Earth Global Reference Atmospheric Model (GRAM) Update
Spring 2019 DOLWG

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Earth-GRAM Lead

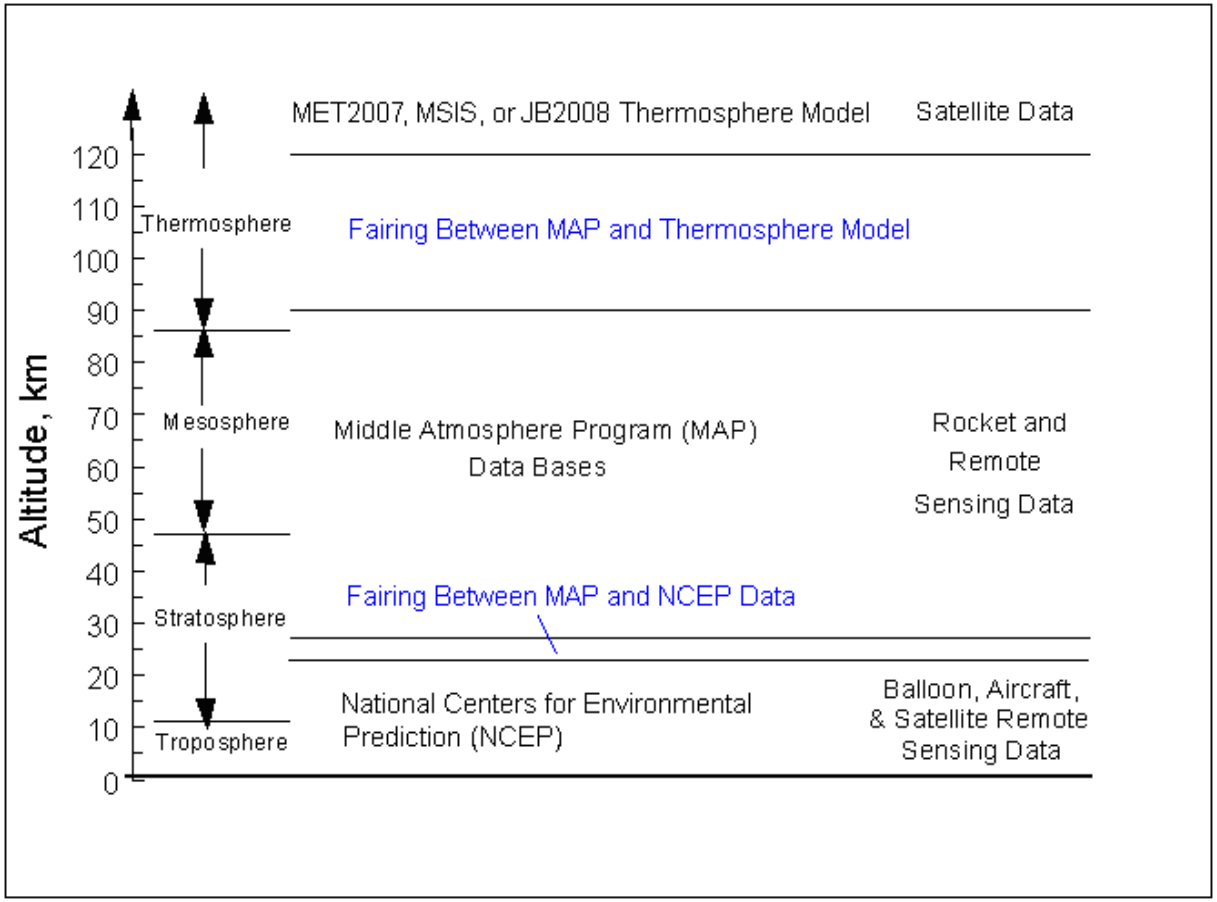
Outline

- GRAM Overview
- Earth-GRAM vs Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) Comparisons
- 3-hr CorrMonte Comparisons
- Earth-GRAM 2016 Version 2.0
- Range Reference Atmosphere (RRA) Development

What is Earth-GRAM???

- Earth Global Reference Atmospheric Model (Earth-GRAM) provides monthly mean and standard deviation for any point in the atmosphere
  - Includes Monthly, Geographic, and Altitude Variation
- Earth-GRAM is a C++ software package
  - Currently distributed as Earth-GRAM 2016
- Atmospheric variables output included: pressure, density, temperature, horizontal and vertical winds, speed of sound, and atmospheric constituents
- Used by engineering community because of ability to create dispersions in the atmosphere at a rapid runtime
  - Often embedded in trajectory simulation software
- Earth-GRAM is not a forecast model
- Does not readily capture localized atmospheric effects

Earth-GRAM Model Input



Range Reference Atmosphere (RRA) Option

Auxiliary Profile Input Option

Range Reference Atmosphere (RRA) Database and Auxiliary Profile Option

- Earth-GRAM has the ability to use the RRA site specific databases
  - Earth-GRAM includes 1983, 2006 and 2013 RRA databases
  - 15 2013 RRA sites developed by MSFC/Natural Environments Branch for the Range Commanders Council – Meteorology Group
- Climatology built from balloon and rocketsonde measurements
- MSFC - Natural Environments recommends the use of the 2013 RRA database and planning development of 2019 RRA database
- Auxiliary Profile option allows users the option to include profile of their choice

Earth-GRAM Perturbation Model

Values From Earth-GRAM =

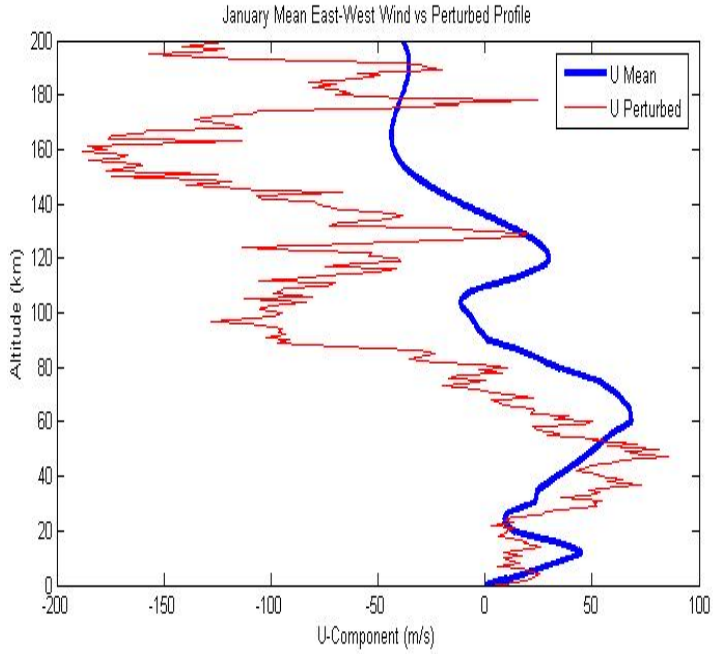
Mean value + Large-scale perturbation + Small-scale perturbation

Modeled as a wave

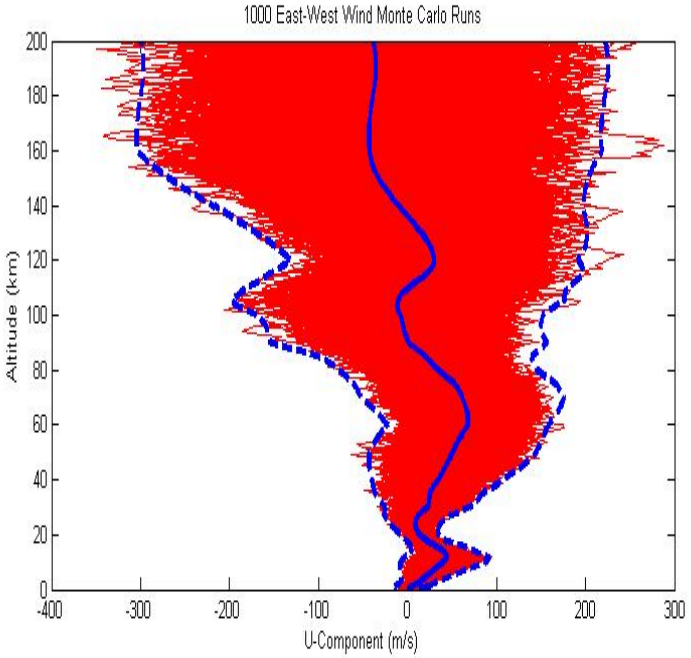
Modeled as a stochastic (random) process

Driven by observed standard deviation

Sample Earth-GRAM Output

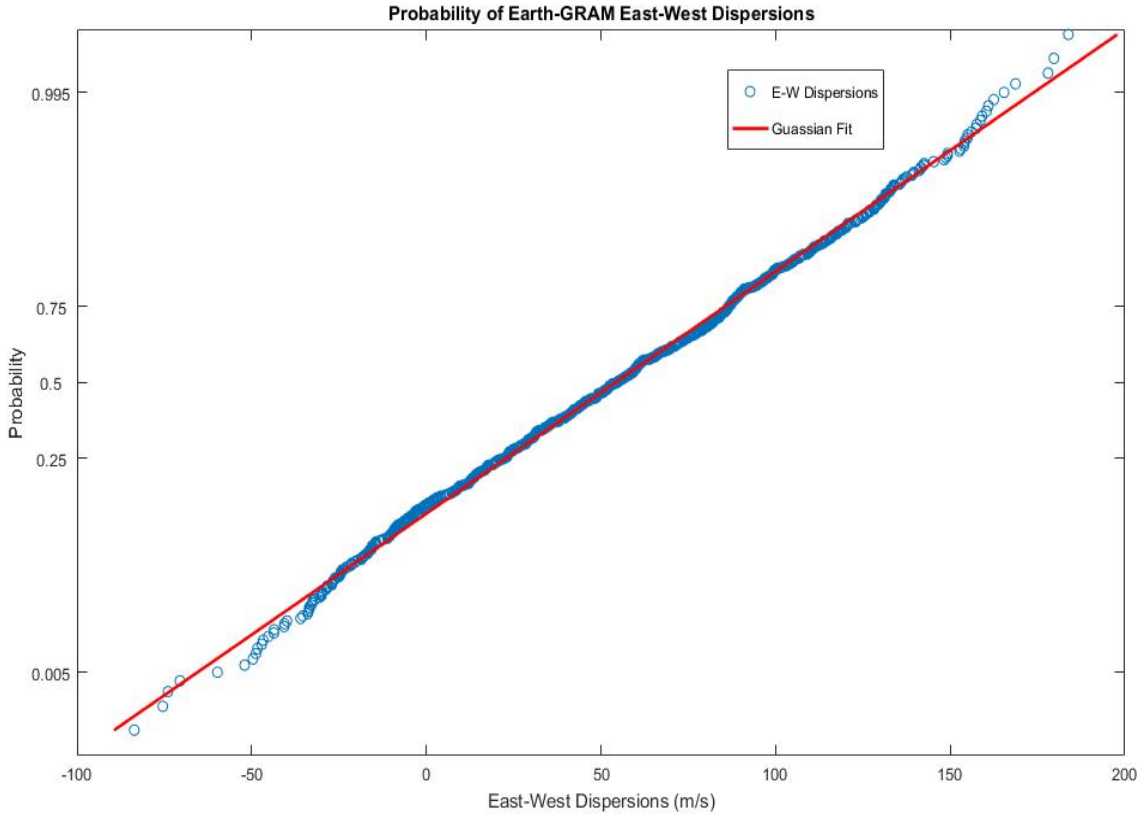


Mean and Dispersed East-West Wind



1000 Monte Carlo Dispersed Profiles with January Monthly 3-Sigma Envelope

Sample Earth-GRAM Output



Earth-GRAM dispersions are approximately Gaussian distributed

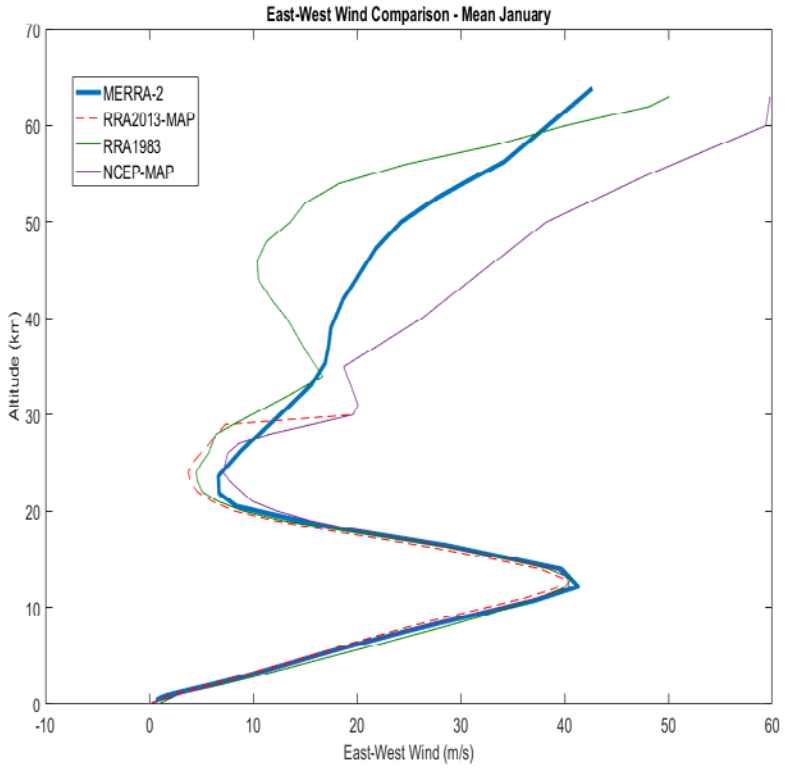
MERRA-2 Background

- Developed by Goddard Modeling and Assimilation Office (GMAO)
- Horizontal Resolution: 0.625°x0.5° longitude-by-latitude grid (NCEP reanalysis I, 2.5°x2.5° currently used in Earth-GRAM)
- Vertical resolution: 72 model layers or interpolated to 42 pressure levels to 0.1 hPa (NCEP reanalysis I, 10hPa)
- Input Observations:
  - Surface: land, ship and buoy observations
  - Upper Air: balloon, radar, wind profiler, satellite derived winds, and satellite retrieved measurements

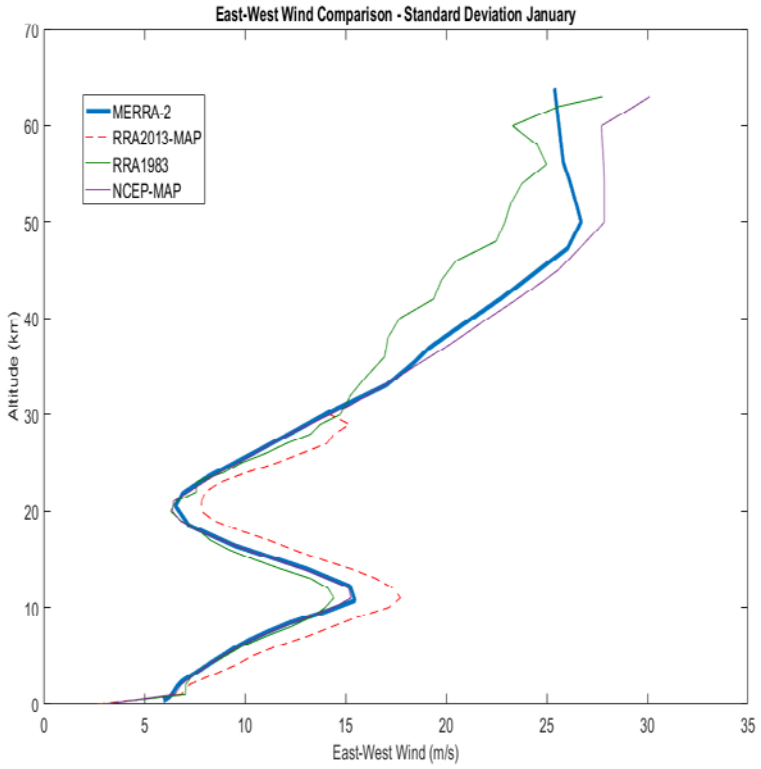
MERRA-2 Comparison to Earth-GRAM

- Compare MERRA-2 subset at several RRA sites
- Use MERRA-2 3-hr daily meteorological files from 1997-2015 (NCEP period-of-record) to develop statistics (Means and Standard Deviations) to compare to Earth-GRAM
- Variables used in comparisons: Temperature, East-West Wind (U), and North-South Wind (V), Geopotential Height
- Data taken from 42 pressure levels
- All RRA2013 has maximum altitude of 30km, most of RRA1983 has a maximum altitude of 70 km

Cape Canaveral, FL Comparison – East-West Wind

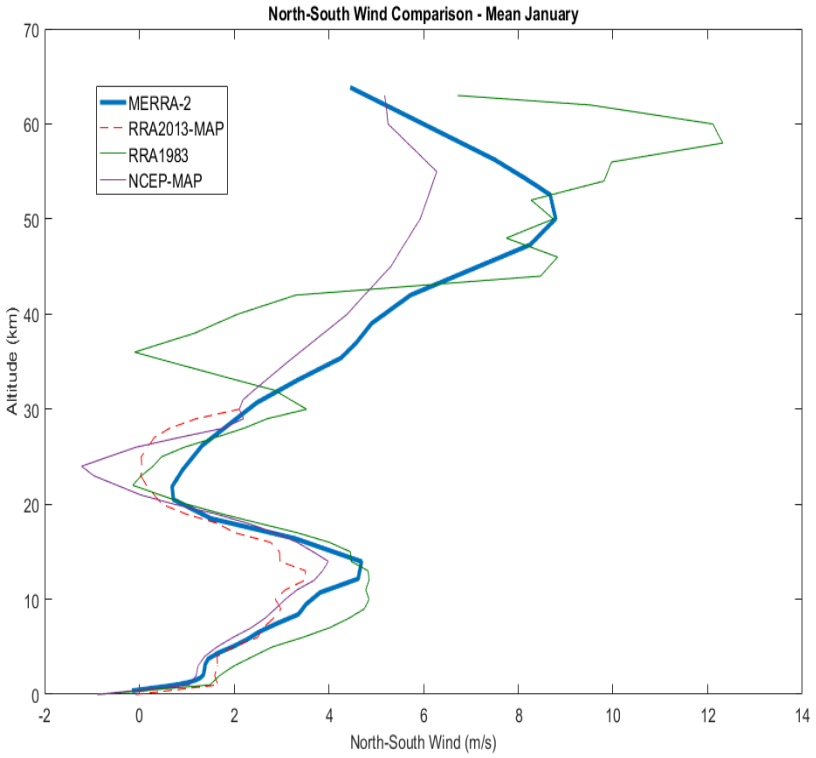


Mean East-West Wind

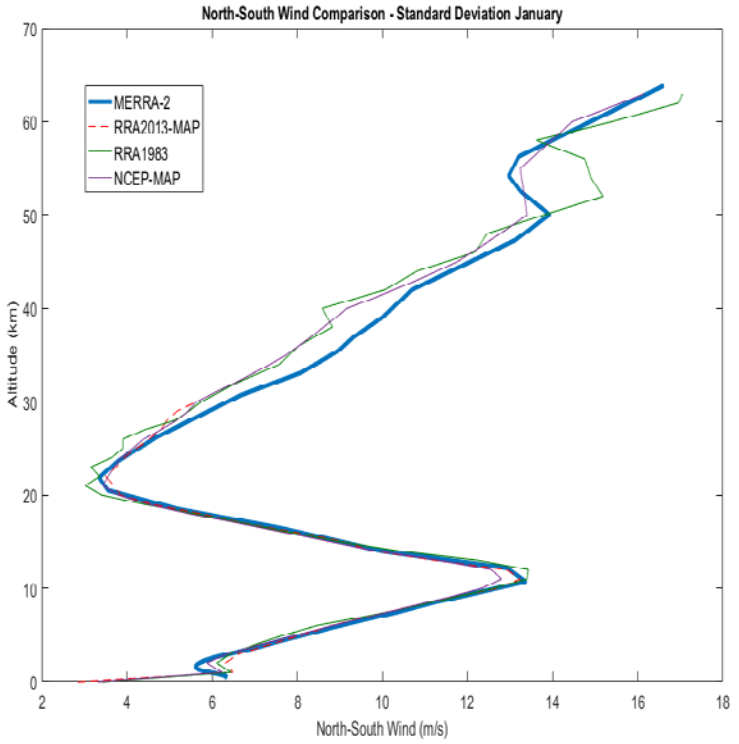


Standard Deviation East-West Wind

Cape Canaveral, FL Comparison – North-South Wind

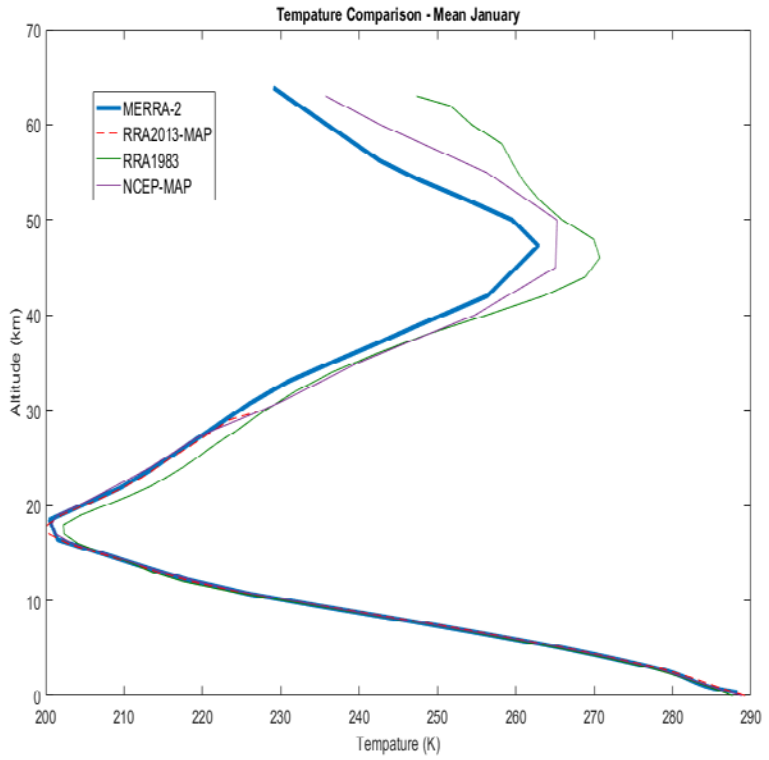


Mean North-South Wind

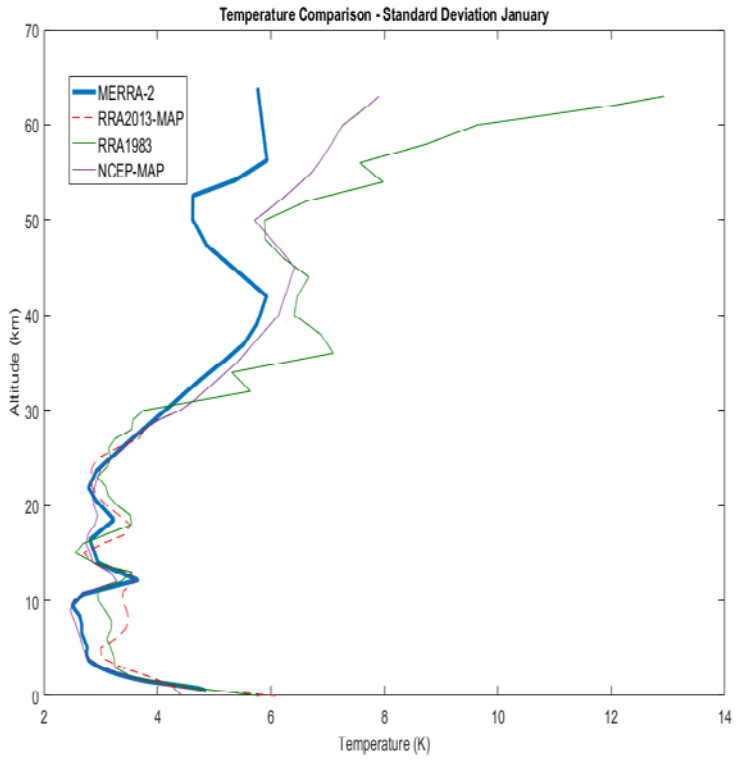


Standard Deviation North-South Wind

Cape Canaveral, FL Comparison – Temperature



Mean Temperature

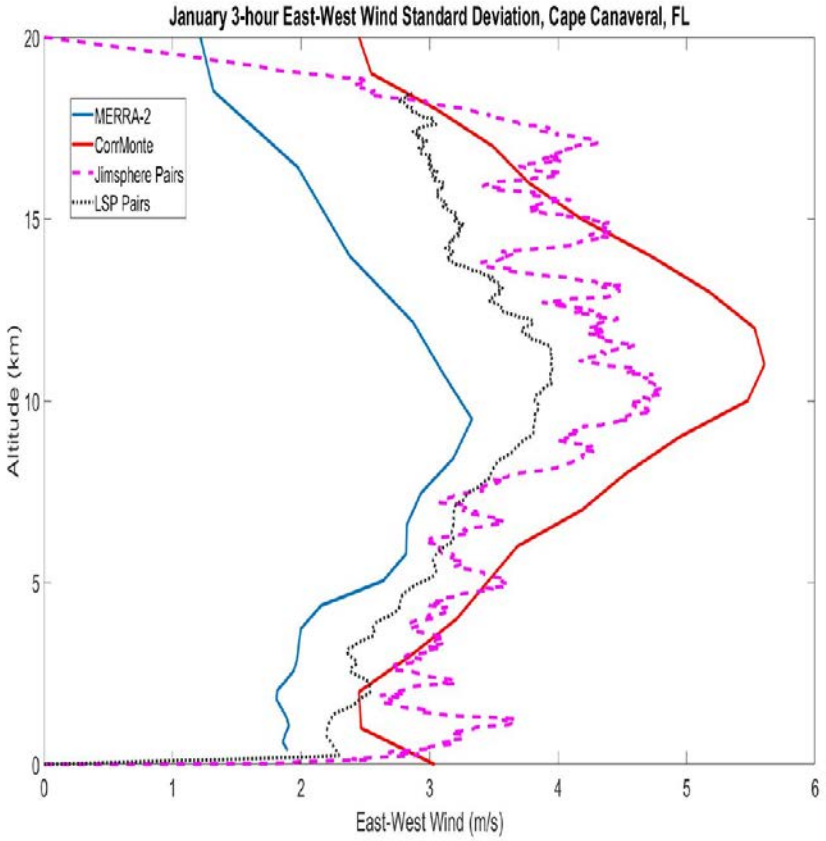


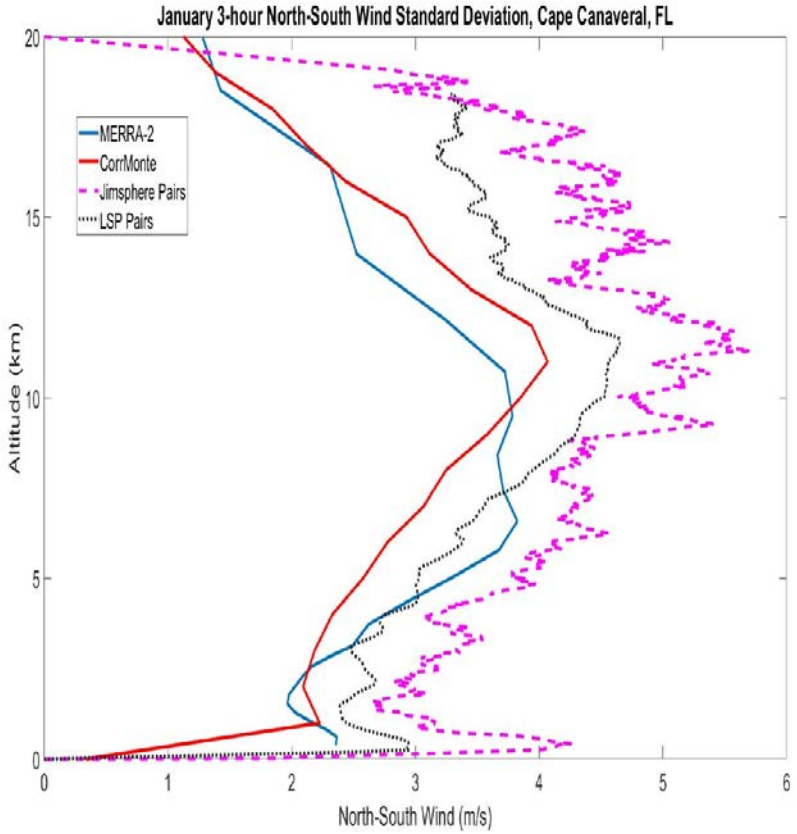
Standard Deviation Temperature

CorrMonte 3-hr Comparisons

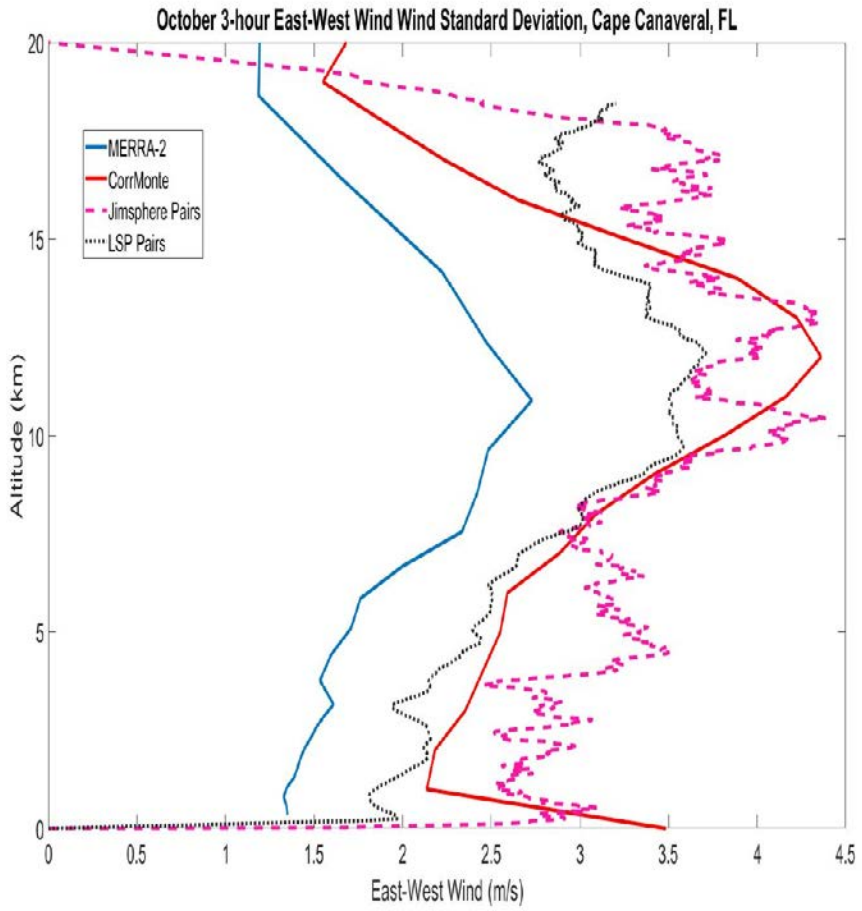
- Comparison was made to determine the ability of CorrMonte to simulate atmospheric persistence
- 3-hr Comparison at Cape Canaveral, FL
  - 3-hour CorrMonte
  - Seasonal Jimsphere Pairs
  - MERRA-2 3-hr
  - Monthly Launch Service Provider (LSP) pairs
- 3-hr Comparison at VAFB, CA
  - 3-hour CorrMonte
  - LSP pairs – broken up by season

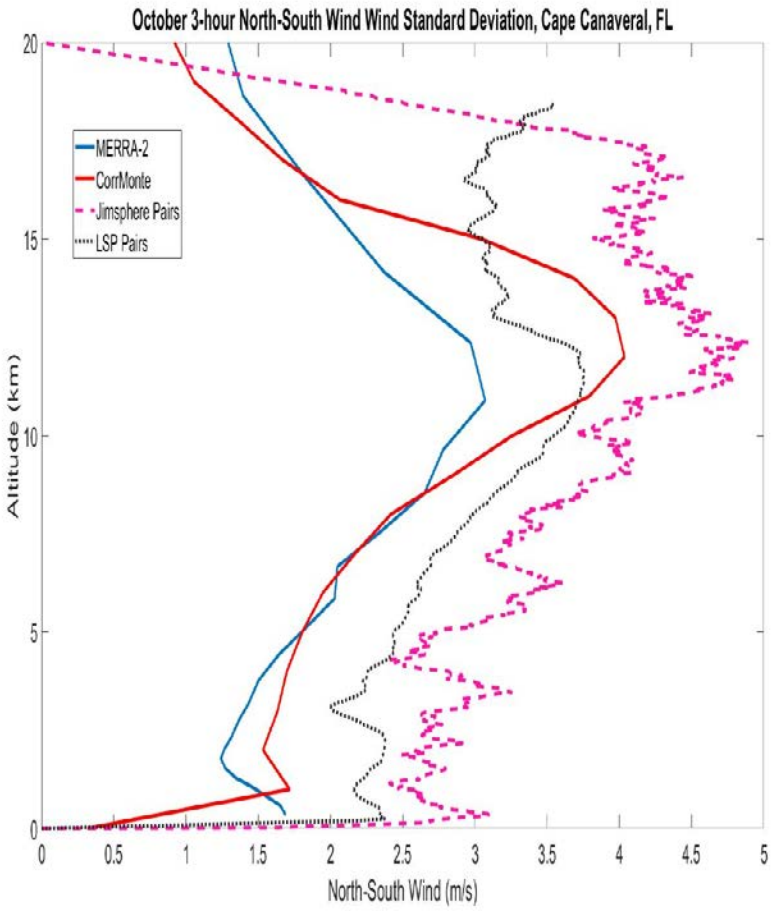
Cape Canaveral, FL 3-hour Comparisons - January



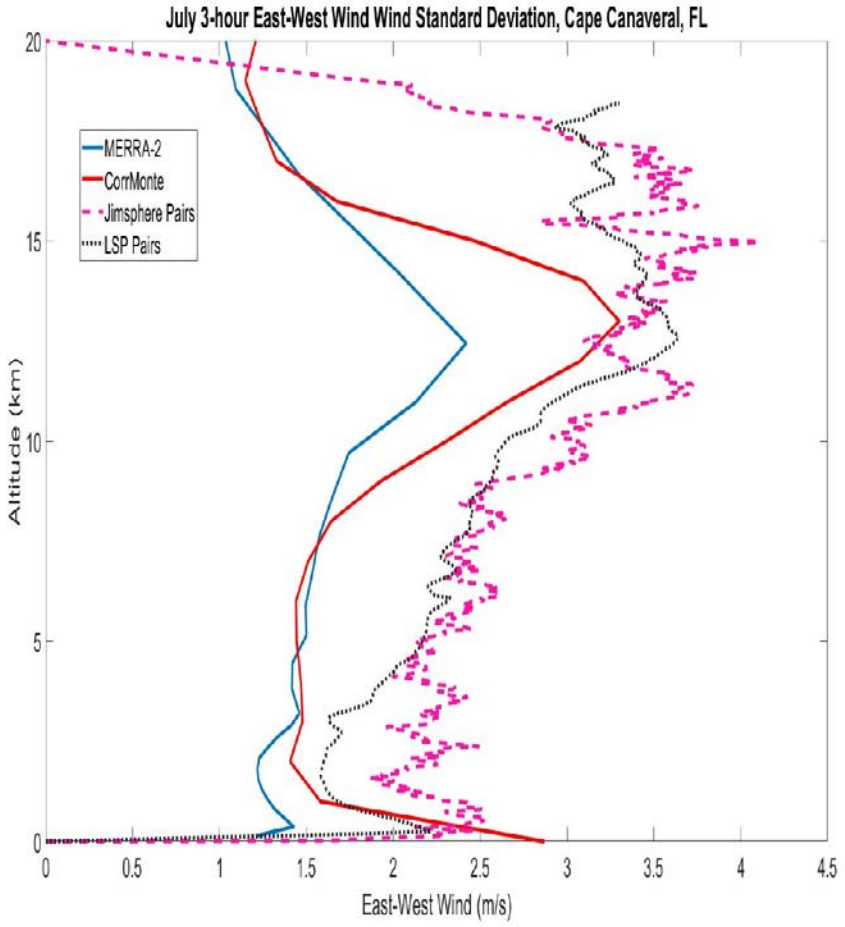


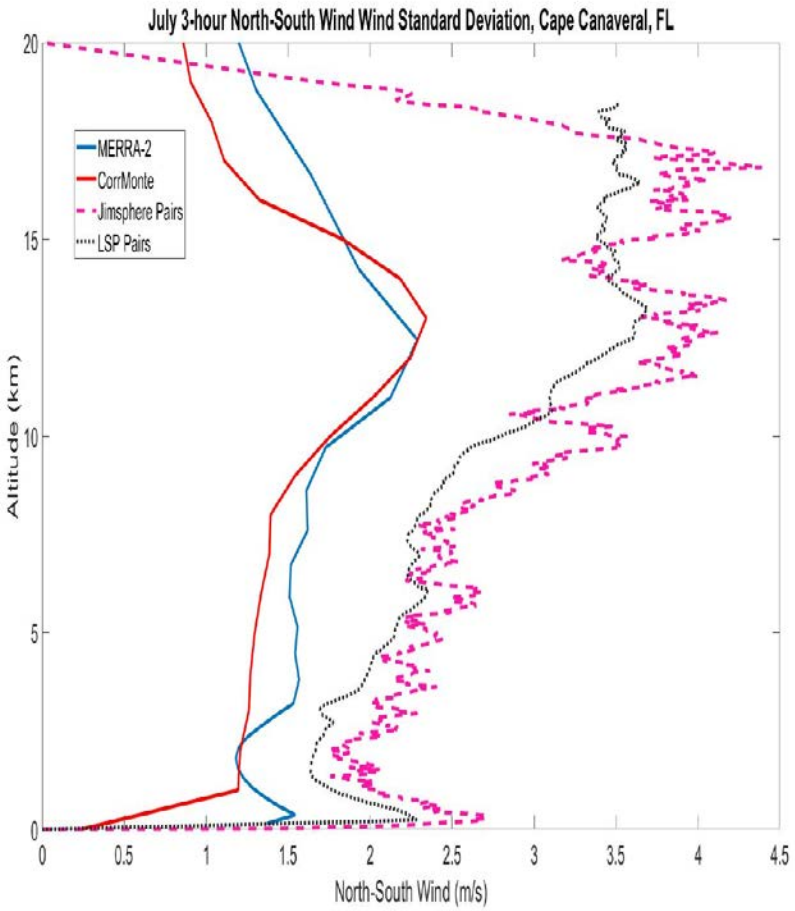
Cape Canaveral, FL 3-hour Comparison - October



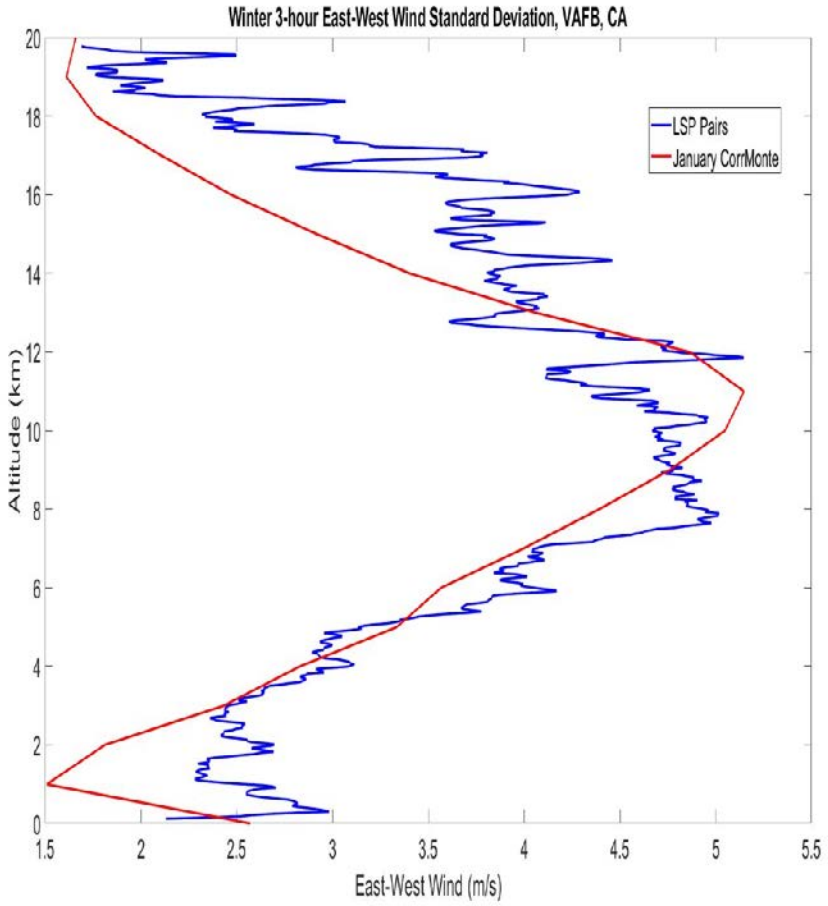


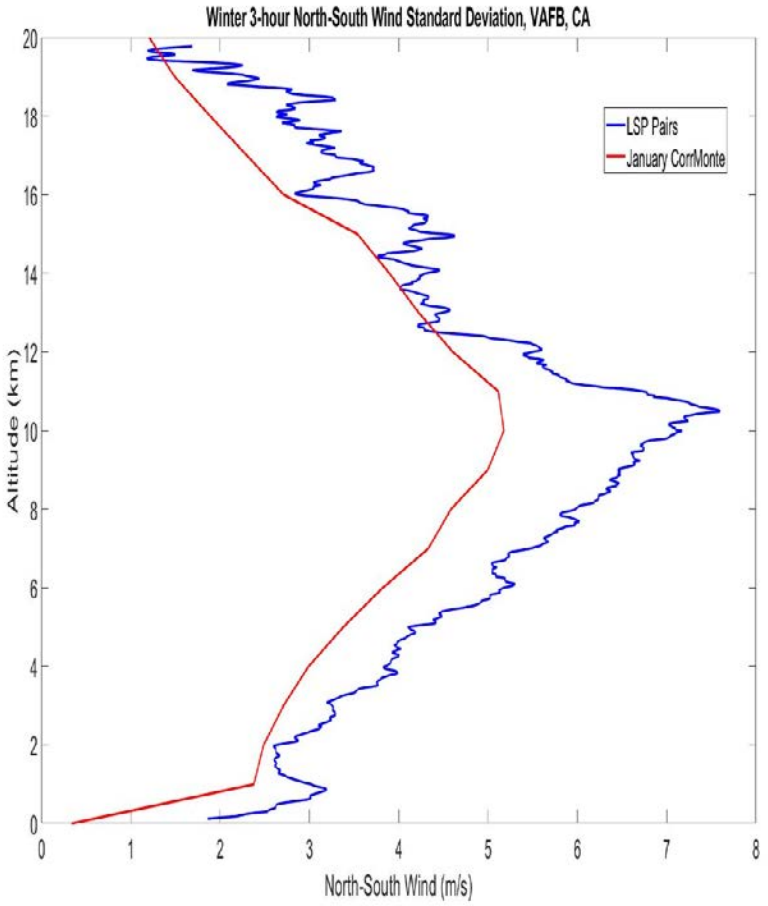
Cape Canaveral, FL 3-hour Comparison - July



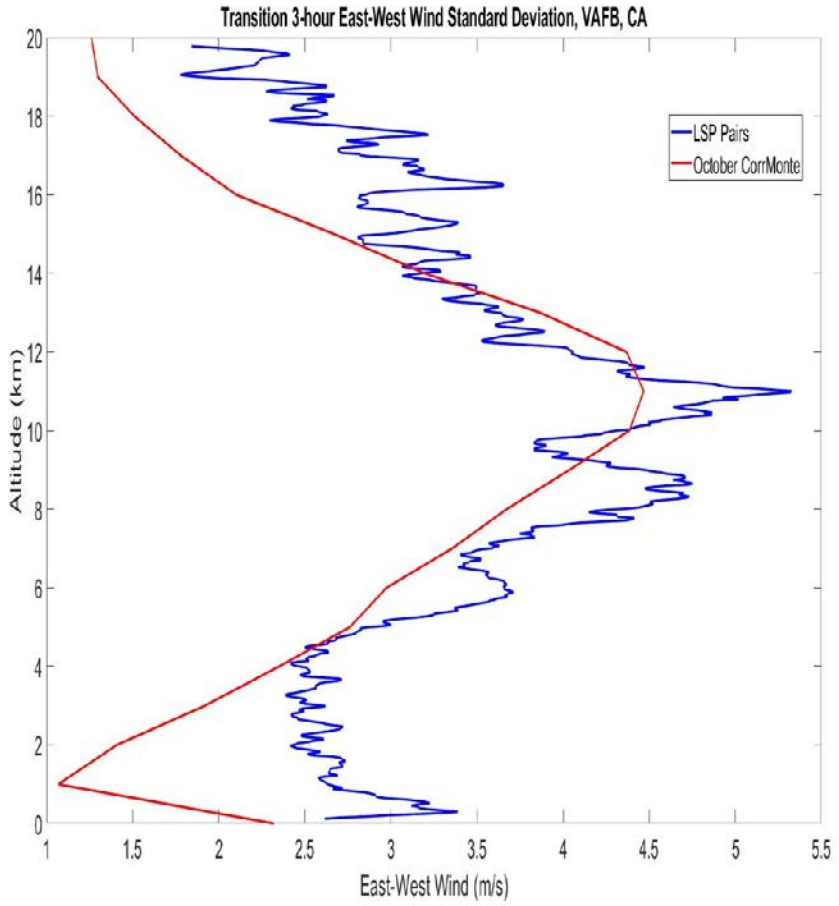


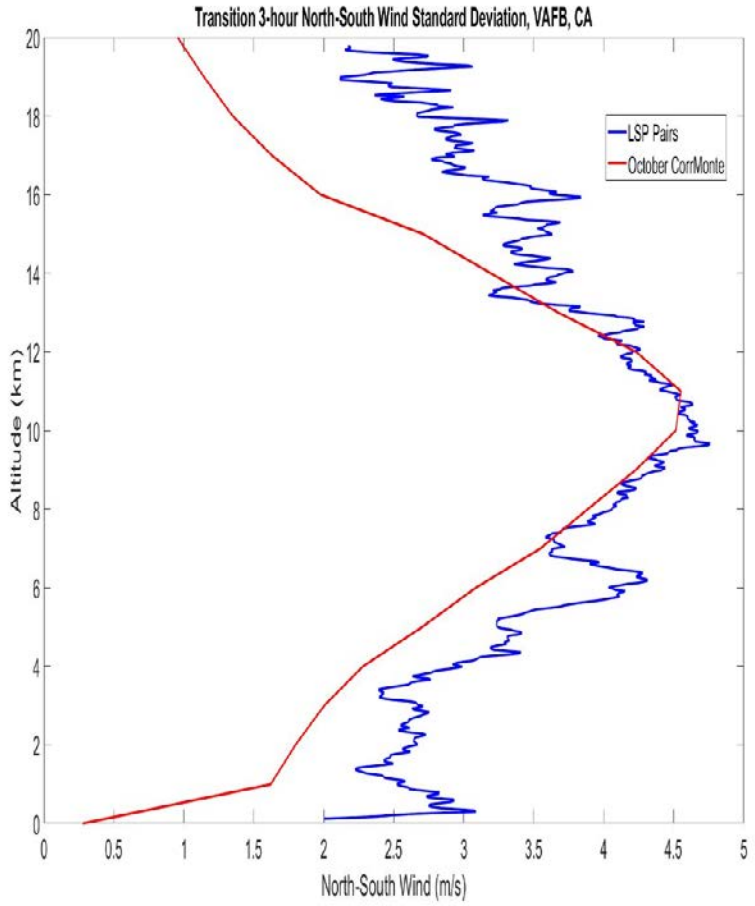
VAFB, CA 3-hour Comparisons - Winter



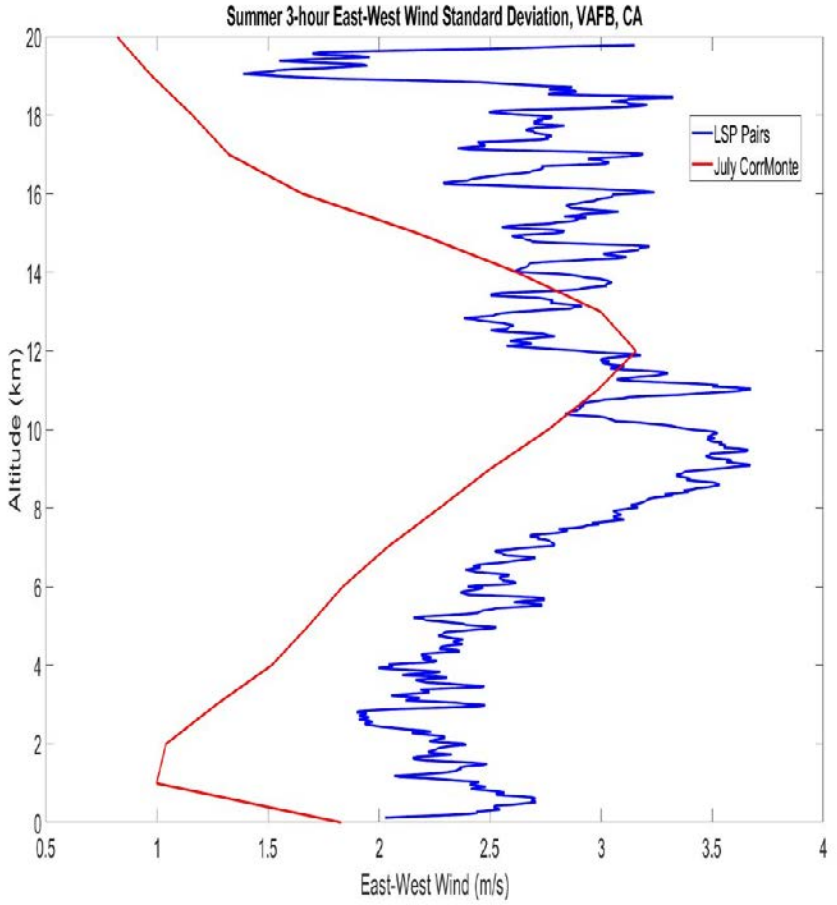


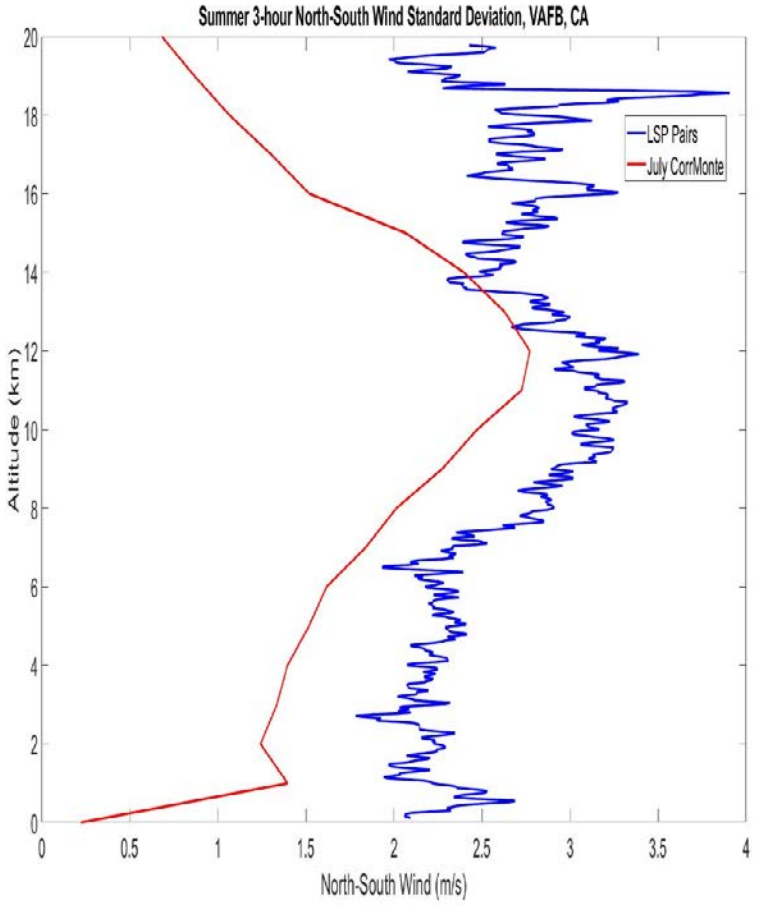
VAFB, CA 3-hour Comparisons - Transition





VAFB, CA 3-hour Comparisons - Summer





Earth-GRAM 2016 Version 2.0

- Beta Release: Spring 2019
- Full Release: Summer/Fall 2019
- Planned Updates Include:
  - CorrMonte – produces hourly dispersions
  - CorrTraj – produces correlated Ballistic (Up-Down) Atmospheric Profile
  - Include vertical fairing between RRA2013 and Earth-GRAM
  - Improve ability to incorporate into multi-body simulation
  - Incorporate Bug Fixes

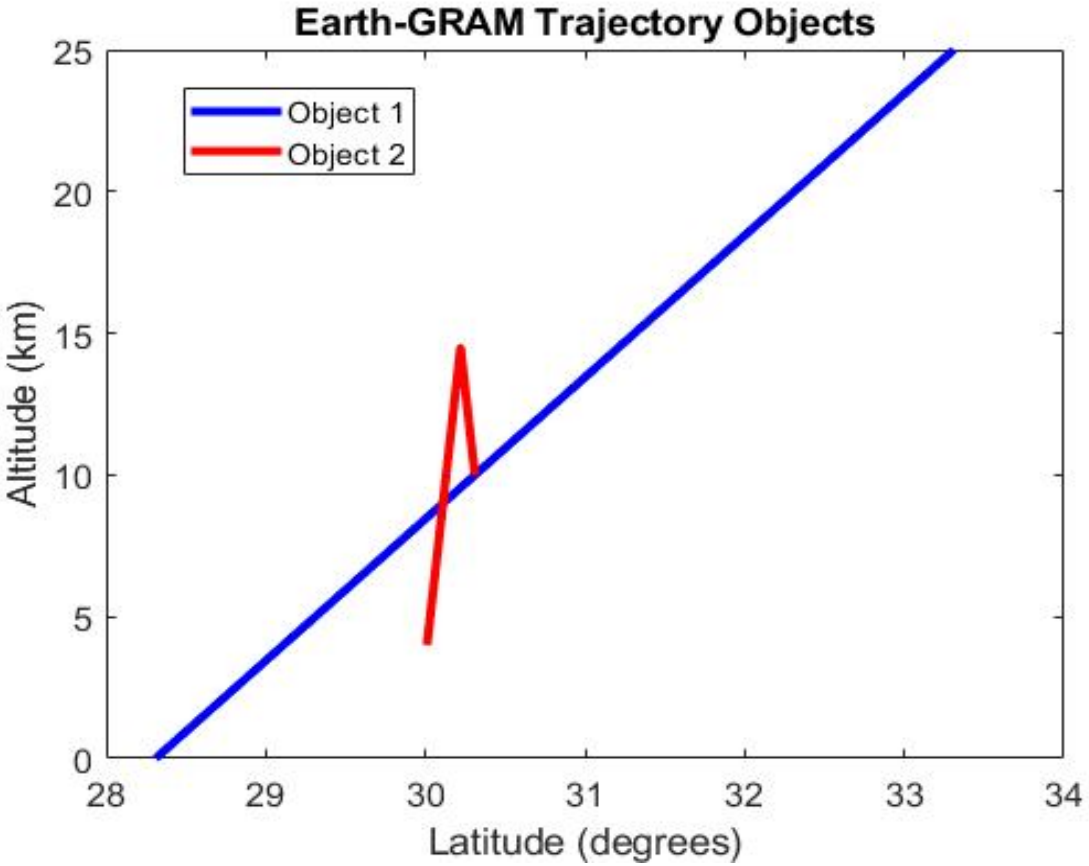
Multi-body Simulation

- Utilize C++ object-oriented programming for multi-body simulations
  - Instantiate multiple atmosphere objects for multiple bodies
- Correlate dispersed atmosphere objects

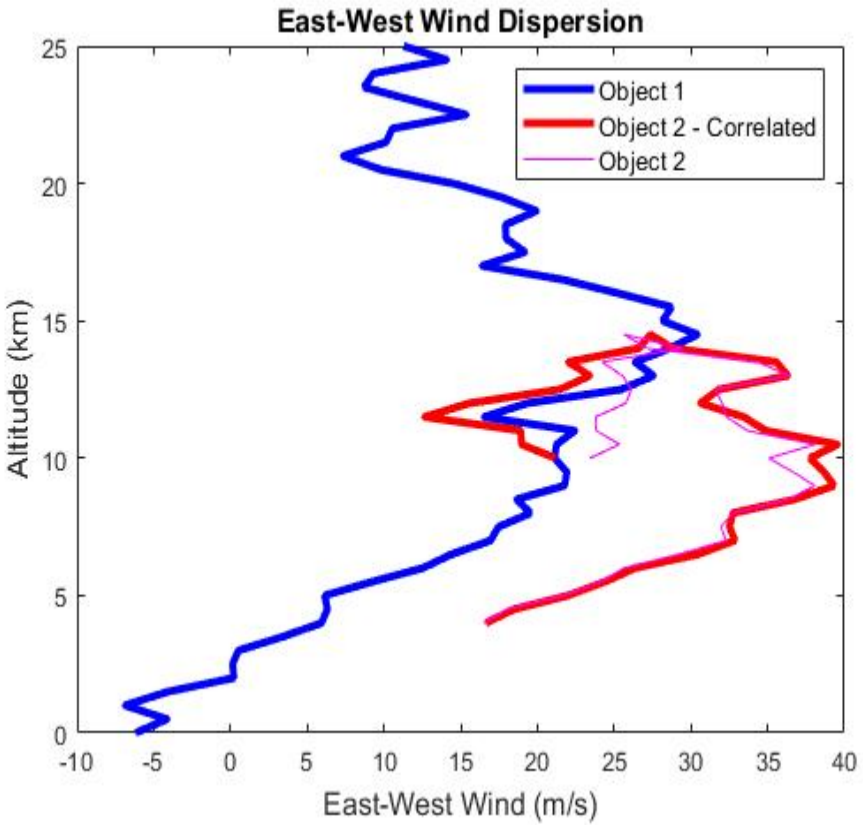
$$r(\delta x) = \exp(-\delta h / L_h)\exp(-\delta z / L_z)\exp(\delta t / \tau)$$

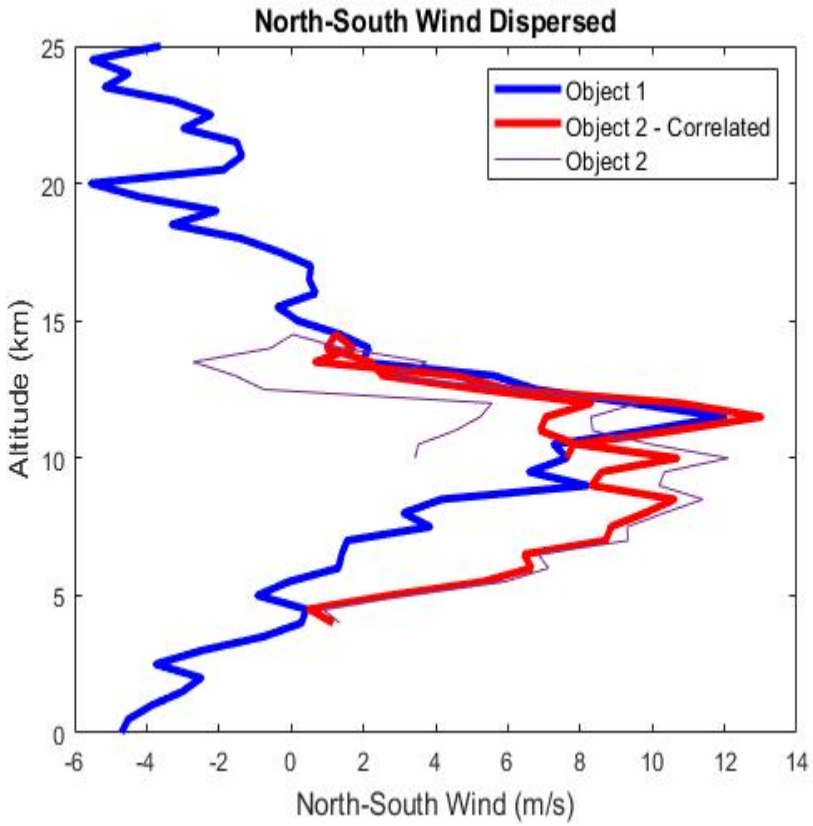
- Earth-GRAM example for multi-body simulations

Multi-body Simulation



Multi-body Simulation





RRA Update

- Important site-specific supplement to GRAM climatology.
- Formal task from the Range Commanders Council Meteorology Group.
- Last update in 2013-2014.
- Temperature, virtual temperature, dewpoint temperature, density, pressure, water vapor pressure, meridional and zonal wind components, wind speed.
- Mean and median values, standard deviations, skewness, U-V correlation.
- Surface to 30 km MSL, 500 m resolution.
- Monthly, annual values.
- Current update will include 11 sites:
  - Barking Sands, HI
  - Cape Canaveral AFS, FL
  - China Lake NAWS, CA
  - Dugway Proving Grounds, UT
  - Edwards AFB, CA
  - Kwajalein, Marshall Islands
  - Point Mugu NAWC, CA
  - Vandenberg AFB, CA
  - Wallops Flight Facility, VA
  - White Sands Missile Range, NM
  - Yuma Proving Grounds, AZ

Summary

- Earth-GRAM shows good comparisons with the MERRA-2 reanalysis database
- 3-hour CorrMonte shows favorable comparisons to 3-hr pairs databases
- Earth-GRAM 2016 Version 2.0 release scheduled for Summer/Fall 2019
- Intend to maximize C++ object-oriented capabilities for multi-body simulations