CalibSoil user manual and recommendations for field work

For successfully doing field work and running *CalibSoil*, it is sufficient to consider this short user manual carefully. On pages 1-5 of this manual you will find information relevant for field work and data acquisition and on pages 5-7 a guide for use of the *CalibSoil* software. For more detailed background information on the logic and derivations underlying the method and the implemented algorithms click on “Help” in the upper left in the *CalibSoil* main window and then on “Derivation of the Method”.

Purpose and main idea

CalibSoil is a calculation system enabling direct comparisons of single-day allochronic and allotopic soil temperature measurements in natural ecosystems by calibration against astronomical and meteorological standard conditions. To explain this with an example, *CalibSoil* can make a single-day soil temperature measurement in a lowland spruce forest of Poland during the cold summer of 1987 directly comparable with a single-day measurement taken in a high-mountain spruce forest of Switzerland in the extremely hot and dry summer of 2003. In other words, the central question answered by *CalibSoil* is “What would have been the maximum and mean soil temperatures if a particular measurement had been taken within a climatic context matching the average situation during the summer season?” Within the algorithms of *CalibSoil*, the average climatic situation is determined by the mean air temperature and sunshine duration from 1 May to 31 August over the 10 years prior to the actual year of measurement. This adaptive, or shifting, 10-year standard is short enough to track climatic developments such as global warming or cooling yet long enough to give a representative indication of the medium-term temperature history of a site.

Regional applicability

CalibSoil version 1.0 with its implemented parameters and functions is applicable to any terrestrial habitat of the northern hemisphere between 45°N and 57°N. The method is probably applicable farther north and south, but this has not been tested so far.

For which organisms are data provided by *CalibSoil* most indicative?

Temperature data provided by *CalibSoil* are applicable to any group of organisms living in soil, on its surface, or slightly above it. This ranges from lichens, mosses, vascular plants, bacteria, fungi, protozoans, arthropods and molluscs to reptiles and small mammals.

Final target values

TSCmax – the maximum calibrated soil temperature at a depth of 35 mm, calibrated for the condition of a “Standard Radiation Day”. The Standard Radiation Day is defined by a sunshine duration equal to 80% of astronomically possible sunshine duration and an air temperature equal to the mean recorded between 1 May and 31 August of the 10 years before the year of investigation. This target value is likely to offer an indication of mean heat stress.

TSCmean – the mean calibrated soil temperature at a depth of 35 mm depth as it would occur in the seasonal average of the full spectrum of weather situations between clear sky and complete cloud coverage. The calibration reference is the mean air temperature and the mean relative sunshine duration recorded between 1 May and 31 August of the 10 years before the year of investigation (for details see “Help” / “Derivation of the Method”: p. 22, section 3.4) . This target value estimates the main environmental variable influencing mean metabolic rate.

TSB – the calibrated basal soil temperature as mean of the period 1 May and 31 August of the 10 years before the year of investigation. TSB is a hypothetic value indicating a situation if meteorological factors would entirely determine the mean soil temperatures in the habitat. In zero-insolation habitats (e.g., forests with a completely closed canopy), TSCmean is considered equal or almost equal to TSB. Reduction of vegetation cover or south-facing slopes, for instance, will significiantly raise TSCmean over the TSB level. In other words, positive deviations of TSCmean indicate the influence of the habitat factors vegetation structure, orography, aspect and soil material.

Errors

The standard deviation of a single-day calibration of TSCmax from the seasonal mean of all calibrations is 1.97°C in full-insolation habitats and 0.73°C in zero-insolation habitats. Averaging three single-day measurements distributed over the season reduces the mean error close to 1°C or 0.5°C respectively. When aiming to monitor an average seasonal temperature regime of a habitat, take care to measure during average structural situations: consider in particular that vegetation growth in spring and summer may cause considerable temperature variation in some habitat types – e.g., TSCmax of a moist cut meadow may drop by 4 °C within a few weeks if the mean height of grasses grows from 10 to 60 cm.

Allowed measuring period

1 May to 31 August (15 April to 15 August if vegetation development is earlier). In case of only one single-day measurement, vegetation density and height should be comparable to the seasonal mean.

Required sunshine duration

Sunshine duration on the measuring day is essential input data for *CalibSoil*. As a rule of thumb and for most situations in the field, a minimum daily sunshine duration of 9 h is required. Sunshine should last until the maximum temperature is achieved – this may be as soon as 0.30 p.m. solar time in SE-exposed full-insolation habitats or as late as 6.30 p.m. solar time in zero-Insolation habitats. In an ideal case, sunshine duration is measured by expensive sunshine sensors at a fully sun-exposed place as near as possible to the study site. Alternatively, data from the next meteorological station or a subjective estimate may be used. Subjective estimates have proved to be better than emergency solutions. Doing this, the sky must be observed until the soil temperature reaches a maximum. It is necessary simply to record the time intervals when clouds cover the sun and to calculate a relative sunshine frequency. This relative sunshine frequency is then transformed by *CalibSoil* into sunshine hours.

Determining the measuring depth

Soil temperature must be measured 35 mm below a "solid surface". In most habitats the determination of the solid surface presents no problem. This may be the true soil surface or the surface of all rather dense structures closely adhering to soil – such as moss, lichen crusts or condensed litter. However, loose and deep layers of leaf litter, for instance in a *Fagus* forest, make the determination of the position of a solid surface impossible. To have some standardisation in such cases, the thermometer sensor is inserted after compressing the litter layer with the index and middle finger of the other hand with a certain pressure. The compression force exerted by both finger tips should be about 1 kp corresponding to ± 0.5 kp /cm². It should be sufficient if one acquires beforehand a subjective feeling of this compression force by training with a balance, but manufacturing an adequate compression device is easily done. In case of strong mechanical resistance by the substrate, the puncture channel should be prepared by a steel rod having the same dimensions as the thermometer. While you maintain the same compression on the litter layer, the rod is then drawn out and afterwards the true sensor inserted into the preformed channel. As well as in this special situation, this procedure is generally recommended for hard substrates, to prevent damage of sensors.

Determining the true measuring points of the thermometers

Prior to measurement, make sure which point of the sensor head of the thermometer is the true reference point. In mercury-in-glass thermometers the true reference point is not the very tip of the thermometer but the centre of its mercury filling – i.e., the tip must be inserted significantly deeper than 35 mm! In resistance thermometers or thermoelements, the true measuring surface is usually a small cone or a slanting plane at the tip. Here, the true measuring point is approximated by the centre of mass of this cone or the centre of the plane.

Insertion is always vertical

Sensors should always be inserted in a vertical position. This is also true on steep slopes – but here a small, less steeply inclined surface point should be selected.

The number of required measuring points per habitat

The number of required measuring points per habitat depends on its structure. In very homogenous habitats, only three thermometers, positioned some two meters from each other, may be sufficient. In heterogeneous habitats, all microhabitats (surface components) of differing heating properties must be measured simultaneously. The overall-habitat soil temperature is then calculated from the data of the different microhabitats weighted by their percentage of surface cover. A total of 12 or more measuring points, with two or three points per microhabitat, may be necessary in such cases. *CalibSoil* requires as input data the mean temperature measured per microhabitat and its percentage cover.

The type of thermometers

CalibSoil does not require a recording of minimum soil temperature at sunrise of the investigation day. Hence, it is sufficient to place the thermometers a few hours before the expected incidence of maximum temperature and they can be recovered certainly by the evening of the same day. A good recording of single-day data is possible with different types of thermometers produced by different manufacturers. What is essential is only calibration, sufficient accuracy (± 0.2 °C is acceptable), and the recording of maxima. Recording of minima is welcome but not essential as *CalibSoil* provides an algorithm estimating minima and daily means. The thermometers should be able to stand stably in loose substrates and to be inserted without damage into harder soils. In very hard substrates, such as exposed bedrock, special solutions for sensor insertion are required. It is good to have at hand different types of thermometers. Mercury-in-glass thermometers with their thicker diameters and larger insertion depth stand stably stand in loose sand or soft *Sphagnum* pads but are easily damaged during transport or insertion into hard substrates. Resistance thermometers with thin sensors and big and weighty display heads do not stand stably in soft substrates but are generally more robust. Data loggers, theoretically the ideal sort of temperature recorder, must have sensors allowing a precise positioning at the 35 mm depth level and they must have recording units not affecting the measurements. Much higher acquisition costs, the need to camouflage them (or dig them in) and to control the position of the sensors accurately over a long period favours their use only when it is impossible to visit a study site at short notice to catch an unpredictable high-radiation day.

Predicting the time of incidence of the temperature maximum

Predicting the time when soil temperature reaches a maximum may be useful when the time budget of the investigator does not allow his long presence at a study site. Additionally, this knowledge may allow you to reuse the same set of thermometers twice or more on the same day if the habitats at a site differ sufficiently in their temperature dynamics. The deciding reference is solar time (ST) and “1 h p. m. ST”, e.g., means in our context one hour after the sun has passed the meridian. Knowing, for instance, that the maximum occurs at 2 h p. m. ST in an open xerothermous grassland, at 4 h p. m. ST in a meagre grassland and at 6 h p. m. ST in a *Fagus* forest, the investigator may transfer the thermometers from one locality to the other. With time given in decimal format, solar time is transformed to Central European Summer Time (CEST) by the function

$$CEST = ST + 1 + (LON-15) /15$$

where LON is geographical longitude of the study site in decimal format.

The following rules of thumb for the incidence of the temperature maximum may be applied :

(1) fully sun-exposed and open sand or rock:
1-3 h p. m. ST (SE-facing slopes a little earlier, SW-facing a little later)

(2) fully sun-exposed, semi-dry grassland with a closed field layer of 20 cm mean height:
3-5 h p. m. ST (SE-facing slopes a little earlier, SW-facing a little later)

(3) Closed grassland or closed tall herb communities of > 50 cm mean height
5-8 h p.m. ST (apect not important)

(4) closed woodland with >80 % canopy cover
5-8 h p.m. ST (aspect not important)

Hints how to get meteorological data

As of March 2012, the situation for data supply in Europe is very heterogeneous.

Switzerland
Free data from apparently each station and of each data type are provided by the IDAWEB Schweiz (https://gate.meteoswiss.ch/idaweb/login.do?language=en) .

Germany
The web site of KlimaCampus Hamburg allows a free download of daily values for 70 main stations of the Deutscher Wetterdienst (DWD) via http://icdc.zmaw.de/dwd_station.html. The site www.dwd.de/cdc allows a free download of many main stations including monthly means. Data of other stations must be ordered directly from the DWD requiring payment of usually about 50 €.

Austria
There is apparently no download possible and all data must be ordered from Section Climatology , Division Customer Service, Zentralanstalt für Meteorologie und Geodynamik , Hohe Warte 38, 1190 Wien (klima@zamg.ac.at) under payment of a project outlay („Bearbeitungsaufwand“).

Software preconditions

-- Microsoft Windows XP SP3 or later
-- Microsoft .NET Framework 3.5

Leading through the display and input schedules of *CalibSoil*

On the start page you find the two main buttons:
“Enter New Data” and “Search Meteo. Stations”.

“Enter New Data” opens a window with the required data inputs. Most of these are self-explanatory but note the following:

-- **“Geographical Latitude of Study Site”** and **“Geographical Longitude of Study Site”** are always in decimal format – i.e., 51° 54’ equals 51.90°
-- **“Cover of Tree Layer”**. This is another terminus for crown density (“Kronenschluss” in German) and must be determined by perpendicular projection against the sky, summing up trees of all heights. Either you perform this by subjective estimation (as the foresters do, which is sufficient for our purposes) or by evaluation of perpendicular canopy photos.
-- **“Cover of Bush Layer”**. Within *CalibSoil*, bushes are considered as lignified, perennial plants with a height > 80 cm and < 500 cm. Dwarf shrubs (such as *Calluna* or *Erica*) belong to the herb layer and “bushes” above this range are considered as trees.

-- **"Mean Height of Herb Layer"**. Take care to make a good estimate of the real mean – in a meadow, for instance, it is not the height of highest grasses! The moss layer does not belong to herb layer.
-- **"Azimuth of Slope"**. This is the exposure direction (aspect) of a slope of the study site following the astronomical convention: South = 0°, W = 90°, N = 180°, E = 270°.
-- **"Inclination"**. This is the angle of slope of the habitat.
-- **"Microhabitats"**. Here you have to input the measured soil temperatures and surface ratio for each microhabitat separately. With "**+**" and "**—**" below the "Microhabitat" window you can add or delete a microhabitat record. In a homogenous habitat without differing microhabitats, you have a single microhabitat with a surface ratio of 100%. The temperature value entered for a microhabitat should be the mean of at least three different measuring spots

Don't forget to click on the "Save" button upper right as there is no automatic saving.

-- **"Determine Nearest 3 Stations"**. This option proposes meteorological stations near to the study site that may be used as climate references. Note that the station list implemented in the current *CalibSoil* version may not necessarily be complete or updated – outside of Germany gaps in the list are to be expected and you are recommended to make also an independent search for the nearest stations that provide the required type of data. To run *CalibSoil*, data from at least one station are required.
-- **"15-Day Mean"** at the next meteorological station/s. Enter the mean daily air temperature at a height of 2 m during the day of your study and on the 14 days before. Also enter the sunshine hours on the study day.
-- **"10-Year Mean"** at the next meteorological station/s. Enter the mean monthly air temperatures at a height of 2 m, and the monthly sum of sunshine hours from May to August over the 10 years before the year of study – altogether 40 + 40 inputs.
-- **"Adjust Sun Hours"** is a sensitive point in the program. Although deducing air temperature conditions of a study site from data from meteorological stations has a low error even if these are rather distant, single-day sunshine conditions at a study site may differ markedly from those of even rather near stations. As a consequence, you cannot automatically take over sunshine duration data of the station or stations and you have to find a local indication using the "Adjust" dialogue.
-- **"Adjust"**. After clicking on this button, you enter a dialogue with three options:
At first you are asked: "Do you have own measurements of sunshine hours at the study site?". If you have run your own solar sensor (operating according to the 120 W m² threshold) at or near to the study site, you answer with YES and enter the data.
If you have answered NO, you are asked "Does the reported sunshine duration of at least one weather station correspond to the sunshine duration perceived at the study site?"
If you have answered YES, select the value of the most similar station.
If you have answered NO, you are presented with a guideline for determining a relative sunshine value RSV and you enter its value.

-- **"Calculate"**. After clicking on this button, you enter a dialogue with two options:
At first you are asked: "Distance-weighted calculation of relative sunshine duration SUNR?"

If there are considered two ore more meteorological reference stations and if there is no extreme orographic structuring of the landscape, you answer with YES and SUNR is calculated as the weighted mean of these stations with the weightings being inversely proportional to their distance from the study site. This should be the standard option. However, if the study site is located in an alpine region with a very strong orographic structure, a weather station situated in the same valley but being more distant may be a better reference than a less distant station which is situated in another valley behind a high mountain barrier.
In this case, you answer with NO and you are prompted to select the most adequate station.

After having done the calculation, don't forget to click on the "Save" button upper right as there is no automatic saving.

"Calculation details". Two internal calculation results , TSB and INSHA, are of more theoretical interest but they may help in checking calculation results. TSB, termed calibrated basal soil temperature, is the mean temperature achieved in zero-insolation soils and is, as a medium-term seasonal standard, correlated with standard air temperature TAS and is, on average over the season, 3.3 °C lower. INSHA is the predicted insolation of the soil surface depending on the inclination of the surface and on how much insolation remains after passage through the tree, bush and herb layers. In habitats with INSHA close to zero, TSCmean should be close to TSB. If there is a strong deviation, you should check for the reasons. One source of deviation, leading to a true error, may be an extreme fluctuation within the 15-day temperature history, which can give a wrong calibration. Another source of deviation, not signifying an error, may be influx of warm air from outside the habitat. This is particularly important if the zero-insolation habitat is only a small spot in an open landscape. For instance, soil in a dense hedgerow within a large area of arable land may have similarly low INSHA values as in a big *Fagus* forest but the soil temperatures should be significantly higher.

"Meteorological Stations" opens a window showing the geographic parameters and the WMO-ID of all the meteorological stations listed for the reference area. You may add missing stations to the list by entering all required parameters and clicking on the **"Save"** button. These new stations are then automatically considered in the next search. If a station has already served as a calibration reference for a certain soil temperature measurement, the measurement data will also be shown. Stations may be selected and their data shown by clicking into the list in the left part of the window or by entering the station name into the **"Meteo. Station"** field in the upper right.

"Calculate Insolation" opens a window to calculate the solar energy input on a surface depending on date, geographical latitude, height above sea level, direction (azimuth) and slope angle (inclination) of the habitat surface for the condition of a clear, cloudless sky. These calculations are accessory and give you a good impression about the energy input on an ideal surface throughout the year. Data may be calculated for a single day or a longer period. The output figures, the Solar Radiation Units (SRU), are relative figures of energy input and have no physically defined unit. If you click on **"Calculate"** to the right of "Output:" you get the maximum 5-minute energy input (“SRU5”), the sum of energy input throughout the day (“Insolation Index”) and the astronomically possible sunshine duration in hours (“Day Arc Sun”) of the predefined surface. Clicking on **“Calculate”** to the right of “Maximum:”, will show the maximum possible energy input on a surface for the date, as well as the geographical latitude and the height above sea level specified above. This calculation varies the slope angle (inclination) of a south-facing surface so as to maximise the potential energy input. As output you get the maximum 5-minute energy input SRUM5, the corresponding Insolation Index and the inclination of the habitat surface which yields these data.

Note: The Altitude Effect (AE) on solar radiation estimated by the *CalibSoil* software refers to total irradiance in the wavelength range between 300 and 3000 nm for clear sky conditions from April to September (northern hemisphere). The average AE is ± 10% / 1000 m from April-September. The significantly larger annual mean of ± 13% / 1000 m is caused by a high AE in winter (Blumthaler et al. 1997).

Blumthaler, M. , W. Ambach, R. Ellinger(1997):Increase in solar UV radiation with altitude. –Journal of Photochemistry and Photobiology B: Biology 39: 130-134.