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Seasonal climates at the Cedar-Sauk Field Station

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SEASONAL CLIMATES AT THE CEDAR-SAUK FIELD STATION

The climate of the Cedar-Sauk Field Station in its annual cycle can be described in terms of (a) energy inputs and their consequences, (b) water inputs and budget, and (c) weather phenomena. All these aspects of climate express a marked seasonality between long, snowy, and cold winters, and fully developed, warm summers. Let us look first at the energy factors in its climate.

(a) *Energy Fluxes.* Energy* is a moving force in ecosystem processes, and its increasing and declining cycle through the year gives rise not only to summer and winter, but also to distinctive transitional seasons of spring and fall, when the energy supply is passing through critical levels. Energy transfers to and from the ecosystems of the Field Station take place in two major modes: by flows of radiant energy, and by the exchanges of energy between ecosystems and the atmosphere carried by turbulence mechanisms. Of the several kinds of flow of radiant energy the most visible is that of incoming solar radiation.

Solar radiation varies through the year as shown in the first lines of Table 1: The daily mean flow in December, 55 W m^{-2}, comes in a 9-hour day, and displays a midday peak flow around 250 W m^{-2}, The daily mean flow in June, at the summer solstice, averages 250 W m^{-2} over the 24-hour period, and peaks at about 700 W m^{-2}. Of these amounts, about 25% is generally reflected in the snow-free season and half or more when the land is snow-covered; thus the amount of energy absorbed and available in ecosystems is somewhat less than the figures cited.

Other flows of radiant energy also exist, though they are not visible and usually not perceived by humans. They are quite large, and one, incoming radiation in long wavelengths (more than 4 micrometers), has been measured at the Field Station from time to time. It varies from approximately 250 W m^{-2} in winter averages to 350 in summer, according to preliminary estimates.

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*Energy is measured in joules; but more biological importance attaches to its rate of flow, which is measured in watts (1 W = 1 J $second^{-1}$). The intensity of this flow is therefore measured in watts per square meter of receiving surface (forest canopy, grass, etc.) exposed to the sky.

For comparison, a flow rate of 100 W m^{-2} is equivalent to an input of about 200 gram-calories per sq centimeter or 720 BTU per square foot in one 24-hour day. From a biological standpoint, 315 W m^{-2} is a critical level of heat supply, because it is this amount that a leaf at $0^{o}C$ must emit. To escape freezing, therefore, it must receive 315 W m^{-2} from its environment.

TABLE 1
Energy Fluxes (watts/sq. Meter)

	Dec.	March	June	Sept.
Probability of Sunshine	40%	50%	62%	62%
Solar Radiation	55	150	250	165
Net surplus (or deficit) of all-wave radiation	-10	+50	+150	+90
Heat exchange between grass and soil	upward +10	-15	from grass -15	+5
Heat exchange between grass and air:				
In sensible form	0	-30	-25	-25
In latent form	0	-5	-110	-70
Corresponding evaporation	0	0.2	4.0	2.5mm.d-1

Units of heat flow:

$1 Wm^{-2} = 0.09 ly . hr^{-1} = 2.1 ly .d^{-1}$

$100 Wm^{-2} = 9 ly . hr^{-1} = 205 ly.d^{-1} = 840 Btu ft^{-2} d^{-1}$

It is customary to lump all the fluxes of radiant energy into one number, called the net surplus (or deficit, as the case may be) of all-wave radiation; this figure is shown in the third line of Table 1. It ranges from a deficit of 10 W m^{-2} in December to a surplus of 150 W m^{-2} in June.

Since this number includes all the radiation fluxes, it must by the law of conservation of energy equal the sum of all the fluxes by nonradiative modes. This is another way of saying that the surplus of radiant energy is partitioned at the surfaces of grass, tree canopy, or marsh ecosystems into three nonradiative flows of energy. Taking the summer situation, one of these nonradiative flows heats the soil, one heats the air, and one supports evaporation and transpiration from ecosystems.

Conversely, when a radiation deficit exists, it is made good by heat coming out of the soil or air. The radiation deficit in December is mostly made good by heat from the soil body (see lower half of Table 1).

By March, the increasing input from the sun results in a surplus of all-wave radiant energy, which melts snow cover, thaws and warms the soil (estimated as 15 W m^{-2}), and begins to heat the air (30 W m^{-2}).

In June a large surplus of radiant energy goes mainly for evaporation and transpiration (110 W m^{-2}). In September these processes continue to take the lion's share of available energy; this energy flow powers the daily evaporation and transpiration of 3 to 4 mm of water, as will be discussed later. During the growing season, an average of 2 to 3 W m^{-2} is fixed in plants by photosynthesis—a small but important item in the overall energy budget that usually follows the variations in the rate of transpiration.

Air temperature during winter days hovers near the freezing level; it reaches the 20's on summer and early fall afternoons. Daily maxima exceeding 33° are uncommon; in the dead of winter, daily maxima that do not reach the freezing level are frequent, although temperatures of the soil are not so low (Table 2).

Nocturnal temperatures are around -10 in winter, +12 in summer. Many nights in winter go below -10° and some below -20°; almost all nights in winter and spring go below freezing, with frosts usually starting by October. The probabilities are shown in Table 3. The growing season for native plants (-2° threshold) at 50% expectation is from 23 April to 20 October, a period of 180 days (but for cultivated crops it is only 125 days).

Although the Field Station is beyond the usual reach of the lake-breeze system as such, a substantial cooling effect of Lake Michigan is felt throughout all eastern Wisconsin in spring, carried inland in the easterly flows in passing cyclonic systems. By most phenological criteria, the arrival of spring comes 15 to 20 days later than in southwestern Wisconsin. These data also show a large variation from year to year, especially in early-spring events for which the standard deviation is about 10 days. For late-spring events, like lilac flowering, the standard deviation is only a few days.

Table 2
Sensible-Heat Flux and Air Temperatures

	Dec.	March	June	Sept.	Year
Heat flow from grass to air	0	-30	-25	-25	–
Daily air temperatures					
Maximum	0°	5°	25°	23°	–
Minimum	-9°	-5°	13°	11°	–
Frequency of days with					
Maximum > 33°	0	0	6%	3%	3%
Maximum < 0°	50%	23%	0	0	16%
Minimum < 0°	95%	87%	1%	3%	42%
Minimum < -18°	13%	3%	0	0	4%

Phenological events, like frost and other extremes in the energy climate, are likely to be highly site-specific; however, in this sketch it was not possible to describe the diverse micro-climates that exist in the variegated terrain of the Field Station. Those seeking additional information should consult the records from meteorological substations in the bog and upland forest.

(b) *Water Budget.* The input of water (Table 4) is about twice as large in summer as in winter; however, the seasonality in energy input is far greater, so that in several summer months evapotranspiration, at rates of 3 to 4 mm per day, as noted earlier, is larger than rainfall. Growth of vegetation continues only insofar as moisture stored in the soil holds up. In some summers, rains are spaced widely, soil moisture declines, and plants undergo moisture stress.

In winter, the season of low energy, much of the precipitation is delivered as snow – on the average, 25 cm in each month from December through March. At a 10% expectancy, snow (2.5 cm) can fall by 5 November; at a 90% expectancy, by Christmas.

Whether snow or rain, however, water delivered in winter is little depleted by evaporation. It fills all available storages: the soil is full, the groundwater table rises, stream channels fill up, wetlands flood, and a snow cover comes into being. Mobilization of this winter storage produced by the rise of energy input in spring is seen in thawing of the soil and melting of the snow mantle, and yields the annual peak of streamflow. Over the year, water yield is about 1.8 mm per day – only a third the volume of water that is evaporated. The rates of rainfall at the 0.5 frequency (Table 5) vary from 3 mm $\cdot$ hr^{-1} over a day to 30 mm $\cdot$ hr^{-1} and even higher over an hour or less.

(c) *Atmospheric Phenomena:* Fewer clouds (Table 6) fill the atmosphere in summer than in winter, since the convective clouds of summer are typically

Table 3
Frost Expectancies

Dates after which a 0° or -2° frost will occur with a given probability in spring		
Probabilities	80%	20%
0° frost	30 April	20 May
-2° (native plants)	13 April	4 May
Dates before which a 0° or -2° frost will occur with a given probability in fall		
Probabilities:	80%	20%
0° frost	18 October	28 September
-2° frost	31 November	9 October

Table 4
Mean Water Fluxes

Mean Conditions	Dec.	March	June	Sept.	Year
Precipitation, mm d^{-1}	1.3	1.7	3.3	2.7	750 mm
Evapotranspiration, mm d^{-1}	0	0.2	4.0	2.5	570 mm
Frequency of days with >2.5 mm precip.	13%	16%	23%	17%	16%
Snowfall depth, cm	20	25	0	trace	110 cm

Table 5
Extreme Precipitation

Maxima in a Day

	Dec.	March	June	Sept.	Year
Precipitation, mm	55	45	95	55	108 mm·d^{-1}
Snowfall, cm	15	27	0	Trace	30 cm·d^{-1}

Intensities Over Short Durations

Duration of Rain	10 min.	1 hour	6 hours	24 hours
Depth, mm	13	30	50	68
Intensity, mm·hr^{-1}	80	30	8	3
(At a frequency of once in two years)				

Table 6
Atmospheric Phenomena

	Dec.	March	June	Sept.	Year
Cloudiness, fraction of sky	0.70	0.67	0.61	0.53	0.62
Clear Days (0.0 to 0.3 (cloud cover)	20%	22%	23%	33%	27%
Thunderstorm Days	Trace	3%	23%	13%	11%
High Winds, m·sec^{-1}	32	38	30	32	

tall and narrow, rather than areally extensive as are the clouds of frontal storms in winter. Thunderstorms are mostly a warm-season phenomenon, occurring on a quarter of the days. Hail occurs only 1 per cent of the days of the year, mostly in summer.

High winds, 30 to 35 $m \cdot sec^{-1}$, can come in any season, since they can be generated by frontal systems as well as in thunderstorms. The extreme wind speed (frequency = 0.01) approaches 50 $m \cdot sec^{-1}$.

Occasional weather events, with frequencies far smaller than 0.1 per year, play an important role in the environment of Field Station ecosystems. An example is the prolonged storm of freezing rain in early March, 1976, which so opened the hardwood canopy that solar energy reaching the understory and forest floor increased from about 10% of that incident on the outer surface of the canopy to 50% or more, a level of intense light that will prevail for a number of years. Early frosts and high winds similarly form a significant part of the environment even though their frequencies might be very small.

The lake-breeze system that is established at the shoreline of Lake Michigan on many days during the period when the lake surface is colder than the land surface does not often reach inland as far as the Field Station. Its effect in confining pollutants in the lowest layers of the atmosphere is thus seldom a factor in the Field Station climate.

Aerosols in the atmosphere are often brought in southerly flow. Ozone, for example, seems to have a region-wide occurrence. Particulates from industrial sources 50 km south of the Field Station are probably less common. Local sources are few. Pollutants are typically associated with anticyclonic flow, especially in dry weather – also likely to be fire weather in spring or fall, although wildfires are not common.

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