COMPARISON OF DEEP-WATER ADCP AND NDBC BUOY MEASUREMENTS TO HINDCAST PARAMETERS

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1. INTRODUCTION

A fundamental need in the wave hindcasting community is the capability to measure fully directional wave spectra in deep water, to be used for validation of wave-hindcast results and to guide research in the underlying physics. Presently, near-bed point-measuring gauges and surface tracking buoys are typically used to supply this information; however, these instruments cannot fully resolve the directional properties of multi-peaked wave spectra in sufficient detail. Newly developed technology based upon the Acoustic Doppler Current Profiler (ADCP) has demonstrated a remarkable improvement in the ability to resolve complex directional wave spectra, including high-frequency wave energy, but only in relatively shallow water.

2. TOWER-MOUNTED ADCP

The idea pursued in this study is to simply raise the ADCP wave gauge above the sea floor a distance sufficient to allow its capabilities to be fully exploited, i.e. to bring it to within nominally 10m of the surface. The major constraint on this problem is that the instrument must be motionless, and consequently, a fixed submerged structure was developed for the study described herein. This structure was essentially a large tripod, mounted to the sea floor using helical anchors. Each leg was fabricated from off-the-shelf galvanized steel antenna tower sections, with aluminum extensions at the tripod apex employed to suppress the influence of the tower on the ADCP compass - see Figure 1.

3. CANAVERAL BIGHT DEPLOYMENT

The ADCP tower was deployed in the Cape Canaveral Bight, approximately 24km offshore at a nominal depth of 22m. Its location is shown in Figure 2, along with the locations of NDBC Station 41009 and the hindcast model node used in this study –

Figure 1 - Apex of tripod tower, showing ADCP wave instrument.

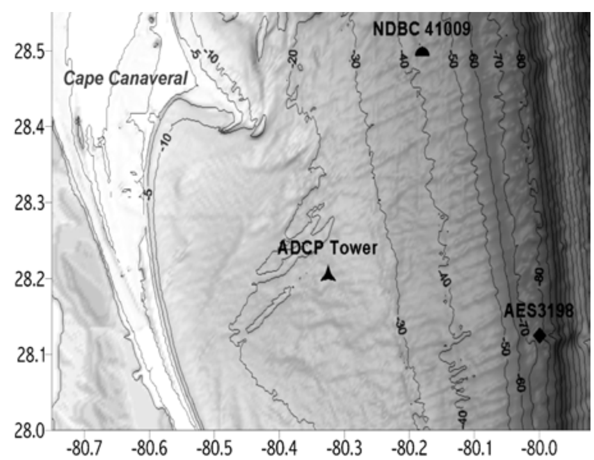

Figure 2 - Eastern central Florida coastal bathymetry with wave measurement and hindcast locations. Contour depths are in meters, vertical axis is latitude and horizontal axis is longitude.

AES3198. A self-recording, 1200kHz ADCP was deployed, retrieved, and redeployed at the tower tripod three times between October 2002 and March 2003. The sampling scheme was restricted mostly by battery life. With the intent of capturing as many storm events as possible, the scheme adopted was to record for 20 minutes every 2 hours, resulting in deployments nominally 34 days in length. A total of approximately 90 days of data were collected. During the deployments, significant wave heights exceeding 2.3m were measured at the tower tripod. The tripod survived an encounter with a fishing trawler during the experiment, but afterwards succumbed to a boat anchor. The analysis and discussion presented below is limited to the second deployment, which ran from December 13, 2002 to January 21, 2003.

4. BASIC OBSERVATIONS

Figure 3a presents a sample directional spectrum measured by the ADCP during a storm that occurred on January 1 driven by southeasterly winds. The spectrum has one predominant peak, but possesses

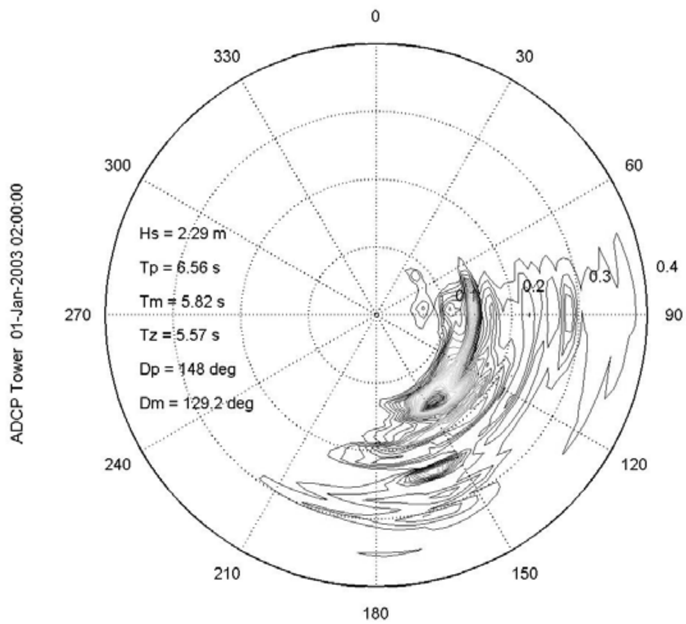

Figure 3a – Sample directional spectrum from tower-elevated ADCP during a southeast storm.

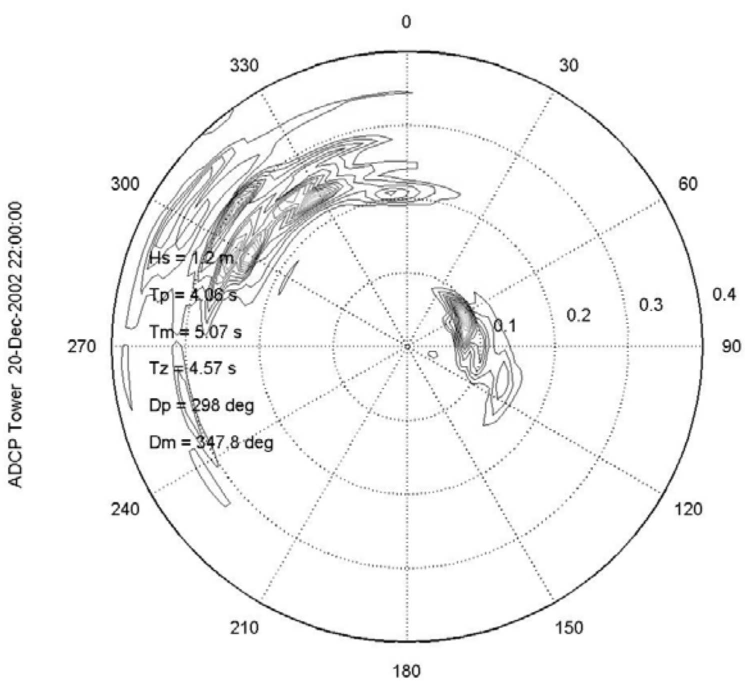

Figure 3b – Sample directional spectrum from tower-elevated ADCP showing distinct wave fields.

secondary peaks in both frequency and direction. Figure 3b presents a directional spectrum measured on December 20, indicating two distinct wave fields with markedly different peak frequencies and directions. It is believed that the spectra collected, over 1080 in all, are the first such high-resolution directional wave spectra measured with ADCPs in 'deep' water.

Figures 4 and 5 present basic wind and wave parameters measured during the deployment. The upper two panels of Figure 4 provide wind direction and wind speed at Buoy 41009, except for the time period from January 1 to January 9 during which the buoy anemometer malfunctioned. Data from Buoy 41010, located 100Nm further to the east are inserted for reference. Energy-based significant wave height is presented in the lower panel of Figure 4, for both the ADCP and Buoy 41009. The wave energy tracks with the wind speed, although some indication of fetch-limitation is evident when winds are from the western quadrant.

Figure 5 presents the significant wave height in the upper panel, followed by the peak wave period and energy-weighted mean wave direction from the ADCP. The buoy does not measure wave direction. The observations of H_s from the buoy are generally greater than those from the ADCP, particularly during storms. The two agree most when energy levels are low and peak periods are large, e.g. 12/24 and 1/05. This is not surprising considering the significantly greater water depth at the buoy (see Figure 1). In general there is remarkable agreement between the buoy and the ADCP observations of peak period

5. FREQUENCY CUT-OFF ANALYSES

In order to study the importance, if any, of the higher frequency resolution capabilities of the tower-elevated ADCP, the data were analyzed using different cut-off frequencies. Figure 6 presents results of significant wave height computed using a high-end cut-off of 0.5 Hz (2 s period) contrasted with 0.25 Hz (4 s period), judged to be a suitable cut-off had the instrument been bottom-mounted. As indicated in the lower panel, the lower cut-off misses a significant portion of the energy – on average about 20% of the significant height (36% of the energy).

Figure 7 examines the importance of the high-frequency capabilities of the elevated ADCP in determining peak period (T_P) and zero-crossing period (T_Z). In the upper panel it appears that the higher cut-off is not critical to the proper selection of peak period during most of the deployment. At a few times it is important, e.g. on 1/09, but this condition has not yet been examined in detail. However, as the lower panel of Figure 7 indicates, zero-crossing period is very sensitive to the high-frequency cut-off, because of the use of the second spectral moment in computing this parameter.

Figure 8 examines the importance of frequency cut-off on the determination of wave direction. As for period, during the deployment peak direction from the ADCP (upper panel) was sensitive to the cut-off value only a small portion of the time, again particularly around 1/09. Mean wave direction is somewhat more sensitive, apparently at times of rapidly changing wind direction when the higher frequency energy is not co-directed with the predominant energy.

6. COMPARISON OF HINDCAST PARAMETERS

By happenstance, Oceanweather, Inc. recently updated its 'AES' deepwater hindcast through the time period of the Canaveral deployments. This hindcast is performed using a 'WAM-like' third generation model, driven by numerically generated global wind fields that have been enhanced for storms, as described by Swail and Cox (2000). The archived grid point closest to the ADCP and NDBC buoy is point 3198 (see Figure 2).

In Figures 9 and 10 results of the hindcast are compared to the two sets of observed spectral parameters. The raw directional spectra were not archived from the hindcast, and parameters are archived every 6 hours. Again, although the data are not collocated, the comparisons are enlightening. The upper panels of Figure 9 provide wind speed and direction, with the AES winds tracking the 41009 measurements quite well. It is noted that during the time period when 41009's anemometer malfunctioned, the speed observations from 41010 are notably greater than the hindcasted winds, as might be expected given that the winds were offshore-directed during this time period. The third panel presents energy-based significant wave height from the ADCP, buoy and AES hindcast, with the AES results typically greater than the buoy observations. Again the fact that the stations are not collocated precludes further direct assessment/conclusion. However, the bottom panel indicates that peak periods from all three locations track well, attesting to the ability of the hindcast model to replicate this parameter, and to its relative immunity to the significant change in water depth between the stations.

Wave direction and its spreading properties are examined in Figure 10 for the hindcast results in comparison to the ADCP measurements. The upper panel is for mean wave direction and the second is for 'dominant' wave direction (Haring and Heideman, 1978). The 'angular spreading function' (Gumbel, Greenwood & Durand) is presented in the third panel, in which the ADCP measurements display less directional spread than the AES results (a value of 1 represents unidirectional waves). The 'in-line' variance ratio' (called 'directional spreading' by Haring and Heideman) is compared in the bottom panel. Again, the ADCP reported less directional spreading than the AES results.

8. CONCLUSIONS

Of course the biggest drawback to the present study was the fact that the instruments and hindcast station were not collocated. Nonetheless, the tower-elevated ADCP concept has been proven, and the ability to measure fully directional spectra, with high resolution in both frequency and direction, in even deeper water appears to be feasible. A side-by-side comparison of a tower-elevated ADCP and a directional wave buoy would be particularly enlightening. Presently, hindcast models are almost exclusively tested against buoy data, and so the ability to test the models and to guide the development of their underlying physics is constrained by the capabilities of the buoys to measure directional wave spectra.

9. REFERENCES

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ACKNOWLEDGEMENTS

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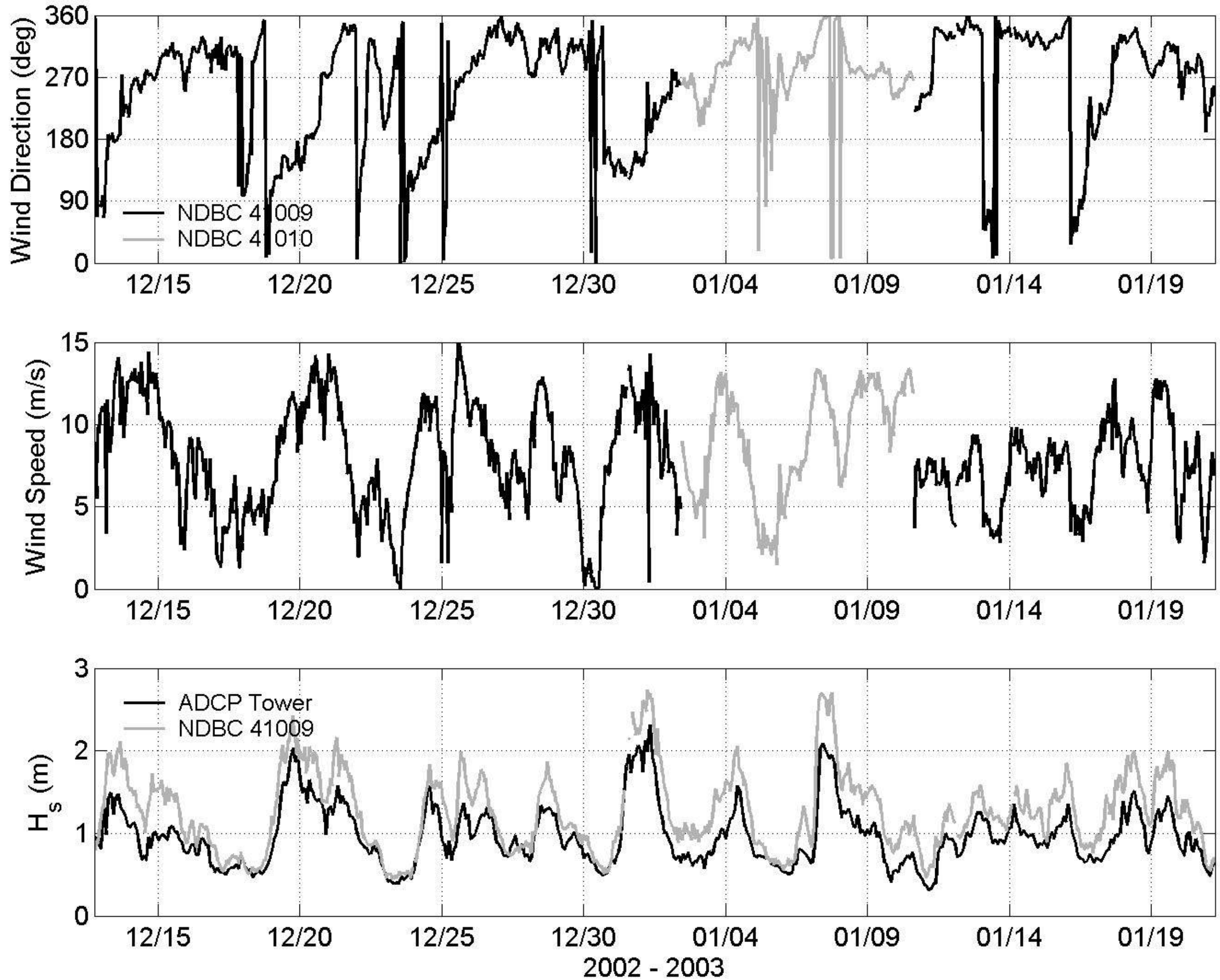

Figure 4 – Wind speed and direction measurements from NDBC buoys 41009 and 41010. Concurrent wave height measurements from the tower-elevated ADCP and NDBC buoy 41009 are presented in the bottom panel.

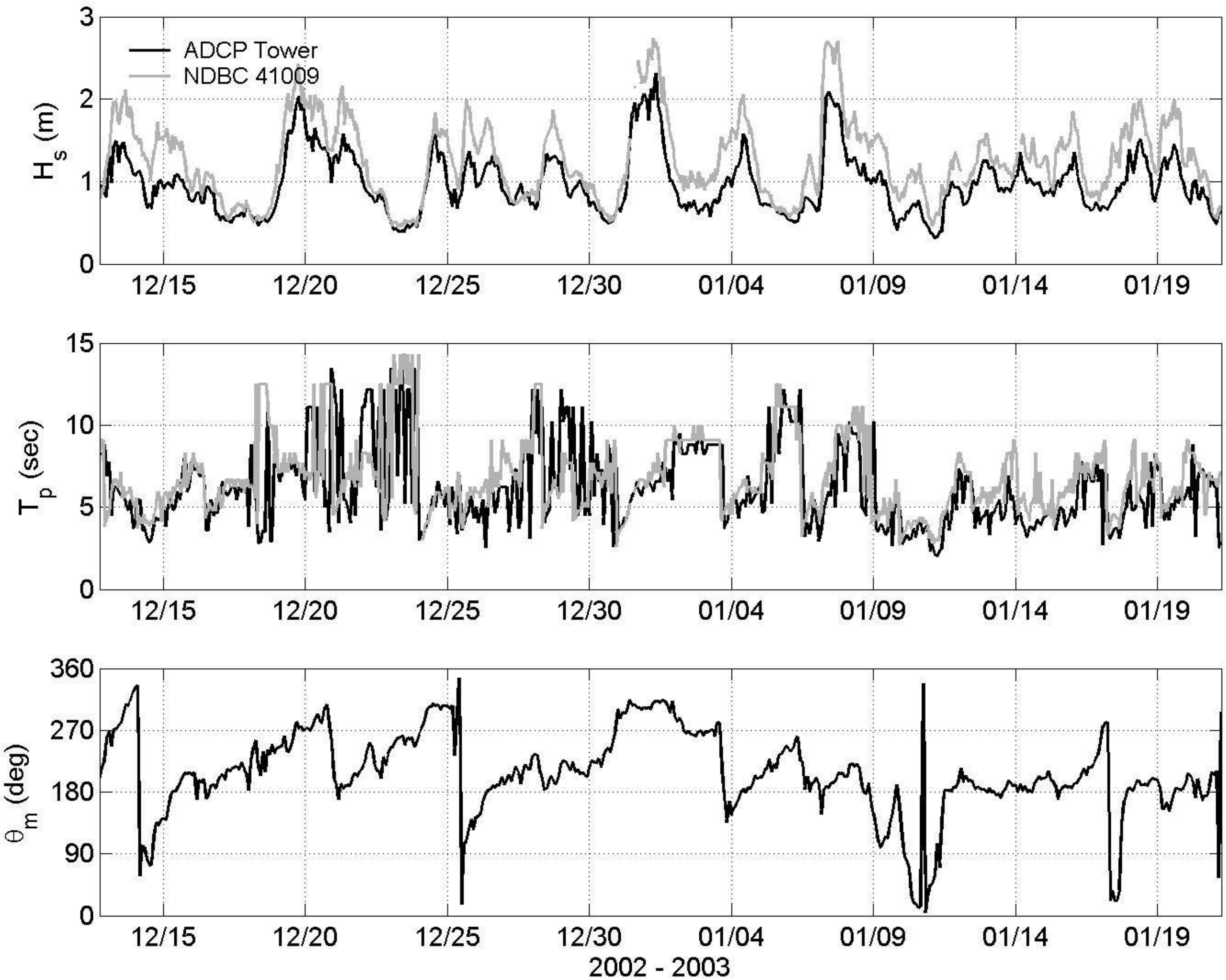

Figure 5 – Significant wave height and peak wave period measurements from the tower-elevated ADCP and NDBC buoy 41009. Energy-weighted mean wave direction measurement is from the ADCP only.

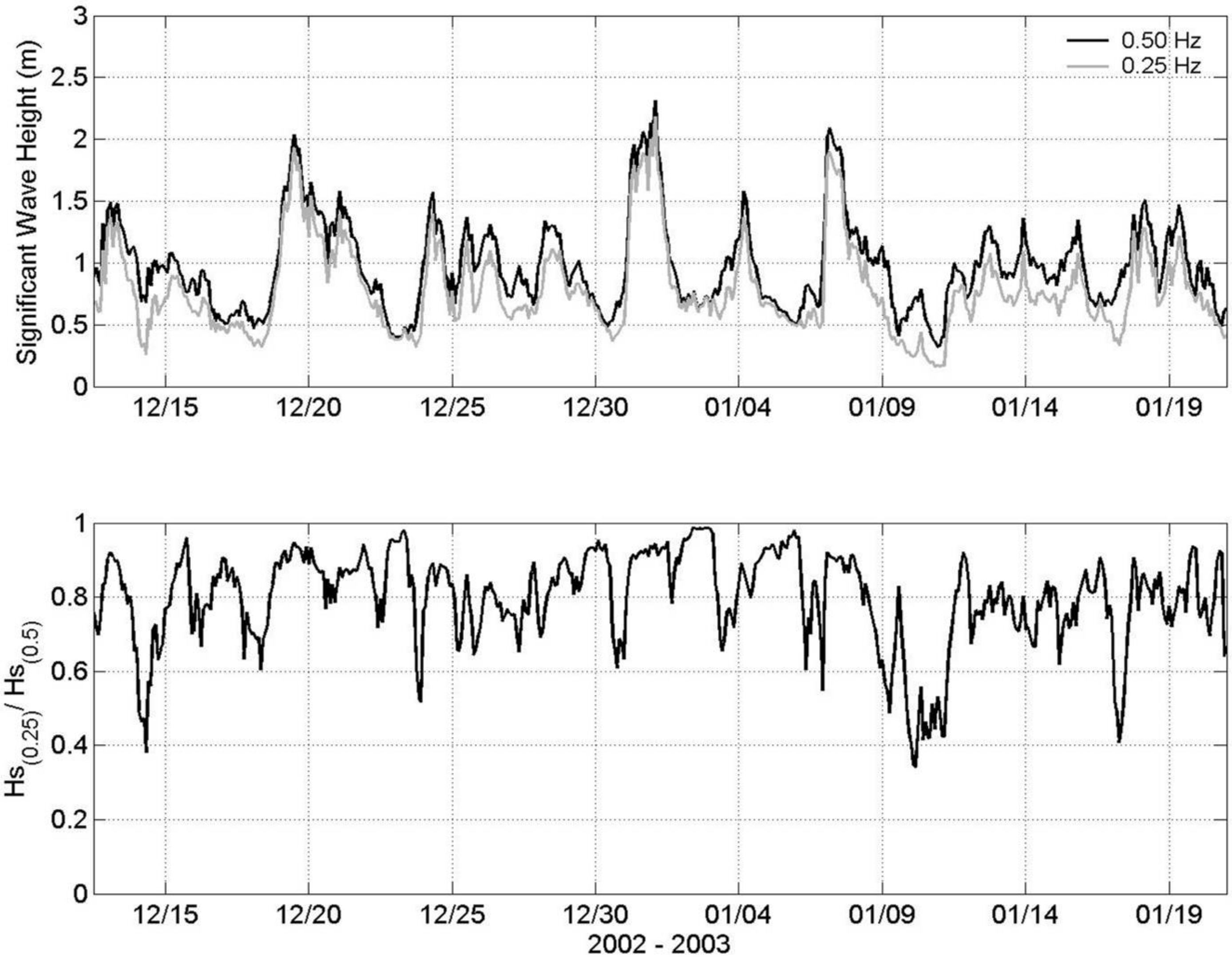

Figure 6 – Significant wave height computed from the tower-elevated ADCP directional wave spectra using an upper frequency limit of 0.5 Hz and 0.25 Hz. The lower panel is the ratio of the two computed wave heights.

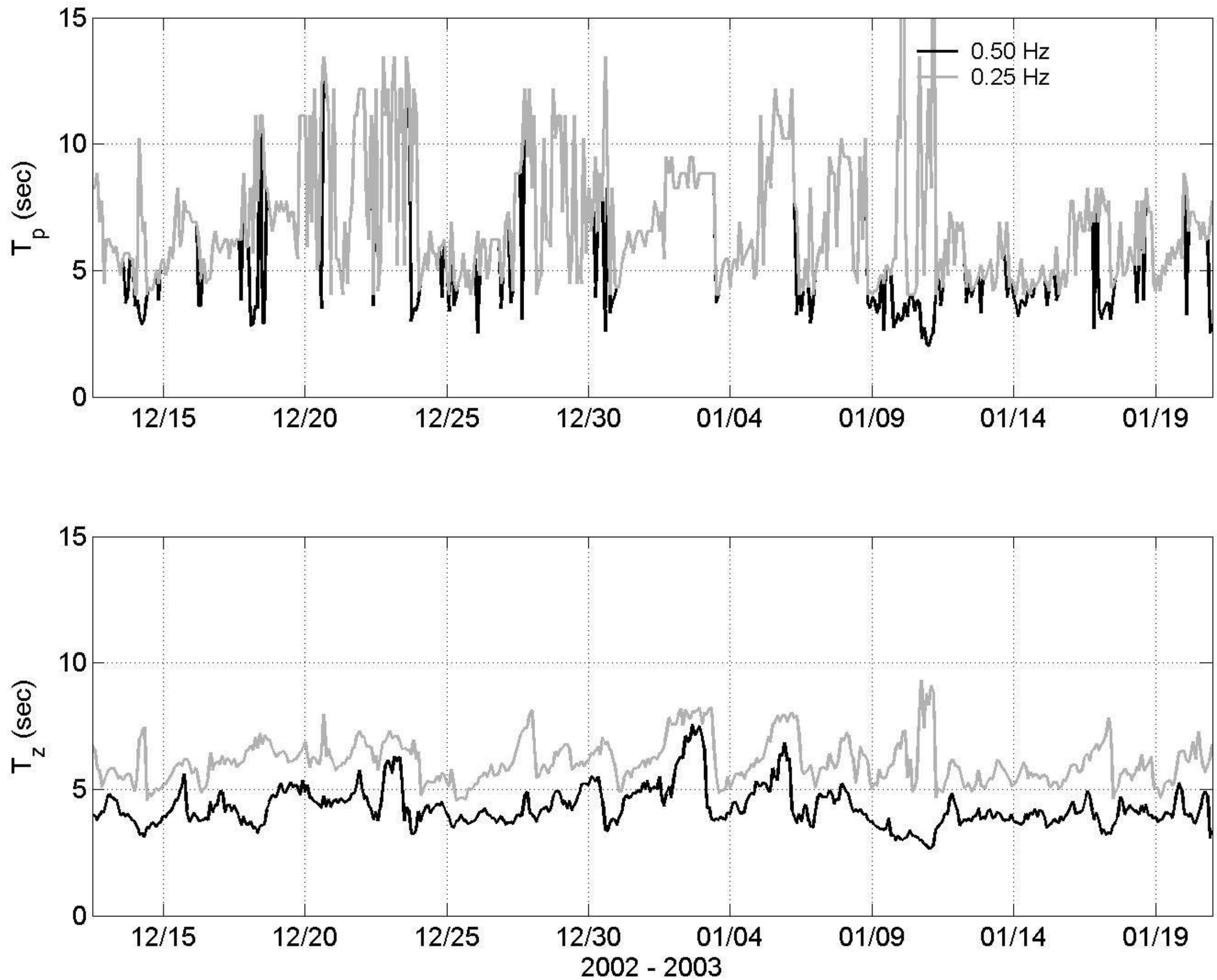

Figure 7 – Peak wave period and zero-crossing period computed from the tower-elevated ADCP directional wave spectra using upper frequency limits of 0.5 Hz and 0.25 Hz.

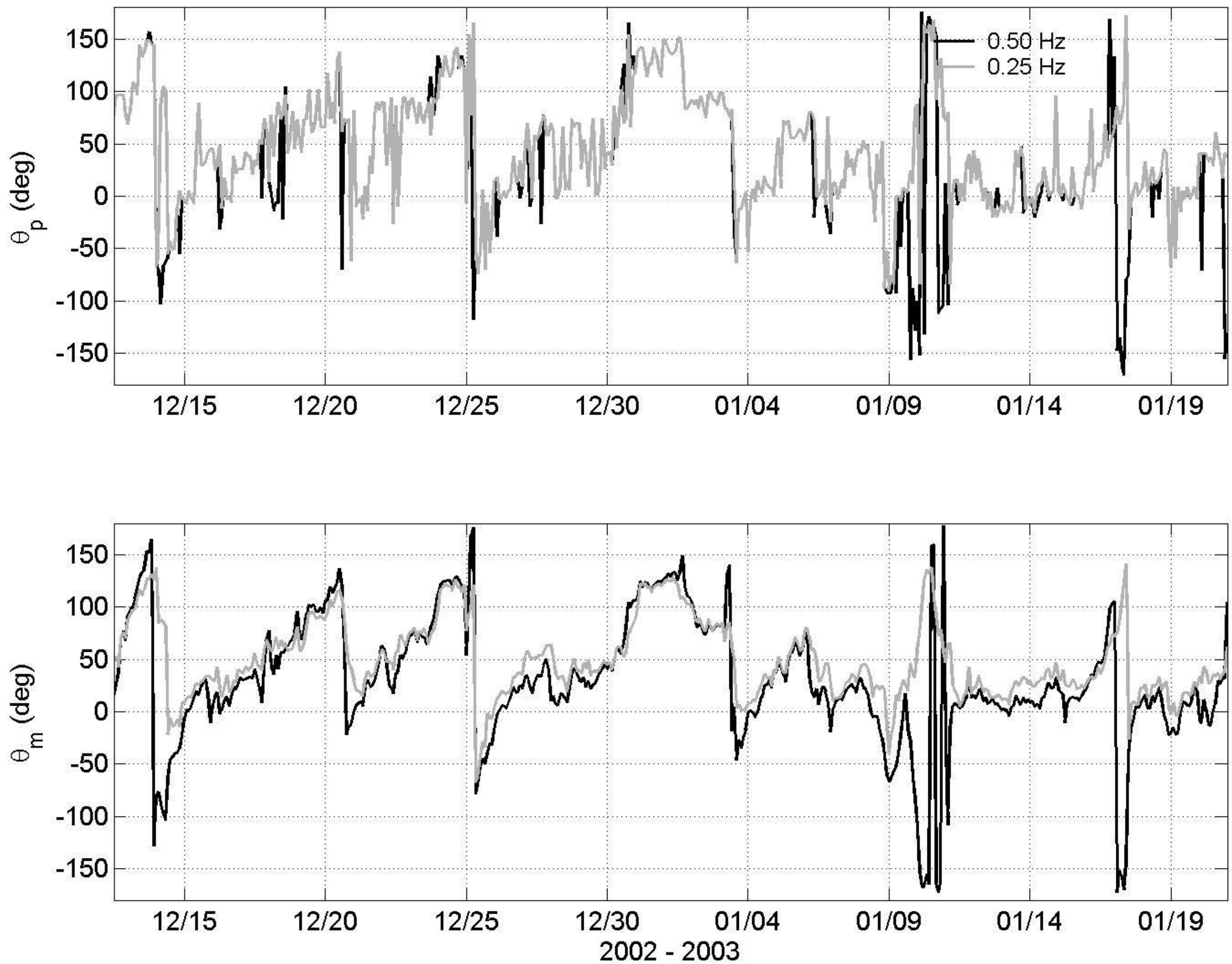

Figure 8 - Peak wave direction and mean wave direction computed from the tower-elevated ADCP directional wave spectra using upper frequency limits of 0.5 Hz and 0.25 Hz.

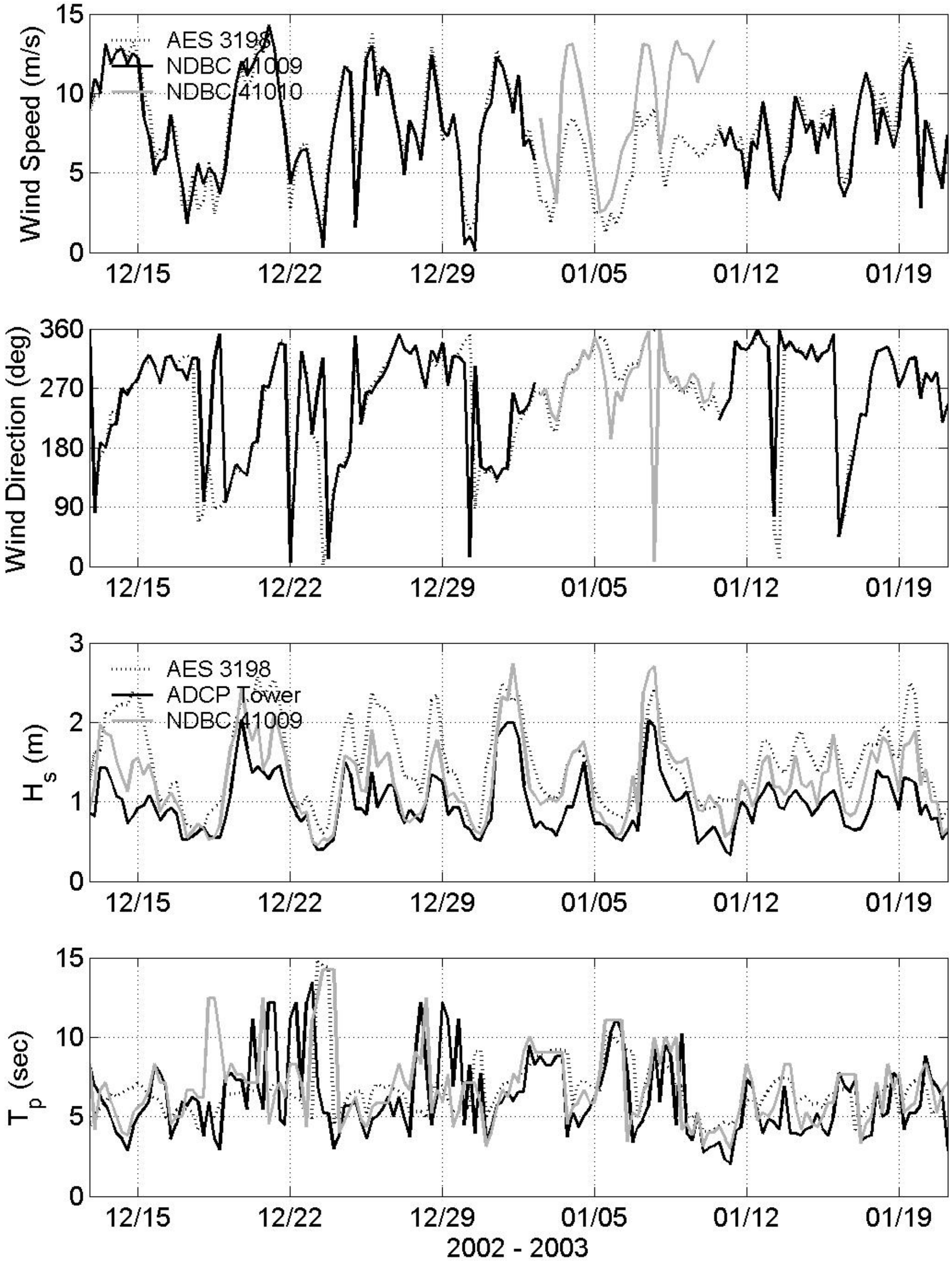

Figure 9 – Wind speed and direction from AES hindcast station 3198, NDBC buoy 41009, and NDBC buoy 41010. Significant wave height and peak wave period from AES hindcast station 3198, tower-elevated ADCP, and NDBC buoy 41009 at 6 hour intervals.

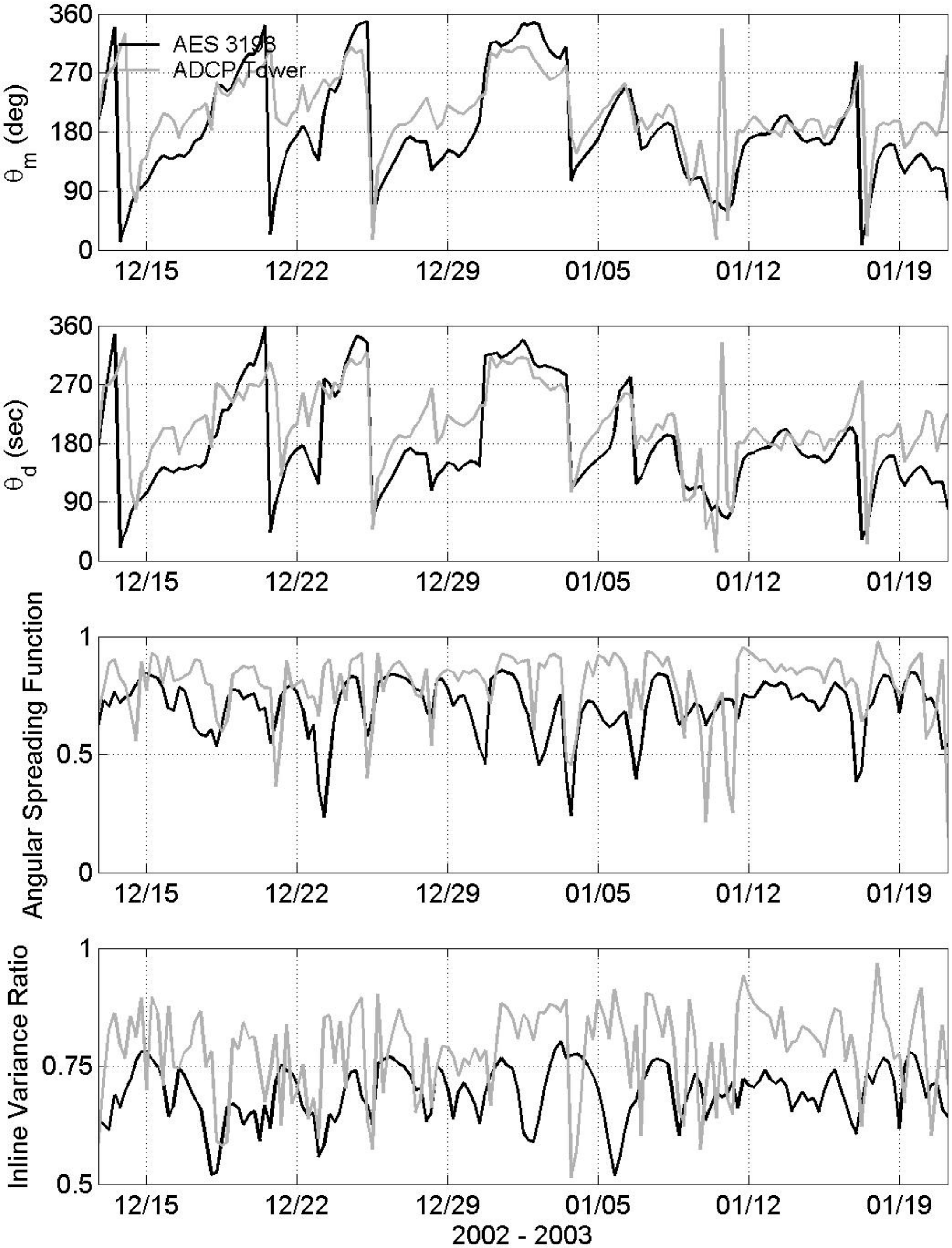

Figure 10 – Mean wave direction and dominant wave direction from AES hindcast station 3198 and the tower-elevated ADCP. The angular spreading function and the inline variance ratio are also presented.