Log-Profile Analysis of the Near-Surface Layer and Air-Sea Turbulent Fluxes in Hurricanes using Dropsondes

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1. Objectives & Motivation

- Improve understanding of the structure of the boundary-layer within Tropical Cyclones (TCs)
  - *Identify features that perturbate 'normal' profile*
- Improve 10m wind speed estimates within TCs
  - *Better understand intensity near the surface*
- Calculate surface fluxes of momentum, sensible heat, and latent heat within a TC
  - *Improve accuracy of the energy budget*
  - *In-situ measurements often taken from ships (too dangerous to enter hurricanes) or buoys (fixed locations – other issues relating to tilting and observation height)*
  - *What about dropsondes?*

3. Monin-Obukhov Similarity (MOS)

Theory relating the vertical profiles of wind, potential temperature, and specific humidity within the **Near-Surface Log Layer** *(blue shading below) to their respective surface fluxes*

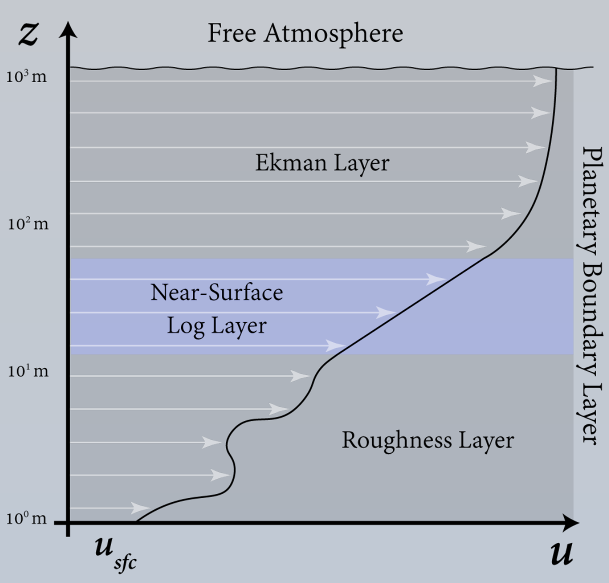


Figure 1. Conceptual model of Boundary Layer

- Mean flow is assumed to follow MOS
  - *Even in high-winds of a TC*
- Dropsonde profiles are not snapshots
  - *As the sondes fall, the space-time sampling is often enough to be representative of a mean profile*
  - *High winds of a TC require less time averaging*
  - *We can apply MOS to single-sonde profiles that exhibit a mean*
  - *Deviations from a log layer indicate something else going on (gust, spray layer, etc.)*

5. Quality Control

- Raw sonde data processed in **A**tmospheric **S**ounding **P**rocessing **En**vironment
  - *Automatic quality control procedures*
  - *Manual QC by NOAA/USAF scientists*
  - *Conversion of data into usable file formats*
- Manual profile & layer selection
  - *Must select sondes with usable profiles for* $\boldsymbol{u}$, $\boldsymbol{\theta}$, *and* $\boldsymbol{q}$
  - *All profiles must have an approximately log-linear layer with a minimum of 3 points*

6. Solving the Log-Profiles

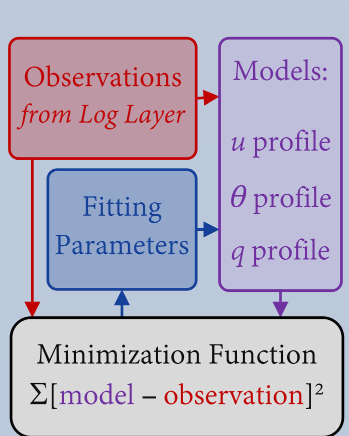
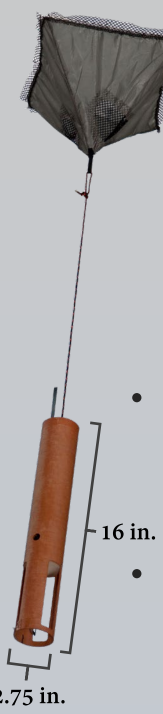


Figure 3. Flowchart of program functionality

- First Step: Assuming Neutral Conditions
  - *The* $\boldsymbol{\Psi}$*-term goes to 0, so the profiles of* $\boldsymbol{u}$, $\boldsymbol{\theta}$, *and* $\boldsymbol{q}$ *are no longer linked – the fitting parameters can be solved directly*
- Second Step: For Non-Neutral Cases
  - *Must consider* $\boldsymbol{\Psi}$*-term – all three profiles connected*
  - *Use function (Powell Method – SciPy Python library) to find fitting parameters from combined model of all three profiles by minimizing combined misfit w/ first guesses taken from the neutral solutions in the First Step above*
  - *Fitting parameters can be used to find surface fluxes via bulk formulae*

2. Current State of Dropsondes



- What is a Dropsonde and How is it Used?
  - *A dropsonde is a device launched from reconnaissance aircraft that contains a variety of sensors (position, wind speed, wind direction, temperature, humidity, pressure), a transmitter to send data, and a parachute to stabilize the device as it falls*
  - *They are used to create vertical profiles of various atmospheric parameters and provide in-situ measurements*
  - *Dropsonde measurements used to train algorithm of the Stepped-Frequency Microwave Radiometer (SFMR), a device used to produce a swath of wind speed beneath a reconnaissance plane as it flies*
- Measuring the Wind at 10m from Dropsonde?
  - *Lowest data points are affected by uncertainties in the height of the surface and are typically located within the* **Roughness Layer** *(see* **Figure 1** *in the next section), where dynamics are dominated by gusts and sea spray*
- WL150
  - *Current standard for 10m wind reporting in TCs*
  - *Layer mean with a reduction coefficient accounting for the height of the layer*
  - *Often misrepresents 10m speeds by combining multiple dynamical regimes*
- Is there another way to analyze dropsonde data?

4. The Log-Profile of Wind Speed

Speed of Surface Current

Friction Velocity
- *Analogous to transfer of momentum*
- *Proportional to speed*

Height Above Surface

Displacement Height
- *Where profile extrapolates to surface value*
- *Could account for errors in estimated surface level*
- *Dependent on sea state*

Note
Similarly formatted profiles exist for potential temperature (θ) and specific humidity (q)

$$u_i = u_{sfc} + \frac{u_*}{k_v}\left[ln\left(\frac{z_i - D}{z_0}\right) - \Psi_M(L, z_i)\right]$$

Mean Wind Speed at Height z_i

Von Kármán Constant (≈ 0.4 ± 0.01)

Roughness Length

Stability Term
- *Parameterizations from COARE 3.0 used*
- *Function of* $\boldsymbol{u}$, $\boldsymbol{\theta}$, *and* $\boldsymbol{q}$
- *0 in neutral conditions*

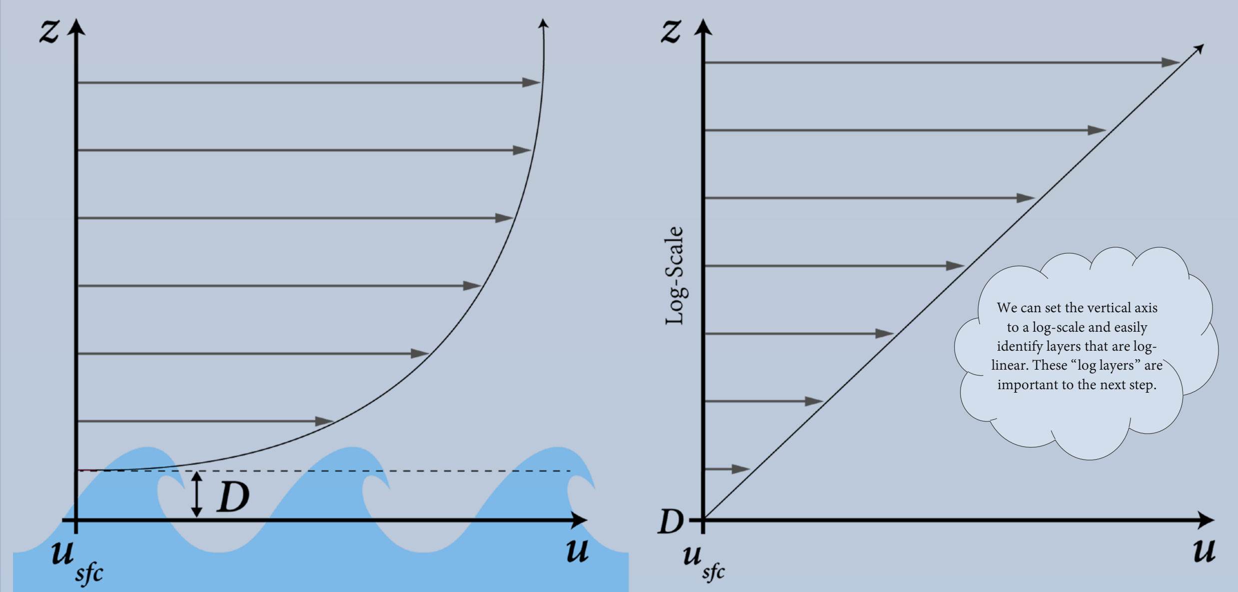
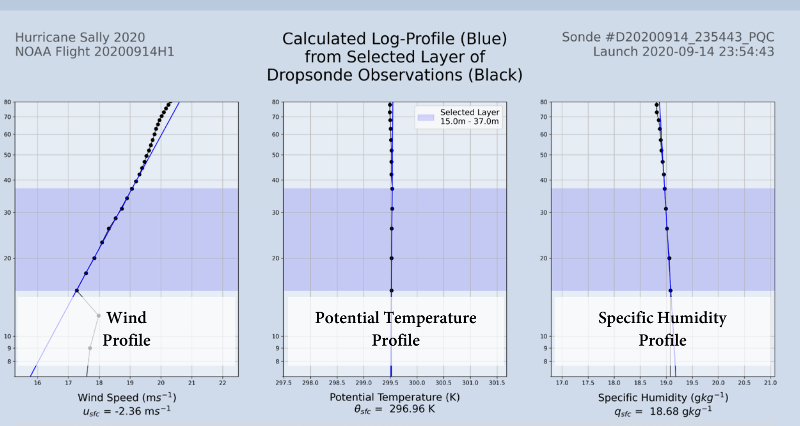


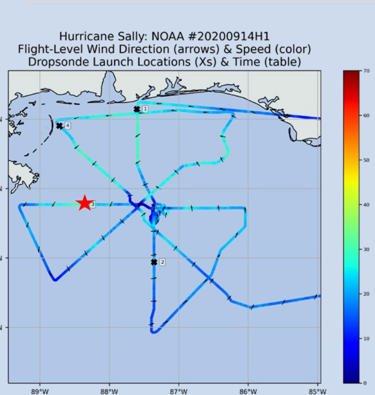
Figure 2. Idealized log-wind profile, displaced upward by wind waves by about 80% of the significant wave height. Standard profile on the left. Log-scale profile starting at $z = D$ for the same profile on the right.

7. Selected Results

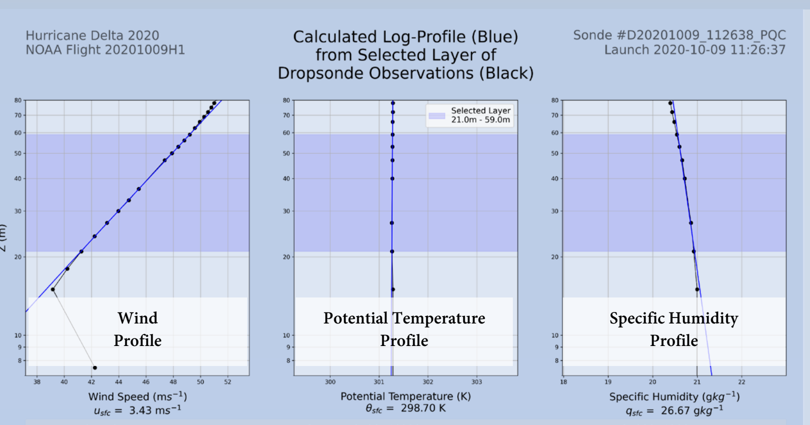


u_{sfc} = -2.36 ms^{-1} | θ_{sfc} = 296.96 K | q_{sfc} = 18.68 gkg^{-1}

u_* = 0.8144 D_u = -0.3754 m	θ_* = 0.00704214 D_θ = -0.3754 m	q_* = -0.00005354 D_q = -0.3754 m
U_{10} = 16.39 ms^{-1} (D rel) 16.46 ms^{-1} (sfc rel)	θ_{10} = 299.51 K (D rel) 299.51 K (sfc rel)	q_{10} = 19.14 gkg^{-1} (D rel) 19.14 gkg^{-1} (sfc rel)
τ = 0.773 Nm^{-2} C_D = 0.00247 (10m, D rel) 0.00245 (10m, sfc rel)	H = -6.721 Wm^{-2} C_H = 0.00683 (10m, D rel) 0.00675 (10m, sfc rel)	E = 127.072 Wm^{-2} C_E = 0.00130 (10m, D rel) = 0.00130 (10m, sfc rel)

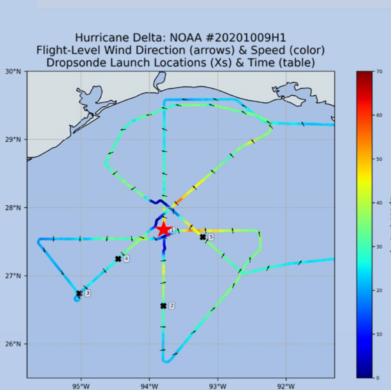


- *Normal profile from outer vortex*
- *Fitting parameters seem reasonable*
- *10m wind more physically consistent with profile than the measurements within a gust at 9-11m*
- *Surface fluxes produced*

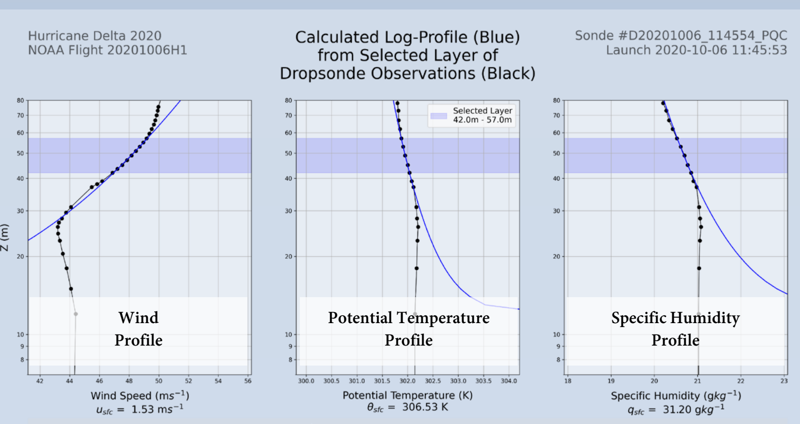


u_{sfc} = 3.43 ms^{-1} | θ_{sfc} = 298.70 K | q_{sfc} = 26.67 gkg^{-1}

u_* = 3.1535 D_u = -0.6206 m	θ_* = 0.00546222 D_θ = -0.6206 m	q_* = -0.00014900 D_q = -0.6206 m
U_{10} = 35.16 ms^{-1} (D rel) 35.64 ms^{-1} (sfc rel)	θ_{10} = 301.25 K (D rel) 301.25 K (sfc rel)	q_{10} = 21.23 gkg^{-1} (D rel) 21.20 gkg^{-1} (sfc rel)
τ = 11.205 Nm^{-2} C_D = 0.00804 (10m, D rel) 0.00783 (10m, sfc rel)	H = -19.519 Wm^{-2} C_H = 0.00983 (10m, D rel) 0.00967 (10m, sfc rel)	E = 1324.081 Wm^{-2} C_E = 0.00454 (10m, D rel) = 0.00451 (10m, sfc rel)

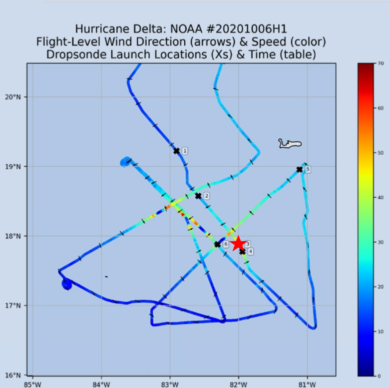


- *Eyewall environment*
- *High stress / momentum flux (*$\boldsymbol{\tau}$*)*
- *Moisture appears saturated below 16m – possibly looking at a spray layer*



u_{sfc} = 1.53 ms^{-1} | θ_{sfc} = 306.53 K | q_{sfc} = 31.20 gkg^{-1}

u_* = 2.4008 D_u = 11.9518 m	θ_* = -0.18459158 D_θ = 11.9518 m	q_* = -0.00036321 D_q = 11.9518 m
U_{10} = 40.58 ms^{-1} (D rel) nan ms^{-1} (sfc rel)	θ_{10} = 302.51 K (D rel) nan K (sfc rel)	q_{10} = 21.78 gkg^{-1} (D rel) nan gkg^{-1} (sfc rel)
τ = 6.395 Nm^{-2} C_D = 0.00350 (10m, D rel) nan (10m, sfc rel)	H = 494.498 Wm^{-2} C_H = 0.00718 (10m, D rel) nan (10m, sfc rel)	E = 2419.692 Wm^{-2} C_E = 0.00310 (10m, D rel) = nan (10m, sfc rel)



- *Eyewall environment with similar wind speeds*
- *Saturated moisture layer extends up to ~50m*
- *Deeper spray layer appears to give a cushioning effect – stress is much lower than previous example*

References

Bakker, A., 2006: Applied Computational Fluid Dynamics Lecture 11 – Boundary Layers and Separation. http://www.bakker.org/dartmouth06/engs150/11-bl.pdf
Bourassa, M. A., 2017: Modularized Flux Testbed (MFT). *Cent. Ocean-Atmospheric Predict. Stud. FSU*,.https://www.coaps.fsu.edu/~bourassa/MFT_html/MFT_docs.php
——, 2021: Solving Log Wind Profile v7.
Carey, W. M., and R. B. Evans, 2011: *Ocean Ambient Noise: Measurement and Theory*. Springer Science & Business Media, 266 pp.
Covey, W., 1983: A Method for the Computation of Logarithmic Wind Profile Parameters and Their Standard Errors. *US Dept Agric. Prod. Res. Rpt*, **72**, 28–33.
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
Franklin, J. L., 2013: Use of Aircraft Data at the National Hurricane Center.
——, M. L. Black, and K. Valde, 2003: GPS Dropwindsonde Wind Profiles in Hurricanes and Their Operational Implications. *Weather Forecast.*, **18**, 32, https://doi.org/10.1175/1520-0434(2003)018<0032:GDWPIH>2.0.CO;2.
Grachev, A. A., C. W. Fairall, and E. F. Bradley, 2000: Convective Profile Constants Revisited. *Bound.-Layer Meteorol.*, **94**, 495–515, https://doi.org/10.1023/A:1002452529672.
Hock, T., 2020: AVAPS Dropsonde System. *Earth Obs. Lab.*,. https://www.eol.ucar.edu/observing_facilities/avaps-dropsonde-system.
Hock, T. F., and J. L. Franklin, 1999: The NCAR GPS Dropwindsonde. *Bull. Am. Meteorol. Soc.*, **80**, 407.
Jiang, Q., S. Wang, and P. Sullivan, 2018: Large-Eddy Simulation Study of Log Laws in a Neutral Ekman Boundary Layer. *J. Atmospheric Sci.*, **75**, 1873–1889.
Paulson, C. A., 1970: The Mathematical Representation of Wind Speed and Temperature Profiles in the Unstable Atmospheric Surface Layer. *J. Appl. Meteorol. Climatol.*, **9**, 857–861, https://doi.org/10.1175/15200450(1970)009<0857:TMROWS>2.0.CO;2.
Pegion, P. J., M. A. Bourassa, D. M. Legler, and J. J. O'Brien, 2000: Objectively Derived Daily "Winds" from Satellite Scatterometer Data. *Mon. Weather Rev.*, **128**, 3150–3168, https://doi.org/10.1175/1520-0493(2000)128<3150:ODDWFS>2.0.CO;2.
Richter, D. H., C. Wainwright, D. P. Stern, G. H. Bryan, and D. Chavas, 2021: Potential Low Bias in High-Wind Drag Coefficient Inferred from Dropsonde Data in Hurricanes. *J. Atmospheric Sci.*, **78**, 2339–2352, https://doi.org/10.1175/JAS-D-20-0390.1.
Schott, T., and Coauthors, 2019: The Saffir-Simpson Hurricane Wind Scale.
Smith, S. D., 1988: Coefficients for sea surface wind stress, heat flux, and wind profiles as a function of wind speed and temperature. *J. Geophys. Res. Oceans*, **93**, 15467.
Stull, R. B., 1988: *An introduction to boundary layer meteorology*. Kluwer Academic Publishers,.
Tennekes, H., 1973: The Logarithmic Wind Profile. *J. Atmospheric Sci.*, **30**, 234–238, https://doi.org/10.1175/1520-0469(1973)030<0234:TLWP>2.0.CO;2.
Wu, J., 1968: Laboratory Studies of Wind-Wave Interactions. *J. Fluid Mech.*, **34**, 91–111.

IOVWST – 03 May 2022

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