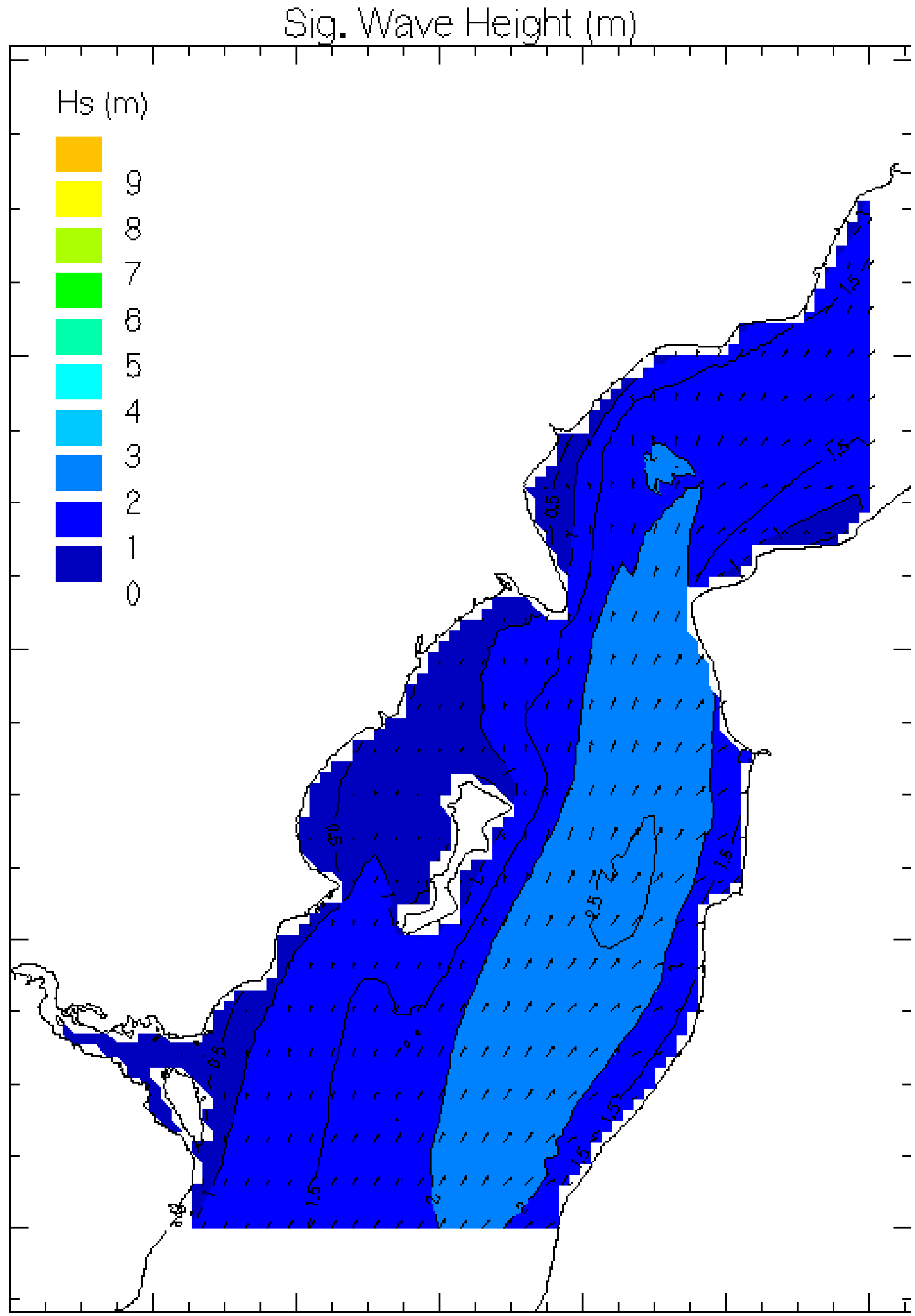
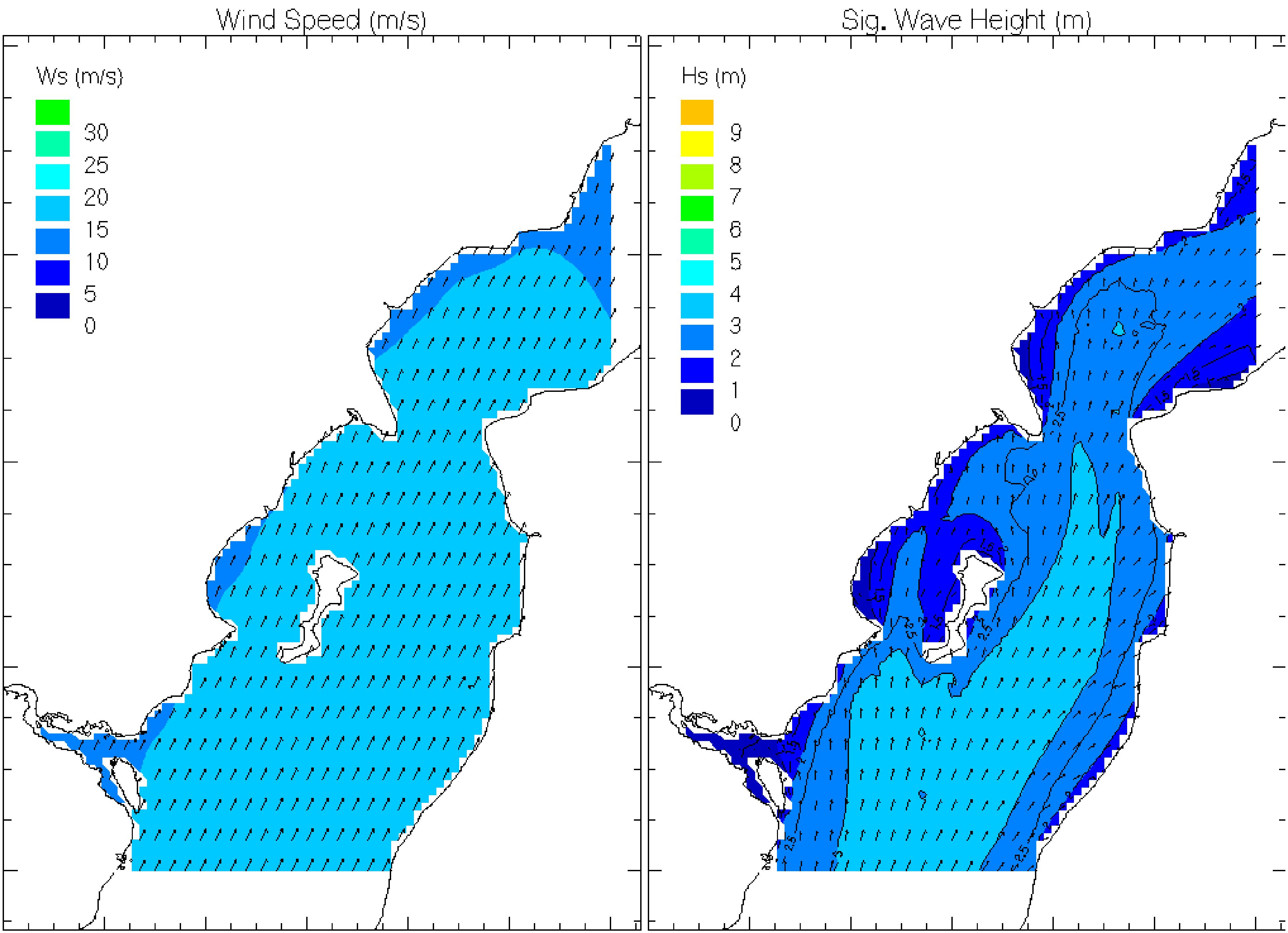
oceanweather inc.

Kenai Maximum Hindcast Winds and Waves during 20020501





Kenai MTR Maximum Hindcast Winds and Waves during 20020927



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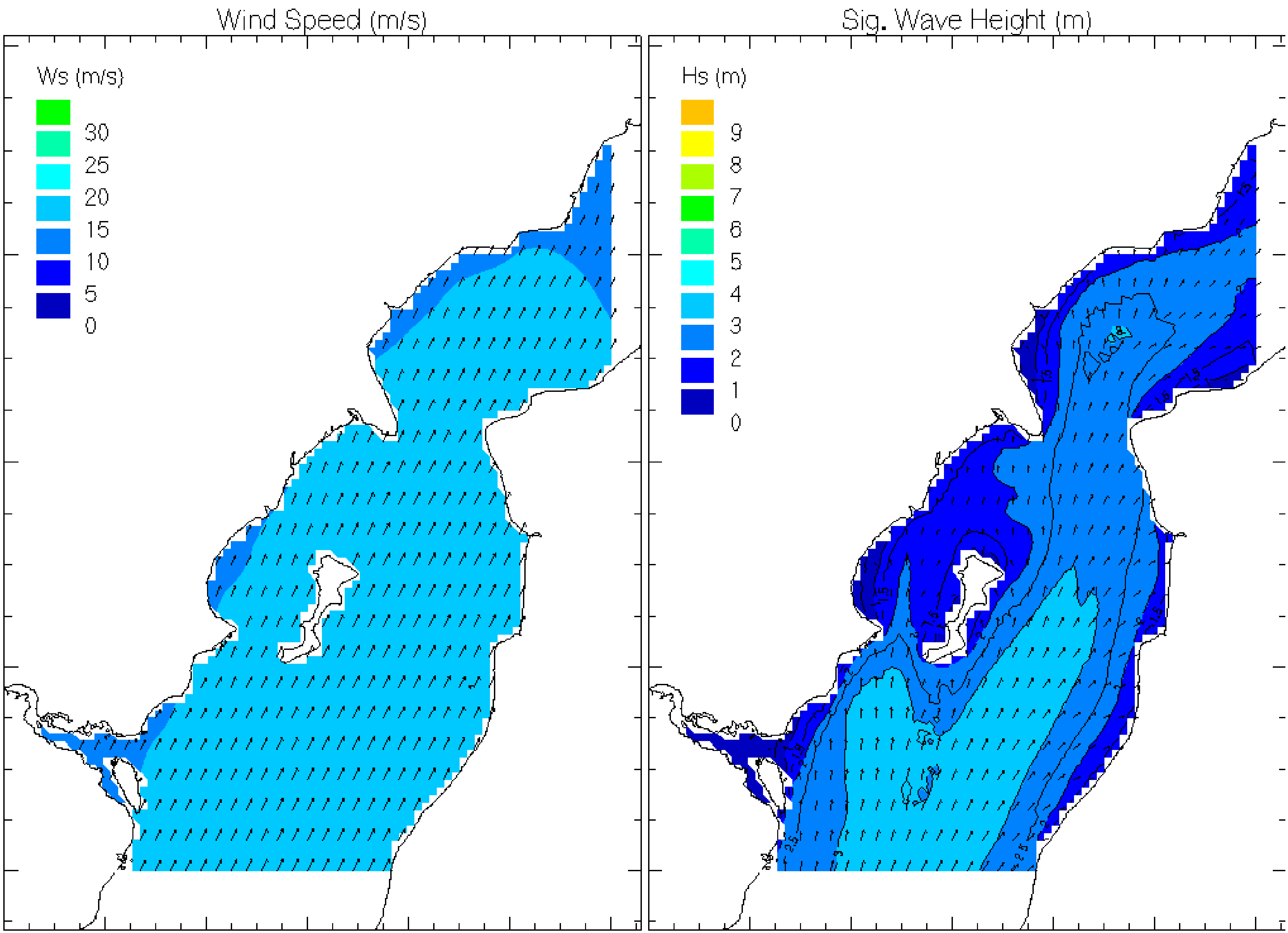
oceanweather inc.

Kenai Maximum Hindcast Winds and Waves during 20020927



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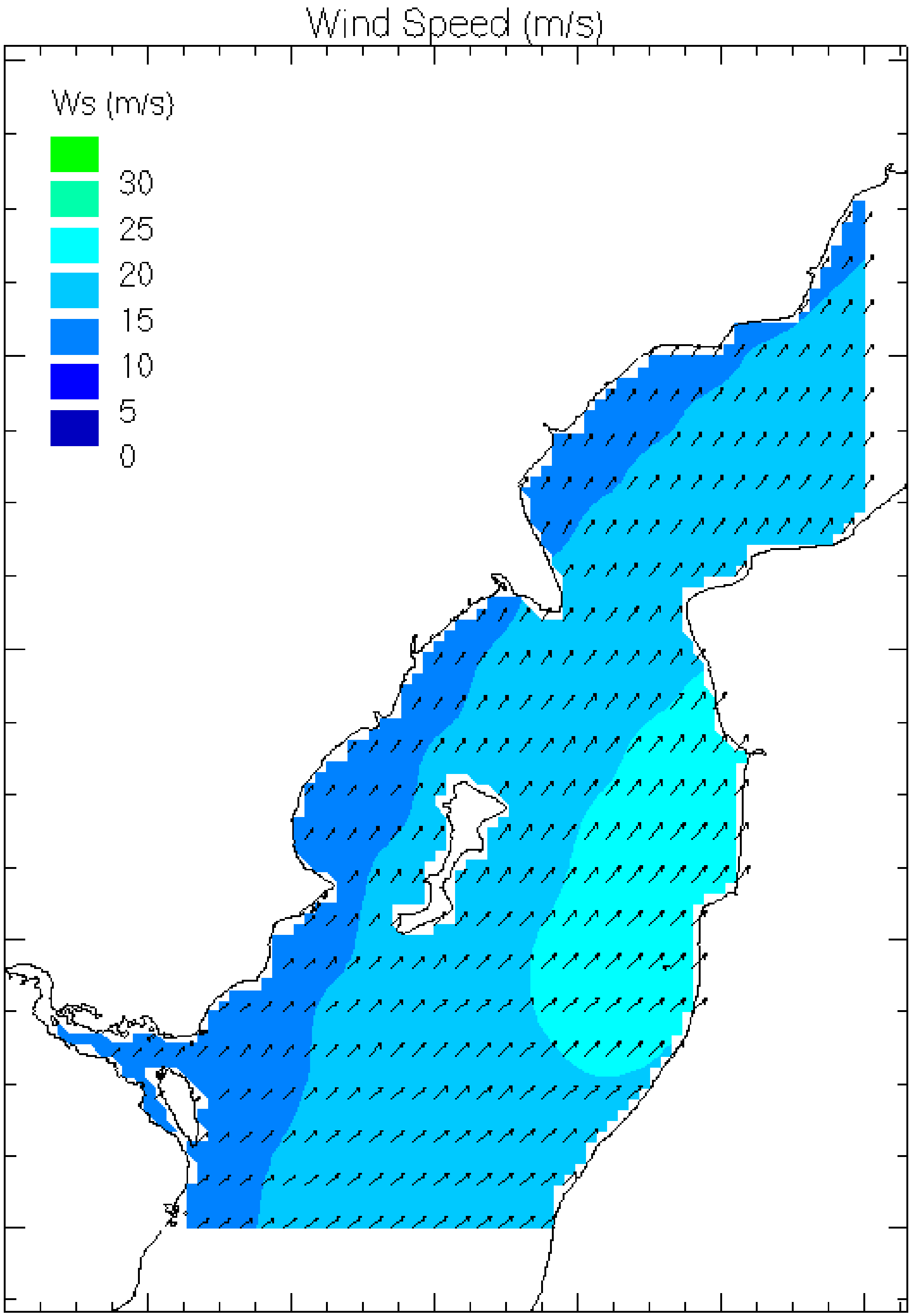
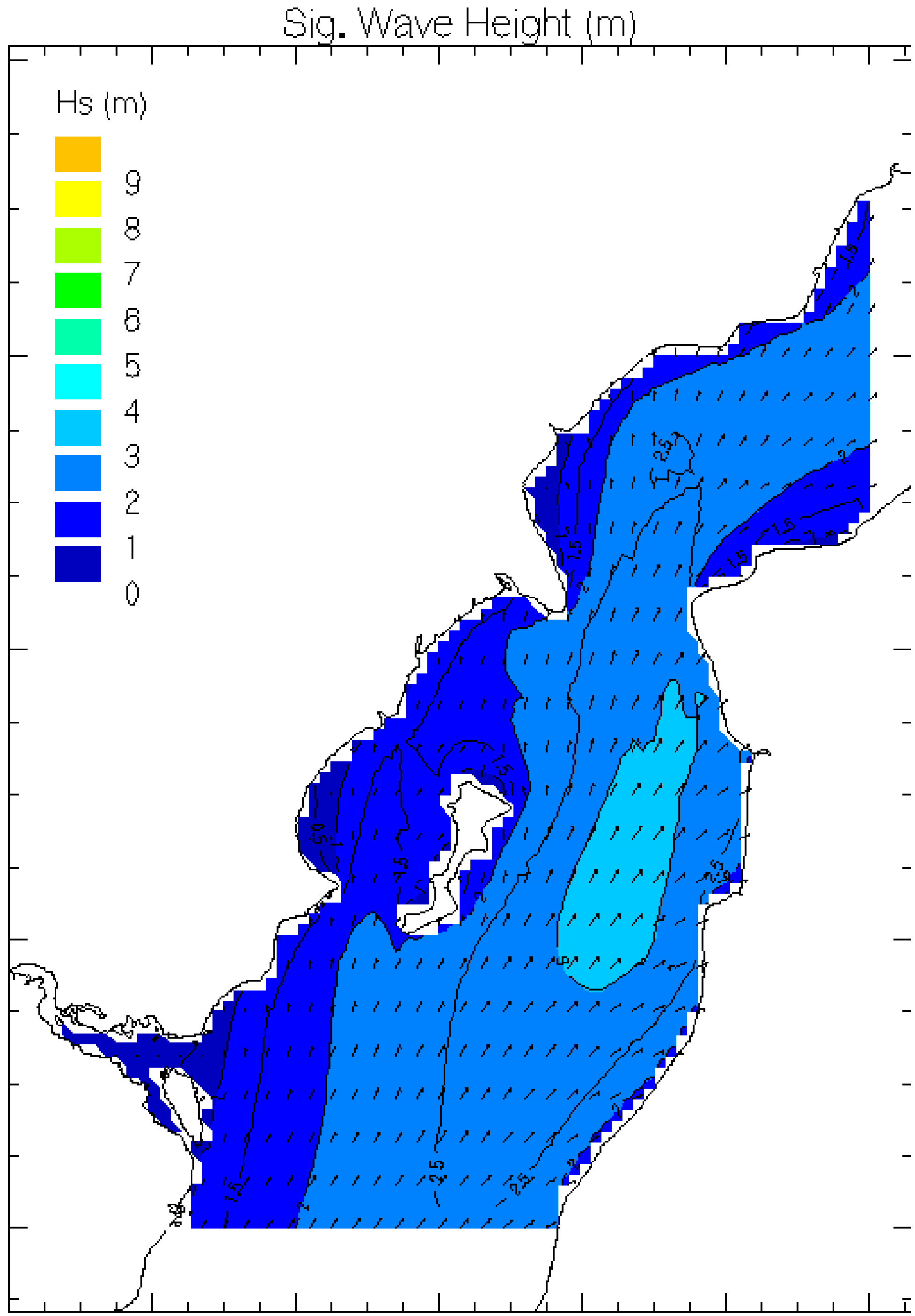
oceanweather inc.

Kenai MTR Maximum Hindcast Winds and Waves during 20021008





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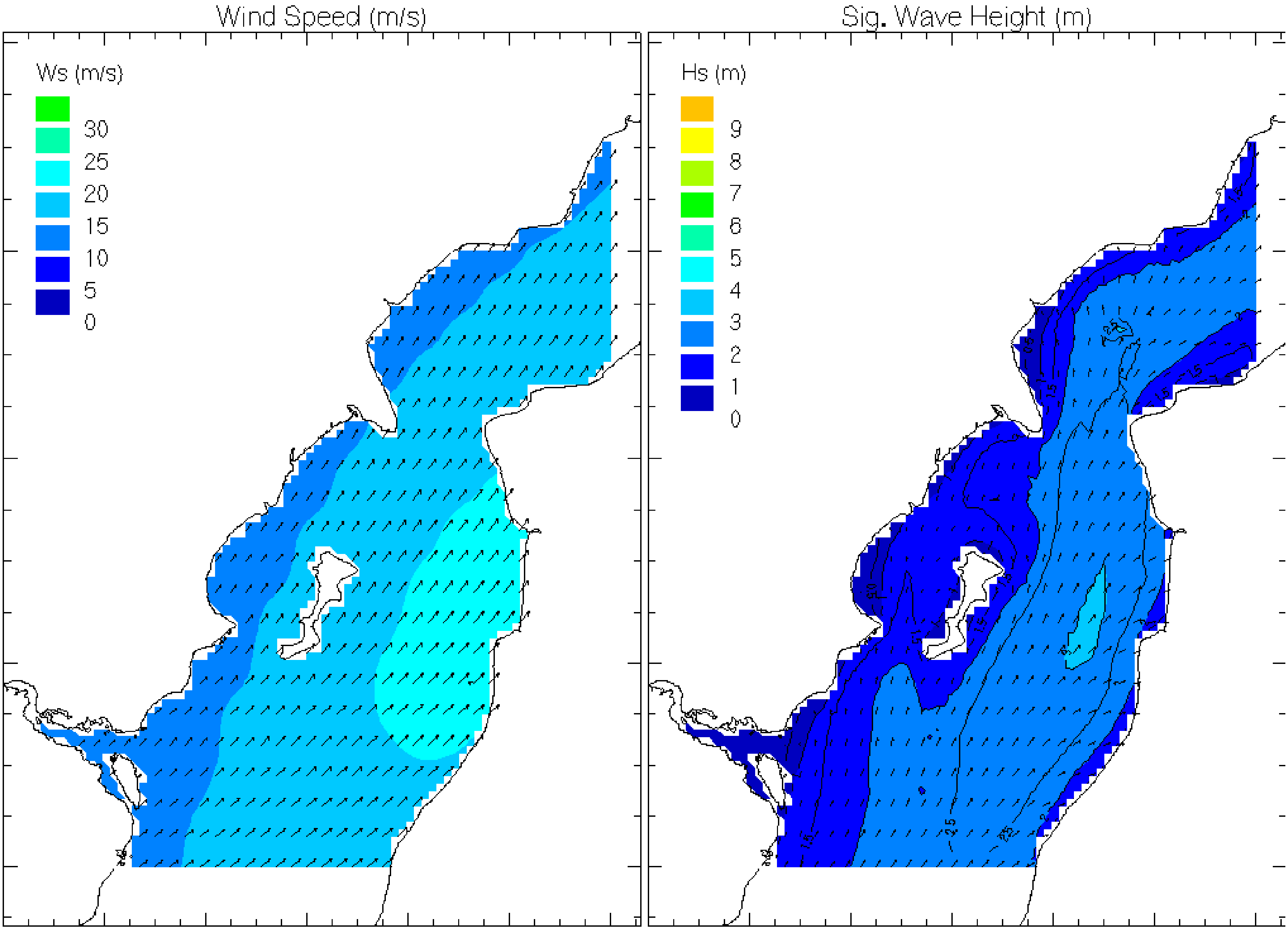
oceanweather inc.

Kenai Maximum Hindcast Winds and Waves during 20021008



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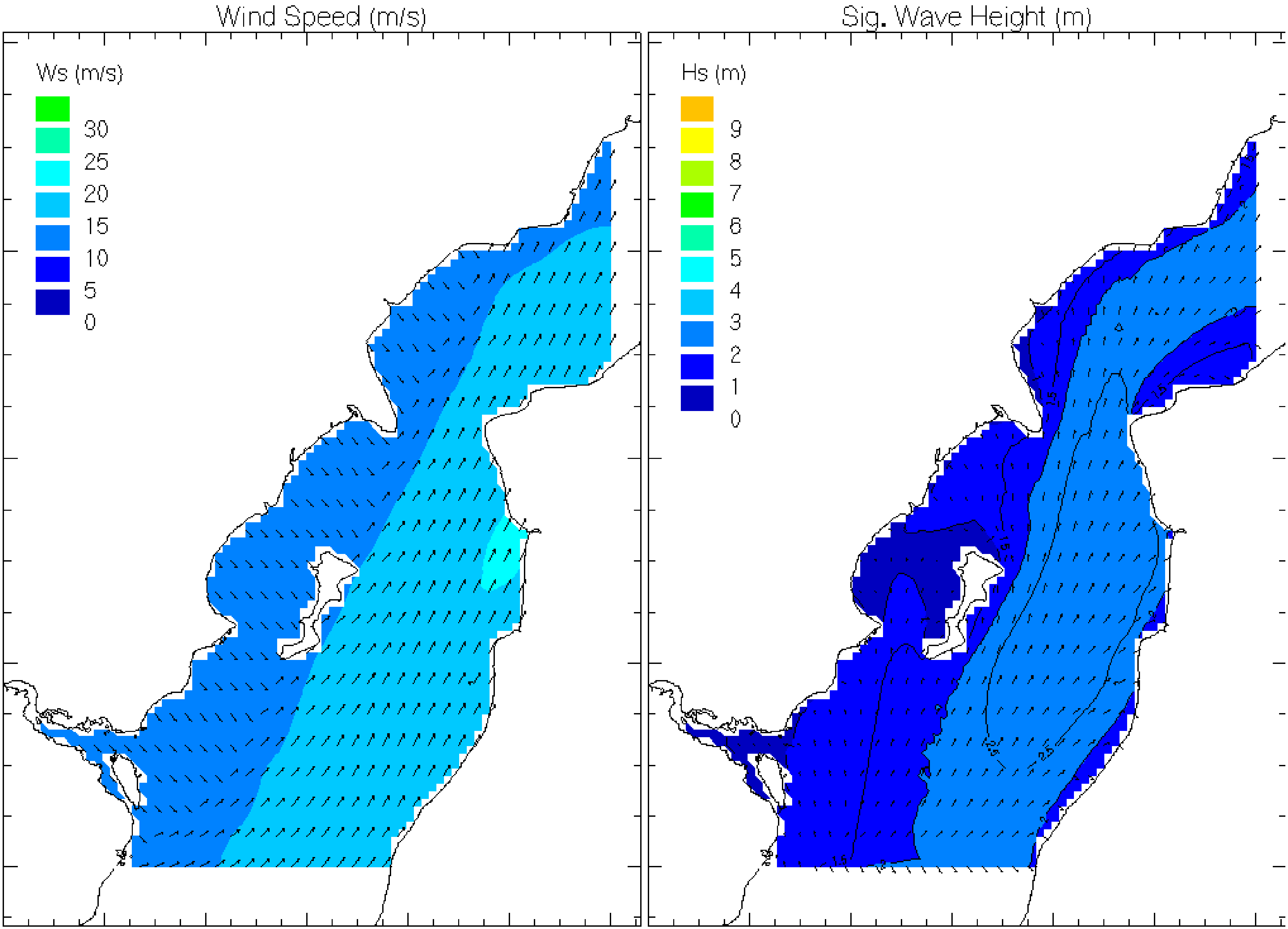
oceanweather inc.

Kenai MTR Maximum Hindcast Winds and Waves during 20030105



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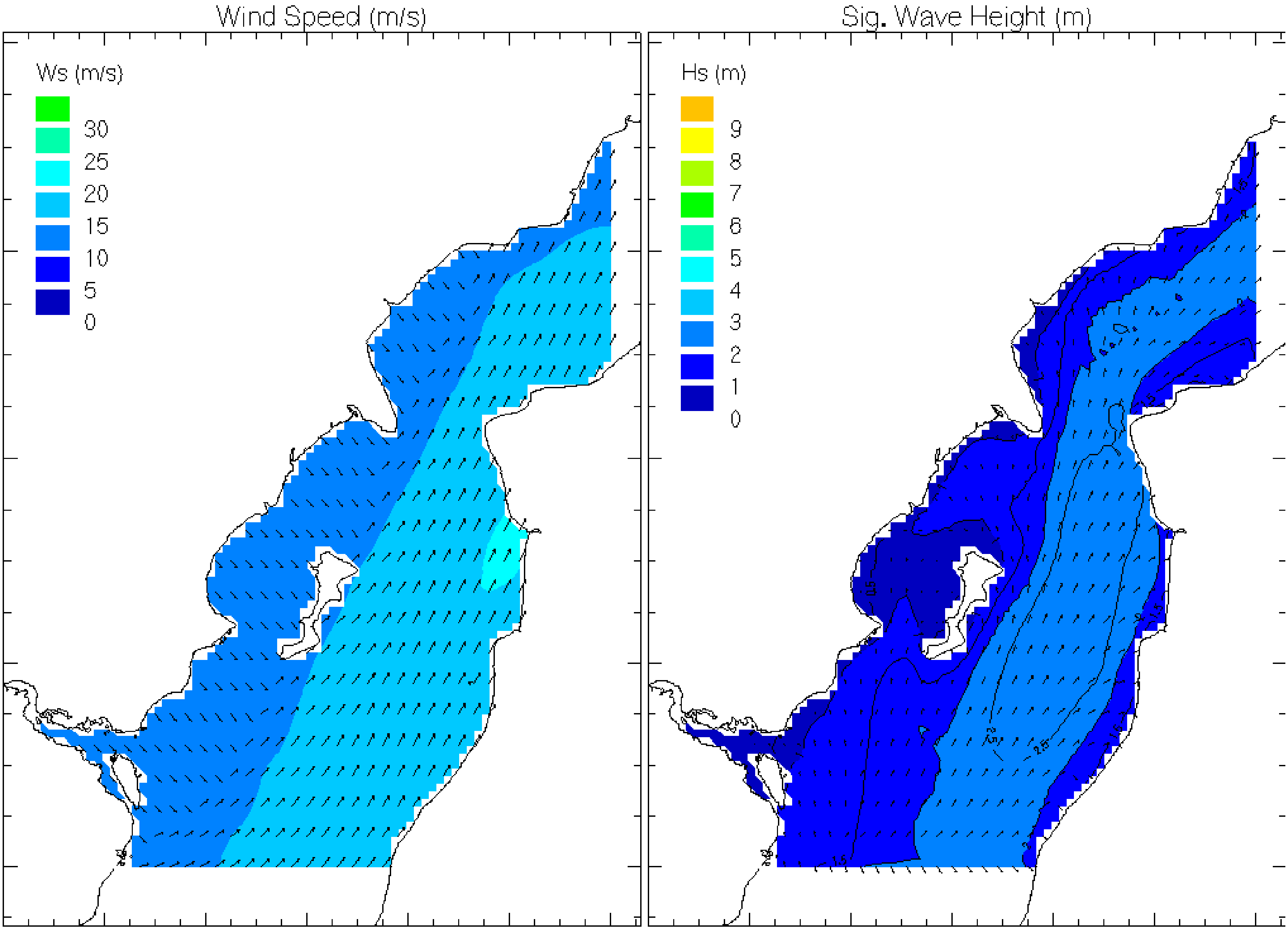
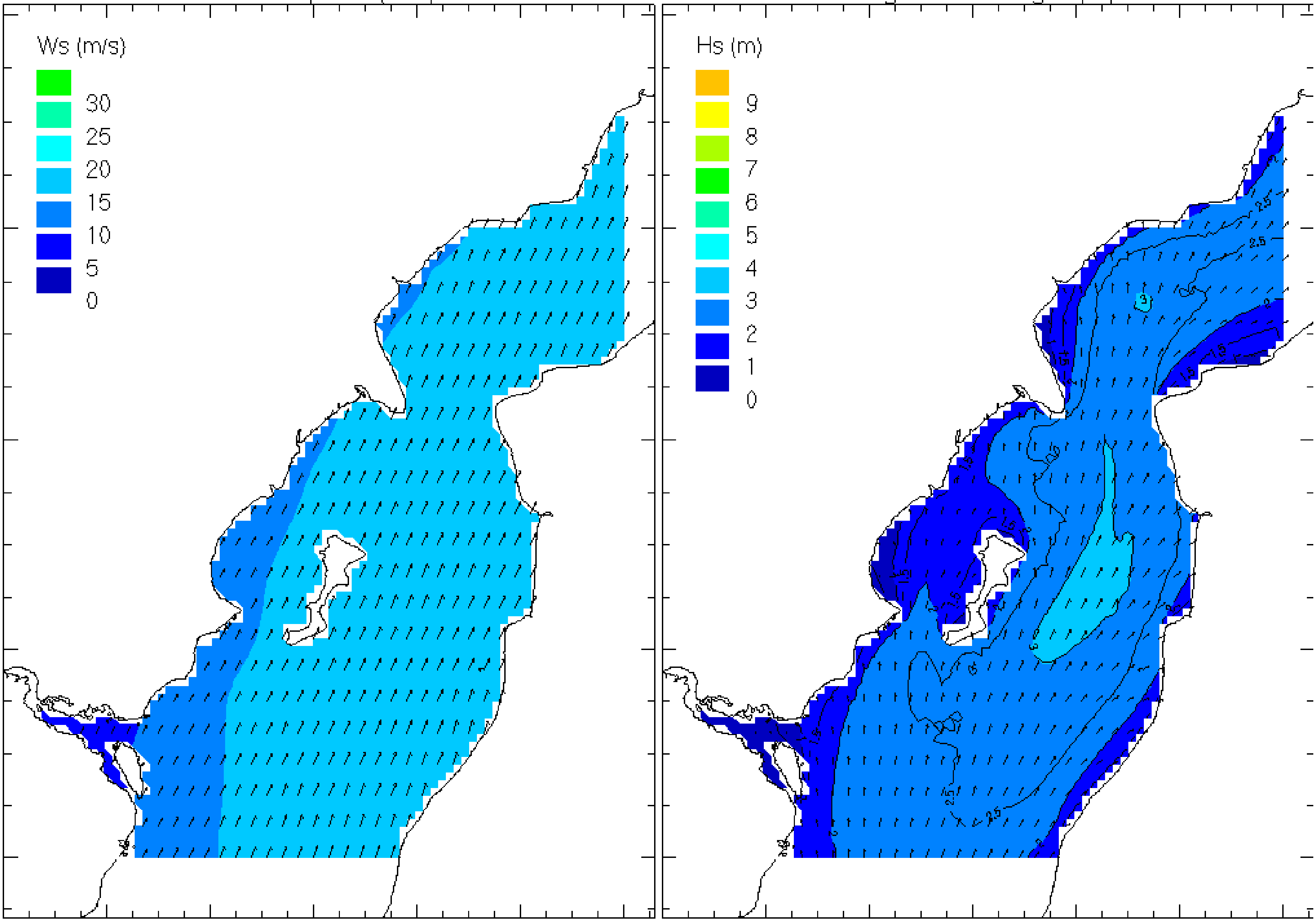
oceanweather inc.

Kenai Maximum Hindcast Winds and Waves during 20030105



Kenai MTR Maximum Hindcast Winds and Waves during 20030727

Wind Speed (m/s) | Sig. Wave Height (m)



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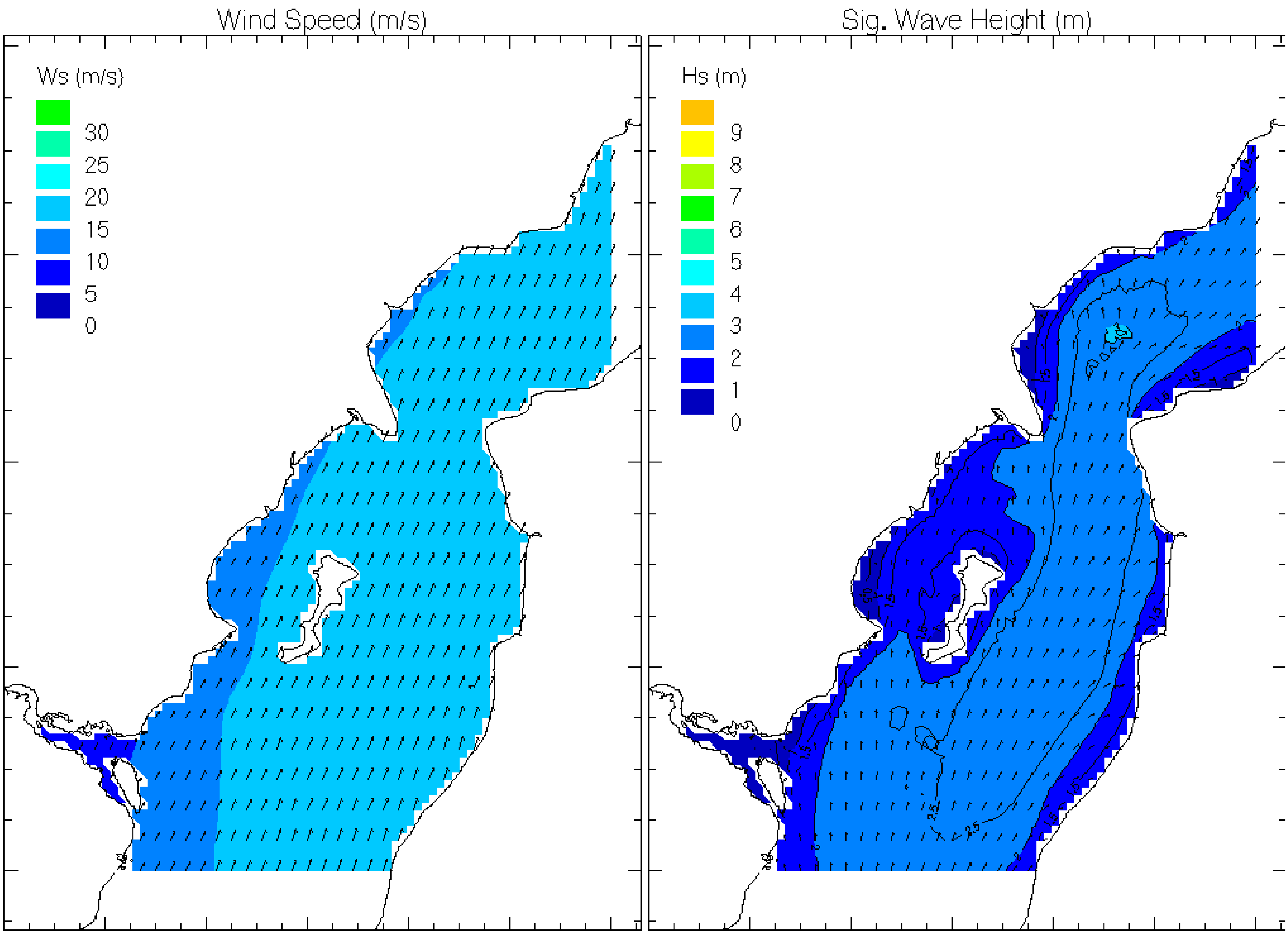
oceanweather inc.

Kenai Maximum Hindcast Winds and Waves during 20030727



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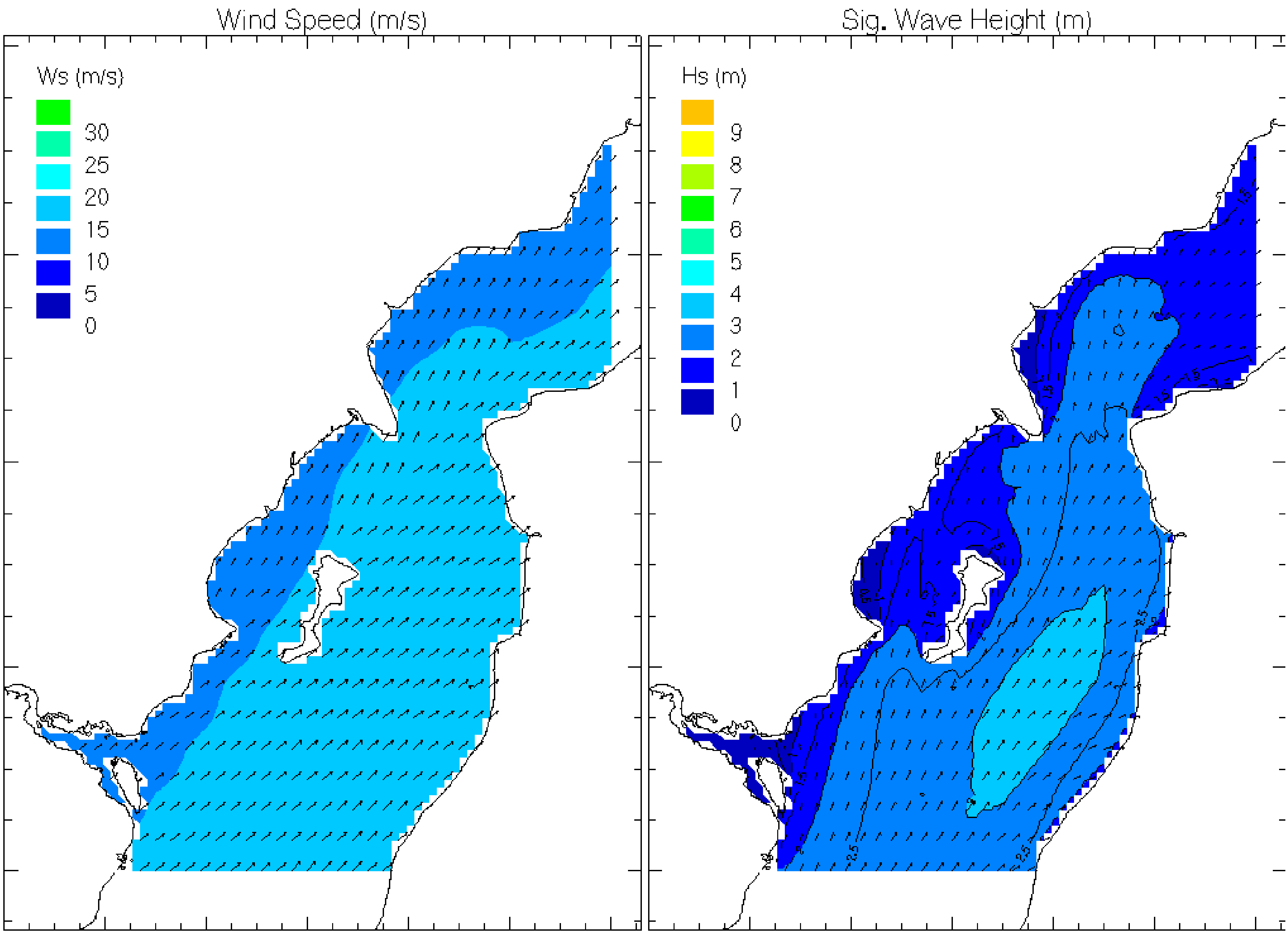
oceanweather inc.

Kenai MTR Maximum Hindcast Winds and Waves during 20050924



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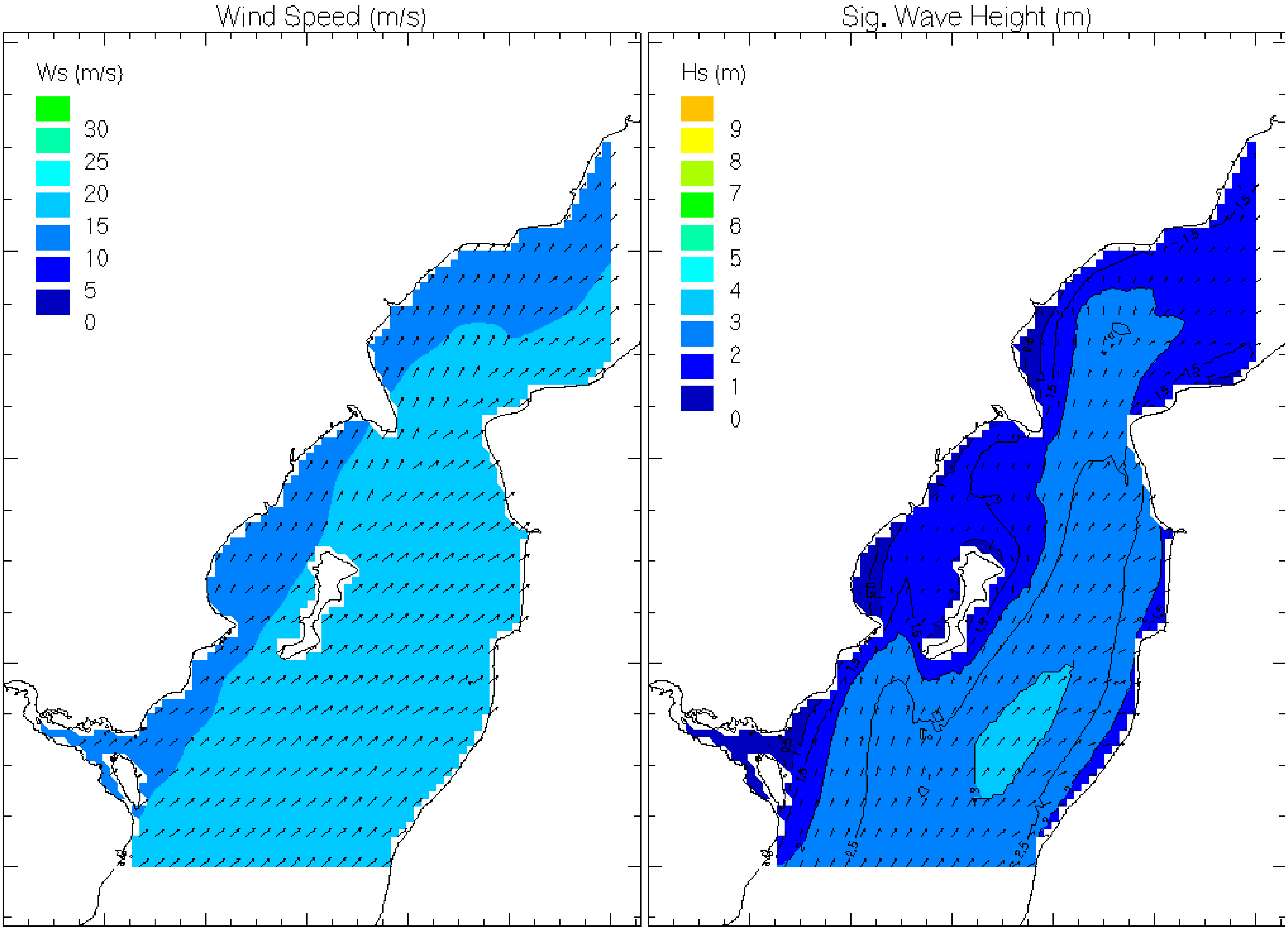
oceanweather inc.

Kenai Maximum Hindcast Winds and Waves during 20050924



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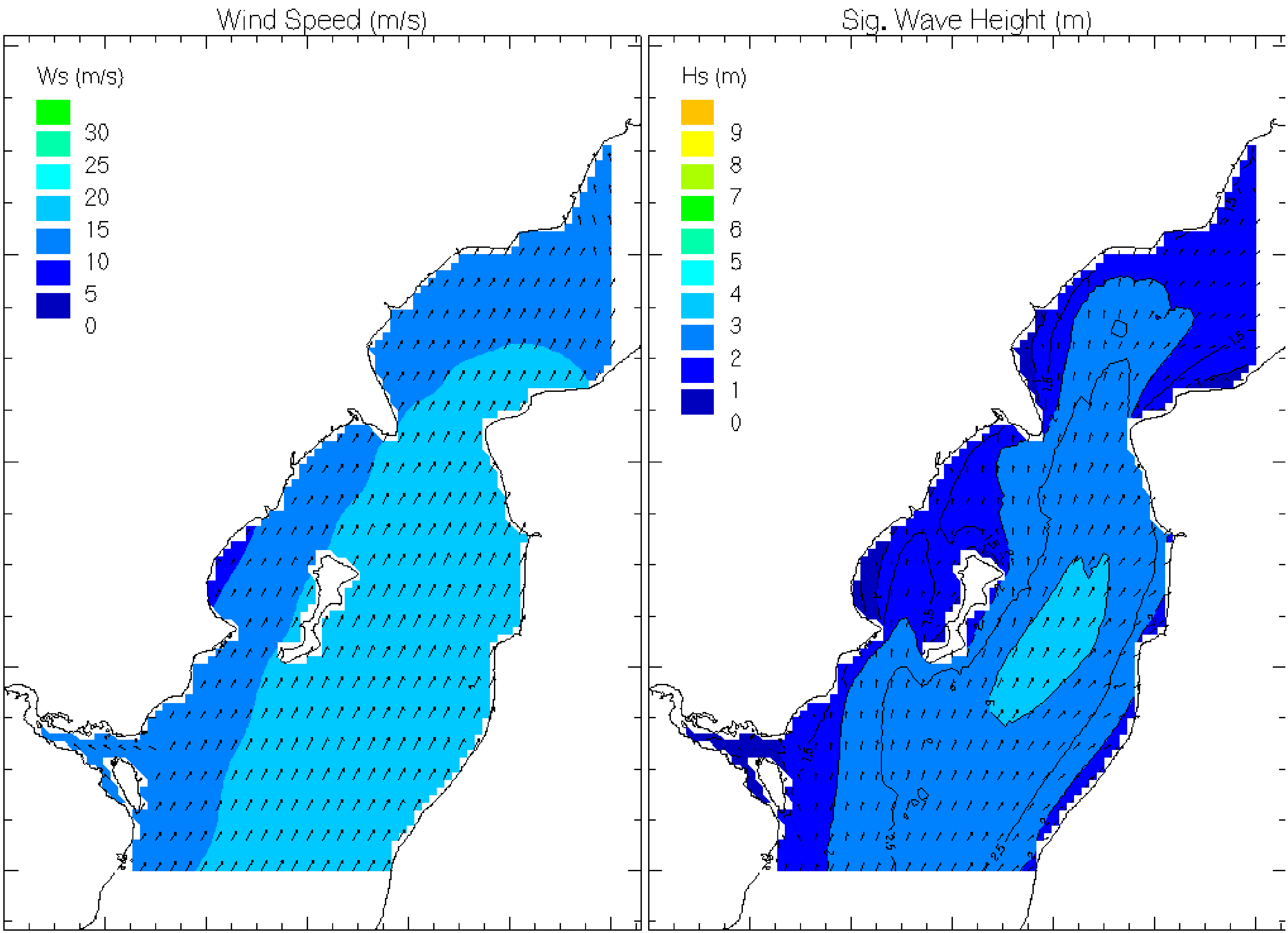
Kenai MTR Maximum Hindcast Winds and Waves during 20051019



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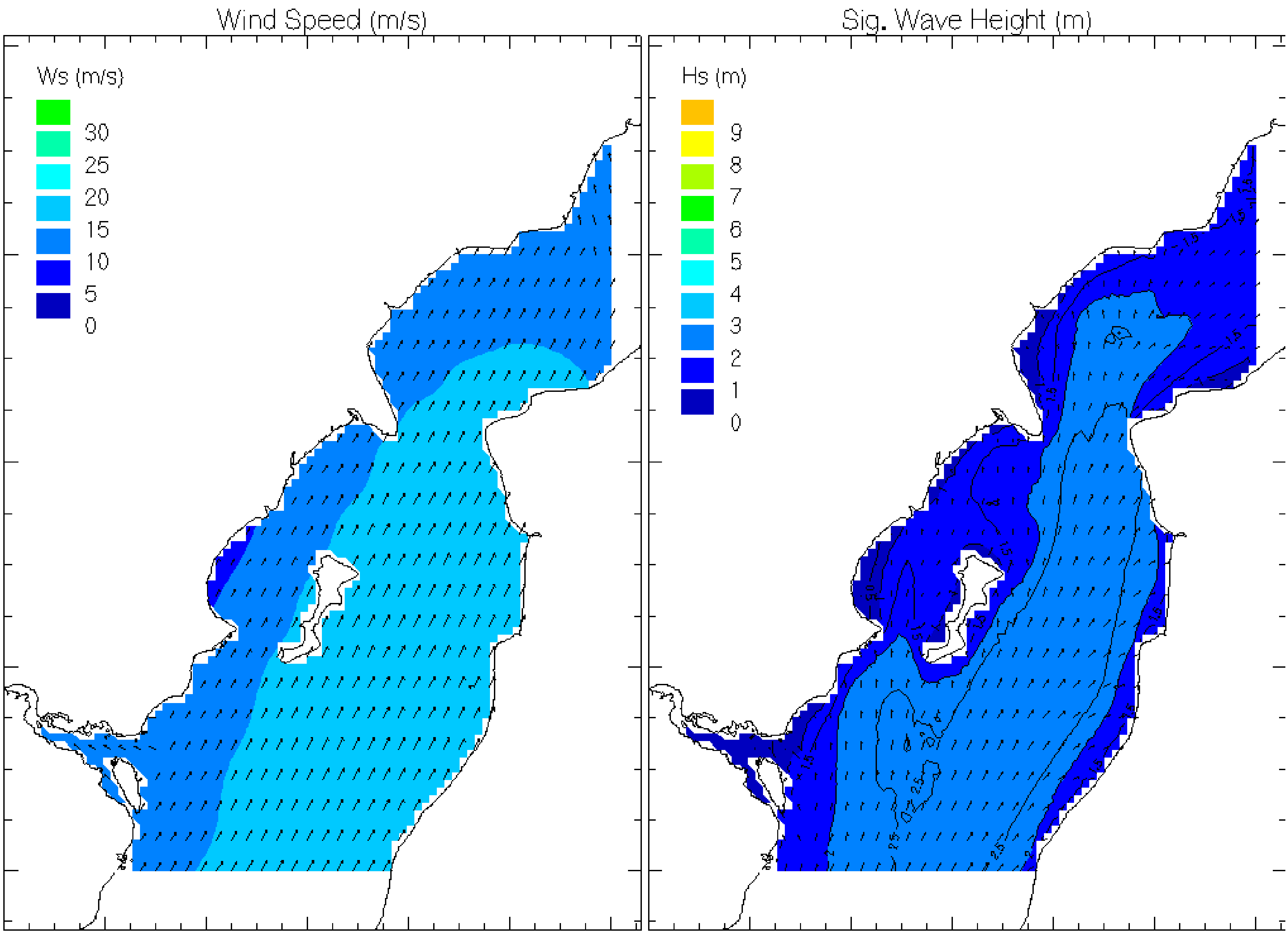
oceanweather inc.

Kenai Maximum Hindcast Winds and Waves during 20051019



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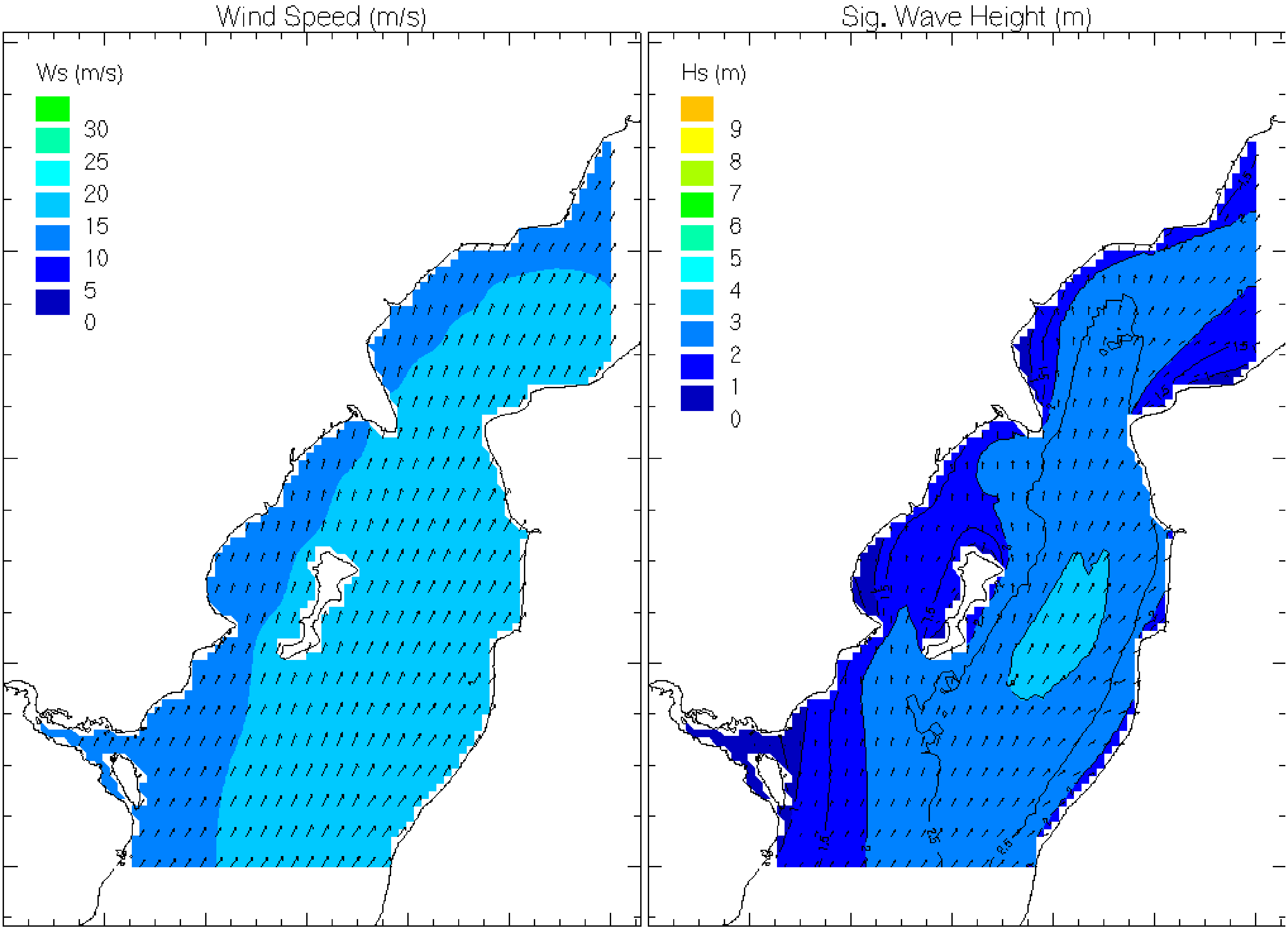
Kenai MTR Maximum Hindcast Winds and Waves during 20051124



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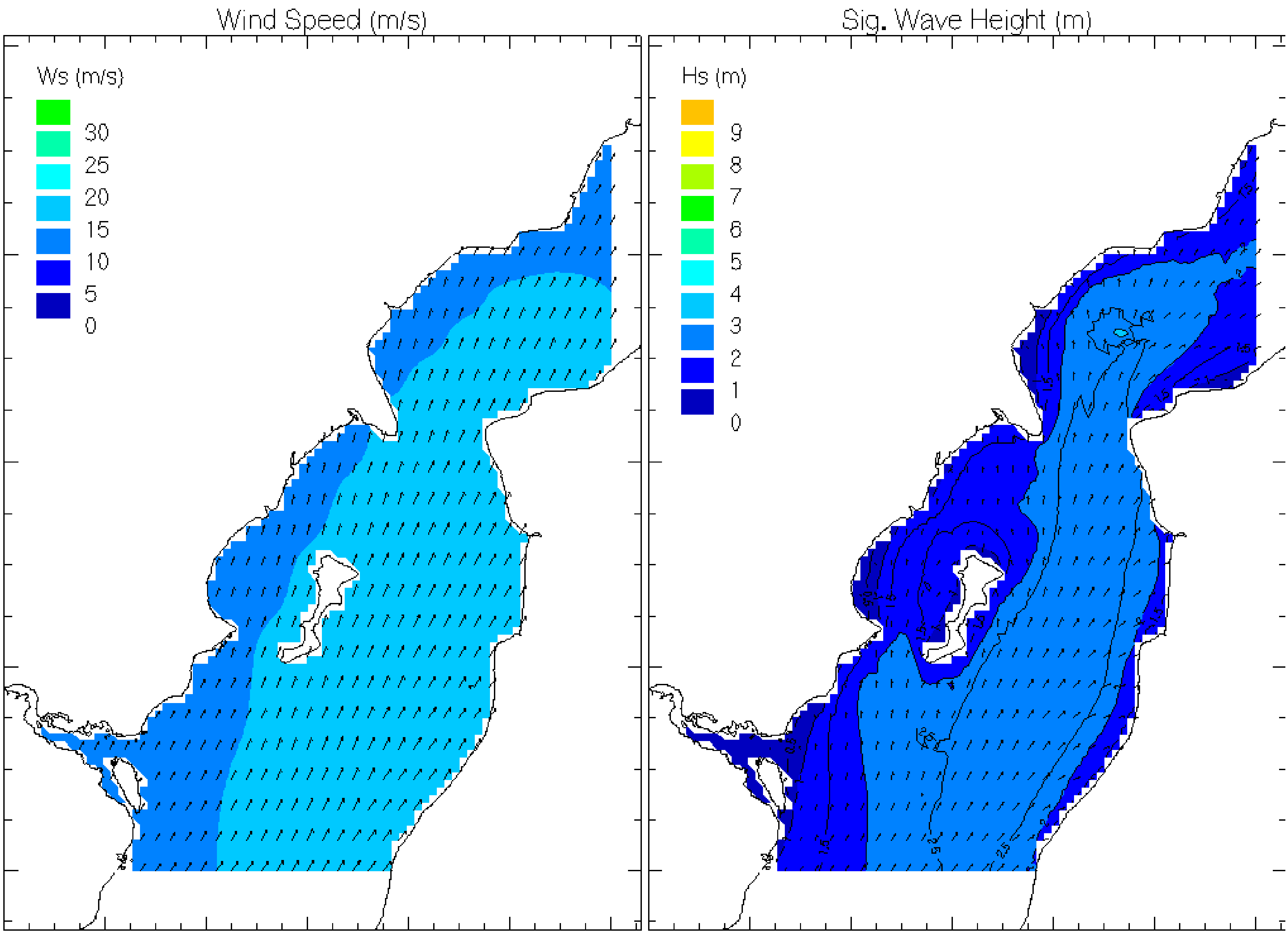
oceanweather inc.

Kenai Maximum Hindcast Winds and Waves during 20051124



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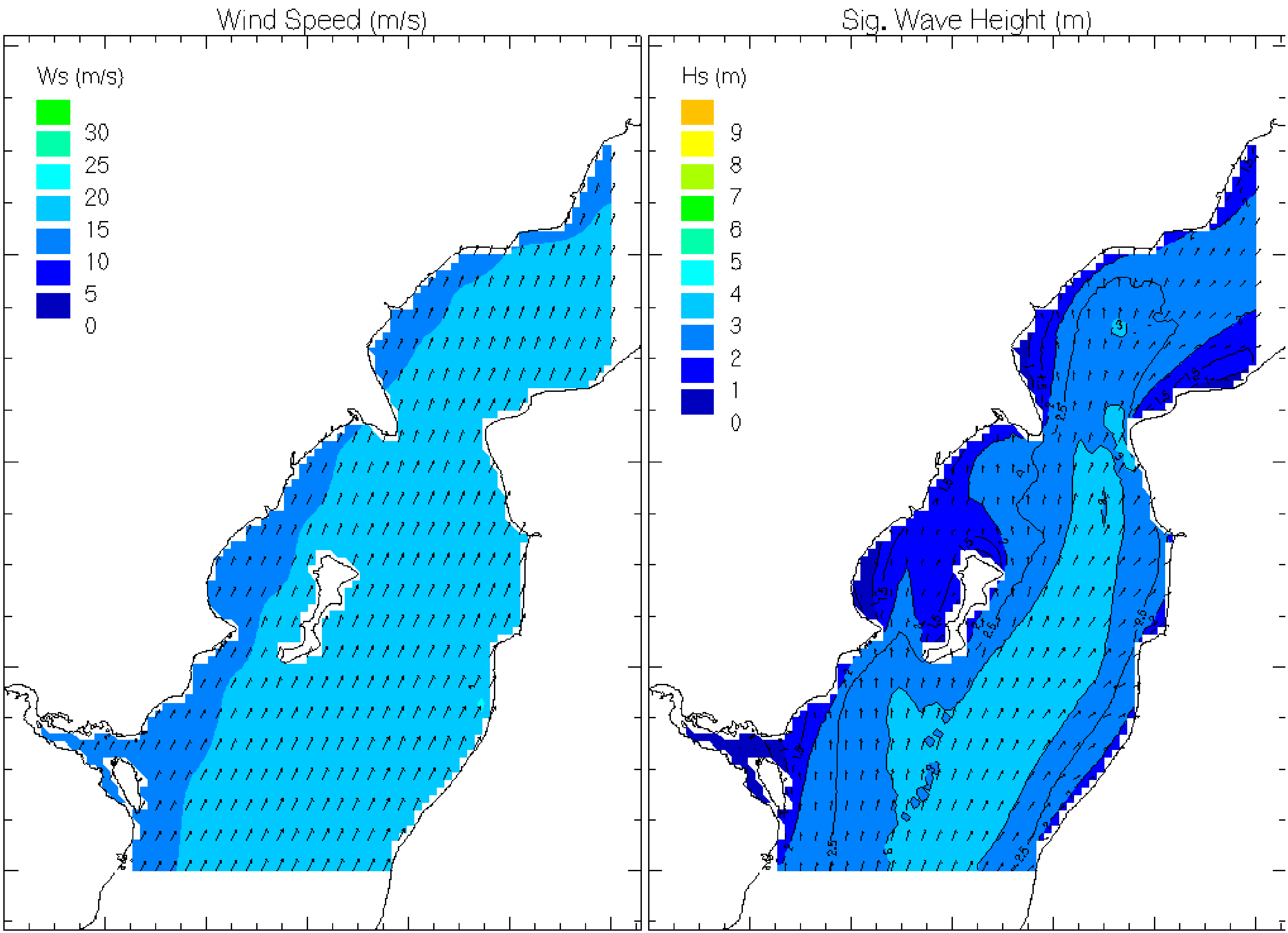
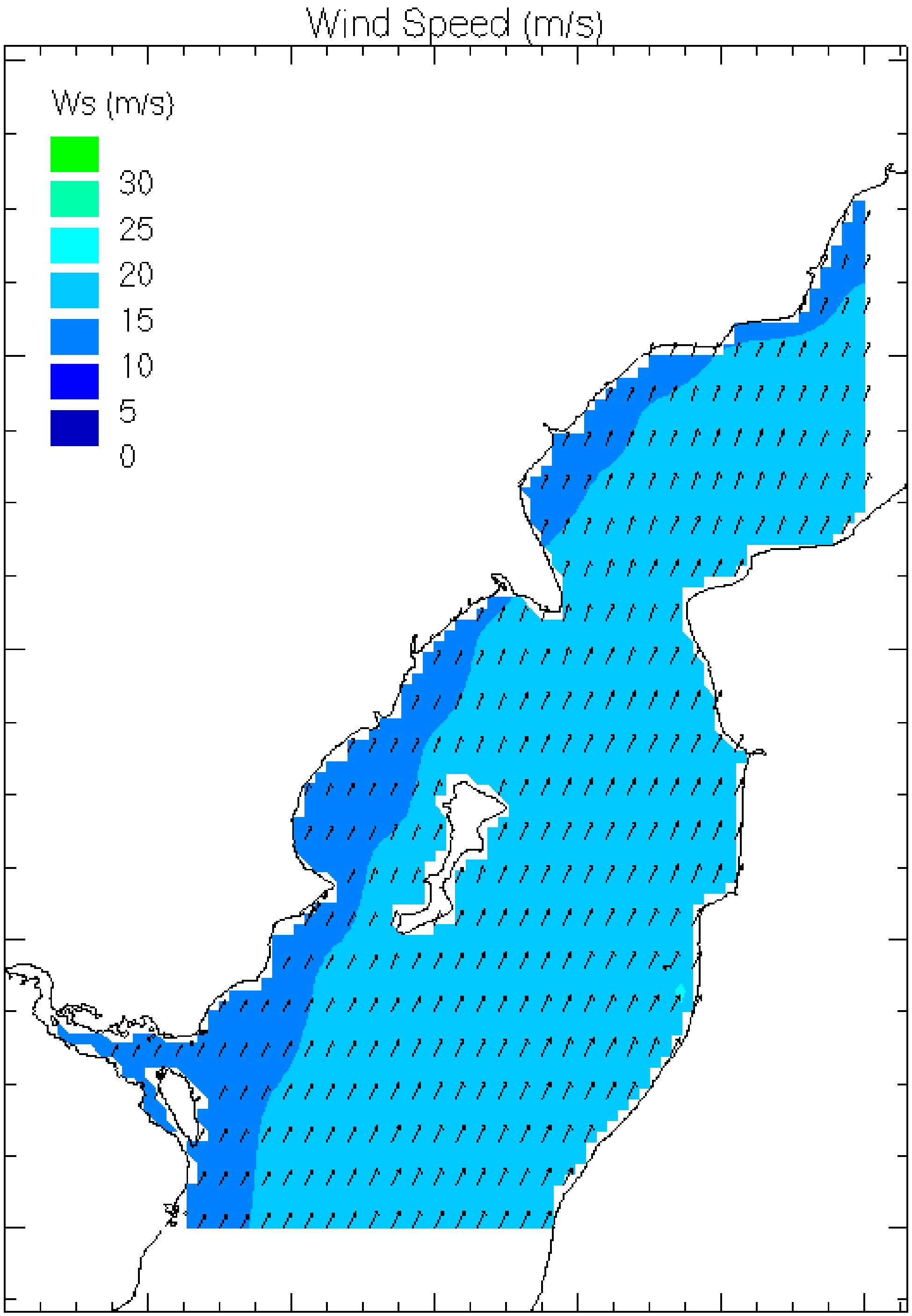
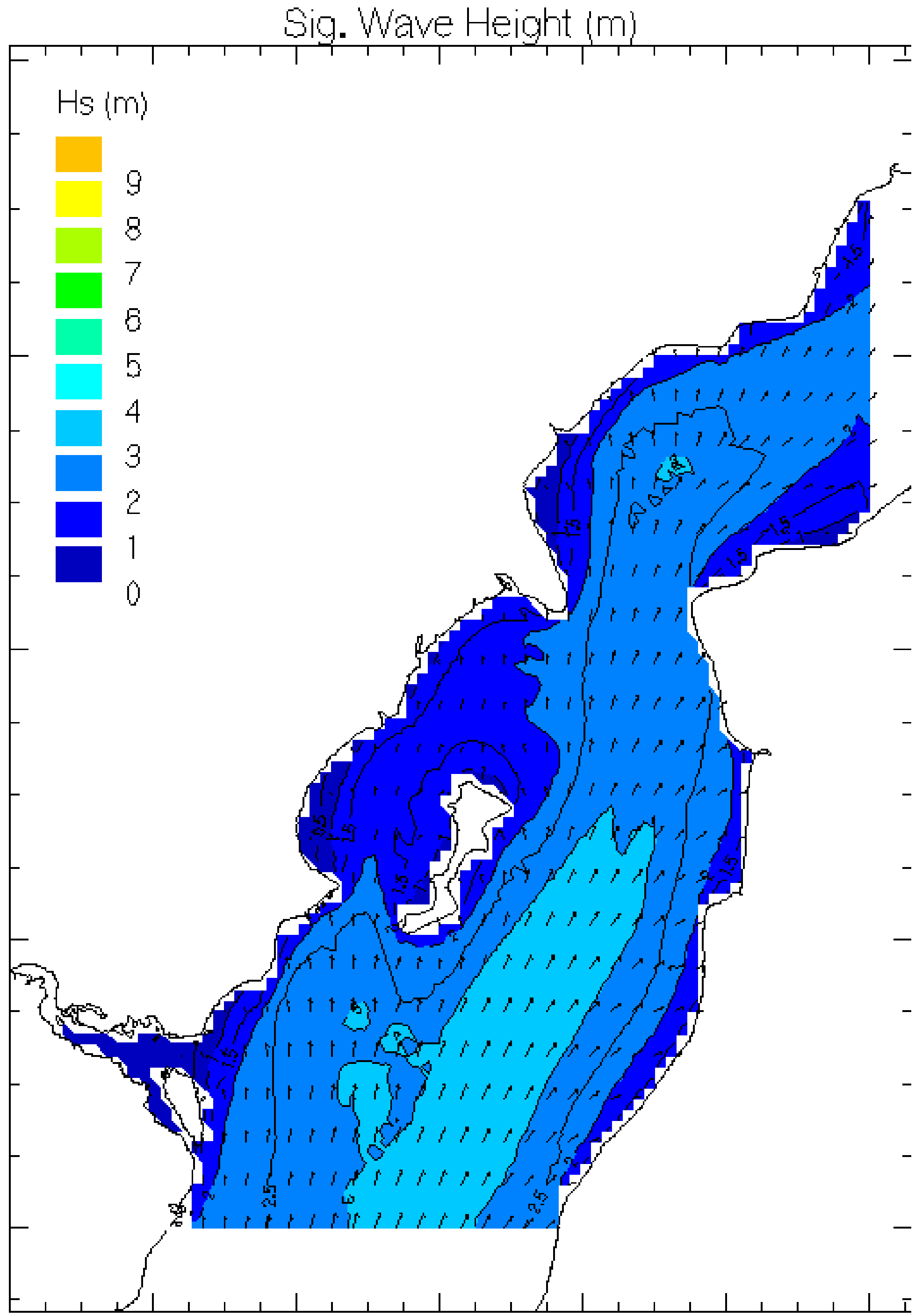
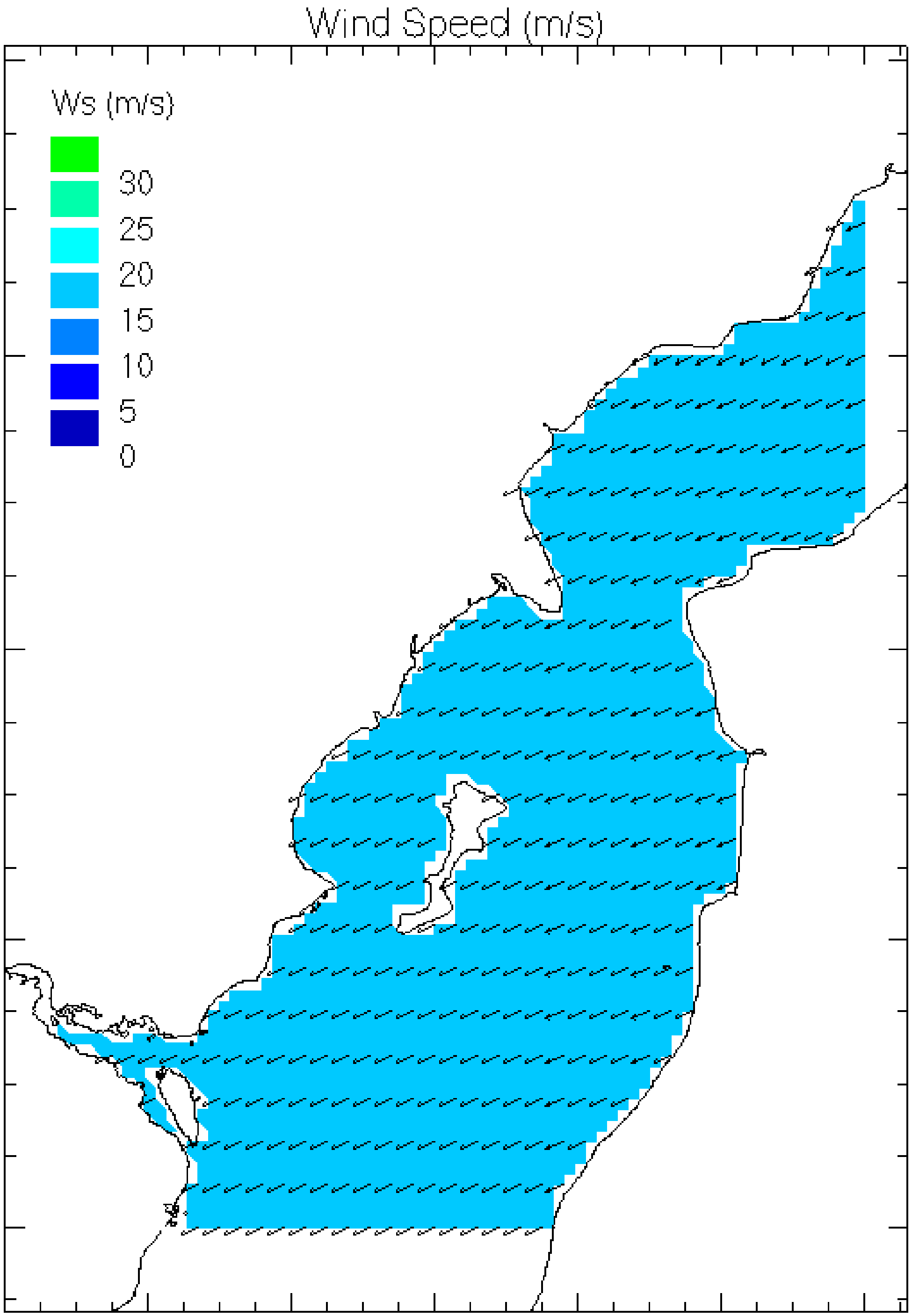


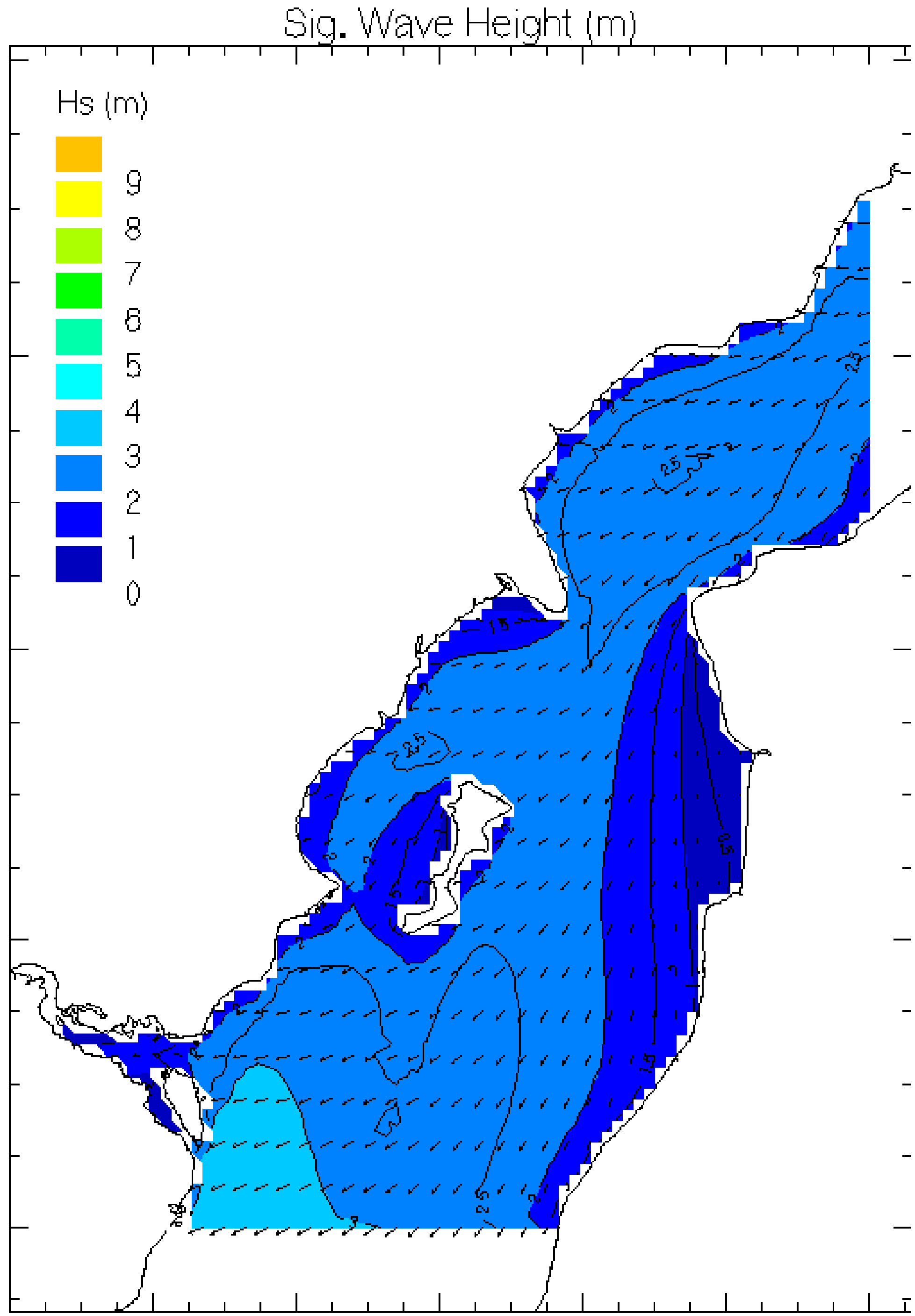
Kenai Maximum Hindcast Winds and Waves during 20060818

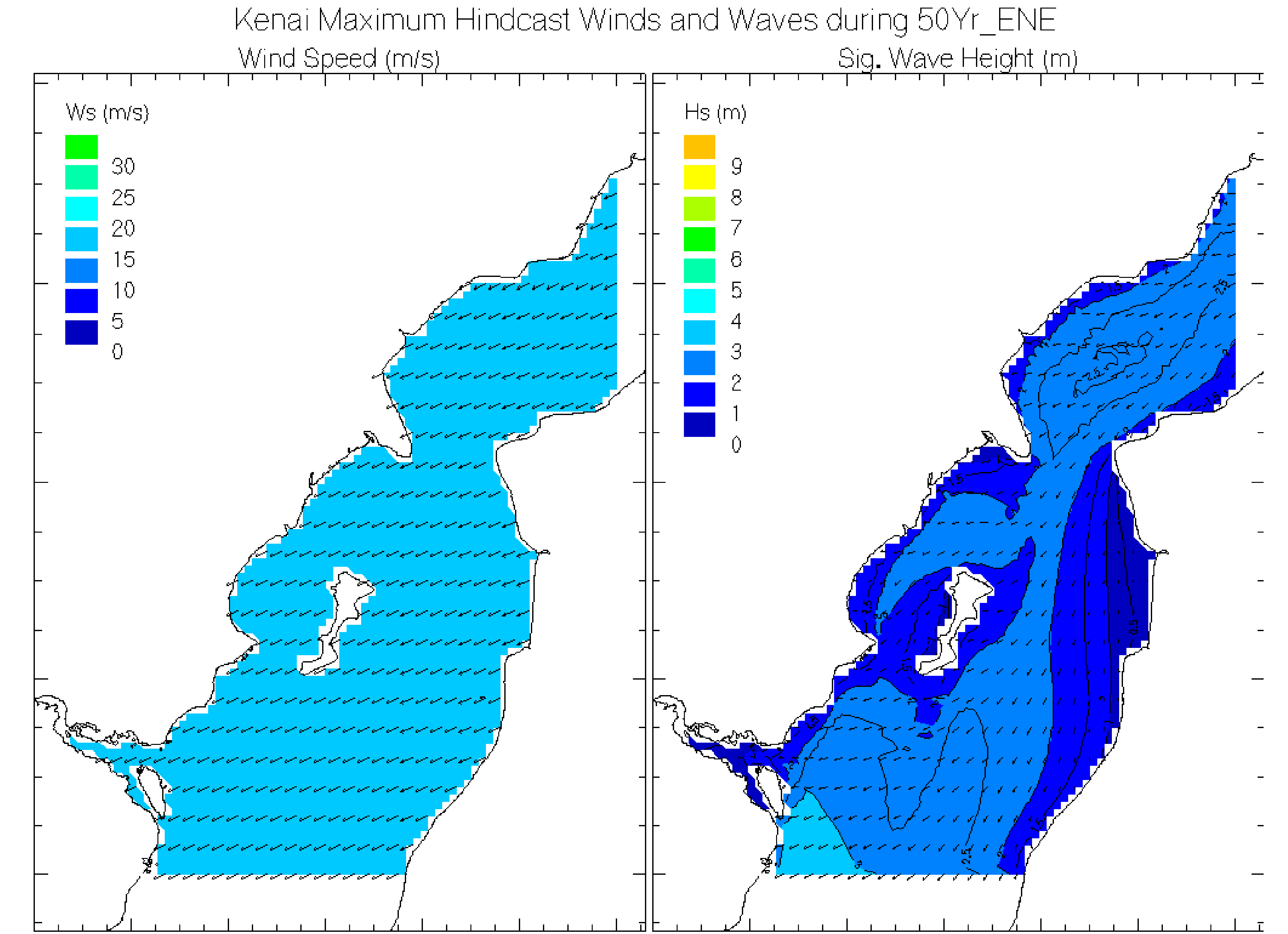




Kenai MTR Maximum Hindcast Winds and Waves during 50Yr_ENE







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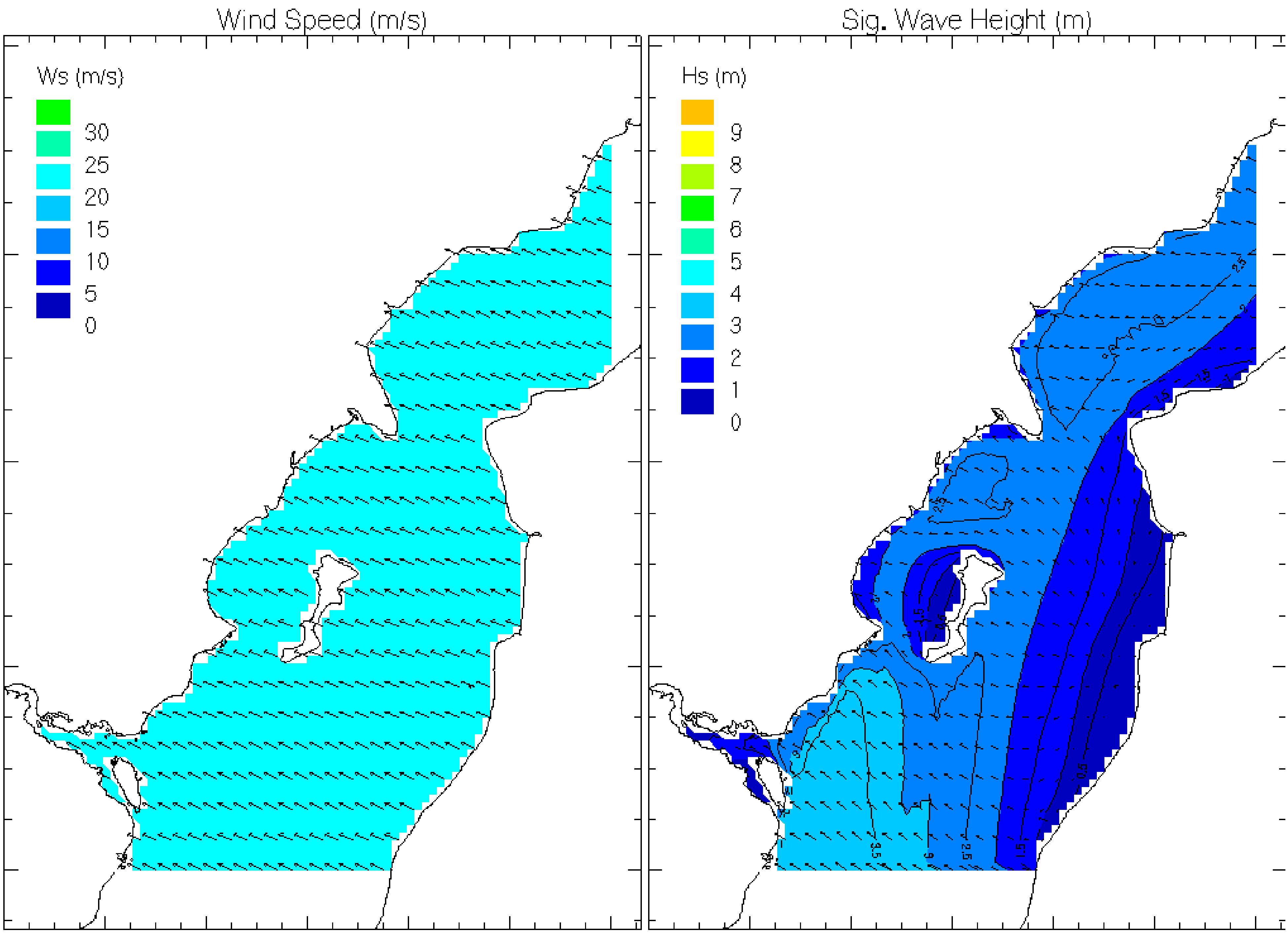
Kenai MTR Maximum Hindcast Winds and Waves during 50Yr_ESE



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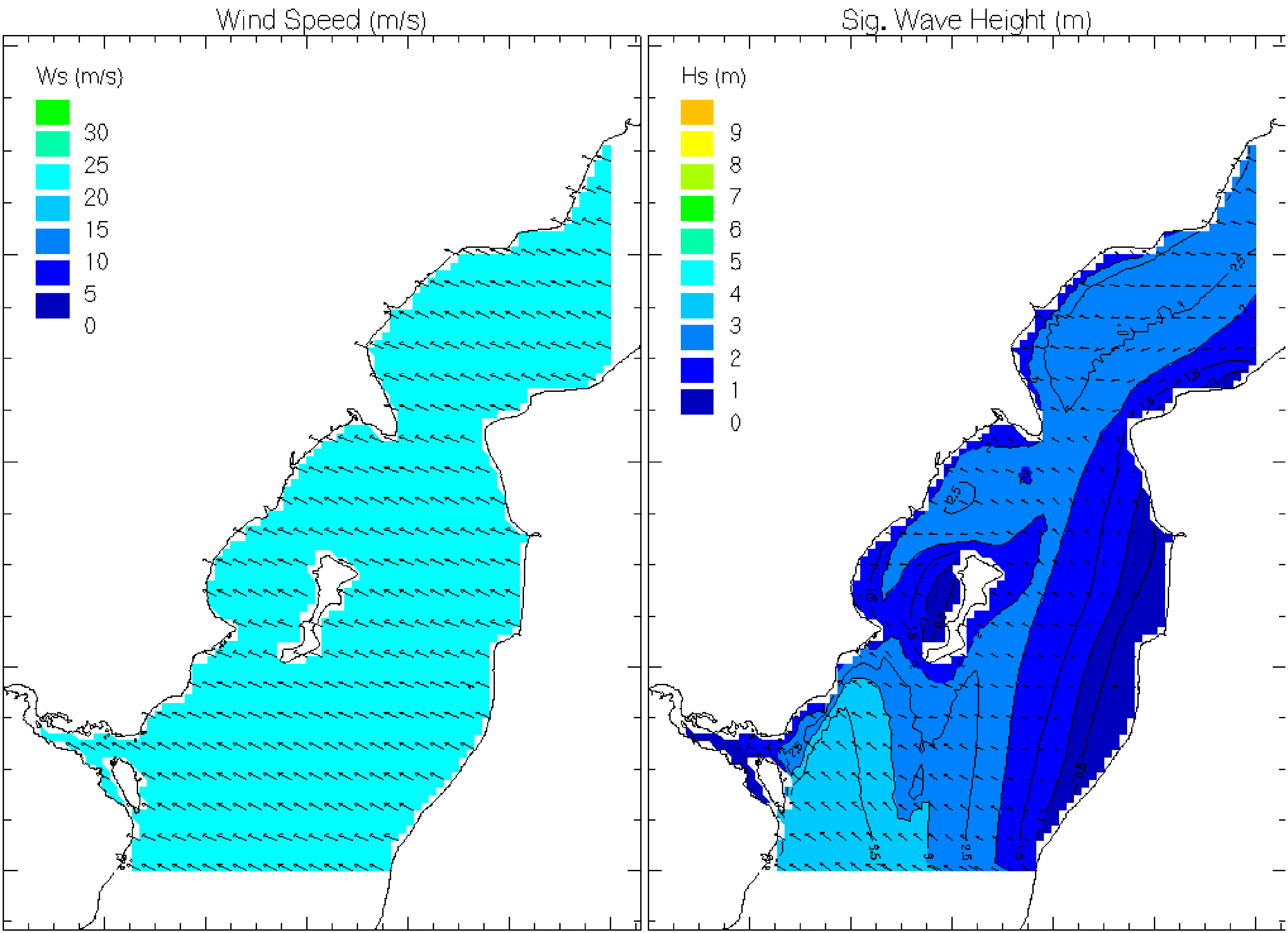
Kenai Maximum Hindcast Winds and Waves during 50Yr_ESE



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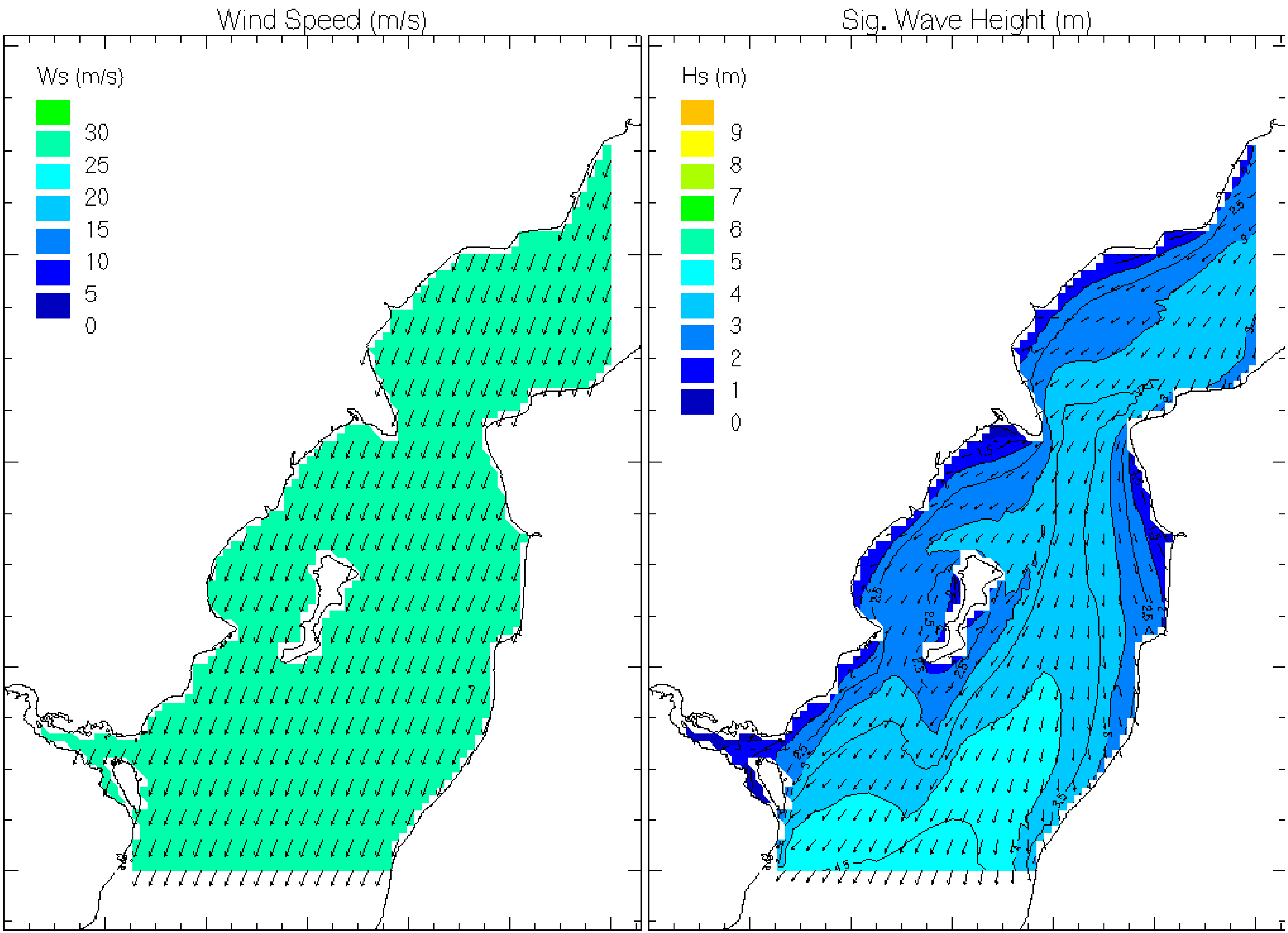
Kenai MTR Maximum Hindcast Winds and Waves during 50Yr_NNE



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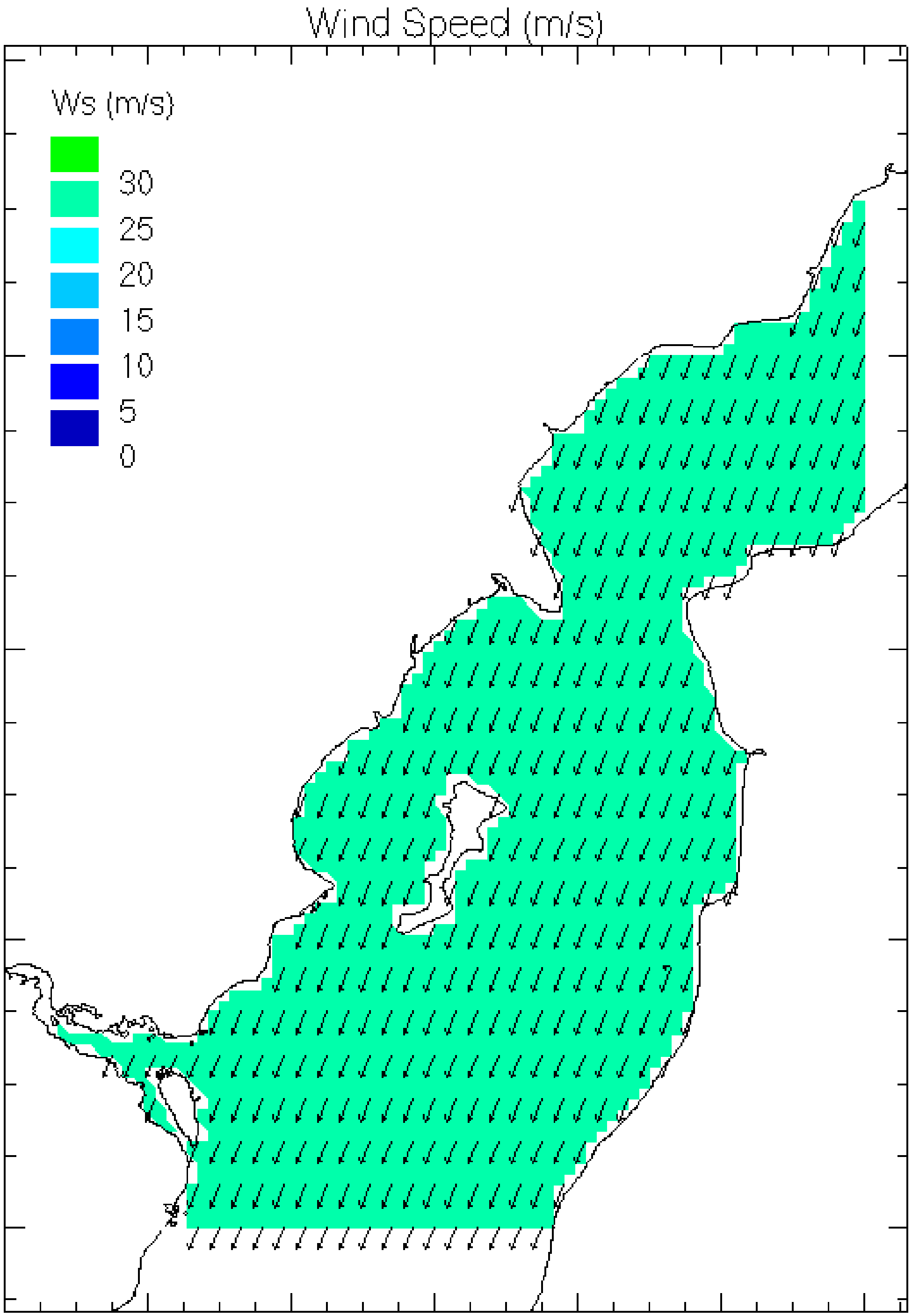
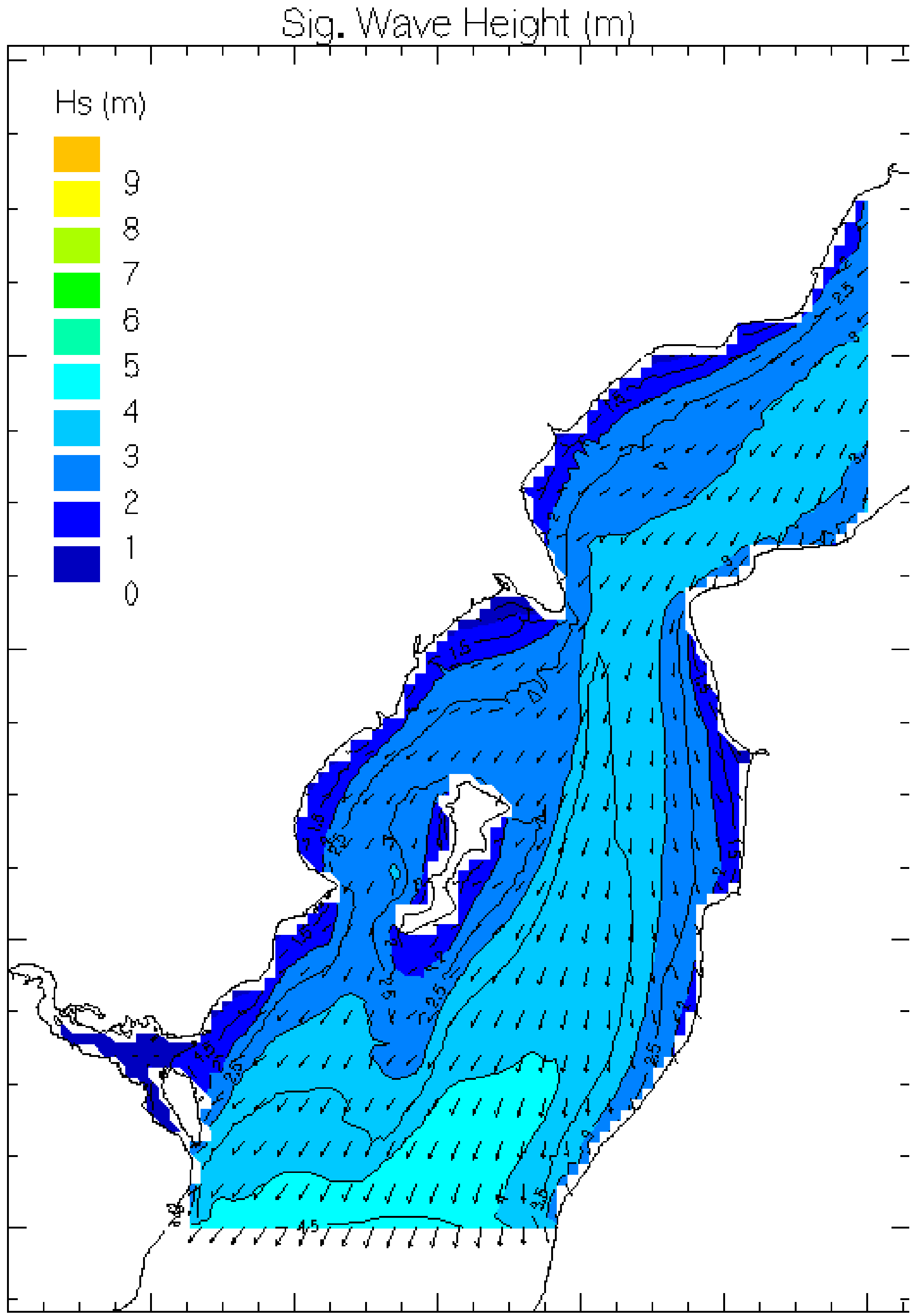
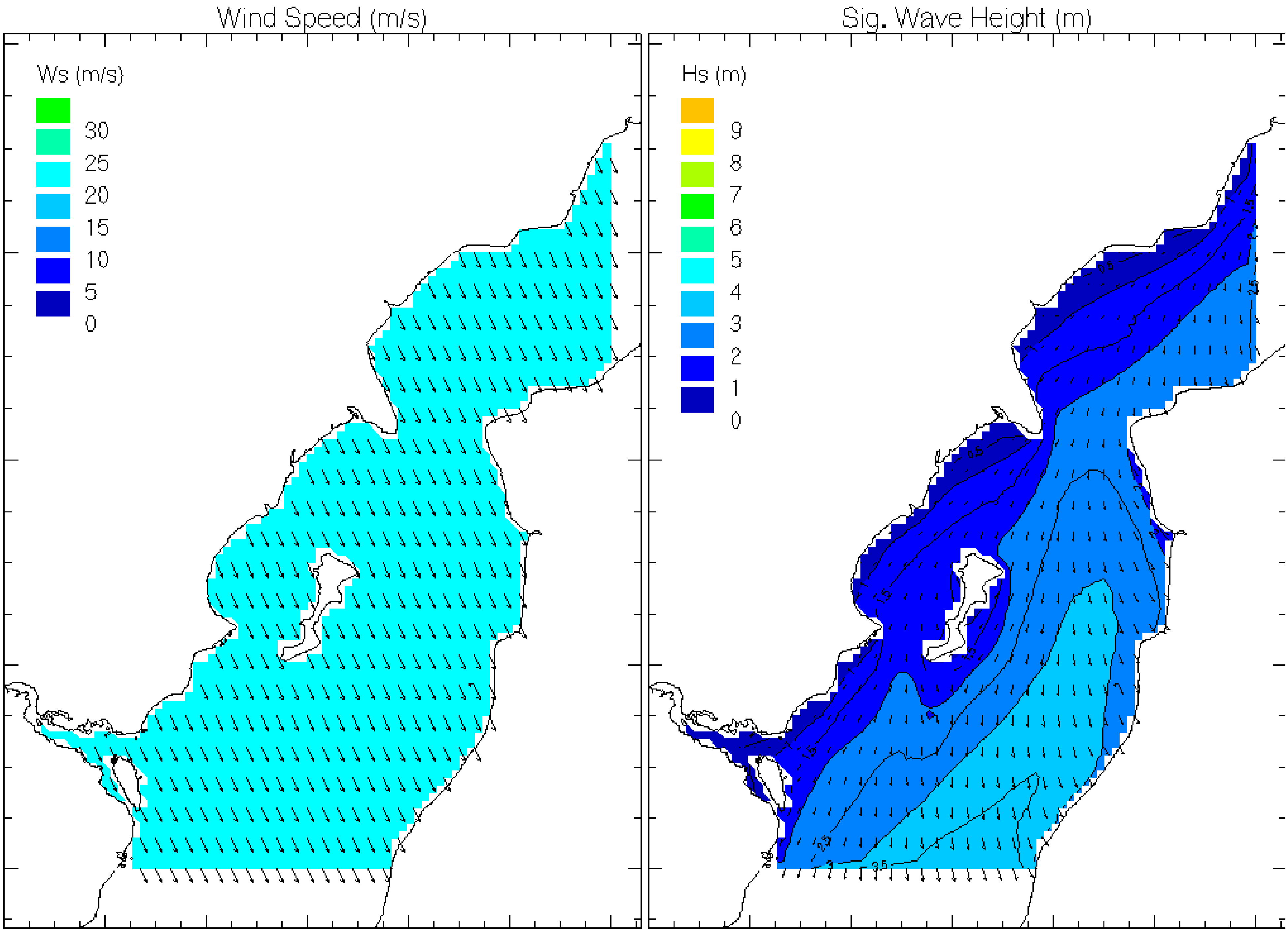
Kenai Maximum Hindcast Winds and Waves during 50Yr_NNE





Kenai MTR Maximum Hindcast Winds and Waves during 50Yr_NNW



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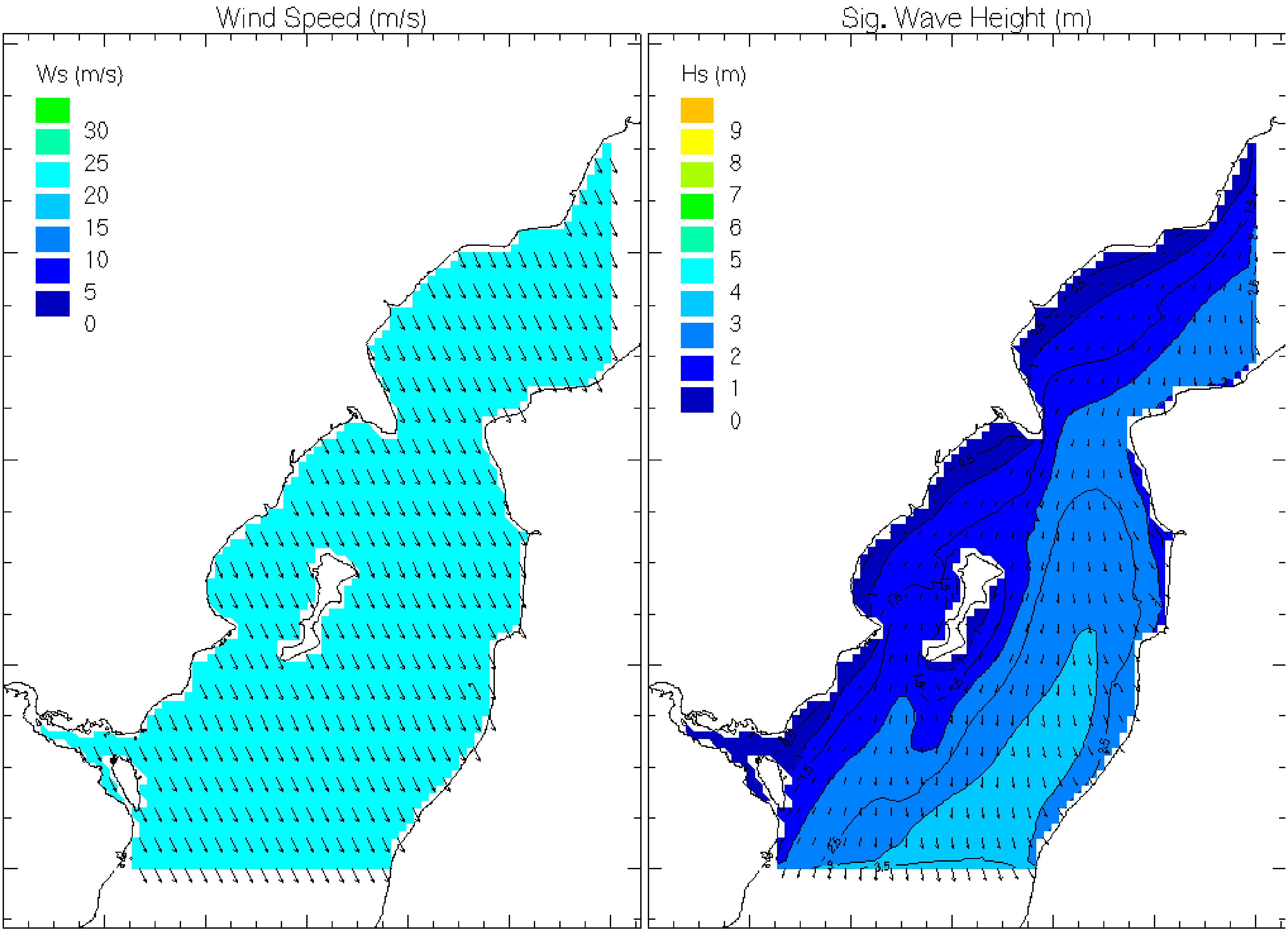
Kenai Maximum Hindcast Winds and Waves during 50Yr_NNW



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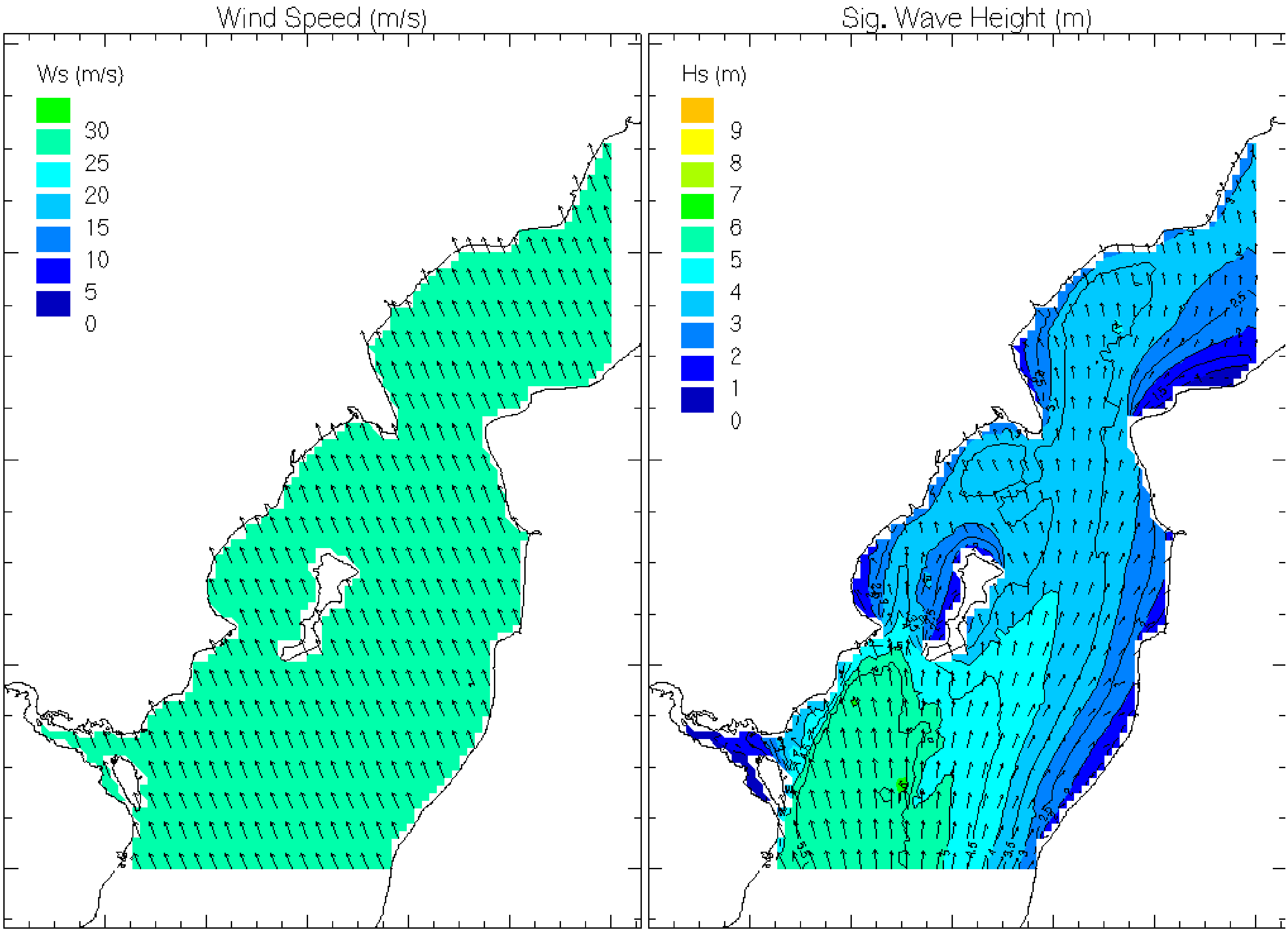
Kenai MTR Maximum Hindcast Winds and Waves during 50Yr_SSE



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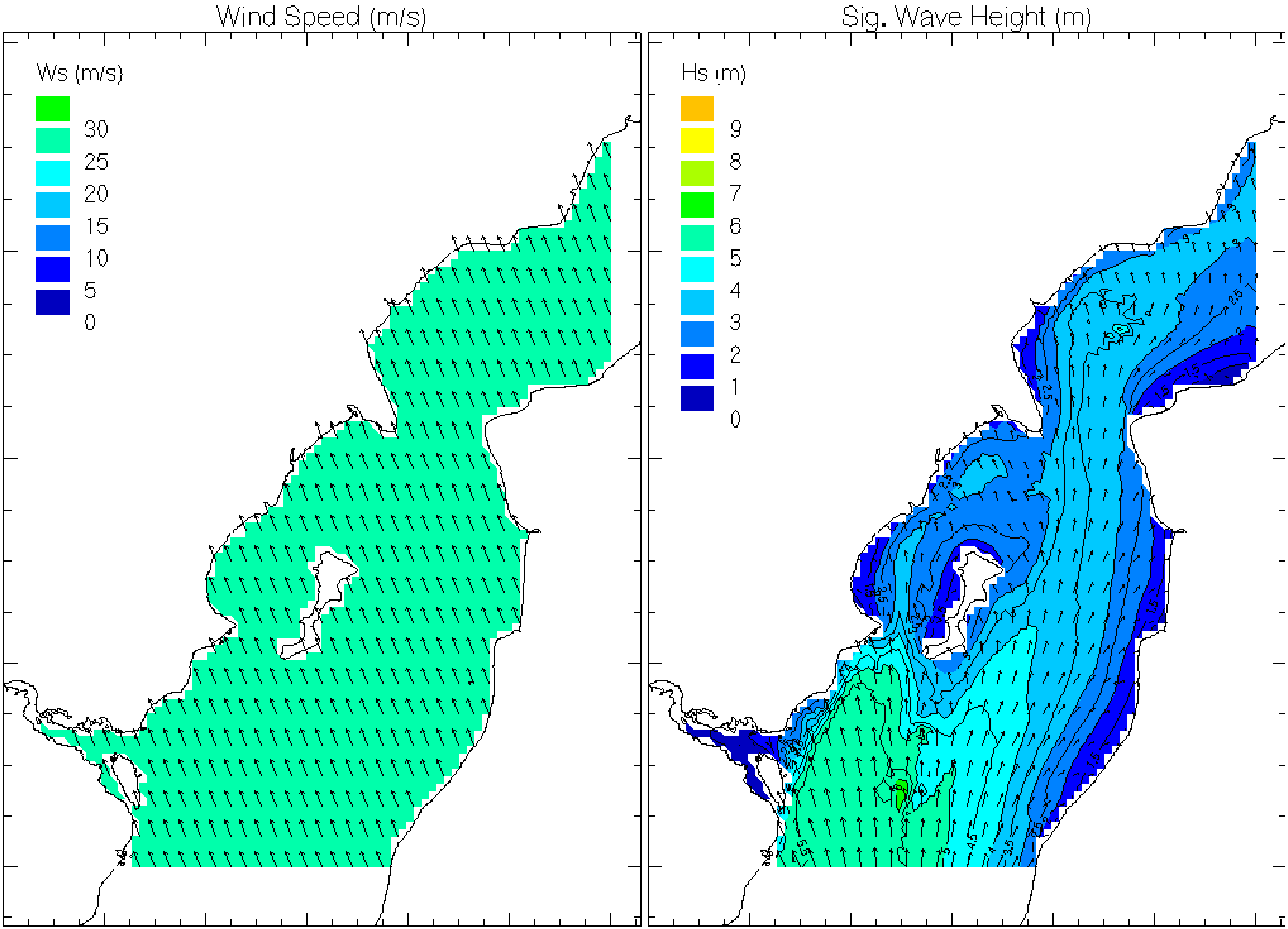
Kenai Maximum Hindcast Winds and Waves during 50Yr_SSE



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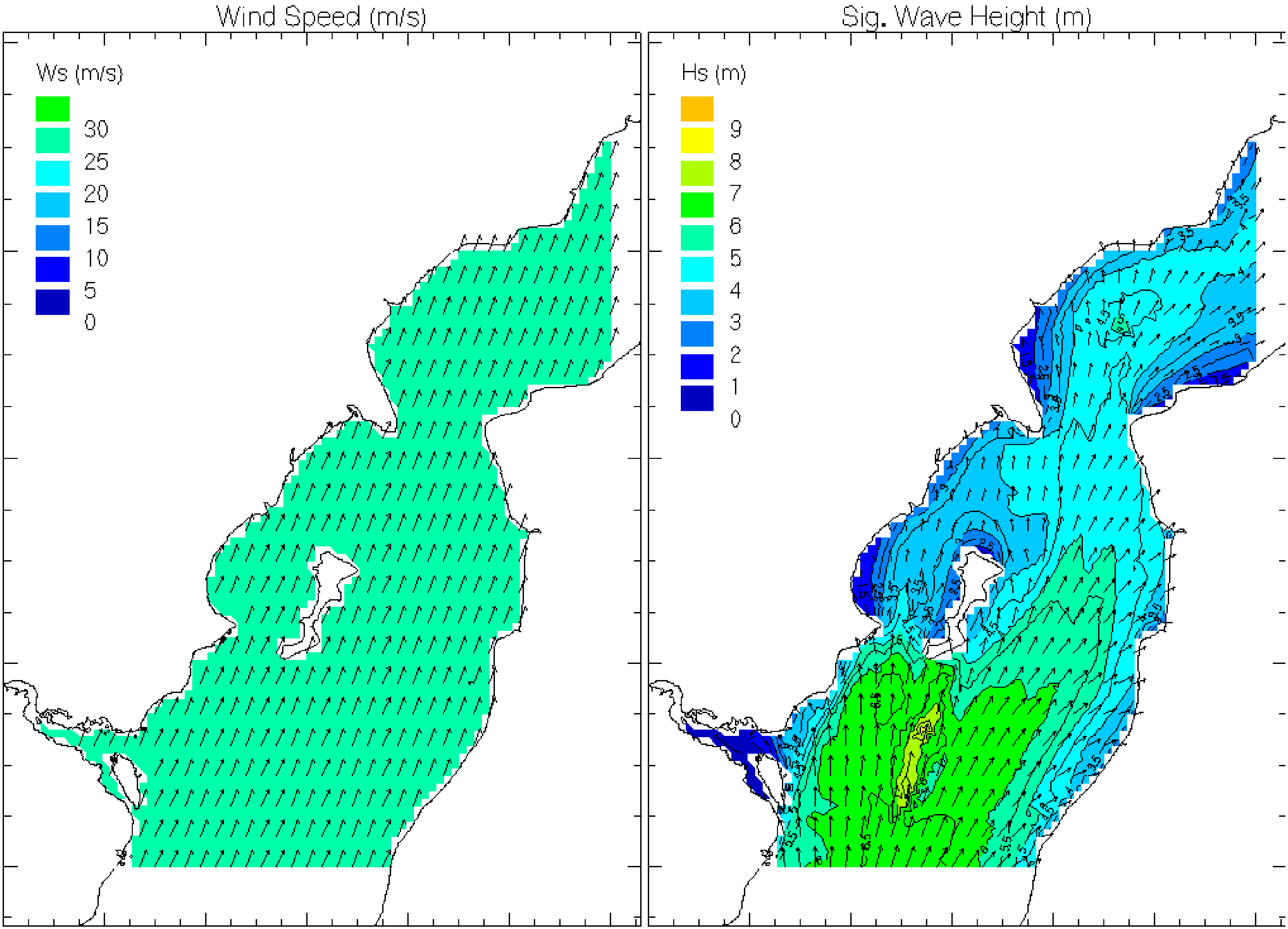
Kenai MTR Maximum Hindcast Winds and Waves during 50Yr_SSW



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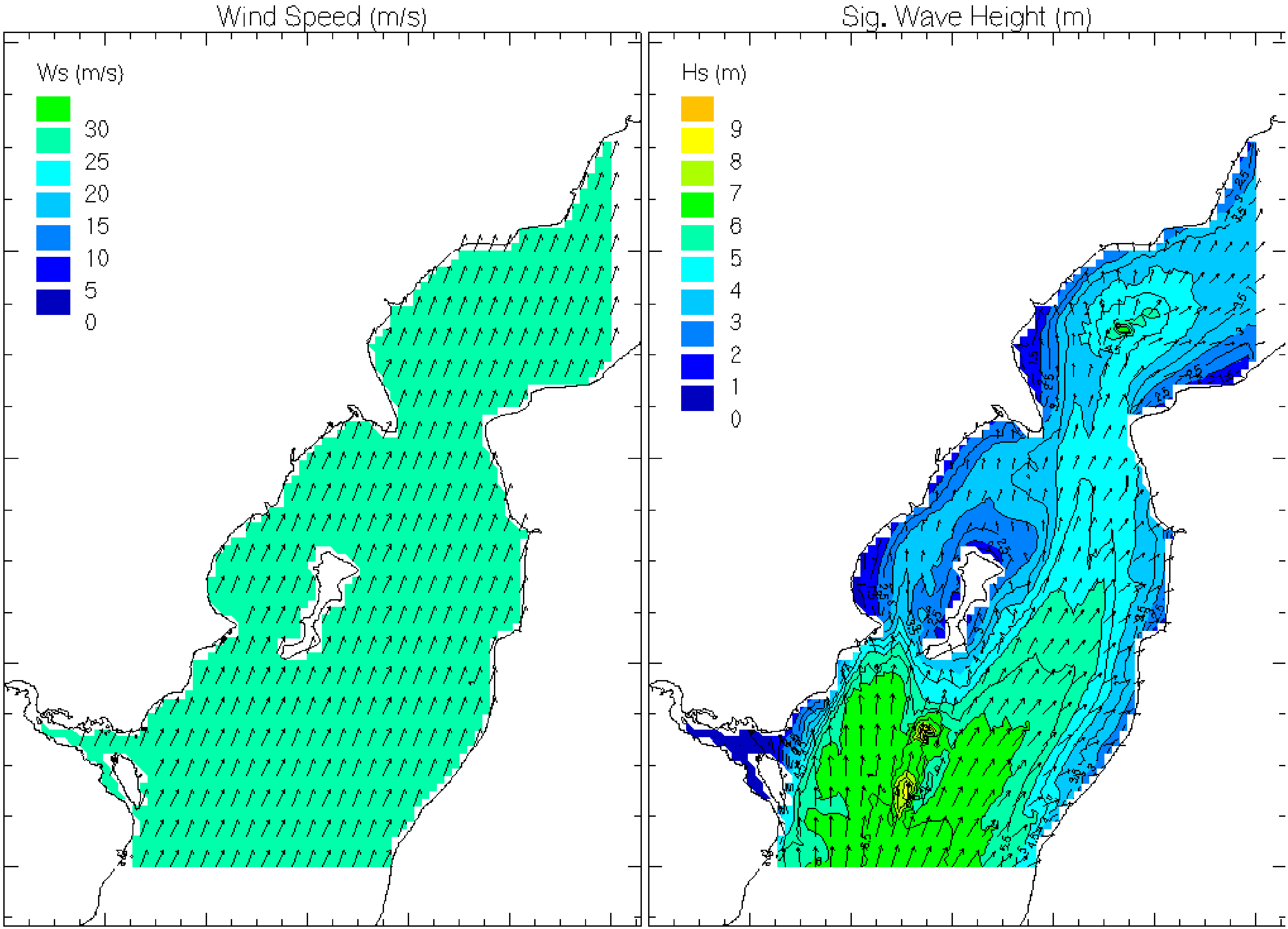
Kenai Maximum Hindcast Winds and Waves during 50Yr_SSW



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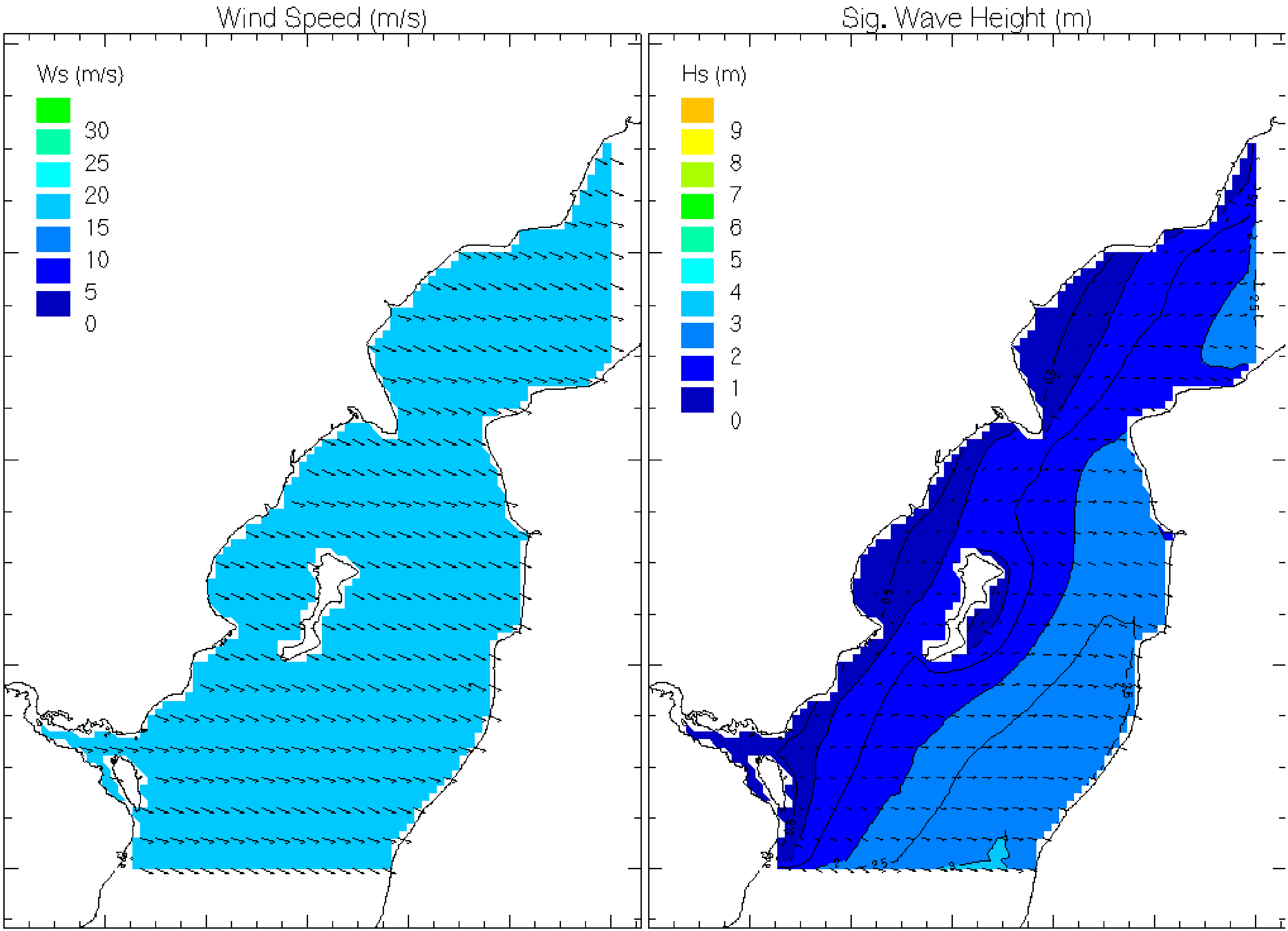
Kenai MTR Maximum Hindcast Winds and Waves during 50Yr_WNW



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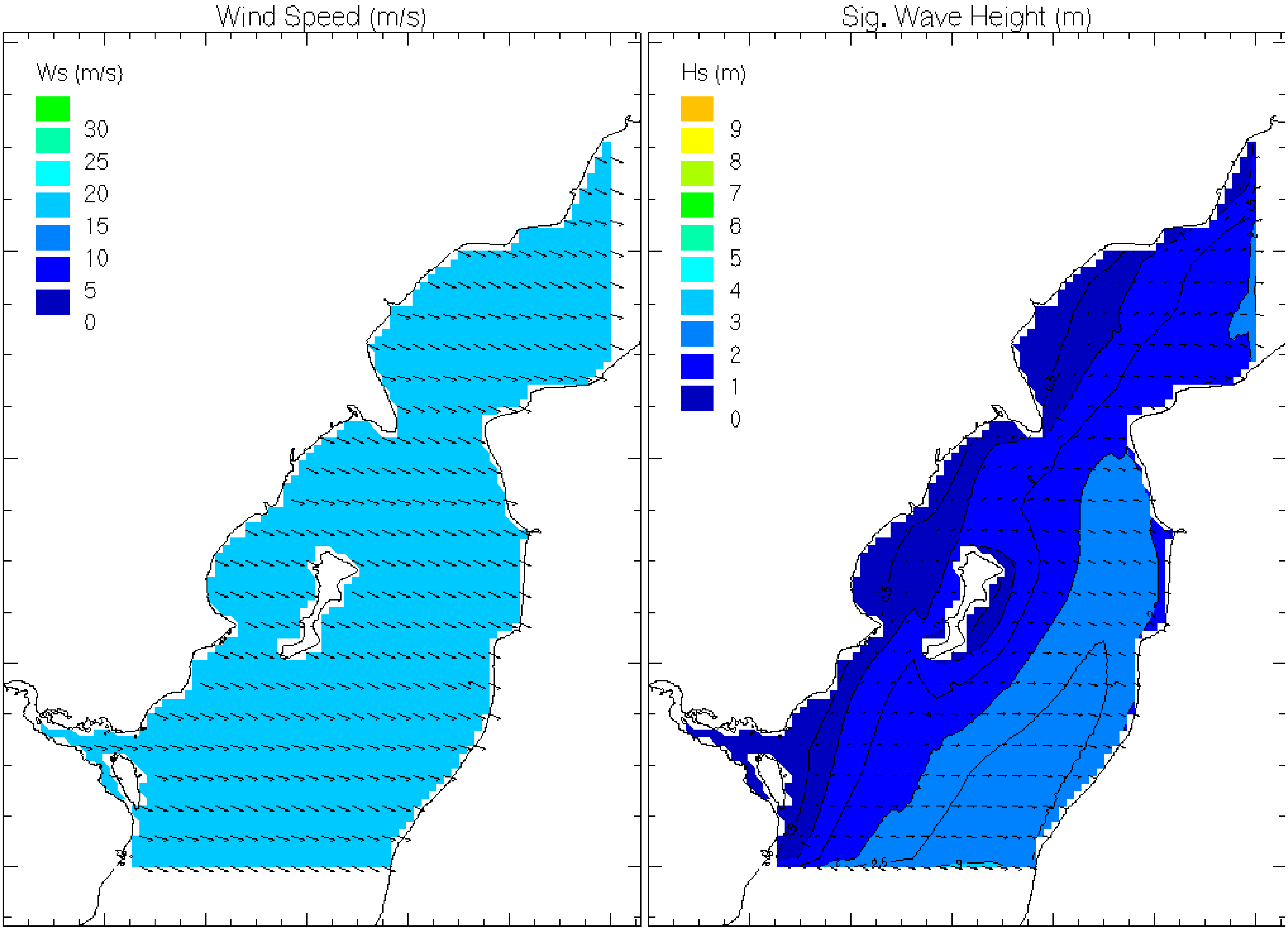
Kenai Maximum Hindcast Winds and Waves during 50Yr_WNW



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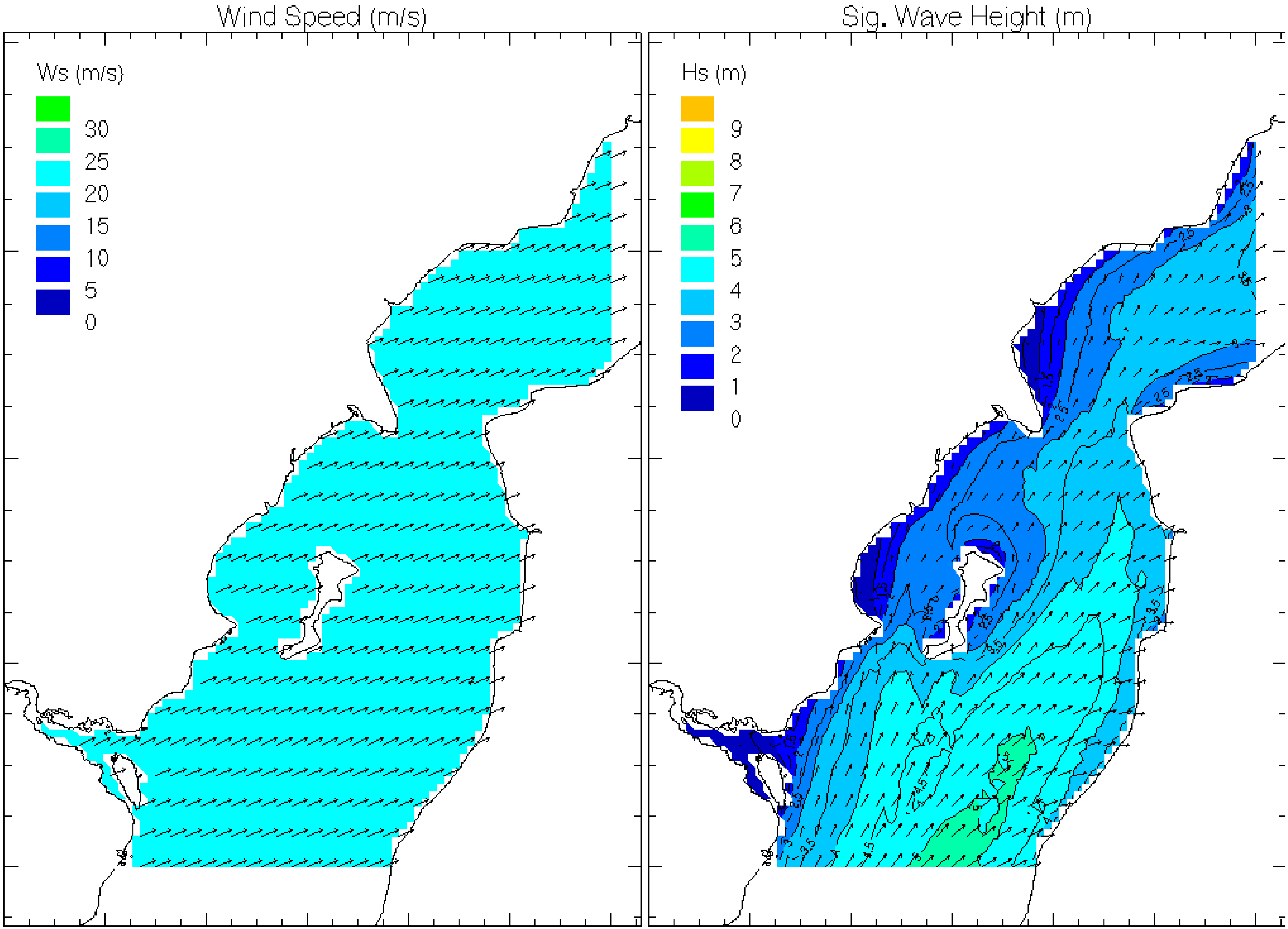

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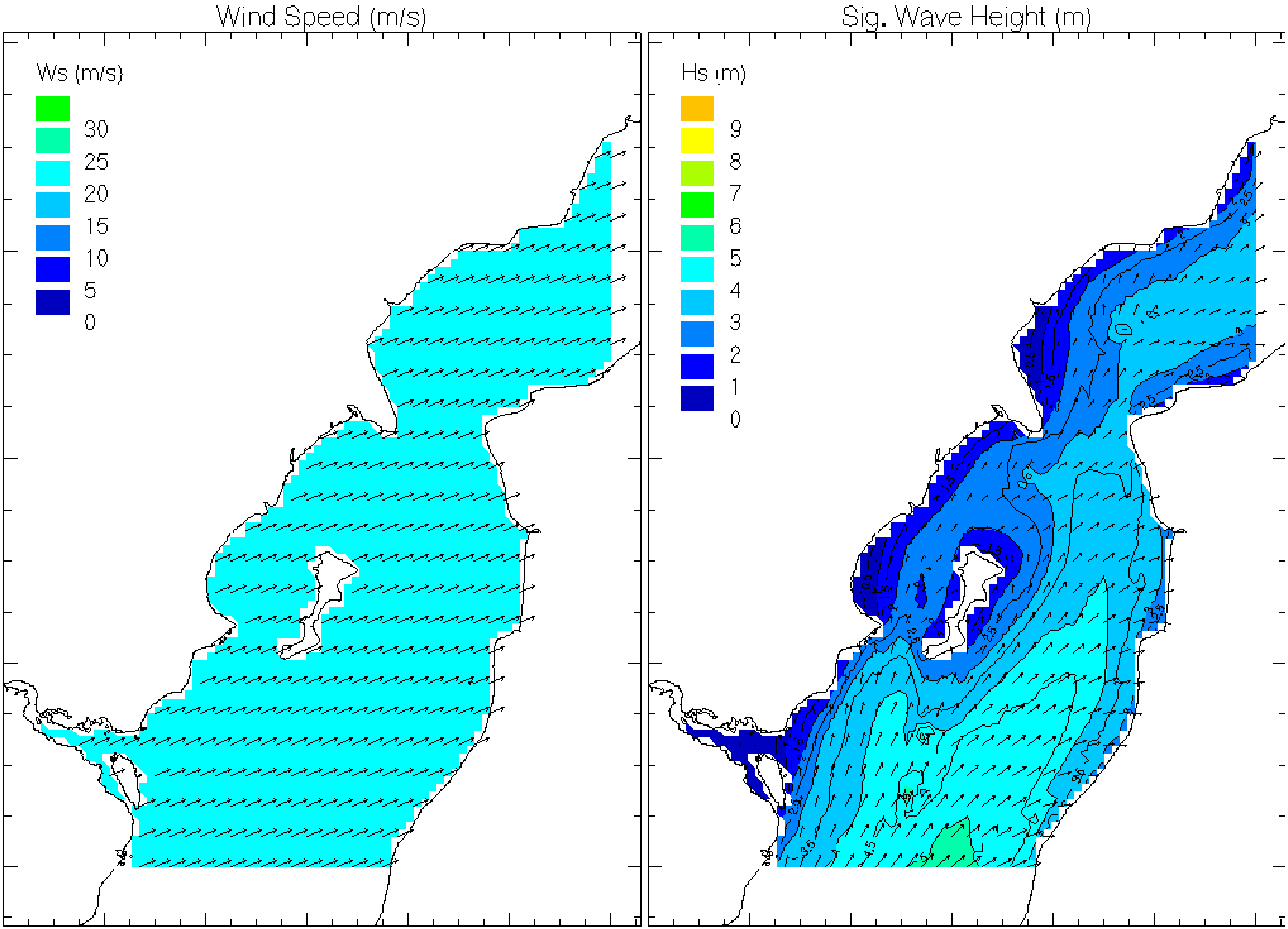
Kenai Maximum Hindcast Winds and Waves during 50Yr_WSW



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