GEO892 (Section 001), Fall 2017, 3 credits; Tu & Th 5:00-6:20 pm; Geography 126

Micrometeorological Instrumentation & Measurements

Class Webpage: http://lees.geo.msu.edu/courses/Geo892

- Wind & Turbulent Transfer (Ch 5)
- Wind profile, aerodynamics, eddy-covariance method, Lagrangian method, surface renewal
- CRBasic by Dr. David Reed on Oct 3.

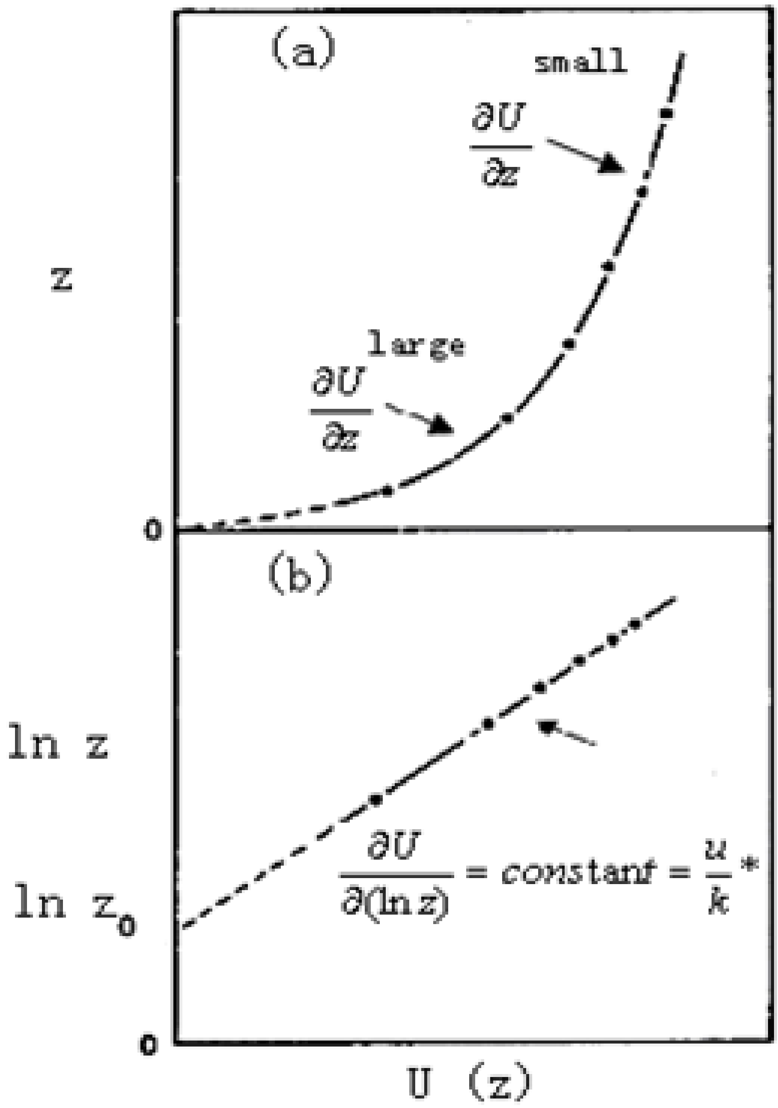
Terminology

- Mechanical turbulence
- Thermal turbulence

Causes

- Wind at higher altitude
- Horizontal temperature/density
- Topographic variation (e.g., cold air drainage)
- Movement of objects
- Instability of atmosphere

Typical wind profile over an open, level (relatively smooth) site: (a) plotted linearly against height z; (b) plotted against the logarithm of z.



Wind profiles

Vertical profiles of winds can be described using a logarithm function:

$$U(z) = \frac{u^*}{\kappa} \ln\left(\frac{z}{z_m}\right)$$

Where

U: horizontal wind speed (m.s^{-1})

Z: height (m) above the ground

u*: friction velocity (m.s^{-1}) which is related to shearing stress (τ) and air density (ρ), or

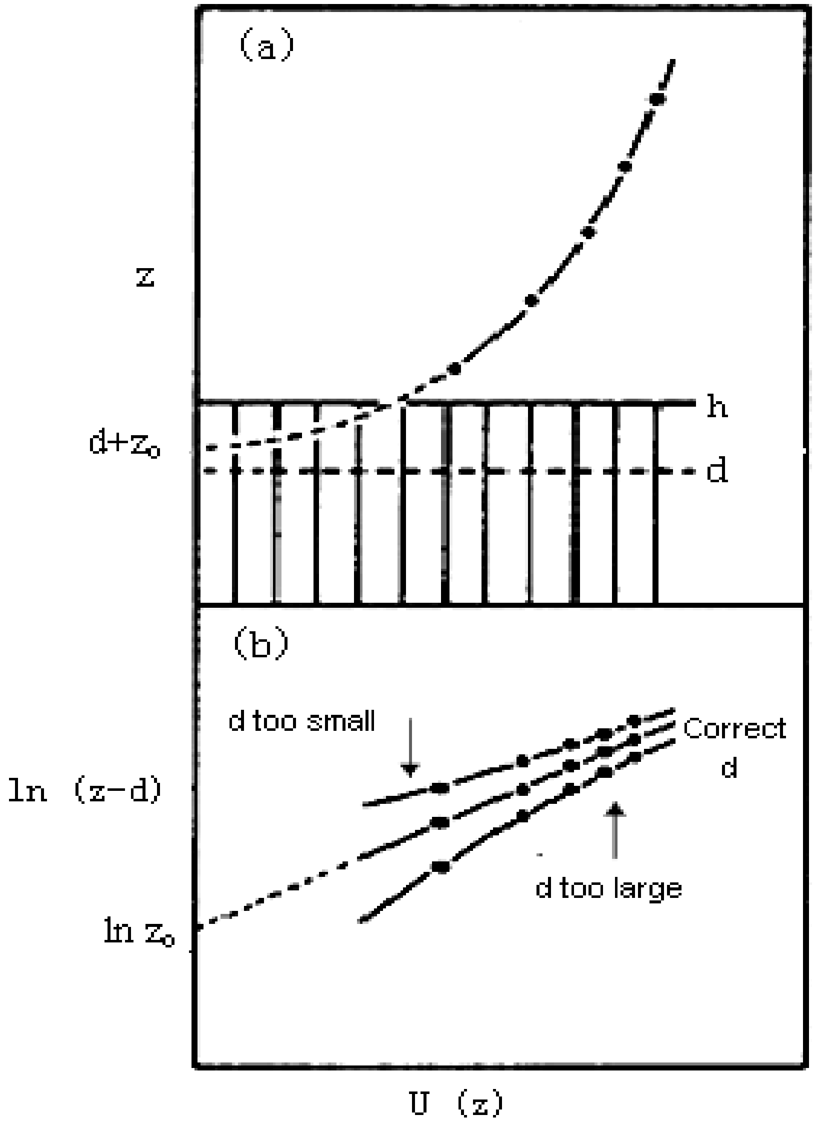
$$u* = \left(\frac{\tau}{\rho}\right)^{1/2}$$

κ: von Karmon’s constant (≈ 0.4)
Z_m: surface roughness or roughness length (m)

The change of U with z is:

$$\frac{\partial(U)}{\partial(\ln[z / z_m])} = \frac{u*}{\kappa}$$

Typical wind profile over uniform level vegetation of height h: (a) plotted linearly against z; (b) plotted against the logarithm of distance above the zero plane displacement level.



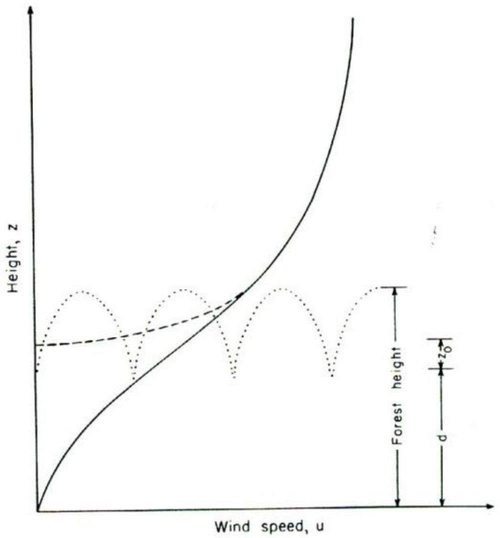


Fig. 4.1. Idealized vertical profile of wind speed over and within a forest canopy.

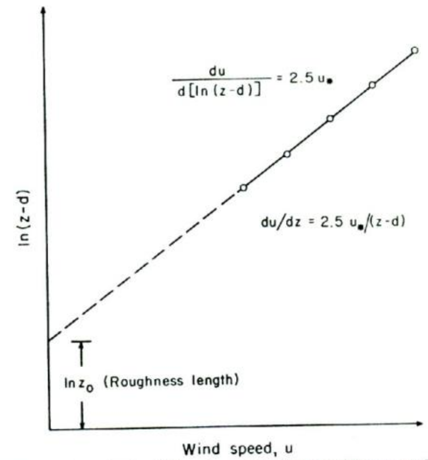


Fig. 4.2. Graphical analysis of the observed wind profile over a forest canopy under neutral conditions.

For wind profiles through vegetation, a zero plane displacement (d) is required (i.e., to shit the curve upward):

$$U(z) = \frac{u^*}{\kappa} \ln\left(\frac{z - d}{z_m}\right)$$

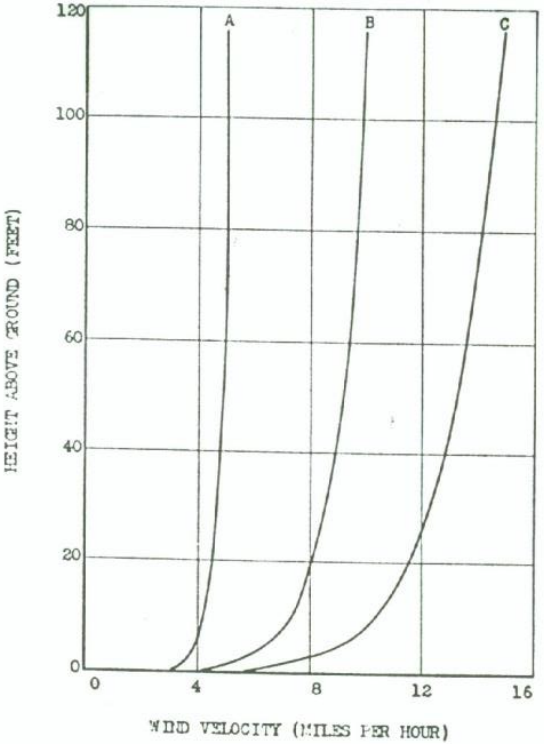


Fig. 3.—Grassland site: Distribution of wind velocities with height for wind velocities of 5 (A), 10 (B), and 15 (C) miles per hour measured 116 feet above the ground.

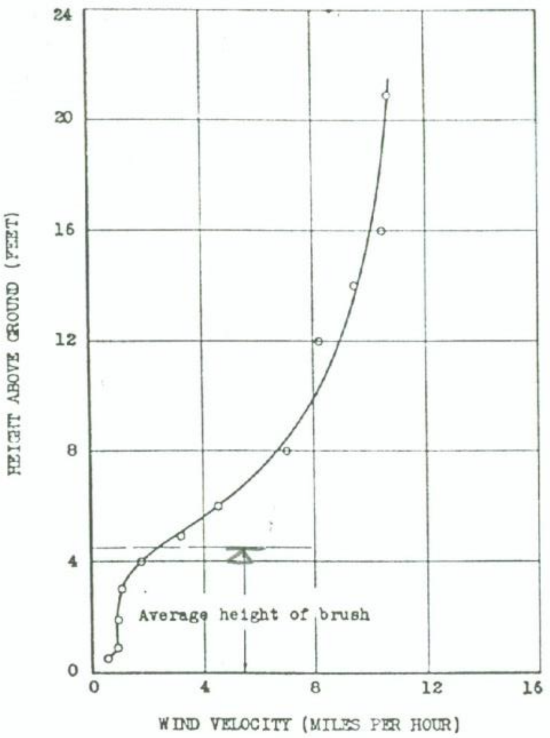


Fig. 5.—Brush site: Distribution of wind velocities near the ground with an average velocity of 10.7 miles per hour measured 21 feet above the ground.

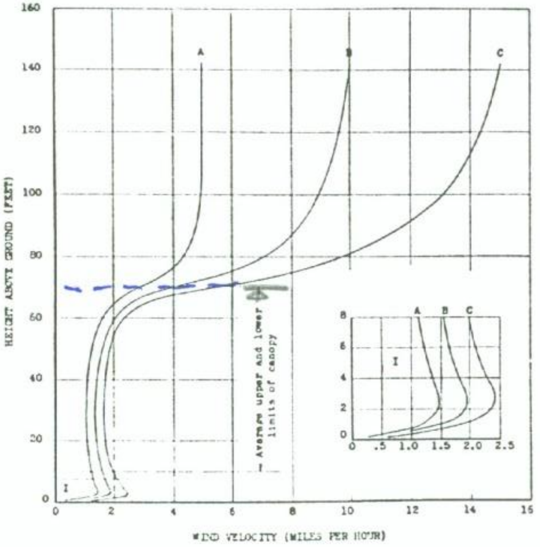


Fig. 4.—Ponderosa pine site: Distribution of wind velocities with height as affected by the timber canopy for wind velocities of 5 (A), 10 (B), and 15 (C) miles per hour measured 142 feet above the ground.

Wind Direction & Windroses

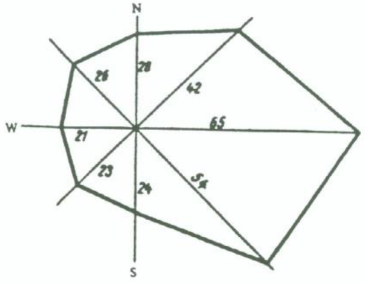


FIGURE 109. Wind rose

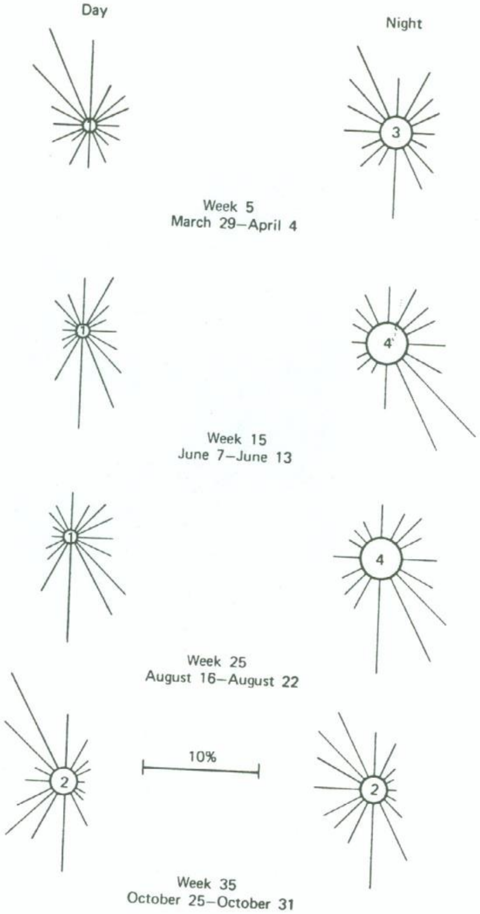


Fig. 4.10 Percentage frequencies of wind direction for day and night during 4 weeks of the growing season at Grand Island, Nebraska. Percent of calm hours indicated in center circle (after Rosenberg, 1965).

Anemometers and applications

Distance constant: the distance of air that must pass an anemometer for it to respond to 63% (i.e., 1-1/e) of the step chance from the initial to the final condition. Fritschen’s 1.5 m!

The threshold (aka starting speed) is the speed at which an anemometer start to operate. Fritschen’s 270 mm.s^{-1}

The pressure on the intake port is equal to $P-\frac{1}{2}\rho U^2$,
the pressure on the side port is equal to $P-\frac{1}{2}C\rho U^2$.

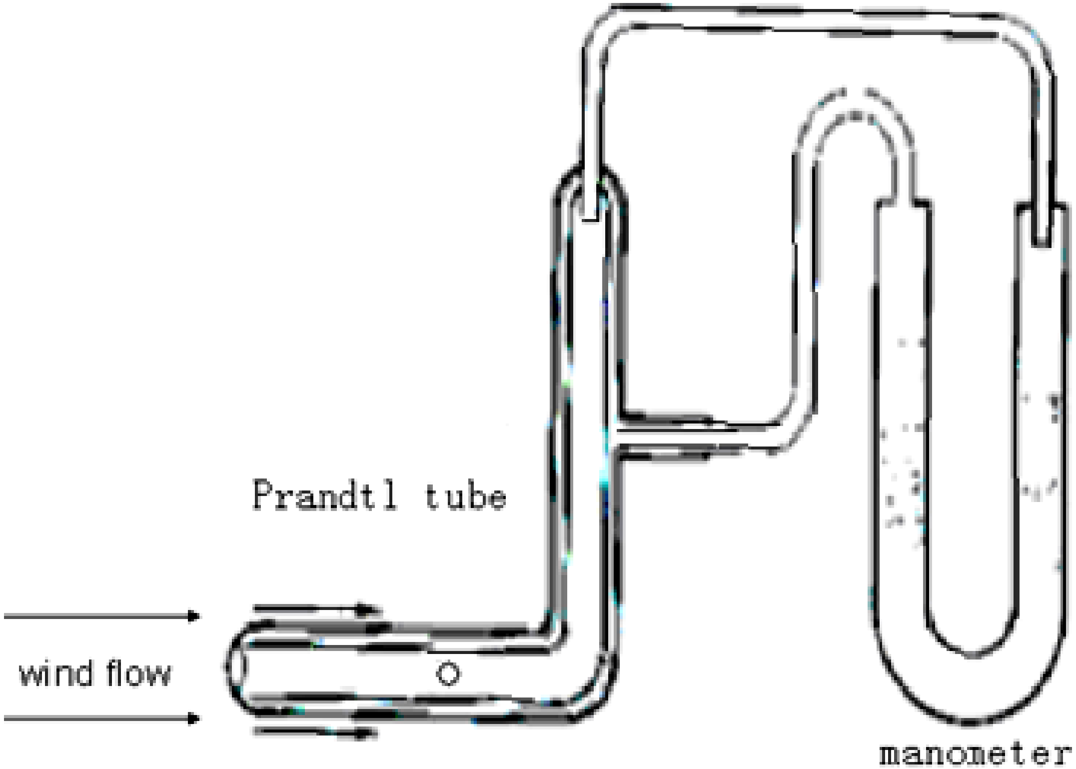


Fig. 7.1. Pressure tube anemometer.

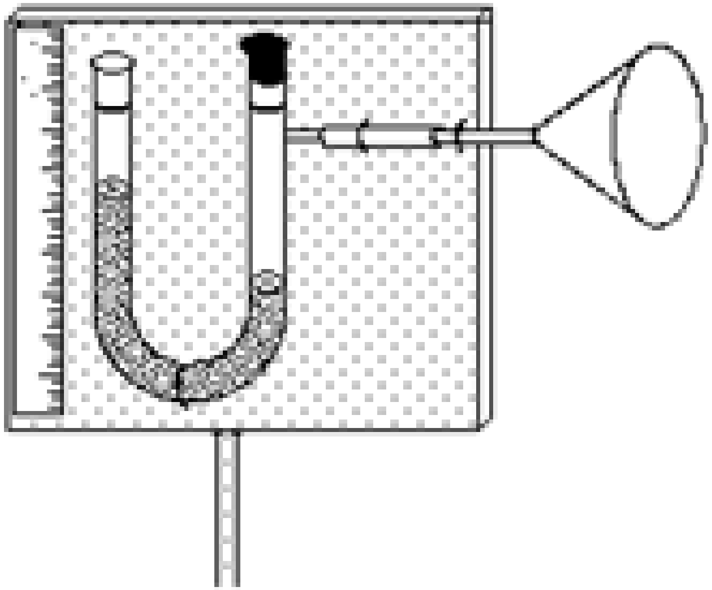


Fig. 7.1. Pressure tube anemometer.

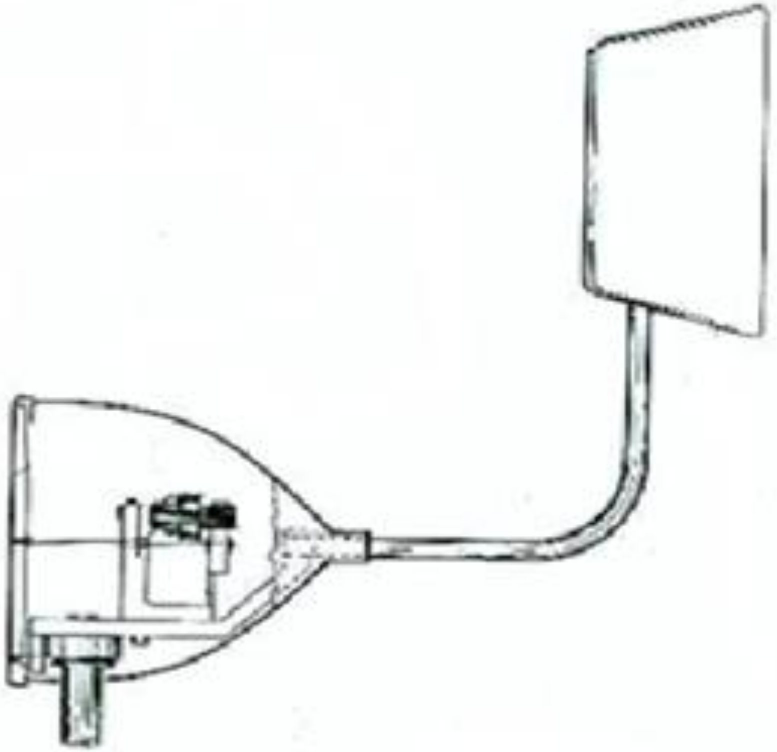
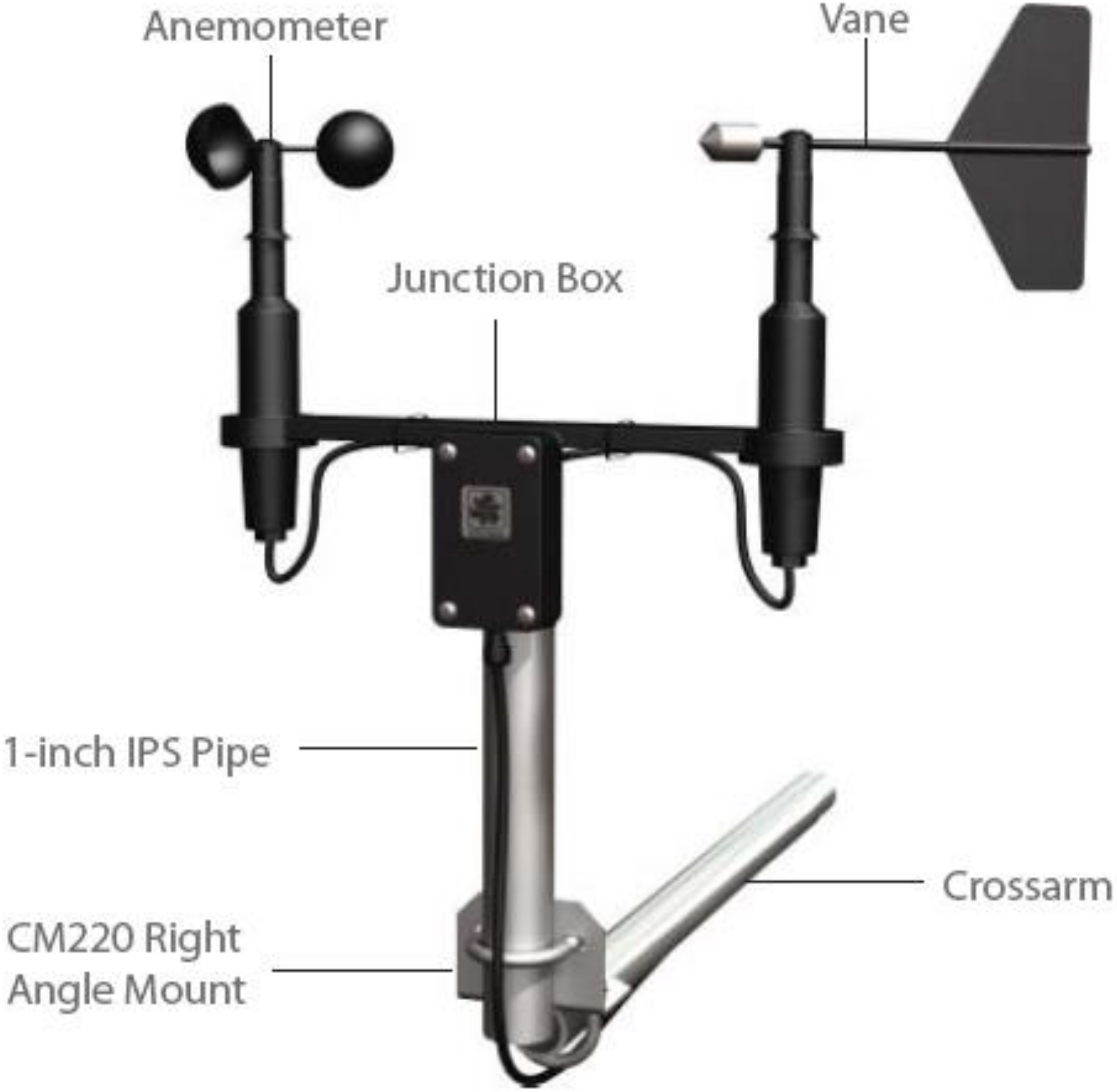
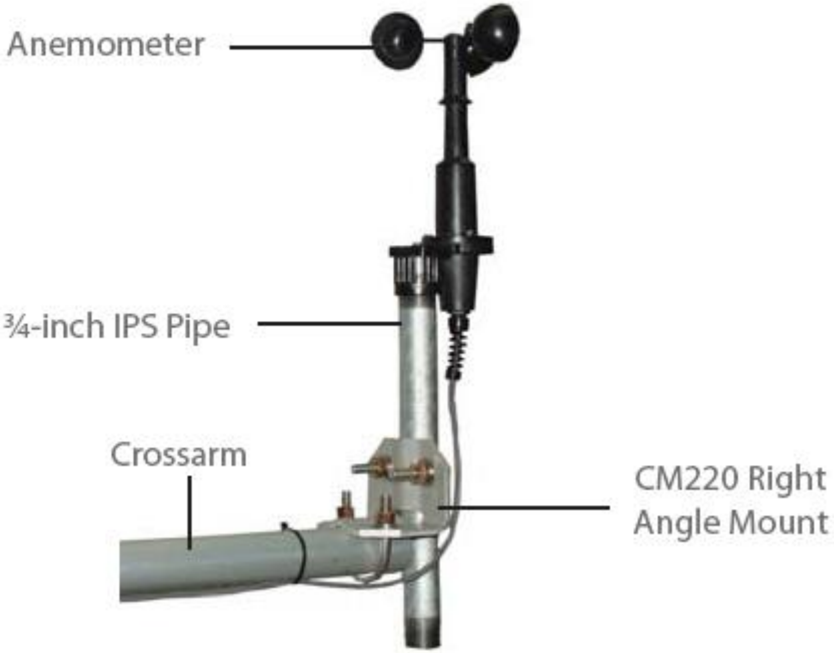
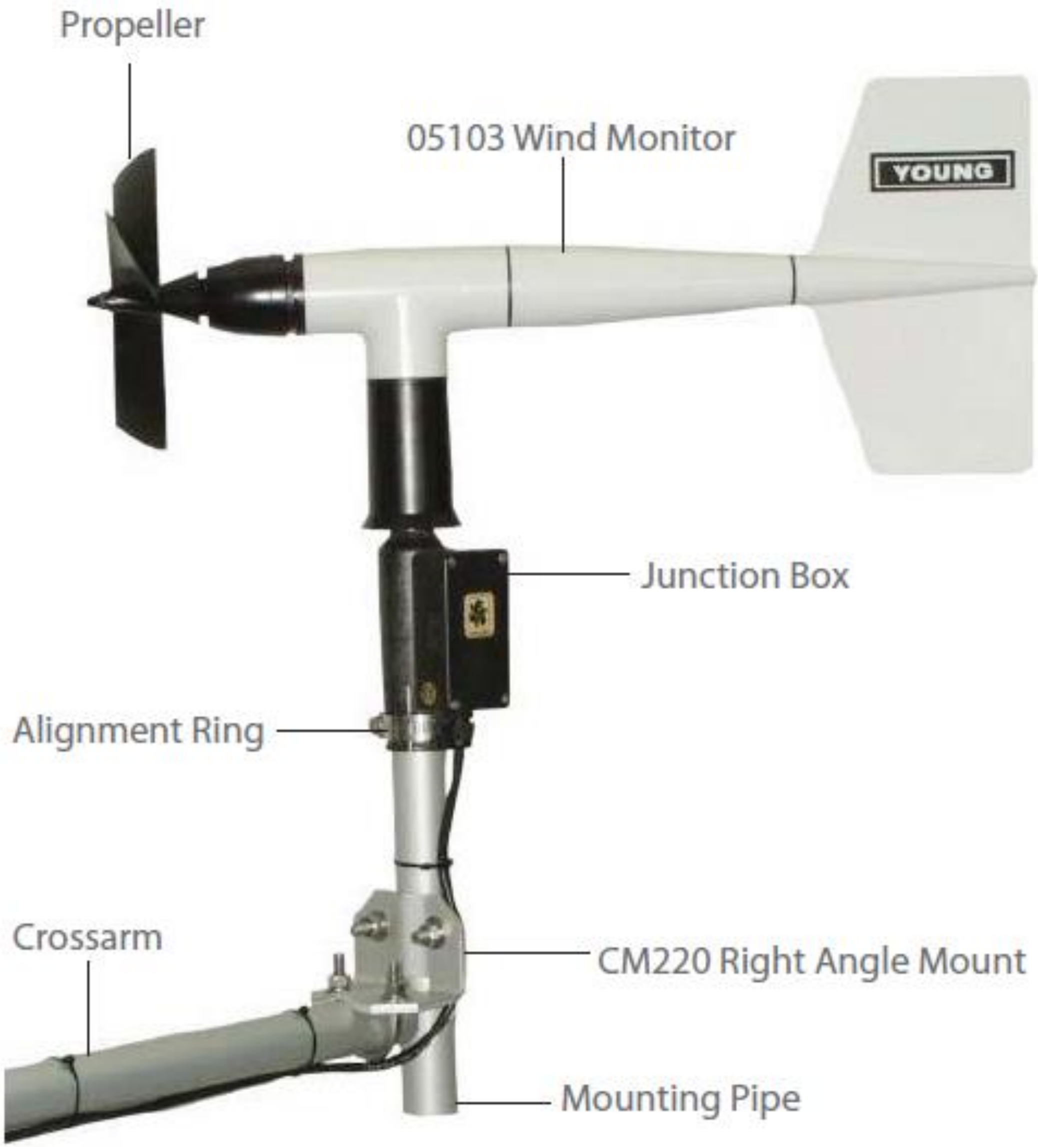


Fig. 7.2. The normal-plate anemometer of Sherlock and Stout (from Middleton and Spilhaus, 1953)



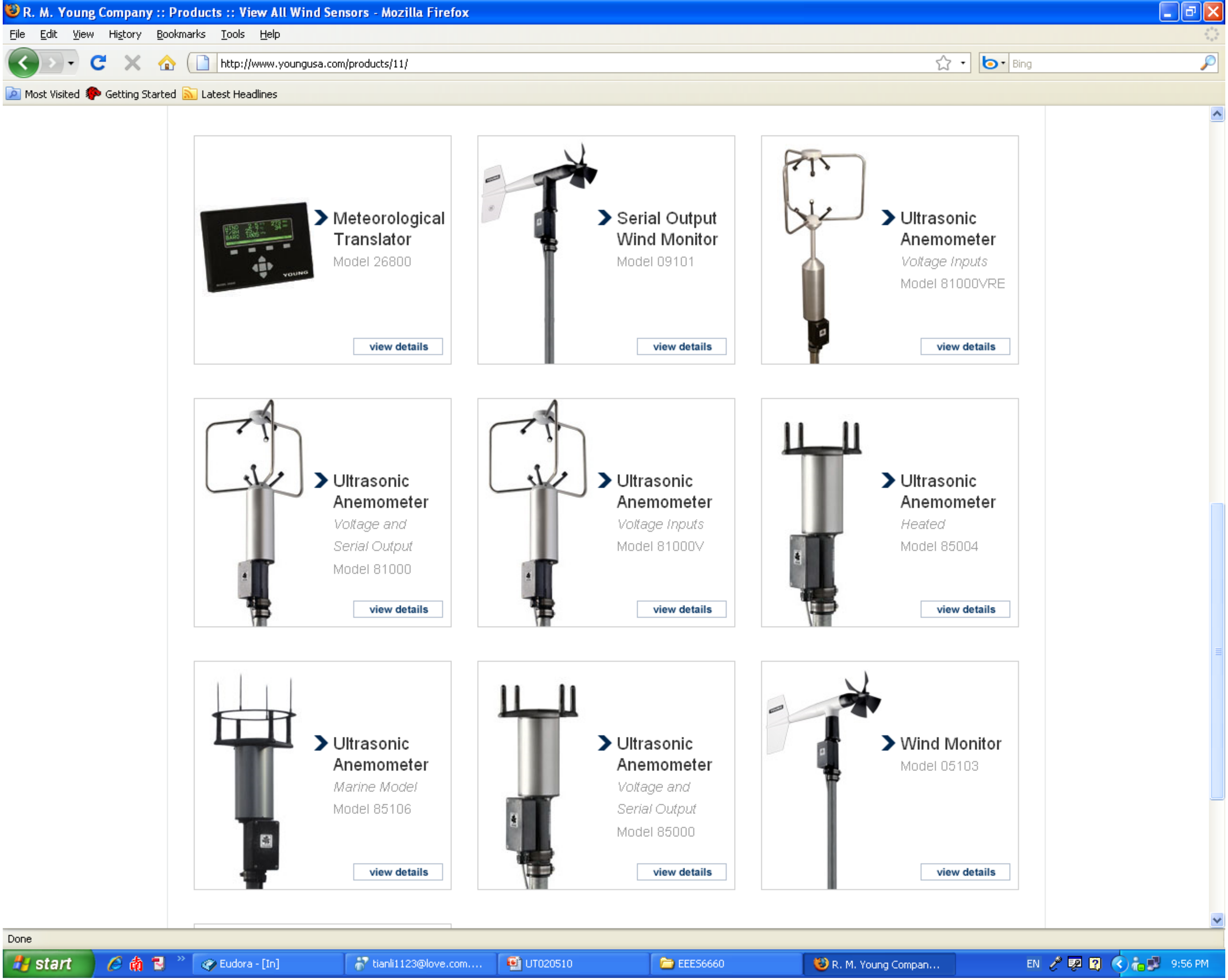
This 03002 is attached to a crossarm via a CM220 Mount and a 12-inch long x 1-inch IPS pipe (shipped with the sensor).


Anemometer
¾-inch IPS Pipe
Crossarm
CM220 Right Angle Mount



This 05103 Wind Monitor is attached to a crossarm via a CM220 Right Angle Mount and a mounting pipe (shipped with the sensor).

http://www.gill.co.uk/products/anemometer/windmaster-range.html



Meteorological Translator
Model 26800

Serial Output Wind Monitor
Model 09101

Ultrasonic Anemometer
Voltage Inputs
Model 81000VRE

Ultrasonic Anemometer
Voltage and Serial Output
Model 81000

Ultrasonic Anemometer
Voltage Inputs
Model 81000V

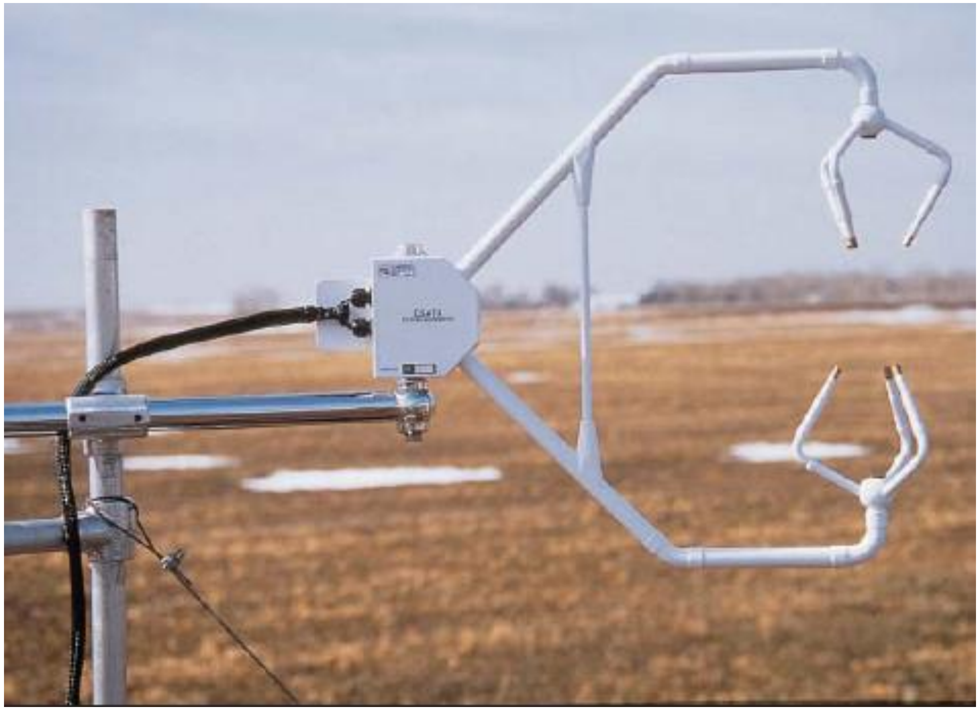
Ultrasonic Anemometer
Heated
Model 85004

Ultrasonic Anemometer
Marine Model
Model 85106

Ultrasonic Anemometer
Voltage and Serial Output
Model 85000

Wind Monitor
Model 05103

Campbell Scientific’s CSAT3 3-D Sonic Anemometer has a 10 cm vertical measurement path, operates in a pulsed acoustic mode, and withstands exposure to harsh weather conditions. Three orthogonal wind components (ux, uy, uz) and the speed of sound (c) are measured and output at a maximum rate of 60 Hz. Analog outputs and two types of digital outputs are provided.



Flux Measurements

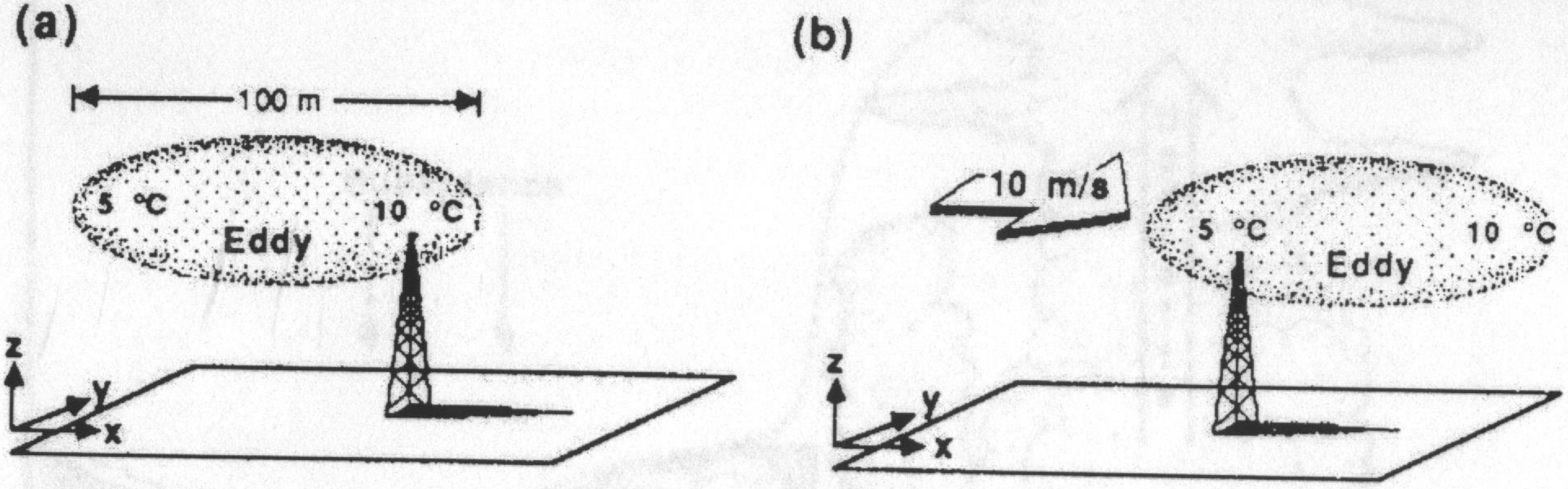
Eddy-Covariance method, Lagrangian method, Surface renewal analysis

Eddy-covariance has been used for almost half a century, but has become relatively easy to use only in the last decade with the availability of reliable instruments. Because eddy-covariance measurements are sensitive to relatively large areas of ecosystems, can be employed almost continuously, and are non-invasive, they have become one of the preferred choices for estimating carbon and water vapor exchange. It is not surprising that the exchange E_x (units of concentration per second) of any scalar X is assumed to be proportional to the vertical eddy-covariance flux, F_x (units of mass per area per second):

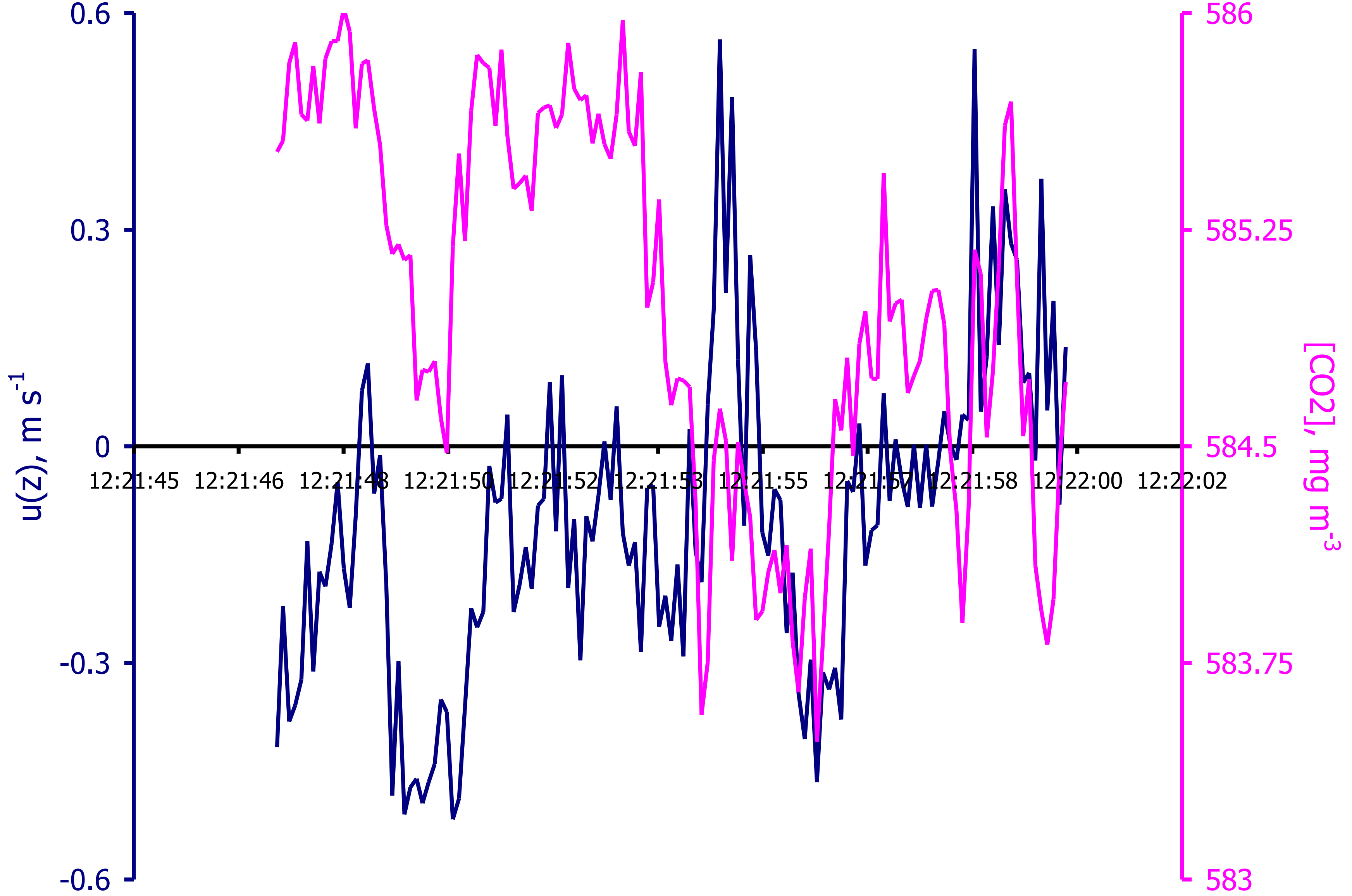
$$E_c \propto F_c = \overline{w'C'}$$

$$E_c \propto F_c = \overline{w'C'}$$

where C' is the perturbation of the scalar concentration from its mean value 1, and w' is the perturbation of the vertical wind velocity from its mean value, . Below, the same type of 'Reynolds decomposition' will be used, and molecular diffusion will be ignored (although under some very low wind speed, stable stratification conditions, molecular diffusion could be non-negligible).

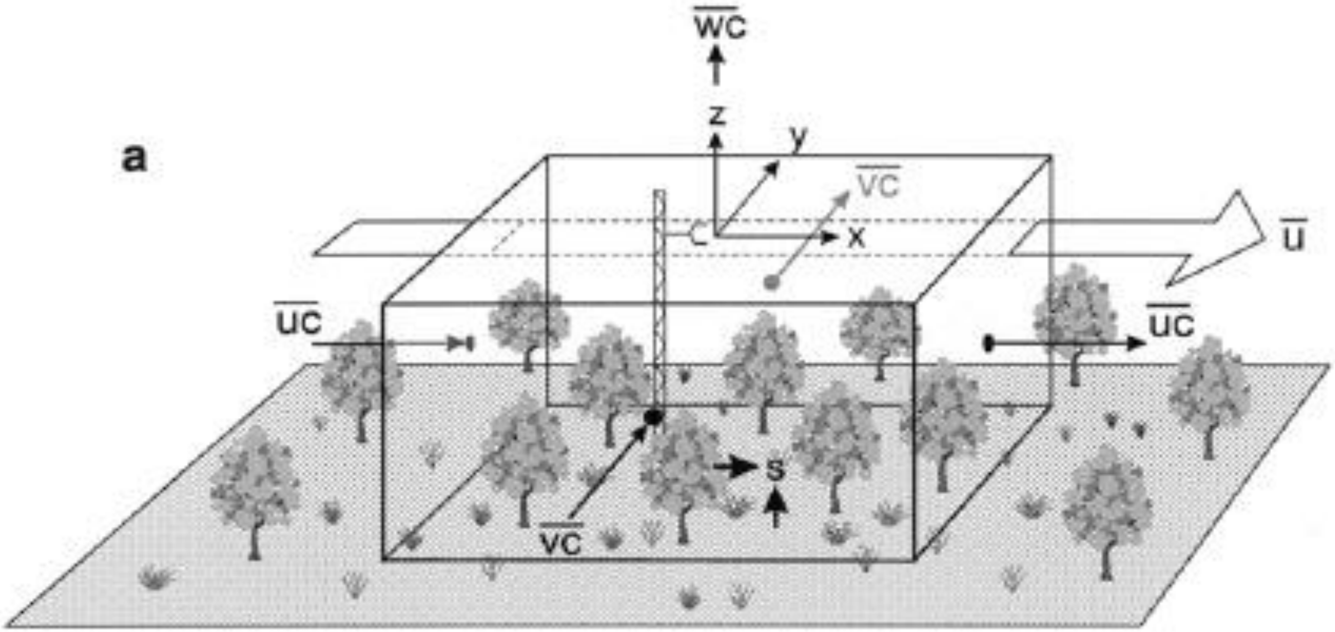

(a)
100 m
5 °C
10 °C
Eddy
z
y
x
(b)
10 m/s
5 °C
10 °C
Eddy
z
y
x

Co-variance


0.6
0.3
0
-0.3
-0.6
u(z), m s-1
586
585.25
584.5
583.75
583
[CO2], mg m-3
12:21:45
12:21:46
12:21:48
12:21:50
12:21:52
12:21:53
12:21:55
12:21:57
12:21:58
12:22:00
12:22:02

How we can measure net ecosystem exchange?

NEE of carbon can be monitored using the Eddy covariance (EC) Technique. EC is based on the covariance between concentration of scalars and vertical wind velocity measurements.



NEE_c & NEE_{H2O}

EC Method:

$$E_C = \frac{\partial C}{\partial t} + \frac{\partial}{\partial x_i}\,[\,\overline{u_i}\,\overline{C} + \overline{u_i' C'}\,]$$

$$\overline{\rho}\frac{\partial \overline{s}}{\partial t} + \frac{\overline{s}}{\overline{T}}\left[\overline{\rho}(1+\mu\sigma)\frac{\partial(\overline{w'T'})}{\partial z} + \mu\frac{\partial(\overline{w'\rho_v'})}{\partial z}\right] + \overline{w}\,\overline{\rho}\frac{\partial \overline{s}}{\partial z} + \frac{\partial(\overline{w'\rho'_c})}{\partial z} = \overline{S}_c$$

OR

$$\frac{\partial \overline{\rho}_c}{\partial t} + \overline{\rho}_c\frac{\partial \overline{u}}{\partial x} + \overline{u}\frac{\partial(\overline{\rho}_c)}{\partial x} + \overline{\rho}_c\frac{\partial \overline{w}}{\partial z} + \overline{w}\frac{\partial(\overline{\rho}_c)}{\partial z} + \frac{\partial(\overline{w'\rho'_c})}{\partial z} = \overline{S}_c$$

$$\frac{d\bar{c}}{dt}=\overset{\text{I}}{\boxed{\frac{\partial\bar{c}}{\partial t}}}+\overset{\text{II}}{\boxed{\bar{u}\frac{\partial\bar{c}}{\partial t}+\bar{v}\frac{\partial\bar{c}}{\partial t}+\bar{w}\frac{\partial\bar{c}}{\partial t}}}=-\left(\overset{\text{III}}{\boxed{\frac{\partial F_z}{\partial z}+\frac{\partial F_x}{\partial x}+\frac{\partial F_y}{\partial y}}}+\overset{\text{IV}}{\boxed{S_B(x,y,z)}}\right)$$

$$F=\overline{w'\rho_c{}'}$$

Flux = change in mixing ratio (**I**)

+ advection (**II**)

+ flux divergence (vertical, lateral & longitudinal) (**III**)

+ biological source/sink strength (**IV**)

Ideally:

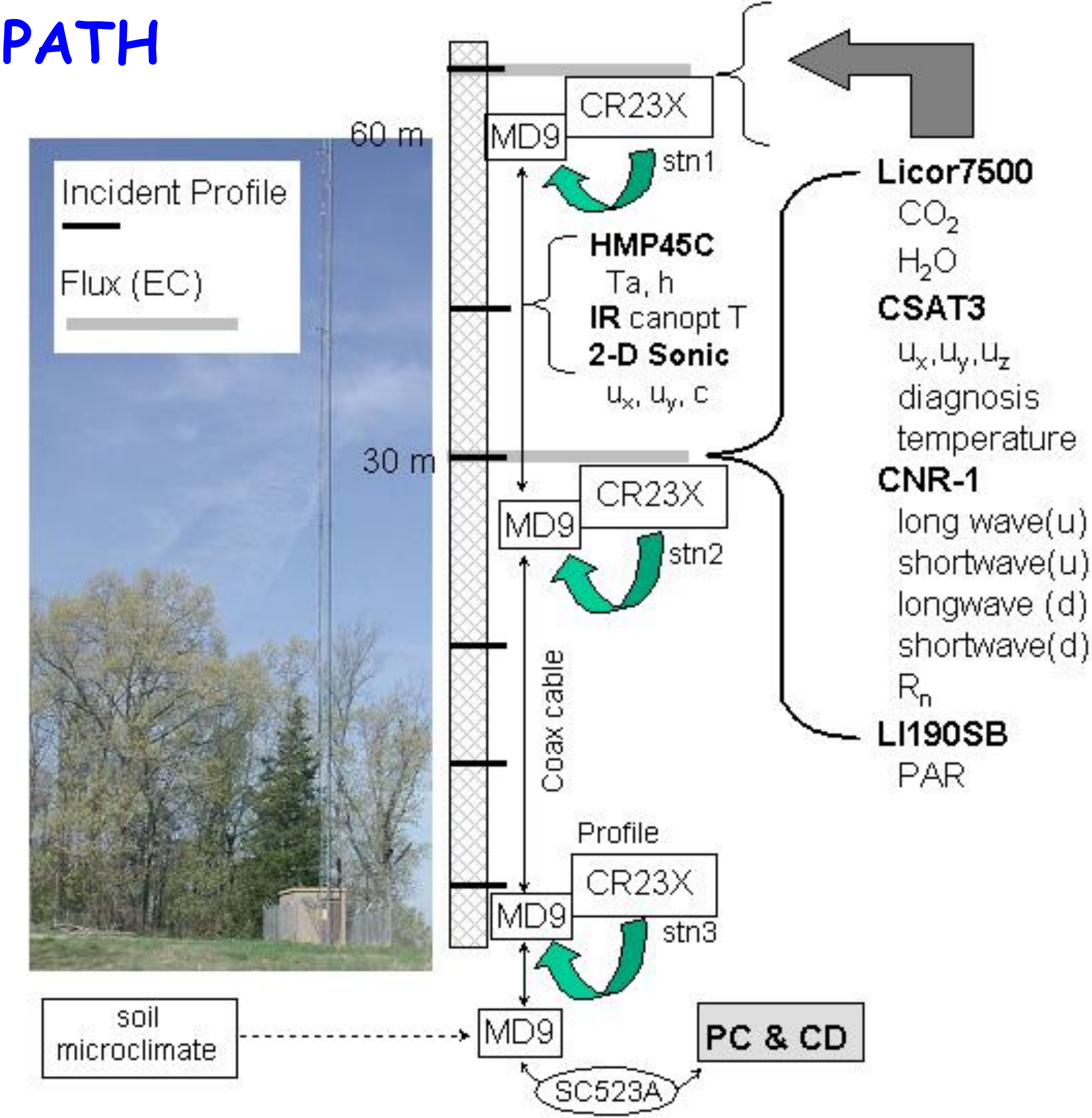
I=0, **II**=0, **III**=0

In reality:

I $\neq$ **II** $\neq$ **III** $\neq 0$

Measured covariance = true covariance + sensor bias

OPEN-PATH



Incident Profile

Flux (EC)

60 m

30 m

CR23X

MD9

stn1

HMP45C
Ta, h
IR canopt T
2-D Sonic
u_x, u_y, c

CR23X

MD9

stn2

Coax cable

Profile

CR23X

MD9

stn3

soil
microclimate

MD9

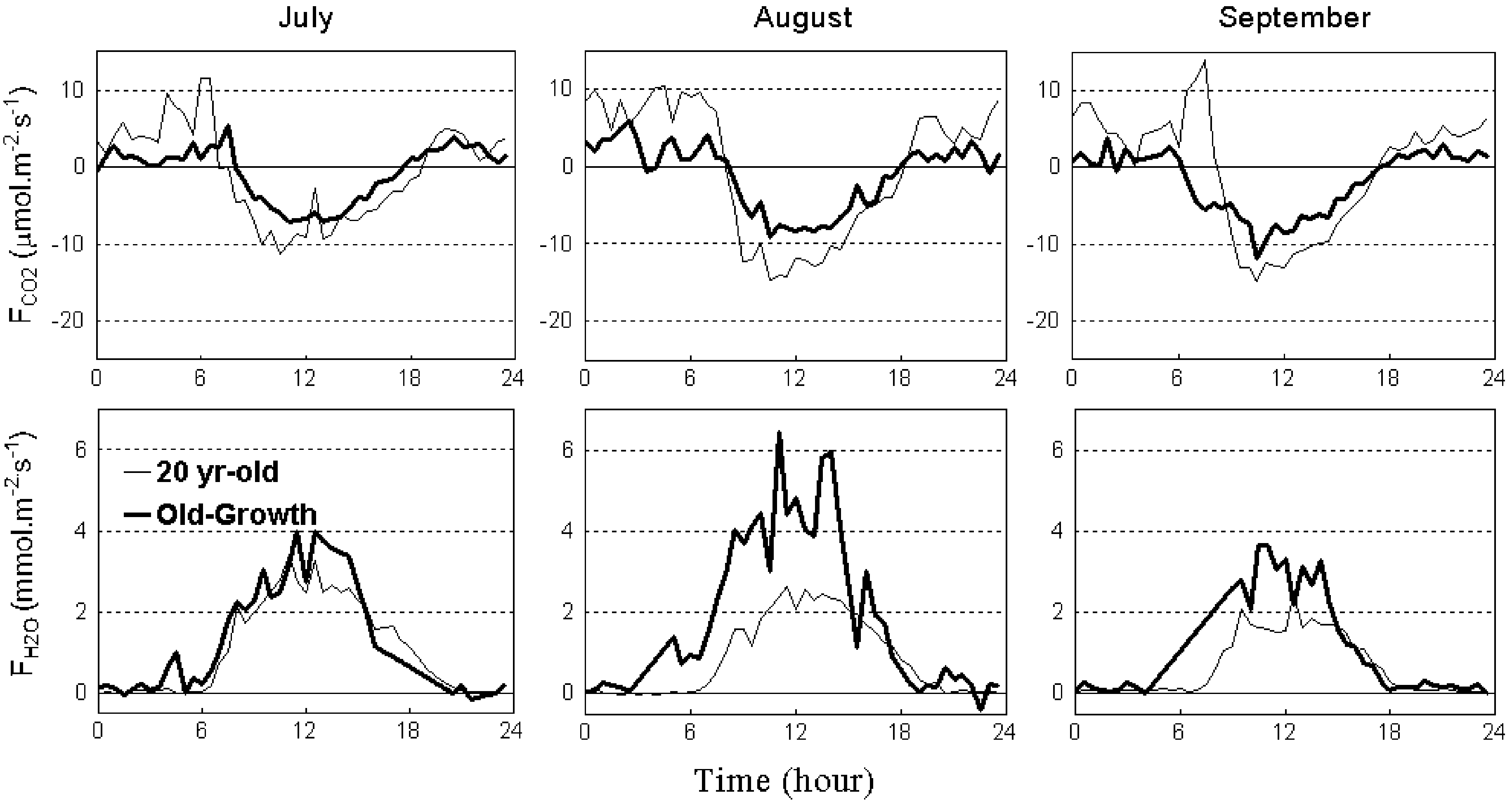
SC523A

PC & CD

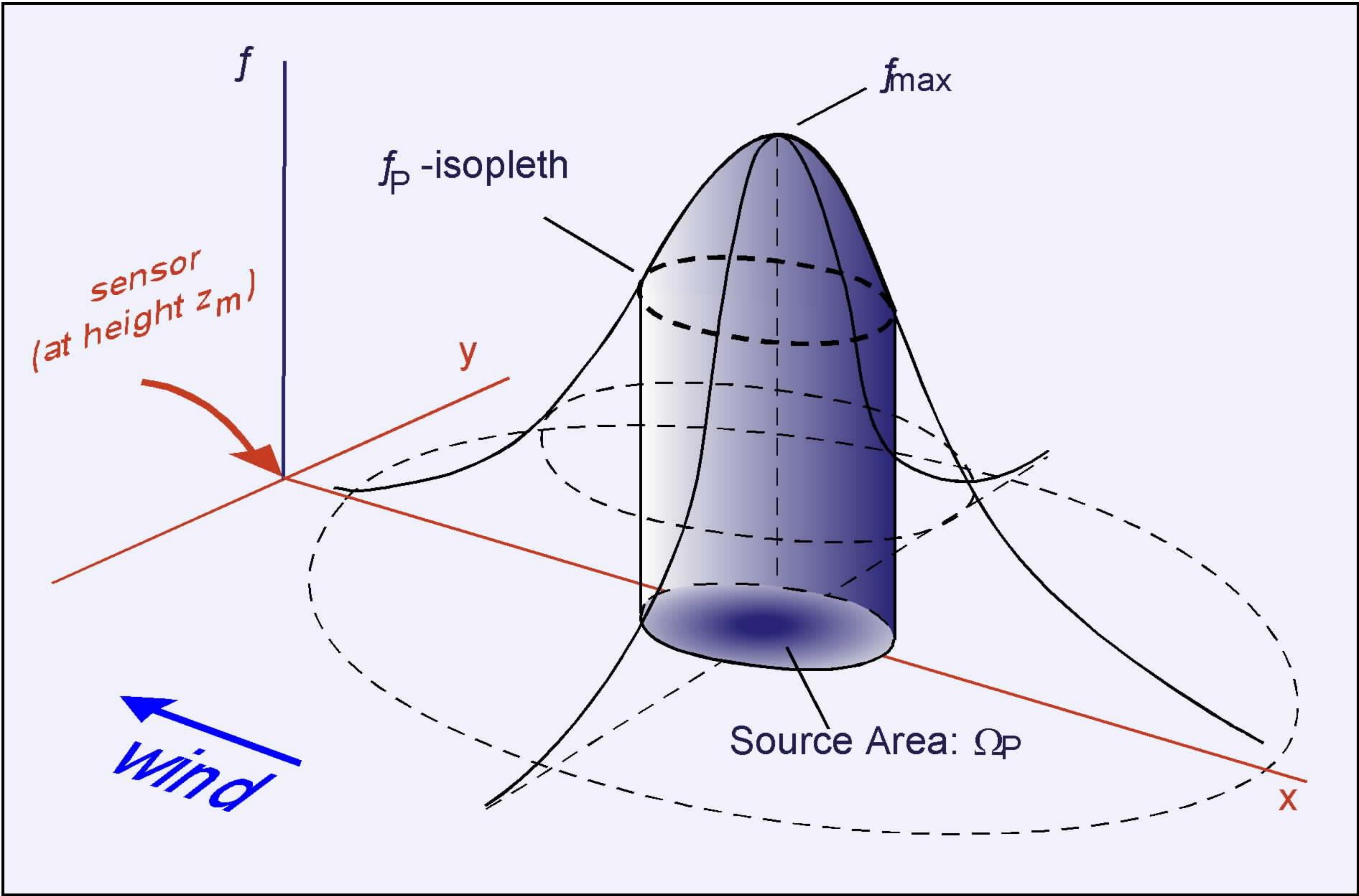
Licor7500
CO_2
H_2O
CSAT3
u_x, u_y, u_z
diagnosis
temperature
CNR-1
long wave(u)
shortwave(u)
longwave (d)
shortwave(d)
R_n
LI190SB
PAR

(b) EC tower at Site 2 (Corn)

Average diurnal fluxes of CO_2 and H_2O in Jul., Aug., and Sept. in 1999 in a 20 and a 500 year-old Douglas-fir forest (WA). Only data from good fetch (200-310°) directions were used. Negative and positive values indicate uptake and loss, respectively (Chen et al. 2002)



The source weight function, or footprint function, and its relation to the source area (Schimid 1997)



Data process & programming

- EC_Processor: LEES Lab
- eddy4R:
- EdiRe: http://www.geos.ed.ac.uk/abs/research/micromet/EdiRe
- etc.

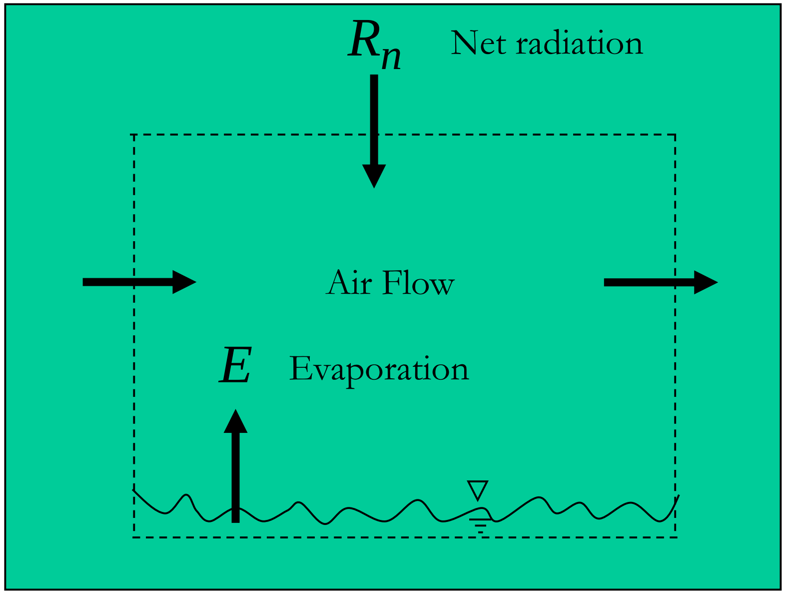
Aerodynamic Method

- Include transport of vapor away from water surface as function of:
  - Humidity gradient above surface
  - Wind speed across surface
- Upward vapor flux

$$\dot{m} = -\rho_a K_w \frac{dq_v}{dz} = \rho_a K_w \frac{q_{v_1} - q_{v_2}}{z_2 - z_1}$$

- Upward momentum flux

$$\tau = \rho_a K_m \frac{du}{dz} = \rho_a K_m \frac{u_2 - u_1}{z_2 - z_1}$$



$$\dot{m} = \tau \frac{K_w (q_{v_1} - q_{v_2})}{K_m (u_2 - u_1)}$$

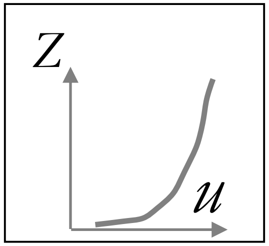
Slides prepared by Daene C. McKinney

Aerodynamic Method

$$\dot{m} = \tau \frac{K_w\left(q_{v_1} - q_{v_2}\right)}{K_m\left(u_2 - u_1\right)}$$

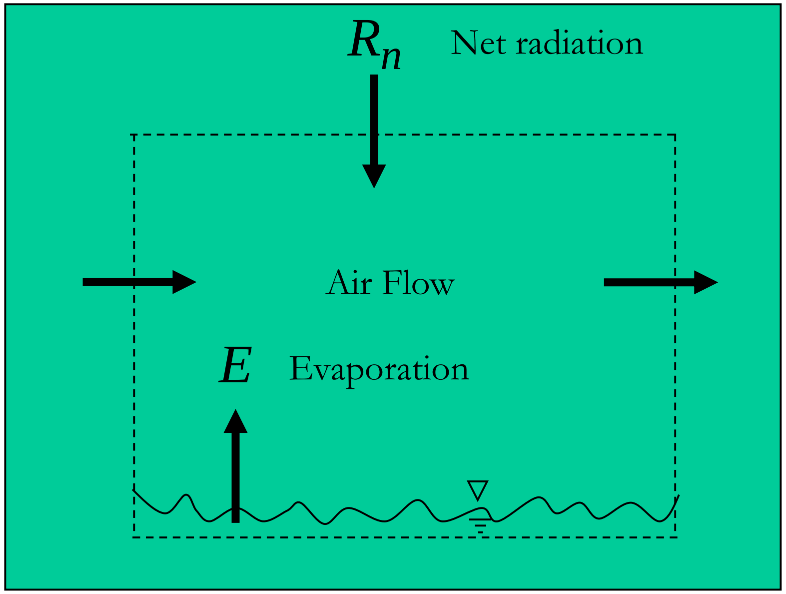
- Log-velocity profile

$$\frac{u}{u*} = \frac{1}{k}\ln\left(\frac{Z}{Z_o}\right)$$



- Momentum flux

$$\tau = \rho_a\left[\frac{k\left(u_2 - u_1\right)}{\ln\left(Z_2/Z_1\right)}\right]^2$$



$$\boxed{\dot{m} = \frac{K_w k^2 \rho_a\left(q_{v_1} - q_{v_2}\right)\left(u_2 - u_1\right)}{K_m\left[\ln\left(Z_2/Z_1\right)\right]^2}}$$

Thornthwaite-Holzman Equation

Aerodynamic Method

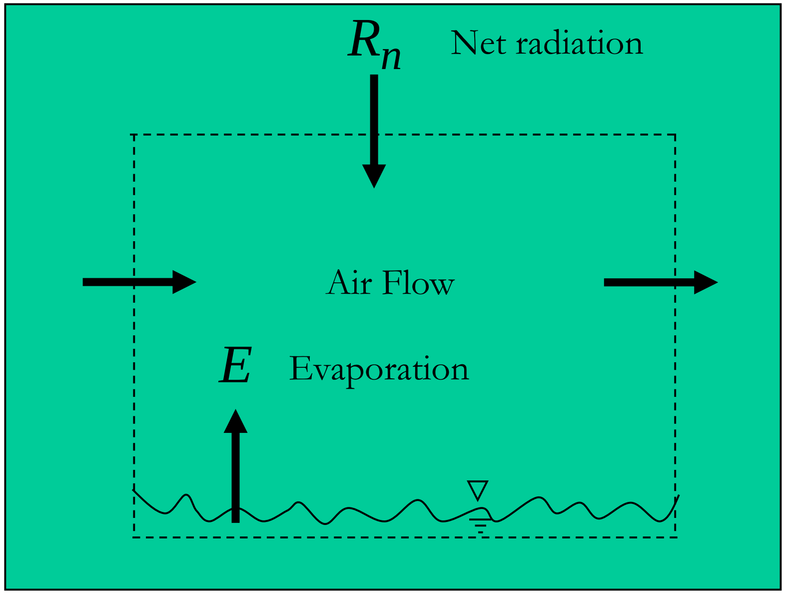
$$\dot{m} = \frac{K_w k^2 \rho_a \left(q_{v_1} - q_{v_2}\right)\left(u_2 - u_1\right)}{K_m \left[\ln\left(Z_2 / Z_1\right)\right]^2}$$

q_v and u

- Often only available at 1 elevation
- Simplifying

$$\dot{m} = \frac{0.622 k^2 \rho_a \left(e_{as} - e_a\right) u_2}{P\left[\ln\left(Z_2 / Z_o\right)\right]^2}$$

$\dot{m} = \rho_w A E$ $\quad$ e_a = vapor pressure @ Z_2



$$\boxed{E_a = B\left(e_{as} - e_a\right)}$$

$$\boxed{B = \frac{0.622 k^2 \rho_a u_2}{P \rho_w \left[\ln\left(Z_2 / Z_o\right)\right]^2}}$$

Lagrangian method:

The Lagrangian framework is based on vertical changes of turbulence and concentrations of focal gases that are related to the statistics of air parcel displacement. The gradient is approximated by finite differences between two measurement heights z_i and z_j, as Dc_{ij}/Dz_{ij}. The gas diffusivity (K_c, also known as the K-theory) is estimated using either the heat flux and temperature gradient or friction velocity (u*):

$$Flux = -\frac{ku^{*} \bullet z}{\phi_h(z/L)} \frac{\Delta c_{ij}}{\Delta z_{ij}} \qquad [1]$$

Where *Flux* represents either the flux of gas, z is the aerodynamically effective height z_{ij} that is between z_i and $z_{j.}$, L is the displacement distance,

Also see gradient method at: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V8W-3YVDBP8-3&_user=7778205&_coverDate=04%2F28%2F2000&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_searchStrId=1192863556&_rerunOrigin=google&_acct=C000062866&_version=1&_urlVersion=0&_userid=7778205&md5=a9f5412df195188103f4e5516e79d3b9