Wind and Turbulence: Canopy Air Space,Part I

- Processes
  - Wind and Turbulence
    - Concepts
    - Conservation equation for wind
    - TKE budget, conceptual
- Variation in Space
  - Mean Wind Profiles within Vegetation
  - Turbulence Statistics in Vegetation

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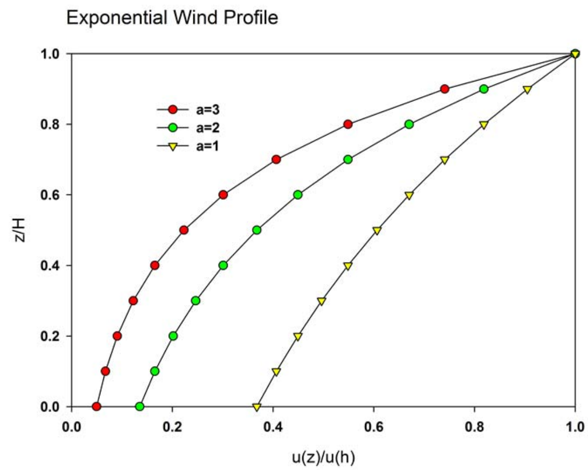
Wind in the canopy is very different from the log wind profile above. Here we will learn about this new complex world

I'll huff and puff and I'll blow your house down,

Big-Bad Wolf

Theoretical Wind Profile in Canopy



$$u(z) = u_h \exp(\alpha(\frac{z}{h} - 1))$$

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The wind profile inside the canopy follows an exponential pattern with depth, like light

Wind Extinction Coefficients, α

$$u(z) = u_h \exp(\alpha(\frac{z}{h} - 1))$$

Vegetation	α	Reference
immature corn	2.8	Cionco (1972)
oats	2.8	Cionco (1972)
wheat	2.5	Cionco (1972)
corn	2.0	Cionco (1972)
Sunflower	1.3	Cionco (1972)
Larch		Cionco (1972)
deciduous forest		Baldocchi and Meyers (1988)
jack pine		Amiro (1990)
Spruce	2.4	Amiro (1990)
Soybean	1.27-2.72	Baldocchi et al. 1983

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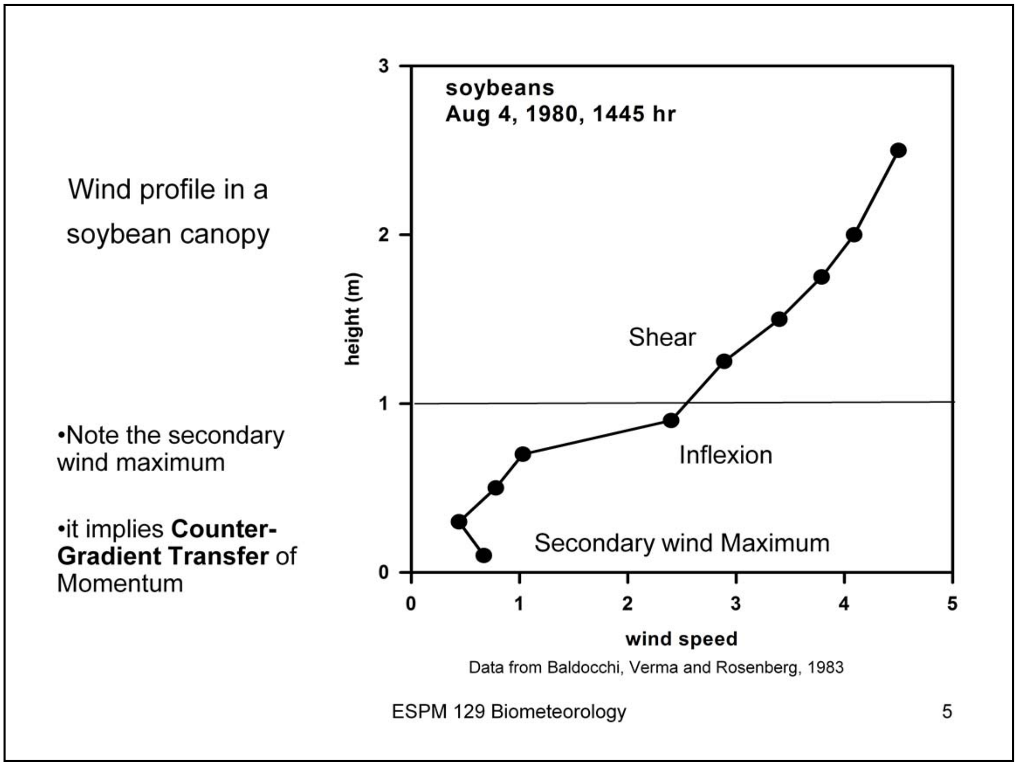
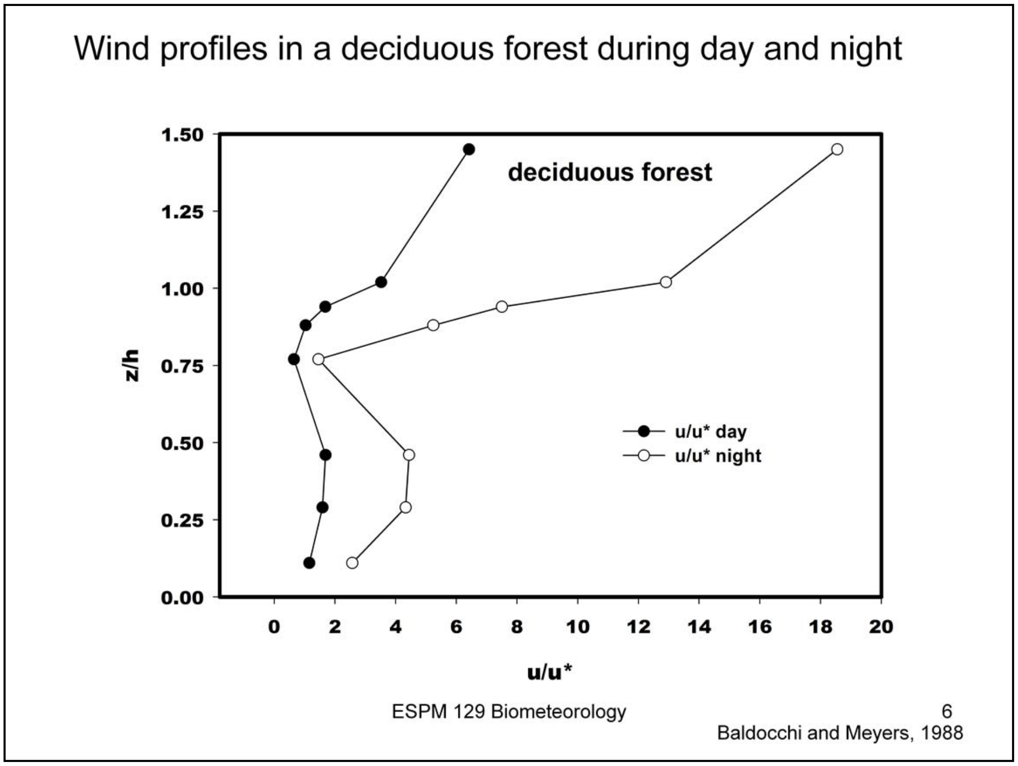
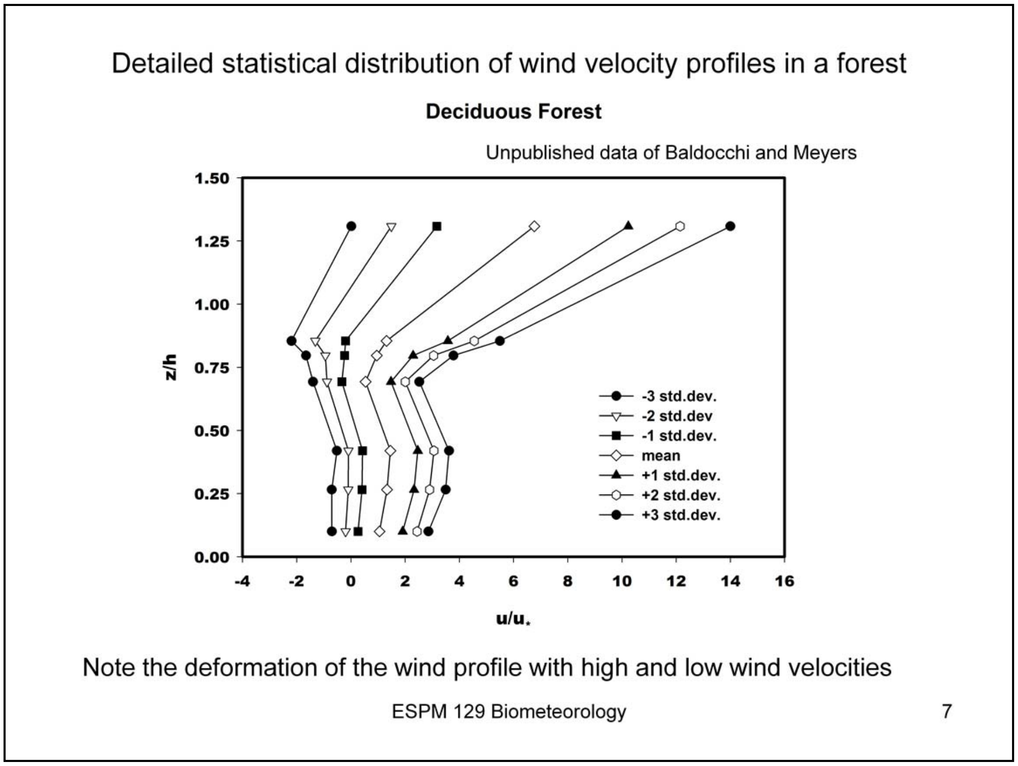
Here is a list of empirical extinction coefficients



The complexity of wind at the canopy – atmosphere interface is fascinating. We have a log wind profile above, there is great shear at the canopy top, followed by an Inflexion in the wind profile. The next layer decreases exponentially with depth, followed by a 2^{nd} wind maxima (where does this come from). Finally adjacent to the ground is yet another small but log wind profile

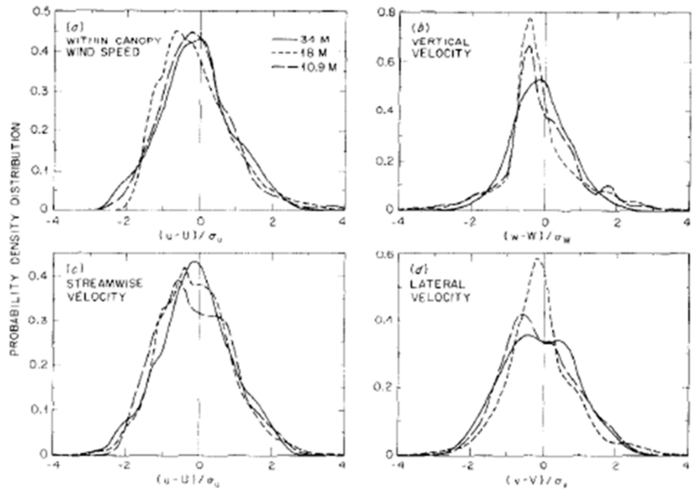


The extent of these layers differ day and night with different stability



The mean conditions are only part of the story. Turbulence in the canopy experiences extreme statistics, which can be skewed and kurtotic

Probability Distributions of Wind Vectors Above and Within a Deciduous Forest



Baldocchi and Meyers, 1988 BLM

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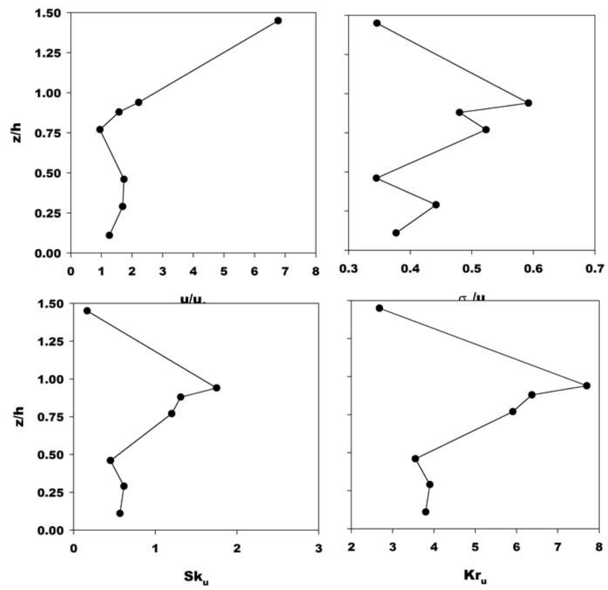
Here is an example of the histograms or pdfs for wind vectors above and within a forest. W is most kurtotic, or peaked. U is most skewed.

Profiles of turbulence statistics in a deciduous forest for horizontal wind velocity



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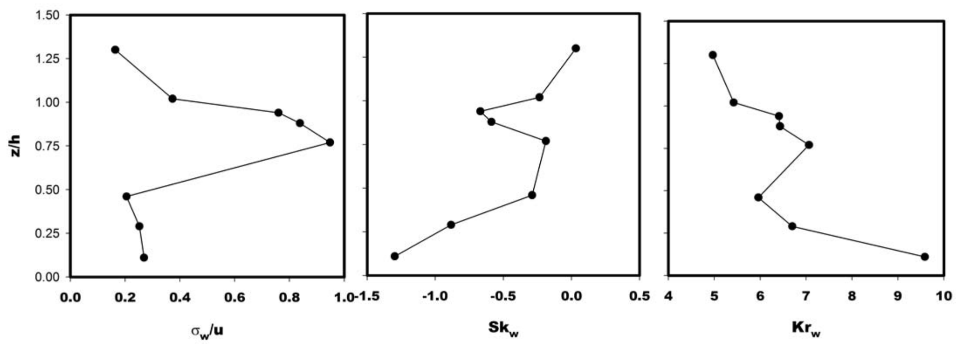
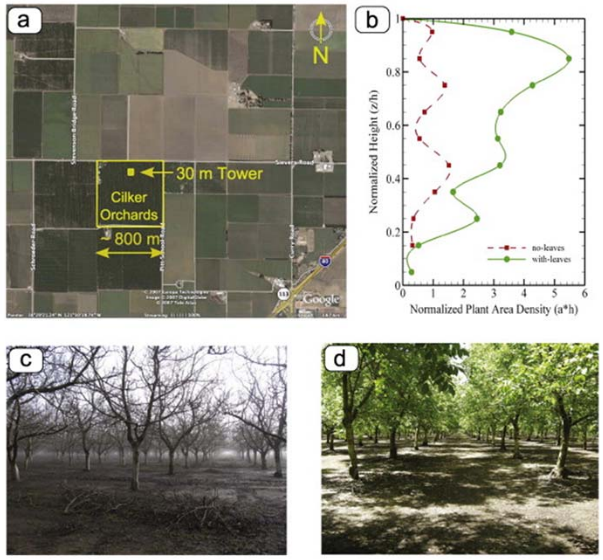
Here are profiles of turbulent statistics in a forest

Statistics of turbulence in a deciduous forest for vertical velocity



Turbulence in a Walnut Orchard



Dupont and Patton, 2012 AgForMet

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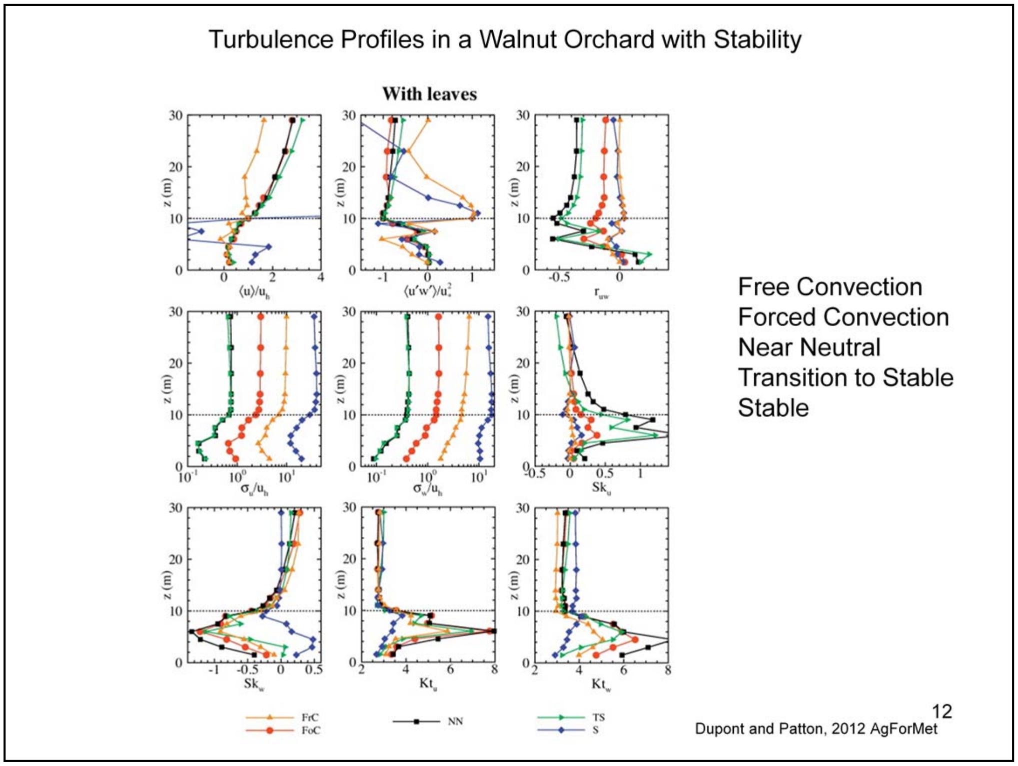
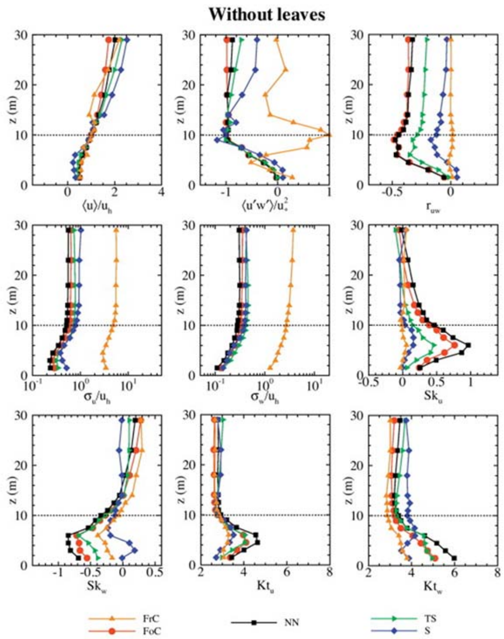
Newer and more detailed data were taken recently near Dixon by a team from NCAR



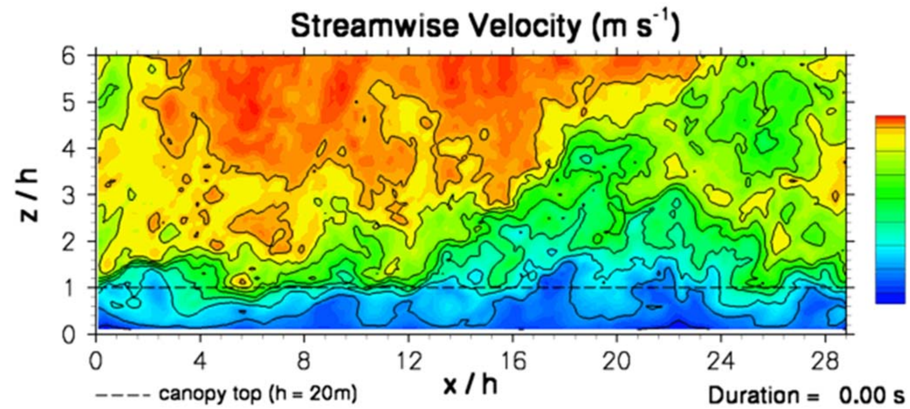
Here are some classic statistics profiles for different stabilities. Motions at the canopy-atmosphere interface are highly organized and coherent with large correlation coefficients between w and u

Turbulence Profiles in a Walnut Orchard with Stability



Free Convection
Forced Convection
Near Neutral
Transition to Stable
Stable

Dupont Patton 2012 AgForMet



LES simulation of Ned Patton, NCAR

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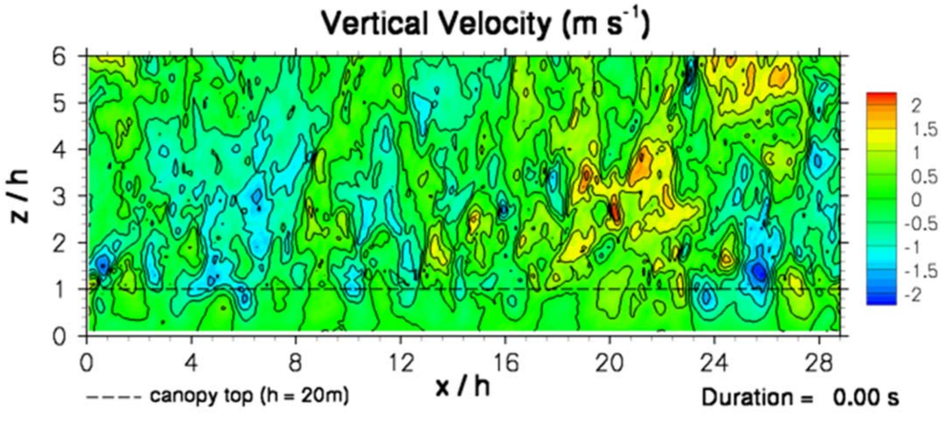
Movie of a large eddy simulation of turbulence at the canopy atmosphere interface. Look at the large coherent structures. These are responsible for large correlations between w and u, for the sweeps and ejections, the non local transport, 2nd wind maxima and the failure of K theory inside the canopy



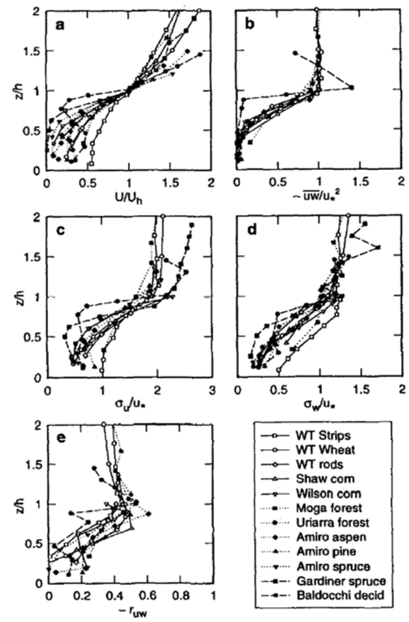
LES simulation of Ned Patton, NCAR

‘Family Portrait’ of turbulence in a vegetation

Wind Profile:
log(z), z>h
Inflexion, z=h
exp(z), z < h
2nd max, z ~ .1 h

Momentum flux:
constant z > h
exp(z), z < h

Turbulent Statistics
Constant, z > h
Decrease, z <h



r_{wu}
max at z ~h
Min @ z ~0

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Here are some of the take home points of turbulent statistics across the canopy atmosphere interfac

Turbulence intensities in vegetation

Canopy	turbulence intensity
Rice	0.33
Vineyard	0.45
wheat	0.50
black spruce	0.51
corn	0.52
soybean	0.52
immature corn	0.52
leafless forest	0.53
broadleaved forest	0.80
larch	0.54
sunflower	0.59
tropical forest	0.76
jungle	1.10
pine plantation	0.53
almond	0.8-1.0
corn	1-4

1st Evidence of Counter-Gradient Transport

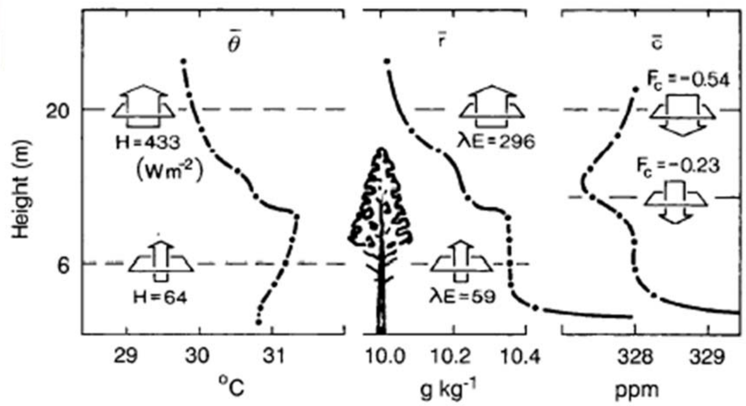

Figure 2 Simultaneous fluxes and gradients of heat and temperature, latent heat and water vapor mixing ratio and carbon dioxide (gm $m^{-2}s^{-1}$) and ppm. Obtained in a pine forest (Canopy G of Table 1). Figure from Denmead & Bradley (1987).

Denmead and Bradley, 1987

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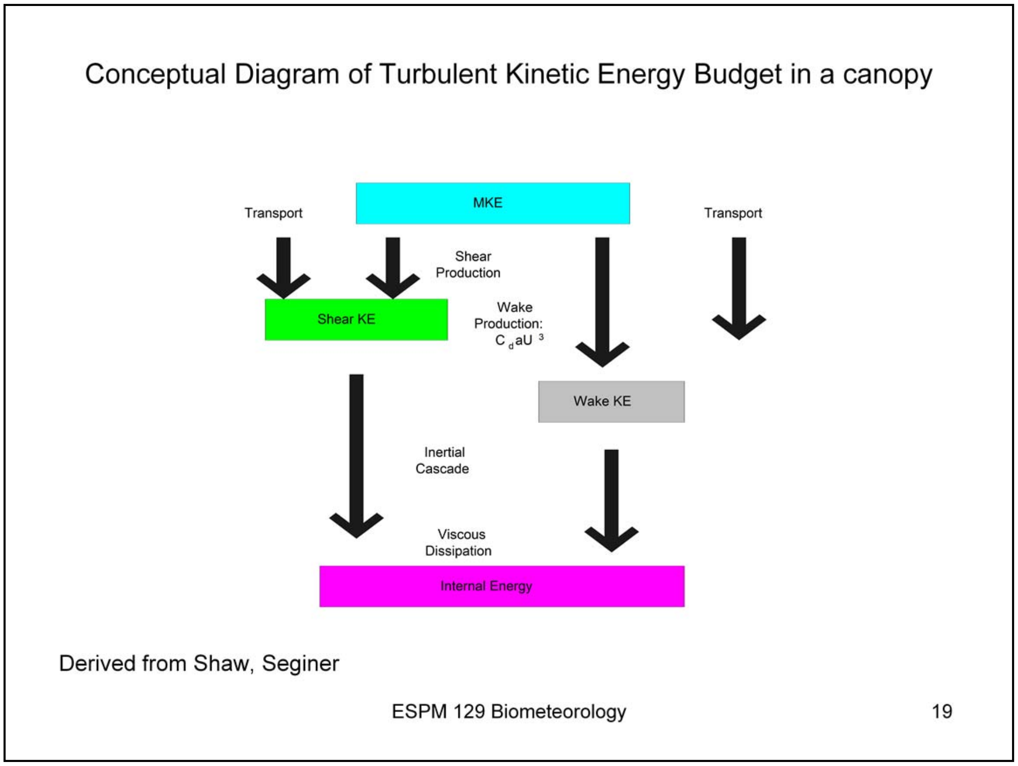
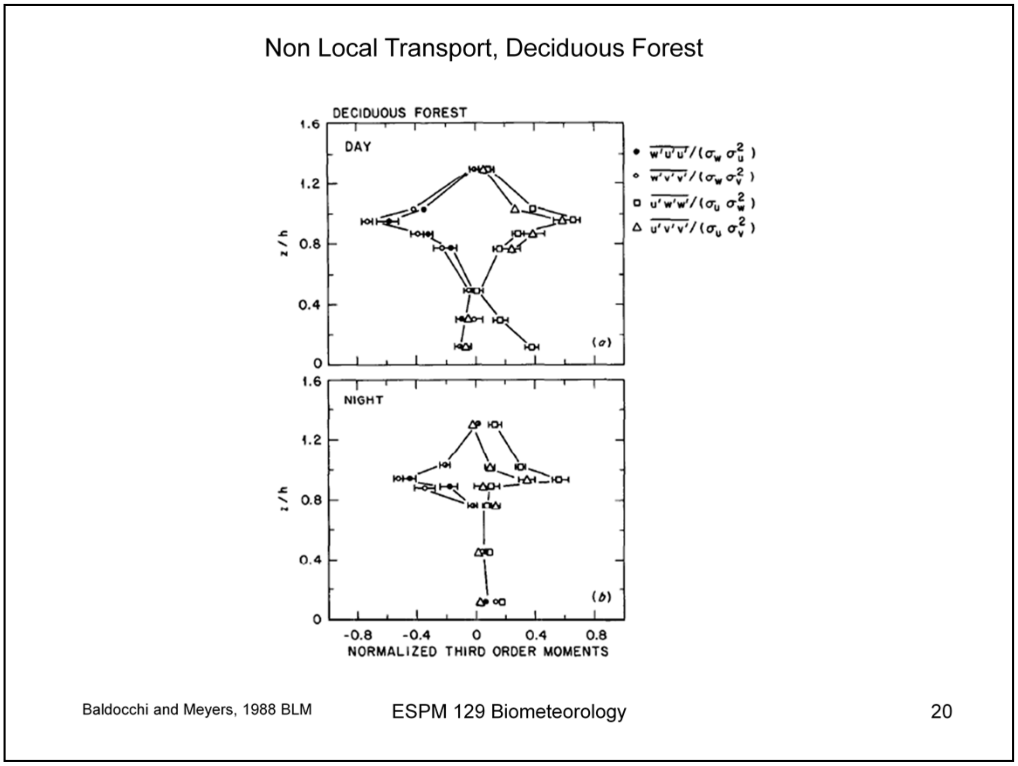
Early studies showed K theory fails in canopies as there is counter gradient transport. What is this and why is it happening?

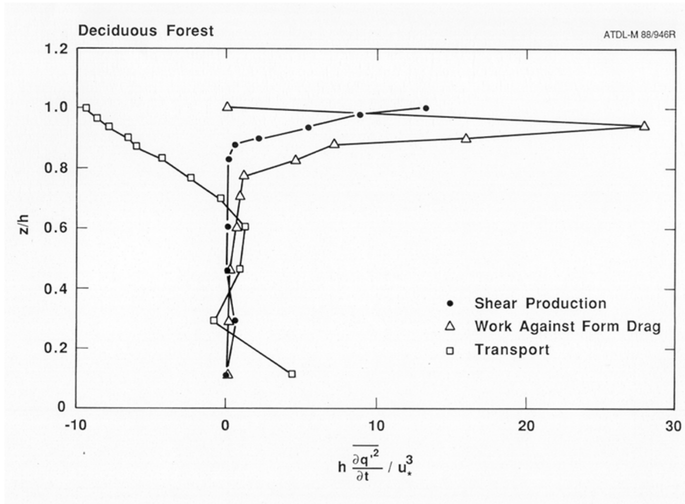


How turbulent kinetic energy is created and destroyed. New processes emerge, like wake turbulence that causes a short circuiting of the inertial casade.



Vertical profile of 3rd order statistical moments. Flux of fluxes determines Non-Local transport. Contributes to break down in K theory in vegetation

Profile of turbulent kinetic energy budget within a deciduous forest



Meyers and Baldocchi, 1987

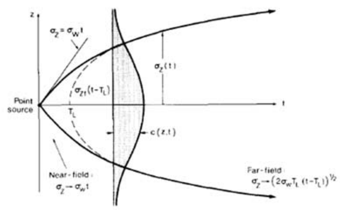
Conditions must hold to apply K-theory

- the length scales of the turbulent transfer must be less than the length scales associated with the curvature of the concentration gradient of the scalar.
- the turbulence length scale must be constant over the distance where the concentration gradient changes significantly.

Stanley Corrsin

Raupach (1987) explains counter-gradient transfer with the following

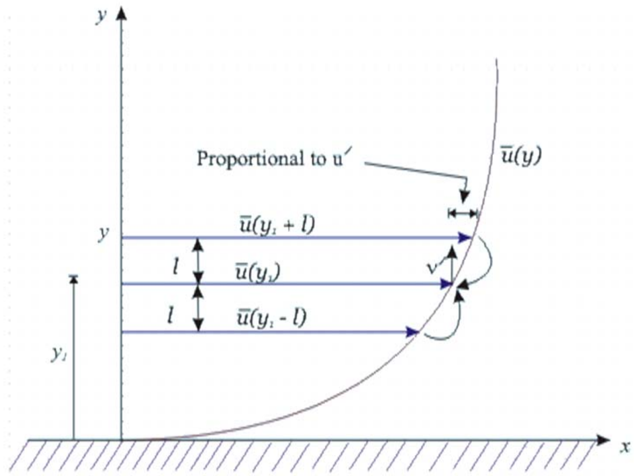
- *'(because) scalar from nearby elementary sources is dispersing in a near-field regime...its contribution to the overall gradient (is) much greater than its contribution to the overall flux density. Just below a fairly localized and intense source in the canopy, the near-field gradient contribution is large and positive; when this is combined with the upward flux of scalar required by conservation of scalar mass, a counter-gradient flux is obtained'.*

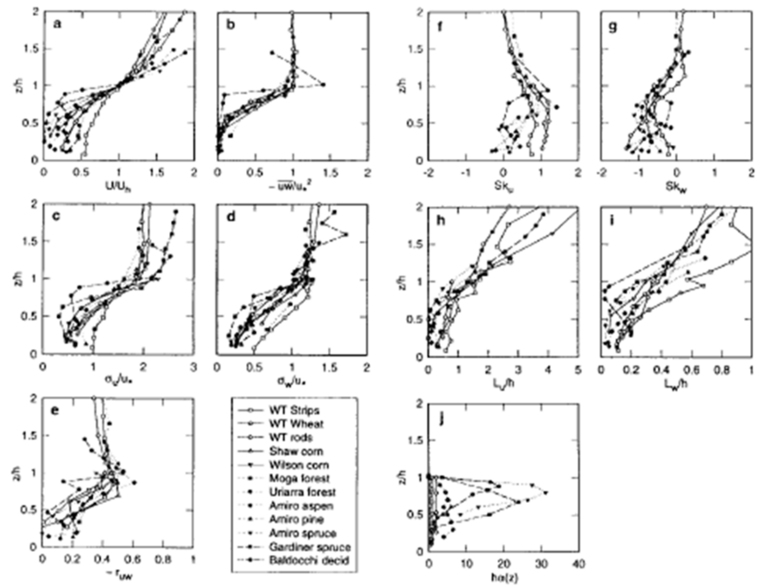


Summary Points

- Wind and turbulence inside vegetation has many unique and distinct attributes, as compared to wind and turbulence observed in the surface layer.
- The mean wind velocity profile experiences great shear and an inflexion point in the upper canopy. This behavior is reminiscent of mixing layer flows
- A secondary wind maximum is observed in the stem space of vegetation. This and the observation of counter-gradient transfer provide evidence that led to the conclusion that K is invalid in canopies.
- Turbulence inside a canopy is highly non-Gaussian. It is skewed and kurtotic.
- The statistical moments (variances of w. u and v) are vertically inhomogeneous in a vegetated canopy. u is positively skewed, w is negatively skewed and the integral length scales are on the order of the canopy height, rather than the scale of the canopy leaf and stem elements.
- Non-Local Transport accounts for Counter-Gradient Transfer

Prandtl Mixing Length, l





Raupach, Finnigan, Brunet and others