

TOPIC 3. WIND CHARACTERISTICS

Wind, or large-scale movements of the atmosphere, follows some definite patterns due to solar energy and air temperature differences that affect air densities and pressures. Warmer air is less dense than cooler air, so it rises and cooler air moves in to take its place, resulting in wind. Thus, atmospheric motion, or wind, is large-scale convection generated by differences in air densities. Wind has two attributes: direction and magnitude. Wind, as atmospheric motion, is a form of momentum, and momentum implies both direction and magnitude (Stringer 1972:20).

There are patterns to wind directions over the surface of the earth, with the term prevailing winds applied to the most commonly observed general direction each season. Wind velocities also vary with height; the distribution of wind velocities in relation to height is called the vertical wind profile.

Large-scale atmospheric movements are composed of small-scale movements, or turbulence. This is due to friction between the air molecules and the surface of the earth, retarding the flow near the surface. When the earth's surface is covered with vegetation, friction is greater, turbulence is greater, and the vertical changes in wind velocities may extend upward for many meters. These are important ecological considerations as turbulence has both thermal and mechanical effects on plants and animals.

Turbulence is very difficult to measure because most instruments designed to measure wind velocities respond most accurately when oriented in one direction with the air movement. Since turbulent flow comes from all directions, a single sensor does not respond accurately, nor is the readout such that turbulent characteristics are displayed. Variations in wind speeds that are so evident in reading hot-wire anemometers, which respond very rapidly to fluctuations in air flow, result from turbulent flow, but represent the effects in only one direction.

A fairly recent technique is now used to visualize and photographically trace air flow patterns. The use of small (0.3 cm diameter), neutrally-boyant bubbles as flow tracers, a technique used in a wind tunnel (Thermal Environment Simulation Tunnel) at the Wildlife Ecology Laboratory at Cornell University (Moen 1974) and in the field by ventilation engineers for determining air flow in livestock shelters (Carpenter et al. 1972), provides good visual impressions of air flow. Bubbles are much more suitable for tracing air flow than smoke, used as an earlier technique, because bubbles remain intact in turbulent flow, but smoke dissipates.

Air motion, or wind, obviously does not occur at random. Mathematical representations of patterns, both large-scale and small-scale, are discussed in the UNITS that follow, with WORKSHEETS that provide practice when evaluating the ecological effects of changes in time and space.

LITERATURE CITED

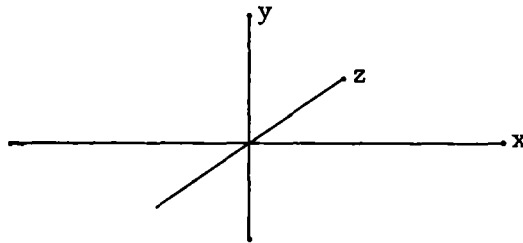
- Moen, A. A. 1974. Turbulence and the visualization of wind flow. Ecology 55(6):1420-1424.
- Carpenter, G. A.; L. J. Moultsley, and J. M. Randall. 1972. Ventilation investigations using a section of a livestock building and air flow visualization by bubbles. J. Agric. Eng. Res. 17:323-331.
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UNIT 3.1: WIND DIRECTIONS

Wind direction seems like a rather simple idea because of our conditioning to weather reports that include statements such as, "The wind is blowing from the northwest at ...". Such statements are based on the average in-line wind direction over a time span of several minutes or hours, the simplest expression of wind direction.

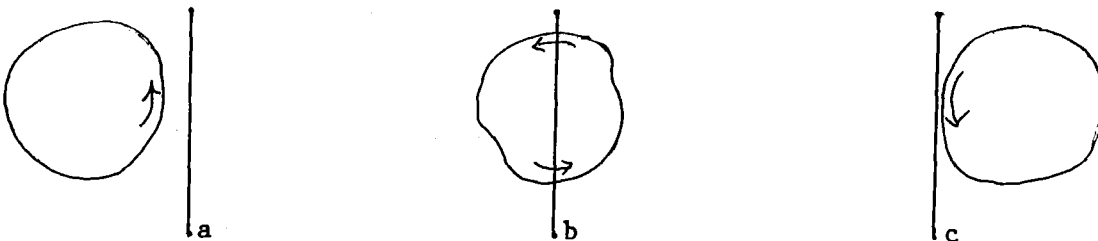
The wind experienced by an organism is composed of the overall average direction of in-line movement of the air mass, and of small scale multi-directional flow, called turbulence. Turbulence is experienced on days when the wind is gusty and erratic, with deviations from the average in-line direction. The amount of turbulence is affected by land features, of course; topographic variations and vegetation generate turbulence, increasing the amount of variability in both direction and velocity.

Turbulence is three-dimensional flow, with x, y, and z axes, as illustrated below.



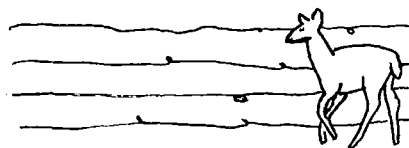
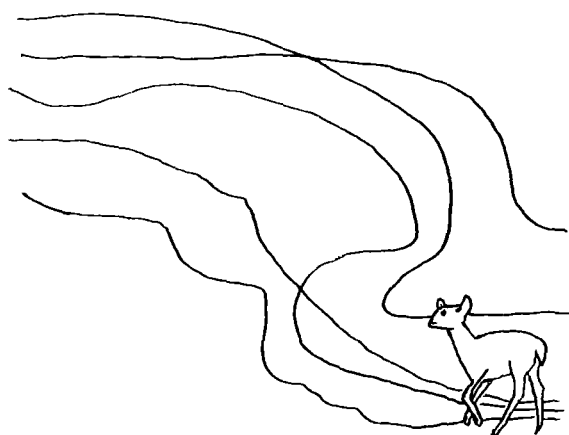
Three-dimensional flow

Three-dimensional flow may be visualized as irregular spheres of air rotating as they move in one general in-line direction. Deviations from the in-line direction is due to the rotation of the eddies. As the leading edge of the eddy reaches point a, the direction as illustrated is mostly vertical. As the eddy moves from left to right and is centered on the plane at point b, directions are both right and left, with essentially no rotation at the center of the eddy. When the vertical plane c is at the trailing edge of the eddy, the air movement is in the downward direction. Overall, however, the general in-line direction is from left to right.



Turbulence may be described by its scale, which is a quantitative measure of the size of the eddies that tend to move as a unit in relation to the sizes of objects or organisms in the path of the flow. When the eddies are very large or very small in relation to a part of or a whole plant or animal, they have lesser thermal effects than if they are about the same size as the part of or whole plant or animal. This is an important consideration in calculating convection, although data on turbulence scale in ecological analyses are practically non-existent, and applications of turbulence scale to organisms are very complex due to the rough aerodynamic geometry of organisms.

The turbulence scale here
is very large compared to
the animal.



The turbulence scale here
is very small compared to
the animal.

The concept of three-dimensional flow is easily understood because each of us has experienced small-scale changes in direction on windy days, but there are many challenging problems to solve by further research so actual mechanisms are understood better.

Theoretical considerations of flow characteristics are more important when studying very small organisms than large ruminants, but concepts should still be recognized so overly-simplistic analyses of weather effects on organisms are avoided. Introductions to velocity characteristics are given next.

REFERENCES, UNIT 3.1

WIND DIRECTIONS

SERIALS

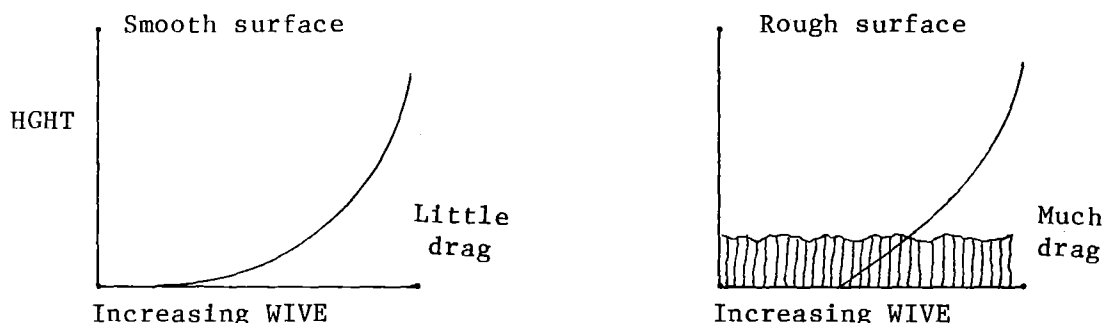
CODEN	VO-NU	BEP	ENPA	KEY WORDS-----	AUTHORS-----	YEAR
ECOLA	55--6	1420	1424	turbulence, visualizat	air flow moen,an	1974
GPNOA	11... 1	69		eddy condition air, smoo	snow f sverdrup,hu	1936
QJRMA	75---	335	350	application micrometo	turb flow sutton,og	1949
TAAEA	10--3	376	377	cup anemometer, behav	angl wind hetzler,re; willi	1967

UNIT 3.2: WIND VELOCITIES

Wind velocities given in weather reports are generally measured at some standard height above the ground. Such reported velocities represent just one point on a vertical profile, and do not represent the conditions animals are exposed to on the range. Average in-line velocities at different heights in different habitats should be considered, and deviations from the averages indicate the effects of multi-directional flow, or turbulence, at different heights.

VERTICAL PROFILES

The vertical profile develops because of friction, and the steepness of the profile is dependent on the amount of friction due to the roughness of the earth's surface. General profiles look like this:



Wind velocities (WIVE) over smooth surfaces or short vegetation can be determined for any desired height with the following formula from Sellers (1965):

$$\text{WIVE} = (u^*/k) \ln(z/z_0)$$

where WIVE = wind velocity (cm per second) at height z (cm)

u^* = friction velocity

k = von Karman constant = 0.4

z_0 = roughness length.

The symbol u^* represents the friction velocity, which is a characteristic velocity that is dependent on the shear stress of turbulent air as it moves through and over the rough surface. It can be calculated from measured physical characteristics of the air, or determined empirically for a given situation with a known reference velocity and height. The latter approach is used here; the formula for calculating u^* is, from Sellers (1965):

$$u^* = u k / [\ln(z/z_0)]$$

where u = wind velocity at $z = 200$ cm, or 2 m

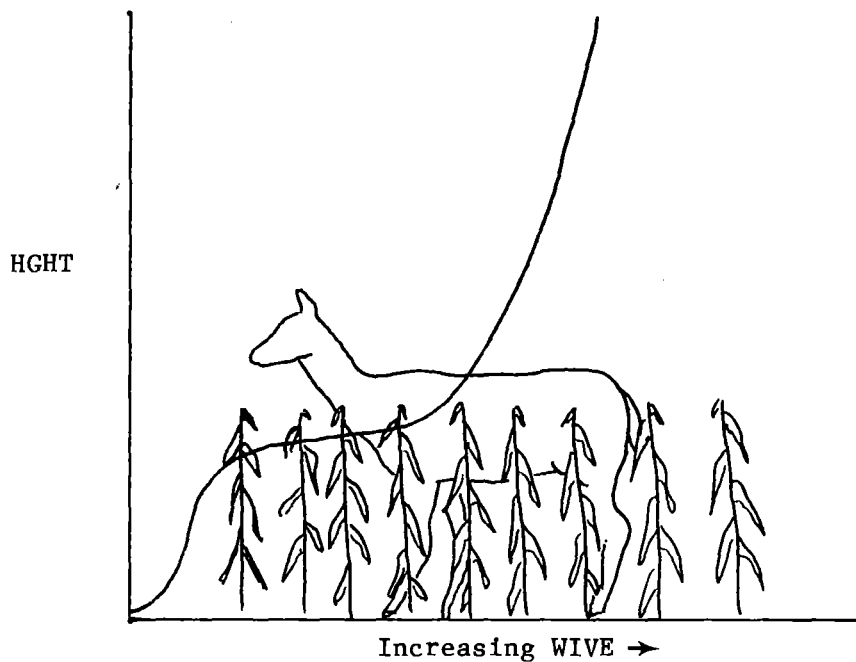
k = von Karman constant = 0.4

\ln = natural log.

The roughness of the earth's surface at a particular point is dependent on both the physical surface and the vegetative cover. Roughness is represented in the general formula used for calculating wind profiles by the symbol z_0 which represents the roughness length, defined as the height above the surface at which wind speed falls to zero. It is equal to about one-tenth of the height of the vegetation (Sellers 1965;140). Representative values (in cm) of z_0 given by three authors for different types of surfaces are given below.

<u>Type of surface</u>	<u>z_0</u>	<u>Reference</u>
Very smooth (mud flats, ice)	0.001	Sutton 1953
Lawn grass to 1 cm tall	0.1	
Downland, thin grass to 10 cm tall	0.7	
Thick grass to 10 cm tall	2.3	
Thin grass to 50 cm tall	5.0	
Thick grass to 50 cm tall	9.0	
Sand	0.01-0.1	Gates 1962
Snow surface	0.1-0.6	
Short grass	0.6-4.0	
Long grass	4.0-10.0	
Grass 5-6 cm tall	0.75	Sellers 1965
Grass 4 cm tall	0.14	
Grass 2-3 cm tall	0.32	
Smooth desert	0.03	
Dry lake bed	0.003	
Smooth mud flats	0.001	
Wheat 60 cm tall	22.0-23.3	
Corn 220 cm tall	74.2-84.5	
Fir forest 555 cm tall	283	

The vertical distribution of velocities over tall vegetation may show a double profile, with two sources of friction between air and substrate: the vegetation and the ground surface. The shape of the profile is dependent on the height and density characteristics of the vegetation. The profile below shows general increases in relation to height both within and above the vegetation.



Animals are exposed to a range of velocities within the velocity profile from the ground surface, where the velocity is 0, to the velocity at the highest point of the its body. The profile may continue vertically beyond the animal until a rather stable velocity is reached outside of the influence of the topography and vegetation.

MULTIDIRECTIONAL FLOW; VELOCITY DISTRIBUTIONS

Air flow near the ground is usually turbulent, with velocity fluctuations in all directions due to local obstructions. This three-dimensional flow is not represented by a general formula for mean velocity. The fluctuating velocity can be decomposed into three components: in-line with the mean velocity vector, a cross-component perpendicular to the ground, and a cross-component parallel to the ground but normal to the in-line vector. These fluctuations are hidden in the time-average velocity expressed with the general formula for wind profiles (Moen 1974; 1420).

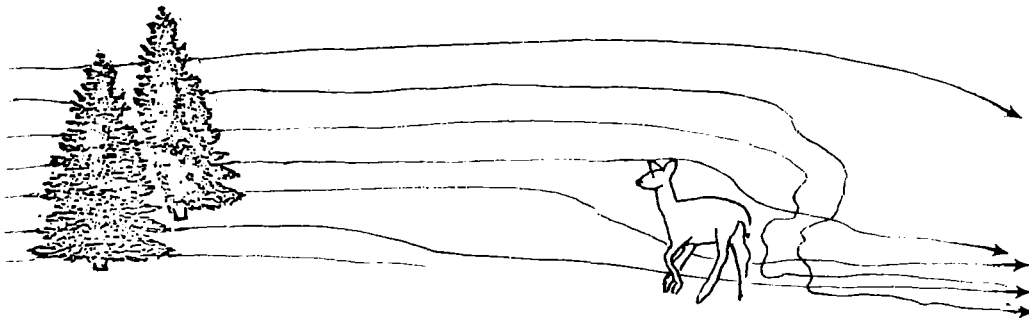
Spherical movements of air masses must result in differences in velocities because of rotational physics. Turbulence intensity is an expression of the turbulent velocity component of the mean velocity over a period of time. If the flow were completely random, the turbulence intensity would be 100% and no directional flow could be detected. When all three (x, y, and z) turbulence components are equal in intensity, the turbulence is said to be isotropic. Turbulence intensity is dependent on the geometry of the vegetation. Outdoors, turbulence may vary from 5% over a relatively smooth open field to 50% in dense woods.

Numerical descriptions of turbulence intensity remain abstractions until related directly to some object. This is difficult in the field because of the complexity of turbulent flow and the need for sensitive and delicate instrumentation. The visualization of air flow is a useful intermediate step that helps one gain a qualitative feeling for the dimensions involved. The fact that dynamic three-dimensional characteristics of wind are not often considered in ecological analyses can be attributed, in part, to the difficulty in visualizing the flow of transparent air masses.

The drawing below is based on a black and white photograph of air flow past a model bedded deer in the Thermal Environment Simulation Tunnel (Stevens and Moen 1970). Note the turbulent flow that develops in the leeward side of the model.

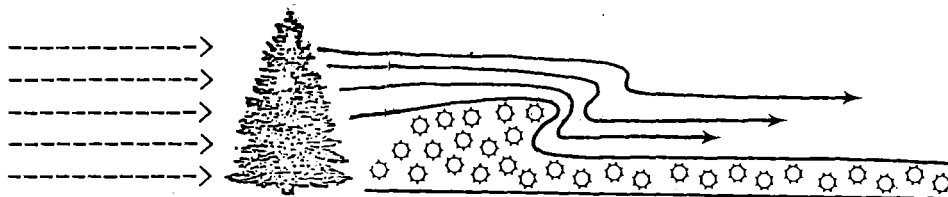


The visualization of air flow on a reduced scale in a wind tunnel is useful for evaluating flow past barriers, plants, and animals. Free-ranging animals are not exposed to a single wind velocity, but to a range of velocities in all three directions that is a function of topographic and vegetation characteristics. The movement of air on the lee side of the canopy has some interesting characteristics. One, it is highly turbulent. The air is moving in three dimensions, including reverse flow illustrated by the trace of bubbles posterior to the deer. Two, there is a general downward trend in the flow of air behind the trees. The deer is located at a point where the wind direction is primarily vertical rather than horizontal. Three, the velocity and direction changes abruptly as the air approaches the surface, and the general profile begins to develop. The drawing below is based on photography of air flow past a model windbreak in the Thermal Environment Simulation Tunnel. Note the recirculation pattern behind the windbreak in the vicinity of the deer.



Visualization of air flow is also useful in designing windbreaks, both artificial and natural, for field use. Observed circulation patterns provide significant insight into the importance of barrier height, porosity, and placement, allowing one to predict the most effective spacing of windbreaks before installing them in the field (Moen 1974). If wind affects the choice of bedding sites by wild ruminants, then knowledge of air flow through wind breaks and plant barriers should help understand these choices. The wind profile that develops over different surfaces plays an important part in the formation of wind-packed snow. Wind flow over a snow surface has a sharp profile with high velocities very near the snow surface. The inertia of drifting snow results in a more densely packed snow layer.

Snow deposition patterns behind a windbreak often show a rounded overhang on the terminal portion of a snowdrift (Moen 1973:70-71) due to the recirculation tendency of the moving air behind the windbreak. This is caused by pressure differences on the windward and leeward sides of the windbreak. Decreased pressure on the lee side results in the tendency of the air to recirculate as indicated in the drawing below.



Another characteristic of snow deposited in a drift is its density. The snow does not "fall" behind the windbreak, but is driven into the drift, resulting in denser snow (Swank and Booth 1970). This is shown behind model windbreaks described in Moen (1973:70-71), and illustrated in the line drawing above.

The validity of velocity data from cup anemometers located in the region of downward flow is questionable because cup anemometers generally do not respond at angles greater than 70 (Hetzler et al. 1967). Since cup anemometers respond primarily to wind flow on a horizontal plane, a cup anemometer placed just posterior to the deer at about the height of its tail would record zero velocity, but the deer would be experiencing the vertical air flow. Snowflakes would follow the flow, and the resulting drift formation would be quite unlike snow accumulation in zero wind. The importance of using instruments that measure the functional relationships between animal and environment must be recognized if meaningful interpretations are to be made.

Staple and Lehane (1955), present velocities behind a shelter belt as a percent of exposed velocity; anemometers located a distance equal to 2.5 times the height of the shelter belt recorded 40% of the exposed velocity, and at distances of 5-15 times the height, velocities ranged from 35 to 73% of the exposed velocity. All of these anemometers were located in regions where one would expect a noticeable downward component of the wind to which the instruments would not respond. This is of interest when determining energy balances of animals, however, because animals respond thermally to all angles of attack by the wind, and forced convection--a significant source of heat loss in the winter (Moen 1968)--will occur on the animal's surface.

Visualizations of turbulent air flow using bubble tracers provide insight into the dynamic motion involved, and the effect of this motion must ultimately be related to heat transfer, not only from the whole animal, but also from its component parts, including appendages and the fine structure of the pelage, if thermal exchange is to be fully understood. All of these conceptual considerations are important, but we are not yet ready to apply them to real field situations. The calculations in CHAPTER 15 give one an opportunity to make the simplest of calculations.

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REFERENCES, UNIT 3.2

WIND VELOCITIES

SERIALS

CODEN	VO-NU	BEP	ENPA	KEY WORDS-----	AUTHORS-----	YEAR
AGMYA	12--1	123	130	drag coeff,forst trees, wnd tun mayhead,gj		1972
ECOLA	55--6	1420	1424	turbulence, visualizat air flow moen,an		1974
FOSCA	17--3	314	321	vert profiles wndspd, pine stnd bergen,jd		1971
FRSTA	27--2	85	95	effcts shltrblts,locl microclim gloyne,rw		1954
GFRPA	33---	1	4	wind movement in pine stands cooper,rw		1965
GPNOA	11...	1	69	eddy condition air, smoo snow f sverdrup,hu		1936
IRFOA	31--2	130	134	topography and wind risk booth,tc		1974
JAMOA	4----	400	408	model velocity distribut, crops plate,ej; quraish		1965
JFUSA	51--3	173	178	wnd tunnl stdies, shltrblt modl woodruff,np; zing		1953
QJFOA	49--4	251	259	air movmnts, effcts on forestry evans,jdd		1955
QJRMA	75---	335	350	application micrometo turb flow sutton,og		1949
TAAEA	10--3	376	377	cup anemometer, behav angl wind hetzler,re; willi		1967
XANFB	137	1	2	eff ovrstry removl,surface wind brown,jm		1972
XARRA	252	1	4	var wndspd, canopy covr,lodgpol bergen,jd		1974

OTHER PUBLICATIONS

Grasso, V. 1965. Characteristic phenomenon of wind in a young pine plantation. Ital. for. mont. 20(2):57-62.

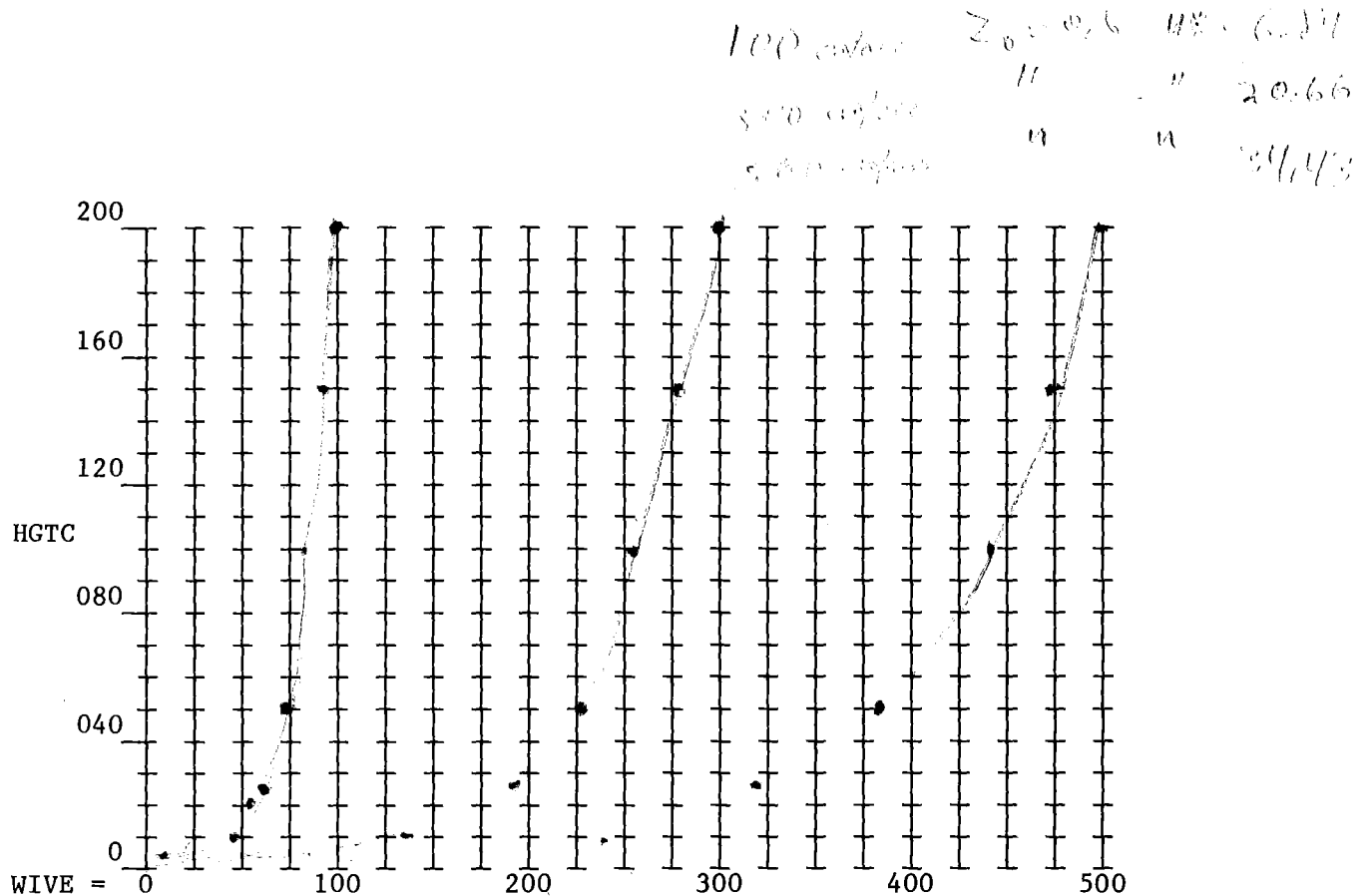
CHAPTER 14, WORKSHEET 3.2a

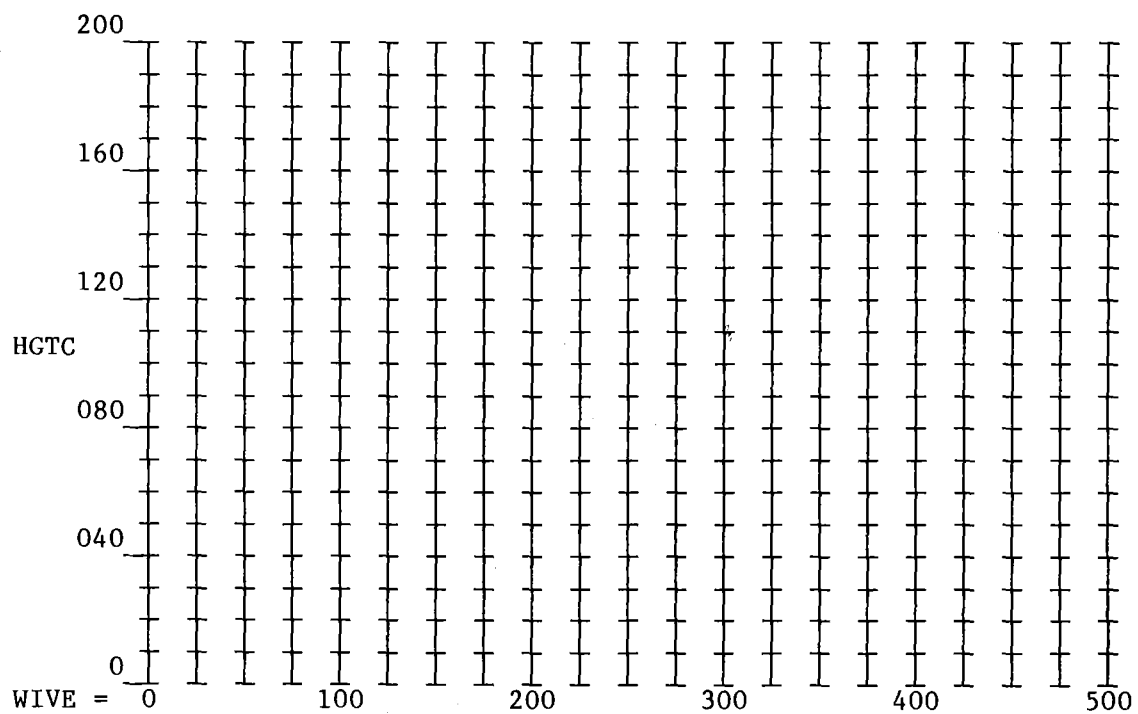
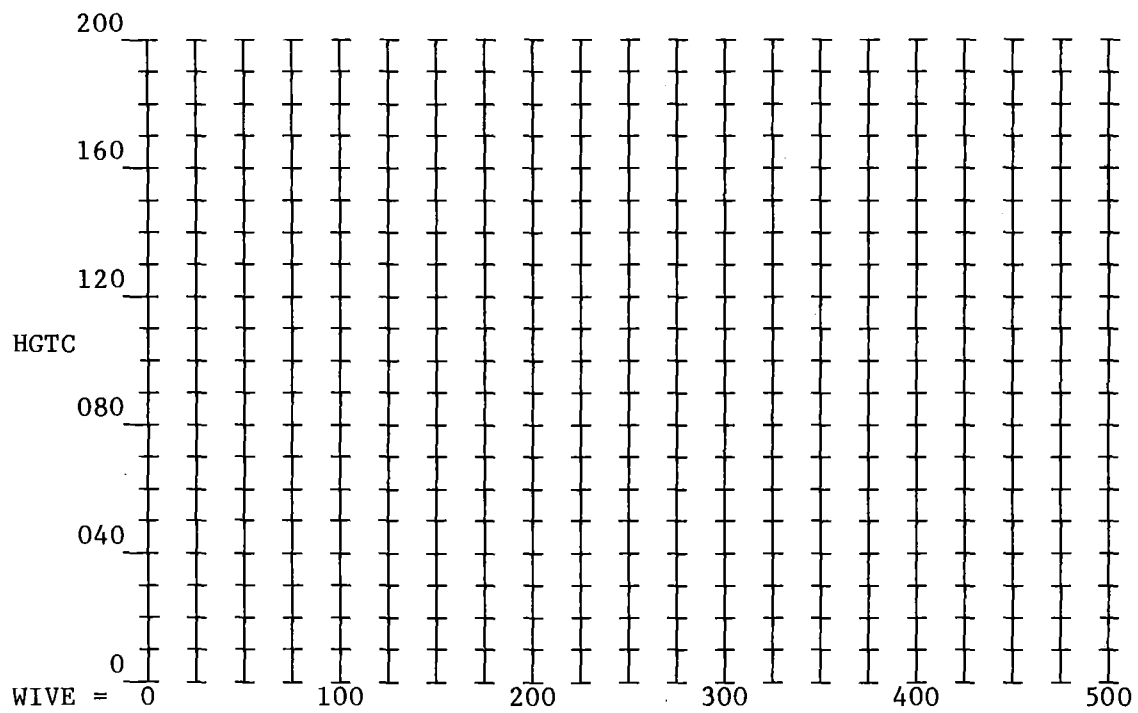
Vertical wind profiles

Vertical wind profiles of mean velocity may be calculated by cycling through the formula for WIVE at successive height intervals. The formula, with the symbols defined in UNIT 3.2, is:

$$WIVE = (u^*/k)\ln(z/z_0)$$

The friction velocity must be calculated before the formula can be employed. Select a z_0 to represent the habitat you are calculating the profile for, and determine u^* with the formula $u^* = uk/[\ln(z/z_0)]$ as explained in UNIT 3.2. Then, selecting reference velocities of 100, 200, 300, 400, and 500 cm/sec, calculate and plot the wind velocities at 20 cm intervals from 1 to 200 cm height (HGTC). Two more grids are available on the next page.

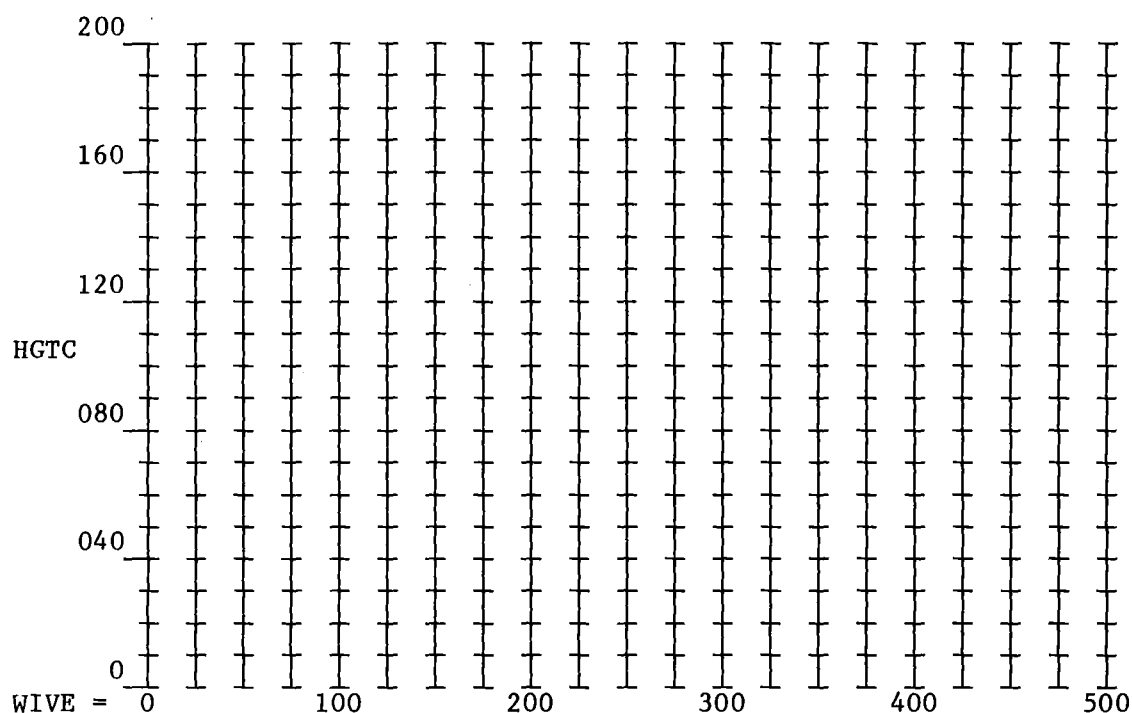


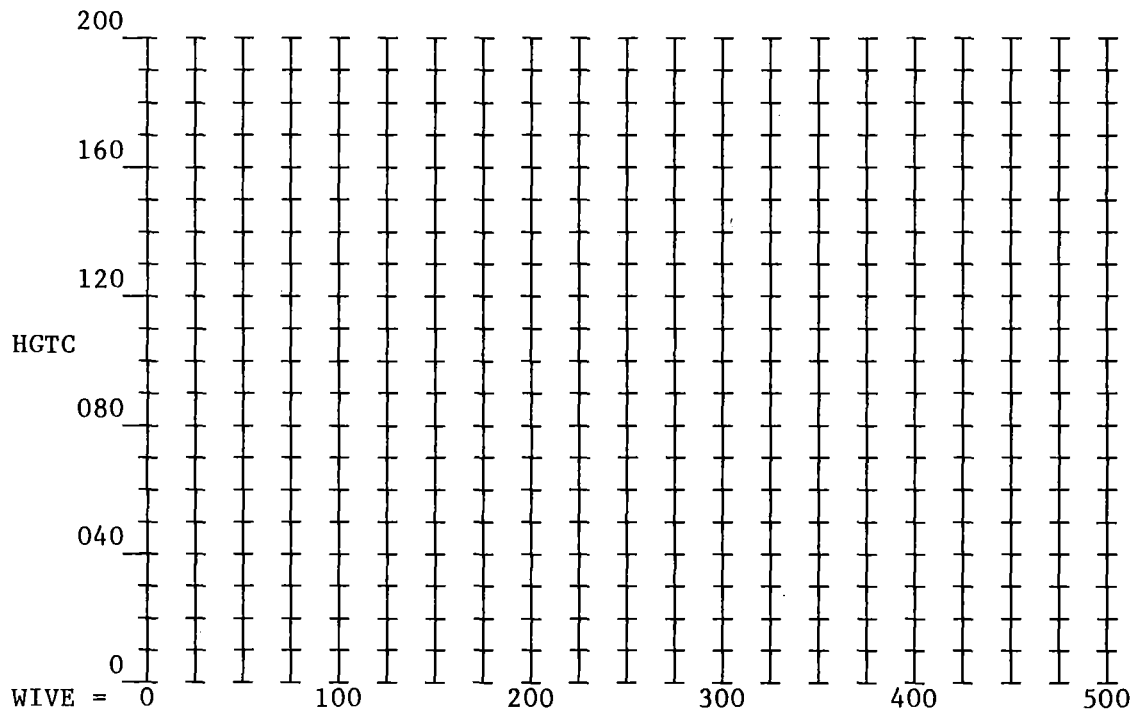
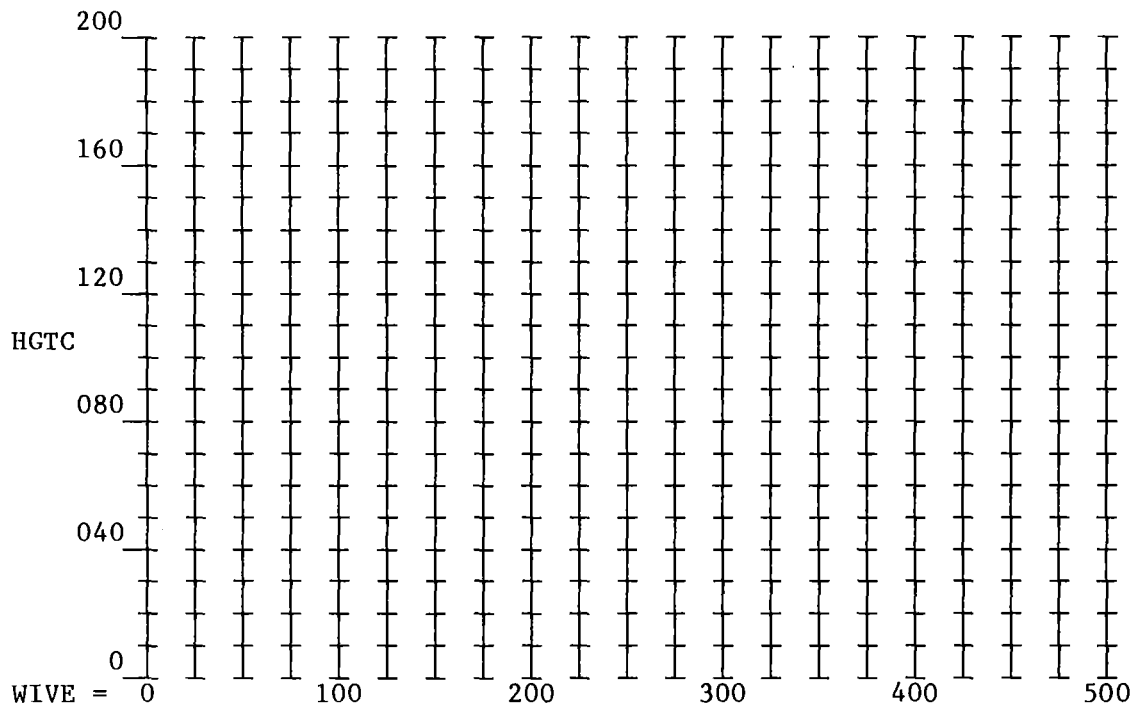


CHAPTER 14, WORKSHEET 3.2b

Wind velocities past bedded and standing animals

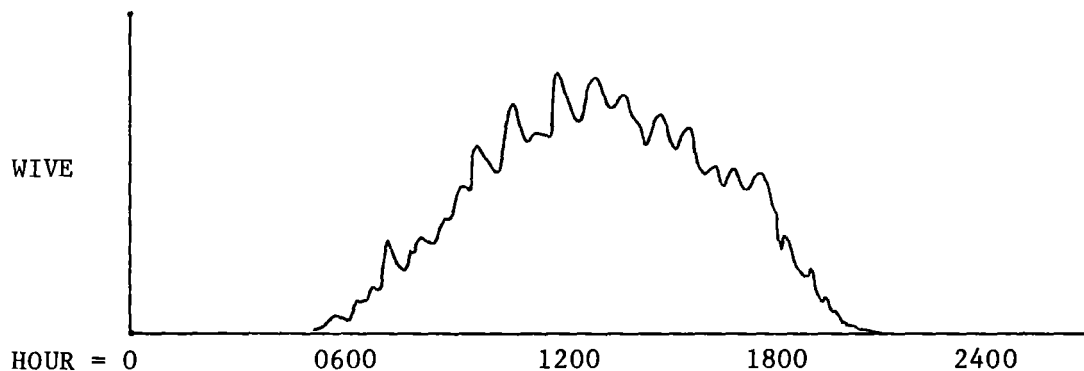
Vertical wind profiles were calculated in WORKSHEET 3.2a. Using the formula given in WORKSHEET 3.2a and selecting z_0 to represent the habitat in which you are interested in evaluating wind velocities past bedded and standing animals, calculate and plot wind velocity profiles for different reference velocities. Then, go back to CHAPTER 1, UNIT 2.2 and calculate vertical geometric profiles for the species of your choice. Sketch the animal on the grid below and determine the wind velocities past different parts of the animal. Wind velocities may be visually estimated (be sure to draw the animal to scale) or calculated mathematically in relation to the heights of different body parts. Two additional grids may be found on the next page.



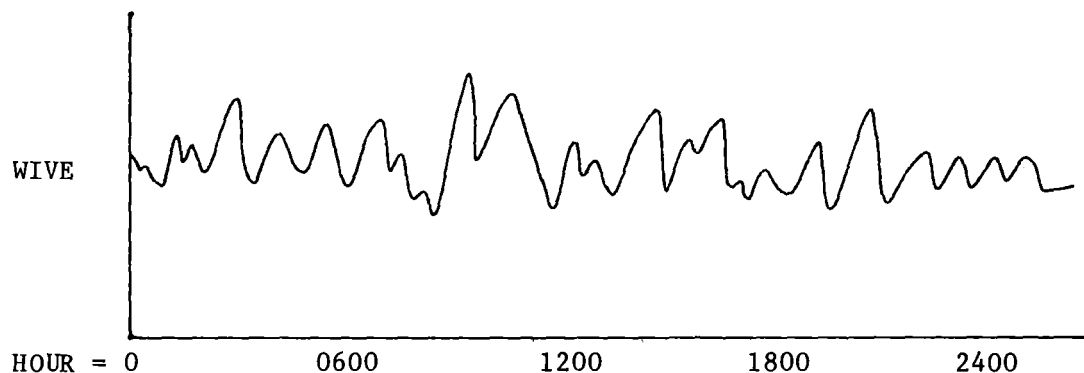


UNIT 3.3: TEMPORAL PATTERNS OF WIND VELOCITY

A general pattern of little or no wind at sunrise, increasing velocities in the morning and early afternoon, maximum velocities by mid to late afternoon, and then decreasing velocities into the evening with little or no wind shortly after sunset is typical of stable, high pressure weather systems with clear or only partly cloudy skies. The pattern looks like this.



Some weather systems result in rather constant velocities through the day, with gusts occurring at frequencies and with magnitudes characteristic of atmospheric turbulence characteristics. The pattern is variable due to the transient conditions, but may look like this.



The use of such idealized patterns through the 24-hour daily cycle, combined with other daily patterns of solar energy, temperature, activities, and others, permits one to calculate changes in the energy balance through time on an idealized day. If that can be done, then the effects of measured transient changes on animals in different habitats can also be calculated.

Average wind velocities over weeks or months may result in an annual patterns, depending on location, topography, water, and other factors. If data are available they may be evaluated in WORKSHEET 3.3a.

REFERENCES, UNIT 3.3

TEMPORAL PATTERNS OF WIND VELOCITY

SERIALS

CODEN	VO-NU	BEP	ENPA	KEY WORDS-----	AUTHORS-----	YEAR
EAFJA	35--2	160	165	diurnal varia, mean wind speed	woodhead,t	1969
FOSCA	1...	289	297	wnd profls, small isolatd forst	reifshyder,we	1955
JAPEA	8---3	729	741	wind profiles in plant canopies	landsberg,jj; jam	1971
TAGUA	34--6	841	848	effct wnd, nght radiatnl coolng	gossard,ee	1953

CHAPTER 14, WORKSHEET 3.3a

Temporal patterns of wind velocity

The sketches in this UNIT are based on actual measurements with a recording anemometer at Cornell's Arnot Forest Teaching and Research Center. Evaluate the patterns and derive equations, where possible, for the different kinds of patterns in relation to atmospheric conditions. How might frequency distributions be used when evaluating maximum and minimum wind velocities each day over an extended period of time?

Compile average wind velocities by month, if available. Is there a pattern that may be expressed as an equation?

	J	F	M	A	M	J	J	A	S	O	N	D
Daily average												
wind velocity:	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____

	J	F	M	A	M	J	J	A	S	O	N	D
Daily average												
wind velocity:	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____

	J	F	M	A	M	J	J	A	S	O	N	D
Daily average												
wind velocity:	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____

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