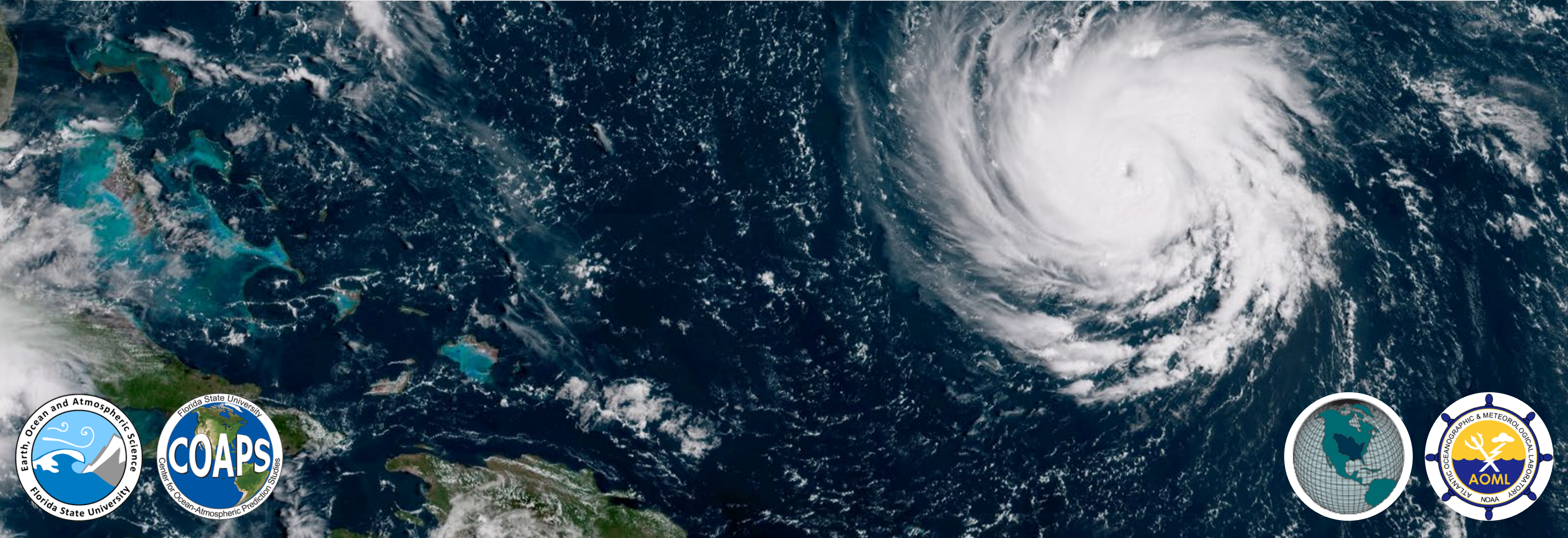
An Analysis of the Near-Surface Layer in Hurricanes Using Dropsondes

Daniel E. Wallace[1], Mark A. Bourassa[1], Heather M. Holbach[2]

[1]EOAS & COAPS, Florida State University [2]FSU, Northern Gulf Institute (NGI), NOAA/AOML/HRD

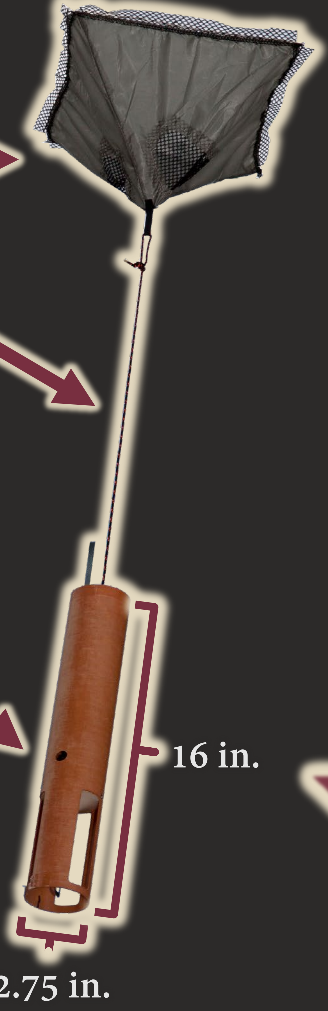


1. BACKGROUND

GPS DROPSONDE

- **Square-Cone Parachute**
  Increases stability of dropsonde
- **Shock Cord**
  Reduces stress when chute opens
- **GPS Receiver & Antenna**
  Uses GPS satellites to calculate position, wind speed / direction
- **Pressure Sensor**
- **Temperature & Humidity Sensors**
- **Microprocessor**
  Controls the transmitter; digitizes data
- **Battery**
- **Radio Transmitter**
  Sends data back to aircraft every 0.25 seconds (0.5 s for some data)

(NCAR 2020)



FALL RATE

Approx. 16 ms^{-1}
(at 6000 m)
Approx. 11 ms^{-1}
(at sea level)

(a drop from 6000m takes about 7 minutes)

1. Background

Boundary Layer

Outer Layer (↑)

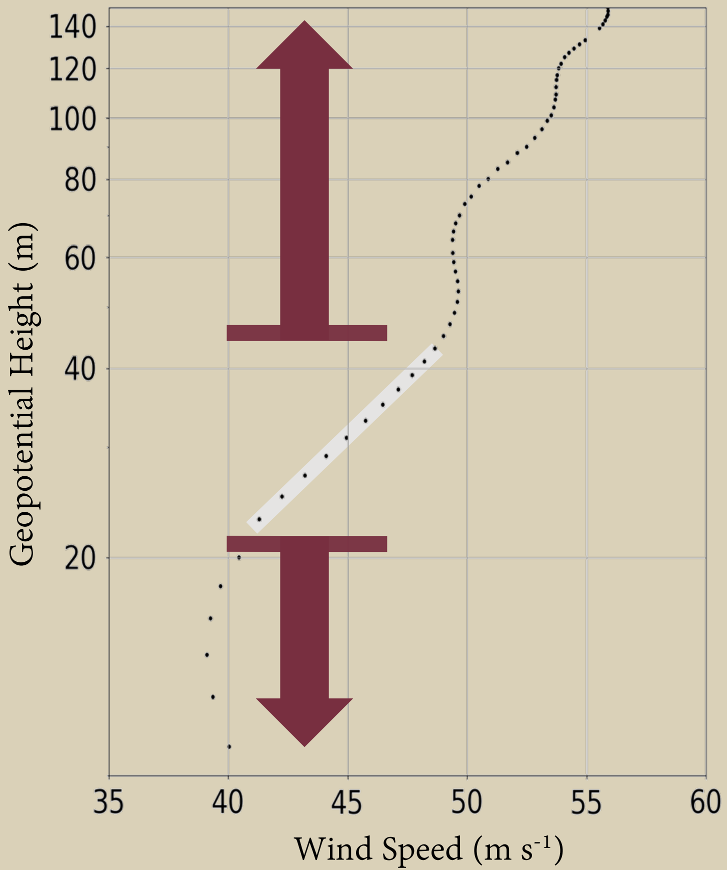
- *Ekman layer up to top of boundary layer*

Near-Surface Log Layer (–)

- *Log-linear layer just above surface layer*
- *Mean flow follows Monin-Obukhov similarity (MOS)*

Lowest Inner Layer (↓)

- *Viscous Sublayer + Buffer Layer*
- *Greatly affected by gusts and sea spray*
- *Inconsistent Wind Profile*
  - *10m measurements often unreliable*



1. BACKGROUND

10-METER WIND

MBL-500 (light gray box)

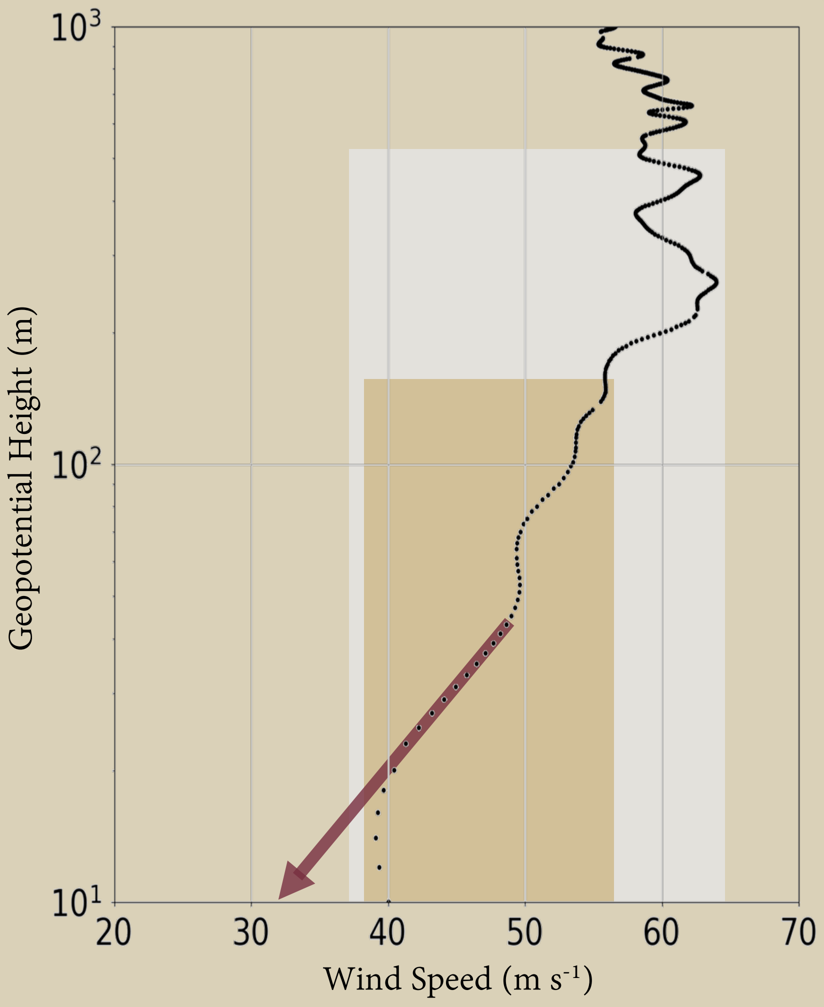
- *Mean Boundary Layer method: average velocity (lower 500m) multiplied by reduction coefficient*
- *$U_{10} = 45.6\ ms^{-1}$ in example at right by MBL-500 method*

WL150 (gold box)

- *Average velocity (lower 150m) multiplied by reduction coefficient*
- *$U_{10} = 41.8\ ms^{-1}$ in example at right by WL150 method*

Log Profile (garnet estimated trendline)

- *Log profile in log-linear layer extrapolated down*
- *Example at right extrapolates to ~ $32\ ms^{-1}$ at 10m*



2. Methodology

Solving for the Log Profile (Neutral Conditions)

$$U_i = \frac{u_*}{k_v} \ln\left[\frac{z_i - D}{z_0}\right]$$

$$z_o = exp\left[\hat{A} - \frac{k_v}{u_*}(\hat{u}_{obs} - u_{sfc})\right]$$

$$k_v = 0.4 \pm 0.02$$

$$a_i = A_i - \hat{A}$$

$$u_* = \frac{k_v \sum_i^N [U_i a_i]}{\sum_i^N [{a_i}^2]}$$

$$U_i = u_{obs_i} - \hat{u}_{obs}$$

$$A_i = \ln(z_i - D)$$

Breakdown

What we have:

- *Observation points for u, the measured wind speed*
- *Observation points for z, the measured height*
- *Assumed surface wind speed of $u_{sfc} = 0$*
- *Von Kármán constant, k_v*

What we need:

- *Displacement height, D* *(more on this on next slide)*

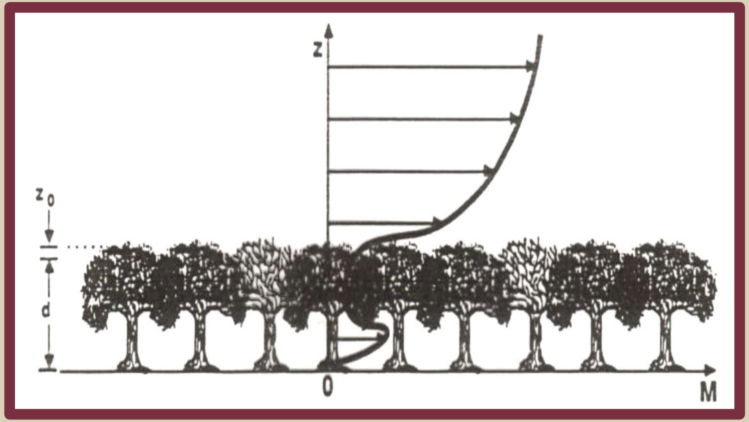
What we can do:

- *Calculate u_* and z_o to fit the observational data to a log profile equation*

Displacement Height (D)

Importance of D

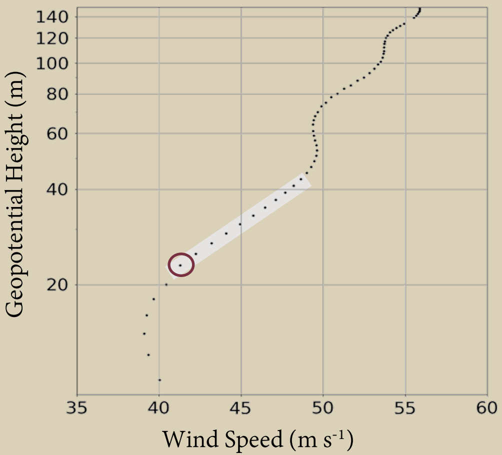
- *Represents level that log profile extrapolates to zero (not necessarily the axis)*
- *Dependent on sea state over ocean*
  - *Roughness*
  - *Swell height*
  - *Sea spray*



(Stull 1988)

Guess + Test to find D

- *Test Range: [$-LL_{low}$, $+LL_{low}$]*
  LL_{low} = the lowest point (○) of user-identified log layer ( )
- *Use test value for D to solve log profile*
  - *Compare to measured points*
  - *Calculate square of residual for each point*
  - *Repeat for entire range with 0.001m steps*
  - *D with the lowest sum of the squares of the residuals (across all points) will be selected*



2. Methodology

Confidence Check of Calculations

Ideal Log Profile Created

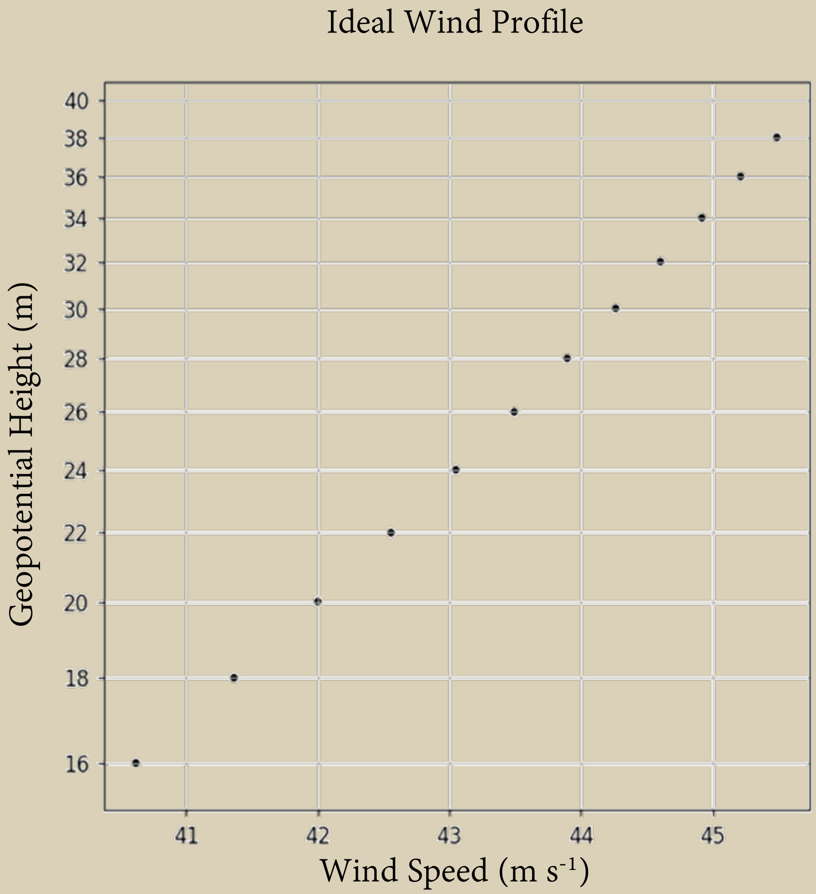
- *Z = 16m to 40m w/ 2m steps*
- *$D = 5.237$ m; $u_* = 1.75$; $z_0 = 0.001$ m (arbitrarily selected to create profile)*
- $U_Z = \frac{u_*}{k_v} \ln\left[\frac{Z-D}{z_0}\right]$

Test Equations with Idealized Data Points

- *Plug in data points from created profile*
- *Solve for D, u_*, and z_0*

Results from Calculations

- *$D = 5.24$ m*
- *$u_* = 1.7497$*
- *$z_0 = 0.000998$ m*
- *All three values are incredibly close to the input values. Slight differences attributed to rounding errors in the calculation. Calculations seem to work!*



Example Profiles with an Identifiable Log Layer

Sonde #g102815174

$D = -0.20$

$u^* = 2.239$

$z0 = 0.1502$

$U_{10} = 23.6\ ms^{-1}$

Sonde #g103515143

$D = 5.44$

$u^* = 1.911$

$z0 = 0.0223$

$U_{10} = 25.4\ ms^{-1}$

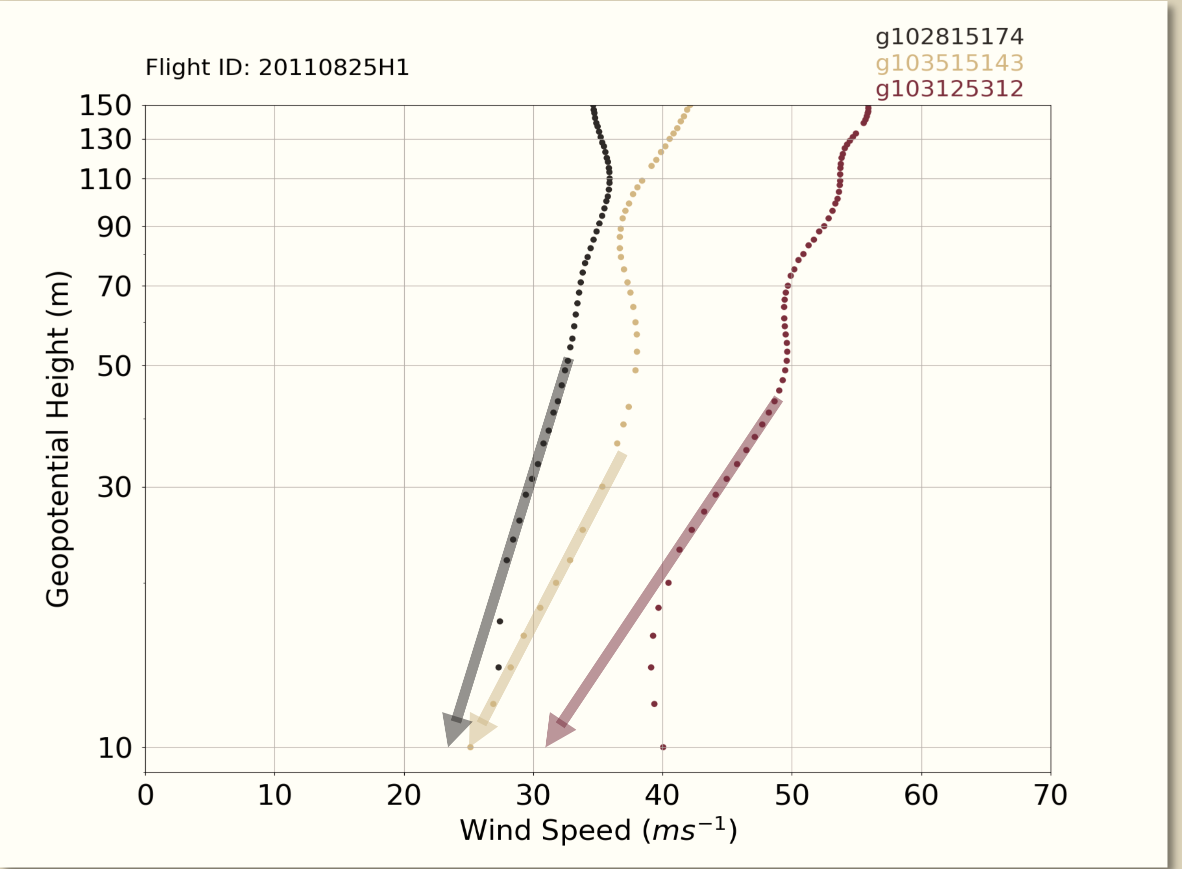
Sonde #g103125312

$D = 0.90$

$u^* = 4.769$

$z0 = 0.693$

$U_{10} = 30.7\ ms^{-1}$



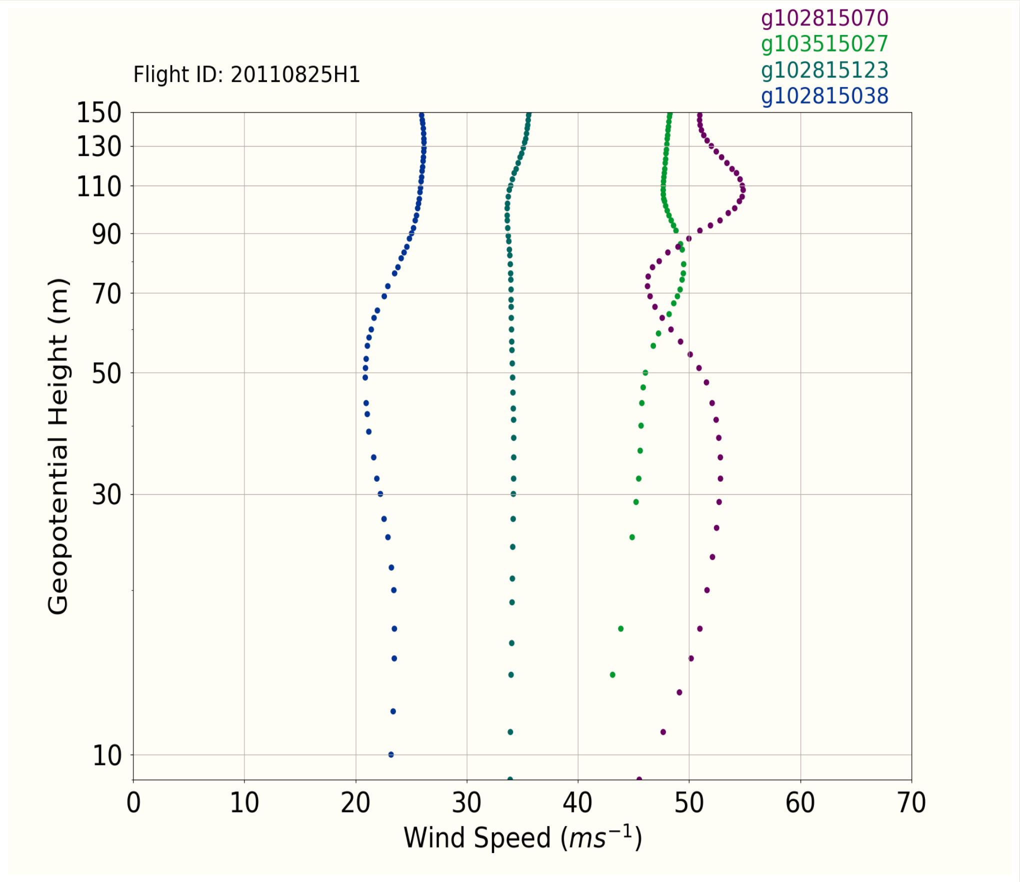
Example Profiles without an Identifiable Log Layer

Why do these not work?

- *No easily-identifiable linear sections on a log-scale*
- *Some apparent missing data at lower levels*
- *Equations require a section of clearly log-linear points in order to fit data to a neutral solution*

Why the non-linearity?

- *Possible non-neutral conditions*
- *Interference from gusts*
- *Effect of sea spray*



4. Conclusion

Analysis of Log Profile Method

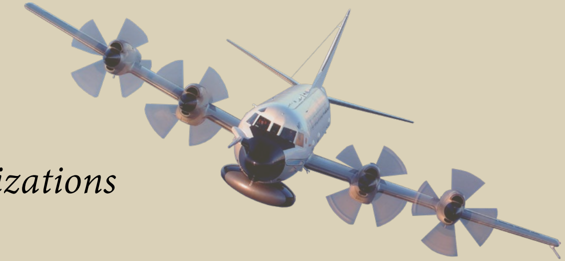
Produces reasonable 10m wind speeds

- *WL150 and MBL500 are layer means that often misrepresent 10m speeds*
- *10m measurements are often representative of gusts as opposed to sustained winds*

Produces flux parameters (u_* and z_0)

- *Provide a good fit to data (where a log layer can be identified)*

Future



Neutral Conditions

- *Start evaluating stress using u_* and z_0*
- *Expand equations to solve for heat and moisture parameterizations*
  - q_* *and* $z_{0,q}$ *– used for moisture flux*
  - θ_* *and* $z_{0,\theta}$ *– used for heat flux*

Non-Neutral Conditions

- *Consider stability parameters and reevaluate all equation sets for non-neutral cases by considering perturbations from neutral cases*

5. Further Info

References

Bakker, A., 2006: Applied Computational Fluid Dynamics Lecture 11 – Boundary Layers and Separation. http://www.bakker.org/dartmouth06/engs150/11-bl.pdf (Accessed December 31, 2020).

Bourassa, M. A., 2020: *Solving Log Wind Profile v5*. Center for Ocean-Atmospheric Prediction Studies (COAPS) at Florida State University,.

Foster, R., and J. Patoux, 2012: *Using Surface Pressure to Improve Tropical Cyclone Surface Wind Retrievals from Synthetic Aperture Radar Imagery*. WASHINGTON UNIV SEATTLE APPLIED PHYSICS LAB, https://apps.dtic.mil/sti/citations/ADA590606 (Accessed December 6, 2020).

NCAR, 2020: What is a Dropsonde? *Earth Obs. Lab.*,. https://www.eol.ucar.edu/content/what-dropsonde.

Stull, R. B., 1988: *An introduction to boundary layer meteorology*. Kluwer Academic Publishers,.

Contact

Daniel Wallace: dwallace@coaps.fsu.edu

Mark Bourassa: bourassa@coaps.fsu.edu

Heather Holbach: heather.holbach@noaa.gov

Please feel free to reach out with any questions

Websites

- Department of Earth, Ocean & Atmospheric Science at FSU: eoas.fsu.edu
- Center for Ocean-Atmospheric Prediction Studies at FSU: coaps.fsu.edu
- Northern Gulf Institute (NOAA Cooperative) at MSU: northerngulfinstitute.org
- NOAA Atlantic Oceanographic and Meteorological Laboratory Hurricane Research Division: aoml.noaa.gov/hrd