Earth Global Reference Atmospheric Model (Earth-GRAM) Overview and Future Improvements COSPAR 2018

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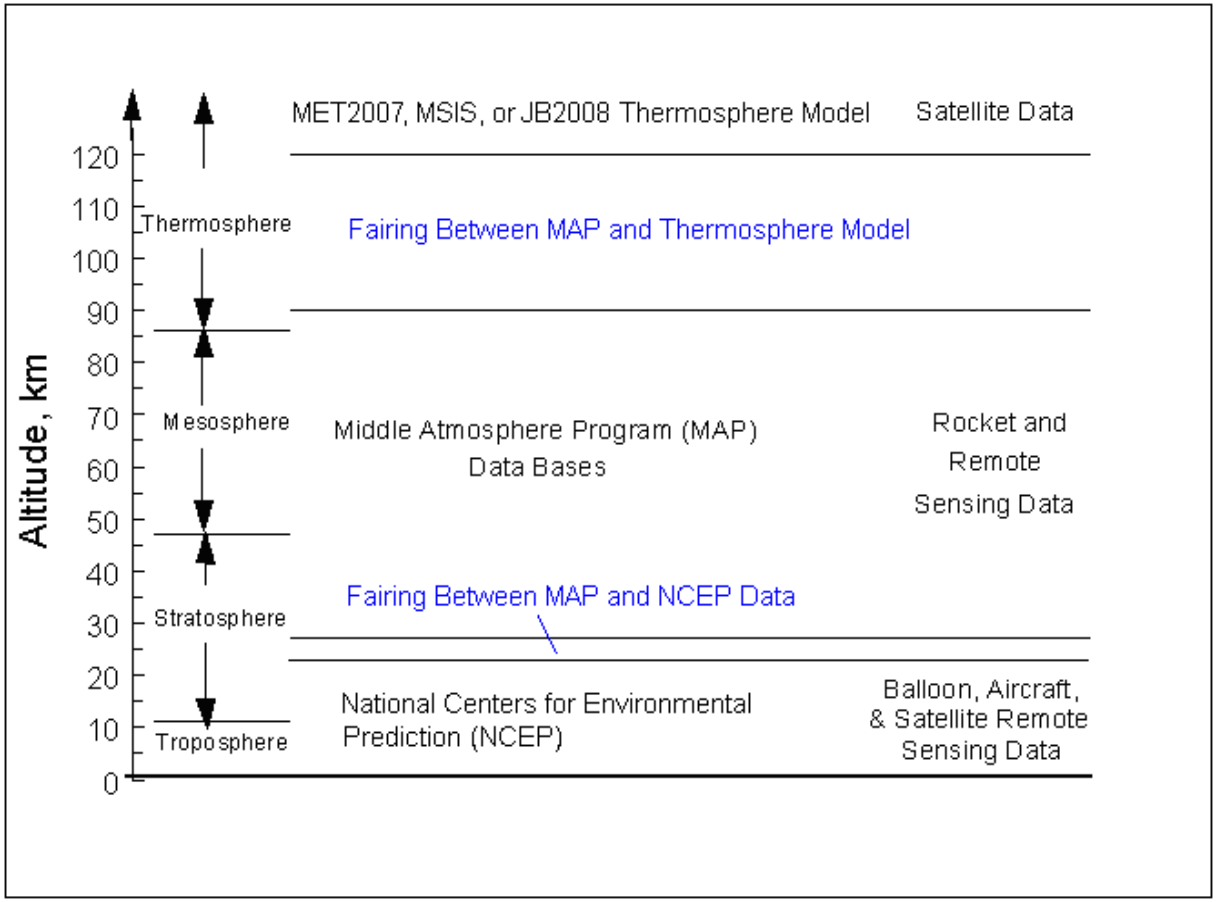
Outline

- Earth-GRAM Overview
- Earth-GRAM Current Status
- Earth-GRAM vs Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) Comparisons
- Near-term Earth-GRAM Update Plans

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

Earth-GRAM Perturbation Model

Values From Earth-GRAM =

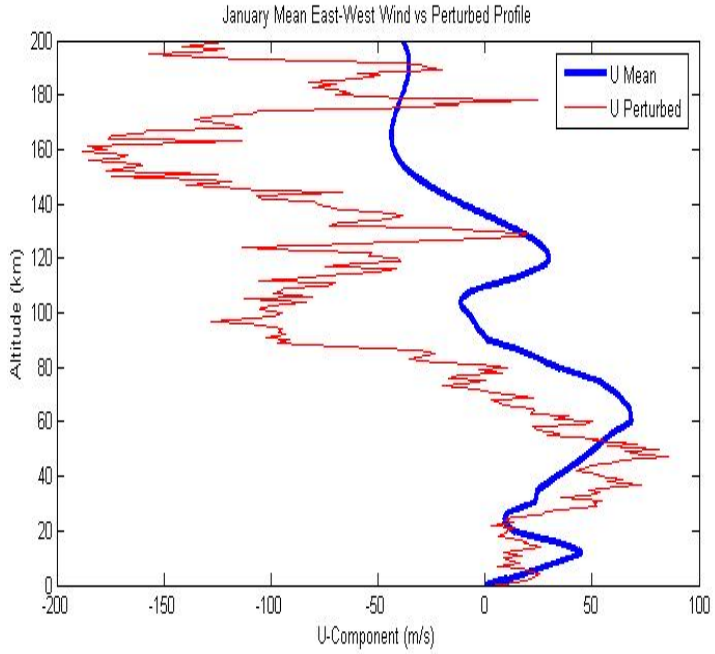
Mean value + Large-scale perturbation + Small-scale perturbation

Modeled as a wave

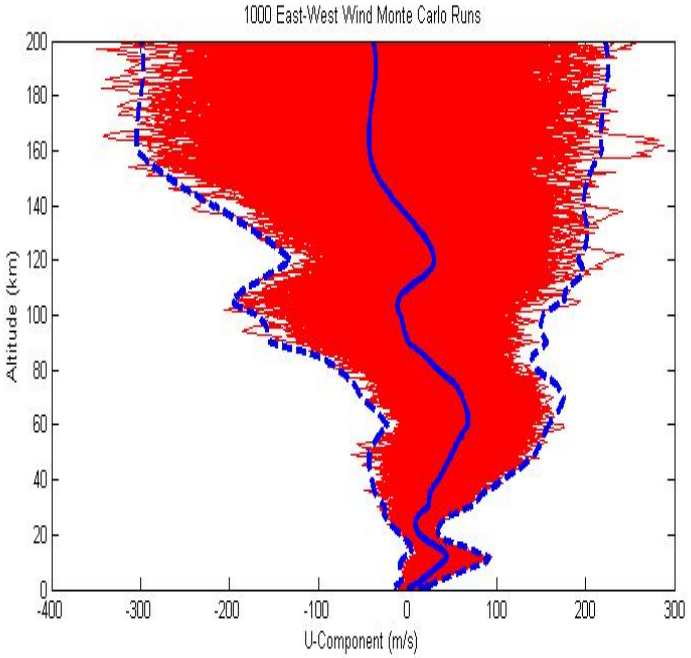
Modeled as a stochastic (random) process

Driven by observed standard deviation

Sample Earth-GRAM Output

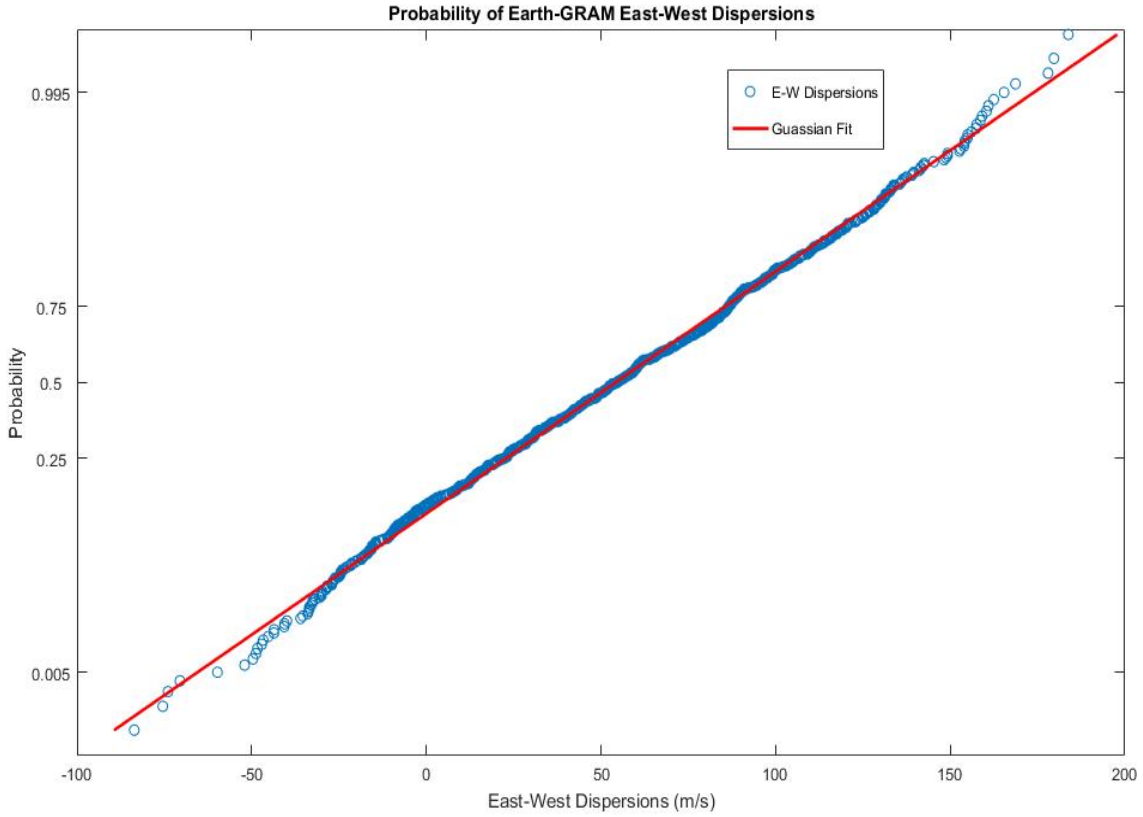


Mean and Dispersed East-West Wind



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

Sample Earth-GRAM Output



Earth-GRAM dispersions are approximately Gaussian distributed

Earth-GRAM Current Status

- Earth-GRAM 2016 Version 1.0 released December 2016
- C++, object-oriented software package
- New Period of Record for NCEP data – 1997-2015
- Includes ability to enter number of Monte Carlo runs from input
  - –No longer need a number seed file
- GRAM team supporting users in the implementation of Earth-GRAM 2016
- Earth-GRAM is available from the NASA Software Catalog:

  https://software.nasa.gov/software/MFS-32780-2

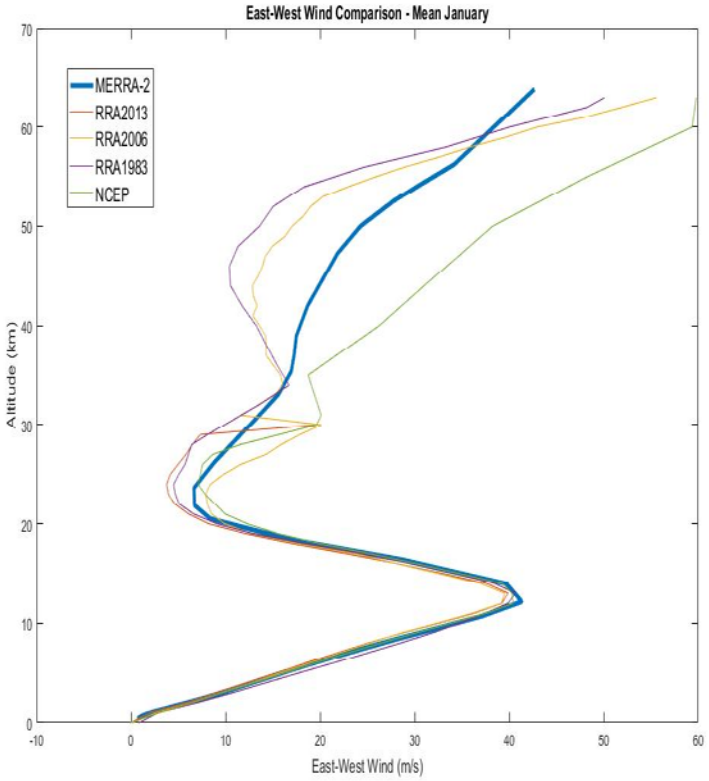
MERRA-2 Background

- 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°)
- 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

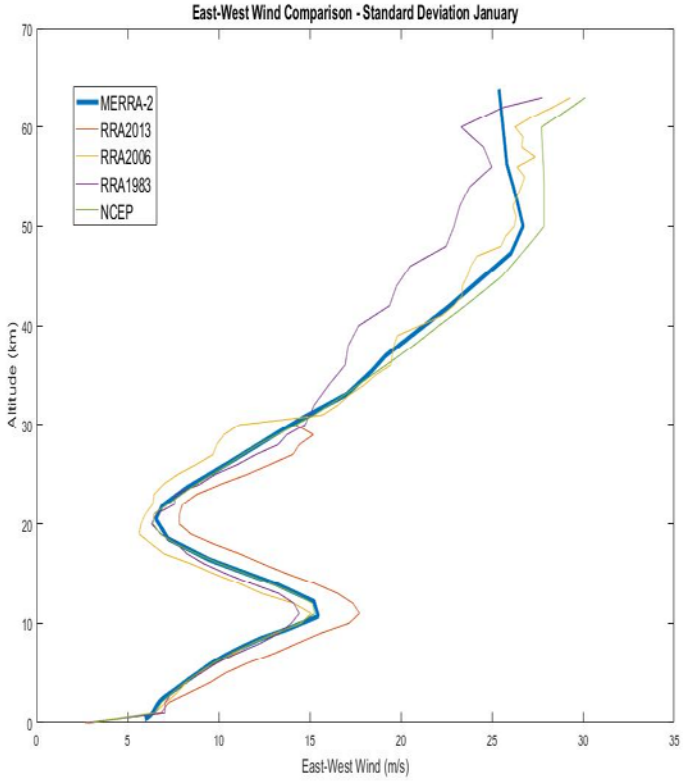
MERRA-2 Comparison to Earth-GRAM

- 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 RRA2006 and RRA1983 has a maximum altitude of 70 km

Cape Canaveral, FL Comparison – East-West Wind

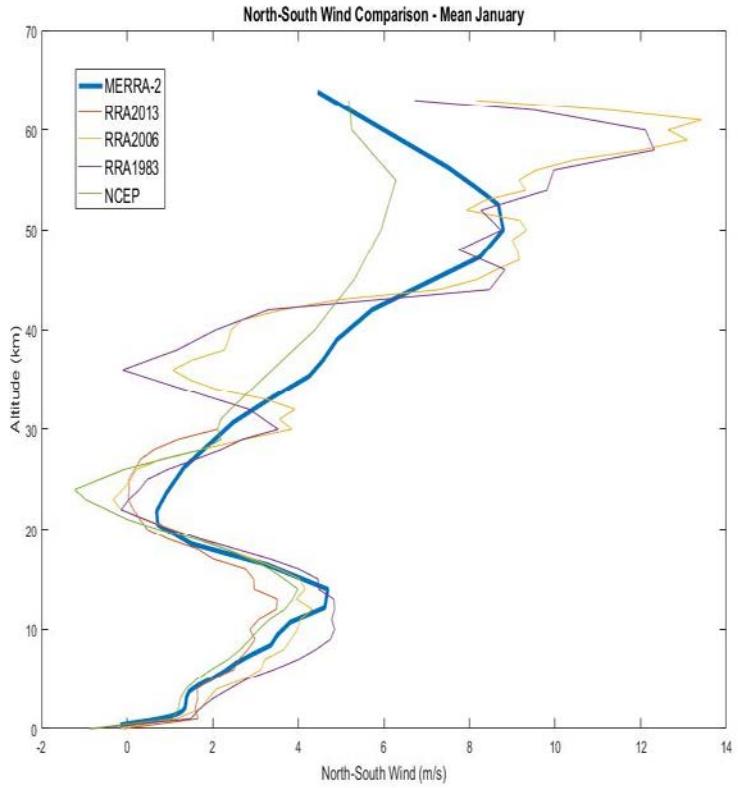


Mean East-West Wind

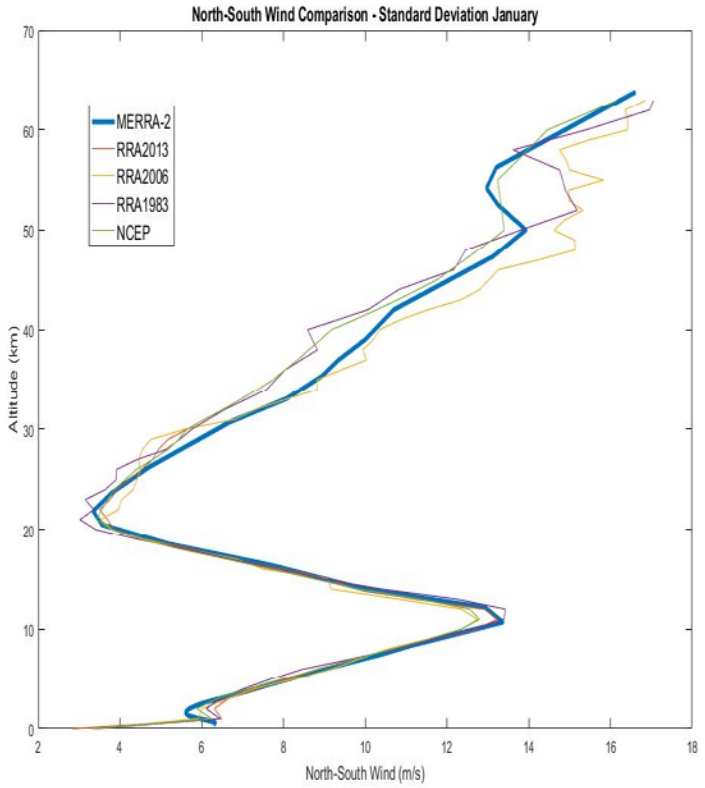


Standard Deviation East-West Wind

Cape Canaveral, FL Comparison – North-South Wind

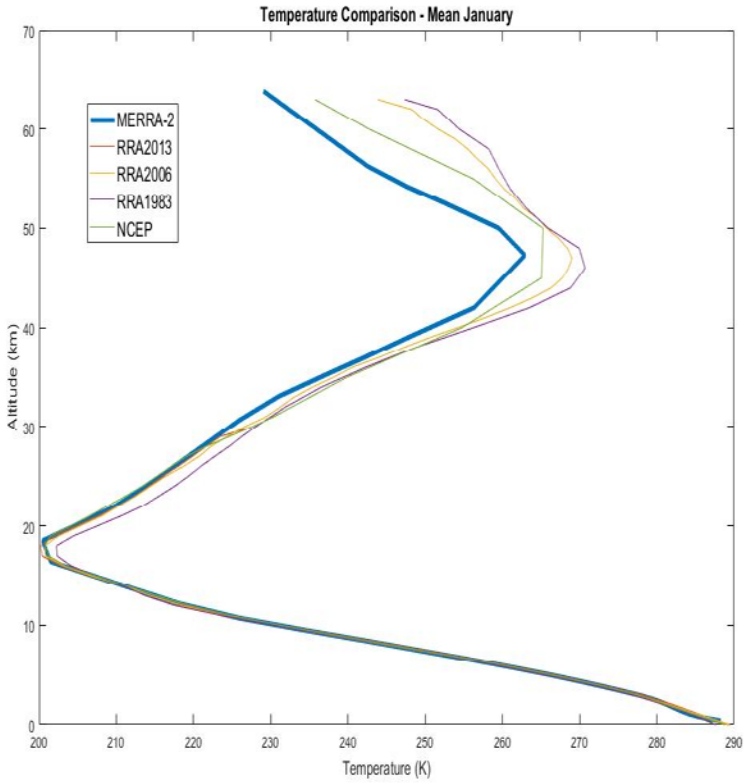


Mean North-South Wind

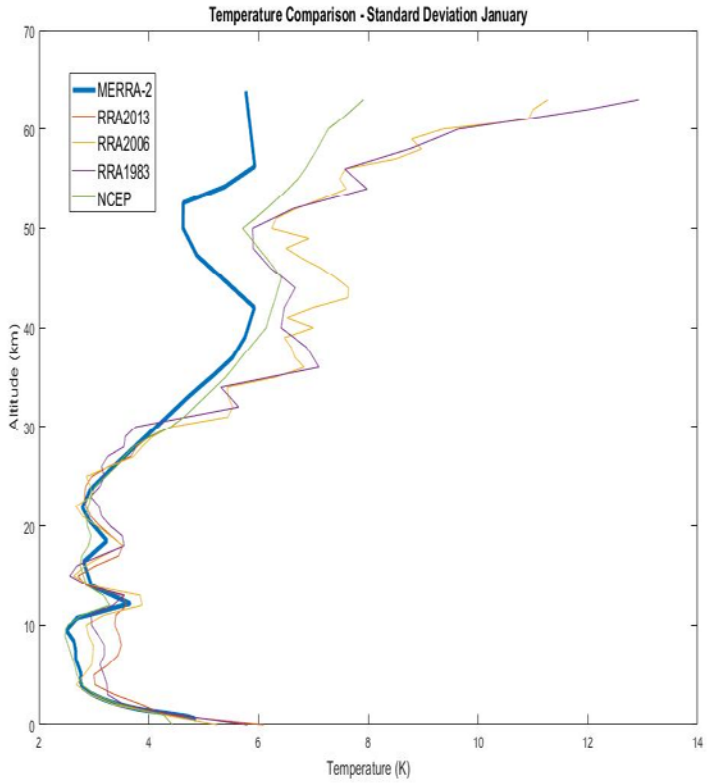


Standard Deviation North-South Wind

Cape Canaveral, FL Comparison – Temperature

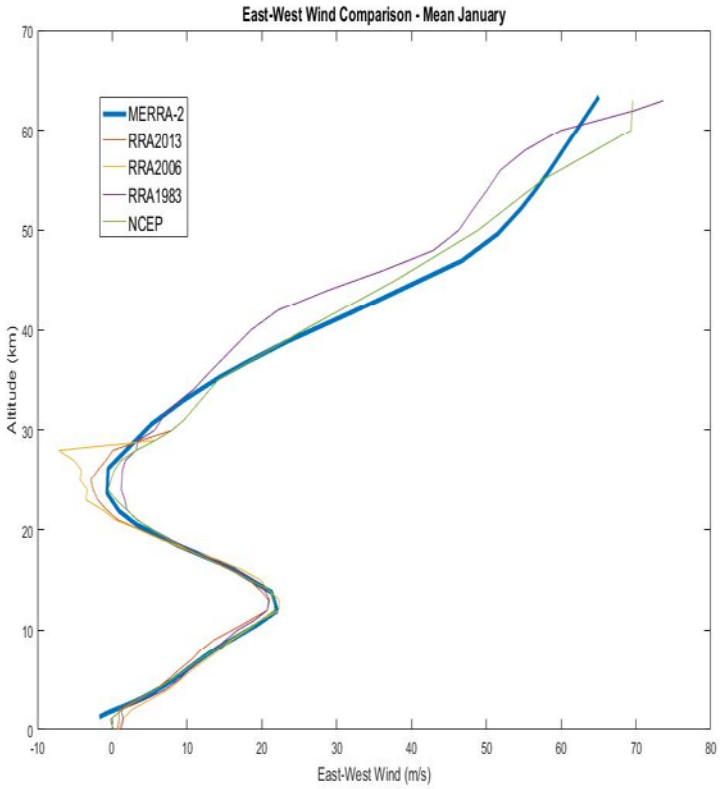


Mean Temperature

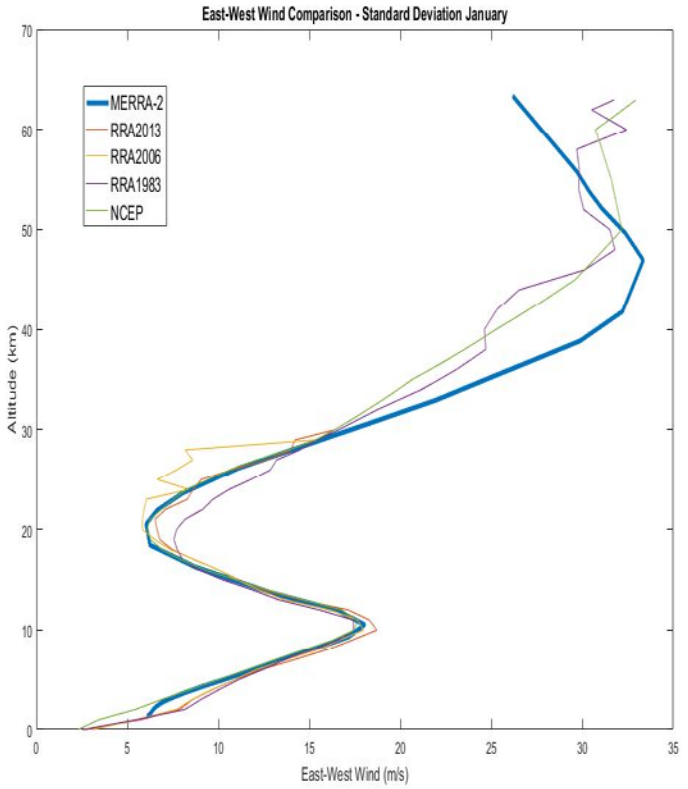


Standard Deviation Temperature

Edwards, CA Comparison – East-West Wind

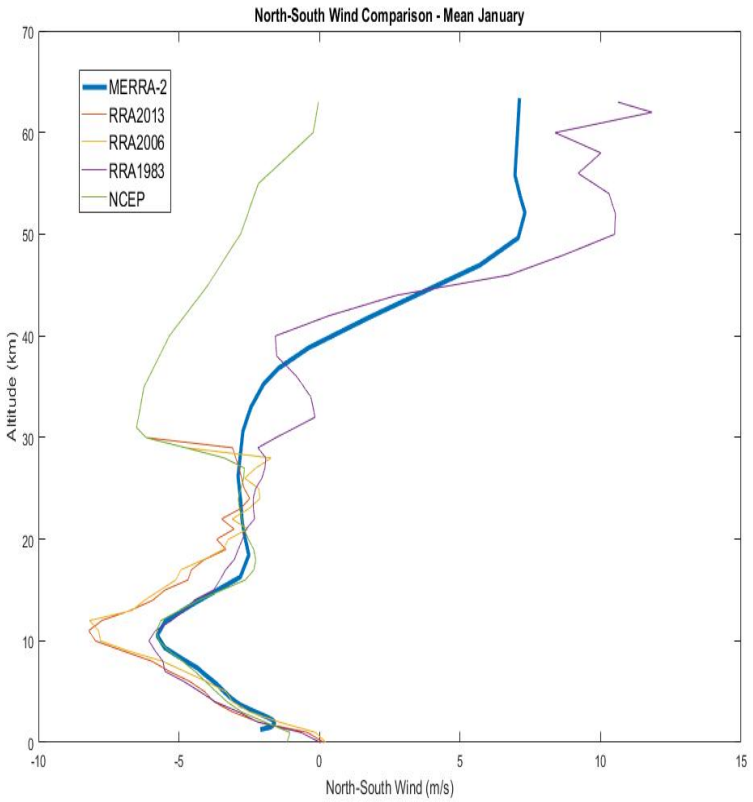


Mean East-West Wind

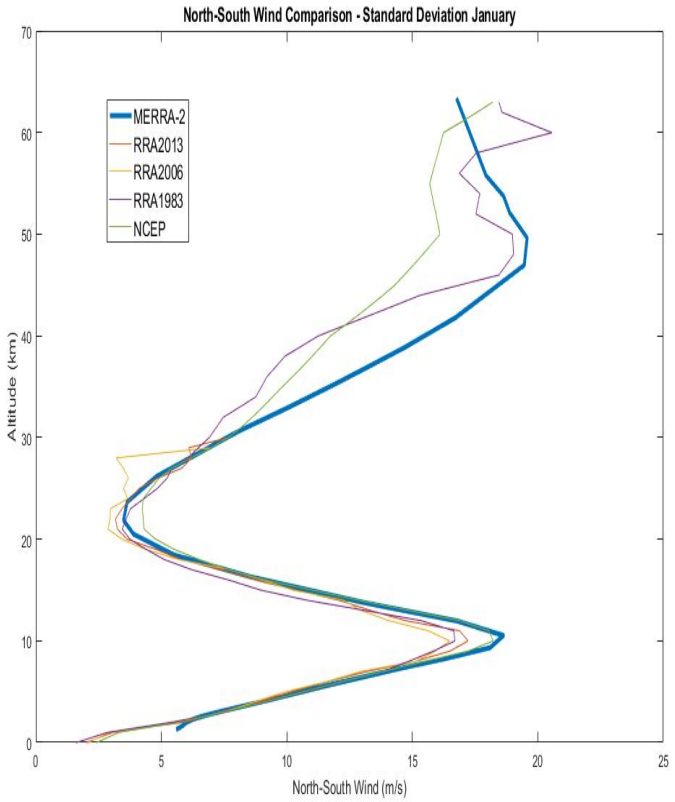


Standard Deviation East-West Wind

Edwards, CA Comparison – North-South Wind

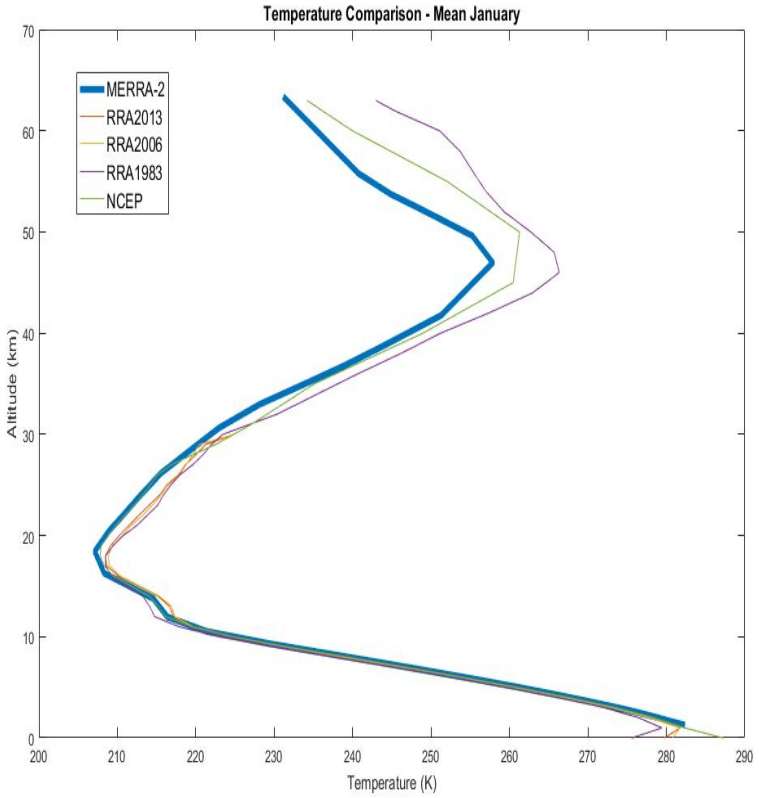


Mean North-South Wind

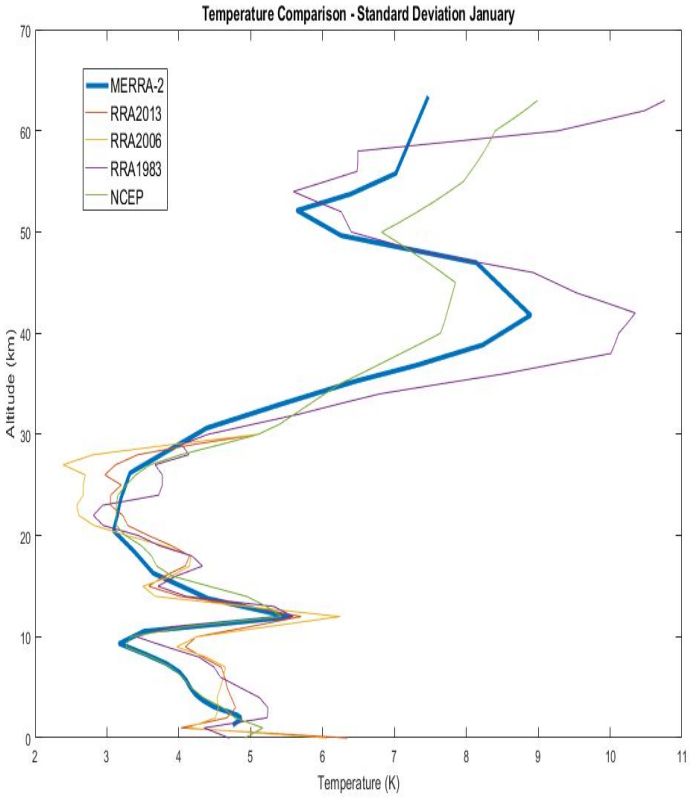


Standard Deviation North-South Wind

Edwards, CA Comparison – Temperature



Mean Temperature



Standard Deviation Temperature

MERRA-2 Comparison Study Summary and Future Work

- MERRA-2 compares well with Earth-GRAM data especially in troposphere
- Expect MERRA-2 to perform better than the Middle Atmosphere Program (MAP) in the Mesosphere
- Plan to complete additional research into the development of MERRA-2
- Plan to complete a wind persistence study with 3-hr MERRA-2, Earth-GRAM CorrMonte hourly dispersions, and measured wind pairs

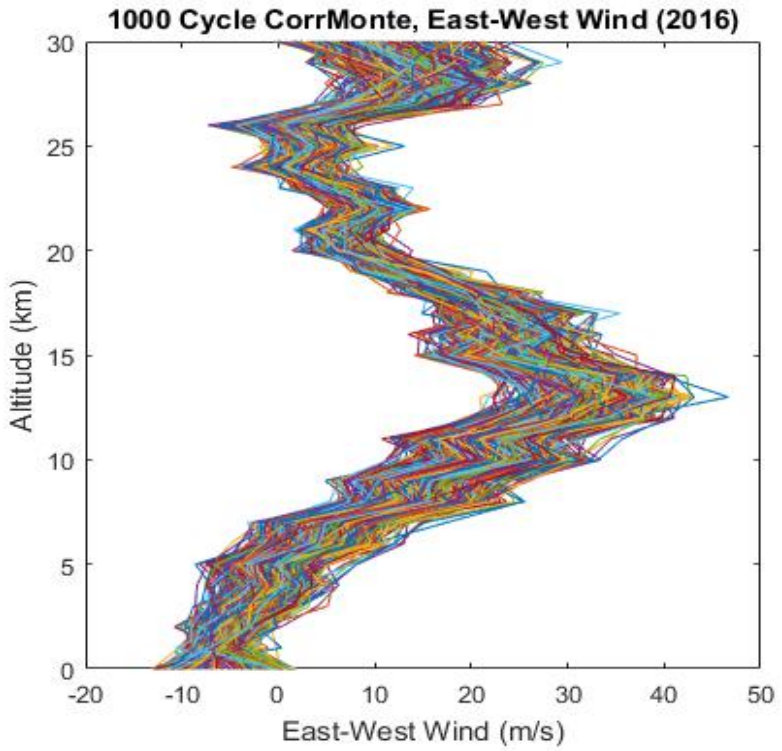
Near-Term Earth-GRAM Update Plans

- Upcoming release: Earth-GRAM 2016 Version 2.0
- Planned Release in late 2018
- Planned Updates Include:
  - CorrMonte – produces hourly dispersions
  - CorrTraj – produces correlated Ballistic (Up-Down) Atmospheric Profile
  - Include fairing between RRA and Earth-GRAM
  - Include a Graphical User Interface (GUI)
  - Incorporate Bug Fixes

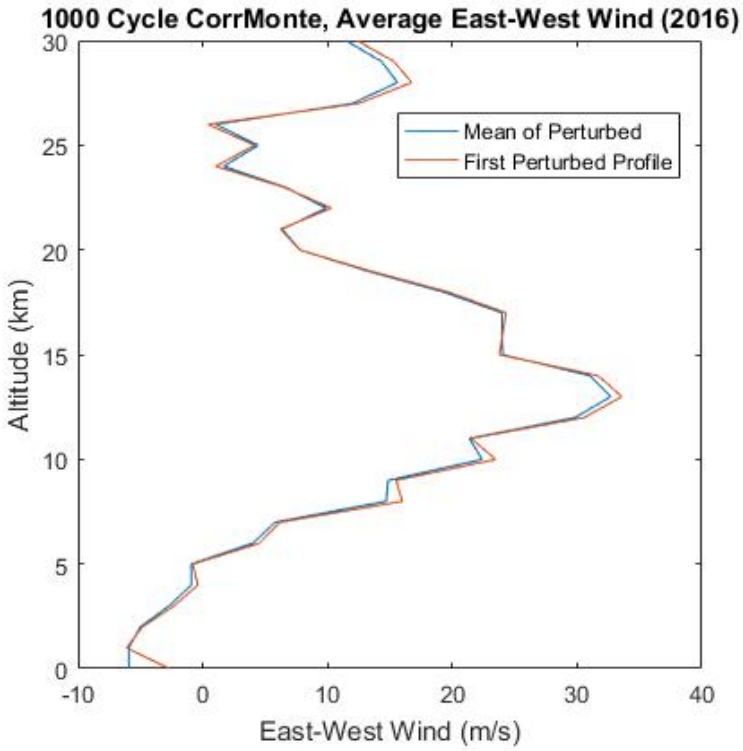
Near-Term Earth-GRAM Update Plans – CorrMonte

- Function within Earth-GRAM that evaluates multiple profiles separated by a fixed time increment
  - –Earth-GRAM provides a monthly dispersion with Monte Carlo runs
  - –CorrMonte provides an hourly dispersion with Monte Carlo runs
  - –CorrMonte produces several profiles that are cross-correlated
- CorrMonte is useful for providing less conservatism in certain spacecraft design and operational situations

Near-Term Earth-GRAM Update Plans – CorrMonte Output

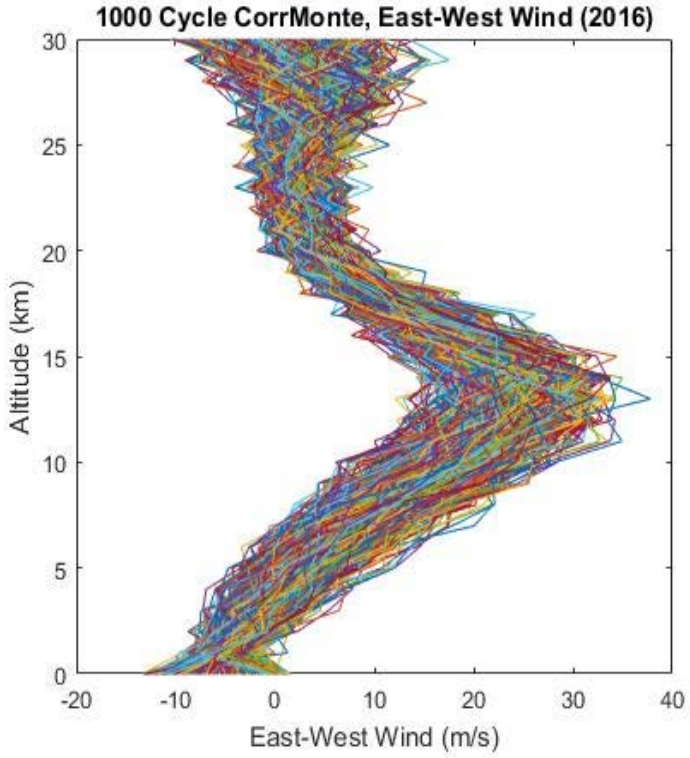


1000 3 hour dispersions

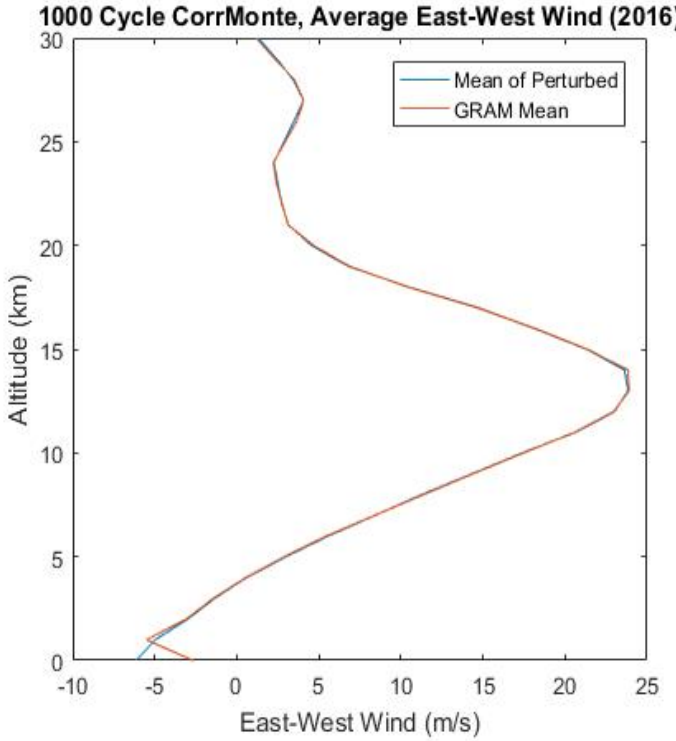


Mean of dispersions vs 1st dispersed profile

Near-Term Earth-GRAM Update Plans – CorrMonte Output



1000 3 hour dispersions



Mean of dispersions vs GRAM Mean

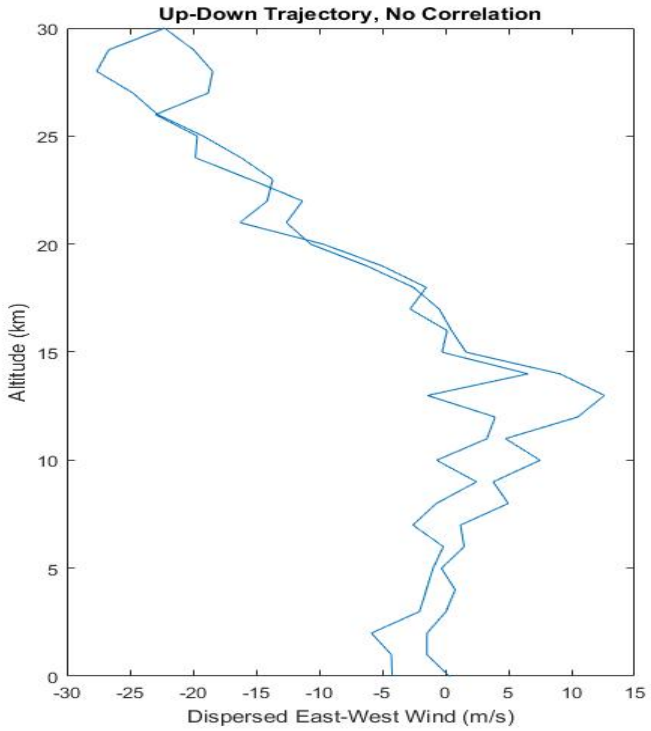
Near-Term Earth-GRAM Update Plans – CorrTraj

- Earth-GRAM users requested the ability to correlate an atmospheric profile for a ballistic (up-down) trajectory
- Used exponential correlation from calculation of small-scale perturbation:

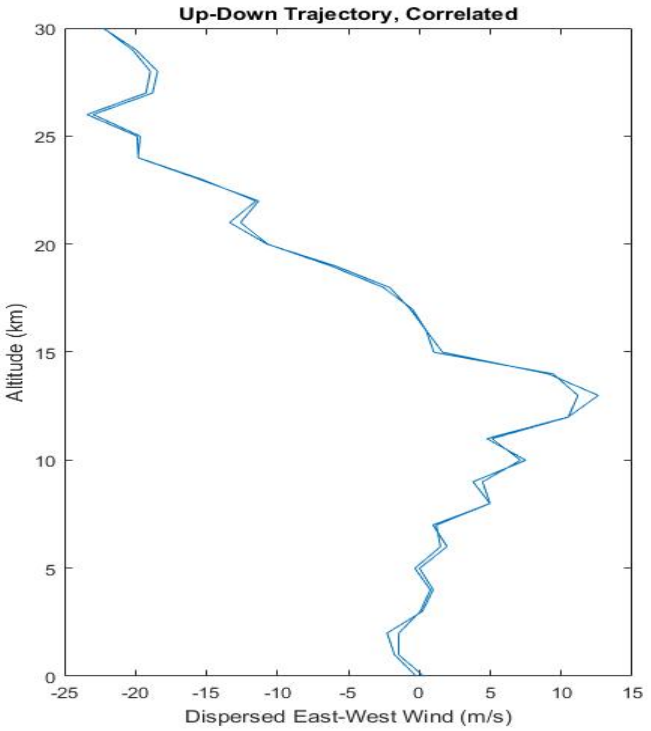
$$r(\delta x) = \exp(-\delta h / L_h) \exp(-\delta z / L_z) \exp(\delta t / \tau)$$

- Test case with dz = 1.0 km, dphi and dthet = 0.01 and apex of trajectory = 30.0 km

Near-Term Earth-GRAM Update Plans – CorrTraj Output



GRAM2010 Dispersed Profile



GRAM2016 Dispersed Profile

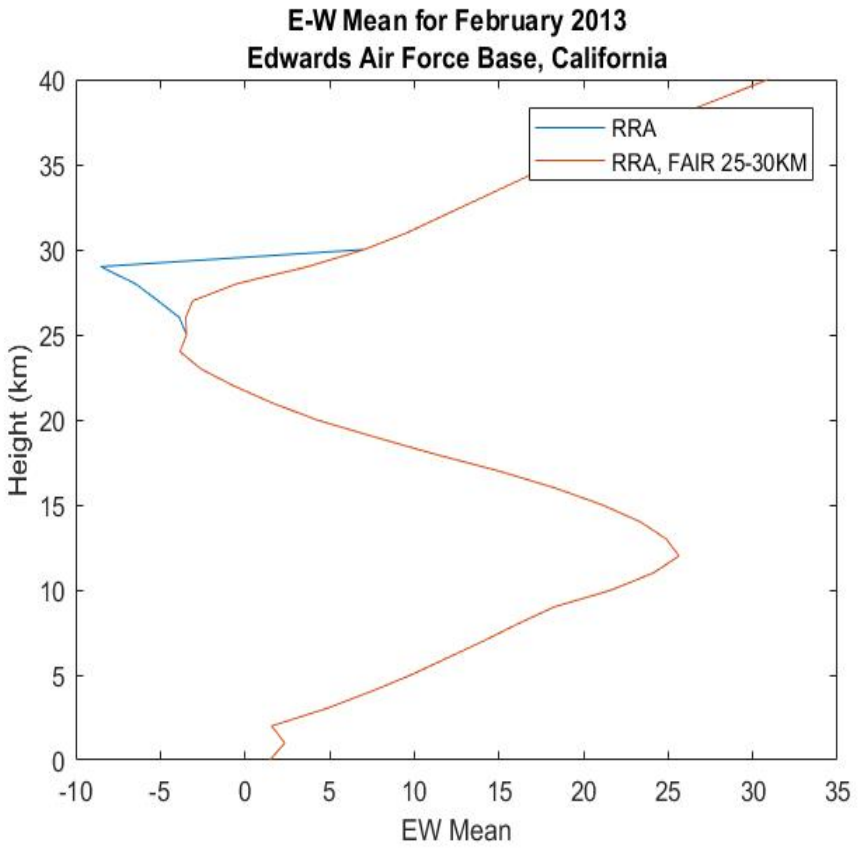
Near-Term Earth-GRAM Update Plans – RRA-GRAM Fairing

- Current methodology in Earth-GRAM does not handle vertical transitions between RRA and Earth-GRAM very well
- Generated 2013 RRA cases to examine effect on Earth-GRAM profiles of temperature, east-west wind and north-south wind
- Faired RRA and Earth-GRAM data over a region of 5 km (25-30 km)
- Examined effect induced feature has on Monte Carlo dispersions

Near-Term Earth-GRAM Update Plans – RRA-GRAM Fairing Example

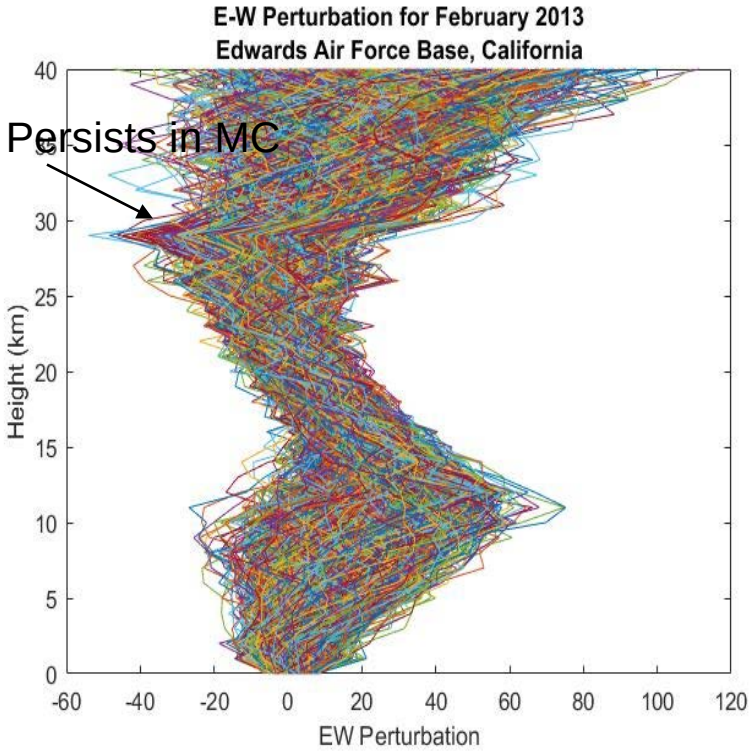
RRA observations at 30 km: 31

Magnitude of E-W Wind Delta: 10 m/s

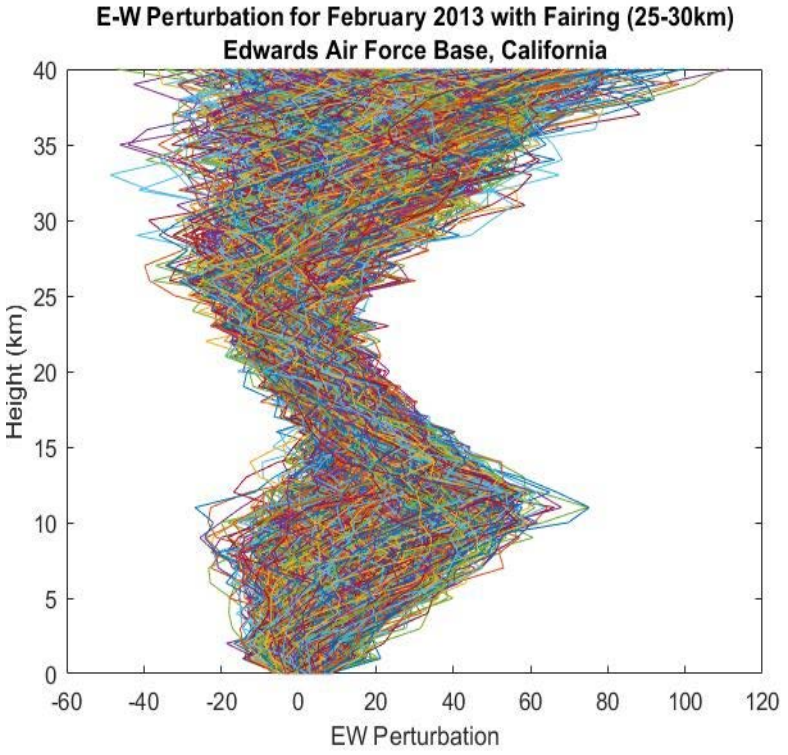


Near-Term Earth-GRAM Update Plans, RRA-GRAM Fairing Example

Feature Persists in MC



Monte Carlo dispersion without fairing



Monte Carlo dispersion with fairing

Earth-GRAM Summary and Future Work

- Planned release of Earth-GRAM 2016 Version 2.0 in late 2018
- Continue comparisons of Earth-GRAM and MERRA-2
- Tentatively plan to use MERRA-2 reanalysis as data input for Earth-GRAM

QUESTIONS?