Measured Current Velocity Characteristics off Tolley Point in Chesapeake Bay

18-October-2005 to 15-November-2005

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Executive Summary

Velocity profile, pressure and temperature data sets were obtained from a Nortek acoustic wave and current meter of Tolley's Point in the Chesapeake Bay. The instrument was deployed in approximately 12 meters of water at the position 38° 56.08676 N Latitude by 76° 25.25433 W Longitude. The data sets were processed to obtain the primary tidal constituents for the region determined by the NOAA National Ocean Service.

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1. Introduction

The purpose of this project is to perform current velocity field measurements using a Nortek Acoustic Wave and Current meter (AWAC) in support of hydrodynamic modeling efforts of the Chesapeake Bay. The instrument was deployed on 18-Oct-2005 at a position near the entrance of the Severn River and the main channel of the Chesapeake Bay and recovered on 15-Nov-2005. The position of the deployed instrument was 38° 56.0868 N Latitude by 76° 25.2543 W Longitude, off Tolley Point in the Chesapeake Bay (Figure 1 – From Louise). The position was determined using a Global Position System with Differential (DGPS) Correction with the receivers located at the stern of the USNA Oceanographic Yard Patrol Craft (YP-686). It also represented a location within meters of a hydrodynamic model grid node so that calibration/validation can be performed with current velocity calculations. The depth of the water is approximately 12 meters.

2. Approach

2.1. Instrument Setup

The instrument was set to record three-dimensional velocity components at 0.5 meter depth bins (22 locations in the water column) in an upward looking configuration. Current velocities representing the East-Going, North-Going and vertical components were averaged for 180 seconds every 1800 seconds. The setup configuration for the AWAC instrument is provided on Table 1.

Table 1: The setup configuration for the AWAC instrument.

Parameter	Value
Sampling Interval	1800 sec
Number of Cells	22
Cell Size	0.50 m
Averaging Interval	180 sec
Blanking Distance	0.4 m

Also included in Table 1 is the blanking distance, which represents the boundary of the geometric position for the first recording depth bin. The position in the water column where the current velocities are obtained can be calculated using,

$$z_i = (Blanking\ Dis\tan ce) + i(Depth\ Cell\ Size), \quad \textbf{(1)}$$

where i is the depth cell number measured from the transducer face. In addition to the velocity current profiles, pressure and temperature data sets were also acquired at the same sampling and averaging intervals. The pressure data set was used to examine the water elevation characteristics while the temperature was recorded near the bottom.

2.2. Deployment

The AWAC instrument was mounted in a tripod frame in an upward looking configuration (Figure 2). Attached to one of the legs was a ground rope, with a length of 18 meters connected to a 45 kgf mushroom anchor. The entire system was deployed on 18-October-2005 at the Tolley Point site from the stern of the YP-686. During the deployment, the tripod and anchor were separately lowered to the bottom of the bay with a block and tackle arrangement and released with a slip line.

Figure 1: The AWAC is shown mounted in a tripod frame in the upward looking configuration.

2.3. Recovery

The system was recovered on 15-November-2005. The YP-686 and the Naval Station Dive Locker vessels left Hendricks Laboratory at approximately 0815 (EST). At the site, the divers located the equipment and placed a surface float at the anchor position. The YP attempted to pull up the anchor from a single point moored position, but had difficulty maintaining a position directly above the anchor due to the wind effects. Using the small dive locker vessel, however, the system was pulled up using a hand winch and the equipment was transferred to the YP. At the Hydromechanics Laboratory, the data sets from the AWAC were downloaded and prepared for processing.

Figure 2: The AWAC was recovered from the Dive Locker vessel using a hand winch located on the bow.

2.4. Data Processing

The pressure, temperature and velocity profile data sets obtained from the instruments were converted to ASCII format using the Nortek AWAC software. Tidal harmonic

analyses were performed for the pressure and velocity profile time series using the techniques described in Pawlowicz et al. (2002). The top seven tidal constituents used in the analysis were determined from information obtained from the National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS) tide station number 8575512 located at the USNA along the Severn River. The position of the tide station is 38° 59.0 N Latitude by 76° 28.8 W Longitude.

Prior to processing the pressure (water elevation) time series, the mean water level above the instrument transducers was removed. Prior to performing the tidal harmonic analysis to the velocity data sets, the east- and north-going components were corrected by 11° to account for magnetic declination.

3. Results

The first set of results presented includes the surface elevation obtained from the pressure sensor and the estimated tidal model (Figure 4). The mean water level above the transducers was found to be 11.22 meters. Also shown on Figure 4 is the elevation residual time series calculated as the difference between the raw data and the tide model. The temperature time series obtained at the instrument is also included on the Figure. Results of the tidal harmonic analysis of the surface elevation, including the amplitude (meters) and phase (degrees), are provided in Table 2. Also shown in Table 2 are the published values from NOS. Results for the top seven constituents appear to be similar.

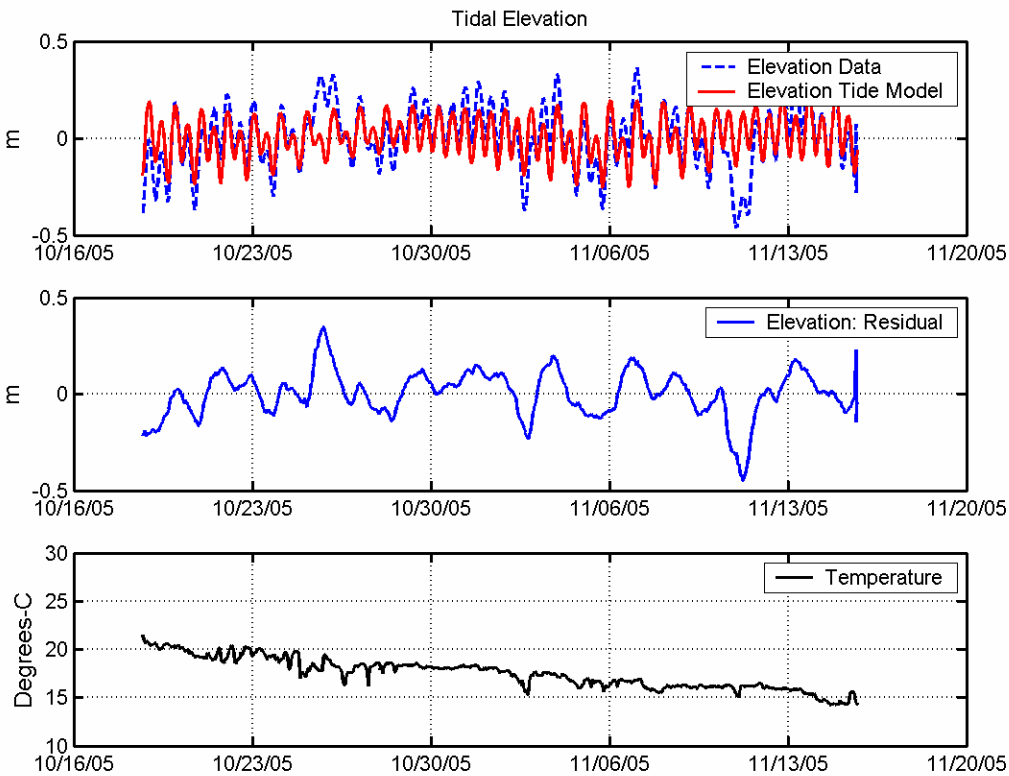

Figure 3: The elevation data set and tidal estimation model acquired from the pressure sensor. Also included are the residual elevation and the temperature time series.

Table 2: The dominant tidal constituents obtained from elevation data set (amplitude values are in meters and phase values are in degrees)

Tidal Constituent	Frequency (hr^{-1})	Calculated Amplitude	Calculated Phase	NOS Amplitude	NOS Phase
M2	0.0805114	0.1262	285.03	0.139	291.6
S2	0.0833333	0.0224	310.02	0.022	319.5
N2	0.0789992	0.0190	265.68	0.029	270.5
K1	0.0417807	0.0420	7.28	0.059	356.7
M4	0.1610228	0.0031	17.14	0.004	58.3
O1	0.0387307	0.0397	359.73	0.048	6.0
M6	0.2415342	0.0012	94.34	0.003	159.6

The raw and processed data sets for each of the three velocity components at each of the 22 depth bins are shown in Appendix A (Figure A-1 through A-22). Also included in these Figures are the estimated east- and north-going tidal estimations and the vertical

component of the velocity vector. Tables A-1 through A-22 provide the amplitude (meters) and phase (degrees) for the top seven NOS constituents. The 22 depth bin time-series were processed to obtain the depth averaged east and north-going components. These results are shown on Figure 5. The corresponding tidal constituent information is provided in Table 3.

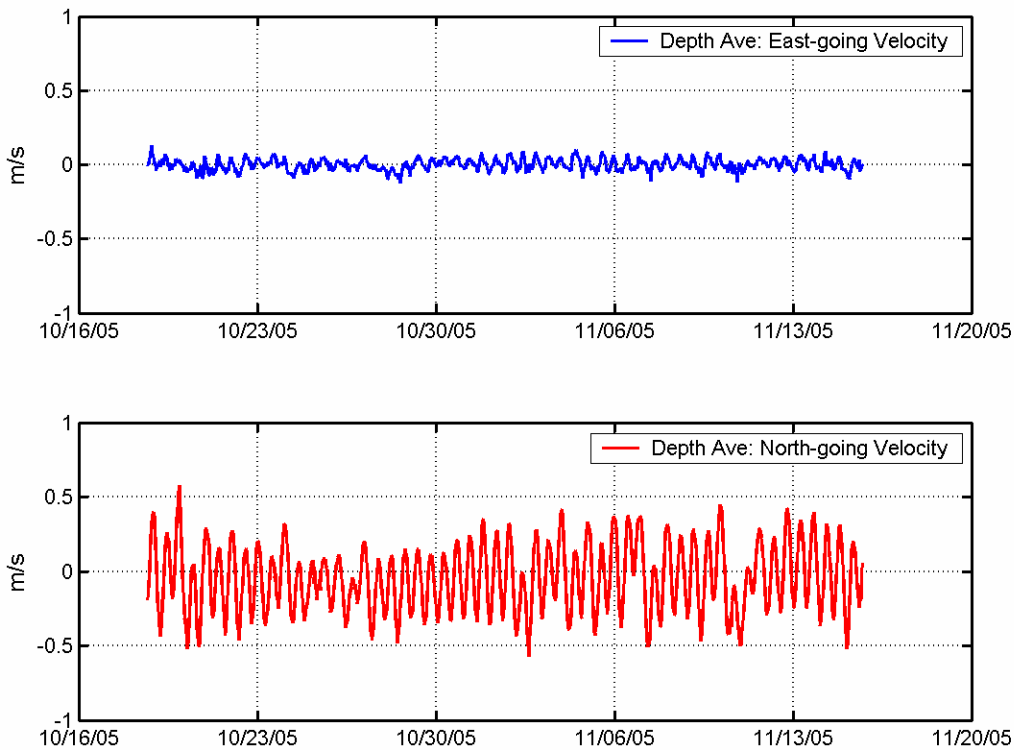

Figure 4: The east- and north-going depth average velocities from the AWAC deployment.

Table 3: The dominant tidal constituents for each of the east- and north-going components of the depth averaged velocity vector (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0323	49.82	0.2664	52.60
S2	0.0833333	0.0083	104.33	0.0478	86.21
N2	0.0789992	0.0015	35.82	0.0333	14.71
K1	0.0417807	0.0017	47.72	0.0517	178.83
M4	0.1610228	0.0090	59.77	0.0046	125.82
O1	0.0387307	0.0060	83.88	0.0437	163.37
M6	0.2415342	0.0013	122.93	0.0045	120.98

4. Discussion

Each of the pressure, temperature and velocity component time series obtained from the AWAC instrument appear to have little noise and the calculated tidal constituents similar to those published by NOS for the Severn River/Chesapeake Bay area. It should be noted that bins 21 and 22 occur near the surface so velocity data accuracy depends upon the water level at the time of sampling (see Figures A-21 and A-22).

5. Conclusion

The data sets acquired using the AWAC instrument appear to be of high quality and should be useful in the validation/calibration of hydrodynamic models of the Chesapeake Bay in the region of the Severn River. This portion of the study involves a two-part effort to study the robustness of particle trajectory computation from data obtained from implementation of QUODDY in the Chesapeake Bay. In the first part, numerical algorithms designed and based on standard Runge-Kutta schemes for computing solutions of ordinary differential equations will be applied to the system of ODEs we obtain from the velocity field constructed from QUODDY data. The robustness of these algorithms will be tested by varying physical parameters, i.e., wind stress, tidal constants and river inputs, as well as by varying geometrical parameters and interpolation methods. The primary deliverable of this portion of the effort will be a robust 2D surface current integrator as well as a 3D particle tracker suitable for the entire basin.

Acknowledgements

References

Pawlowicz, R, Beardsley, B and S. Lentz, "Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE", Computers and Geosciences 28 (2002), 929-937.

Appendix A: The raw data sets and tidal estimations for each of the 22 bin locations

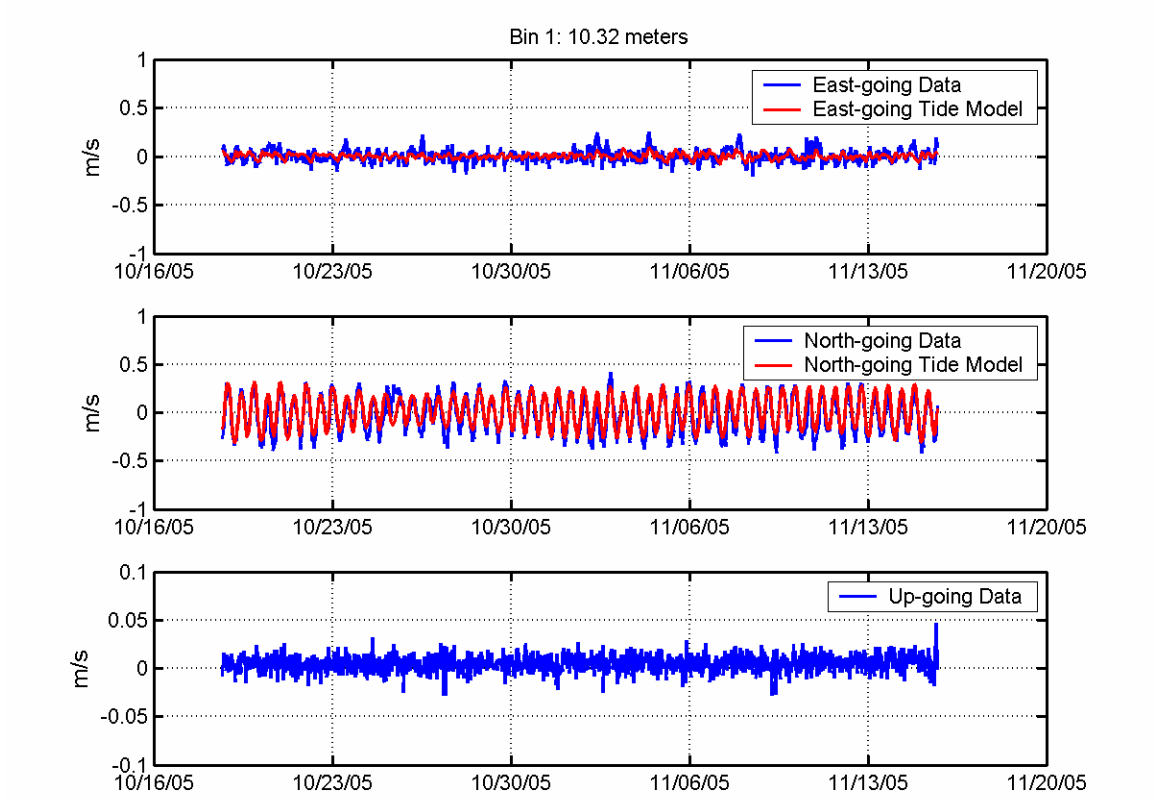

Figure A-1: The East- and North-going data sets at a depth of 10.32 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table4: The dominant tidal constituents for each of the east- and north-going components of the velocity vector at a depth of 10.32 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0158	210.39	0.2579	271.23
S2	0.0833333	0.0053	277.80	0.0356	280.47
N2	0.0789992	0.0033	122.89	0.0362	236.74
K1	0.0417807	0.0101	151.32	0.0452	262.09
M4	0.1610228	0.0107	199.73	0.0077	168.26
O1	0.0387307	0.0112	183.41	0.0228	278.89
M6	0.2415342	0.0051	290.46	0.0042	57.84

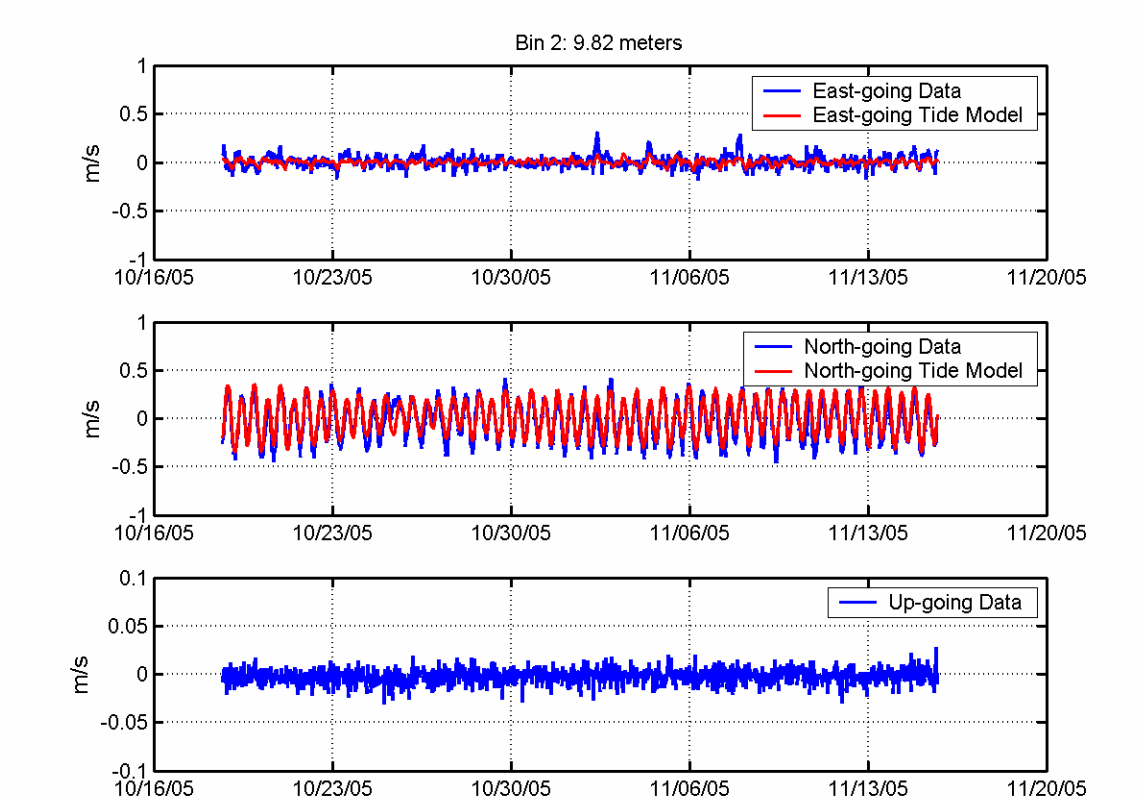

Figure A-2: The East- and North-going data sets at a depth of 9.82 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table5: The dominant tidal constituents for each of the east- and north-going components of the velocity vector at a depth of 9.82 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0158	210.39	0.2579	271.23
S2	0.0833333	0.0053	277.80	0.0356	280.47
N2	0.0789992	0.0033	122.89	0.0362	236.74
K1	0.0417807	0.0101	151.32	0.0452	262.09
M4	0.1610228	0.0107	199.73	0.0077	168.26
O1	0.0387307	0.0112	183.41	0.0228	278.89
M6	0.2415342	0.0051	290.46	0.0042	57.84

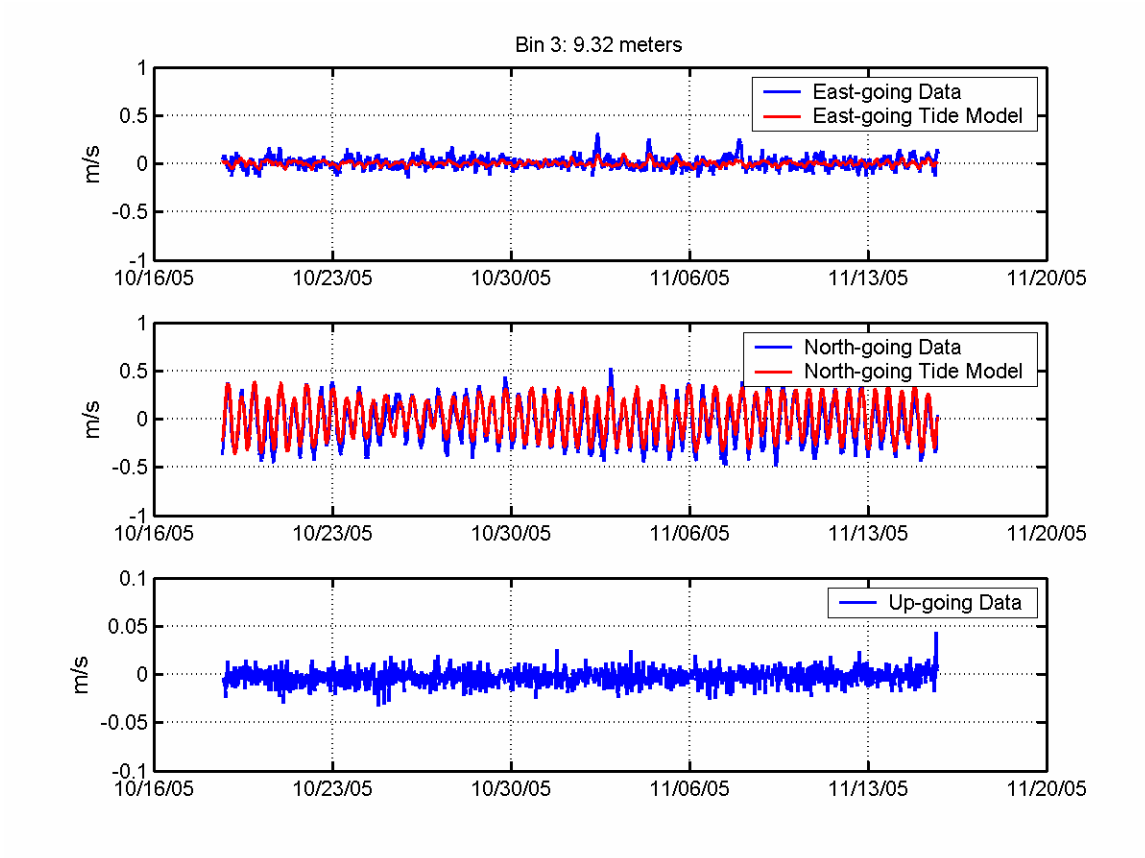

Figure A-3: The East- and North-going data sets at a depth of 9.32 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table6: The dominant tidal constituents for the east- and north-going components of velocity vector at a depth of 9.32 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0166	170.65	0.2323	269.10
S2	0.0833333	0.0049	296.59	0.0346	280.61
N2	0.0789992	0.0068	94.15	0.0337	237.21
K1	0.0417807	0.0075	161.46	0.0392	259.75
M4	0.1610228	0.0082	189.94	0.0103	162.90
O1	0.0387307	0.0119	186.93	0.0169	282.75
M6	0.2415342	0.0063	272.55	0.0006	107.12

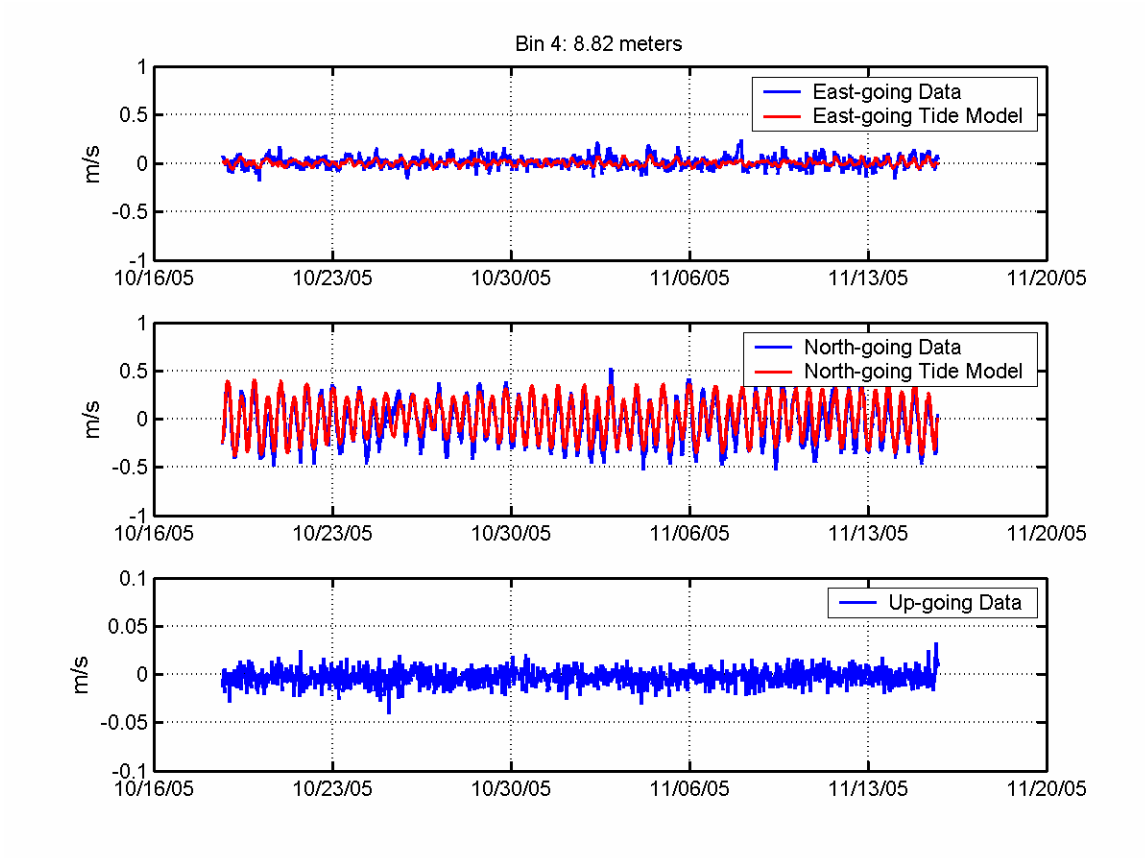

Figure A-4: The East- and North-going data sets at a depth of 8.82 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table7: The dominant tidal constituents for the east- and north-going components of velocity vector at a depth of 8.82 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0223	274.04	0.2820	274.97
S2	0.0833333	0.0088	256.66	0.0463	284.13
N2	0.0789992	0.0069	155.82	0.0362	227.48
K1	0.0417807	0.0118	160.37	0.0509	268.11
M4	0.1610228	0.0047	200.39	0.0089	197.18
O1	0.0387307	0.0079	158.64	0.0308	288.72
M6	0.2415342	0.0035	89.00	0.0082	64.45

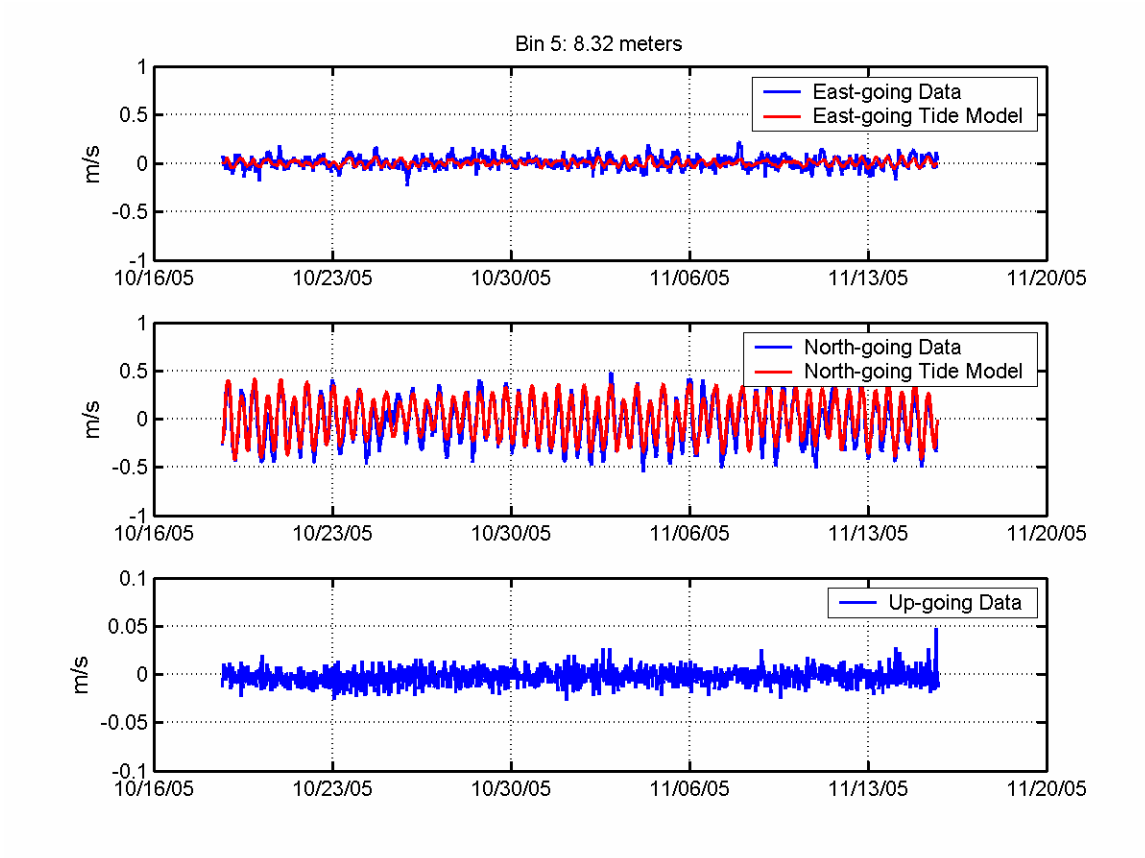

Figure A-5: The East- and North-going data sets at a depth of 8.32 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table8: The dominant tidal constituents for the east- and north-going components of velocity vector at a depth of 8.32 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0270	277.55	0.2883	276.70
S2	0.0833333	0.0086	282.44	0.0525	284.40
N2	0.0789992	0.0074	193.22	0.0361	227.11
K1	0.0417807	0.0108	177.22	0.0523	271.15
M4	0.1610228	0.0020	197.08	0.0106	235.20
O1	0.0387307	0.0065	158.74	0.0388	290.85
M6	0.2415342	0.0020	117.06	0.0100	74.59

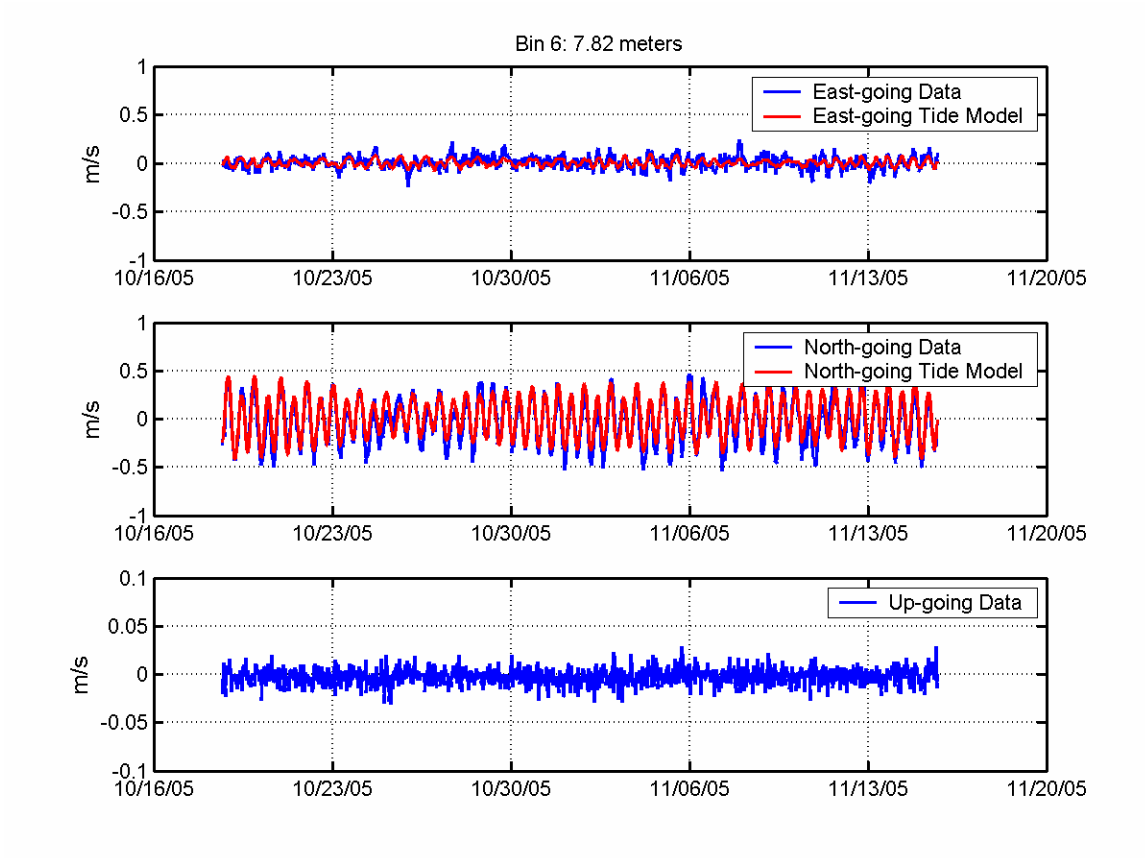

Figure A-6: The East- and North-going data sets at a depth of 7.82 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table9: The dominant tidal constituents for the east- and north-going components of velocity vector at a depth of 7.82meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0313	279.09	0.2892	278.61
S2	0.0833333	0.0076	293.51	0.0574	287.06
N2	0.0789992	0.0053	172.66	0.0367	232.17
K1	0.0417807	0.0136	185.38	0.0522	274.77
M4	0.1610228	0.0015	116.25	0.0113	233.33
O1	0.0387307	0.0081	123.57	0.0436	294.43
M6	0.2415342	0.0015	108.69	0.0092	74.72

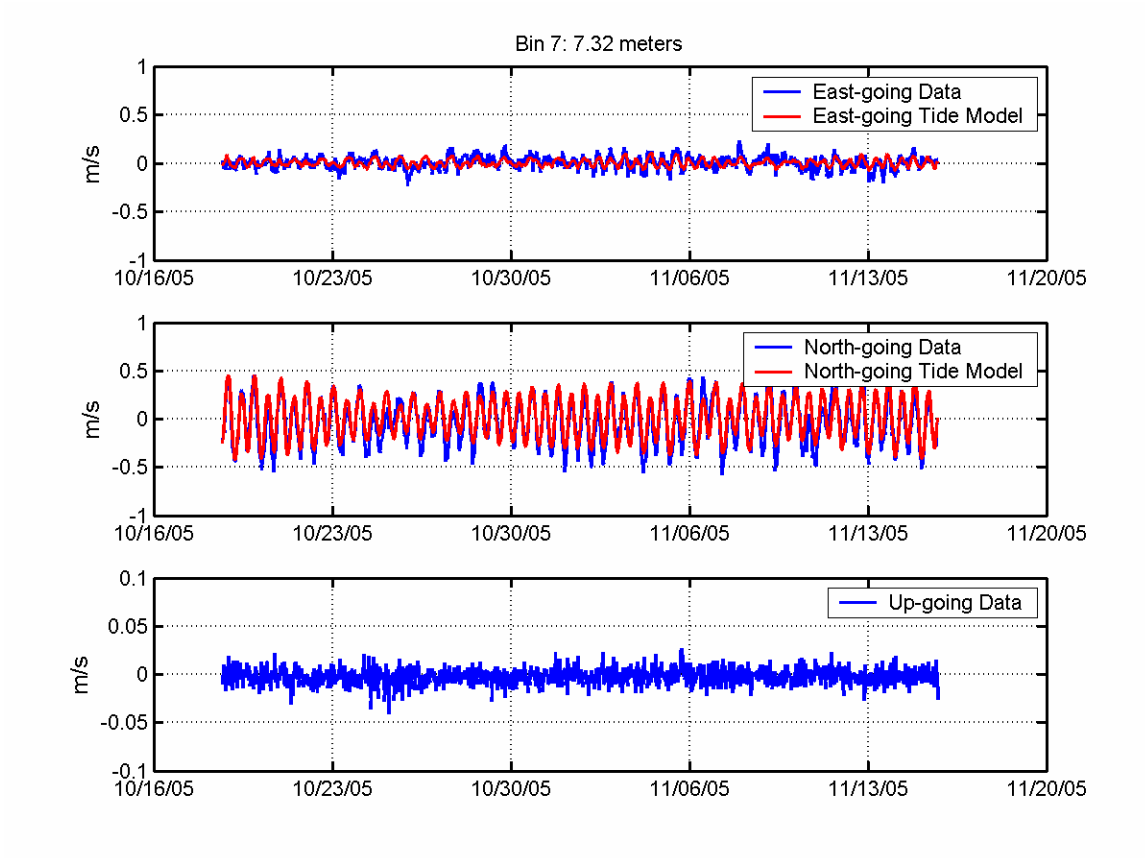

Figure A-7: The East- and North-going data sets at a depth of 7.32 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table10: The dominant tidal constituents for the east- and north-going components of velocity vector at a depth of 7.32 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0375	275.23	0.2894	280.20
S2	0.0833333	0.0066	319.69	0.0599	292.27
N2	0.0789992	0.0053	256.71	0.0378	230.39
K1	0.0417807	0.0138	196.08	0.0497	273.20
M4	0.1610228	0.0044	91.74	0.0116	224.79
O1	0.0387307	0.0055	114.32	0.0478	293.56
M6	0.2415342	0.0033	110.80	0.0064	102.86

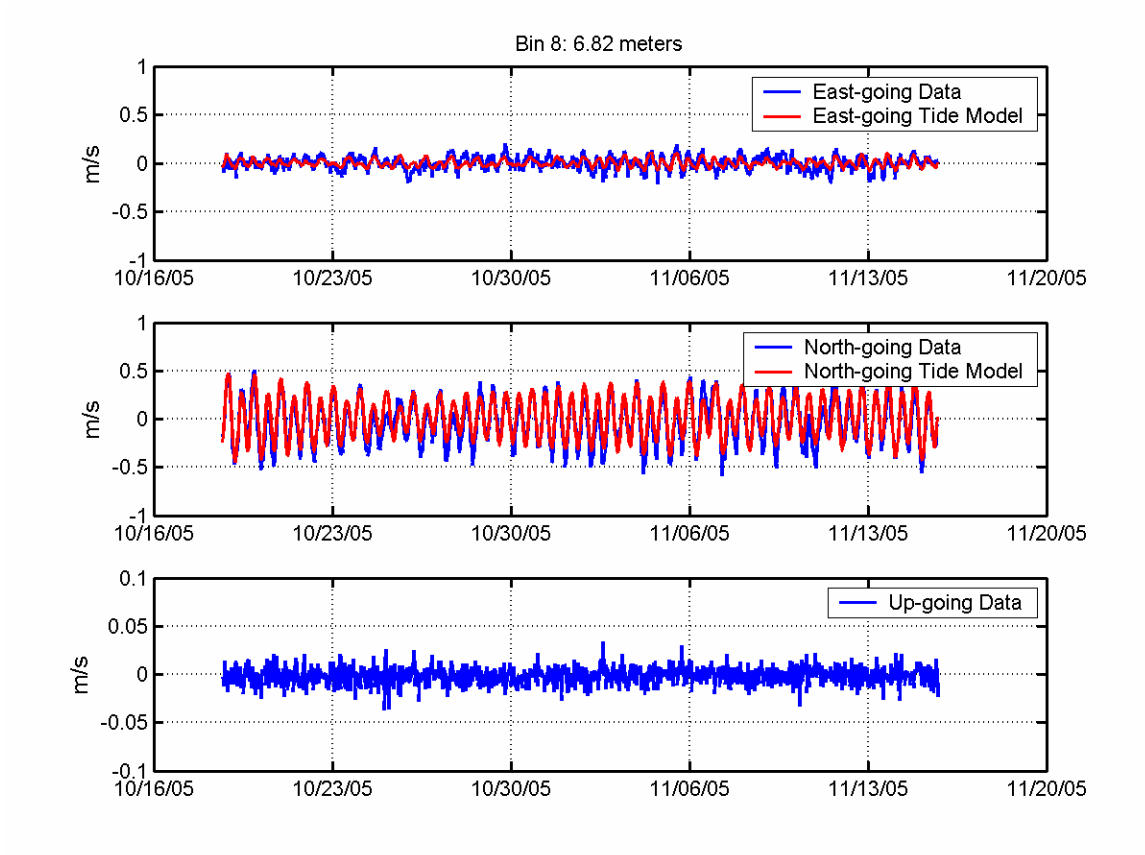

Figure A-8: The East- and North-going data sets at a depth of 6.82 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table11: The dominant tidal constituents for the east- and north-going components of velocity vector at a depth of 6.82 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0410	272.10	0.2908	281.46
S2	0.0833333	0.0064	320.09	0.0605	295.86
N2	0.0789992	0.0083	268.61	0.0366	230.28
K1	0.0417807	0.0149	198.87	0.0516	272.02
M4	0.1610228	0.0062	91.34	0.0085	215.79
O1	0.0387307	0.0057	100.09	0.0504	293.97
M6	0.2415342	0.0024	190.39	0.0069	124.48

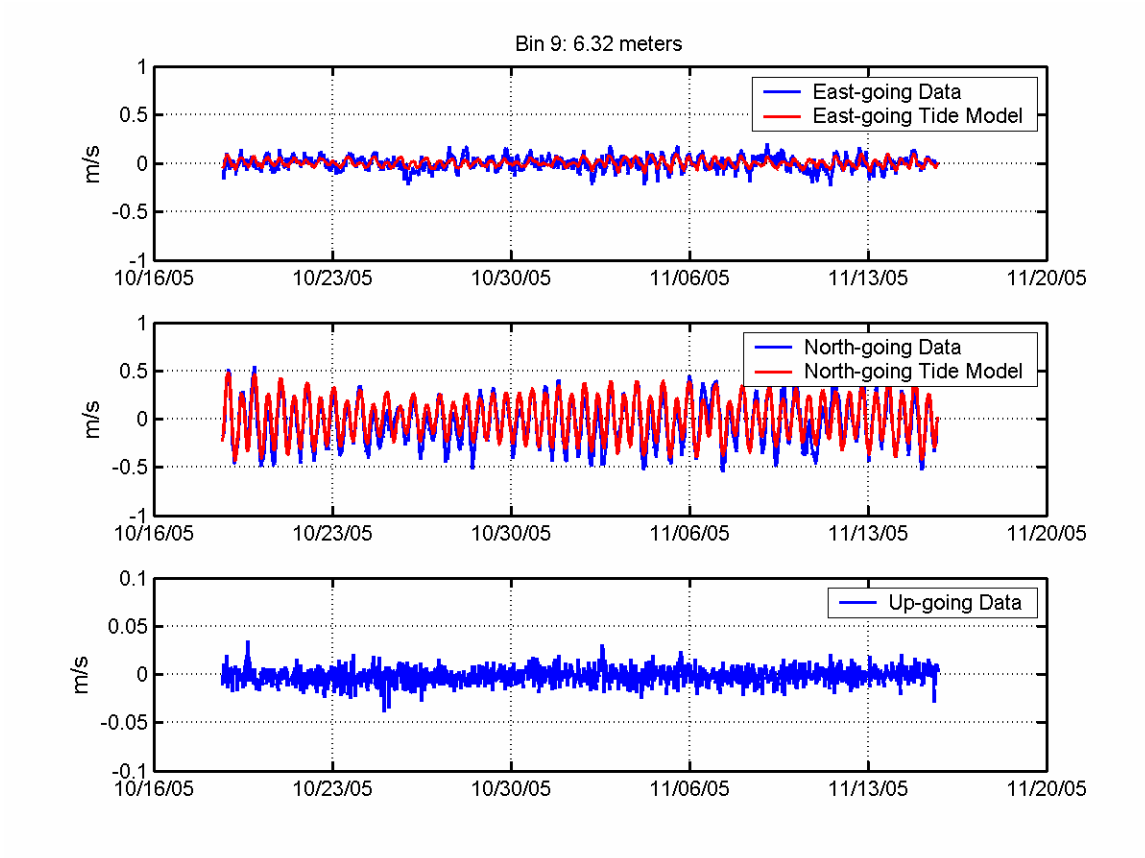

Figure A-9: The East- and North-going data sets at a depth of 6.32 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table12: The dominant tidal constituents for the east- and north-going components of velocity vector at a depth of 6.32 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0429	270.44	0.2897	282.24
S2	0.0833333	0.0055	342.73	0.0623	300.27
N2	0.0789992	0.0080	267.41	0.0351	232.55
K1	0.0417807	0.0121	209.24	0.0498	272.81
M4	0.1610228	0.0101	100.86	0.0062	236.59
O1	0.0387307	0.0023	101.63	0.0524	296.42
M6	0.2415342	0.0038	193.10	0.0048	126.36

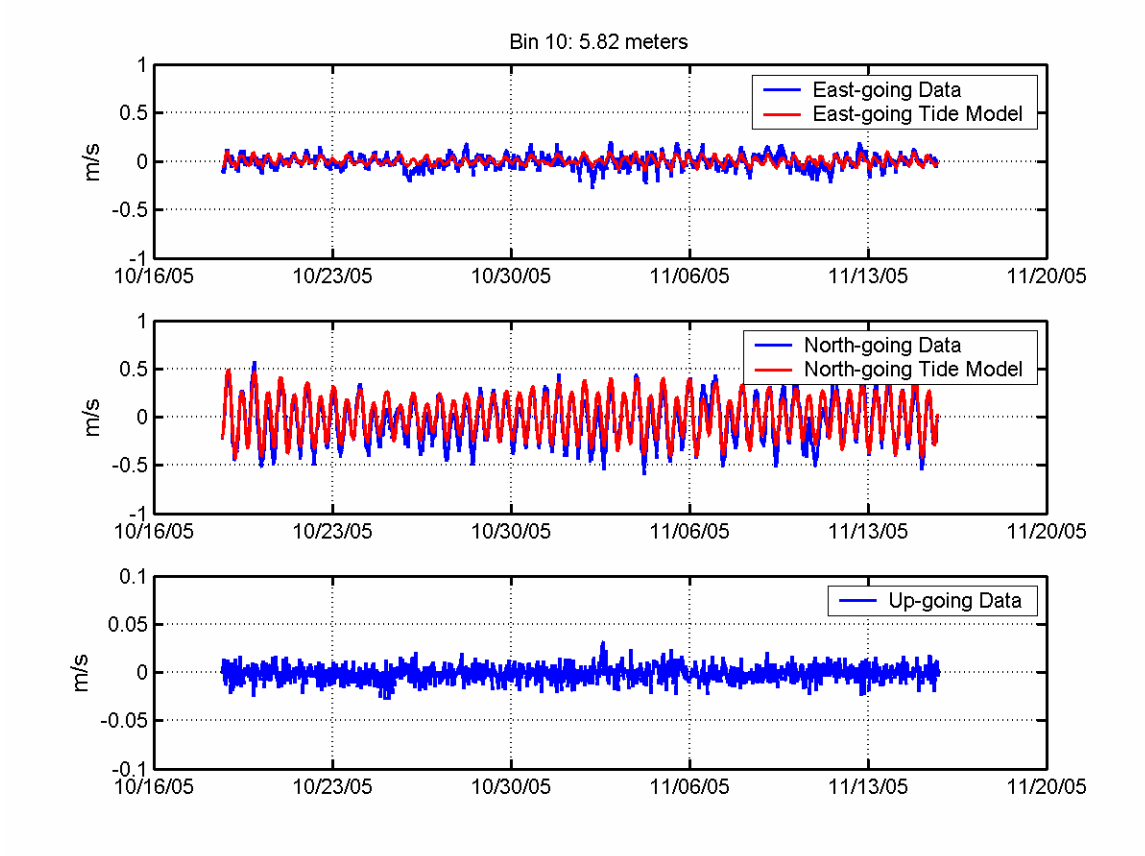

Figure A-10: The East- and North-going data sets at a depth of 5.82 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table13: The dominant tidal constituents for the east- and north-going components of velocity vector at a depth of 5.82 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0457	273.28	0.2878	282.63
S2	0.0833333	0.0046	347.25	0.0617	299.56
N2	0.0789992	0.0093	262.71	0.0364	232.50
K1	0.0417807	0.0114	231.10	0.0500	273.07
M4	0.1610228	0.0135	115.29	0.0047	281.45
O1	0.0387307	0.0023	105.09	0.0534	296.37
M6	0.2415342	0.0025	224.82	0.0042	131.46

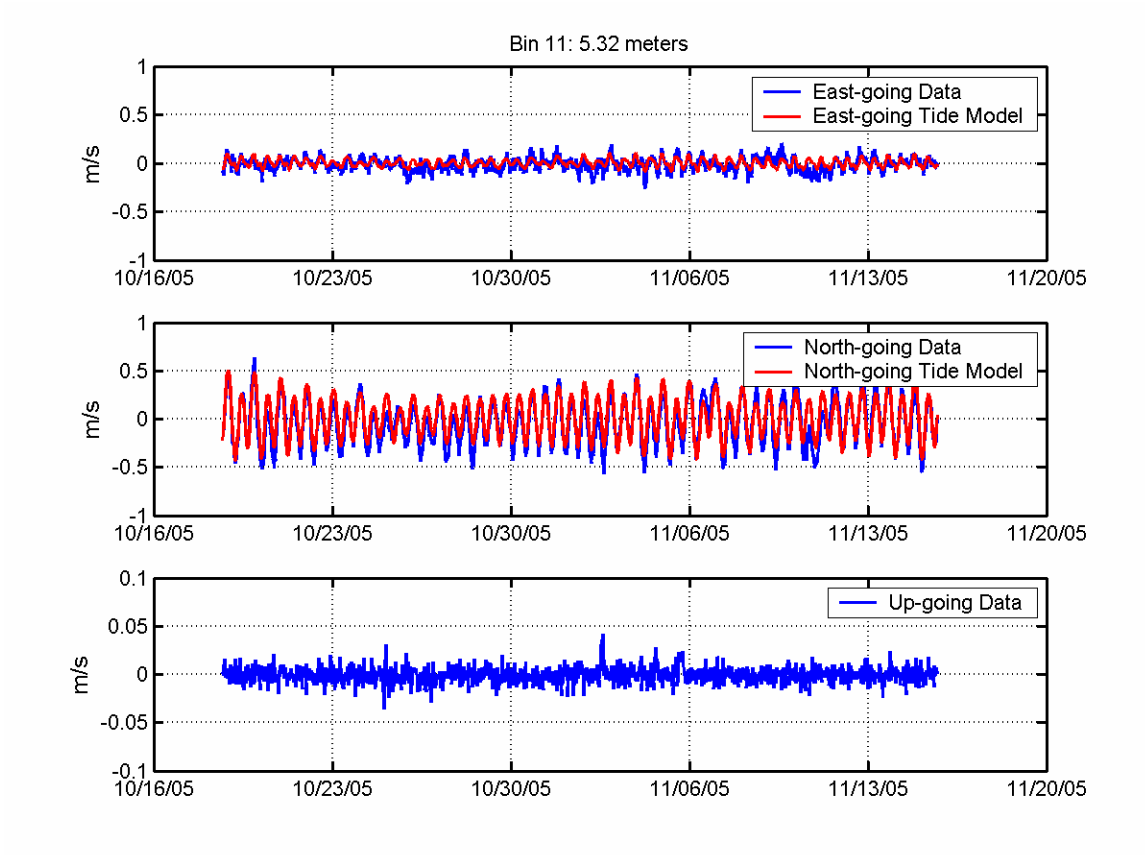

Figure A-11: The East- and North-going data sets at a depth of 5.32 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table14: The dominant tidal constituents for the east- and north-going components of velocity vector at a depth of 5.32 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0480	274.00	0.2876	282.24
S2	0.0833333	0.0035	347.21	0.0607	298.84
N2	0.0789992	0.0086	264.23	0.0363	234.81
K1	0.0417807	0.0091	240.82	0.0500	275.26
M4	0.1610228	0.0160	121.92	0.0015	295.09
O1	0.0387307	0.0017	75.22	0.0539	295.20
M6	0.2415342	0.0019	238.84	0.0048	114.10

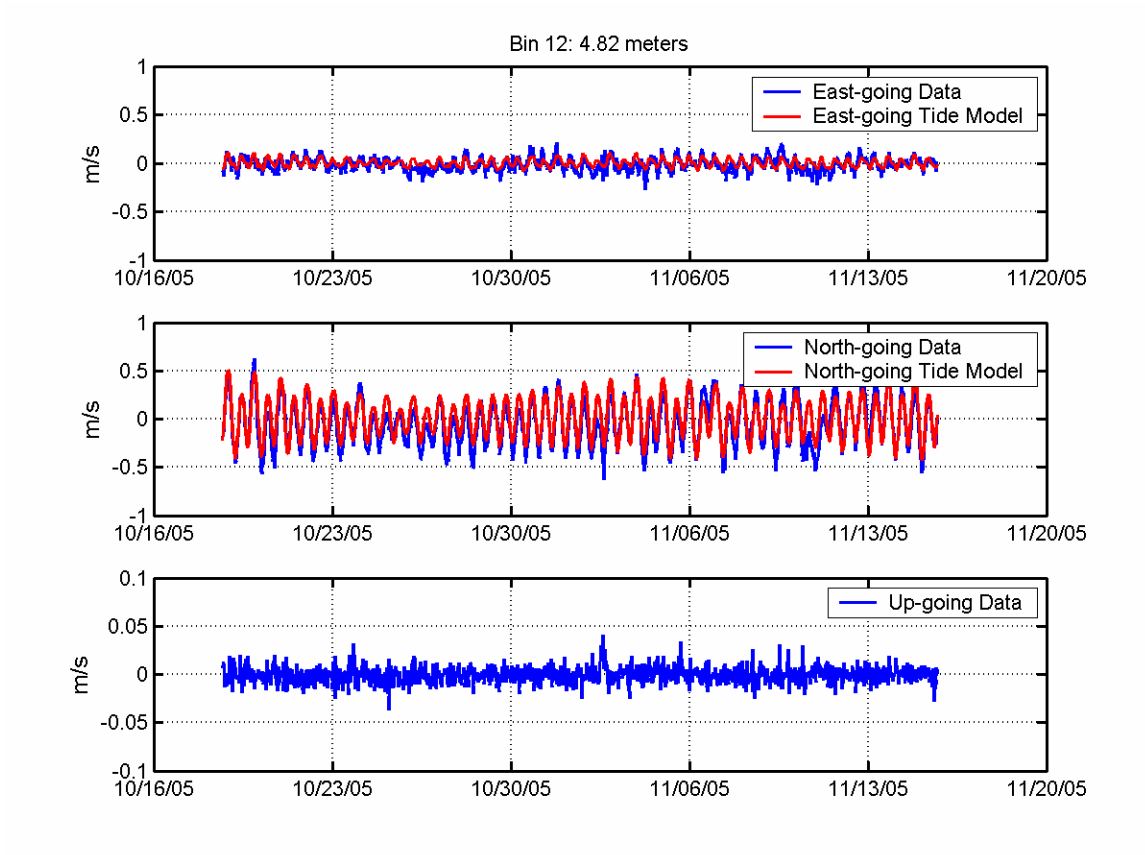

Figure A-12: The East- and North-going data sets at a depth of 4.82 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table15: The dominant tidal constituents for the east- and north-going components of velocity vector at a depth of 4.82 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0512	276.54	0.2848	282.27
S2	0.0833333	0.0038	297.59	0.0614	299.30
N2	0.0789992	0.0058	267.70	0.0361	238.83
K1	0.0417807	0.0088	252.77	0.0501	277.91
M4	0.1610228	0.0151	136.78	0.0013	228.20
O1	0.0387307	0.0021	69.10	0.0544	294.75
M6	0.2415342	0.0042	302.50	0.0035	132.35

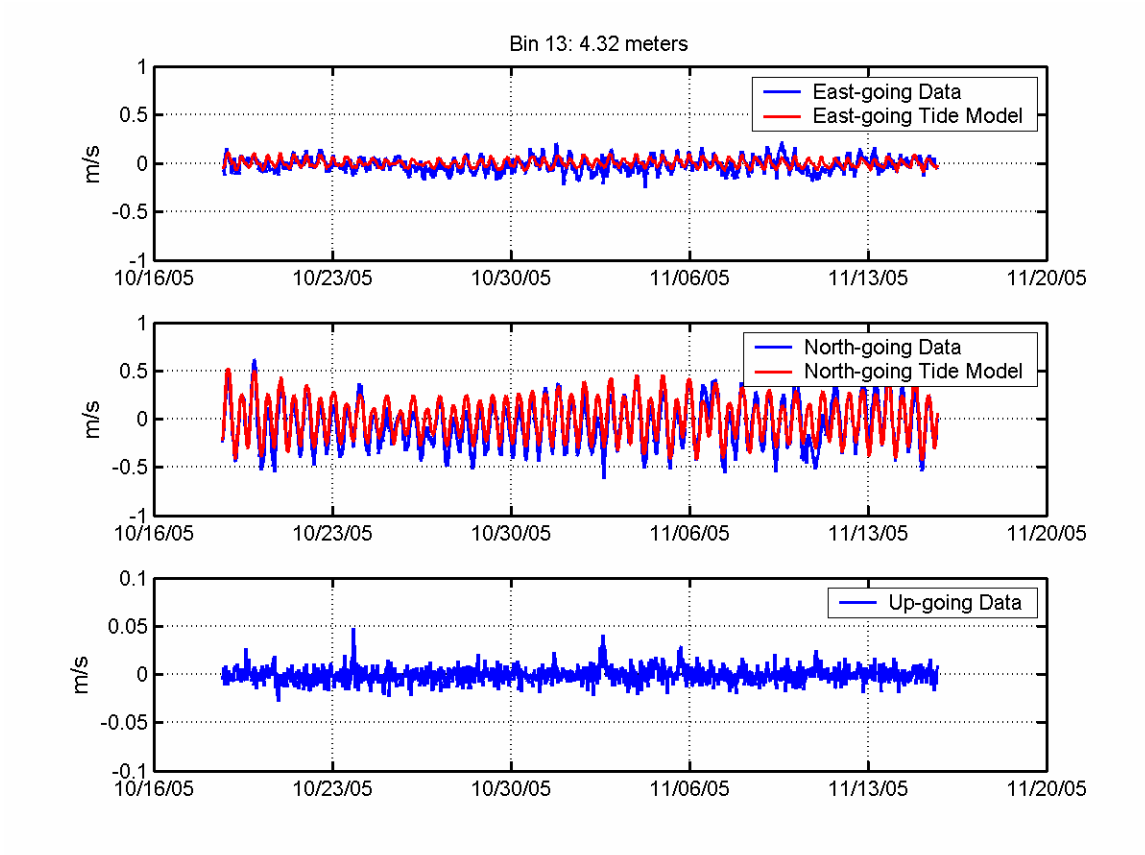

Figure A-13: The East- and North-going data sets at a depth of 4.32 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table16: The dominant tidal constituents for the east- and north-going components of velocity vector at a depth of 4.32 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0505	280.63	0.2839	282.06
S2	0.0833333	0.0047	295.82	0.0613	298.47
N2	0.0789992	0.0057	266.61	0.0368	241.92
K1	0.0417807	0.0070	273.17	0.0498	282.23
M4	0.1610228	0.0163	134.89	0.0023	19.63
O1	0.0387307	0.0023	62.08	0.0540	293.14
M6	0.2415342	0.0038	3.24	0.0027	143.93

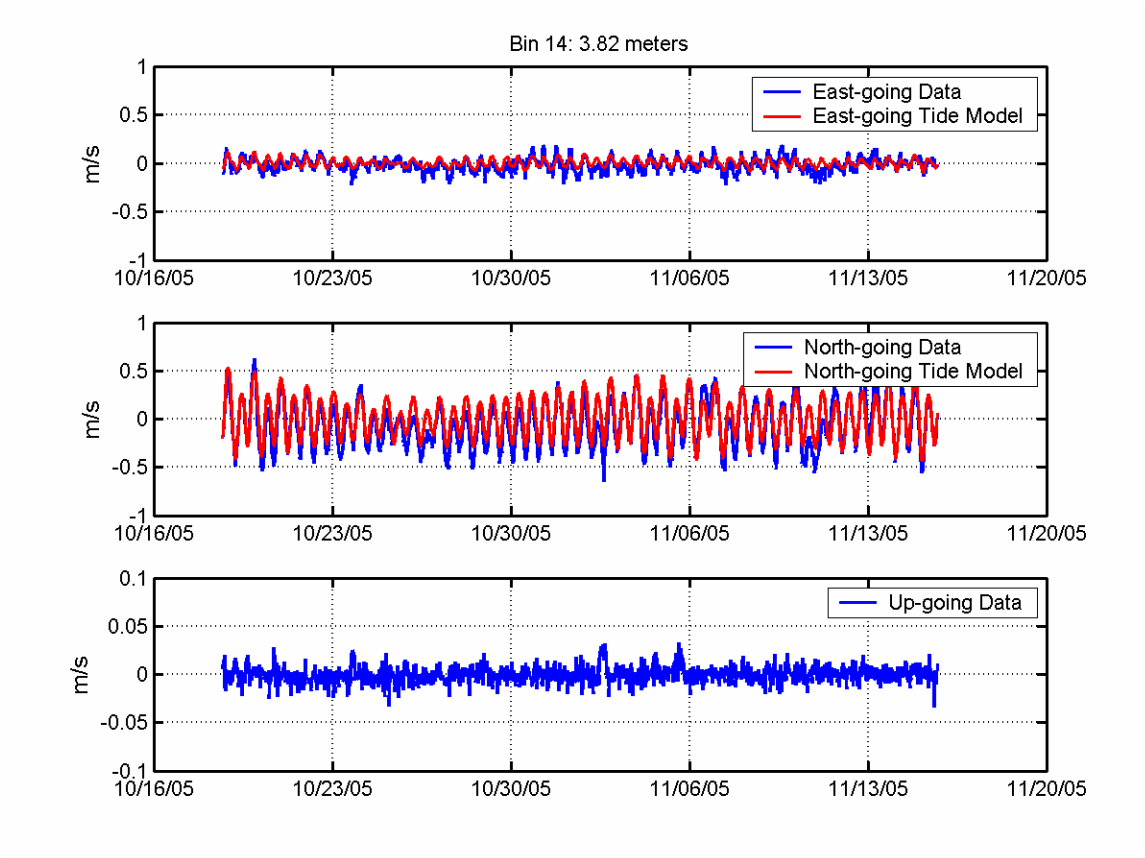

Figure A-14: The East- and North-going data sets at a depth of 3.82 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table17: The dominant tidal constituents for the east- and north-going components of velocity vector at a depth of 3.82 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0509	281.58	0.2854	282.03
S2	0.0833333	0.0091	296.88	0.0605	296.93
N2	0.0789992	0.0045	251.19	0.0400	245.49
K1	0.0417807	0.0065	293.68	0.0522	284.48
M4	0.1610228	0.0132	137.92	0.0023	202.77
O1	0.0387307	0.0015	306.26	0.0545	291.37
M6	0.2415342	0.0022	29.49	0.0021	84.17

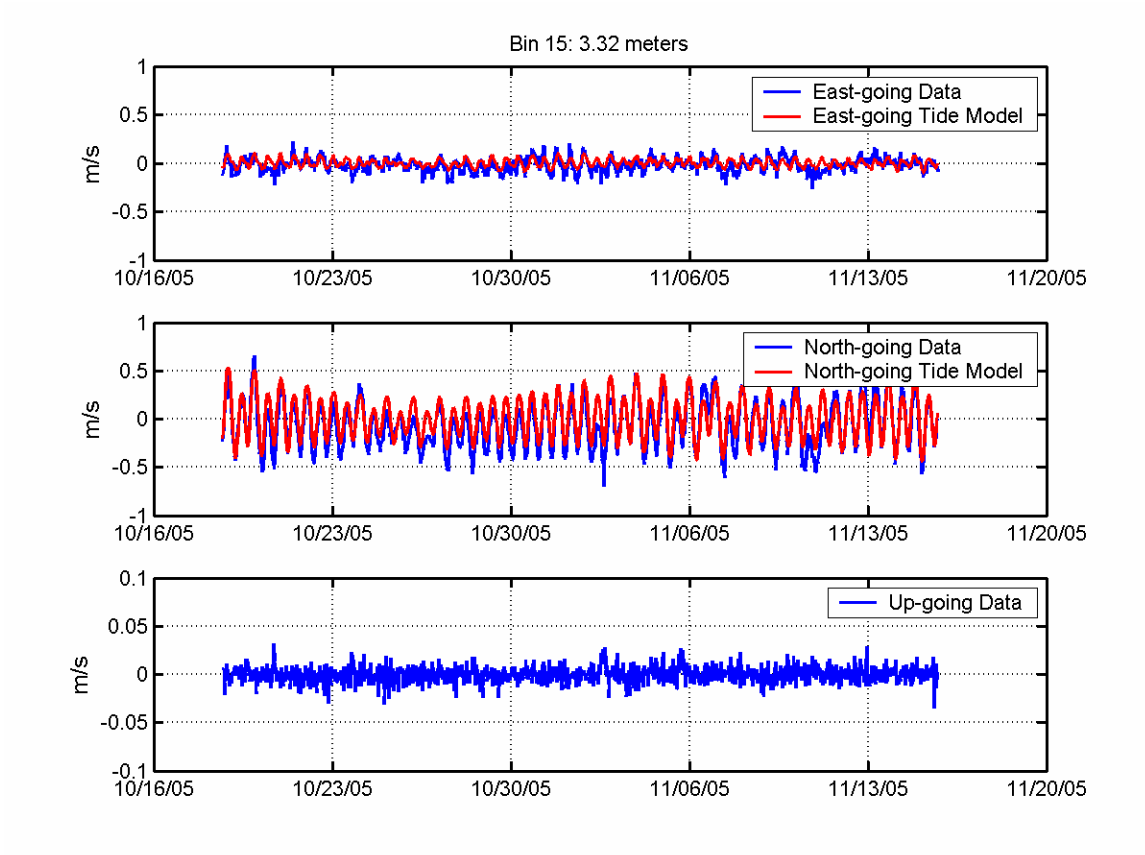

Figure A-15: The East- and North-going data sets at a depth of 3.32 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table18: The dominant tidal constituents for the east- and north-going components of velocity vector at a depth of 3.32 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0480	283.83	0.2858	281.97
S2	0.0833333	0.0083	286.20	0.0612	295.24
N2	0.0789992	0.0028	259.19	0.0435	248.00
K1	0.0417807	0.0059	294.37	0.0559	283.56
M4	0.1610228	0.0132	143.31	0.0031	354.75
O1	0.0387307	0.0036	304.98	0.0568	291.05
M6	0.2415342	0.0047	66.79	0.0024	104.74

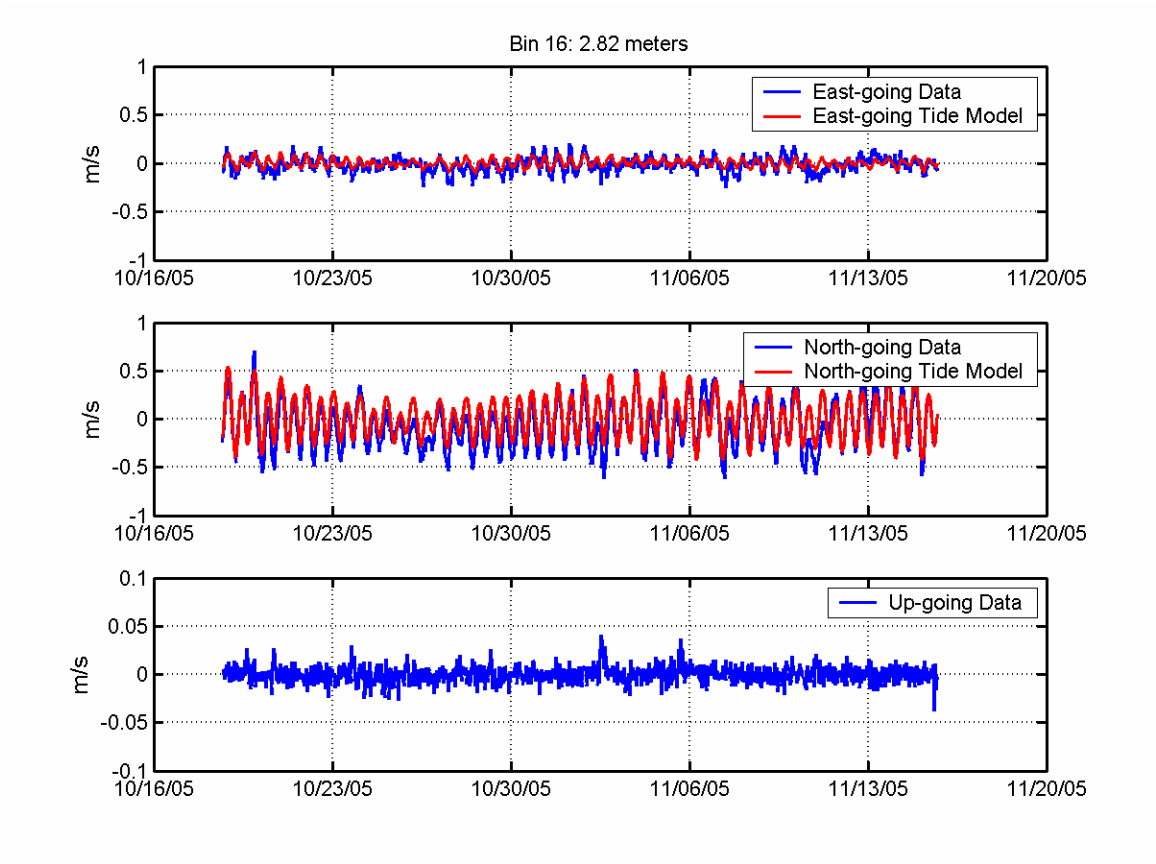

Figure A-16: The East- and North-going data sets at a depth of 2.82 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table19: The dominant tidal constituents for the east- and north-going components of velocity vector at a depth of 2.82 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0462	284.15	0.2846	281.29
S2	0.0833333	0.0096	282.70	0.0609	296.80
N2	0.0789992	0.0031	242.10	0.0472	251.48
K1	0.0417807	0.0070	303.31	0.0588	285.05
M4	0.1610228	0.0121	159.88	0.0016	289.22
O1	0.0387307	0.0056	292.64	0.0578	289.93
M6	0.2415342	0.0052	84.58	0.0038	61.09

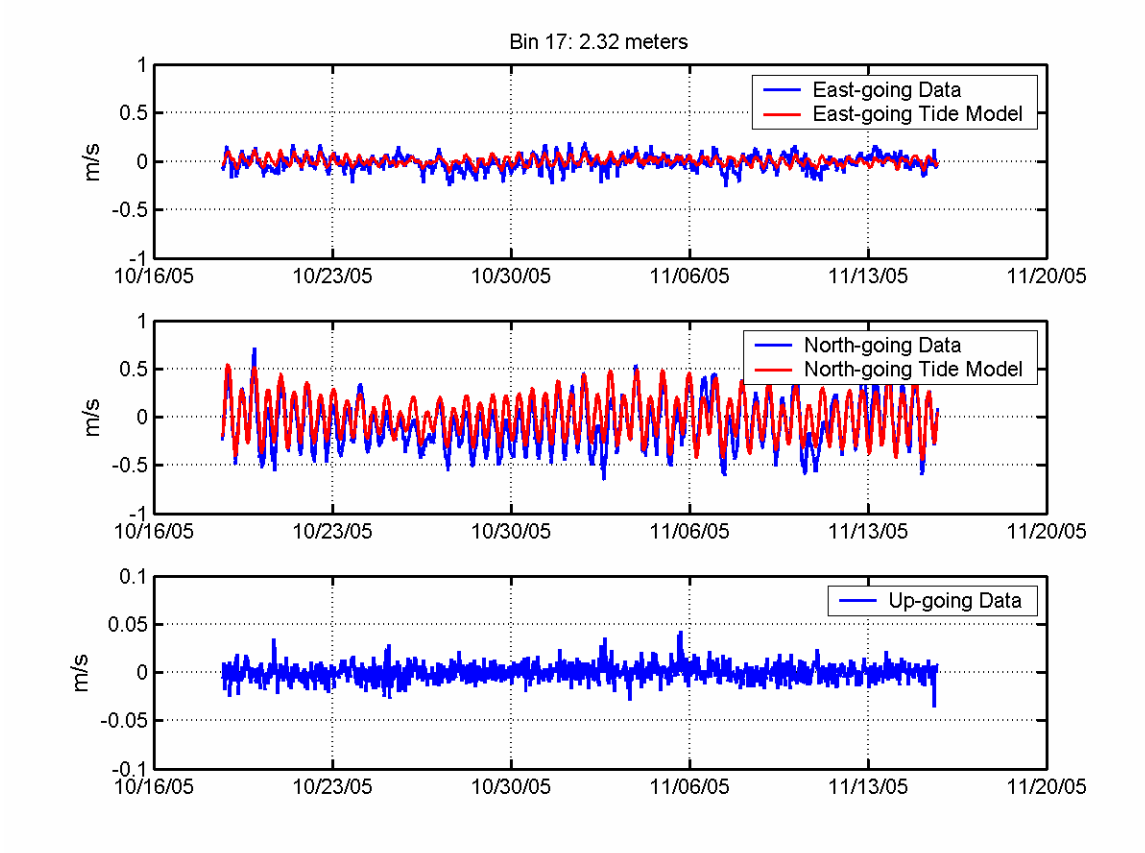

Figure A-17: The East- and North-going data sets at a depth of 2.32 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table20: The dominant tidal constituents for the east- and north-going components of velocity vector at a depth of 2.32 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0438	288.28	0.2845	280.74
S2	0.0833333	0.0100	294.56	0.0616	294.20
N2	0.0789992	0.0027	213.39	0.0504	251.27
K1	0.0417807	0.0040	154.97	0.0630	285.75
M4	0.1610228	0.0146	160.45	0.0013	350.56
O1	0.0387307	0.0076	277.66	0.0571	288.60
M6	0.2415342	0.0055	96.50	0.0038	74.08

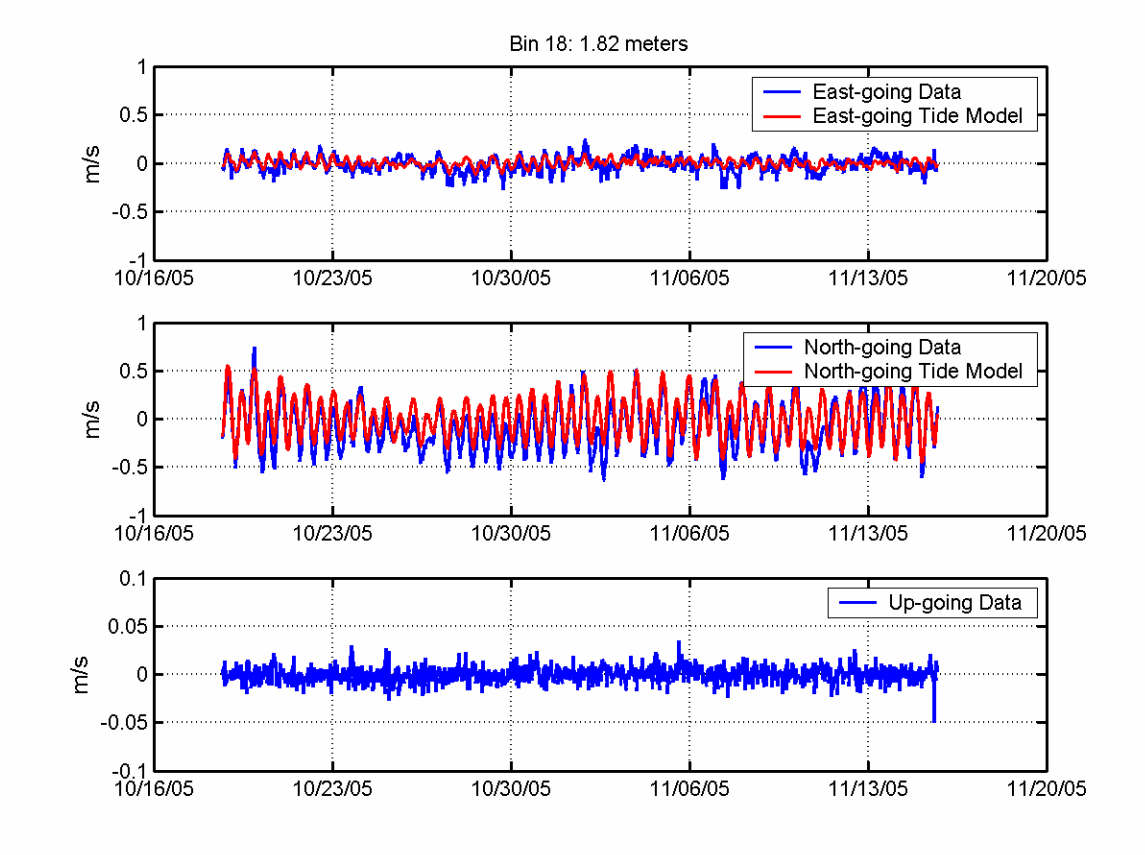

Figure A-18: The East- and North-going data sets at a depth of 1.82 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table21: The dominant tidal constituents for the east- and north-going components of velocity vector at a depth of 1.82 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0422	290.16	0.2839	280.86
S2	0.0833333	0.0118	304.79	0.0618	291.69
N2	0.0789992	0.0023	143.45	0.0522	251.06
K1	0.0417807	0.0021	3.14	0.0652	285.53
M4	0.1610228	0.0136	155.97	0.0026	269.66
O1	0.0387307	0.0122	272.38	0.0565	288.52
M6	0.2415342	0.0052	93.79	0.0069	73.73

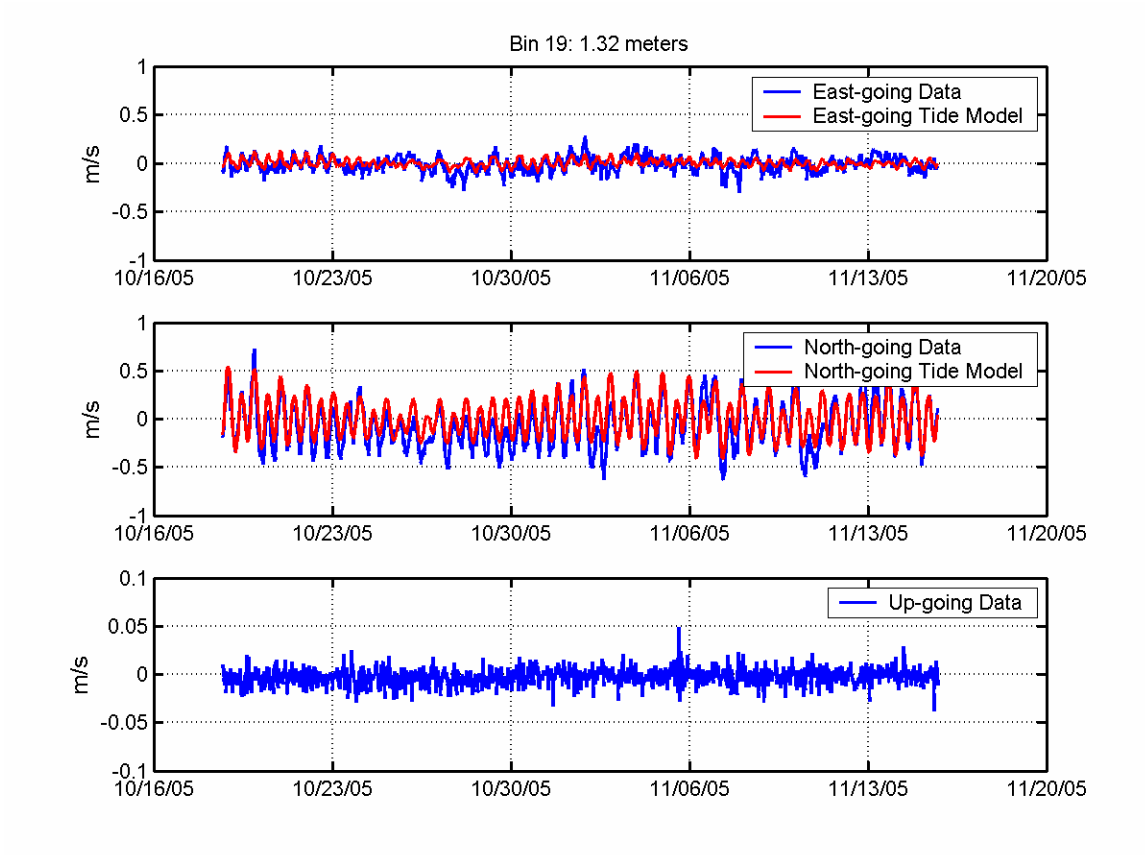

Figure A-19: The East- and North-going data sets at a depth of 1.32 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table22: The dominant tidal constituents for the east- and north-going components of velocity vector at a depth of 1.32 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0376	287.25	0.2628	280.02
S2	0.0833333	0.0137	308.49	0.0582	294.67
N2	0.0789992	0.0008	246.59	0.0505	252.60
K1	0.0417807	0.0037	90.40	0.0647	283.22
M4	0.1610228	0.0105	172.90	0.0090	234.04
O1	0.0387307	0.0145	273.07	0.0560	286.42
M6	0.2415342	0.0065	94.33	0.0057	38.80

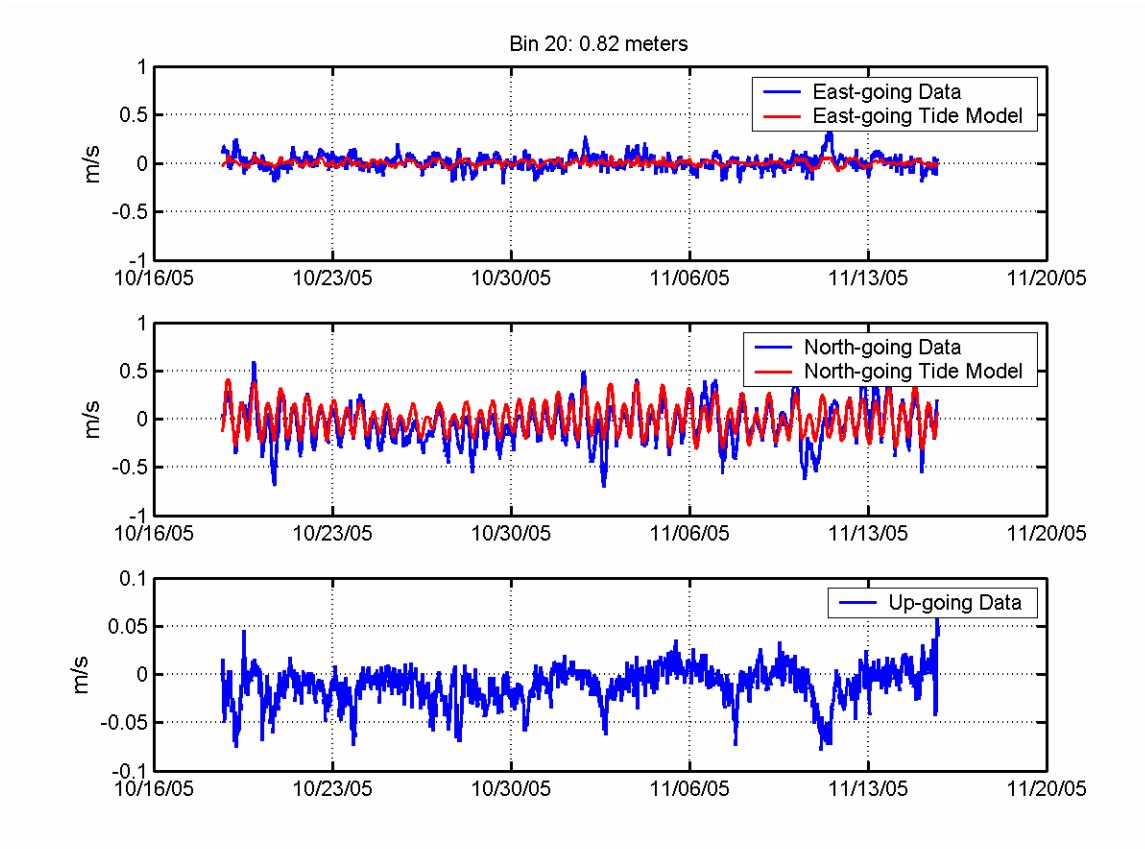

Figure A-20: The East- and North-going data sets at a depth of 0.82 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table23: The dominant tidal constituents for the east- and north-going components of velocity vector at a depth of 0.82 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0088	298.36	0.2005	280.93
S2	0.0833333	0.0058	335.99	0.0460	295.77
N2	0.0789992	0.0043	114.64	0.0326	248.86
K1	0.0417807	0.0020	97.98	0.0502	293.42
M4	0.1610228	0.0090	209.75	0.0049	273.37
O1	0.0387307	0.0088	271.43	0.0420	291.02
M6	0.2415342	0.0044	94.65	0.0046	55.12

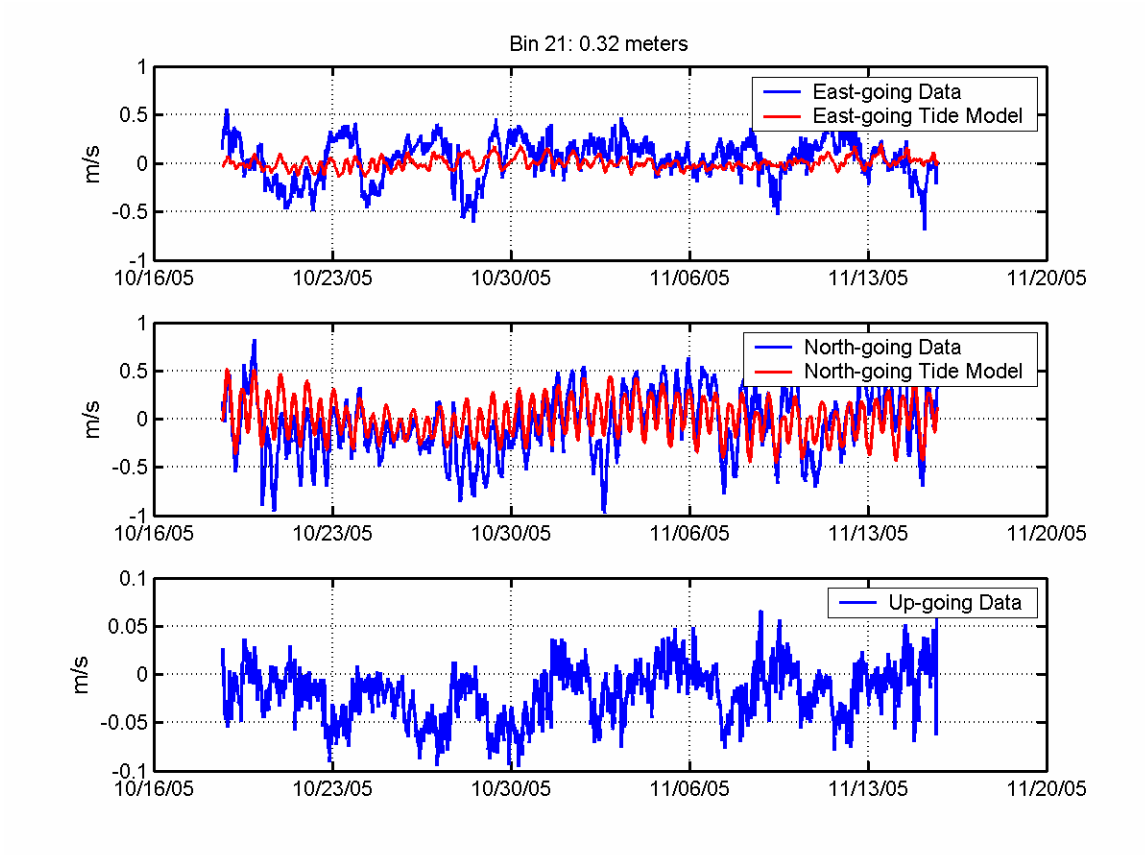

Figure A-21: The East- and North-going data sets at a depth of 0.32 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table24: The dominant tidal constituents for the east- and north-going components of velocity vector at a depth of 0.32 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0149	272.75	0.2441	282.48
S2	0.0833333	0.0312	333.71	0.0481	299.03
N2	0.0789992	0.0091	69.58	0.0312	255.68
K1	0.0417807	0.0145	54.24	0.0420	291.97
M4	0.1610228	0.0127	156.57	0.0013	275.67
O1	0.0387307	0.0273	247.02	0.0509	280.83
M6	0.2415342	0.0015	238.55	0.0021	21.21

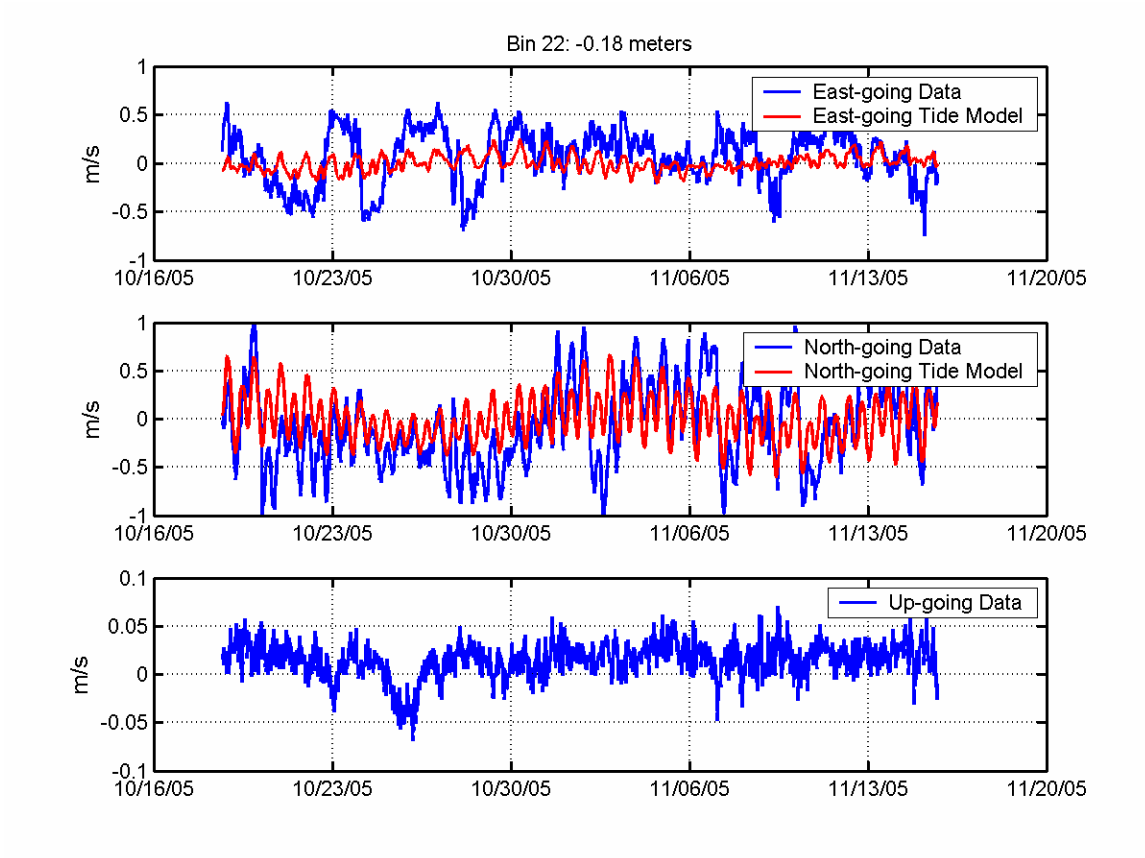

Figure A-22: The East- and North-going data sets at a depth of -0.82 meters along with the respective tide model estimations. The up-going component of the velocity vector is also included.

Table25: The dominant tidal constituents for the east- and north-going components of velocity vector at a depth of -0.82 meters (amplitude values are in meters and phase values are in degrees).

Tidal Constituent	Frequency (hr^{-1})	East-Going Amplitude	East-Going Phase	North-Going Amplitude	North-Going Phase
M2	0.0805114	0.0327	273.29	0.2797	281.85
S2	0.0833333	0.0342	322.18	0.0578	303.54
N2	0.0789992	0.0134	8.16	0.0448	270.24
K1	0.0417807	0.0197	59.12	0.0699	291.35
M4	0.1610228	0.0191	157.95	0.0016	238.05
O1	0.0387307	0.0346	259.69	0.0664	282.75
M6	0.2415342	0.0017	68.48	0.0030	36.03