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

Daniel E. Wallace¹, Mark A. Bourassa¹, Heather M. Holbach²

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

---

**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**

(© NCAR 2020)
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
10-METER WIND

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

WL150 (gold box)
- Average velocity (lower 150m) multiplied by reduction coefficient
- $U_{10} = 41.8 \text{ ms}^{-1}$ 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 $\text{ms}^{-1}$ at 10m
SOLVING FOR THE LOG PROFILE
(NEUTRAL CONDITIONS)

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

\[ z_0 = \exp \left[ \hat{A} - \frac{k_v}{u_*} (\hat{u}_{obs} - u_{sfc}) \right] \]

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

\[ k_v = 0.4 \pm 0.02 \]

\[ a_i = A_i - \hat{A} \]

\[ A_i = \ln(z_i - D) \]

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 \( z_0 \) to fit the observational data to a log profile equation
2. METHODOLOGY

**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

**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

(Stull 1988)
2. METHODOLOGY

CONFIDENCE CHECK OF CALCULATIONS

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

Test Equations with Idealized Data Points
- Plug in data points from created profile
- Solve for \( D, u_\ast, \) and \( z_0 \)

Results from Calculations
- \( D = 5.24 \text{ m} \)
- \( u_\ast = 1.7497 \)
- \( z_0 = 0.000998 \text{ m} \)
- 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**
- $D = -0.20$
- $u^* = 2.239$
- $z0 = 0.1502$
- $U_{10} = 23.6 \text{ ms}^{-1}$

**Sonde #g103515143**
- $D = 5.44$
- $u^* = 1.911$
- $z0 = 0.0223$
- $U_{10} = 25.4 \text{ ms}^{-1}$

**Sonde #g103125312**
- $D = 0.90$
- $u^* = 4.769$
- $z0 = 0.693$
- $U_{10} = 30.7 \text{ ms}^{-1}$

3. **Results**
**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

3. Results
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 \((u_*, z_0)\)
- 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
  - \(\theta_*\) 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
REFERENCES


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


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