

Commentary on “SoilTemp: a global database of near-surface temperature” by Lembrechts et al.

On the importance of getting fine-scale temperature records near any surface

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Abstract

The pressing need to identify the ecological consequences of climate changes boosted the development of macroecological approaches as well as climatological tools. Nevertheless, the major pitfall remains that the actual climatic conditions experienced by organisms in their microhabitat and across their home range are largely ignored. In this context, Lembrechts et al. (2020) are initiating a new global database of near-surface temperatures, especially focusing on above ground (up to 2 m) and below ground soil temperatures. This approach is welcome to assess the amplitude of microclimate change around the world and across biomes. Here, I extend this approach by highlighting that fine-scale temperature heterogeneity can be large over short times frames (minutes to hours) and short distances (centimeters to meters) in forest covers. This mosaic of microclimates likely influences the response of organisms to climate change. Further, the SoilTemp database could be expanded to the other interfaces with atmosphere.

Main text

Our climate is changing globally. The pressing need to identify the ecological consequences of these changes boosted the development of macroecological approaches as well as climatological tools (e.g., Worldclim climate data provider). These approaches revealed some of the complex trends in the response of biodiversity to global changes (Scheffers et al. 2016) and sometimes the mechanisms underlying these trends were identified (Sunday et al. 2014). Nevertheless, the major pitfall remains that the actual climatic conditions experienced by organisms in their microhabitat and across their home range are largely ignored (Pincebourde et al. 2016). The notion of microclimate is part of our daily lives and this concept was also applied to natural systems long ago to detail the abiotic conditions experienced by organisms in their microhabitat. For instance, an aphid lives at the temperature of the leaf it attacks (Pincebourde and Casas 2019) and a mussel experiences a body temperature resulting from the complex interaction of multiple environmental variables in the rocky intertidal (Helmuth 1998). In both cases, the temperature experienced *in fine* can deviate from atmospheric temperature, sometimes strongly by $>15^{\circ}\text{C}$ (Pincebourde et al. 2016). Therefore, it is crucial to identify these microclimatic deviations for any kind of microhabitat anywhere on Earth. Such a huge task inevitably calls for collaborative work to develop global databases on microclimates.

In this context, Lembrechts et al. (2020) are initiating a new global database of near-surface temperatures, especially focusing on above ground (up to 2 m) and below ground soil temperatures. Mounting such a database of soil temperatures across biomes, continents and microhabitats is the first step towards (i) the empirical quantification of the buffering property of surfaces (i.e., how much of atmospheric temperature variation is buffered at the different soil layers) and (ii) the assessment of the amplitude microclimatic change actually experienced by organisms (plants, animals, fungi and microorganisms) living in or near the ground (i.e., how much of the global/regional warming is transferred into the soil microhabitat over long temporal scales). This initiative of Lembrechts et al. (2020) is more than welcome for climate change biologists and more generally for ecologists.

Lembrechts et al. (2020) propose several environmental factors driving the surface temperature deviation to be reported in the database, including horizontal (topography, land cover type, distance to water bodies) and vertical (vegetation characteristics, snow cover, soil properties) features that are operating at the local or landscape scale. This approach is reasonable especially because most microclimatic loggers deployed around the world are

operating at these spatial scales. Nevertheless, the SoilTemp database would gain in strength and pertinence by including the micro-scale as well. Local heterogeneity in surface temperatures is important for species maintenance via various processes including behavioral thermoregulation (Woods et al. 2015). We exemplify this point based on unpublished data (from the project CANOPEE funded by Region Centre-Val de Loire, France) illustrating (near) surface temperature heterogeneity at the meter scale or below along both the vertical and horizontal gradients of a broadleaf temperate forest (Fig. 1). Along the vertical gradient of forests, different surfaces from below ground to the canopy top show quite distinct temperature signature with deviations of up to 20°C between the soil 15 cm deep and the air at the canopy surface (Fig. 1A). This gradient illustrates the buffering effect of forest understory (Zellweger et al. 2020). Canopy gaps that allow solar radiation to reach the ground can rapidly and markedly influence soil temperature, while they have little effect on air temperature at 2 m (Fig. 1 A). Therefore, over short times frames, the temperature experienced by organisms living in the soil versus at the different heights in the canopy can differ as much as macroclimate temperature varies across 20° of latitude.

In addition, soil surface temperature can be quite heterogeneous at micro-scale over the horizontal layer. The temperature at the leaf litter surface in early spring, as measured with an infrared camera, can be quite variable with a temperature range of about 16°C across a short distance of less than 1 m (Fig. 1B). This variability results from the interaction of sun angle, leaf litter microtopography, and shading effects by vegetative elements above the ground. This effect is extremely dynamics and depends on the sun course in the sky. Soil surface can quickly reach high temperature when receiving direct solar radiation. This effect influences the temperature within the soil at 5 cm below ground (Fig. 1A,B). Two dataloggers only 40 cm apart can measure soil temperatures differing by as much as 4°C due to this effect. Obviously, deploying a single temperature logger within this thermal mosaic will sample only a fraction of the local temperature range, and therefore temporal series from logger networks are better candidates to estimate these levels of thermal heterogeneity at micro-scale.

Determining the amplitude of the buffer ability of near-ground surfaces requires high temporal resolution when measuring temperatures. Lembrechts et al. (2020) are judiciously calling for “time series spanning one month or more, with temperature measurements a maximum of 4 hours apart”. In the context of meta-analysis, getting series with a temporal resolution of few hours will certainly add up to the bunch of temperature data obtained at a finer temporal resolution, thereby enriching the analysis. Nevertheless, soil temperature

recorded with a time step of > 1 hour may not provide an accurate estimate of maximal temperature experienced by some soil organisms (Fig. 1B: the duration of the temporal series is 4 hours). Acute thermal events of about 1 hour matter for ectotherms by promoting their thermal tolerance threshold (heat hardening) or by inducing irreversible physiological damage (Ma et al. 2021). A high temporal resolution may be especially important for organisms with a weak dispersal ability such as *Isotoma* Collembola which disperse by only 5 cm per week (Ojala and Huhta 2001) and which may not be able to escape from acute exposure.

The SoilTemp database focuses on temperatures near soil surfaces, including air temperature 2 m above ground and below ground temperatures (Lembrechts et al. 2020). We see this important call for data as a first step towards a more global near-surface temperature database. In the future, the call could be expanded to other types of interfaces with atmosphere including plant organ temperature (e.g., leaf surfaces and plant inner tissues such as stems, woody tissues or galls) and temperature of different layers in water bodies (ponds, rivers, wetlands). Indeed, the forest canopy is with soil one of the two key forest ‘compartments’ supporting tremendous forest biodiversity (e.g., Parmain et al. 2020) and aquatic thermal environments are still missing for global analysis (van Klink et al. 2020). Moreover, the SoilTemp database would also integrate near-surface temperatures for urban areas to analyze how the urban heat island influences temperature patterns near the ground in green areas. Urban areas can be seen as simulators of climate warming and urban surface temperature data may help to anticipate the thermal behavior of surfaces in natural areas in the future.

Given the accumulating evidence that fine-scale microclimates can play a crucial role in the fate of organisms thriving at the interface with a changing atmosphere, strong collaborative work among multiple disciplines (incl. computer and atmospheric sciences, ecology and physiology) is likely to become the streamline towards a global assessment of microclimate buffering. This empirical approach should be combined with mechanistic modelling (Maclean 2020) in particular to generate microclimatic data for places and/or periods that were not covered by dataloggers.

Figure legend

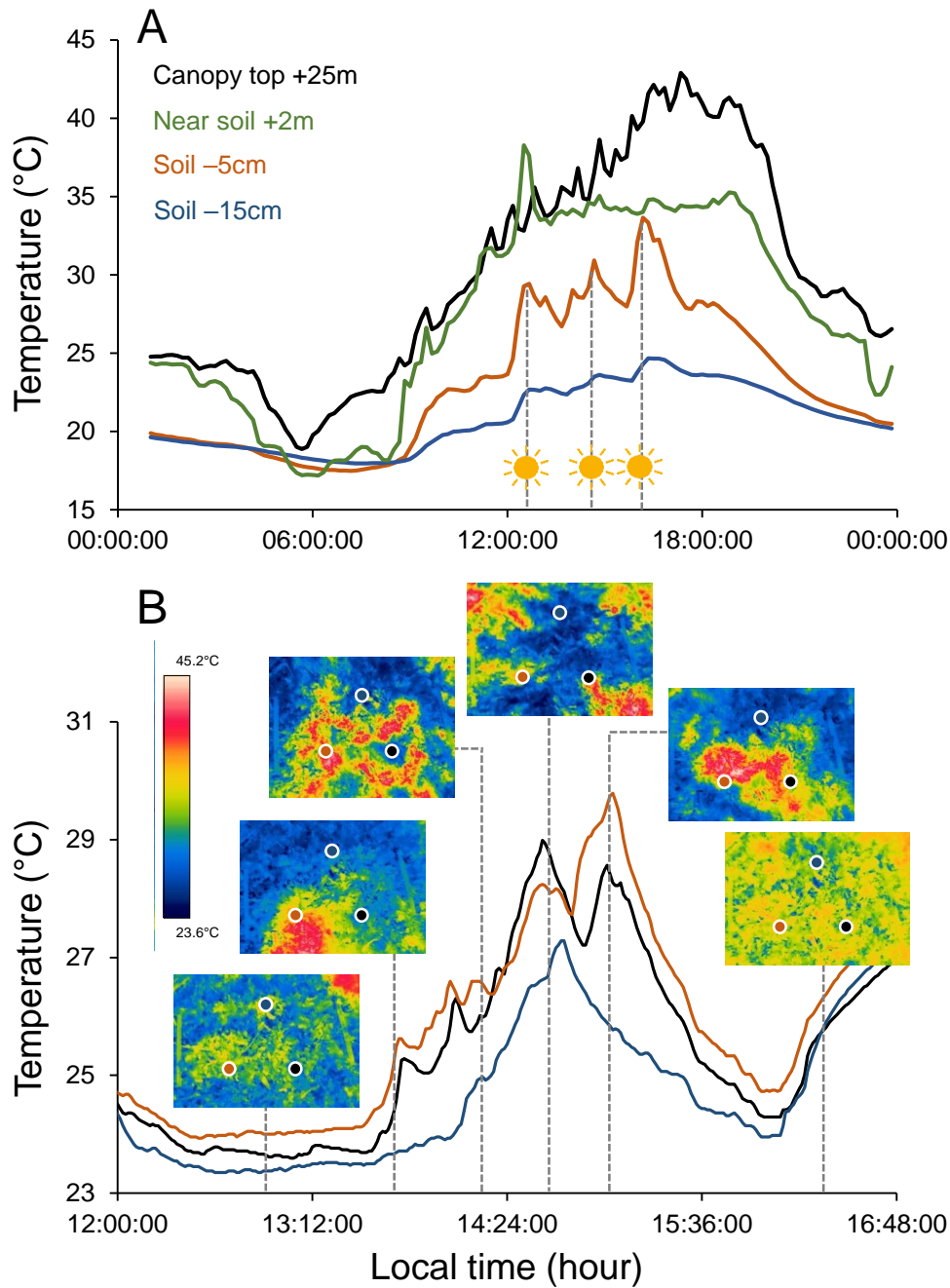


Fig. 1. Near-surface temperature heterogeneity across fine-scale vertical (A) and horizontal (B) gradients in a broadleaf temperate forest (Vierzon, France). (A) Daily dynamics of temperature (on August 26, 2019) in the soil (at 15 and 5 cm deep) and for air at 2 m and 25 m (canopy top). The three dotted lines indicate the moment at which solar radiation directly reached the soil surface. The dataloggers (Hobo Tidbit v2) were set to record temperatures every 10 minutes. The loggers measuring air temperature were shielded (Hobo solar shield RS3). (B) Temperature dynamics during a sunny day (on July 14, 2019) at -5cm underground,

measured using three dataloggers (Hobo Tidbit v2) separated by 40 cm. The dashed lines indicate when an infrared image of the leaf litter surface was taken (using an infrared camera FLIR B335). The position of the three dataloggers in these thermal images is shown by the color dots (their color corresponds to the color of the lines). In general, the thermal heterogeneity at the litter surface generates temperature deviations among the three dataloggers. The entire peak of soil temperature illustrated in this graph was linked to incoming solar radiation directly reaching the ground via a canopy gap.

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