European Mountain lake Ecosystems: Regionalisation, diaGnostics & socio-economic Evaluation

EMERGE

01

CLIMATOLOGY AND METEOROLOGY

David M. Livingstone

Water Resources Dept.
EAWAG
Switzerland

Climatology and Meteorology

1) Automatic Weather Stations (AWS)

Location and Installation

Automatic weather stations should be installed as close to the lakes as is practically possible, preferably directly at the lake shore. The mast must be well-anchored and sufficiently robust for the conditions likely to be encountered at each site (e.g. high winds and lateral snow pressure). It may be necessary to bolt the mast to a cement foundation or to a rock base. If a large permanently-moored raft is being used for other sampling, it might be possible to mount the weather station on the raft (this may also reduce security problems). Weather stations should in general be installed on flat land well away from obstructions affecting the wind field (e.g. cliffs, trees), and the site chosen should be as representative of the lake as possible. This is particularly difficult to achieve in the case of radiation measurements made at mountain lakes subject to varying amounts of shade from the surrounding topography.

Each site operator should take appropriate measures to ensure the security of the weather station. The measures necessary will have to be decided by the site operator based on his/her local knowledge. At the very least, warning notices should be posted.

Meteorological Variables

The following meteorological variables should be measured:

AT: air temperature (every 30 minutes)
RH: relative humidity(every 30 minutes)
WS: wind speed (every 30 minutes)
WS: wind direction (every 30 minutes)
SR: short-wave (solar) radiation (every 30 minutes)
PP: precipitation (daily mean values, 07.00h - 07.00h)

If possible, the following meteorological variables should also be measured:

AP: air pressure (at least every day). AP measurements from a neighbouring meteorological station are also acceptable (these can easily be corrected to the altitude of the lake).
LR: Long-wave (infra-red) radiation (every 30 minutes) or
NR: net radiation (every 30 minutes)

The data logger should be set to measure on the hour and on the half-hour. Modern data loggers should allow storage of half-hourly output data from, say, 10 sensors over a period of as much as six months (86,400 data points plus date and time) without any problem. Before being sent on from each site, the raw meteorological data must be calibrated according to the instructions of the manufacturer; uncalibrated data are not useable.

Wind speed and direction measurements should be made 10 m above ground level (the standard meteorological height for wind measurements). This can be reduced to, say, 5 m, if it is not practicable to use a 10 m mast, since the logarithmic form of the wind speed profile means that the difference is usually relatively small between 5 and 10 m. At heights lower than 5 m, however, especially in mountainous terrain, roughness elements are likely to have a substantial effect on the wind speed. If wind measurements are being made on a raft in the lake, it would be valuable to make two simultaneous sets of wind speed measurements (say at 10 m and 3 m), which would allow the wind speed drag coefficient over water to be determined (there is little point in doing this over land for our purposes). Make sure from the firm supplying the weather station that the anemometer will function properly in winter (problems frequently arise with snow in the cups and freezing up, for instance).

Variables other than wind speed and direction can be measured at heights much lower than 10 m; however, please make sure the sensors are mounted high enough so that they are always well above the maximum possible height of snow cover. Air temperature and relative humidity sensors should have ventilated radiation shields. The heights of the sensors above ground level and above the surface of the lake should be noted.

If additional sensors and spare channels are available, site operators may wish to duplicate some measurements i) in case of possible malfunction of one sensor; and ii) to obtain an estimate of horizontal variability (precipitation, for instance, is very heterogeneous spatially: the possibility of using several precipitation gauges distributed over an area might therefore be worth considering).

At some sites, a permanent meteorological station belonging to some other organisation already exists within a few kilometres from the site. In this case, if the data can be made available to us, it may not be considered necessary to install a weather station, or it may only be necessary to install a cut-down version. Assuming all necessary meteorological variables are measured at the permanent station, such a cut-down version should at least measure wind speed and direction, precipitation and air temperature.

Potential problems

Most practical problems with the weather station are likely to occur in winter. Anemometers ice up, snow covers the radiation gauges, the electronics become unreliable, batteries lose power, etc. etc. Measuring precipitation in winter is definitely a problem. Continuous automatic recording of precipitation using a standard unheated gauge is only feasible when the air temperature is above zero. However, heating the precipitation gauge requires a large amount of power and drains batteries rapidly, and so will not be possible at most EMERGE sites. Another possible solution to this problem involves the use of special automatic precipitation gauges containing anti-freeze, but such sensors tend to be expensive. Thus, in general, continuous precipitation measurements will not be available in winter. Precipitation estimates at most stations during a large part of the year will therefore have to be based on totalisator-type gauges (containing a measured amount of anti-freeze to melt snow falling into the totalisator before it is blown out again by the wind, and possibly a thin layer of oil to reduce evaporation; contact your national meteorological office for advice on this). Because precipitation tends to be spatially very heterogeneous, if possible several totalisators should be set up at different points within the lake catchment area to give an idea of the spatial variation present. This may not be feasible for reasons of cost (totalisators are not cheap), but even normal large buckets containing a measured amount of anti-freeze, fixed on a platform about 2 m above ground (above the maximum snow level), and distributed around the catchment area, would be better than nothing for this purpose.

Radiation measurements in winter are also a problem, since the sensors are sometimes covered with snow, which may or may not then be blown off by the wind. One possible solution to the this problem might be to use two sensors, one receiving direct radiation, the other receiving radiation reflected upwards from the snow on the ground. However, the problem of winter measurements is less serious than it seems, since meteorological effects on a lake are much less important during periods of ice cover than otherwise.

Data quality checking

Please set the data logger's internal clock to UCT, not to local time. This avoids potential problems with daylight saving time and also allows direct comparisons to be made between data from different time zones without first having to correct for local time. If the internal clock has however been set to local time, the time and date should be corrected to UCT before the data is sent on anywhere else.

If necessary, the data should be converted from the units in which they were measured to the following standard units: AT [°C]; RS [%]; WS [m/s]; WD [°N]; SR [W/m2]; LR [W/m2]; NR [W/m2]; AP [hPa]; PP [mm/d].

Special Excel tables with a specific format will be sent to each AWS operator. The data should be pasted into these tables and an initial data quality analysis made according to the instructions that will accompany the Excel tables.

Missing data should be set to "NaN" (the MatLab label for "not a number"). The initial data quality analysis should include the following checks:
1) Are blocks of data or individual records missing? Check (i) whether the data have not been recorded or (ii) whether the problem lies with the data logger's internal clock. If (i), insert blank records (NaN). If (ii), correct the date and time.
2) Was the sampling interval constant throughout the measuring period? If not, check whether there is a problem with the internal clock.
3) Check for erroneous non-numeric data (e.g. 2.3a5). Correct or set to NaN.
4) Check for obviously out-of-scale numerical data (e.g. AT = 324°C; WS = 1054 m/s). Correct or set to NaN.
3) AT: check for implausible values (-30°C in summer? +30°C in winter?). Correct or set to NaN.
4) RH: Check that 0%≤RH≤100%. Check that very low values of RH are real; if in doubt, set to NaN.
5) WS: Check that WS≥0. If AT<0 and WS=0 over a suspiciously long period of time, the anemometer is probably iced up, so set WS=NaN.
6) WD: Check that 0°≤WD<360°. Set 360° to 0°. If WS=0, set WD=NaN (because WD is not defined under calm conditions). Check that the wind

direction sensor did not stick at one value because of icing up at low air temperatures (obvious from a plot of the data). If it did, set to NaN.
7) SR: If SR<0, set SR=0 (solar radiation cannot be negative). Check to make sure SR is approximately zero at night (unless of course your measurements are being made in summer in the arctic). If the sun appears to be shining during the night, this suggests problems with the internal clock rather than with the SR sensor.
8) AP: Determine the normal range of AP at your lake (usually quite narrow) and check to make sure the recorded AP remains approximately within this range.
9) PP: For unheated rain gauges, if AT<0, set PP=NaN.

Calibrated data from the meteorological stations should be quality checked and entered into the Excel tables supplied before sending them on. Please send enough accompanying documentation to allow the data to be interpreted (e.g. exact location of station; height of sensors above ground level, above lake surface level and above sea level; any information on sensor or data logger malfunctioning or other possible sources of bad data).

2) Local skyline measurements

To obtain an estimate of local topographic shading, please measure the vertical angle of the topographical horizon (with a theodolite or clinometer) approximately every 10° around the horizon. This should be done (i) at all lakes with an AWS; (ii) at all lakes with a full thermistor chain; (iii) at as many lakes as possible with surface thermistors (ideally of course at all). The reason for making these skyline measurements is to determine the effect of local topographic shading on the lake surface water temperature. At lakes with an AWS these measurements should be made twice: once at the approximate centre of the lake surface (not necessarily identical with the deepest point of the lake) and once, for comparison purposes, at the weather station itself. Please also take one or two photographs of the weather station in situ to show the character of the surroundings. At lakes with no AWS, one set of skyline measurements is sufficient. It is probably easiest to make the skyline measurements from the ice. If this is not possible, it may be necessary to make several sets of skyline measurements from points around the lake shore. Measurements made from a boat tend to be unreliable.

3) Data from miniature thermistors

Miniature thermistors with integrated data loggers will be employed in EMERGE (i) to measure lake surface water temperatures (LSWTs) and (ii) to measure water temperature profiles. In general, a sampling interval of 1 hour is sufficient. The data capacity of Vemco 8-TR Minilogs is 8064 temperature readings; assuming a sampling interval of 1 hour, this corresponds to 11 months of data. It is therefore theoretically possible to leave the minithermistors unattended for almost a year before downloading the data. If it is impossible to visit a lake within 11 months after installing a minithermistor, set the sampling interval to 2 hours, giving 22 months. However, experience has shown it to be advisable to download data more frequently if possible, especially in less remote lakes where, in addition to natural disturbance, the minithermistors may be subject to human interference (fishermen removing the minithermistors from the water, children throwing stones at the floats, etc.). The possibility of an error occurring during the programming of the logger, or of installing the wrong minithermistor (they all look the same!), or of a technical malfunction occurring, should also not be underestimated, especially when dealing with 20 or 30 minithermistors. In such a case, the sooner the problem is noticed, the less data will be lost. As in the case of the AWSs, the internal clock of the minithermistor data loggers should be set to UCT, and the logger set to record on the hour. This facilitates comparison between lakes and between lake districts. The altitudes of all lakes in which minithermistors are installed must be known.

(i) Minithermistors used to measure LSWTs should have their sensors about 5 cm under the lake surface. This can be achieved, for example, by inserting them into the undersides of rectangular styrofoam blocks. In addition to acting as floats, the styrofoam blocks shade the temperature sensor from direct solar radiation. Another solution would be to attach the minithermistor with string to a small buoy. Where possible, the thermistors should be anchored near the lake outflow to ensure a continual flow of epilimnetic water past them, thus minimizing local littoral effects. They can be anchored by attaching them with strong string to a sufficiently heavy brick. They should be anchored close enough to shore to allow deployment and retrieval without the use of a boat (e.g. with fishermen's waders), but in deep enough water (~1.5 m) and far enough from the lake shore to minimize disturbance and to make unauthorized retrieval unlikely. Please make sure that the temperature range of the thermistor chosen is suitable for the range of LSWTs expected!

(ii) Minithermistor chains will have to be deployed from a boat or from the ice. The number of minithermistors on the chain depends to some extent on the depth of the lake, but since the resolution of the minithermistors is very coarse (±0.1°C or ±0.2°C) there is little point in putting more than two or three of these in the hypolimnion. As a suggestion, in a lake 20 m deep, a string of 10 thermistors might be spaced as follows: 5 cm, 50 cm, 1, 2, 3, 5, 7, 10, 15, 20 m. The range of the uppermost thermistor should be chosen to cope with the maximum water temperature expected.

According to the manufacturer, the minithermistors will withstand being frozen into lake ice. However, the float you use may not. Also, any horizontal ice movement (e.g. during the spring thaw) may drag the thermistor into deeper water, possibly necessitating the use of a boathook (or a treebranch with a nail attached). One possible way of installing the surface minithermistors is from the ice, by drilling a hole and pushing the thermistor, attached to its float, sideways under the ice. If this is done, it might be advisable to attach a second float to the minithermistor with a long string, and to leave this float on the upper surface of the ice (possibly covered with snow to hide it from inquisitive eyes). Thus, even if the lower float is damaged by the ice, the upper float will prevent loss of the thermistor (and, more importantly, loss of the data). If you do install surface minithermistors from the ice, remember they may have to be removed during the open-water period, so unless a boat is available the water depth should still not exceed about 1.5 m.

If enough minithermistors are avaliable, some partners may wish to install several of them at the surface of some of their lakes, or perhaps at different depths in the epilimnion. This is a useful way of checking how representative the individual minithermistor records are (i) of the mean lake surface temperature (horizontally) and (ii) of the epilimnetic temperature (vertically). However, experience has shown that, although LSWTs measured in the littoral zone during the day can be slightly higher than those measured in the centre of the lake, the variability tends to be very similar. Vertical differences within the epilimnion are greater, but even in this case the day-to-day water temperature variability that is a result of the day-to-day variability in local meteorological forcing is very similar. In fact, the variability in LSWT from lake to lake within one lake district is remarkably high (see Fig. 4b of Livingstone et al., 1999).

Please remember that the purpose of the LSWT regionalisation study is to gather as much useful data as possible with the minimum of cost and effort.

4) Data on Lake Ice Cover

a) EMERGE sites

Any information on the ice cover of the EMERGE lakes which may be obtained during the sampling program is requested. This information includes i) date of freeze-up (defined as the first date on which the lake is completely covered with ice); ii) date of break-up (defined as the first date on which the lake is completely ice-free); iii) thickness of ice at the sampling hole; (iv) thicknesses of layers of snow, slush and water over the ice proper.

b) Other Lakes

Information on the dates of freeze-up and break-up of any other lakes in your area is also requested, especially if long series of such data already exist. An effort should be made to discover if any long series of observations of freeze-up and break-up exist.

Please send enough accompanying documentation to allow the data to be interpreted (e.g. exact location of station; height of sensors above ground level, above lake surface level and above sea level; any information on sensor or data logger malfunctioning or other possible sources of bad data).

Please send the AWS data, the local skyline measurements, the minithermistor data and information on lake ice cover in the first instance by e-mail to:

Dr. David M. Livingstone
Water Resources Dept.
EAWAG
Ueberlandstrasse 133
CH-8600 Dübendorf
Switzerland
e-mail: living@eawag.ch

Please also send enough accompanying documentation to allow the data to be interpreted (e.g. exact location of AWS; height of AWS sensors above ground level, above lake surface level and above sea level; any information on sensor or data logger malfunctioning or other possible sources of bad data; latitude and longitude of lake; altitude of lake above sea level).