Pend Oreille River, Box Canyon Model

Model Development and Calibration


Water Quality Research Group
Department of Civil and Environmental Engineering
Maseeh College of Engineering and Computer Science

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Pend Oreille River, Box Canyon Model: Model Development and Calibration

by

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Table of Contents

List of Figures

List of Tables

Introduction

The Washington Department of Ecology is interested in developing a temperature Total Maximum Daily Load (TMDL) allocation for the Pend Oreille River between the Albeni Falls Dam (U.S. Army Corps of Engineer's reservoir) and Box Canyon Dam as shown in Figure 1. The Pend Oreille drainage basin is shown in Figure 2. An existing model of the Box Canyon reach was developed using CE-QUAL-W2 Version 3.0. This current research involves improving the calibration of the original model (1997 and 1998) and expanding the model using 2004 as an additional data set for calibration.

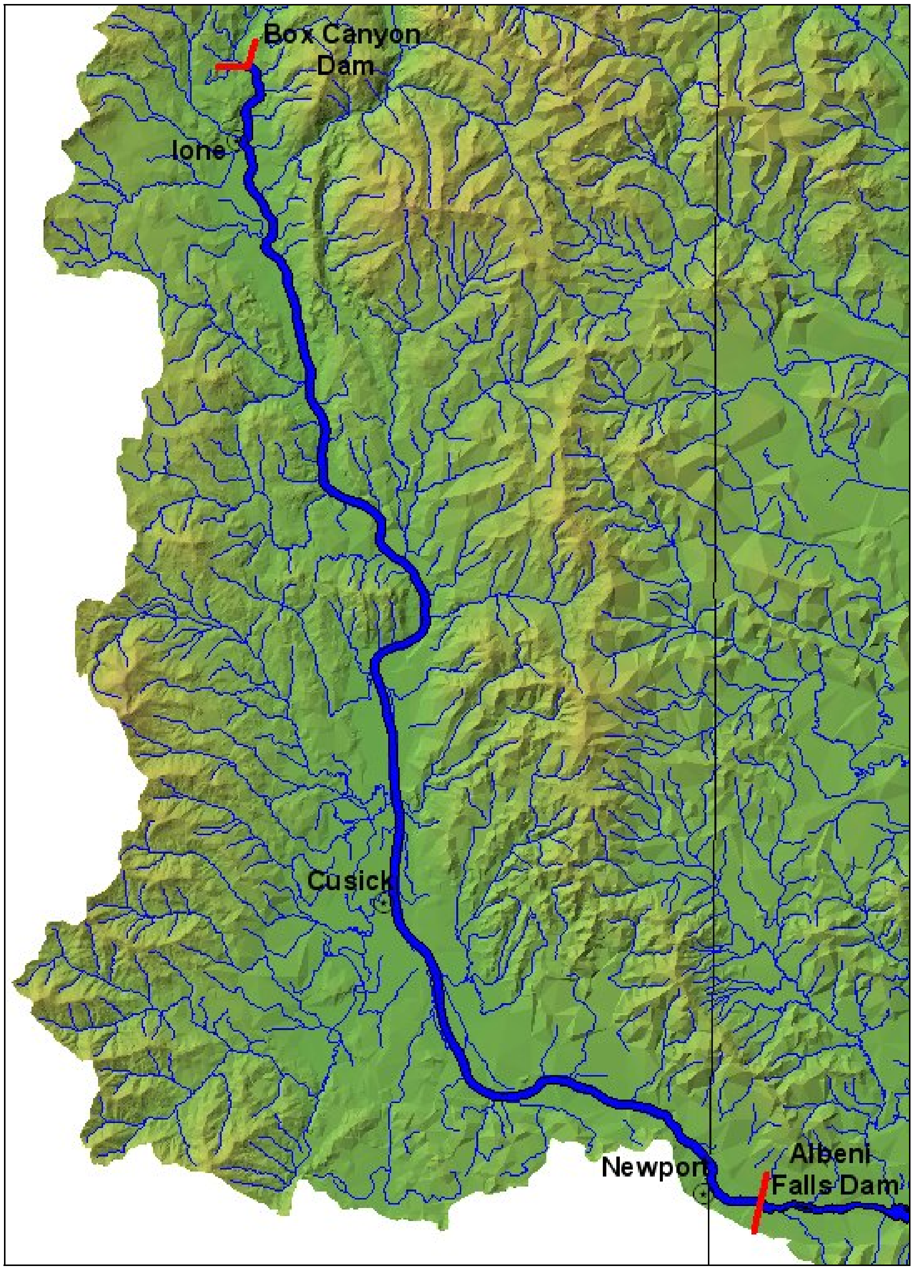

Figure 1: Pend Oreille River downstream of Albeni Falls Dam.

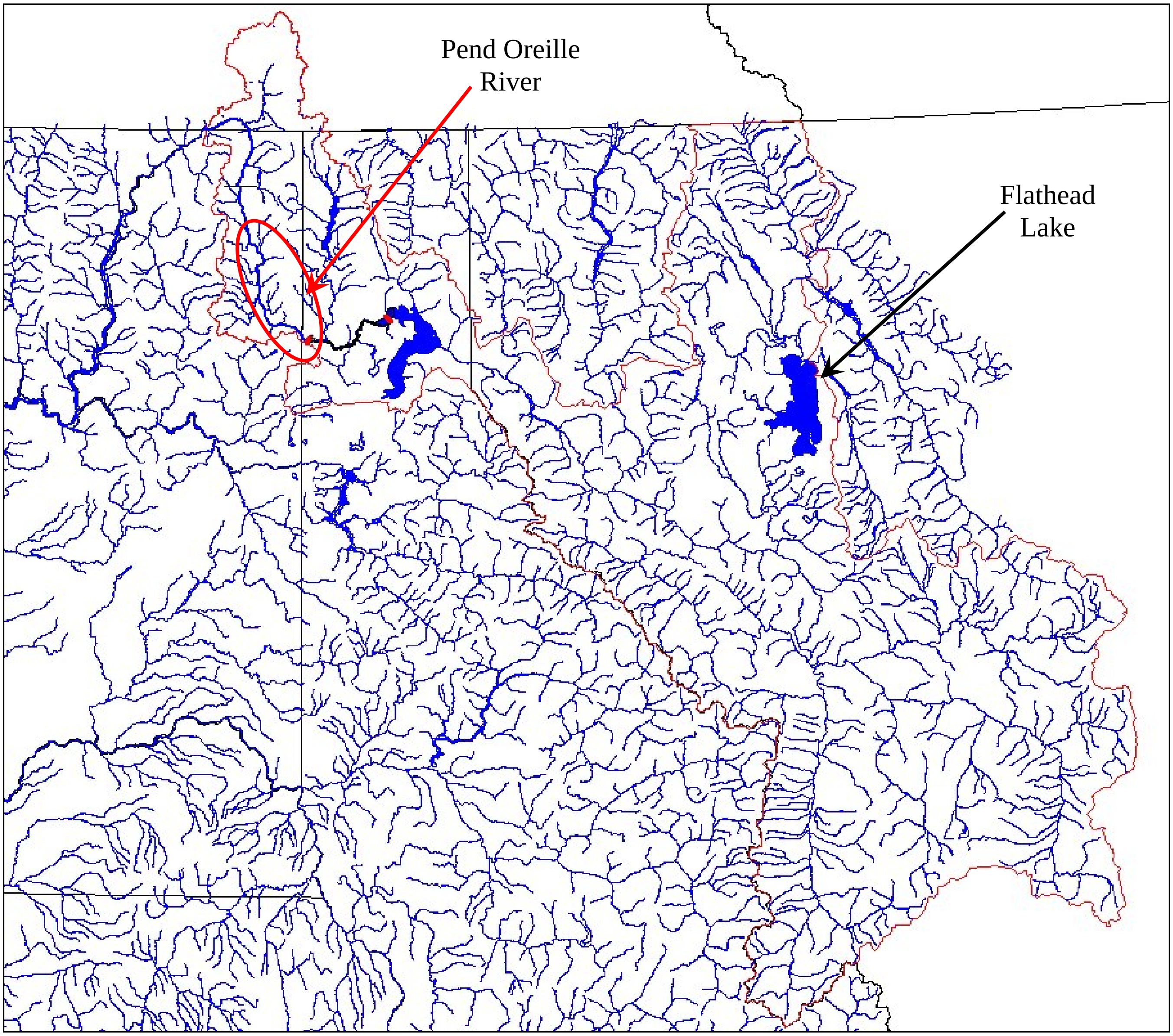

Figure 2: Pend Oreille River Basin.

In order to improve the earlier CE-QUAL-W2 temperature model of Box Canyon reach, Portland State University's Water Quality Research Group (PSU-WQRG) made the following suggestions:

- Cloud cover data should be used
- Tributary (point and distributed) inflows should be added
- "Dead zones" in the bathymetry; i.e. single segment deep pools which exhibit very little exchange vertically, and no exchange horizontally, should be removed
- The slope of the "without project" scenario needs to be corrected so that the elevations of the model segments are correct
- Improved meteorological data should be developed for 1997 and 1998 by correlating meteorological station data from Spokane to closer sites
- The term-by-term method rather than the equilibrium temperature approach should be used.
- Topographic shading should be added to the model

- The model predictions of the vertical temperature structure as it relates to flow rate in the system should be determined since no vertical temperature data were included in the model-data comparisons.
- If the model were to be calibrated to more recent field data, the meteorological data from a closer site than Spokane airport should be used
- The model should be updated to V3.5 because of the potential use of the macrophyte algorithm in future model applications

The purpose of this study was to improve the existing Version 3.0 application of CE-QUAL-W2 of the Pend Oreille River between Box Canyon Dam and Albeni Falls Dam by performing the tasks outlined above. In addition, the use of field data from 2004 as an additional calibration year would improve the confidence in the model's predictive ability for temperature. The model simulations were run from January 1st to December 31st in each of the 3 years of model simulation: 1997, 1998 and 2004.

The model chosen for development is CE-QUAL-W2 Version 3.5 (Cole and Wells, 2006). This is a two-dimensional unsteady hydrodynamic and water quality model that includes typical eutrophication parameters (algae, nutrients, temperature, organic matter, dissolved oxygen, pH). The PSU-WQRG is a center for development of this modeling tool (see http://www.cee.pdx.edu/w2).

Model Development

Model Geometry

Bathymetry

Bathymetry data for the Pend Oreille River consisted mainly of river channel cross sections provided by Kent Doughty (formerly with Foster Wheeler consulting) from surveys conducted in 1997 and 1998, as shown in Figure 3.

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 4 shows a map of the river with a line indicating the extent of the DEM data used.

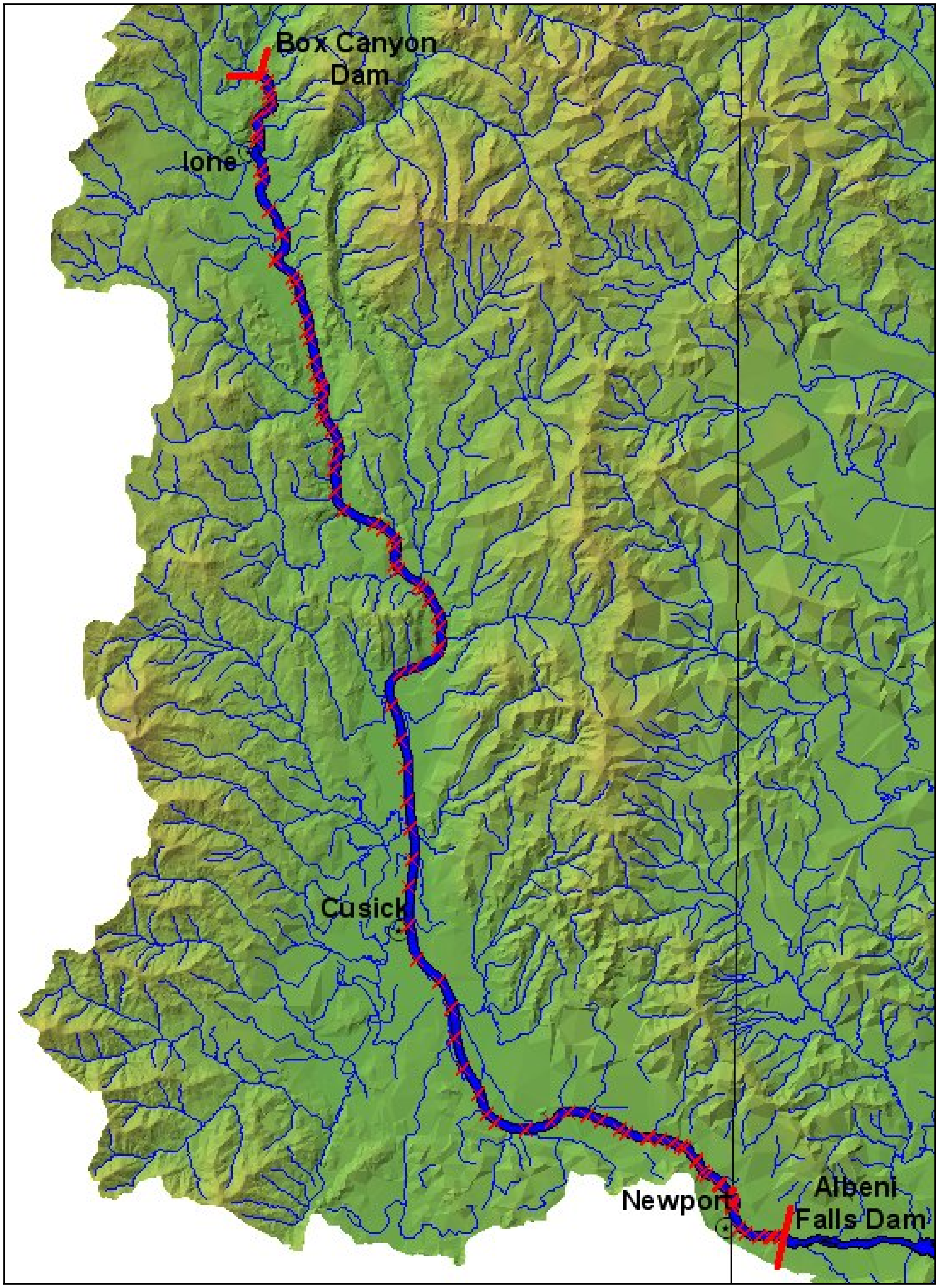

Figure 3: Bathymetric transects collected by Foster Wheeler in 1997 and 1998.

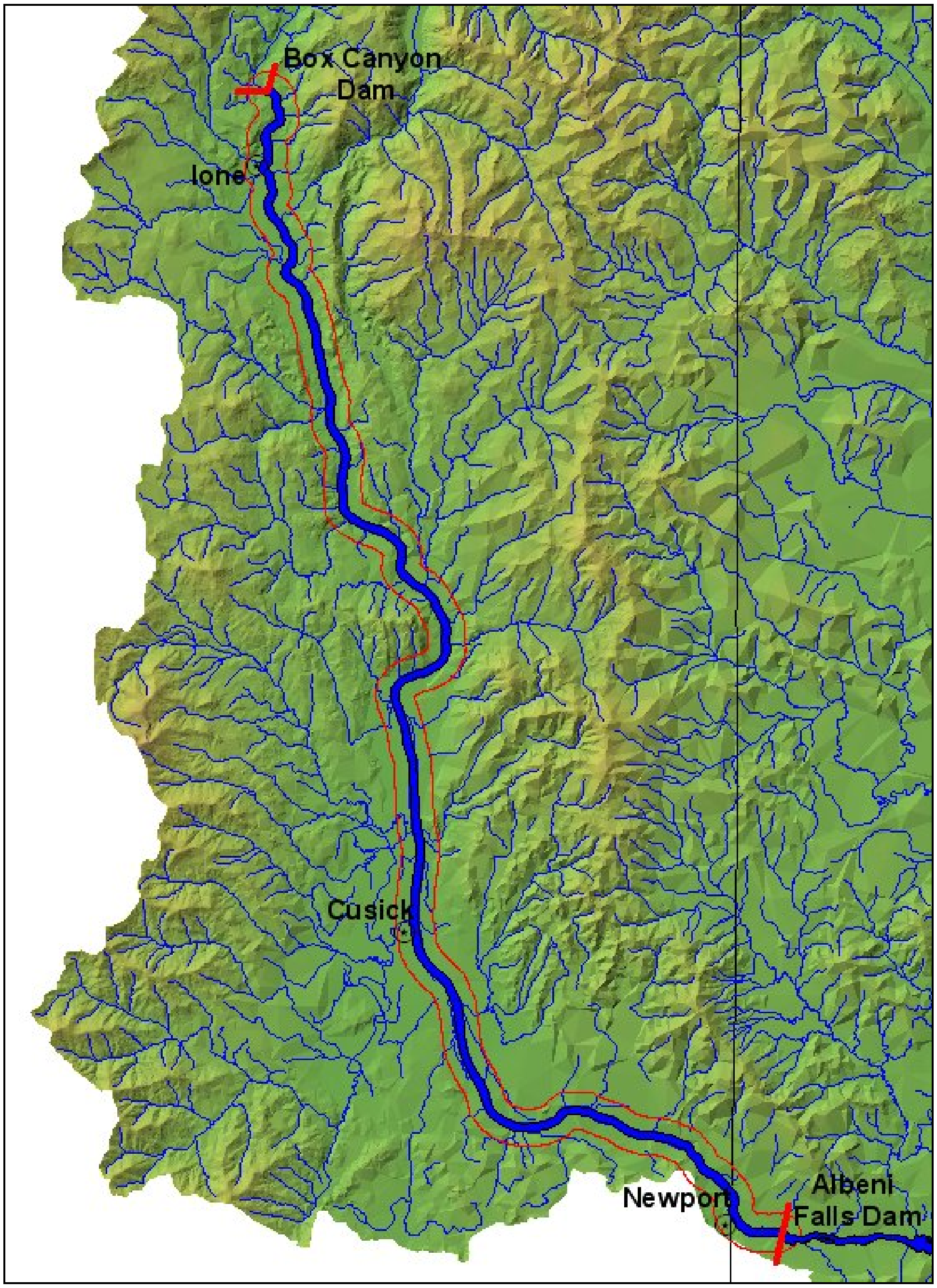

Figure 4: 100 m buffer surrounding the Pend Oreille River to obtain river bank topography.

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 1998. 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 5 shows the Box Canyon Reach bathymetry used to generate the grid, and Figure 6 shows the model grid layout with surrounding rivers and topography. Table 1 provides the list of model grid characteristics.

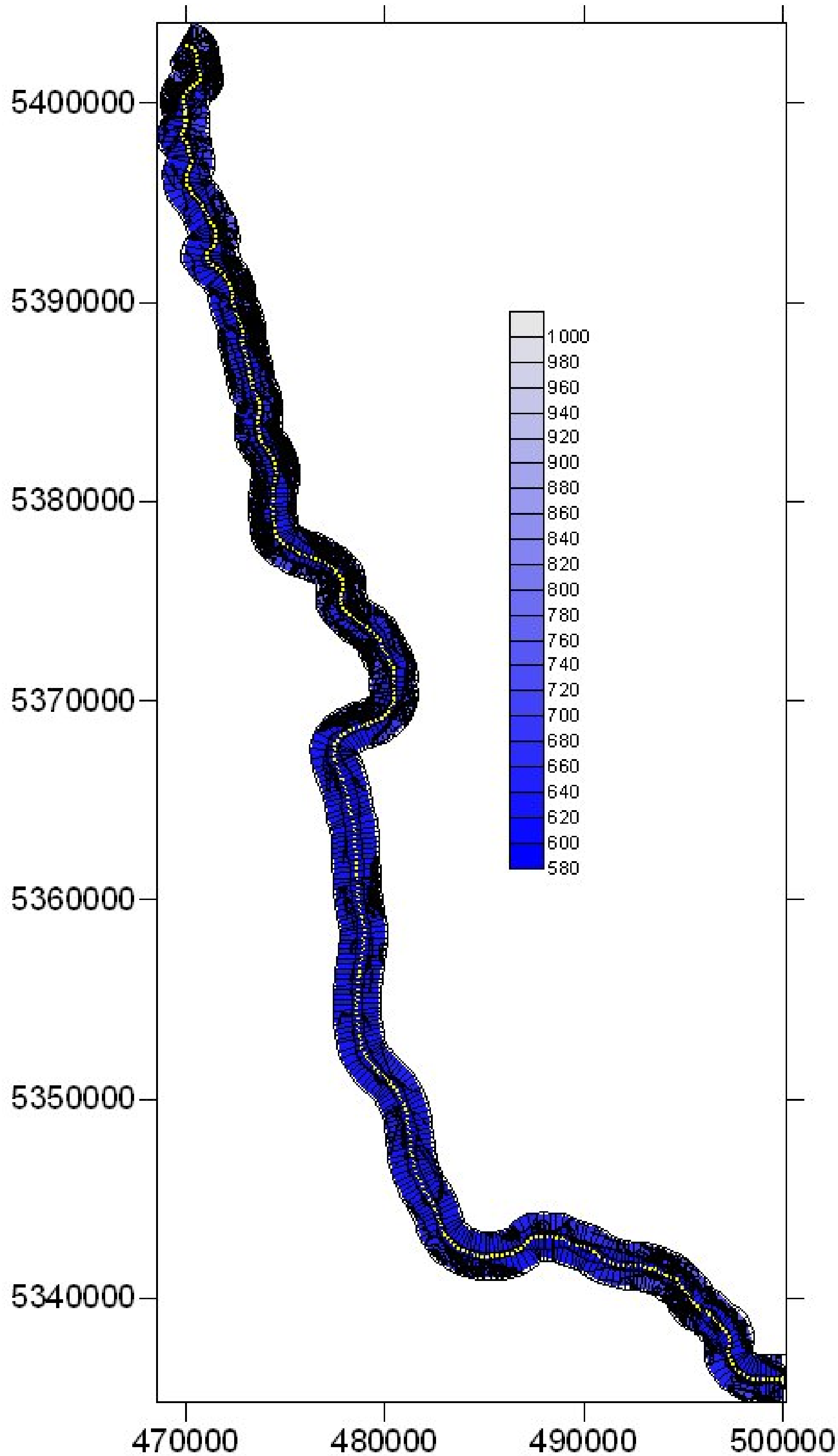

Figure 5: Pend Oreille River, Box Canyon Reach model grid layout with channel bathymetry.

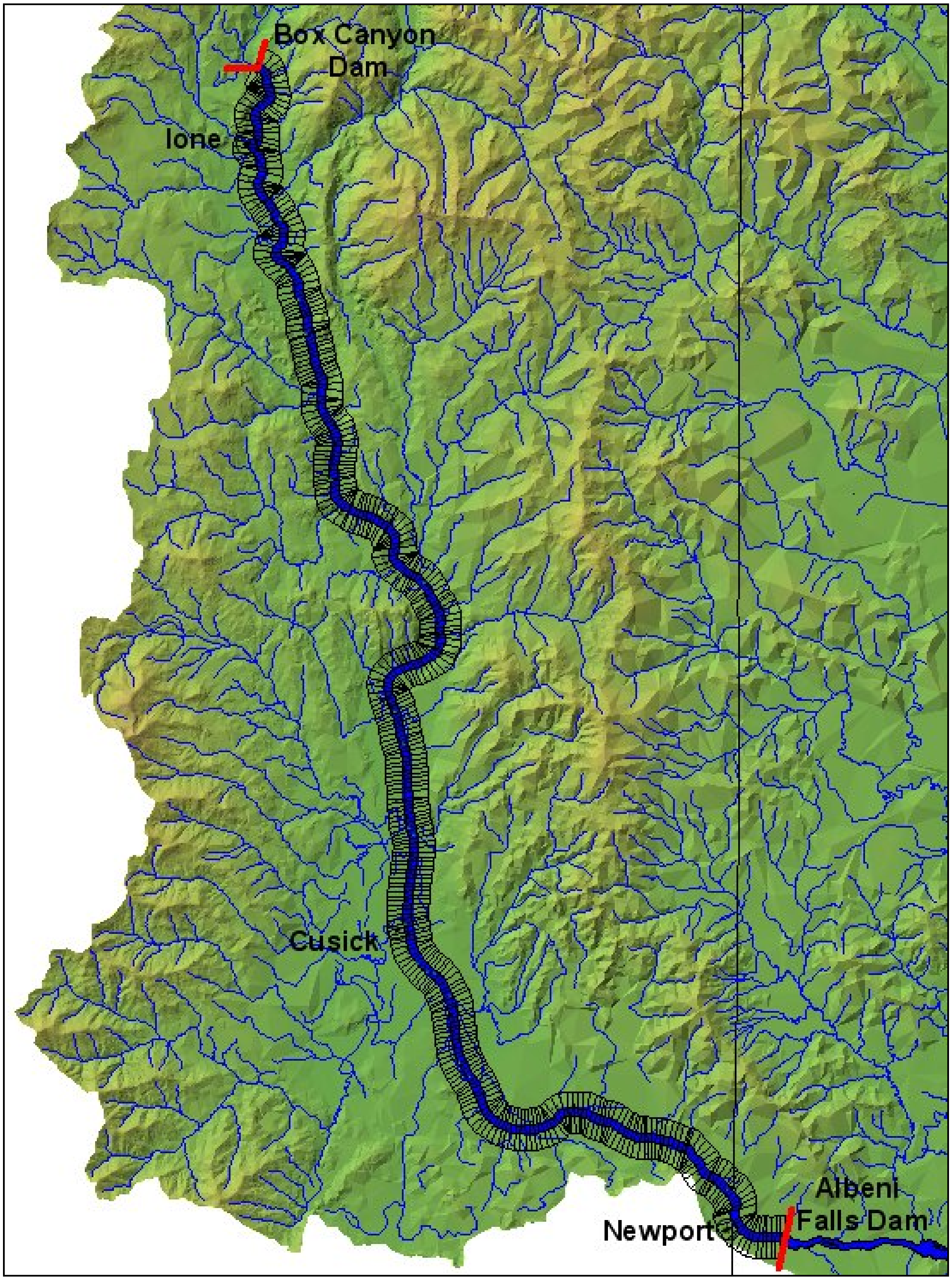

Figure 6: Pend Oreille River, Box Canyon Reach model grid layout.

Table 1: Pend Oreille River, Box Canyon Reach 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	358	90.10	34.51	250.36	0.00	external flow	structure outflow

Boundary Conditions

The boundary conditions for the model include inflows from the Albeni Falls Dam, tributaries, and point sources and outflows from the Boundary Dam. These flow rate and temperature data were obtained from several different agencies and sources to develop the model input files and for the model during the calibration years of 1997, 1998 and 2004. Data used for boundary conditions and for model-data comparisons are shown in Appendix A, where maps of monitoring sites and tables listing the sites and extent of data are shown.

Upstream Boundary Conditions

Hydrodynamics

The upstream boundary condition for the Pend Oreille River, Box Canyon Reach model was based on outflow from Albeni Falls Dam. Data were primarily used from the USGS gage station just downstream of the dam at Newport, WA (12395500). Data gaps were filled using data from the U.S. Army Corps of Engineers monitoring site, ALF just below the dam. Both sites are shown in Figure 7.

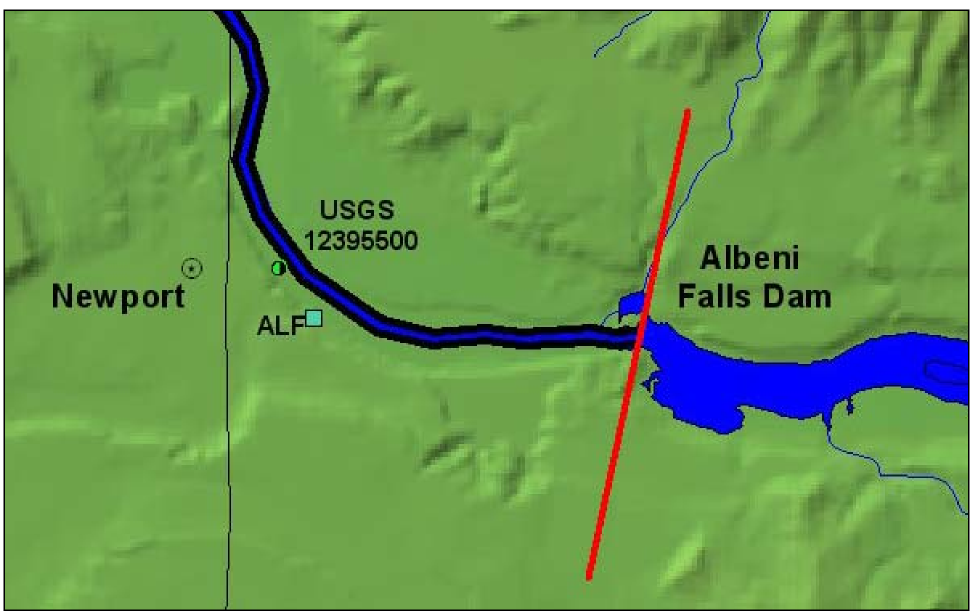

Figure 7: Pend Oreille River below Albeni Falls Dam flow monitoring sites.

Data gaps were filled in 1997 using data from the monitoring site, ALF. Figure 8 shows a time series plot of the flow data for 1997. A short data gap in December, 1998 was filled using data from the ACOE ALF monitoring site. The ALF site measured flows were increased by 5% to account for bias in the flows recorded when compared to flows at the USGS gage site for 2 weeks prior to the data gap. Figure 9 shows a time series plot of the flow data for 1998. Data from the USGS gage were used for 2004, with no data gaps. Figure 10 shows a time series plot of the flow data for 2004.

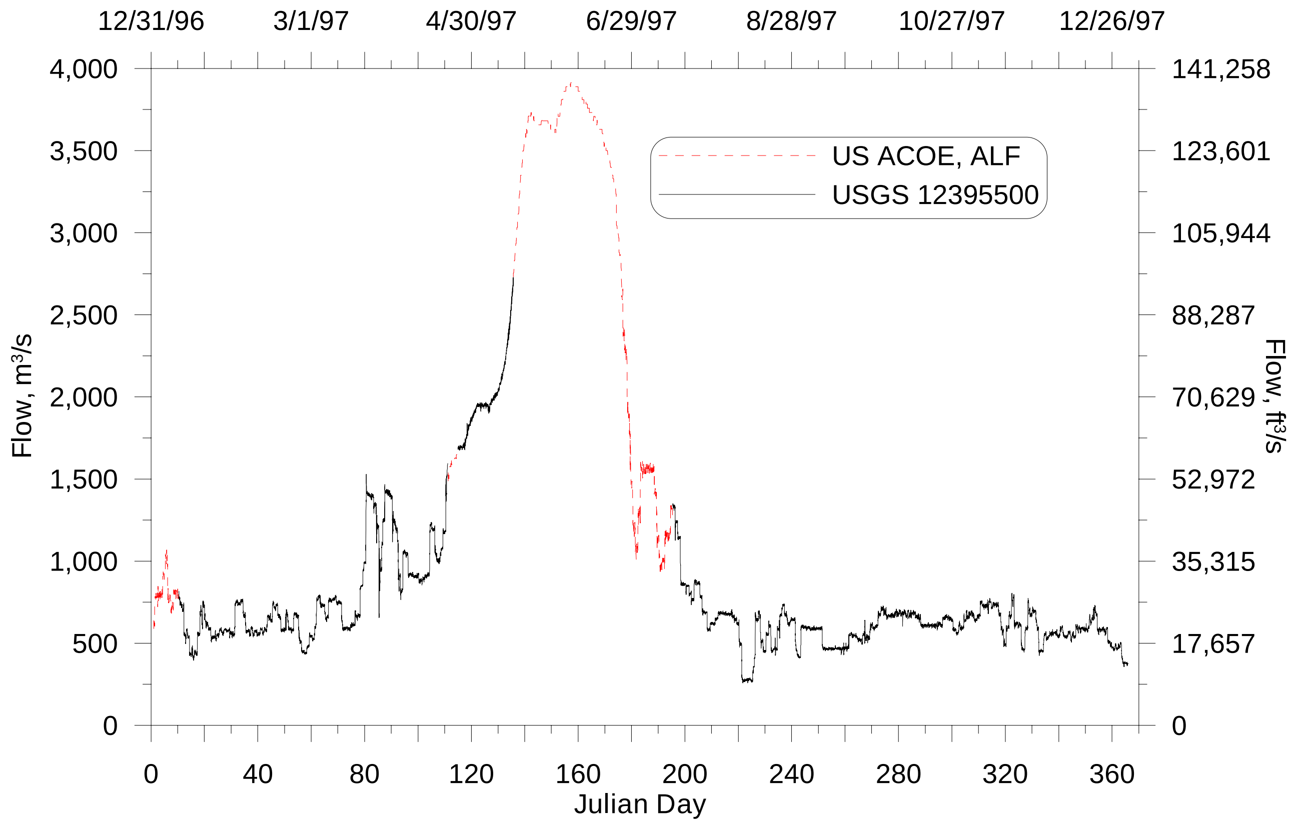

Figure 8: Upstream boundary condition, outflow from Albeni Falls Dam, 1997.

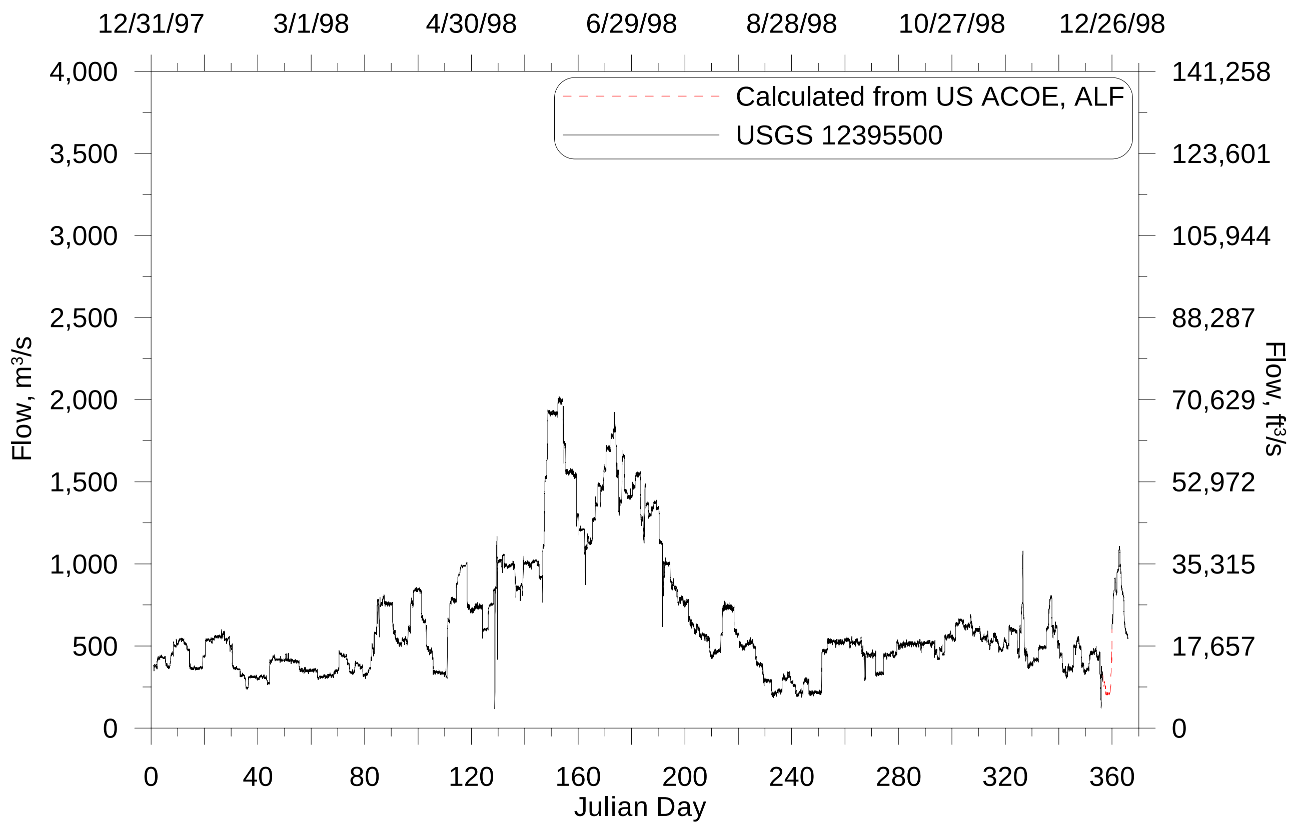

Figure 9: Upstream boundary condition, outflow from Albeni Falls Dam, 1998.

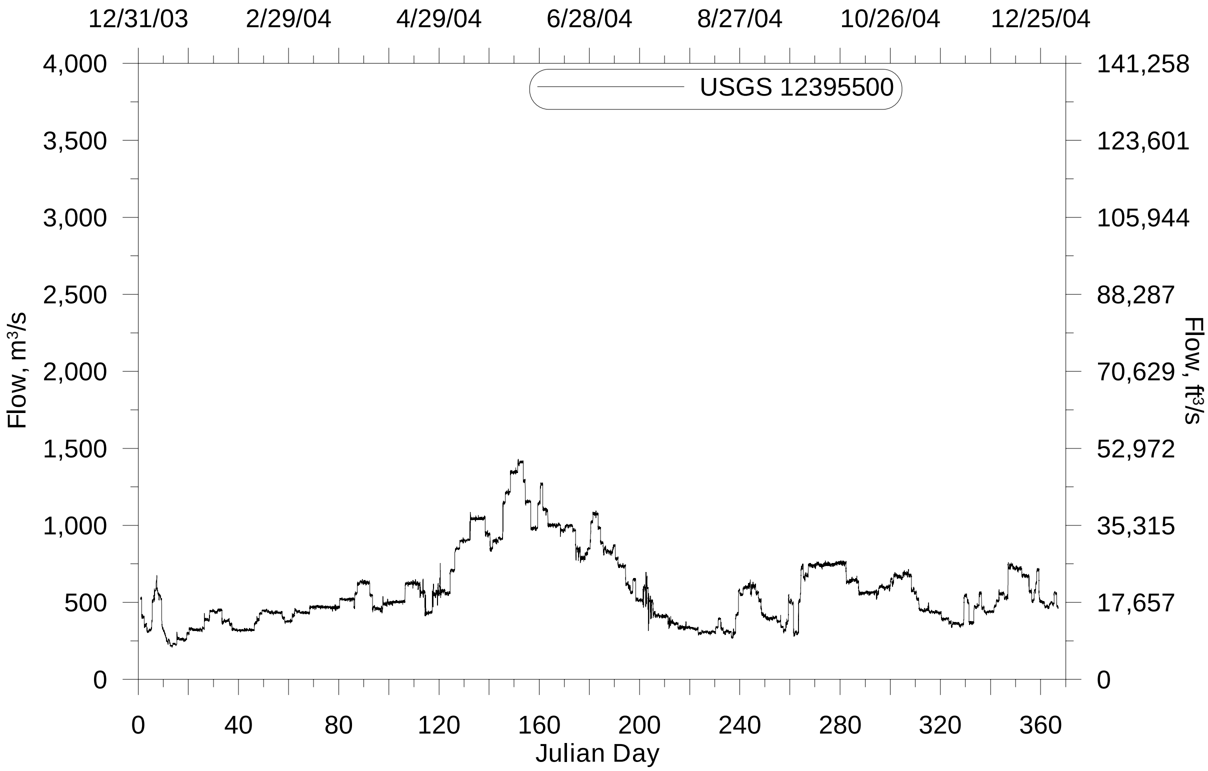

Figure 10: Upstream boundary condition, outflow from Albeni Falls Dam, 2004.

Temperature

Several temperature monitoring site were used to characterize the upstream boundary condition for the model. Figure 11 shows a map with the locations of the temperature monitoring sites near Albeni Falls Dam. Table 2 lists the site names, descriptions and the data available at each site.

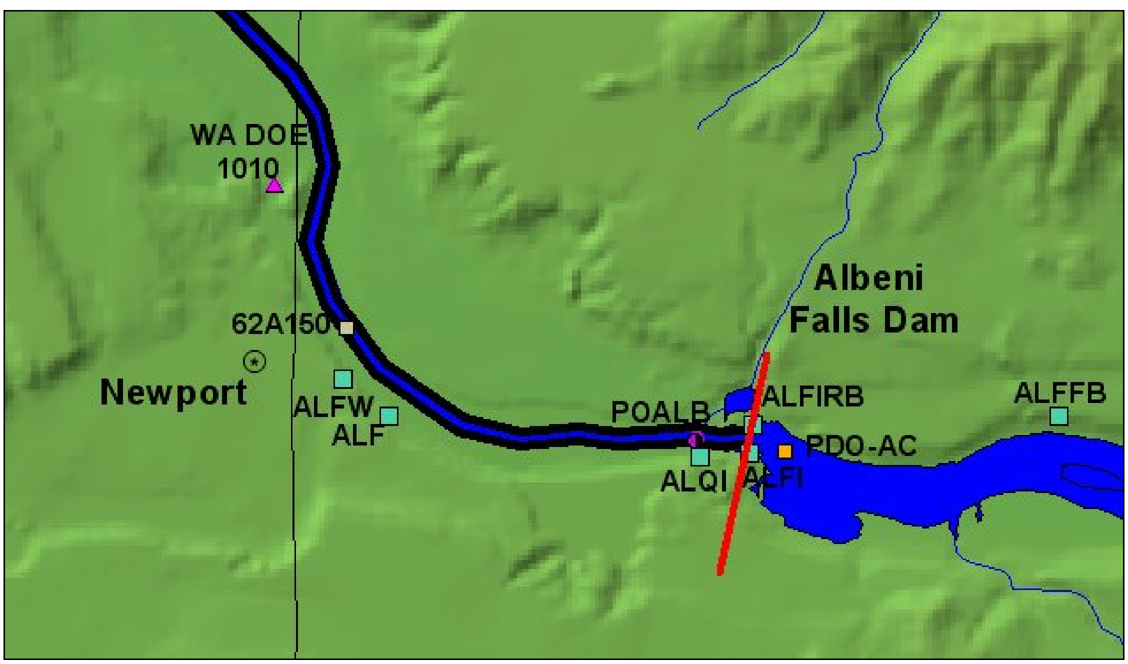

Figure 11: Pend Oreille River below Albeni Falls Dam temperature monitoring sites.

Table 2: Upstream boundary water temperature monitoring site locations 1997, 1998 and 2004

Site ID	Agency	Site Description	Data available
1010	WADOE	Pend Oreille River near Newport (Kelly Island)	2004
62A150	WADOE	Pend Oreille River at Newport	2004, grab samples
ALF	ACOE	Albeni Falls Dam On Pend Oreille River Below Lake	1997, 1998, 2004
ALFI	ACOE	Albeni Falls Dam Forebay Left Bank	2004
ALFW	ACOE	Albeni Falls Dam Tailwater Left Bank	2004
POALB	Foster Wheeler	Pend Oreille River Below Albeni	1997

Water temperature data from two sites (USACOE, ALF and Foster Wheeler POALB) were used to characterize the upstream boundary condition for the Box Canyon Reach in 1997. The data from the U.S. Army Corps of Engineer's site (ALF) consisted of daily data while the other data set (POALB) consisted of hourly data. Figure 12 shows a time series plot of the upstream boundary temperature for Box Canyon Reach in 1997.

The only water temperature data available in 1998 consisted of daily temperatures from the U.S. Army Corps of Engineer's site (ALF). Figure 12 shows a time series plot of the upstream boundary temperature for Box Canyon Reach in 1999. In 2004 there were several data sets collected by different agencies which could be used to characterize the upstream boundary condition. Figure 14 shows a plot of the time series data sets available in 2004. Figure 15 shows a time series plot of the upstream boundary temperature for Box Canyon Reach in 2004.

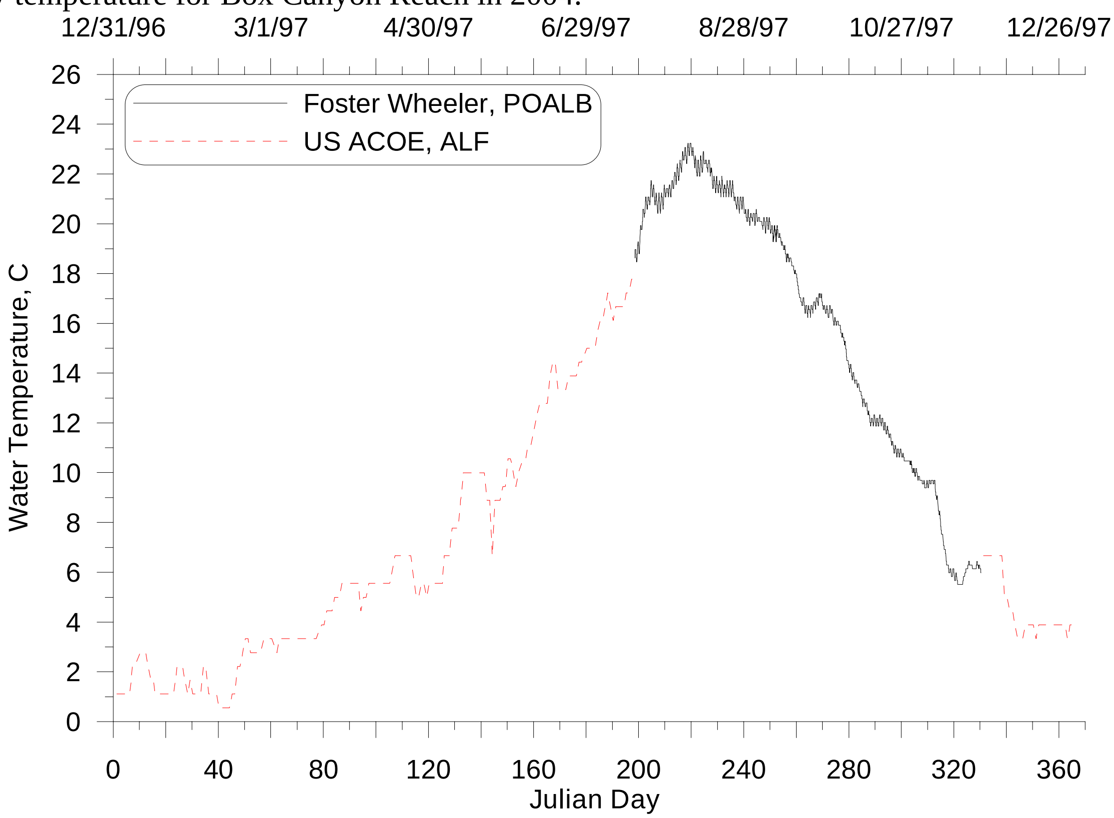

Figure 12: Upstream boundary condition, Albeni Falls Dam outflow temperature, 1997.

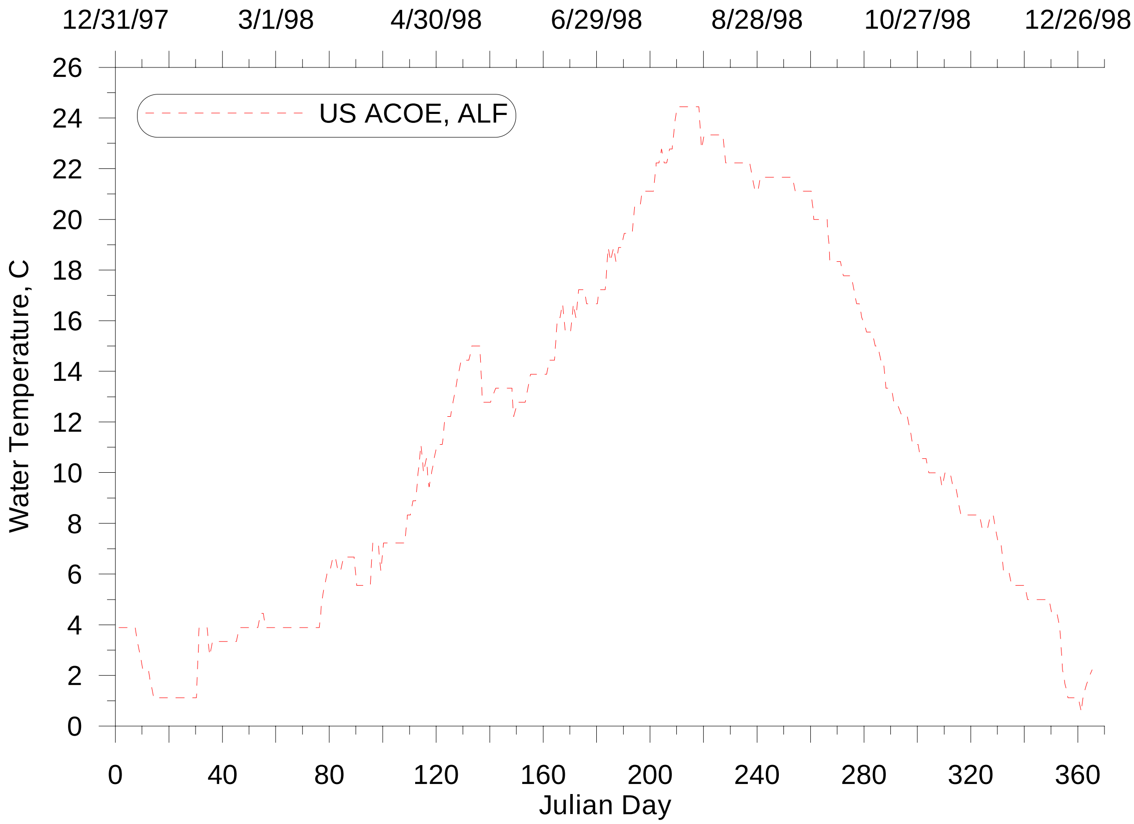

Figure 13: Upstream boundary condition, Albeni Falls Dam outflow temperature, 1998.

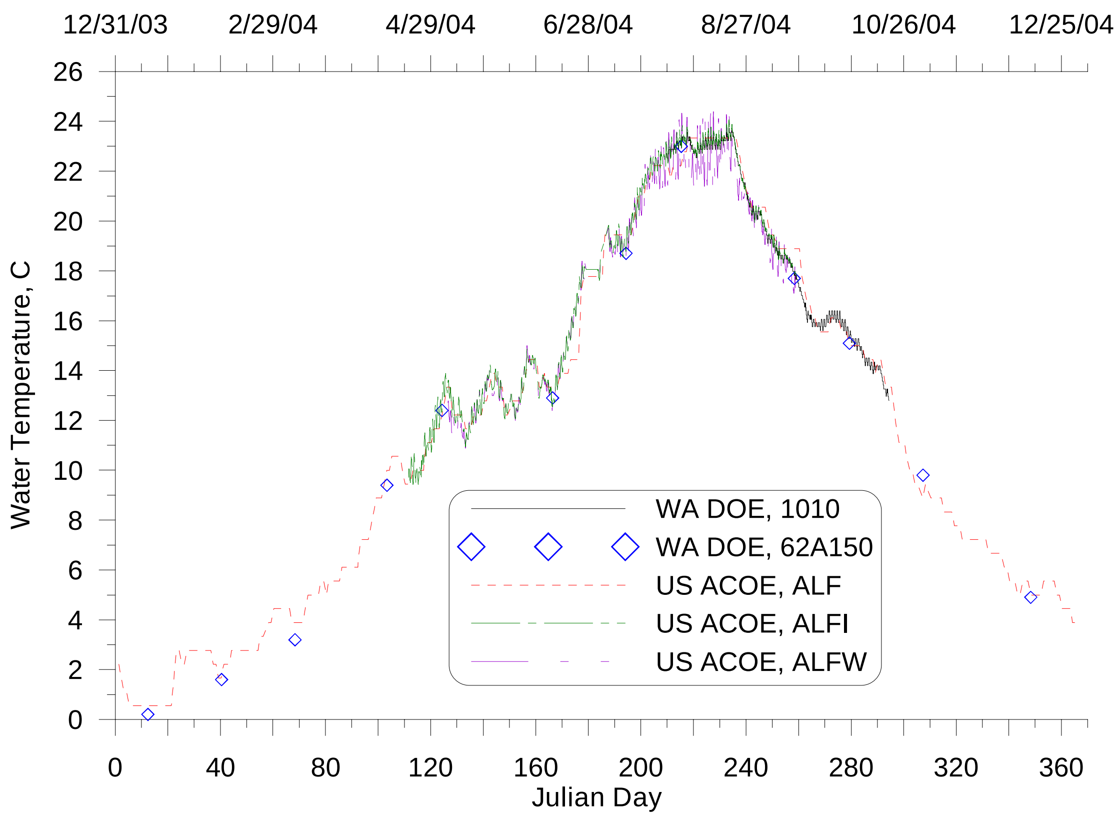

Figure 14: Albeni Falls Dam outflow temperature data sets, 2004.

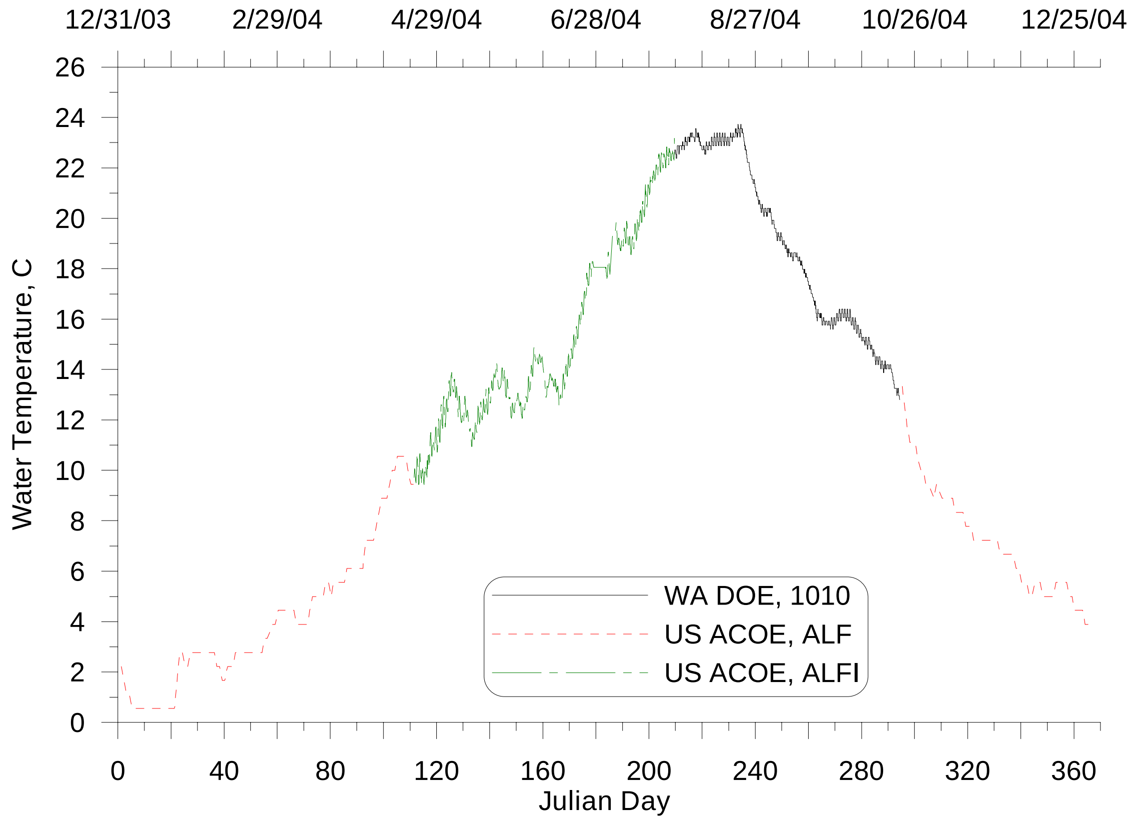

Figure 15: Upstream boundary condition, Albeni Falls Dam outflow temperature, 2004.

Downstream Boundary Conditions

The downstream boundary condition for the Box Canyon reach of the Pend Oreille River consisted of using the USGS gage station below Box Canyon Dam (12396500) with gaps in the data set filled in using data from another USGS gage station, just below Albeni Falls Dam (12395500). In January and December 1997 there were several data gaps in the flow record below Box Canyon Dam. A flow correlation was developed between the USGS gage below Box Canyon Dam and below Albeni Falls Dam as shown in Figure 16. The correlation equation was then used with the flow data below Albeni Falls Dam to calculate the flow below Box Canyon Dam. Figure 17 shows a time series plot of the flow data and calculated values below Box Canyon Dam for 1997. The same flow correlation equation was used to fill data gaps in January and February, 1998. Figure 19 shows a time series plot of the flow data below Box Canyon Dam for 2004.

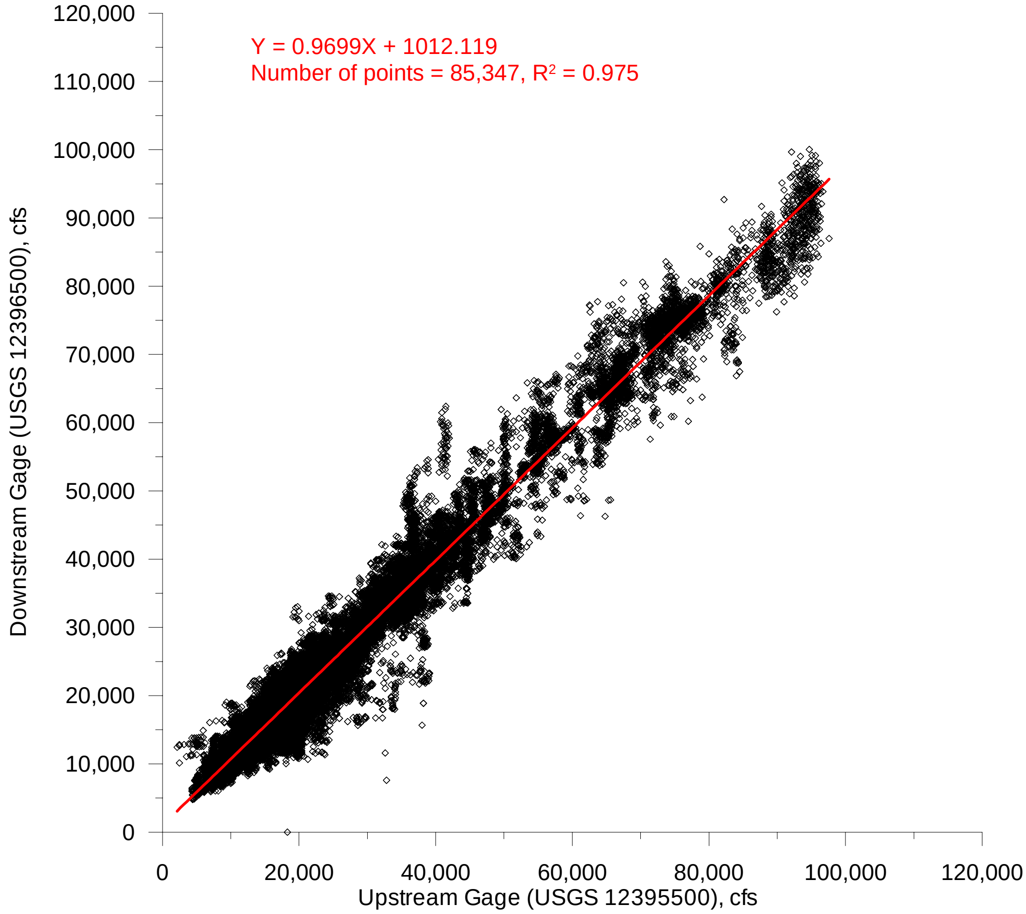

Figure 16: Flow correlation between the gage below Box Canyon Dam and below Albeni Falls Dam.

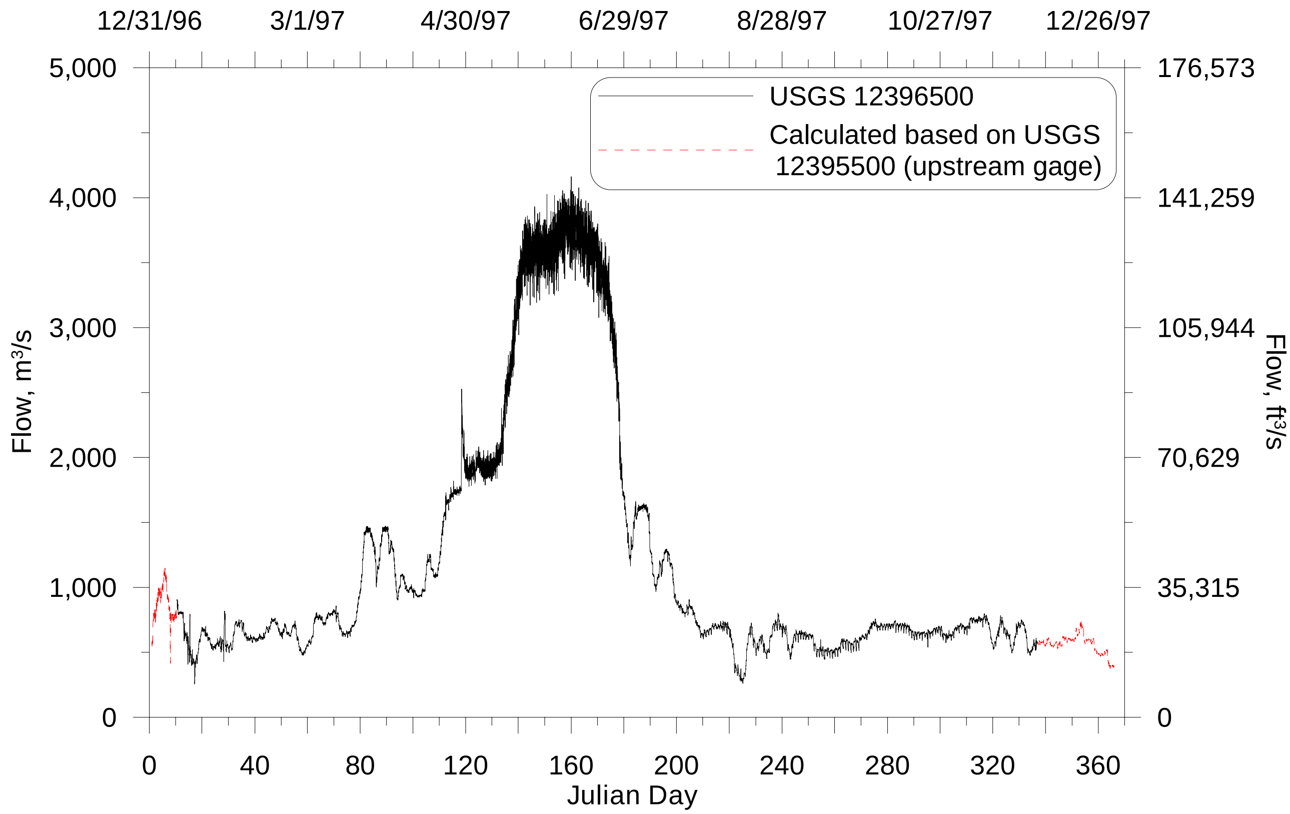

Figure 17: Box Canyon Dam outflow boundary condition, 1997.

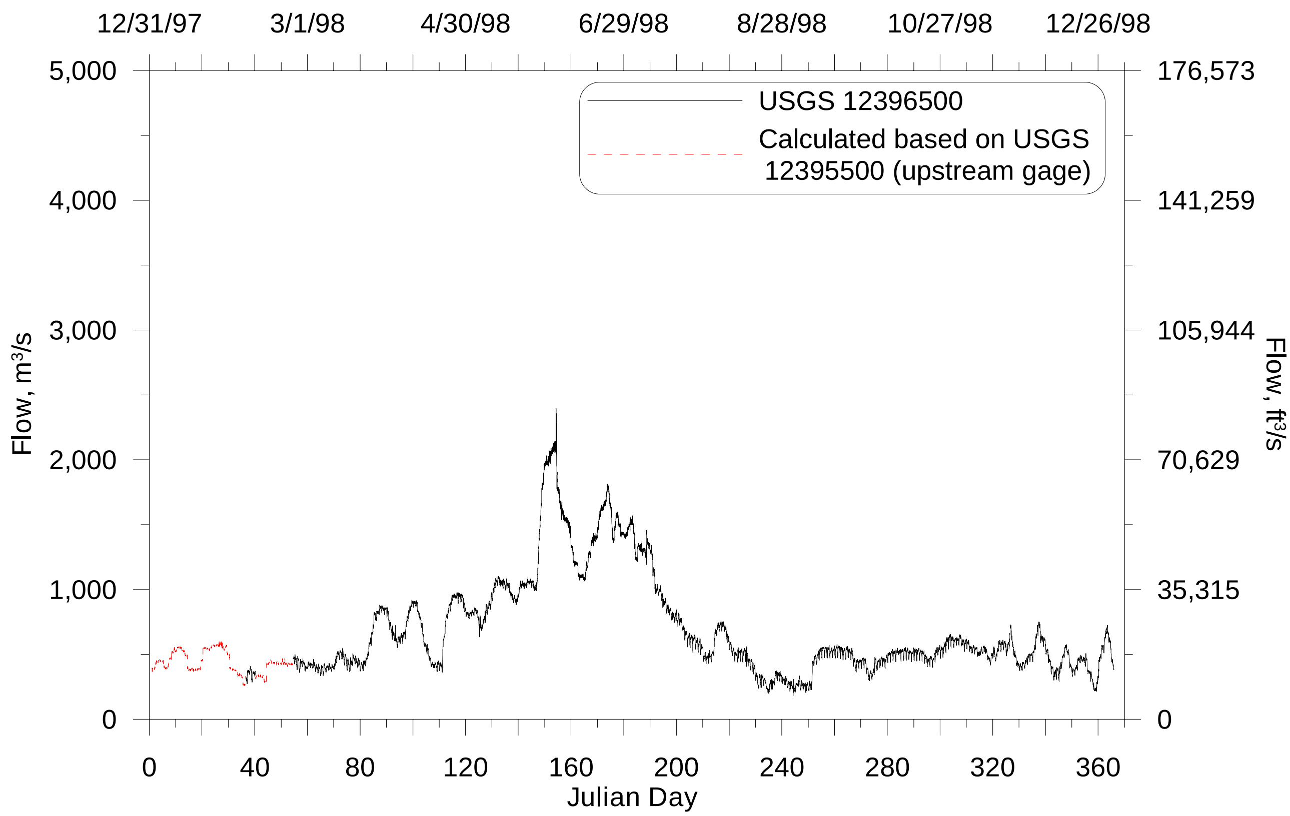

Figure 18: Box Canyon Dam outflow boundary condition, 1998.

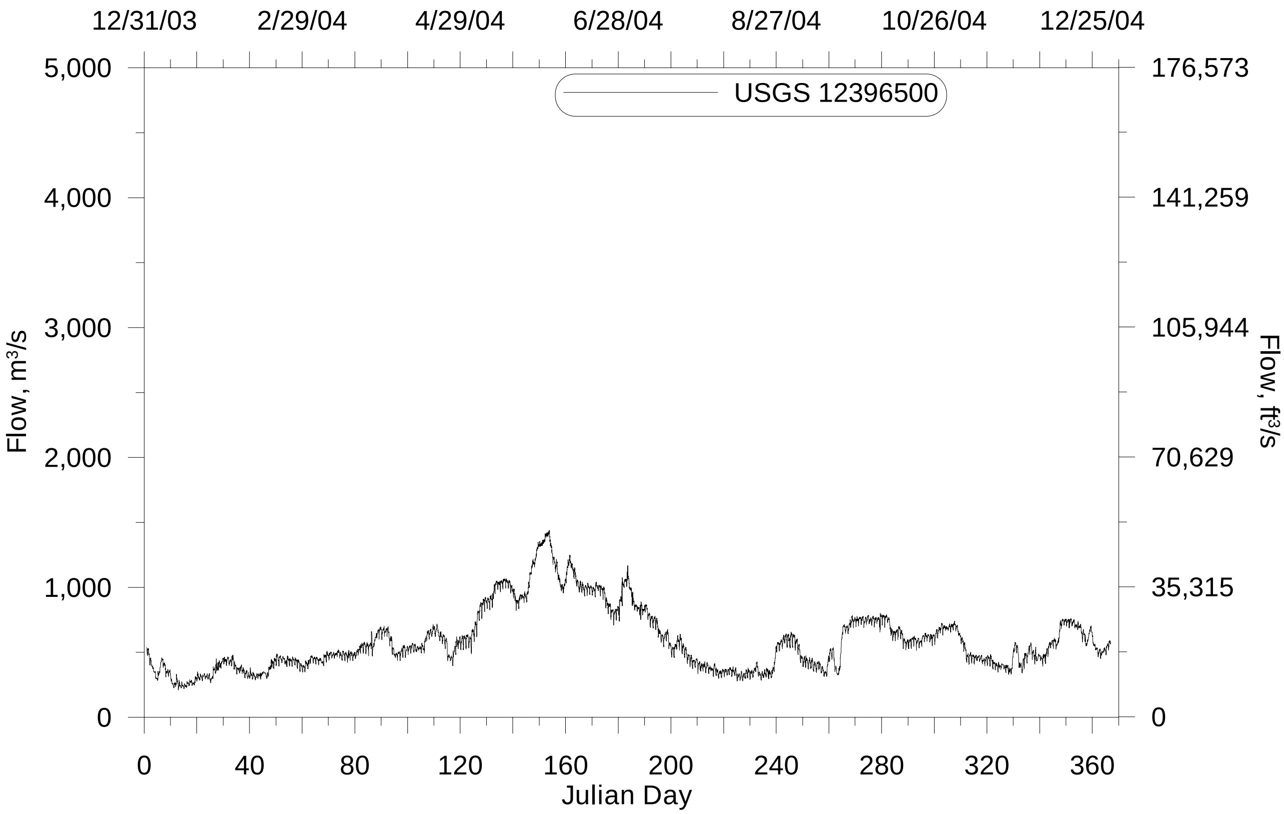

Figure 19: Box Canyon Dam outflow boundary condition, 2004.

Tributaries

There are 22 subbasins that characterize the drainage area for the Box Canyon Reach of the Pend Oreille River. Figure 20 shows a map of the Box Canyon Reach and the subbasins within the drainage area. Table 3 lists the subbasins, their tributaries, the fraction of the overall drainage are and their location along the river. The tributaries are currently not included in the model individually but are incorporated into a distributed tributary. As more data become available these will be included individually.

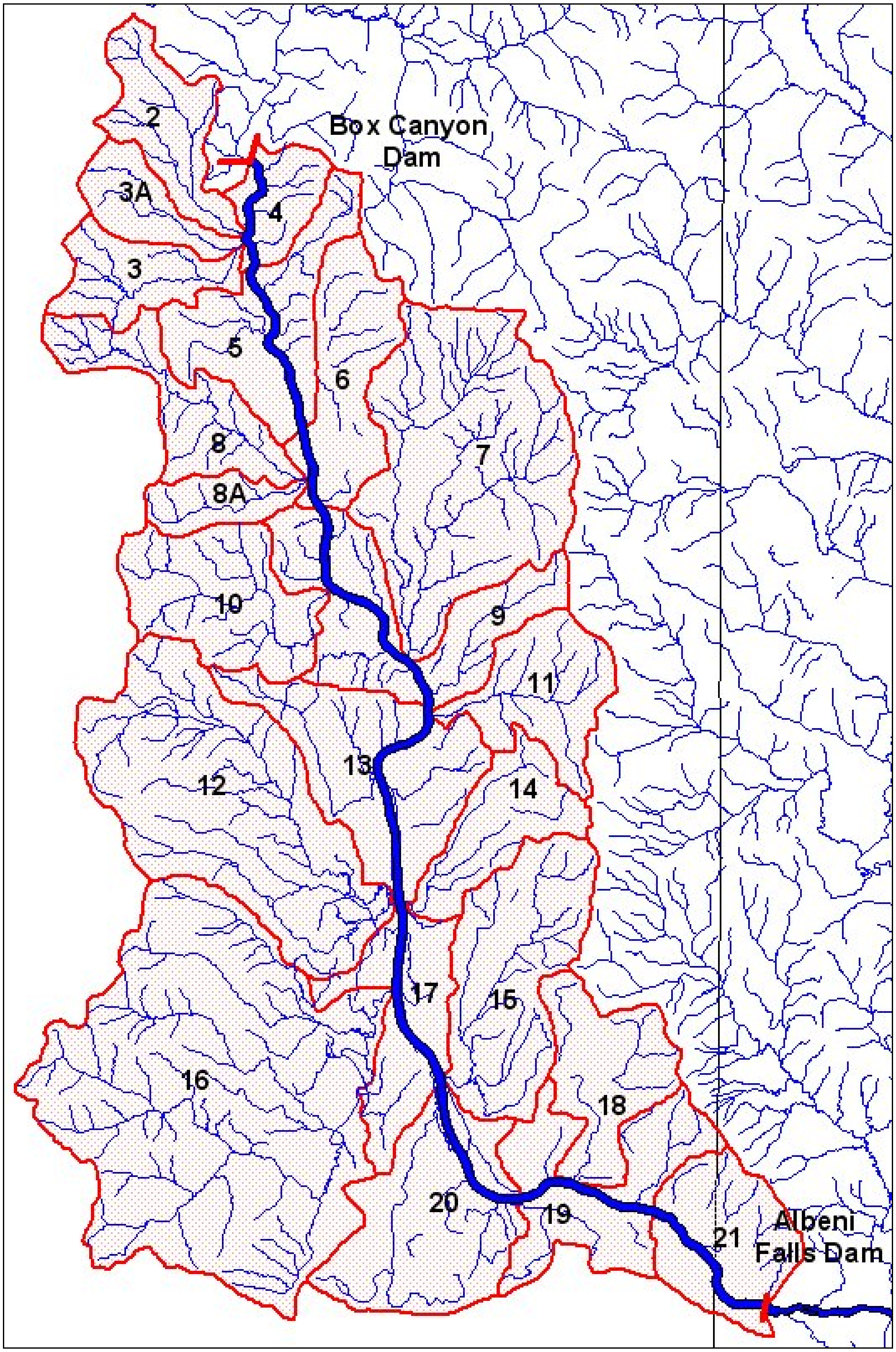

Figure 20: Subbasins and Tributaries to the Box Canyon Reach, Pend Oreille River

Table 3: Subbasin tributary names, drainage areas and locations

Tributary Basin	Area km^2	Fraction of Total Area	Tributary Basin Name	RM	Model Segment
2	48.3	2.5%	Cedar Creek	37.75	338
3	40.7	2.1%	Big Muddy Creek	37.93	337
3A	30.3	1.6%	Little Muddy Creek	37.93	337
4	28.7	1.5%	Exposure & Mickey Creeks	36.83 & 35.53	344 & 352
5	77.6	4.0%	Maitlen & Renshaw Creeks	40.11 & 41.98	323 & 312
6	65.1	3.4%	Cato, Tioga, & Yocum Creeks	48.53	268
7	181.5	9.4%	LeClerc Creek	55.95	221
8	57.1	3.0%	Lost Creek	47.62	275
8A	23.7	1.2%	South Fork Lost Creek	47.62	275
9	94.2	4.9%	Middle Creek	57.43	211
10	77.5	4.0%	Ruby Creek	51.80	248
11	57.2	3.0%	Mill Creek	58.18	207
12	186.3	9.6%	Tacoma Creek	66.12	156
13	102.2	5.3%	Cusick & Gardner Creeks	61.46	186
14	50.1	2.6%	Cee Cee Ah Creek	66.12	156
15	99.9	5.2%	Skookum Creek	73.01	111
16	343.4	17.8%	Calispell Creek	69.43	135
17	61.9	3.2%	Unknown	69.44 & 66.58	135 & 153
18	60.6	3.1%	Indian Creek	81.05	60
19	77.5	4.0%	Marshall & McCloud Creeks	83.56 & 78.61	44 & 76
20	103.6	5.4%	Davis Creek	72.74	113
21	64.9	3.4%	Briar & Freeman Creeks	86.46	25

Point Sources

There are 3 point sources included in the model as shown in Figure 21. Table 4 lists the point sources included in the model, representing two municipal discharges and one industrial discharge. Currently, the discharge flow rates and temperatures are characterized by monthly values.

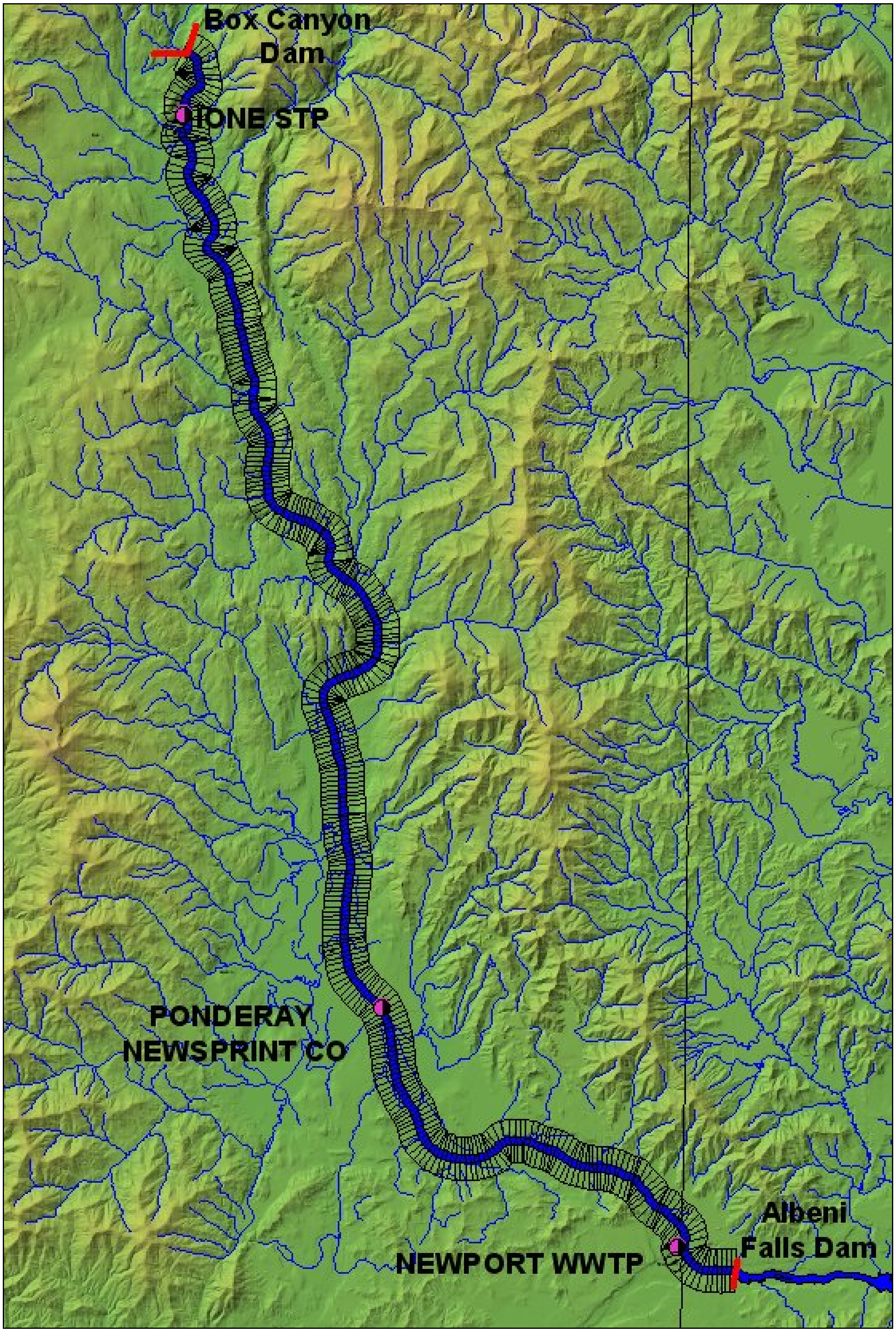

Figure 21: Tributary inflows to the Pend Oreille River.

Table 4: Point Source dischargers to the Pend Oreille River, Box Canyon Reach.

Point Source	Name	Segment
1	City of Newport WWTP discharge	15
2	Ponderay Newsprint Company discharge	116
3	City Ione STP discharge	342

Flow Rates

Monthly discharge flow rates were provided for each point source by Paul Pickett with the WA Department of Ecology, who provided the following comment (Pickett, 2006):

"Flows at point sources are reported by each discharger. Effluent flow at Ione and Pend Oreille Newsprint are directly measured, while only influent flow is reported for Newport."

Figure 22 to Figure 24 show time series plots of the discharge flows for the City of Newport WWTP for 1997, 1998, and 2004, respectively. Figure 25 to Figure 27 show time series plots of the discharge flows for the Ponderay Newsprint Co. for 1997, 1998, and 2004, respectively. Figure 28 to Figure 30 show time series plots of the discharge flows for the City of Ione STP for 1997, 1998, and 2004, respectively.

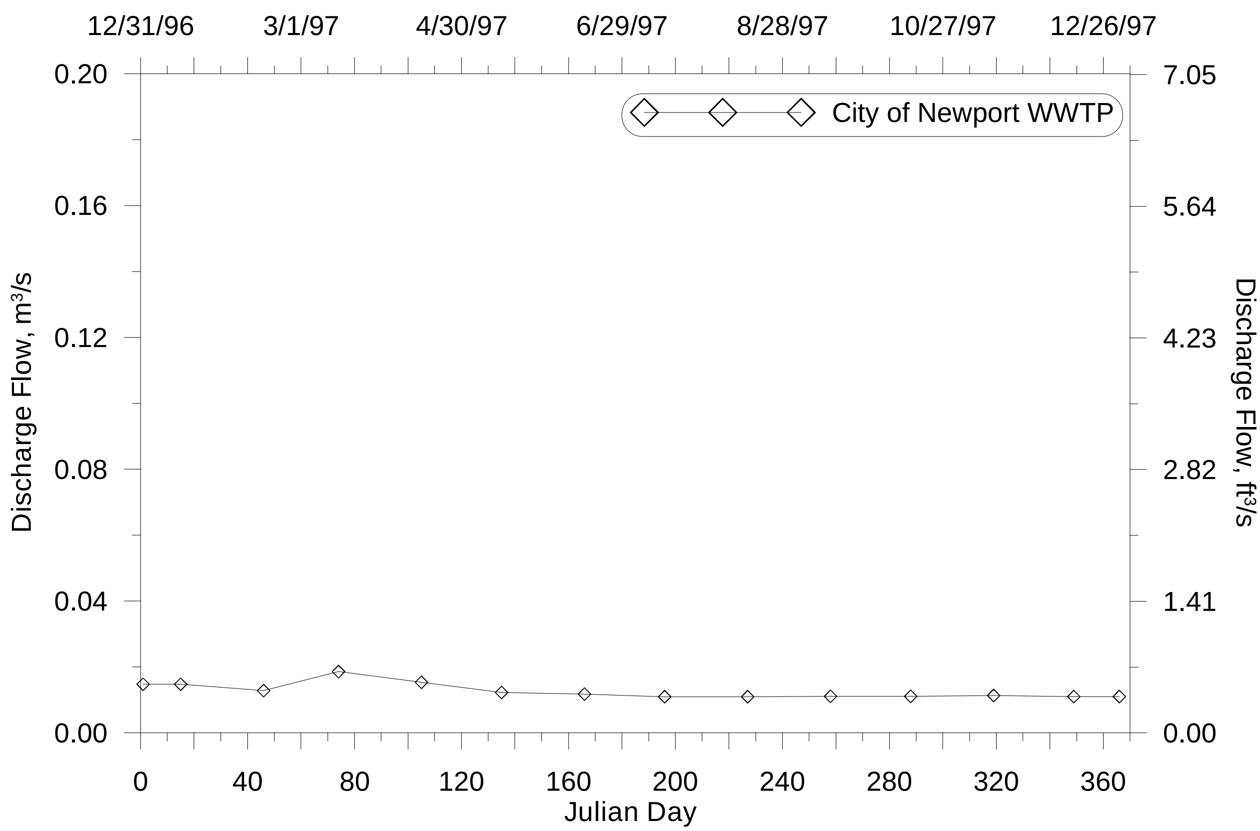

Figure 22: City of Newport WWTP discharge flow, 1997.

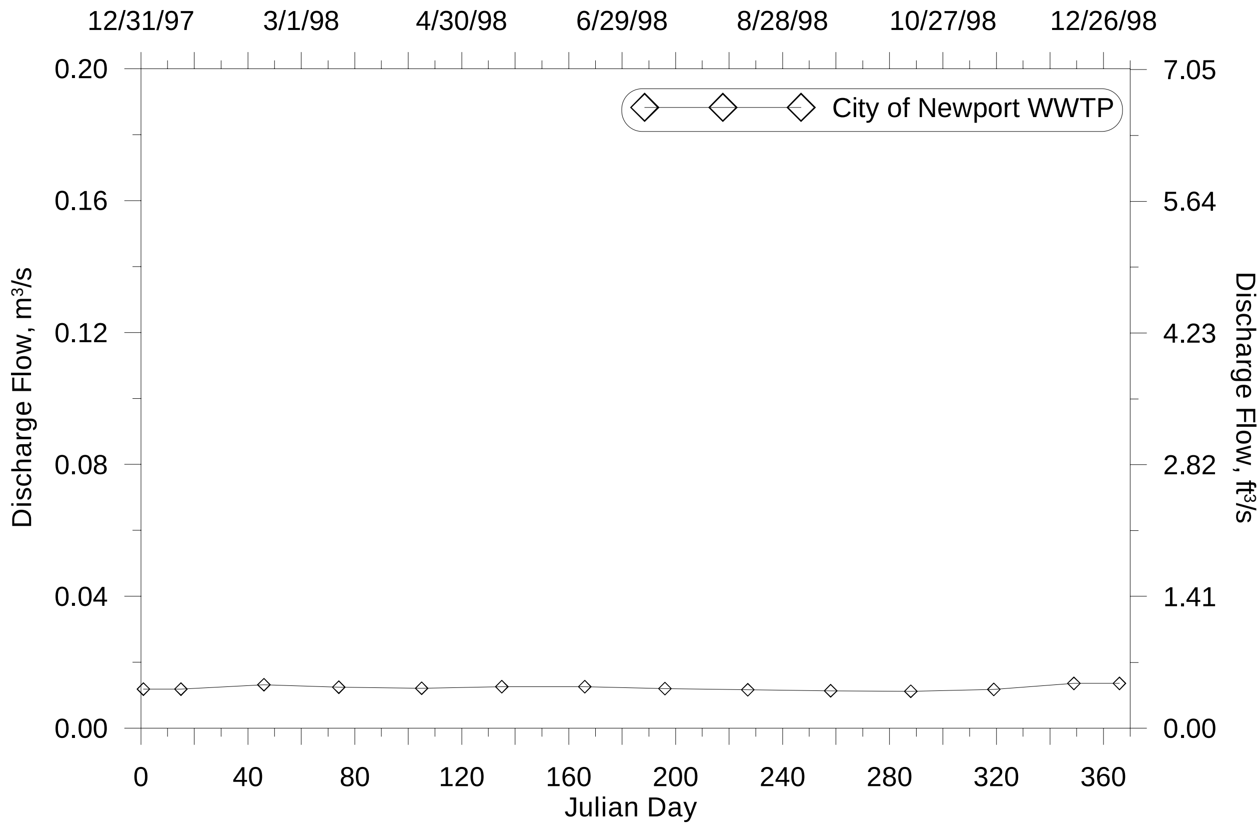

Figure 23: City of Newport WWTP discharge flow, 1998.

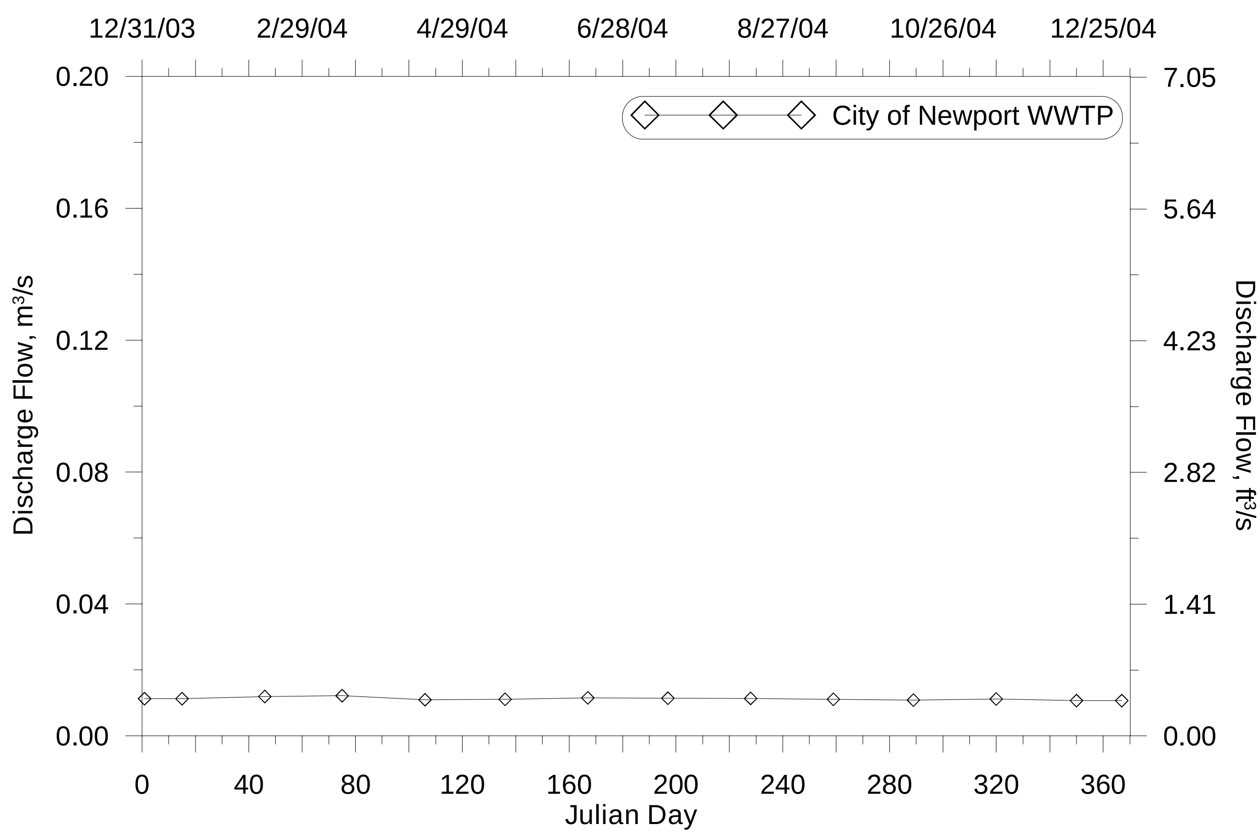

Figure 24: City of Newport WWTP discharge flow, 2004.

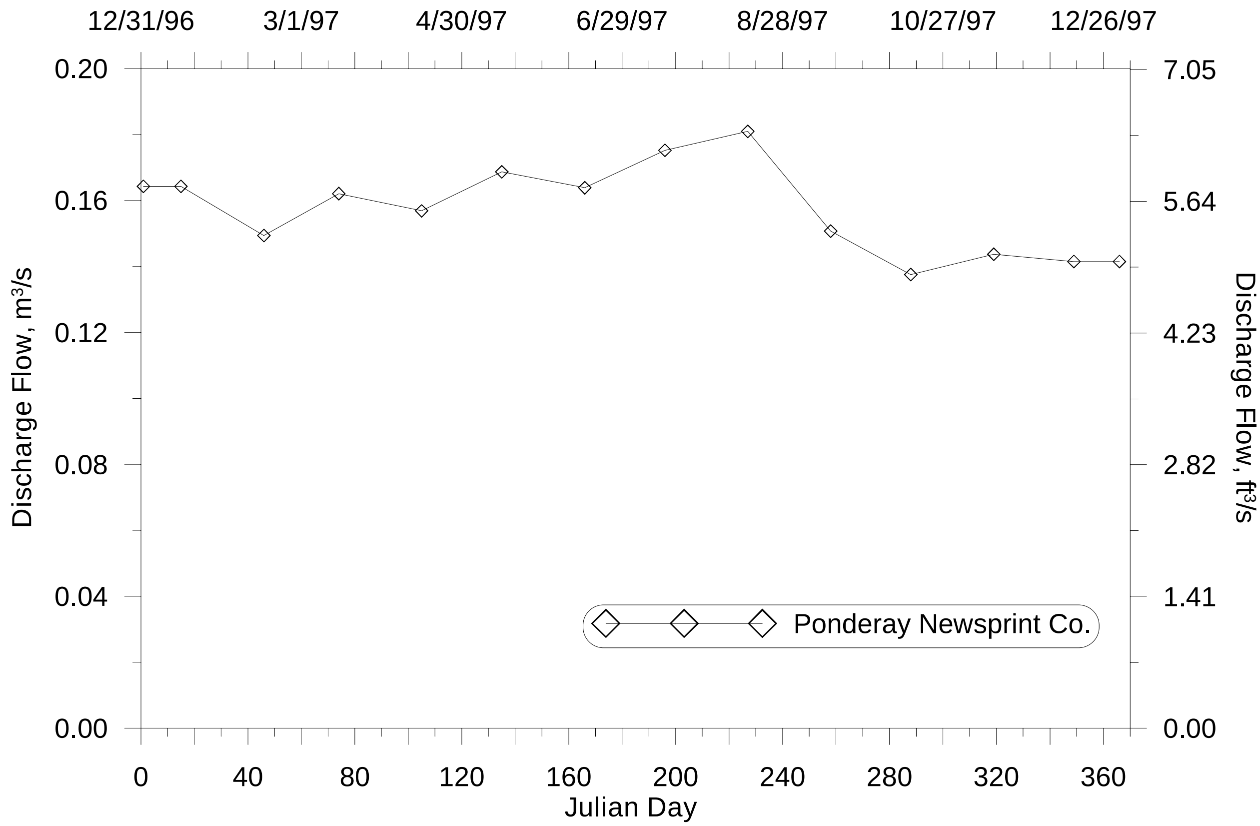

Figure 25: Ponderay Newsprint Co. discharge flow, 1997.

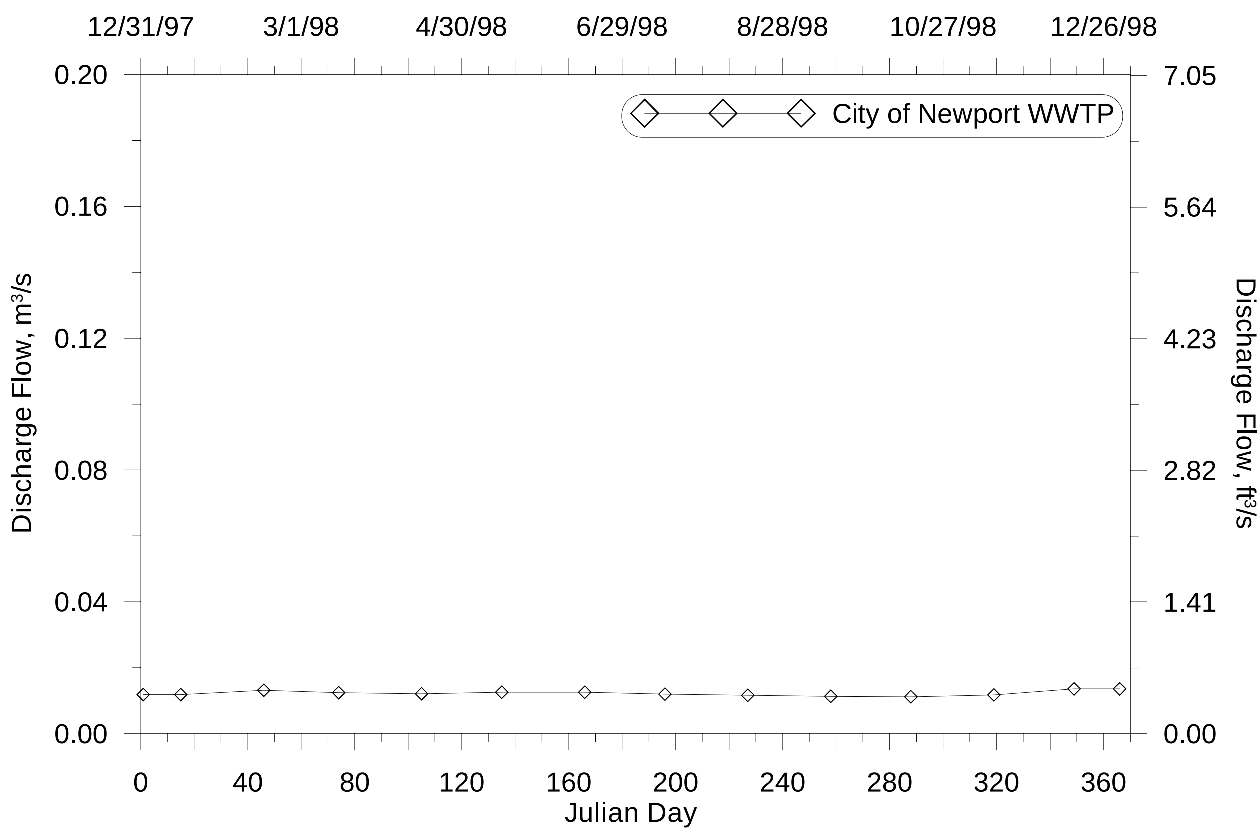

Figure 26: Ponderay Newsprint Co. discharge flow, 1998.

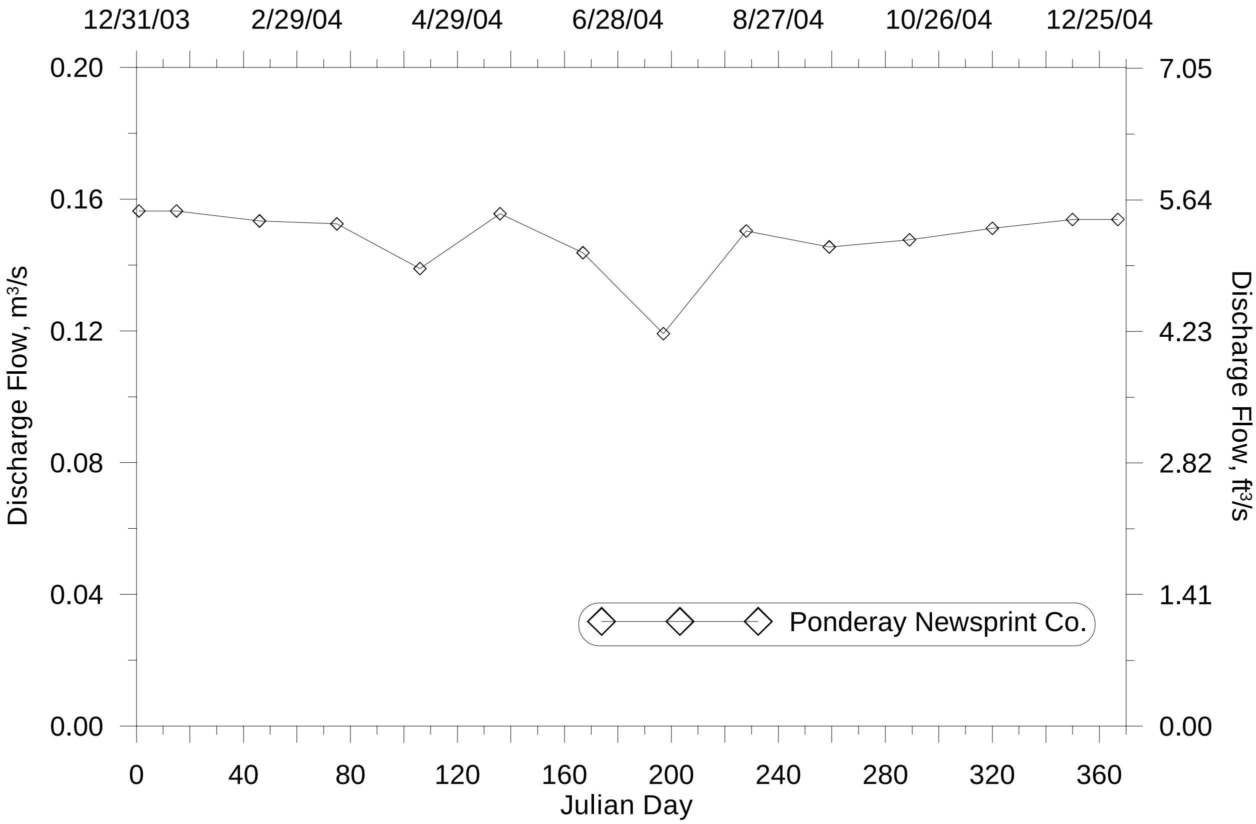

Figure 27: Ponderay Newsprint Co. discharge flow, 2004.

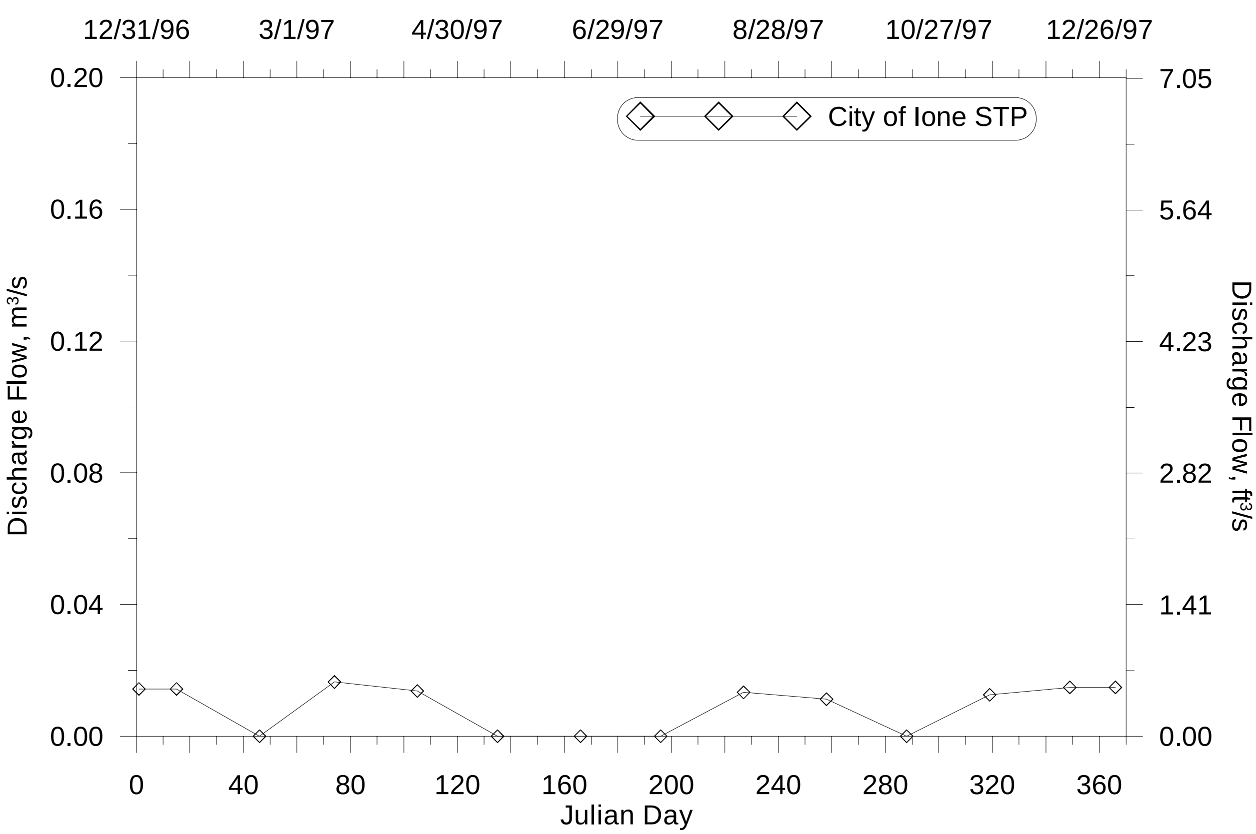

Figure 28: City of Ione STP discharge flow, 1997.

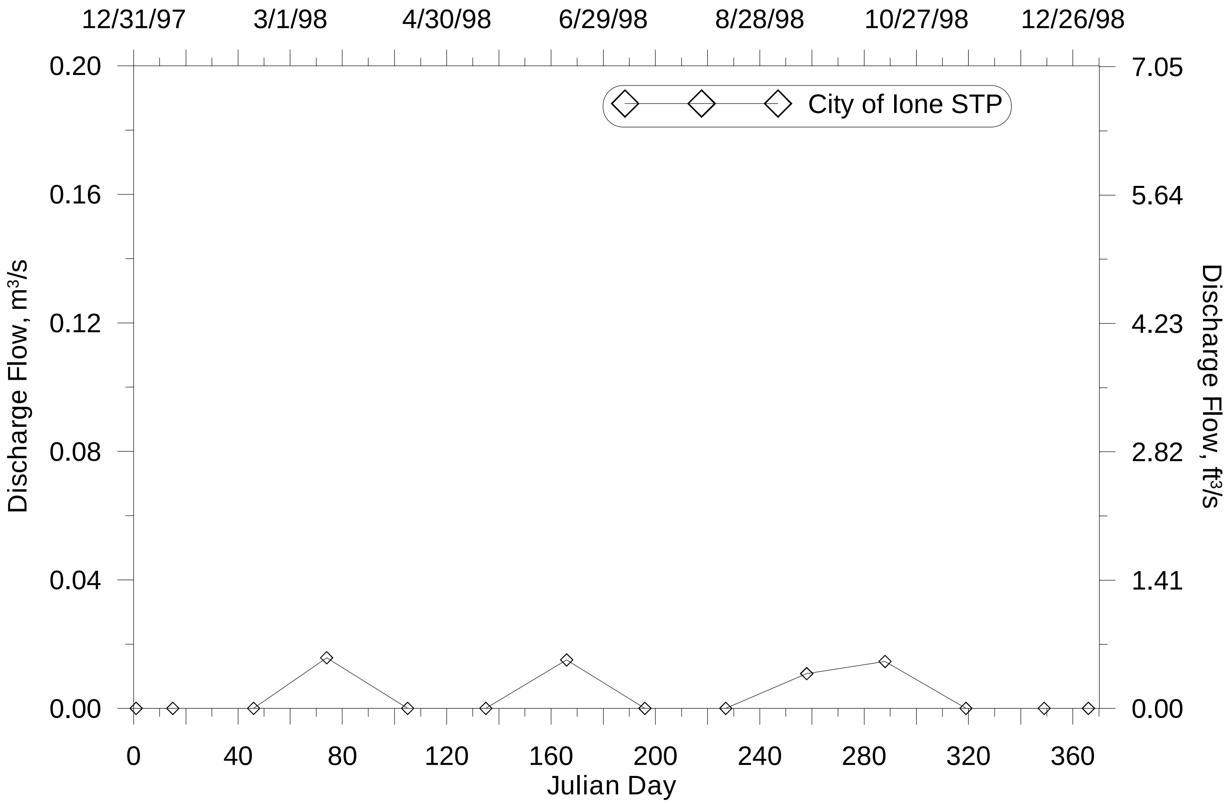

Figure 29: City of Ione STP discharge flow, 1998.

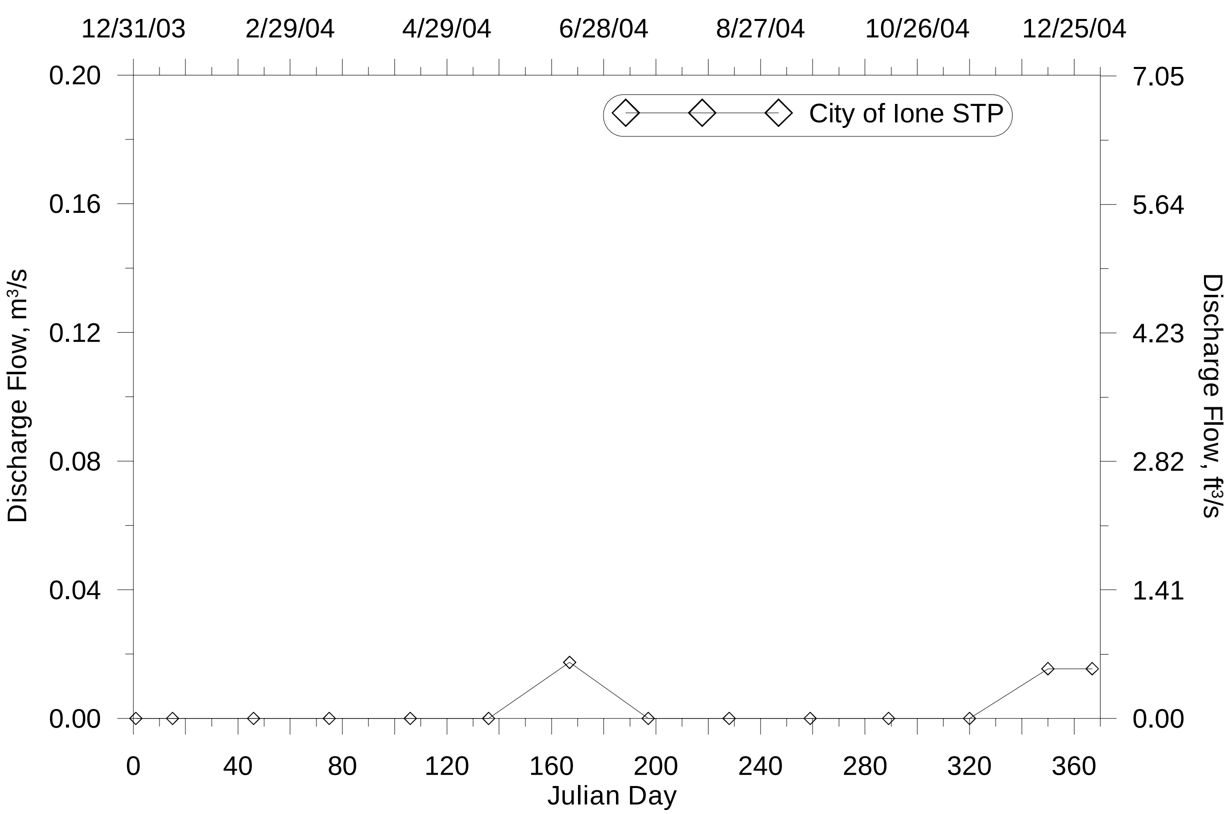

Figure 30: City of Ione STP discharge flow, 2004.

Temperature

Monthly discharge temperatures were provided for each point source by Paul Pickett with the WA Department of Ecology, who provided the following comments (Pickett, 2006):

"Ione treats wastewater with an aerated stablization lagoon. Discharge to the river is intermittent, and the lagoons are open to the sun. Time series for the Ione effluent temperature model inputs were developed from spot measurements with data gaps filled using a sine function regression (to capture seasonality) combined with a multiple linear regression to air temperature, dew point temperature, and cloud cover.

Newport treats wastewater with an oxidation ditch. There is no routine temperature monitoring. Effluent temperature time series were developed using the regression developed for Ione.

Ponderay Newsprint is a pulp mill that treats wastewater with an oxidation ditch and clarifier system. They monitor for temperature regularly, so model inputs are based on observed values."

Figure 31 to Figure 33 show time series plots of the discharge temperatures for the City of Newport WWTP for 1997, 1998, and 2004, respectively. Figure 34 to Figure 36 show time series plots of the discharge temperatures for the Ponderay Newsprint Co. for 1997, 1998, and 2004, respectively. Figure 37 to Figure 39 show time series plots of the discharge temperatures for the City of Ione STP for 1997, 1998, and 2004, respectively.

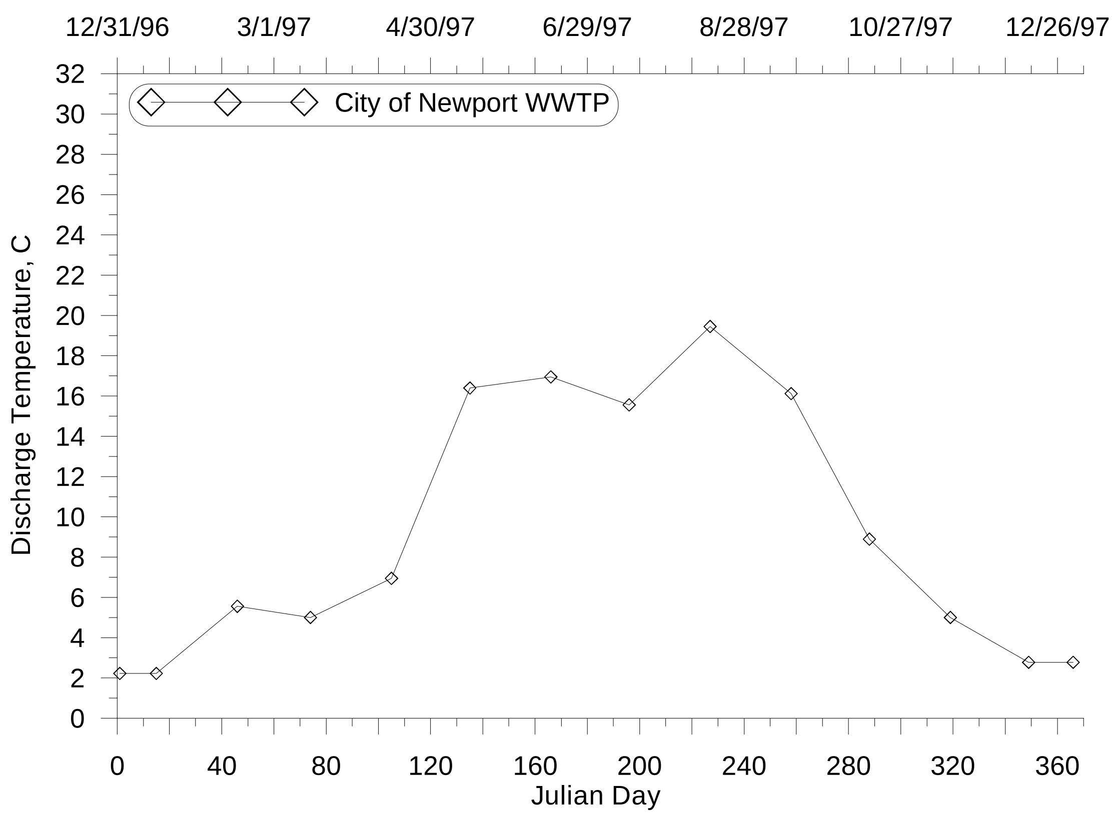

Figure 31: City of Newport WWTP discharge temperature, 1997.

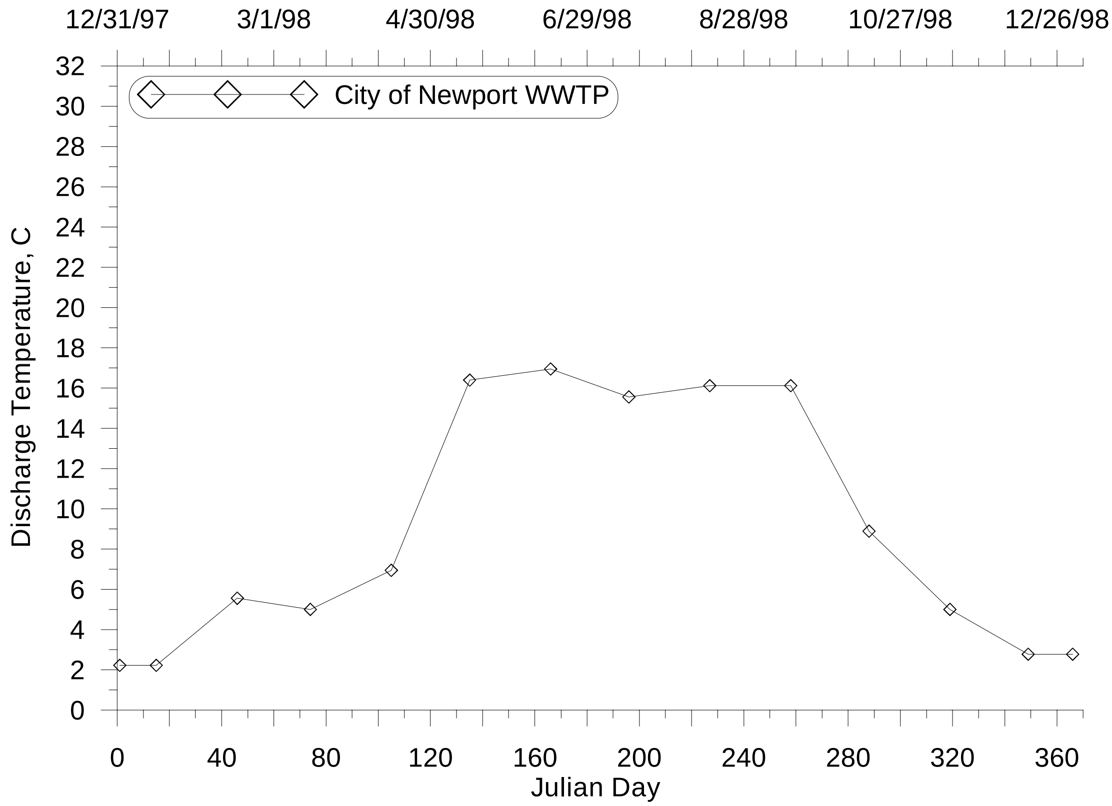

Figure 32: City of Newport WWTP discharge temperature, 1998.

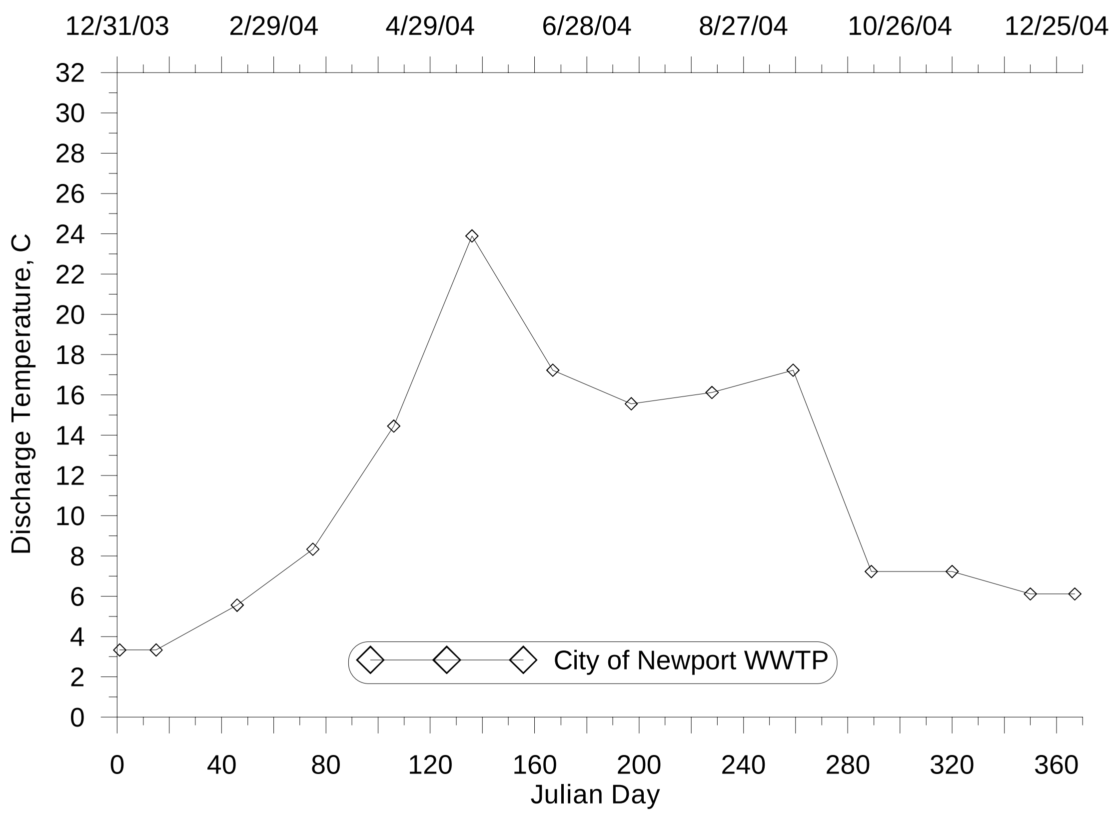

Figure 33: City of Newport WWTP discharge temperature, 2004.

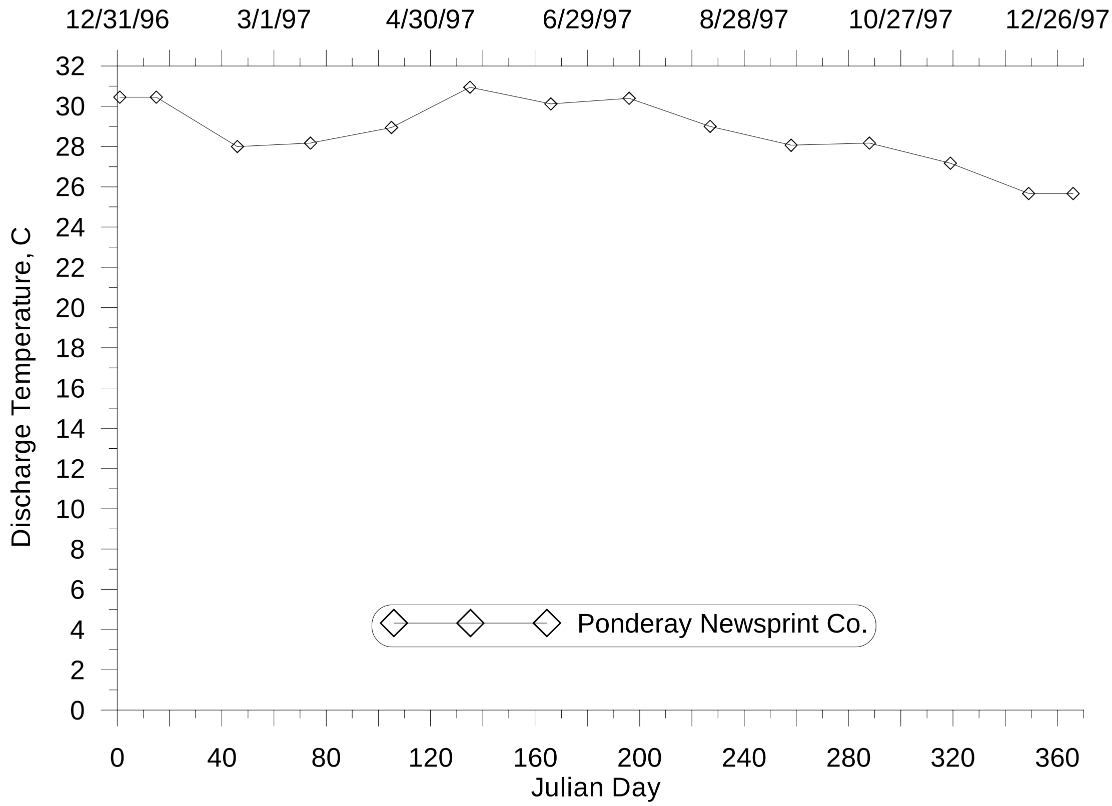

Figure 34: Ponderay Newsprint Co. discharge temperature, 1997.

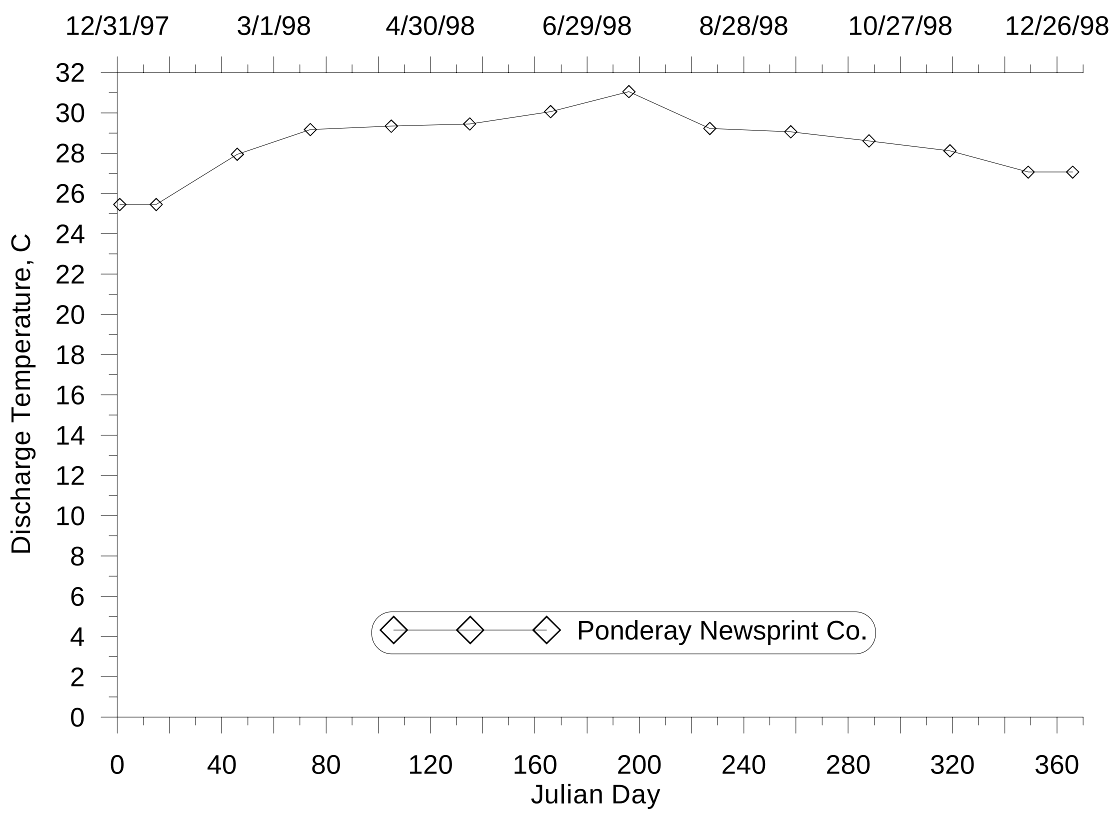

Figure 35: Ponderay Newsprint Co. discharge temperature, 1998.

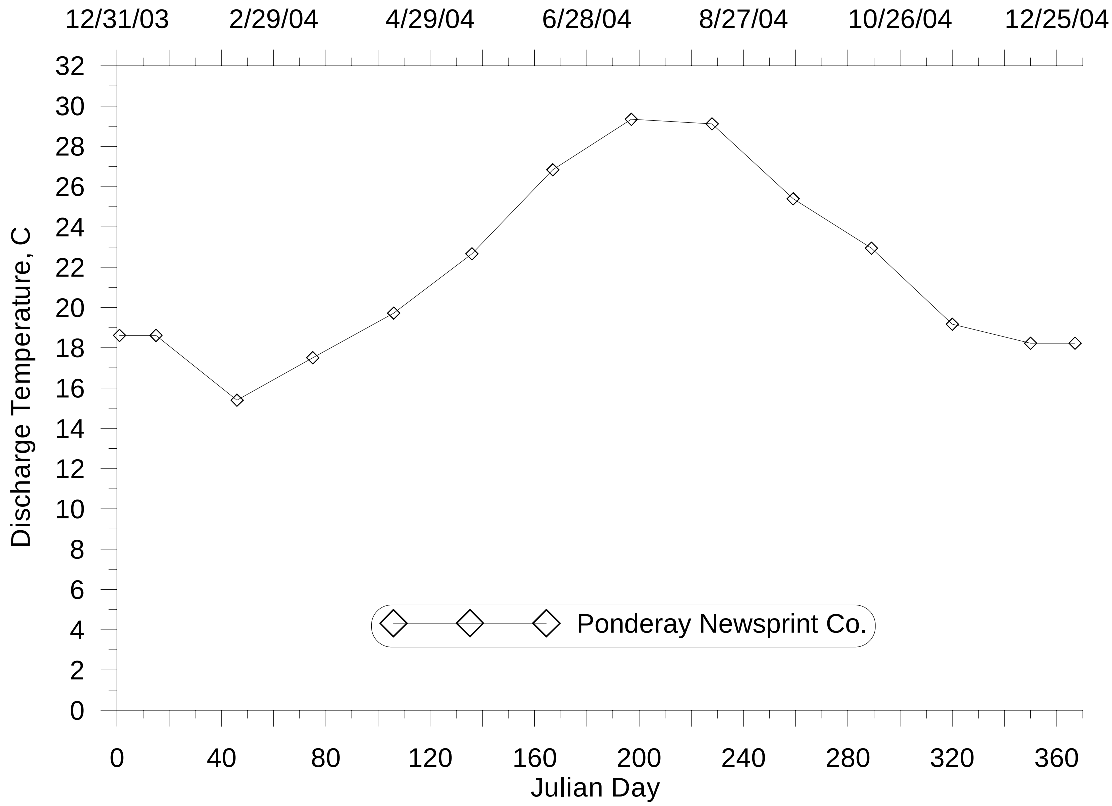

Figure 36: Ponderay Newsprint Co. discharge temperature, 2004.

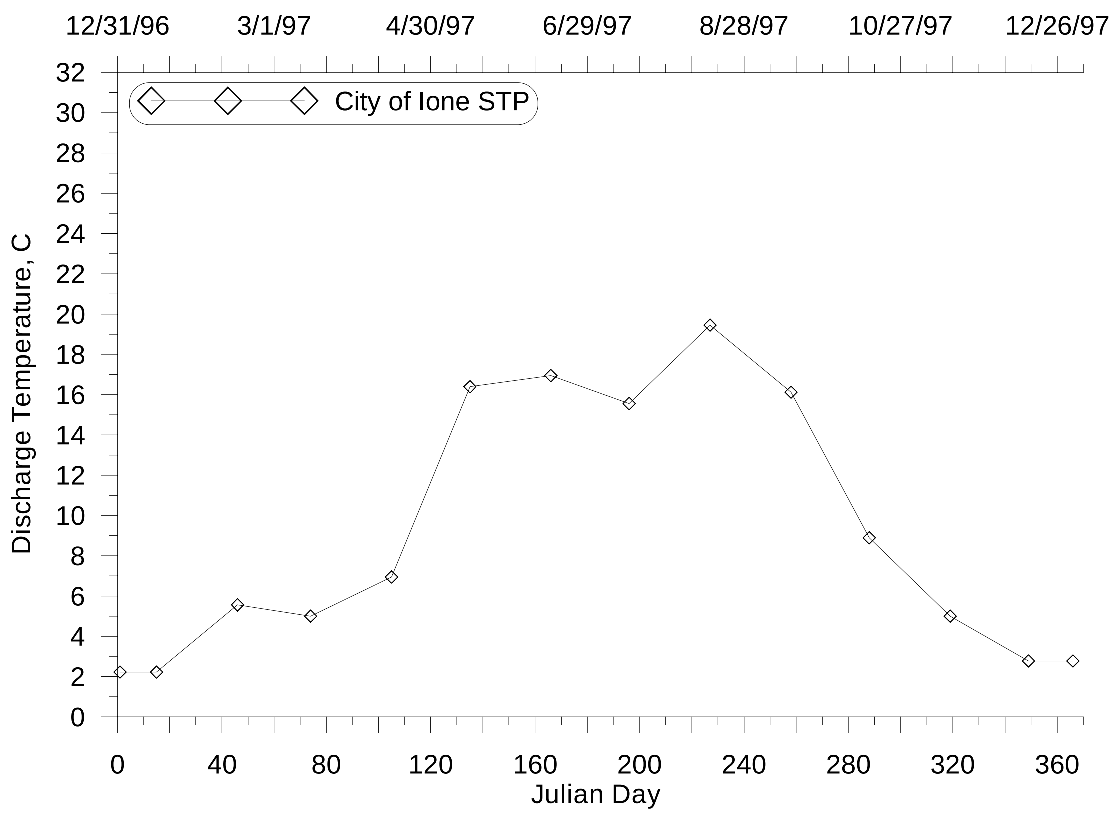

Figure 37: City of Ione discharge temperature, 1997.

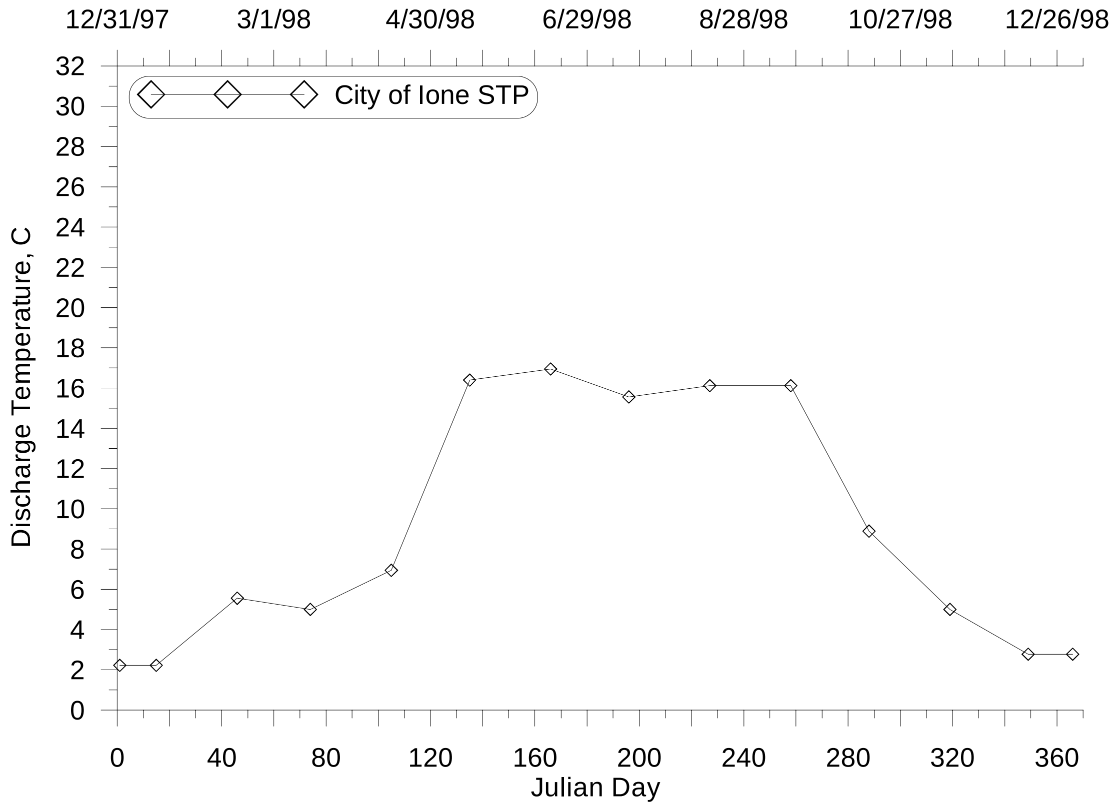

Figure 38: City of Ione discharge temperature, 1998.

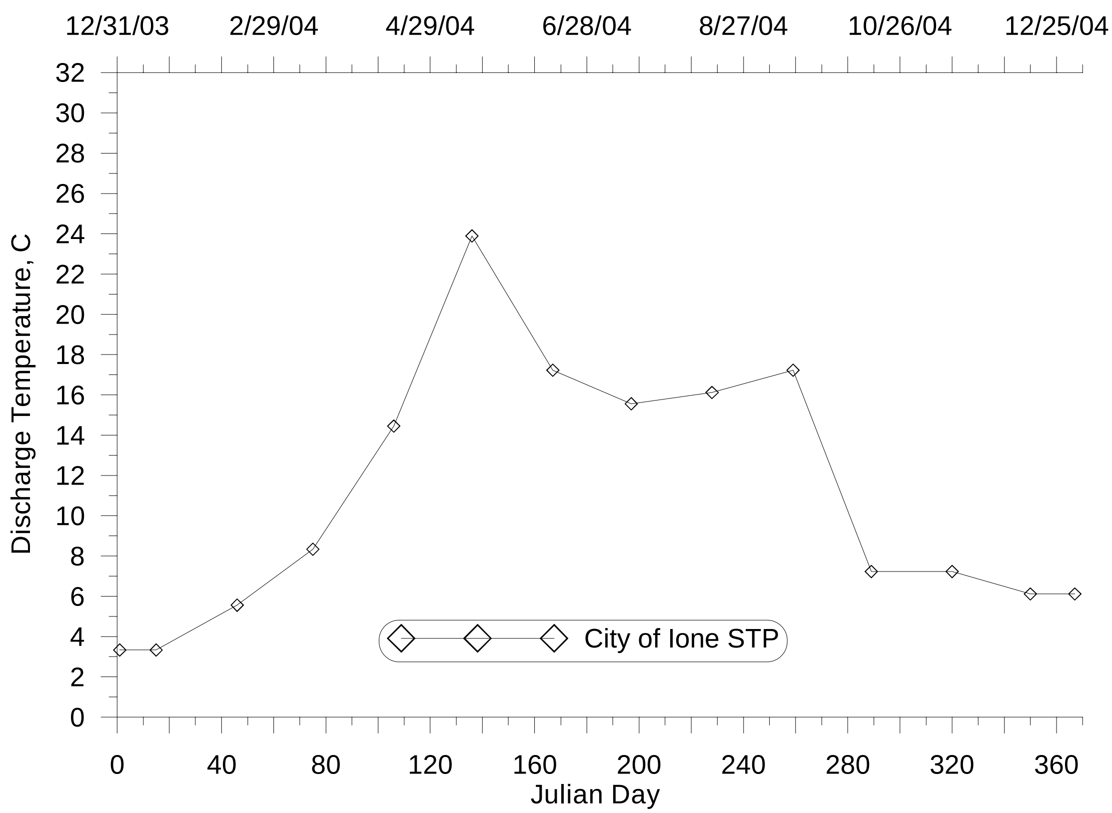

Figure 39: City of Ione discharge temperature, 2004.

Topographic Shade

Topographic shade data were developed for the Pend Oreille River between Albeni Falls Dam and Box Canyon 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. A shaded relief map of the topography in GIS was used to isolate the controlling topography around the river out to a distance of 12 km.

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 40 shows a plot of the arrays for model segment 201. 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. Vegetative shade will be included when the data becomes available.

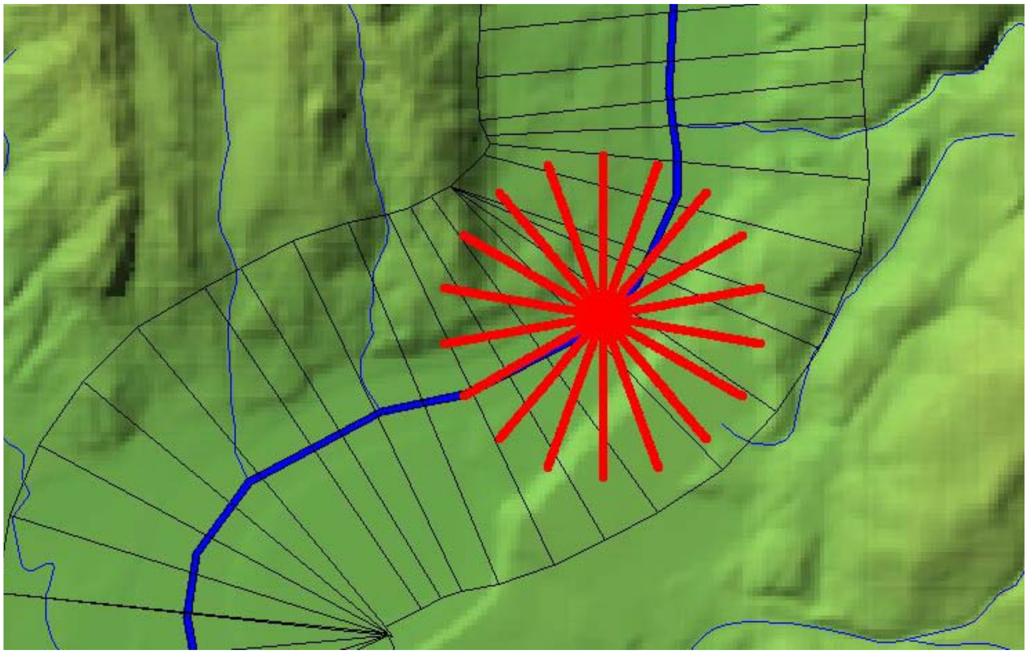

Figure 40: Inclination angle arrays for model segment 201

Meteorology

The Pend Oreille River, Box Canyon Reach model includes 55.7 miles from Albeni Falls Dam to Box Canyon 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 input for the model.

The model uses the meteorological constituents: air and dew point temperature, wind speed and direction, cloud cover and solar radiation. Figure 41 shows the locations of the meteorological stations used in developing the meteorological inputs. Table 5 lists the sites and the organizations responsible for data collection. Additional meteorological data was provided by the Kalispell Tribe for 2004 and 2005. The data was reviewed and compared to the meteorological data from other sites listed in Table 5 but was not used as model input in 2004. The Pend Oreille Utility District/Seattle City Light also provided meteorological data from on top of the Box Canyon Dam. The data was from May 23rd, 2005 to April 25th, 2006 which fell outside the model simulation time periods.

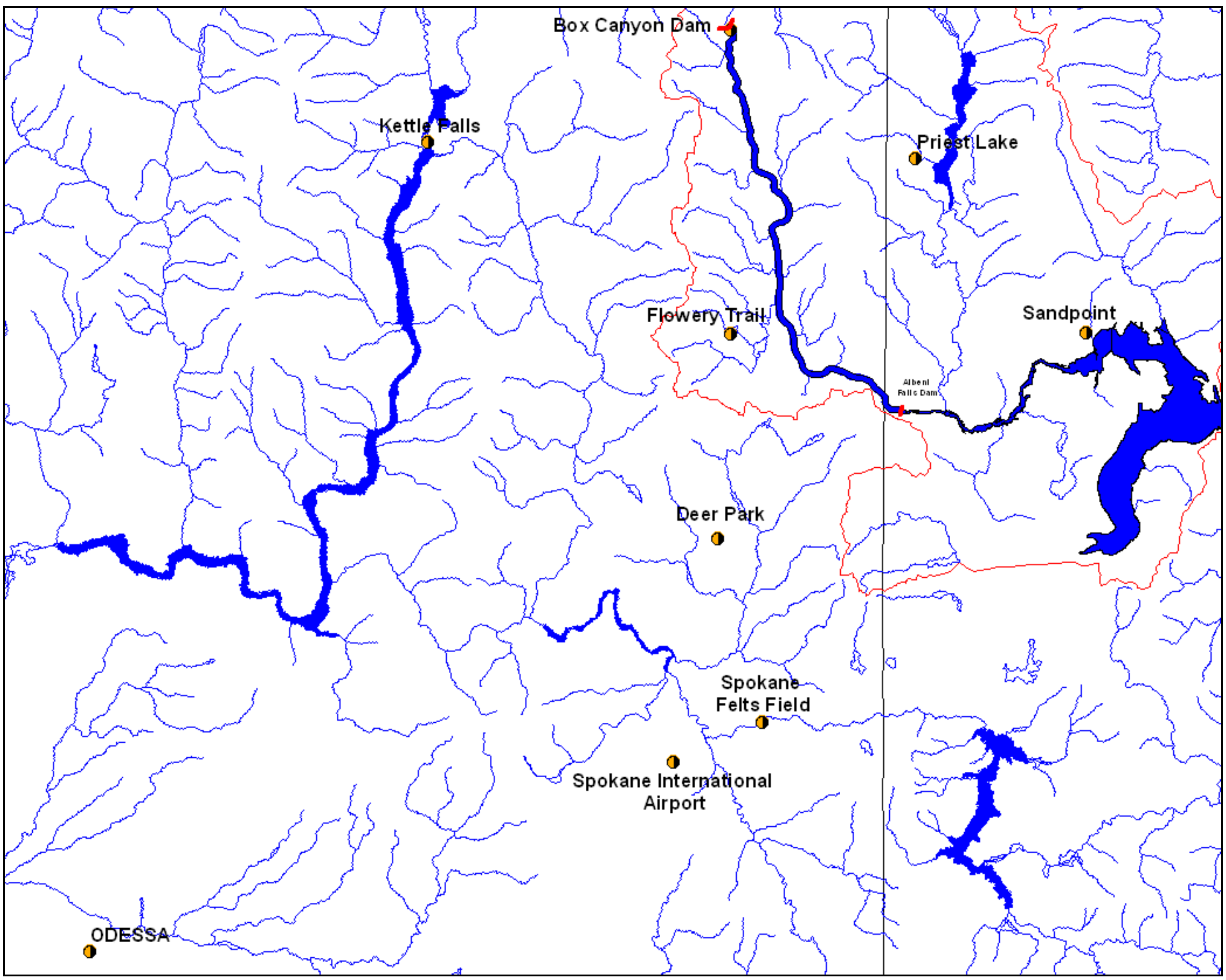

Figure 41: Pend Oreille River, ID model meteorological site locations.

Table 5: 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
Deer Park Airport	National Weather Service (AWOS)	Air Temperature, Dew Point Temperature, Wind Speed, Wind Direction, Cloud Cover
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

1997

The nearest site to the Box Canyon Reach with the most complete data record for the model time period was Flowery Trail (RAWS site). There was a long data gap in the time series of air temperature for 1997. An air temperature correlation was developed between the Flowery Trail site and the Spokane International Airport as shown in Figure 42 and the correlation equation was used to calculate the air temperature at Flowery Trail based on the Spokane Airport record. Figure 43 shows the time series air temperature data at Flowery Trail, including the calculated values from the correlation. There was also a data gap in the dew point temperature data so a similar correlation was developed with the Spokane International Airport as shown in Figure 44. Figure 45 shows a time series plot of the dew point temperature data and calculated values from the correlation.

Because wind speed and direction data are so variable and dependant on location no correlation was developed to fill in data gaps in the time record for 1997 at Flowery Trail. Instead wind speed and direction data were used directly from the Spokane International Airport since this site was the closest to the Flowery Trail site with the most complete record. Figure 46 and Figure 47 show time series of the wind speed and direction data, respectively, including the values from the Spokane Airport. Figure 48 shows the wind direction data as a rose diagram, showing the orientation of the wind relative to the orientation of the Box Canyon Reach of the river

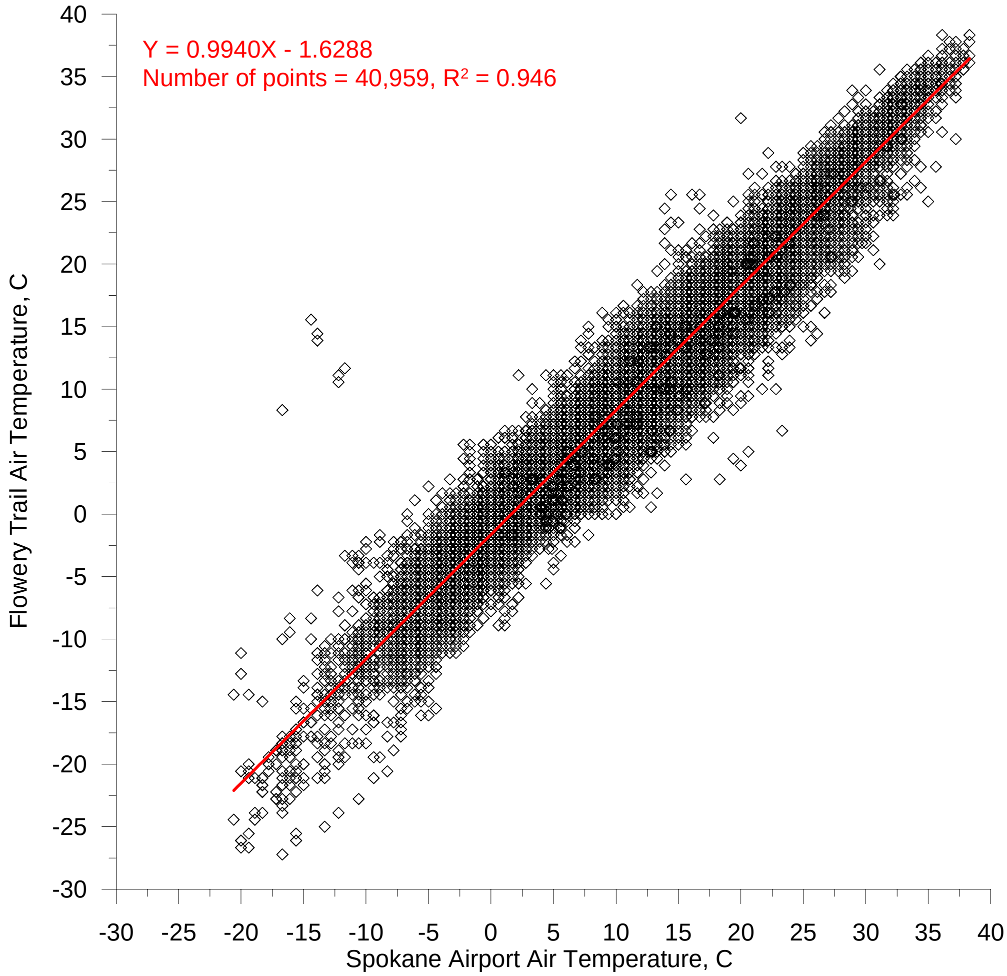

Figure 42: Air temperature correlation between Spokane International Airport and Flowery Trail.

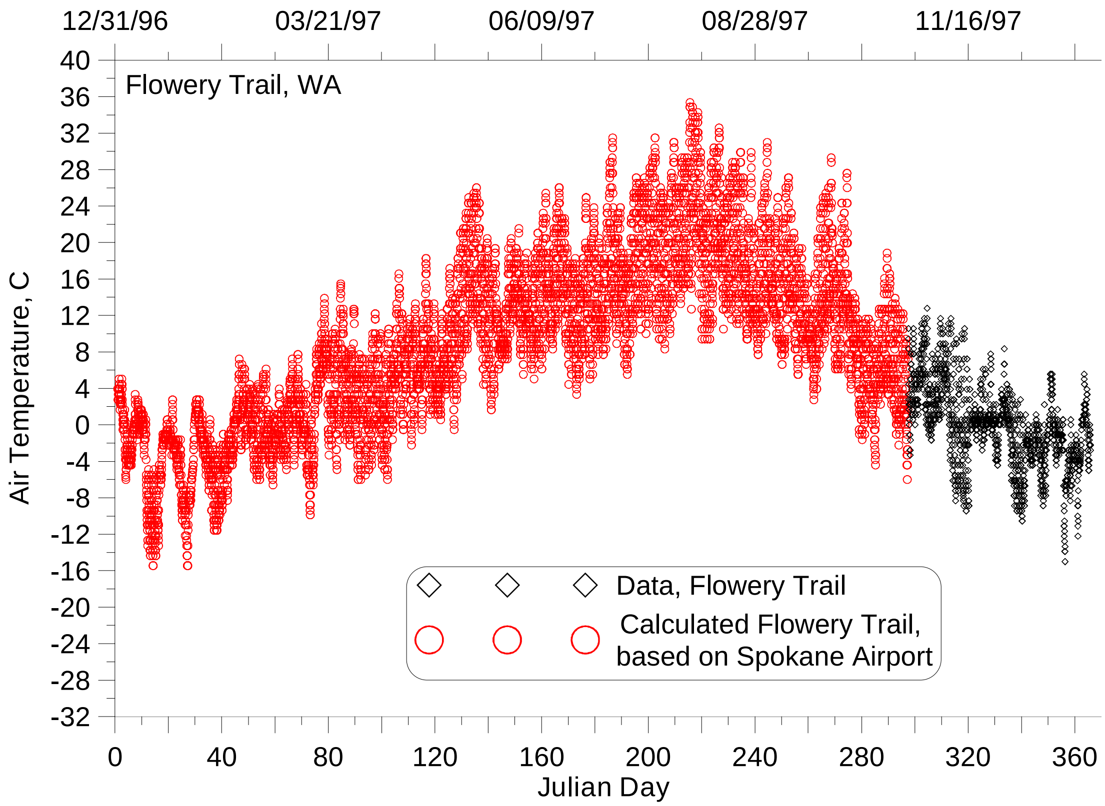

Figure 43: Air temperature at Flowery Trail, 1997.

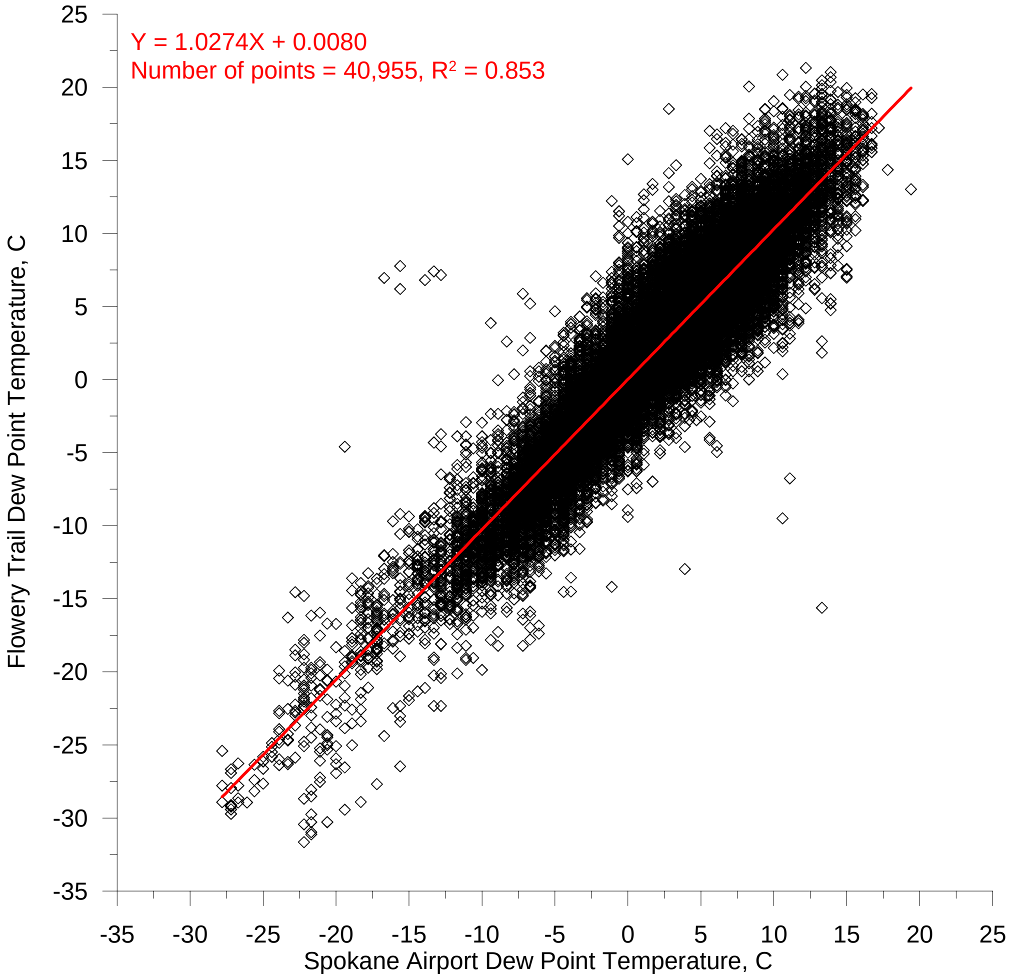

Figure 44: Dew point temperature correlation between Spokane International Airport and Flowery Trail.

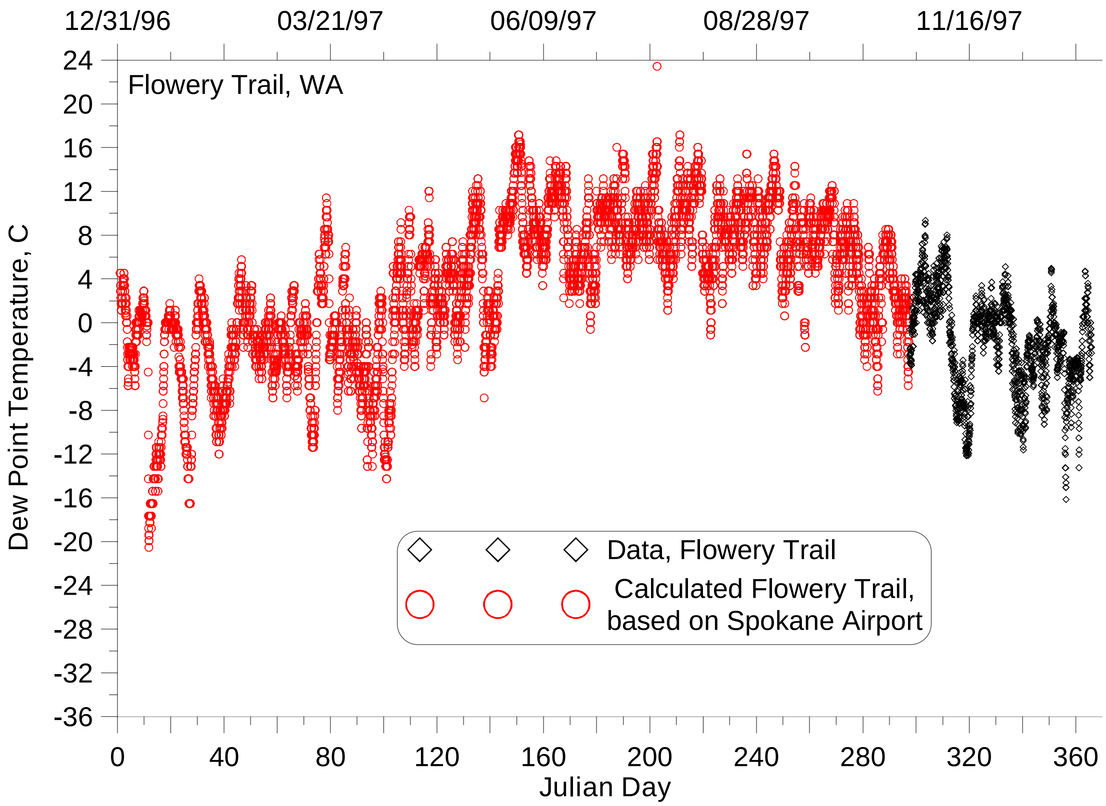

Figure 45: Dew point temperature at Flowery Trail, 1997.

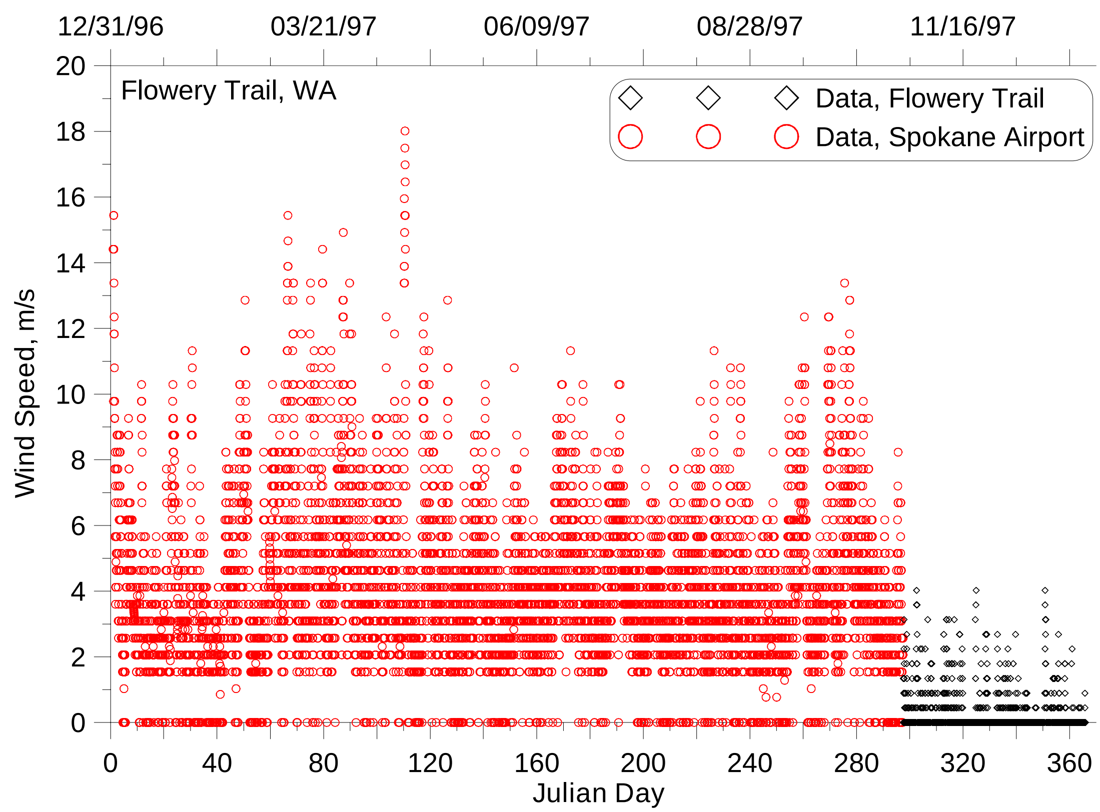

Figure 46: Wind Speed at Flowery Trail and Spokane Airport, 1997

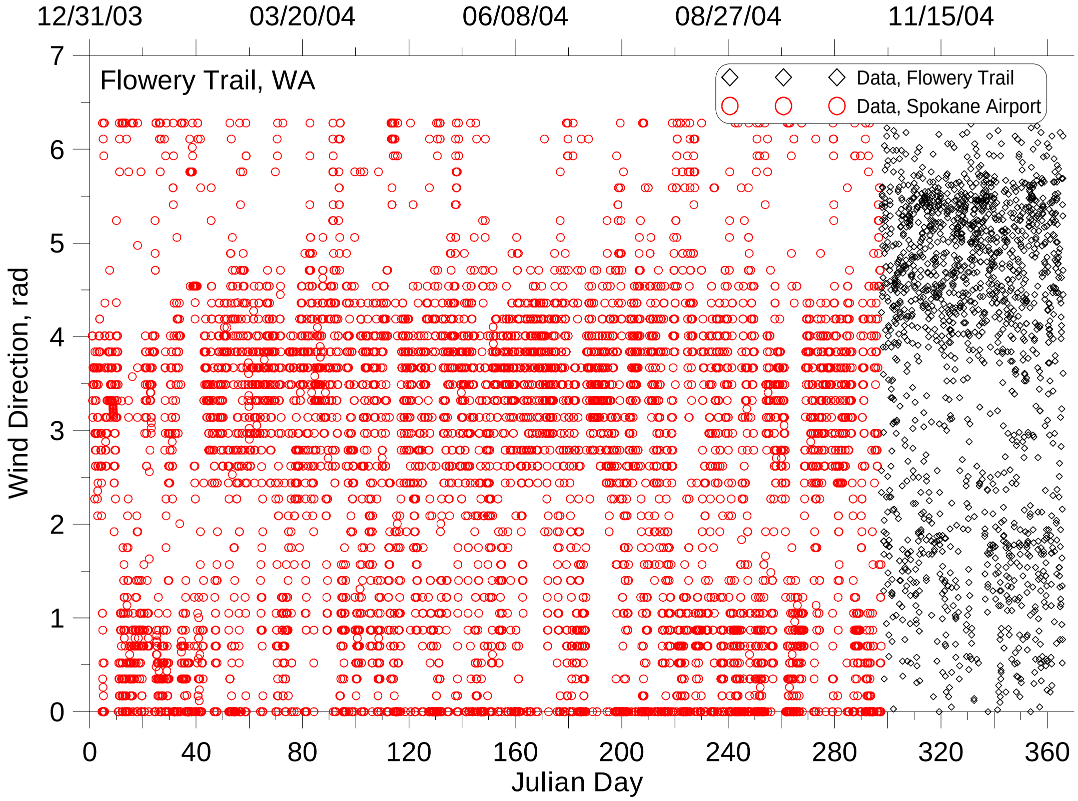

Figure 47: Wind Direction at Flowery Trail, 1997

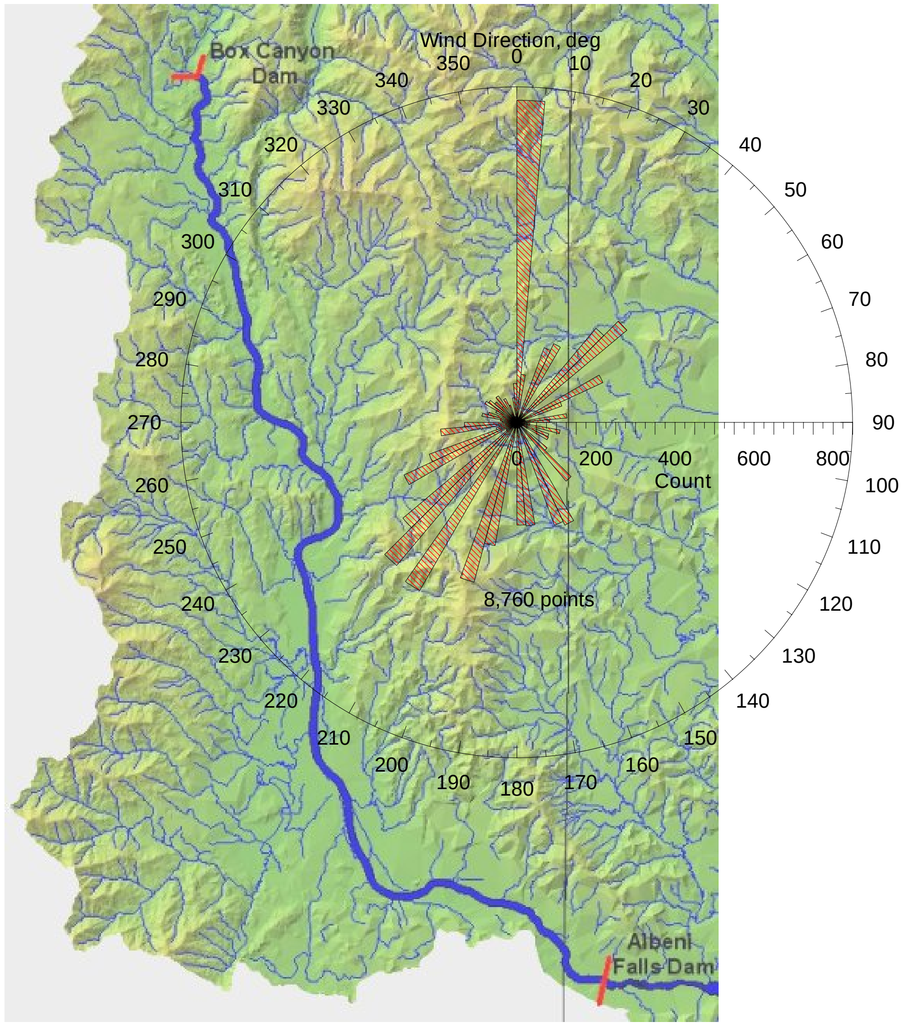

Figure 48: Wind Orientation at Flowery Trail, 1997

The nearest site monitoring solar radiation was Kettle Falls, WA, next to Lake Roosevelt, but no data was collected in 1997 and 1998. A solar radiation correlation was developed between Odessa, WA and Kettle Falls, WA as shown in Figure 49. The correlation equation was then used to calculate the solar radiation at Kettle Falls for 1997. Figure 50 shows a time series plot of the calculated solar radiation at Kettle Falls.

The cloud cover data recorded at several sites in the area were found to be limited with large data gaps and values fixed at one of five categories. The solar radiation data at Kettle Falls were compared with the calculated theoretical clear sky solar radiation for the 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 51 show time series plot of the calculated cloud cover at Kettle Falls, WA which was used in the model.

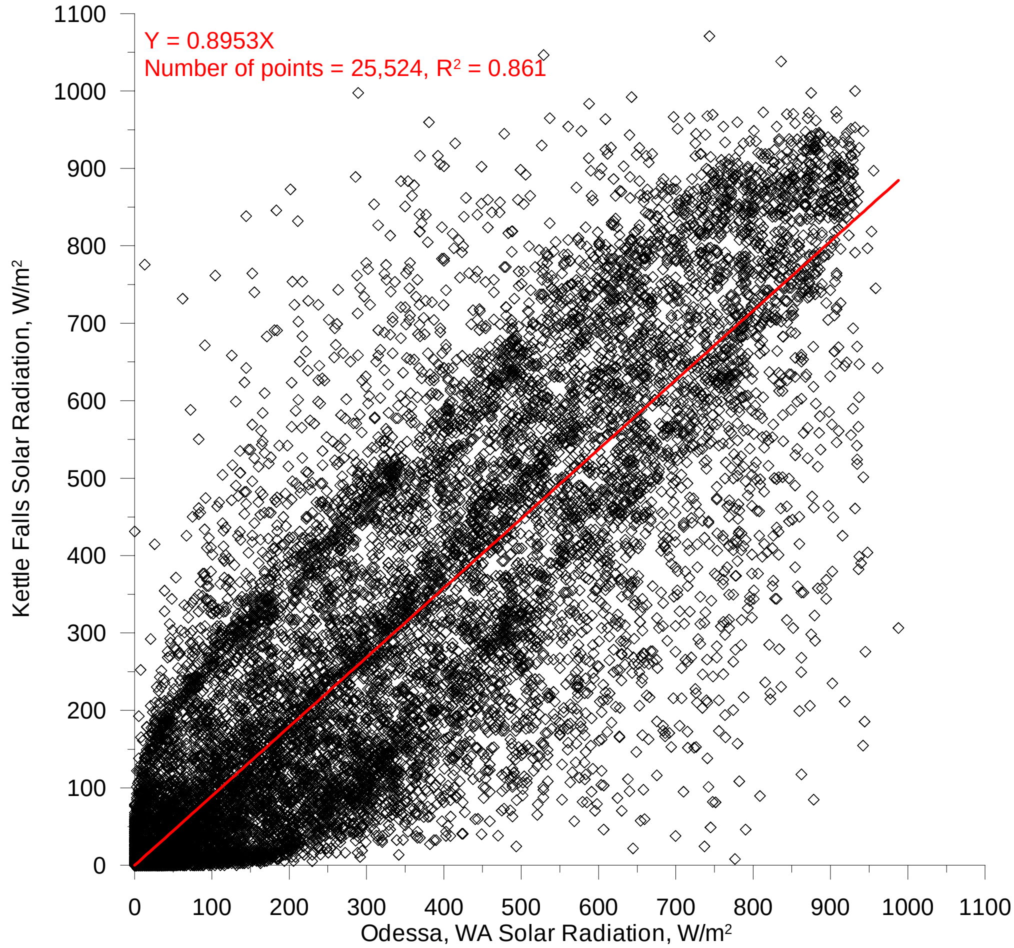

Figure 49: Solar radiation correlation between Odessa and Kettle Falls

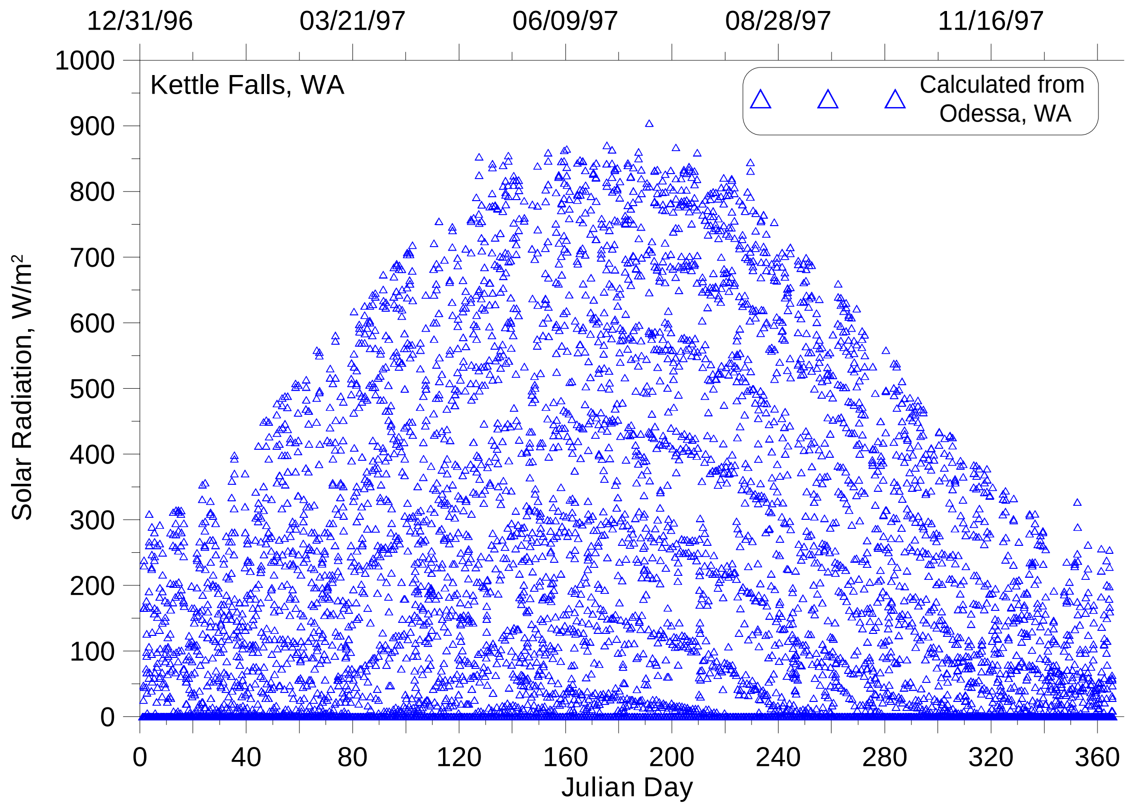

Figure 50: Solar radiation at Kettle Falls, 1997

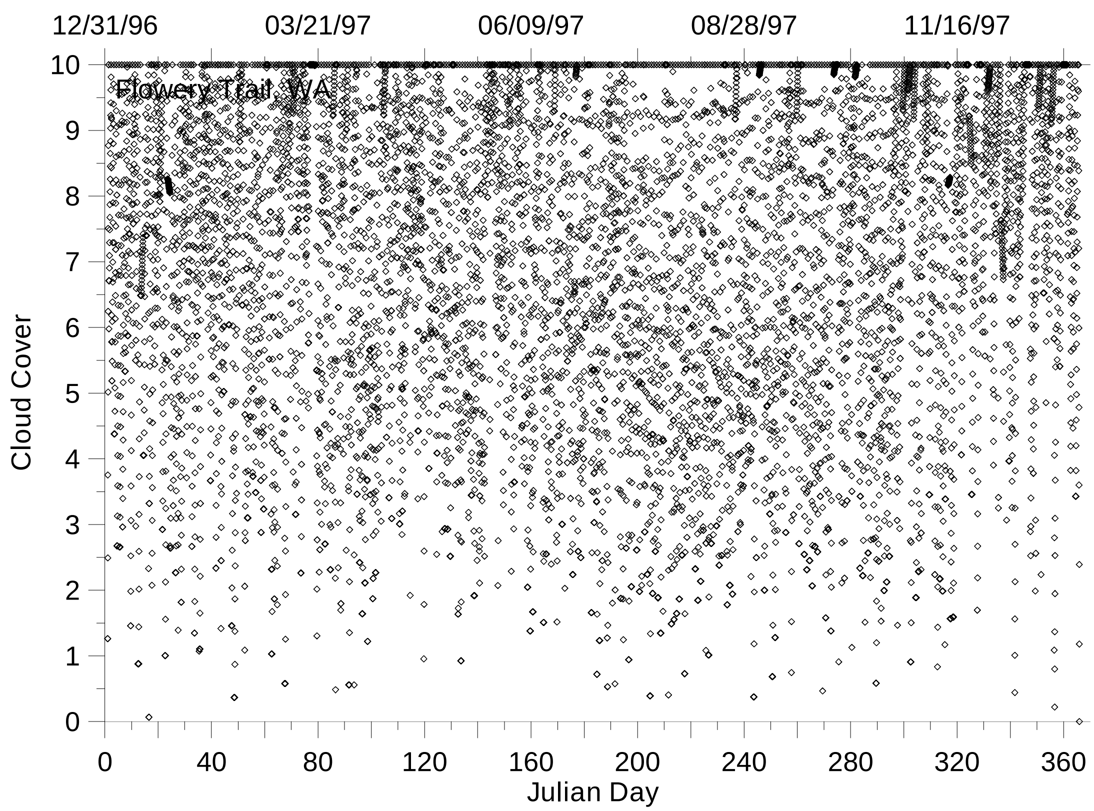

Figure 51: Cloud cover at Kettle Falls, 1997.

1998

The data set at Flowery Trail (RAWS) was most complete in 1998. Figure 52 shows a time series plot of the air temperature at Flowery Trail and Figure 53 shows a time series plot of the dew point temperature at the same site. Figure 54 shows time series plots of the wind speed at the monitoring site and Figure 55 shows a time series of the wind direction data. Figure 56 shows an orientation of the wind relative to the orientation of the Box Canyon Reach of the Pend Oreille River.

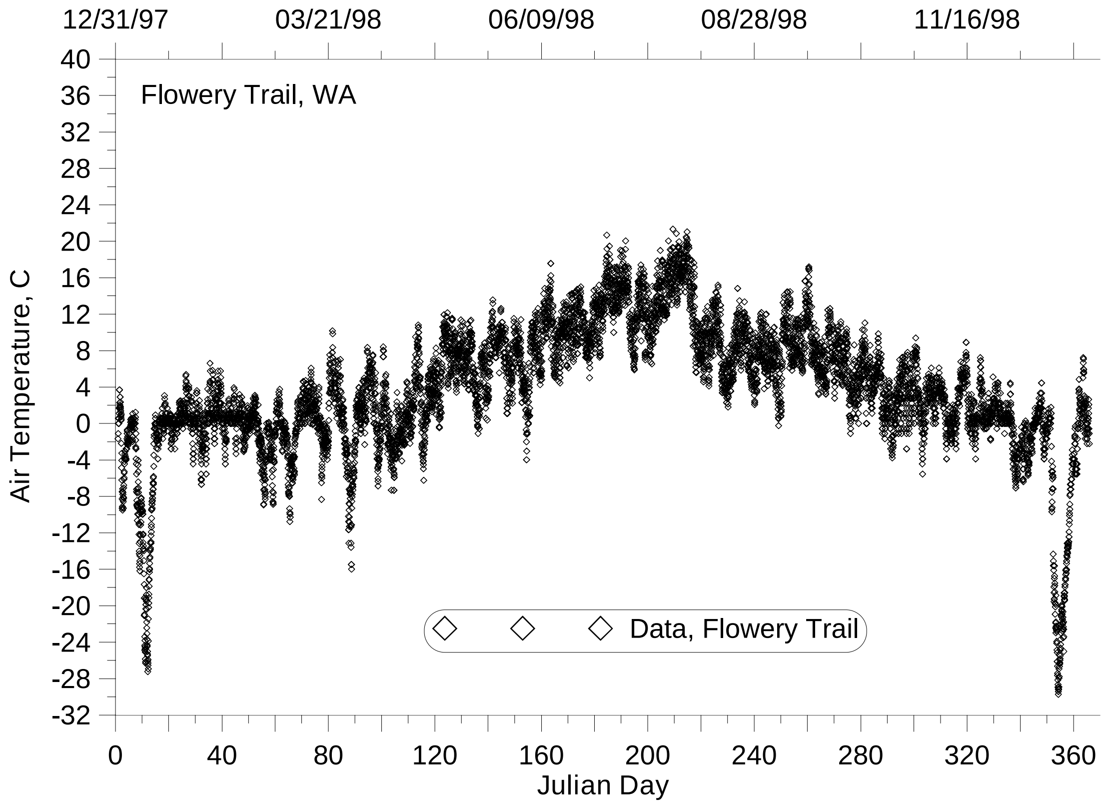

Figure 52: Air temperature at Flowery Trail, 1998.

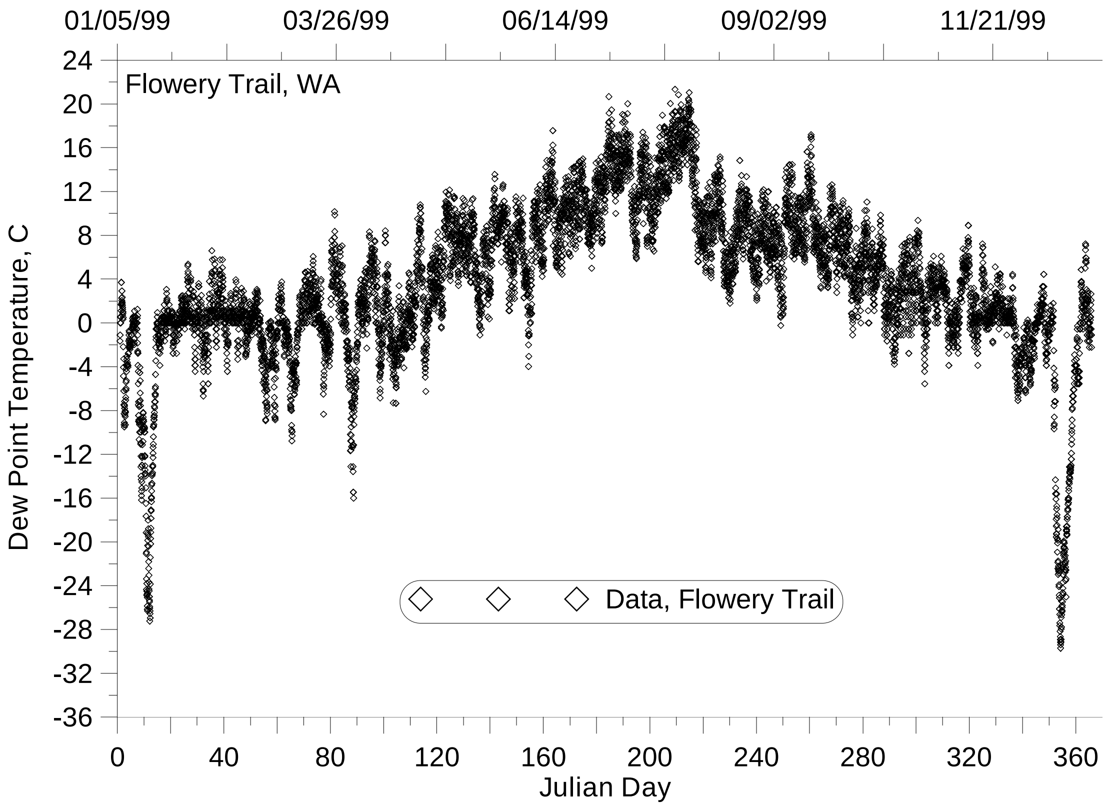

Figure 53: Dew point temperature at Flowery Trail, 1998.

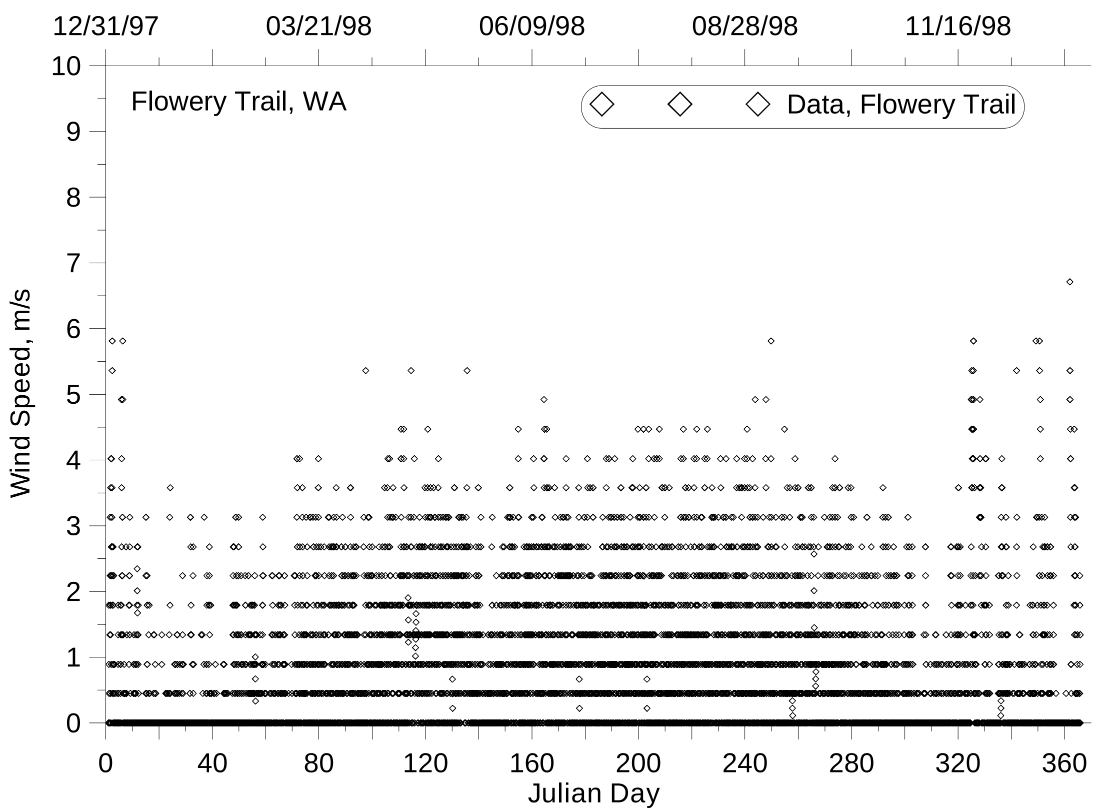

Figure 54: Wind Speed at Flowery Trail, 1998.

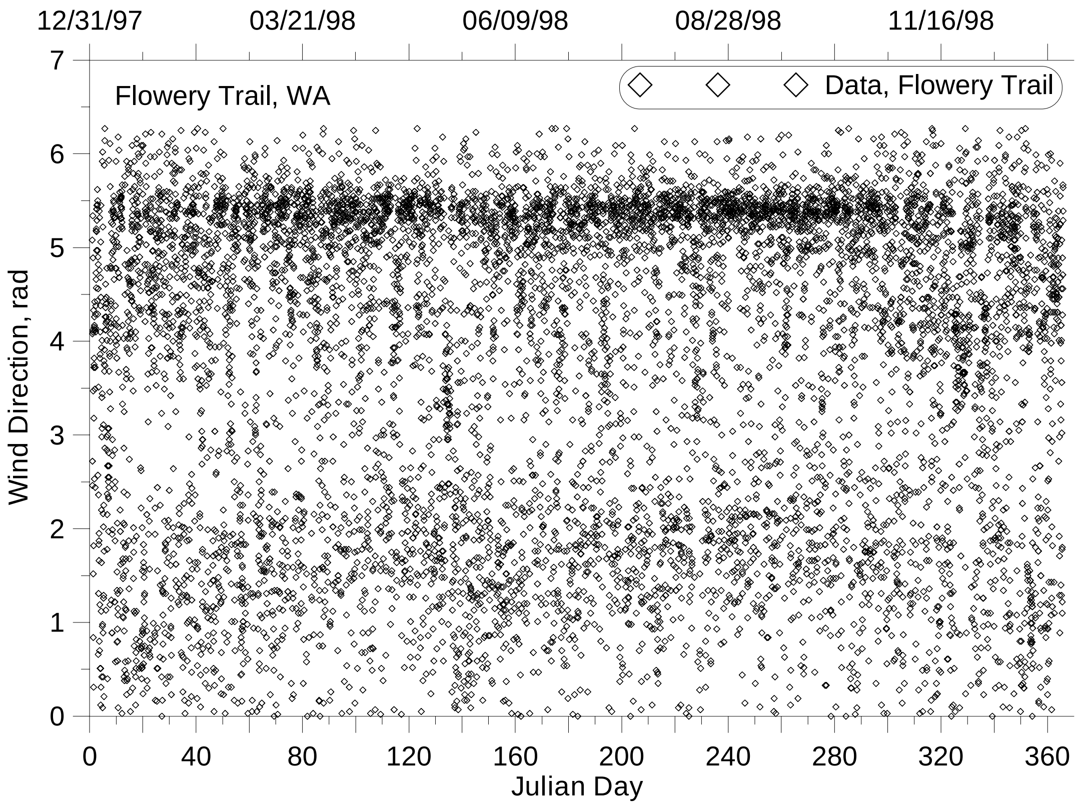

Figure 55: Wind Direction at Flowery Trail, 1998.

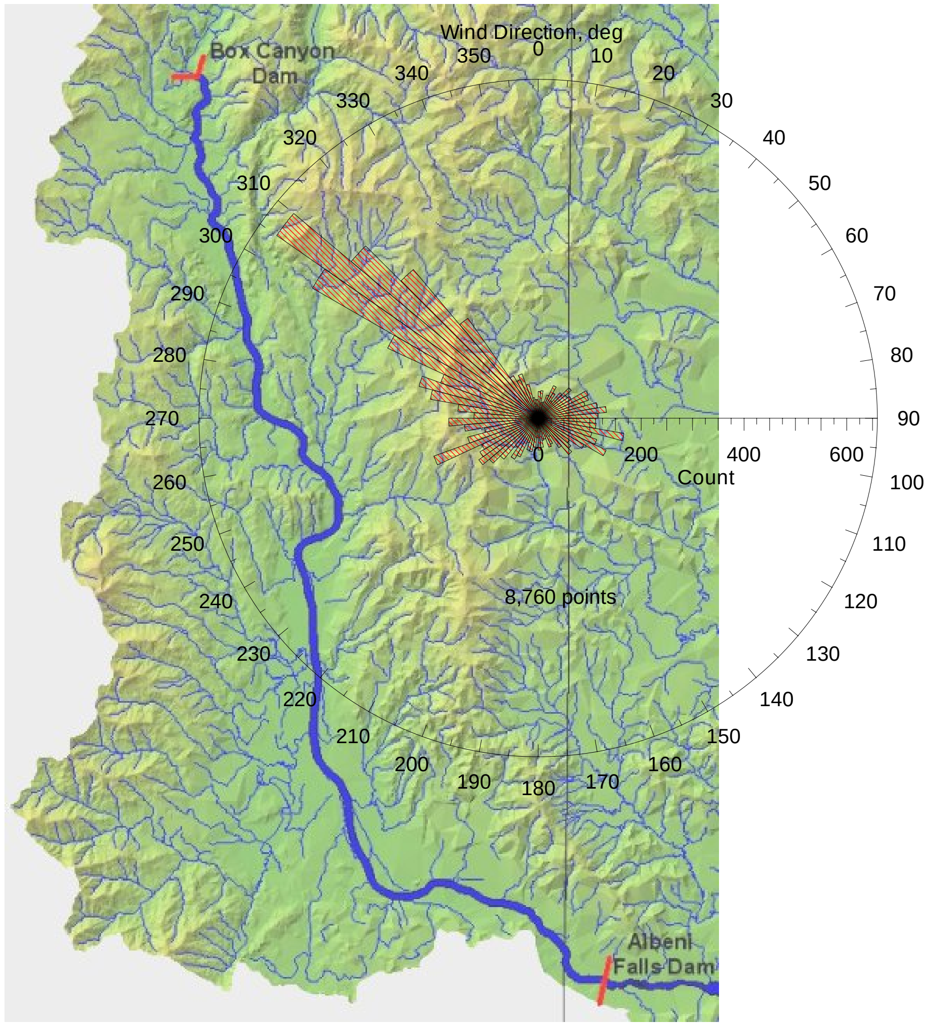

Figure 56: Wind orientation at Flowery Trail, 1998.

Similar to the data set in 1997 the nearest site monitoring solar radiation was Kettle Falls, WA, next to Lake Roosevelt, but no data were collected in 1997 and 1998. The same correlation developed and presented in Figure 49 was used to calculate the solar radiation at Kettle Falls as shown in Figure 57.

The solar radiation data at Kettle Falls were compared with the calculated theoretical clear sky solar radiation for the site and used to calculate the cloud cover for each site using the same equation from Cole and Wells (2004) as with the 1997 data set. Figure 58 shows a time series plot of the calculated cloud cover at Kettle Falls, WA which was used in the model.

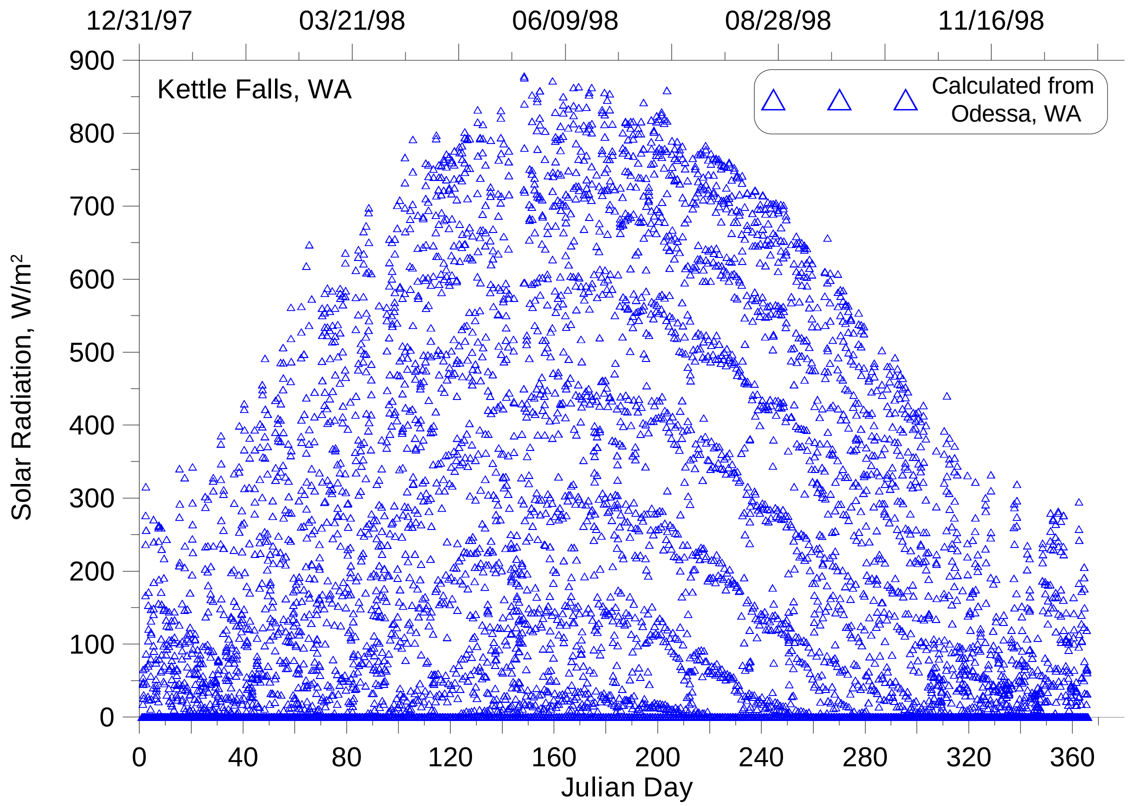

Figure 57: Solar radiation at Flowery Trail, 1998.

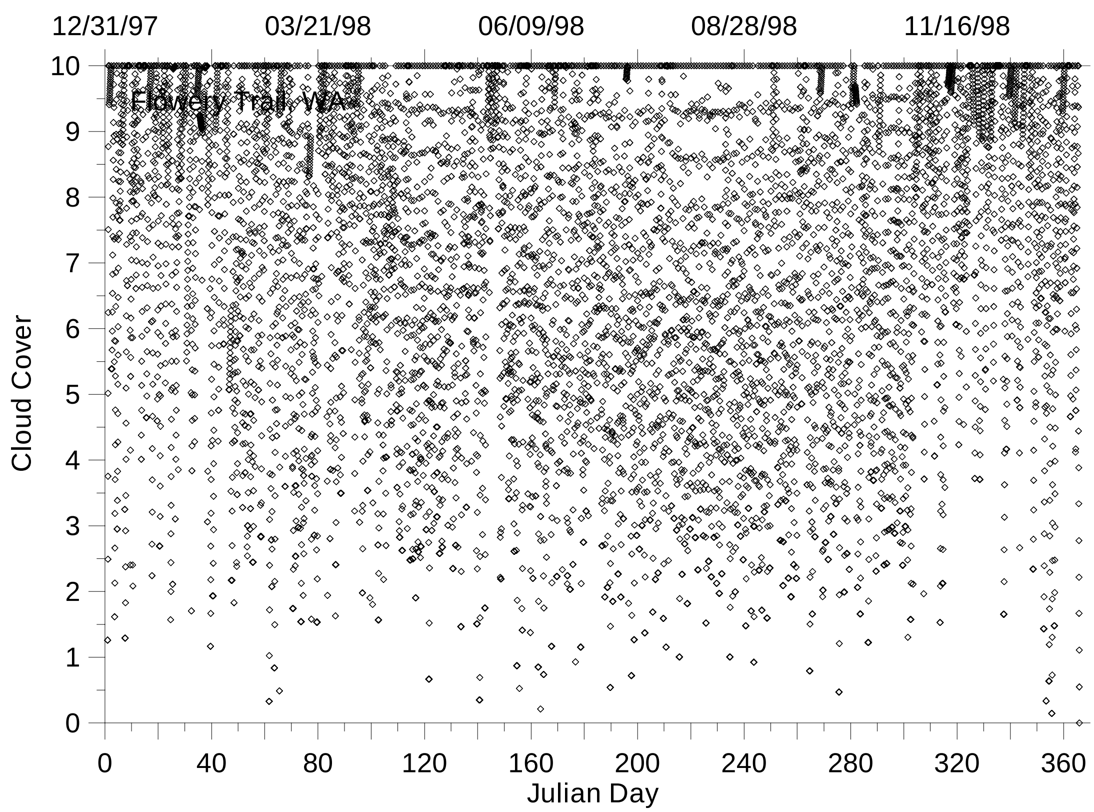

Figure 58: Cloud cover at Flowery Trail, 1998.

2004

The meteorological input to the model for 2004 consisted of data from the Deer Park Airport site in WA. There was only limited data in 1998, but a complete year of data in 2004. Figure 59 shows a time series plot of the air temperature at the Deer Park Airport. Figure 60 shows a time series plot of the dew point temperature at the Deer Park Airport.

Figure 61 and Figure 62 show time series plots of the wind speed and direction, respectively. The figure shows the minimum wind speed the instrument detects is 1.54 m/s. Wind speed below this value are recorded as zero with the wind direction reported as zero. Figure 63 shows a rose diagram illustrating the orientation of the wind relative the river orientation for the box Canyon Reach. In this figure the wind direction values were removed from the plot (2,735 points) to allow the rest of the wind direction data to be shown.

Figure 64 shows a time series plot of the solar radiation data monitored at Kettle Falls, WA in 2004 and used in the model since there was no solar radiation data at Deer Park Airport. Figure 65 shows a time series plot of the cloud cover data at the Deer Park Airport which was used in the model.

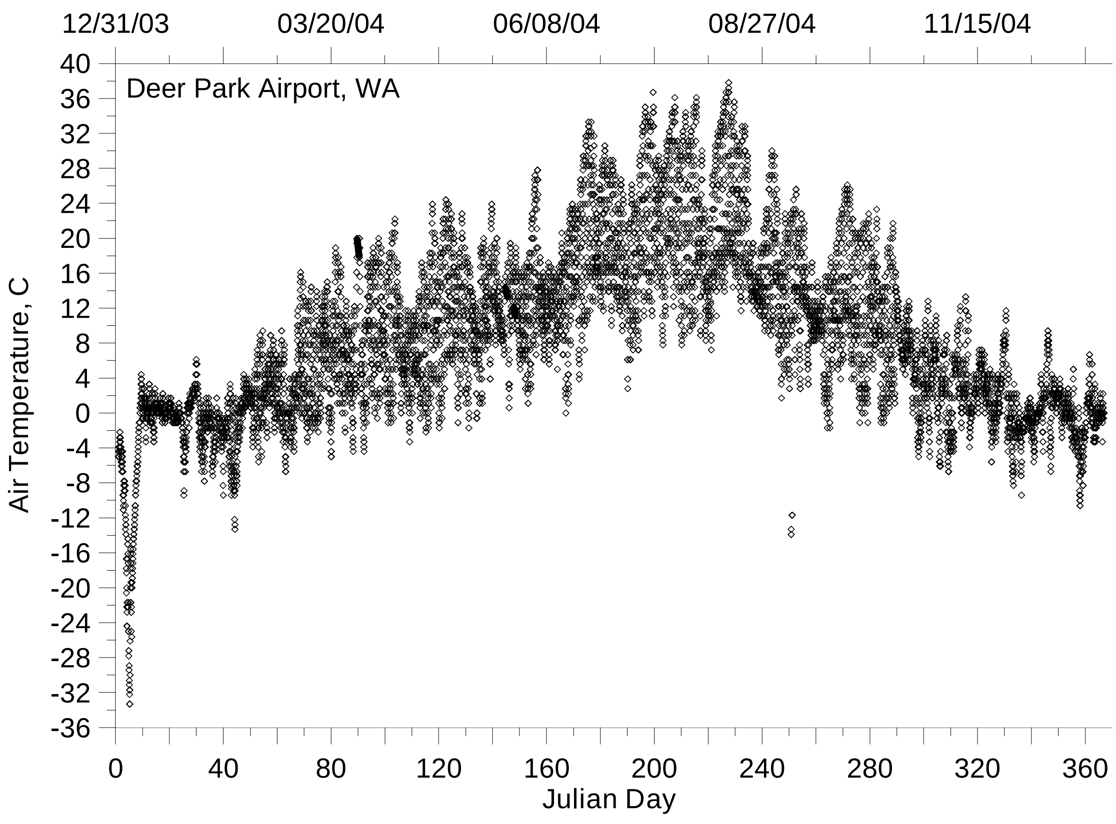

Figure 59: Air temperature at Deer Park Airport, 2004.

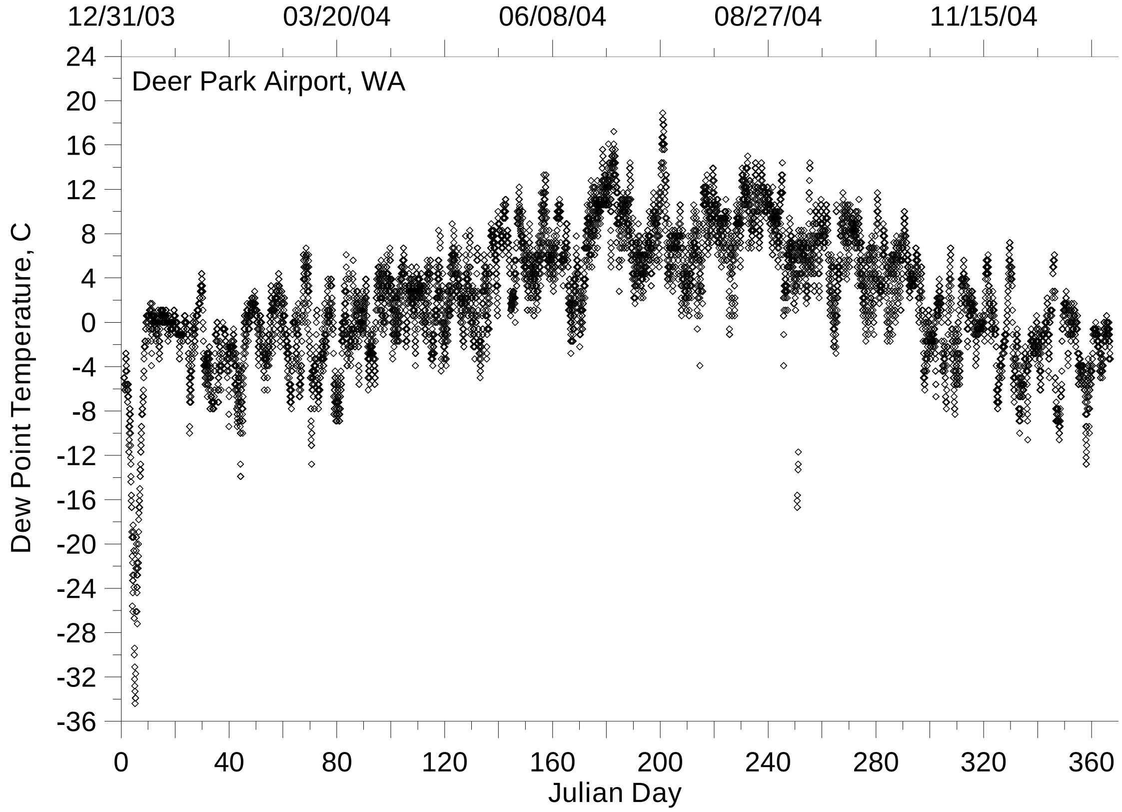

Figure 60: Dew point temperature at Deer Park Airport, 2004.

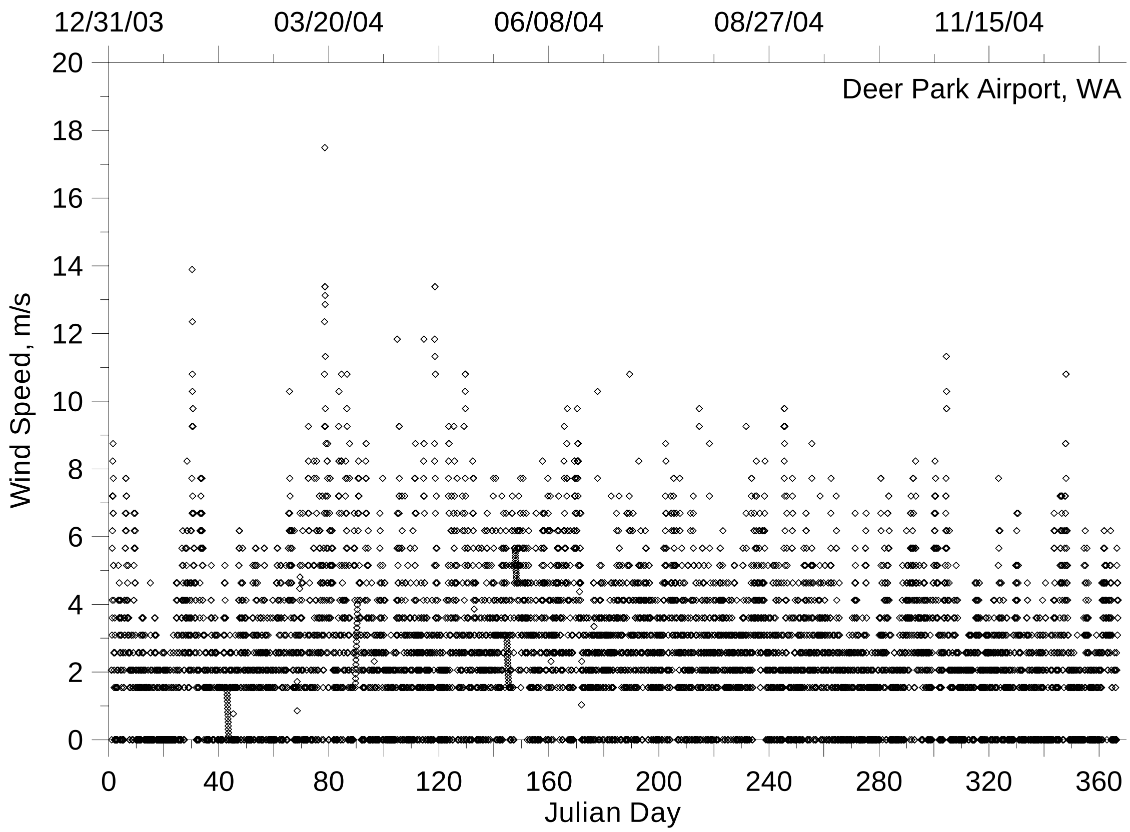

Figure 61: Wind speed at Deer Park Airport, 2004.

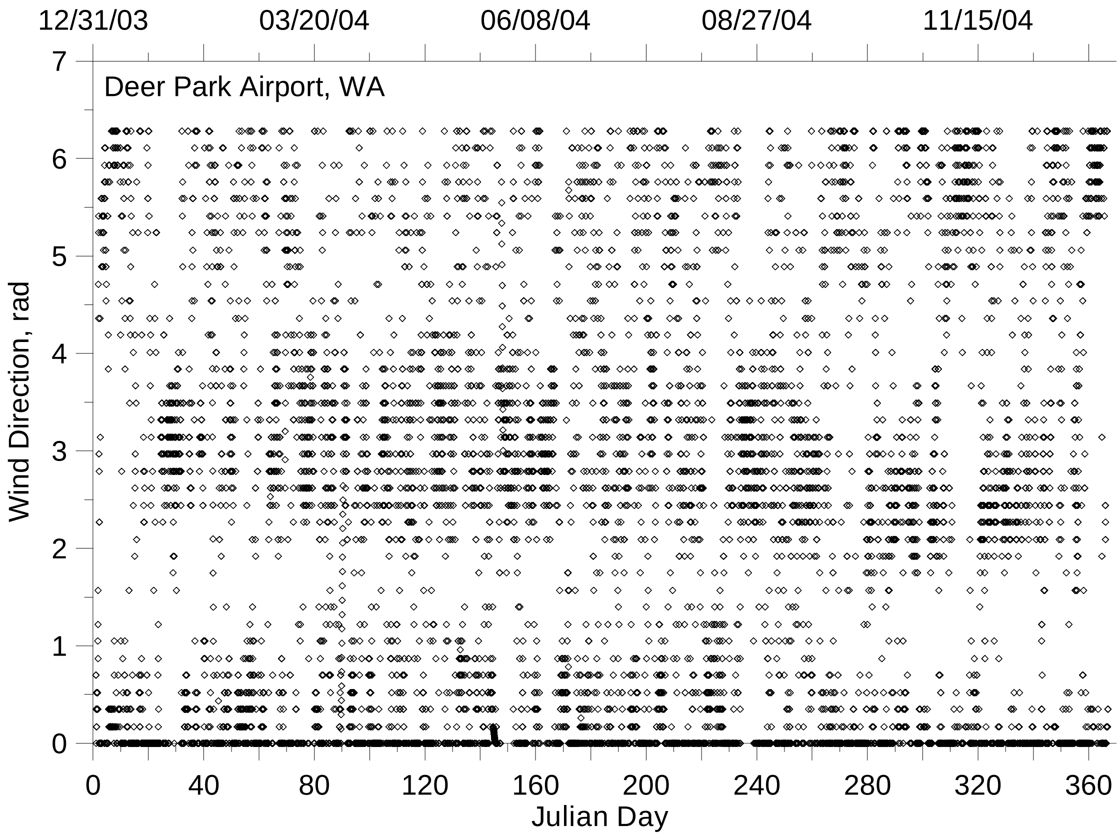

Figure 62: Wind Direction at Deer Park Airport, 2004.

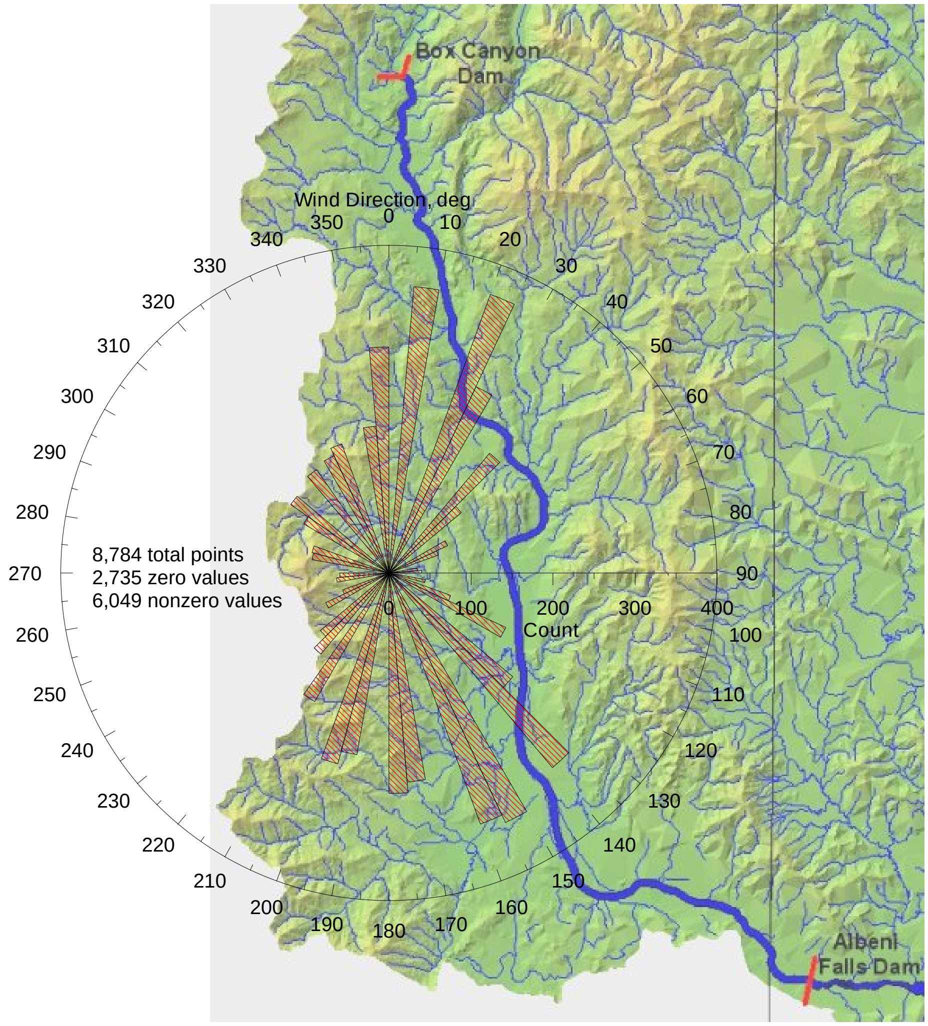

Figure 63: Wind orientation at Deer Park Airport, 2004.

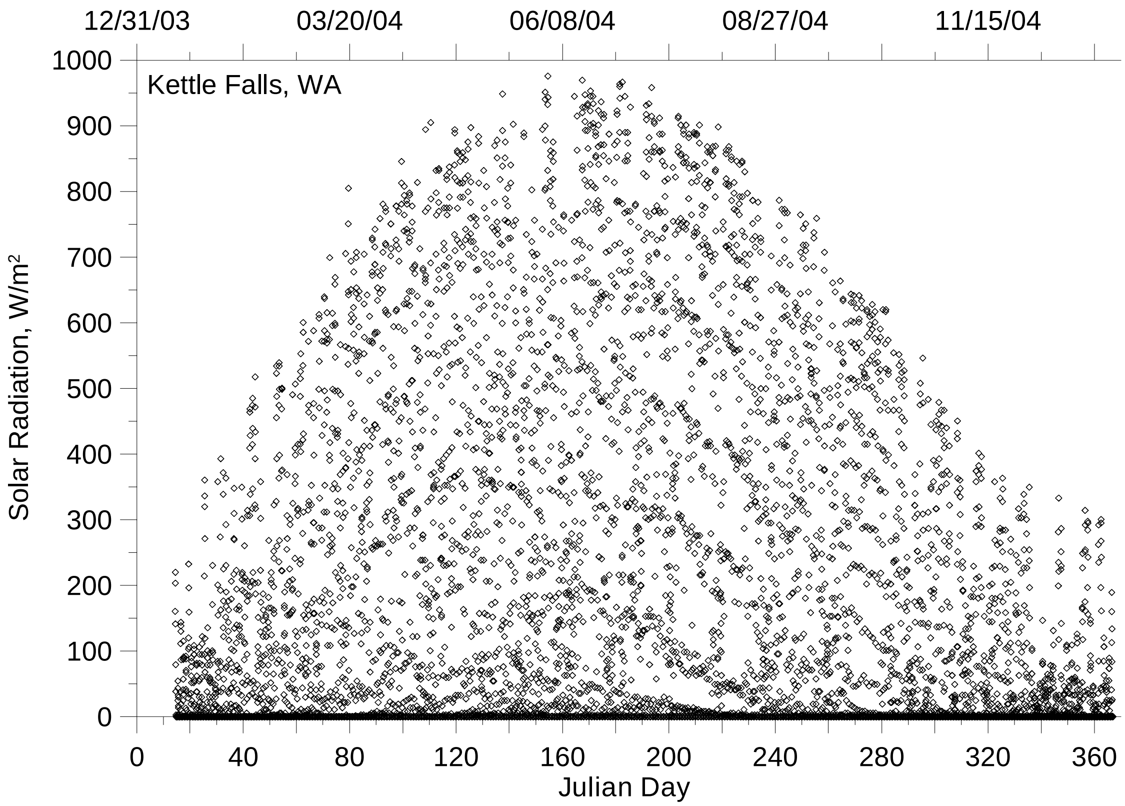

Figure 64: Solar radiation at Flowery Trail, 2004.

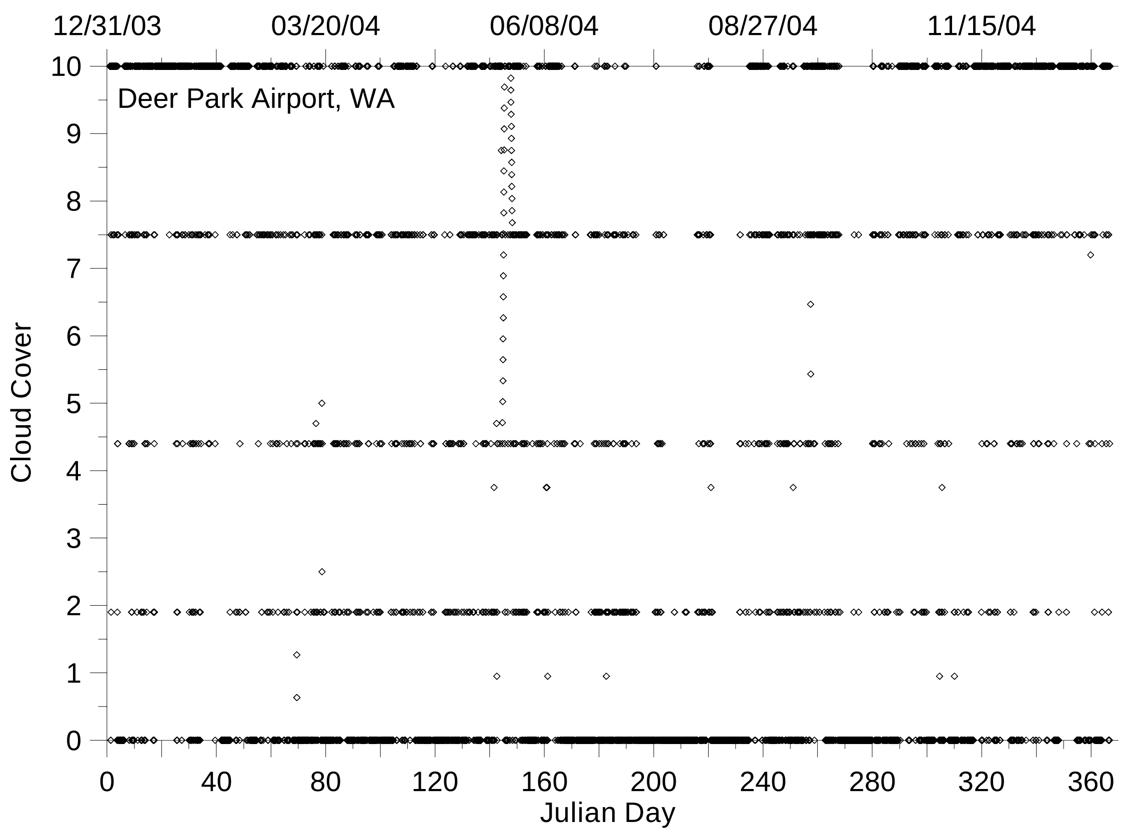

Figure 65: Cloud cover at Deer Park Airport, 2004.

Calibration

The Pend Oreille River, Box Canyon Reach model was calibrated from January 1st to December 31st for 1997 and 1998. The 2004 calibration period was from January 14th to December 31st. The calibration consisted of evaluating model hydrodynamics (flow rate and water level) first, then evaluating temperature. The data for calibrating the model consisted primarily of continuous flow rate and water level and temperature data with some temperature profiles.

Hydrodynamics

Figure 66 shows a map of the Box Canyon Reach with the hydrodynamic monitoring sites where data were used in the model calibration. Table 6 lists the hydrodynamic monitoring sites, site descriptions, and the types of data monitored.

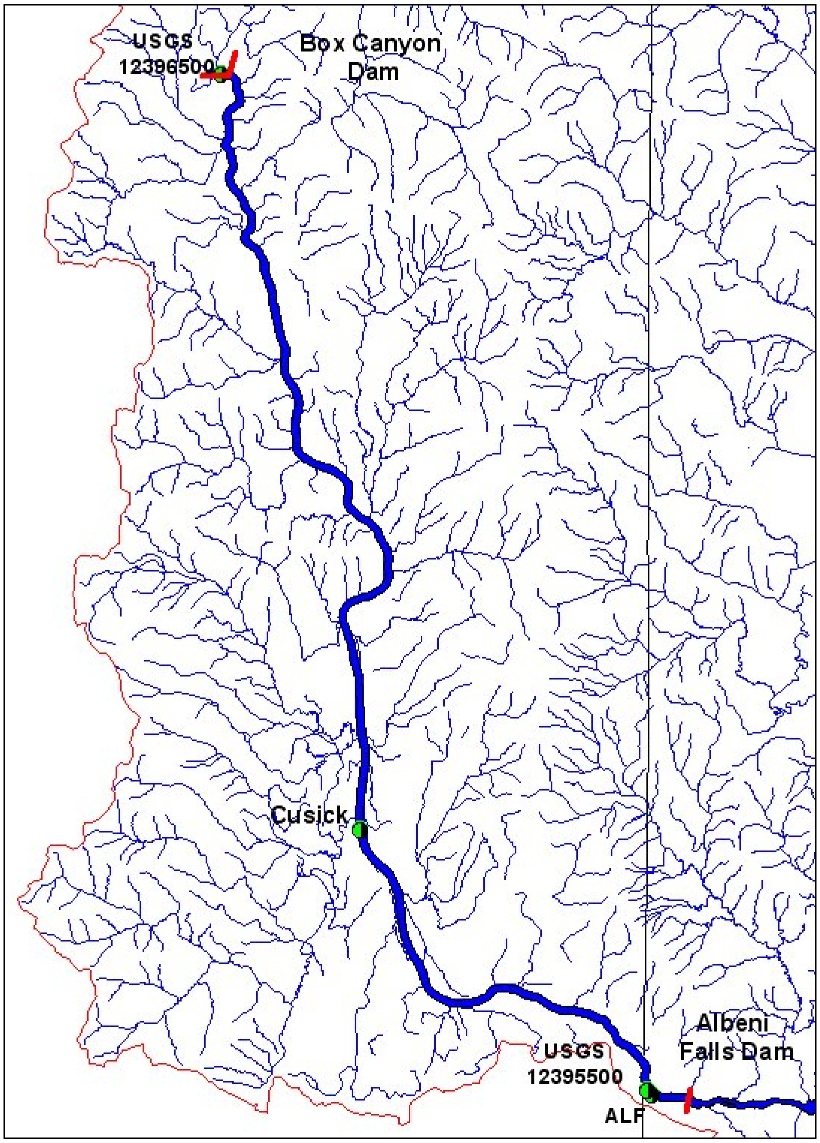

Figure 66: Pend Oreille River, Box Canyon Reach hydrodynamic calibration site locations.

Table 6: Pend Oreille River, Box Canyon Reach water level and flow measurement sites.

Site ID	Site Name	Agency	Model Seg	RM	Data Types	Years
ALF	Albeni Falls Dam On Pend Oreille River Below Lake	ACOE	11	88.78	Flow and Stage	1997, 1998, & 2004
USGS 12395500	Pend Oreille River at Newport	USGS	12	88.54	Flow and Stage	1997, 1998, & 2004
USGS 12396500	Pend Oreille River Below Box Canyon Near Ione	USGS	358	34.51	Flow	1997, 1998, & 2004
Cusick	Box Canyon Reservoir water level at Cusick, WA	PDO PUD	131	69.94	Stage	1997, 1998, & 2004

Data measured at the hydrodynamic monitoring sites ALF, USGS 12395500, and USGS 12396500 were used to develop the model's boundary conditions and were not used for model calibration. The water level site at Cusick was used for water level calibration. Water level data were available from this site during all calibration years except for two periods in 1997. These periods were from 3/2/1997 through 3/31/1997 and 5/25/1997 through 6/30/1997. Water levels were estimated by developing a correlation between water levels measured at Cusick and flow rates below Box Canyon near Ione (USGS 12396500). Figure 67 shows the comparison between water levels measured at Cusick and flow rates measured below Box Canyon using 1997 data. To estimate water levels at Cusick two correlations were developed, one for flow rates less than 1900 cms, and the other for flow rates greater than 1900 cms. In the data set there were several zero flow rates and these data were not used in the correlations. Figure 68 (for flow rates <1900 cms) and Figure 69 (for flow rates >1900 cms) show the two correlations. Water level data and estimated water levels for Cusick during 1997 were shown in Figure 70. The estimated water levels were required to develop the water balance flow file.

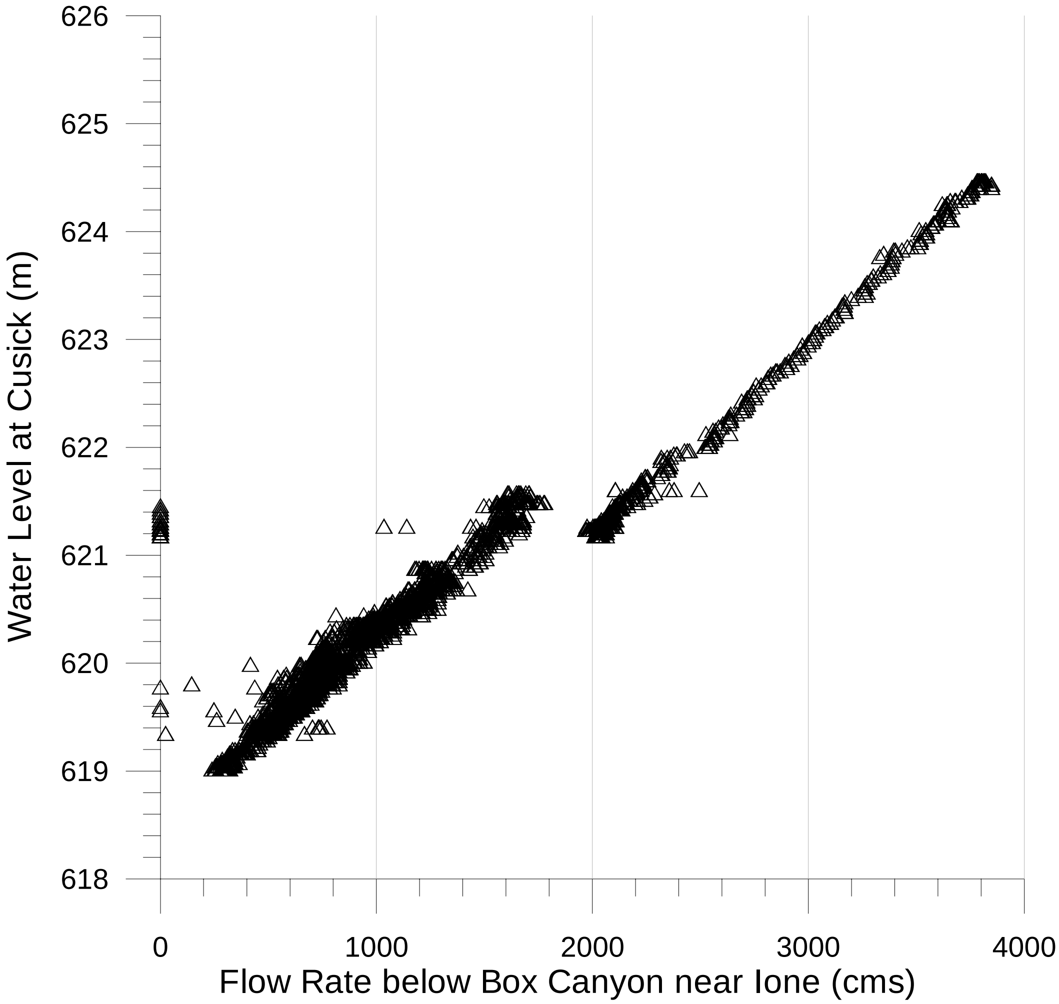

Figure 67: Comparison between water levels measured at Cusick and flow rates measured below Box Canyon near Ione.

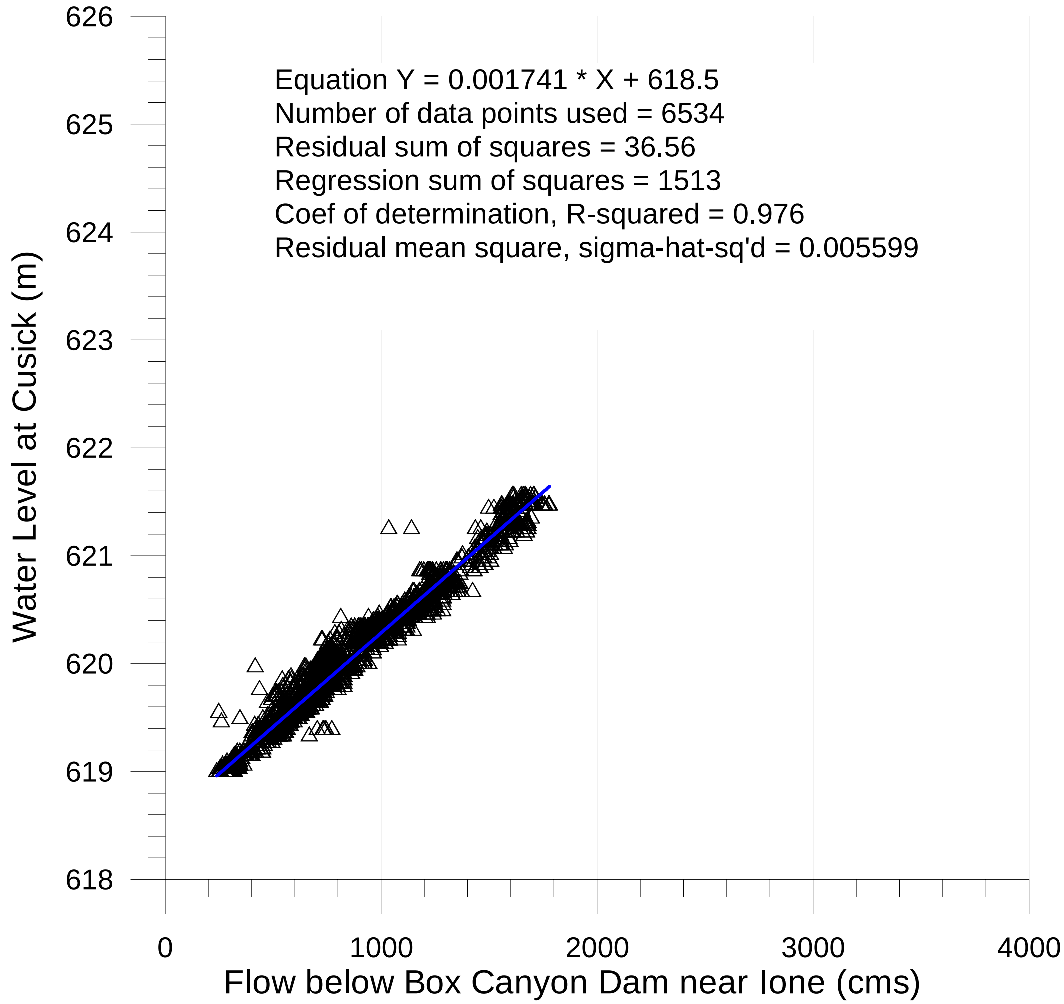

Figure 68: Correlation between water levels measured at Cusick and flow rates below 1900 cms which were measured below Box Canyon near Ione.

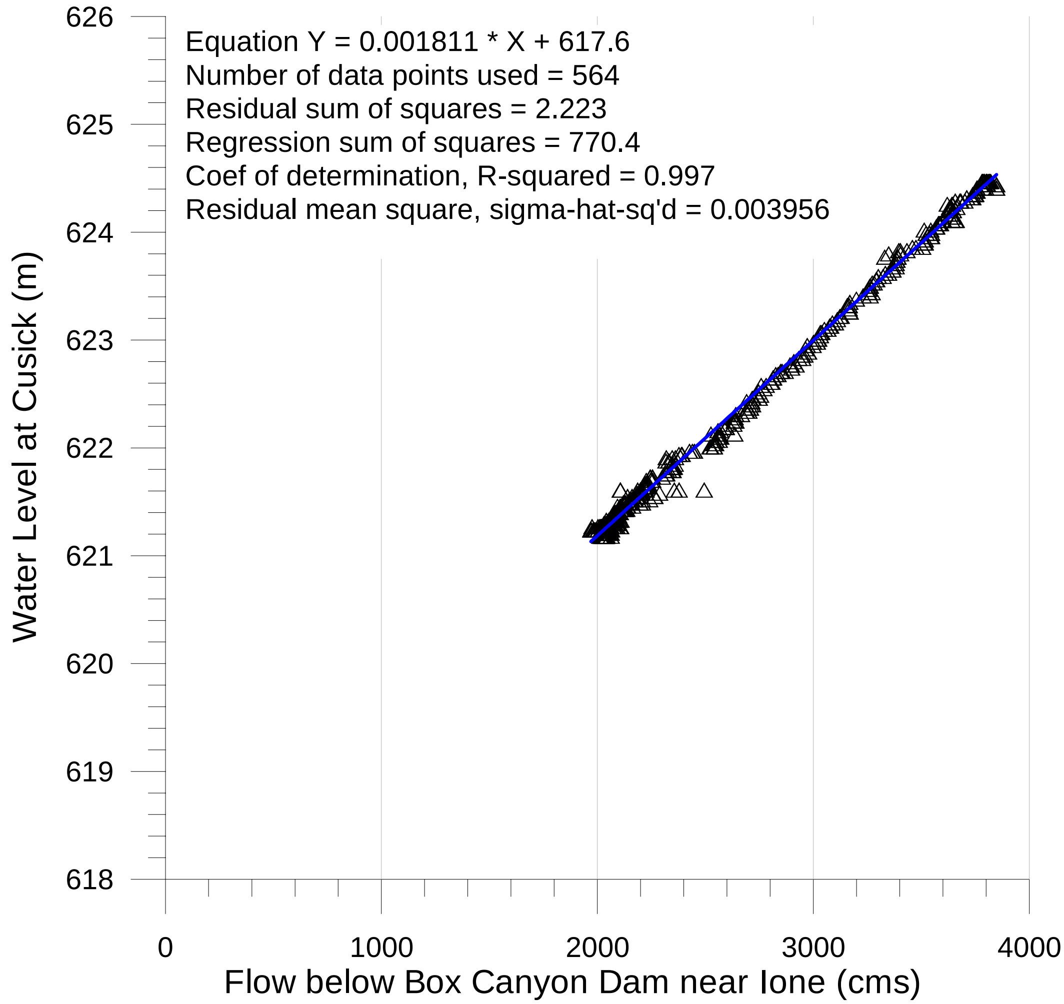

Figure 69: Correlation between water levels measured at Cusick and flow rates below greater than cms which were measured below Box Canyon near Ione.

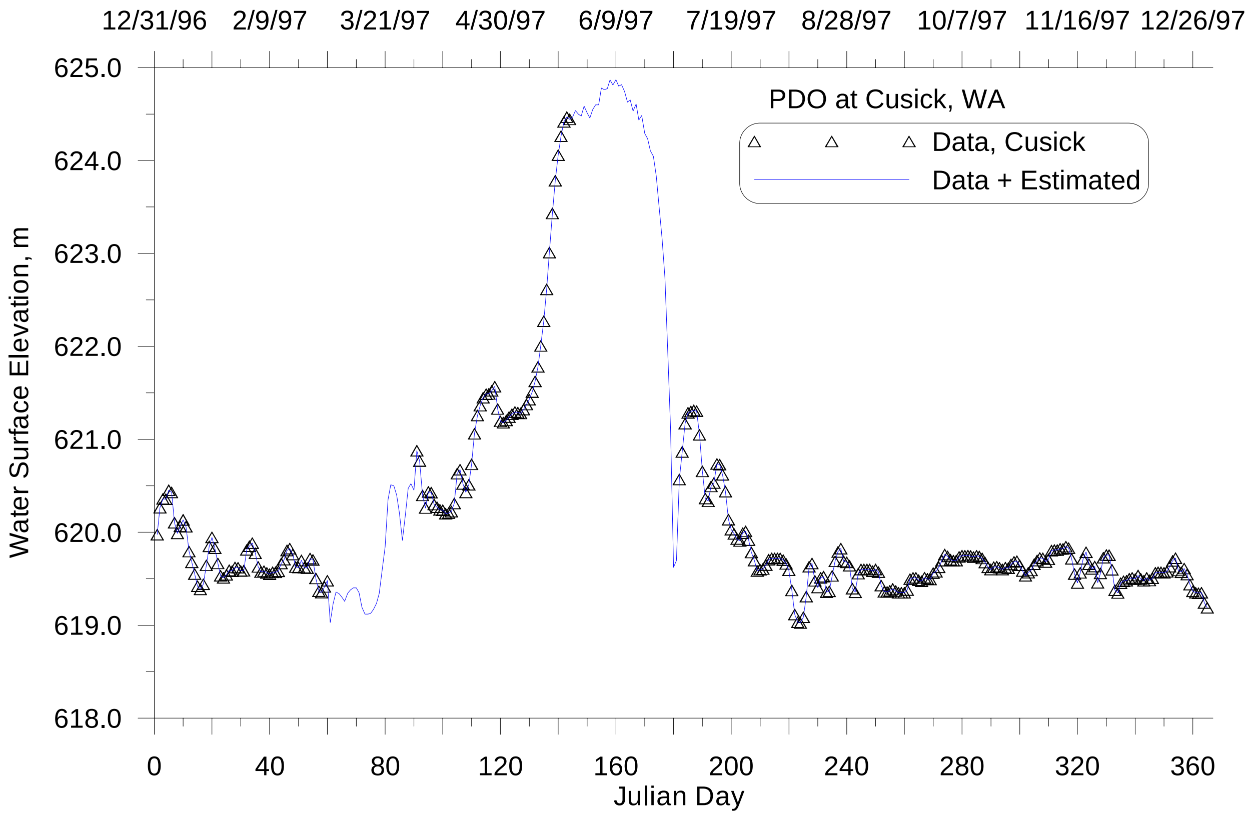

Figure 70: 1997 water level data and estimated water levels for the Cusick, WA monitoring site.

The model predicted water level errors for all 3 years were shown in Table 7. Comparisons between model predictions and data for 1997, 1998, and 2004 were shown in Figure 71, Figure 72, and Figure 73. The average mean absolute error for all three years was 0.04 m.

Table 7: Model error statistics for water levels measured at Cusick.

Year	Number of Comparisons	Mean Error, m	Mean Absolute Error, m	Root Mean Square Error, m
1997	297	0.000	0.026	0.047
1998	364	-0.001	0.03	0.054
2004	352	-0.041	0.048	0.058
Average		-0.014	0.035	0.053

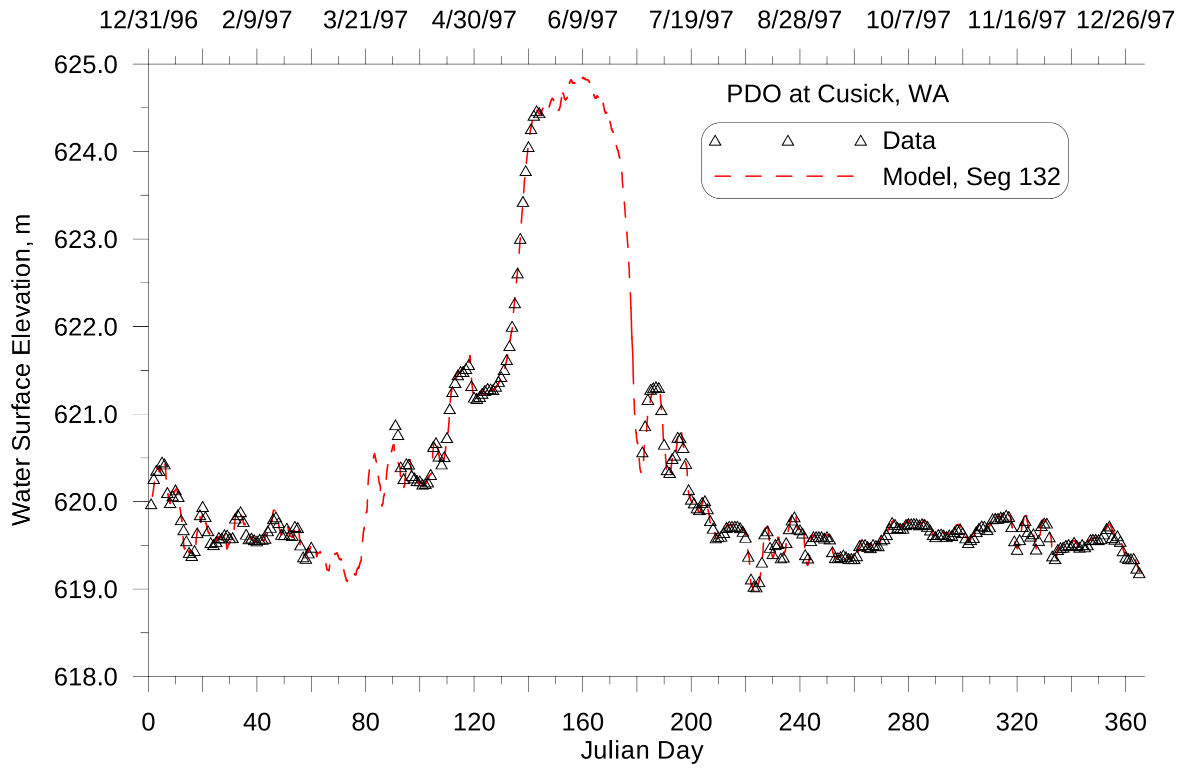

Figure 71: Model predicted water levels for 1997 compared with data.

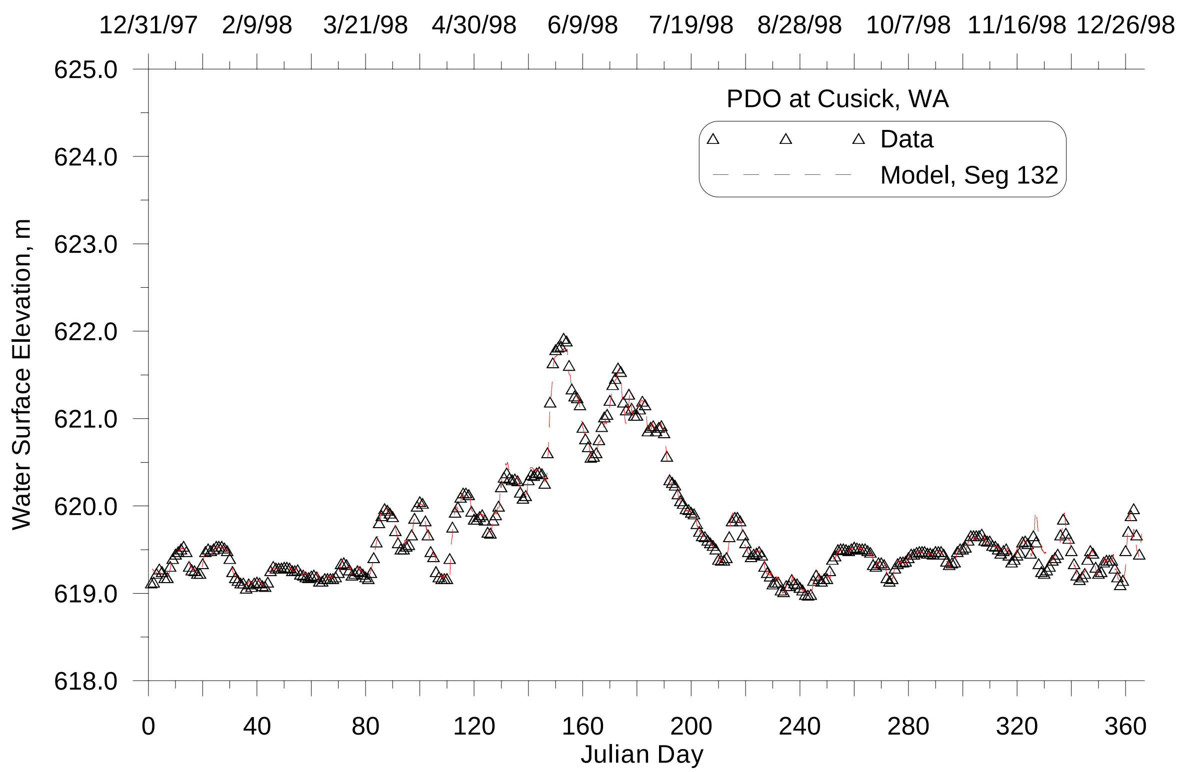

Figure 72: Model predicted water levels for 1998 compared with data measured at Cusick.

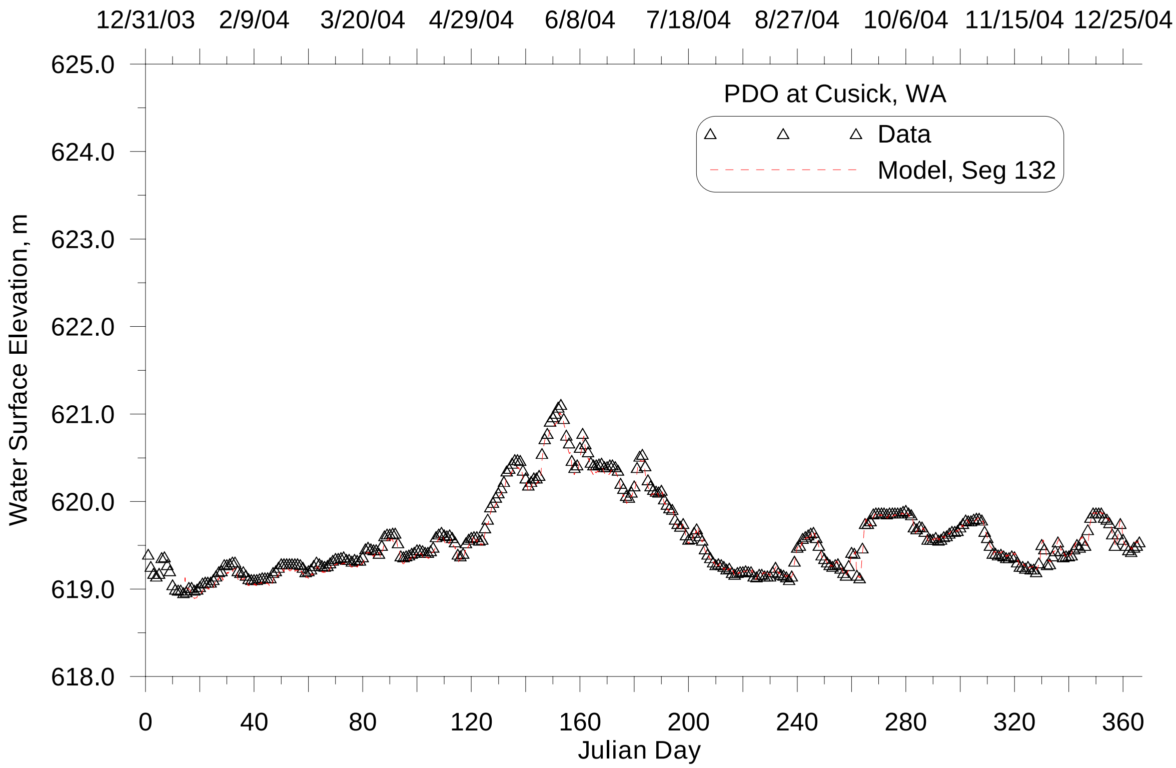

Figure 73: Model predicted water levels for 2004 compared with data measured at Cusick.

Temperature

Figure 74 shows a map of the Box Canyon Reach with the temperature monitoring sites where data were used in the model calibration. Table 8 lists the temperature monitoring sites and site descriptions.

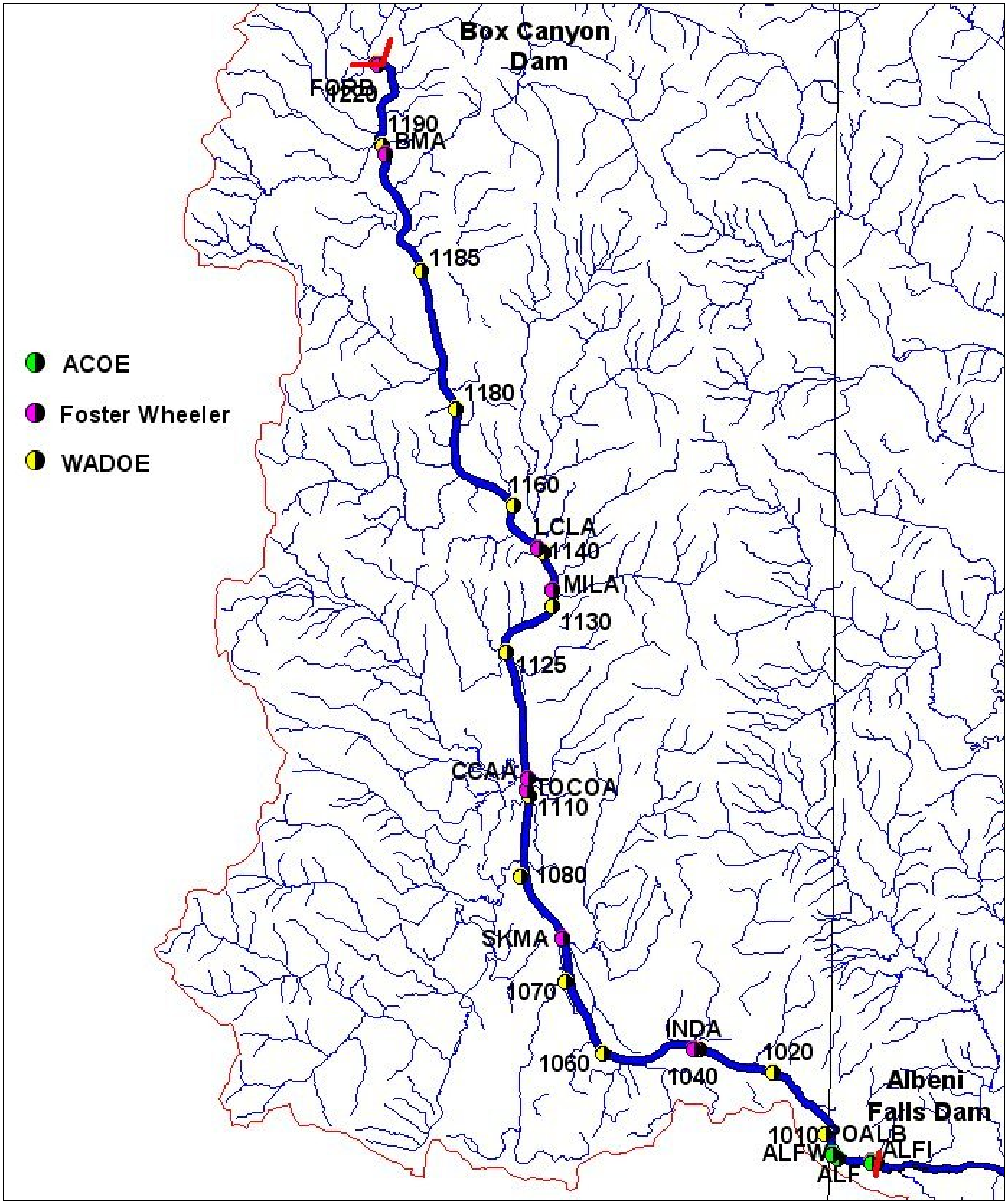

Figure 74: Pend Oreille River, Box Canyon Reach temperature calibration site locations.

Table 8: Pend Oreille River, Box Canyon Reach temperature calibration sites.

Site ID	Site Name	Agency	Model Seg	RM	Data Types	Years
1010	POR near Newport (Kelly Island)	WDOE	17	87.82	Time Series & Profiles	2004
1020	POR above Marshall Creek	WDOE	38	84.43	Time Series & Profiles	2004
1040	POR above Indian Island	WDOE	57	81.46	Time Series & Profiles	2004
1060	POR near Dalkena	WDOE	83	77.58	Time Series & Profiles	2004
1070	POR above Skookum Creek	WDOE	102	74.53	Time Series & Profiles	2004
1080	POR near Cusick	WDOE	131	70.01	Time Series & Profiles	2004
1110	POR above Tacoma Creek	WDOE	150	66.99	Time Series & Profiles	2004
1125	POR near River Bend (near Cusick Creek)	WDOE	187	61.43	Profile	2004
1130	POR above Mill Creek	WDOE	204	58.62	Profile	2004
1140	POR above LeClerc Creek	WDOE	217	56.52	Time Series & Profiles	2004
1160	POR above Blueslide	WDOE	232	54.14	Time Series & Profiles	2004
1180	POR above Lost Creek	WDOE	264	49.26	Time Series & Profiles	2004
1185	POR near Tiger	WDOE	300	43.76	Profile	2004
1190	POR near Ione	WDOE	334	38.28	Time Series & Profiles	2004
1220	Box Canyon Dam draft tube deck (replicate SCL), tailrace,	WDOE	358	34.51	Time Series & Profiles	2004
ALF	Albeni Falls Dam On Pend Oreille River Below Lake	ACOE	2	90.22	Time Series	1997, 1998, 2004
ALFI	Albeni Falls Dam Forebay Left Bank	ACOE	2	90.22	Time Series	2004
ALFW	Albeni Falls Dam Tailwater - Pend Oreille River at Newport (discontinued)	ACOE	12	88.59	Time Series	2004
BMABOT	PDO River at Big Muddy Creek (near bottom)	Foster Wheeler	333	38.56	Time Series	1998
BMATOP	PDO River at Ione, top (about 1-2m below surface)	Foster Wheeler	333	38.56	Time Series	1997
CCAA	PDO River at Cee Cee Ah Creek	Foster Wheeler	155	66.29	Time Series	1997, 1998
FORB	Box Canyon Forebay	Foster Wheeler	358	35.51	Time Series	1998
INDA	PDO River above Indian Creek	Foster Wheeler	59	81.24	Time Series	1997
LCLA	PDO River at LeClerc Creek	Foster Wheeler	219	56.28	Time Series	1997

Site ID	Site Name	Agency	Model Seg	RM	Data Types	Years
MILA	PDO River at Mill Creek	Foster Wheeler	208	58.02	Time Series	1997, 1998
POALB	PDO River Below Albeni	Foster Wheeler	3	90.04	Time Series	1997, 1998
SKMA	PDO River at Skookum Cr	Foster Wheeler	112	77.89	Time Series	1997, 1998
TACOA	PDO River at Tacoma Cr, bottom in a shallow area (1-2 m?) with very dense aquatic plants	Foster Wheeler	152	66.77	Time Series	1997

Error statistics for continuous recorded data were shown for years 1997, 1998 and 2004 in Table 9, Table 10, and Table 11, respectively. Table 12 shows the error statistics for temperature profile data measured in 2004. Plots of model prediction and data are shown in "Appendix B: Plots of Model Predicted Temperatures and Data". Table 13 through Table 15 list the error statistics for maximum daily temperature.

Model predicted temperatures were largely dependent on the upstream boundary condition. For 2004 temperatures measured at the site ALFW (Figure 11) were initially chosen for the upstream boundary condition, but that site recorded relatively large diurnal fluctuations in temperature (Figure 14) causing larger than measured temperature swings to be predicted downstream at site 1010 (segment 17). Daily mean temperatures measured at ALFW were also cooler than at other nearby sites. The upstream boundary condition was reworked using data from sites ALF, 1010, and ALFI (Figure 15) and model error was considerably reduced.

Also affecting model calibration was wind sheltering. For 1998 and 2004 a value of 0.85 was used, whereas for 1997 a value of 0.30 was chosen. Model meteorological inputs used wind data from the Spokane Airport for a large part of 1997, whereas wind data for 1998 and 2004 were obtained from Flowery Trail and Deer Park Airport, respectively. The Spokane Airport is at a greater distance from the modeled area and wind speeds measured there were of greater magnitude (Figure 46).

A number of additional simulations were run to determine model sensitivity to calibration parameters. The error statistics for these runs were shown in "Appendix C: Additional Simulations to determine model sensitivity".

The average mean absolute error of the continuous data for all three years was 0.33 degrees Celsius. The average absolute mean error of the 2004 vertical profile data was 0.24 degrees Celsius. Predicted maximum daily temperature had an average mean absolute error of 0.31 degrees Celsius. Calibrated model parameters are shown in "Appendix D: Model Parameter Values"

Table 9: Year 1997 error statistics for continuous temperature data.

Site ID	Model Segment	Number of Comparisons	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
POALB	3	3165	0.00	0.01	0.01
INDA	59	3070	-0.06	0.14	0.17
SKMA	112	2461	-0.06	0.28	0.36
TACOA	152	2497	0.04	0.33	0.41

Site ID	Model Segment	Number of Comparisons	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
CCAA	155	2728	0.00	0.24	0.31
MILA	208	2711	0.17	0.33	0.42
LCLA	219	2650	-0.06	0.32	0.40
BMATOP	333	3146	-0.10	0.35	0.43
Average			-0.01	0.25	0.31

Table 10: Year 1998 error statistics for continuous temperature data.

Site ID	Model Segment	Number of Comparisons	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
POALB	3	3647	-0.08	0.42	0.54
SKMA	112	5858	-0.07	0.46	0.57
CCAA	155	1306	0.03	0.58	0.69
MILA	208	3647	0.19	0.45	0.60
BMABOT	333	4657	-0.19	0.45	0.57
FORB	358	4667	0.00	0.40	0.53
Average			-0.02	0.46	0.58

Table 11: Year 2004 error statistics for continuous temperature data.

Site ID	Model Segment	Number of Comparisons	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
1010	17	4069	-0.02	0.11	0.14
1020	38	5588	-0.15	0.20	0.27
1040	57	2035	-0.11	0.22	0.36
1060	83	5589	-0.16	0.23	0.31
1070	102	5589	-0.15	0.32	0.42
1080	131	5843	-0.19	0.28	0.35
1110	150	4204	-0.13	0.34	0.42
1140	217	5548	-0.11	0.31	0.39
1160	232	5548	-0.07	0.31	0.39
1180	264	4921	-0.14	0.32	0.39
1190	334	5542	-0.16	0.34	0.42
1220	358	3589	0.01	0.31	0.38
Average			-0.11	0.27	0.35

Table 12: Year 2004 error statistics for vertical profile data.

Site ID	Model Segment	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
1010	17	0.22	0.30	0.30
1020	38	-0.11	0.14	0.15

Site ID	Model Segment	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
1040	57	-0.04	0.11	0.12
1060	83	-0.06	0.14	0.15
1070	102	0.01	0.19	0.20
1080	131	-0.17	0.18	0.19
1110	150	-0.20	0.26	0.26
1125	187	-0.22	0.22	0.23
1130	204	-0.25	0.39	0.40
1140	217	-0.10	0.24	0.26
1160	232	-0.07	0.15	0.16
1180	264	0.01	0.15	0.16
1185	300	-0.33	0.33	0.34
1190	334	-0.12	0.36	0.38
1220	358	-0.47	0.47	0.47
Average		-0.13	0.24	0.25

Table 13: Year 1997 error statistics for maximum daily temperature.

Site ID	Model Segment	Number of Comparisons	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
POALB	3	132	0.01	0.01	0.01
INDA	59	128	-0.02	0.11	0.14
SKMA	112	103	0.07	0.24	0.30
TACOA	152	104	-0.03	0.31	0.40
CCAA	155	113	0.10	0.25	0.33
MILA	208	113	0.05	0.26	0.33
LCLA	219	111	-0.08	0.29	0.37
BMATOP	333	131	0.01	0.40	0.46
Average			0.01	0.23	0.29

Table 14: Year 1998 error statistics for maximum daily temperature.

Site ID	Model Segment	Number of Comparisons	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
POALB	3	152	-0.30	0.50	0.62
SKMA	112	245	0.02	0.43	0.54
CCAA	155	54	0.03	0.53	0.64
MILA	208	152	0.04	0.36	0.47
BMABOT	333	194	-0.11	0.40	0.52
FORB	358	195	0.08	0.39	0.53
Average			-0.04	0.43	0.55

Table 15: Year 2004 error statistics for maximum daily temperature.

Site ID	Model Segment	Number of Comparisons	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
1010	17	85	0.15	0.16	0.22
1020	38	116	-0.03	0.16	0.25
1040	57	42	-0.04	0.21	0.32
1060	83	116	-0.24	0.27	0.34
1070	102	116	-0.15	0.31	0.39
1080	131	94	-0.05	0.24	0.35
1110	150	87	0.00	0.28	0.35
1140	217	115	-0.08	0.26	0.32
1160	232	115	-0.06	0.32	0.39
1180	264	102	-0.05	0.31	0.38
1190	334	115	-0.09	0.30	0.38
1220	358	80	0.09	0.33	0.40
Average			-0.05	0.26	0.34

Summary

A water quality and hydrodynamic model, CE-QUAL-W2 Version 3.5 (Cole and Wells, 2006; http://www.cee.pdx.edu/w2), was applied to the Pend Oreille River, Box Canyon Reach, Washington. This report summarizes model development and calibration of the CE-QUAL-W2 Version 3.5 model of the Box Canyon Reach 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 meteorological data (air temperature, dew point temperature, wind speed, wind direction and cloud cover or short wave solar radiation)
- Model bathymetry”

The Pend Oreille River Box Canyon Reach temperature model has been calibrated for the years 1997, 1998, and 2004. Temperatures within the Box Canyon Reach are strongly dependent on the temperature of outflows from Albeni Falls dam. Wind sheltering was another important calibration parameter. This was a result of lacking high-quality on-site meteorological data. The average mean absolute error for water level predictions for all three calibration years was 0.035 m. The average mean absolute error of continuous temperature data for all three years was 0.33^{o}C with typical values ranging between 0.25^{o}C to 0.46^{o}C. The error in the prediction of the maximum daily temperature was similar to the instantaneous data with typical absolute mean errors ranging from 0.23^{o}C to 0.43^{o}C.

Tributaries and shading will be added to the model when the input data has been prepared. These inputs will further refine the model.

References

Annear, R. L.; Berger, C. J.; and Wells, S.A. (2006) “Pend Oreille River Model: Model Development and Calibration,” Technical Report EWR-2-06, Department of Civil and Environmental Engineering, Portland State University, Portland, OR.

Cole, T. and Wells, S.A. (2006) “CE-QUAL-W2: A Two-Dimensional, Laterally Averaged, Hydrodynamic and Water Quality Model, Version 3.5,” Instruction Report EL-2006-1, USA Engineering and Research Development Center, Waterways Experiment Station, Vicksburg, MS.

Pickett, Paul (2006) Personal Communication. Washington Department of Ecology.

Appendix A: Extent of Data

Hydrodynamic and temperature data were primarily obtained from 1997, 1998 and 2004 from a variety of sources. Figure 75 shows the hydrodynamic monitoring sites and Table 16 list the sites and the extent of the data. Figure 76 shows a map of the temperature and monitoring sites and Table 17 list the sites and the extent of the continuous temperature data. Table 18 lists the sites and the extent of the vertical profile temperature data.

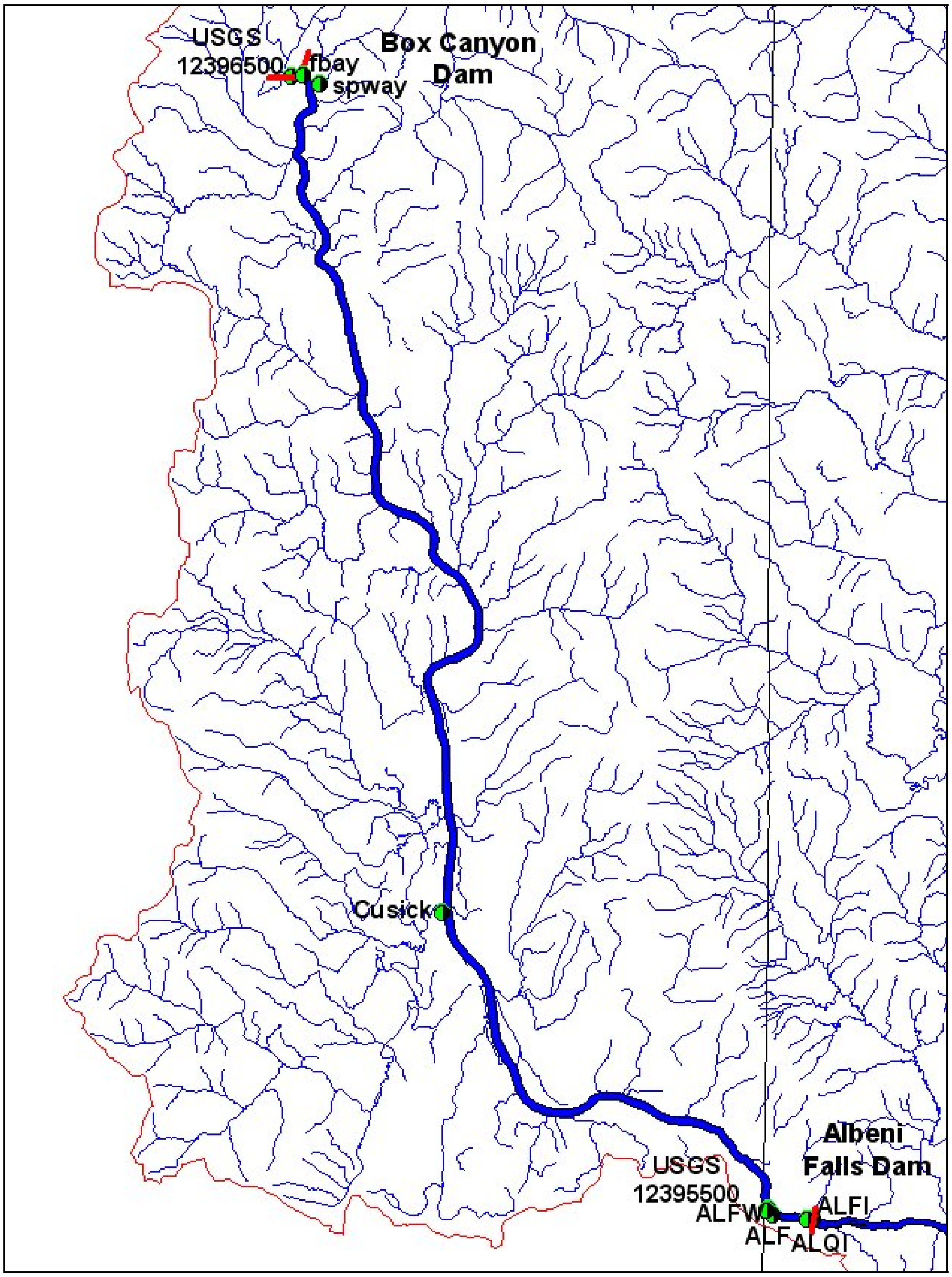

Figure 75: Hydrodynamic monitoring sites

Table 16: Hydrodynamic monitoring sites and extent of data

Site ID	Site Name	Agency	State	Minimum Date	Maximum Date	Count flow, cfs	Count gage height, ft	Frequency
ALF	Albeni Falls Dam On Pend Oreille River Below Lake	ACOE	ID	01/01/1997	09/09/2005	77,759	77,584	hourly
ALFI	Albeni Falls Dam Forebay Left Bank	ACOE	ID	04/20/2004	09/30/2005	7,952		hourly
ALFW	Albeni Falls Dam Tailwater - Pend Oreille River at Newport (discontinued)	ACOE	ID	04/29/2004	09/09/2005	6,056	11,261	hourly
ALQI	Albeni Falls Dam Tailwater Left Bank (new site)	ACOE	ID	07/28/2005	09/30/2005	1,536		hourly
USGS123 95500	Pend Oreille River at Newport	USGS	WA	01/01/1997	11/28/2005	243,360	246,029	15 min
USGS123 96500	Pend Oreille River Below Box Canyon Near Ione	USGS	WA	10/01/1996	04/05/2006	161,762	161,762	30 min
fbay	Box Canyon Dam Forebay elevation at unit generation intake	PDO PUD	WA	04/01/1990	04/11/2006		140,457	hourly
spway	Box Canyon Dam spillway elevation, a couple hundred feet from intake	PDO PUD	WA	04/01/1990	04/11/2006		140,445	hourly
cusick	Box Canyon Reservoir water level at Cusick, WA	PDO PUD	WA	04/01/1990	04/11/2006		122,276	hourly

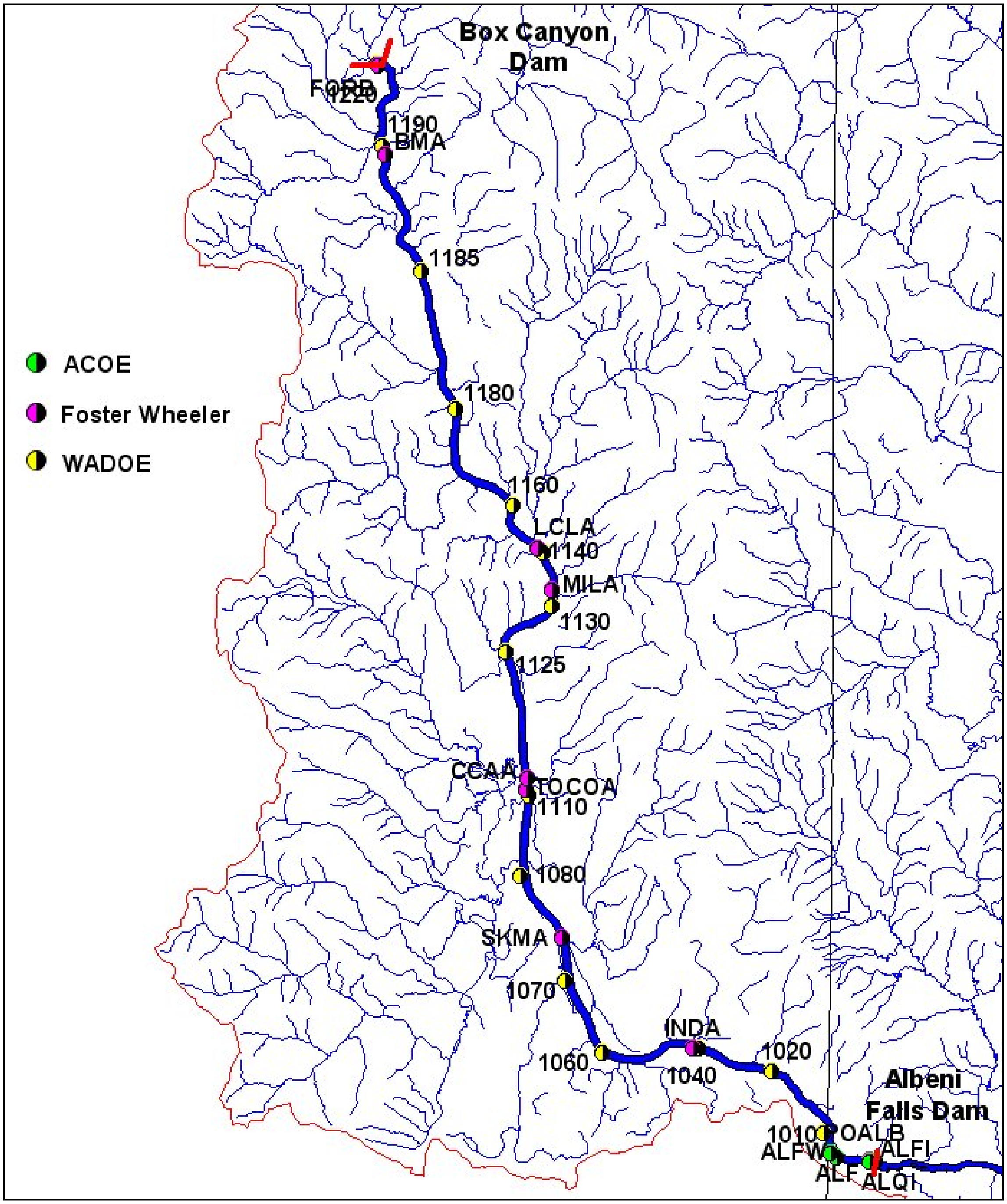

Figure 76: Temperature monitoring sites

Table 17: Temperature monitoring sites and extent of time series data

Site ID	Site Name	Agency	Minimum Date	Maximum Date	Count Temp, C
1010	POR near Newport (Kelly Island)	WDOE	07/27/2004	10/20/2004	4069
1020	POR above Marshall Creek	WDOE	06/26/2004	10/20/2004	5588
1040	POR above Indian Island	WDOE	06/26/2004	08/07/2004	2035
1060	POR near Dalkena	WDOE	06/26/2004	10/20/2004	5589
1070	POR above Skookum Creek	WDOE	06/26/2004	10/20/2004	5589
1080	POR near Cusick	WDOE	06/26/2004	10/19/2004	5843
1110	POR above Tacoma Creek	WDOE	06/26/2004	09/21/2004	4204

Site ID	Site Name	Agency	Minimum Date	Maximum Date	Count Temp, C
1140	POR above LeClerc Creek	WDOE	06/26/2004	10/19/2004	5548
1160	POR above Blueslide	WDOE	06/26/2004	10/19/2004	5548
1180	POR above Lost Creek	WDOE	07/09/2004	10/19/2004	4921
1190	POR near Ione	WDOE	06/26/2004	10/19/2004	5542
1220	Box Canyon Dam draft tube deck (replicate SCL), tailrace,	WDOE	07/29/2004	10/19/2004	3589
ALF	Albeni Falls Dam On Pend Oreille River Below Lake	ACOE	01/01/1997	09/30/2005	3029
ALFI	Albeni Falls Dam Forebay Left Bank	ACOE	04/20/2004	09/30/2005	7802
ALFW	Albeni Falls Dam Tailwater - Pend Oreille River at Newport (discontinued)	ACOE	05/05/2004	07/28/2005	8016
ALQI	Albeni Falls Dam Tailwater Left Bank (new site)	ACOE	07/28/2005	09/30/2005	1500
BMABOT	PDO River at Big Muddy Creek (near bottom)	Foster Wheeler	05/07/1998	11/17/1998	4657
BMATOP	PDO River at Ione, top (about 1-2m below surface)	Foster Wheeler	07/17/1997	11/25/1997	3146
CCAA	PDO River at Cee Cee Ah Creek	Foster Wheeler	07/16/1997	06/17/1998	4034
FORB	Box Canyon Forebay	Foster Wheeler	04/30/1998	11/24/1998	4978
INDA	PDO River above Indian Creek	Foster Wheeler	07/17/1997	11/26/1997	3070
LCLA	PDO River at LeClerc Creek	Foster Wheeler	07/17/1997	11/06/1997	2650
MILA	PDO River at Mill Creek	Foster Wheeler	07/16/1997	11/17/1998	7030
POALB	PDO River Below Albeni	Foster Wheeler	07/17/1997	11/17/1998	6812
SKMA	PDO River at Skookum Cr	Foster Wheeler	07/18/1997	12/31/1998	8321
TACOA	PDO River at Tacoma Cr, bottom in a shallow area (1-2 m?) with very dense aquatic plants	Foster Wheeler	07/17/1997	10/29/1997	2497

Table 18: Temperature monitoring sites and extent of profile data

Site ID	Site Name	Agency	Minimum Date	Maximum Date	Count Temp, C
1010	POR near Newport (Kelly Island)	WDOE	07/27/2004	10/20/2004	34
1020	POR above Marshall Creek	WDOE	06/24/2004	10/20/2004	33
1040	POR above Indian Island	WDOE	06/24/2004	09/23/2004	27
1060	POR near Dalkena	WDOE	06/24/2004	10/20/2004	46
1070	POR above Skookum Creek	WDOE	06/24/2004	10/20/2004	37
1080	POR near Cusick	WDOE	06/23/2004	10/19/2004	43
1110	POR above Tacoma Creek	WDOE	06/24/2004	10/19/2004	37
1125	POR near River Bend (near Cusick Creek)	WDOE	06/24/2004	09/22/2004	23
1130	POR above Mill Creek	WDOE	06/22/2004	09/22/2004	46
1140	POR above LeClerc Creek	WDOE	06/22/2004	10/19/2004	45
1160	POR above Blueslide	WDOE	06/24/2004	10/19/2004	61
1180	POR above Lost Creek	WDOE	06/22/2004	10/19/2004	70
1185	POR near Tiger	WDOE	06/25/2004	09/22/2004	29

Site ID	Site Name	Agency	Minimum Date	Maximum Date	Count Temp, C
1190	POR near Ione	WDOE	06/25/2004	10/19/2004	62
1220	Box Canyon Dam draft tube deck (replicate SCL), tailrace,	WDOE	10/19/2004	10/19/2004	4

Appendix B: Plots of Model Predicted Temperatures and Data

Plots of model predicted temperatures and data are shown below. Figure 77 through Figure 102 show continuous temperature predictions and data for 1997, 1998, and 2004. Comparisons of 2004 vertical profile data and model predictions are shown in Figure 103 through Figure 178.

1997

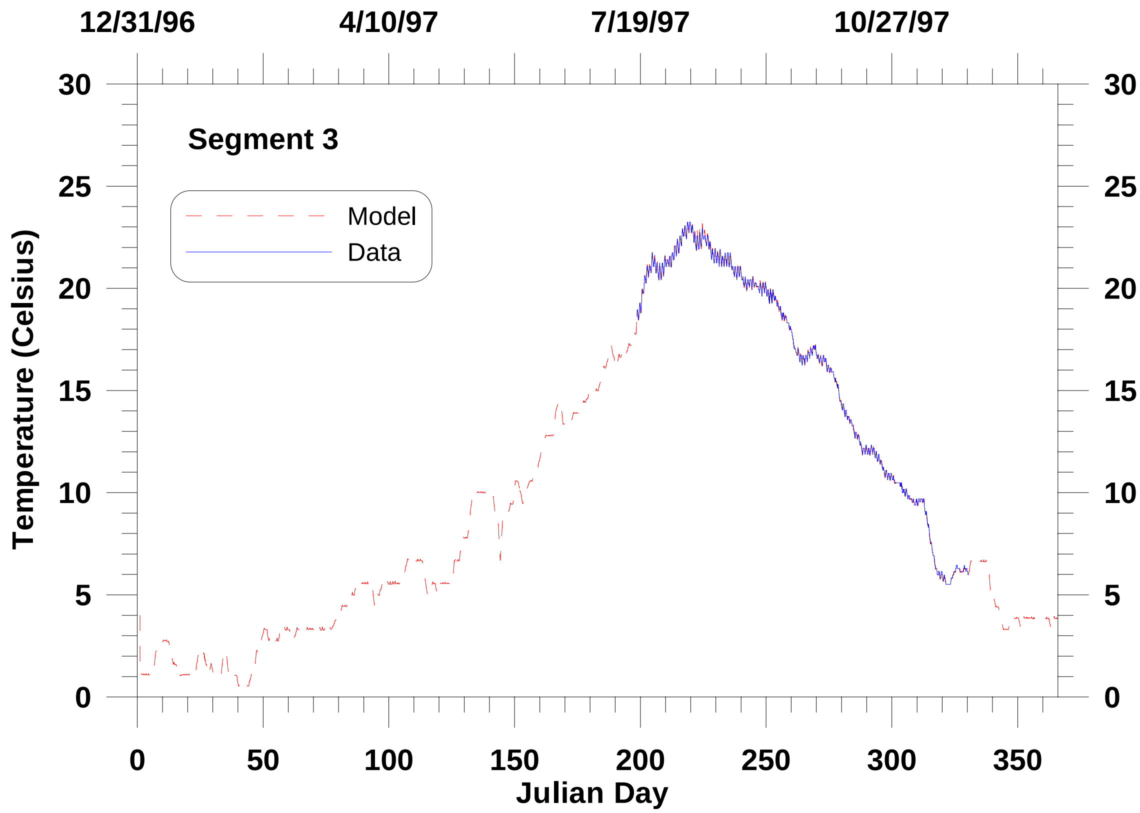

Figure 77: Model predictions and 1997 continuous temperature data measured at segment 3 (site POALB).

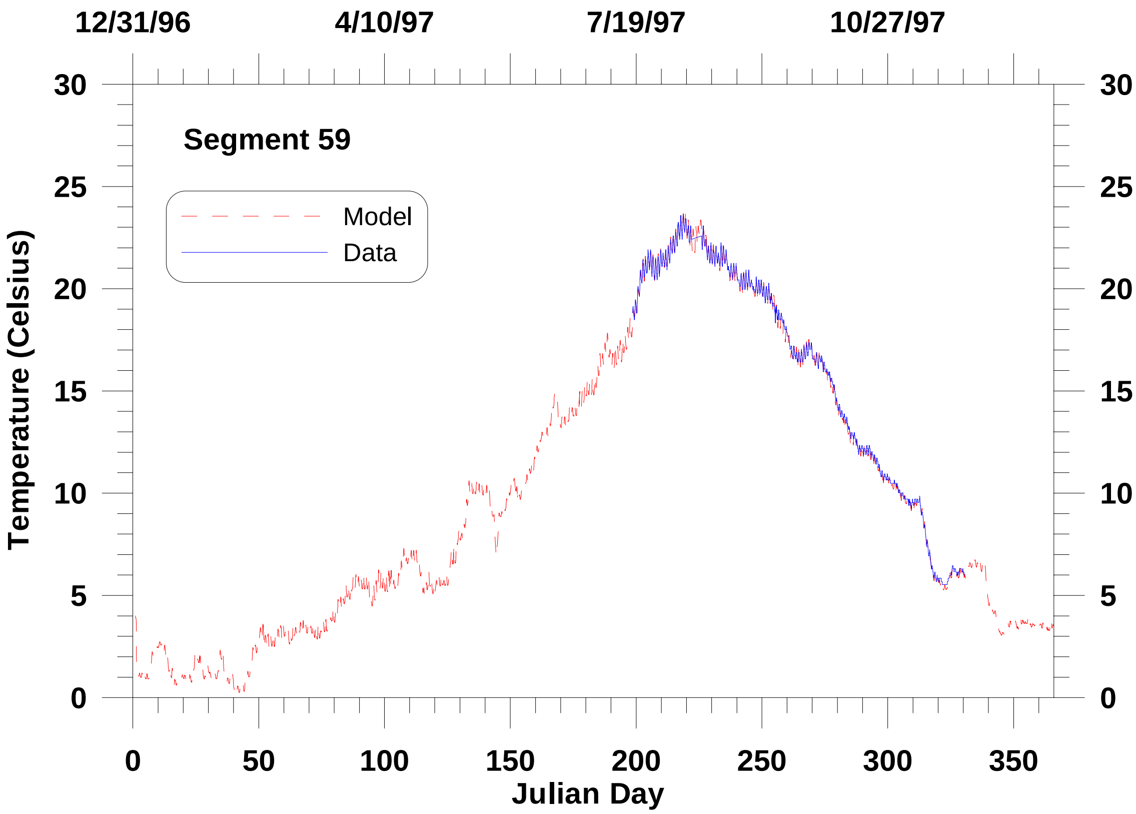

Figure 78: Model predictions and 1997 continuous temperature data measured at segment 59 (site INDA).

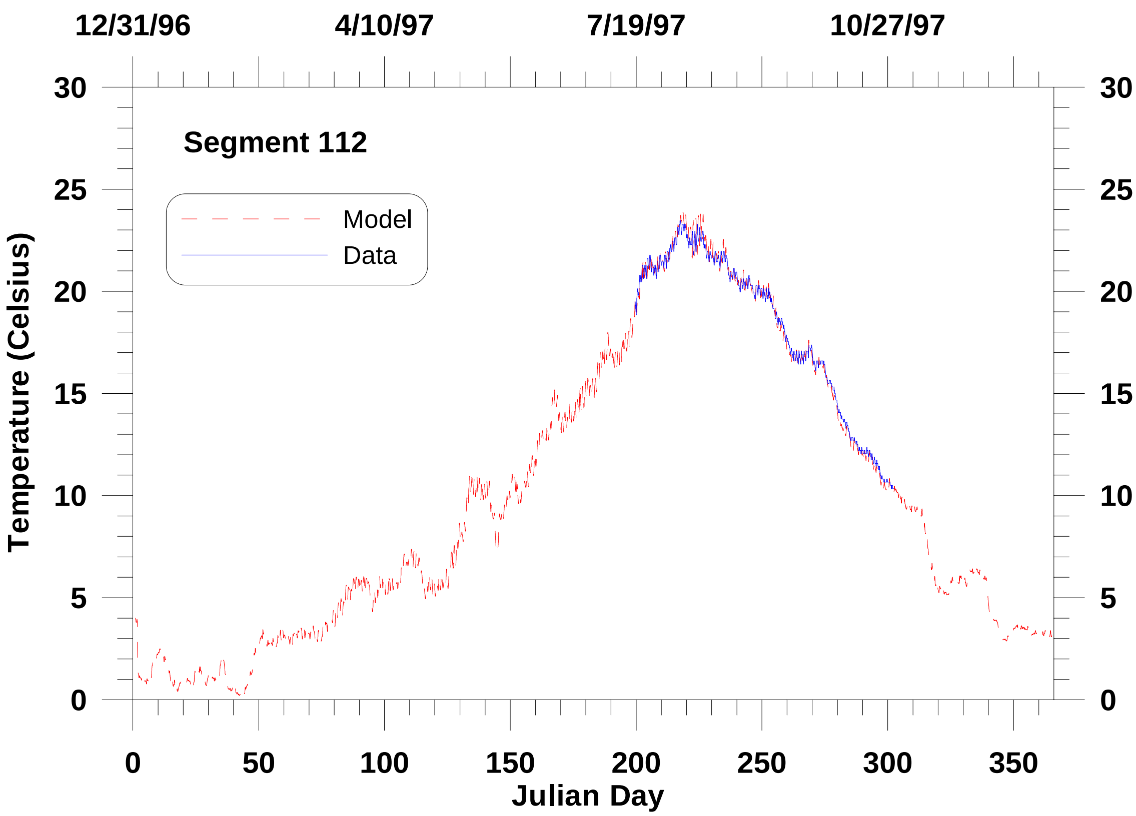

Figure 79: Model predictions and 1997 continuous temperature data measured at segment 112 (site SKMA).

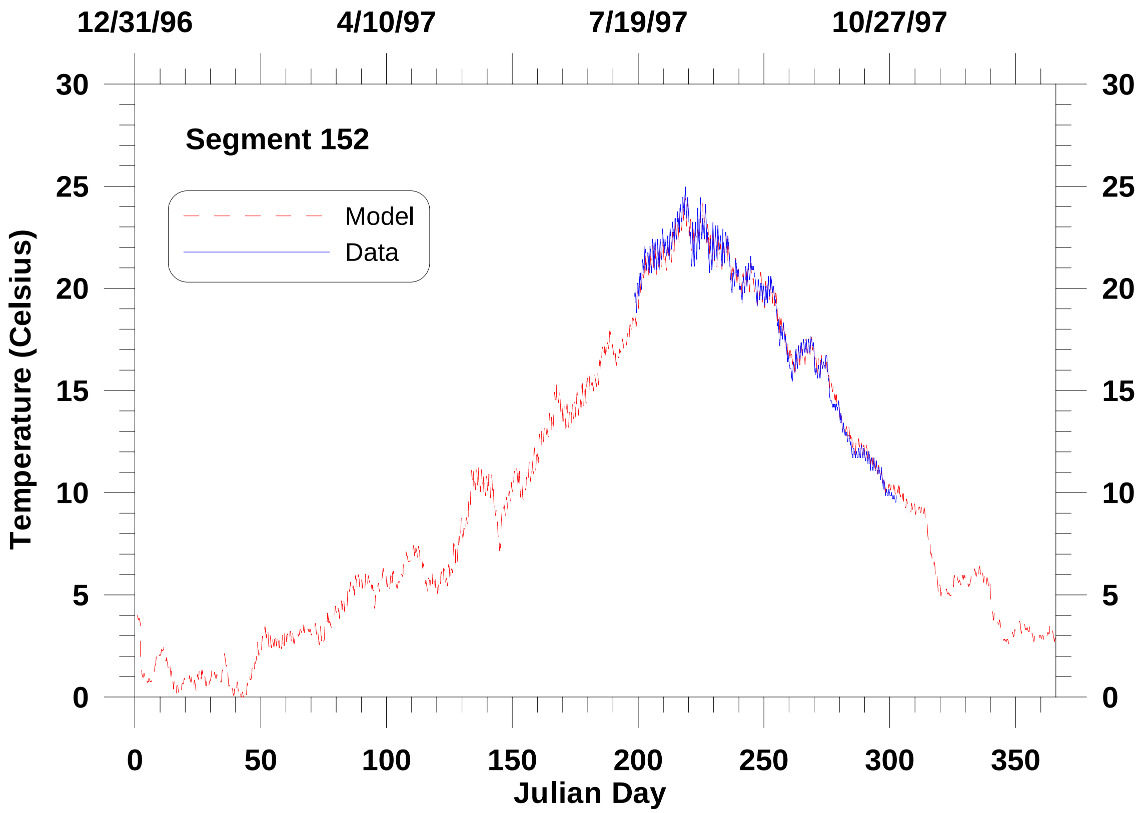

Figure 80: Model predictions and 1997 continuous temperature data measured at segment 152 (site TACOA).

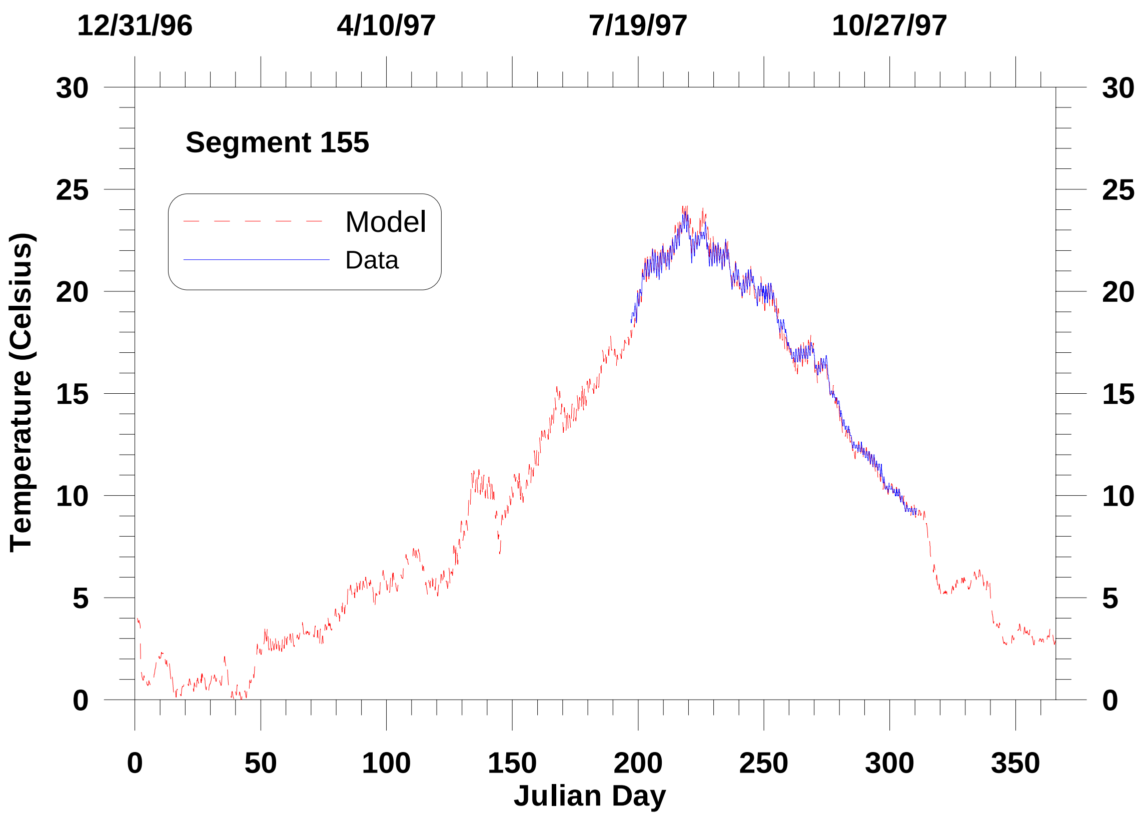

Figure 81: Model predictions and 1997 continuous temperature data measured at segment 155 (site CCAA).

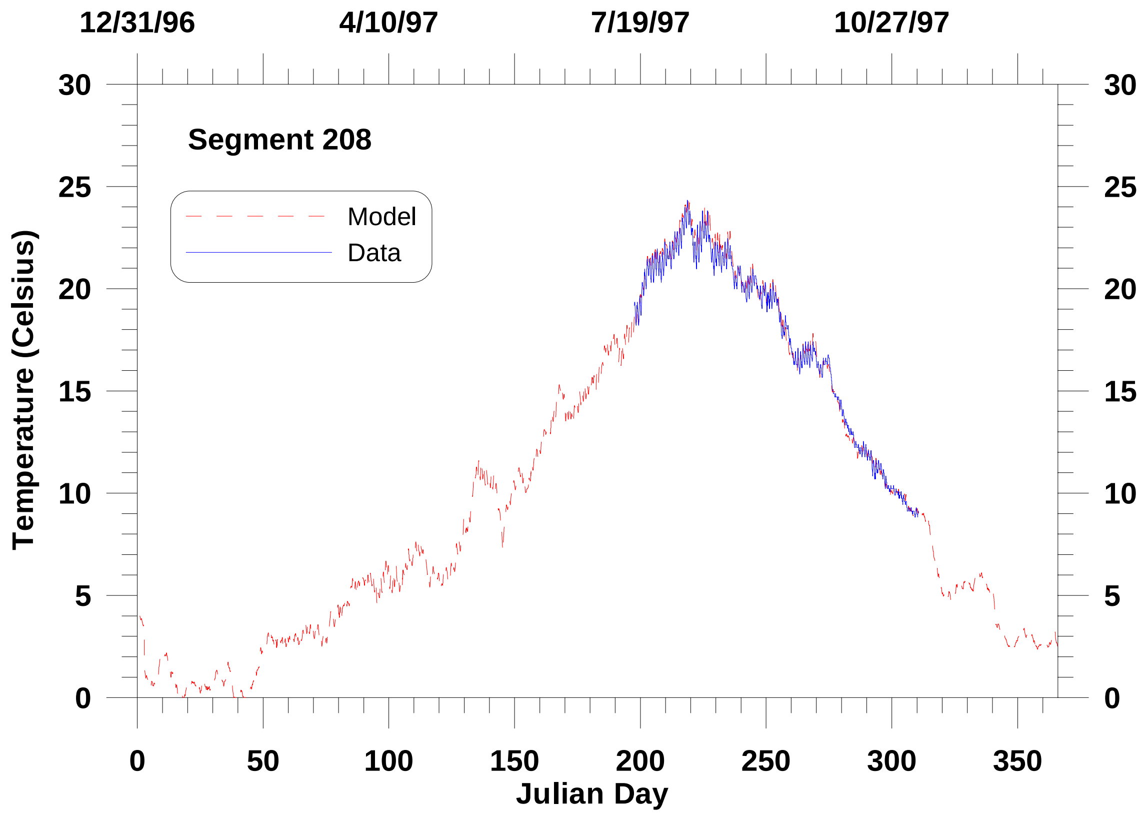

Figure 82: Model predictions and 1997 continuous temperature data measured at segment 208 (site MILA).

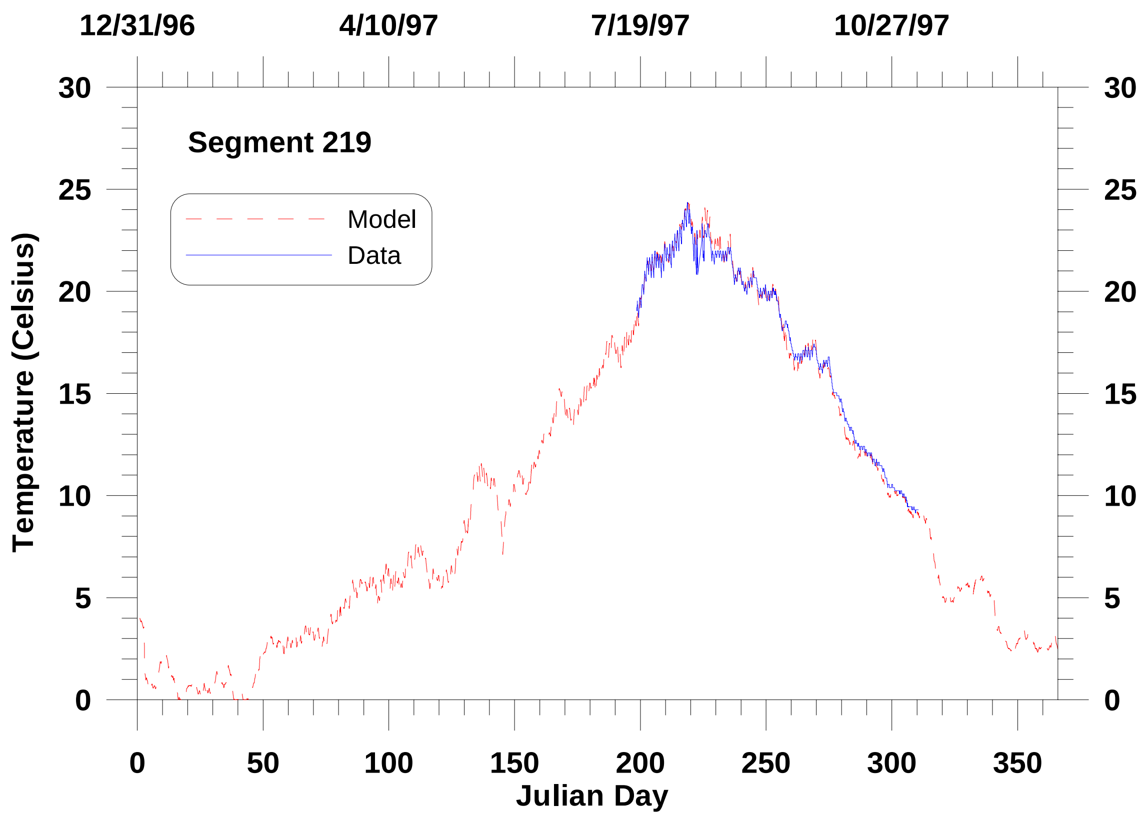

Figure 83: Model predictions and 1997 continuous temperature data measured at segment 219 (site LCLA).

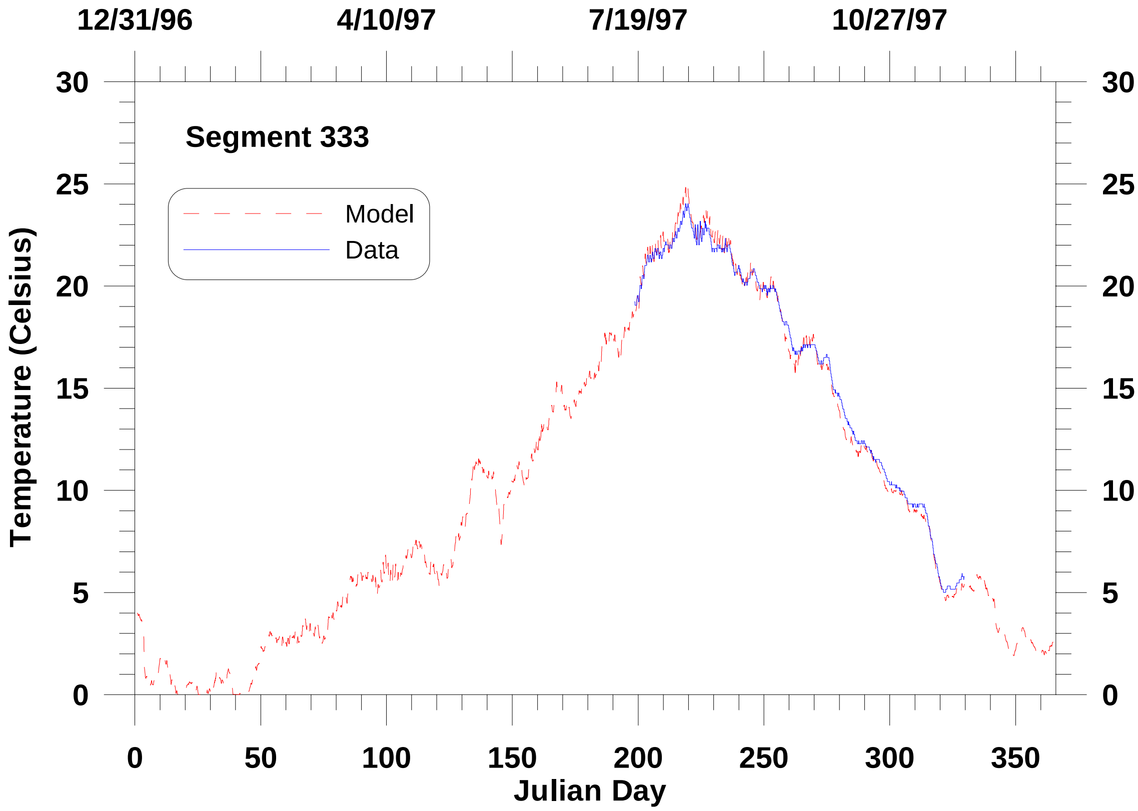

Figure 84: Model predictions and 1997 continuous temperature data measured at segment 333 (site BMATOP).

1998

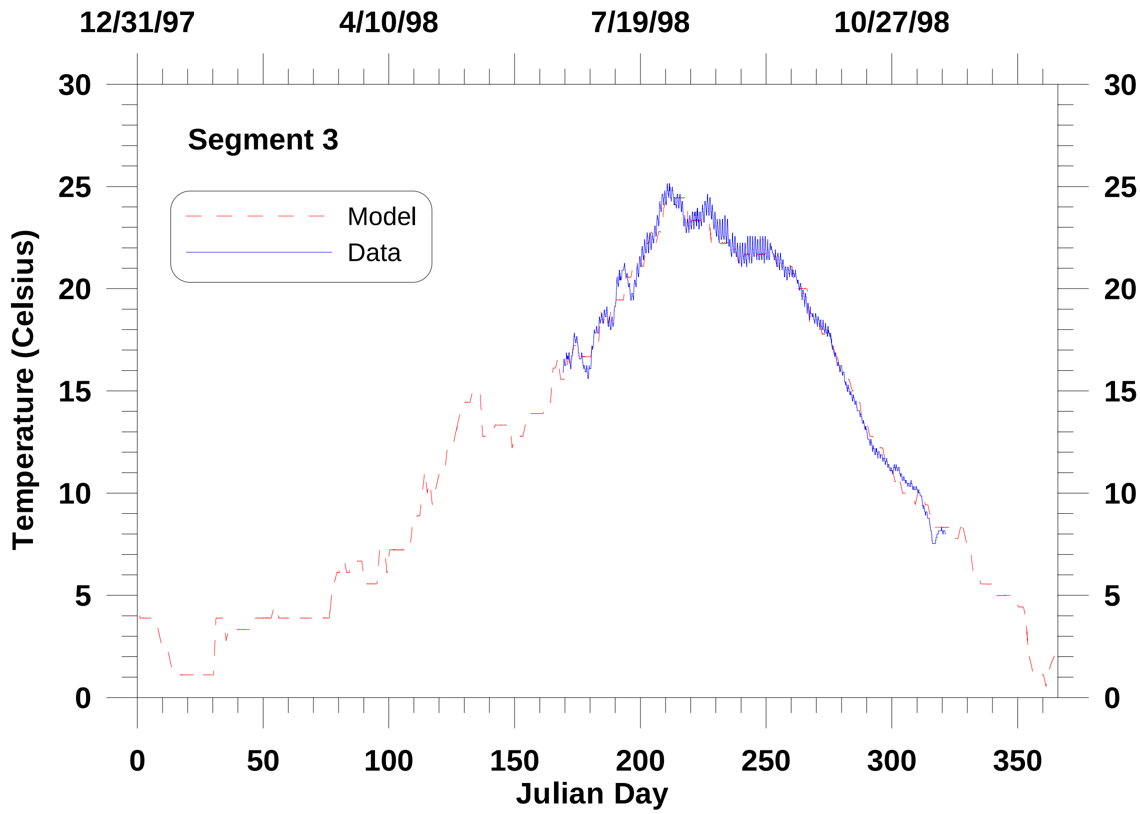

Figure 85: Model predictions and 1998 continuous temperature data measured at segment 3 (site POALB).

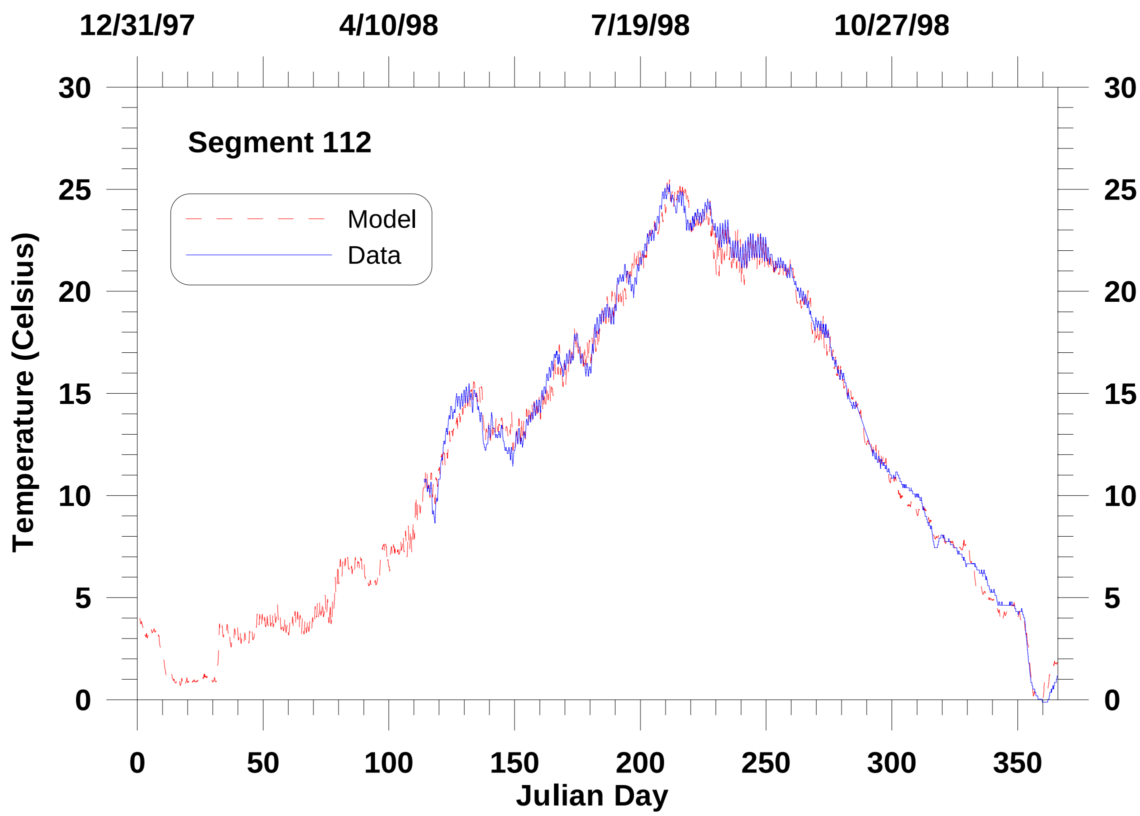

Figure 86: Model predictions and 1998 continuous temperature data measured at segment 112 (site SKMA).

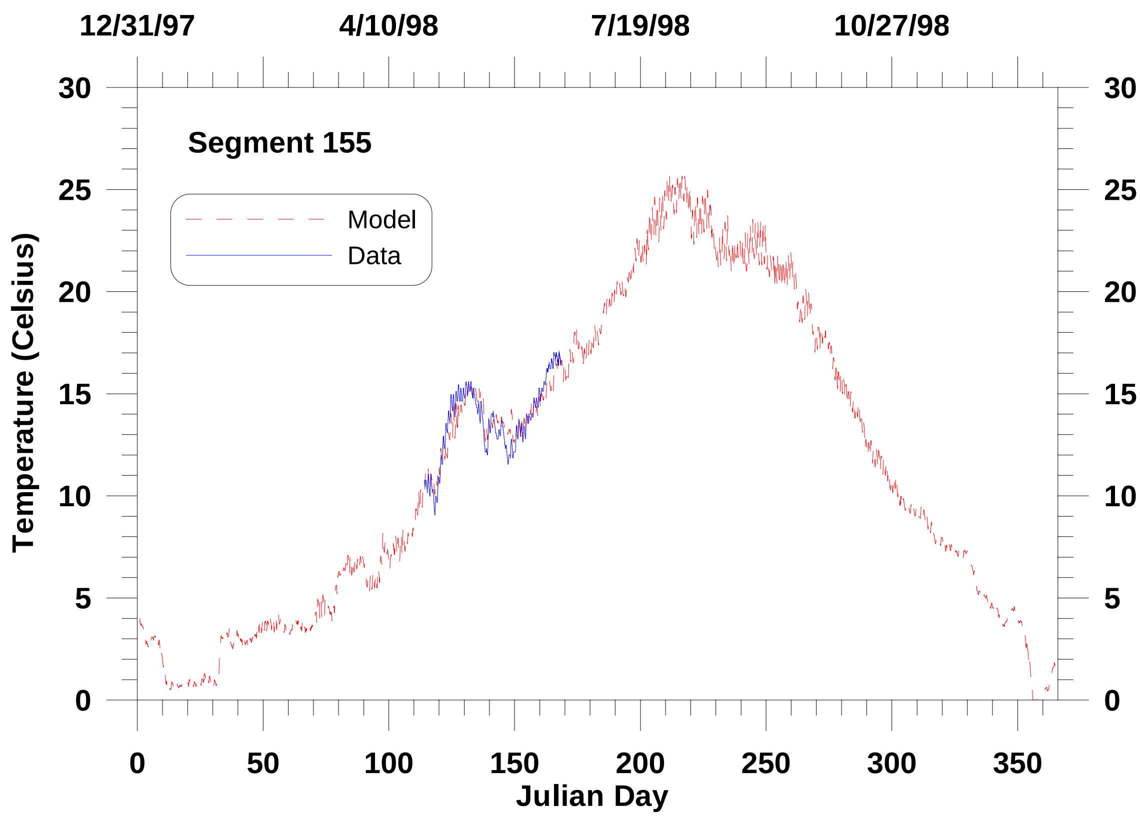

Figure 87: Model predictions and 1998 continuous temperature data measured at segment 155 (site CCAA).

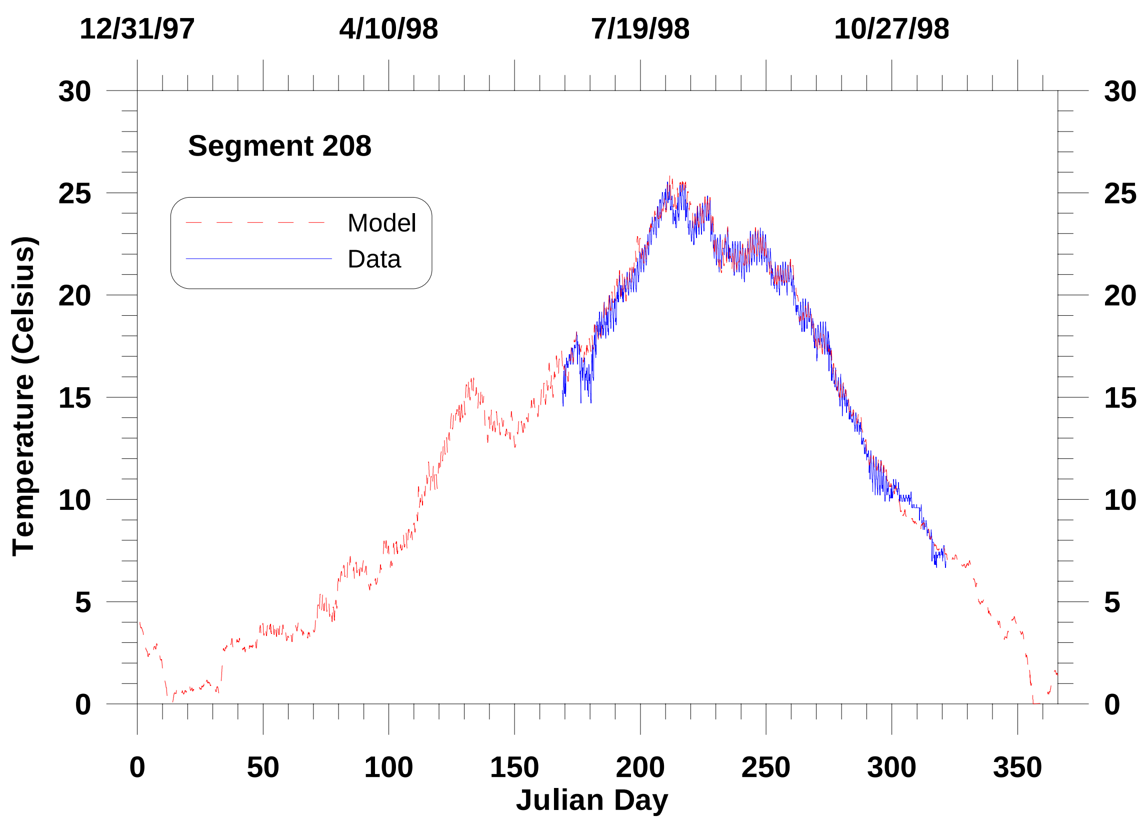

Figure 88: Model predictions and 1998 continuous temperature data measured at segment 208 (site MILA).

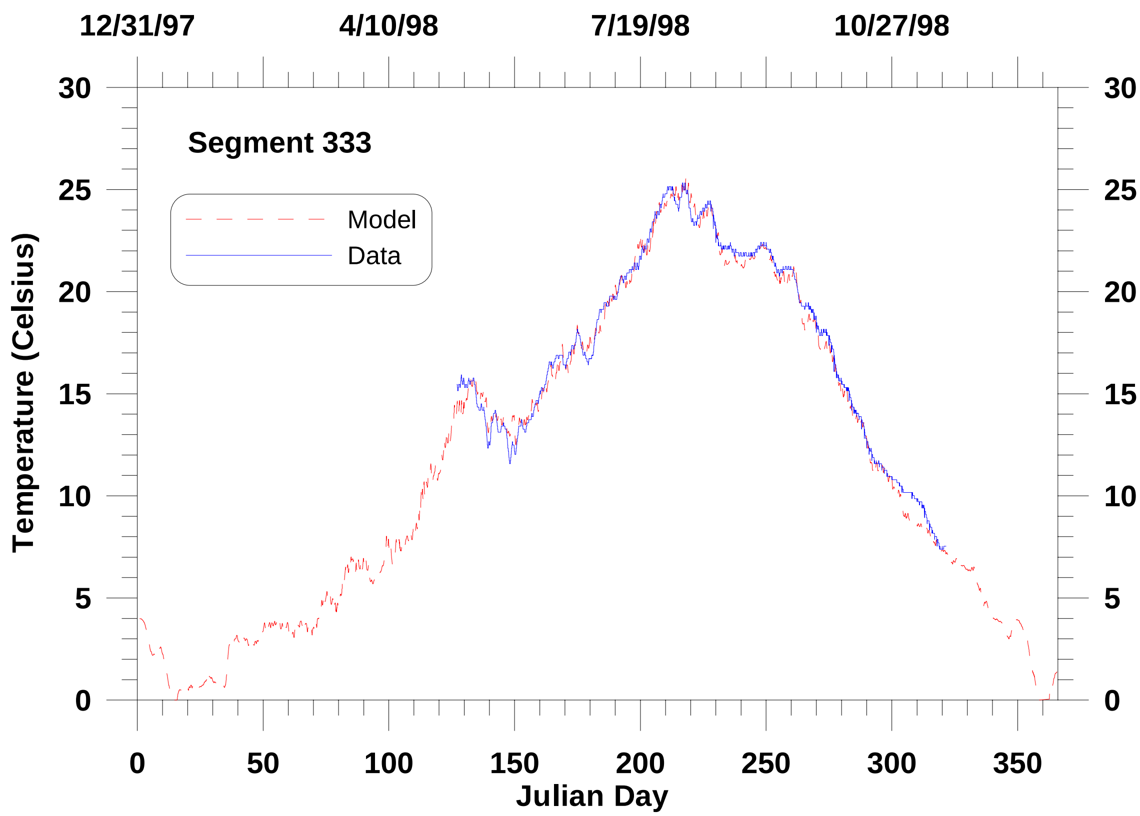

Figure 89: Model predictions and 1998 continuous temperature data measured at segment 333 (site BMABOT).

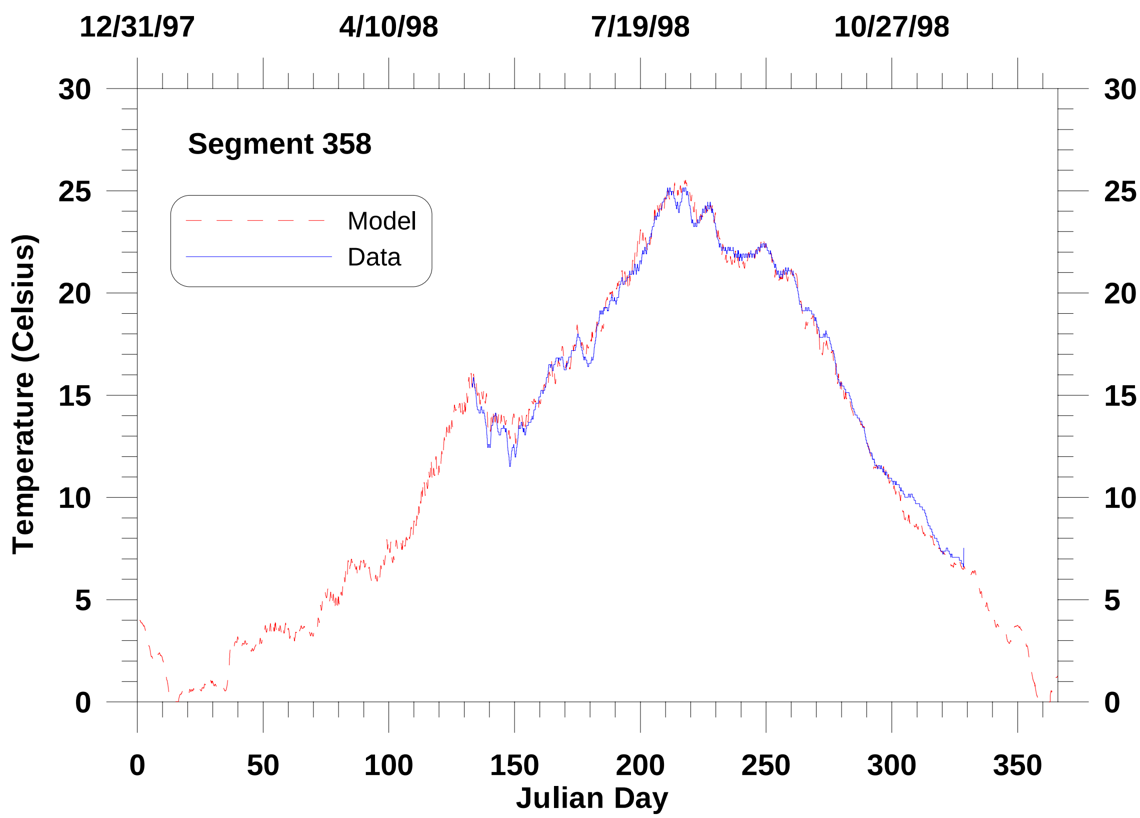

Figure 90: Model predictions and 1998 continuous temperature data measured at segment 358 (site FORB).

2004

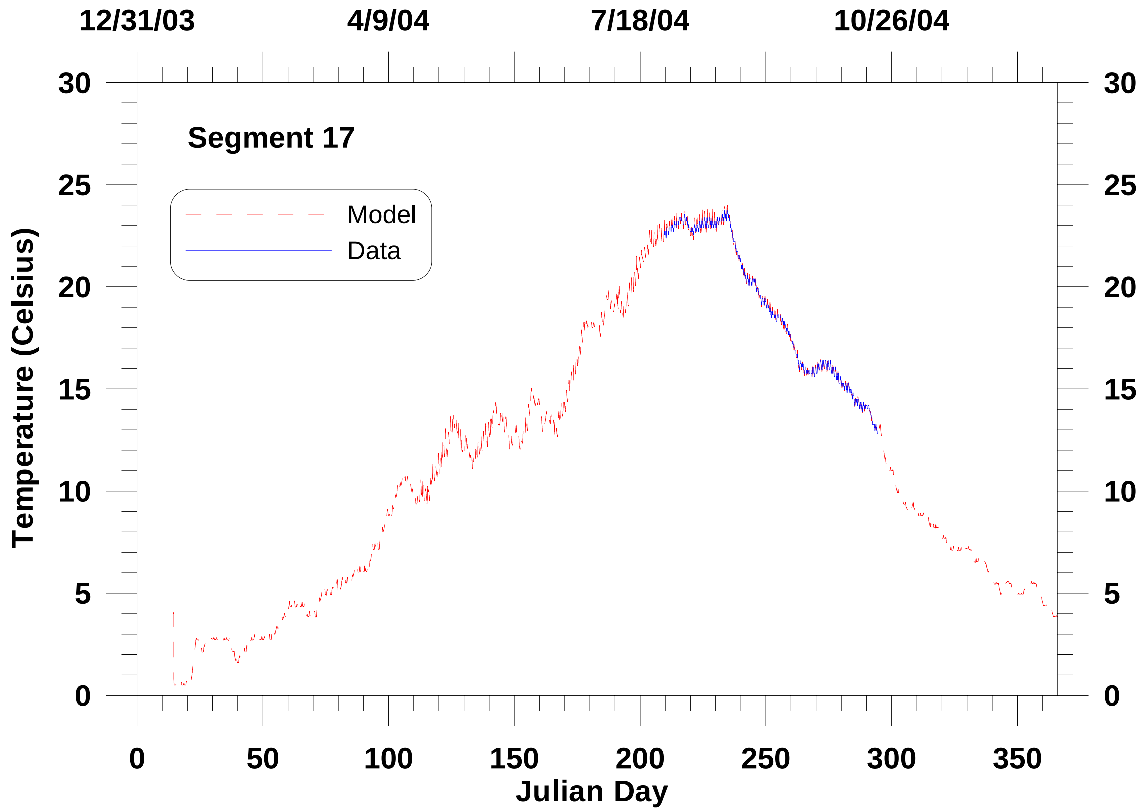

Figure 91: Model predictions and 2004 continuous temperature data measured at segment 17 (site 1010).

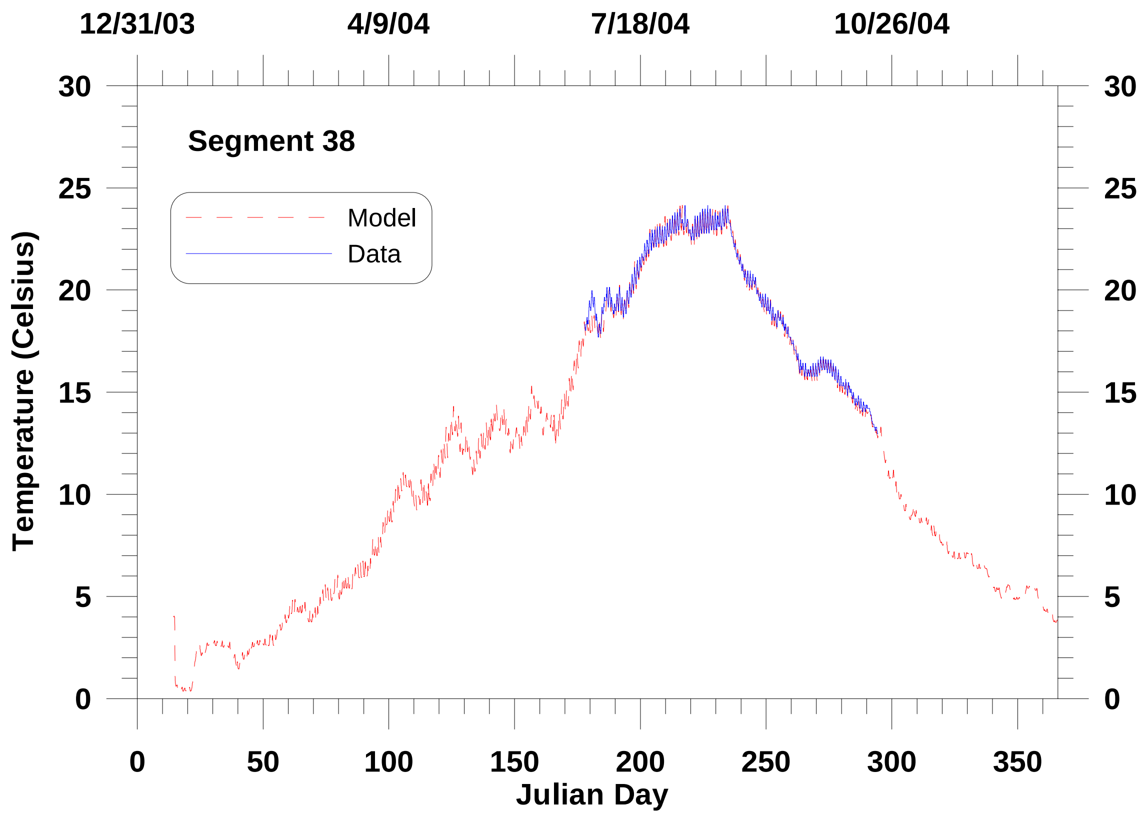

Figure 92: Model predictions and 2004 continuous temperature data measured at segment 38 (site 1020).

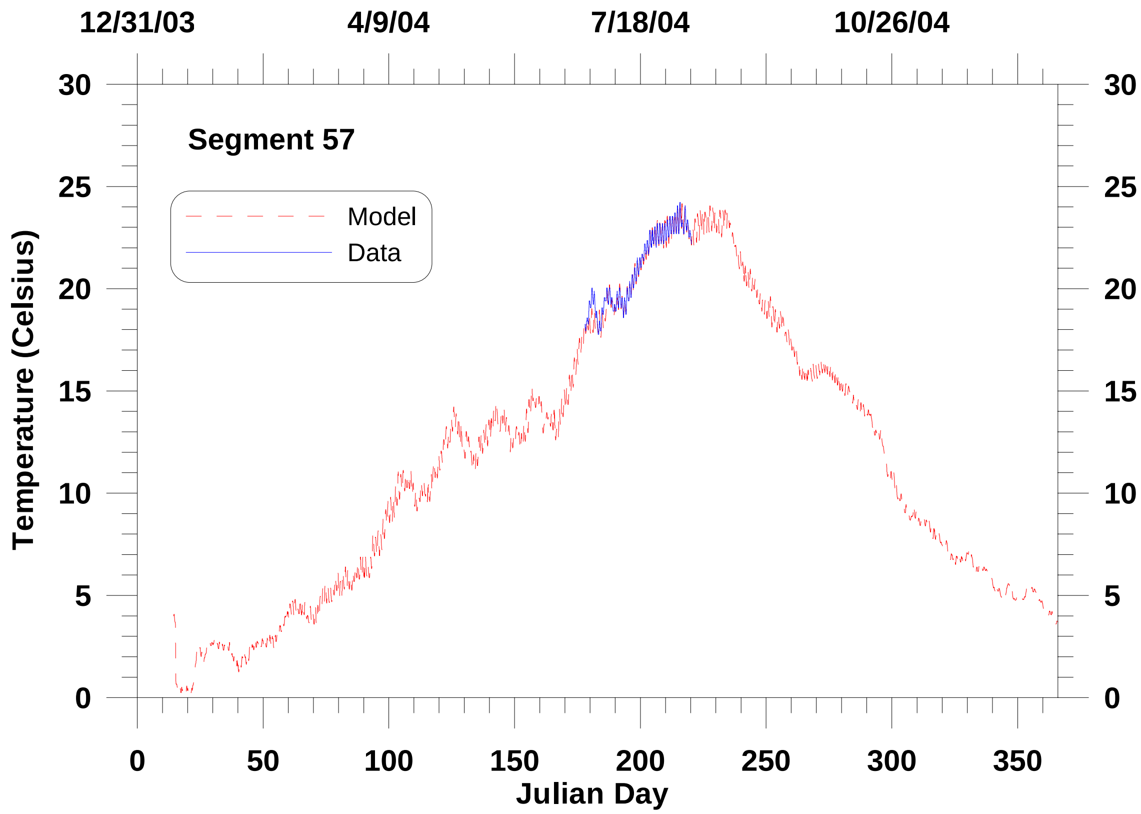

Figure 93: Model predictions and 2004 continuous temperature data measured at segment 57 (site 1040).

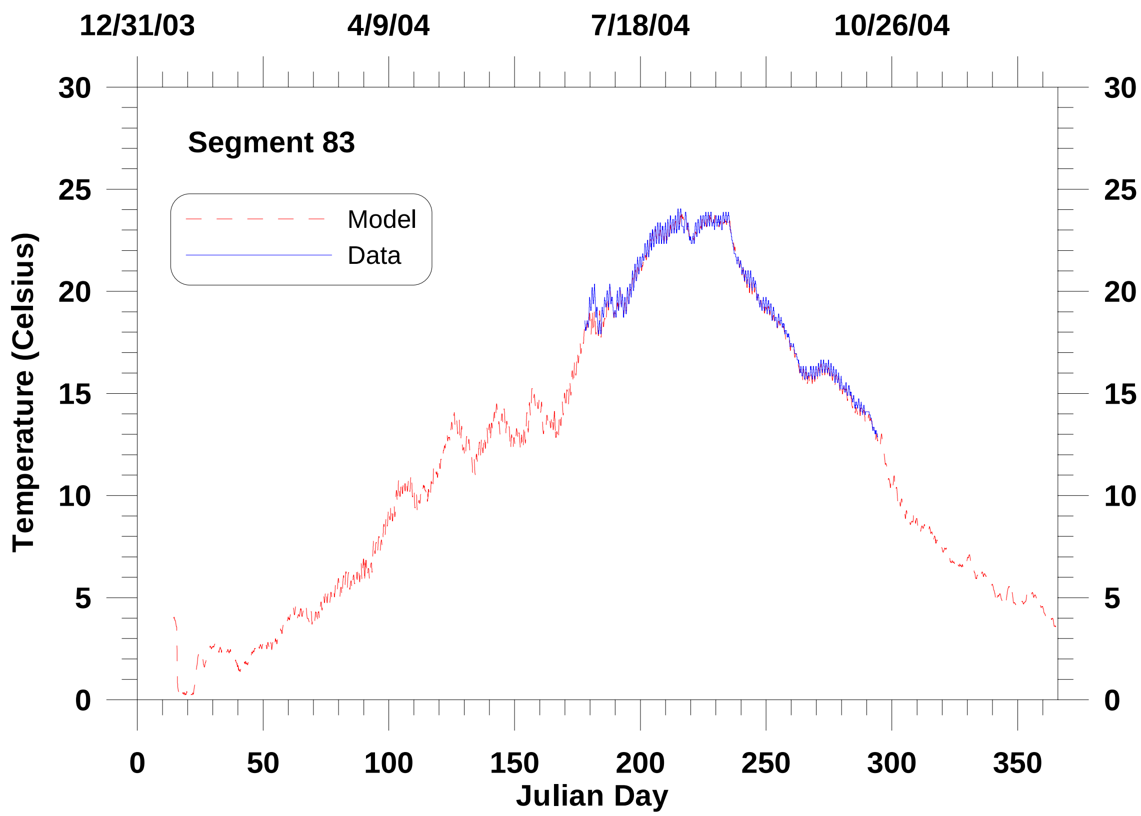

Figure 94: Model predictions and 2004 continuous temperature data measured at segment 83 (site 1060).

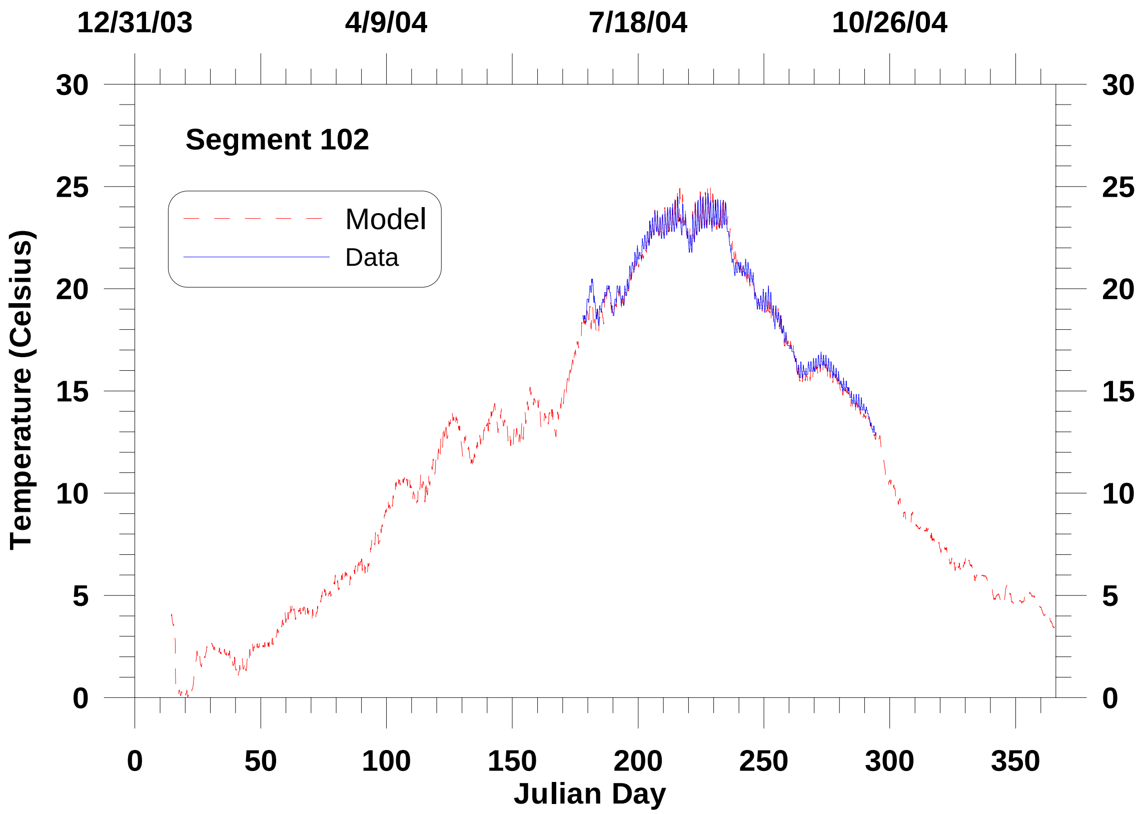

Figure 95: Model predictions and 2004 continuous temperature data measured at segment 102 (site 1070).

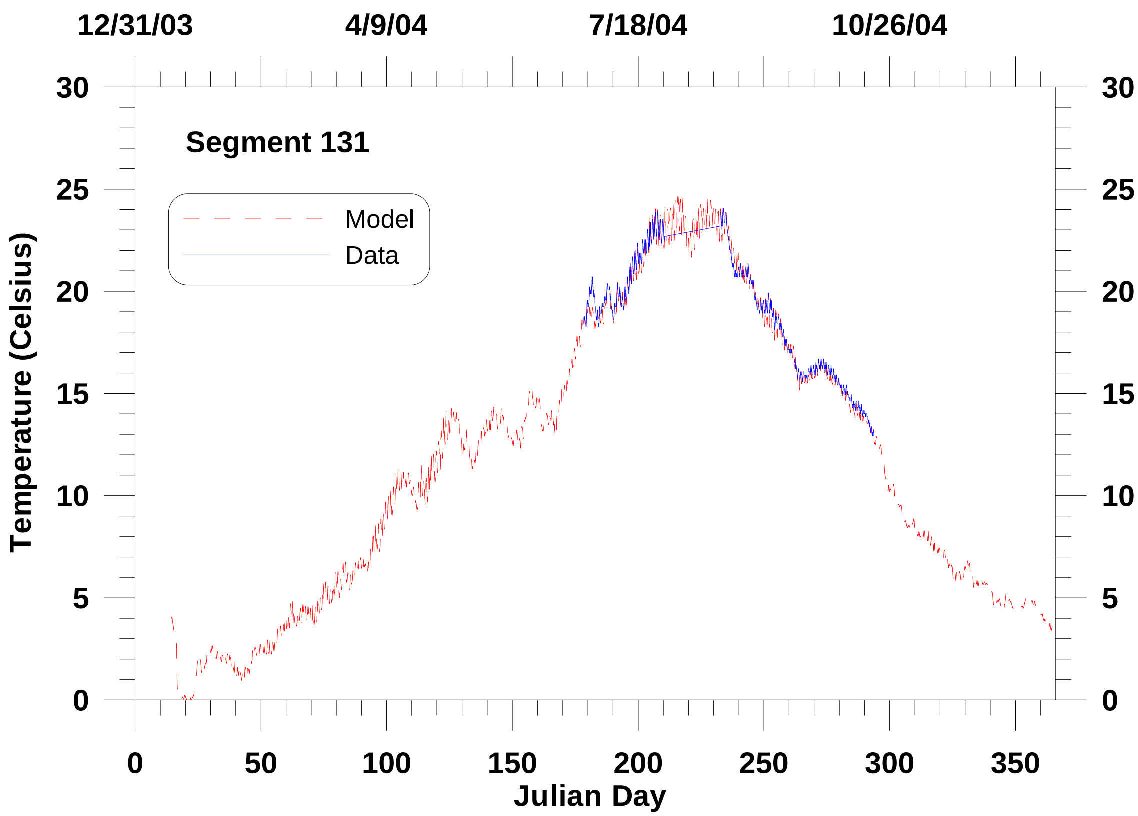

Figure 96: Model predictions and 2004 continuous temperature data measured at segment 131 (site 1080).

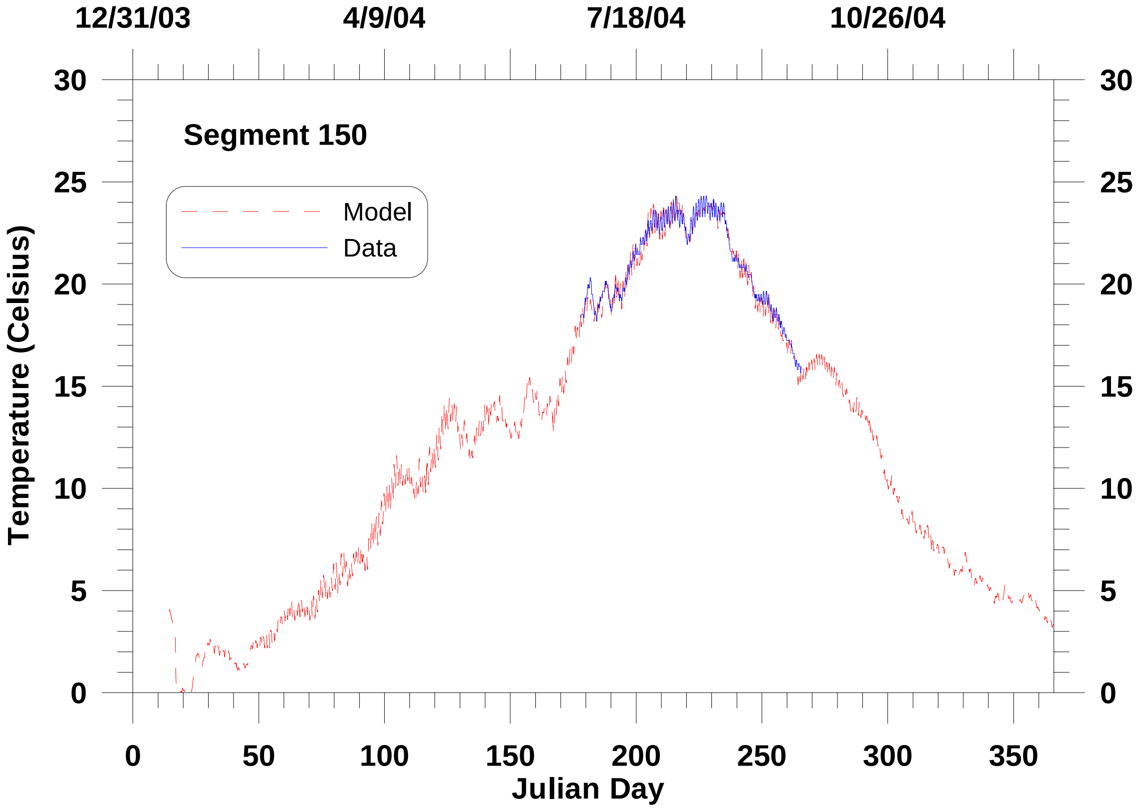

Figure 97: Model predictions and 2004 continuous temperature data measured at segment 150 (site 1110).

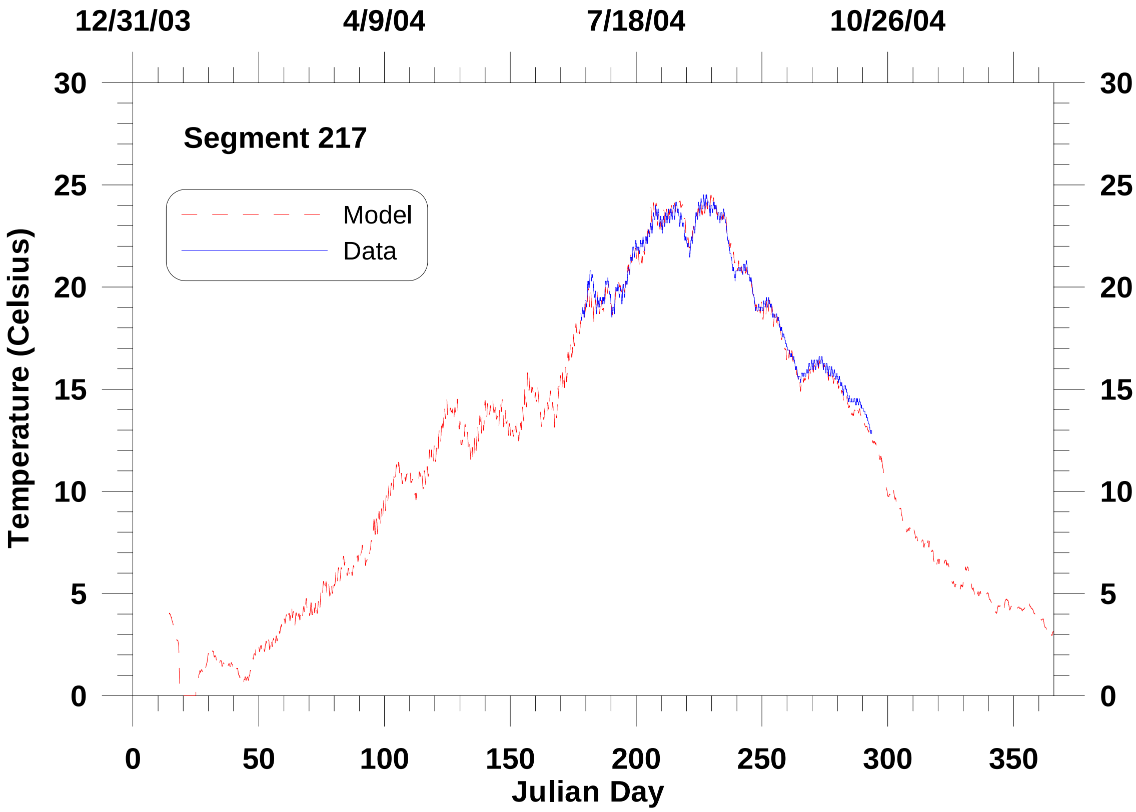

Figure 98: Model predictions and 2004 continuous temperature data measured at segment 217 (site 1140).

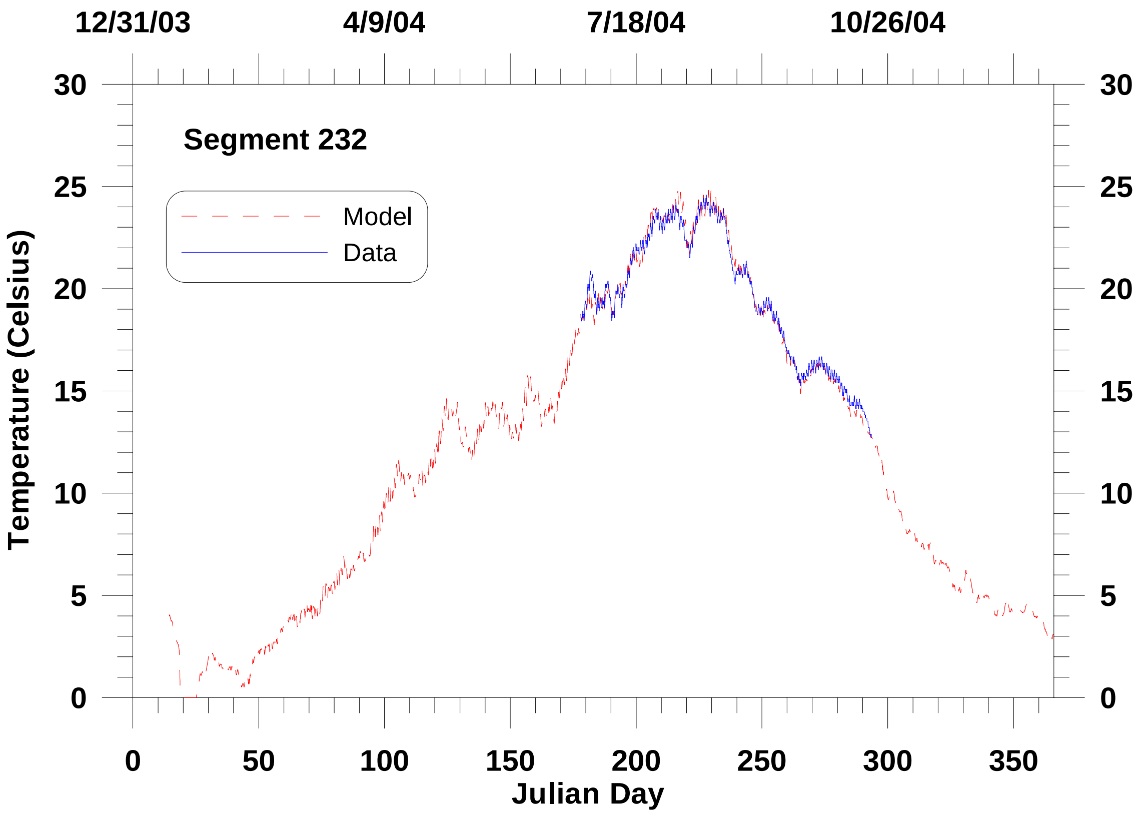

Figure 99: Model predictions and 2004 continuous temperature data measured at segment 232 (site 1160).

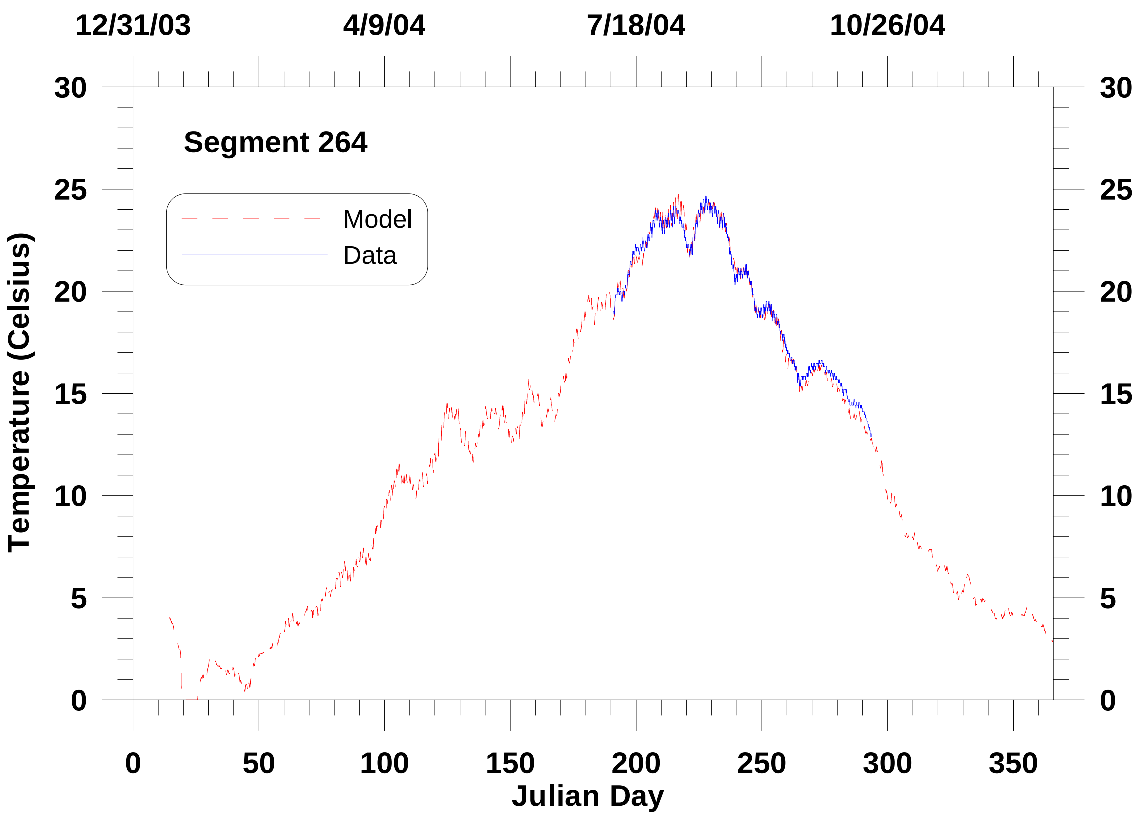

Figure 100: Model predictions and 2004 continuous temperature data measured at segment 264 (site 1180).

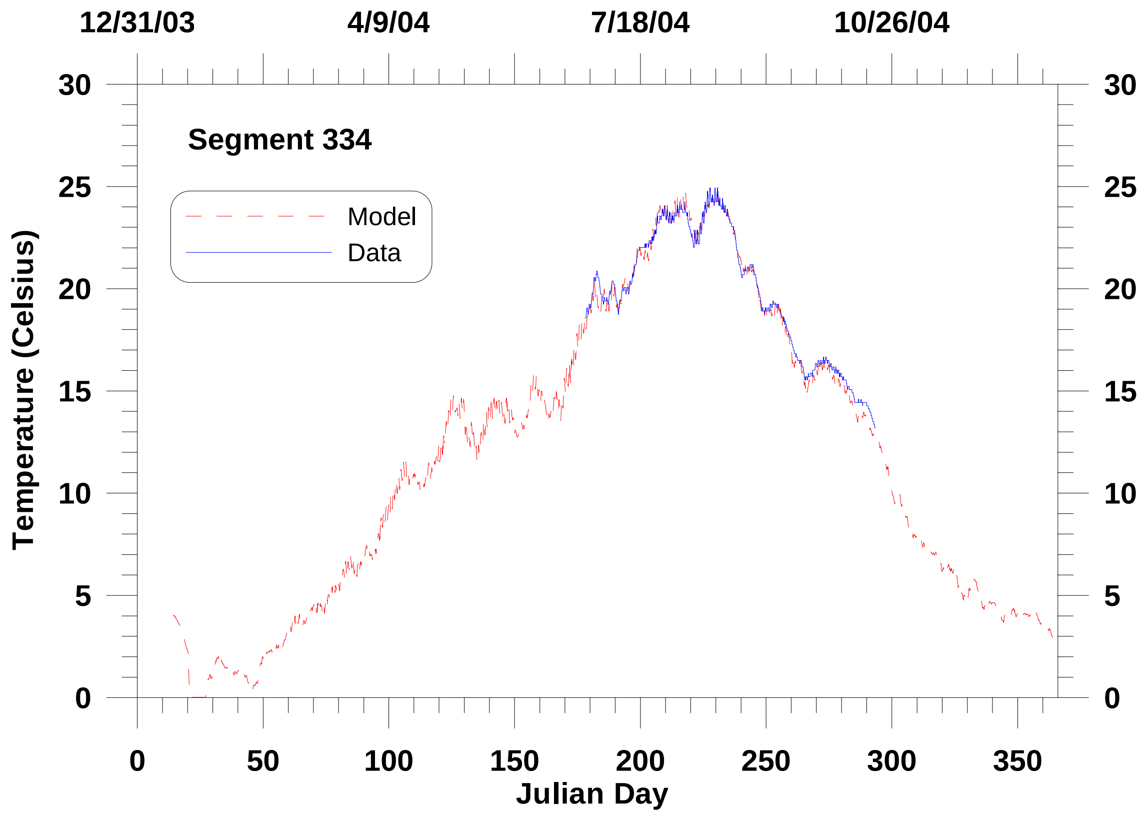

Figure 101: Model predictions and 2004 continuous temperature data measured at segment 334 (site 1190).

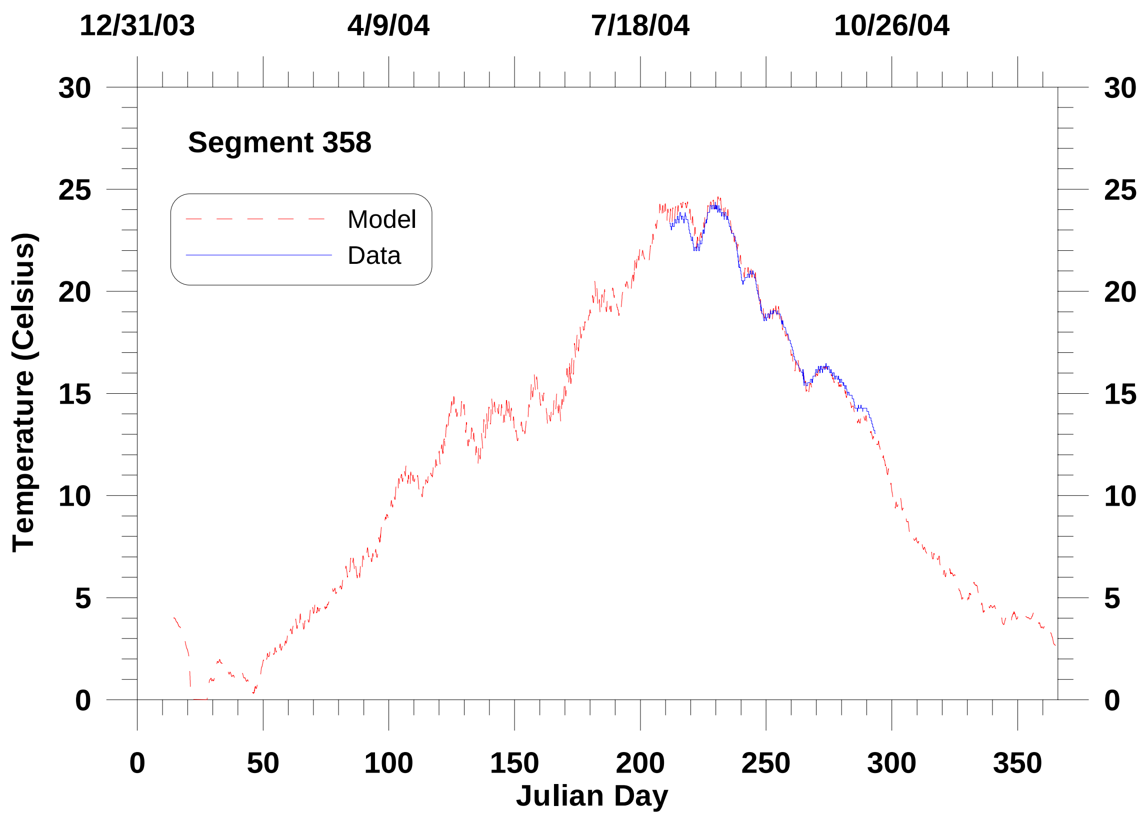

Figure 102: Model predictions and 2004 continuous temperature data measured at segment 358 (site 1220).

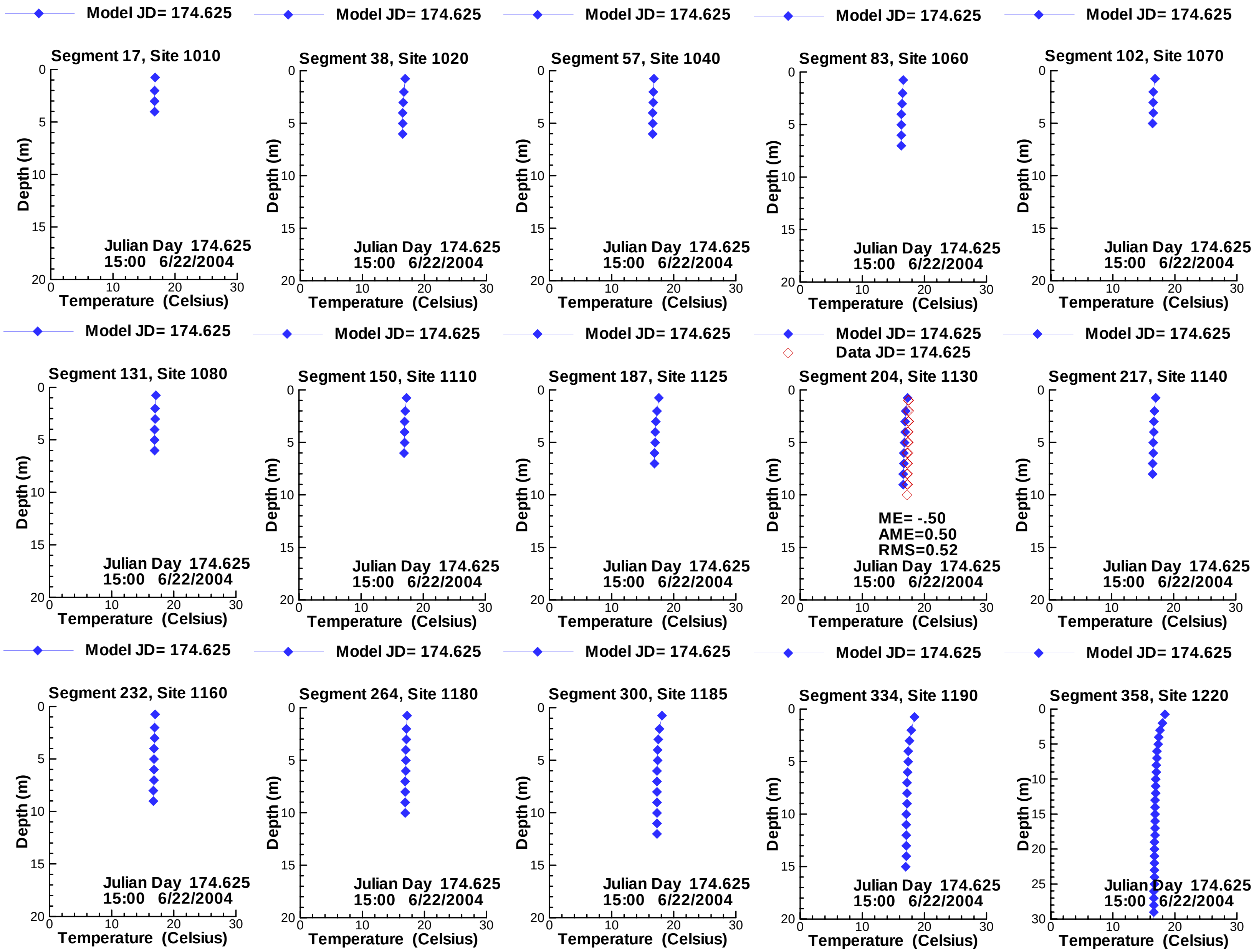

Figure 103: Vertical profiles of temperature compared with data for 6/22/2004 15:00.

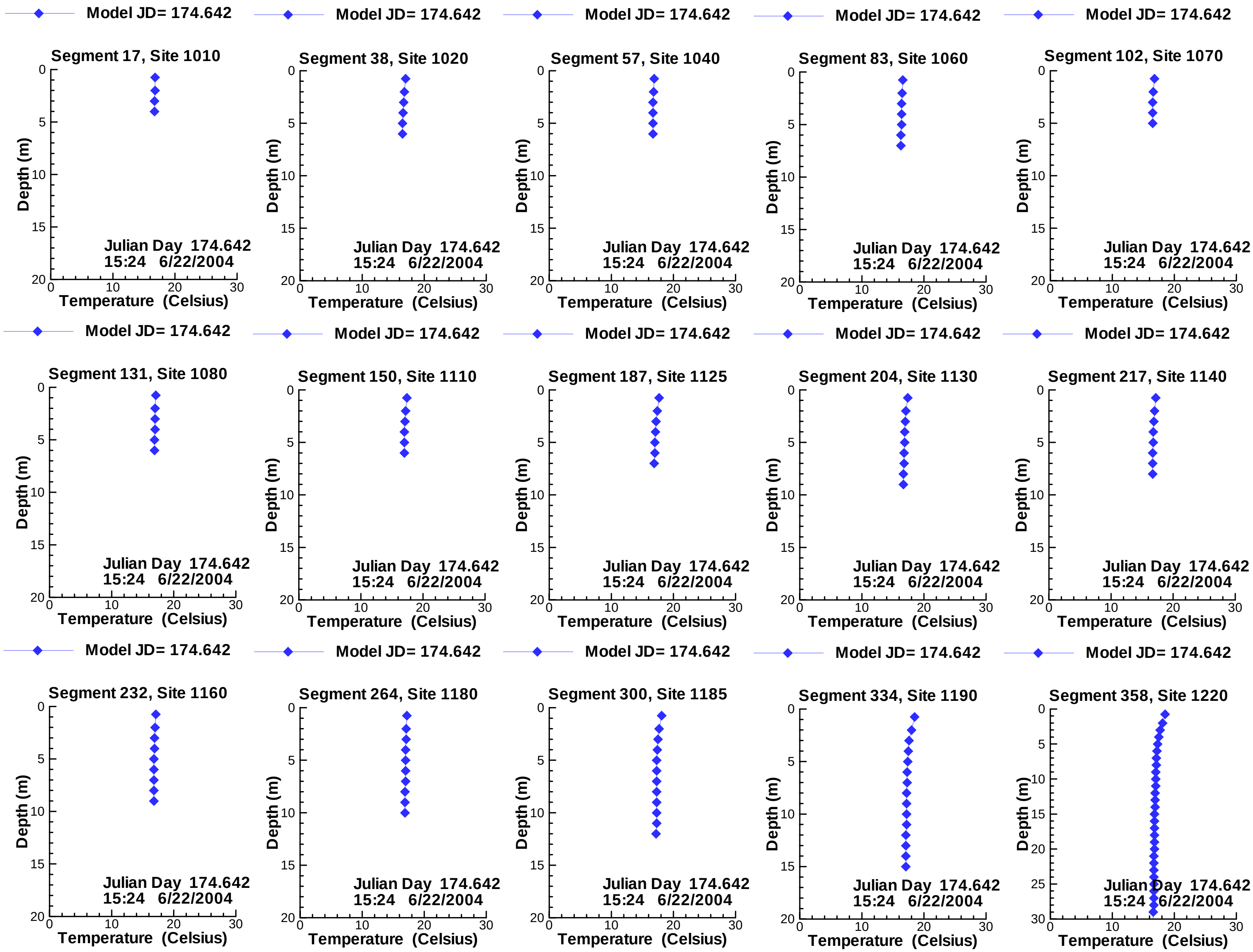

Figure 104: Vertical profiles of temperature compared with data for 6/22/2004 15:24.

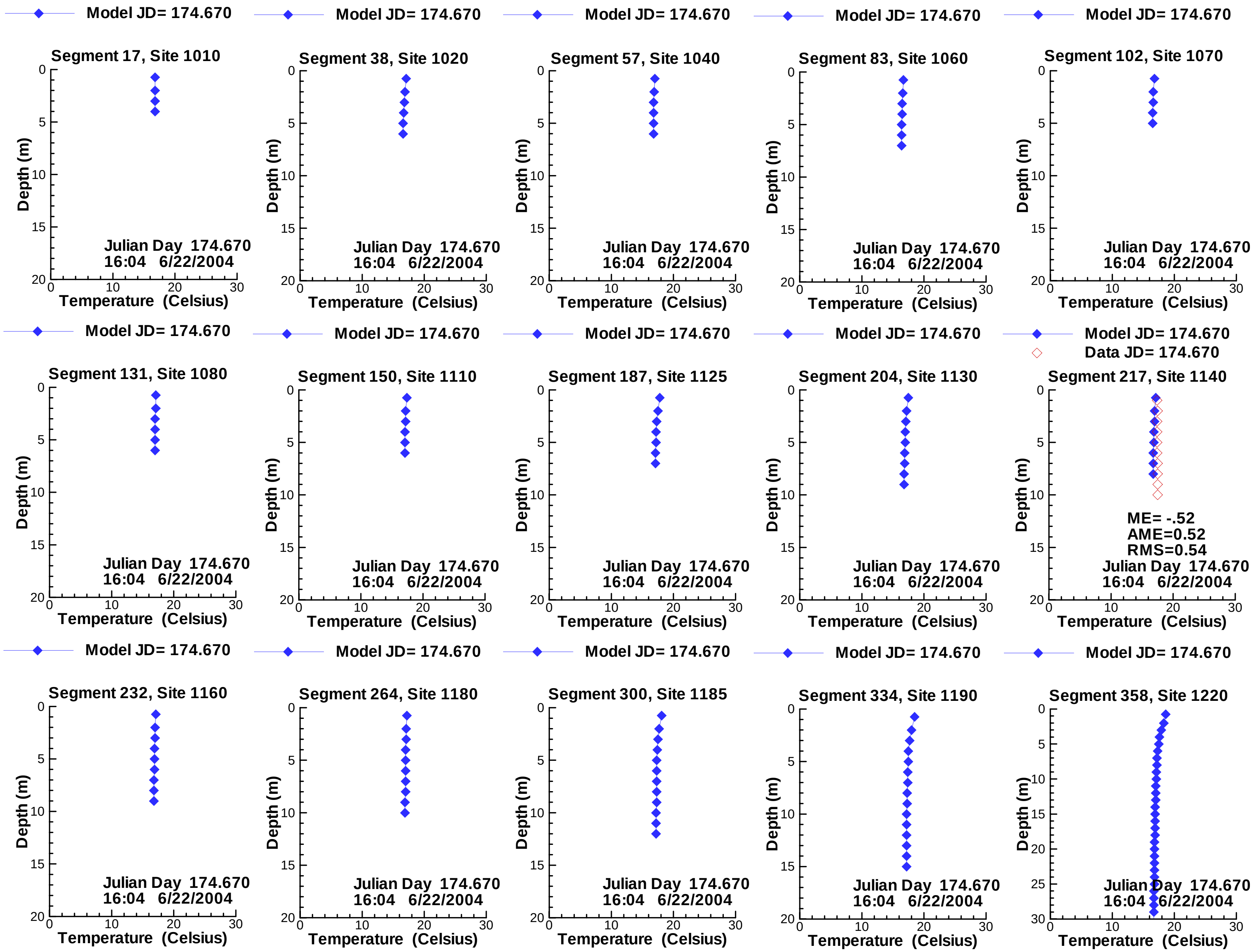

Figure 105: Vertical profiles of temperature compared with data for 6/22/2004 16:04.

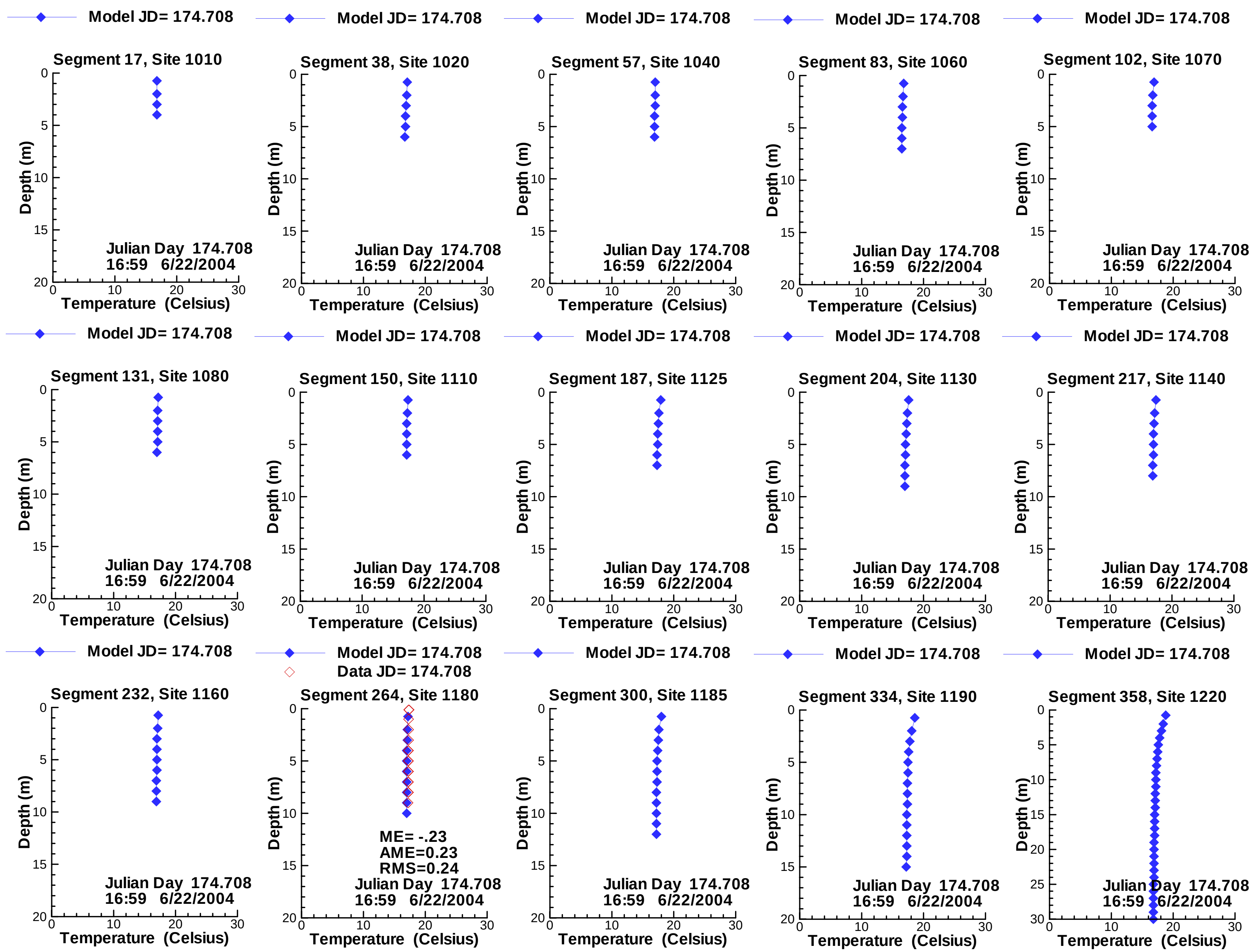

Figure 106: Vertical profiles of temperature compared with data for 6/22/2004 16:59.

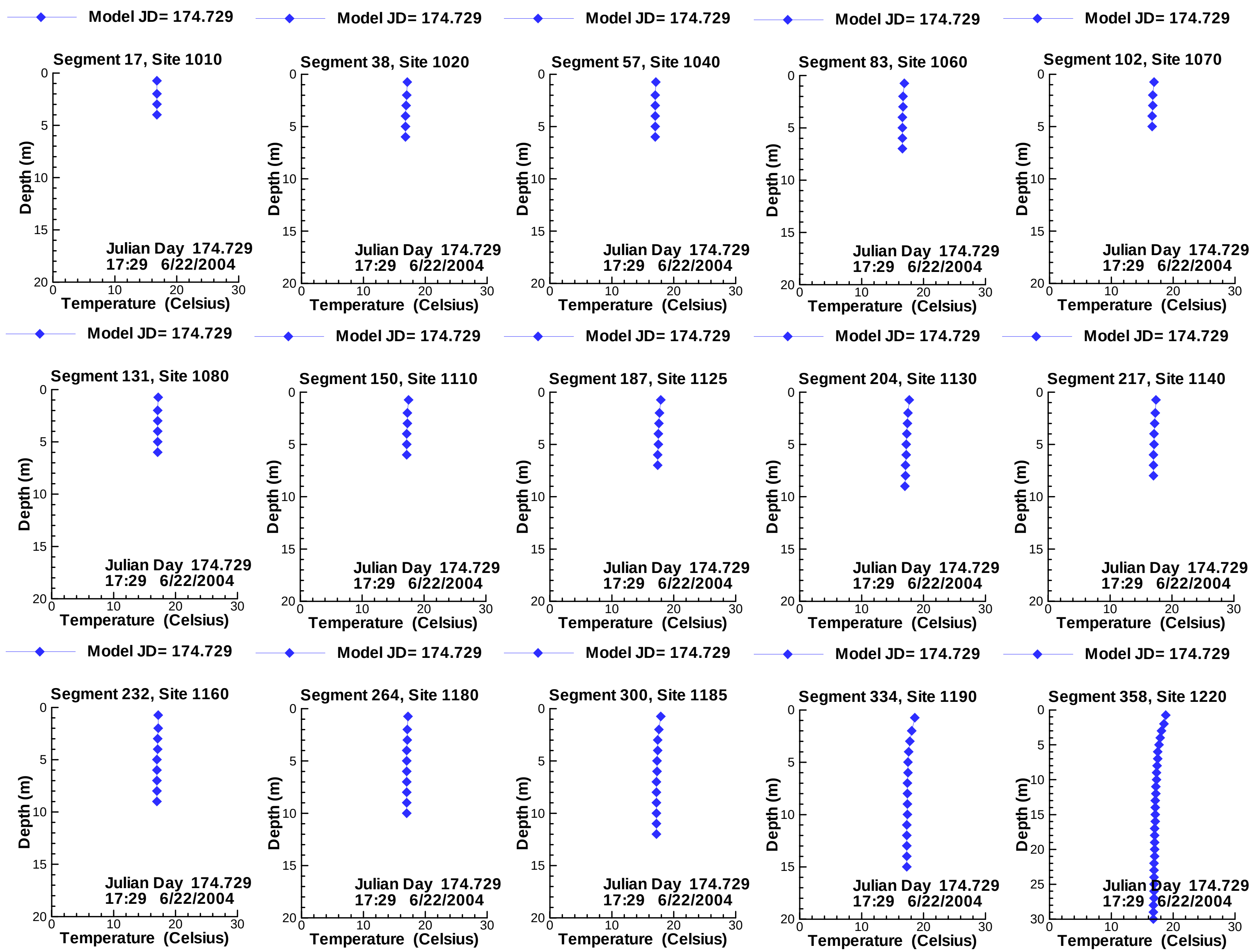

Figure 107: Vertical profiles of temperature compared with data for 6/22/2004 17:29.

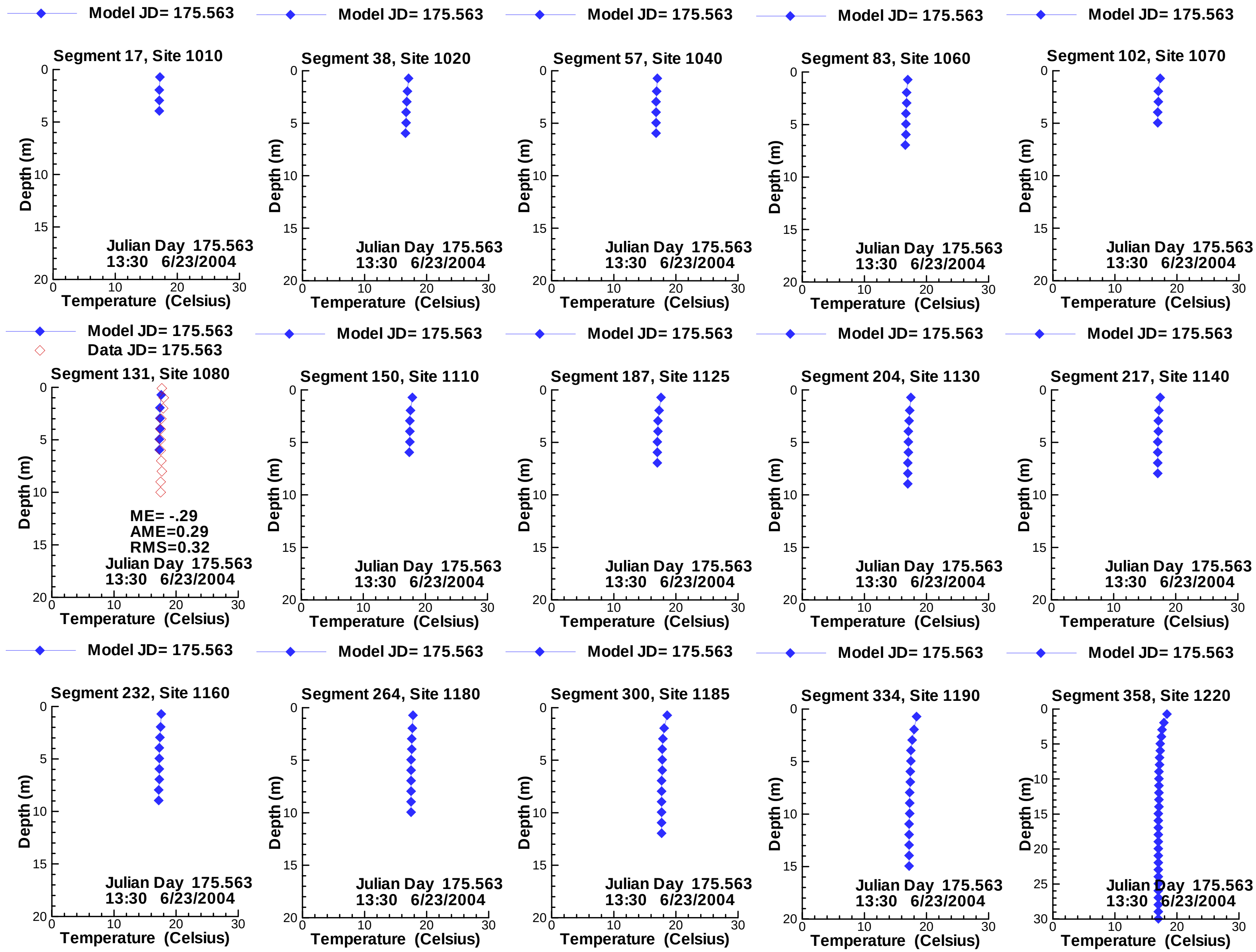

Figure 108: Vertical profiles of temperature compared with data for 6/23/2004 13:30.

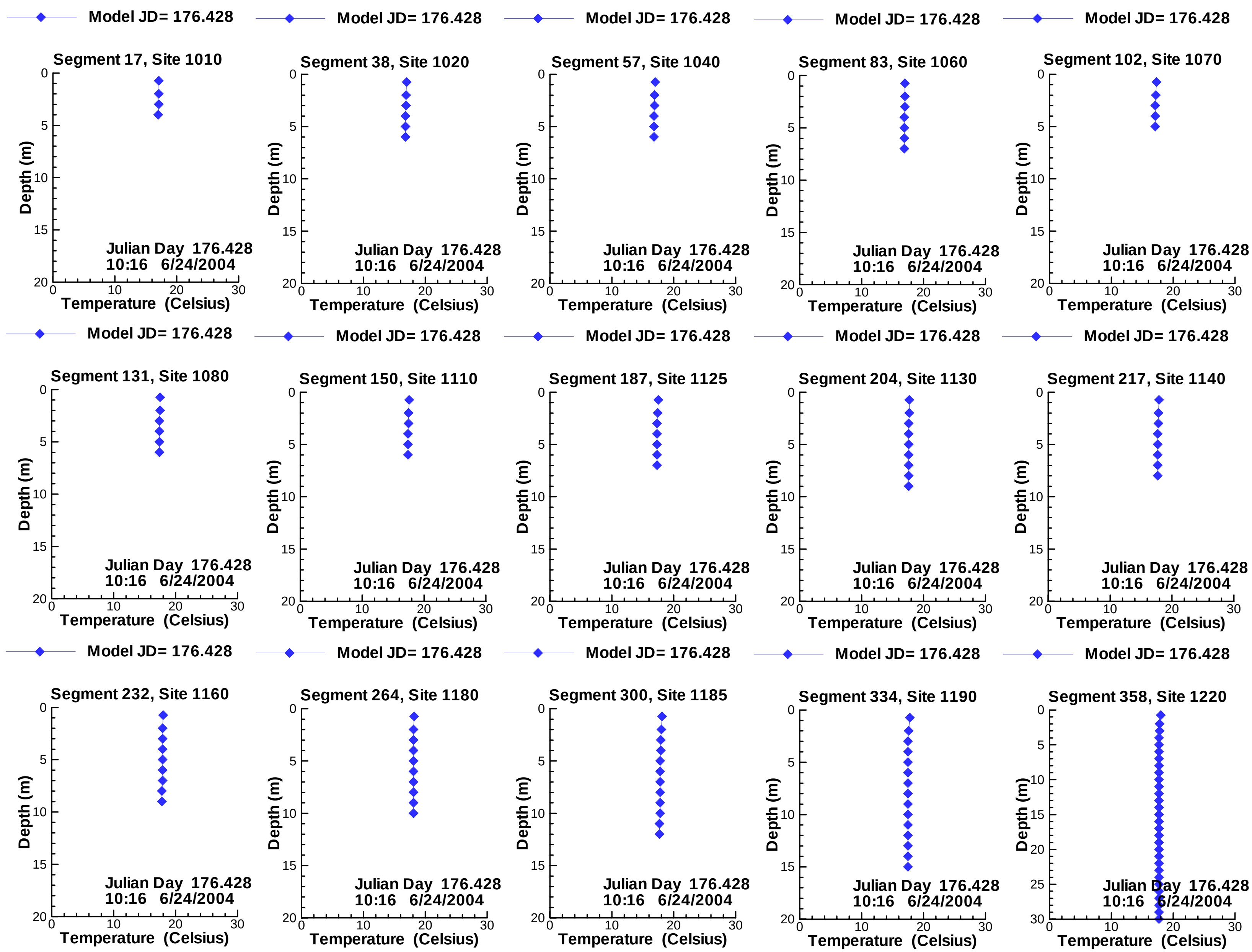

Figure 109: Vertical profiles of temperature compared with data for 6/24/2004 10:16.

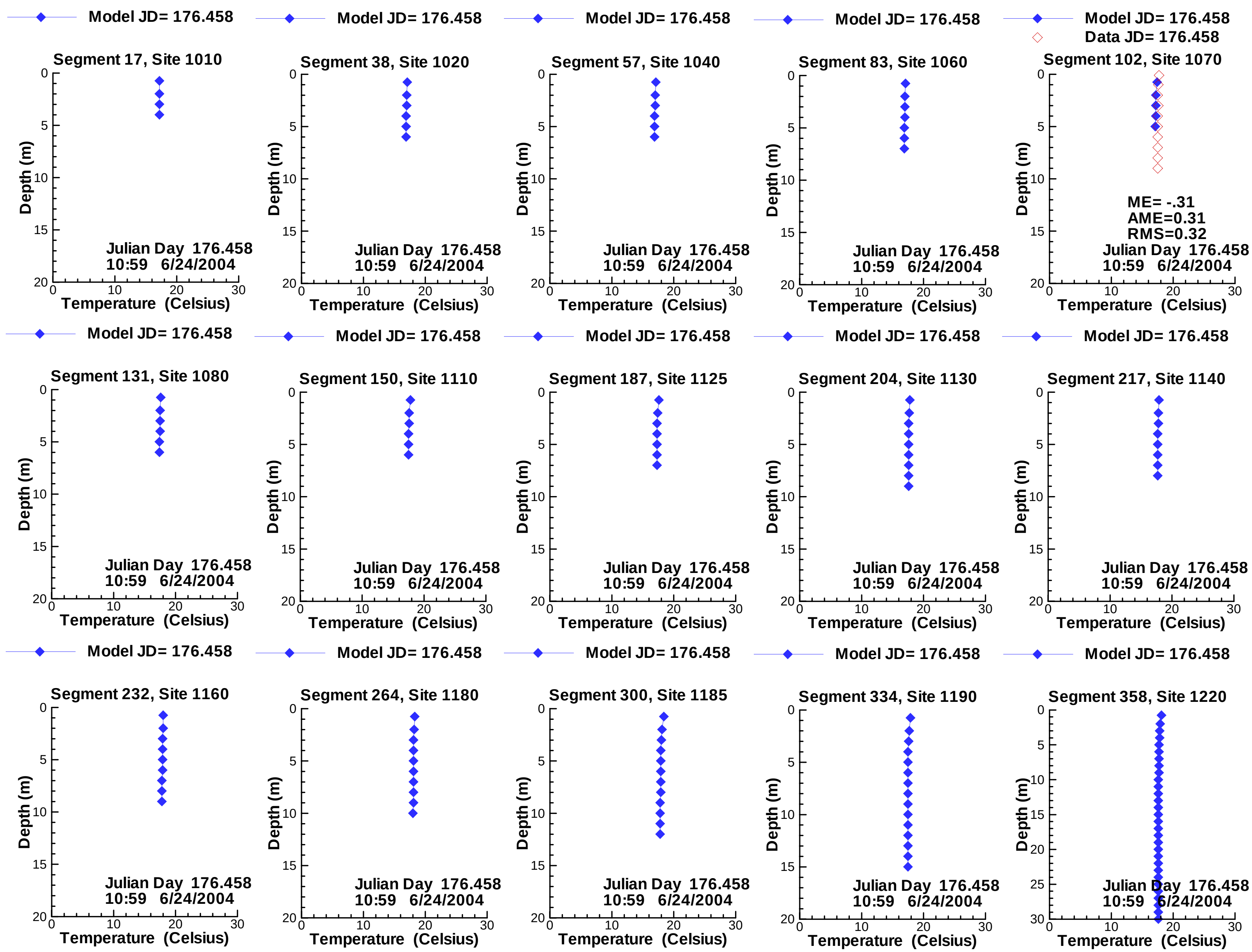

Figure 110: Vertical profiles of temperature compared with data for 6/24/2004 10:59.

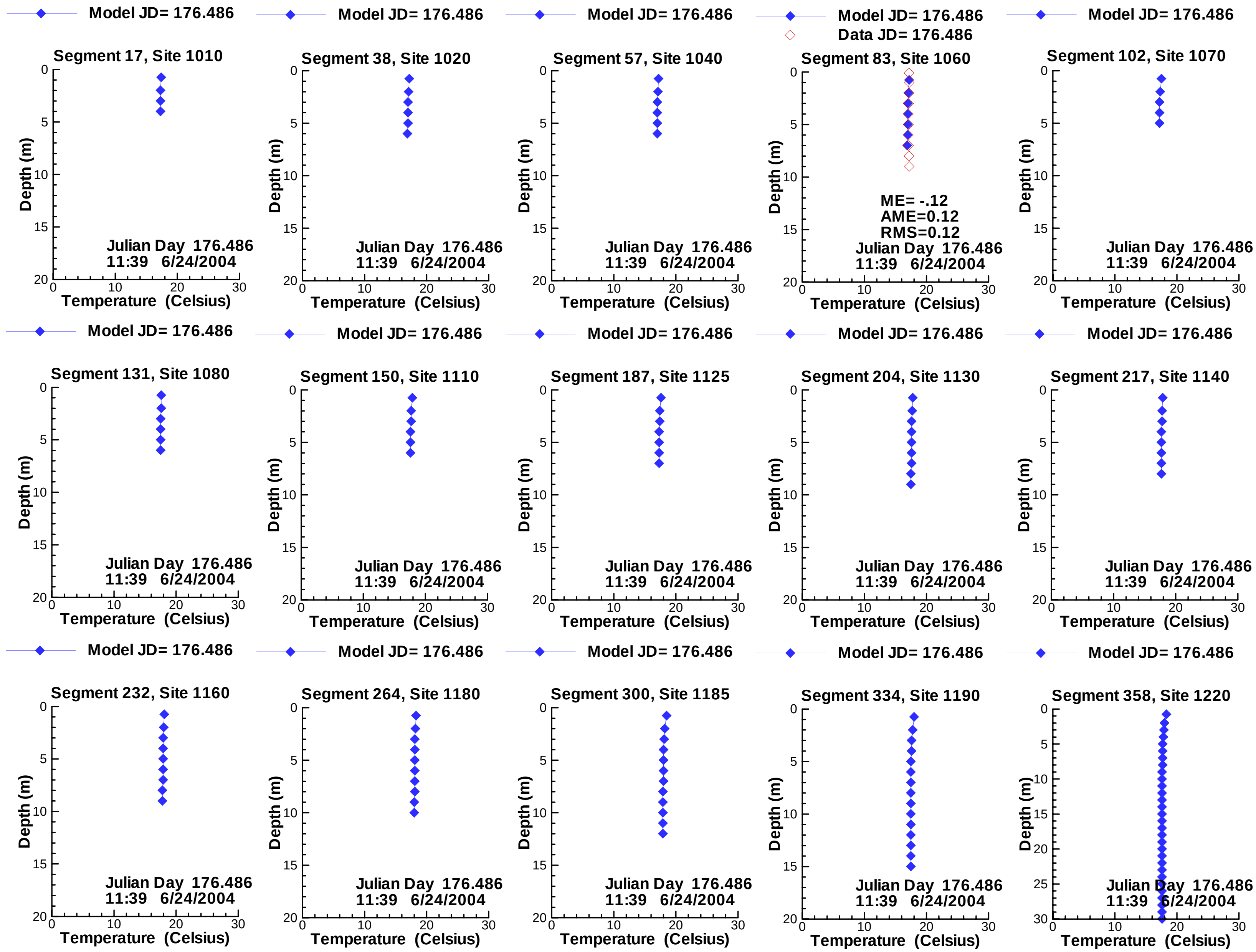

Figure 111: Vertical profiles of temperature compared with data for 6/24/2004 11:39.

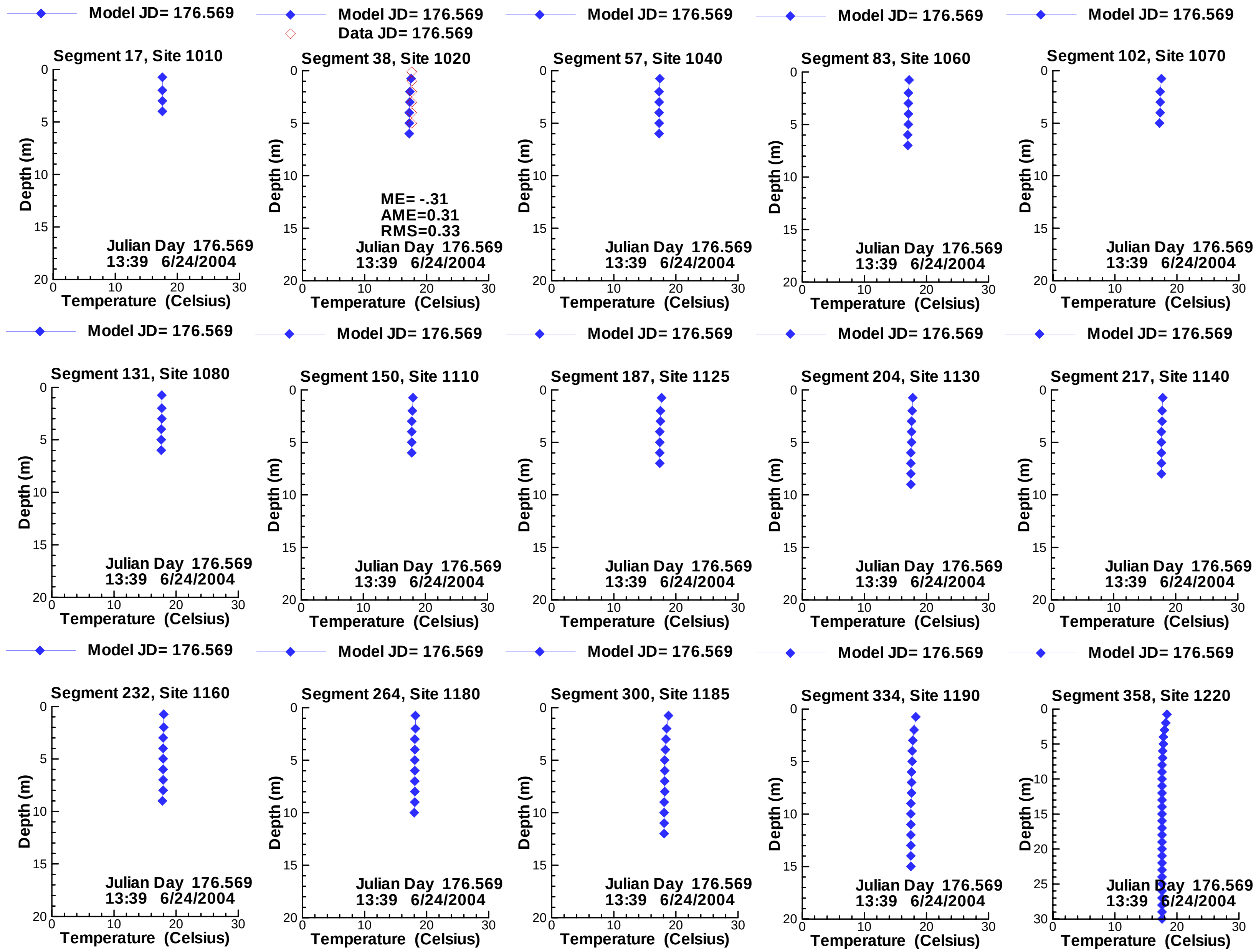

Figure 112: Vertical profiles of temperature compared with data for 6/24/2004 13:39.

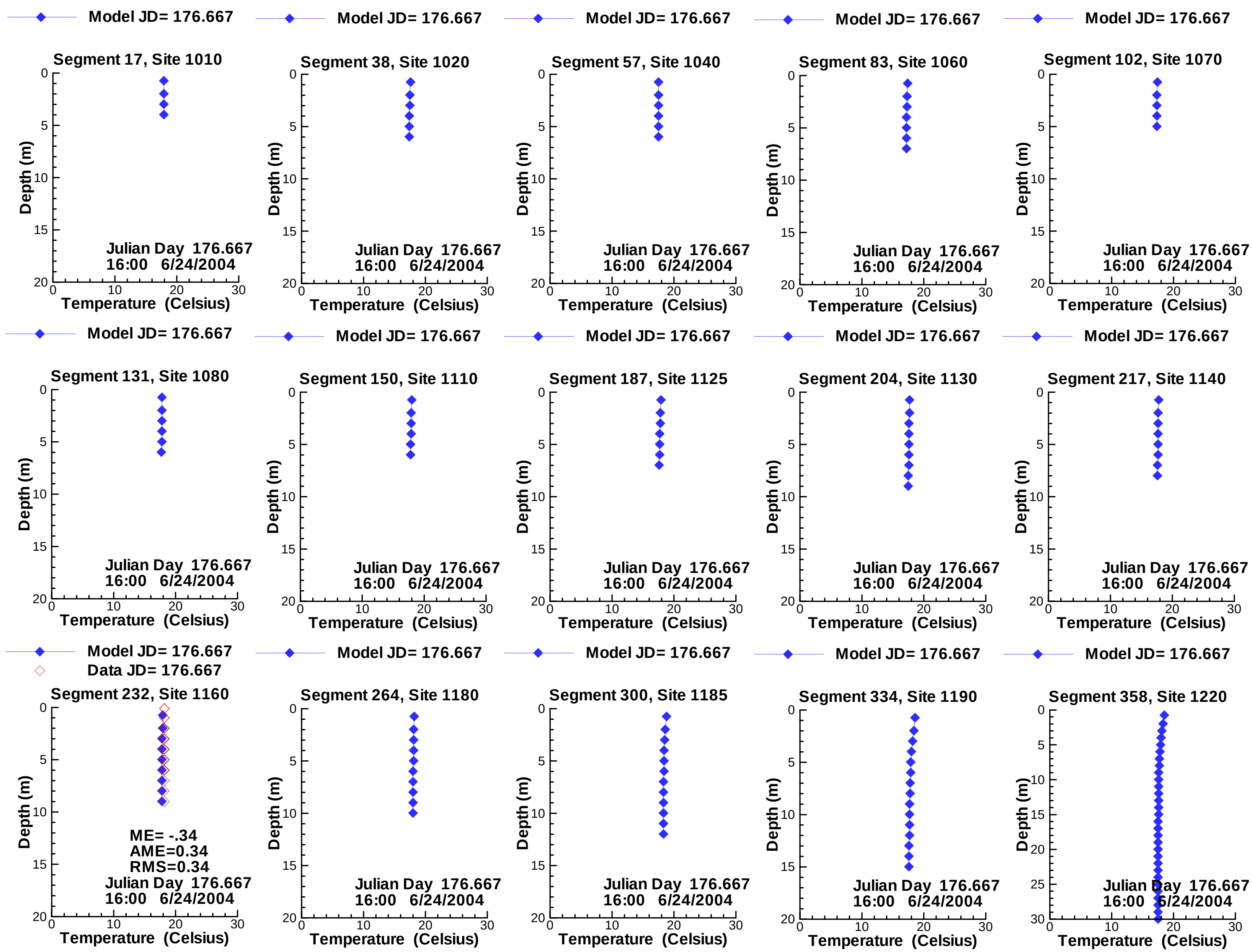

Figure 113: Vertical profiles of temperature compared with data for 6/24/2004 16:00.

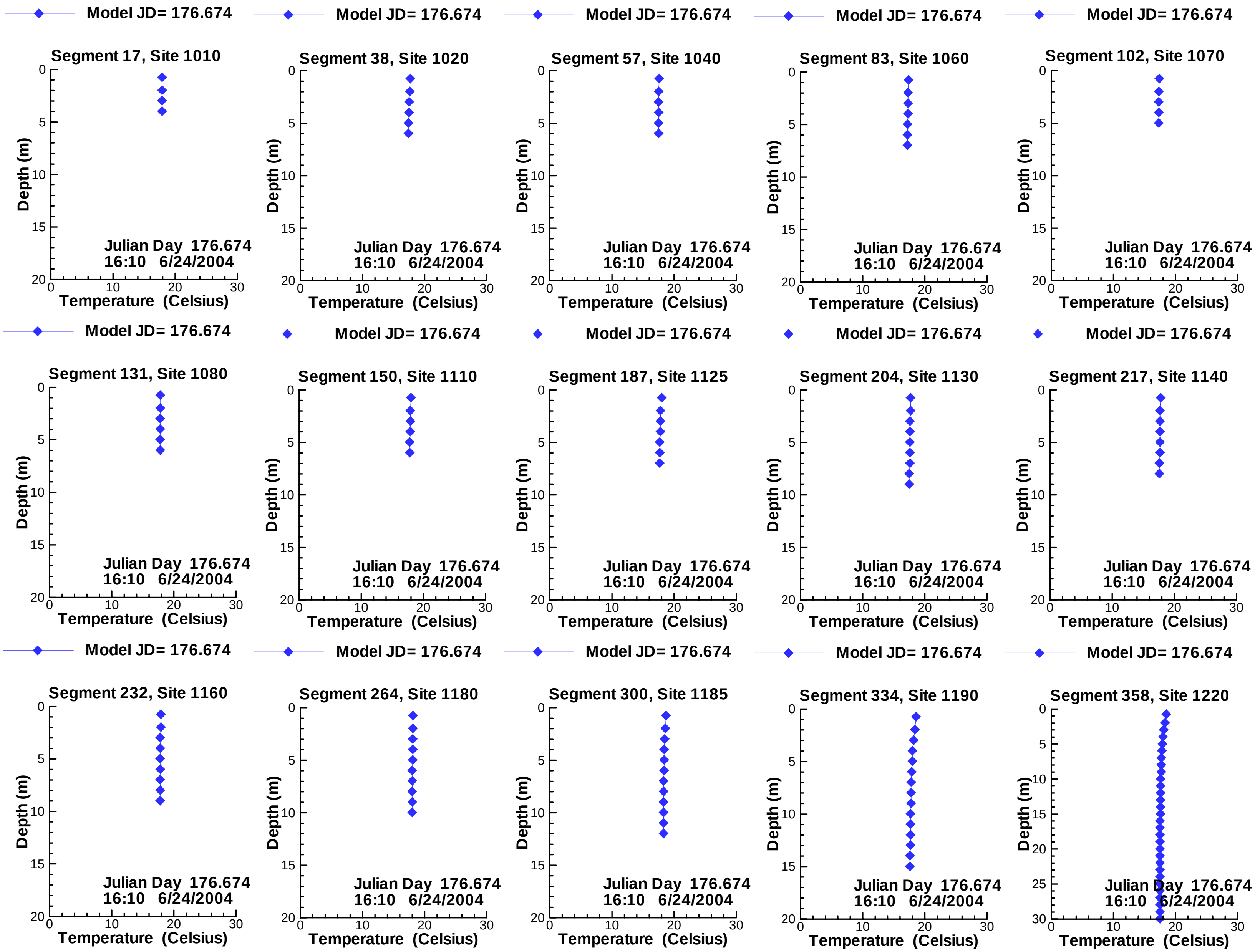

Figure 114: Vertical profiles of temperature compared with data for 6/24/2004 16:10.

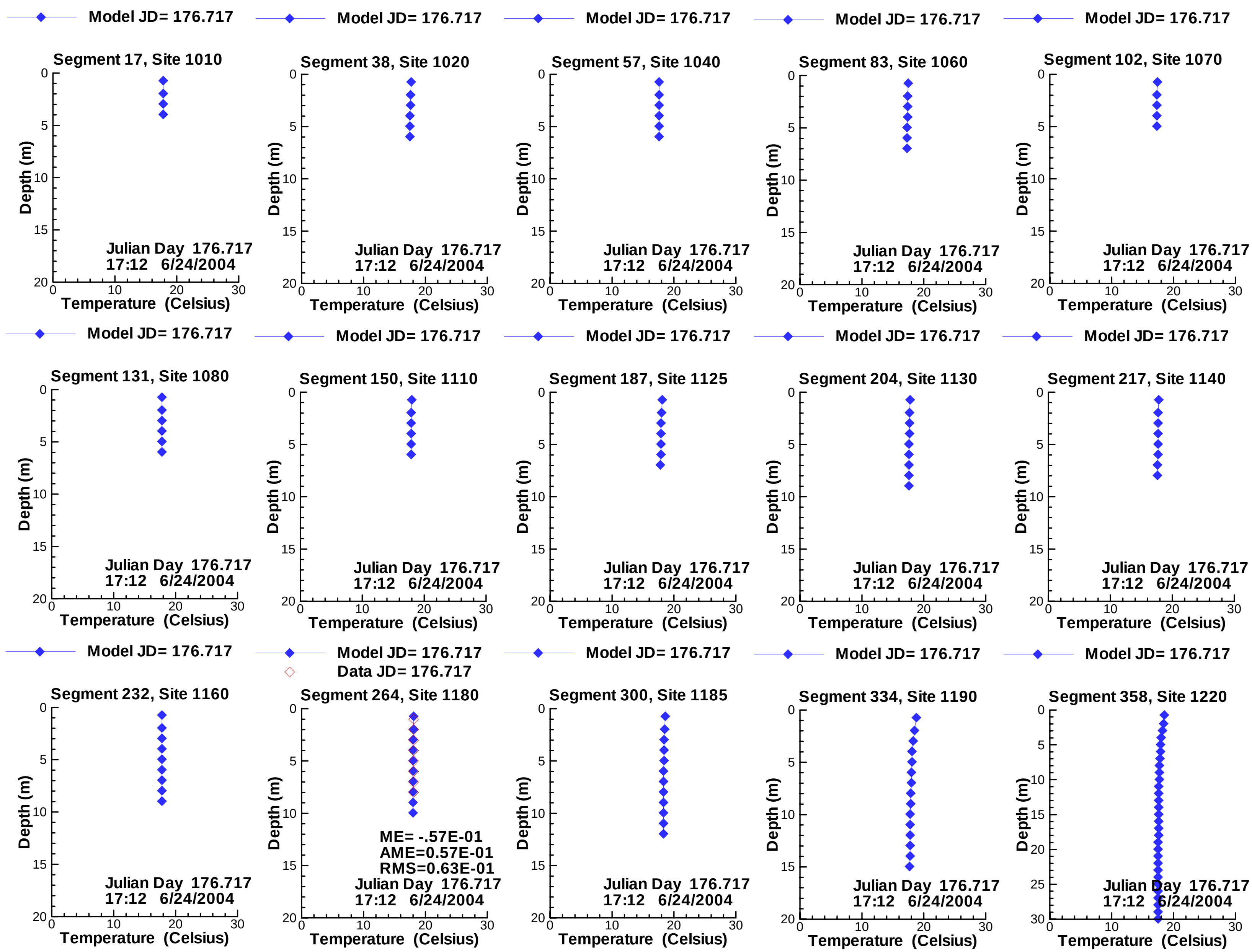

Figure 115: Vertical profiles of temperature compared with data for 6/24/2004 17:12.

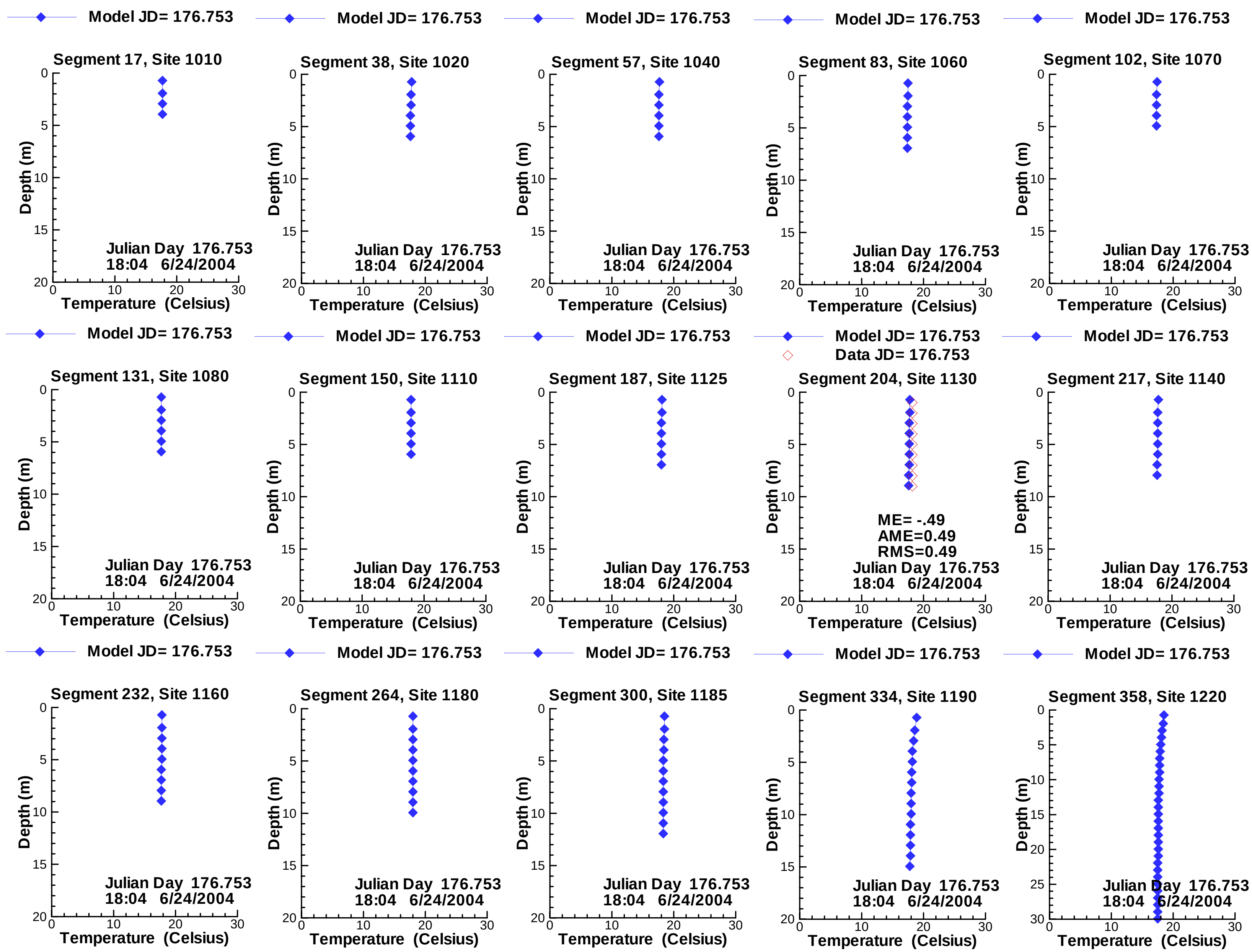

Figure 116: Vertical profiles of temperature compared with data for 6/24/2004 18:04.

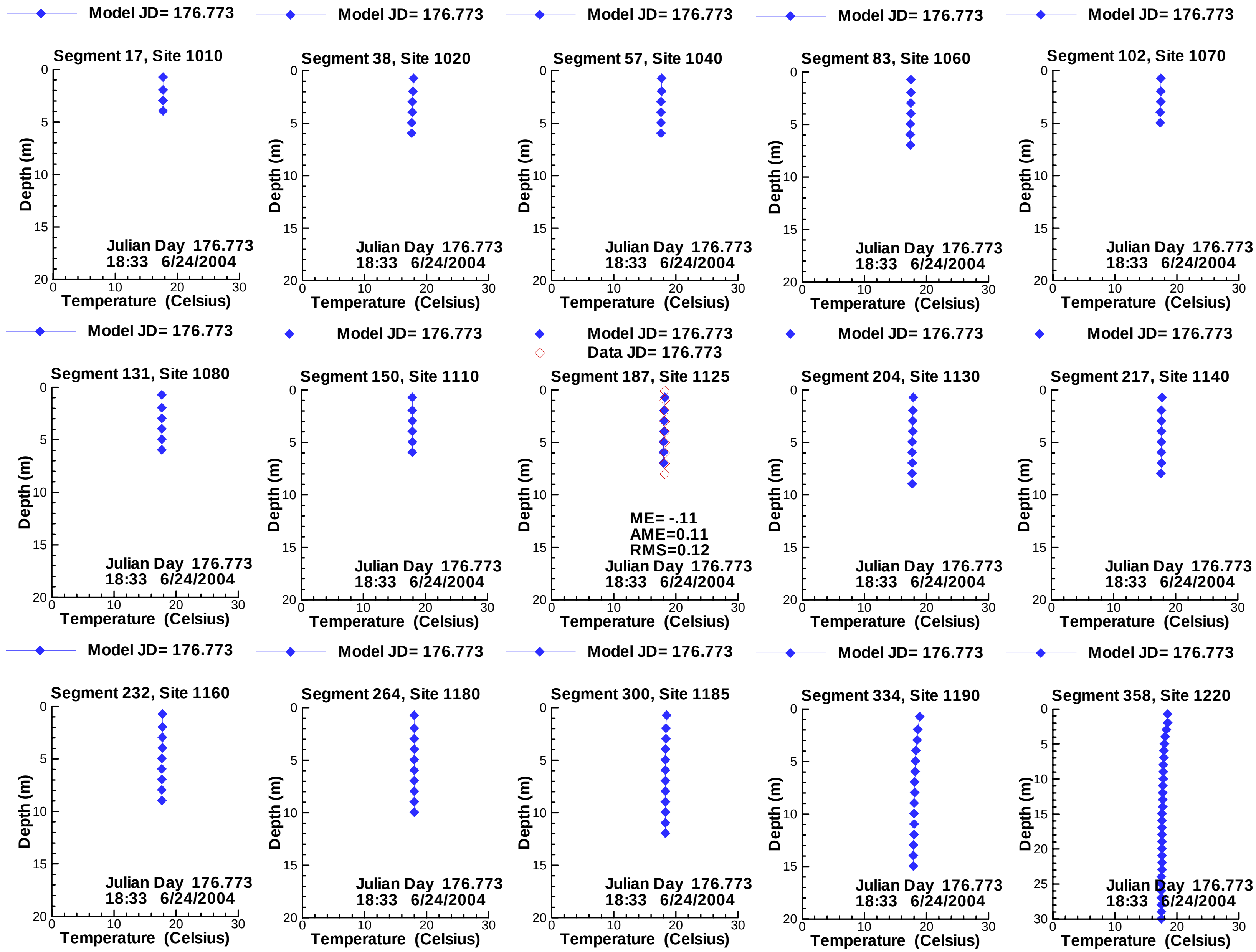

Figure 117: Vertical profiles of temperature compared with data for 6/24/2004 18:33.

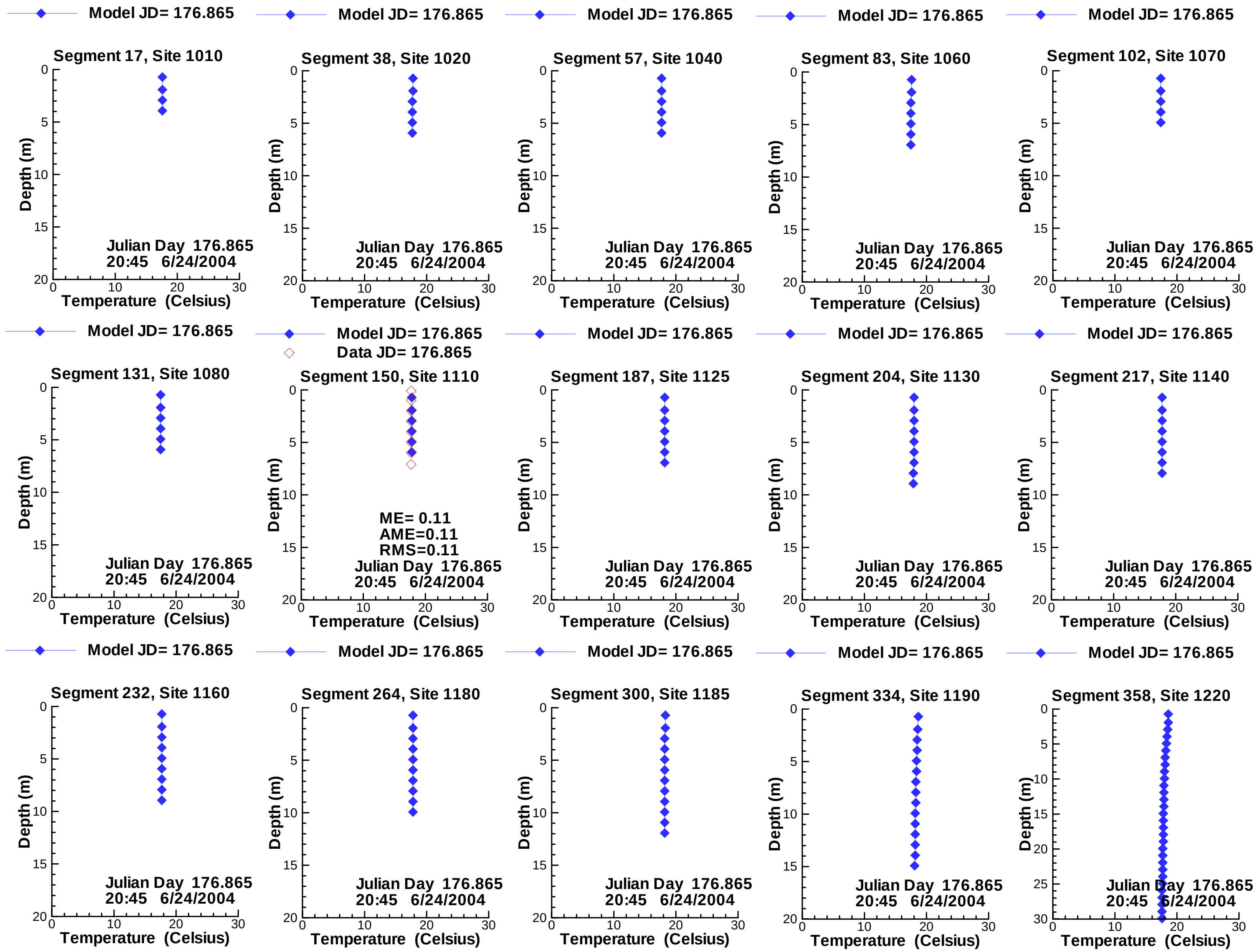

Figure 118: Vertical profiles of temperature compared with data for 6/24/2004 20:45.

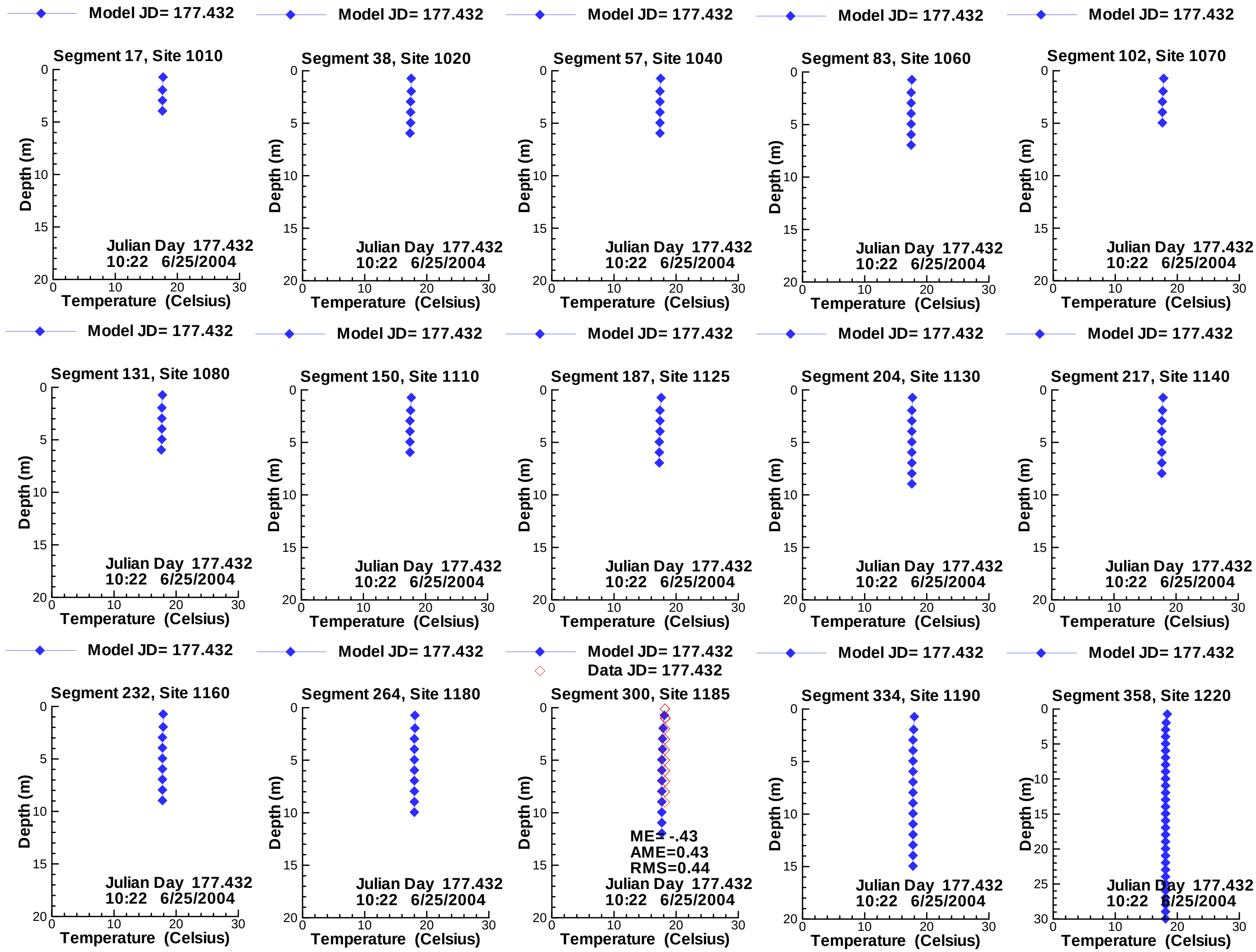

Figure 119: Vertical profiles of temperature compared with data for 6/25/2004 10:22.

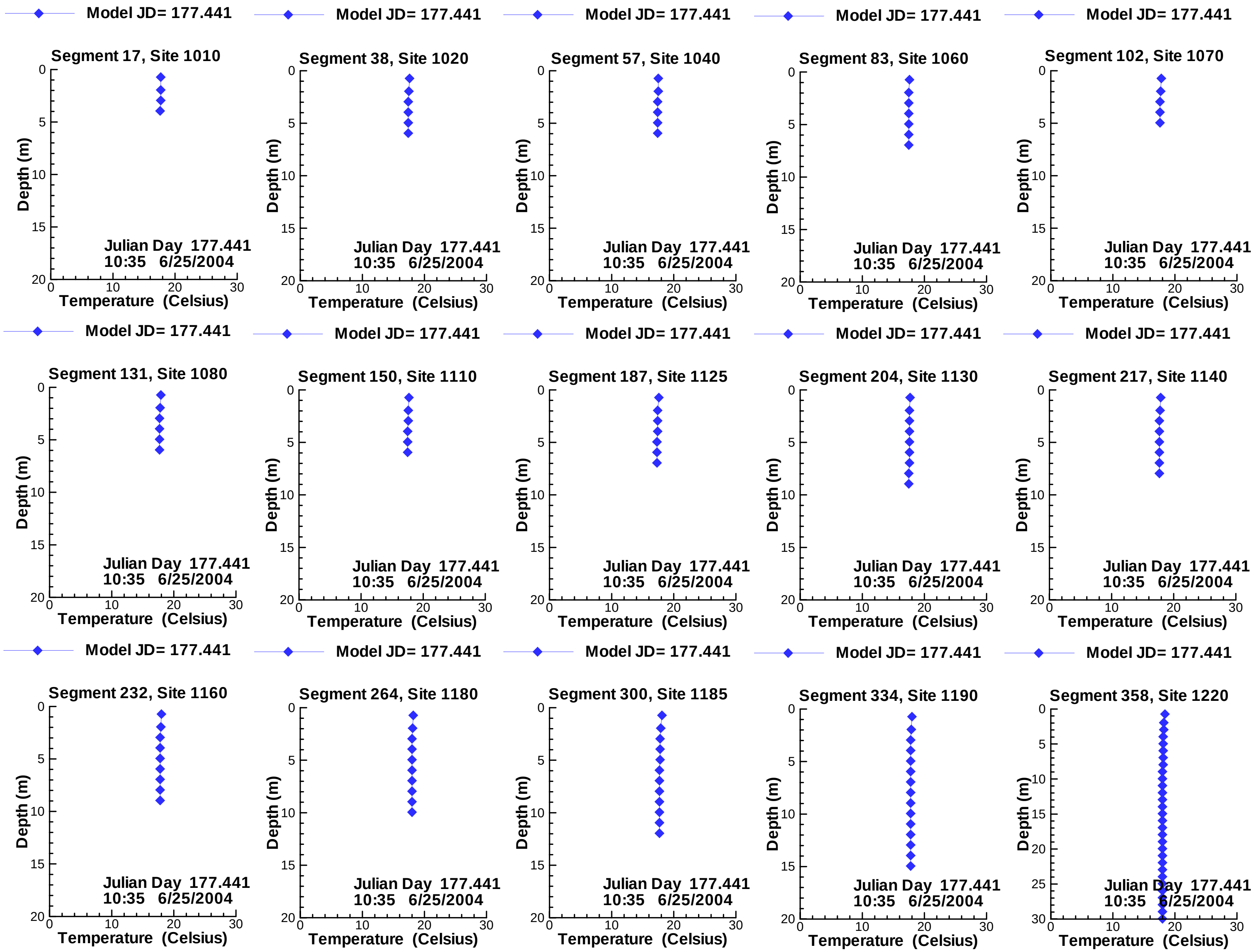

Figure 120: Vertical profiles of temperature compared with data for 6/25/2004 10:35.

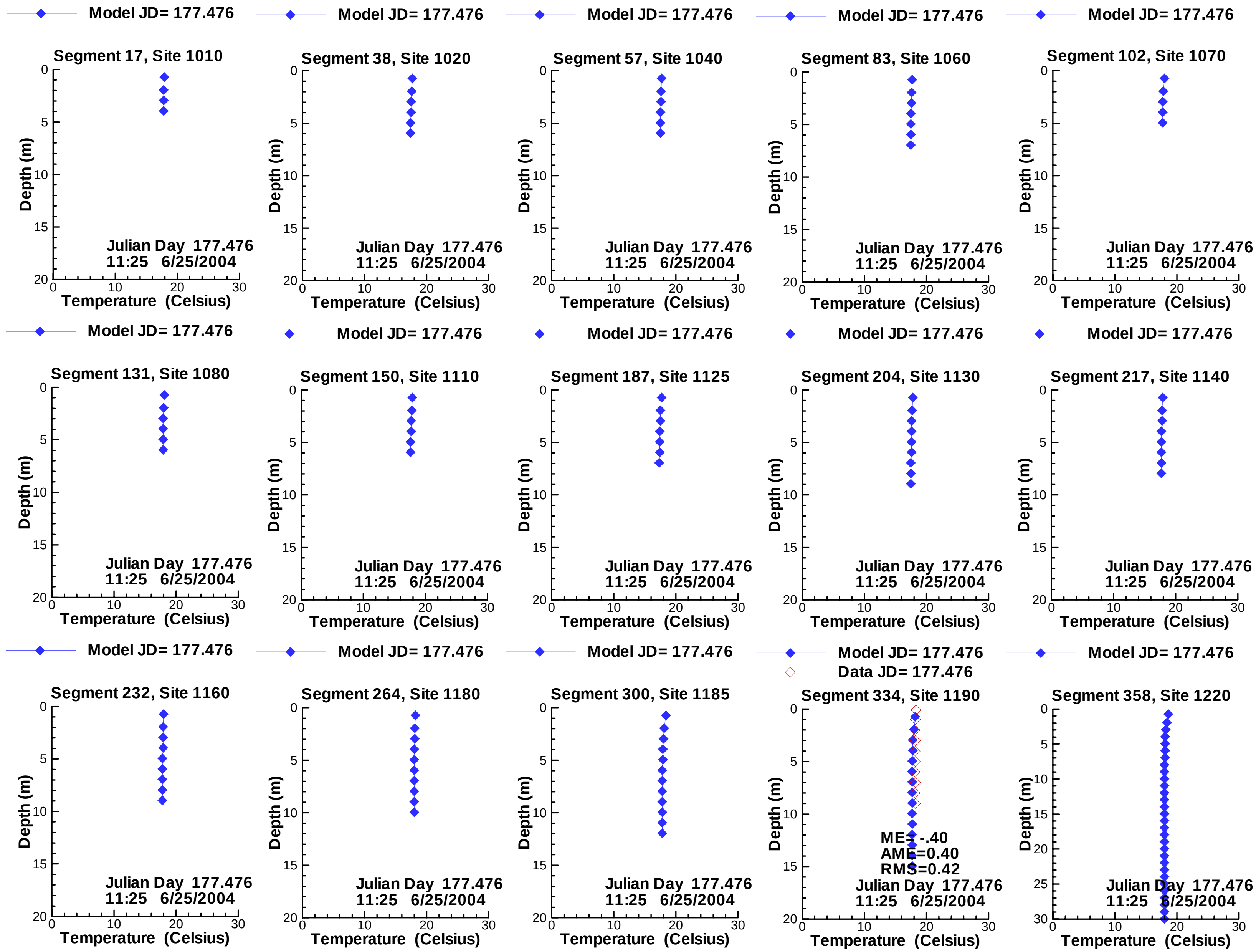

Figure 121: Vertical profiles of temperature compared with data for 6/25/2004 11:25.

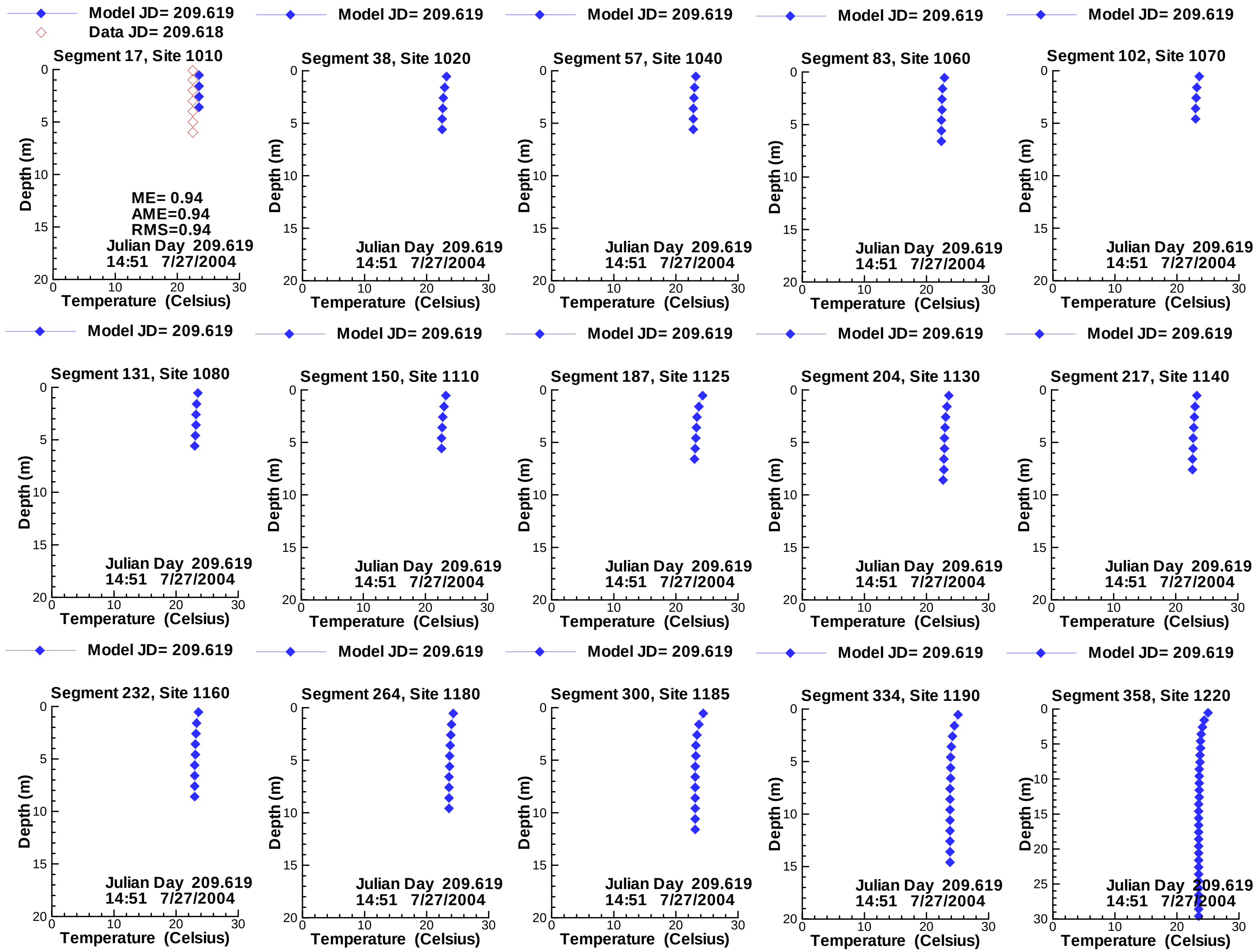

Figure 122: Vertical profiles of temperature compared with data for 7/27/2004 14:51.

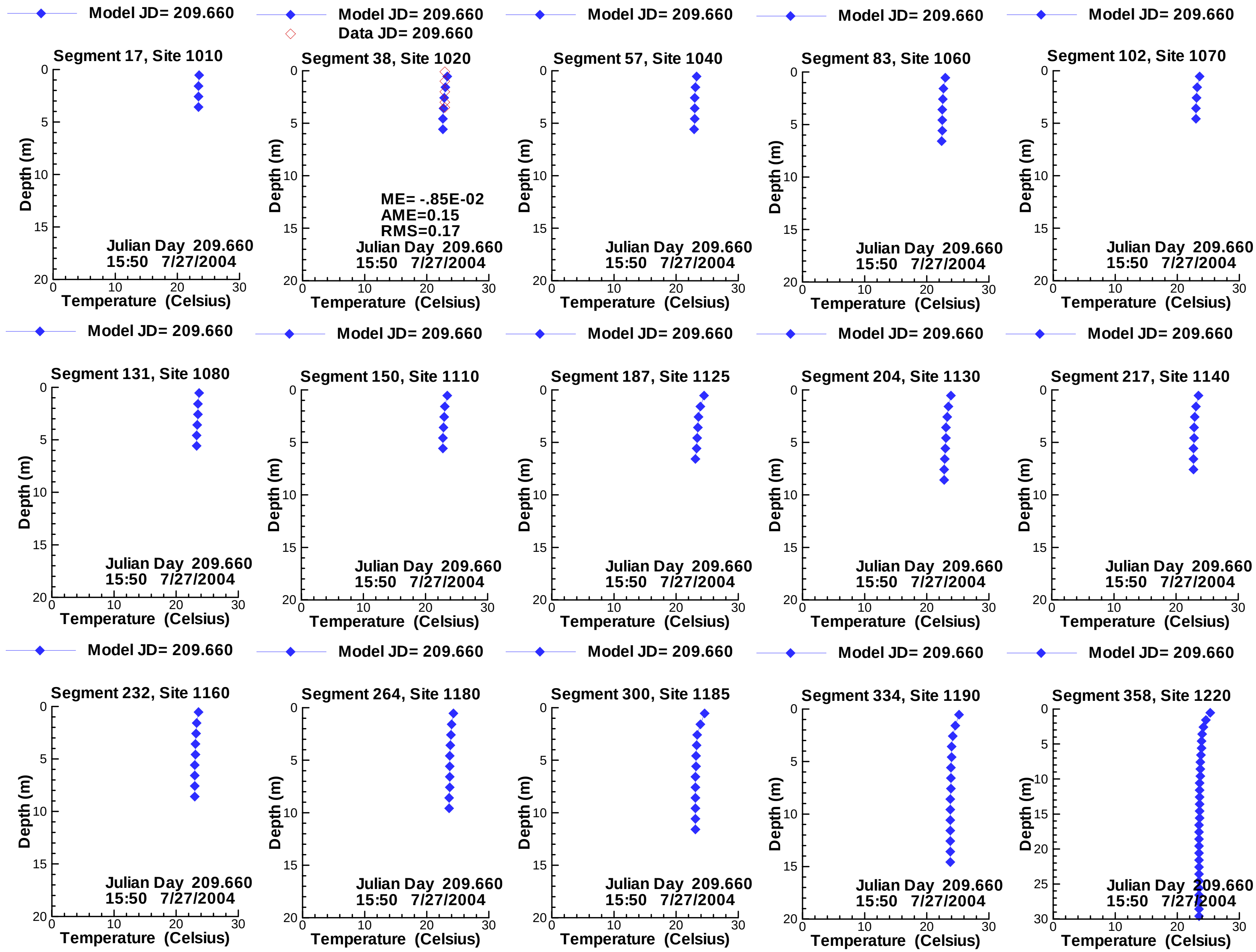

Figure 123: Vertical profiles of temperature compared with data for 7/27/2004 15:50.

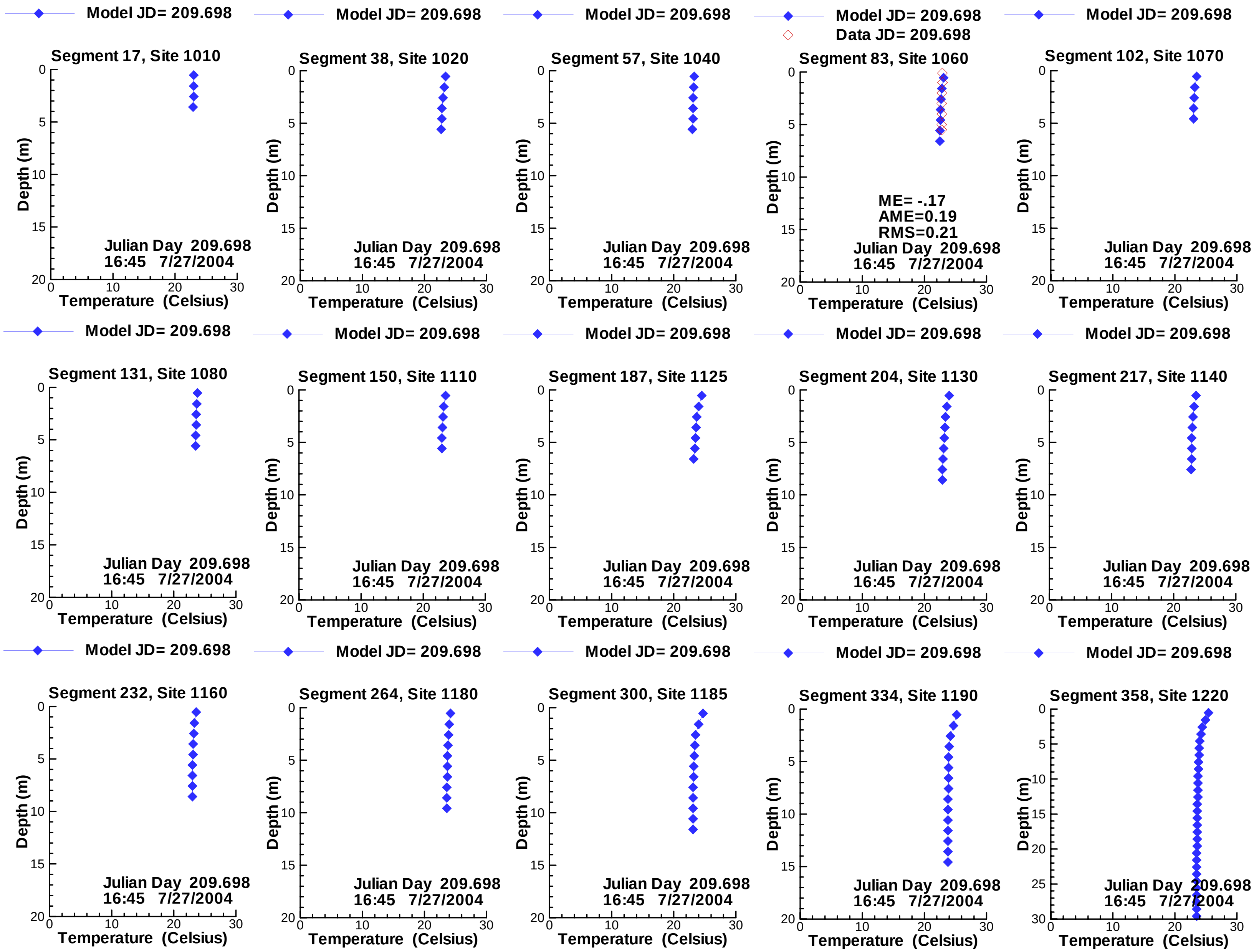

Figure 124: Vertical profiles of temperature compared with data for 7/27/2004 16:45.

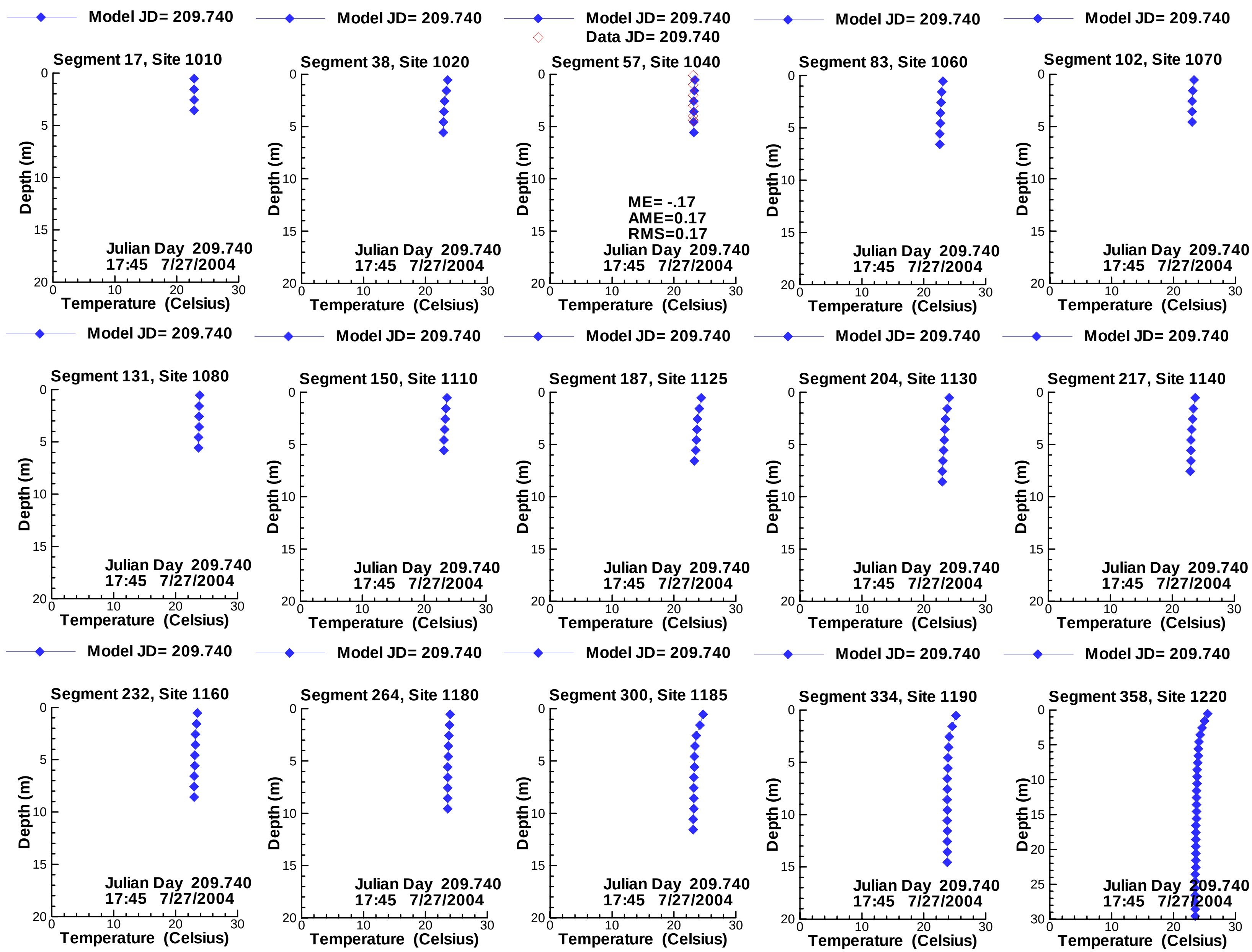

Figure 125: Vertical profiles of temperature compared with data for 7/27/2004 17:45.

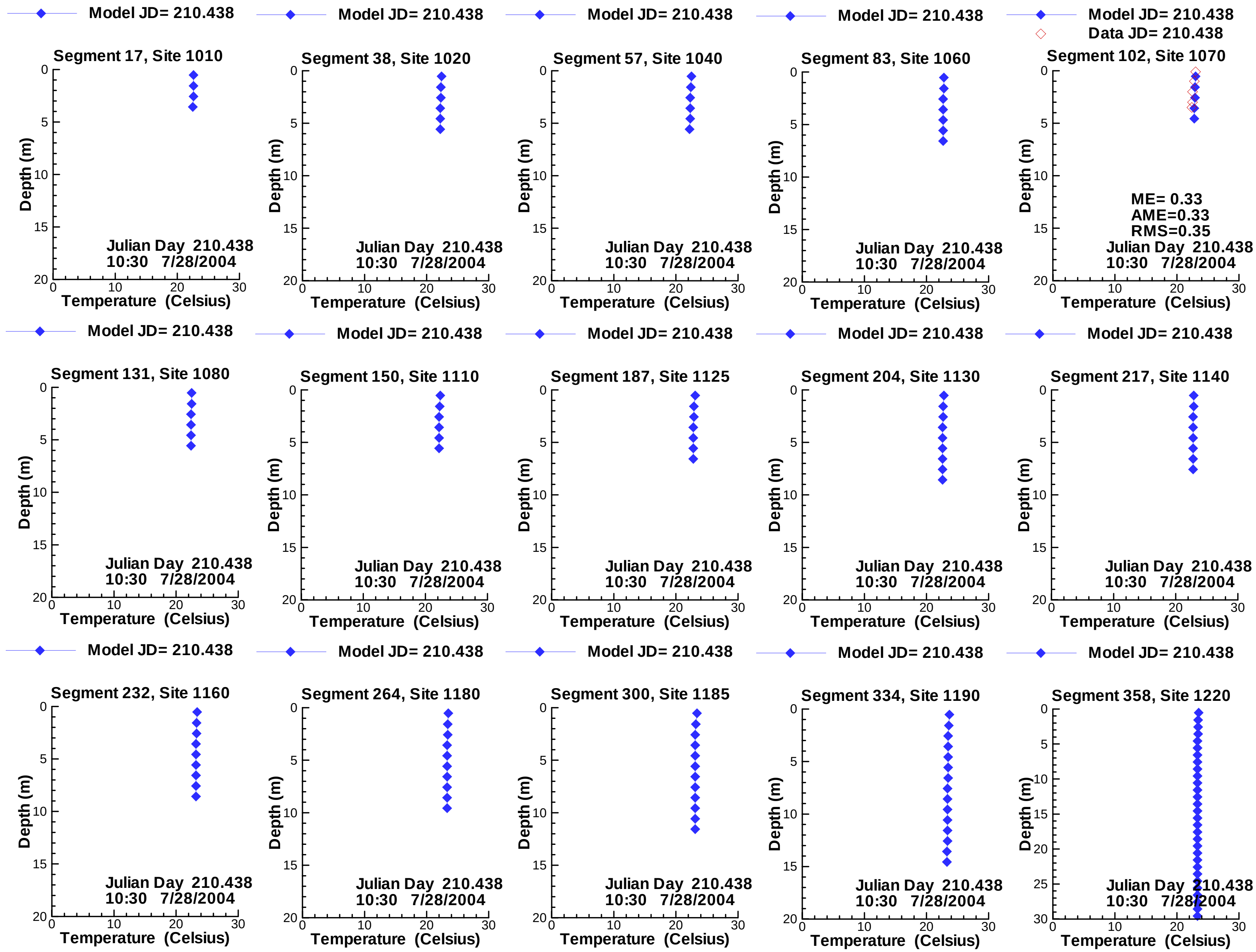

Figure 126: Vertical profiles of temperature compared with data for 7/28/2004 10:30.

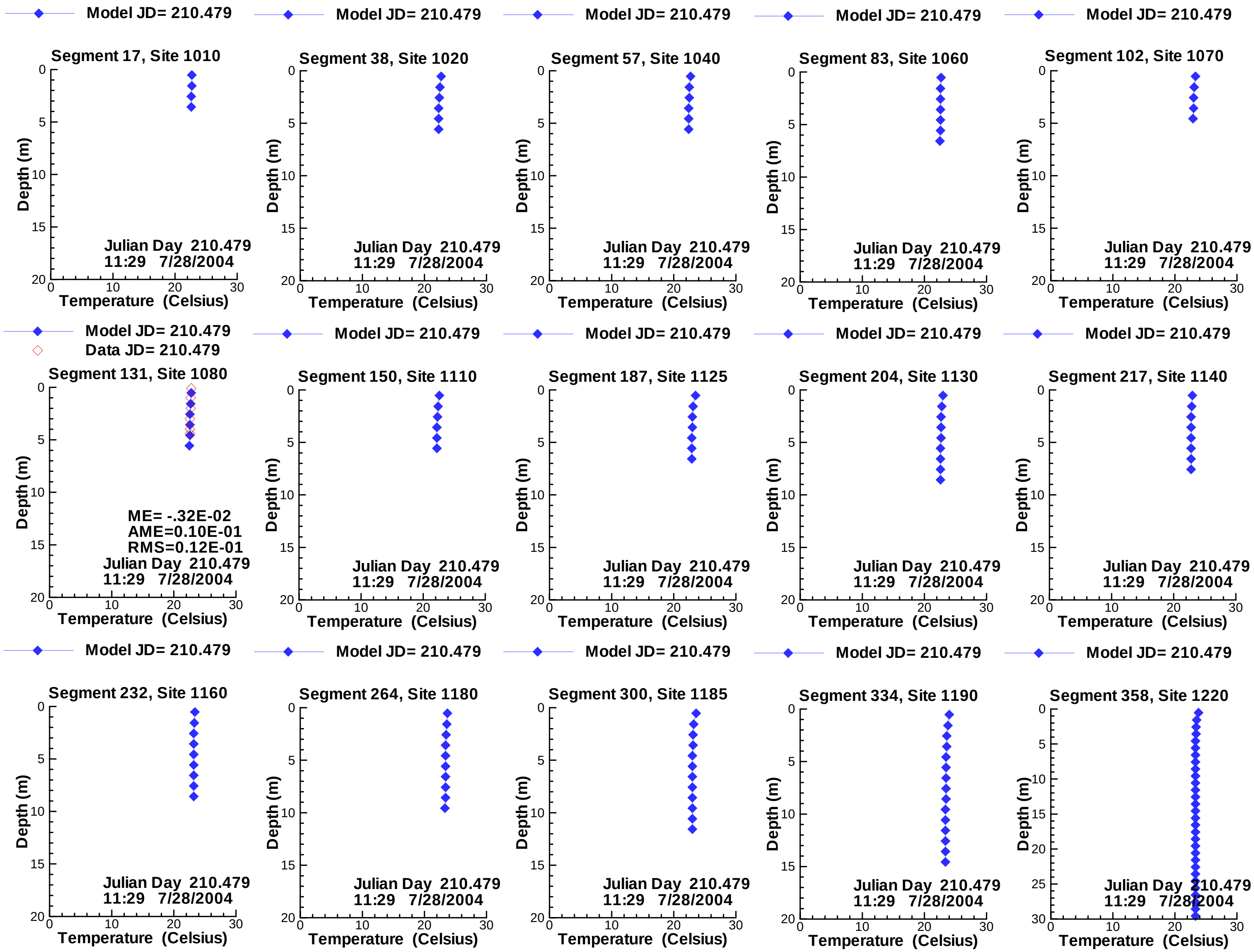

Figure 127: Vertical profiles of temperature compared with data for 7/28/2004 11:29.

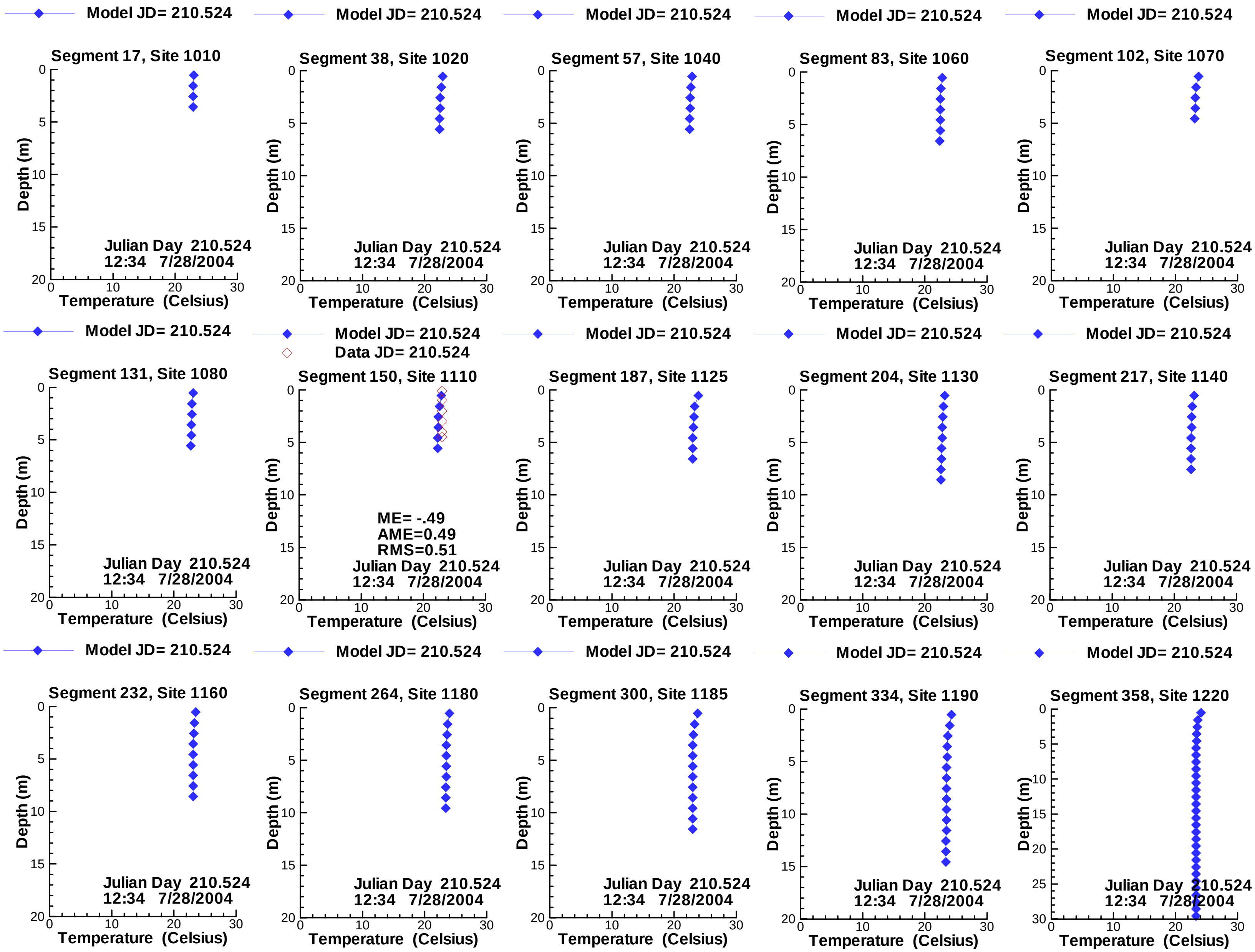

Figure 128: Vertical profiles of temperature compared with data for 7/28/2004 12:34.

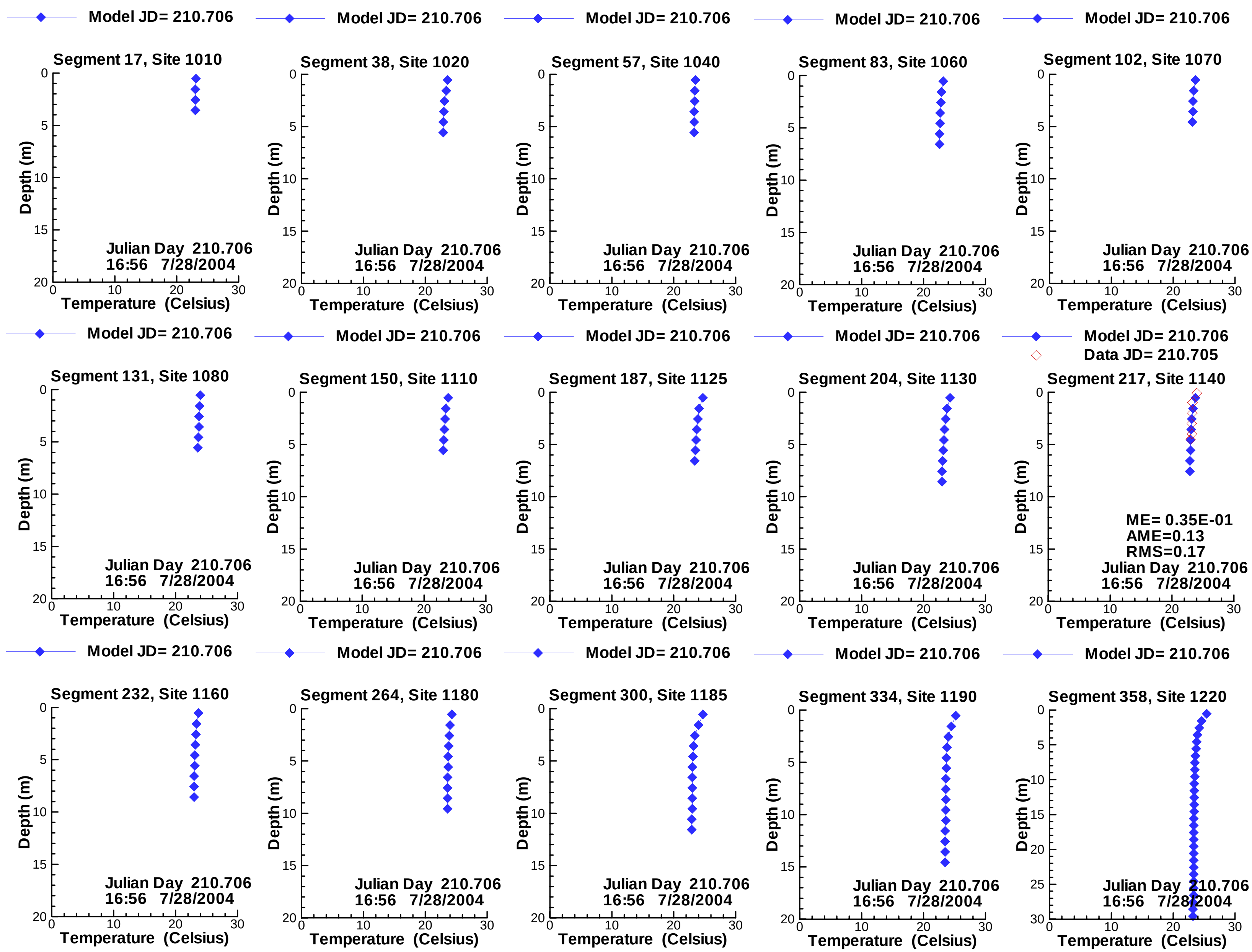

Figure 129: Vertical profiles of temperature compared with data for 7/28/2004 16:56.

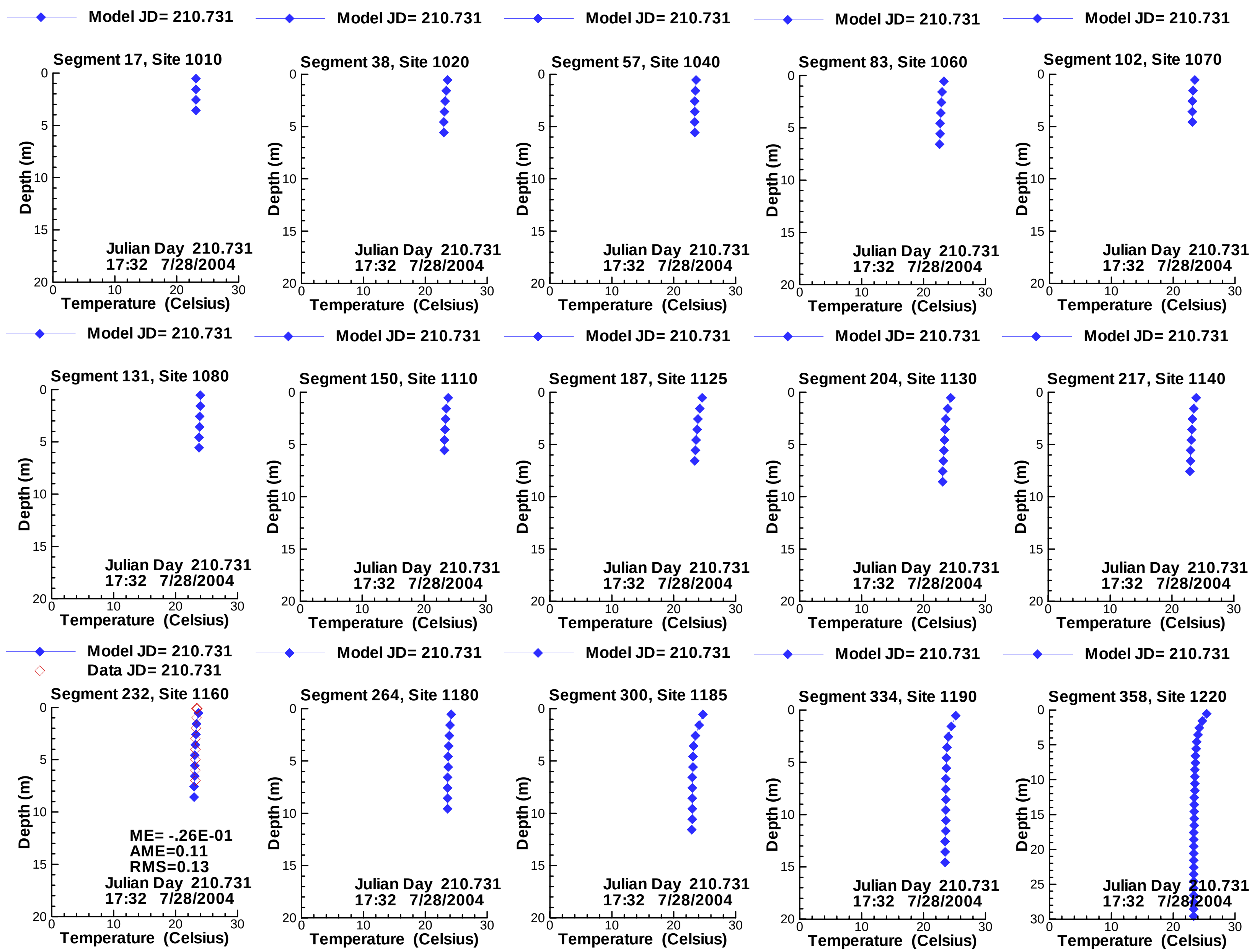

Figure 130: Vertical profiles of temperature compared with data for 7/28/2004 17:32.

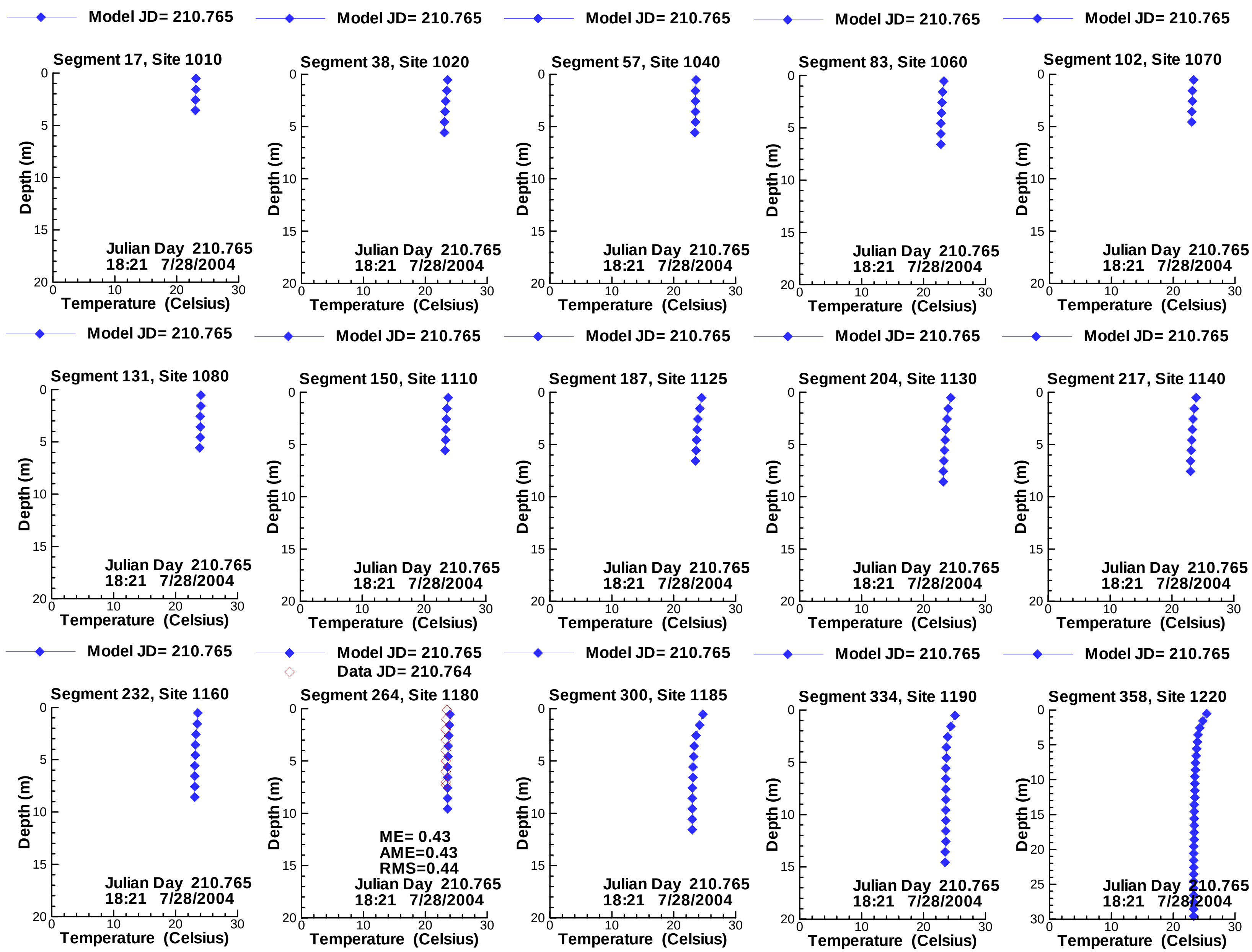

Figure 131: Vertical profiles of temperature compared with data for 7/28/2004 18:21.

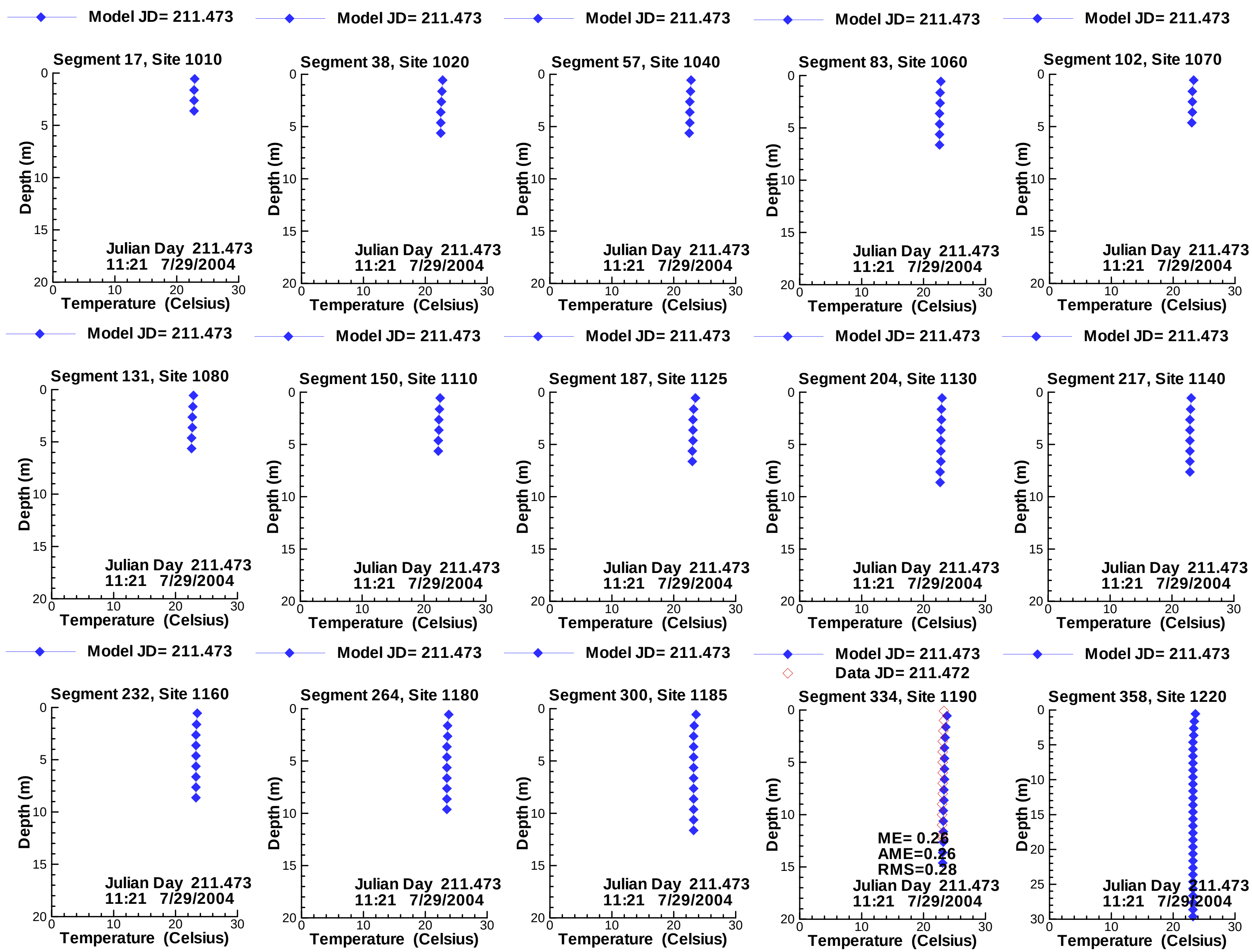

Figure 132: Vertical profiles of temperature compared with data for 7/29/2004 11:21.

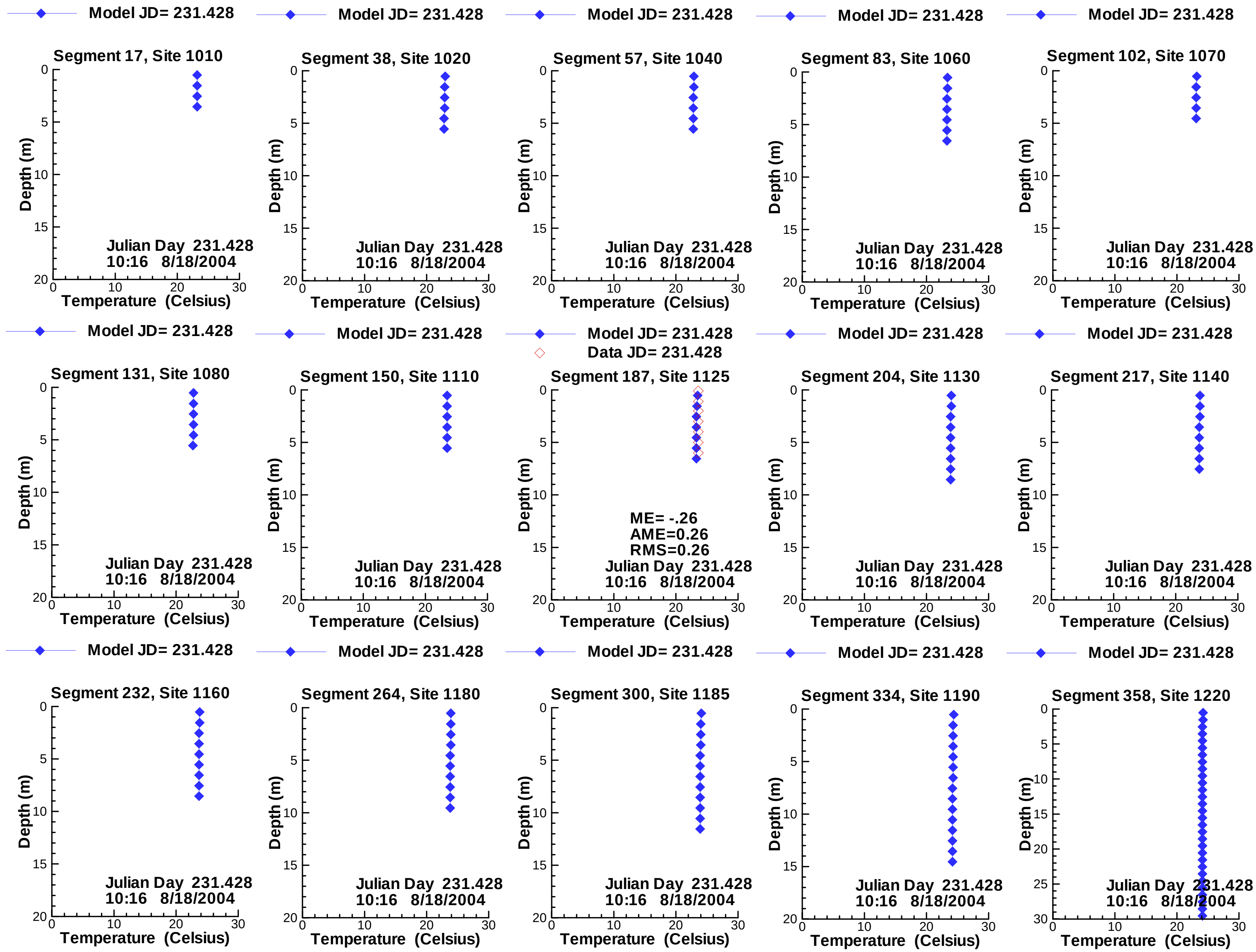

Figure 133: Vertical profiles of temperature compared with data for 8/18/2004 10:16.

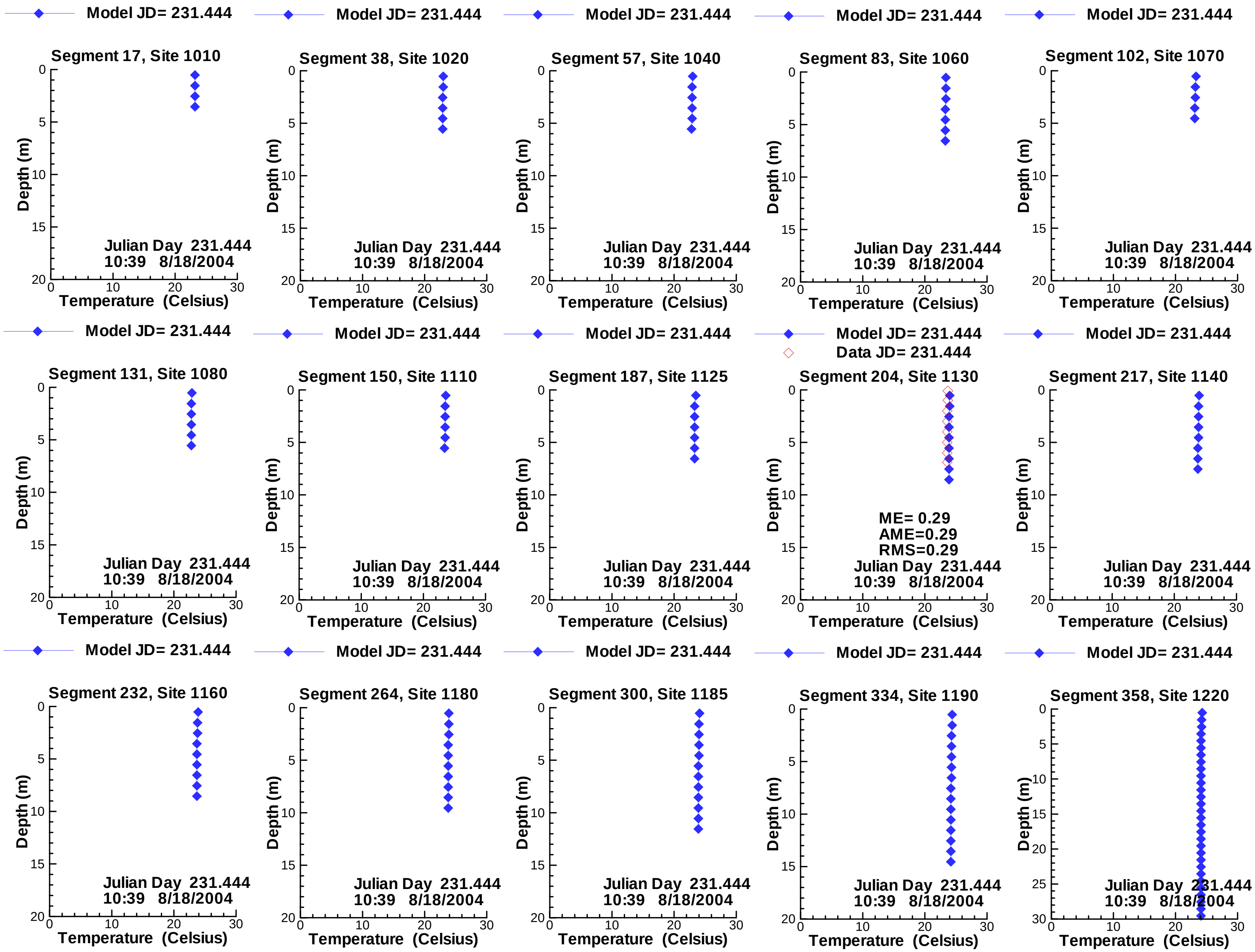

Figure 134: Vertical profiles of temperature compared with data for 8/18/2004 10:39.

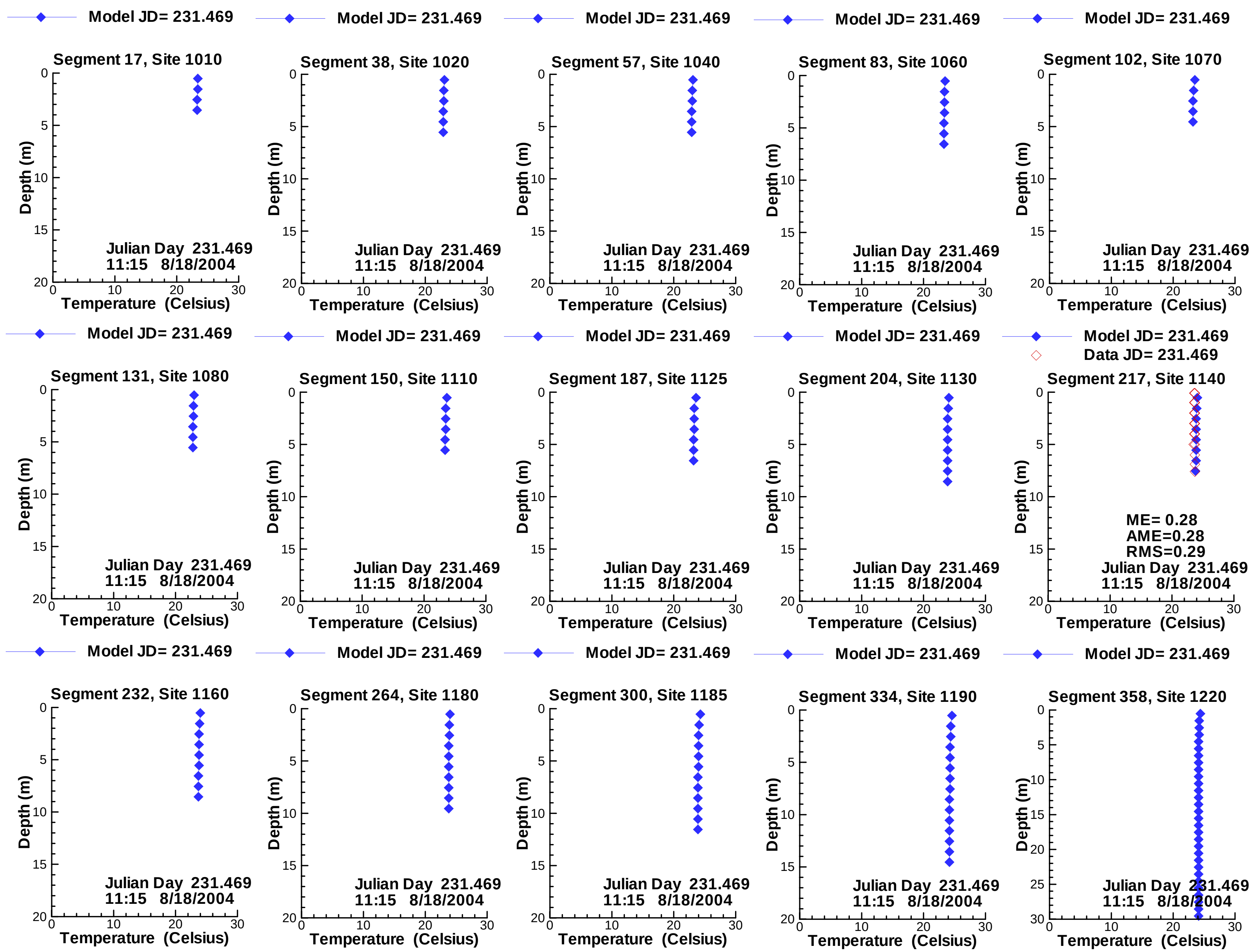

Figure 135: Vertical profiles of temperature compared with data for 8/18/2004 11:15.

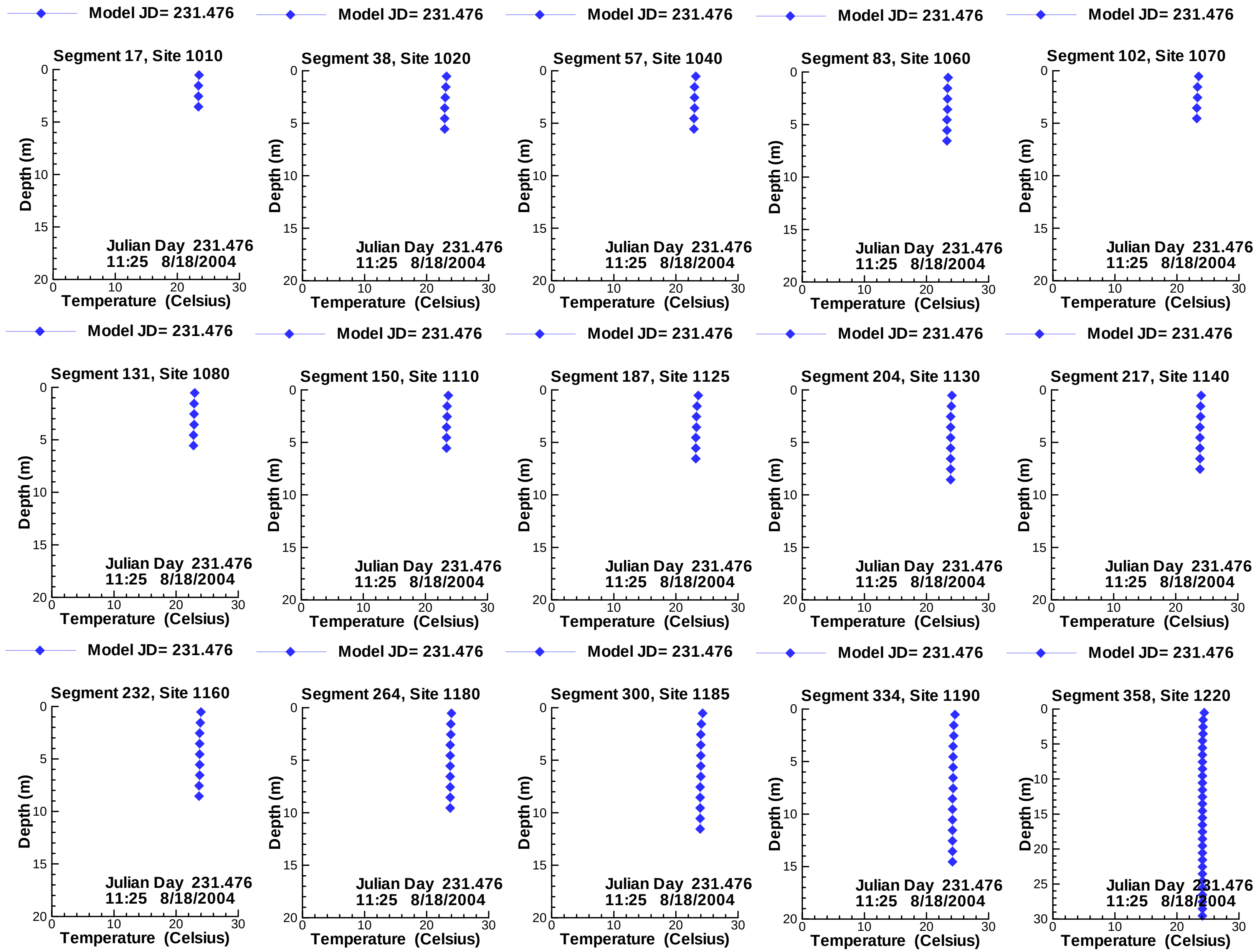

Figure 136: Vertical profiles of temperature compared with data for 8/18/2004 11:25.

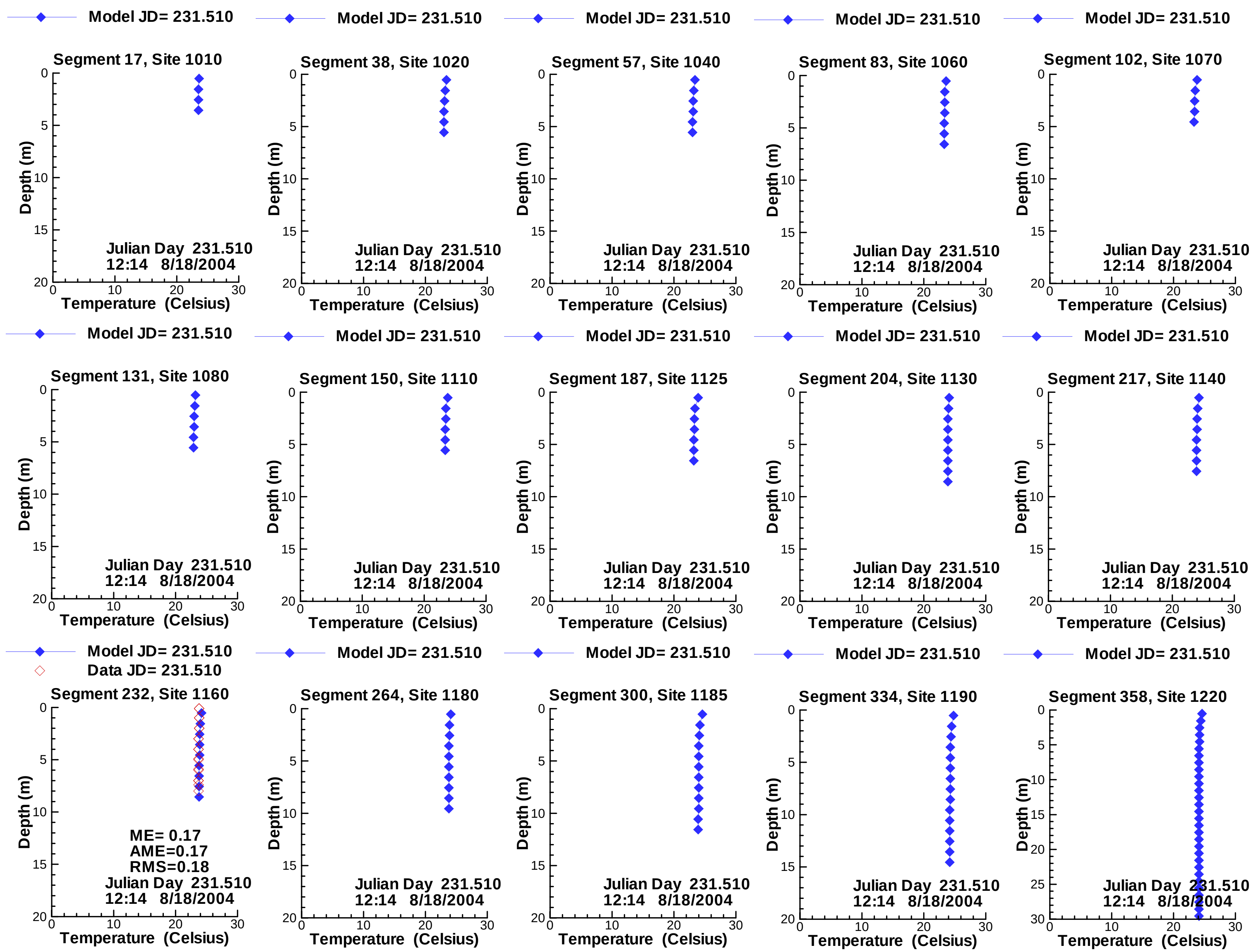

Figure 137: Vertical profiles of temperature compared with data for 8/18/2004 12:14.

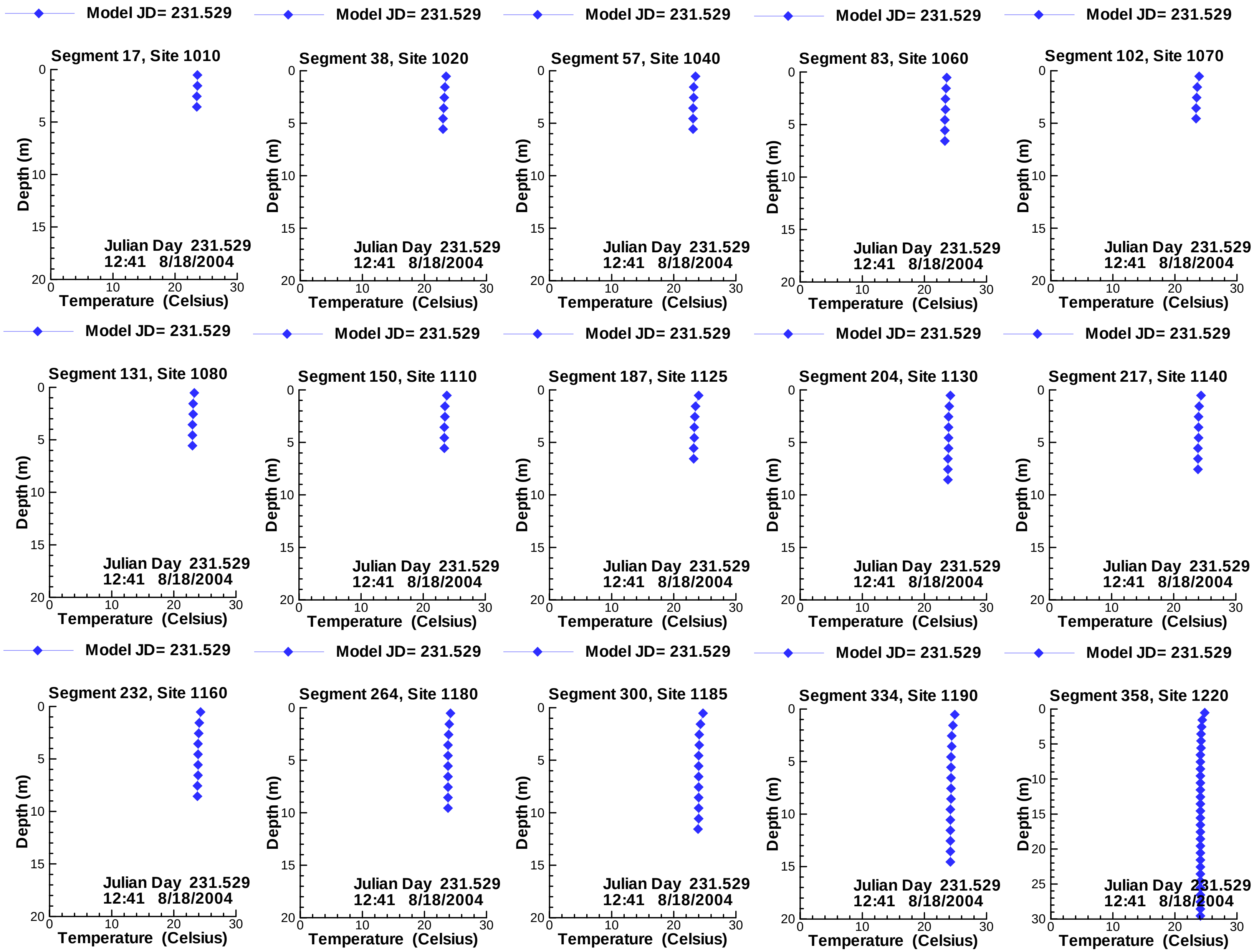

Figure 138: Vertical profiles of temperature compared with data for 8/18/2004 12:41.

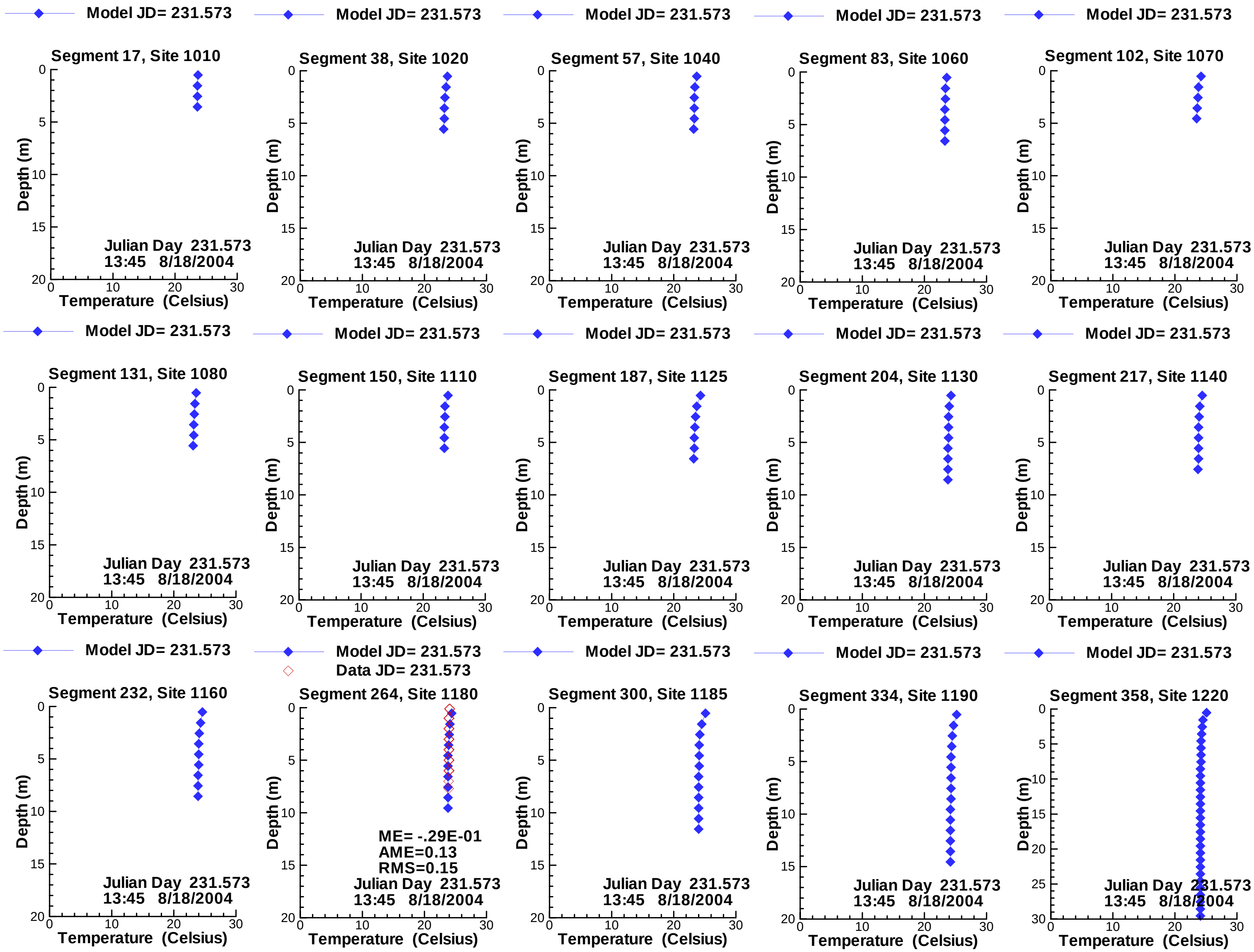

Figure 139: Vertical profiles of temperature compared with data for 8/18/2004 13:45.

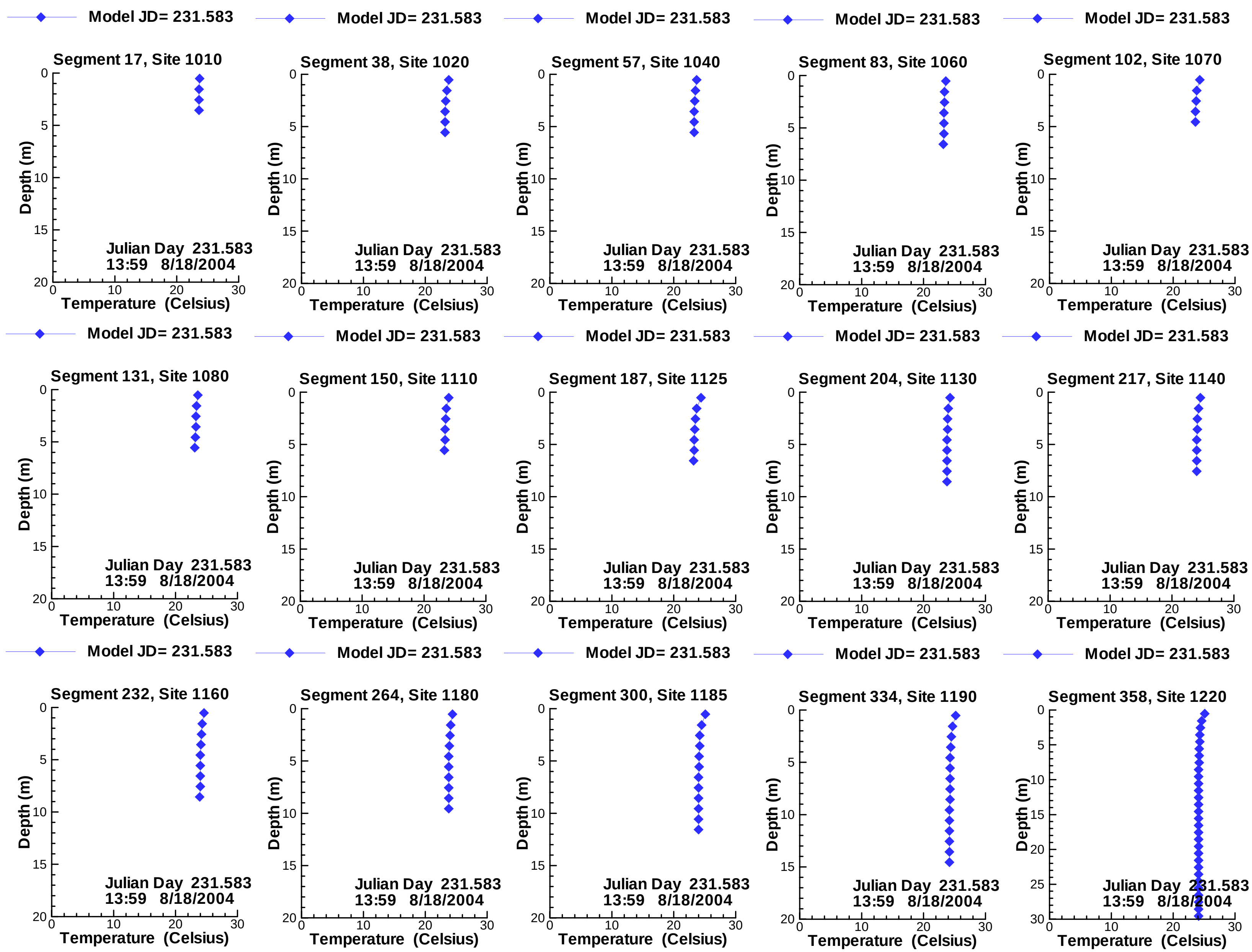

Figure 140: Vertical profiles of temperature compared with data for 8/18/2004 13:59.

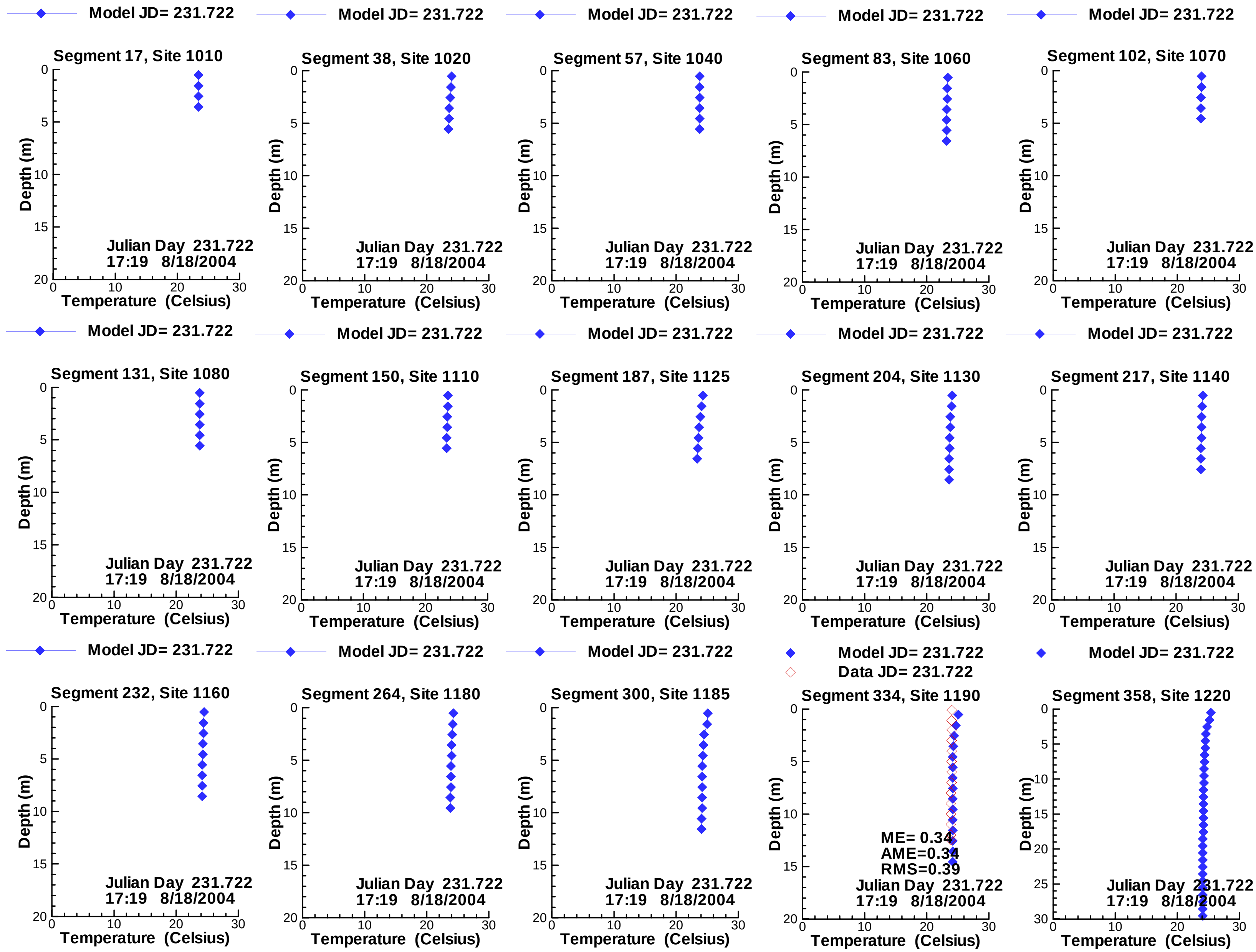

Figure 141: Vertical profiles of temperature compared with data for 8/18/2004 17:19.

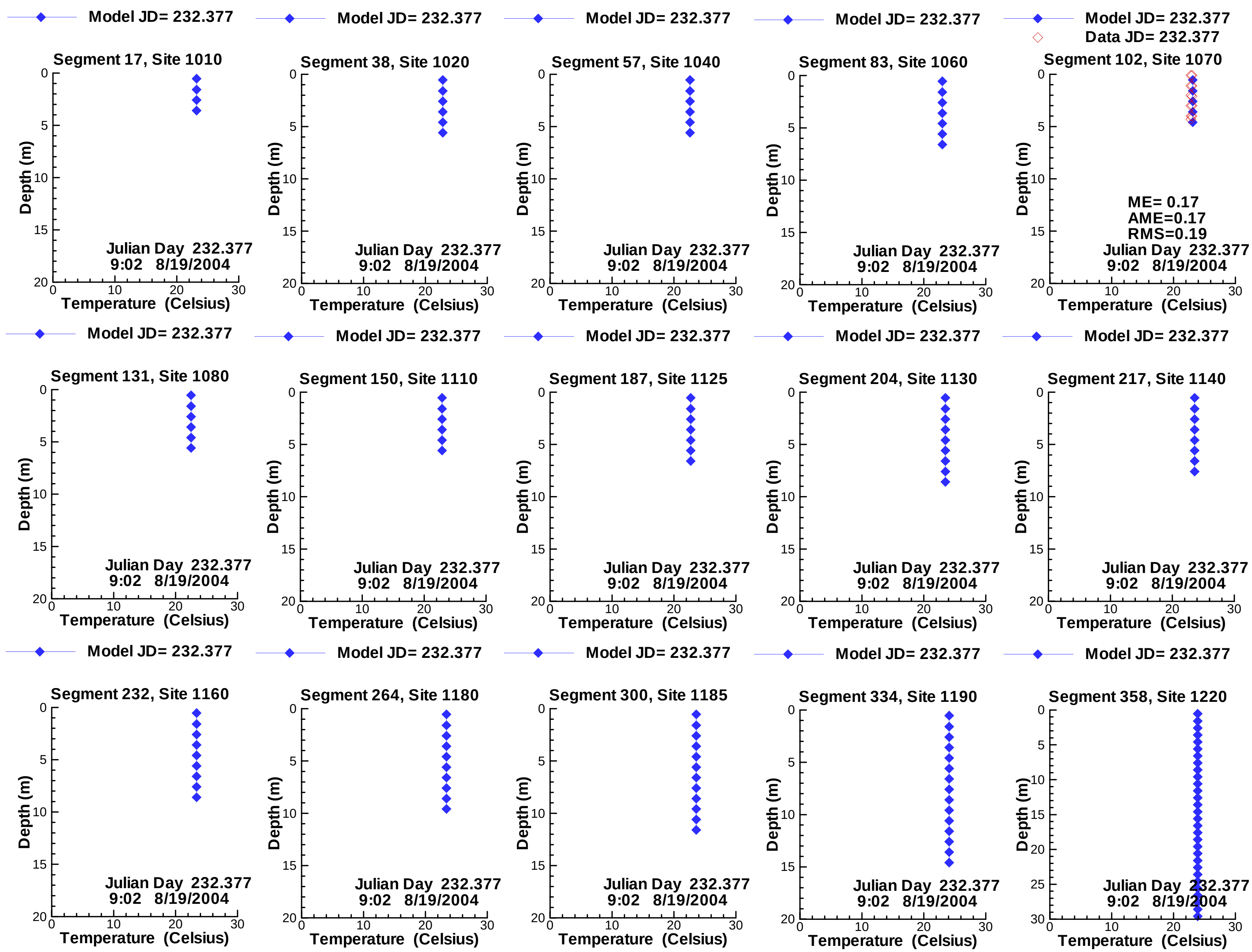

Figure 142: Vertical profiles of temperature compared with data for 8/19/2004 9:02.

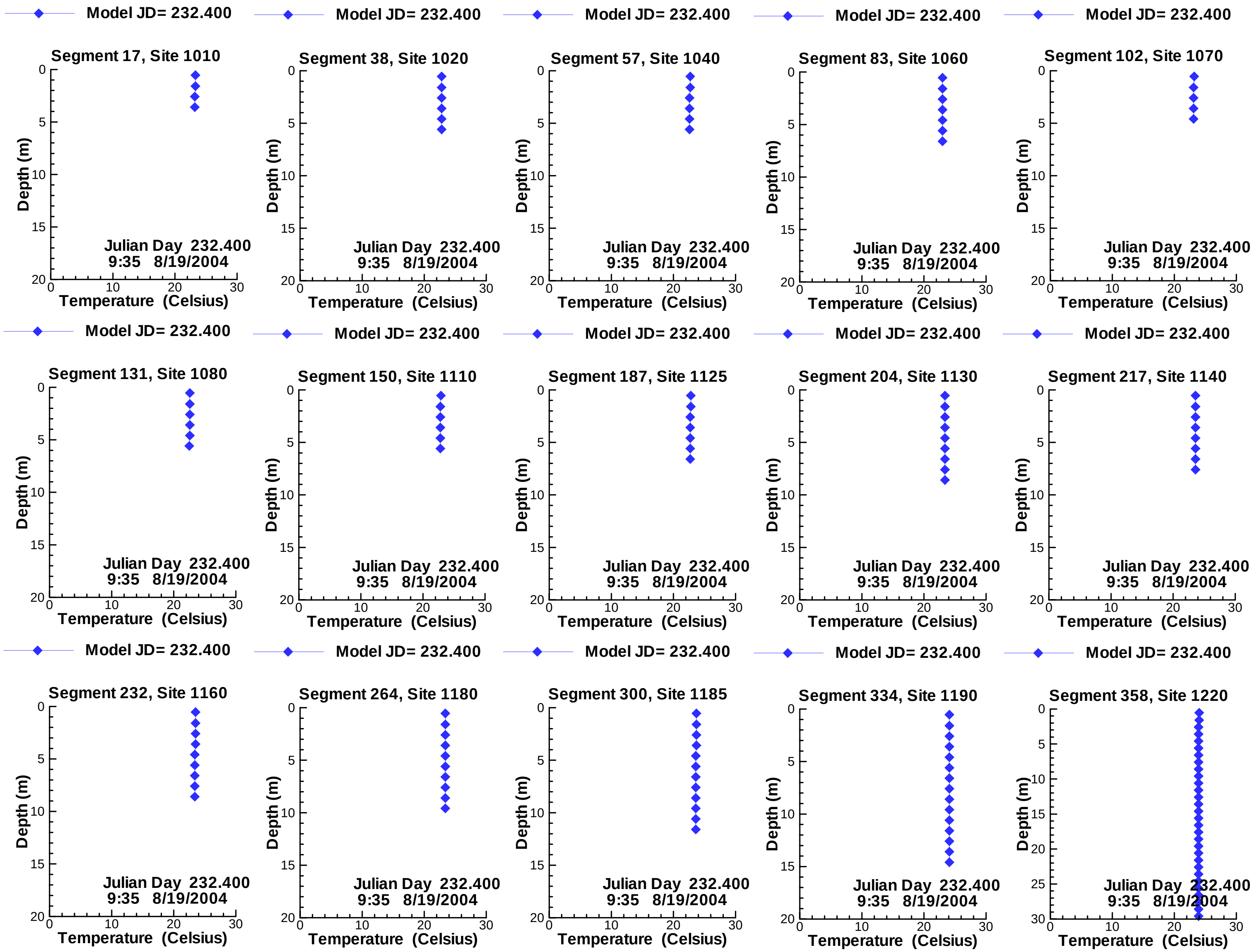

Figure 143: Vertical profiles of temperature compared with data for 8/19/2004 9:35.

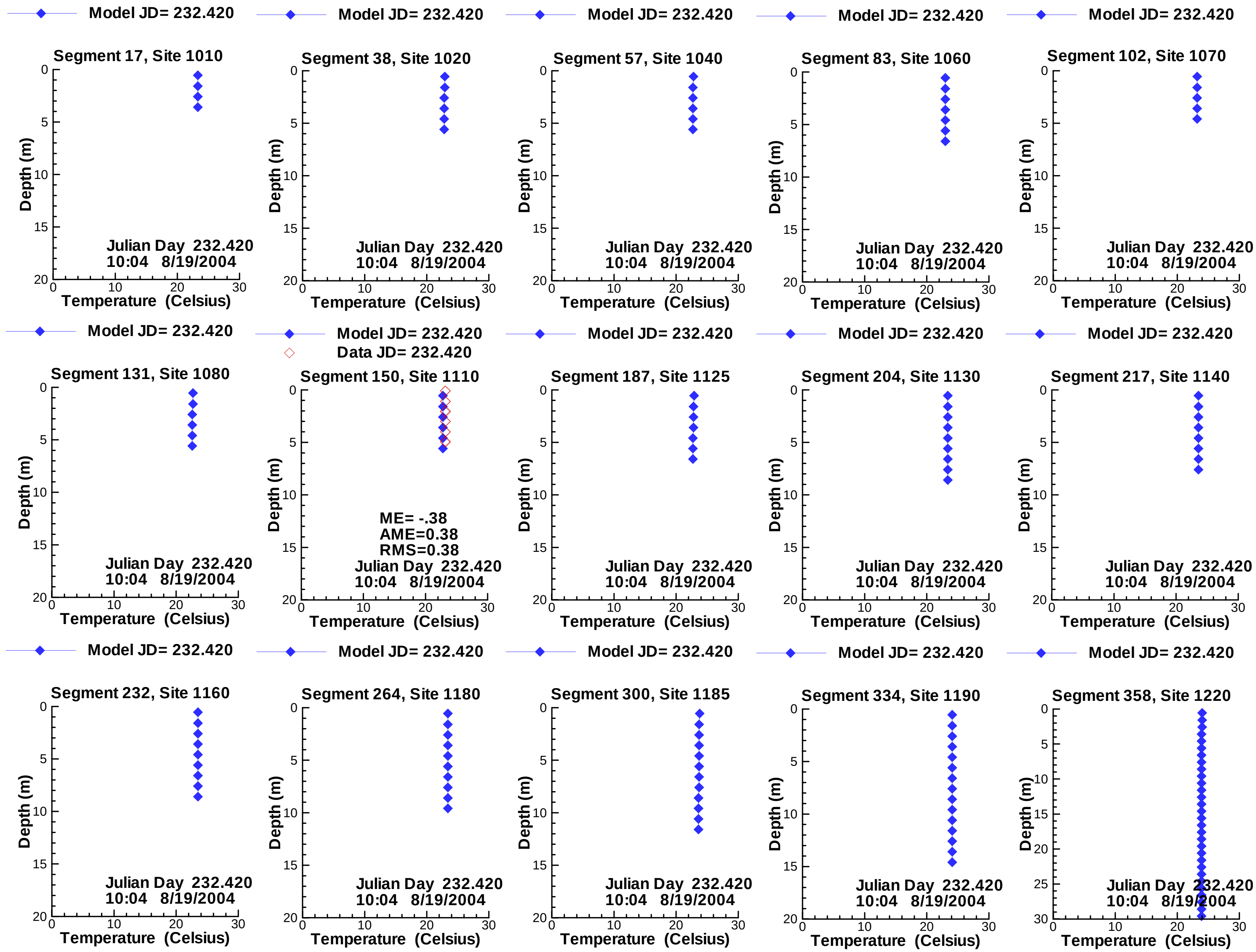

Figure 144: Vertical profiles of temperature compared with data for 8/19/2004 10:04.

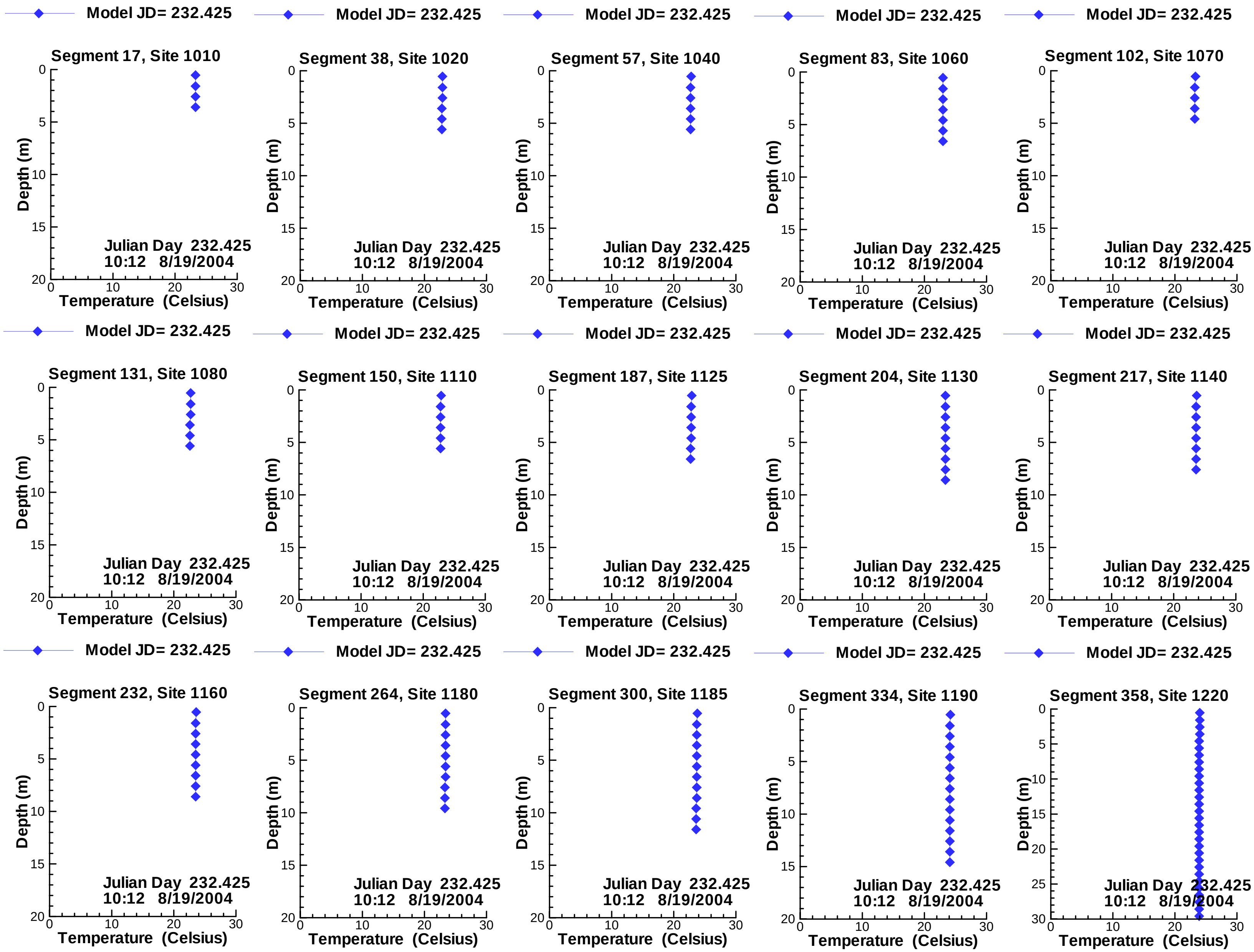

Figure 145: Vertical profiles of temperature compared with data for 8/19/2004 10:12.

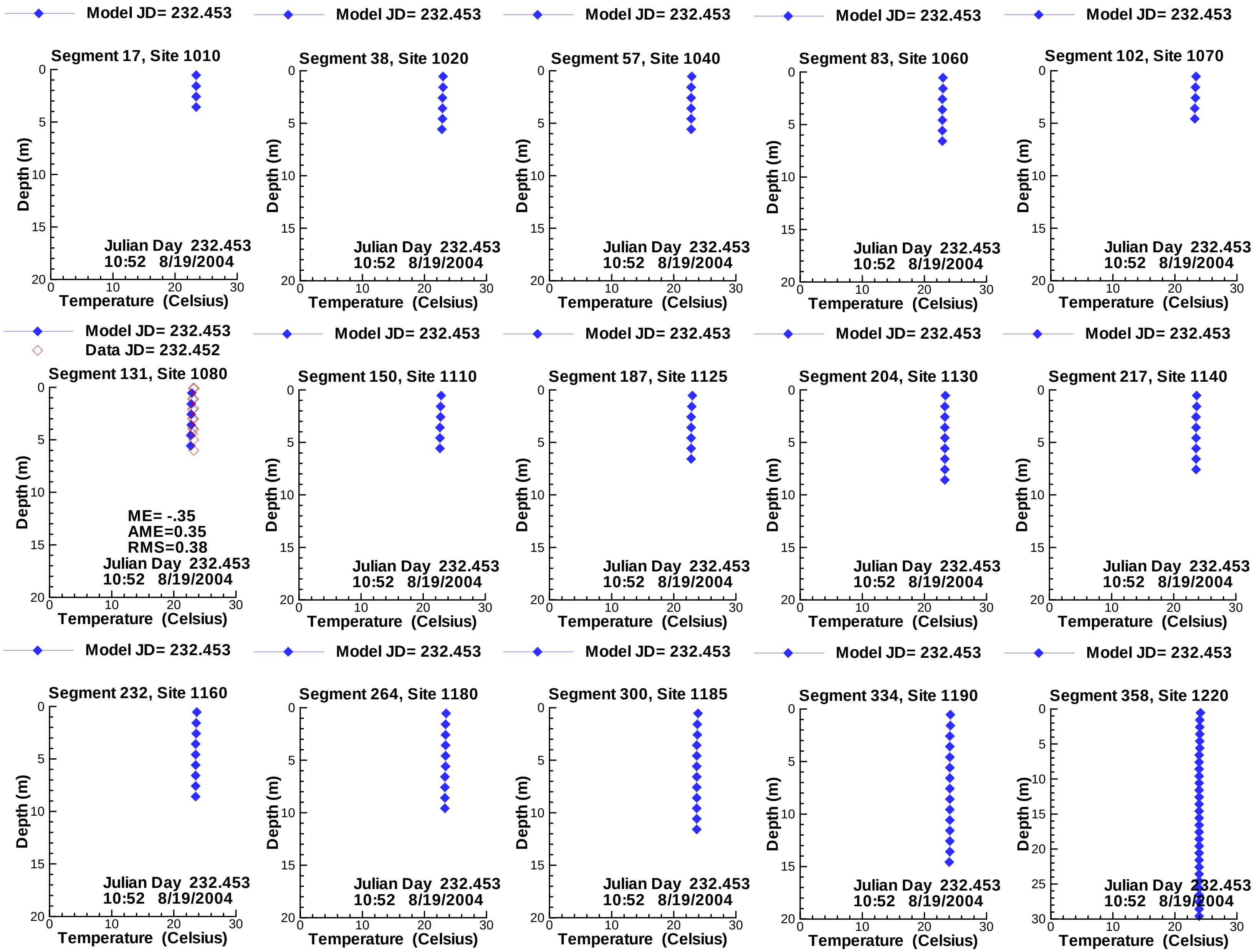

Figure 146: Vertical profiles of temperature compared with data for 8/19/2004 10:52.

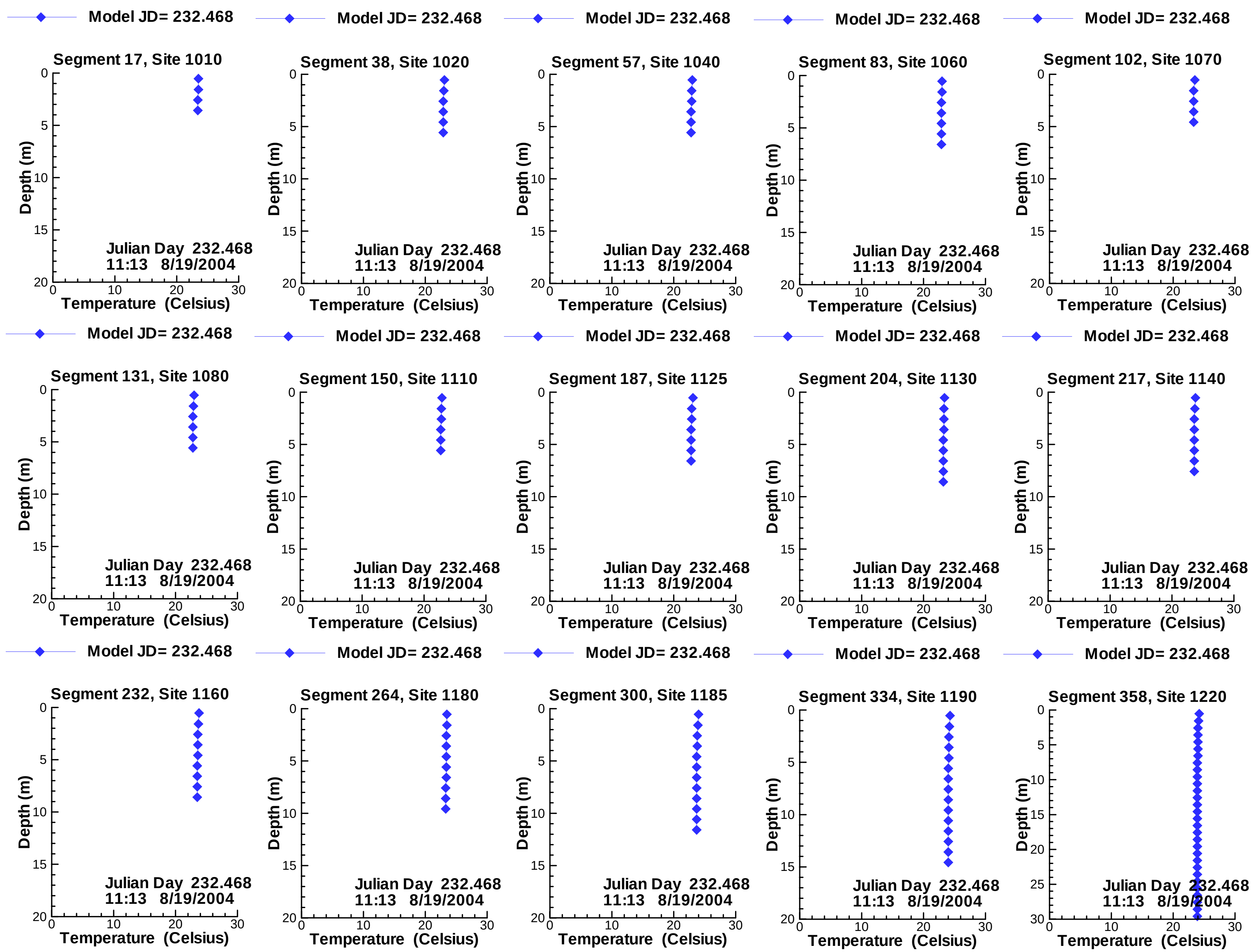

Figure 147: Vertical profiles of temperature compared with data for 8/19/2004 11:13.

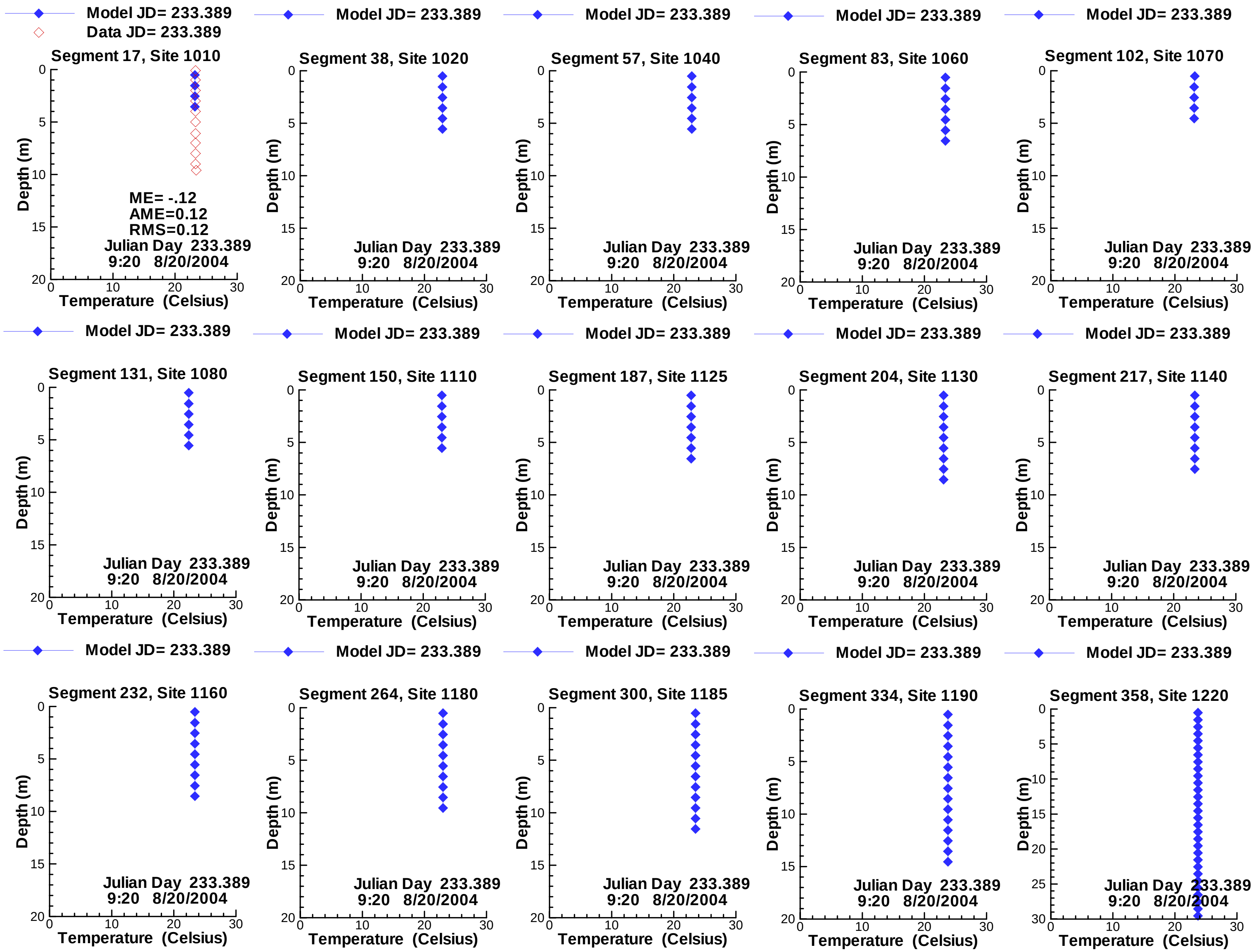

Figure 148: Vertical profiles of temperature compared with data for 8/20/2004 9:20.

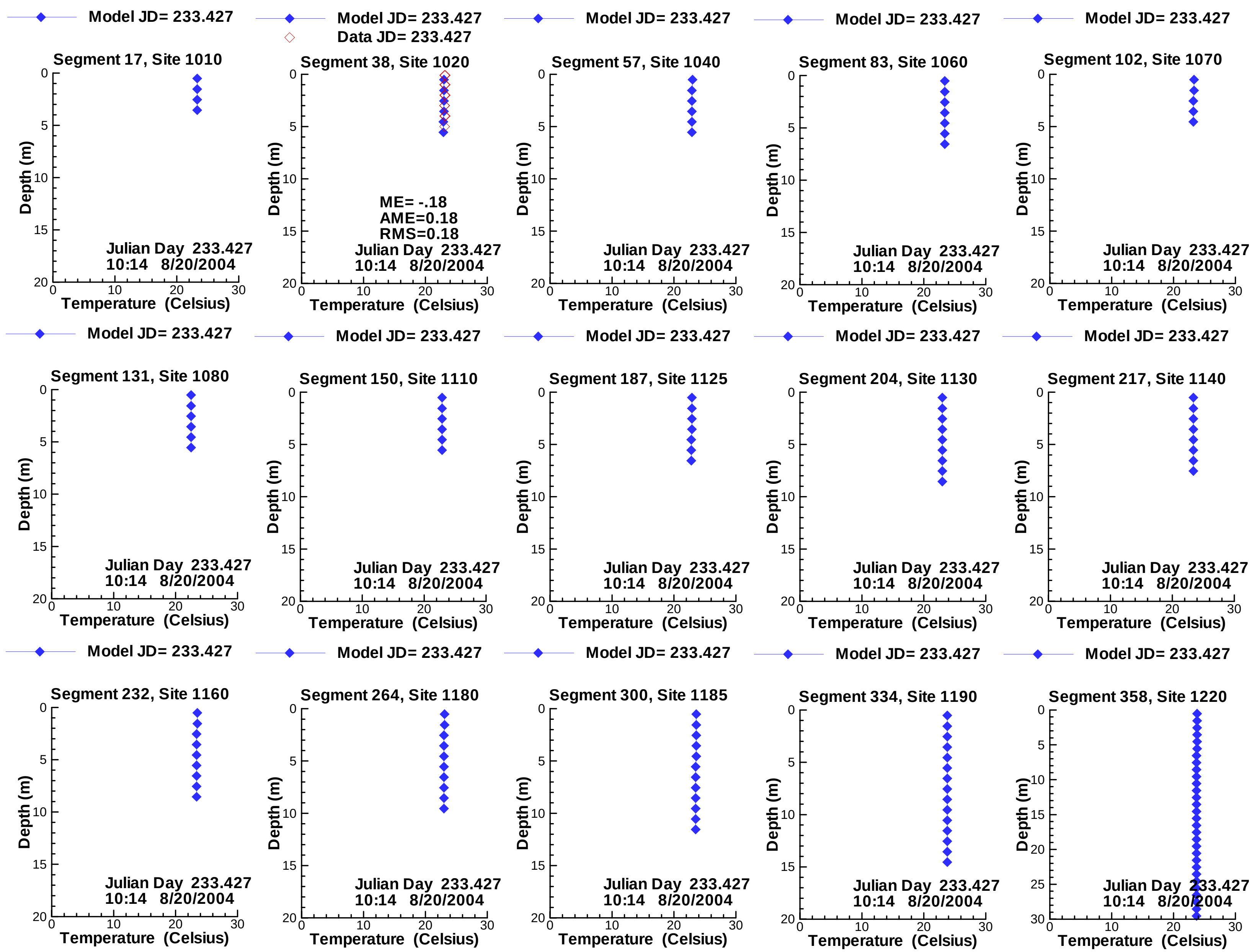

Figure 149: Vertical profiles of temperature compared with data for 8/20/2004 10:14.

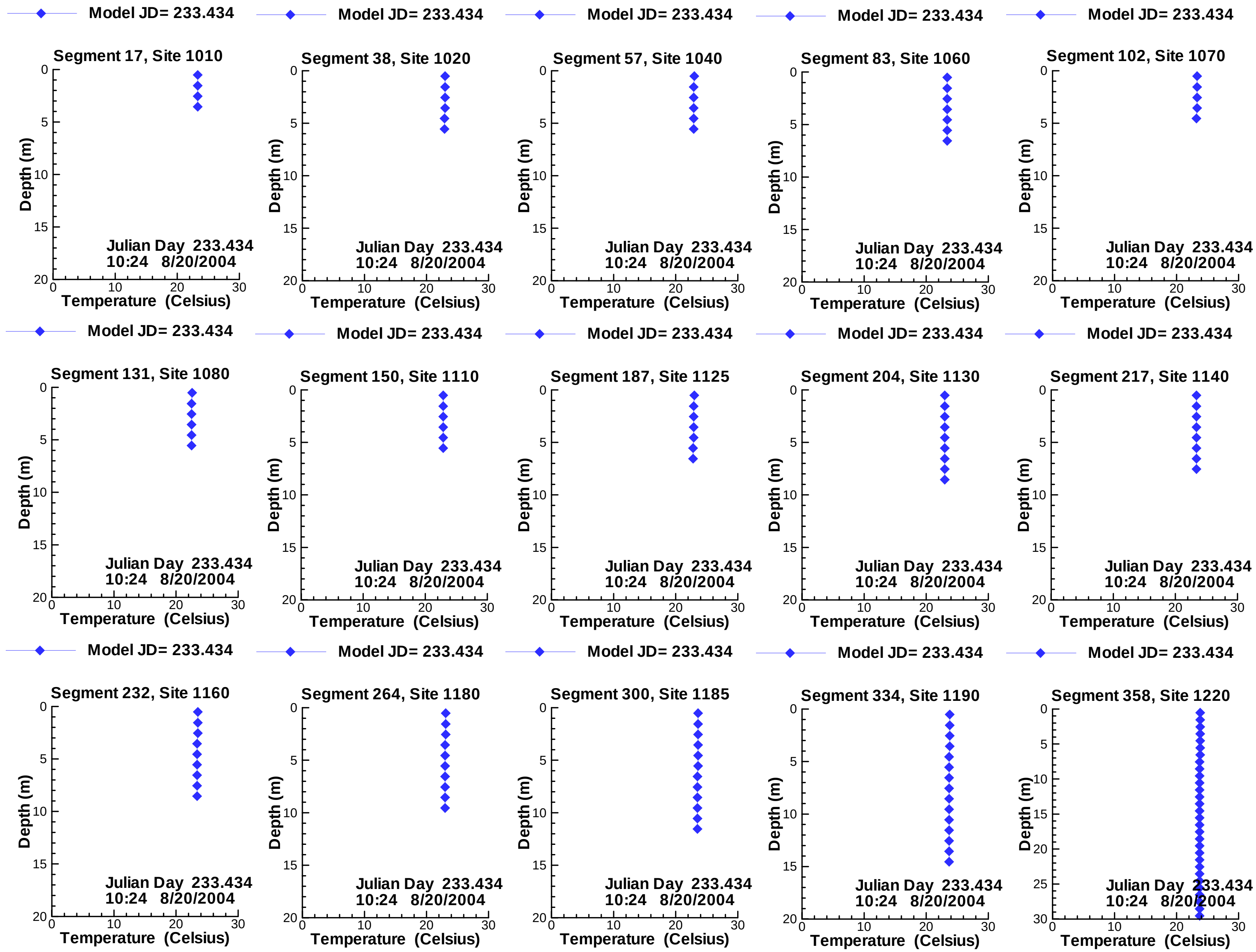

Figure 150: Vertical profiles of temperature compared with data for 8/20/2004 10:24.

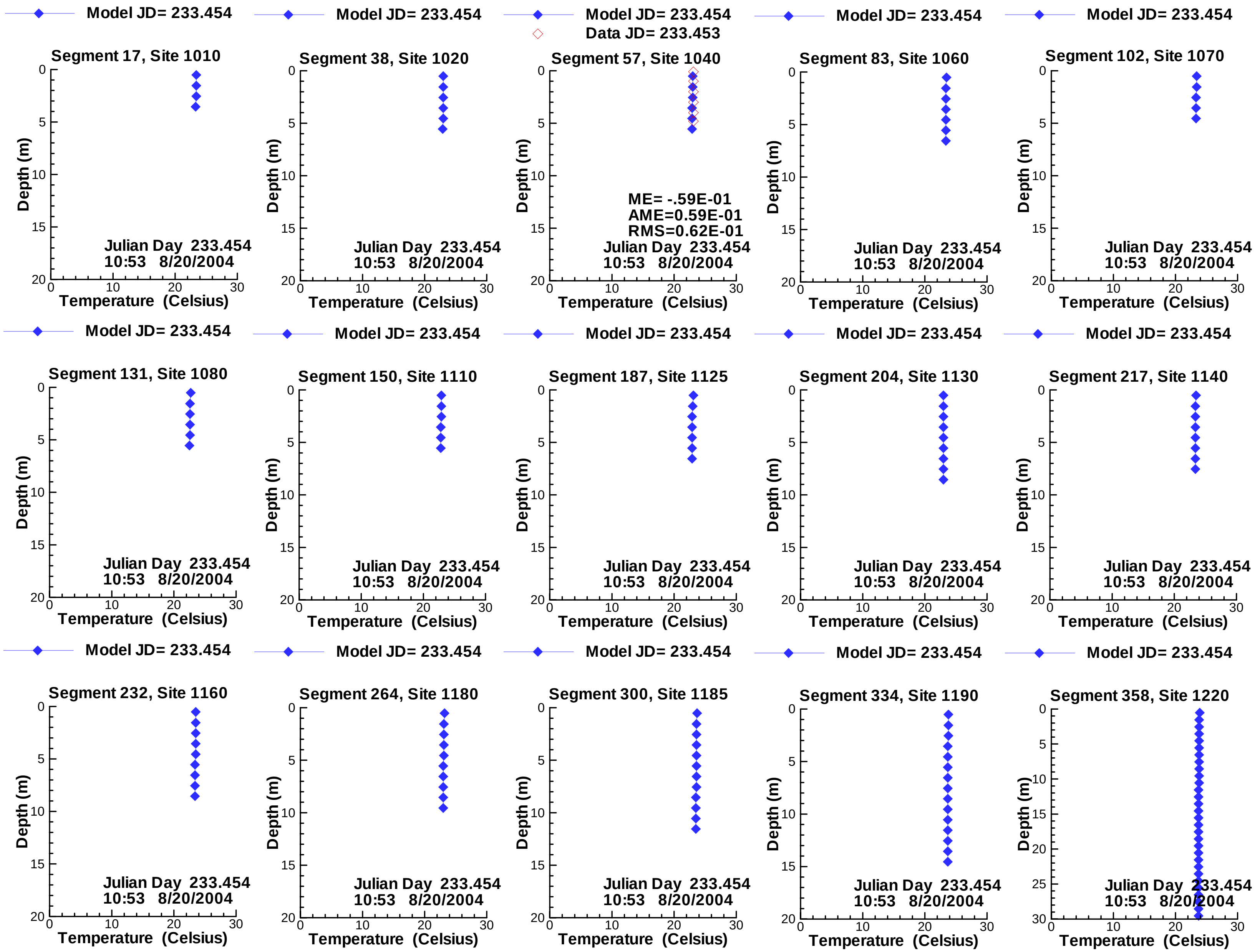

Figure 151: Vertical profiles of temperature compared with data for 8/20/2004 10:53.

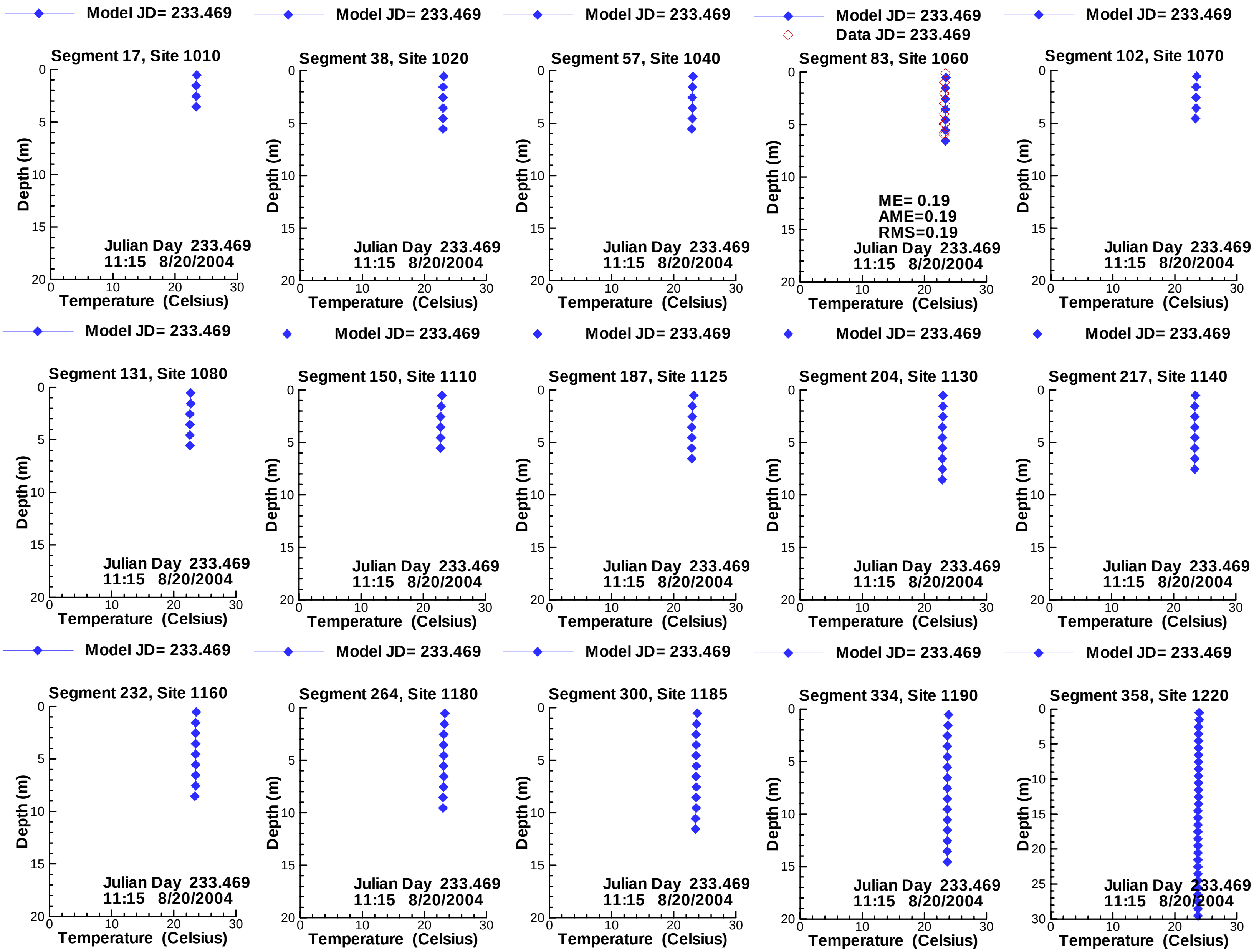

Figure 152: Vertical profiles of temperature compared with data for 8/20/2004 11:15.

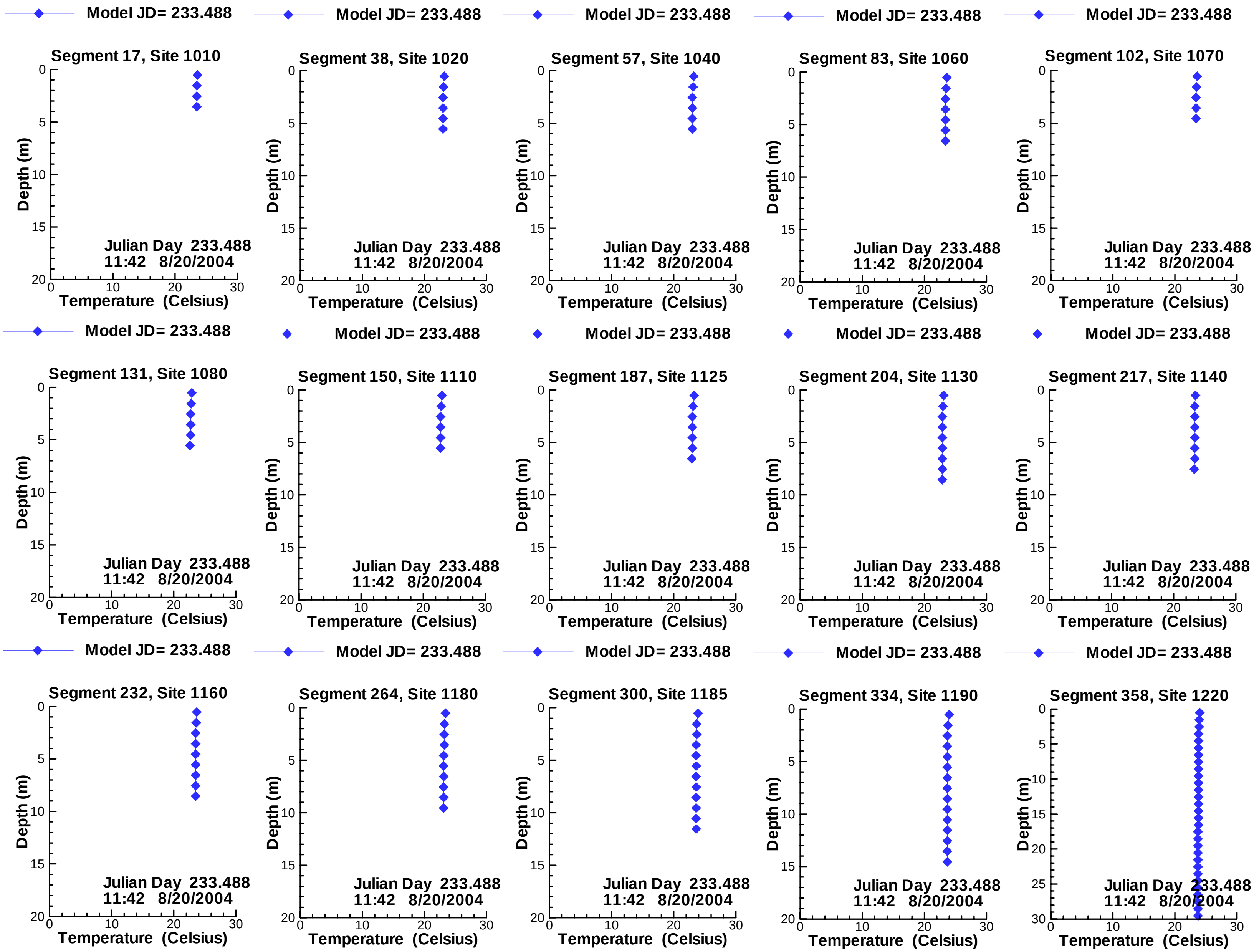

Figure 153: Vertical profiles of temperature compared with data for 8/20/2004 11:42.

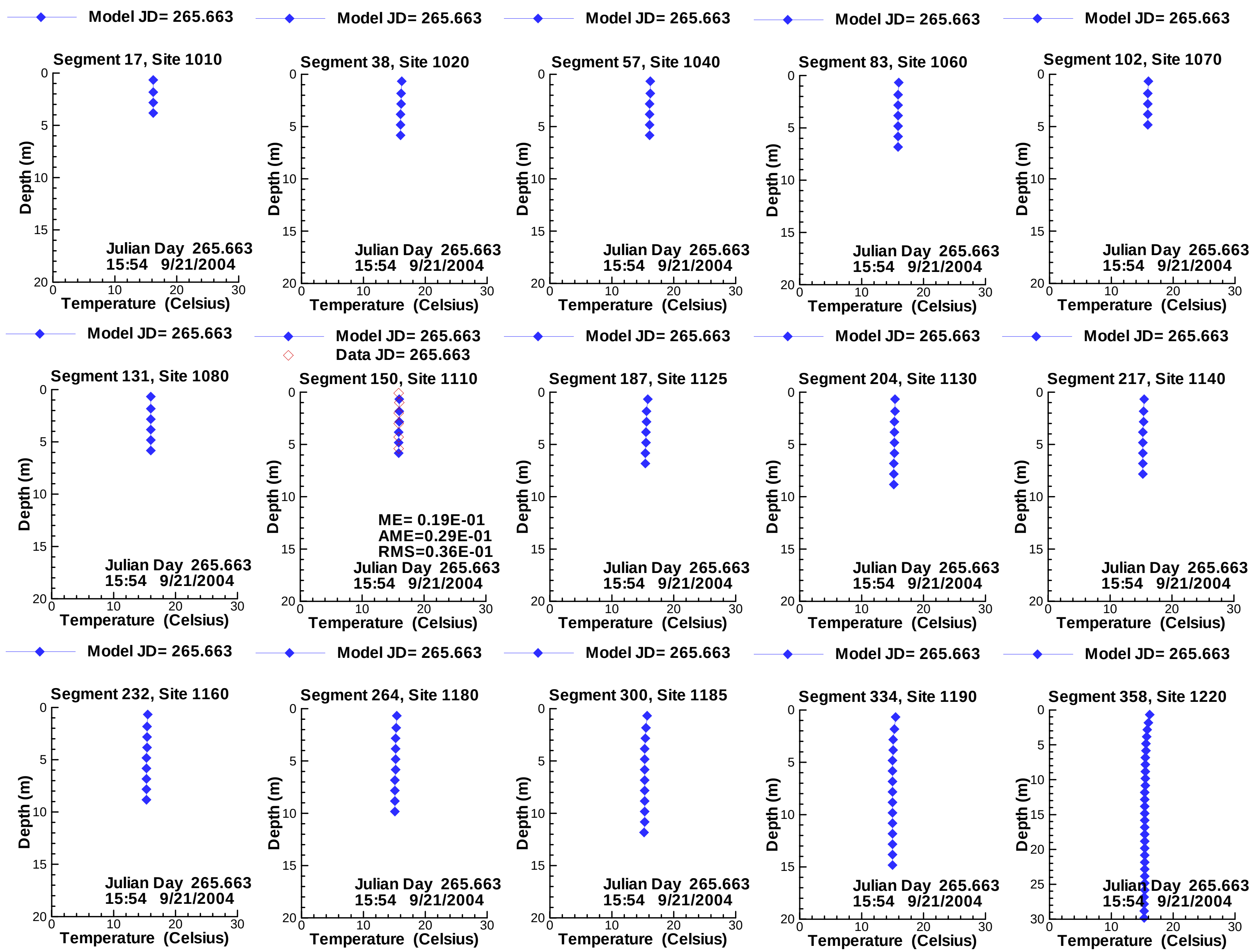

Figure 154: Vertical profiles of temperature compared with data for 9/21/2004 15:54.

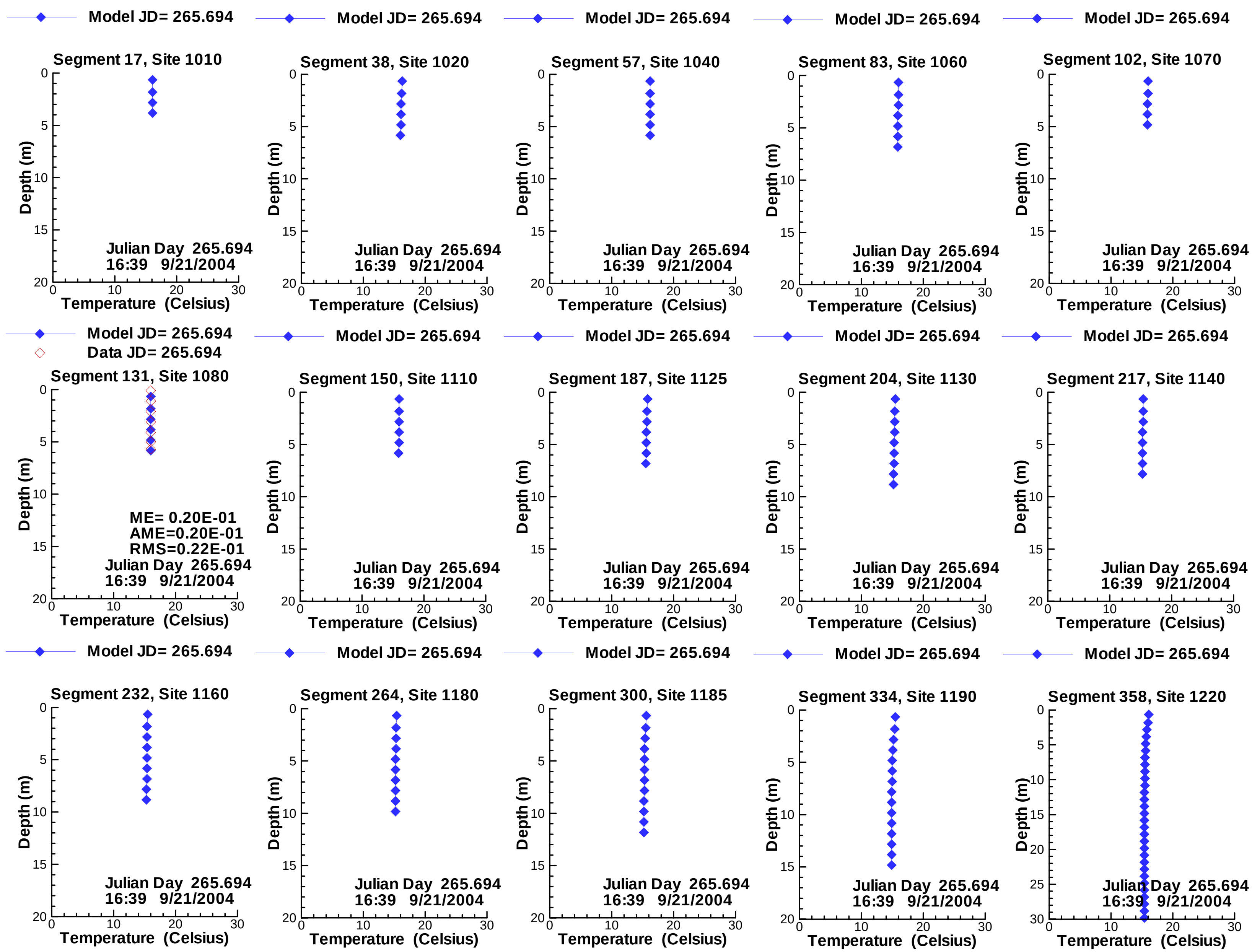

Figure 155: Vertical profiles of temperature compared with data for 9/21/2004 16:39.

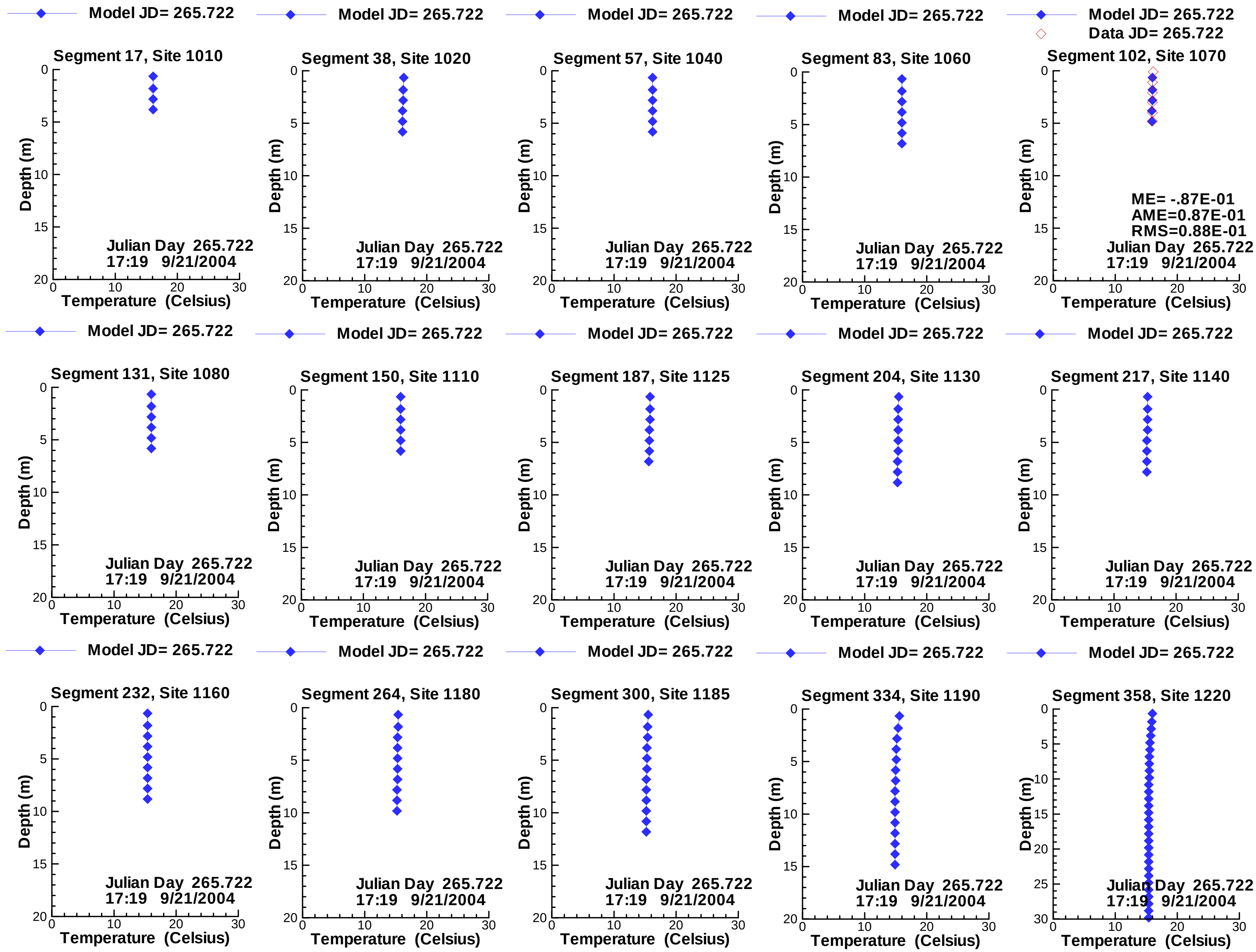

Figure 156: Vertical profiles of temperature compared with data for 9/21/2004 17:19.

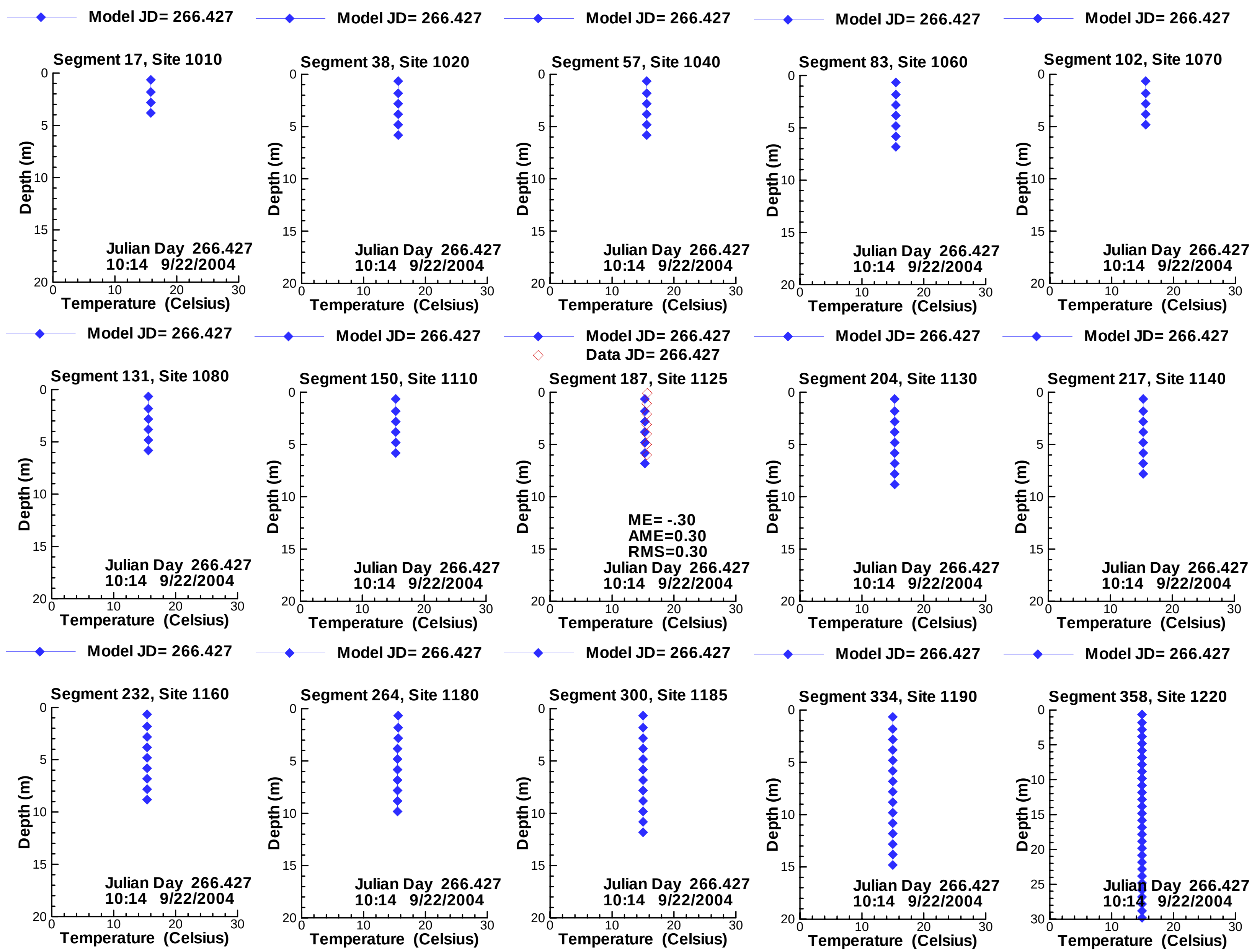

Figure 157: Vertical profiles of temperature compared with data for 9/22/2004 10:14.

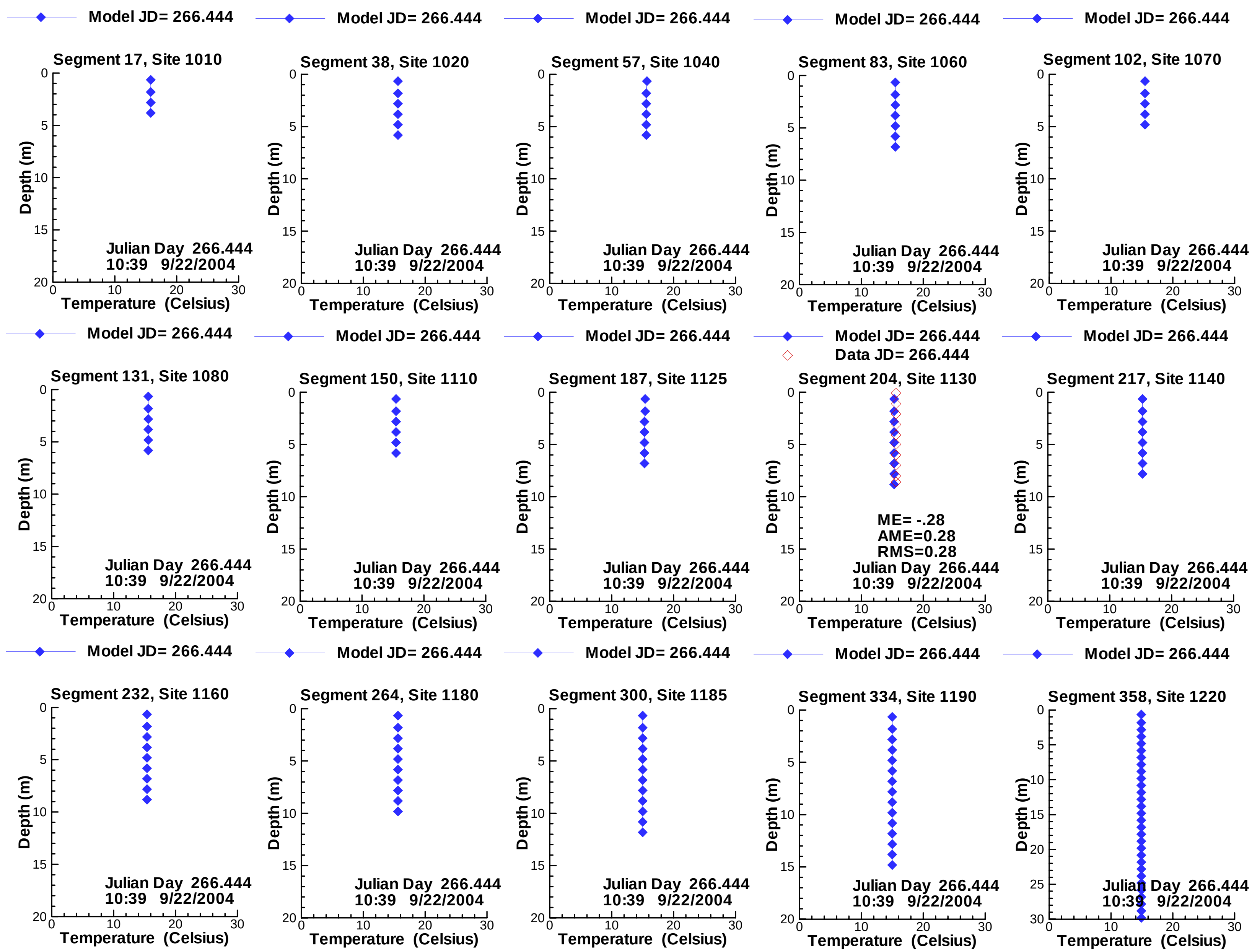

Figure 158: Vertical profiles of temperature compared with data for 9/22/2004 10:39.

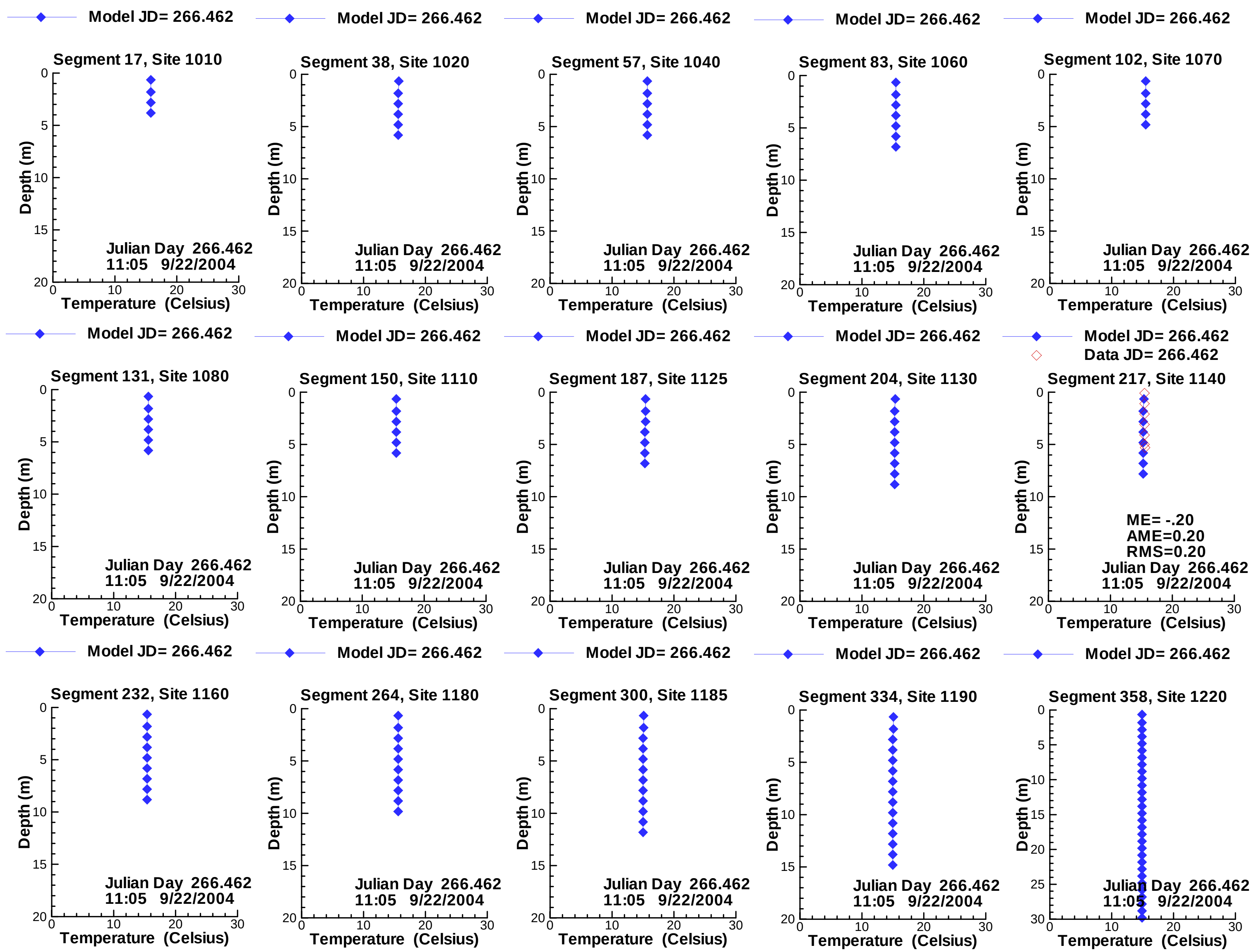

Figure 159: Vertical profiles of temperature compared with data for 9/22/2004 11:05.

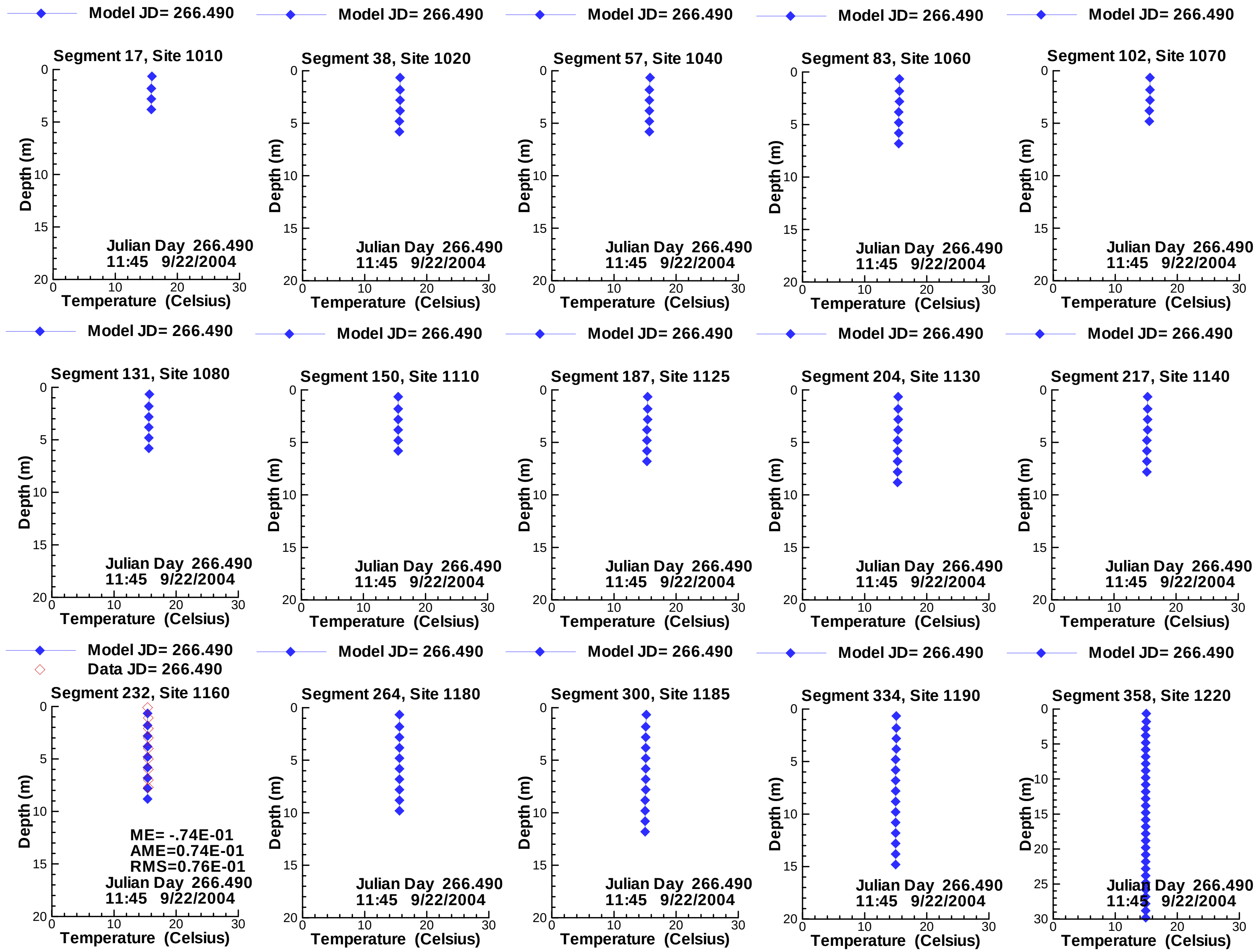

Figure 160: Vertical profiles of temperature compared with data for 9/22/2004 11:45.

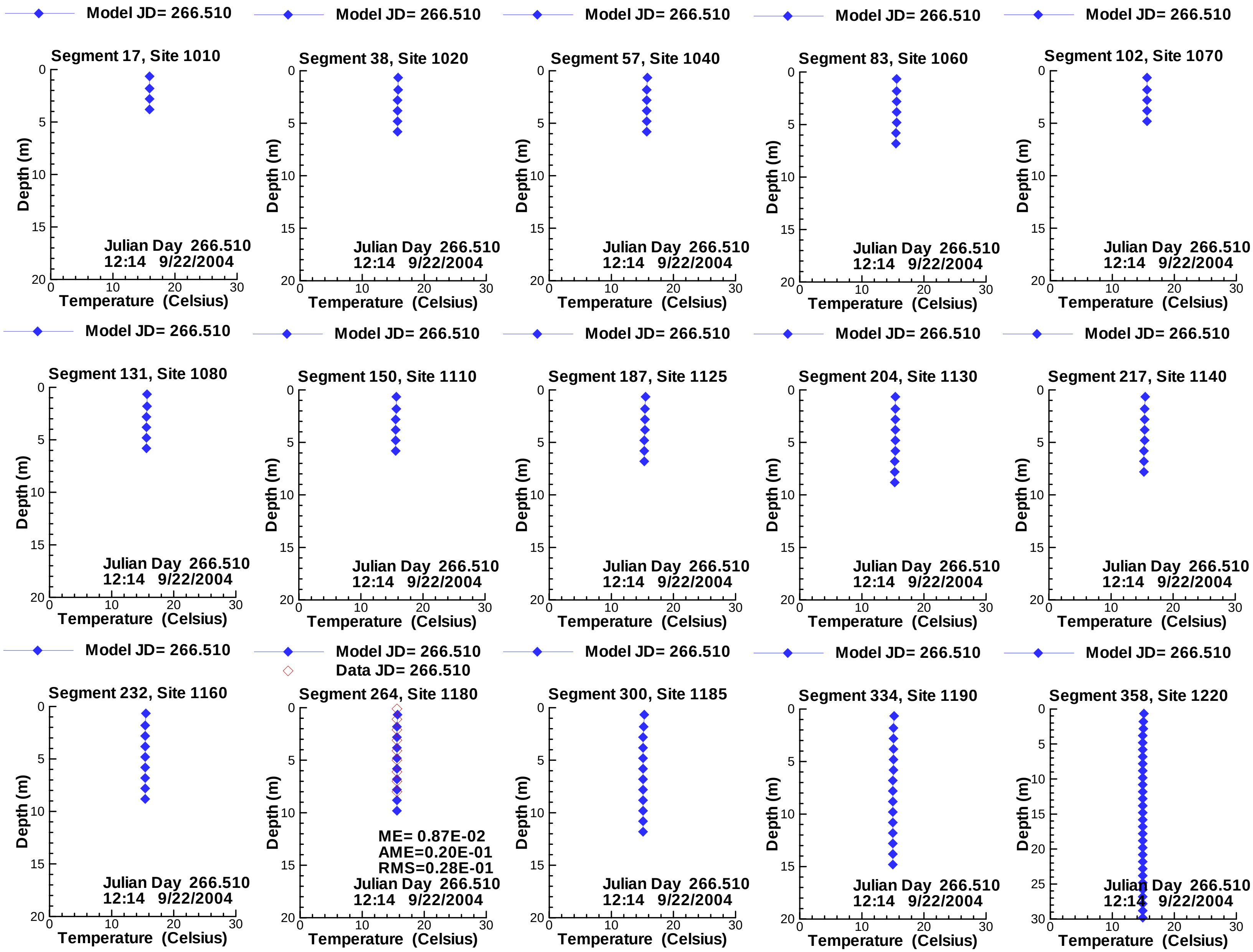

Figure 161: Vertical profiles of temperature compared with data for 9/22/2004 12:14.

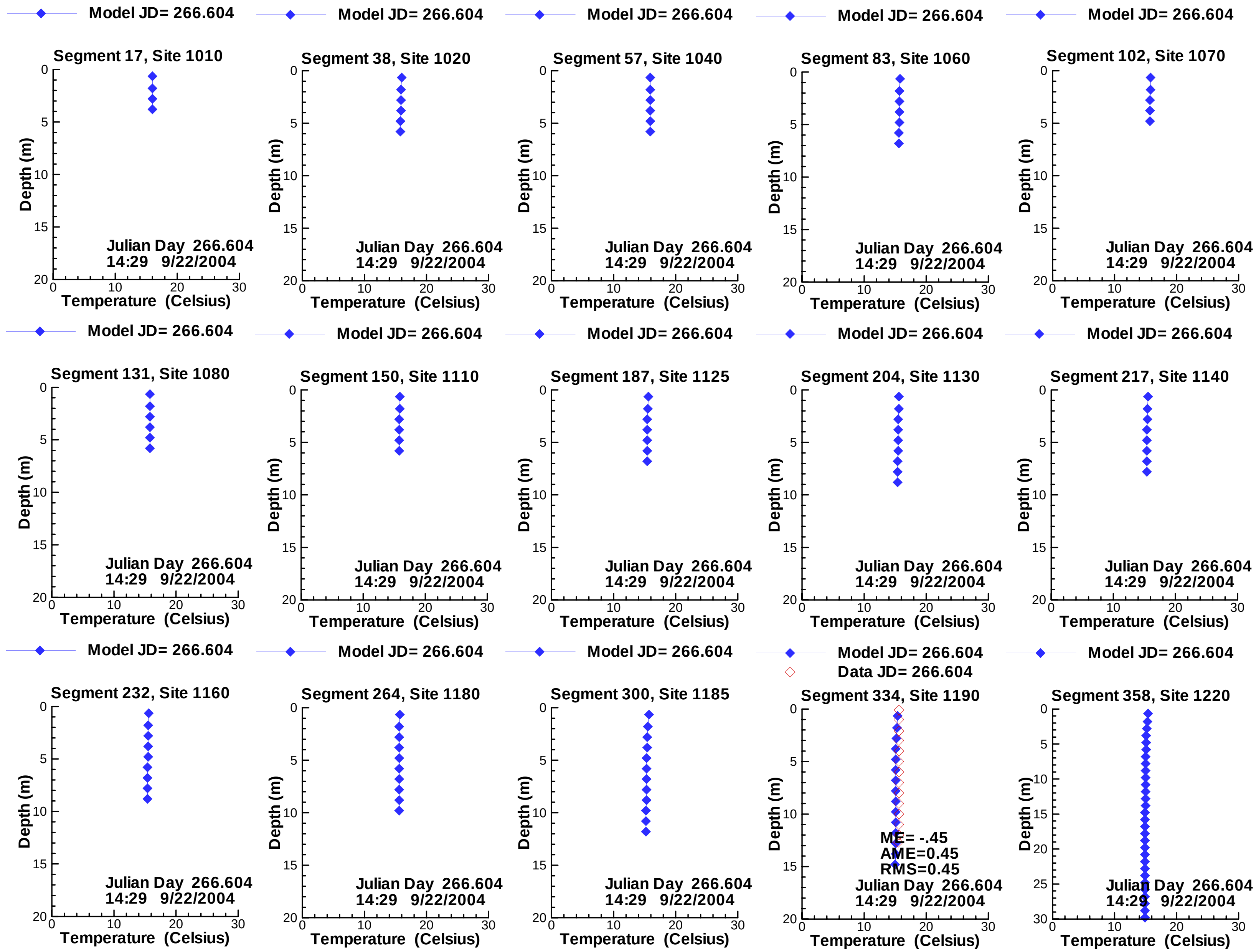

Figure 162: Vertical profiles of temperature compared with data for 9/22/2004 14:29.

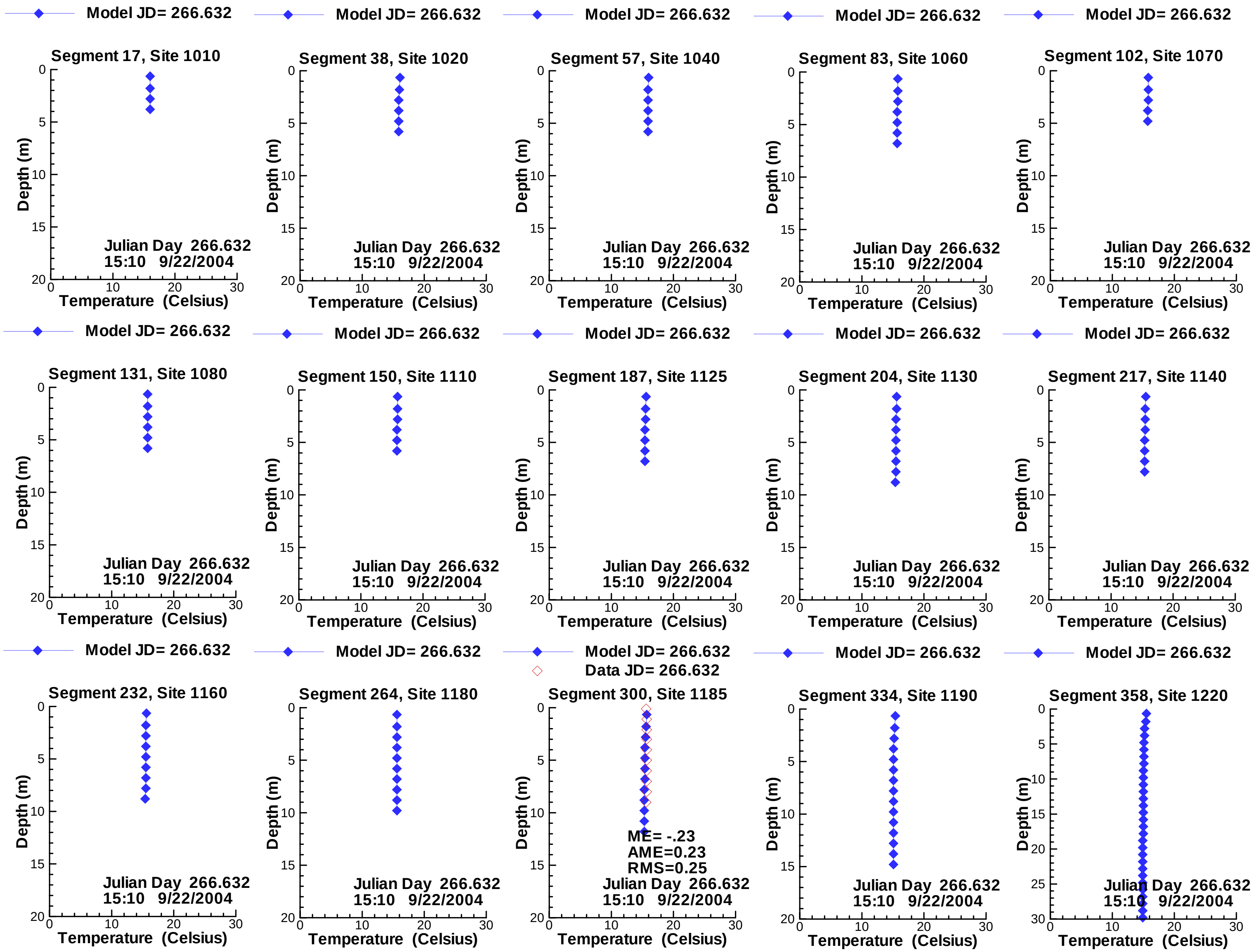

Figure 163: Vertical profiles of temperature compared with data for 9/22/2004 15:10.

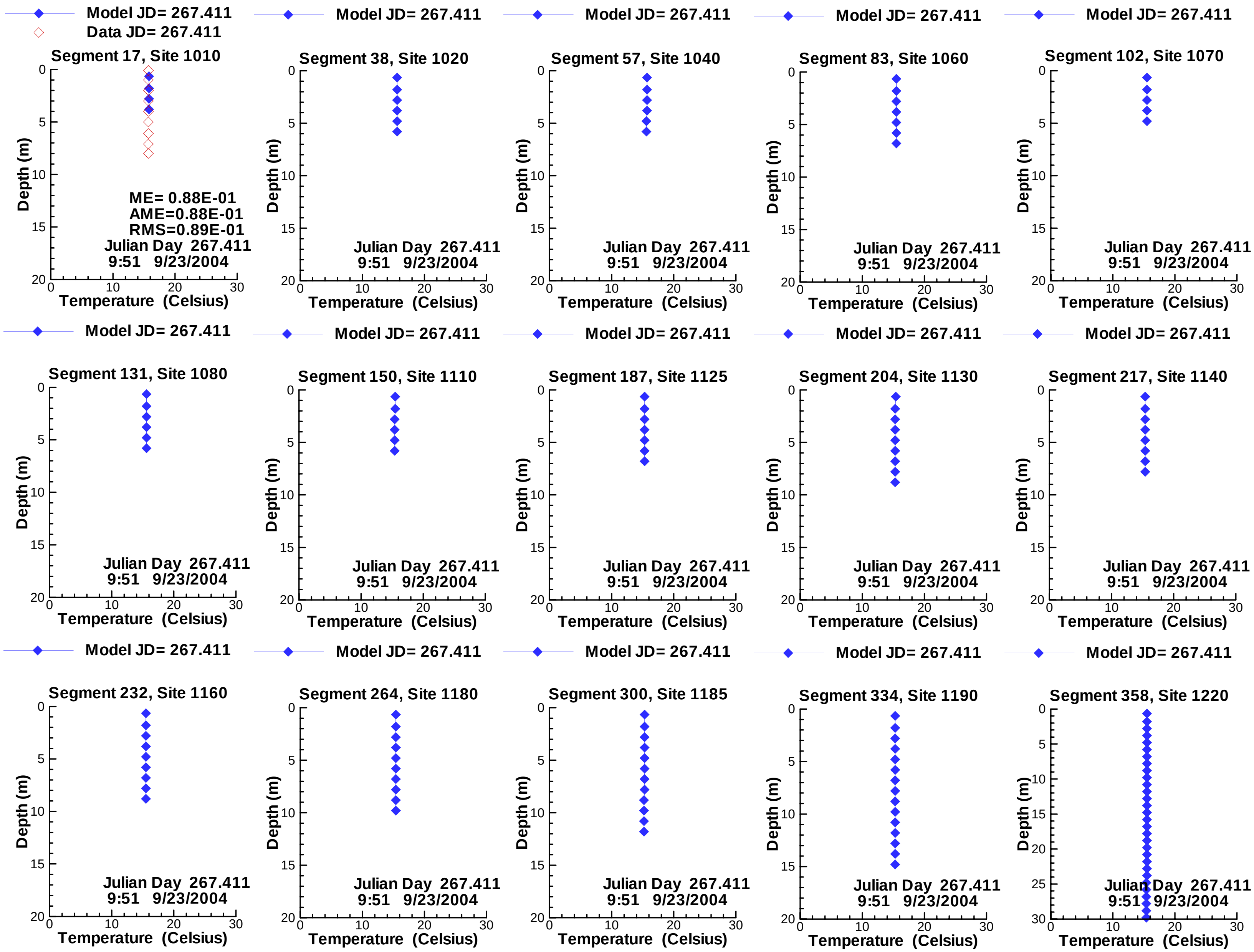

Figure 164: Vertical profiles of temperature compared with data for 9/23/2004 9:51.

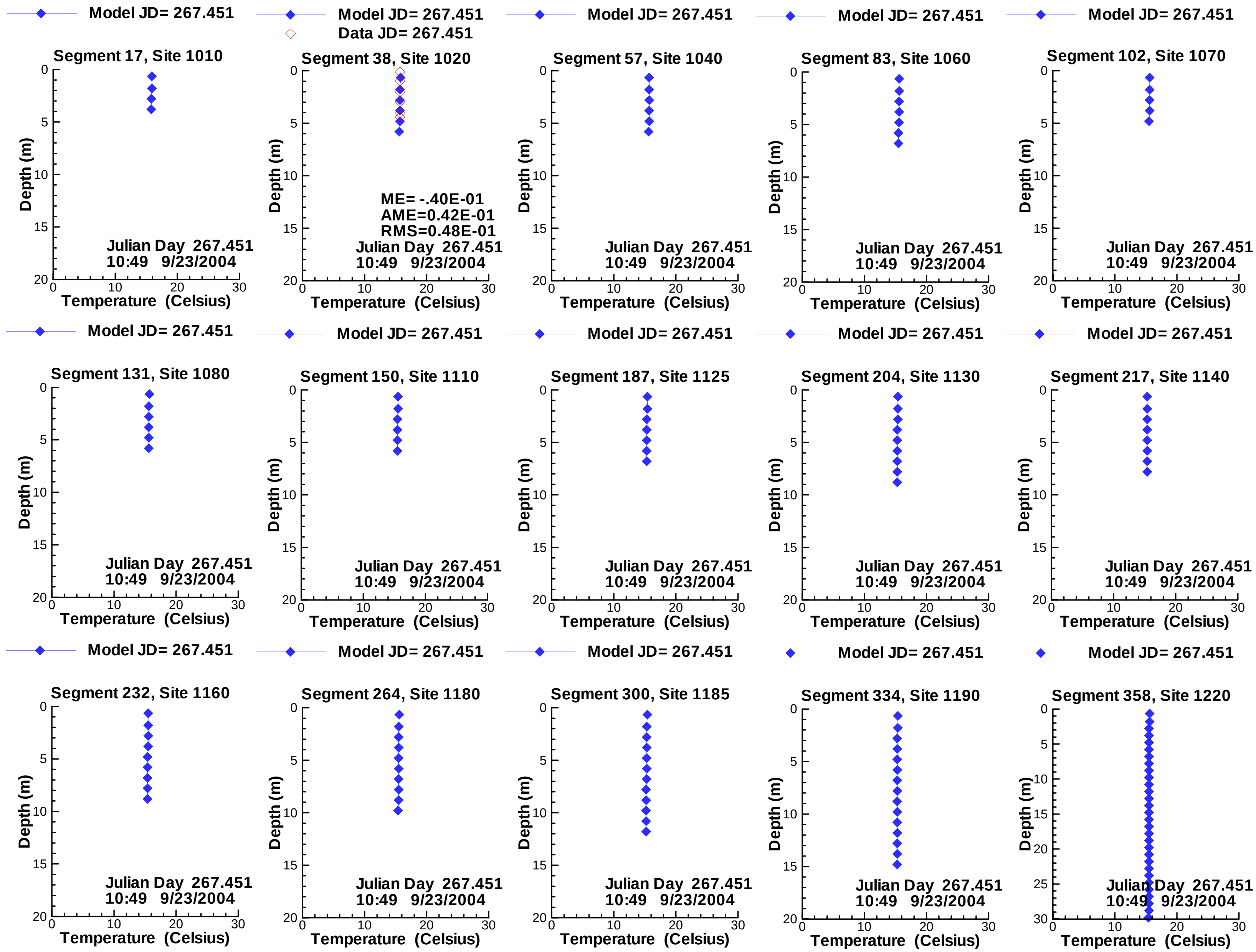

Figure 165: Vertical profiles of temperature compared with data for 9/23/2004 10:49.

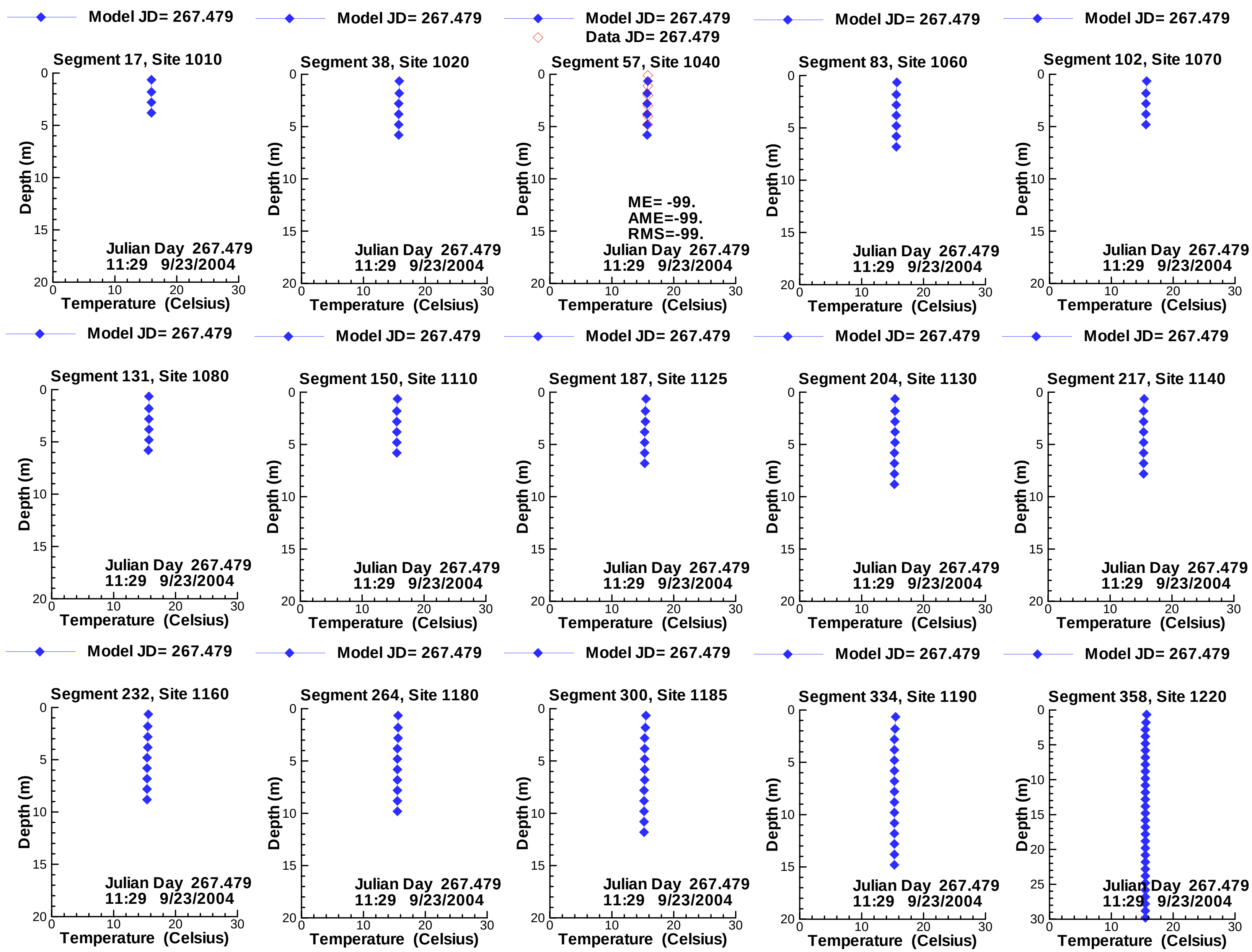

Figure 166: Vertical profiles of temperature compared with data for 9/23/2004 11:29.

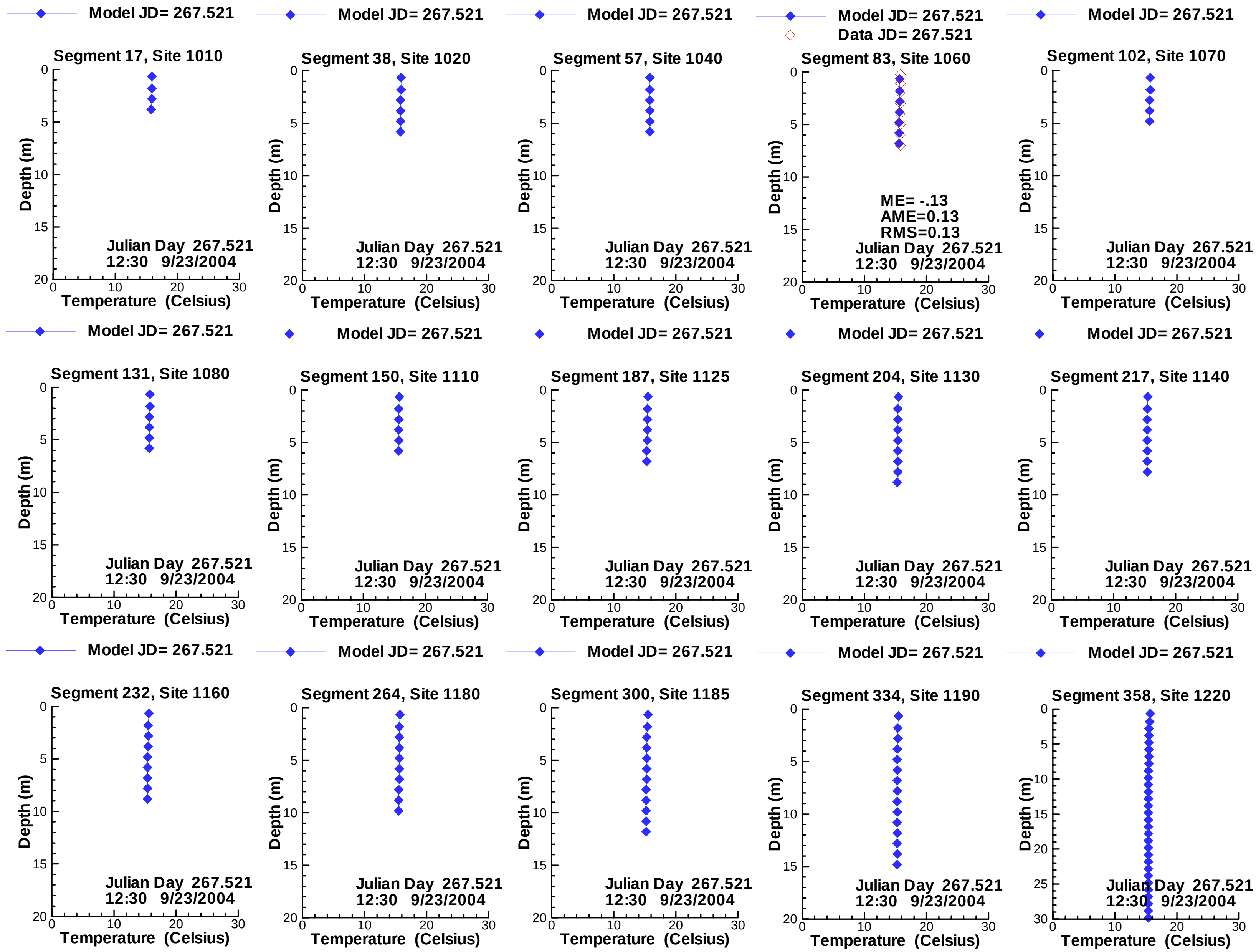

Figure 167: Vertical profiles of temperature compared with data for 9/23/2004 12:30.

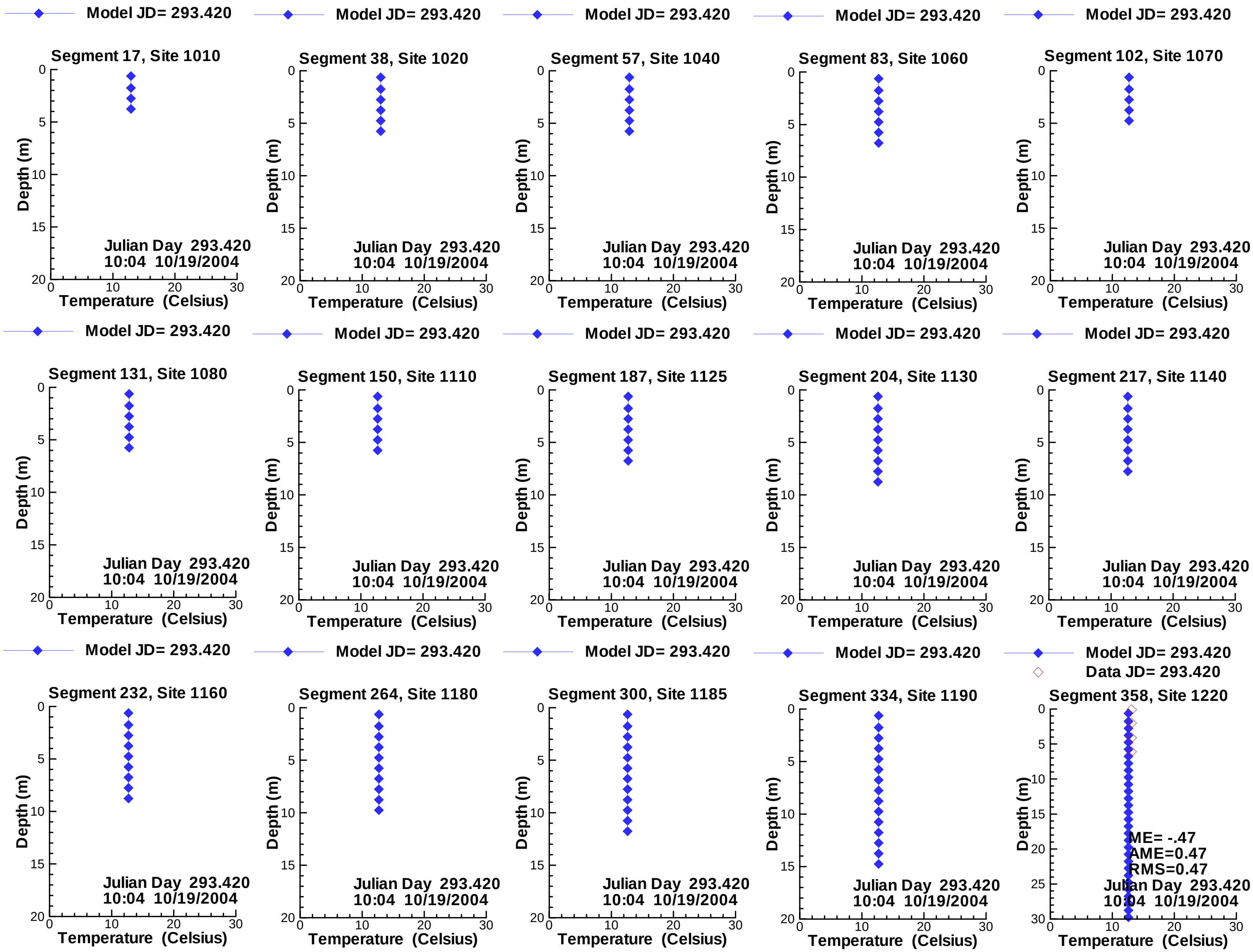

Figure 168: Vertical profiles of temperature compared with data for 10/19/2004 10:04.

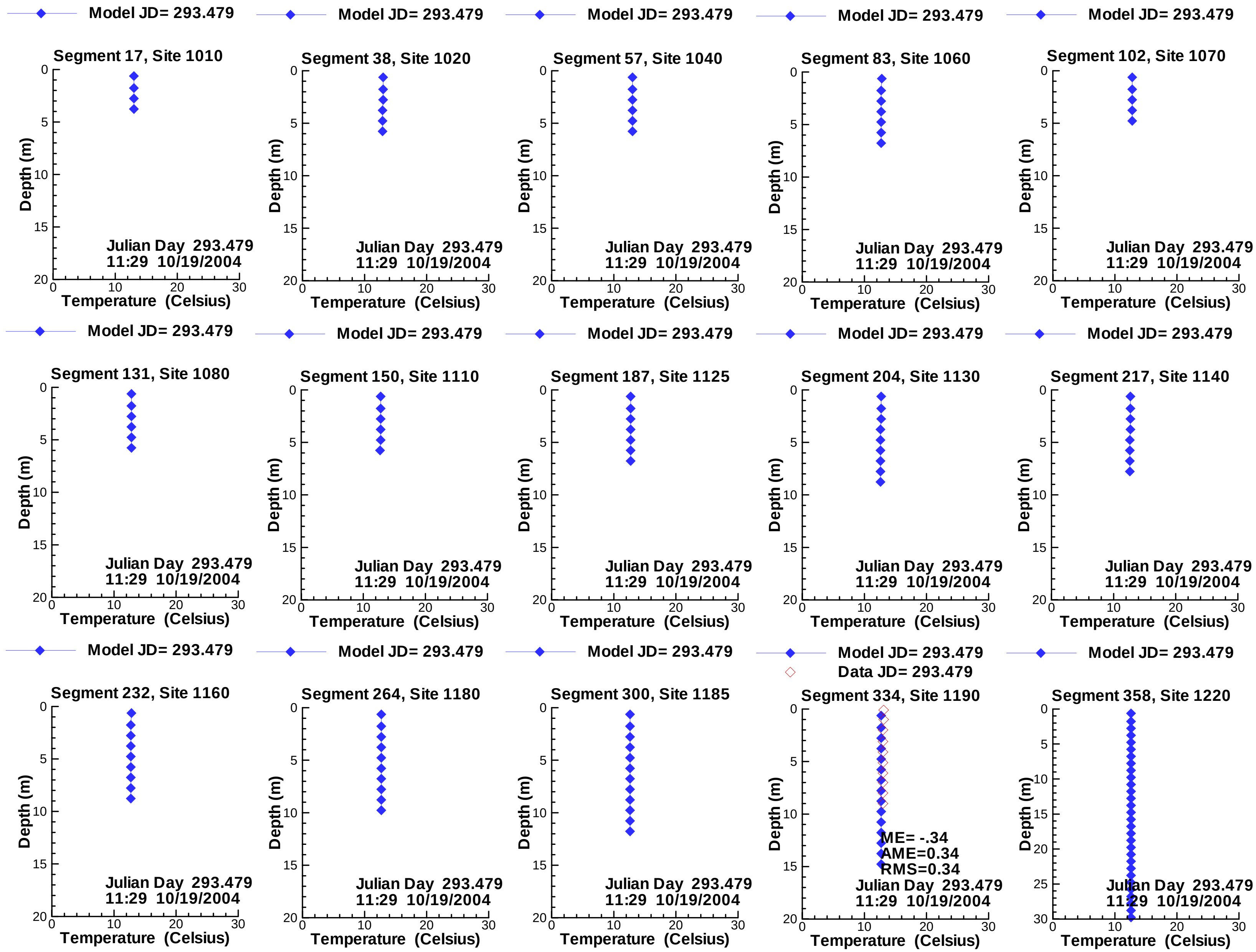

Figure 169: Vertical profiles of temperature compared with data for 10/19/2004 11:29.

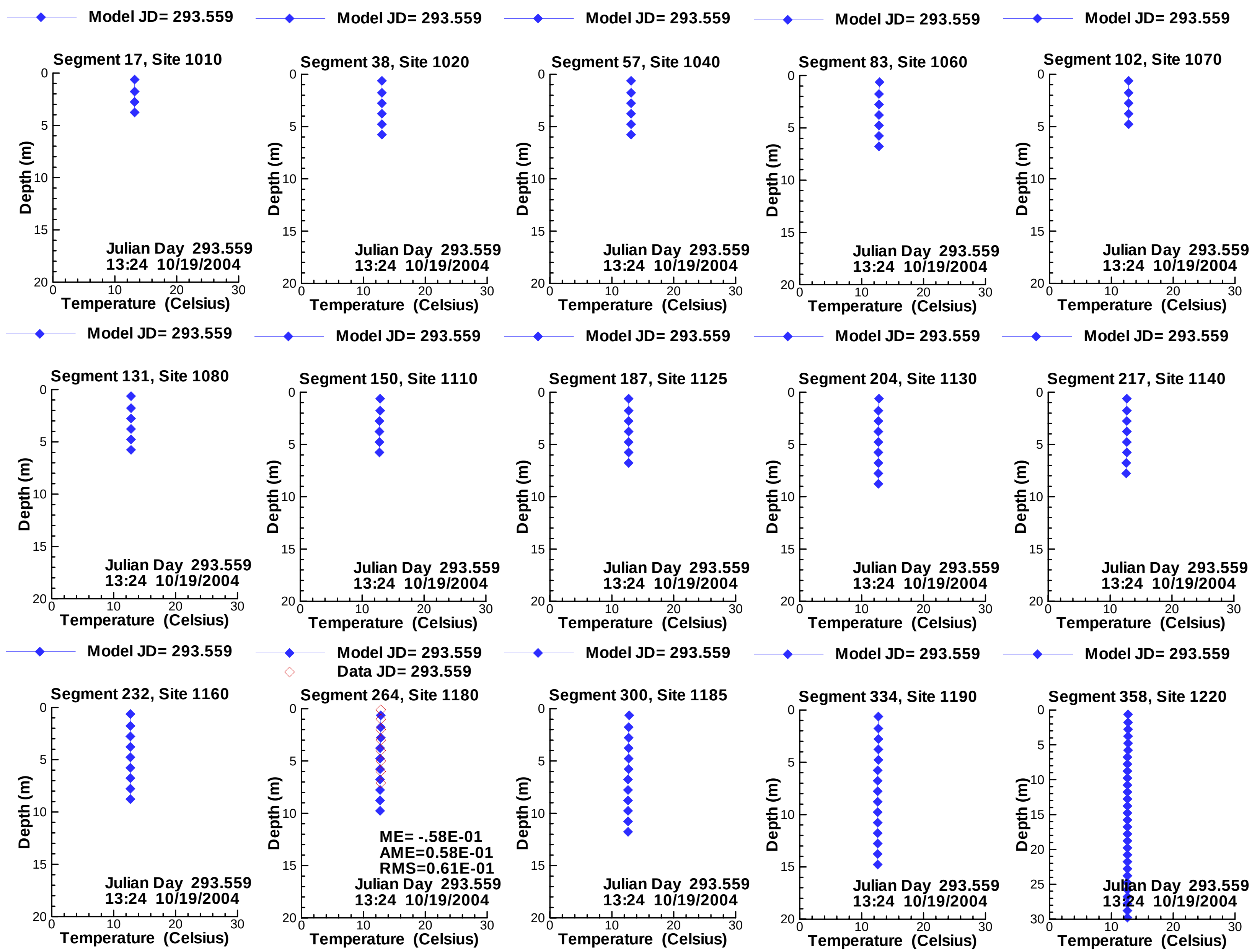

Figure 170: Vertical profiles of temperature compared with data for 10/19/2004 13:24.

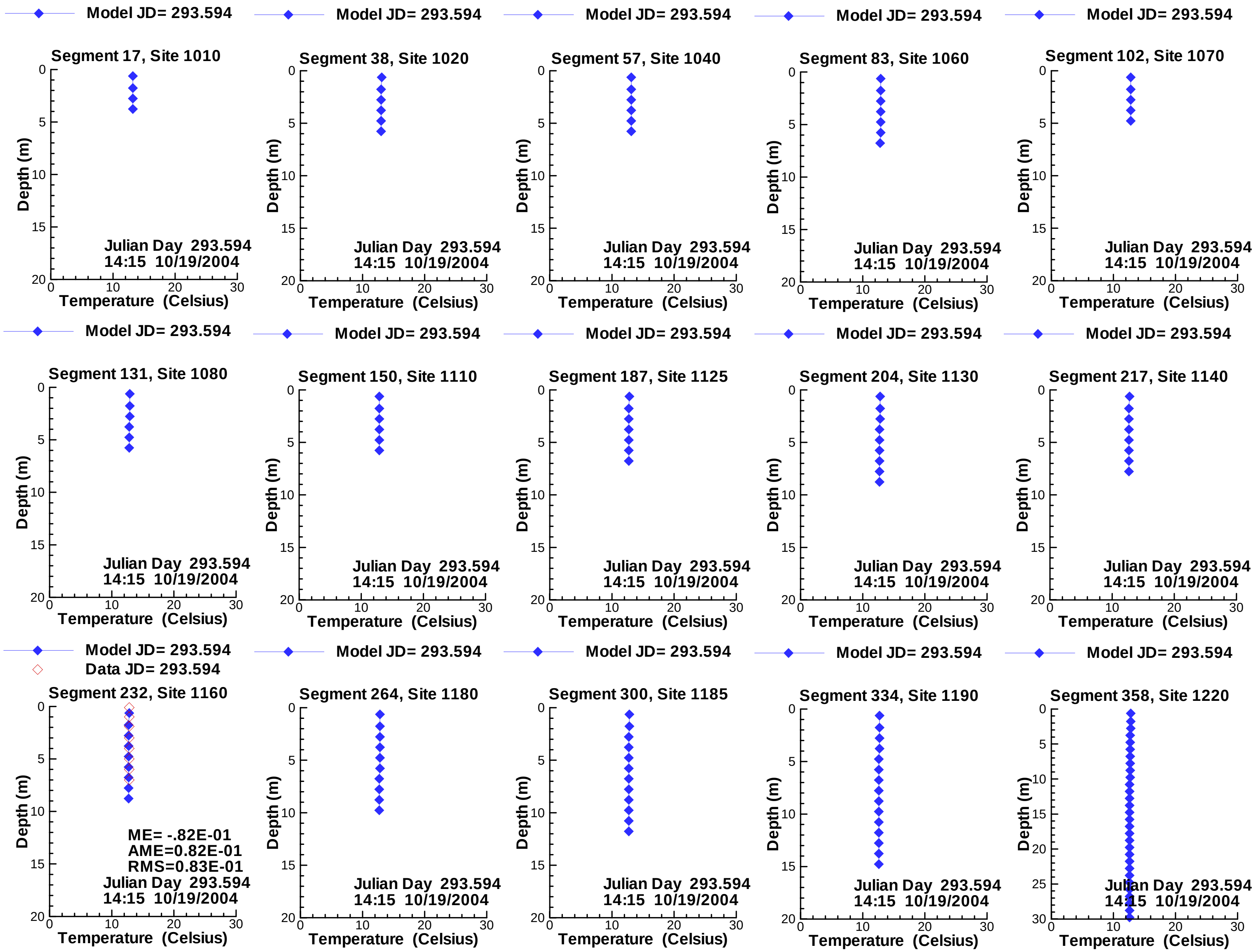

Figure 171: Vertical profiles of temperature compared with data for 10/19/2004 14:15.

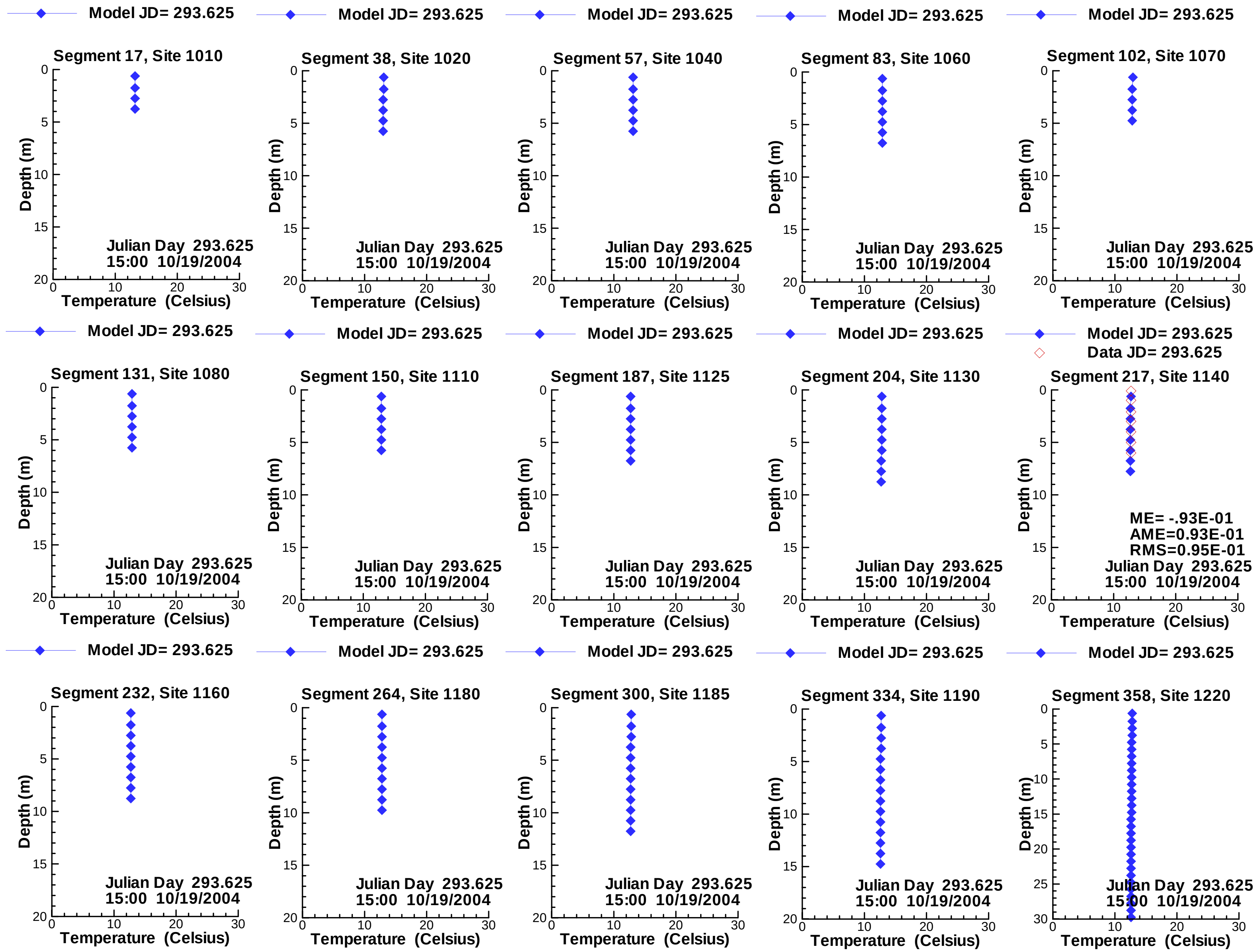

Figure 172: Vertical profiles of temperature compared with data for 10/19/2004 15:00.

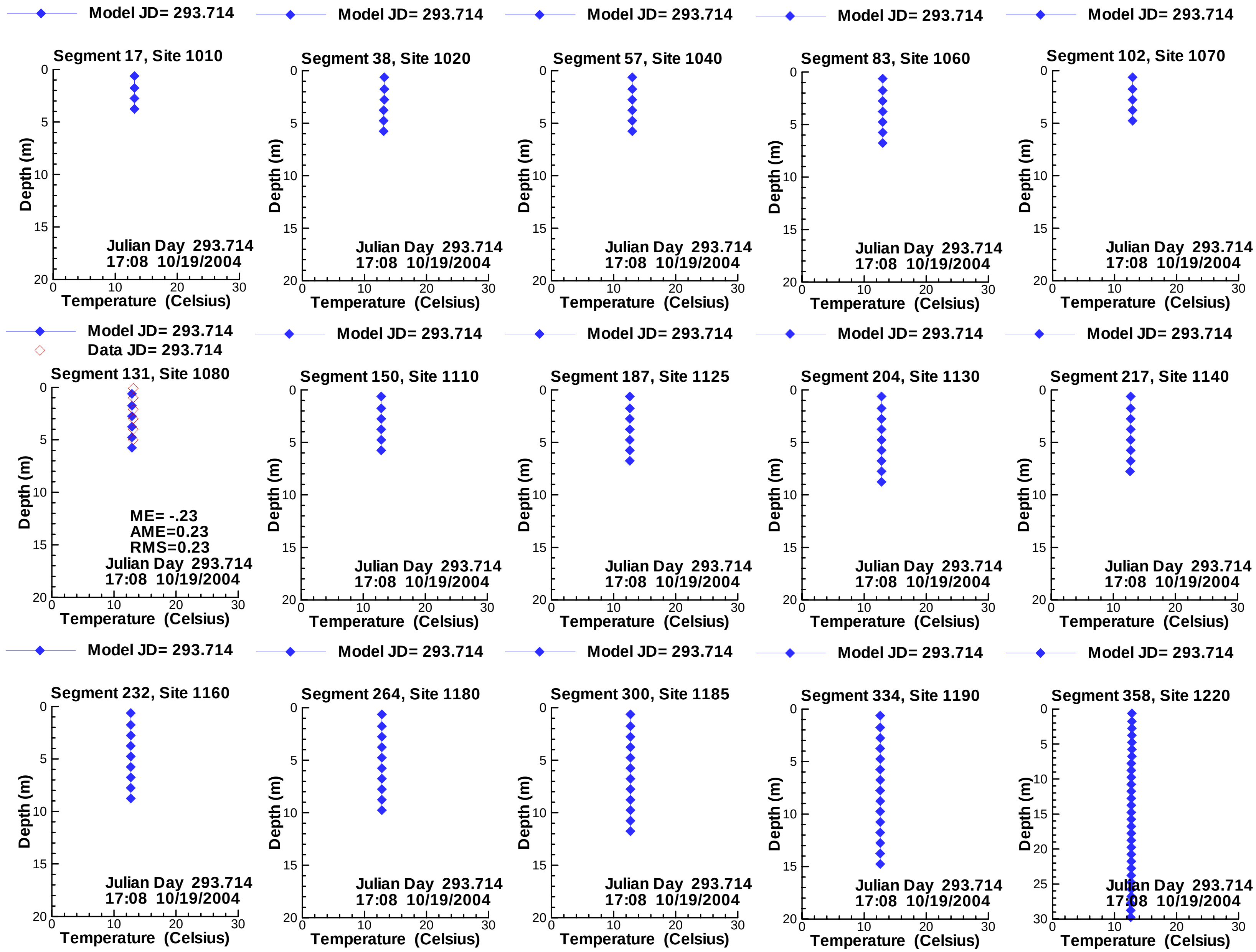

Figure 173: Vertical profiles of temperature compared with data for 10/19/2004 17:08.

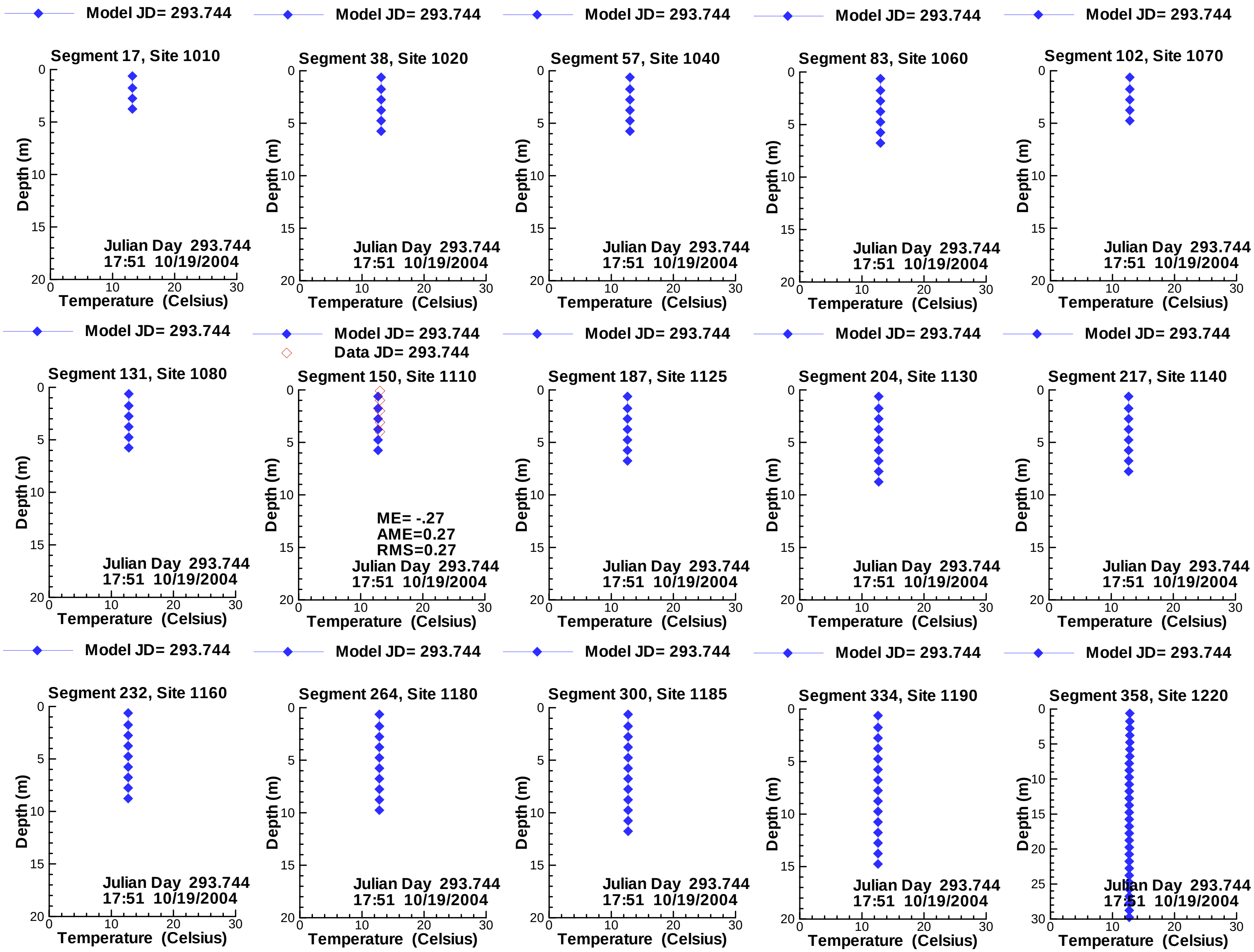

Figure 174: Vertical profiles of temperature compared with data for 10/19/2004 17:51.

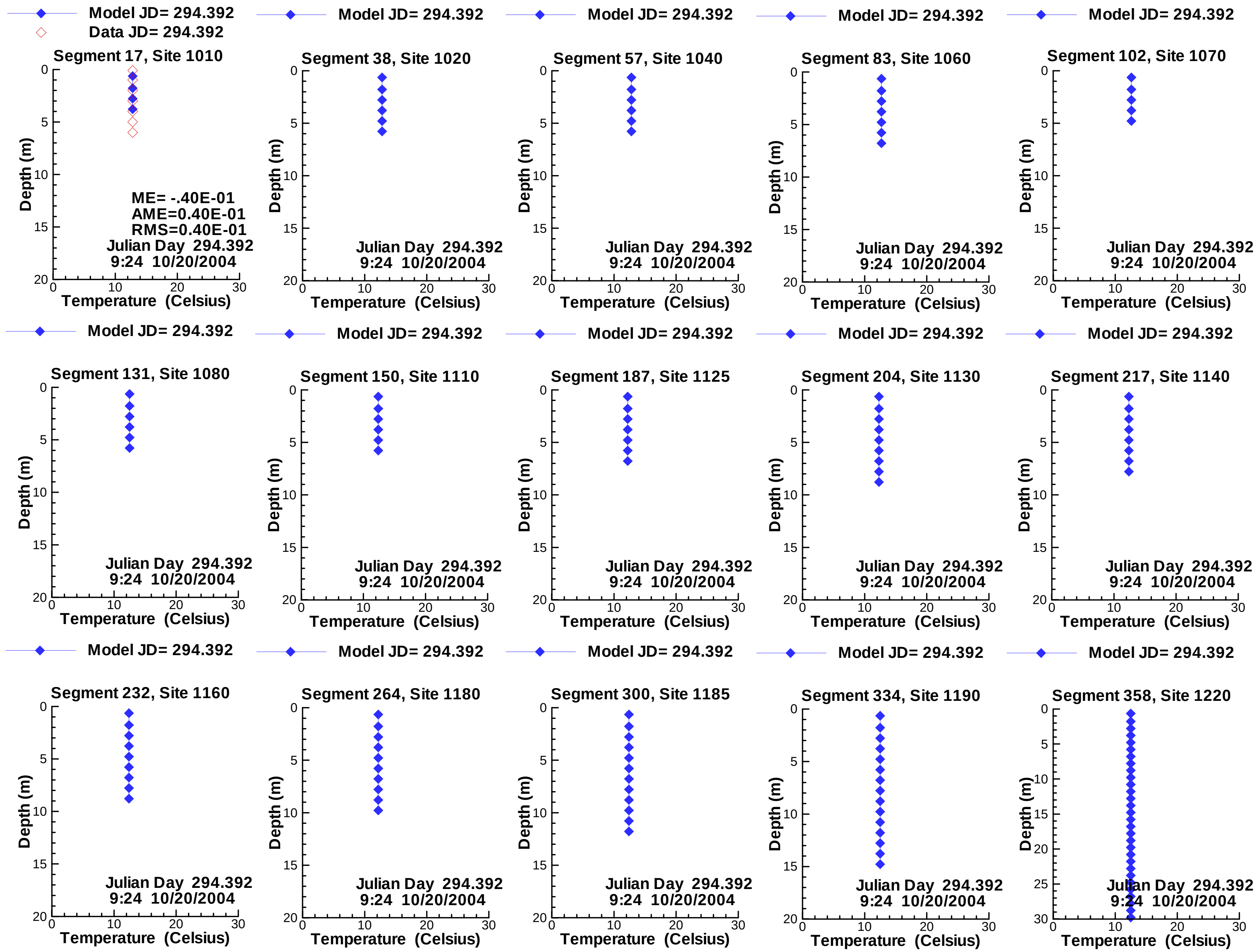

Figure 175: Vertical profiles of temperature compared with data for 10/20/2004 9:24.

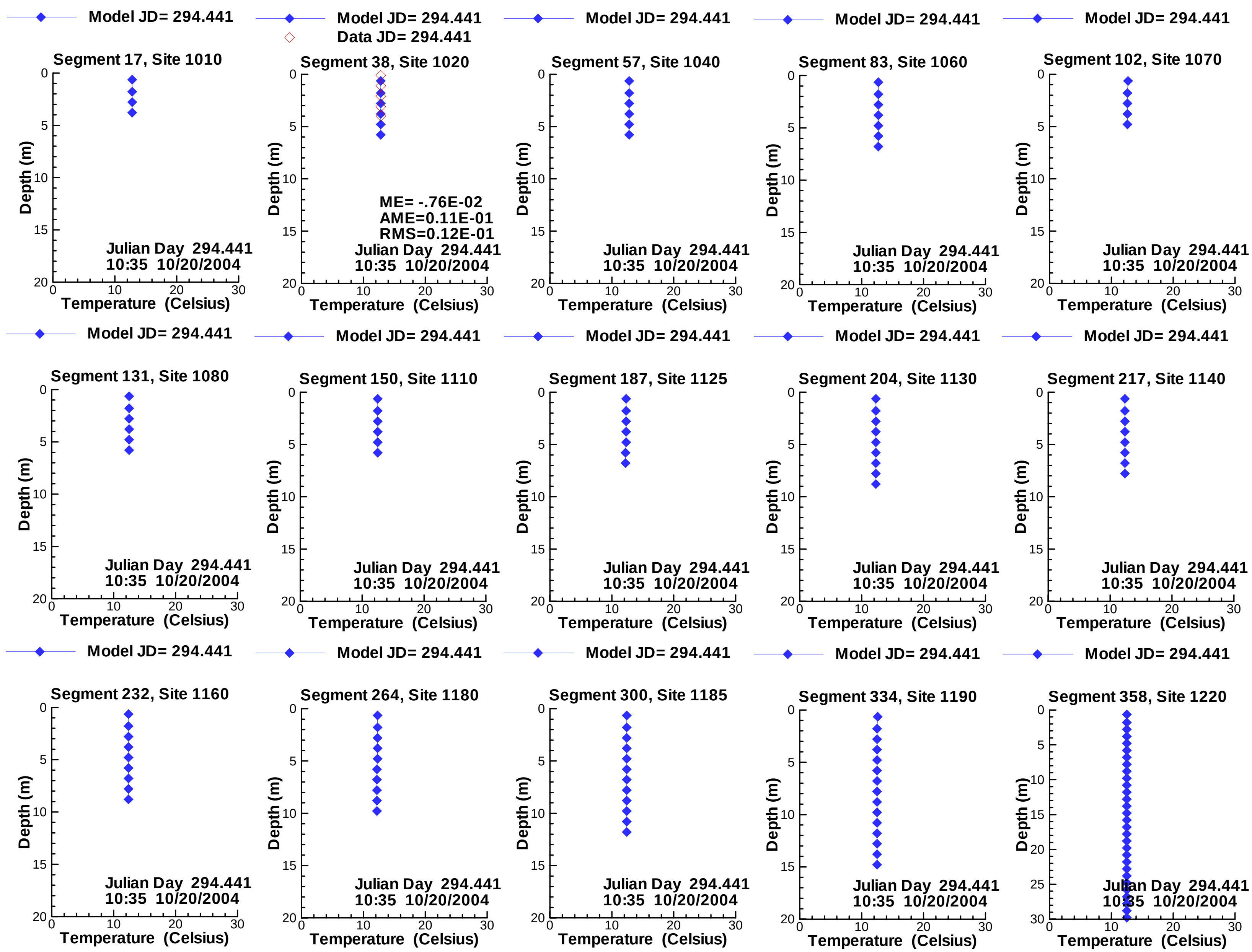

Figure 176: Vertical profiles of temperature compared with data for 10/20/2004 10:35.

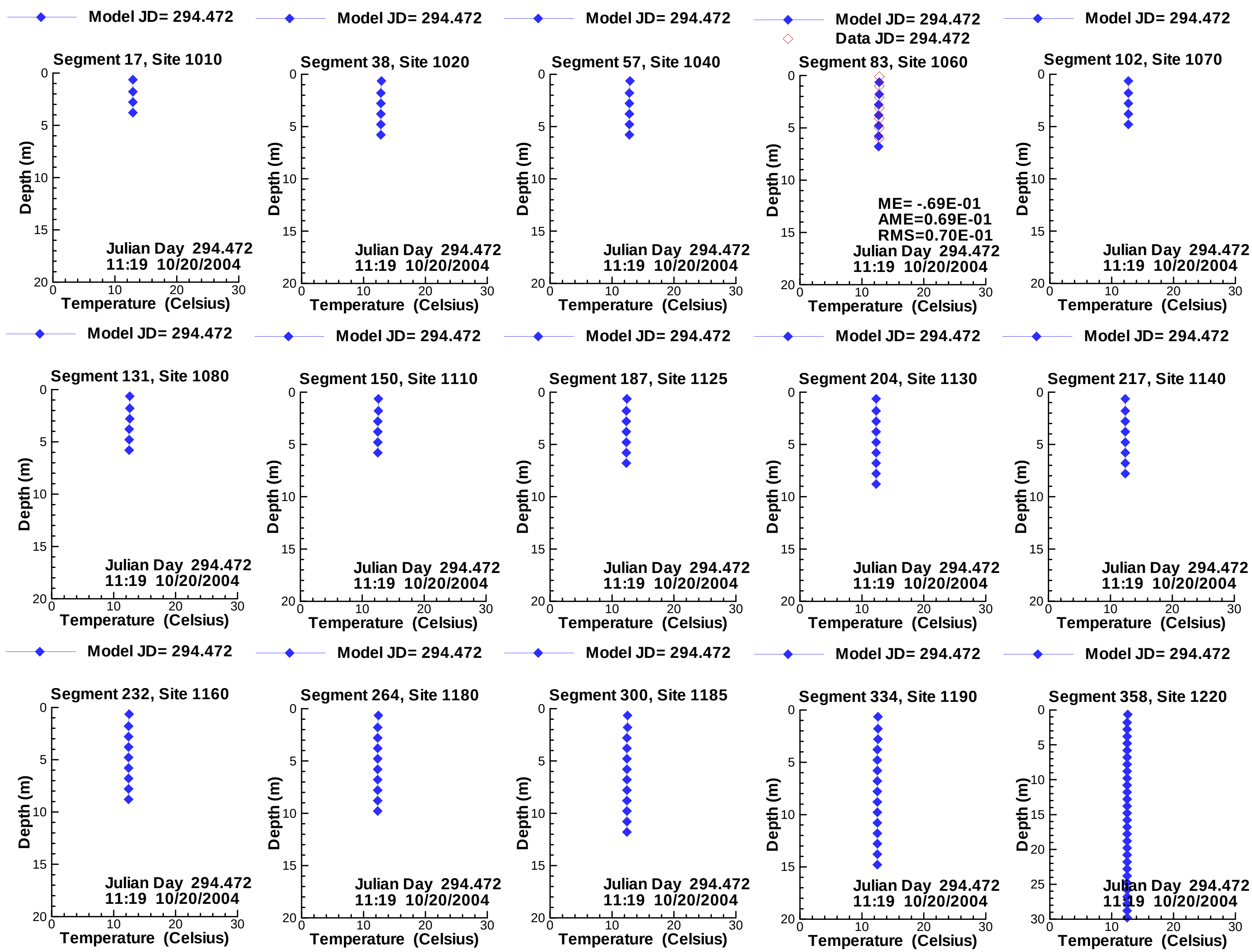

Figure 177: Vertical profiles of temperature compared with data for 10/20/2004 11:19.

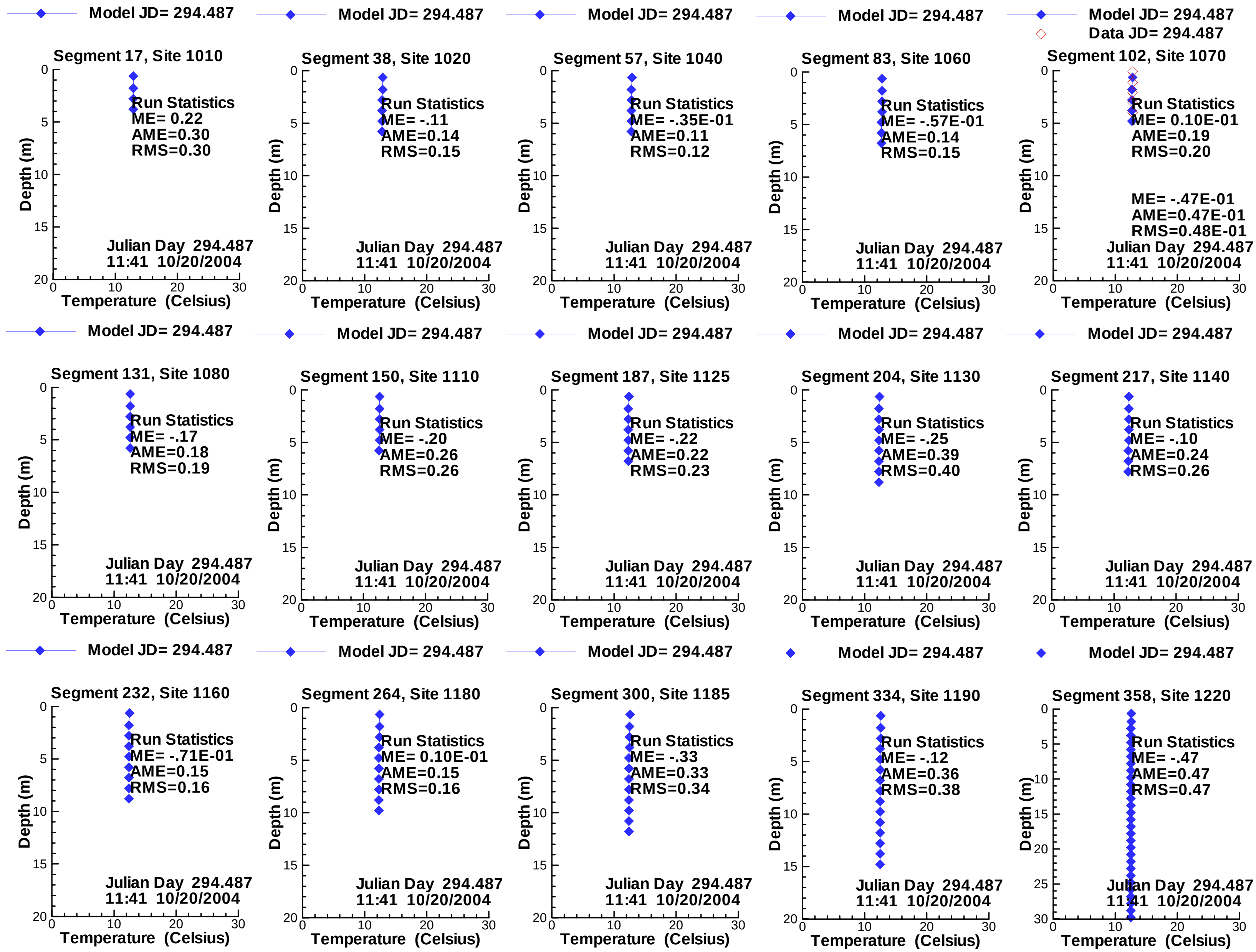

Figure 178: Vertical profiles of temperature compared with data for 10/20/2004 11:41.

Appendix C: Additional Simulations to determine model sensitivity

Additional model runs were performed to help to determine model sensitivity to calibration parameters. These simulations were described below.

Year 1997 simulation with wind sheltering of 0.85

The error statistics for a year 1997 simulation using a wind sheltering coefficient of 0.85 were listed in Table 19. Predicted temperatures are cooler than measured. The average mean error was -0.27 degrees Celsius, significantly cooler than the average mean error of -0.01 for the calibrated model.

Table 19: Year 1997 error statistics for continuous temperature data. Statistics are for simulation using a wind sheltering of 0.85.

Site ID	Model Segment	Number of Comparisons	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
POALB	3	3165	-0.001	0.009	0.012
INDA	59	3070	-0.149	0.179	0.228
SKMA	112	2461	-0.273	0.355	0.446
TACOA	152	2497	-0.261	0.388	0.486
CCAA	155	2728	-0.287	0.328	0.425
MILA	208	2711	-0.218	0.352	0.475
LCLA	219	2650	-0.453	0.48	0.612
BMATOP	333	3146	-0.527	0.549	0.682
Average			-0.271	0.330	0.421

Year 1997 simulation, shade predicted using controlling topography around the river out to a distance of 12 km

The error statistics for a year 1997 simulation using controlling topography out to a distance of 1.1 km to predict shading were listed in Table 19. Wind sheltering was set to a value of 0.3, which is the same as used in the calibrated model. Predicted temperatures were very close to those predicted in the calibrated model, which used controlling topography out to a distance of 12 km. The average mean error was 0.00 degrees Celsius, only slightly warmer than the average mean error of -0.01 of the calibrated model.

Table 20: Year 1997 error statistics for continuous temperature data. Statistics are for a simulation shade controlled by topography out to a distance of 1.1 km.

Site ID	Model Segment	Number of Comparisons	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
POALB	3	3165	0.00	0.01	0.01
INDA	59	3070	-0.06	0.14	0.17
SKMA	112	2461	-0.05	0.29	0.36

Site ID	Model Segment	Number of Comparisons	Mean Error, C	Mean Absolute Error, C	Root Mean Square Error, C
TACOA	152	2497	0.05	0.32	0.40
CCAA	155	2728	0.01	0.23	0.30
MILA	208	2711	0.19	0.34	0.42
LCLA	219	2650	-0.05	0.32	0.40
BMATOP	333	3146	-0.09	0.35	0.42
Average			0.00	0.25	0.31

Year 2004 simulation, upstream boundary condition for temperature developed using data measured at site ALFW

The upstream boundary condition for the 2004 model was initially developed using temperature data measured at site ALFW (Figure 14). This site recorded temperatures which were cooler and had greater diurnal temperature swings than nearby sites. Error statistics for a simulation using data from the site ALFW for the upstream boundary condition were shown in Table 21. The average mean absolute error was 0.40 degrees Celsius. The calibrated model, which used data from sites ALF, ALFI, and 1010 for the boundary condition, had an average mean absolute error of 0.24 degrees Celsius.

Table 21: Year 2004 error statistics for continuous temperature data. Statistics are for a simulation using temperature data from site ALFW for the upstream boundary condition.

Site ID	Model Segment	# of comparisons	Mean Error (C)	Mean Absolute Error (C)	Root Mean Square Error (C)
1010	17	4069	-0.198	0.505	0.639
1020	38	5588	-0.304	0.459	0.572
1040	57	2035	-0.252	0.384	0.485
1060	83	5589	-0.288	0.437	0.549
1070	102	5589	-0.267	0.420	0.516
1080	131	5843	-0.245	0.356	0.442
1110	150	4204	-0.245	0.465	0.550
1140	217	5548	-0.157	0.352	0.439
1160	232	5548	-0.105	0.347	0.434
1180	264	4921	-0.194	0.372	0.454
1190	334	5542	-0.181	0.372	0.457
1220	358	3589	-0.023	0.292	0.368
Average			-0.205	0.397	0.492

Appendix D: Model Parameter Values

Model calibrated parameters are shown below.

Table 22: CE-QUAL-W2 Model Parameters

Variable	Description	Units	Default 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		8.3
BETA	Fraction of incident solar radiation absorbed at the water surface		0.45	0.45
EXH20	Extinction for water	/m	0.25	0.45
WSC	Wind sheltering coefficient		0.85	0.85 for 1998 and 2004; 0.3 for 1997
* Cole and Wells (2006)				