Hawaiian Islands Severe Wave Climate 1995-2004

Barbara Tracy, Jeffrey Hanson, Alan Cialone,
Hendrik Tolman*,
Douglas Scott**, and Robert Jensen
Coastal and Hydraulics Laboratory,
Engineer Research and Development Center
*** NOAA/NCEP**
**** Baird and Associates**

The location of the Hawaiian Islands makes them vulnerable to damaging wave conditions from north Pacific ocean storms. The northwest coast of Oahu is known for its big surf generated from Pacific storms—the rocky coast shields the island from most wave damage. The northeastern coast of Oahu is barely above sea level and high surf events coming from the northeast cause extensive damage. The wave climate for the Hawaiian Islands is an important asset for coastal planning and design. The Wave Information Studies (WIS) has recently completed a ten year (1995-2004) basin level hindcast (0.5 deg resolution) for the Pacific Ocean. Hourly wave parameters are available via the WIS website: http://frf.usace.army.mil/cgi-bin/wis/atl/atl_main.html. Spectral information at 3 hour intervals is also available from the WIS staff. The Wavewatch III numerical hindcast model (Tolman,2002 and 1996) was used for this hindcast with wind fields developed by Oceanweather, Inc. Hindcast details are presented in Hanson et al., 2006. For more information on the WIS hindcasts for the U.S. coastlines, see Tracy and Cialone, 2004. This poster will show the monthly maximum wave events from this hindcast and will analyze two events (the maximum event for November and January) from the 1995-2004 hindcast that impacted the island of Oahu. Station 125, a station in the open ocean northeast of the island of Oahu, located at 24 deg. N, 157 deg. W, with a depth of 4216 m was chosen for this analysis (see Figure 1). The goal of this poster is to showcase the availability of ten years of wave climate information in the Hawaiian Islands and display some of the tools that can be used to analyze the available wave parameter and spectral information.

The WIS validation scheme includes spectral analysis using a system called WaveMEDS (Hanson and Phillips, 2001: Hanson and Jensen, 2004). This analysis procedure looks at a frequency-direction wave spectrum and produces “partitions” that represent the various sea and swell components present in the spectral representation. This procedure developed from a digital watershed technique from Vincent and Soille, 1991, was used to analyze two Oahu severe wave events from the 1995-2004 hindcast. Two types of plots are shown for the two storms. One plot (CONTOUR-PARTITION) shows a plot of the frequency-direction matrix with partition identifying numbers at each frequency-direction intersection—1 corresponds to partition 1 and so forth. The twenty-five frequency numbers correspond to the frequencies used in the hindcast model and begin with 0.03 Hz. Each partition represents energy associated with the local energy peak for that partition. Each partition is also represented by a different background color. This plot also includes line contours of the energy in the spectrum. A scale on the right hand side of the plot identifies the color contour line energy values in m**2/Hz. This contour partition plot only shows the wave spectra at one time during the storm. The second analysis plot (STORM-VECTOR) displays vectors showing the magnitude and direction of the energy plotted using a date/time scale for the x-axis and a wave period scale for the y-axis. This second type of plot gives an overview of all the wave components with their respective wave periods for the whole storm. The arrows are color-coded for the amount of energy and show what direction the wave component is heading.

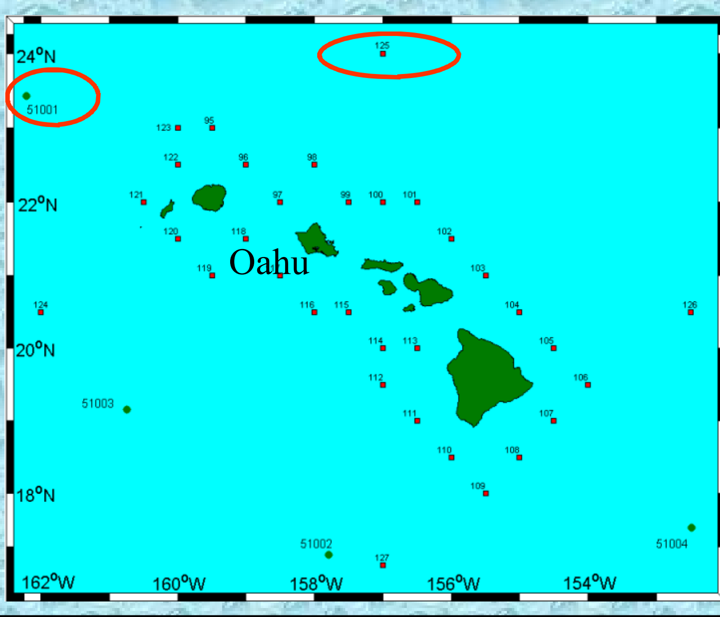

Figure 1. WIS stations in the Hawaiian Islands.
Station 125 and NDBC 51001 are circled.

Figure 2 shows the monthly maximum wave heights for November from the WIS 1995-2004 hindcast at station 125. The largest event was an 8+m wave coming from 30 deg (Meteorological convention) in November 2003. This event was responsible for considerable coastal flooding and damage to the low-lying northeastern coastline of Oahu (see http://www.prh.noaa.gov/hnl/pages/events/nov_surf/nov_surf.php for storm details and damage pictures). Figure 3 was taken from the www.prh.noaa.gov website and shows a satellite picture of the winds on November 20, 2003. Note the region of > 40 knot winds shown in magenta. An unusual combination of weather systems produced this event. Most maximum November storm waves come from events to the northwest of Oahu.

Figure 4 shows the three partitions of the spectrum for the 21st hour on November 21, 2003. Partition 1 (shaded in light blue and labeled with the number 1) represents the swell coming from the northeast. Energy contour lines are also plotted. Note that the bulk of the wave energy is within partition 1 and is from the storm system in Figure 3. Partition 2 shows energy coming from about 220 deg, and partition 3 shows energy coming from about 110 deg.

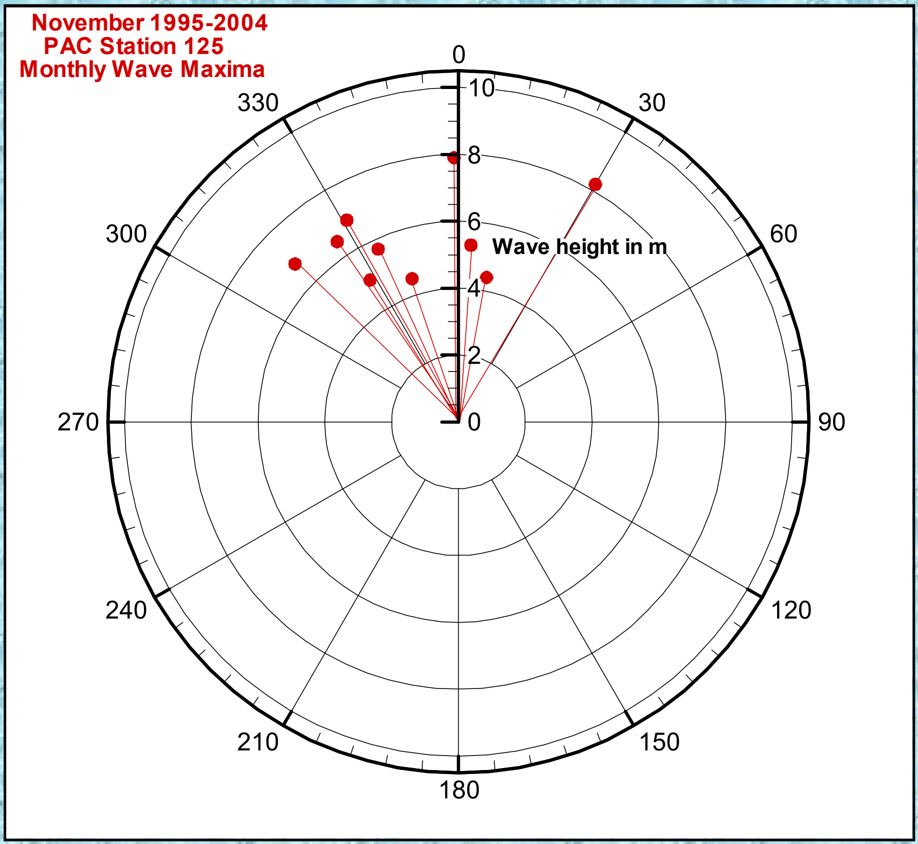

Figure 2. Monthly maximum wave heights for November from the WIS 1995-2004 Pacific Basin hindcast. Direction uses meteorological convention and wave heights are in meters.

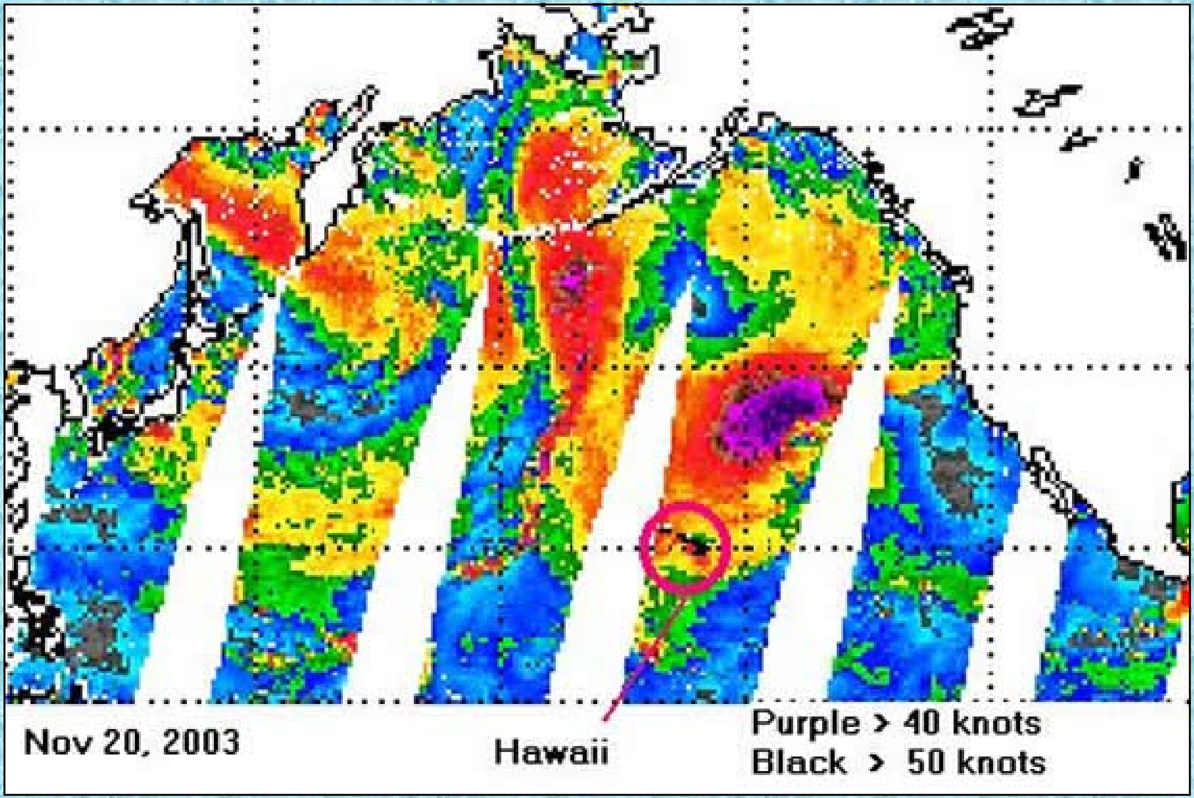

Figure 3. Satellite picture of winds for November 20, 2003, taken from http://www.prh.noaa.gov/hnl/pages/events/nov_surf/nov_surf.php

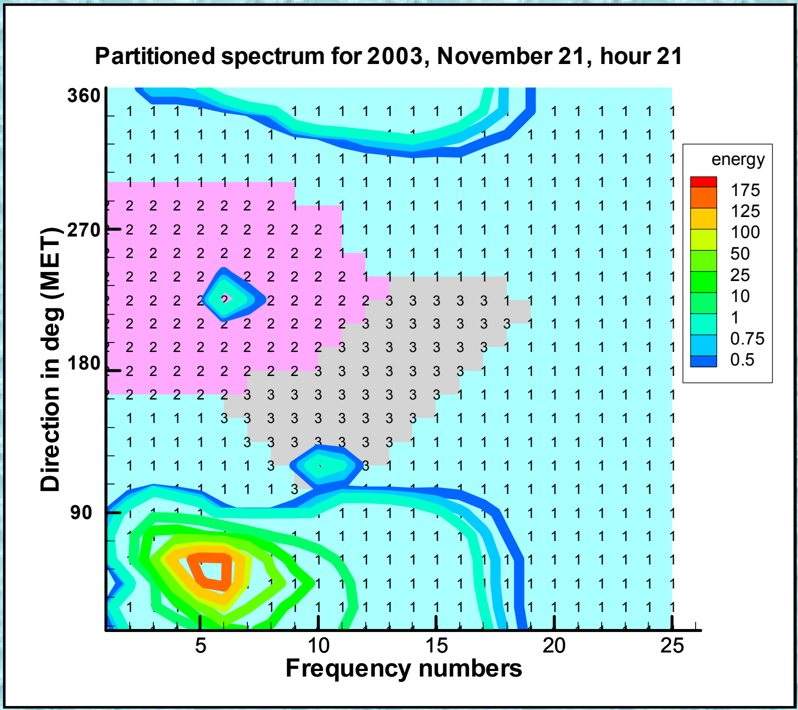

Figure 4. Frequency-direction spectrum at WIS Station 125 showing the three energy partitions on November 21, hour 21, 2003. Partition one is colored light blue, partition 2 is pink and partition 3 is gray. The colored contour lines show the energy contours of the spectrum in m**2/Hz.

Figure 5 shows a plot of the wave component vectors over the life of the November 2003 storm. Dates are plotted on the x-axis and wave period of each vector component is plotted on the y-axis. The vectors are colored coded to show the wave height present in each component. Direction is shown by the direction of the arrowhead. Note again that most of the energy is from the storm shown in Figure 3 but there is background energy from other Pacific events. Figure 6 is the same type plot as Figure 5 but it highlights the peak of the storm.

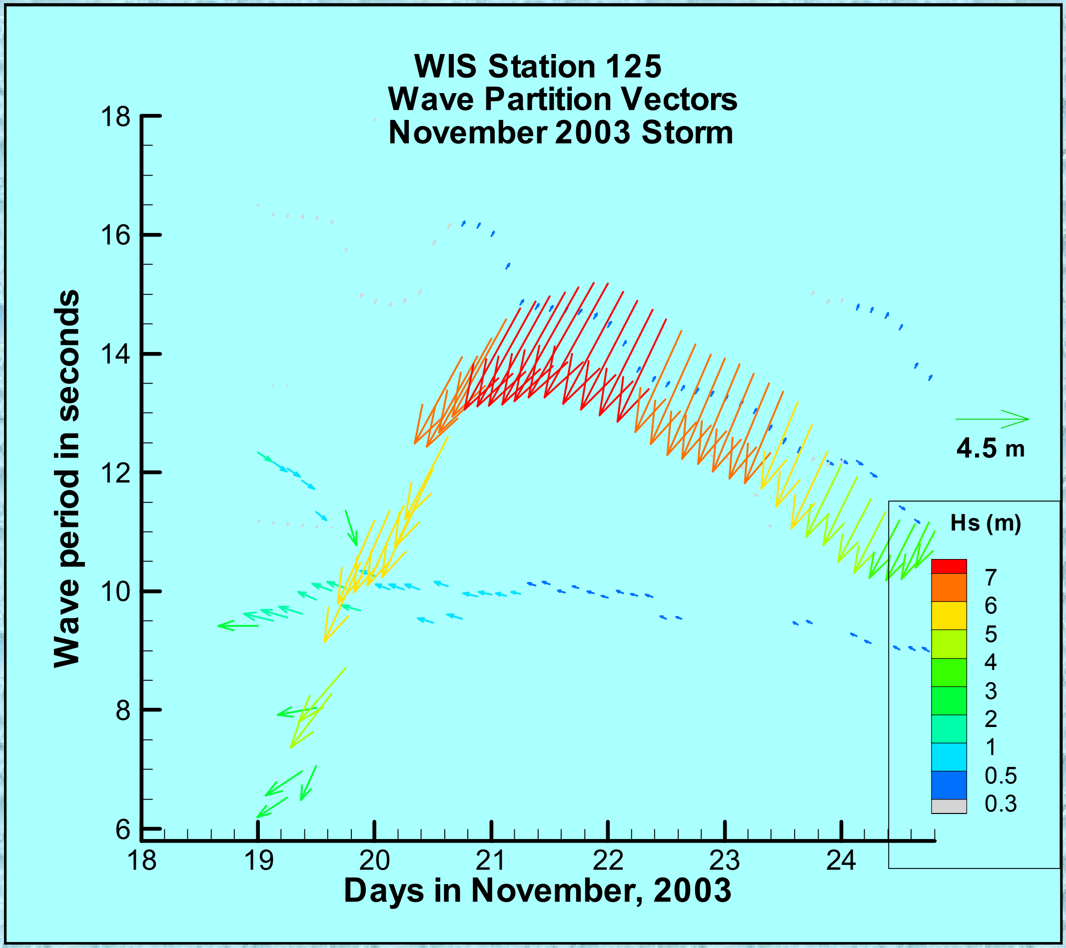

Figure 5. Vector wave component plot for November 18-24, 2003. Days in November are shown on the x-axis and wave period associated with each of the vector components is shown on the y-axis. Vectors show direction of travel for each of the wave components, and vectors are color-coded to show the wave height (Hs in m) associated with that component.

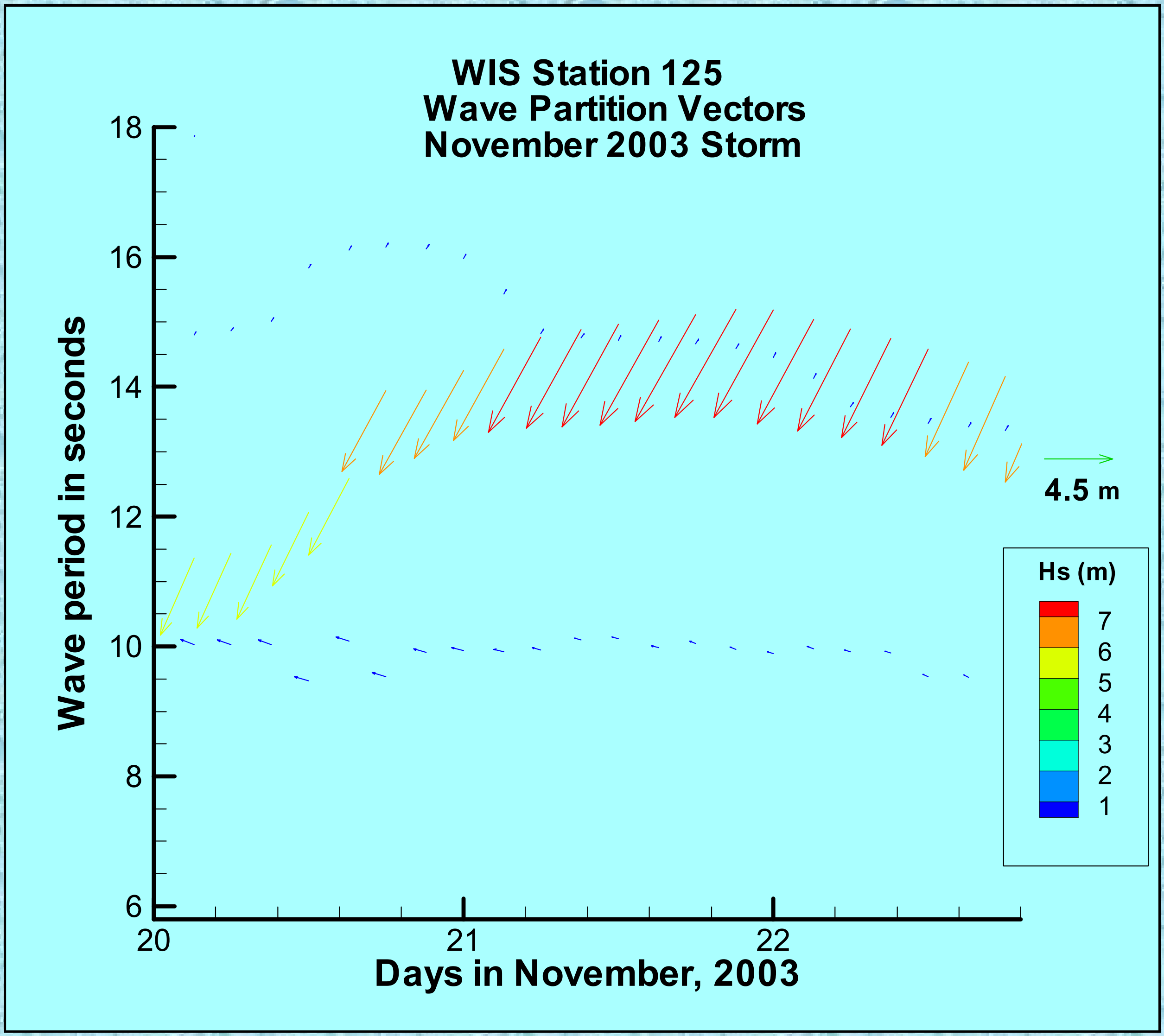

Figure 6. Vector wave component plot for November 20-22, 2003, showing the peak period of the storm. Days in November are shown on the x-axis and wave period associated with each of the vector components is shown on the y-axis. Vectors show direction of travel for each of the wave components and vectors are color-coded to show the wave height (Hs in m) associated with that component.

Figure 7 shows the monthly wave height maximums and their associated directions for January during the 1995-2004 WIS Pacific Basin hindcast. The 10+m maximum wave shown occurs in January, 1998. This is a typical storm event for the Hawaiian Islands since it shows energy coming from 318 deg (from northwest). Figure 8 shows a PARTITION–CONTOUR plot of the spectrum on the 6th hour of January 28, 1998. Note that there are 4 energy partitions represented (partition 1 shaded in light blue, partition 2 in pink, partition 3 in gray, and partition 4 in green). Energy contour lines are plotted to show the amount of energy in the spectrum. Note that the maximum is from the northwest but there is a representation of some energy from the south in partitions 3 and 4. Figure 9 is the same type plot as Figure 8 but it shows the partitioning of the spectrum at the 18th hour on January 28, 1998 (12 hours later than Figure 8). Note that all energy is now in the one partition coming from the northwest. Partitions having energy less than 0.3m are not shown.

Figure 10 shows the wave component vectors from January 24-31, 1998. Dates are plotted on the x-axis and wave period of each component is plotted on the y-axis. Each wave component is shown in the direction that it is traveling and is colored coded to show how much wave energy (Hs in m) is represented by that component. Note the small contributions of southern swell shown by the small arrows from 12-16 sec in Figure 10. Figure 11 is similar to Figure 10 but shows only January 28-31.

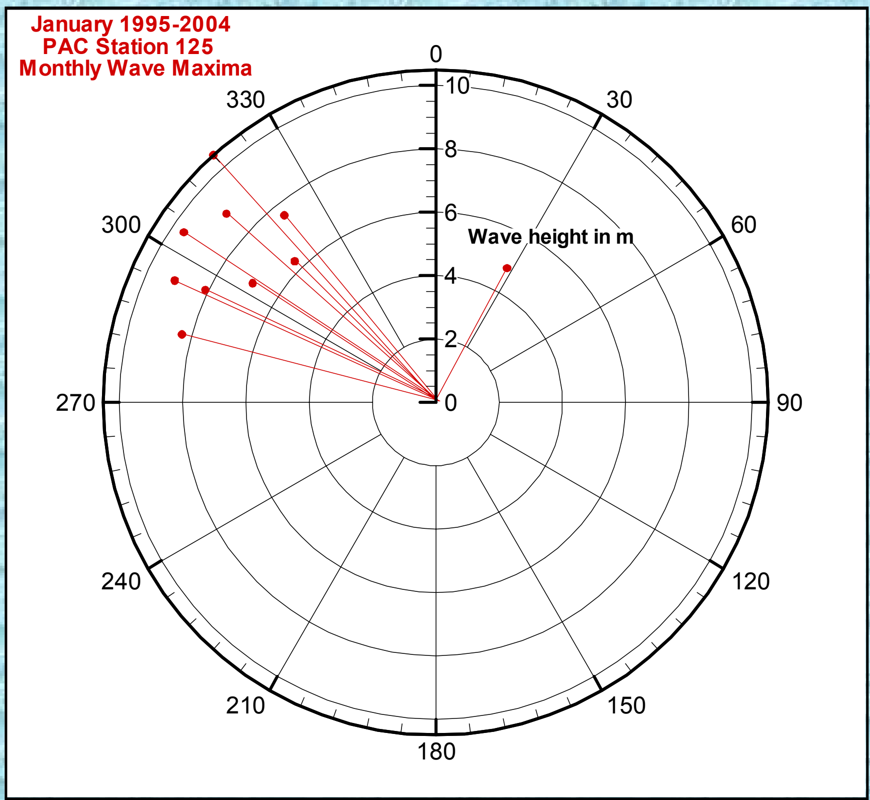

Figure 7. Monthly maximum wave heights for January from the WIS 1995-2004 Pacific Basin hindcast. Direction uses meteorological convention and wave heights are in meters.

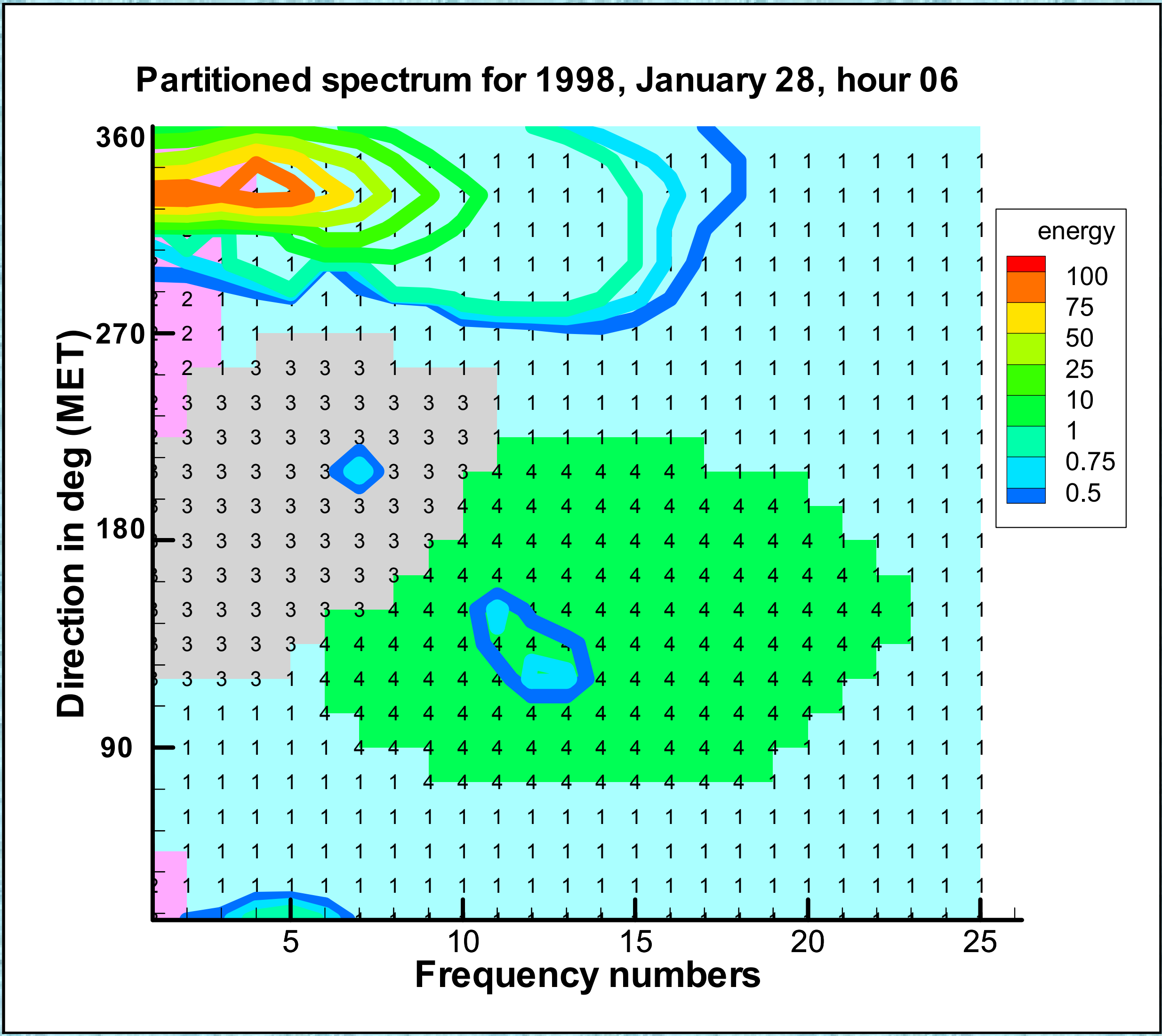

Figure 8. Frequency-direction spectrum at WIS Station 125 showing the four energy partitions on January 28, hour 06, 1998. Partition one is colored light blue, partition 2 is pink, partition 3 is gray, and partition 4 in green. The colored contour lines show the energy contours of the spectrum in m**2/Hz.

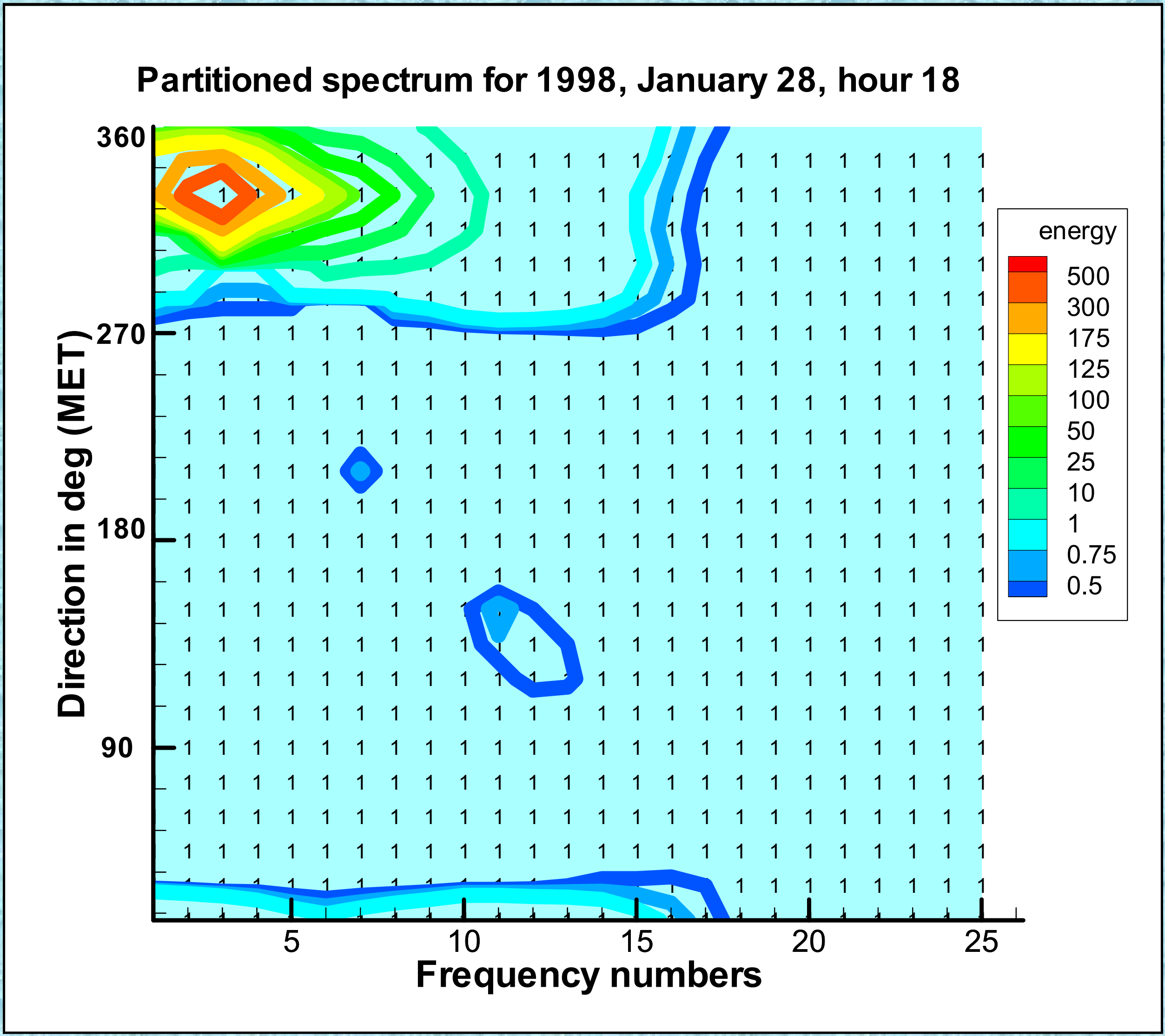

Figure 9. Frequency-direction spectrum at WIS Station 125 showing the one energy partition on January 28, hour 18, 1998. Partition one is colored light blue. The colored contour lines show the energy contours of the spectrum in m**2/Hz.

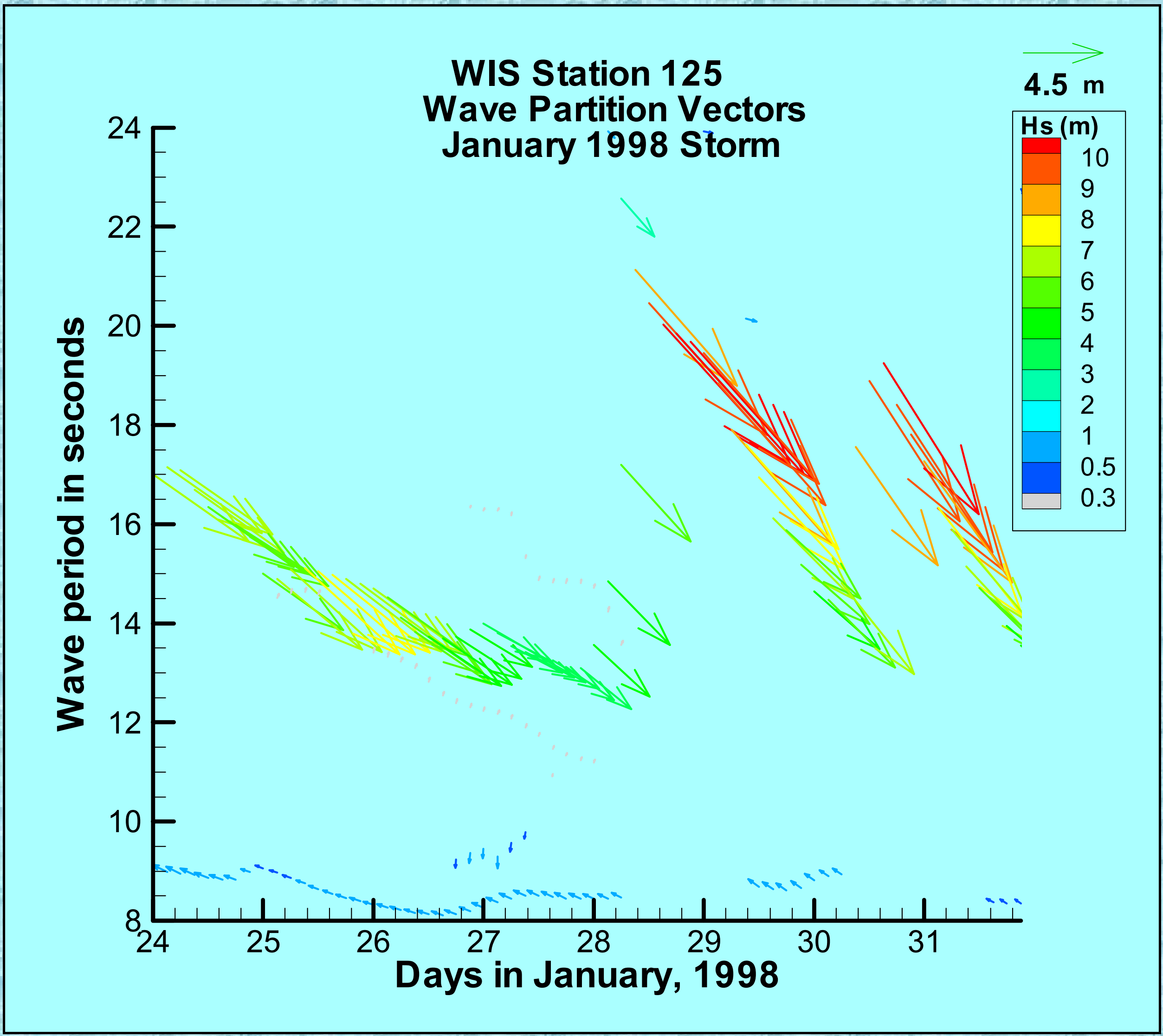

Figure 10. Vector wave component plot for January 24-31, 1998, showing a full week of the storm. Days in January are shown on the x-axis and wave period associated with each of the vector components is shown on the y-axis. Vectors show direction of travel for each of the wave components and vectors are color-coded to show the wave height (Hs in m) associated with that component.

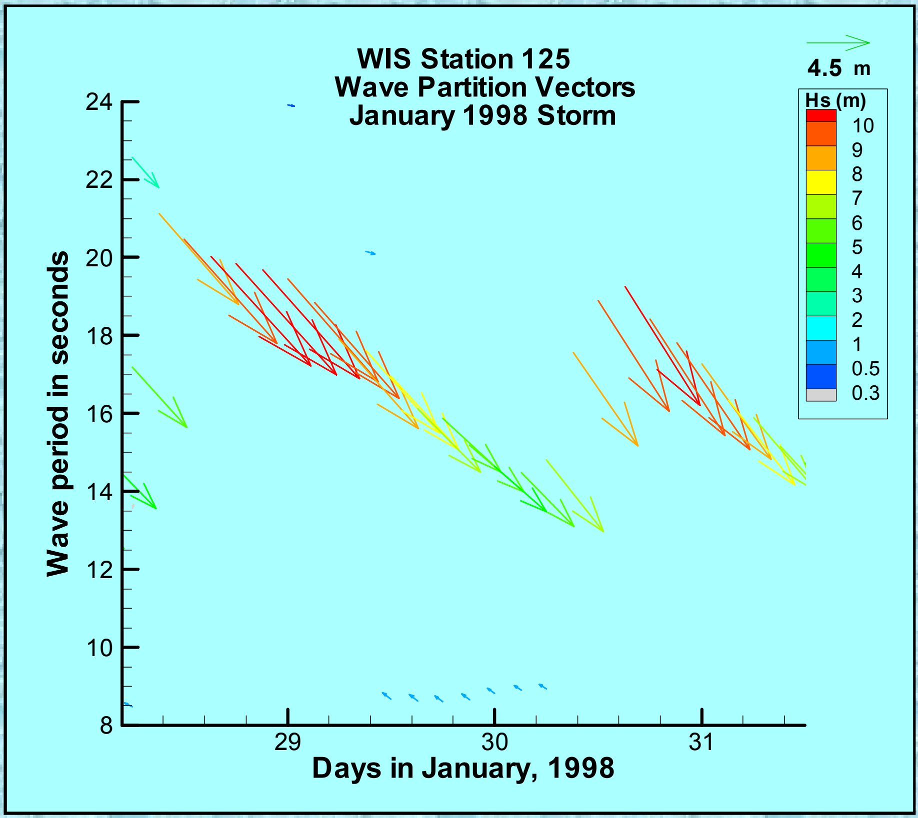

Figure 11. Vector wave component plot for January 28-31, 1998, showing the peak of the storm. Days in January are shown on the x-axis and wave period associated with each of the vector components is shown on the y-axis. Vectors show direction of travel for each of the wave components and vectors are color-coded to show the wave height (Hs in m) associated with that component.

Validation results for the WIS 1995-2004 Pacific Basin hindcast are important because matching results at measured locations give credence to the WIS values at sites where no measurements are available. Hanson et al. (2006) discusses the performance and validation of the Pacific Basin hindcast, and other publications will present more statistics and validations in the future. Figures 12 and 13 show the measured results for November 2003 and January 1998 at NDBC 51001 shown in Figure 1. These plots include the two severe storms that were analyzed in this poster. Wind information was not available at 51001 for January 1998 and measured wave direction is not available at 51001 . Note the excellent agreement for all available measured parameters especially the wave period. Hanson et al. (2006) presents the validation results of the hindcast for 2000 and notes that the WIS hindcast significant wave heights tend to run a little higher than measurements and discusses the reasons for this extra energy in the hindcast. The WIS webpage has an extensive set of validations of the WIS Pacific Basin hindcast with available satellite information during the hindcast period. Baird and Associates prepared the satellite comparisons.

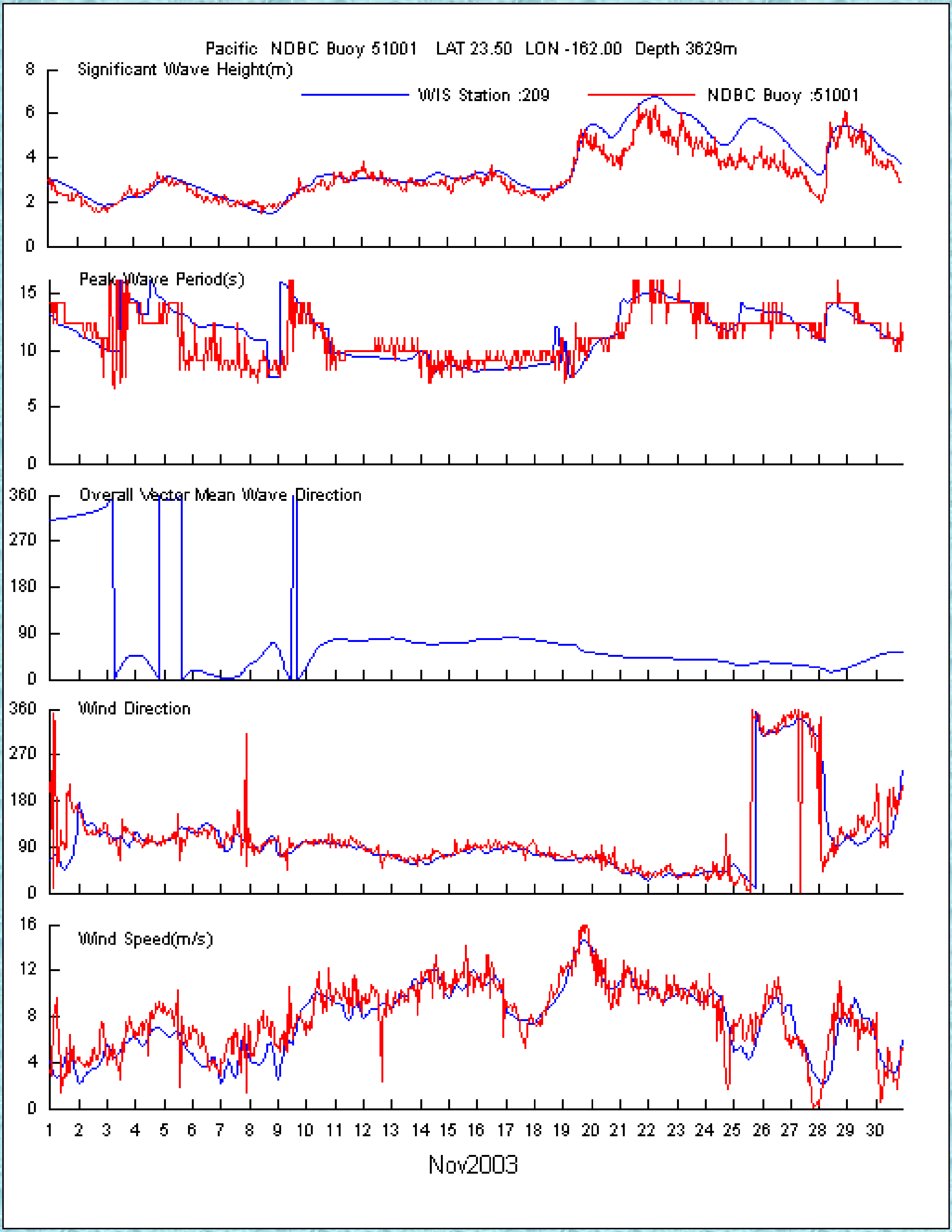

Figure 12. Pacific NDBC Buoy 51001 results for November 2003 are shown in red on the plot above. The WIS hindcast results are shown in blue. Parameters plotted (from the top) include significant wave height, wave period, mean wave direction (not available for buoy), wind direction, and wind speed.

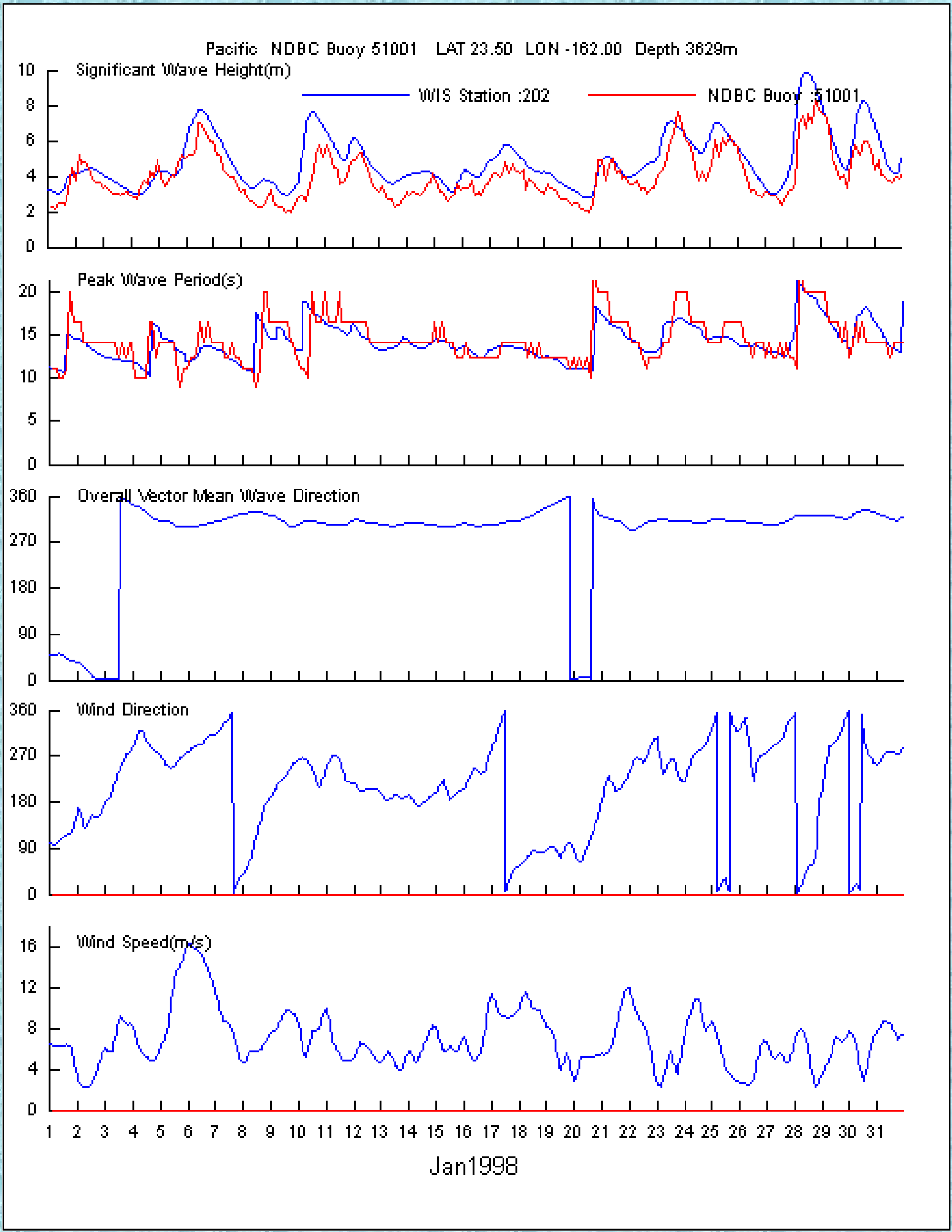

Figure 13. Pacific NDBC Buoy 51001 results for January 1998 are shown in red on the plot above. The WIS hindcast results are shown in blue. Parameters plotted (from the top) include significant wave height, wave period, mean wave direction , wind direction, and wind speed. Wave direction and wind information were not available at the buoy in January 1998.

Figures 14-23 show the monthly wave height maximums for the months other than January and November for WIS station 125 for 1995-2004. These plots provide insight into the monthly wave climate at station 125. Note the general trends for waves from the east in the summer and waves from the northwest in the winter.

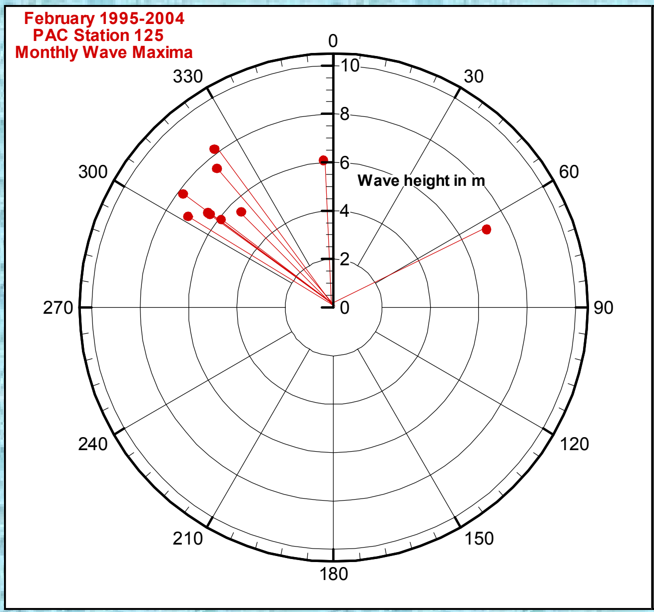

Figure 14. February maximum wave heights and directions for WIS Pacific Basin hindcast 1995-2004

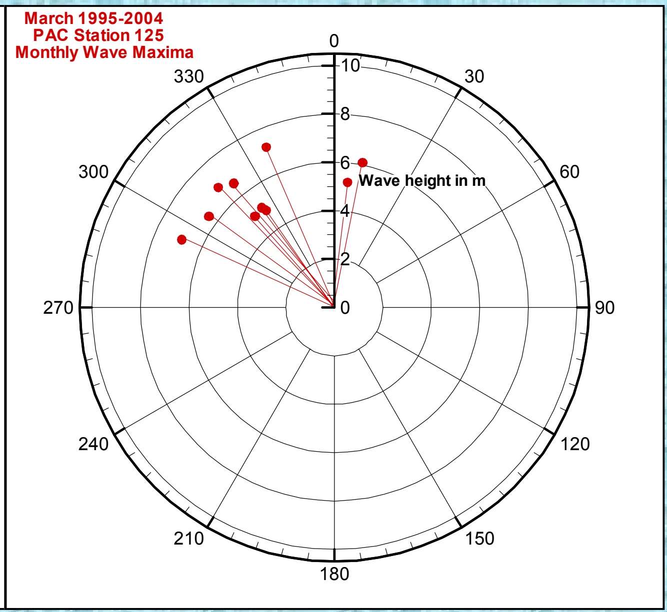

Figure 15. March maximum wave heights and directions for WIS Pacific Basin hindcast 1995-2004

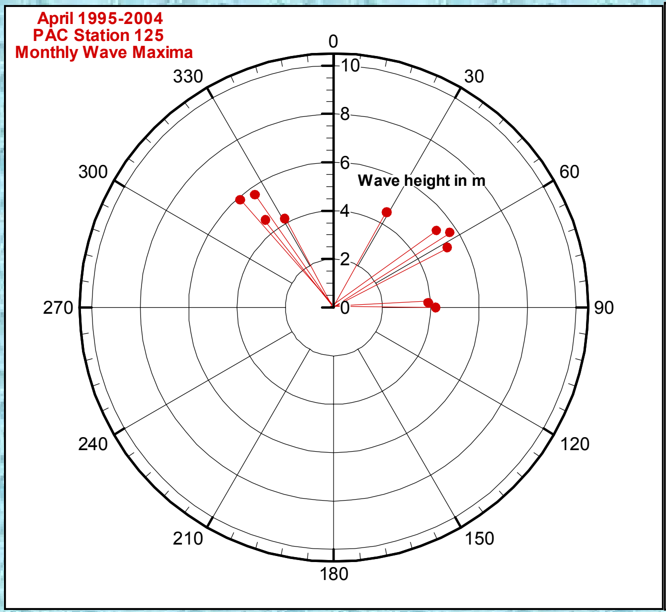

Figure 16. April maximum wave heights and directions for WIS Pacific Basin hindcast 1995-2004

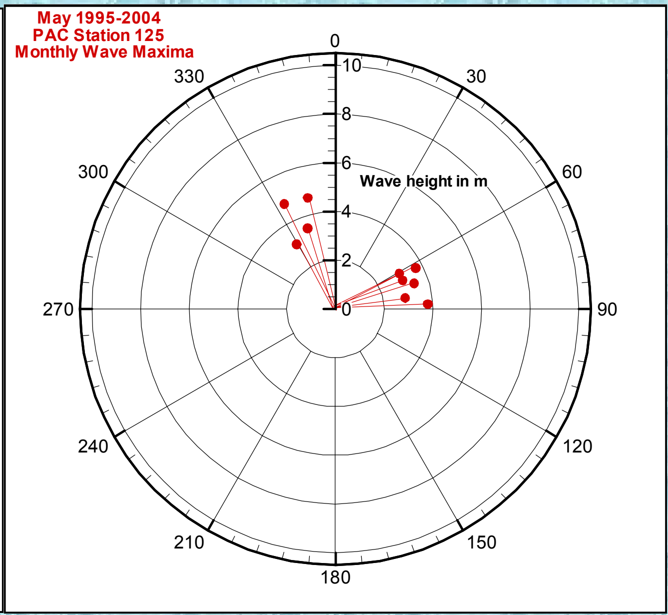

Figure 17. May maximum wave heights and directions for WIS Pacific Basin hindcast 1995-2004

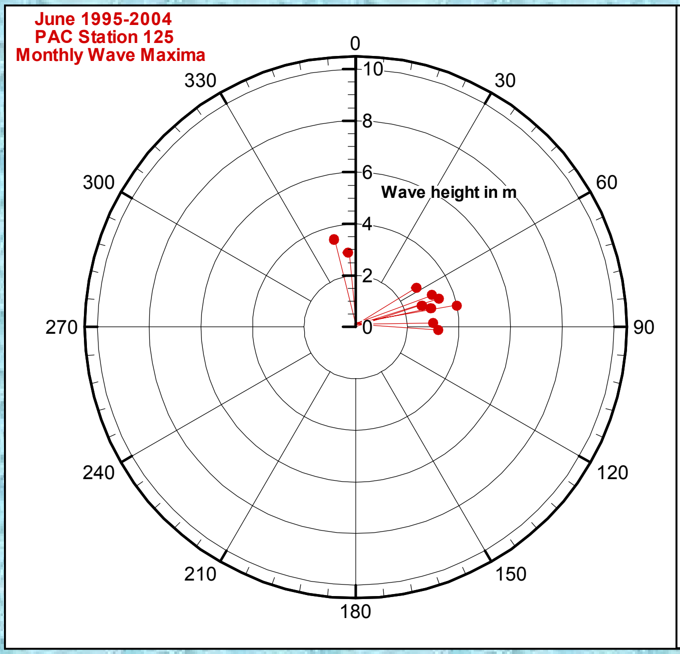

Figure 18. WIS June maximum wave heights and directions 1995-2004

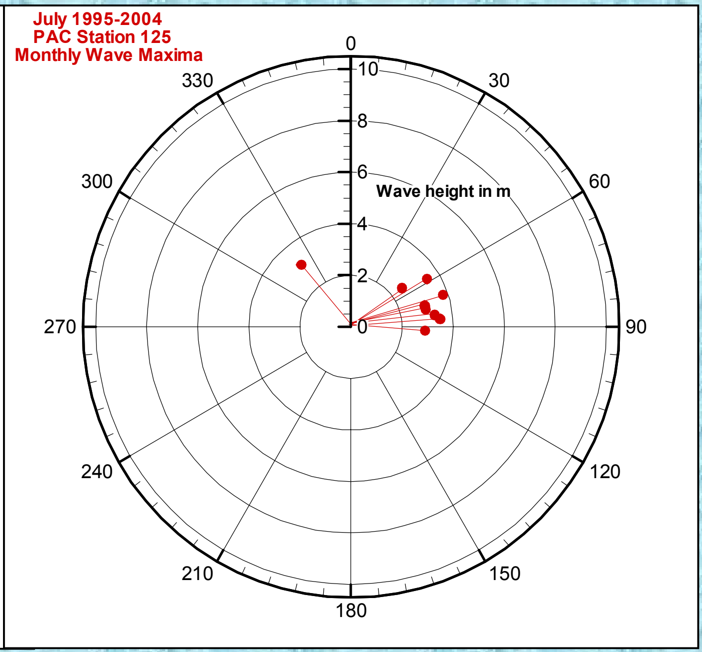

Figure 19. WIS July maximum wave heights and directions 1995-2004

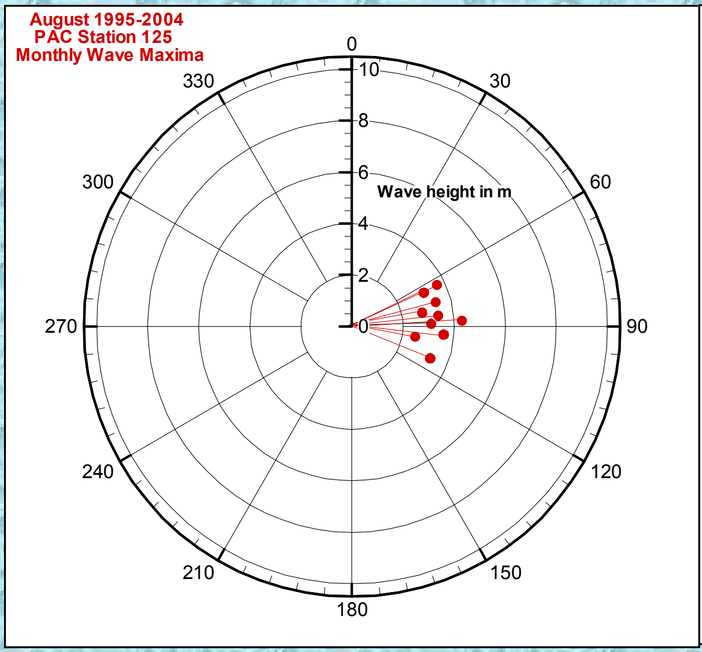

Figure 20. WIS August maximum wave heights and directions 1995-2004

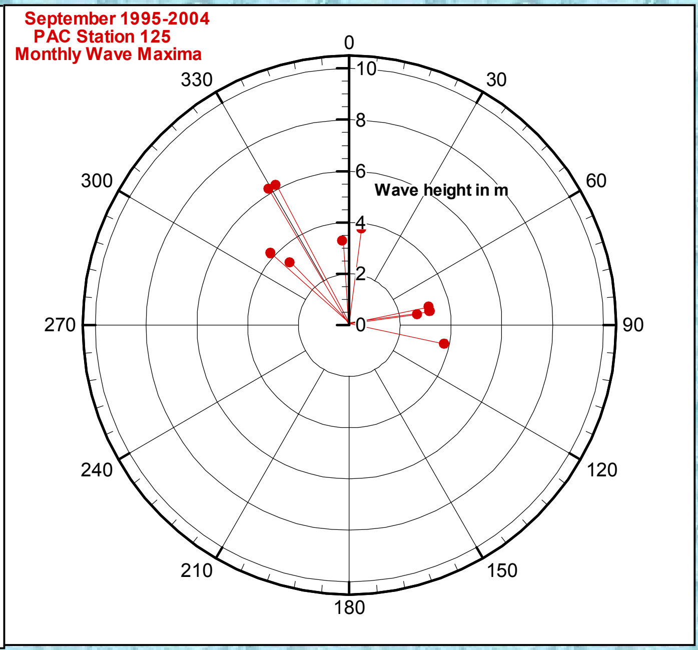

Figure 21. WIS September maximum wave heights and directions 1995-2004

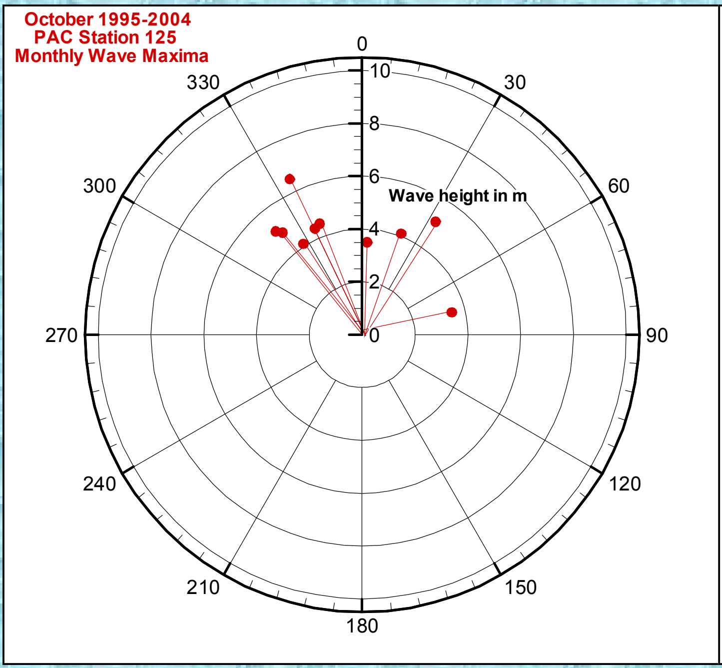

Figure 22. WIS October maximum wave heights and directions 1995-2004

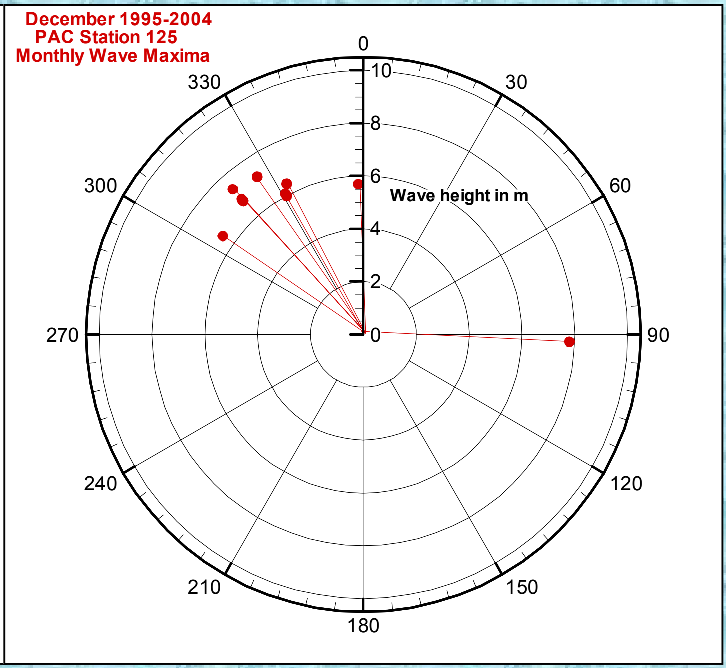

Figure 23. WIS December maximum wave heights and directions 1995-2004

References

1. Hanson, J. L., B. Tracy, H. Tolman, and D. Scott: (2006) Pacific hindcast performance evaluation of three numerical wave models, 9th International Workshop on Wave Hindcasting and Forecasting, Victoria, B.C., Canada, September 2006**.**

2. Hanson, J. L., and O. M. Phillips, (2001): Automated analysis of ocean surface directional wave spectra. *J. Atmos. Oceanic. Technol.*, **18**, 277-293.

3. Hanson, J.L. and R. E. Jensen, (2004): Wave system diagnostics for numerical wave models, 8th International Workshop on Wave Hindcasting and Forecasting, Oahu, Hawaii, November 2004, Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology Technical Report No. 29, WMO/TD-No. 1319.

4. Tolman, H. L. (2002a): User manual and system documentation of WAVEWATCH III version 2.22. Technical Note, U.S. Department of Commerce, NOAA, NWS, NCEP, Washington, DC.

5. Tolman, H. L., (2002b): The 2002 Release of WAVEWATCH III. *7th International Workshop on Wave Hindcasting and Forecasting*, Meteorological Service of Canada, 188-197.

6. Tolman, H. L. and D. V. Chalikov. 1996. Source terms in a third-generation wind-wave model. *J. Phys. Oceanogr.*, 26, 2497-2518.

7. Tracy, B. A and A. Cialone, (2004): Comparison of Gulf of Mexico Wave Information Studies (WIS) 2-G hindcast with 3-G hindcasting, 8th International Workshop on Wave Hindcasting and Forecasting, Oahu, Hawaii, November 2004, Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology Technical Report No. 29, WMO/TD-No. 1319.

8. Vincent, L. and P. Soille, (1991): Watersheds in digital spaces: an efficient algorithm based on immersion simulations, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 13,No. 6, June 1991, p. 583-598.