Mars 2020 Atmospheric Modeling for Flight Mechanics Simulations

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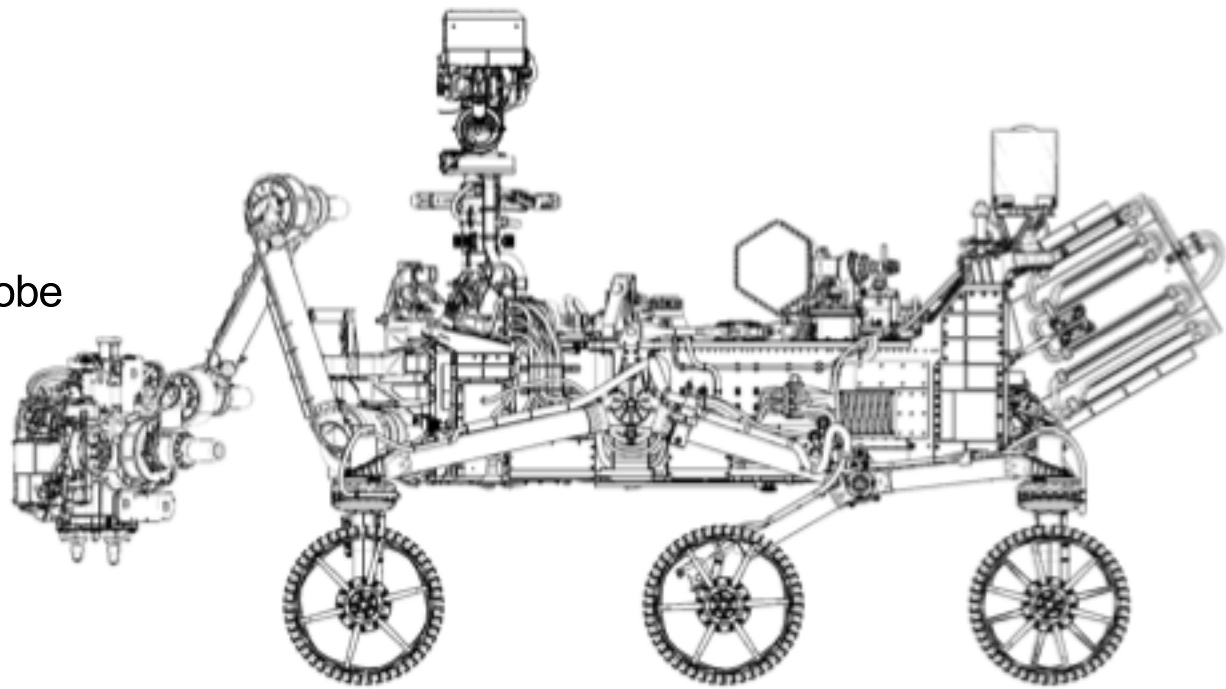
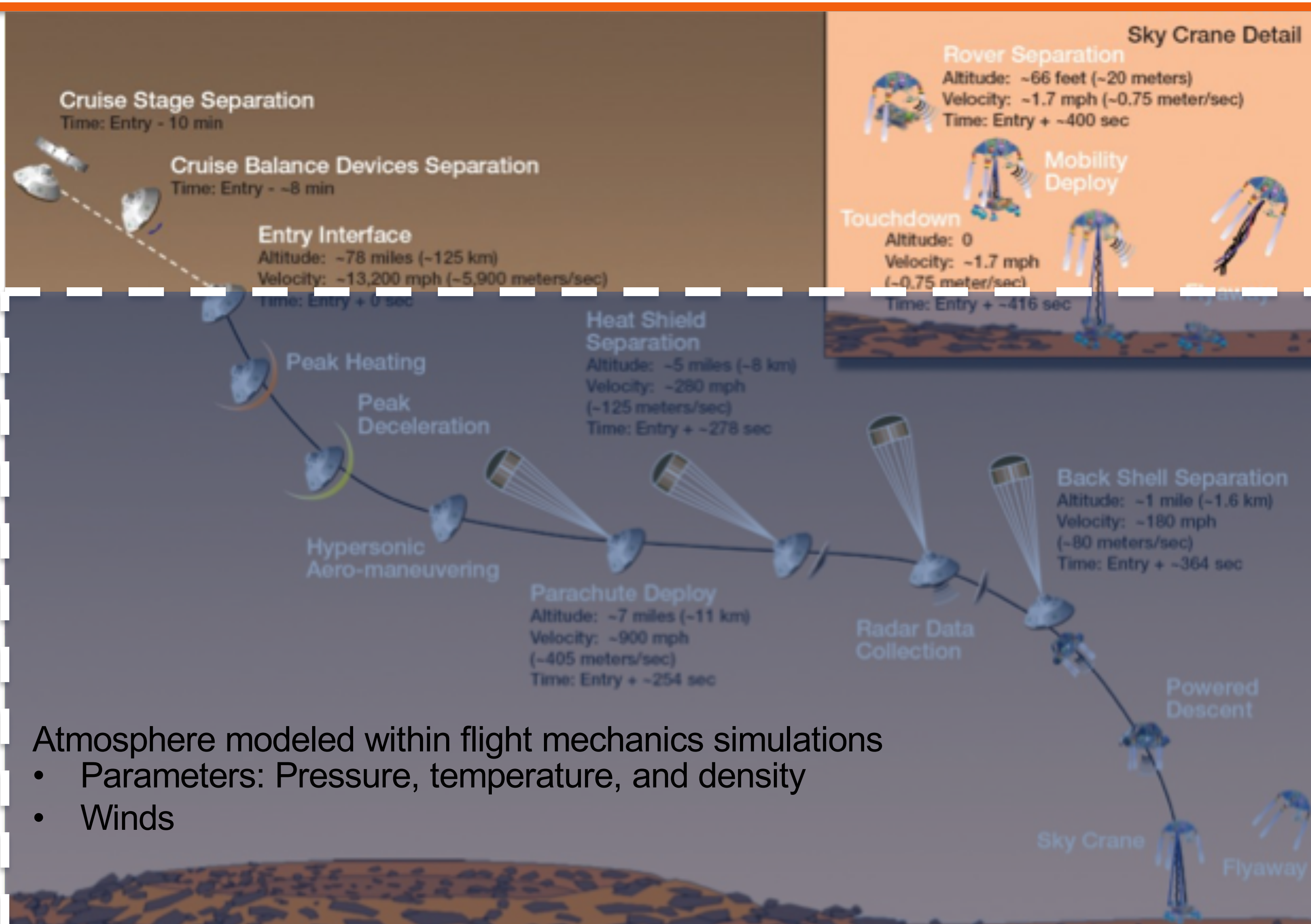


International Planetary Probe Workshop 2018

Boulder, CO

June 14, 2018

Mars 2020 concept of operations

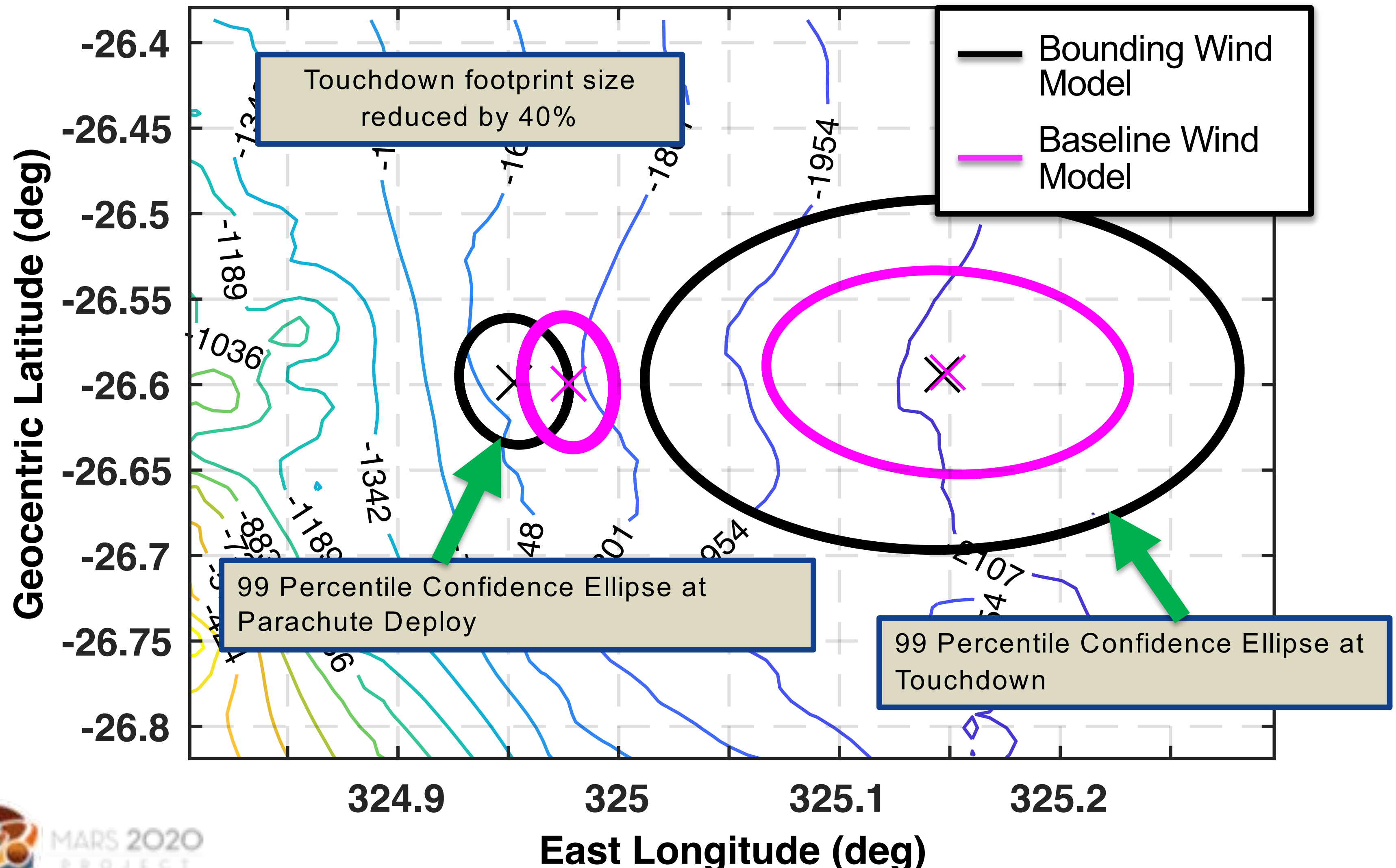


Atmosphere modeled within flight mechanics simulations

- Parameters: Pressure, temperature, and density
- Winds

Example of Atmospheric Effect

- Winds have large effect on trajectory dispersions during the long time on parachute



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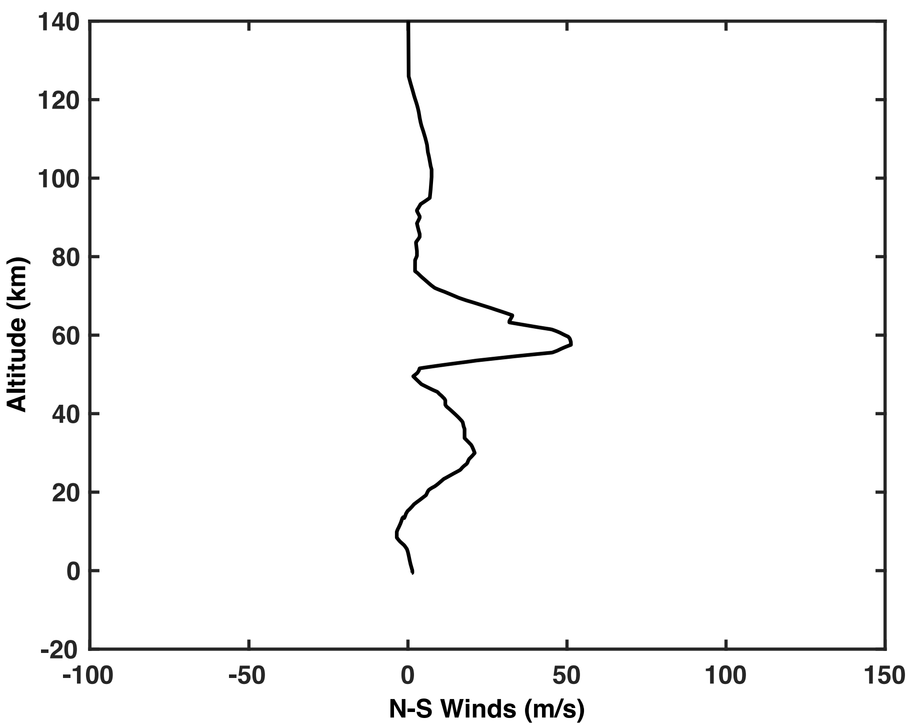
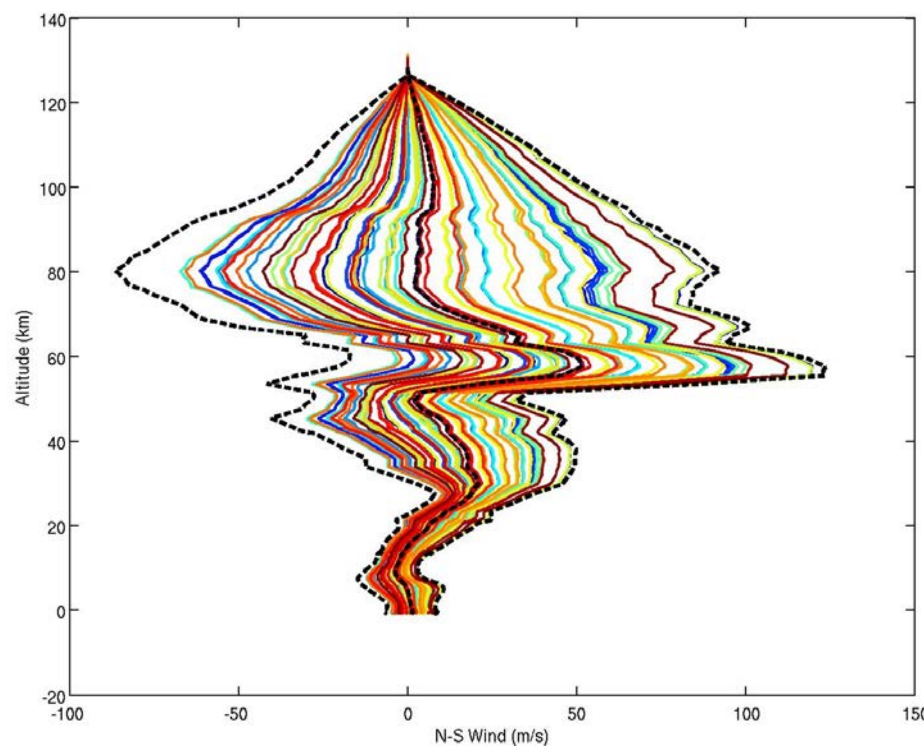
Atmospheric Need for EDL Simulations

- Nominal atmosphere as a function of independent variable
  - Usually function of space – altitude, latitude, and longitude
- Way to create dispersed atmospheric properties for Monte Carlo runs
  - Have to capture spatial and temporal dispersions





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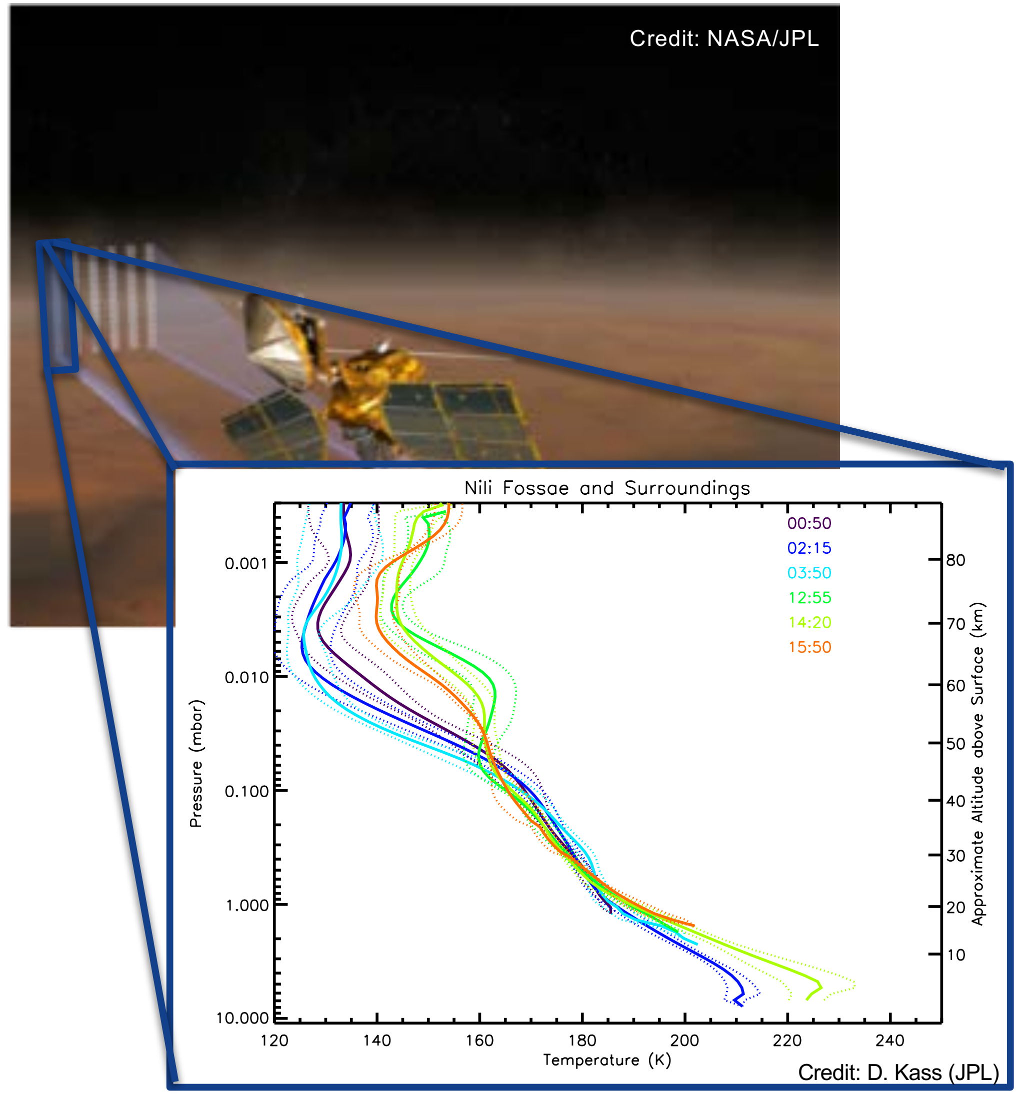
Historical Approaches

1. Engineering Models
   - GRAM = Global Reference Atmospheric Models are a good example
   - Useful during early design phases when a flight atmospheric team may not exist
2. Climate Sounder Data-based Profiles
   - Combine Mars orbiter sounder data with global circulation models
   - Range of profiles created that are queried by flight mechanics simulations in Monte Carlo fashion



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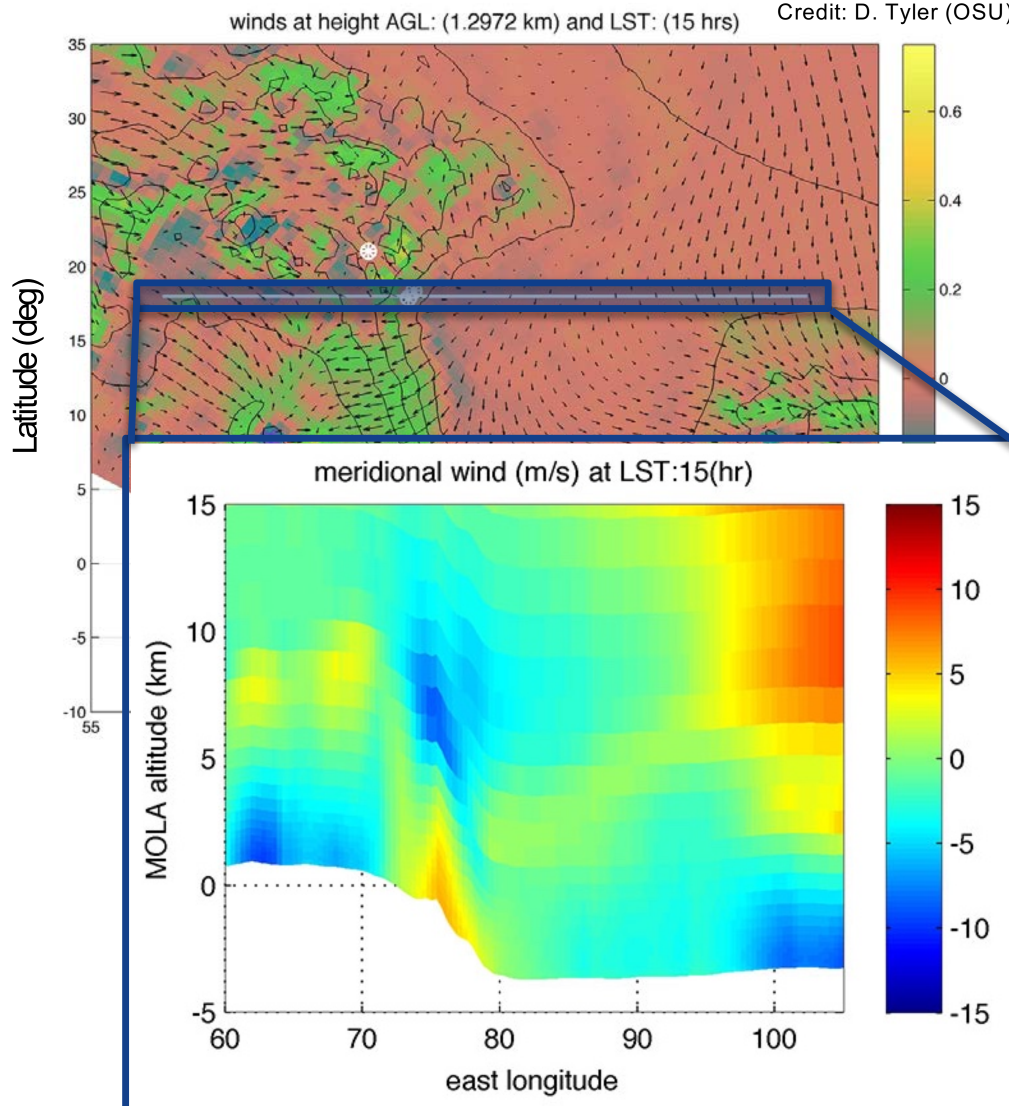
3. Mesoscale Atmospheric Models (Mars 2020 Approach)
   - Initialized from global circulation models
   - Model the atmospheric evolution using partial differential equations that govern atmospheric dynamics
   - Can capture effect of surface interactions and provides good resolution near target sites by using nested grids

Credit: D. Tyler (OSU)



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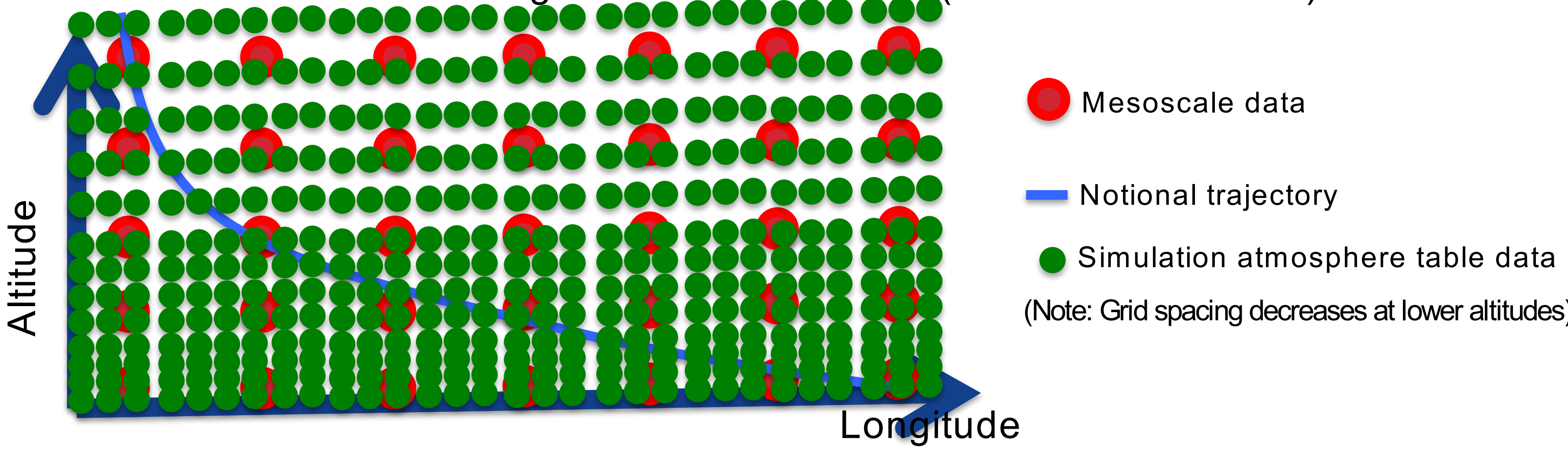
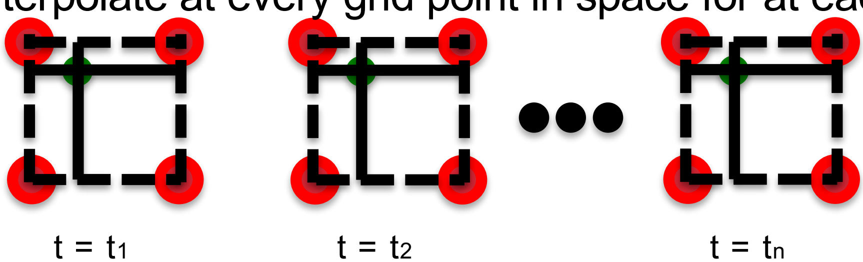
Atmospheric Integration into EDL Simulations

1. Look at Mesoscale data along a constant latitude line (or a constant azimuth)



2. Interpolate at every grid point in space for at each time of interest t_i where $i = 1 \ldots n$



Note: Interpolation is done at every height above areoid point where table data is desired.

3. Generate mean and standard deviation at each grid point by looking at the interpolated data at all time points t_i where $i = 1 \ldots n$. Note, for statistics, the sample size is just n (number of time points being used for analysis).

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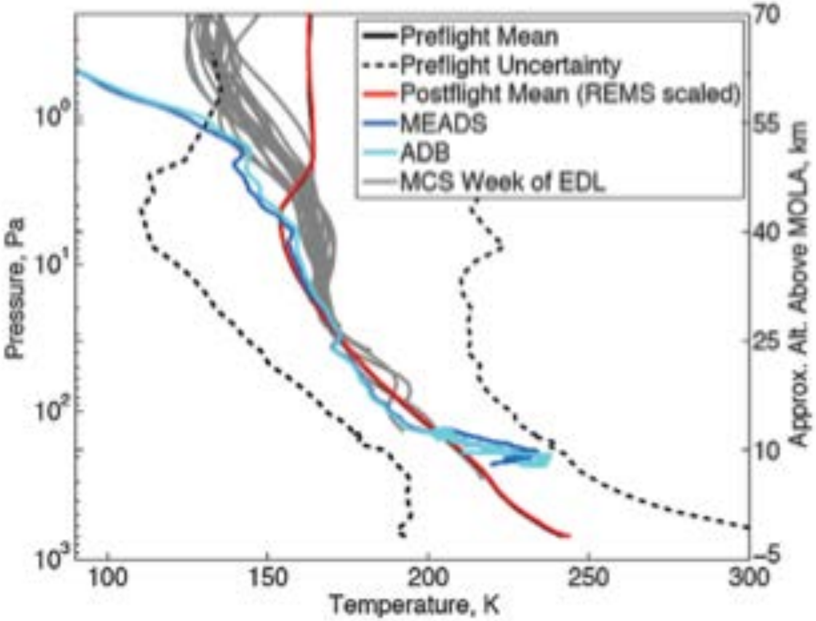
Notes on the Current Incorporation Method

- Has been accepted by the Mars 2020 atmospheric team
- Successfully used for Mars Science Laboratory.
- Provides means to stress flight mechanics simulation
  - Captures model output from Mesoscale models
  - Allows atmospheric property dispersions
- Does not preserve hydrostatic equilibrium
  - Hydrostatic equilibrium – pressure gradient balanced by gravity; physics in Mesoscale models
  - Broken by current incorporation method due to statistics being taken across the time axis
- Does not capture spatial and temporal correlations in atmospheric properties during Monte Carlo analysis

Credit: A. Chen (JSR 2014)



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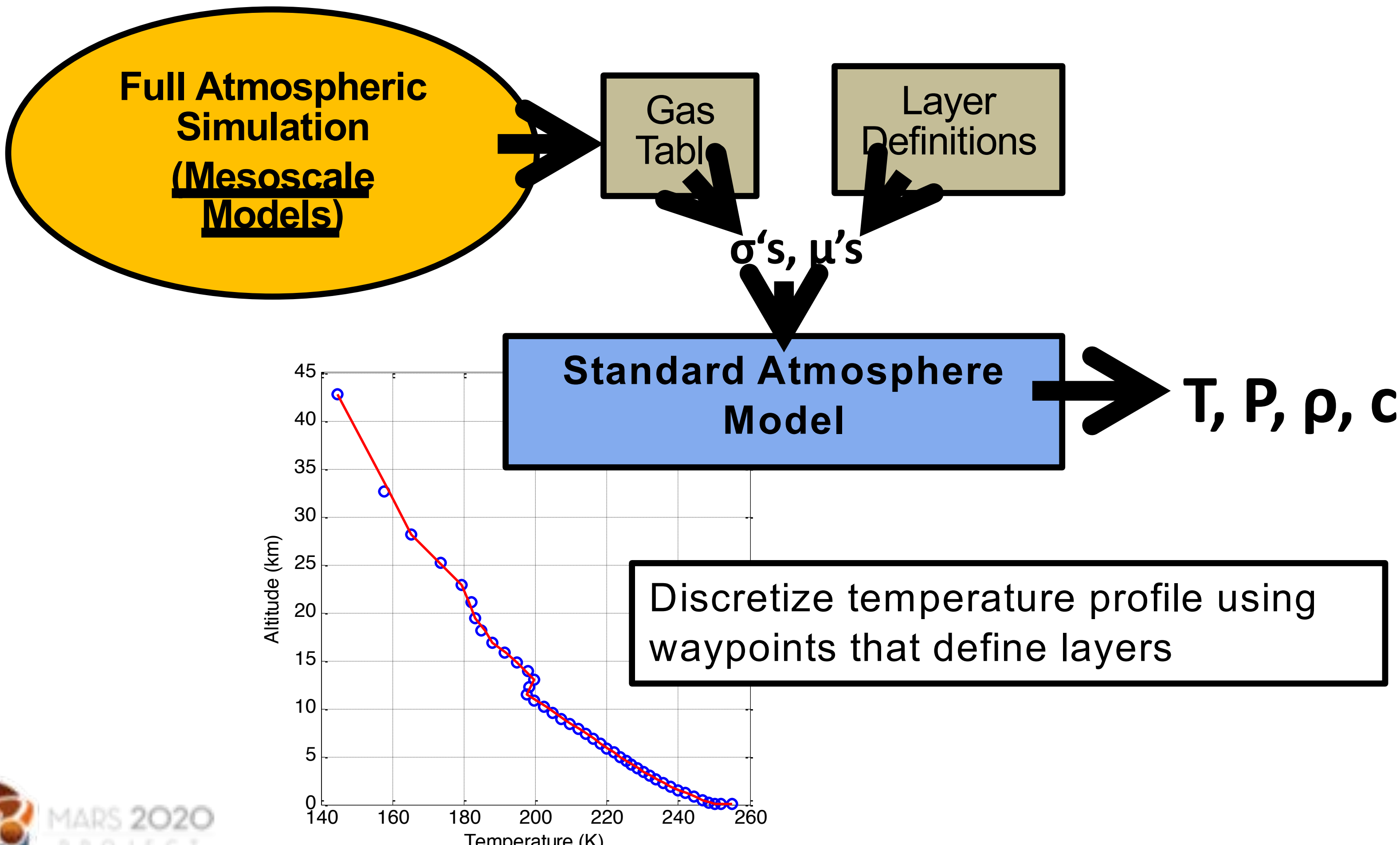
Alternate Approaches: Standard atmosphere model

- Modeling the temperature profiles using constant lapse rates (variation of temperature with altitude) in layers and dispersing lapse rates
- Creating a standard atmosphere model tuned to mesoscale data



Alternate Approaches: Pre-generated covariance matrices

- Use Mesoscale model data to create covariance matrices *a priori*
- Utilize hydrostatic equilibrium to get pressure based on integrating the ground pressure and temperature; calculate density from equation of state
- Preserves physics and spatial correlations
- Drawback: Large matrices that need to be handled for each Monte Carlo case
  - Full temperature grid is $(144 \times 144 \times 56)^2$
  - ~10 TB of RAM

Calculate Surface Pressure Grid (off-line) Covariance Matrix → Generate Random Surface Pressure from Covariance Matrix

Calculate Temperature Grid (off-line) Covariance Matrix → Generate Random Temperature Grid from Covariance Matrix

→ Integrate Pressure Grid using Hydrostatic Equilibrium → Calculate Atmospheric Density Grid via Equation of State

Calculate Wind Grid (off-line) Covariance Matrix → Generate Random Wind Grid from Covariance Matrix

Either off-line on in-line with EDL simulation

Adapted from B. Robertson (GT ASDL)

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Summary

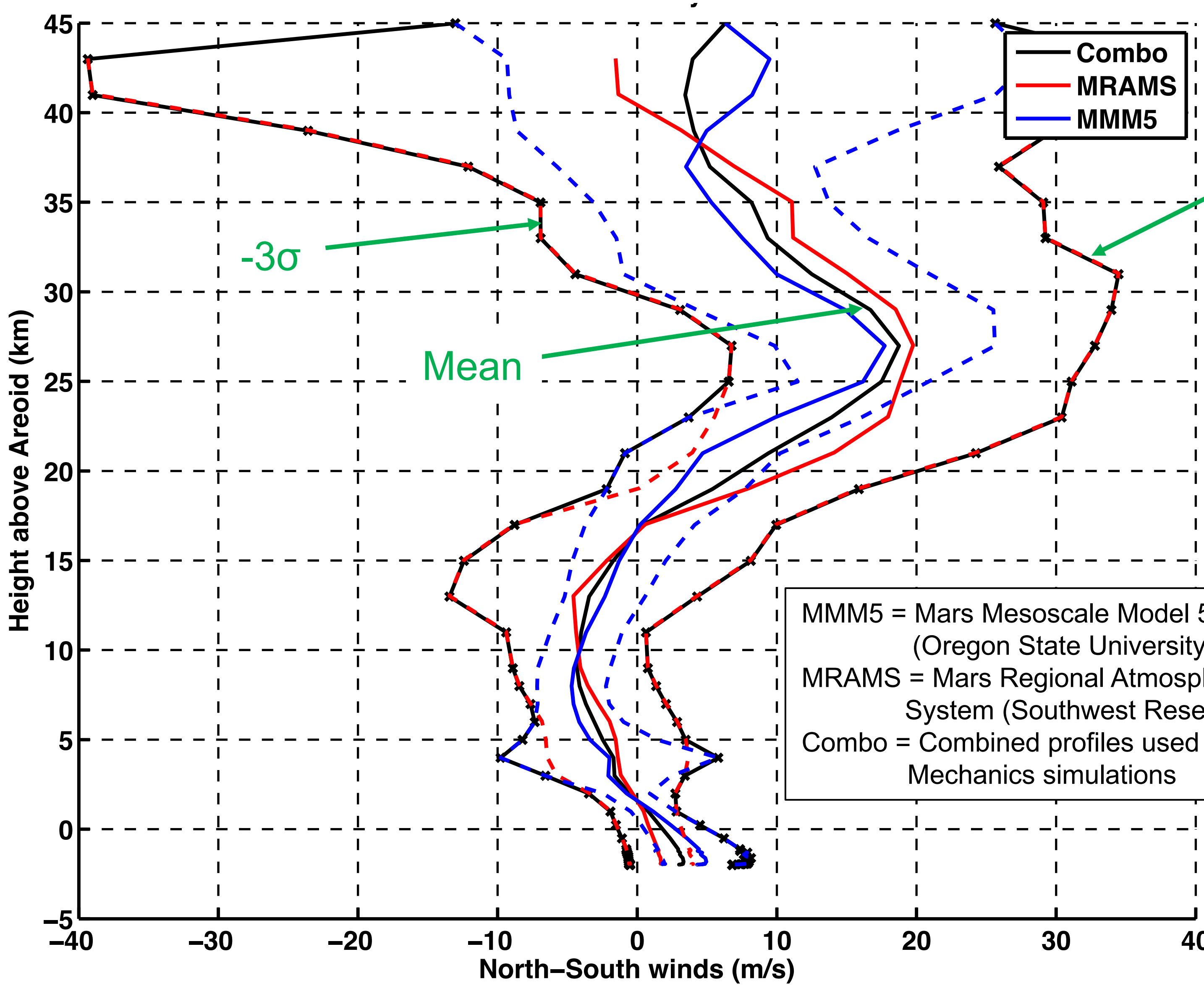
- Atmospheric models for flight mechanics simulations need to provide both nominal information and means of dispersions for Monte Carlo cases
- Three traditional approaches have been used to provide atmospheric information to EDL simulations in the past – MSL and Mars 2020 used Mesoscale model-based atmospheres
- Current approach provides ways to incorporate Mesoscale data in flight mechanics simulation and model dispersions but breaks some physical properties like hydrostatic equilibrium
- Future projects may want to consider other approaches that preserve the physics
  - Model temperature profiles as piece-wise continuous profiles governed by lapse rates. Use standard atmosphere approach to calculate pressure and density
  - Compute covariance matrices of atmospheric properties

Acknowledgements

- Mars 2020 Council of Atmospheres – specifically OSU MMM5 team and SwRI MRAMS team
- Georgia Tech Aerospace Systems Design Laboratory Team that supported the CDT project on Mesoscale Atmosphere incorporation

Back-Up Slides

Example of combo wind profiles created from mesoscale data



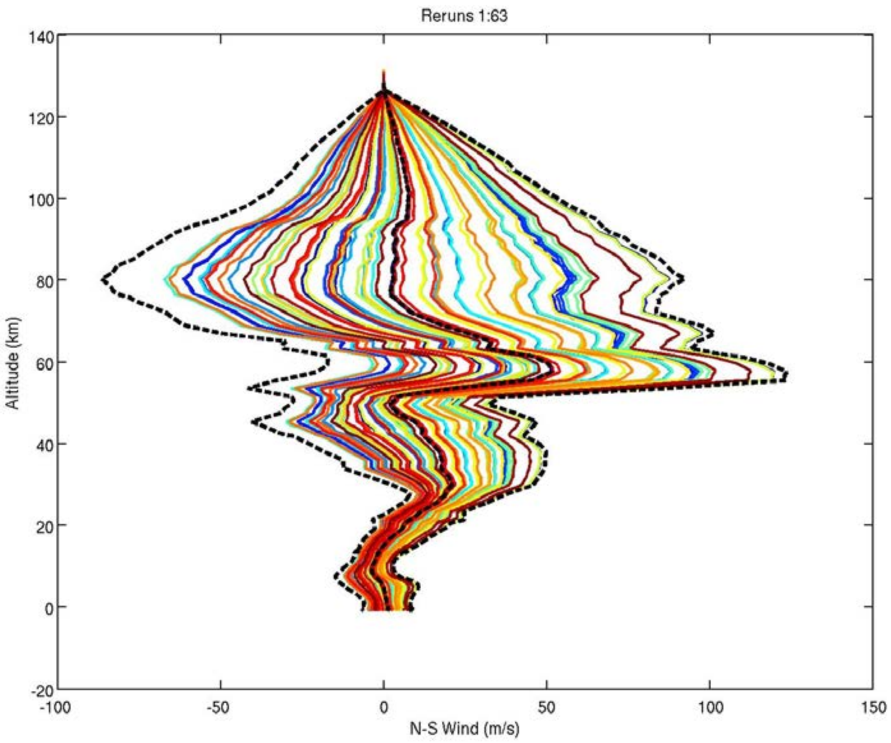
MMM5 = Mars Mesoscale Model 5th Gen (Oregon State University)
MRAMS = Mars Regional Atmospheric Modeling System (Southwest Research Institute)
Combo = Combined profiles used in Flight Mechanics simulations

Wind dispersions in EDL simulation: Individual effects of 3+3 winds

The combo profiles are used within the flight mechanics simulation in a “3+3” way. First 3 is mean shift and the second 3 is shift in uncertainties. 3 refers to a “3-sigma” or 3 standard deviation shift.

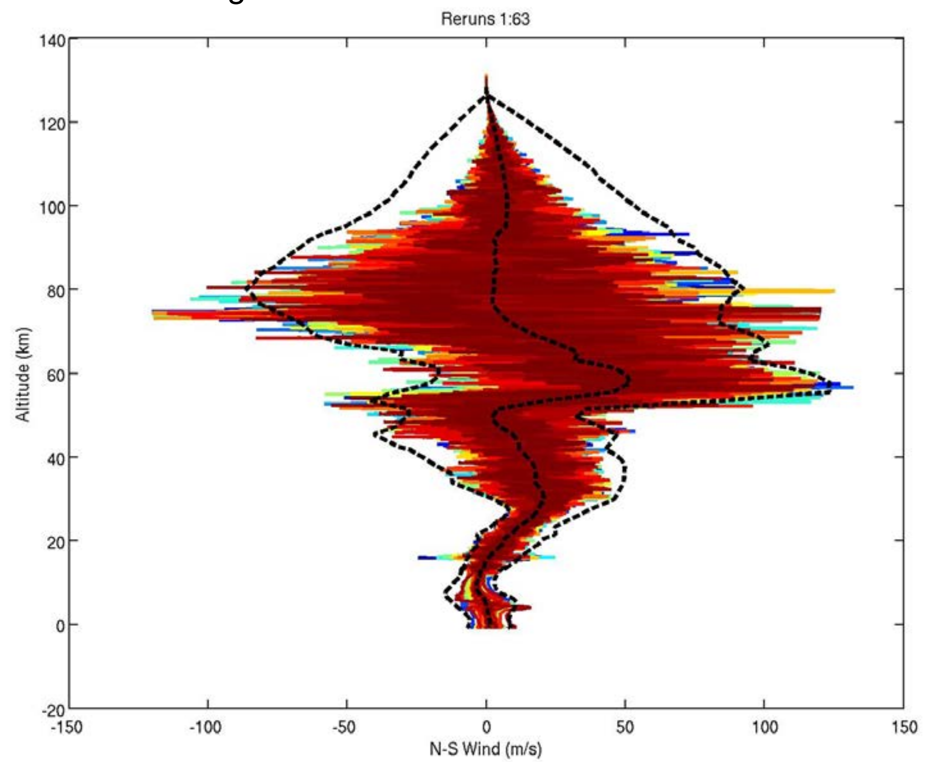
Effect of 3 + 0:

Mean shift is controlled by Monte Carlo input Uniform Distribution



Effect of 0 + 3:

Additional random noise perturbations are added based on standard deviation data from Mesoscale models to stress the flight mechanics simulation.



Note: The black dashed lines are same in the two figures

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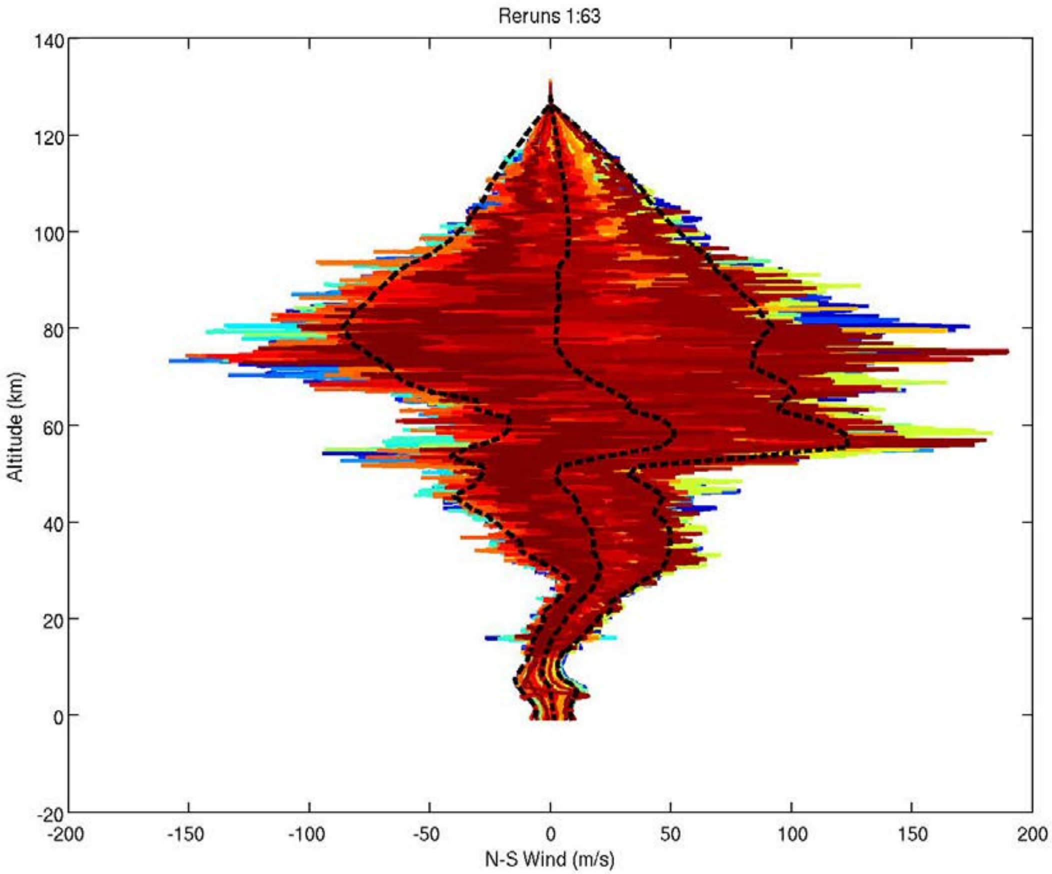
Wind dispersions in EDL simulation: Total effect of 3+3 winds

Two effects are independent; therefore, the results is like an RSS. Should expect total variability to be something like 4.24-sigma, rather than 6-sigma.



Note: The black dashed lines are the same as the other figures

Effect of atmosphere on flight performance statistics

- Atmospheric density affects aerodynamic forces on the vehicle and manifests itself in things like altitude history and parachute loads; closed-loop nature of Mars 2020 entry guidance means density perturbation effects could be amplified
- Winds have large effect on trajectory dispersions during the long time on parachute