***Lecture 1. Introduction and Overview***

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ESPM/EPS 129, Biometeorology
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Lecture 1 Outline

1. Introduction: What is Biometeorology?
2. Goals of the Course, Philosophy and Expectations
3. Course Outline

## L1.1 Introduction

**Biometeorology** involves the study of interactions between the physical environment and all of Life's forms, including terrestrial and marine vertebrates, invertebrates, plants, funghi and bacteria. In ESPM/EPS 129, we will focus on a narrower aspect of biometeorology: 'how the terrestrial biosphere breathes?'

Principles taught in this course will serve students interested in quantitative and qualitative aspects of environmental sciences. Lectures draw on principles derived from a diverse but interconnected set of fields like atmospheric science, ecosystem ecology, plant physiology, biogeochemistry, hydrology, soil physics, agriculture and forestry. Agricultural and Forest Management problems that require biometeorological information include integrated management of pests, frost and spray drift, irrigation scheduling, crop modeling, vineyard, orchard and plantation site selection, optimal crop design, wind breaks, and cultural practices (e.g. tillage practice, row orientation and soil mulching). Science problems using biometeorological principles and data involve the predicting and diagnosing weather and climate, biogeochemical cycles of carbon, water and nutrients, water balance of watersheds and the growth and dynamics of forests and ecosystems.

**L1.2 Topic Overview**

A link between **climate** and **vegetation** have long been recognized by farmers, foresters and playwrights for hundreds, if not thousands, of years. The word **climate** is coined from the Greek word for slope, '*klima*'. The Greeks understood that different types of vegetation and weather occurred on different hill slopes.

Citations to plant-atmosphere interactions can also be drawn from more contemporary literature. In the play, **Uncle Vanya** by Anton Checkov (1899), the Doctor refers to plants and climate, with a modern sense:

> *"... forests tremble under the axe, millions of trees are lost, animals and birds have to flee, rivers dry out, beautiful landscapes are lost forever.....waters are polluted, wildlife disappears, the climate is harsher...".*

In a latter passage he says:

> *"...the forest teaches us to appreciate beauty, it softens the harshness of the climate",*

The physical status of the atmosphere is defined by its **temperature**, **humidity**, **wind speed**, and **pressure**. But how does the atmosphere maintain its physical state? To answer this question we must assess the fluxes of **heat**, **energy** and **momentum** into and out of the atmosphere, which is analogous to studying the flows of water into and out of a bathtub to determine the level of water inside.

For an illustrative example, let's consider the factors that control **atmospheric humidity** (Figure 1). Its content in the atmosphere depends on gains by surface evaporation and losses by precipitation (rain, snow) and dew formation. The pertinent question asked by the biometeorologist is: what controls evaporation? To answer this question we must start invoking explanations that involve plants. Plants intercept **sunlight** and the intercepted sunlight heats the soil and leaves and drives transpiration and evaporation. Plants also exert drag on the **wind.** This alters turbulent mixing and the transfer of moisture from the surface to the atmosphere.

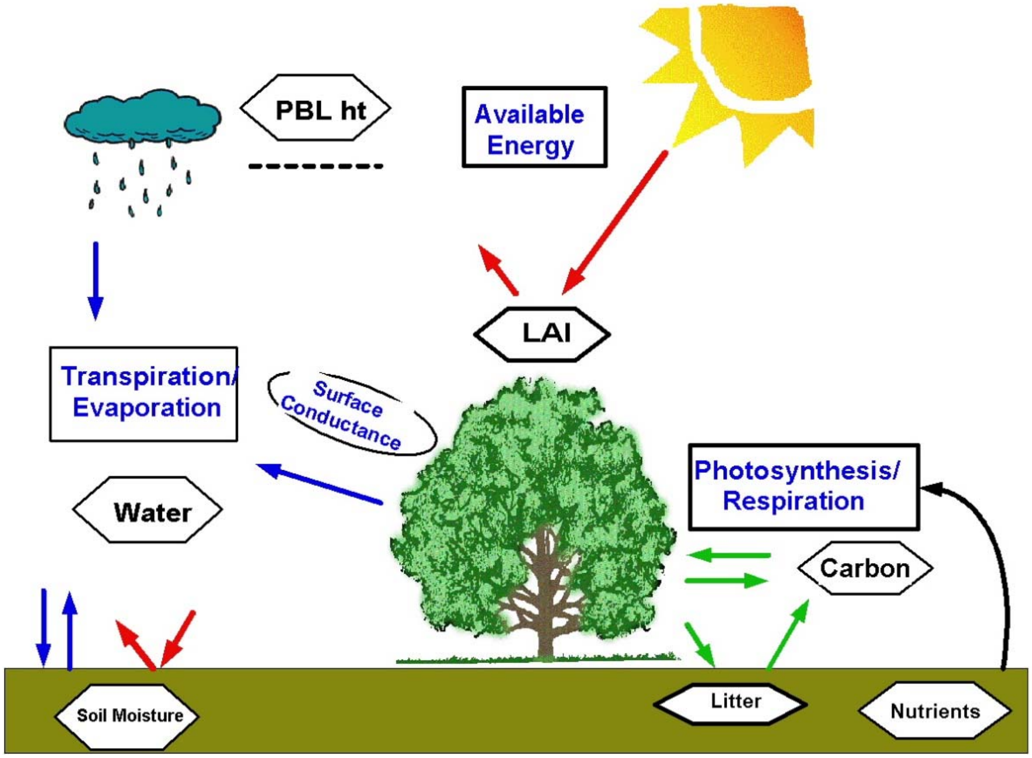


**Figure 1 Links between plants and the flow of heat, water, CO2 and sunlight.**

The ability of plants to exert an influence on the humidity budget of the atmosphere also depends upon how plants respond to their environment. The **humidity** of the air alters the opening of stomata on leaves and rates of transpiration. The heat budget and the consequential **temperature** of the leaves controls respiration (leaves, roots, microbes), photosynthesis, trace gas volatilization, saturation vapor pressure, plant growth, kinetic rates of biochemical reactions. **Sunlight** drives photosynthesis, which is linked to stomatal conductance and growth. Photosynthesis and photorespiration depend upon $CO_2$ levels. Finally, if moisture in the atmosphere condenses, it forms clouds and these clouds can **precipitate**. On climatic time scales, the water balance of the soil affects transpiration, stomatal conductance, photosynthesis, soil respiration, plant growth, plant competition, species and leaf area.

The rates at which trace gases and energy are transferred between the biosphere and atmosphere depend upon a **complex** and **non-linear** interplay among physiological, ecological, biochemical, chemical and edaphic factors and meteorological conditions. Contemporary theories consider the exchanges of **energy** and **mass** in concert. Flows of energy need to be calculated because the biosphere requires energy to perform work. Gas exchange activities requiring energy and work include biosynthesis, evaporation, transport of nutrients and carbon dioxide fixation. Concurrently, these activities require flows of **substrate** material. Water and carbon and nitrogen based compounds are the most important forms of matter for the sustenance of life.

**Scale** is an important concept we must concern ourselves with when studying biometeorology. To understand why, let's consider the functioning of a plant canopy, 1 m tall. It consists of leaves, an order of magnitude smaller, and it is the functioning of the leaves, a smaller scale phenomenon, that helps us understand the functioning of the canopy. Now the environment imposed on the canopy comes from a much larger scale, that of the planetary boundary layer and regional weather, with scales of kilometers.

Another concept to consider is **emergent processes**. As we transcend scales new processes emerge, while others may become less important. For example, the net exchange of water vapor at the canopy scale is not simply the average rate of transpiration of a leaf multiplied by the number of leaves and their area. We must also consider soil evaporation. In addition, as one adds more and more leaves, their contribution to canopy evaporation diminishes, as their upper neighbors have already harvested most of the photons and solar energy that drives evaporation.

Issues relating to scale, non-linear, coupled processes and emergent processes are important as they are attributes of **complex systems**, which are deterministic, but can have chaotic responses, and are sensitive to initial conditions.

The plant, weather and climate processes of interest are associated with a huge range of time and space scales.

Space scales of interest include:

1. **cell**: microns ($10^{-6}$m)
2. **leaf**: 0.01 to 0.1 m (needles to broad-leaves)
3. **plants and vegetation canopies**: 0.1 to 100 m (grass to redwoods)
4. **surface boundary layer** (50 to 1000m): scale of individual fields
5. **planetary boundary layers** (100 to 3000m): scale of the planetary boundary layer, where the earth surface affects the properties of the overlying atmosphere.
6**. landscape**: (1 km to 10 km): patch size of mosaic of extended fields, lakes and forests. Patches are large enough to affect convection and advection.
7. **region to globe** (100 km to 10000km): the scale of biomes, continents and oceans, scales of atmospheric waves, fronts and storms

Temporal scales of interest to us include:

**1-10 hz**: sunflecks and wind fluctuations:
**30-500 s**: coherent turbulent structures and sun patches:
**100 to 3000 s**: photosynthetic and stomatal inductance
**3600-86400s**: hourly and diurnal movement of earth/sun, water movement through stems, convective cloud generation and dissipation:
**~7 days**: weekly sequence of frontal passages, swings in temperature, humidity
**60 to 120 days**: season variations in phenology, growth, adaptation, drought, frost, soil temperature wave
**year:** 365 days: summation of seasonal effects

**decade**: climate, inter-annual variability, El Nino, volcanos).

Overall, spatial and temporal information, of interest to biometeorologists span 8 to 10 orders of magnitude ($10^{-6}$ to $10^4$ m; $10^{-2}$ to $10^6$ s).

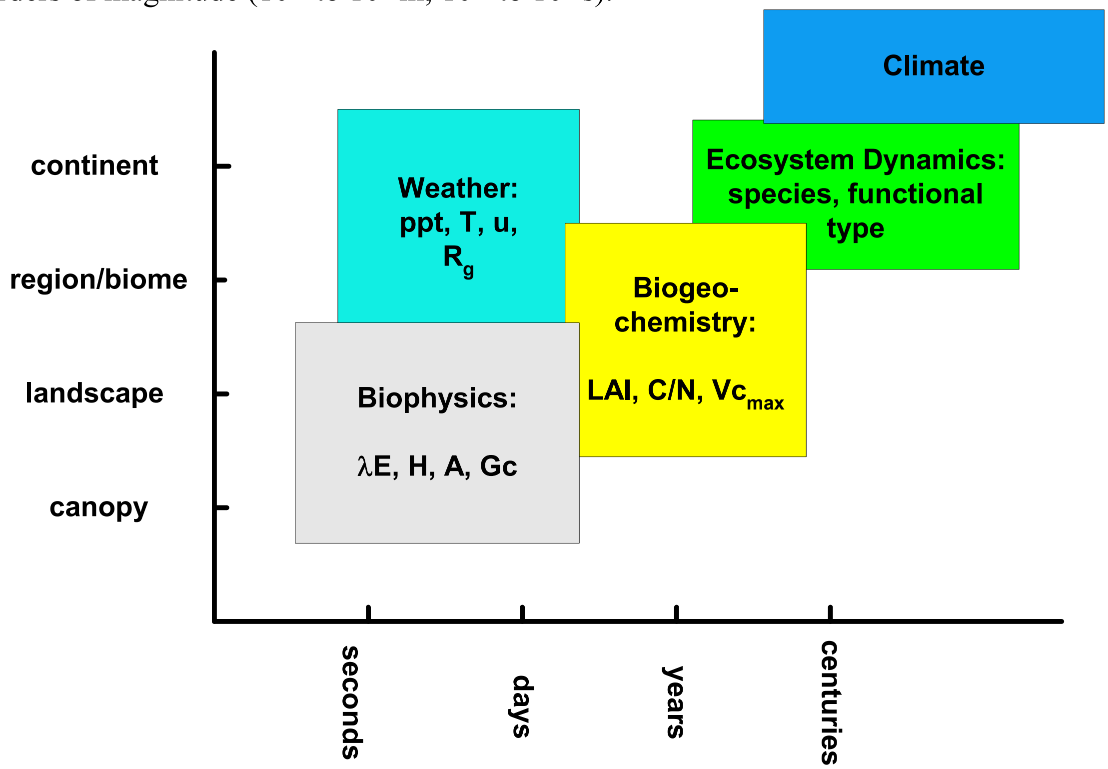


**Figure 2 Conceptual diagram showing the link between biometeorological processes and time and space scales**

### Points to Ponder:

Does biodiversity and species matter when considering plant microclimates and mass and energy exchange?

How does the plant microclimate and mass and energy exchange differ by substituting an evergreen forest with a deciduous forest?; by substituting a forest with a grassland?

How has the evolution of the Earth's climate affected the evolution of plant physiognomy and ecosystem structure and function? Does leaf size, for instance, correlate with water balance and climate?

### Summary

- Physical attributes of a canopy include leaf area index, canopy height, and leaf size.
- Physiological attributes of a canopy include photosynthetic pathway, stomatal distribution (amphi or hypostomatous)

- Structural and functional properties of plant canopies alter: 1) wind and turbulence within and above the canopy, **by exerting drag**; 2) the **interception and scattering of photons** throughout the canopy; 3) the **heat load** on leaves and the soil; 4) the **physiological resistances** to water and $CO_2$ transfer and 5) the **biochemical capacity** to consume or respire carbon dioxide.
- The physical and physiological attributes of a canopy can vary in space (vertically and horizontally) and in time (seasonally and decadally).

**References/Bibliography**

Baldocchi DD, Wilson KB, Gu L (2002) Influences of structural and functional complexity on carbon, water and energy fluxes of temperate broadleaved deciduous forest. *Tree Physiology*. **22**, 1065-1077.

Breuer L, Eckhardt K, Frede H-G (2003) Plant parameter values for models in temperate climates. *Ecological Modelling* **169**, 237-293.

Horn HS (1971) *The Adaptive Geometry of Trees* Princeton Univeristy Press.

Myneni RB, Nemani RR, Running SW (1997) Estimation of global leaf area index and absorbed par using radiative transfer models. *Ieee Transactions on Geoscience and Remote Sensing* **35**, 1380-1393.

Nobel PS (1999) *Physicochemical and Environmental Plant Physiology* Academic Press.

Norman JM, Campbell GS (1989) Canopy Structure. In: *Plant Physiological Ecology*.

Parker GG (1995) Structure and Microclimate of Forest Canopies. In: *Forest Canopies*, pp. 73-106.

Ross J (1980) *The Radiation Regime and Architecture of Plant Stands.* Dr. W Junk, The Hague.

Saugier B, Roy J, Mooney H (2001) Estimations of global terrestrial productivity: converging toward a single number. In: *Terrestrial Global Productivity* (ed. J Roy BS, HA Mooney), pp. 543-557. Academic Press.

Sprugel DG (1989) The Relationship of Evergreenness, Crown Architecture, and Leaf Size. *American Naturalist* **133**, 465-479.

**L1.6 Educational Resources**

**Key Journal in the Field**

Main Journals

*Agricultural and Forest Meteorology*
*Boundary Layer Meteorology*
*Journal of Geophysical Research, Biogeosciences*
*Plant, Cell and Environment*

Journals with Occasional Articles

*Global Change Biology*
*Biogeosciences*
*Journal of Applied Meteorology*
*Tree Physiology*
*Journal of Hydrology*
*Water Resources Research*
*Oecologia*
*Ecological Applications*
*Ecology*
*Quarterly Journal of the Royal Meteorological Society*
*Atmospheric Environment*
*International journal of Biometeorology*

**Key Web pages**

**Key Societies and Organizations with Activities in Biometeorology and Agricultural and Forest Meteorology:**

American Meteorological Society: http://www.ametsoc.org/AMS/

American Geophysical Union: http://www.agu.org/

Ecological Society of American: http://esa.sdsc.edu/
Physiological Ecology Section: http://www.biology.duke.edu/jackson/ecophys/

International Society of Biometeorology: http://www.es.mq.edu.au/ISB/

American Agronomy Society: http://www.agronomy.org/

International Society for Agrometeorology: http://www.agrometeorology.org/

World Meteorological Organization, Commission for Agricultural Meteorology: http://www.wmo.ch/web/wcp/agm/agmp.html

Biospheric Aspects of the Hydrological Cylcle, IGBP: http://www.pik-potsdam.de/~bahc/

Canadian Society of Agricultural Meteorology: http://www.uoguelph.ca/~csam/

**Key Text books, Biometeorology, Micrometeorology, Environmental Physics, Ecophysiology, Ecohydrology.**

Arya, S. P. 1988. Introduction to Micrometeorology. Academic Press.

Bonan, G. 2002. Ecological Climatology. Cambridge University Press

Campbell,G.S. and Norman, J.M. 1998. An Introduction to Environmental Biophysics. Springer.

Eagleson P.S. 2002. Ecohydrology. Cambridge University Press.

Foken, T. Micrometeorology. Springer.

Garratt, J.R. 1992. The Atmosphere Boundary Layer. Cambridge Press.

Grace, J. 1983. Plant-Atmosphere Relations. Chapman and Hall.

Jones, H.G. 1992. Plants and Microclimate. Cambridge Press

Kaimal, J.C. and J.J. Finnigan. 1994. Atmospheric Boundary Layer Flows: Their Structure and Measurement. Oxford Press.

Larcher W. 1975. Physiological Plant Ecology. Springer-Verlag. Berlin. 252 pp.

Monson, R. and Baldocchi, D.D. 2014. Terrestrial Biosphere-Atmosphere Fluxes. Cambridge.
http://ebooks.cambridge.org/ebook.jsf?bid=CBO9781139629218

Monteith, J.L. and M.H. Unsworth. 1990. Principles of Environmental Physics. E.A. Arnold.

Nobel, P.S. 1991. Physiochemical and Environmental Plant Physiology. Academic Press

Oke, T.R. 1987. Boundary Layer Climates. Metheun.

Panofsky, H.A. and J.A. Dutton. 1984. Atmospheric Turbulence. Wiley and Sons, 397 pp.

Stull, R.B. 1988. An Introduction to Boundary Layer Meteorology, Kluwer Academic Publishers.

Rosenberg, N.J., B.L. Blad and S.B.Verma. 1983. Microclimate. J. Wiley and Sons.

Tindall, J.A. and J.R. Kunkel. 1999. Unsaturated Zone Hydrology for Scientists and Engineers. Prentice Hall.624 pp.

Wyngaard, J.C. Turbulence in the Atmosphere. 2010 Cambridge University Press.

**Specialized Proceedings**

Andreae, M.O. and D.S. Schimel. 1989. Exchange of Trace Gases between Terrestrial Ecosystems and the Atmosphere. Dahlem Workshop. J. Wiley.

Barfield, B.J. and J.F. Gerber. 1979. Modification of the Aerial Environment of Plants. ASAE Monograph. St. Joseph, MI

Brutsaert, W.H. 1982. Evaporation into the Atmosphere. D. Reidel Pub.

Ehleringer, J.R. and C.B. Field. 1993. Scaling Physiological Processes: Leaf to Globe. Academic Press.

Gash, JHC, C. Nobre, J. Roberts and R. Victoria. 1996. Amazonian Deforestation and Climate. J. Wiley.

Grace, J, E.D. Ford and P.G. Jarvis. 1980. Plants and Their Atmospheric Environment. Blackwell. Oxford.

Griffiths, J.F (eds). 1994. Handbook of agricultural meteorology. New York : Oxford University Press, 1994

Hutchison, B.A. and B.B. Hicks. 1985. Forest-Atmosphere Interactions. D. Reidel.

Moore, B. and D.S. Schimel. 1992. Trace Gases and the Biosphere. NCAR.

Noormets Phenology book

Ross, J. 1981. The Radiation Regime and Architecture of Plant Stands. Dr. Junk, The Hague.

Roy, J., Saugier, B. Mooney, H. 2001. Terrestrial Global Productivity. Academic Press.

Steffen, W.L. and O.T. Denmead. 1988. Flow and Transport in the Natural Environment: Advances and Applications. Springer-Verlag.

Sharkey, T.D., E.A. Holland and H.A. Mooney. 1991. Trace Gas Emission by Plants. Academic Press.

Tenhunen, J. and P. Kabat. 1999. Integrating Hydrology, Ecosystem Dynamics and Biogeochemistry in Complex Landscapes. Dahlem Konferenzen

Varlet-Grancher, C., R. Bonhomme and H. Sinoquet. 1993. Crop Struction and Light Microclimate. INRA, France.

Von Caemmerer, S. 2000. Biochemical models of leaf photosynthesis. CSIRO Publishing.

Woodward, I. 1986. Climate and Plant Distributions. Cambridge

**Methods**

Fritschen, L.J. and L.W. Gay. 1979. Environmental Instrumentation. Springer Verlag.

Hall, D.O. et al. 1993. Photosynthesis and Production in a Changing Environment: a Field and Laboratory Manual. Chapman and Hall.

Matson, P.A. and R.C. Harriss. 1995. Biogenic Trace Gases: Measuring Emissions from Soil and Water. Blackwell.

Pearcy, R.W., J. Ehleringer, H.A. Mooney and P.W. Rundel. 1985. Plant Physiological Ecology: Field Methods and Instrumentation. Chapman Hall.

**Classic Books**

Baver, L.D., W.H. Gardner and W.R. Gardner. 1972. Soil Physics. John Wiley and Sons. New York. 497 pp.

Brooks, F.A. 1960. Physical Microclimatology. University of California, Davis.

Budyko, M.I. 1974. Climate and Life. Academic Press.

deVries, D.A. and N.H. Afgan. 1975. Heat and Mass Transfer in the Biosphere. John Wiley and Sons.

Gates, D. M. 1980. Biophysical Ecology. Dover, Mineola, NY.

Geiger, R. 1961. The Climate Near the Ground. Harvard University Press.

Haugen et al. 1973. Workshop on Micrometeorology, American Meteorological Society, Boston

Lowry, W.P. 1969. Weather and Life: an Introduction to Biometeorology.

Lumley, J.L. and H.A. Panofsky. 1964. The Structure of Atmospheric Turbulence. John Wiley and Son. New York.

Monin, A.S. and A.M. Yaglom. 1975. Statistical Hydrodynamics. MIT Press. Cambridge.

Monteith, J.L. 1975. Vegetation and the Atmosphere, I, Academic Press. London.

Monteith, J.L. 1975. Vegetation and the Atmosphere, II, Academic Press, London

Munn, R.E. 1966. Descriptive Micrometeorology. Academic Press. New York.

Pasquill, F.A. 1974. Atmospheric Diffusion. Wiley.

Rose, CW. 1966. Agricultural Physics. Pergamon Press.  230 pp.

Sestak, Z., J. Catsky and P.G. Jarvis. 1971. Plant Photosynthetic Production: Manual of Methods. Dr. W Junk, The Hague.

Setlik et al. 1970. Prediction and measurement of Photosynthetic Productivity. Pudoc.

Sutton, O.G. 1953. Micrometeorology. McGraw-Hill.