Memorandum

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To: Caroline Heim, Tsolum River Restoration Society
From: K. O'Neill, MSc

Date: December 11, 2020
Pages: 20

Subject(s): 2020 Tsolum River Thermal Refugia Study – Data Analysis and Recommendations

Introduction

Tidbit V2 temperature loggers were installed at various locations in the Tsolum River during summer 2020. Locations were selected based on recommendations from a thermal refugia study conducted in 2019. Current Environmental Limited (CEL) was retained by the Tsolum River Restoration Society (TRRS) to analyze the 2020 temperature data to determine whether groundwater inflows are present at any of the 2020 sites, as well as to provide recommendations for future temperature studies. Tidbits were buried in the gravel at two locations (W10 and W14) and were installed on the stream bed at the remaining 10 locations within the Tsolum River watershed for the 2020 thermal refugia study. One tidbit was installed in a gravel bar to measure air temperatures in order to determine whether air temperatures are the primary driver of stream temperatures at the 12 locations. Table 1 shows the 12 monitoring sites.

Table 1. Names, Descriptions, and Locations of 2020 Temperature Monitoring Sites.

Site Name and Description	Site Location (Decimal Degrees)
W2 – In Dove Creek, approx. 15 m upstream of Tsolum River confluence	49.74741, -125.08665
W4 – In Tsolum River, 30 m upstream of Headquarters Creek confluence	49.7676, -125.1182
W6 - In Tsolum River, 90 m downstream of Headquarters Creek confluence	49.76749, -125.11792
W7 - In Tsolum River, approx. 190 m downstream of Dove Creek confluence	49.74675, -125.08434
W9 - In Tsolum River, approx. 10 m downstream of Portuguese Creek confluence	49.71804, -125.01185
W10 – In Portuguese Creek, approx. 20 m upstream of Tsolum River confluence	49.71834, -125.01189
W11 - In Tsolum River, approx. 25 m upstream of Portuguese Creek confluence	49.71816,-125.01228
W13 – In Tsolum River, approx. 115 m downstream of Dove Creek Confluence	49.74671,-125.08534
W14 – Downstream of large boulder across from McNaughton's property	49.74699, -125.07603
W17 – Comox Valley Exhibition Grounds, upstream of old pink counting fence	49.70357,-125.00555

Upstream of McNaughton property – opposite pool at 6019 Tsolum River Road	49.747497, -125.076732
Murex Creek at Duncan Bay Main	49.78745, -125.22891

Comparison between Sites
Stream temperatures were compared at all twelve sites from August 4 – September 21, 2020, since these are the dates when all loggers were recording temperatures (Figure 1). Generally, stream temperatures increased with distance downstream, which is similar to the 2019 trend. The Murex Creek site was the coolest (average stream temperature of 15.8°C) and it is the farthest upstream. The average stream temperatures of the downstream sites (W9, W11, and W17) were 19.0°C, 18.9°C, and 18.9°C, respectively. There were a few exceptions to this trend, including: W2, W14, and W10, which were cooler than the surrounding sites and did not following the increasing temperatures with increasing distance trend. W10 and W14 were buried in the sediment which may have contributed to the cooler temperatures. All three of these sites showed the potential for groundwater influence based on the 2019 results, and the 2020 results also indicate that they are cooler than the surrounding tidbits, which may be a result of groundwater inflows.

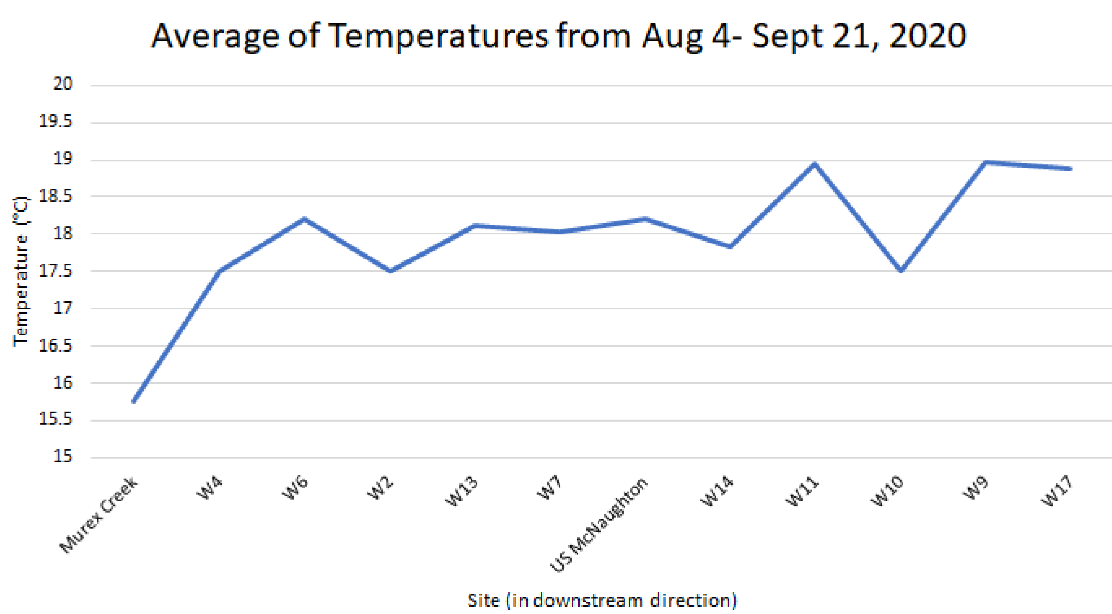

Figure 1. Average stream temperatures from August 4 – September 21, 2020.

The daily mean temperatures were calculated for each of the twelve water temperature sites and one air temperature site from August 5- September 20, 2020. Figure 2 shows the median of the daily mean temperatures for each site as well as the variation in daily mean temperatures.

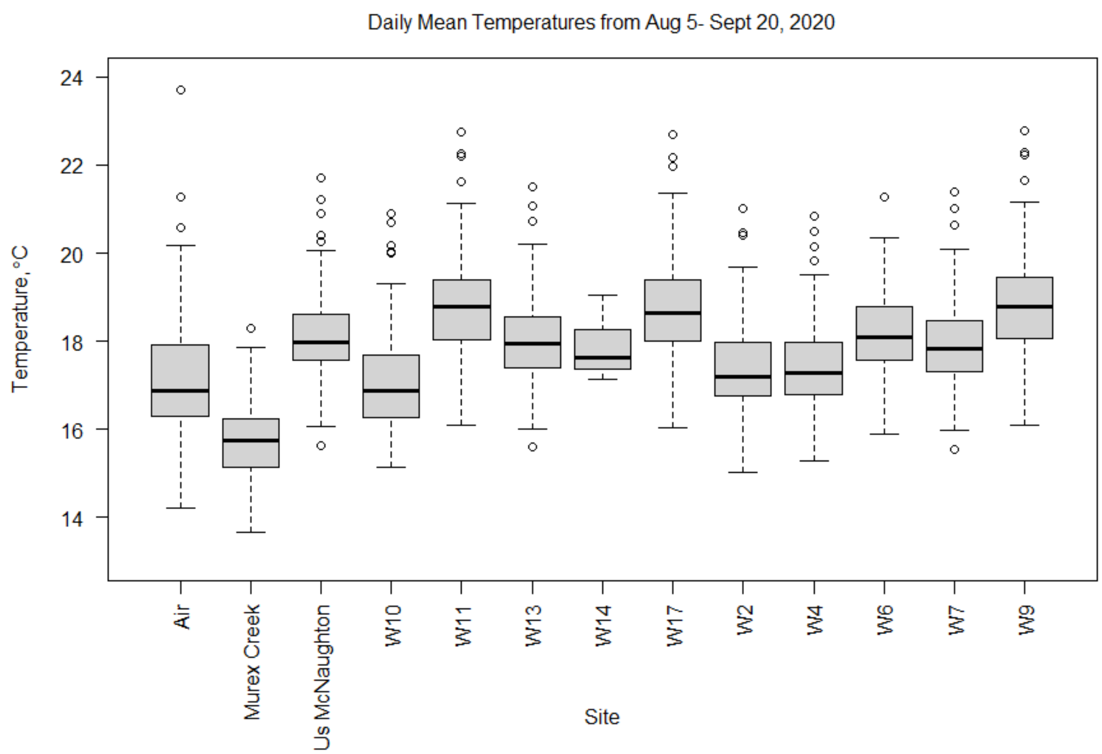

Figure 2. Daily mean temperatures from August 5 – September 20, 2020 showing median of daily means and variation in daily means.

The median daily mean temperature is lowest at Murex Creek and highest at W9, W11, and W17, which is the same trend as the overall average temperatures shown in Figure 1. <u>The smallest variation in daily mean temperatures is shown at W14, suggesting more stable temperatures throughout the monitoring period.</u> This may be because the tidbit was buried in the sediment instead of placed on the streambed, however the tidbit at W10 was also buried in the sediment and showed a variation in daily mean temperatures similar to all other sites. This suggests that the temperature at W14 may be influenced by groundwater upwelling, reducing the variation in temperatures throughout the monitoring period. The largest variation in daily mean stream temperatures were exhibited at W9, W10, W11, and W17, suggesting that temperatures at these loggers were influenced diurnally and seasonally by atmospheric conditions and were likely not influenced by groundwater inflows.

Comparison between Water and Air Temperatures

<u>Time Series Graphs</u>
Each water temperature logger was compared to the air temperature logger for the time period when each logger was recording temperatures. Time series graphs were created for each water and air temperature pair to visually determine whether water temperature changed diurnally and seasonally with air temperature, or whether water temperatures stayed more constant and stable compared to air temperatures for the same time period. The time series graphs for each water and air temperature pair are presented in Appendix A below.

The time series graphs show how water temperature changed in relation to air temperature throughout the monitoring period. The slopes of the trendlines allow for a comparison between the rates of change for each air and water temperature pair. Based on these time series graphs, there does not appear to be groundwater input at W2, W7, W9, W11, W13, W17, or upstream McNaughton. Water temperature tracked air temperature at these sites with similar rates of change for both the water and air temperature at these locations throughout the study period. Conversely, the rate of change was lower for water temperatures compared to air temperatures at W4, W6, W14, and Murex Creek, indicating more stable temperatures compared to air temperatures. Water temperatures were decoupled from air temperatures at W14, staying very consistent compared to the air temperatures that varied diurnally and seasonally. W14 was the only site with a strong groundwater signal, however it is important to note that the tidbit was buried in the sediment at this site which may have produced the lower and more stable stream temperatures.

Statistical Analysis - Linear Regression

Weekly means for water temperature and air temperature were compared using a linear regression model in R version 3.6.1[1] for the sites that were measured in both 2019 and 2020 with sufficient data points (W2, W4, W6, W9, W10, W11, W13, W14, and W17). The length of time that the tidbits recorded temperatures in 2020 ranged from 7-12 weeks, which is an insufficient number of weeks for a linear regression, resulting in the need to combine the 2019 and 2020 data to conduct linear regressions. A similar study conducted by Krider et al. in 2013 only performed linear regressions between air and water temperatures at sites that had a minimum of 15 weekly averages[2]. The number of weeks for the 2019 and 2020 data combined ranged from 19 – 24, therefore linear regressions were conducted on the combined data over the two years. Four assumptions needed to be met before linear regressions could be conducted which were: (1) the relationship between the independent and dependent variables were linear, (2) the residuals were homoscedastic, (3) the observations were independent, and (4) the data was normally distributed[3]. Assumptions 1, 3, and 4 were all met, however the residual plots indicated that the residuals were not homoscedastic for every site.

The significance of the linear regression models were tested for each air/water temperature logger pair. The null hypothesis was that there was not a significant relationship between water and air temperatures, suggesting that air temperature is not the primary driver of stream temperature in that location. The alternative hypothesis was that there was a significant relationship between water and air temperatures, suggesting that air temperature is the primary driver of stream temperature in that location. If p-values were less than the significance value of 0.05, then the null hypothesis was rejected and if p-values were greater than the significance value of 0.05, then there was a failure to reject the null hypothesis. There was the

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[1] Webb BW, Hannah DM, Moore RD, Brown LE, Nobilis F (2008) Recent advances in stream and river temperature research. Hydrological Processes 22(7):902-918

[2] Krider LA, Magner JA, Perry J, Vondracek B, Ferrington LC (2013) Air-water temperature relationships in the Trout Streams of Southeastern Minnesota's carbonate-sandstone landscape. Journal of the American Water Resources Association. 49(4):896-907

[3] Boston University School of Public Health (2016) Simple linear regression. Correlation and regression with R. http://sphweb.bumc.bu.edu/otlt/MPH-Modules/BS/R/R5_Correlation-Regression/R5_Correlation-Regression4.html (accessed 20 February 2020)

potential for type I errors to occur (falsely rejecting a true hypothesis) since multiple hypothesis tests were conducted[4]. The p-values were therefore adjusted to minimize this risk[4].

The results of the linear regressions are presented in Table 2, however due to the limited sample size these results may not be defensible.

Table 2. Results of linear regression for the 2019 and 2020 data.

Site Name	Adjusted p-value	Adjusted r^2 value	Accept or Reject Null Hypothesis (based on adjusted p-value)
W2	3.16e-06	0.76	Reject
W4	1.112-05	0.64	Reject
W6	2.24e-04	0.50	Reject
W9	1.87e-06	0.77	Reject
W10	1.11e-05	0.70	Reject
W11	1.43e-06	0.79	Reject
W13	2.25e-04	0.59	Reject
W14	0.119	0.17	Fail to reject
W17	3.43e-05	0.87	Reject

With the exception of W14, the null hypothesis (that there was not a significant relationship between air and water) was rejected at all sites, meaning air temperature is likely the primary driver of stream temperatures at these locations. The adjusted p-value at W14 was greater than the significance value of 0.05, meaning there was a failure to reject the null hypothesis. This indicates that there is not a significant relationship between air and water, with the temperature at W14 being driven by something other than air temperature. These results suggest that groundwater may be influencing stream temperatures at W14.

Along with a p-value, the linear regression models produced a slope and an intercept for each air/water temperature logger pair (Table 2). Typically, the slope will be gentle and the intercept will be large when graphically comparing air and surface water temperatures if groundwater is contributing to the temperature of the stream[5]. Lower slopes indicate that air is not a driving force in the determination of water temperature[6]. Slopes versus intercepts were plotted for the weekly stream/air linear regressions (Figure 3) to determine whether the stream temperature at each site was more likely to be influenced by atmospheric conditions or by groundwater input[5].

[4] Benjamin Y, Yekutieli D (2001) The control of the false discovery rate in multiple testing under dependency. The Annals of Statistics 29(4):1165-1188

[5] Driscoll MO, DeWalle DR (2004) Stream-air temperature relationships as indicators of groundwater input. Watershed Update, ARA Hydrology and Watershed Management Technical Committee 2(6)

[6] Erickson TR, Stefan HG (2000) Linear air/water temperature correlations for streams during open water periods. Journal of Hydrologic Engineering 5(3):317-321

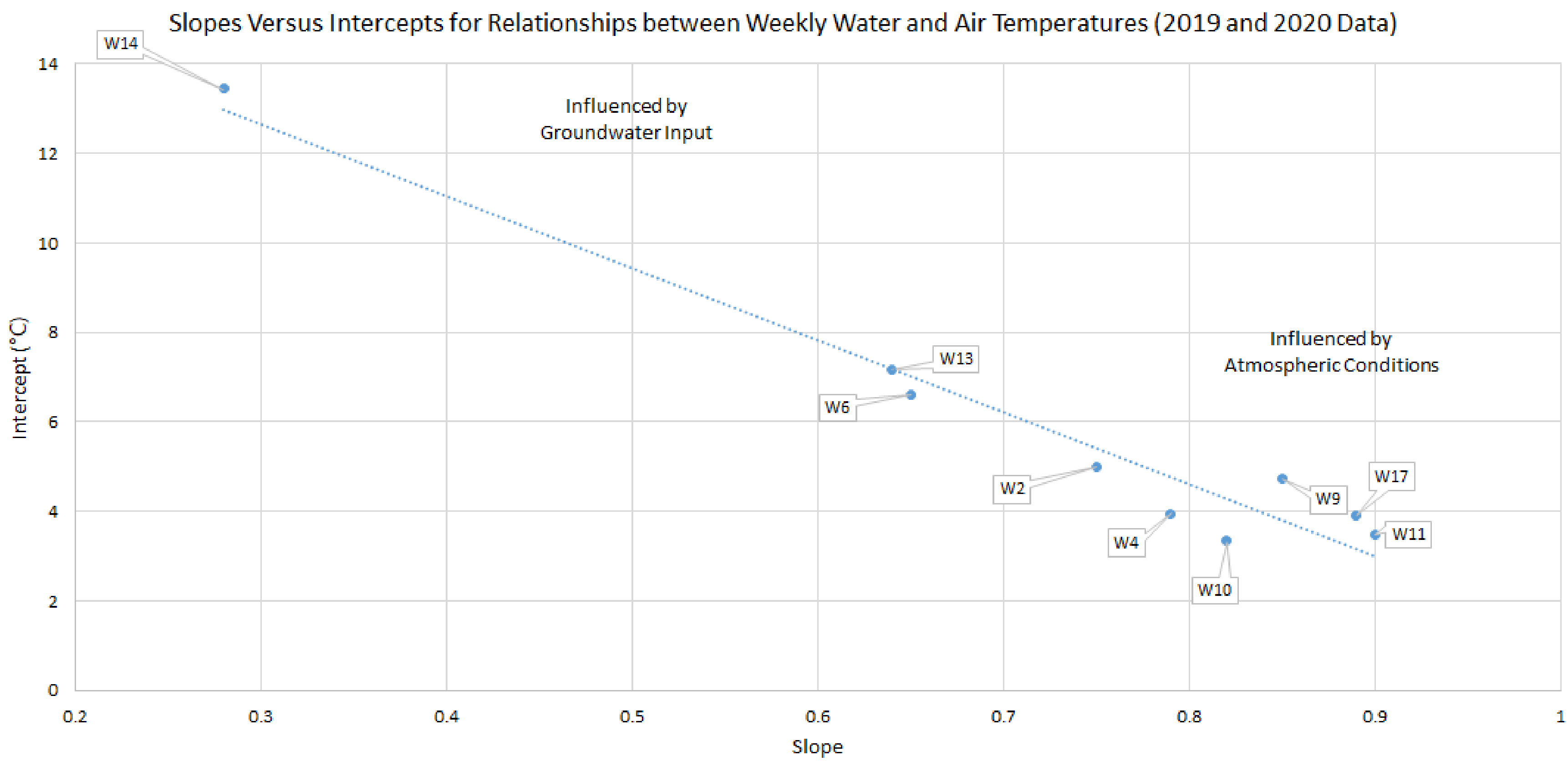

Figure 3. Slope vs. intercepts when comparing weekly means of water and air temperatures for each logger.

Figure 3 shows that the majority of the sites have higher slopes and lower intercepts, indicating that they are likely influenced by atmospheric conditions. Conversely, W14 has a high intercept and low slope, indicating that it may be influenced by groundwater input.

Conclusion and Recommendations for Further Studies

Overall, stream temperatures tend to increase with distance downstream, however there were a few anomalies. W2 and W10 were cooler than surrounding sites, indicating that they are influenced by temperatures in Dove Creek and Portuguese Creek, respectively. Neither of these sites showed a characteristic groundwater signal, although they may be influenced by groundwater inflows upstream in the tributaries.

The rate of change over the monitoring period was lower for water temperatures compared to air temperatures at W4, W6, W14 and Murex Creek, indicating more stable temperatures compared to air temperatures. However, the time series graphs and linear regression results did not show strong groundwater signals at W4, W6, or Murex Creek. Conversely, a strong groundwater signal was observed at W14, with lower average temperatures compared to nearby sites, less variation in the daily means, and a more stable water temperature compared to air temperature. The results of the linear regression for W14 also indicated that there is not a significant relationship between air temperature and water temperature, with the possibility of groundwater influencing stream temperatures at this location. This tidbit was buried in the sediment, so it is unclear whether the lower temperatures are a result of the installation method or potential groundwater inflow.

Based on the results from the 2019 and 2020 study, recommendations for future studies include:

- Temperature measurements at W4, W6, and W14 – these three sites showed the potential for groundwater inflow during the 2020 summer season (signal was the strongest at W14).
- Temperature measurements at W20 and W28 – these two sites showed the potential for groundwater inflow during the 2019 summer season and were not measured in 2020.
- Air temperature measurements in the gravel bar at the end of Stephen Road (same location as 2019 and 2020).
- Two loggers should be installed at each of the water monitoring locations – one should be buried in the sediment and one should be located on the streambed. These two water loggers can then be compared to each other and compared to the air temperature to determine whether groundwater inflow is influencing temperatures. W14 was installed on the stream bed in 2019 and showed a slight groundwater signal. It was then buried in the sediment in 2020 and showed a strong groundwater signal. A study by Silliman and Booth in 1993 showed that it is possible to identify areas of groundwater input into a stream by comparing sediment and stream temperatures over time[7]. Additionally, it would be beneficial to compare temperatures of loggers buried in the sediment at multiple locations to determine whether the cool and stable temperatures at W14 were caused by being buried in the sediment rather than on the streambed, or whether they indicate a groundwater upwelling.

[7] Silliman SE, Booth DF (1993) Analysis of time-series measurements of sediment temperature for identification of gaining vs. losing portions of Juday Creek, Indiana. Journal of Hydrology 146:131-148

- Conductivity measurements should be taken at each of the monitoring locations since electrical conductivity (EC) is higher in areas with groundwater input compared to areas without groundwater input[8]. This is because groundwater usually has higher levels of dissolved solids and therefore elevated specific conductance values compared to surface water[8]. See Section 5.4.1 of the ARP report to determine typical EC values for groundwater versus surface water. These EC measurements should be taken multiple times throughout the monitoring period (e.g. once or twice per month) on the same day around the same time for each site since EC in streams changes as water temperature and flow change, both daily and seasonally[9].
- Statistical analyses could not be conducted for the 2020 data alone since there was an insufficient number of data points. Krider et al. state that there should be a minimum of 15 data points in order to conduct linear regressions[2], therefore there should be a minimum of 15 weeks of temperature data for future studies. The linear regression will be more accurate with a greater number of data points, so the loggers should be installed as early in the spring as possible and removed as late in the fall as possible (i.e. early May to late September).

Disclaimer

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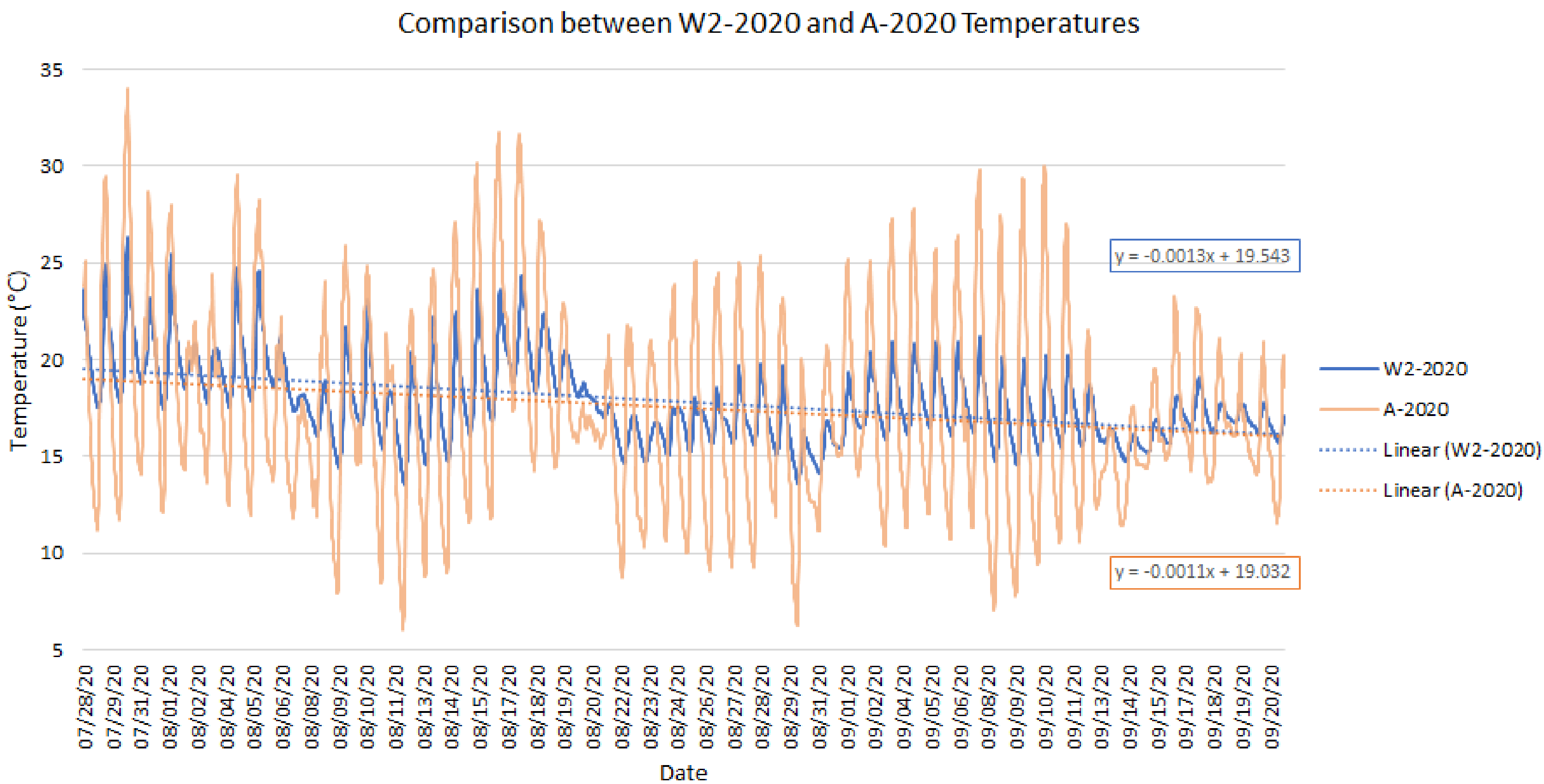
[8] LakeSuperiorStreams (2009) Electrical Conductivity (EC25) and TDS https://www.lakesuperiorstreams.org/general/citation.html (accessed 27 March 2020)

[9] Fondriest Environmental Inc. (2014) Conductivity, Salinity, and Total Dissolved Solids. Fundamentals of Environmental Measurements https://www.fondriest.com/environmental-measurements/parameters/water-quality/conductivity-salinity-tds/ (accessed 27 March 2020)

Appendix A



Comparison between W2-2020 and A-2020 Temperatures
Temperature (°C)
35
30
25
20
15
10
5
y = -0.0013x + 19.543
y = -0.0011x + 19.032
W2-2020
A-2020
Linear (W2-2020)
Linear (A-2020)
07/28/20
07/29/20
07/31/20
08/01/20
08/02/20
08/04/20
08/05/20
08/06/20
08/08/20
08/09/20
08/10/20
08/11/20
08/13/20
08/14/20
08/15/20
08/17/20
08/18/20
08/19/20
08/20/20
08/22/20
08/23/20
08/24/20
08/26/20
08/27/20
08/28/20
08/29/20
08/31/20
09/01/20
09/02/20
09/04/20
09/05/20
09/06/20
09/08/20
09/09/20
09/10/20
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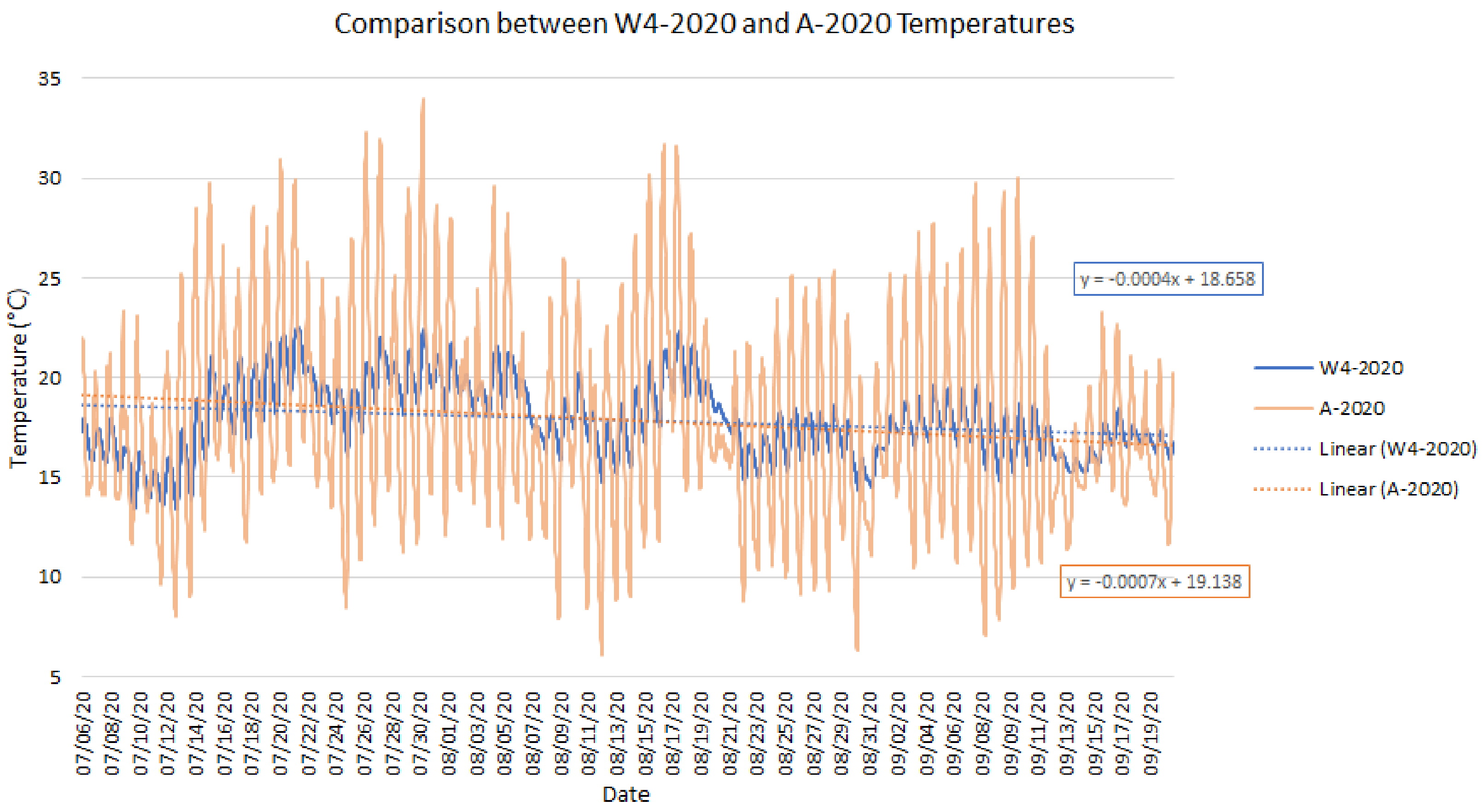
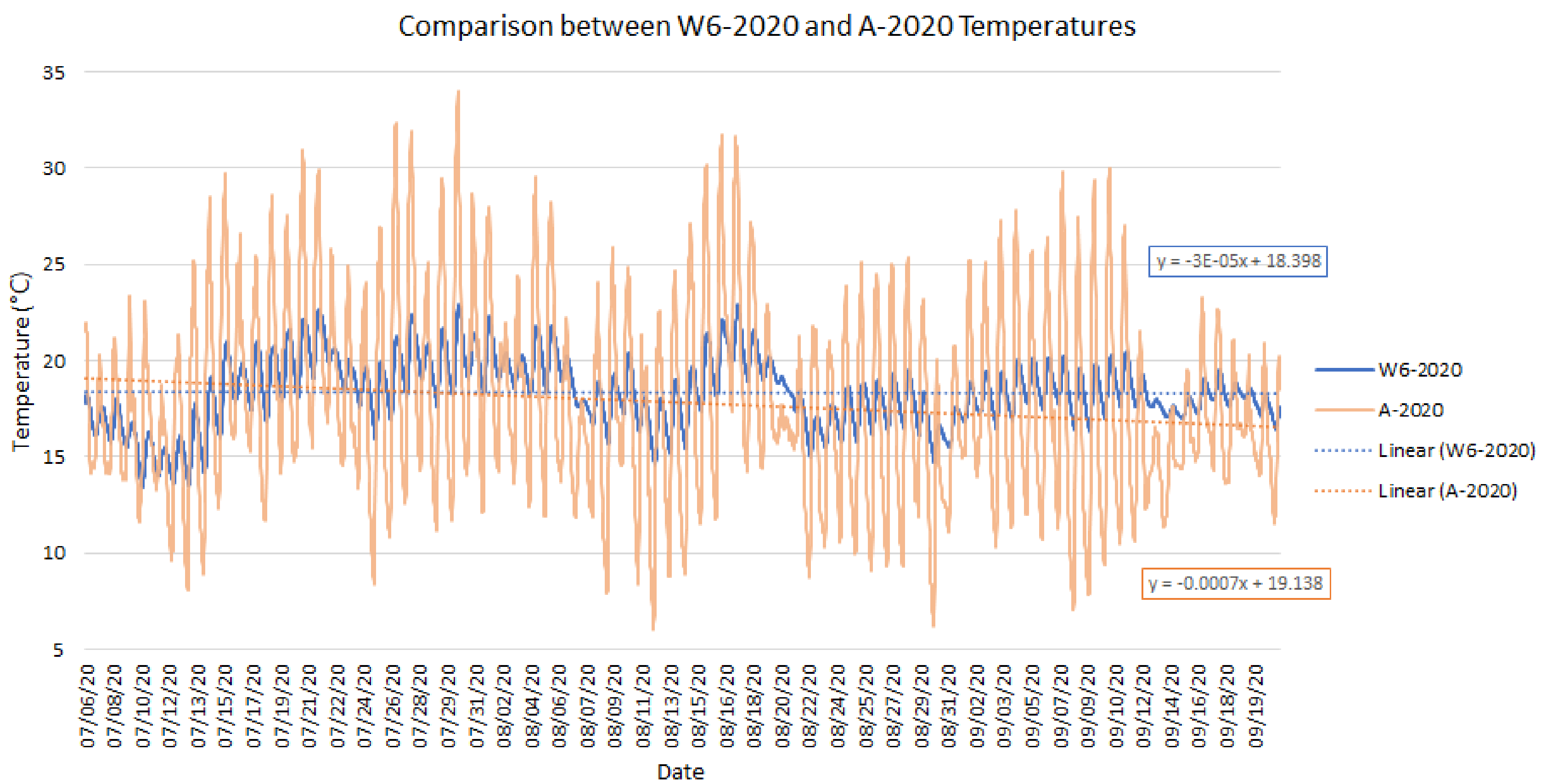
09/18/20
09/19/20
09/20/20
Date


Comparison between W4-2020 and A-2020 Temperatures
Temperature (°C)
35
30
25
20
15
10
5
Date
07/06/20
07/08/20
07/10/20
07/12/20
07/14/20
07/16/20
07/18/20
07/20/20
07/22/20
07/24/20
07/26/20
07/28/20
07/30/20
08/01/20
08/03/20
08/05/20
08/07/20
08/09/20
08/11/20
08/13/20
08/15/20
08/17/20
08/19/20
08/21/20
08/23/20
08/25/20
08/27/20
08/29/20
08/31/20
09/02/20
09/04/20
09/06/20
09/08/20
09/09/20
09/11/20
09/13/20
09/15/20
09/17/20
09/19/20
y = -0.0004x + 18.658
y = -0.0007x + 19.138
W4-2020
A-2020
Linear (W4-2020)
Linear (A-2020)


Comparison between W6-2020 and A-2020 Temperatures
Temperature (°C)
35
30
25
20
15
10
5
y = -3E-05x + 18.398
y = -0.0007x + 19.138
W6-2020
A-2020
Linear (W6-2020)
Linear (A-2020)
07/06/20
07/08/20
07/10/20
07/12/20
07/13/20
07/15/20
07/17/20
07/19/20
07/21/20
07/22/20
07/24/20
07/26/20
07/28/20
07/29/20
07/31/20
08/02/20
08/04/20
08/06/20
08/07/20
08/09/20
08/11/20
08/13/20
08/15/20
08/16/20
08/18/20
08/20/20
08/22/20
08/24/20
08/25/20
08/27/20
08/29/20
08/31/20
09/02/20
09/03/20
09/05/20
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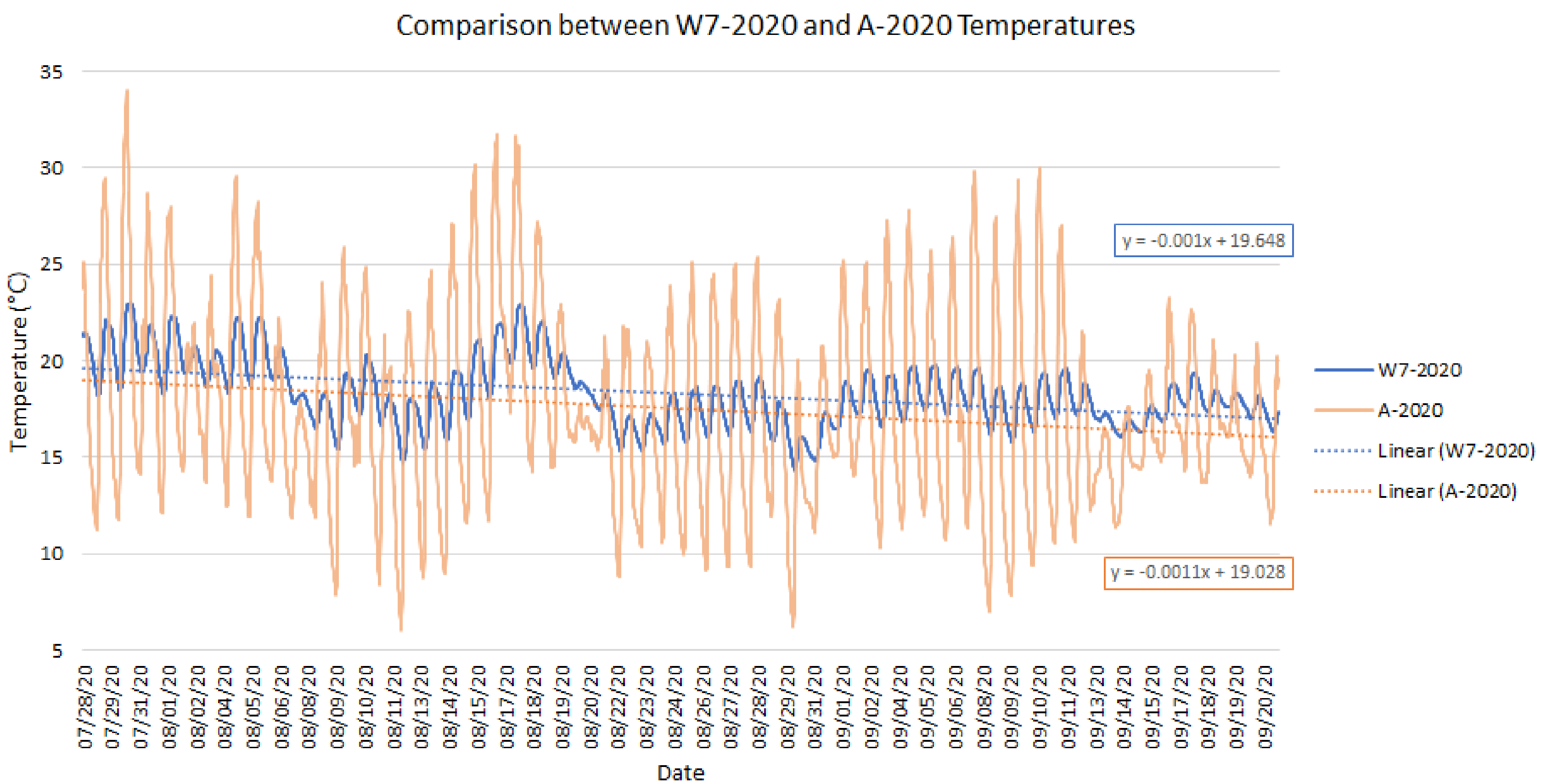
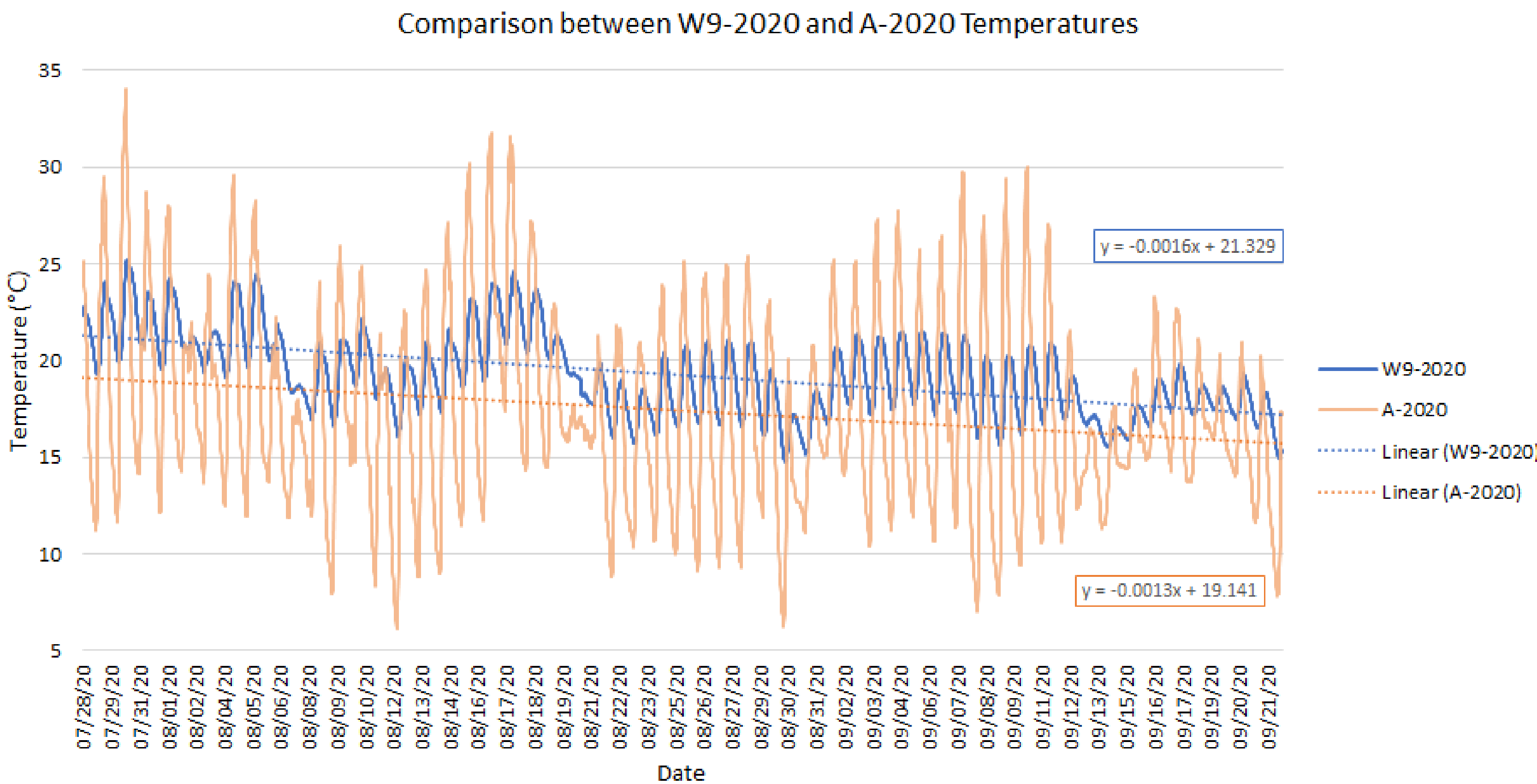
09/18/20
09/19/20
Date


Comparison between W7-2020 and A-2020 Temperatures
Temperature (°C)
Date
y = -0.001x + 19.648
y = -0.0011x + 19.028
W7-2020
A-2020
Linear (W7-2020)
Linear (A-2020)



Comparison between W9-2020 and A-2020 Temperatures
Temperature (°C)
35
30
25
20
15
10
5
y = -0.0016x + 21.329
y = -0.0013x + 19.141
W9-2020
A-2020
Linear (W9-2020)
Linear (A-2020)
07/28/20
07/29/20
07/31/20
08/01/20
08/02/20
08/04/20
08/05/20
08/06/20
08/08/20
08/09/20
08/10/20
08/12/20
08/13/20
08/14/20
08/16/20
08/17/20
08/18/20
08/19/20
08/21/20
08/22/20
08/23/20
08/25/20
08/26/20
08/27/20
08/29/20
08/30/20
08/31/20
09/02/20
09/03/20
09/04/20
09/06/20
09/07/20
09/08/20
09/09/20
09/11/20
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09/16/20
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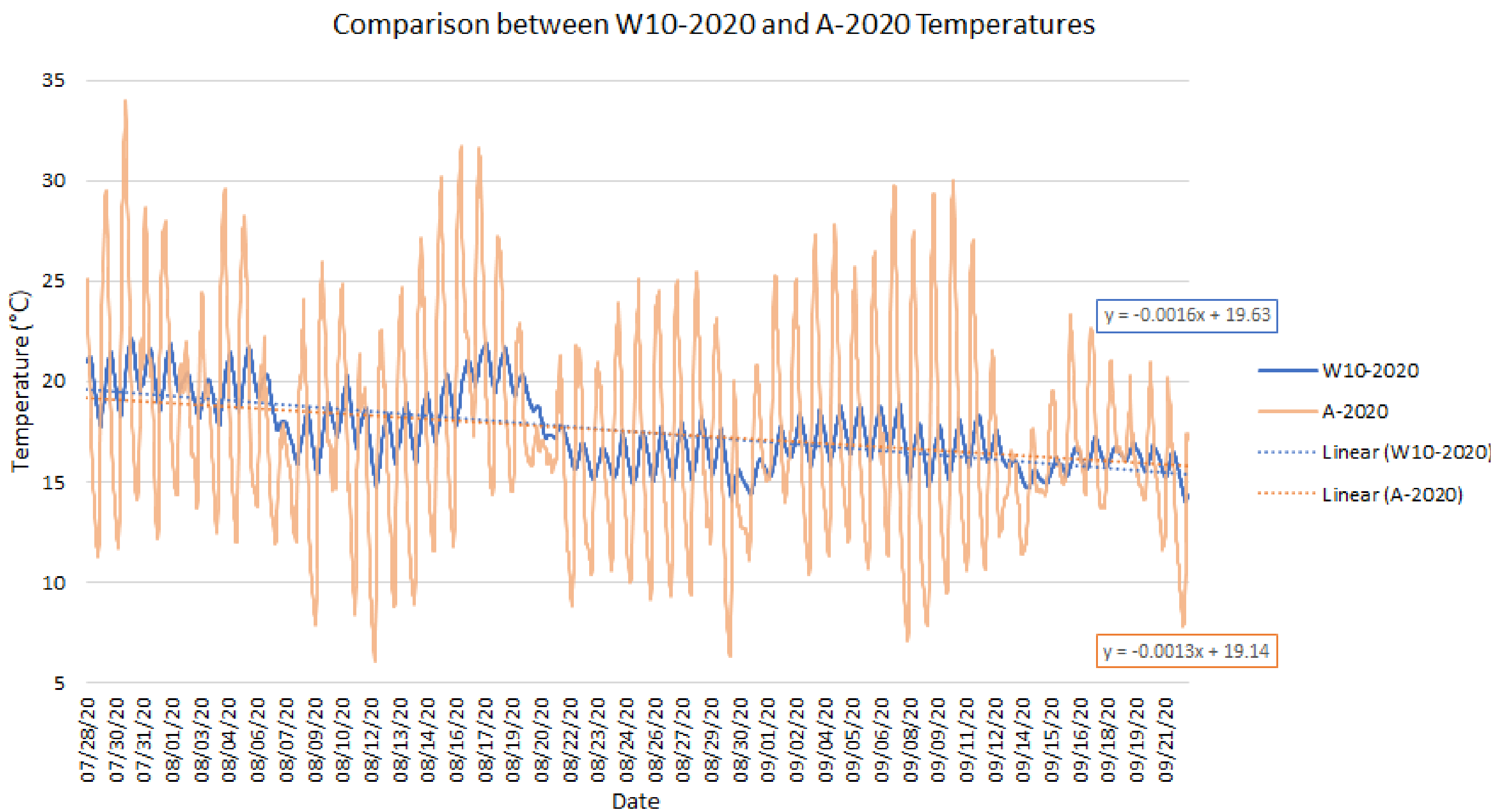
09/20/20
09/21/20
Date



Comparison between W10-2020 and A-2020 Temperatures
Temperature (°C)
35
30
25
20
15
10
5
y = -0.0016x + 19.63
y = -0.0013x + 19.14
W10-2020
A-2020
Linear (W10-2020)
Linear (A-2020)
07/28/20
07/30/20
07/31/20
08/01/20
08/03/20
08/04/20
08/06/20
08/07/20
08/09/20
08/10/20
08/12/20
08/13/20
08/14/20
08/16/20
08/17/20
08/19/20
08/20/20
08/22/20
08/23/20
08/24/20
08/26/20
08/27/20
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08/30/20
09/01/20
09/02/20
09/04/20
09/05/20
09/06/20
09/08/20
09/09/20
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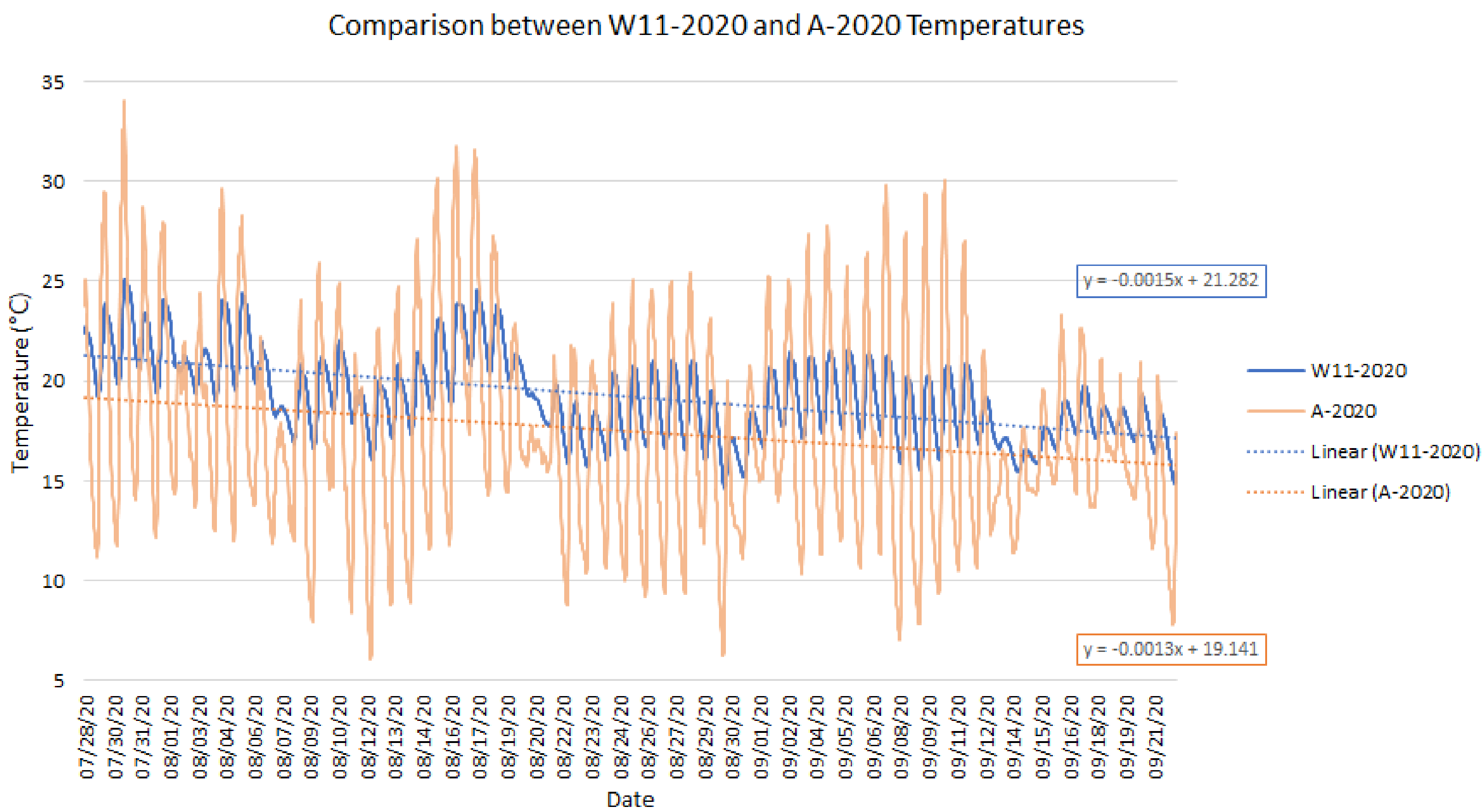
09/19/20
09/21/20
Date


Comparison between W11-2020 and A-2020 Temperatures
Temperature (°C)
35
30
25
20
15
10
5
y = -0.0015x + 21.282
y = -0.0013x + 19.141
07/28/20
07/30/20
07/31/20
08/01/20
08/03/20
08/04/20
08/06/20
08/07/20
08/09/20
08/10/20
08/12/20
08/13/20
08/14/20
08/16/20
08/17/20
08/19/20
08/20/20
08/22/20
08/23/20
08/24/20
08/26/20
08/27/20
08/29/20
08/30/20
09/01/20
09/02/20
09/04/20
09/05/20
09/06/20
09/08/20
09/09/20
09/11/20
09/12/20
09/14/20
09/15/20
09/16/20
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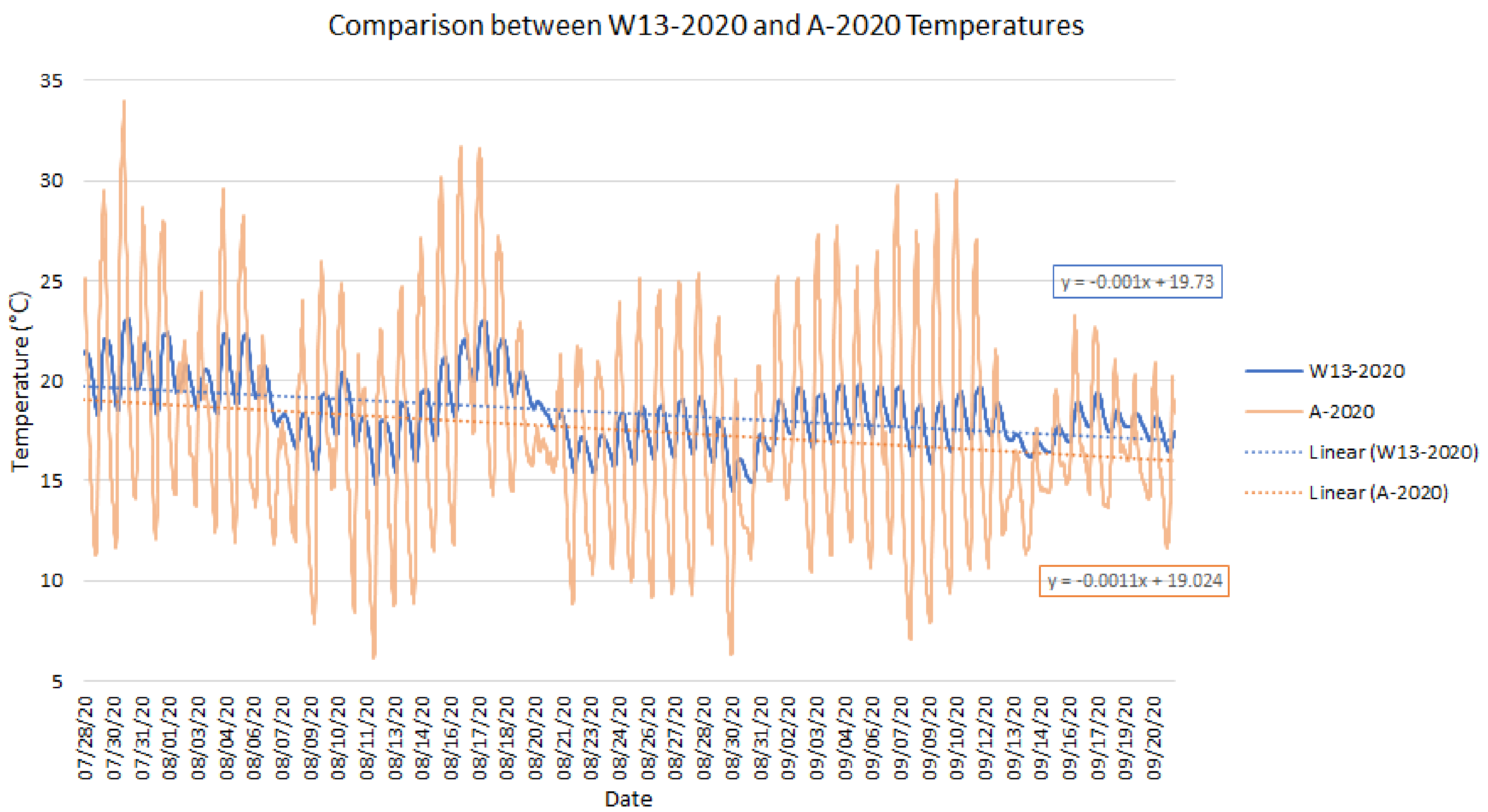
09/19/20
09/21/20
Date
W11-2020
A-2020
Linear (W11-2020)
Linear (A-2020)


Comparison between W13-2020 and A-2020 Temperatures
35
30
25
20
15
10
5
Temperature (°C)
y = -0.001x + 19.73
y = -0.0011x + 19.024
07/28/20
07/30/20
07/31/20
08/01/20
08/03/20
08/04/20
08/06/20
08/07/20
08/09/20
08/10/20
08/11/20
08/13/20
08/14/20
08/16/20
08/17/20
08/18/20
08/20/20
08/21/20
08/23/20
08/24/20
08/26/20
08/27/20
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09/13/20
09/14/20
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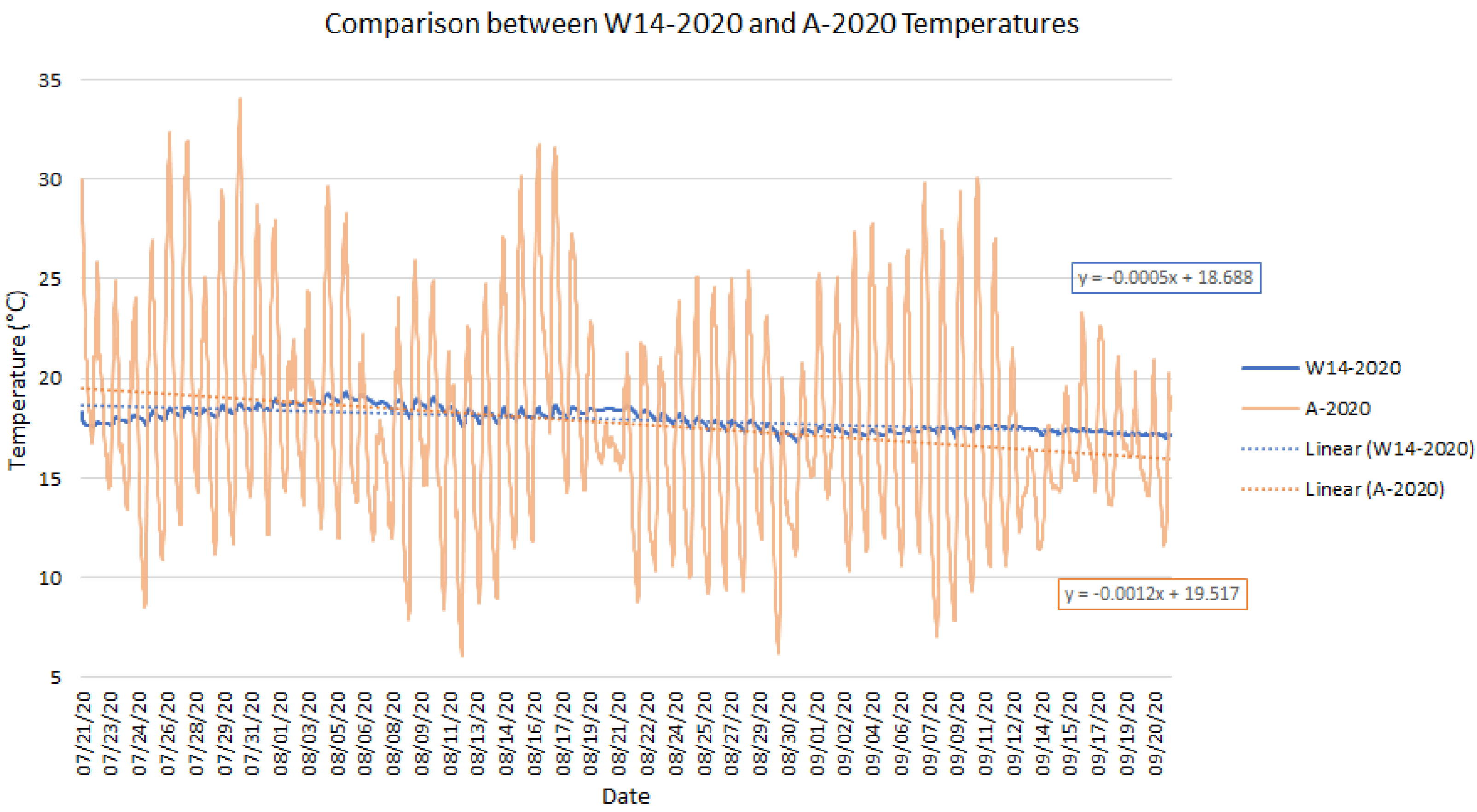
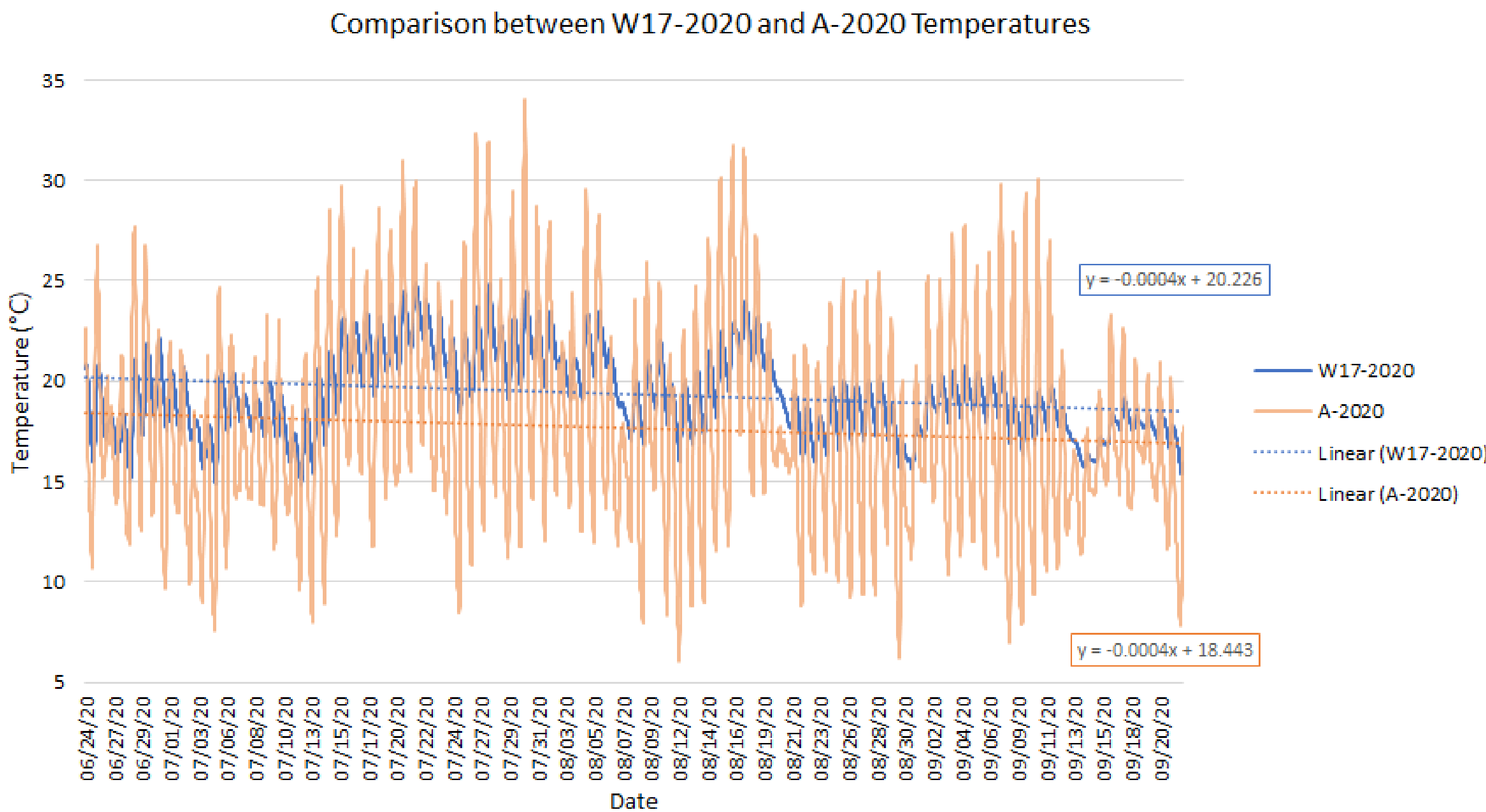
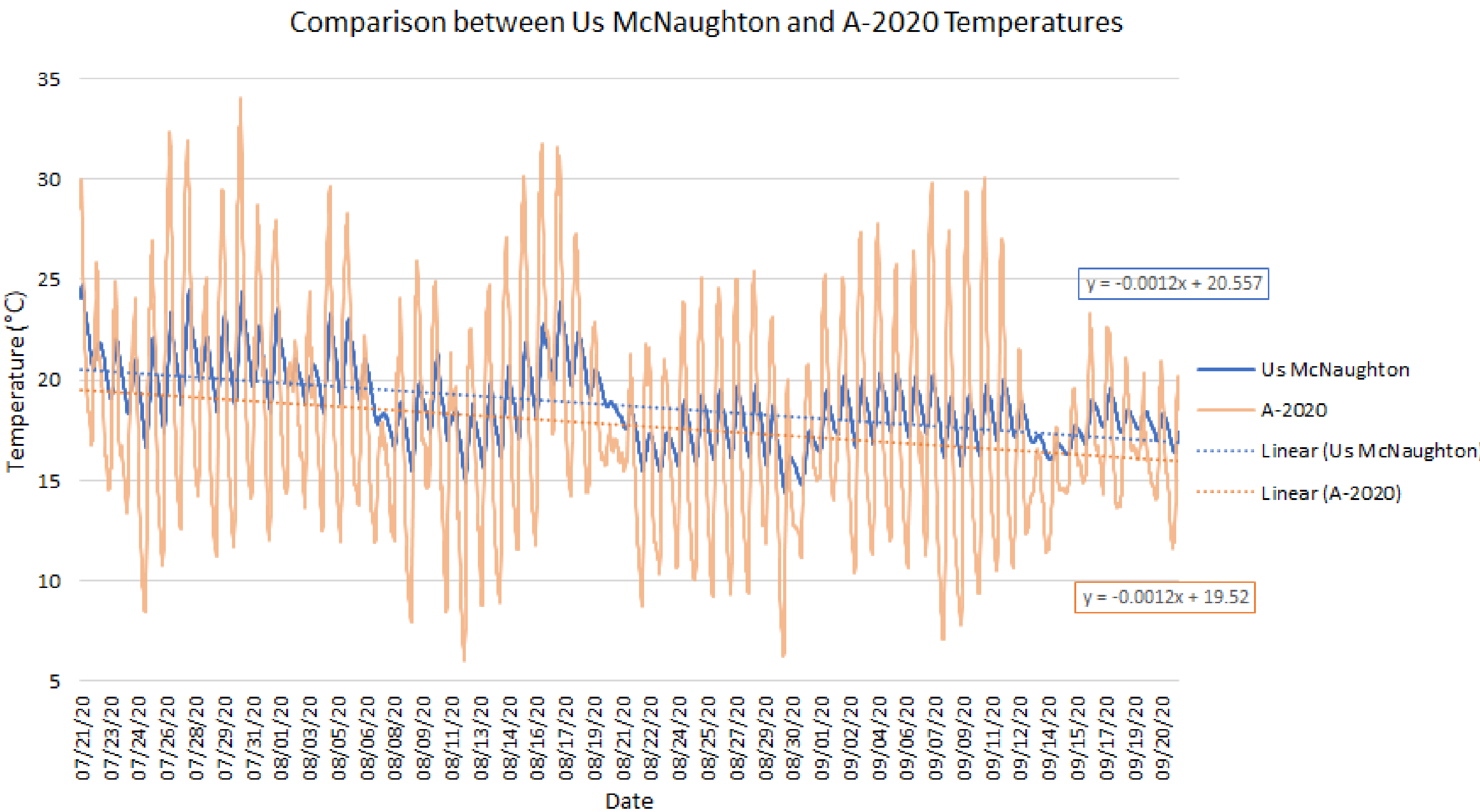
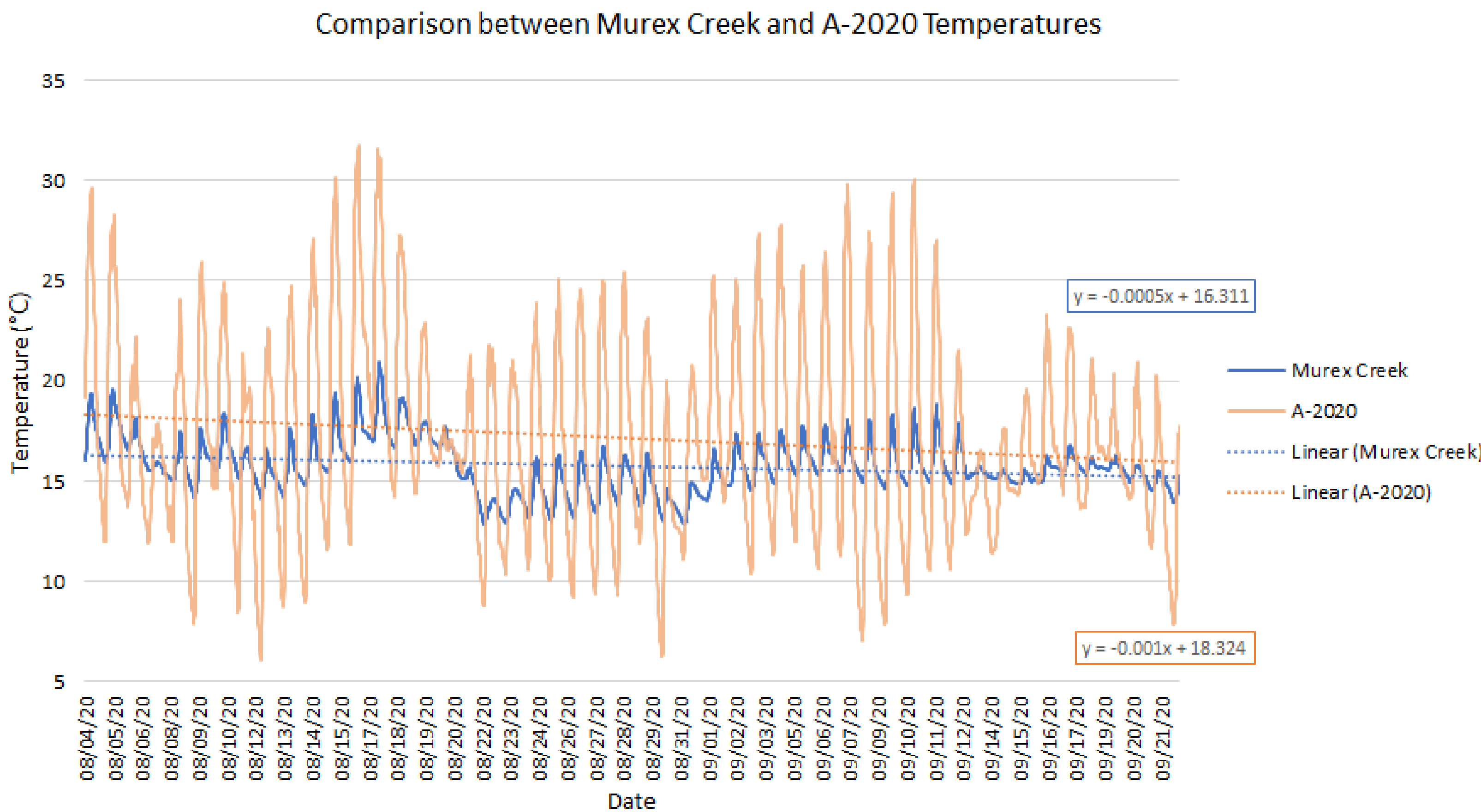
Date
W13-2020
A-2020
Linear (W13-2020)
Linear (A-2020)


Comparison between W14-2020 and A-2020 Temperatures
Temperature (°C)
35
30
25
20
15
10
5
y = -0.0005x + 18.688
y = -0.0012x + 19.517
W14-2020
A-2020
Linear (W14-2020)
Linear (A-2020)
07/21/20
07/23/20
07/24/20
07/26/20
07/28/20
07/29/20
07/31/20
08/01/20
08/03/20
08/05/20
08/06/20
08/08/20
08/09/20
08/11/20
08/13/20
08/14/20
08/16/20
08/17/20
08/19/20
08/21/20
08/22/20
08/24/20
08/25/20
08/27/20
08/29/20
08/30/20
09/01/20
09/02/20
09/04/20
09/06/20
09/07/20
09/09/20
09/11/20
09/12/20
09/14/20
09/15/20
09/17/20
09/19/20
09/20/20
Date


Comparison between W17-2020 and A-2020 Temperatures
Temperature (°C)
35
30
25
20
15
10
5
y = -0.0004x + 20.226
y = -0.0004x + 18.443
W17-2020
A-2020
Linear (W17-2020)
Linear (A-2020)
06/24/20
06/27/20
06/29/20
07/01/20
07/03/20
07/06/20
07/08/20
07/10/20
07/13/20
07/15/20
07/17/20
07/20/20
07/22/20
07/24/20
07/27/20
07/29/20
07/31/20
08/03/20
08/05/20
08/07/20
08/09/20
08/12/20
08/14/20
08/16/20
08/19/20
08/21/20
08/23/20
08/26/20
08/28/20
08/30/20
09/02/20
09/04/20
09/06/20
09/09/20
09/11/20
09/13/20
09/15/20
09/18/20
09/20/20
Date



Comparison between Us McNaughton and A-2020 Temperatures
35
30
25
20
15
10
5
Temperature (°C)
y = -0.0012x + 20.557
y = -0.0012x + 19.52
Us McNaughton
A-2020
Linear (Us McNaughton)
Linear (A-2020)
07/21/20
07/23/20
07/24/20
07/26/20
07/28/20
07/29/20
07/31/20
08/01/20
08/03/20
08/05/20
08/06/20
08/08/20
08/09/20
08/11/20
08/13/20
08/14/20
08/16/20
08/17/20
08/19/20
08/21/20
08/22/20
08/24/20
08/25/20
08/27/20
08/29/20
08/30/20
09/01/20
09/02/20
09/04/20
09/06/20
09/07/20
09/09/20
09/11/20
09/12/20
09/14/20
09/15/20
09/17/20
09/19/20
09/20/20
Date


Comparison between Murex Creek and A-2020 Temperatures
35
30
25
20
15
10
5
Temperature (°C)
08/04/20
08/05/20
08/06/20
08/08/20
08/09/20
08/10/20
08/12/20
08/13/20
08/14/20
08/15/20
08/17/20
08/18/20
08/19/20
08/20/20
08/22/20
08/23/20
08/24/20
08/26/20
08/27/20
08/28/20
08/29/20
08/31/20
09/01/20
09/02/20
09/03/20
09/05/20
09/06/20
09/07/20
09/09/20
09/10/20
09/11/20
09/12/20
09/14/20
09/15/20
09/16/20
09/17/20
09/19/20
09/20/20
09/21/20
Date
y = -0.0005x + 16.311
y = -0.001x + 18.324
Murex Creek
A-2020
Linear (Murex Creek)
Linear (A-2020)