Ocean Current and Wave Measurements at the Canaveral Harbor Ocean Dredged Material Disposal Site

January 2003 through February 2004

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1.0 INTRODUCTION

It is the responsibility of the U.S. Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers (COE) under the Marine Protection, Research, and Sanctuaries Act (MPRSA) of 1972 to manage and monitor each of the Ocean Dredged Material Disposal Sites (ODMDSs) designated by the EPA pursuant to Section 102 of MPRSA. MPRSA, the Water Resources Development Act (WRDA) of 1992, and a Memorandum of Agreement between EPA and COE require the joint development of site management and monitoring plans (SMMP) to specifically address the disposal of dredged material at ODMDSs. Additionally, the Memorandum of Understanding (MOU) between EPA Region 4 and the COE South Atlantic Division specifies that it is in the best interest of the EPA and the COE to act in partnership concerning the management and monitoring of all ODMDSs.

Management of ODMDSs involves regulating the times, the quantity, and the physical/chemical characteristics of dredged material that is dumped at the site; establishing disposal controls, conditions, and requirements to avoid and minimize potential impacts to the marine environment; and monitoring the site environs to verify that unanticipated or significant adverse effects are not occurring from past or continued use of the site and that permit terms are met.

A SMMP was developed and finalized by the EPA and COE for the Canaveral ODMDS in October 2001. The SMMP outlines strategies for monitoring the ODMDS and provides as an appendix a Long-Term Monitoring Strategy (LTMS) for the ODMDS. A study of the disposed material nearfield fate and disposal site capacity was included as part of the Canaveral ODMDS SMMP and Long-Term Monitoring Strategy (LTMS). As part of such a study, site specific data are needed. This includes physical properties such as grain size, density, and erosive properties of disposed dredged material and current and wave data at the ODMDS. The physical properties of the dredged material have been characterized under a previous work effort (SNL, 2001).

In February 2003, EPA Region 4 and the COE Jacksonville District entered into a joint agreement to jointly manage and monitor ODMDSs within the Jacksonville District. Task 1, subtask A of the agreement was to characterize the current and wave climate at the Canaveral ODMDS over a year. This report details the results of that study.

2.0 METHODS

2.1 Study Area

An area approximately 0.5 nautical miles west of the Canaveral ODMDS and 2.6 nautical miles east of Cocoa Beach, Florida (28º19.456' N, 80º33.506' W) was selected for the instrument deployment.

The instrument location is shown in figure 1. The location was selected based on an survey of the area of bottom sediments with the highest bearing capacity (McArthur, 2002). The depth at the instrument deployment was 15 meters (48 feet).

2.2 Deployment Periods

The base for the instrumentation was designed and built for EPA by the National Oceanic and Atmospheric Administration Atlantic Oceanographic and Meteorological Laboratory in Miami, Florida. The base was deployed in June, 2002. The instrument required four deployments each of 3 to 4 months beginning on January 22, 2003. The deployment periods are shown in Table 1.

Table 1: Deployment Periods

Deployment Date-Time	**Recovery Date-Time**	**Duration**
1/22/2003 1:30PM	4/26/2003 1:00PM	93 days, 23.5 hrs
4/27/2003 1:30PM	7/11/2003 3:15PM	75 days, 1.75 hrs
7/11/2003 1:45PM	10/26/03 1:15PM	106 days, 23.5 hrs
10/26/03 5:00PM	2/22/04 1:45AM[1]	118 days, 8.75 hrs

[1] Instrument stopped recording due to power limits. Instrument recovered on 2/24/04.

2.3 Instrumentation

A 600 kHz Acoustic Doppler Current Profiler(ADCP) developed by RD Instruments was used to measure wave parameters and currents. ADCPs work by transmitting sound along four separate beams at a fixed frequency and listening to the echoes returned by sound scatterers, such as plankton or small particles, in the water. By calculating the Doppler shift and time of travel of the echoes, the ADCP can calculate velocities for various depths in the water. The calculations performed by the instrument split the water column into equally sized depth cells or bins (in this case the bin size was set at 0.5 m). In each bin, an average velocity vector is calculated. The raw data from the instrument is reported as a velocity magnitude and direction for each bin.

To calculate wave parameters, the wave orbital velocities below the surface are measured by the ADCP. To get a surface height spectrum the velocity spectrum is translated to surface displacement using linear wave kinematics. The ADCP can also measure wave height spectra from its pressure sensor and from echo ranging the surface. For directional spectrum, each depth cell of the ADCP can be considered to be an independent sensor that makes a measurement of one component of the wave field velocity. The ensemble of depth cells along the four beams constitutes an array of sensors from which magnitude and directional information about the wave field can be determined. (Strong, 2000)

In this study the velocity or current profile is sampled every 15 minutes and waves every three hours. Instrument settings are summarized in table 2.

Table 2: ADCP Settings

Number of Bins	35
Bin Size	0.50 m
Pings per Ensemble- Currents	360
Interval - Currents (h:m:s)	00:15:00
Burst Duration - Waves (minutes)	20
Burst Interval - Waves (h:m:s)	03:00:00
Salinity (ppt)	35
Magnetic Variation (degrees)	-5.7
Temperature (C)	27.3
First Bin Range (m)	1.5
Last Bin Range (m)	19.02
Battery Usage (Wh) / Maximum Deployment Duration (days)	1310 / 121.5
Available Storage / Required Storage (MB)	192 / 183
Minimum Observable Wave Period for non-directional (sec)	2.04
Minimum Observable Wave Period for directional (sec)	3.05
Samples per Wave Burst	2400

The ADCP was mounted in a concrete base with it's face oriented up at approximately 0.5 meters above the bottom. Therefore, the first bin measurement is actually approximately two meters above the bottom. The base appears to have subsided into the substrate over the course of the deployment as evidenced by an increase in the average depth reading of approximately 0.4 meters and visual observations.

2.4 Data Analysis

Raw binary data files from the instrument were converted utilizing the RD Instruments software WaveMon® into binary waves data files and a binary current data files. Current data was further extracted utilizing the RD Instruments software BBLIST® for further analysis. BBLIST® exports current velocities and directions for each bin (depth) over the entire time series. Wave data was extracted utilizing the RD Instruments software WaveView® for further analysis. Output included water depth, significant wave height (average of the 1/3 largest wave), dominant wave period, and dominant wave direction.

Because the ADCP reports current data for bins beyond the surface, the bins beyond the surface need to be removed from the record. The depth and surface bins were determined using the depths reported in the WaveView® software from the pressure sensor and echo return intensity. The depth was determined to vary from 13 to 15 meters above the ADCP corresponding to bins 24 to 28. Additionally, the surface can provide scatterers in the water column that can overwhelm the side lobe suppression of the transducers. Therefore, RD Instruments (1996) cautions that data from the upper 6% of the water column can be contaminated. Echo intensity and percent good values for each bin were examined. Percent good values report percentages of 1) 3-beam transformations, 2) transformations rejected, 3) more than one bad beam and 4) 4-beam transformations for each bin and ensemble. These were examined and it was found that there was consistently a high percentage of 4 beam transformations in bins 1 through 21. Therefore, it was determined that bins 1 through 21 provide reliable current data for this analysis. This correlates to 1.5 to 12 meters above the instrument face.

Surface, bottom and depth average currents were analyzed. Bin 20 (11.5 meters) and bin 2 (2.5 meters) were selected to represent surface and bottom currents respectively. To determine average currents, the bins were averaged from bin 1 to 21. To average over the bins, each corresponding magnitude and direction value were used to calculate a north and east component for that bin at the specific time(ensemble). The north and east components were then averaged for each ensemble. These average north and average east components were then used to calculate an average current magnitude and direction for each ensemble. A C++ program, CurAvg.cpp, was written to perform these calculations over the entire data set. Tidal components were examined after smoothing the data over one hour periods utilizing both a low pass filter (Godin, 1972) and classical tidal harmonic analysis using a set of MATLAB programs, T_Tide (Pawlowicz et. al., 2002). Harmonic analysis was conducted for a 1 year data record beginning February 1, 2003.

3.0 RESULTS

3.1 Currents

A current rose for depth average currents for the entire deployment period is shown in figure 2. Currents are predominately in the north and south direction and rarely exceed 25 cm/sec in magnitude. Quarterly current roses for depth average currents are shown in figure 3. Seasonal differences due not appear to be significant. However, the second quarter lacked a strong southerly component. In both figures 2 and 3, it can be seen that northerly currents occur twice as frequently as southerly currents. Figure 4 also shows the directional difference between the four quarters. The second quarter (May-July) had the highest percentage of northerly directed currents, but in all quarters, northerly directed currents accounted for approximately 50 percentage of the measurements. Figure 5 compares the magnitude of the currents for the four quarters. The highest percentage of measurements for each quarter was between 2.5 and 5 cm/sec accounting for about 25 percent of the measurements and in all quarters 75 percent of the measurement were below 10 cm/sec. The net direction of transport as shown by a progressive vector diagram is to the north northeast (see figure 6).

The above discussions were for depth averaged currents. Near surface and near bottom currents were also examined independently. Near surface currents are 1.5 to 3.5 meters below the surface depending on tidal state. Near bottom currents are approximately 2.5 meters above the instrument face (3 meters above the bottom). Both near surface and near bottom currents were dominated by north and south currents with the predominate current direction to the north (see figure 7). Figure 7 also shows that surface currents had more frequent easterly directed currents than westerly and bottom currents had more frequent westerly directed currents than easterly currents. As is typically the case, surface currents are stronger than near bottom currents (see figure 8). The median surface current was 10 cm/sec whereas the median bottom currents was 6 cm/sec. The depth average median current velocity was 7 cm/sec. The net direction of transport (figure 6) is to the northeast for near surface currents and to the northwest for near bottom currents.

A low pass filter was applied to data smoothed over one hour periods to analyze non-tidal variability. Results for the north/south and east/west current components for August are shown in figures 9 and 10, respectively. Harmonic analysis revealed that the principal tidal constituents are K_1, O_1, M_2, N_2 and S_2 (see table 3) with M_2 dominating. Peak north/south tidal currents were on the order of 2 to 5 cm/sec and peak east/west tidal currents were on the order of 1 to 4 cm/sec. Corresponding tidal excursions are 500 meters in the north/south direction and 250 meters in the east/west direction. Tables 4 and 5 provide a summary of the tidal constituent parameters for water depth and currents, respectively. Appendix C provides the complete tidal analysis output from T_tide. Figure 11 shows the tidal cycle as represented by water depth for both the actual data set and a synthesized data set utilizing the calculated tidal constituents. Two distinct tides are seen per day.

Table 3: Principal Tidal Constituents at the Canaveral ODMDS

Symbol	**Name**	**Frequency (cycles/hour)**	**Period (hours)**
O_1	Principal lunar diurnal	0.0387	25.84
K_1	Lunisolar diurnal	0.0418	23.92
N_2	Lunar elliptic semidiurnal	0.0790	12.66
M_2	Principal lunar semidiurnal	0.0805	12.42
S_2	Principal solar semidiurnal	0.0833	12.00

Table 4: Summary of Harmonic Analysis of Water Depth

Symbol	Amplitude (meters)	Phase (degrees)
O_1	0.0691	146.06
K_1	0.1251	129.83
N_2	0.1200	225.97
M_2	0.4815	241.13
S_2	0.0601	239.79

Table 5: Summary of Harmonic Analysis of Currents

Symbol	Major Axis (cm/s)	Minor Axis (cm/s)	Inclination (cc from east-degrees)	Phase (degrees)
Surface Currents				
O_1	0.9272	0.0590	54.50	303.23
K_1	0.6333	0.1823	157.89	10.41
N_2	0.6849	0.1222	152.92	126.18
M_2	2.2153	0.0227	155.2	149.14
S_2	0.9283	-0.1942	169.01	140.7
Bottom Currents				
O_1	.04235	0.2303	90.92	316.73
K_1	0.9214	0.1702	68.44	293.00
N_2	0.375	0.1078	140.97	112.08
M_2	1.8874	-0.0112	146.19	131.33
S_2	0.3538	-0.1212	112.40	111.78
Depth Averaged Currents				
O_1	0.6614	0.1266	79.17	324.60
K_1	1.0264	-0.1280	92.76	312.50
N_2	0.5299	0.0274	151.87	128.32
M_2	2.0654	-0.0252	151.98	146.75
S_2	0.4097	0.0534	134.89	115.56

3.2 Waves

A wave rose for the entire deployment period is shown in figure 12. Waves are predominately out of the east and few exceed 2.5 meters in height. Figure 13 shows the wave roses for each quarter. Figures 14 and 15 show box plots of the monthly significant wave heights and wave periods, respectively. Monthly median significant wave heights ranged from 0.5 to 1.0 meters. The highest median wave heights and waves occurred during hurricane season. Figure 16 shows the major tropical storms for 2003. The peak wave height of greater than 3 meters occurred during the passage of Hurricane Isabel on September 17^{th}. Wave periods were typically in the 5 to 10 second range. Histograms of significant wave height and wave period are shown in figures 17 and 18. The median and mean wave height was 0.75 and 0.82 meters, respectively. The median and mean wave period was 8.5 and 8.1 seconds, respectively.

Significant wave height values were compared to offshore values collected by the National Data Bouy Center (NDBC). NDBC values are from station 41009, which is located twenty nautical miles east of Cape Canaveral, FL at 28.50° N and 80.18° W. Box plots of wave height and wave period for station 41009 are provided in figures 19 and 20. Figure 21 shows comparisons of wave height and period measurements for portions of January, February, and March, 2003. Figure 22 shows a plot of NDBC significant wave height versus the ADCP collected significant wave height. There appears to be a linear relationship for these months with a R^2 value of 0.54. Overall, the NDBC data seems to trend well with the measured significant wave height considering the distance between the measurements. The Canaveral ADCP wave heights are approximately one third of that measured at the NDBC station.

4.0 SUMMARY AND CONCLUSIONS

Currents in the vicinity of the Canaveral ODMDS tend to the north northeast paralleling the coast. There are no seasonal trends in the data, however, the highest depth averaged currents were observed during the first deployment quarter (February - April 2003). Maximum surface currents exceeded 40 cm/sec. The median surface current was 10 cm/sec whereas the median bottom current was 6 cm/sec. The depth averaged median current was 7 cm/sec. Currents are not dominated by tides although there exists a tidal component. Sandia National Labs (2001) determined that velocities on the order of 16 cm/sec are needed to initiate erosion of Canaveral Harbor dredged material. Near bottom currents of this magnitude or greater occur approximately 20 percent of the time.

As expected, waves in the vicinity of the Canaveral ODMDS are out of the east. The highest measured waves were in excess of 3 meters. The highest waves occurred during late hurricane season through the winter months (August 2003 - February 2004). The median significant wave height was 0.75 meters and the median wave period was 8.5 seconds. Wave periods are of sufficient length to influence bottom velocities at the depths of the ODMDS.

Current data from this study will be used to update the STFATE model inputs for dredged material evaluations. According to the data in this report, these should be revised in accordance with table 6:

Table 6: Recommended STFATE ambient velocity parameters

Existing Velocities (fps)			**Proposed Revised Velocities**		
Depth (ft)	Magnitude	Direction	Depth (ft)	Magnitude	Direction
average-logarithmic	0.33	0	8.2	0.33	15º from North
			37.7	0.2	348º from North

Data will also be used to model the long-term fate of dredged material at the Canaveral ODMDS utilizing MDFATE and LTFATE. Required MDFATE and LTFATE input parameters include: wave height, wave period and wave direction at three hour intervals and the tidal harmonic constituents as determined either from analysis of current and water depth measurements or from databases.

Sufficient site specific data now exists to conduct site capacity and disposed dredged material nearfield fate studies for the Canaveral ODMDS. The MDFATE and LTFATE models that will be used for the studies are currently under revision by the Corps of Engineers Engineering Research and Development Center (ERDC). Once completed, modeling of the disposal site can commence.

5.0 REFERENCES

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APPENDIX A

FIGURES

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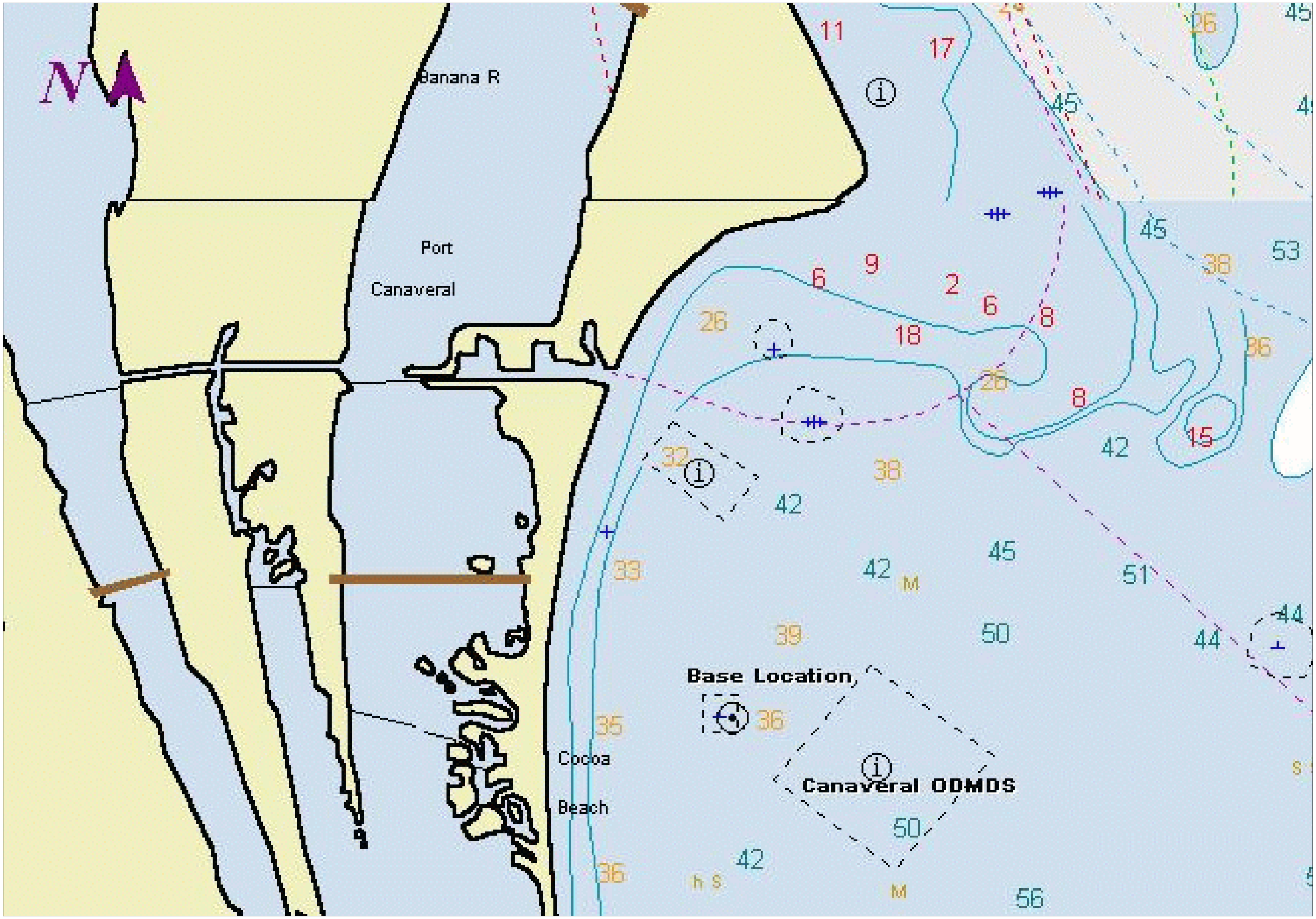


Figure 1: Instrument Location

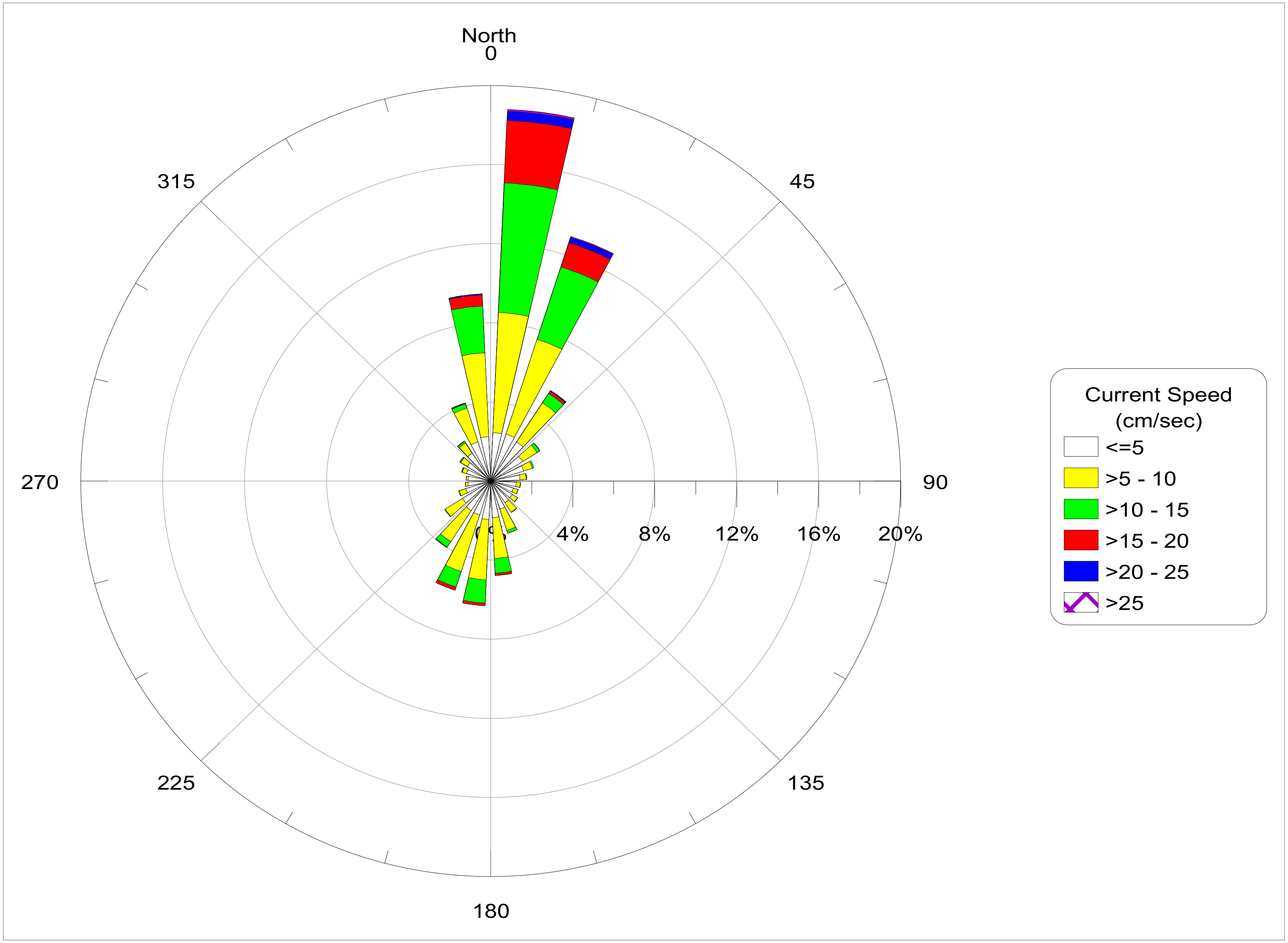


Figure 2: Depth averaged current rose.

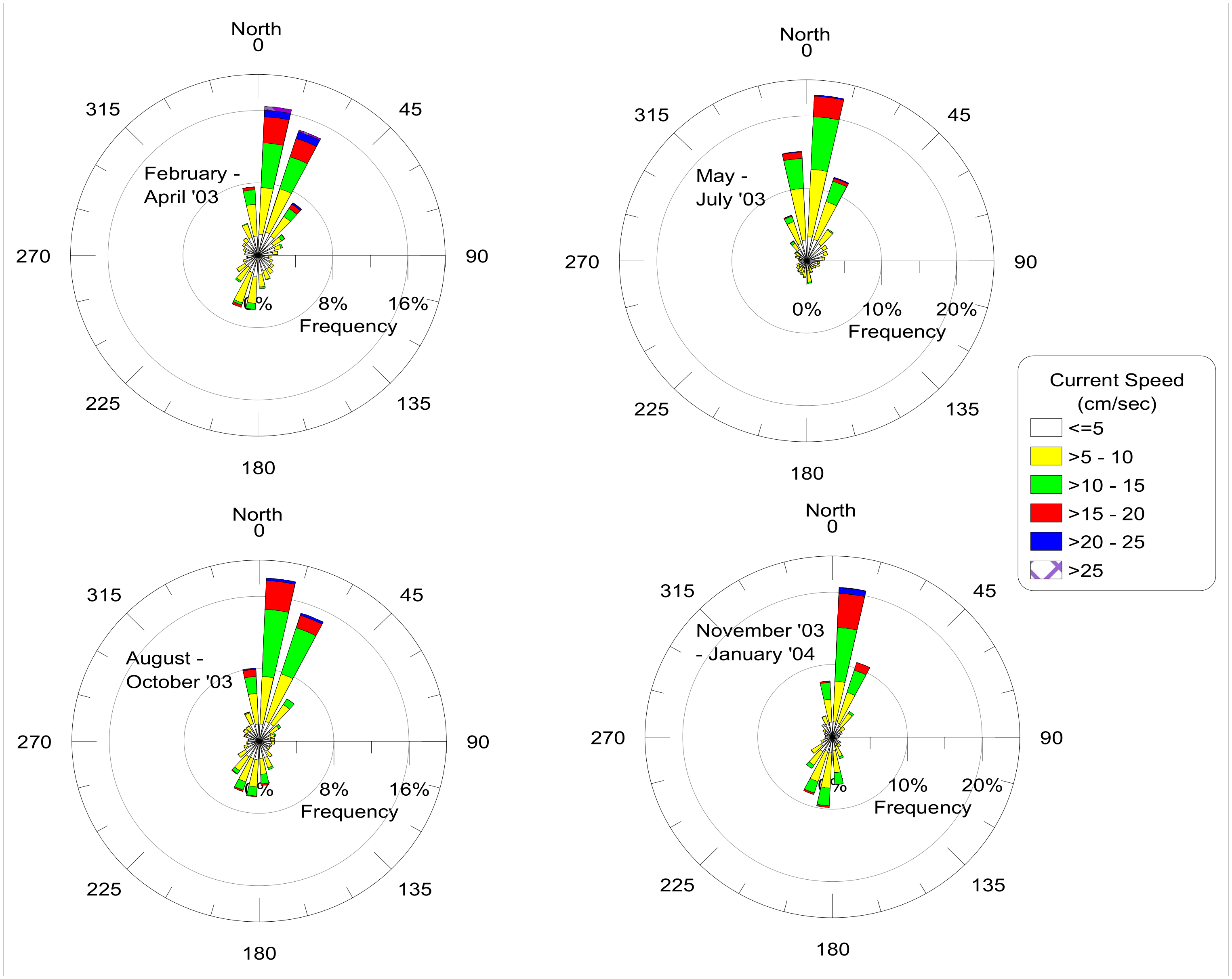


Figure 3: Quarterly depth averaged current roses.

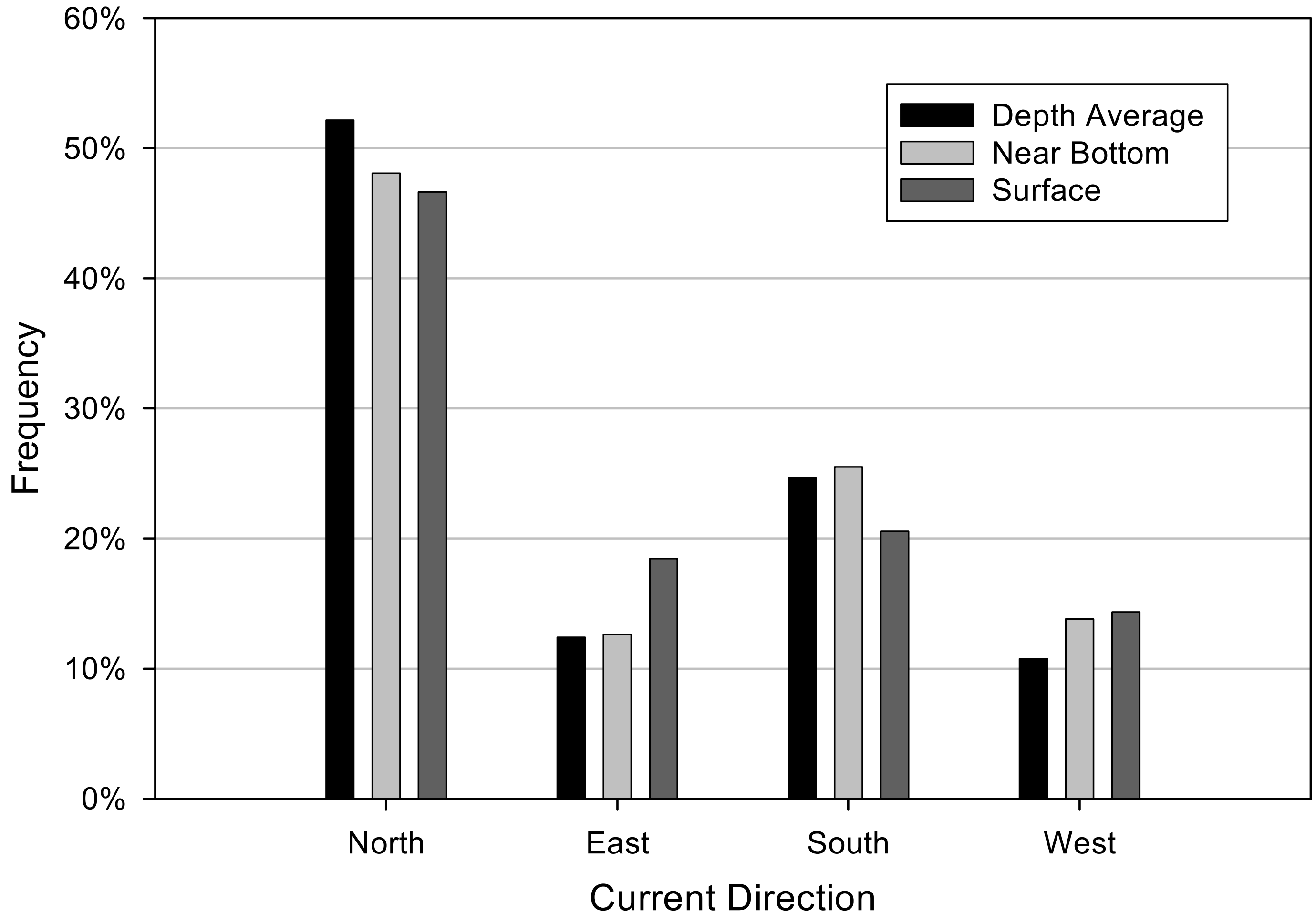


Figure 4: Quarterly current direction histograms.

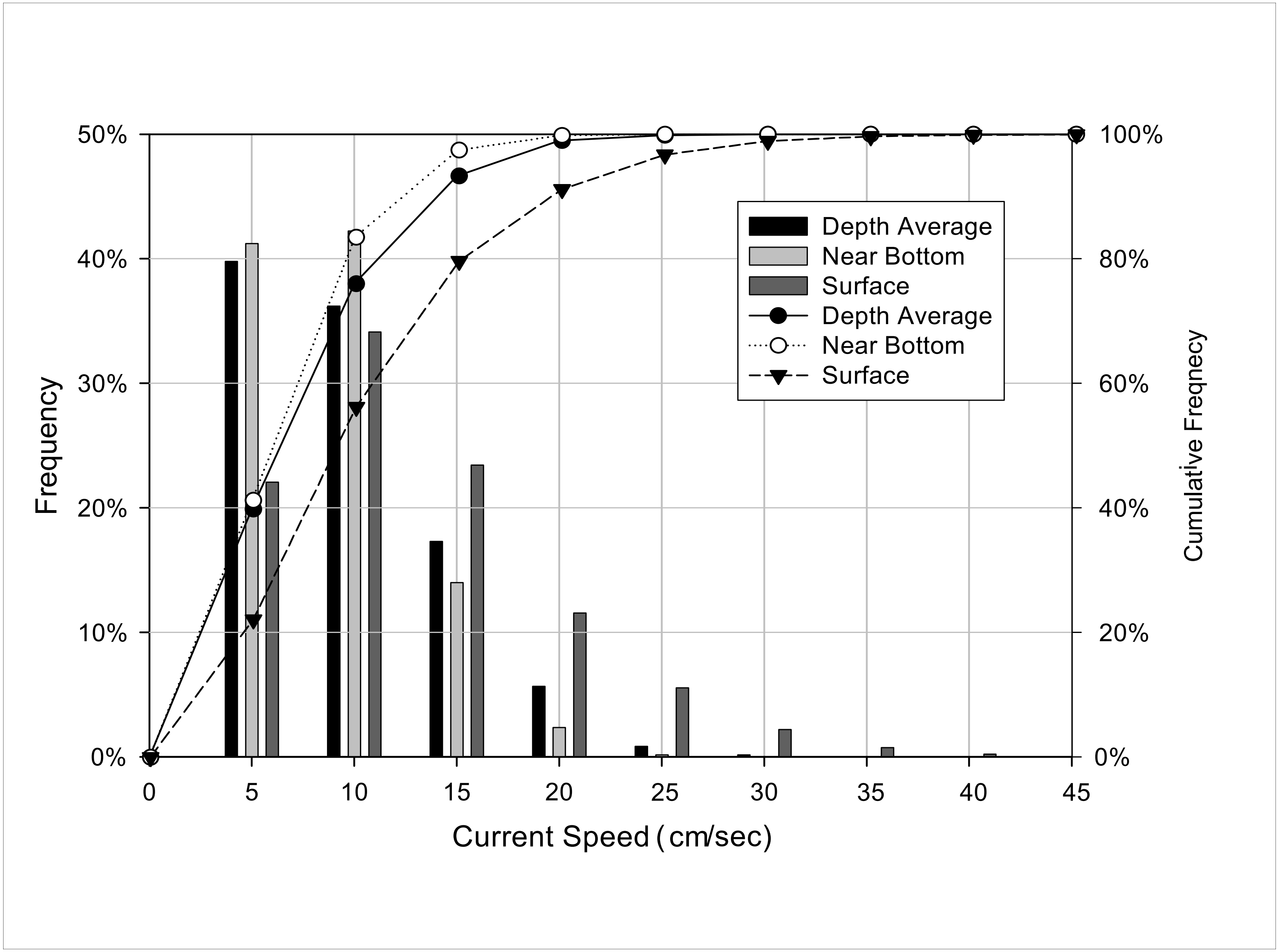


Figure 5: Quarterly current magnitude histograms.

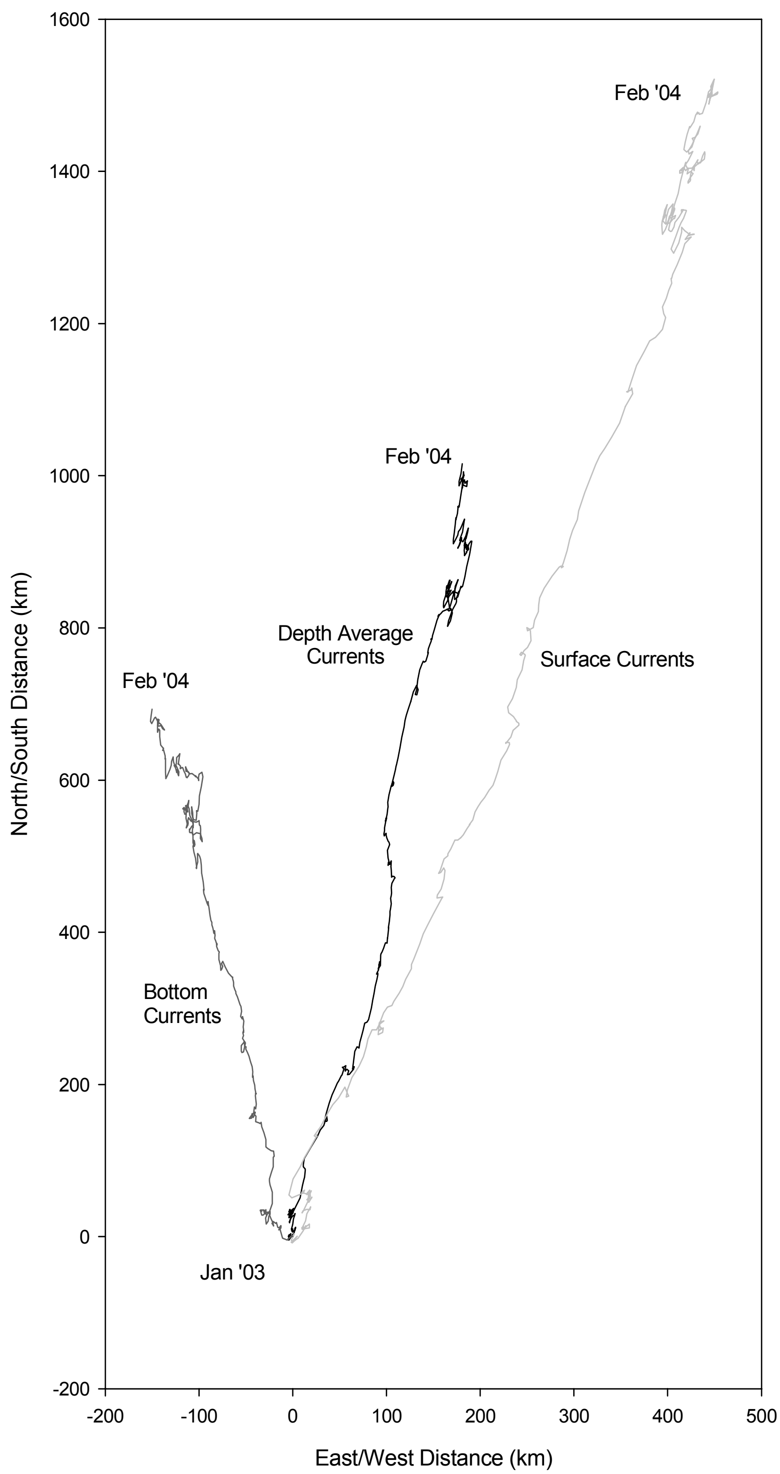


Figure 6: Progressive vector diagram.

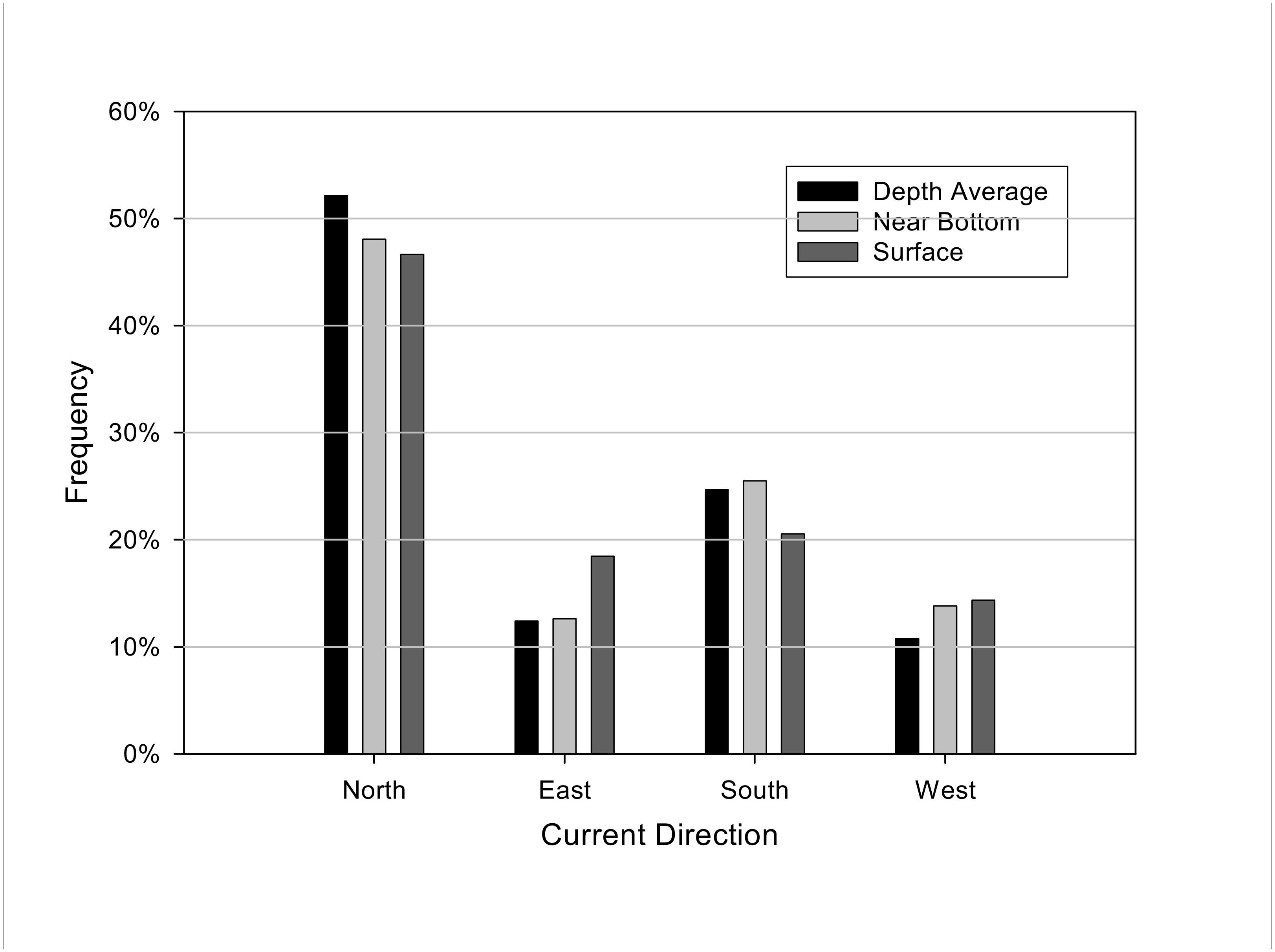


Figure 7: Current direction histogram for depth average, bottom and surface currents.

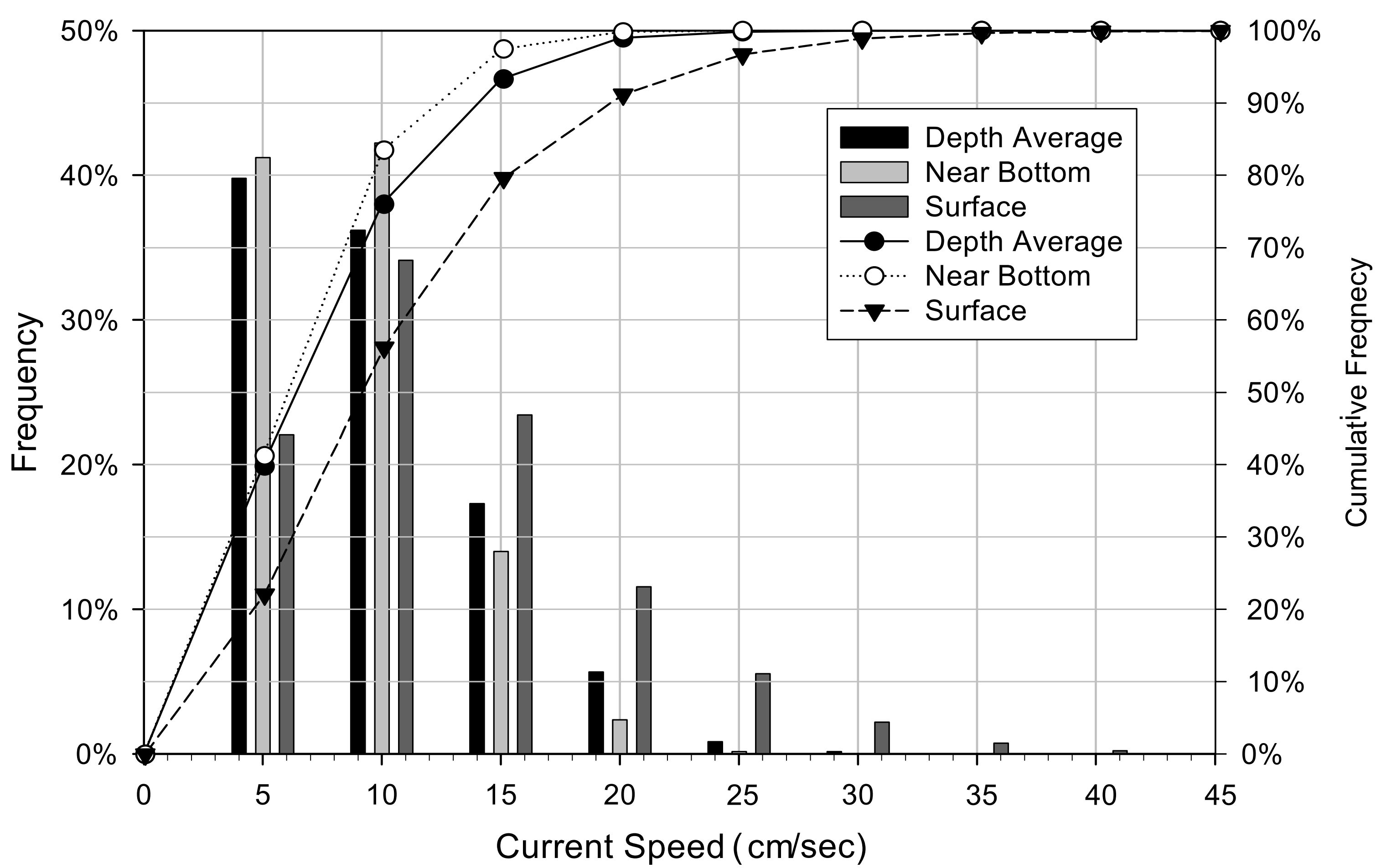


Figure 8: Current magnitude histograms for depth average, bottom, and surface currents.

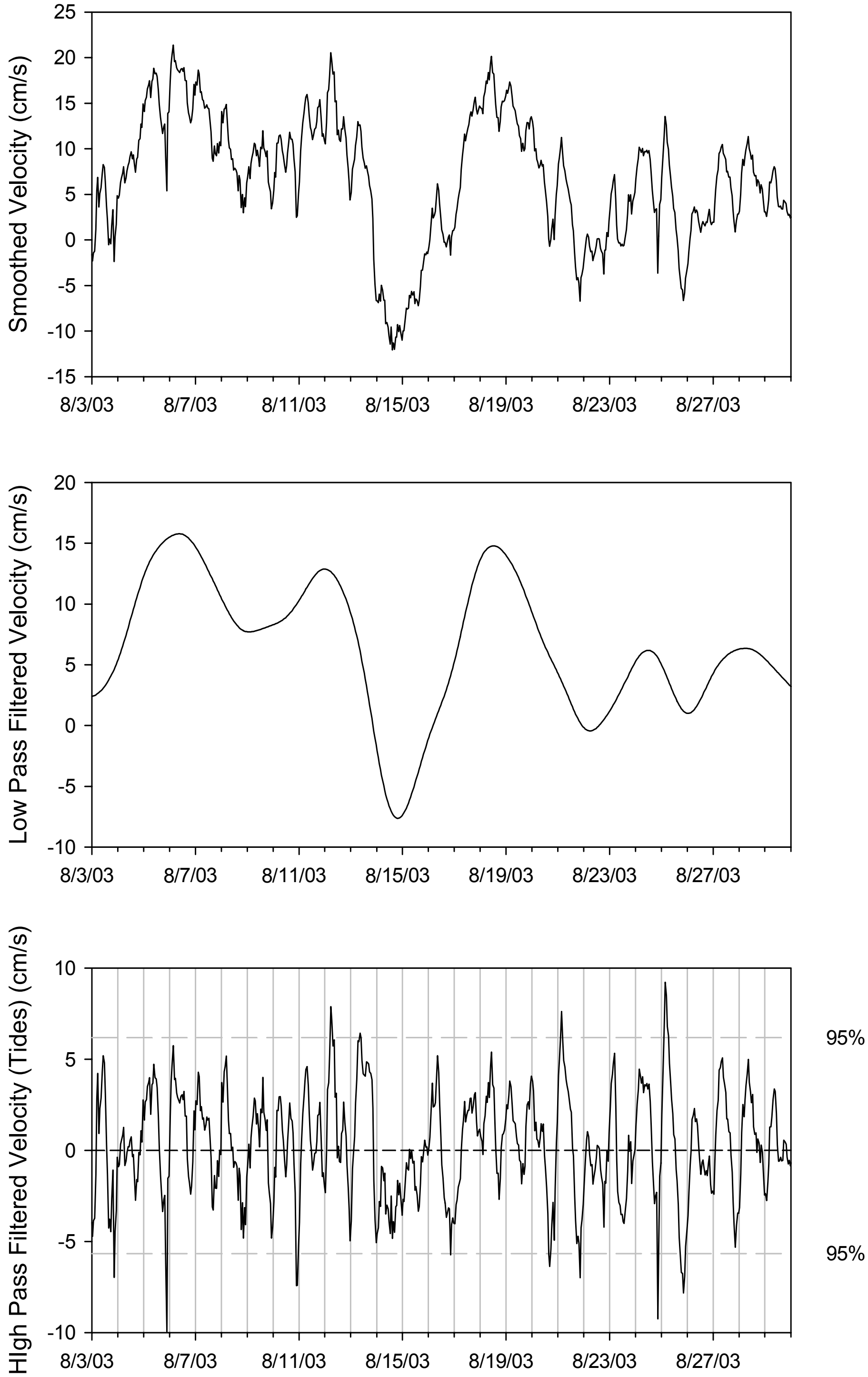


Figure 9: Filtered currents (north component) for August 2003.

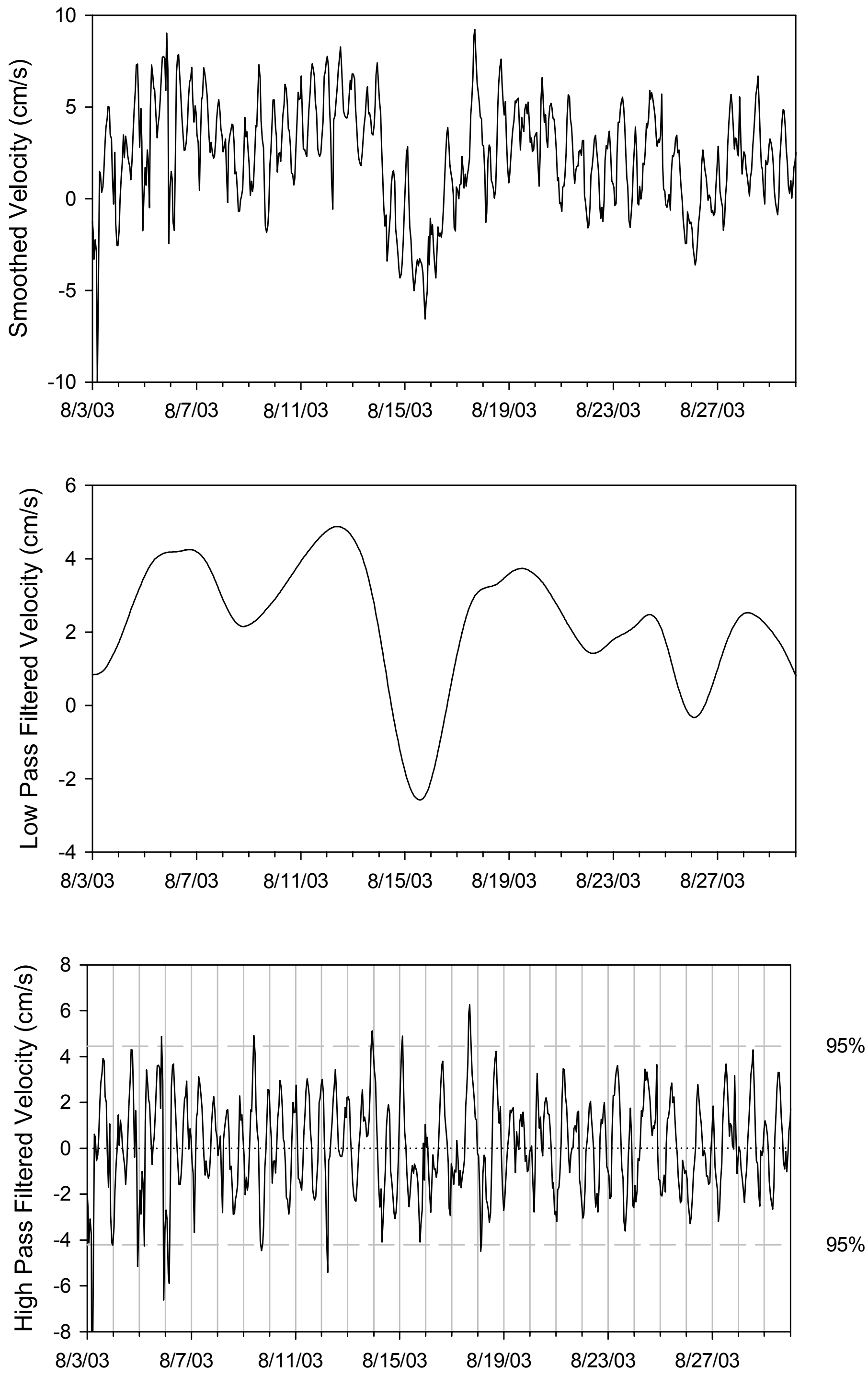


Figure 10: Filtered currents (east component) for August 2003.

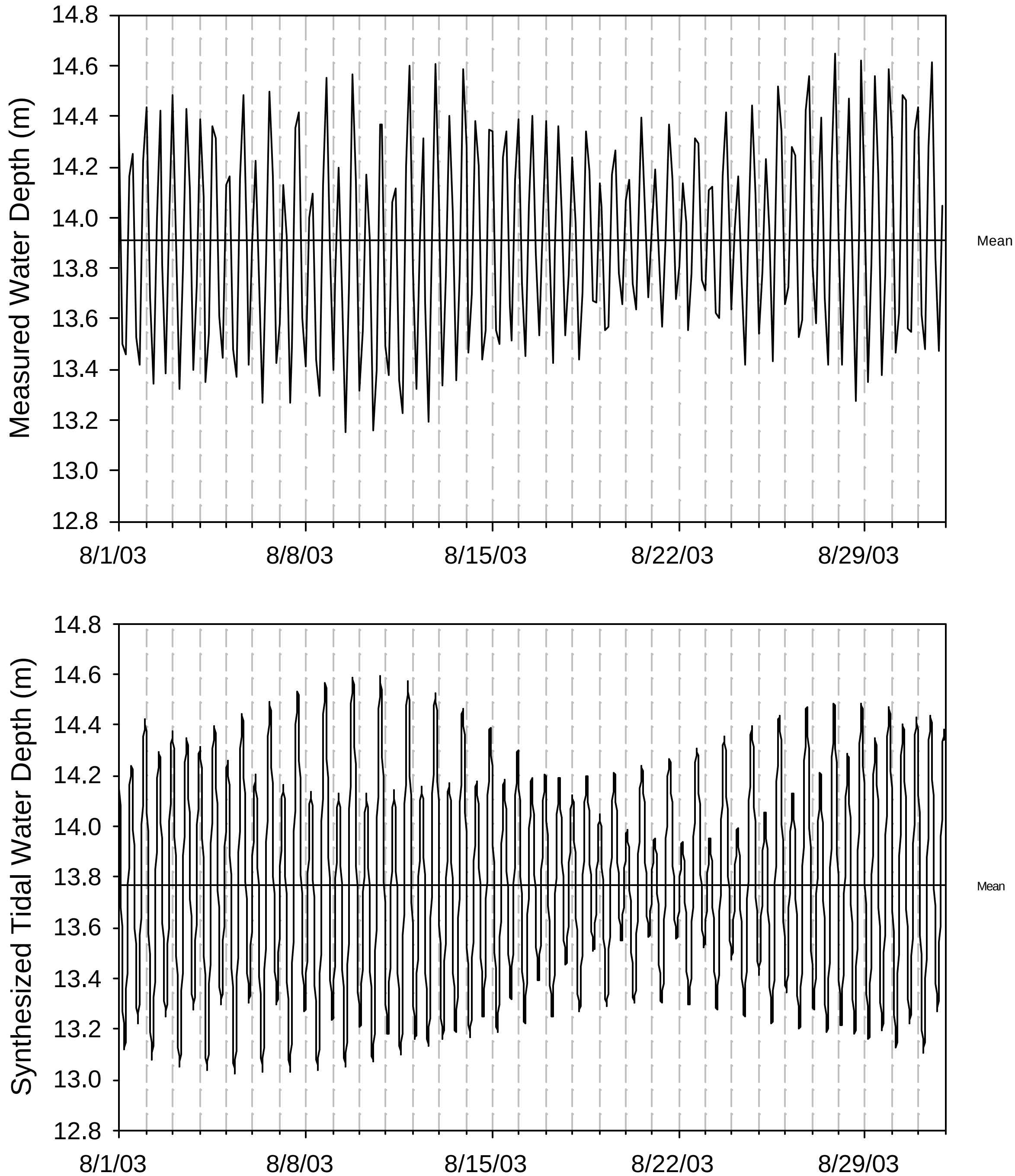


Figure 11: August 2003 measured and synthesized water depth. Synthesized water depth from harmonic constituents.

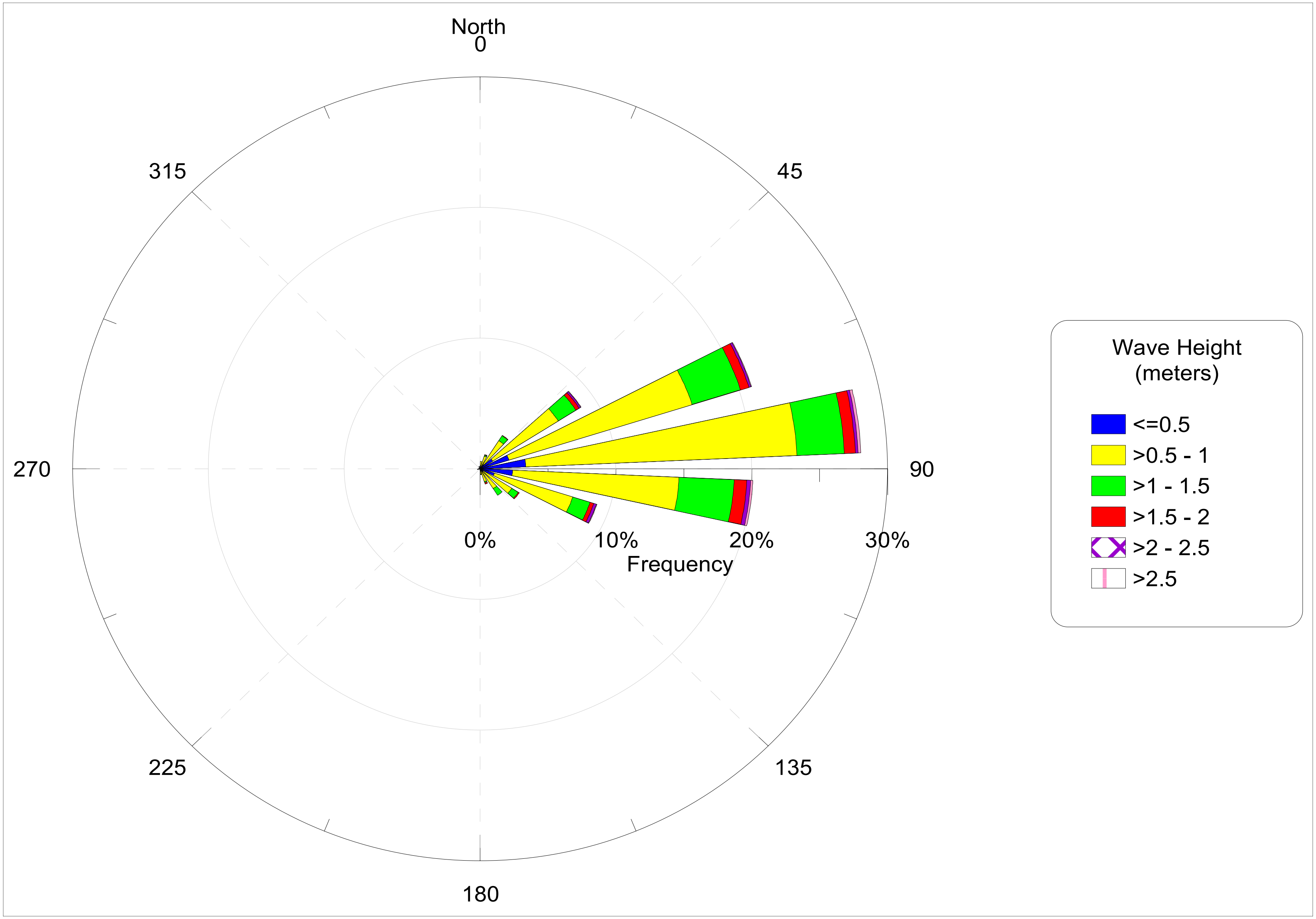


Figure 12: Wave height rose.

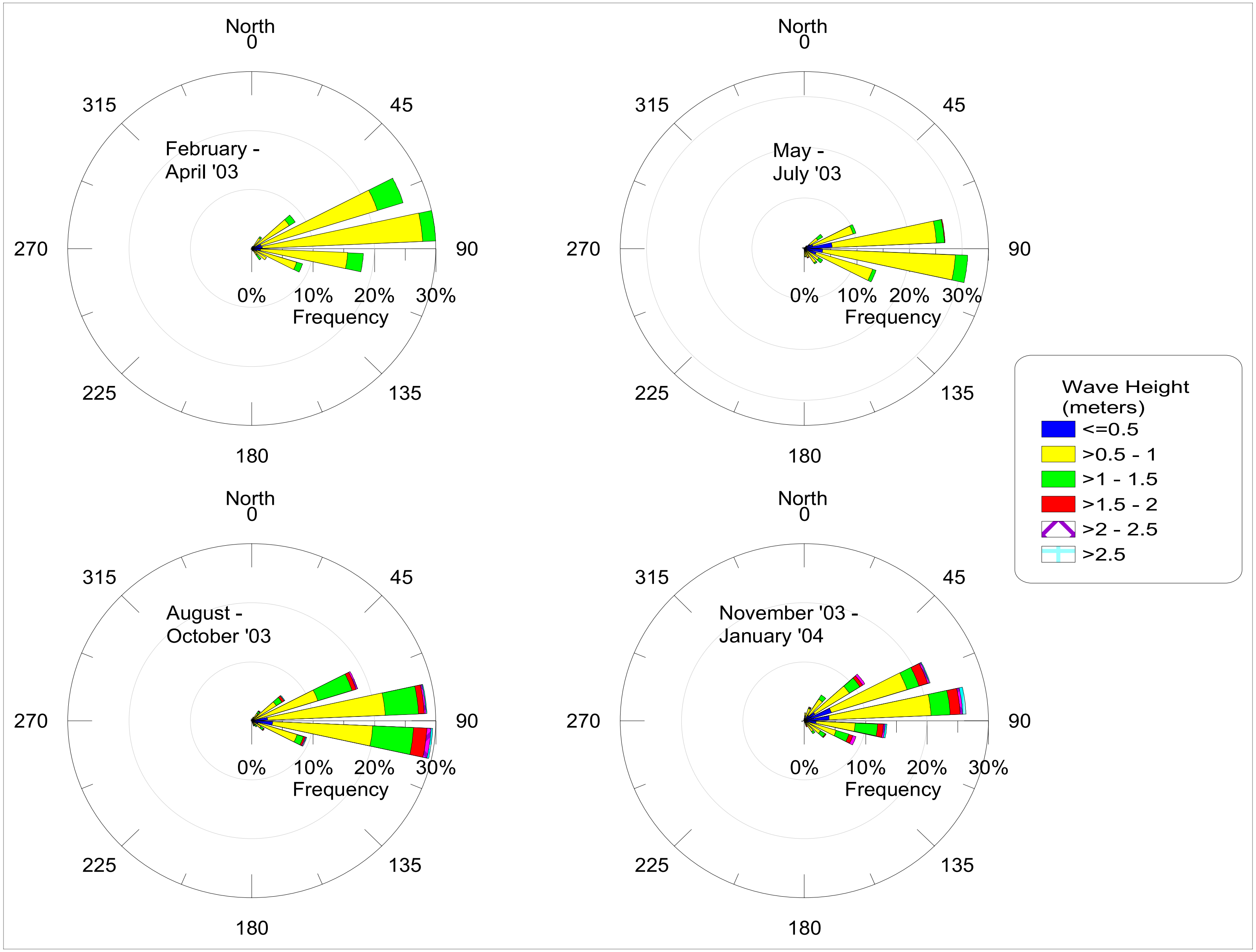


Figure 13: Quarterly wave roses.

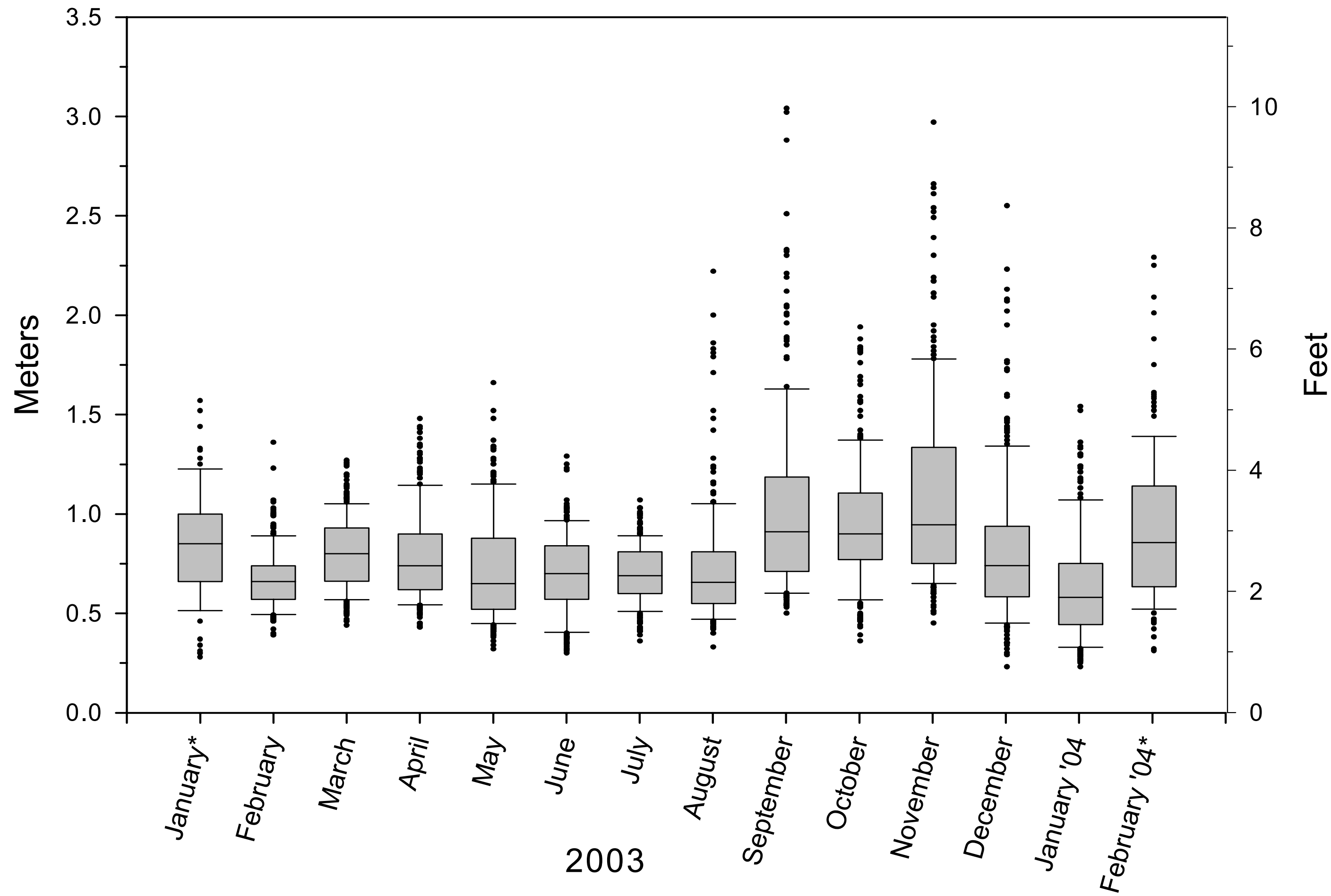


Figure 14: Box plot of significant wave height. The boundary of the box closest to zero indicates the 25th percentile, the line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers above and below the box indicate the 90th and 10th percentiles. Dots represents outliers. * indicates partial month.

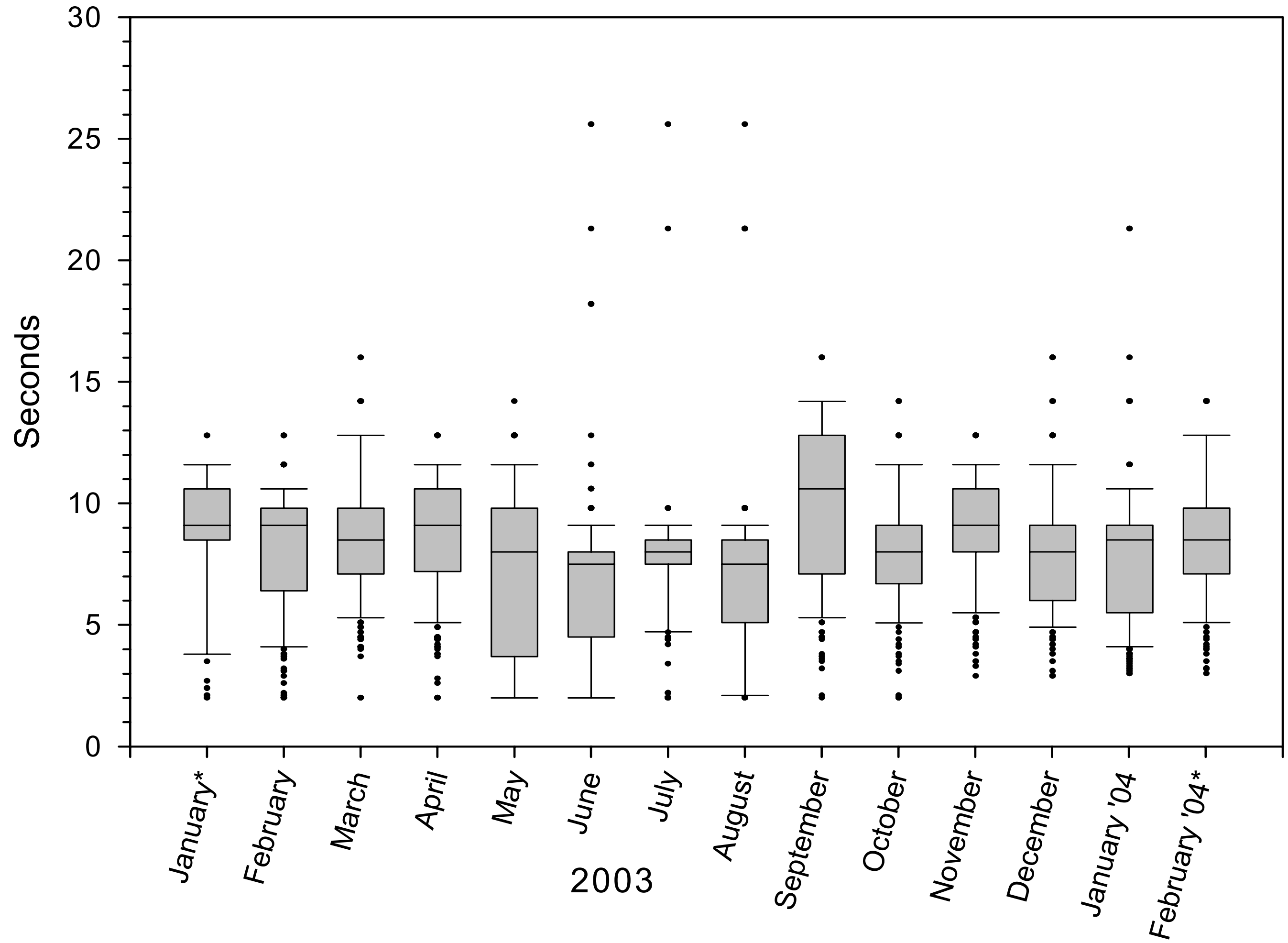


Figure 15: Box plot of peak wave period. The boundary of the box closest to zero indicates the 25th percentile, the line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers above and below the box indicate the 90th and 10th percentiles. Dots represents outliers. * indicates partial month.

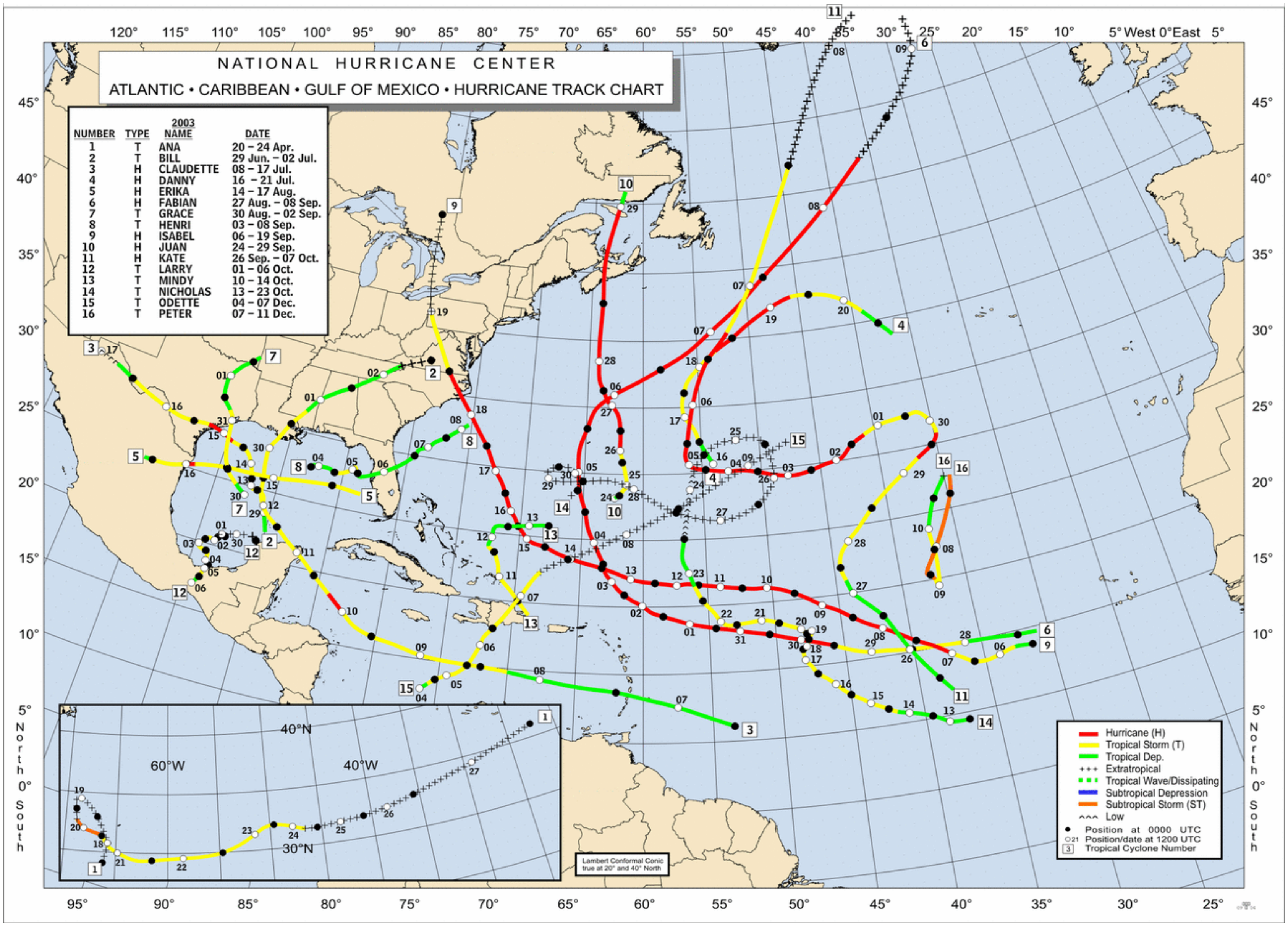


Figure 16: National Hurricane Center 2003 storm track chart.

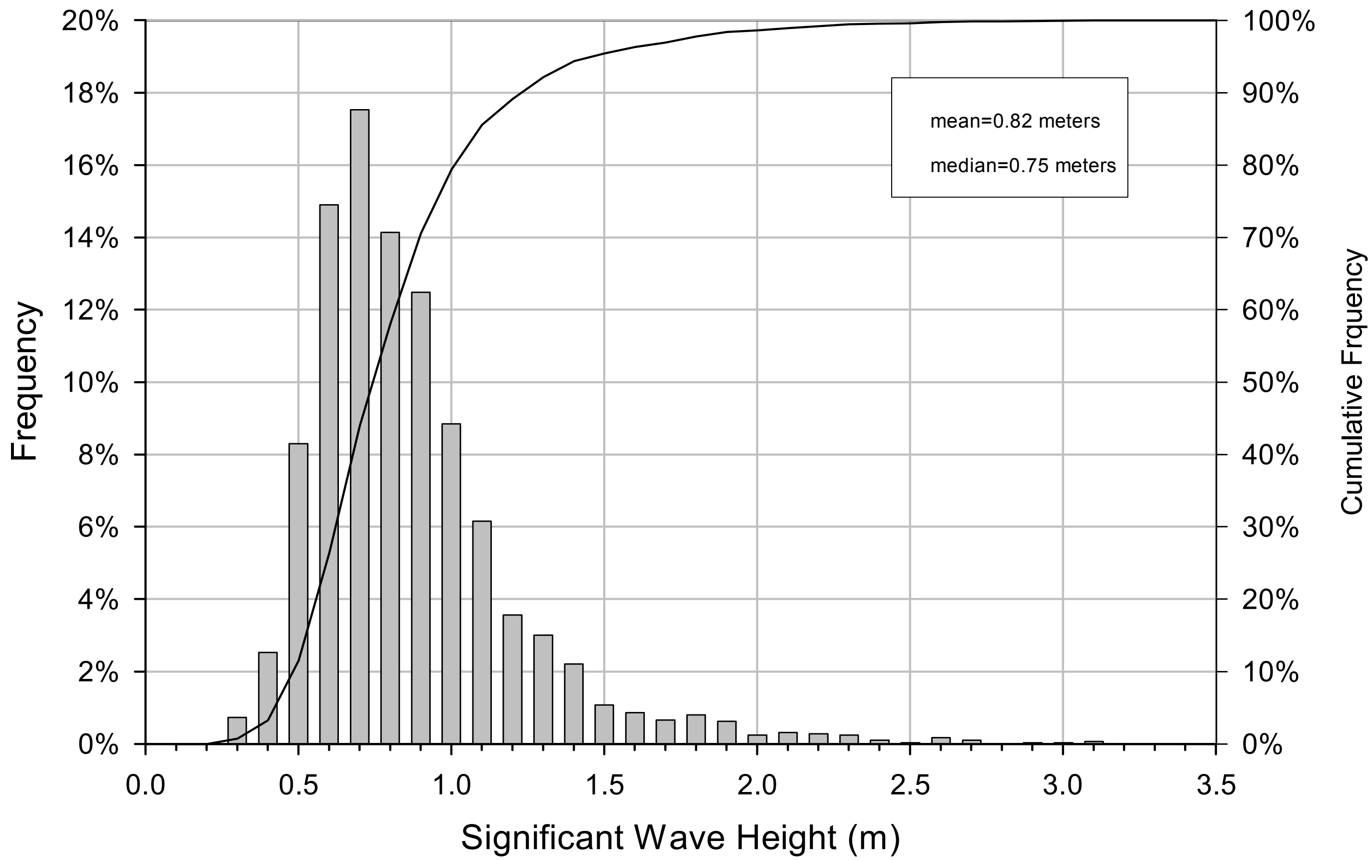


Figure 17: Significant wave height histogram.

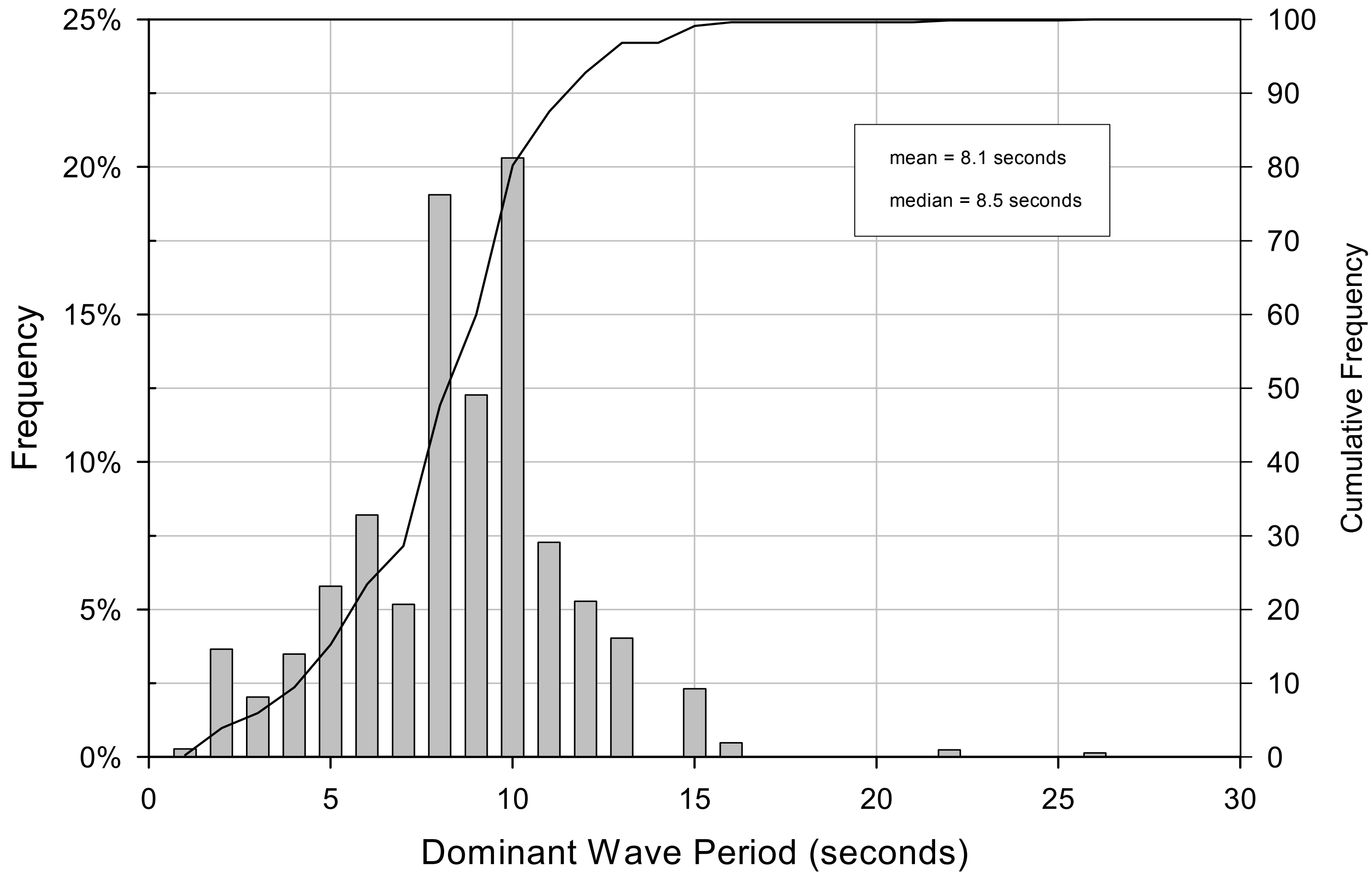


Figure 18: Dominant wave period histogram.

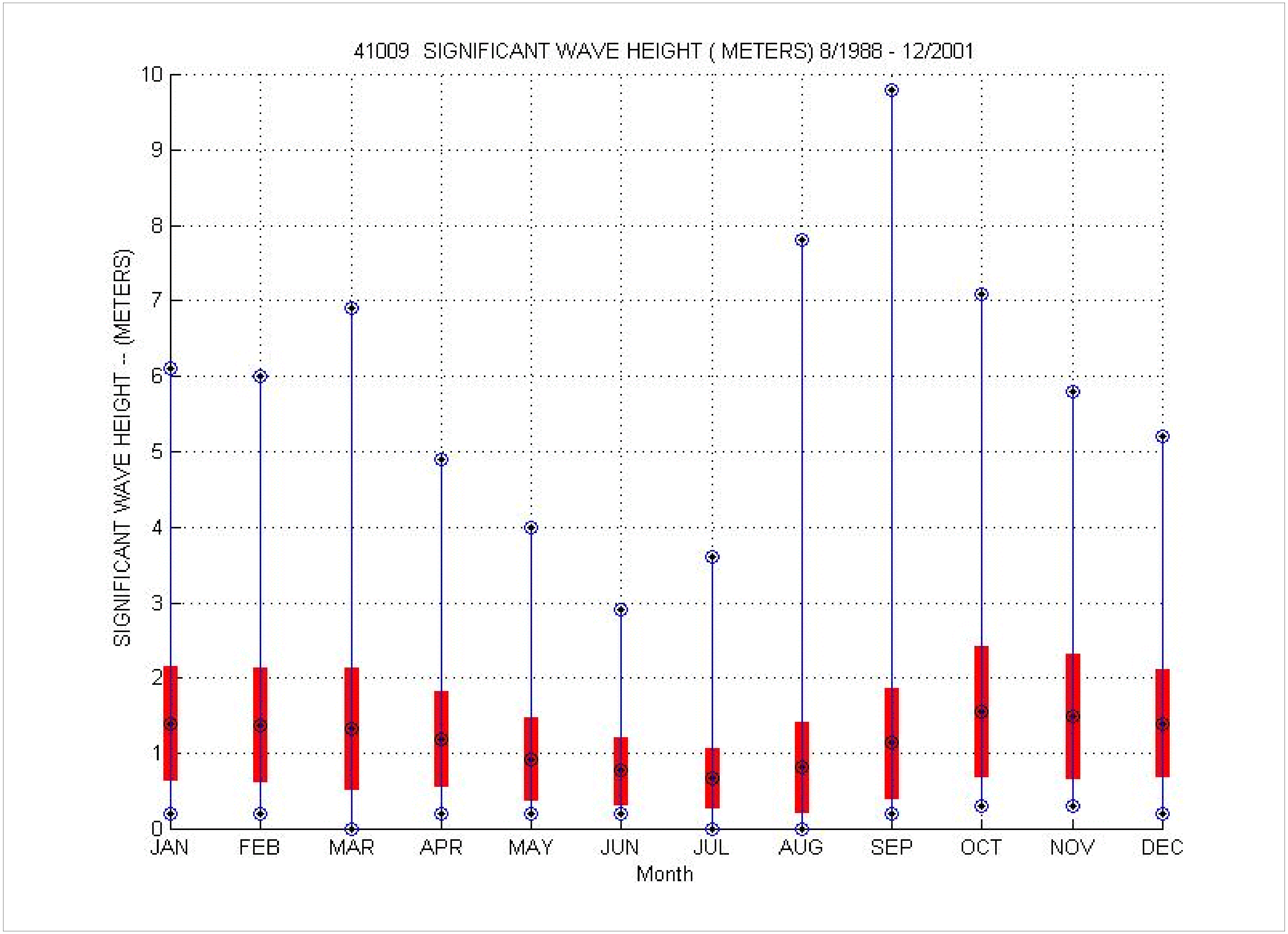
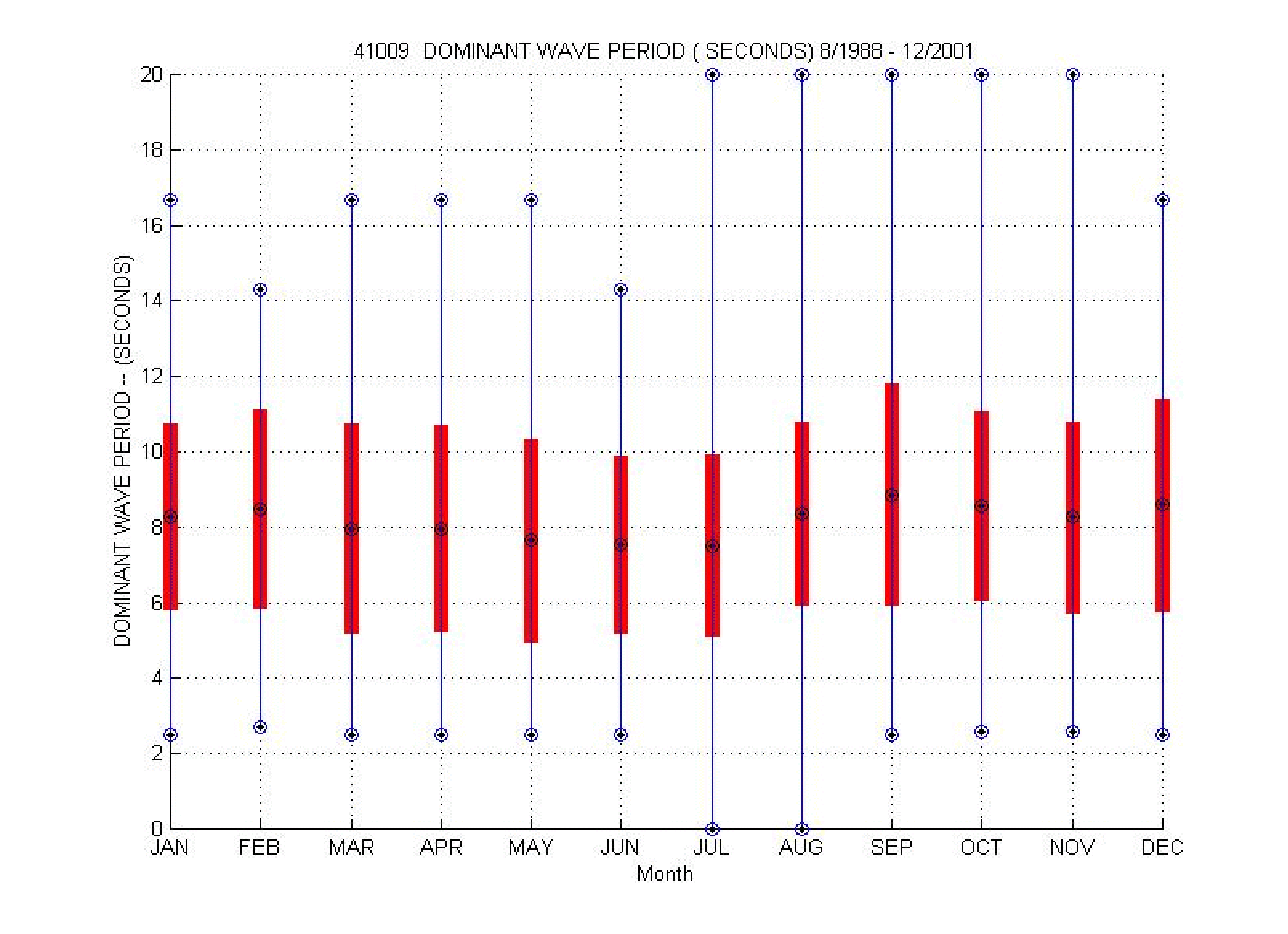


Figure 19: Box plot of significant wave height at the National Data Buoy Center station 41009.



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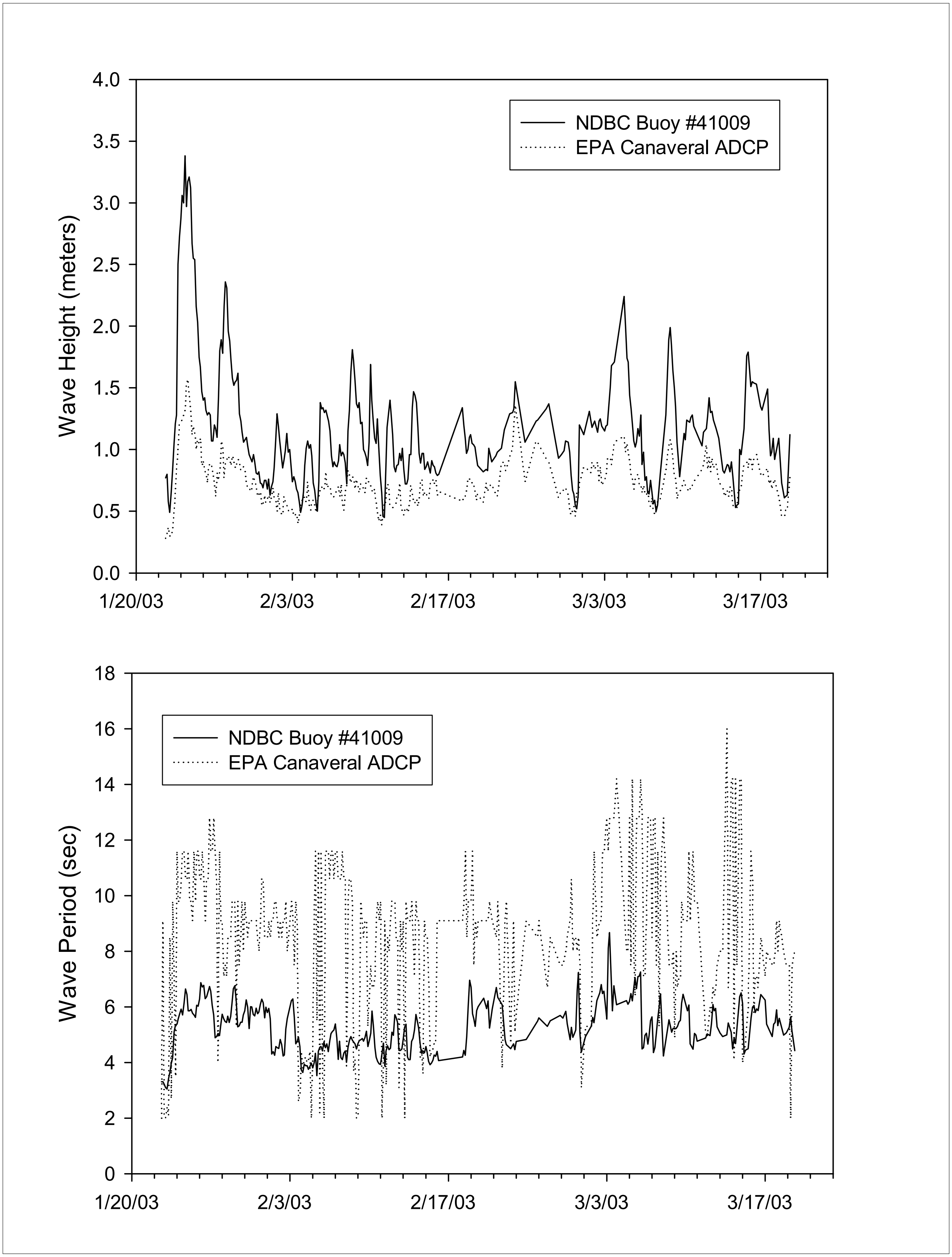

Figure 21: Comparison of National Data Buoy Center station 41009 and EPA ADCP significant wave height and dominant wave period measurements for portions of January, February and March, 2003.

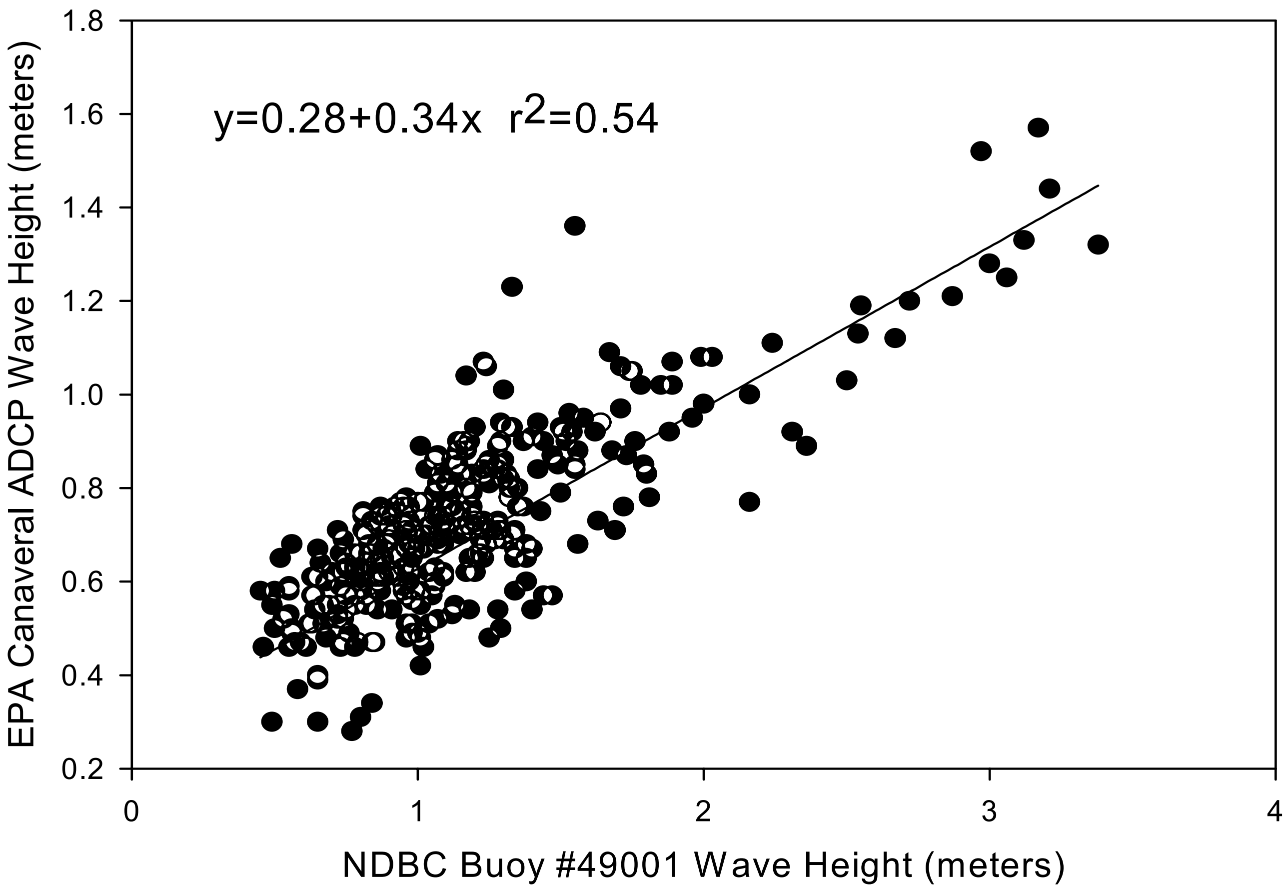

Figure 22: Regression analysis of National Data Buoy Center station 41009 and EPA ADCP significant wave height measurement for portions of January, February, and March of 2003.

APPENDIX B

DATA FILES

Processed Data
Canaveral_ODMDS_Current_Wave_Study.pdf . . . . Study Report
Canaveral_Bottom_Currents.xls . . . . Bottom currents listed by month.
Canaveral_Surface_Currents.xls . . . . Surface currents listed by month.
Canaveral_depth_avg_currents.xls . . . . Depth averaged currents listed by month.
Canaveral_waves.xls . . . . Wave height, period, direction and water depth by month.
1yr_bottom_currents.csv . . . . Bottom current series from 2/1/03 to 1/31/04
1yr_surface_currents.csv . . . . Surface current series from 2/1/03 to 1/31/04
1yr_depth_average.csv . . . . Depth average current series from 2/1/03 to 1/31/04

Binary Current Data
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Canaveral01_CurrentsData.002
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Canaveral02_CurrentsData.001
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Canaveral04_CurrentsData.003
Canaveral04_CurrentsData.004 . . . . Deployment 4 binary ADCP current data

Binary Wave Data
Canaveral01_ProcWvsData_000.wvs
Canaveral01_ProcWvsData_001.wvs . . . . Deployment 1 binary wave data

Canaveral02_ProcWvsData_000.wvs
Canaveral02_ProcWvsData_001.wvs . . . . Deployment 2 binary wave data

Canaveral03_ProcWvsData_000.wvs
Canaveral03_ProcWvsData_001.wvs . . . . Deployment 3 binary wave data

Canaveral04_ProcWvsData_000.wvs
Canaveral04_ProcWvsData_001.wvs
Canaveral04_ProcWvsData_002.wvs . . . . Deployment 4 binary wave data

APPENDIX C

COMPLETE TIDAL ANALYSIS OUTPUT FROM T_TIDE

T_TIDE output includes the following columns:

- tide: tidal constituent
- freq: frequency (cycles/hour)

Currents

- major: major axis of tidal ellipse (mm/sec)
- emaj: error estimate (95% confidence limit) for major axis (mm/sec)
- minor: minor axis of tidal ellipse (mm/sec)
- emin: error estimate (95% confidence limit) for minor axis (mm/sec)
- inc: inclination of major axis (counter clockwise from east in degrees)
- einc: error estimate (95% confidence limit) for inclination (degrees)

Water Depth

- amp: amplitude (meters)
- amp_err: error estimate (95% confidence limit) for amplitude (meters)

- phase: constituent phases (degrees relative to Greenwich)
- epha: error estimate (95% confidence limit) of phase (degrees)
- snr: signal to noise ratio

Bottom Currents

file name: bottom_vel
date: 21-Jan-2005
nobs = 8760, ngood = 8707, record length (days) = 365.00
start time: 01-Feb-2003
rayleigh criterion = 1.0
Greenwich phase computed with nodal corrections applied to amplitude \n and phase relative to center time

x0= -4.19, x trend= 0

var(x)= 856.7993   var(xp)= 136.6313   var(xres)= 719.1858
percent var predicted/var original= 15.9 %

y0= 21.1, x trend= 0

var(y)= 3892.6318   var(yp)= 133.4274 var(yres)= 3757.5217
percent var predicted/var original= 3.4 %

ellipse parameters with 95%% CI estimates

tide	freq	major	emaj	minor	emin	inc	einc	pha	epha	snr
SSA	0.0002282	3.304	8.129	0.569	5.73	170.84	56.39	206.83	172.40	0.17
MSM	0.0013098	5.906	11.653	0.124	3.55	96.36	26.52	211.93	124.77	0.26
MM	0.0015122	6.241	10.504	0.832	4.19	97.08	31.55	282.04	113.82	0.35
MSF	0.0028219	16.083	11.888	0.373	3.66	81.81	14.62	219.64	52.31	1.8
MF	0.0030501	3.315	8.990	-0.369	4.16	109.03	33.53	38.93	168.42	0.14
ALP1	0.0343966	1.493	2.079	-0.556	1.79	108.94	105.49	114.06	126.57	0.52
2Q1	0.0357064	1.259	2.103	-0.609	2.04	54.83	97.59	103.71	140.25	0.36
SIG1	0.0359087	2.487	2.005	-1.385	2.39	40.08	87.62	270.04	95.96	1.5
Q1	0.0372185	1.916	2.038	0.199	2.21	49.14	76.42	229.96	93.70	0.88
RHO1	0.0374209	1.645	1.818	-0.987	2.09	148.56	109.00	43.07	135.12	0.82
*O1	0.0387307	4.235	2.428	2.303	2.21	90.92	56.27	316.73	67.76	3
TAU1	0.0389588	1.233	2.501	0.213	2.40	123.74	109.70	95.72	168.19	0.24
BET1	0.0400404	1.237	1.809	-0.164	1.98	51.75	94.61	346.03	125.96	0.47
*NO1	0.0402686	3.978	2.319	-0.136	2.17	66.06	34.58	340.07	35.09	2.9
CHI1	0.0404710	1.981	2.125	-1.092	2.01	70.53	91.57	281.66	102.62	0.87
*P1	0.0415526	4.336	2.903	-0.857	2.70	81.33	43.28	326.00	48.79	2.2
*K1	0.0417807	9.214	3.013	1.702	2.61	68.44	19.63	293.00	20.25	9.3
PHI1	0.0420089	2.939	2.931	-2.612	2.91	69.96	124.26	76.58	128.81	1
THE1	0.0430905	1.887	2.153	-1.388	2.16	13.99	114.11	18.50	112.08	0.77
J1	0.0432929	2.608	2.280	-0.149	2.30	57.47	62.57	321.35	74.67	1.3
SO1	0.0446027	1.755	2.173	-0.080	2.25	90.88	89.14	3.28	109.29	0.65
OO1	0.0448308	1.559	1.588	-0.402	1.69	25.93	91.19	60.47	79.18	0.96
UPS1	0.0463430	0.381	1.321	-0.005	1.31	71.06	121.27	234.62	241.52	0.083
OQ2	0.0759749	1.639	1.608	0.068	1.77	96.00	80.16	340.57	91.12	1
EPS2	0.0761773	0.994	1.397	-0.011	1.40	15.32	107.41	193.29	128.48	0.51
2N2	0.0774871	1.804	1.627	-0.454	1.67	65.92	73.63	43.33	72.09	1.2
MU2	0.0776895	0.707	1.231	-0.465	1.33	81.52	123.67	221.04	161.44	0.33
*N2	0.0789992	3.750	1.839	1.078	1.74	140.97	34.93	112.08	27.88	4.2
NU2	0.0792016	1.362	1.493	0.276	1.47	146.42	92.39	112.79	86.87	0.83
*M2	0.0805114	18.874	1.574	-0.112	1.71	146.19	5.18	131.33	6.06	1.4e+002
MKS2	0.0807396	1.504	1.252	-0.858	1.23	175.70	96.07	336.31	94.36	1.4
LDA2	0.0818212	1.881	1.576	-0.377	1.56	7.63	60.68	5.39	61.40	1.4
L2	0.0820236	1.433	1.403	-0.034	1.29	116.36	72.02	4.57	74.91	1
*S2	0.0833333	3.538	1.795	-1.212	1.57	112.40	34.88	111.78	37.94	3.9

K2	0.0835615	1.025	1.071	-0.553	1.21	171.40	98.07	89.78	108.24	0.92
MSN2	0.0848455	1.023	1.384	0.046	1.40	4.82	98.04	14.14	104.61	0.55
ETA2	0.0850736	0.653	1.062	0.042	0.93	45.37	110.81	33.56	129.70	0.38
MO3	0.1192421	0.753	0.864	0.113	0.63	143.27	66.83	175.45	72.96	0.76
M3	0.1207671	0.332	0.635	0.149	0.74	142.63	109.72	160.42	174.74	0.27
SO3	0.1220640	0.540	0.687	0.131	0.56	165.96	84.56	147.10	132.16	0.62
MK3	0.1222921	0.305	0.628	0.167	0.63	76.57	131.68	311.07	169.69	0.24
SK3	0.1251141	0.779	0.765	0.162	0.71	37.12	70.33	264.66	70.82	1
MN4	0.1595106	0.481	0.523	-0.081	0.52	86.25	93.37	88.68	99.29	0.85
M4	0.1610228	0.734	0.533	0.537	0.63	130.80	95.39	109.47	102.40	1.9
SN4	0.1623326	0.294	0.606	0.209	0.51	102.08	132.25	277.94	152.35	0.24
MS4	0.1638447	0.775	0.596	-0.657	0.59	7.22	104.08	244.57	115.87	1.7
MK4	0.1640729	0.159	0.346	-0.085	0.41	144.43	114.17	219.30	160.82	0.21
S4	0.1666667	0.805	0.698	-0.156	0.61	3.35	55.08	352.55	55.13	1.3
SK4	0.1668948	0.288	0.404	-0.117	0.45	50.29	116.52	291.36	123.54	0.51
2MK5	0.2028035	0.391	0.401	0.073	0.44	99.12	94.24	246.28	86.09	0.95
2SK5	0.2084474	0.399	0.439	-0.044	0.38	147.74	71.97	149.92	89.54	0.82
2MN6	0.2400221	0.633	0.498	-0.114	0.42	179.36	50.28	112.28	51.60	1.6
M6	0.2415342	0.667	0.477	0.082	0.42	167.31	46.34	159.90	50.74	1.9
2MS6	0.2443561	0.617	0.488	-0.083	0.46	150.16	44.70	204.05	56.16	1.6
2MK6	0.2445843	0.133	0.267	-0.033	0.27	114.38	121.72	74.01	176.42	0.25
2SM6	0.2471781	0.361	0.435	-0.051	0.39	52.56	83.56	82.69	77.05	0.69
MSK6	0.2474062	0.381	0.344	-0.089	0.37	106.34	80.20	81.51	71.59	1.2
3MK7	0.2833149	0.279	0.324	-0.174	0.34	132.22	117.89	36.57	126.54	0.74
M8	0.3220456	0.305	0.313	-0.077	0.32	18.78	85.90	244.03	93.21	0.95

total var= 4749.4311   pred var= 270.0586
percent total var predicted/var original= 5.7 %

Surface Currents

file name: surf_vel
date: 21-Jan-2005
nobs = 8760, ngood = 8707, record length (days) = 365.00
start time: 01-Feb-2003
rayleigh criterion = 1.0
Greenwich phase computed with nodal corrections applied to amplitude \n and phase relative to center time

x0= 14.5, x trend= 0

var(x)= 3294.5787   var(xp)= 271.5265   var(xres)= 3023.6051
percent var predicted/var original= 8.2 %

y0= 49.1, x trend= 0

var(y)= 9107.6782   var(yp)= 86.1805 var(yres)= 9020.7478
percent var predicted/var original= 0.9 %

ellipse parameters with 95%% CI estimates

tide	freq	major	emaj	minor	emin	inc	einc	pha	epha	snr
SSA	0.0002282	16.755	23.123	0.957	12.62	78.67	35.89	260.20	91.32	0.53
MSM	0.0013098	11.708	17.506	0.342	13.34	53.04	59.73	204.76	121.83	0.45
MM	0.0015122	14.171	19.217	0.203	10.55	89.31	43.60	282.72	110.87	0.54
MSF	0.0028219	15.467	21.016	-0.147	13.44	65.05	49.20	240.20	88.59	0.54
MF	0.0030501	3.599	17.239	1.100	10.77	94.05	57.67	339.94	221.43	0.044
ALP1	0.0343966	2.146	4.390	0.294	4.01	88.99	113.53	99.12	167.10	0.24
2Q1	0.0357064	0.996	4.121	-0.675	3.72	115.03	119.58	87.60	209.34	0.058
SIG1	0.0359087	3.320	4.700	-1.369	3.76	33.95	103.26	104.76	121.02	0.5
Q1	0.0372185	3.201	3.824	-1.824	4.31	53.40	113.12	294.67	125.38	0.7
RHO1	0.0374209	1.898	4.275	-1.292	3.61	59.39	119.16	19.90	181.99	0.2
*O1	0.0387307	9.272	5.764	0.590	4.94	54.50	35.85	303.23	38.56	2.6
TAU1	0.0389588	2.357	5.326	0.180	5.01	46.34	124.35	352.85	149.45	0.2
BET1	0.0400404	2.573	4.280	0.665	3.92	170.02	135.22	129.01	158.54	0.36
NO1	0.0402686	2.421	3.804	-0.646	3.63	157.48	115.91	334.66	129.93	0.4
CHI1	0.0404710	3.706	4.623	-0.903	4.57	88.24	84.55	118.98	106.26	0.64
P1	0.0415526	4.483	4.607	0.680	4.90	110.80	73.48	222.07	84.33	0.95
K1	0.0417807	6.333	5.223	1.823	5.37	157.89	79.09	10.41	74.05	1.5
PHI1	0.0420089	1.731	4.567	-0.382	4.18	127.43	114.55	156.51	165.59	0.14
THE1	0.0430905	2.856	4.194	0.927	3.82	16.55	107.29	250.49	129.17	0.46
J1	0.0432929	4.486	4.591	-0.964	4.15	75.79	74.34	126.84	79.00	0.96
SO1	0.0446027	5.468	4.999	-2.886	5.01	22.32	87.13	319.55	84.54	1.2
OO1	0.0448308	4.286	3.656	-2.211	3.68	75.65	83.24	204.76	89.13	1.4
UPS1	0.0463430	1.669	3.257	-0.137	2.94	14.60	103.62	54.37	146.11	0.26
OQ2	0.0759749	1.386	3.239	0.304	2.68	23.25	122.57	350.72	168.89	0.18
EPS2	0.0761773	0.808	2.730	-0.126	2.49	119.55	132.60	330.69	182.30	0.088
2N2	0.0774871	1.301	2.522	0.067	2.80	138.28	126.41	88.86	152.64	0.27
MU2	0.0776895	2.453	2.559	-1.509	3.27	15.42	103.55	236.48	117.55	0.92
*N2	0.0789992	6.849	3.833	1.222	3.29	152.92	32.00	126.18	31.28	3.2
NU2	0.0792016	2.071	2.950	-0.093	2.40	62.69	118.76	138.24	113.40	0.49
*M2	0.0805114	22.153	3.934	0.227	3.76	155.20	8.24	149.14	9.55	32
MKS2	0.0807396	1.881	2.154	0.257	2.43	146.71	90.78	9.19	110.44	0.76
LDA2	0.0818212	3.202	3.090	-1.974	3.26	11.36	85.40	161.35	111.73	1.1
L2	0.0820236	2.411	3.281	-0.188	2.76	161.67	83.59	117.50	92.10	0.54
*S2	0.0833333	9.283	3.513	-1.942	3.22	169.01	25.35	140.70	22.99	7

K2	0.0835615	2.443	2.604	-0.275	2.35	135.50	76.71	299.50	79.89	0.88
MSN2	0.0848455	2.752	3.156	-1.748	2.81	31.05	111.19	183.89	115.25	0.76
ETA2	0.0850736	1.961	2.292	-0.611	2.51	43.19	94.02	104.09	96.27	0.73
MO3	0.1192421	1.481	1.645	-0.739	1.57	111.29	105.62	265.55	96.87	0.81
M3	0.1207671	1.153	1.649	-0.527	1.68	86.65	129.59	102.12	113.51	0.49
SO3	0.1220640	1.974	1.725	-1.079	1.83	120.03	93.89	133.23	84.71	1.3
MK3	0.1222921	1.264	1.514	-0.403	1.60	169.37	92.30	160.17	106.34	0.7
SK3	0.1251141	2.255	1.888	0.132	1.83	138.33	66.62	314.33	55.68	1.4
MN4	0.1595106	0.638	1.093	0.180	1.01	74.02	128.60	34.06	137.56	0.34
M4	0.1610228	1.291	1.565	0.316	1.37	42.55	76.81	50.84	83.30	0.68
SN4	0.1623326	0.707	1.292	-0.141	1.11	150.95	106.68	174.58	144.88	0.3
MS4	0.1638447	1.070	1.220	-0.541	1.31	169.78	94.09	190.06	162.45	0.77
MK4	0.1640729	1.014	1.079	-0.669	1.17	163.17	101.22	76.88	135.21	0.88
S4	0.1666667	2.027	1.616	-0.532	1.40	5.35	44.81	90.27	52.43	1.6
SK4	0.1668948	1.179	1.131	0.217	1.01	0.89	62.41	310.15	81.85	1.1
2MK5	0.2028035	0.387	0.867	0.150	0.91	81.26	157.82	339.98	160.40	0.2
*2SK5	0.2084474	2.399	1.268	-0.071	1.03	155.27	26.94	121.06	33.61	3.6
2MN6	0.2400221	0.451	0.760	0.031	0.71	135.62	114.01	130.76	132.63	0.35
M6	0.2415342	0.820	0.906	-0.162	0.84	3.79	72.83	355.63	94.18	0.82
2MS6	0.2443561	0.658	0.767	-0.090	0.69	178.52	90.08	233.80	94.52	0.74
2MK6	0.2445843	0.480	0.660	0.180	0.62	61.37	94.70	349.69	113.84	0.53
2SM6	0.2471781	0.520	0.781	-0.234	0.73	2.95	88.69	131.66	110.64	0.44
MSK6	0.2474062	0.381	0.649	-0.222	0.64	154.29	118.77	282.17	138.72	0.34
3MK7	0.2833149	0.534	0.612	-0.073	0.53	142.31	83.12	80.50	94.77	0.76
M8	0.3220456	0.451	0.498	-0.114	0.53	135.86	89.66	299.72	96.72	0.82

total var= 12402.257   pred var= 357.707
percent total var predicted/var original= 2.9 %

Depth Averaged Currents

file name: avg_vel
date: 19-Jan-2005
nobs = 8760, ngood = 8707, record length (days) = 365.00
start time: 01-Feb-2003
rayleigh criterion = 1.0
Greenwich phase computed with nodal corrections applied to amplitude \n and phase relative to center time

x0= 7.26, x trend= 0

var(x)= 828.4887   var(xp)= 184.8524   var(xres)= 643.2663
percent var predicted/var original= 22.3 %

y0= 33, x trend= 0

var(y)= 5279.1252   var(yp)= 169.85 var(yres)= 5109.4204
percent var predicted/var original= 3.2 %

ellipse parameters with 95%% CI estimates

tide	freq	major	emaj	minor	emin	inc	einc	pha	epha	snr
SSA	0.0002282	5.442	11.472	-3.587	7.12	131.98	59.59	246.07	161.03	0.23
MSM	0.0013098	9.550	11.915	-0.555	6.43	65.96	30.78	214.30	103.16	0.64
MM	0.0015122	8.391	14.345	1.170	5.16	97.38	24.44	288.43	120.05	0.34
MSF	0.0028219	17.887	16.007	-1.534	6.62	74.01	19.60	231.35	53.45	1.2
MF	0.0030501	3.687	11.936	1.252	4.65	85.66	29.28	339.48	194.18	0.095
ALP1	0.0343966	1.590	1.931	-0.217	1.60	95.82	64.64	77.19	104.16	0.68
2Q1	0.0357064	0.602	1.533	-0.593	1.69	83.74	105.00	74.90	200.33	0.15
SIG1	0.0359087	2.025	1.899	-1.157	1.81	113.32	86.22	238.36	96.42	1.1
Q1	0.0372185	1.403	2.009	0.400	1.71	100.68	74.12	282.74	119.68	0.49
RHO1	0.0374209	1.126	1.392	-0.197	1.81	2.21	138.90	207.76	111.57	0.65
*O1	0.0387307	6.614	2.737	1.266	1.94	79.17	17.83	324.60	23.18	5.8
TAU1	0.0389588	1.058	2.196	0.012	1.79	97.65	86.20	39.48	163.16	0.23
BET1	0.0400404	1.823	1.900	-0.777	1.71	125.44	87.13	95.94	110.19	0.92
*NO1	0.0402686	3.576	2.123	-0.942	1.44	83.33	31.31	337.94	42.42	2.8
CHI1	0.0404710	1.592	1.800	-1.025	1.83	100.39	92.59	171.66	133.88	0.78
*P1	0.0415526	6.468	2.818	-2.938	2.16	85.65	27.56	291.53	37.33	5.3
*K1	0.0417807	10.264	2.908	-1.280	1.91	92.76	10.50	312.50	15.65	12
PHI1	0.0420089	1.885	2.078	-1.046	2.22	31.54	100.53	323.29	97.65	0.82
THE1	0.0430905	1.255	1.810	-0.231	1.55	99.83	75.88	1.05	117.88	0.48
J1	0.0432929	1.589	1.609	-0.816	1.76	169.58	124.68	182.14	88.78	0.98
SO1	0.0446027	1.227	1.860	-0.177	1.49	90.85	69.26	358.75	125.25	0.44
OO1	0.0448308	0.646	1.208	-0.274	1.09	116.85	100.12	290.99	172.20	0.29
UPS1	0.0463430	0.785	1.459	-0.018	1.04	63.27	90.80	108.56	129.18	0.29
*OQ2	0.0759749	1.652	1.104	-0.547	1.11	53.35	60.99	351.52	47.68	2.2
EPS2	0.0761773	0.258	0.829	0.012	0.83	174.81	121.10	74.04	192.56	0.097
2N2	0.0774871	0.962	1.060	-0.068	0.99	116.57	83.91	156.71	91.32	0.82
MU2	0.0776895	0.762	0.824	-0.475	0.95	18.94	107.85	301.68	112.56	0.86
*N2	0.0789992	5.299	1.122	0.274	1.08	151.87	11.54	128.32	13.33	22
NU2	0.0792016	1.242	0.981	0.105	1.08	126.18	60.66	131.40	63.36	1.6
*M2	0.0805114	20.654	1.232	-0.252	1.19	151.98	3.31	146.75	3.30	2.8e+002
*MKS2	0.0807396	1.421	0.844	-0.394	0.93	149.85	47.51	32.58	49.73	2.8
LDA2	0.0818212	0.675	1.028	-0.373	0.83	170.42	116.11	283.54	134.99	0.43
*L2	0.0820236	1.596	1.107	0.376	1.12	135.30	50.41	60.57	44.94	2.1
*S2	0.0833333	4.097	1.118	0.534	1.17	134.89	16.73	115.56	16.25	13

K2	0.0835615	0.746	0.790	-0.233	0.76	146.11	84.02	313.24	83.48	0.89
MSN2	0.0848455	0.360	0.765	-0.141	0.84	148.11	122.60	278.00	185.20	0.22
ETA2	0.0850736	0.457	0.733	0.103	0.70	77.90	118.01	140.33	128.67	0.39
MO3	0.1192421	0.470	0.542	-0.008	0.57	134.26	86.88	205.48	88.17	0.75
M3	0.1207671	0.504	0.555	0.012	0.58	99.02	86.86	100.52	86.49	0.82
SO3	0.1220640	0.465	0.498	-0.091	0.52	121.57	80.29	158.56	89.90	0.87
MK3	0.1222921	0.378	0.566	-0.169	0.53	8.14	109.32	285.85	124.91	0.45
*SK3	0.1251141	0.869	0.559	0.492	0.57	116.97	74.03	295.80	76.77	2.4
MN4	0.1595106	0.492	0.413	0.080	0.38	132.17	61.78	103.46	55.93	1.4
*M4	0.1610228	0.683	0.463	0.396	0.43	171.22	69.64	153.91	76.02	2.2
SN4	0.1623326	0.188	0.327	-0.036	0.36	73.43	116.44	113.20	128.40	0.33
MS4	0.1638447	0.532	0.393	-0.077	0.41	135.61	52.95	115.70	57.46	1.8
MK4	0.1640729	0.350	0.347	-0.206	0.30	3.28	74.13	234.37	95.72	1
*S4	0.1666667	0.808	0.457	-0.154	0.40	173.64	35.73	257.09	40.47	3.1
SK4	0.1668948	0.463	0.431	-0.109	0.29	179.64	53.76	120.99	56.52	1.2
2MK5	0.2028035	0.212	0.371	0.032	0.36	99.50	133.29	328.64	137.42	0.33
*2SK5	0.2084474	1.236	0.479	-0.159	0.41	151.43	21.21	130.60	24.64	6.7
2MN6	0.2400221	0.497	0.423	-0.067	0.44	168.01	54.47	128.35	59.29	1.4
*M6	0.2415342	0.730	0.364	-0.144	0.40	9.15	36.54	345.76	38.88	4
*2MS6	0.2443561	0.677	0.382	-0.186	0.43	176.00	43.63	210.23	42.88	3.1
2MK6	0.2445843	0.173	0.283	0.050	0.24	138.12	109.94	82.24	140.43	0.37
2SM6	0.2471781	0.294	0.354	-0.226	0.35	0.10	113.89	121.44	112.02	0.69
MSK6	0.2474062	0.094	0.271	-0.005	0.23	80.81	120.94	112.80	171.11	0.12
3MK7	0.2833149	0.167	0.224	-0.095	0.24	117.69	123.77	59.31	141.04	0.56
M8	0.3220456	0.194	0.248	-0.027	0.23	98.79	85.14	303.85	106.30	0.61

total var= 6107.6139   pred var= 354.7023
percent total var predicted/var original= 5.8 %

Water Depth

file name: tide
date: 12-Jan-2005
nobs = 35040, ngood = 34744, record length (days) = 365.00
start time: 01-Feb-2003
rayleigh criterion = 1.0
Greenwich phase computed with nodal corrections applied to amplitude \n and phase relative to center time

x0= 13.6, x trend= 0

var(x)= 0.25378   var(xp)= 0.14498   var(xres)= 0.10869
percent var predicted/var original= 57.1 %

tidal amplitude and phase with 95% CI estimates

tide	freq	amp	amp_err	pha	pha_err	snr
*SSA	0.0002282	0.1493	0.092	89.54	38.41	2.6
MSM	0.0013098	0.0104	0.065	207.64	219.61	0.025
MM	0.0015122	0.0271	0.077	21.19	140.57	0.12
MSF	0.0028219	0.0358	0.070	105.20	147.21	0.26
MF	0.0030501	0.0225	0.077	255.20	198.84	0.086
ALP1	0.0343966	0.0041	0.014	13.24	192.46	0.09
2Q1	0.0357064	0.0026	0.015	337.90	221.06	0.031
SIG1	0.0359087	0.0113	0.017	54.94	103.67	0.42
Q1	0.0372185	0.0191	0.019	127.70	57.77	0.97
RHO1	0.0374209	0.0026	0.015	68.23	223.32	0.032
*O1	0.0387307	0.0691	0.023	146.06	17.20	9
TAU1	0.0389588	0.0092	0.017	224.58	142.97	0.3
BET1	0.0400404	0.0059	0.014	271.21	170.37	0.18
NO1	0.0402686	0.0078	0.012	102.65	132.95	0.4
CHI1	0.0404710	0.0040	0.016	22.11	182.67	0.066
*P1	0.0415526	0.0579	0.023	105.29	23.81	6.2
*K1	0.0417807	0.1251	0.023	129.83	10.84	30
PHI1	0.0420089	0.0098	0.017	27.36	136.95	0.35
THE1	0.0430905	0.0159	0.018	15.38	75.20	0.78
J1	0.0432929	0.0154	0.018	165.71	87.99	0.77
SO1	0.0446027	0.0033	0.015	2.70	207.40	0.049
OO1	0.0448308	0.0102	0.012	138.91	77.57	0.71
UPS1	0.0463430	0.0055	0.012	337.80	157.28	0.21
OQ2	0.0759749	0.0101	0.017	229.68	116.06	0.33
EPS2	0.0761773	0.0070	0.016	164.20	137.49	0.19
2N2	0.0774871	0.0187	0.021	204.67	77.05	0.76
MU2	0.0776895	0.0105	0.017	237.62	100.52	0.38
*N2	0.0789992	0.1200	0.020	225.97	9.59	34
NU2	0.0792016	0.0099	0.018	198.44	123.60	0.29
*M2	0.0805114	0.4815	0.020	241.13	2.26	6e+002
*MKS2	0.0807396	0.0363	0.016	117.76	24.98	4.8
LDA2	0.0818212	0.0064	0.015	253.02	152.23	0.18
L2	0.0820236	0.0153	0.017	218.52	73.99	0.79
*S2	0.0833333	0.0601	0.019	239.79	17.98	9.8
*K2	0.0835615	0.0235	0.014	266.76	40.80	2.8
MSN2	0.0848455	0.0052	0.014	227.29	156.57	0.14
ETA2	0.0850736	0.0061	0.012	259.81	136.31	0.24
MO3	0.1192421	0.0060	0.009	53.60	94.03	0.5
M3	0.1207671	0.0045	0.008	253.61	137.26	0.35

SO3	0.1220640	0.0043	0.007	20.26	118.72	0.38
MK3	0.1222921	0.0029	0.007	309.87	136.15	0.17
SK3	0.1251141	0.0065	0.009	74.78	84.79	0.53
MN4	0.1595106	0.0005	0.006	173.20	258.97	0.0075
M4	0.1610228	0.0026	0.007	330.39	162.85	0.14
SN4	0.1623326	0.0007	0.005	116.70	249.17	0.019
MS4	0.1638447	0.0054	0.006	179.33	92.14	0.76
MK4	0.1640729	0.0039	0.007	182.01	97.87	0.36
S4	0.1666667	0.0017	0.006	147.58	193.29	0.092
SK4	0.1668948	0.0038	0.005	17.31	99.41	0.51
2MK5	0.2028035	0.0048	0.007	109.13	98.67	0.5
2SK5	0.2084474	0.0066	0.007	149.28	73.21	0.9
2MN6	0.2400221	0.0015	0.005	224.12	188.26	0.095
M6	0.2415342	0.0068	0.007	289.43	55.06	1
2MS6	0.2443561	0.0062	0.006	297.48	67.17	1.1
2MK6	0.2445843	0.0051	0.005	188.92	61.04	0.9
2SM6	0.2471781	0.0014	0.005	119.58	199.27	0.092
MSK6	0.2474062	0.0042	0.006	81.58	80.49	0.53
3MK7	0.2833149	0.0024	0.005	192.25	117.17	0.27
M8	0.3220456	0.0013	0.004	235.17	170.68	0.11