Columbia/Snake River Temperature Modeling
Preliminary Results

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1 1977 Conditions Scenario

The simulation period was limited to April 1, 1977 to October 31, 1977. The heat exchange component of MASS1 was recalibrated for this period and the conditions listed below. Simulated temperatures were compared to observed at several locations. Table 1 summarizes the comparison for the period. Several figures follow showing graphical comparisons.

This simulation was performed using the following conditions:

- Observed 1977 flows for model boundaries:
  - Columbia River at Grand Coulee (hourly),

  - Snake River at Anatone (daily),
  - North Fork Clearwater River at Dworshak (hourly), and
  - Clearwater River at Orofino (daily)

- Observed 1977 flows at all gaged tributaries;
- Constant project forebay stages (normal pool elevation);
- Observed 1977 daily water temperatures at Grand Coulee;
- Observed 1977 daily water temperatures at Anatone;
- Dworshak and Orofino temperatures set to that observed at Spalding;
- Water temperatures at tributaries were set to observed 1977 daily values when available, long term monthly averages when observed data not available;
- Gas levels were assumed to be 100% saturated in the Grand Coulee and Dworshak forebays, and at all tributaries;
- At all projects, spill was assumed to occur only if the powerhouse capacity was exceeded[1]; and
- Meteorology data was used from the following stations (see Figures 134 and 135):
  - Pranghorn Airport, Wenatchee,
  - Hanford Meteorological Station, and
  - Portland International Airport.

[1]The application of this rule resulted in zero spill at all projects for the entire season.

Table 1: Statistical comparison of simulated and observed temperatures from April through September (RMS and AME units are degrees Celsius)

	N	R^2	Bias	RMS	AME
LMN Scroll Case	128	0.89	-0.36	1.52	1.17
LGS Scroll Case	124	0.89	-0.30	1.49	1.18
IHR Scroll Case	200	0.94	-0.17	1.31	1.02
RIS Scroll Case	212	0.98	-0.30	0.59	0.49
MCN Scroll Case	151	0.97	-0.94	1.26	1.06
BON Scroll Case	85	0.97	-1.25	1.56	1.35
Snake R. @ Burbank	210	0.95	-0.33	1.27	0.95
Columbia R. @ Vernita Bridge	214	0.98	-0.29	0.62	0.51
Columbia R. @ Richland	214	0.98	-0.57	0.82	0.68
Columbia R. @ Umatilla	201	0.98	-0.47	0.77	0.62
Columbia R. @ Warrendale	214	0.98	-0.37	1.26	0.95
Columbia R. @ Vancouver	191	0.97	-0.69	1.46	1.10
Columbia R. @ Kalama	214	0.98	-0.75	1.28	1.01

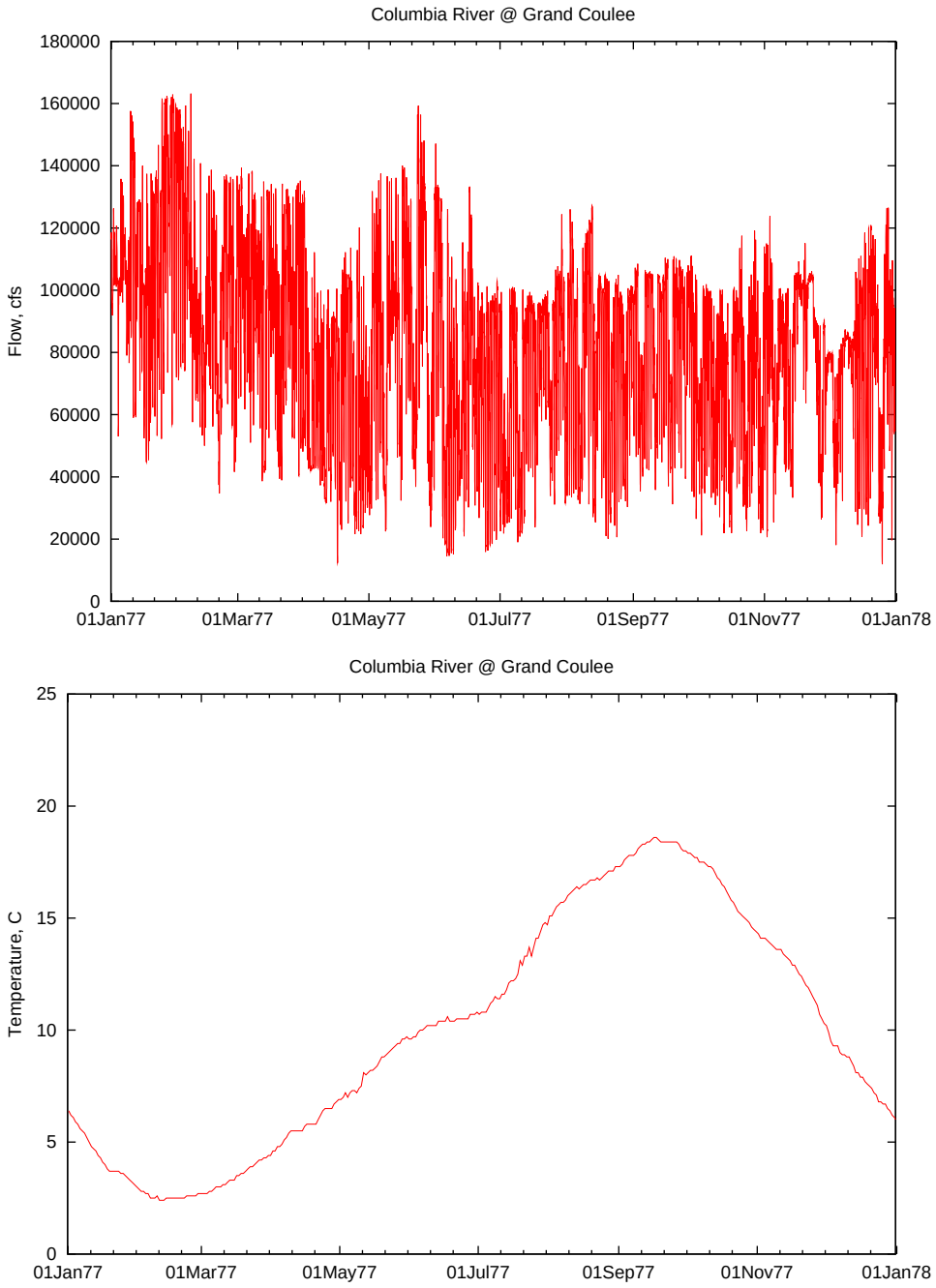

Figure 1: Flow and temperature boundary conditions at Grand Coulee dam.

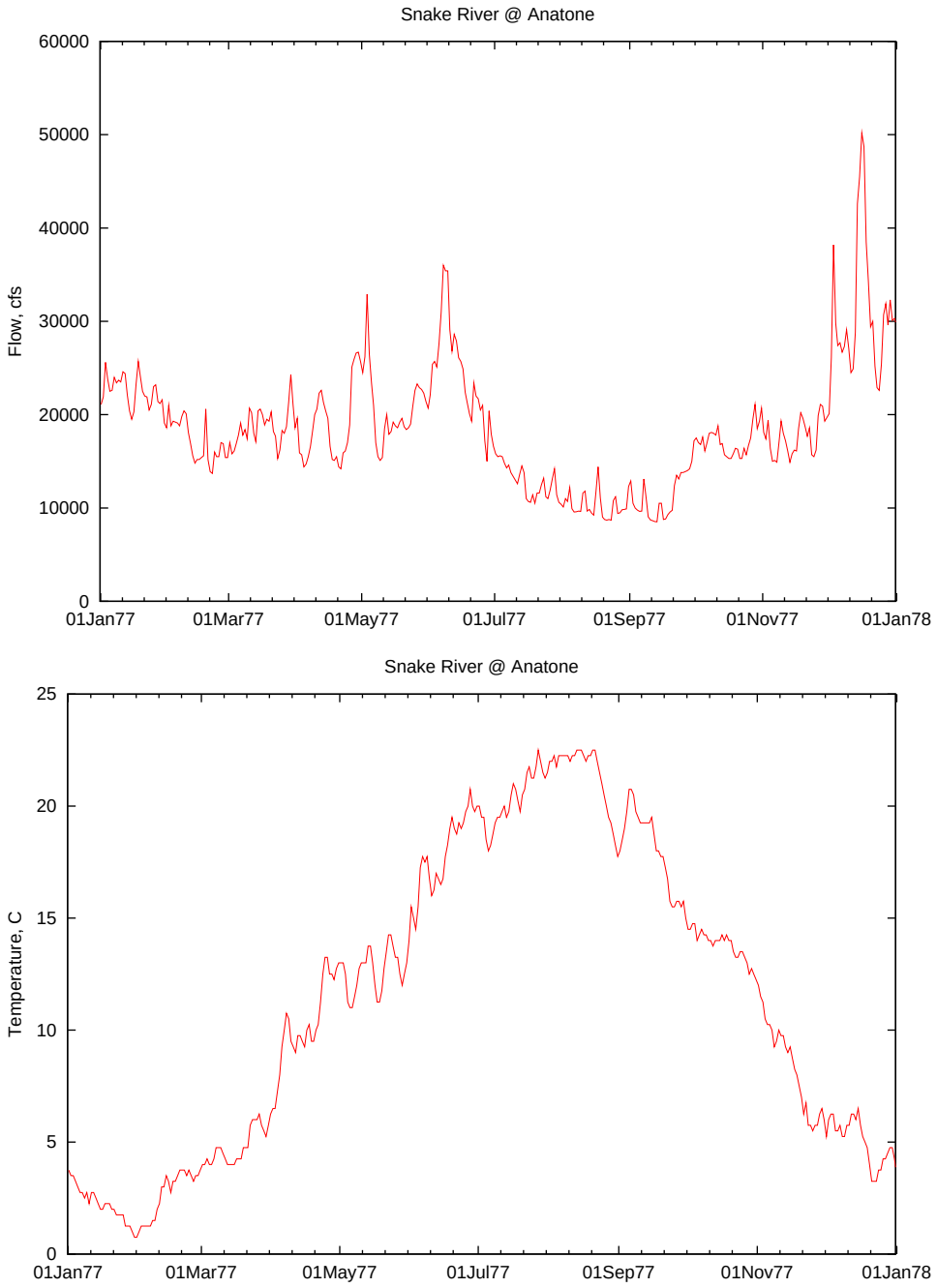

Figure 2: 1977 Snake River flow and temperature boundary conditions at Anatone.

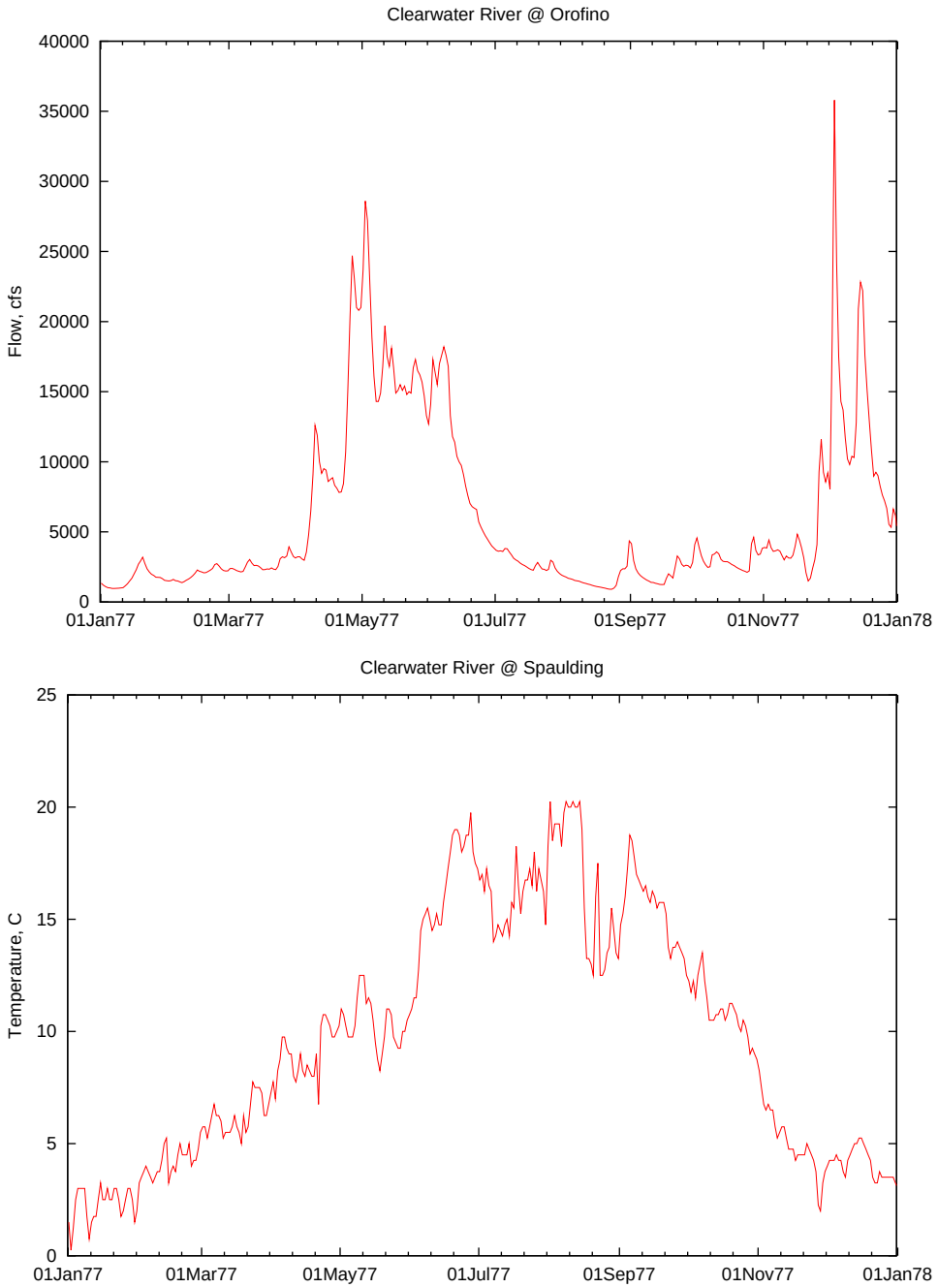

Figure 3: 1977 Clearwater River flow and temperature boundary conditions at Orofino. Temperature is taken from the Spaulding gage downstream.

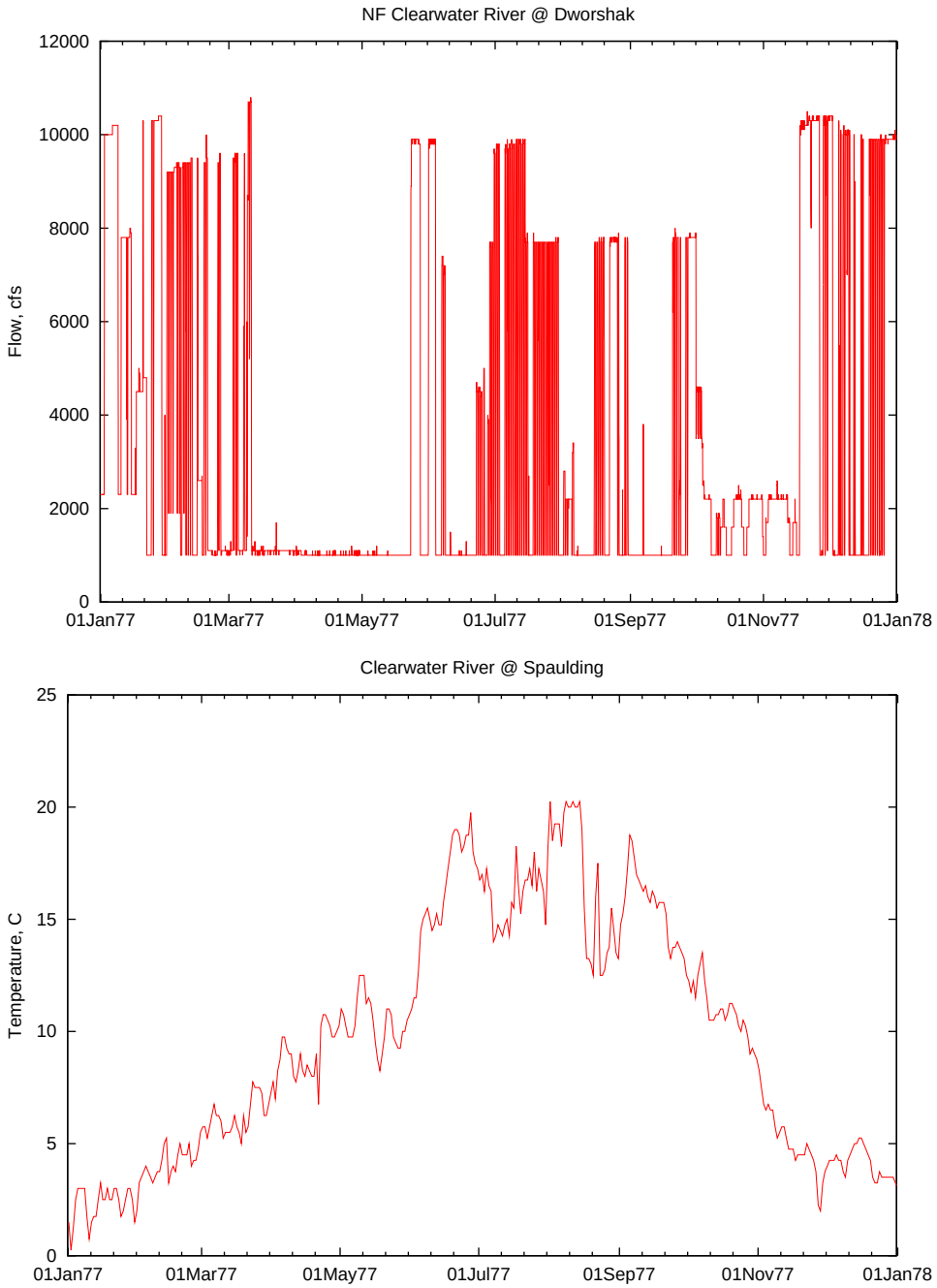

Figure 4: 1977 North Fork Clearwater River flow and temperature boundary conditions at Dworshak dam. Temperature is taken from the Spaulding gage downstream.

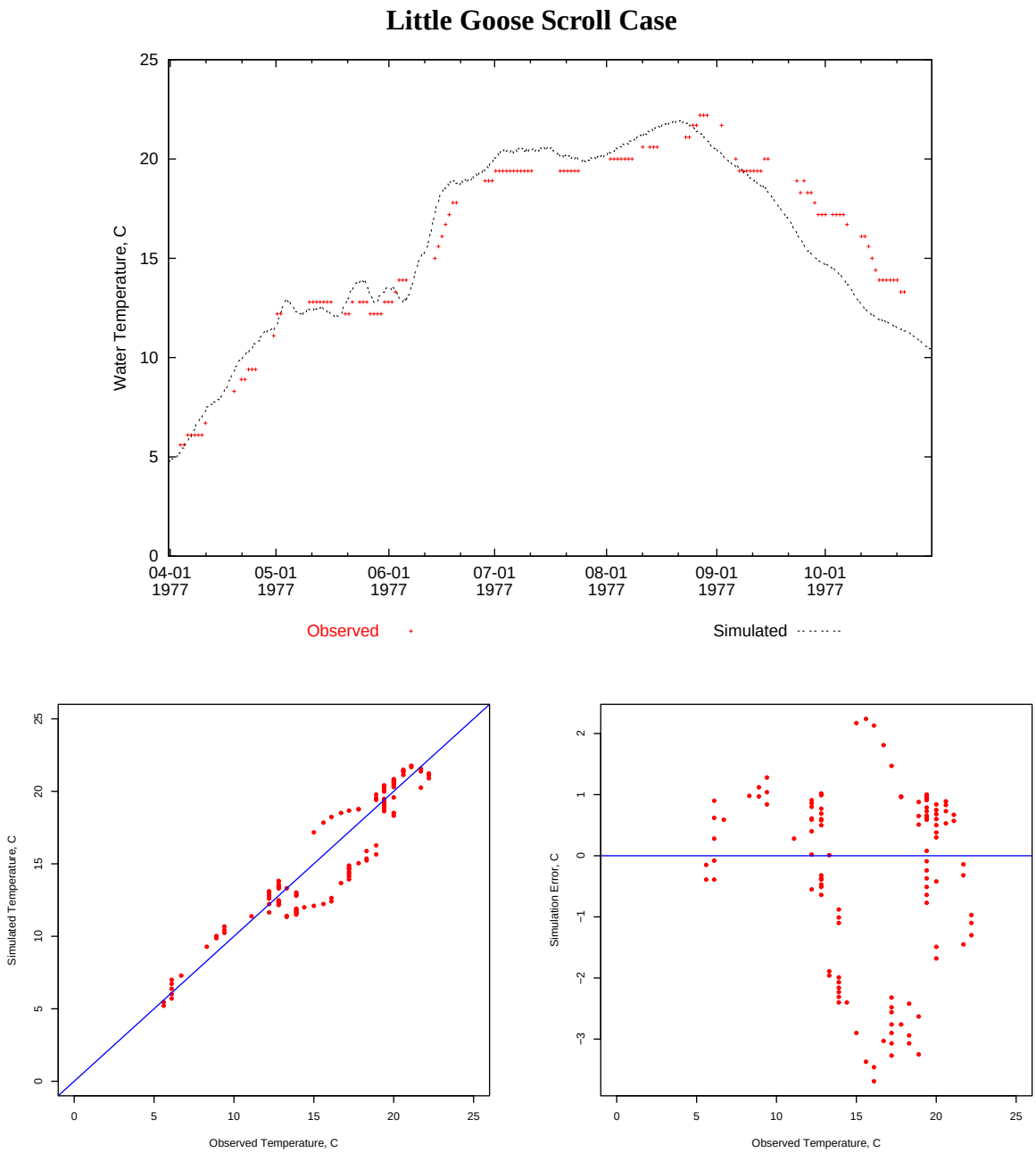

Figure 5: Comparison of simulated temperature and observed scroll case temperature (instantaneous) at Little Goose dam.

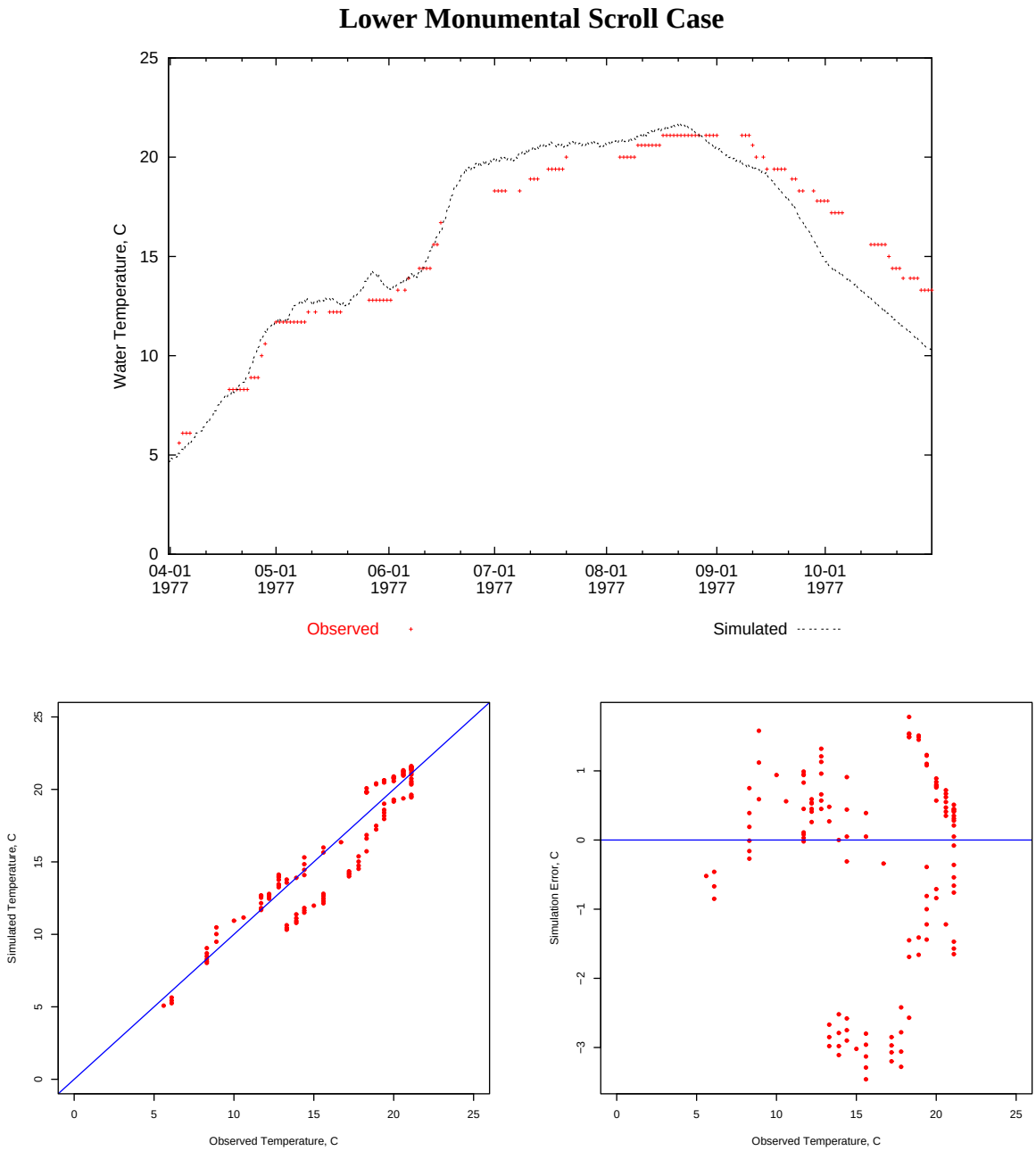

Figure 6: Comparison of simulated temperature and observed scroll case temperature (instantaneous) at Lower Monumental dam.

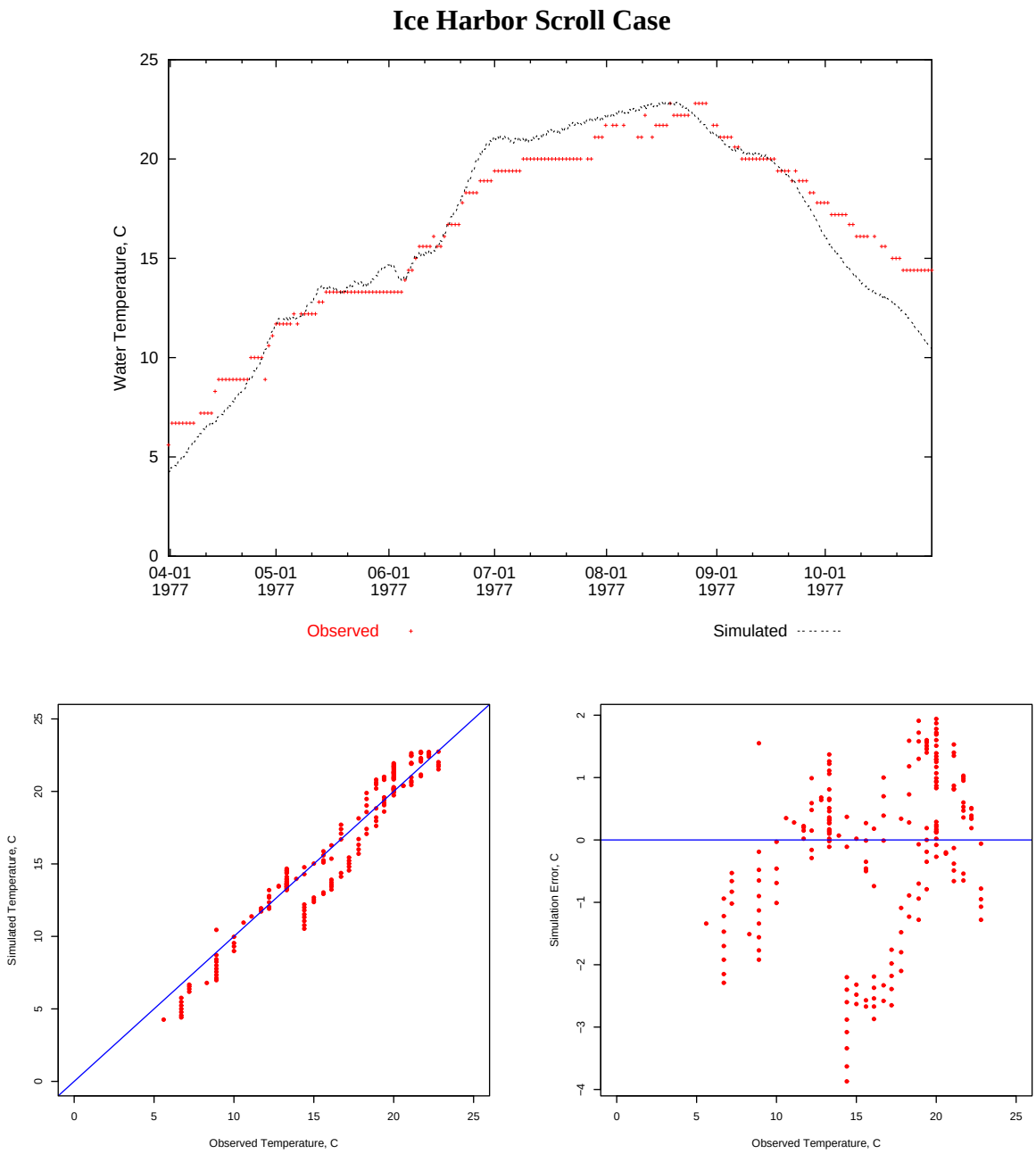

Figure 7: Comparison of simulated temperature and observed scroll case temperature (instantaneous) at Ice Harbor dam.

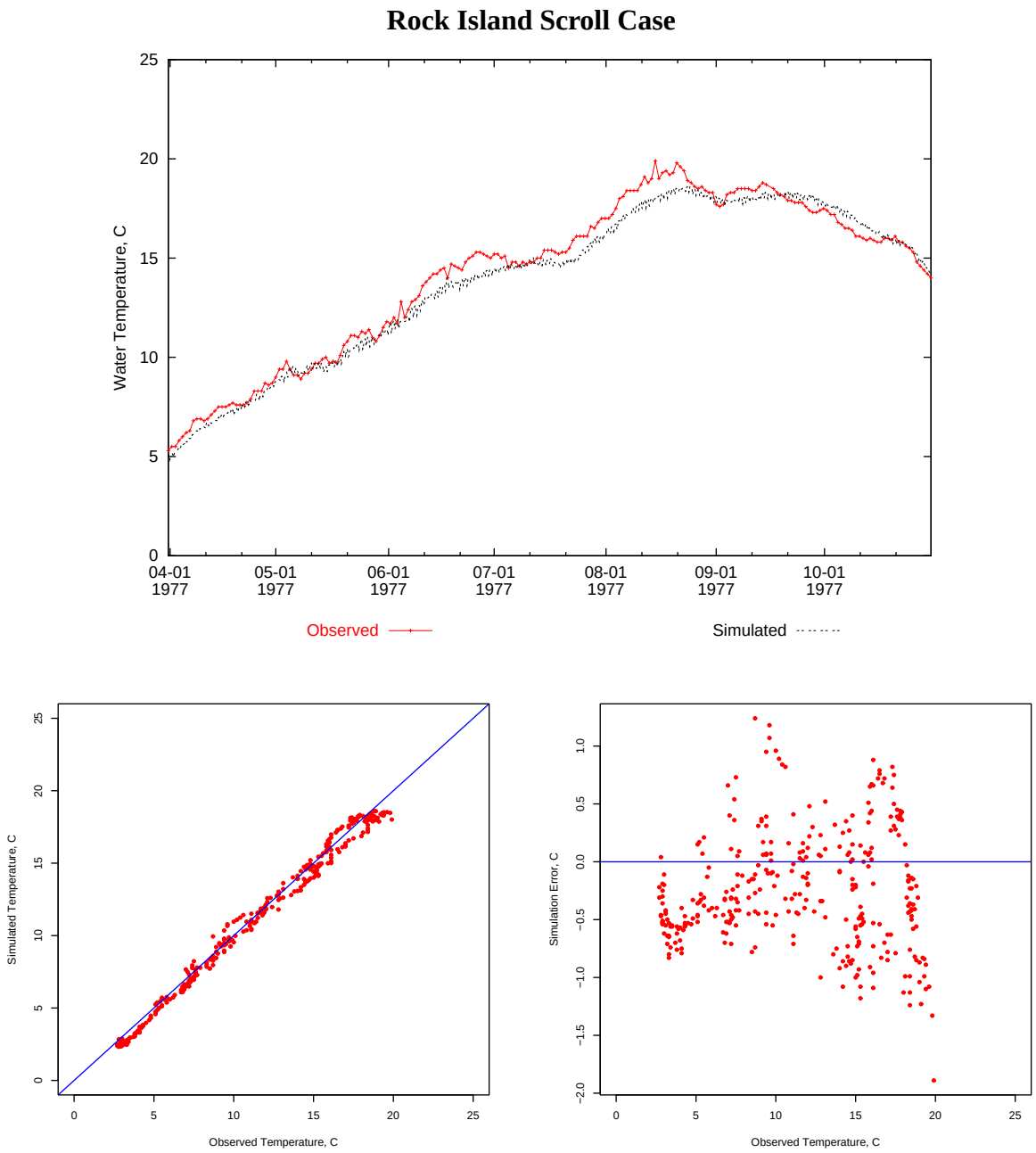

Figure 8: Comparison of simulated temperature and observed scroll case temperature (instantaneous) at Rock Island dam.

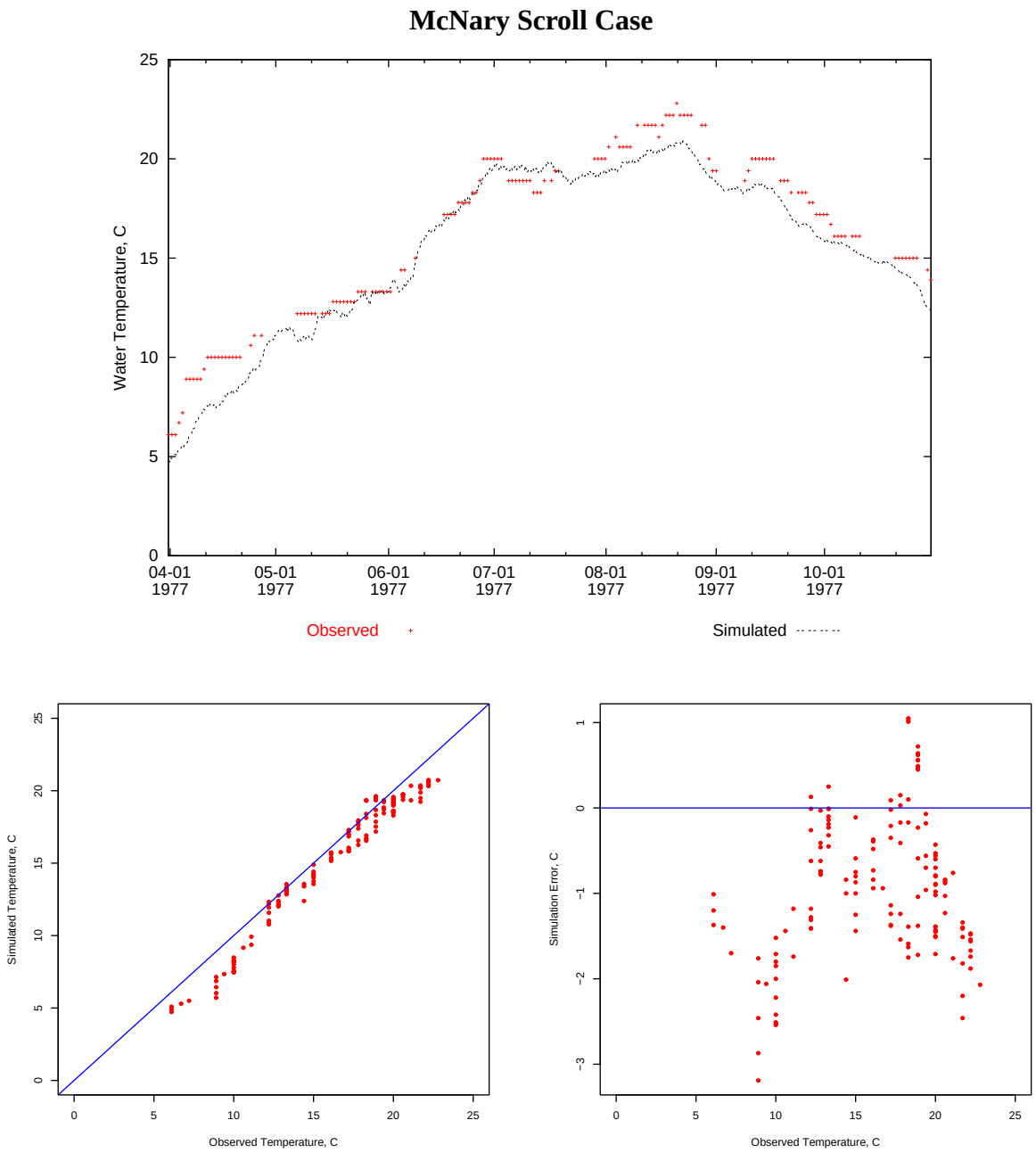

Figure 9: Comparison of simulated temperature and observed scroll case temperature (instantaneous) at McNary dam.

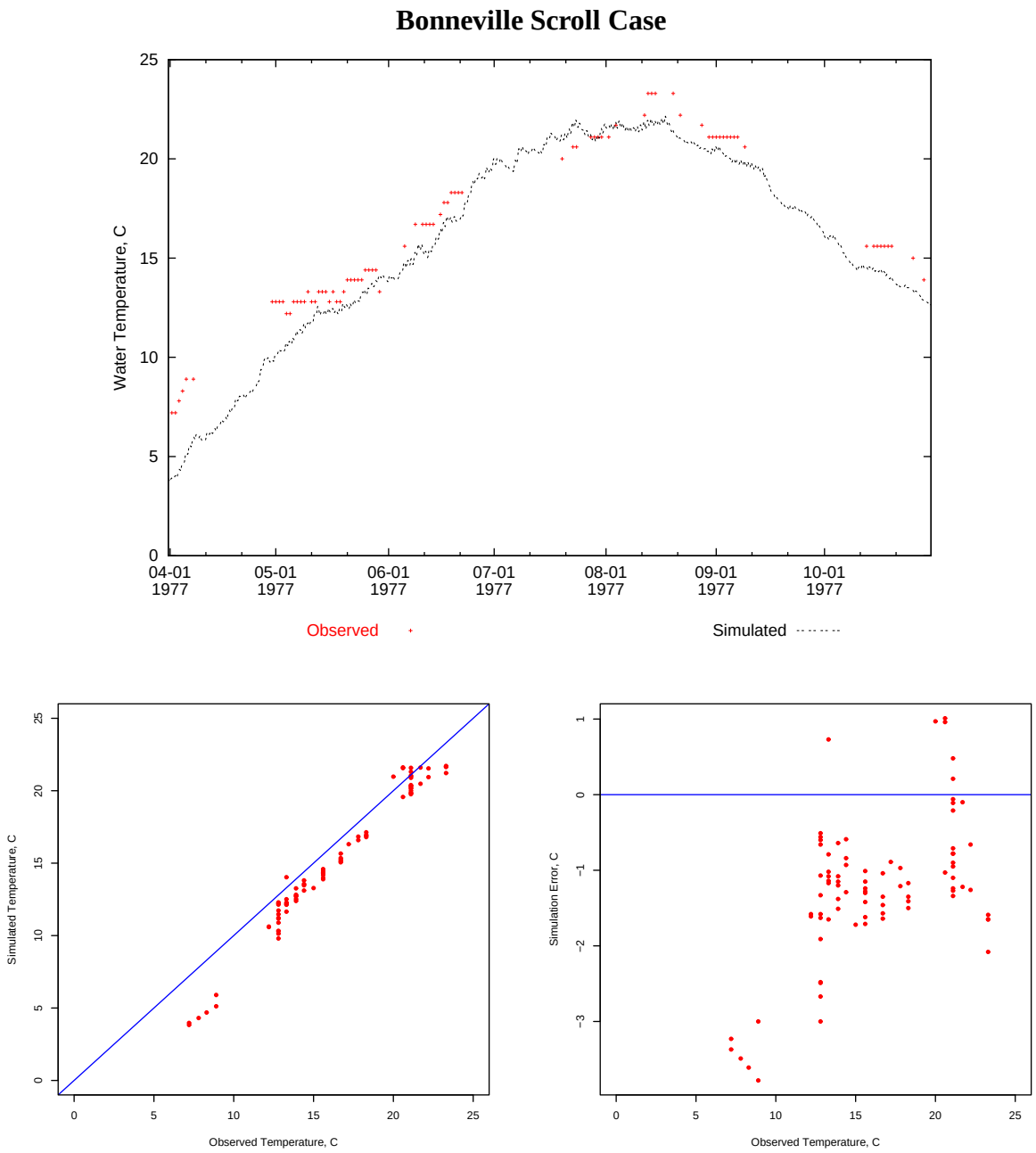

Figure 10: Comparison of simulated temperature observed scroll case temperature (instantaneous) at Bonneville dam.

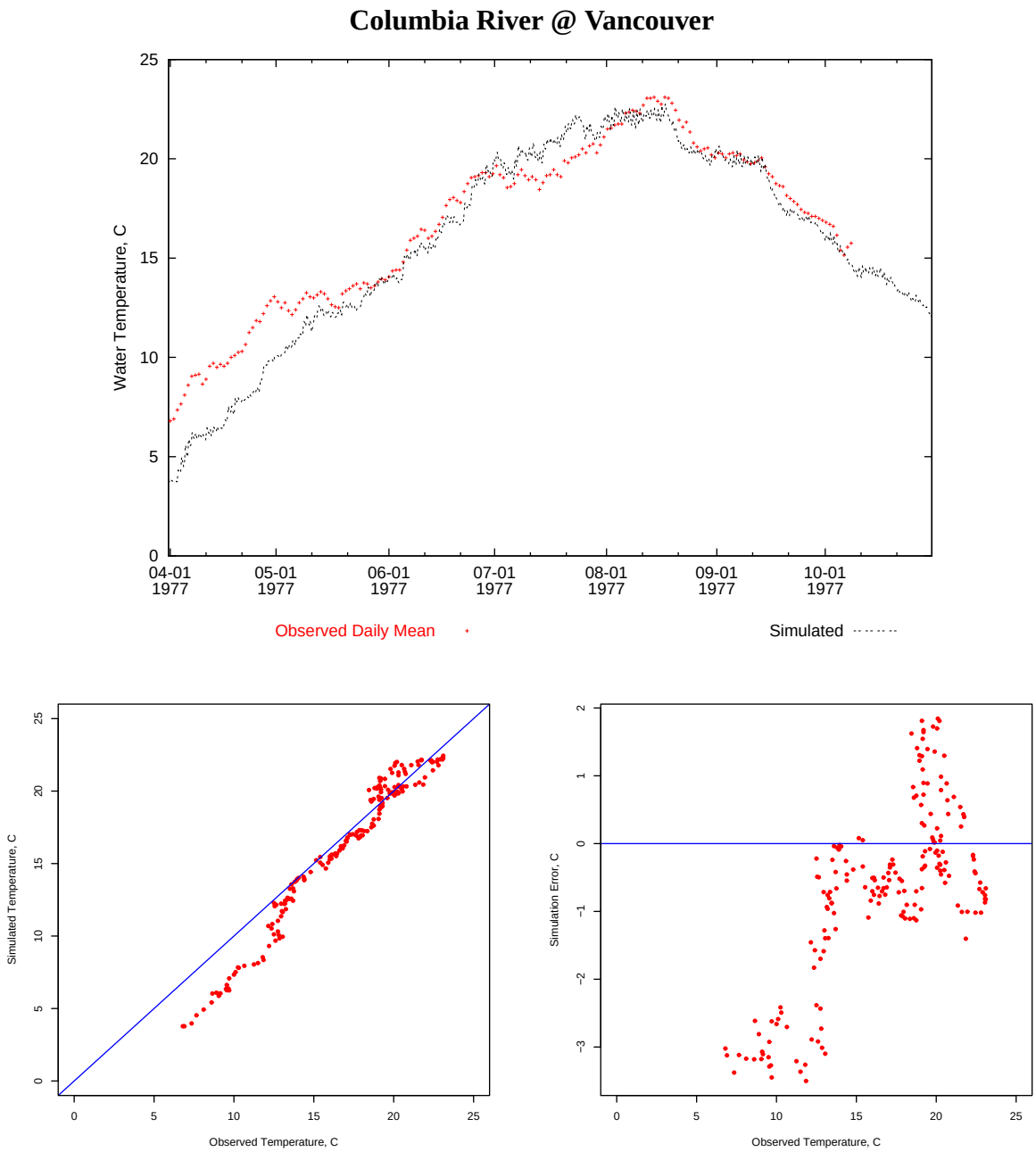

Figure 11: Comparison of simulated and observed daily mean Columbia River temperature at the USGS gage near Vancouver, Washington.

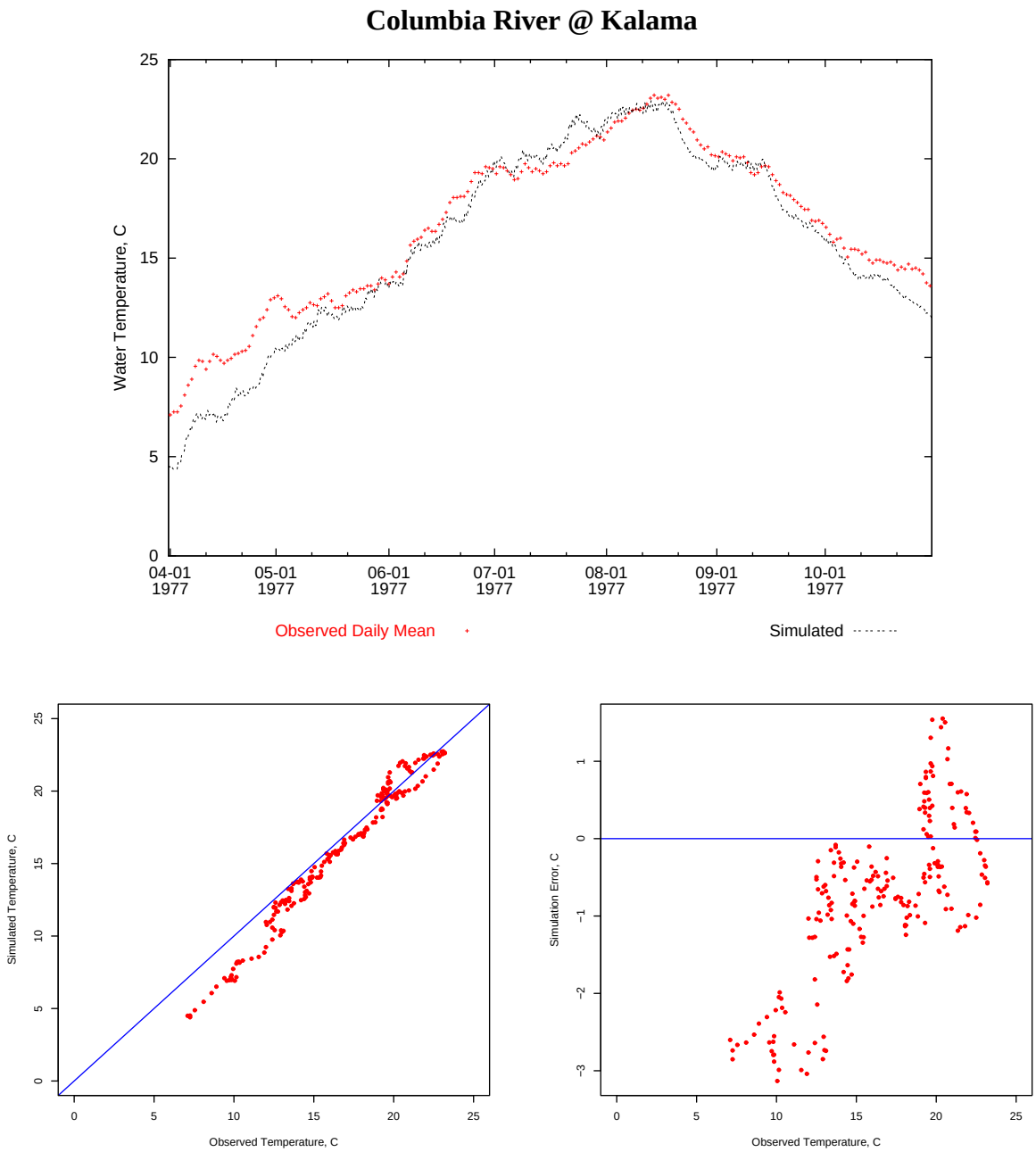

Figure 12: Comparison of simulated and observed daily mean Columbia River temperature at the USGS gage near Kalama, Washington.

2 1994 Weather Scenario

This scenario is the same as the 1977 conditions scenario, except that 1994 weather, from the same stations (Wenatchee, Hanford, Portland), was used. This means that the same water temperatures were used at the boundaries (Grand Coulee and Clearwater and Snake Rivers).

Graphical comparisons to the 1977 conditions scenario at several locations follow. Note that the change in weather conditions only apply within the MASS1 domain, so water temperature differences near model boundaries (Chief Joseph forebay, Figure 13, for example) are very small. Those differences grow as the water travels through the system.

Simulated TDG saturations were very similar to the 1997 conditions, because the same flows were used, that is, there was no spill. Any differences are due to heating and cooling of water within the MASS1 domain.

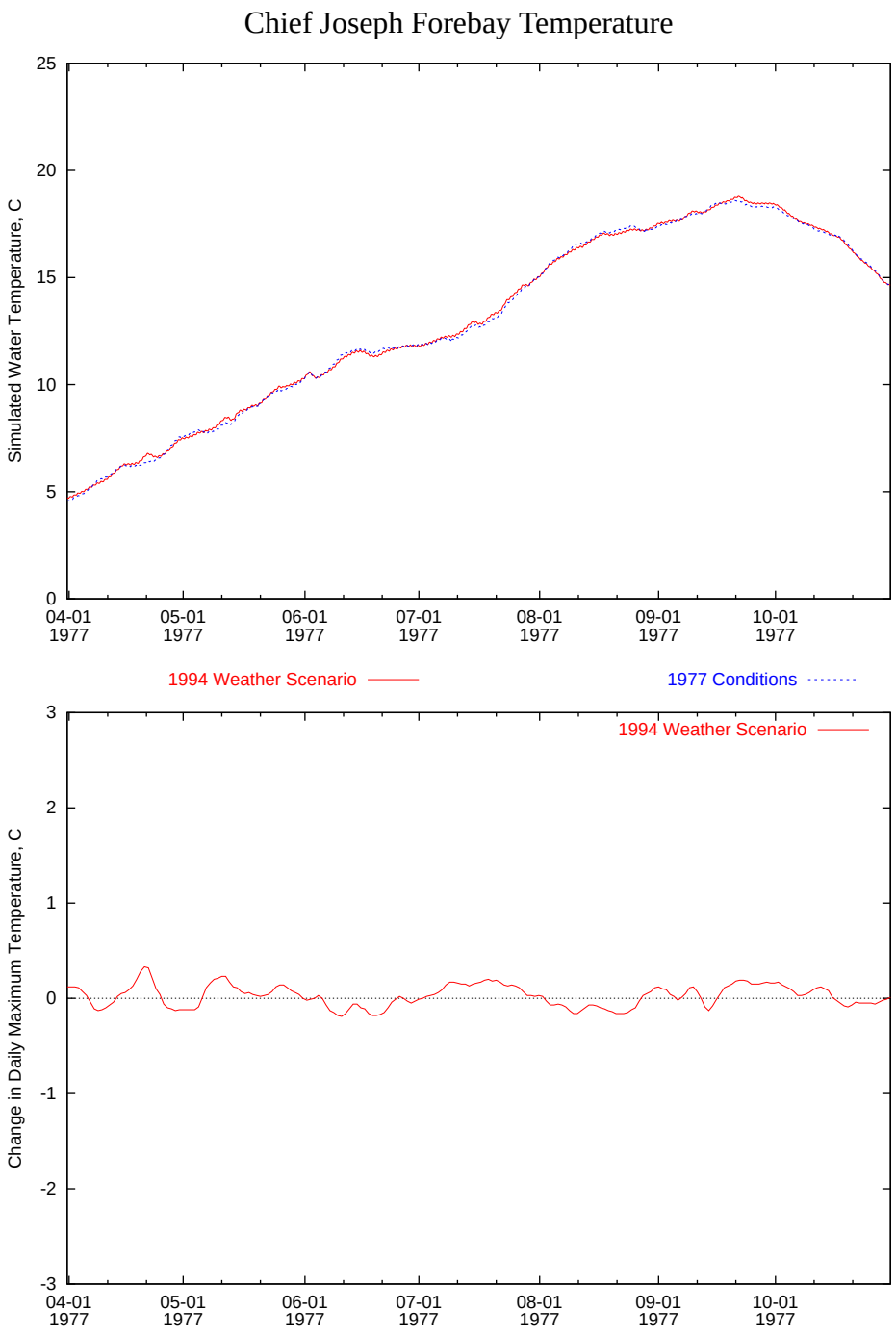

Figure 13: Time series comparison at Chief Joseph forebay of the 1994 weather and 1977 conditions scenario.

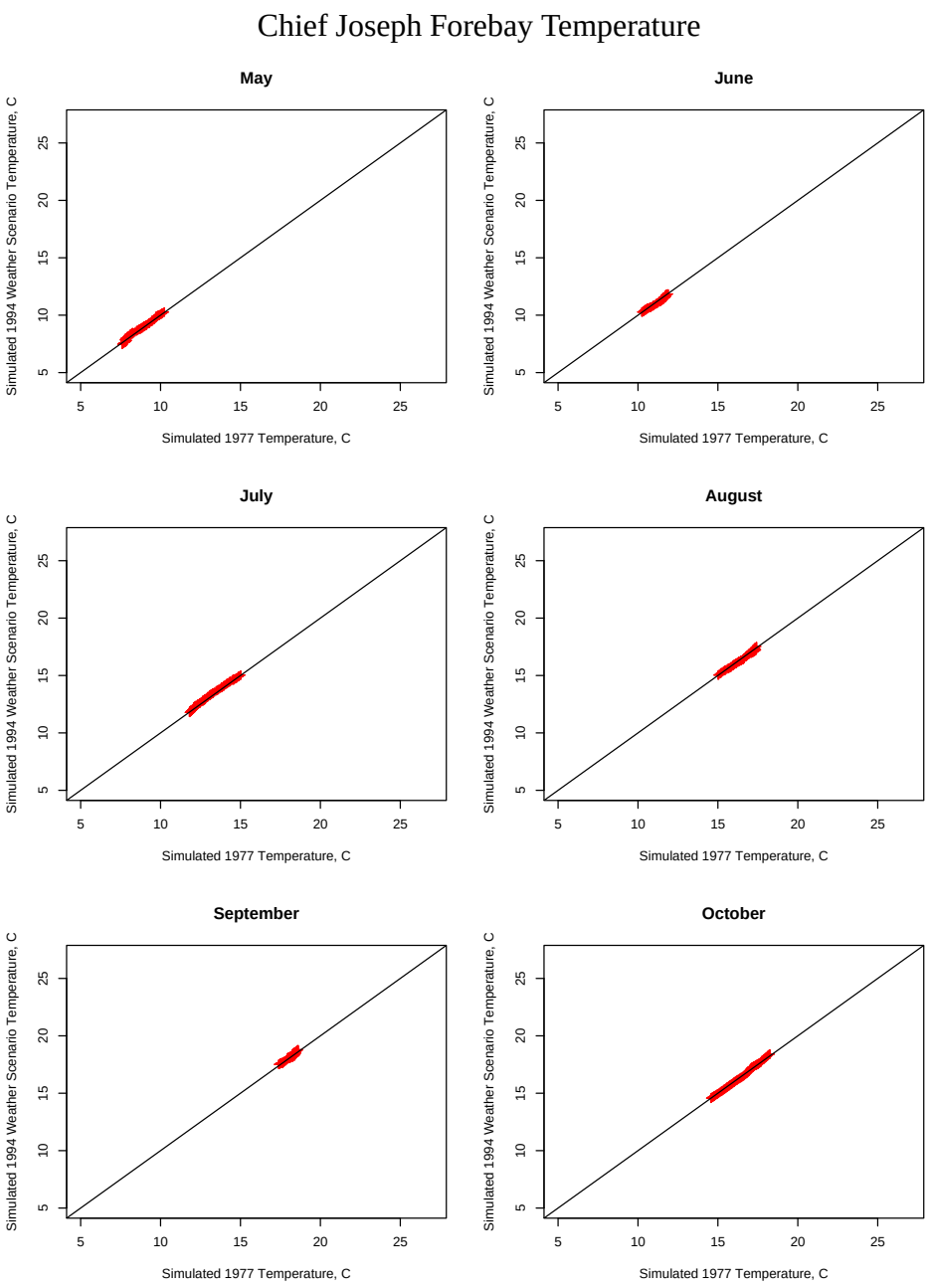

Figure 14: Scatter plot comparison, by month, at Chief Joseph forebay of the 1994 weather and 1977 conditions scenario.

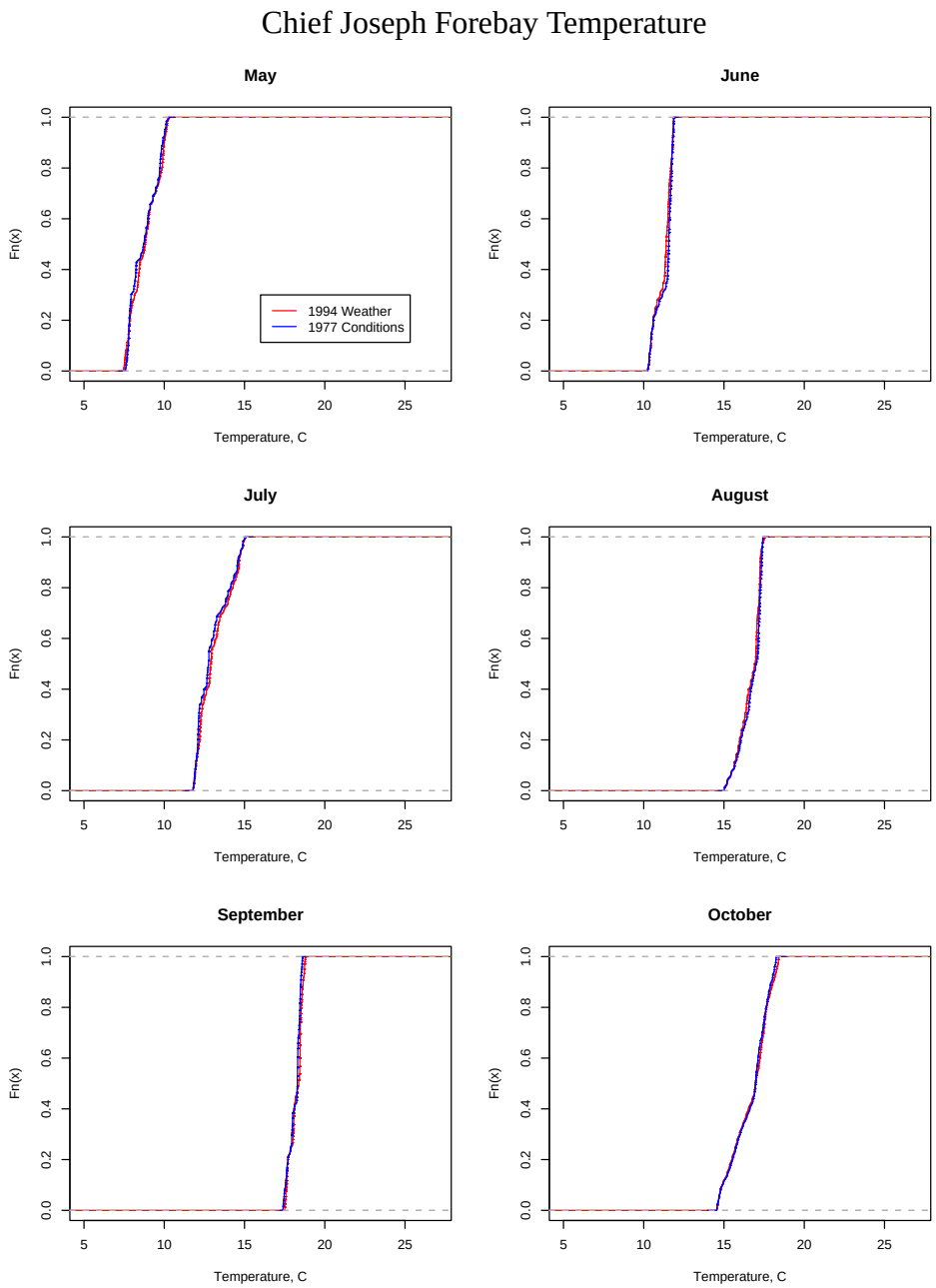

Figure 15: Cumulative frequency distribution (CFD) plot comparison, by month, at Chief Joseph forebay of the 1994 weather and 1977 conditions scenario.

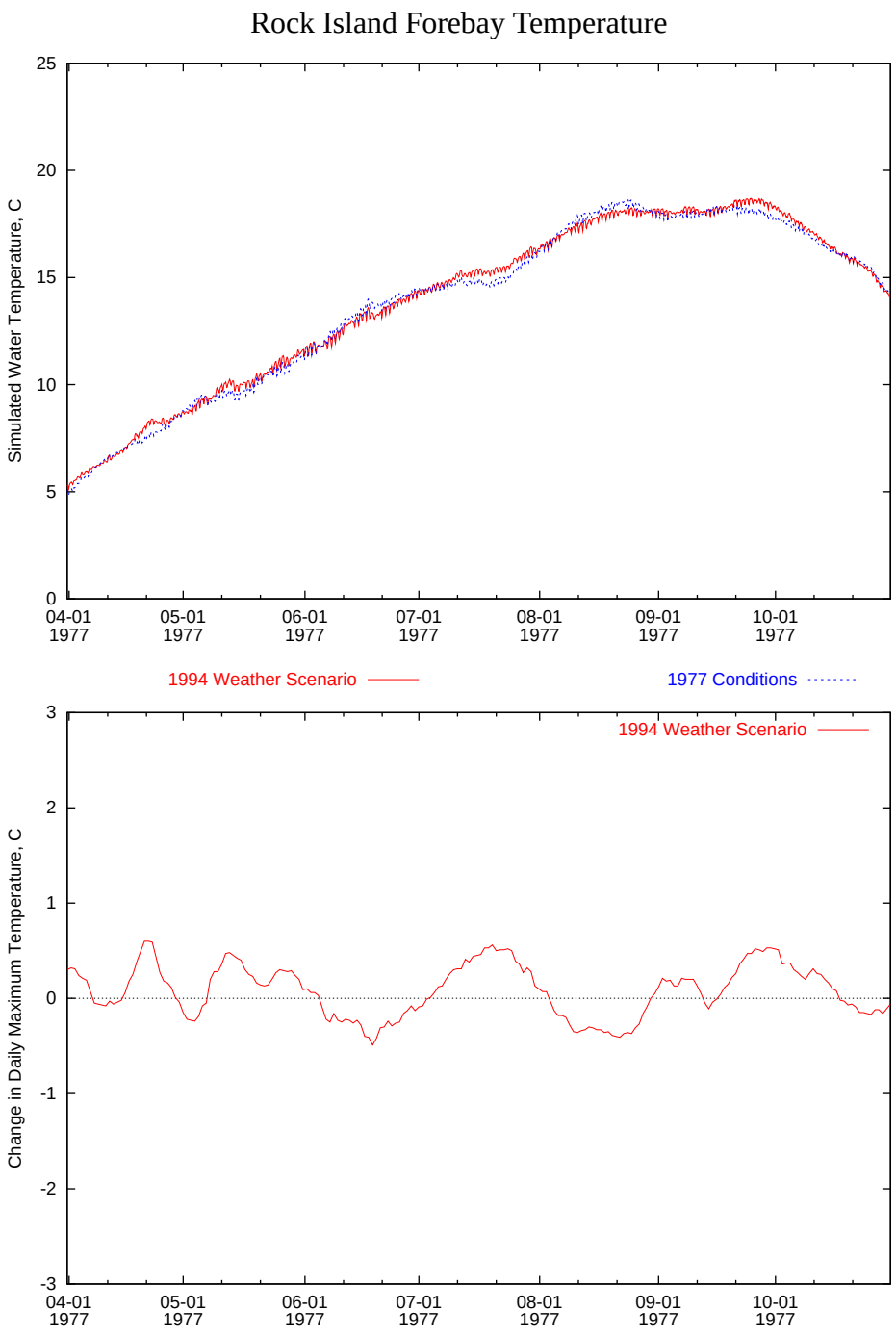

Figure 16: Time series comparison at Rock Island forebay of the 1994 weather and 1977 conditions scenario.

Rock Island Forebay Temperature

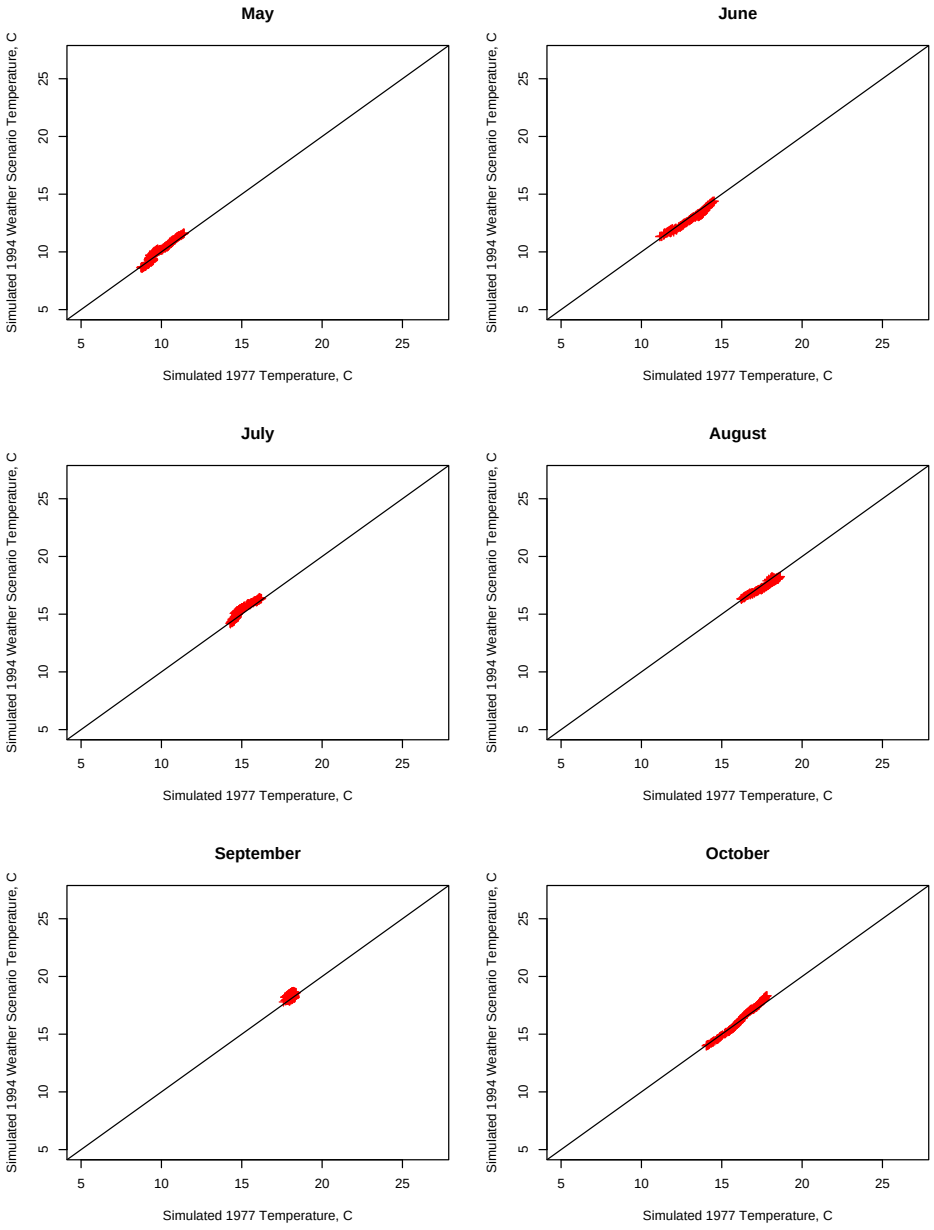

Figure 17: Scatter plot comparison, by month, at Rock Island forebay of the 1994 weather and 1977 conditions scenario.

Rock Island Forebay Temperature

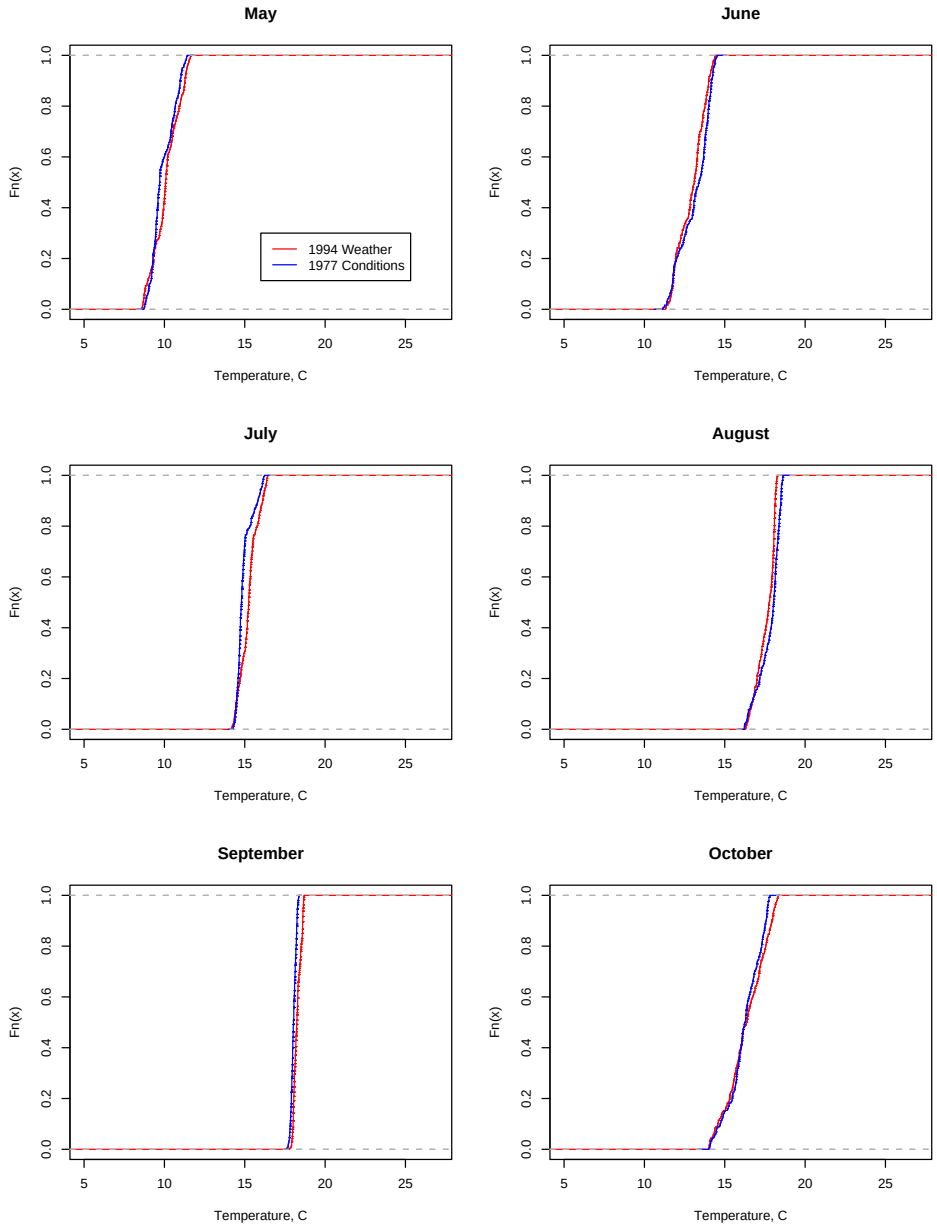

Figure 18: Cumulative frequency distribution (CFD) plot comparison, by month, at Rock Island forebay of the 1994 weather and 1977 conditions scenario.

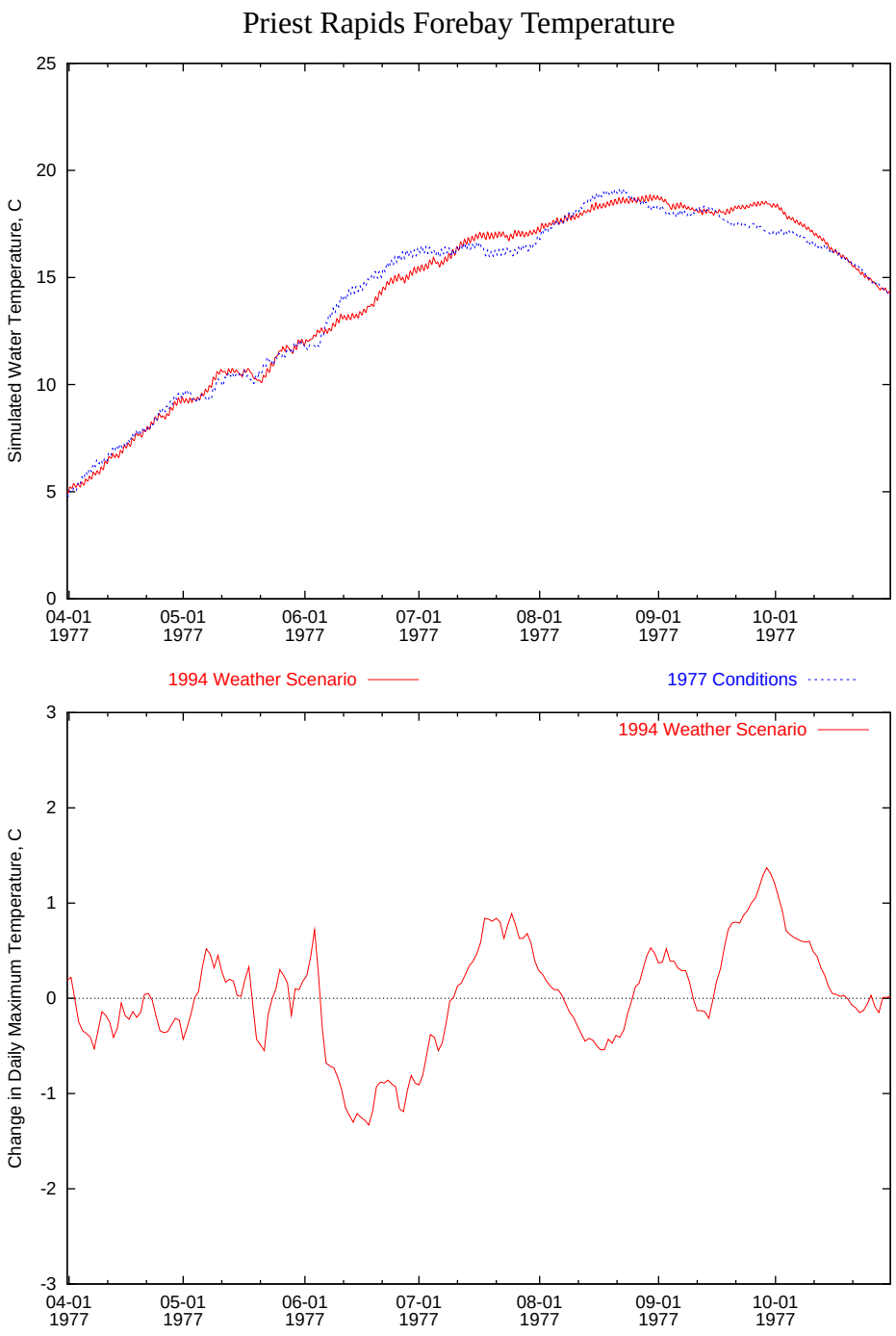

Figure 19: Time series comparison at Priest Rapids forebay of the 1994 weather and 1977 conditions scenario.

Priest Rapids Forebay Temperature

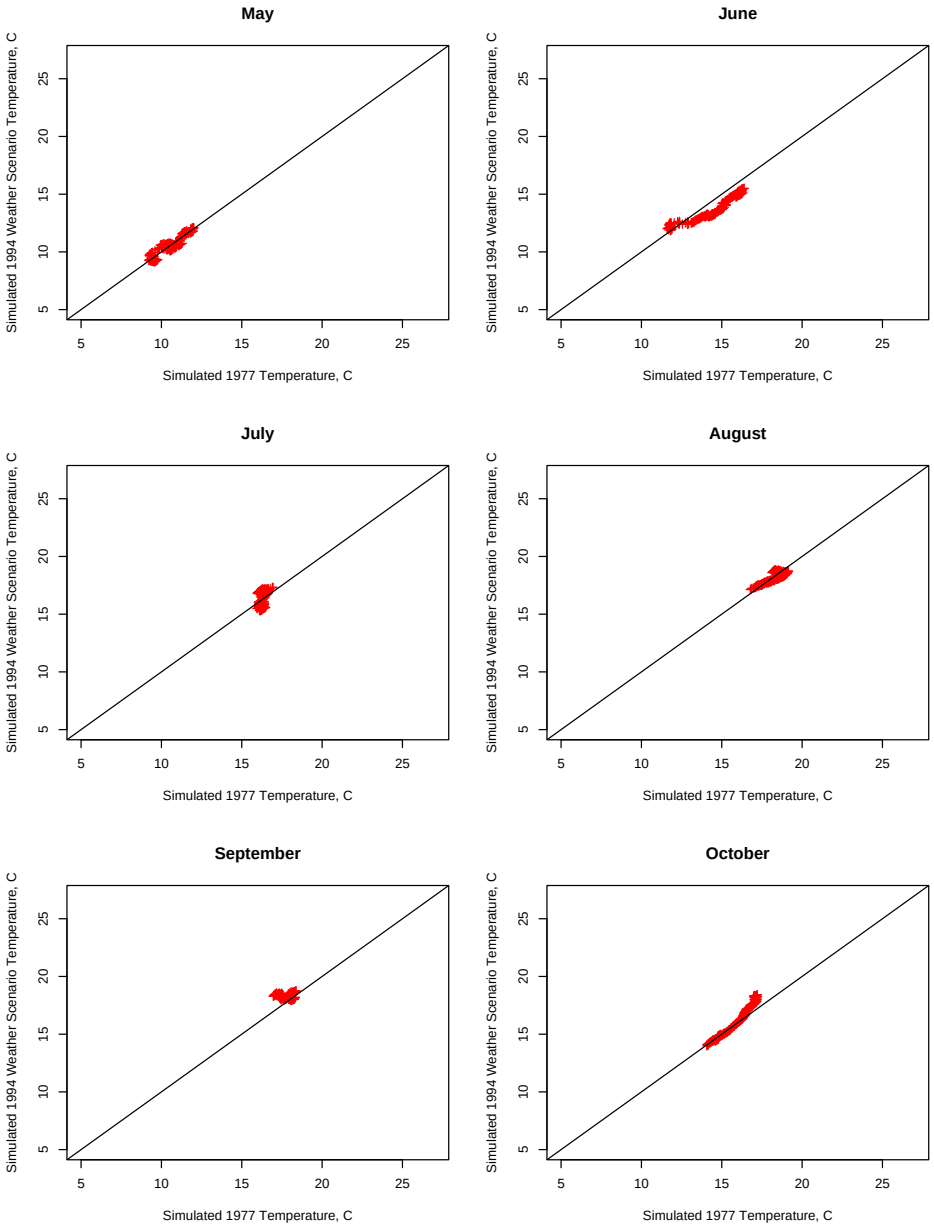

Figure 20: Scatter plot comparison, by month, at Priest Rapids forebay of the 1994 weather and 1977 conditions scenario.

Priest Rapids Forebay Temperature

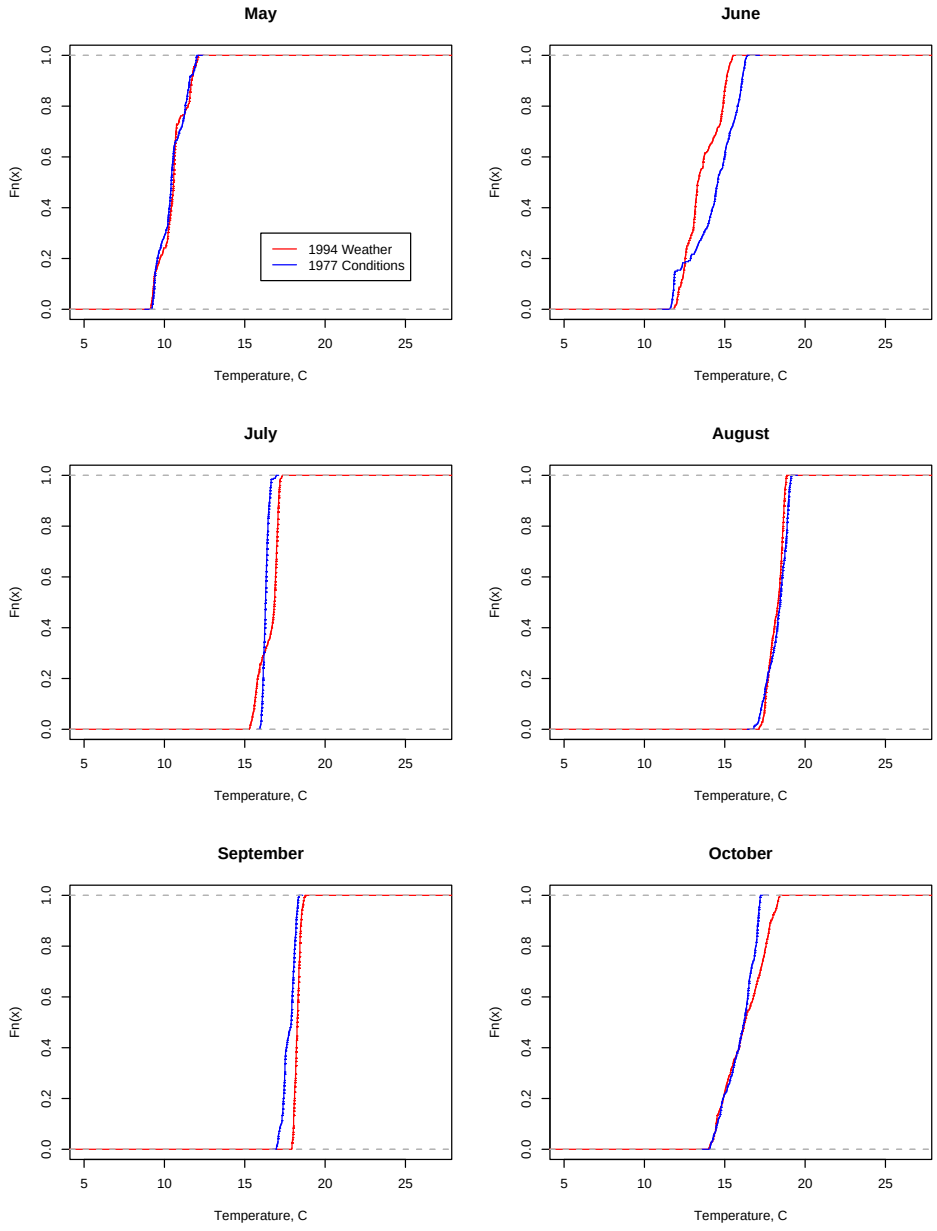

Figure 21: Cumulative frequency distribution (CFD) plot comparison, by month, at Priest Rapids forebay of the 1994 weather and 1977 conditions scenario.

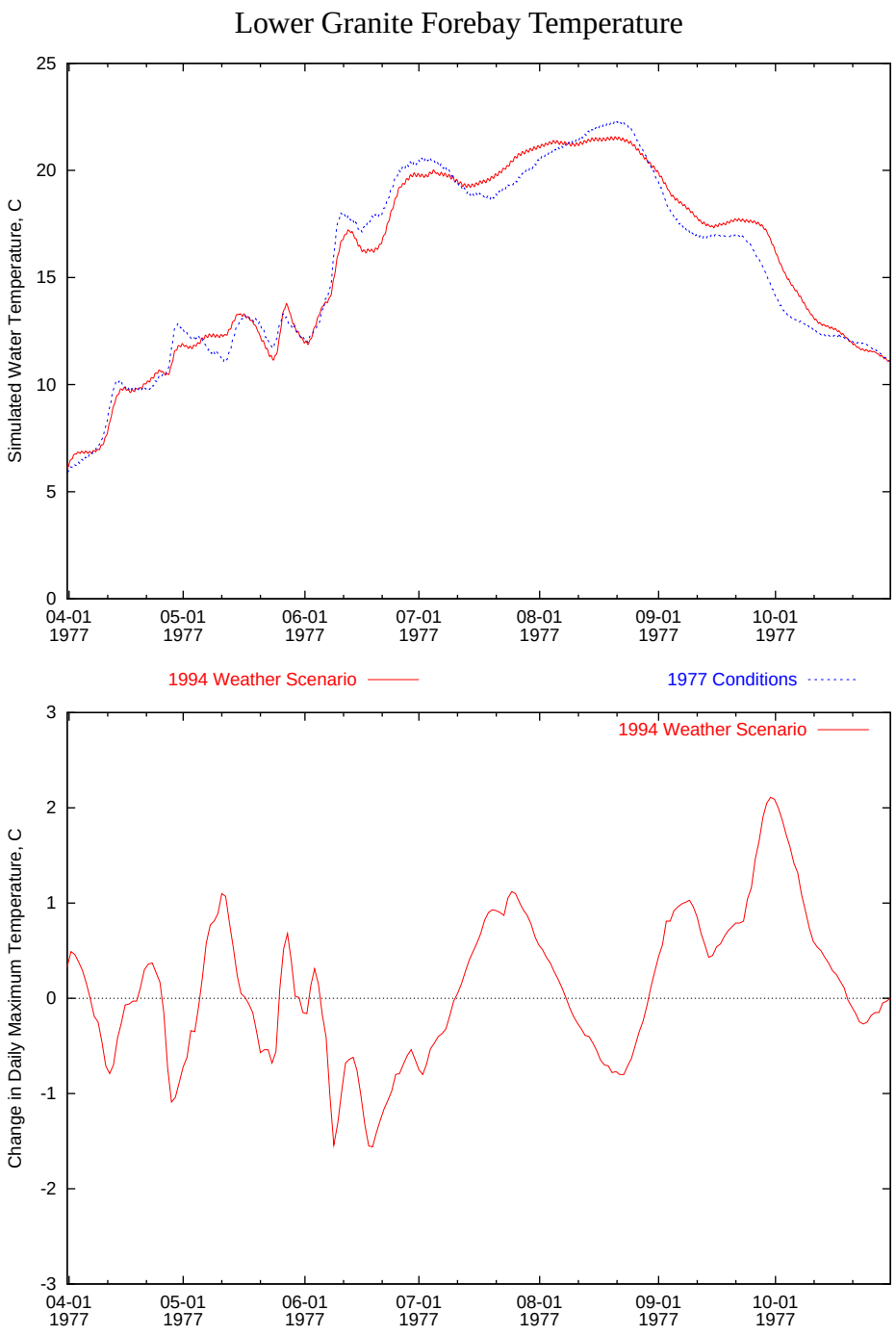

Figure 22: Time series comparison at Lower Granite forebay of the 1994 weather and 1977 conditions scenario.

Lower Granite Forebay Temperature

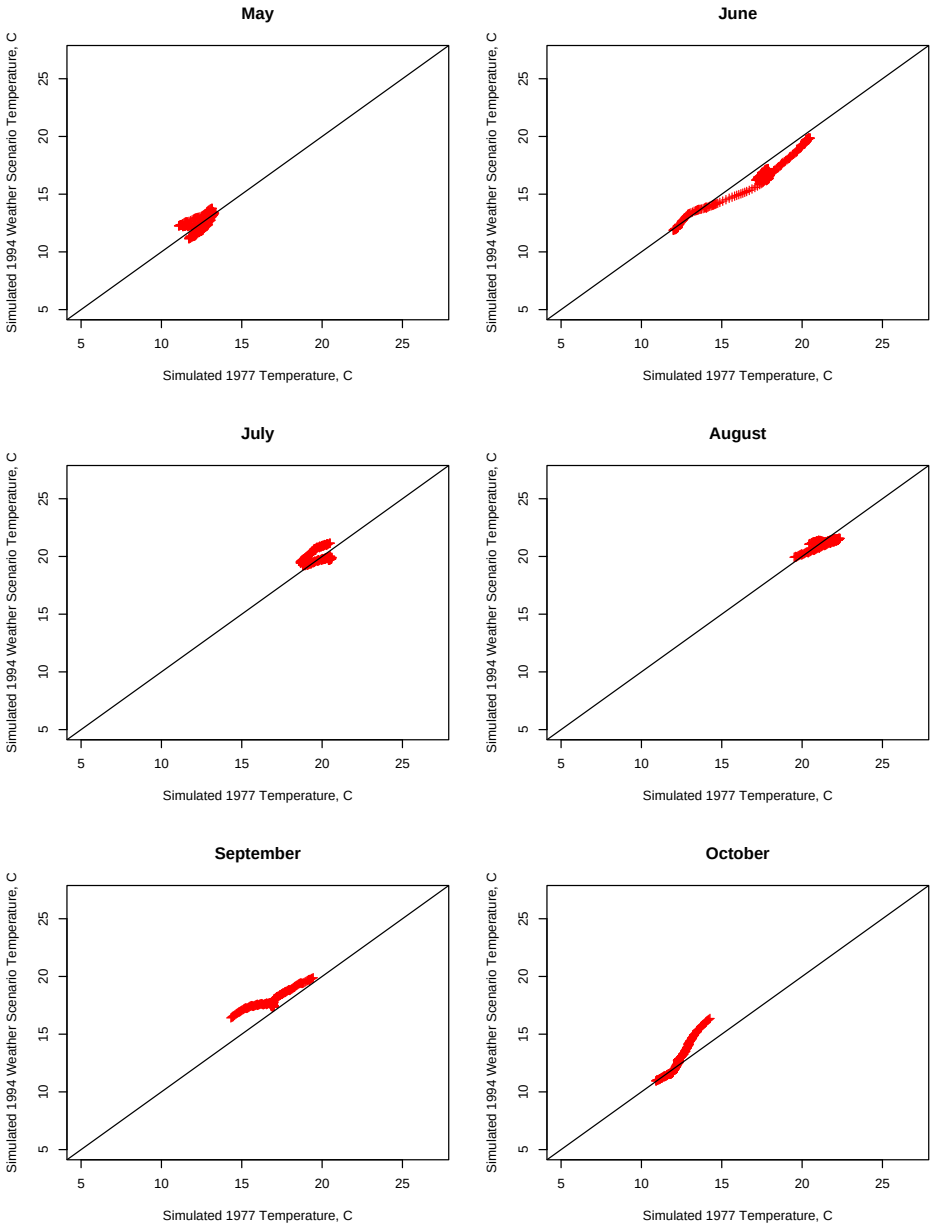

Figure 23: Scatter plot comparison, by month, at Lower Granite forebay of the 1994 weather and 1977 conditions scenario.

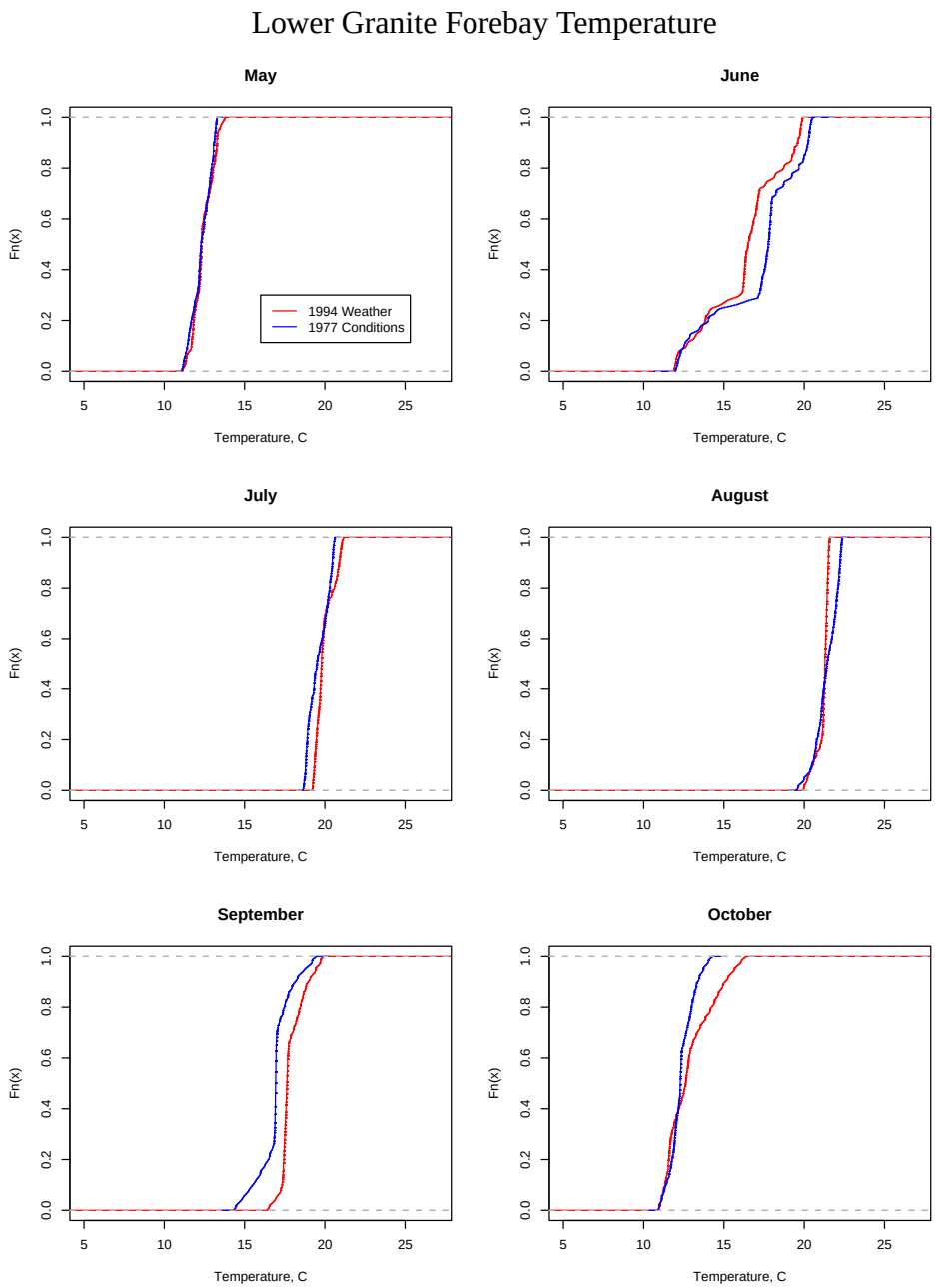

Figure 24: Cumulative frequency distribution (CFD) plot comparison, by month, at Lower Granite forebay of the 1994 weather and 1977 conditions scenario.

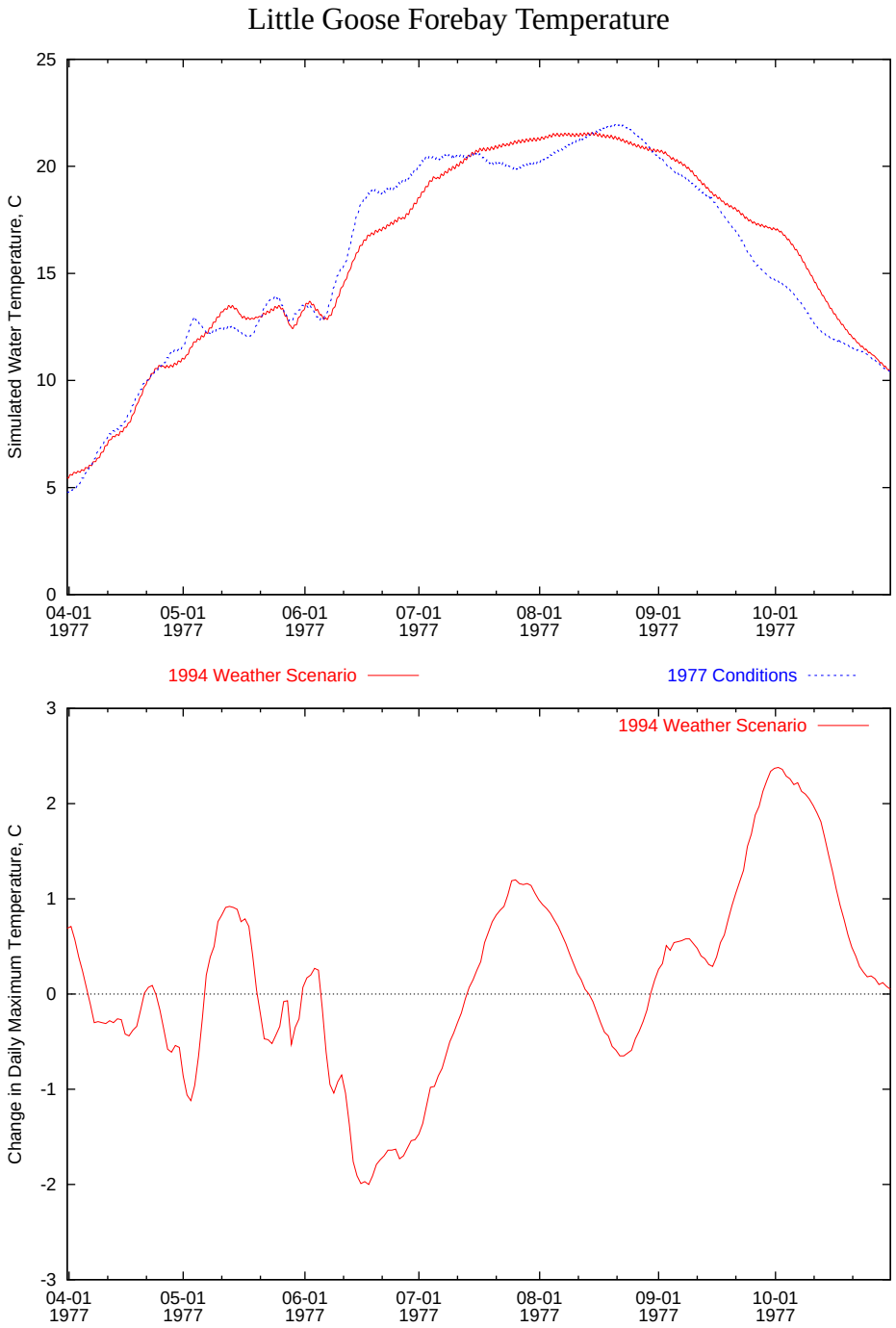

Figure 25: Time series comparison temperature in the Little Goose forebay for the 1994 weather and 1977 conditions scenario.

Little Goose Forebay Temperature

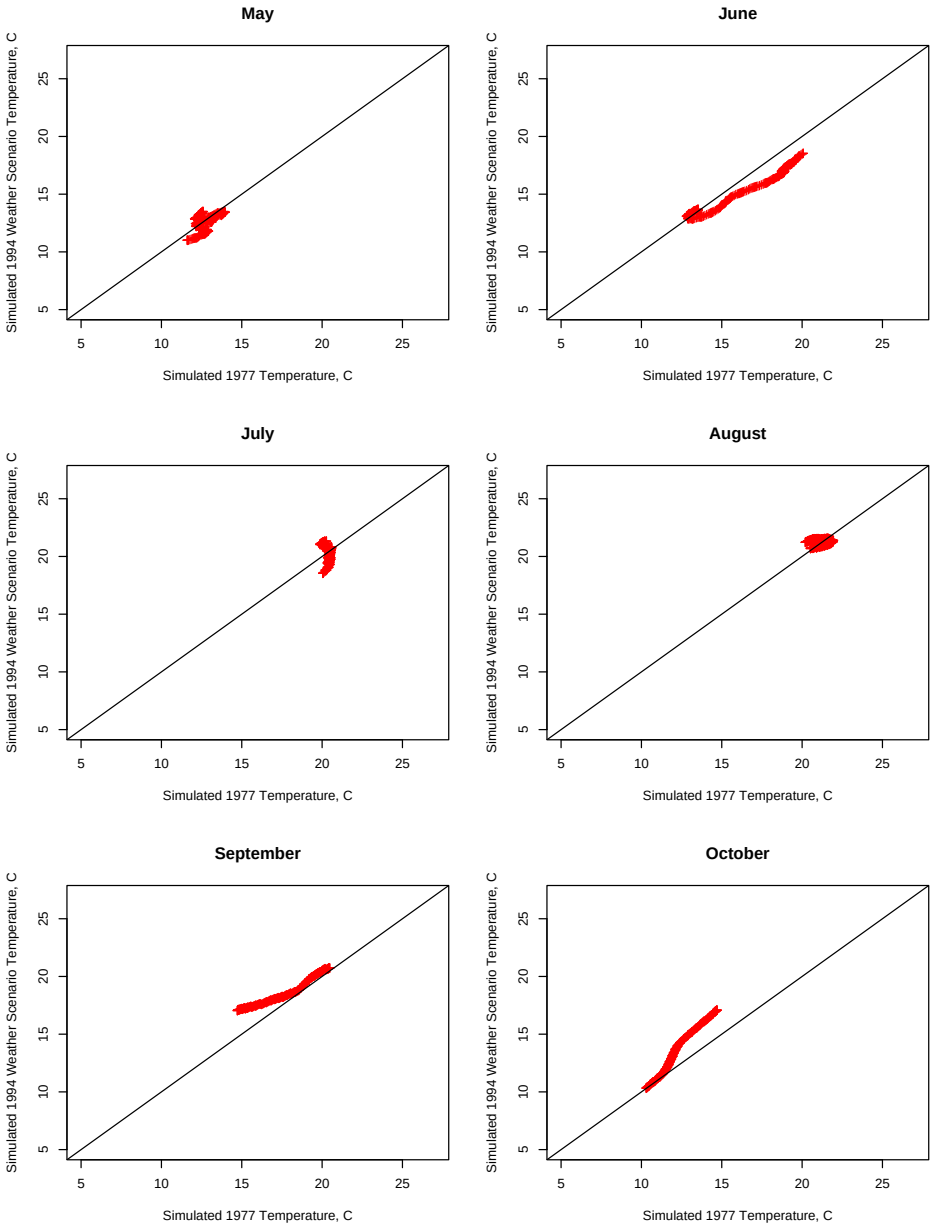

Figure 26: Scatter plot comparison, by month, of temperature in the Little Goose forebay for the 1994 weather and 1977 conditions scenario.

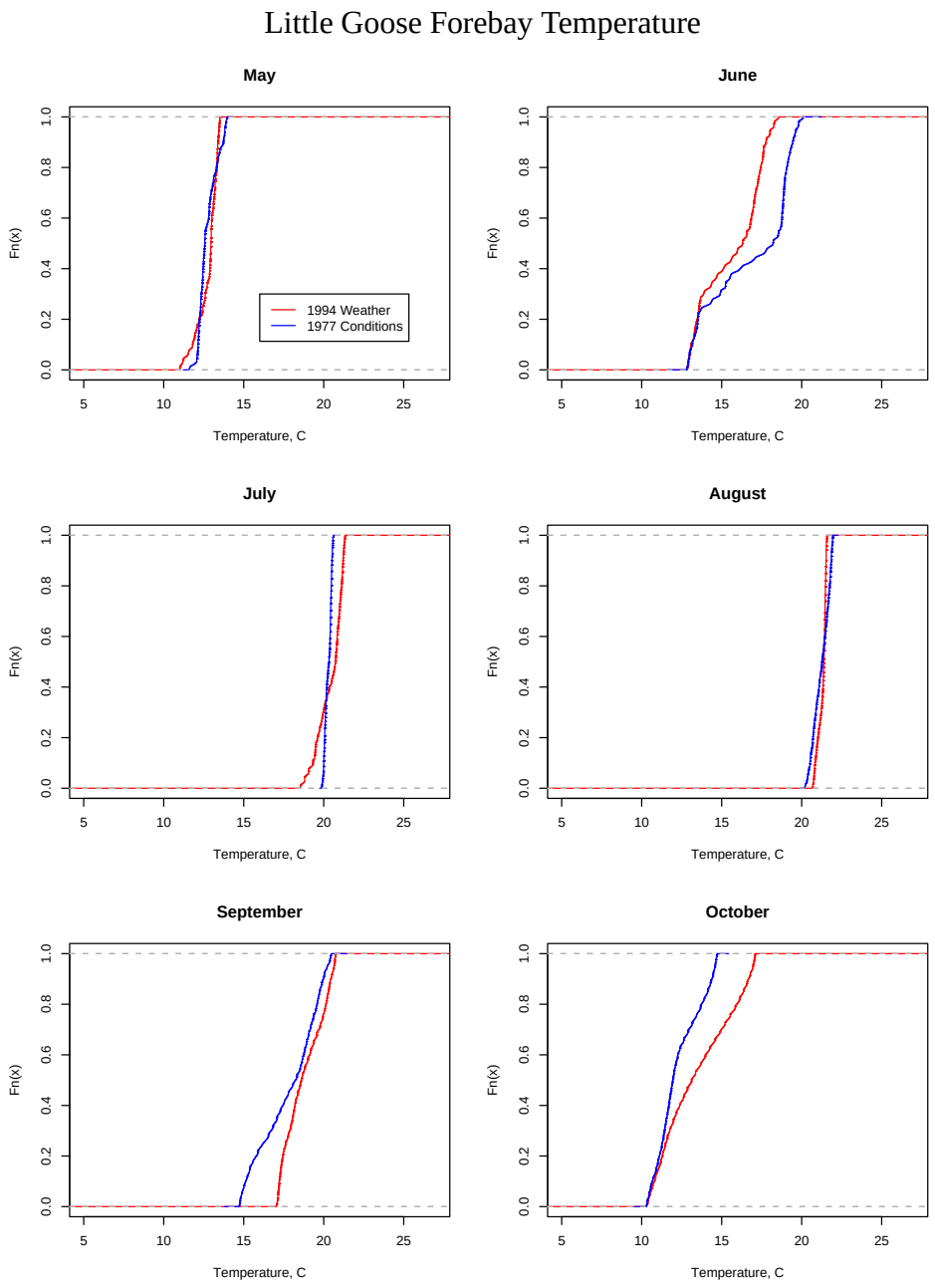

Figure 27: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature in the Little Goose forebay for the 1994 weather and 1977 conditions scenario.

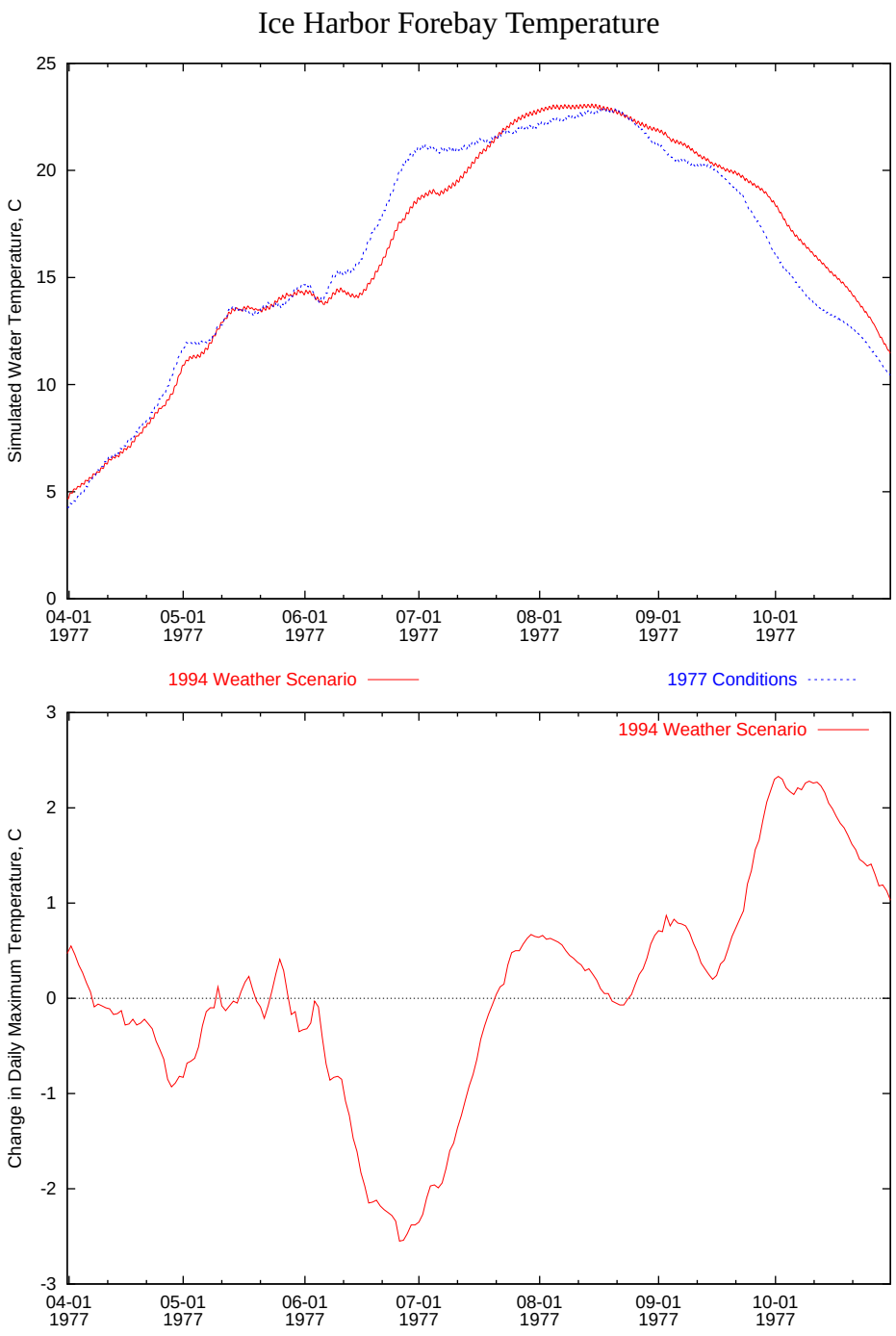

Figure 28: Time series comparison at Ice Harbor forebay of the 1994 weather and 1977 conditions scenario.

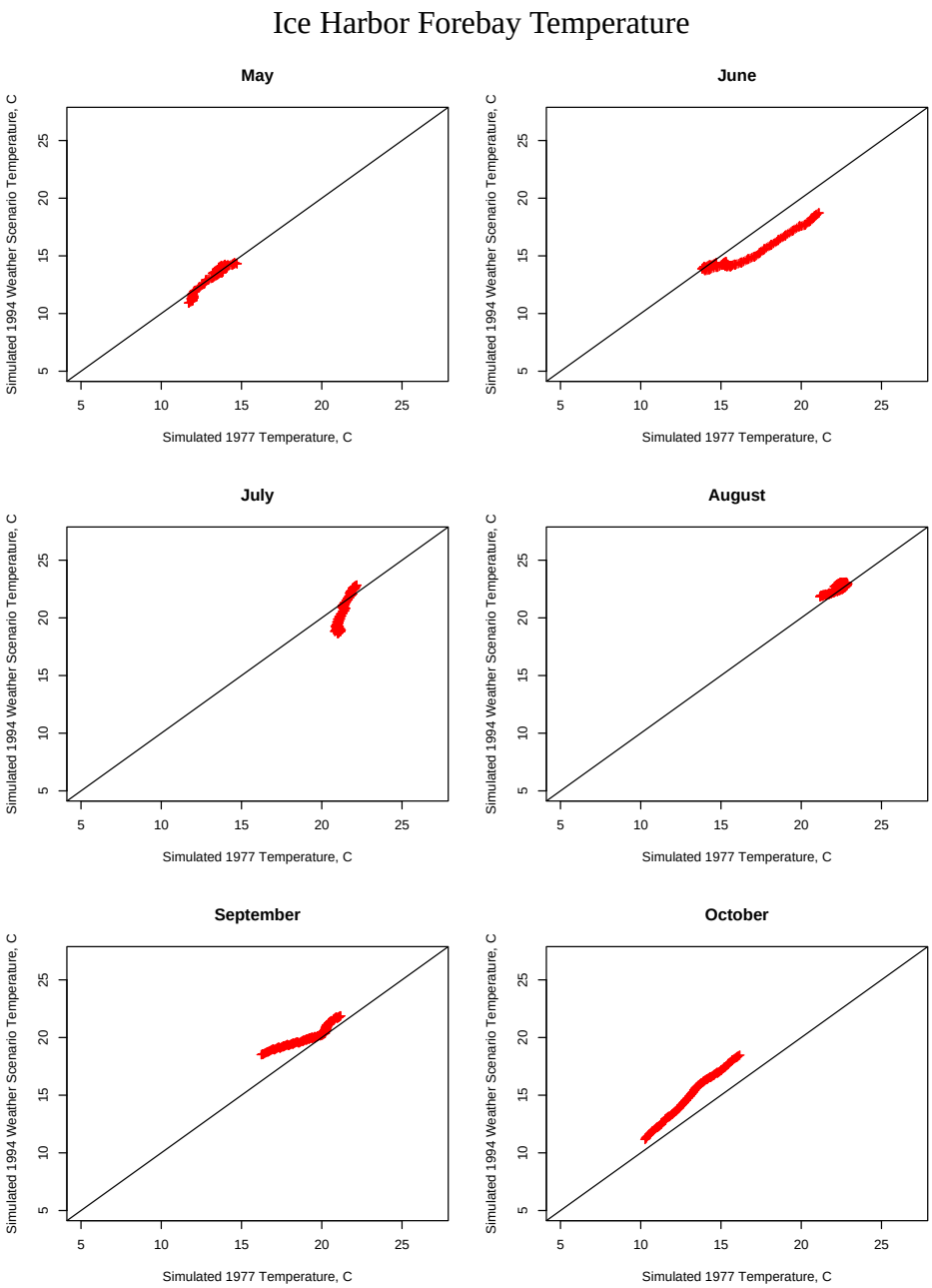

Figure 29: Scatter plot comparison, by month, at Ice Harbor forebay of the 1994 weather and 1977 conditions scenario.

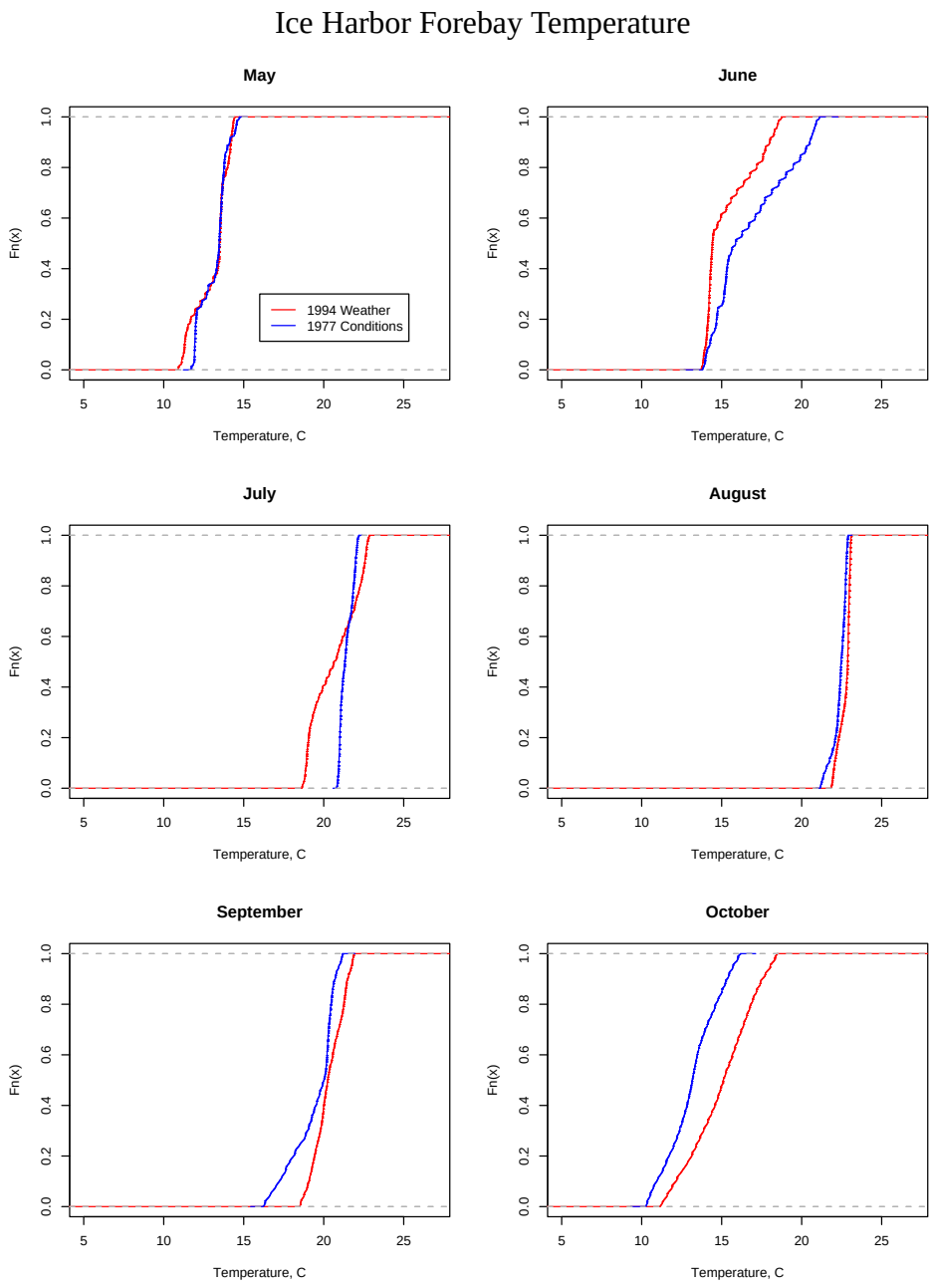

Figure 30: Cumulative frequency distribution (CFD) plot comparison, by month, at Ice Harbor forebay of the 1994 weather and 1977 conditions scenario.

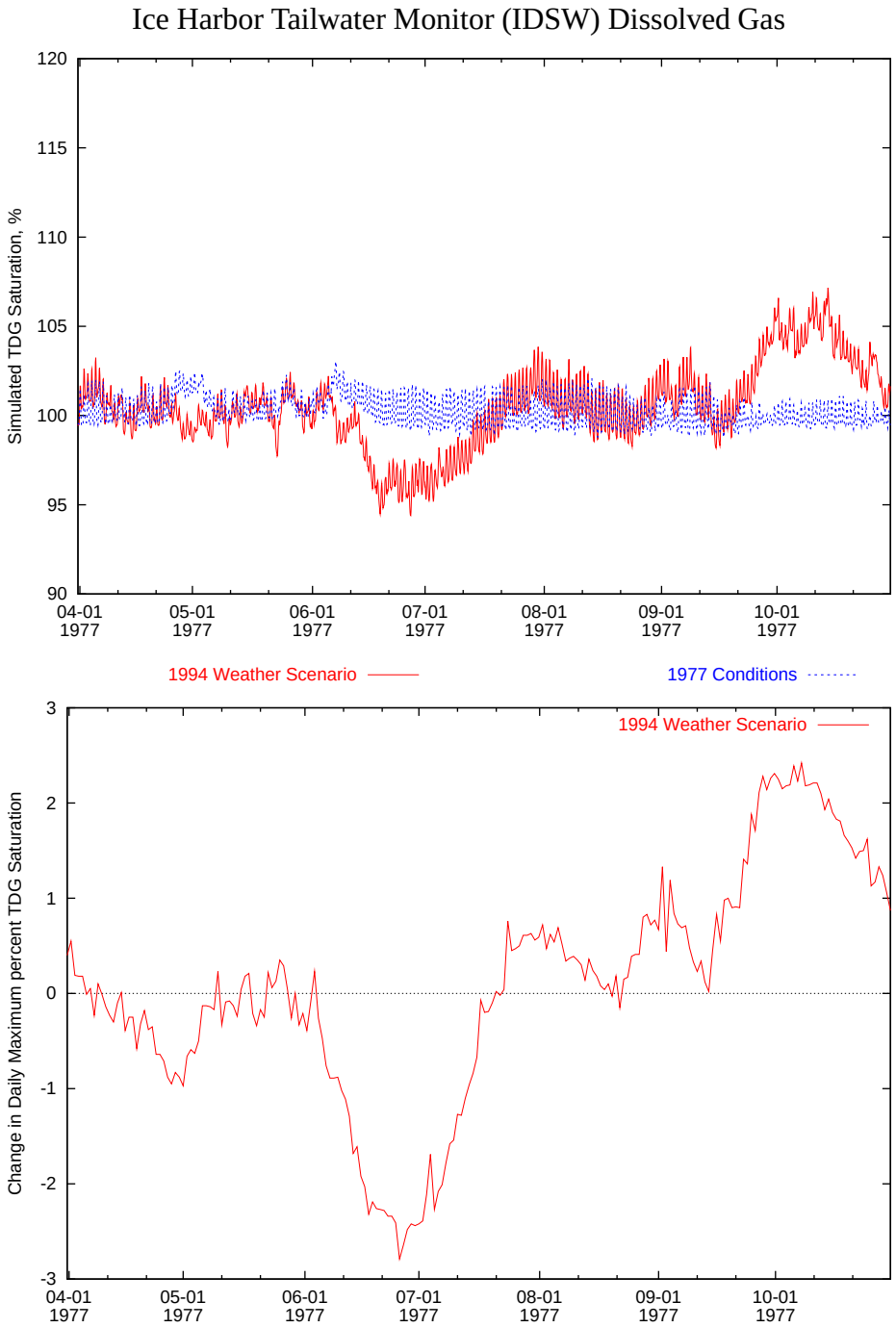

Figure 31: Time series comparison of TDG saturatio at the Ice Harbor tailwater monitor in the 1994 weather and 1977 conditions scenario.

Ice Harbor Tailwater Monitor (IDSW) Dissolved Gas

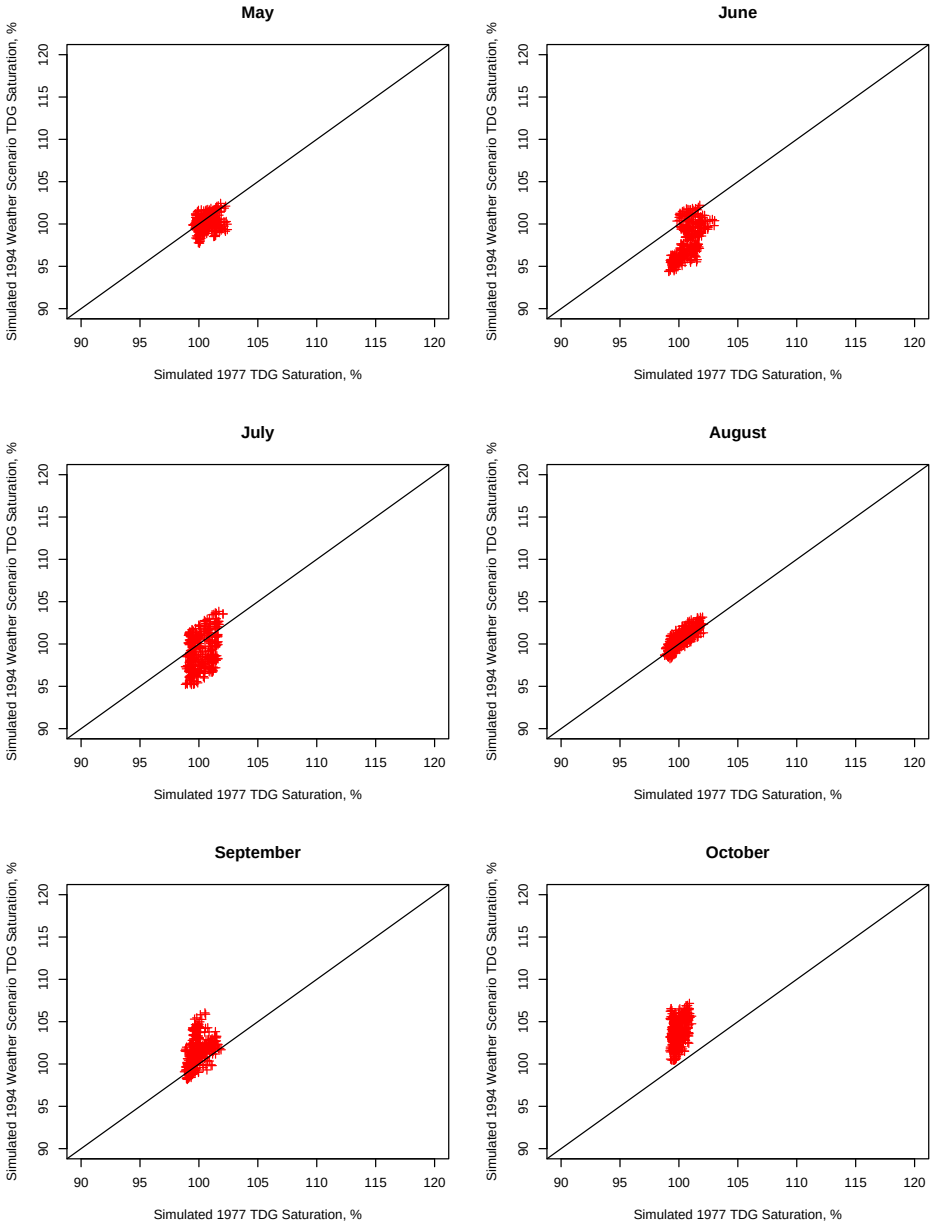

Figure 32: Scatter plot comparison, by month, of TDG saturation at the Ice Harbor tailwater monitor in the 1994 weather and 1977 conditions scenario.

Ice Harbor Tailwater Monitor (IDSW) Dissolved Gas

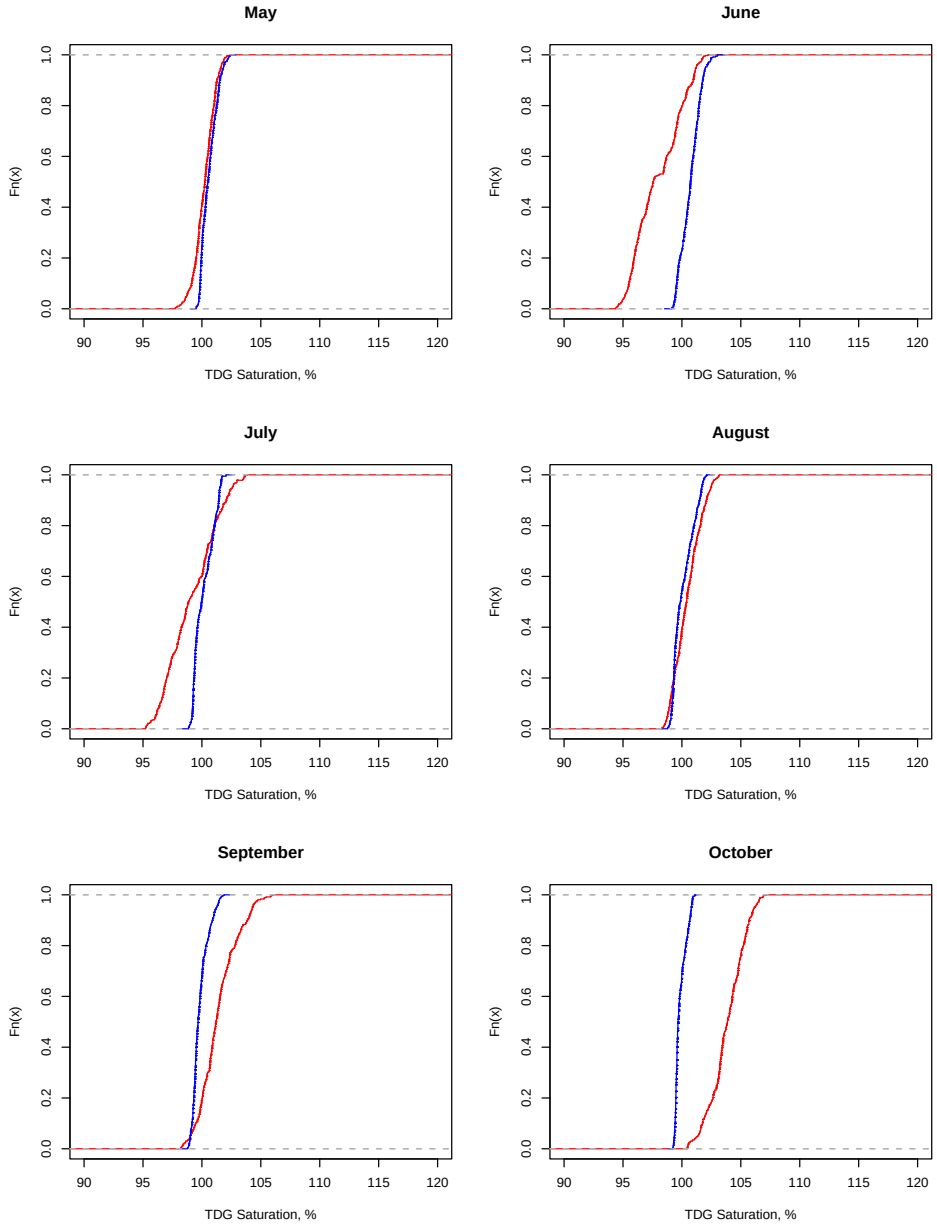

Figure 33: Cumulative frequency distribution (CFD) plot comparison, by month, of TDG saturation at the Ice Harbor tailwater monitor in the 1994 weather and 1977 conditions scenario.

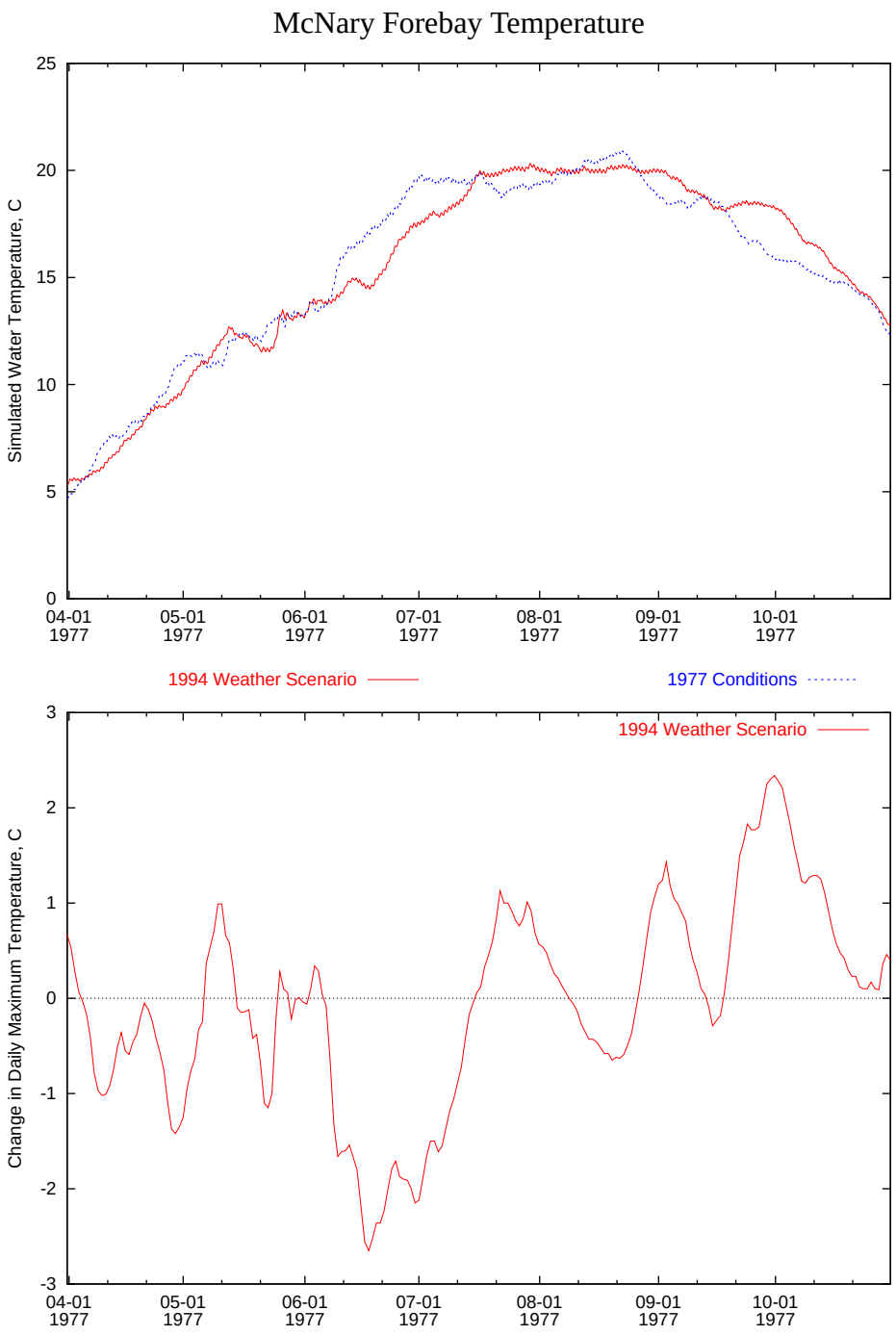

Figure 34: Time series comparison at McNary forebay of the 1994 weather and 1977 conditions scenario.

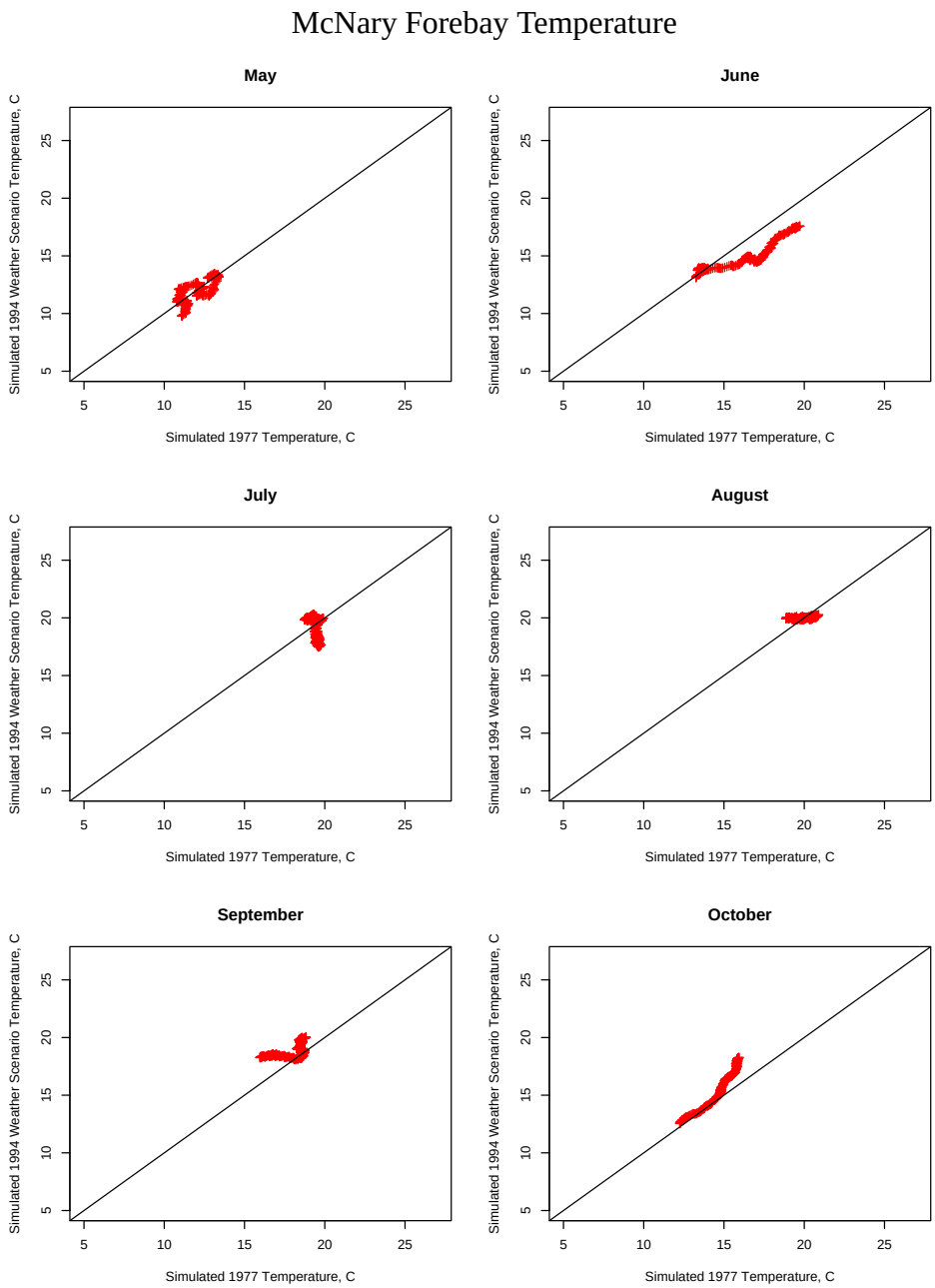

Figure 35: Scatter plot comparison, by month, at McNary forebay of the 1994 weather and 1977 conditions scenario.

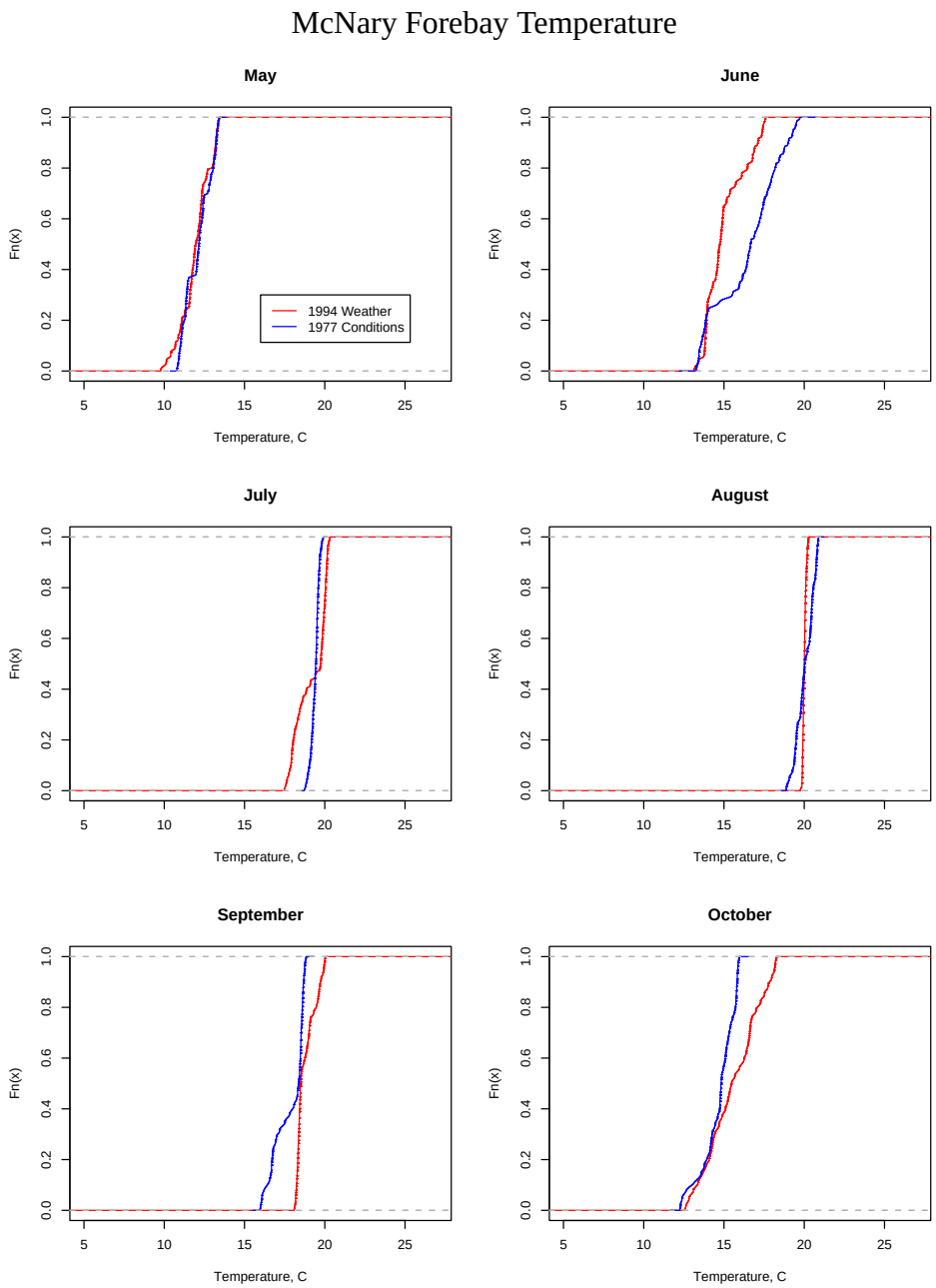

Figure 36: Cumulative frequency distribution (CFD) plot comparison, by month, at McNary forebay of the 1994 weather and 1977 conditions scenario.

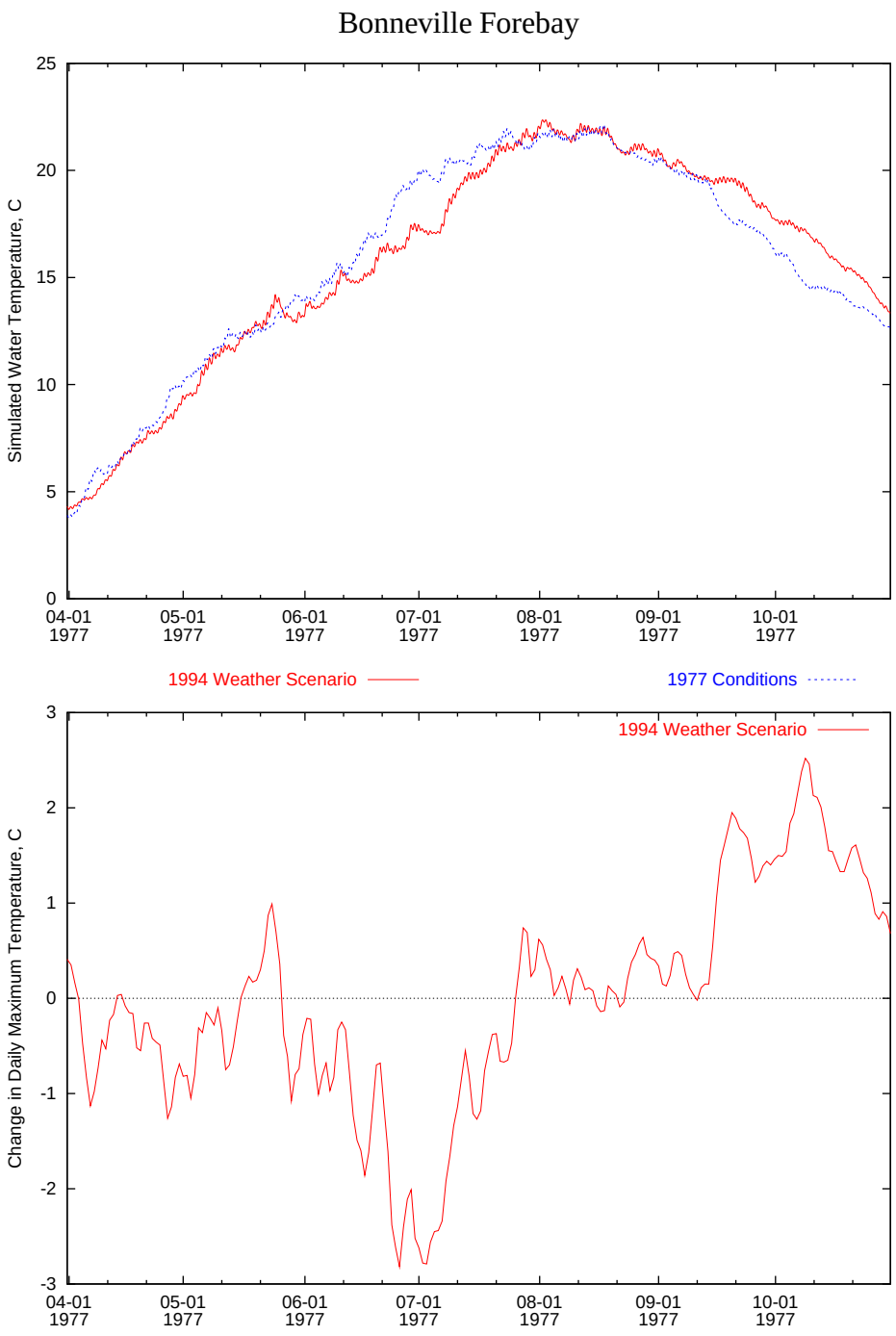

Figure 37: Time series comparison at Bonneville forebay of the 1994 weather and 1977 conditions scenario.

Bonneville Forebay

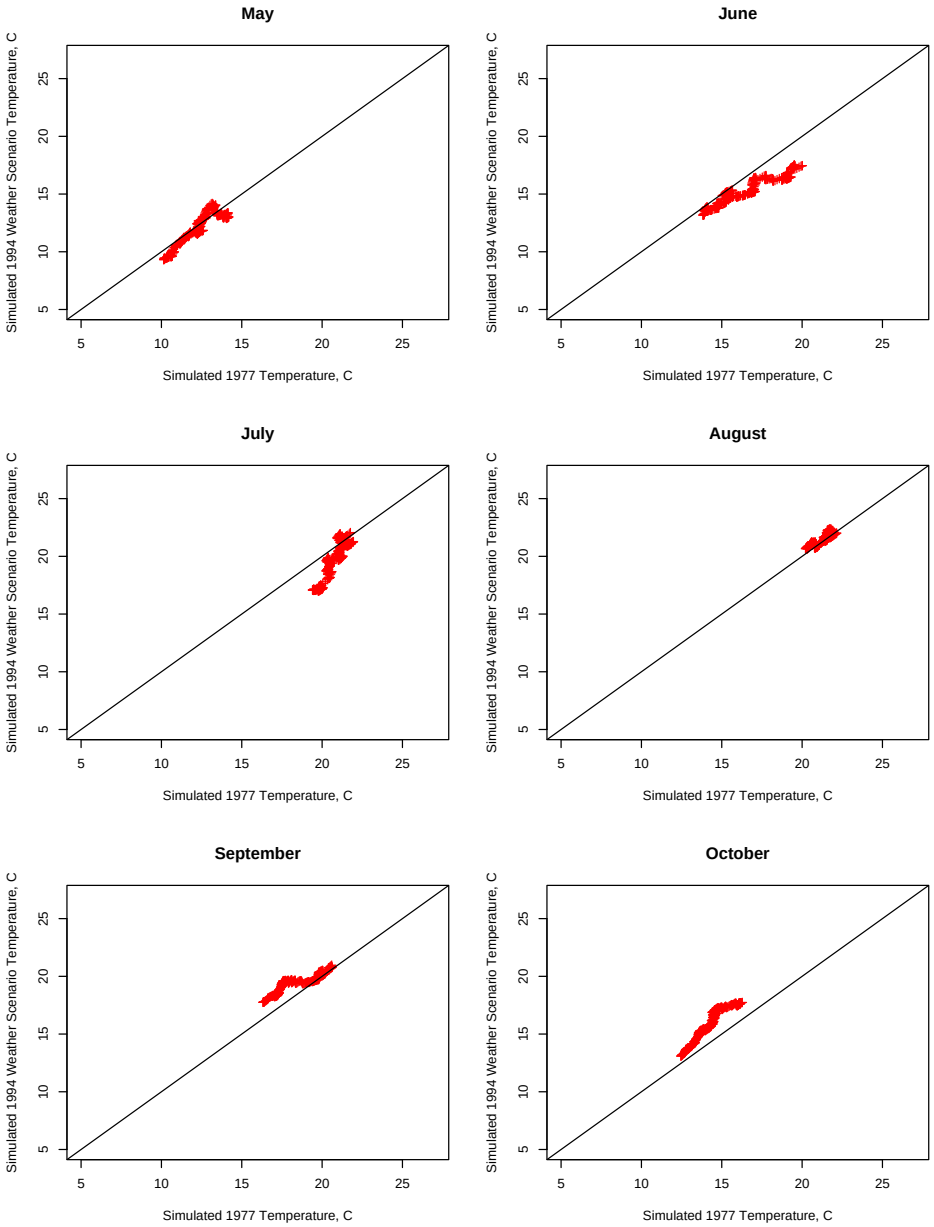

Figure 38: Scatter plot comparison, by month, at Bonneville forebay of the 1994 weather and 1977 conditions scenario.

Bonneville Forebay

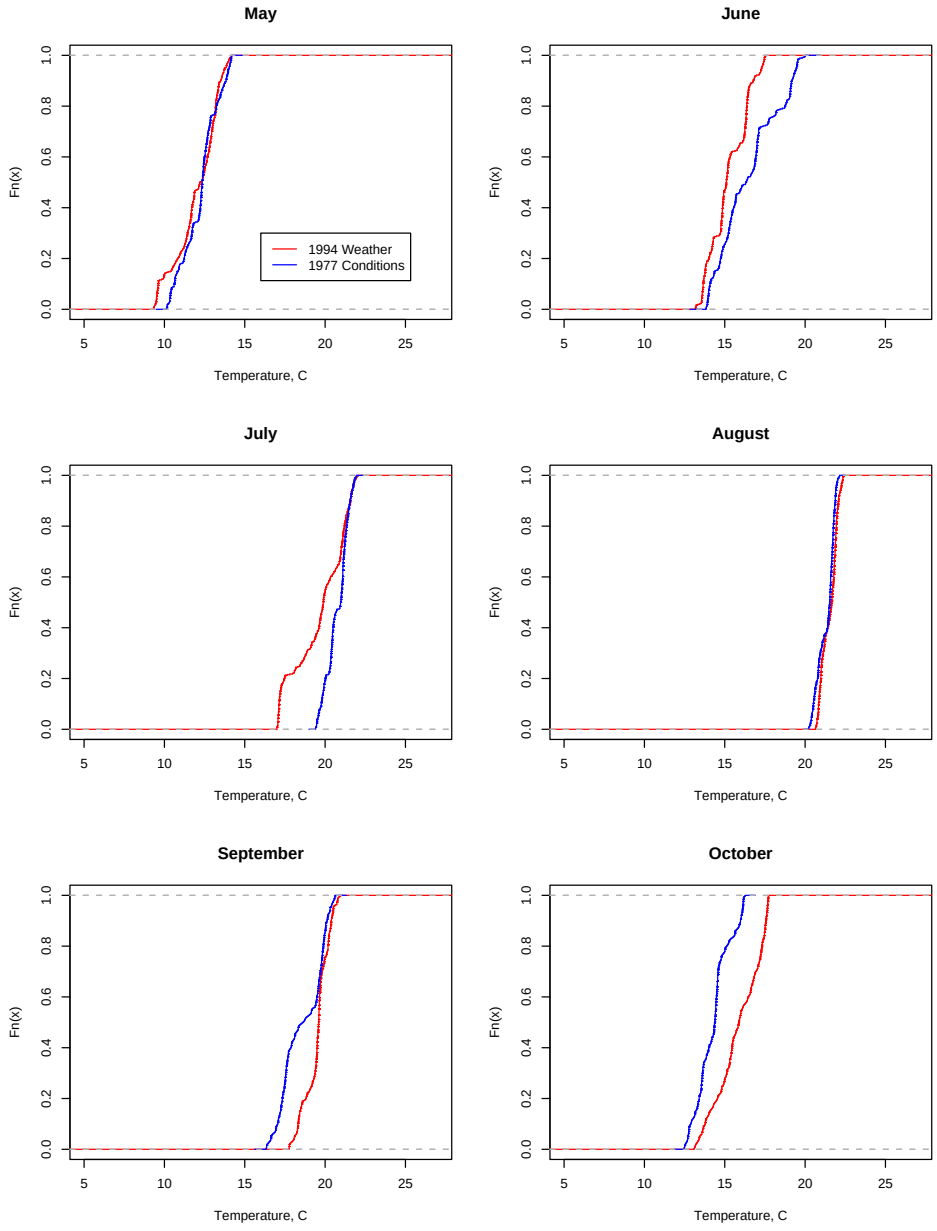

Figure 39: Cumulative frequency distribution (CFD) plot comparison, by month, at Bonneville forebay of the 1994 weather and 1977 conditions scenario.

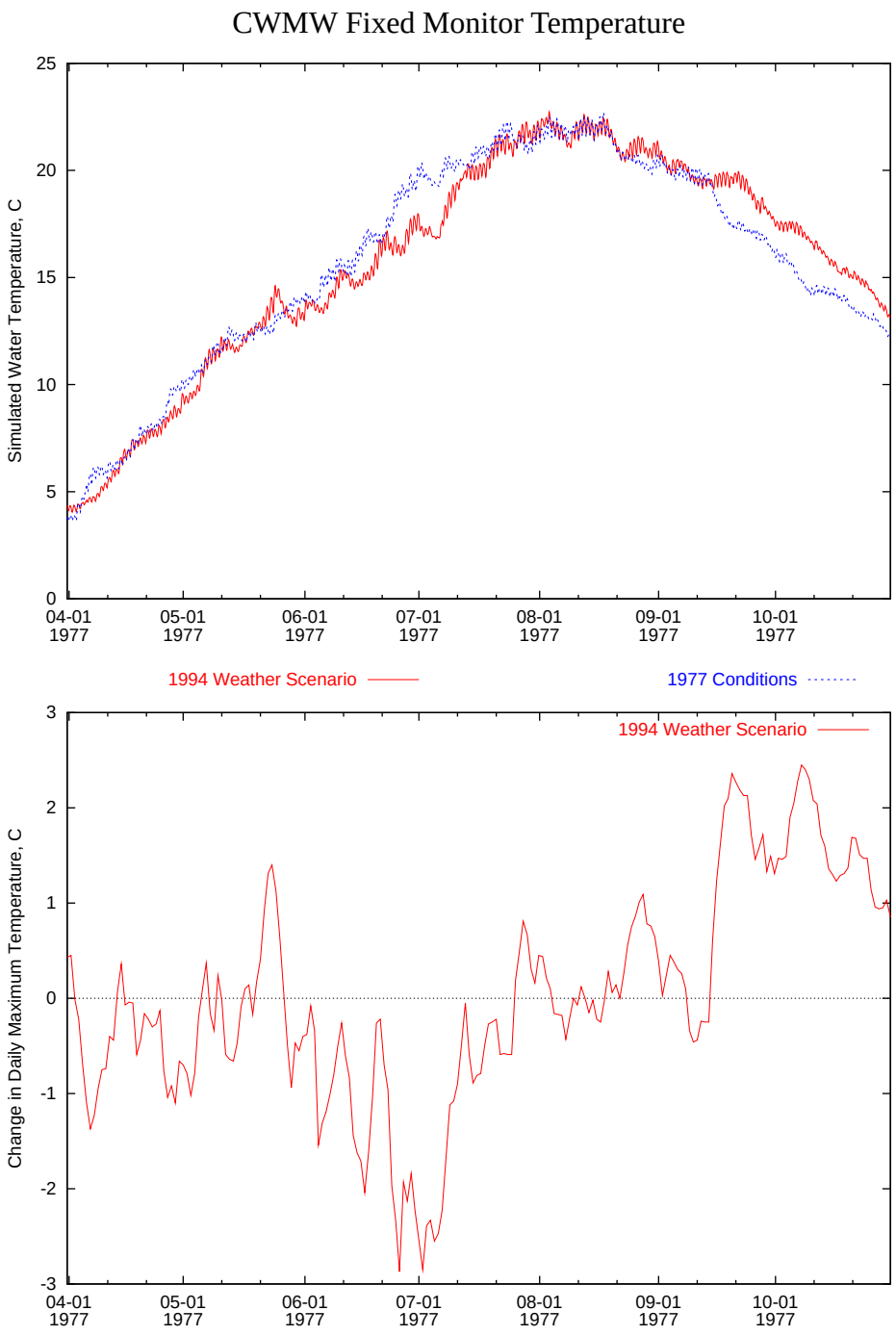

Figure 40: Time series comparison at Camas/Washougal fixed monitor of the 1994 weather and 1977 conditions scenario.

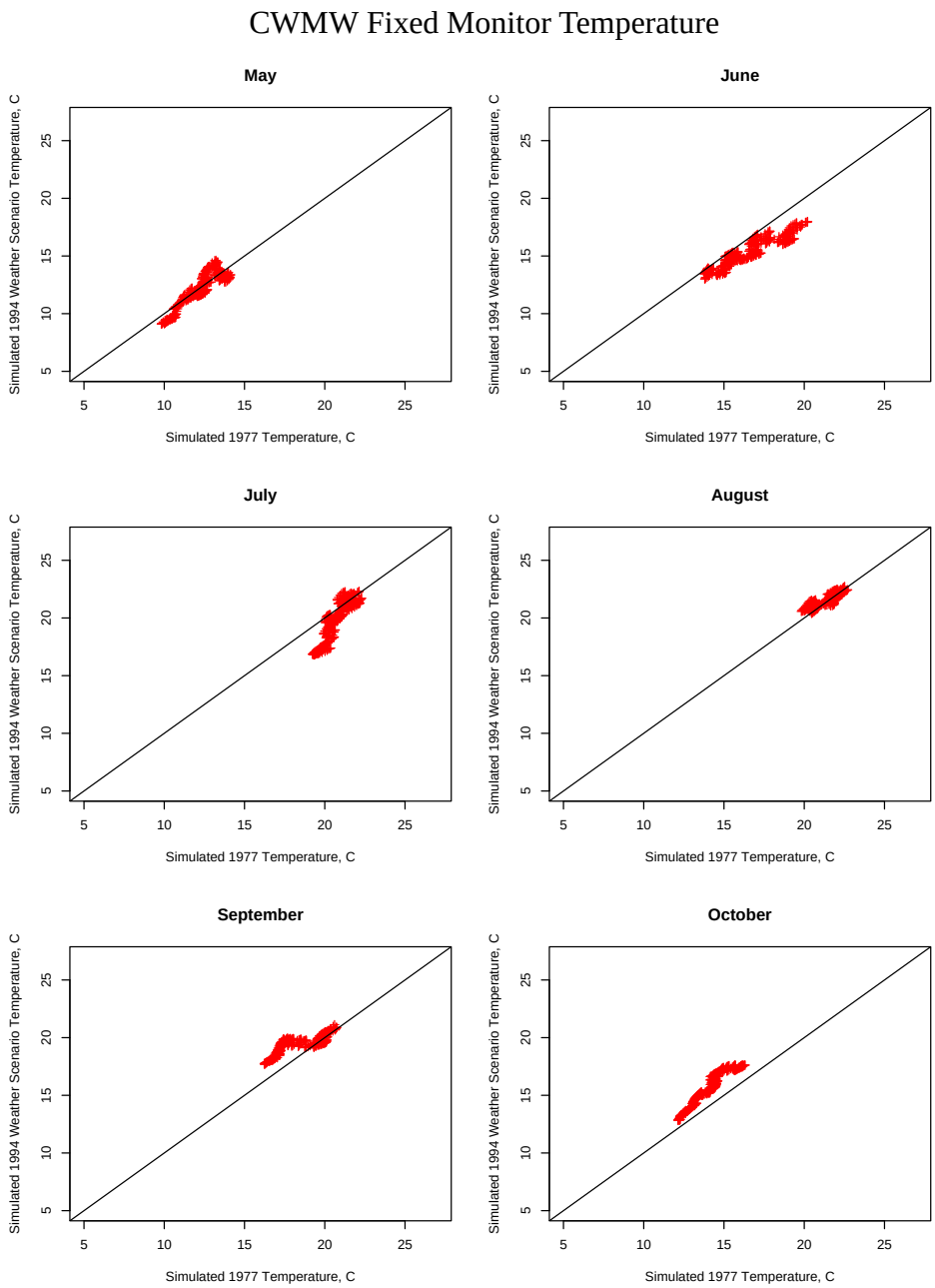

Figure 41: Scatter plot comparison, by month, at Camas/Washougal fixed monitor of the 1994 weather and 1977 conditions scenario.

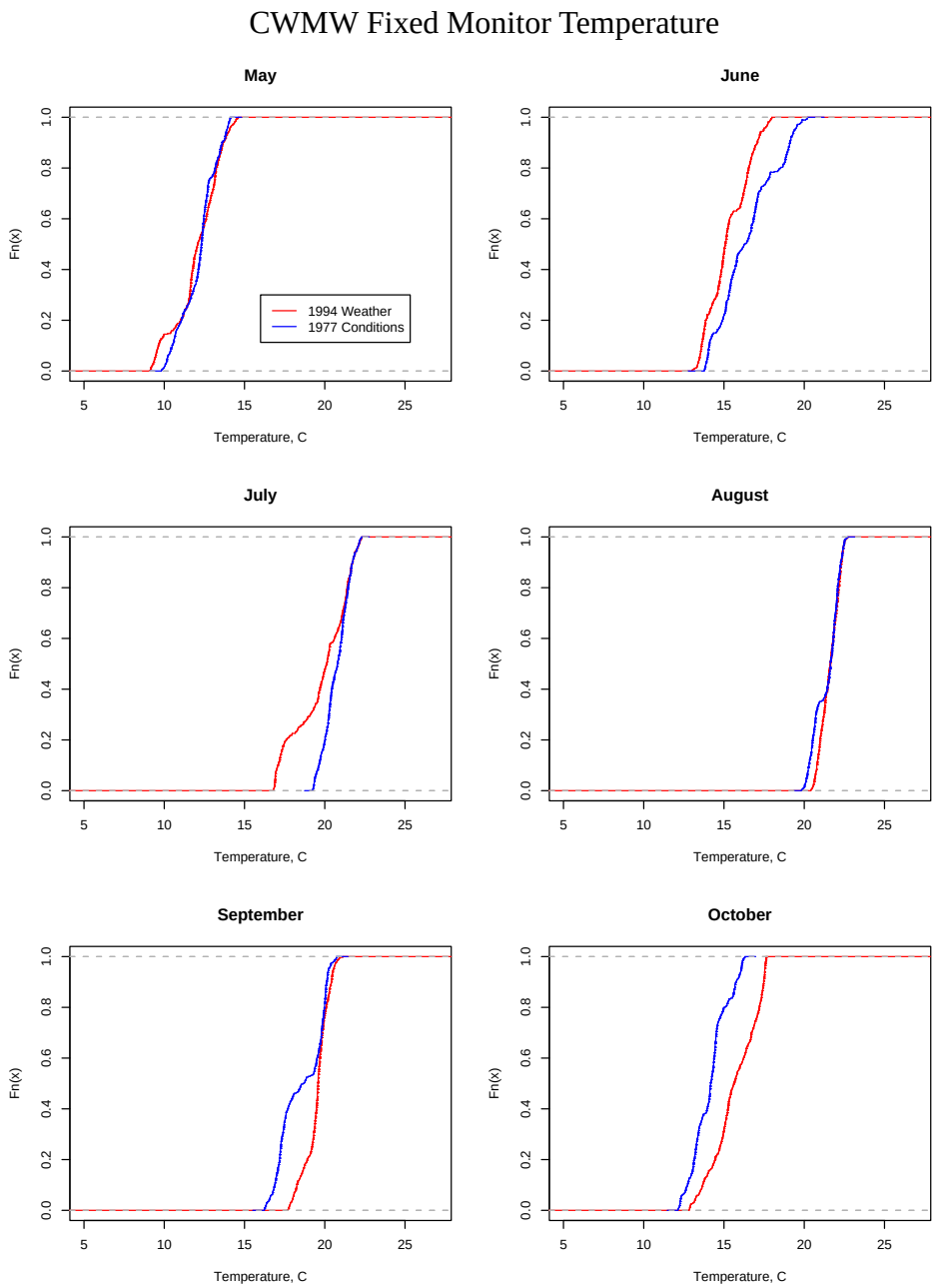

Figure 42: Cumulative frequency distribution (CFD) plot comparison, by month, at Camas/Washougal fixed monitor of the 1994 weather and 1977 conditions scenario.

3 Base Case Scenario

Simulation of this scenario was the same as the 1994 Weather Scenario, with the following modifications:

- Dworshak discharge was increased to 10.0 kcfs from July 1 to September 30, with 1977 flows for remainder of the season;
- Dworshak temperature during that period was assumed to be 8.89°C (48°F) July 1 to September 30, with temperatures the same as the 1994 Weather Scenario for the remainder of the season;
- Clearwater main stem temperature during the July 1 to September 30 were estimated using the method described in Appendix A; and
- Flow is augmented on the Columbia in order to maintain flows at Priest Rapids above 65 kcfs.

Figure 43 compares the Clearwater River boundary conditions used in the Base Case scenario to those used in the 1994 Weather scenario. When the Priest Rapids discharge (in the 1994 Weather scenario) dropped below 65 kcfs, the amount required to bring it to 65 kcfs was lagged 6 hours (the approximate wave travel time from Grand Coulee to Priest Rapids) and added to the original (1977) Grand Coulee discharge. Figure 44 compares the discharge used at Grand Coulee with the 1994 Weather scenario, and also shows the result change in flow at Priest Rapids. In general, this augmentation had the desired effect – Priest Rapids minimum flows were raised, but minimum flows were closer to 60 kcfs than 65 kcfs. This is probably because the wave travel time between Grand Coulee was not precisely 6 hours. Any augmentation done in this fashion in going to be imprecise.

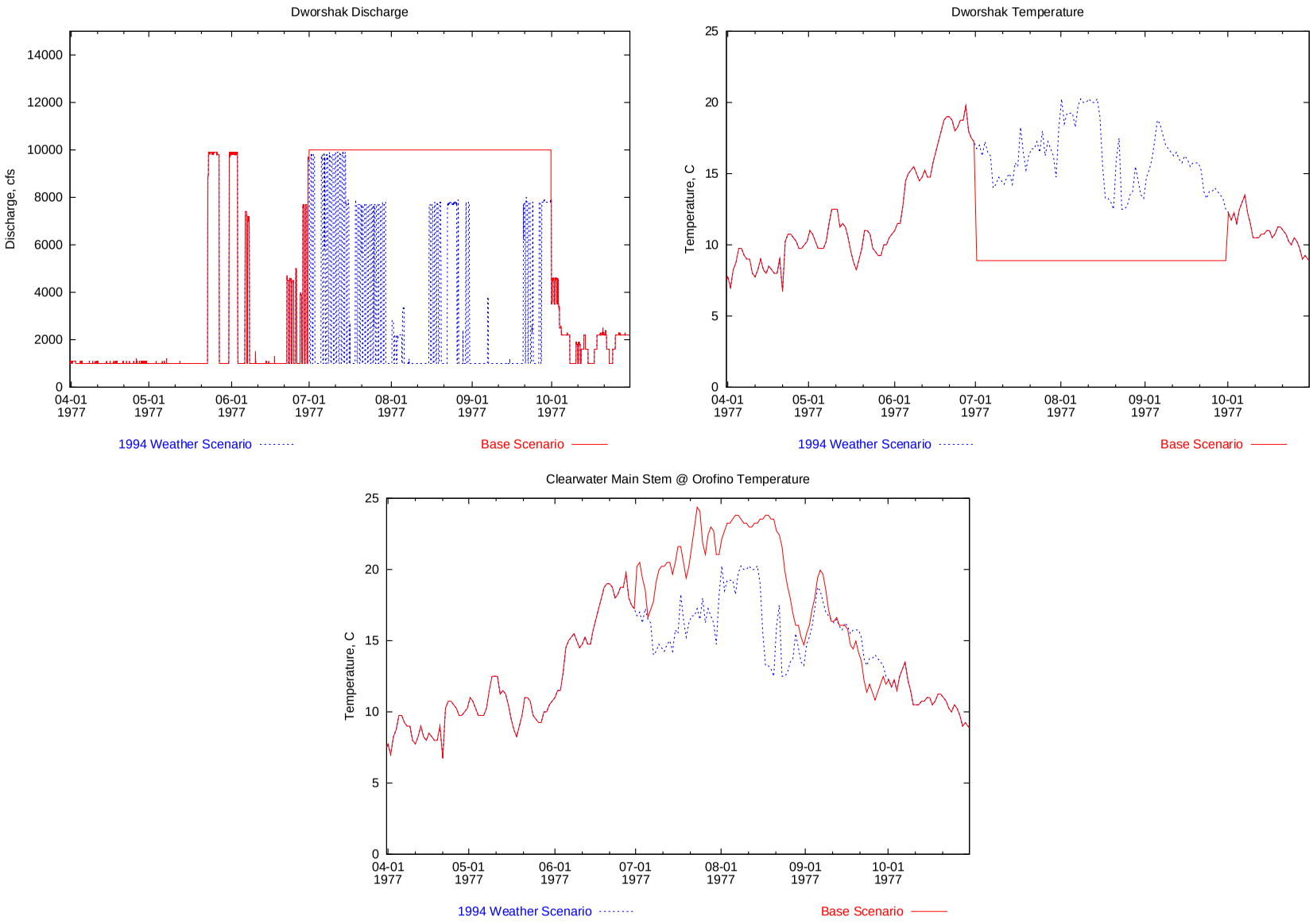

Figure 43: Altered Clearwater River boundary conditions for the Base Case scenario.

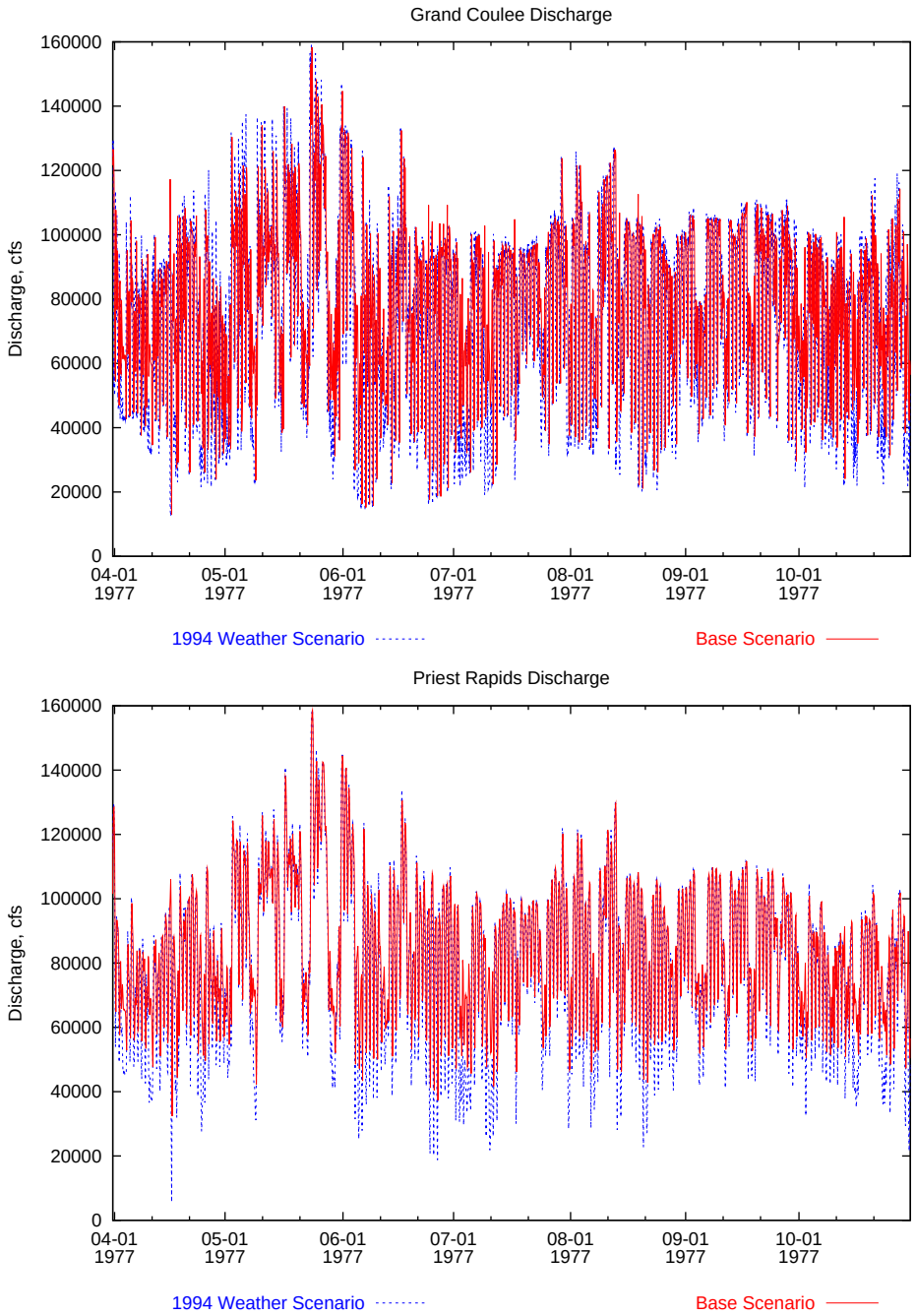

Figure 44: Altered flow boundary conditions at Grand Coulee and comparison of resulting flow at Priest Rapids.

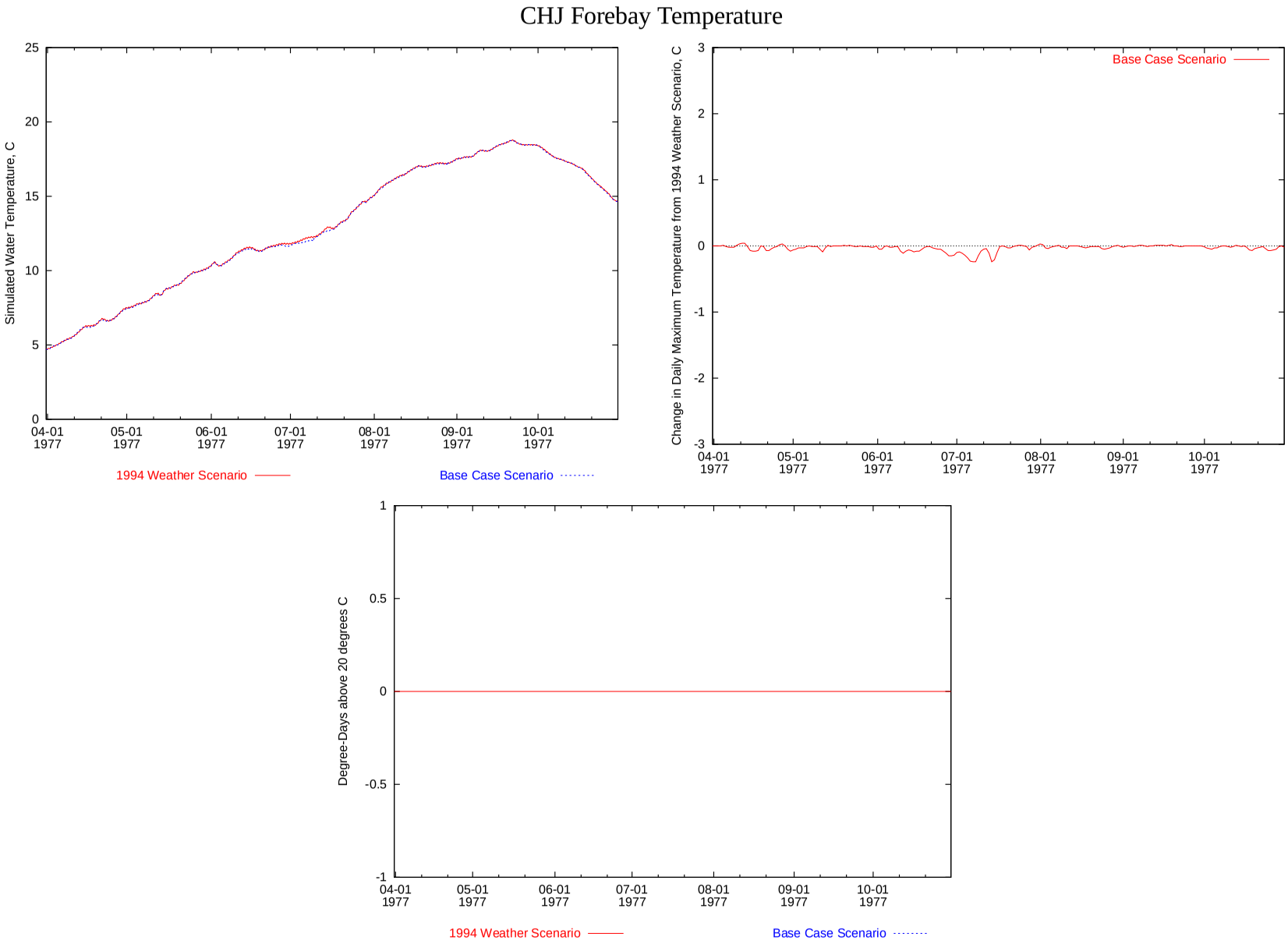

Figure 45: Time series comparison of temperature at the CHJ Forebay in the Base Case and 1994 Weather scenario.

CHJ Forebay Temperature

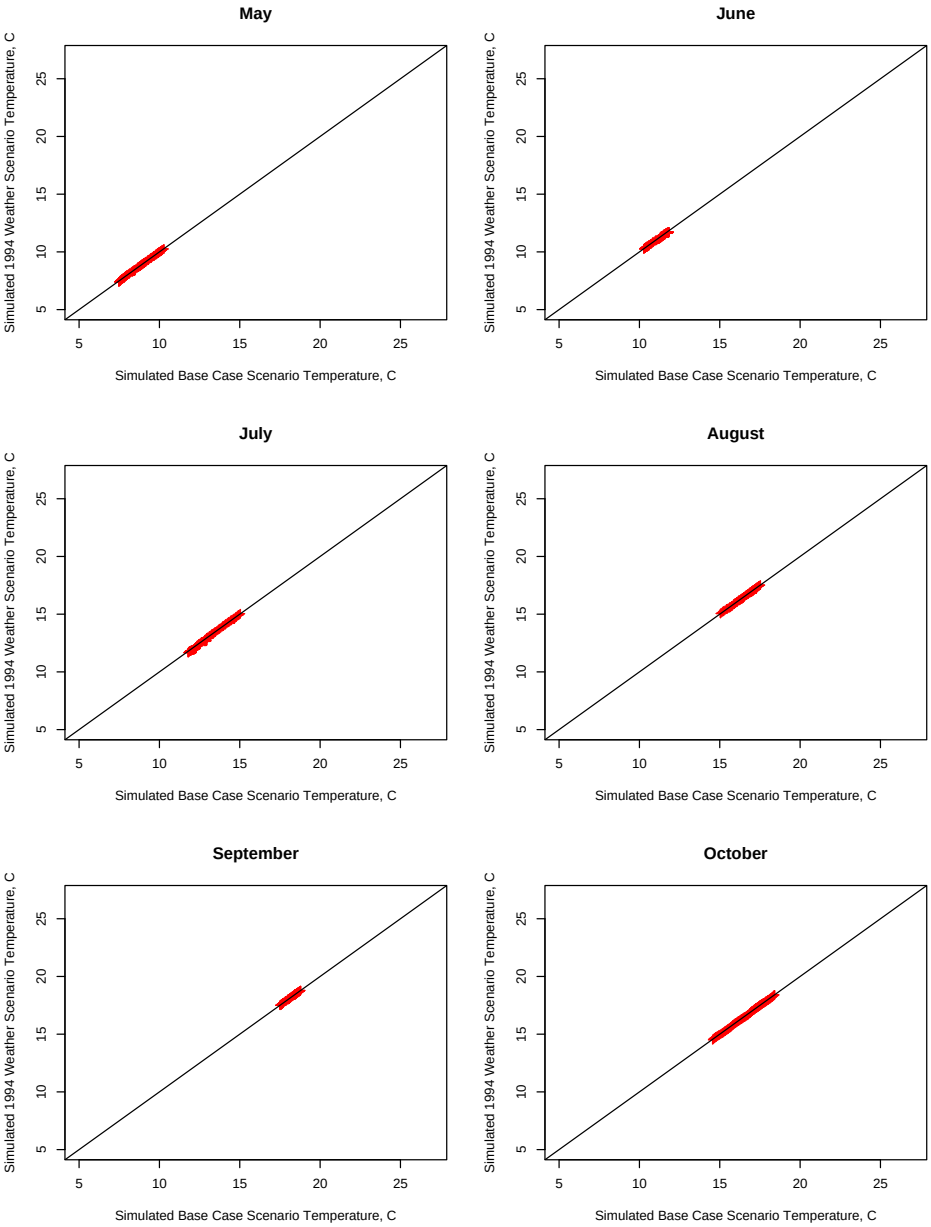

Figure 46: Scatter plot comparison, by month, of temperature at the CHJ Forebay in the Base Case and 1994 Weather scenario.

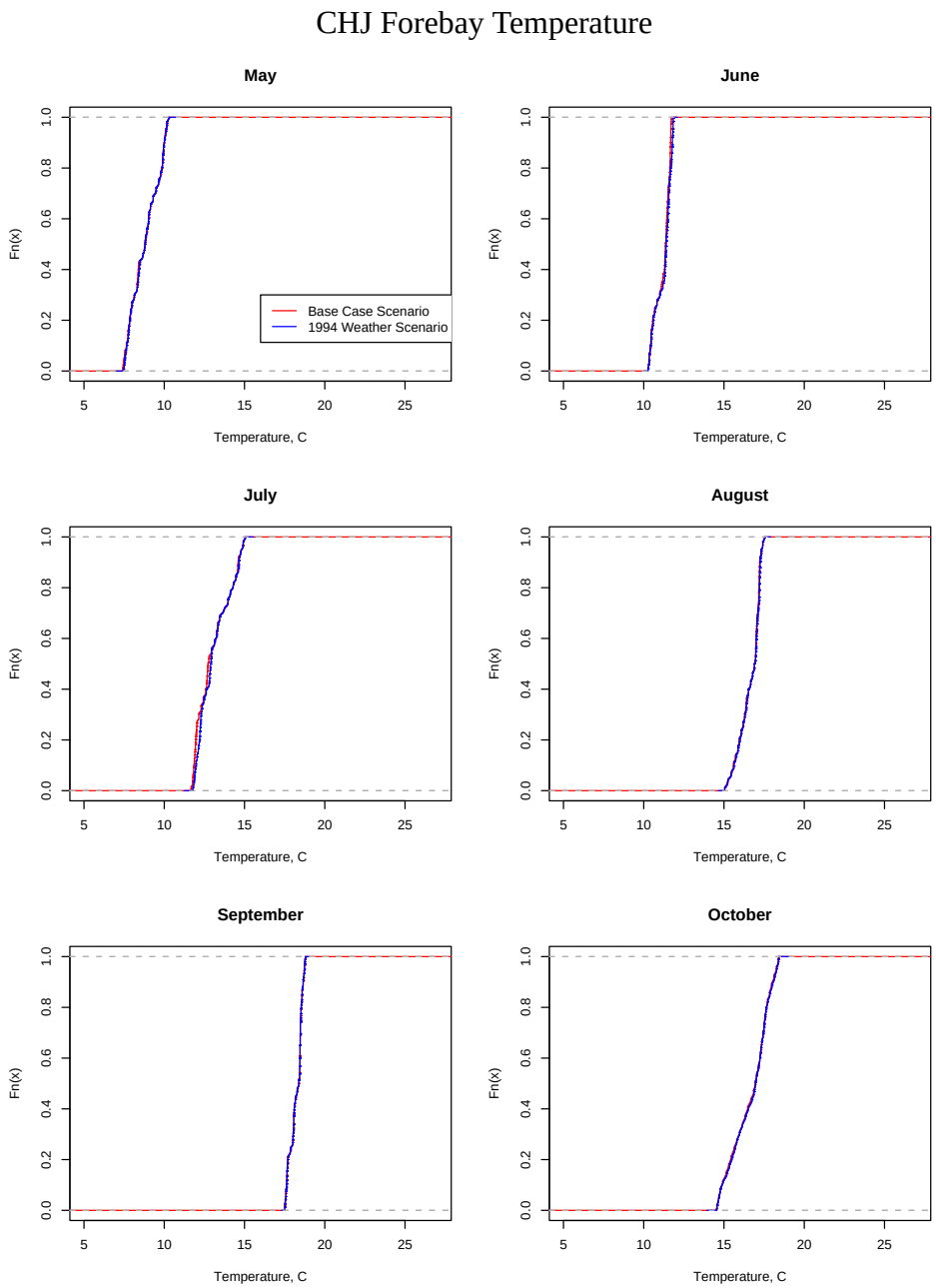

Figure 47: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the CHJ Forebay in the Base Case and 1994 Weather scenario.

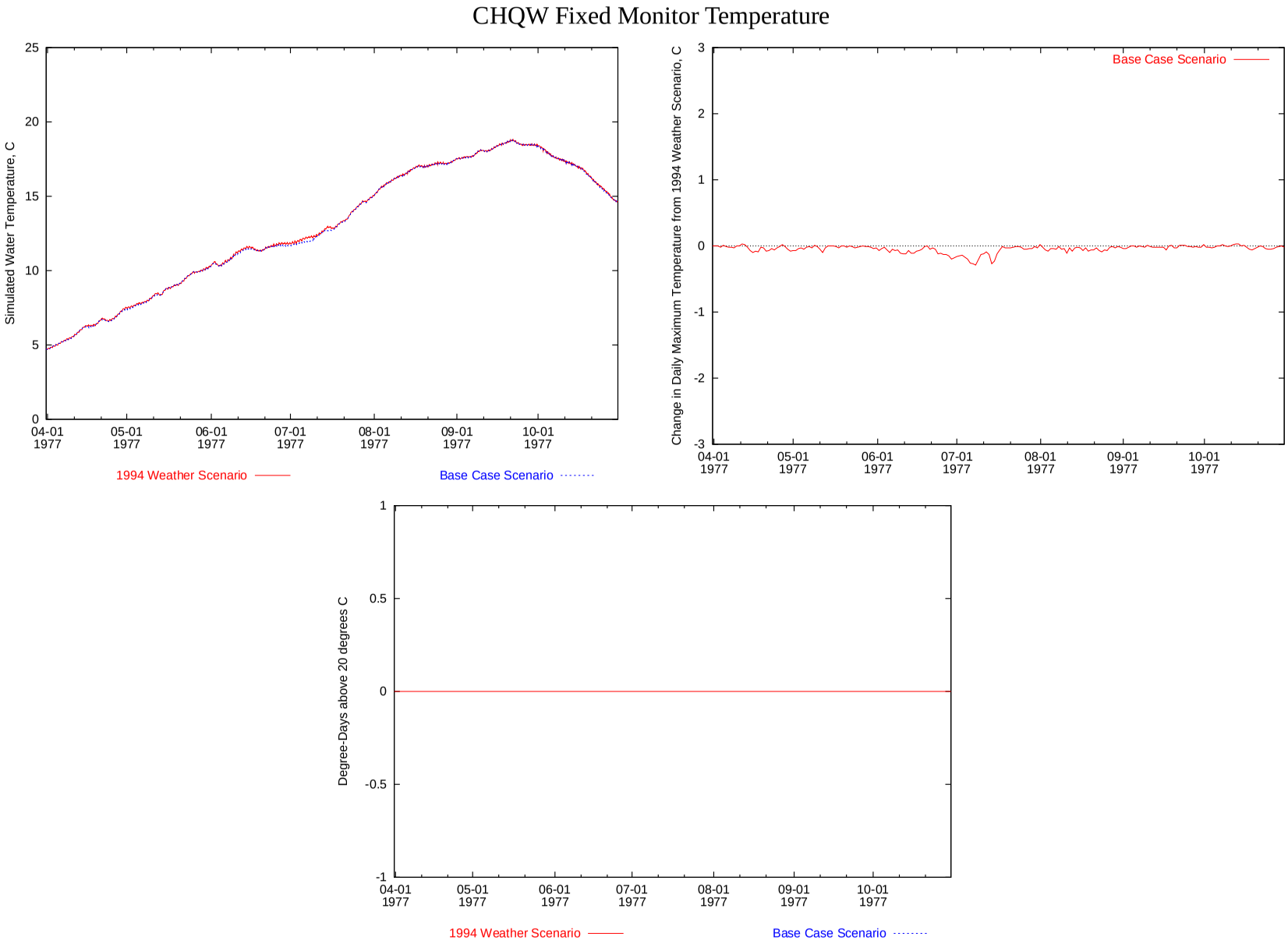

Figure 48: Time series comparison of temperature at the CHQW Fixed Monitor in the Base Case and 1994 Weather scenario.

CHQW Fixed Monitor Temperature

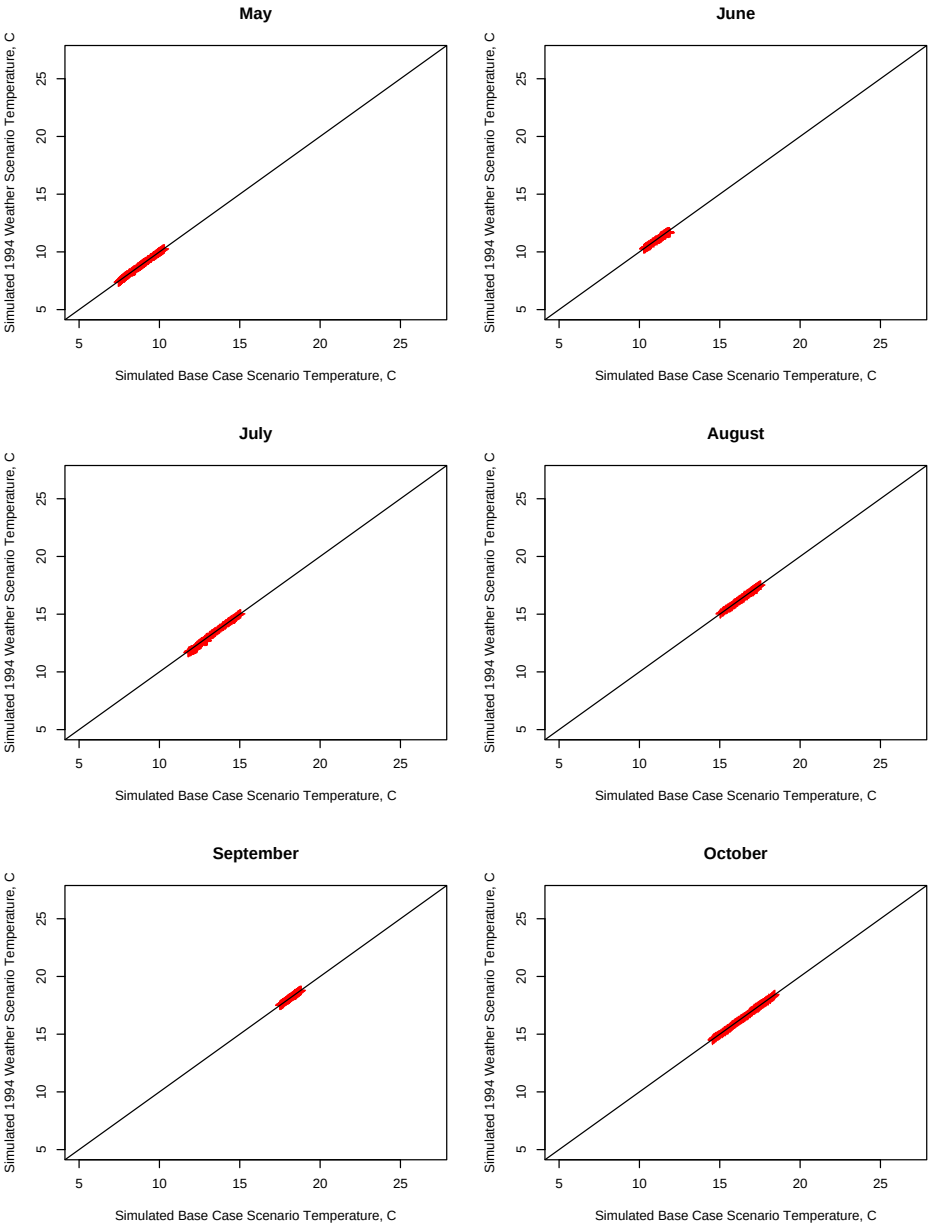

Figure 49: Scatter plot comparison, by month, of temperature at the CHQW Fixed Monitor in the Base Case and 1994 Weather scenario.

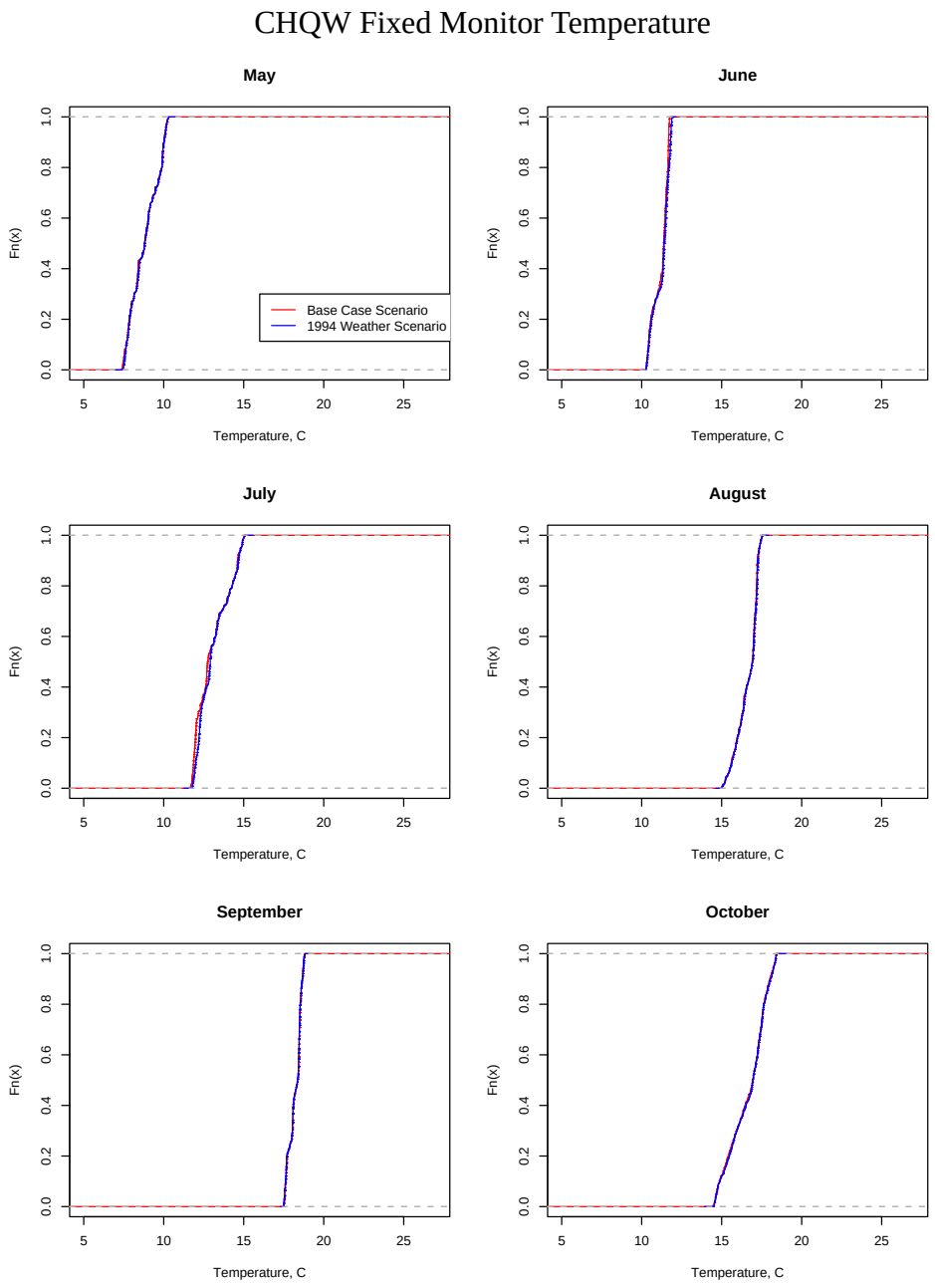

Figure 50: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the CHQW Fixed Monitor in the Base Case and 1994 Weather scenario.

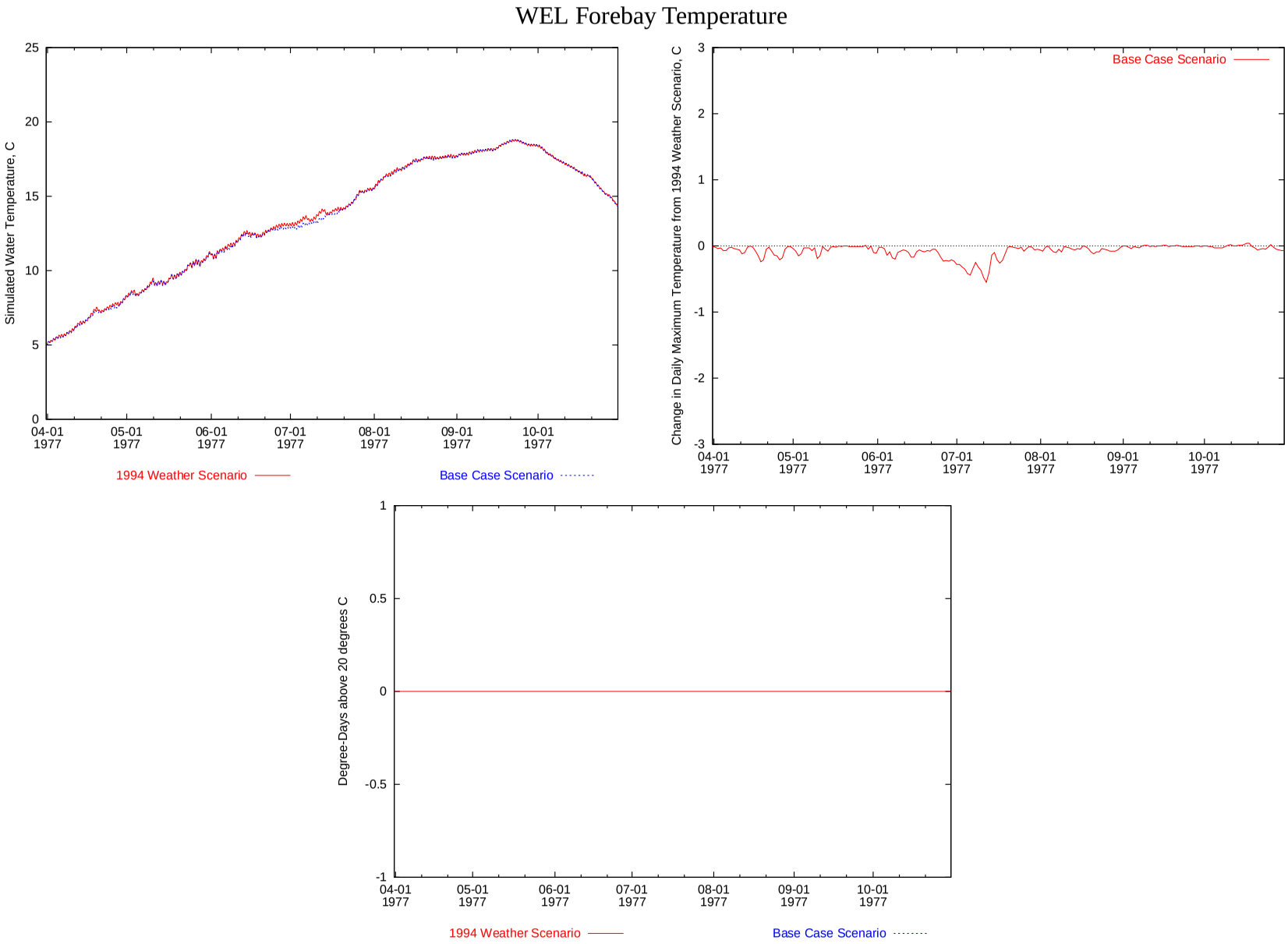

Figure 51: Time series comparison of temperature at the WEL Forebay in the Base Case and 1994 Weather scenario.

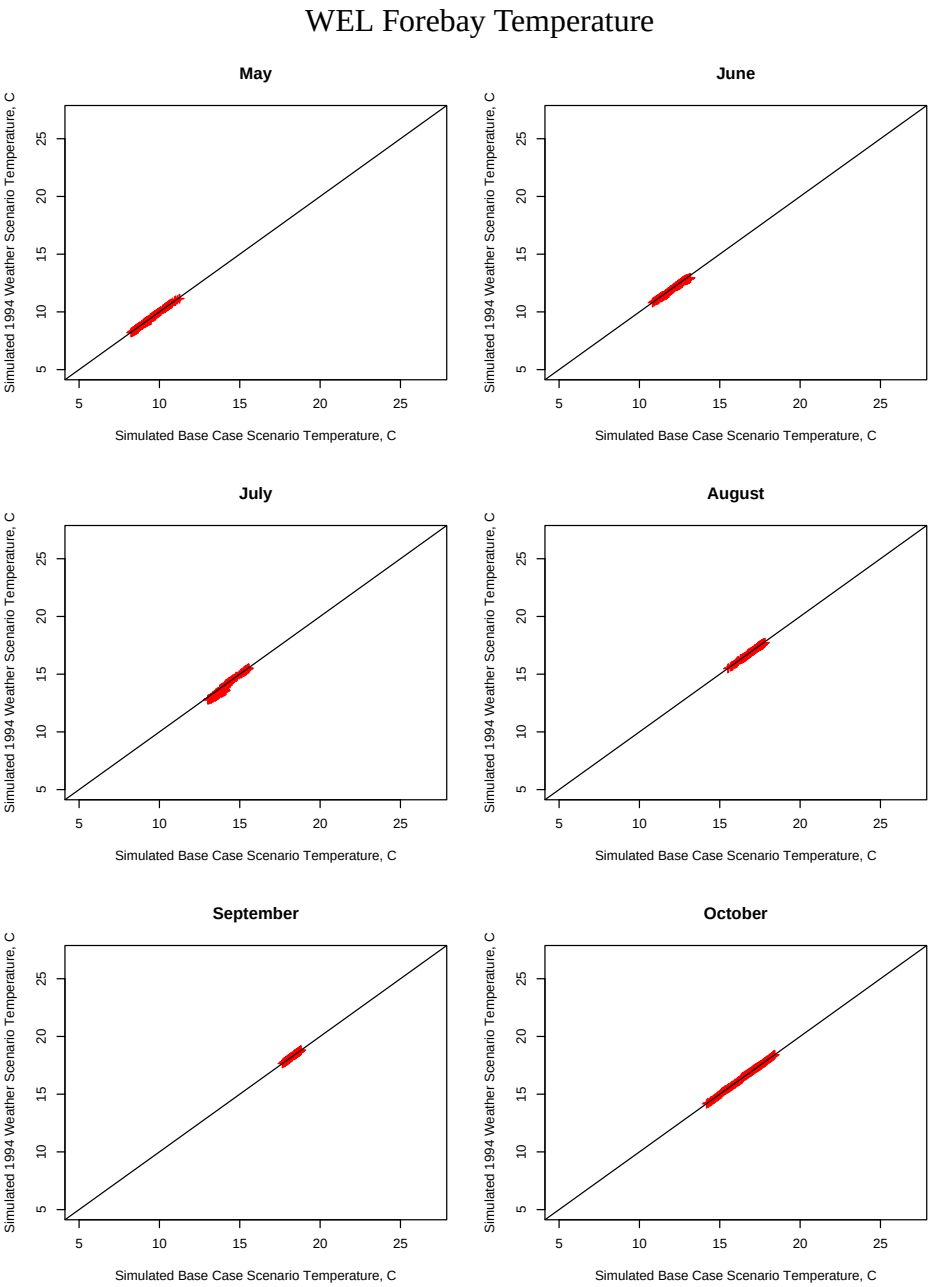

Figure 52: Scatter plot comparison, by month, of temperature at the WEL Forebay in the Base Case and 1994 Weather scenario.

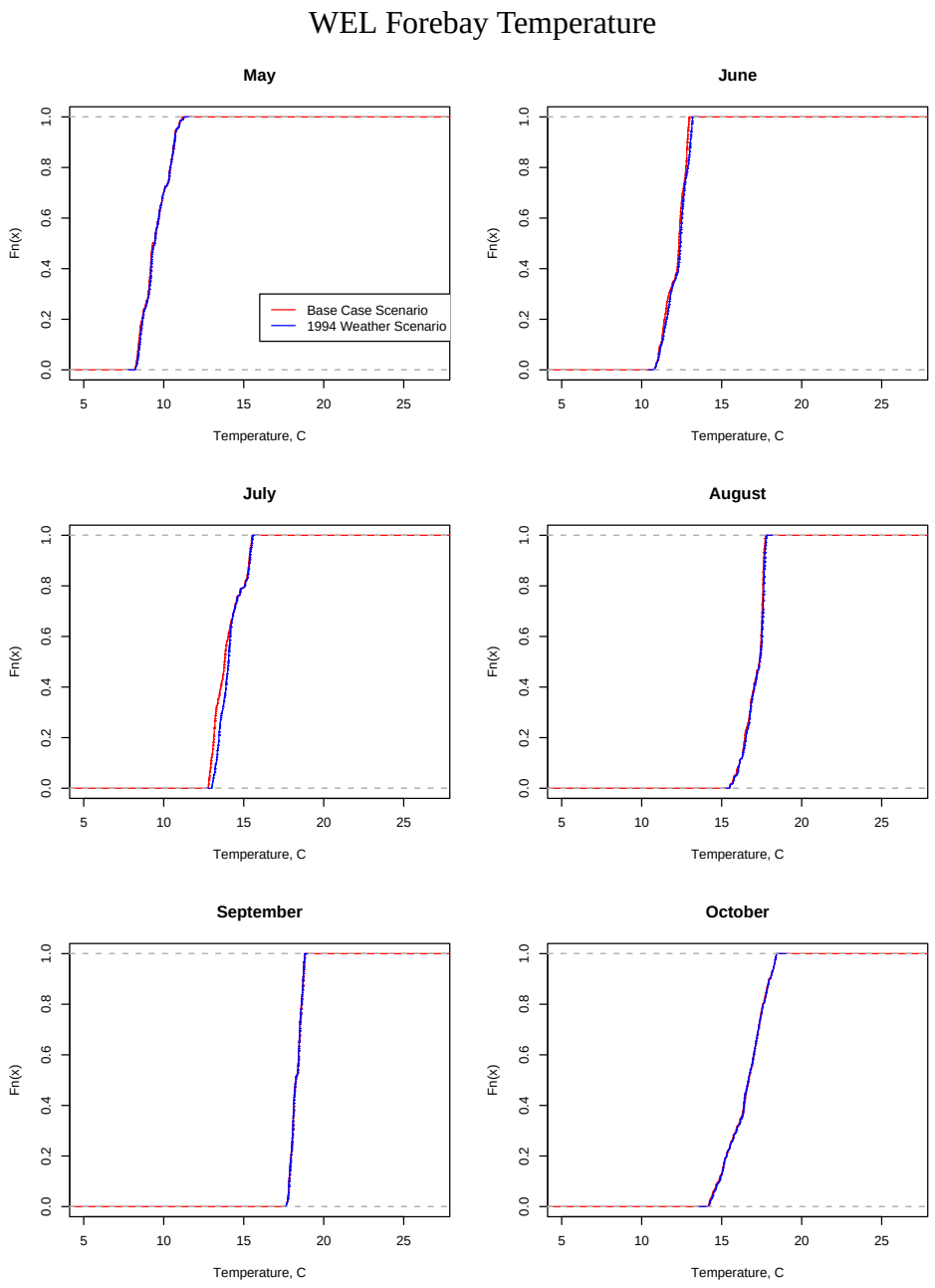

Figure 53: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the WEL Forebay in the Base Case and 1994 Weather scenario.

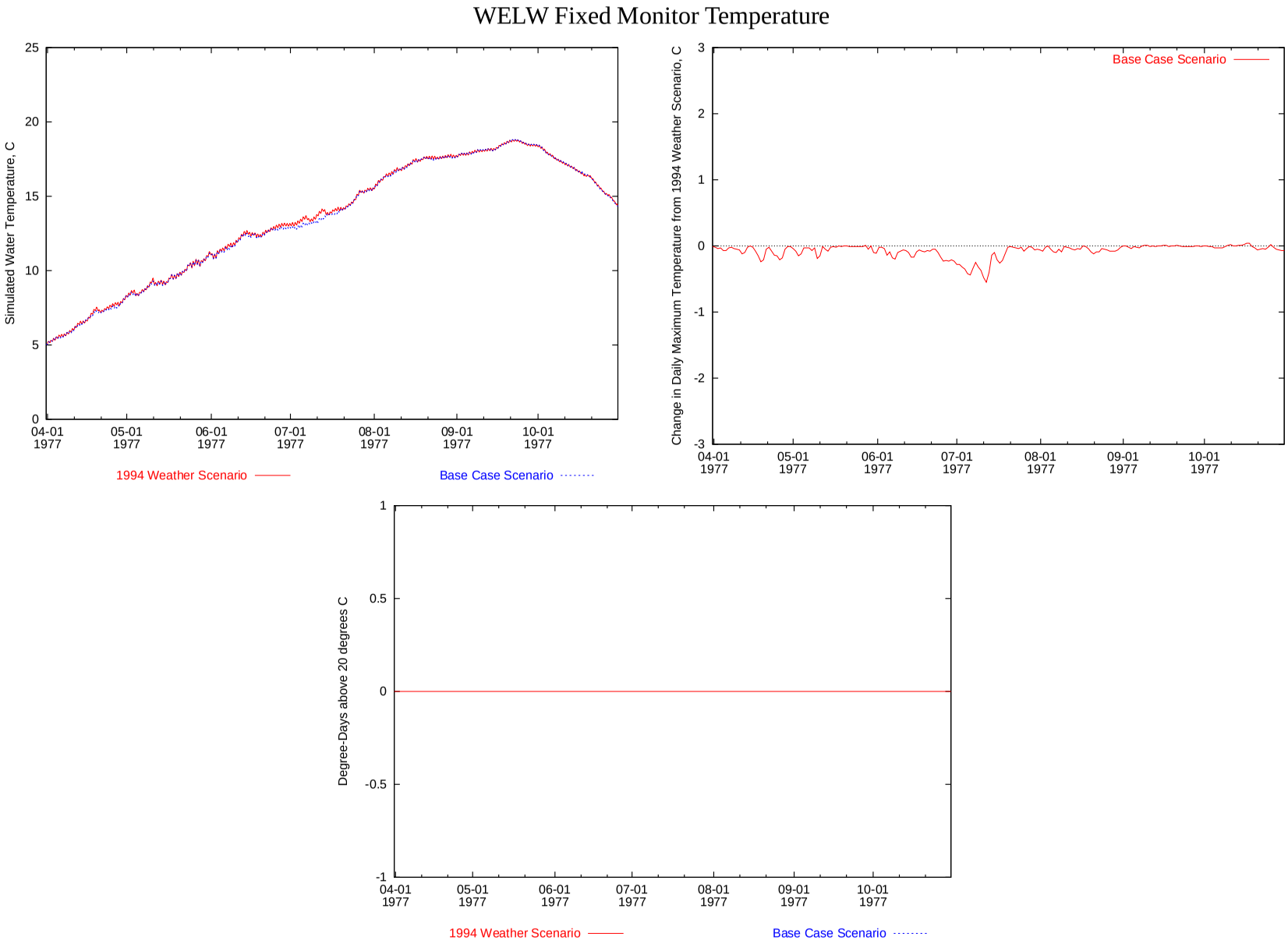

Figure 54: Time series comparison of temperature at the WELW Fixed Monitor in the Base Case and 1994 Weather scenario.

WELW Fixed Monitor Temperature

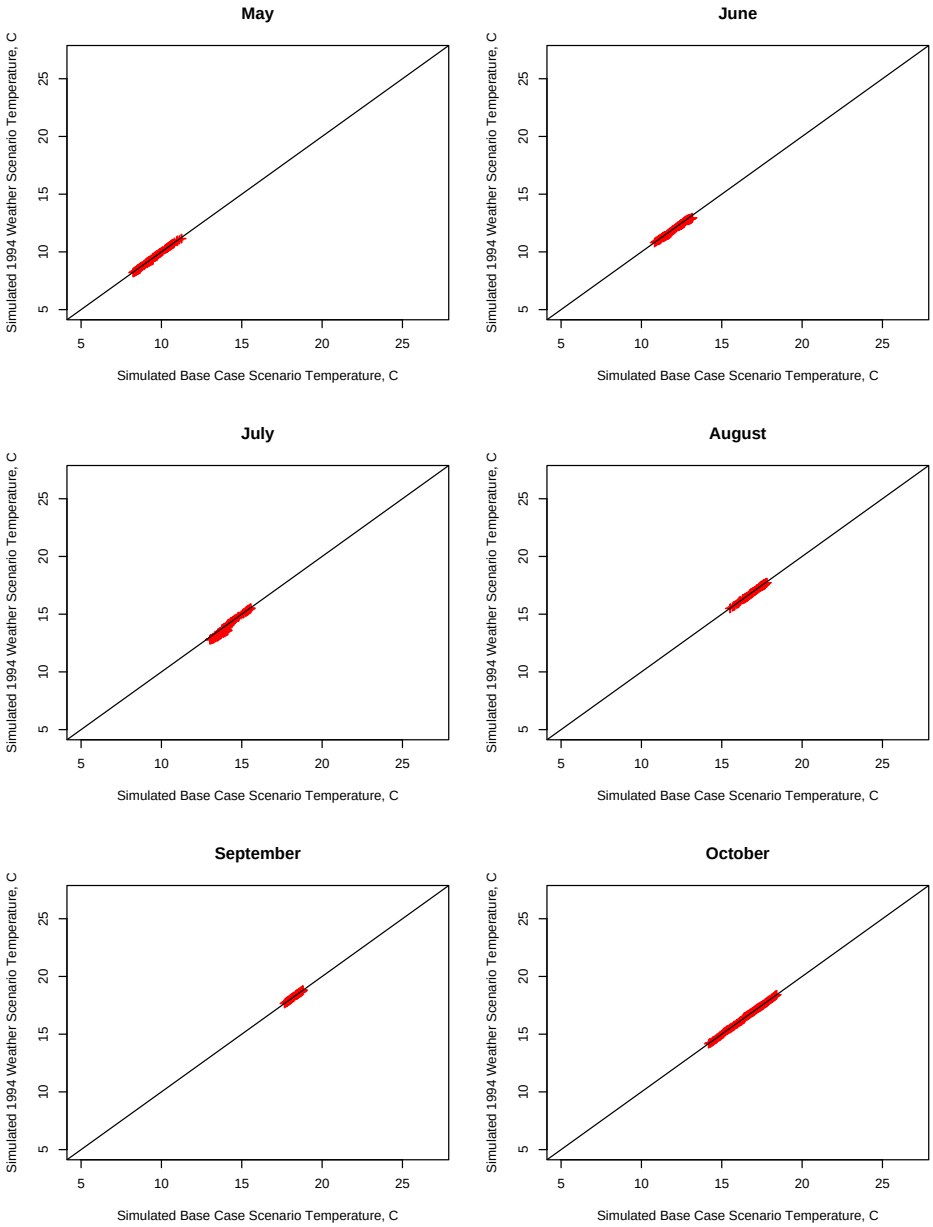

Figure 55: Scatter plot comparison, by month, of temperature at the WELW Fixed Monitor in the Base Case and 1994 Weather scenario.

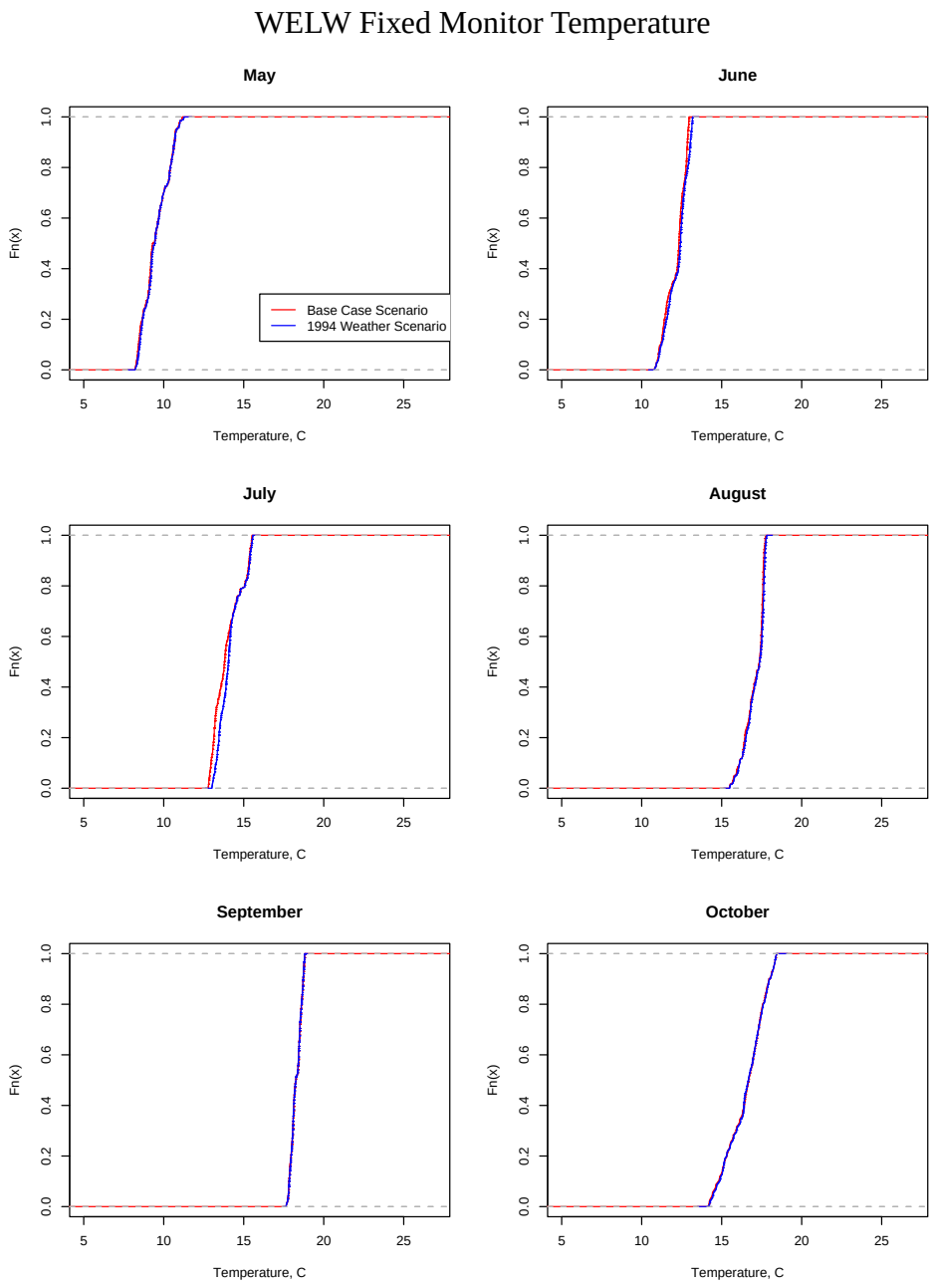

Figure 56: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the WELW Fixed Monitor in the Base Case and 1994 Weather scenario.

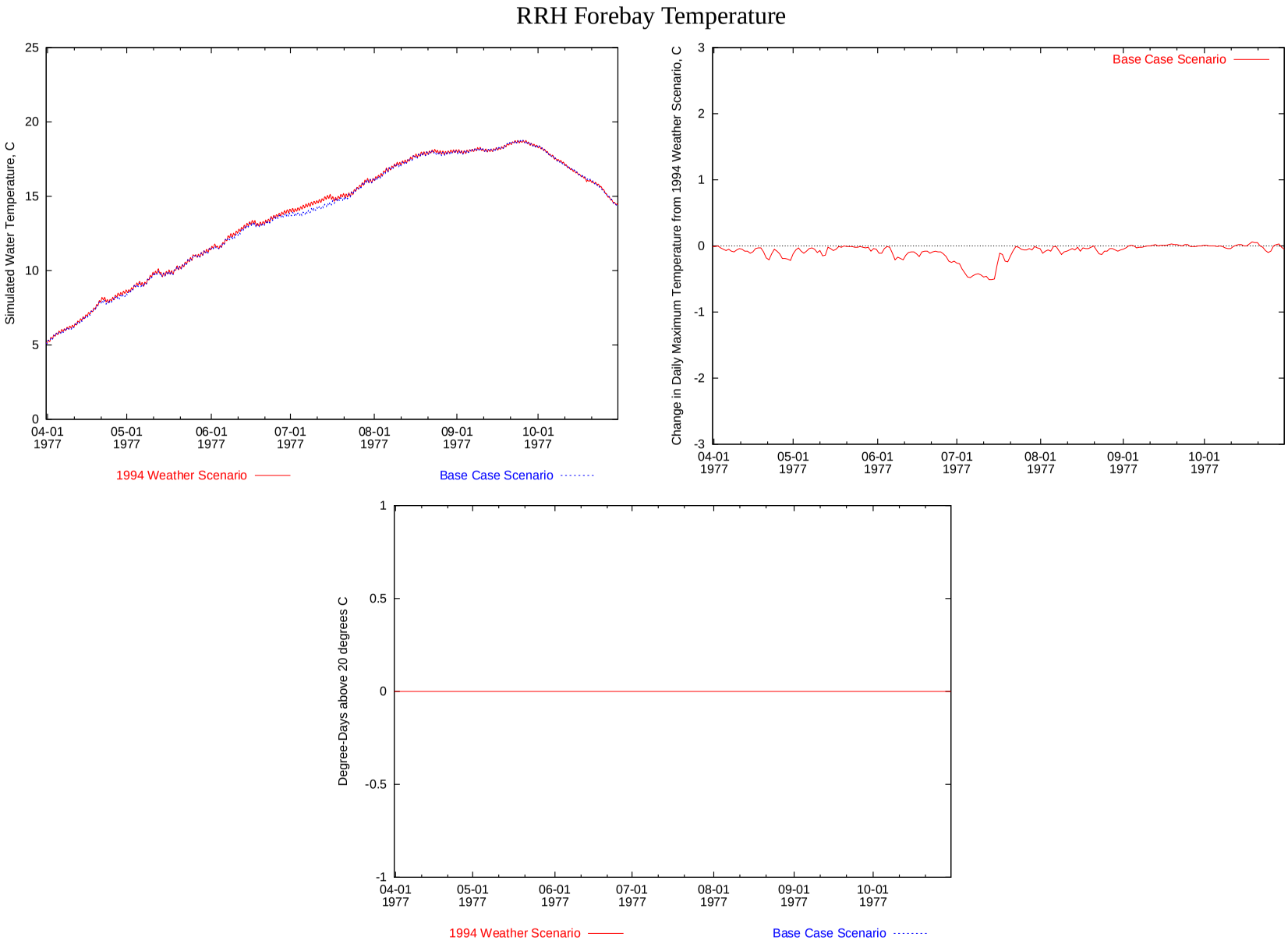

Figure 57: Time series comparison of temperature at the RRH Forebay in the Base Case and 1994 Weather scenario.

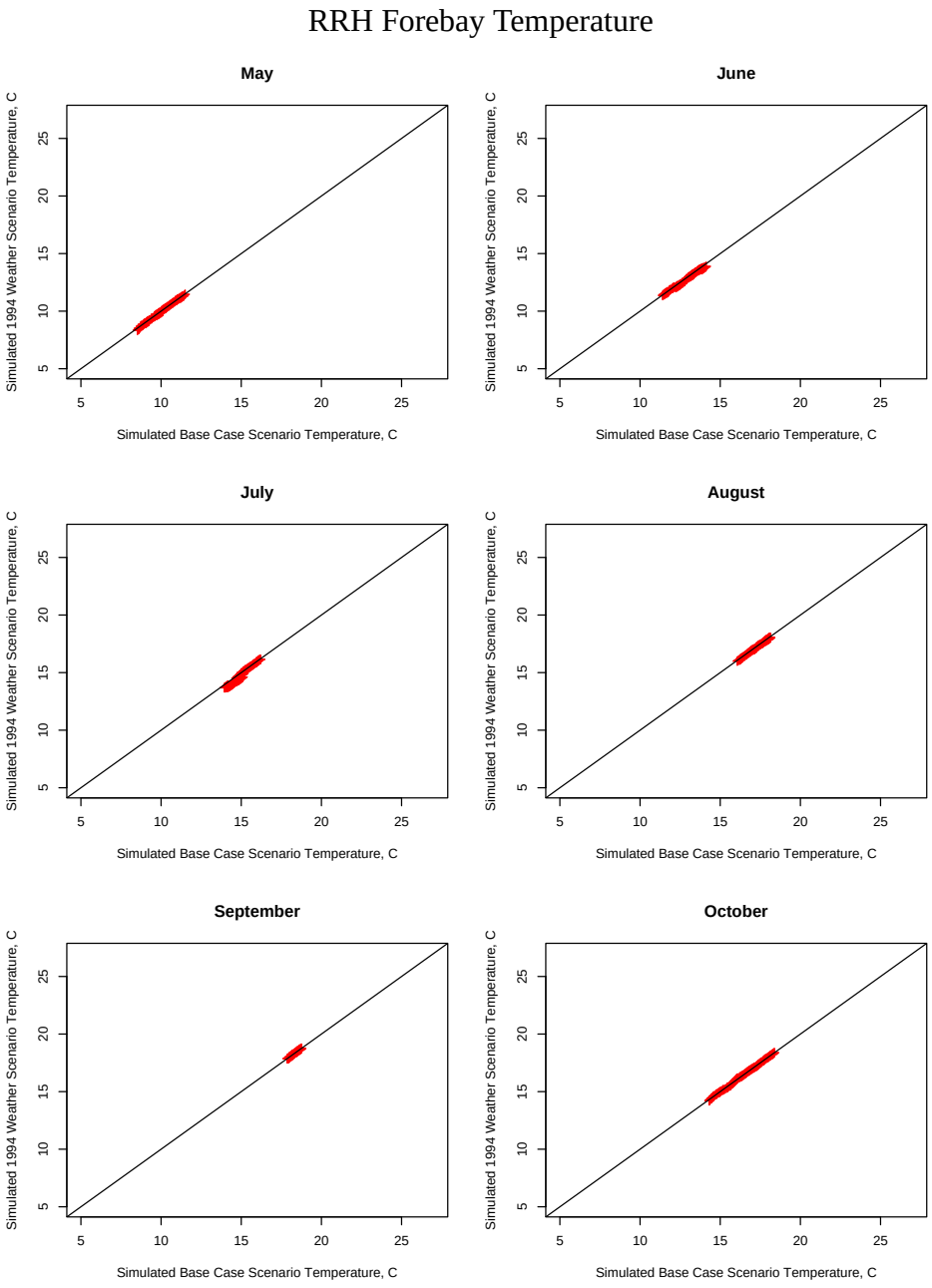

Figure 58: Scatter plot comparison, by month, of temperature at the RRH Forebay in the Base Case and 1994 Weather scenario.

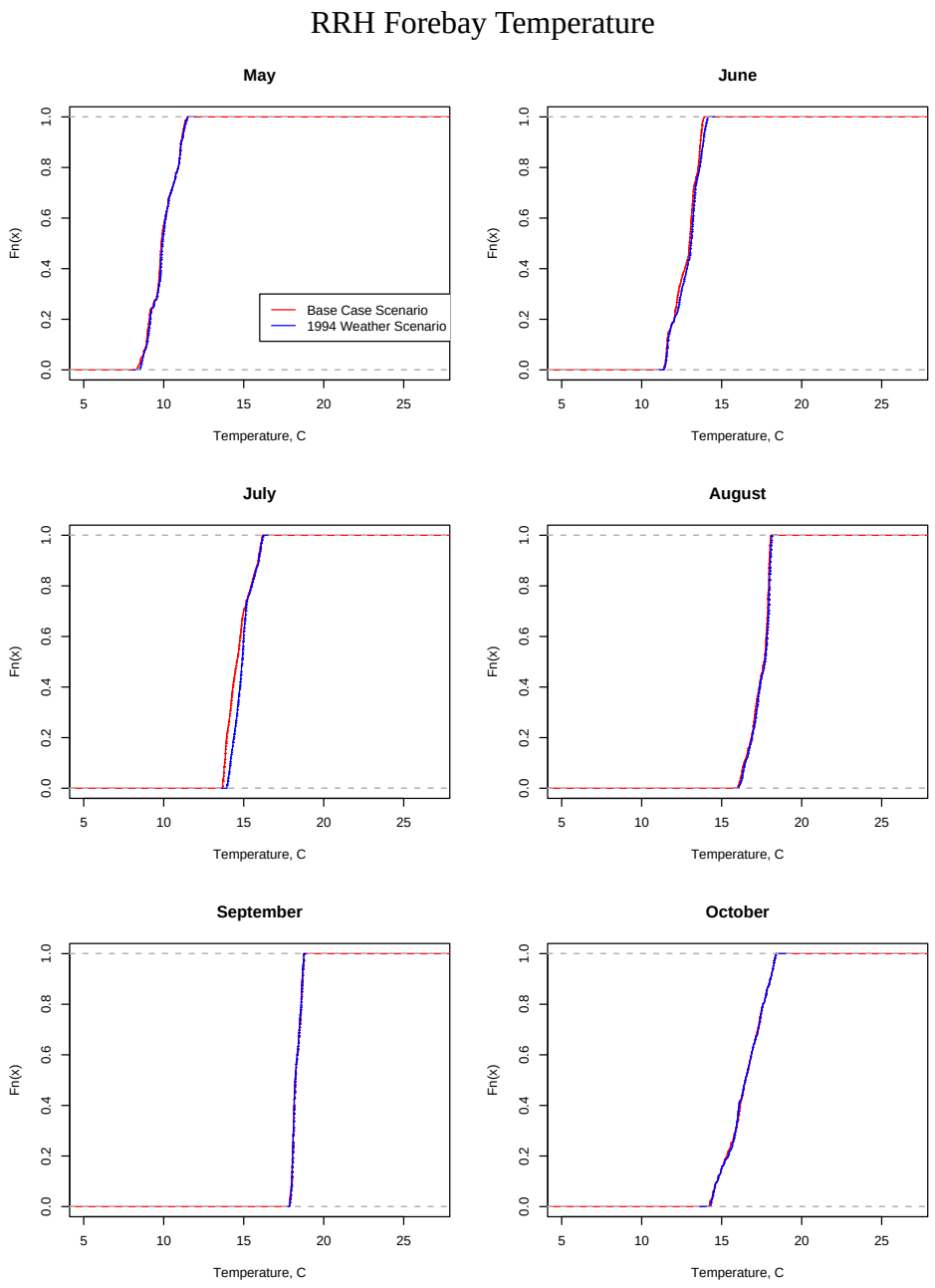

Figure 59: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the RRH Forebay in the Base Case and 1994 Weather scenario.

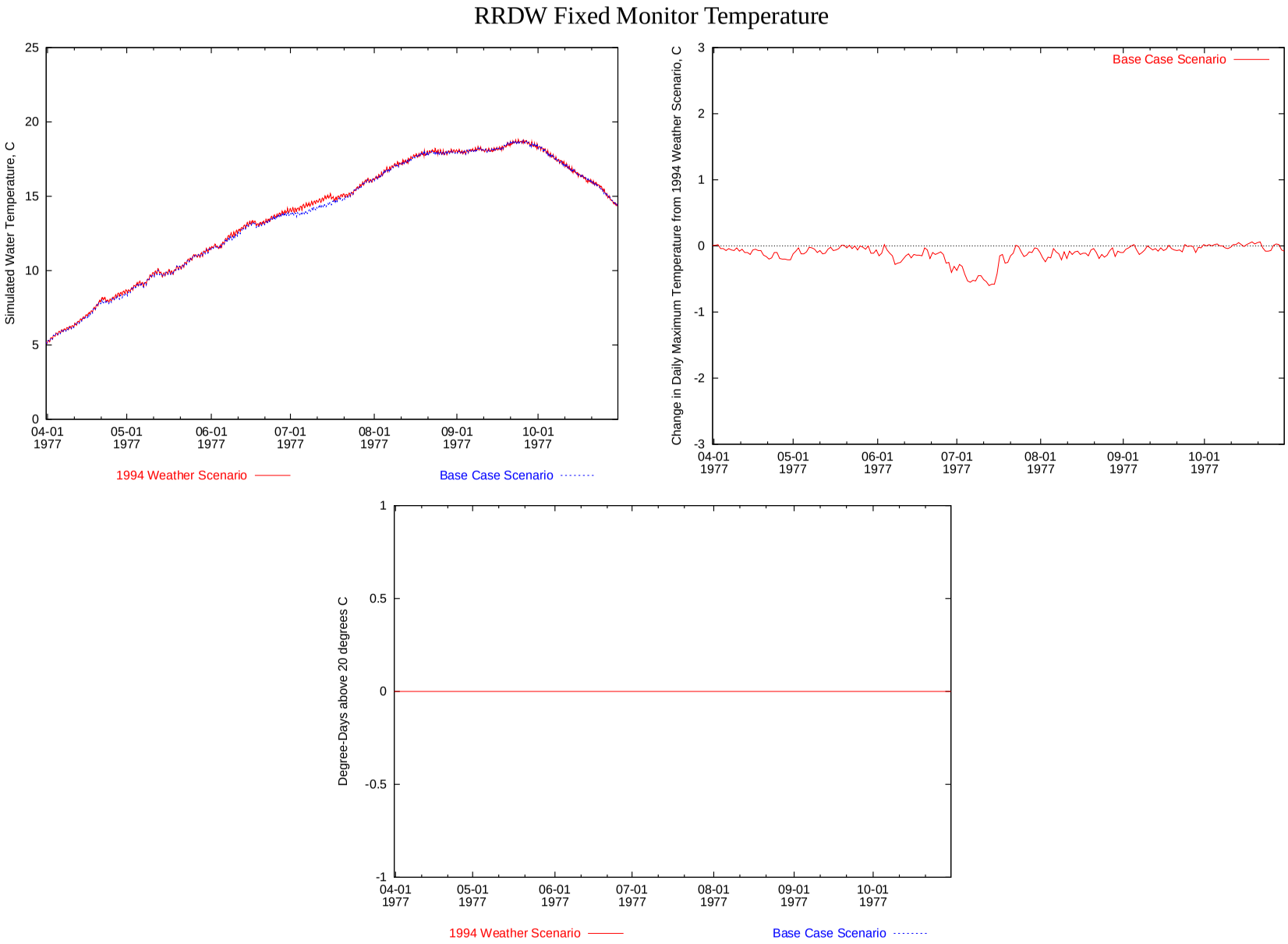

Figure 60: Time series comparison of temperature at the RRDW Fixed Monitor in the Base Case and 1994 Weather scenario.

RRDW Fixed Monitor Temperature

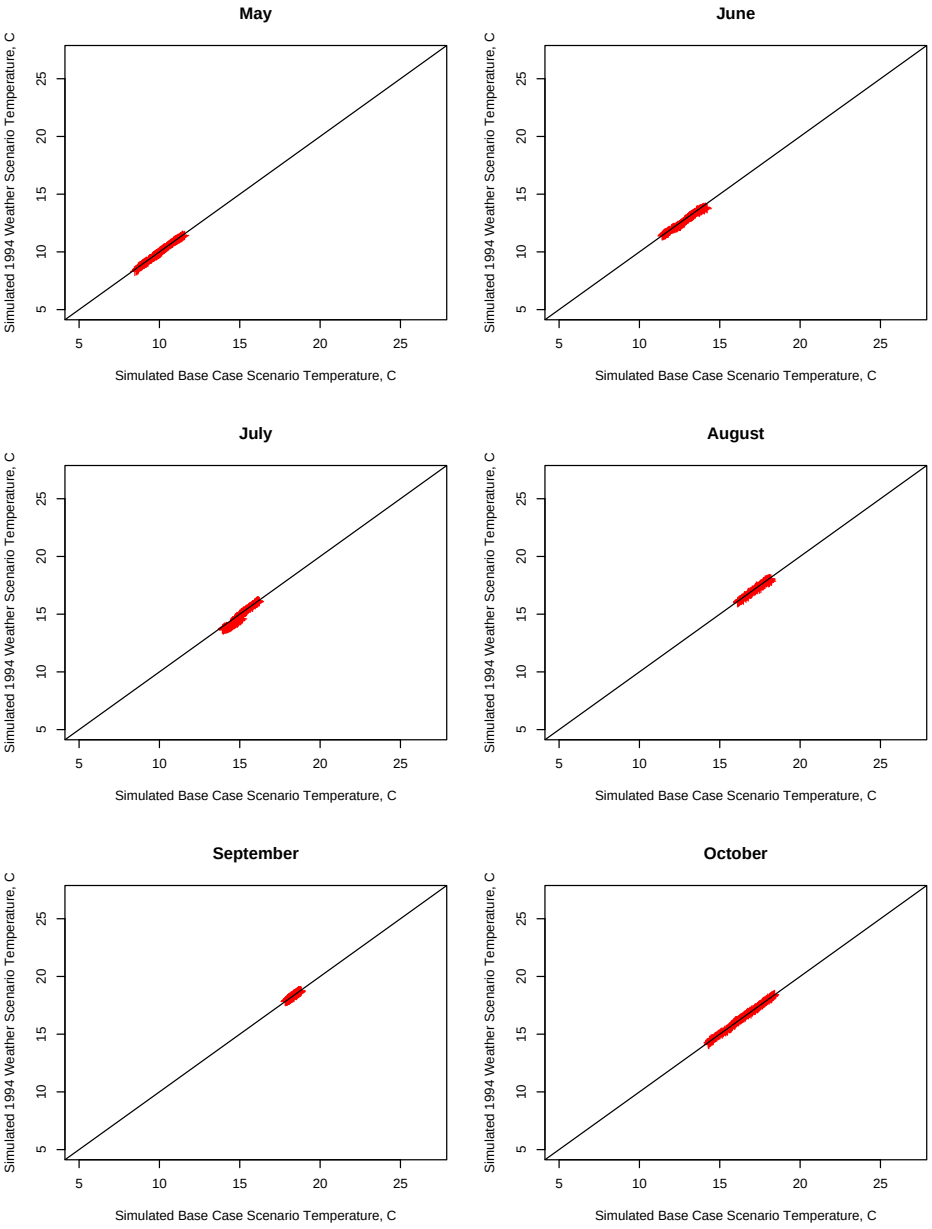

Figure 61: Scatter plot comparison, by month, of temperature at the RRDW Fixed Monitor in the Base Case and 1994 Weather scenario.

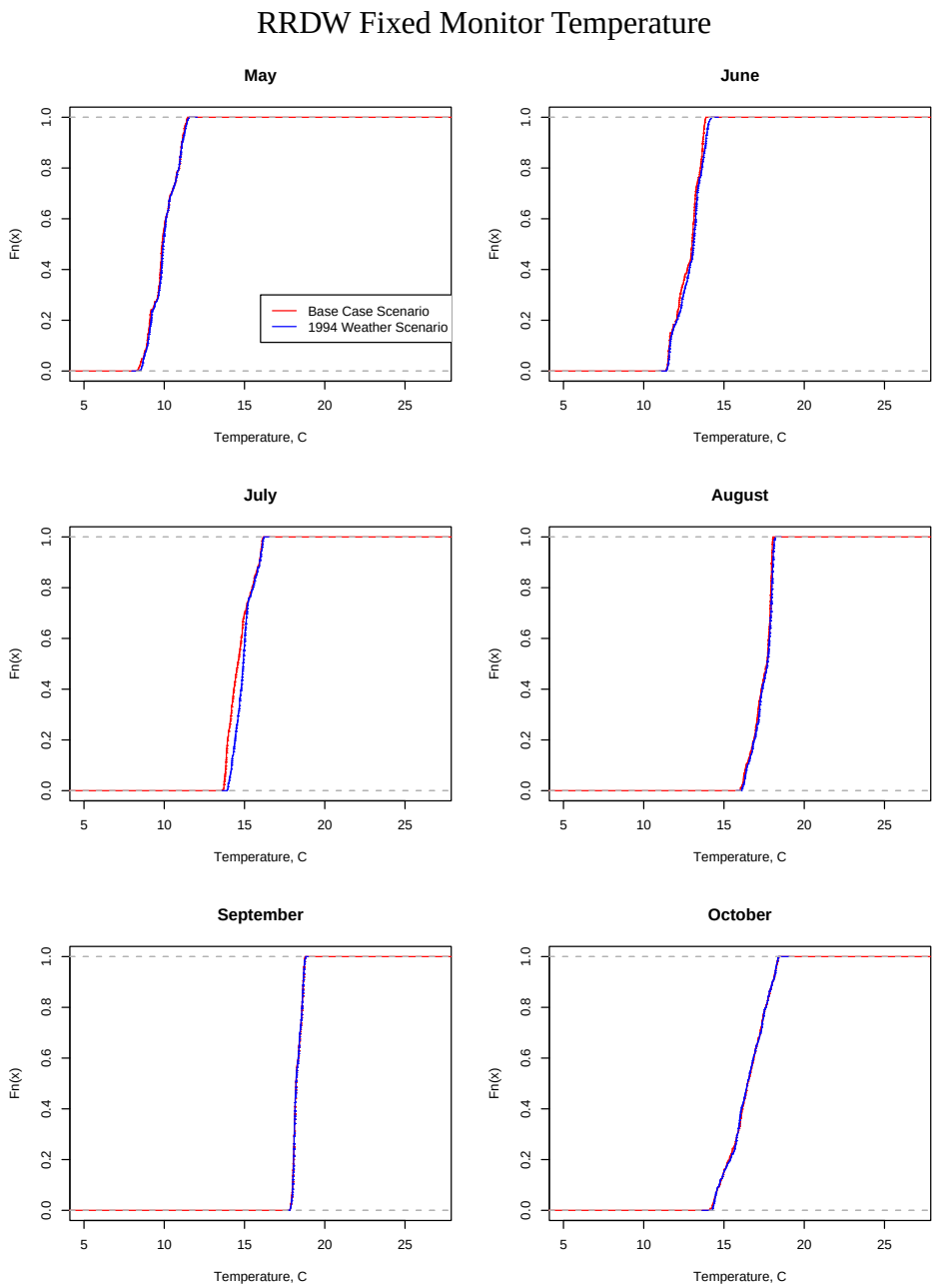

Figure 62: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the RRDW Fixed Monitor in the Base Case and 1994 Weather scenario.

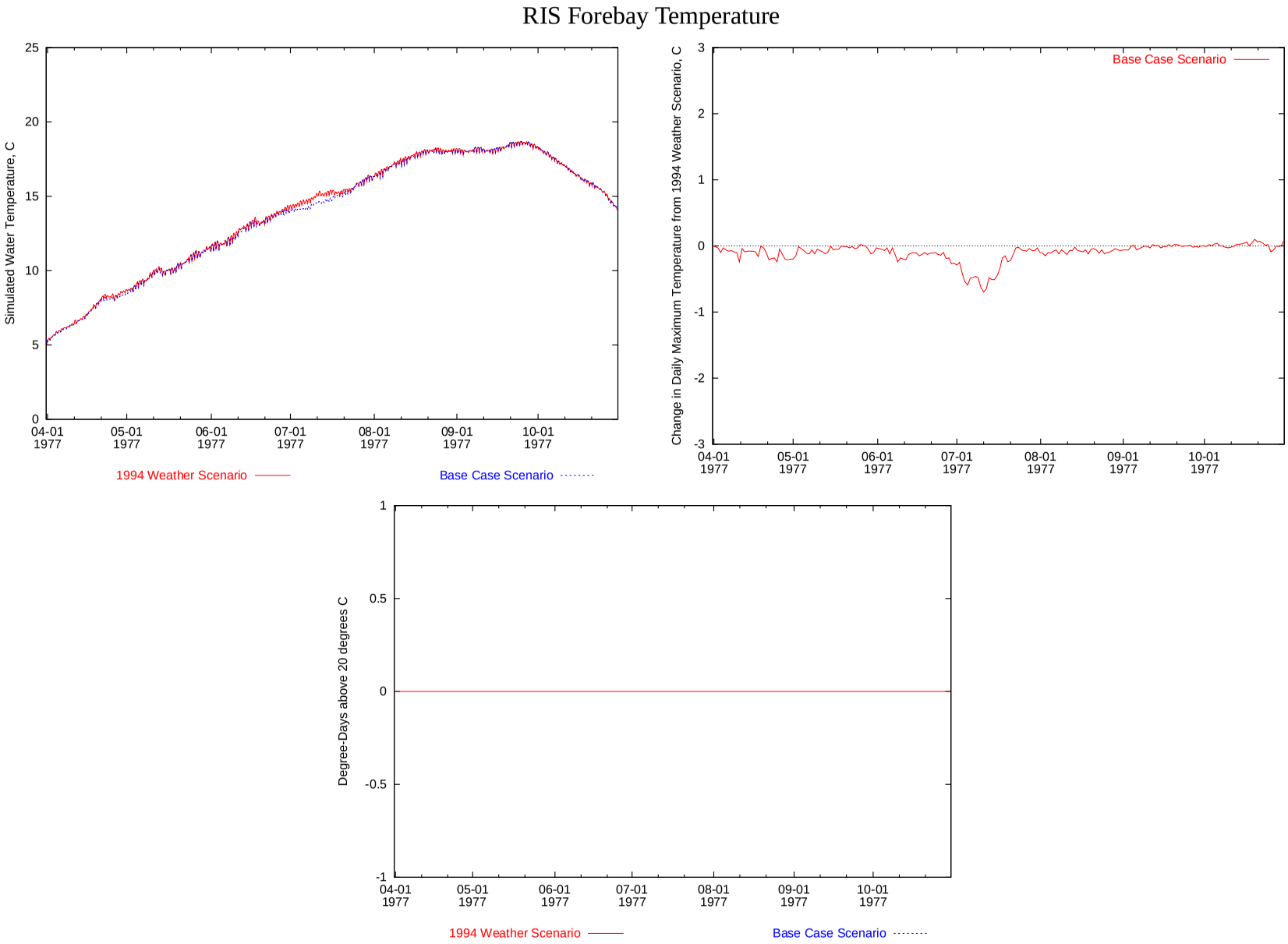

Figure 63: Time series comparison of temperature at the RIS Forebay in the Base Case and 1994 Weather scenario.

RIS Forebay Temperature

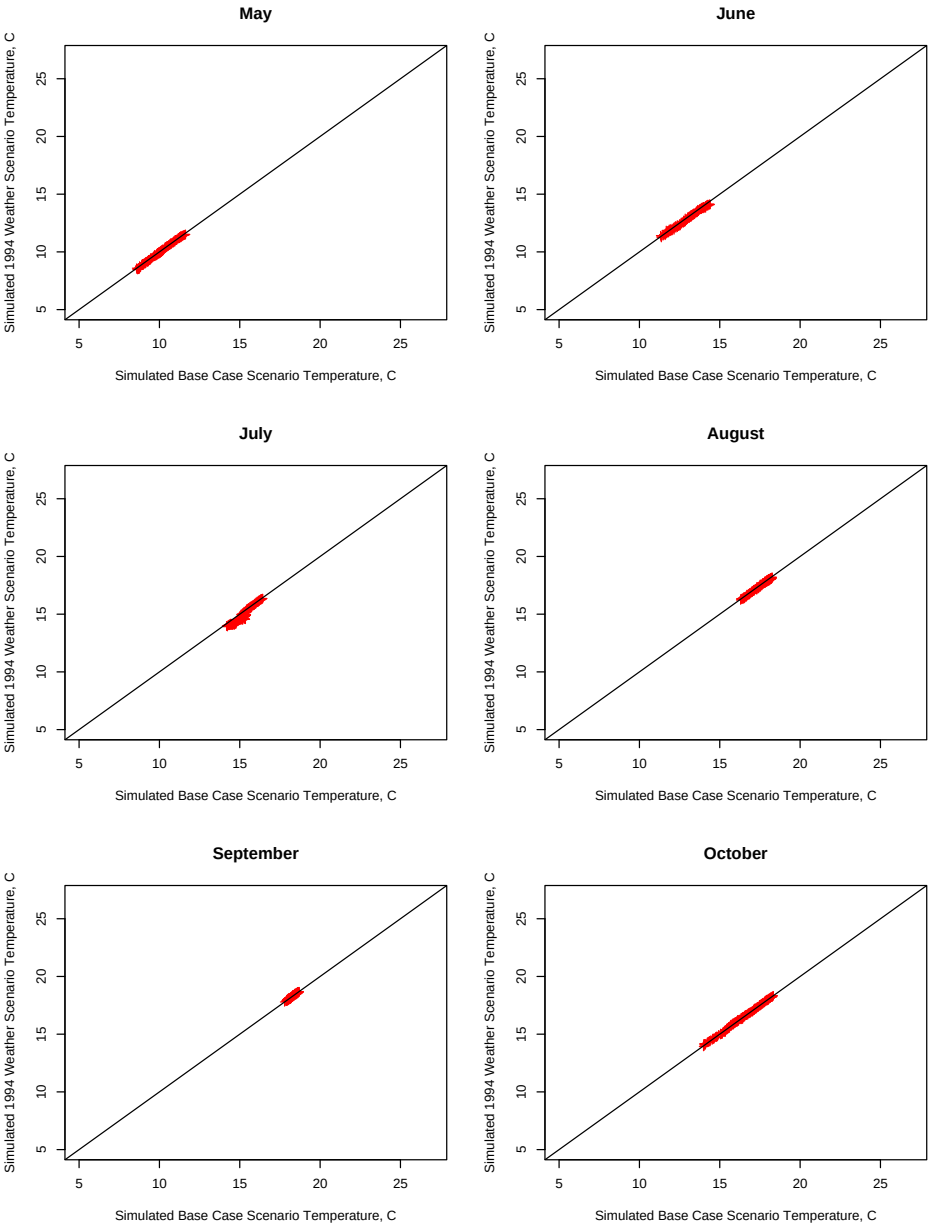

Figure 64: Scatter plot comparison, by month, of temperature at the RIS Forebay in the Base Case and 1994 Weather scenario.

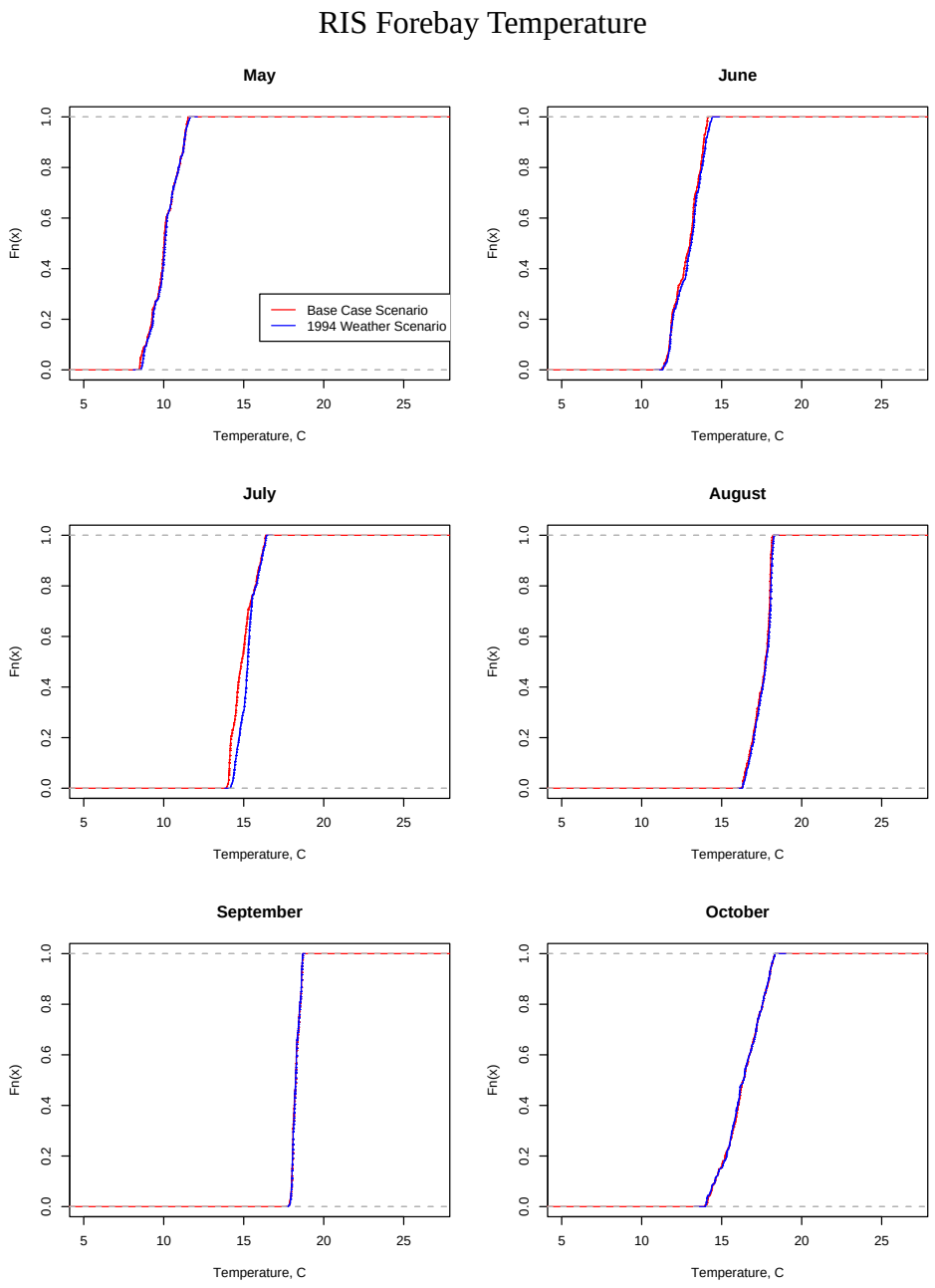

Figure 65: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the RIS Forebay in the Base Case and 1994 Weather scenario.

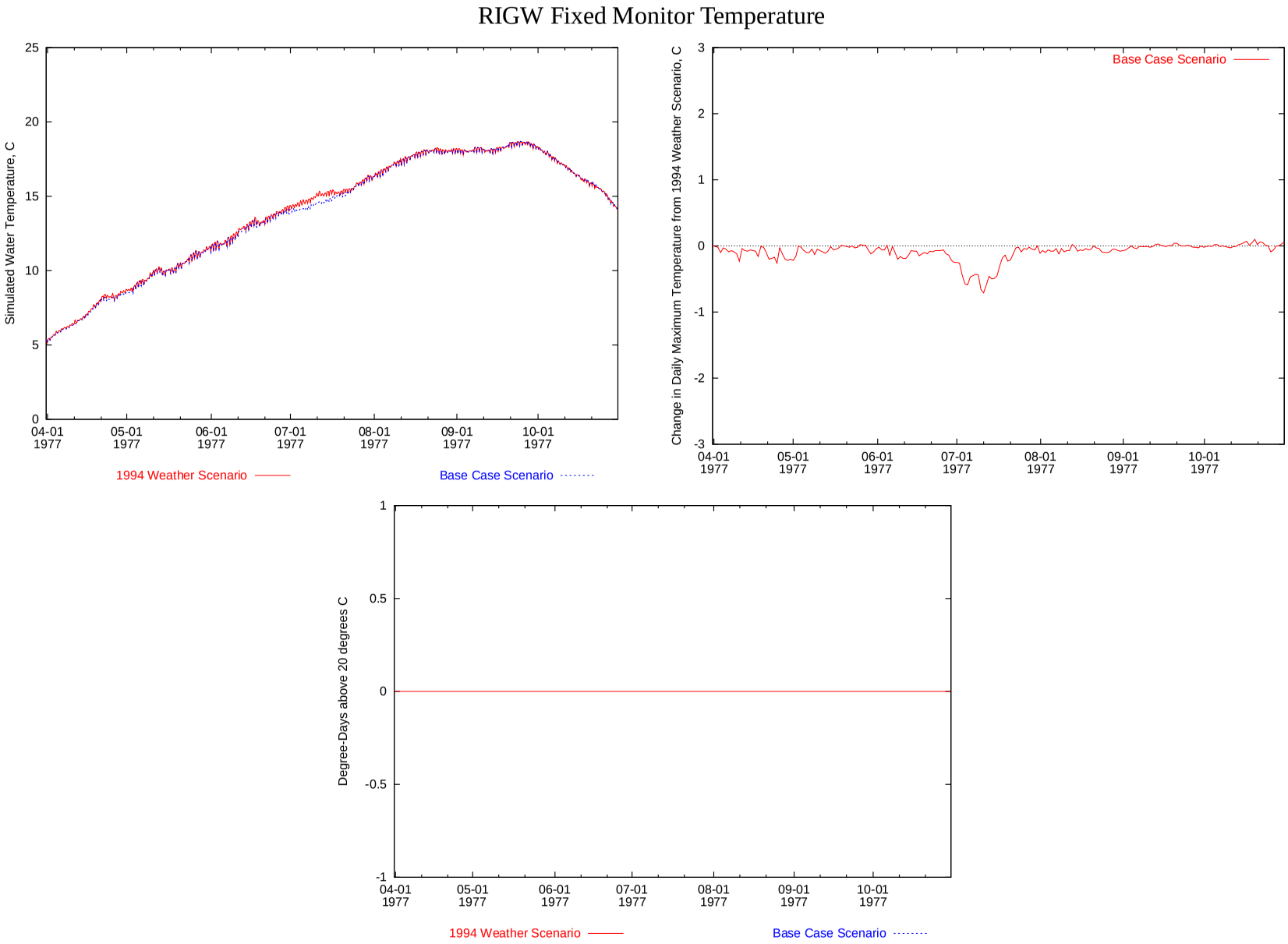

Figure 66: Time series comparison of temperature at the RIGW Fixed Monitor in the Base Case and 1994 Weather scenario.

RIGW Fixed Monitor Temperature

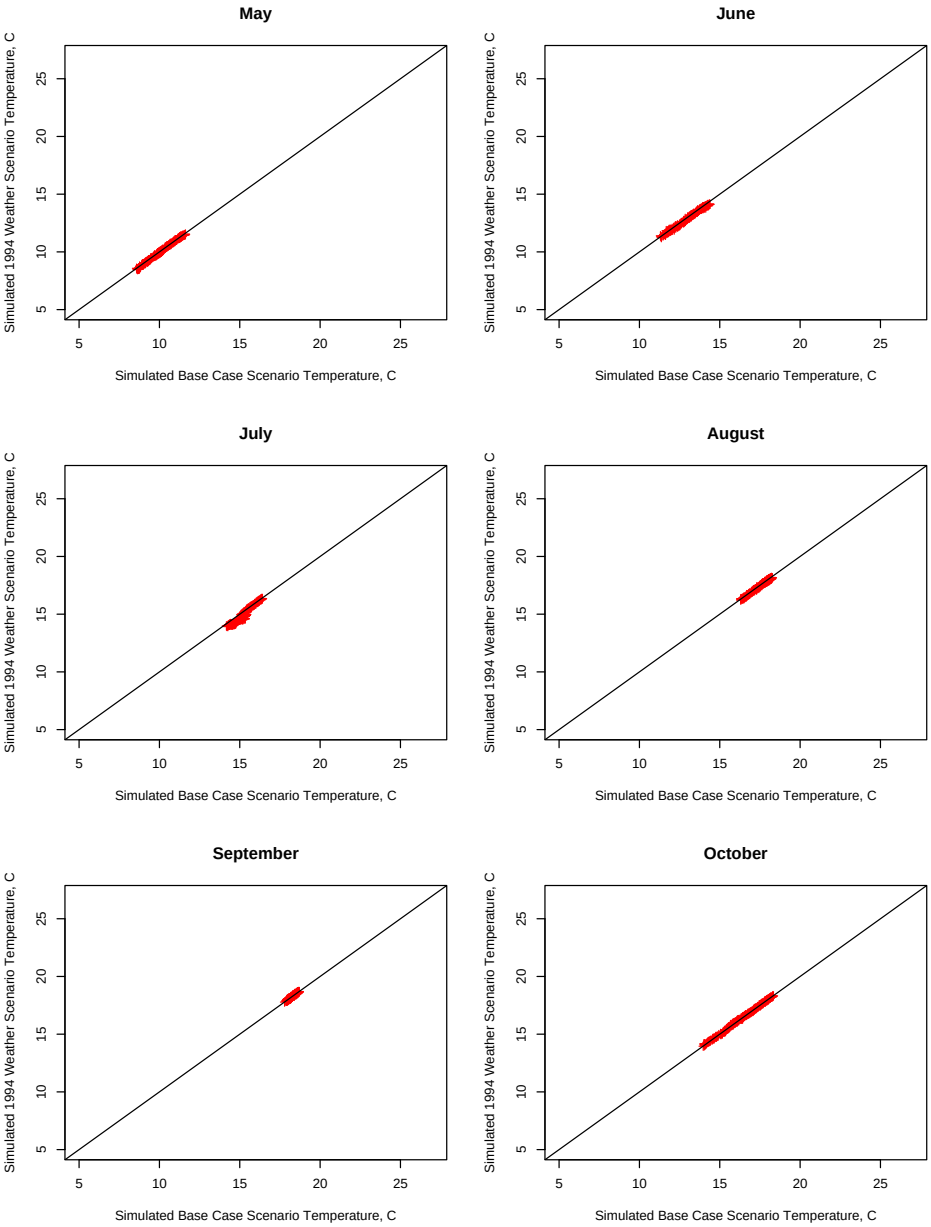

Figure 67: Scatter plot comparison, by month, of temperature at the RIGW Fixed Monitor in the Base Case and 1994 Weather scenario.

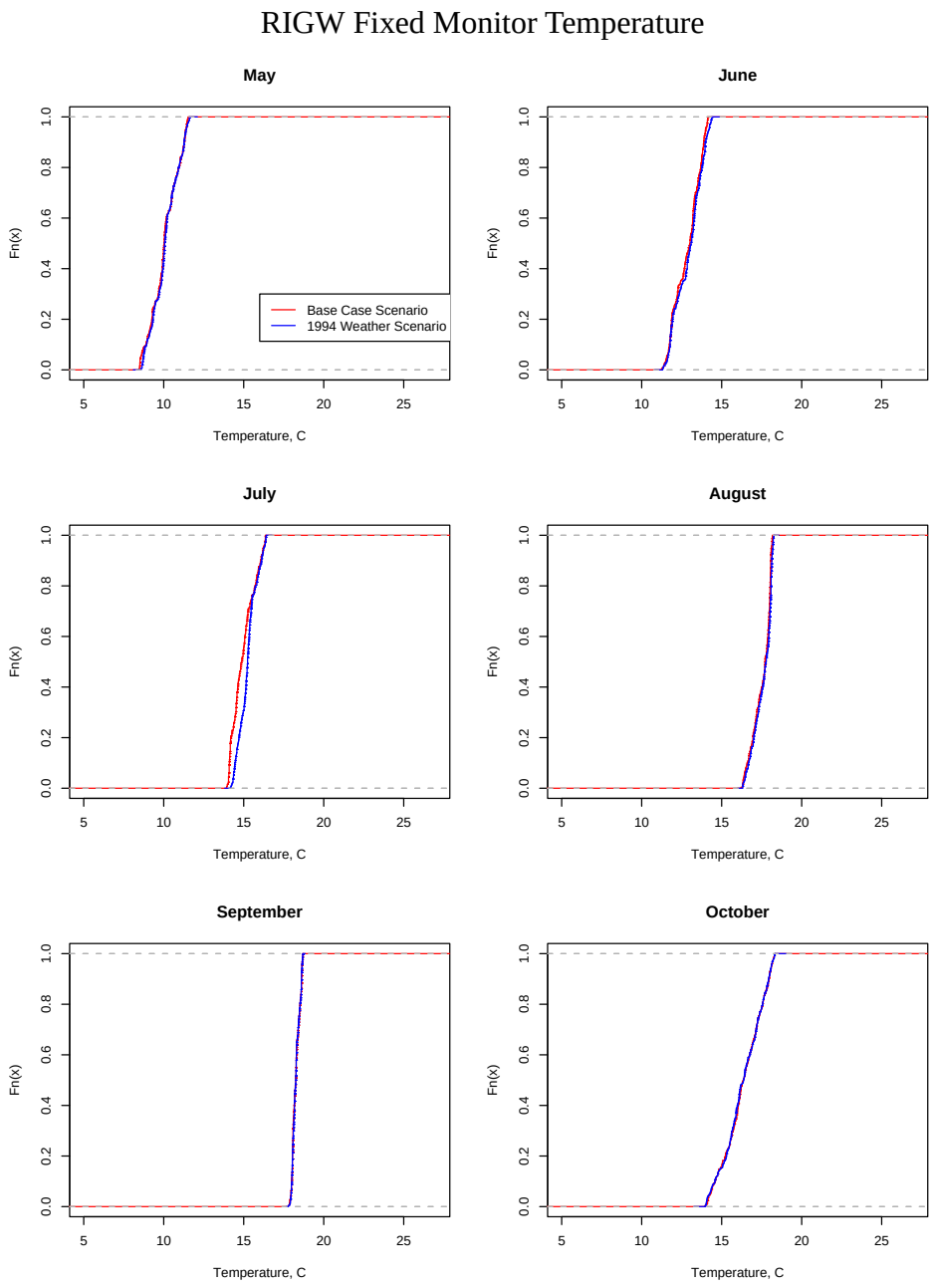

Figure 68: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the RIGW Fixed Monitor in the Base Case and 1994 Weather scenario.

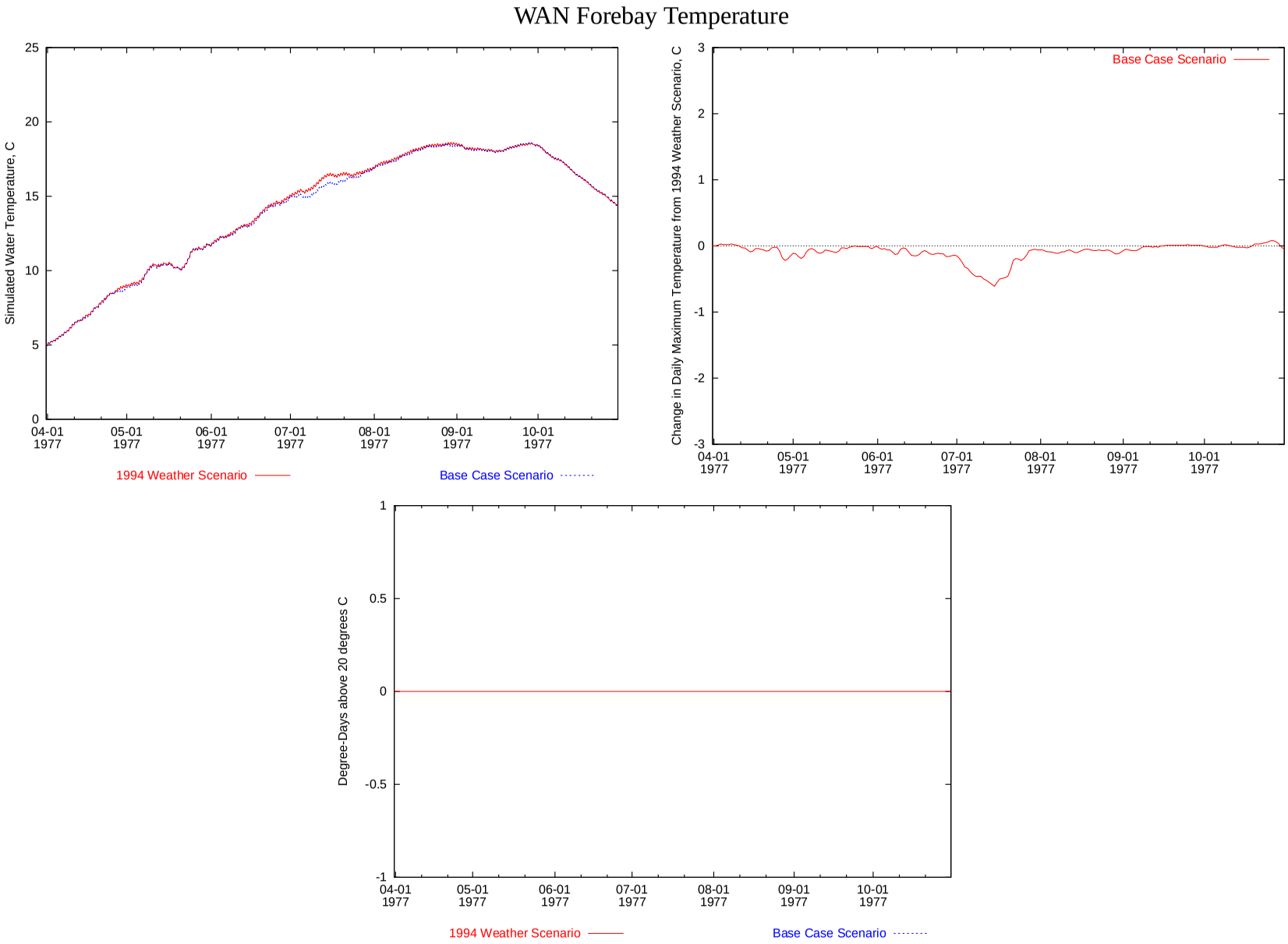

Figure 69: Time series comparison of temperature at the WAN Forebay in the Base Case and 1994 Weather scenario.

WAN Forebay Temperature

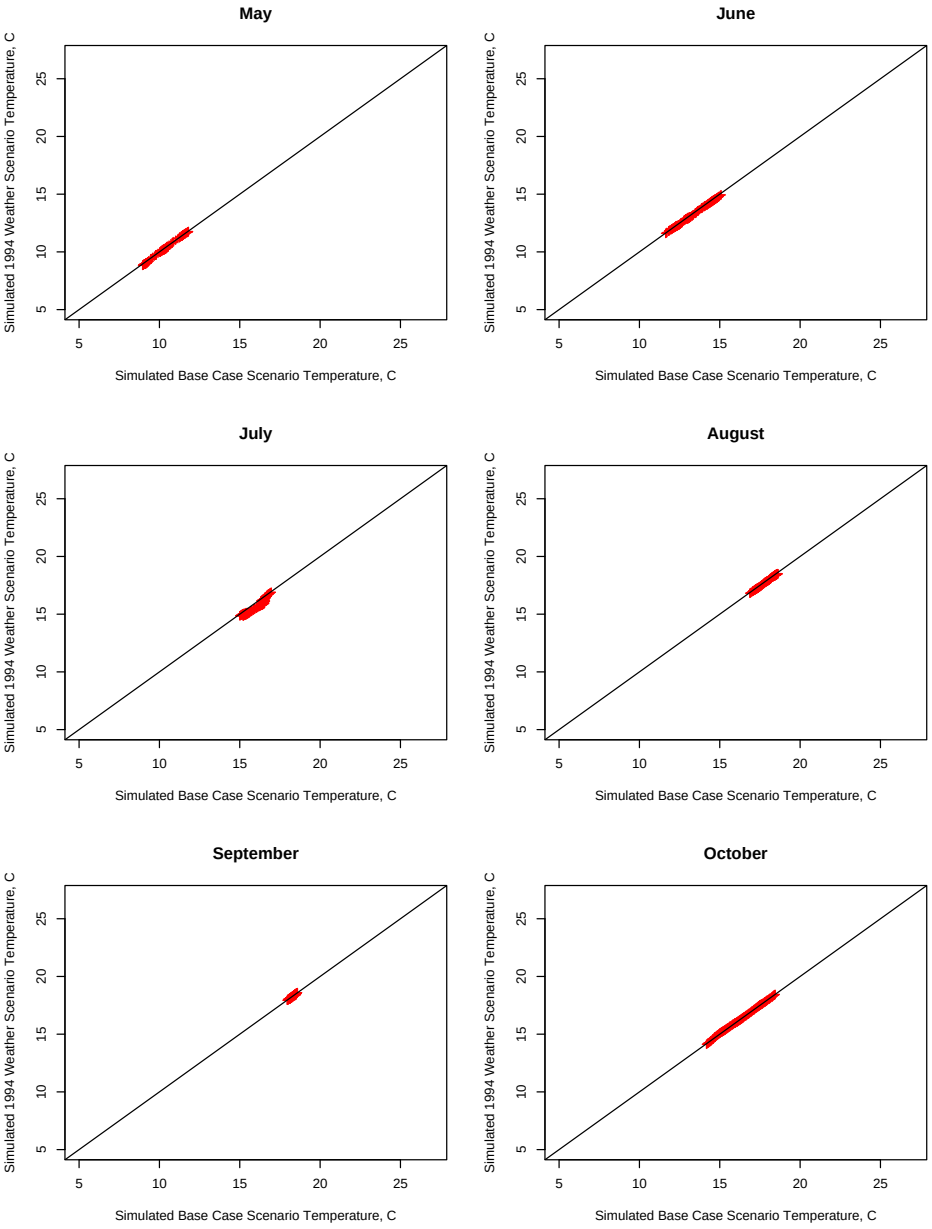

Figure 70: Scatter plot comparison, by month, of temperature at the WAN Forebay in the Base Case and 1994 Weather scenario.

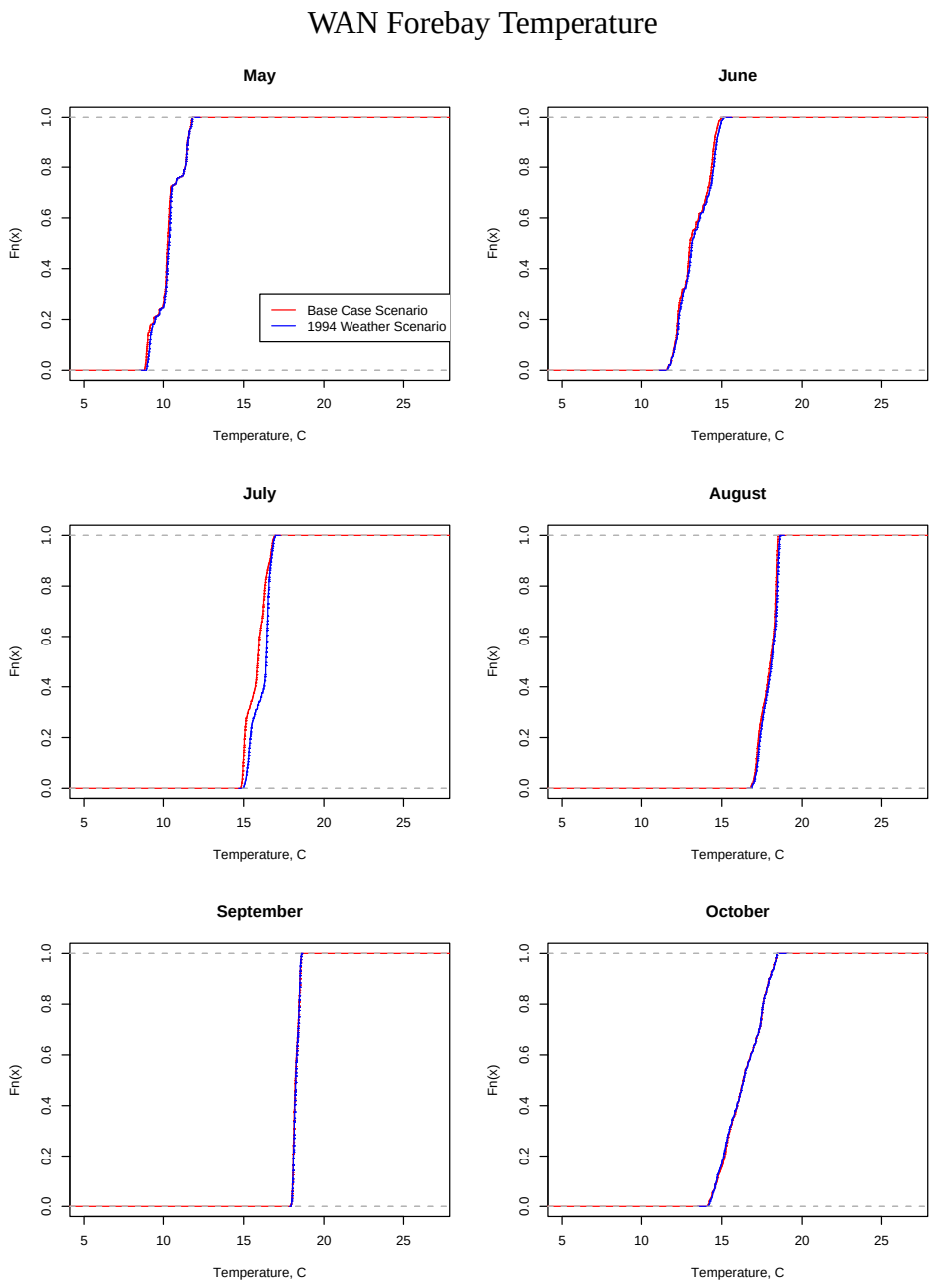

Figure 71: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the WAN Forebay in the Base Case and 1994 Weather scenario.

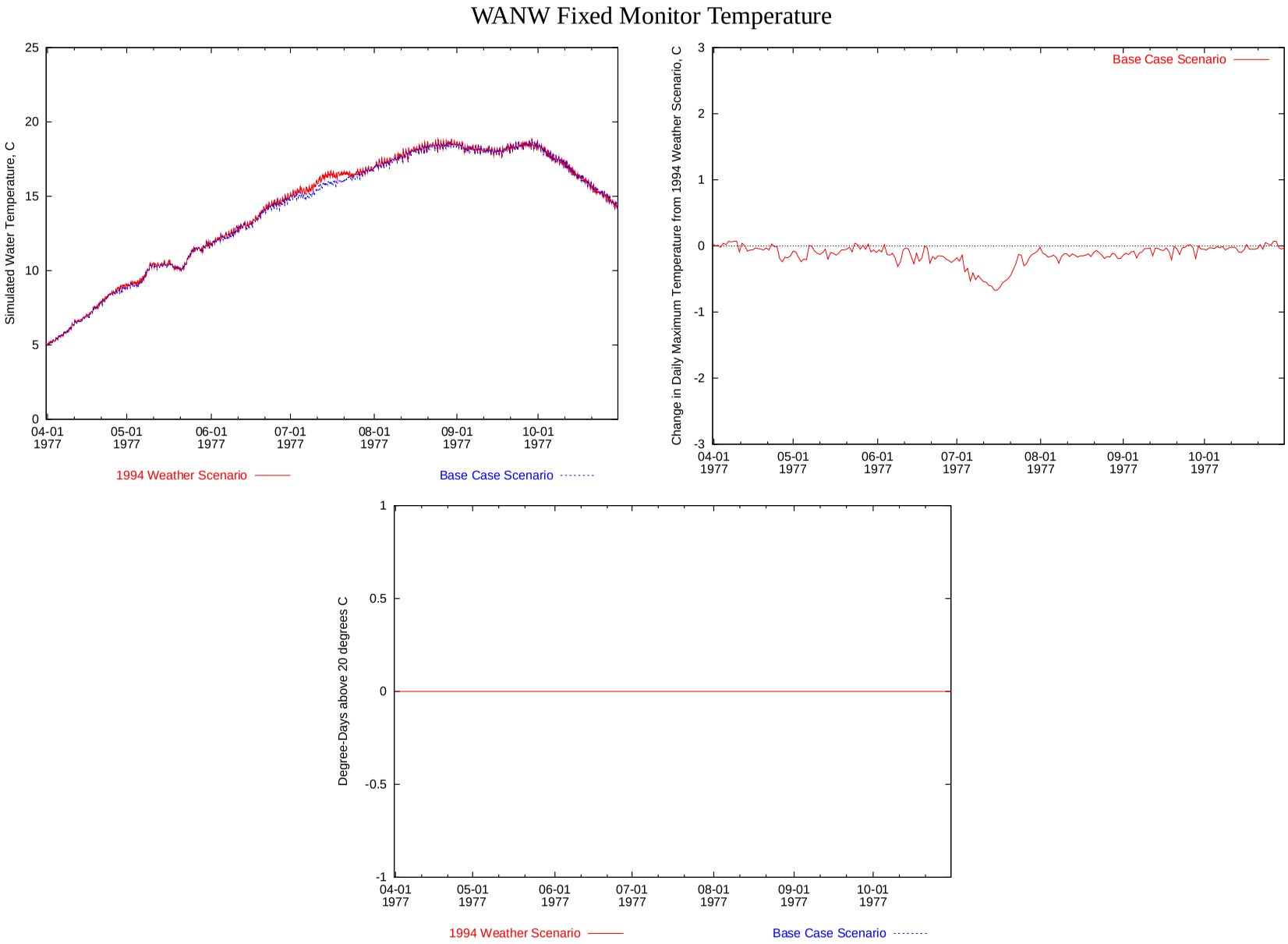

Figure 72: Time series comparison of temperature at the WANW Fixed Monitor in the Base Case and 1994 Weather scenario.

WANW Fixed Monitor Temperature

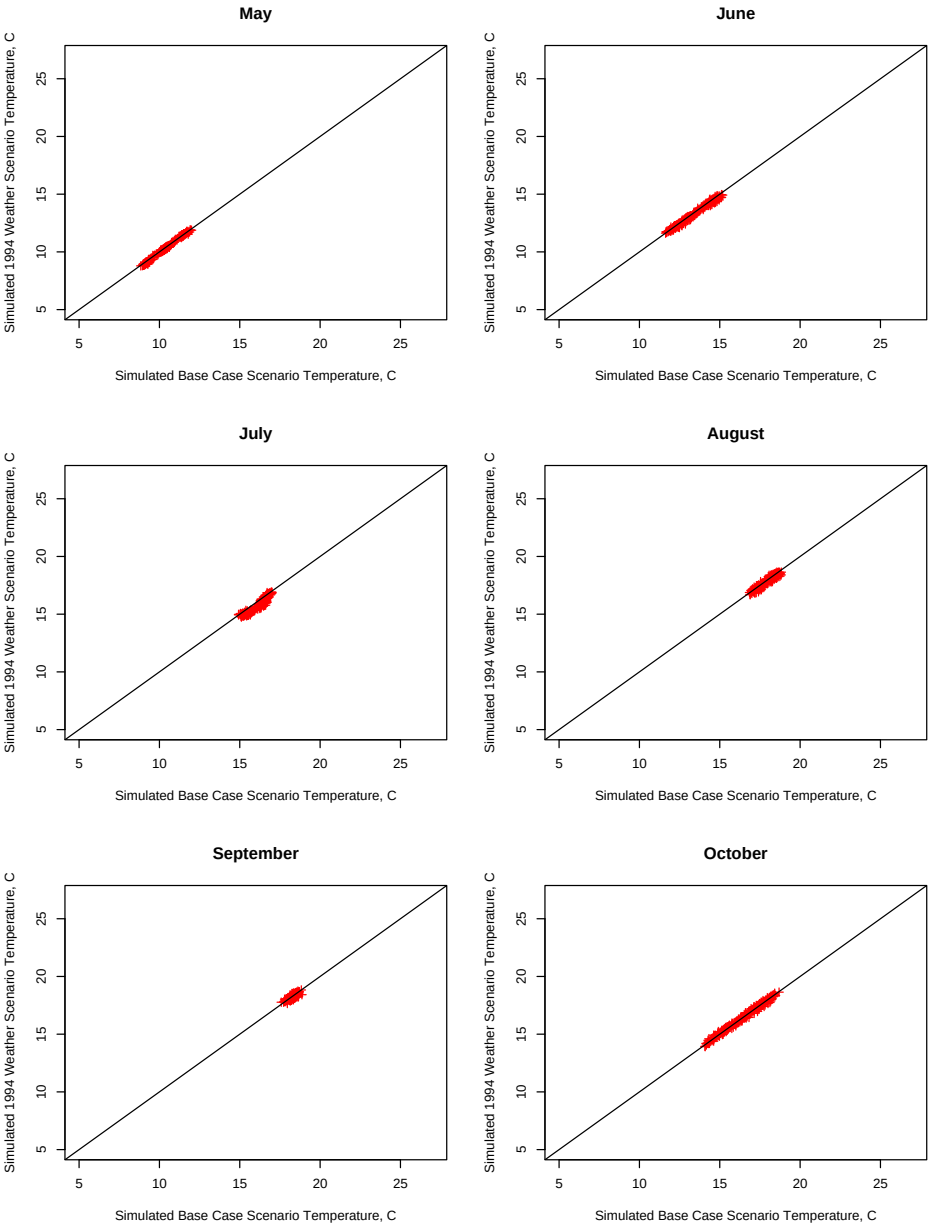

Figure 73: Scatter plot comparison, by month, of temperature at the WANW Fixed Monitor in the Base Case and 1994 Weather scenario.

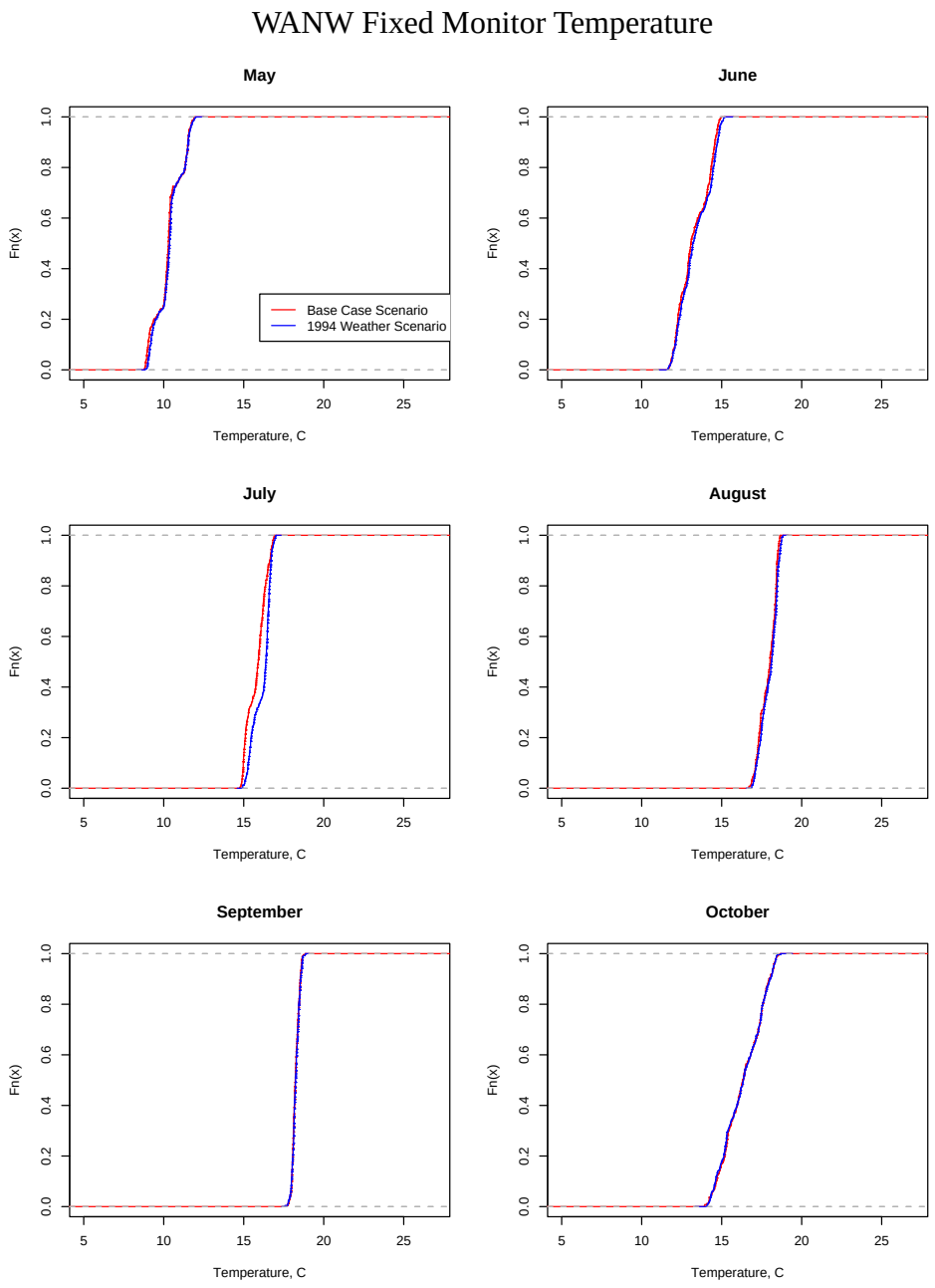

Figure 74: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the WANW Fixed Monitor in the Base Case and 1994 Weather scenario.

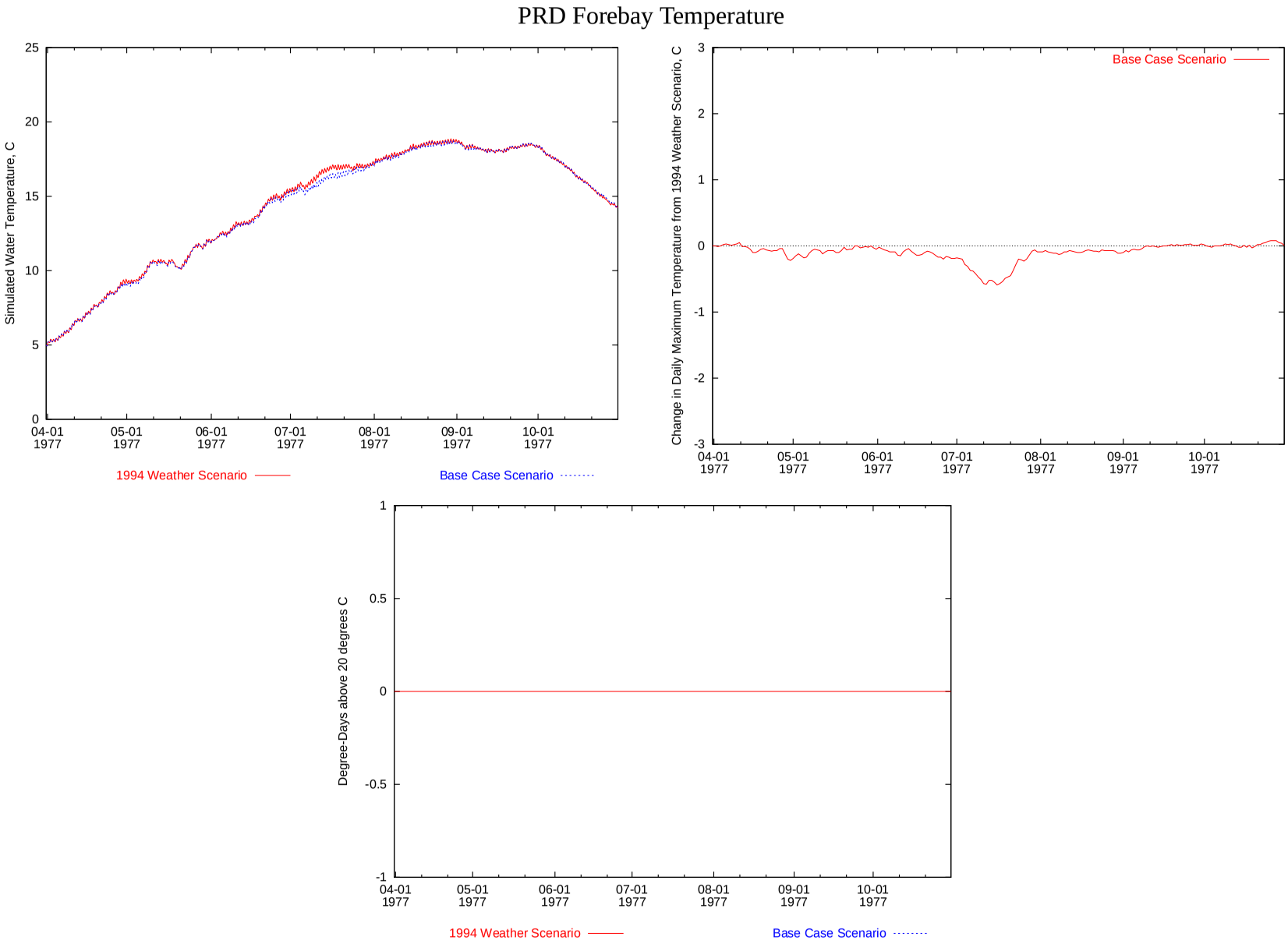

Figure 75: Time series comparison of temperature at the PRD Forebay in the Base Case and 1994 Weather scenario.

PRD Forebay Temperature

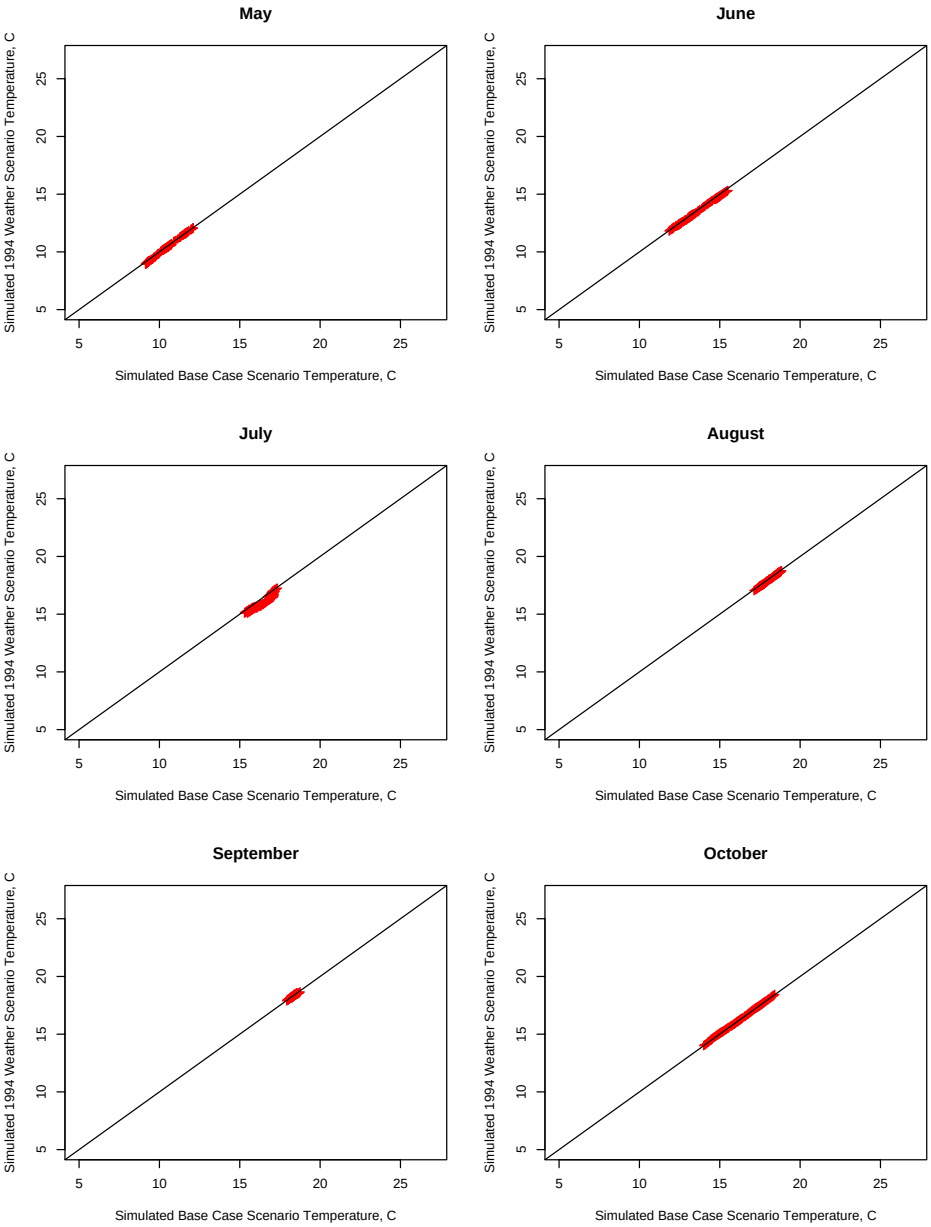

Figure 76: Scatter plot comparison, by month, of temperature at the PRD Forebay in the Base Case and 1994 Weather scenario.

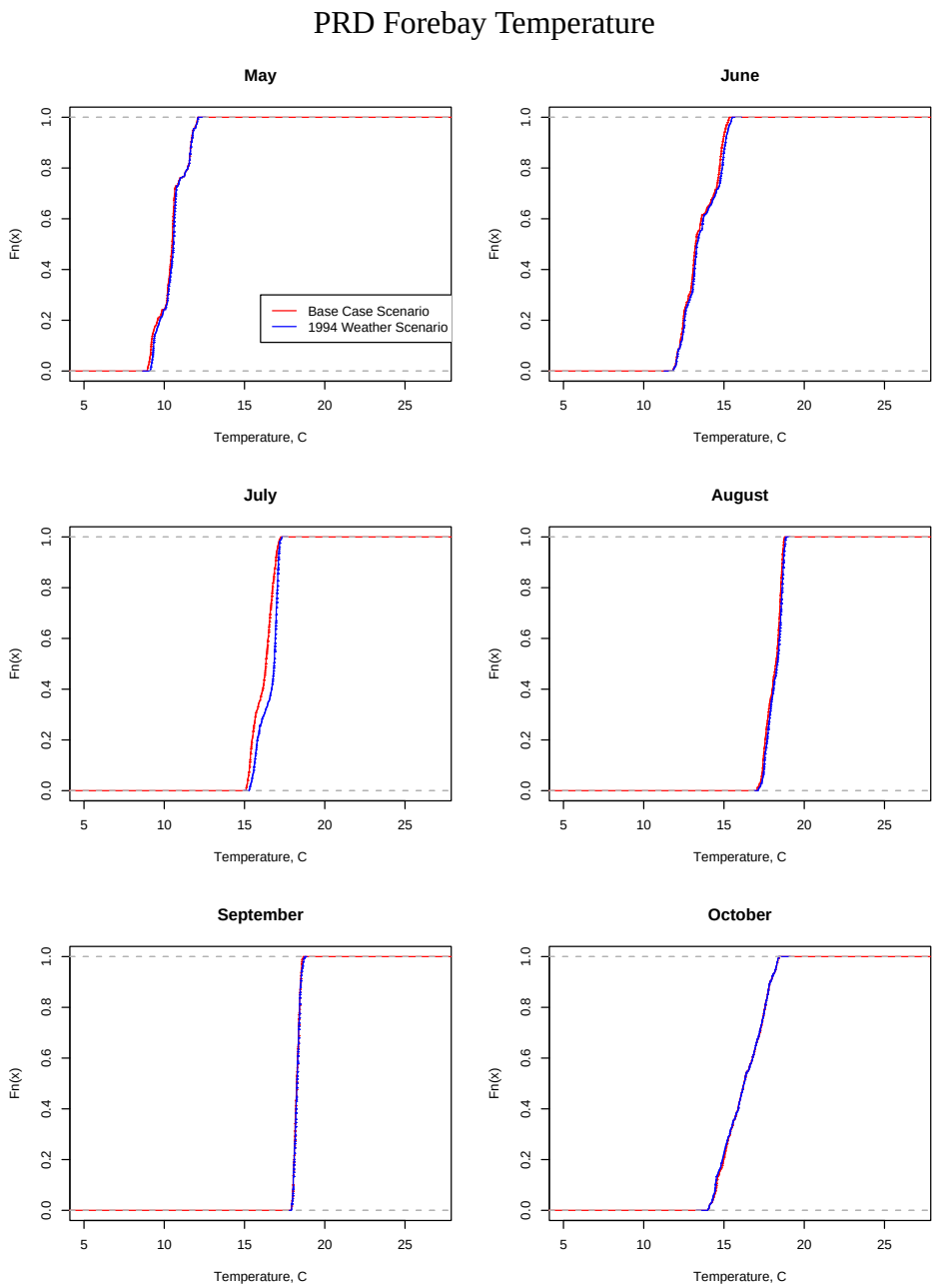

Figure 77: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the PRD Forebay in the Base Case and 1994 Weather scenario.

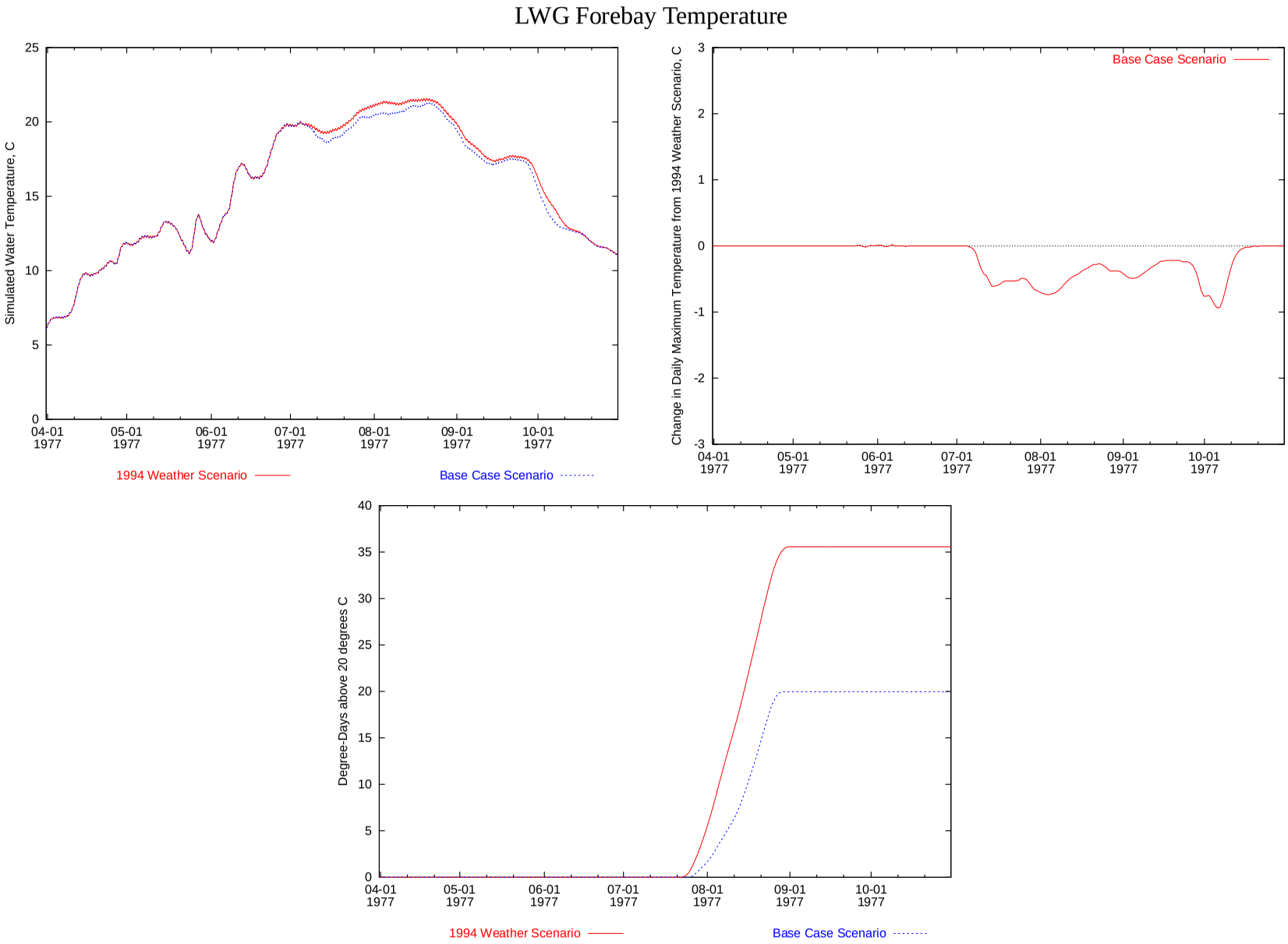

Figure 78: Time series comparison of temperature at the LWG Forebay in the Base Case and 1994 Weather scenario.

LWG Forebay Temperature

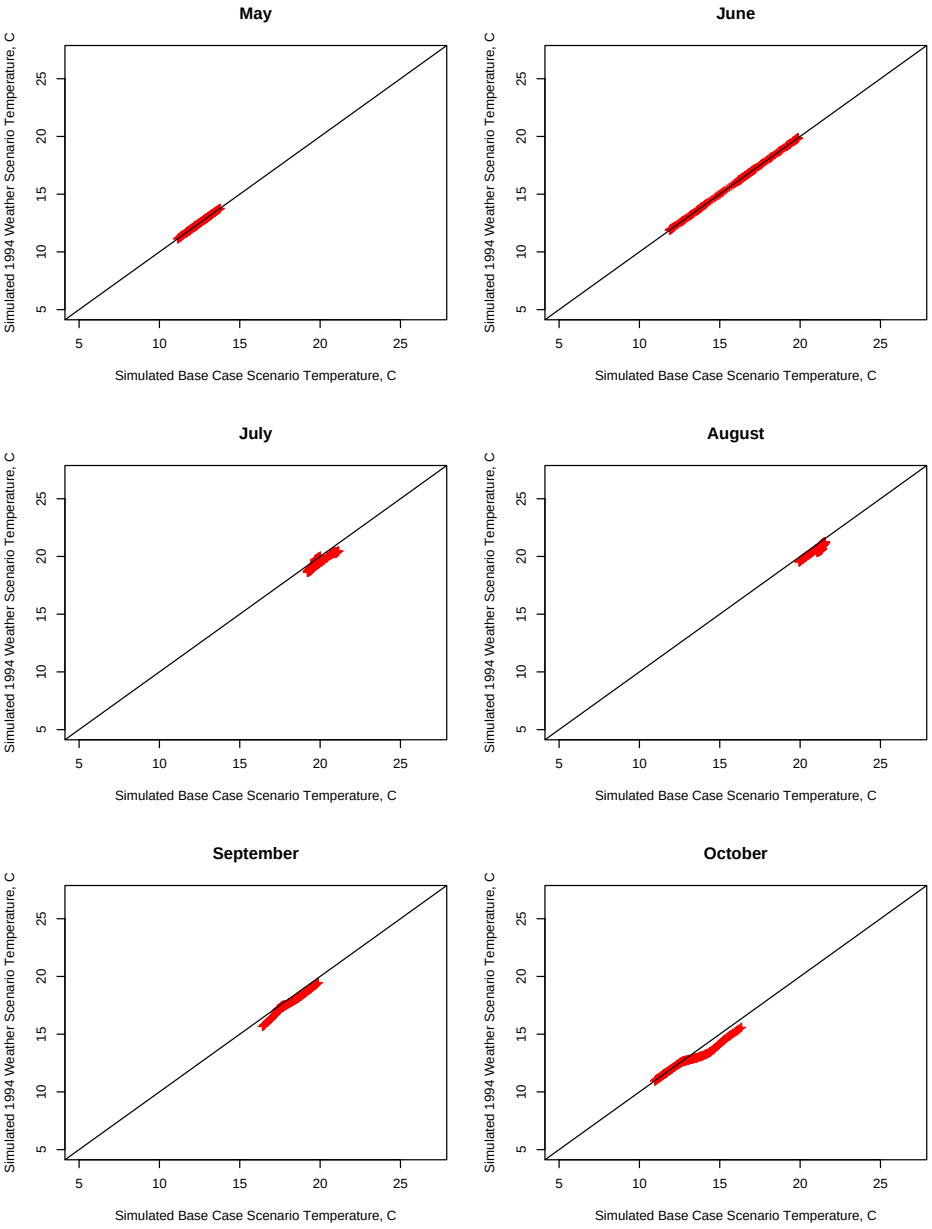

Figure 79: Scatter plot comparison, by month, of temperature at the LWG Forebay in the Base Case and 1994 Weather scenario.

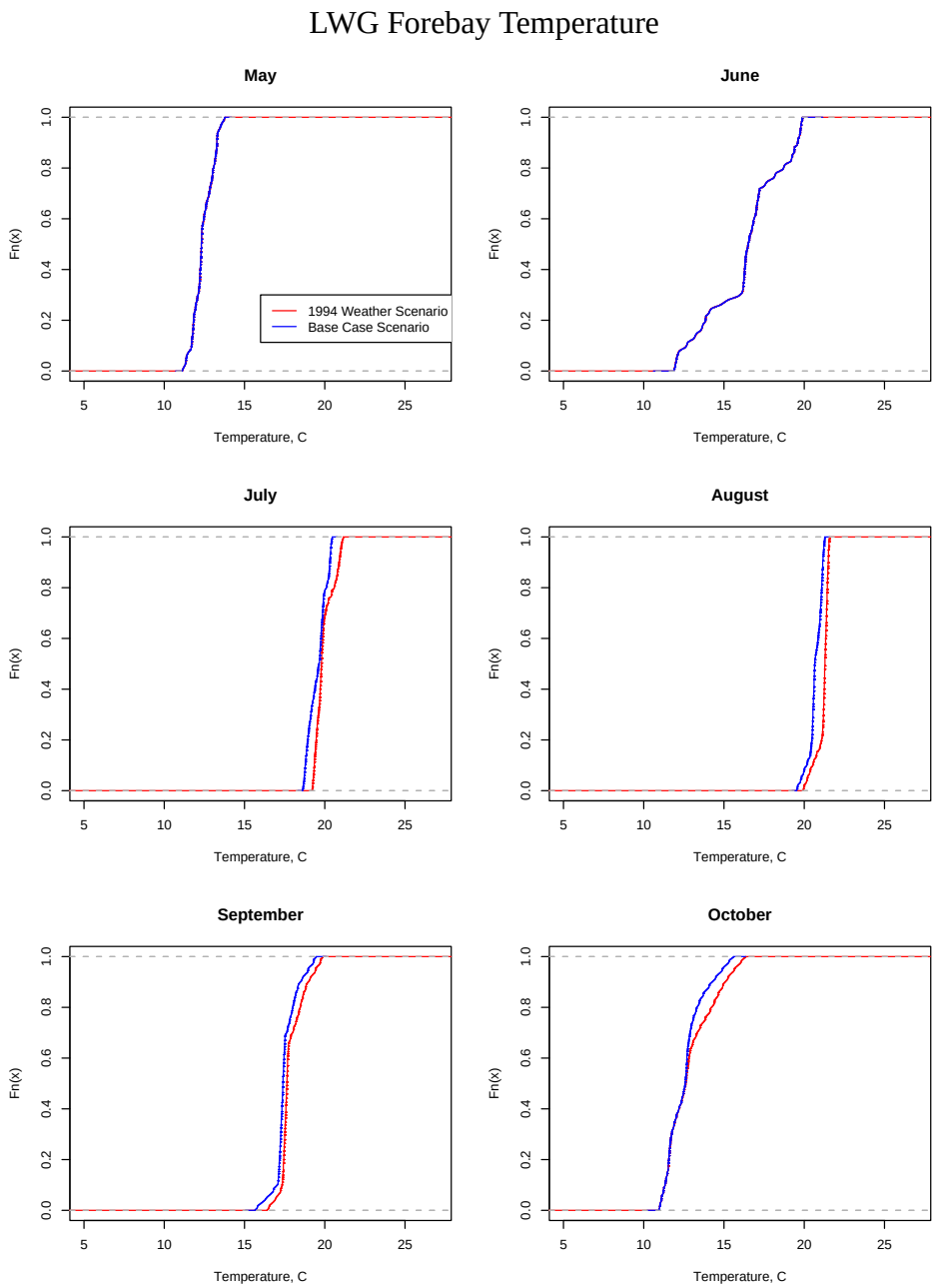

Figure 80: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the LWG Forebay in the Base Case and 1994 Weather scenario.

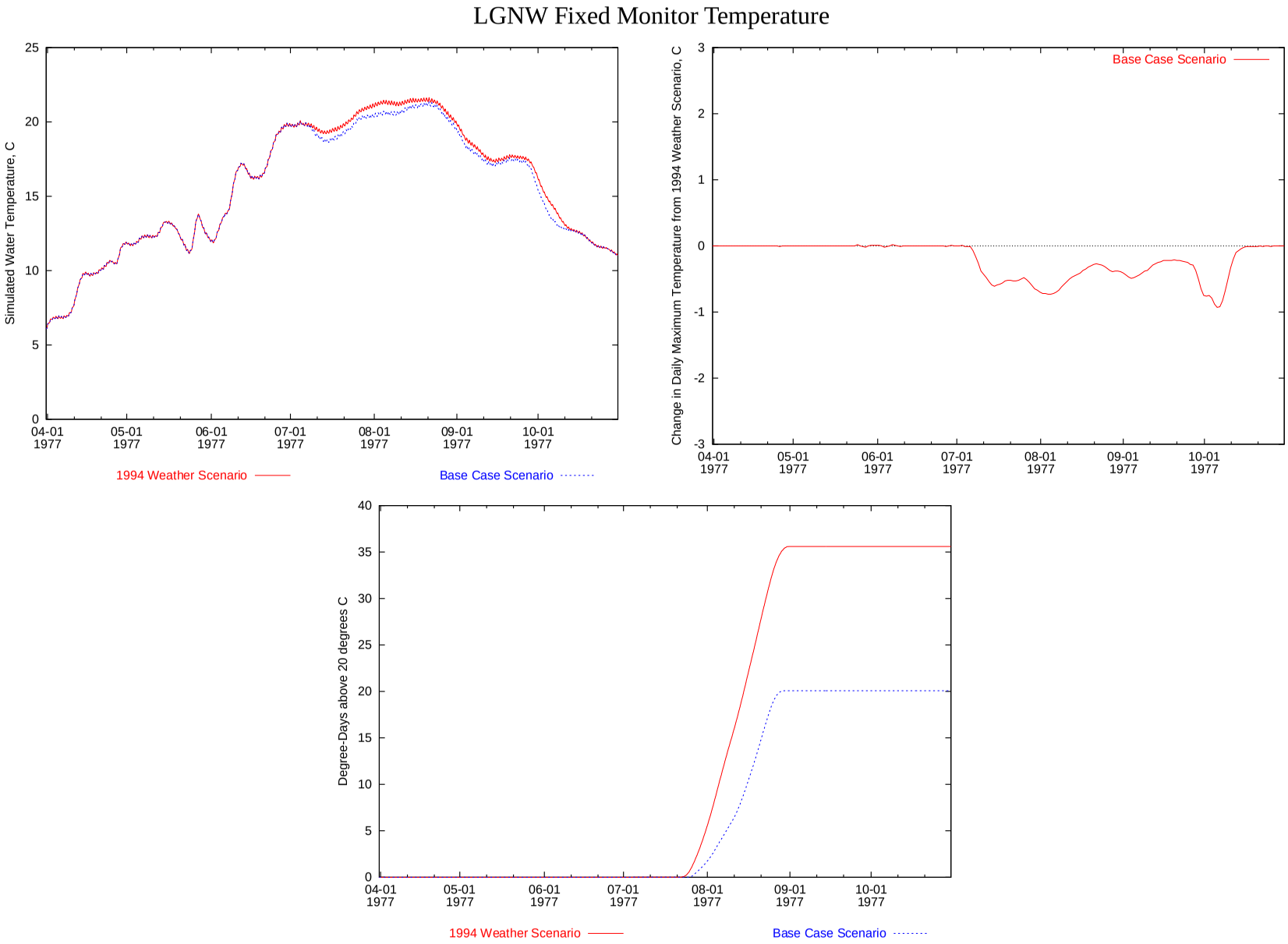

Figure 81: Time series comparison of temperature at the LGNW Fixed Monitor in the Base Case and 1994 Weather scenario.

LGNW Fixed Monitor Temperature

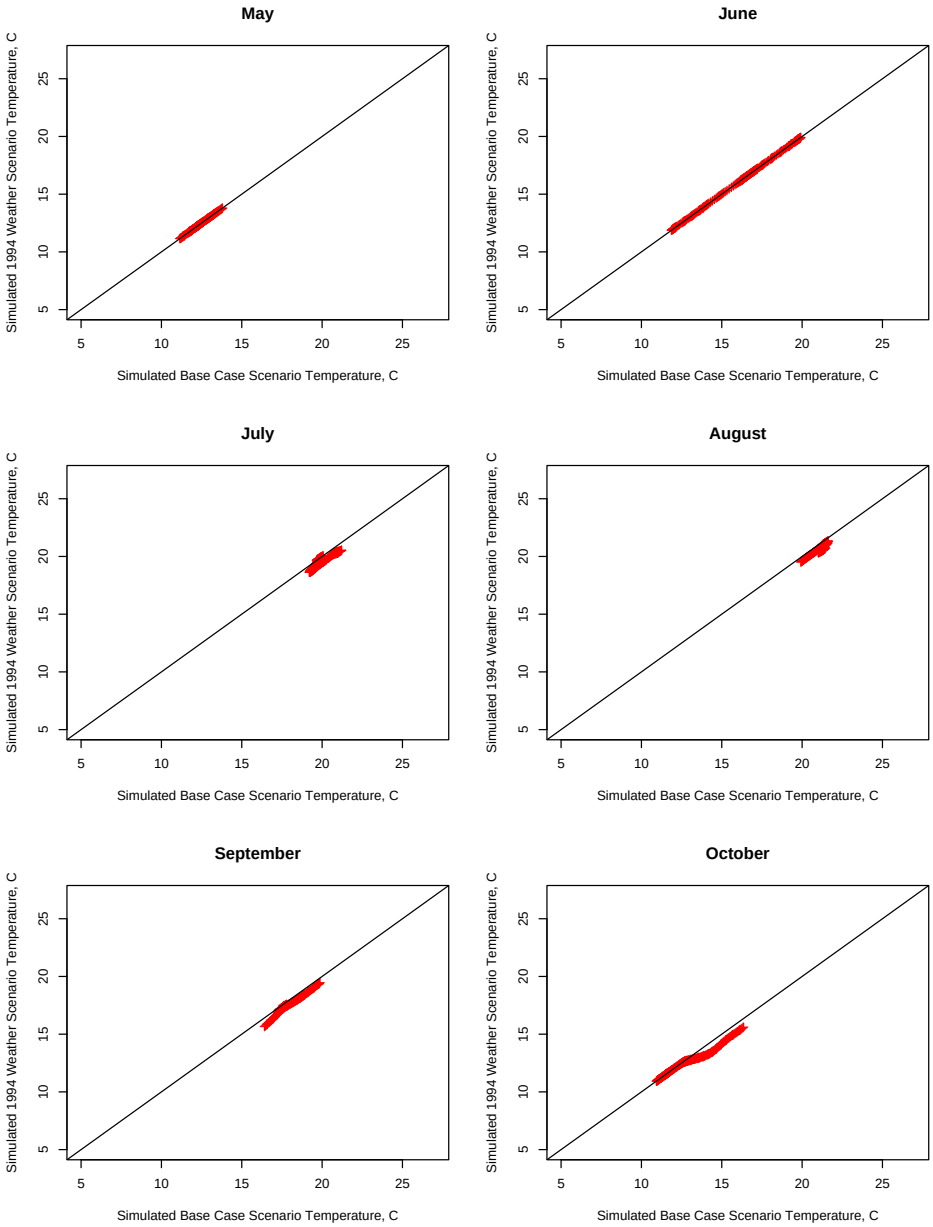

Figure 82: Scatter plot comparison, by month, of temperature at the LGNW Fixed Monitor in the Base Case and 1994 Weather scenario.

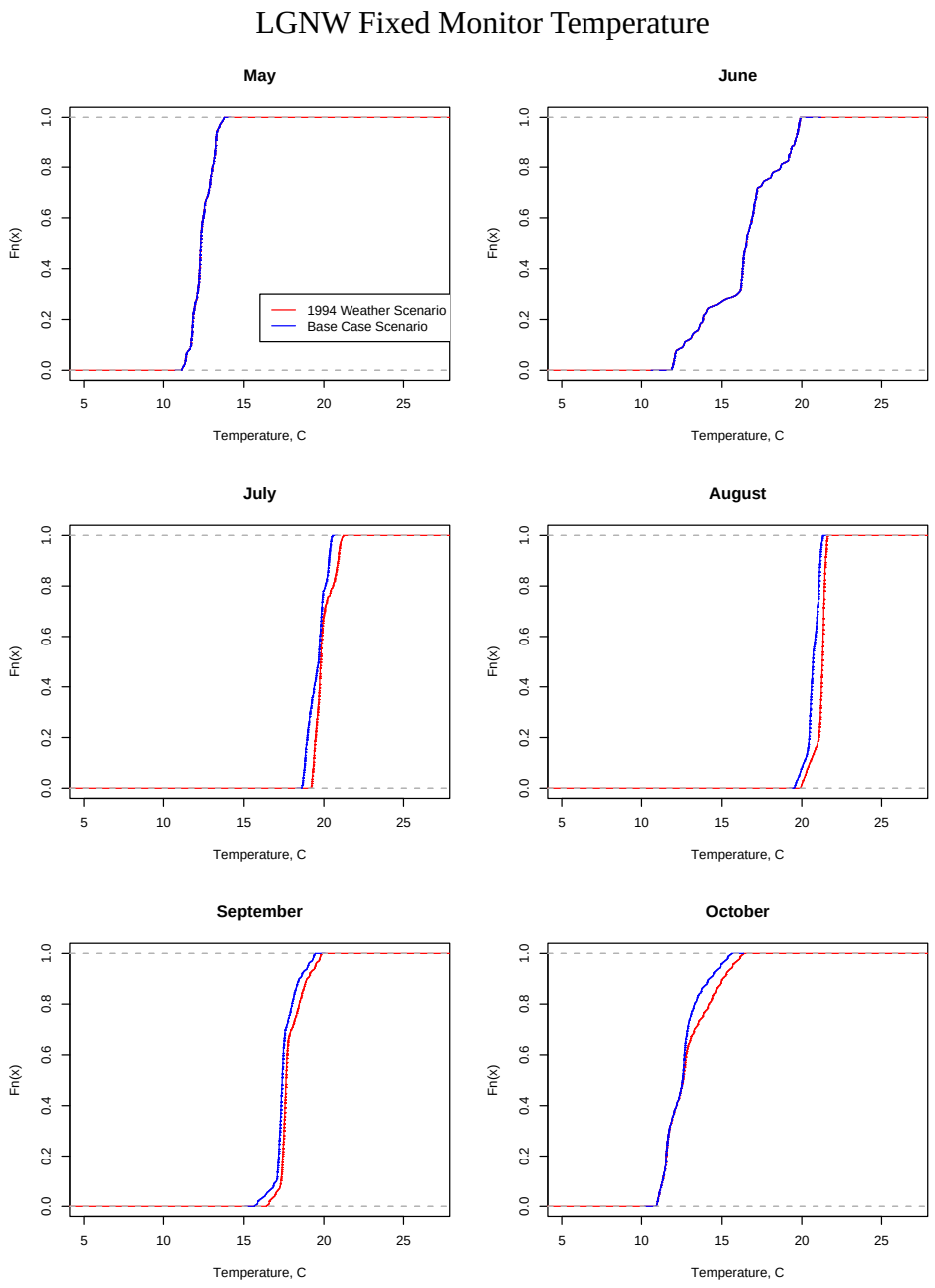

Figure 83: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the LGNW Fixed Monitor in the Base Case and 1994 Weather scenario.

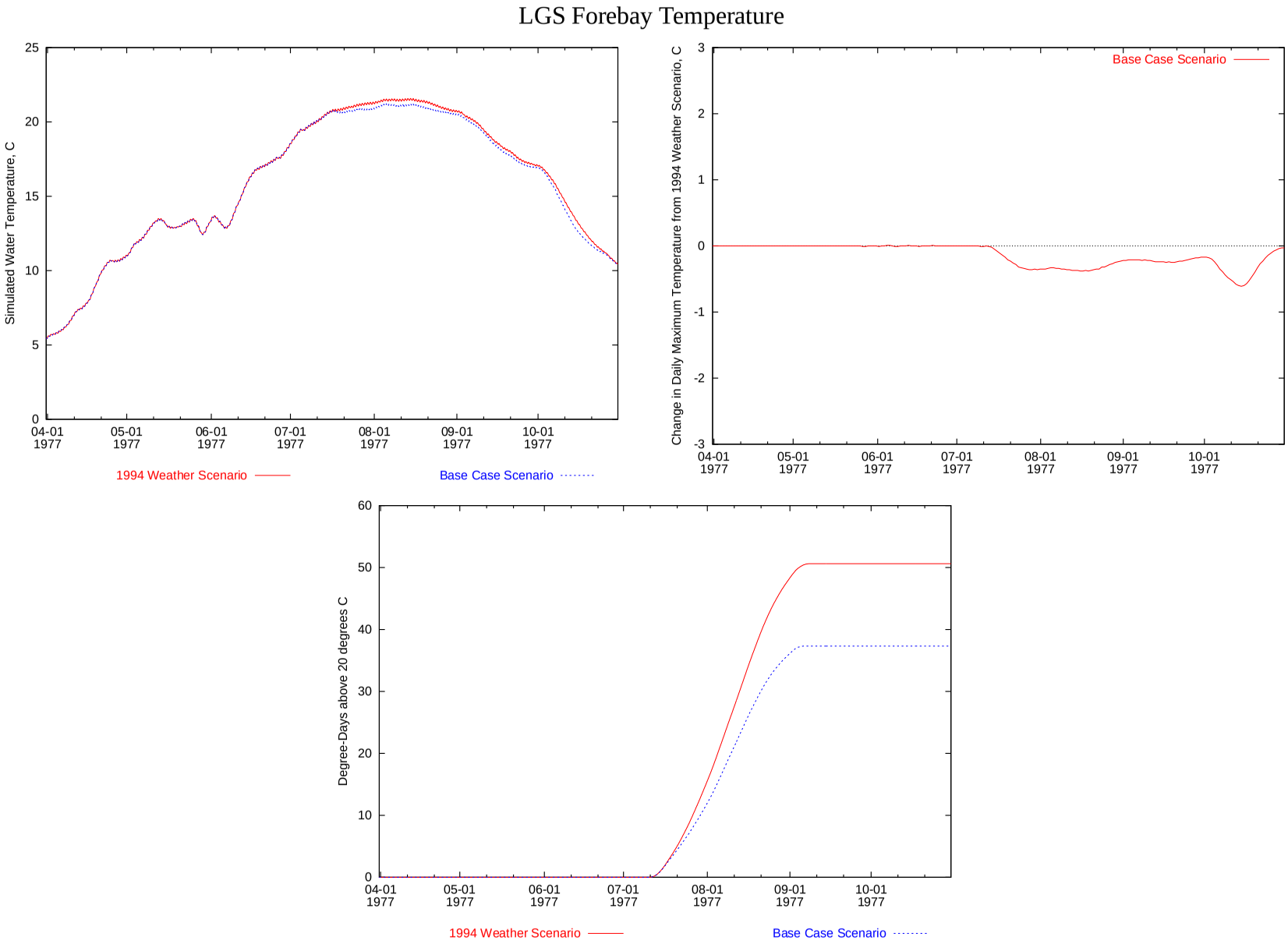

Figure 84: Time series comparison of temperature at the LGS Forebay in the Base Case and 1994 Weather scenario.

LGS Forebay Temperature

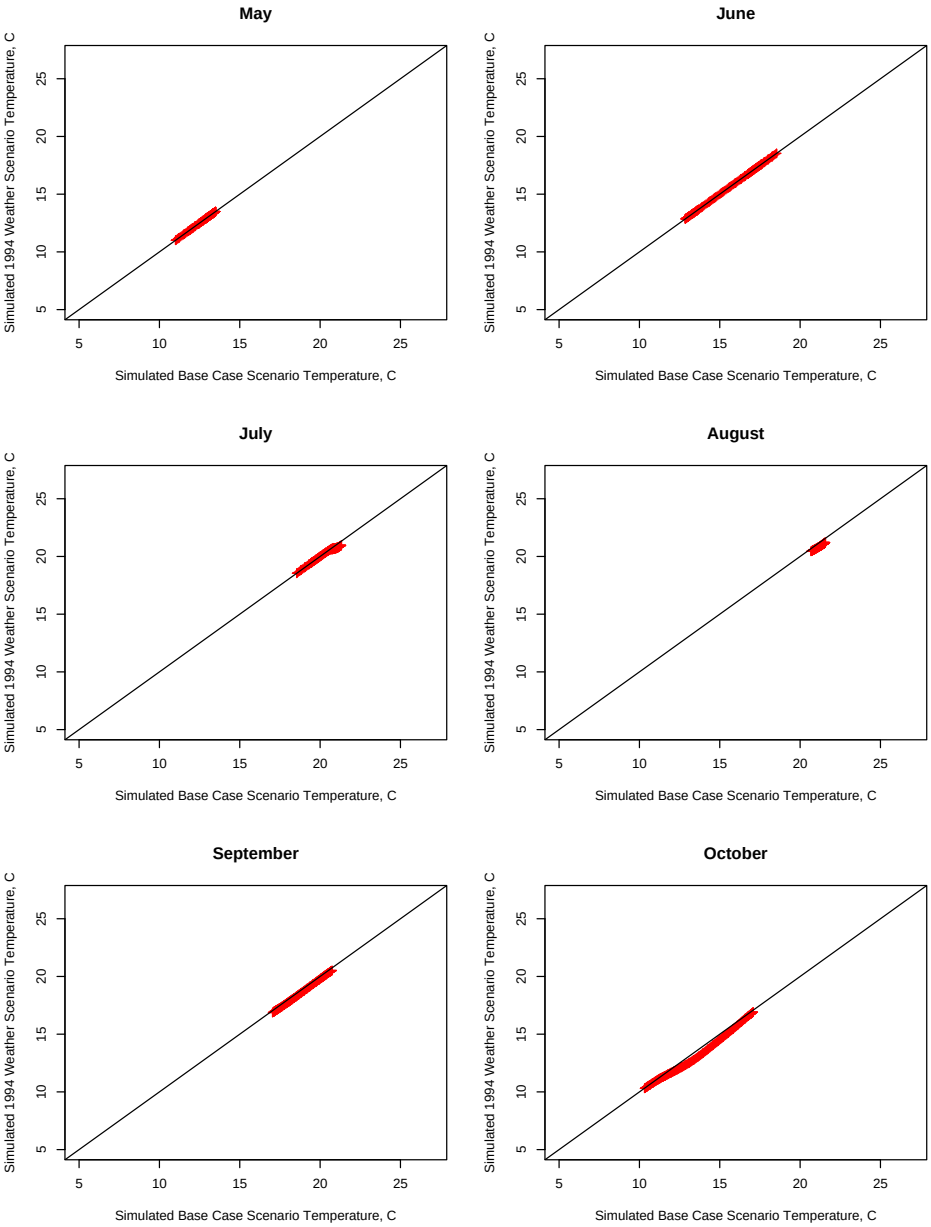

Figure 85: Scatter plot comparison, by month, of temperature at the LGS Forebay in the Base Case and 1994 Weather scenario.

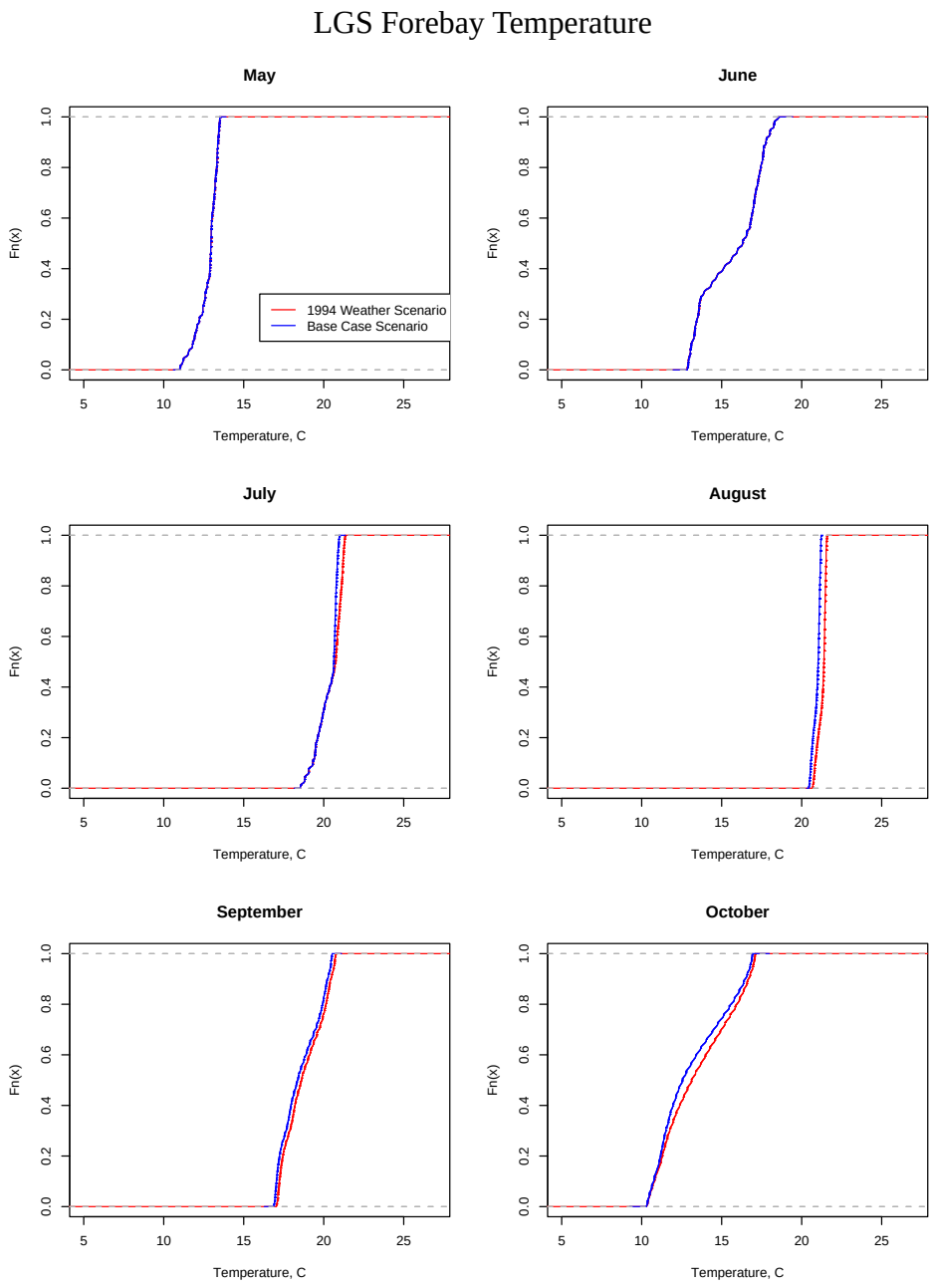

Figure 86: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the LGS Forebay in the Base Case and 1994 Weather scenario.

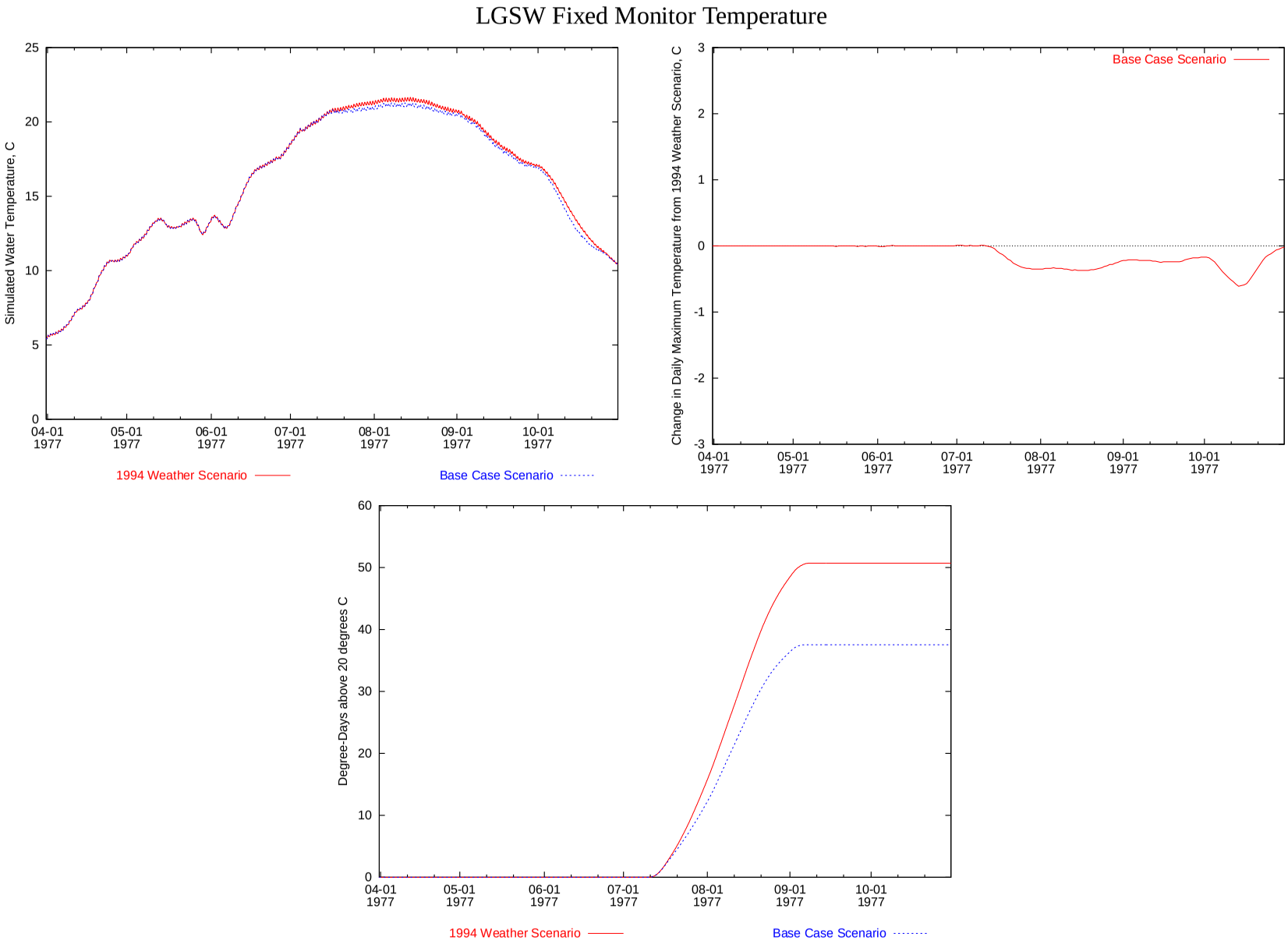

Figure 87: Time series comparison of temperature at the LGSW Fixed Monitor in the Base Case and 1994 Weather scenario.

LGSW Fixed Monitor Temperature

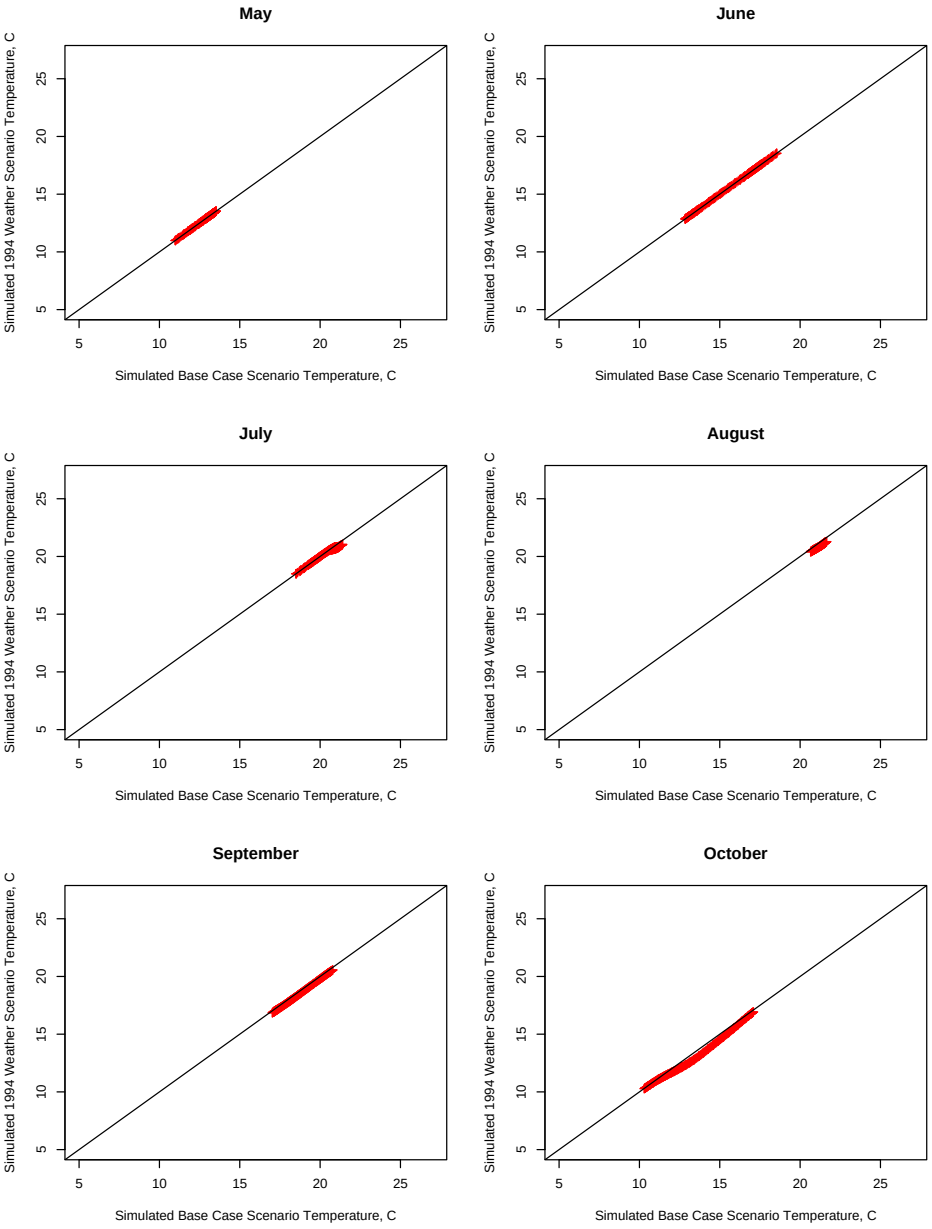

Figure 88: Scatter plot comparison, by month, of temperature at the LGSW Fixed Monitor in the Base Case and 1994 Weather scenario.

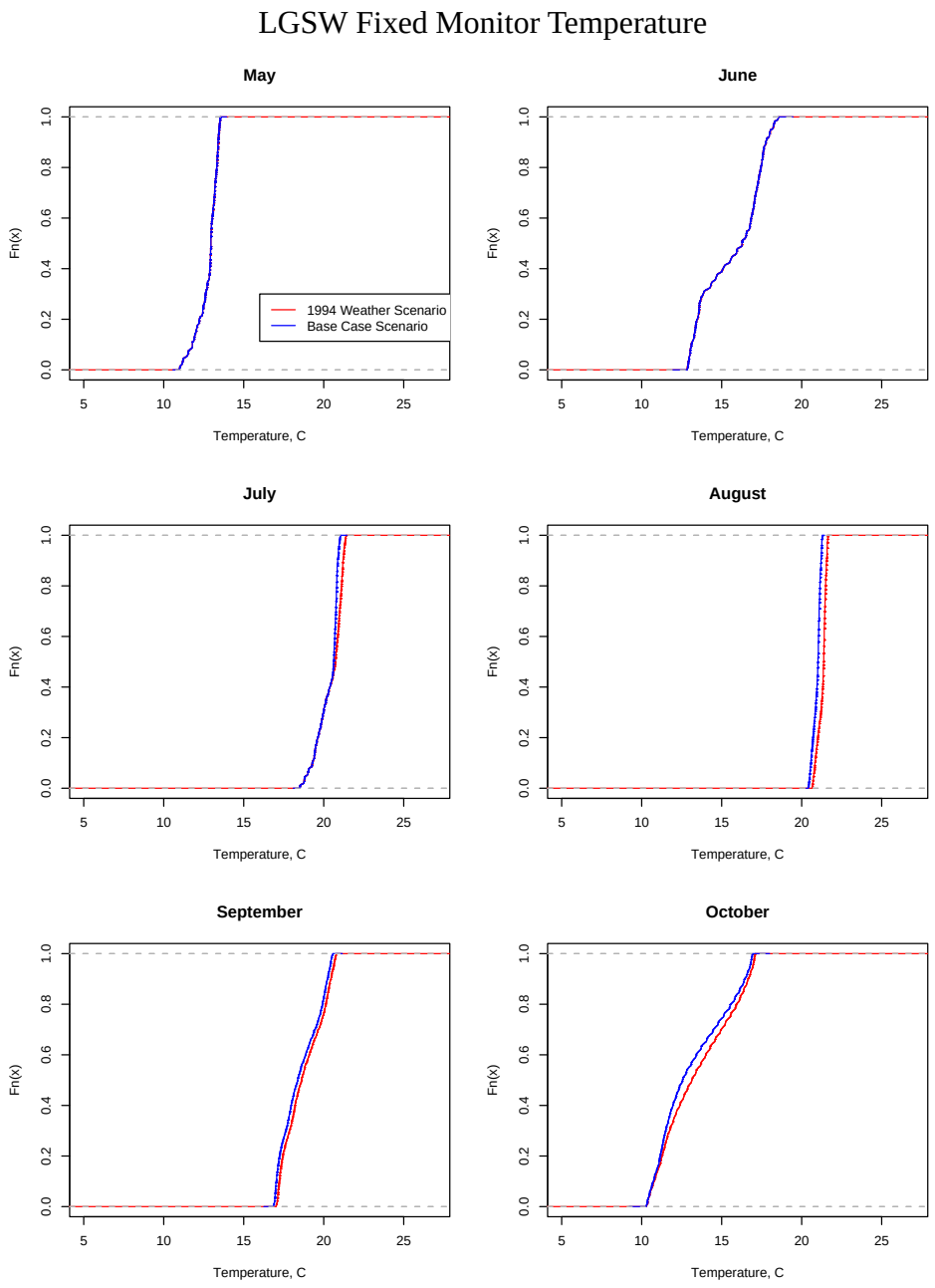

Figure 89: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the LGSW Fixed Monitor in the Base Case and 1994 Weather scenario.

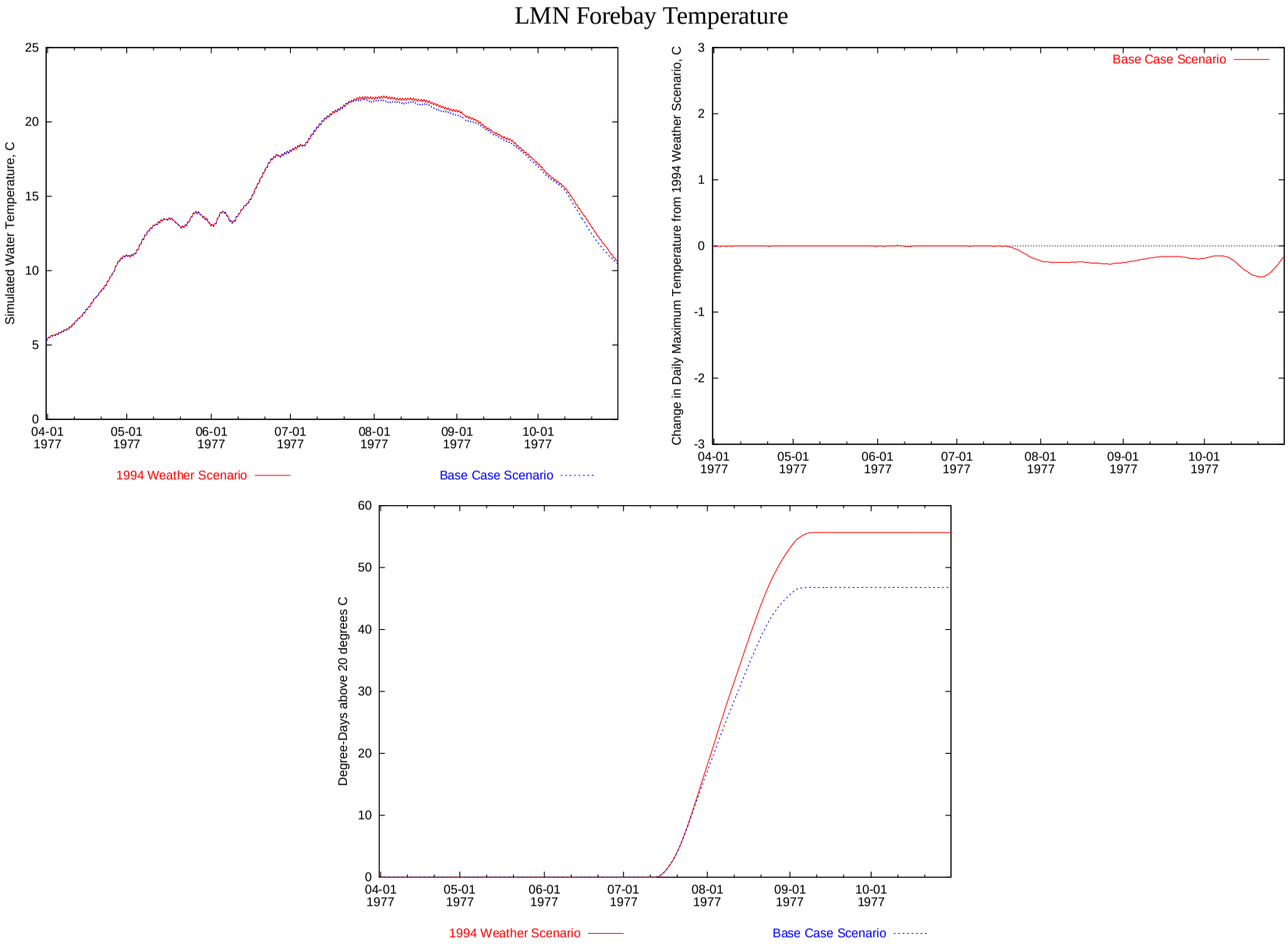

Figure 90: Time series comparison of temperature at the LMN Forebay in the Base Case and 1994 Weather scenario.

LMN Forebay Temperature

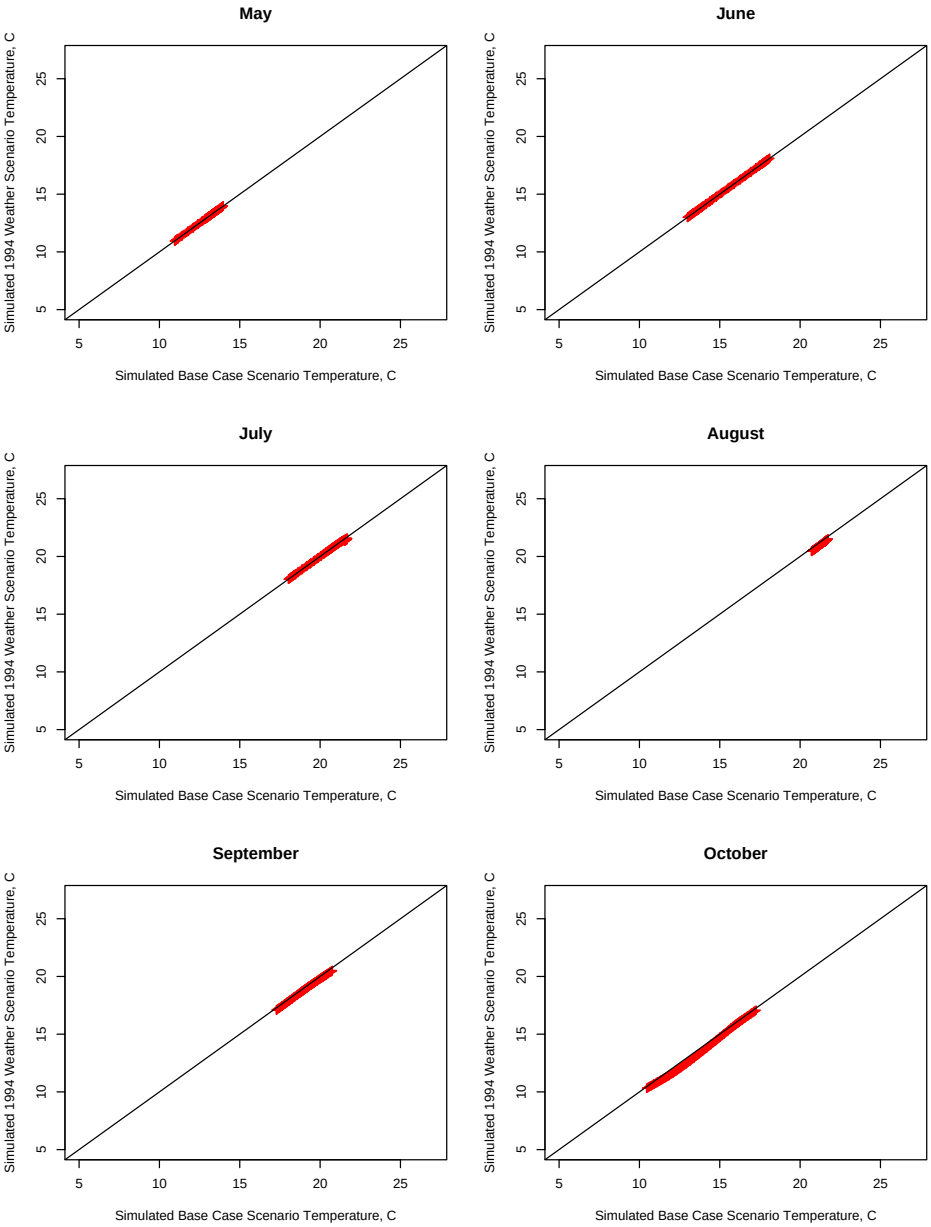

Figure 91: Scatter plot comparison, by month, of temperature at the LMN Forebay in the Base Case and 1994 Weather scenario.

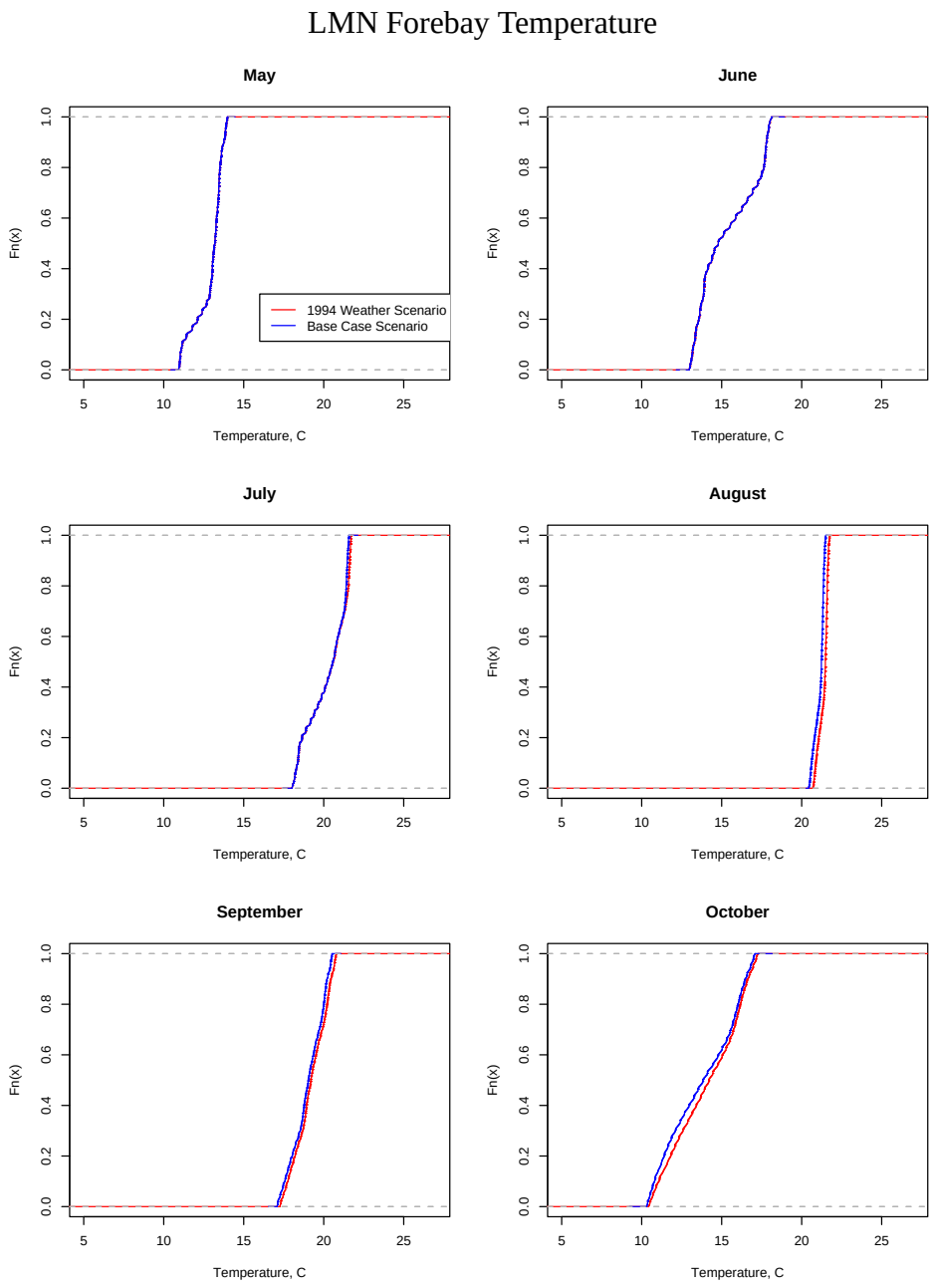

Figure 92: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the LMN Forebay in the Base Case and 1994 Weather scenario.

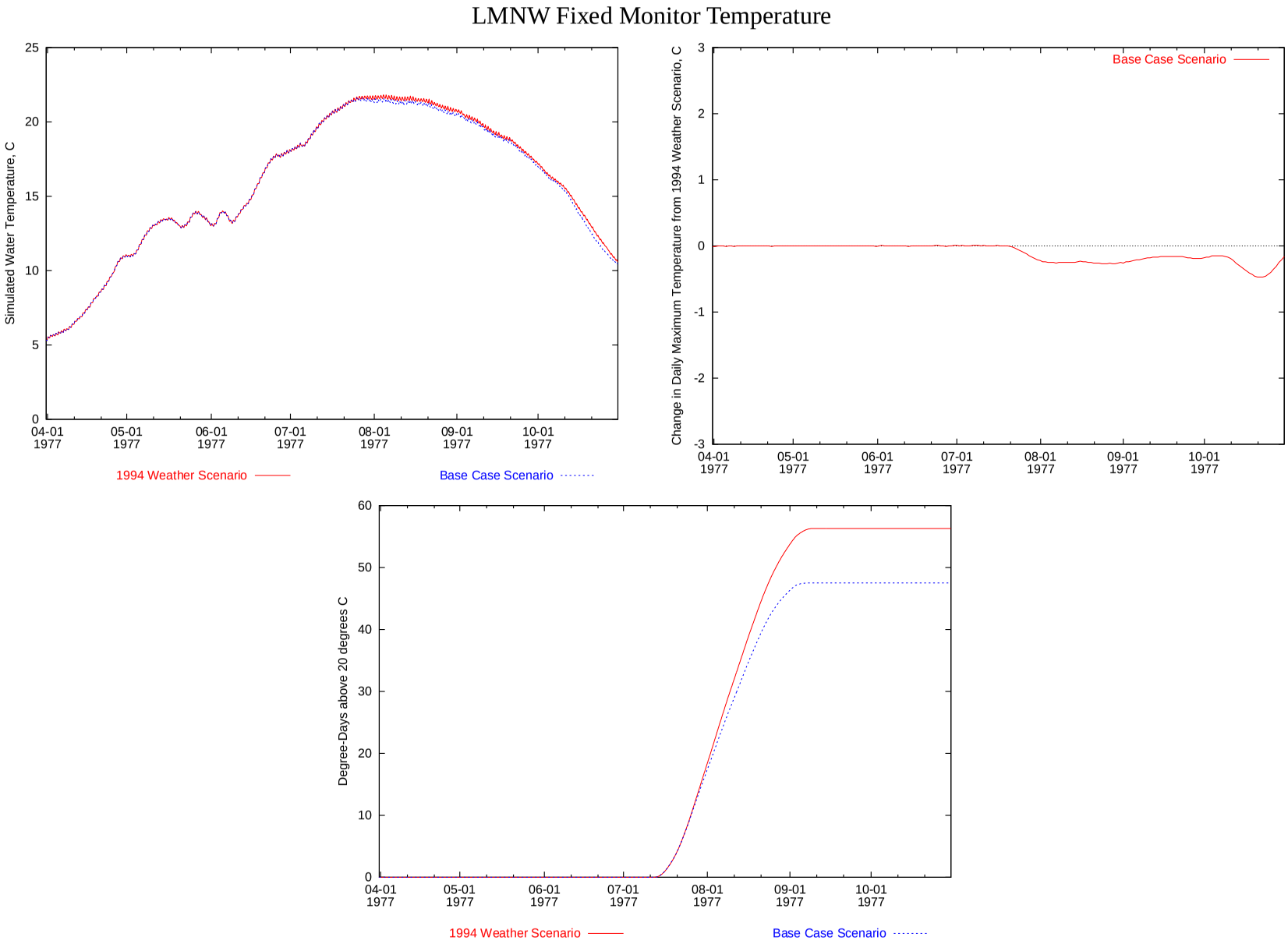

Figure 93: Time series comparison of temperature at the LMNW Fixed Monitor in the Base Case and 1994 Weather scenario.

LMNW Fixed Monitor Temperature

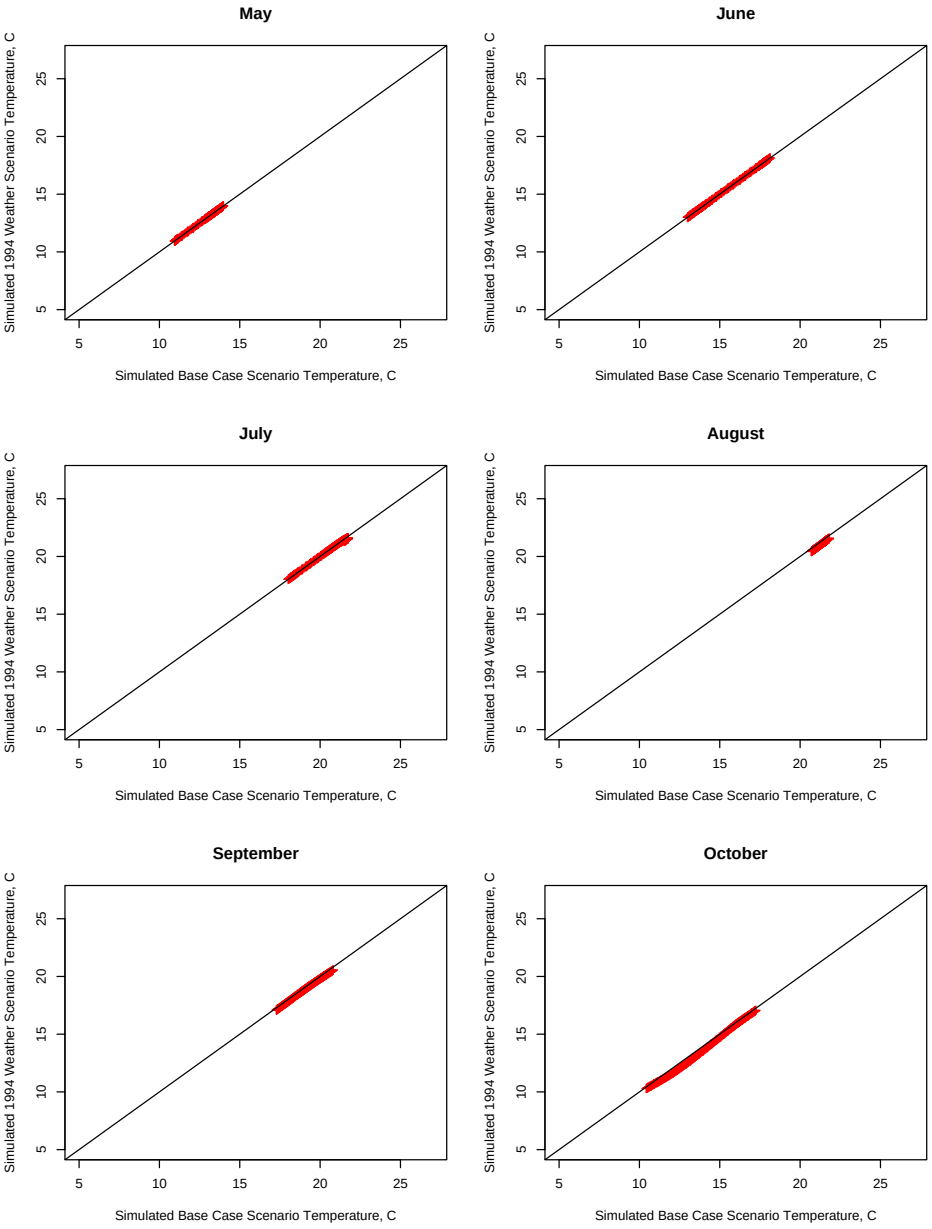

Figure 94: Scatter plot comparison, by month, of temperature at the LMNW Fixed Monitor in the Base Case and 1994 Weather scenario.

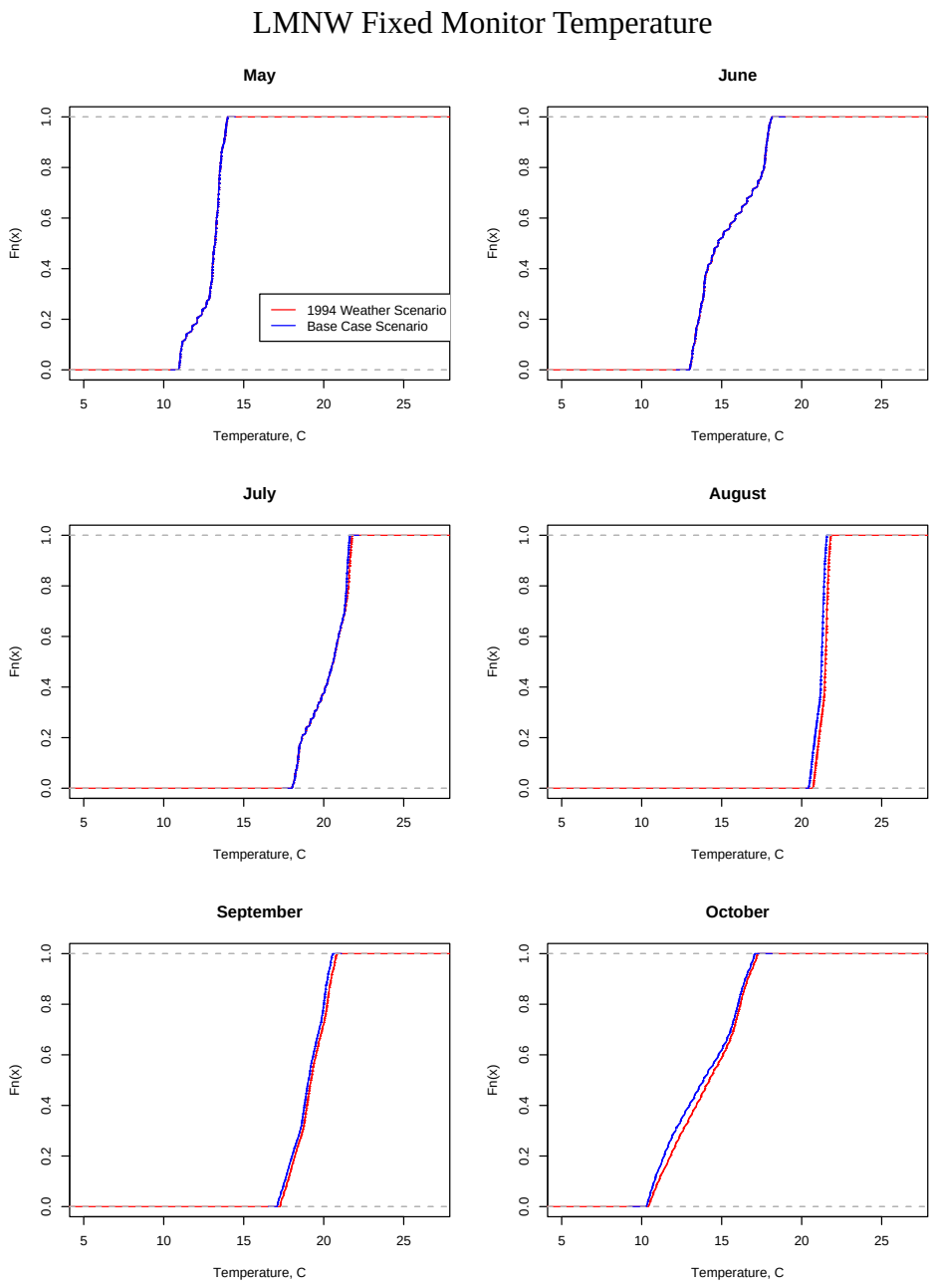

Figure 95: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the LMNW Fixed Monitor in the Base Case and 1994 Weather scenario.

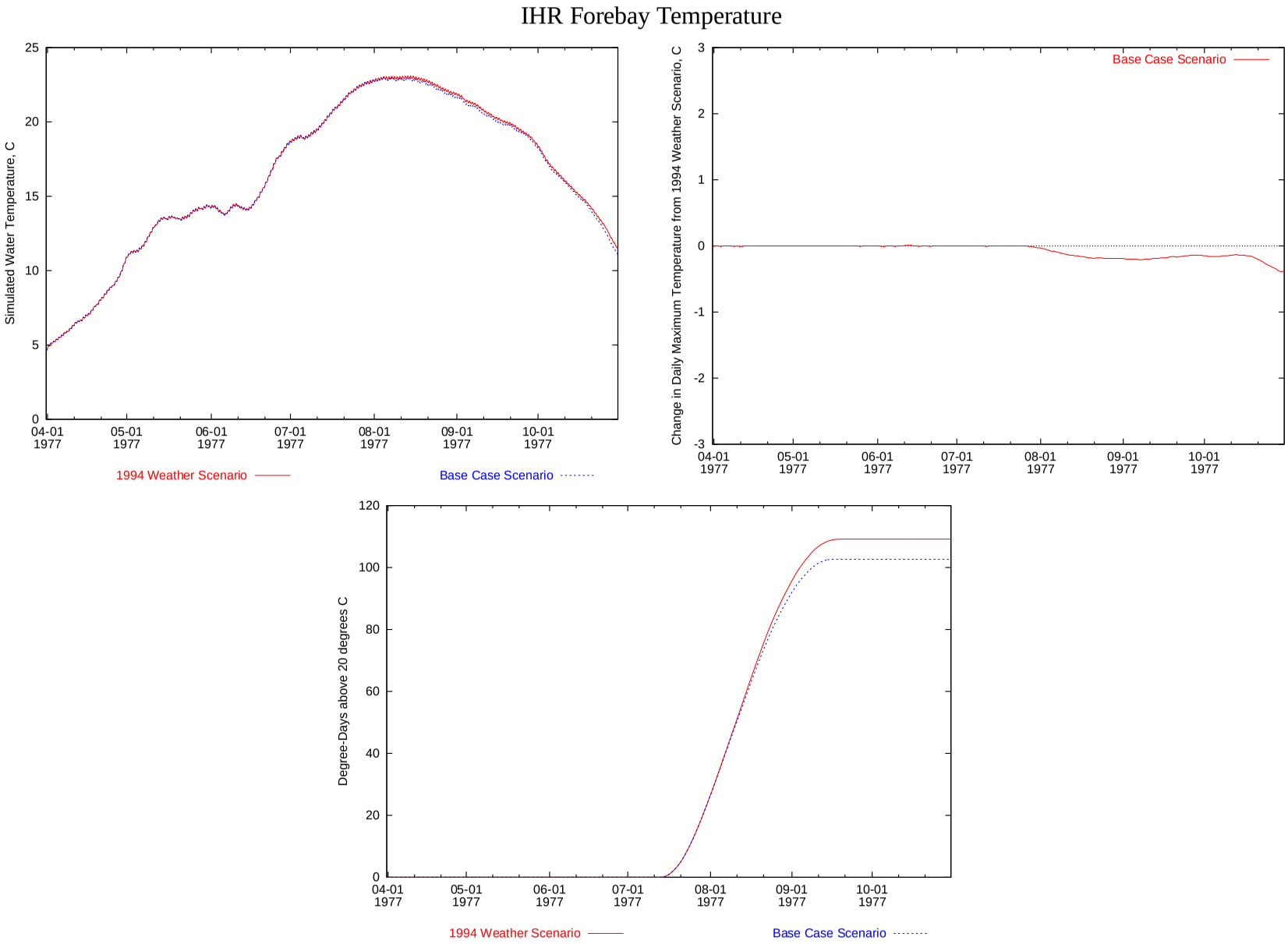

Figure 96: Time series comparison of temperature at the IHR Forebay in the Base Case and 1994 Weather scenario.

IHR Forebay Temperature

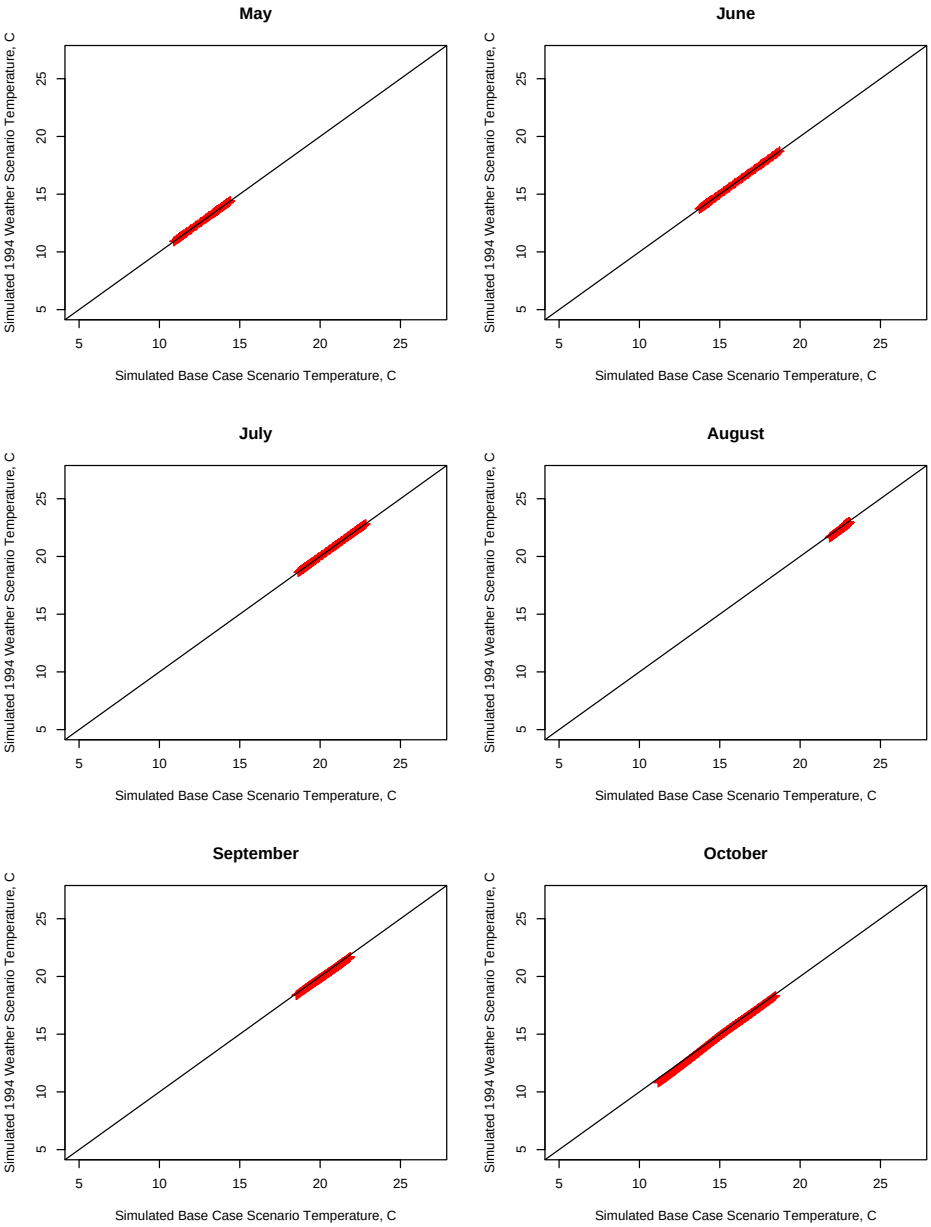

Figure 97: Scatter plot comparison, by month, of temperature at the IHR Forebay in the Base Case and 1994 Weather scenario.

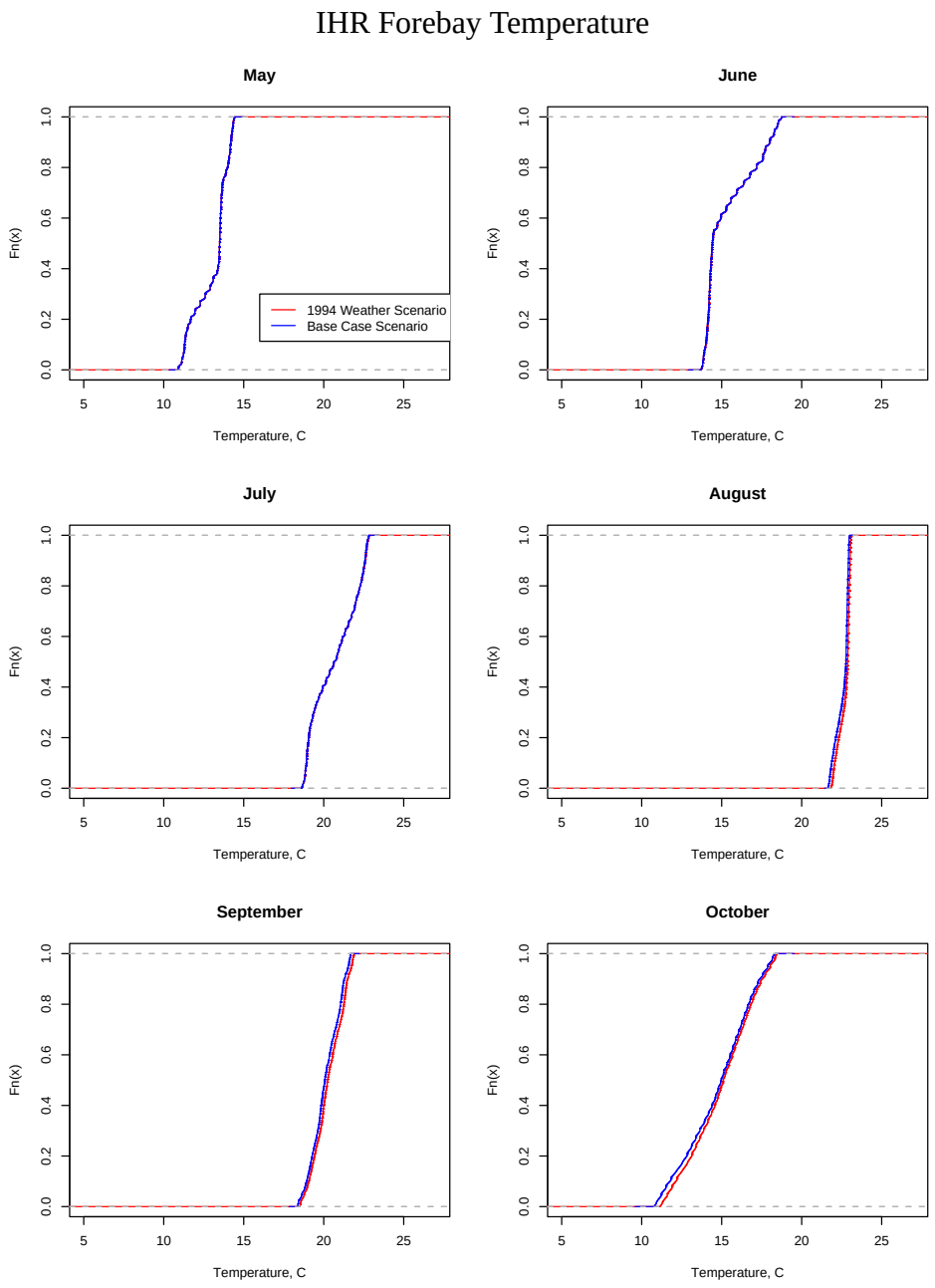

Figure 98: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the IHR Forebay in the Base Case and 1994 Weather scenario.

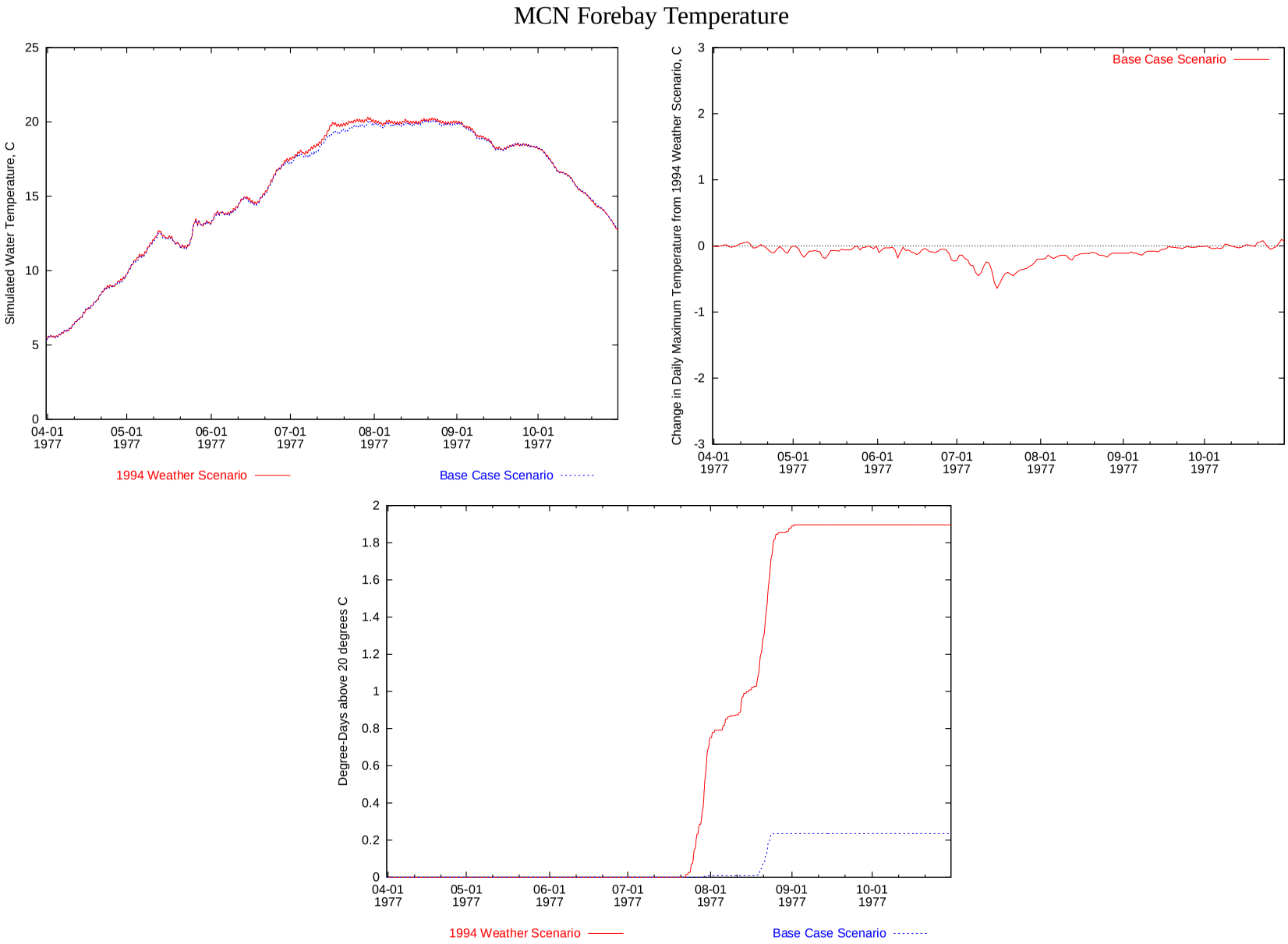

Figure 99: Time series comparison of temperature at the MCN Forebay in the Base Case and 1994 Weather scenario.

MCN Forebay Temperature

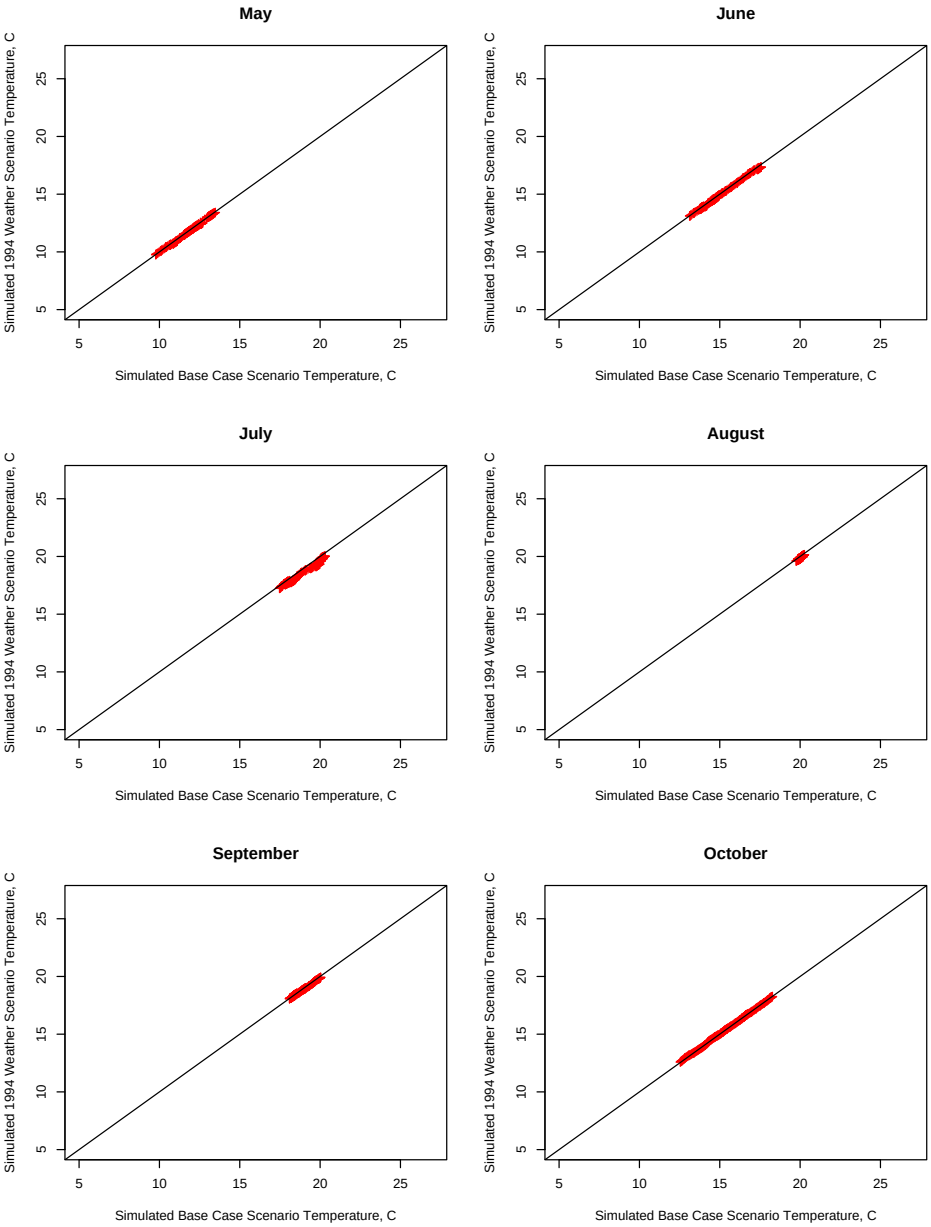

Figure 100: Scatter plot comparison, by month, of temperature at the MCN Forebay in the Base Case and 1994 Weather scenario.

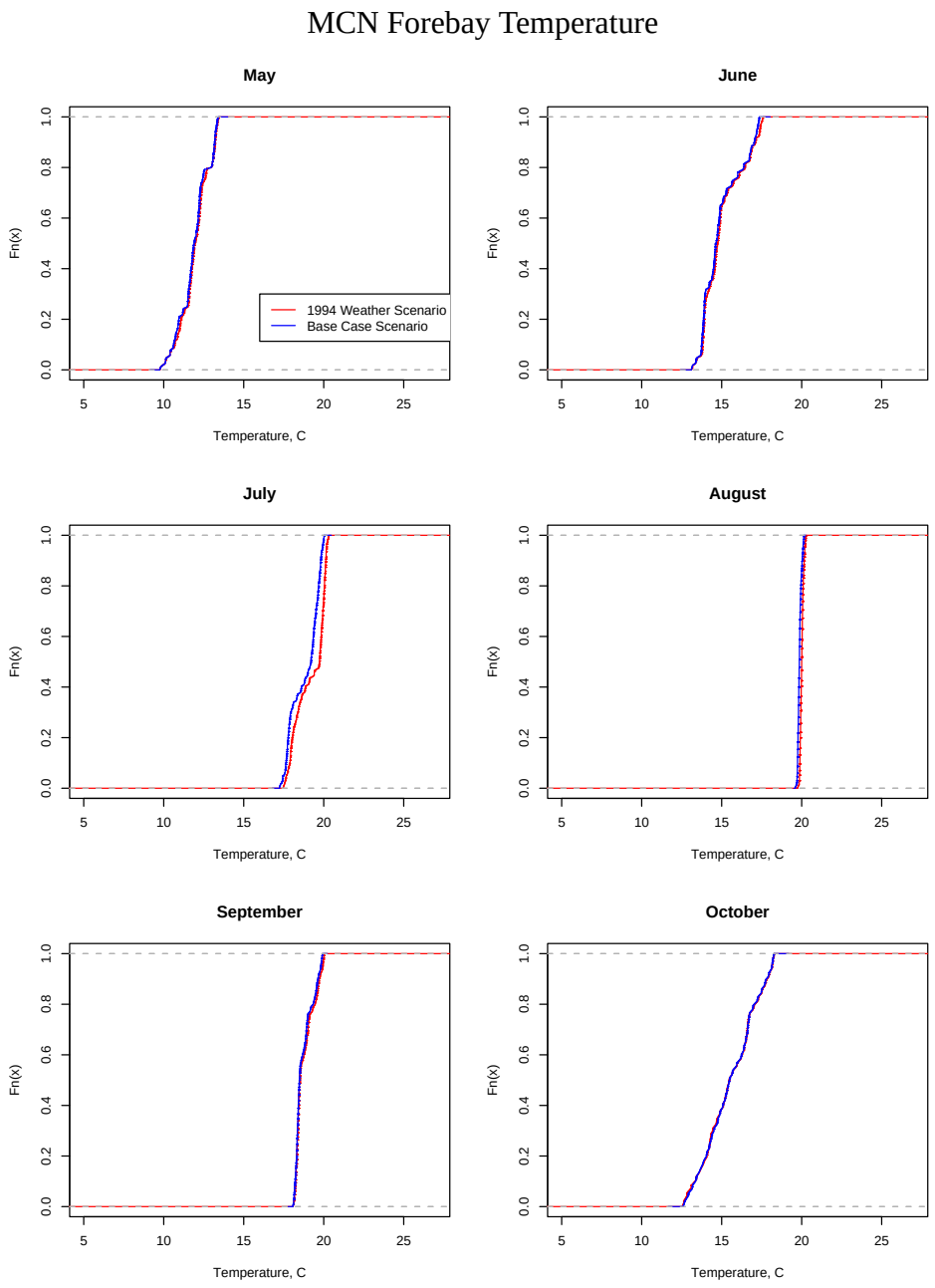

Figure 101: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the MCN Forebay in the Base Case and 1994 Weather scenario.

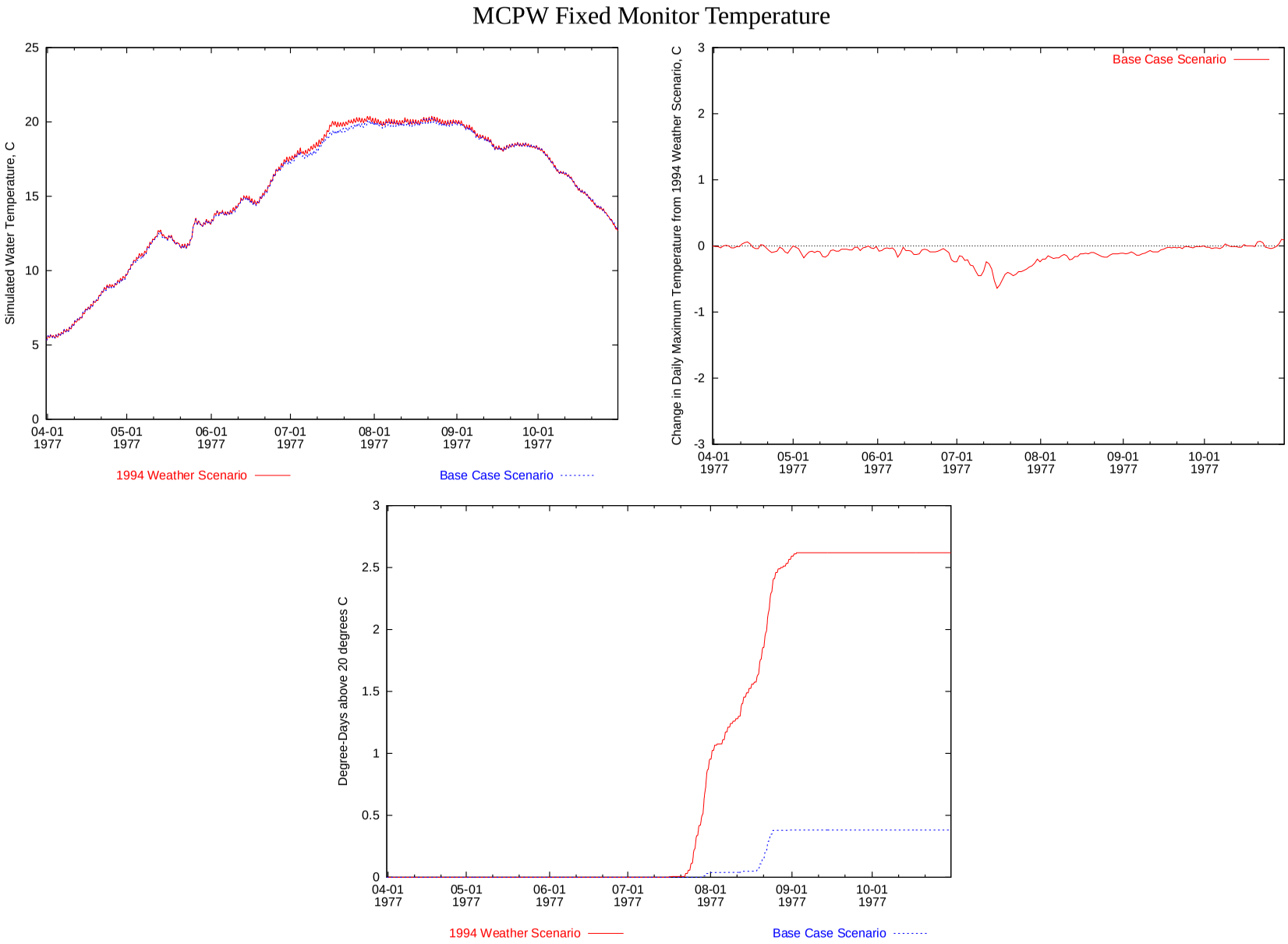

Figure 102: Time series comparison of temperature at the MCPW Fixed Monitor in the Base Case and 1994 Weather scenario.

MCPW Fixed Monitor Temperature

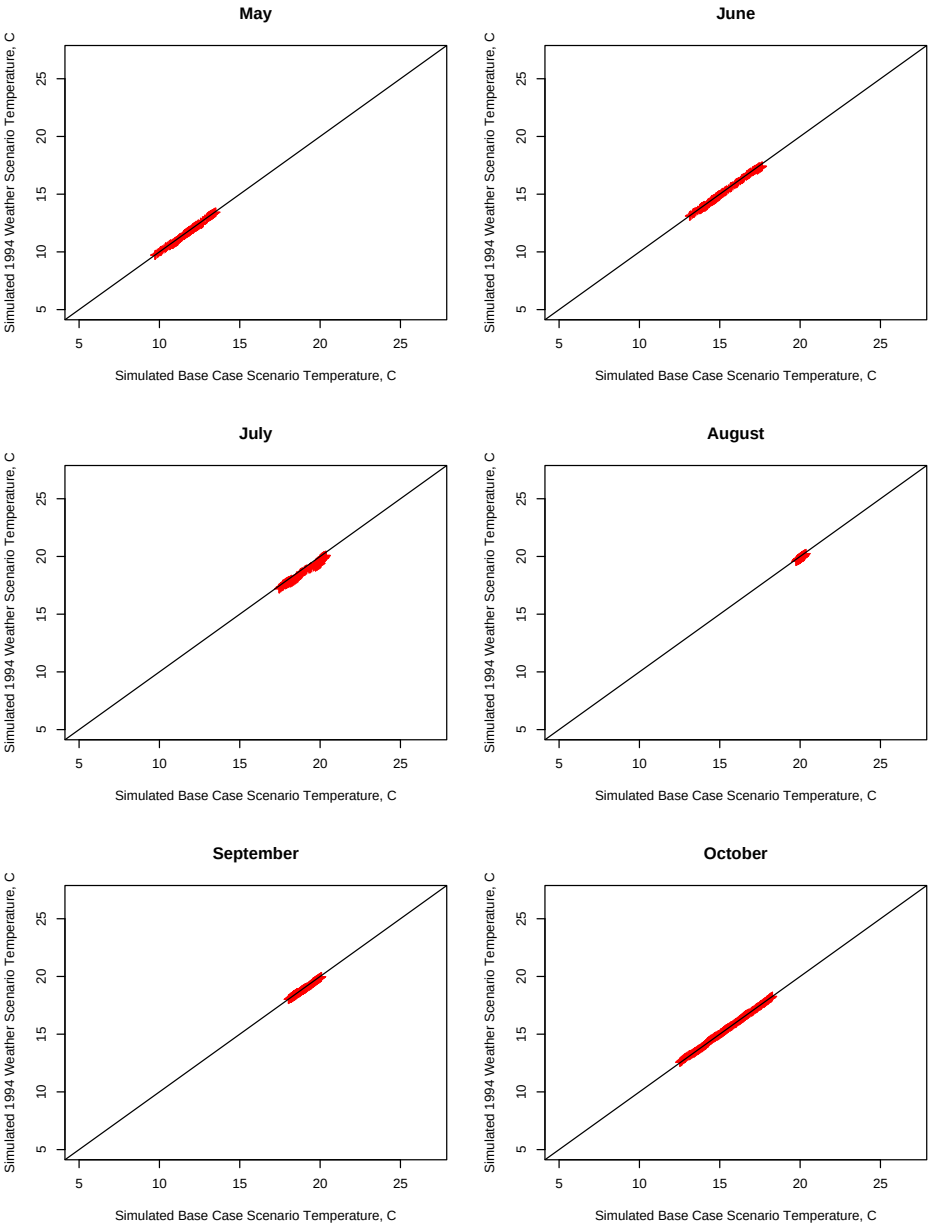

Figure 103: Scatter plot comparison, by month, of temperature at the MCPW Fixed Monitor in the Base Case and 1994 Weather scenario.

MCPW Fixed Monitor Temperature

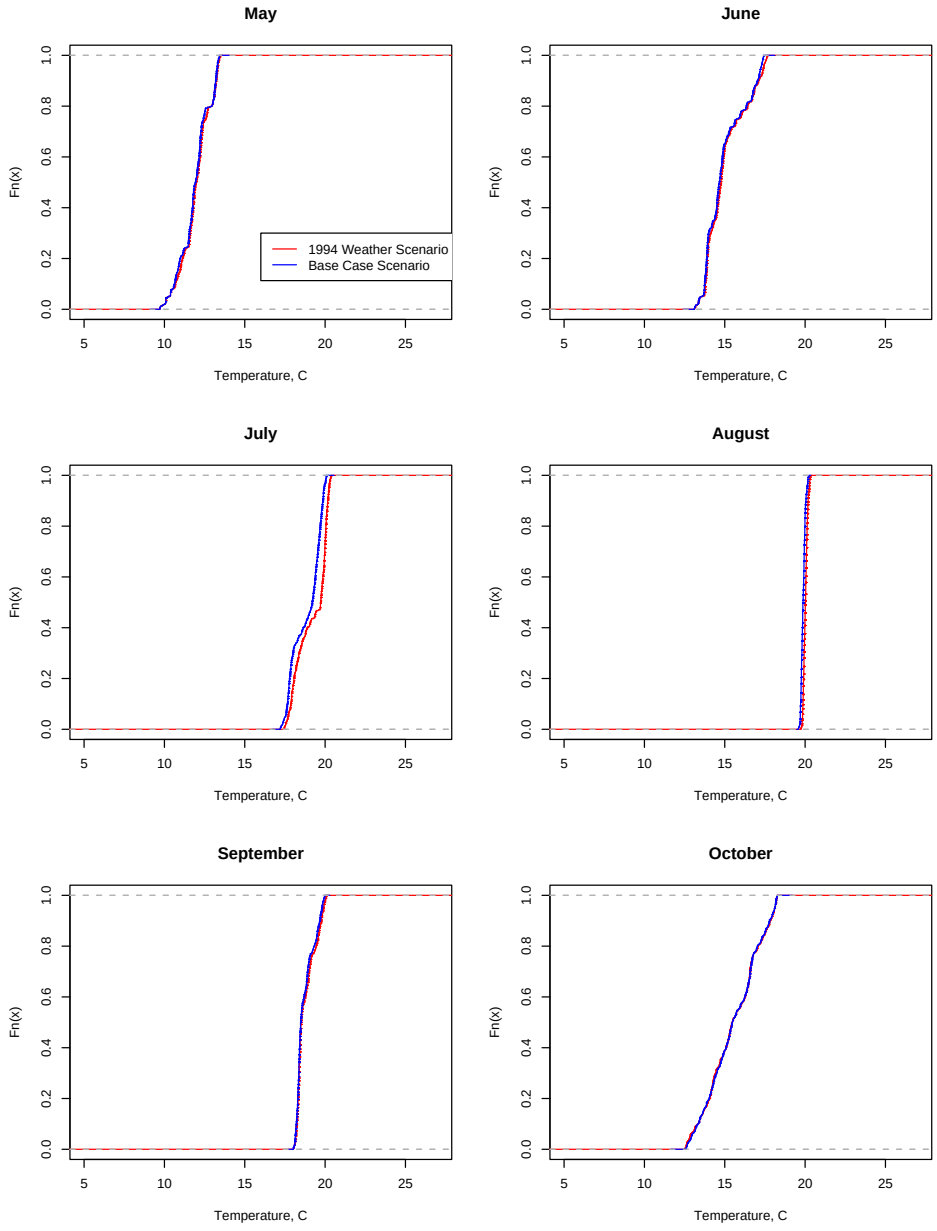

Figure 104: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the MCPW Fixed Monitor in the Base Case and 1994 Weather scenario.

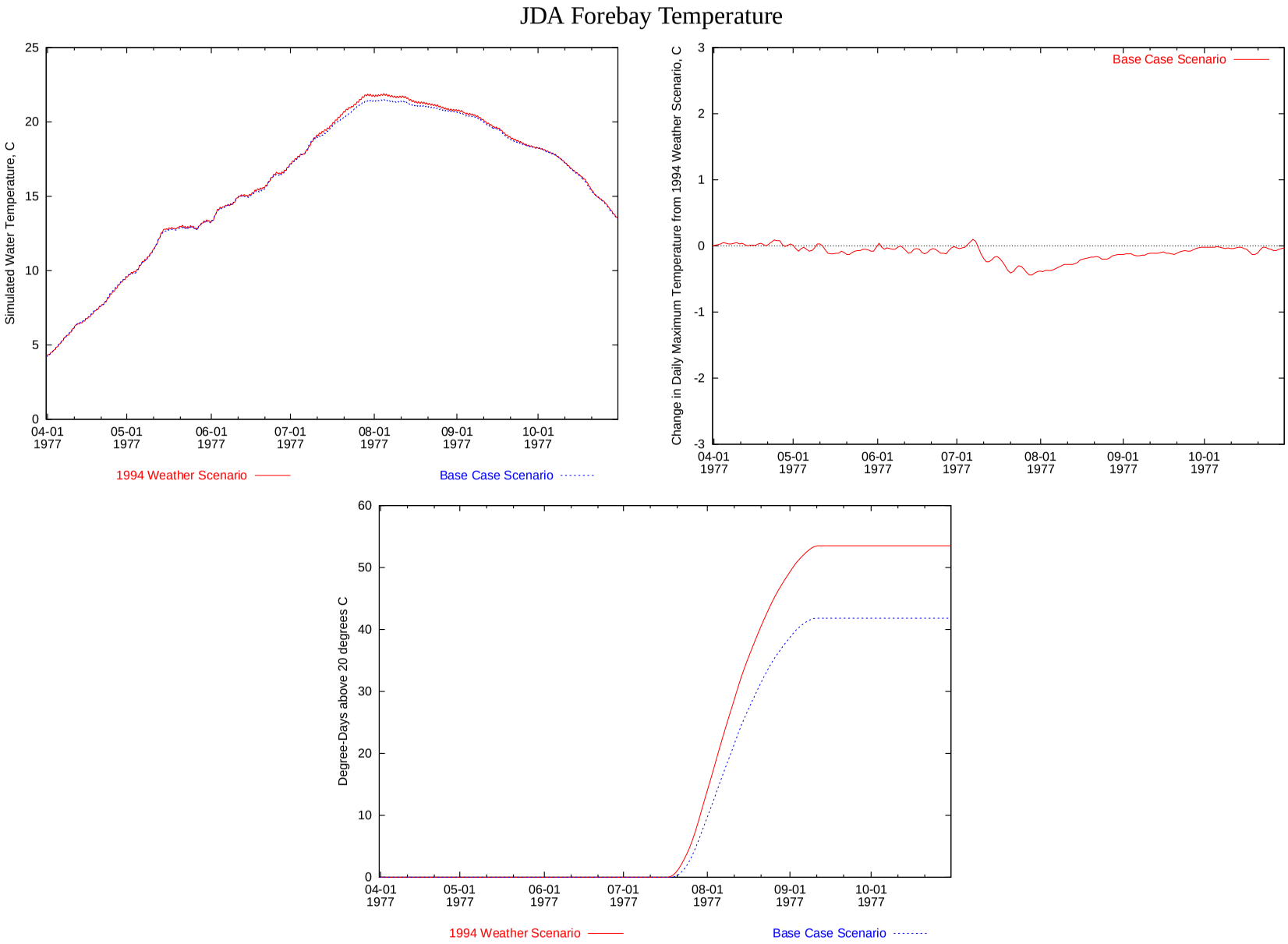

Figure 105: Time series comparison of temperature at the JDA Forebay in the Base Case and 1994 Weather scenario.

JDA Forebay Temperature

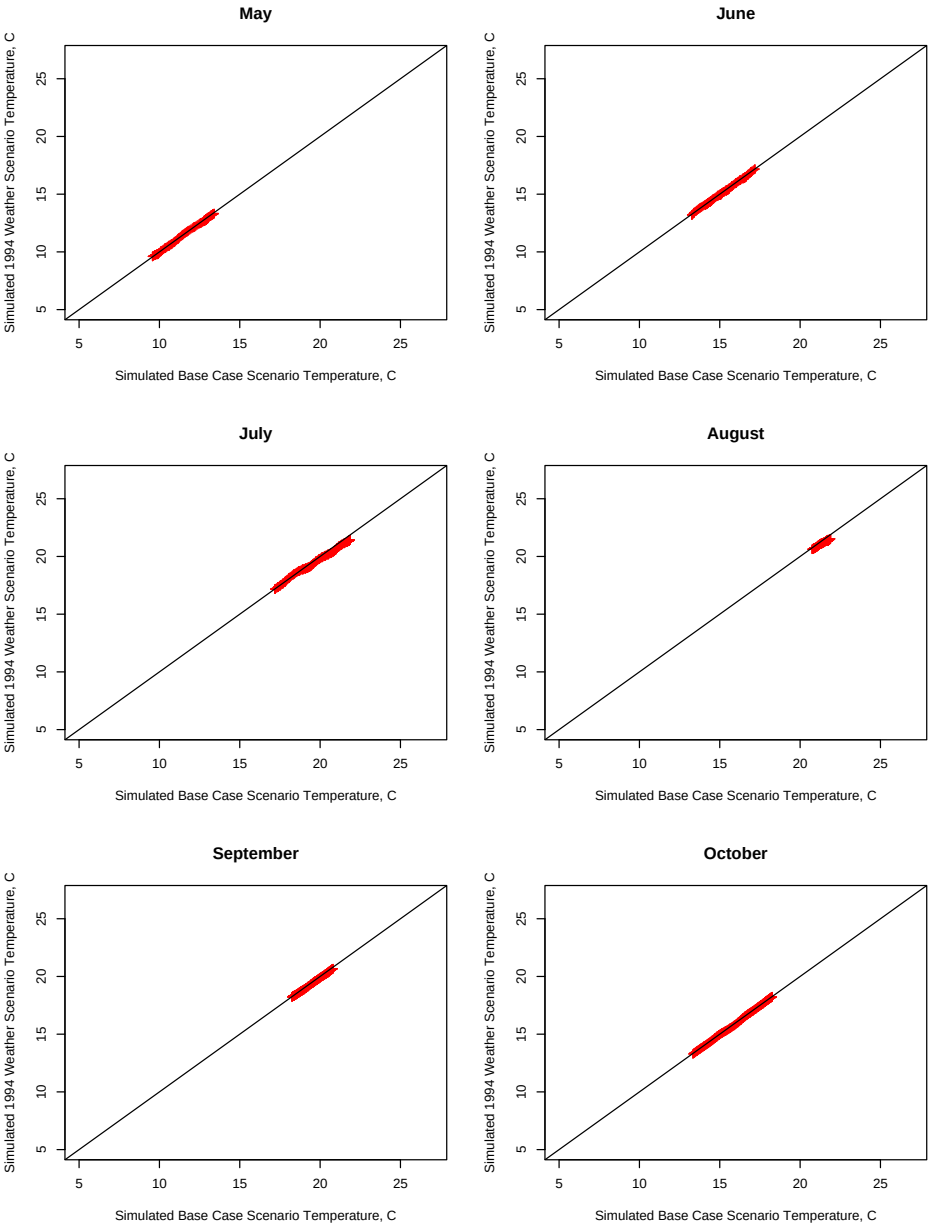

Figure 106: Scatter plot comparison, by month, of temperature at the JDA Forebay in the Base Case and 1994 Weather scenario.

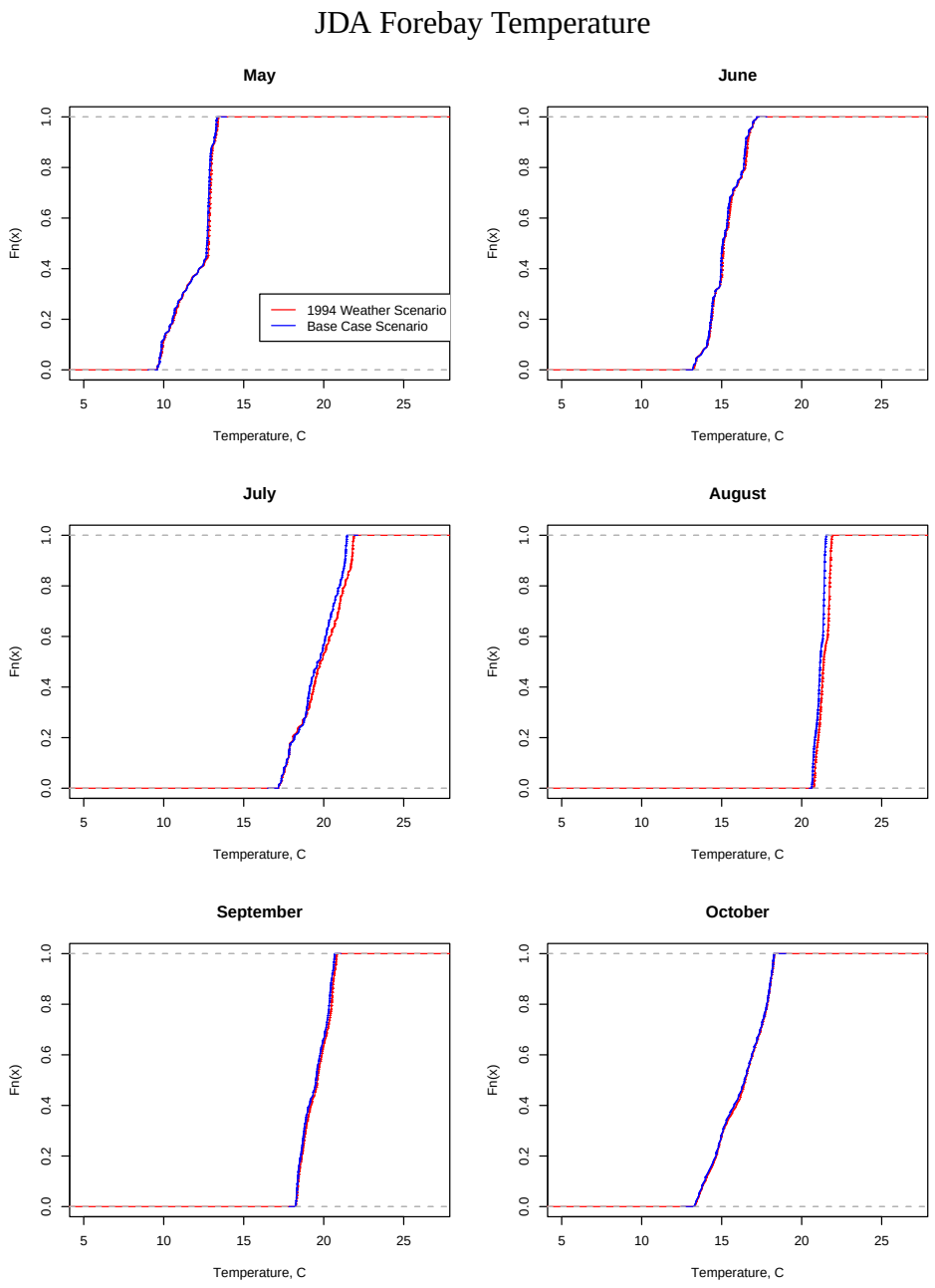

Figure 107: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the JDA Forebay in the Base Case and 1994 Weather scenario.

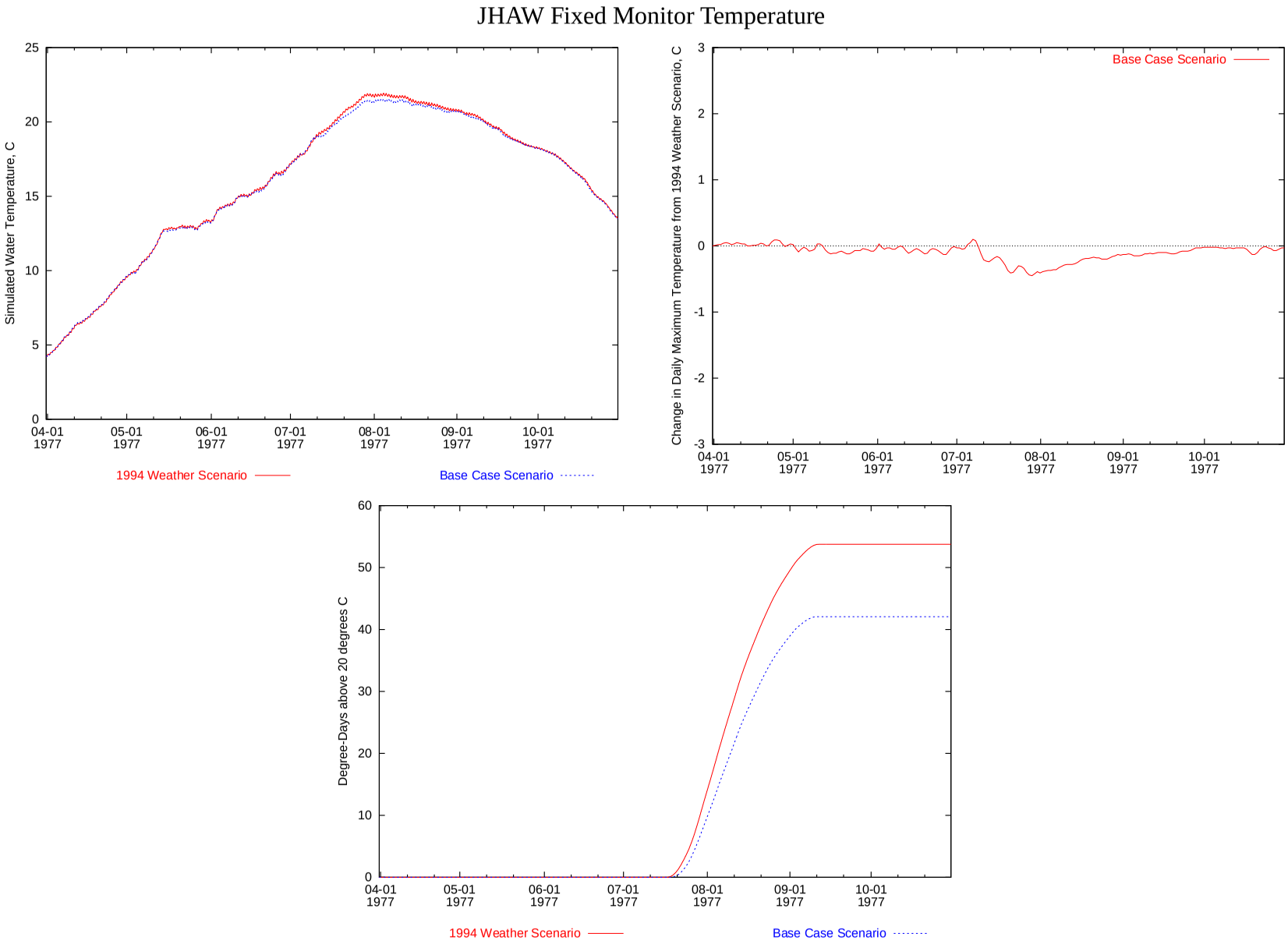

Figure 108: Time series comparison of temperature at the JHAW Fixed Monitor in the Base Case and 1994 Weather scenario.

JHAW Fixed Monitor Temperature

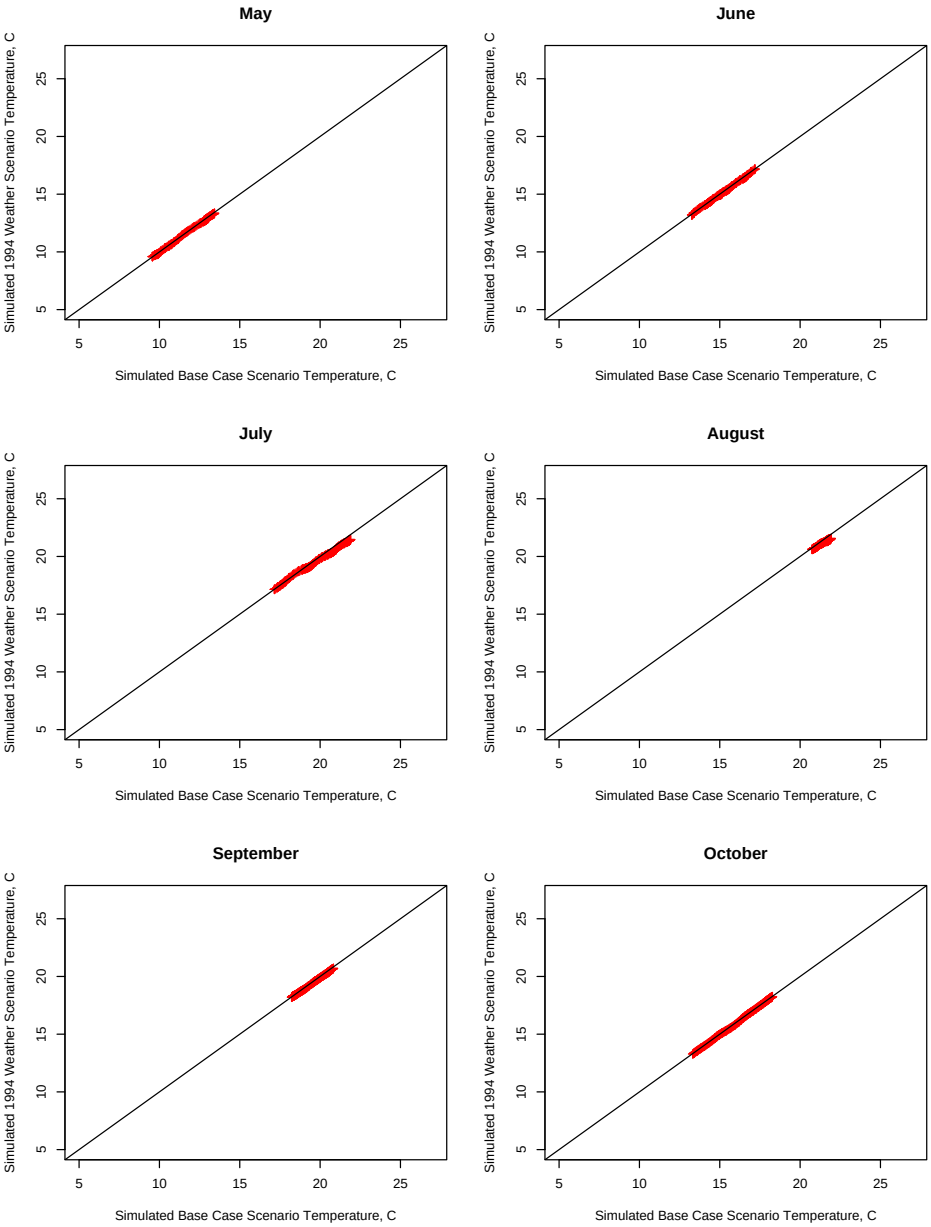

Figure 109: Scatter plot comparison, by month, of temperature at the JHAW Fixed Monitor in the Base Case and 1994 Weather scenario.

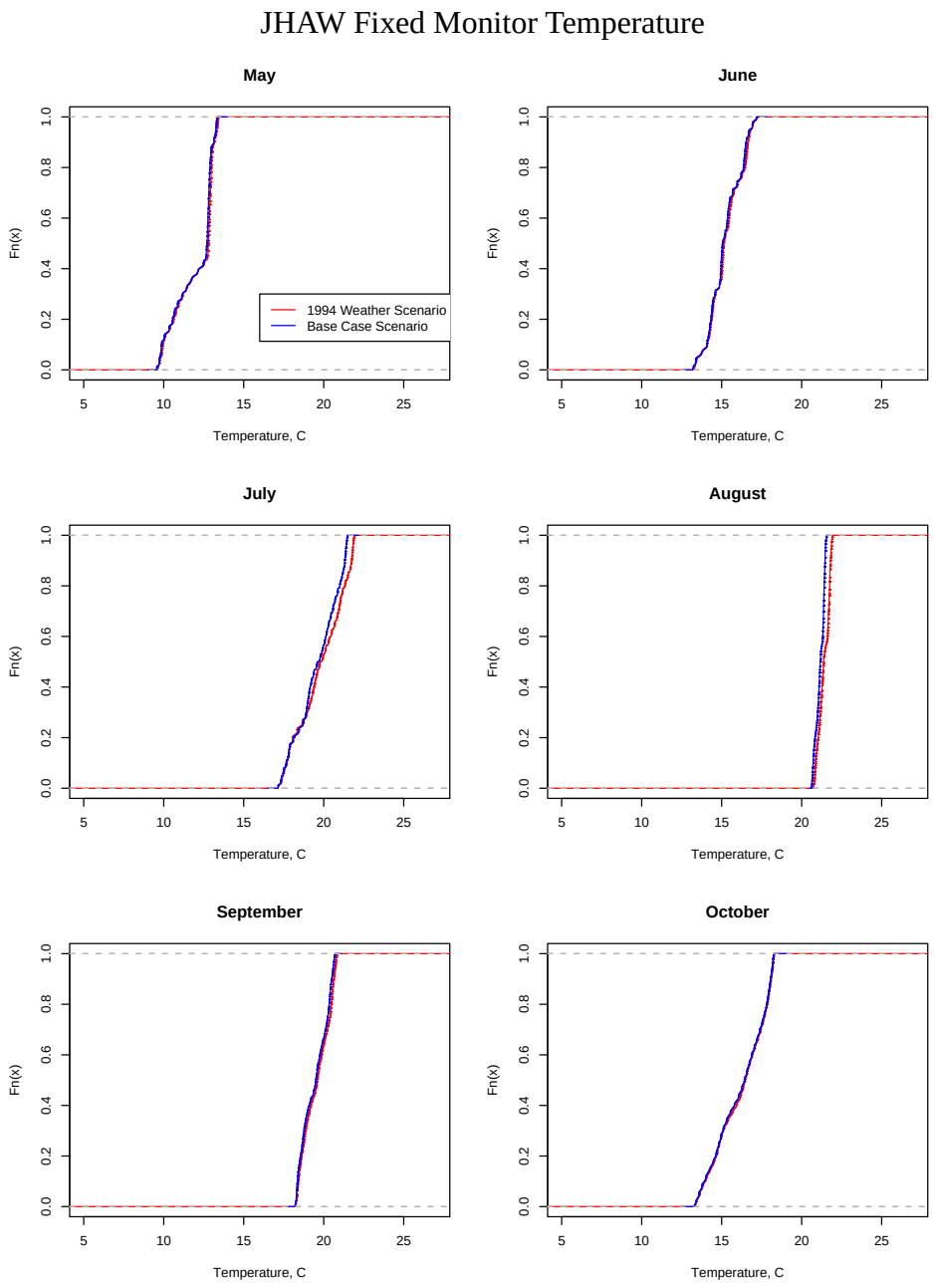

Figure 110: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the JHAW Fixed Monitor in the Base Case and 1994 Weather scenario.

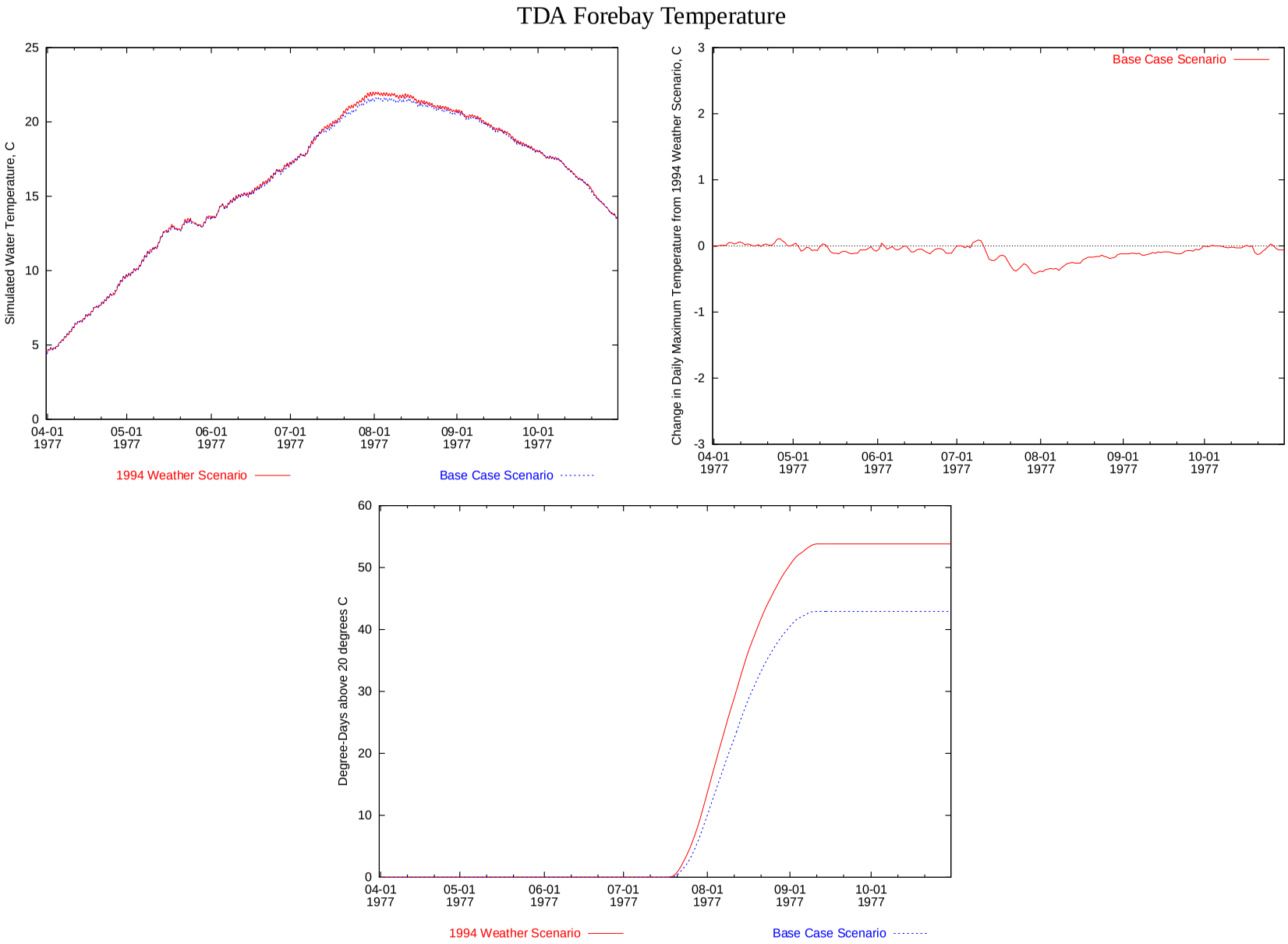

Figure 111: Time series comparison of temperature at the TDA Forebay in the Base Case and 1994 Weather scenario.

TDA Forebay Temperature

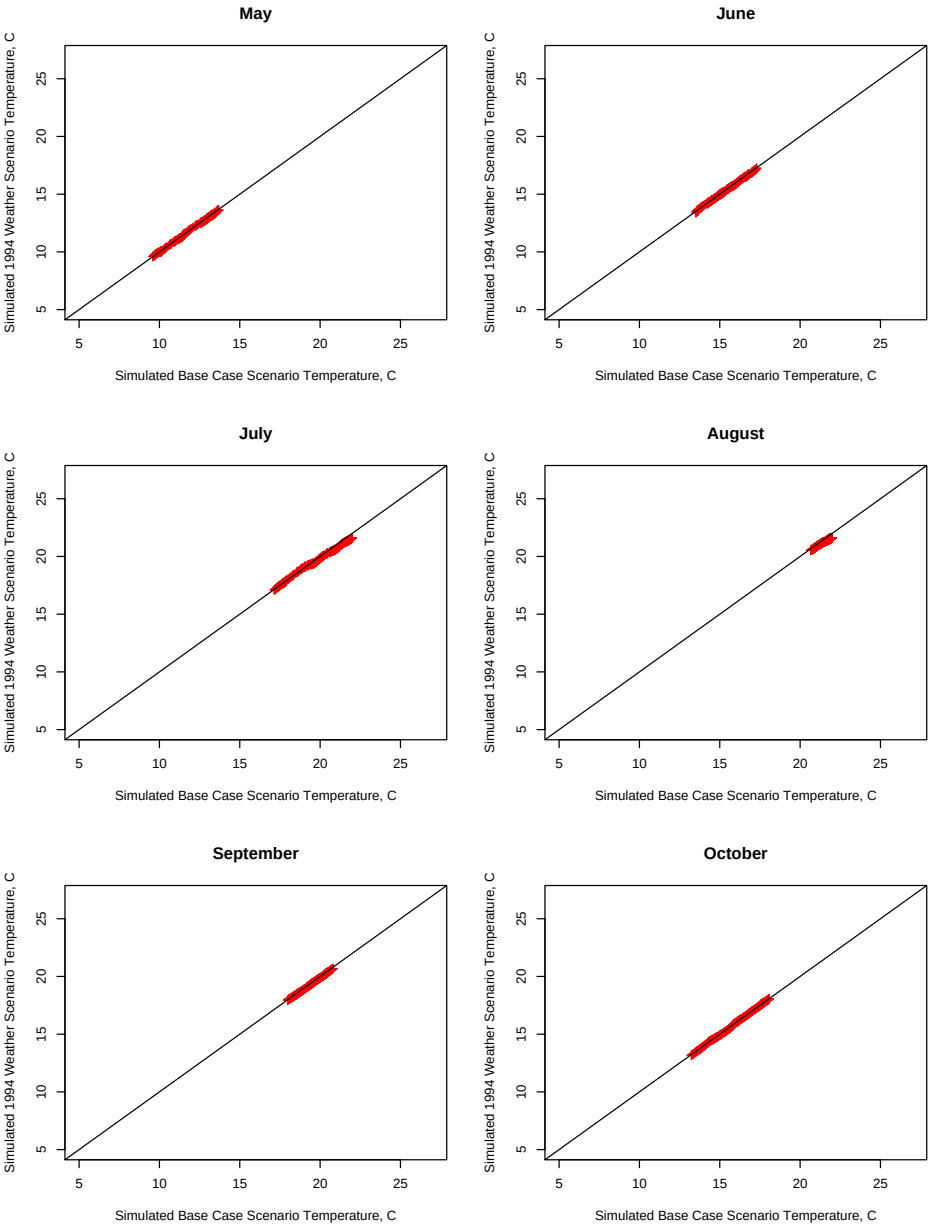

Figure 112: Scatter plot comparison, by month, of temperature at the TDA Forebay in the Base Case and 1994 Weather scenario.

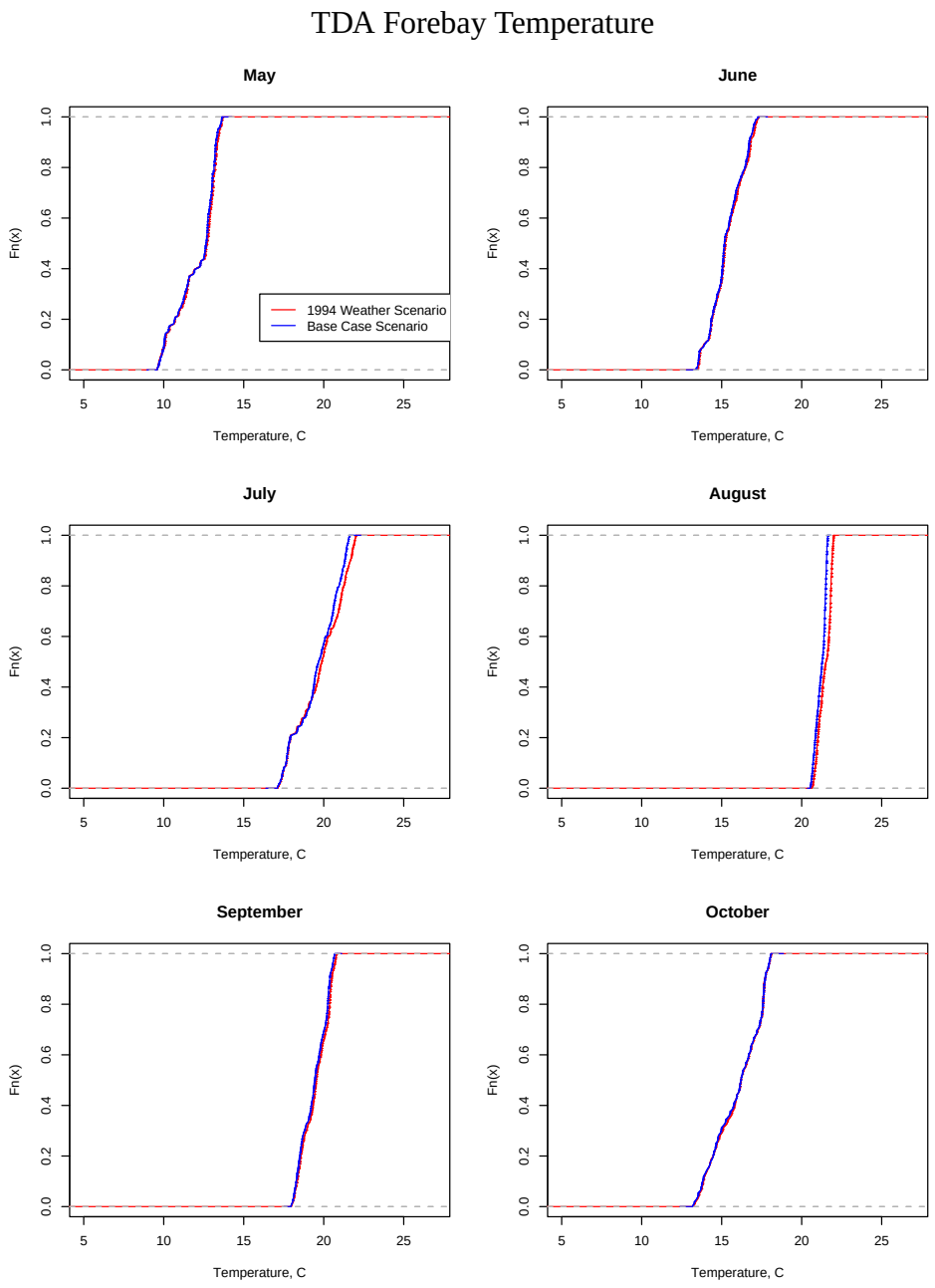

Figure 113: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the TDA Forebay in the Base Case and 1994 Weather scenario.

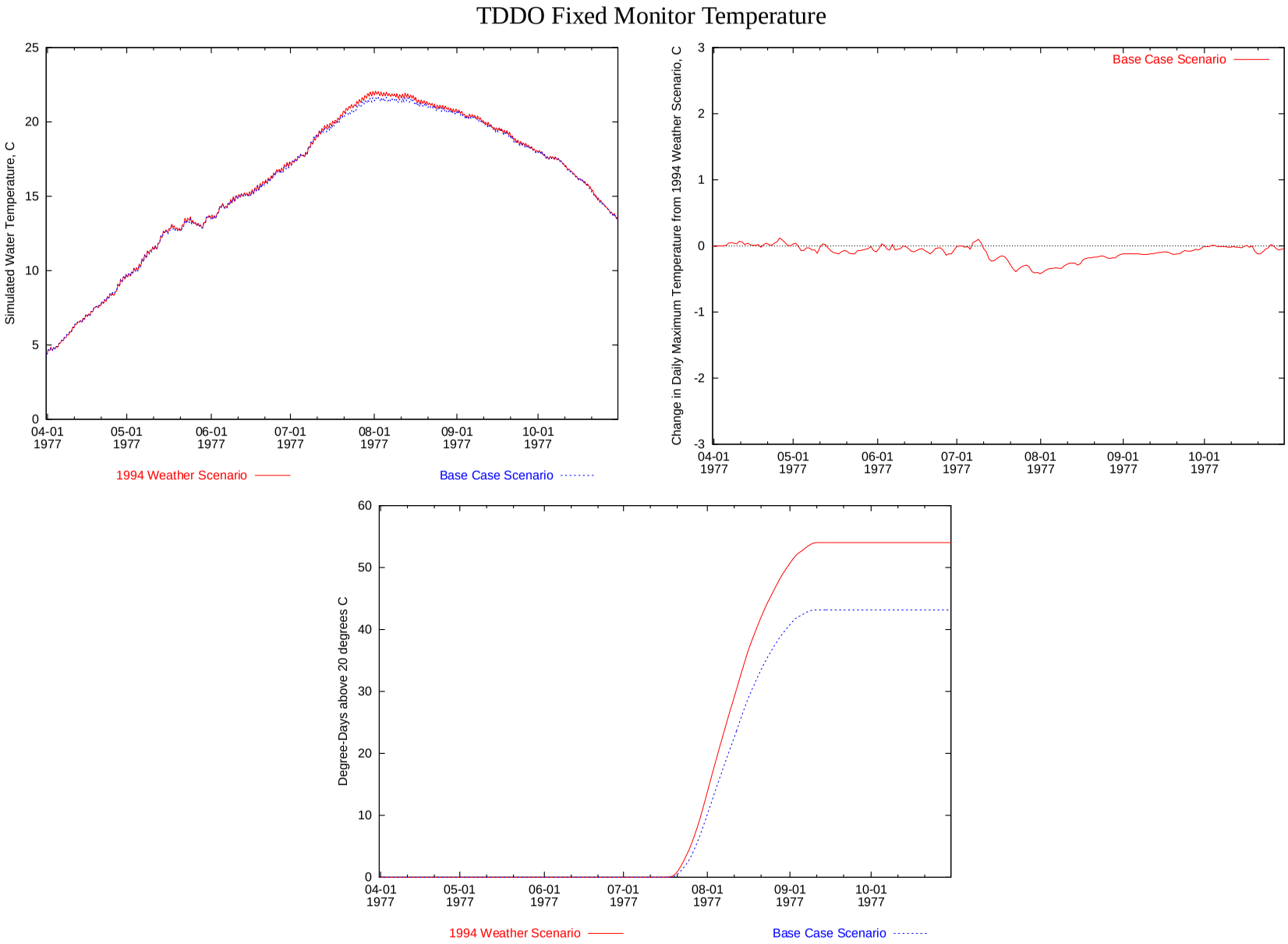

Figure 114: Time series comparison of temperature at the TDDO Fixed Monitor in the Base Case and 1994 Weather scenario.

TDDO Fixed Monitor Temperature

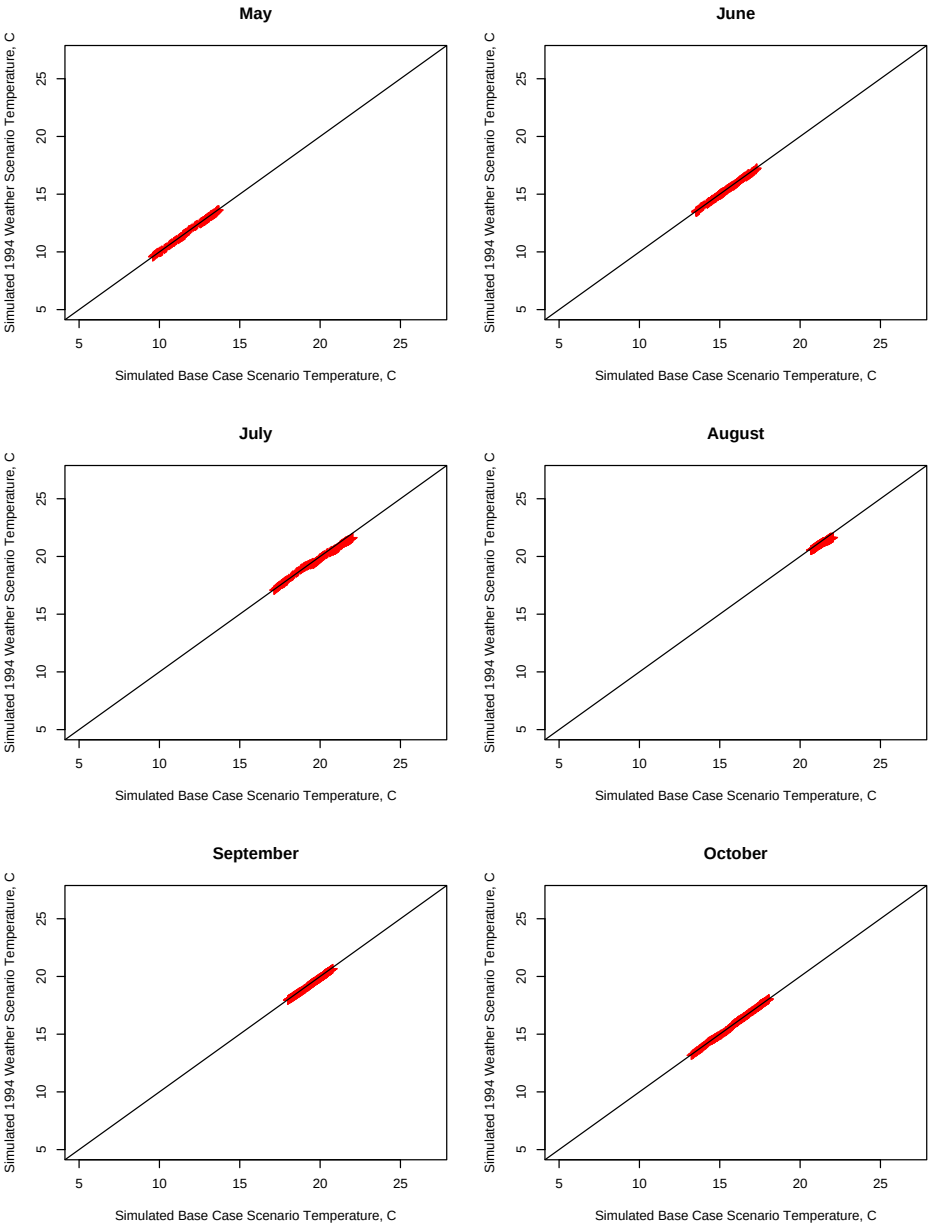

Figure 115: Scatter plot comparison, by month, of temperature at the TDDO Fixed Monitor in the Base Case and 1994 Weather scenario.

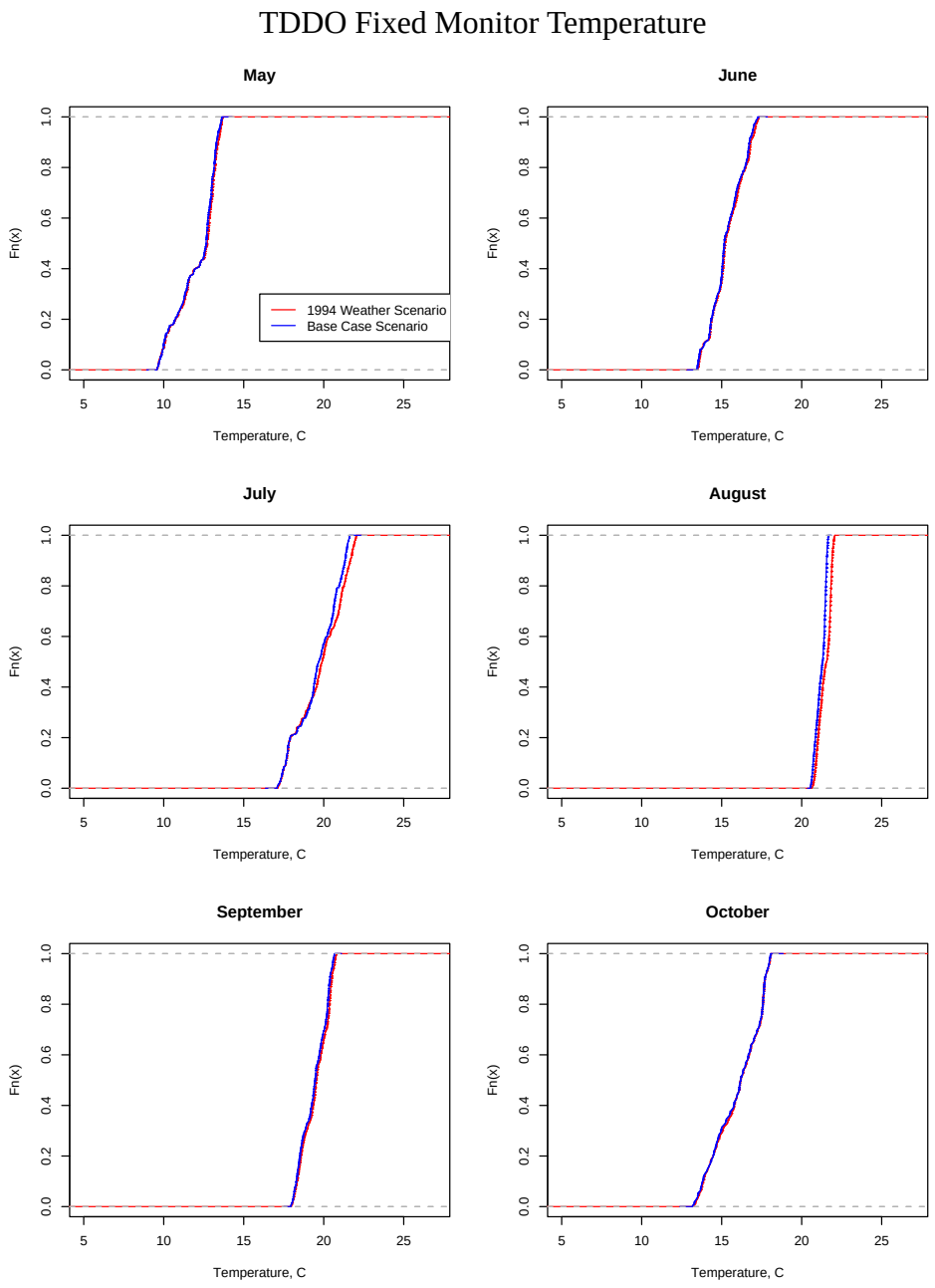

Figure 116: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the TDDO Fixed Monitor in the Base Case and 1994 Weather scenario.

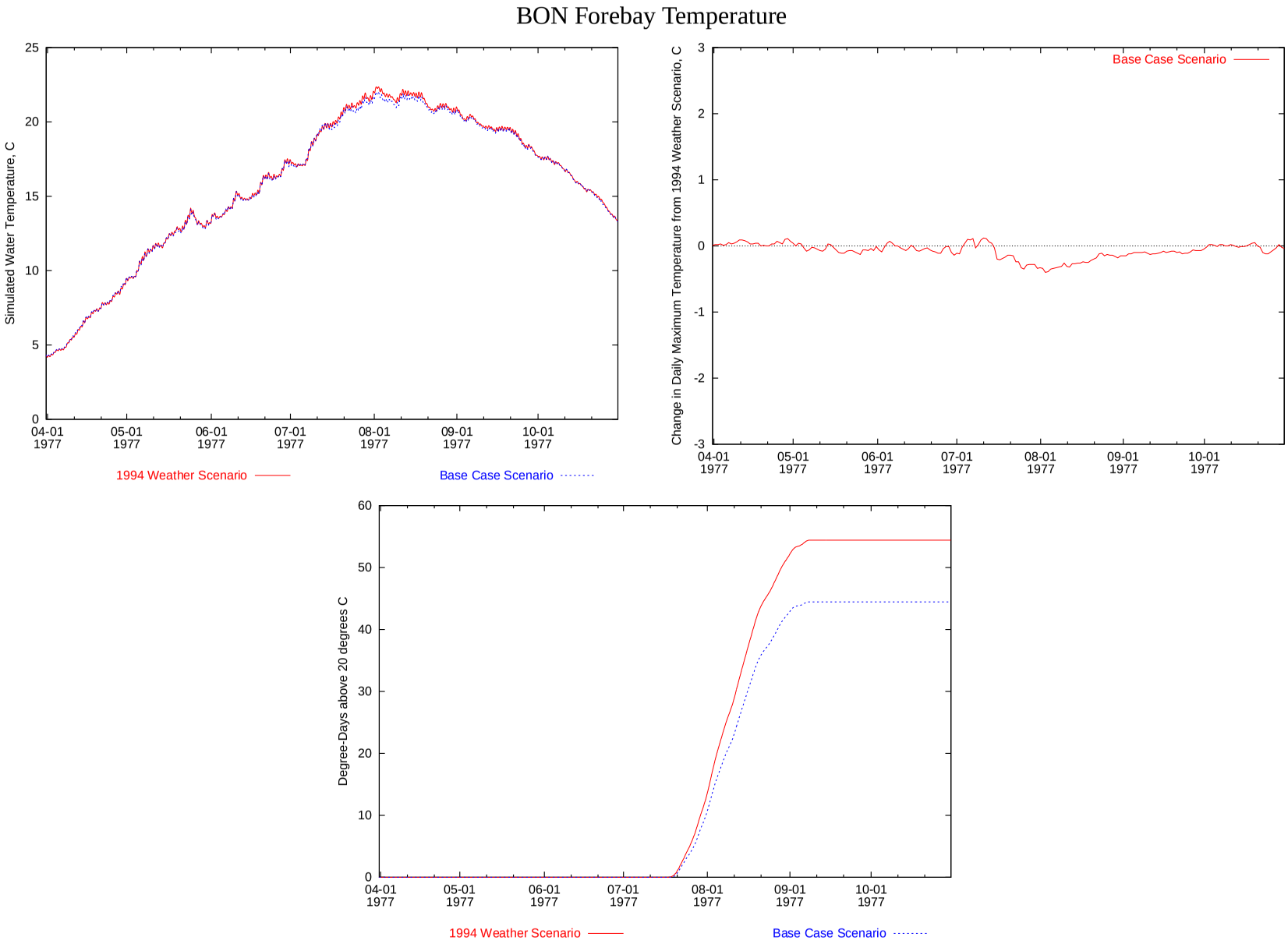

Figure 117: Time series comparison of temperature at the BON Forebay in the Base Case and 1994 Weather scenario.

BON Forebay Temperature

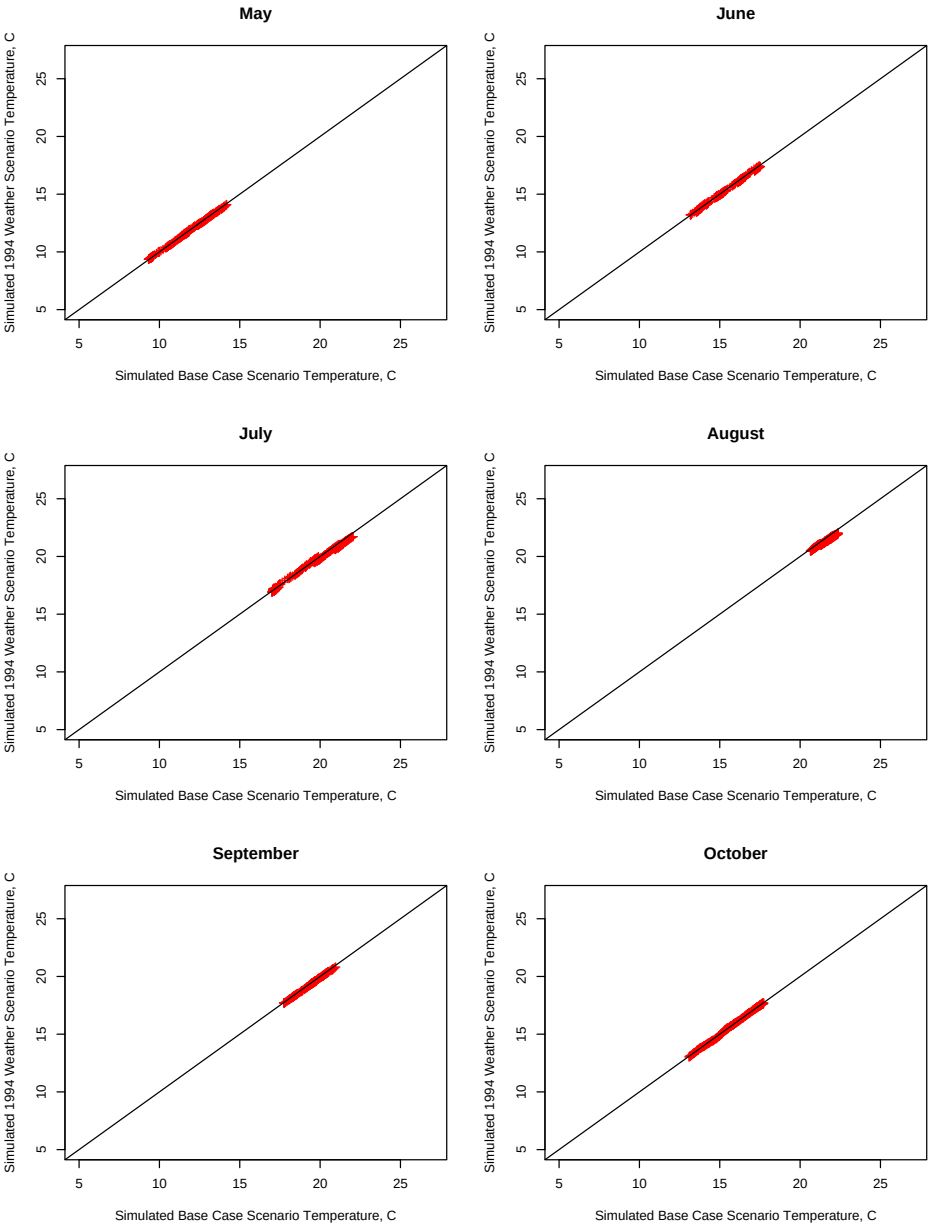

Figure 118: Scatter plot comparison, by month, of temperature at the BON Forebay in the Base Case and 1994 Weather scenario.

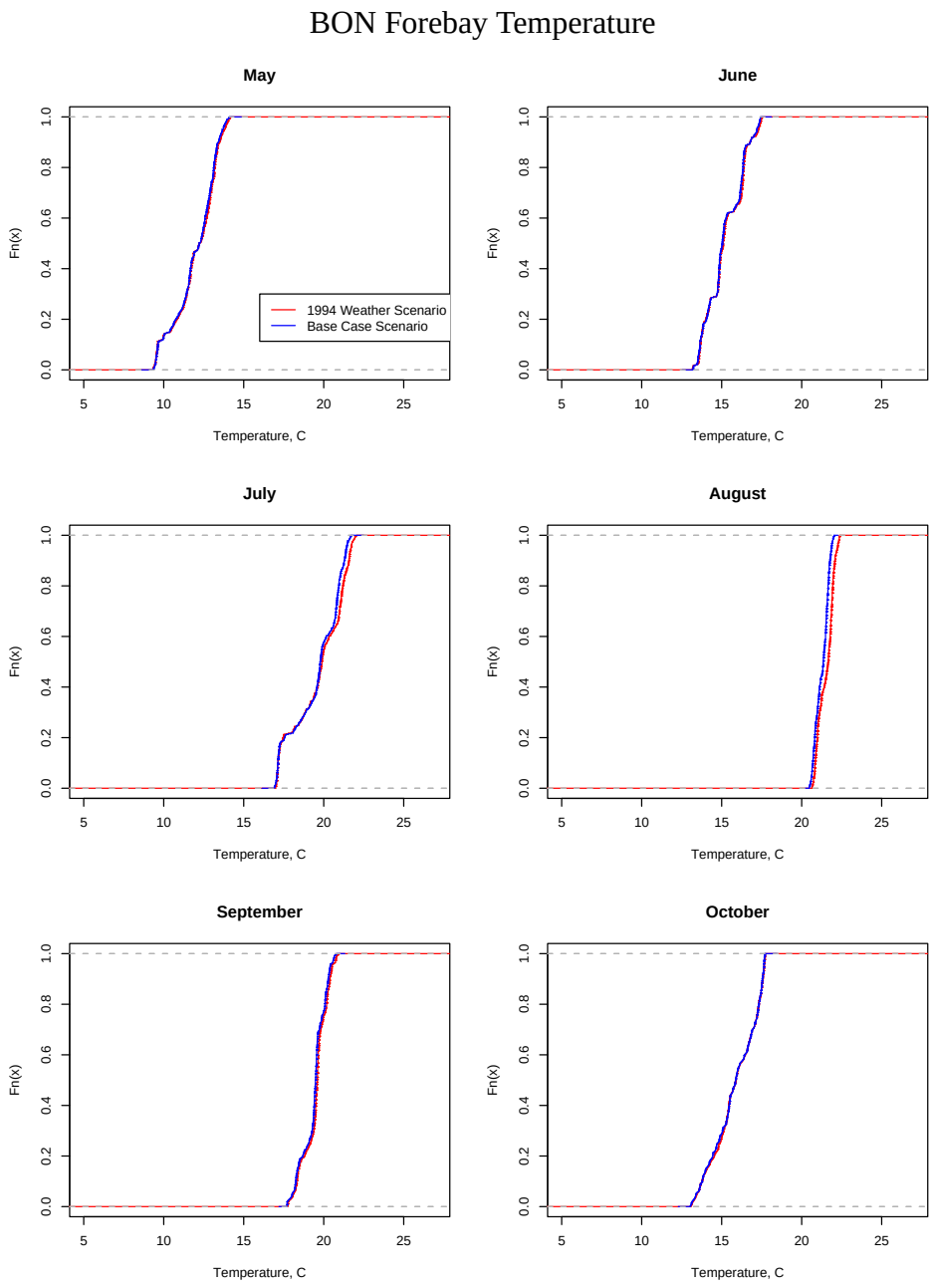

Figure 119: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the BON Forebay in the Base Case and 1994 Weather scenario.

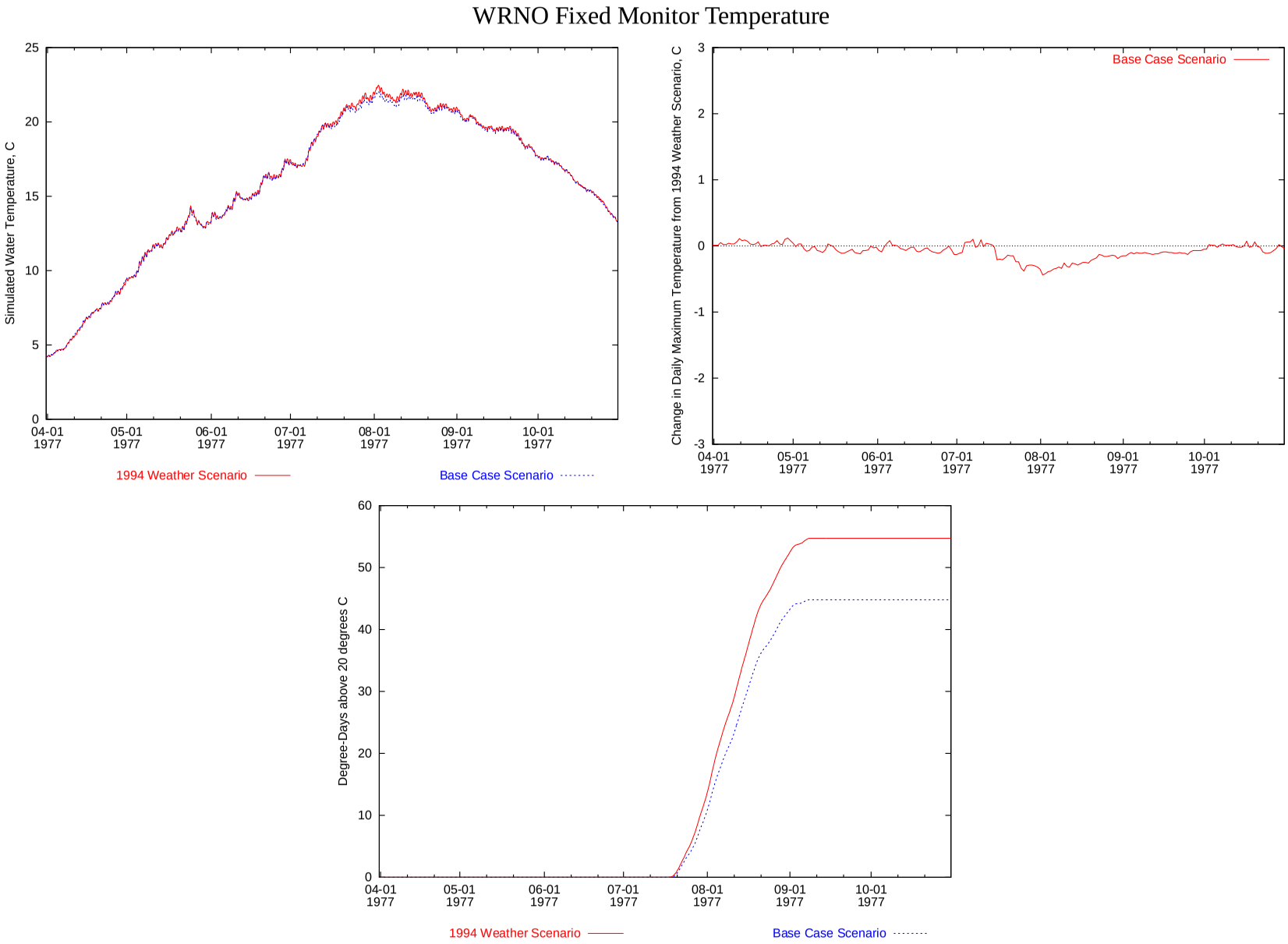

Figure 120: Time series comparison of temperature at the WRNO Fixed Monitor in the Base Case and 1994 Weather scenario.

WRNO Fixed Monitor Temperature

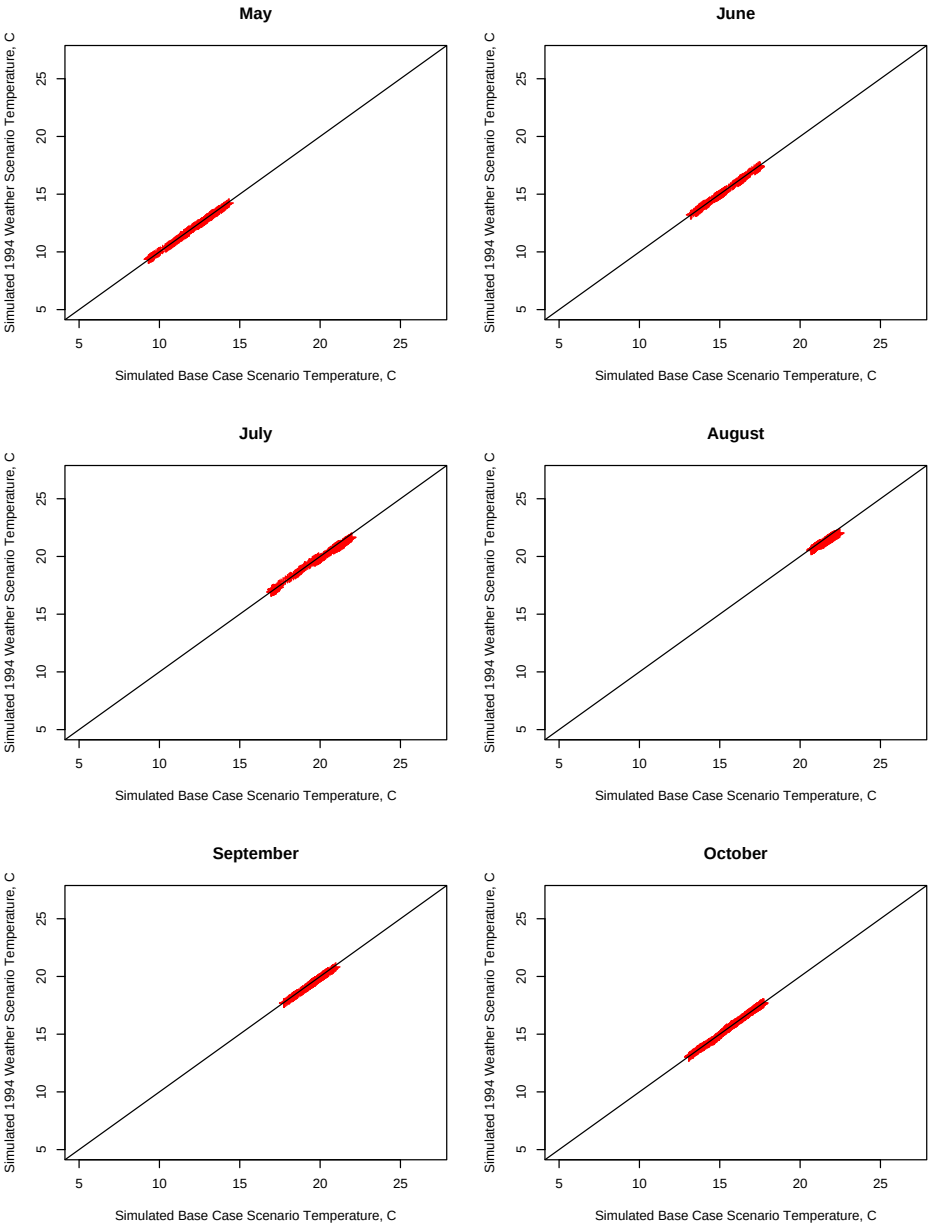

Figure 121: Scatter plot comparison, by month, of temperature at the WRNO Fixed Monitor in the Base Case and 1994 Weather scenario.

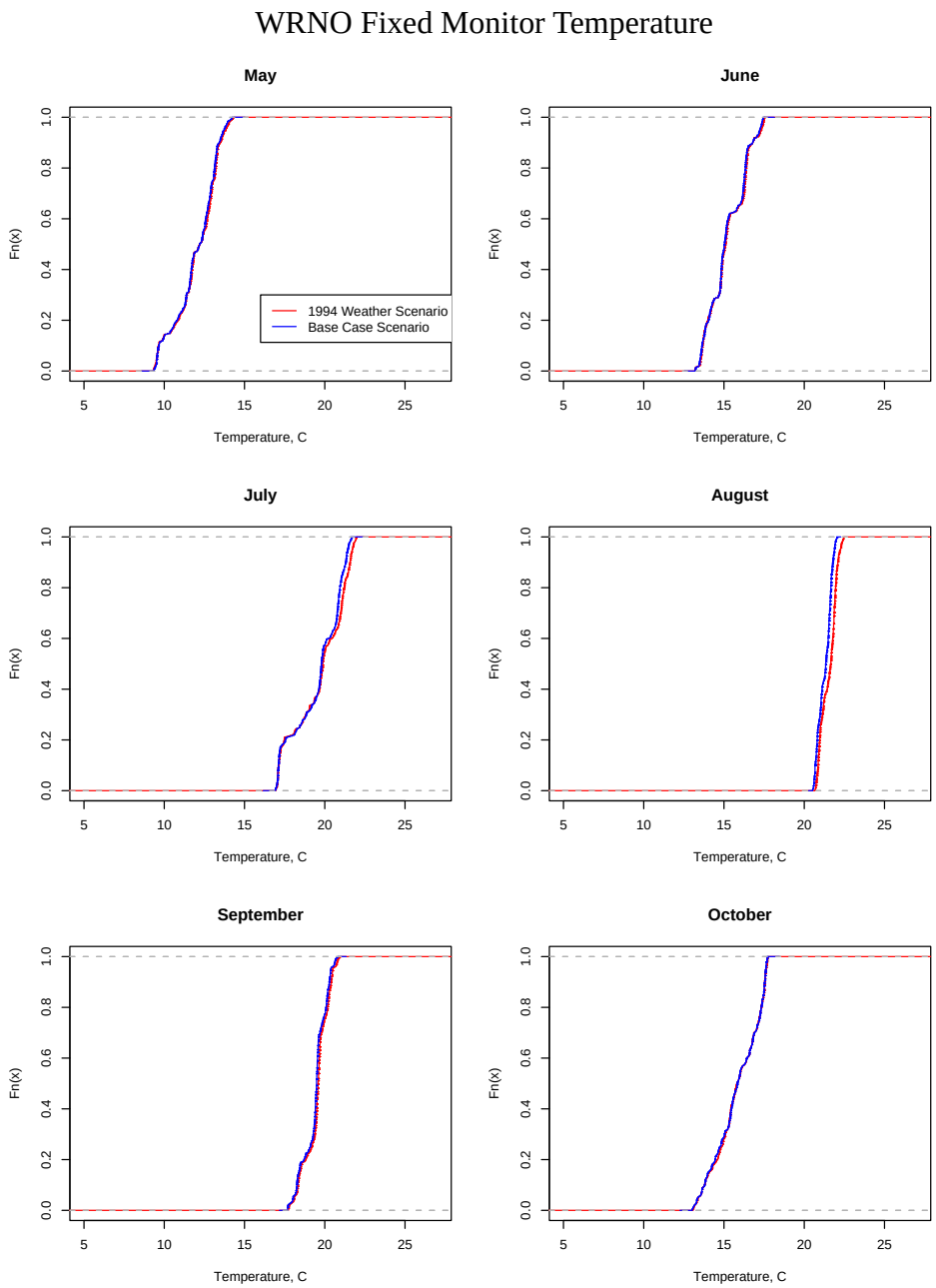

Figure 122: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the WRNO Fixed Monitor in the Base Case and 1994 Weather scenario.

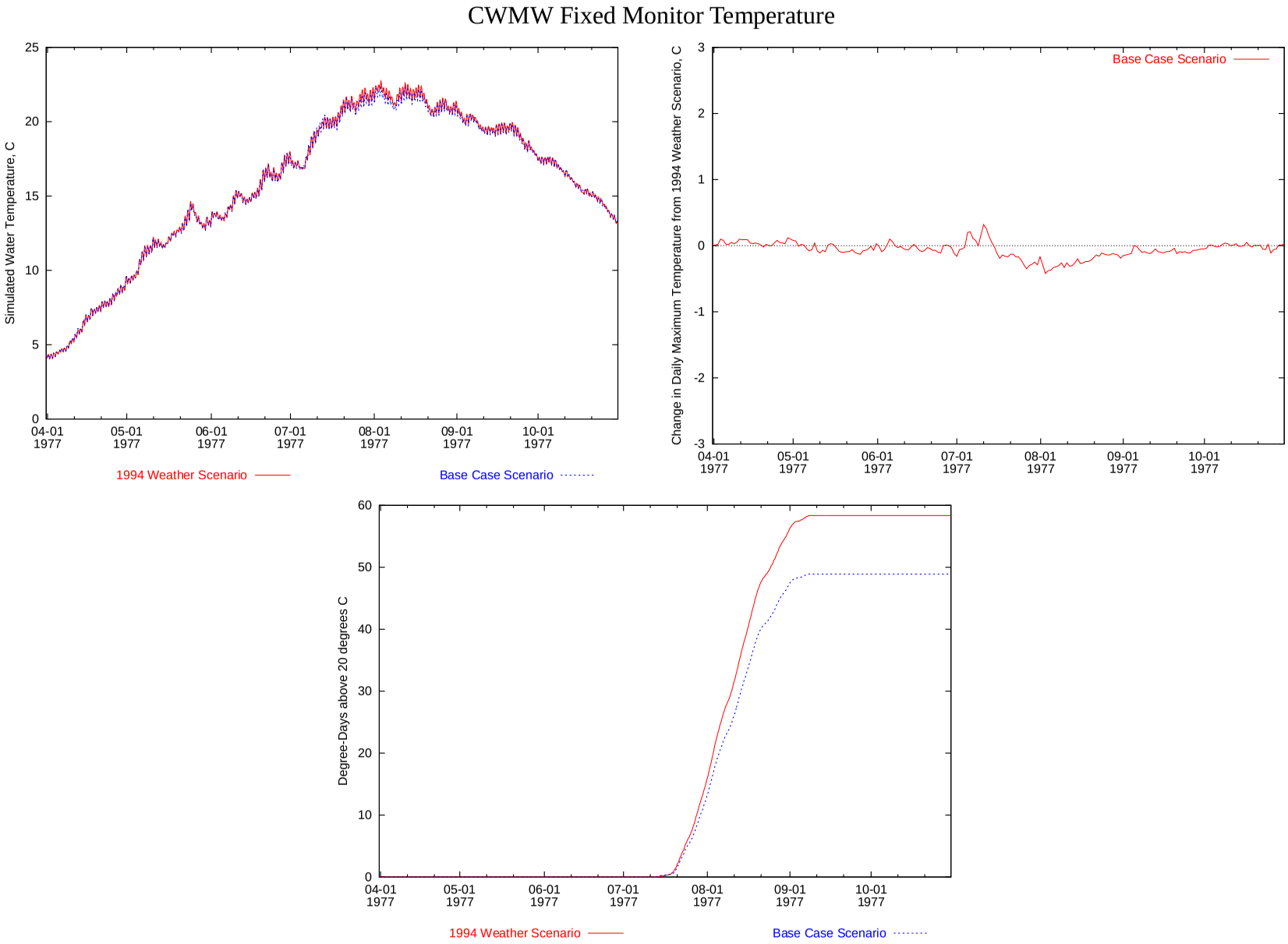

Figure 123: Time series comparison of temperature at the CWMW Fixed Monitor in the Base Case and 1994 Weather scenario.

CWMW Fixed Monitor Temperature

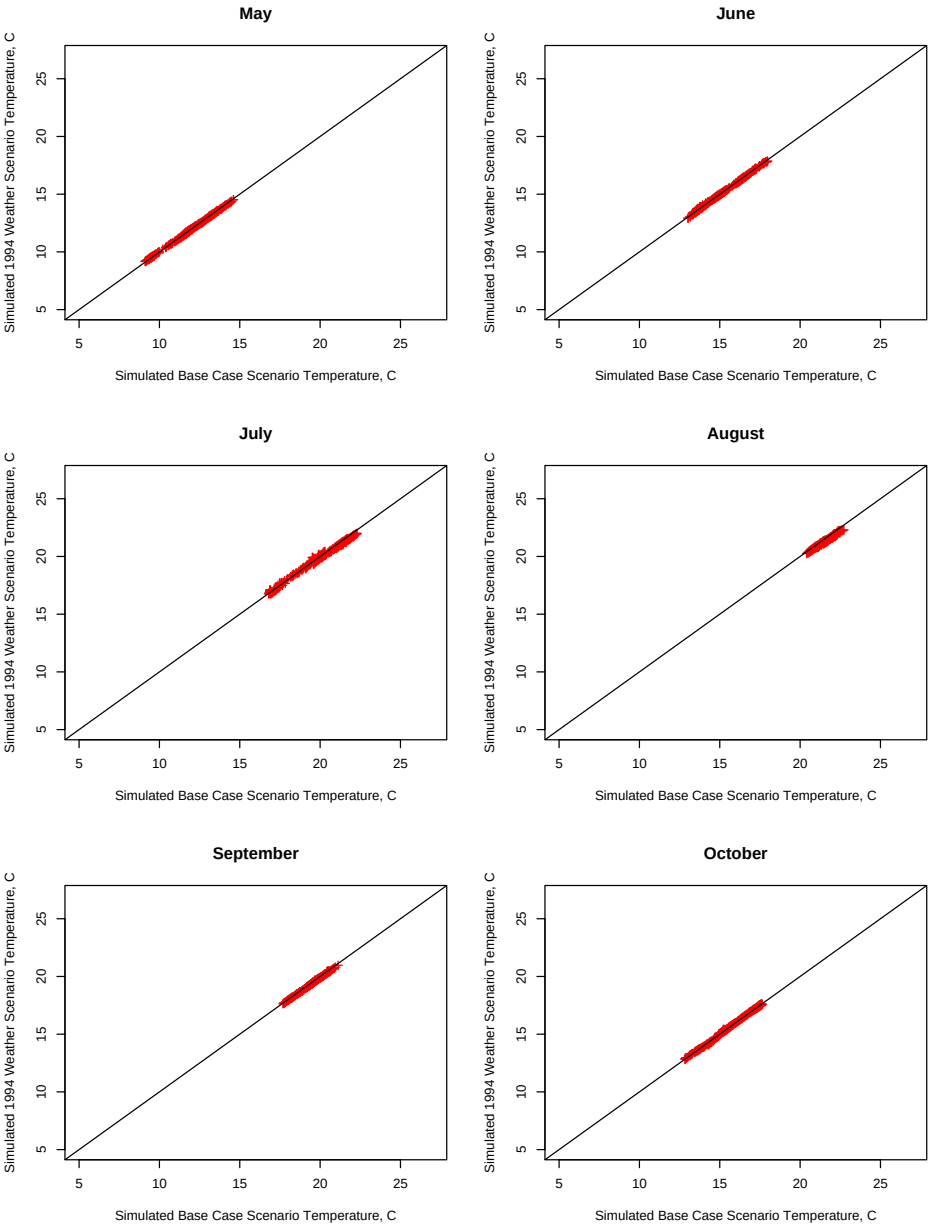

Figure 124: Scatter plot comparison, by month, of temperature at the CWMW Fixed Monitor in the Base Case and 1994 Weather scenario.

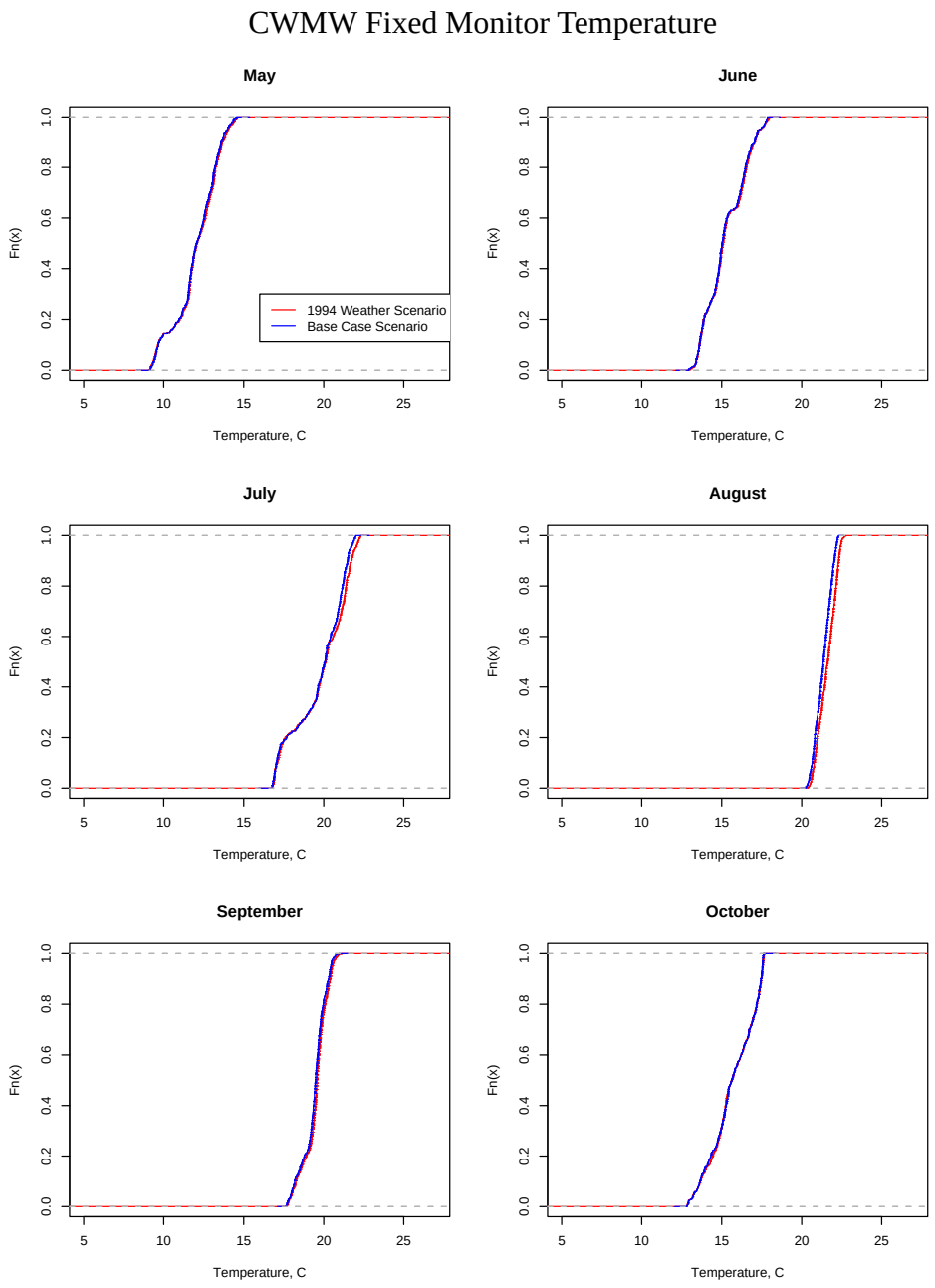

Figure 125: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the CWMW Fixed Monitor in the Base Case and 1994 Weather scenario.

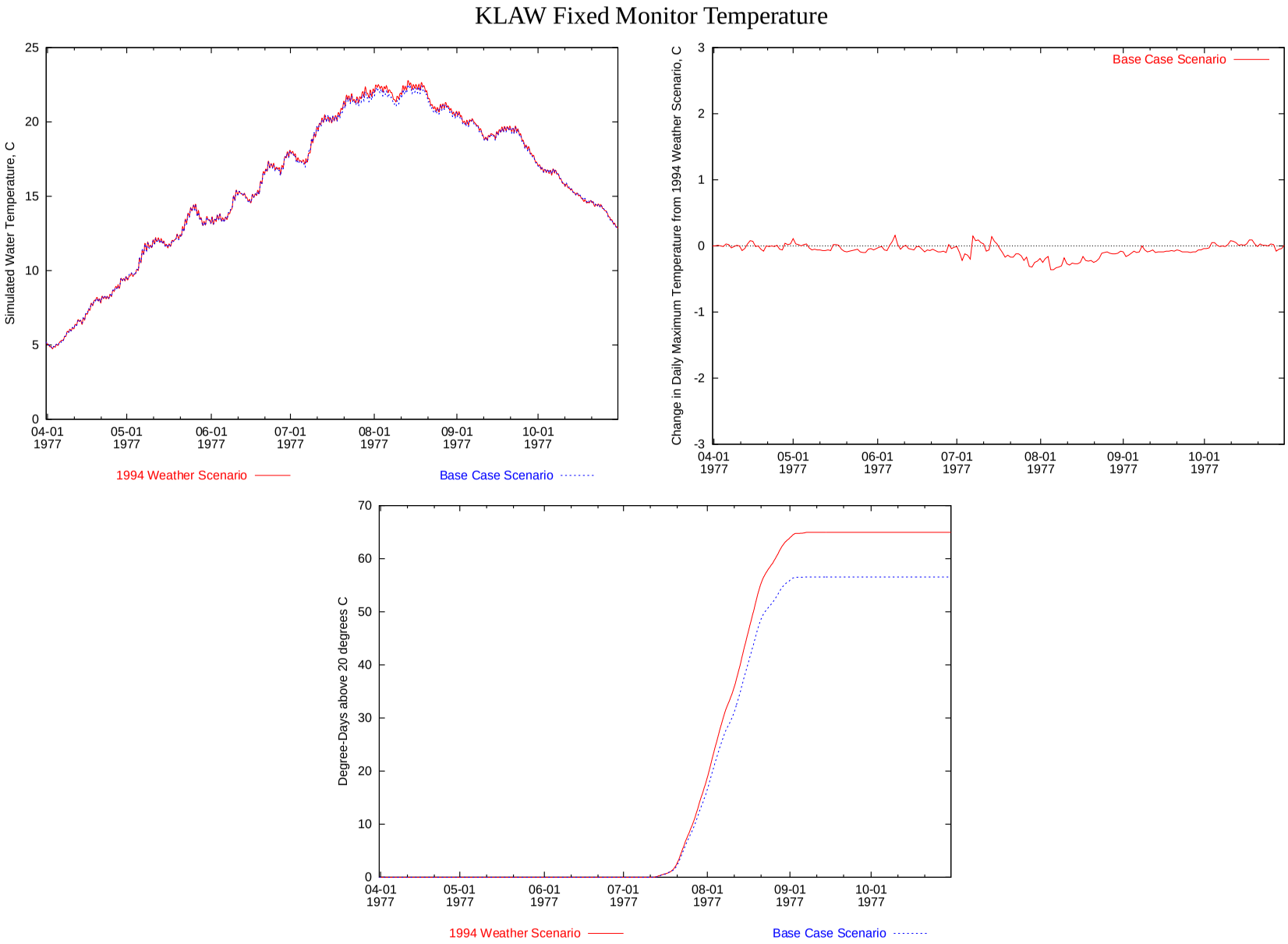

Figure 126: Time series comparison of temperature at the KLAW Fixed Monitor in the Base Case and 1994 Weather scenario.

KLAW Fixed Monitor Temperature

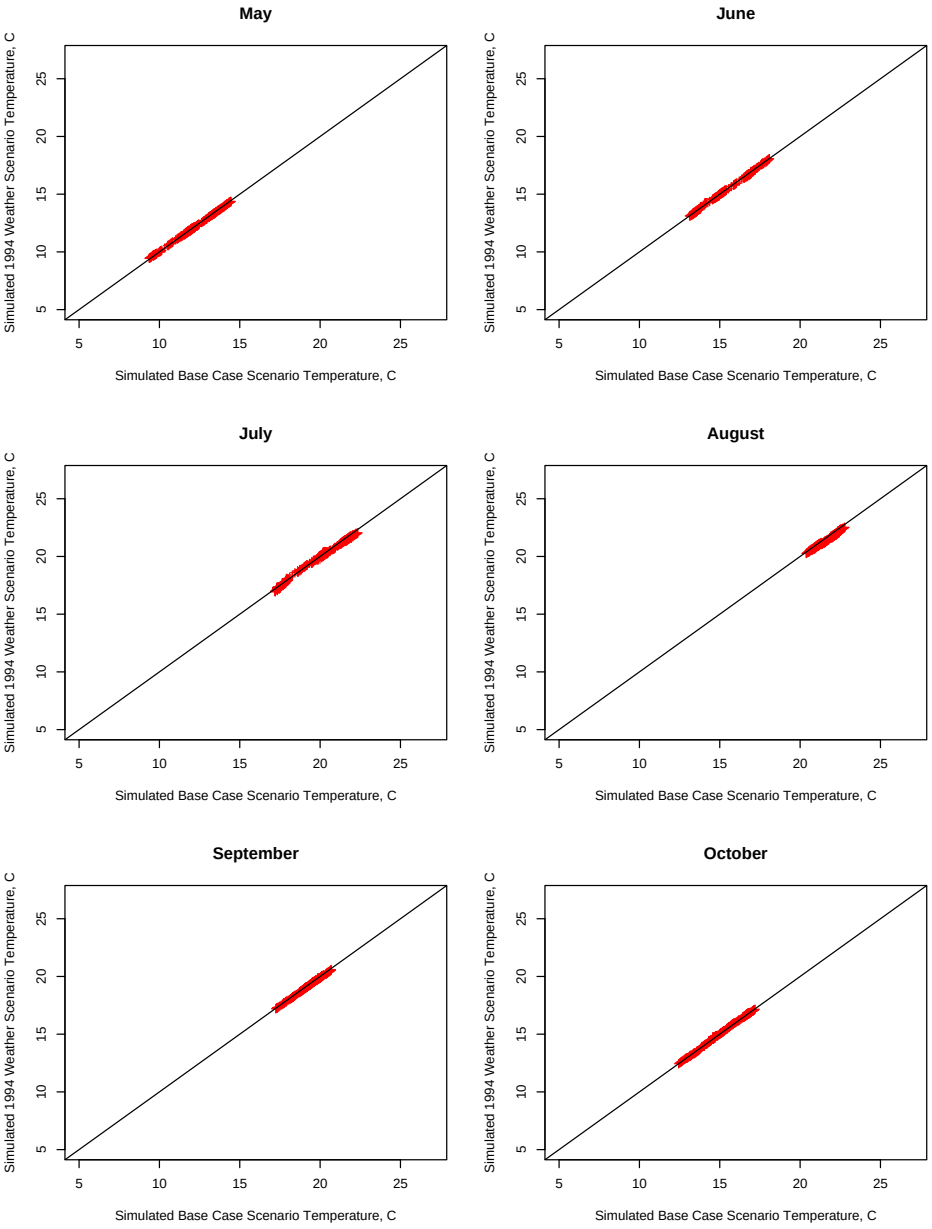

Figure 127: Scatter plot comparison, by month, of temperature at the KLAW Fixed Monitor in the Base Case and 1994 Weather scenario.

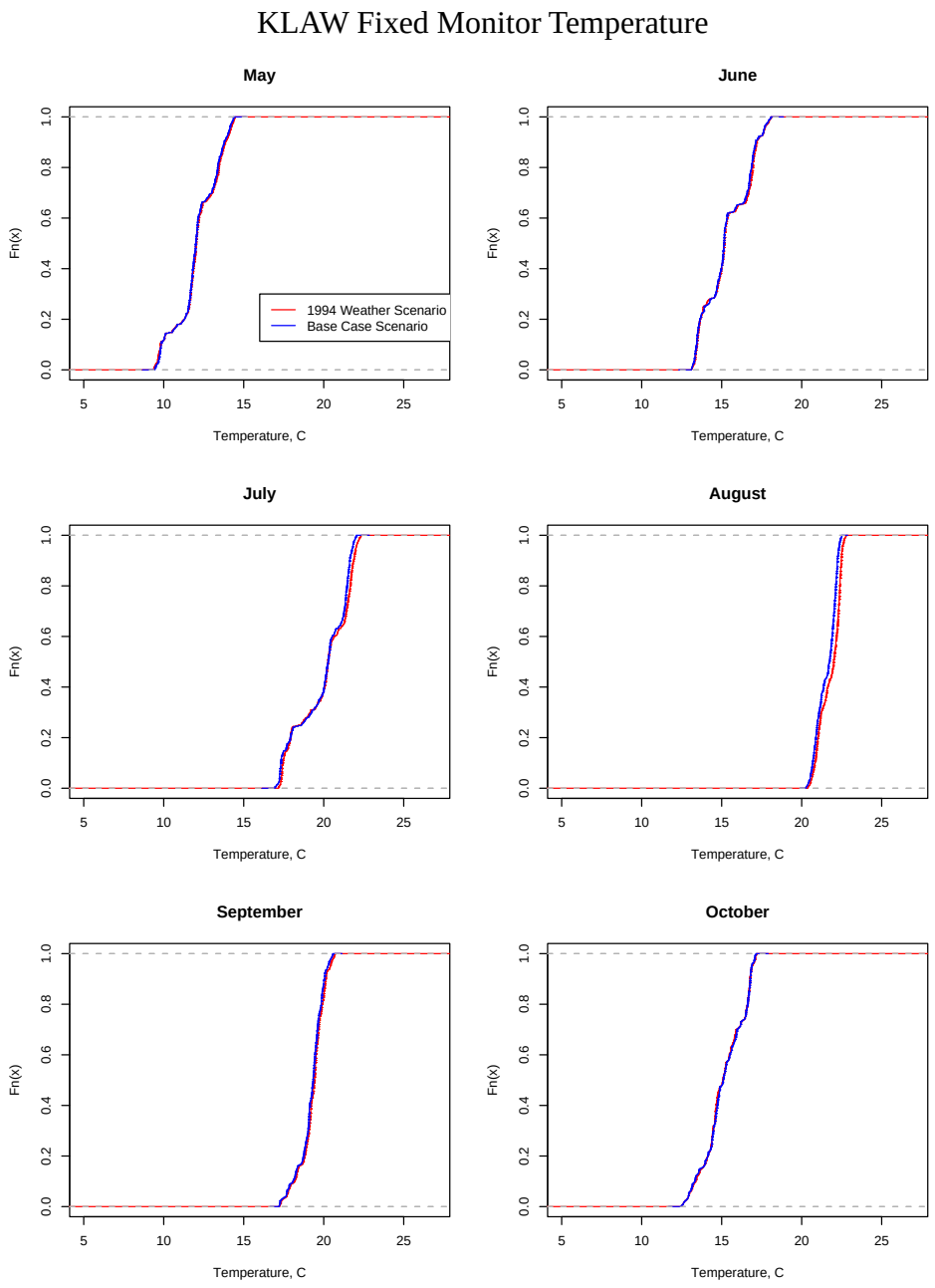

Figure 128: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the KLAW Fixed Monitor in the Base Case and 1994 Weather scenario.

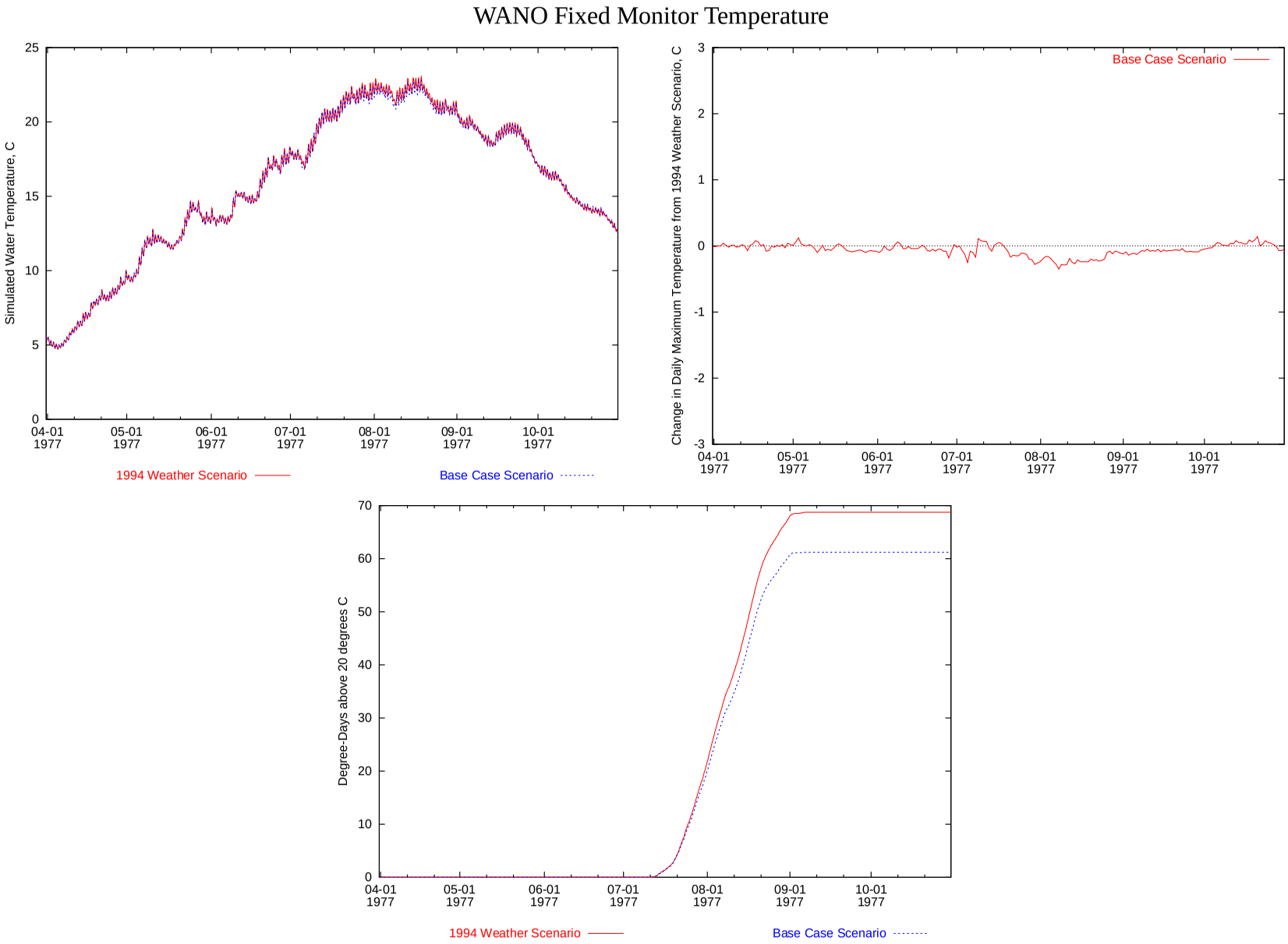

Figure 129: Time series comparison of temperature at the WANO Fixed Monitor in the Base Case and 1994 Weather scenario.

WANO Fixed Monitor Temperature

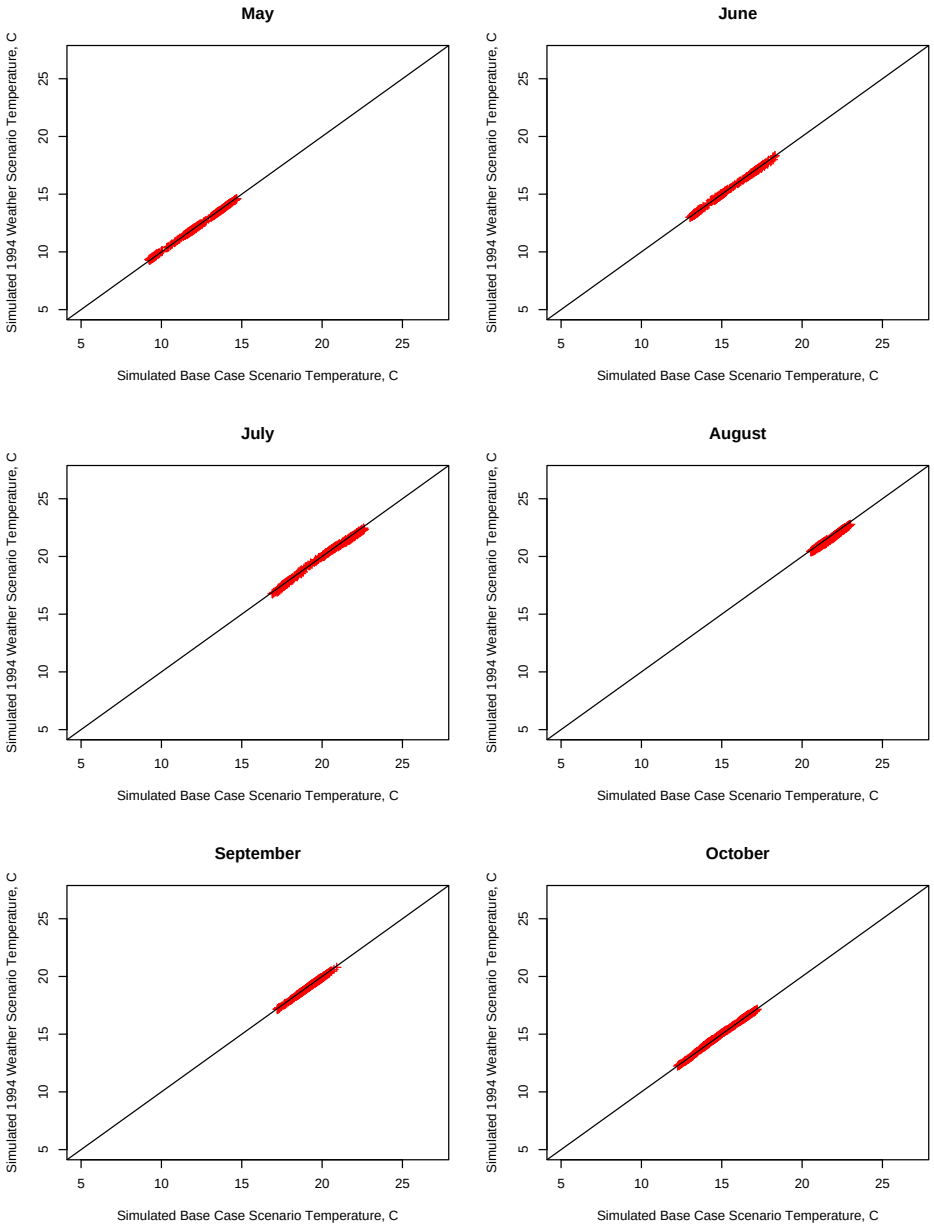

Figure 130: Scatter plot comparison, by month, of temperature at the WANO Fixed Monitor in the Base Case and 1994 Weather scenario.

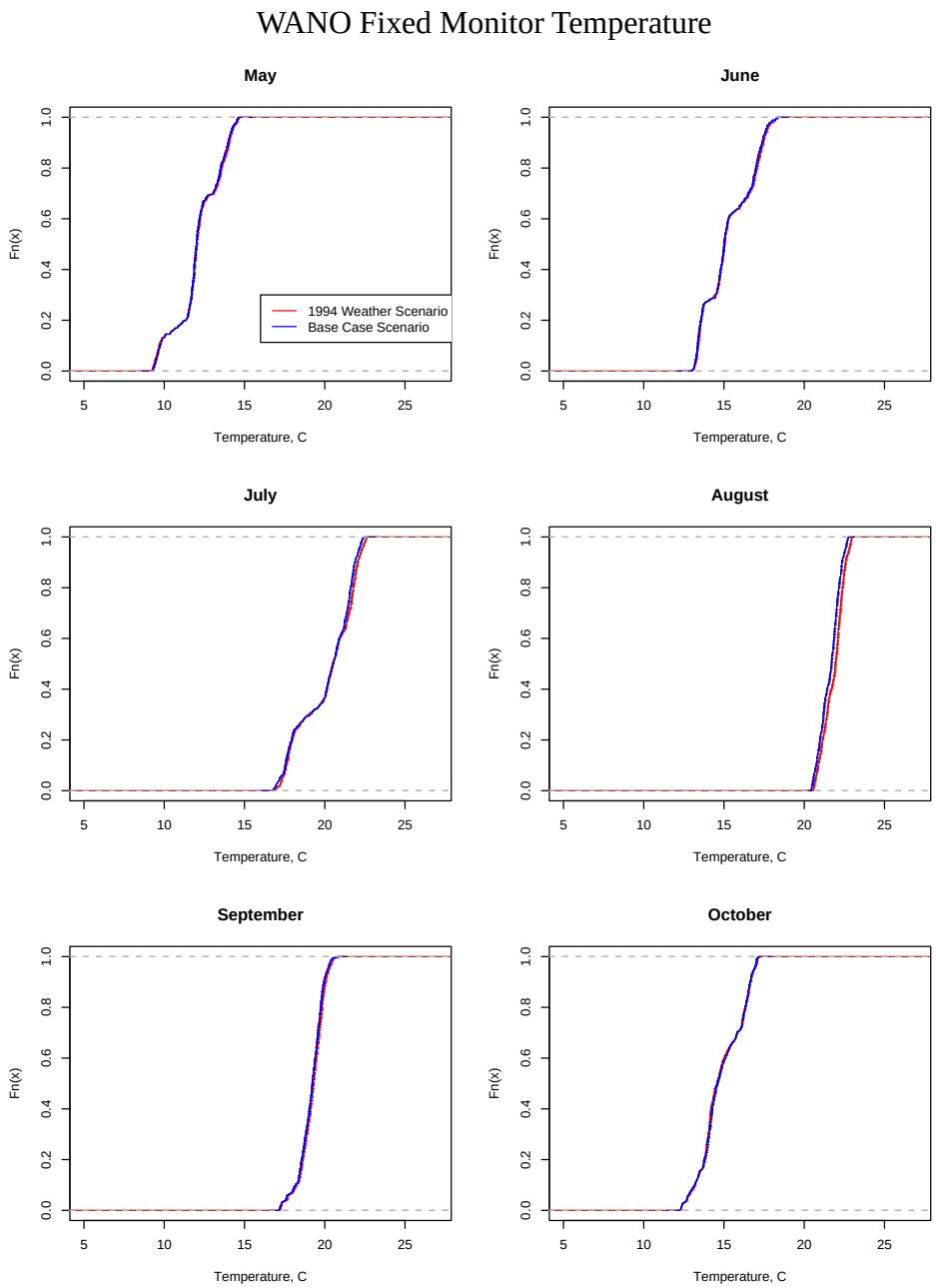

Figure 131: Cumulative frequency distribution (CFD) plot comparison, by month, of temperature at the WANO Fixed Monitor in the Base Case and 1994 Weather scenario.

A Estimation of Clearwater Main Stem Temperature

In the 1997 conditions and 1994 weather scenarios, water temperatures for the Clearwater main stem at Orofino and the North Fork Clearwater at Dworshak are assumed to be that observed at the USGS Spaulding gage downstream. This is acceptable since observed flows were used at both of those model boundaries.

In other scenarios, the flows used at the Dworshak model boundary differ from observed, and temperatures are synthetic, so that using the Spaulding temperatures at the Orofino boundary is not acceptable. In these scenarios, a temperature record is estimated for the Clearwater main stem at Orofino using the temperatures from the USGS gage on the North Fork of the Clearwater near Canyon Ranger station (13340600). The Canyon Ranger station was in operation during 1977 and overlaps the Orofino record from 1993 to 1996 (data in hand).

A simple linear regression of daily means at these two station was performed. The results are shown in Figure 132. The developed relation is

$$T_{\text{Orofino}} = 1.1049 T_{\text{Canyon}} + 0.6110$$

The adjusted coefficient of determination (r^2) of this relation is 0.9876 and the standard error is 0.79°C. Clearwater main stem temperatures estimated for 1977 using the above relation are shown in Figure 133.

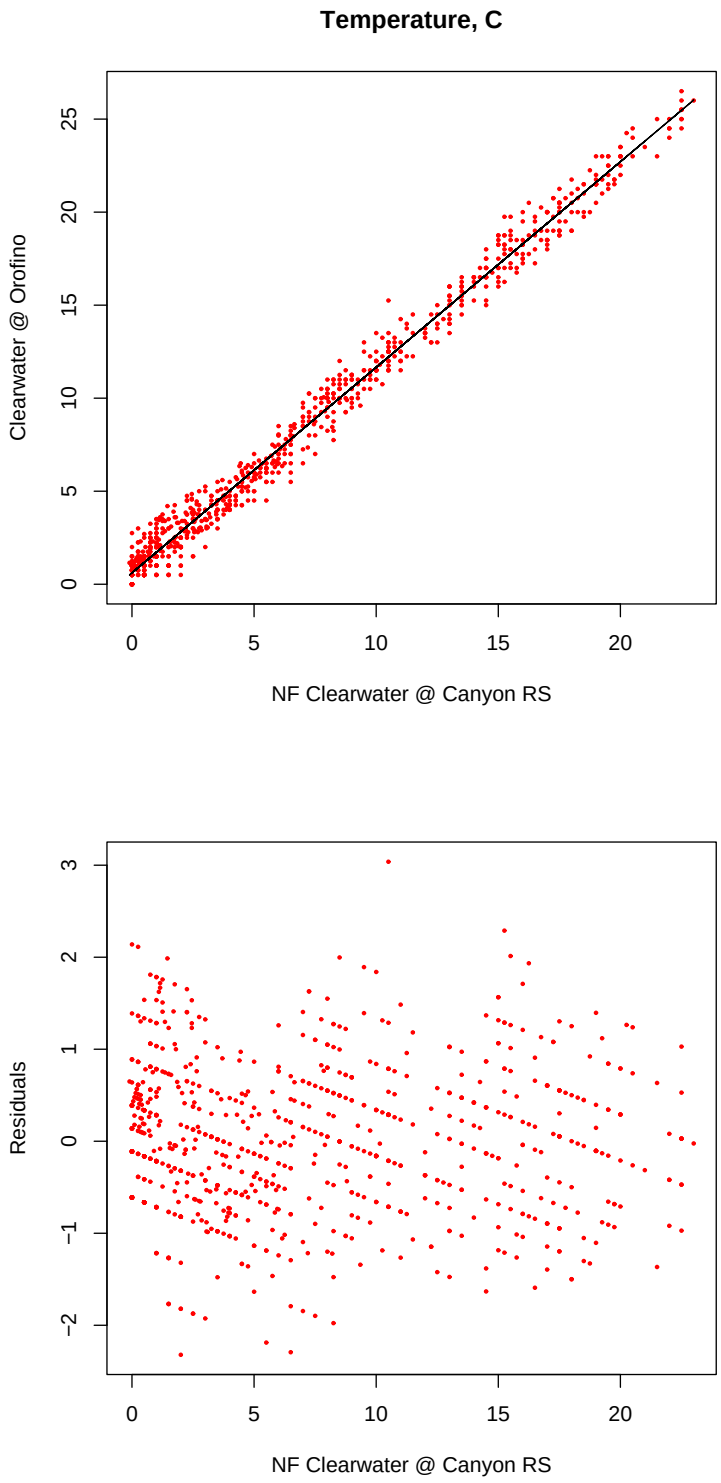

Figure 132: Linear regression estimating Clearwater main stem temperature from North Fork Clearwater temperatures.

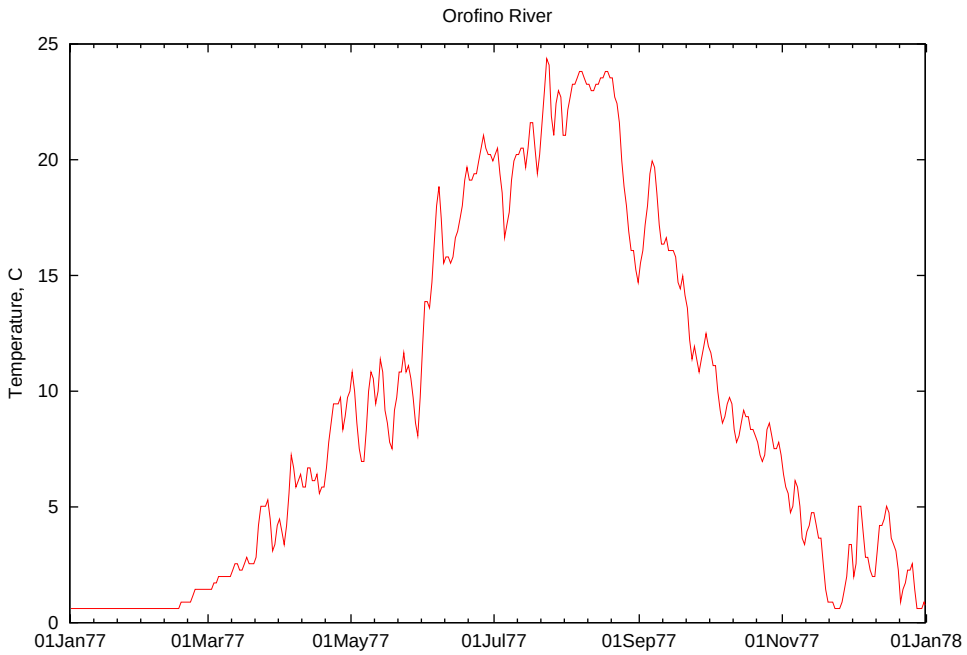

Figure 133: Estimated Clearwater main stem temperatures for 1977.

B MASS1 Model Schematics

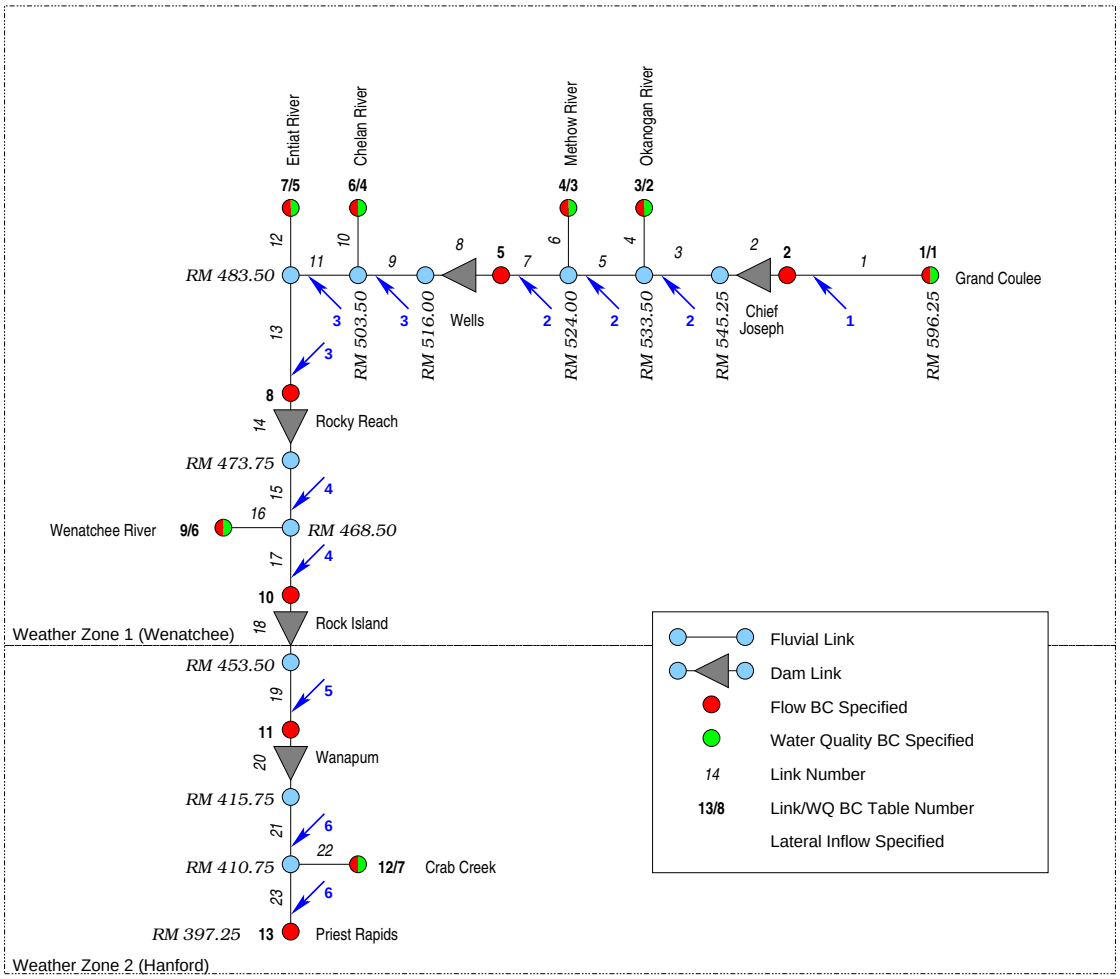

Figure 134: Schematic of MASS1 application to the mid-Columbia.

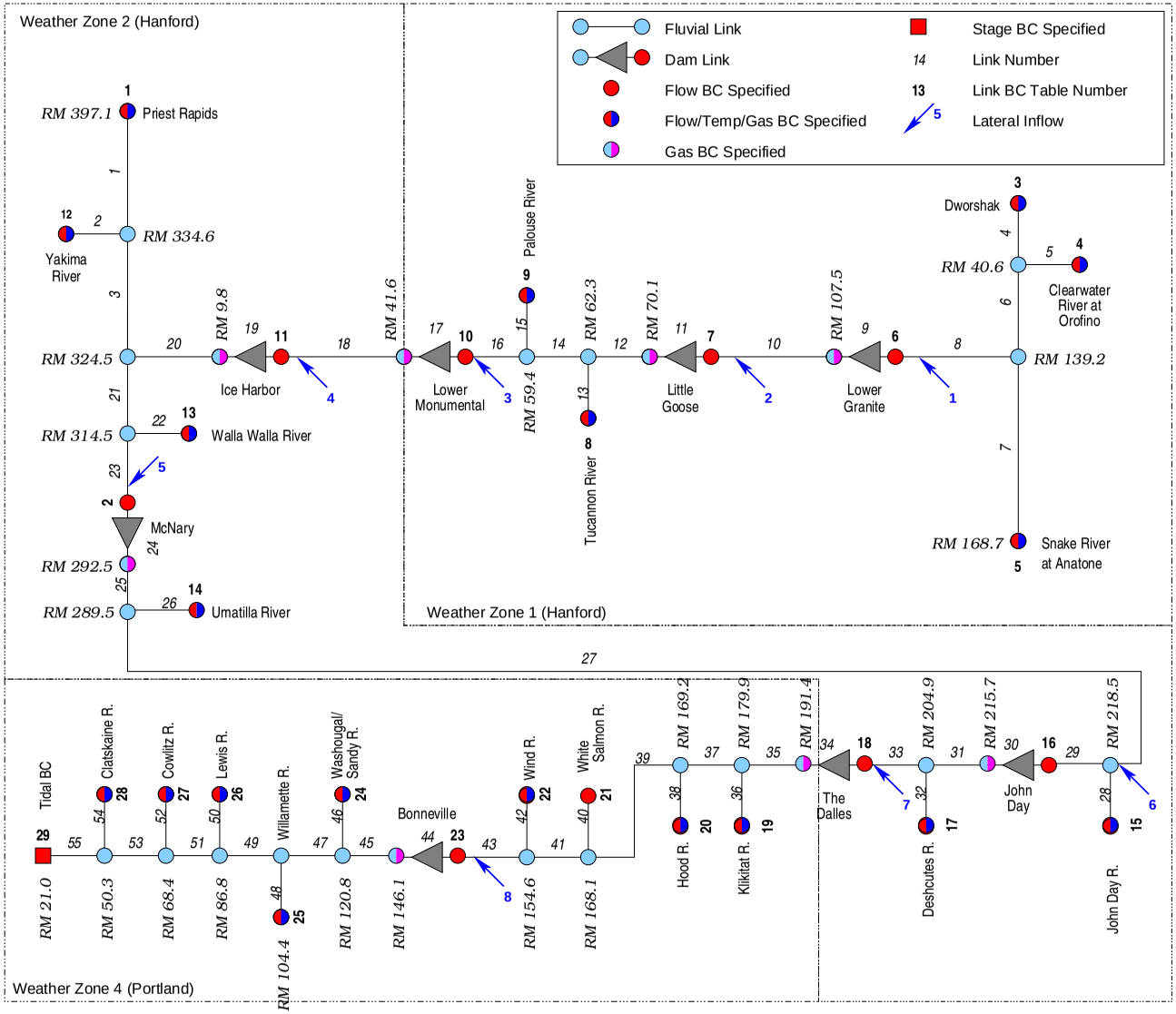

Figure 135: Schematic of MASS1 application to the lower Snake and Columbia Rivers.