EcoNum laboratory protocols: Temperature calibration and measurement

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1 Introduction

Temperature measures the agitation (kinetic energy) of particles in a medium[1]. It is a key physical property because the speed of chemical and biological reactions is depending on temperature. Temperature is expressed in *Kelvin* (in the International System of units - SI), using symbol *K*[1]. It is one of the seven basic units in this system. It is an absolute scale because 0 K is called *absolute zero* and corresponds to a null kinetic energy, i.e;, the *thermodynamic* temperature. It is defined as the 1/273.16 fraction of the thermodynamic temperature of the triple point of water (273.16 K = 0.01 °C). Temperature is usually measured and expressed in another unit in biology: the *degree Celsius*[2] with symbol °C[3]. It was previously defined with 0 °C and 100 °C as the respective temperatures of melting ice and boiling water at a pressure of one atmosphere. Today, it is related to the Kelvin scale, with absolute zero being -273.15 °C and the tripe point of water being 0.01 °C. Hence K and °C relate to each other as:

$$[\mathrm{K}] = [°\mathrm{C}] + 273.15$$

Note that 1 °C matches 1 K. It is only a shift in the origin of measurements between the two unit systems. With the **econum** package, use functions `TK()` and `TdegC()` respectively to convert degrees Celsius to and from degrees Kelvin (simple task, but that way, you avoid typing errors in the conversion!). There are also Fahrenheit degrees (°F) which relate to Celsius degrees as:

$$[°\mathrm{C}] = ([°\mathrm{F}] - 32) \cdot {}^{5}/_{9}$$

Temperature is measured using a thermometer. There are many different types of thermometers, but we use three kinds mainly in the lab:

- ▷ The mercury-in-glass thermometer, which contains mercury in a bulb connected to a capillary tube where mercury expands according to temperature,

[1] Warning: don't use the degree sign (°) in front of K on the contrary to Celsius or Fahrenheit degrees (°C or °F).

[2] Degrees Celsius are also sometimes called degrees centigrades, but this is a synonym that should be avoided because it was abandoned in 1948.

[3] Take care to write the number, then a space (use a thin space in LyX or LaTeX), then the degree sign immediately followed by C (no space between the two symbols)!

- ▷ The alcohol thermometer is identical to mercury thermometer but contains alcohol colored in red or blue. It is less toxic (in case of breakage), but usually less accurate,
- ▷ The electronic thermometer with a resistive thermal device (RTD). We use two types of RTDs: PT1000 (e.g., for Consort devices) and PT100 (e.g. for WTW devices). With such a device, stability in time, and also self-heating risk (the current passing in the thermal resistance can heat the item being used) should not be a problem with good quality laboratory devices like the one used at EcoNum.

2 Calibration

In aquatic biology or ecology or in oceanography, we are mostly interested in temperatures between -3 °C and +35 °C, measured to the nearest 0.1 °C, and with an uncertainty no larger than 0.2 °C. At the lab, there are occasions to measure temperatures down to -20 °C (e.g., check freezer temperature) and up to 100 °C (e.g., drying oven, chemical reactions that require elevated temperatures) with a larger tolerated uncertainty (1-2 °C, sometimes even 5 °C). Thermometer calibration requires expensive equipment, like triple-point cells or melt cells[4]. We don't have access to such an equipment at EcoNum. So, we use an accurate mercury-in-glass reference thermometer (tagged '*T01*', Prolabo code 09630030, that should be used only for calibration!) as a secondary reference and we calibrate all of our other thermometers against it. That way, all temperature measurements are, at least, consistent one with other. This thermometer has a scale ranging from -2 °C to 32 °C, is graduated every 0.1 °C and is readable at ± 0.05 °C.

The simplest procedure (mostly to check a thermometer more than to calibrate it) uses a two-points calibration technique: we compare temperature measured with *T01* and the thermometer to check in melting ice first, and then, in water at room temperature.

Calibration coefficients ($T_{mes} = a + b \cdot T_{ref}$ with T_{mes}, the temperature measured with the thermometer to check and T_{ref} the temperature of the *T01* reference thermometer to the nearest 0.05 °C). Parameters a and b are calculated as:

$$b = \frac{T_{mes2} - T_{mes1}}{T_{ref2} - T_{ref1}}$$

$$a = T_{mes1} - b \cdot T_{ref1}$$

Using this calibration line, an unknown temperature red with the checked thermometer is:

$$T_{corr} = \frac{T_{mes} - a}{b}$$

[4]Note that it is possible to build an inexpensive water triple point cell (WTP) which has a temperature of exactly 0.01 °C (see http://www.scientificamerican.com/article.cfm?id=tackling-the-triple-point&sc=I100322). A two points calibration is possible using also a Gallium Melt Cell (GaMC) which provides a stable temperature at 29.76 °C, see http://www.seabird.com/technical_references/TPW&GMPAccuracy.htm.

Table 1: Thermometers calibration against *T01* done by Ph. Grosjean on 8/11/2011.

Thermometer	0.05 °C	12.60 °C	21.45 °C	31.50 °C	Calibration coefs. ($T_{corr} = a + b \cdot T$)
T01 (mercury,-2 to +32 °C by 0.1 °C)	0.05	12.60	21.45	31.50	none - secondary ref.
T02 (mercury, -10 to +50 °C by 1 °C)	-0.5	13.0	21.5	32.0	a = 0.536, b = 0.973
T03 (mercury, -20 to +50 °C by 1 °C)	2.0	13.0	21.5	32.0	a = -2.145, b = 1.097
T04 (alcohol, -1 to +51 °C by 0.2 °C)	1.3	12.6	21.2	31.2	a = -1.348, b = 1.075
T05 (alcohol, -1 to +51 °C by 0.2 °C)	1.1	12.7	21.1	31.0	a = -1.127, b = 1.070
T06 (mercury, -2 to +105 °C by 0.5 °C)	1.5	13.0	21.5	31.5	a = -1.555, b = 1.070
T07 PT1000 glass - Consort P602	-0.7	12.2	21.0	31.3	a = 0.740, b = 0.986
WTW tetracon 325 - WTW Cond 340i	0.1	12.7	21.5	31.7	none required - cste = 2.000%/K
...					

A better calibration procedure is used preferably, by measuring no less than four different temperatures with both thermometers, and preferably, seven different temperatures more or less equally spread along the targeted calibration range (usually from 0 °C to 31-32 °C). Near 0 °C temperature is measured on melting ice. Room temperature should be close to 20 °C and a thermostated bath could provide water à 31-32 °C. Intermediate temperatures are easily obtained by mixing two of there three waters. For thermometers spanning over 100 °C, a point close to 100 °C could be checked on boiling water. Table 1 presents calibrations made on 8/11/2011 by Ph. Grosjean for 8 thermometers used at EcoNum.

TODO: integrate calibration curves in EcoNumData processes... we use `calib2p()` to create a 2-points calibration object in `R` with package **econum**.

```
> # TODO: exemple code for temperature calibration...
```

3 Use of the thermometers

Reserve mercury-in-glass thermometers to measure temperature of chemicals.

> **Never use a thermometer that contains mercury to measure the temperature of an aquarium, a chemostat, or any other device connected to them**. If the thermometer breaks, mercury flows into the water and poison it rapidly! Use only alcohol or electronic thermometers in the mesocosms or chemostats.

When you measure temperature, place the thermometer inside the liquid. Respect the depth of immersion for your particular thermometer (8 cm, completely, or above a given mark). Agitate slightly the solution and wait long enough for the temperature to stabilize in the thermometer. Make sure that the mass of liquid measured is large enough to avoid its temperature change when you plunge the thermometer in it. Read the temperature at the meniscus with your eyes perpendicular to the thermometer, down to half a graduation (e.g., for a thermometer graduated every 1 °C, interpolate reading to the nearest 0.5 °C). Besides these precautions, you should just care of calibration coefficients as provided in Table 1, and of course, to calibrate new devices or recalibrate existing ones periodically (every year or so).

If you have a calibration object `"Tcalib"` in `R` memory for a given thermometer, you apply the correction to temperatures in *TempC* simply using `predict(Tcalib, TempC)`. TODO: a method to save and retrieve calibration objects from EcoNumData repository... and in case there are several calibration objects for the same instrument, use the correct one according to the dates of calibration and measurements, respectively.

References

[1] Lynds, B.T., 1995. About temperature. [online: http://eo.ucar.edu/skymath/tmp2.html]