Lecture 1. Introduction and Overview

August 23, 2016

ESPM/EPS 129, Biometeorology
MWF 11-12
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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, fungi 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 Chekov (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 CO2 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 (10⁻⁶m)
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).

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**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 CO2 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


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
ESPM 129, Biometeorology, Dennis Baldocchi Instructor
Lecture 1, Introduction

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/


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

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

Key Textbooks, Biometeorology, Micrometeorology, Environmental Physics, Ecophysiology, Ecohydrology.


Foken, T. Micrometeorology. Springer.


[http://ebooks.cambridge.org/ebook.jsf?bid=CBO9781139629218]


**Specialized Proceedings**


Noormets Phenology book


Methods


Classic Books


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


