EXHIBIT ARWA-904

Technical Memorandum 6

Lake Natoma
CE-QUAL-W2 Model and Calibration

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November 2017

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Cardno, 2017

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1.0 INTRODUCTION

A hydrodynamic and water temperature CE-QUAL-W2 model of Lake Natoma was developed to connect the Folsom Reservoir water temperature modeling (Technical Memorandum 5 Folsom Reservoir CE-QUAL-W2 Temperature Model Report) to the Lower American River. Since the American River water temperature objectives are typically set at Watt Avenue on the American River, it is necessary to either use a regression model (see Technical Memorandum 9 Lower American River Water Temperature Regression Relationships) or a hydrodynamic temperature model(s) to translate water temperature from Folsom Dam through Lake Natoma and the Lower American River to Watt Avenue (or other locations on the river). Here we report the development and calibration of the Lake Natoma model.

2.0 MODEL DEVELOPMENT

2.1 MODEL BATHYMETRY AND GRID

Topographic transect data for Lake Natoma were collected by CBEC, Inc.[1] A total of 34 transects were collected. The locations of the transects ranged from 1,700 feet downstream of Folsom Dam to within a few feet of Nimbus Dam. Figure 1 shows the location of each of the collected transects in dark blue superimposed on a DEM of the surrounding topography. Each of the 34 transects were made the center of a model grid segment for the Lake Natoma CE-QUAL-W2 model. The length of each segment varied from between 315 ft. (96 m) and 1529 ft. (466 m). The location and number of each segment is shown in Figure 2. A side view of the centerline elevation of the reservoir is shown in Figure 3.

The volume-elevation curve of the model grid was compared to the volume-elevation curve derived from CDEC (reported storage and elevation data) and the volume-elevation curve of a previous US Bureau of Reclamation (Reclamation) CE-QUAL-W2 model of the same system (Bender et al. 2007). A plot of these curves is shown in Figure 4. The new CE-QUAL-W2 curve generally matched the other curves.

2.2 MODEL OUTLET STRUCTURES

The Nimbus Dam outlets consist of three structures: the power generation intake; the spillways; and the fish hatchery withdrawal. The structure type, width/diameter, and elevation of each of these outlet structures are summarized in Table 1.

[1] Data provided by Chris Hammersmark (CBEC, Inc.) to Sacramento Water Forum

3.0 MODEL DATA

3.1 METEOROLOGICAL DATA

The meteorological (MET) data required for the Lake Natoma water temperature modeling included the following parameters: air temperature; dew point temperature; wind speed and direction; cloud cover; and solar radiation. These data were obtained from the nearby Fair Oaks CIMIS station, with the exception of cloud cover, which was obtained from Mather Air Force Base. For a complete summary of the data and full details on the data collection sites, please see Technical Memorandum 5 Folsom Reservoir CE-QUAL-W2 Temperature Model Report and Technical Memorandum 8 Historical 1922-2003 Meteorological Dataset (Folsom Reservoir Lake Natoma and Lower American River).

3.2 BOUNDARY CONDITION DATA

3.2.1 Inflow and Outflow

Upstream inflow rates to Lake Natoma were obtained from the CDEC American River below Folsom Dam (FOL) gage, which includes hourly flow out of Folsom Reservoir into the Lower American River as shown in Figure 5. The corresponding outflow from Nimbus Dam was available from CDEC stations Lake Natoma – Nimbus Dam (NAT) and Folsom South Canal (FSC). Outflow from Nimbus Dam is split between the outlet structures described in the proceeding section. The outflow rates for each of these structures for the calibration period are plotted in Figure 6. The FSC was the only other withdrawal from Lake Natoma. It was modeled as a side withdrawal from segment 33. The volume of water withdrawn during the calibration period is plotted in Figure 7.

When the total inflow and outflow from the Lake Natoma were compared, there were times when the two did not balance given the observed change in water surface elevation (WSE). Likely this was related to gage error or gage timing. In order to compensate for these data discrepancies, the hourly inflow data were put through a pre-processor that adjusted the inflow amount when necessary in order for the model not to “dry up”, and to meet the observed WSE. A spillway/gate was also used to ensure WSE levels did not exceed measured data. The overall flow impact was less than 6% of measured flows. The WSE was fairly stable throughout the calibration period and generally varied between 120 and 125 ft.

4.0 MODEL CALIBRATION

4.1 TEMPERATURE CALIBRATION DATA

4.1.1 Lake Profiles

Daily water temperature profiles from Lake Natoma near Nimbus Dam were collected for four periods during the calibration period: 7/18/2001 – 10/08/2001, 3/29/2002 - 6/19/2002,

3/28/2003 – 5/28/2003, and 7/10/2003-11/13/2003. These data profiles were obtained from a previous modeling effort by Reclamation (Bender et al. 2007). The details of the source of these data were not indicated in the Reclamation documentation.

4.1.2 Downstream American River Temperature Time-series

Two water temperature time series data sets were available online for the location immediately downstream of Nimbus Dam (USGS 11446500 American River at Fair Oaks and CDEC AHZ American River at Hazel Ave Bridge). These are, it appears, from the same USGS sensor, but the data were frequently different. There is also confusion both on the USGS website and the CDEC website regarding the location of the sensor. Based on information from Michael Hedgpeth[2], USGS technician currently responsible for operating the American River temperature probes, the current location of the sensor is immediately downstream of the Hazel Avenue Bridge on river right shown in Figure 8. Historically, prior to May 10, 2001, the sensor was 1,000 feet farther downstream (note: this is the location presently shown on the USGS website, but is in error now that the sensor has been moved) (Figure 8).

The water temperature data from the USGS and CDEC "stations" for some periods differed significantly indicating some type of instrument or recording bias. It was often not possible to identify which of the stations was in error. The periods of concern for the USGS data are circled in light blue in Figure 9 (e.g., excessive daily variability). They were not included when calculating model vs. data error statistics. On various other occasions the two data sets also differed significantly in temperature. These periods are circled in black in Figure 9.

4.2 CALIBRATION PROCEDURE

Minimal water temperature calibration was necessary in order to achieve fairly tight model versus data agreement. It was determined that wind data from the Fair Oaks CIMIS station provided much better results than the higher wind speed data collected close to Folsom Reservoir, which had been used for the Folsom CE-QUAL-W2 model. This is a reasonable conclusion given the close proximity of the Fair Oaks station to Natoma Lake and the sheltered nature of much of the lake.

It was found that the default values for model heat exchange coefficients resulted in the best model-data agreement.

[2] Data provided by Michael Hedgpeth (USGS) by email to Craig Addley (Cardno) on 3/4/2015

5.0 MODEL RESULTS

5.1 WATER TEMPERATURE PROFILES

Model results were compared to water temperature profiles collected near Nimbus Dam. The exact time the profiles were collected is not known, so for comparison purposes it was assumed to be at mid-day (note: this could interject significant error as Lake Natoma and flows into Lake Natoma are very dynamic within a day). The mean error for the temperature profiles is 0.61^{o}F (0.34^{o}C) and the absolute mean error is 0.97^{o}F (0.54^{o}C). Attachment A contains a full visual comparison of each of the water temperature profiles that were collected during the model calibration period. The final error statistics are summarized in Table 2.

5.2 DOWNSTREAM TIME SERIES TEMPERATURE

A comparison of water temperature data collected at the USGS/CDEC temperature "stations" downstream of Nimbus Dam is shown in Figure 10. The model versus data error statistics for each are summarized in Table 3.

The negative mean error indicates a slight negative bias; however, when looking at the data, it becomes apparent that this occurs only during the winter months, and does not impact summer water temperatures. The low bias during cold months is a known issue with the CE-QUAL-W2 modeling platform and can be reduced by selectively decreasing evaporation (and hence heat loss) during the colder months. This time dependent evaporative heat loss capability has not yet be included in CE-QUAL-W2, but will likely be added to the next version of the code. For this modeling application the evaporative heat loss coefficient was constant.

Winter temperatures in some years (2003, 2004, 2006, 2007, 2008) are consistently about half a degree cooler than recorded temperatures at USGS 11446500 or CDEC AHZ. During other years (2001, 2002, 2005), the winter temperatures appear to line up well with recorded data. This indicates an issue with boundary conditions rather than a systematic model bias. It was also observed that when the Folsom Dam river outlet was in use, the upstream temperature gage would register a colder temperature than would be consistent with a fully mixed stream (river outlet pulse powerhouse flows fully mixed). The gage, located on the same side of the stream as the river outlet flows would enter the stream, potentially could have been preferentially registering the river outlet temperatures. This would explain why the model is under-predicting downstream temperatures during these river outlet flow events.

6.0 CONCLUSION

A fully calibrated CE-QUAL-W2 model of Lake Natoma was developed to link outflow from Folsom Reservoir to the American River from Nimbus Dam. The Lake Natoma model was calibrated for water surface elevation and temperature. The water temperature results showed close model

versus data agreement, with a temperature profile absolute mean error of 0.97°F and an average time-series absolute mean error of about 0.7 °F.

7.0 REFERENCES

Bender, M., Kubitschek, J., and T. Vermeyen. 2007. Temperature Modeling of Folsom Lake, Lake Natoma, and the Lower American River, Special Report. Prepared for U. S. Bureau of Reclamation, Sacramento County, California.

8.0 TABLES

Table 1. Summary of Outlet Structures for Nimbus Dam.

Structure Name	Structure Type	Elevation	Width/Diameter
Power Generation Intake	Weir	107 ft. (32.61m)	82 ft. (25 m)
Spillways	Weir	103.4 ft. (31.52m)	656 ft. (200m)
Hatchery Withdrawal	Pipe	109.5 ft. (33.38m)	5 ft. (1.52m)

Table 2. Temperature Profile Error Statistics.

Location	Mean Error	Absolute Mean Error	Root Mean Squared Error	# of Profiles	Number of Measurements
Segment 34	0.61°F (0.34°C)	0.97°F (0.54°C)	1.47°F (0.81°C)	308	2820

Table 3. Temperature Time Series Error Statistics.

Location	Mean Error	Absolute Mean Error	Root Mean Squared Error	Number of Measurements
Hazel Ave (AHZ)	-0.30°F (-0.16°C)	0.73°F (0.40°C)	0.93°F (0.51°C)	324138
Fair Oaks (AFO)	0.41°F (-0.22°C)	0.69°F (0.38°C)	0.87°F (0.48°C)	268457

9.0 FIGURES

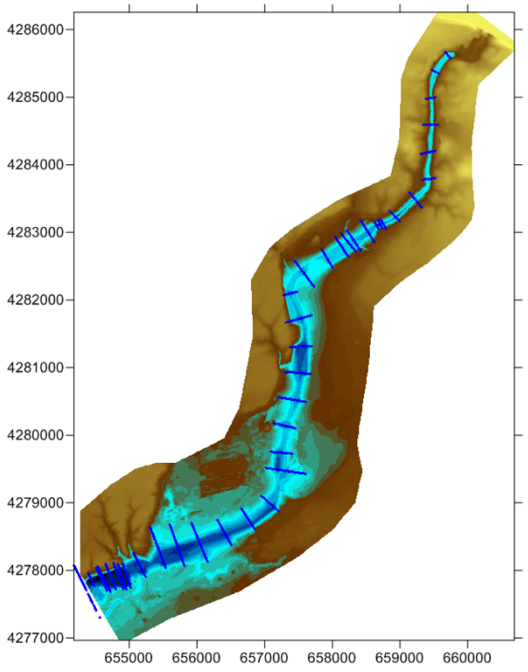


Figure 1. Natoma Lake Transects and Surrounding Topography.

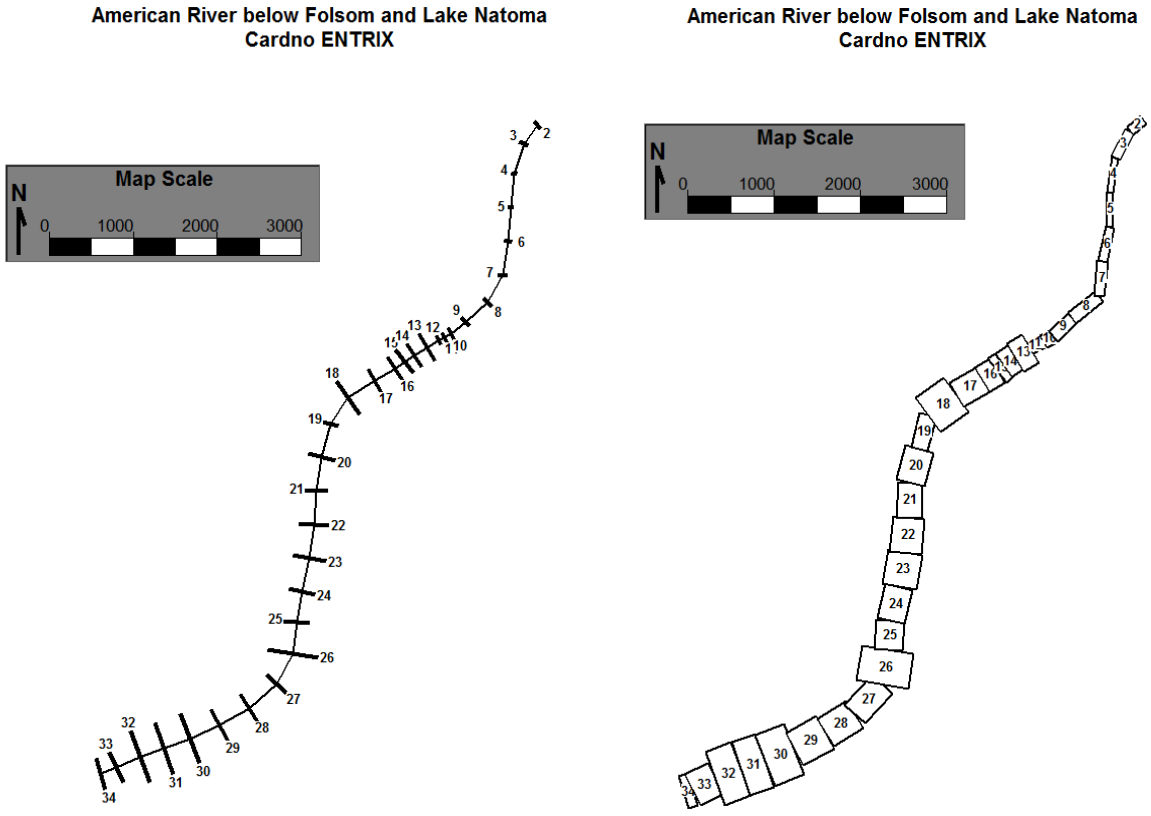


Figure 2. Lake Natoma Model Grid Top View.

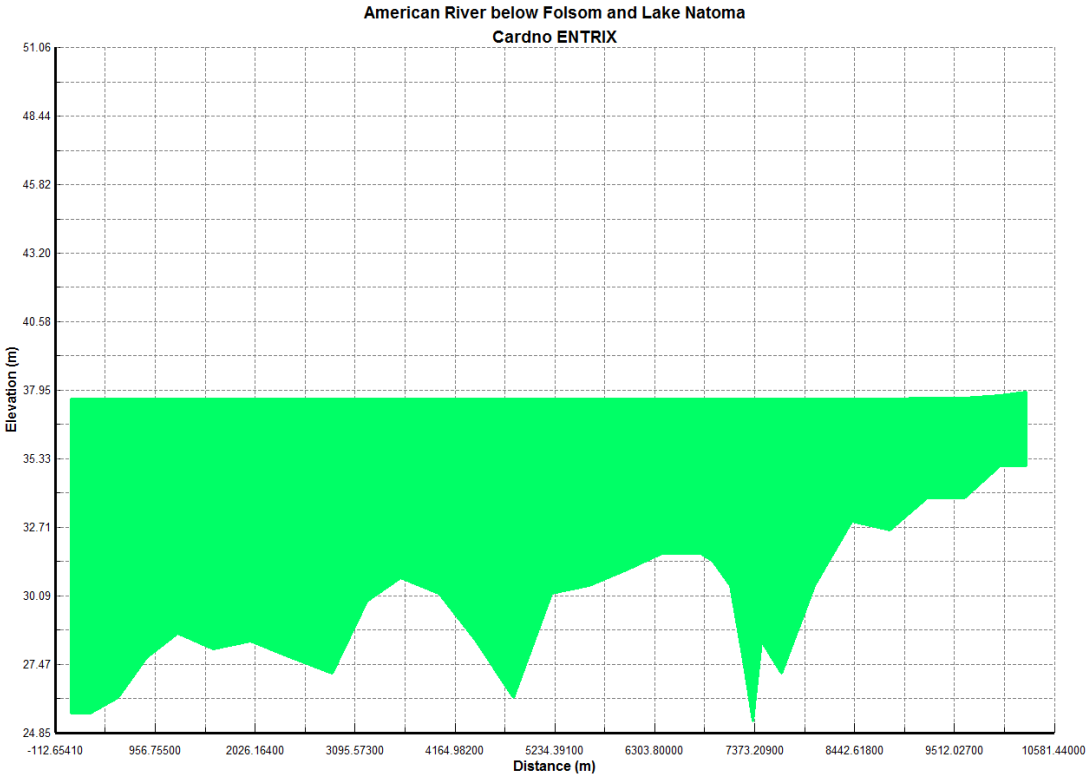


Figure 3. Lake Natoma Model Grid Side View.

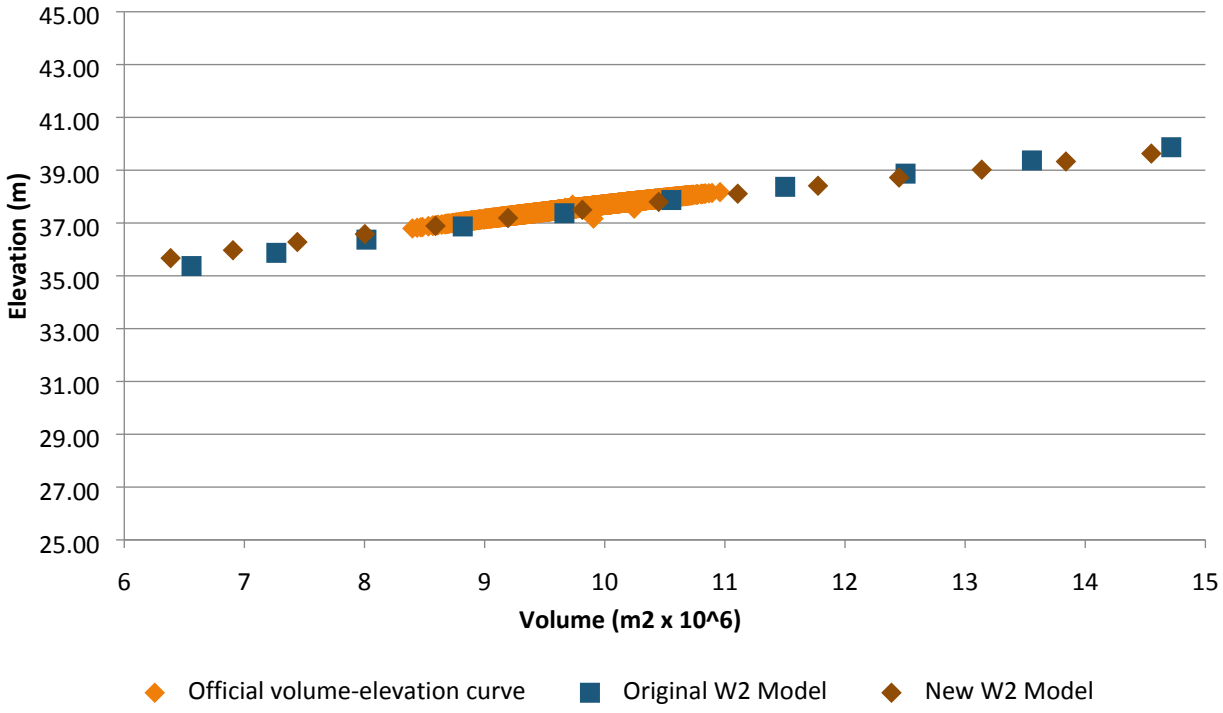


Figure 4. CE-QUAL-W2 Model Grid Volume-Elevation Curve vs. Official Volume-Elevation Curve.

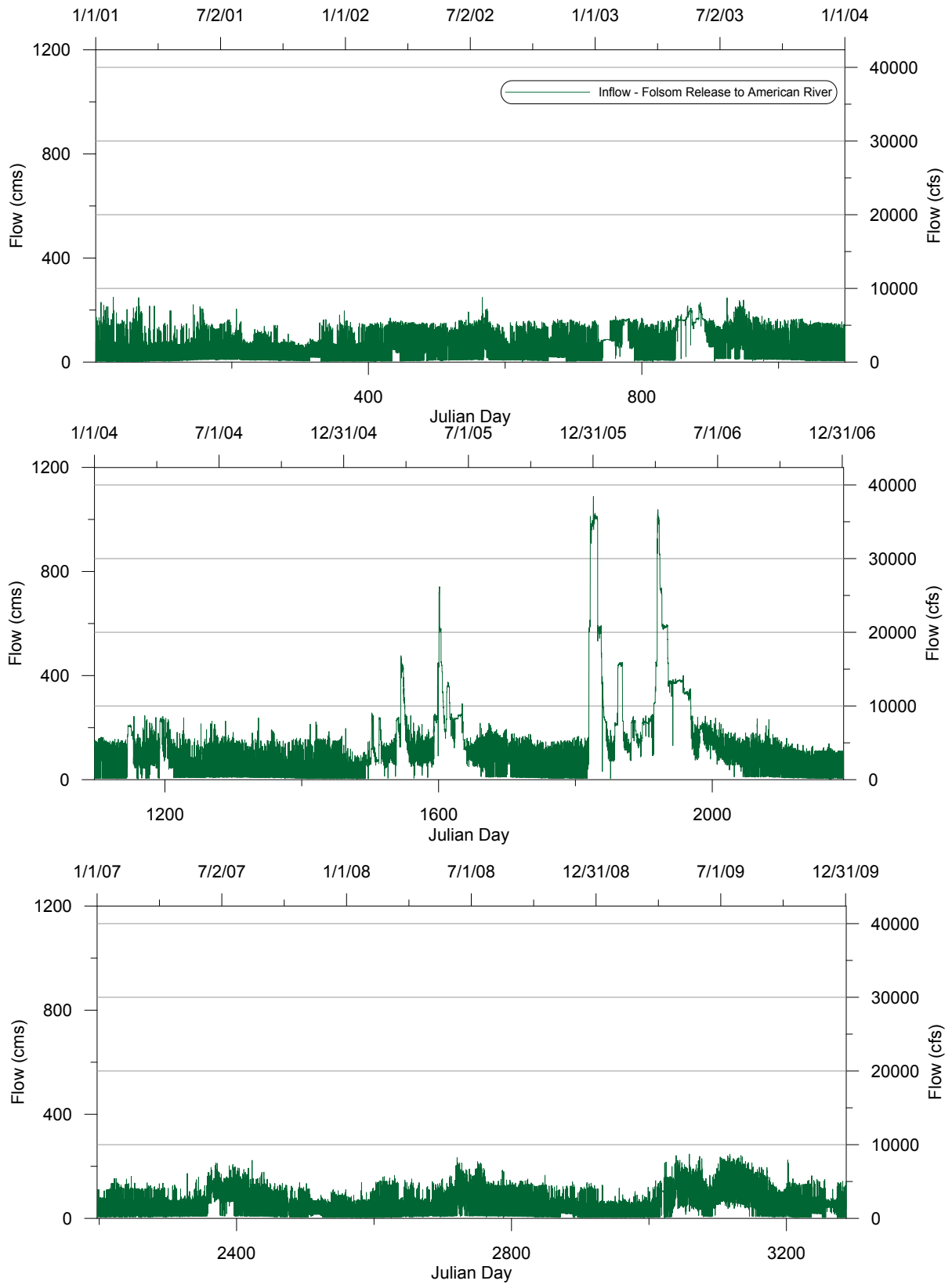


Figure 5. Inflow into Lake Natoma (2001-2009).

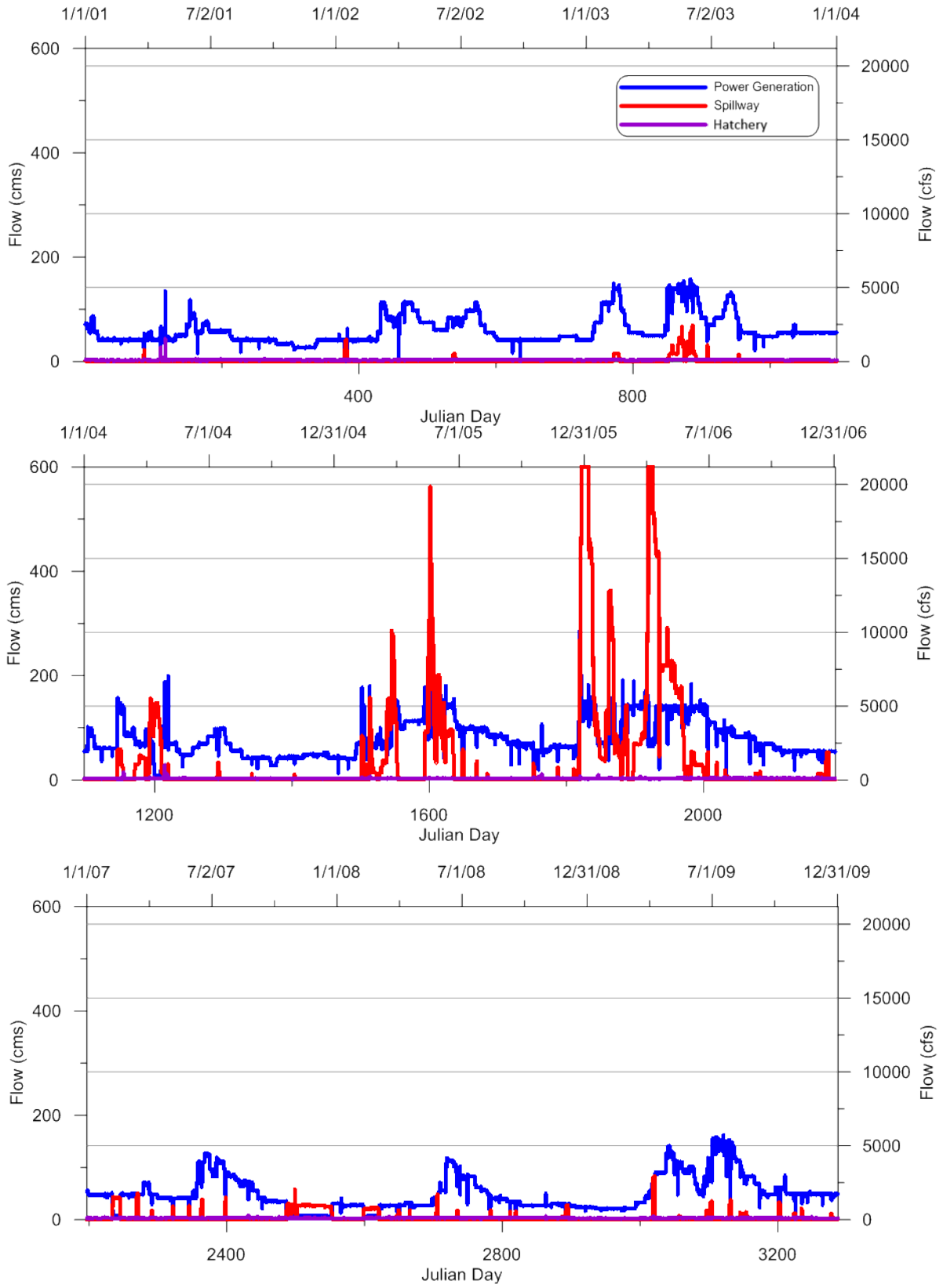


Figure 6. Outflows from Lake Natoma (2001-2009).

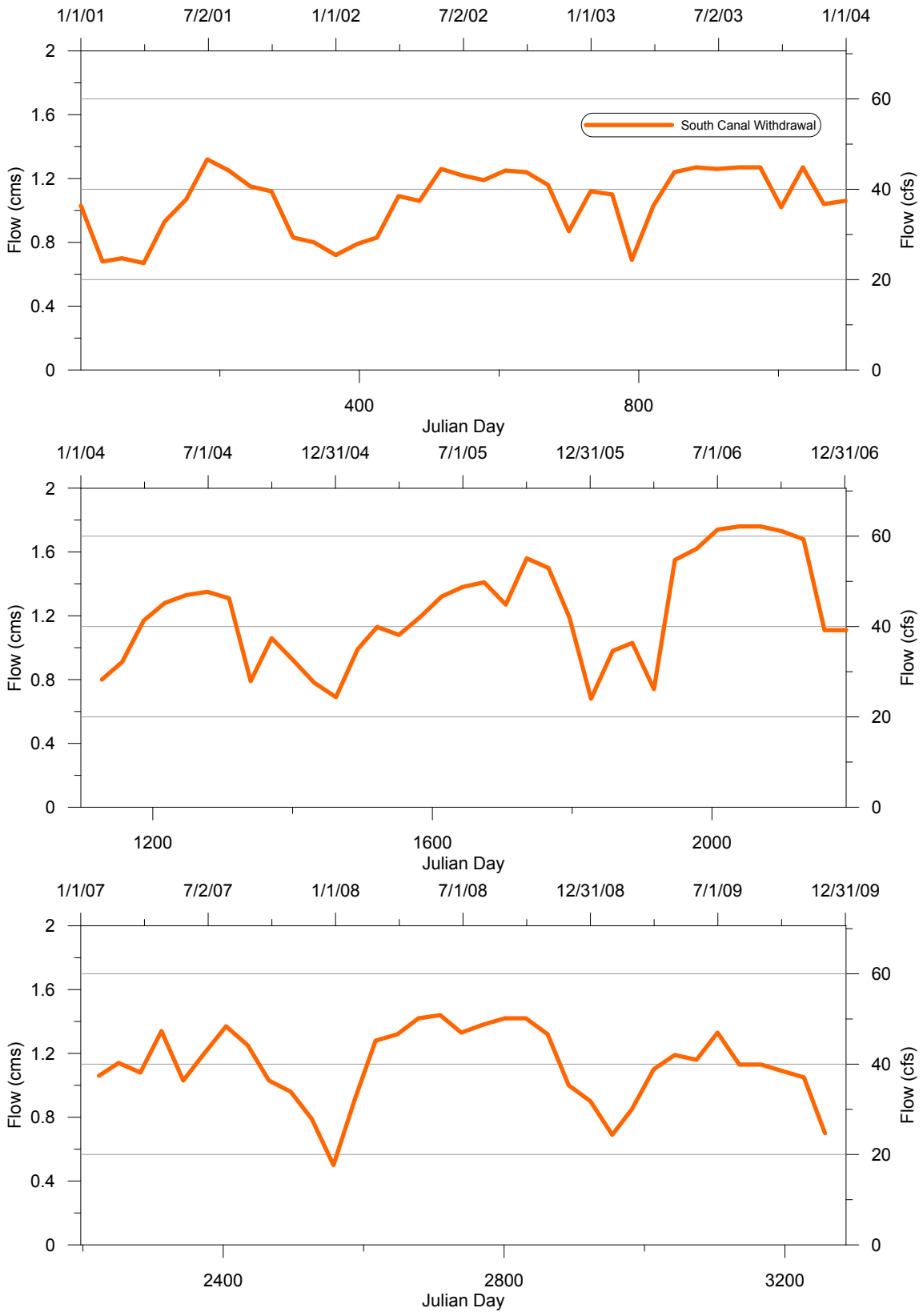


Figure 7. South Canal Withdrawals (2001-2009).

Figure 8. Current Location Map of the USGS 11446500 Temperature Gage Immediately Downstream of the Hazel Ave Bridge (triangle leader). This is also the current location of the CDEC AHZ and AFO "gages", although the CDEC website shows the AHZ gage as being upstream of the bridge). Prior to May 10, 2001 the sensor was 1,000 ft downstream (small orange dot). Source; Michael Hedgpeth, USGS, March 4, 2015 email to Craig Addley.

Source: http://cdec.water.ca.gov/cdecstation/

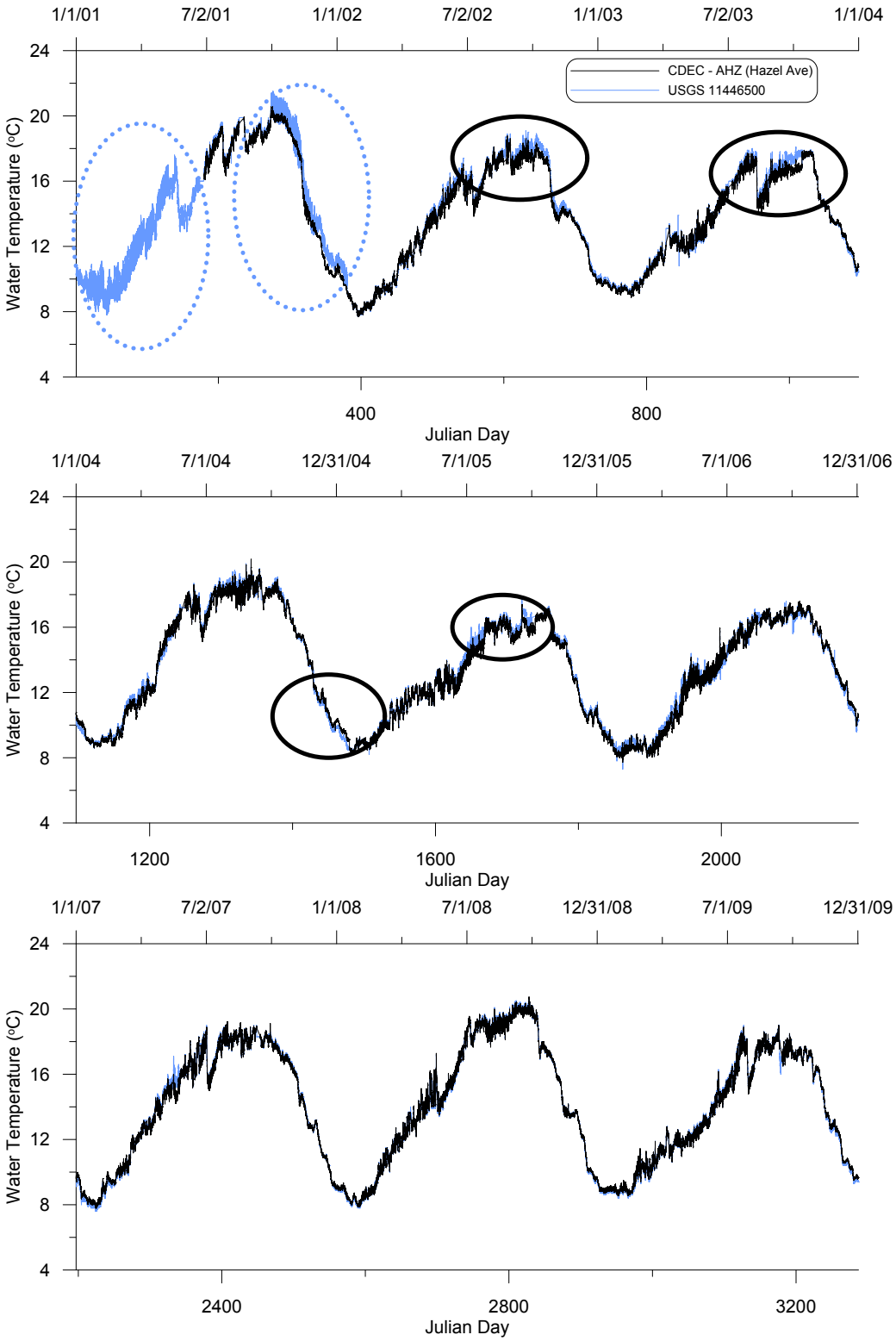


Figure 9. Comparison of the Recorded Temperature data for the USGS 11446500 and CDEC AHZ Stations. Blue Circled Data Indicate Questionable Data (high variability) and Black Circled Data Indicate Differences in the Data.

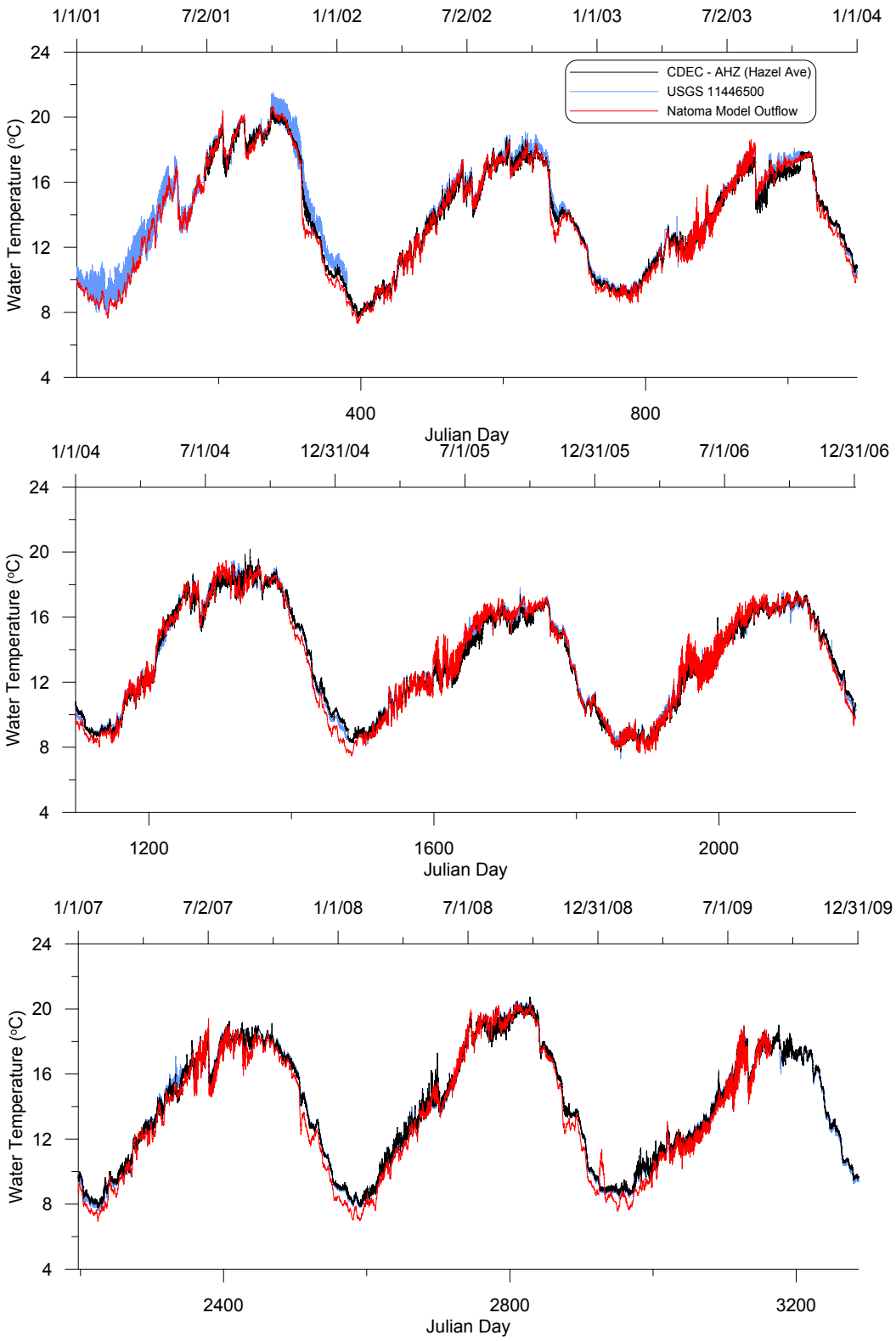
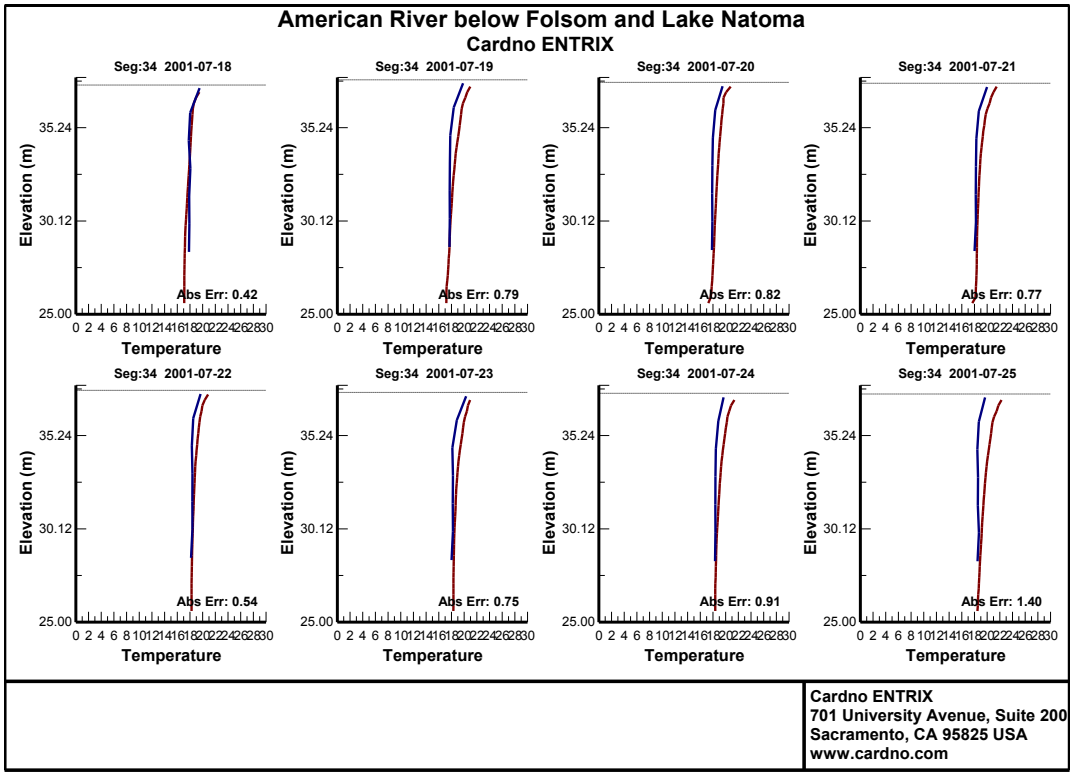


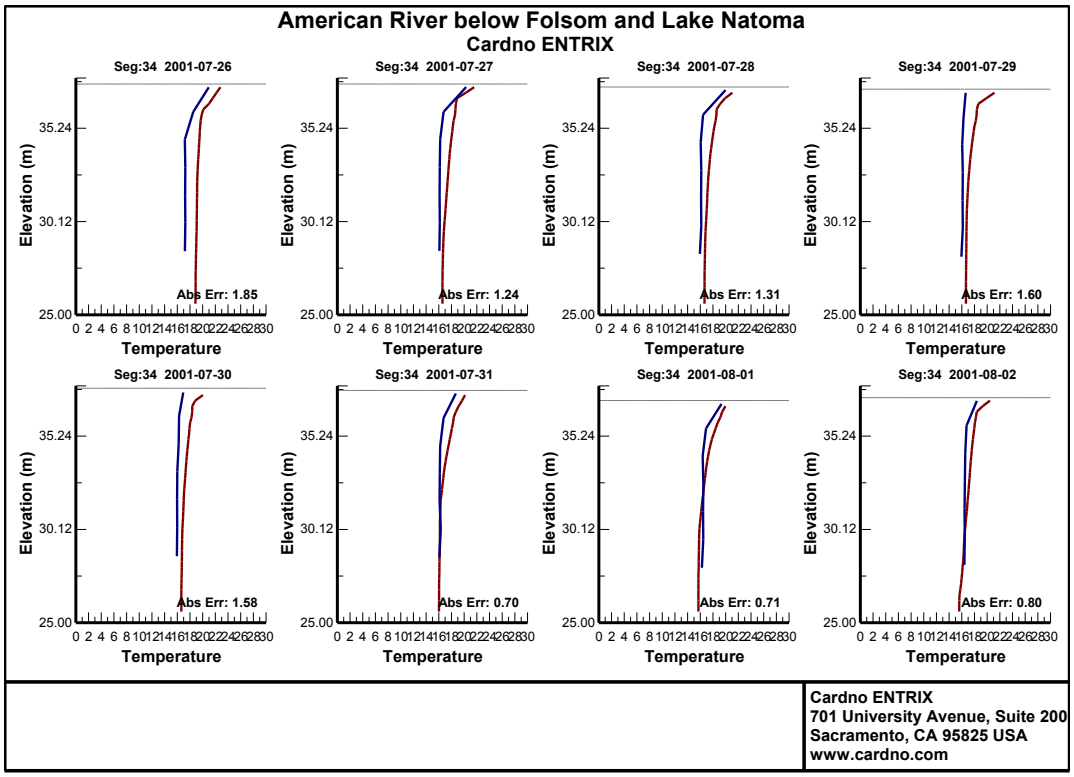
Figure 10. Lake Natoma Outflow Model vs. Data Comparison.

TECHNICAL MEMORANDUM 6 ATTACHMENT A

Model vs. Data Comparison

The following graphs show model vs. data comparison temperature profiles for Lake Natoma for all available periods with recorded data during the 2001-2009 calibration period. These data cover parts of 2001, 2002 and 2003. The red line shows model results at segment 34 and the blue line shows measured profiles close to Nimbus Dam.




American River below Folsom and Lake Natoma
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Abs Err: 1.85
Seg:34 2001-07-27
Abs Err: 1.24
Seg:34 2001-07-28
Abs Err: 1.31
Seg:34 2001-07-29
Abs Err: 1.60
Seg:34 2001-07-30
Abs Err: 1.58
Seg:34 2001-07-31
Abs Err: 0.70
Seg:34 2001-08-01
Abs Err: 0.71
Seg:34 2001-08-02
Abs Err: 0.80
Elevation (m)
35.24
30.12
25.00
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Temperature
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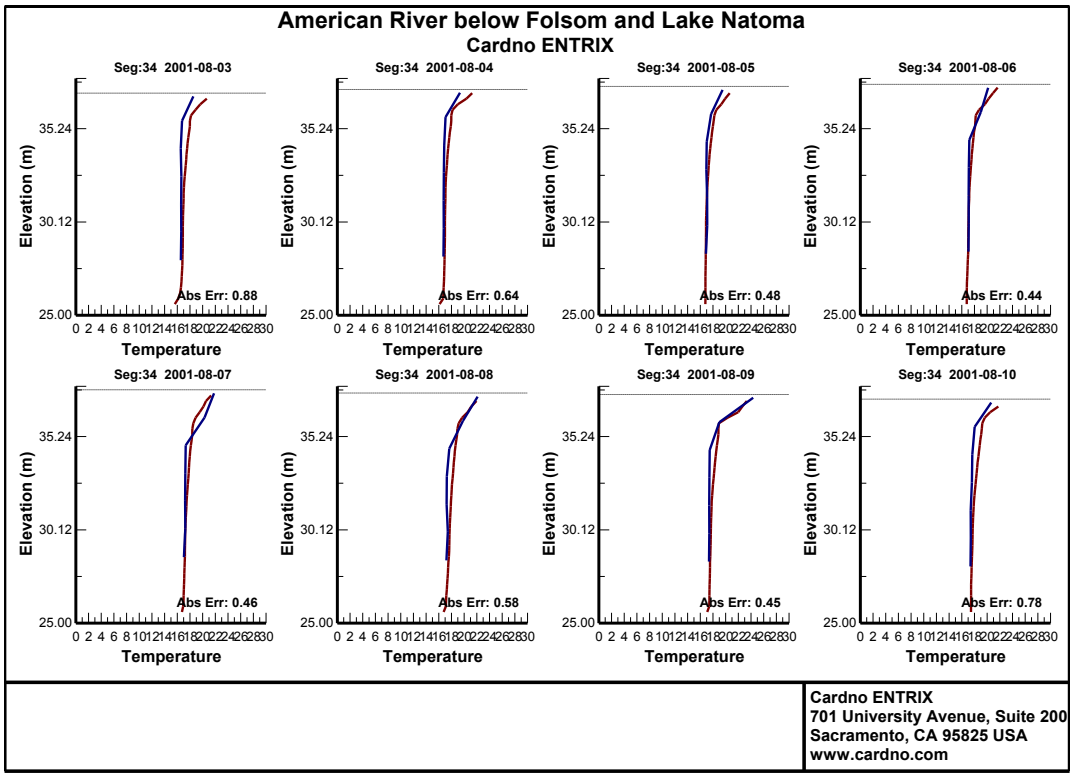
701 University Avenue, Suite 200
Sacramento, CA 95825 USA
www.cardno.com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Seg:34 2001-08-07
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Seg:34 2001-08-09
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Elevation (m)
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30.12
25.00
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Temperature
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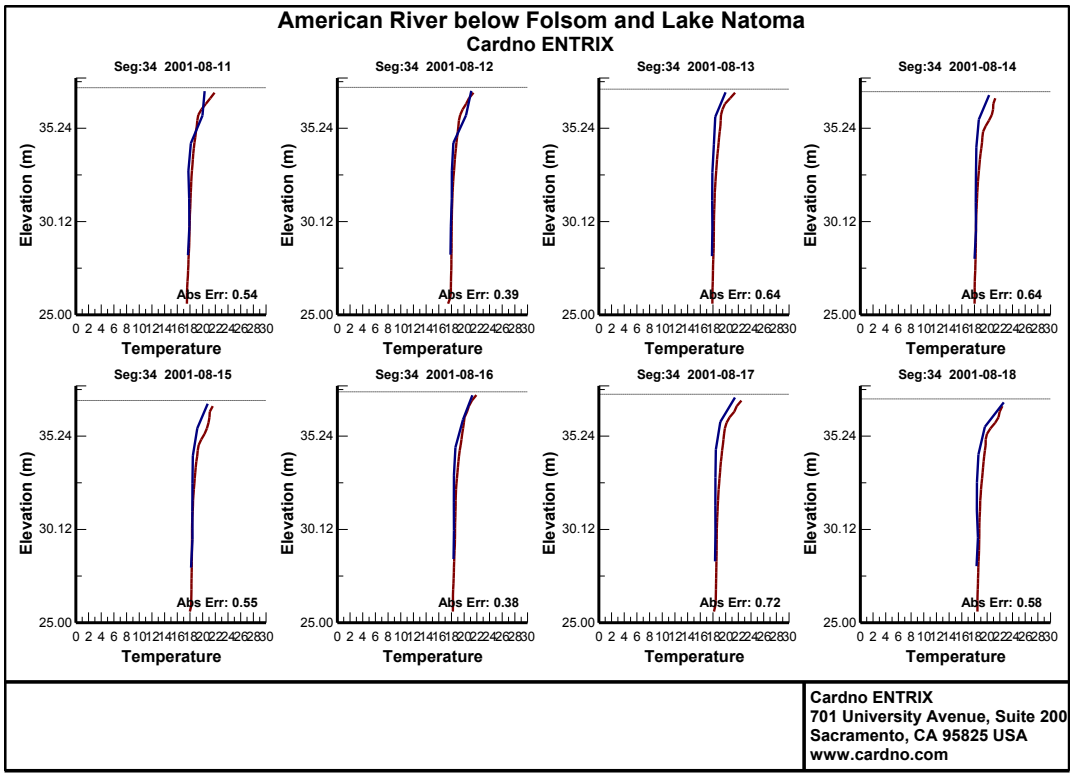
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Elevation (m)
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30.12
25.00
Temperature
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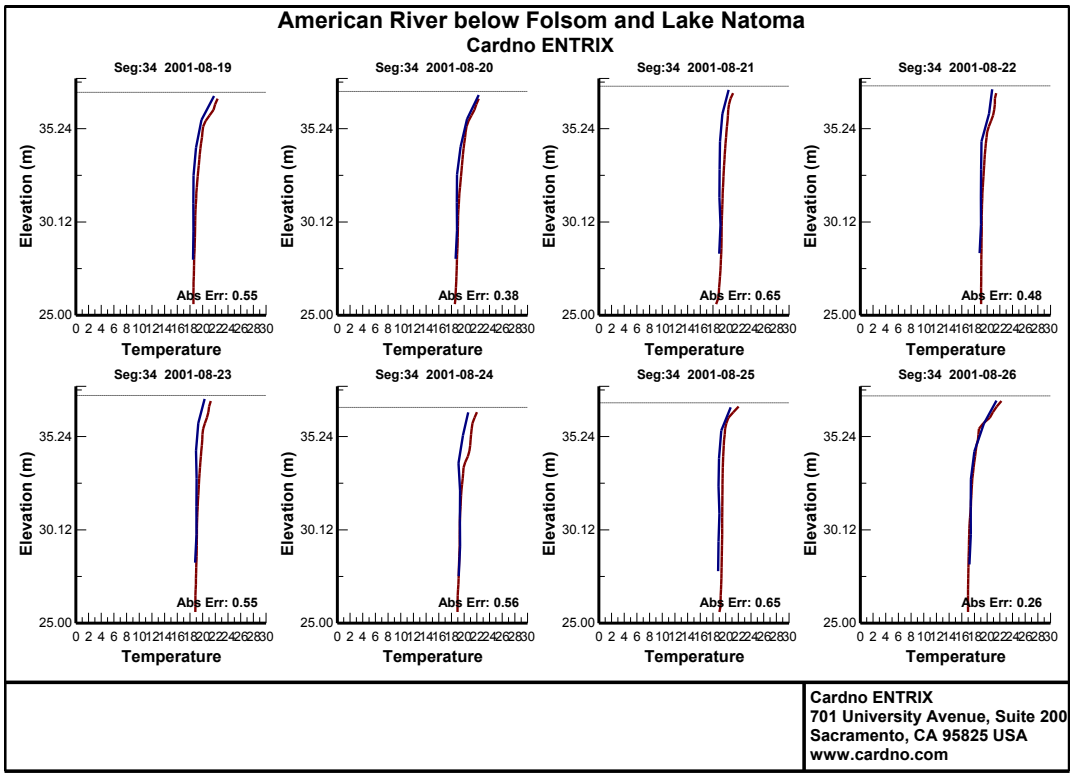
American River below Folsom and Lake Natoma
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30.12
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Temperature
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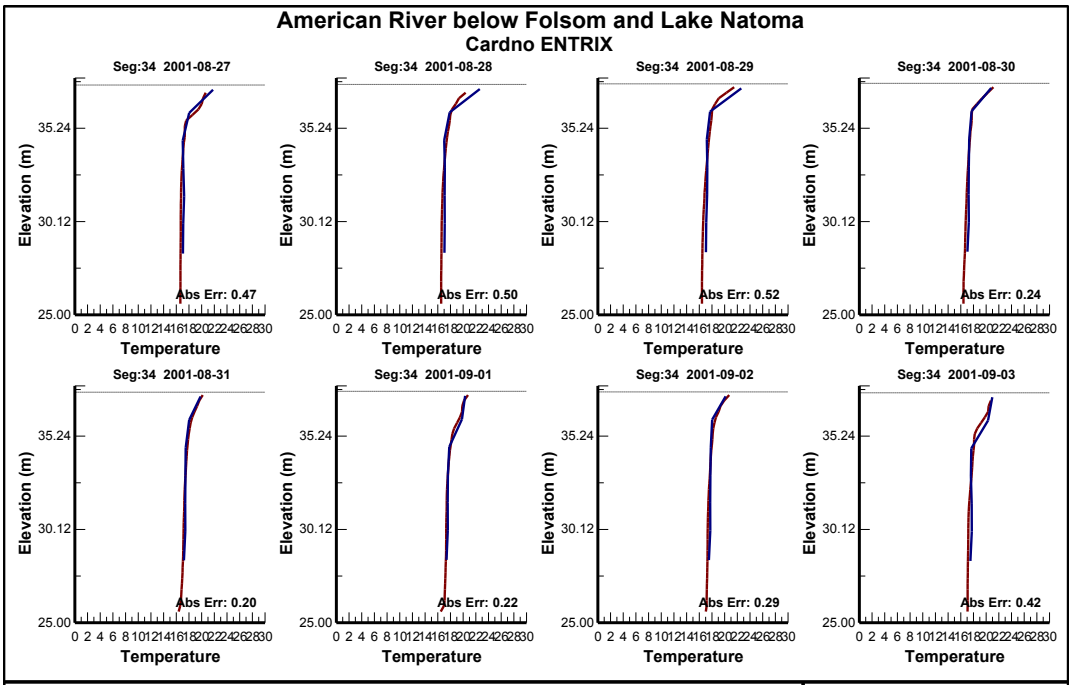

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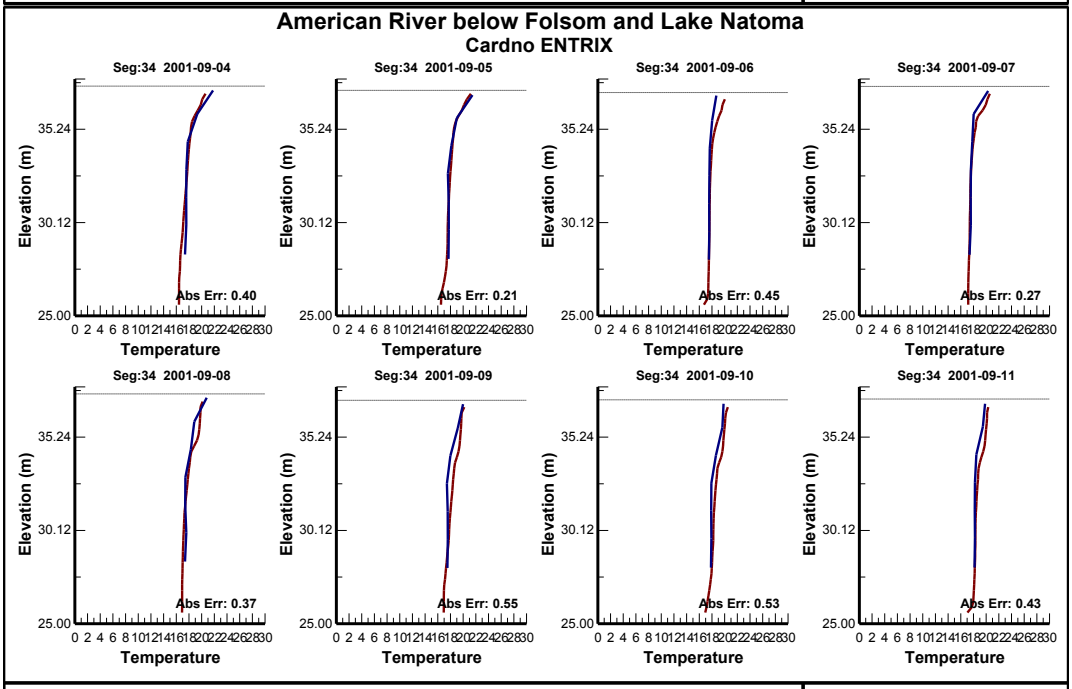

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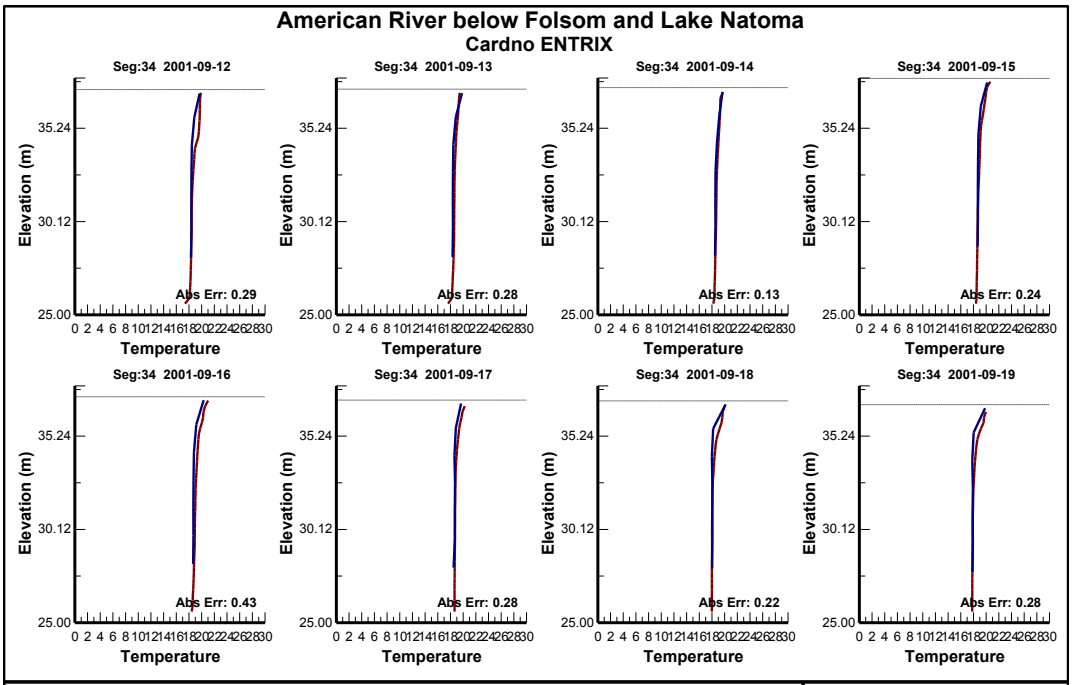

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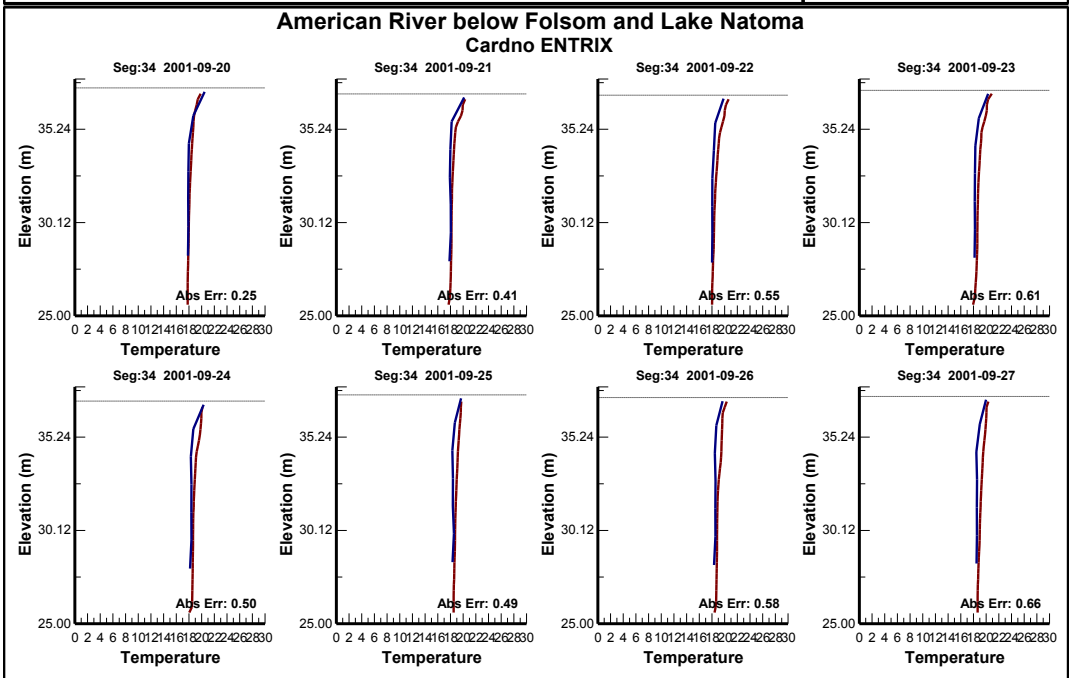

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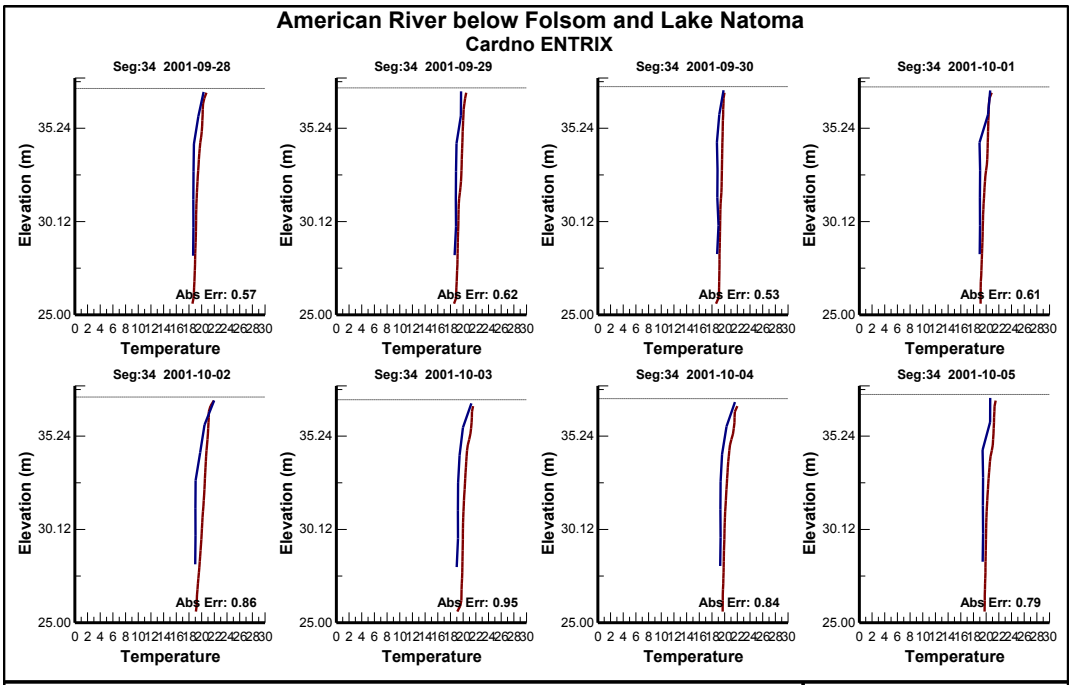

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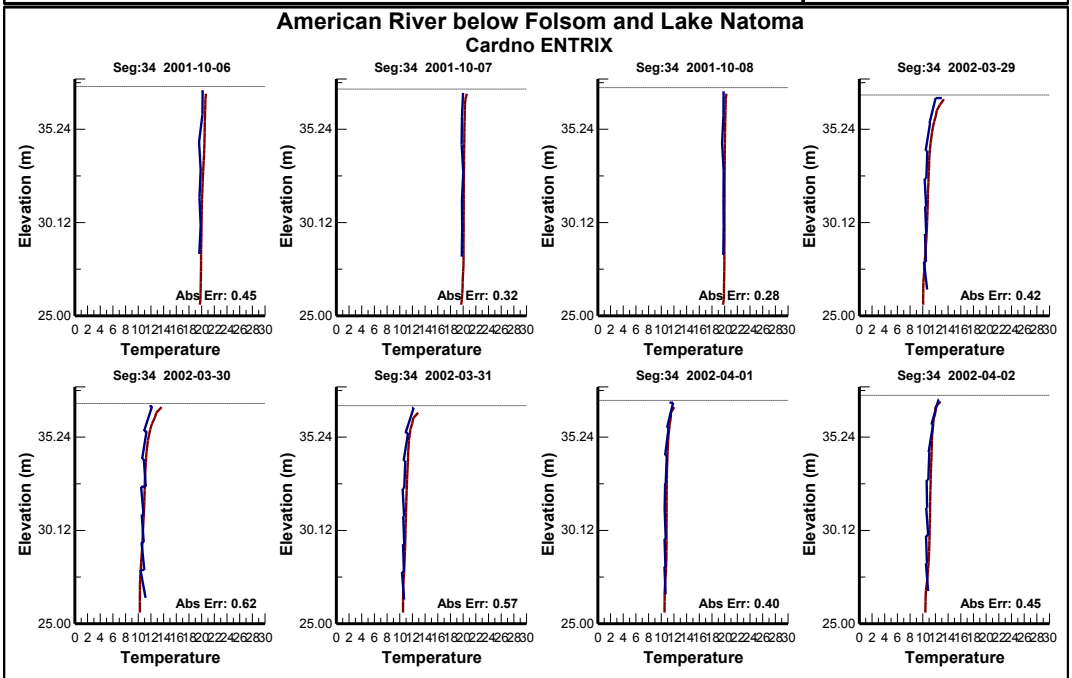

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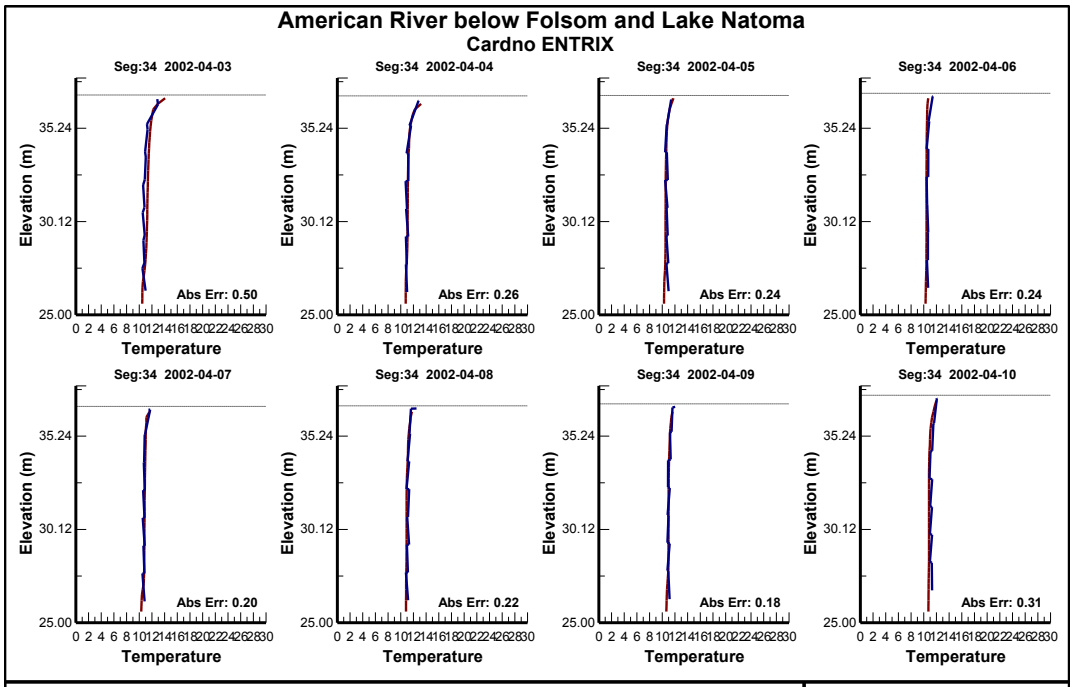

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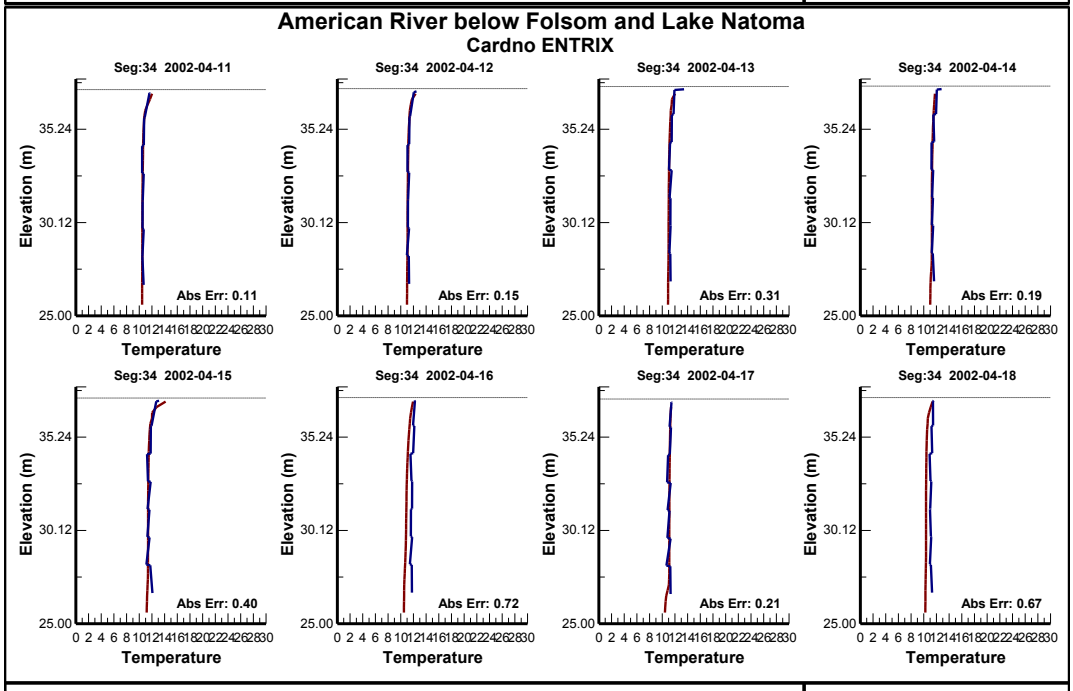

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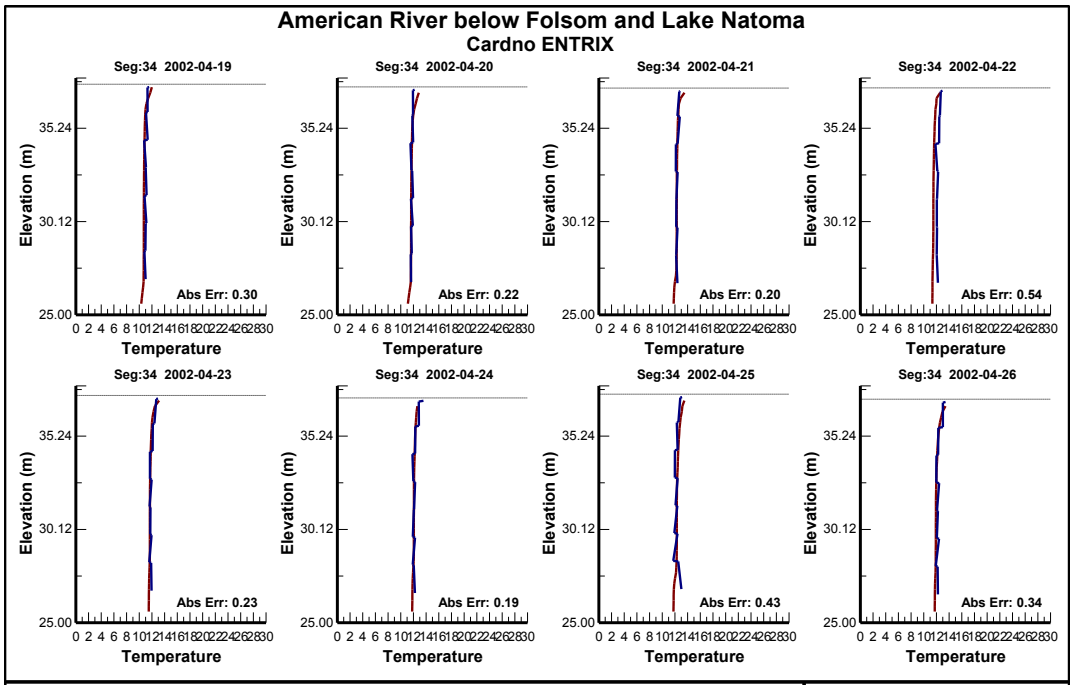

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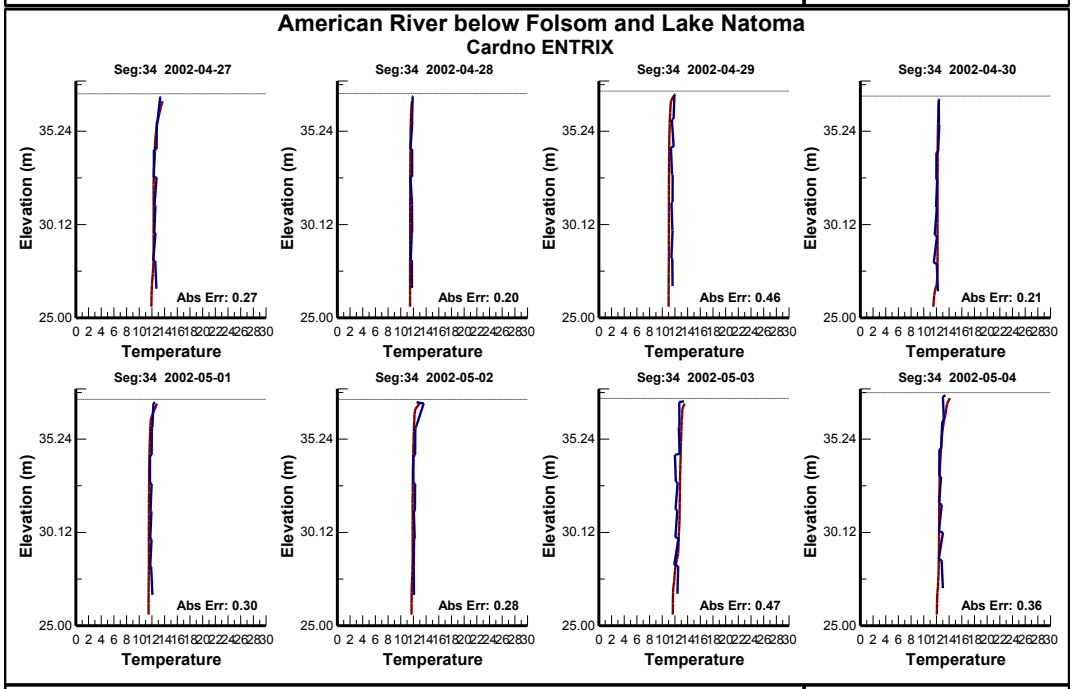

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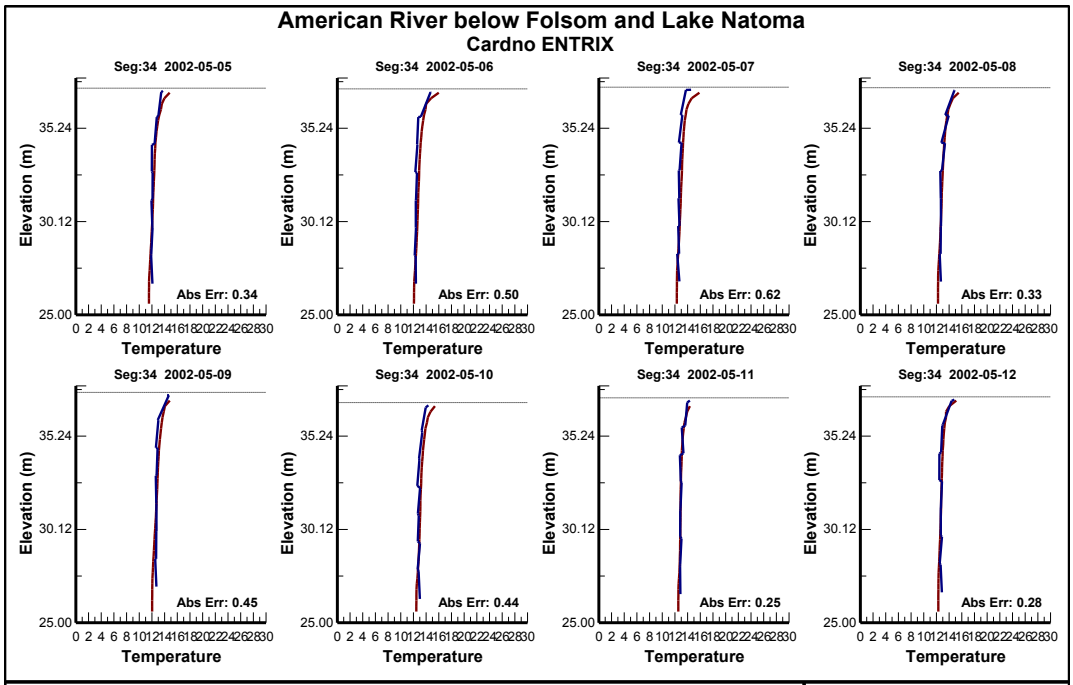

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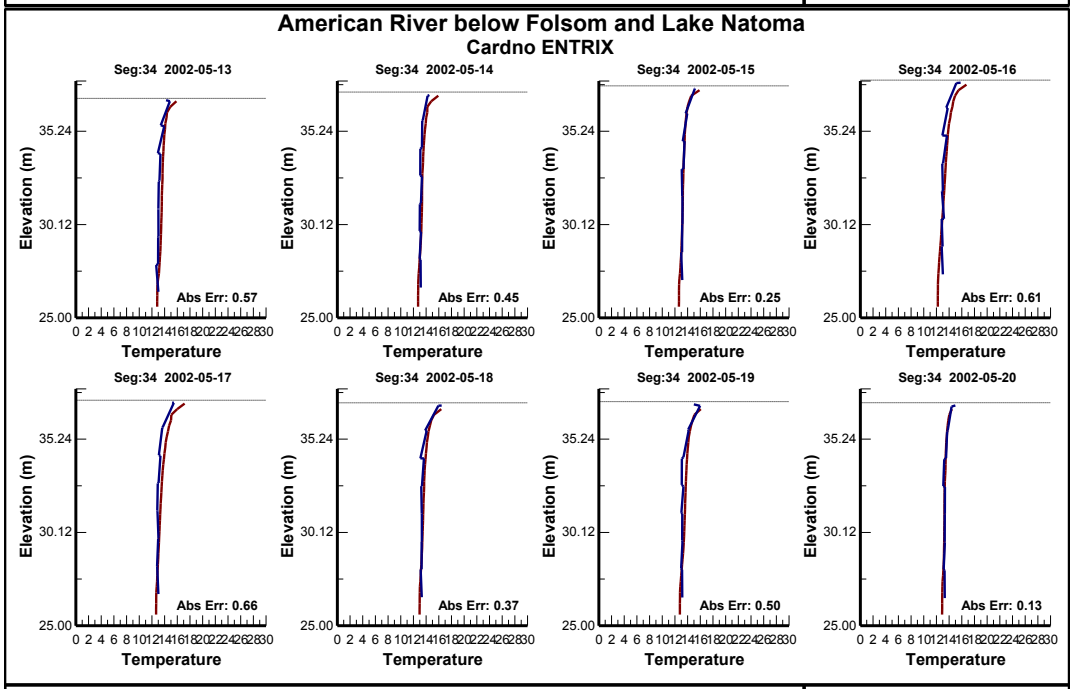

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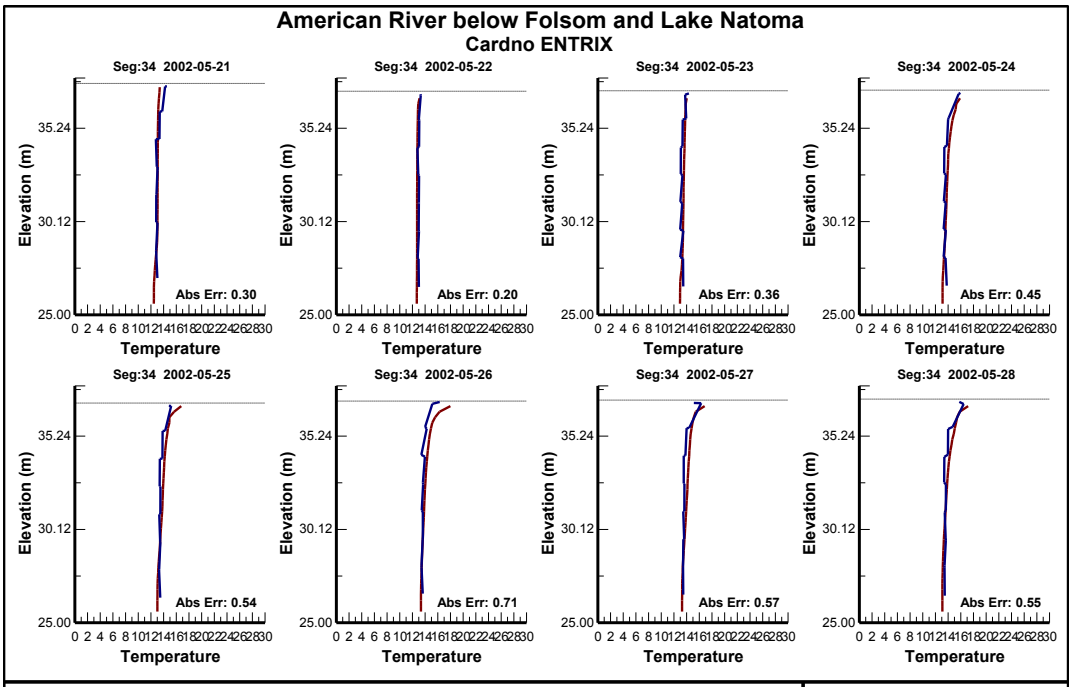

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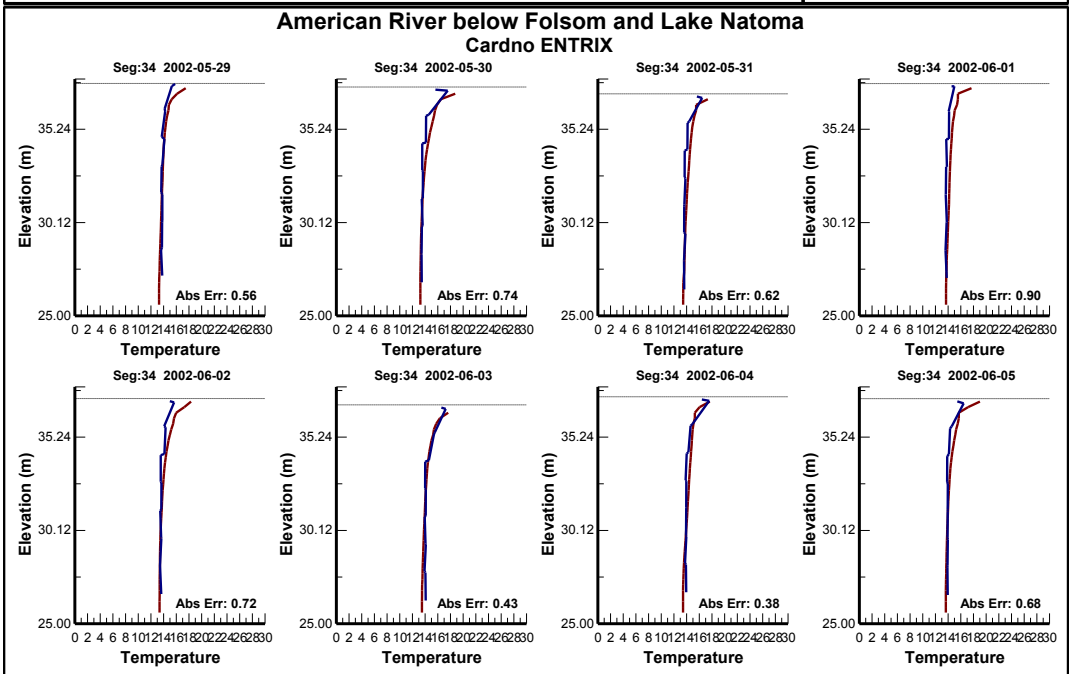

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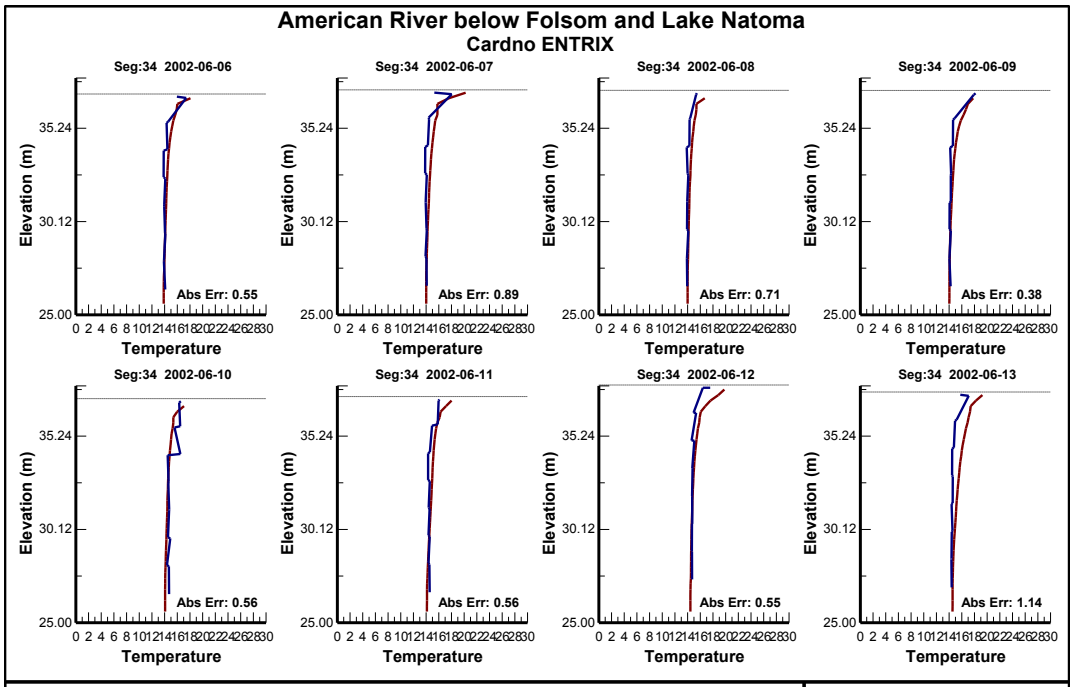

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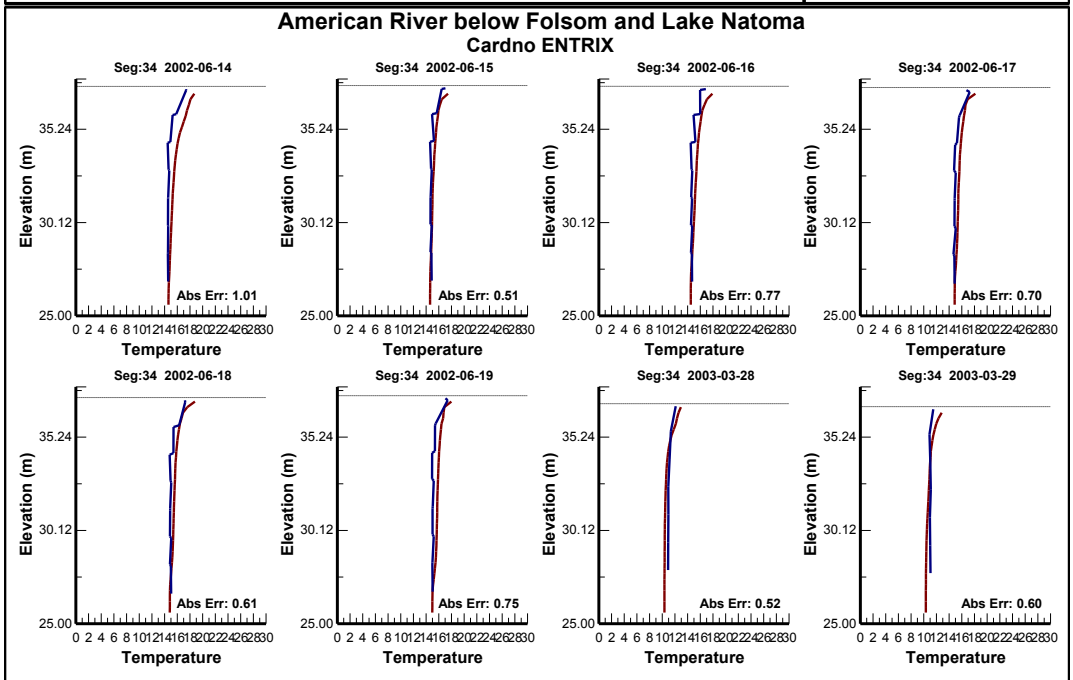

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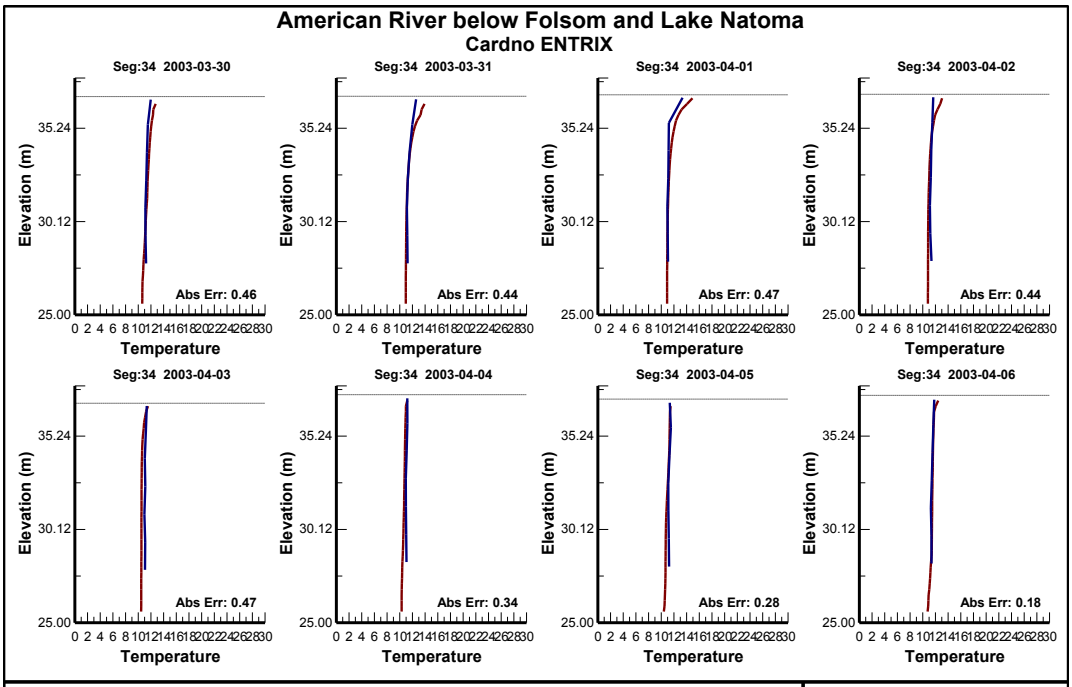

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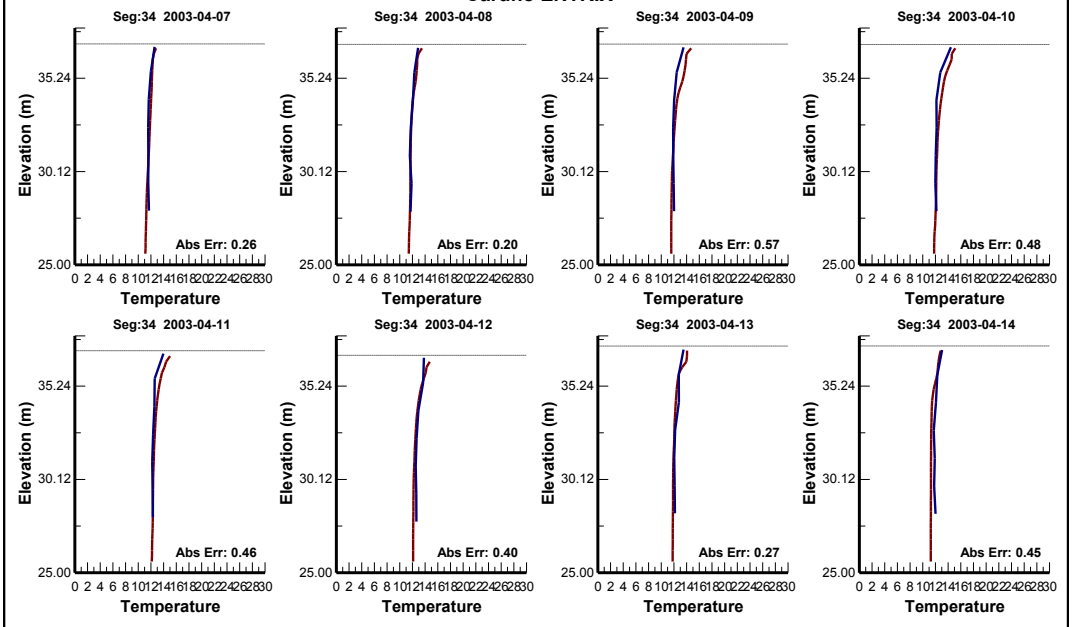

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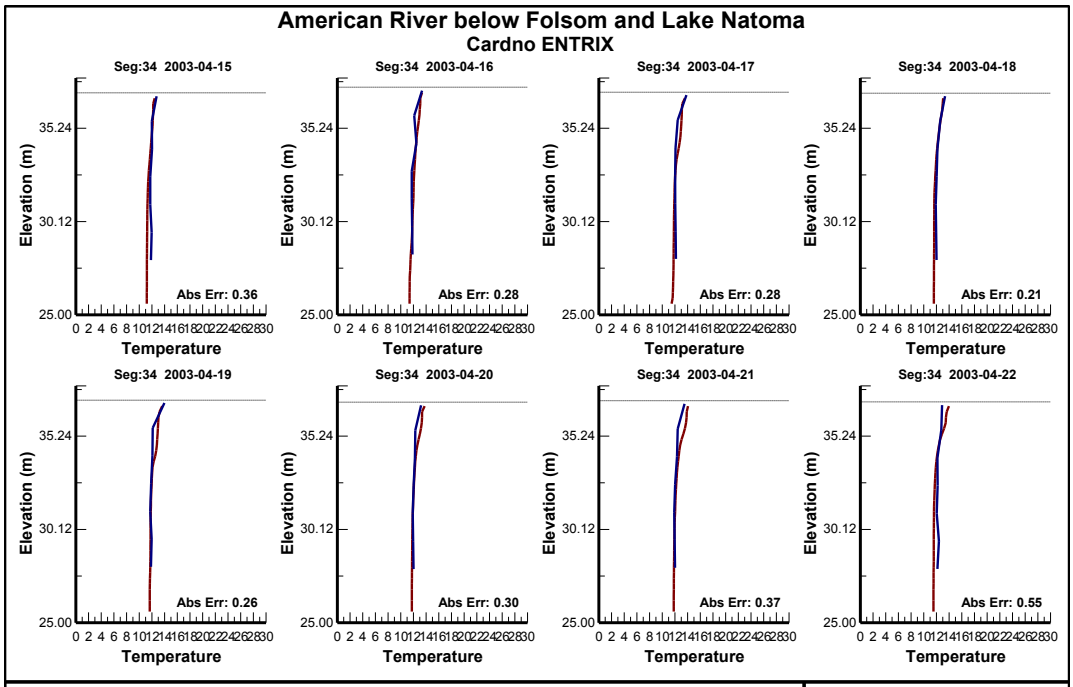

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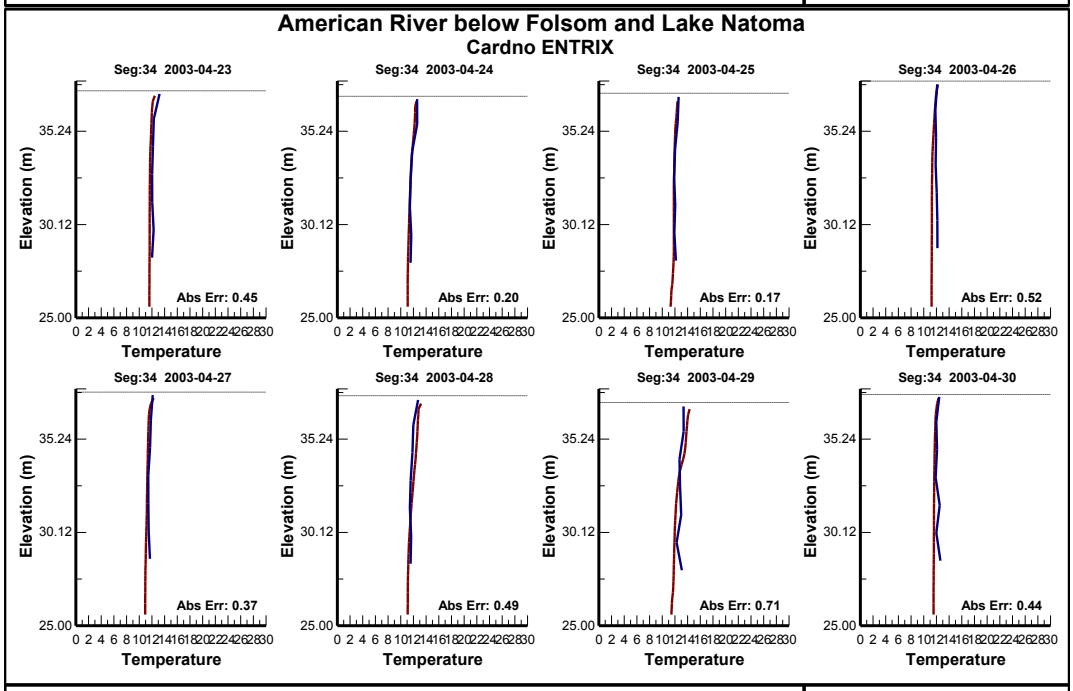

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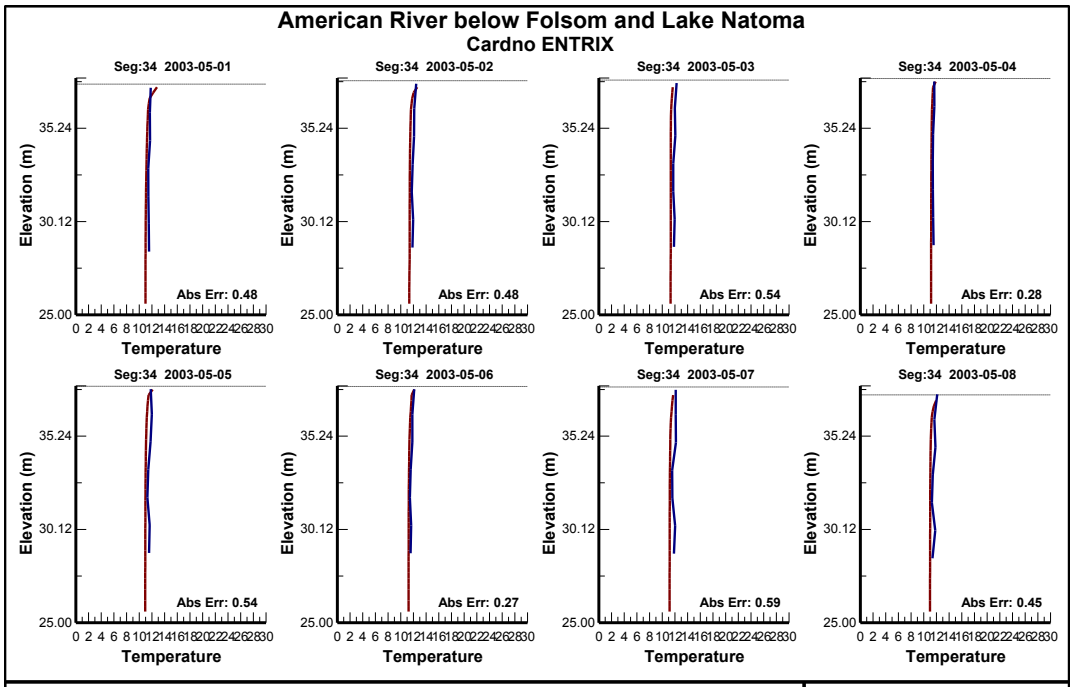

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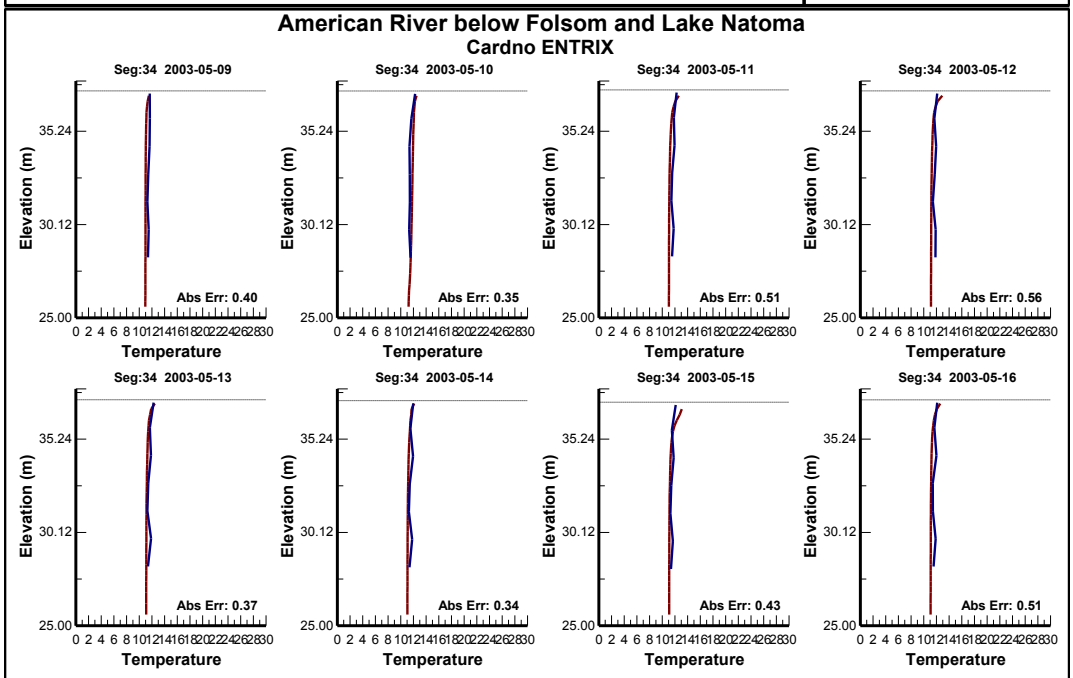

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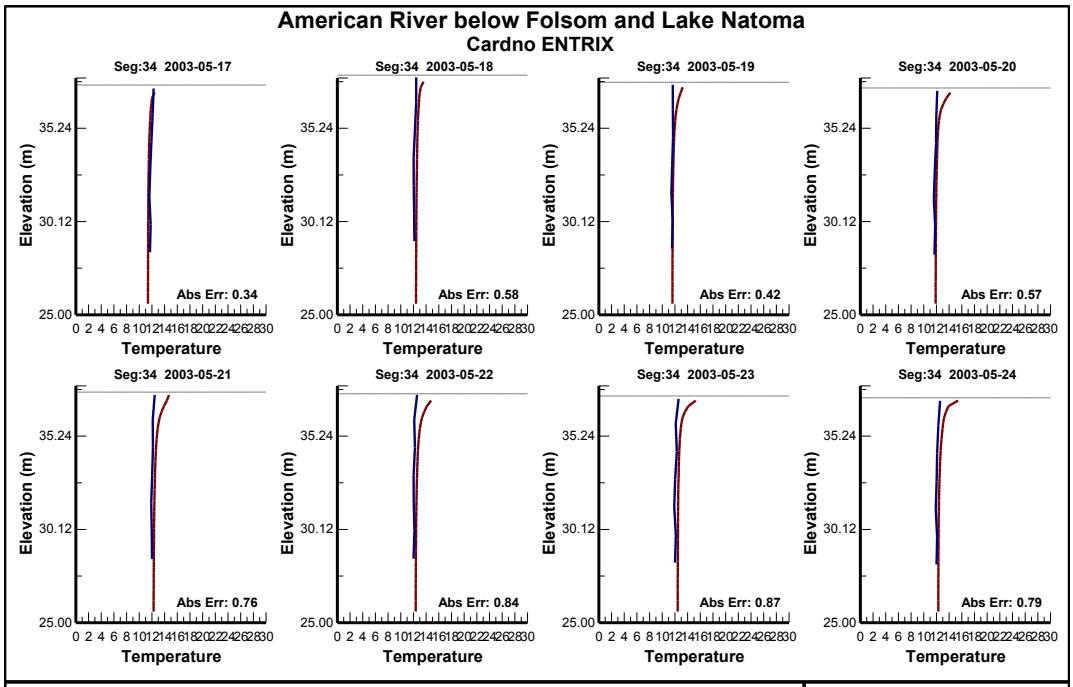
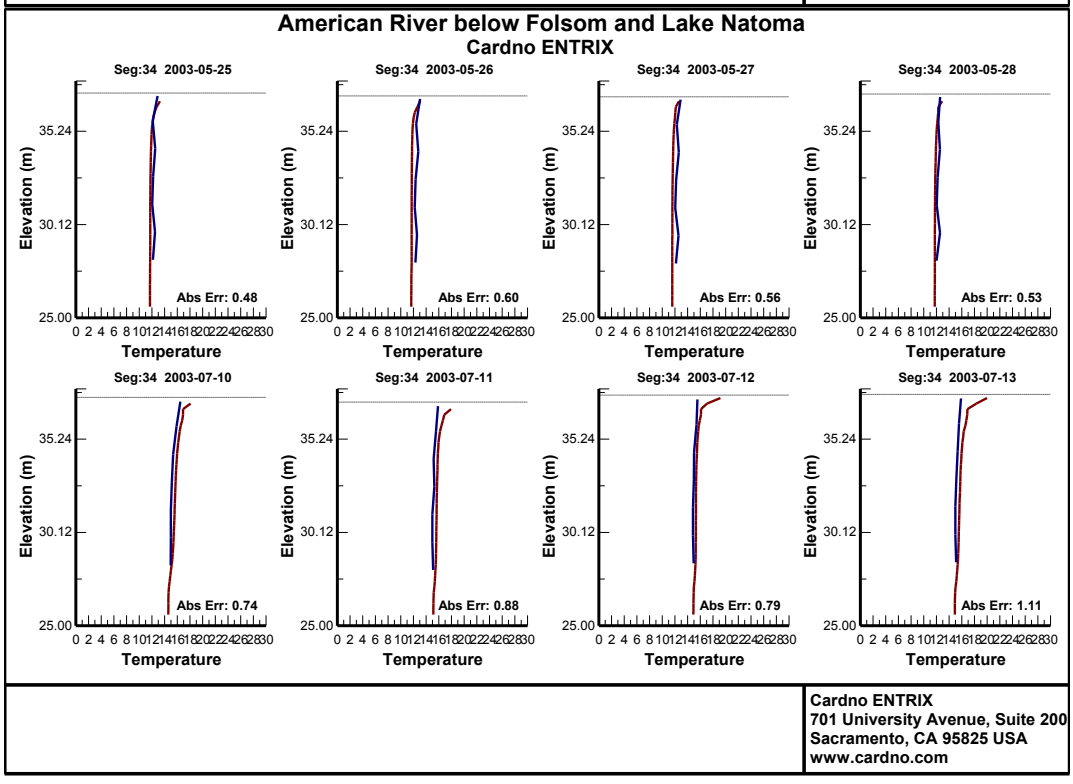

American River below Folsom and Lake Natoma
Cardno ENTRIX
Seg:34 2003-05-17
Abs Err: 0.34
Seg:34 2003-05-18
Abs Err: 0.58
Seg:34 2003-05-19
Abs Err: 0.42
Seg:34 2003-05-20
Abs Err: 0.57
Seg:34 2003-05-21
Abs Err: 0.76
Seg:34 2003-05-22
Abs Err: 0.84
Seg:34 2003-05-23
Abs Err: 0.87
Seg:34 2003-05-24
Abs Err: 0.79
Elevation (m)
35.24
30.12
25.00
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Temperature
Cardno ENTRIX
701 University Avenue, Suite 200
Sacramento, CA 95825 USA
www.cardno.com


American River below Folsom and Lake Natoma
Cardno ENTRIX
Seg:34 2003-05-25
Abs Err: 0.48
Seg:34 2003-05-26
Abs Err: 0.60
Seg:34 2003-05-27
Abs Err: 0.56
Seg:34 2003-05-28
Abs Err: 0.53
Seg:34 2003-07-10
Abs Err: 0.74
Seg:34 2003-07-11
Abs Err: 0.88
Seg:34 2003-07-12
Abs Err: 0.79
Seg:34 2003-07-13
Abs Err: 1.11
Elevation (m)
35.24
30.12
25.00
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Temperature
Cardno ENTRIX
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Sacramento, CA 95825 USA
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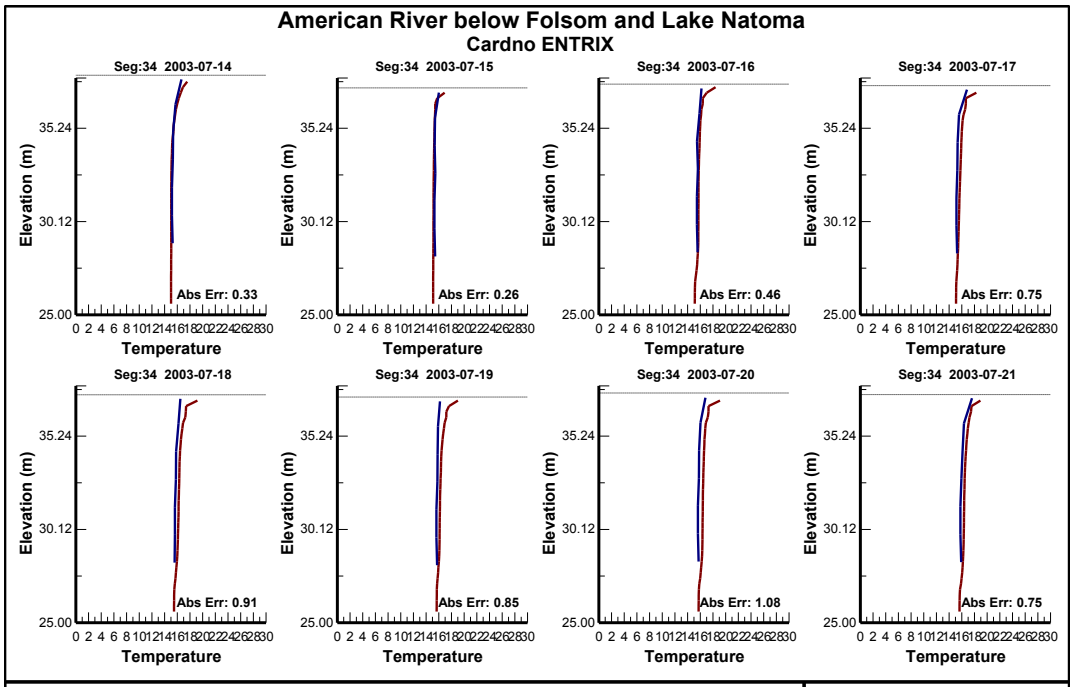

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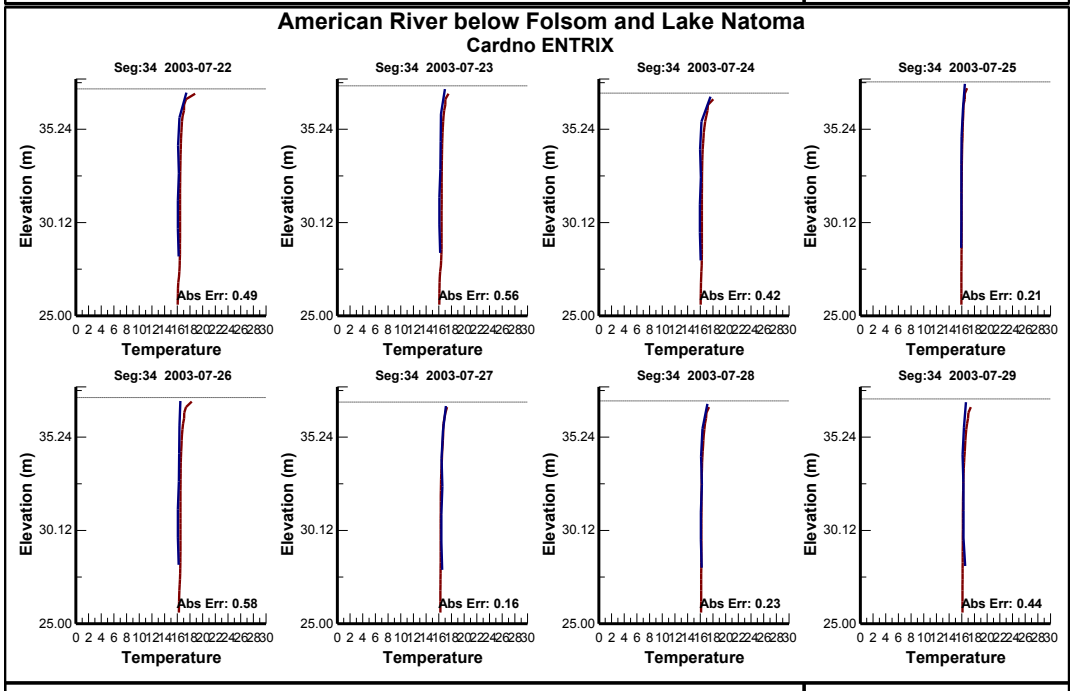

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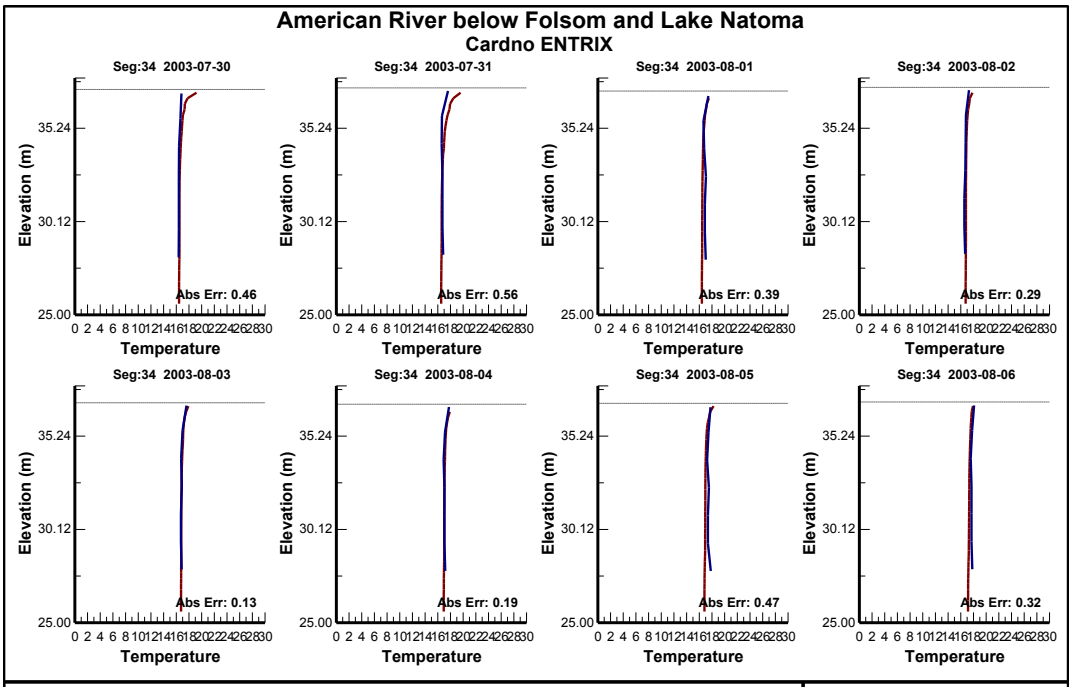

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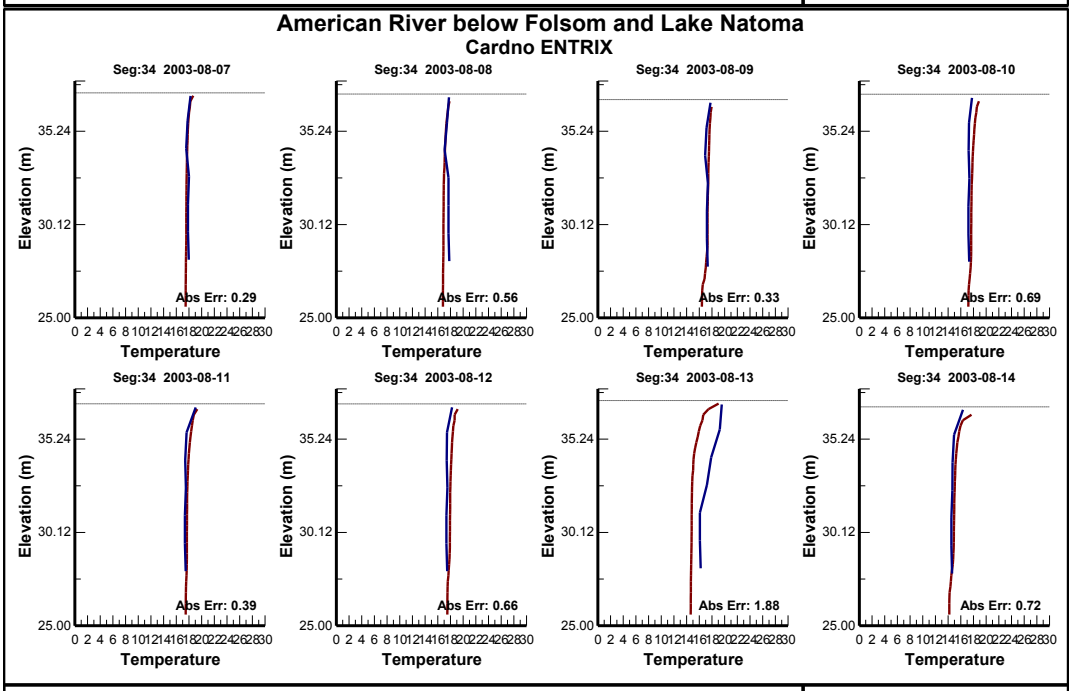

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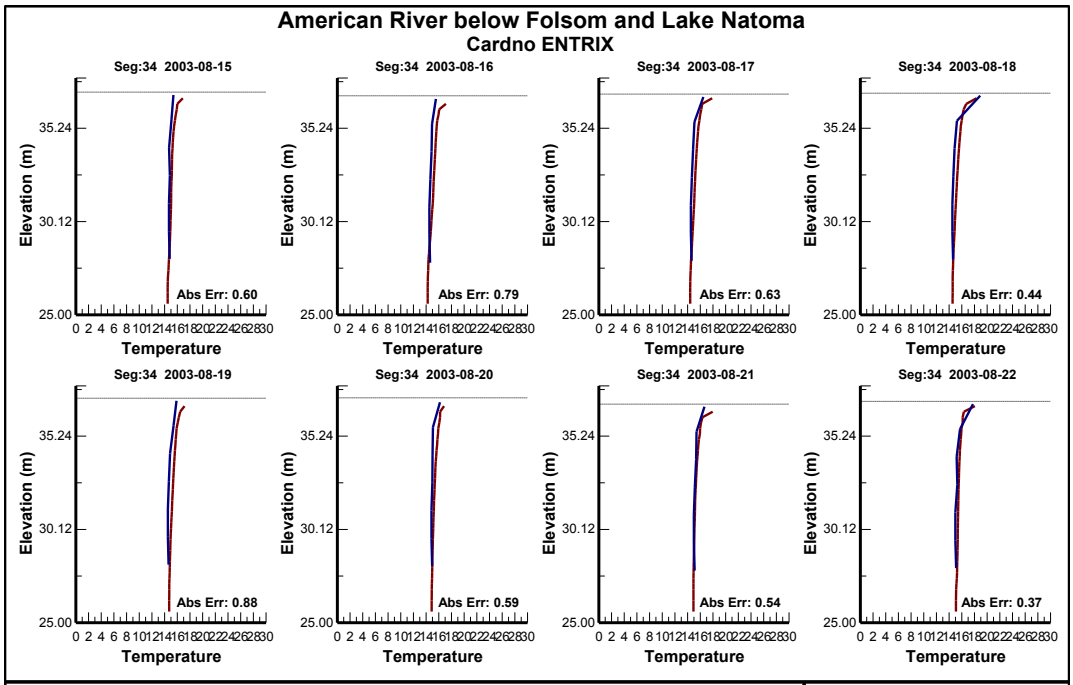

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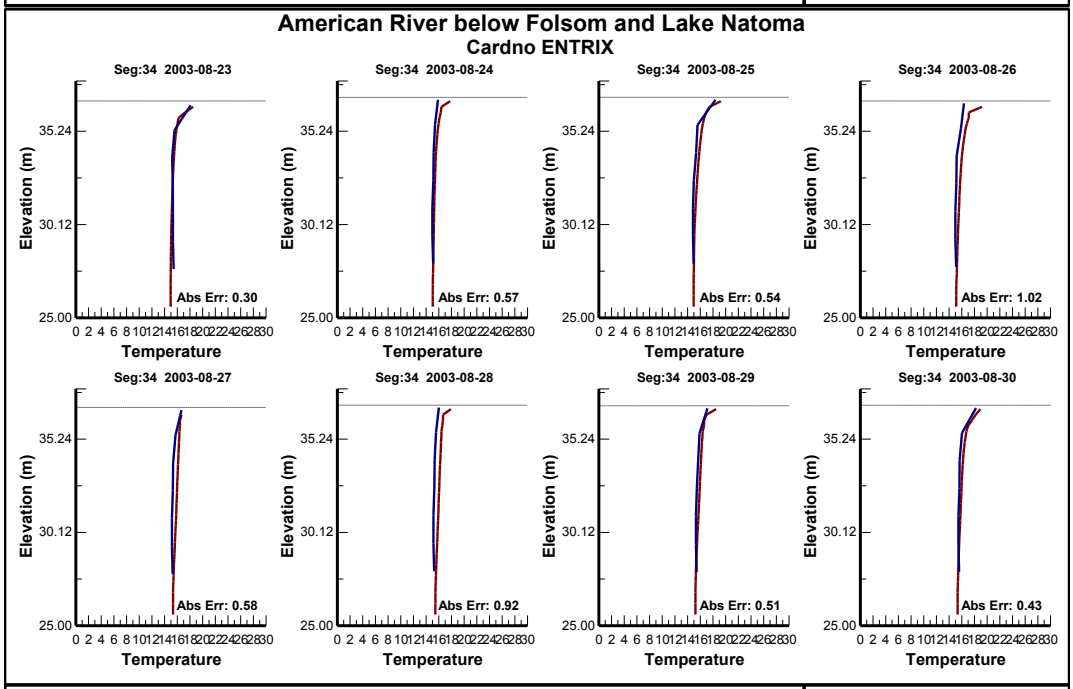

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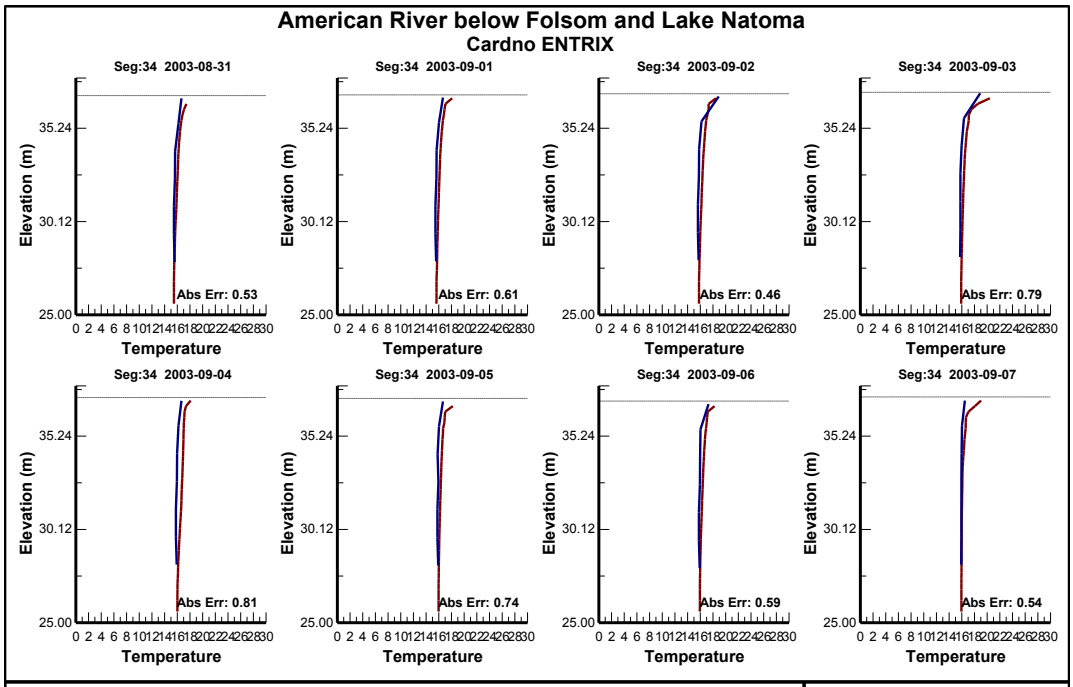

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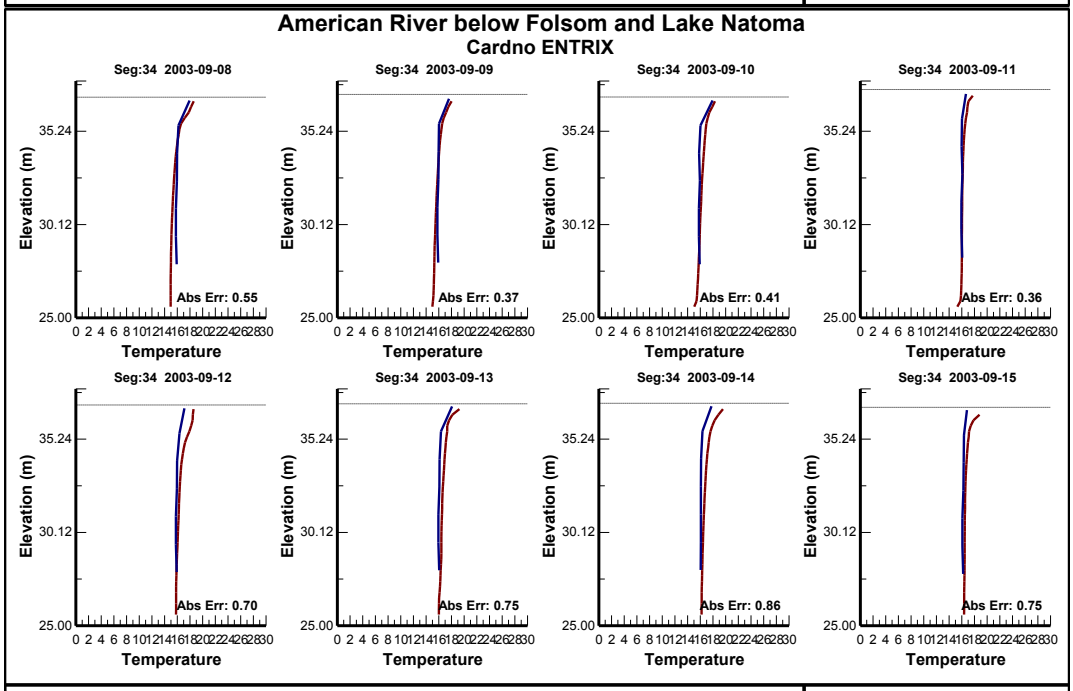

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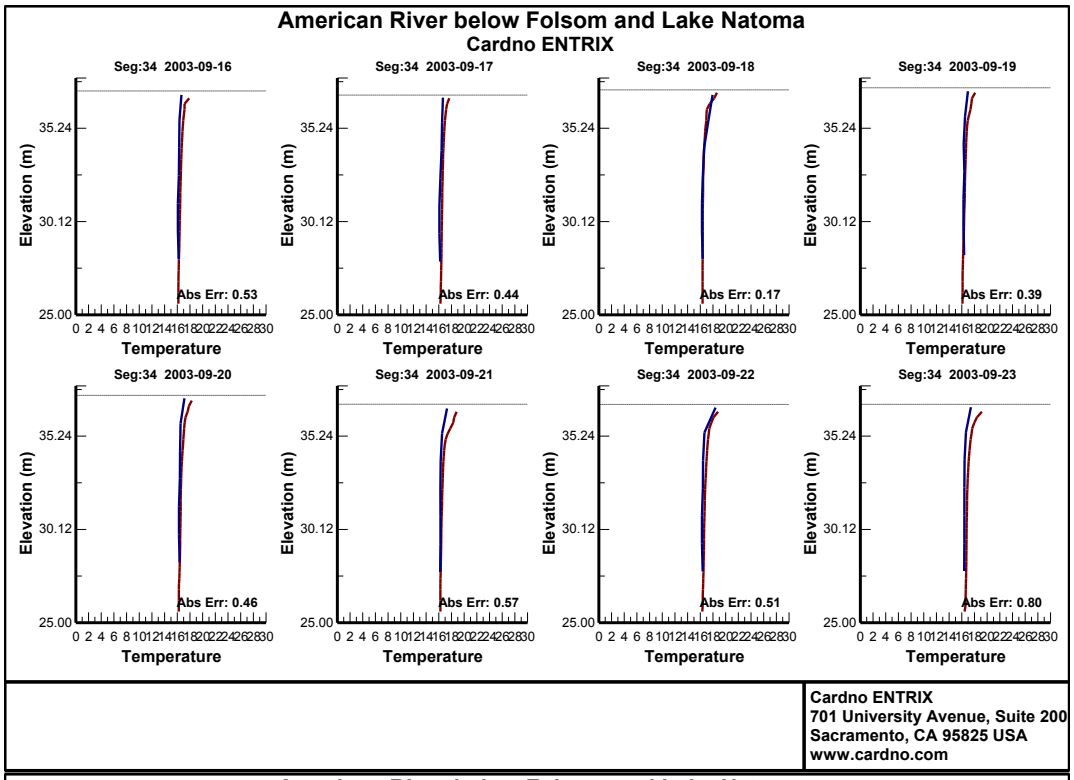

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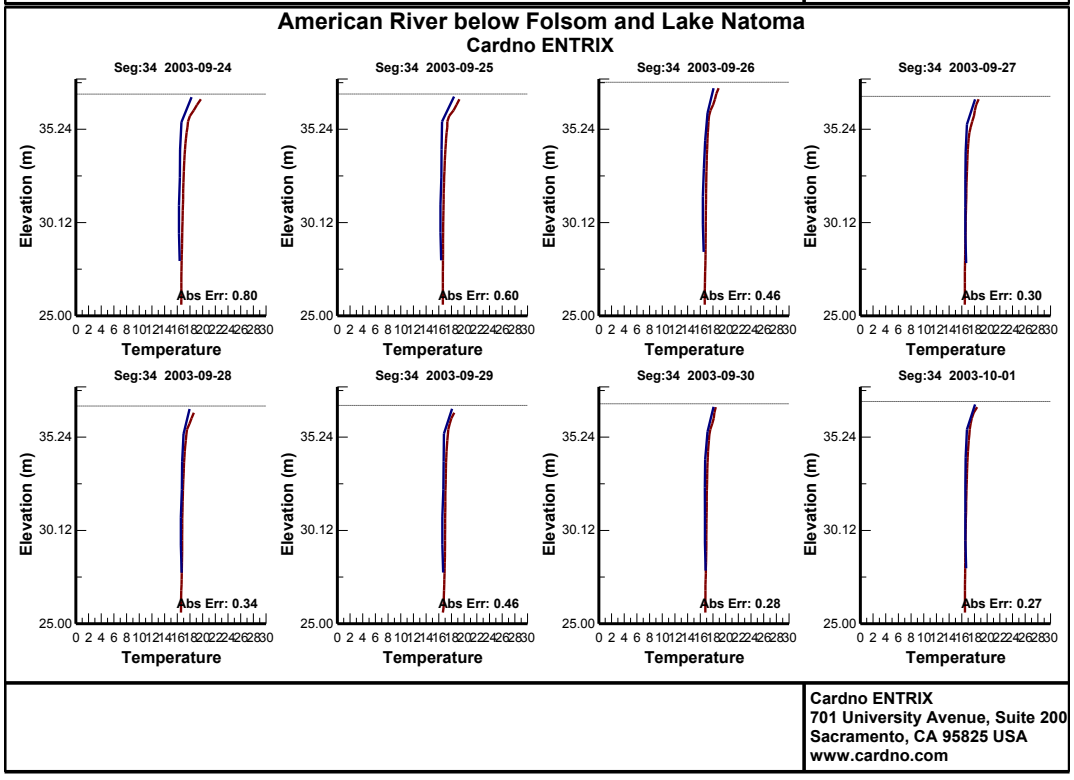

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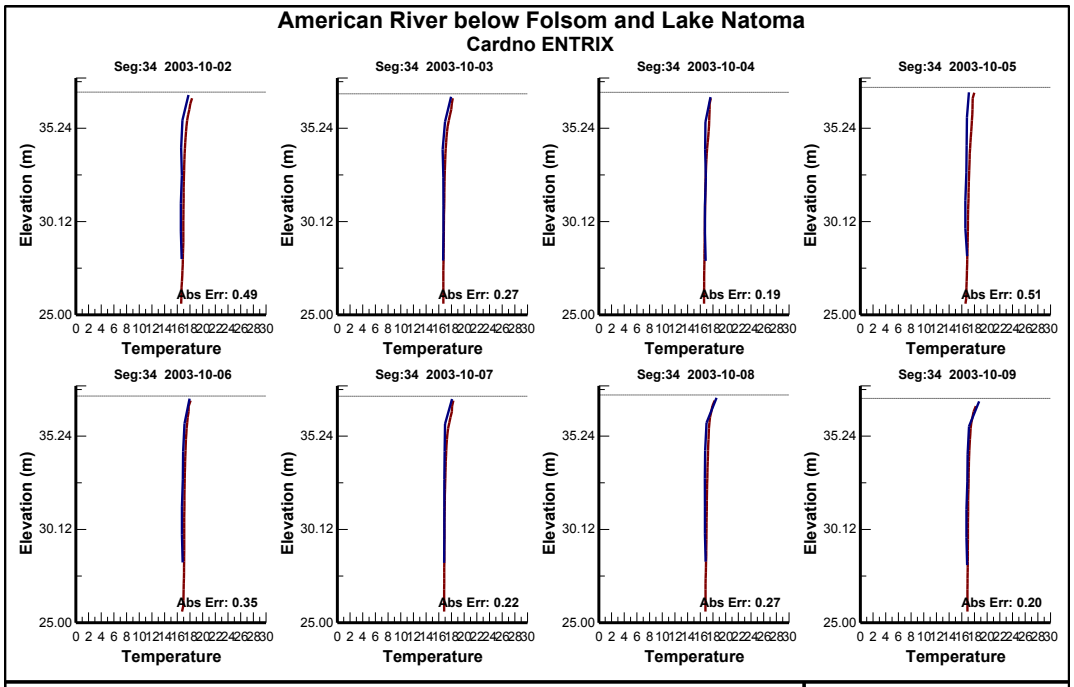
American River below Folsom and Lake Natoma
Cardno ENTRIX
Seg:34 2003-10-02
Abs Err: 0.49
Seg:34 2003-10-03
Abs Err: 0.27
Seg:34 2003-10-04
Abs Err: 0.19
Seg:34 2003-10-05
Abs Err: 0.51
Seg:34 2003-10-06
Abs Err: 0.35
Seg:34 2003-10-07
Abs Err: 0.22
Seg:34 2003-10-08
Abs Err: 0.27
Seg:34 2003-10-09
Abs Err: 0.20
Elevation (m)
35.24
30.12
25.00
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Temperature
Cardno ENTRIX
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Sacramento, CA 95825 USA
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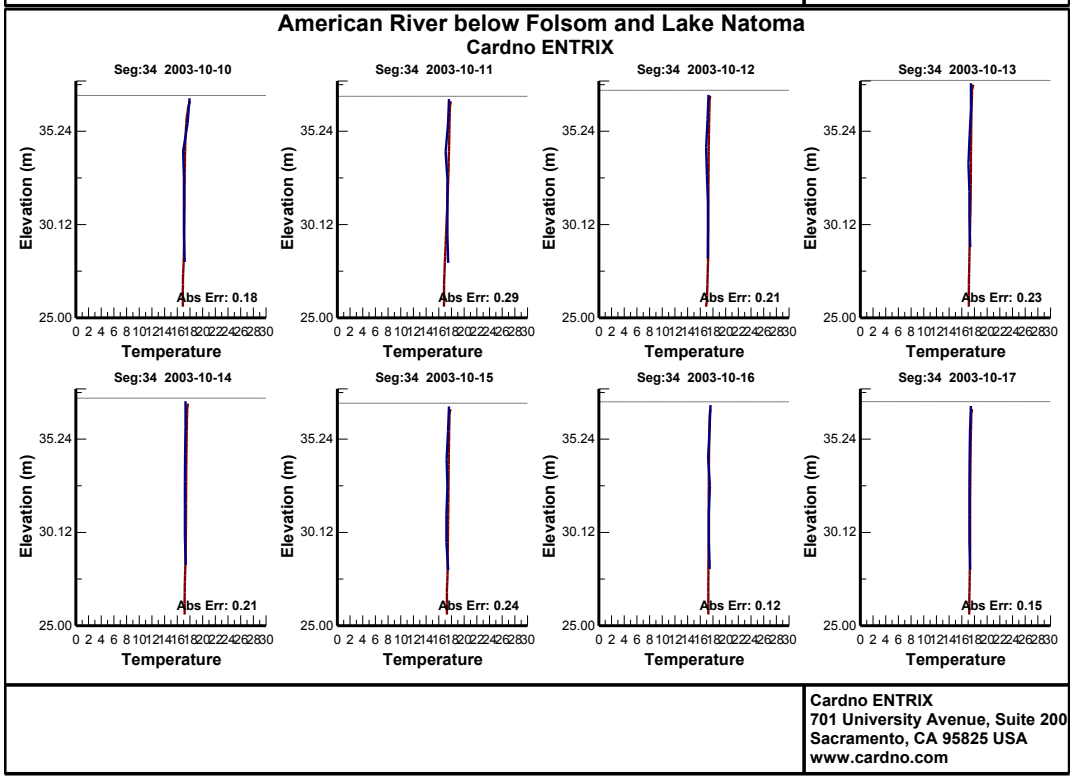
American River below Folsom and Lake Natoma
Cardno ENTRIX
Seg:34 2003-10-10
Abs Err: 0.18
Seg:34 2003-10-11
Abs Err: 0.29
Seg:34 2003-10-12
Abs Err: 0.21
Seg:34 2003-10-13
Abs Err: 0.23
Seg:34 2003-10-14
Abs Err: 0.21
Seg:34 2003-10-15
Abs Err: 0.24
Seg:34 2003-10-16
Abs Err: 0.12
Seg:34 2003-10-17
Abs Err: 0.15
Elevation (m)
35.24
30.12
25.00
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Temperature
Cardno ENTRIX
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Sacramento, CA 95825 USA
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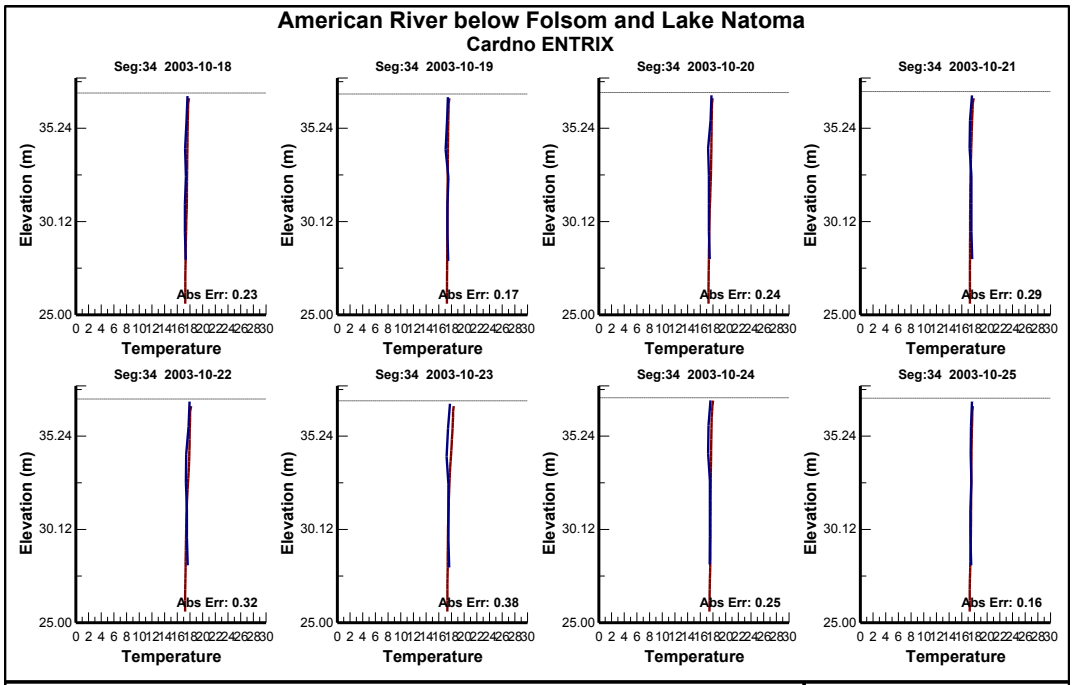

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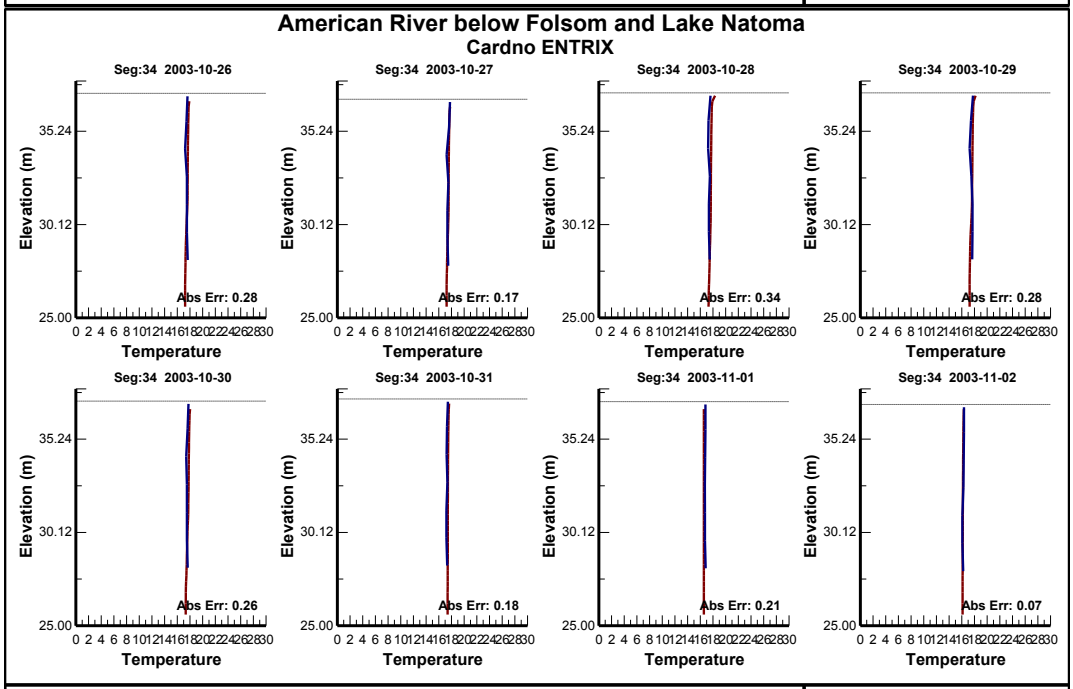

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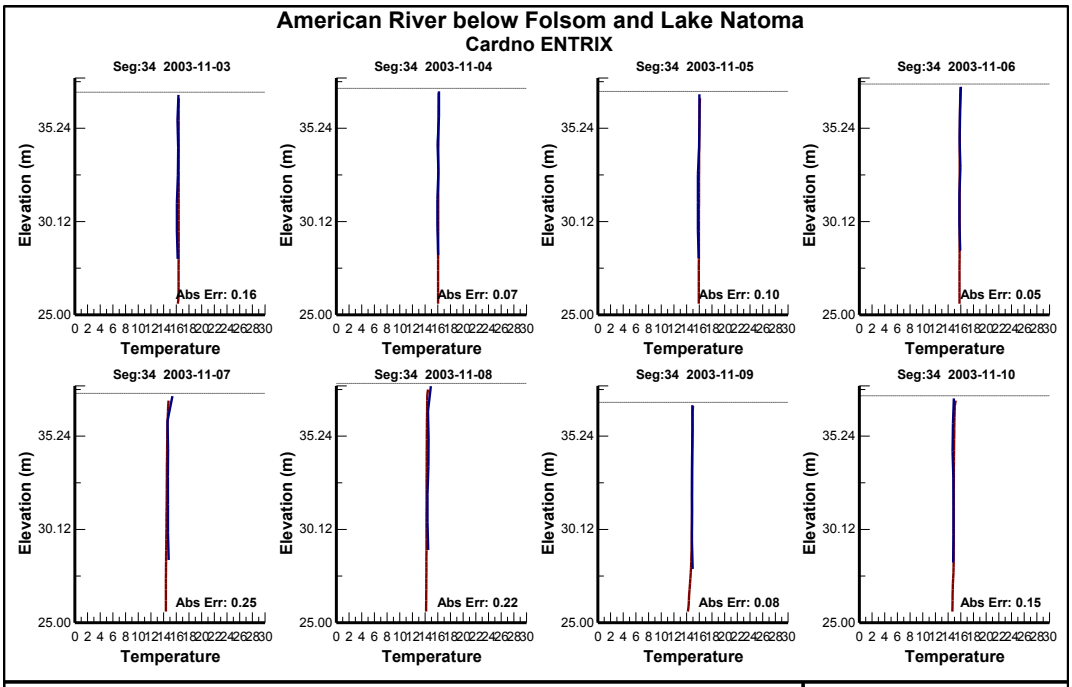

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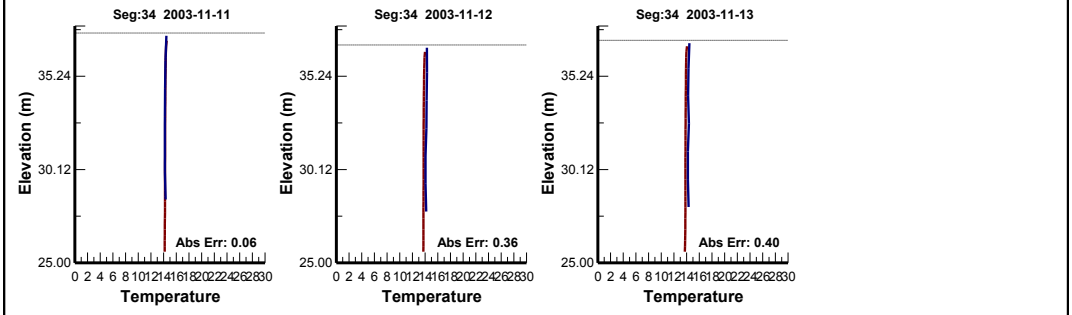

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