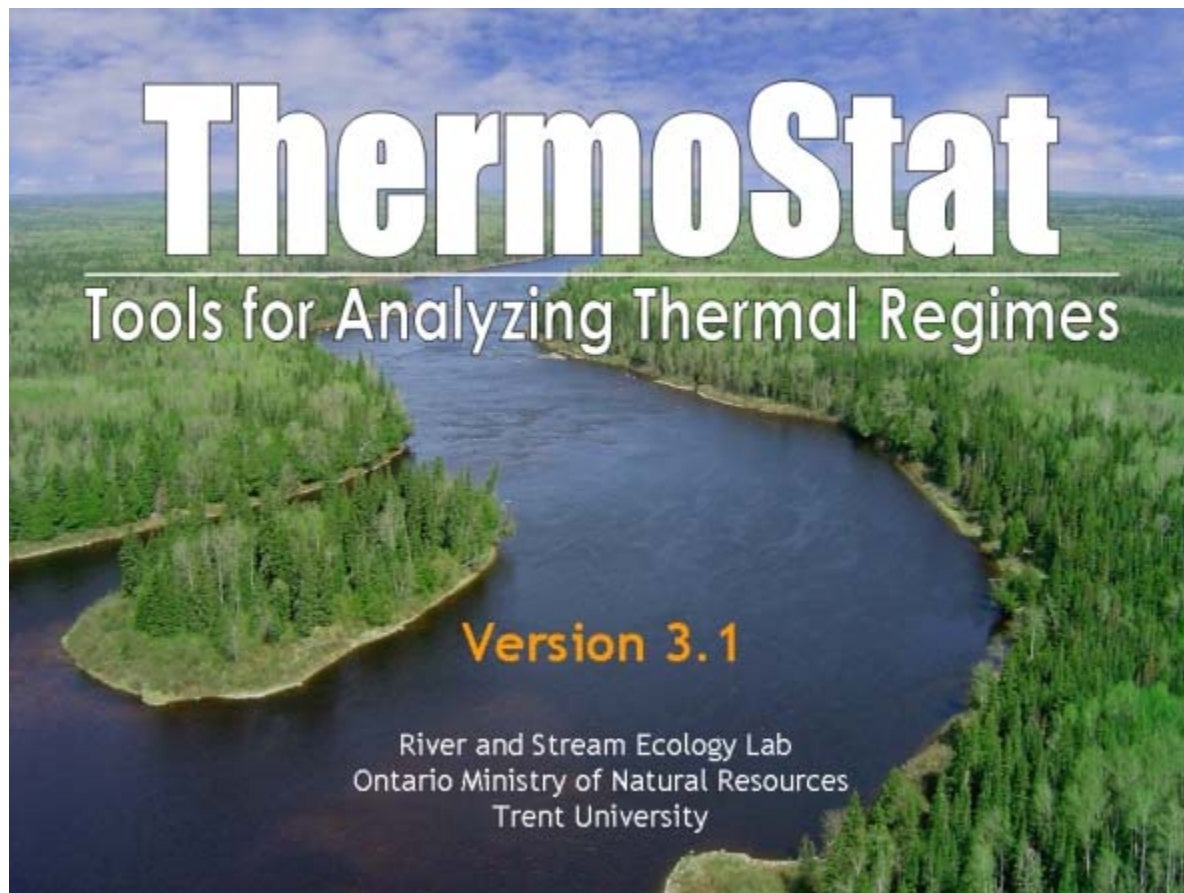


ThermoStat 3.1

Tools for Analyzing Thermal Regimes

Reference Manual



Published on March 12th, 2013

USER AGREEMENT

This Software (including source code), data, and related materials remain the property of the Developers. The User may not attempt to modify this Software in any way whatsoever. All rights, including distribution rights, are reserved by the Aquatic Research and Development Section, Ontario Ministry of Natural Resources. The User is NOT allowed to make a charge for distributing the Software (either for profit or merely to recover media and distribution costs) whether as a stand-alone product, or as part of a compilation or anthology, without obtaining explicit prior written permission from the Developers. By using this Software, you agree to these terms and the terms of the Disclaimer as follows:

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About ThermoStat

ThermoStat can be used to describe a thermal regime in a variety of ways that incorporate measures of timing, magnitude, variability, duration, rate of change, and species specific temperatures. ThermoStat does not perform statistical tests or generate p-values. Output from ThermoStat can be used in statistical tests to examine trends through time, before-after, or control-impact experimental designs.

ThermoStat will calculate measures even if you feed it an insufficient quantity or quality of input data (e.g., missing data, poor data). It is the responsibility of the user to know the limitations of their input data and make appropriate judgment calls on the quality of the resulting output.

The software was developed at the River and Stream Ecology Lab to help analyze stream temperature data and to better understand lotic ecosystems of Ontario. Our lab is within the Aquatic Research and Development Section of the Ontario Ministry of Natural Resources. This software was developed as an internal research tool and is provided "as-is" and free-of-charge.

We are sharing this software freely but ask that you register as a user of the software so we can inform you of any updates and to get a better understanding of the software's user community. Any registration information you provide to us will not be shared with anyone outside the River and Stream Ecology Lab.

Aside from this reference manual technical support is very limited.

Citing ThermoStat

If you appreciate the effort that has gone into ThermoStat, please credit the application and its authors in any published work that makes use of results from ThermoStat, citing ThermoStat as an electronic publication and giving the ThermoStat website address if the journal permits it.

Here is one possible form for a References Cited entry: Jones N.E. and B. Schmidt. 2013. ThermoStat Version 3.1: Tools for Analyzing Thermal Regimes. Ontario Ministry of Natural Resources, Aquatic Research and Development Section.
<http://people.trentu.ca/nicholasjones/thermostat.htm>

If the journal or book editor will not permit an entry in the References Cited section, you might try this text citation: "...computed using ThermoStat (Version 3.1, Jones and Schmidt, <http://people.trentu.ca/nicholasjones/thermostat.htm>)...."

Failing that, you might write: "...computed using ThermoStat (Version 3.1, Jones and Schmidt, unpublished)...," perhaps slipping in the ThermoStat website address (<http://people.trentu.ca/nicholasjones/thermostat.htm>) in the Acknowledgment section.

We would be most grateful if you would kindly send a reprint of any paper based on your use of the program. Send a PDF to nicholas.jones@ontario.ca

You are most welcome to use ThermoStat in any way you like for your own research, as long as such use is acknowledged as outlined above.

Changes from version 3:

- The time series trimming process has been improved during analysis setup.
- Added the ability to load legacy ThermoStat2 processed files for improved backward compatibility.
- Fixed a bug that prevented loading of time series starting and ending in January and/or were *exactly* one year in length.
- Fixed a bug that prevented users from loading alternate time-stamp formatted files.

Changes from version 2:

- Matlab Compiler Run-time 7.13 (R2011b) must be installed on your computer to run the program.
- Adjusted the size of the program window to work with wide screen displays of resolution 1440x900 or higher (4:3 ratio screens of 1280x768 or higher remain compatible with this new design).
- Added several new analysis algorithms:
 - Timing, magnitude and variability of annual and daily minima and maxima.
 - Analysis of daily maximum warming/cooling rates-of-change.
- Added the ability to load a variety of input time-stamp formats.
- Added input data gap checking and correction (insert null records) plus duplicate/reversed timestamp checking and correction (condense and/or insert null records).
- Fixed seasonal analysis issues when the winter season starts before January 1st.
- Season definitions are now set to the following default ranges:
 - Winter = December 1 to February 28
 - Spring = March 1 to May 31
 - Summer = June 1 to August 31
 - Autumn = September 1 to November 30
- The 10% missing data threshold for excluding periods from analysis has been removed (i.e. results are reported regardless of how much data is missing from a period. Sample size is reported for each period for transparency).
- Fixed issues merging multiple time series that included leap years.
- Fixed issues merging multiple time series that overlapped.
- The Day-of-Year calculator now works in both directions (i.e. Date to DOY and DOY to Date).
- Multiple user interface tweaks to provide an enhanced user experience.
- Added new data processing and management procedures to facilitate building a temperature database from logger data text files.
- Improved text file output formatting.
- Added an automated Adobe PDF report generator.

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General Information

Files included in the compressed installation package (ThermoStat31.zip):

- ThermoStat31_2013.exe
- ThermoStat31_2013.ctf
- Reference Manual and Demonstration Data

How does a MATLAB application work?

This is a MATLAB stand-alone Windows application, meaning that it does not require any additional third party software to run. However, in order to run a MATLAB application the user must first install the MATLAB Compiler Runtime (MCR) on their system. The MCR can be installed free-of-charge on any machine running Windows XP or later Windows operating system. Once the MCR has been installed on a computer you can run the application executable (EXE) file on that machine. The MCR Installer EXE and the application EXE files are packaged together. The steps for installing and running these files are outlined in the installation instruction that follow.

The MATLAB Compiler Runtime (MCR)

Before running ThermoStat the most recent *MCRinstaller.exe* file must be run. Upon execution the installer file will take the user through the MCR installation process using the familiar Windows “wizard” approach. Once the MCR has been installed the user can run any MATLAB application (i.e. executable file) without installing the MCR again. Administrative privileges are required to install the MCR.

Note: The *ThermoStat31_2013.exe* file requires MCR version 7.13. If the user has an earlier version of the MCR installed (e.g. 7.11) then the new version will need to be installed as well. There is no need to remove the earlier version of the MCR. Multiple MCR versions can exist on one computer system without conflict. The application executable file knows which MCR to use. However, if you do want to uninstall an MCR from your computer use the Windows *Add/Remove Programs* function to perform a clean uninstall.

The relationship between the EXE and CTF file

The EXE and CTF (Component Technology File) files need to reside in the same directory (i.e. folder) on your system. The CTF file contains the compressed and encrypted MATLAB m-file code and data that define the custom application and allow the application to communicate with the MCR. The first time that the EXE is executed the CTF file will automatically “unpack” any required files to a new folder (i.e. *ThermoStat31_2013_mcr*) which is automatically created in the same directory in which both the CTF and EXE reside. In the event that the *ThermoStat31_2013_mcr* folder is accidentally moved or deleted it will be regenerate next time the EXE is executed.

Software Installation

1. Unzip the *ThermoStat31_2013.zip* file into a directory to which you have write-to-disk privileges.
2. Run the *MCRInstaller.exe* from the new location on your hard drive. This will start the automated MATLAB MCR installation process.
3. Continue to follow the “wizard’s” prompts until installation is complete. You may be prompted to install required files that were not installed on your computer or that are outdated. If this is the case, choose to install the required files when prompted. A Visual C++ 2005 Redistributable package is also installed. It is required to allow ThermoStat to run as a Windows Stand-alone program.
4. Check if the C:\TEMP folder exists on your computer. If it does not exist, then create this directory. This folder is required for writing temporary image files while creating PDF reports.

Note: The software requires a minimum resolution of 1440 x 900 for wide screens or 1280 x 1024 for 4:3 aspect ratio screens. Any resolution lower than these will not allow the software to display correctly.

Analysis Setup

**It may take some time when the software is run for the first time.
Please be patient !**

1. Start the application by clicking on the *ThermoStat31_2013.exe*
2. Read the user license agreement and choose the “I Agree” option and press the *Continue* button
3. The initial setup screen contains the preliminary setup steps leading up to the analysis. These procedures need to be completed in the order to set a working directory, load temperature time series, load/create metadata and then run the Analyses (Figure 1).

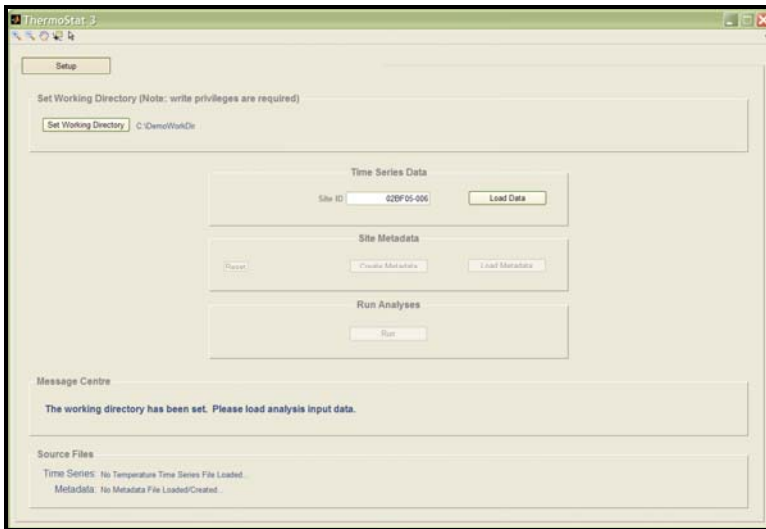


Figure 1: The process control screen of the Setup process

4. Set the working directory. This directory is the location where **ALL** permanent ThermoStat output will be stored (e.g. processed time series files, exported tables, reports, metadata etc., temporary files are written to the C:\TEMP folder). This must be a directory to which you have permission to write files. ThermoStat performs a quick test to verify that the directory you have chosen does indeed have write privileges and will notify you if it does not.
5. Enter a site identification into the text box. This identification will be used to label all output files.
6. Press the *Load Data* button. You may load a single or multiple temperature time series files for analysis using the graphical user interface. Multiple time series should be sequential without overlap. They will be merged into a single time series for analysis.
7. Once the time series are loaded and processed (process described in more detail below) the *Load Metadata* and the *Create Metadata* buttons become active. To load an existing metadata file click the *Load Metadata* button and browse to file (the file extensions of a metadata files is *.mat).
8. If no metadata file exists, or you wish to start a new one press the *Create Metadata* button. This will initiate a series of screens that will guide you through the necessary steps.

Loading Data

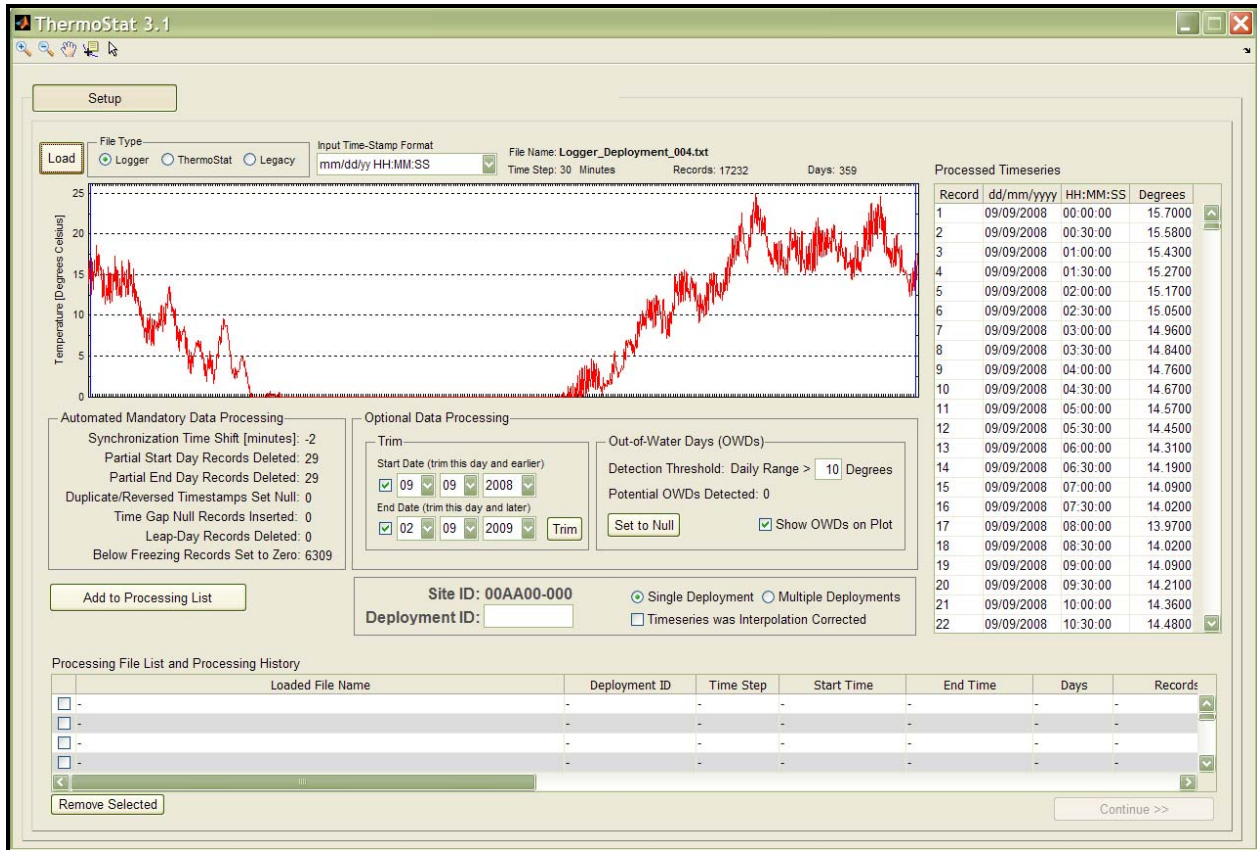


Figure 2: The data loading screen of the Setup process

Choose the *ThermoStat* option loading a text files which was previously processed by ThermoStat 3 (*.txt) or choose the *Logger* option to load a raw logger data text file or you can load ThermoStat 2 *Legacy* files (*.mat) (Figure 3). Loading large files (e.g. >30,000 records) may take a few minutes each.

The following data formatting is mandatory for loading raw logger data text files:

1. The text file MUST have one (1) header line (any text is permissible in this first line).
2. The time-stamp format MATCHES the format of the drop-down menu (see Table 1, time-stamps that do not have a leading zero from single digit days and months, i.e. "8" vs "08", are permissible);
3. The data MATCHES the delimiter white space (i.e. invisible spaces and tabs) configuration outlined in exactly! The areas highlighted in red on (B) are superfluous "tabs" that will prevent the data from loading into ThermoStat. These "invisible" white spaces can be made visible by opening the text file in any text editor that supports this function (including MS-Word using the "Show/Hide ¶" button on the "Standard" Toolbar). Temperature values should have 1 to 3 decimal places (Figure 4)
4. The time-stamps are recorded in 24 hour format (i.e. 15:00:00 versus 3:00:00 PM)

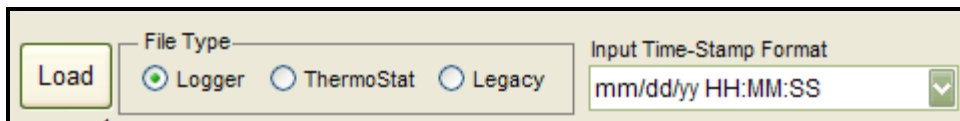


Figure 3: Input format option controls

<pre> Date-Time → Temp.(°C):c:1¶ 06/29/2005·17:39:00→25.81¶ 06/29/2005·18:09:00→25.98¶ 06/29/2005·18:39:00→25.98¶ 06/29/2005·19:09:00→25.81¶ 06/29/2005·19:39:00→25.81¶ 06/29/2005·20:09:00→25.81¶ 06/29/2005·20:39:00→25.63¶ 06/29/2005·21:09:00→25.63¶ 06/29/2005·21:39:00→25.46¶ 06/29/2005·22:09:00→25.29¶ </pre> <p>(A)</p>	<pre> Date-Time → Temp.(°C):c:1¶ 06/29/2005· → 17:39:00 → → 25.81 → → ¶ 06/29/2005· → 18:09:00 → → 25.98 → → ¶ 06/29/2005· → 18:39:00 → → 25.98 → → ¶ 06/29/2005· → 19:09:00 → → 25.81 → → ¶ 06/29/2005· → 19:39:00 → → 25.81 → → ¶ 06/29/2005· → 20:09:00 → → 25.81 → → ¶ 06/29/2005· → 20:39:00 → → 25.63 → → ¶ 06/29/2005· → 21:09:00 → → 25.63 → → ¶ 06/29/2005· → 21:39:00 → → 25.46 → → ¶ 06/29/2005· → 22:09:00 → → 25.29 → → ¶ </pre> <p>(B)</p>
--	--

→ represents a single tab (superfluous tabs will prevent loading)
· represents a single whitespace (superfluous "spaces" maybe able to load but its best to avoid them)
¶ represents a carriage (hard) return

Figure 4: Data formatting requirements

Table 1: Available Time-Stamp Formats

24-Hour Time	Example	Date AM/PM Time	Example
mm/dd/yy HH:MM:SS	08/31/84 15:35:22	mm/dd/yy HH:MM:SS PM	08/31/84 3:35:22 PM
mm/dd/yyyy HH:MM:SS	08/31/1984 15:35:22	mm/dd/yyyy HH:MM:SS PM	08/31/1984 3:35:22 PM
dd/mm/yy HH:MM:SS	31/08/84 15:35:22	dd/mm/yy HH:MM:SS PM	31/08/84 3:35:22 PM
dd/mm/yyyy HH:MM:SS	31/08/1984 15:35:22	dd/mm/yyyy HH:MM:SS PM	31/08/1984 3:35:22 PM
yy/mm/dd HH:MM:SS	84/08/31 15:35:22	yy/mm/dd HH:MM:SS PM	84/08/31 3:35:22 PM
yyyy/mm/dd HH:MM:SS	1984/08/31 15:35:22	yyyy/mm/dd HH:MM:SS PM	1984/08/31 3:35:22 PM
yy/dd/mm HH:MM:SS	84/31/08 15:35:22	yy/dd/mm HH:MM:SS PM	84/31/08 3:35:22 PM
yyyy/dd/mm HH:MM:SS	1984/31/08 15:35:22	yyyy/dd/mm HH:MM:SS PM	1984/31/08 3:35:22 PM
mm-dd-yy HH:MM:SS	08-31-84 15:35:22	mm-dd-yy HH:MM:SS PM	08-31-84 3:35:22 PM
mm-dd-yyyy HH:MM:SS	08-31-1984 15:35:22	mm-dd-yyyy HH:MM:SS PM	08-31-1984 3:35:22 PM
dd-mm-yy HH:MM:SS	31-08-84 15:35:22	dd-mm-yy HH:MM:SS PM	31-08-84 3:35:22 PM
dd-mm-yyyy HH:MM:SS	31-08-1984 15:35:22	dd-mm-yyyy HH:MM:SS PM	31-08-1984 3:35:22 PM
yy-mm-dd HH:MM:SS	84-08-31 15:35:22	yy-mm-dd HH:MM:SS PM	84-08-31 3:35:22 PM
yyyy-mm-dd HH:MM:SS	1984-08-31 15:35:22	yyyy-mm-dd HH:MM:SS PM	1984-08-31 3:35:22 PM
yy-dd-mm HH:MM:SS	84-31-08 15:35:22	yy-dd-mm HH:MM:SS PM	84-31-08 3:35:22 PM
yyyy-dd-mm HH:MM:SS	1984-31-08 15:35:22	yyyy-dd-mm HH:MM:SS PM	1984-31-08 3:35:22 PM
dd-mmm-yyyy HH:MM:SS	31-Aug-1984 15:35:22	dd-mmm-yyyy HH:MM:SS PM	31-Aug-1984 3:35:22 PM
dd-mmm-yy HH:MM:SS	31-Aug-84 15:35:22	dd-mmm-yy HH:MM:SS PM	31-Aug-84 3:35:22 PM
mmm.dd,yyyy HH:MM:SS	Aug.31,1984 15:35:22	mmm.dd,yyyy HH:MM:SS PM	Aug.31,1984 3:35:22 PM

Pre-Processing Data

The temperature data time series must be pre-processed. This series of processing steps is necessary to detect potential errors in the time series as well as optimize the time series format for analysis and reporting. It is important to note that although the following thermal regime measures can technically be calculated by ThermoStat from very few data points it is highly recommended that no more than 10% of the record is missing within each analysis period (i.e. years, seasons, months), especially those belonging to the summer season (Figure 13). The results of the pre-processing procedure is saved to new text files within the working directory to provide a record of the processing that was performed.

Temporal and Temperature Resolutions

The data time step (i.e. sampling interval) determines the temporal resolution of the time series. ThermoStat requires one of the following factors of 60 minutes: 1, 2, 3, 4, 5, 6, 10, 15, 20, 30 or 60 minutes. If you need to merge multiple time series with different time steps into a single time series they must share a common time step. This can be accomplished by resampled the data down to the lowest common resolution or resampled up to a common resolution via interpolated. The time step must also be full minutes, in other words the interval can not contain fractions of a minutes (e.g. 30 minutes and 1 second is not a valid time step. It is recommended that the data used for analysis have a measurement resolution of at least a 0.1 °C).

Mandatory Data Processing

When data is being loaded it is checked for a variety of data integrity standards. The data is automatically processed to ensure that the data conforms to these standards. Any adjustments made to the data are reported for transparency (Figure 5). More detailed explanations of these data adjustments are provided below.

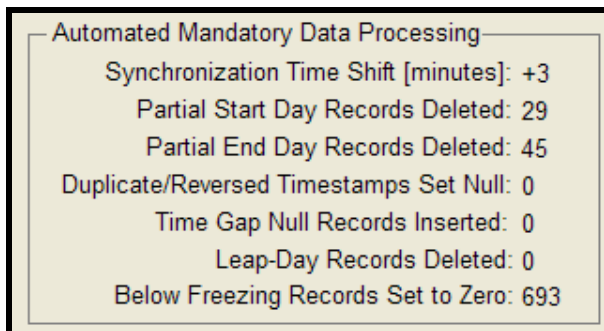


Figure 5: List of mandatory data processing alterations

Synchronization Time Shift

The data time stamps must start at a common time, on any full hour (e.g. 12:00:00, 23:00:00 etc.). This makes a direct comparison between multiple time series possible (e.g. from different sampling sites). Ideally, data loggers should be setup to collect measurements using this criterion. However, if this is not the case, the time stamps must be synchronized by “rounding” them up or down in time. In order to minimize the temporal “distance” the time stamps need to

be shifted, the shift should be in the direction of the nearest whole multiple of the sampling interval. For example, consider the following series of 30 minute interval data: 12:11:43, 12:41:43, 13:11:43 ... This should be shifted backward by 11 minutes and 43 seconds backwards to 12:00:00, 12:30:00, 13:00:00 ... Now consider this series: 12:15:00, 12:45:00, 13:15:00 ... This series is right on the dividing line between shifting forward or backward. In this type of scenario the times will be shifted backwards to 12:00:00, 12:30:00, 13:00:00 ...

Note: The largest shift introduced using this method will be one half of the sampling interval. The shorter the time step the less shifting will be required. Ideally loggers

Partial Start/End Day Records Deleted

The smallest unit of time for which statistics are calculated by ThermoStat is single days (i.e. 24 hours midnight-to-midnight). In order to maintain the same number of samples per day for all days found within the time series partial days (< 24 hours) are removed from the start and end of the time series.

Duplicate and Reversed Timestamps Set Null

Duplicate timestamps are not allowed in the time series. ThermoStat automatically identifies and corrects any duplicate records. There are two types of duplicate time stamps: non-contiguous blocks (e.g. A,x,x, A,x,x, A,x,x) and contiguous blocks (e.g. A,A,A, x,x,x, A,A,A). Both types of duplicates are condensed to a single null record representing the entire block. Setting to null is a conservative method. If you see duplicates being identified by ThermoStat and you would like to use a different method of dealing with these records, you may manually seek out and address these duplicates prior to loading the time series into ThermoStat. Any blocks of time stamps that are reversed (i.e. going backwards in time) are also set to null automatically.

Time Gap Null Records Inserted

Missing records are gaps in the data. These gaps must be filled. ThermoStat inserts null records into the time series automatically. Gaps that were introduced during the duplicate/reverse time stamp processing are also filled with null during this process.

Note: Gaps could be filled manually using more complex gap filling methods prior to loading the data into ThermoStat. These complex gap filling methods are not dealt with here.

Leap-Day Records Deleted

The extra day that is introduced during a leap year has some very profound impacts on the complexity of the programming required to calculate the annual, seasonal, monthly and weekly statistics and therefore the records of that extra day (i.e. February 29th) are deleted from the time series. The rationale being that this will have very little impact on the statistical results since it represents a very small proportion of the data collected and it occurs during a time when the water flowing in most streams of Ontario will be constantly at or near zero degrees Celsius. It was the significant reduction in programming overhead in combination with the relatively minor impact on the accuracy of the results that lead to the decision to include this step in the required processing queue.

Below Freezing Records set to Zero

Negative temperatures are assumed to be the result of less than ideal logger installation, resulting in the logger being embedded in ice during parts of the winter. ThermoStat will accept this data but set these records to zero.

Additional Null padding

The time series to be analyzed needs to be completely continuous (i.e. no gaps). Any data gaps occurring within individual time series and between multiple time series are filled with null values. Partial calendar years are also null padded at the beginning and end of the time series. An additional full year of null data is also added to the start and end of the time series. This final step is required to allow for analysis of winter seasons that span across the end of the calendar year (i.e. December 31) allowing the autumn season to end and winter to start before December 31 (Figure 6).

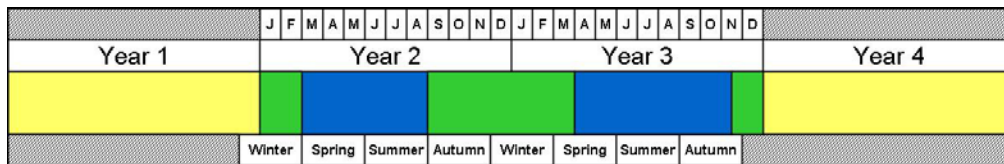


Figure 6: The time series data (blue) is automatically “padded” with null values (green) to produce full continuous years. In addition to these partial year pads the software adds a full year null pad to beginning and end of the time series (yellow).

Optional Data Processing

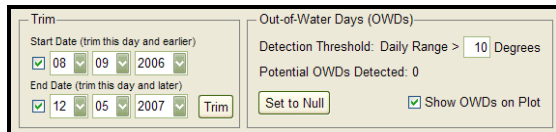


Figure 7: Optional data processing controls

Data trimming

The data trimming function allows for the removal of data from the start and end of the time series. This is useful for trimming data when loggers were recording data while out of water leading up to their installation or after retrieval. The checkboxes are used to activate/deactivate trimming.

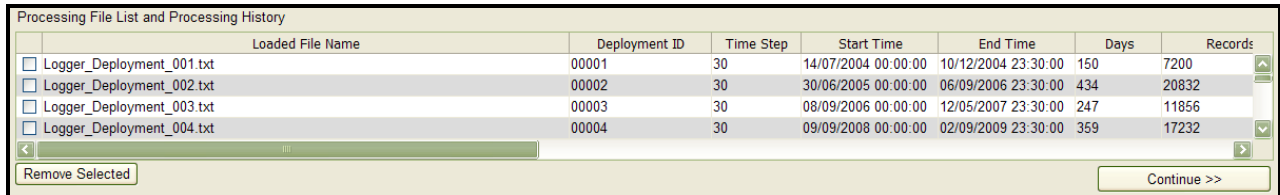
Out-of-water day removal

This function allows for the identification of records that are suspected to be the result of the logger being exposed to the air (i.e. drying). The default detection value is set to a daily (midnight-to-midnight) temperature range 10 degrees Celsius per day or more. This value can be adjusted, but only if you can provide a valid reason for doing so. For example, small streams can vary more than large rivers. Urban streams and streams without riparian vegetation can also vary considerably over the course of a day. Low groundwater contributions can result in higher temperature fluctuations.

Additional Steps of Input Preparation

The Input Time Series List

ThermoStat can process a single or multiple deployment time series. After each individual input time series is loaded/processed it must be added to the list of files to be further merged. Temporal ordering of this list is not required since ThermoStat will automatically sort the input into an appropriate sequence prior to merging (Figure 8).



Loaded File Name	Deployment ID	Time Step	Start Time	End Time	Days	Records
<input type="checkbox"/> Logger_Deployment_001.txt	00001	30	14/07/2004 00:00:00	10/12/2004 23:30:00	150	7200
<input type="checkbox"/> Logger_Deployment_002.txt	00002	30	30/06/2005 00:00:00	06/09/2006 23:30:00	434	20832
<input type="checkbox"/> Logger_Deployment_003.txt	00003	30	08/09/2006 00:00:00	12/05/2007 23:30:00	247	11856
<input type="checkbox"/> Logger_Deployment_004.txt	00004	30	09/09/2008 00:00:00	02/09/2009 23:30:00	359	17232

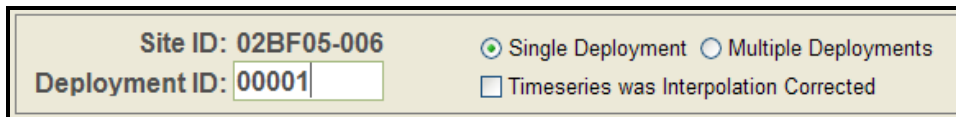
Figure 8: The input time series list

Note: Review the list carefully for completeness before clicking *Continue >>* because you can not return to this page without having to reload all the input files again.

Labeling Deployments

A deployment is defined as a single time series that starts when a data logger is placed into a stream in the field and ends when the logger is retrieved and its memory downloaded. A research site may have several (usually temporally sequential) deployments associated with it. ThermoStat is designed to merge multiple sequential deployments into a single site time series for analysis. It is good practice to assign each deployment a unique identifier. This allows for the effective storage, retrieval and analysis of large quantities of temperature data from multiple deployments across multiple research sites without any ambiguity. ThermoStat creates a processing history text file for future reference of what processing was performed on the raw data.

Note: Deployment ID 99999 is reserved for when previously processed/merged multi-deployment files need to be loaded back into ThermoStat. Selecting the Multiple Deployments Option (Figure 9) will automatically do this for you.



Site ID: 02BF05-006
Deployment ID:

Single Deployment Multiple Deployments
 Timeseries was Interpolation Corrected

Figure 9: Entering the user defined Deployment ID

Files Automatically Created by ThermoStat

ThermoStat creates the following output files during time series processing (these are written to the user defined working directory):

1. A tab delimited ASCII text file (*.txt) for each deployment that was loaded.
2. A single tab delimited ASCII text file (*.txt) merged time series file.
3. A single tab delimited ASCII text file (*.txt) capturing processing history file.
4. A MATLAB formatted metadata file (*.mat) that captures user defined season definition and other user entered metadata.

ThermoStat File Structures

All ThermoStat processed time series files have the following tab delimited fields:

Field Name	Description
DeploymentID	the user assigned five digit identifier
RecDate	the dates of the records in dd/mm/yyyy format
RecTime	the time of the records in 24 hour HH:MM:SS format
Temperature	the recorded temperatures in Degrees Celsius

ThermoStat will label all output file names with the user defined DeploymentID. A DeploymentID must be 5 characters in length and composed of numerals padded with zeros (e.g. 00001, 02012, 01890, 78654).

Note: Null records (i.e. NaN) are included in the individual deployment time series text files. **However** null records are excluded in the merged time series text file.

The processing history file contains the following tab delimited fields:

Field Name	Description
DEPLOYMENT_ID	The user assigned five digit identifier
ORIGIN_FILENAME	The name of the original deployment input text file
PROC_INTERVAL	The time-step of the time series.
START_DATETIME	The start time of the processed deployment time series
END_DATETIME	The end time of the processed deployment time series
NDAYS	The number of days contained within the processed deployment time series
NRECS	The number of records (measurements) within the processed deployment time series
SYNCHRONIZATION	The direction and magnitude of the shift in time required to synchronize the processed deployment time series in minutes (a negative value indicates a backward shift)
NULL_RECS	The number of null records that were inserted to fill any data gaps in the processed deployment time series
BELOWZERO_CORR	The number of below freezing measurements that were set to zero degrees Celsius within the processed deployment time series
LEAPDAYS_REM	The number of leap day records (February 29 th) that were removed from the Processed deployment time series.
DUP_CORR	The number of duplicate records (identical time-stamp and temperature) and/or number of reversed time-stamps (backwards in time) that were set null within the processed deployment time series
PARTSRECS_REM	The number of records of any partial 24 hour day that were removed from the start of the processed deployment time series
PARTERECS_REM	The number of records of any partial 24 hour day that were removed from the end of the processed deployment time series
SDAYS_TRIMMED	The number of records that were removed from the start of the processed deployment time series as optionally define by the user
EDAYS_TRIMMED	The number of records that were removed from the end of the processed deployment time series as optionally define by the user
OWD_APPTHRESH	The user defined out-of-water threshold range used to flag days whose midnight to midnight temperature range exceeds this value (e.g. daily temperature range in Degrees Celsius)
OWDS_SETNULL	The number of records set to null (user optional) as flagged by the out-of-water threshold range above)
INTERPCORR_REQD	User set flag indicating that the original deployment input time series was already interpolated prior to being loaded (e.g. time step adjustments)

Merging Files

The files are chronologically ordered and analyzed for gaps and overlap between them. Gaps are filled with null values during the merging process. When overlap occurs the earlier file (higher in the list) will be used for the values. If this is a problem then you have to manually trim the input text files prior to loading into ThermoStat. A default file name is provided for the new merged time series, but you may choose to provide an alternate name (Figure 10).

File Name	Time Step	Start Date	End Date	Days	Records	Gap to Next	Overlap with Previous
ProcessedSite_00AA00-000_Deployment_00001_Data	30 Minutes	14/07/2004	10/12/2004	150	7200	201	N/A
ProcessedSite_00AA00-000_Deployment_00002_Data	30 Minutes	30/06/2005	06/09/2006	434	20832	1	0
ProcessedSite_00AA00-000_Deployment_00003_Data	30 Minutes	08/09/2006	12/05/2007	247	11856	485	0
ProcessedSite_00AA00-000_Deployment_00004_Data	30 Minutes	09/09/2008	02/09/2009	359	17232	1	0
ProcessedSite_00AA00-000_Deployment_00005_Data	30 Minutes	04/09/2009	20/08/2010	351	16848	N/A	0
-	-	-	-	-	-	-	-

Merged Time Series File Name
 ProcessedSite_00AA00-000_TimeSeries

Process File(s)...

Figure 10: The chronologically ordered files to merge and process list

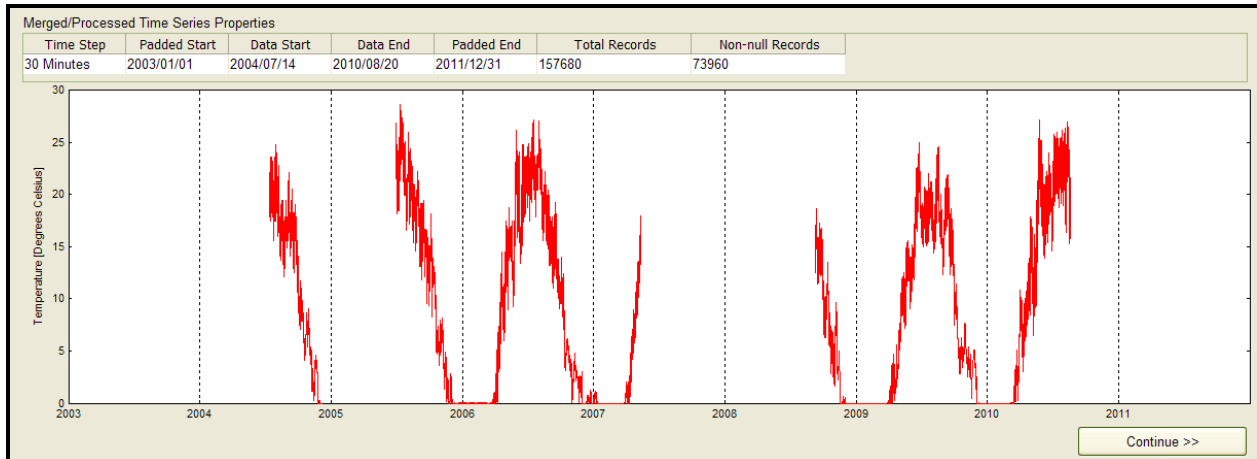


Figure 11: The graphical results of the merging process including the null padding within and at wither end of the time series

Notes on Data Quantity and Quality

It is recommended that at the very least one full summer period of data is used for stream temperature analysis. Ideally there should be multiple years of data within each sub-annual analysis period (i.e. months and seasons) with these periods being represented over multiple years (Figure 12). Less data means greater uncertainty in the results. 5 or more full years of data is ideal.

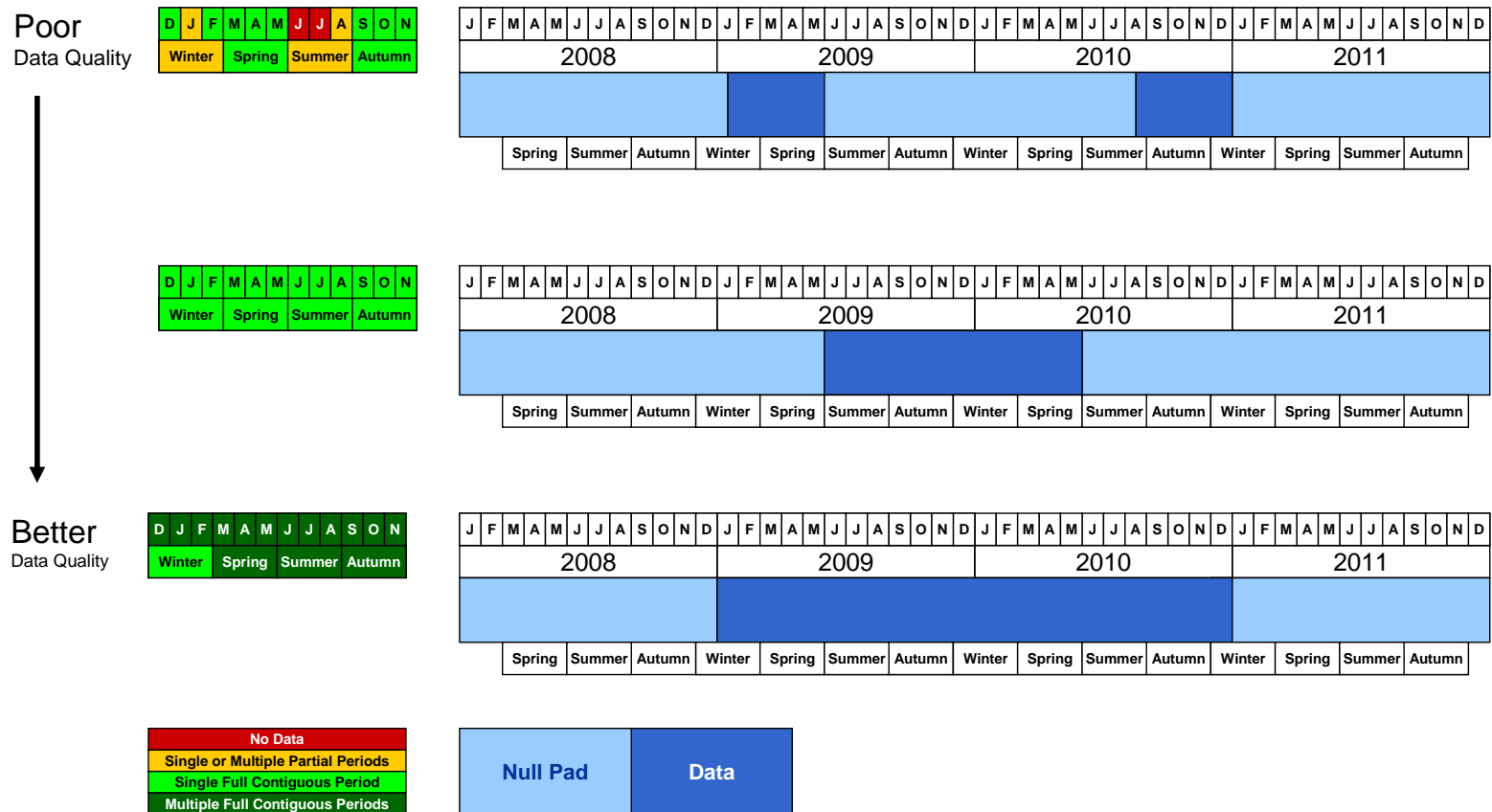


Figure 12: Data quantity and quality illustration showing the continuum of data quality.

Defining Seasons

1. Press the *Apply and Continue* button to proceed to the Season Definitions screen. This lets the user define the seasonal periods to be used by the analysis. The “Date to DOY Converter” can be used to convert dates to DOY values and vice-versa (Figure 13).
2. Press the *Apply and Continue* button to proceed to the descriptive metadata screen.

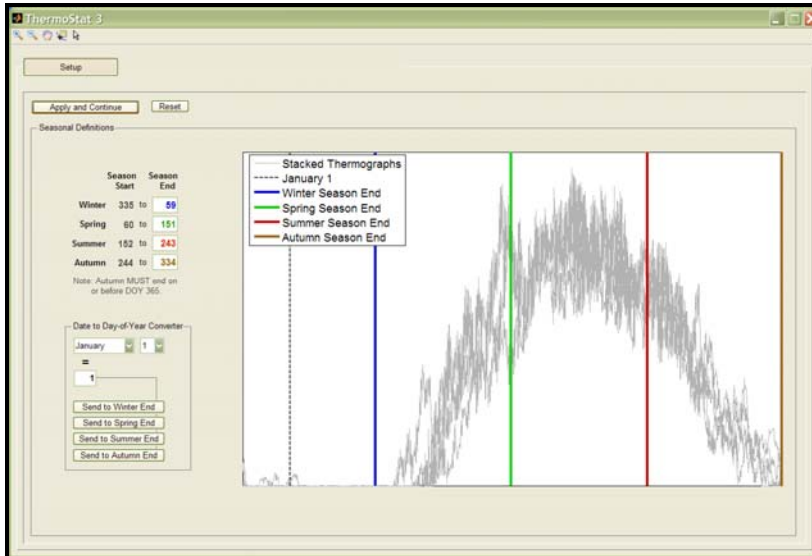


Figure 13: Season definition controls including graphical representation of the loaded temperature time series to assist in setting the seasonal boundaries

Descriptive Metadata

1. Fill in the metadata fields.

The screenshot shows the 'Descriptive Metadata' window in ThermoStat 3. The window title is 'ThermoStat 3' and it has a 'Setup' button. The main area contains several sections:

- Site Description:** Fields for Site ID (02BFD5-006), Drainage (sq km), Site Name, and River Name.
- Site Location:** Fields for Country (Canada), Province / State (Not Provided), OMNR Region (Not Provided), OMNR District (Not Provided), X-Coordinate, Y-Coordinate, and Coordinate System (e.g. UTM, NAD83, Zone 18N).
- Seasonal Definitions:** A list of seasons with their start and end dates: Winter: December 1 to February 28; Spring: March 1 to May 31; Summer: June 1 to August 31; Autumn: September 1 to November 30.
- Data Source Description:** A text area for describing the data source.
- Analysis Notes:** A large text area for notes.
- Comments on Site Location:** A text area for comments.

Buttons for 'Save and Continue' and 'Reset' are visible at the top of the window.

Figure 14: Descriptive metadata controls

2. Press the *Save and Continue* button to proceed with saving the metadata you have created. Saving the metadata is mandatory even if you did not provide any information (the blank fields will be automatically filled with the text "Not Provided". This action can be cancelled but you will not be able to proceed to run the analyses without actually saving a metadata file).
3. Click the *Run Analyses* button and use the control buttons to navigate through the results (Figure 15). When large time series with tens (or even hundreds) of thousands of records are analyzed it may take a few minutes to complete all the analyses. Please be patient.

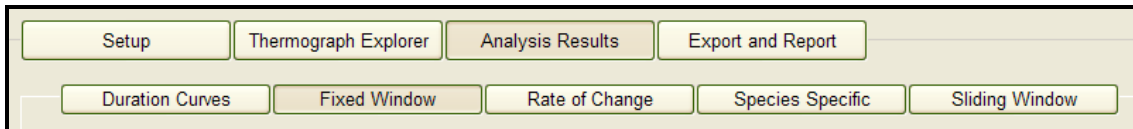


Figure 15: Primary and secondary navigation control bars used to toggle between the various screens of the program

Analysis Results

Thermograph Explorer

Thermal Classification

This classification procedure determines the proportion of the total number of temperature measurements that are: greater than 25°C (warm-water), greater than or equal to 19°C and less or equal to than 25°C (cool-water), and less than 19°C (cold-water) (Coker et al., 2001) for the duration of each season as defined in the metadata (Figure 16).

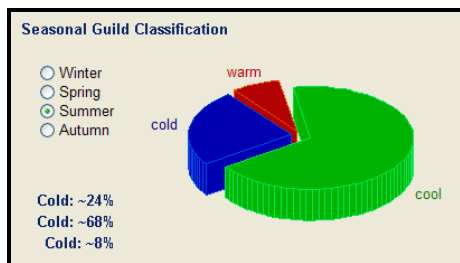


Figure 16: Thermal classification graphic output and season display controls

Calculation Procedure:

- All records within each seasonal period are collected
- The records are binned into the three thermal classes of greater than to 25°C, greater than or equal to 19 and less than or equal to 25°C, and proportion less than 19°C.
- The number of records in each thermal class is divided by the total number of records of all three classes (excluding null values) and then multiplied by 100 to get the percentage of each class.

Species Specific Durations

Species Specific Metrics

This procedure calculates species specific temperature durations for the range of ± 2 °C around the optimal temperature range and the duration above lethal exceedence for the entire period of record (Figure 17). The proportion of the period of record that fall within the optimal ranges and the percentage proportion that exceed the lethal thresholds (see Table 2 for acronym definitions). More information regarding the species specific temperature metrics can be found in Hasnain et al. (2010).

Common Procedure for both Predefined and User Defined Durations:

- All records that fall within the optimal range metric range of ± 2 °C (inclusive) are collected OR
- All records that are greater than or equal to the lethal threshold metric are collected.
- The proportion (%) of the number of records within the or above the metric are reported in the legend of the Thermograph plot.



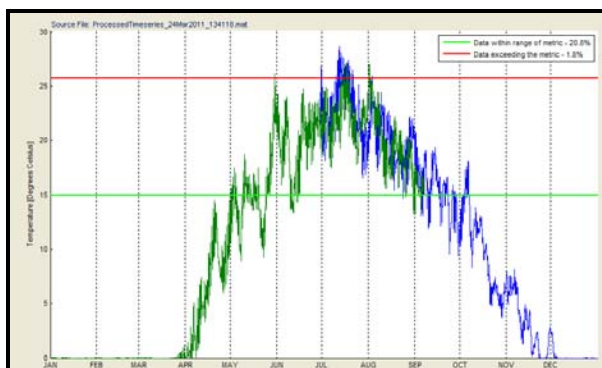
Figure 17: Thermograph display and species specific metric controls

Table 2

Optimal Range Metrics	
OGT	Optimal Growth Temperature
FTP	Final Temperature Preferendum
OST	Optimal Spawning Temperature
OET	Optimal Egg Development Temperature

Lethal Threshold Metrics	
UILT	Upper Incipient Lethal Temperature
CT _{max}	Critical Thermal Maxima

User Defined Metrics



User Defined Metrics						
<input type="checkbox"/>	Ranged Metric Name	Value	Range Bounds (+/-)	<input type="checkbox"/>	Limiting Metric Name	Value
<input checked="" type="checkbox"/>	Data within range of metric	15	3.2500	<input checked="" type="checkbox"/>	Data exceeding the metric	25.7500

Figure 18: Thermograph display and user defined metric controls

Fixed Window Analyses

Fixed Interval Summary Statistics

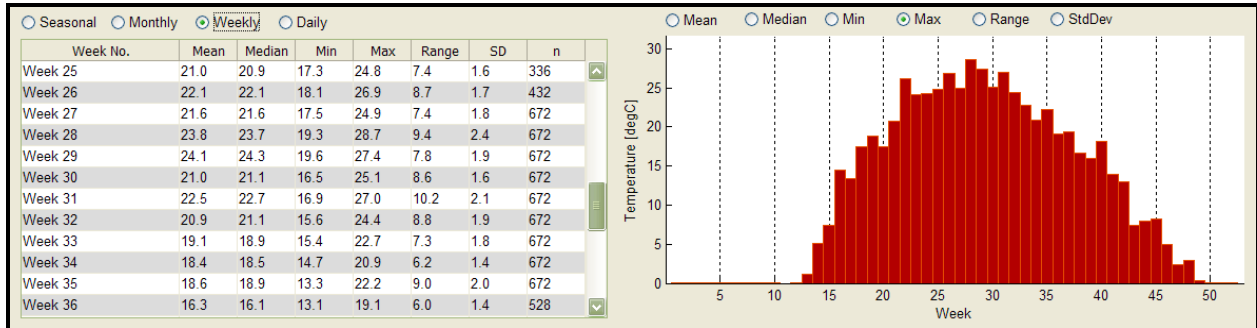


Figure 19: Fixed interval graphic output and display controls

This procedure calculates summary statistics on a block of time called a fixed window. The available window sizes are seasons, months, weeks or days. Data records within each window are collected for each annual window occurrence over the entire period of record. For example: A 5 year long time series would include 5 occurrences of Week 1 (Jan.1 to Jan.7), one occurrence per year. All the records from these Week 1's would be collected into one bin for analysis.

Timing of Annual Extremes

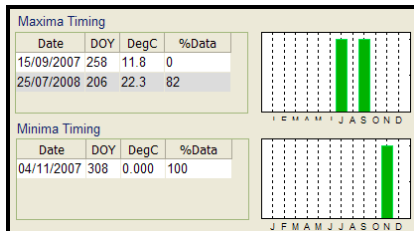


Figure 20: Annual extreme timing graphic output

This procedure determines a list of the dates of the annual maxima and minima for each year within the period of record. The output is a list of minimum and maximum dates for each year of the record in "dd/mm/yyyy" format and the corresponding day-of-year (DOY).

- All records are binned into years (i.e. 365 day periods). Two sets of bins are created: 1 with bins centered on the winter minimum time and one centered on the summer maximum time. The bin periods (Winter centered = July 1 – June 30; Summer centered = January 1 to December 31).

Note: Two sub-windows are used to indicate the data quality of the timing results (November 1 to February 28 for the minima and June 1 to August 31 for maxima). The *%Data* field represents the percentage of time each sub-window contains non-null data values. If this field contains anything less than 100% you should interpret the results with caution since you may be missing the times when the actual maxima/minima occurred.

- A single mean value of these DOYs can be calculated using day-of-year values. For the maxima it is as simple as taking the mean of the DOY values. For data where one or more minima DOYs occurs before December 31st (DOY = 365) the following procedure must be used:
 1. Determine the earliest DOY in the list and subtract this value from 365.
 2. Temporarily set this earliest DOY value to 1 and add the calculated value from the step #1 to each of the remaining DOY value in the list.
 3. Take the average of all these temporarily "shifted" DOY values from step #2.
 4. Subtract the calculated value from step #1 from the average value calculated in step #3. The result is the average minima DOY of occurrence.

Note: Using partial years with null data produce less meaningful results especially if the data gap coincides with the expected timing of annual minima and maxima for the sampling site. Thermographs can flat-line during winter at or near 0°C. When this occurs the minimum timing is determined by reporting the earliest time the minima occurs (i.e. the start of the flat-line).

Timing of Daily Extremes

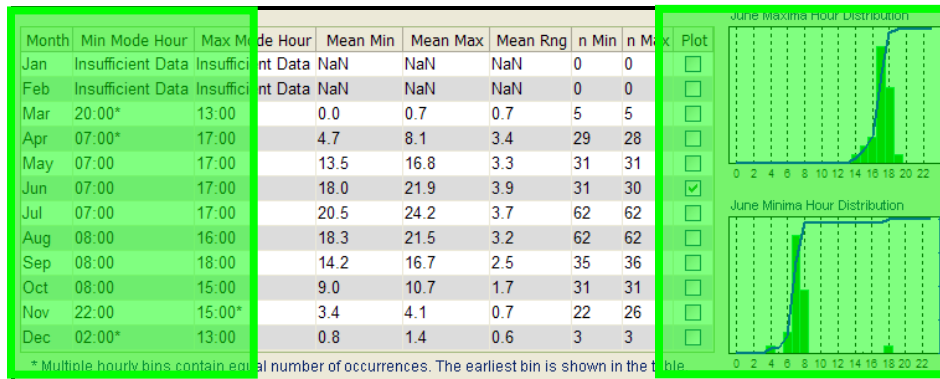


Figure 21: Daily extreme timing specific graphic output highlighted in green

This procedure determines the most common time that stream temperatures peak and trough on a daily basis (i.e. daily high and low points of stream temperature). The output one minimum and one maximum set of monthly modal hours of occurrence.

- All records are binned by month (12 bins).
- The time of occurrence of the daily minimum and maximum for each day within each monthly bin is determined.
 - Check each daily period for presence of peaks and troughs and record the timestamp of occurrence as well as the magnitude of the peak/trough.
 - If no peaks or troughs are detected then no extreme event information is recorded for that day.
 - If multiple troughs/peaks occur within one day the lowest/highest troughs/peaks are used to calculate the timing.
 - If troughs/peaks include several consecutive equal temperature values (e.g. plateaus) then the earliest time of occurrence is assigned to that trough/peak.
 - Bin the gathered times of through/peak occurrence by month.

- Bin the records within each monthly bin further into hourly bins (e.g. 13:00 to 13:59, 14:00 to 14:59 etc.).
- Determine the mode of all the daily minima and maxima occurrence hours within each monthly bin (i.e. the hourly bin within each month with the most occurrences). If two or more hourly intervals contain equal number of occurrences then the earliest hour interval is reported.

Note: Using this method will intentionally exclude days that have no significant sinusoidal trough or peak in the daily extreme analysis. For example winter temperatures remain virtually constant at 0°C at some sites, such days are identified and excluded if they have a daily range of less than 0.25°C. Days with steady cooling/warming trends are also excluded (when stream temperature declines/rises steadily from midnight to midnight). The sample sizes of the maxima and minima bins may be different for the same month because it is possible for a day to have a peak, but no through, and vice versa.

Magnitude of Annual Extremes

Mean Annual Magnitude & Variability		
Min	Max	Range
0.0	27.9	27.9

Figure 22: Annual extreme magnitude specific graphic output highlighted in green

This procedure determines the mean annual minimum and maximum temperatures. The output is two values (i.e. averages of all annual minima, averages of all annual maxima).

- All records are placed into annual bins (one bin for each calendar year)
- The minimum and maximum temperature value within each bin are determined.
- The average of both the minima and maxima within each annual bin are calculated.

Magnitude of Daily Extremes

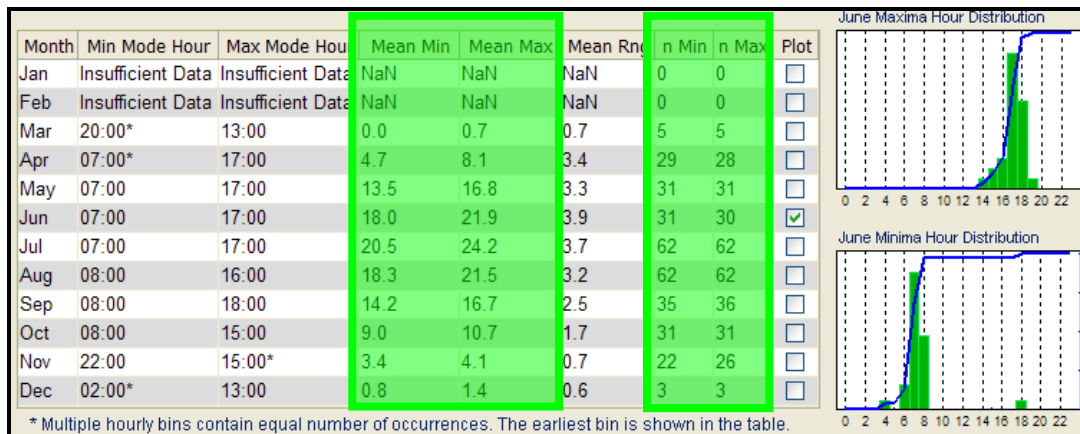
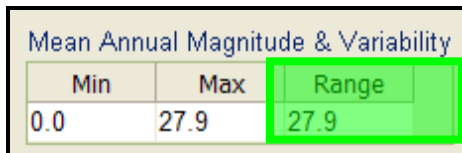


Figure 23: Daily extreme magnitude specific graphic output highlighted in green

This procedure determines the monthly means of daily minimum and maximum temperatures. The output is 24 values: 12 monthly average minima and 12 monthly average maxima.

- All records are binned into months (12 bins).
- The daily minimum and maximum for each day within each bin are determined.
- Each daily period is checked for presence of peaks and troughs and the timestamp of each occurrence and the magnitude of the peak/trough is captured.
 - If no peaks or troughs are detected no extreme event information is captured for that day.
 - If multiple troughs/peaks occur within one day the lowest/highest trough/peak is used to calculate the magnitude.
 - If troughs/peaks include several consecutive equal temperature values (e.g. plateaus) then the magnitude of the earliest time of occurrence is assigned to that trough/peak.
- The captured magnitudes of through/peak occurrence are binned by month
- The mean of all the daily minima and maxima magnitudes is determined within each monthly bin

Variability of Annual Extremes



Mean Annual Magnitude & Variability		
Min	Max	Range
0.0	27.9	27.9

Figure 24: Annual extreme variability specific graphic output highlighted in green

This procedure determines the mean annual temperature range. The output is a single value representing the average of all annual ranges

- All records are binned into years (one bin for each calendar year).
- The minimum and maximum temperature value for each bin are determined.
- The annual temperature range for each bin is calculated by subtracting the minimum temperature from the maximum temperature for each bin.
- The average of all the annual range values is calculated.

Variability of Daily Extremes

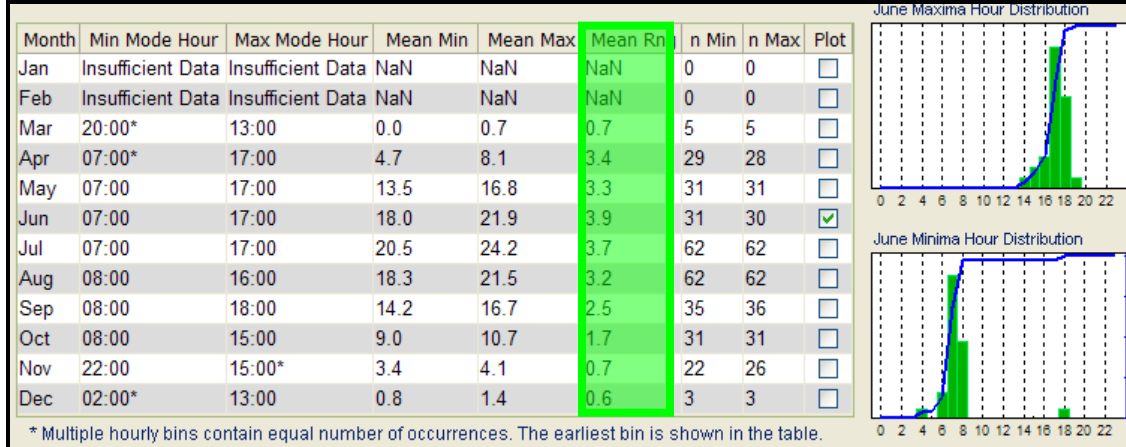


Figure 25: Daily extreme variability specific graphic output highlighted in green

This procedure determines the monthly means of daily temperature ranges. The output is 12 values representing the monthly averages of all daily ranges.

- For each month the monthly mean daily minimum is subtracted from the monthly mean daily maximum to arrive at the monthly mean daily ranges.

Rate of Change Analyses

The following Rate of Change (ROC) calculation procedure is used for both subsequent Fixed Window Rate-of-Change Statistics and Daily Maxima Rates of Change analyses.

- The temperature time series is re-sampled by capturing only full hour records (e.g. 12:00:00, 13:00:00, 14:00:00 ...) of the full sub-hourly time series
- An hourly ROC time series is calculated by moving through the temperature time series and subtracting the next record from the current record (e.g. record(i+1) – record(i)). Positive rates represent warming rates and negative rates cooling rates.
- All the new ROC records are binned according to their sign (1 positive rate bin, 1 negative rate bin). Zero rates are excluded since they cannot be classified into these two bins.

Fixed Interval Rate-of-Change Statistics

This procedure calculates summary statistics for Rate of Change (ROC) on a block of time called a fixed window. The available window sizes are seasons, months, weeks or days. Data records within each window are collected for each annual window occurrence over the entire period of record. For example: A 5 year long time series would include 5 occurrences of Week 1 (Jan.1 to Jan.7), one occurrence per year. All the records from these Week 1's would be collected into one bin for analysis.

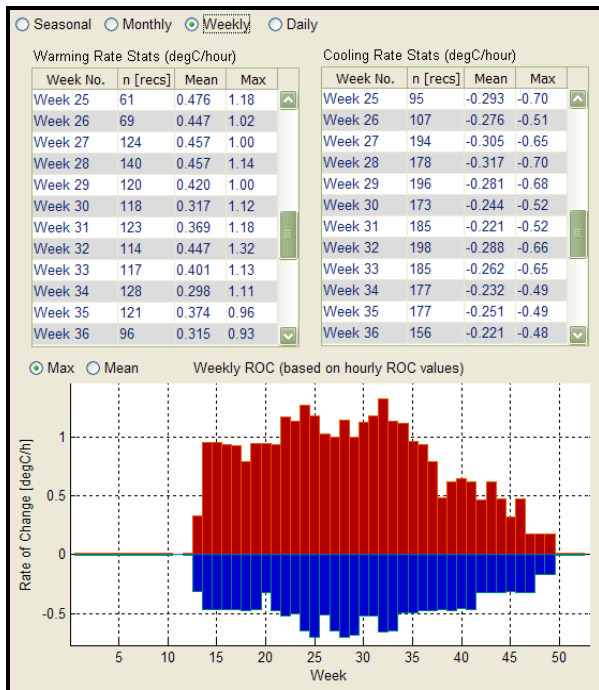


Figure 26: Fixed Interval Rate-of-Change Statistics graphical output and controls

In addition to the common ROC procedure outlined above the following calculations are performed:

- The positive and negative bins are further binned according the four sub-annual fixed interval time period (i.e. seasons, month, weeks and days)
- The average and the maximum are calculated for each sub-annual time period bin.

Note: Since zero rates of change and null values are excluded from calculations. Zero rates are excluded because they can not be grouped into either positive or negative bins.

Monthly Means of Daily Extreme Rates of Change

This procedure determines the monthly means of daily maximum hourly positive and negative ROC for the period of record. The output is 24 values representing the monthly averages of all daily maximum hourly positive and negative rates of change. In addition to the procedure outlined above the following calculations are performed:

- The records within positive and negative bins are further binned according to month (24 bins: 12 positive monthly bins, 12 negative monthly bins).
- The average of each bin is calculated (24 mean values in total)
- The maximum daily positive and negative ROCs are determined for each day.
- The average of all daily maxima is calculated for each monthly bin.

Note: Null (NaN) values are excluded from the analysis. Monthly bins that do not contain any data will produce a NaN result. Flat-lined days (i.e. days that have nothing but zero rates of change) are included as zero rates when calculating both warming and cooling monthly average rates.

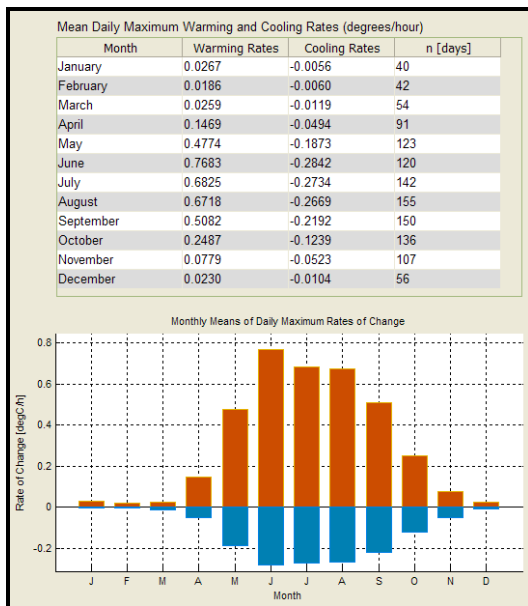


Figure 27: Monthly means of daily extreme rates of change graphical output

Species Specific Preferred and Lethal Durations

This procedure calculates species specific temperature durations for the range of ± 2 °C around the Final Temperature Preferendum (FTP) and the duration of Upper Incipient Lethal Temperature (UILT) exceedence during the months of June, July and August (i.e. the summer period). The output is 2 percentage values for each species; one representing the proportion of the summer records that fall within the FTP range and one representing the proportion of summer records that exceed the UILT threshold (graphical plots of these values are available from the Thermograph Explorer screen).

Analysis Period
 Summer Period of Record

Summer Percentages of Data Within Optimal Ranges and Above Critical Thresholds

Common Name	%OGT	%FTP	%UILT	%CTmax	%OST	%OET	Scientific Name
Alewife	51.8	20.4	21.9	0.0	3.2	30.0	<i>Alosa pseudoharengus</i>
American Eel	22.9	51.1	---	---	---	---	<i>Anguilla rostrata</i>
Atlantic Salmon	3.2	8.7	0.4	0.0	---	---	<i>Salmo salar</i>
Banded Killifish	---	42.4	0.0	---	42.4	28.8	<i>Fundulus diaphanus</i>
Bigmouth Buffalo	---	50.3	---	---	22.1	51.1	<i>Ictiobus cyprinellus</i>
Black Bullhead	---	---	0.0	0.0	---	---	<i>Ictalurus melas</i>
Black Crappie	32.2	36.4	0.0	0.0	43.9	34.3	<i>Pomoxis nigromaculatus</i>
Blackchin Shiner	---	---	0.0	0.0	---	---	<i>Notropis heterodon</i>
Blacknose Dace	---	49.0	0.0	0.0	---	---	<i>Rhinichthys atratulus</i>
Bloater	39.5	0.0	2.7	---	---	---	<i>Coregonus hoyi</i>
Bluegill	1.0	0.1	0.0	0.0	22.9	42.4	<i>Lepomis macrochirus</i>
Bluntnose Minnow	12.6	29.7	0.0	0.0	---	---	<i>Pimephales notatus</i>
Bowfin	---	0.1	---	0.0	---	---	<i>Amia calva</i>
Brook Stickleback	---	52.2	0.0	---	2.4	36.1	<i>Culaea inconstans</i>
Brook Trout	4.2	6.7	8.6	0.0	0.0	0.0	<i>Salvelinus fontinalis</i>
Brown Bullhead	0.2	12.6	0.0	0.0	54.1	43.7	<i>Ameiurus nebulosus</i>
Brown Trout	1.6	11.5	7.6	0.1	0.0	0.0	<i>Salmo trutta</i>
Burbot	17.7	2.4	20.0	---	0.0	0.0	<i>Lota lota</i>
Carp	6.2	4.9	0.0	0.0	31.9	51.8	<i>Cyprinus carpio</i>
Central Mudminnow	---	---	0.0	---	---	---	<i>Umbra limi</i>
Central Stoneroller	24.1	31.3	0.0	0.0	---	---	<i>Camptostoma anomalum</i>
Channel Catfish	0.6	6.2	0.0	0.0	---	---	<i>Ictalurus punctatus</i>
Chinook Salmon	4.6	3.5	18.1	7.6	---	---	<i>Oncorhynchus tshawytscha</i>
Chum Salmon	2.1	4.2	---	---	---	---	<i>Oncorhynchus keta</i>
Coho Salmon	3.2	5.1	11.6	0.4	0.0	0.0	<i>Oncorhynchus kisutch</i>
Common Shiner	49.9	52.4	0.0	0.0	---	---	<i>Notropis cornutus</i>
Creek Chub	---	22.9	0.0	0.0	---	---	<i>Semotilus atromaculatus</i>

Figure 28: Species specific temperature values for FTP and UILT are found in Hasnain et al. (2010). If a FTP value is not available use the Optimum Growth Temperature (OGT) instead. If a UILT value is not available use the maximum Critical Temperature (CT_{max}) value instead

- All records that fall within the period of June 1st and August 31st are collected.
- Using the collection from step (a) all records that fall within the FTP range of ± 2 °C (inclusive) are collected.
- Using the collection from step (a) all records that are greater than or equal to the UILT threshold are collected.
- The proportion (%) of the number of summer records within the FTP range to the total number of summer records is calculated.
- The proportion (%) of the number of summer records exceeding the UILT threshold to the total number of summer records is calculated.

Sliding Window Analyses

This procedure moves a sliding window along the time series one sample at a time and calculates summary statistics for the values within that sliding time window while writing the results back to a new time series, essentially creating four new statistical time series (i.e. minimum, mean, maximum and range). Three window sizes (3-, 5- and 7-days) are passed over the temperature time series.

A second type of sliding window analysis is also run. This is the Mean Weekly Maximum Temperature (MWMT). This analysis calculates the daily maximums for each day and then passes a 7-day wide window over this daily maximum time series and writes the results to a new MWMT time series.

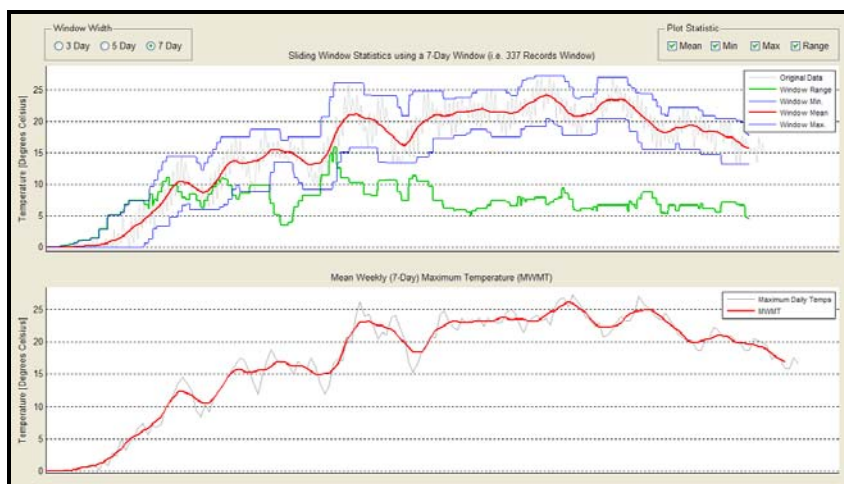


Figure 29: Sliding window graphical output and controls

Exporting Results

Text Files

Many of the tables and time series generated during the analysis can be exported as tab delimited text files. These files can be easily opened in other software for further processing or display. An export time stamp is added to each text file's name automatically.

PDF Report

This function generates a standardized Adobe Acrobat (PDF) document. The contents of the report capture many key measures of a stream's temperature regime in a standardized format. An export time stamp is added to the report's file name automatically.

References

Coker G.A., Portt C.B., Minns C.K. 2001. Morphological and Ecological Characteristics of Canadian Freshwater Fishes. Canadian Manuscript Report Fisheries Aquatic Sciences 2554: iv+89p.

Hasnain S., Minns K., Shuter B. 2010. Key Ecological Temperature Metrics for Canadian Freshwater Fishes. Climate change research report: CCRR-17. Applied Research and Development Branch, Ontario Ministry of Natural Resources, Canada. 54 p.