Appendix B. Hydrodynamic Model Calibration and Validation Results

The objective of the calibration and validation process is to ensure that the hydrodynamic model, using the modified numerical grid developed by Arega and Hayter (2004), produces results that are consistent with the original version of the model developed by King County (1999).

King County (1999) conducted a field survey in the Lower Duwamish Waterway (LDW) from August 1996 through June 1997. Sampling locations for tidal stage, current velocity and salinity are shown in Figures B–1 through B-3. Sampling locations for acoustic Doppler current profiling are shown in Figure B-4. Model calibration and validation was accomplished using the data collected during the August-December period in 1996.

Prior to the period of model calibration and validation, a 30-day spin-up simulation was conducted to minimize the effects of initial conditions on model results. Model calibration was performed, for the period from August 28 to September 12, by adjusting the harmonic tidal amplitudes at the open boundary in Elliott Bay such that the predicted water surface elevation matched National Oceanic and Atmospheric Administration (NOAA) observation data at the Seattle Pier 52 ferry terminal. The harmonic tidal amplitudes resulting from model calibration are listed in Table B-1. The values in this table represent the averages for each tidal component along the open boundary; the tidal components are spatially variable along this boundary. Note that a uniform bottom roughness height of 2 cm was used in all simulations. Validation of the model was performed through simulation of the period from August through December, 1996. Boundary conditions for freshwater flow rate in the Green River and tidal elevations at the open boundary during the calibration and validation periods are shown in Figure B-5 through B-12. Comparisons of predicted and observed tidal elevations at four locations are shown in Figure B-13 through B-20. Predicted water surface elevations are compared with tidal data at these locations: Seattle Pier 52 ferry terminal, Spokane Street Bridge, 16th Avenue S Bridge, and Duwamish Yacht Club (Figure B-1). The Seattle Pier 52 ferry terminal data are collected at a NOAA tidal station. Tidal data at the other three locations were calculated from the observed amplitude and phase of six tidal constituents (King County 1999). These results show that the model is able to reproduce tidal elevation with satisfactory accuracy throughout the system.

Table B-1. Harmonic tidal amplitudes for hydrodynamic model

HARMONIC TIDAL COMPONENT	AVERAGE AMPLITUDE (m)
M2	1.11
S2	0.27
N2	0.22
K1	0.73
O1	0.37
P1	0.26

Model-data comparisons of current velocity during various periods in 1996 at three locations are presented in Figures B-21 through B-39. The three sampling stations are: Boeing, Sea Boil Wks, and Arco #1 (Figure B-2). Generally, the model is able to simulate tidal currents at different levels in the water column with reasonable accuracy.

An evaluation of the model's ability to simulate salt transport in the LDW was conducted using salinity data collected at these stations during 1996: Duwamish Yacht Club, 16th Avenue S Bridge, and Spokane Street Bridge (Figure B-3). Model-data comparisons of salinity at surface, mid-depth and bottom locations in the water column are presented in Figures B-40 through B-61. These results indicate that the model is able to adequately simulate salt transport in the LDW; the model reproduces vertical salinity gradients in the LDW for a range of flow and tidal conditions.

Additional validation of the model was performed using acoustic Doppler current profiler data collected from December 10, 2003, through January 12, 2004. Sampling locations are shown in Figure B-4. These measurements were designed to examine both the vertical velocity distribution and differences between currents in the navigation channel and on the side slopes (King County 2005). Comparisons between predicted and measured current velocities at stations BRD1, BRD2, BRD3 and BRD4 are shown in Figures B-62 through B-71. Similar to the 1996 current velocity comparisons, the 2003 comparisons show that the model is able to reproduce tidal currents in the LDW.

A high-flow event occurred in the Green River during January-February 2004, with freshwater flow rates reaching 6,000 to 8,000 cfs (Figure B-72). The effect on current speed at station BRD3 is shown in Figure B-73, which demonstrates that the model is able to adequately capture the effects of the high-flow event on current speed. A one-to-one comparison of predicted and measured current speed at station BRD3 during this high-flow event is presented in Figure B-74. These results indicate that the model produces no significant bias in current speed and that predicted current speeds are typically within a factor of 2 of the measured values.

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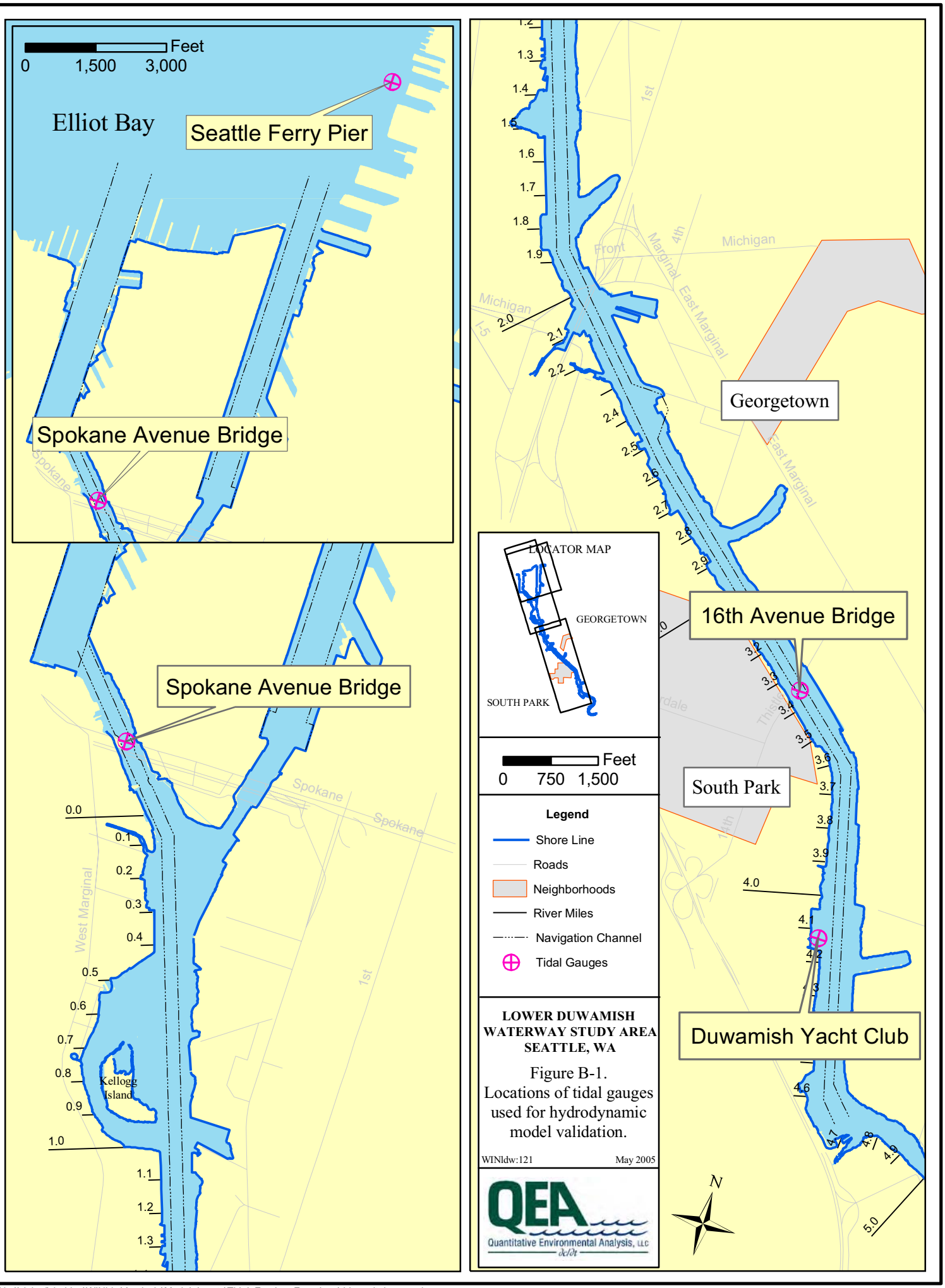
LIST OF FIGURES CITED IN APPENDIX B



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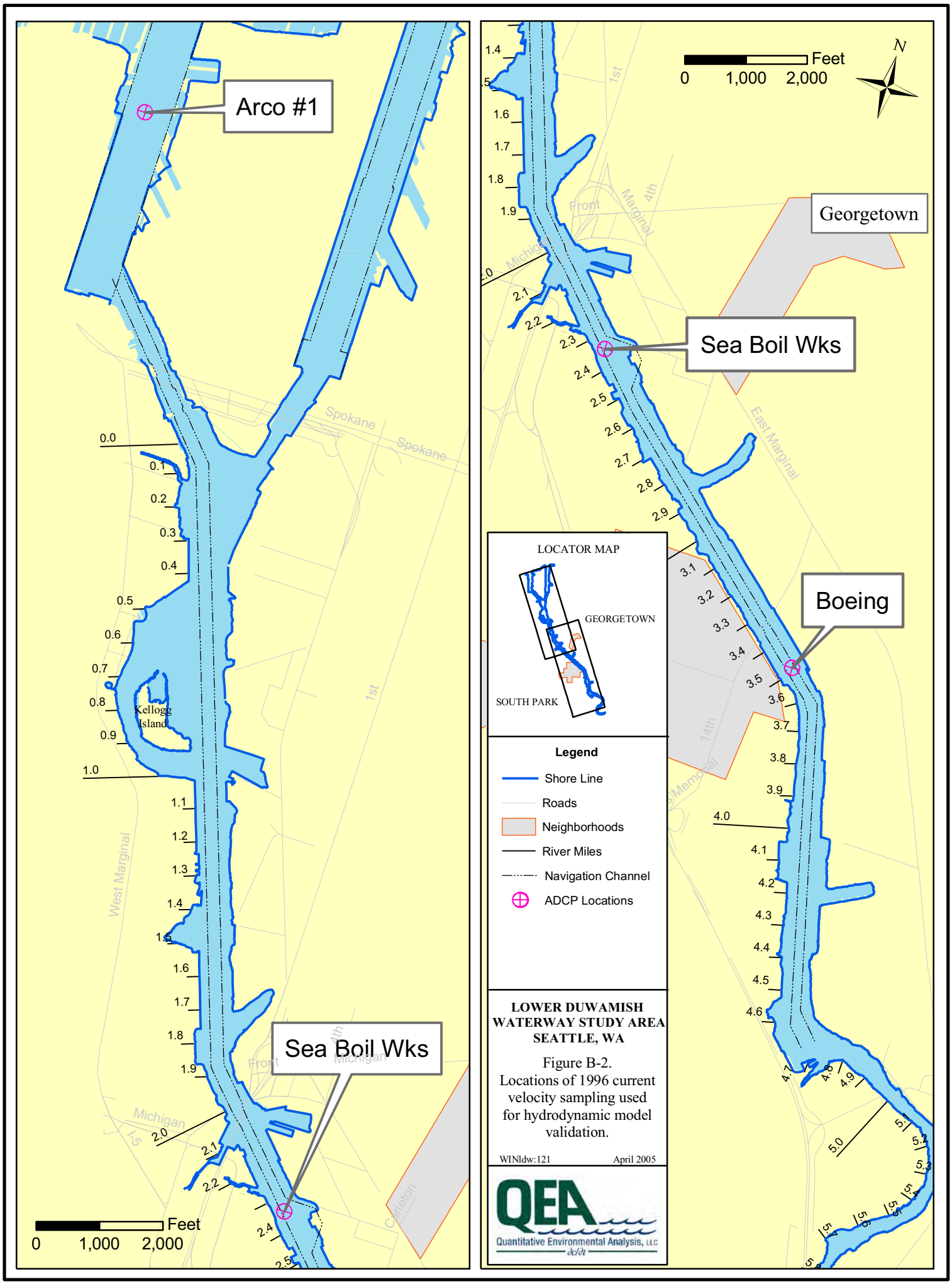

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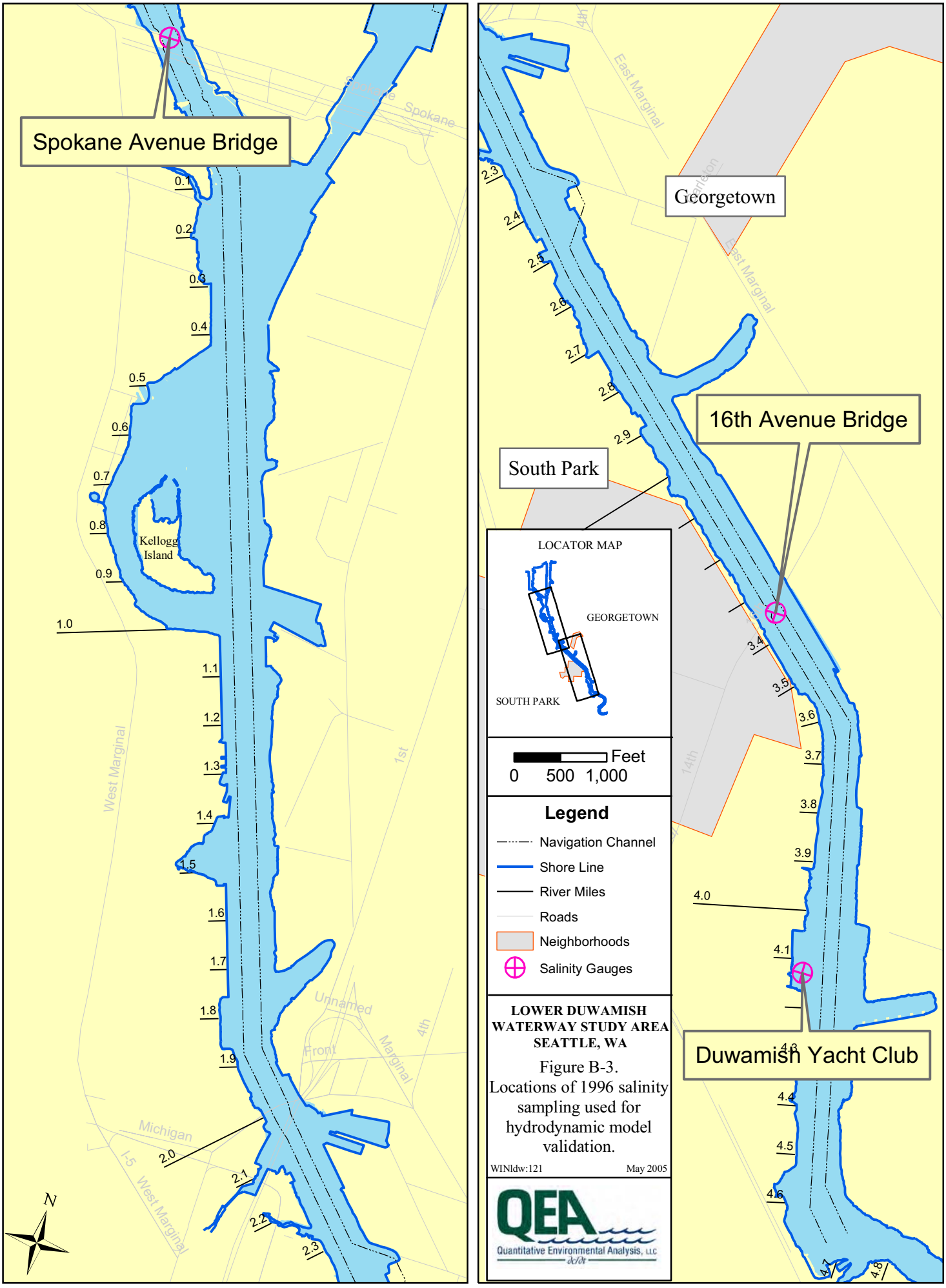

LOWER DUWAMISH WATERWAY STUDY AREA SEATTLE, WA

Figure B-3. Locations of 1996 salinity sampling used for hydrodynamic model validation.

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QEA Quantitative Environmental Analysis, LLC

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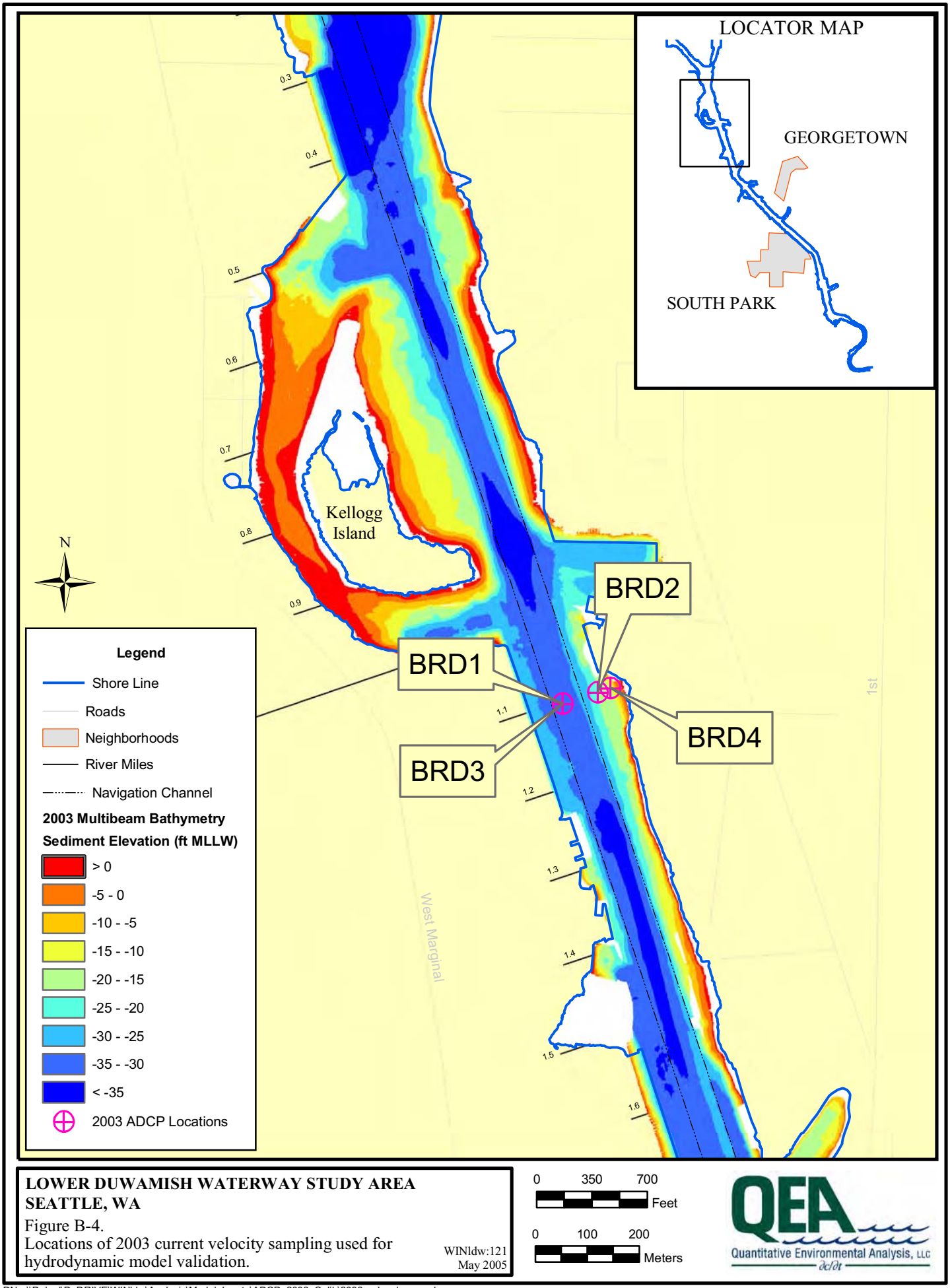

LOWER DUWAMISH WATERWAY STUDY AREA
SEATTLE, WA

Figure B-4.
Locations of 2003 current velocity sampling used for hydrodynamic model validation.

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Quantitative Environmental Analysis, LLC

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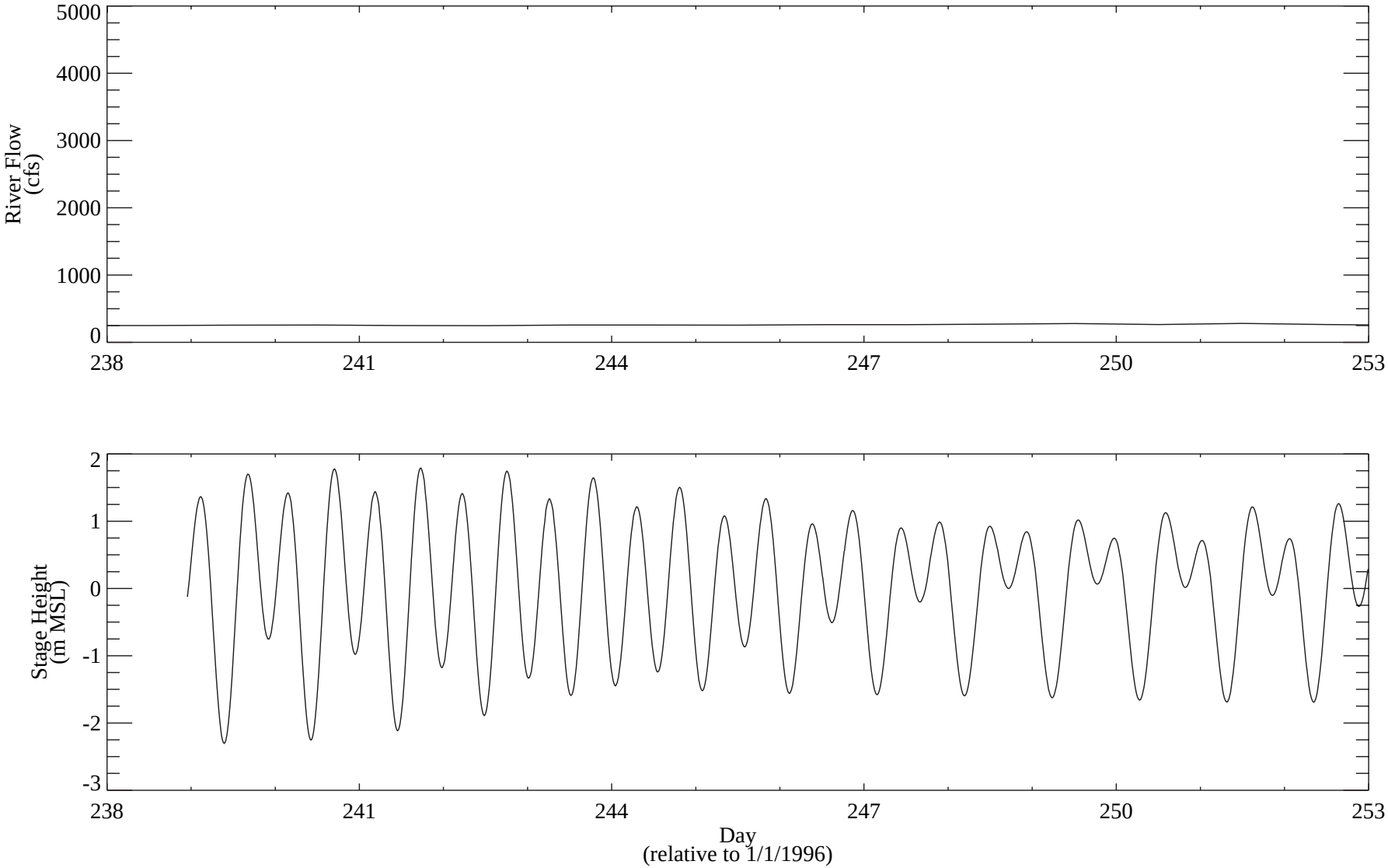

Figure B-5. River flow and stage height time series used as boundary conditions in the numerical model for Julian days 238 to 253, 1996.

Upstream boundary daily-average river flow from USGS gauge station on the Green River near Auburn, WA (12113000). Downstream boundary 15-minute stage height based on periodic forcing constituent coefficients.

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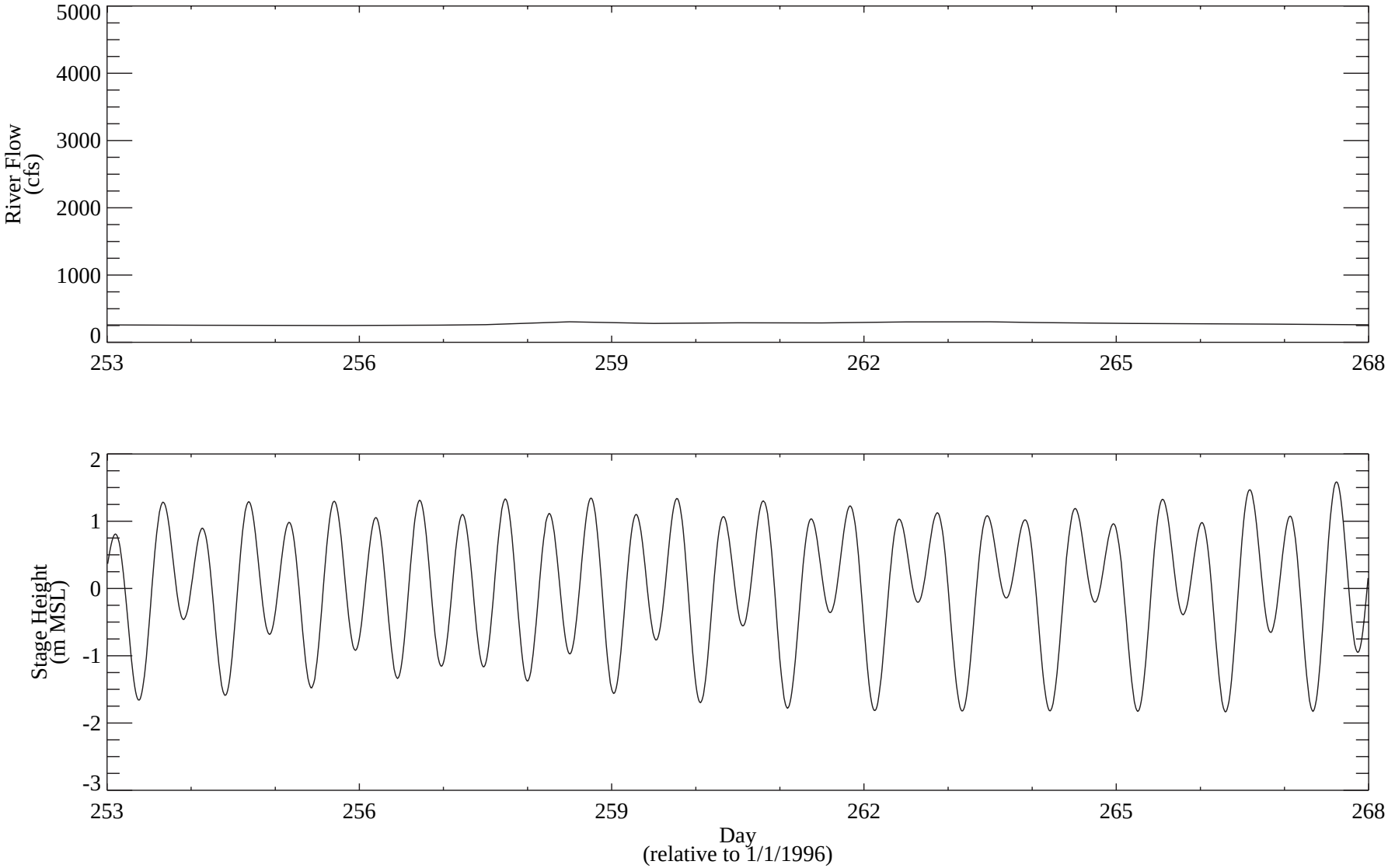

Figure B-6. River flow and stage height time series used as boundary conditions in the numerical model for Julian days 253 to 268, 1996.

Upstream boundary daily-average river flow from USGS gauge station on the Green River near Auburn, WA (12113000). Downstream boundary 15-minute stage height based on periodic forcing constituent coefficients.

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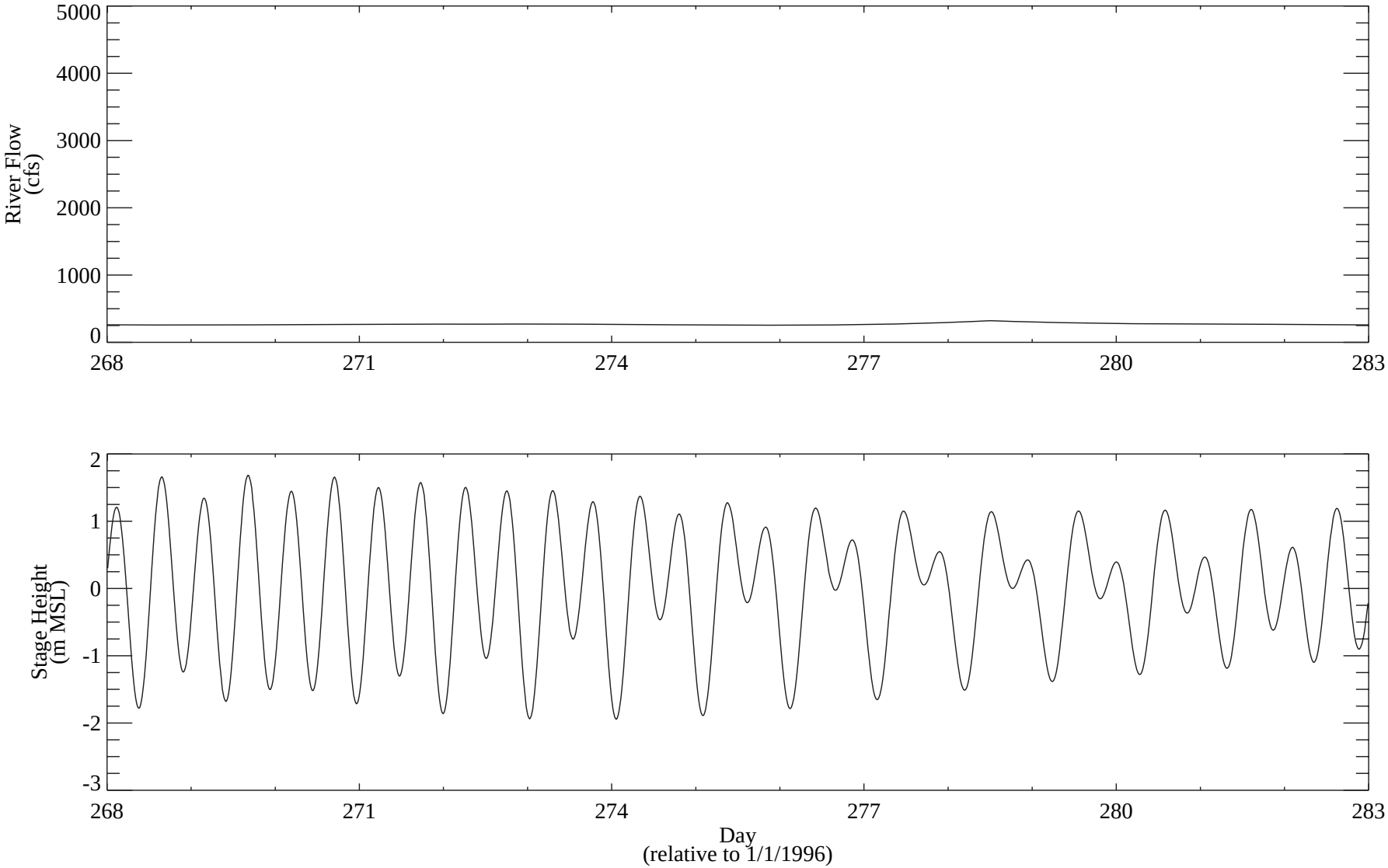

Figure B-7. River flow and stage height time series used as boundary conditions in the numerical model for Julian days 268 to 283, 1996.

Upstream boundary daily-average river flow from USGS gauge station on the Green River near Auburn, WA (12113000). Downstream boundary 15-minute stage height based on periodic forcing constituent coefficients.

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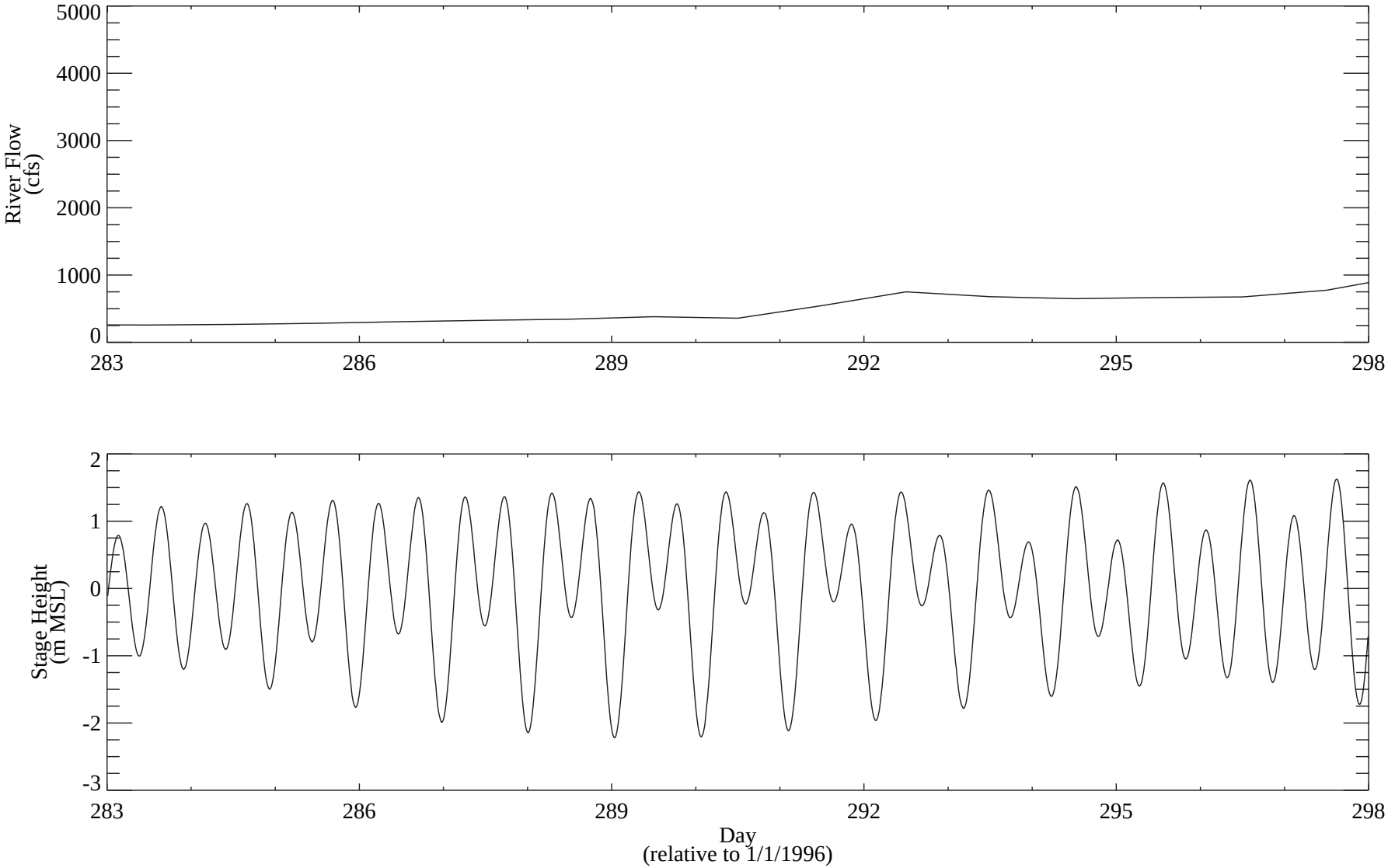

Figure B-8. River flow and stage height time series used as boundary conditions in the numerical model for Julian days 283 to 298, 1996.

Upstream boundary daily-average river flow from USGS gauge station on the Green River near Auburn, WA (12113000). Downstream boundary 15-minute stage height based on periodic forcing constituent coefficients.

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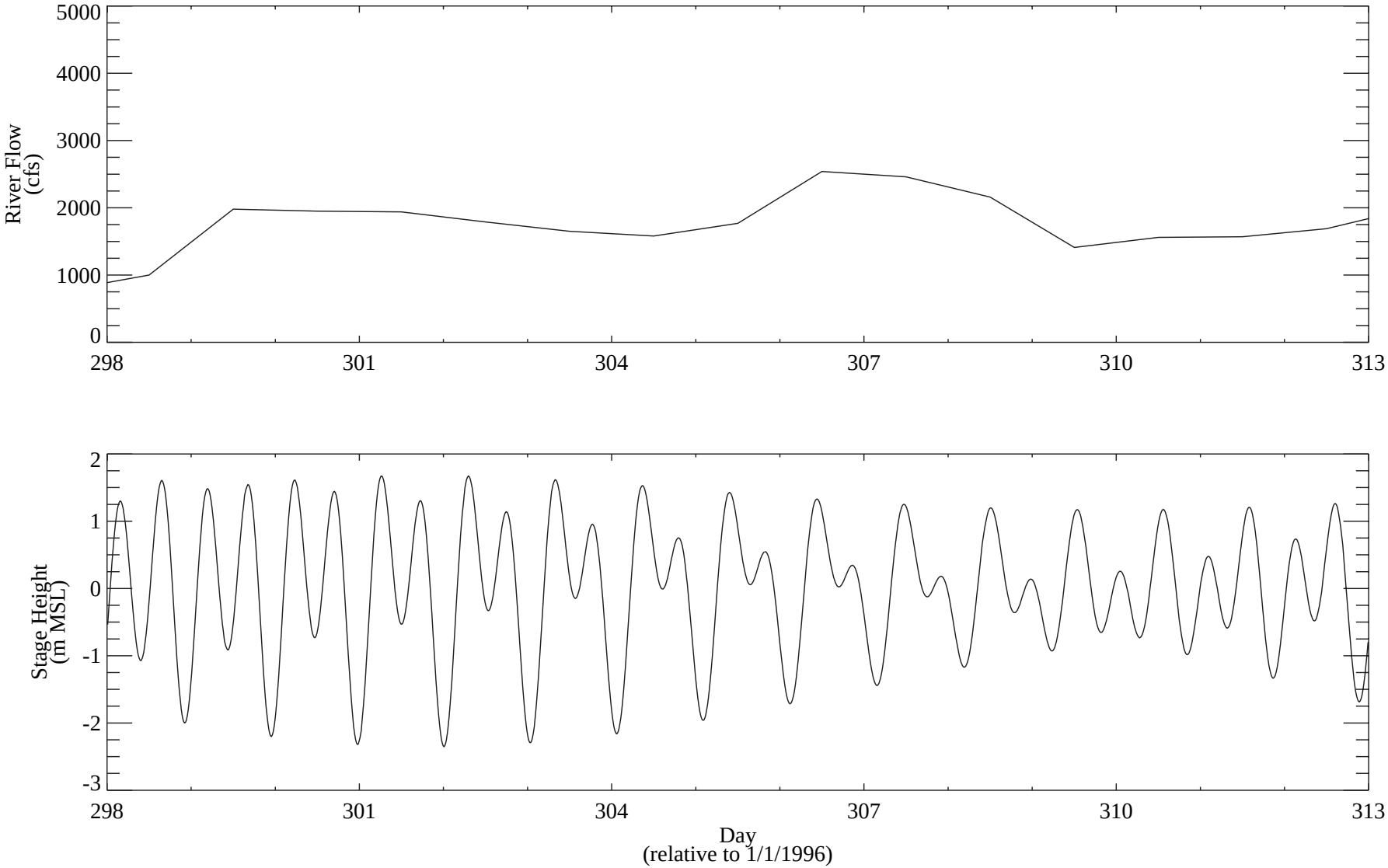

Figure B-9. River flow and stage height time series used as boundary conditions in the numerical model for Julian days 298 to 313, 1996.

Upstream boundary daily-average river flow from USGS gauge station on the Green River near Auburn, WA (12113000). Downstream boundary 15-minute stage height based on periodic forcing constituent coefficients.

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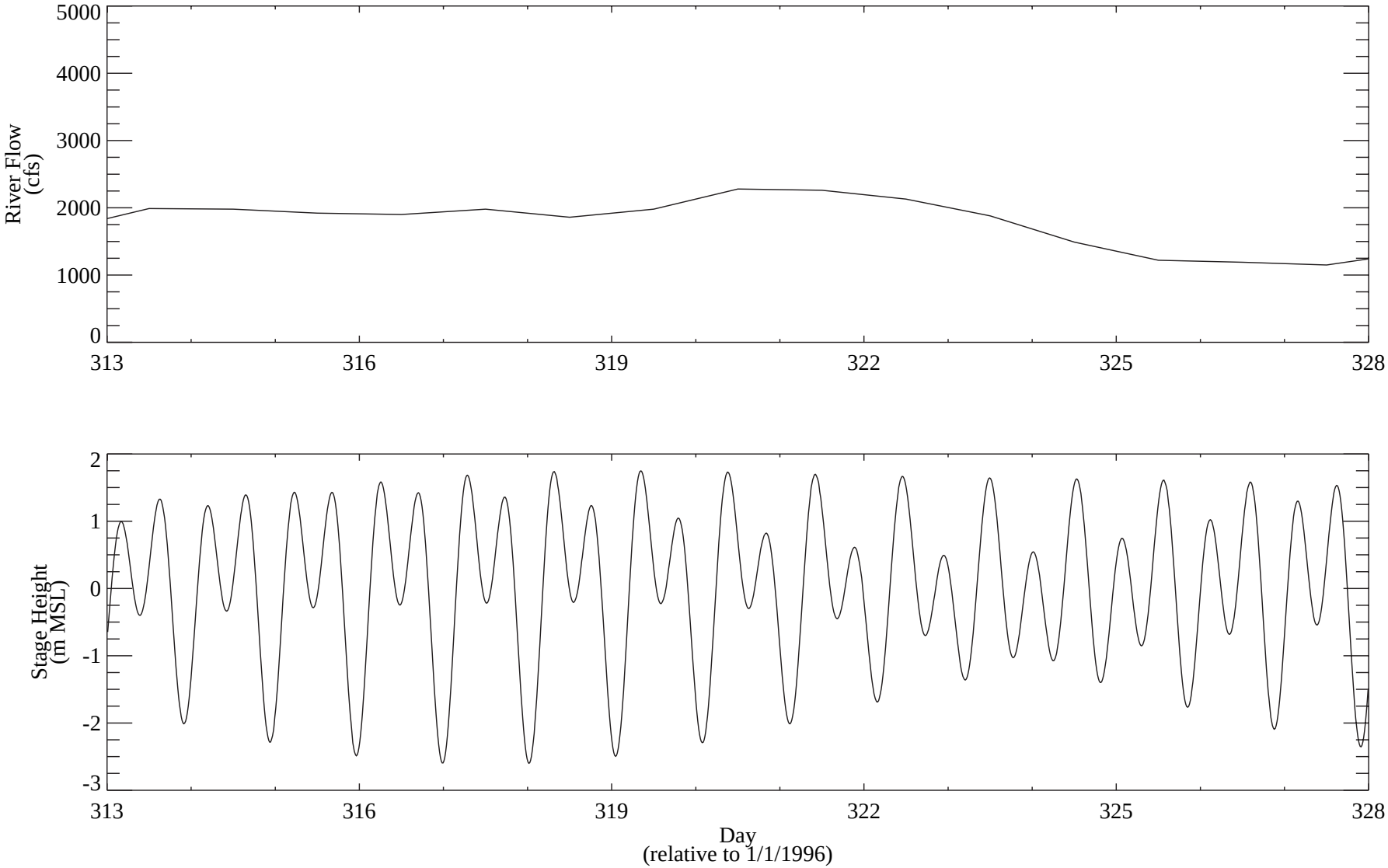

Figure B-10. River flow and stage height time series used as boundary conditions in the numerical model for Julian days 313 to 328, 1996.

Upstream boundary daily-average river flow from USGS gauge station on the Green River near Auburn, WA (12113000). Downstream boundary 15-minute stage height based on periodic forcing constituent coefficients.

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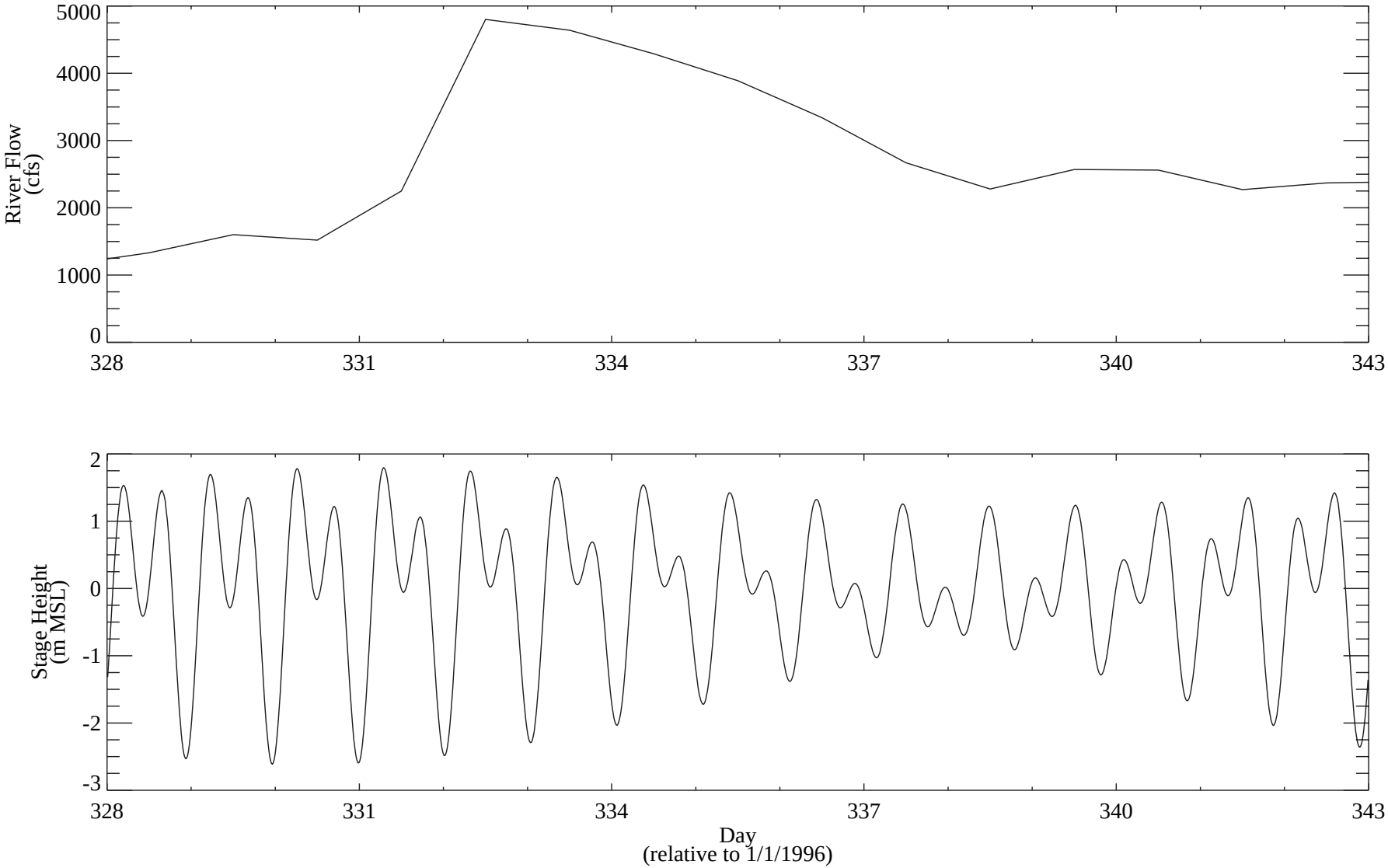

Figure B-11. River flow and stage height time series used as boundary conditions in the numerical model for Julian days 328 to 343, 1996.

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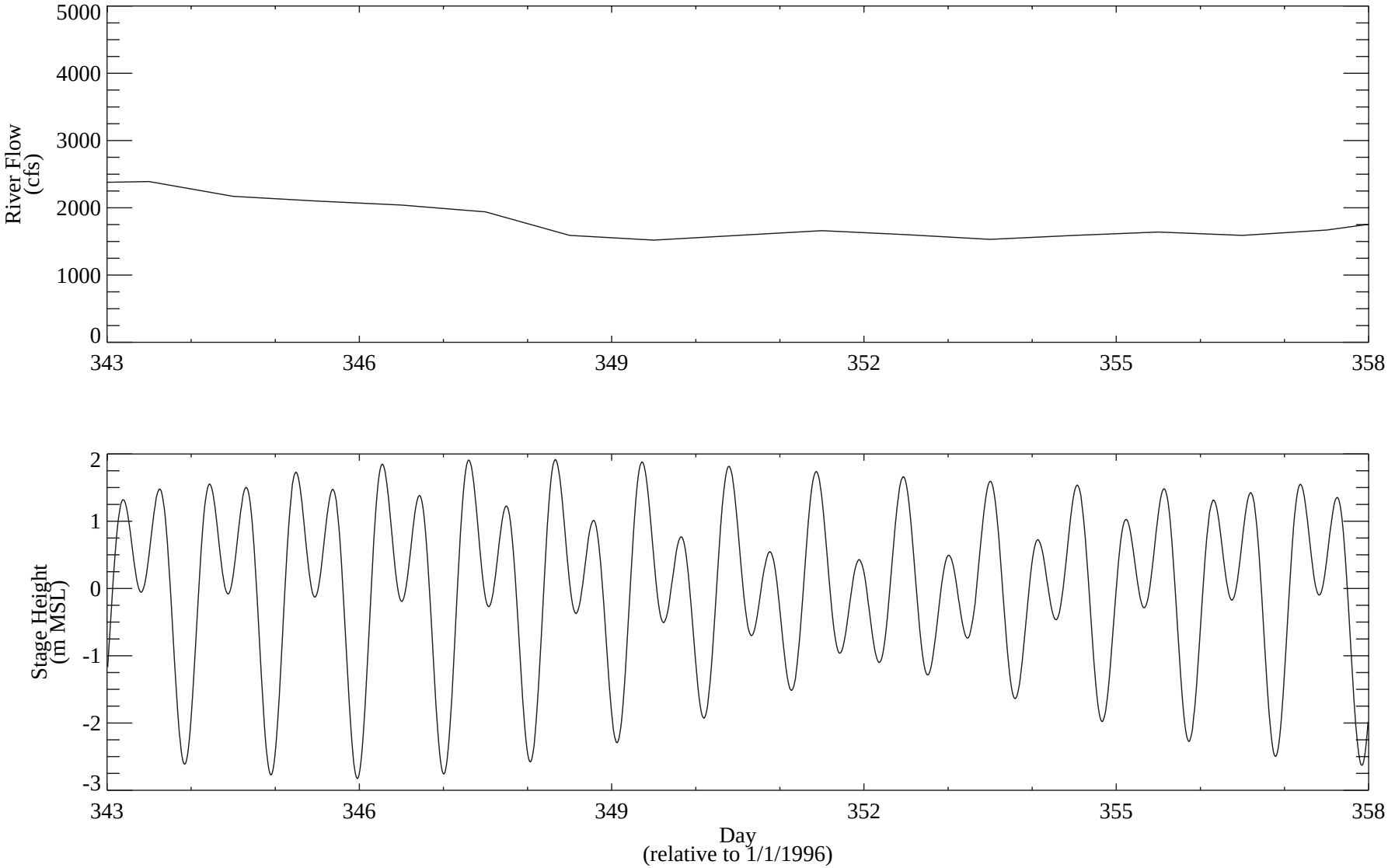

Figure B-12. River flow and stage height time series used as boundary conditions in the numerical model for Julian days 343 to 358, 1996.

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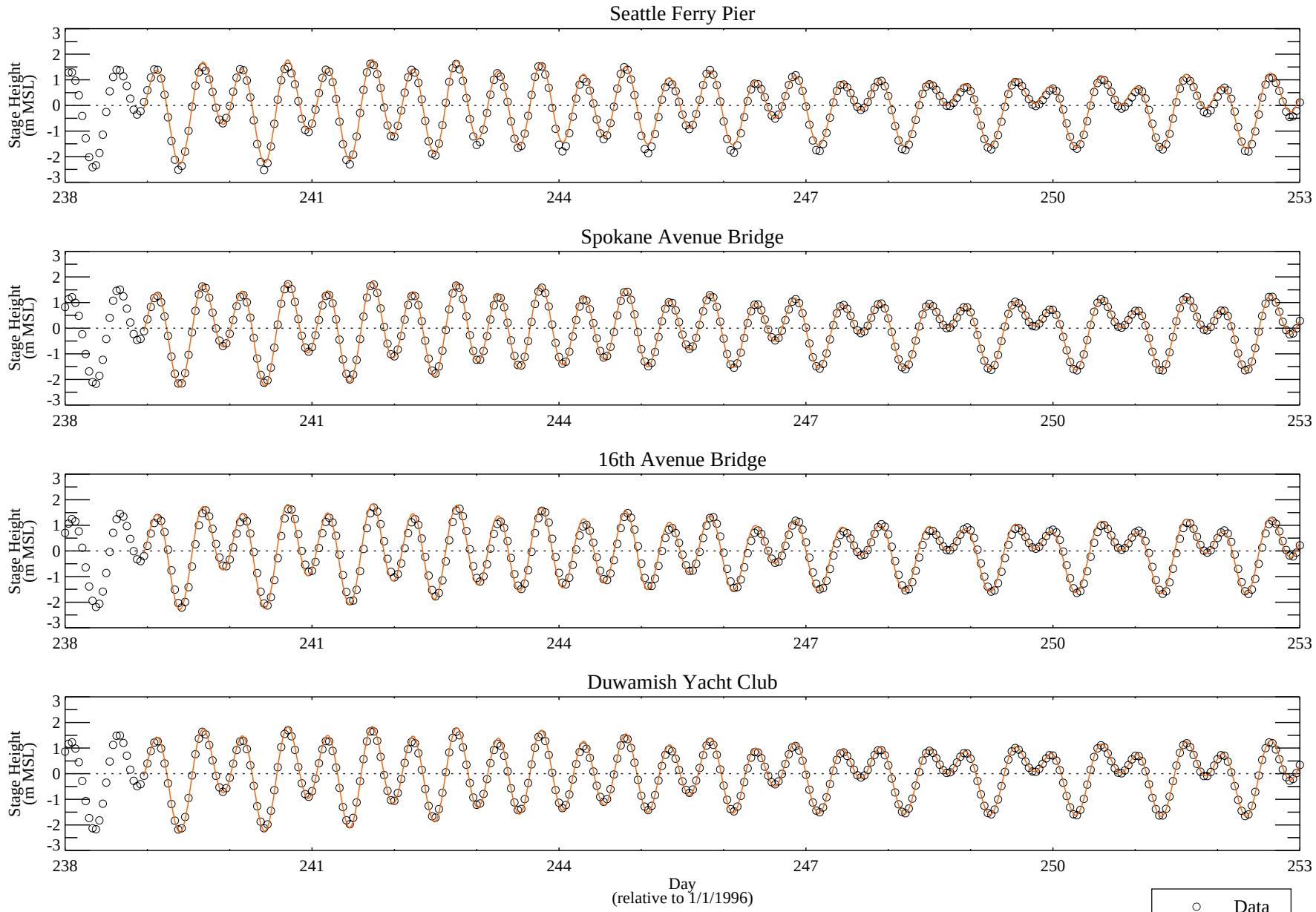

Figure B-13. Comparison of predicted and observed tidal elevation at four locations for Julian days 238 to 253, 1996.

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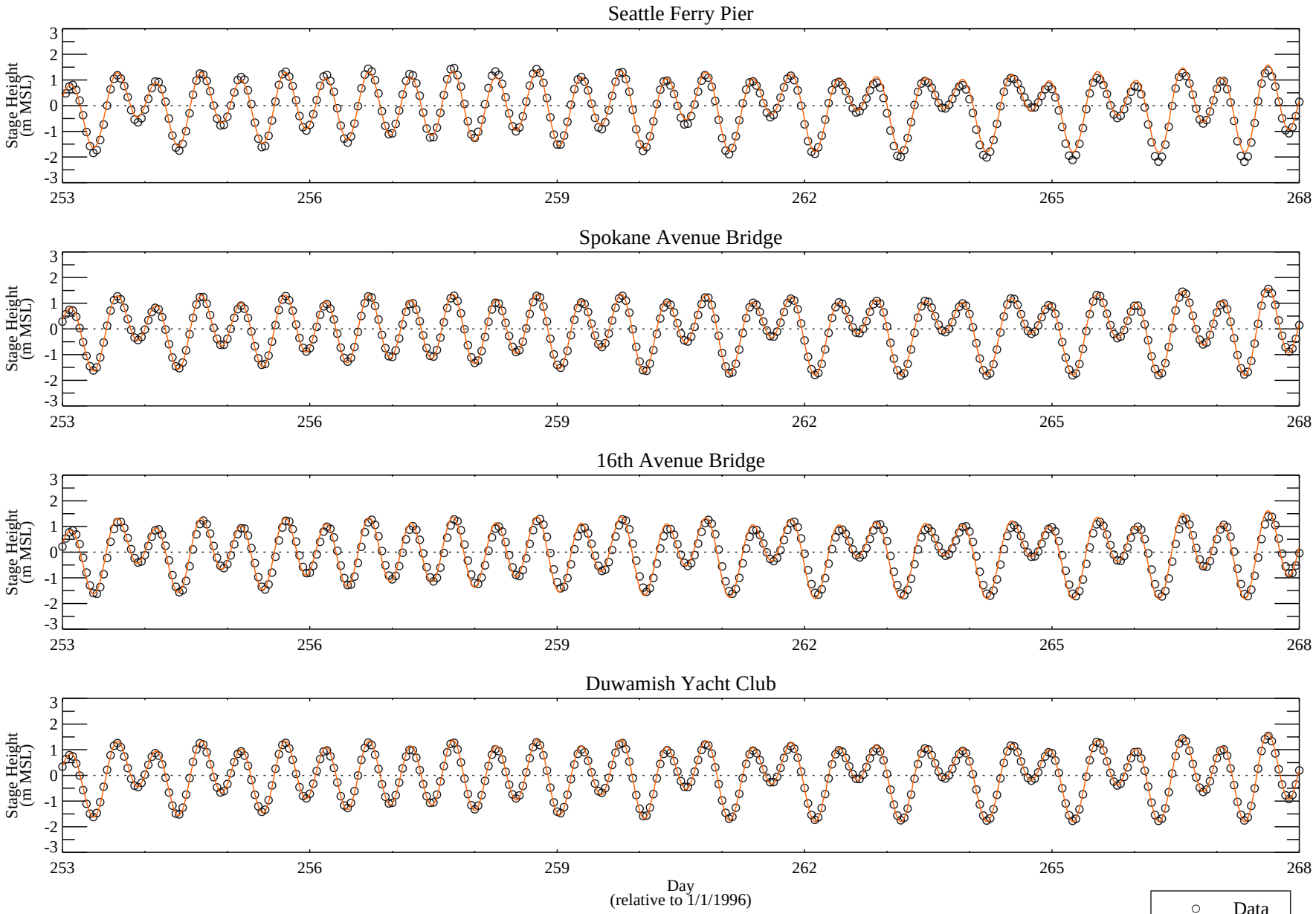

Figure B-14. Comparison of predicted and observed tidal elevation at four locations for Julian days 253 to 268, 1996.

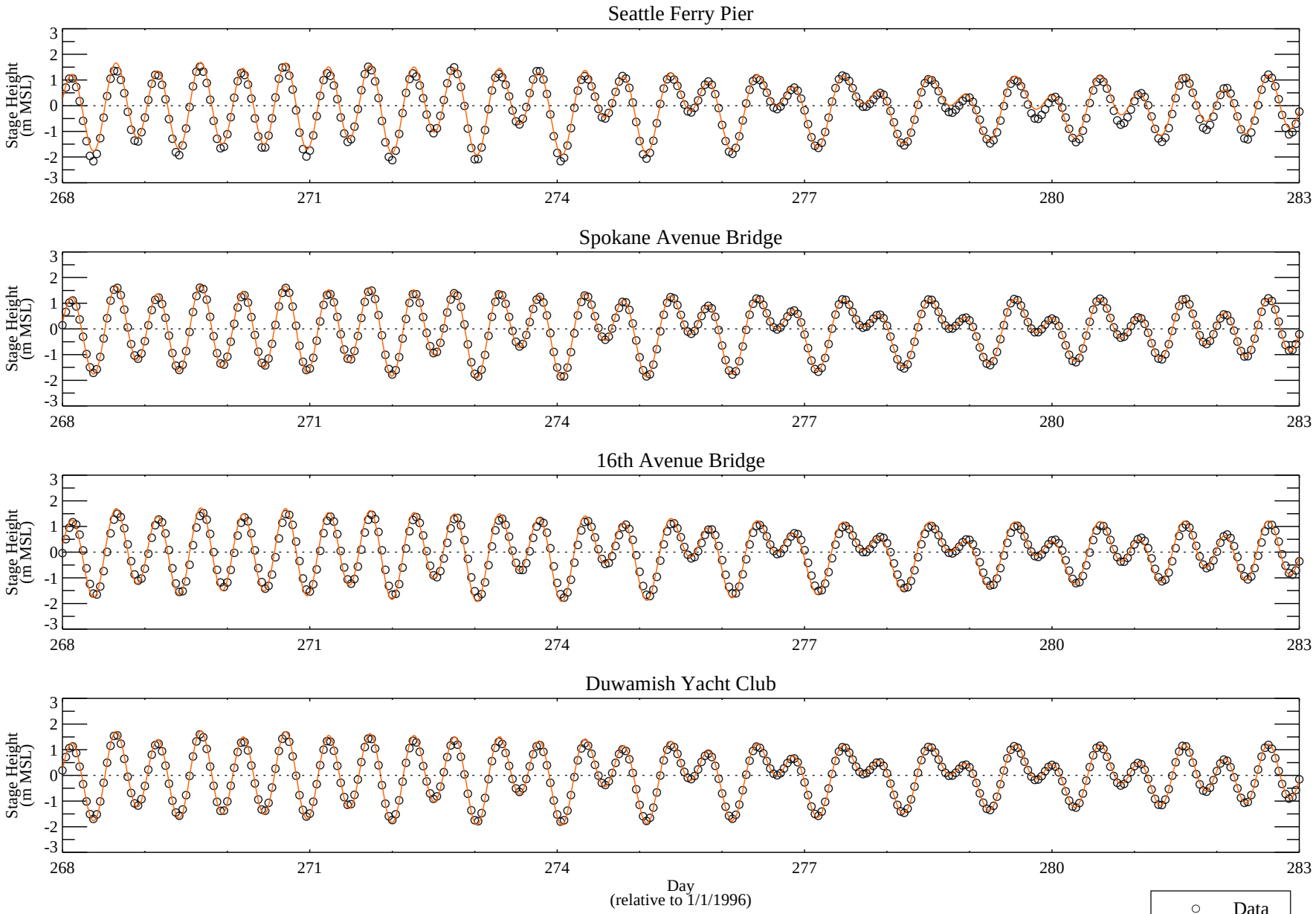

Figure B-15. Comparison of predicted and observed tidal elevation at four locations for Julian days 268 to 283, 1996.

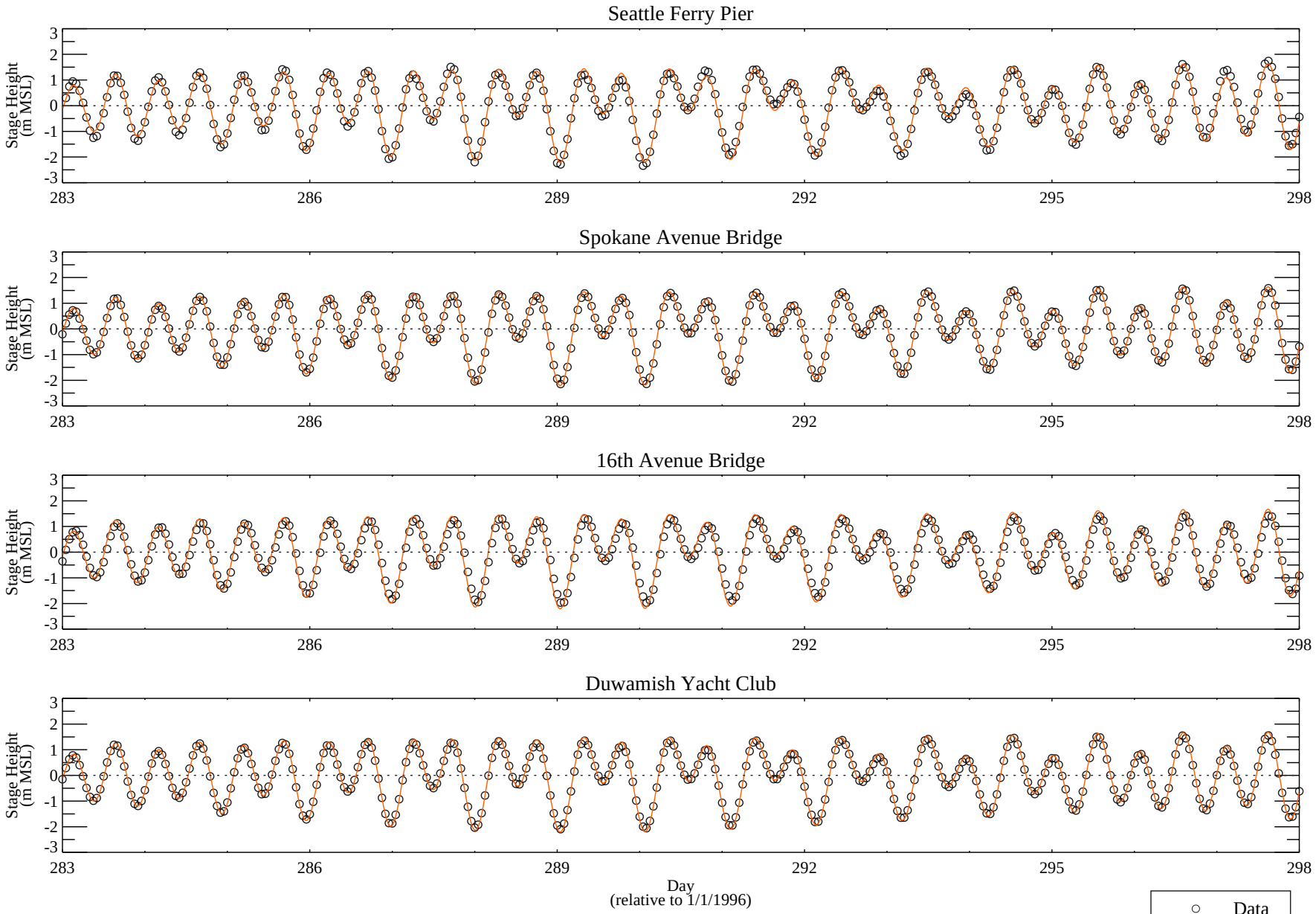

Figure B-16. Comparison of predicted and observed tidal elevation at four locations for Julian days 283 to 298, 1996.

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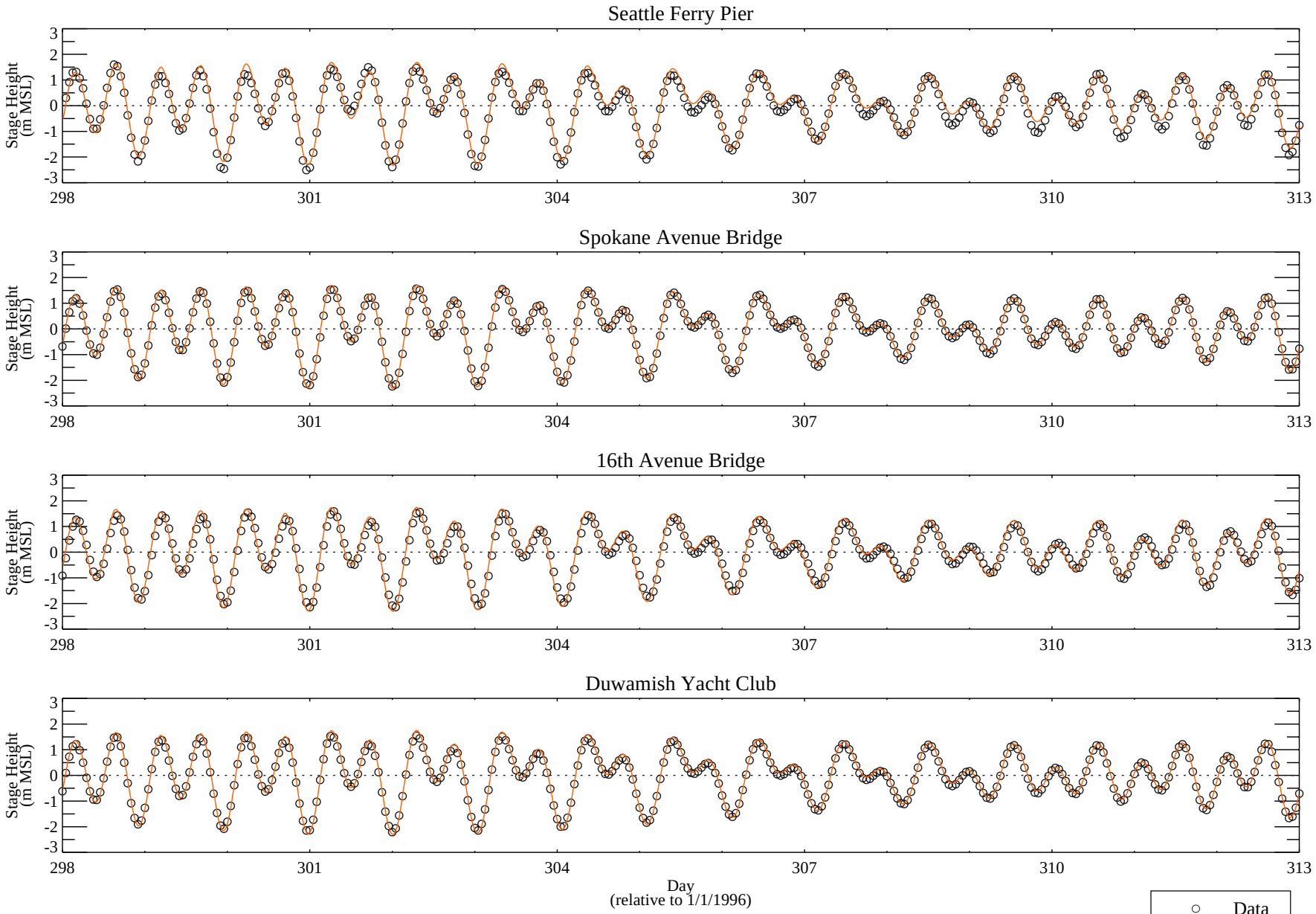

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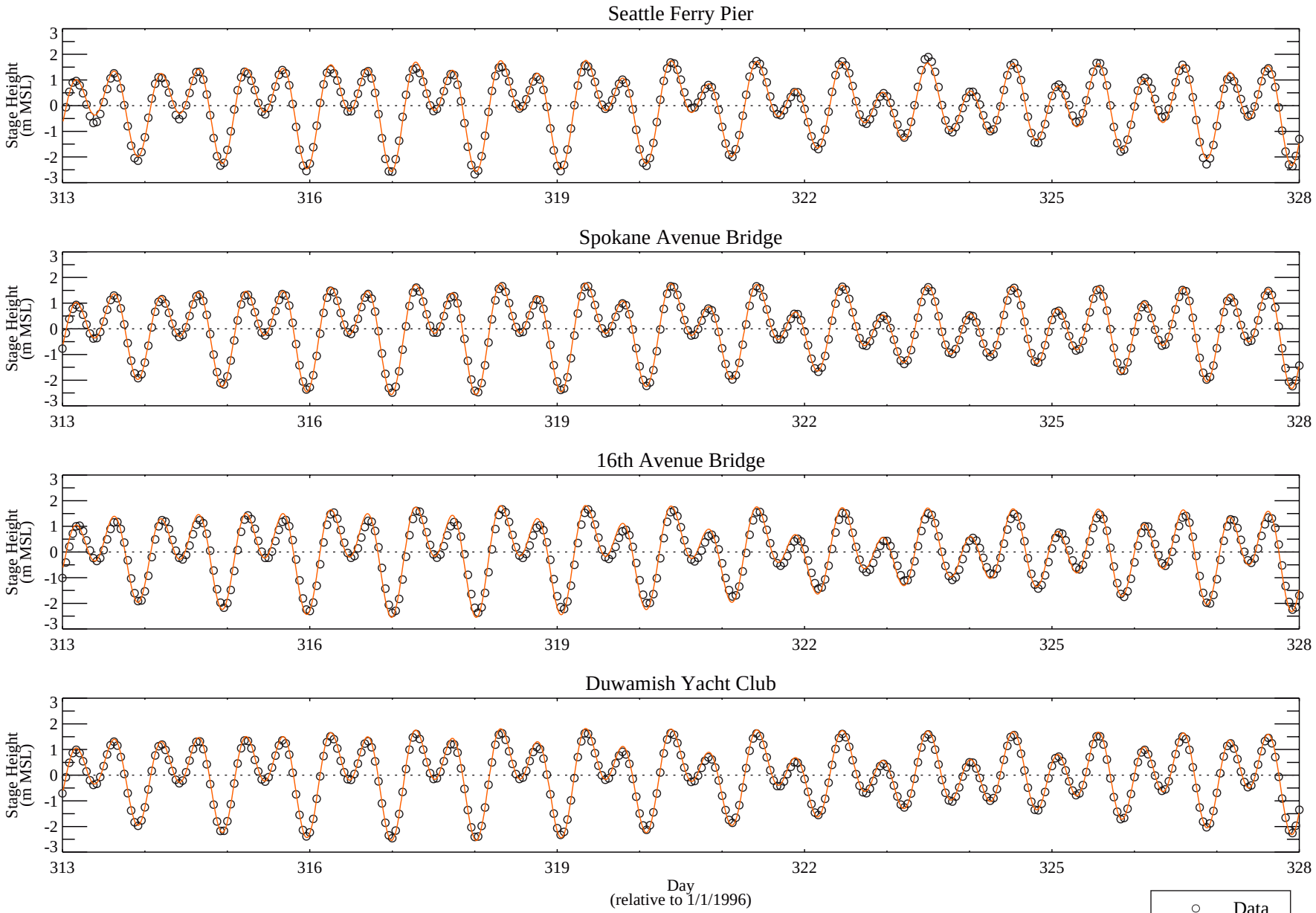

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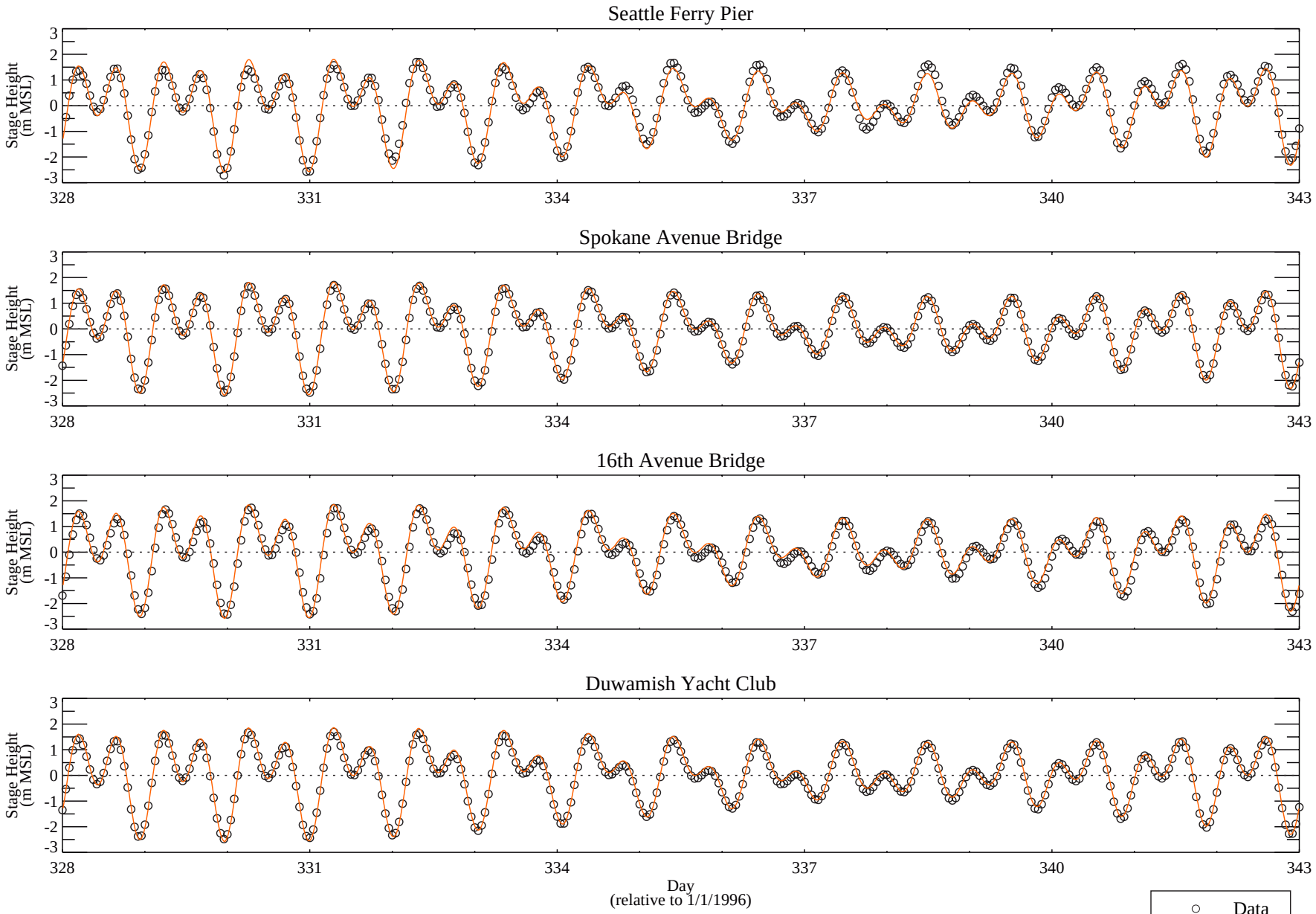

Figure B-19. Comparison of predicted and observed tidal elevation at four locations for Julian days 328 to 343, 1996.

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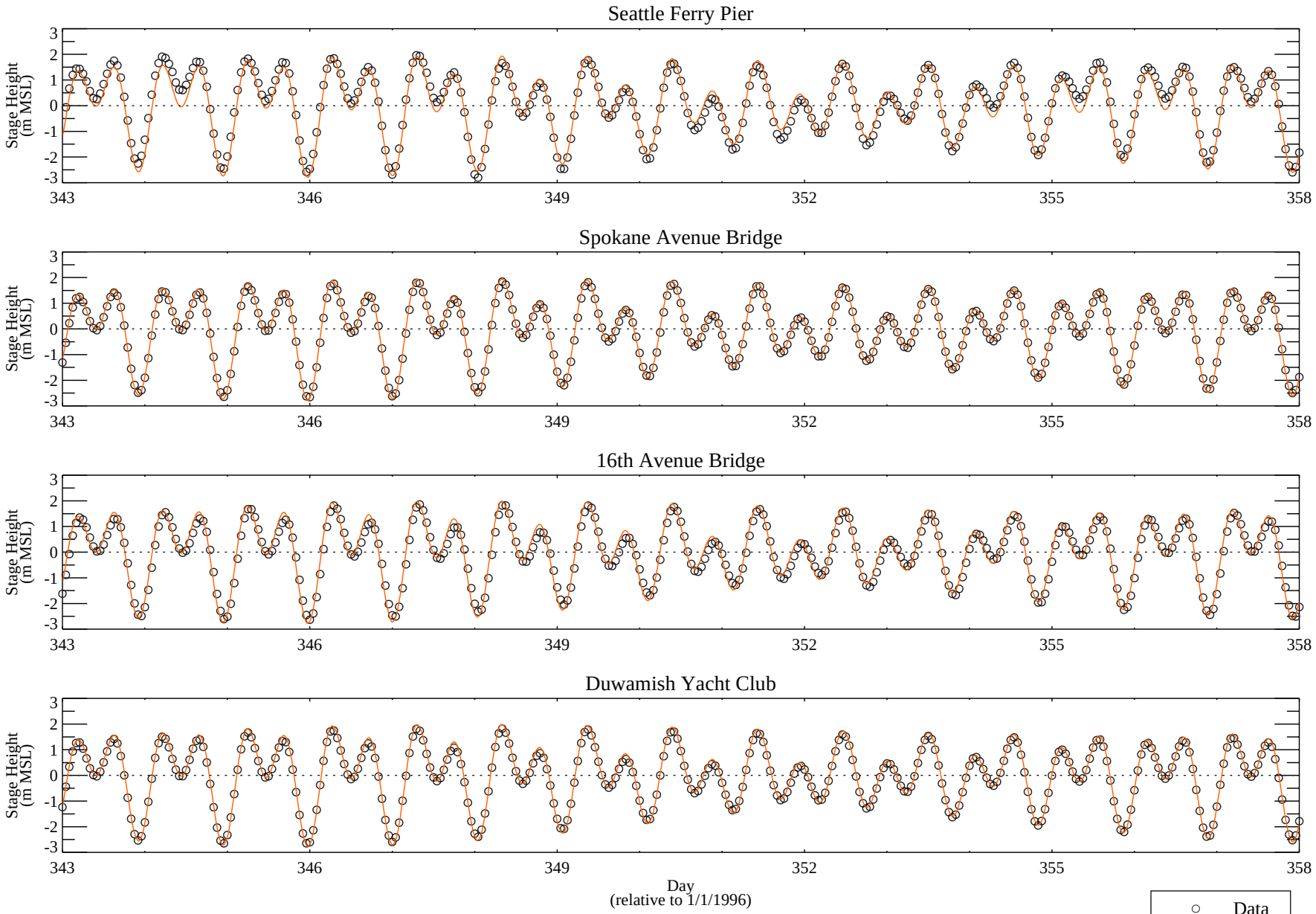

Figure B-20. Comparison of predicted and observed tidal elevation at four locations for Julian days 343 to 358, 1996.

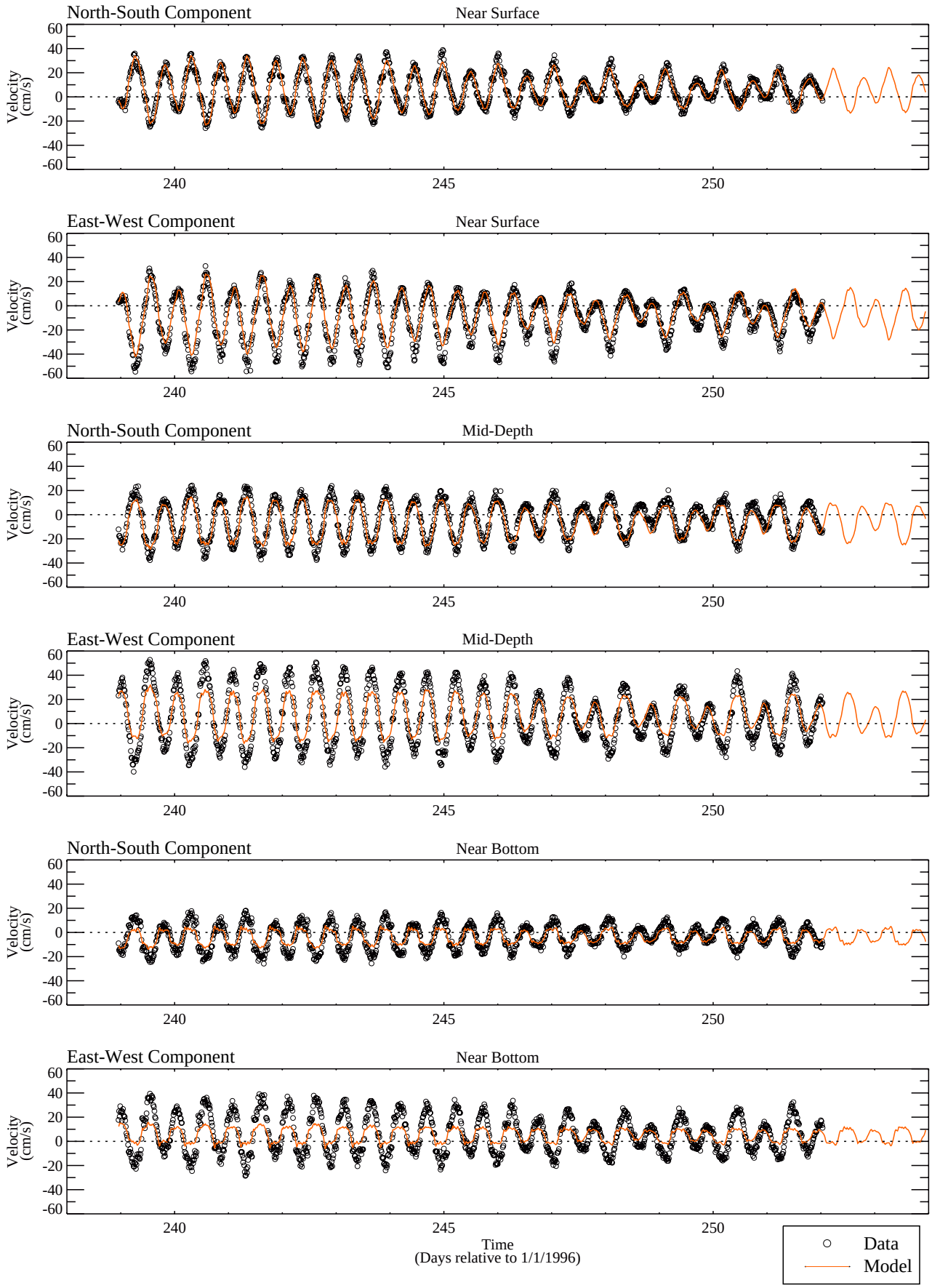

Figure B-21. Comparison of predicted and observed current velocity at Boeing station for Julian days 238 to 254, 1996.

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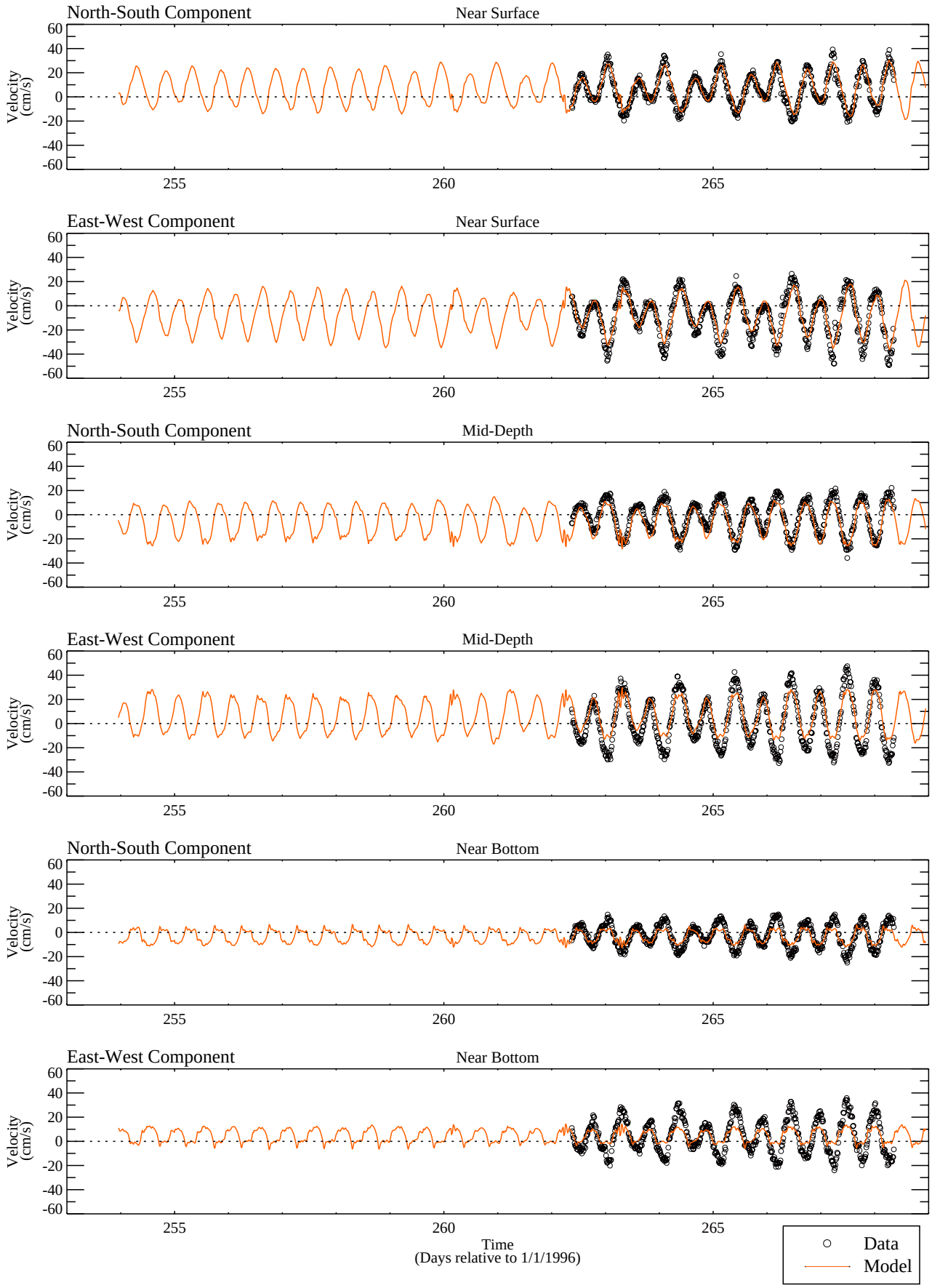

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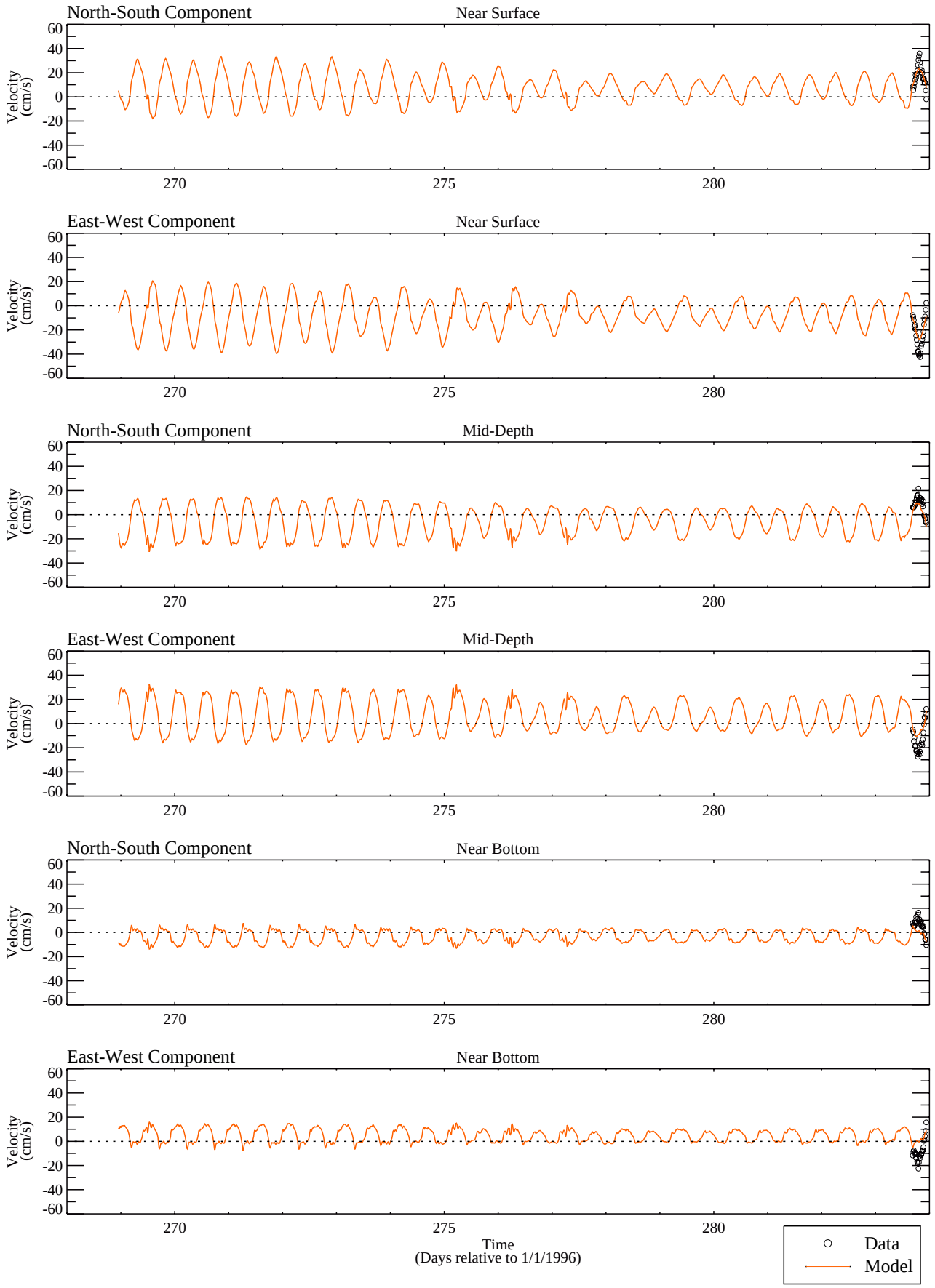

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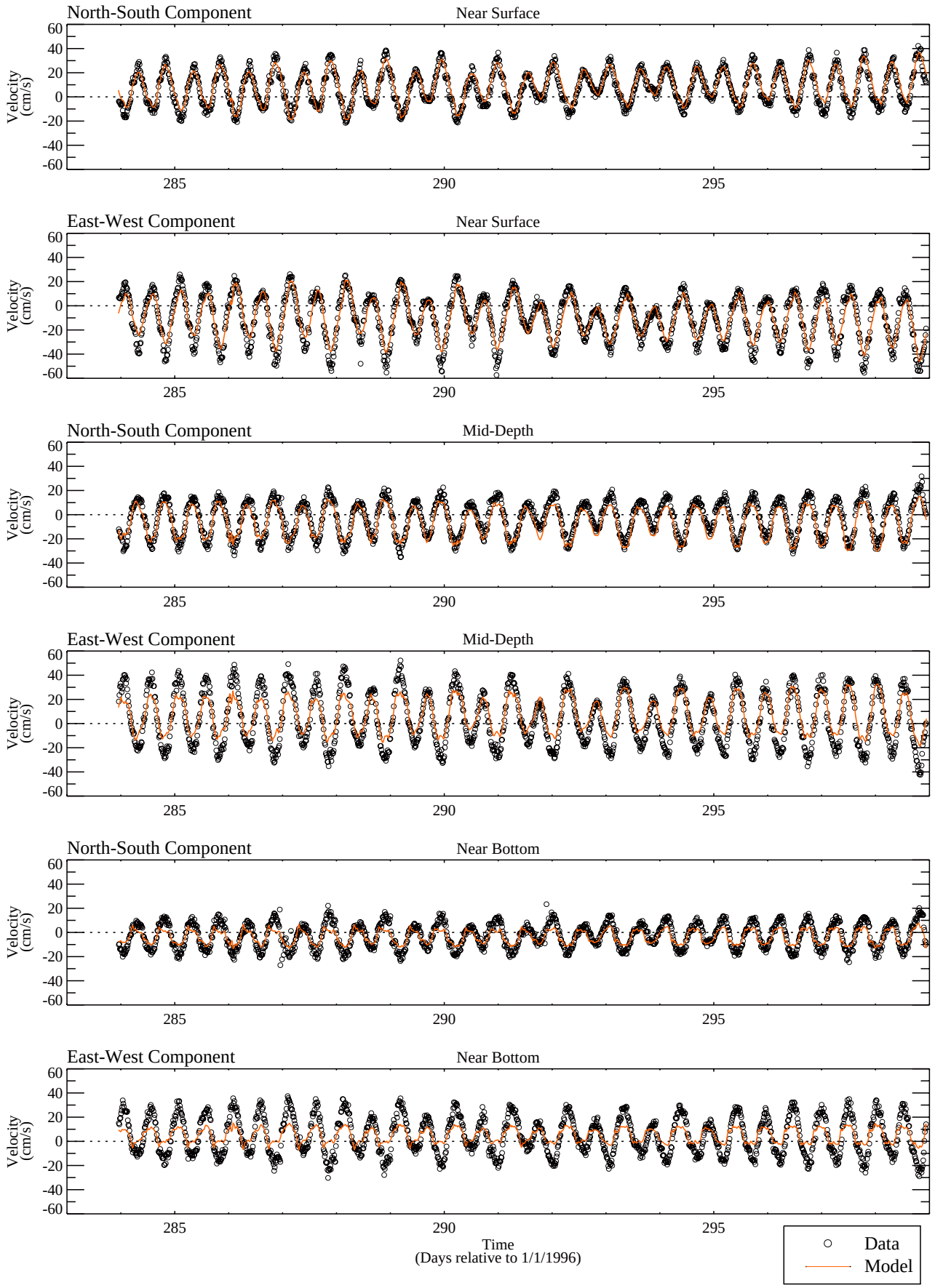

Figure B-24. Comparison of predicted and observed current velocity at Boeing station for Julian days 283 to 299, 1996.

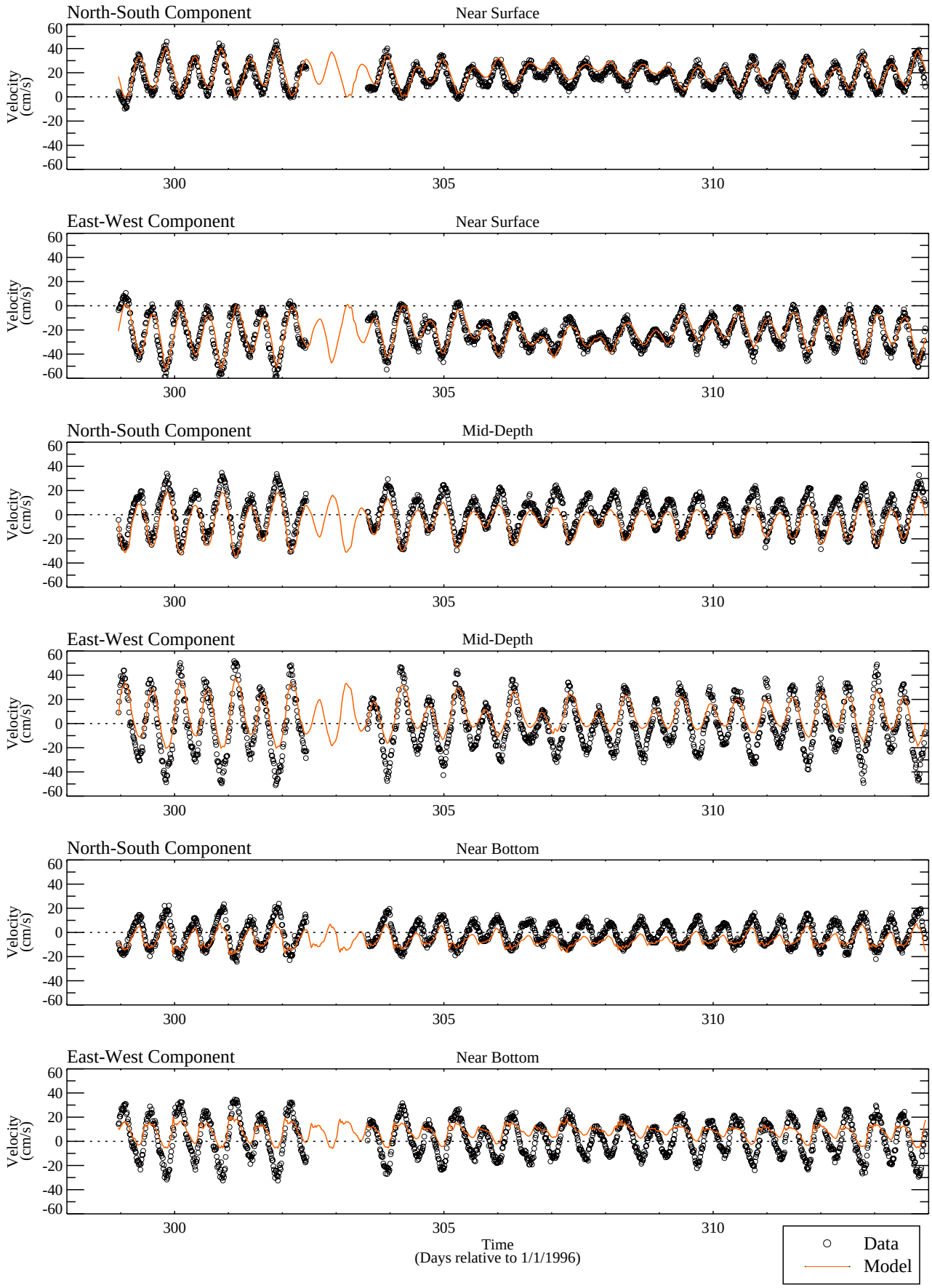

Figure B-25. Comparison of predicted and observed current velocity at Boeing station for Julian days 298 to 314, 1996.

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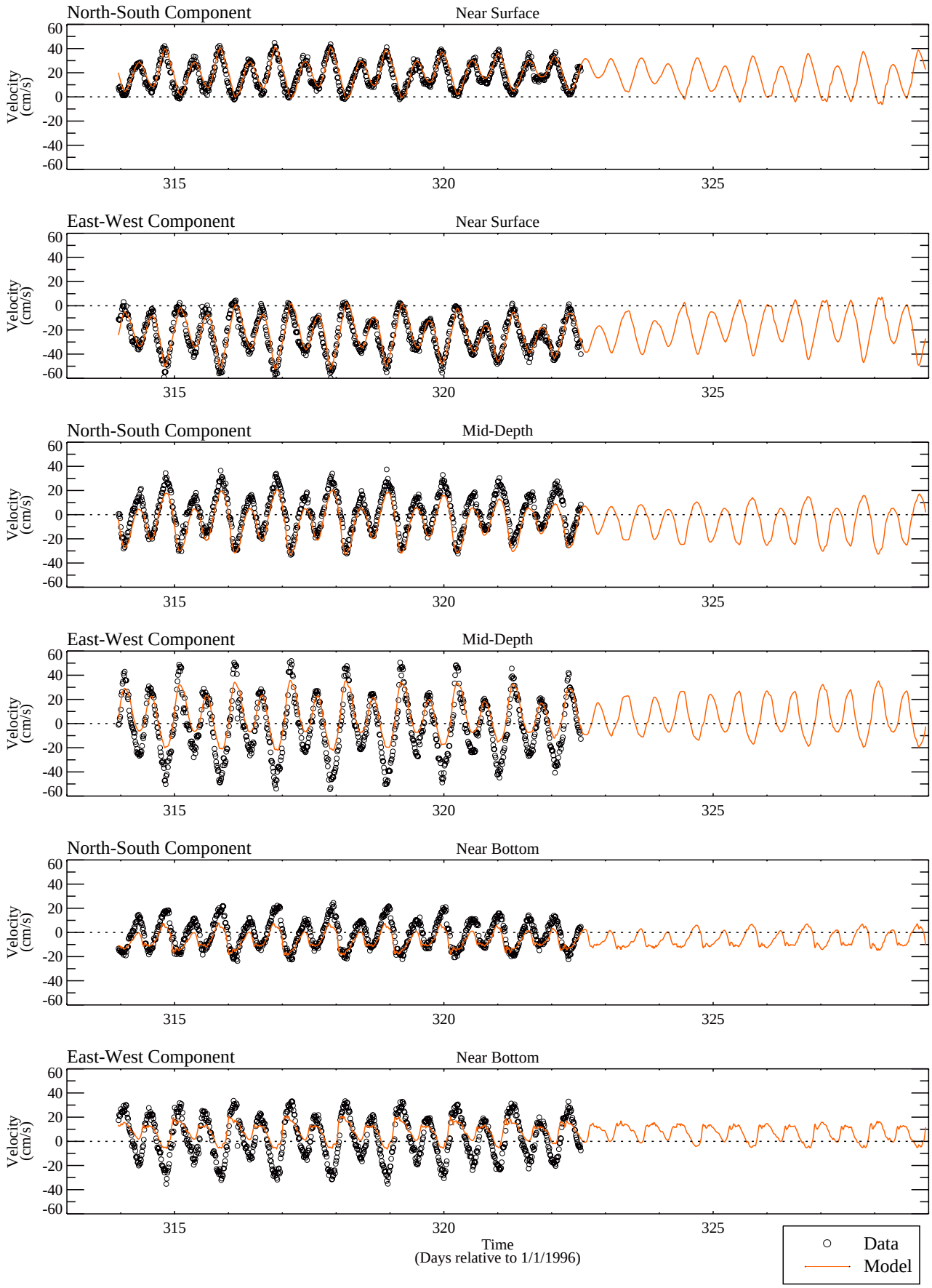

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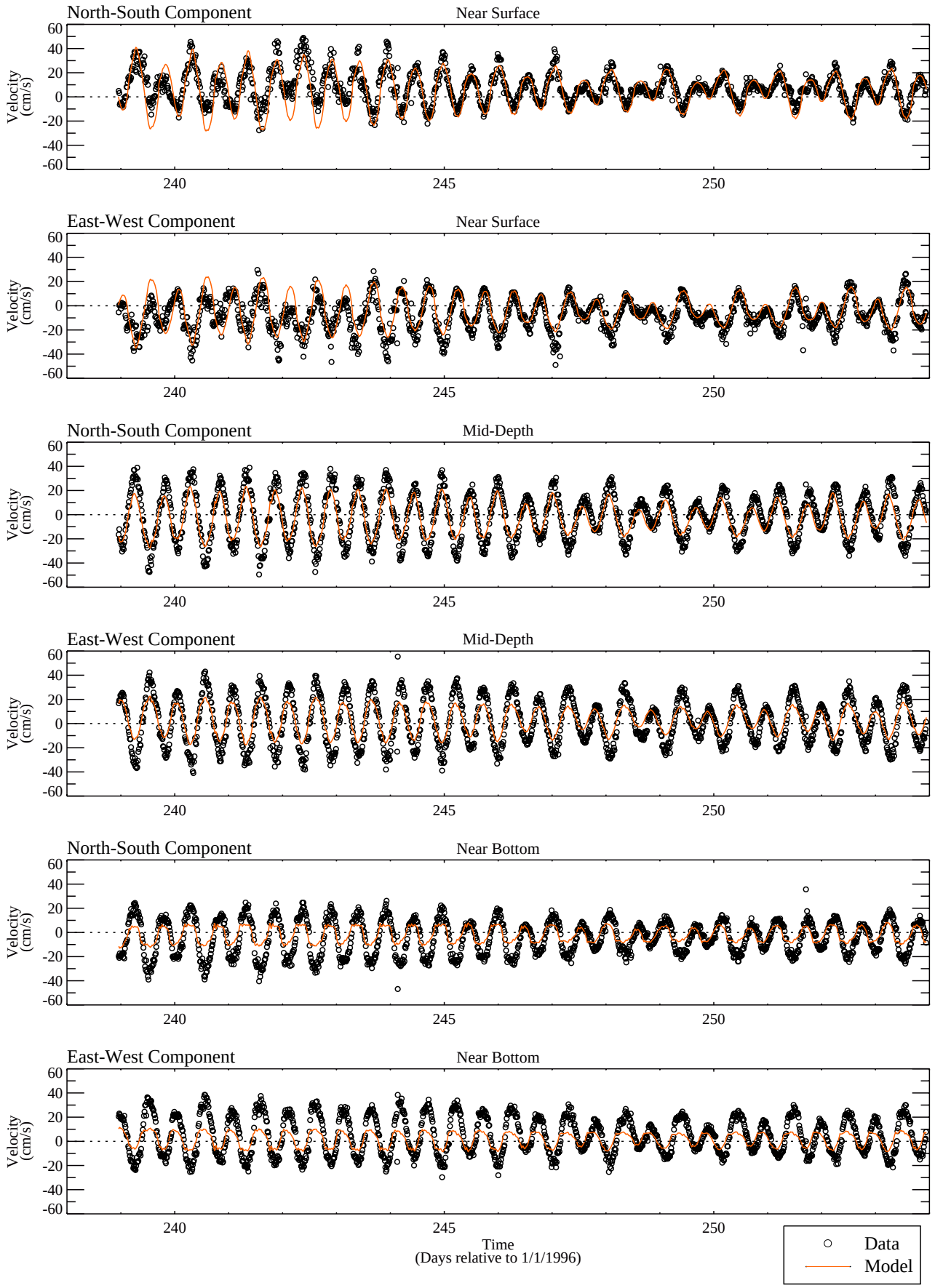
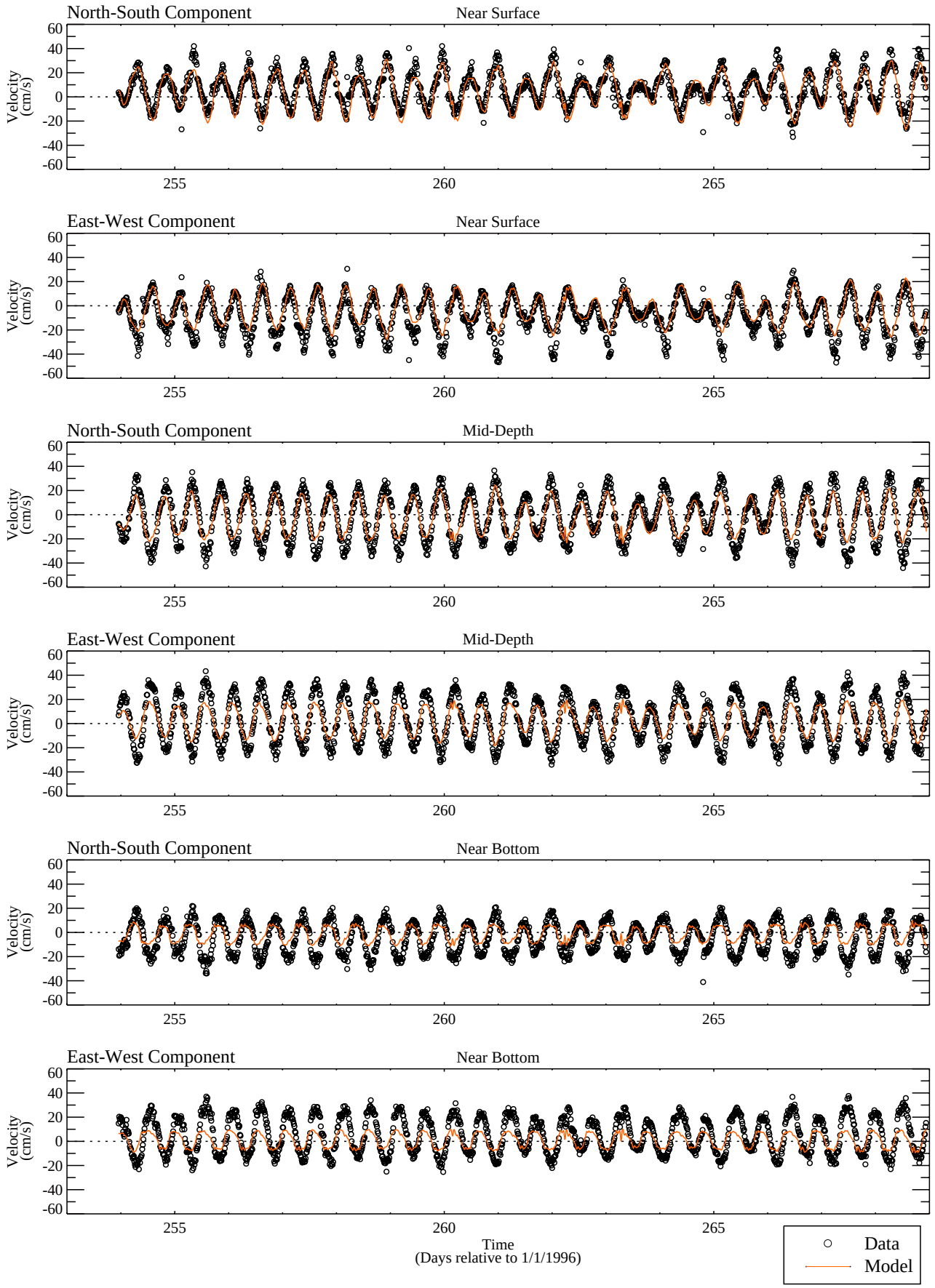


Figure B-27. Comparison of predicted and observed current velocity at Sea Boil Wks station for Julian days 238 to 254, 1996.



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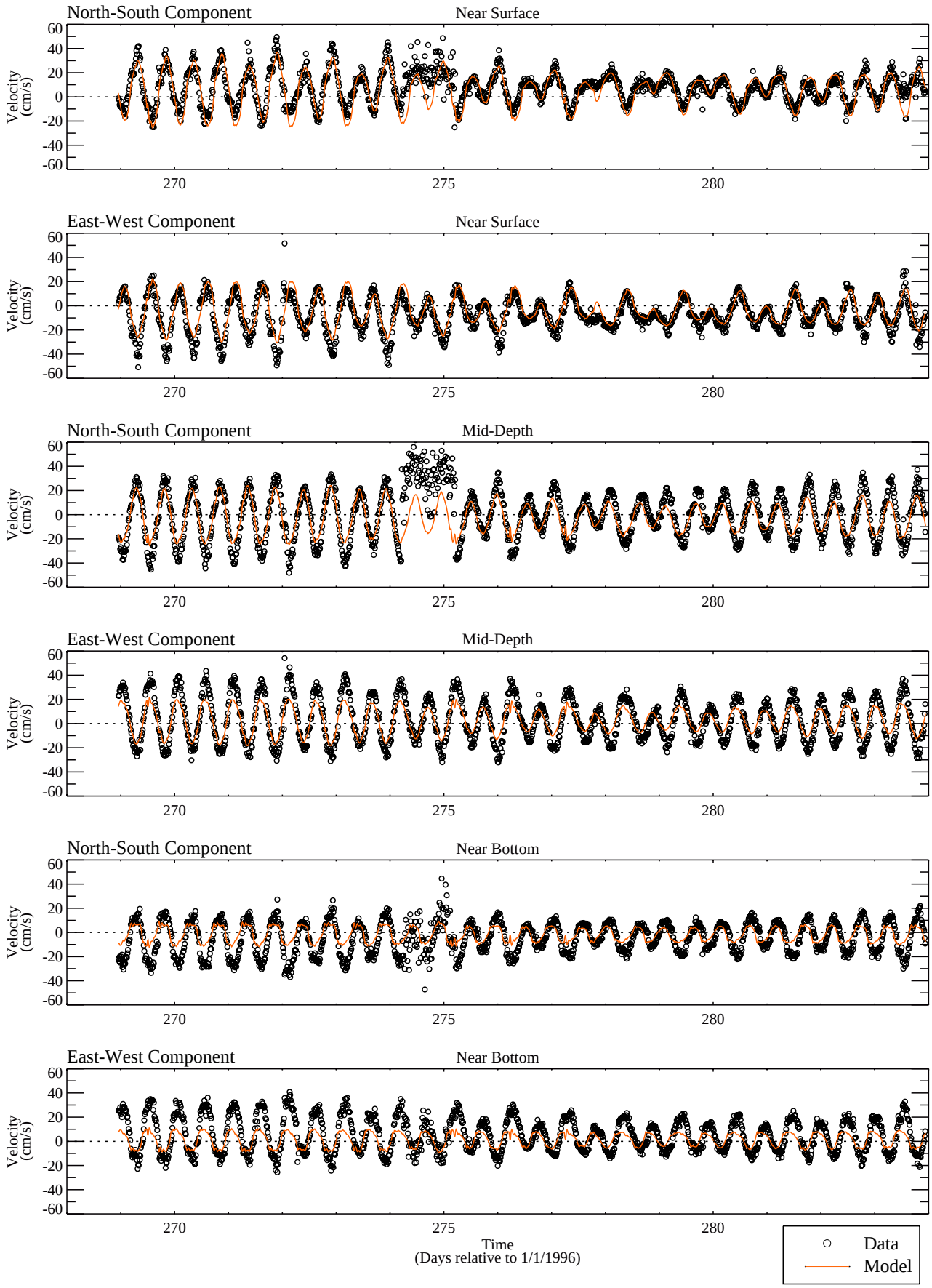


Figure B-29. Comparison of predicted and observed current velocity at Sea Boil Wks station for Julian days 268 to 285, 1996.

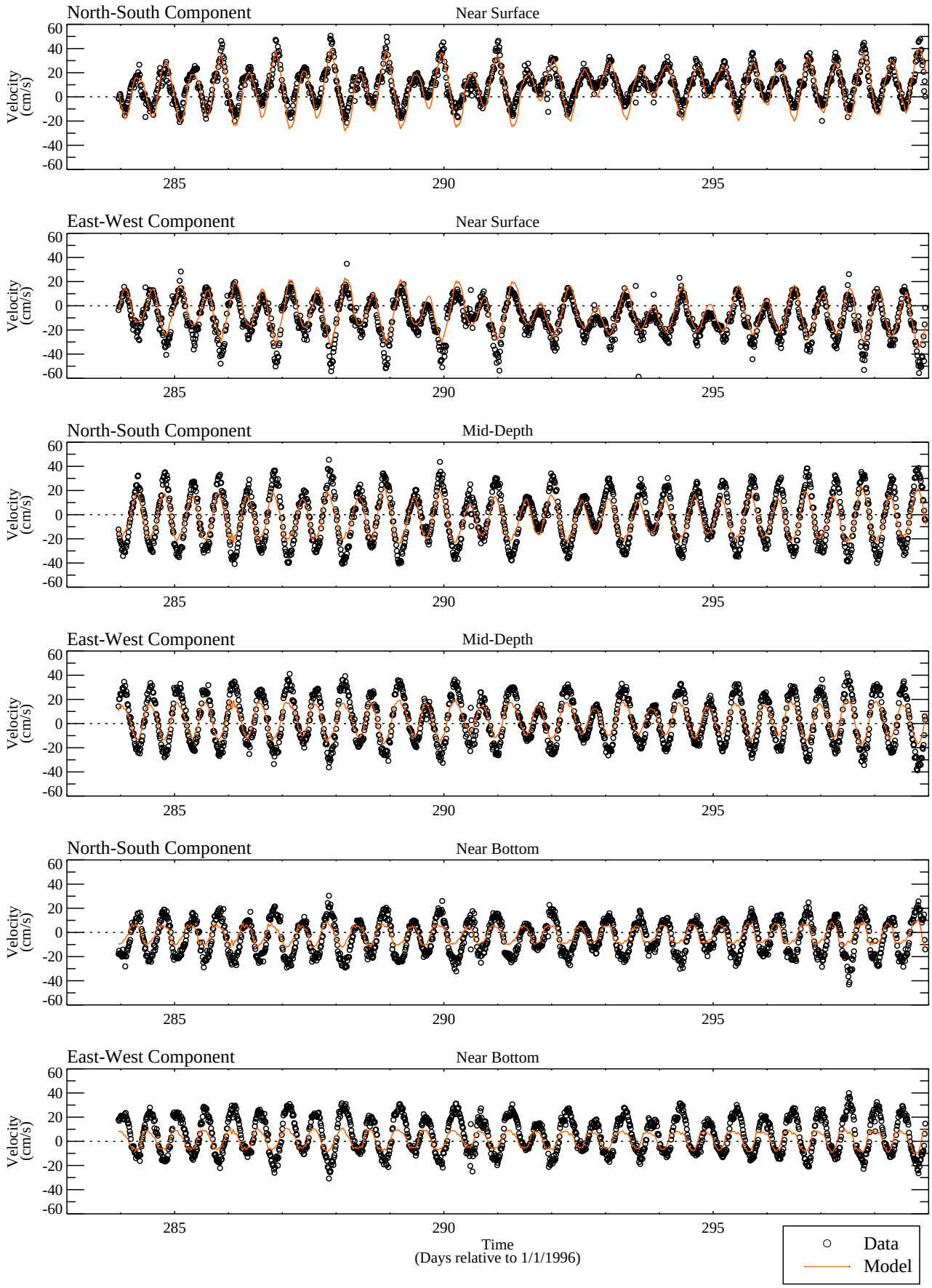
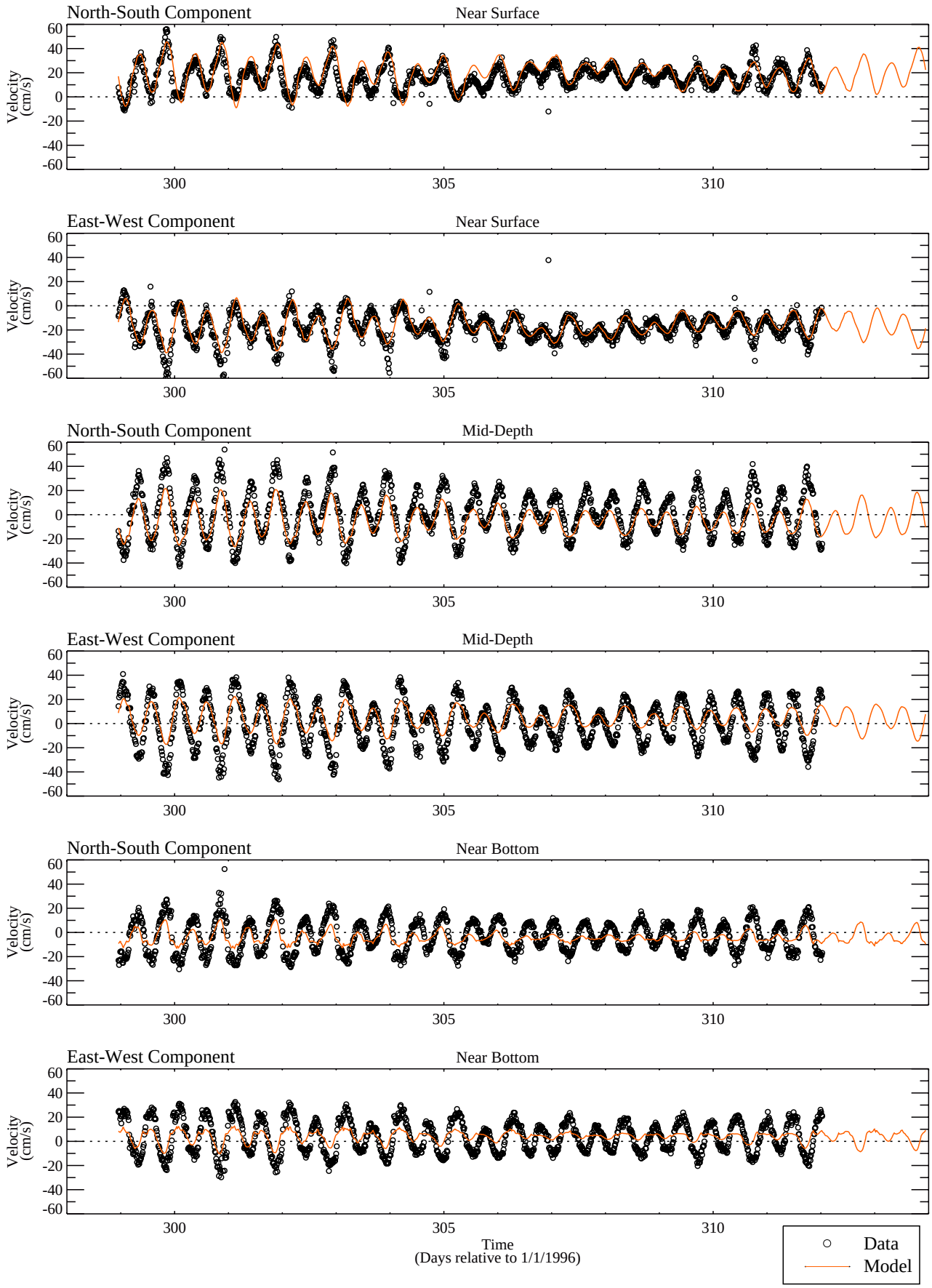


Figure B-30. Comparison of predicted and observed current velocity at Sea Boil Wks station for Julian days 283 to 299, 1996.



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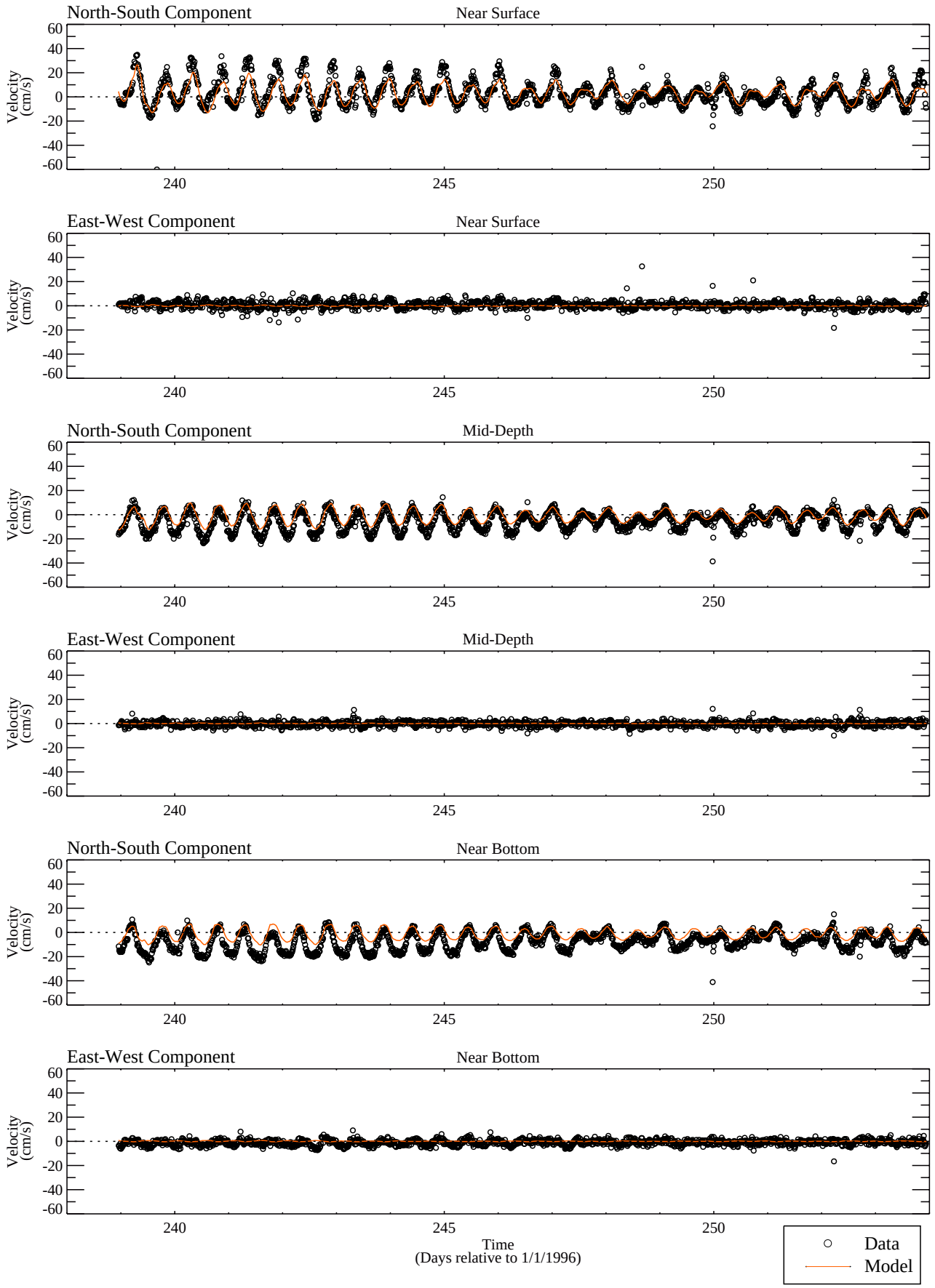

Figure B-32. Comparison of predicted and observed current velocity at Arco #1 station for Julian days 238 to 254, 1996.

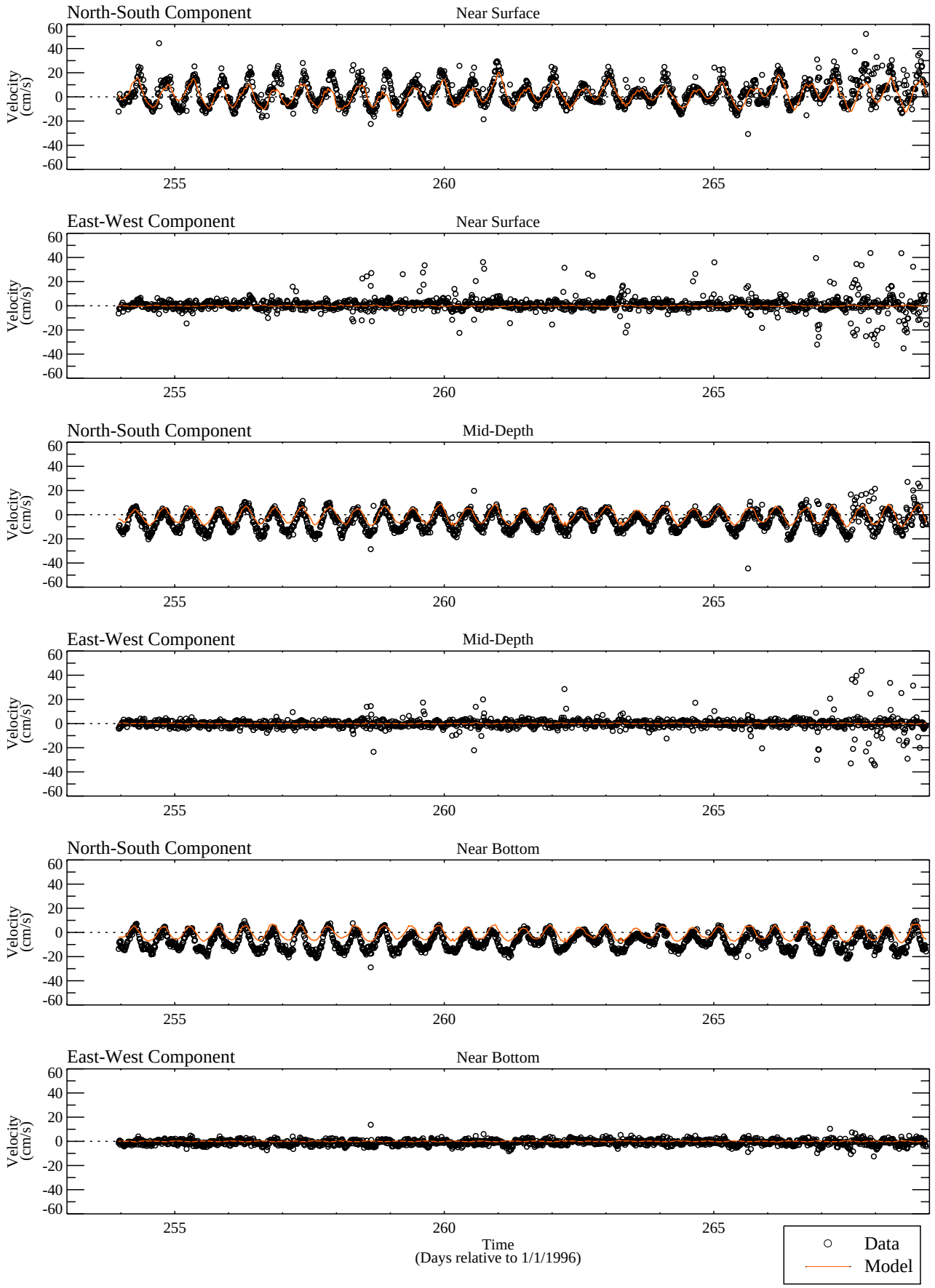

Figure B-33. Comparison of predicted and observed current velocity at Arco #1 station for Julian days 253 to 269, 1996.

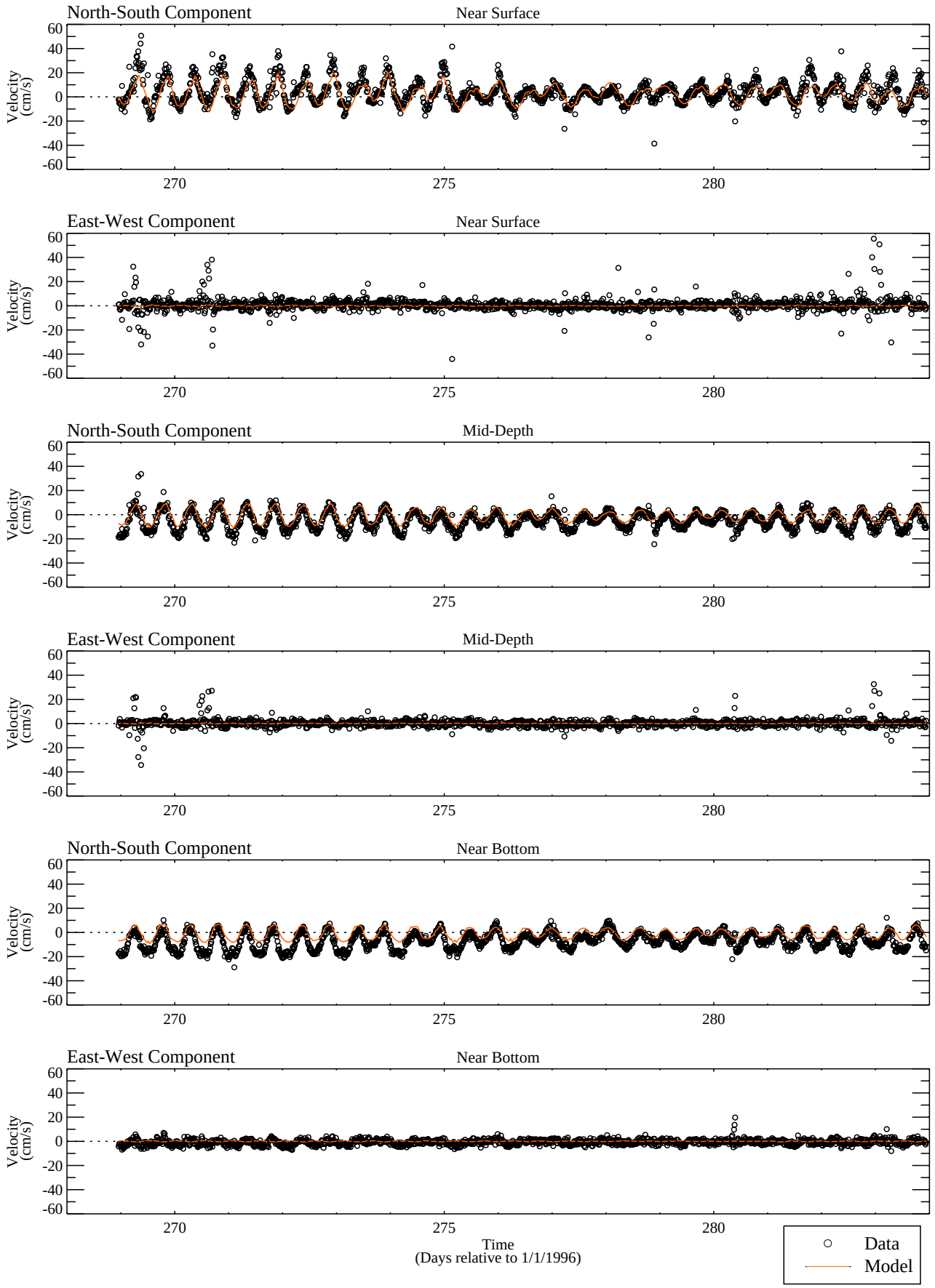

Figure B-34. Comparison of predicted and observed current velocity at Arco #1 station for Julian days 268 to 285, 1996.

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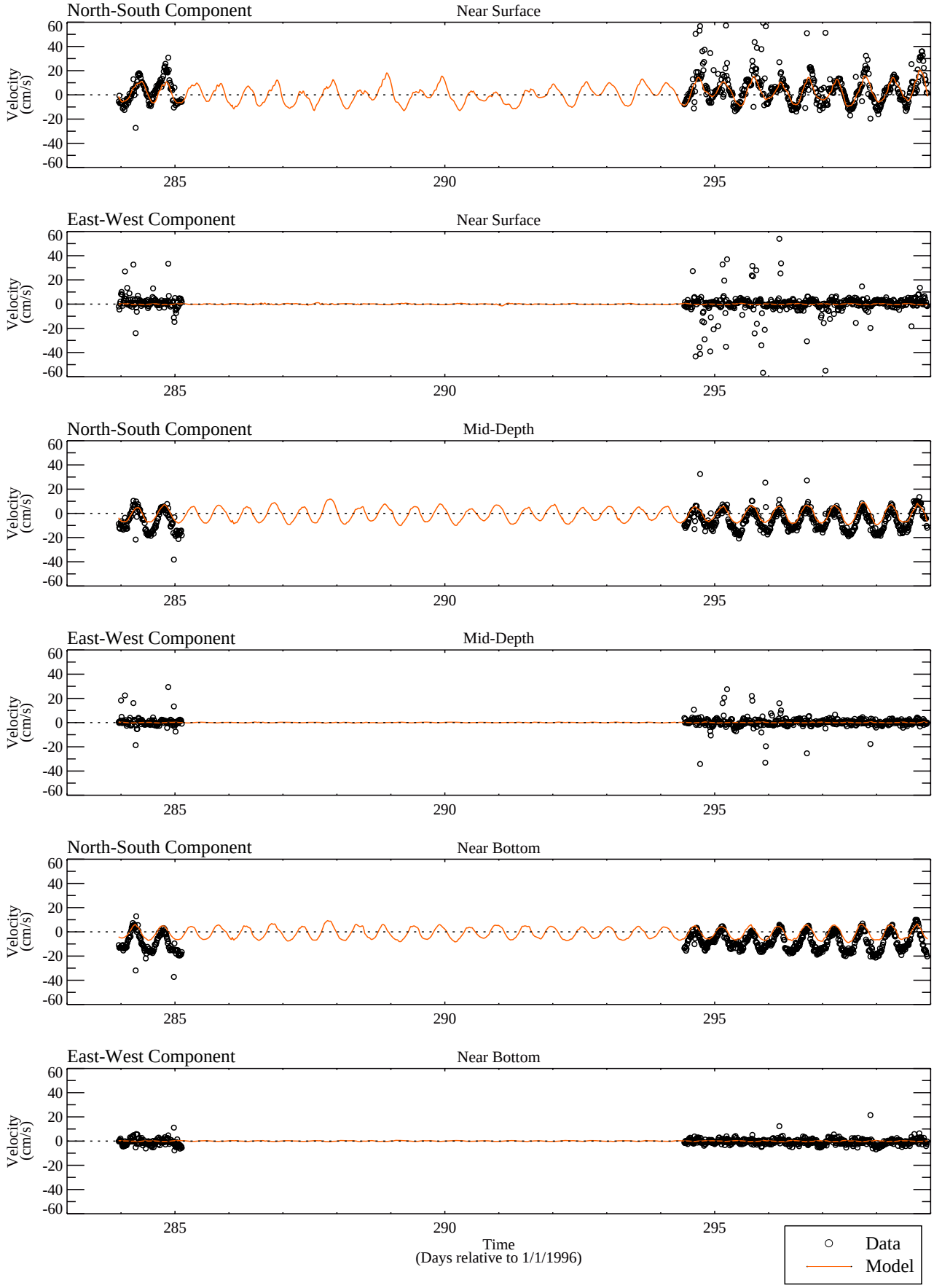

Figure B-35. Comparison of predicted and observed current velocity at Arco #1 station for Julian days 283 to 299, 1996.

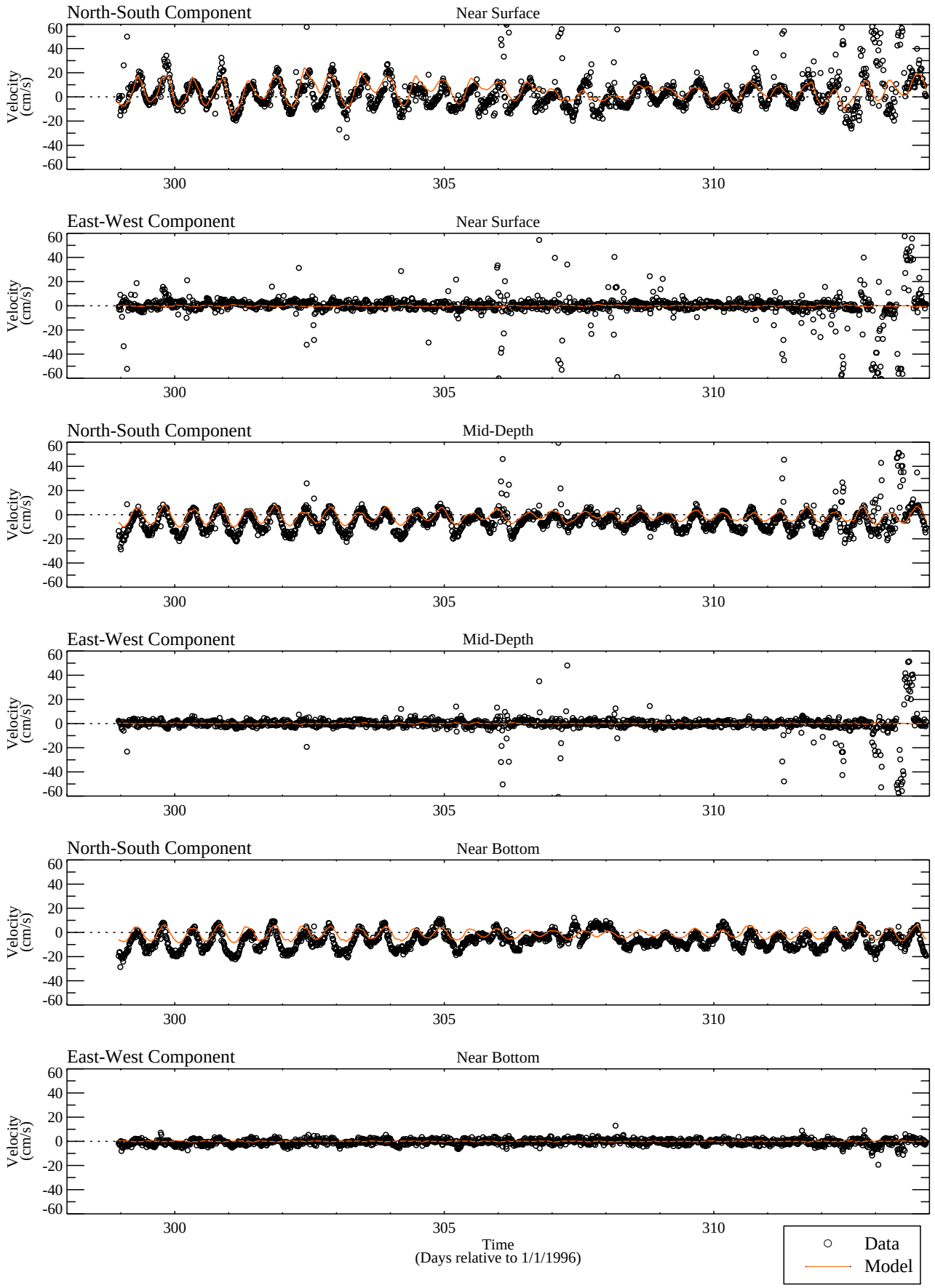

Figure B-36. Comparison of predicted and observed current velocity at Arco #1 station for Julian days 298 to 314, 1996.

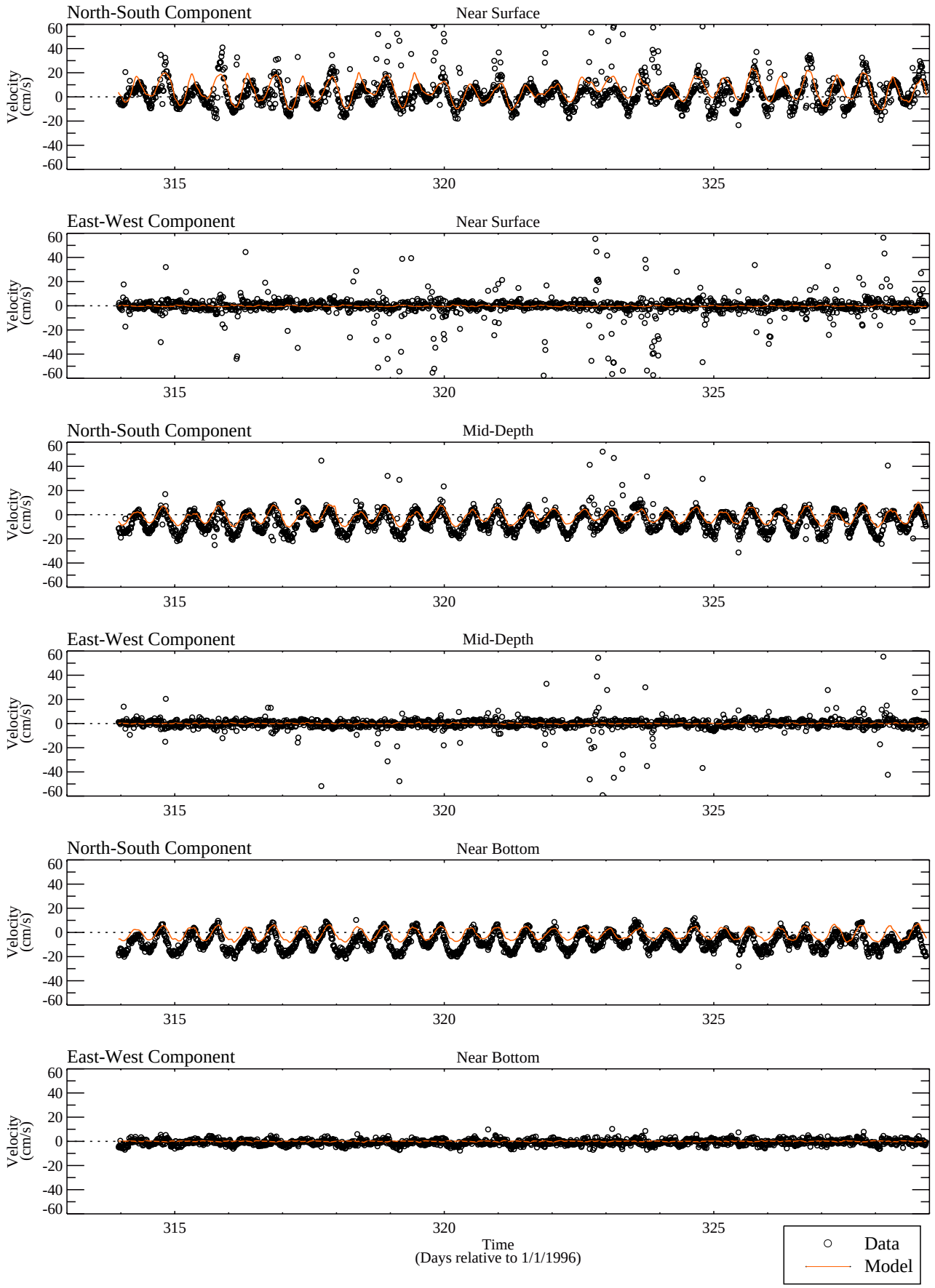

Figure B-37. Comparison of predicted and observed current velocity at Arco #1 station for Julian days 313 to 329, 1996.

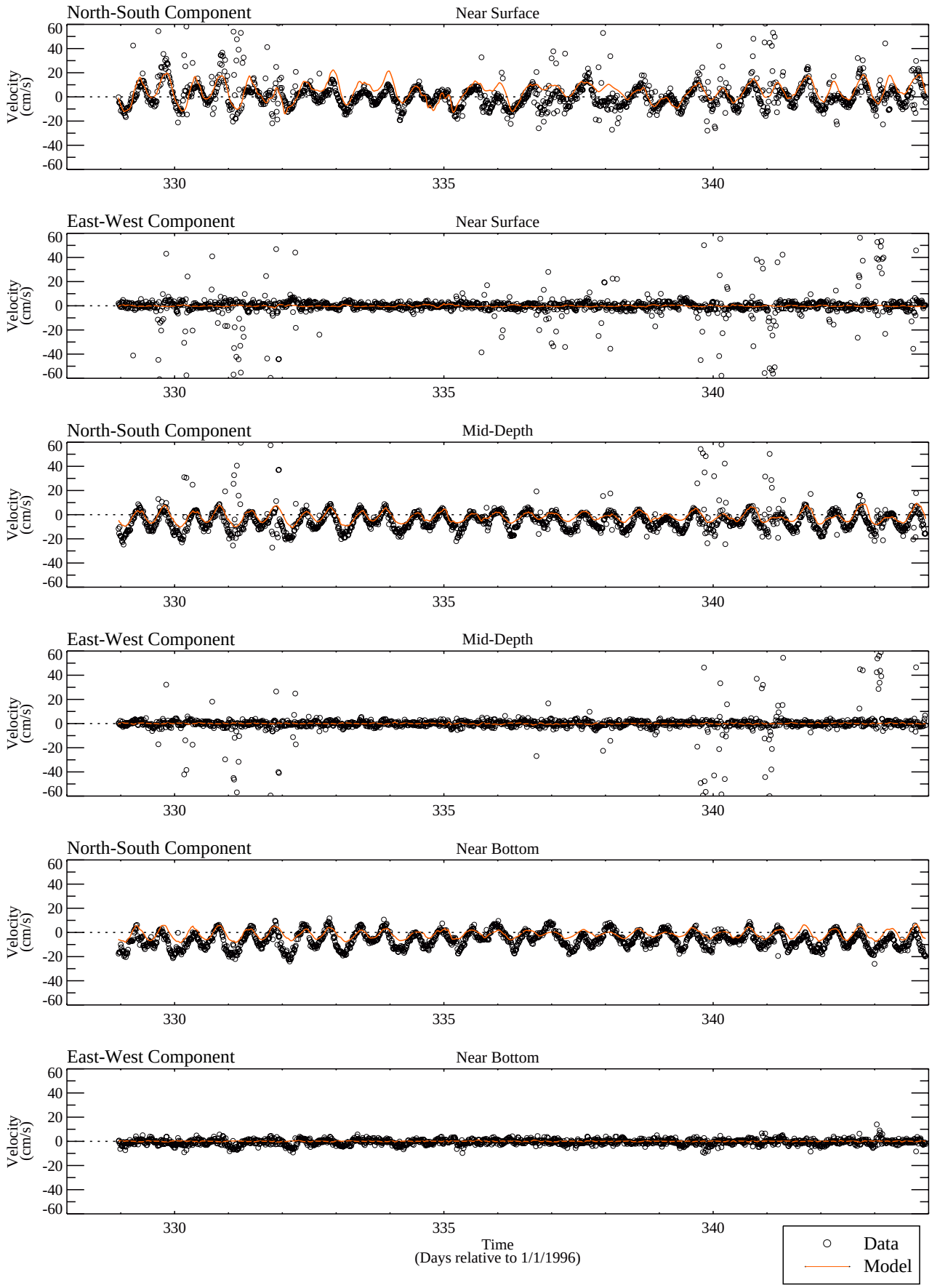

Figure B-38. Comparison of predicted and observed current velocity at Arco #1 station for Julian days 328 to 344, 1996.

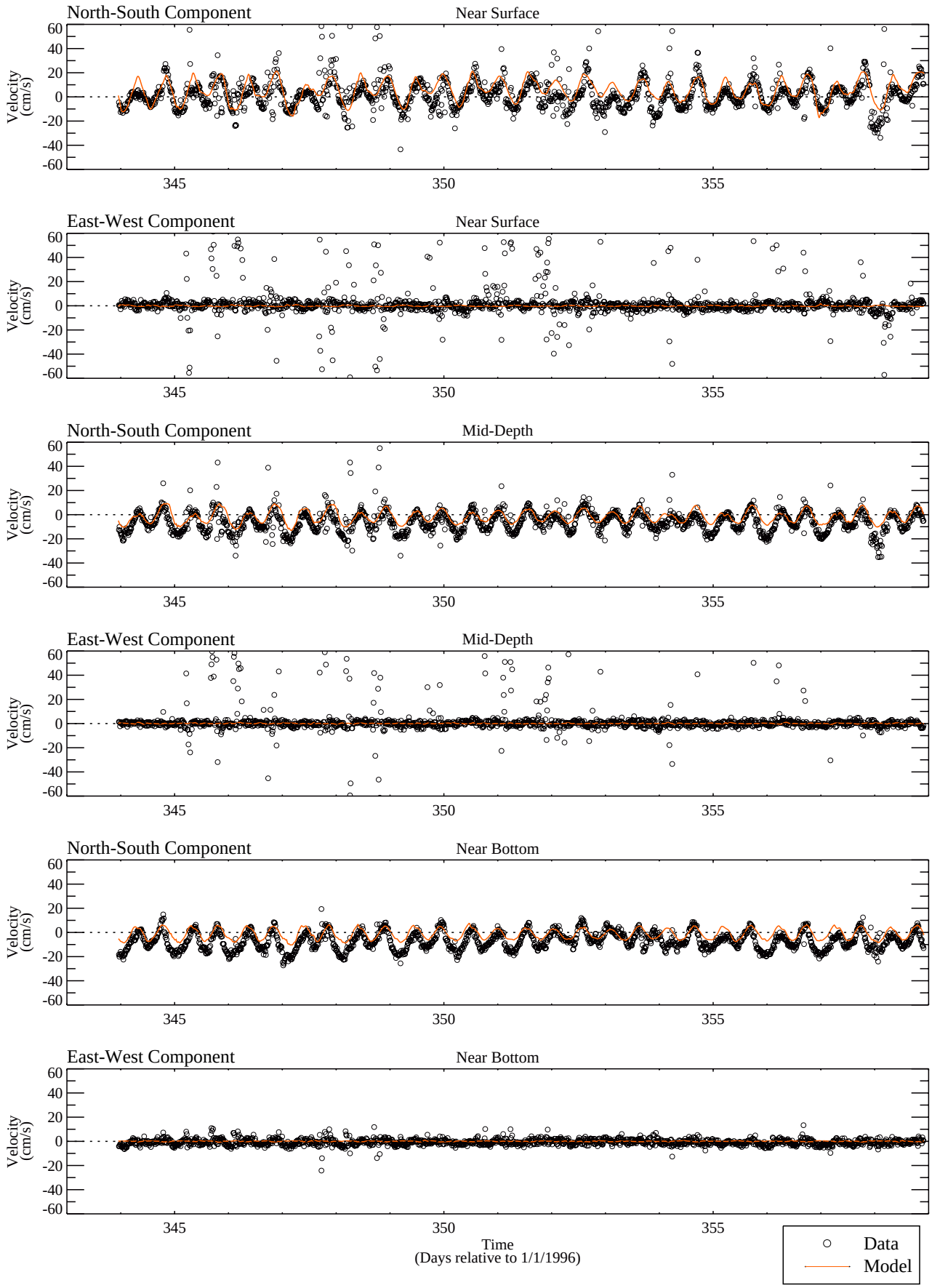

Figure B-39. Comparison of predicted and observed current velocity at Arco #1 station for Julian days 343 to 358, 1996.

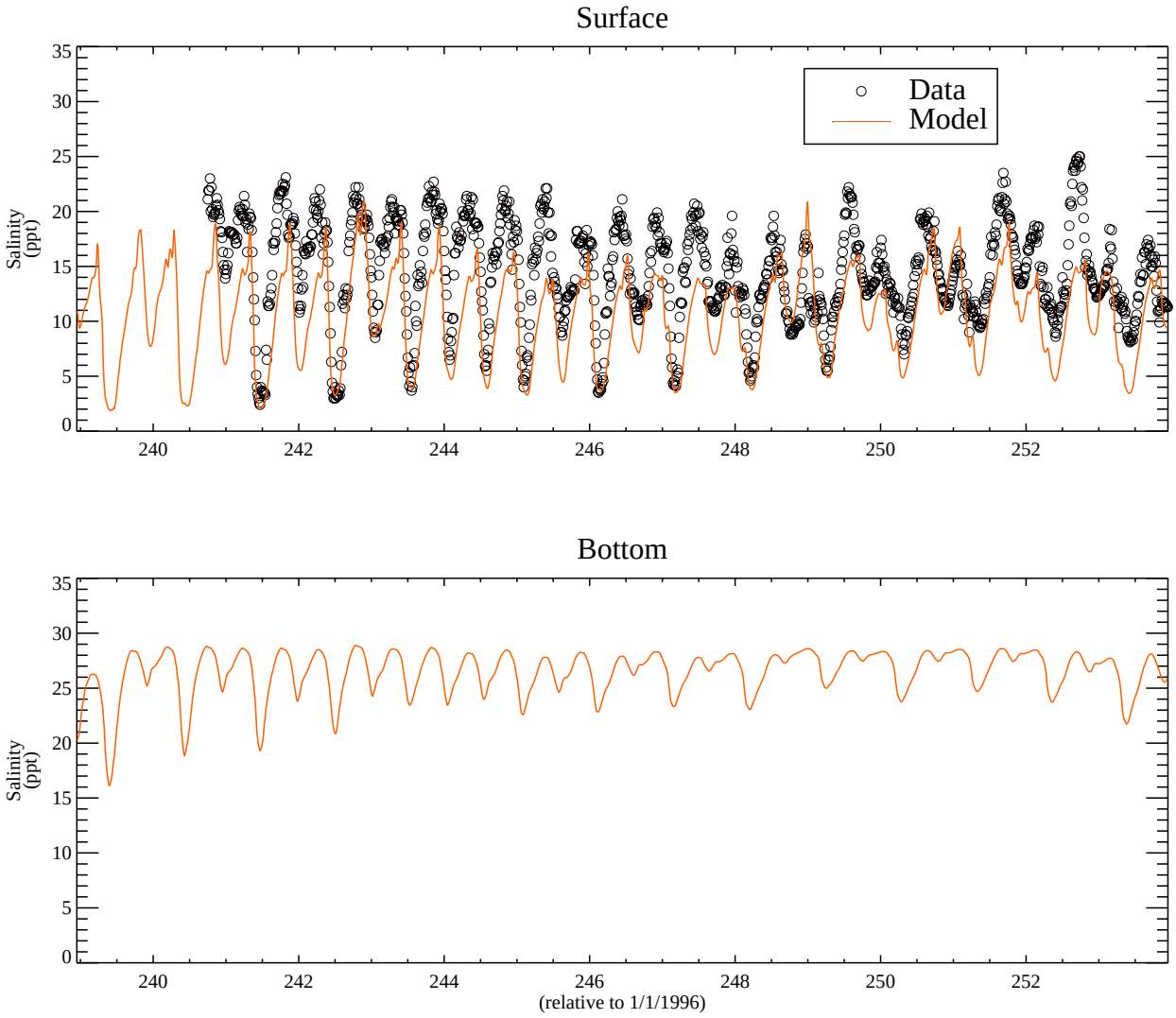

Figure B-40. Comparison of predicted and observed salinity at Duwamish Yacht Club station for Julian day 239 to 254, 1996.

lz - \\Li\D_DRIVE\WINldw\Analysis\Model_Outputs\Plot_Salinity_Calib\plot_salinity_calib_k_rpt.pro
Fri Oct 14 18:34:39 2005

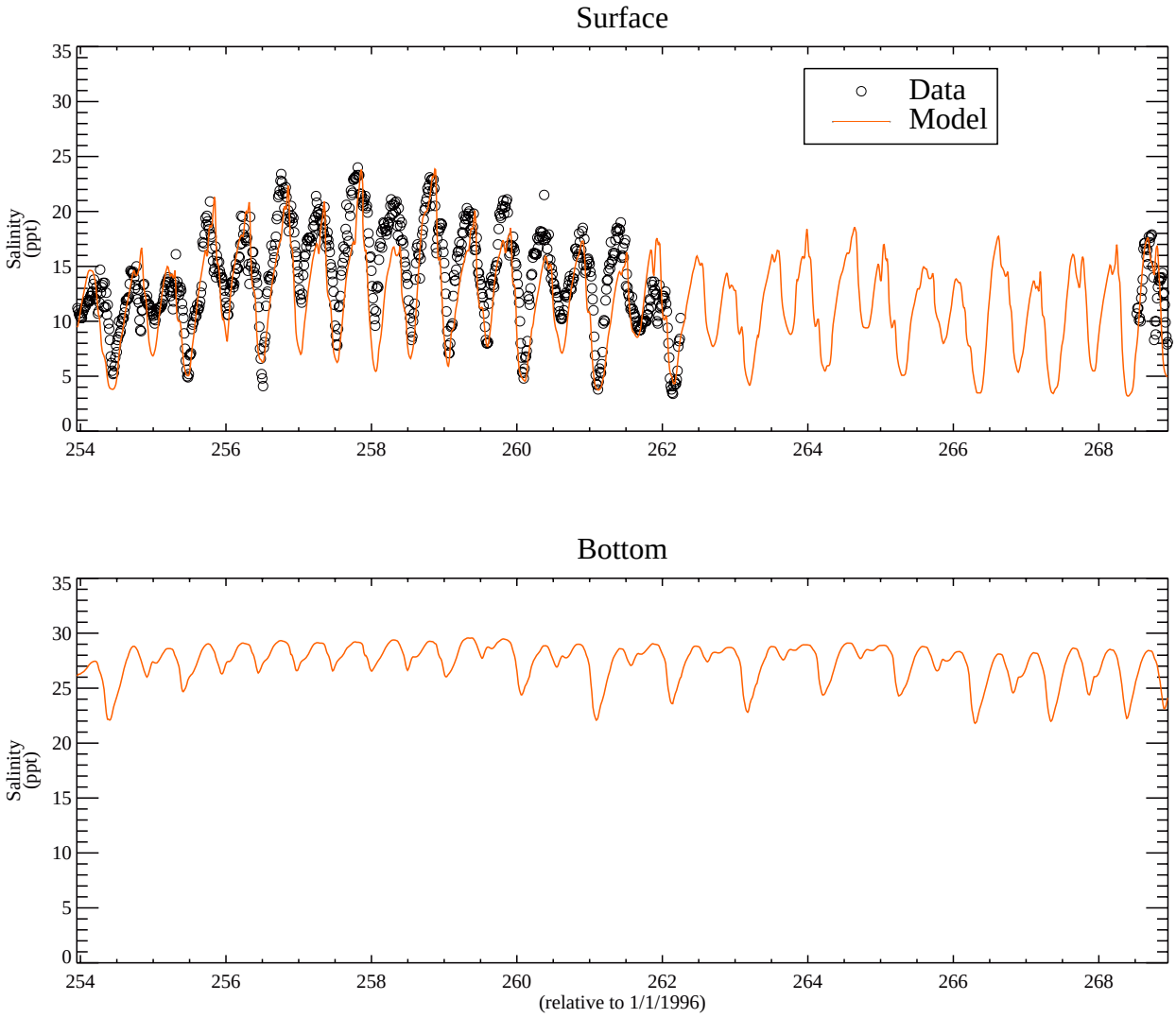

Figure B-41. Comparison of predicted and observed salinity at Duwamish Yacht Club station for Julian day 254 to 269, 1996.

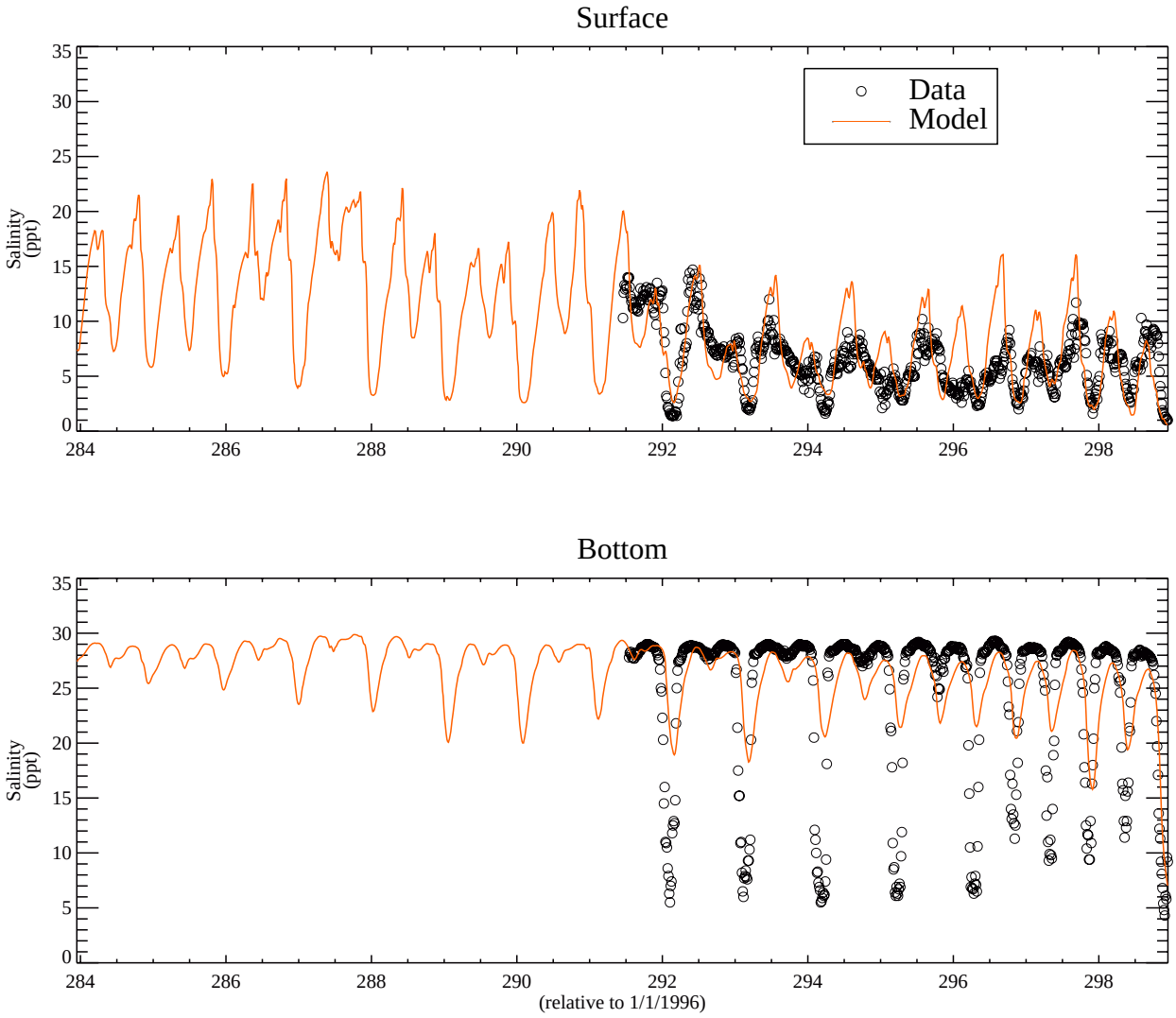

Figure B-42. Comparison of predicted and observed salinity at Duwamish Yacht Club station for Julian day 284 to 299, 1996.

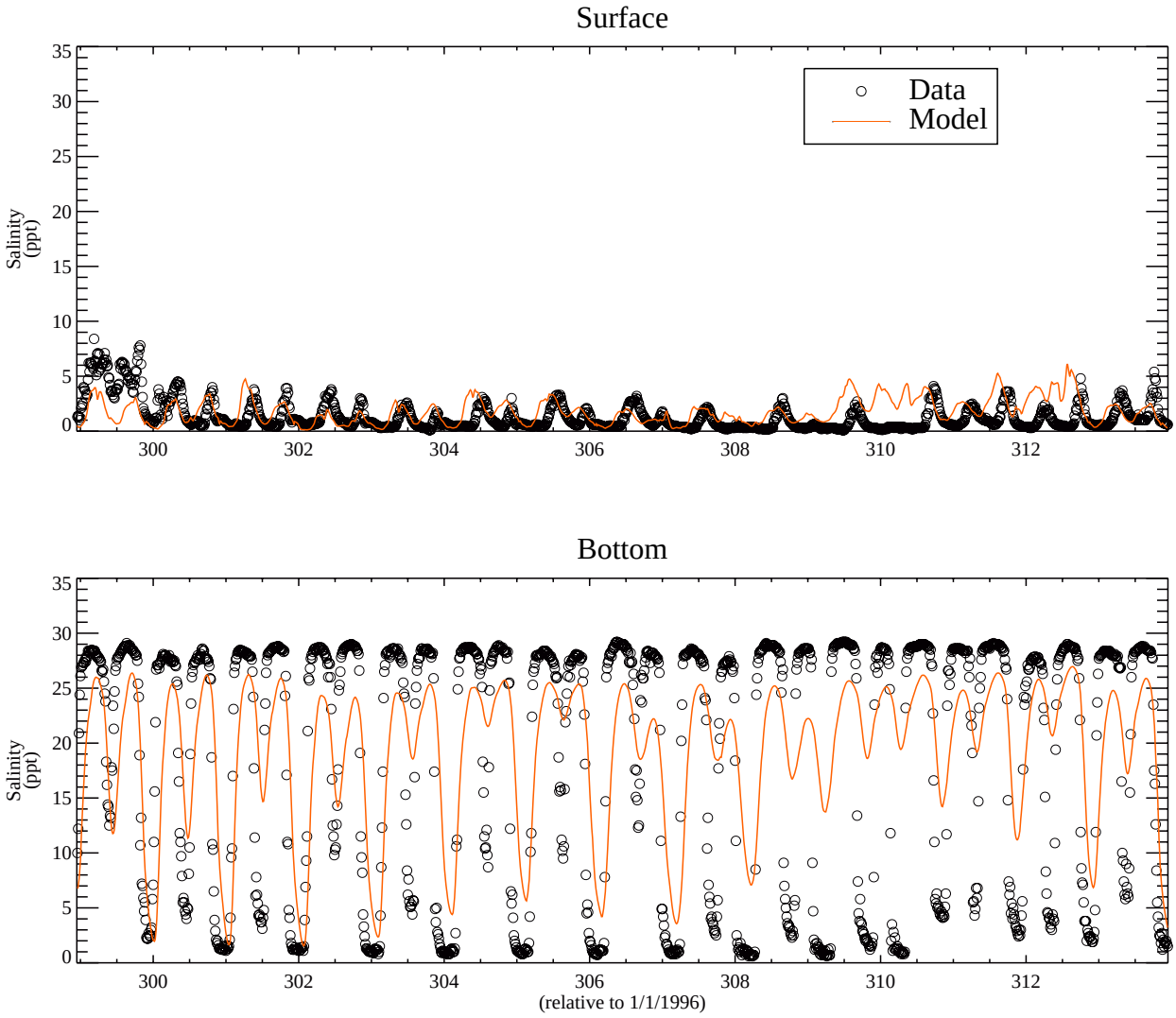

Figure B-43. Comparison of predicted and observed salinity at Duwamish Yacht Club station for Julian day 299 to 314, 1996.

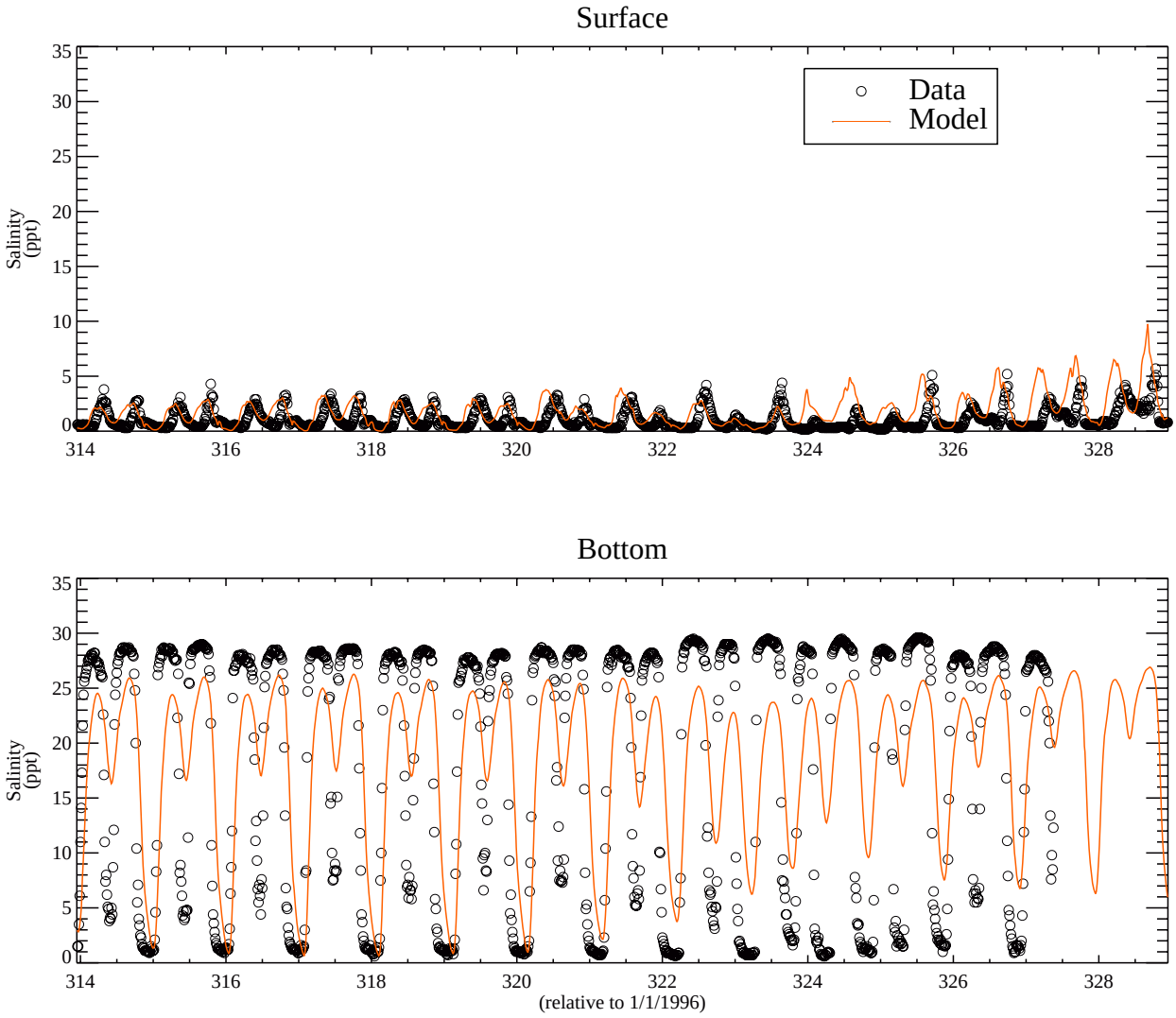

Figure B-44. Comparison of predicted and observed salinity at Duwamish Yacht Club station for Julian day 314 to 329, 1996.

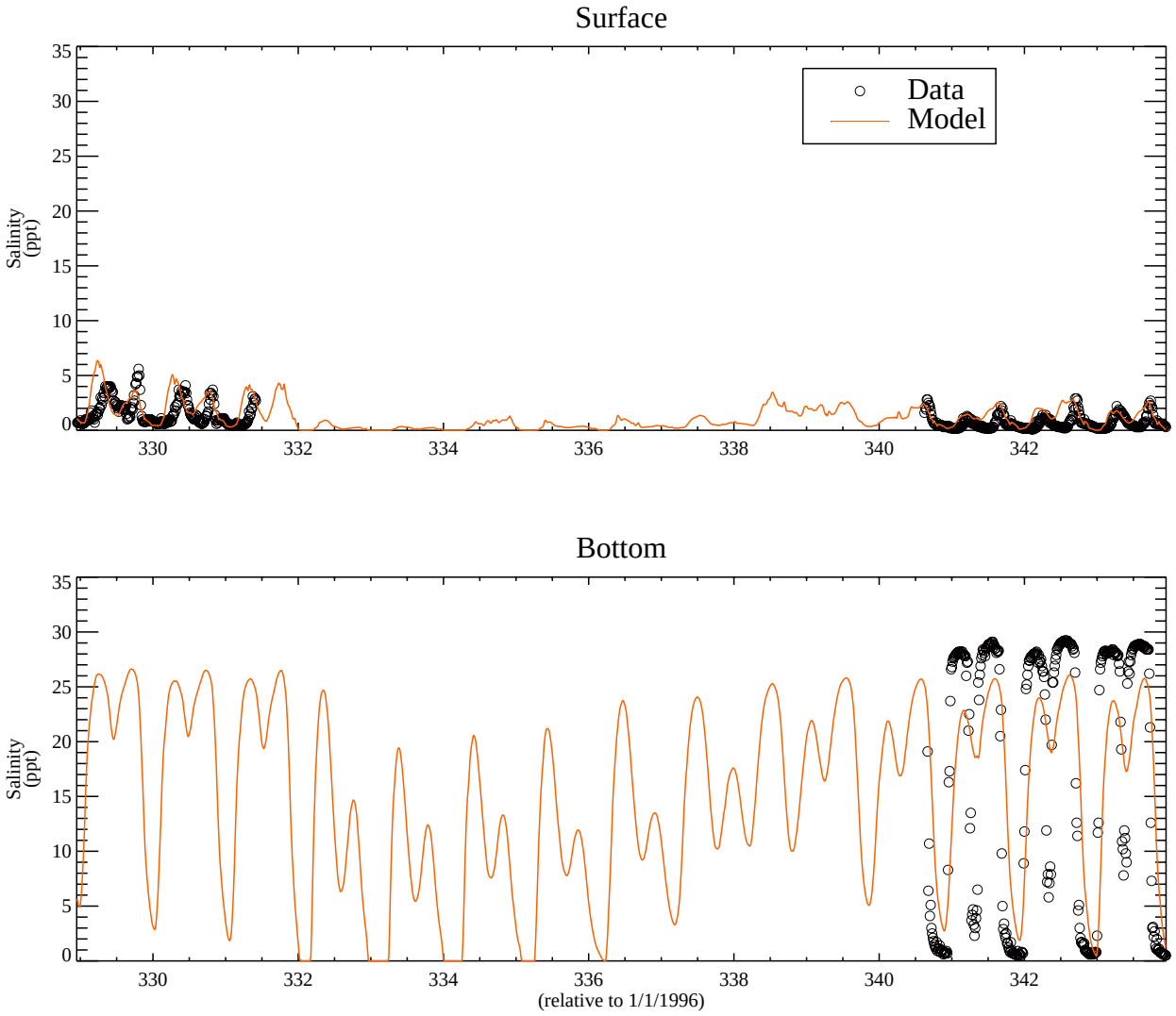

Figure B-45. Comparison of predicted and observed salinity at Duwamish Yacht Club station for Julian day 329 to 344, 1996.

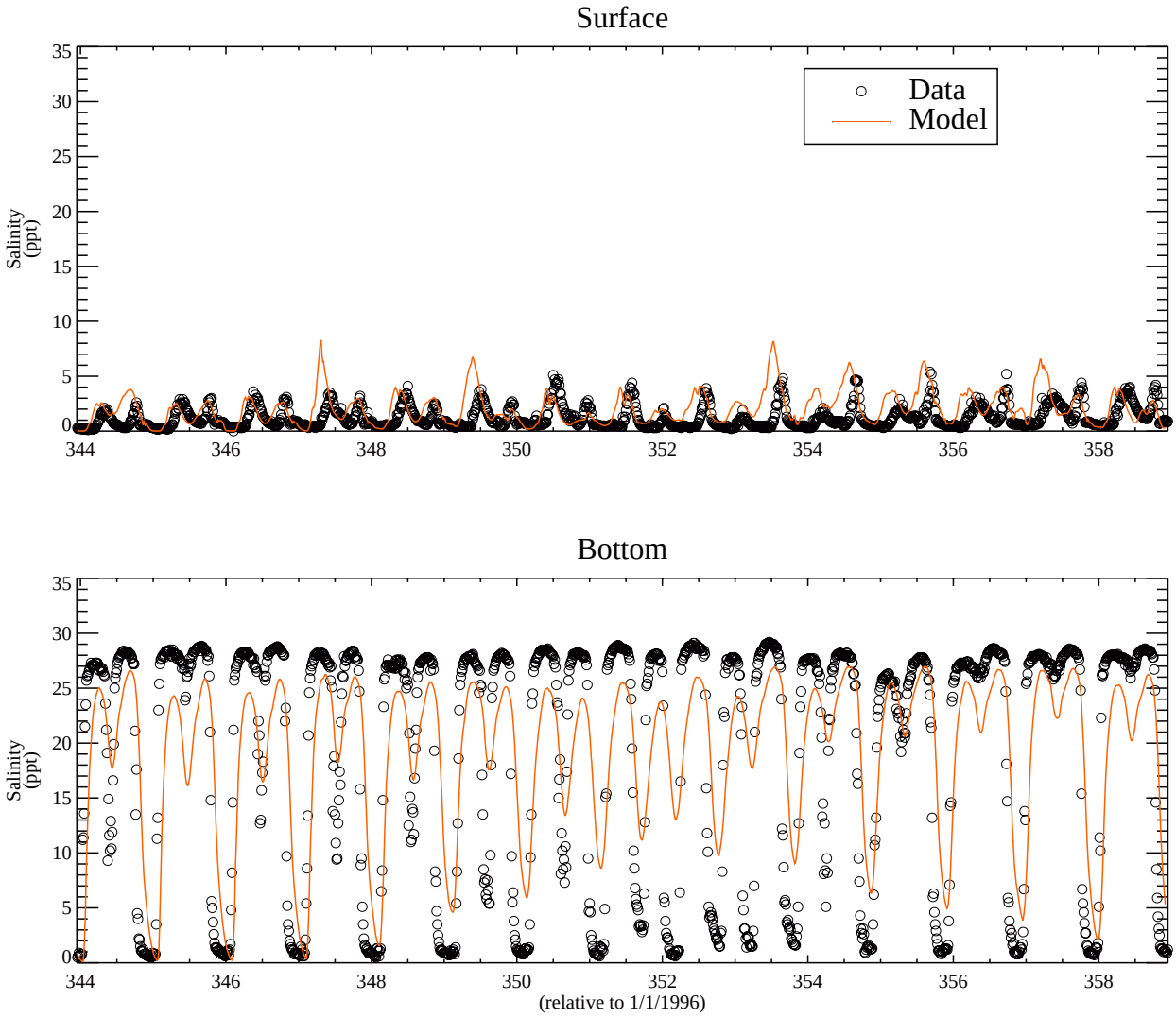

Figure B-46. Comparison of predicted and observed salinity at Duwamish Yacht Club station for Julian day 344 to 359, 1996.

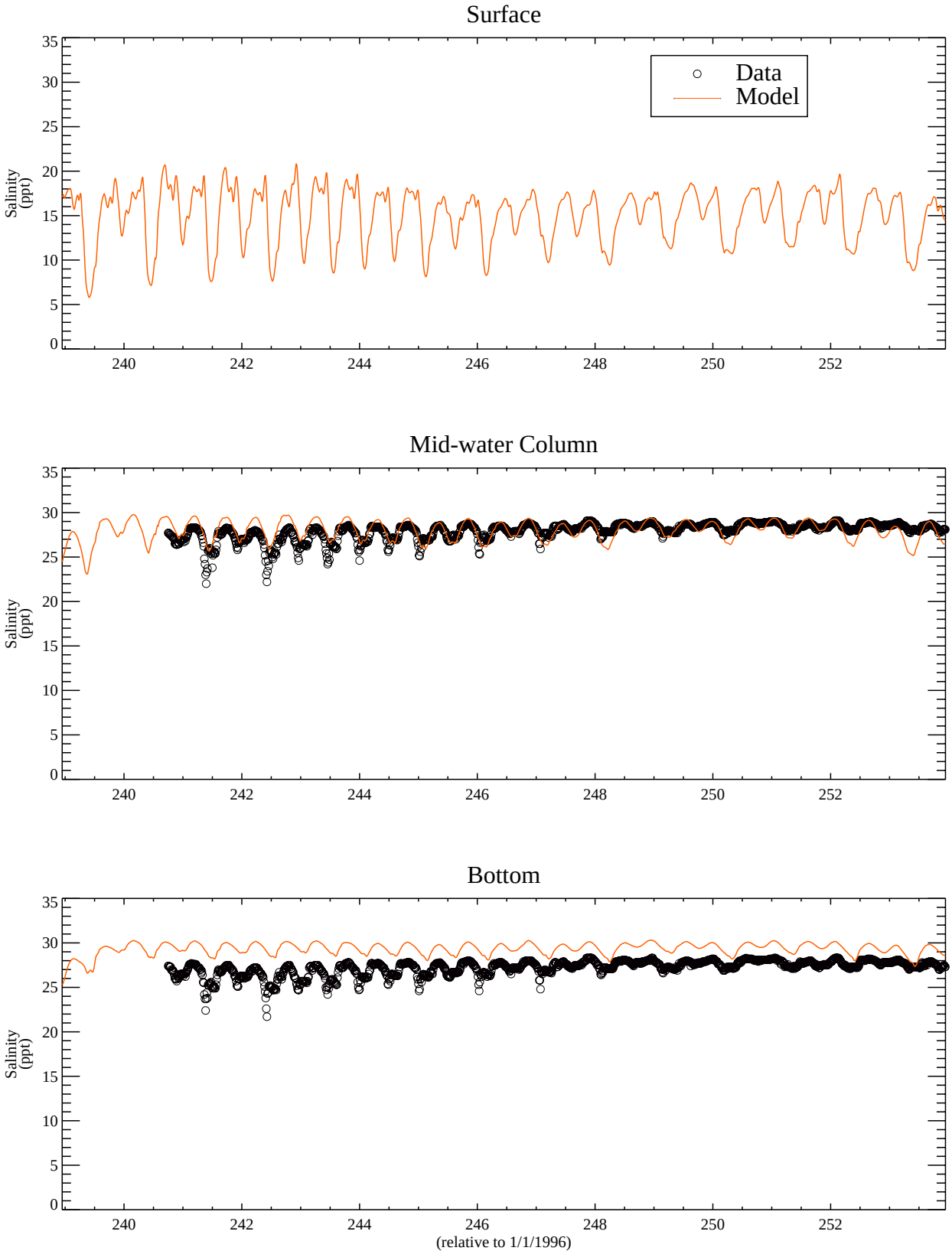

Figure B-47. Comparison of predicted and observed salinity at 16th Avenue Bridge station for Julian day 239 to 254, 1996.

lz - \\Li\D_DRIVE\WINldw\Analysis\Model_Outputs\Plot_Salinity_Calib\plot_salinity_calib_k_rpt.pro
Fri Oct 14 18:34:37 2005

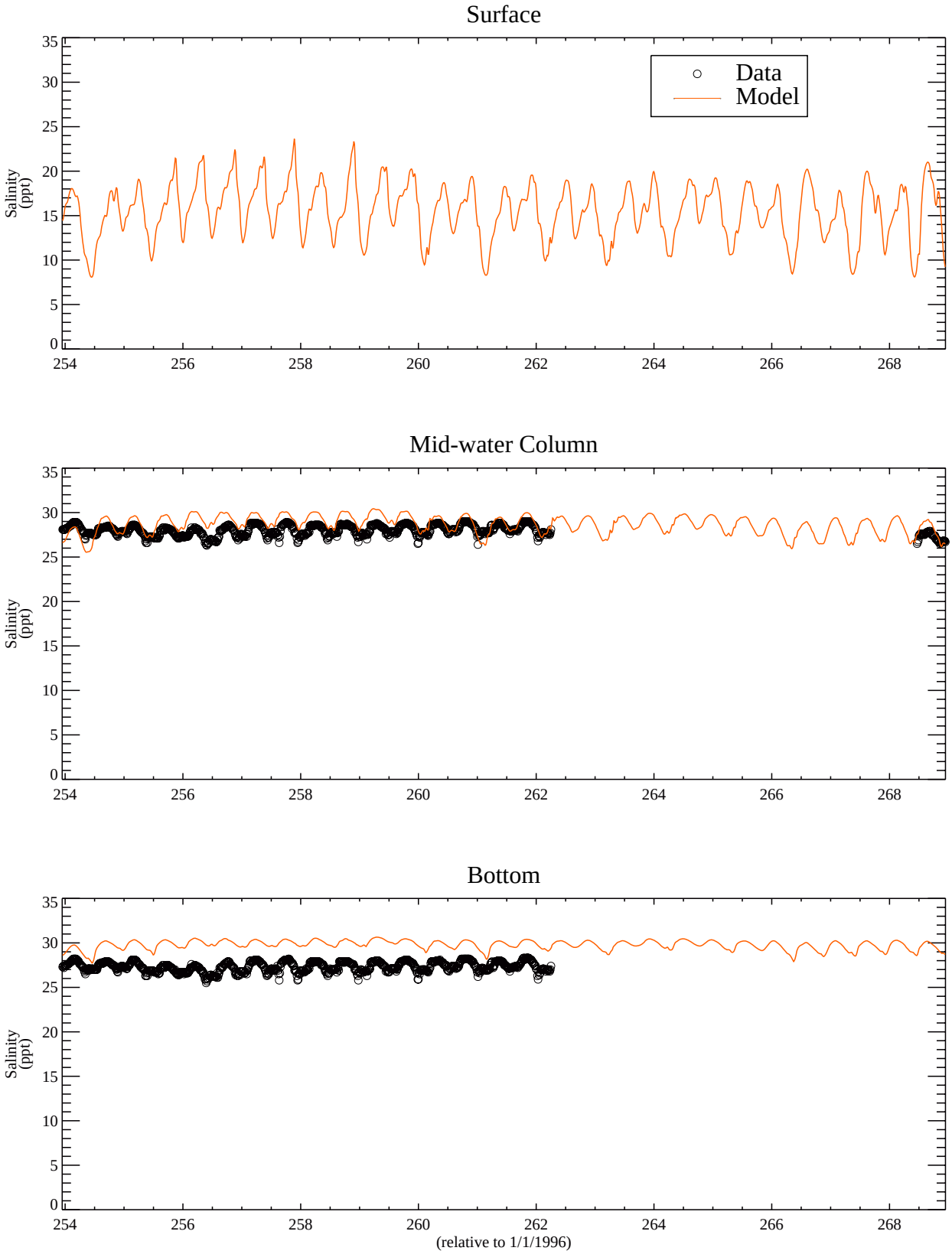

Figure B-48. Comparison of predicted and observed salinity at 16th Avenue Bridge station for Julian day 254 to 269, 1996.

lz - \\Li\D_DRIVE\WINldw\Analysis\Model_Outputs\Plot_Salinity_Calib\plot_salinity_calib_k_rpt.pro
Fri Oct 14 18:36:19 2005

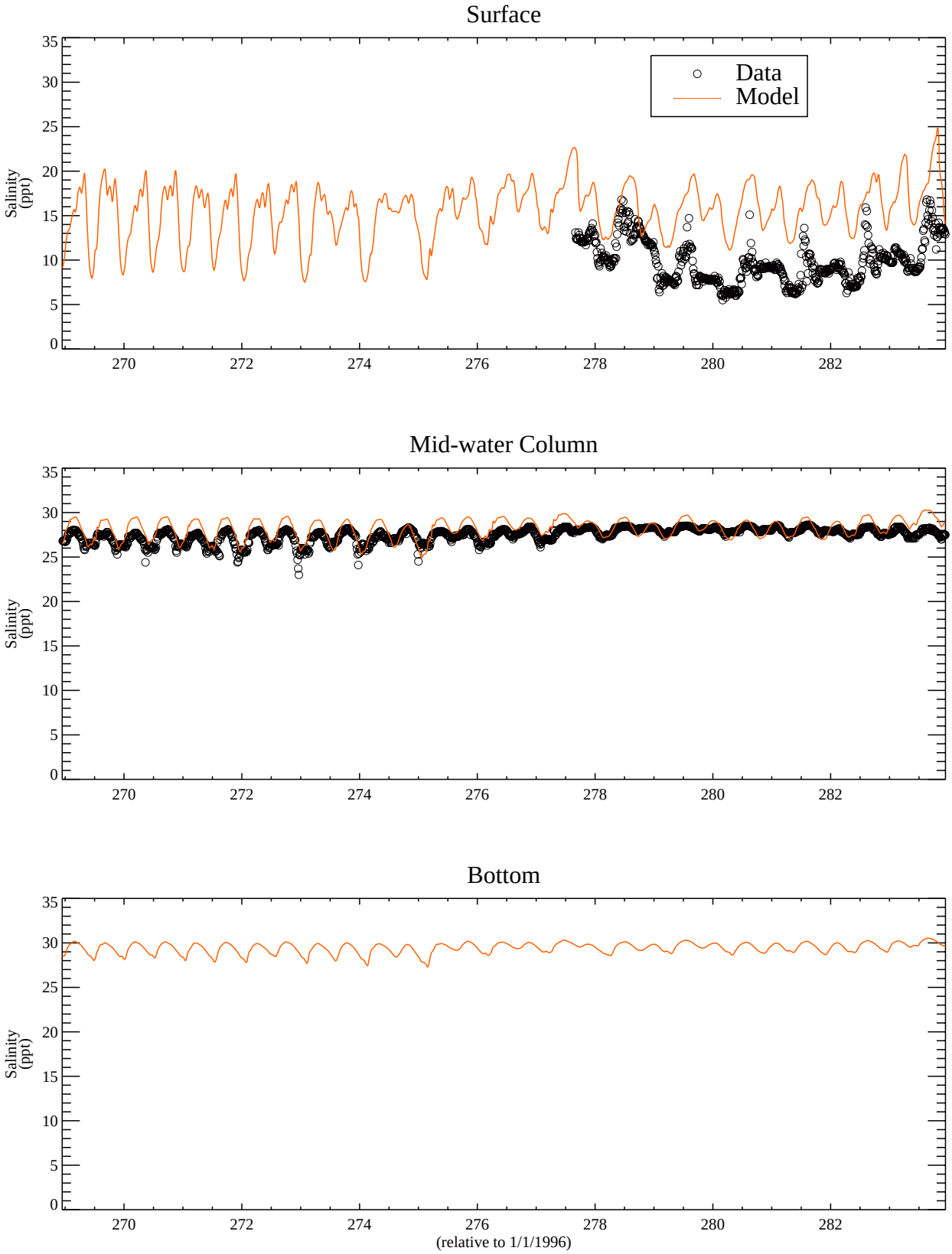

Figure B-49. Comparison of predicted and observed salinity at 16th Avenue Bridge station for Julian day 269 to 284, 1996.

lz - \\Li\D_DRIVE\WINldw\Analysis\Model_Outputs\Plot_Salinity_Calib\plot_salinity_calib_k_rpt.pro
Fri Oct 14 18:38:01 2005

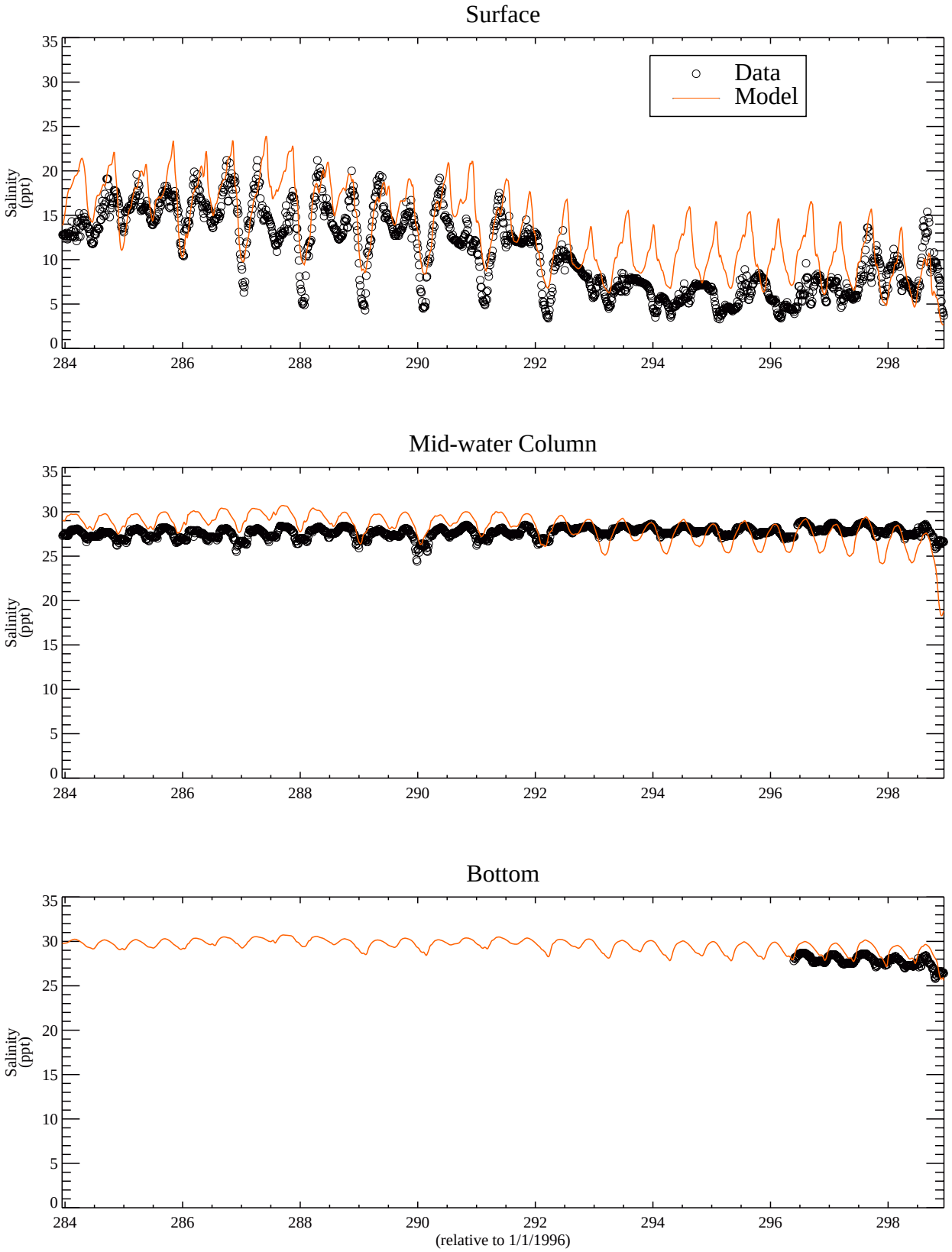

Figure B-50. Comparison of predicted and observed salinity at 16th Avenue Bridge station for Julian day 284 to 299, 1996.

lz - \\Li\D_DRIVE\WINldw\Analysis\Model_Outputs\Plot_Salinity_Calib\plot_salinity_calib_k_rpt.pro
Fri Oct 14 18:54:43 2005

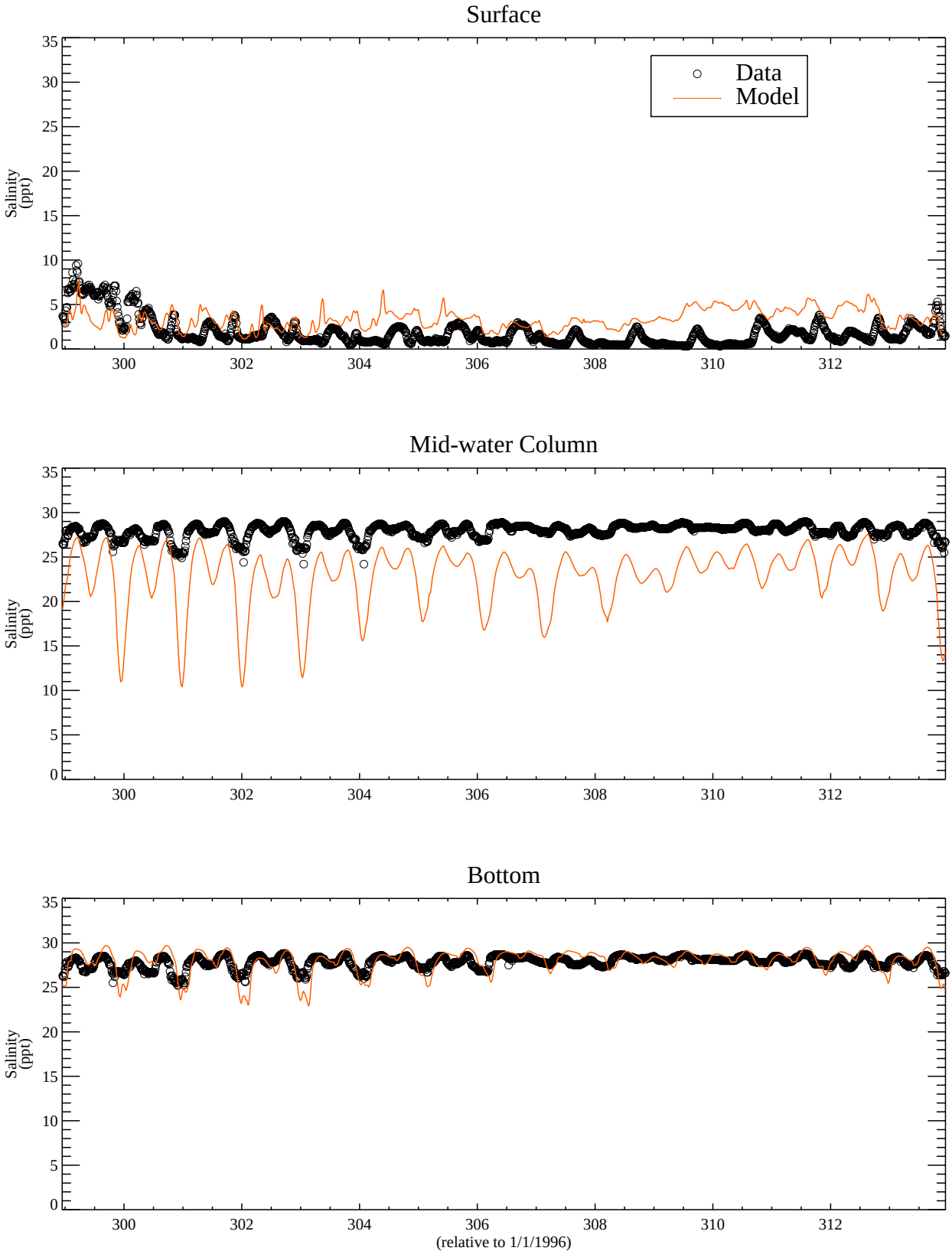

Figure B-51. Comparison of predicted and observed salinity at 16th Avenue Bridge station for Julian day 299 to 314, 1996.

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Fri Oct 14 18:41:26 2005

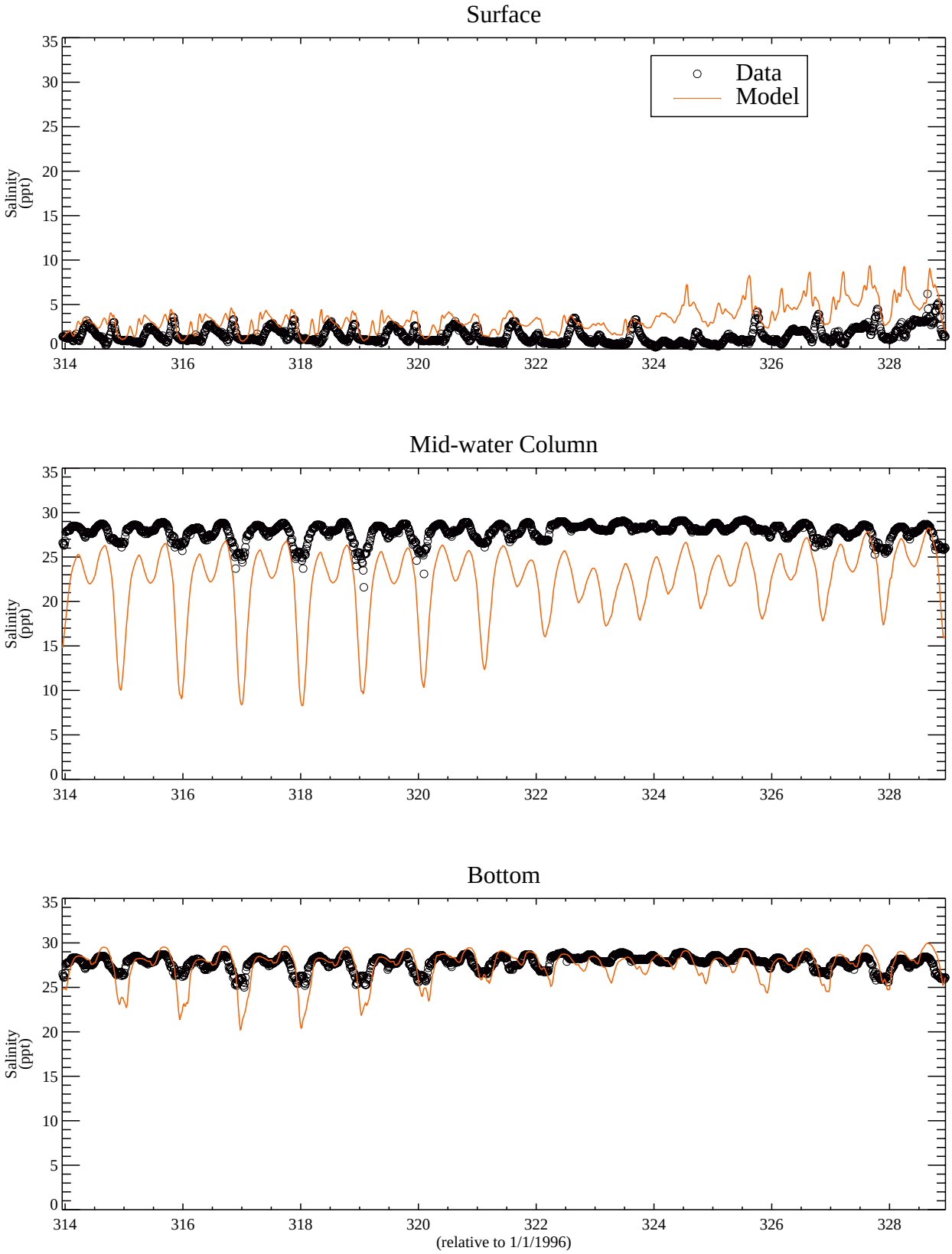

Figure B-52. Comparison of predicted and observed salinity at 16th Avenue Bridge station for Julian day 314 to 329, 1996.

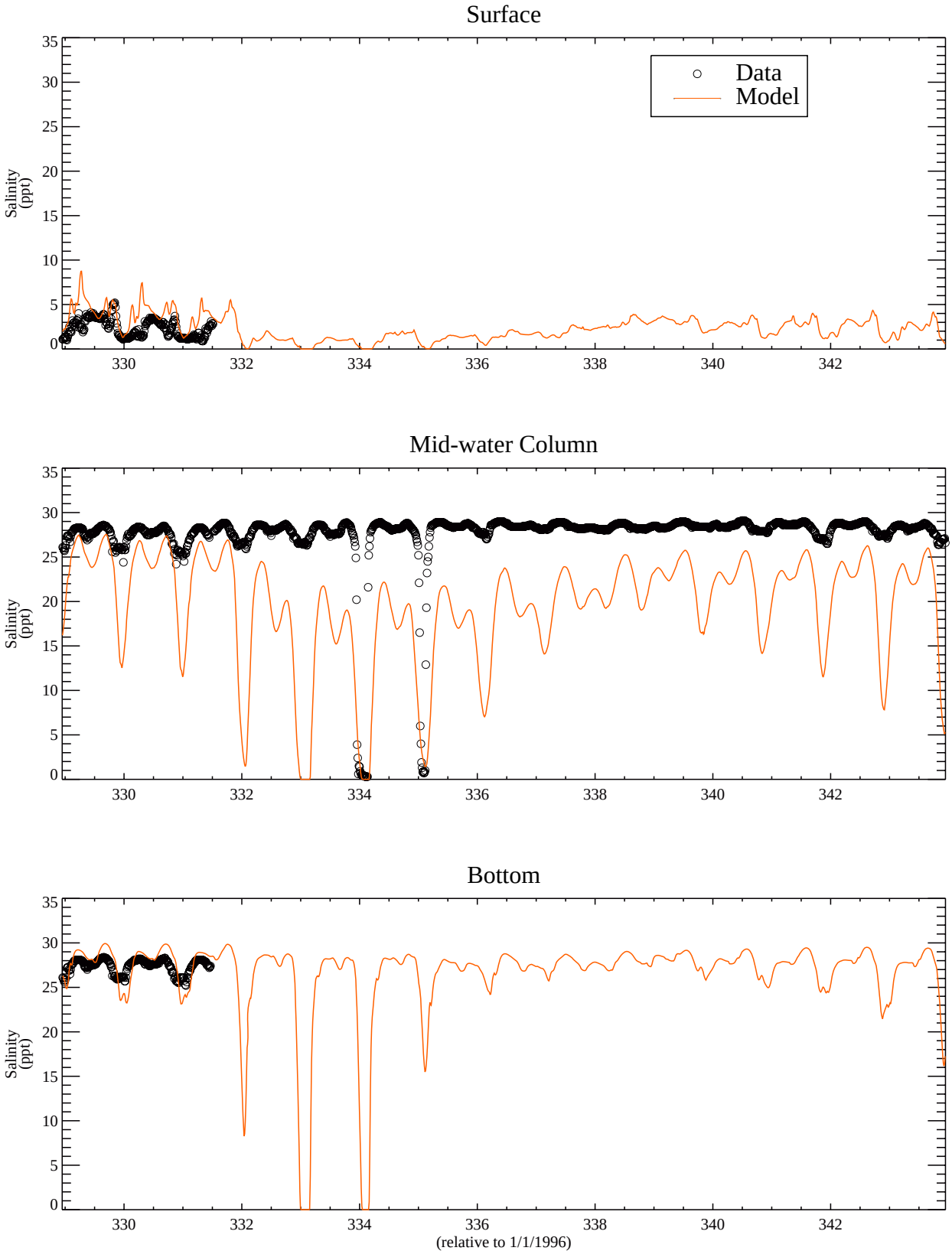

Figure B-53. Comparison of predicted and observed salinity at 16th Avenue Bridge station for Julian day 329 to 344, 1996.

lz - \\Li\D_DRIVE\WINldw\Analysis\Model_Outputs\Plot_Salinity_Calib\plot_salinity_calib_k_rpt.pro
Fri Oct 14 18:45:20 2005

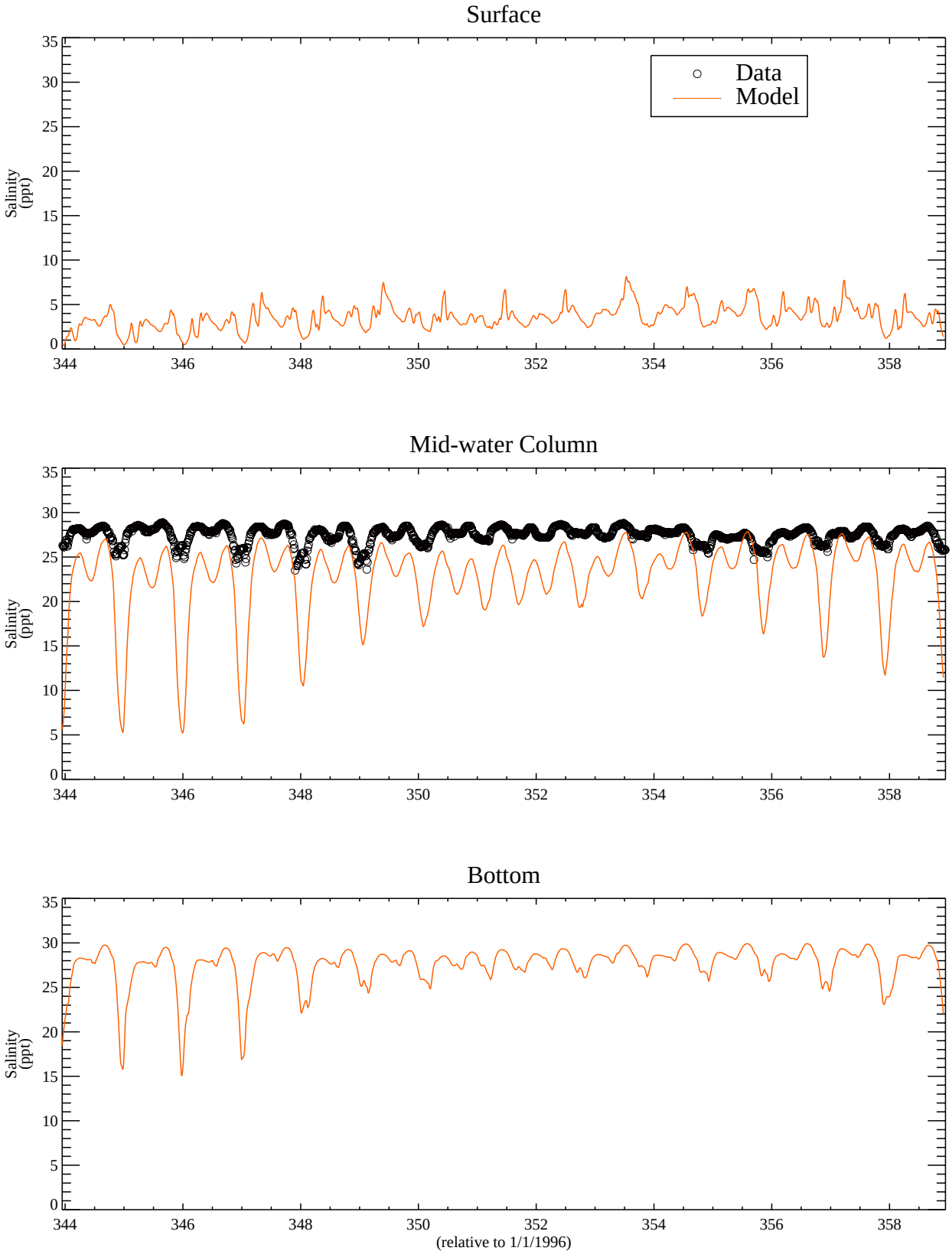

Figure B-54. Comparison of predicted and observed salinity at 16th Avenue Bridge station for Julian day 344 to 359, 1996.

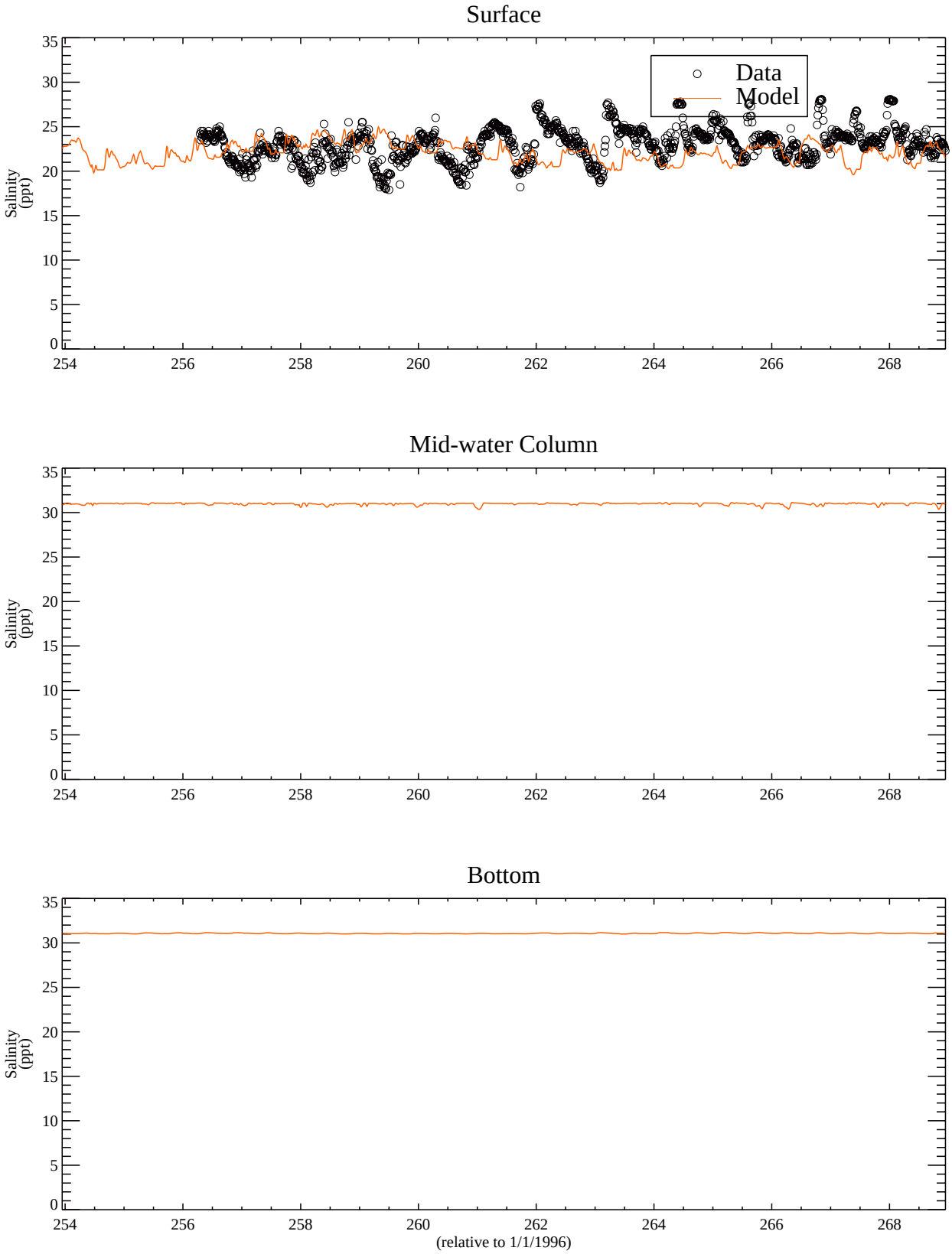

Figure B-55. Comparison of predicted and observed salinity at Spokane Avenue Bridge station for Julian day 254 to 269, 1996.

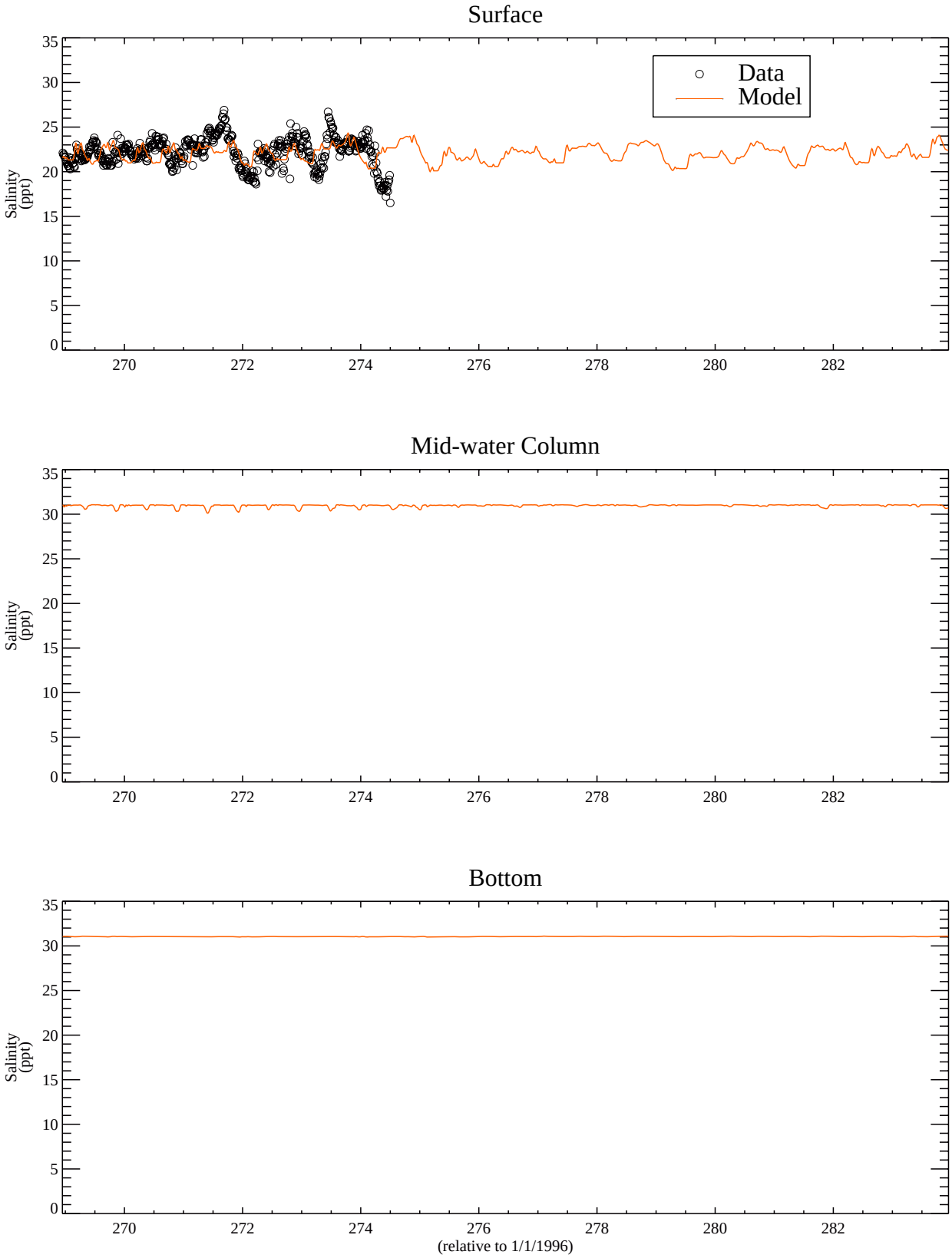

Figure B-56. Comparison of predicted and observed salinity at Spokane Avenue Bridge station for Julian day 269 to 284, 1996.

lz - \\Li\D_DRIVE\WINldw\Analysis\Model_Outputs\Plot_Salinity_Calib\plot_salinity_calib_k_rpt.pro
Fri Oct 14 18:38:00 2005

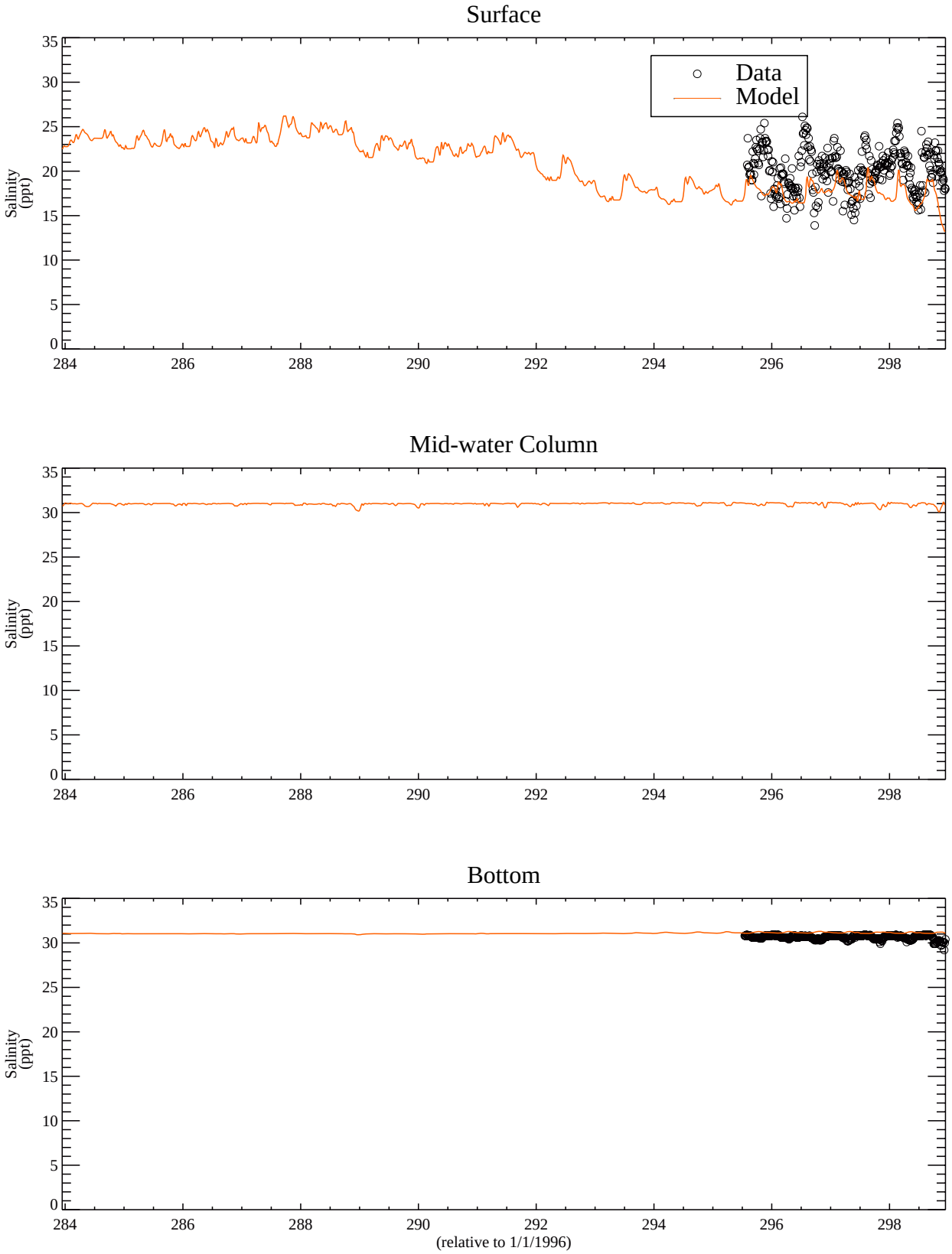

Figure B-57. Comparison of predicted and observed salinity at Spokane Avenue Bridge station for Julian day 284 to 299, 1996.

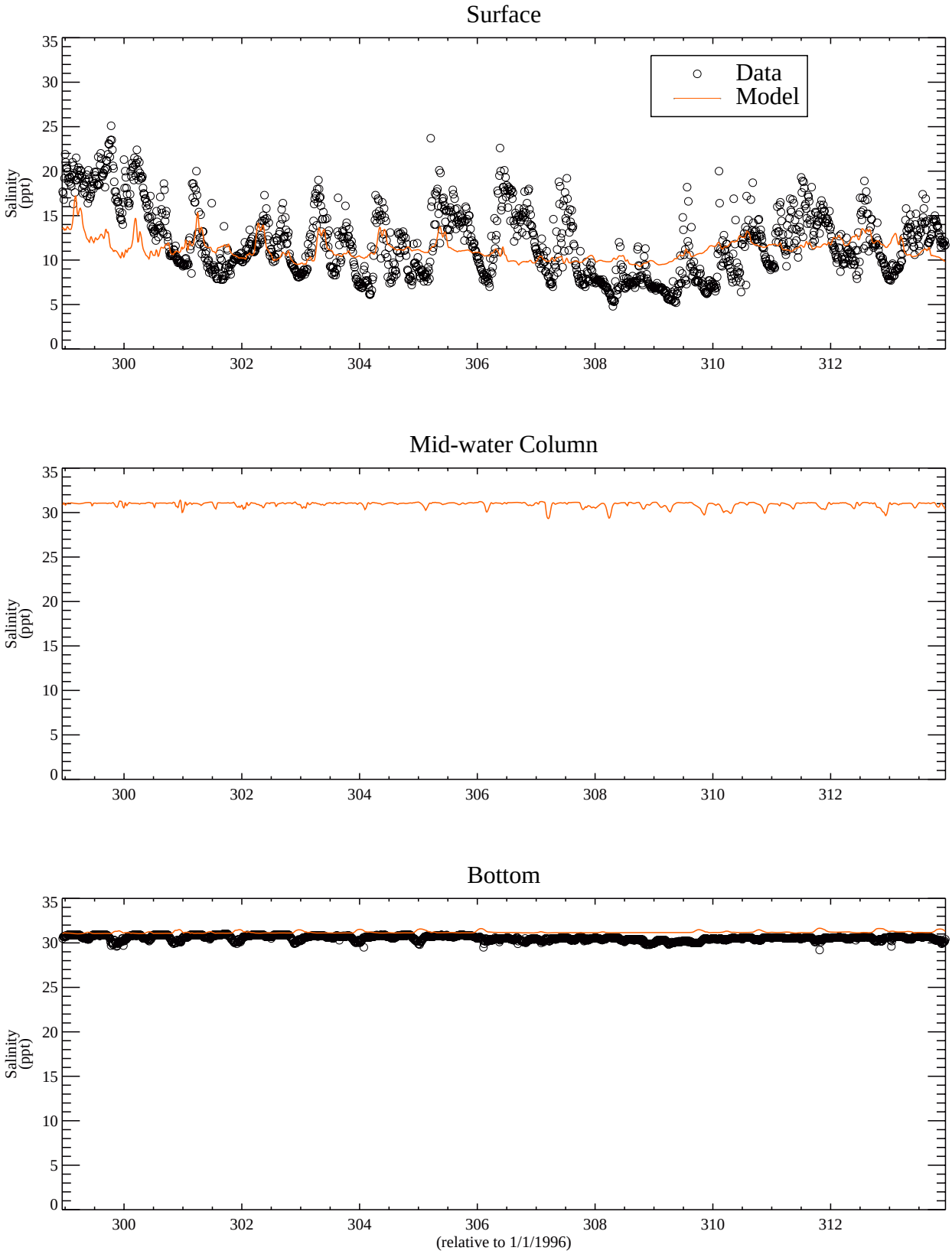

Figure B-58. Comparison of predicted and observed salinity at Spokane Avenue Bridge station for Julian day 299 to 314, 1996.

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Fri Oct 14 18:41:25 2005

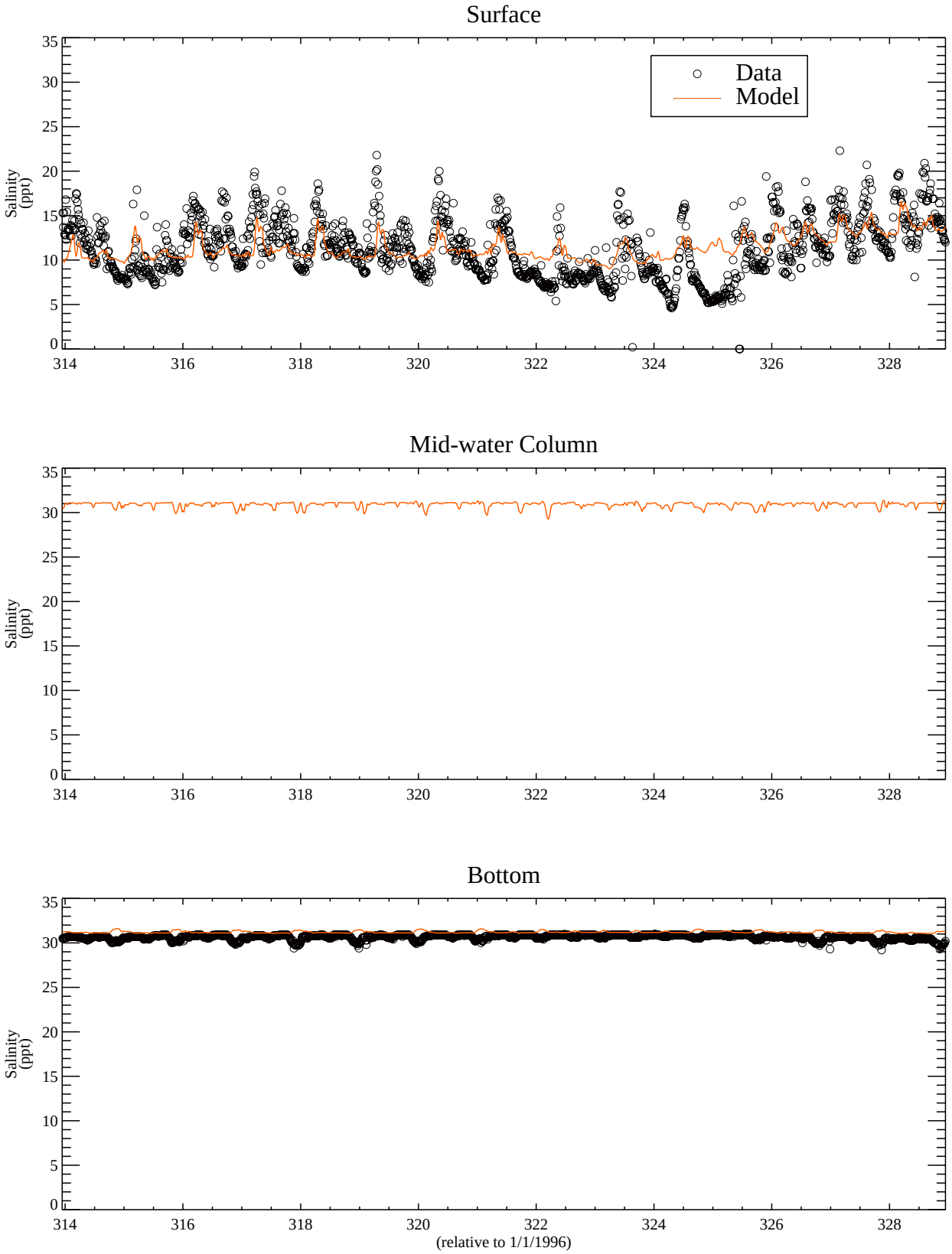

Figure B-59. Comparison of predicted and observed salinity at Spokane Avenue Bridge station for Julian day 314 to 329, 1996.

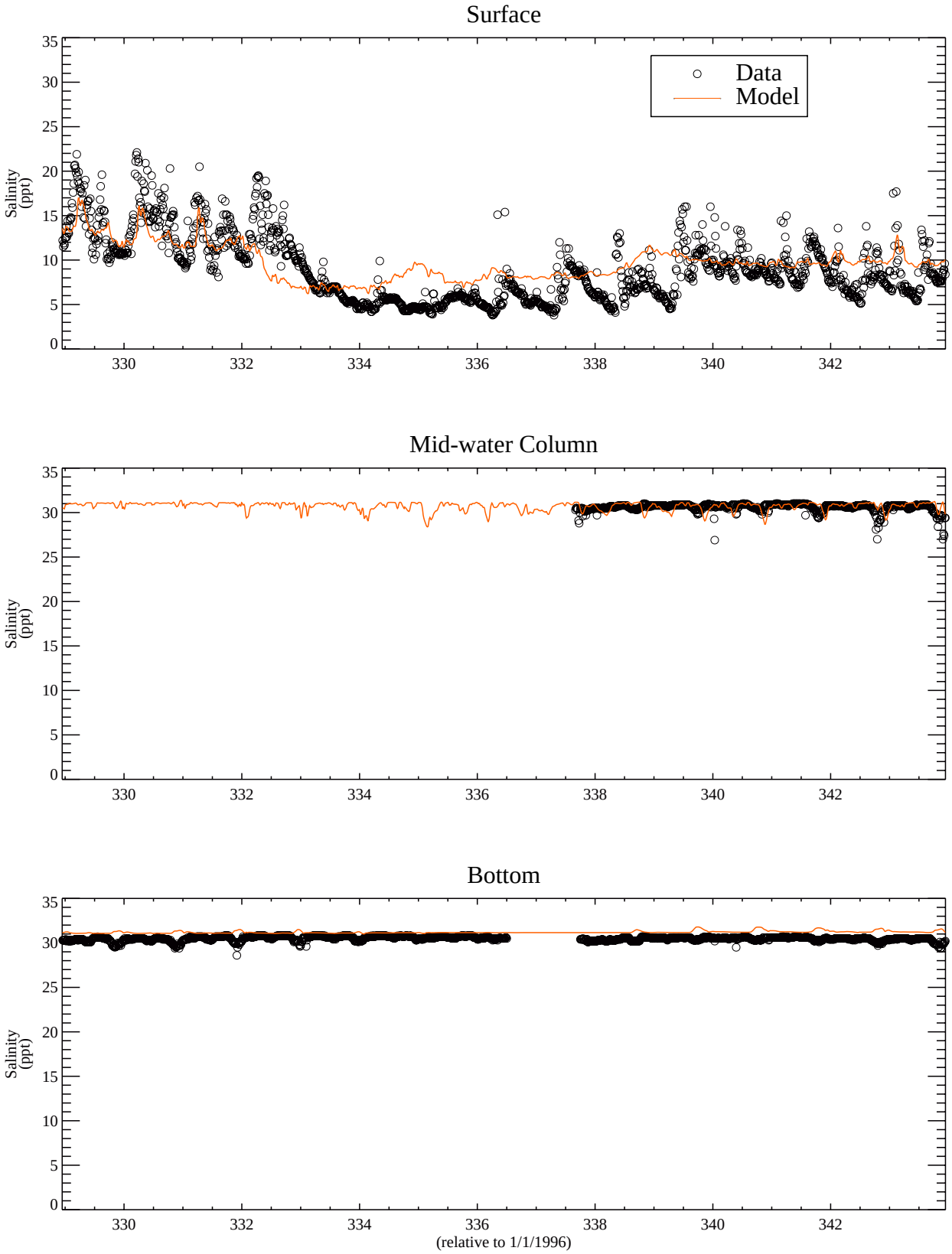

Figure B-60. Comparison of predicted and observed salinity at Spokane Avenue Bridge station for Julian day 329 to 344, 1996.

lz - \\Li\D_DRIVE\WINldw\Analysis\Model_Outputs\Plot_Salinity_Calib\plot_salinity_calib_k_rpt.pro
Fri Oct 14 18:45:19 2005

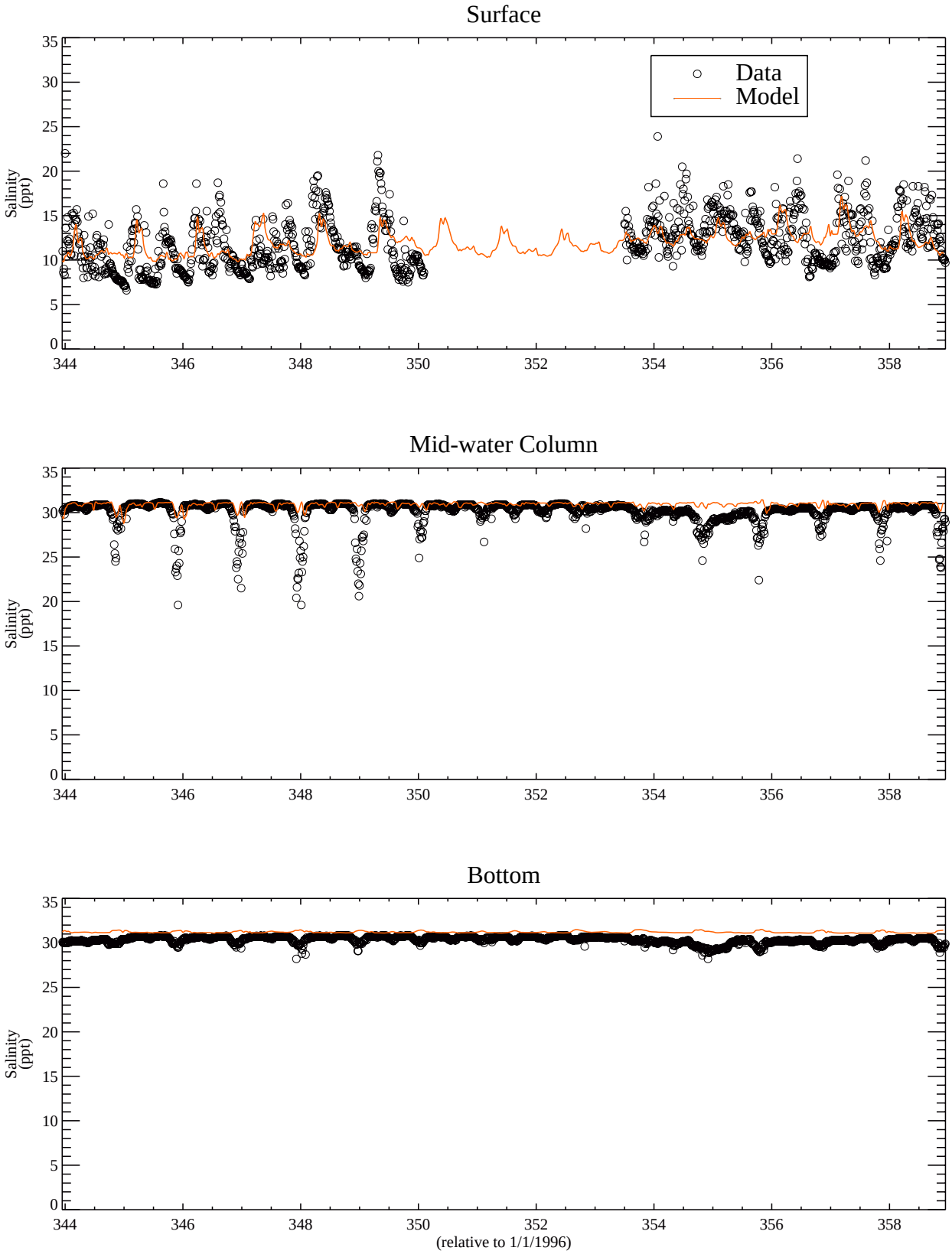

Figure B-61. Comparison of predicted and observed salinity at Spokane Avenue Bridge station for Julian day 344 to 359, 1996.

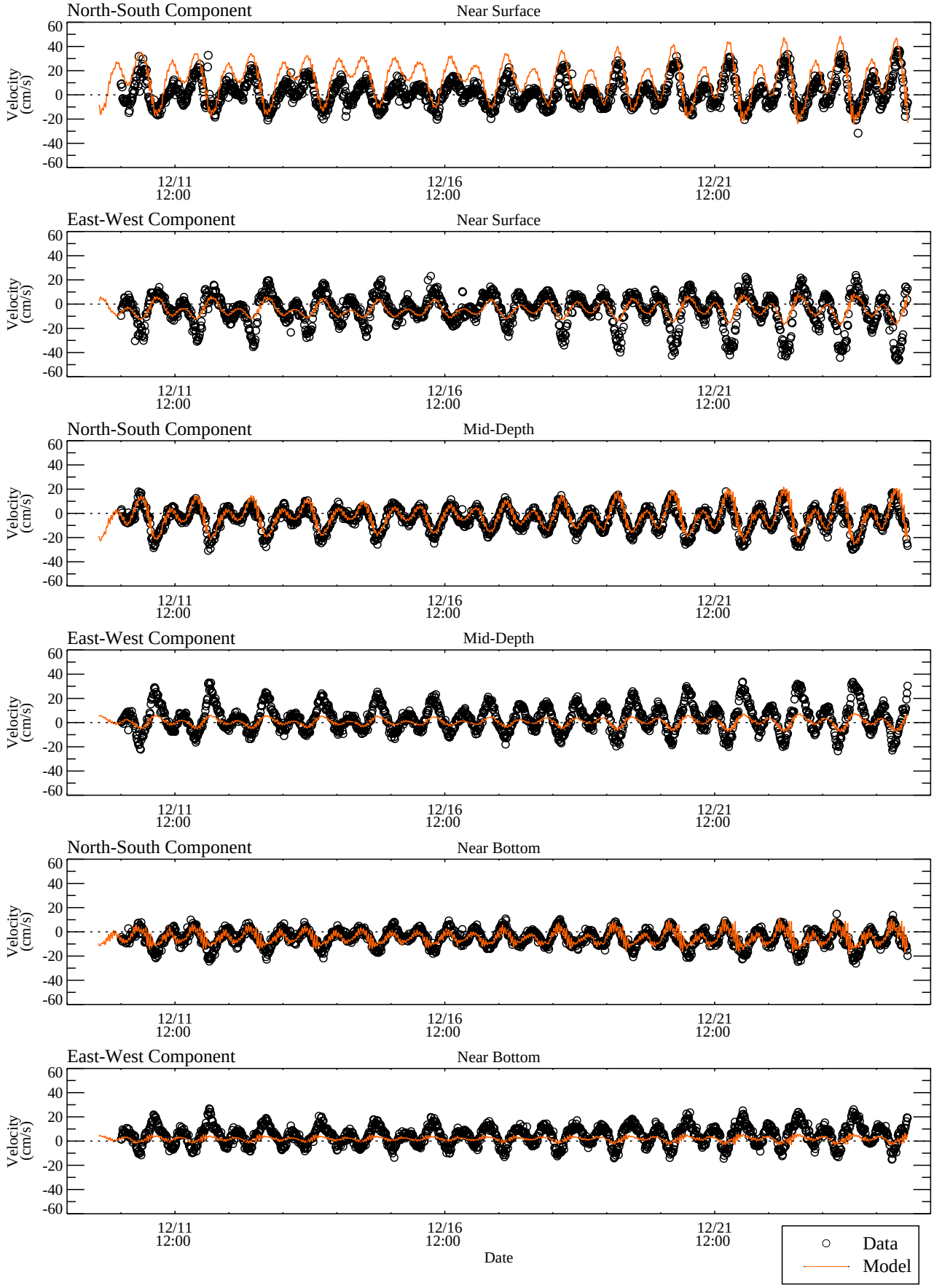

Figure B-62. Comparison of predicted and observed current velocity at BRD1 for December 10 to December 25, 2003.

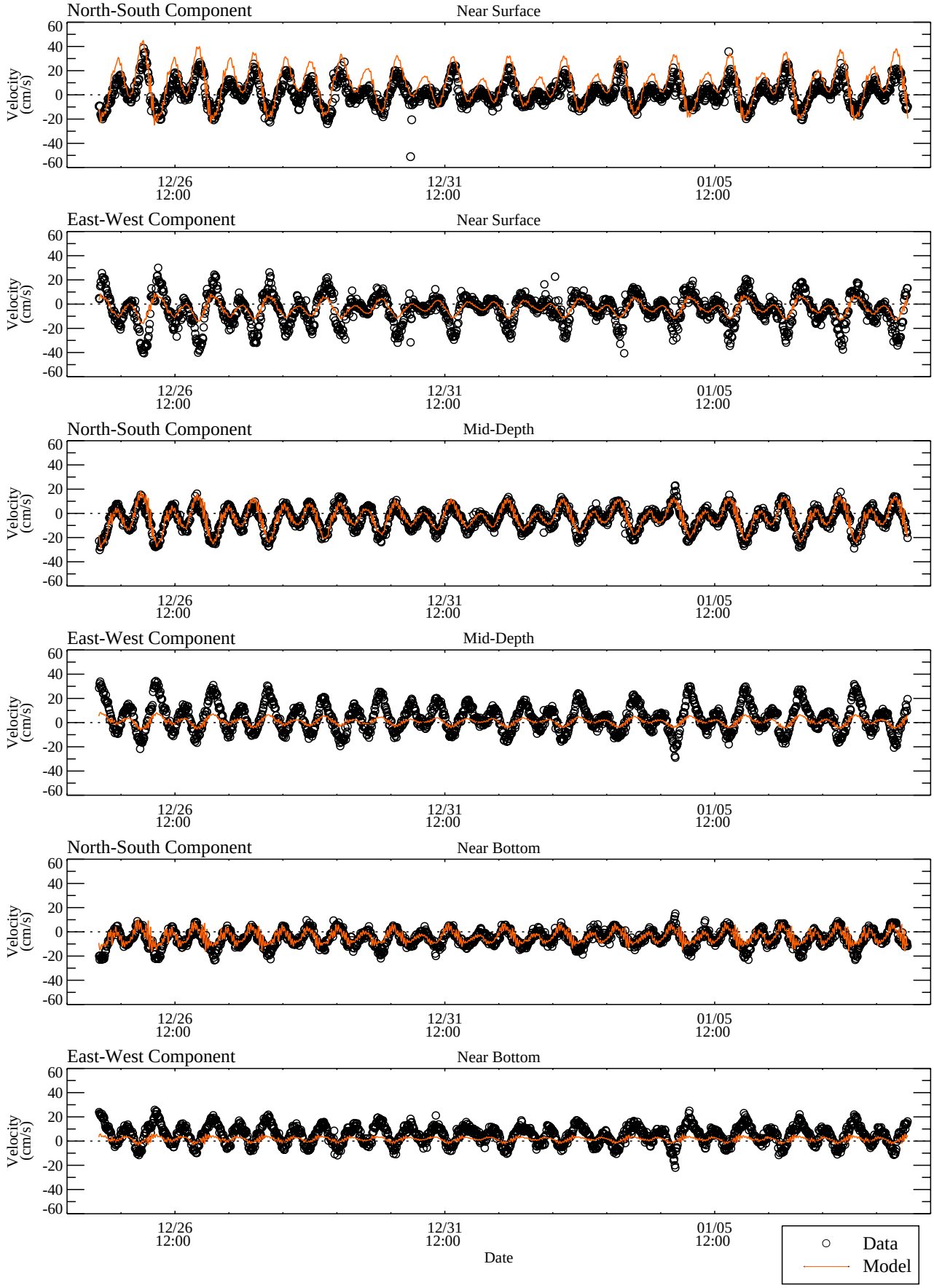

Figure B-63. Comparison of predicted and observed current velocity at BRD1 for December 24, 2003 to January 9, 2004.

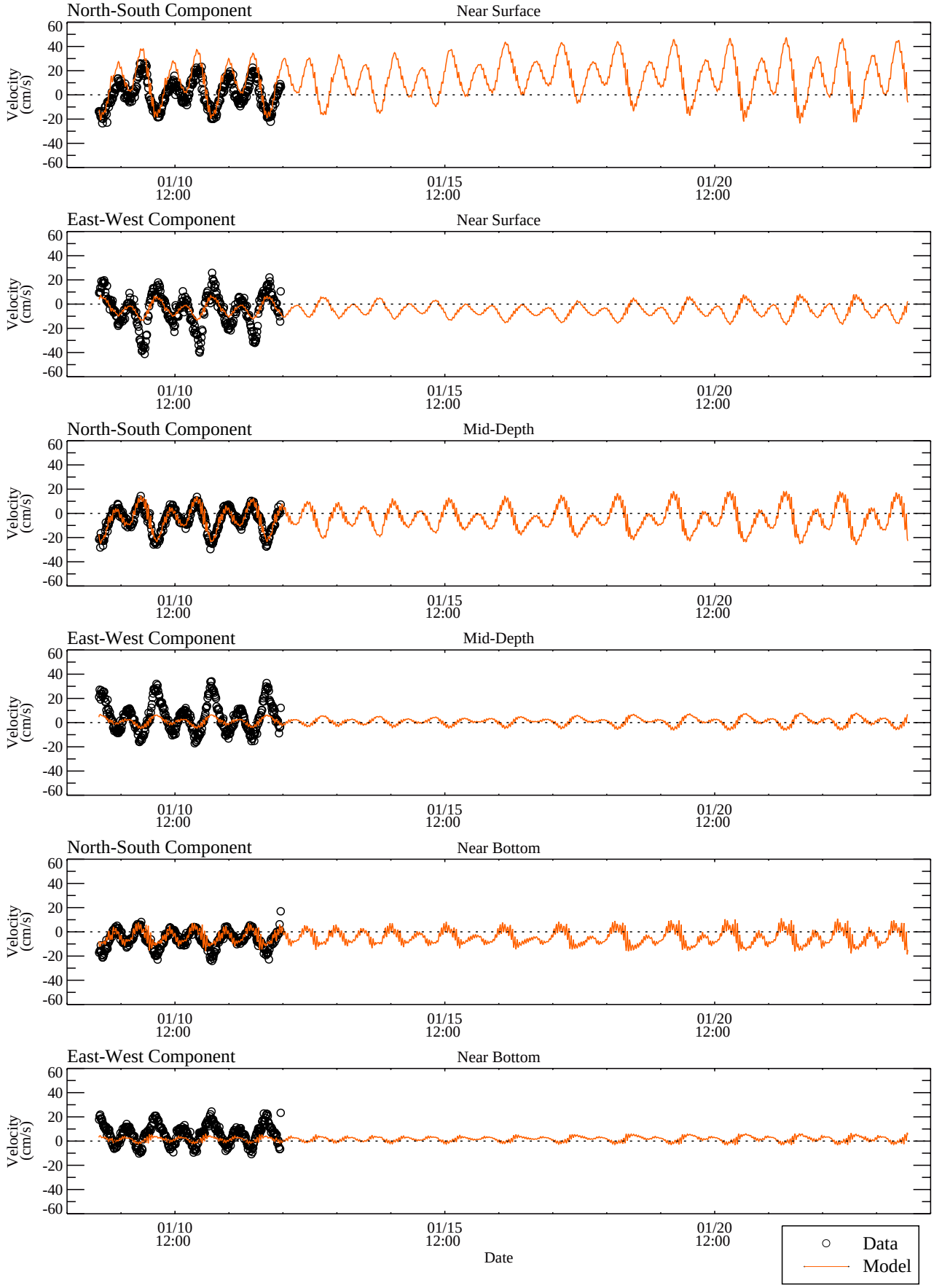

Figure B-64. Comparison of predicted and observed current velocity at BRD1 for January 8 to January 12, 2004.

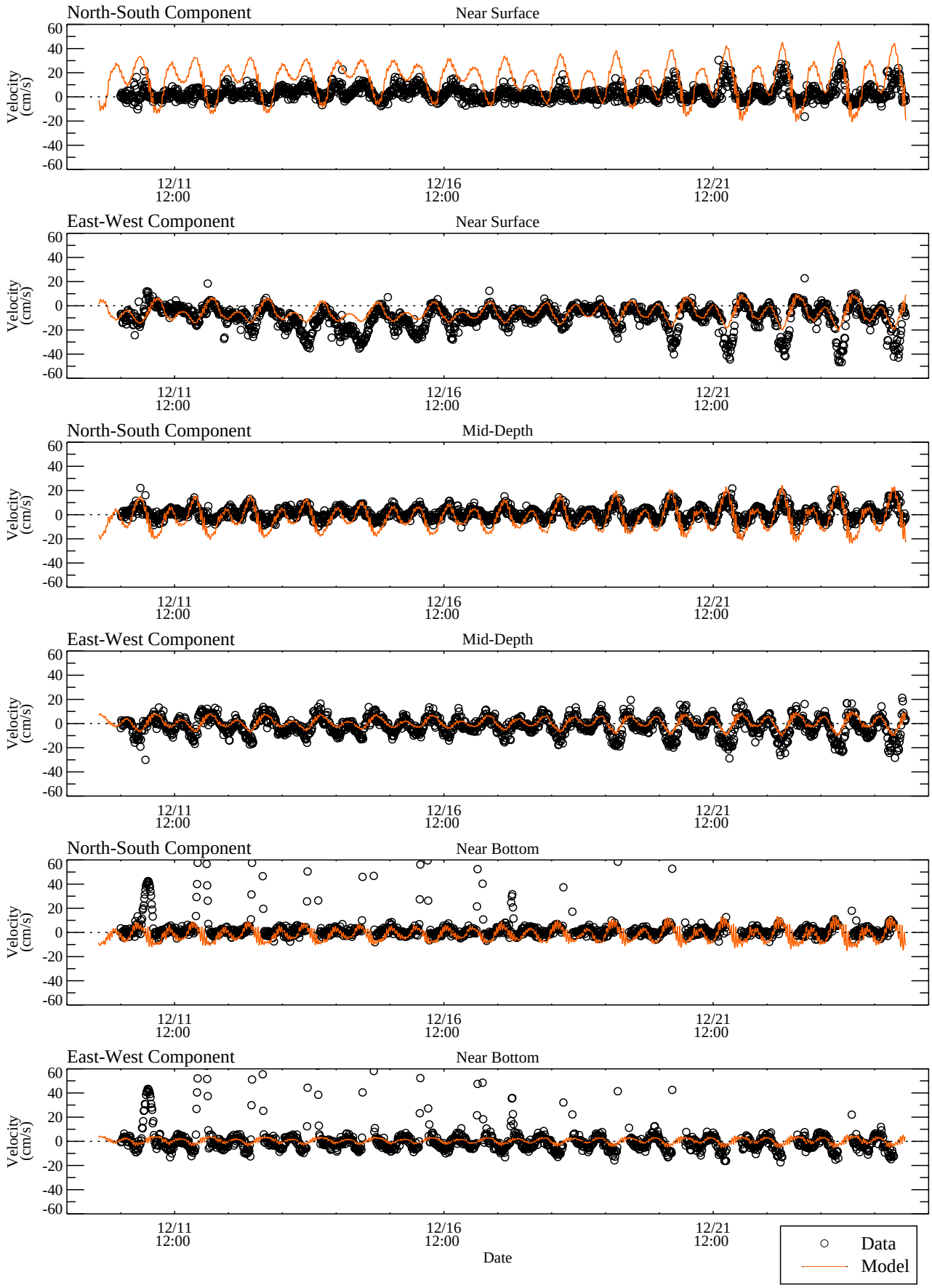

Figure B-65. Comparison of predicted and observed current velocity at BRD2 for December 10 to December 25, 2003.

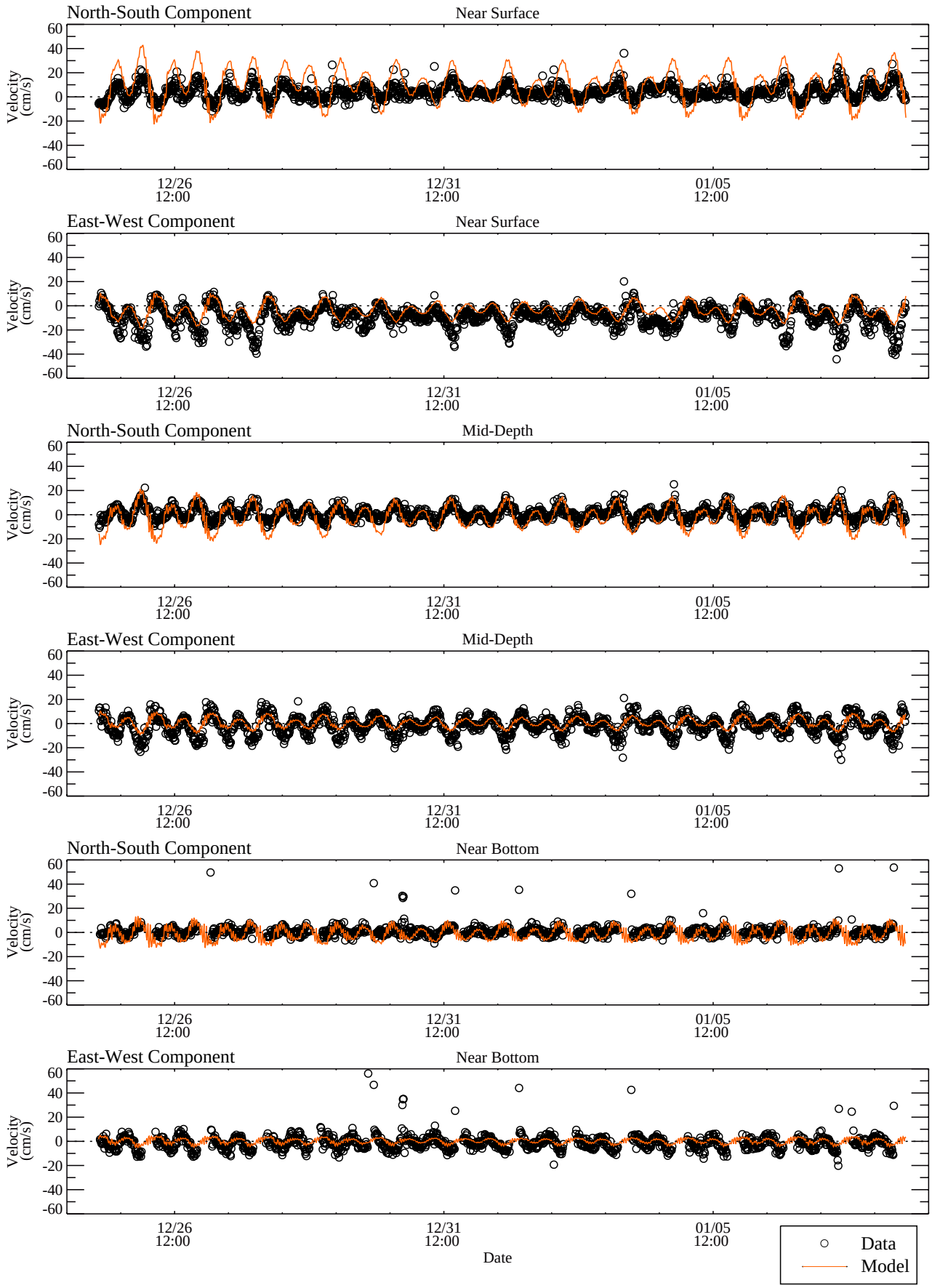

Figure B-66. Comparison of predicted and observed current velocity at BRD2 for December 24, 2003 to January 9, 2004.

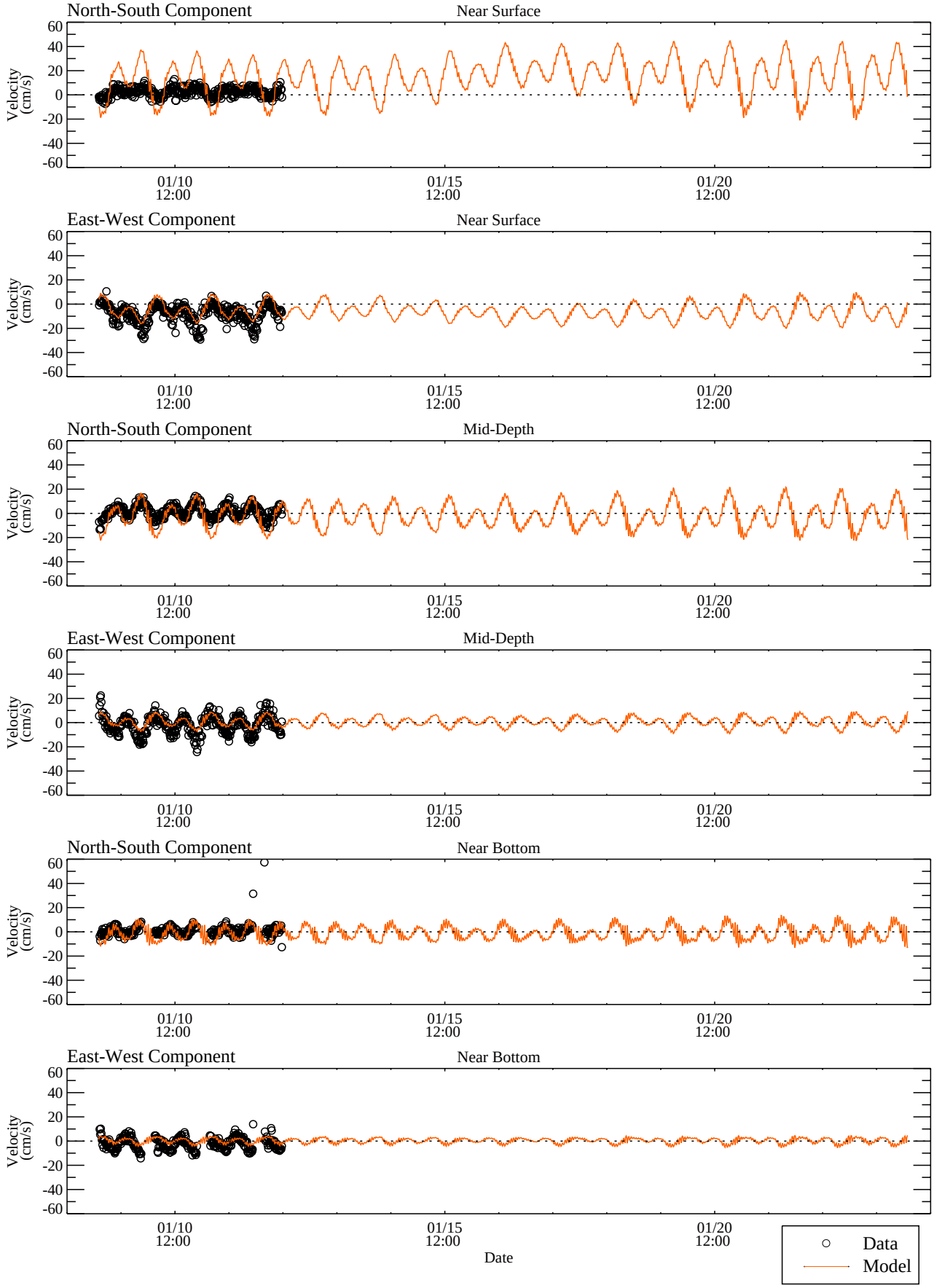

Figure B-67. Comparison of predicted and observed current velocity at BRD2 for January 8 to January 12, 2004.

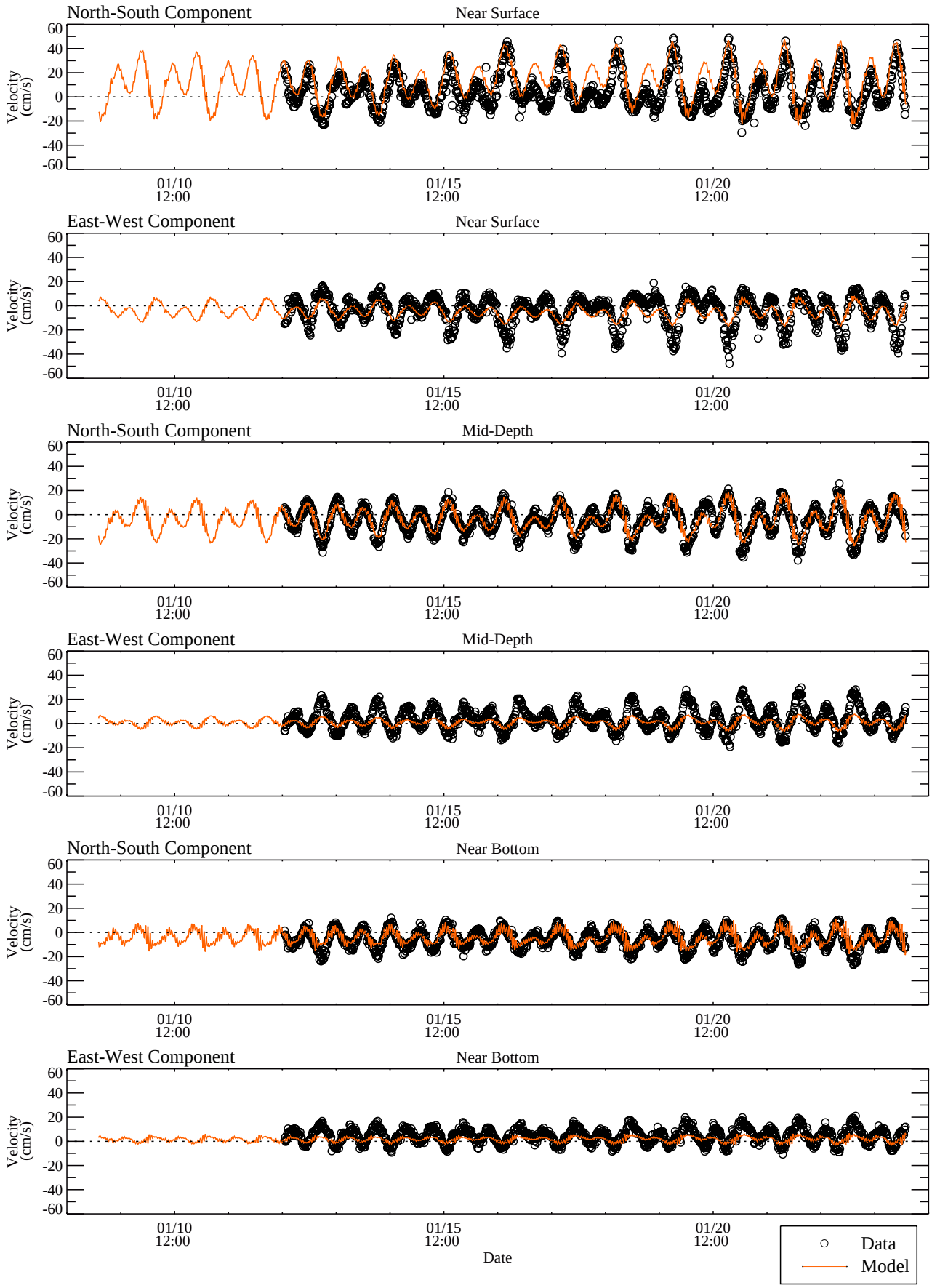

Figure B-68. Comparison of predicted and observed current velocity at BRD3 for January 8 to January 12, 2004.

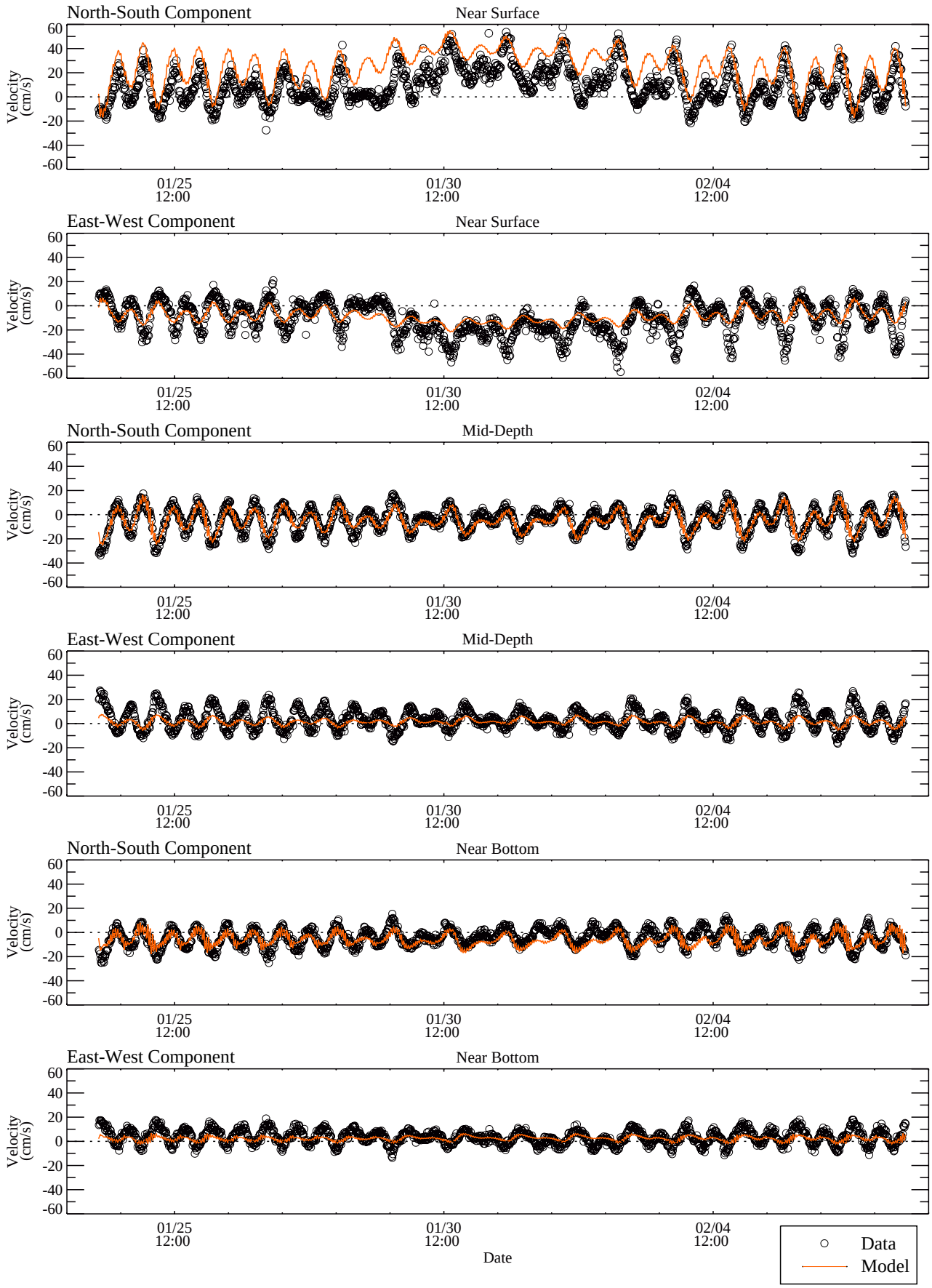

Figure B-69. Comparison of predicted and observed current velocity at BRD3 for January 23 to February 8, 2004.

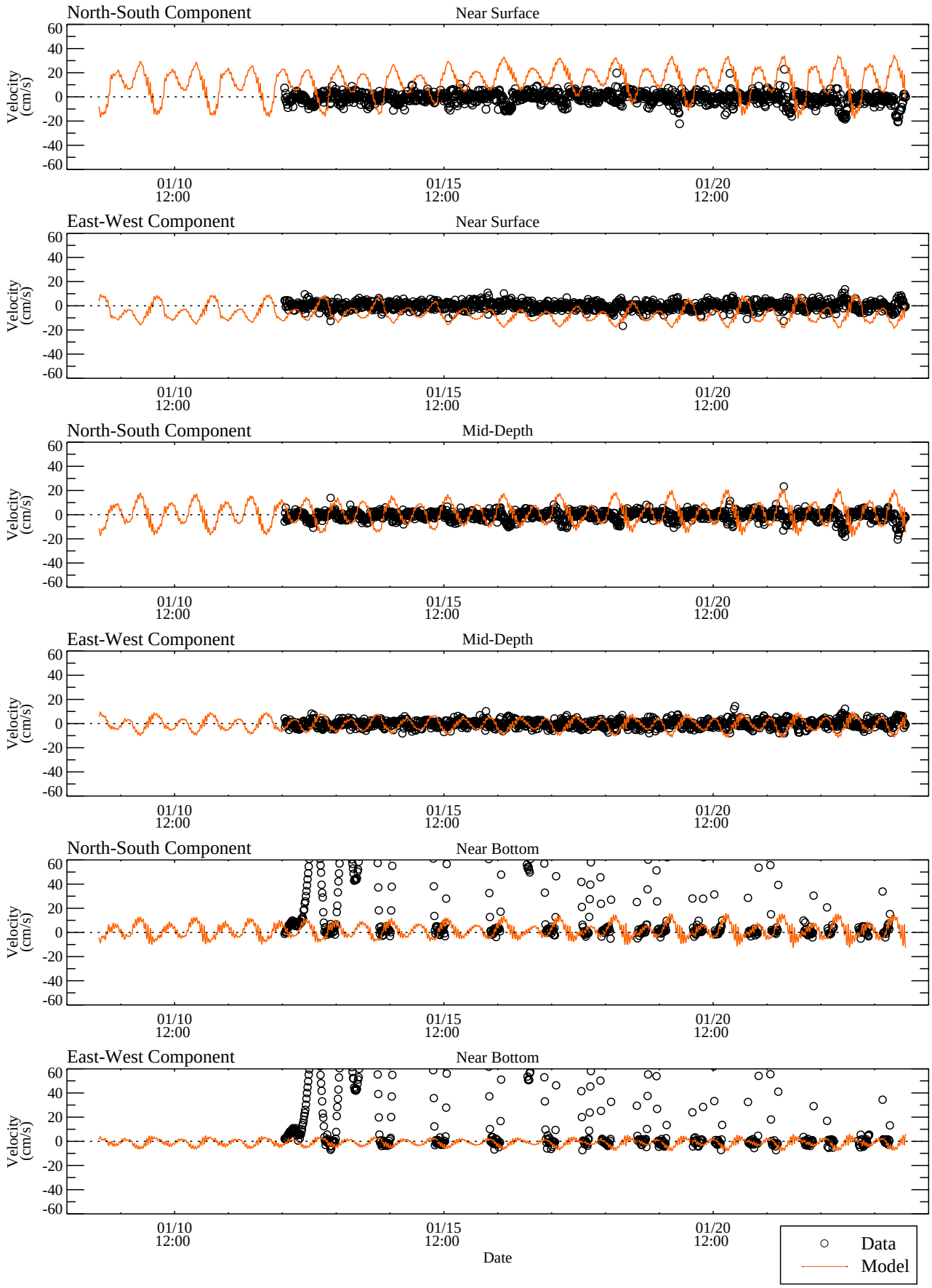

Figure B-70. Comparison of predicted and observed current velocity at BRD4 for January 8 to January 12, 2004.

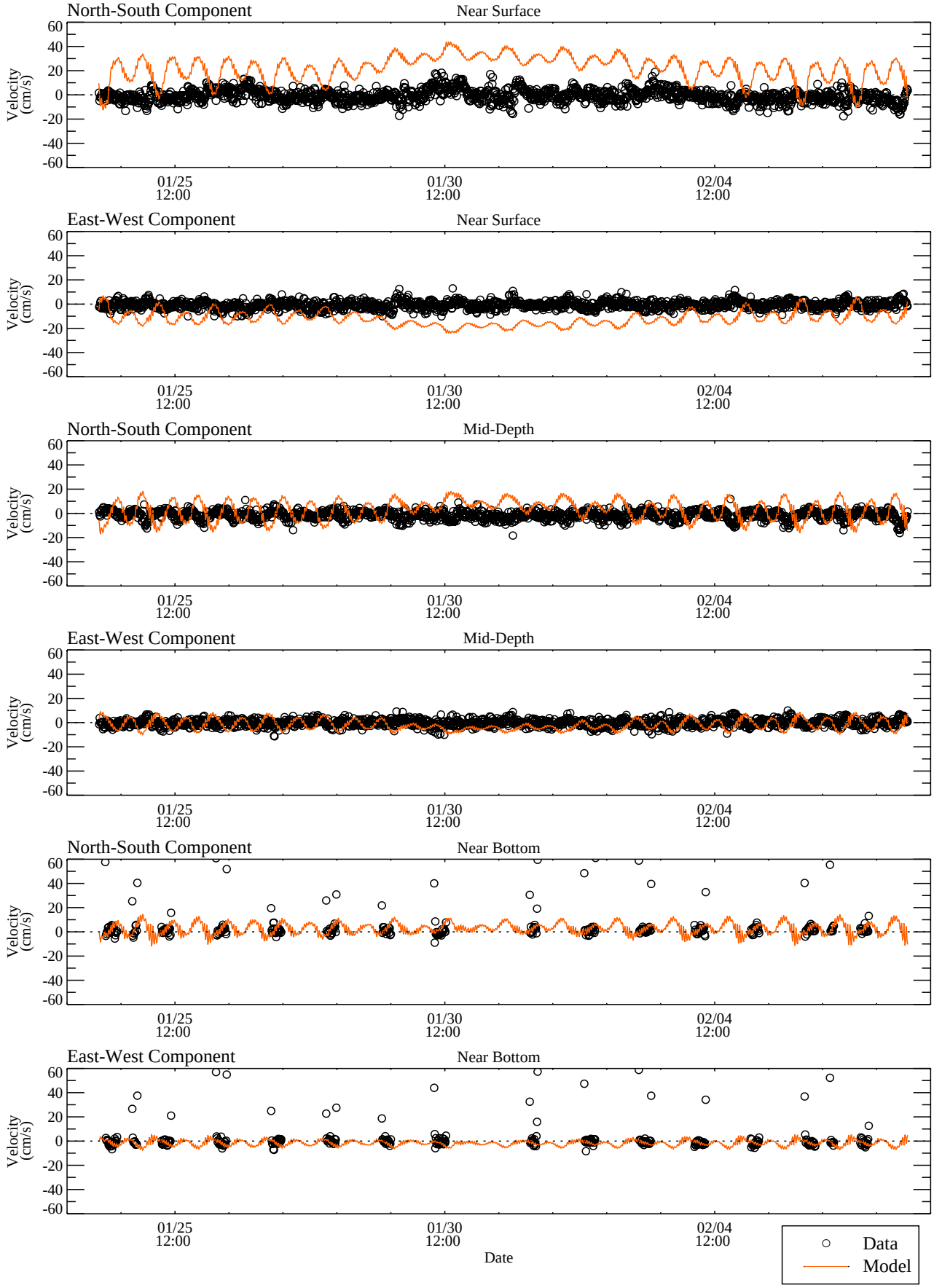

Figure B-71. Comparison of predicted and observed current velocity at BRD4 for January 23 to February 8, 2004.

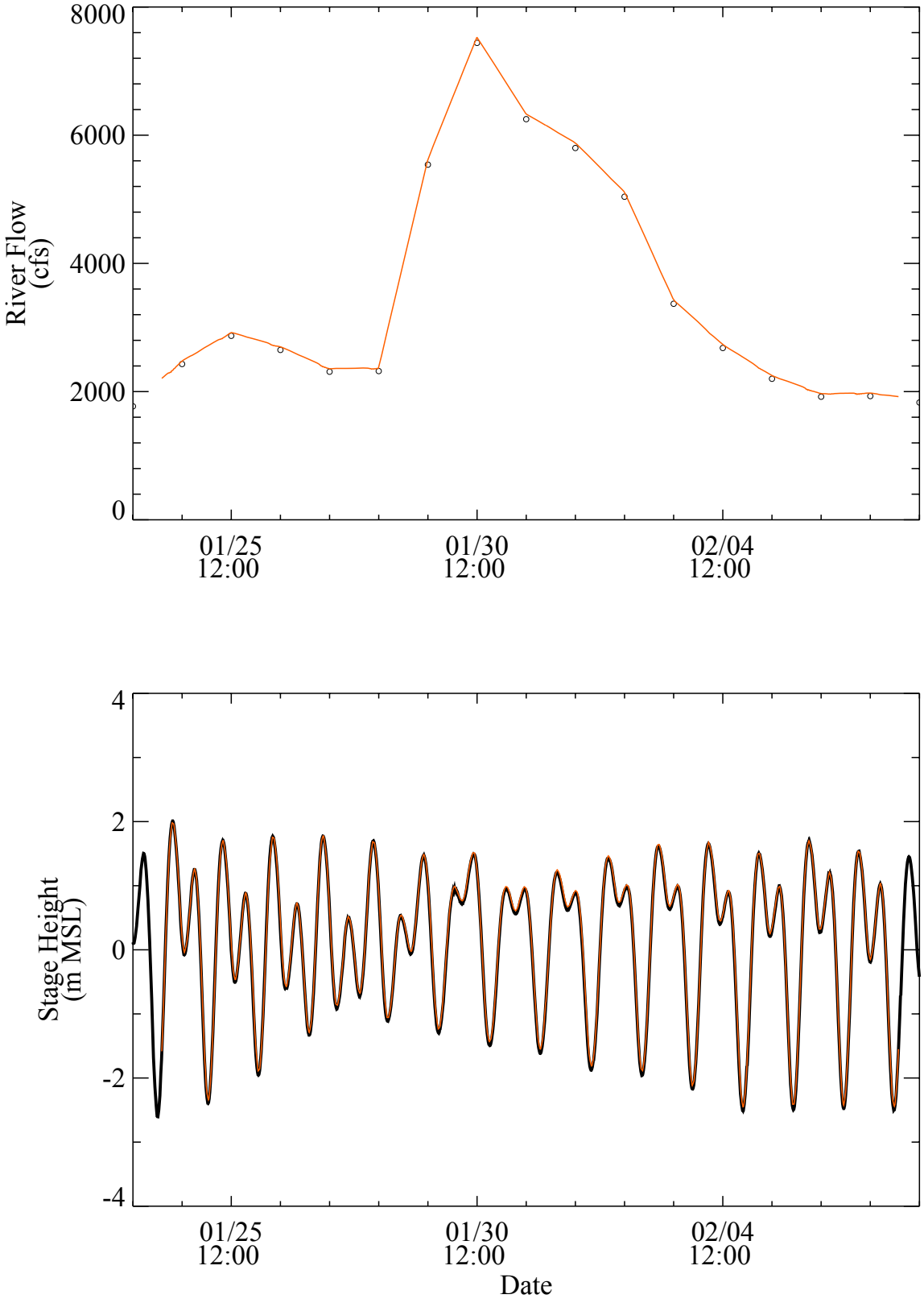

Figure B-72. Flow rate in Green River and tidal stage height during January-February 2004 deployment of current meter at BRD3 station.

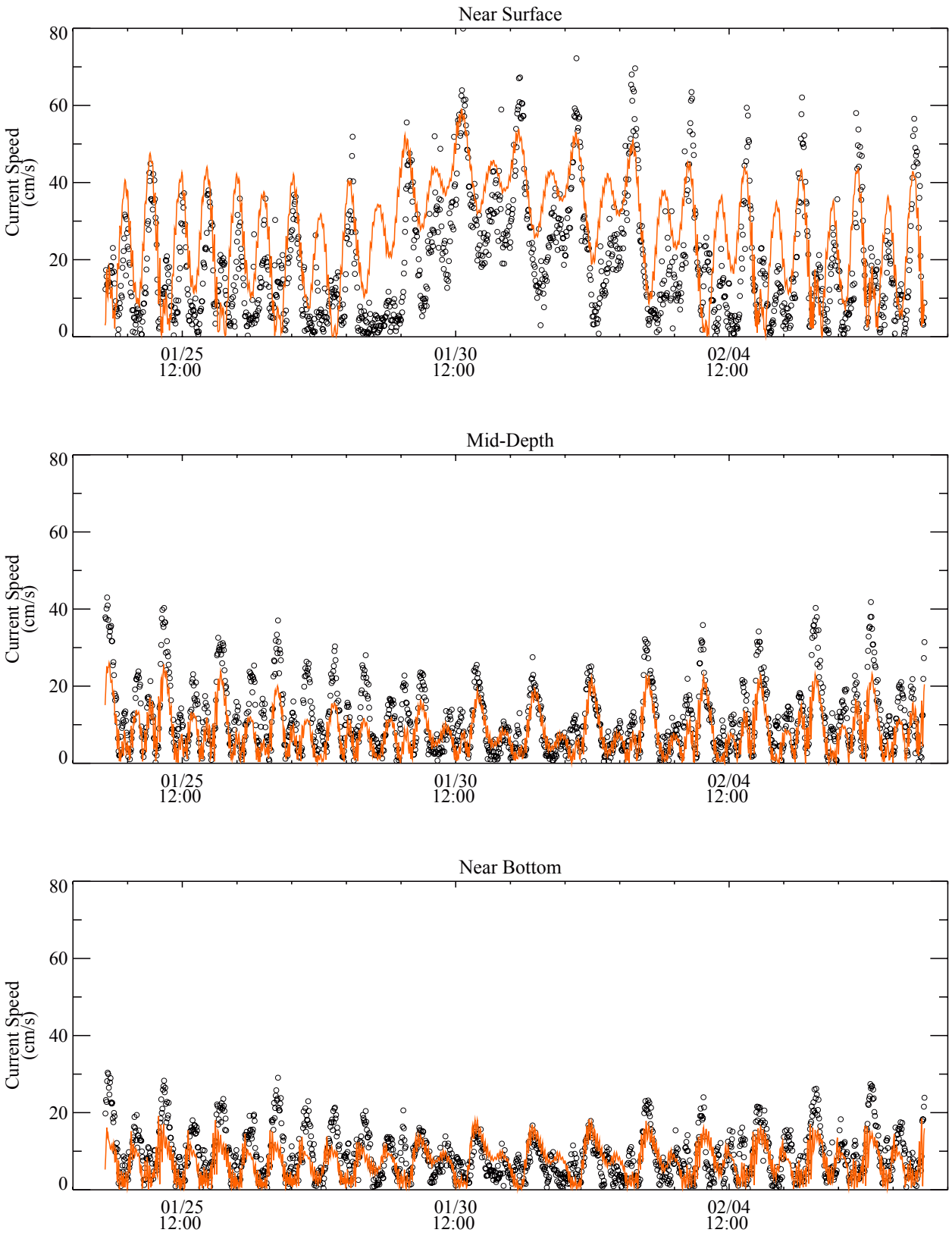

Figure B-73. Comparison of predicted (solid line) and observed (open circle) current speed at BRD3 station for January 23, 2004 to February 8, 2004.

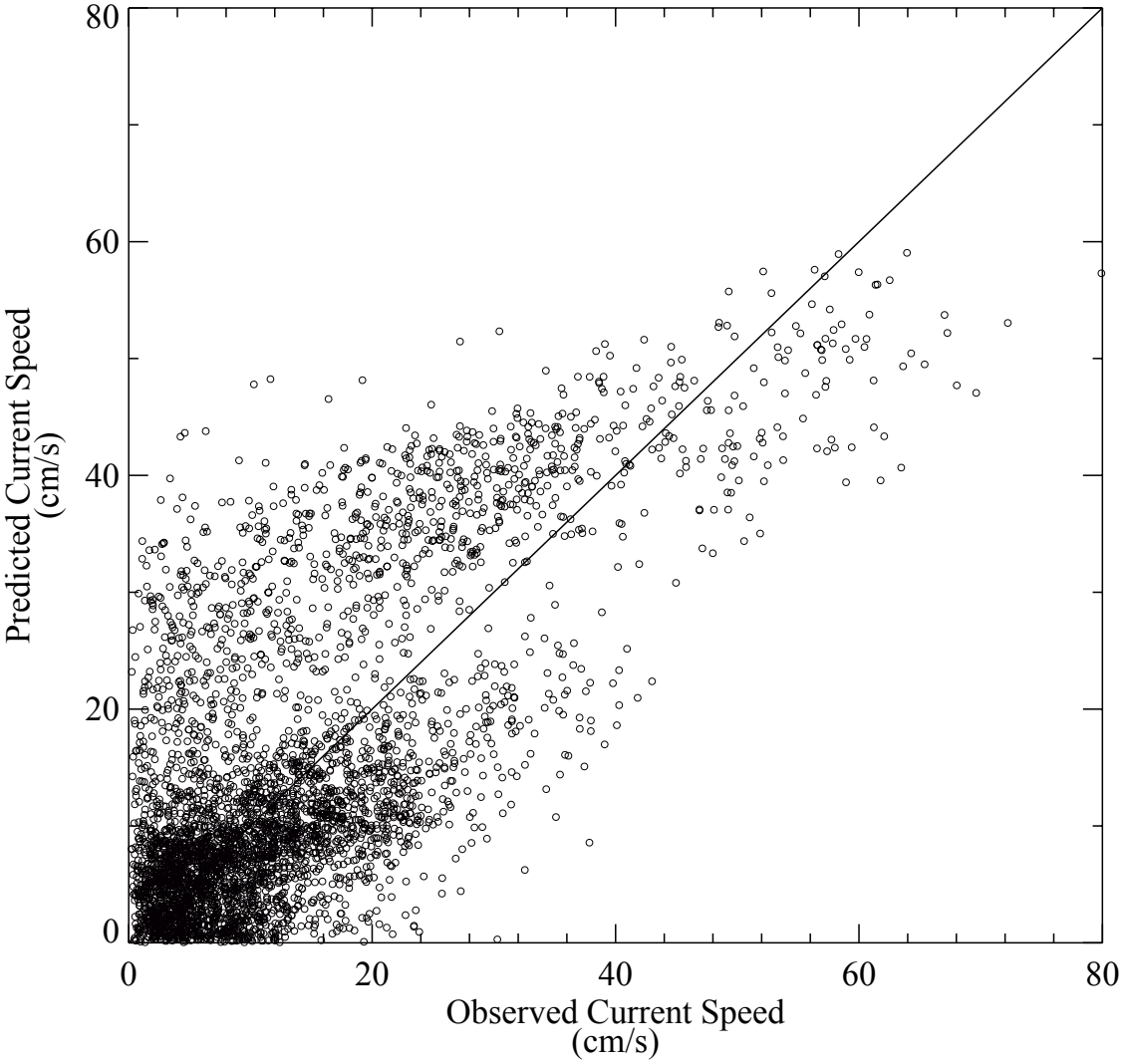

Figure B-74. Correlation between predicted and observed current speed at BRD3 station for January 23, 2003 to February 8, 2004.

Dashed line represents one-to-one correspondence.