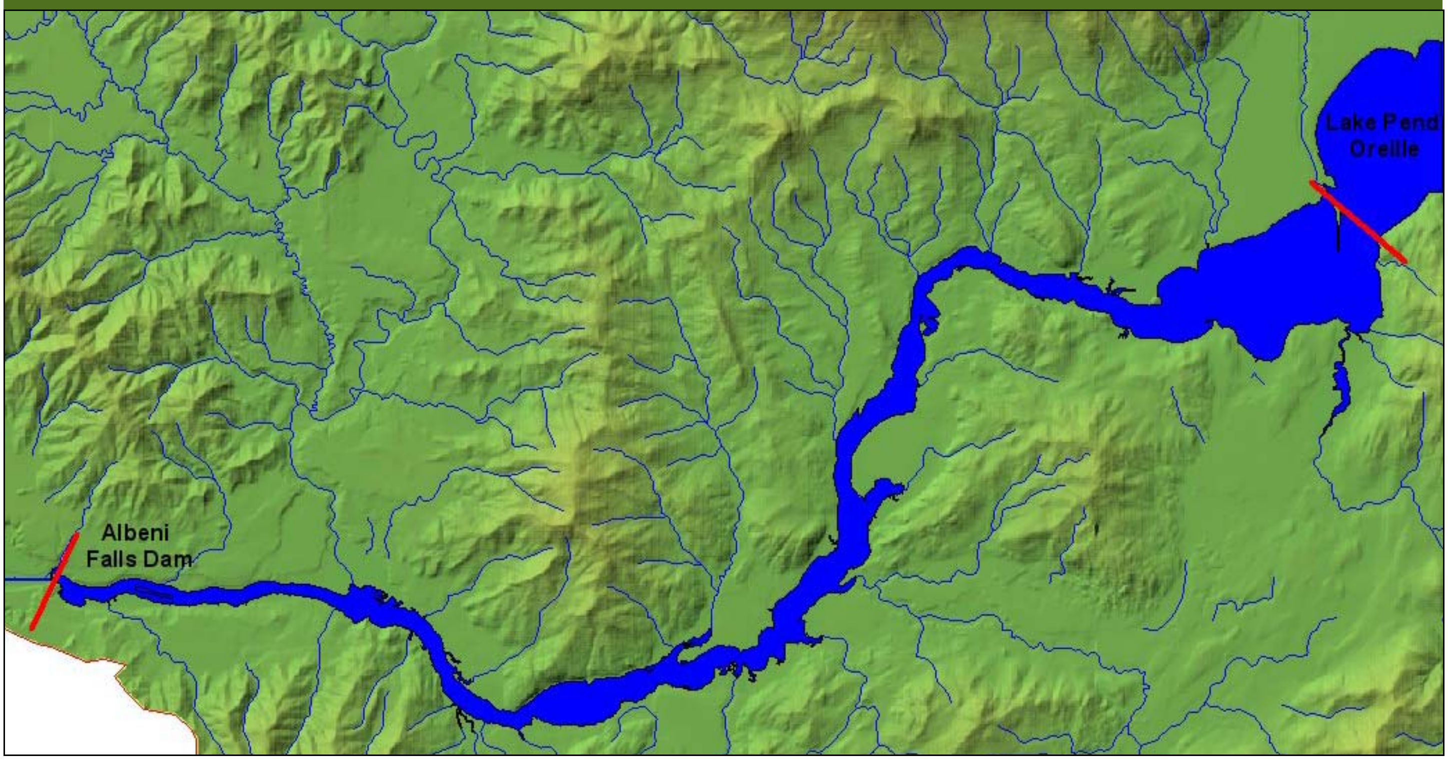
Idaho Pend Oreille River Model

Model Development and Calibration



Water Quality Research Group

Department of Civil and Environmental Engineering
Maseeh College of Engineering and Computer Science

Technical Report EWR-02-06, November 2006

Portland State UNIVERSITY

Pend Oreille River Model:
Model Development and Calibration

By

Robert Annear,

Chris Berger,

And

Scott Wells

Technical Report EWR-02-06

Water Quality Research Group
Department of Civil and Environmental Engineering
Maseeh College of Engineering and Computer Science
Portland State University
Portland, Oregon 97201-0751

Prepared for Idaho Department of Environmental Quality
Project Manager: Robert Steed

November, 2006

Table of Contents

List of Figures

List of Tables

Introduction

The Idaho Department of Environmental Quality is interested in developing a temperature and water quality Total Maximum Daily Load (TMDL) allocation for the Pend Oreille River between the Long Bridge near the historical Lake Pend Oreille outlet and the Albeni Falls Dam (U.S. Army Corps of Engineer's reservoir) as shown in Figure 1. The Pend Oreille drainage basin is shown in Figure 2 and Figure 3.

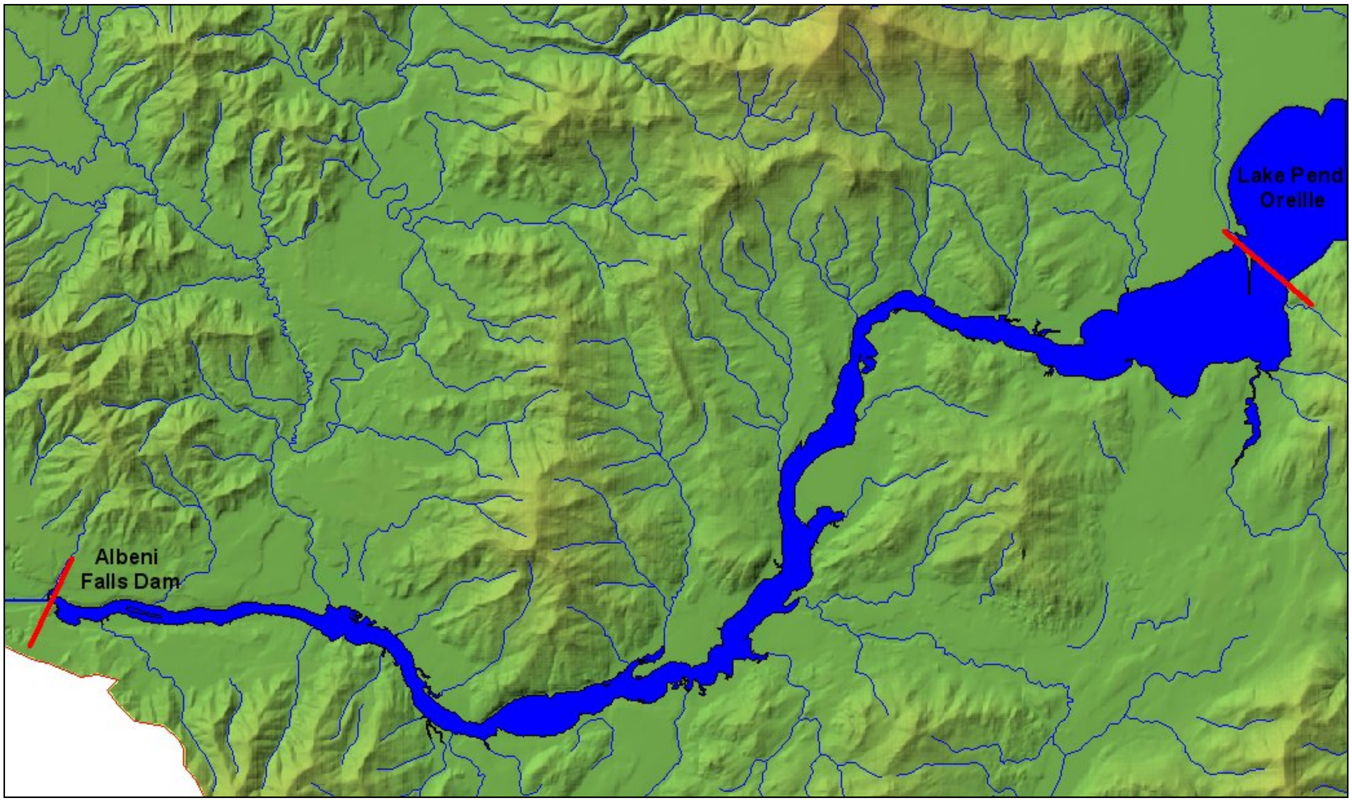


Figure 1: Pend Oreille River downstream of Lake Pend Oreille.

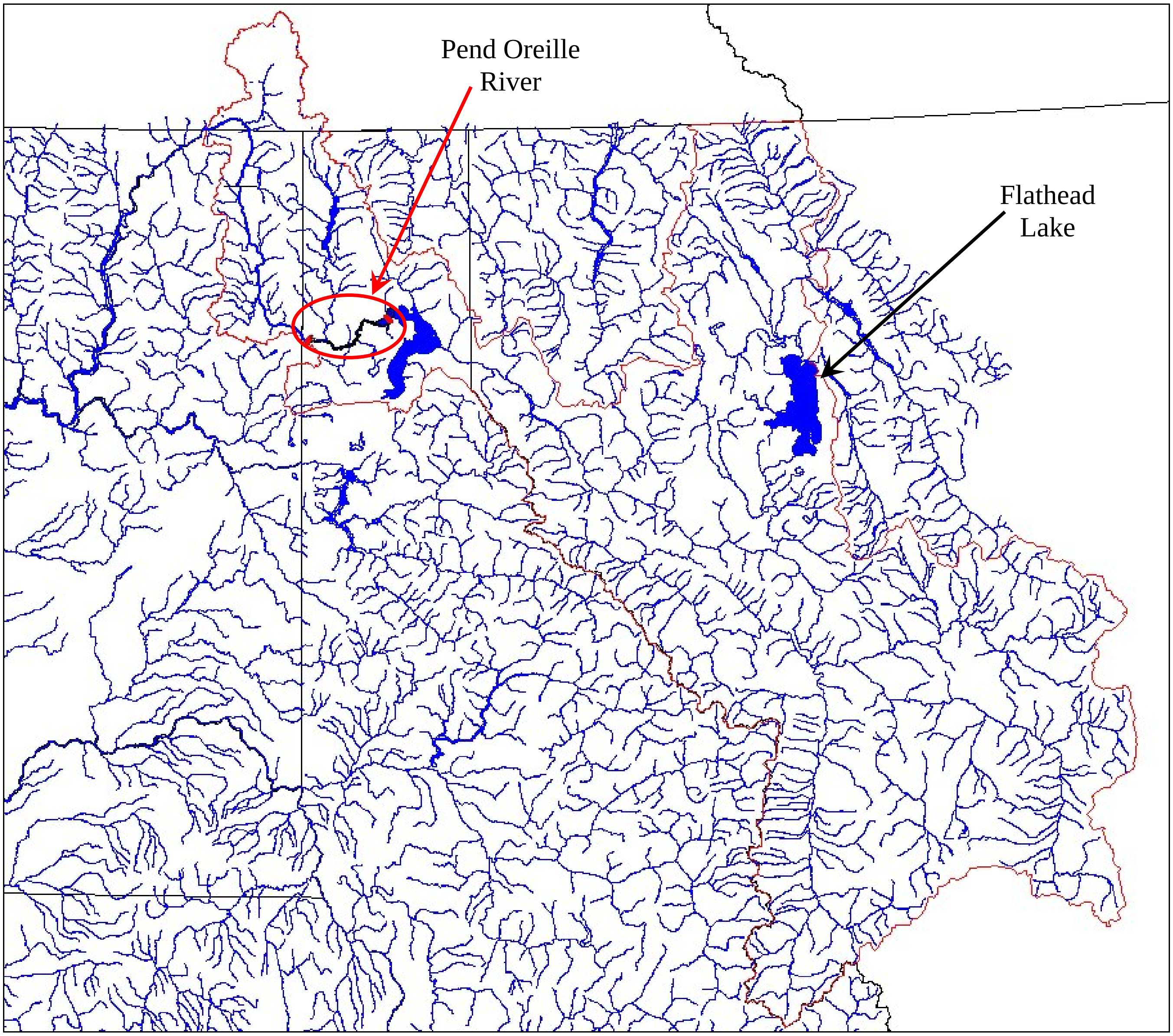


Figure 2: Pend Oreille River Basin.

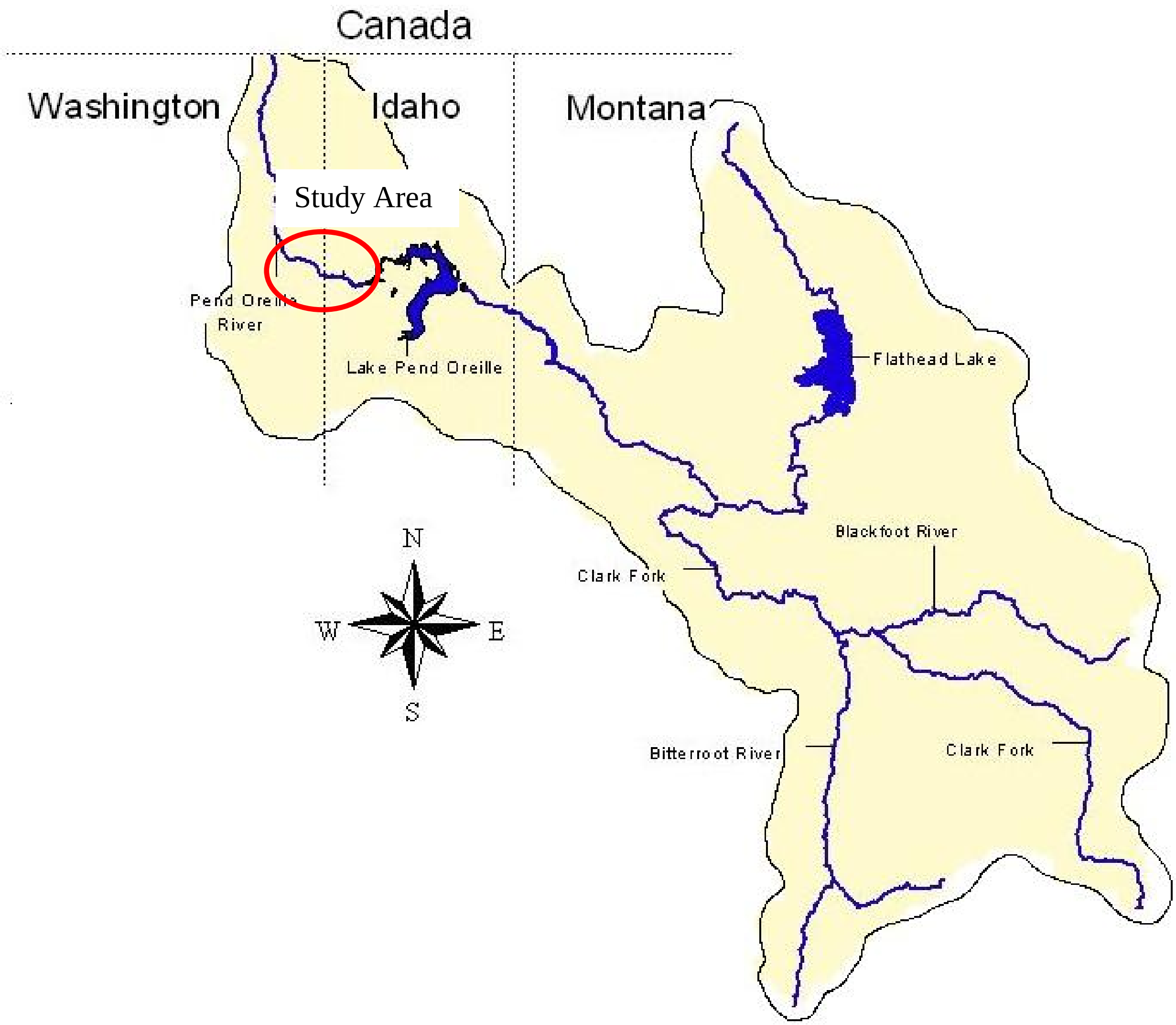


Figure 3: Pend Oreille drainage basin (Idaho DEQ, 2004).

The objectives of this project were to

- Develop a hydrodynamic and temperature model of Pend Oreille River using CE-QUAL-W2 Version 3.2
- Calibrate the CE-QUAL-W2 model to field data collected during 2004 and 2005 using the following water quality variables:
  - flow, water surface elevation, and velocity
  - temperature
  - dissolved oxygen
  - nutrients (NO_3-N+NO_2-N, NH_4-N, PO_4-P)
  - algae – chlorophyll a
  - BOD_5 and dissolved organic matter and particulate organic matter compartments (both labile and refractory) for the organic matter cycling with algae
  - periphyton

The model chosen for development was CE-QUAL-W2 Version 3.2 (Cole and Wells, 2004). This is a two-dimensional unsteady hydrodynamic and water quality model that includes typical eutrophication constituents (algae, nutrients, temperature, organic matter, dissolved oxygen, pH). Portland State

University's Water Quality Research Group is a center for development of this modeling tool (see http://www.cee.pdx.edu/w2).

The model simulation was run from January 1st, 2004 to September 25th, 2005. The calibration period focused on the summers during each year when water quality data were obtained.

Model Development

Model Geometry

Bathymetry

Bathymetry data for the Pend Oreille River consisted mainly of river channel cross sections and shoreline data collected by the U.S. Geological Survey in 1996 (Fields et al., 1996) as shown in Figure 4. The full pool elevation when the survey was conducted was 628.5 m (NGVD29).

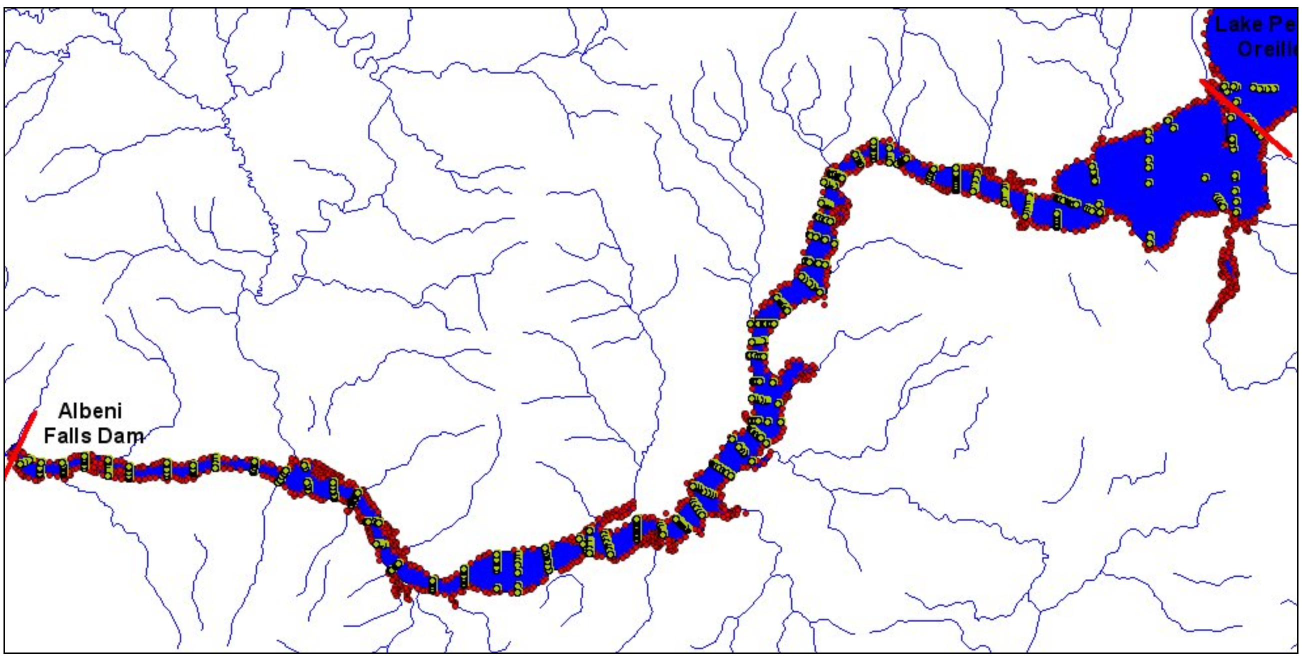


Figure 4: Bathymetric survey data from U.S. Geological Survey (Fields et al, 1996)

Additional data used to support the river channel bathymetry were digital elevation model (DEM) GIS (Geographic Information System) data from the U.S. Geological Survey. These data were used to tie in the river channel shorelines with the surrounding topography. Figure 5 shows a map of the river with a line indicating the extent of the DEM data used.

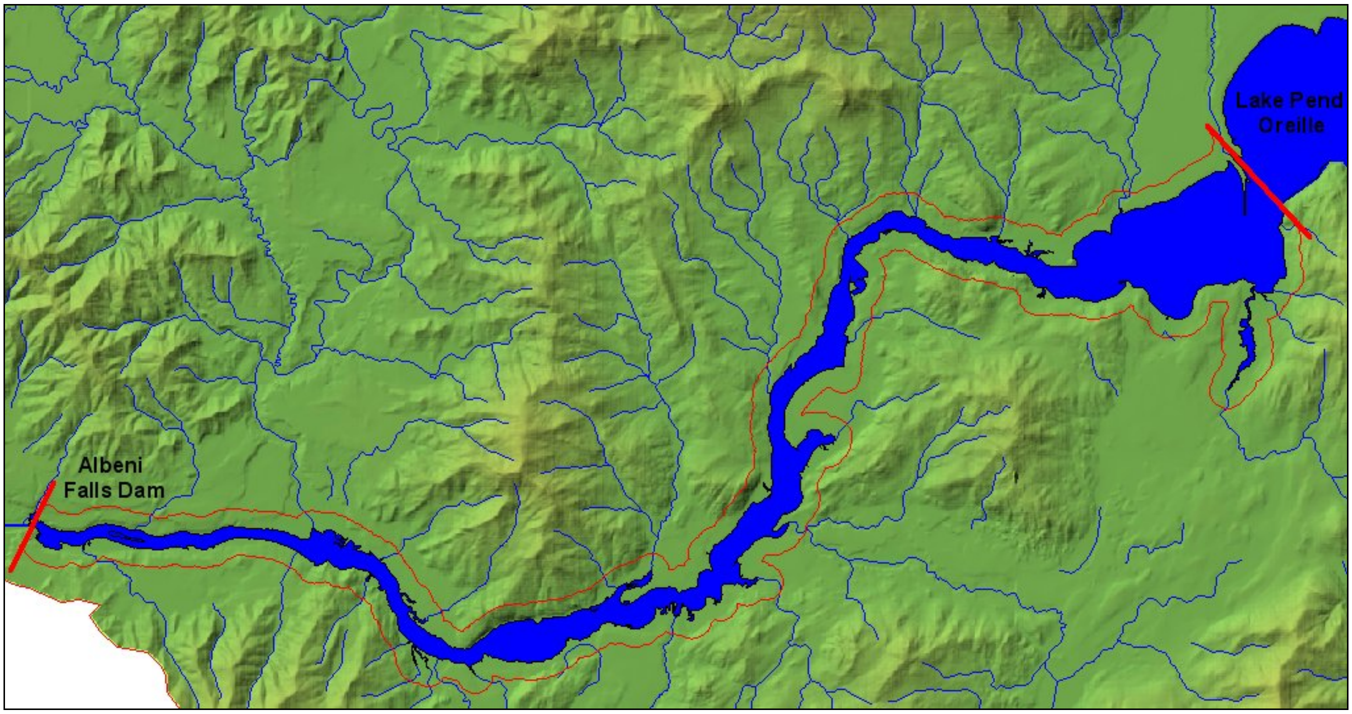


Figure 5: 500 m buffer surrounding the Pend Oreille River to obtain river bank topography

Model Grid Development

The river bathymetry was developed by creating a series of interpolated cross sections between the surveyed cross sections along with interpolated elevations and channel widths obtained from detailed GIS data developed from aerial photography from 2000. The complete set of cross sections, both surveyed and computed, were combined with topographic data from the stream banks to generate a detailed surface plot of the river channel using the contour plotting program SURFER. Figure 6 shows the Pend Oreille River bathymetry with the model grid layout, including 6 side channels. Figure 7 shows the model grid layout with surrounding rivers and topography. Table 1 provides the list of model grid characteristics.

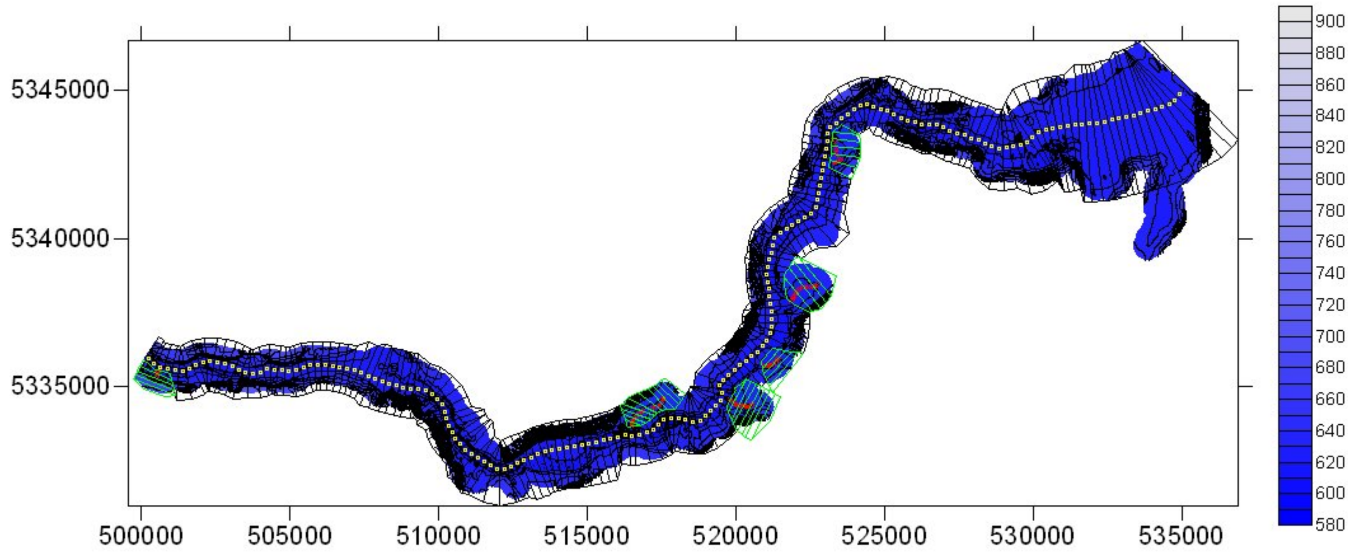


Figure 6: Pend Oreille River model grid layout with channel bathymetry

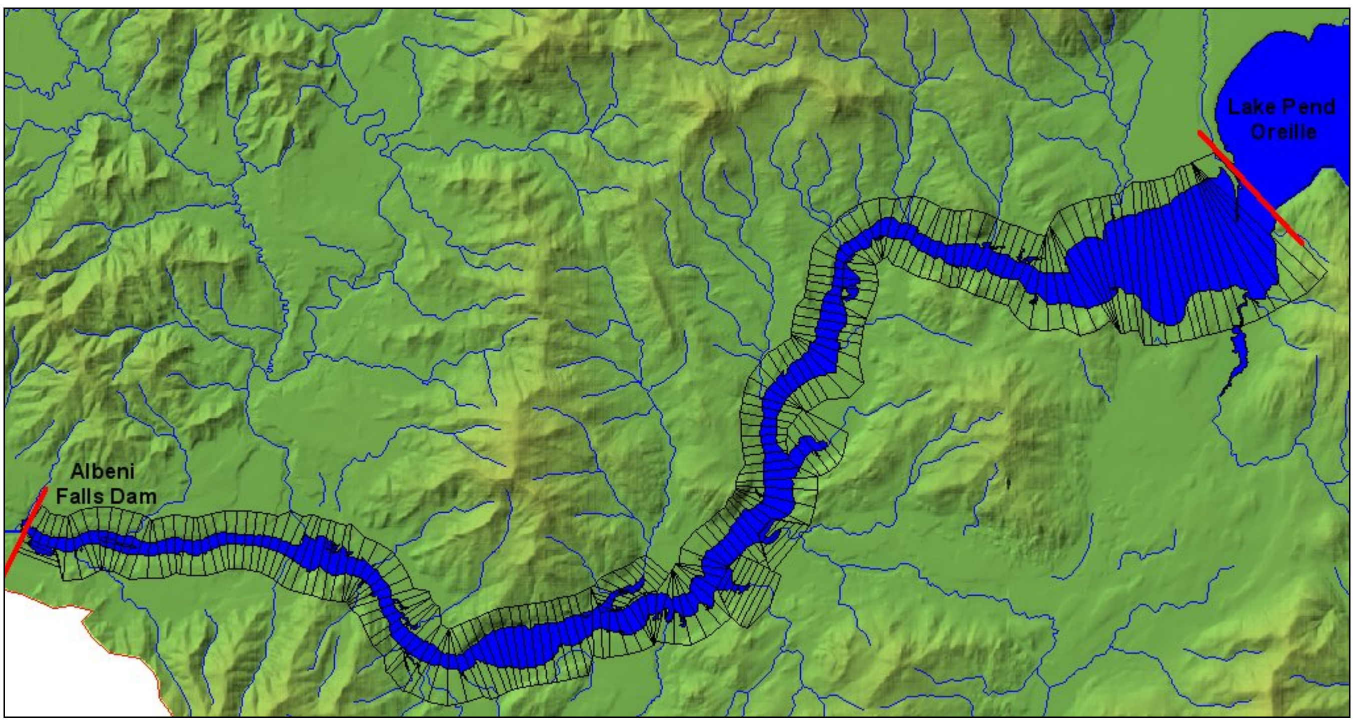


Figure 7: Pend Oreille River model grid layout

Table 1: Pend Oreille River Model Grid Characteristics

Water Body	Branch	Description	Starting Segment	Ending Segment	Starting RM	Ending RM	Segment Length, m	Slope	Upstream BC	Down-stream BC
1	1	Pend Oreille River	2	183	118.44	90.10	250.54	0.0000	external head	structure outflow
	2	Muskrat Slough	186	191	0.93	0.00	250.54	0.0000	flow	internal
	3	Morton Slough	194	198	0.78	0.00	250.54	0.0000	flow	internal
	4	Cocolalla Creek	201	205	0.78	0.00	250.54	0.0000	flow	internal
	5	Jewel Creek	208	215	1.25	0.00	250.54	0.0000	flow	internal
	6	Riley Creek	218	228	1.71	0.00	250.54	0.0000	flow	internal
	7	Albeni Cove	231	233	0.47	0.00	250.54	0.0000	flow	internal

Boundary Conditions

Hydrodynamic, temperature and water quality data were obtained from several different agencies and sources to develop the model input files for the the model calibration years 2004 and 2005. Appendix A has several maps of monitoring sites and tables listing the sites and extent of data.

Upstream Boundary Conditions

Hydrodynamics

The upstream boundary condition for the Pend Oreille River model was based on the water surface elevation measured near Hope, ID on Lake Pend Oreille (USGS 12392500) as shown in Figure 8. The data recorded at this site were compared with data collected at two additional sites: HOPI, Lake Pend Oreille at Hope, ID and ALF, Albeni Falls Dam forebay, both provided by U.S. Army Corps of Engineers (US ACOE). The water surface elevation data recorded in the Albeni Dam forebay, ALF, are believed to be close to hydropower turbines and therefore influenced locally by their operations. The data collected by the USGS were considered to be the most accurate. Figure 10 and Figure 11 show time series plots of the water surface elevation data for 2004 and 2005, respectively.

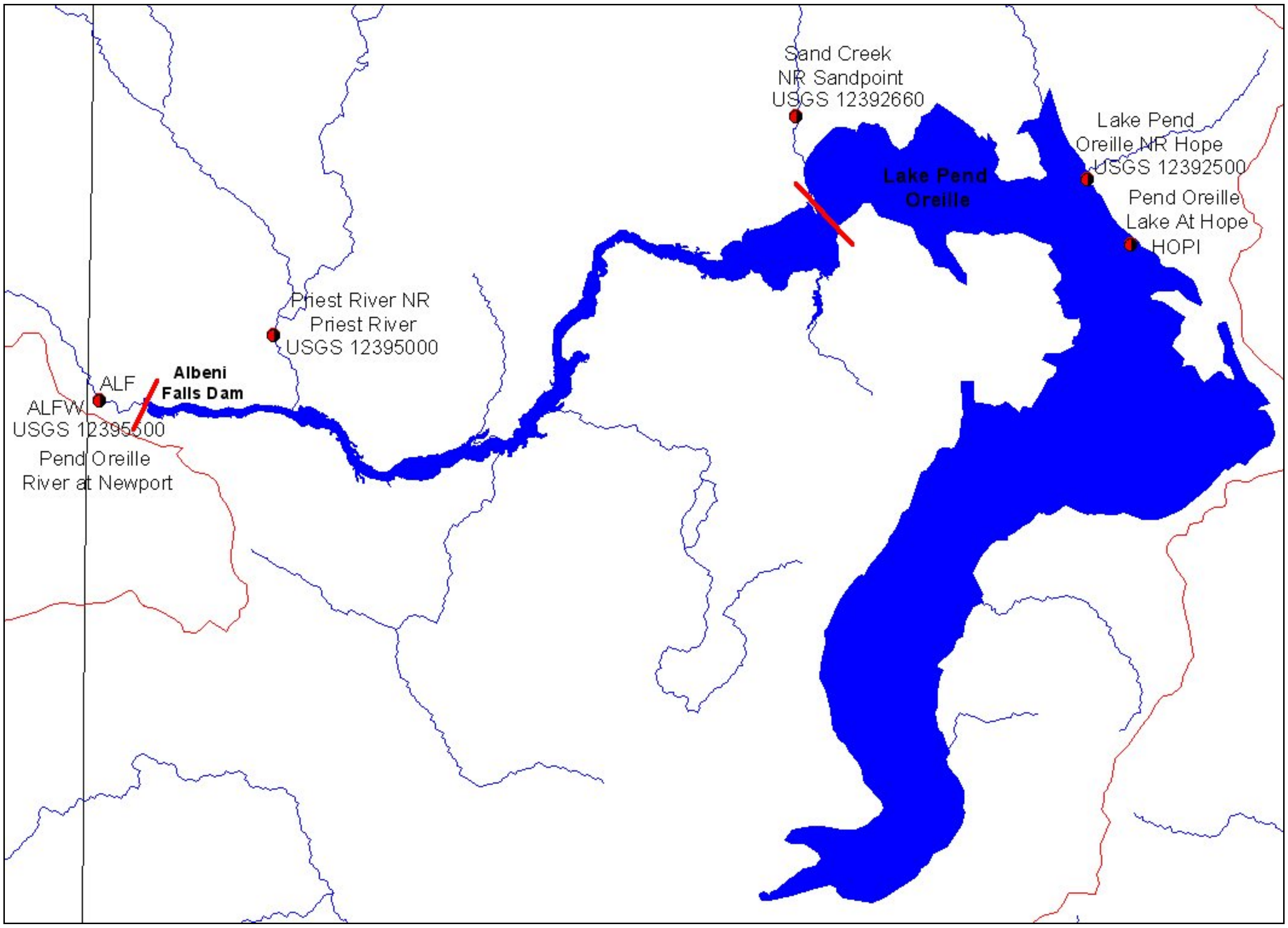


Figure 8: Water surface elevation and discharge monitoring sites

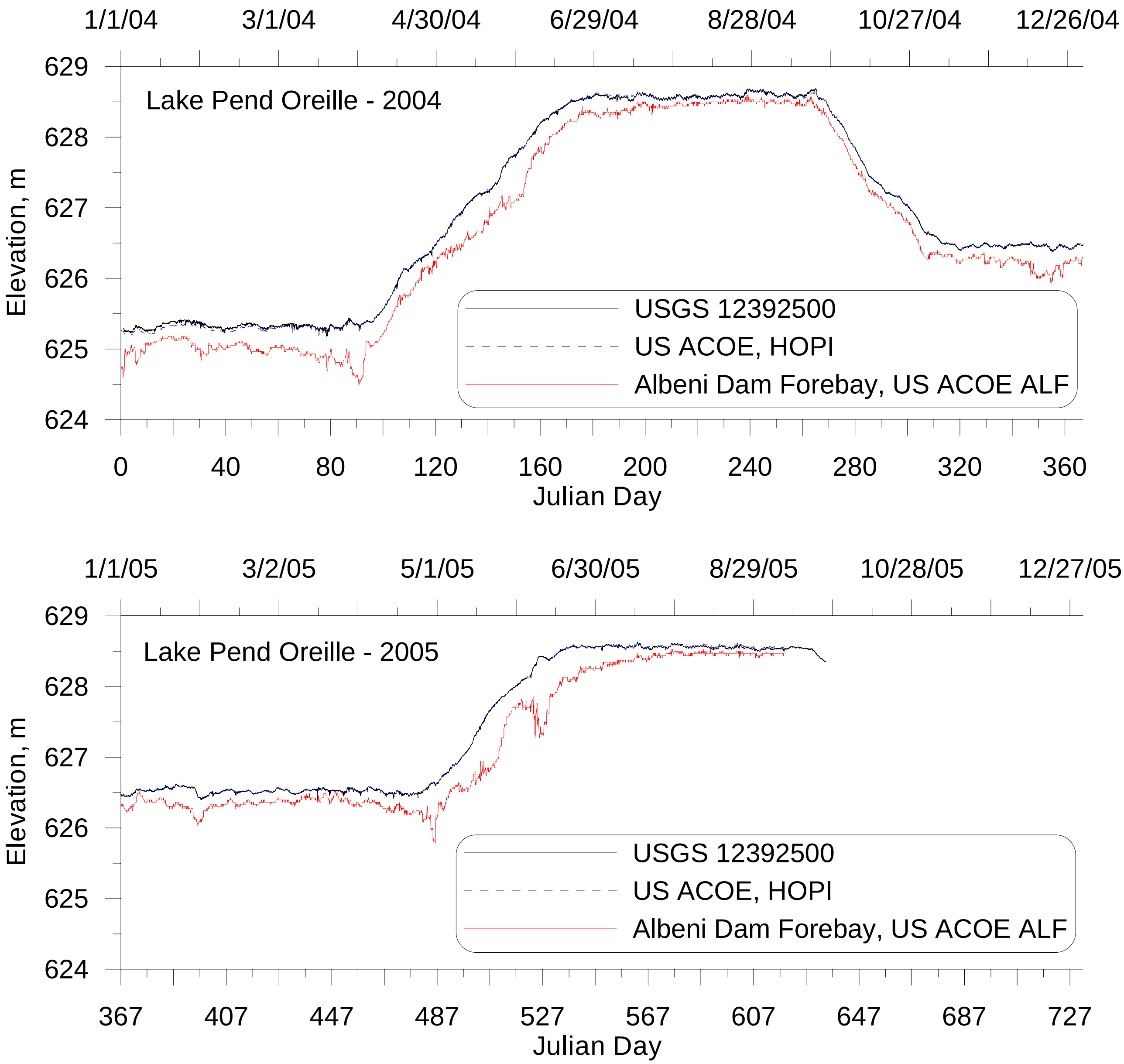


Figure 9: Lake Pend Oreille water surface elevation comparison, 2004 and 2005.

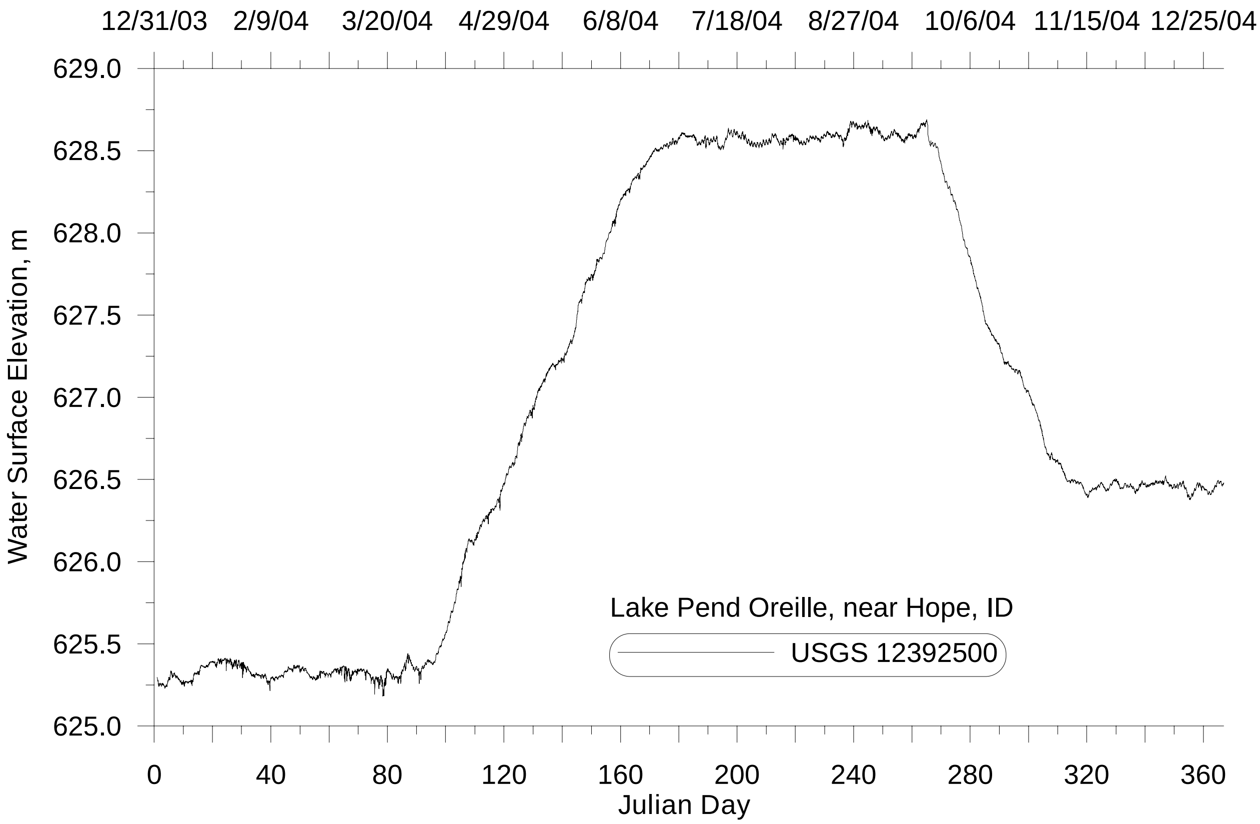


Figure 10: Upstream head boundary condition, Lake Pend Oreille water surface elevation, 2004.

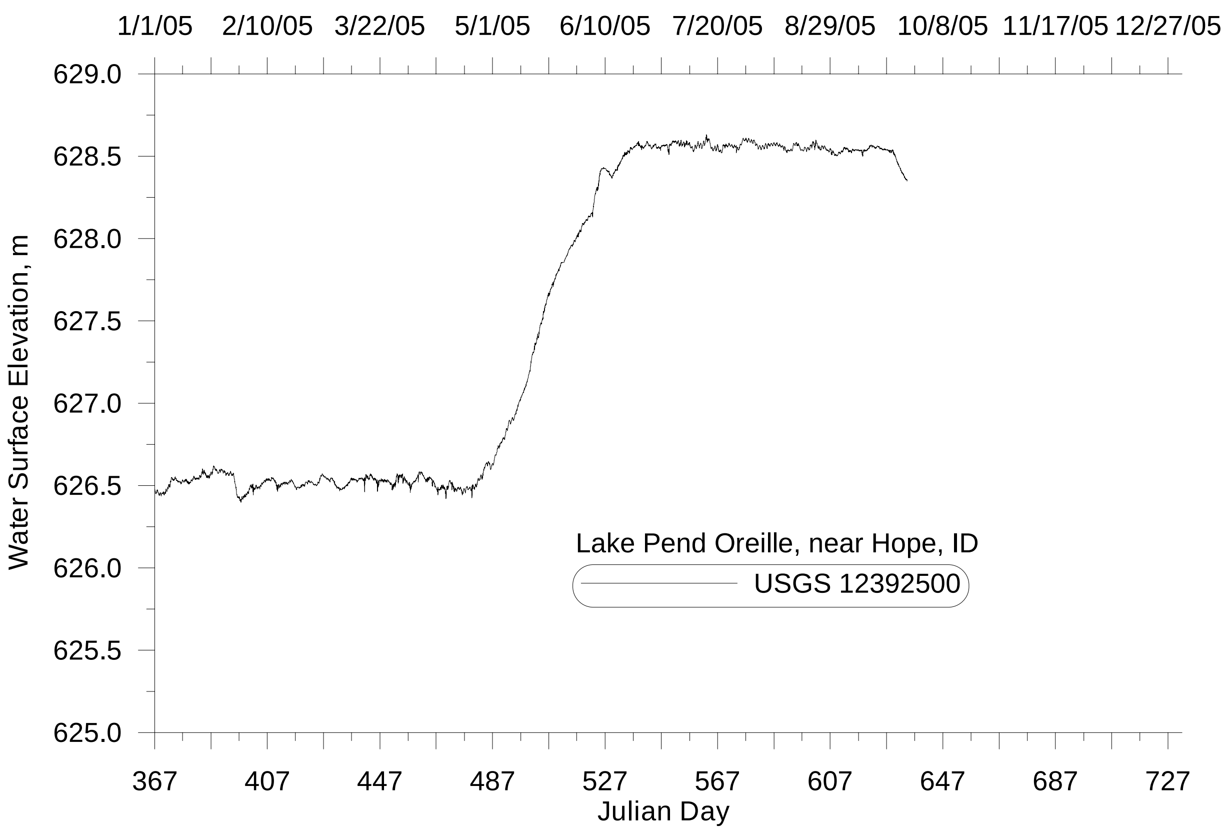


Figure 11: Upstream head boundary condition, Lake Pend Oreille water surface elevation, 2005.

Temperature

Water temperatures were monitored at the upstream end of the river by several agencies periodically in 2004 and 2005. Figure 12 shows a map with the locations of the temperature monitoring sites in Lake Pend Oreille and just downstream on the river. Table 2 lists the site names, descriptions and the types of data available at each site. The most complete data sets consisted of continuous water temperature measurements at various depths in the lake using buoys from the U.S. Navy and the U.S. Army Corps of Engineers (ALFLPS). The data from U.S. Navy buoy was available only in a poor format with hourly data placed in daily files for each depth. The U.S. Army Corps of Engineers temperature monitoring buoy site on the lake near Contest Point (ALFLPS) provided time series and vertical profile data near the model upstream boundary. Figure 13 shows temperature vertical profiles take at the site ALFLPS in 2005. The figure indicates there is thermal stratification in the lake in the middle of the summer. The river and model are shallower than the lake with a resulting sill representing the connection between the river bottom and the deeper lake. Using the water level data shown in Figure 11 the depth of the river to the bottom at model segment 2, the first segment, was calculated and included in Figure 13 as "sill depth". The figure indicates that even with the shallow nature of the river model the lake stratification is important to incorporate in the model upstream boundary condition. Figure 14 and Figure 15 show the continuous temperature data at different depths at the same site in the lake, ALFLPS, on the buoy. The two figures also include the calculated sill depth at model segment 2 using the water level data from Figure 10 and Figure 11. Figure 14 and Figure 15 indicate there is thermal stratification occurring throughout the summer and will be captured by the upstream end of the river. The figures also indicate there are large temperature fluctuations at several depths. Figure 16 shows the temperature fluctuates at several depths from July 18th to July 28th, 2004. The figures indicate there are large temperature swings of several degrees with a temporal period of 2 days. This oscillation may be due seiching in the lake.

Figure 17 and Figure 18 are times series plots of the surface water temperature data from the various sources in 2004 and 2005, respectively. Figure 19 and Figure 20 show time series plots of the water temperature at different depths at the Long Bridge on the Pend Oreille River in 2005 and 2005, respectively. The figures indicate there is still a thermal stratification present in river 1.5 km downstream from the lake.

Model input characterizing the upstream boundary condition temperature for 2004 consisted of data from the U.S. Navy buoy on Lake Pend Oreille in the winter and the data from the U.S. Army Corps of Engineers temperature monitoring buoy site on the lake near Contest Point (ALFLPS) in the spring through fall. The data from the two sources was used to linearly interpolate the water temperature for each model layer elevation in the upstream model segment for the model simulation period. Figure 21 and Figure 22 show times series plots of the water temperature upstream boundary condition for 2004 and 2005, respectively.

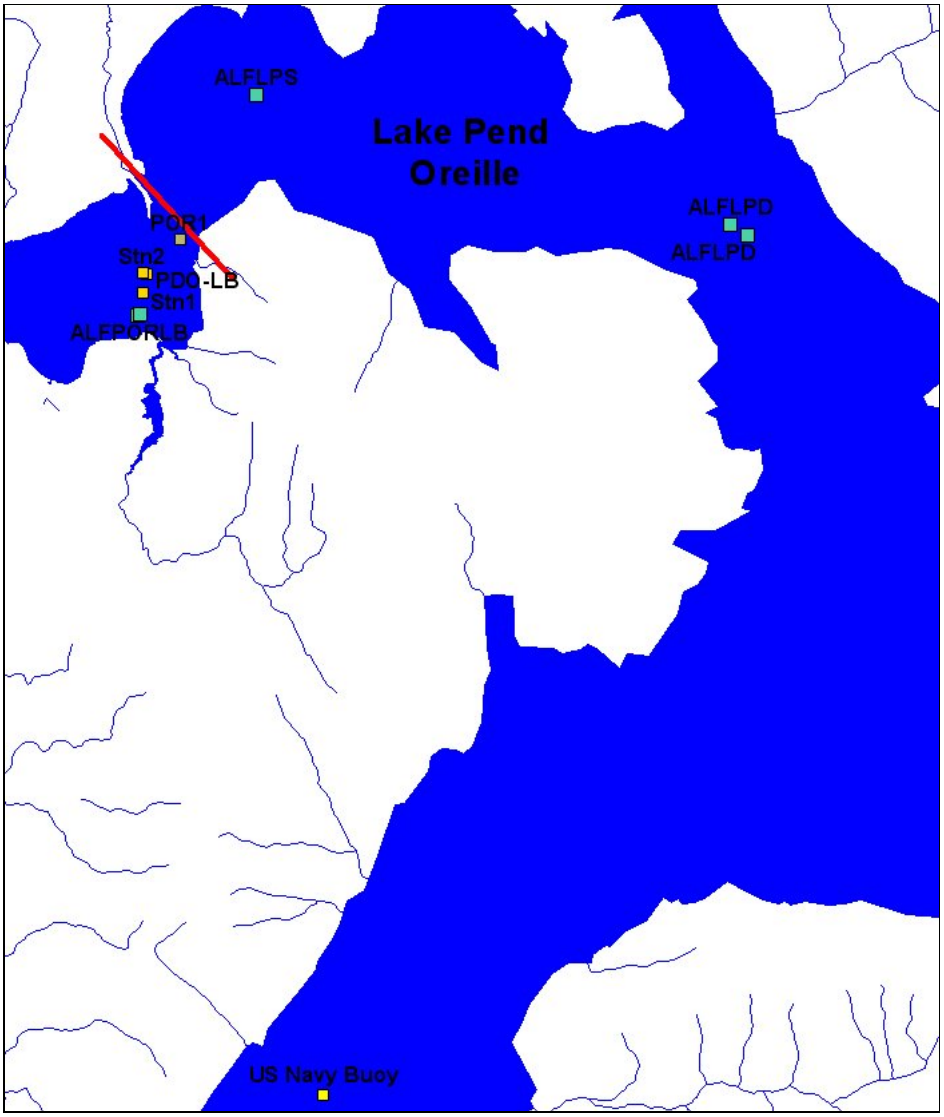


Figure 12: Water temperature monitoring sites in 2004 and 2005.

Table 2: Water temperature monitoring site locations in 2004 and 2005

Site ID	Agency	Site Description	Data available
PDO-LB	IDEQ	Long Bridge	Vertical profiles at two dates in 2004
POR1	Tetra Tech Inc.	Pend Oreille River 95 bridge, Lake Pend Oreille	Time series data in 2004
Stn1	IDEQ	Long Bridge	Time series data at multiple depths in 2005
Stn2	IDEQ	Long Bridge, North of Stn1	Time series data at multiple depths in 2005
US Navy	US Navy	Lake Pend Oreille, Buoy on arm of lake	Time series data at multiple depths in 2004 and 2005
Sandpt	City of Sandpoint	City of Sandpoint drinking water intake	Grab sample data in 2004 and 2005
ALFLPS	US ACOE	Lake Pend Oreille near Contest Point, Buoy	Time series data at multiple depths in 2004 and 2005

Site ID	Agency	Site Description	Data available
ALFPORLB	US ACOE	Pend Oreille River at Long Bridge, Buoy	Time series data at multiple depths in 2004 and 2005
ALFLPD	US ACOE	Lake Pend Oreille near Anderson Point, Buoy	Time series data at multiple depths in 2004 and 2005

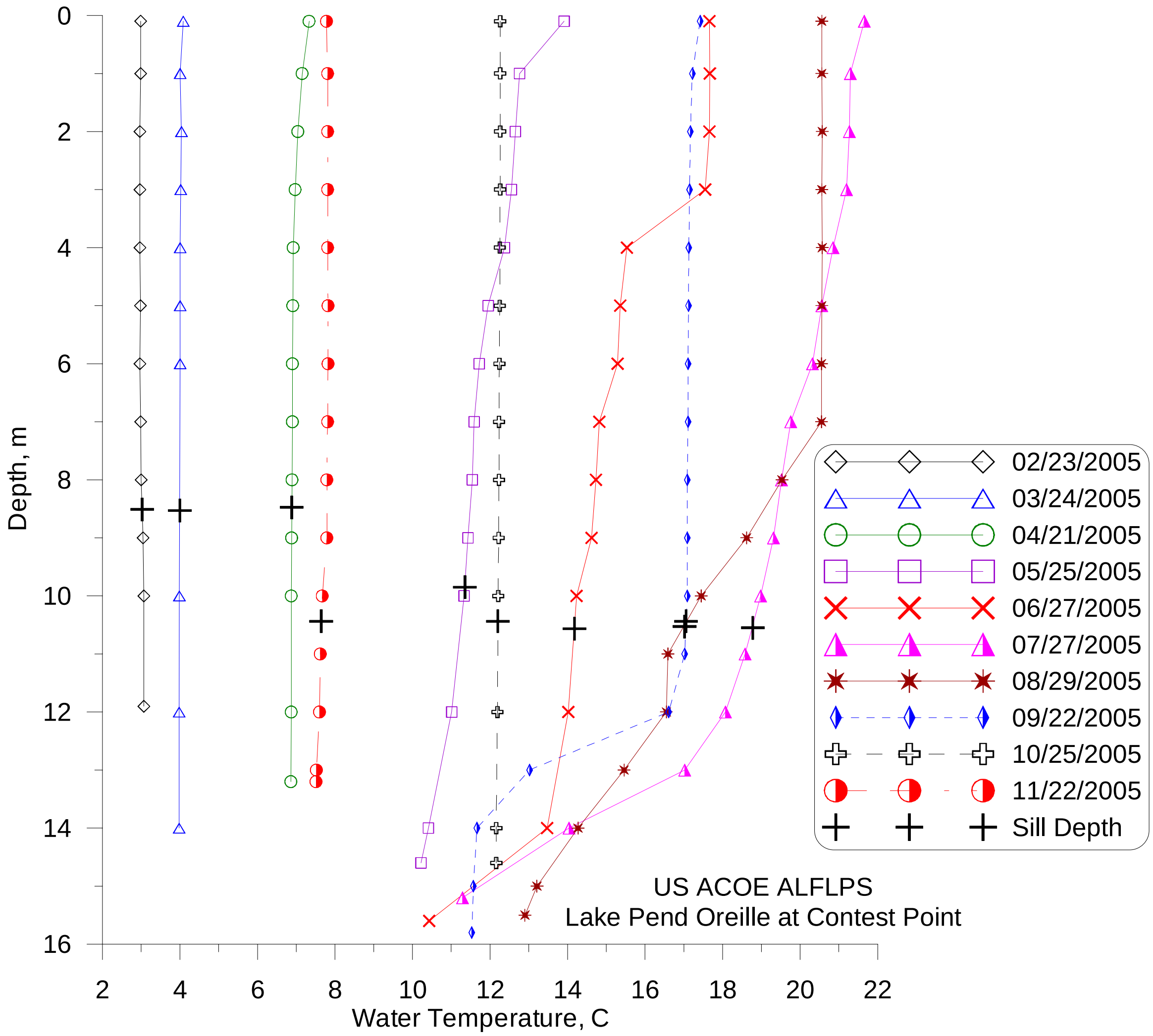


Figure 13: Vertical Temperature Profiles in Lake Pend Oreille near Contest Point, 2005.

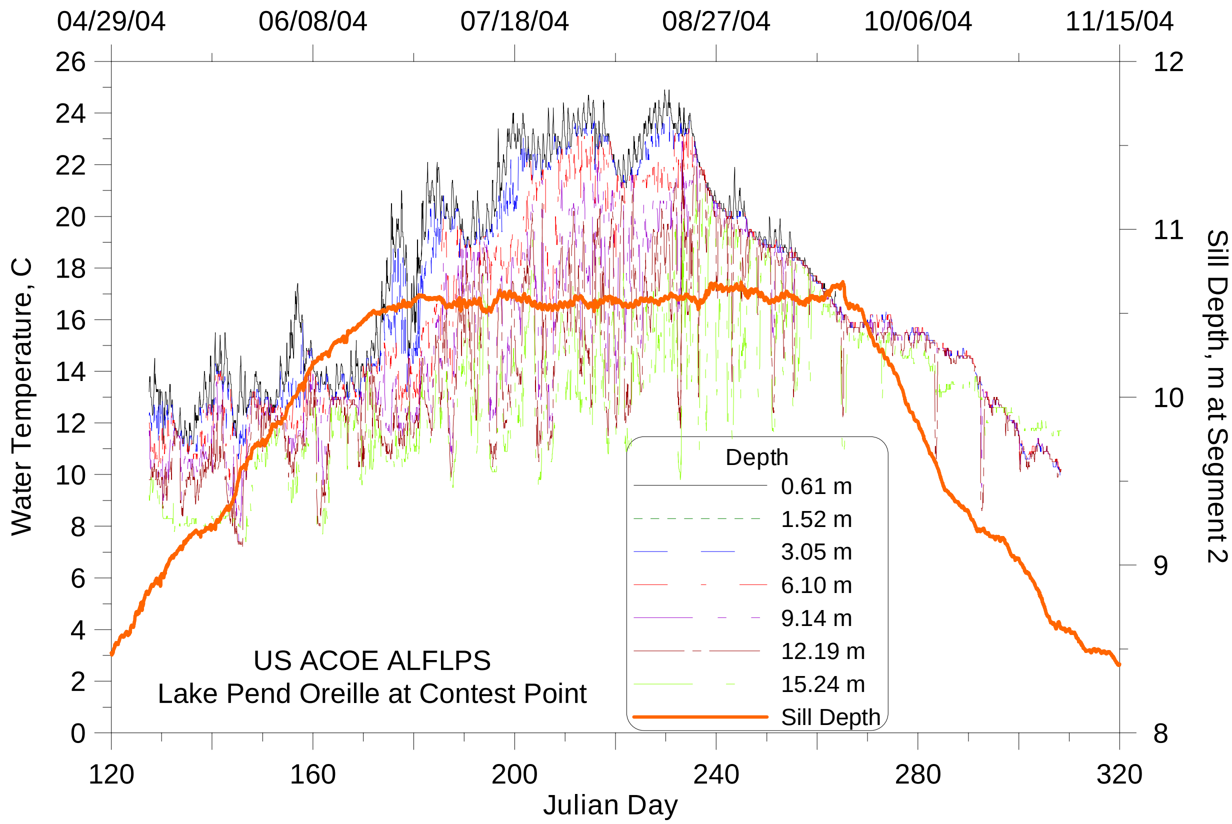


Figure 14: Continuous temperature data at various depths in Lake Pend Oreille near Contest Point, 2004.

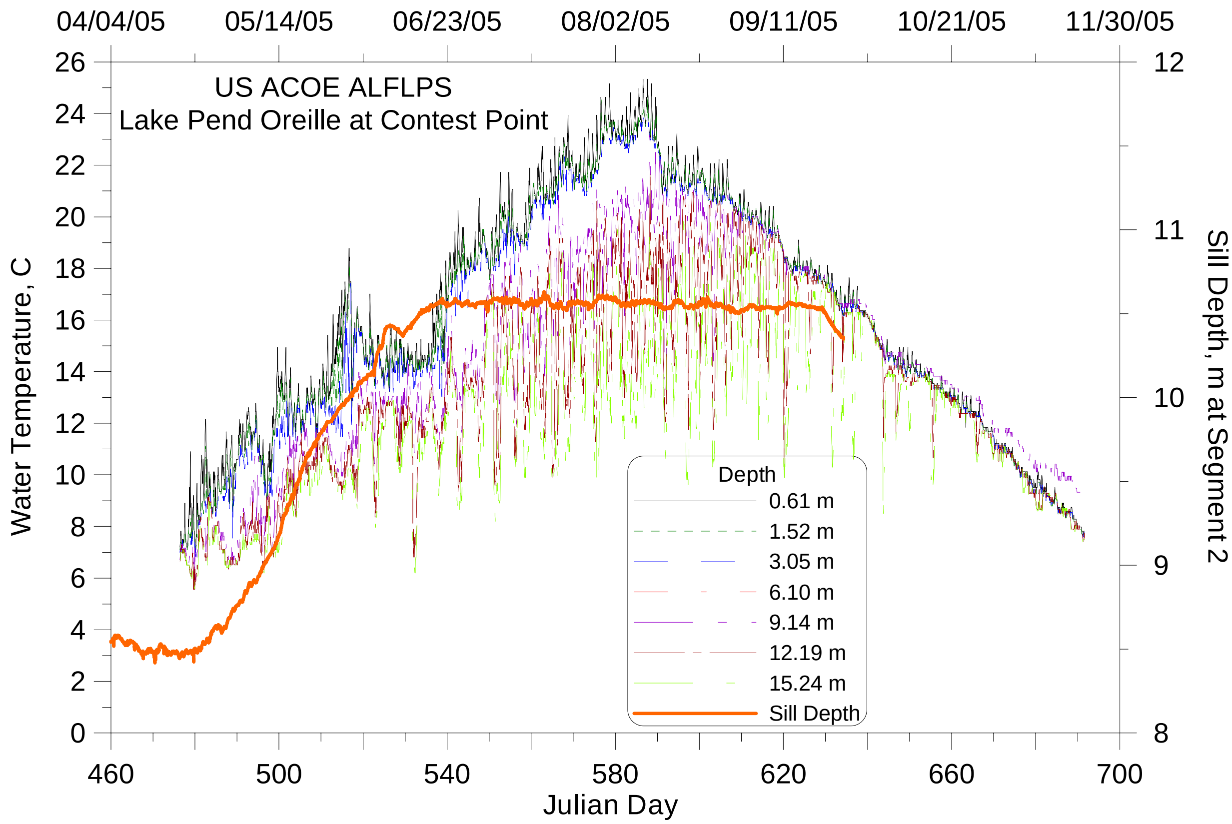


Figure 15: Continuous temperature data at various depths in Lake Pend Oreille near Contest Point, 2005.

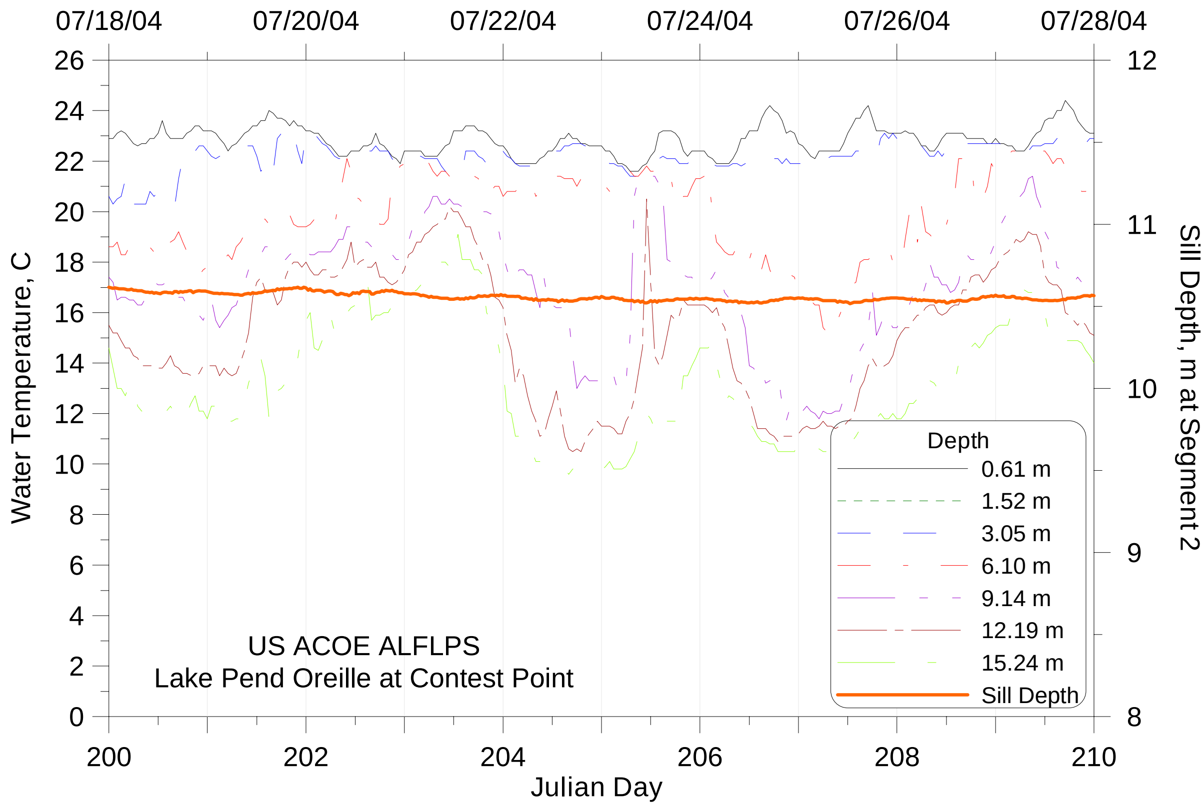


Figure 16: Continuous temperature data at various depths in Lake Pend Oreille near Contest Point, July 2004.

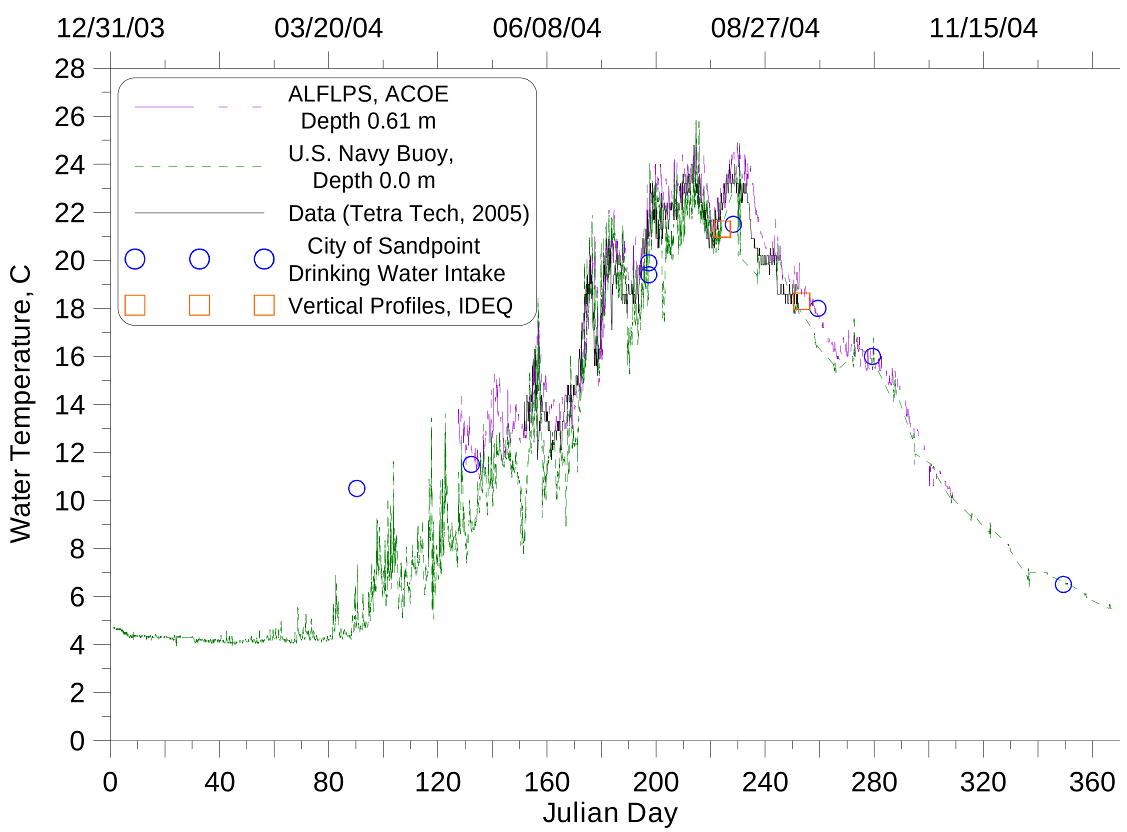


Figure 17: Surface water temperature data in Lake Pend Oreille and the Pend Oreille River near the model upstream boundary condition, 2004.

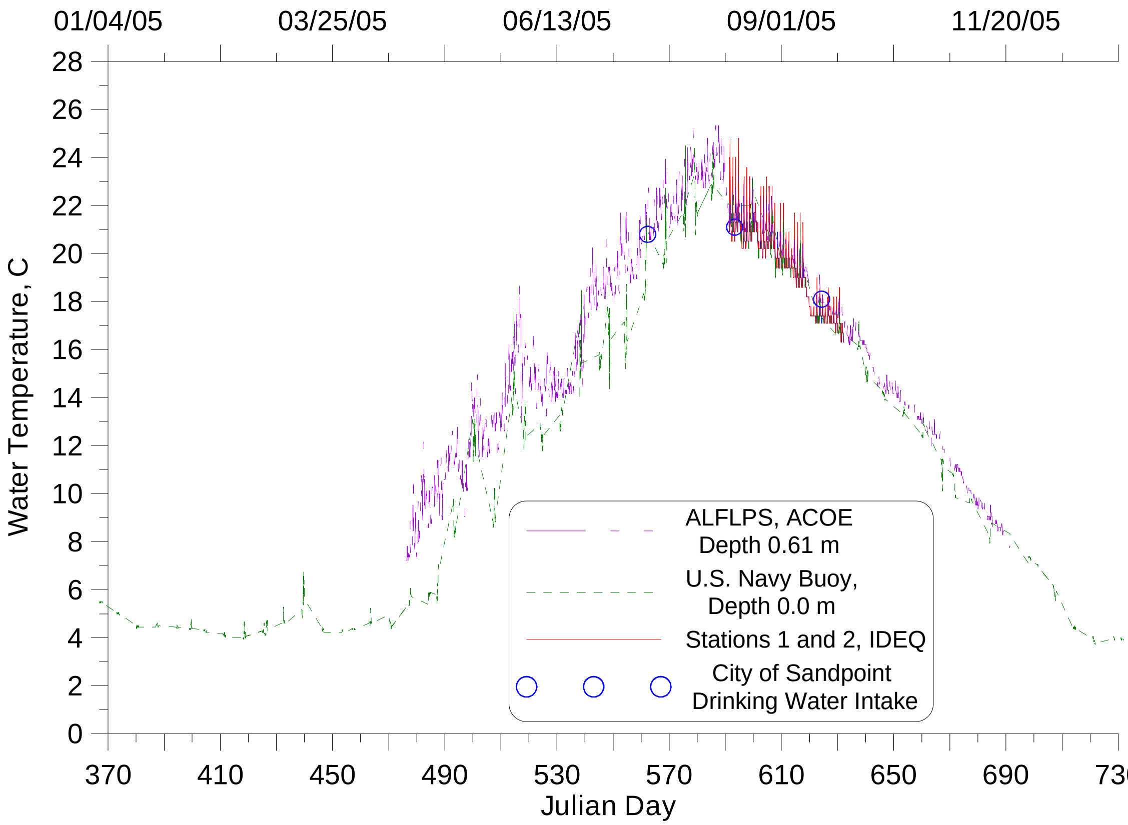


Figure 18: Surface water temperature data in Lake Pend Oreille and the Pend Oreille River near the model upstream boundary condition, 2005.

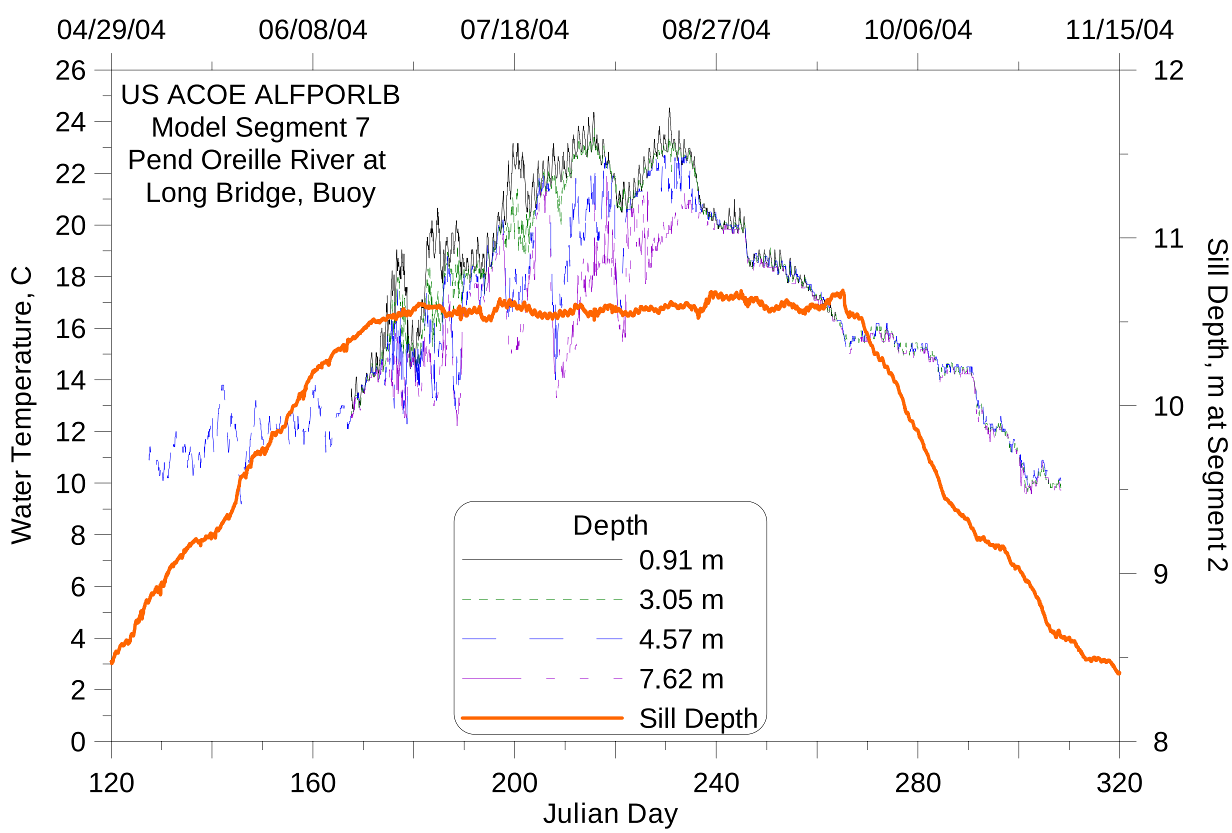


Figure 19: Continuous temperature data at various depths in the Pend Oreille River at Long Bridge, 2004.

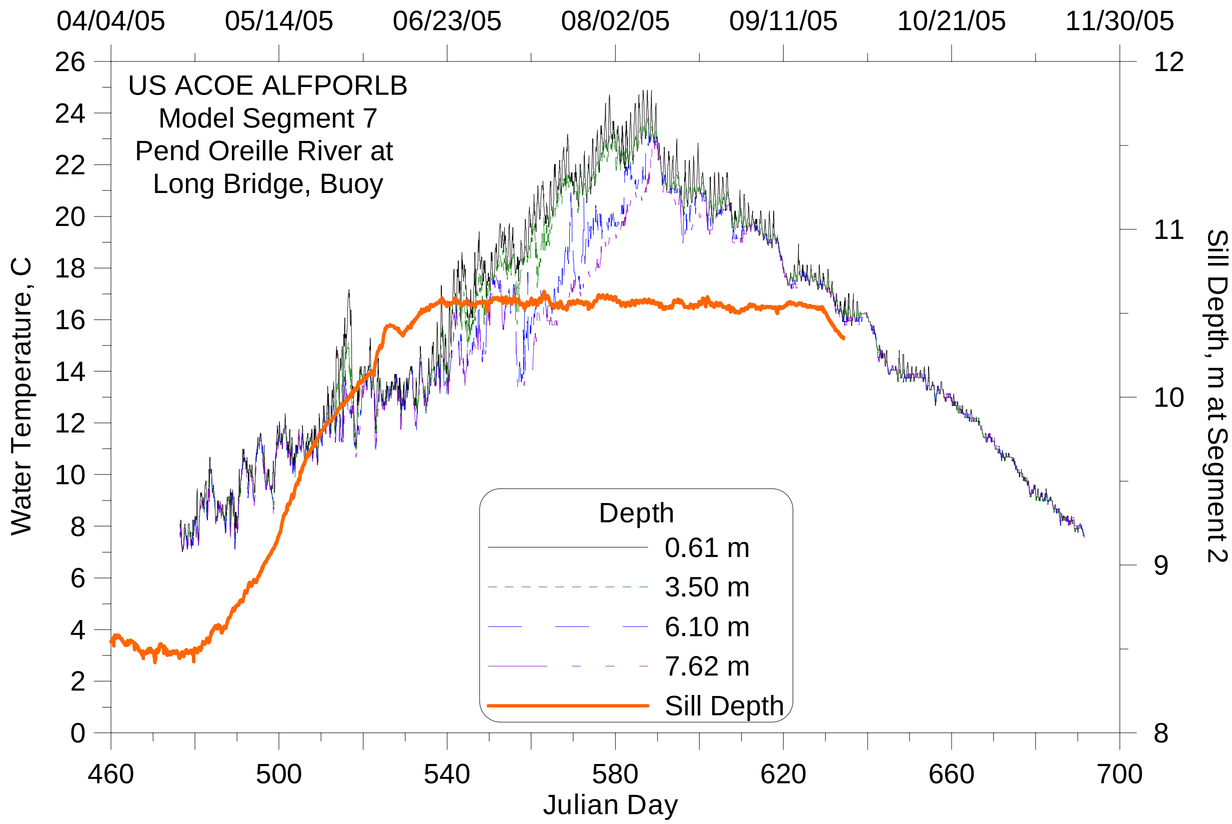


Figure 20: Continuous temperature data at various depths in the Pend Oreille River at Long Bridge, 2005.

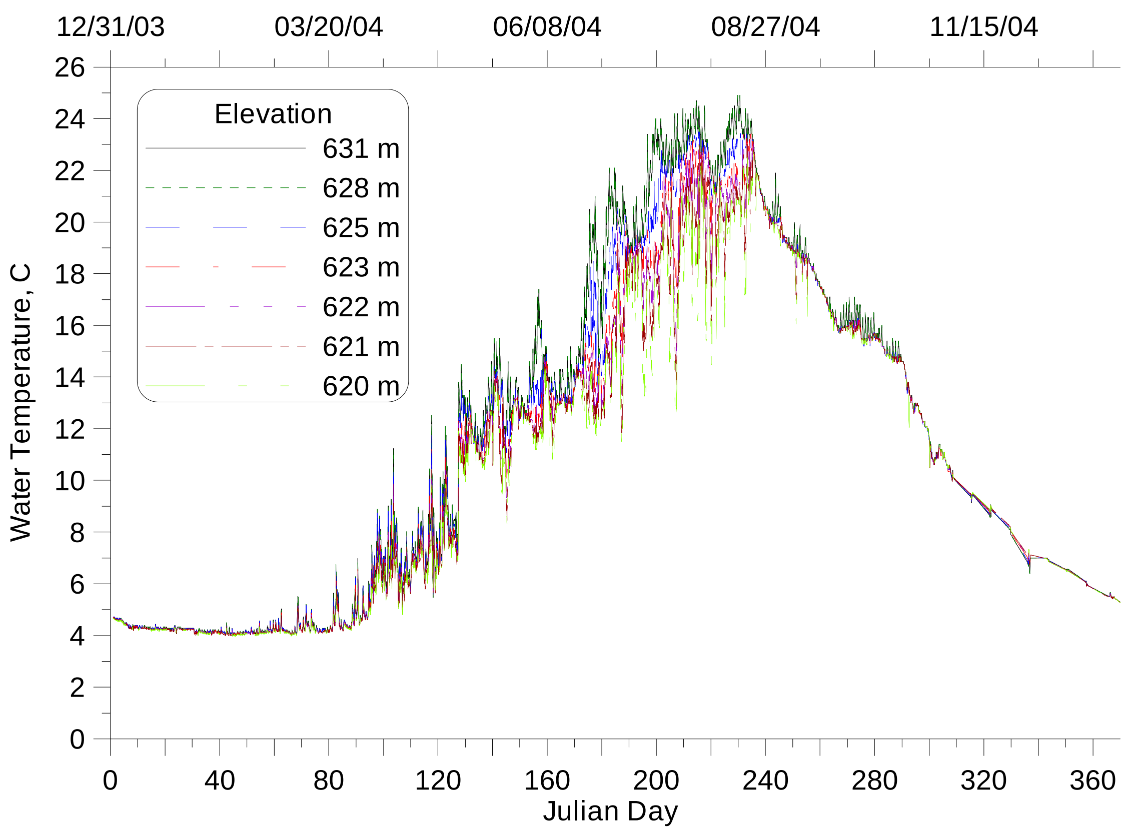


Figure 21: Model upstream water temperature boundary condition, 2004.

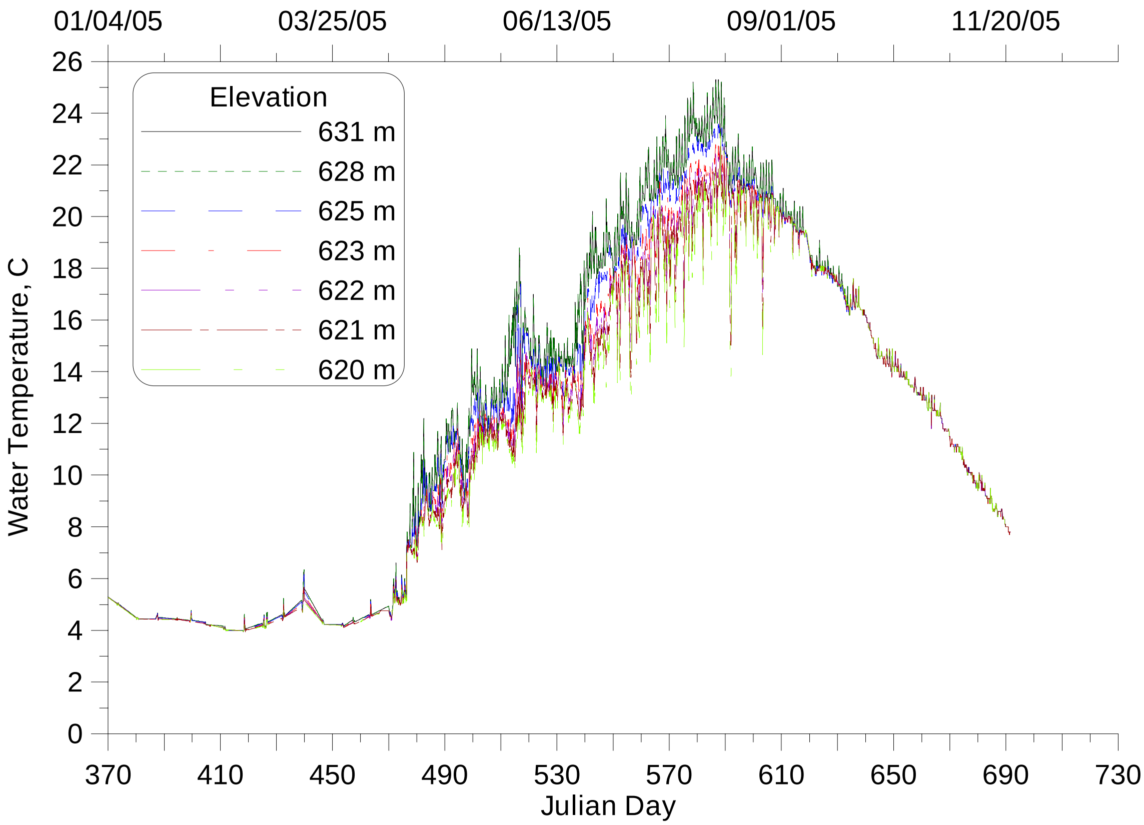


Figure 22: Model upstream water temperature boundary condition, 2005.

Water Quality

Water quality data was obtained for several different agencies and sources to develop the model input files and for use in the model calibration. Appendix A has a map indicating the location of monitoring sites and a table listing the sites and extent of data.

The constituent concentrations for the upstream boundary were estimated using dissolved oxygen, pH, chlorophyll a, ammonia nitrogen (NH_4-N), nitrite-nitrate nitrogen (NO_3-N), soluble reactive phosphorus (PO_4-P), total phosphorus, alkalinity, total organic carbon (TOC) and dissolved organic carbon (DOC) data.

Constituent concentrations used in the upstream boundary condition were plotted in Figure 23 through Figure 25. The equations used in developing the constituent file for the upstream boundary were:

Algae:

$$\sum \Phi_{algae} = \Phi_{algae(total)} = \Phi_{Chl\_a(total)} \times \text{Algae\_to\_Chla\_ratio} \quad (1)$$

Algae_to_Chla_Ratio = 100, this is the ratio between algae biomass and chlorophyll a mass

Total Organic Matter (TOM)

$$\Phi_{TOM} = \frac{\Phi_{TOC}}{\delta_C} - \sum \Phi_{algae} \quad (2)$$

$\delta_C = 0.45$, carbon-biomass ratio

Φ_{TOC} : Total Organic Carbon, from regression

Dissolved Organic Matter (DOM)

$$\Phi_{DOM} = \frac{\Phi_{DOC}}{\delta_C} \quad (3)$$

Φ_{DOC} : Dissolved Organic Carbon

POM (particulate organic matter) or Detritus:

$$\Phi_{POM} = \Phi_{TOM} - \Phi_{DOM} \quad (4)$$

LDOM (Labile Dissolved Organic Matter)

$$\Phi_{LDOM} = f_{LDOM}\Phi_{DOM} \quad (5)$$

$f_{LDOM} = 0.50$

RDOM (Refractory Dissolved Organic matter)

$$\Phi_{RDOM} = (1 - f_{LDOM})\Phi_{DOM} \quad (6)$$

LPOM (labile particulate organic matter)

$$\Phi_{LPOM} = f_{LPOM}\Phi_{POM} \quad (7)$$

$f_{LPOM} = 0.5$

RPOM (refractory particulate organic matter)

$$\Phi_{RPOM} = (1 - f_{LPOM})\Phi_{POM} \quad (8)$$

ISS (inorganic suspended solids):

$$\Phi_{ISS} = \Phi_{TNVSS} \quad (9)$$

Φ_{TNVSS} : Total non-volatile suspended solids, from data

Total Inorganic Carbon:

$$\Phi_{TIC} = function(\Phi_{alk} + pH + Temp) \quad (10)$$

Φ_{alk} : Alkalinity, used regression developed from data

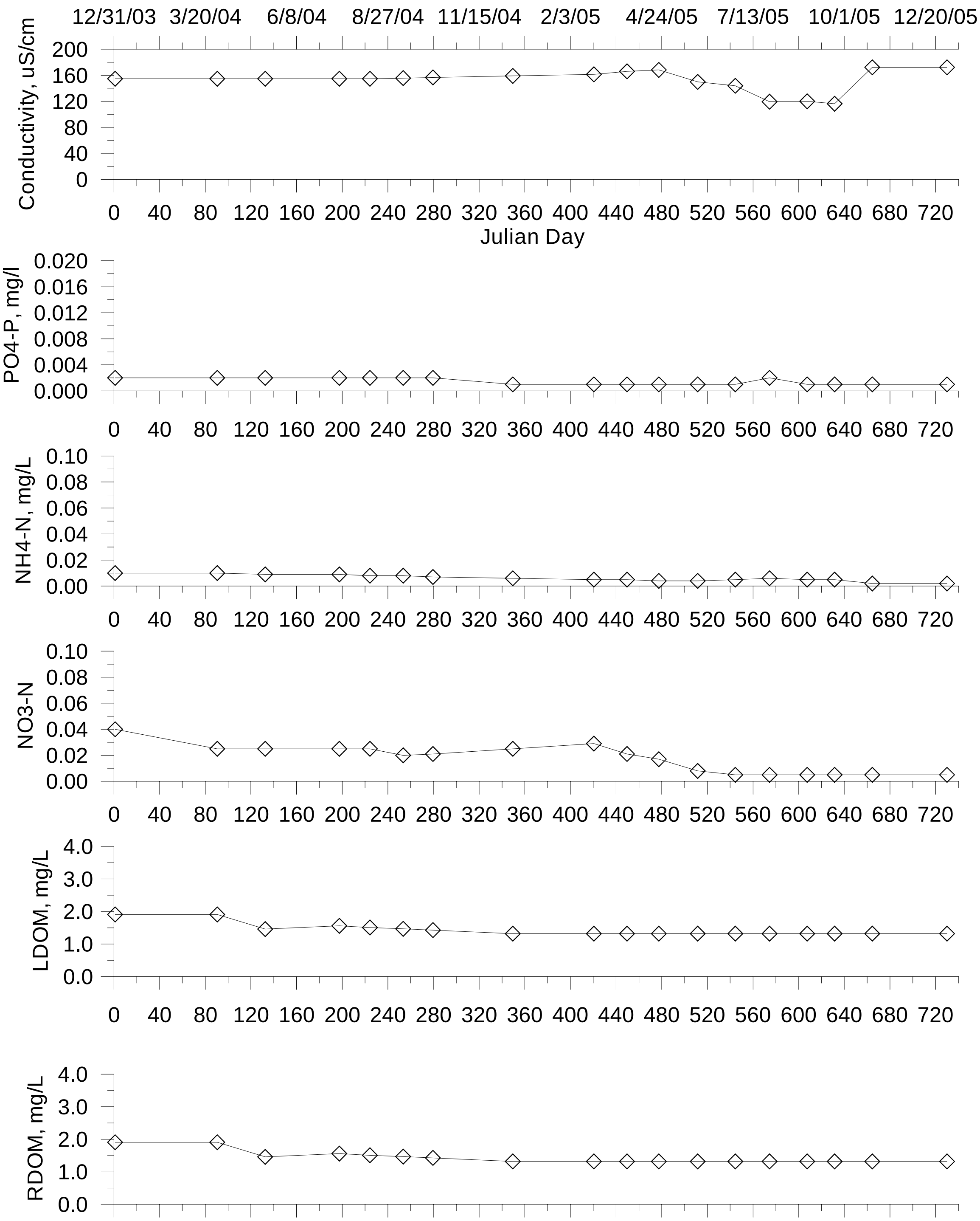


Figure 23: Constituent Concentrations for upstream boundary condition.

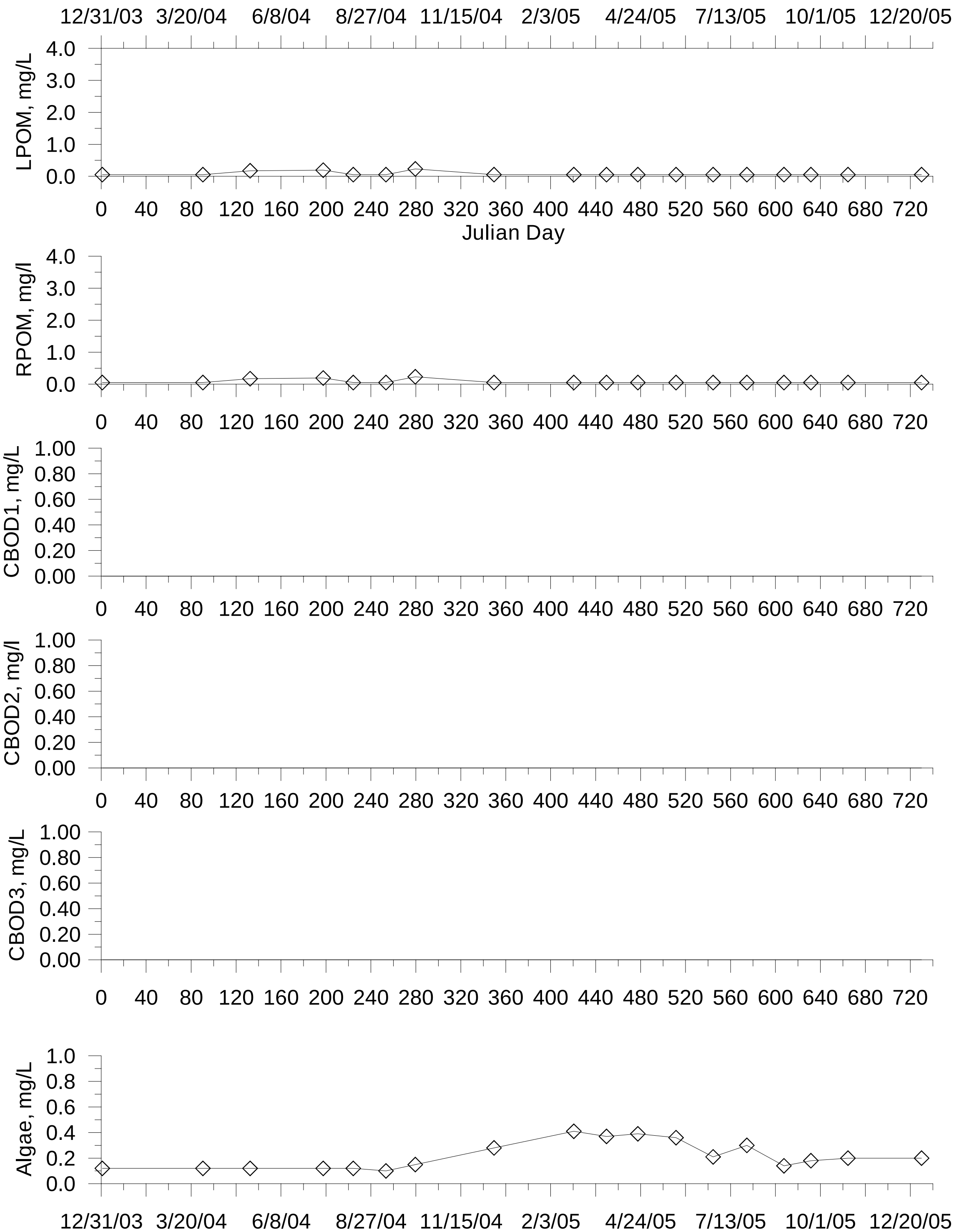


Figure 24: Constituent Concentrations for upstream boundary condition.

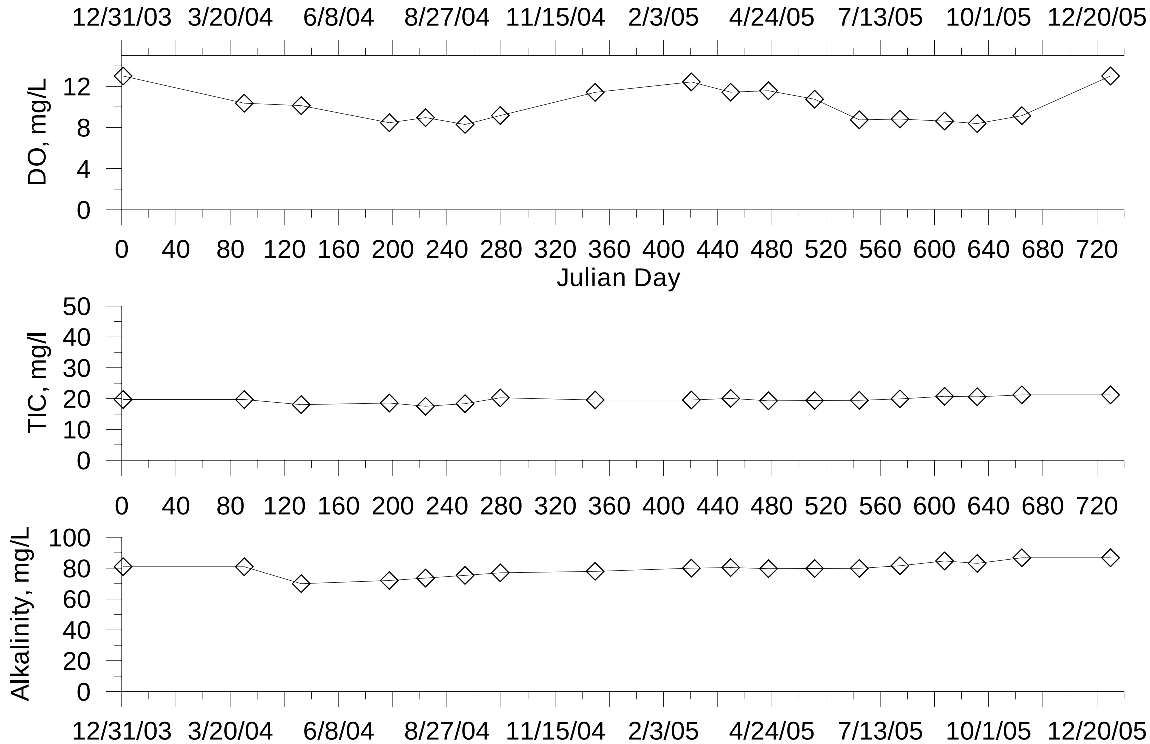


Figure 25: Constituent Concentrations for upstream boundary condition.

Downstream Boundary Conditions

<u>Hydrodynamics</u>

The downstream boundary condition for the Pend Oreille River model was based on the discharge out of Albeni Falls Dam. There are two data sets recorded near the dam. The first is the USGS gage just below the dam at Newport (USGS 12395500). The second data set is the total flow through the dam structure including the turbines and the spillway monitored by the US ACOE (ALF). Figure 26 compares the discharges from the two sites. The data collected by the USGS was considered to be more accurate since there are often larger errors associated with turbine flow rates than the stage-flow relationships on the river. Figure 27 and Figure 28 show time series plots of the river discharge data for 2004 and 2005, respectively.

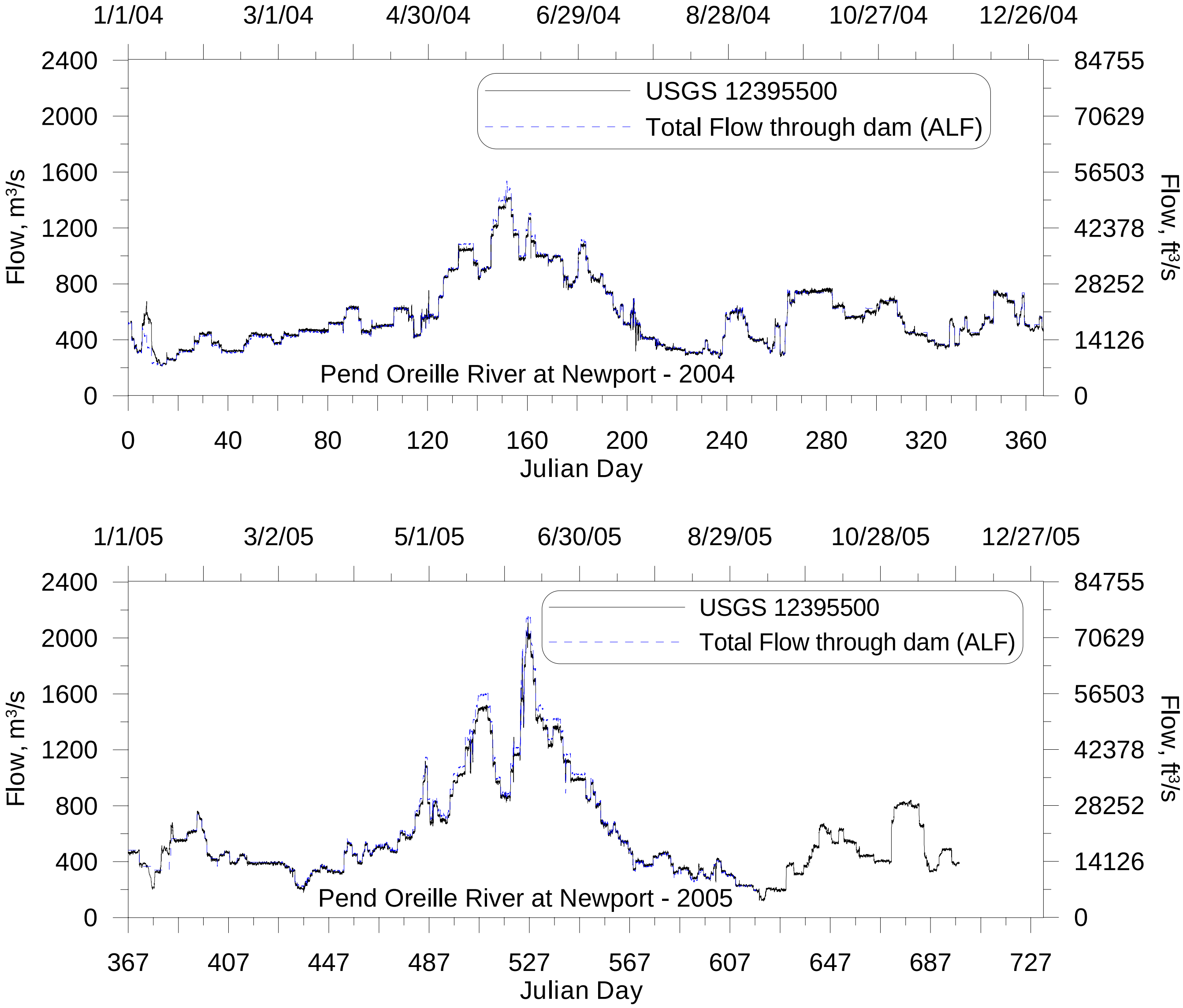


Figure 26: Pend Oreille River flow below Albeni Falls Dam comparison, 2004 and 2005.

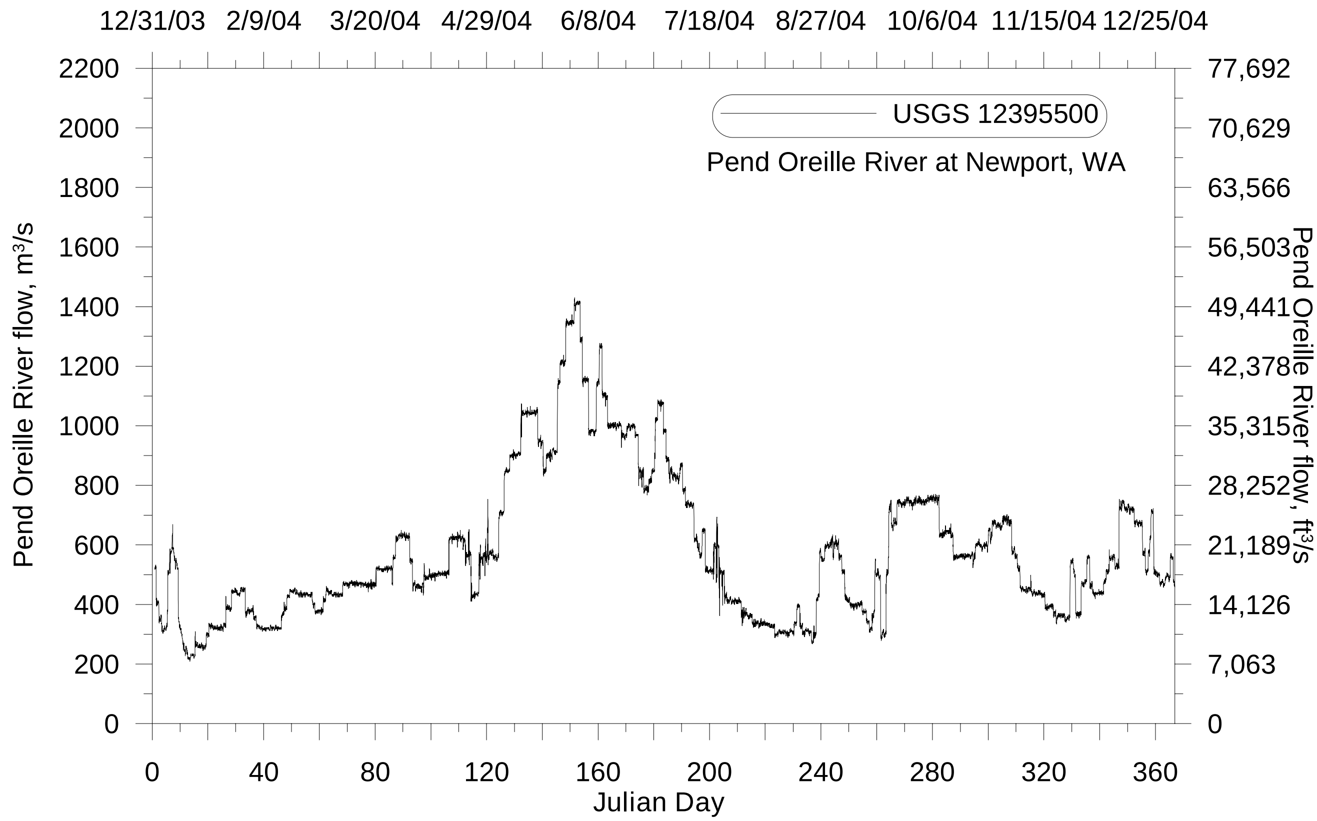


Figure 27: Pend Oreille River flow below Albeni Falls Dam, 2004.

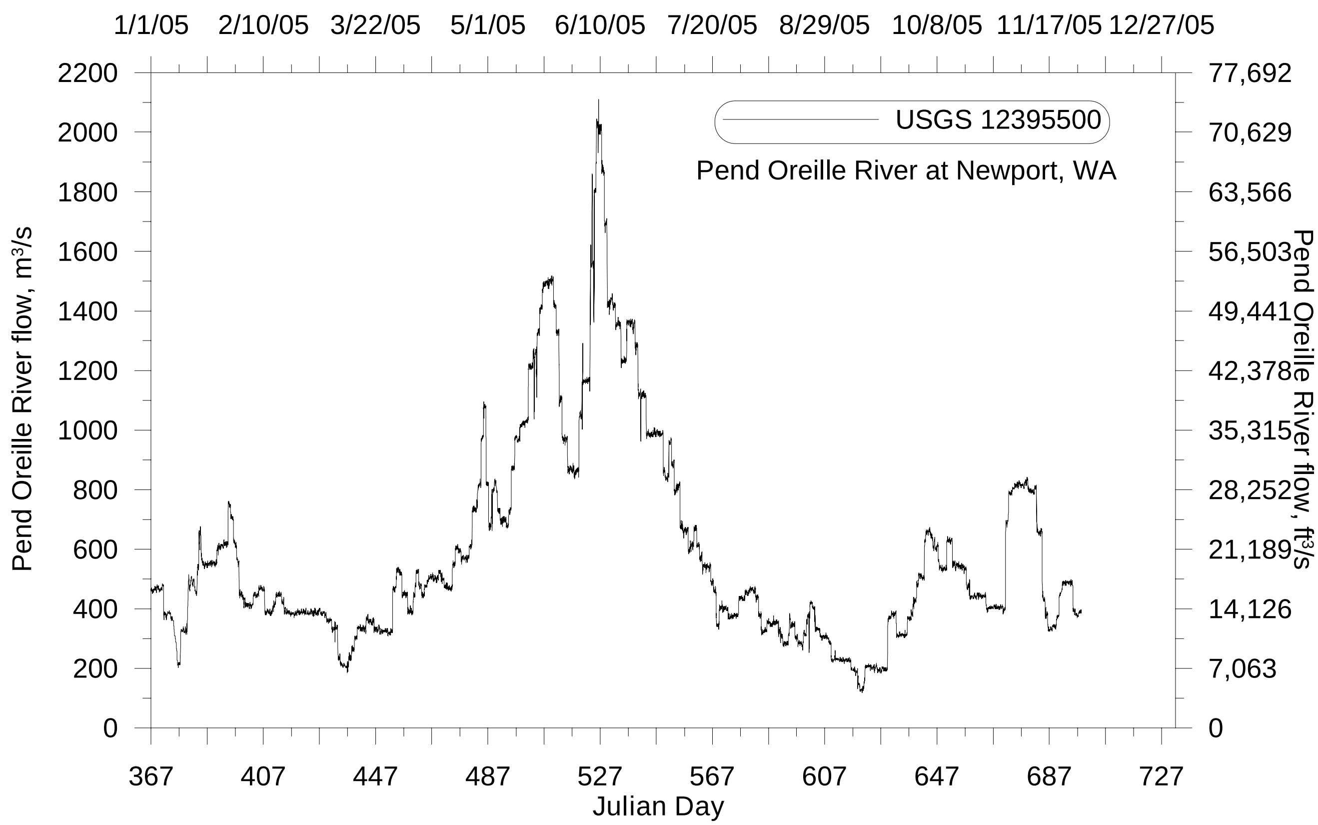


Figure 28: Pend Oreille River flow below Albeni Falls Dam, 2005.

Tributaries

There are a total of 15 tributaries included in the model as shown in Figure 29. Table 3 lists the tributaries included in the model. The list includes many small streams which are characterized by only one flow grab sample and one large river, the Priest River, which is monitored continuously. Three of the tributaries are discharges from local municipal wastewater treatment plants (WWTPs). The three remaining tributaries were included in the model as branch inflows because the channel geometry where the tributaries enter the Pend Oreille River was characterized by separate model branches. The three branch inflows are listed in Table 4.

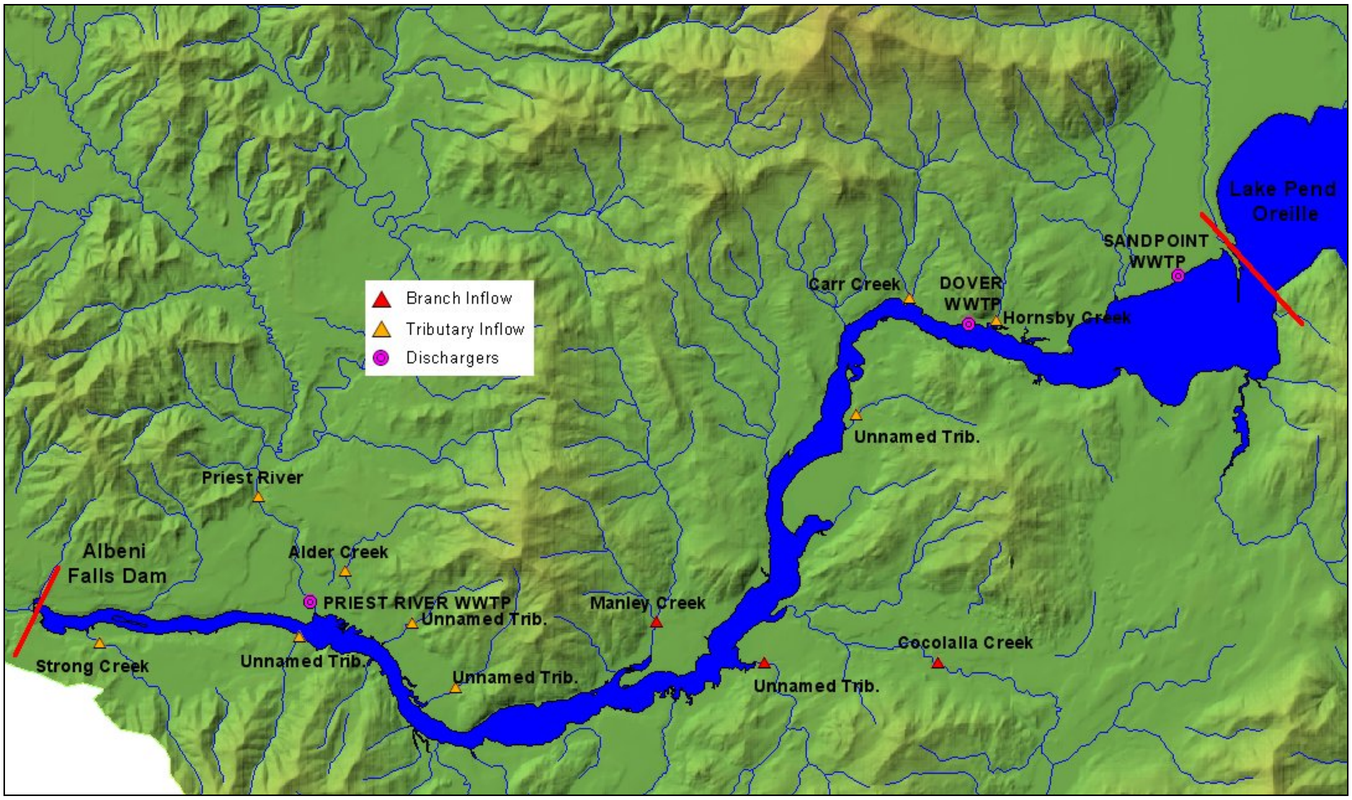


Figure 29: Tributary inflows to the Pend Oreille River.

Table 3: Tributary and discharger inflows to the Pend Oreille River.

Tributary	Name	Segment	Flow, m^3/s
1	Hornsby Creek	35	0.024
2	Carr Creek	45	0.039
3	Unnamed Trib. to Pend Oreille	63	0.000
4	Unnamed Trib. to Pend Oreille	135	0.005
5	Unnamed Trib. to Pend Oreille	143	0.001
6	Alder Creek	147	0.000
7	Priest River	151	Variable
8	Unnamed Trib. to Pend Oreille	152	0.003
9	Strong Creek	177	0.003
10	City of Sandpoint, ID WWTP discharge	11	Variable
11	City of Dover, ID WWTP discharge	37	Variable
12	City of Priest River, ID WWTP discharge	151	Variable

Table 4: Tributary Inflows to the Pend Oreille River included as model branch inflows.

Branch	Name	Segment	Flow, m^3/s
4	Cocolalla Creek	201	0.049
5	Unnamed Trib. to Pend Oreille	208	0.004
6	Manley Creek	218	0.020

Inflow rates

Since most of the smaller tributaries are characterized by constant flows from one measurement, no time series plots were generated. The Priest River was monitored regularly by the USGS near the mouth of the river (USGS 12395000). Figure 30 and Figure 31 show time series plots of the Priest River inflow to the Pend Oreille River for 2004 and 2005, respectively.

The cities of Sandpoint, Dover and Priest River provided either daily or monthly discharge values for their wastewater treatment plants. Figure 32 and Figure 33 show time series plots of the City of Sandpoint WWTP discharge to the Pend Oreille River for 2004 and 2005, respectively. Figure 34 and Figure 35 show time series plots of the City of Dover WWTP discharge for 2004 and 2005, respectively. Figure 36 and Figure 37 show time series plots of the City of Priest River WWTP discharge for 2004 and 2005, respectively.

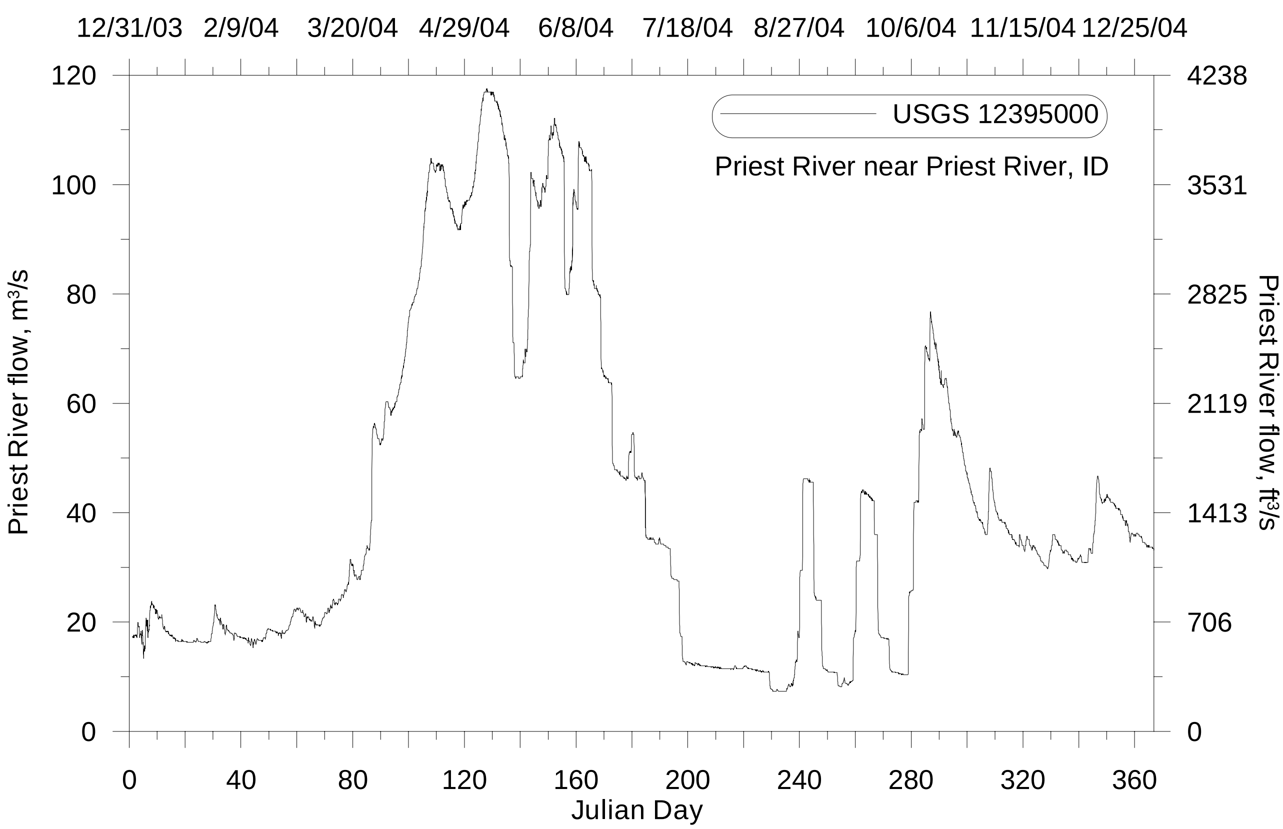


Figure 30: Priest River flow, 2004.

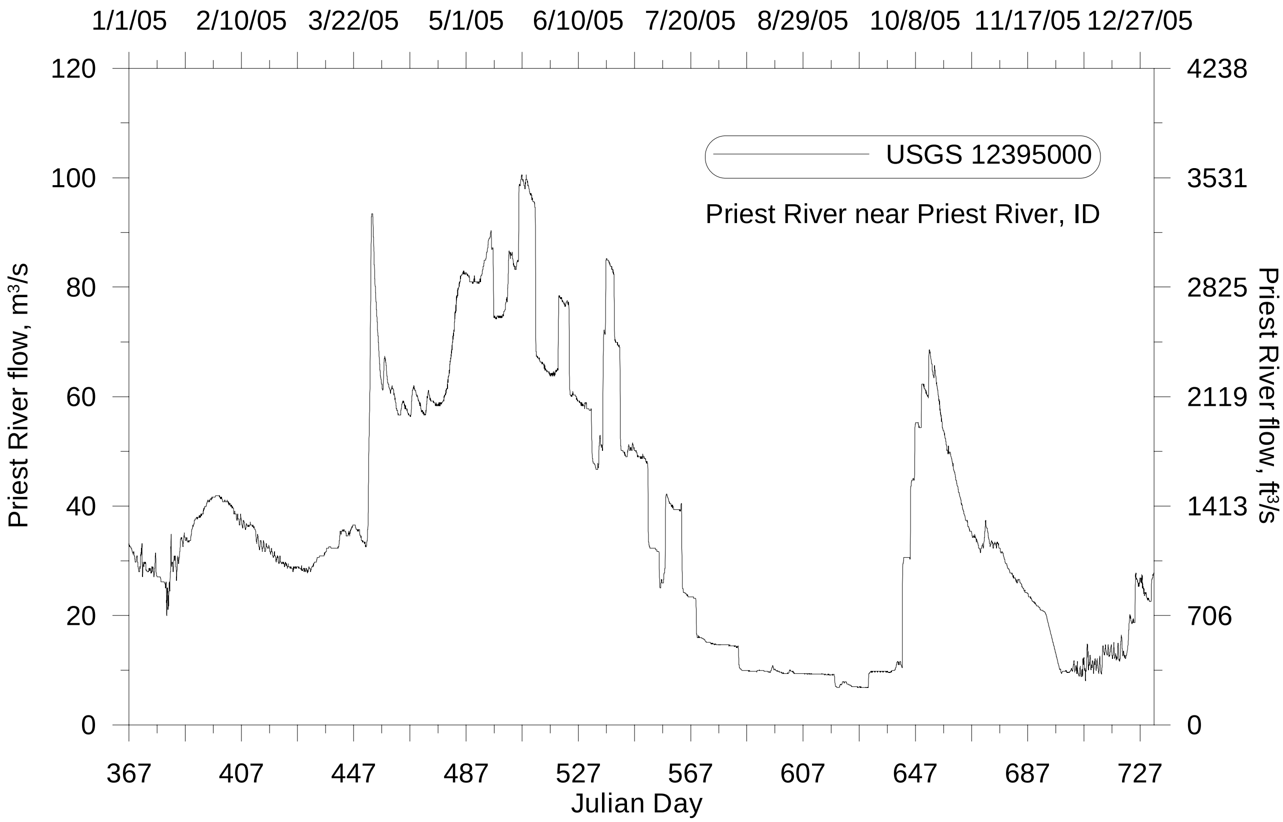


Figure 31: Priest River flow, 2005.

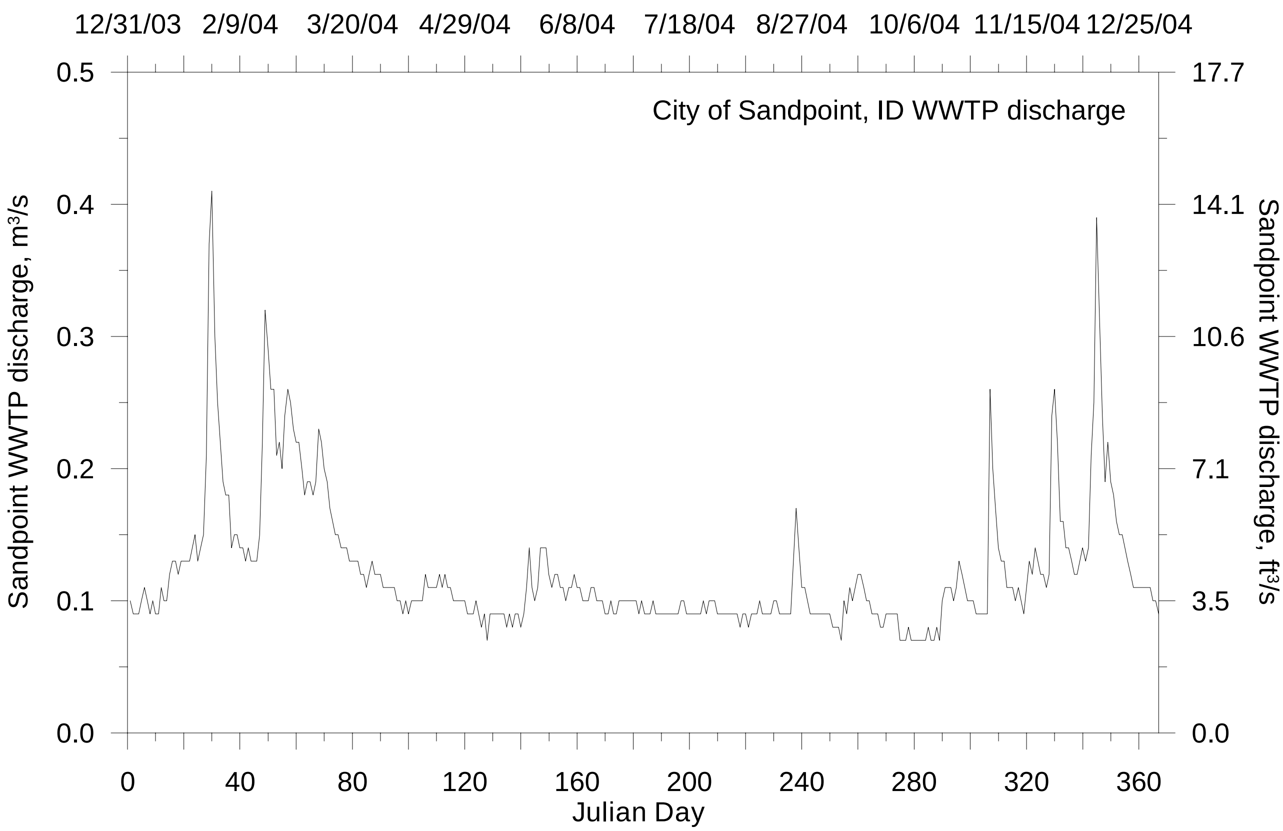


Figure 32: City of Sandpoint, ID wastewater treatment plant discharge, 2004.

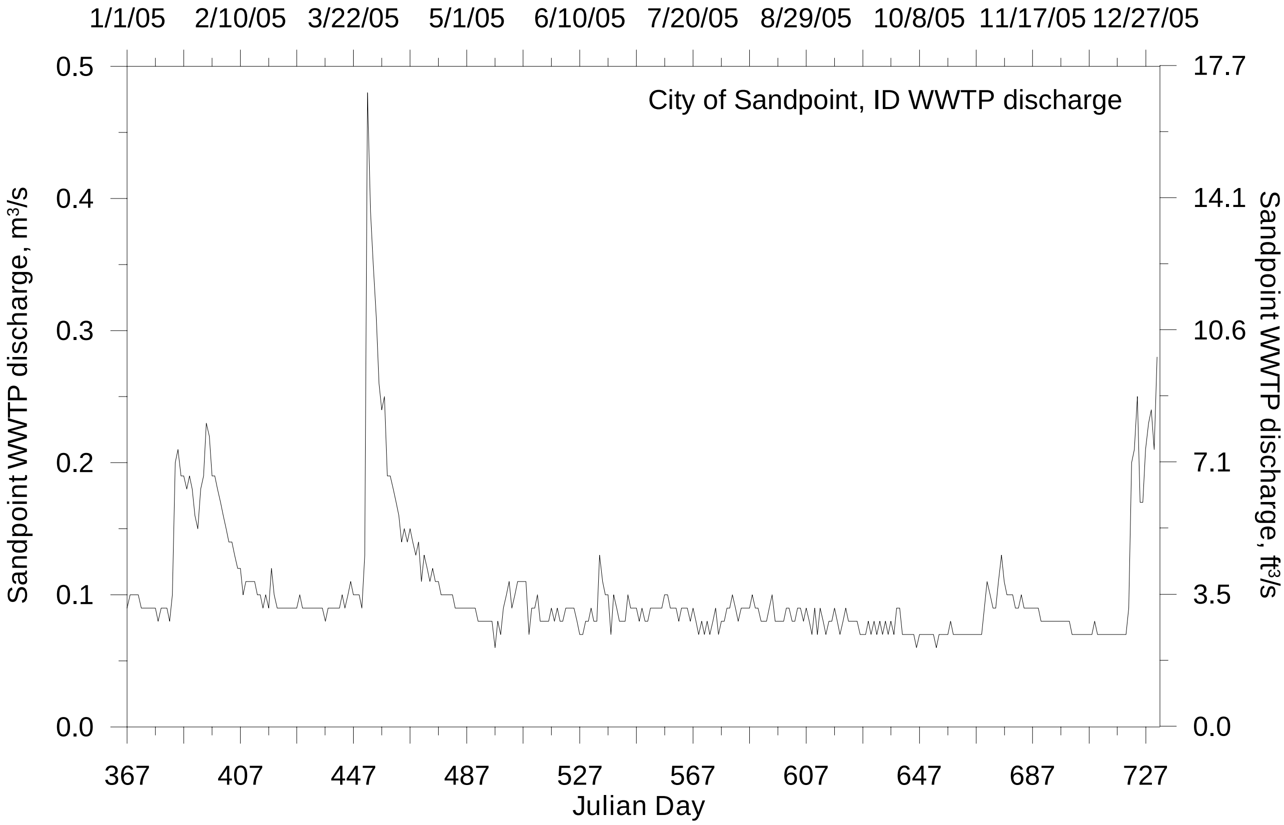


Figure 33: City of Sandpoint, ID wastewater treatment plant discharge, 2005.

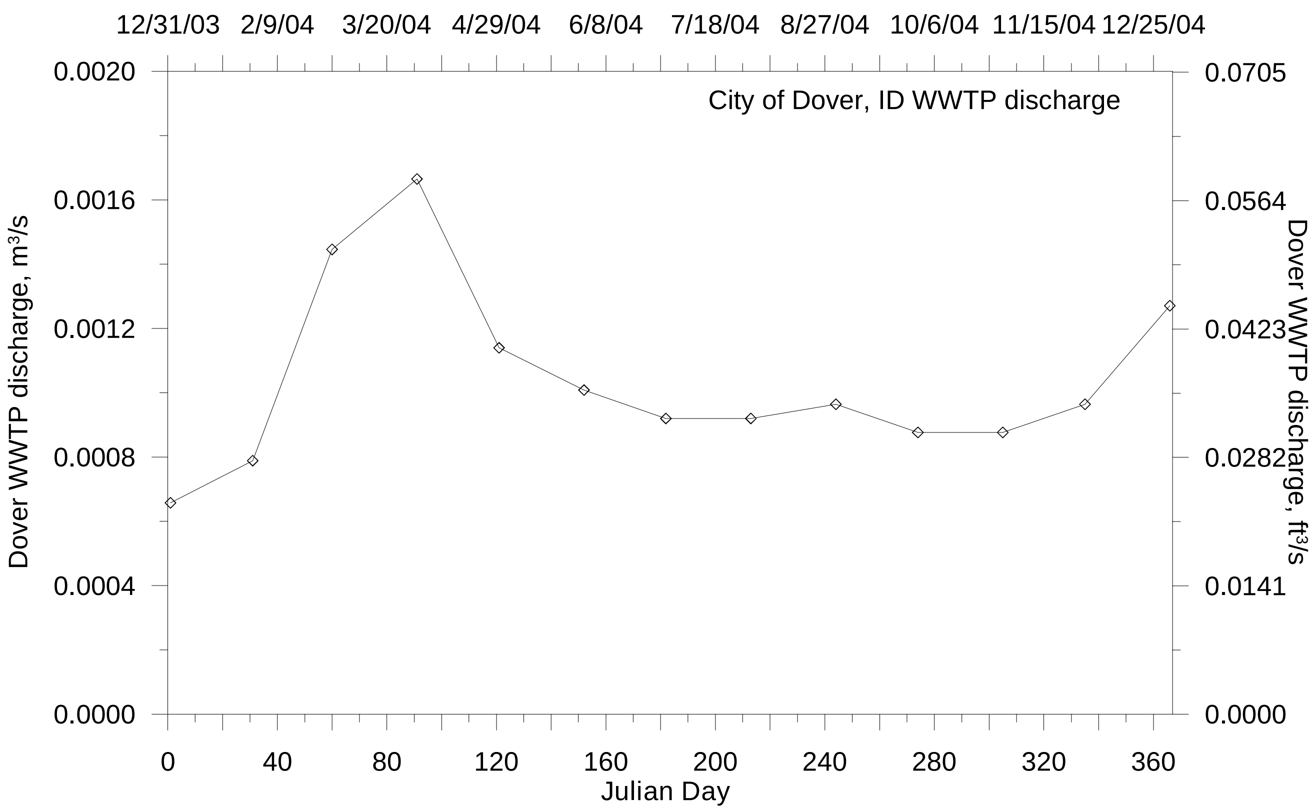


Figure 34: City of Dover, ID wastewater treatment plant discharge, 2004.

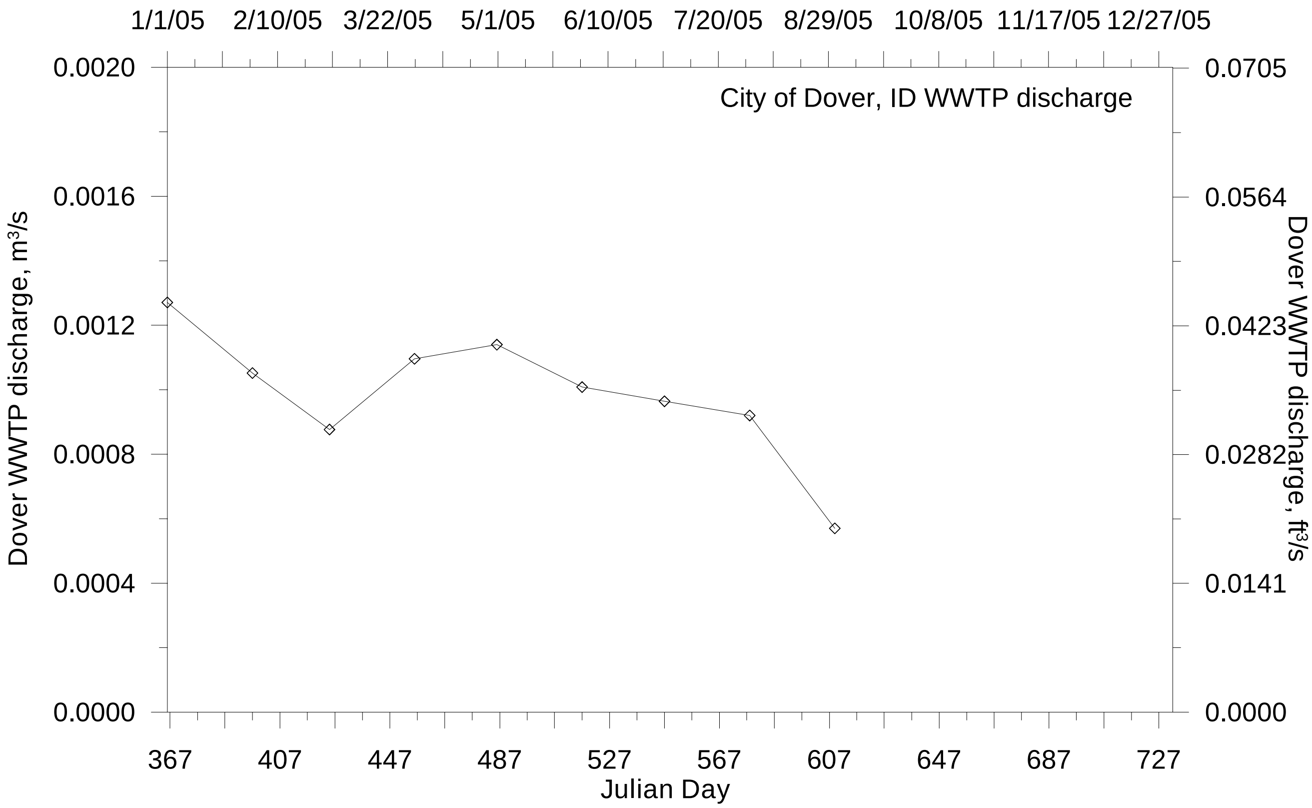


Figure 35: City of Dover, ID wastewater treatment plant discharge, 2005.

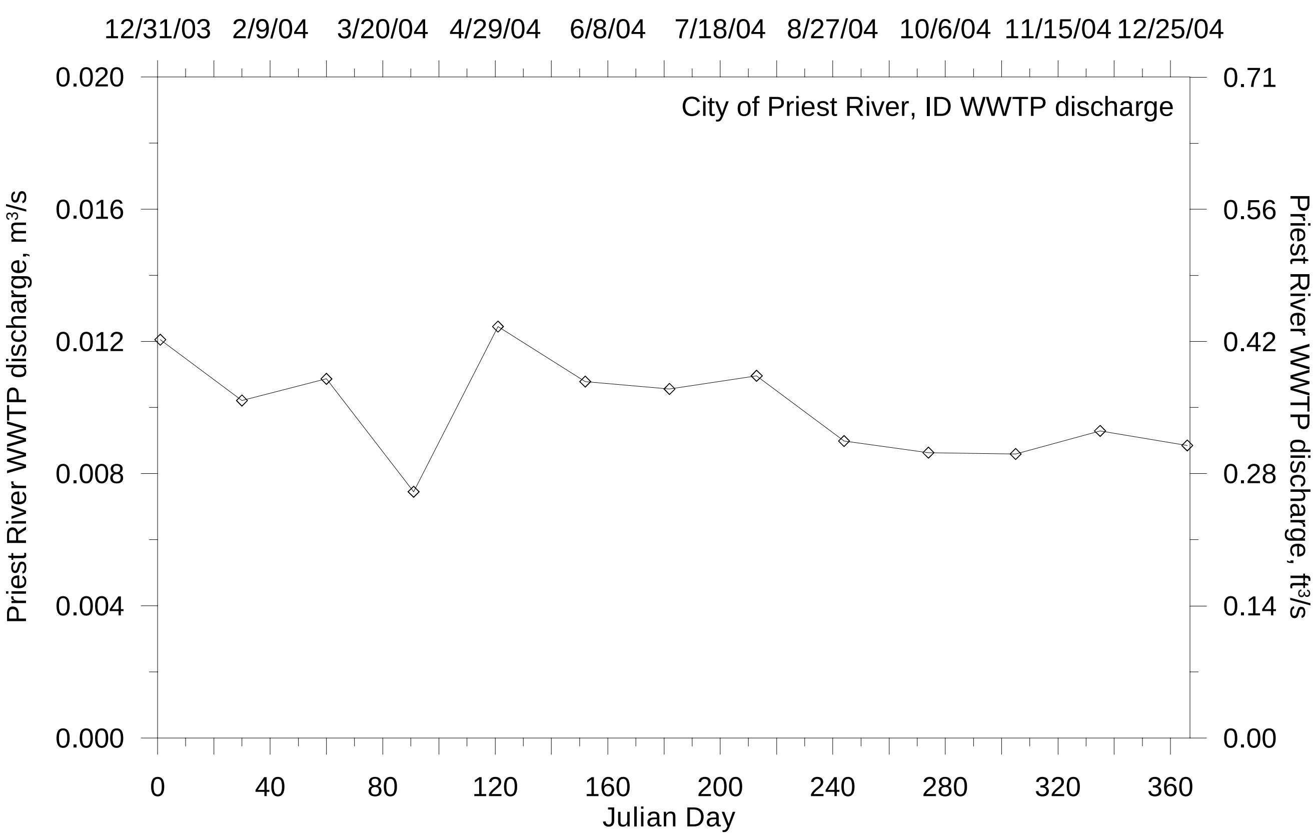


Figure 36: City of Priest River, ID wastewater treatment plant discharge, 2004.

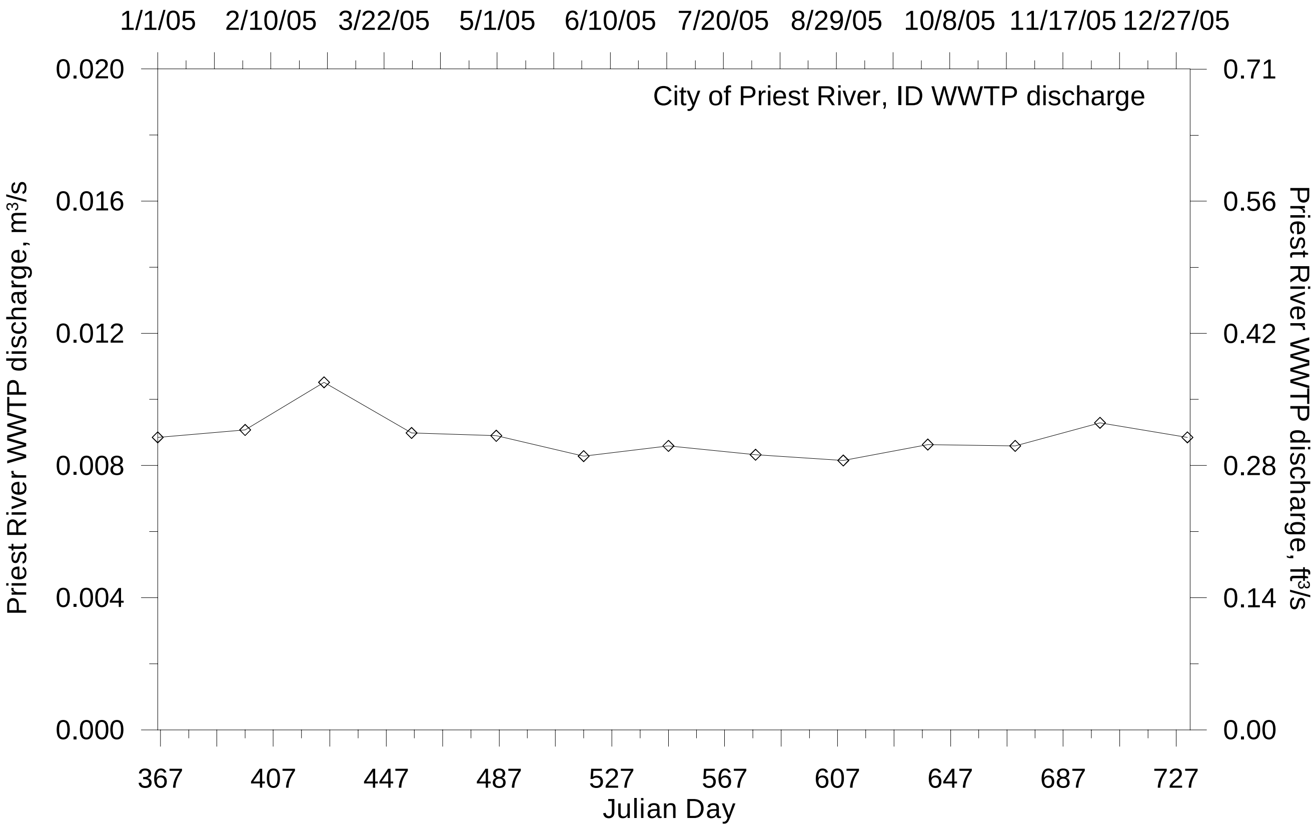


Figure 37: City of Priest River, ID wastewater treatment plant discharge, 2005.

Temperature

The Priest River was monitored by the USGS near the mouth of the river (USGS 12395000) from April or May to October or November for most years, except in 2004. Additionally, the U.S. Army Corps of Engineers monitored the river temperature in 2004 and 2005 at the same USGS gage station location (ALFPRIEST). In 2004, the data gap from January 1st to May 8th was filled using hourly averages of the water temperature across all years from 1998 to 2005. In 2005, the data from the USGS and U.S. Army Corps of Engineers were used but the data gaps from January 17th to April 12th and from November 22nd to December 31st were filled using hourly averages of the water temperature across all years from 1998 to 2005.

Figure 38 and Figure 39 show time series plots of the Priest River inflow temperature for 2004 and 2005, respectively. Since most of the smaller tributaries are characterized by low flows and no temperature data, the temperature record for the Priest River was used for each of these minor inflows.

The cities of Sandpoint, Dover and Priest River provided either daily or monthly discharge temperature values for their wastewater treatment plants. Figure 40 and Figure 41 show time series plots of the City of Sandpoint WWTP discharge temperature for 2004 and 2005, respectively. Figure 42 and Figure 43 show time series plots of the City of Dover WWTP discharge temperature for 2004 and 2005, respectively. Figure 44 and Figure 45 show time series plots of the City of Priest River WWTP discharge for 2004 and 2005, respectively.

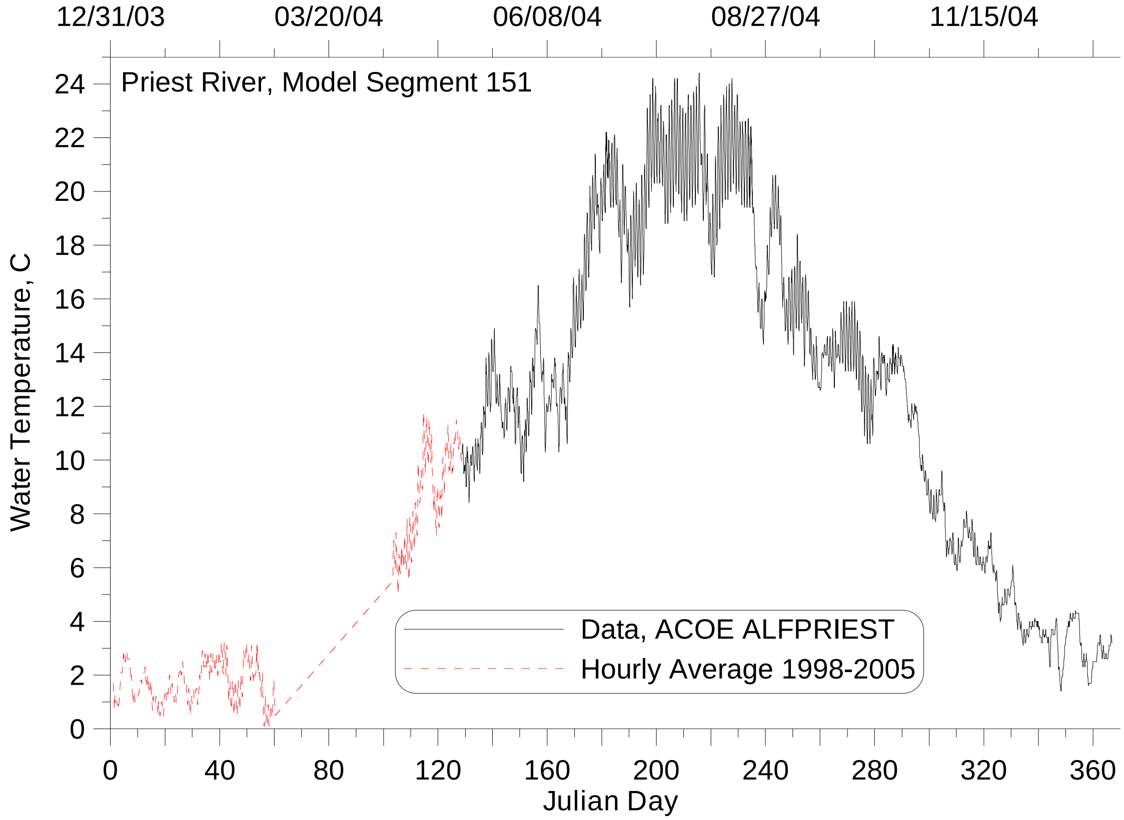


Figure 38: Priest River water temperature, 2004.

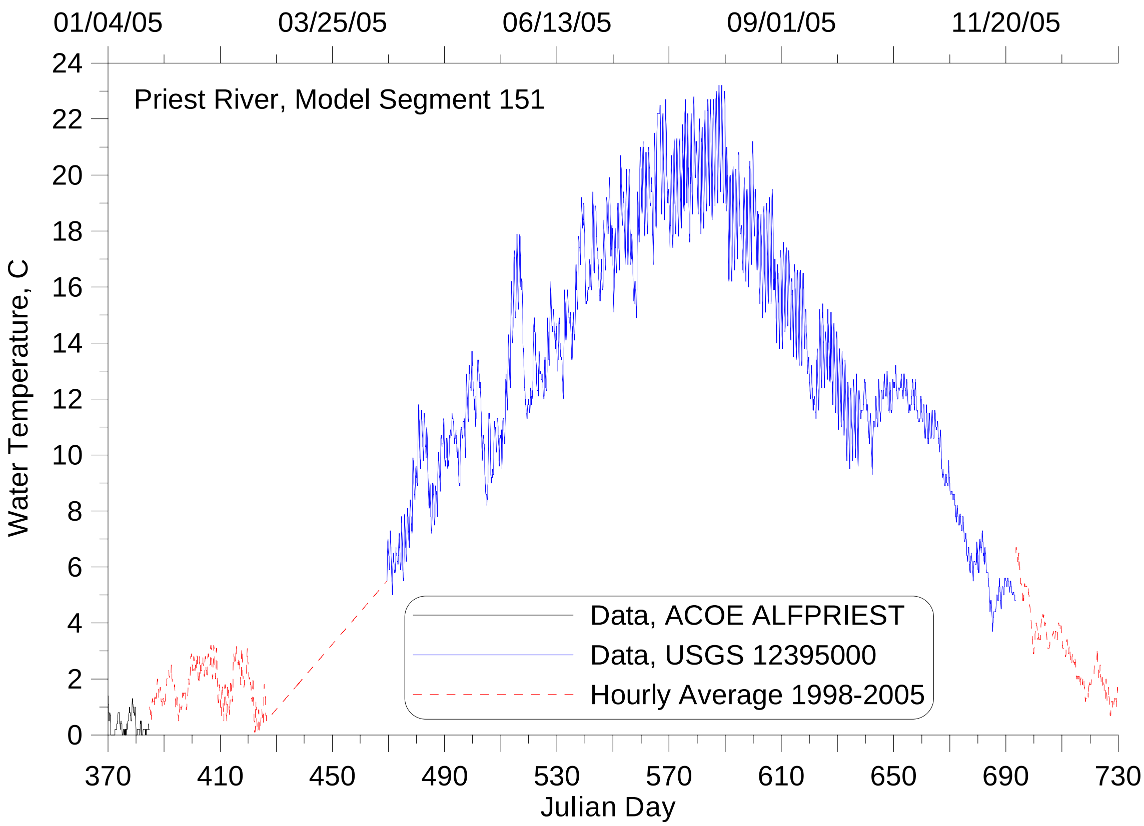


Figure 39: Priest River water temperature, 2005.

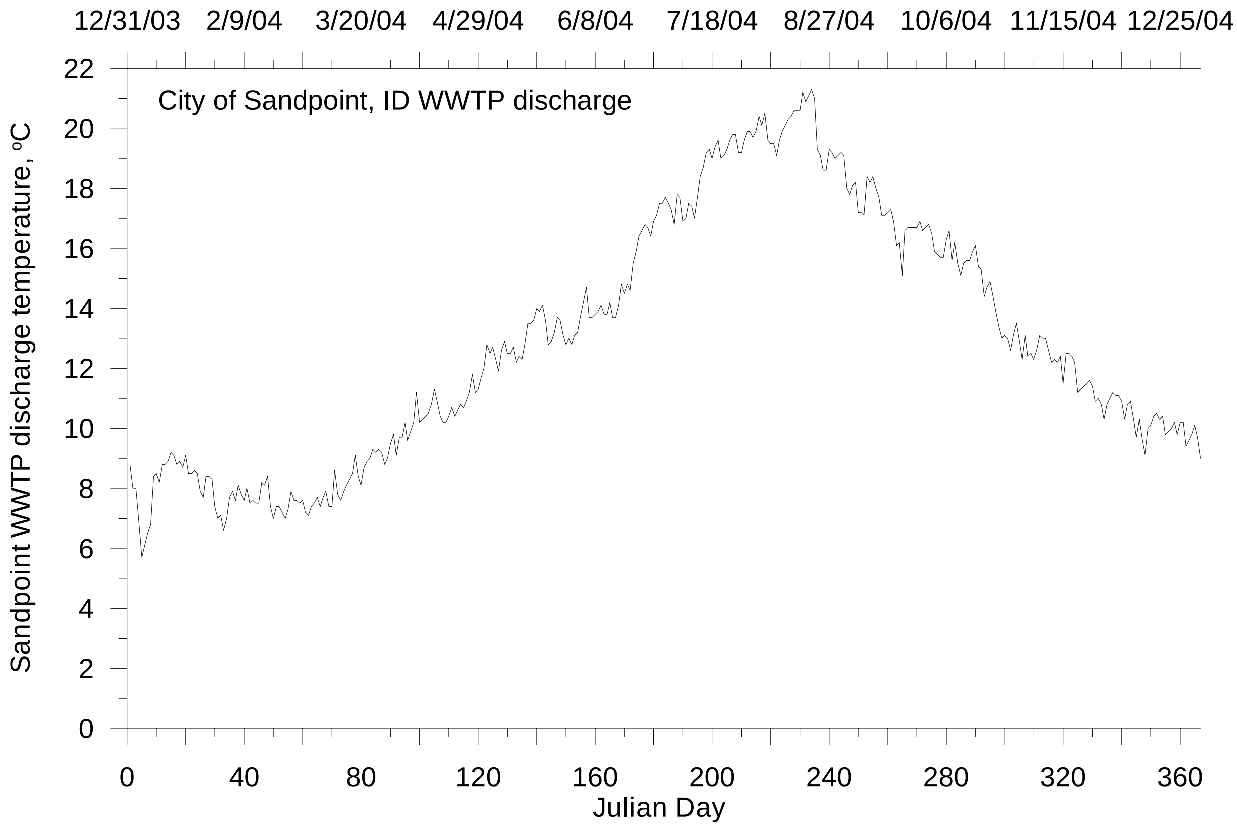


Figure 40: City of Sandpoint, ID wastewater treatment plant discharge temperature, 2004.

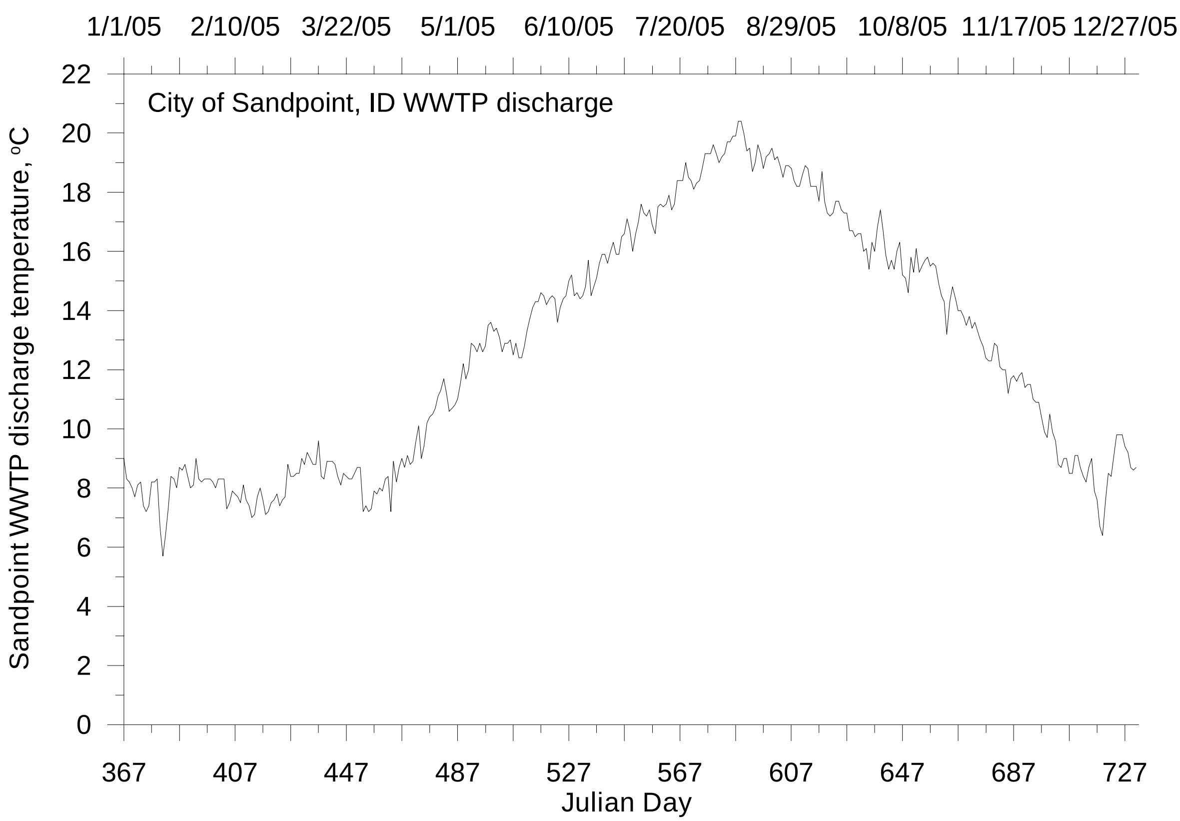


Figure 41: City of Sandpoint, ID wastewater treatment plant discharge temperature, 2005.

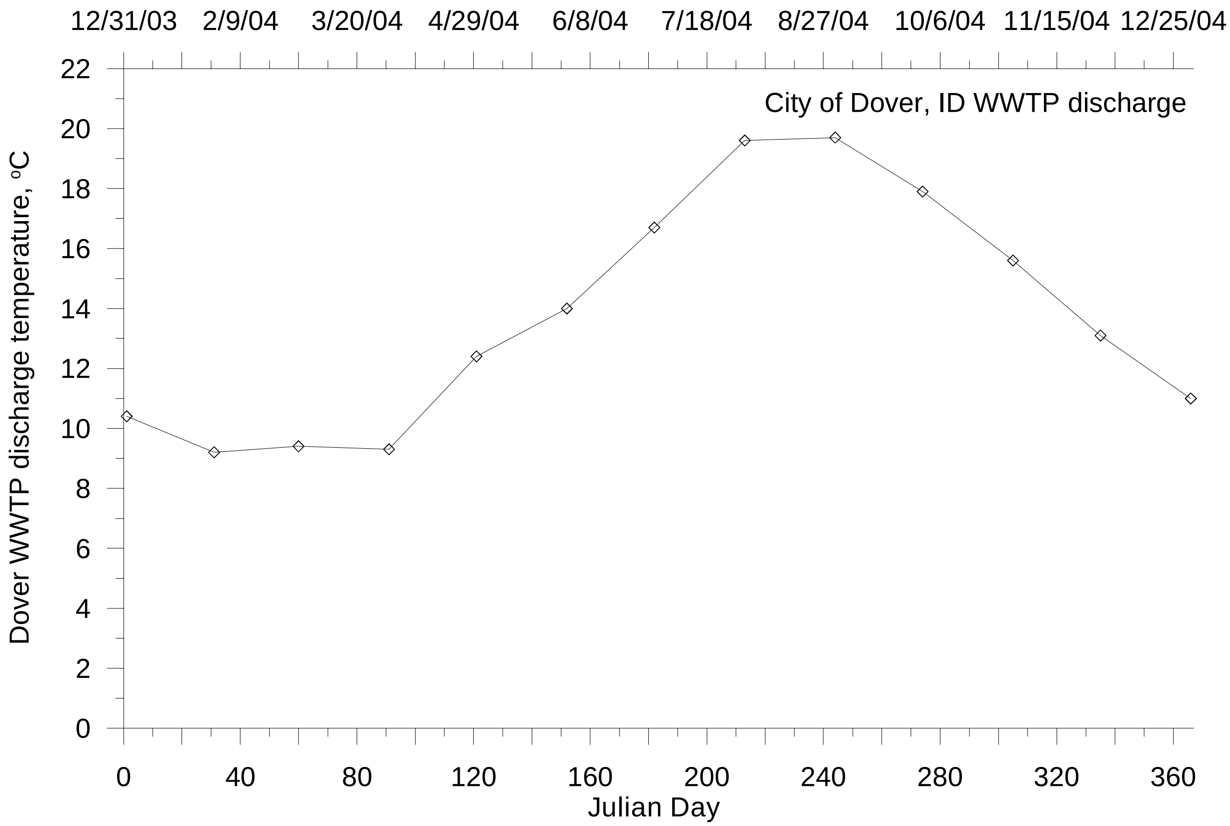


Figure 42: City of Dover, ID wastewater treatment plant discharge temperature, 2004.

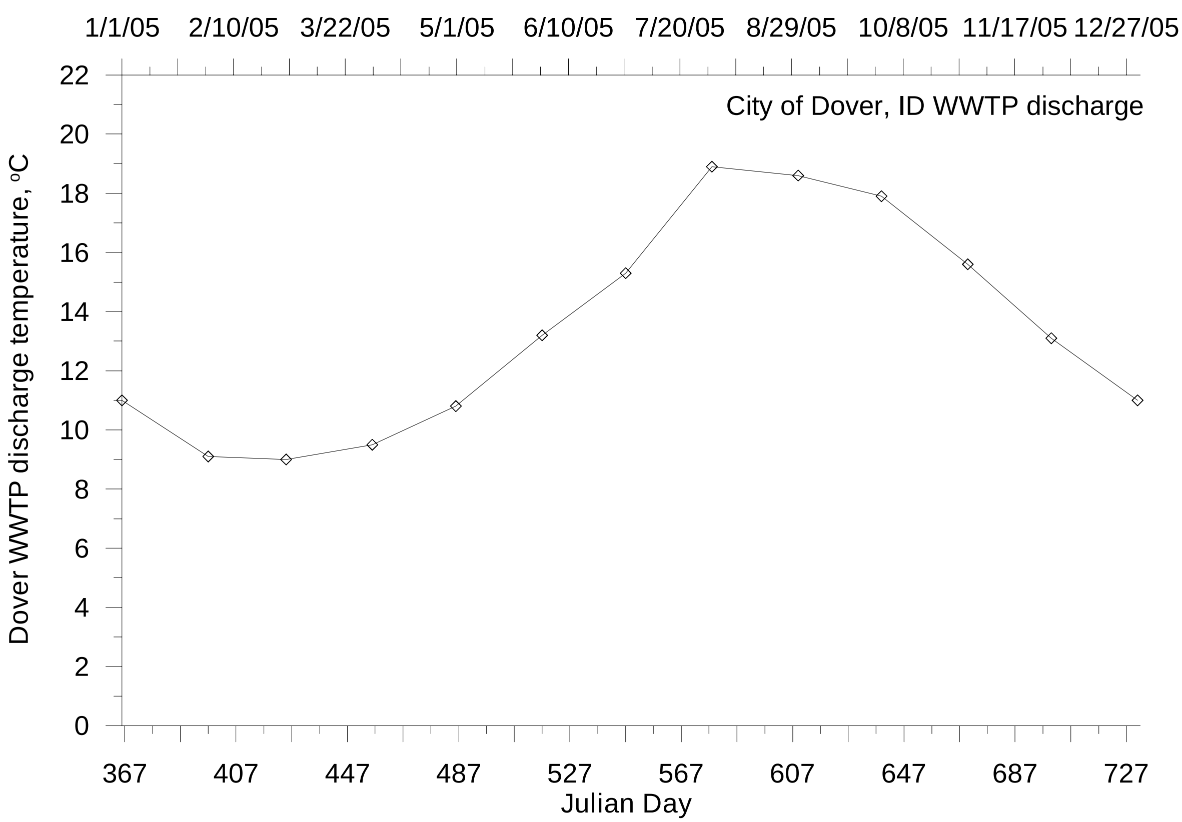


Figure 43: City of Dover, ID wastewater treatment plant discharge temperature, 2004.

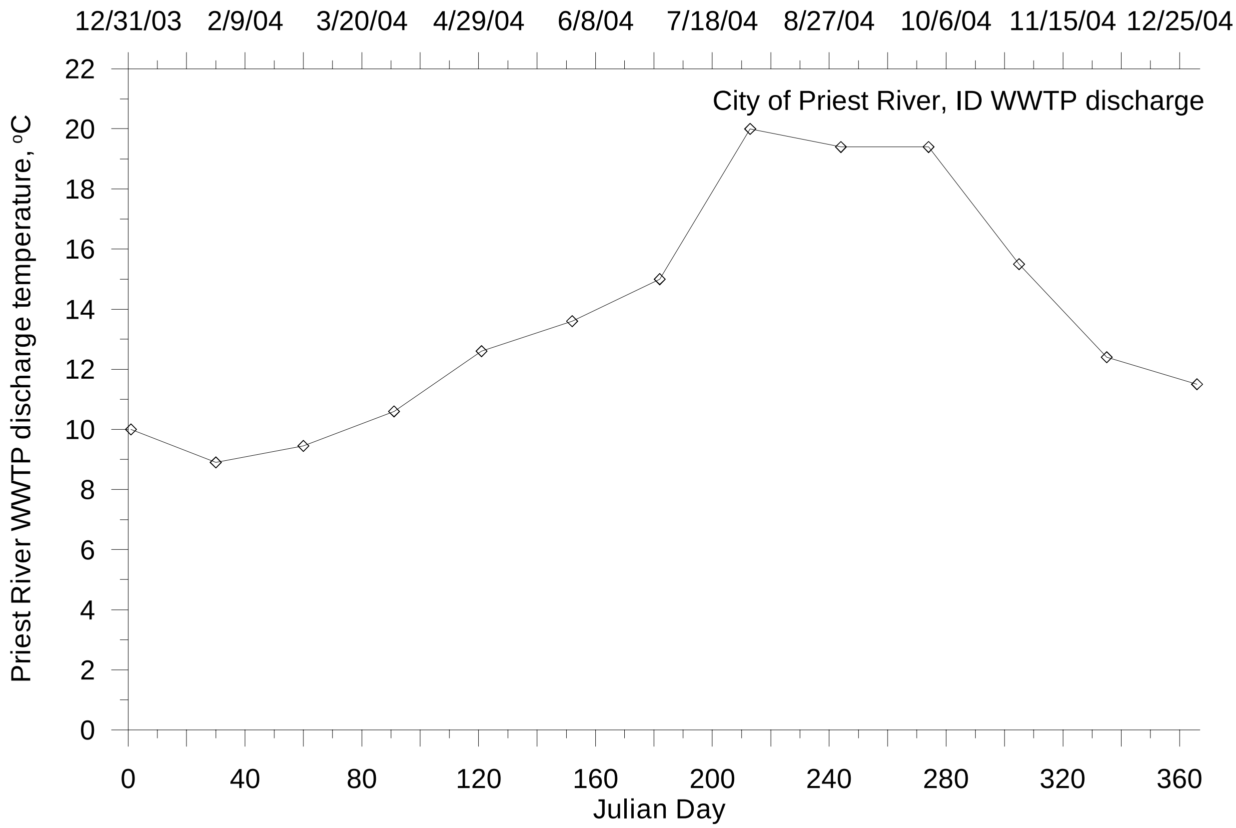


Figure 44: City of Priest River, ID wastewater treatment plant discharge temperature, 2004.

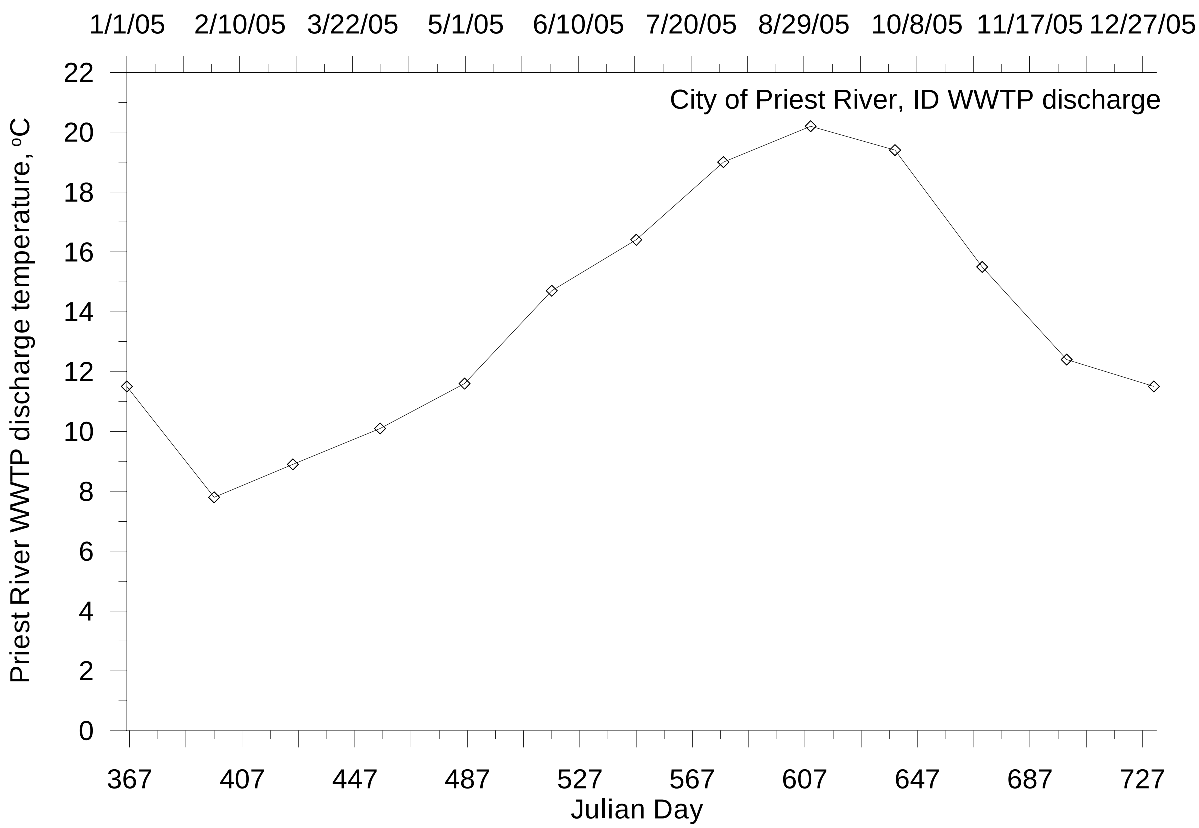


Figure 45: City of Priest River, ID wastewater treatment plant discharge temperature, 2004.

Water Quality

Except for the wastewater treatment plants, there were no data to describe the water quality of the tributaries. The constituent concentrations of the tributaries lacking data were assumed to be equivalent to that of the upstream boundary condition.

Water quality data from the wastewater treatment plants included ammonia nitrogen (NH4-N), nitrate-nitrogen (NO3-N), pH, dissolved ortho-phosphate (PO4-P), Total phosphorus (TP), Total Kjeldahl nitrogen, BOD-5. There were no phosphorus data available for the Dover and Priest River WWTP, so phosphorus concentrations of those WWTP's were assumed equal to that of Sandpoint WWTP.

CBOD was modeled using separate CBOD groups for each wastewater treatment plant: Sandpoint, Dover, and Priest River WWTP. This will facilitate accurate simulation of the oxygen demand exerted by effluent originating from each discharger since each CBOD group can be decayed at its own rate. Table 5 shows the CBOD decay compartments used in the model.

Table 5: WWTP and their corresponding CBOD compartment

CBOD compartment	Description
1	City of Sandpoint WWTP
2	City of Dover WWTP
3	City of Priest River WWTP

Since CBOD compartments were used, the concentration of organic matter originating from wastewater treatment plants, labile DOM, refractory DOM, labile POM and refractory POM, were set to zero. The dissolved oxygen concentrations of the effluent were assumed equal to 9 mg/l, and alkalinity was assumed to be equal to 100 mg/l. Inorganic carbon concentrations were estimated using pH data and the assumed alkalinity concentration.

Constituent concentrations used in for the Sandpoint WWTP were shown in Figure 46 through Figure 48. The City of Dover WWTP constituent concentrations were plotted in Figure 49 through Figure 51, and the City of Priest River WWTP constituent concentrations were shown in Figure 52 through Figure 54.

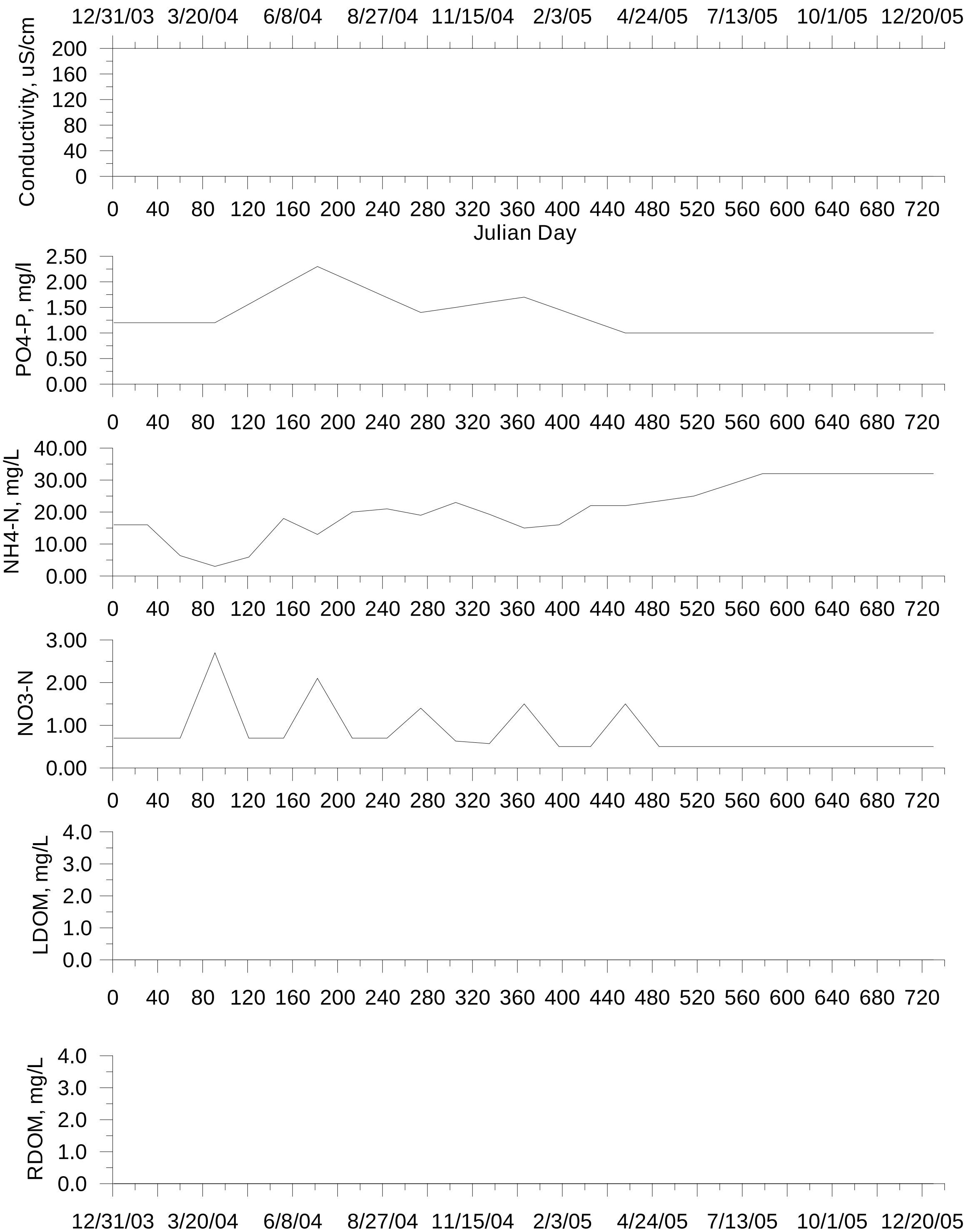


Figure 46: Constituent concentrations used for Sandpoint WWTP.

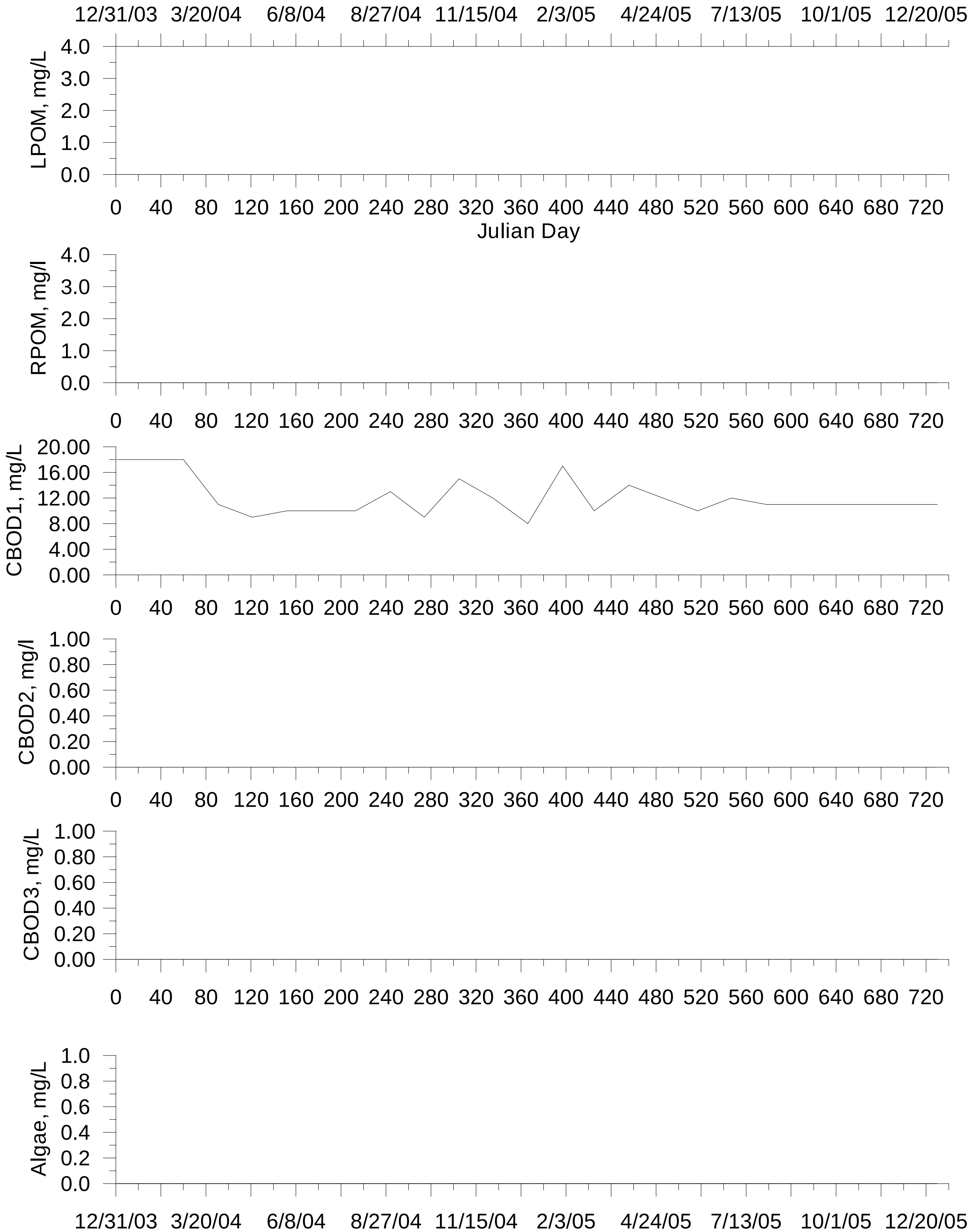


Figure 47: Constituent concentrations used for Sandpoint WWTP.

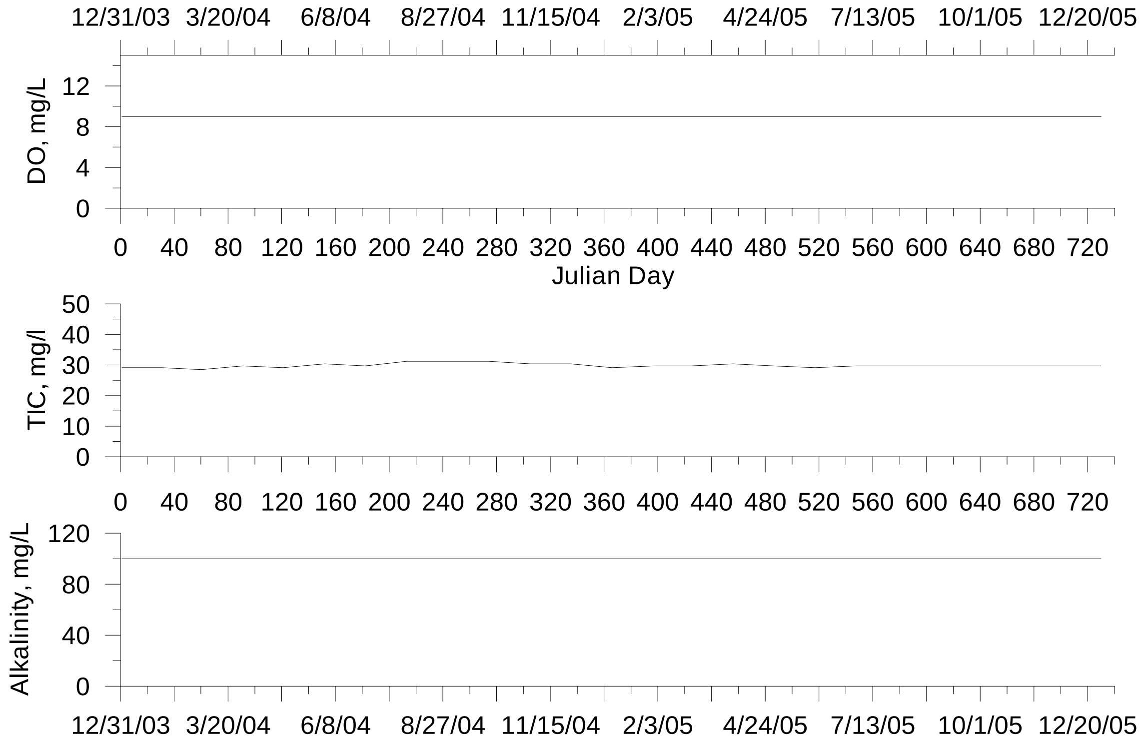


Figure 48: Constituent concentrations used for Sandpoint WWTP.

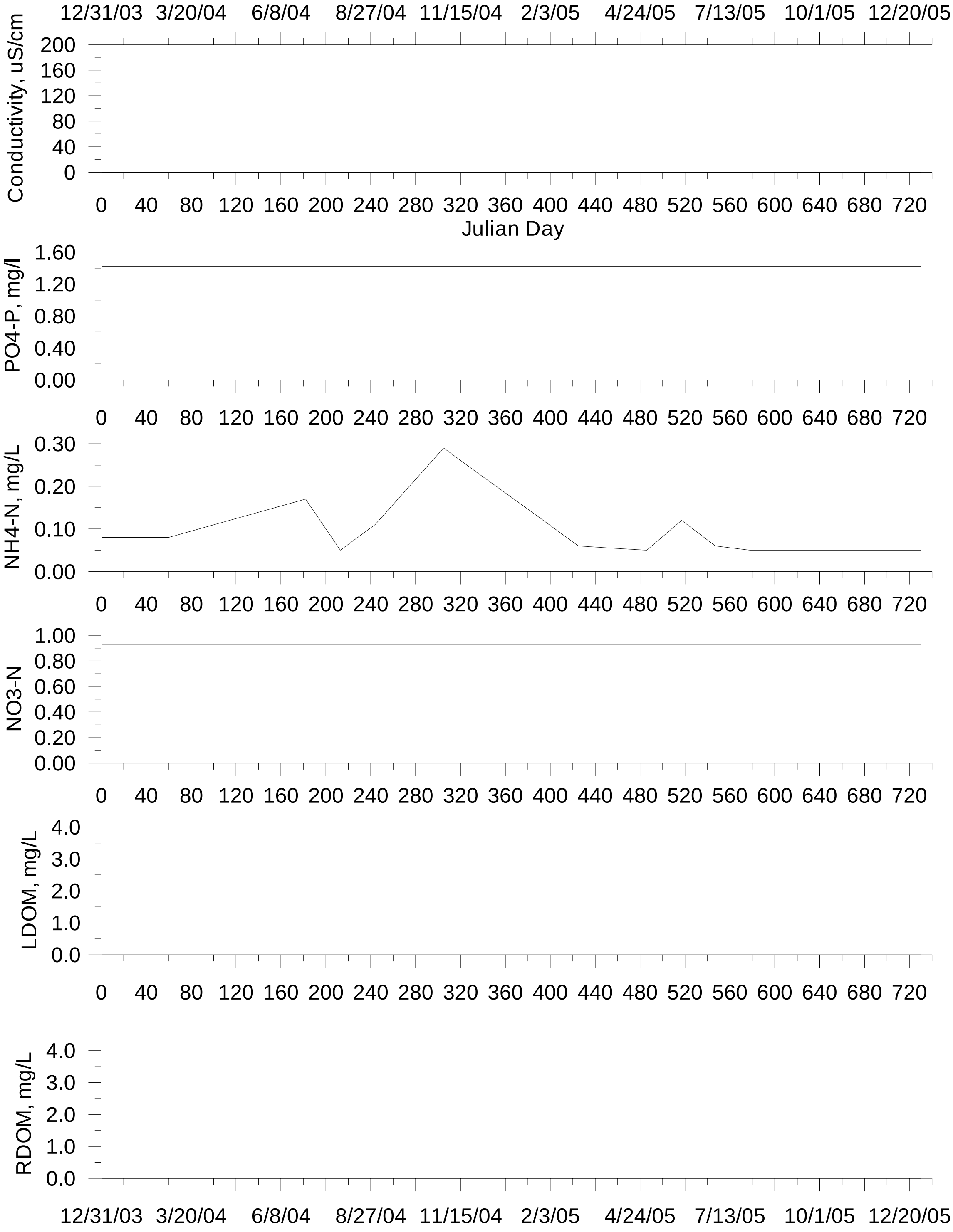


Figure 49: Constituent concentrations used for Dover WWTP.

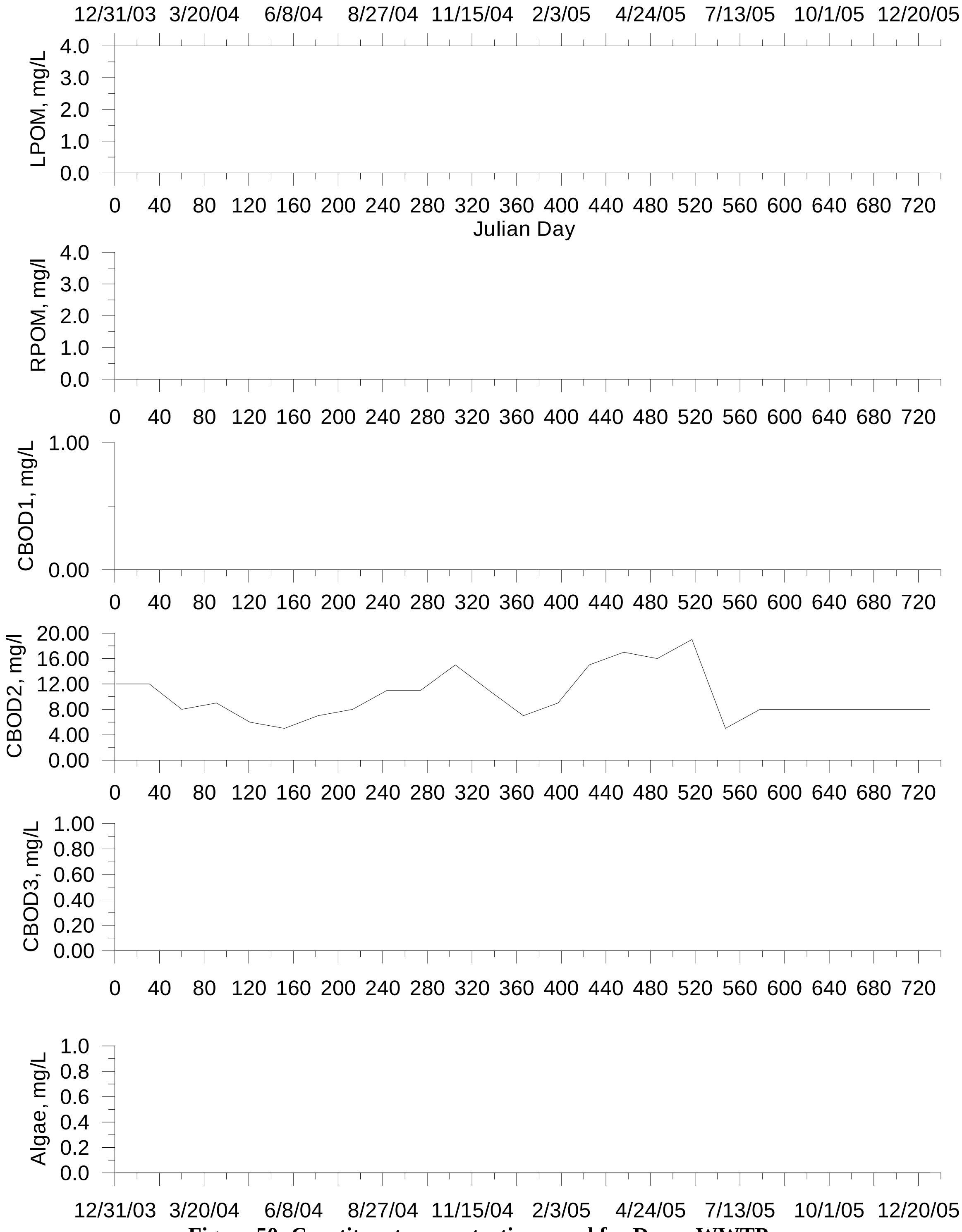


Figure 50: Constituent concentrations used for Dover WWTP.

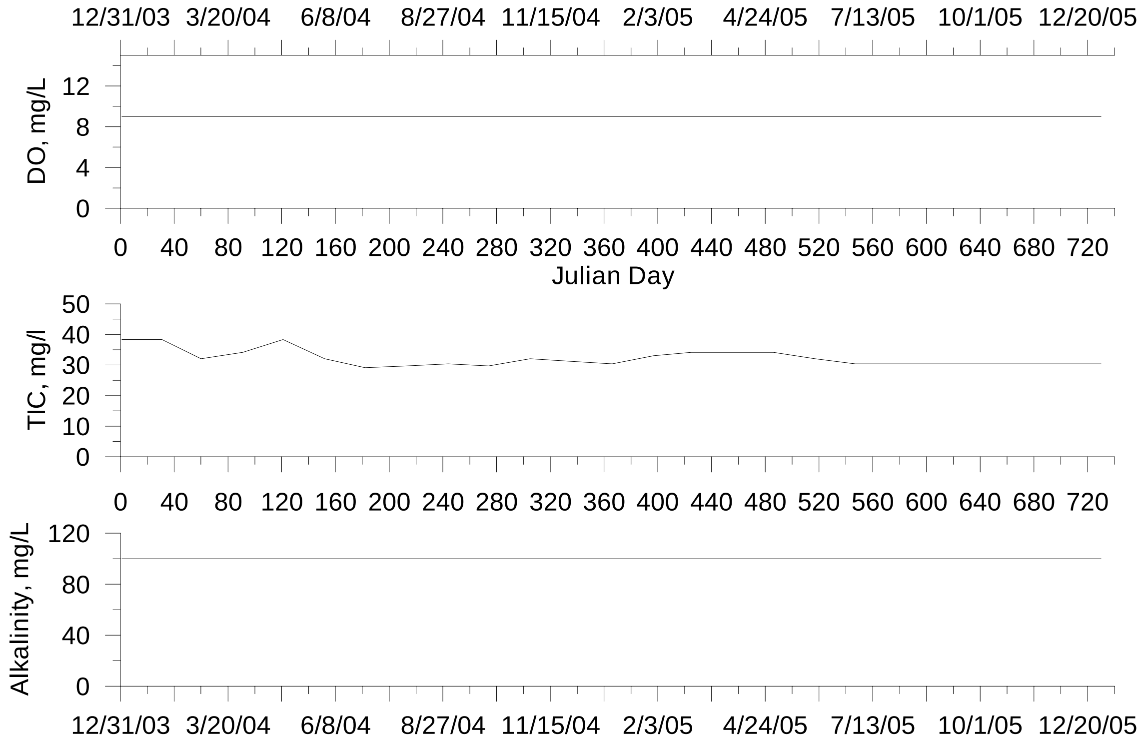


Figure 51: Constituent concentrations used for Dover WWTP.

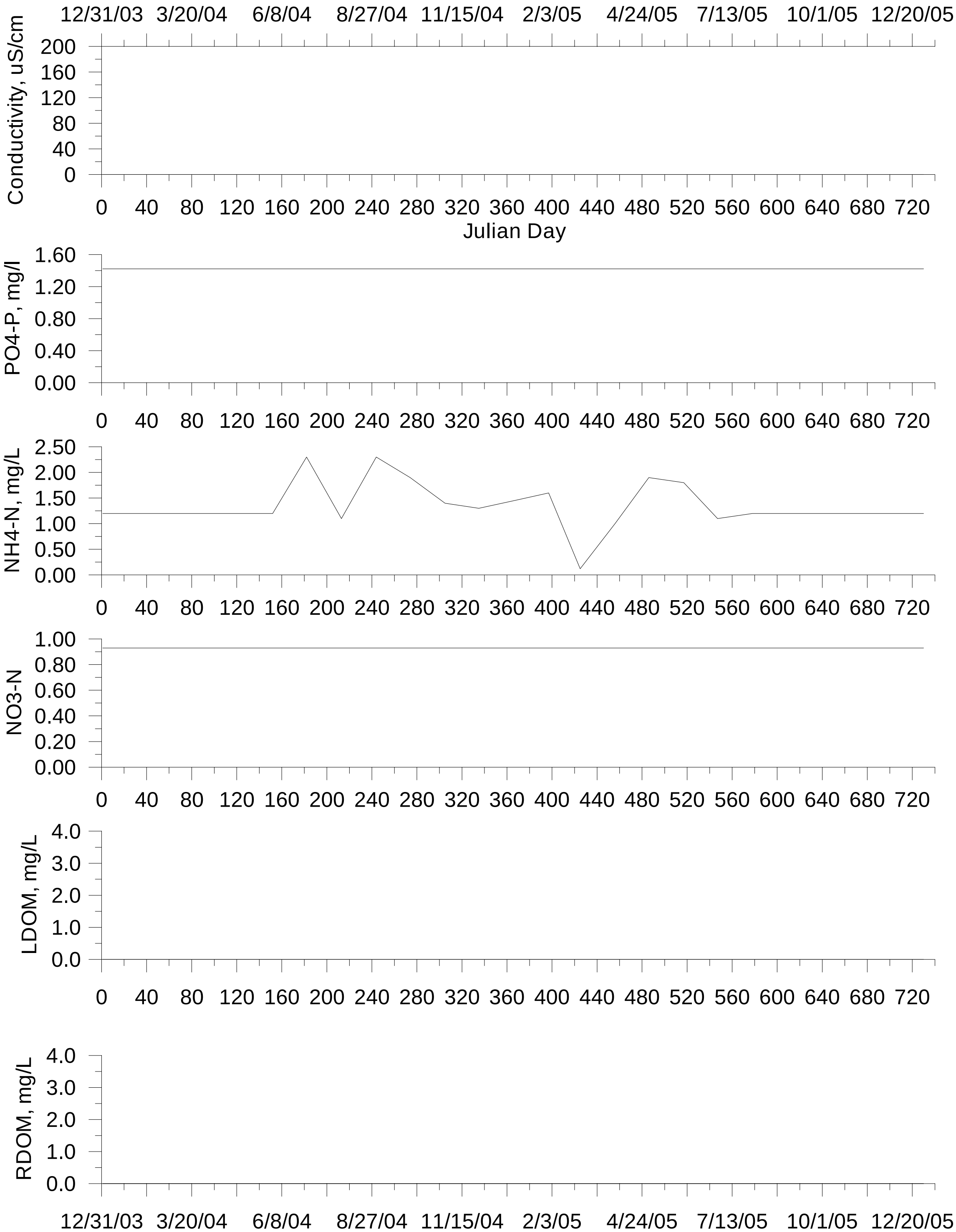


Figure 52: Constituent concentrations used for Priest River WWTP.

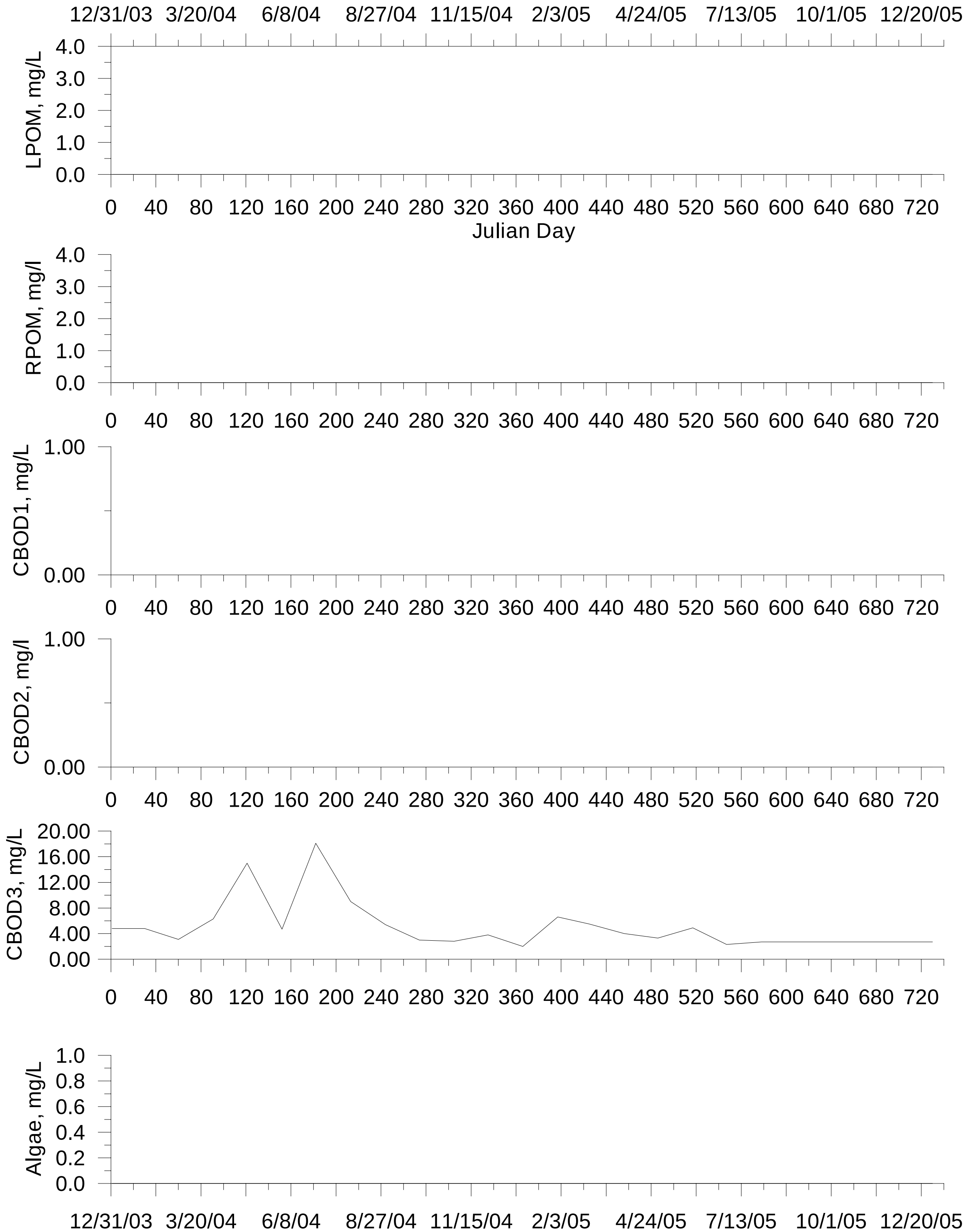


Figure 53: Constituent concentrations used for Priest River WWTP.

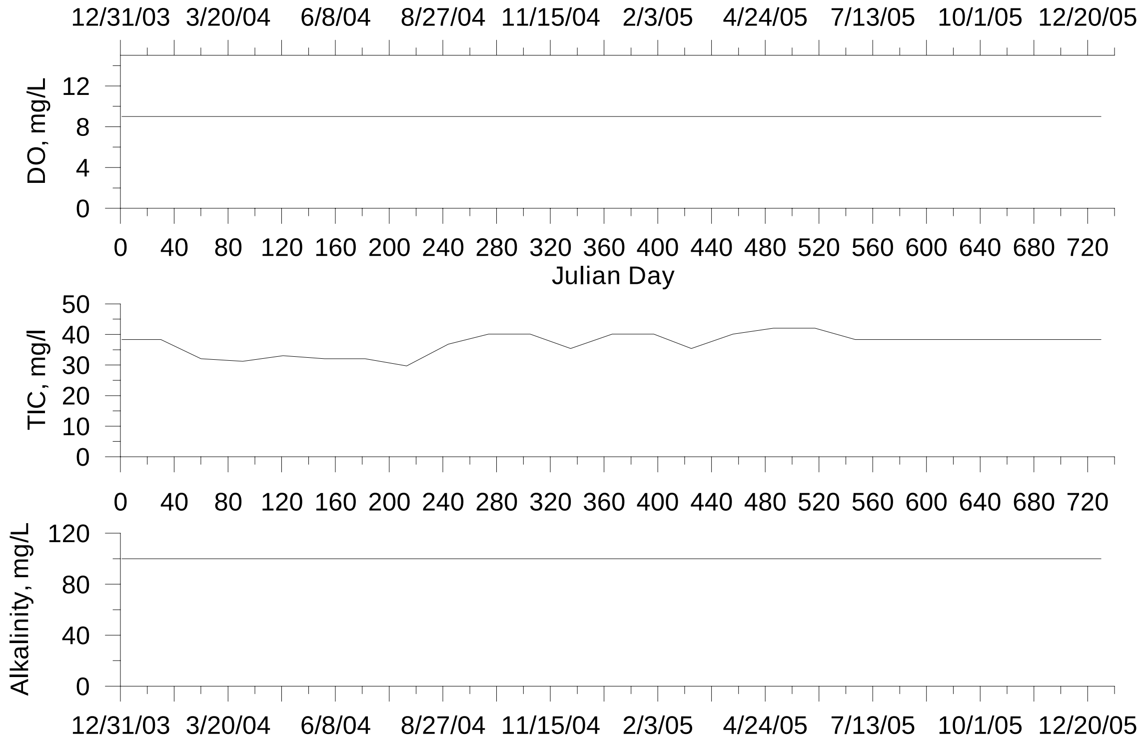


Figure 54: Constituent concentrations used for Priest River WWTP.

Topographic Shade

Topographic shade data were developed for the Pend Oreille River between Lake Pend Oreille and the Albeni Falls Dam. The GIS database for the Pend Oreille River included the topography around the river model area (DEM) and the model segment center point coordinates were determined in the grid development.

The first step in the analysis was determining how far away from the river the topography would be analyzed. Using a shaded relief of the topography in GIS, the maximum distance away from the river to the controlling topography was approximately 1,100 m.

The next step was to calculate the end points of 18 arrays surrounding each model segment (every 20 degrees). The topography data were then used to create a grid data set in SURFER, a contour plotting program. The array endpoints were then used to “slice” the grid in SURFER to create a series of points, with associated elevations, for each of the 18 arrays around each model segment. Figure 55 shows a plot of the arrays for model segment 52. The elevation points along each array were used to calculate the highest slope between each point and the model segment center point. The arc tangent of the highest slope was then calculated for each array. The inclination angles for each array were then put in a shade input file for the CE-QUAL-W2 model (shade.npt). The shade file did not include vegetative shade along the banks of the channels.

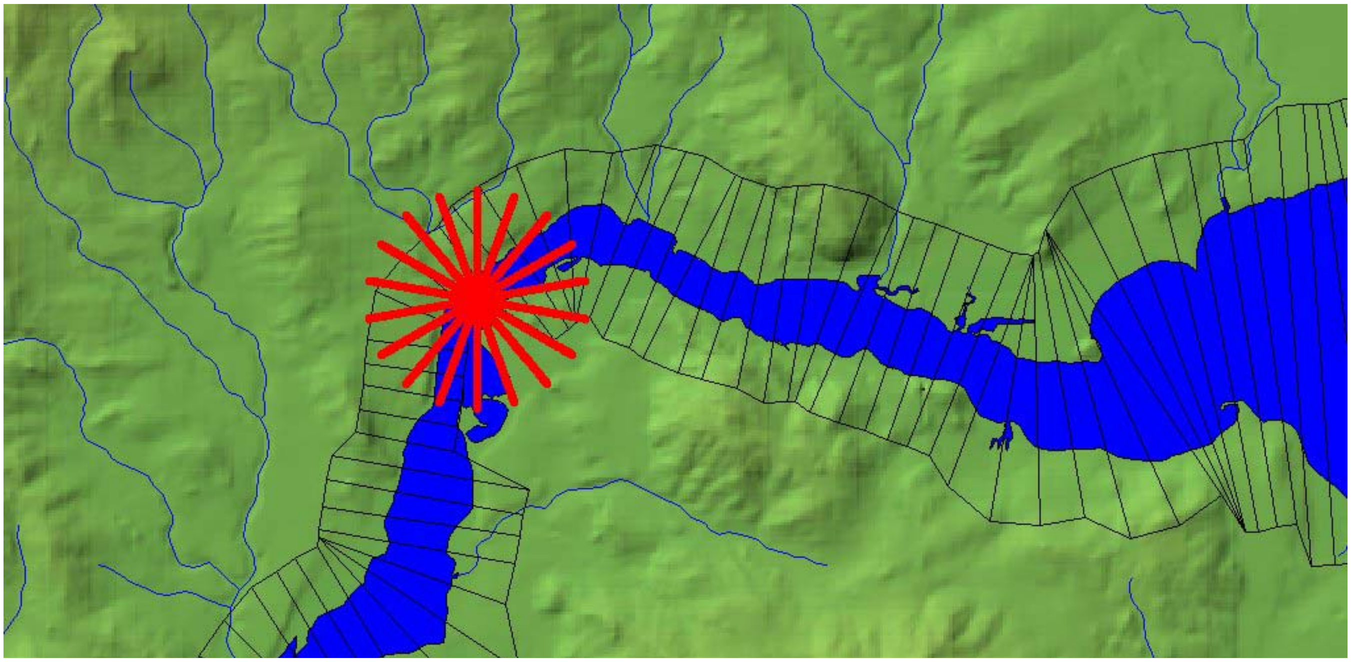


Figure 55: Inclination angle arrays for model segment 52

Meteorology

The Pend Oreille River model includes 28.3 miles from Lake Pend Oreille to Albeni Falls Dam. Meteorological monitoring conducted by the National Weather Service, the Bureau of Reclamation, and the U.S Forest Service were used to develop the meteorological data for the model domain.

The model uses the meteorological parameters: air and dew point temperature, wind speed and direction, cloud cover and solar radiation. Figure 56 shows the locations of the meteorological stations used in developing the meteorological conditions. Table 6 lists the sites and the organizations responsible for data collection.

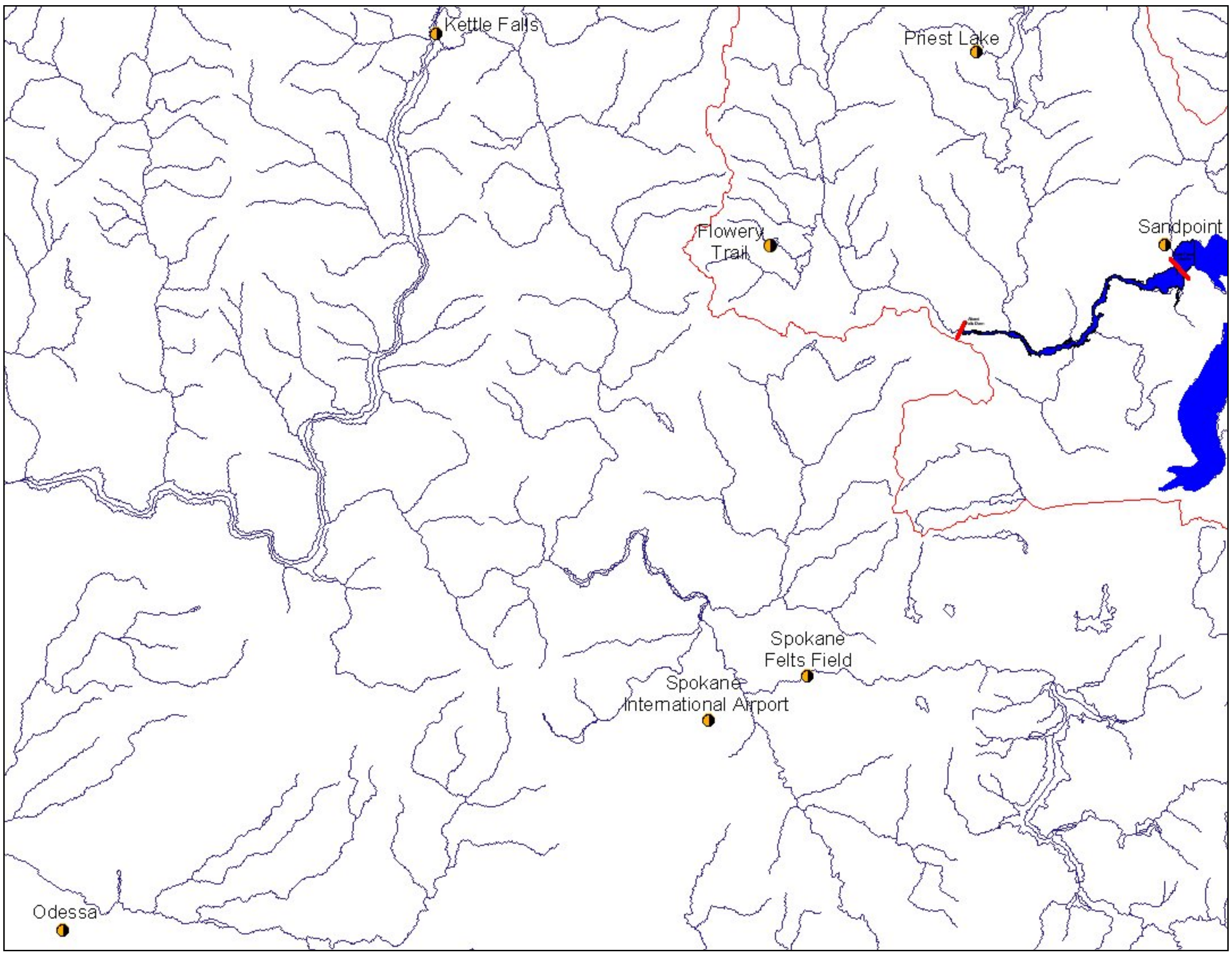


Figure 56: Pend Oreille River, ID model meteorological site locations.

Table 6: Pend Oreille River model meteorological monitoring sites

Site	Agency (Program)	Meteorological Parameters
Sandpoint Municipal Airport	National Weather Service (AWOS)	Air Temperature, Dew Point Temperature, Wind Speed, Wind Direction, Cloud Cover

Site	Agency (Program)	Meteorological Parameters
Priest Lake	U.S. Forest Service (RAWS)	Air Temperature, Relative Humidity, Wind Speed, Wind Direction, Solar Radiation
Flowery Trail	U.S. Forest Service (RAWS)	Air Temperature, Relative Humidity, Wind Speed, Wind Direction
Kettle Falls	Bureau of Reclamation (AgriMet)	Air Temperature, Dew Point Temperature, Relative Humidity, Wind Speed, Wind Direction, Solar Radiation
Spokane International Airport	National Weather Service (METAR)	Air Temperature, Dew Point Temperature, Relative Humidity, Wind Speed, Wind Direction, Cloud Cover
Spokane Felts Field	National Weather Service (METAR)	Air Temperature, Dew Point Temperature, Relative Humidity, Wind Speed, Wind Direction, Cloud Cover
Odessa, WA	Bureau of Reclamation (AgriMet)	Air Temperature, Dew Point Temperature, Relative Humidity, Wind Speed, Wind Direction, Solar Radiation

Air temperature data were primarily used from the Sandpoint, ID monitoring site, but due to data gaps in 2004 and 2005 an air temperature correlation was developed with the monitoring site at Priest Lake, ID. Figure 57 shows the air temperature correlation between the two sites and their correlation equation. Figure 58 and Figure 59 show time series of the air temperature at Sandpoint for 2004 and 2005, respectively. The figures include both data and the calculated values from the correlation with Priest Lake.

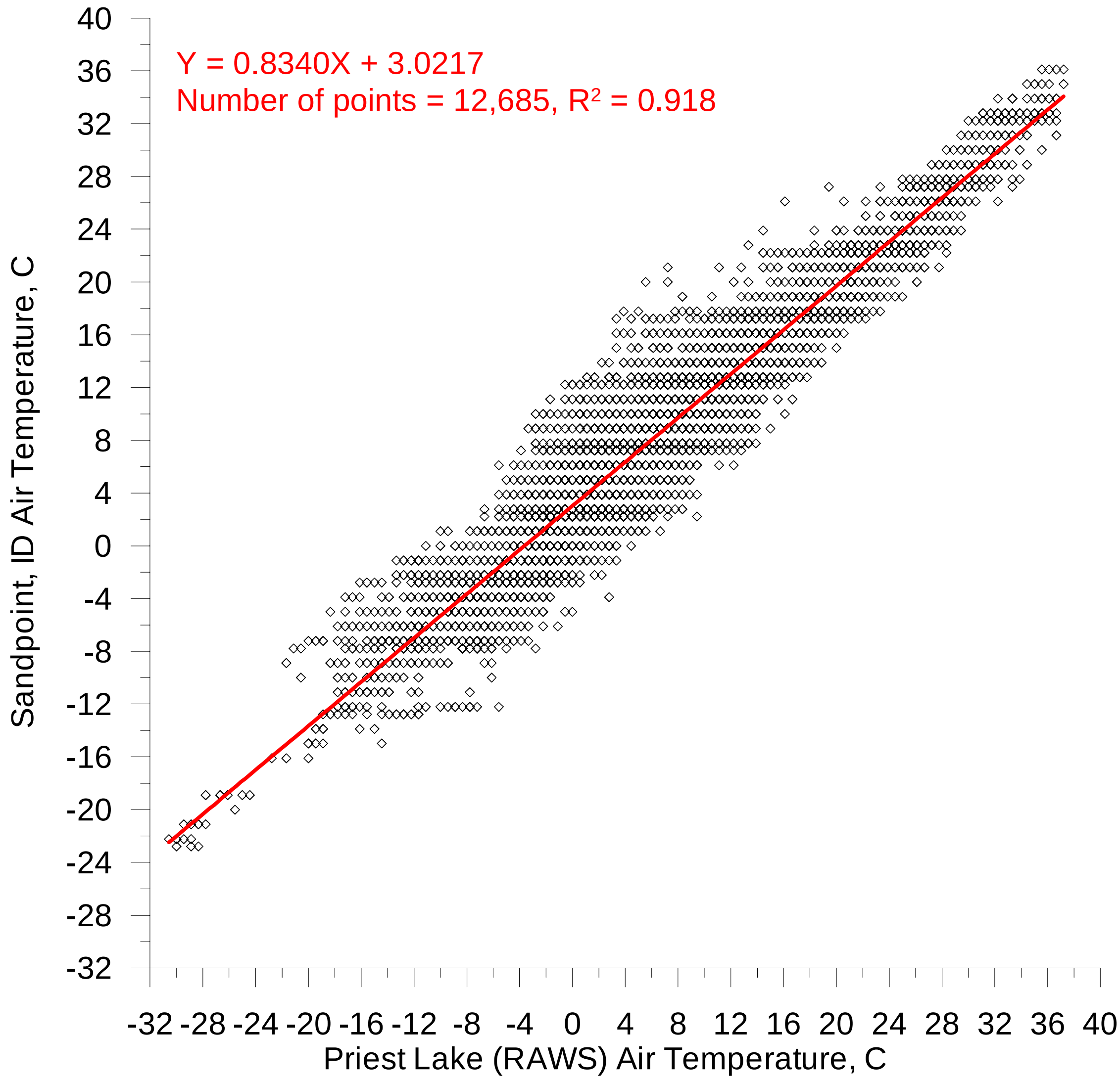


Figure 57: Air temperature correlation between Priest Lake and Sandpoint, ID.

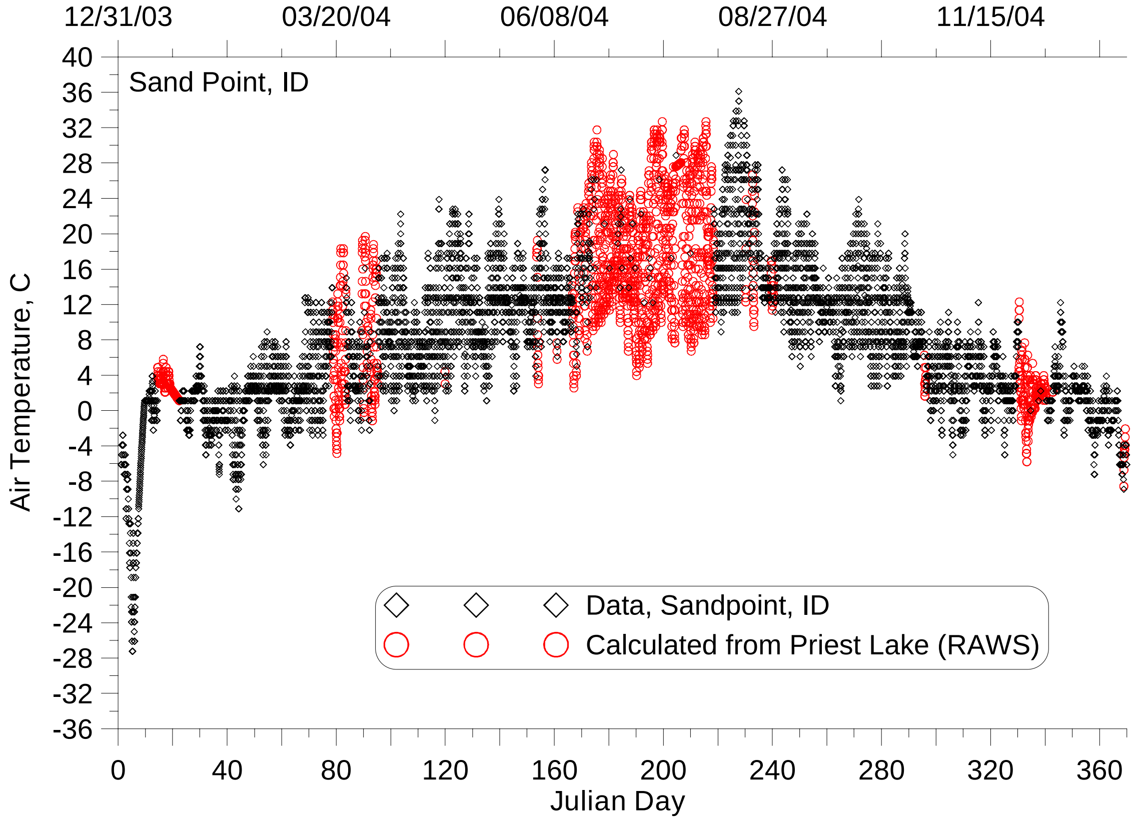


Figure 58: Air temperature at Sandpoint, ID, 2004.

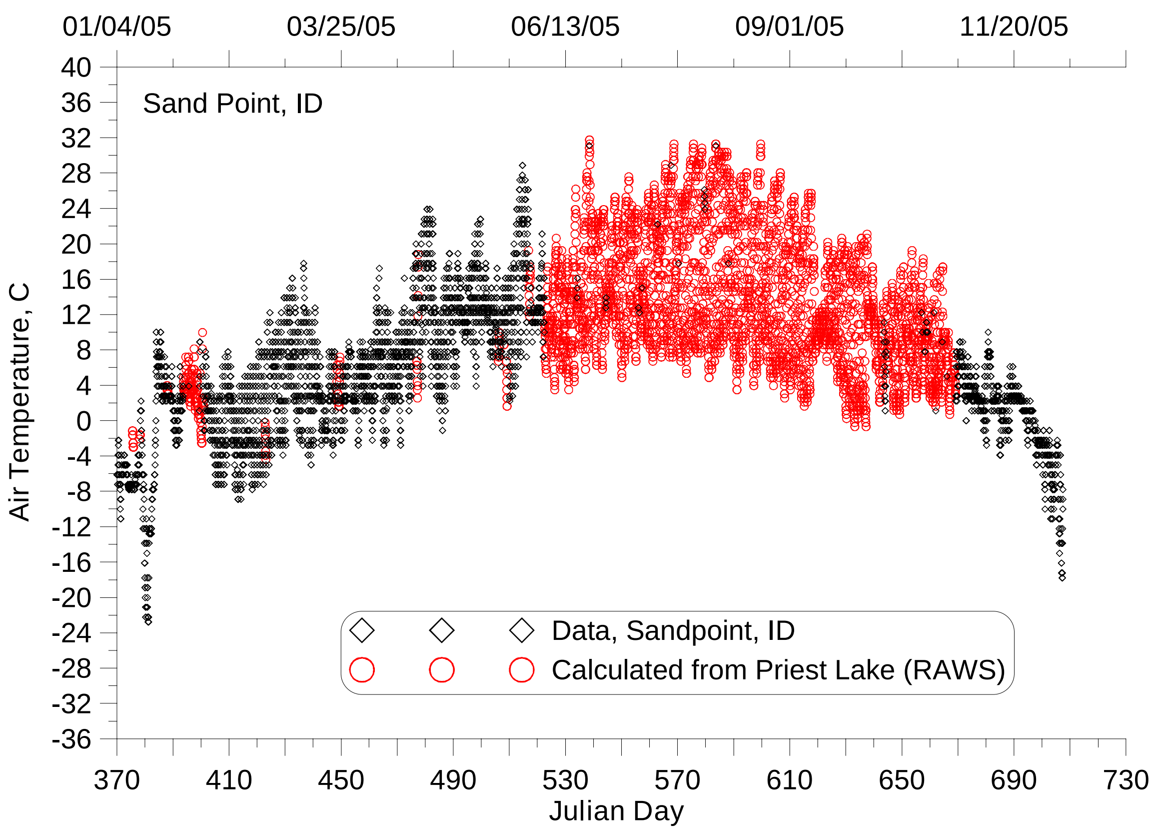


Figure 59: Air temperature at Sandpoint, ID, 2005.

The dew point temperature data was primarily from the Sandpoint, ID monitoring site, but due to data gaps in 2004 and 2005 a dew point temperature correlation was developed with the monitoring site at Priest Lake, ID. Figure 60 shows the air temperature correlation between the two sites and their correlation equation. Figure 61 and Figure 62 show time series of the dew point temperature at Sandpoint for 2004 and 2005, respectively. The figures include both data and the calculated values from the correlation with Priest Lake.

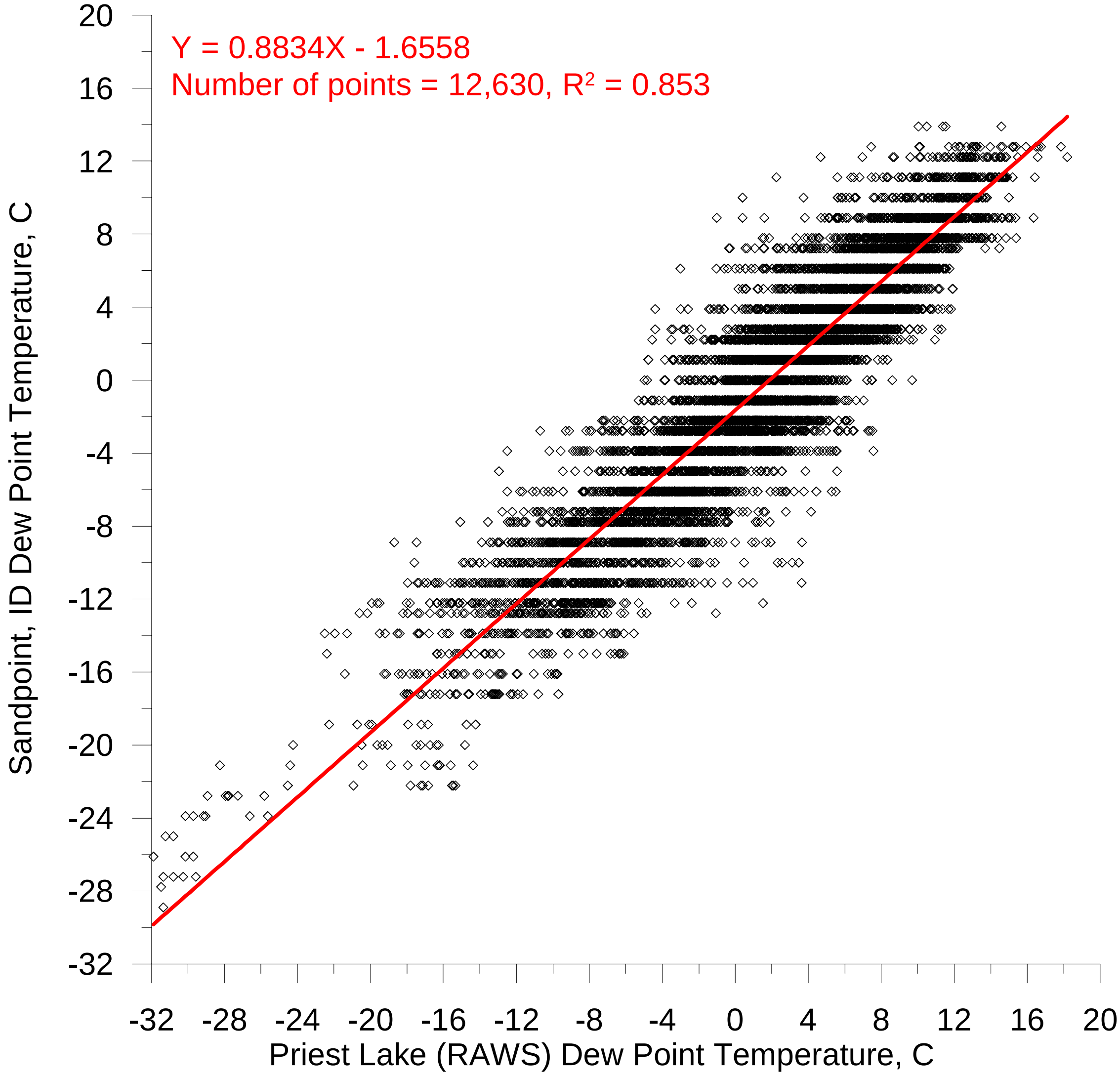


Figure 60: Dew point temperature correlation between Priest Lake and Sandpoint, ID.

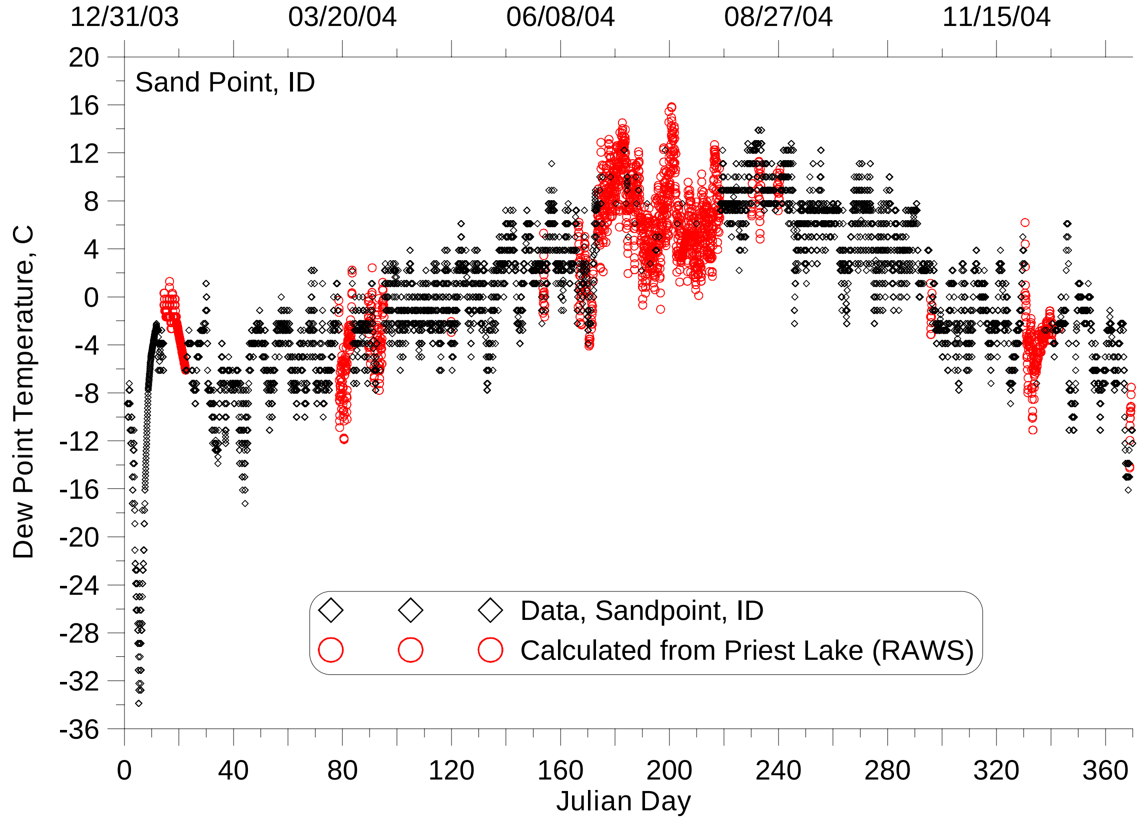


Figure 61: Dew point temperature at Sandpoint, ID, 2004.

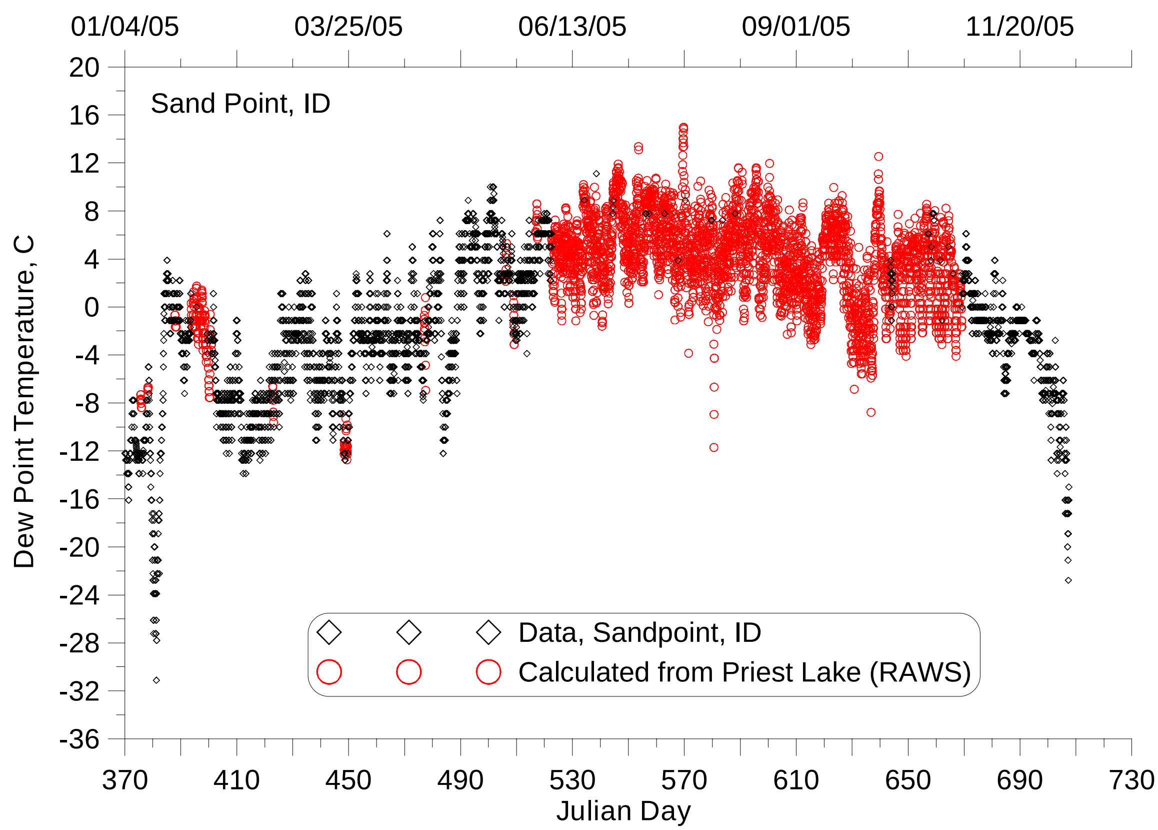


Figure 62: Dew point temperature at Sandpoint, ID, 2005.

The wind speed and direction data were primarily taken from the Sandpoint, ID monitoring site, but due to data gaps in 2004 and 2005 wind speed and direction data from Priest Lake, ID were used directly for the model. Figure 63 and Figure 64 show time series of the wind speed data at Sandpoint for 2004 and 2005, respectively, with data gaps filled in from Priest Lake, ID. Figure 65 and Figure 66 show time series of the wind direction data at Sandpoint for 2004 and 2005, respectively. Figure 67 shows a rose diagram of the wind direction data for both 2004 and 2005. In this figure all wind directions of zero (which mostly correspond to zero wind speeds) were removed from the diagram.

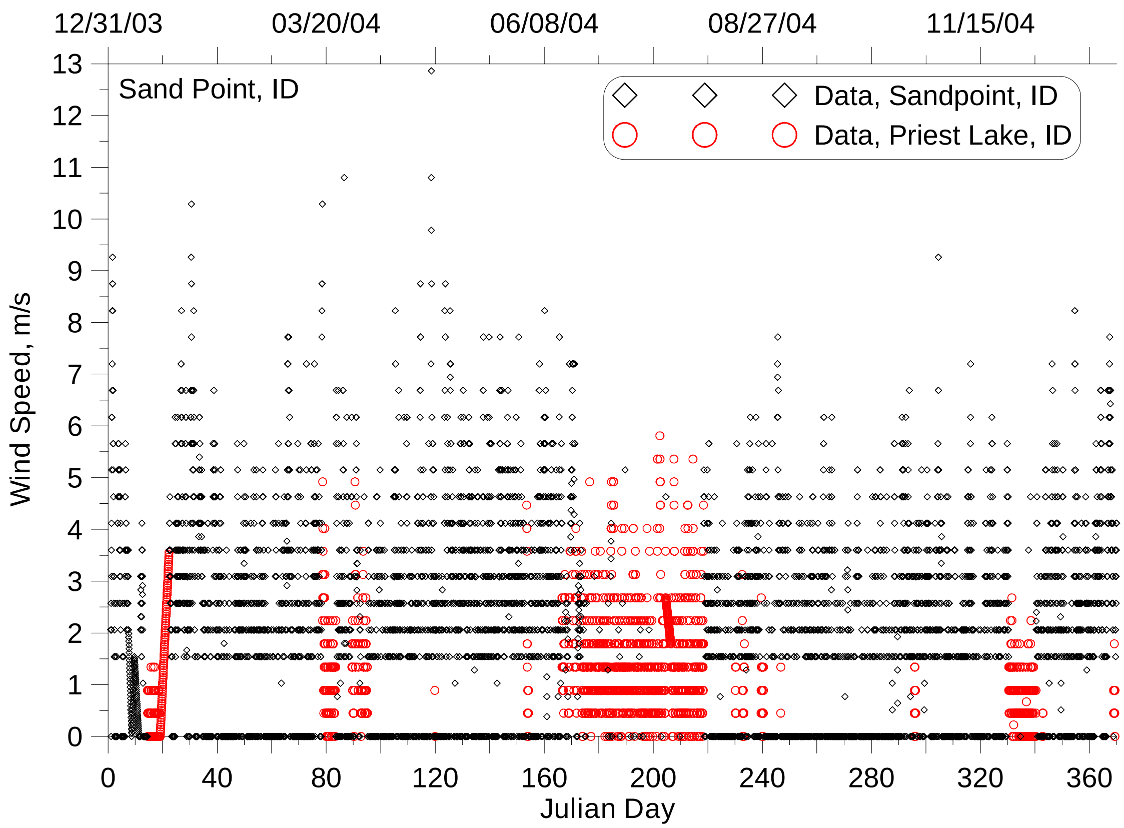


Figure 63: Wind Speed at Sandpoint, ID, 2004.

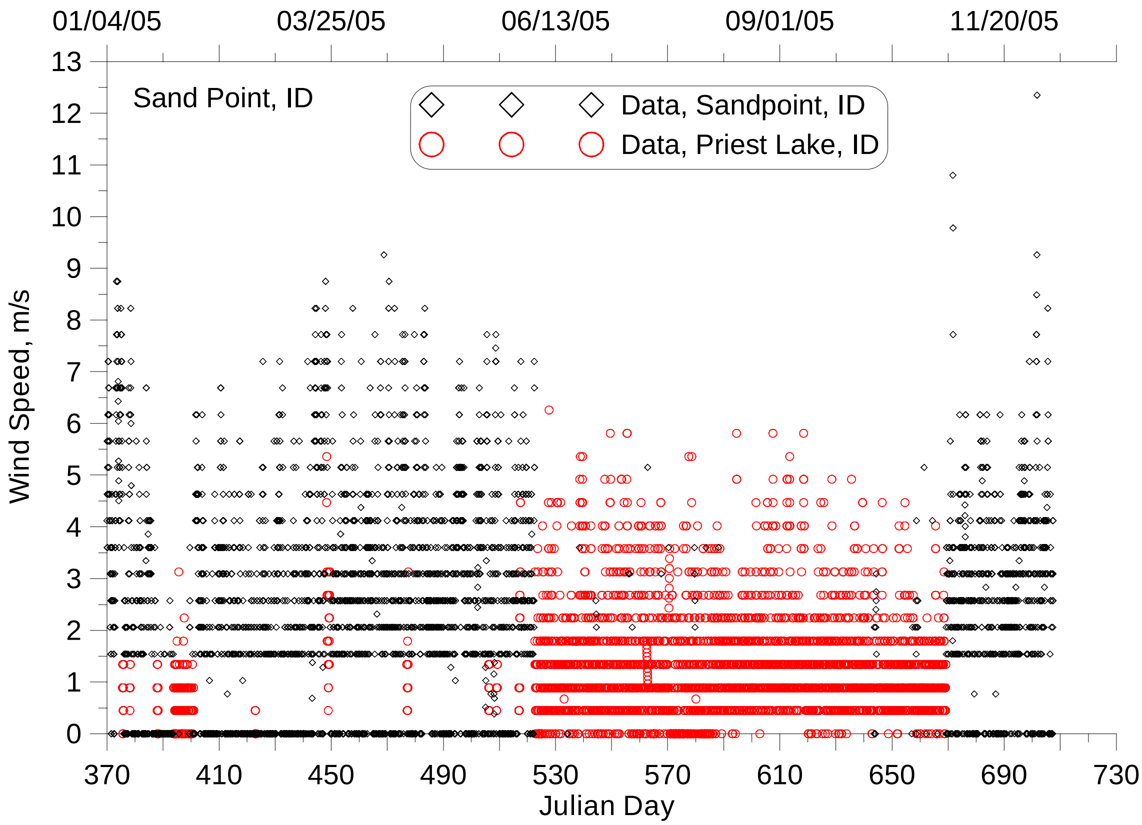


Figure 64: Wind Speed at Sandpoint, ID, 2005.

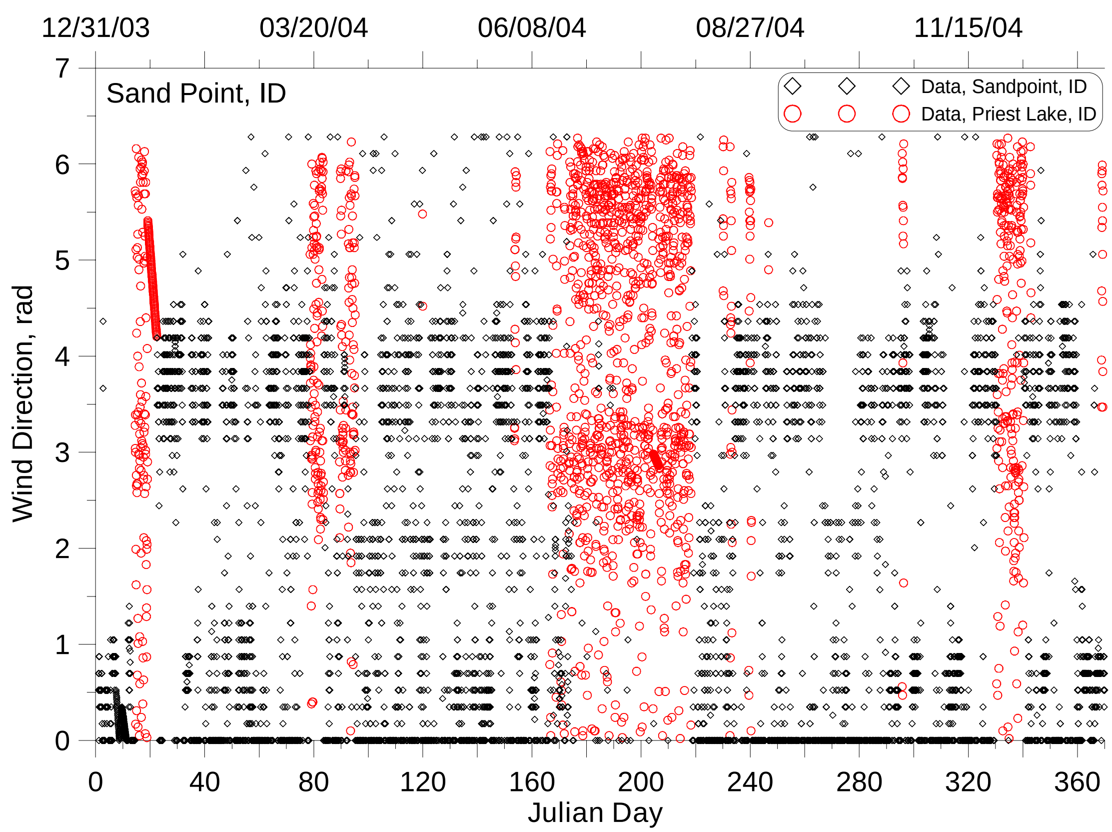


Figure 65: Wind Direction at Sandpoint, ID, 2004.

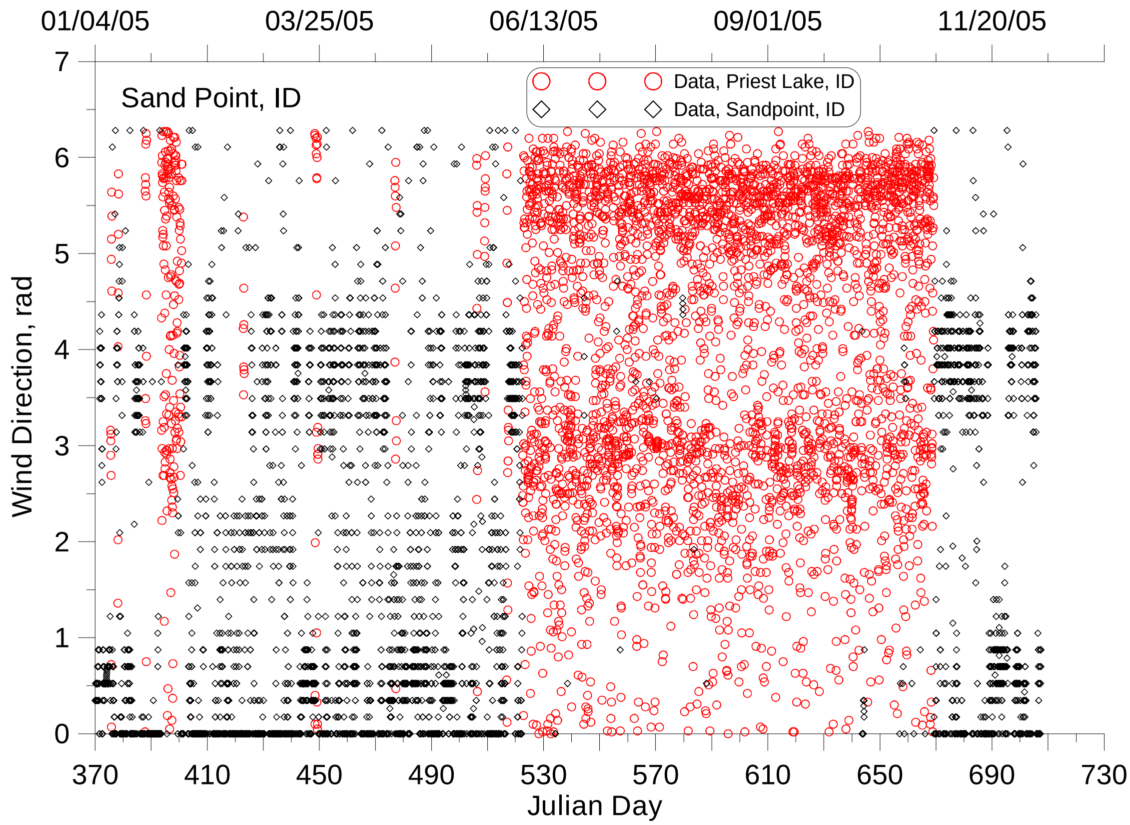


Figure 66: Wind Direction at Sandpoint, ID, 2005.

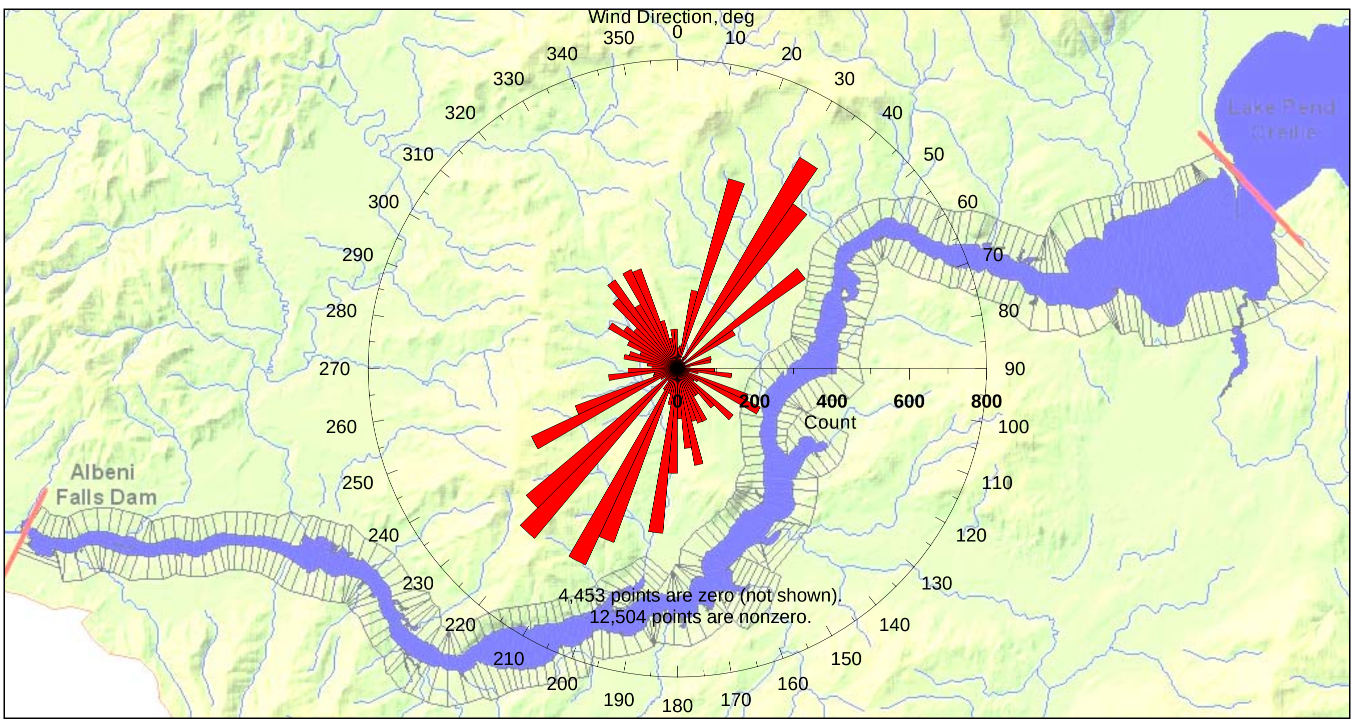


Figure 67: Wind Direction at Sandpoint, ID, 2004 and 2005.

Solar radiation was not monitored at Sandpoint, ID so solar radiation data from Kettle Falls, WA, and Priest Lake, ID were reviewed. Figure 68 and Figure 69 show time series of the solar radiation data from both sites, for 2004 and 2005, respectively. Based on a review of the solar radiation data from both sites, the data at Priest Lake were found to contain more erroneous and suspect values. As a result the solar radiation data at Kettle Falls, WA was used in the model.

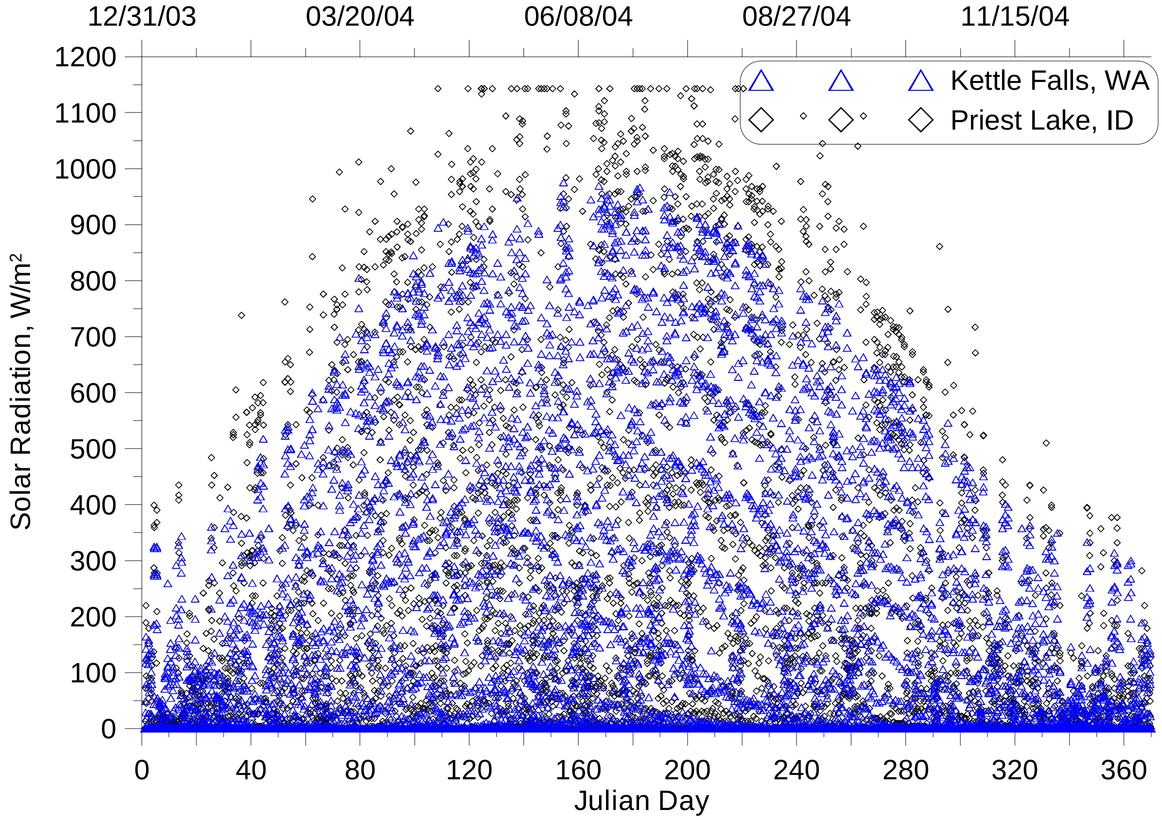


Figure 68: Solar radiation near the Pend Oreille River, 2004.

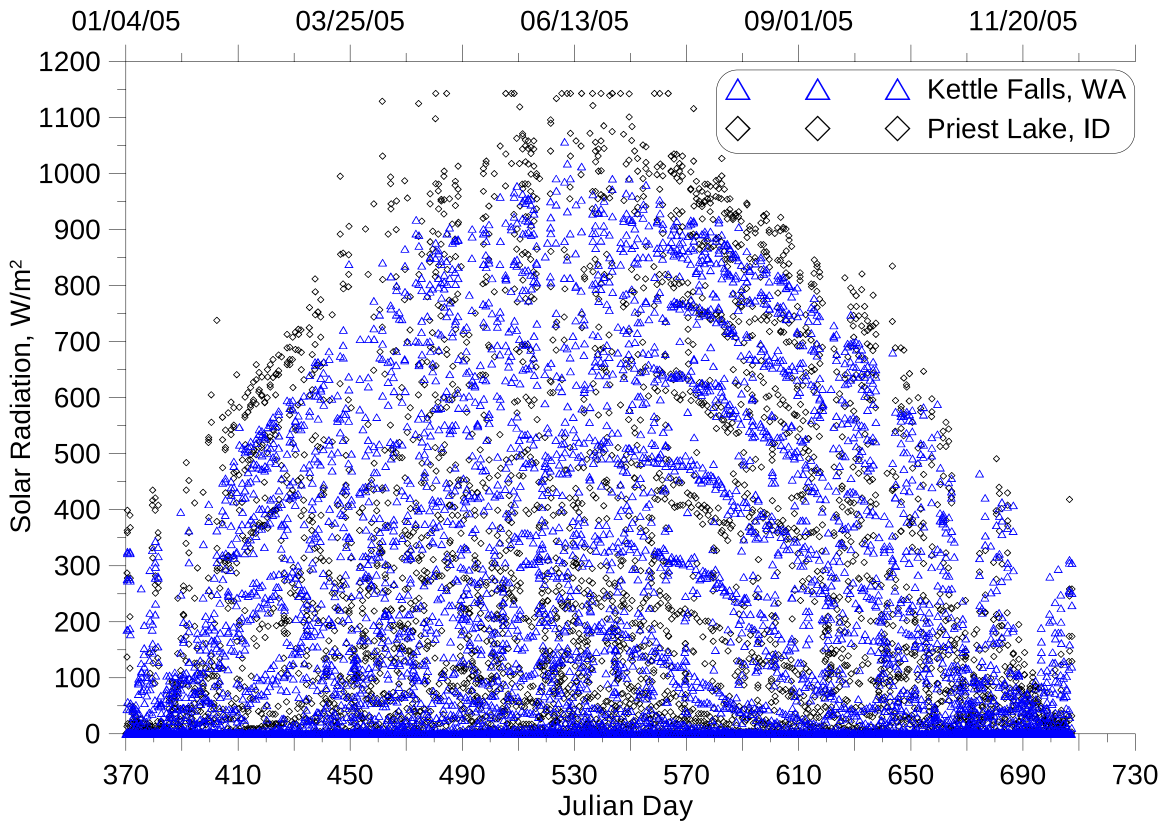


Figure 69: Solar radiation near the Pend Oreille River, 2005.

The cloud cover data recorded at Sandpoint, ID was found to be limited in 2004 and 2005 with large data gaps and values fixed at one of five categories. The solar radiation data at Priest Lake and Kettle Falls were compared with the calculated theoretical clear sky solar radiation for each site and used to calculate the cloud cover for each site using the equation (Cole and Wells, 2004):

$$C = \sqrt{\frac{1}{0.0065}\left(1 - \frac{\varphi_{measured}}{\varphi_{theoretical\,clearsky}}\right)}$$

where C: cloud cover in tenths

$\varphi_{measured}$: measured short-wave solar radiation

$\varphi_{theoretical\ clear\ sky}$: computed from theoretical formulae with no cloud cover

Figure 70 and Figure 71 show time series of cloud cover data from Sandpoint, with some gaps linearly interpolated, calculated cloud cover from Priest Lake solar radiation data and calculated cloud cover from Kettle Falls, WA solar radiation data. The cloud cover calculated from the Kettle Falls, WA solar radiation data was used in the model.

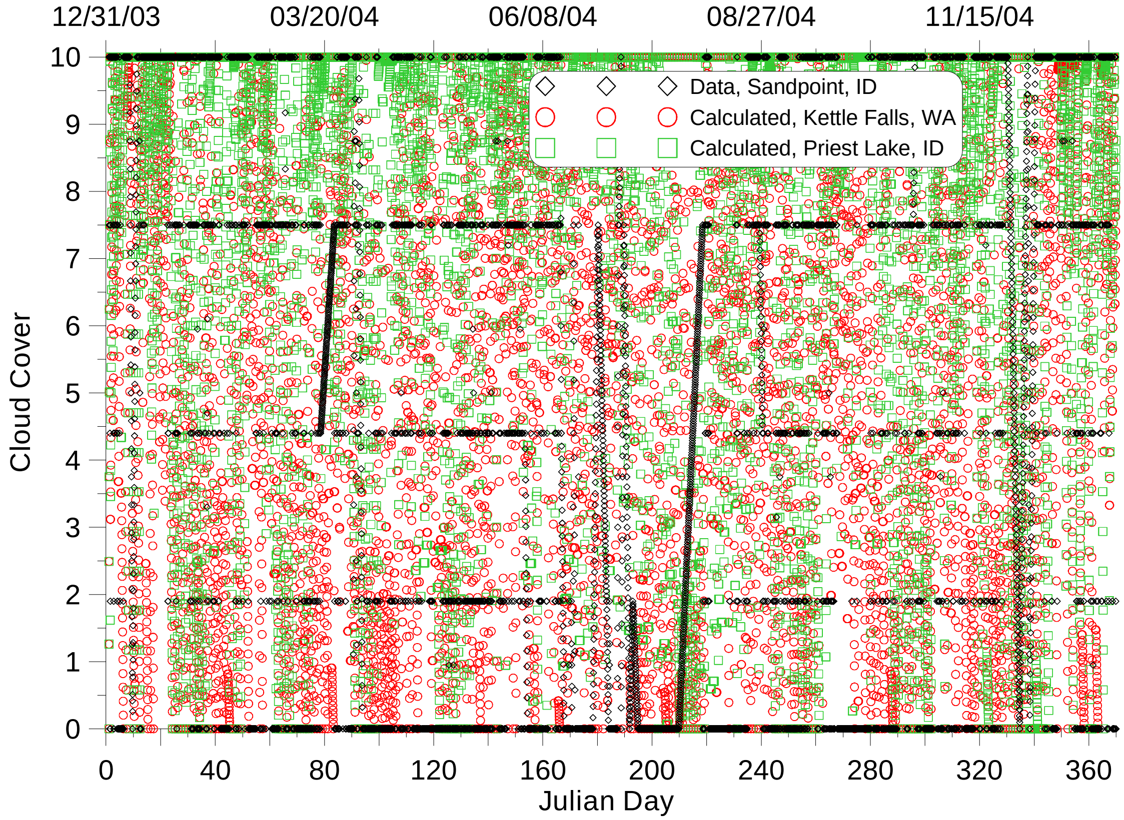


Figure 70: Cloud Cover near the Pend Oreille River, 2004.

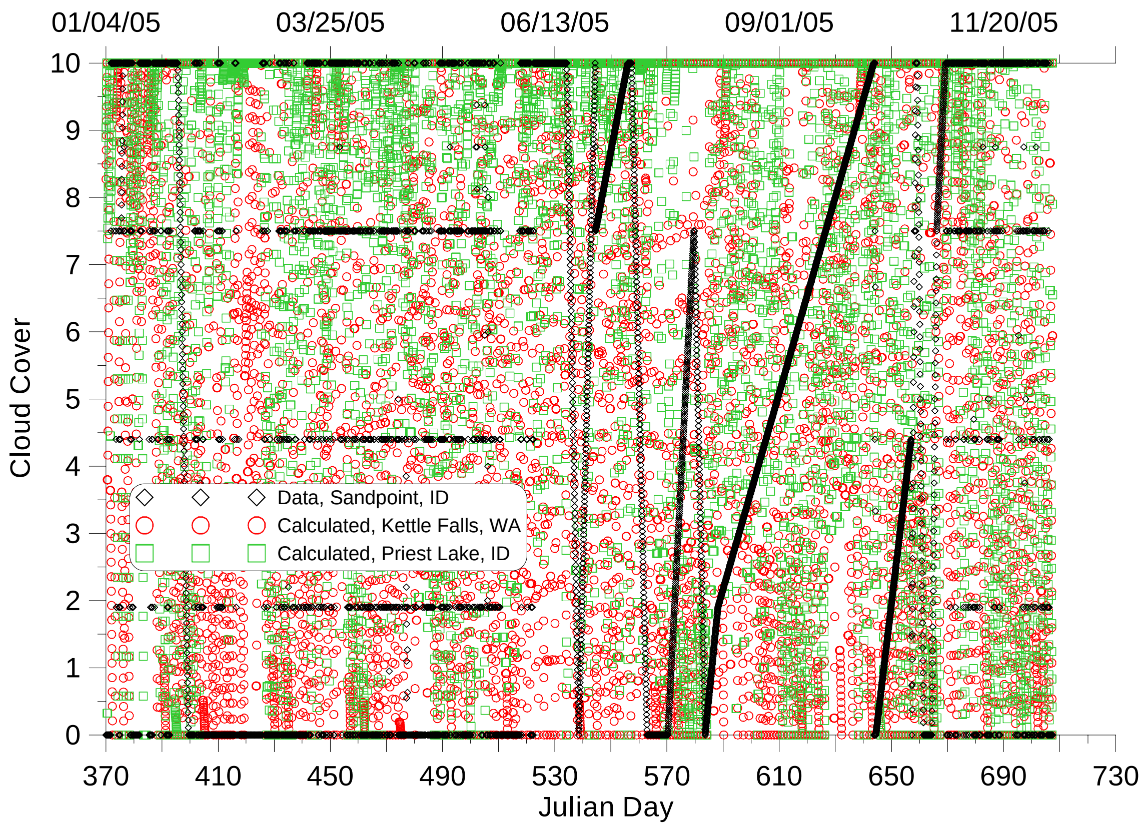


Figure 71: Cloud Cover near the Pend Oreille River, 2005.

Calibration

The Pend Oreille River model was calibrated from January 1st, 2004 to August 31st, 2005. The calibration consisted of first calibrating the hydrodynamics and then temperature and water quality. The data for calibrating the model consisted primarily of continuous hydrodynamic and temperature data with some temperature profiles and some water quality grab sample and vertical profiles. Figure 72 shows a map of the Pend Oreille River in Idaho with the monitoring sites where data was used in the model calibration. Table 7 lists the monitoring sites, site descriptions, and the types of data monitored.

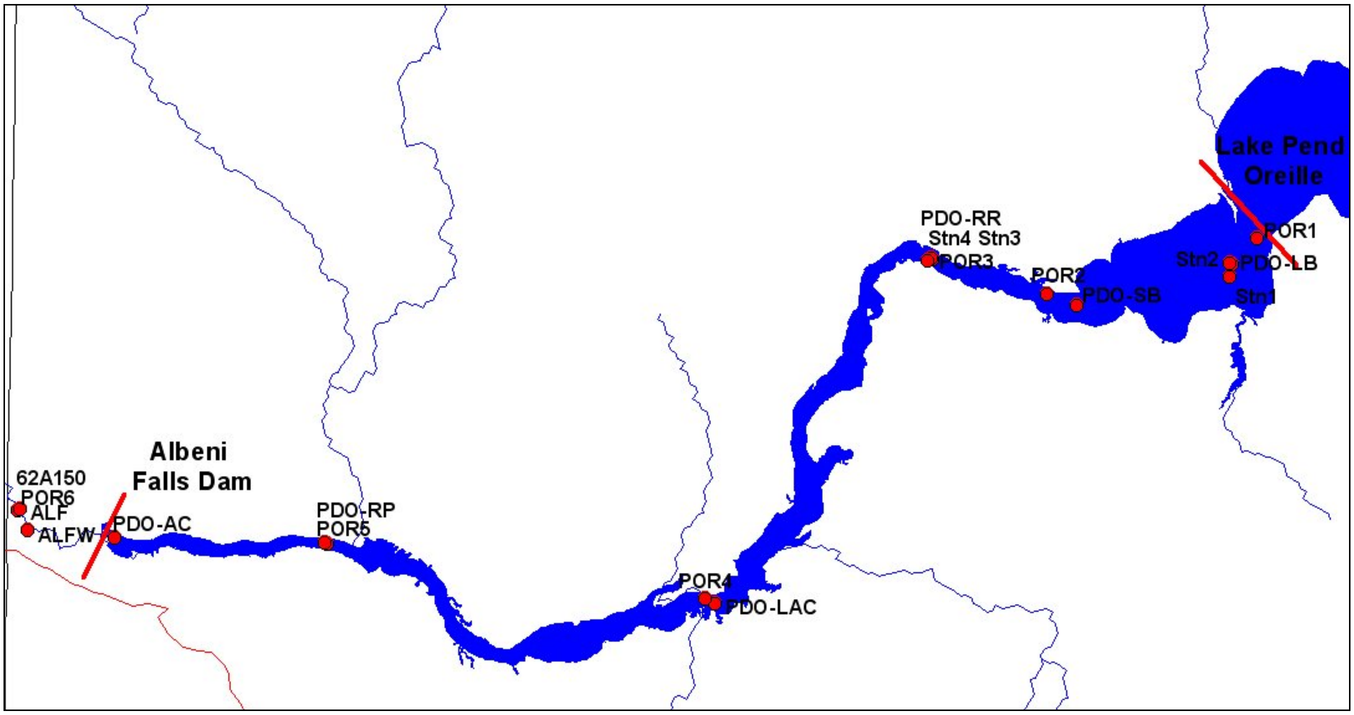


Figure 72: Pend Oreille River water temperature and quality calibration site locations.

Table 7: Pend Oreille River water temperature and quality calibration sites.

Site ID	Agency	Site Name	Model Seg	RM	Data Types	Years of Data
Sandpt	City of Sandpoint	City of Sandpoint drinking water intake	2	118.50	Temp and WQ	2004 & 2005
POR1	Tetra Tech, Inc.	Pend Oreille River 95 bridge-2004, Lake Pend Oreille	2	118.44	Temp	2004
PDO-LB	IDEQ	Long Bridge	2	117.81	Temp and WQ	2004
Stn2	IDEQ	Long Bridge, North of Stn1	2	117.81	Temp	2005
Stn1	IDEQ	Long Bridge	2	117.67	Temp	2005
PDO-SB	IDEQ	Springy Point	25	114.71	Temp and WQ	2004
POR2	Tetra Tech, Inc.		29	114.05	Temp and WQ	2004
PDO-RR	IDEQ	Railroad Bridge	44	111.82	Temp and WQ	2004
Stn3	IDEQ	Railroad Bridge Crossing	44	111.77	Temp	2005
POR3	Tetra Tech, Inc.		44	111.73	Temp and WQ	2004

Site ID	Agency	Site Name	Model Seg	RM	Data Types	Years of Data
Stn4	IDEQ	Railroad Bridge Crossing, South of Stn3	44	111.73	Temp	2005
PDO-LAC	IDEQ	Laclede	101	102.94	Temp and WQ	2004
POR4	Tetra Tech, Inc.		102	102.76	WQ	2004
PDO-RP	IDEQ	Priest River Bridge	155	94.48	Temp and WQ	2004
POR5	Tetra Tech, Inc.	Pend Oreille River at City of Priest River	156	94.41	WQ	2004
PDO-AC	IDEQ	Albany Cove	182	90.30	Temp and WQ	2004
ALFW	ACOE	Albeni Tailwater - Pend Oreille River at Newport	183	88.66	Temp	2004
ALF	ACOE	Albeni Falls Dam On Pend Oreille River Below Lake	183	88.66	Temp	2004
62A150	WADOE	Pend Oreille R at Newport	183	88.27	Temp and WQ	2004 & 2005
POR6	Tetra Tech, Inc.		183	88.27	Temp and WQ	2004

Hydrodynamics

The only hydrodynamic available for calibration were water level data measured at Albeni Dam. Other data available within the model domain existed at the boundaries and were used to describe the boundary conditions. Water level data at the model's upstream boundary were used for the upstream head boundary condition (Figure 10 and Figure 11). Outflow data at Albeni Dam were used to describe the downstream flow boundary condition (Figure 27 and Figure 28). A comparison between model predicted water levels at Albeni Dam and data was shown in Figure 73. The Manning's friction factor was set to a value of 0.036 for all model segments. Table 8 list the model water level error statistics.

Table 8: Model-data error statistics for water level (m) measured at Albeni Falls Dam (segment 183).

Site	Model Segment #	Mean Error (ME)	Absolute Mean Error (AME)	Root Mean Square Error (RMS)
Albeni Falls Dam	183	0.046	0.053	0.063

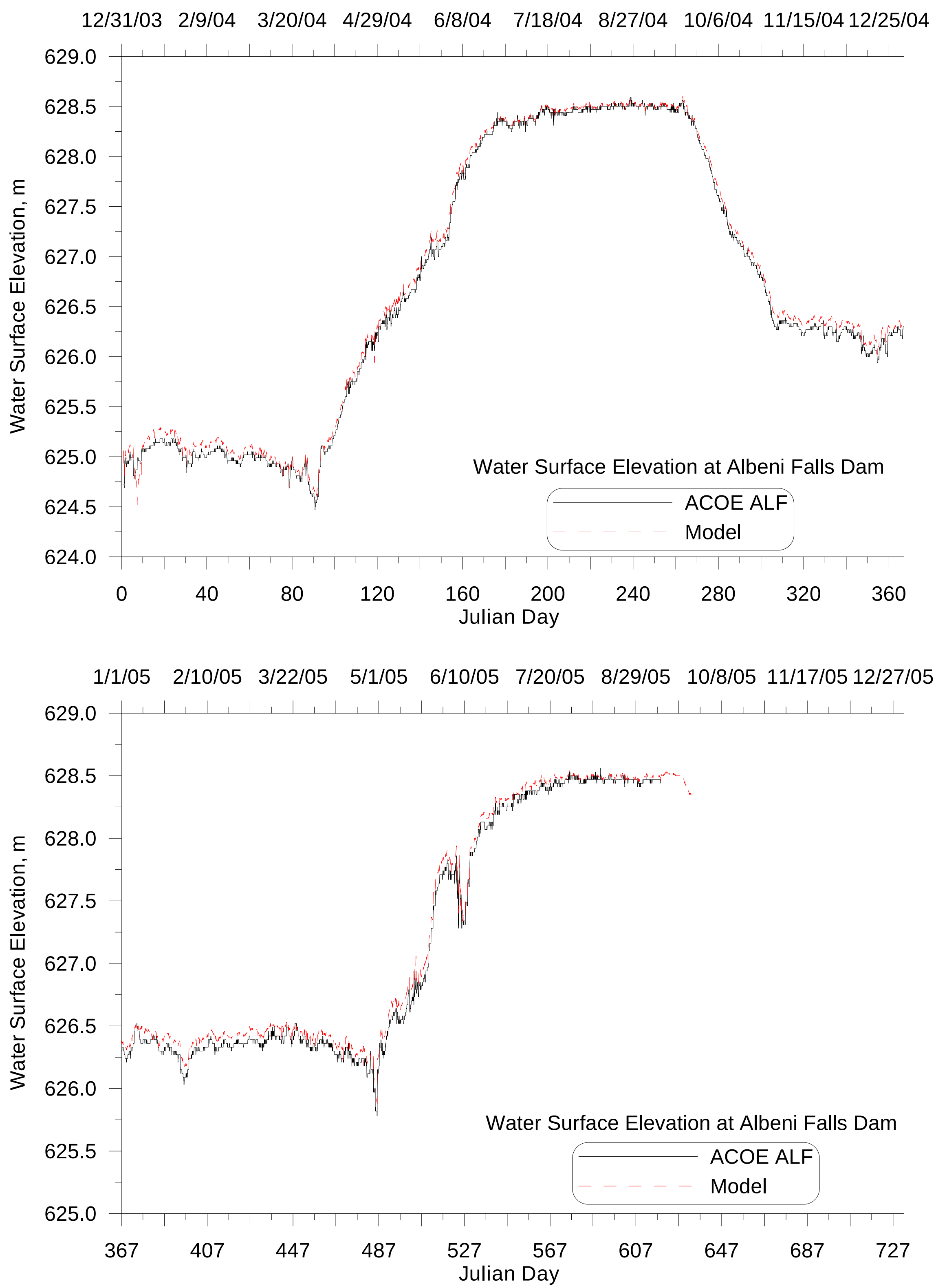


Figure 73: Comparison between model predicted water levels and data measured at Albeni Falls Dam.

Temperature

Temperatures within the model domain were strongly influenced by the upstream boundary condition. The wind sheltering coefficient was set to 0.85. Comparisons between model predictions and temperature data measured at Albeni Falls dam were shown in Figure 74. Comparisons of vertical profiles and data were shown in Appendix B: Calibration Plots. Table 9 and Table 10 list error statistics between model predictions and data. Error statistics for profiles were calculated by comparing measured data at a particular depth with the model prediction (interpolated between layers) at that depth. The mean absolute error average was less than 0.37 degrees Celsius for vertical profile data and 0.54 degrees Celsius for continuous data.

Model error was greater at the upstream boundary condition because of the seiching that occurs in Lake Pend Oreille was not captured by the model. The effects of seiching can be seen in the temperature fluctuations measured at site ALFPORLB (segment 7) at the 4.57 m and 7.62 m depths (Figure 19). Sites downstream toward the dam are not affected by lake seiching and the temperature error at these sites are less.

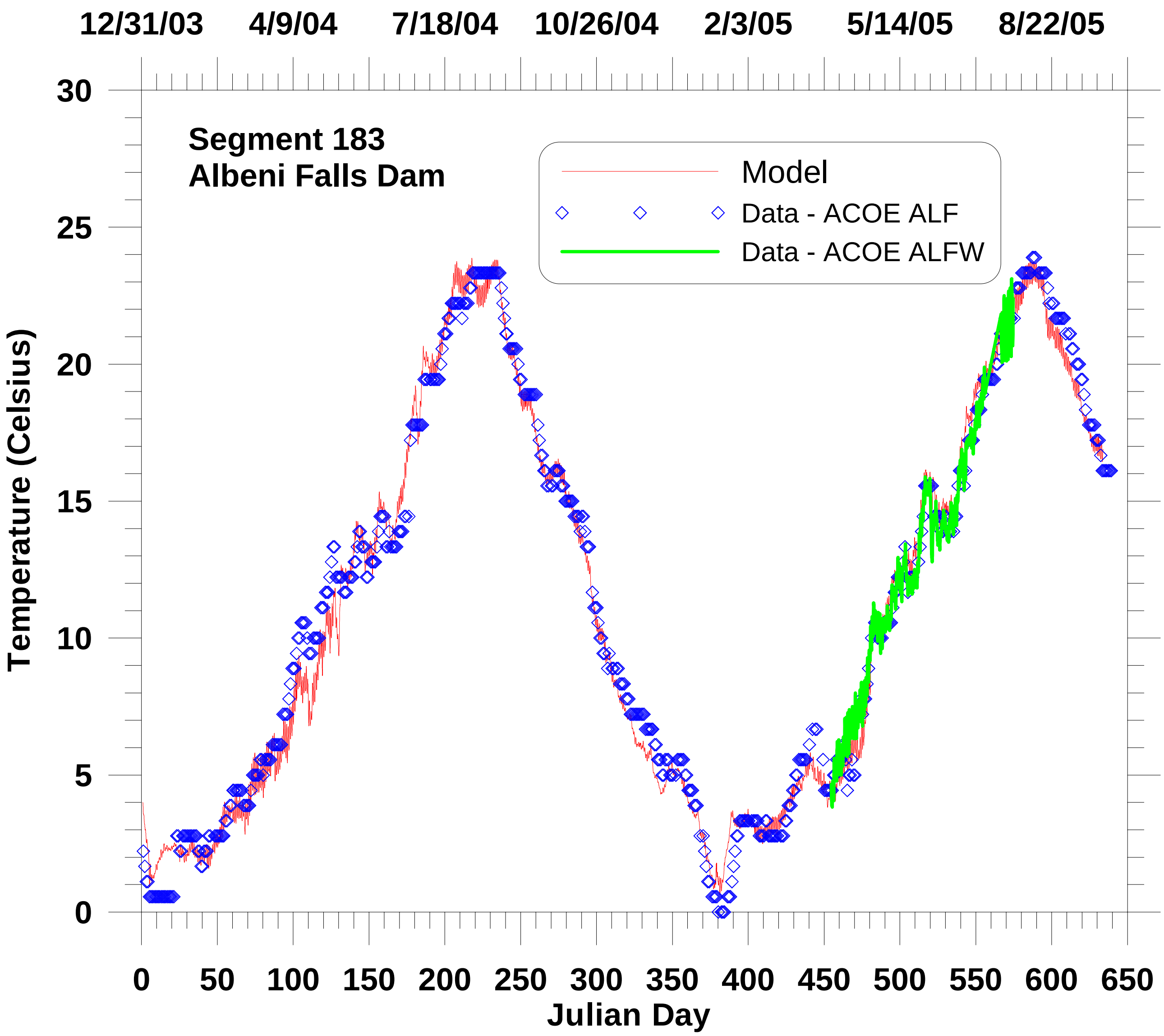


Figure 74: Comparison between model predictions and temperature data at Albeni Falls Dam.

Table 9: Model-data error statistics for continuous temperature data.

Site	Segment	Depth (m)	# of Comparisons	Mean Error (ME)	Absolute Mean Error (AME)	Root Mean Square Error (RMS)
ALFPORLB	7	0.6	3782	0.79	0.88	1.14
ALFPORLB	7	0.9	3379	0.68	0.69	0.86
ALFPORLB	7	3.1	7161	0.64	0.69	0.95
ALFPORLB	7	4.6	4342	0.84	0.91	1.44
ALFPORLB	7	6.1	3782	0.39	0.82	1.11
ALFPORLB	29	4.0	1617	0.25	0.79	1.00
Stn3	44	1.0	984	-0.12	0.42	0.64
Stn3	44	3.3	984	-0.04	0.34	0.47
Stn3	44	5.7	984	-0.01	0.24	0.29
Stn3	44	8.0	984	0.11	0.22	0.27
Stn3	44	10.3	984	0.10	0.23	0.27
Stn4	44	1.0	984	-0.21	0.68	1.07
Stn4	44	3.3	984	0.01	0.28	0.36
Stn4	44	5.6	984	0.01	0.22	0.27
Stn4	44	7.9	984	0.13	0.24	0.29
Stn4	44	10.2	983	0.23	0.28	0.34
ALFPORRC	107	0.6	3781	0.35	0.67	0.85
ALFPORRC	107	0.9	3181	0.38	0.48	0.70
ALFPORRC	107	3.5	3781	0.36	0.59	0.77
ALFPORRC	107	6.1	7166	0.18	0.44	0.60
ALFPORRC	107	12.2	7159	0.01	0.41	0.56
ALFFB	174	0.6	2145	-0.10	0.48	0.57
ALFFB	174	3.5	2145	-0.14	0.47	0.57
ALFFB	174	6.1	2145	-0.08	0.45	0.55
ALFW	183	-	2554	0.22	0.68	0.80
ALF	183	-	594	-0.31	0.72	0.92
Average				0.18	0.51	0.68

Table 10: Model-data error statistics for vertical temperature profiles.

Site	Model Segment #	Mean Error (ME)	Absolute Mean Error (AME)	Root Mean Square Error (RMS)
PDO-LB	2	0.43	0.43	0.45
PDO-RB	25	0.55	0.55	0.55
PDO-RR	44	0.27	0.27	0.28
PDO-LAC	101	0.06	0.13	0.14
PDO-RP	155	0.06	0.27	0.27
PDO-AC	182	0.05	0.33	0.34
ALFFB	183	0.42	0.60	0.61
Average		0.26	0.37	0.38

Water Quality

Like temperature, water quality was largely controlled by the upstream boundary condition. The calibrated water quality kinetic coefficients were shown in Table 11.

Table 11: W2 Model Water Quality Parameters

Variable	Description	Units	Typical values*	Calibration Values
Hydrodynamics and Longitudinal Transport				
AX	Longitudinal eddy viscosity (for momentum dispersion)	m^2/sec	1	1
DX	Longitudinal eddy diffusivity (for dispersion of heat and constituents)	m^2/sec	1	1
Temperature				
CBHE	Coefficient of bottom heat exchange	Wm^2/sec	0.30	0.30
TSED	Sediment (ground) temperature	^oC	12.8	11.5
WSC	Wind sheltering coefficient		0.85	0.85
BETA	Fraction of incident solar radiation absorbed at the water surface		0.45	0.45
Water Quality				
EXH20	Extinction for water	/m	0.25	0.25
EXSS	Extinction due to inorganic suspended solids	m^3/m/g	0.01	0.1
EXOM	Extinction due to organic suspended solids	m^3/m/g	0.17	0.1
EXA	Extinction due to algae	m^3/m/g	0.1	0.2
SSS	Suspended solids settling rate	m/day	2	1.5
AG	Algal growth rate	/day	1 – 2.5	2.0
AM	Algal mortality rate	/day	0.01-0.2	0.1
AE	Algal excretion rate	/day	0.01-0.04	0.04
AR	Algal dark respiration rate	/day	0.01-0.04	0.04
AS	Algal settling rate	/day	0.1-0.3	0.1
ASAT	Saturation intensity at maximum photosynthetic rate	W/m^2	150	75
APOM	Fraction of algal biomass lost by mortality to POM		0.8	0.8
AT1	Lower temperature for algal growth	^oC	4-10	2
AT2	Lower temperature for maximum algal growth	^oC	6-20	6
AT3	Upper temperature for	^oC	15-25	16

Variable	Description	Units	Typical values*	Calibration Values
	maximum algal growth			
AT4	Upper temperature for algal growth	^{o}C	20-30	30
AK1	Fraction of algal growth rate at AT1		0.1	0.1
AK2	Fraction of maximum algal growth rate at AT2		0.99	0.99
AK3	Fraction of maximum algal growth rate at AT3		0.99	0.99
AK4	Fraction of algal growth rate at AT4		0.1	0.1
ALGP	Stoichiometric equivalent between organic matter and phosphorus		0.005	0.003
ALGN	Stoichiometric equivalent between organic matter and nitrogen		0.08	0.08
ALGC	Stoichiometric equivalent between organic matter and carbon		0.45	0.45
EG	epiphyton growth rate	/day	1 – 2.5	2.0
EM	epiphyton mortality rate	/day	0.01-0.2	0.1
EE	epiphyton excretion rate	/day	0.01-0.04	0.04
ER	epiphyton dark respiration rate	/day	0.01-0.04	0.04
EHS	Biomass limitation factor	$g\text{-}m^{-2}$		20.0
ESAT	Saturation intensity at maximum photosynthetic rate	W/m^2	150	150
EPOM	Fraction of algal biomass lost by mortality to POM		0.8	0.8
ET1	Lower temperature for epiphyton growth	^{o}C	4-10	2
ET2	Lower temperature for maximum epiphyton growth	^{o}C	6-20	6
ET3	Upper temperature for maximum epiphyton growth	^{o}C	15-25	16
ET4	Upper temperature for algal growth	^{o}C	20-30	30
EK1	Fraction of epiphyton l growth rate at AT1		0.1	0.1
EK2	Fraction of maximum epiphyton l growth rate at AT2		0.99	0.60

Variable	Description	Units	Typical values*	Calibration Values
EK3	Fraction of maximum epiphyton growth rate at AT3		0.99	0.99
EK4	Fraction of epiphyton growth rate at AT4		0.1	0.1
ELGP	Stoichiometric equivalent between organic matter and phosphorus		0.005	0.003
ELGN	Stoichiometric equivalent between organic matter and nitrogen		0.08	0.08
ELGC	Stoichiometric equivalent between organic matter and carbon		0.45	0.45
LDOMDK	Labile DOM decay rate	/day	0.12	0.10
LRDDK	Labile to refractory decay rate	/day	0.001	0.001
RDOMDK	Maximum refractory decay rate	/day	0.001	0.001
LPOMDK	Labile Detritus decay rate	/day	0.06	0.08
POMS	Detritus settling rate	m/day	0.35	0.1
RPOMDK	Refractory Detritus decay rate	/day		0.001
OMT1	Lower temperature for organic matter decay	^oC	4	4
OMT2	Lower temperature for maximum organic matter decay	^oC	20	30
OMK1	Fraction of organic matter decay rate at OMT1		0.1	0.1
OMK2	Fraction of organic matter decay rate at OMT2		0.99	0.99
SEDK	Sediment decay rate	/day	0.06	0.10
PARTP	Phosphorous partitioning coefficient for suspended solids		1.2	0
AHSP	Algal half-saturation constant for phosphorous	g/m	0.003	0.003
NH4DK	Ammonia decay rate (nitrification rate)	/day	0.12	0.4
AHSN	Algal half-saturation constant for ammonia	g/m^3	0.014	0.014
NH4T1	Lower temperature for ammonia decay	^oC	5	5

Variable	Description	Units	Typical values*	Calibration Values
NH4T2	Lower temperature for maximum ammonia decay	^oC	20	25
NH4K1	Fraction of nitrification rate at NH4T1		0.1	0.1
NH4K2	Fraction of nitrification rate at NH4T2		0.99	0.99
NO3DK	Nitrate decay rate (denitrification rate)	/day	0.102	0.05
NO3T1	Lower temperature for nitrate decay	^oC	5	5
NO3T2	Lower temperature for maximum nitrate decay	^oC	20	25
NO3K1	Fraction of denitrification rate at NO3T1		0.1	0.1
NO3K2	Fraction of denitrification rate at NO3T2		0.99	0.99
O2NH4	Oxygen stoichiometric equivalent for ammonia decay		4.57	4.57
O2OM	Oxygen stoichiometric equivalent for organic matter decay		1.4	1.4
O2AR	Oxygen stoichiometric equivalent for dark respiration		1.4	1.1
O2AG	Oxygen stoichiometric equivalent for algal growth		1.4	1.4
ORGP	Stoichiometric equivalent between organic matter and phosphorus		0.005	0.0005
ORGN	Stoichiometric equivalent between organic matter and nitrogen		0.08	0.01
ORGC	Stoichiometric equivalent between organic matter and carbon		0.45	0.45
O2LIM	Dissolved oxygen concentration at which anaerobic processes begin	g/m^3	0.05	0.1
* Cole and Wells (2004)				

Dissolved Oxygen

Figure 75 shows comparisons between dissolved oxygen data measured at Albeni Falls dam and model predictions. Comparisons of vertical profiles and data were shown in Appendix B: Calibration Plots. Error statistics for continuous data measured at Alben Falls dam were listed in Table 12 and error statistics for the dissolved oxygen profiles were listed in Table 13. Zero order sediment oxygen demand (SOD) rates were set at 0.1 g m^{-2} d^{-1} for all model segments.

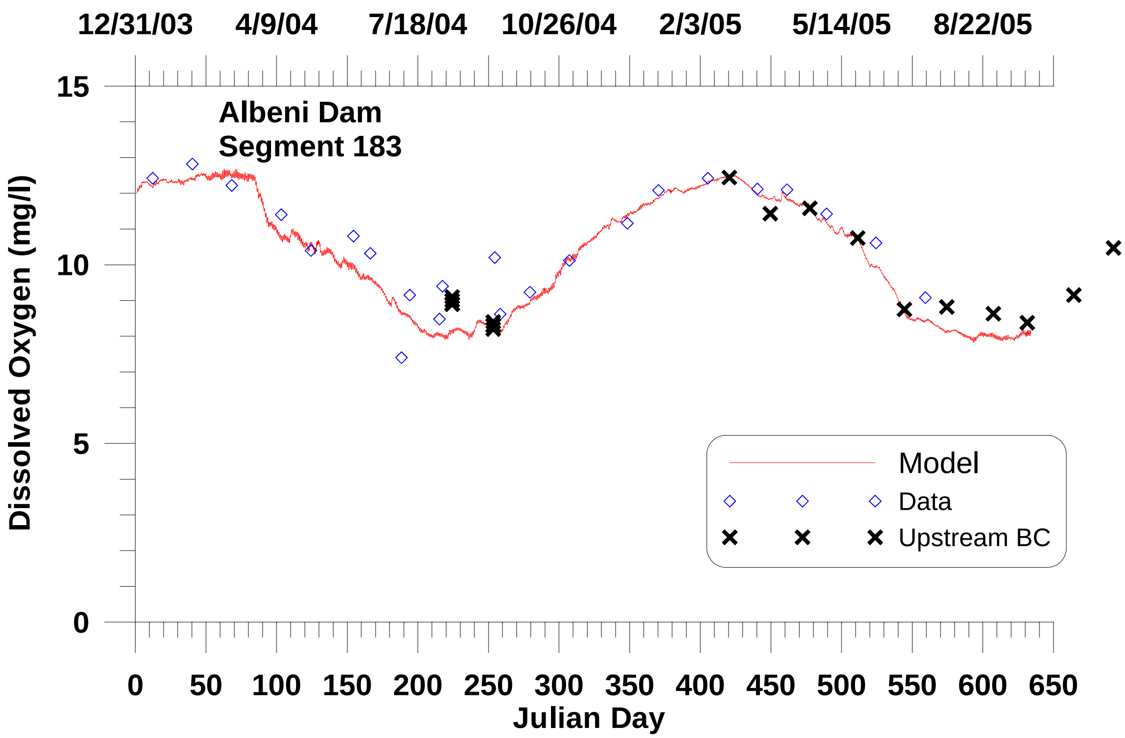


Figure 75: Comparison between model predictions and dissolved oxygen data at Albeni Dam.

Table 12: Model-data error statistics for dissolved oxygen (mg/l) measured at Albeni Falls Dam (segment 183).

Site	Model Segment #	Mean Error (ME)	Absolute Mean Error (AME)	Root Mean Square Error (RMS)
Albeni Falls Dam	183	-0.38	0.54	0.70

Table 13: Model-data error statistics for vertical dissolved oxygen profiles.

Site	Model Segment #	Mean Error (ME)	Absolute Mean Error (AME)	Root Mean Square Error (RMS)
PDO-LB	2	0.07	0.08	0.09
PDO-RB	25	0.03	0.27	0.27
PDO-RR	44	0.14	0.14	0.16
PDO-LAC	101	-0.01	0.07	0.08
PDO-RP	155	-0.13	0.13	0.15
PDO-AC	182	-0.03	0.15	0.16
ALFFB	183	-0.26	0.47	0.47
Average		-0.03	0.19	0.20

pH

pH data collected at Albeni Falls dam were compared with model predictions in Figure 76. Comparisons of vertical profiles and data were shown in Appendix B: Calibration Plots. Error statistics for the data measured at Albeni Falls Dame were listed in Table 14 and the error statistics of the pH vertical profiles were shown in Table 15. The difference between data and model predictions were mostly due to the sparseness of the upstream boundary condition. Figure 76, which shows model predictions compared with data measured at Albeni Falls Dam, also shows pH data used to develop the upstream boundary condition. The conditions at the upstream boundary conditions might have been estimated from data measured further downstream, but it was decided to develop the upstream boundary condition using only data measured at that location.

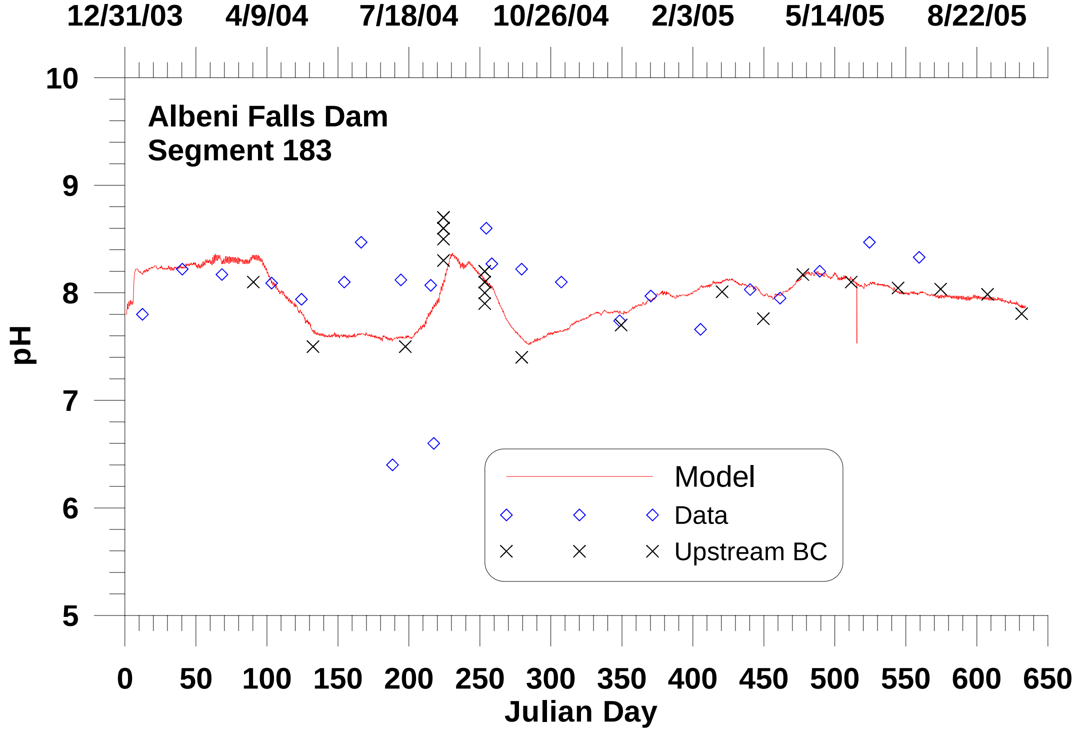


Figure 76: Comparison between model predictions and pH data measured at Albeni Dam. The data used to develop the upstream boundary condition were also shown.

Table 14: Model-data error statistics for pH measured at Albeni Falls Dam (segment 183).

Site	Model Segment #	Mean Error (ME)	Absolute Mean Error (AME)	Root Mean Square Error (RMS)
Albeni Falls Dam	183	-0.06	0.36	0.50

Table 15: Model-data error statistics for vertical pH profiles.

Site	Model Segment #	Mean Error (ME)	Absolute Mean Error (AME)	Root Mean Square Error (RMS)
PDO-LB	2	-0.02	0.07	0.08
PDO-RB	25	-0.08	0.12	0.12
PDO-RR	44	-0.24	0.26	0.27
PDO-LAC	101	-0.33	0.34	0.35
PDO-RP	155	-0.25	0.28	0.28

Site	Model Segment #	Mean Error (ME)	Absolute Mean Error (AME)	Root Mean Square Error (RMS)
PDO-AC	182	-0.28	0.29	0.30
ALFFB	183	-0.10	0.29	0.29
Average		-0.19	0.23	0.24

Algae

Chlorophyll a data were used to calibrate algae. Algae concentrations were low in the river. The ratio between algae biomass and chlorophyll a was assumed to be 100. Figure 77 shows the comparison between model predictions and chlorophyll a measured at Albeni Dam. Error statistics were listed in Table 16.

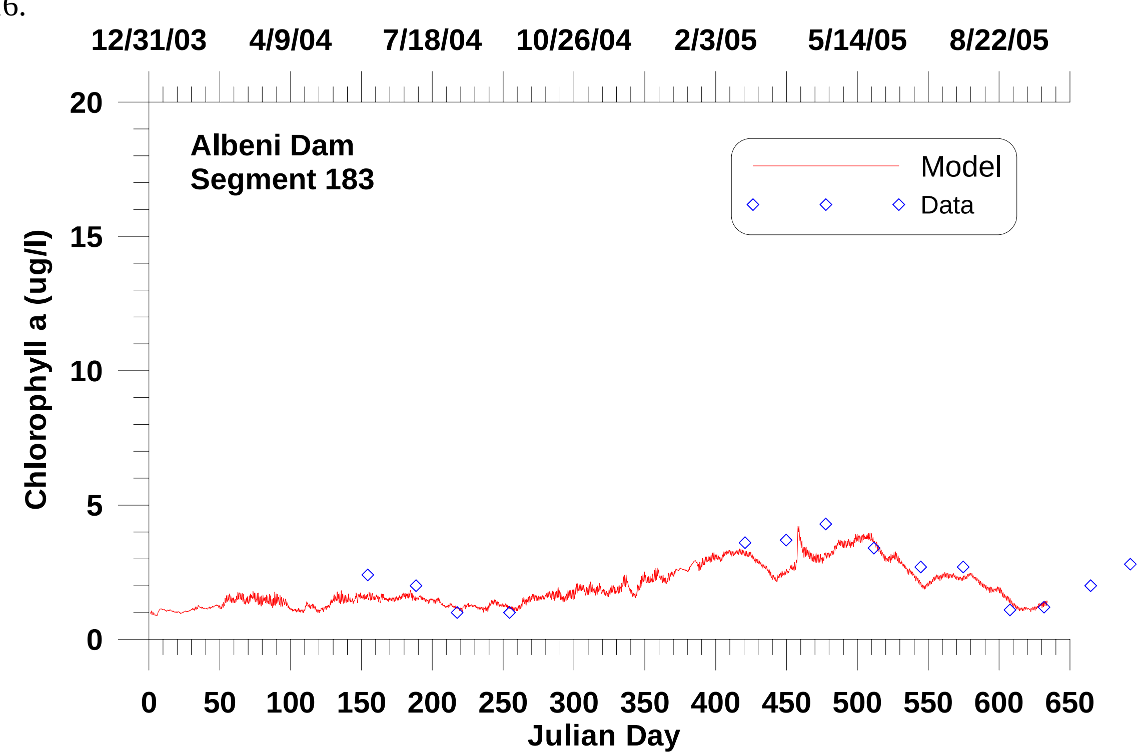


Figure 77: Comparison between model predictions and chlorophyll a data measured at Albeni Falls Dam.

Table 16: Model-data error statistics for chlorophyll a measured at Albeni Falls Dam (segment 183).

Site	Model Segment #	Mean Error (ME)	Absolute Mean Error (AME)	Root Mean Square Error (RMS)
Albeni Falls Dam	183	-0.30	0.50	0.60

Phosphorus

Phosphorus concentrations were low, often at or below detection limits. Ortho-phosphorus data were compared with model predictions in Figure 78. Figure 79 shows the comparison between predictions and total phosphorus data measured at Albeni Falls Dam. Error statistics were shown in Table 17 and Table 18.

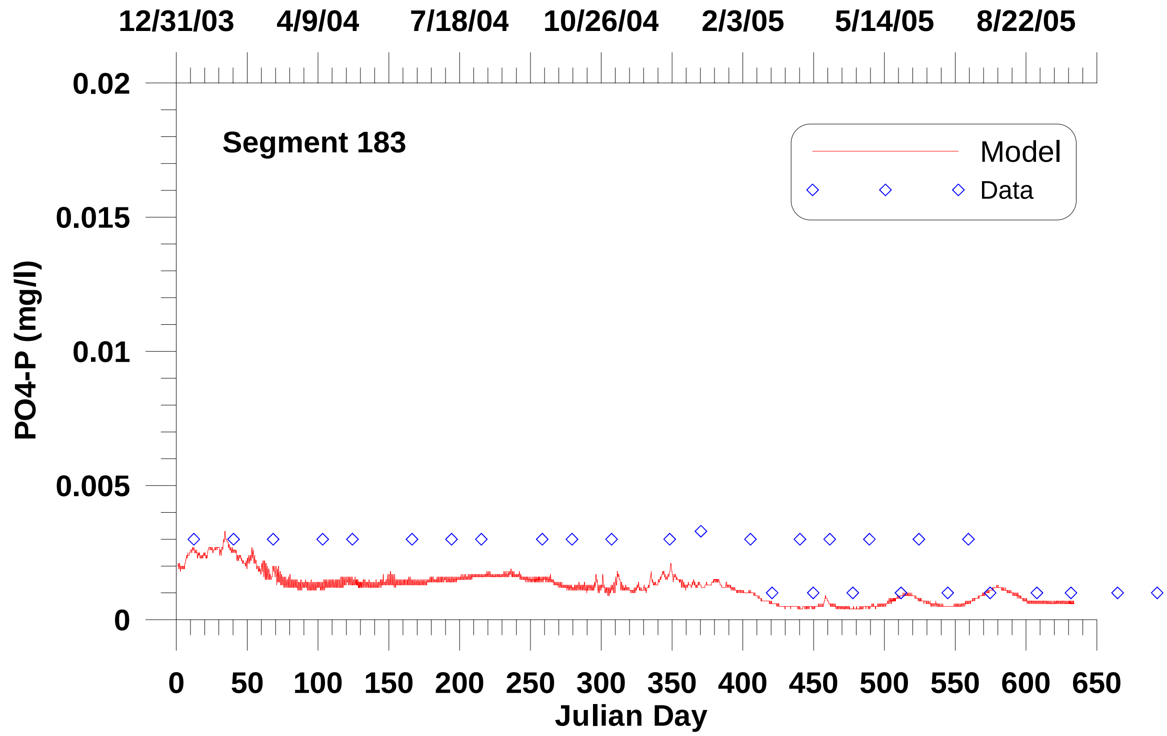


Figure 78: Comparison between model predictions and ortho-phosphorus data measured at Albeni Dam. Mostly all the data were minimum detects.

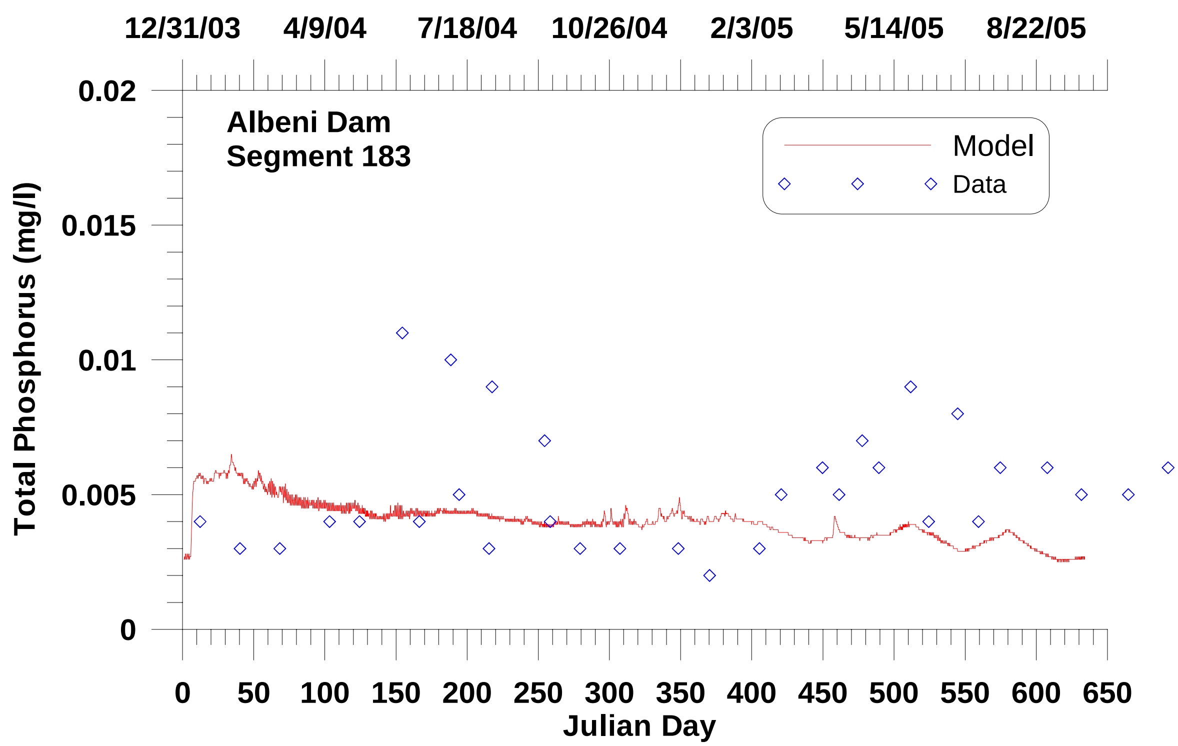


Figure 79: Comparison between model predictions and total phosphorus data measured at Albeni Dam.

Table 17: Model-data error statistics for ortho-phosphorus measured at Albeni Falls Dam (segment 183).

Site	Model Segment #	Mean Error (ME)	Absolute Mean Error (AME)	Root Mean Square Error (RMS)

Albeni Falls Dam	183	-0.001	0.001	0.002

Table 18: Model-data error statistics for total phosphorus measured at Albeni Falls Dam (segment 183).

Site	Model Segment #	Mean Error (ME)	Absolute Mean Error (AME)	Root Mean Square Error (RMS)
Albeni Falls Dam	183	-0.001	0.002	0.003

Nitrogen

Ammonia nitrogen, nitrate nitrogen and total nitrogen were compared with data in Figure 80, Figure 81, and Figure 82, respectively.   Error statistics were listed in Table 19 through Table 21.

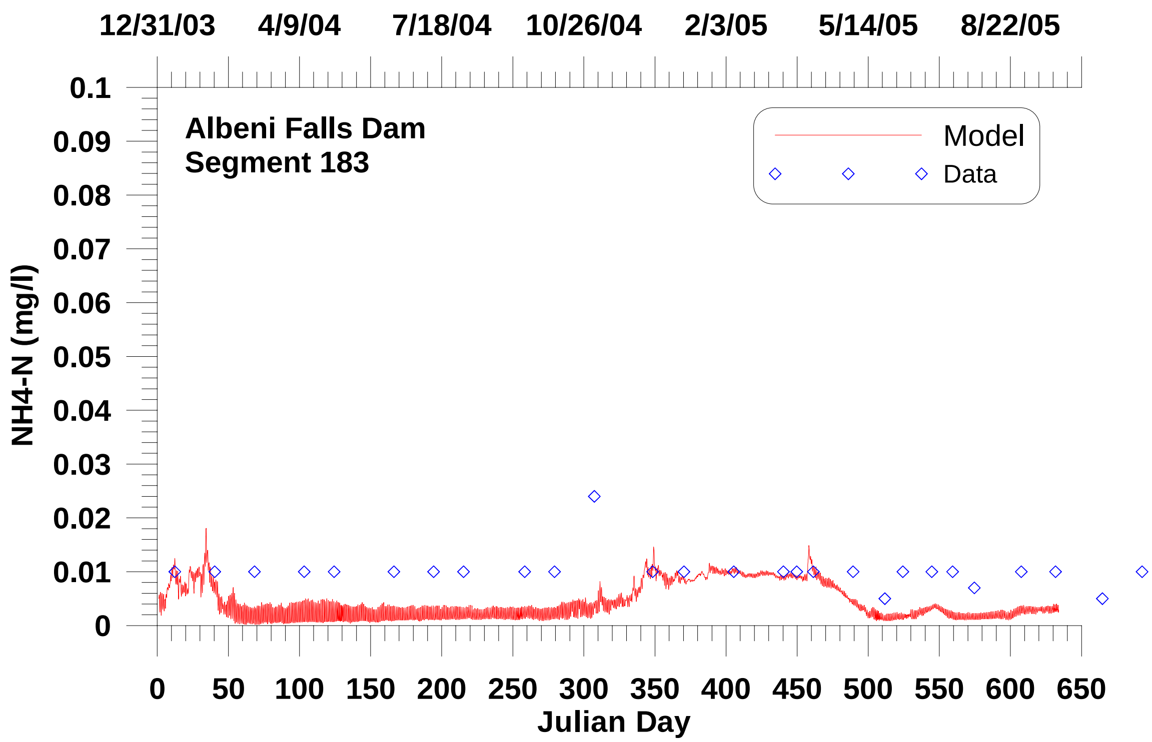


Figure 80: Comparison between model predictions and ammonia nitrogen data measured at Albeni Dam.

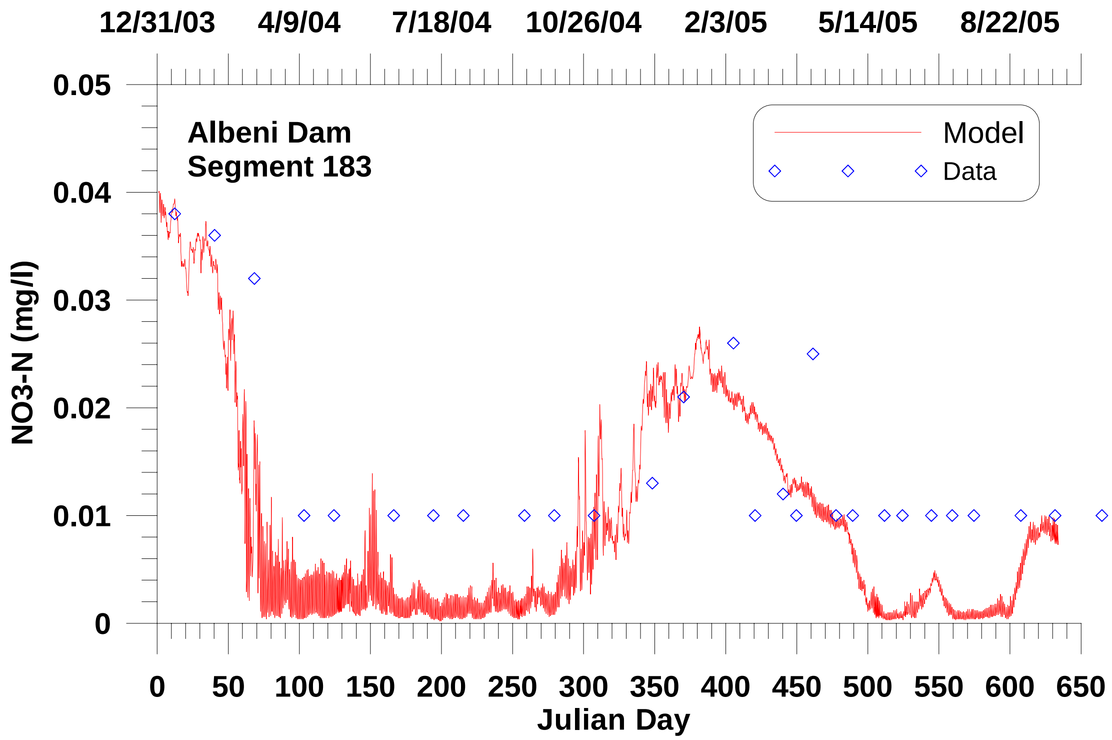


Figure 81: Comparison between model predictions and nitrate nitrogen data measured at Albeni Dam.

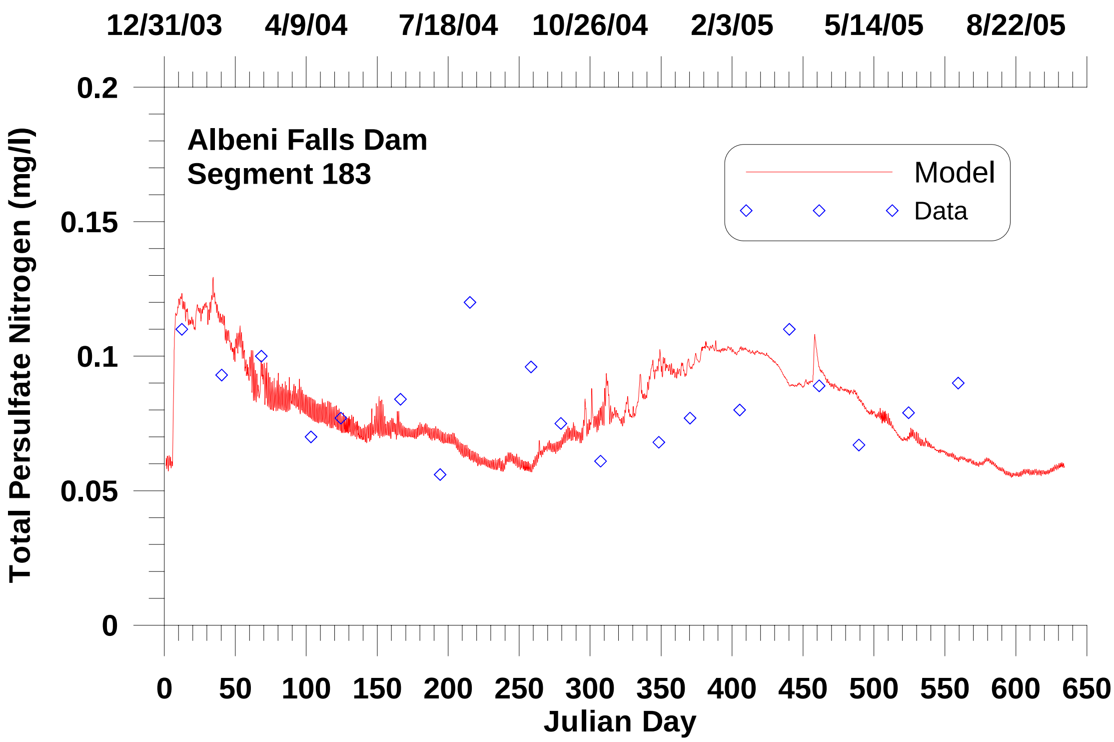


Figure 82: Comparison between model total nitrogen predictions and total persulfate nitrogen data measured at Albeni Dam.

Table 19: Model-data error statistics for ammonia nitrogen measured at Albeni Falls Dam (segment 183).

Site	Model Segment #	Mean Error (ME)	Absolute Mean Error (AME)	Root Mean Square Error (RMS)
Albeni Falls Dam	183	-0.005	0.006	0.007

Table 20: Model-data error statistics for nitrate nitrogen measured at Albeni Falls Dam (segment 183).

Site	Model Segment #	Mean Error (ME)	Absolute Mean Error (AME)	Root Mean Square Error (RMS)
Albeni Falls Dam	183	-0.004	0.006	0.007

Table 21: Model-data error statistics for total nitrogen measured at Albeni Falls Dam (segment 183).

Site	Model Segment #	Mean Error (ME)	Absolute Mean Error (AME)	Root Mean Square Error (RMS)
Albeni Falls Dam	183	0.000	0.018	0.022

Summary

A water quality and hydrodynamic model, CE-QUAL-W2 Version 3.2 (Cole and Wells, 2004; http://www.cee.pdx.edu/w2), was applied to the Pend Oreille River, Idaho. This report summarizes model development and calibration of the CE-QUAL-W2 Version 3.2 model of the Pend Oreille River.

The system model required that boundary conditions and the topography be determined. Data in support of this modeling effort were shown in this report. This includes data such as:

- Dynamic inflow/discharge rates
- Dynamic inflow/discharge temperatures
- Dynamic inflow/discharge water quality constituents
- Dynamic meteorological data (air temperature, dew point temperature, wind speed, wind direction and cloud cover or short wave solar radiation)
- Model bathymetry

The outflow from Albeni Falls dam is a short distance from the state line, and the model predicted water quality of dam outflows is close to the water quality at the state line.

In general, the model reproduces the river responses to the known boundary conditions. The average absolute mean error (AME) of model predicted temperatures compared with vertical profile data was 0.37 degrees Celsius. Model predictions compared with continuous temperature data had an error of 0.51 degrees Celsius. The AME for vertical profile data was 0.19 mg/l for dissolved oxygen and 0.23 for pH. The root mean square error for data measured at Albeni Falls dam was 0.60 ug/l for chlorophyll a, 0.001 mg/l for ortho-phosphorus, 0.002 mg/l for total phosphorus, 0.006 mg/l for ammonia nitrogen, 0.006 mg/l for nitrate nitrogen, and 0.018 mg/l for total nitrogen.

Model error for temperature was greatest nearest the upstream boundary condition, but improved at sites closer to Albeni Falls dam. The larger error near the upstream boundary condition was due to data reflecting seiching action in Lake Pend Oreille. Only a small portion of the lake is simulated by the model. Sites downstream toward the dam were not affected by seiching and thus model predictions improved downstream.

The model was very sensitive to the upstream boundary conditions. Differences between model predictions and data were often due to the sparseness of data measured at the upstream boundary condition. Travel times from the upstream boundary to Albeni Falls dam were shown in Figure 83. Generally the shorter the travel time within a system, the greater influence the boundary condition has on model predictions. The travel time in 2004 ranged from less than 3 days to 9 days. Important calibration parameters included algae growth rate, algae temperature coefficients, periphyton half saturation coefficient, periphyton growth rate, and periphyton temperature coefficients.

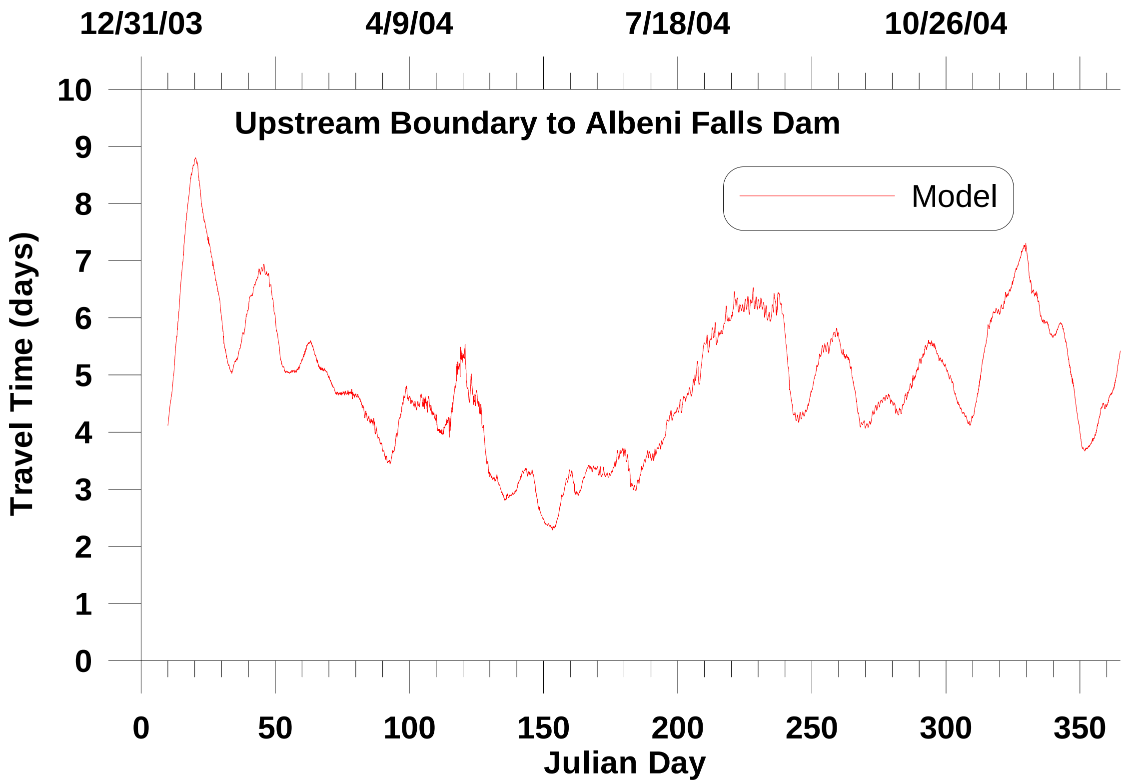


Figure 83. Travel time from model upstream boundary to Albeni Falls dam in 2004.

Improvements that could be made to the model include the following:

- Use the new v3.5 model with macrophytes rather than just periphyton
- Attempt to improve the water quality boundary condition at Pend Oreille Lake by modeling the lake itself (this may not be important in the short term), or by adjusting boundary condition data to account for diurnal dynamics
- Gather data on periphyton/macrophyte densities and compare with model predictions
- Monitor water quality at the upstream boundary condition continuously for temperature, dissolved oxygen and pH. There is little continuous water quality data available in the study area to evaluate diurnal dynamics of temperature, dissolved oxygen, and pH.

References

Cole, T. and Wells, S.A. (2004) "CE-QUAL-W2: A Two-Dimensional, Laterally Averaged, Hydrodynamic and Water Quality Model, Version 3.2," Instruction Report EL-2004-, USA Engineering and Research Development Center, Waterways Experiment Station, Vicksburg, MS.

Fields, R. L.; Woods, P. F., and Berenbrock, C. (1996) "Bathymetric Map of Lake Pend Oreille and Pend Oreille River, Idaho." *U. S. Geological Survey Water Resources Investigations Report 96-4189*, U.S Geological Survey, Boise, ID.

Tetra Tech, Inc. and DVS Environmental, Inc. (2005) "Pend Oreille River Water Quality Monitoring," prepared for Tri-State Water Quality Council, Sandpoint, ID.

Appendix A: Extent of Data

Hydrodynamic, temperature and water quality data were primarily obtained from 2004 and 2005 for a variety of sources. Figure 84 shows the hydrodynamic monitoring sites and Table 22 list the sites and the extent of the data. Figure 85 and Figure 86 show the temperature and water quality monitoring sites and Table 23 lists the sites and their site descriptions. Table 24 lists the monitoring sites with continuous (sub-daily) temperature data. Table 25 lists the extent of the temperature array data at various depths. Table 26 to Table 28 lists the sites and the extent of grab sample water quality data. Table 29 lists the sites and extent of vertical profile data on the Pend Oreille River and Lake.

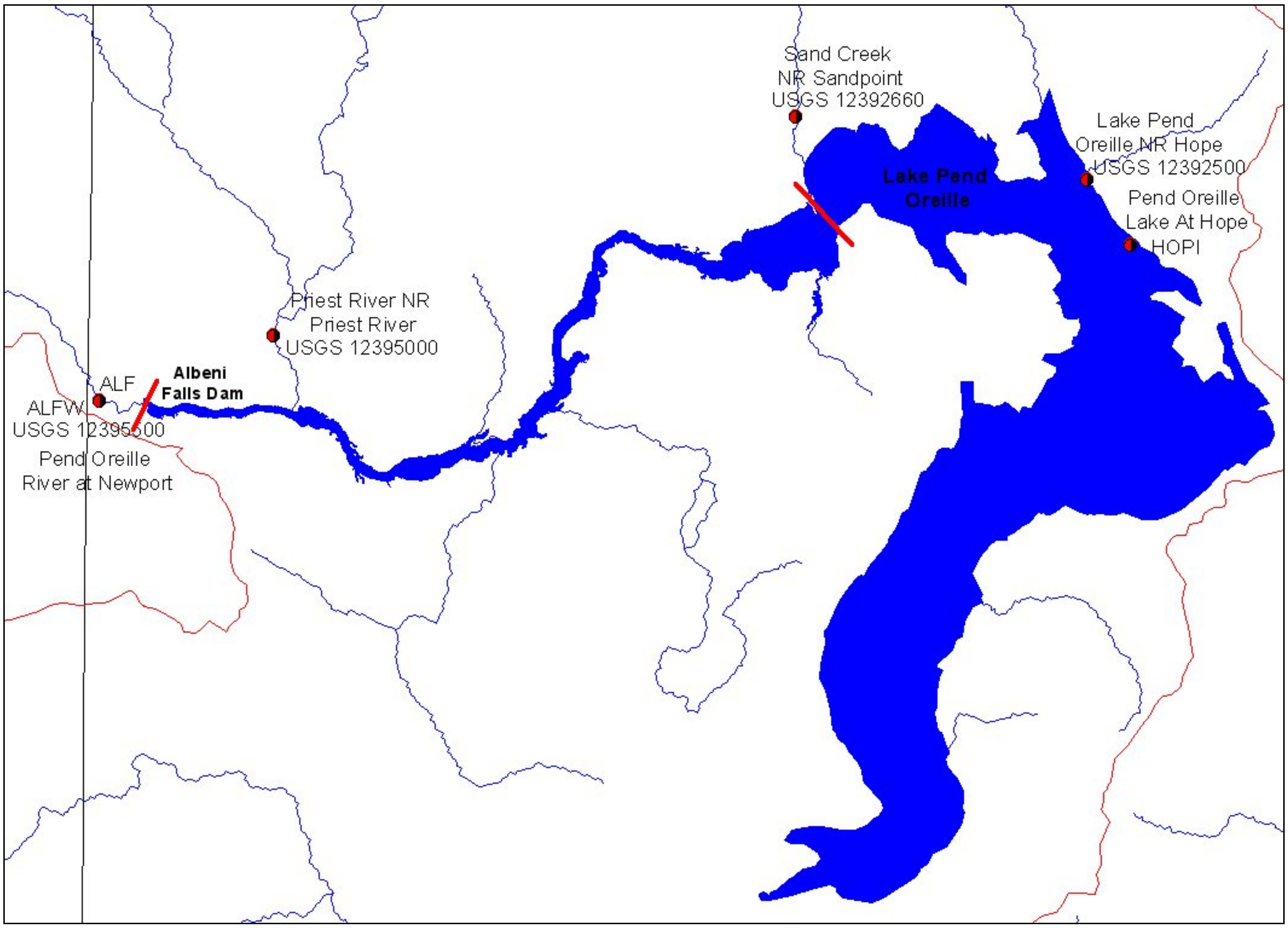


Figure 84: Hydrodynamic monitoring sites

Table 22: Hydrodynamic monitoring sites and extent of data

Site ID	Site Name	Agency	State	Minimum Date	Maximum Date	Count flow, cfs	Count gage height, ft	Count Storage, acre-ft	Frequency
ALF	Albeni Falls Dam On Pend Oreille River Below Lake	ACOE	ID	01/01/1997	09/09/2005	77,759	77,706	77,701	hourly
ALFW	Albeni Tailwater - Pend Oreille River at Newport	ACOE	ID	04/29/2004	09/09/2005		11,261		hourly
HOPI	Pend Oreille Lake At Hope	ACOE	ID	01/01/1997	09/10/2005		45,231	9,545	hourly/ 8 hours
USGS 12392500	Lake Pend Oreille NR Hope	USGS	ID	01/01/1997	09/25/2005		244,878		15 min
USGS 12392660	Sand Creek NR Sandpoint	USGS	ID	10/01/1988	09/30/1993	1,652			daily
USGS 12395000	Priest River NR Priest River	USGS	ID	01/01/1997	01/31/2006	249,882	247,686		15 min
USGS 12395500	Pend Oreille River at Newport	USGS	WA	01/01/1997	11/28/2005	243,360	246,029		15 min

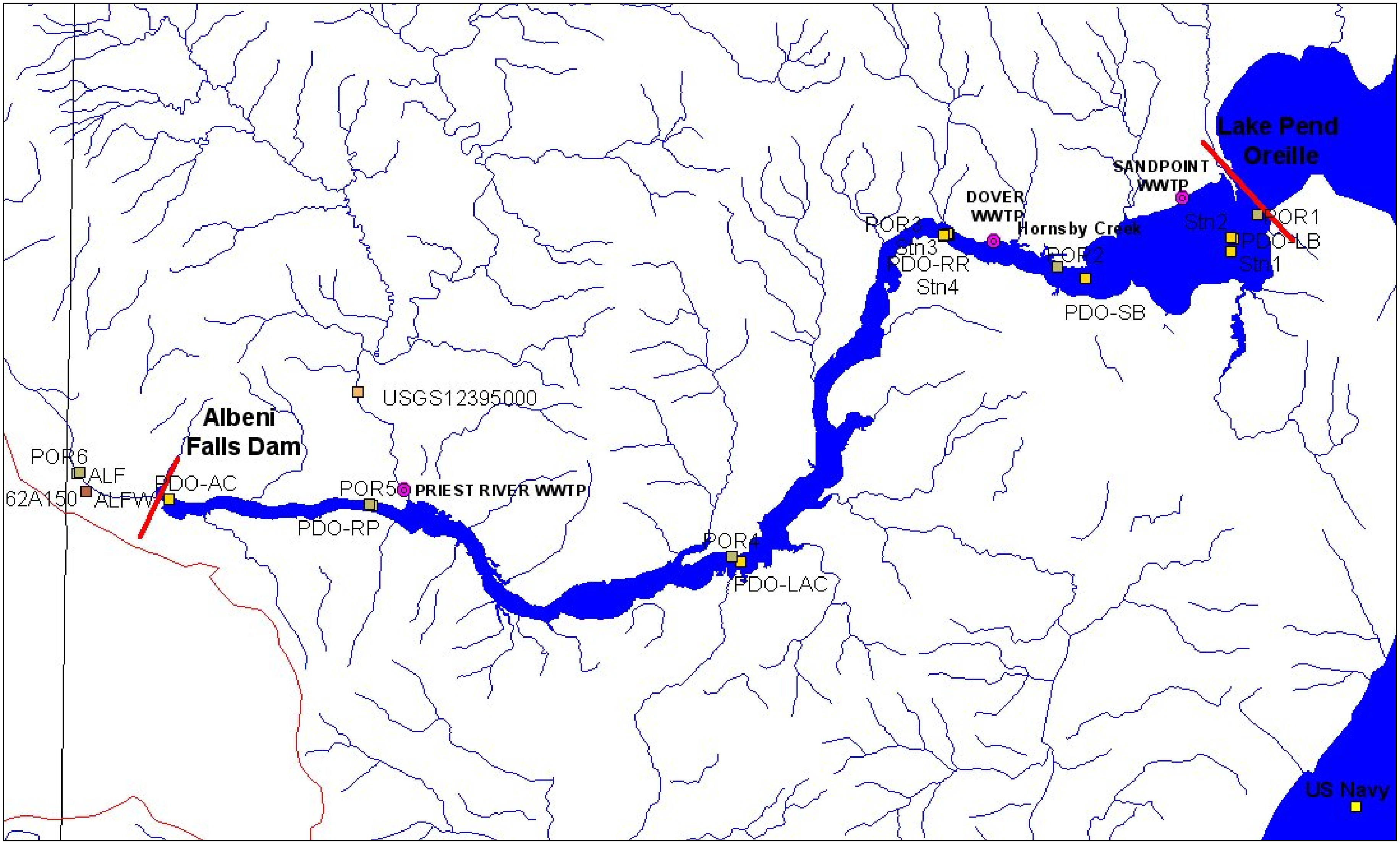


Figure 85: Temperature and water quality monitoring sites, part 1

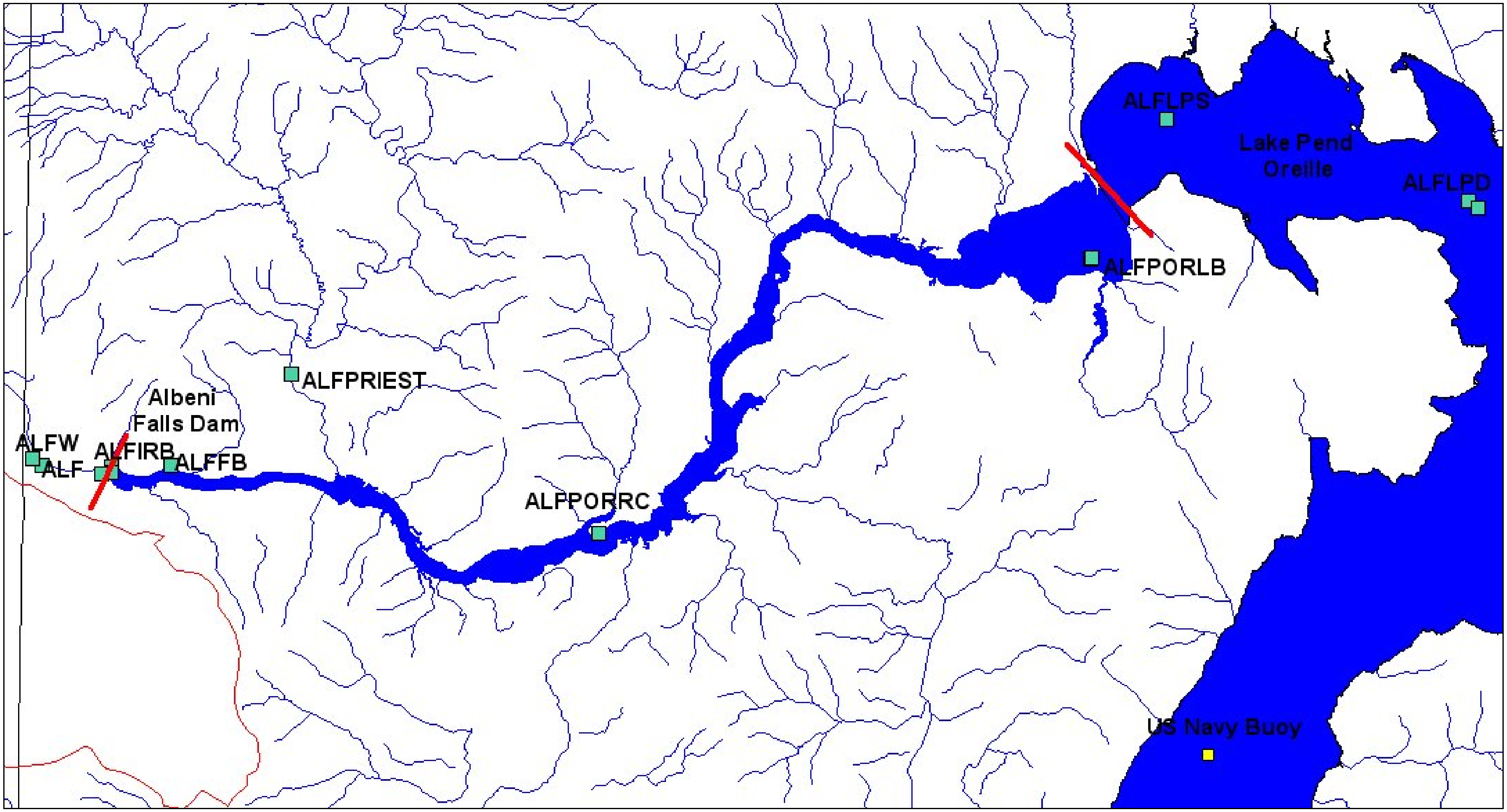


Figure 86: Temperature and water quality monitoring sites, part 2

Table 23: Temperature and water quality monitoring sites and descriptions

Site ID	Agency	State	Site Name
62A150	WADOE	WA	Pend Oreille R at Newport
ALF	ACOE	ID	Albeni Falls Dam On Pend Oreille River Below Lake
ALFW	ACOE	ID	Albeni Tailwater - Pend Oreille River at Newport
PDO-AC	IDEQ	ID	Albany Cove
PDO-LAC	IDEQ	ID	Laclede
PDO-LB	IDEQ	ID	Long Bridge
PDO-RP	IDEQ	ID	Priest river Bridge
PDO-RR	IDEQ	ID	Railroad Bridge
PDO-SB	IDEQ	ID	Springy Point
POR1	Tetra Tech, Inc.	ID	Pend Oreille River 95 bridge-2004, Lake Pend Oreille
POR2	Tetra Tech, Inc.	ID	
POR3	Tetra Tech, Inc.	ID	
POR4	Tetra Tech, Inc.	ID	
POR5	Tetra Tech, Inc.	ID	Pend Oreille River at City of Priest River
POR6	Tetra Tech, Inc.	ID	
Stn1	IDEQ	ID	Long Bridge
Stn2	IDEQ	ID	Long Bridge, North of Stn1
Stn3	IDEQ	ID	Railroad Bridge Crossing
Stn4	IDEQ	ID	Railroad Bridge Crossing, South of Stn3
USGS 12395000	USGS	ID	Priest River near Priest River, ID
US Navy Buoy	US Navy	ID	Buoy on Lake Pend Oreille, 5 depths
SandPt	City of Sandpoint	ID	City of Sandpoint WWTP discharge
ALFFB	ACOE	ID	Albeni Falls Dam Forebay, 5 depths
ALFIRB	ACOE	ID	Albeni Falls Dam Forebay Right Bank
ALFLPD	ACOE	ID	Lake Pend Oreille near Anderson Point, Buoy, 11 depths
ALFLPS	ACOE	ID	Lake Pend Oreille near Contest Point, Buoy, 7 depths
ALFPORLB	ACOE	ID	Pend Oreille River at Long Bridge, Buoy, 6 depths
ALFPORRC	ACOE	ID	Pend Oreille River at Riley Creek Campground, 5 depths
ALFPRIEST	ACOE	ID	Priest River at USGS staff gage

Table 24: Extent of continuous temperature data

Site ID	Min Date	Max Date	Count Temp, C
ALF	01/01/1997	09/30/2005	3,029
ALFW	03/29/2005	07/27/2005	2,554
POR1	05/30/2004	09/09/2004	1,634
POR2	07/30/2003	09/09/2004	3,434
POR3	05/30/2004	09/09/2004	1,632

POR5	07/30/2003	10/13/2003	1,800
POR6	05/31/2004	08/11/2004	1,157
USGS 12395000	05/29/1998	11/23/2005	15,751
ALFIRB	5/7/2004	11/22/2005	9,505
ALFPRIEST	5/7/2004	10/25/2005	16,796

Table 25: Extent of continuous temperature array data

Site ID	Depth, m	Min Date	Max Date	Count Temp, C
Stn1	1.00	08/13/2005	09/23/2005	984
Stn1	2.65	08/13/2005	09/23/2005	984
Stn1	4.30	08/13/2005	09/23/2005	996
Stn2	1.00	08/13/2005	09/23/2005	984
Stn2	2.60	08/13/2005	09/23/2005	984
Stn2	4.20	08/13/2005	09/23/2005	984
Stn3	1.00	08/13/2005	09/23/2005	984
Stn3	3.30	08/13/2005	09/23/2005	984
Stn3	5.65	08/13/2005	09/23/2005	984
Stn3	8.00	08/13/2005	09/23/2005	984
Stn3	10.30	08/13/2005	09/23/2005	984
Stn4	1.00	08/13/2005	09/23/2005	984
Stn4	3.30	08/13/2005	09/23/2005	984
Stn4	5.60	08/13/2005	09/23/2005	984
Stn4	7.90	08/13/2005	09/23/2005	984
Stn4	10.20	08/13/2005	09/23/2005	984
ALFFB	0.61	06/27/2005	11/22/2005	3,550
ALFFB	3.05	06/27/2005	11/22/2005	3,550
ALFFB	6.10	06/27/2005	11/22/2005	3,550
ALFFB	12.19	06/27/2005	11/22/2005	3,550
ALFFB	18.29	06/27/2005	11/22/2005	3,550
ALFLPD	0.61	05/06/2004	11/21/2005	9,479
ALFLPD	1.52	05/06/2004	11/21/2005	9,479
ALFLPD	3.05	05/06/2004	11/21/2005	9,480
ALFLPD	7.62	05/06/2004	11/21/2005	9,480
ALFLPD	15.24	05/06/2004	11/21/2005	9,476
ALFLPD	22.86	05/06/2004	11/21/2005	9,480
ALFLPD	30.48	05/06/2004	11/21/2005	9,480
ALFLPD	45.72	05/06/2004	11/22/2005	9,505
ALFLPD	60.96	05/06/2004	11/22/2005	9,504
ALFLPD	76.20	05/06/2004	11/22/2005	9,503
ALFLPD	91.44	05/06/2004	11/21/2005	9,480
ALFLPS	0.61	05/06/2004	11/23/2005	9,552
ALFLPS	1.52	04/20/2005	11/21/2005	5,164
ALFLPS	3.05	05/06/2004	11/21/2005	9,505
ALFLPS	6.10	05/06/2004	11/03/2004	4,341
ALFLPS	9.14	05/06/2004	11/22/2005	9,528
ALFLPS	12.19	05/06/2004	11/21/2005	9,504
ALFLPS	15.24	05/06/2004	11/21/2005	9,505

Site ID	Depth, m	Min Date	Max Date	Count Temp, C
ALFPORLB	0.61	04/20/2005	11/21/2005	5,164
ALFPORLB	0.91	06/15/2004	11/03/2004	3,379
ALFPORLB	3.05	06/15/2004	11/21/2005	8,543
ALFPORLB	4.57	05/06/2004	11/03/2004	4,342
ALFPORLB	6.10	04/20/2005	11/21/2005	5,164
ALFPORLB	7.62	06/15/2004	11/21/2005	8,543
ALFPORRC	0.61	04/20/2005	11/21/2005	5,164
ALFPORRC	0.91	06/15/2004	11/03/2004	3,381
ALFPORRC	3.05	04/20/2005	11/21/2005	5,164
ALFPORRC	6.10	06/15/2004	11/21/2005	8,549
ALFPORRC	12.19	06/15/2004	11/23/2005	8,587
US Navy Buoy	0	01/01/2001	12/31/2005	192,090
US Navy Buoy	15.24	01/12/2001	04/21/2005	183,899
US Navy Buoy	30.48	01/12/2001	12/31/2004	121,807
US Navy Buoy	60.96	01/12/2001	12/31/2004	125,473
US Navy Buoy	121.9	01/12/2001	12/31/2004	81,399

Table 26: Extent of grab sample water quality data, part 1 (counts of measurements)

Site ID	Min Date	Max Date	Temp, C	pH	BOD, mg/L	Chl a, ug/L	TPN, mg/L	NH3, mg/L	NO2+NO3, mg/L	SRP, mg/L	TP, mg/L	Turb, NTU	Ca, mg/L	Mg, mg/L	Mn, mg/L
PDO-AC	08/11/2004	09/09/2004		3	3	6	6	6	6	3	6				
PDO-LAC	08/11/2004	09/09/2004		5	5	10	10	10	10	5	10				
PDO-LB	08/11/2004	09/09/2004		2	2	4	4	4	4	2	4				
PDO-RP	08/11/2004	09/09/2004		3	3	6	6	6	6	3	6				
PDO-RR	08/11/2004	09/09/2004		7	7	11	11	11	11	7	11				
PDO-SB	08/11/2004	09/09/2004		3	3	6	6	6	6	3	6				
SandPt	03/30/2004	12/14/2004	5	5								5	5	5	4
POR2	06/01/2004	09/10/2004		4		4	4				4				
POR3	06/01/2004	09/10/2004		4		4	4				4				
POR4	06/01/2004	09/10/2004		4		4	4				4				
POR5	06/02/2004	09/10/2004		4		4	4				4				
POR6	06/02/2004	09/10/2004		4		4	4				4				
62A150	01/12/2004	07/12/2005	19	19			19	19	19	19	18	19			
ALFFB	02/23/2005	11/22/2005				10	10	8	10	10	10		4	4	
ALFLPD	02/23/2005	11/22/2005				9	18	15	18	18	18		7	7	
ALFLPS	02/23/2005	11/22/2005				10	15	13	15	15	15		6	6	

Table 27: Extent of grab sample water quality data, part 2 (counts of measurements)

Site ID	Min Date	Max Date	SiO2, mg/L	Si, mg/L	Fe, mg/L	Hardness	Alkalinity	TOC, mg/L	DOC, mg/L	TDS, mg/L	Cond mS/cm	DO, mg/L	Secchi Depth, m	SS, mg/L	Fecal Col
PDO-AC	08/11/2004	09/09/2004													
PDO-LAC	08/11/2004	09/09/2004													
PDO-LB	08/11/2004	09/09/2004													
PDO-RP	08/11/2004	09/09/2004													

Site ID	Min Date	Max Date	SiO_2, mg/L	Si, mg/L	Fe, mg/L	Hardness	Alkalinity	TOC, mg/L	DOC, mg/L	TDS, mg/L	Cond mS/cm	DO, mg/L	Secchi Depth, m	SS, mg/L	Fecal Col
PDO-RR	08/11/2004	09/09/2004													
PDO-SB	08/11/2004	09/09/2004													
SandPt	03/30/2004	12/14/2004	5	4	5	5	5	5	4						
POR2	06/01/2004	09/10/2004								4	4	4	4		
POR3	06/01/2004	09/10/2004								4	4	4	4		
POR4	06/01/2004	09/10/2004								4	4	4	4		
POR5	06/02/2004	09/10/2004								4	4	4	4		
POR6	06/02/2004	09/10/2004								4	4	4	4		
62A150	01/12/2004	07/12/2005									19	19		19	19
ALFFB	02/23/2005	11/22/2005				4	9		0						
ALFLPD	02/23/2005	11/22/2005				7	16		0						
ALFLPS	02/23/2005	11/22/2005				6	13		0						

Table 28: Extent of grab sample water quality data, part 3 (counts of measurements)

Site ID	Min Date	Max Date	Transmissivity, ft	Transmissivity, m	Sulfate, mg/L	CL, mg/L	K, mg/L	Na, mg/L	Phaeo a, ug/L
PDO-AC	08/11/2004	09/09/2004							
PDO-LAC	08/11/2004	09/09/2004							
PDO-LB	08/11/2004	09/09/2004							
PDO-RP	08/11/2004	09/09/2004							
PDO-RR	08/11/2004	09/09/2004							
PDO-SB	08/11/2004	09/09/2004							
SandPt	03/30/2004	12/14/2004							
POR2	06/01/2004	09/10/2004							
POR3	06/01/2004	09/10/2004							
POR4	06/01/2004	09/10/2004							
POR5	06/02/2004	09/10/2004							
POR6	06/02/2004	09/10/2004							
62A150	01/12/2004	07/12/2005							
ALFFB	02/23/2005	11/22/2005	10	10	4	4	4	4	10
ALFLPD	02/23/2005	11/22/2005	10	10	8	8	7	7	9
ALFLPS	02/23/2005	11/22/2005	10	10	6	6	6	6	10

Table 29: Extent of vertical profile data

Site ID	Min Date	Max Date	Count Temp, C	Count DO, mg/L	Count DO %Sat	Count pH	Count Cond, umhos
PDO-AC	08/11/2004	09/09/2004	17	17	17	17	17
PDO-LAC	08/11/2004	09/09/2004	22	22	22	22	22
PDO-LB	08/11/2004	09/09/2004	12	12	12	12	12
PDO-RP	08/11/2004	09/09/2004	16	16	16	16	16
PDO-RR	08/11/2004	09/09/2004	33	33	33	33	33
PDO-SB	08/11/2004	09/09/2004	13	13	13	13	13

ALFFB	2/23/2005	11/22/2005	138	138	0	138	138
ALFLPD	2/23/2005	11/22/2005	225	225	0	225	225
ALFLPS	2/23/2005	11/22/2005	142	142	0	142	142

Appendix B: Calibration Plots

Plots showing temperature predictions compared with continuous temperature data were shown in Figure 87 through Figure 110. Vertical profile plots of temperature compared with data were shown in Figure 111 through Figure 130. Dissolved oxygen profiles were shown with data in Figure 131 through Figure 150. Model-data comparisons of pH profiles were shown in Figure 151 through Figure 170.

Temperature

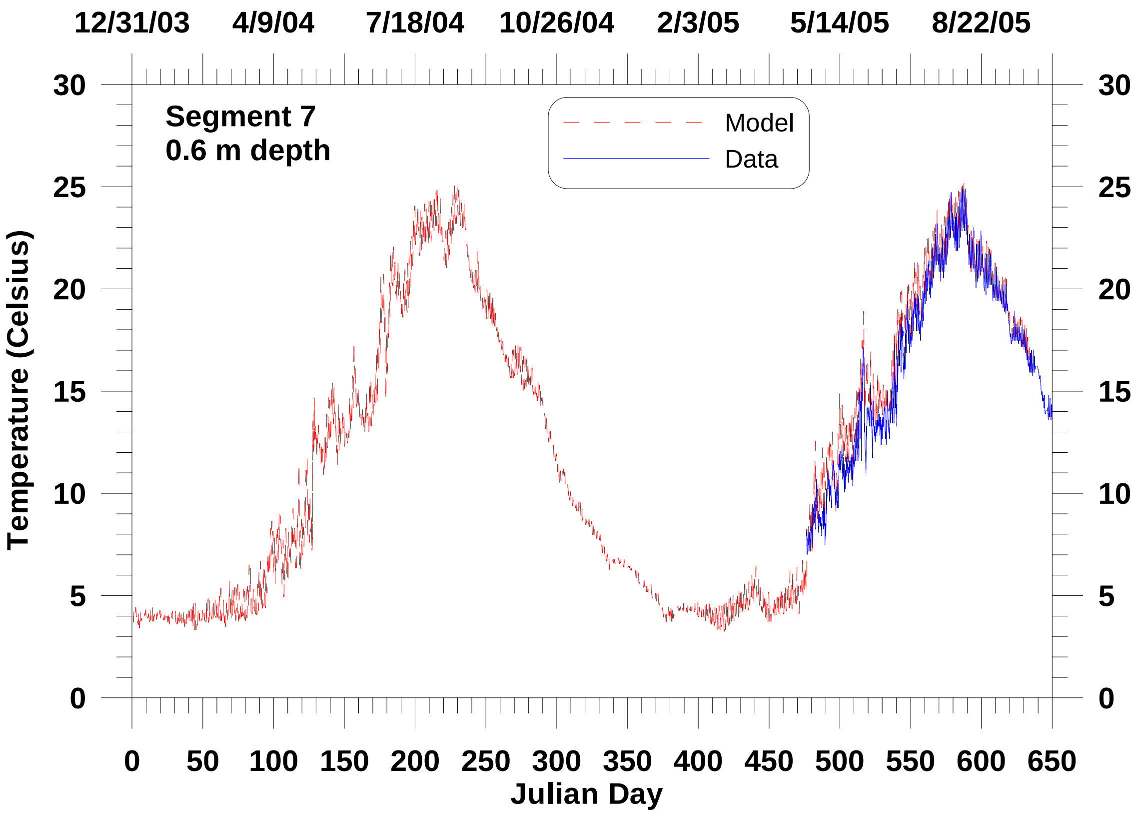


Figure 87: Comparisons of model temperature predictions with data measured at a depth of 0.6 m at segment 7.

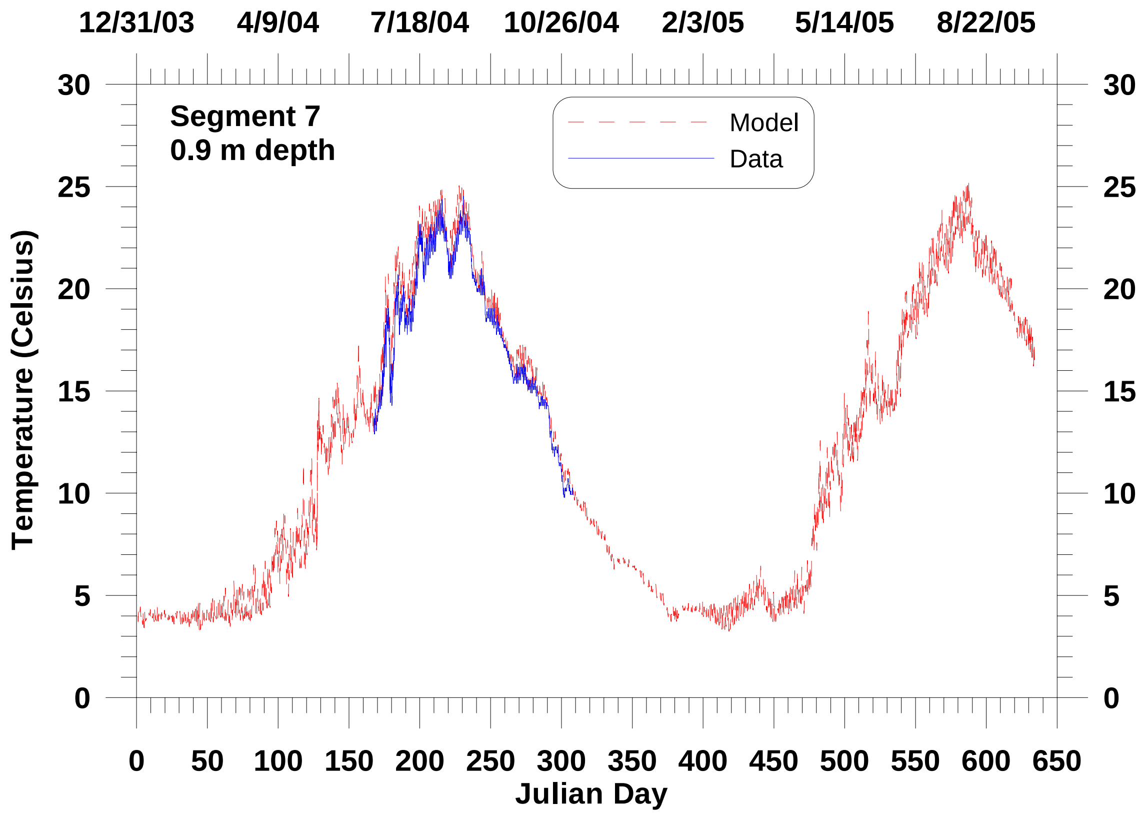


Figure 88: Comparisons of model temperature predictions with data measured at a depth of 0.6 m at segment 7.

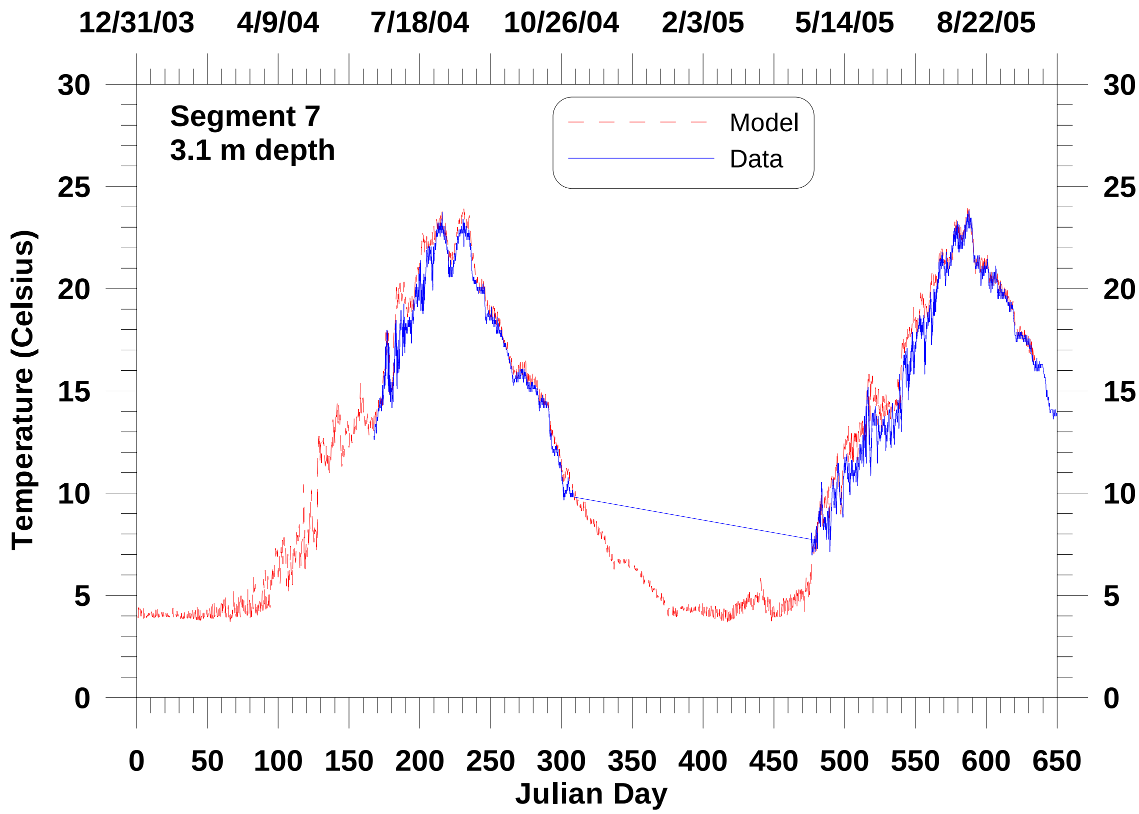


Figure 89: Comparisons of model temperature predictions with data measured at a depth of 3.1 m at segment 7.

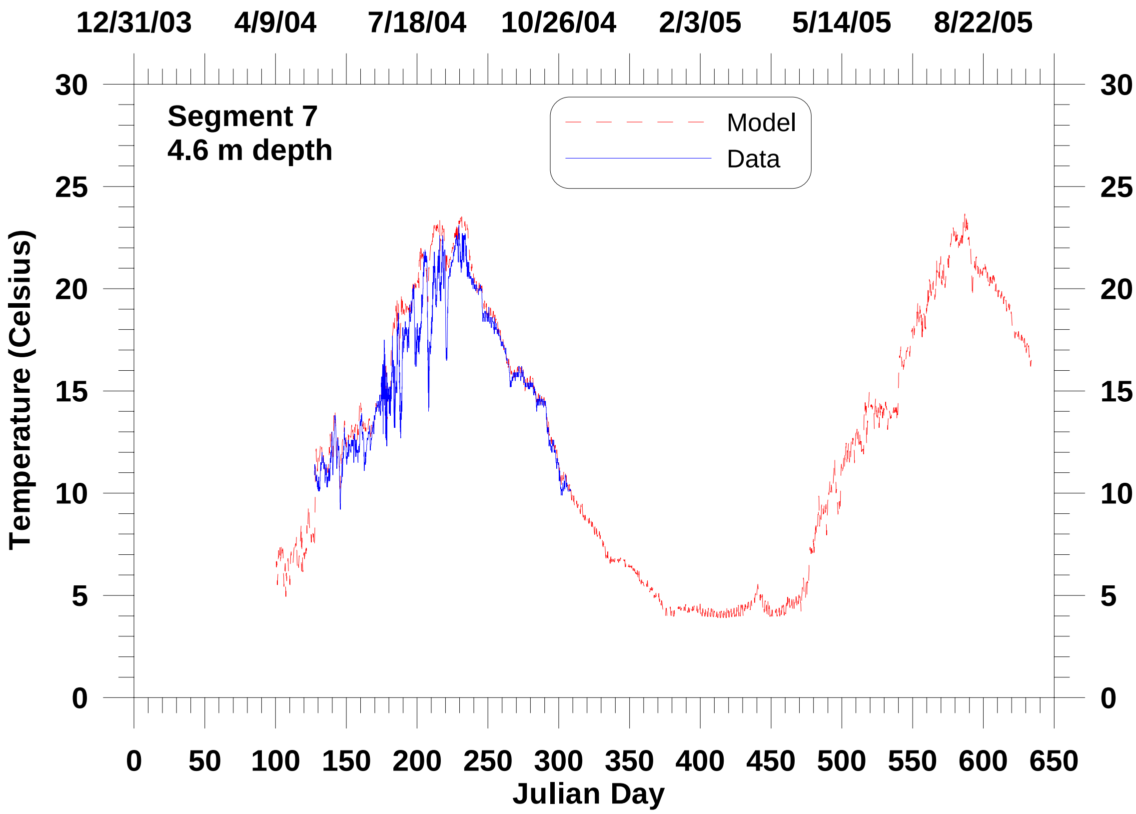


Figure 90: Comparisons of model temperature predictions with data measured at a depth of 4.6 m at segment 7.

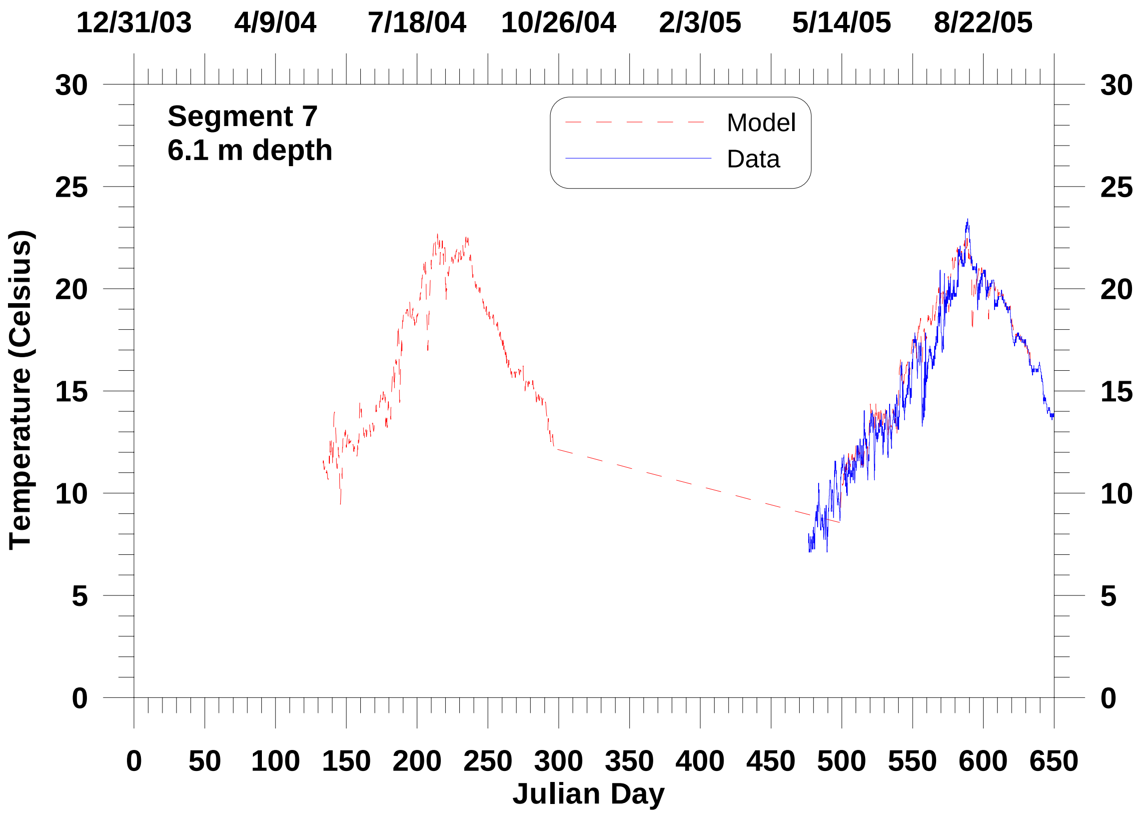


Figure 91: Comparisons of model temperature predictions with data measured at a depth of 6.1 m at segment 7.

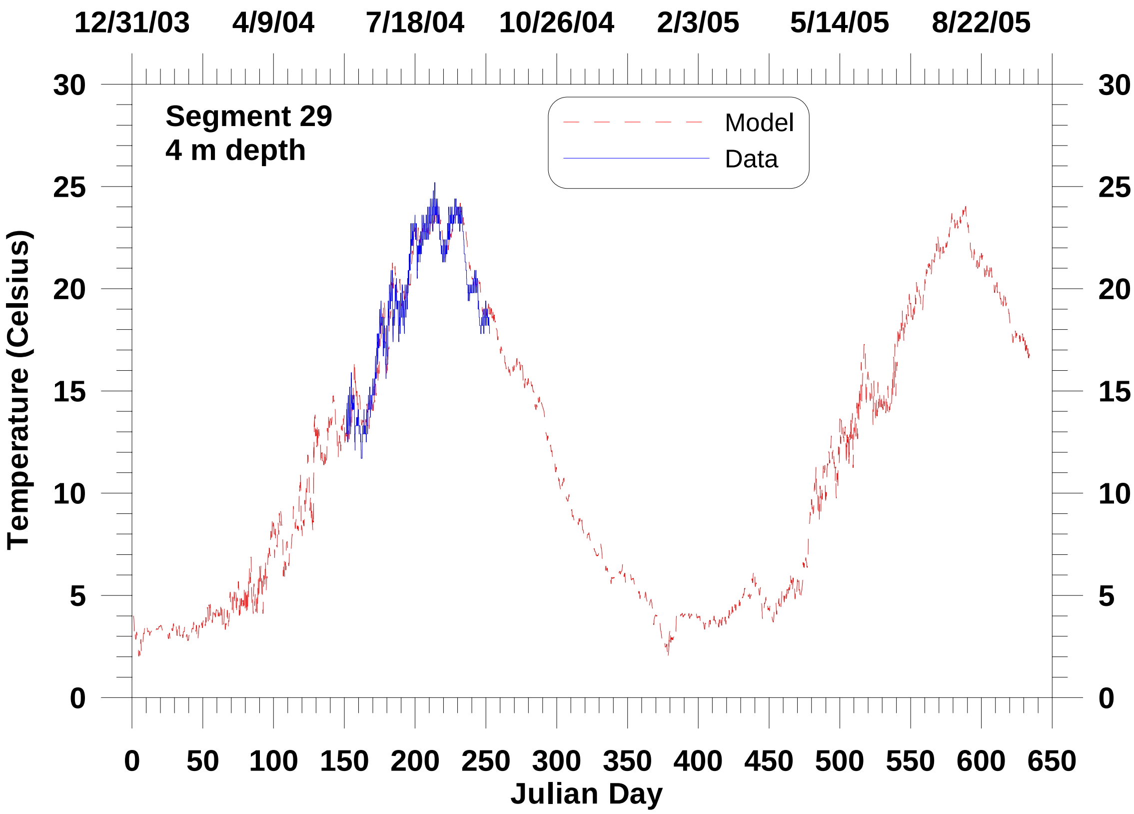


Figure 92: Comparisons of model temperature predictions with data measured at a depth of 4 m at segment 29.

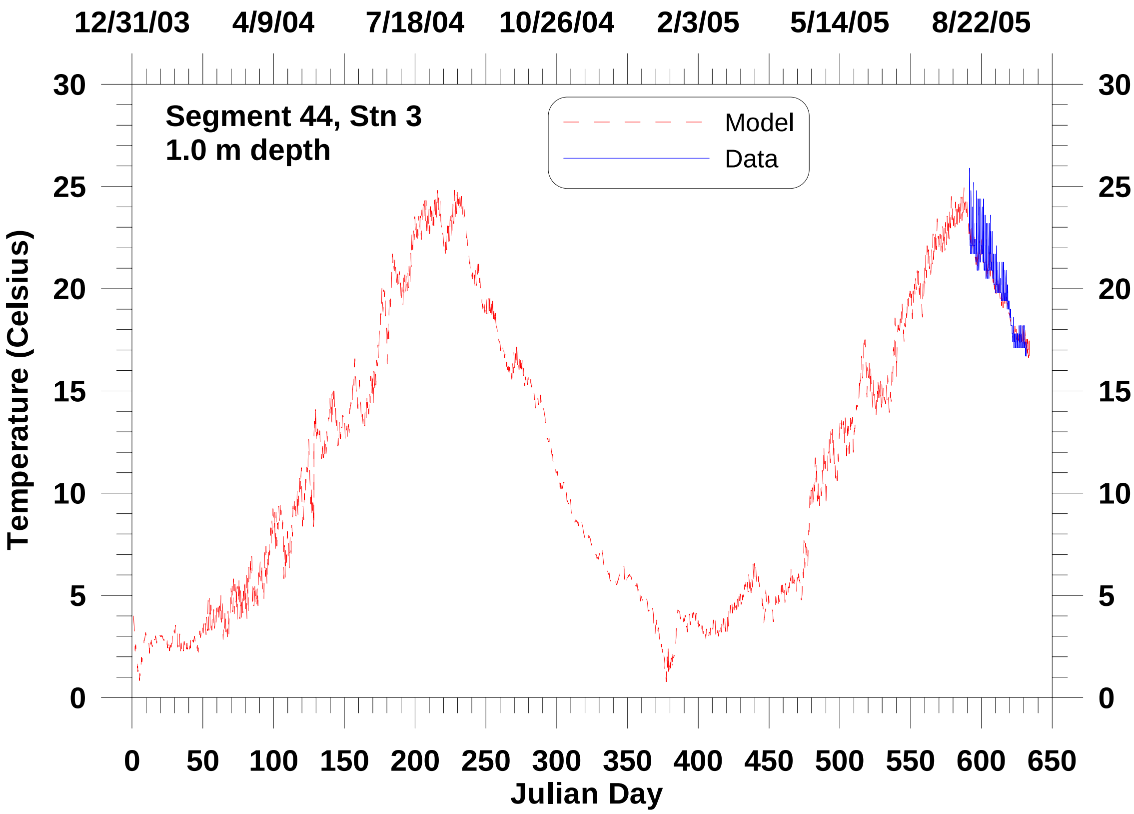


Figure 93: Comparisons of model temperature predictions with data measured at a depth of 1.0 m at segment 44 (site Stn 3).

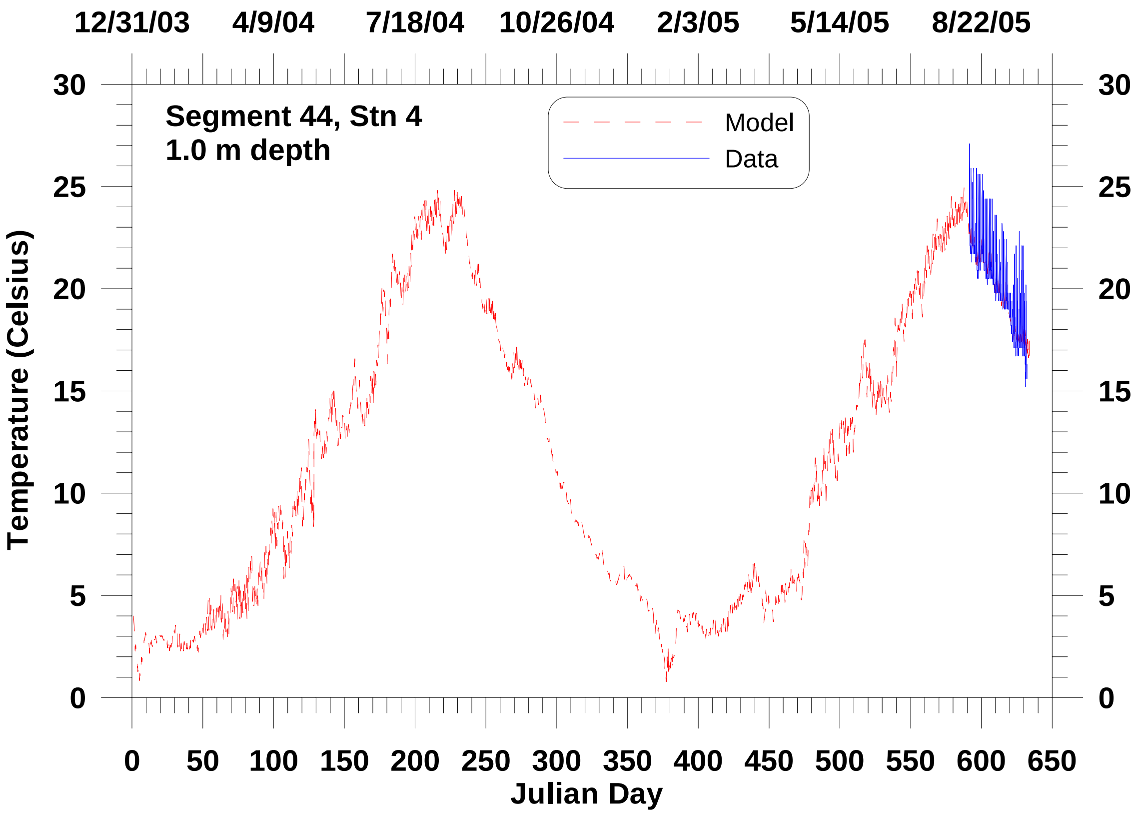


Figure 94: Comparisons of model temperature predictions with data measured at a depth of 1.0 m at segment 44 (site Stn 4).

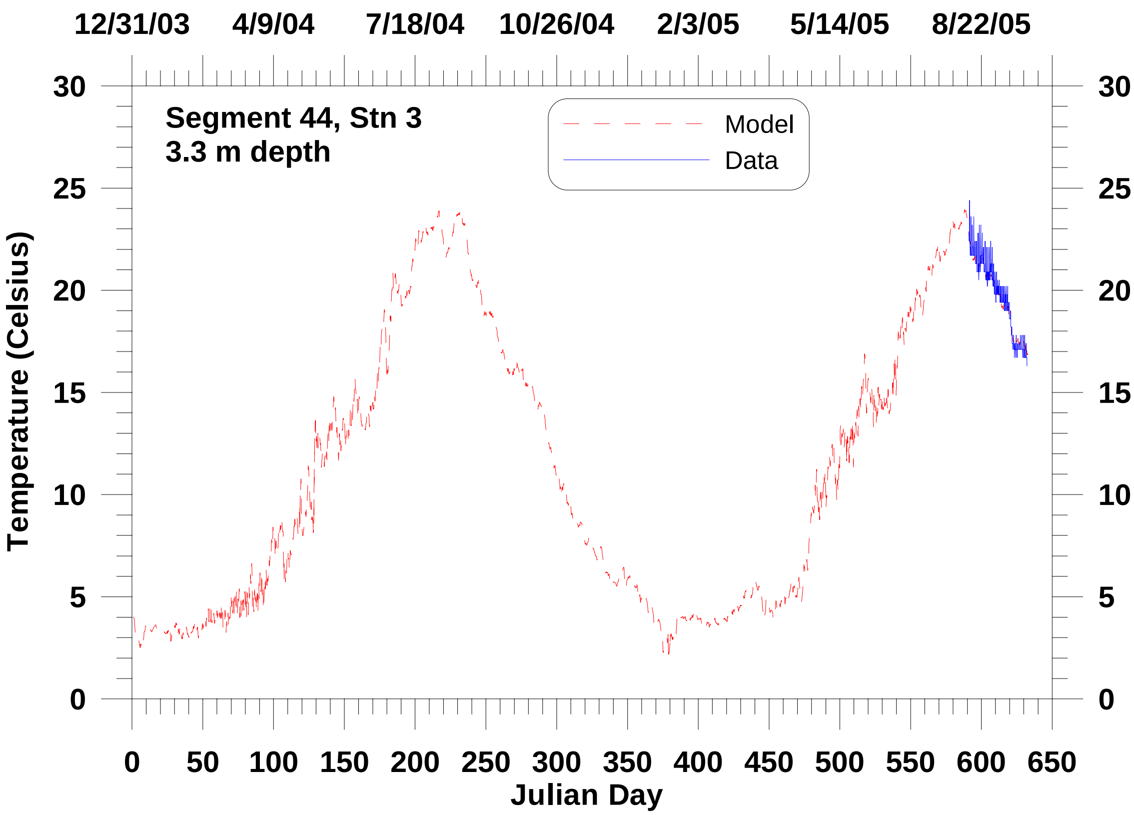


Figure 95: Comparisons of model temperature predictions with data measured at a depth of 3.3 m at segment 44 (site Stn 3).

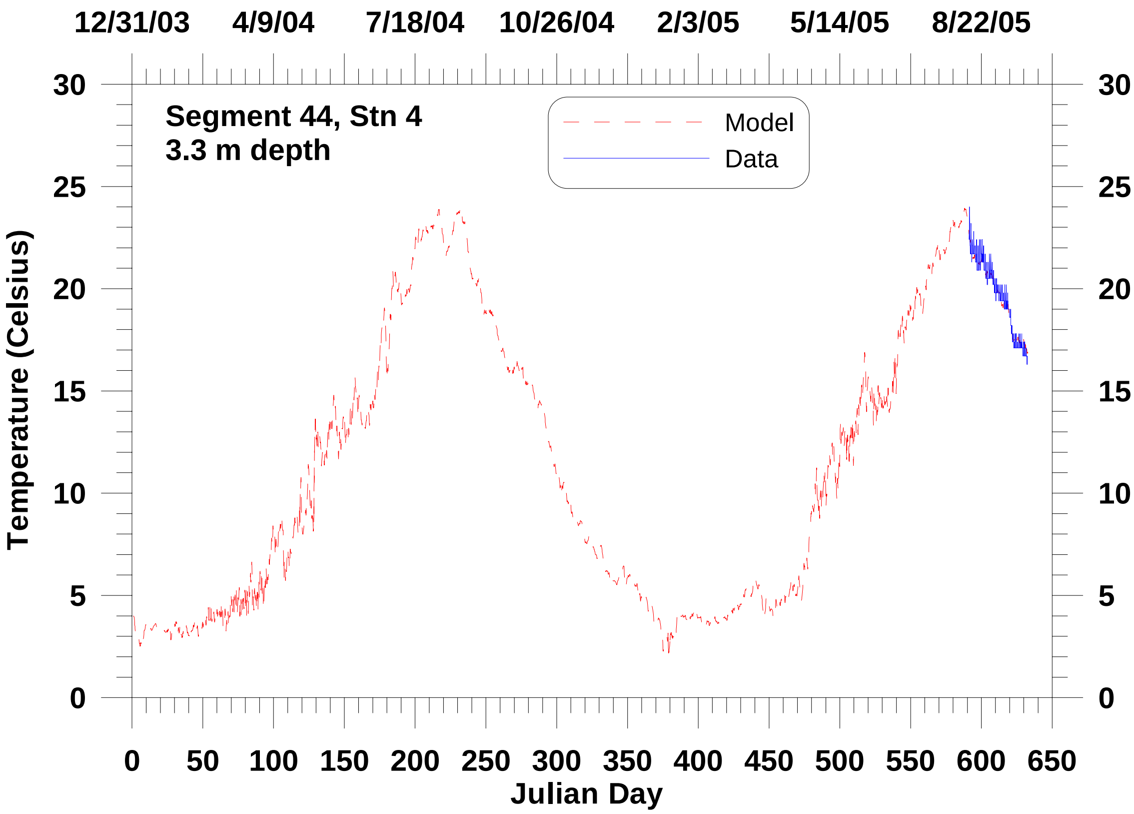


Figure 96: Comparisons of model temperature predictions with data measured at a depth of 3.3 m at segment 44 (site Stn 4).

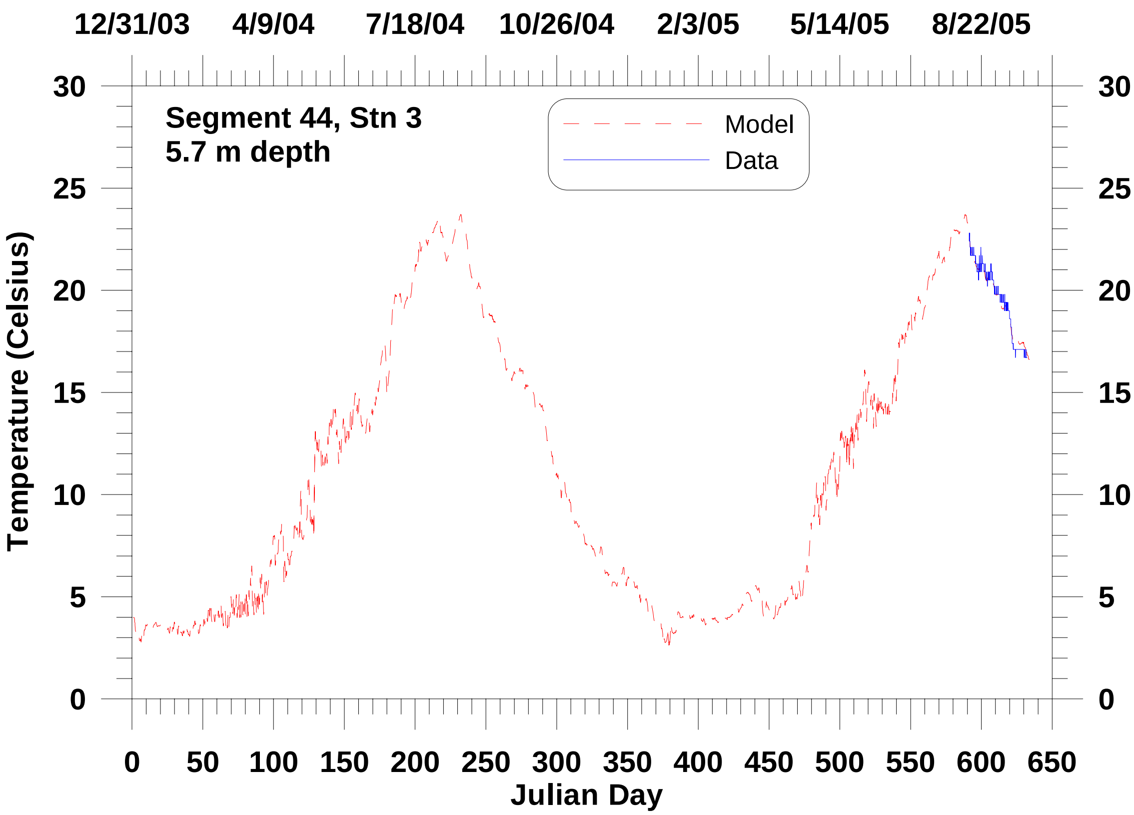


Figure 97: Comparisons of model temperature predictions with data measured at a depth of 5.7 m at segment 44 (site Stn 3).

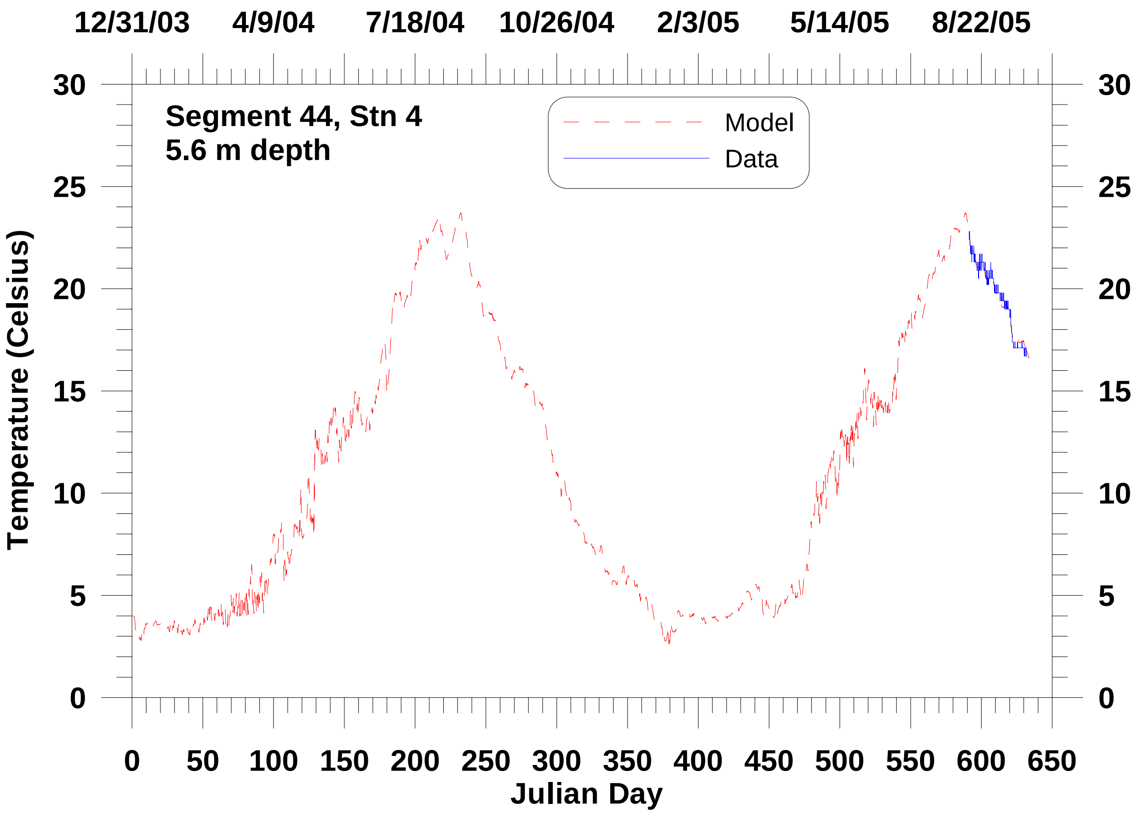


Figure 98: Comparisons of model temperature predictions with data measured at a depth of 5.6 m at segment 44 (site Stn 4).

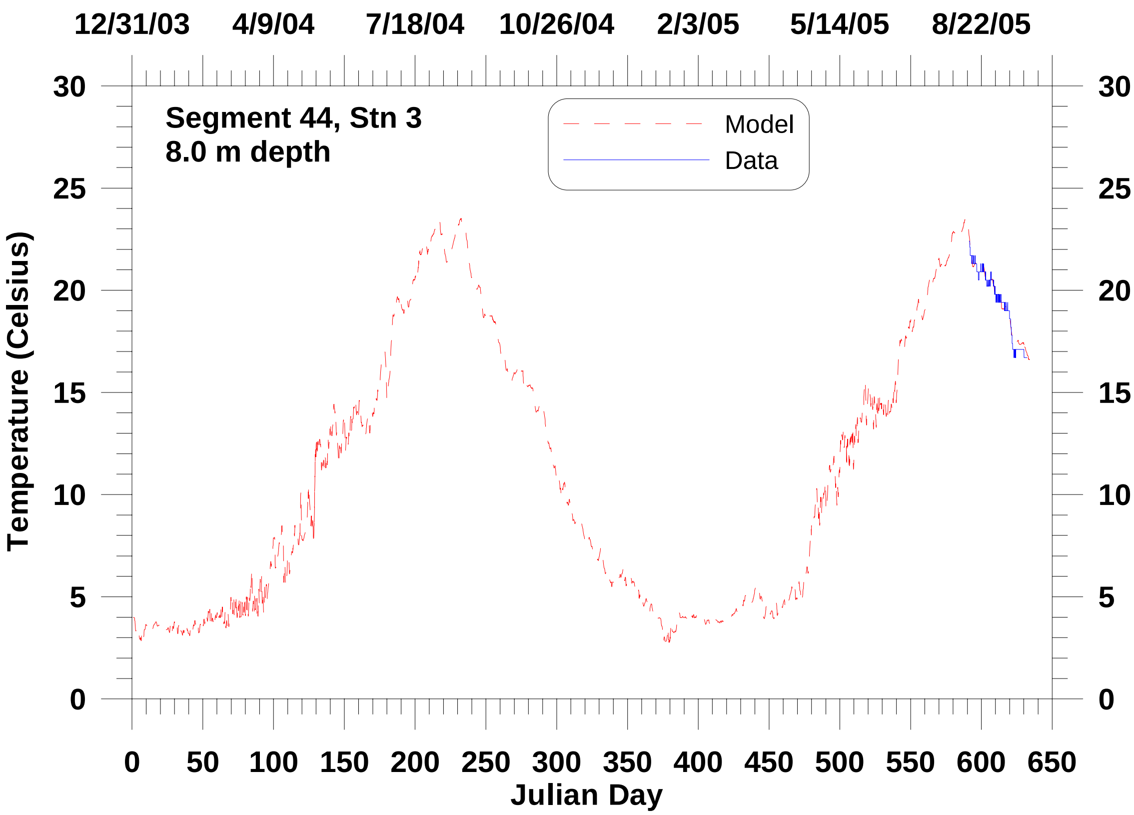


Figure 99: Comparisons of model temperature predictions with data measured at a depth of 8.0 m at segment 44 (site Stn 3).

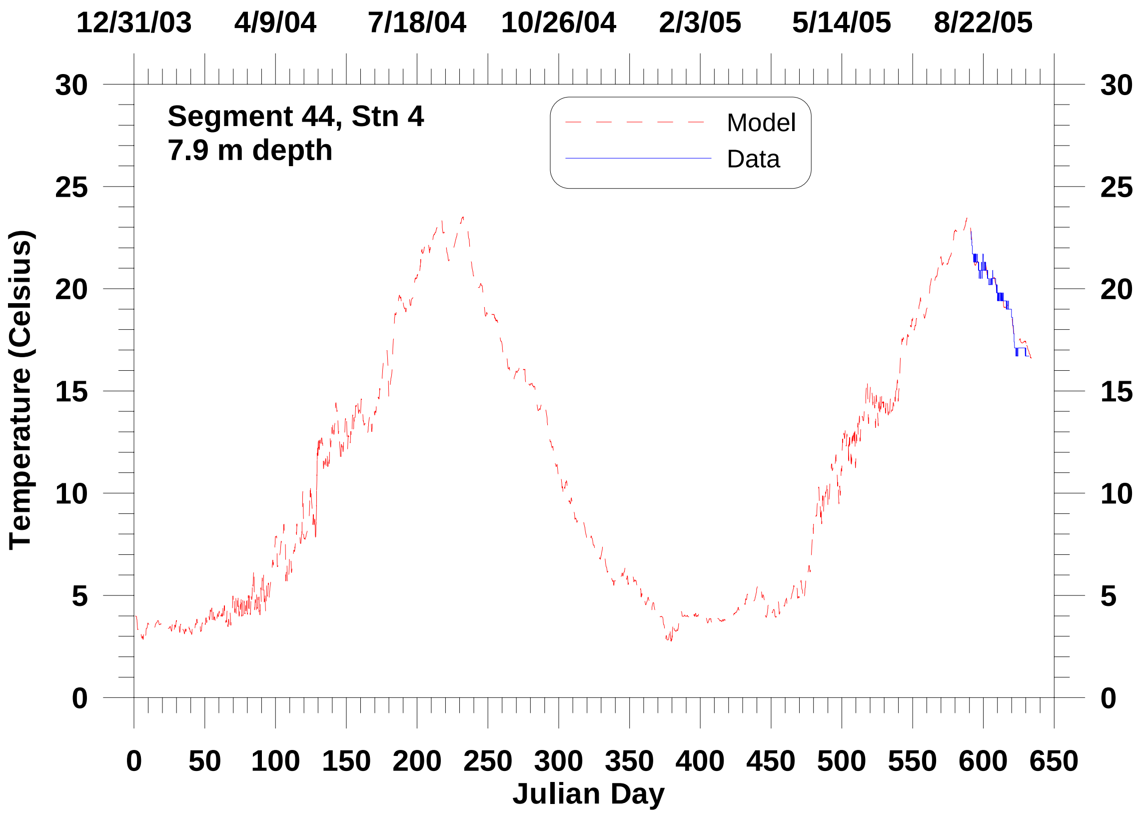


Figure 100: Comparisons of model temperature predictions with data measured at a depth of 7.9 m at segment 44 (site Stn 4).

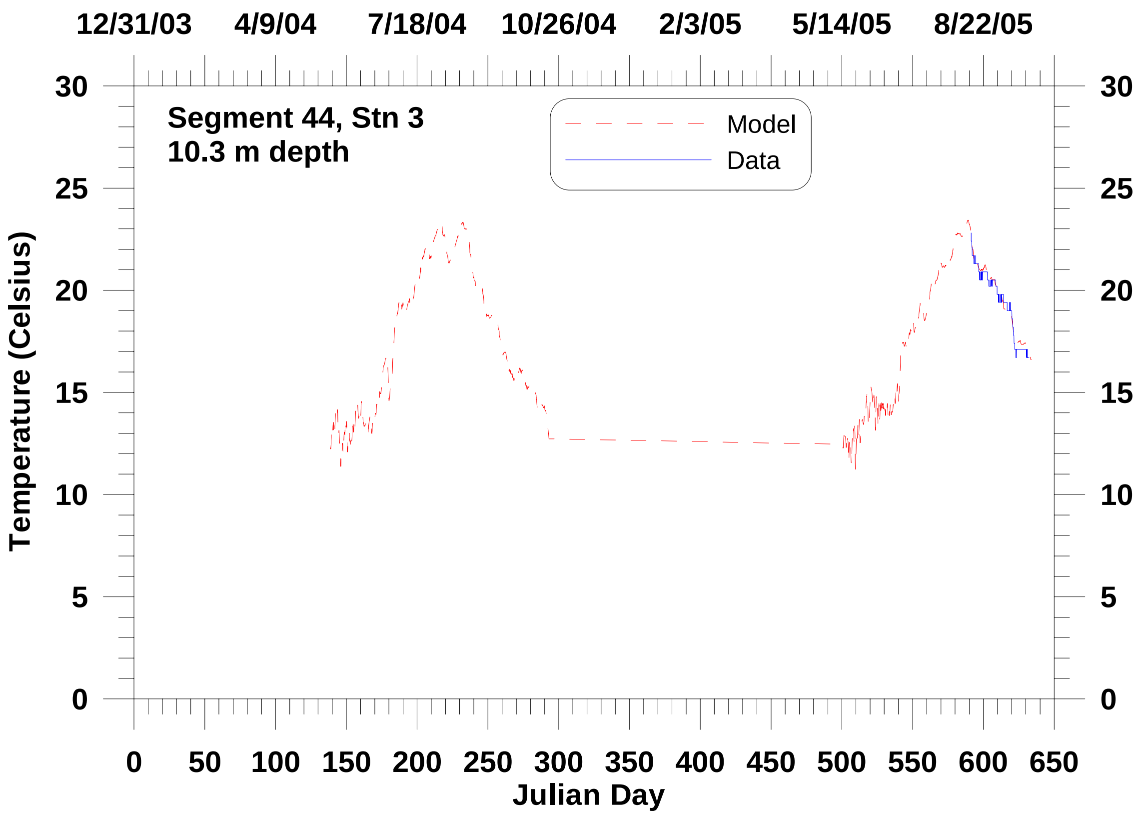


Figure 101: Comparisons of model temperature predictions with data measured at a depth of 10.3 m at segment 44 (site Stn 3).

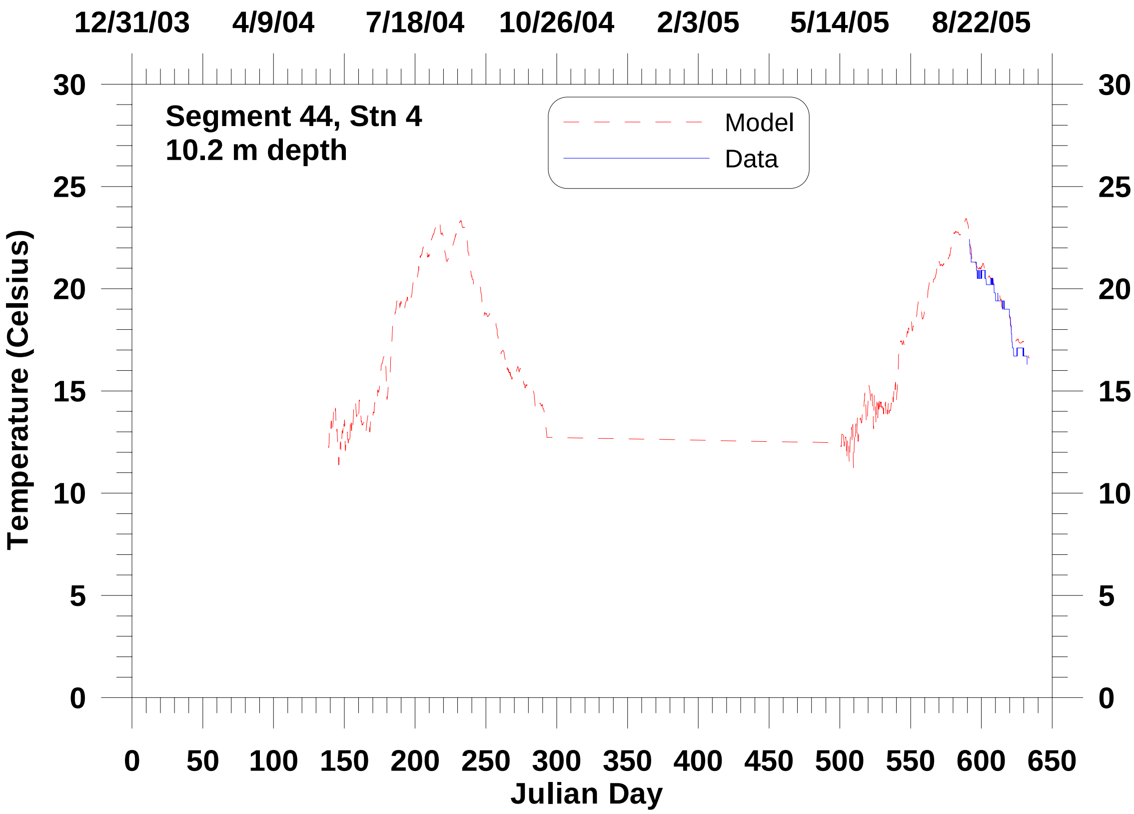


Figure 102: Comparisons of model temperature predictions with data measured at a depth of 10.2 m at segment 44 (site Stn 4).

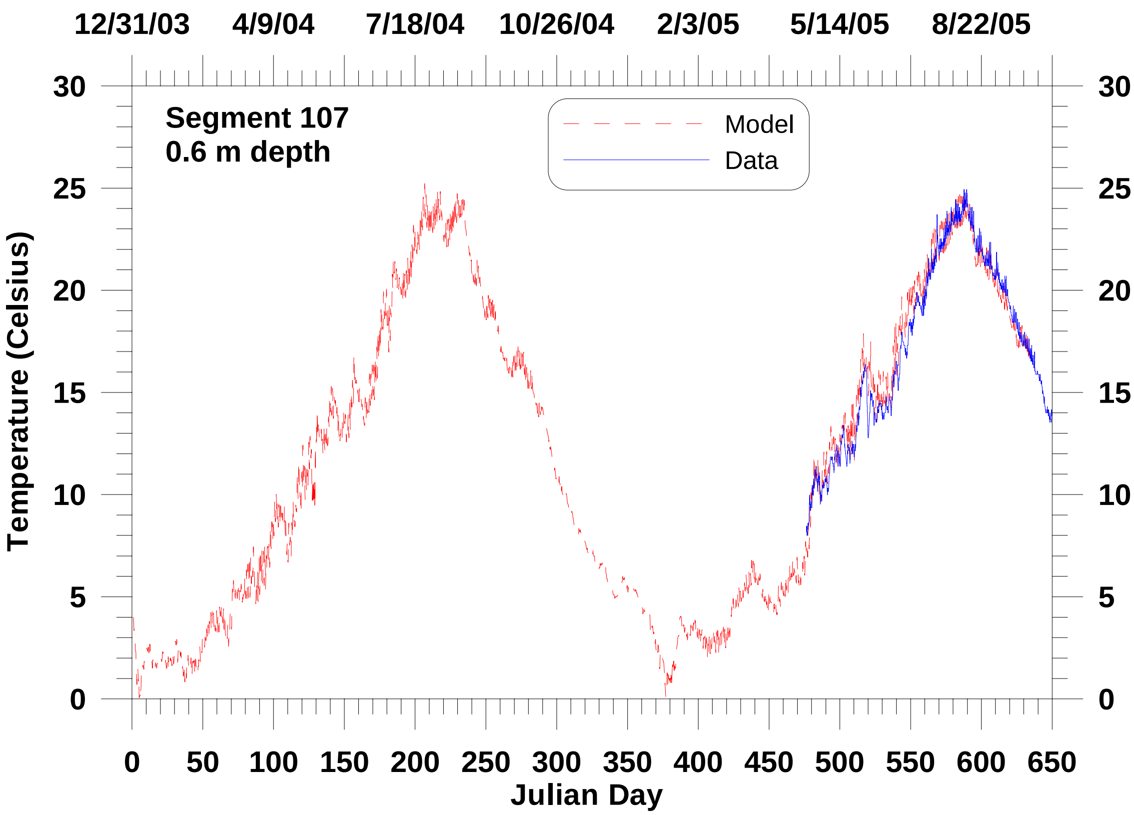


Figure 103: Comparisons of model temperature predictions with data measured at a depth of 0.6 m at segment 107.

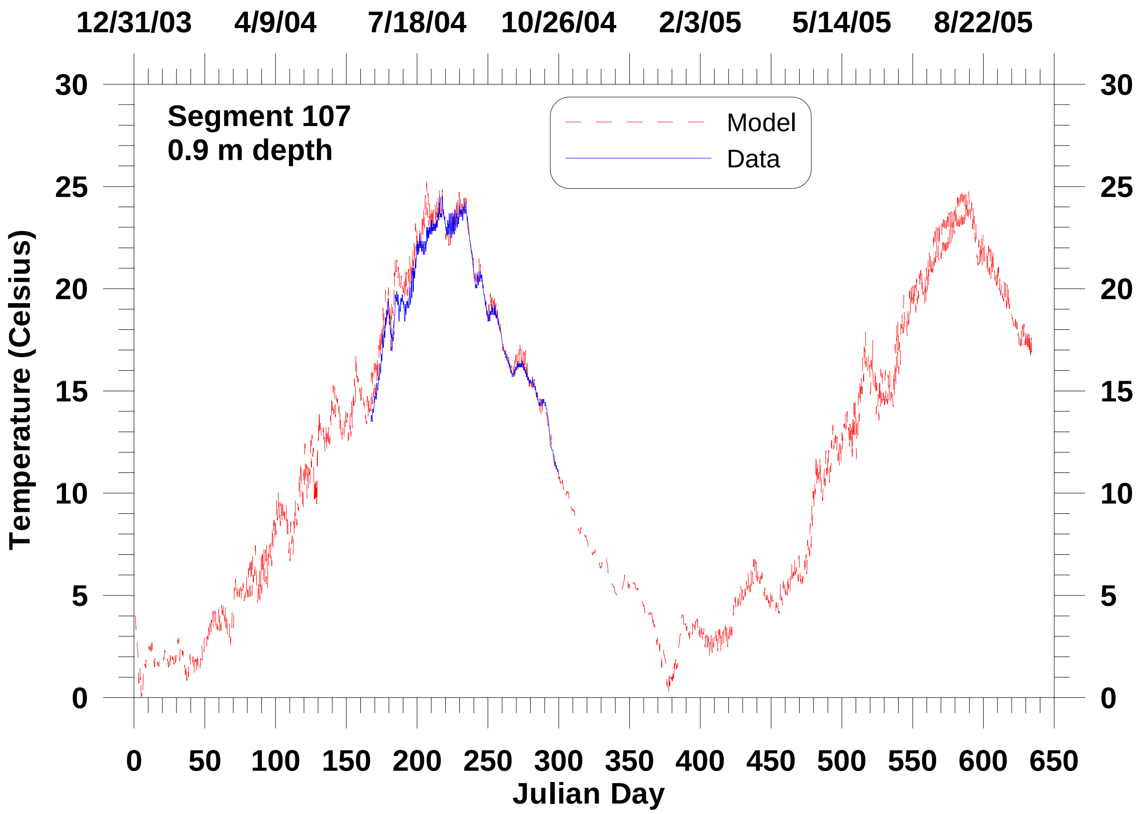


Figure 104: Comparisons of model temperature predictions with data measured at a depth of 0.9 m at segment 107.

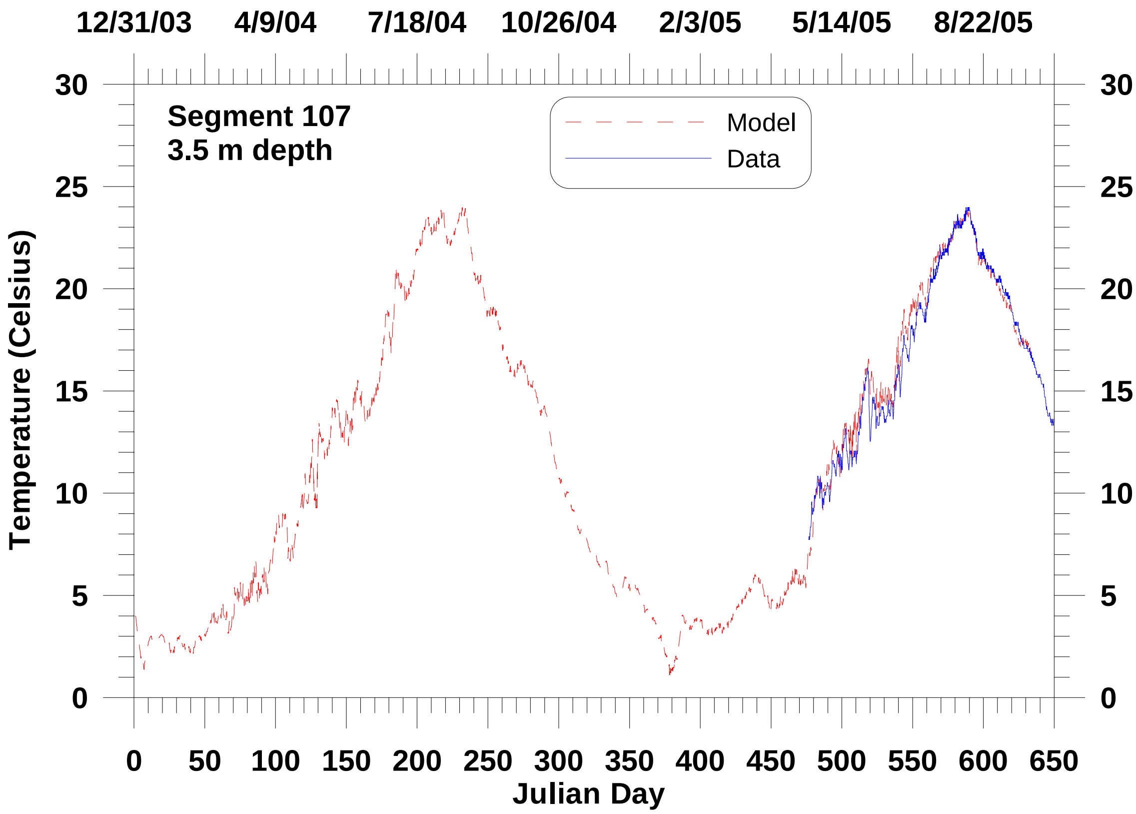


Figure 105: Comparisons of model temperature predictions with data measured at a depth of 3.5 m at segment 107.

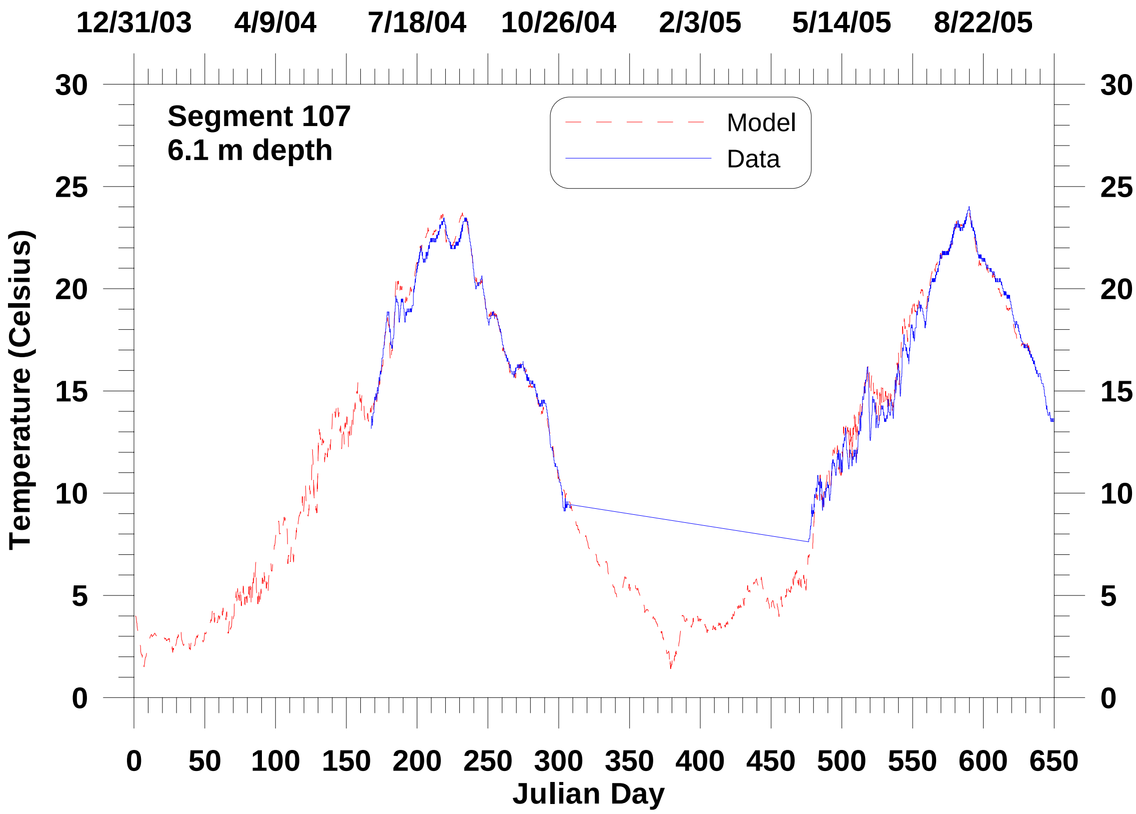


Figure 106: Comparisons of model temperature predictions with data measured at a depth of 6.1 m at segment 107.

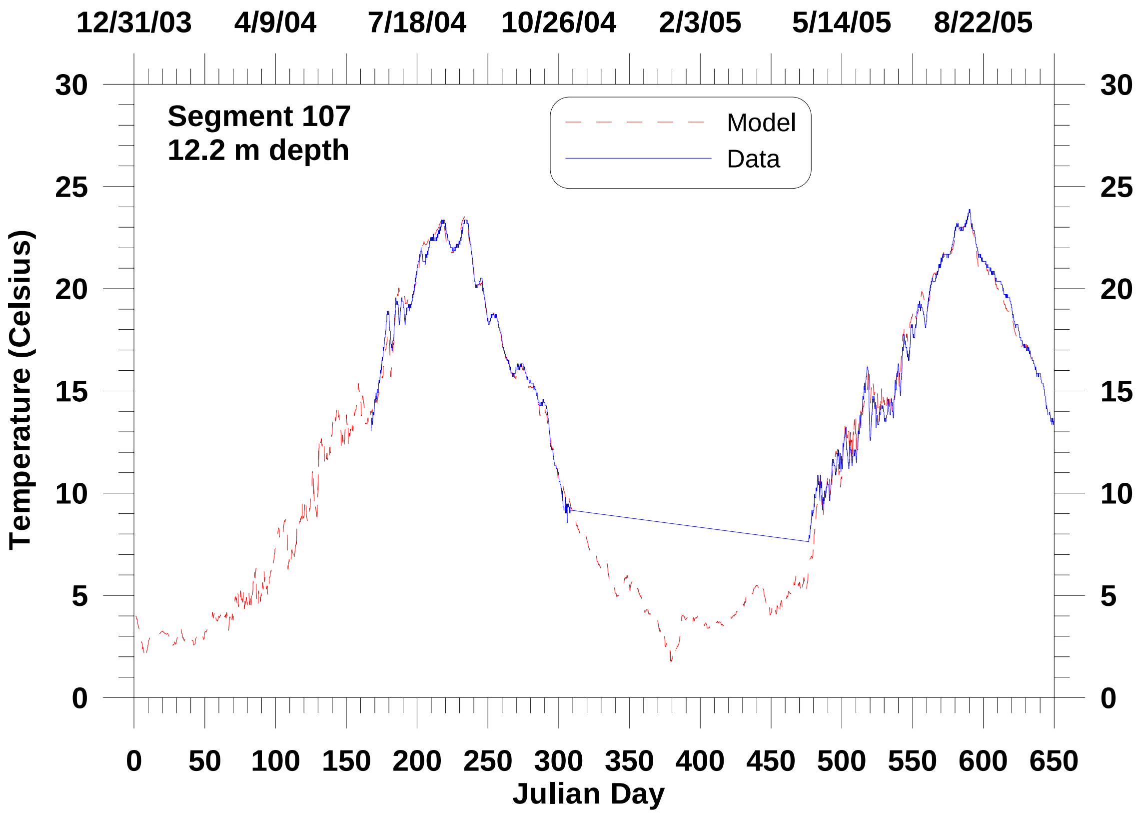


Figure 107: Comparisons of model temperature predictions with data measured at a depth of 12.2 m at segment 107.

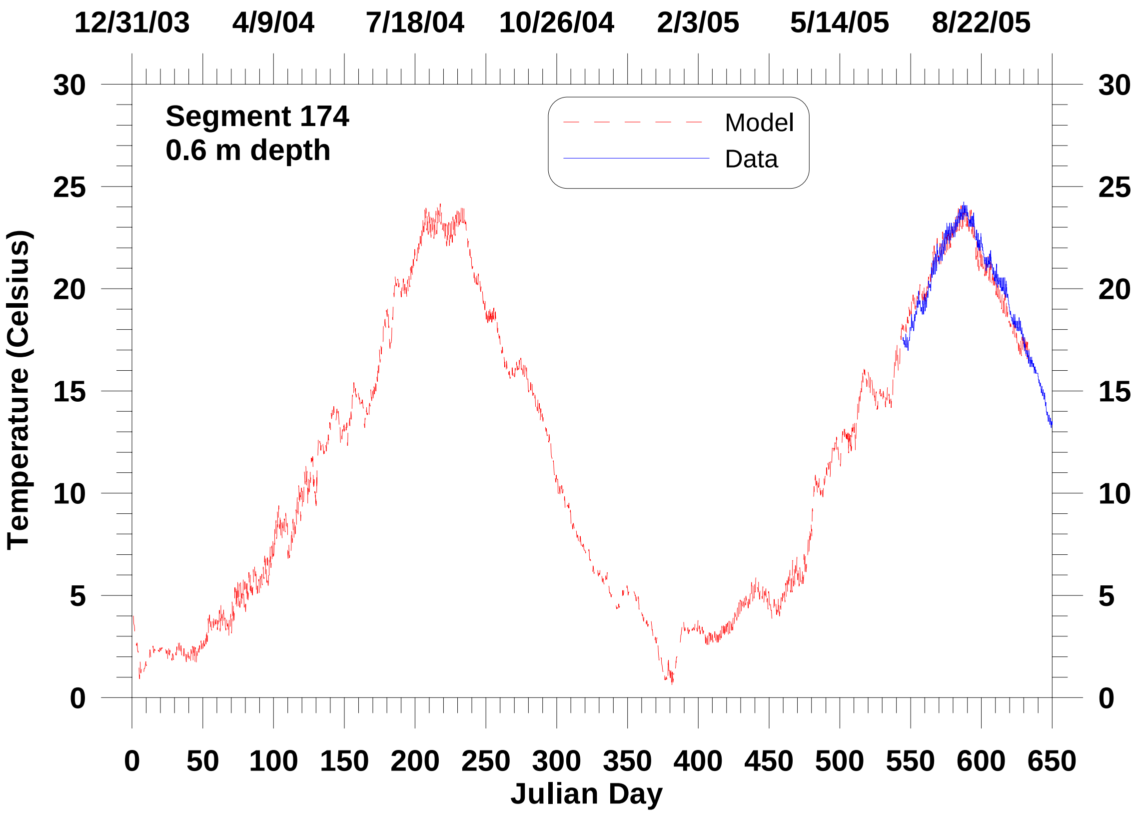


Figure 108: Comparisons of model temperature predictions with data measured at a depth of 0.6 m at segment 107.

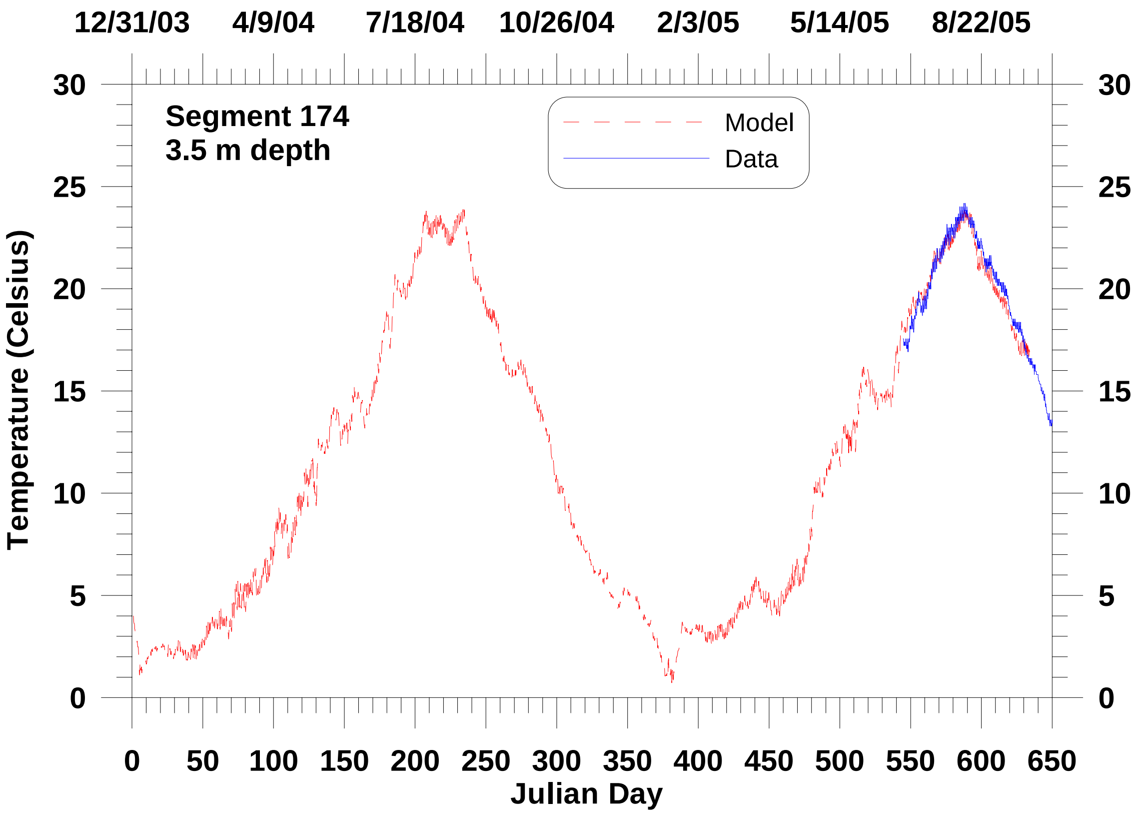


Figure 109: Comparisons of model temperature predictions with data measured at a depth of 3.5 m at segment 107.

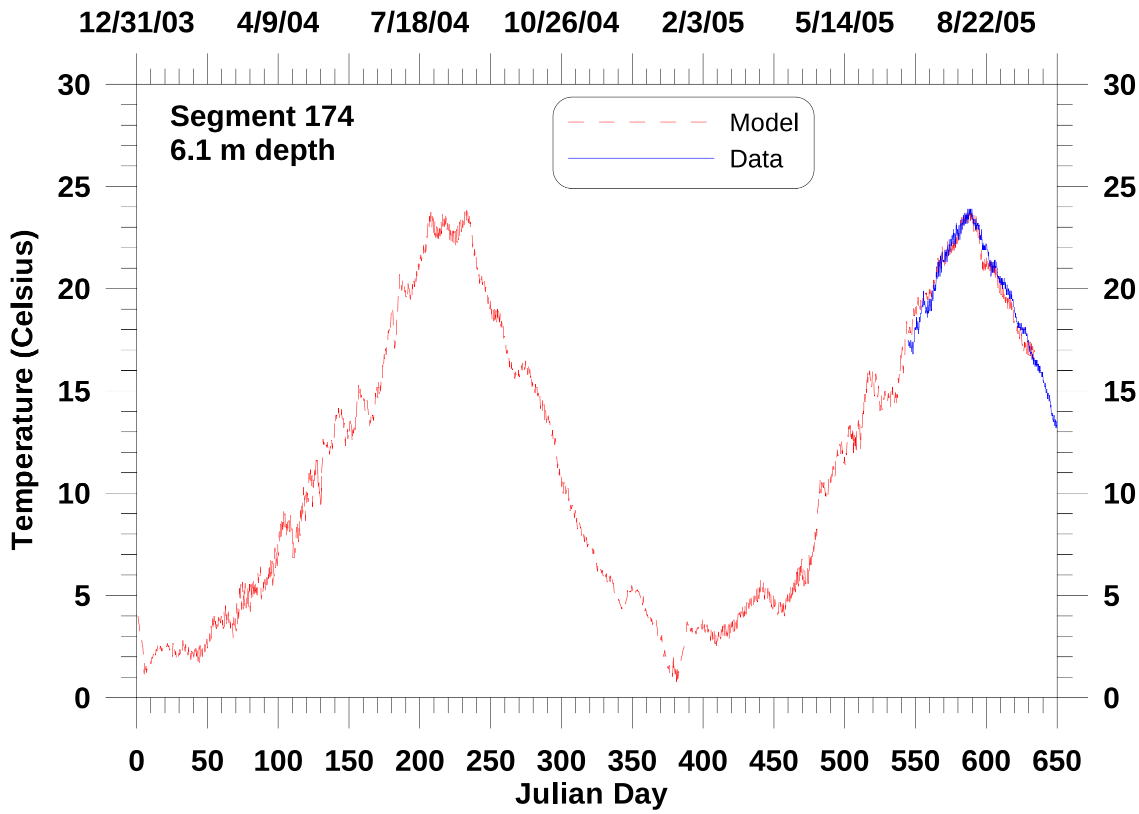


Figure 110: Comparisons of model temperature predictions with data measured at a depth of 6.1 m at segment 107.

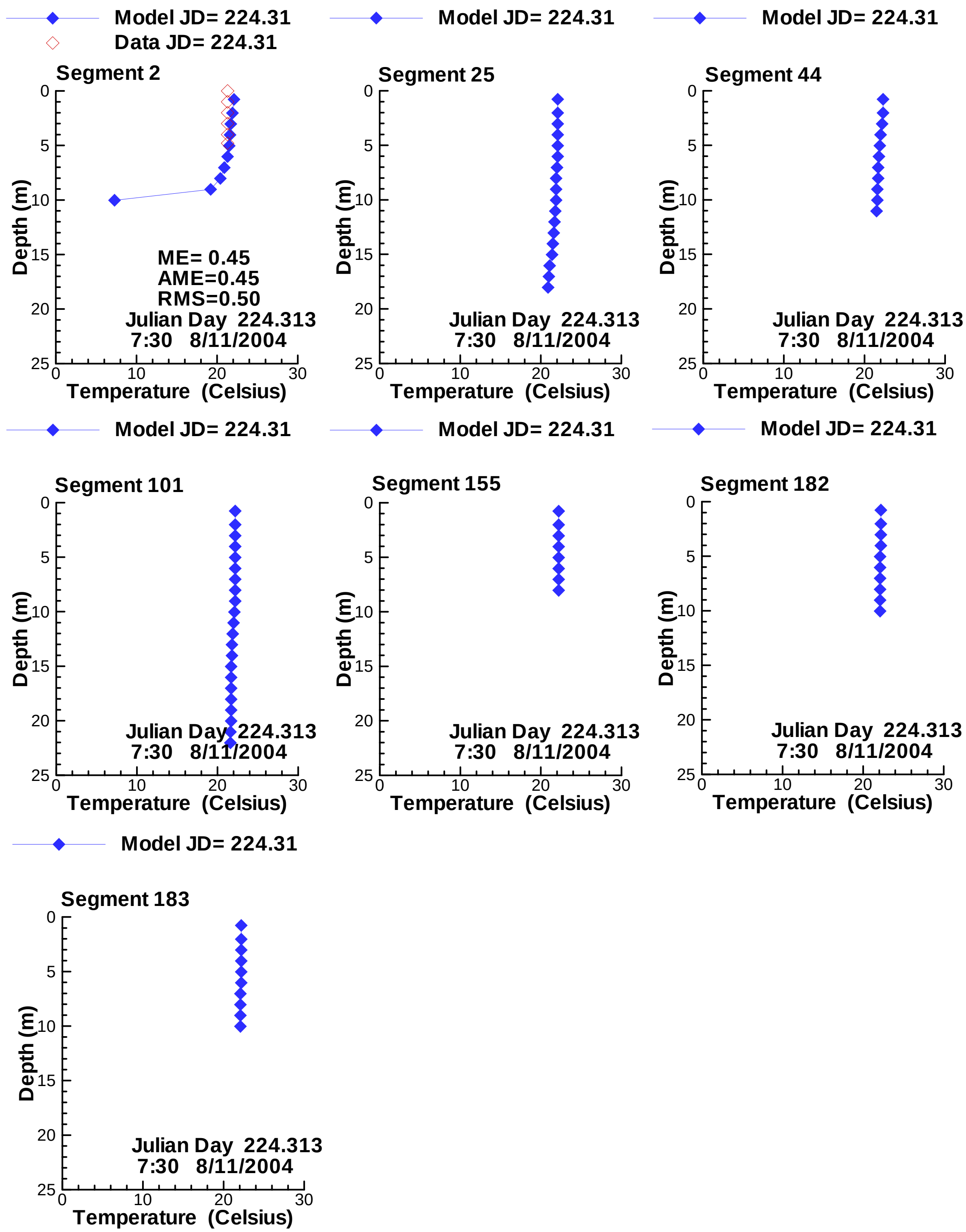


Figure 111: Vertical profiles of TEMPERATURE compared with data for 8/11/2004 7:30.

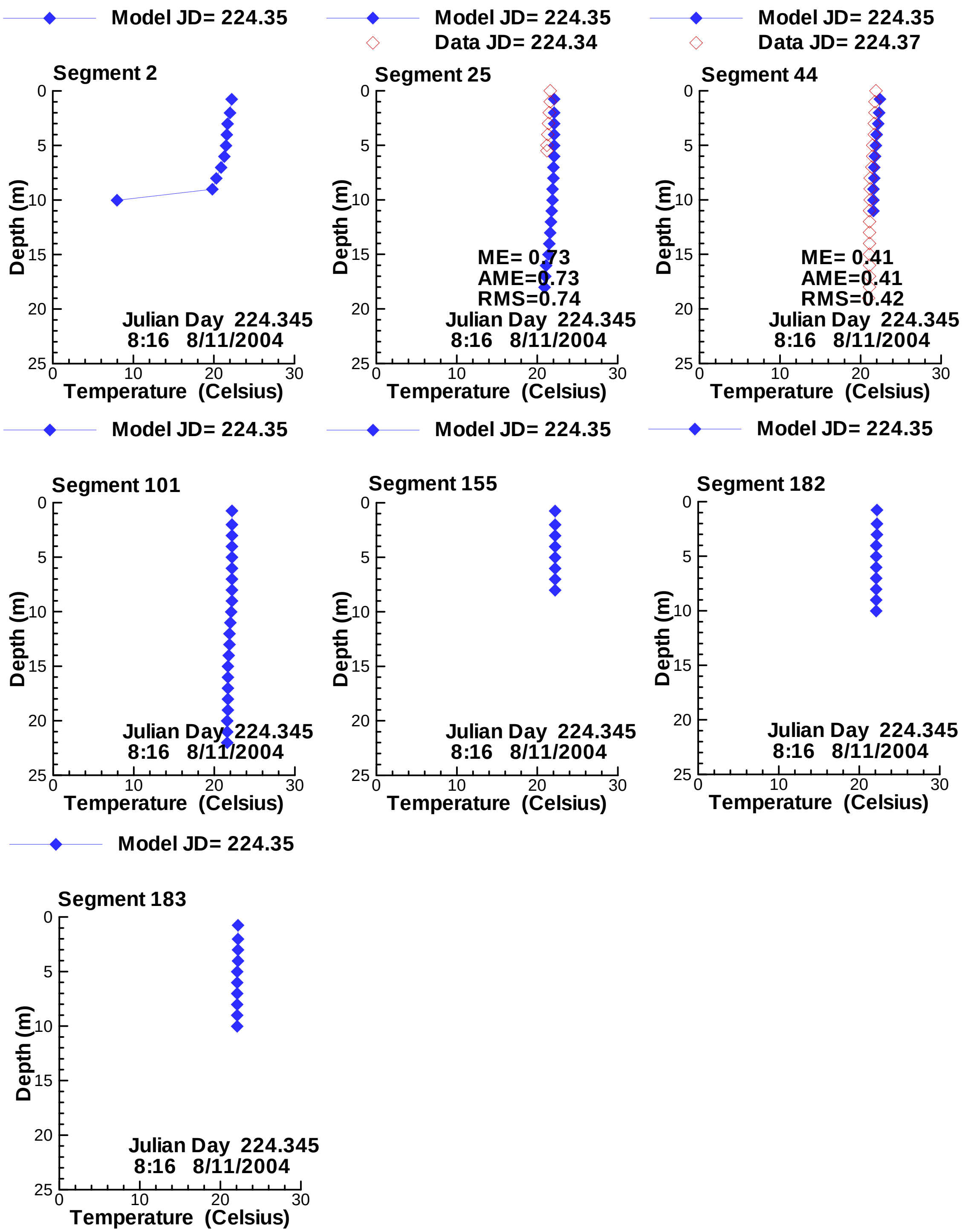


Figure 112: Vertical profiles of TEMPERATURE compared with data for 8/11/2004 8:16.

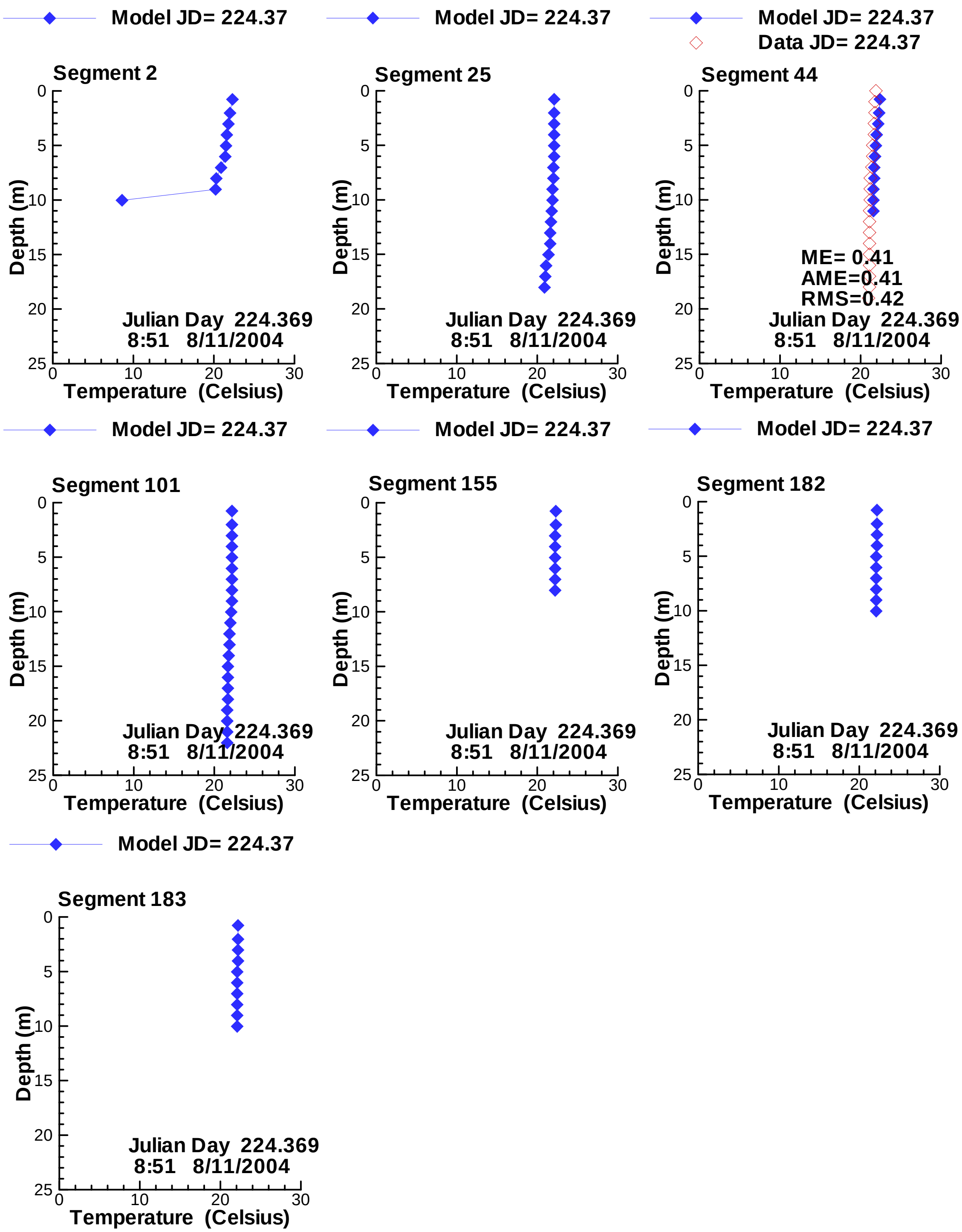


Figure 113: Vertical profiles of TEMPERATURE compared with data for 8/11/2004 8:51.

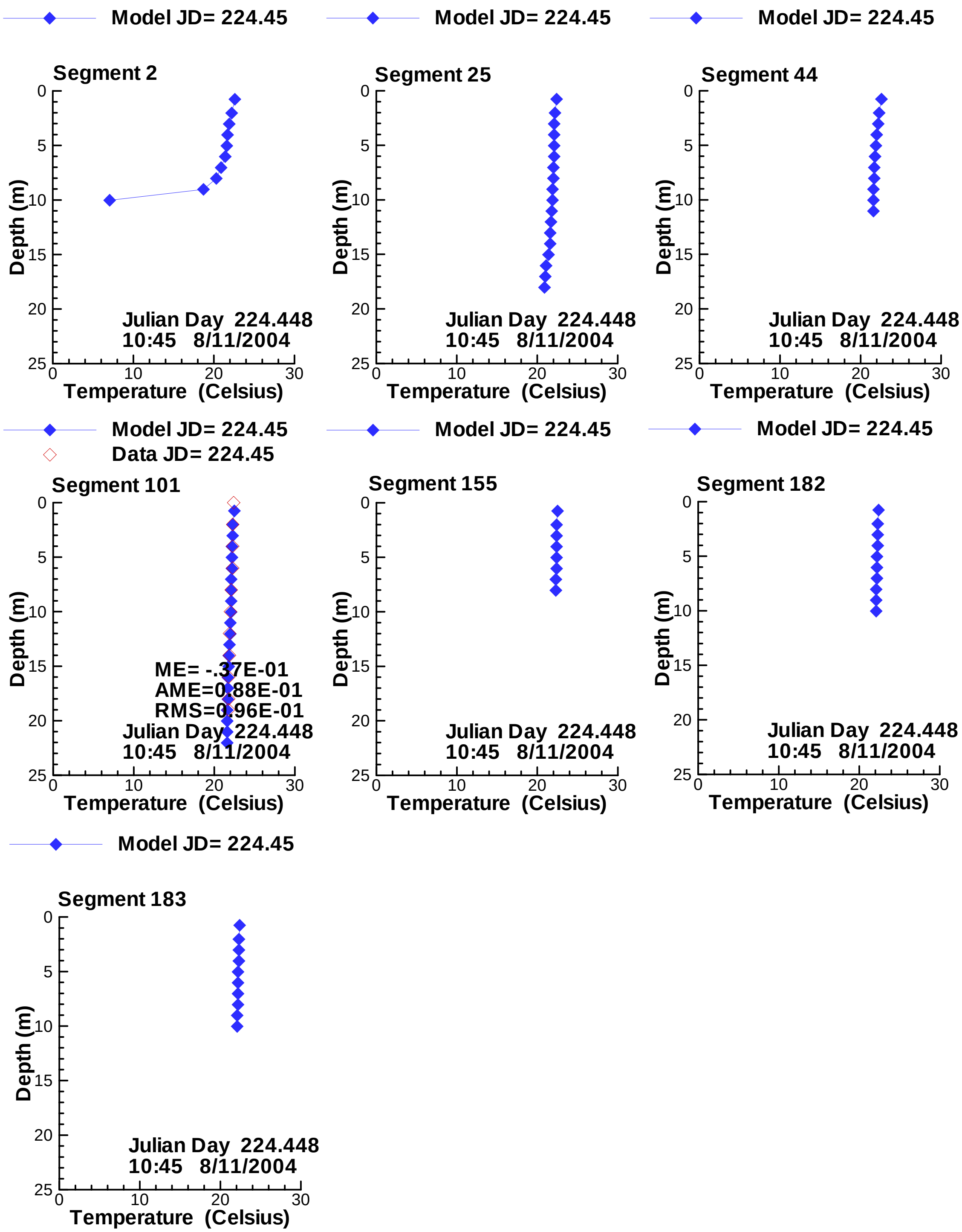


Figure 114: Vertical profiles of TEMPERATURE compared with data for 8/11/2004 10:46.

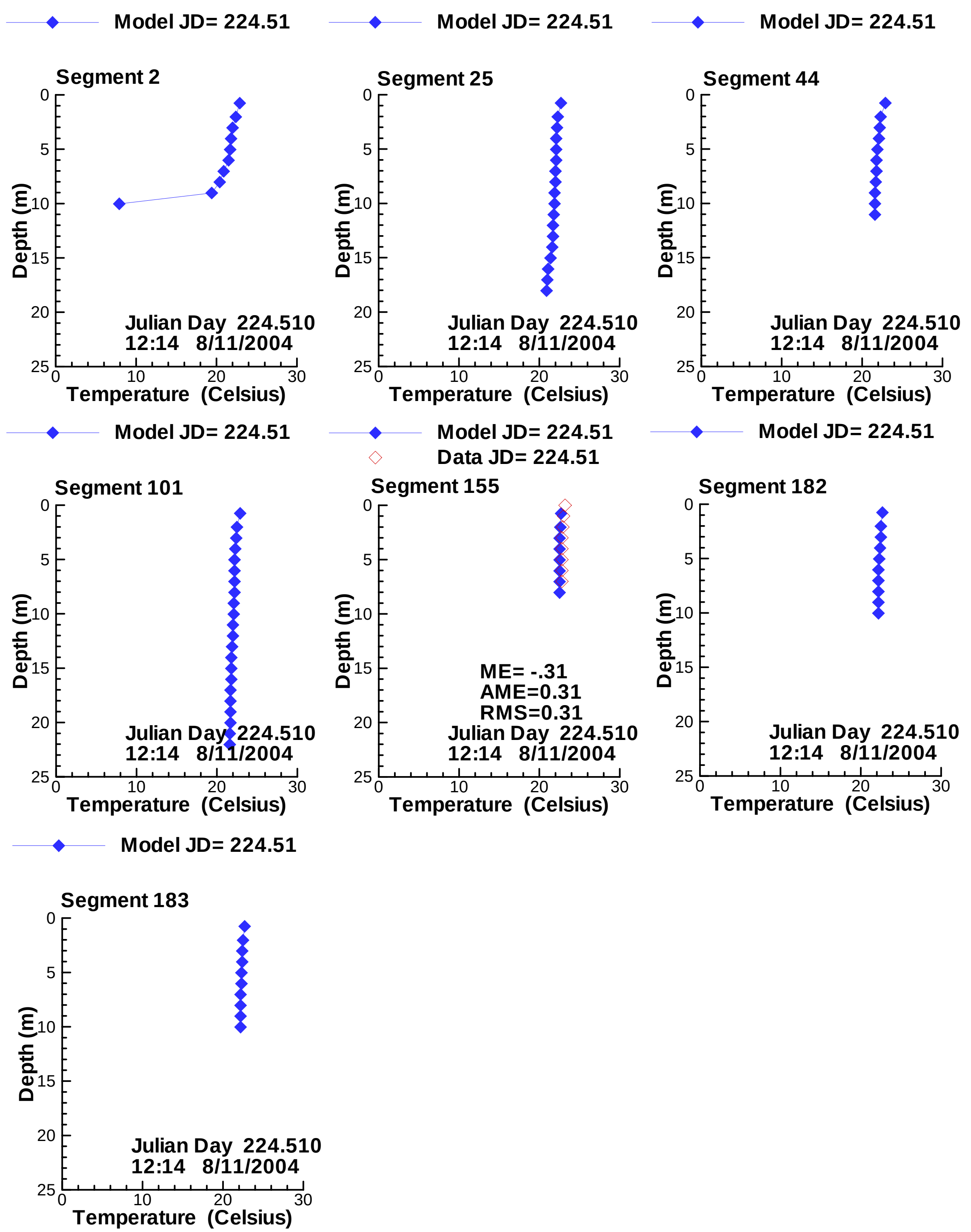


Figure 115: Vertical profiles of TEMPERATURE compared with data for 8/11/2004 12:14.

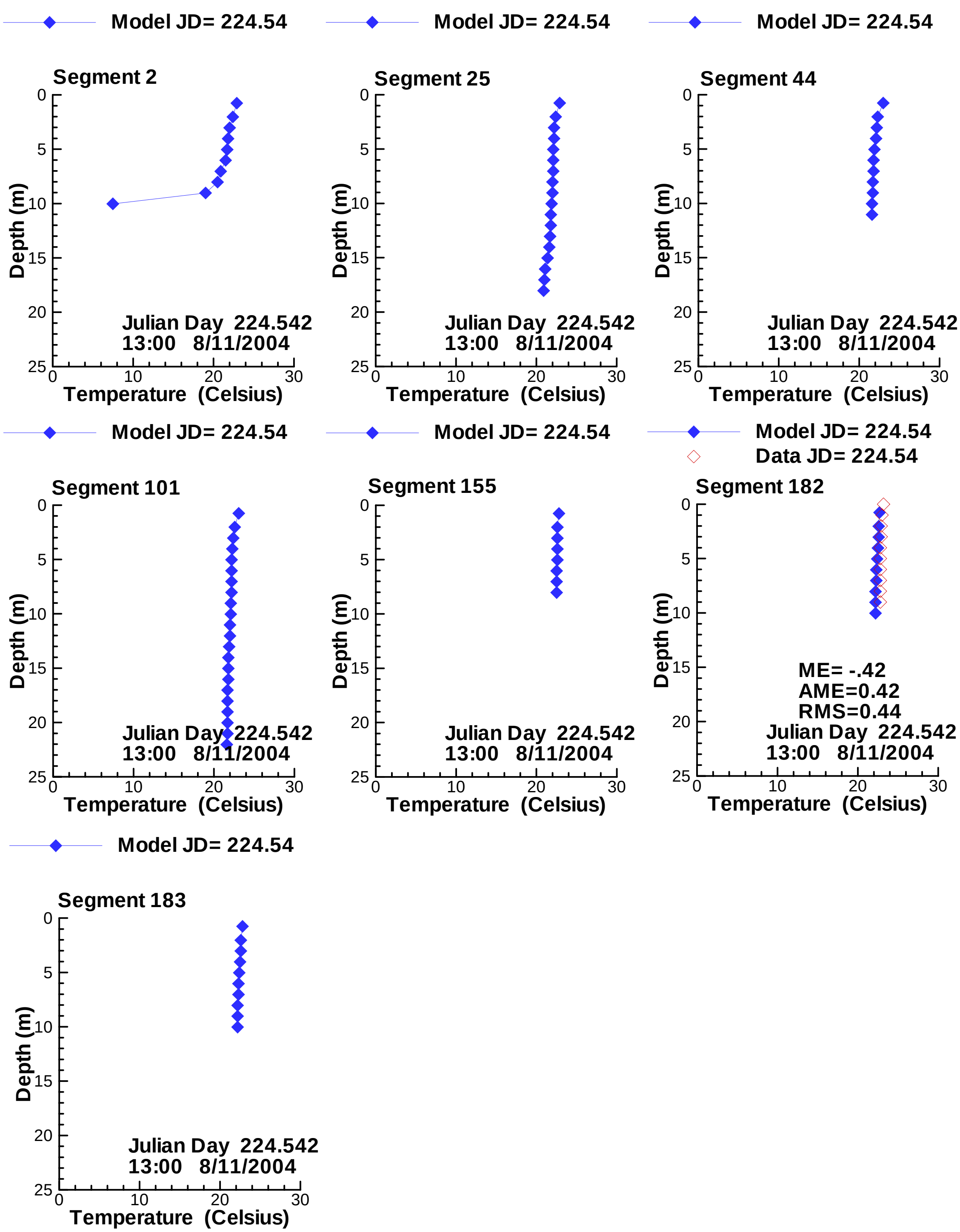


Figure 116: Vertical profiles of TEMPERATURE compared with data for 8/11/2004 13:00.

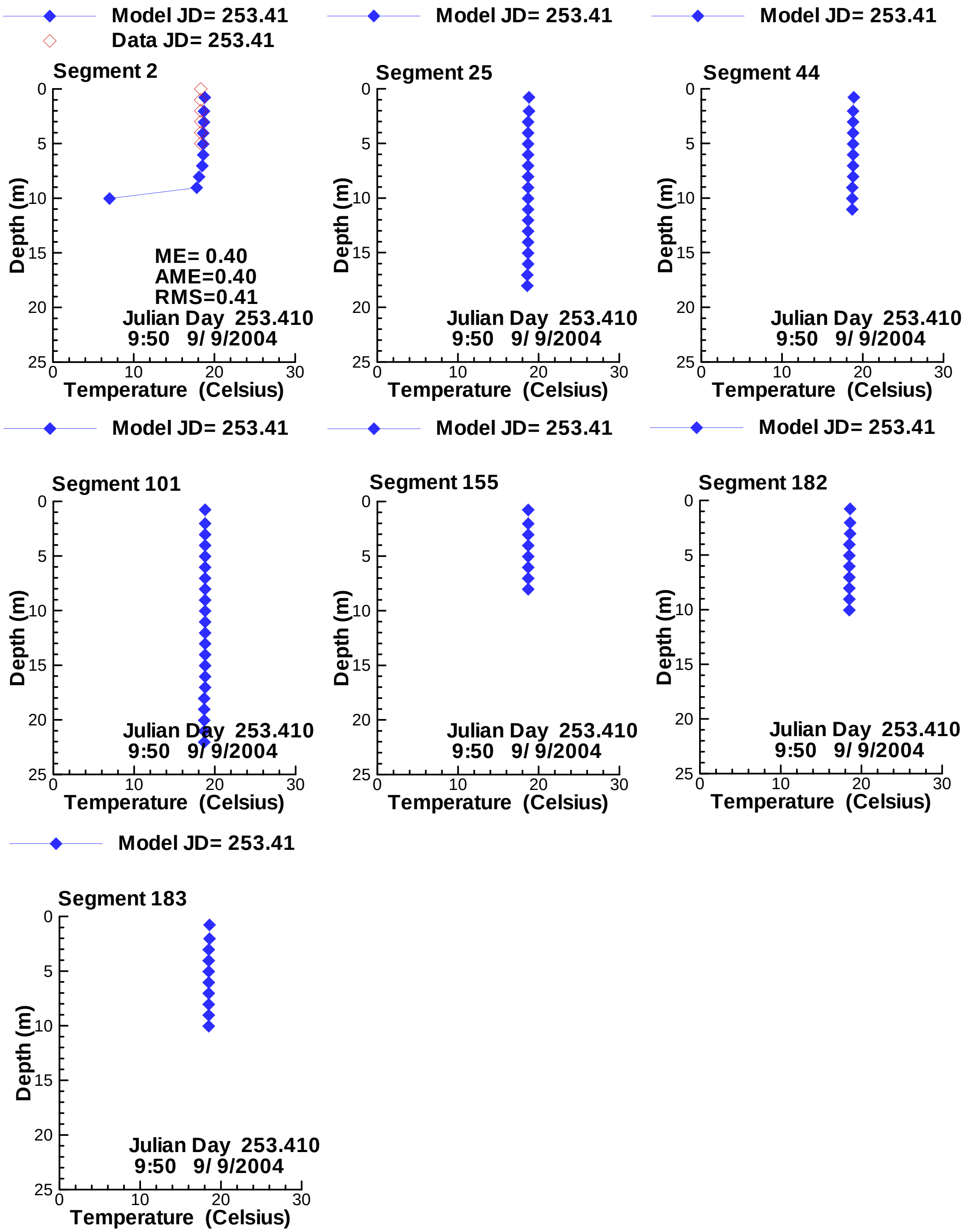


Figure 117: Vertical profiles of TEMPERATURE compared with data for 9/ 9/2004 9:50.

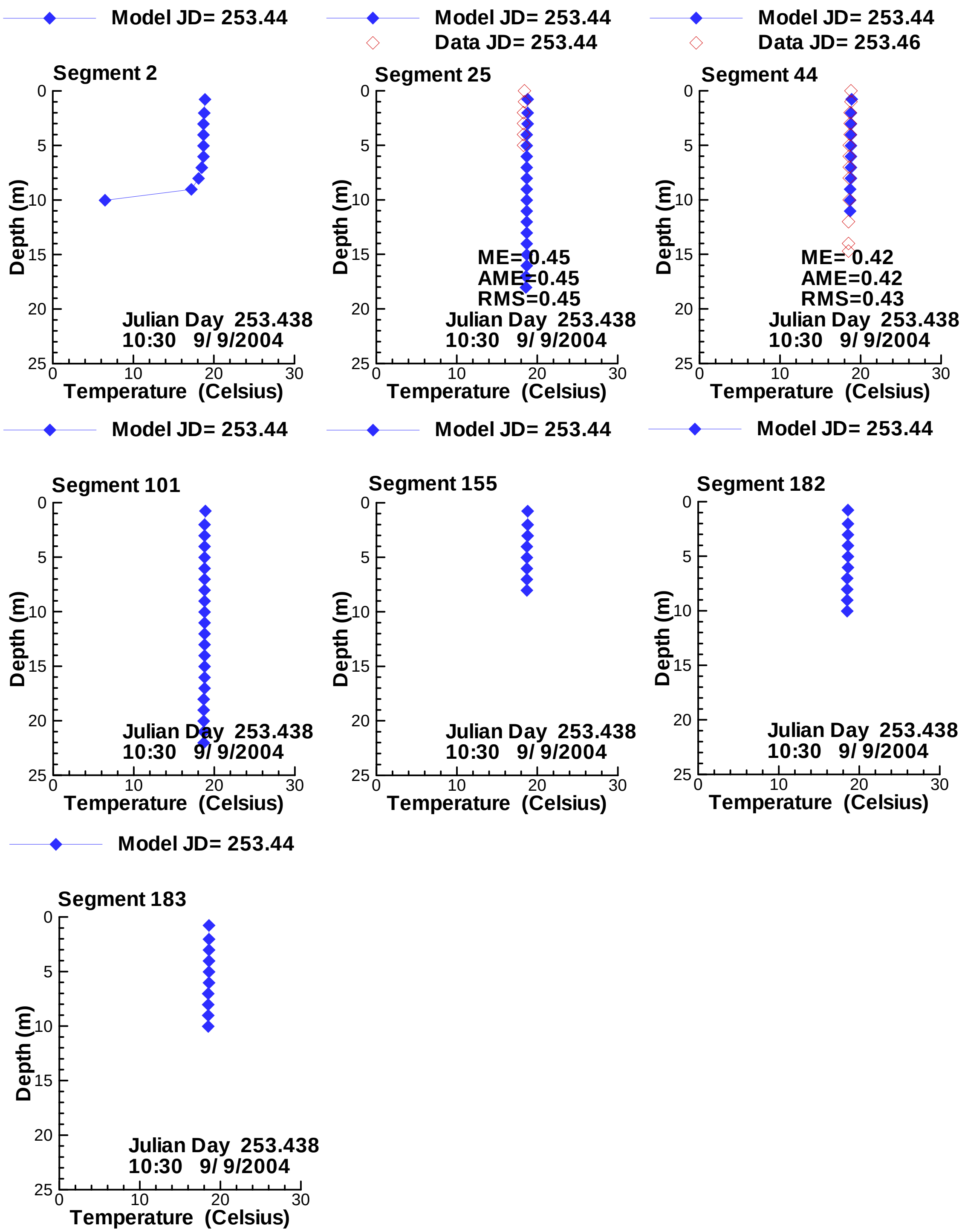


Figure 118: Vertical profiles of TEMPERATURE compared with data for 9/ 9/2004 10:30.

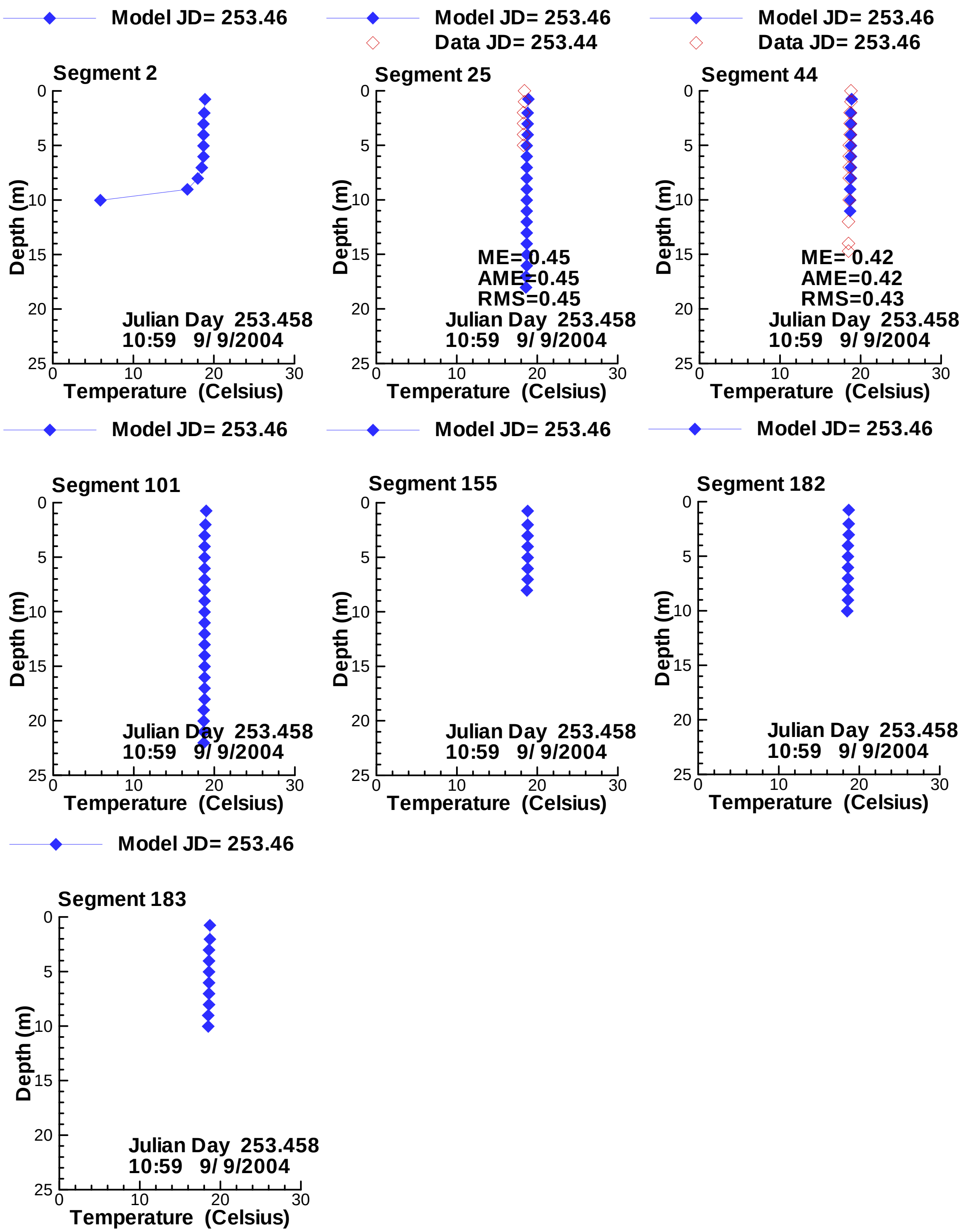


Figure 119: Vertical profiles of TEMPERATURE compared with data for 9/ 9/2004 10:59.

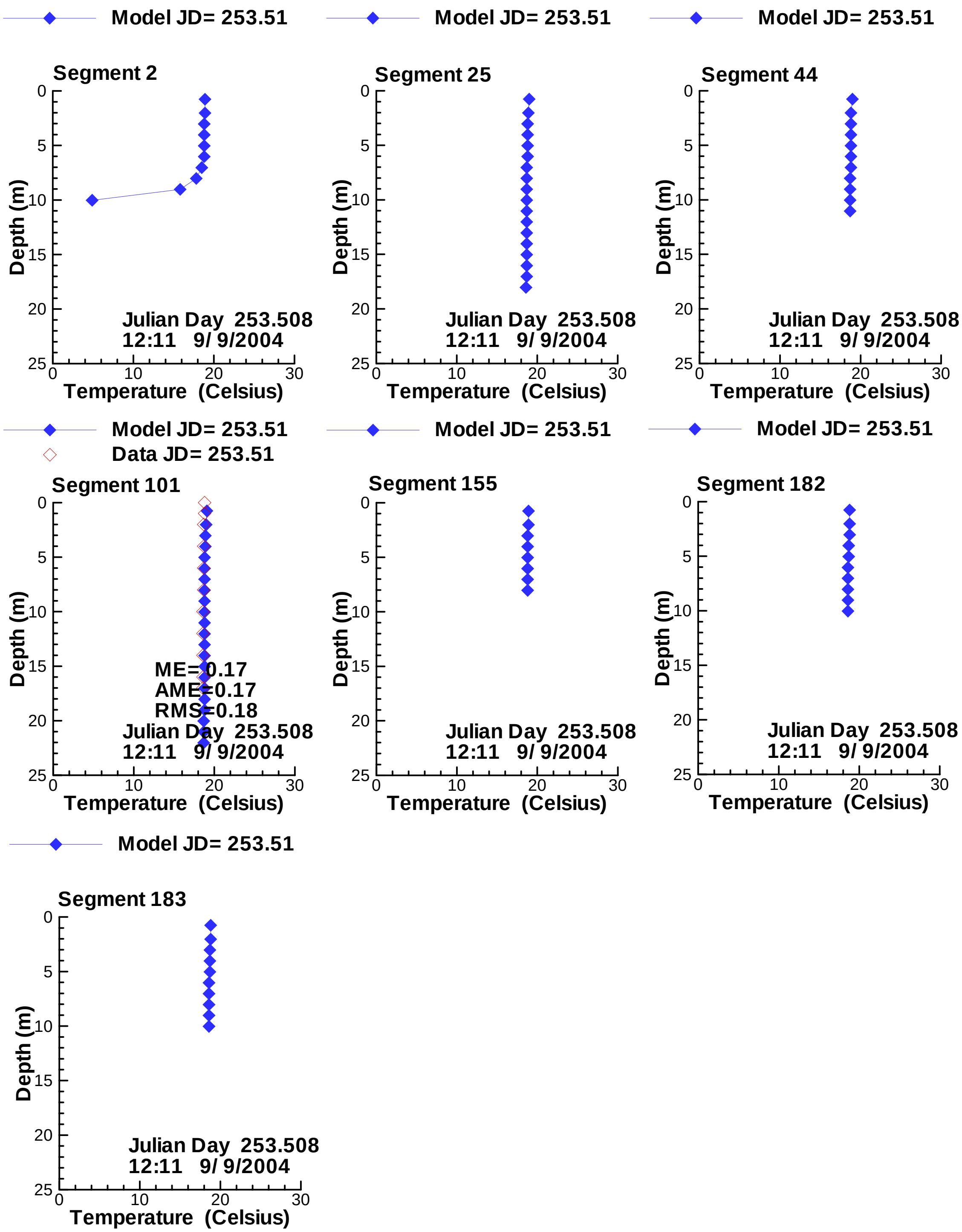


Figure 120: Vertical profiles of TEMPERATURE compared with data for 9/ 9/2004 12:11.

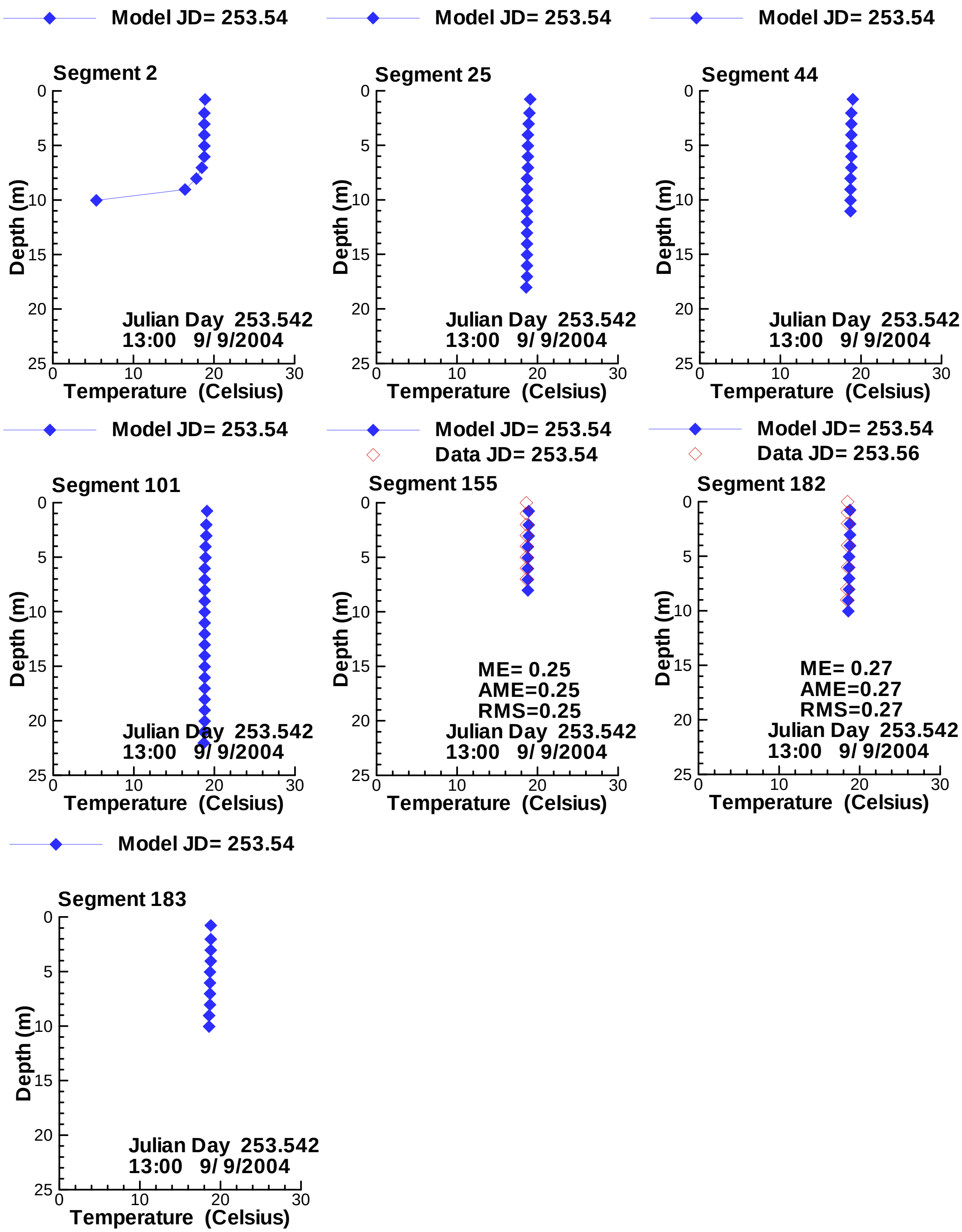


Figure 121: Vertical profiles of TEMPERATURE compared with data for 9/ 9/2004 13:00.

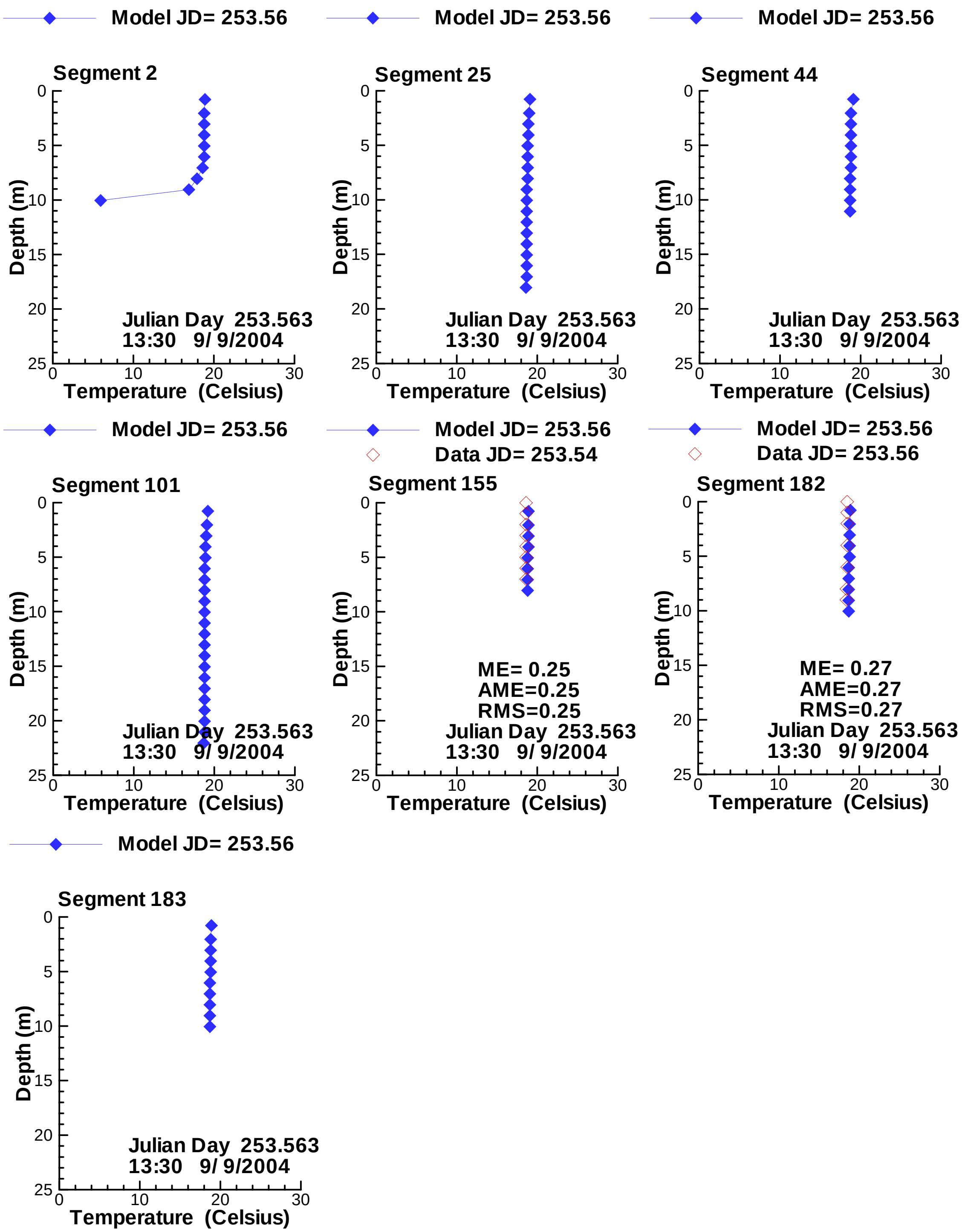


Figure 122: Vertical profiles of TEMPERATURE compared with data for 9/ 9/2004 13:30.

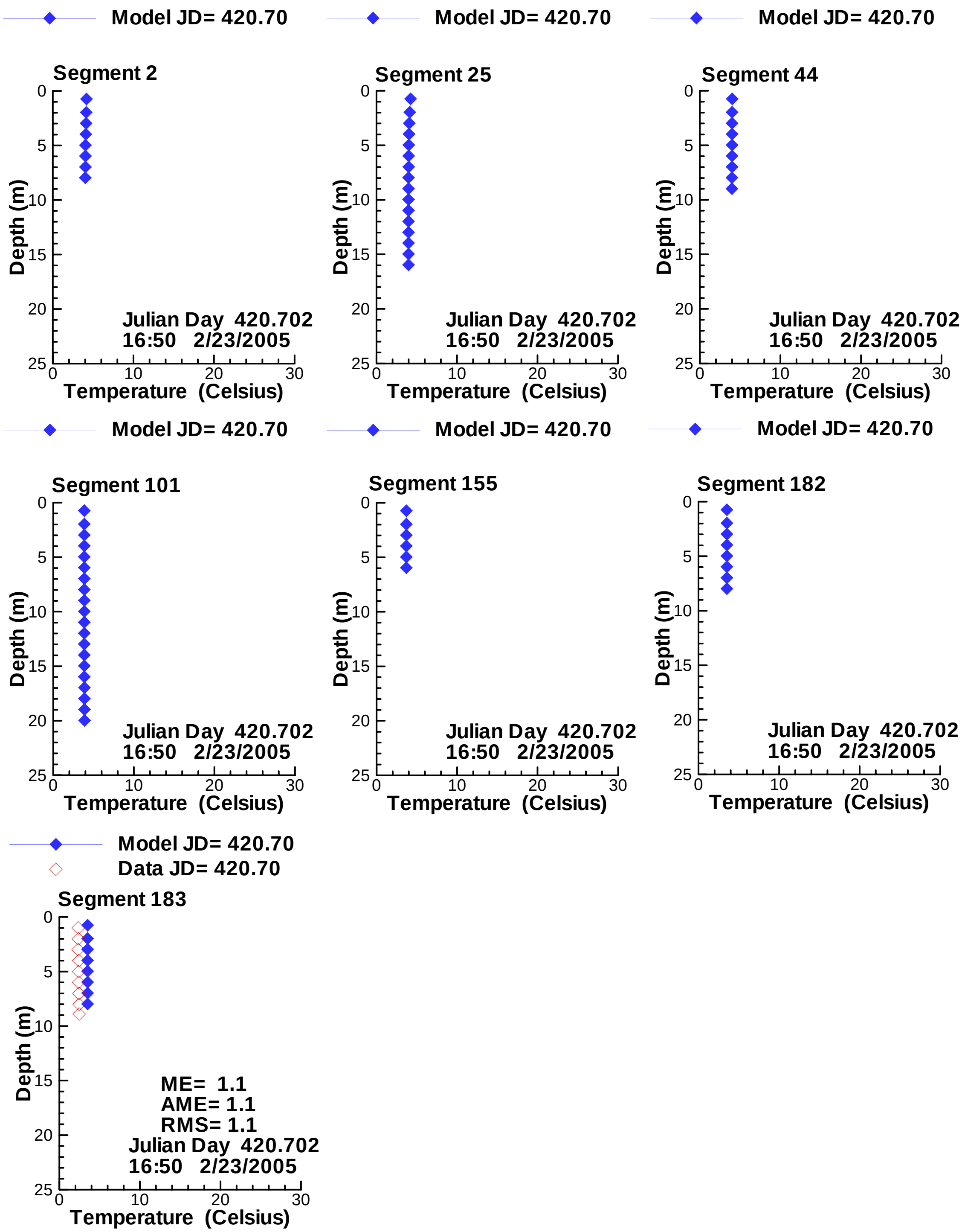


Figure 123: Vertical profiles of TEMPERATURE compared with data for 2/23/2005 16:50.

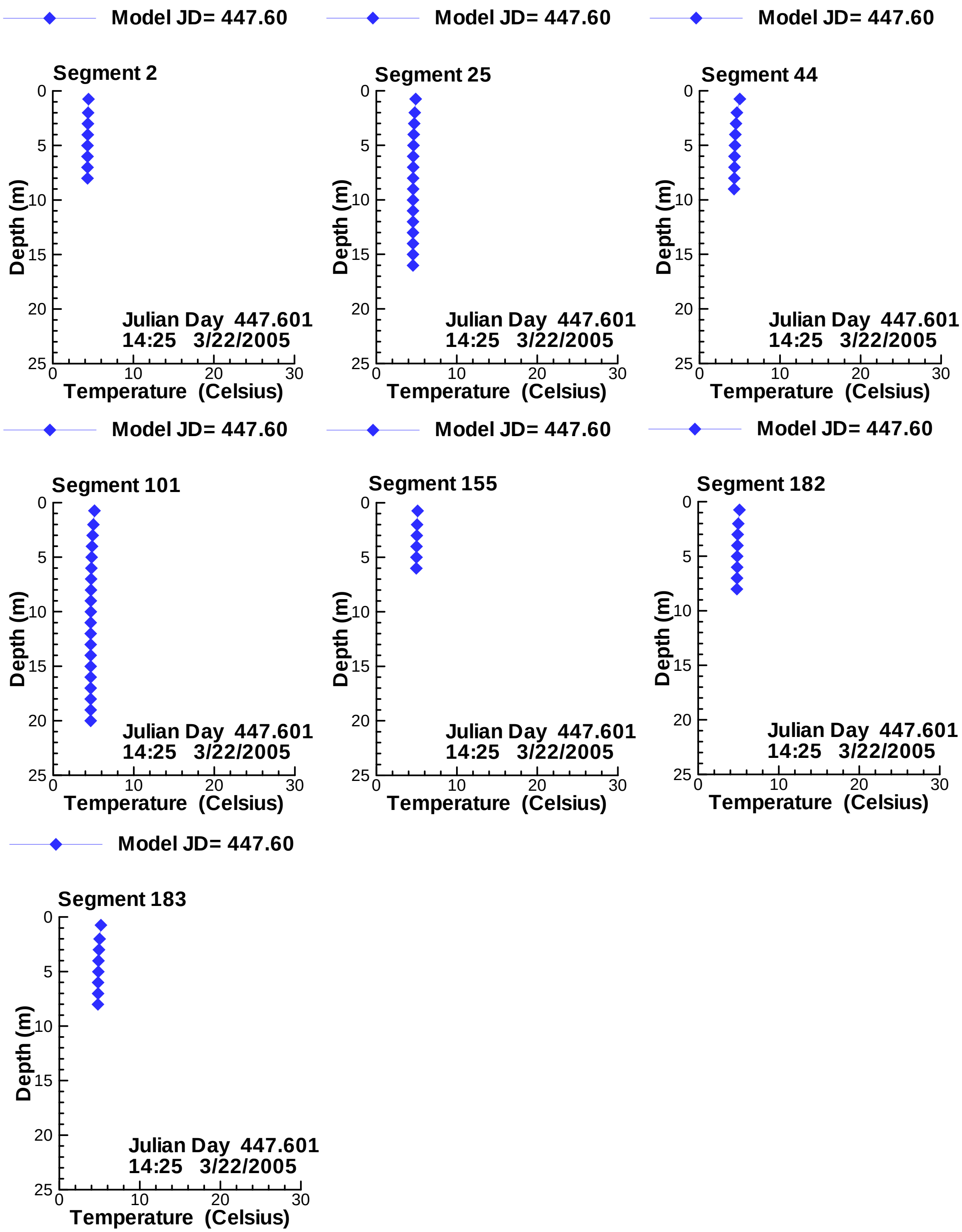


Figure 124: Vertical profiles of TEMPERATURE compared with data for 3/24/2005 16:33.

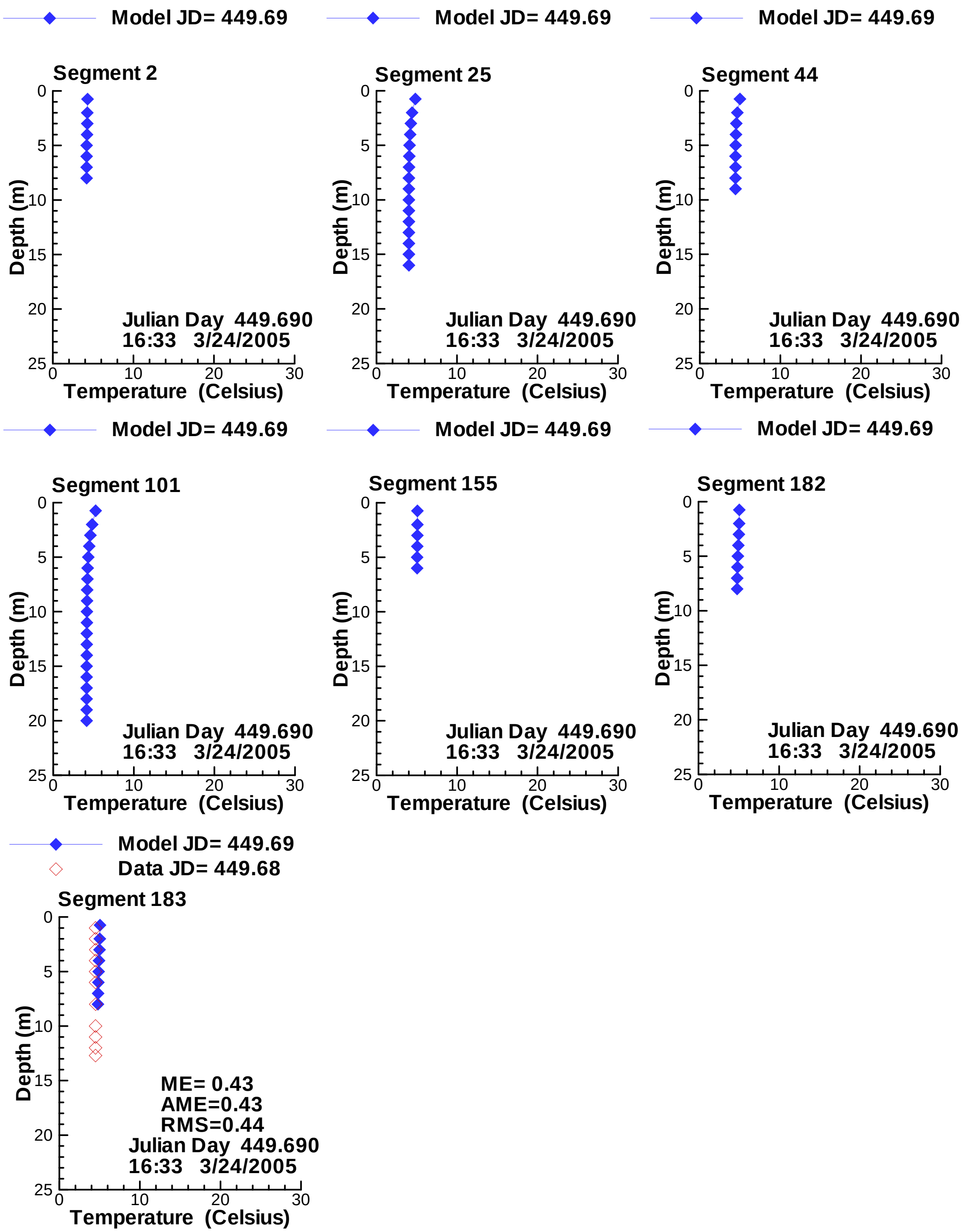


Figure 125: Vertical profiles of TEMPERATURE compared with data for 3/24/2005 16:36.

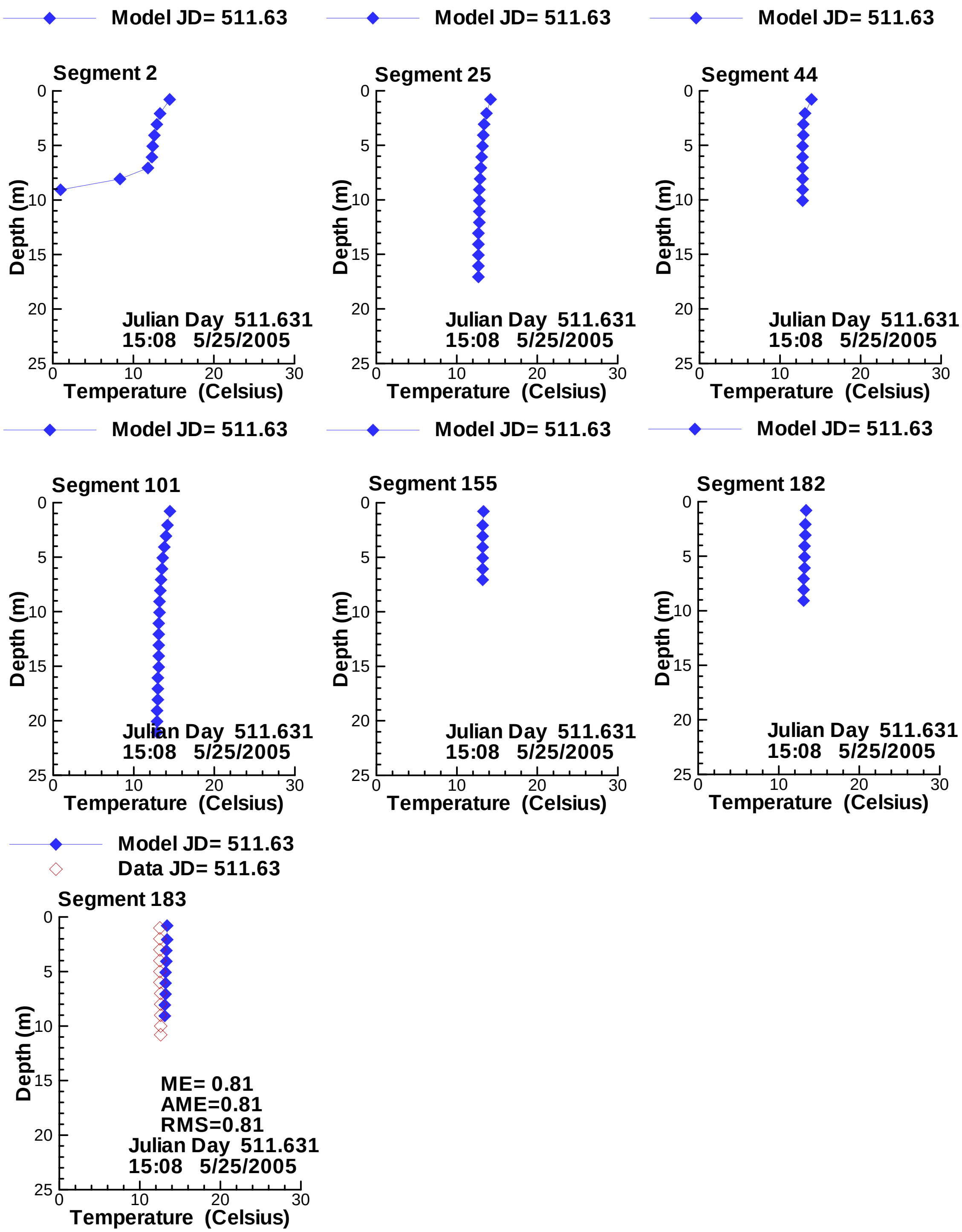


Figure 126: Vertical profiles of TEMPERATURE compared with data for 5/25/2005 15:08.

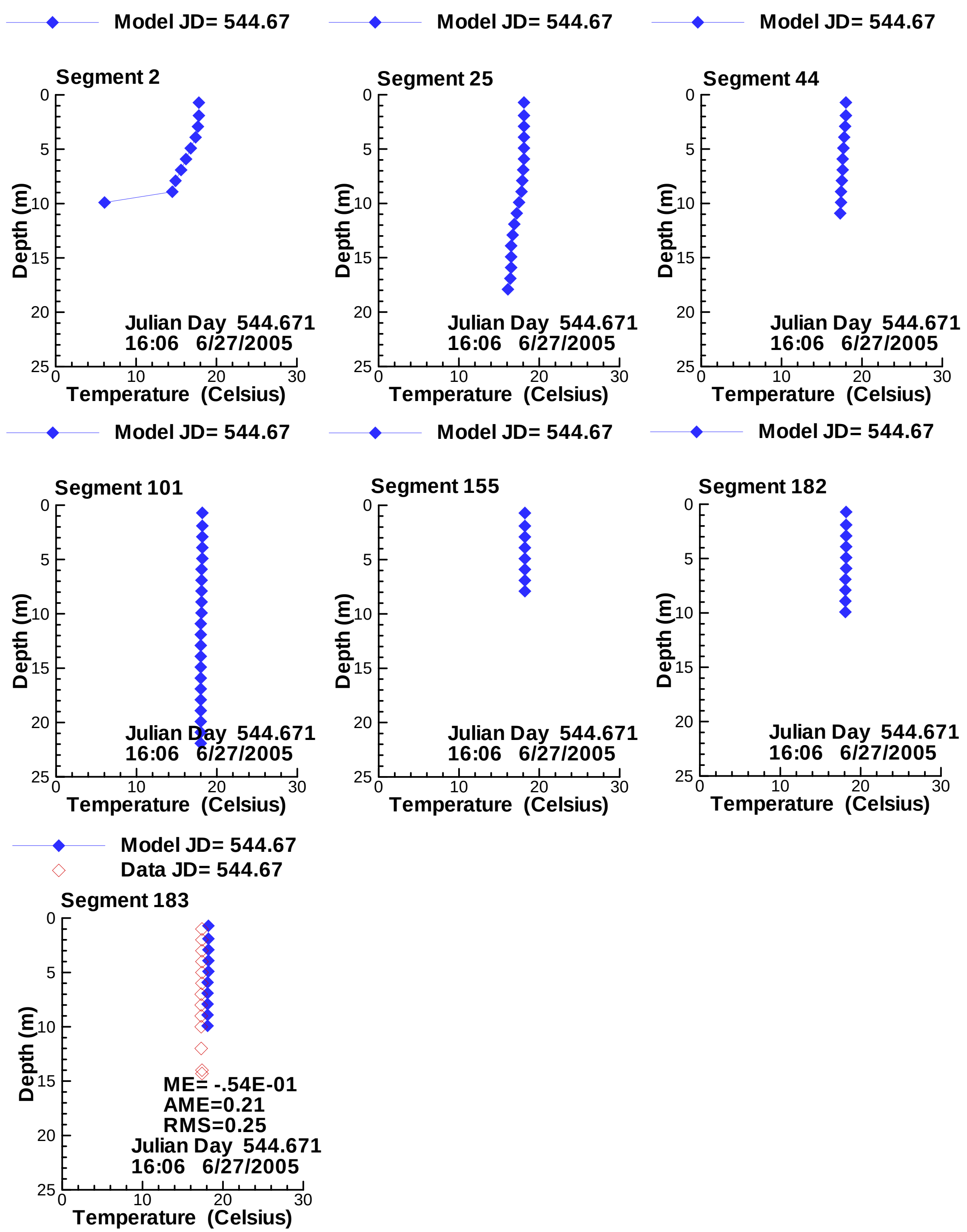


Figure 127: Vertical profiles of TEMPERATURE compared with data for 6/27/2005 16:06.

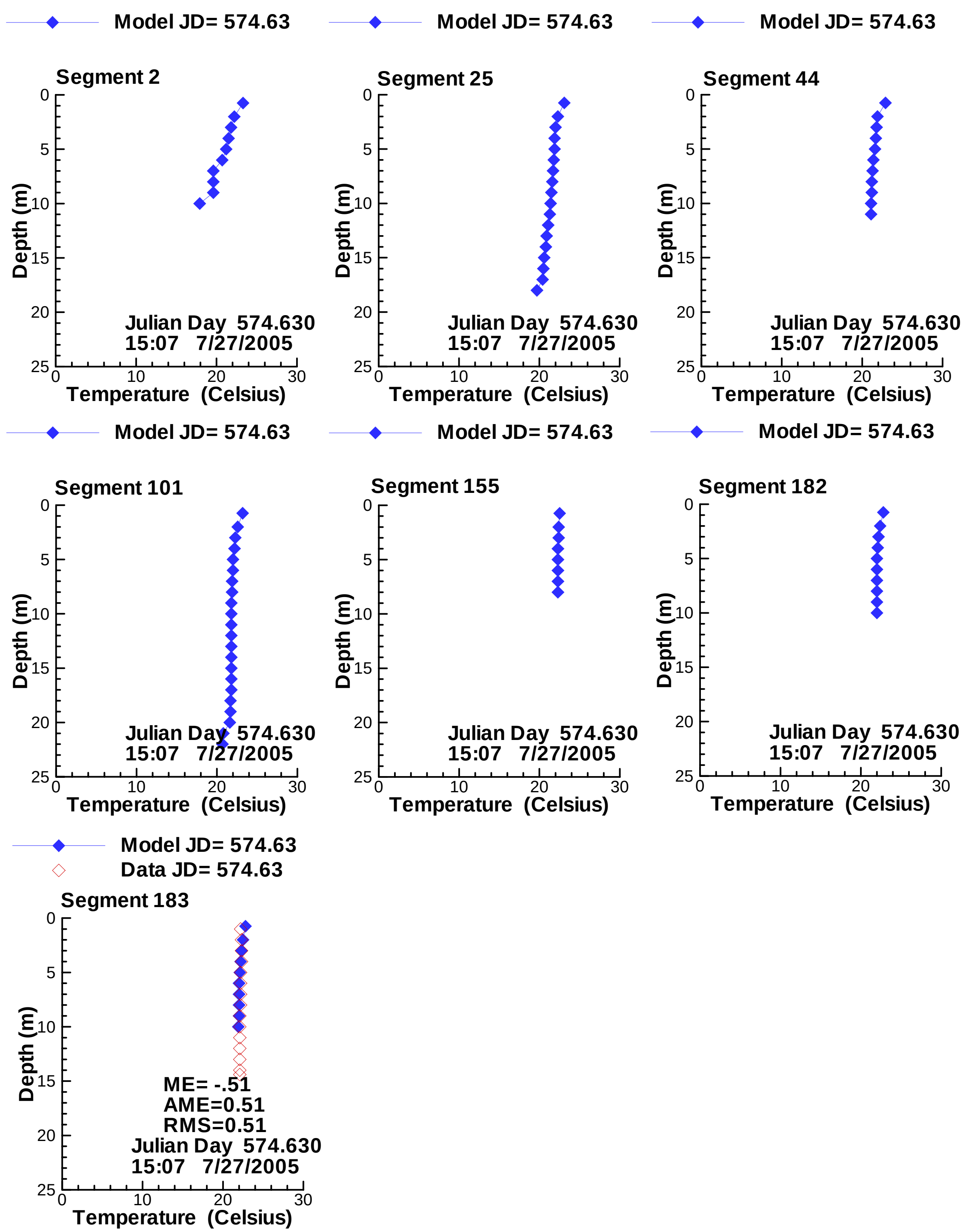


Figure 128: Vertical profiles of TEMPERATURE compared with data for 7/27/2005 15:07.

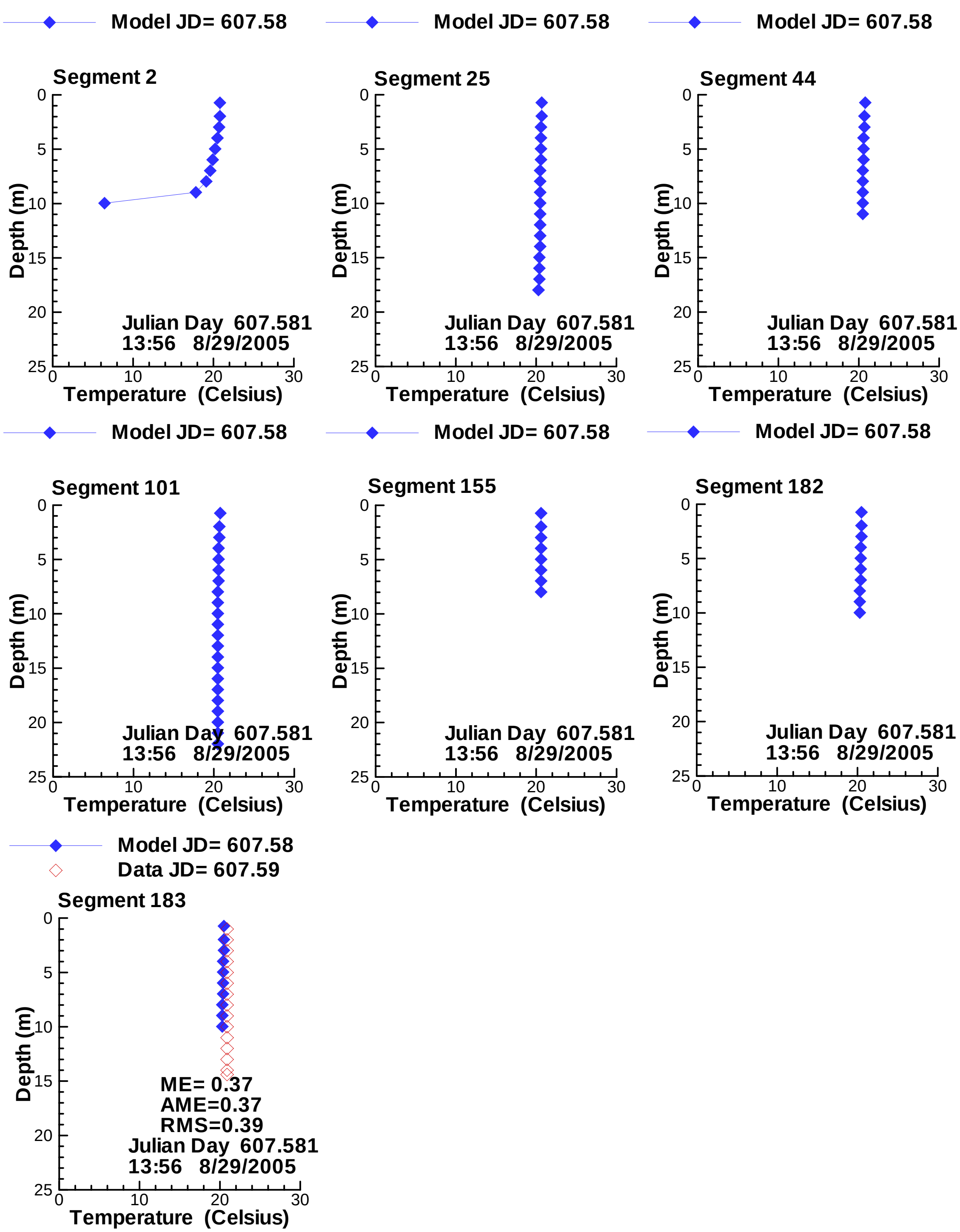


Figure 129: Vertical profiles of TEMPERATURE compared with data for 8/29/2005 13:55.

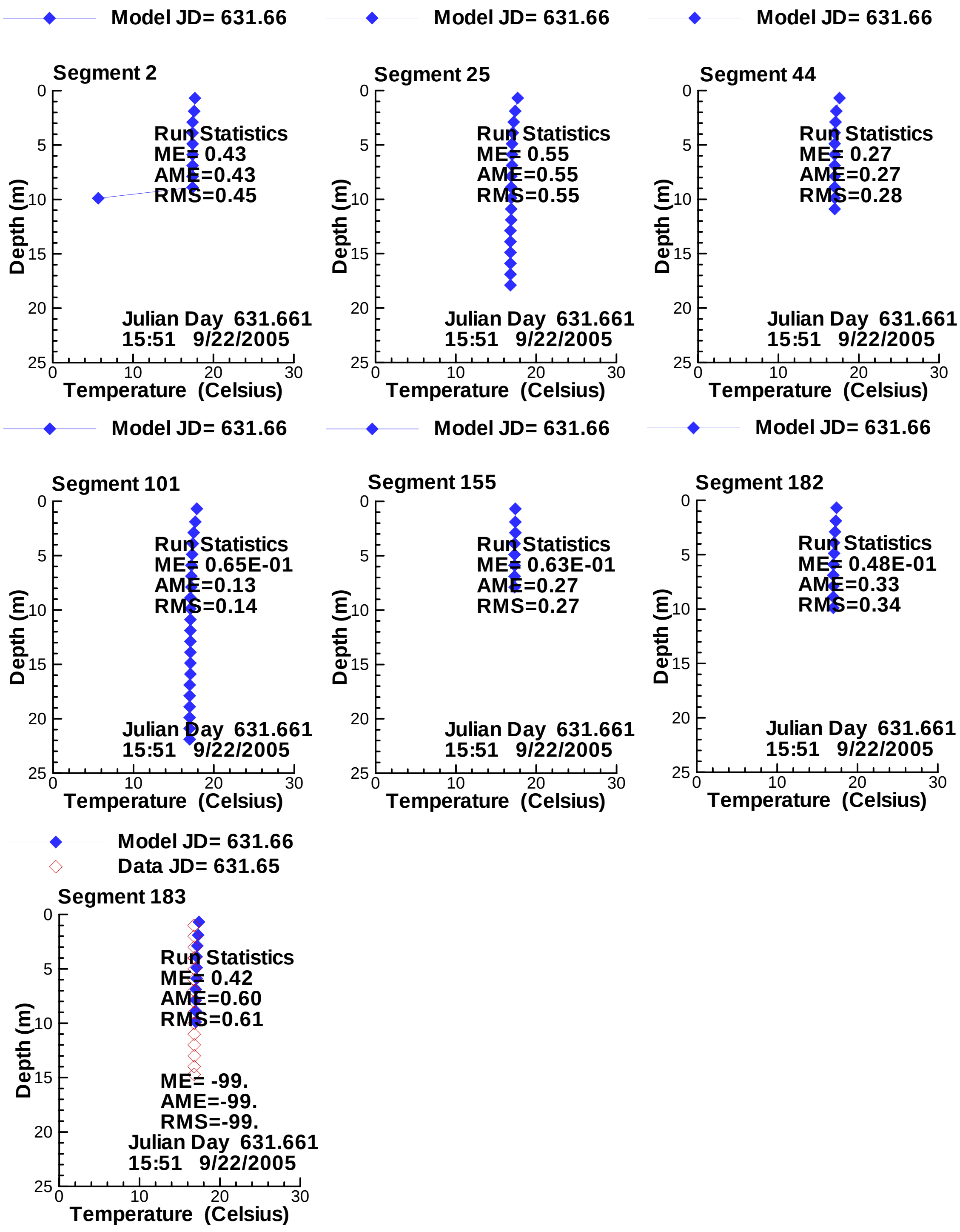


Figure 130: Vertical profiles of TEMPERATURE compared with data for 9/22/2005 15:50.

Dissolved Oxygen

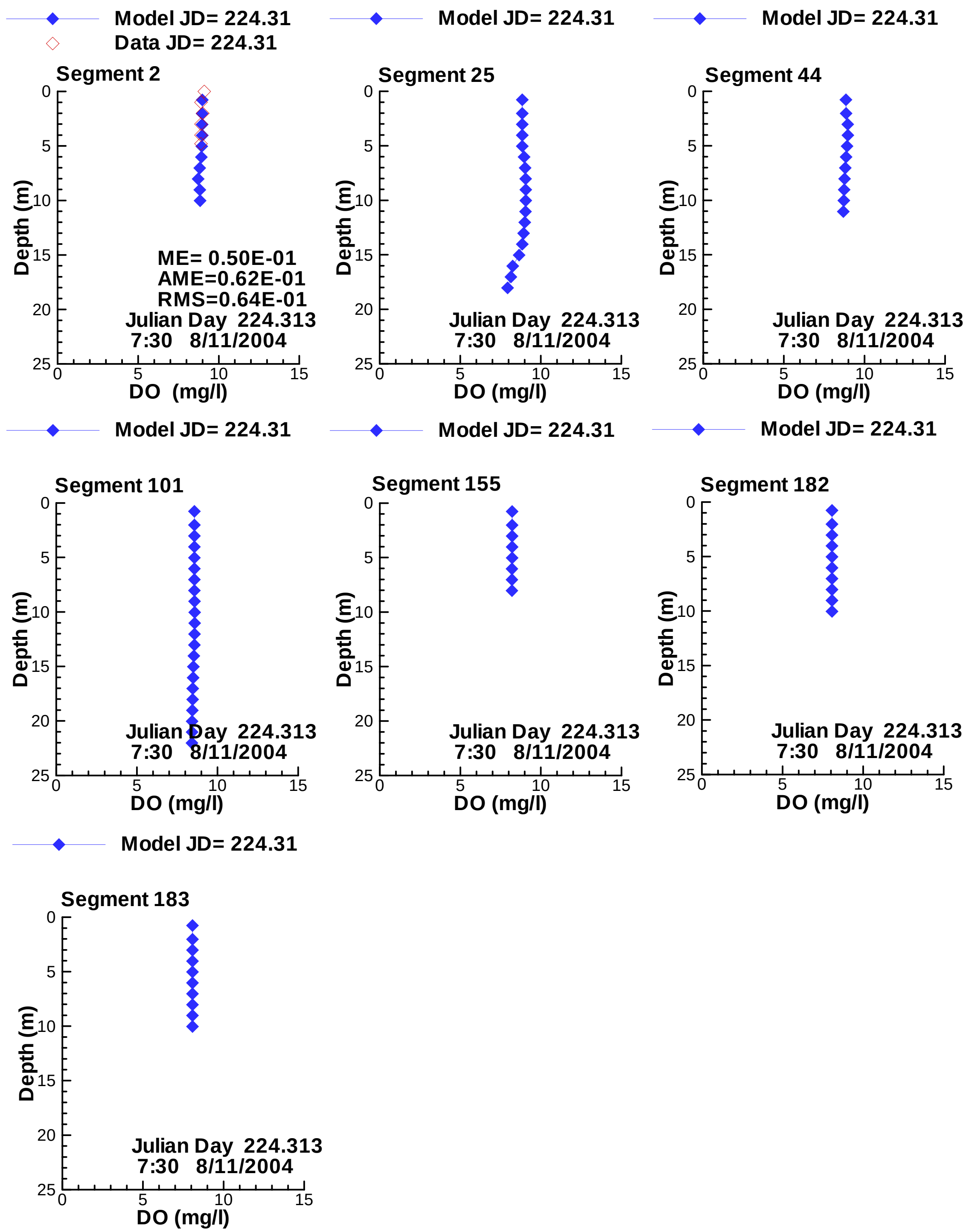


Figure 131: Vertical profiles of DISSOLVED OXYGEN compared with data for 8/11/2004 7:30.

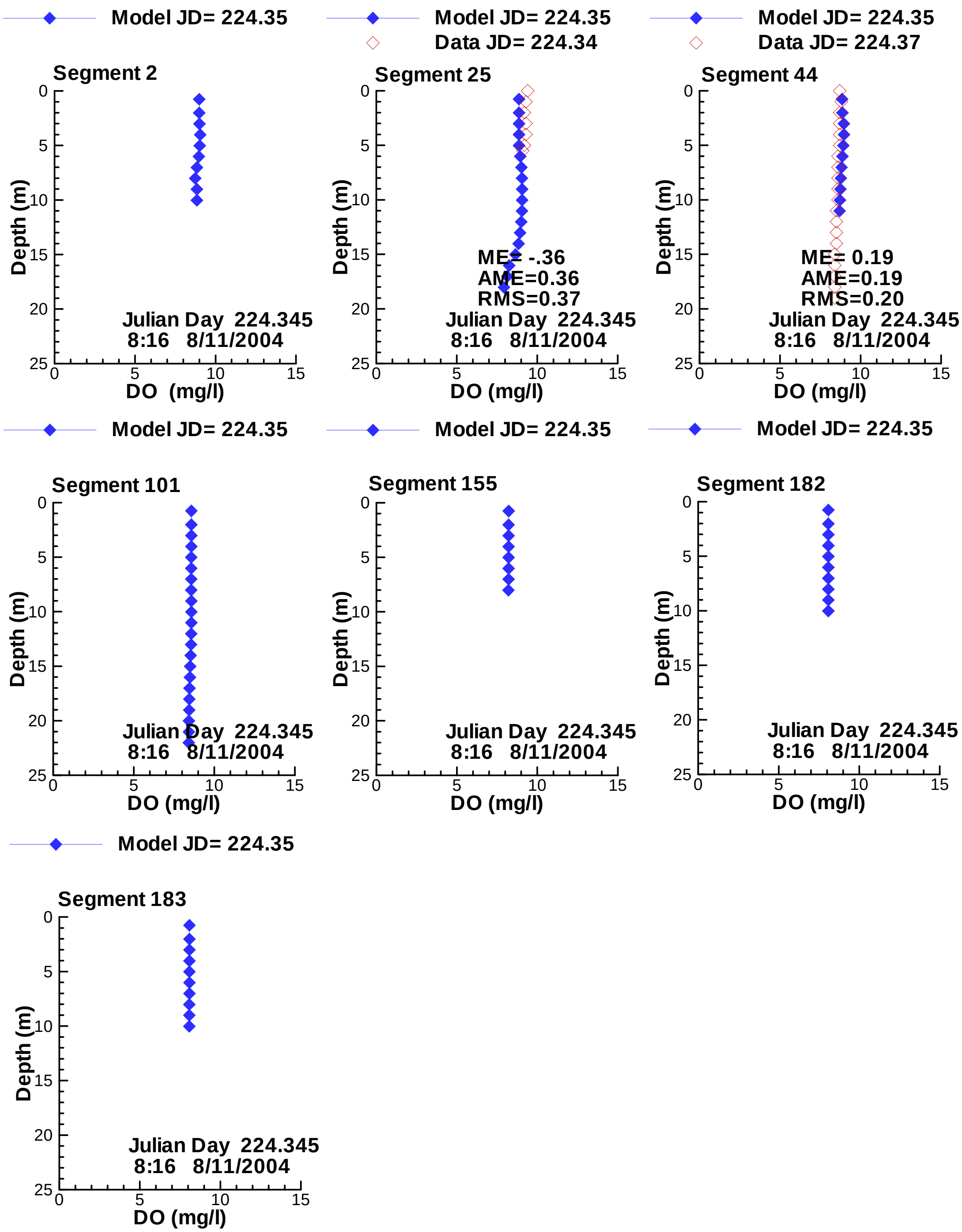


Figure 132: Vertical profiles of DISSOLVED OXYGEN compared with data for 8/11/2004 8:16.

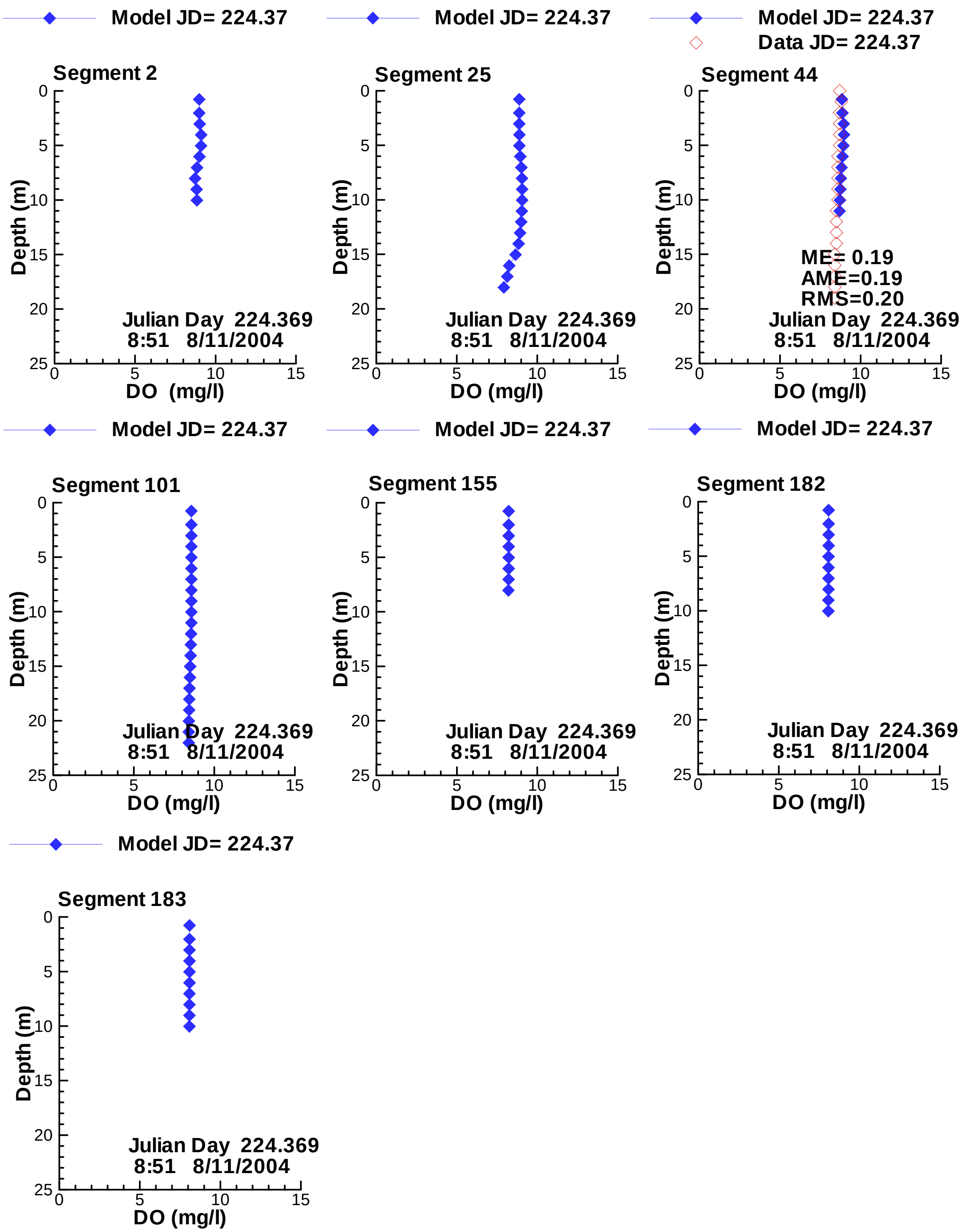


Figure 133: Vertical profiles of DISSOLVED OXYGEN compared with data for 8/11/2004 8:51.

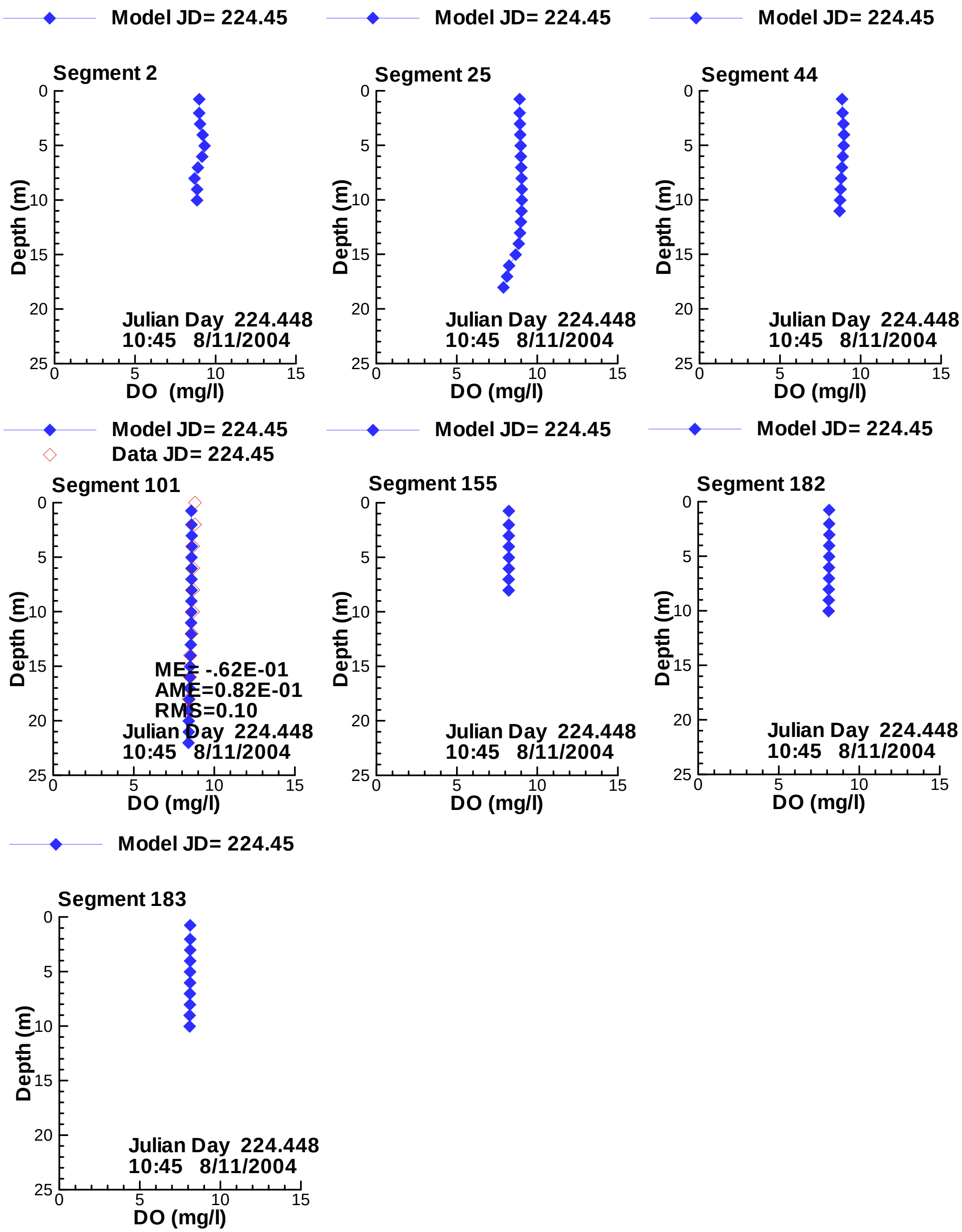


Figure 134: Vertical profiles of DISSOLVED OXYGEN compared with data for 8/11/2004 10:46.

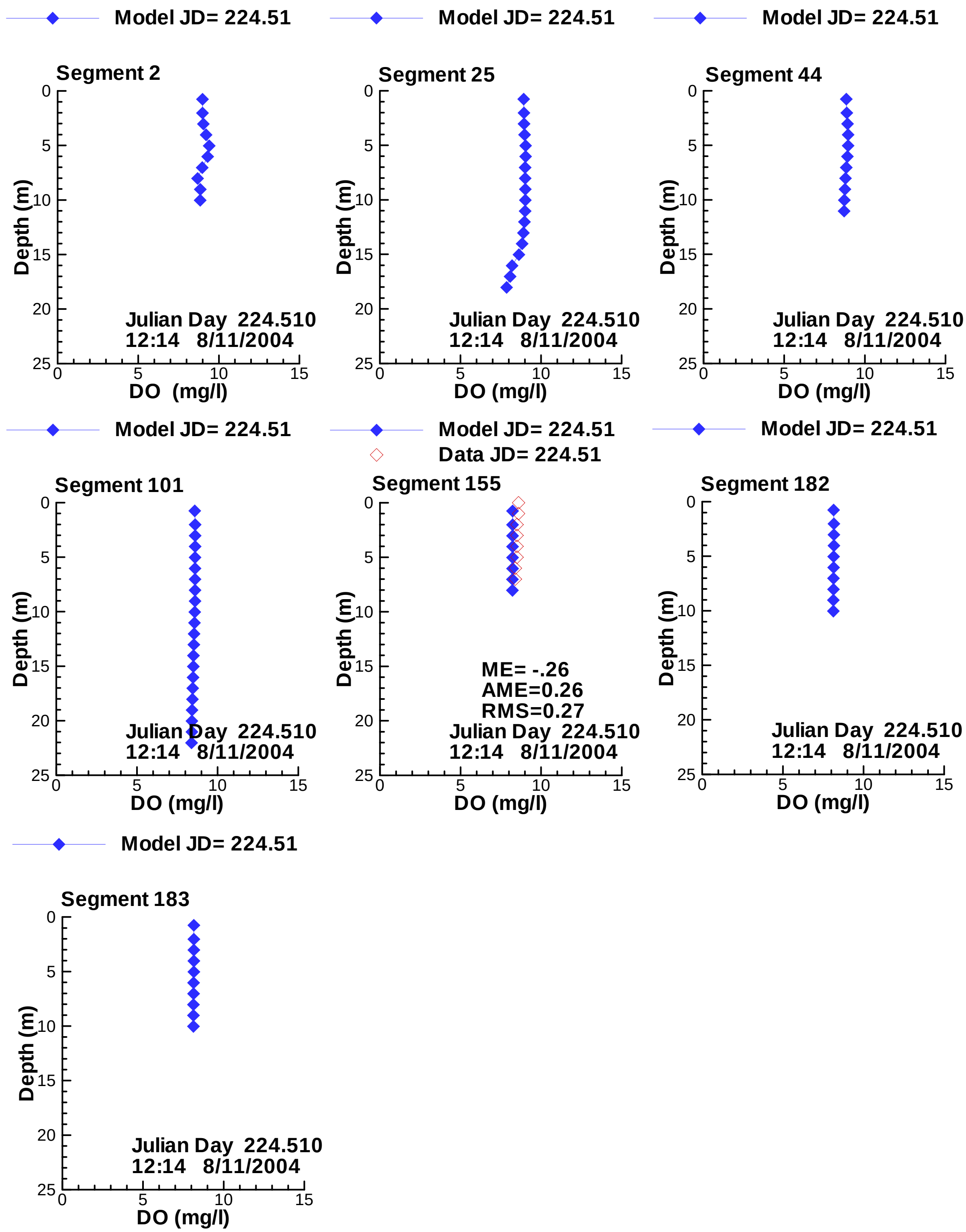


Figure 135: Vertical profiles of DISSOLVED OXYGEN compared with data for 8/11/2004 12:14.

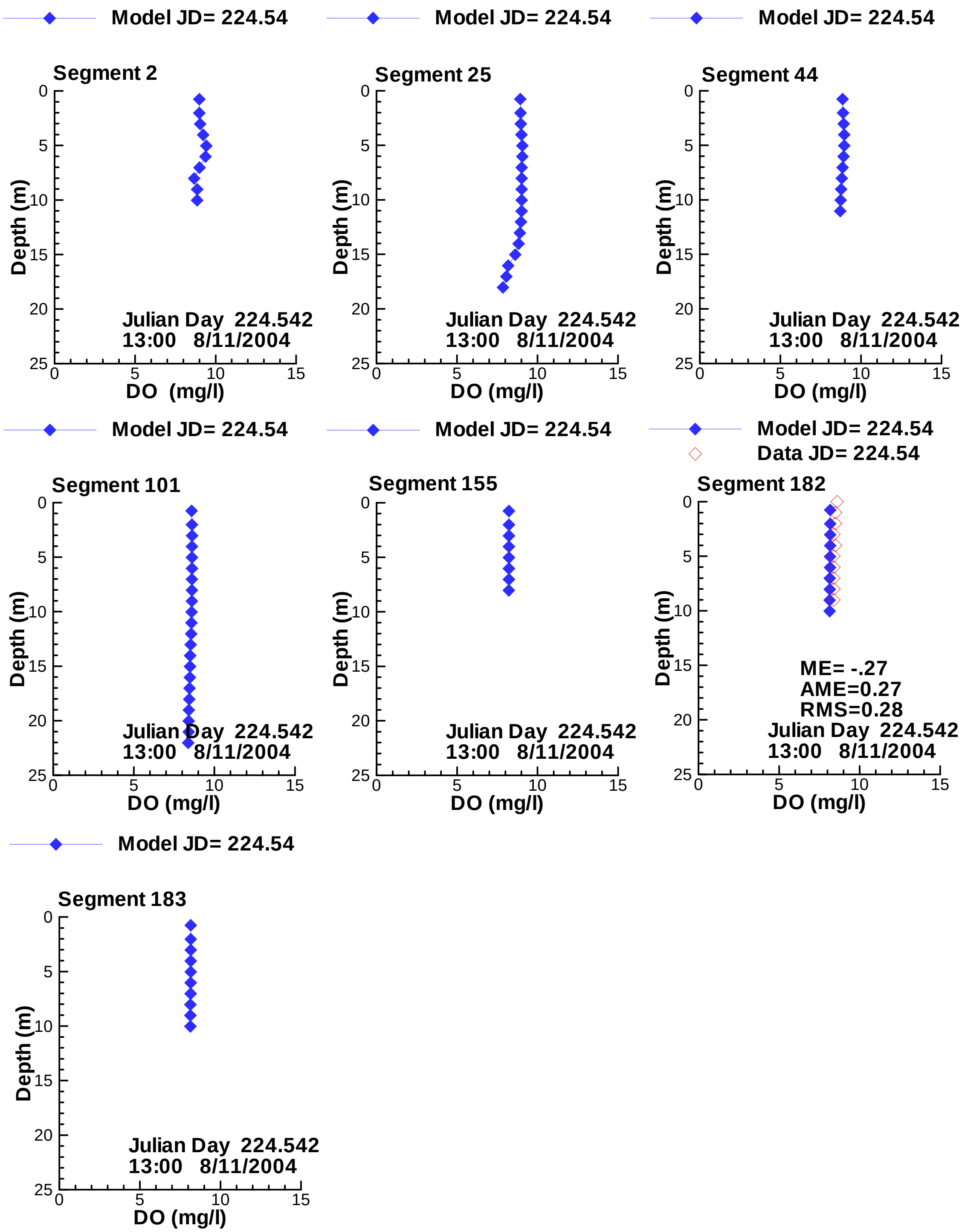


Figure 136: Vertical profiles of DISSOLVED OXYGEN compared with data for 8/11/2004 13:00.

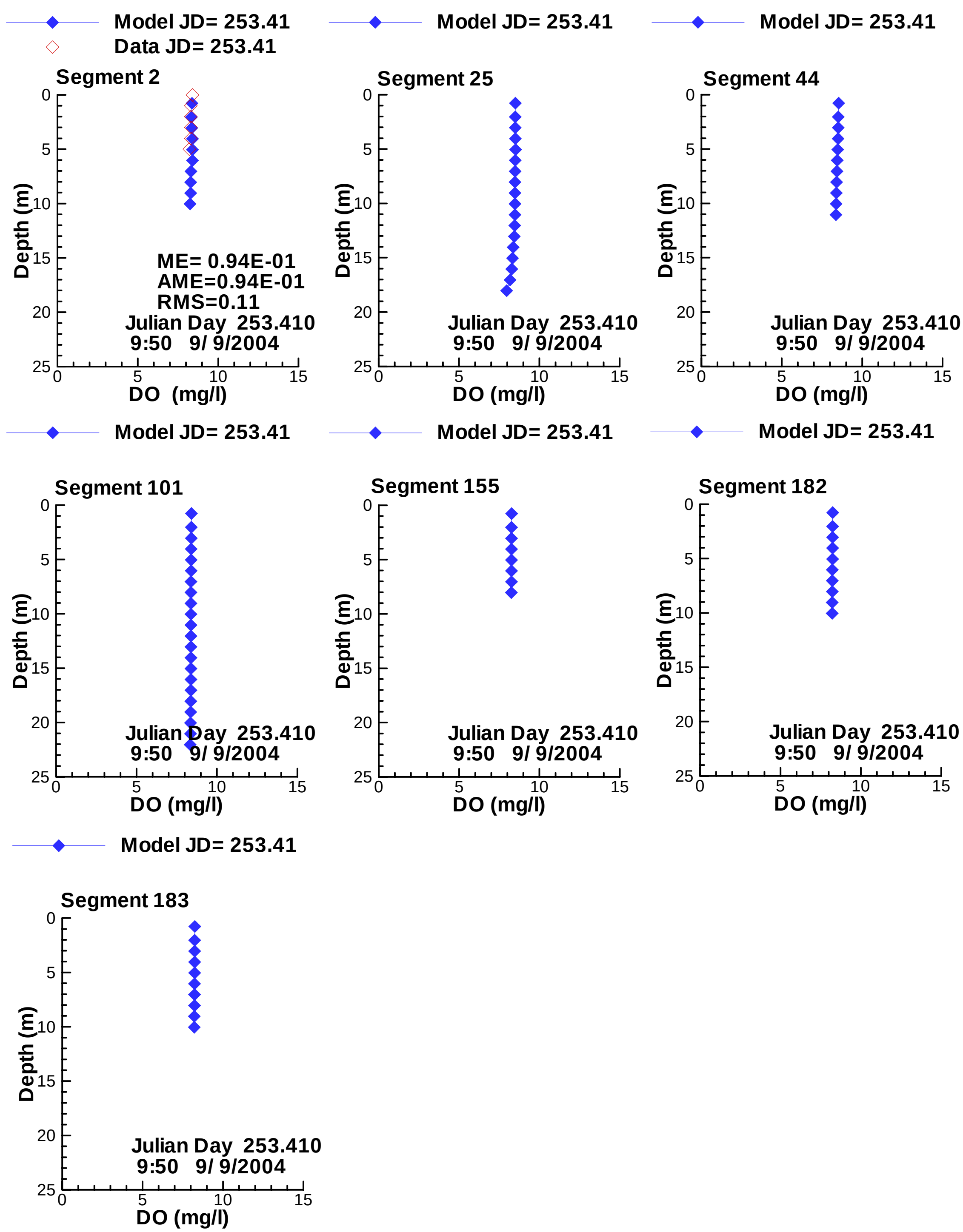


Figure 137: Vertical profiles of DISSOLVED OXYGEN compared with data for 9/ 9/2004 9:50.

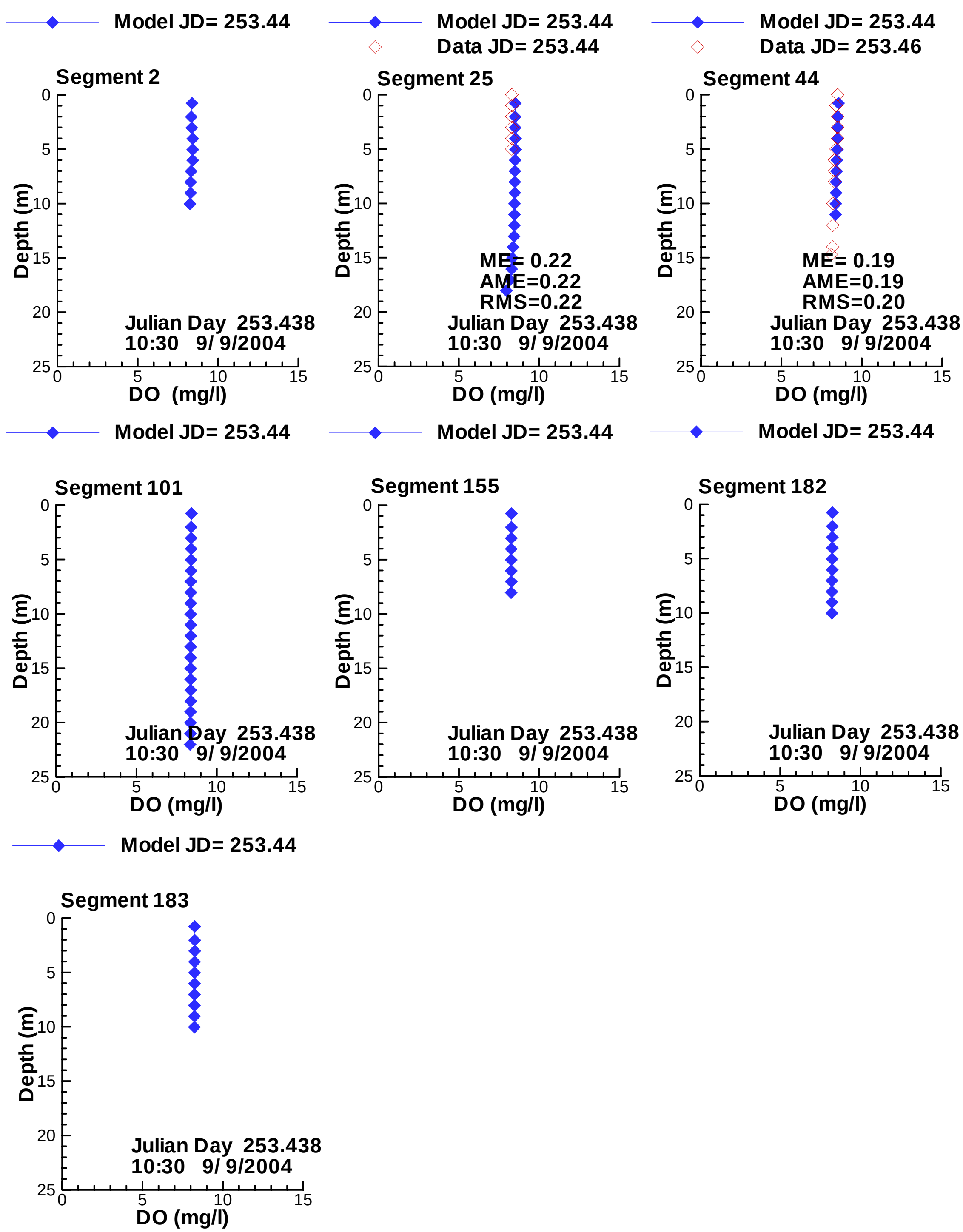


Figure 138: Vertical profiles of DISSOLVED OXYGEN compared with data for 9/ 9/2004 10:30.

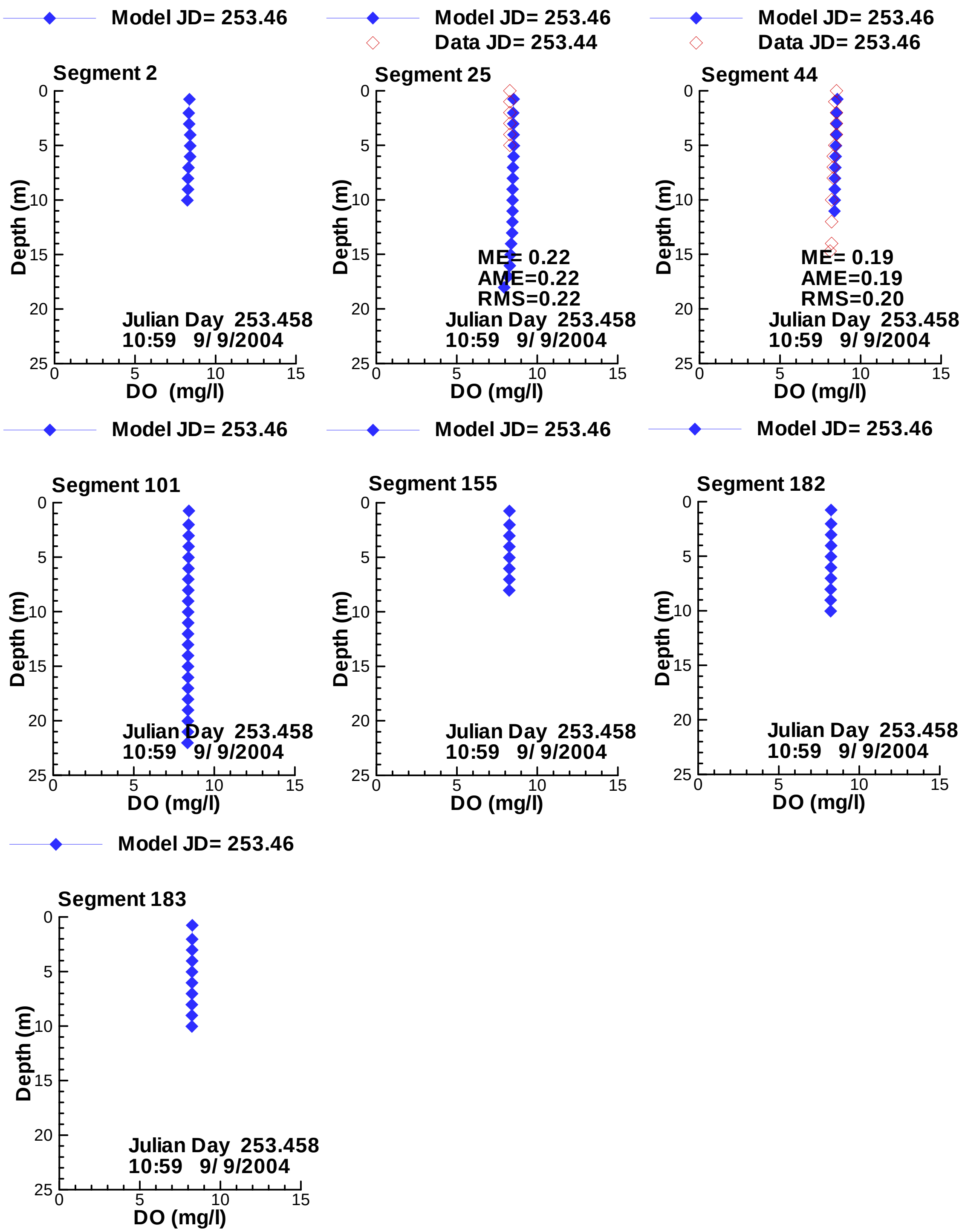


Figure 139: Vertical profiles of DISSOLVED OXYGEN compared with data for 9/ 9/2004 10:59.

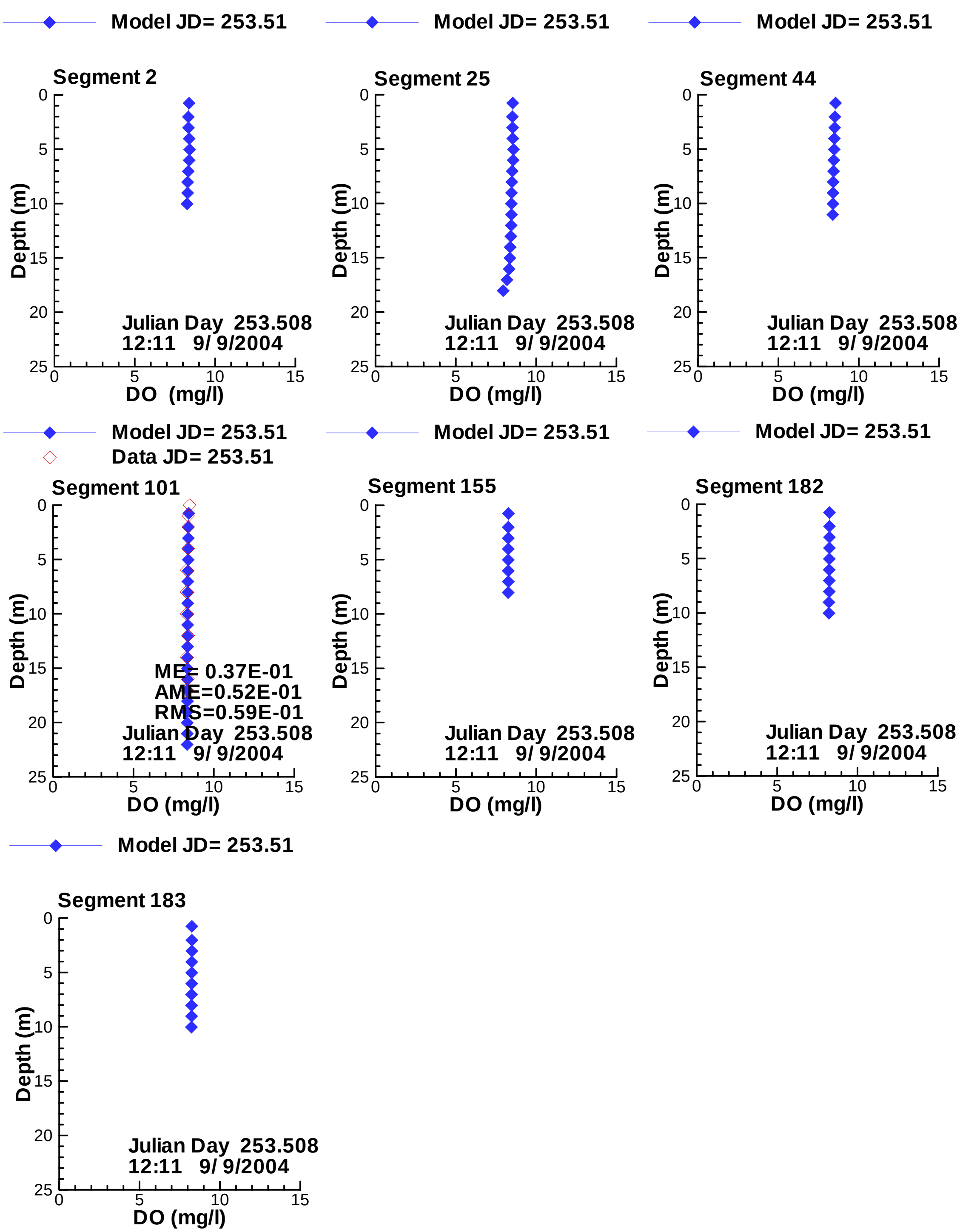


Figure 140: Vertical profiles of DISSOLVED OXYGEN compared with data for 9/ 9/2004 12:11.

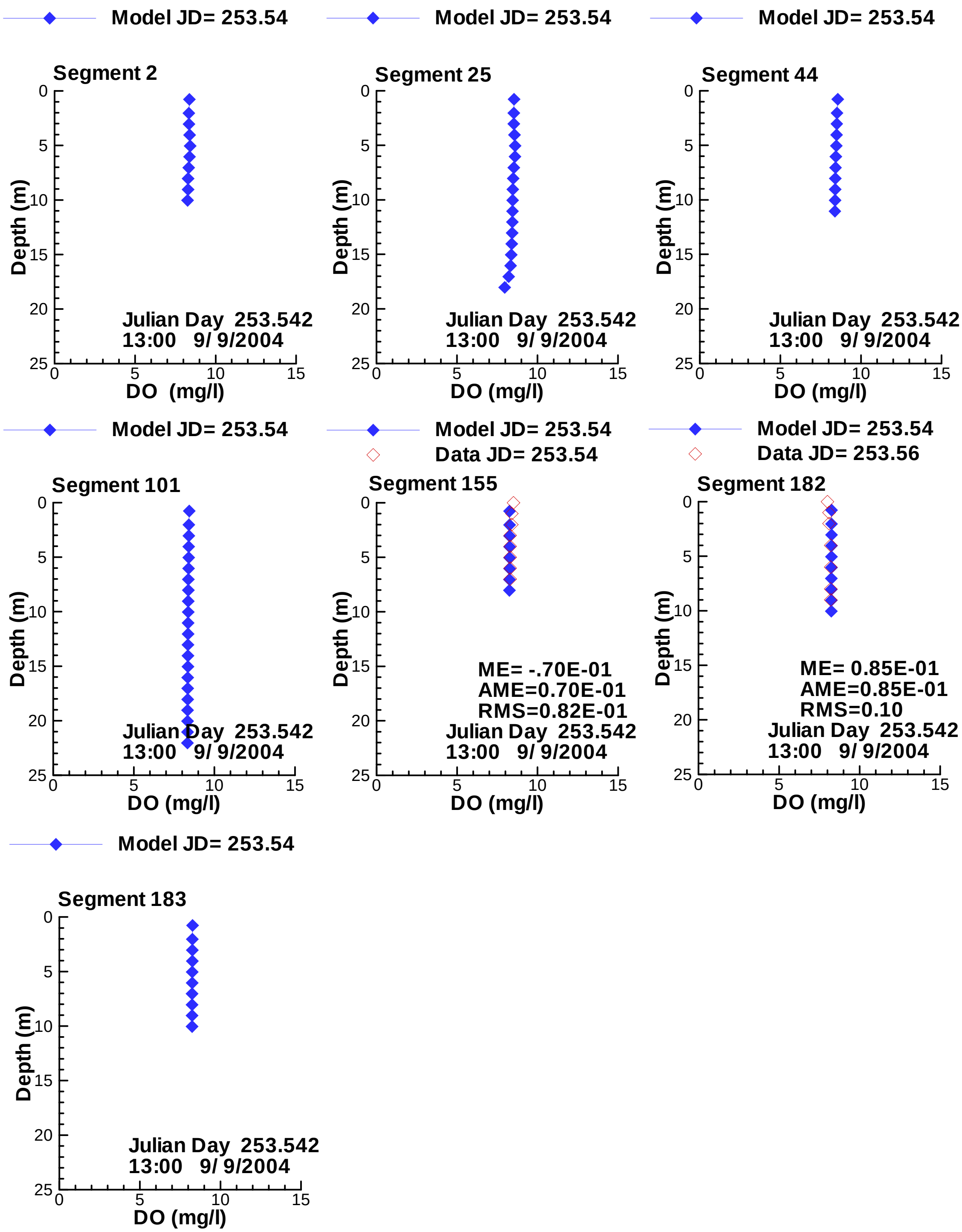


Figure 141: Vertical profiles of DISSOLVED OXYGEN compared with data for 9/ 9/2004 13:00.

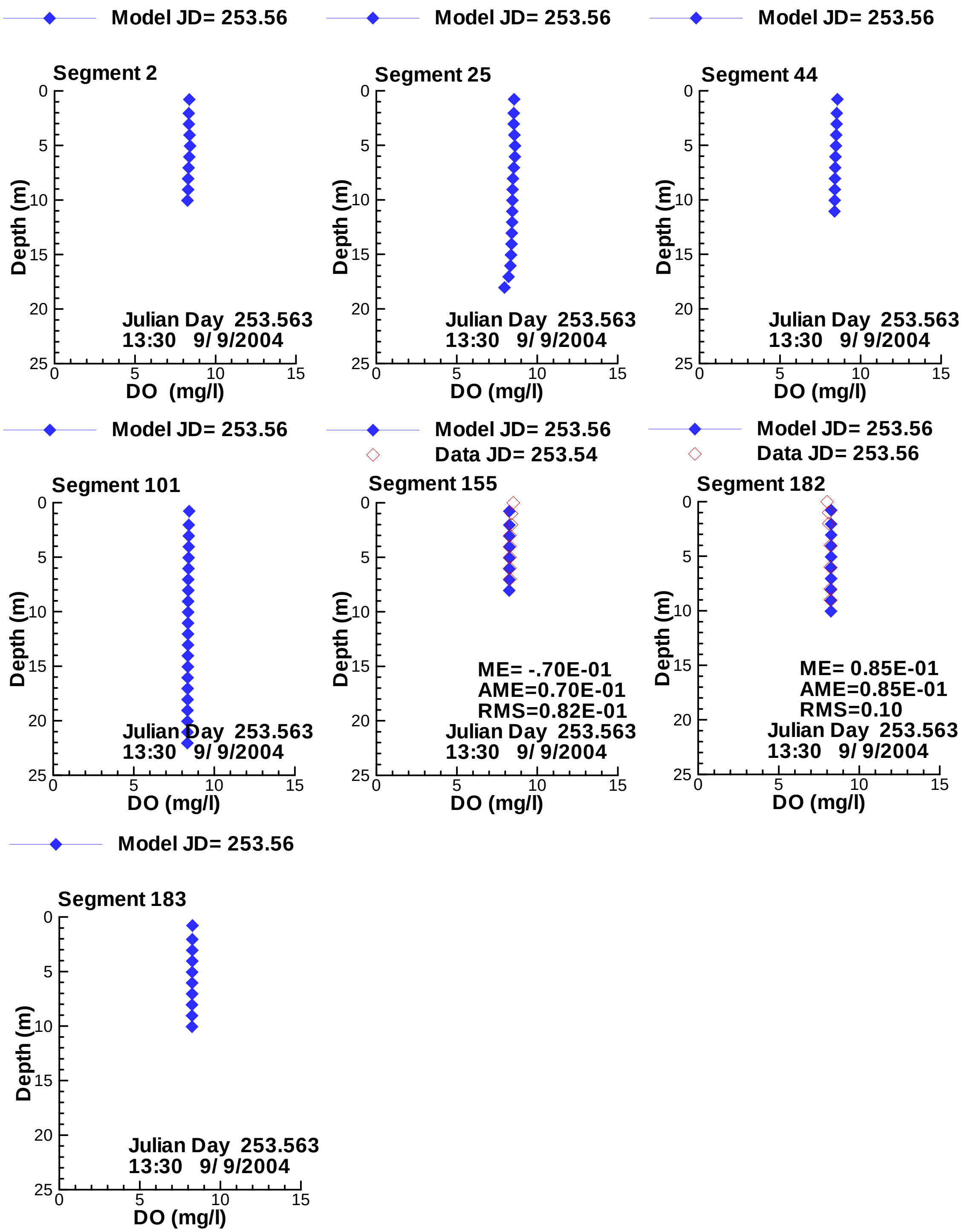


Figure 142: Vertical profiles of DISSOLVED OXYGEN compared with data for 9/ 9/2004 13:30.

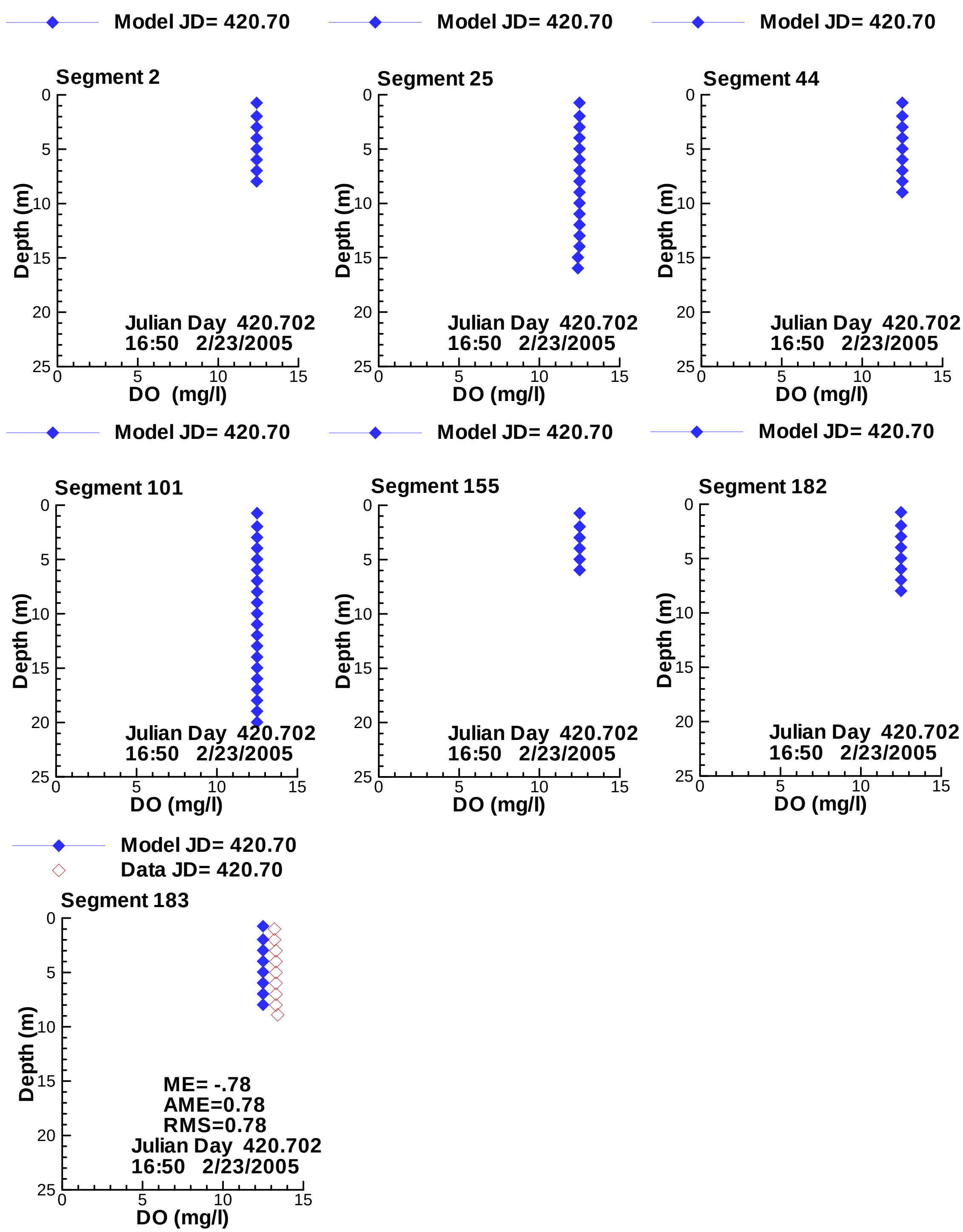


Figure 143: Vertical profiles of DISSOLVED OXYGEN compared with data for 2/23/2005 16:50.

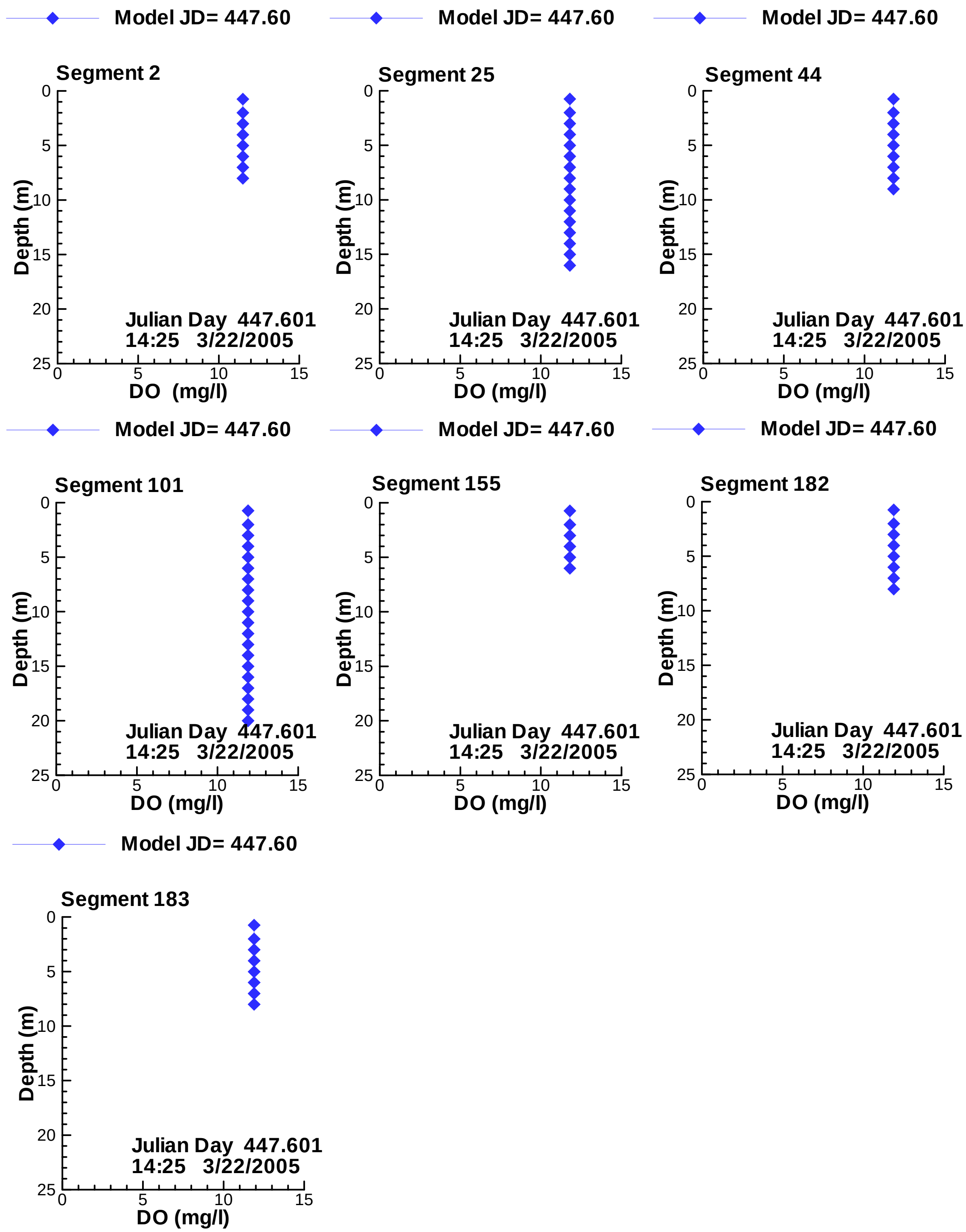


Figure 144: Vertical profiles of DISSOLVED OXYGEN compared with data for 3/24/2005 16:33.

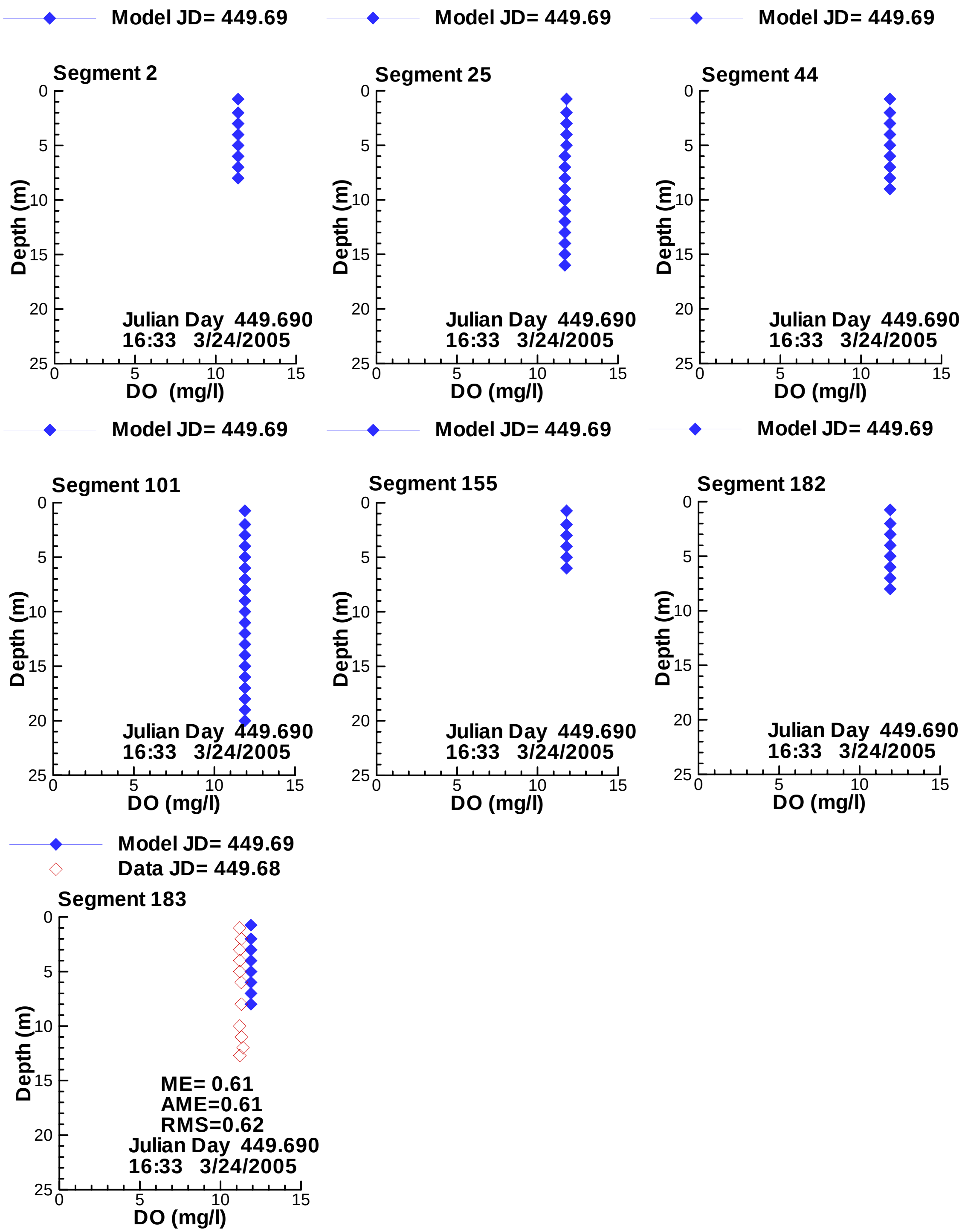


Figure 145: Vertical profiles of DISSOLVED OXYGEN compared with data for 3/24/2005 16:36.

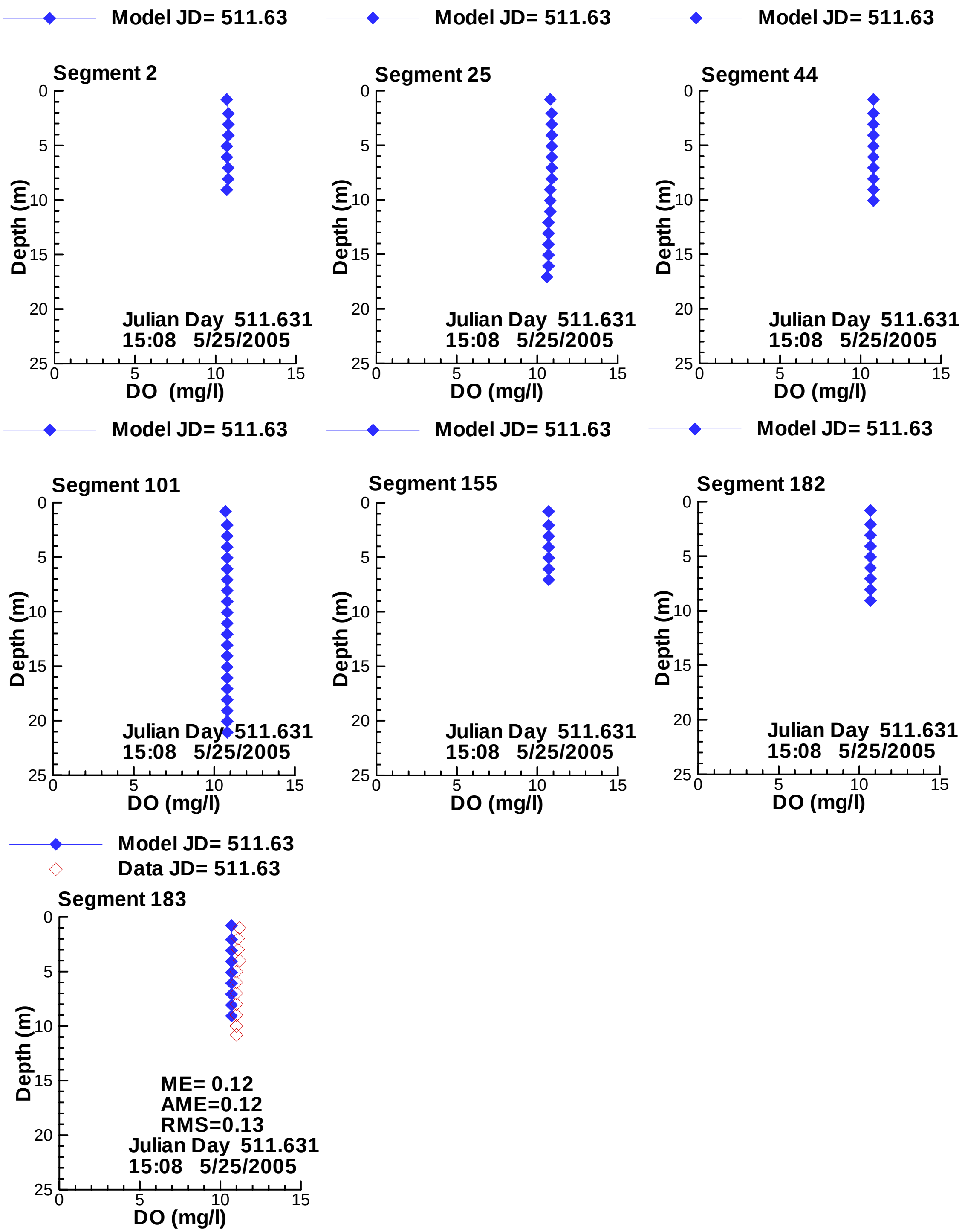


Figure 146: Vertical profiles of DISSOLVED OXYGEN compared with data for 5/25/2005 15:08.

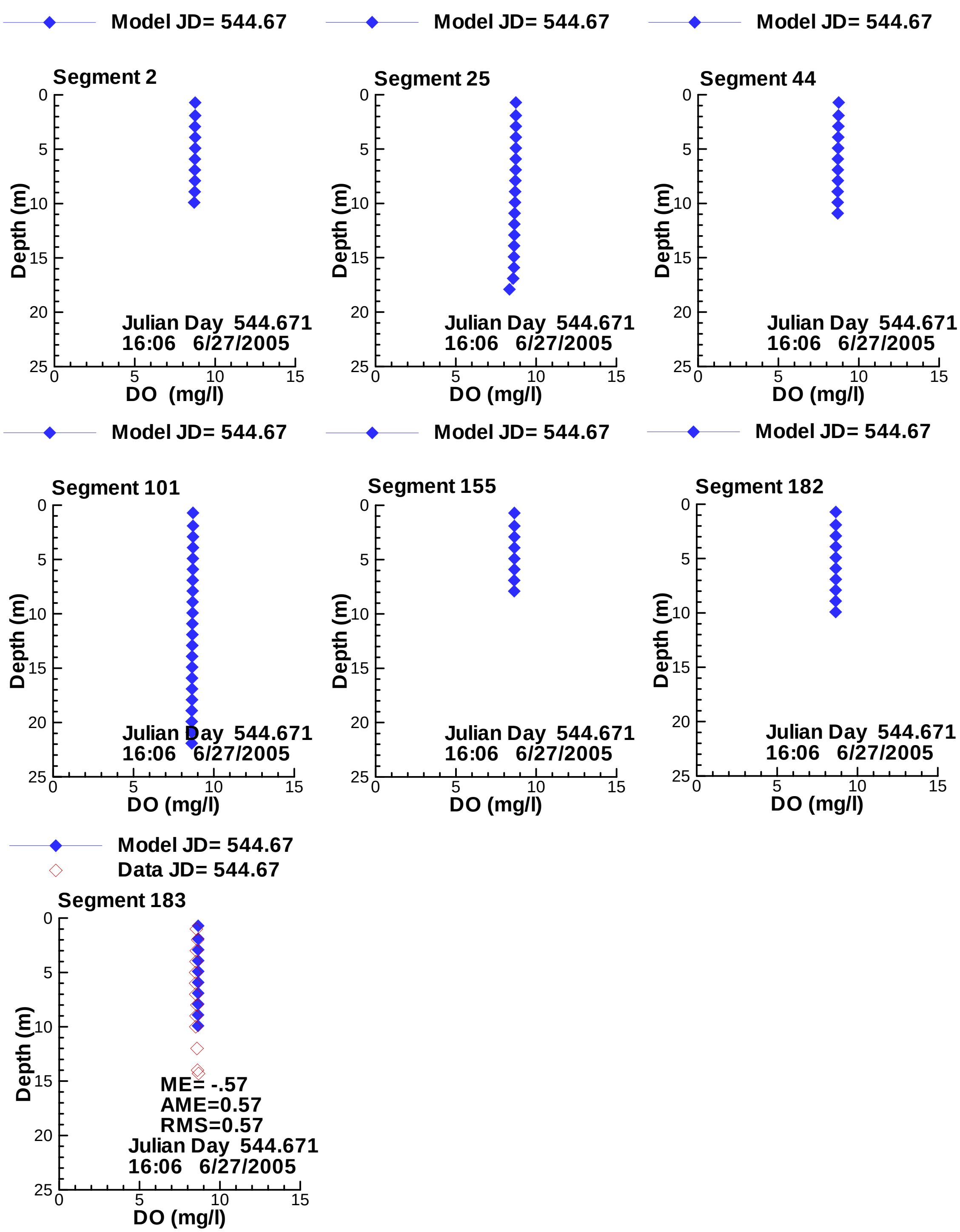


Figure 147: Vertical profiles of DISSOLVED OXYGEN compared with data for 6/27/2005 16:06.

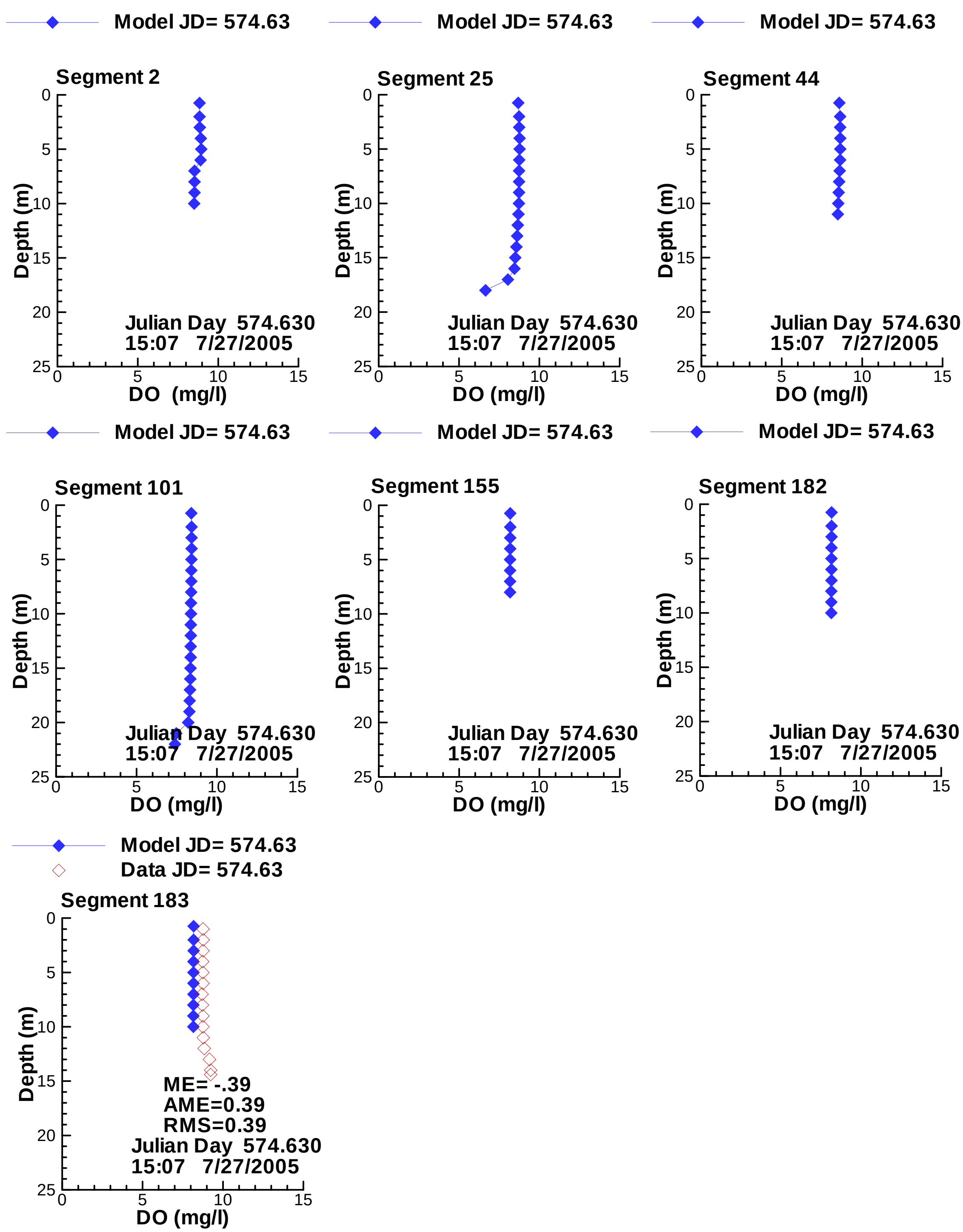


Figure 148: Vertical profiles of DISSOLVED OXYGEN compared with data for 7/27/2005 15:07.

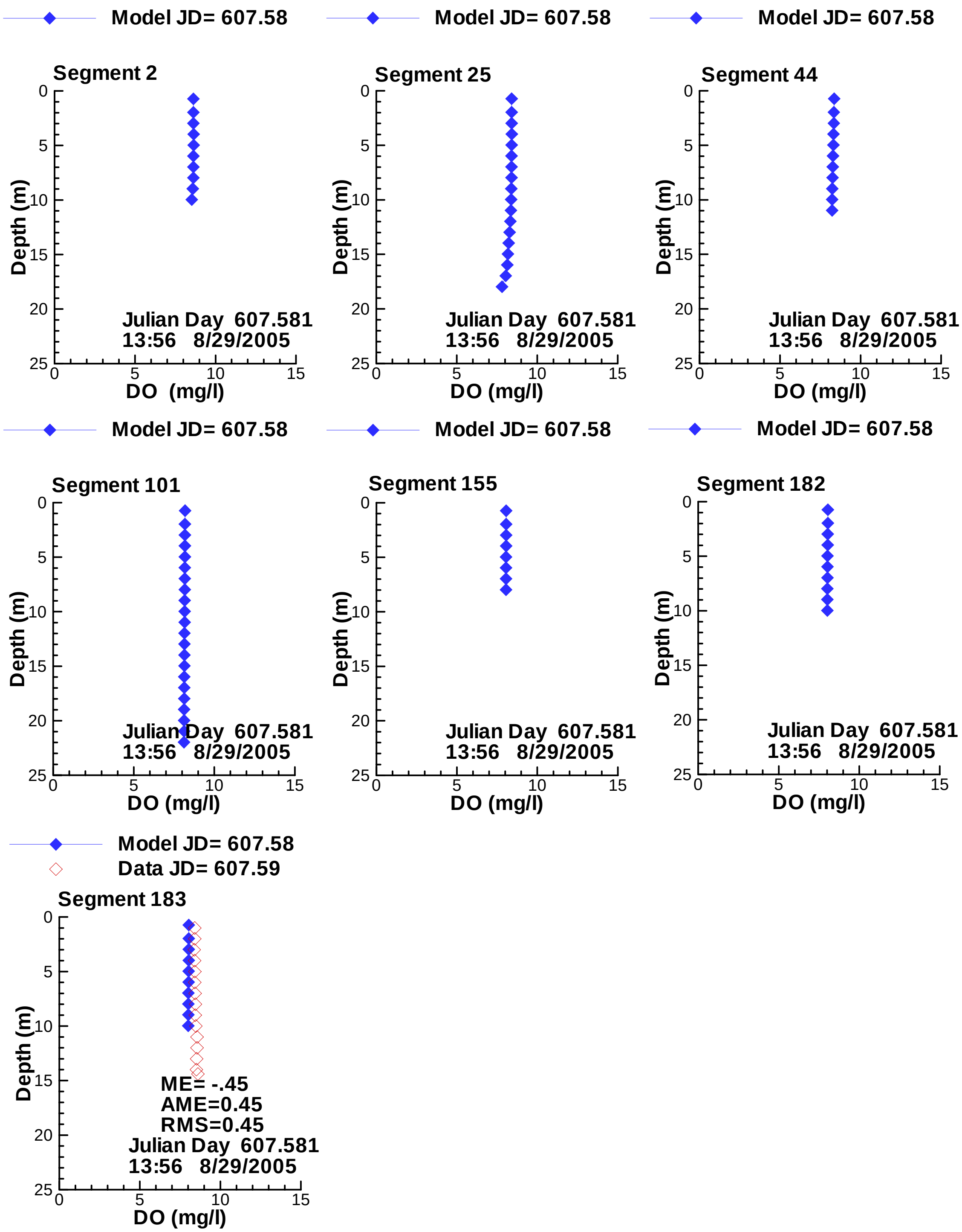


Figure 149: Vertical profiles of DISSOLVED OXYGEN compared with data for 8/29/2005 13:55.

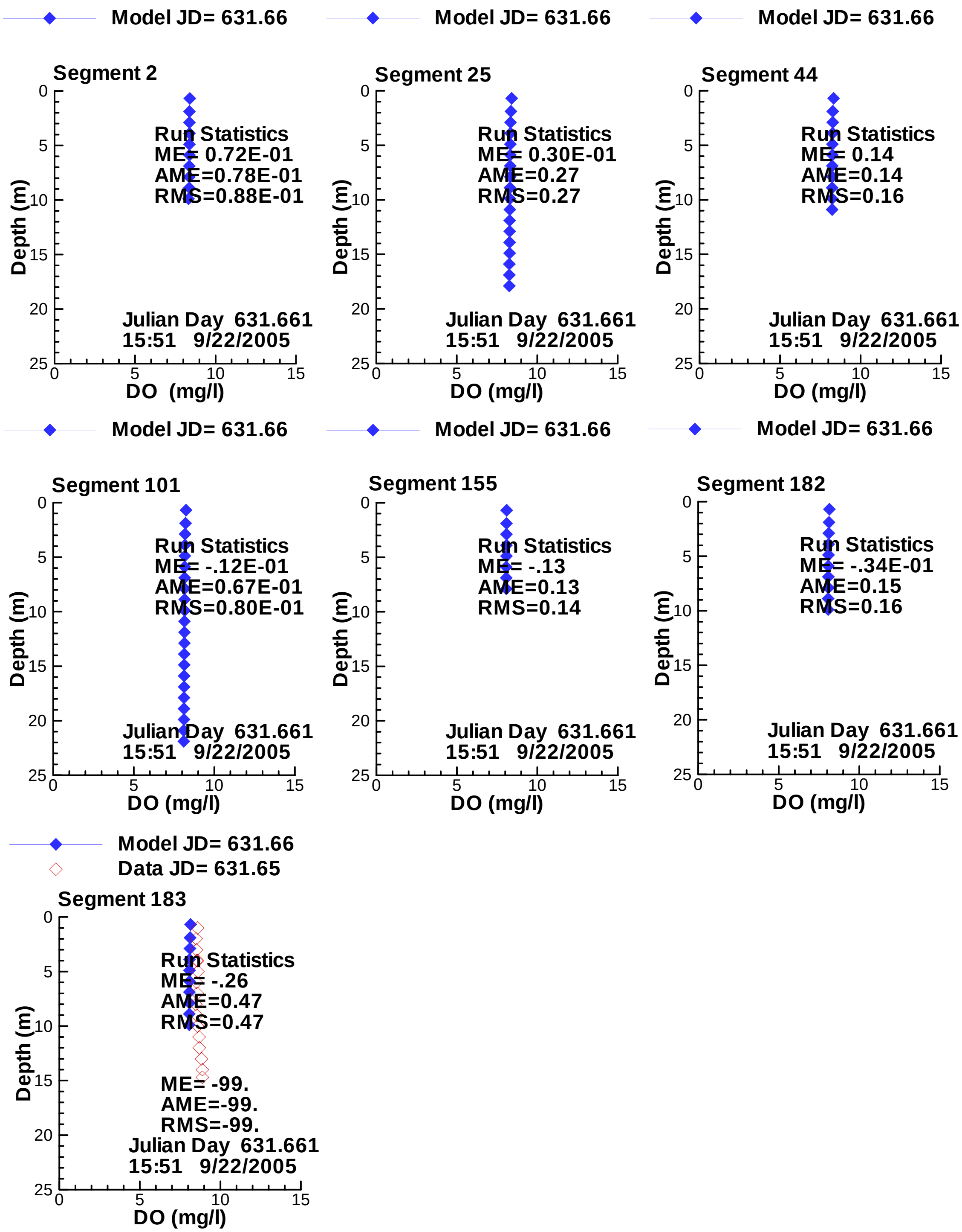


Figure 150: Vertical profiles of DISSOLVED OXYGEN compared with data for 9/22/2005 15:50.

pH

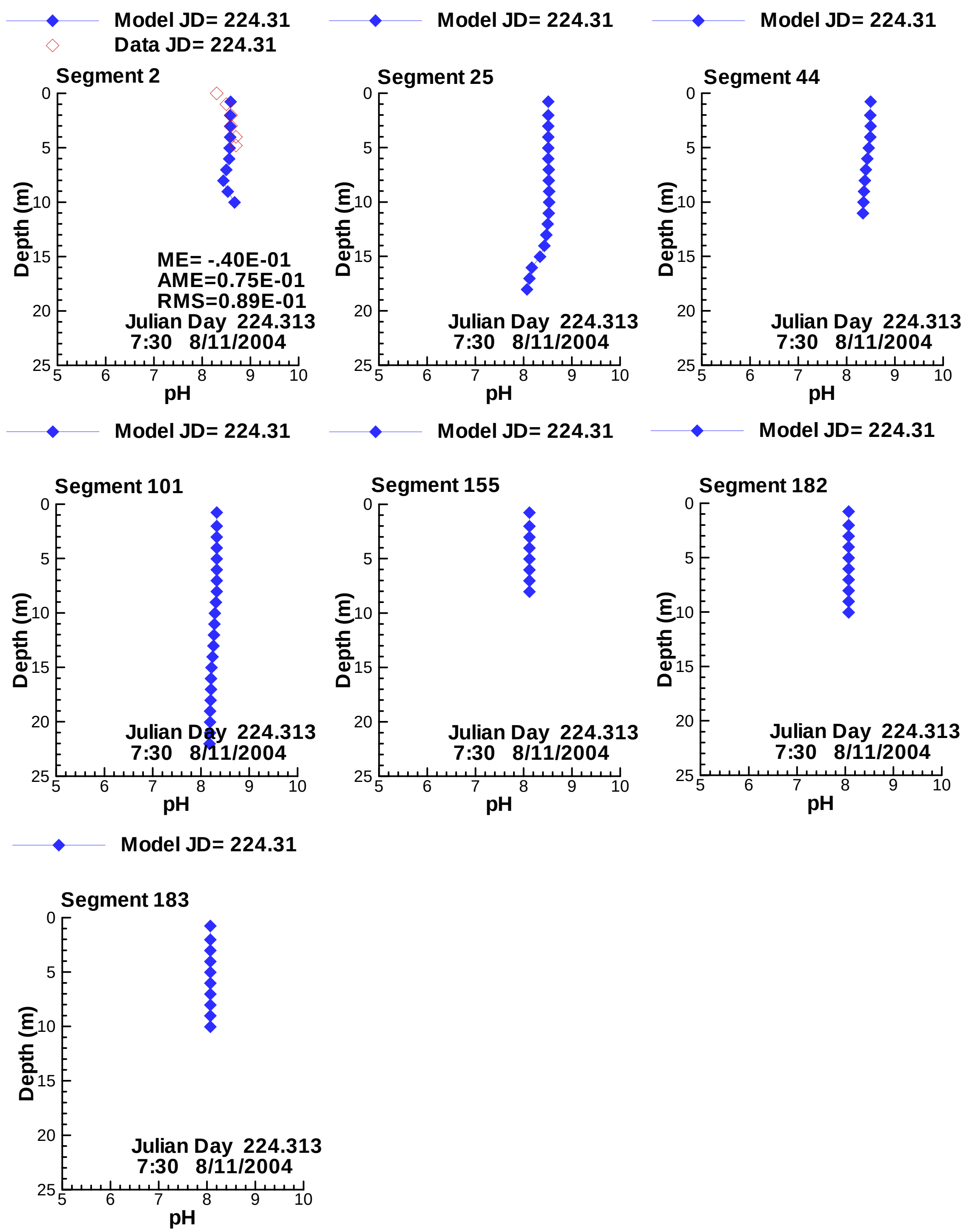


Figure 151: Vertical profiles of pH compared with data for 8/11/2004 7:30.

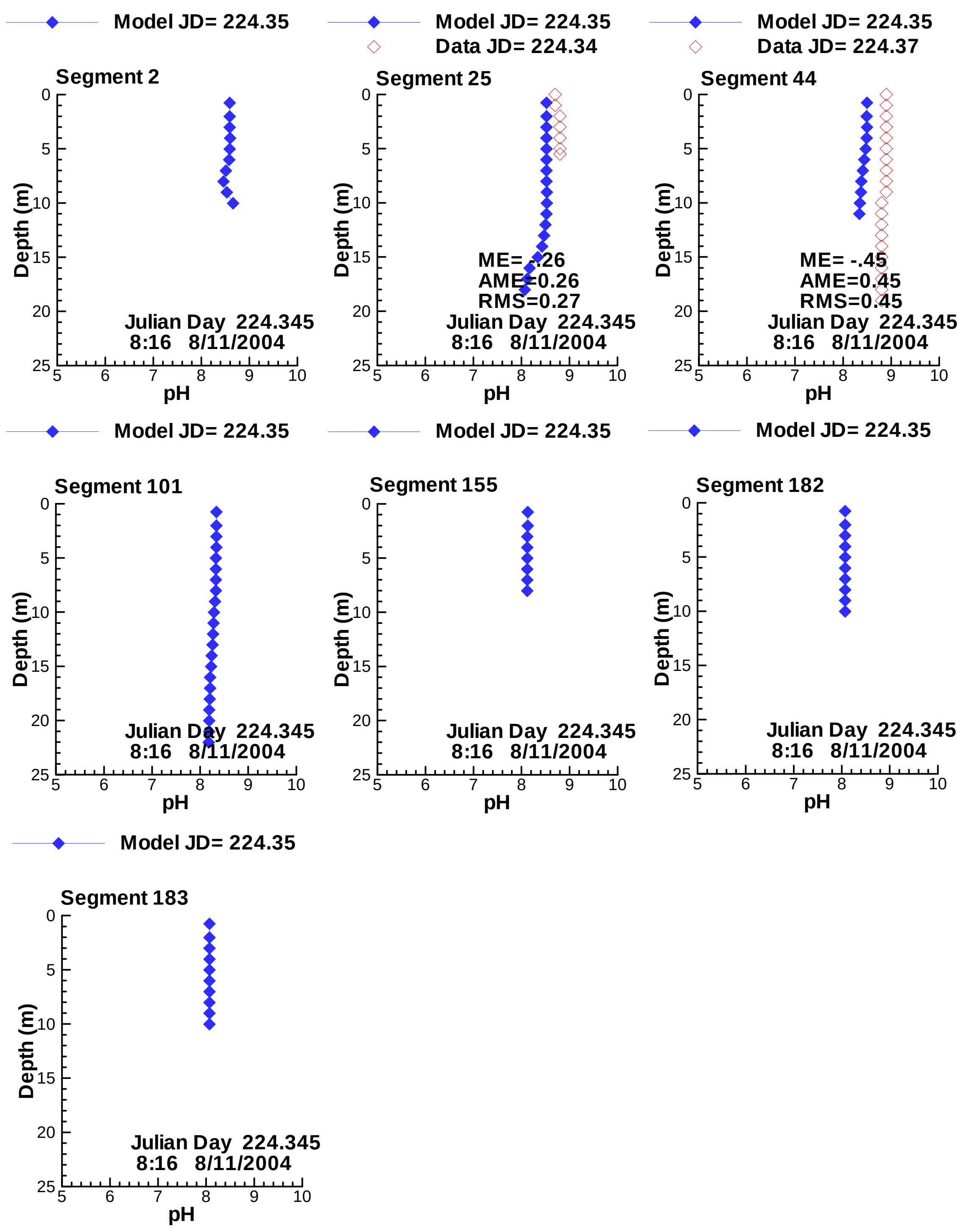


Figure 152: Vertical profiles of pH compared with data for 8/11/2004 8:16.

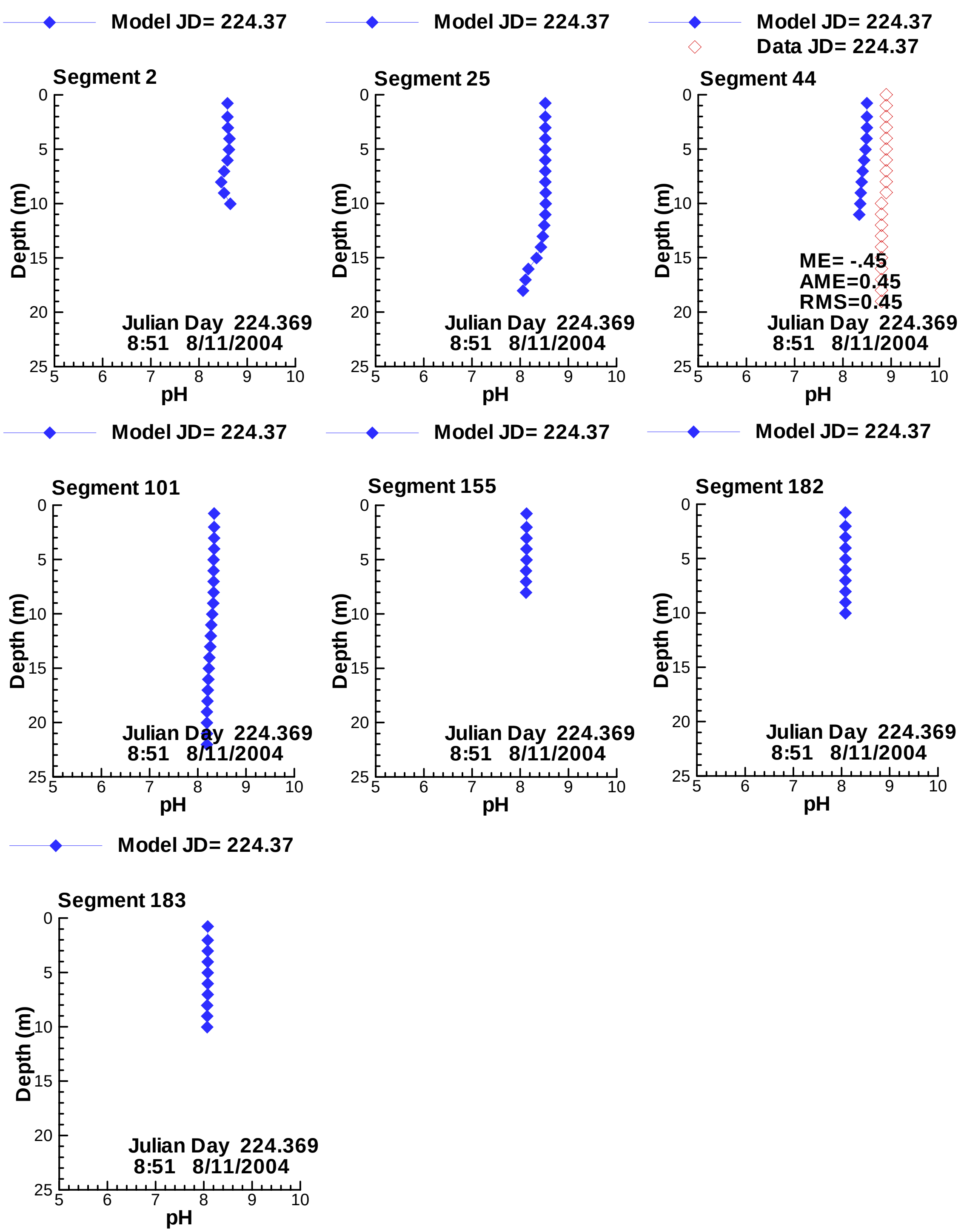


Figure 153: Vertical profiles of pH compared with data for 8/11/2004 8:51.

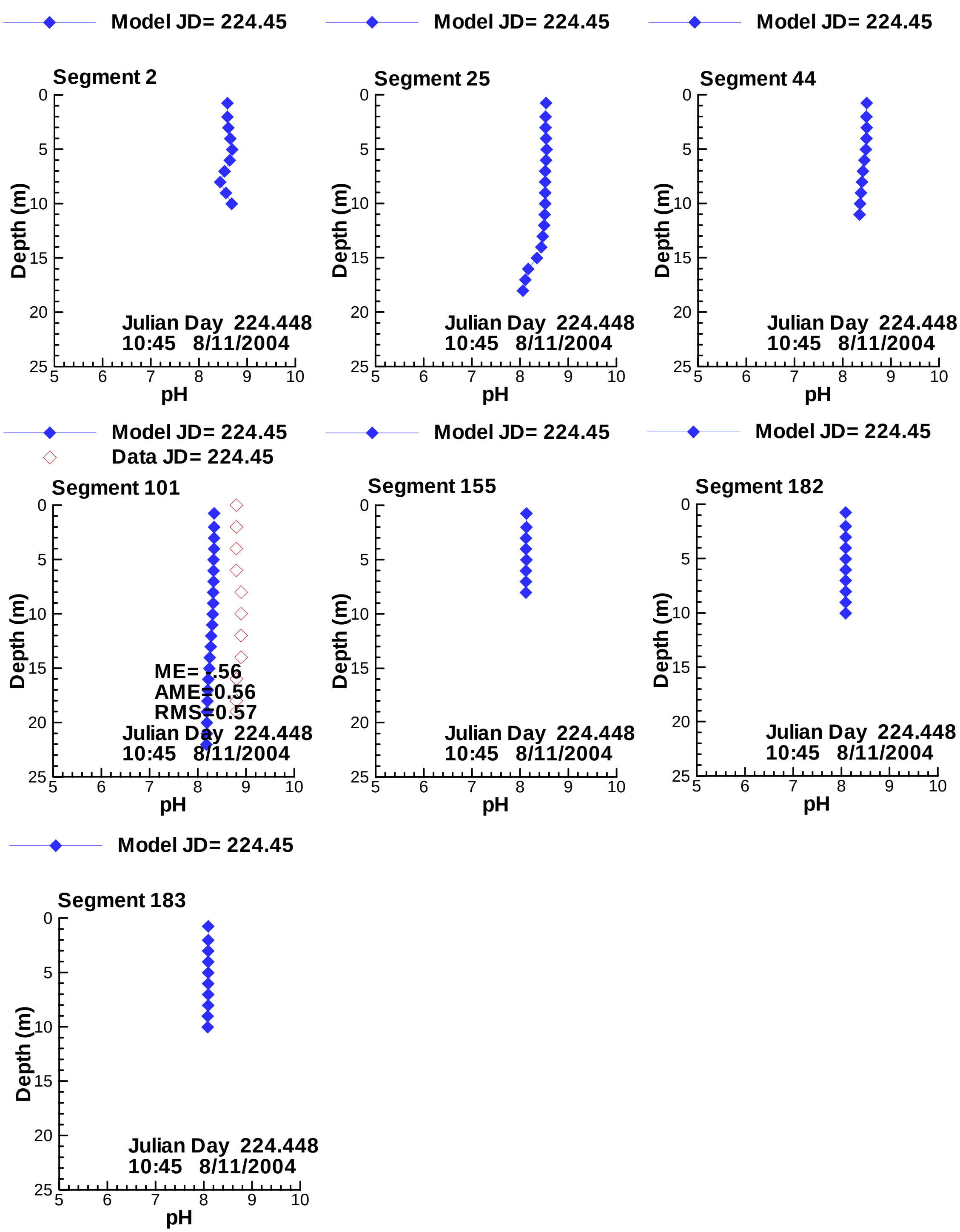


Figure 154: Vertical profiles of pH compared with data for 8/11/2004 10:46.

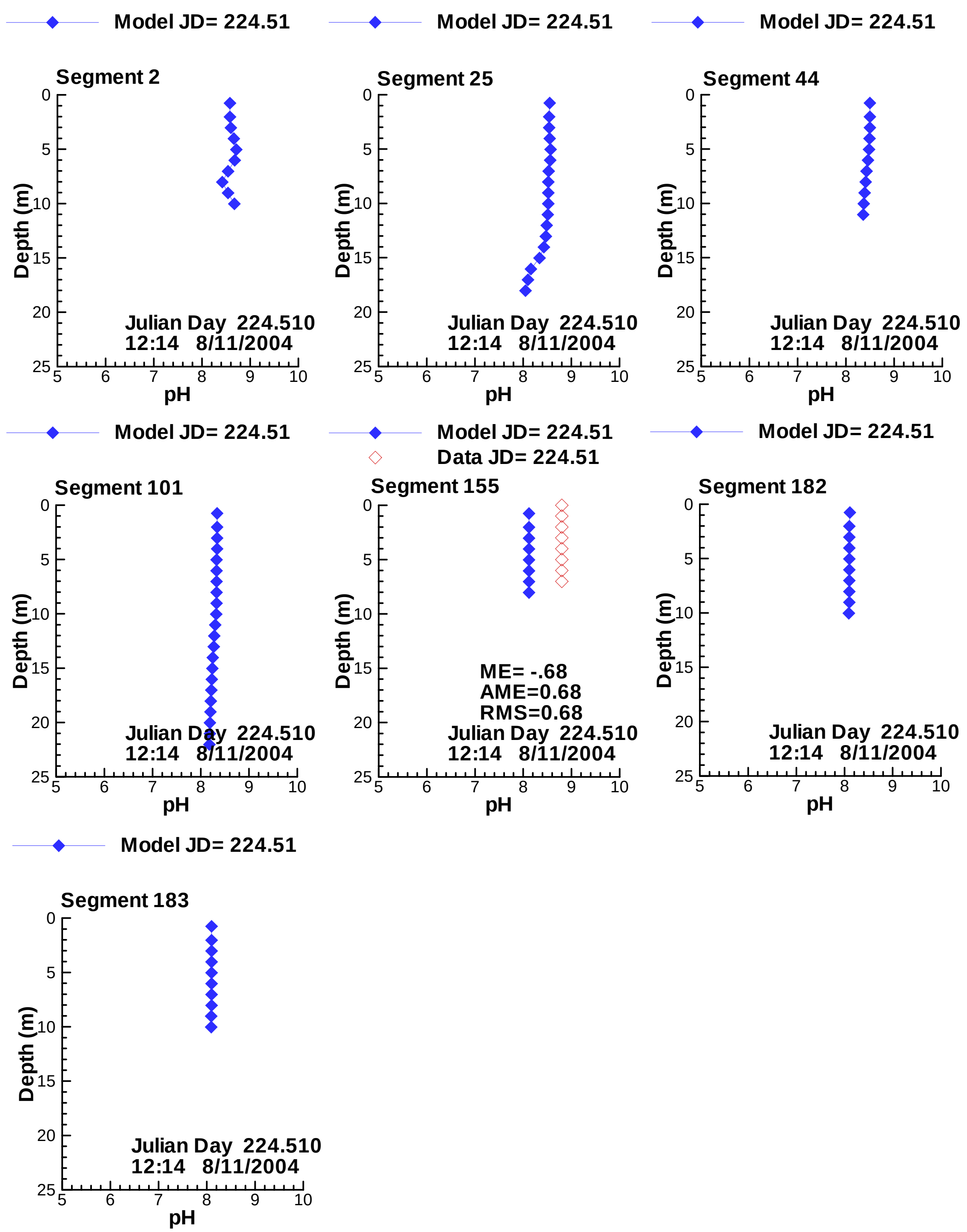


Figure 155: Vertical profiles of pH compared with data for 8/11/2004 12:14.

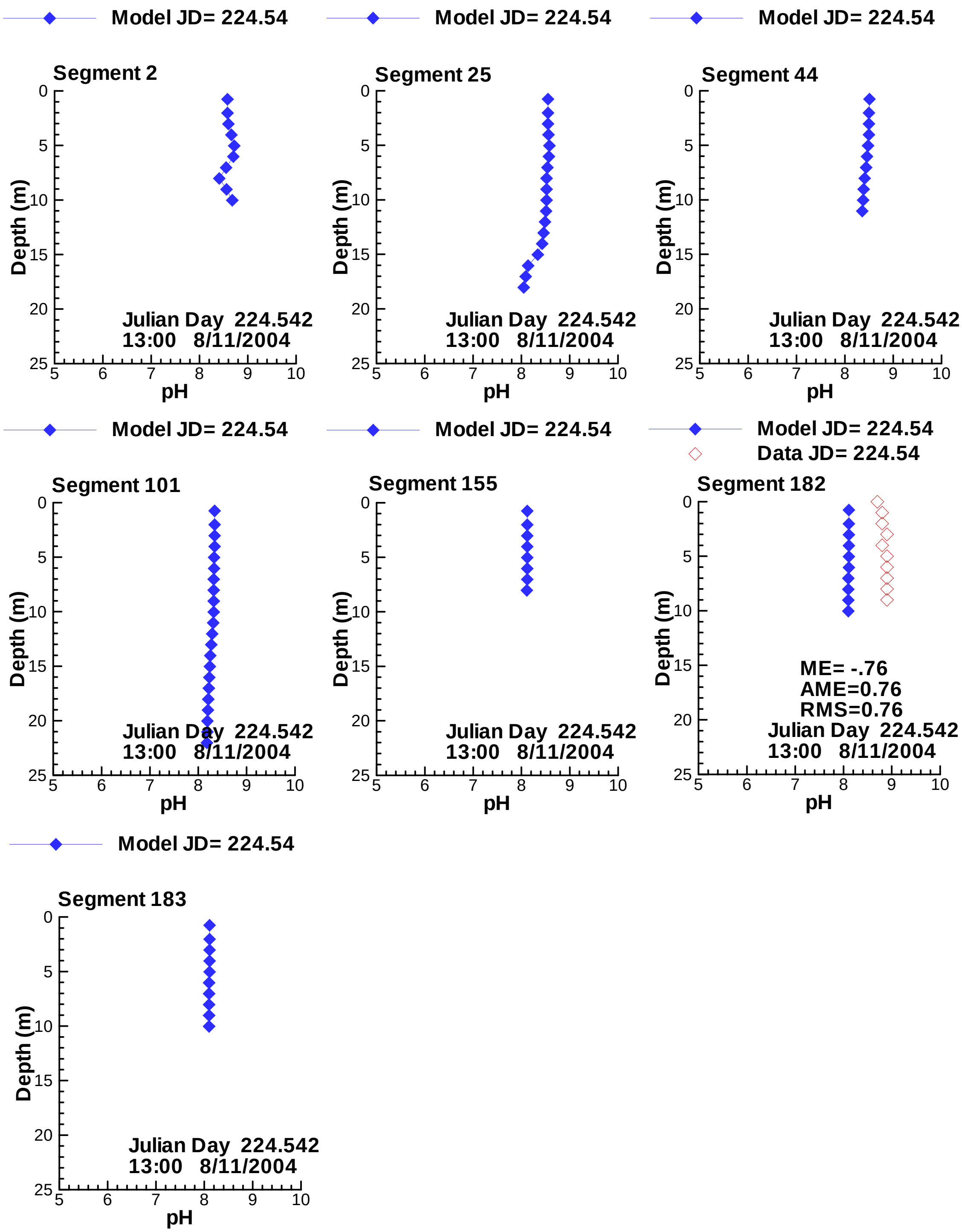


Figure 156: Vertical profiles of pH compared with data for 8/11/2004 13:00.

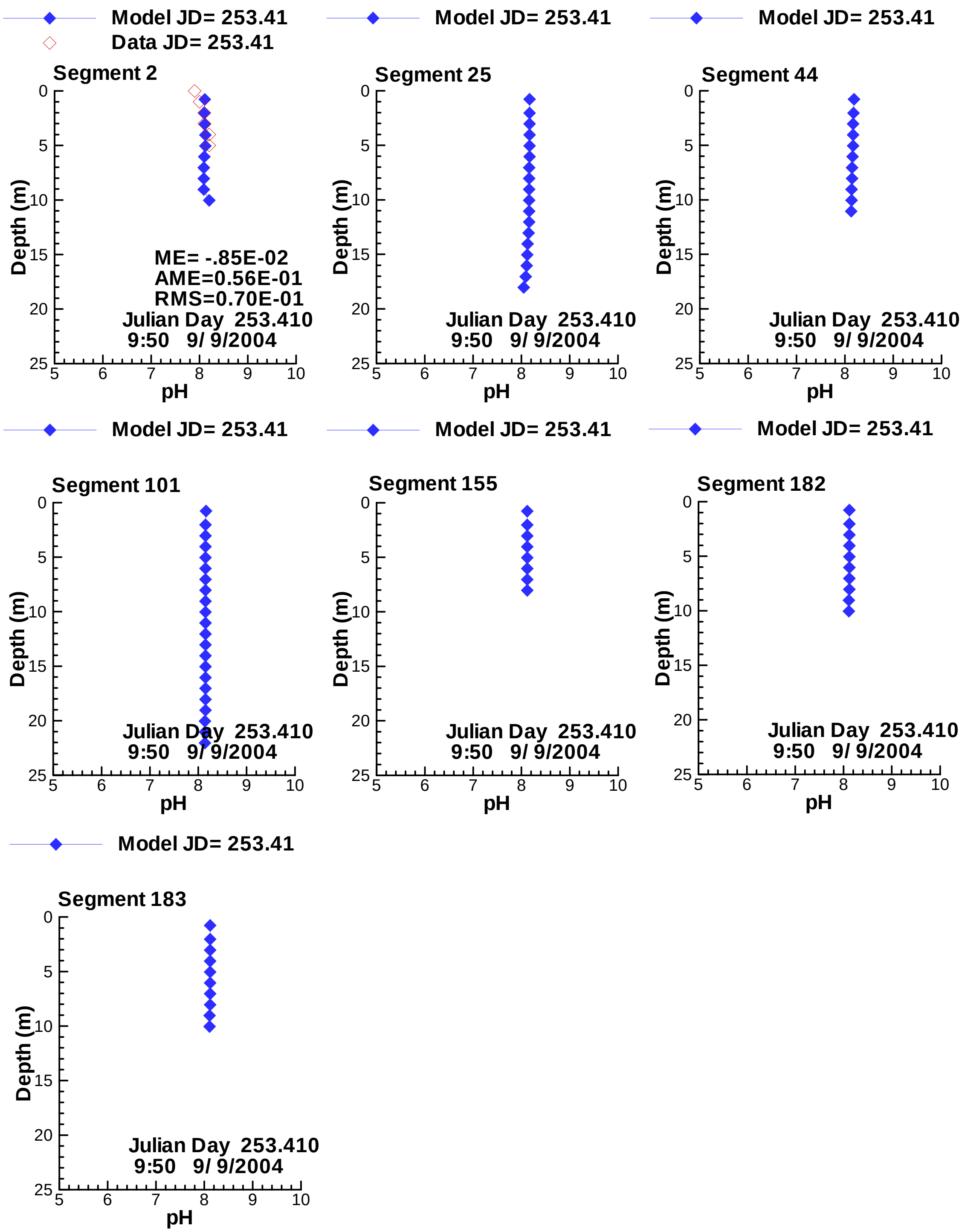


Figure 157: Vertical profiles of pH compared with data for 9/ 9/2004 9:50.

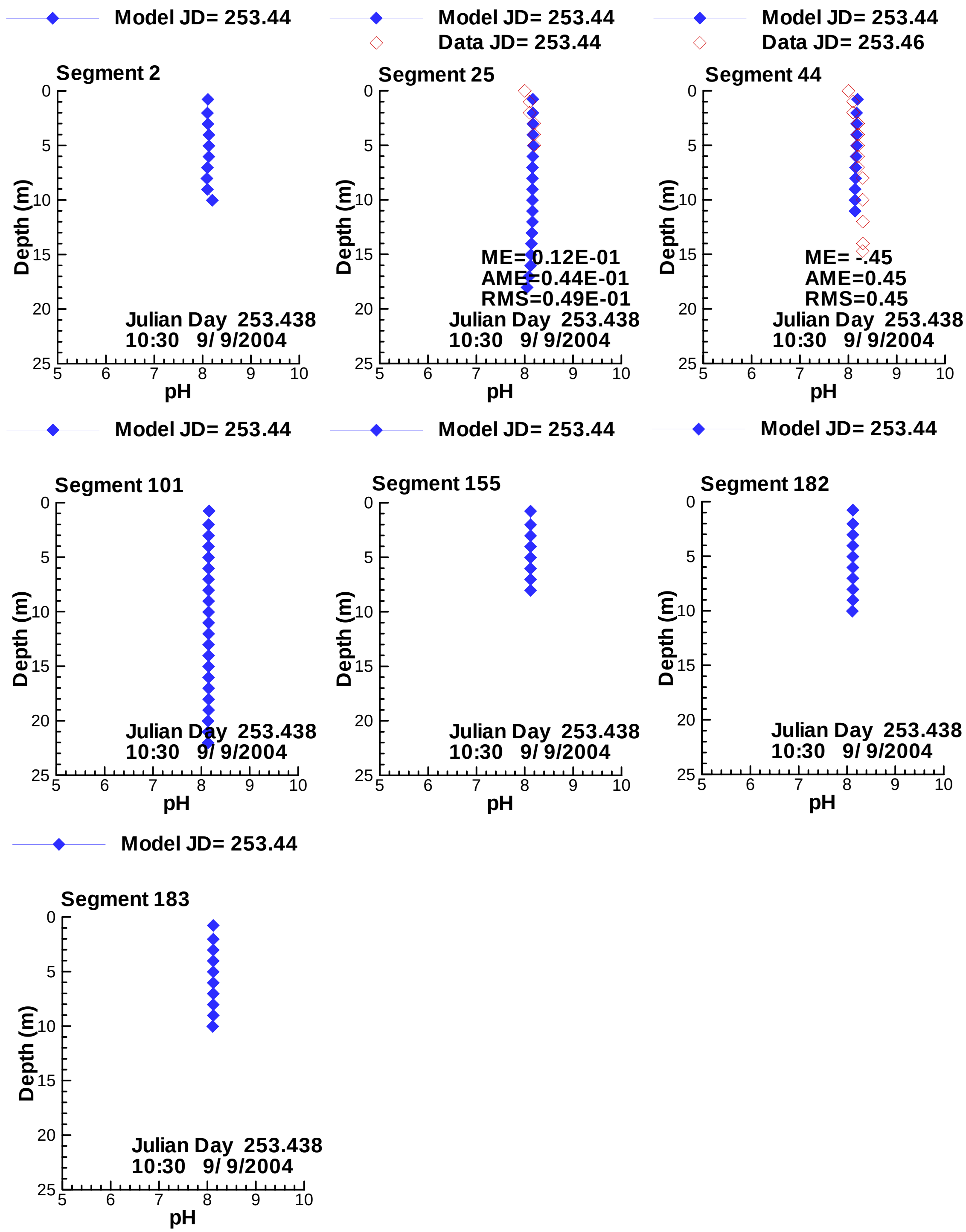


Figure 158: Vertical profiles of pH compared with data for 9/ 9/2004 10:30.

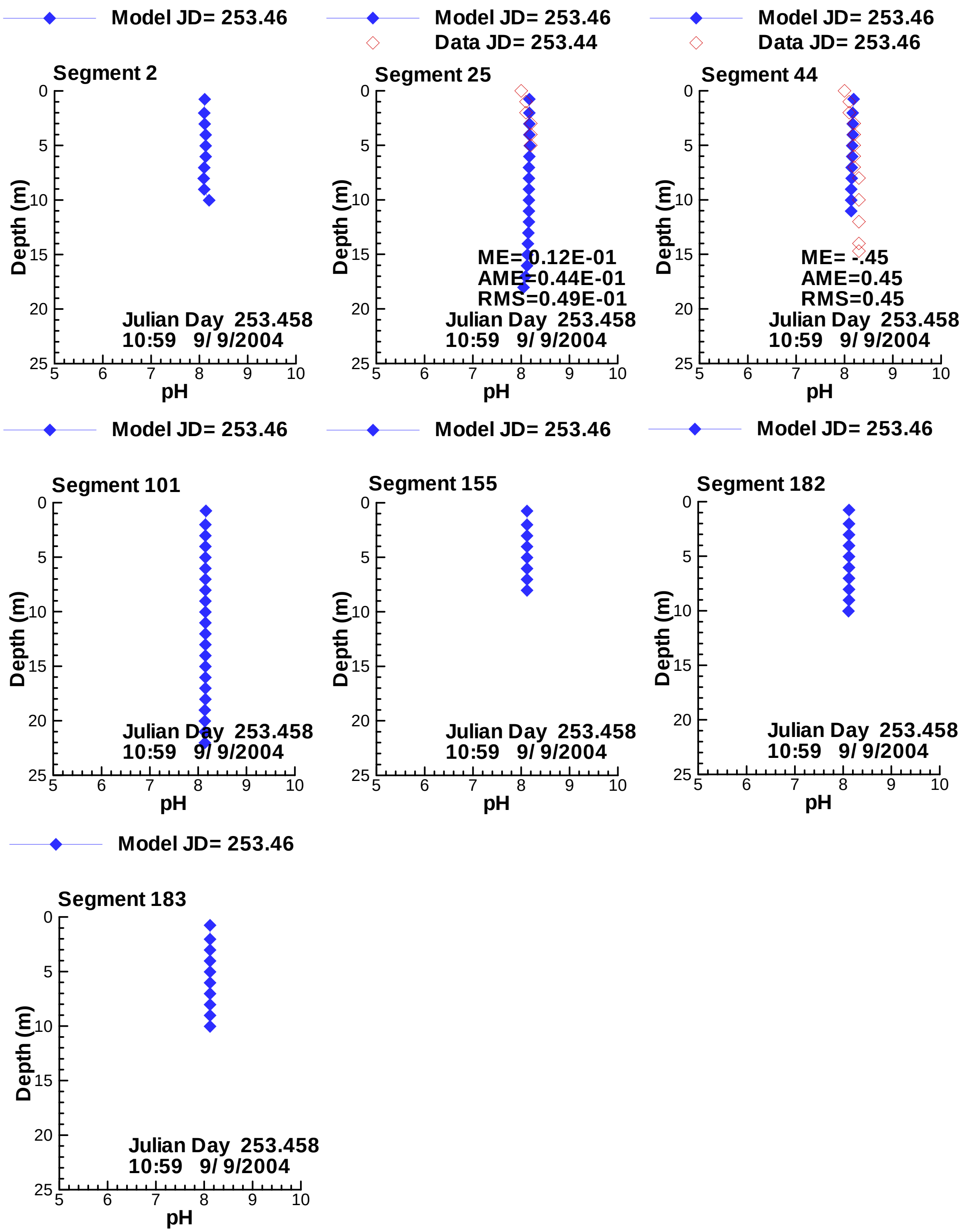


Figure 159: Vertical profiles of pH compared with data for 9/ 9/2004 10:59.

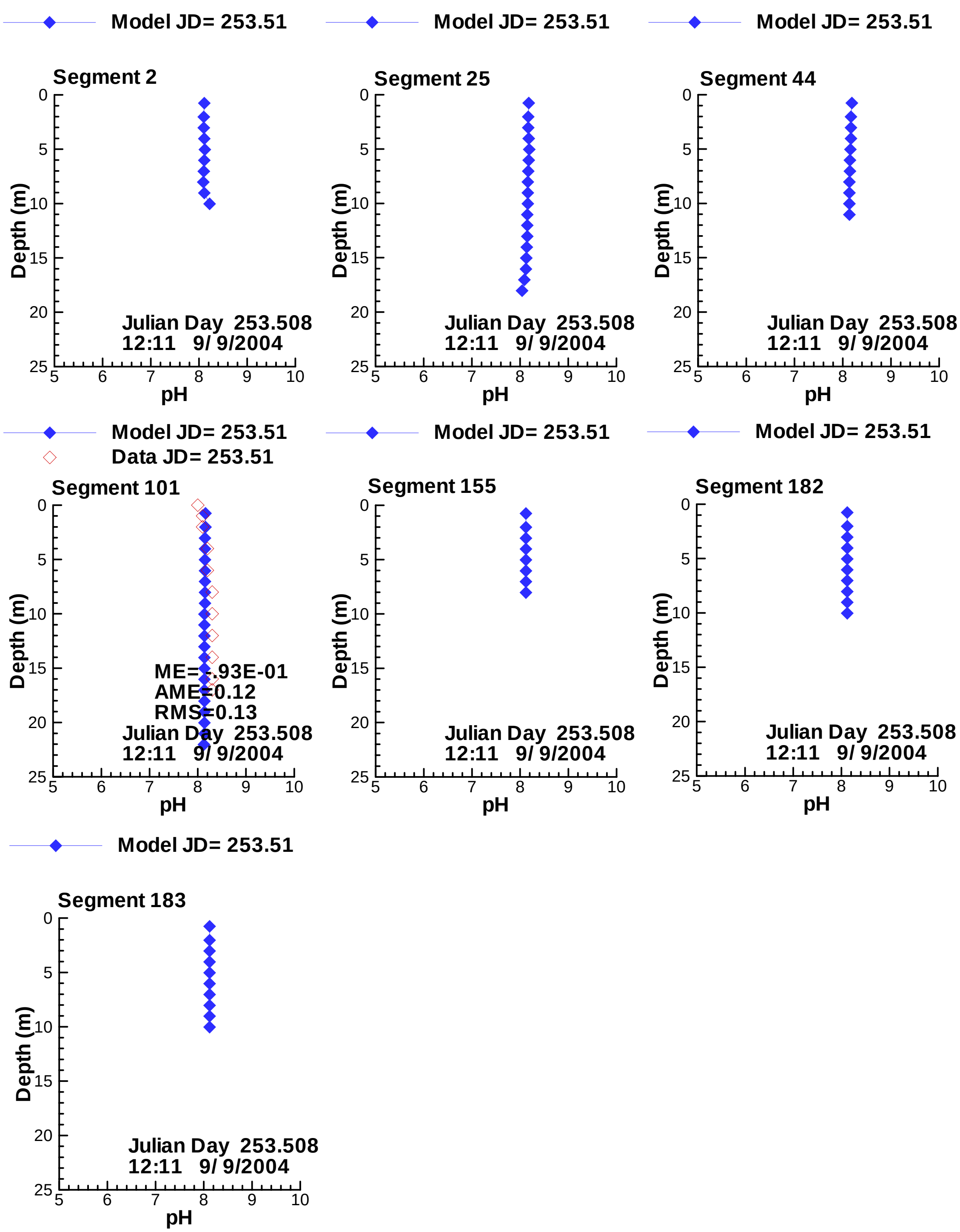


Figure 160: Vertical profiles of pH compared with data for 9/ 9/2004 12:11.

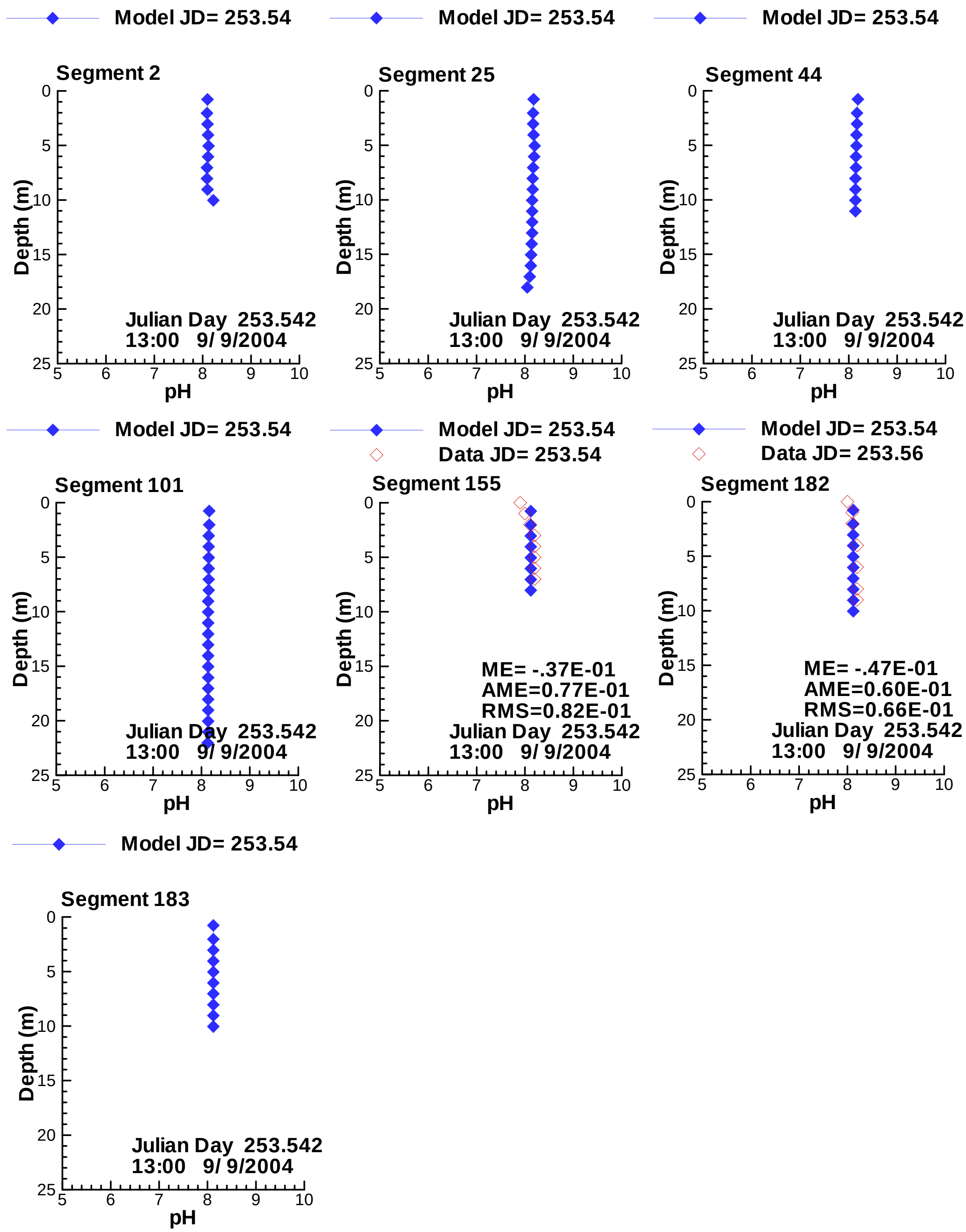


Figure 161: Vertical profiles of pH compared with data for 9/ 9/2004 13:00.

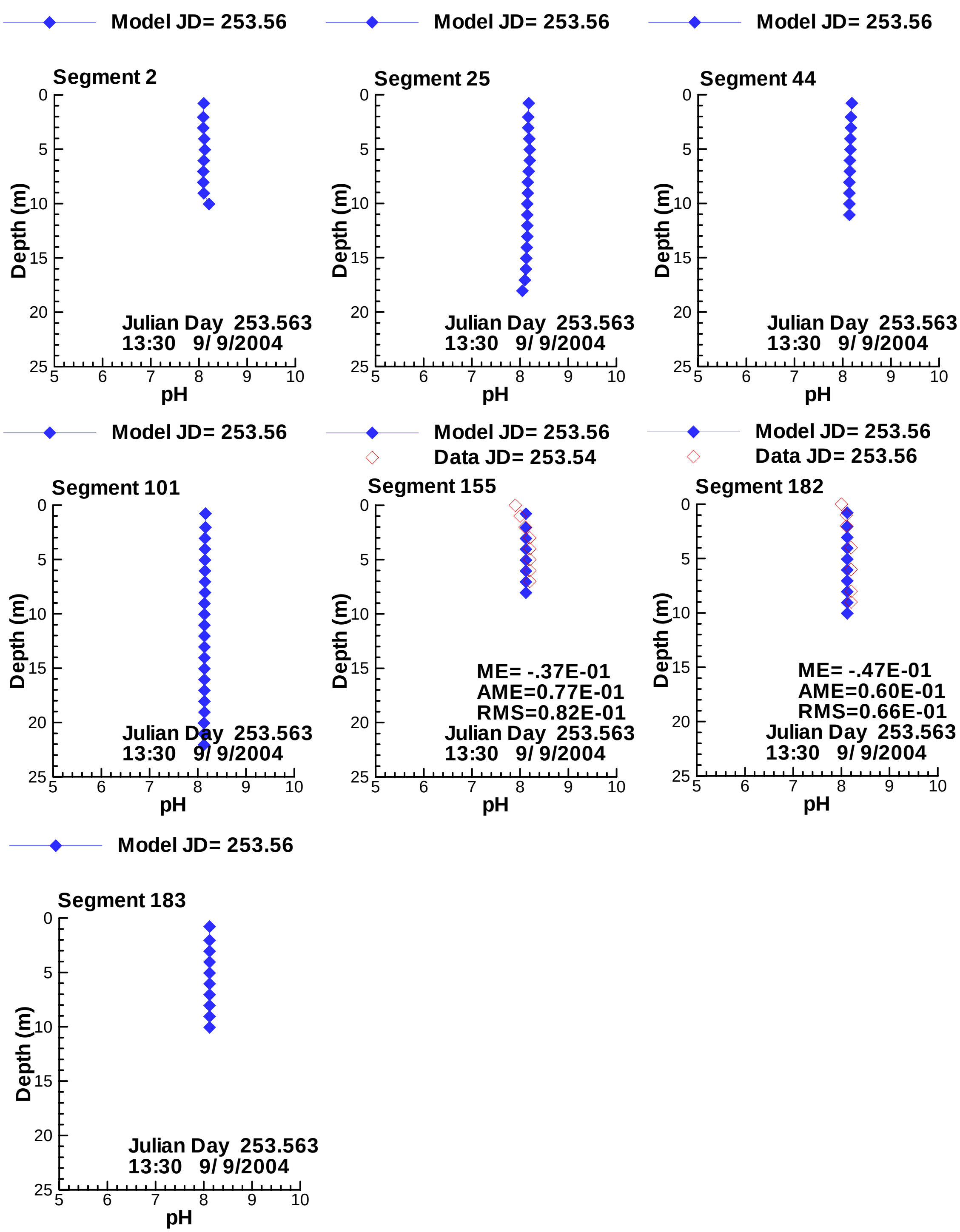


Figure 162: Vertical profiles of pH compared with data for 9/ 9/2004 13:30.

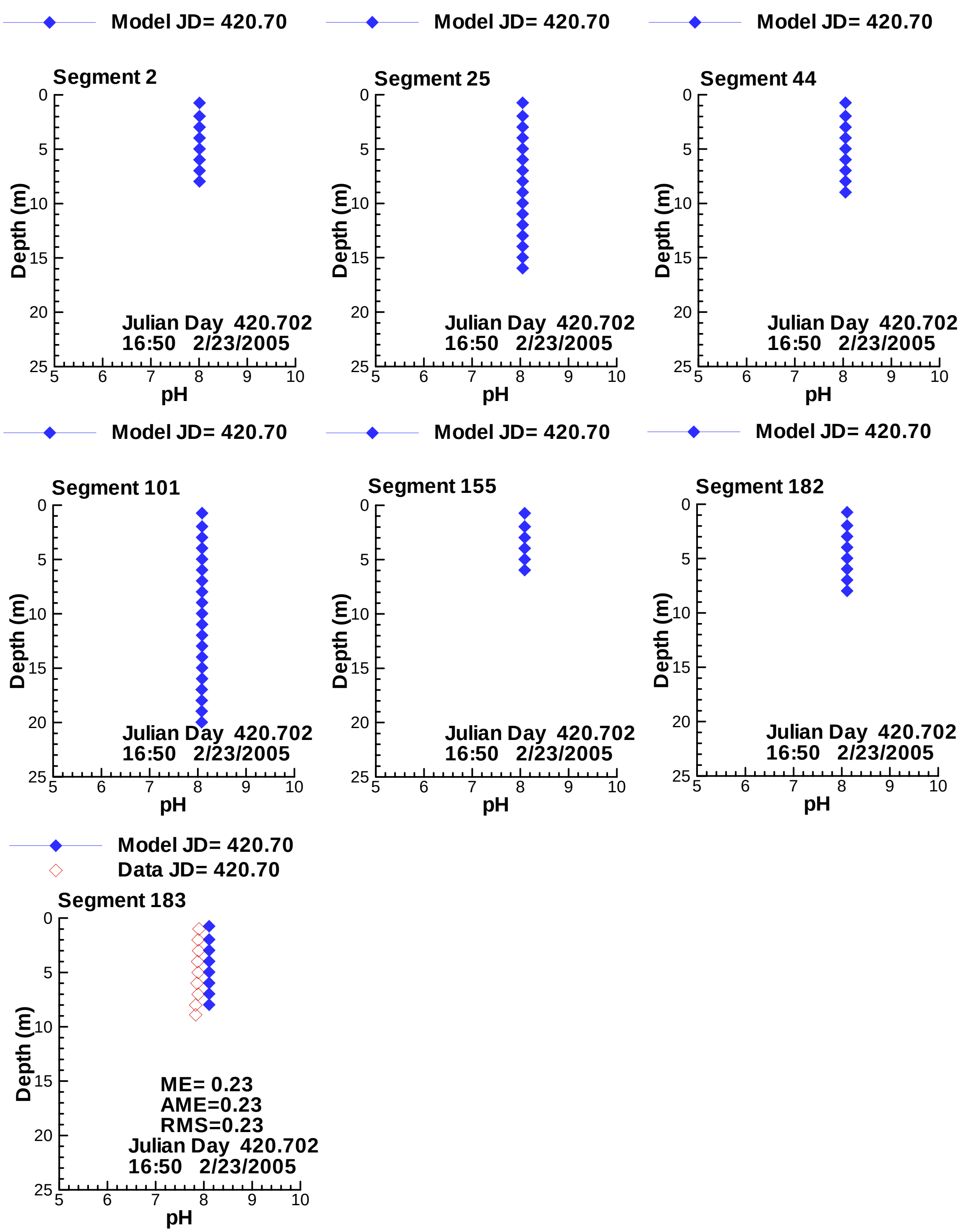


Figure 163: Vertical profiles of pH compared with data for 2/23/2005 16:50.

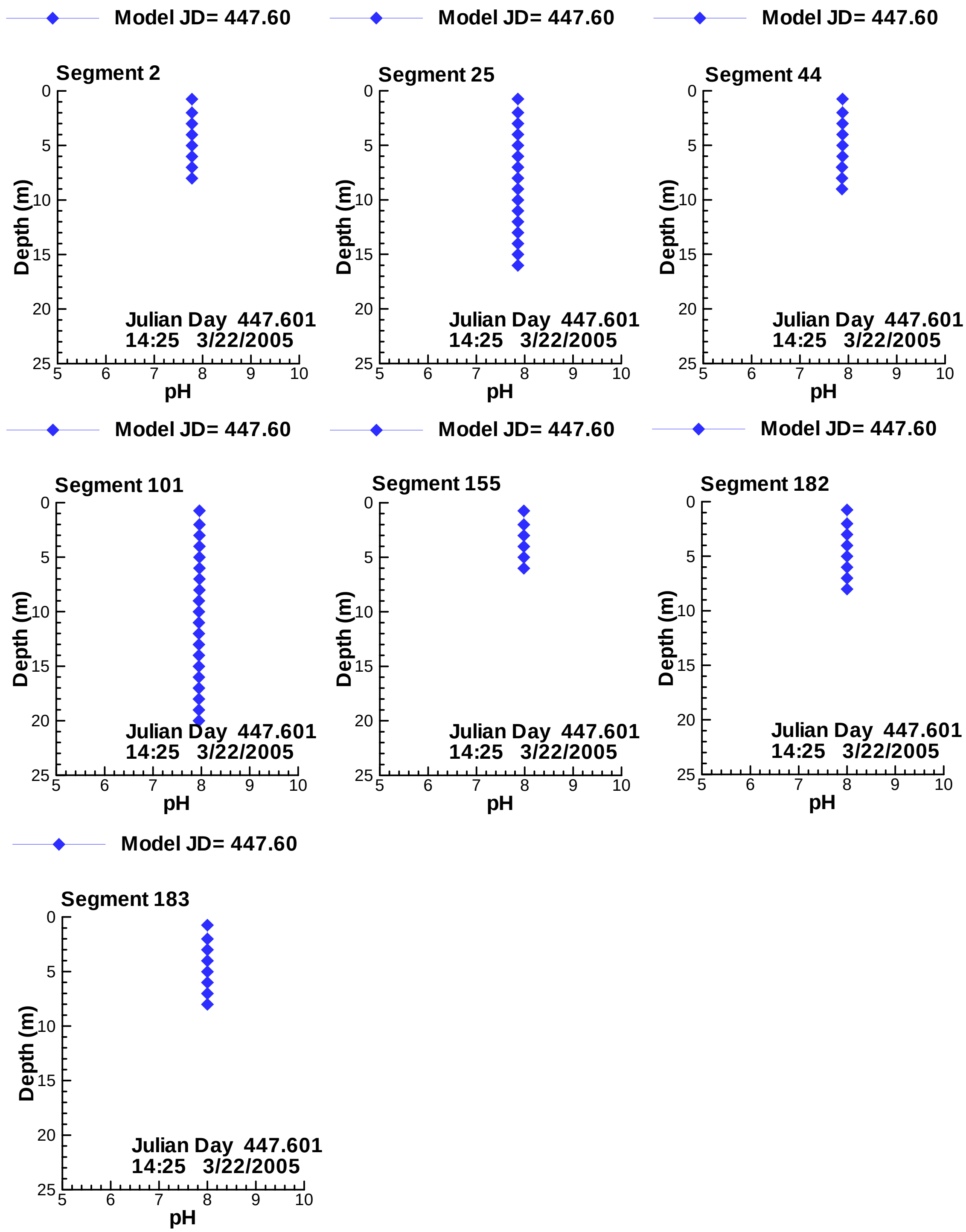


Figure 164: Vertical profiles of pH compared with data for 3/24/2005 16:33.

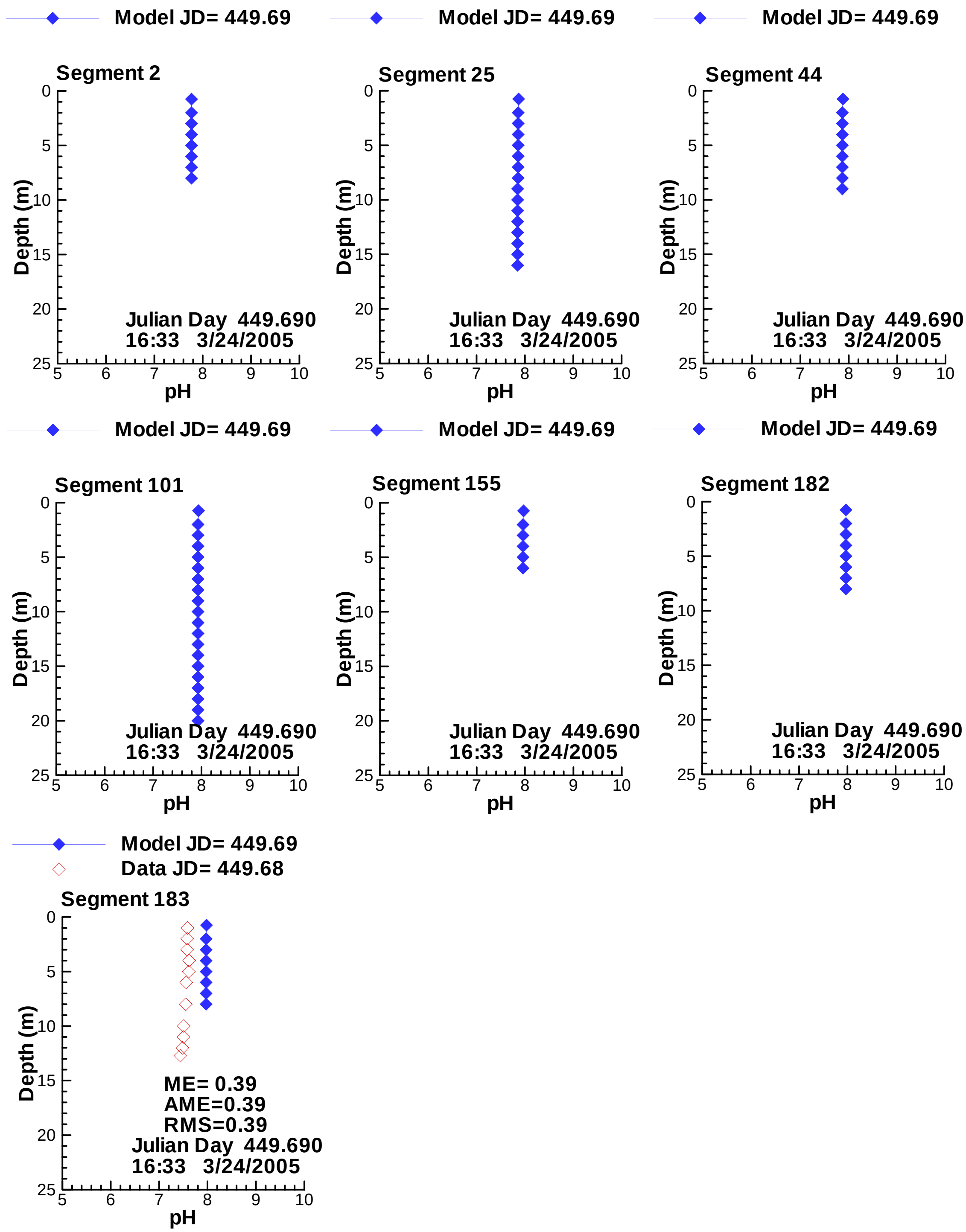


Figure 165: Vertical profiles of pH compared with data for 3/24/2005 16:36.

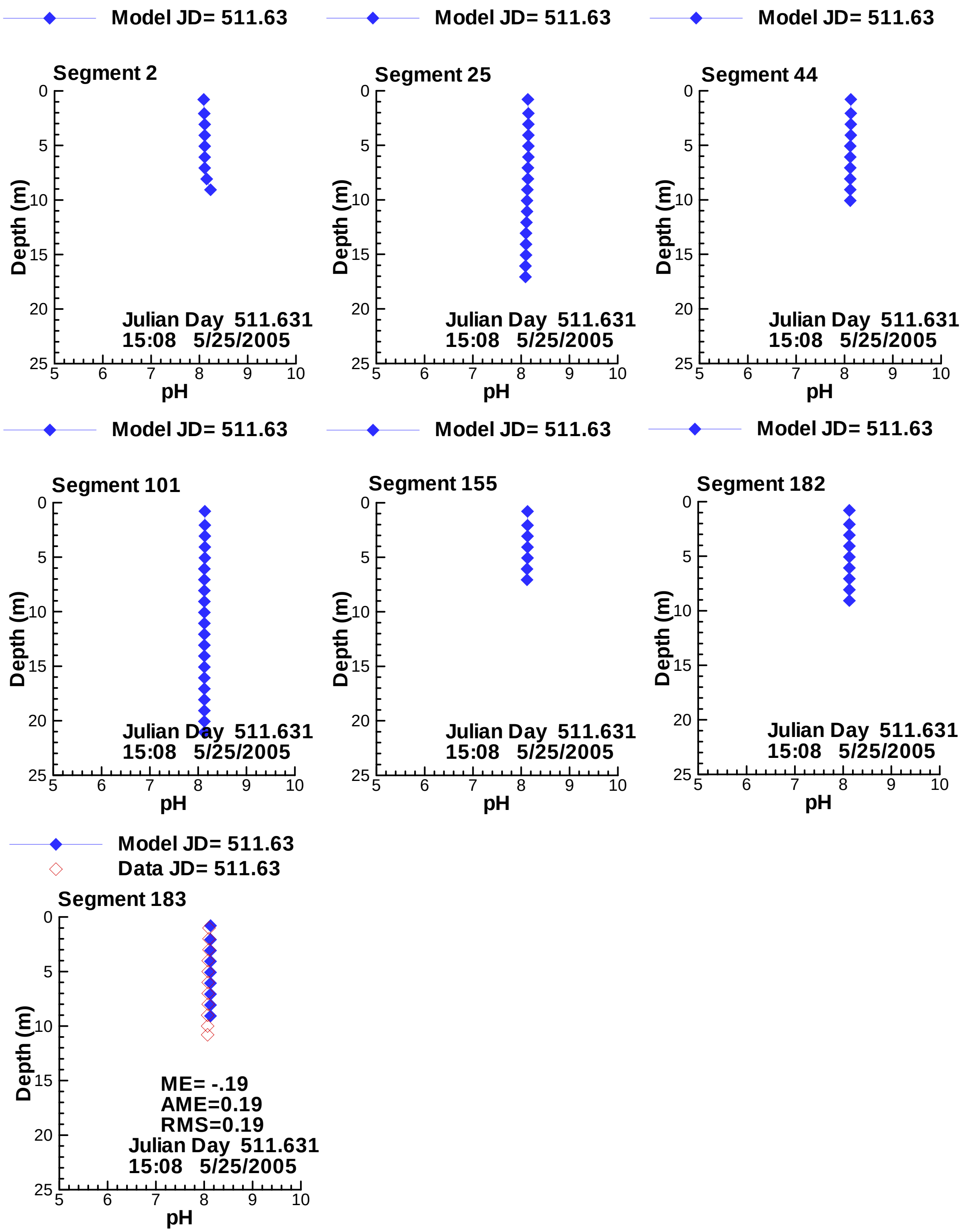


Figure 166: Vertical profiles of pH compared with data for 5/25/2005 15:08.

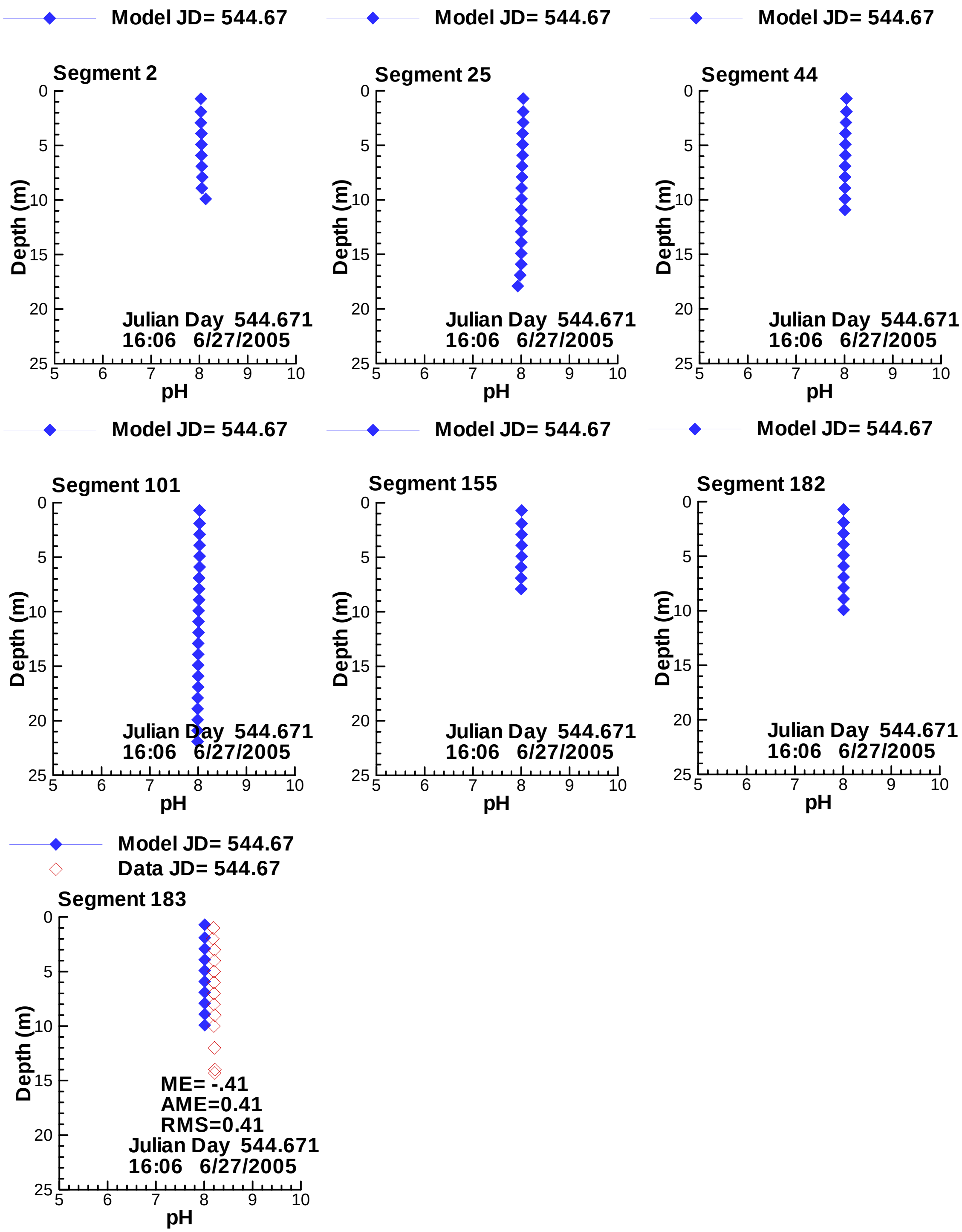


Figure 167: Vertical profiles of pH compared with data for 6/27/2005 16:06.

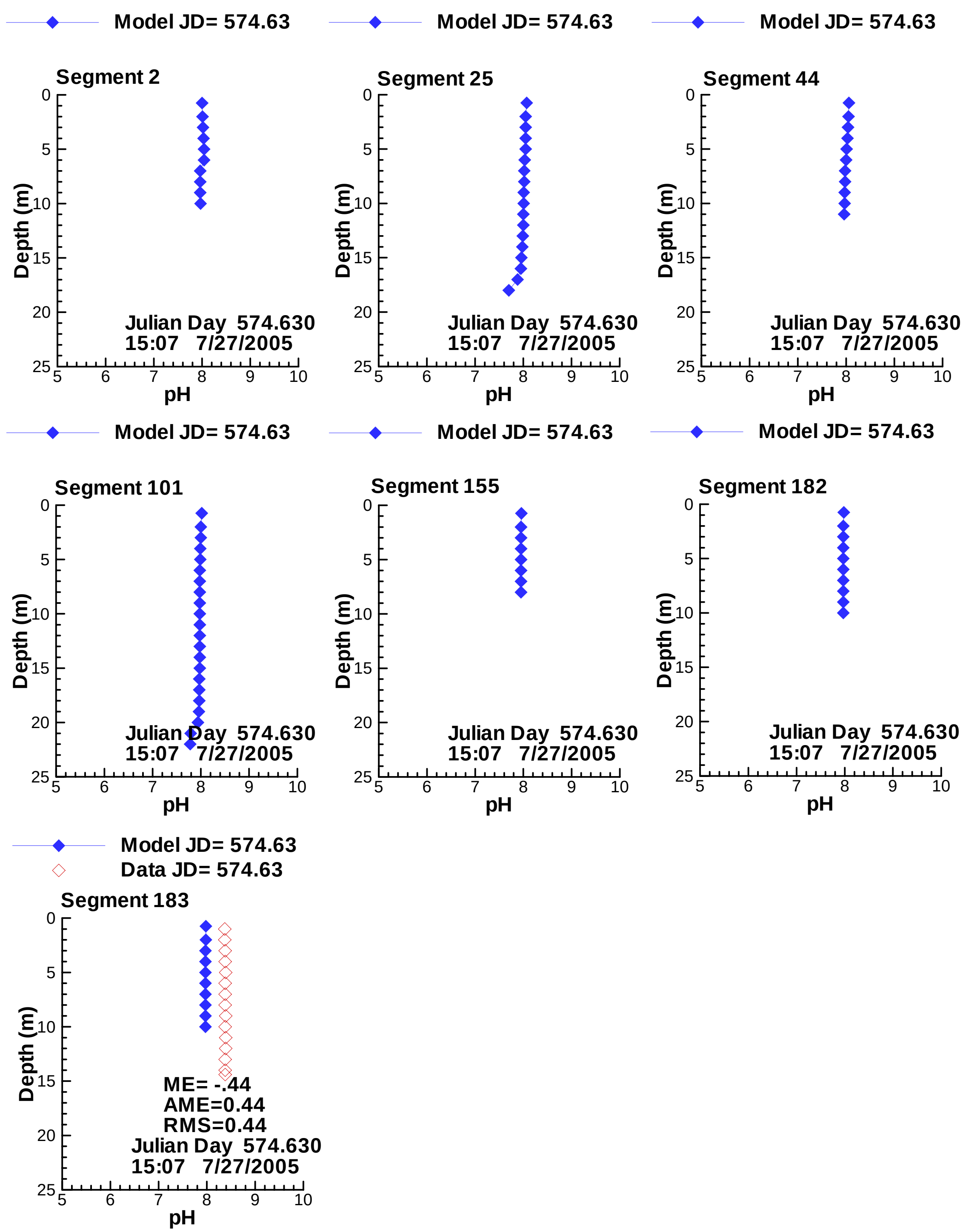


Figure 168: Vertical profiles of pH compared with data for 7/27/2005 15:07.

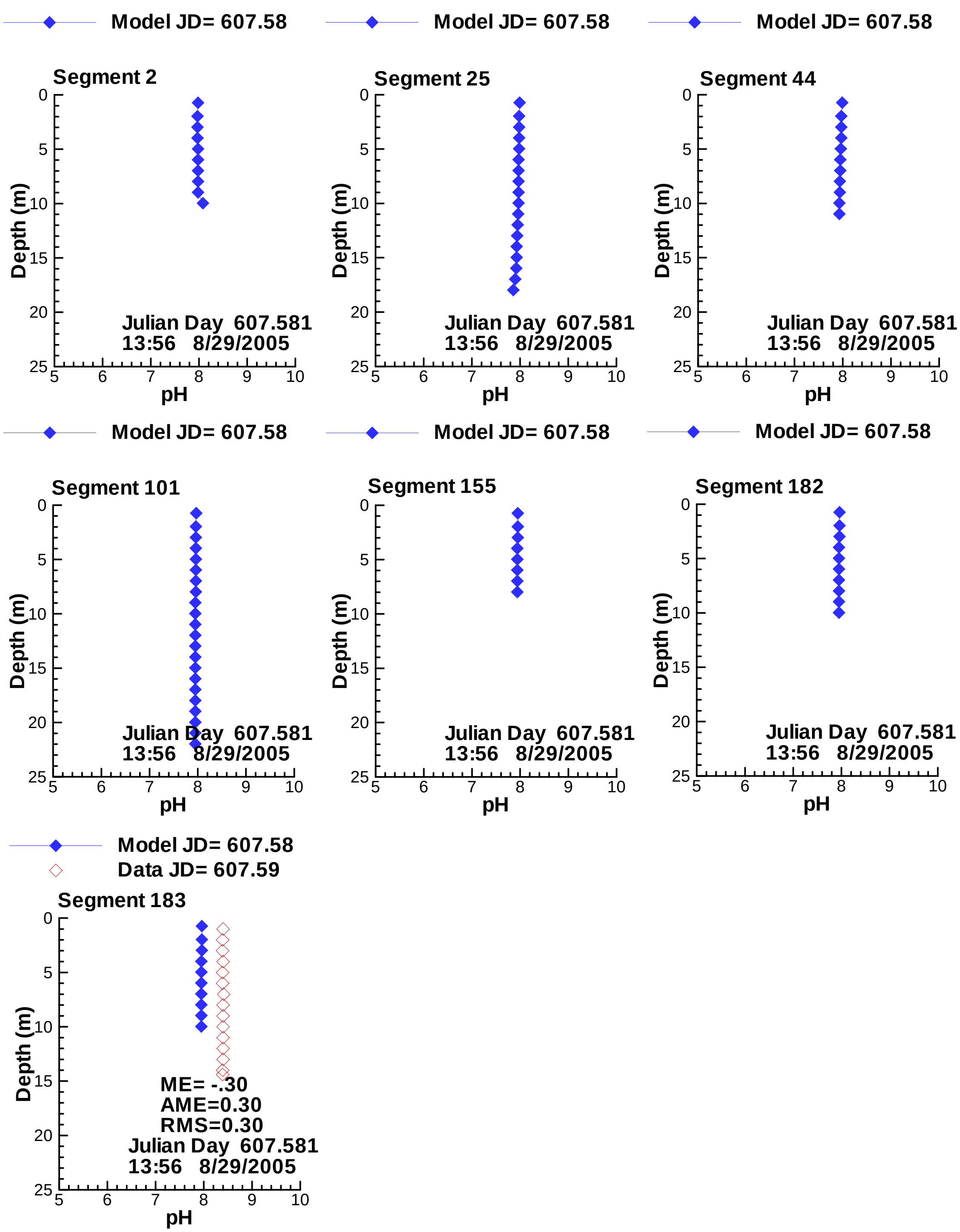


Figure 169: Vertical profiles of pH compared with data for 8/29/2005 13:55.

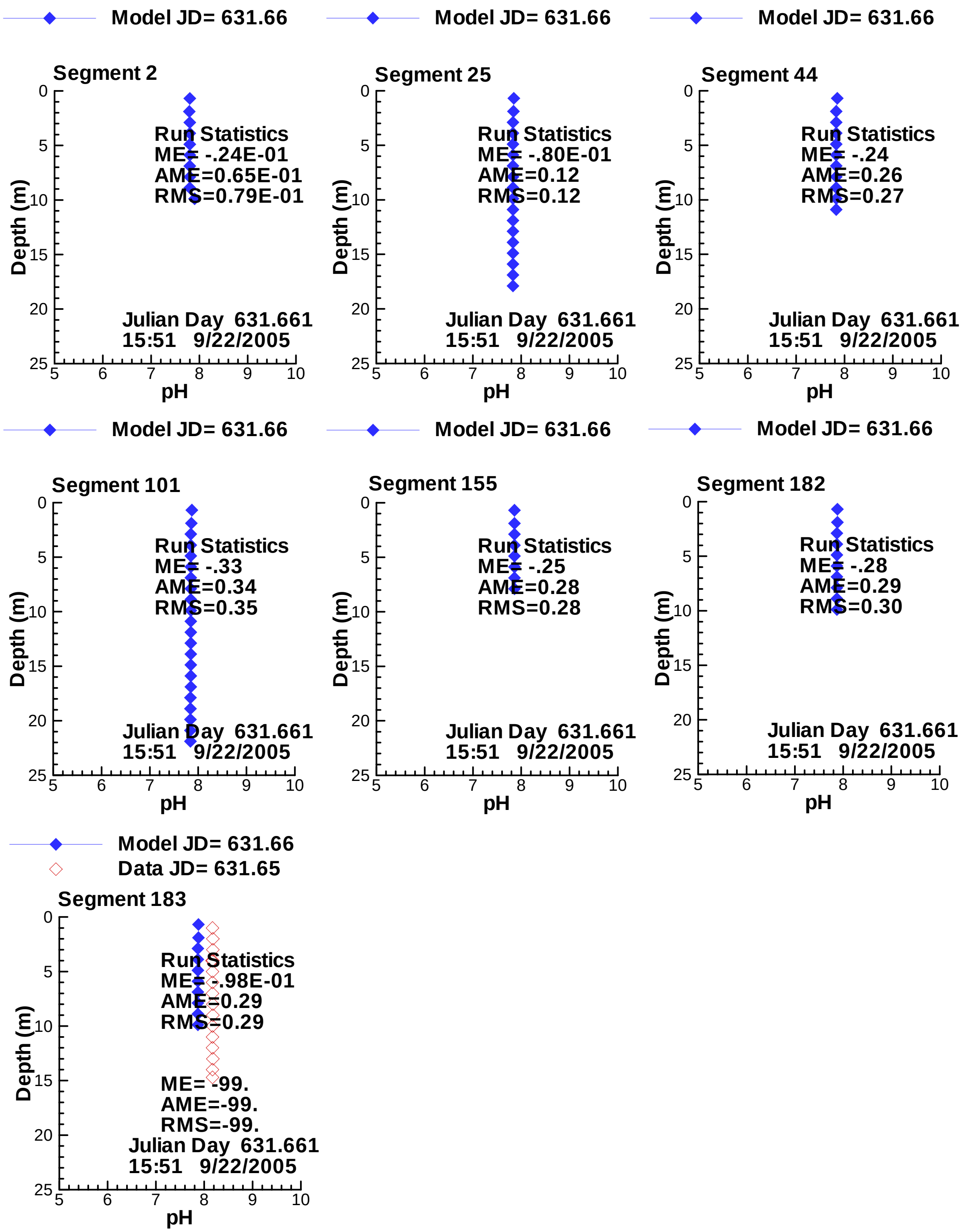


Figure 170: Vertical profiles of pH compared with data for 9/22/2005 15:50.