Table 5-2 Error measures for water levels

Period	Location	IOA	MAE (m)	RMSE (m)
May to July 2006	Mangles Bay	0.983	0.040	0.051
January to March 2007		0.987	0.039	0.048
January to April 2008		0.986	0.038	0.053
July to October 2008		0.988	0.037	0.046
March 2011		0.984	0.033	0.039
April 2013	Stirling Channel Beacon 5	0.968	0.049	0.060
October to November 2015		0.979	0.036	0.045
Calibration goals		≥ 0.8	≤ 0.10	≤ 0.15

5.2 Velocity comparisons

5.2.1 Measurement specifications

Acoustic Doppler Current Profiler (ADCP) velocity measurements were collected in winter 2006 and summer 2007 at two locations for each campaign (the locations of the instruments are presented in Figure 2-4). Station *Spoil Grounds* was located within the eastern shore area at a depth of approximately 6.5 m. Station *Northern Basin* was located in the deep basin at approximately 19.0 m depth. Details of the ADCP arrangements are summarised in Table 5-3.

Table 5-3 Details of ADCP arrangements

Station	Deployment depth	Number of bins	Bin heights	Bin spacing	Sampling Interval
Spoil Grounds	6.0 m	8 (winter) 9 (summer)	1.6 m to 5.1 (winter) 1.6 m to 5.6 (summer)	0.5 m	10 minutes
Northern Basin	18.5 m	14 (winter) 15 (summer)	2.5 m to 15.5 (winter) 2.5 m to 16.5 (summer)	1.0 m	10 minutes

The winter deployment was undertaken between 10 May and 07 July 2006, whilst the summer deployment was undertaken between 31 January and 29 March 2007.

5.2.2 Model comparisons

5.2.2.1 May to July 2006

Comparisons between simulated velocities and ADCP measurements in the transition from autumn to winter (May to July 2006) at Spoil Grounds and Northern Basin are shown in Figure 5-7 to Figure 5-12, respectively. The comparisons in Figure 5-7 and Figure 5-11 are shown in terms of velocity components colour contours, where the colours indicate either of the velocity components (E-W being east-west component, with negative values being water directed west and analogously N-S being north-south component, with negative values being water travelling south), as given by the respective colour bars. The x- and y-axes show time and height above the seabed, respectively. The same comparison figures are shown over shorter time intervals (i.e. with higher temporal resolution) in Appendix E. Time series of velocity components at different ADCP bins near the surface (Figure 5-8 and Figure 5-12), mid water column (Figure 5-9 and Figure 5-13) and near the bed (Figure 5-10 and Figure 5-14) are also presented for comparisons and shown over shorter intervals in Appendix E.

The contours shown in Figure 5-7 and Figure 5-11 demonstrate that the model reproduced key characteristics of the velocity field at the different stations. For example, at Spoil Grounds, observed and simulated E-W velocities were generally weaker than N-S velocities. In addition, vertical shear of the E-W component was more prominent than for the N-S component. The velocity components were generally lower than 0.05 m/s with episodic northerly winds driving increased velocity magnitudes up to 0.15 m/s every 7 to 10 days. The model captured these transitions to southerly flows during the wind events, as well as the velocity increases throughout the water column. This points to the model’s ability to respond appropriately to wind driving and also to reproduce vertical momentum exchange at Spoil Grounds.

At Northern Basin, and in contrast with Spoil grounds, both measured and simulated velocities presented a three-layered structure at times, with surface and bottom velocities exceeding those at mid depth. This structure was more evident with the passage of cold fronts when winds shifted from the north and the northwest to southwest. Under these occasions, velocity components in the surface and bottom layers were up to 0.15 m/s (see Section 2.2.2.1).

The model reproduced some of these events well (i.e. 28 to 30 May, 20 to 21 June, and 27 to 28 June – see e.g. Figure 5-15; also Appendix E). However, in a similar event on 15 May, the model showed a stronger tendency to move water in the northerly direction, whilst field measurements indicated velocities moving in more of a south-easterly direction (Figure 5-16; also Appendix E). This indicates that, for that particular event, the model was more responsive to an increase in the N-S component of the wind direction, whilst the field data indicated a stronger response to the wind moving in the easterly direction.

It was evident in both field data and model results that the deep basin of the Sound is subject to internal motions (i.e. internal waves), and these are also influenced by the Earth’s rotation (see e.g. D’Adamo 2002). The response to a wind event will depend on the phase and amplitude of these internal motions. As a result, model agreement in terms of velocities will depend on correspondence of the internal motion phase prior to an event start. This may explain why a similar event was better reproduced on 28 May (Figure 5-15) than on 15 May (Figure 5-15). BMT is not aware of studies that have specifically considered internal wave activity in Cockburn Sound.

On the other hand, the water motion in the shallow areas (i.e. Spoil Grounds) was not layered, so that correspondence with the internal motions was less impactful on model performance.

The model predictive skill was also tested statistically with calculations of the Index of Agreement (IOA), Mean Absolute Error (MAE), and Root Mean Square Error (RMSE) as defined in Appendix D. At project inception, the following calibration targets were agreed as indicators of satisfactory model validation (Table 5-4):

Table 5-4 Calibration goals for velocity

Variable	IOA (-)	MAE (m/s)	RMSE (m/s)
X-component Velocity	≥ 0.5	≤ 0.05	≤ 0.06
Y-component Velocity	≥ 0.5	≤ 0.05	≤ 0.06

This statistical evaluation of the predicted currents at the ADCP locations during the May to July 2006 period is provided in Table 5-5 and Table 5-6 for Spoil Grounds and Northern Basin, respectively. These statistics confirm the model's predictive ability with velocity IOA's generally above 0.5 (only a few instances with lower values that coincided with the regions of low current velocities, i.e., large noise to signal ratio in measurements). MAE was between 0.02 and 0.03 m/s for Spoil Grounds and between 0.02 and 0.04 m/s for Northern Basin. RMSE was between 0.02 and 0.03 m/s for Spoil Grounds and 0.03 and 0.05 m/s for Northern Basin. These results are similar to other modelling investigations compared to the same data set (CWR 2009) and within the model ranges agreed at project inception (Table 5-4).

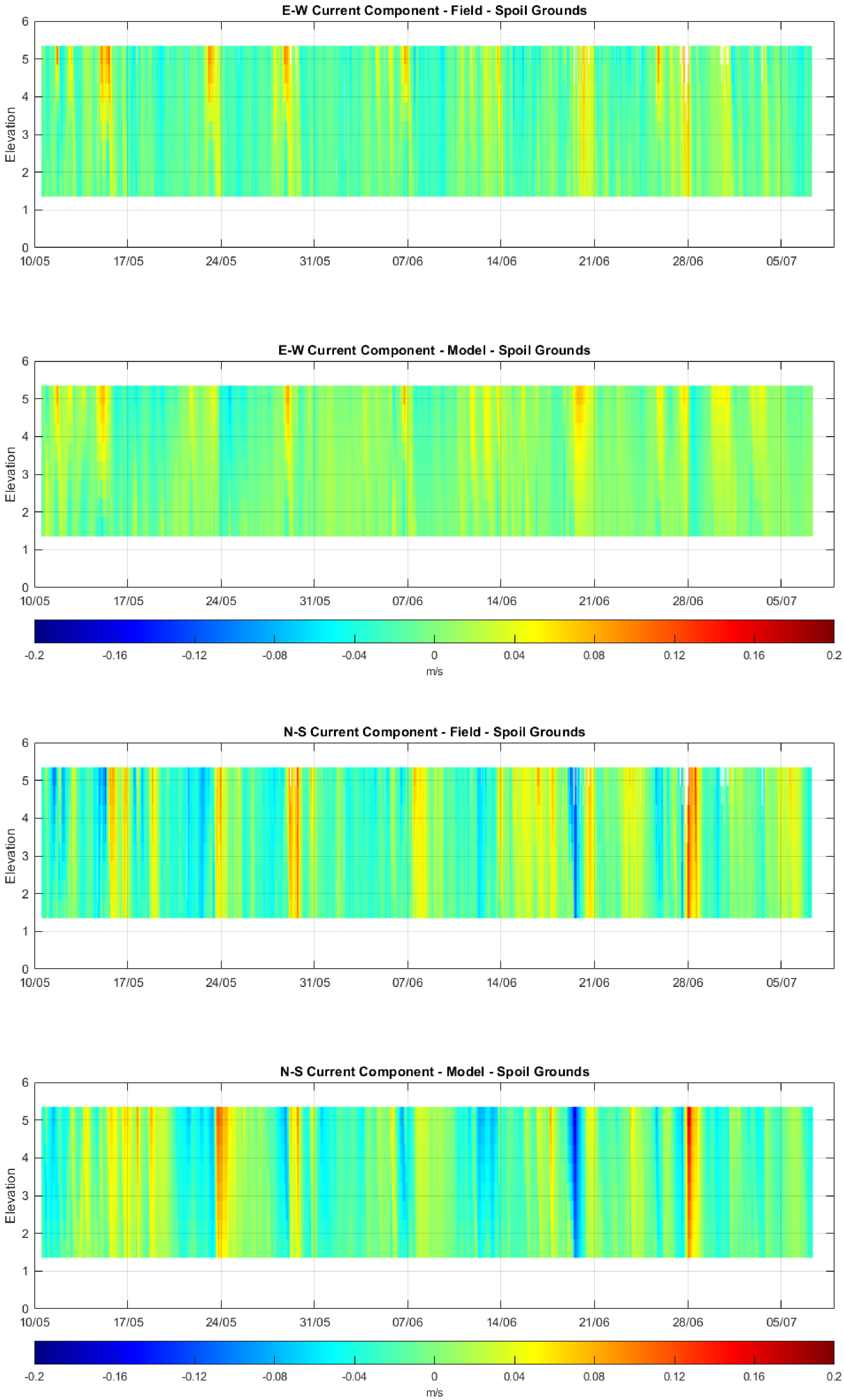

Figure 5-7 Comparisons between simulated velocities and ADCP measurements at Spoil Grounds for May to July 2006

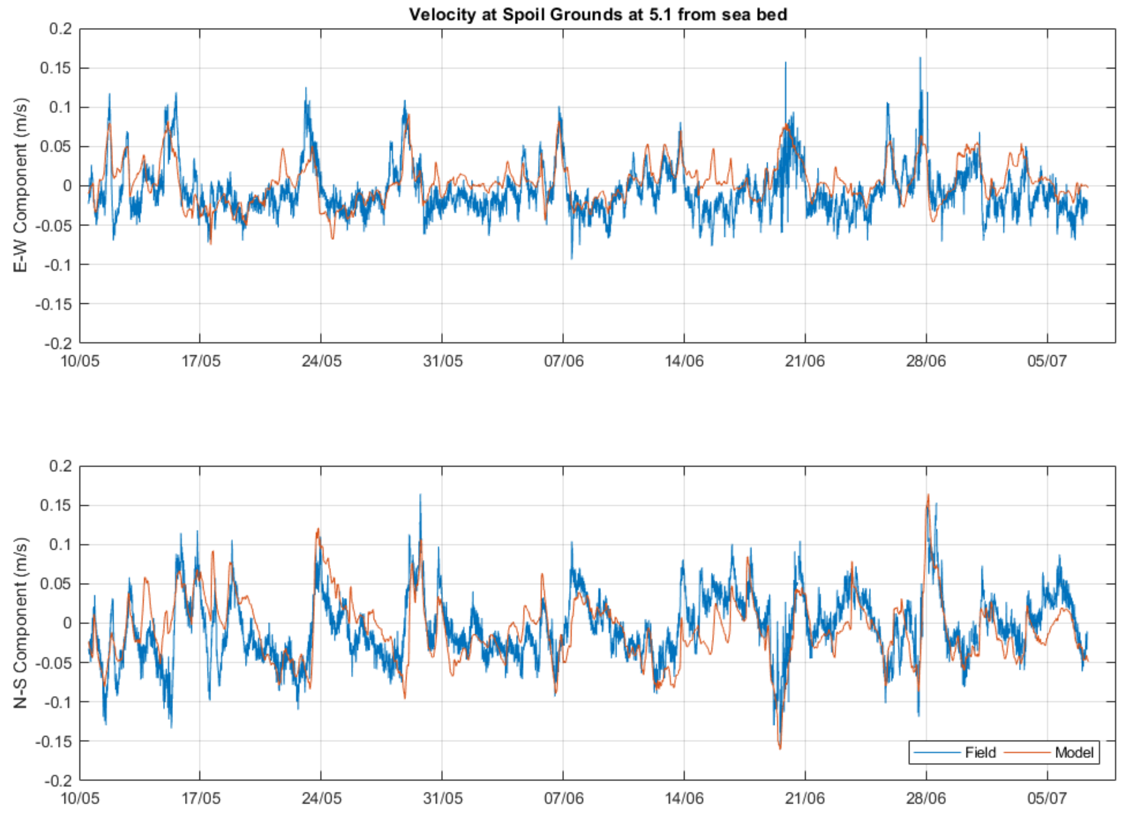

Figure 5-8 Comparison between simulated and measured ADCP velocities at 5.1m from sea bed at Spoil Grounds for May to July 2006

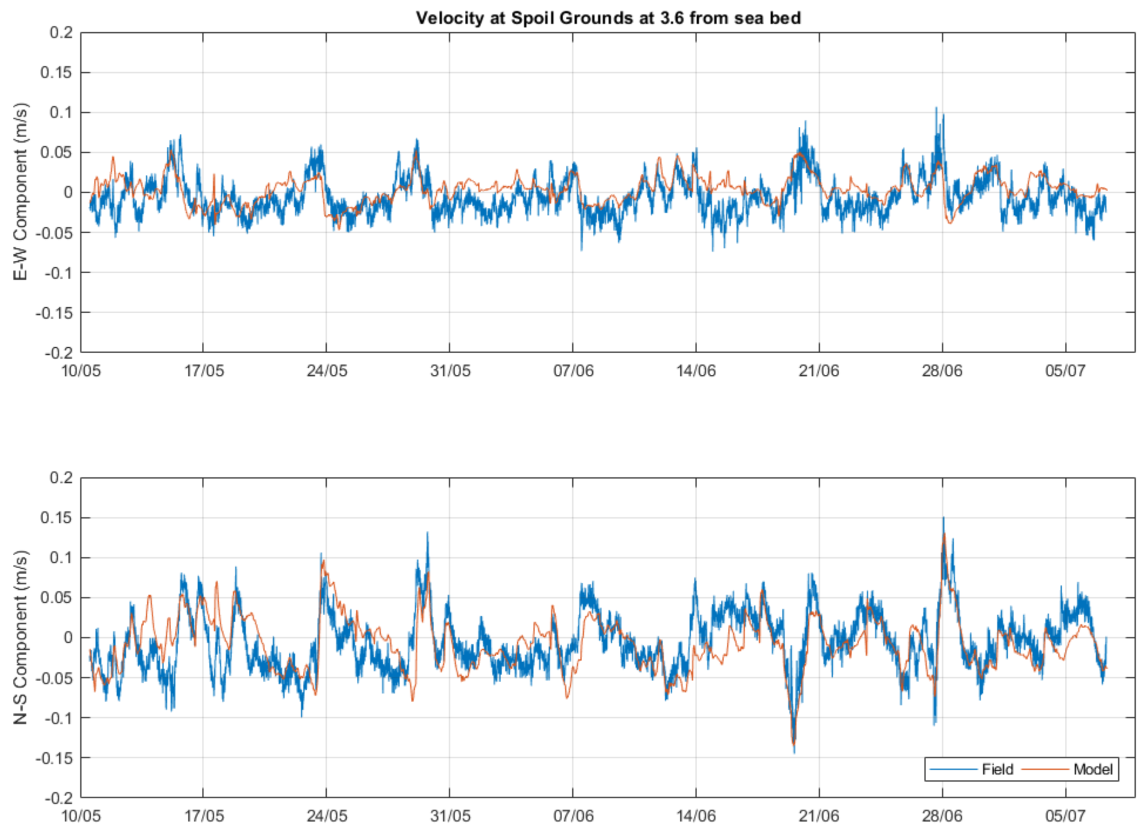

Figure 5-9 Comparison between simulated and measured ADCP velocities at 3.6m from sea bed at Spoil Grounds for May to July 2006

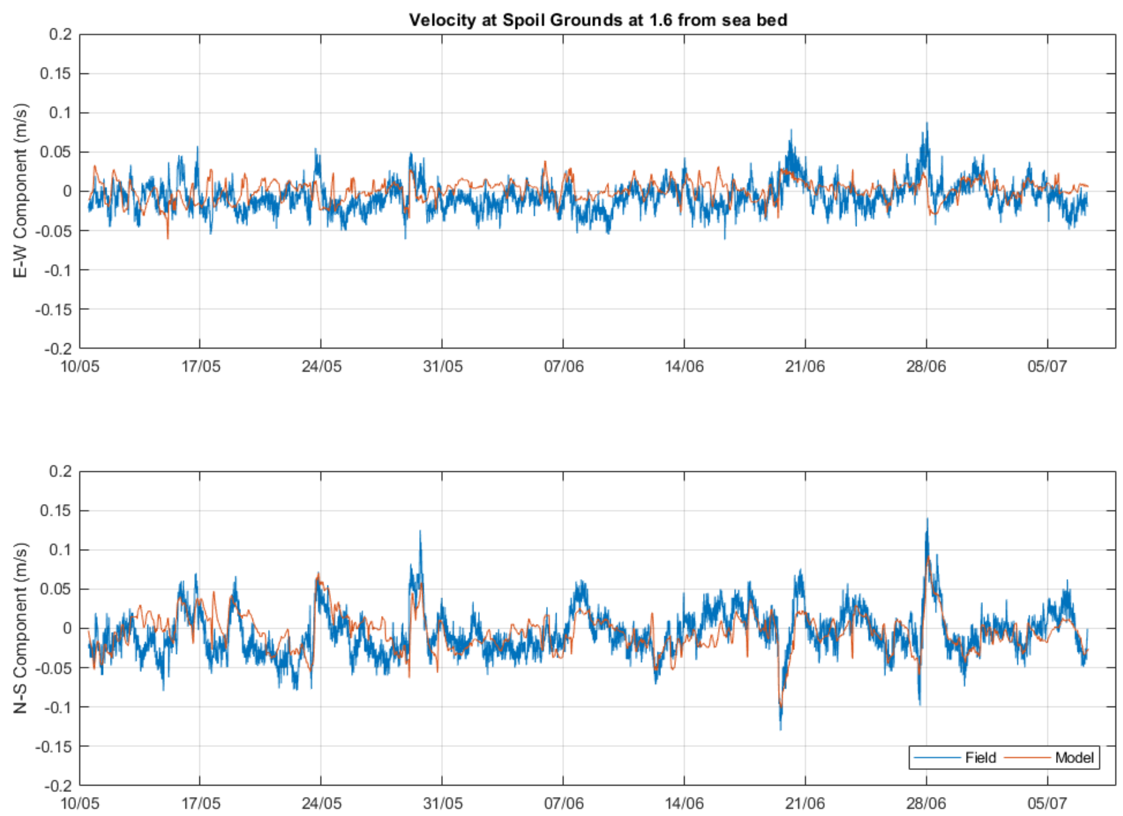

Figure 5-10 Comparison between simulated and measured ADCP velocities at 1.6m from sea bed at Spoil Grounds for May to July 2006

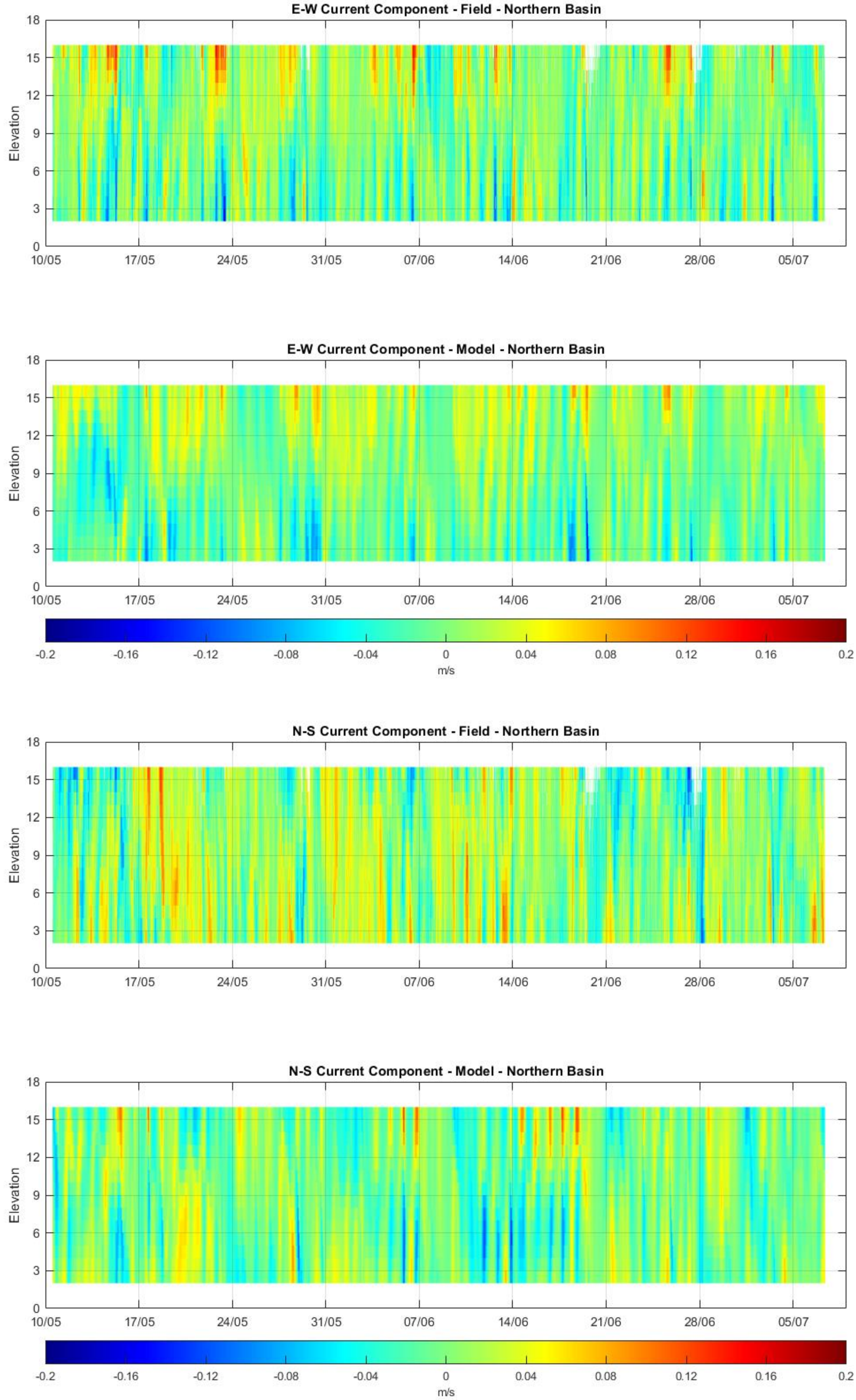

Figure 5-11 Comparisons between simulated velocities and ADCP measurements at Northern Basin for May to July 2006

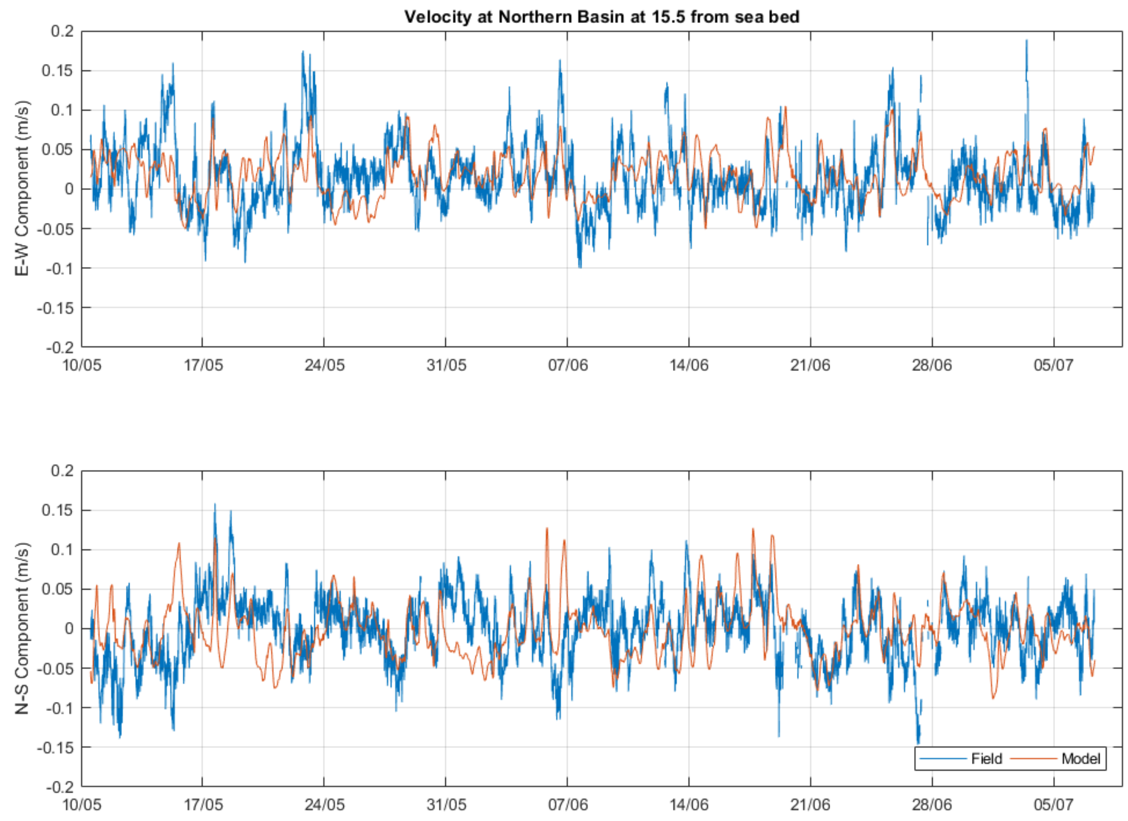

Figure 5-12 Comparison between simulated and measured ADCP velocities at 15.5m from the sea bed at Northern Basin for May to July 2006

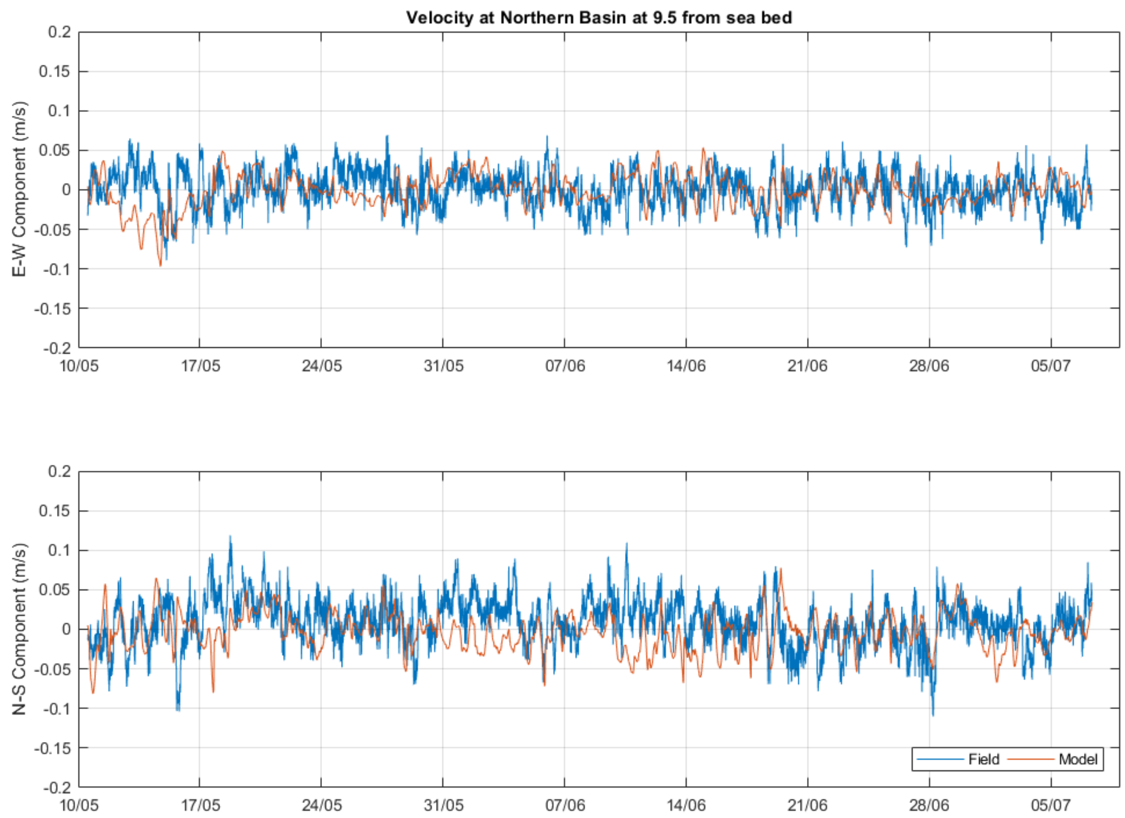

Figure 5-13 Comparison between simulated and measured ADCP velocities at 9.5m from the sea bed at Northern Basin for May to July 2006

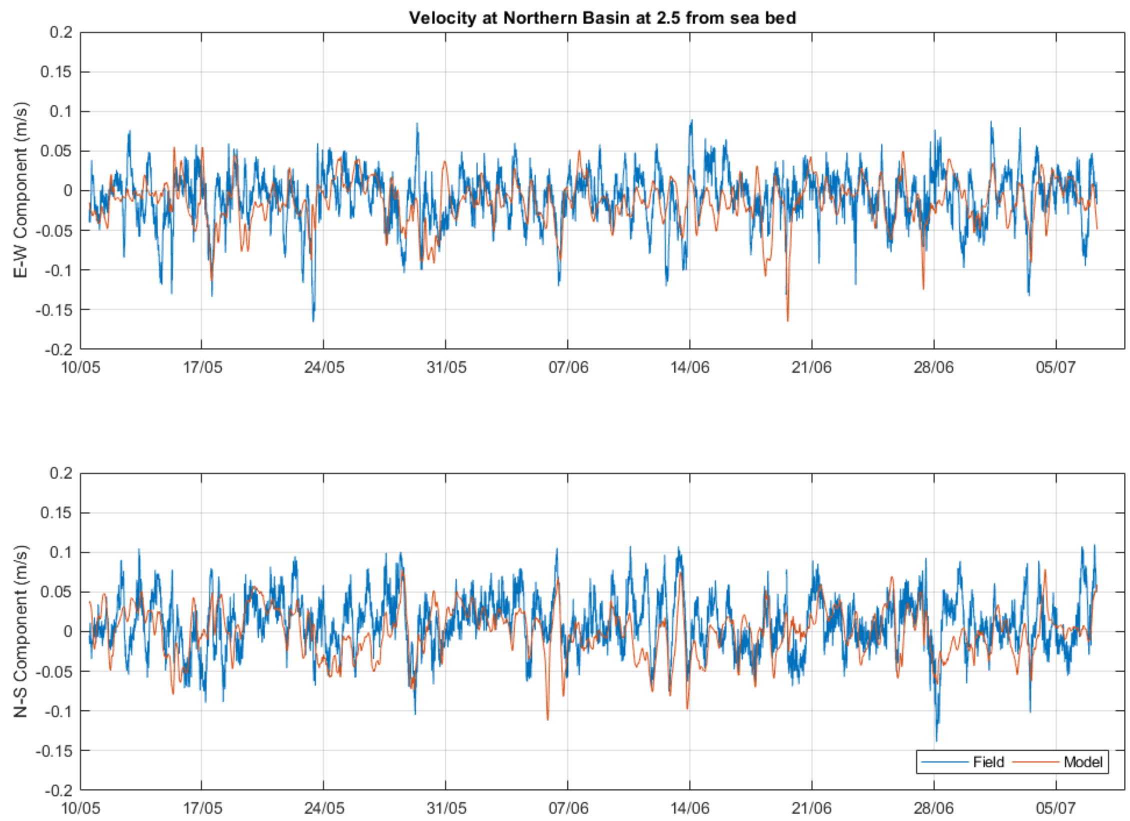

Figure 5-14 Comparison between simulated and measured ADCP velocities at 2.5m from the sea bed at Northern Basin for May to July 2006

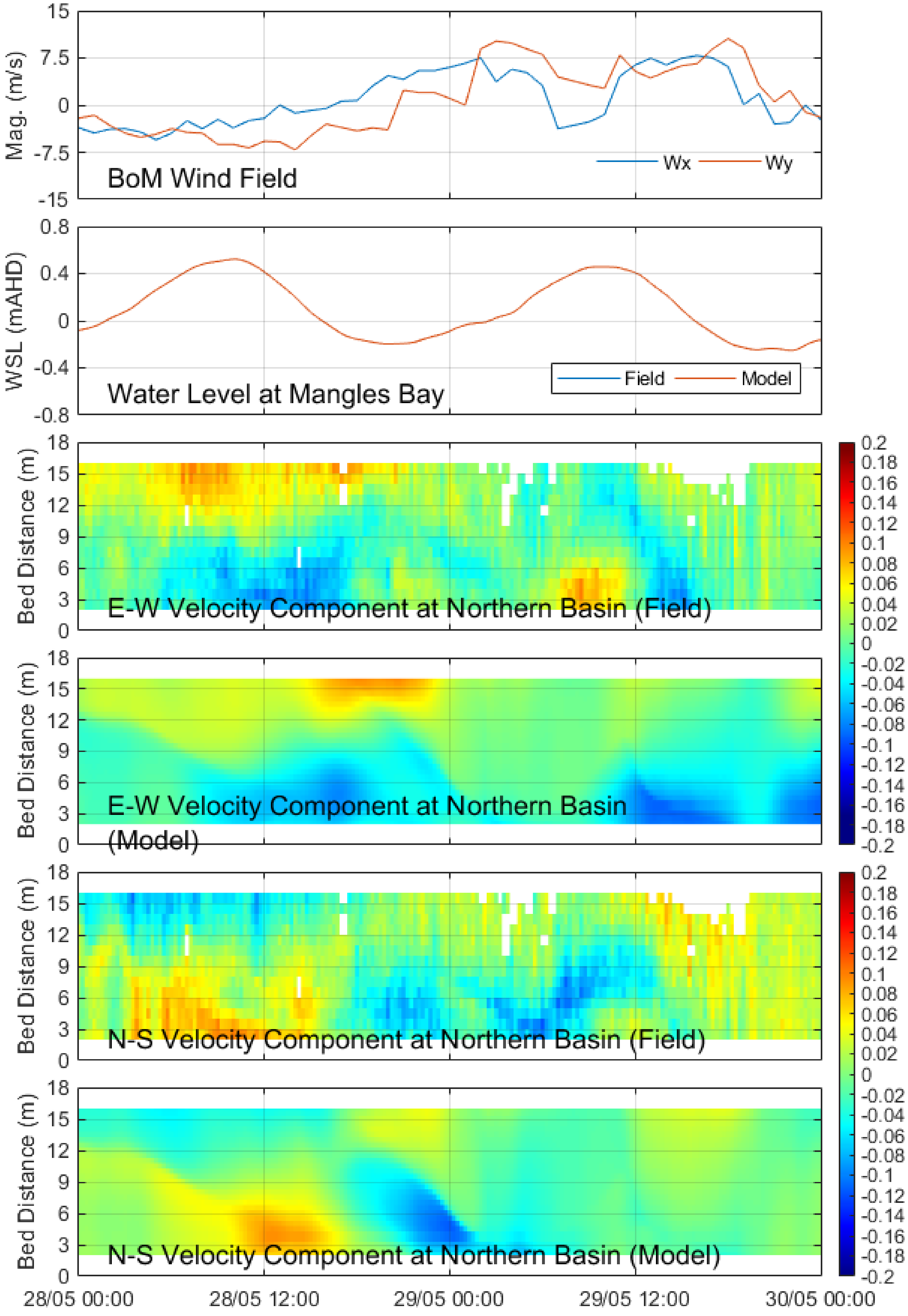

Figure 5-15 Response to field data and simulation results to a wind shifting from north to south-east (28 to 30 May 2006)

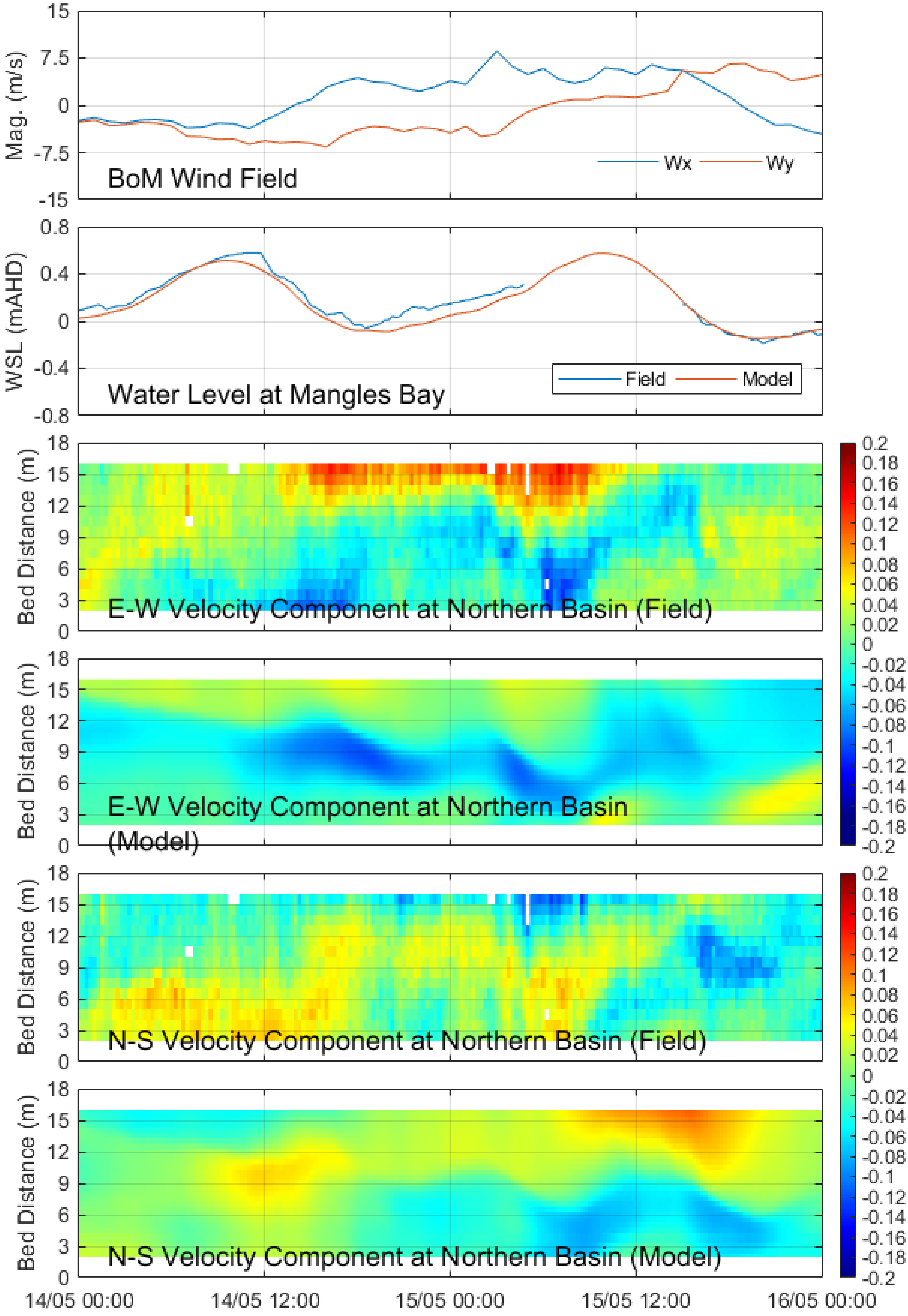

Figure 5-16 Response to field data and simulation results to a wind shifting from north to south-east (14 to 16 May 2006)

Table 5-5 Summary of model predictive skill statistics for currents at Spoil Grounds in Winter 2006

Height (m)	X-component IOA (-)	Y-component IOA (-)	X-component MAE (m/s)	Y-component MAE (m/s)	X-component RMSE (m/s)	Y-component RMSE (m/s)
1.6	0.50	0.78	0.017	0.019	0.021	0.024
2.1	0.53	0.79	0.017	0.020	0.022	0.025
2.6	0.57	0.80	0.018	0.021	0.022	0.027
3.1	0.63	0.80	0.018	0.022	0.022	0.028
3.6	0.68	0.80	0.018	0.023	0.022	0.029
4.1	0.72	0.81	0.019	0.024	0.023	0.031
4.6	0.75	0.81	0.020	0.025	0.025	0.032
5.1	0.76	0.81	0.021	0.026	0.027	0.034
CG	≥ 0.5	≥ 0.5	≤ 0.05	≤ 0.05	≤ 0.06	≤ 0.06

Table 5-6 Summary of model predictive skill statistics for currents at Northern Basin in Winter 2006

Height (m)	X-component IOA (-)	Y-component IOA (-)	X-component MAE (m/s)	Y-component MAE (m/s)	X-component RMSE (m/s)	Y-component RMSE (m/s)
2.5	0.61	0.64	0.027	0.030	0.035	0.037
3.5	0.62	0.64	0.028	0.031	0.035	0.038
4.5	0.64	0.63	0.026	0.031	0.033	0.039
5.5	0.65	0.61	0.025	0.032	0.031	0.040
6.5	0.64	0.58	0.022	0.032	0.029	0.040
7.5	0.62	0.55	0.021	0.031	0.027	0.039
8.5	0.57	0.52	0.021	0.030	0.027	0.038
9.5	0.49	0.48	0.023	0.029	0.029	0.037
10.5	0.44	0.45	0.024	0.029	0.030	0.036
11.5	0.48	0.44	0.024	0.030	0.031	0.037
12.5	0.55	0.47	0.025	0.031	0.031	0.039
13.5	0.61	0.51	0.026	0.032	0.033	0.041
14.5	0.64	0.55	0.028	0.034	0.035	0.043
15.5	0.65	0.59	0.030	0.035	0.038	0.045
CG	≥ 0.5	≥ 0.5	≤ 0.05	≤ 0.05	≤ 0.06	≤ 0.06

5.2.2.2 January to March 2007

The measured and simulated colour contours and time series velocities comparisons for the period of January to March 2007 (transition from summer to autumn) at Spoil Grounds and Northern Basin are shown in Figure 5-17 to Figure 5-24. Again, the same comparisons are shown over shorter time intervals in Appendix E.

At Spoil Grounds, measured and simulated velocities were generally low (< 0.10 m/s), with velocity components again increasing up to 0.15 m/s during stronger wind events. An example of how the model captured the different water motion as subjected to different wind conditions can be seen in Figure 5-21. The period depicted (27 February to 11 March) starts with calm wind conditions associated with a West Coast trough (see Section 2.2.2.1) followed by the passage of low pressure system approaching from the north and subsequent establishment of a land-sea breeze pattern. A high-pressure system swept the west Australian coast at the end of the period. Note the period corresponded with formation and passage of TCs George and Jacob across the north west of Australia. The model replicated the associated water response to the wind forcing remarkably well, showing velocities to the south under the northerly winds (low-pressure system) and velocities to the north under the high-pressure-system-induced southerly winds. During the land-sea breeze period, the model predicted both intensity of the surface layer and near bed flow as the system intensity diminished.

At Northern Basin, measured and simulated velocities also presented a three-layered structure, similarly to the winter period. Corresponding simulated velocities in the surface layer were up to 0.20 m/s and lower near the bottom, at up to approximately 0.08 m/s. The representation of water velocities at the station under the different wind patterns between 27 February and 11 March is illustrated in Figure 5-26. Again, the model reproduced the features of the measured velocity components, however, the model response during the land-sea breeze patterns were generally more accentuated in comparison to the measurements. The predictions were nonetheless in very good agreement with the field data.

The evaluation of model error for the measurement period is presented in Table 5-7 and Table 5-8 for Spoil Grounds and Northern Basin, respectively. Again, velocity IOAs were generally well above 0.5 (with exception to a few instances associated again with low velocity components at high noise to signal ratios). MAE was similar to winter measurements, between 0.02 and 0.03 m/s for both Spoil Grounds and Northern Basin. RMSE was between 0.03 and 0.04 m/s for both locations. As for winter simulations, these results were similar to other modelling investigations compared to the same data set (CWR 2009) and within the model ranges agreed at project inception (Table 5-4).

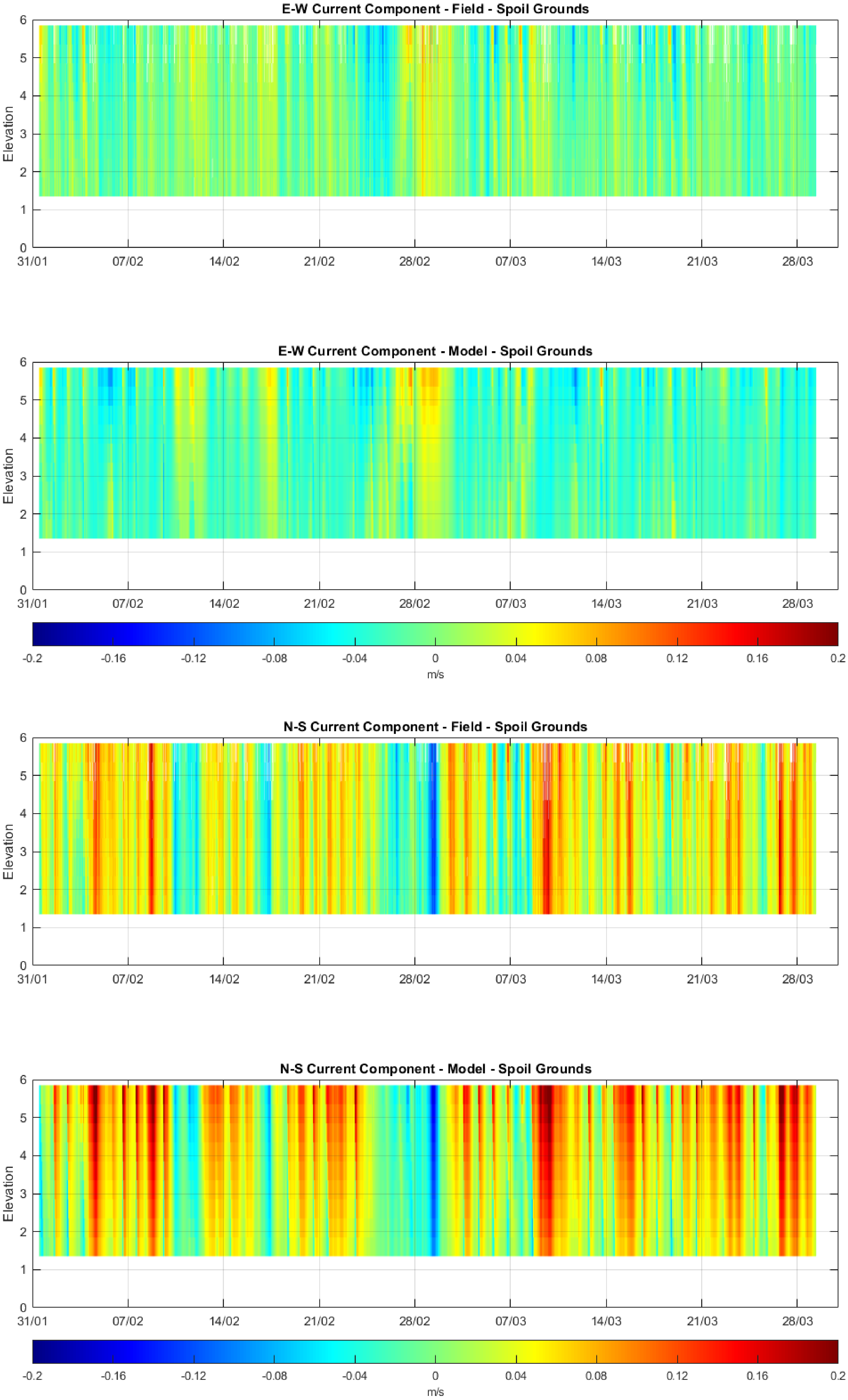

Figure 5-17 Comparisons between simulated velocities and ADCP measurements at Spoil Grounds for February to March 2007

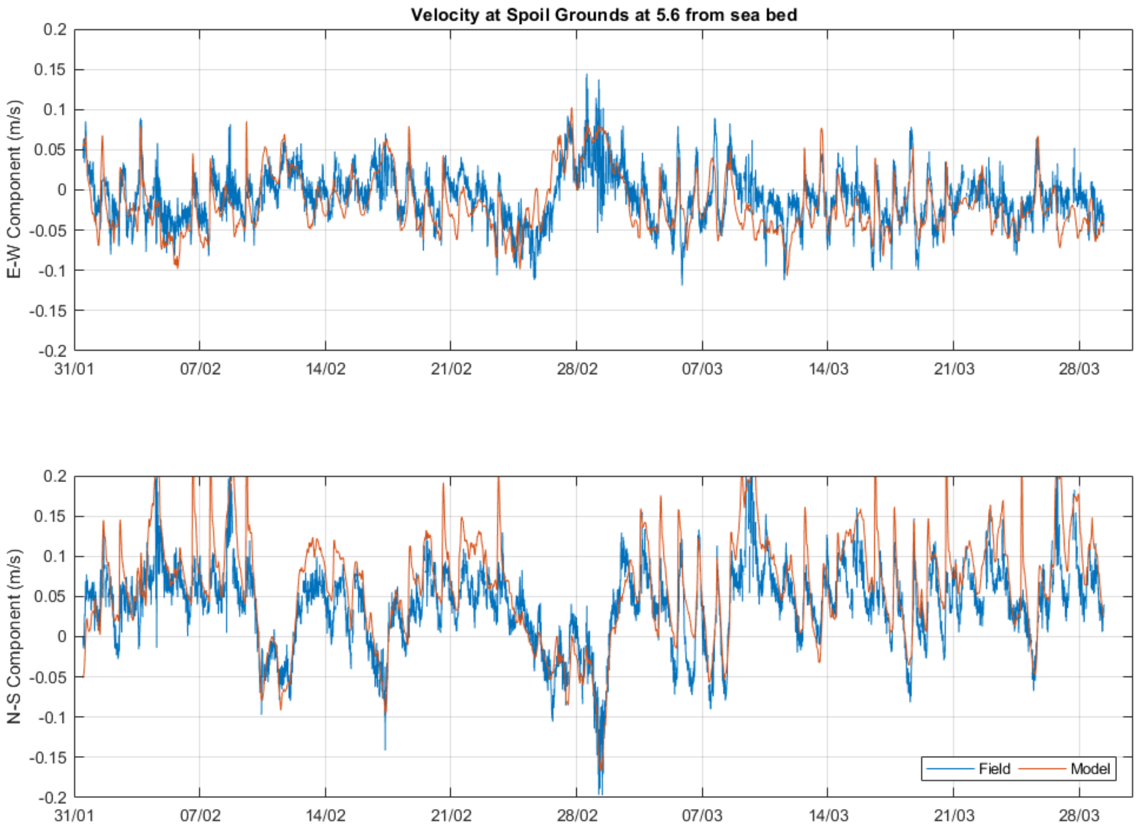

Figure 5-18 Comparison between simulated and measured ADCP velocities at 5.1m from sea bed at Spoil Grounds for February to March 2007

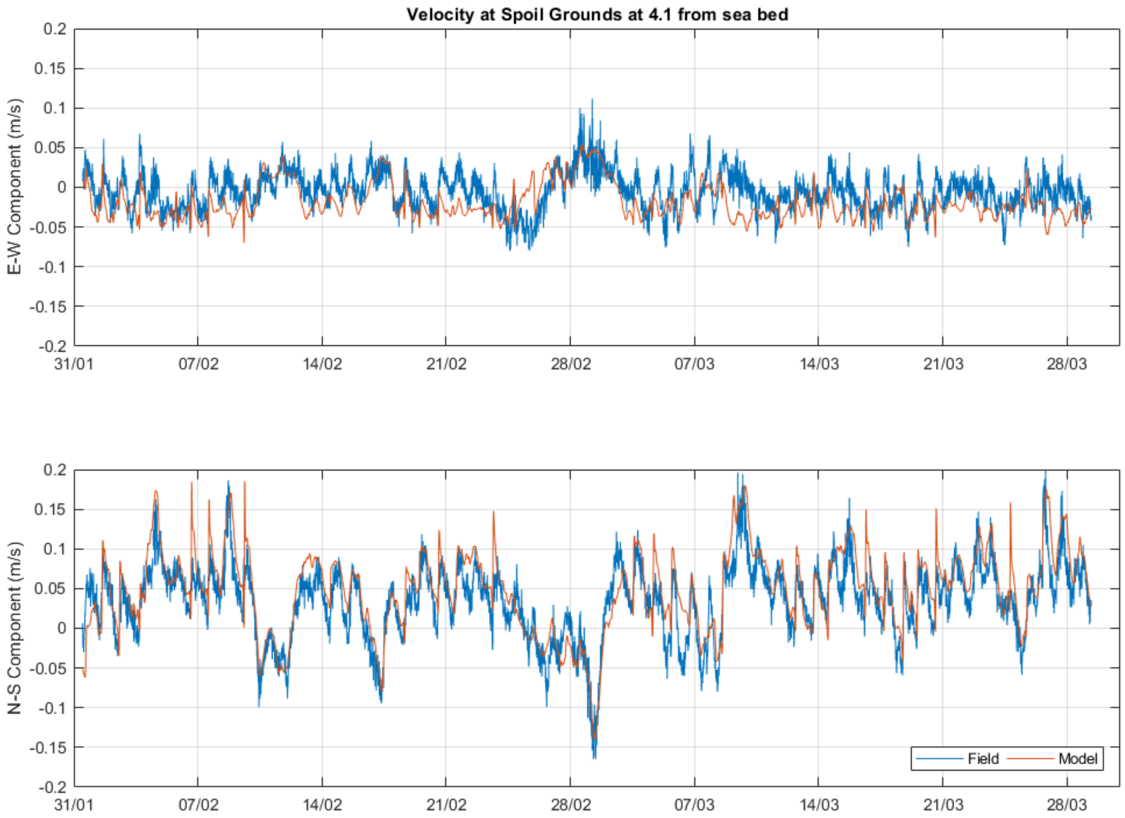

Figure 5-19 Comparison between simulated and measured ADCP velocities at 3.6m from sea bed at Spoil Grounds for February to March 2007

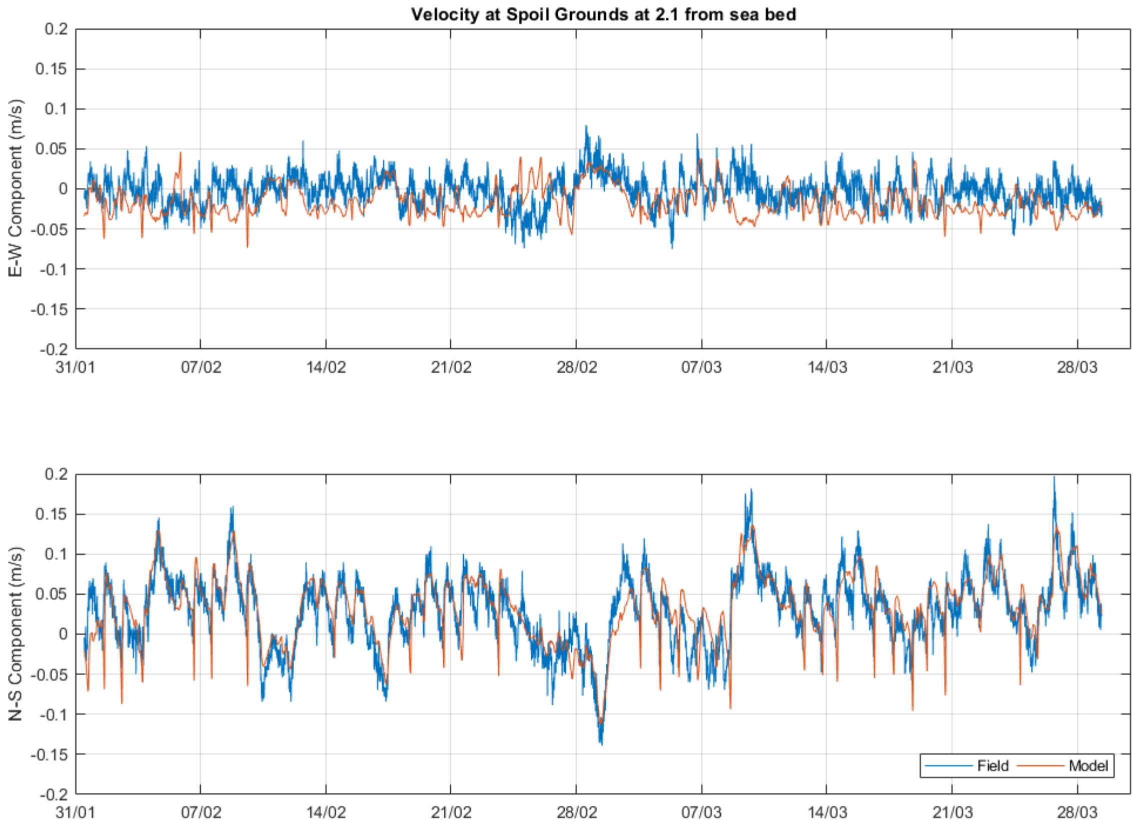

Figure 5-20 Comparison between simulated and measured ADCP velocities at 1.6m from sea bed at Spoil Grounds for February to March 2007

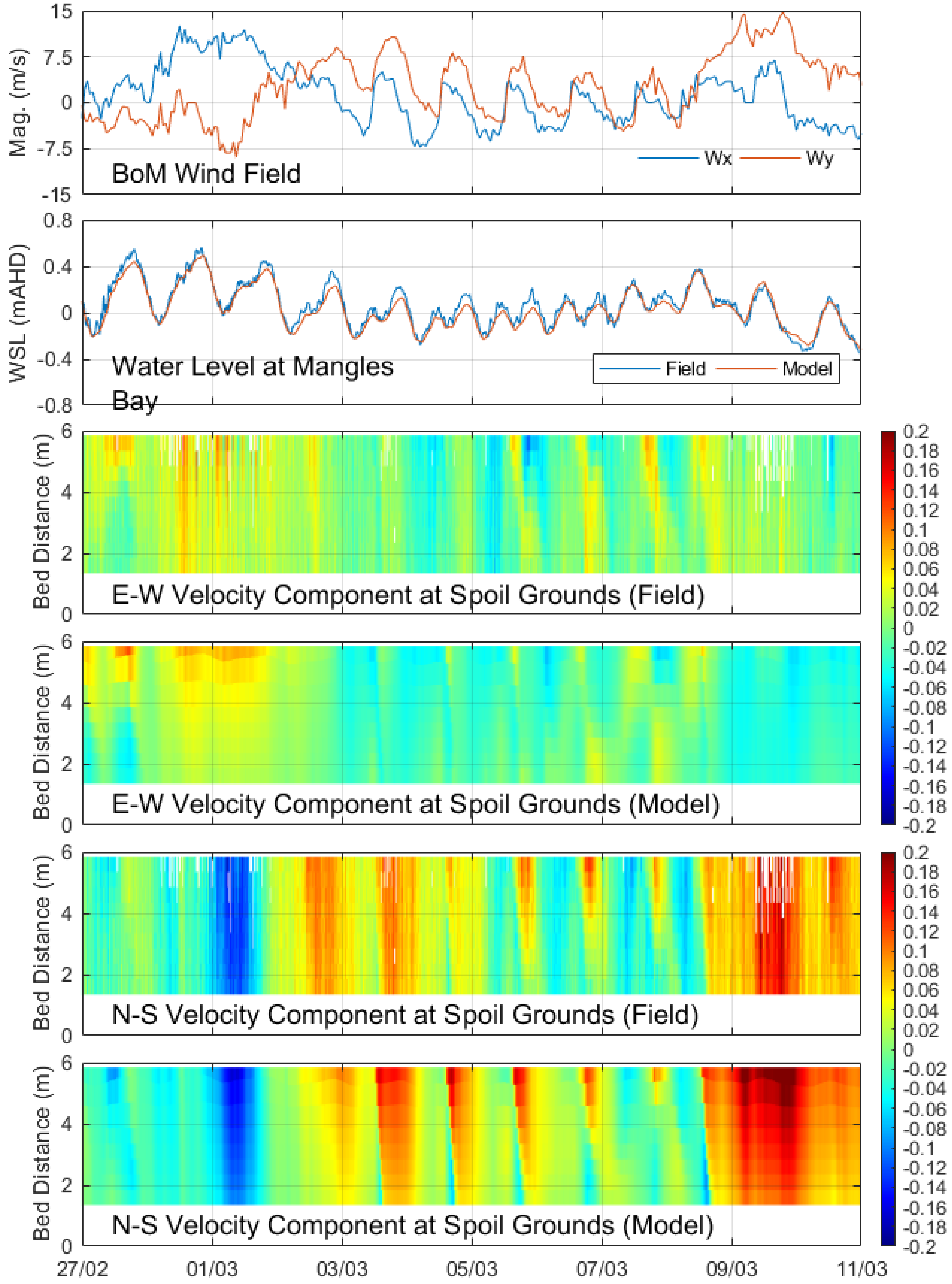

Figure 5-21 Response to field data and simulation results to different wind regimes at Spoil Grounds (27 February to 11 March 2007)

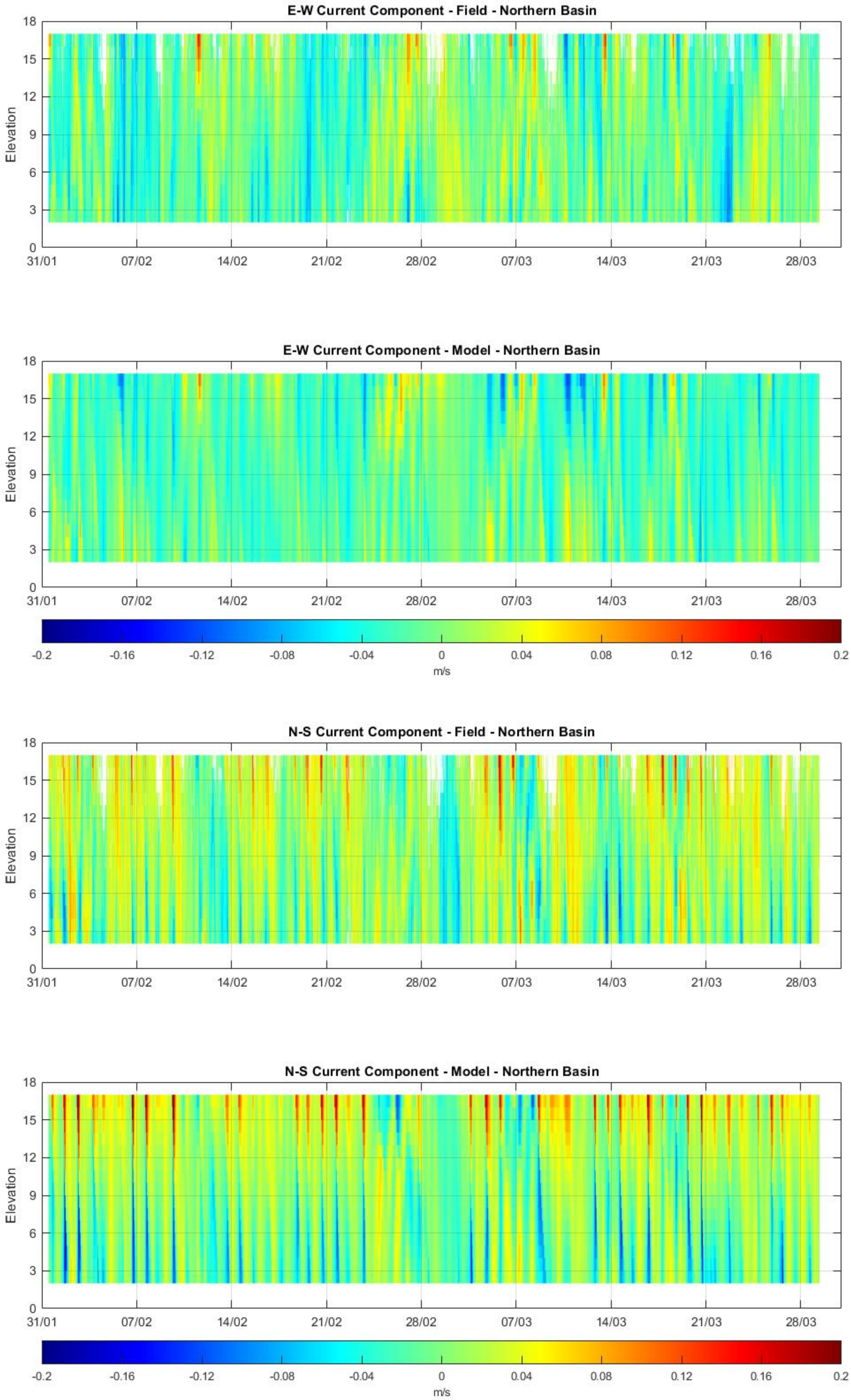

Figure 5-22 Comparisons between simulated velocities and ADCP measurements at Northern Basin for February to March 2007

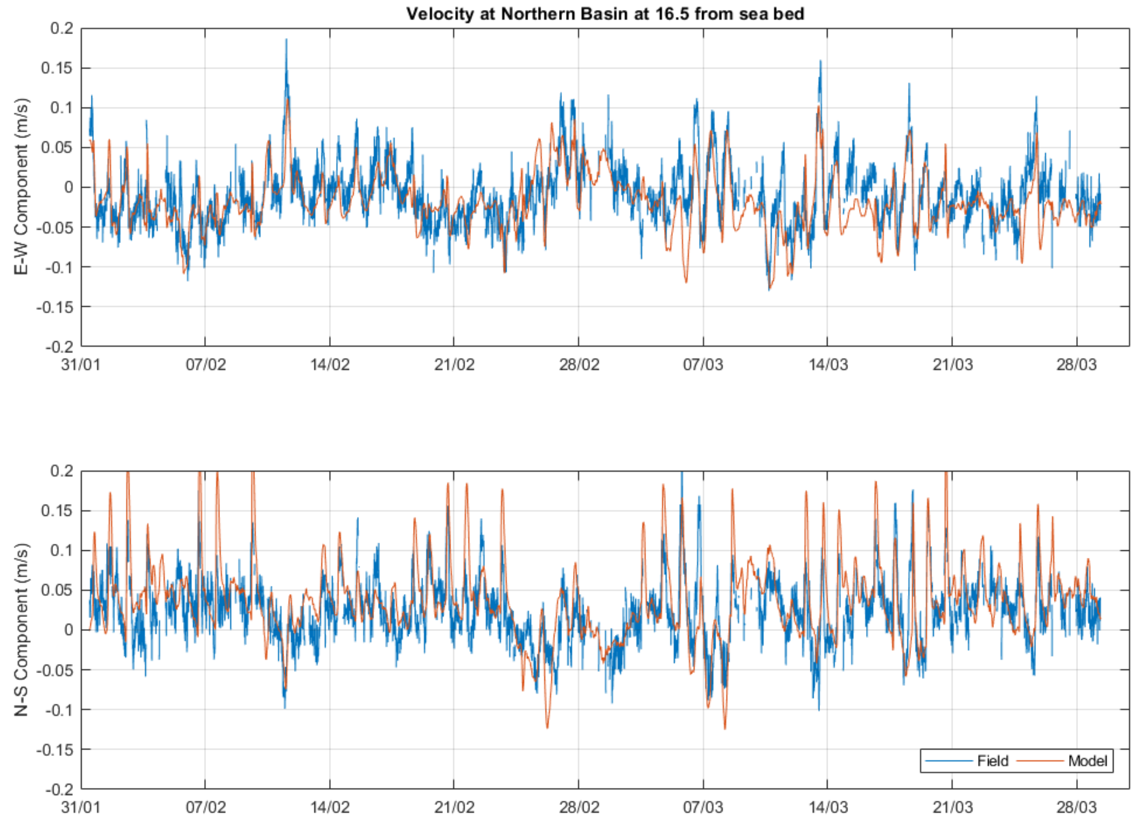

Figure 5-23 Comparison between simulated and measured ADCP velocities at 5.1m from sea bed at Northern Basin for February to March 2007

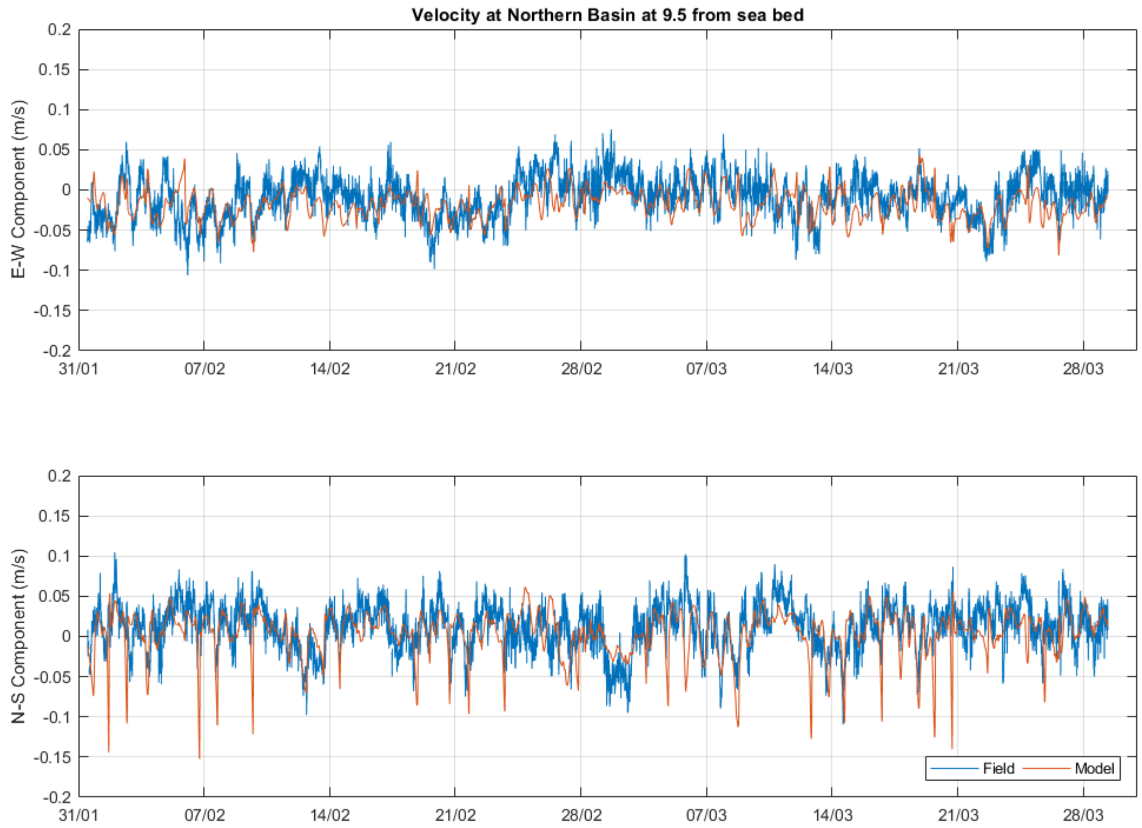

Figure 5-24 Comparison between simulated and measured ADCP velocities at 3.6m from sea bed at Northern Basin for February to March 2007

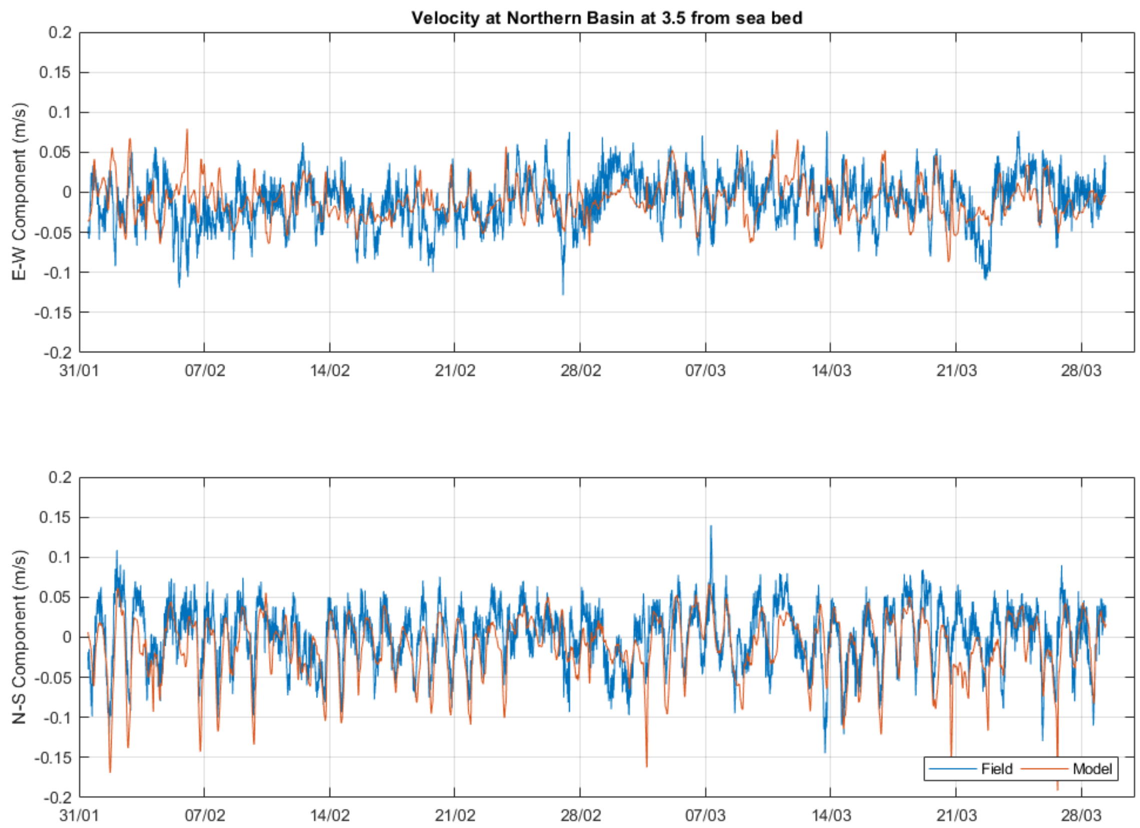

Figure 5-25 Comparison between simulated and measured ADCP velocities at 1.6m from sea bed at Northern Basin for February to March 2007

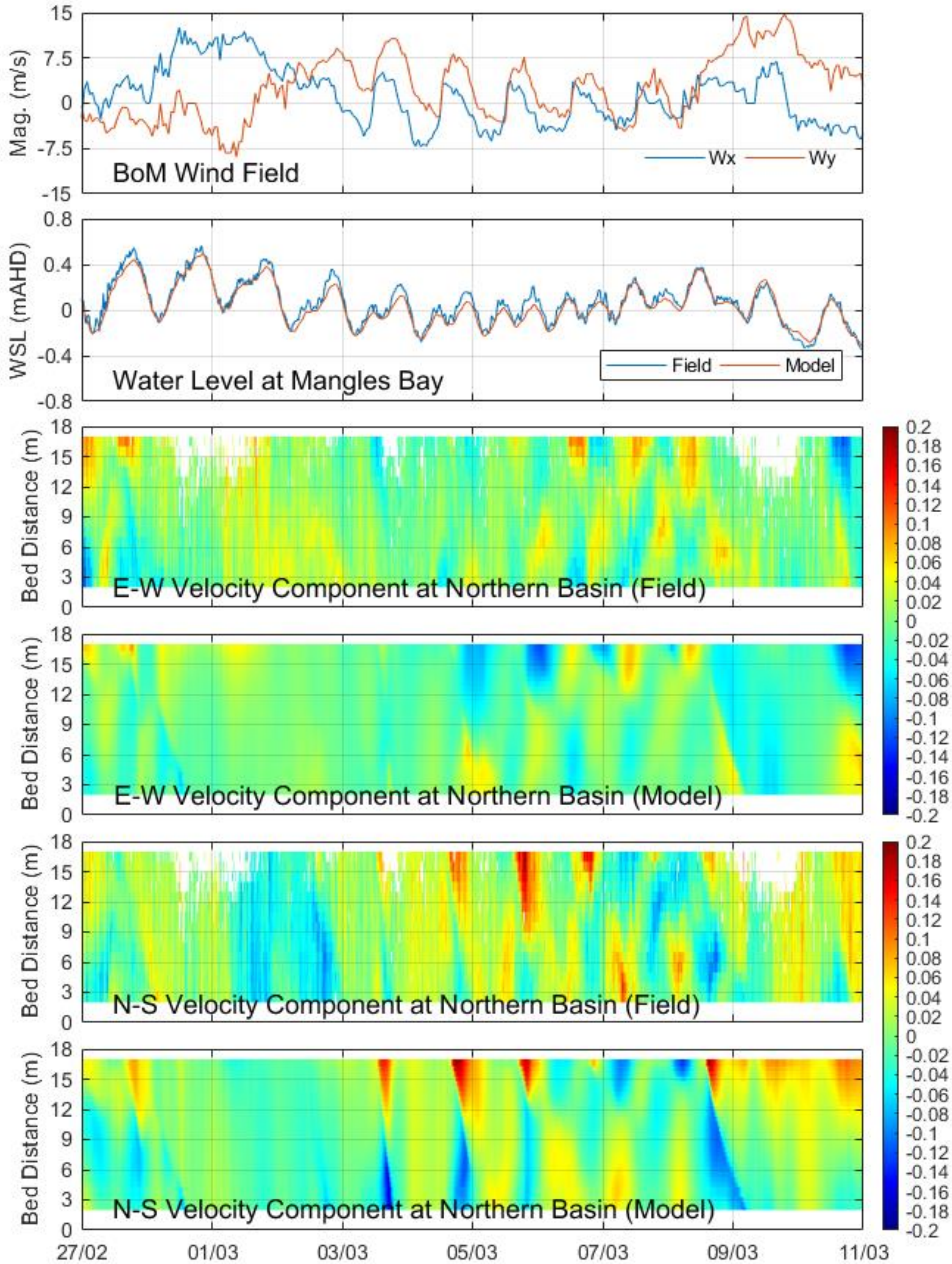

Figure 5-26 Response to field data and simulation results to different wind regimes at Northern Basin (27 February to 11 March 2007)

Table 5-7 Summary of model predictive skill statistics for currents at Spoil Grounds in Summer 2007

Height (m)	X-component IOA (-)	Y-component IOA (-)	X-component MAE (m/s)	Y-component MAE (m/s)	X-component RMSE (m/s)	Y-component RMSE (m/s)
1.6	0.46	0.89	0.022	0.019	0.027	0.026
2.1	0.47	0.90	0.023	0.019	0.028	0.026
2.6	0.51	0.91	0.023	0.020	0.028	0.026
3.1	0.54	0.91	0.022	0.021	0.028	0.027
3.6	0.60	0.91	0.022	0.021	0.027	0.027
4.1	0.66	0.91	0.022	0.023	0.027	0.029
4.6	0.73	0.90	0.021	0.025	0.026	0.032
5.1	0.77	0.88	0.022	0.028	0.027	0.036
5.6	0.81	0.86	0.023	0.032	0.029	0.041
CG	≥ 0.5	≥ 0.5	≤ 0.05	≤ 0.05	≤ 0.06	≤ 0.06

Table 5-8 Summary of model predictive skill statistics for currents at Northern Basin in Summer 2007

Height (m)	X-component IOA (-)	Y-component IOA (-)	X-component MAE (m/s)	Y-component MAE (m/s)	X-component RMSE (m/s)	Y-component RMSE (m/s)
2.5	0.59	0.78	0.024	0.026	0.030	0.033
3.5	0.59	0.78	0.025	0.026	0.032	0.034
4.5	0.59	0.77	0.025	0.027	0.032	0.035
5.5	0.59	0.76	0.024	0.026	0.031	0.035
6.5	0.60	0.74	0.023	0.025	0.029	0.034
7.5	0.62	0.71	0.022	0.024	0.028	0.033
8.5	0.63	0.67	0.021	0.024	0.027	0.033
9.5	0.63	0.63	0.021	0.024	0.026	0.032
10.5	0.64	0.60	0.021	0.024	0.027	0.032
11.5	0.66	0.59	0.021	0.024	0.027	0.033
12.5	0.69	0.61	0.022	0.024	0.028	0.033
13.5	0.72	0.66	0.023	0.025	0.029	0.034
14.5	0.74	0.71	0.024	0.027	0.030	0.036
15.5	0.77	0.75	0.024	0.028	0.031	0.038
16.5	0.80	0.78	0.025	0.031	0.033	0.041
CG	≥ 0.5	≥ 0.5	≤ 0.05	≤ 0.05	≤ 0.06	≤ 0.06

Sensitivity testing around bottom roughness was undertaken as part of the velocity calibration process and outcomes are presented in Appendix F.