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COMMENTARY

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Microclimatic conditions anywhere at any time!

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Many questions in global change ecology deal with large-scale patterns, with global databases of species distributions, species traits and ecosystem processes becoming increasingly available (e.g. Bruelheide et al., 2018). Current analyses of these large-scale patterns—and their predictions under anthropogenic climate change—often rely on spatially coarse-resolution global climatic data interpolated from weather station measurements. These weather stations are systematically located in open landscapes, where the wind continuously mixes the air, and are shielded from direct solar radiation, thus ignoring many climate-forcing processes that operate near the ground, at very fine spatial resolutions, and in microhabitats that vary in their terrain, exposure to winds and vegetation cover (De Frenne & Verheyen, 2016). Importantly, while these microclimatic processes often operate at fine spatial resolutions, they do affect broad-scale ecological processes like species distributions and ecosystem functioning. While climatologists did their best to remove what they consider as 'noise' in climatology, by designing a global network of standardized weather stations, they actually removed what ecologists would consider meaningful information to understand species distributions and ecosystem functioning. Ignoring this microclimatic 'noise', modulated by microhabitat conditions, when modelling species distribution and ecosystem processes results in erroneous model calibrations, and thus untrustworthy predictions of future conditions (Lenoir, Hattab, & Pierre, 2017). Several recent studies have, for example, shown that distribution models overestimate species movement and extinction in future climatic conditions as they ignore local microclimates brought up by microhabitat conditions. Indeed, when working with spatially coarse-resolution data only, one overlooks the so-called microrefugia, small pockets of favourable conditions in which species can survive the changing macroclimate (Lenoir et al., 2017).

If global change ecology wants to get its forecasts right, it is thus of utmost importance to incorporate these microclimatic processes together with macroclimate. Luckily, a myriad of new techniques and technologies are now available, ranging from in situ logging over thermal remote sensing to mechanistic models (Bramer et al., 2018). Up until now, however, most of these datasets were either limited to small spatial extents or by the coarse spatial resolution of the currently available global climatic grids (Lembrechts, Nijs, & Lenoir, 2018).

Yet, a paradigm shift is happening, and that is why we are writing this commentary. That paradigm shift is happening thanks, among others, to the work of Ilya Maclean, which culminated in a recent 'technical advances' paper in *Global Change Biology* (Maclean, 2019). In that paper, he presents the methods for providing fine-grained, hourly and daily estimates of current and future temperature and soil moisture over decadal timescales (Figure 1). For that, he builds on mechanistic models available in the 'microclima'-package in R that allow the inclusion of mesoclimatic effects (like cold-air drainage, coastal exposure and elevation) as well as microclimatic effects modulated by microtopographic variation in the terrain, vegetation cover and ground properties using energy balance equations. Combining these major methodological advances with the recent work of Kearney, Gillingham, Bramer, Duffy, and Maclean (2019), which uses similar techniques to obtain microclimate data for all past conditions from 1957 to date, opens the door for a bright microclimatic future: we can now get realistic microclimatic data for any place on earth at any spatial and temporal resolution one might wish for. And all of us ecologists should be using it.

The results of Maclean's predictions of future microclimatic conditions, at an hourly resolution, indeed indicate that there is fine spatiotemporal resolution variability in climatic changes within a landscape, driven primarily by interactions between that landscapes' horizontal and vertical features and weather conditions. Moreover, he shows that the climatic extremes under future climate change are considerably less novel, at the fine spatiotemporal resolution of microclimates, than the extremes estimated using seasonally aggregated variables. Indeed, maximum temperatures varied by almost

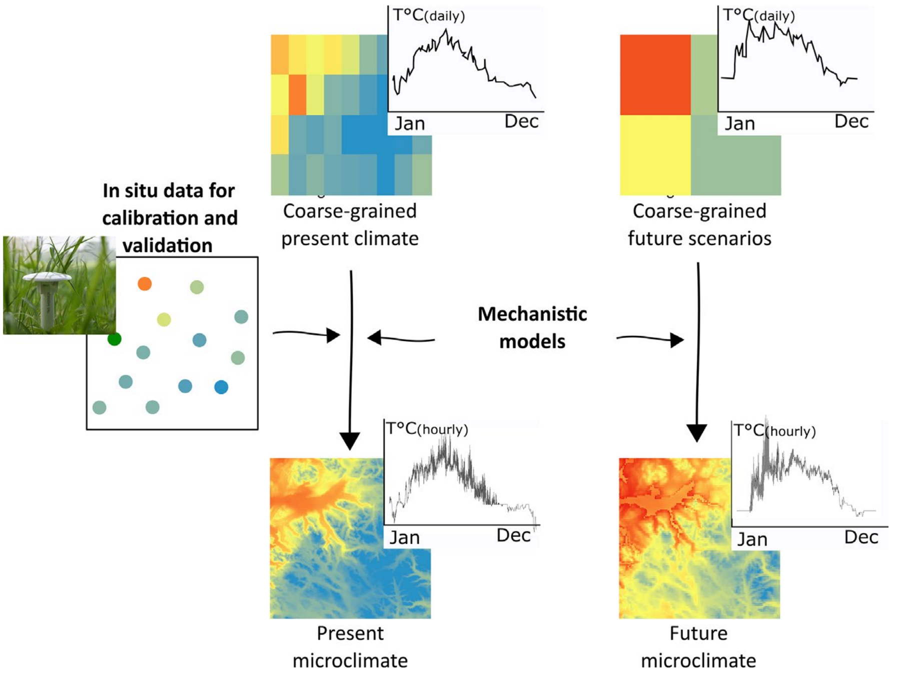

FIGURE 1 Conceptual figure summarizing the process of modelling present and future microclimatic data, as used in Maclean (2019). Present-day climate with a coarse spatiotemporal resolution (e.g. 1 km, daily averages) is converted into fine-grained microclimate data (e.g. 100 m, hourly values) using mechanistic models. These models are calibrated and validated using in situ data (time series at specific coordinates) as for example provided in the SoilTemp-database. Finally, the same mechanistic models are used to turn coarse-grained future climate scenarios with the same temporal yet a coarser spatial (12 km) resolution into future microclimate data

20°C within a 4 ha area, almost as much as the coarse-resolution models predict over an entire continent (Maclean, 2019). Climate variables derived using spatiotemporally coarse-resolution data, at best providing the mean of this 20°C temperature range mentioned above, might thus differ considerably from conditions experienced by organisms, especially the ground-dwelling ones. Using such coarse-resolution predictions thus leaves us with increased uncertainty or, even worse, yields highly erroneous predictions.

What matters even more is that many organisms (particularly small-stature plants, certain types of insects and soil microbes) experience temperatures at ground or even at the subsurface level, which can differ greatly from ambient-air temperatures traditionally used to model their distribution and performance (Lembrechts et al., 2019). It is indeed not sufficient to incorporate fine-scale climate-forcing factors by reducing the spatial resolution and cater for topographically induced changes in radiation and cold-air pooling. You also have to consider observation height, and the biases introduced by vegetation cover, snow cover and soil depth. The mechanistic modelling family from Maclean (2019) allows incorporating this vertical variability, thanks to an energy balance equation in which the difference between microclimatic and mesoclimatic reference temperature at 2 m height is modelled as a function of energy fluxes occurring at the surface.

So now, what is next in global change ecology research, given the new possibilities of modelling microclimatic conditions anywhere at any time? The framework provided by Maclean (2019) is a real game-changer for species distribution modellers aiming at predicting the impact of future climate change on the redistribution of biodiversity and its associated ecosystem services. Conservation biologists may now calibrate species distribution models (SDMs) with the right climatic conditions experienced by the organisms under study and test whether SDMs' performances increase in comparison with SDMs calibrated with coarser climatic grids. If this is the case, future predictions from SDMs based on microclimatic conditions for past, present and future will more accurately inform landscape managers and policy makers on the fate of biodiversity and its benefits for society.

However, while these mechanistic models allow us to obtain microclimatic data at any time and anywhere, their predictions still need to be validated against ground-truthed in situ measurements, for which global-scale microclimatic time series are needed (Figure 1). We thus would like to make a call to all researchers having microclimatic data records for a given location and microhabitat to share their data in a common and global geo-database. Scaling microclimate up to a global extent has up until now been challenged by the lack of coordinated efforts to unite global in situ microclimatic measurements. Indeed, while many valuable regional microclimatic datasets exist, their power has never been combined across multiple biomes. To tackle this issue and provide a common repository for microclimate researchers, we recently launched a database initiative, compiling microclimatic data from all over the world into a global geo-database. This database initiative, called SoilTemp, will allow relating patterns in soil temperature and the boundary layer to what is happening in the upper layers, and to calibrate and validate global mechanistic models of soil temperature and (micro)climate. With the microclimatic time series currently stored in the database, many of which are covering increasingly long time periods of up to a decade and more, we hope to validate predictions from current models of microclimate and eventually further inform these models to improve forecasts of microclimate data into the future.

To reach these goals, we herewith encourage scientists with in situ measured soil and near-surface temperature data to submit these to our database. Time series spanning 1 month or more are welcomed, with temperature measurements a maximum of 4 hr apart. All depths or near-surface heights, all biomes and all the data coming from different logger types and brands will be accepted, yet we especially encourage submissions from extreme cold and hot environments to fill the remaining gaps in our global coverage. More information and especially criteria for inclusion are available at soiltemp.weebly.com.

Combining mechanistic models of past, present and future microclimate together with a global geo-database of in situ microclimatic measurements will define the future of spatial ecology. And we are here to witness it.

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