Cambridge University Press
978-1-107-14562-7 - Microclimate and Local Climate
Roger G. Barry and Peter D. Blanken
Excerpt
More information

1
Introduction

This chapter starts by defining micro- and local climates. It then outlines the scope of the book, and this section is followed by a survey of the historical development of these fields of study. The central problem of scales of local and microclimates is then addressed, and the chapter concludes with the results of a case study of microclimatic variations.

A. Definitions

Climate is typically described from standard measurements of temperature and humidity recorded by instruments exposed in a meteorological shelter (Stevenson screen) at a height of about 1.5–2 m. Wind velocity is recorded on a mast at a height of 10 m. However, conditions change rapidly in the underlying air layer immediately above ground where plants, animals, and insects live. In the case of forest canopies, the effective surface on which atmospheric processes operate is elevated well above the ground. The climate of these complex environments cannot be determined from the standard meteorological measurements, and hence special observations and a whole theoretical framework are required to describe them. This is the domain of micrometeorology and microclimatology.

Microclimatology is the study of climates near the ground and in the soil, the factors that affect them, and the relationships and interactions between plants, insects, and other animals and their local environment. Microclimates are usually defined vertically in terms of the plant canopy height and so range from a few centimeters in tundra areas to about 50 m in tropical rain forests. Horizontally, they may extend between a meter and several kilometers. Micrometeorological processes operate on a time scale of seconds to minutes and spatial scales of centimeters to a few hundred meters (see Figure 1.1).

Microclimatic phenomena involve climatic averages (hours to years) on these same spatial scales. Scale concepts in climatology (Barry, 1970) illustrate the spatial and temporal characteristics of microclimates.

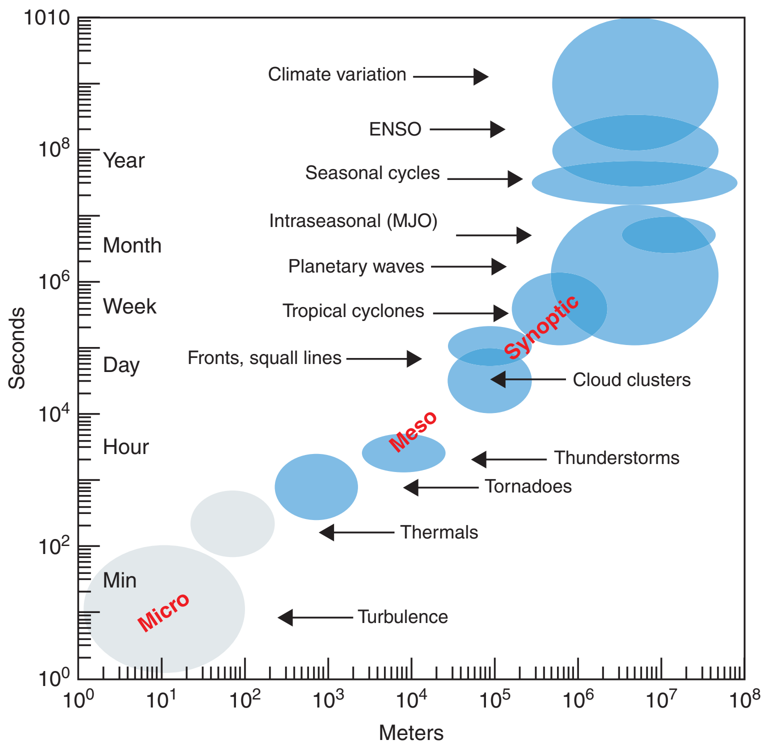

Figure 1.1. The space and time scales of meteorological phenomena illustrating the micro, meso, and synoptic scales.
Source: The COMET program, UCAR

Baum and Court (1949) defined microclimatology as the study of the geographical distributions, both horizontally (up to a few kilometers) and vertically, of air layers near the ground and the understanding of their physics. However, this appears to merge micro- and topoclimatology. Contemporary definitions of microclimate are focused on the critical layer of the interface between the surface and atmosphere, where the boundary conditions have a large impact not only on the troposphere, but also on the abiotic conditions for life itself. This layer where the majority of energy and mass exchange occurs extends from a few meters above to a few meters below the air-surface interface. Because of this relatively small scale, and the large variation that can occur spatially and temporally within this critical zone, the term "microclimate" has often been adopted in reference to the study of the long-term atmosphere-surface properties within this zone.

Microclimates have typically been studied empirically in specific situations. Most studies examine differences within a vegetation or crop canopy, or around a boulder, as well as conditions in the upper soil layers. Microclimatology therefore involves meteorology, soil physics, and the ecology and physiology of plants and animals. We are concerned primarily with the exchanges of energy and water between the atmosphere and different natural and built surfaces and their orientation and slope.

Local climates, also called topoclimates, are identified on a horizontal scale of hundreds of meters to ~10 km (areas < 100 km^2). They are primarily determined by elements of topography – valley bottoms, slopes, ridge tops – as well as the built environments of cities. Their vertical dimension is the planetary boundary layer that varies diurnally between about 500 and 1,500 m. In 1949 Knoch introduced the concept of landscape climate (*Geländeklima*) on a scale of 1:25,000. He defined it as the local climate under the influence of the local relief. Troll (1950) referred to it as the "topographical climate," but it has subsequently been translated as topoclimate. That term was introduced by Thornthwaite (1953), who defined it as the climate of a very small space.

B. The Scope of the Book

This text covers microclimates in Part I and local climates in Part II. Chapter 2 examines the microclimatic elements – temperature, moisture, wind, carbon dioxide, the carbon and nitrogen cycles, and pollutants. Chapter 3 describes the theory and methods for observing microclimates. Chapter 4 presents the basics of radiation. Chapter 5 describes the terms of the energy balance at the surface. Chapter 6 treats the monitoring and modeling of radiation and the energy balance through remote sensing and land surface models. Chapter 7 describes microclimatic conditions in the major types of land cover (tundra, grassland, farmland, wetland, and forests) while Chapter 8 extends this to lakes, rivers, snow cover, mountains, and cities. We illustrate the characteristics of microclimates in different types of canopy and different macroclimates and their variations with season and time of day. Chapter 9 on bioclimatology focuses on how microclimate affects living organisms, especially humans. Part II presents the characteristics of the major categories of local climate. Chapter 10 treats urban climates. Chapter 11 examines topoclimatic effects on microclimates. Part III (Chapter 12) examines the impacts of climate change on microclimates.

C. Historical Development

Microclimatology had its origins in the later nineteenth century with temperature observations relating to agriculture. One of the earliest microclimatic studies was carried out on soil temperatures by Kerner (1891) in the Inntal and Gschnitztal, Austria. In Finland, Homén (1893, 1897) published extensively on soil and air temperatures, giving special attention to night frosts, and a detailed paper on soil temperatures and radiative exchanges. Kraus (1911) wrote a book on soils and small-scale climate based on observations near Karlstadt-am-Main, Germany. Baum and Court (1949)

Table 1.1. Number of Citations of Microclimatological Temperature Studies by Region between the Years 1920–9 and 1930–9

Region	1920–9	1930–9
Austria and Germany	29	49
North America	13	10
England and India	12	10
Russia	6	10
All others	6	9

Source: From Baum and Court (1949).

list citations of microclimatological temperature studies by region for 1920–9 and 1930–9, showing the dominance of the German-speaking world (Table 1.1):

Rudolf Geiger wrote the first book (in German) on *The climate near the ground* in 1927. He published a fourth English edition in 1961, and this was updated and extended by Geiger et al. (2003). O. G. Sutton (1953) published *Micrometeorology*, treating the physical processes. Slatyer and McIlroy (1961) at CSIRO in Australia published *Practical microclimatology*. Berényi (1967) published a text in German on microclimatology. Gol'tsberg (1969) published *Microclimates of the USSR*. N. Rosenburg et al. (1983), at the University of Nebraska, published *Microclimate: The biological environment*. Bailey et al. (1997) published *Surface climates of Canada*. Ecological works have appeared in recent years. Jones (1992) published *Plants and microclimate*. Campbell and Norman (1998) published *An introduction to environmental biophysics*, which has chapters on plants, animals, and humans and their environments. Bonan (2008) wrote an *Ecological climatology* and Monson and Baldochhi (2014) published *Terrestrial biosphere-atmosphere fluxes*, both from a plant ecological background. Monteith and Unsworth (2014) published a fourth edition of *Principles of environmental physics*: *Plants, animals and the atmosphere*.

Books on local or topoclimates include M. M. Yoshino's (1975) *Climate in a small area*, *The atmospheric boundary layer* by J. R. Garratt (1994), and *Boundary layer climatology* by T. R. Oke (2002).

D. A Central Problem of Microclimatology

The need to relate microclimates and macroclimates quantitatively has been pointed out many times, as processes acting on the small scale should integrate to the larger scale. Holmes and Dingle (1965) addressed this question and noted that there are three broad approaches to the problem. The first is the analog method. Small-scale conditions can be extrapolated if radiation, shade, slope, moisture, and so on, are comparable between locations. The second method is by linear correlation, with which the degree of dependence of microclimatic variables on macroclimatic factors is determined. Multiple and partial correlation techniques can be employed to determine the effect of a single variable independently of the effect of other variables. Non-linear data have to be linearized before being analyzed. The third approach is by building physical models.

Scale issues are of great importance in microclimatology. Franklin et al. (2013) produced climate data sets by separately downscaling 4 km climate models to three finer resolutions based on 800, 270, and 90 m digital elevation models and deriving bioclimatic predictors from them. As climate-data resolution became coarser, statistical downscaling models (SDMs) predicted larger habitat area with diminishing spatial congruence between fine- and coarse-scale predictions. These trends were most pronounced at the coarsest resolutions and depended on climate scenario and species' range size. On average, SDMs projected onto 4 km climate data predicted 42 percent more stable habitat (the amount of spatial overlap between predicted current and future climatically suitable habitat) compared with 800 m data. They found only modest agreement between areas predicted to be stable by 90 m models generalized to 4 km grids compared with areas classified as stable on the basis of 4 km models, suggesting that some climate refugia captured at finer scales may be missed using coarser scale data.

Sears et al. (2011) point out that models used to predict shifts in the ranges of species during climate change rarely incorporate data resolved to <1 km^2, although most organisms integrate climatic drivers at much smaller scales. Furthermore, variation in abiotic factors ignores thermoregulatory behaviors that many animals use to balance heat loads.

A recent paper sets out the problem of relating microclimatic conditions experienced by fauna and flora to standard climatic data (Potter et al., 2013). The researchers illustrate the problem by infrared mapping of surface temperature in the Loire River valley, at scales ranging from 10 to 150 cm, over a single patch of grass and forbs. Higher resolution data show a shift in the frequency distribution toward higher temperatures. They also show that there is a scale difference of the order of three orders of magnitude between the size of plants, and four orders of magnitude between organisms, on the one hand, and conventional climatic data (1 or 10 km), on the other. This raises the question of how best to assess the microclimatic conditions affecting the organisms without specifically tailored measurements. We can illustrate this by a case study carried out in the 1940s.

E. A Case Study

For a small valley in central Ohio, Wolfe et al. (1943) found large local differences in temperature conditions in woodrat (*Neotoma*) habitats (see Tables 1.2, 1.3 and 1.4).

The range in absolute minima was from – 25 °C in a frost pocket to +32.5 °C in leaf litter in a cove in January with corresponding values in September of 29 °C and 52 °C.

Absolute monthly maxima had a 19 °C range between sites in January, but a 41 °C range in August. The frost-free period ranged from 124 days in the frost pocket to 235

Table 1.2. Absolute Monthly Minimum Temperatures (°C) at *Neotoma* Habitats

	JAN	SEPT
Frost pocket	–25.0	29.0
Lower NE slope	–19.5	38.0
Upper NE slope	–15.5	42.5
Ridge top	–19.0	44.5
Covehead	–16.0	40.0
Crevice	+10.0	54.0
Leaf-litter (cove)	+32.5	52.0

Table 1.3. Absolute Monthly Maximum Temperatures (°C) at *Neotoma* Habitats and at Lancaster Weather Service Office 25 km from the *Neotoma* Sites

	J	F	M	A	M	J	J	A	S	O	N	D
Lancaster	13	16	17	31	33	35	39	29	33	22	22	19
Cliff top	20	22	29	39	43	43	45	47	46	42	29	23
Cove	9	6	9	27	20	23	24	24	25	23	14	13
Red maple	13	12	16	32	30	31	31	31	28	27	21	17
Chestnut oak	12	16	18	32	32	31	32	34	30	30	24	19
Hemlock	15	12	14	28	31	29	32	32	28	29	24	18

Table 1.4. Length of the 1941 Frost-free Period at *Neotoma* Sites and at Lancaster

	Spring Last Frost	Fall First Frost	Frost Free Days
Frost pocket	25-May	26-Sep	124
Lower NE slope	14-May	11-Oct	150
Upper NE slope	22-Apr	29-Oct	190
Cove	3-Apr	11-Nov	209
Crevice	3-Apr	26-Nov	235
Lancaster	5-May	26-Sep	144

in a crevice. The number for the Lancaster weather station was only 144 days, close to the 150-day value for the lower northeast slope site (Table 1.4).

A further issue in describing ecological niches arises in the temporal domain. Kearney et al. (2012) argue that data collection at a daily time interval is required to prevent biases in environmental predictions. In some cases, hourly data may be important.

Suggitt et al. (2011) note that species sometimes survive where the average background climate appears unsuitable, and equally may be eliminated from sites within apparently suitable grid cells where microclimatic extremes are intolerable. Local vegetation structure and topography can be important determinants of fine-resolution microclimate. They show that habitat type (grassland, heathland, deciduous woodland) is a major modifier of the temperature extremes experienced by organisms. They recorded differences among these habitats in north Yorkshire, United Kingdom, of more than 5 °C in monthly temperature maxima and minima, and of 10 °C in thermal range in September and January, on a par with the level of warming expected for extreme future climate change scenarios. Temperature minima were around 5 ° C lower in grassland and heathland than under woodland canopy in both September and January, and maxima were around 5 ° C higher in these habitats in September, when the woodland was in leaf. Comparable differences were found in relation to variation in local topography (15° slope and south/north aspect) in Lake Vyrnwy, Wales, and the Peak District of Derbyshire. Maximum temperatures in September were 6–7 °C higher on south- compared with north-facing slopes. However, mean temperatures were not affected.

References

Bailey, W. G., Oke, T. R., and Rouse, W. R. 1997. *Surface climates of Canada*. Montreal: McGill-Queen's Press.

Barry, R. G. 1970. A framework for climatological research with particular reference to scale concepts. *Inst. Brit. Geogr. Trans.* 49, 61–70.

Baum, W. A., and Court, A. 1949. Research status and needs in microclimatology. *Trans. Amer. Geophys. Union*, 30, 488–93.

Berényi, D. 1967. *Mikroklimatologie: Mikroklima der bodennahen Atmosphäre*. Stuttgart: Gustav Fischer Verlag.

Bonan, G. 2008. *Ecological climatology: Concepts and applications*. Cambridge: Cambridge University Press.

Campbell, G. S., and Norman, J. M. 1998. *An introduction to environmental biophysics*, 2nd ed. New York: Springer-Verlag.

Franklin, J. et al. 2013. Modeling plant species distributions under future climates: How fine scale do climate projections need to be? *Global Change Biol.* 19, 473–83.

Garratt, J. R. 1994.*The atmospheric boundary layer*. New York: Cambridge University Press.

Geiger, R., Aron R. H., and Todhunter, P. 2003. *The climate near the ground*, 6th ed. Lanham, MD: Rowman & Littlefield.

Gol'tsberg, I, A. (ed.) 1969. *Microclimate of the USSR*. Jerusalem: Israel Program for Scientific Translations.

Holmes, R. M., and Dingle, A. N. 1965. The relationship between the macro- and microclimate. *Agric. Met.* 2, 127–33.

Homén, T. 1893. Bodenphysikalische und meteorologische Beobachtungen mit besonderer Berücksichtigung des Nachtfrostphänomens. *Finlands Natur och Folk* 53–4, 187–415.

Homén, T. 1897. Der tägliche Wärmeumsatz im Boden und die Wärmestrahlung zwischen Himmel und Erde. *Acta Soc. Sci. Fenn*. 23(2):1–147.

Jones, H. G. 1992. *Plants and microclimate: A quantitative approach to environmental plant physiology*. Cambridge: Cambridge University Press.

Kearney, M. R., Matzelle, A., and Helmuth, B. 2012. Biomechanics meets the ecological niche: The importance of temporal data resolution. *J. Exper. Biol.* 215, 922–33.

Kerner, A. 1891. Die Änderumg der Bodentemperatur mit der Exposition. *Sitzungsbericht d. Akademie d. Wissensschaft, Wien* 100, 704–29.

Knoch, K. 1949. Die Geländeklimatologie, ein wichtiger Zweig der angewandten Klimatologie. *Berichte deutsch. Landeskunde* 7:115–23.

Kraus, G. 1911. *Boden und Klima auf kleinem Raum*. Jena: Fischer.

Monson, R., and Baldochhi, D. 2014. *Terrestrial biosphere-atmosphere fluxes*. New York: Cambridge University Press.

Monteith, J. L. (ed.) 1975. *Vegetation and the atmosphere.* Vol. 1. *Principles.* London: Academic Press.

Oke, T. R. 2002. *Boundary layer climatology*. London: Routledge.

Potter, K. A., Woods, H. A., and Pincebourde, S. 2013. Microclimatic challenges in global change biology. *Global Change Biol*. 19, 2932–9)

Rosenburg, R. J., Blad, B. L., and Verma, S. B. 1983. *Microclimate: The biological environment*. New York: J. Wiley & Sons.

Sears, M. W., Raskin, E., and Angilletta, M. J., Jr. 2011. The world is not flat: Defining relevant thermal landscapes in the context of climate change. *Integrat. Compar. Biol.* 51, 666–75.

Slatyer, R. O., and McIlroy, I. C. 1961. *Practical microclimatology*. Melbourne, Australia: CSIRO.

Suggitt, A. J. et al. 2011. Habitat microclimates drive fine-scale variation in extreme temperatures. *Oikos* 120, 1–8.

Sutton, O. G. 1953. *Micrometeorology*. New York: McGraw-Hill.

Thornthwaite, C. W. 1953. Topoclimatology. *Proceedings Toronto Meteorological Conference.* London: Royal Meteorological Society, pp. 227–32.

Troll, C. 1950. Die geographische Landschaft und ihre Erforschung. *Studium generale* 3, 163–81.

Wolfe, J. N. et al. 1943. The microclimates of a small valley in central Ohio. *Trans. Amer. Geophys. Union* 24, 154–66.

Yoshino, M. M. 1975. *Climate in a small area: An introduction to local meteorology*. Tokyo: University of Tokyo Press.

Part I

Controls of Microclimate

Chapter 2 introduces the microclimatic elements and the methods and instruments used to observe them are described in Chapter 3. The following two chapters treat radiation and the energy balance. Chapter 6 examines monitoring and modeling of radiation and energy balance via remote sensing and land surface models. Chapters 7 and 8 discusses microclimates of different vegetated environments and of physical systems. Chapter 9 describes the field of bioclimatology.

Cambridge University Press
978-1-107-14562-7 - Microclimate and Local Climate
Roger G. Barry and Peter D. Blanken
Excerpt
More information