Surface Stress for Hurricane Winds

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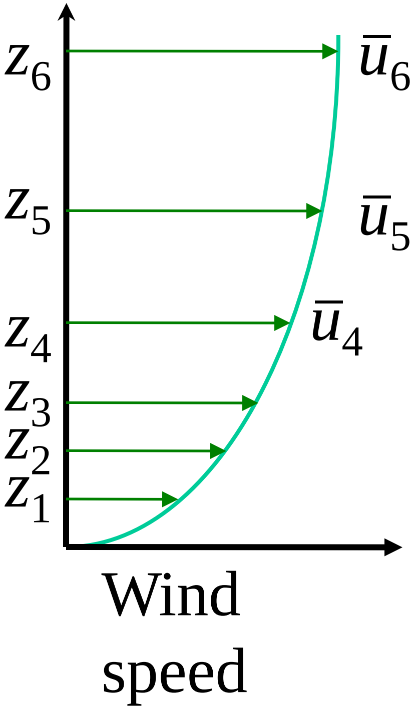
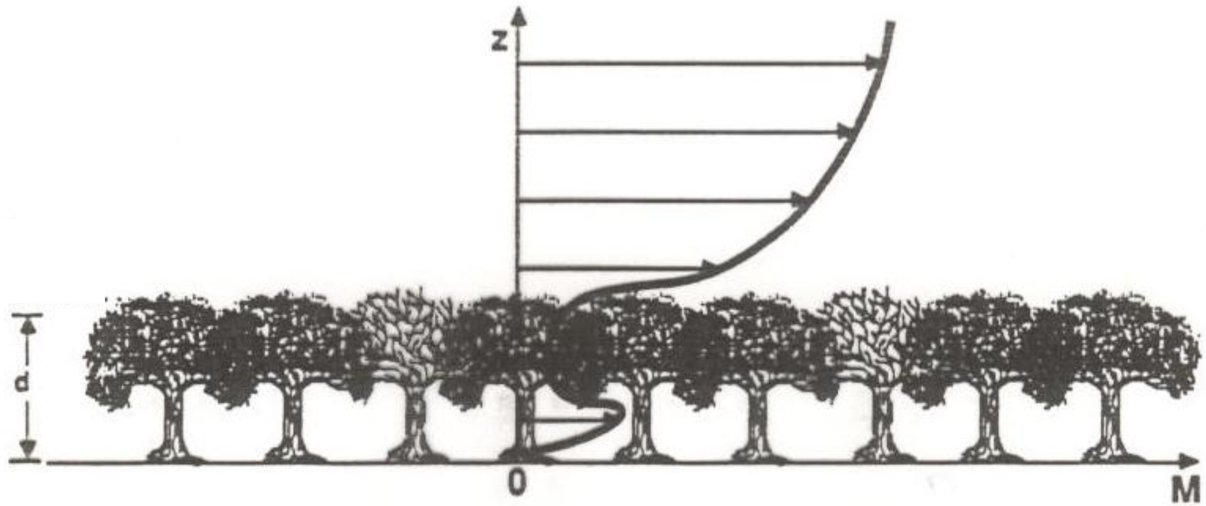
Log-Profile Method



- Time averaged wind speed observations are taken at a variety of heights.
  - Time averaged indicated by an overbar
- The greatest impact and hence most important observations are those close to the surface
  - But not too close, since these have great impact, and this approach works only for heights at which the theory applies!
  - Exclude data from several times the significant wave height based solely on wind waves.
- Many more levels are used in wind/wave tunnel experiments

Displacement Height (*d*)

- Displacement height (*d*) is easily understood for flow over canopies.
  - It is a vertical offset of the wind profile: $U(z = d) = 0$.



  - For crops, *d* is approximately 70% of the height of the crop.
- Water waves also cause a small vertical displacement (Bourassa et al., 1999, *JAS*)
  - the value is much smaller than the wave amplitude (approximately 10 to 20% of the wave height, based on wave tank experiments).

Graphic from R.B. Stull's (1988) An Introduction to Boundary Layer Meteorology

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Non Neutral Wind Profiles

- Starting point: a non-neutral profile

$$\overline{u}(z) - u_{sfc} = \frac{u_*}{k_v} \log\left[\left(\frac{z-d}{z_o}+1\right) - \phi\left(z, z_o, L\right)\right]$$

z_o = roughness length

u_* = friction velocity

z = height relative to something

d = vertical displacement relative to the same something

- Most analysis techniques assume
  - u_{sfc} = 0; the surface is not moving
    - Obviously wrong over the ocean
    - Influences the estimate of roughnesslength
  - d = 0; no vertical offset
  - $1/L$ = 0; neutral stability
    - Arguably a pretty good assumption for very strong winds

Averaging methodology

- Dropsondes are not dropped in sufficient density to determine a mean profile at a single point in a storm
- Profiles are combined based on SS scale
- Data were provided by Mark Powell
  - Already binned as function of height
  - Profiles are roughly logarithmic up to 300 to 500m

Log-Profile Methods

- The procedure used herein to determine the parameters in the modified log–current profile roughly follows *Covey's* [1983] method for determining the modified log–wind profile parameters for flow over a solid surface.
- The methodology is derived as follows:
  - the best fit solution is defined as that which minimizes (in a root–mean–square sense) the differences between theory (the log profile equation) and observations ($\overline{u}_i$).
  - At each measurement height in the log–wind region, the residual (ρ) is

$$\rho_i = \overline{u}_i - \overline{u}_s - \frac{u_*}{\kappa} \ln\left(\frac{z_i - d + z_o}{z_o}\right)$$

  - where u_i is the observed mean wind at height z_i, and the subscript i refers to the different observation heights.
  - Note that data above and below (z < about 2 d) the log-profile region must be excluded.

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Solving for Roughness Length

- To minimize the error with respect to roughness length, the partial derivative of Eq. (18) is taken with respect to z_o and the result is set equal to zero. Rearranging the resulting equation and dividing by N produces a solution for B:

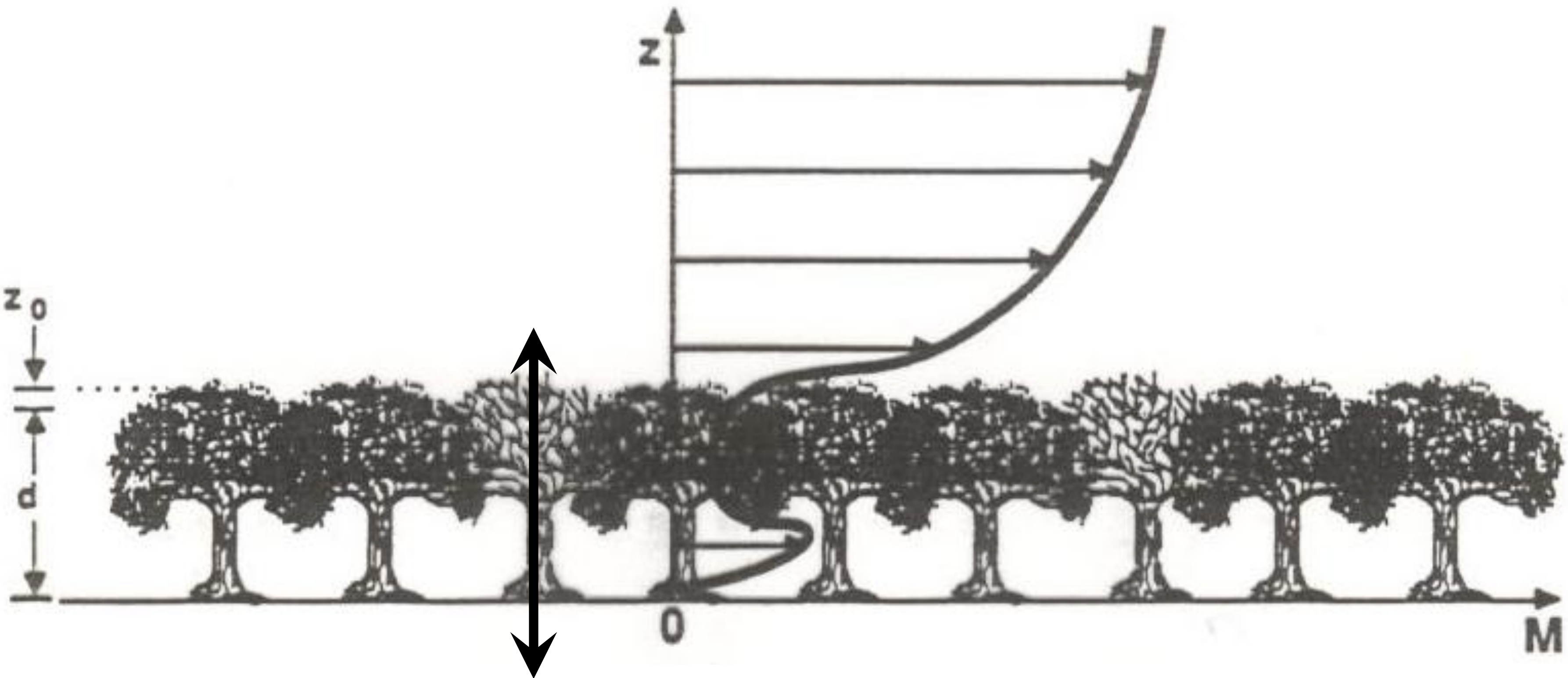
$$z_o = \exp\left[\widehat{ln(z_i - d + z_o)} - \frac{k_v}{u_*}\left(u_{sfc} - \hat{\bar{u}}_i\right)\right]$$

- Band News:
  - Roughness length depends on variables often ignored (d and u_{sfc})
  - Displacement height is highly dependent on the extrapolated surface horizontal motion
- Good news
  - The derived friction velocity is independent the distinction between u_{sfc} and z_o
  - It is dependent on a displacement height, but the extrapolated surface current can be accounted for in this term

Fit to Observed Mean Winds

- The RMS misfit in wind speed is very small
  - Cat 1: 8 cm/s
  - Cat 2: 7 cm/s
  - Cat 3: 22 cm/s
- friction velocity
  - Cat 1: 1.2 m/s
  - Cat 2: 1.8 m/s
  - Cat 3: 2.8 m/s

Resulting Wind Profile



- Displacement height is negative!
  - Which means there is extrapolation to a substantially non-zero speed if the surface really is where we think it is.

Graphic from R.B. Stull's (1988) An Introduction to Boundary Layer Meteorology

Conclusions

- We can estimate stress from averaged dropsonde profiles
  - As has been done before, but a little more accurately
- However, calibration of U10EN is more challenging!
  - U10EN is relative to the surface
  - and it is 10 above the displacement height, which we can't determine from remotely sensed observations, so we assume it is near zero.
- The combination of 'surface' motion and displacement height makes the definition of U10EN difficult (U10S as well, but easier)
  - However we could develop a proxy designed for specific applications
  - but we need to think about the characteristics we want to capture
    - Stress?
    - Wind?