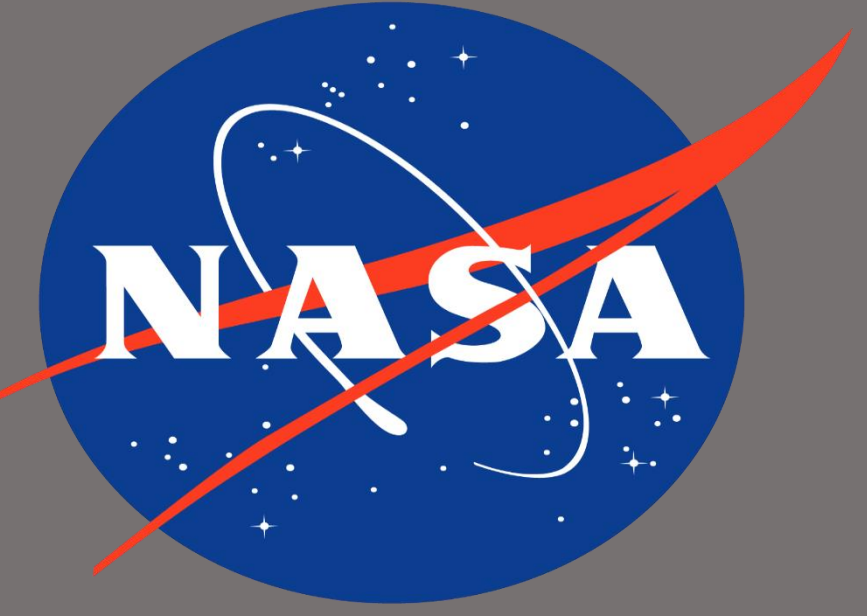




Earth Global Reference Atmospheric Model (GRAM) Overview and Modern Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) Global Atmosphere Upgrade



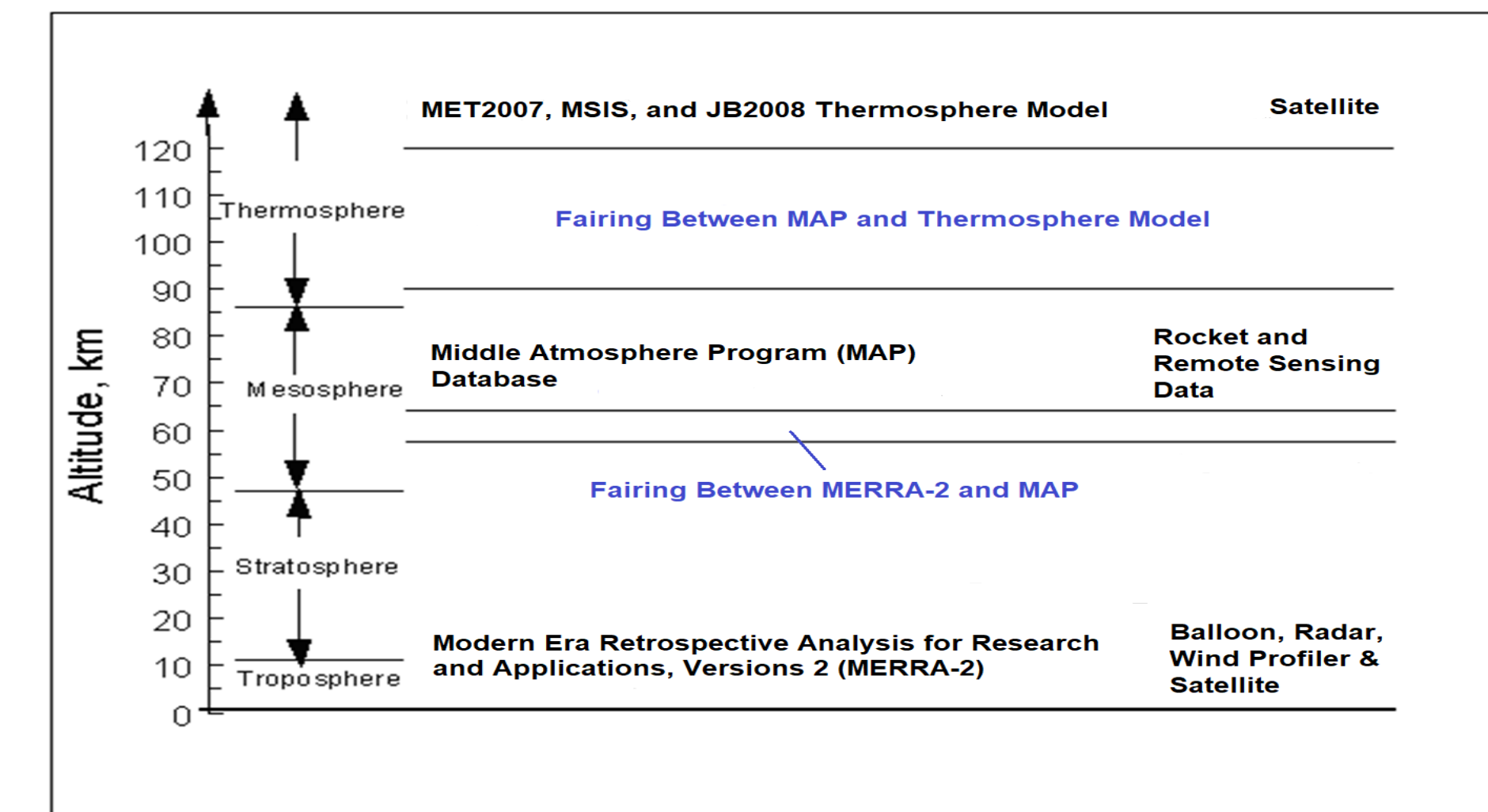
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Earth-GRAM Overview

- Provides monthly statistics at any point in the atmosphere
- Monthly, geographic, altitude variation
- Current Version: GRAM Suite 2.0 (Earth-GRAM 2023)
- Output Includes: pressure, density, temperature, horizontal and vertical winds, speed of sound, atmospheric constituents
- Used by engineering community to create atmospheric dispersions at a rapid runtime.
- Often embedded in spaceflight trajectory simulation software
- Not a forecast model
- **Earth-GRAM 2023 Update:**
- Global atmosphere upgrade developed from MERRA-2 reanalysis dataset
- Python API for the GRAM Suite
- **GRAM Suite Development:**
- Includes all GRAM models (Earth, Mars, Jupiter, Neptune, Titan, Uranus, and Venus) in a common object-oriented C++ framework
- Includes a common GRAM library of data models and utilities
- All future GRAM upgrades will be released in the GRAM Suite

Model Input

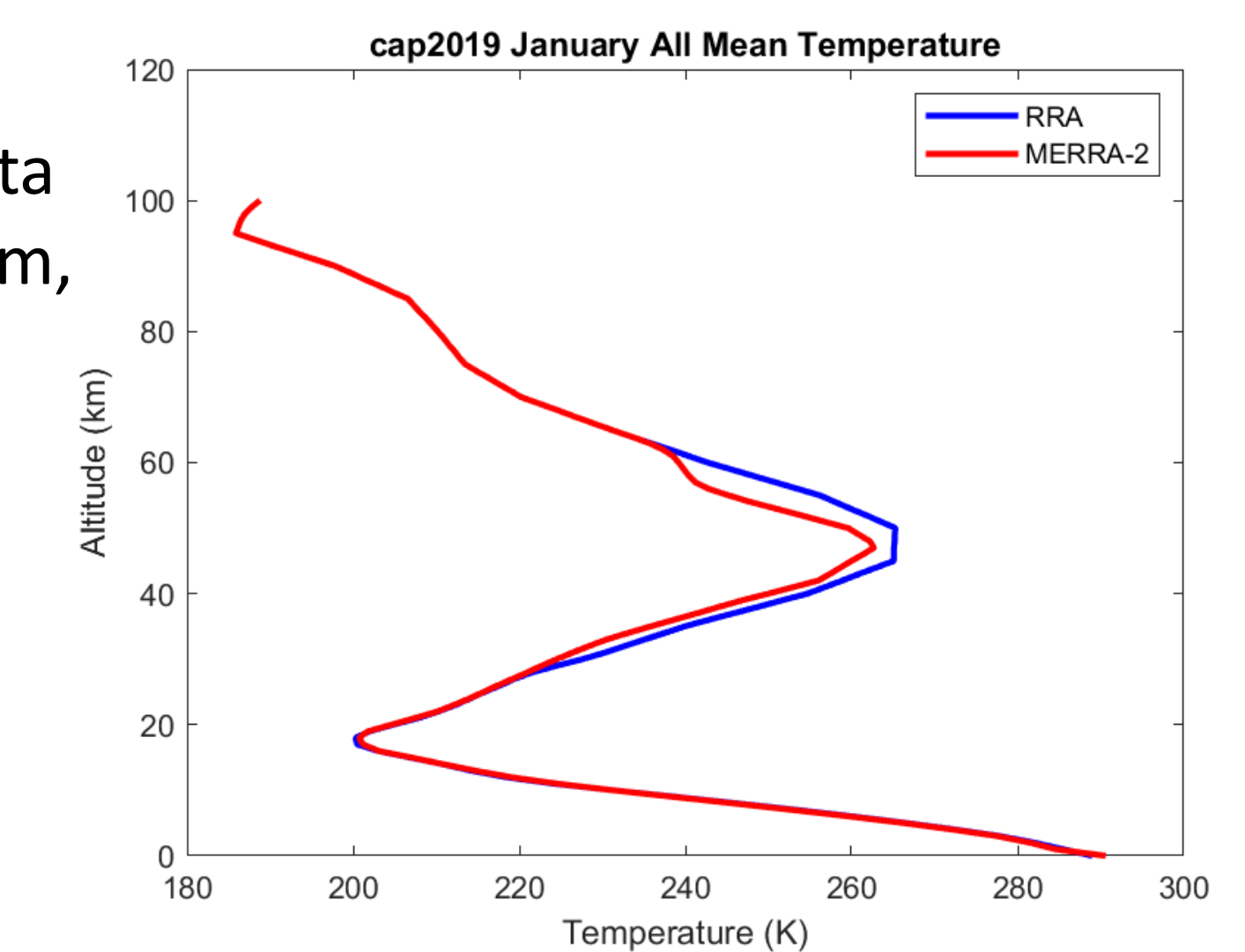
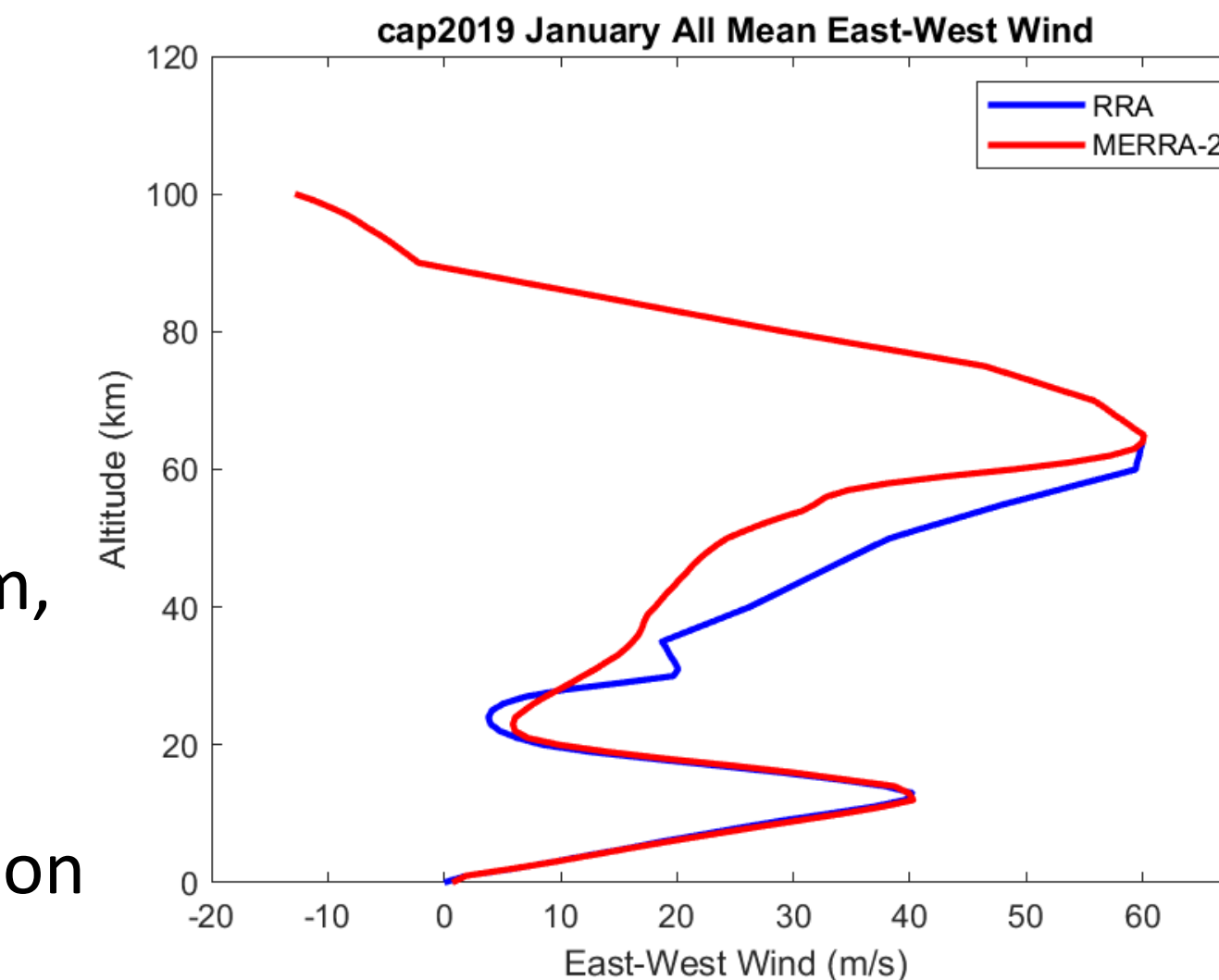
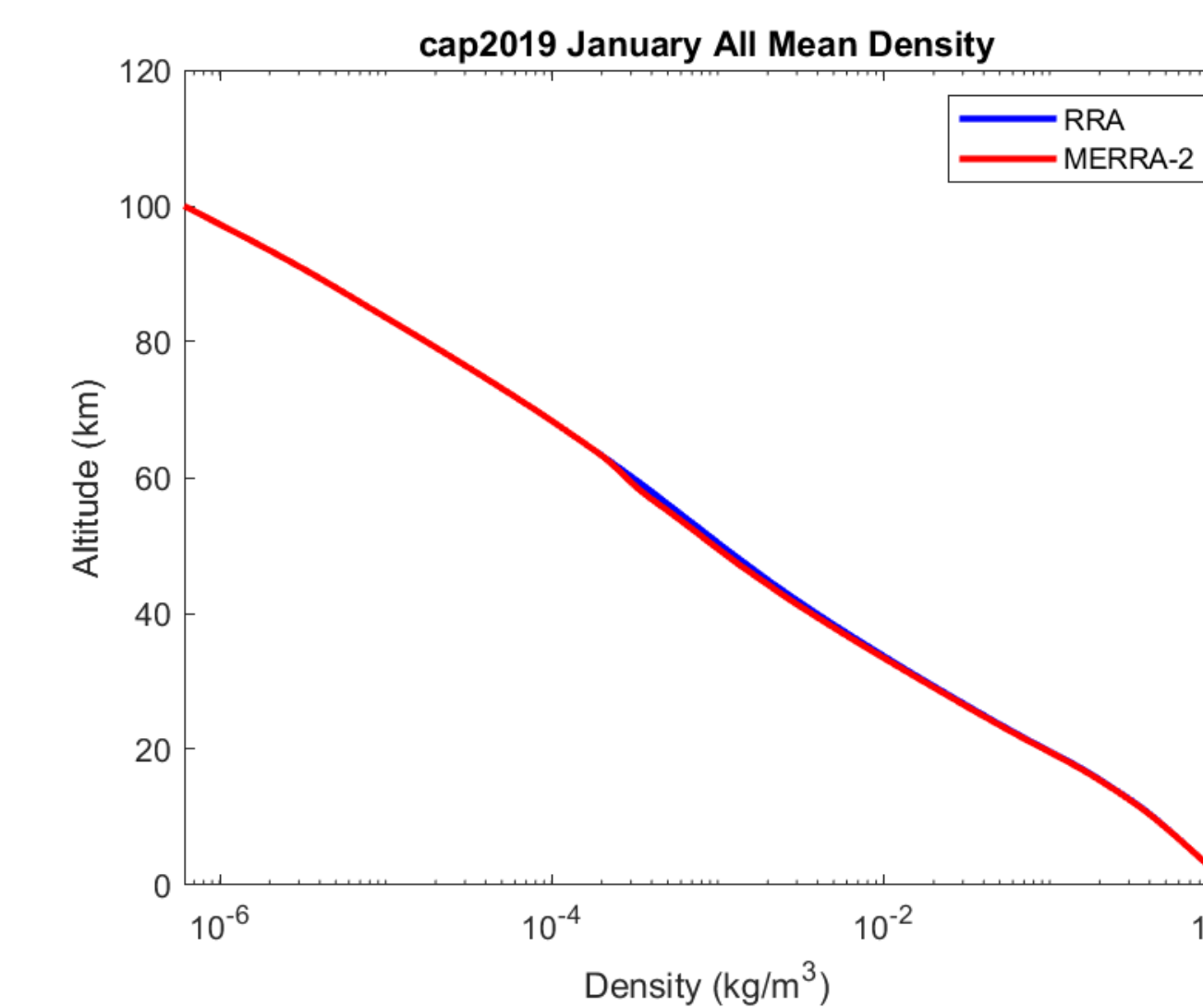


- Additional Data Options Include:
- Range Reference Atmosphere (RRA): site specific data options.
 - Available sets: 2019, 2013, 2006, 1983
 - Auxiliary user-defined data option

MERRA-2 Implementation and Comparison

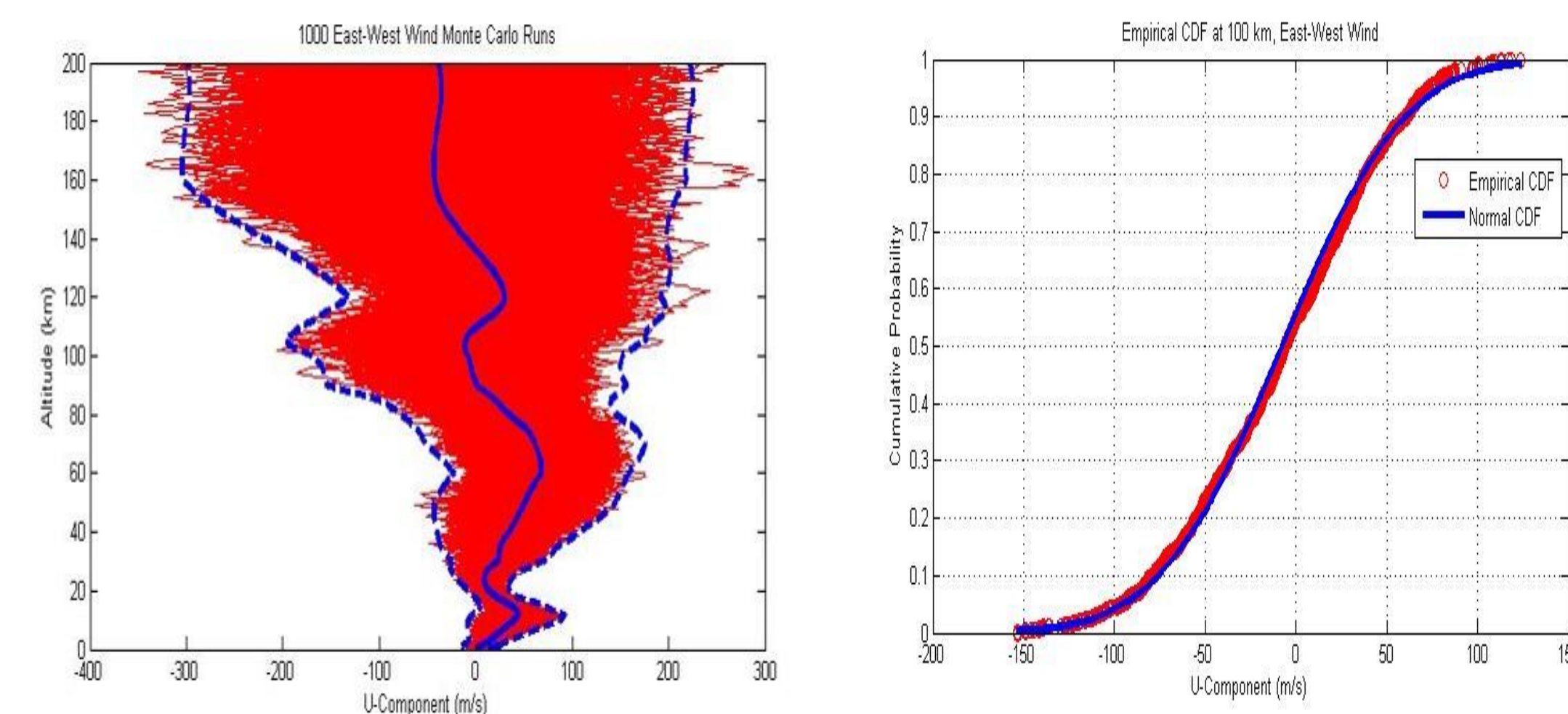
The MERRA-2 climatological dataset in Earth-GRAM was developed from daily atmosphere files from 1999 to 2018. The data from filename "inst3_3d_asm_Np (M2I3NPASM): Assimilated Meteorological Fields" was used to develop the atmosphere variables on the 42 pressure levels and the filename for the surface variables "inst1_2d_asm_Nx (M2I1NXASM): Single-Level Diagnostics". These daily files were compiled to calculate the monthly mean and standard deviation at every grid point for the surface and all 42 pressure levels. A mean and standard deviation was calculated for the eight times a day and from all times of day. Binary files were created for each month for the eight times of day (00, 03, 06, 09, 12, 15, 18, 21 UTC) and the total mean at the original file resolution.

Comparison was conducted between MERRA-2 dataset and 2019 RRA data from January Cape Canaveral, FL. RRA data reaches an altitude of 30 km. Above 30 km, Earth-GRAM utilizes Middle Atmosphere Program (MAP) data. MERRA-2 reaches an altitude near 60 km.



MERRA-2 compares well with 2019 RRA January Cape Canaveral, FL. Above 30 km, differences exist between MAP and MERRA-2. Greater confidence should be placed in the modern and higher resolution MERRA-2 dataset compared to MAP.

Perturbation Model



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

MERRA-2 Overview

- MERRA-2 reanalysis data set developed by Goddard Modeling and Assimilation Office (GMAO)
- Improved horizontal resolution: 0.625°x0.5° longitude-by-latitude grid (NCEP reanalysis I, 2.5°x2.5° currently used in Earth-GRAM)
- Improved altitudinal coverage: 72 model layers or interpolated to 42 pressure levels to 0.1 hPa (NCEP reanalysis I, 10hPa)
- MERRA-2 provides lower and middle atmosphere coverage and provides improvement over aging Middle Atmosphere Program (MAP) data set.
- Input Observations:
- Surface: land, ship and buoy observations
- Upper Air: balloon, radar, wind profiler, satellite derived winds, and satellite retrieved measurements



Summary and Future Upgrades

- Earth-GRAM 2023 implemented MERRA-2 as a global atmosphere option and added a Python API to the GRAM Suite
- MERRA-2 compares well to RRA databases and greater confidence is placed in MERRA-2 compared with MAP for characterizing the middle atmosphere
- **Planned Updates:**
- Ability to incorporate gridded forecast data in Earth-GRAM – Spring 2024 Release
- Update Naval Research Mass Spectrometer Incoherent Scatter thermosphere model
- Boundary layer improvements with focus on horizontal winds