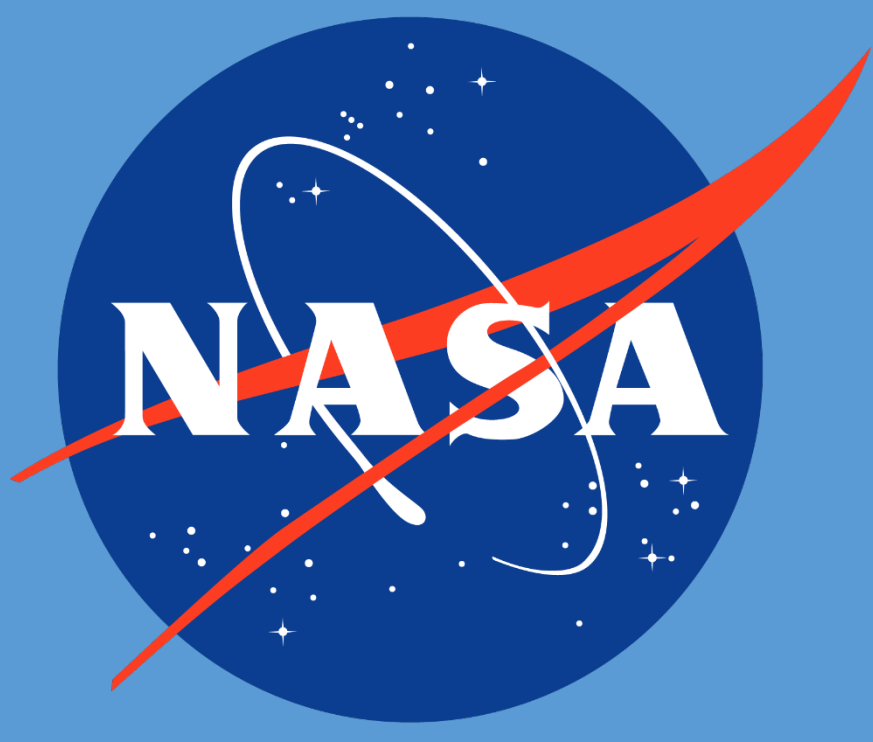




Earth Global Reference Atmospheric Model (GRAM) Overview and Boundary Layer Comparison

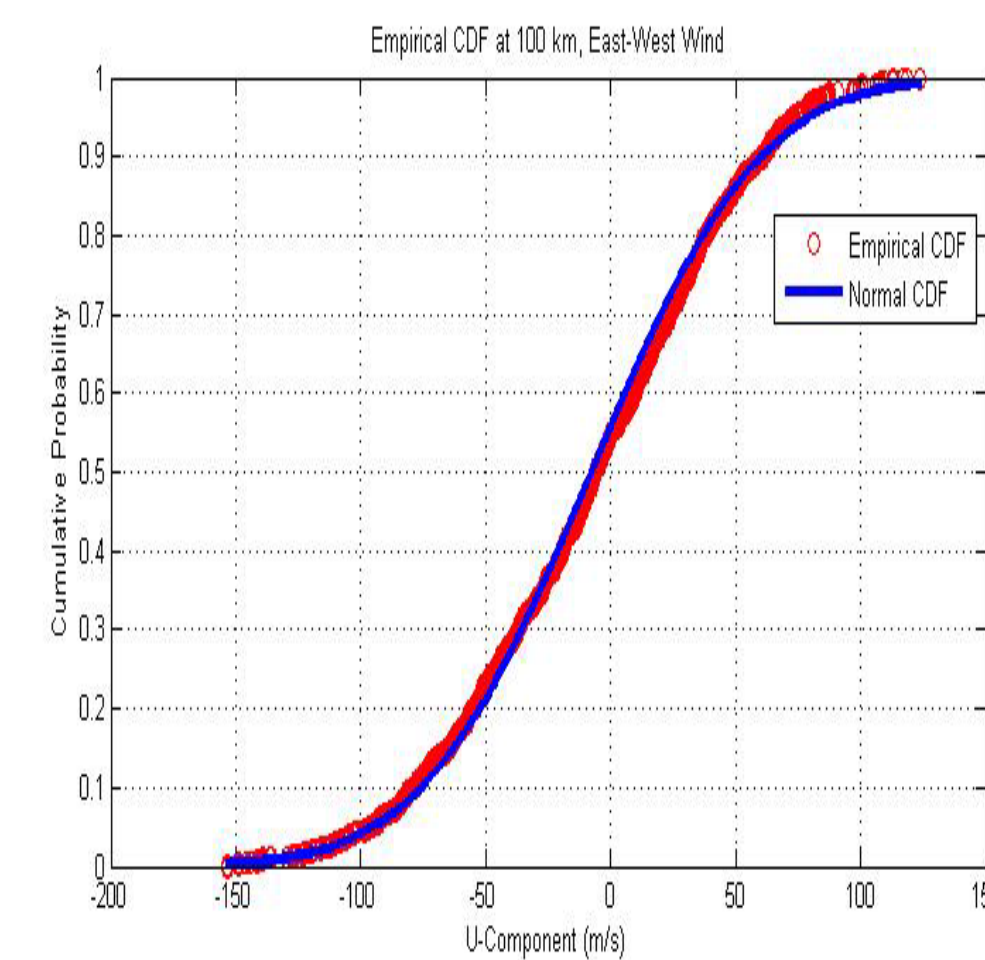
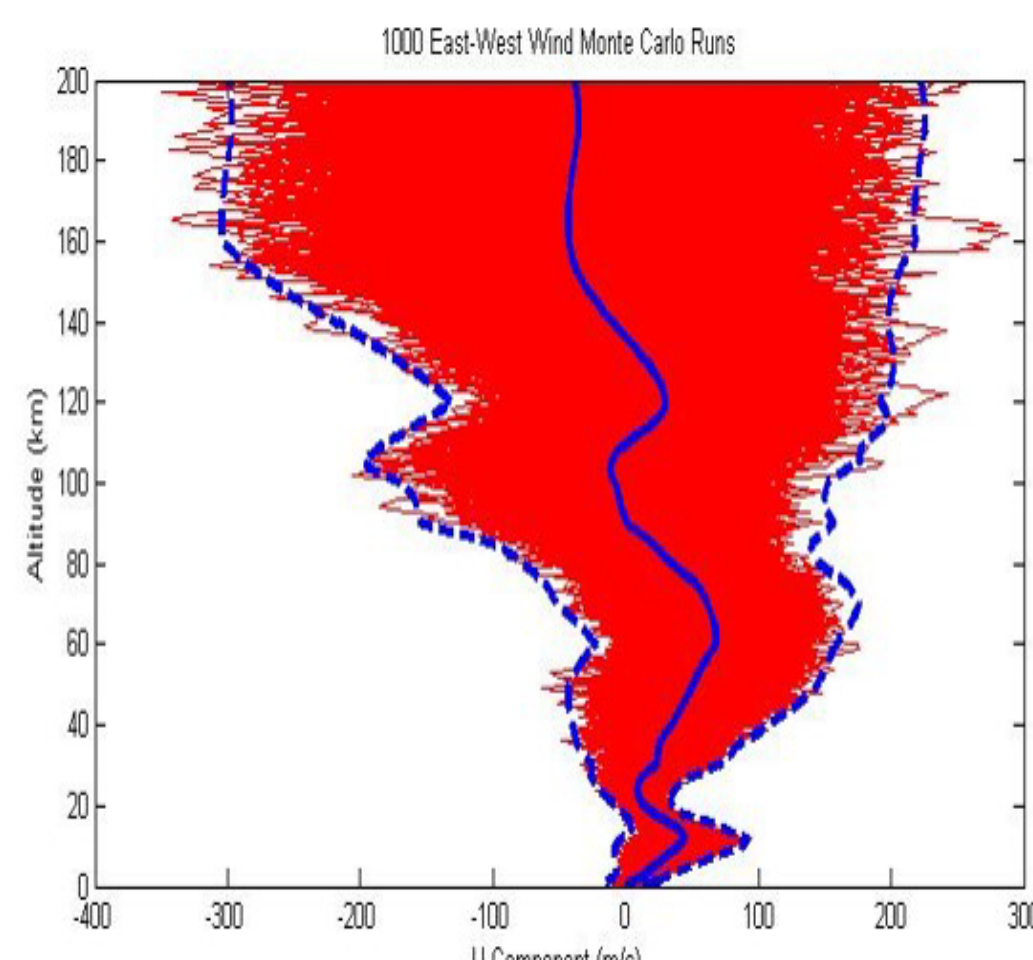
Patrick White

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Earth-GRAM Overview

- Provides monthly statistics at any point in the atmosphere
- Includes monthly, geographic, and altitude variations
- Current Version: Earth-GRAM 2016 Version 2.0 - C++
- Available through the NASA Software Catalog: <https://software.nasa.gov/>
- Output Includes: pressure, density, temperature, horizontal and vertical winds, speed of sound, and atmospheric constituents
- Used by engineering community to create atmospheric dispersions at a rapid runtime.
- Not a forecast model
- Earth-GRAM 2016 Version 2.0 Updates:
 - CorrMonte – produces hourly dispersions
 - CorrTraj – produces correlated Ballistic (Up-Down) Atmospheric Profile
 - Includes vertical fairing between RRA2013 and Earth-GRAM
 - Improves ability to incorporate Earth-GRAM into multi-body simulation
 - Incorporates Bug Fixes

Earth-GRAM Perturbation Model



- Dispersions in Earth-GRAM generated by the perturbation model
- Divided into small-scale and large-scale portions
- Driven by standard deviation
- Gaussian based dispersions

Earth-GRAM Boundary Layer Model

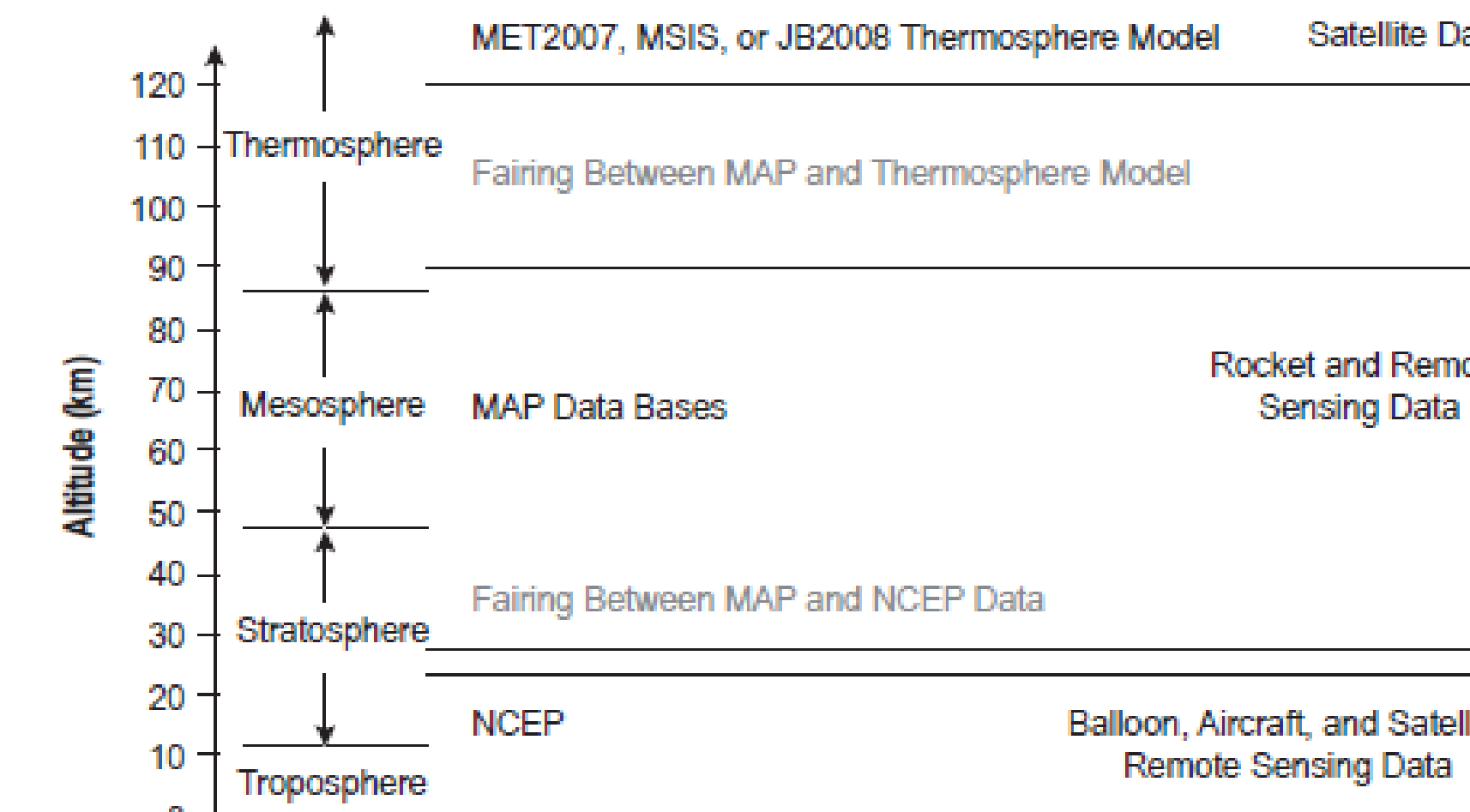
- Earth-GRAM uses a boundary layer model to approximate vertical wind standard deviation
- Vertical wind standard deviation dependent on: surface roughness (based on 1 degree surface code map), friction velocity, surface elevation, solar elevation angle and time of day, and Monin-Obukhov length

Friction velocity (u_*) based on Monin-Obukhov length (L), surface roughness z_0 , and wind speed at 10 meters (U_{10})

$$u_* = \frac{0.4U_{10}}{\ln\left(\frac{10}{z_0}\right) - \psi\left(\frac{10}{L}\right)} \quad \text{if } 1/L > 0 \text{ (stable)} \quad = -50/L$$
$$u_* = \frac{0.4U_{10}}{\ln\left(\frac{10}{z_0}\right) - \psi\left(\frac{10}{L}\right)} \quad \text{if } 1/L = 0 \text{ (neutral)} \quad \psi(10/L) = 0.0$$
$$u_* = \frac{0.4U_{10}}{\ln\left(\frac{10}{z_0}\right) - \psi\left(\frac{10}{L}\right)} \quad \text{if } 1/L < 0 \text{ (unstable)} \quad 1.0496(-10/L)^{0.4591}$$

Code	Land Cover Class	z_0 (m)
0	Water	u-dependent
1	Broadleaf evergreen forest	0.6
2	Coniferous evergreen forest and woodland	0.48
3	High-latitude deciduous forest and woodland	0.42
4	Tundra	0.0056
5	Mixed coniferous forest and woodland	0.45
6	Wooded grassland	0.12
7	Grassland	0.046
8	Bare ground	0.015
9	Shrubs and bare ground	0.042
10	Cultivated crops	0.065
11	Broadleaf deciduous forest and woodland	0.45
12	Data unavailable (reassigned to codes 4, 6, or 13, as appropriate)	--
13	Ice	3.2×10^{-4}

Earth-GRAM Model Input



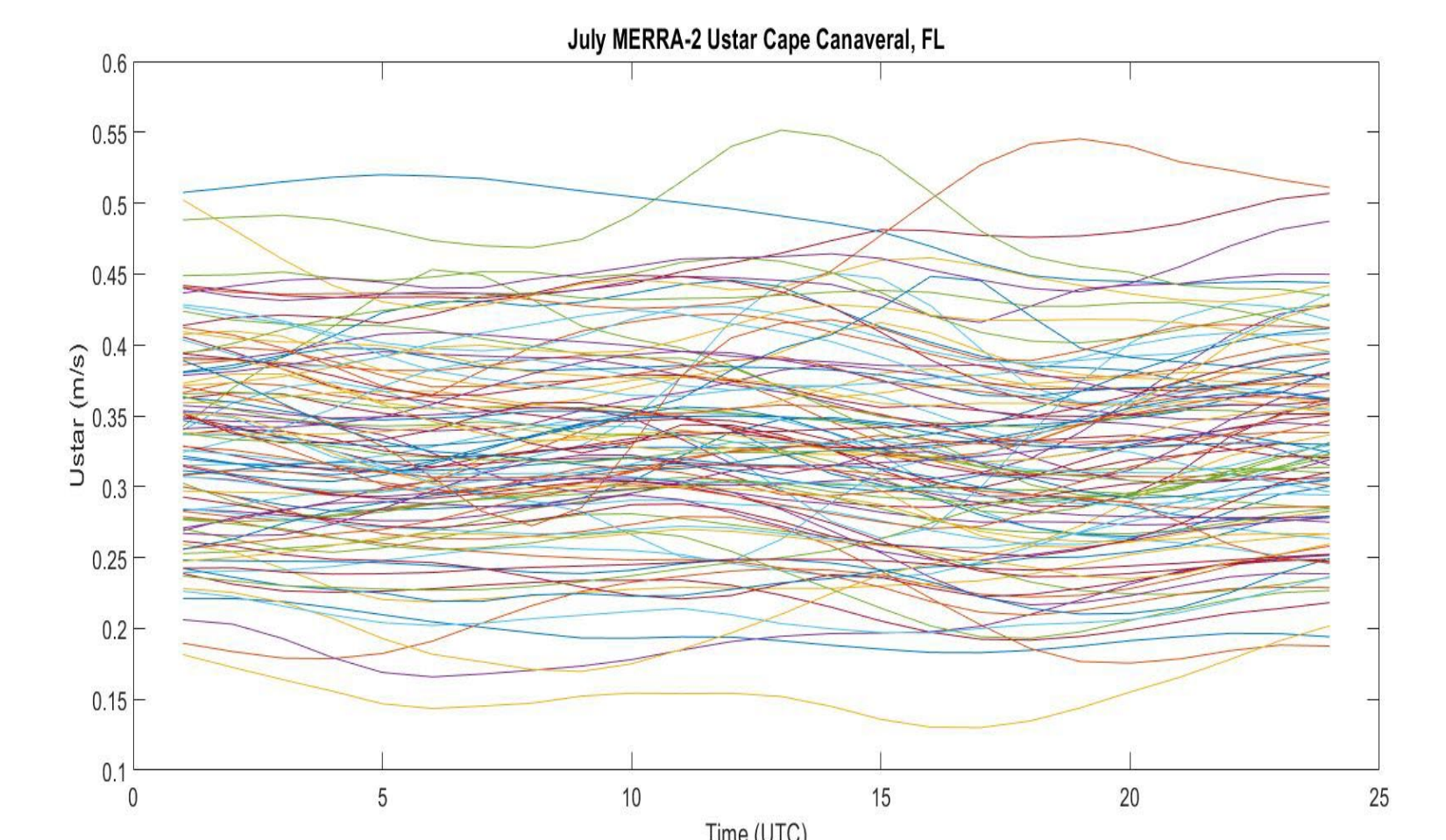
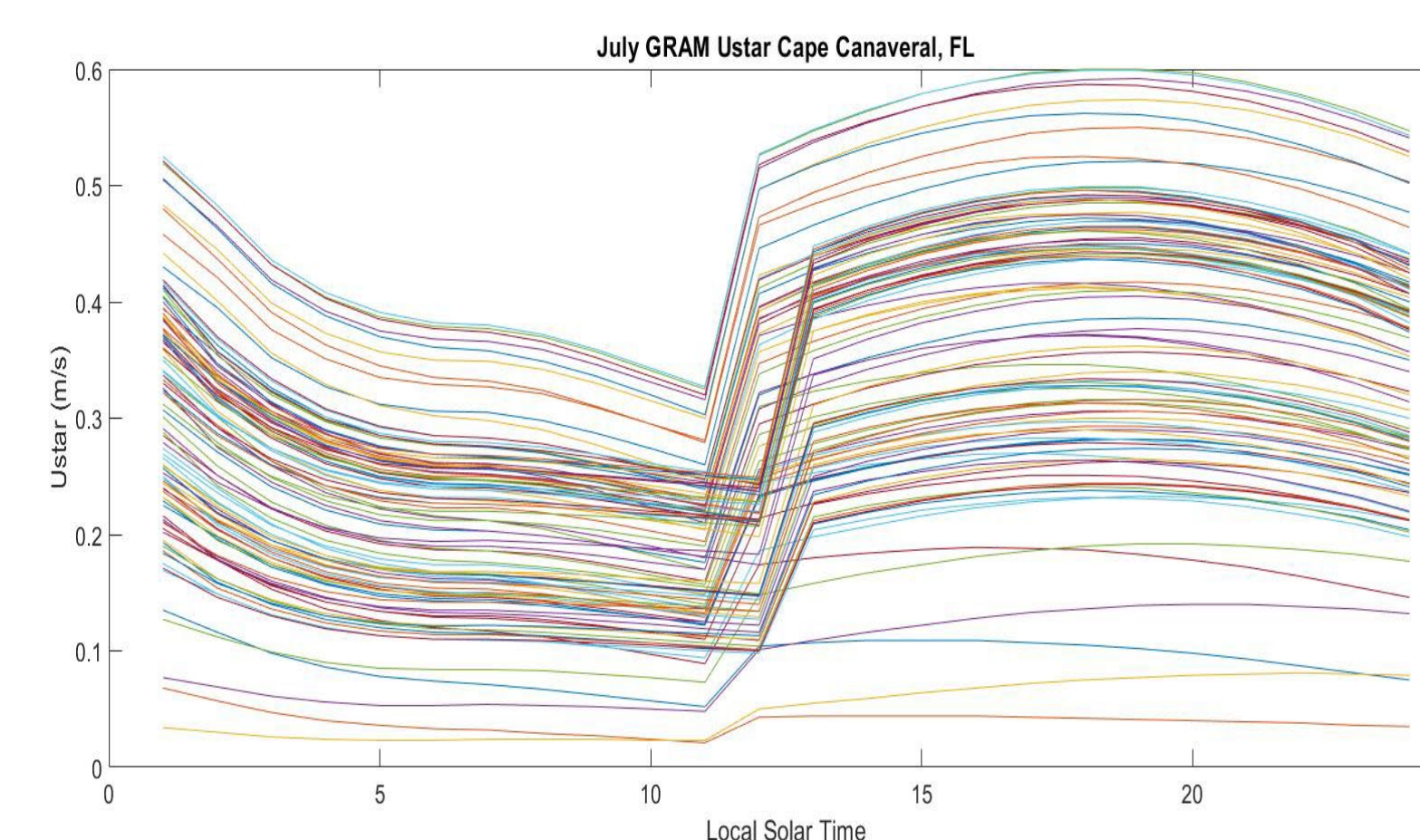
Additional Input Data Options Include:

- Range Reference Atmosphere (RRA): site specific data
- Available sets: 2013, 2006, and 1983
- Planning release of 2019 RRAs
- User-defined auxiliary profile

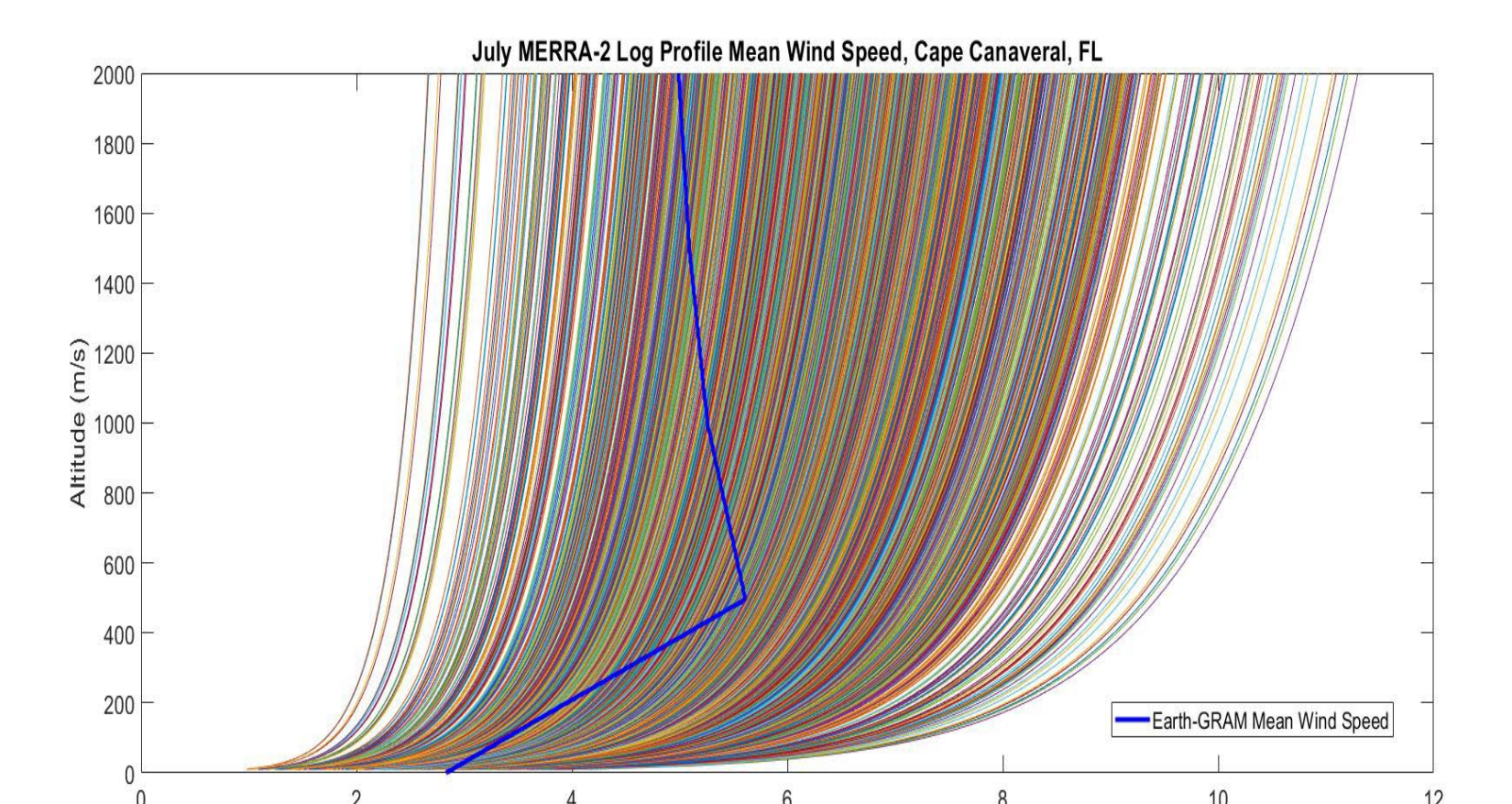
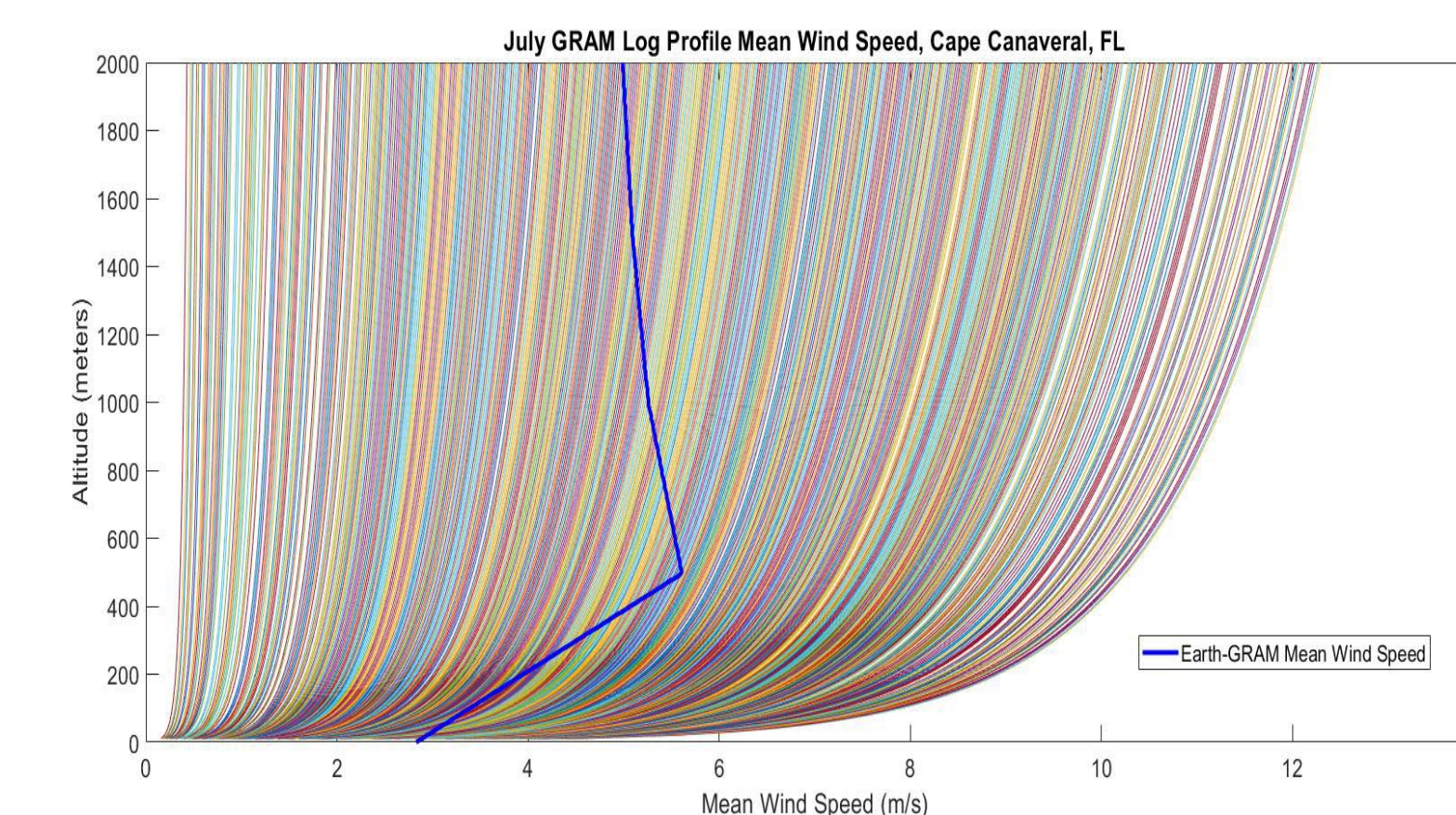
Boundary Layer Comparison

This comparison applies the friction velocity (u_{star}) term and surface roughness to the log profile for mean wind speed to examine boundary layer horizontal winds in Earth-GRAM. This study also used u_{star} from the Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2).

$$\bar{U} = (u_* / k) \ln(z / z_{0,m}) \quad \text{Log Profile for Mean Wind Speed}$$



- Earth-GRAM vs MERRA-2 Ustar for 100 days in July for Cape Canaveral, FL



- Earth-GRAM mean wind speed compared to log profile mean wind speed using Earth-GRAM and MERRA-2 u_{star}
- The log profile wind speed ranges with varying stability cases

Conclusion

Earth-GRAM has limitations for boundary layer horizontal winds. These limitations have been identified during re-entry parachute deploy cases. Earth-GRAM mean wind speed does not compare well with the log mean wind profile in the boundary layer when considering unstable cases. The Earth-GRAM mean wind speed also fails to capture to log nature of boundary layer winds. The Earth-GRAM team plans to improve boundary layer limitations for horizontal winds.