



# EDL Atmosphere Reconstruction

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# Overview



- Atmospheric conditions directly impact EDL performance, but our historic ability to reconstruct the as-flown atmosphere has been limited
- More data at our disposal than ever before, but no single data source reveals the whole atmosphere profile
- Assembled a best-estimate atmosphere using remote sensing from orbiters, onboard inflight measurements, post landing measurements, and preflight model results

*The reconstructed MSL as-flown atmosphere compares favorably to preflight predictions*

## Guided Entry

- Lift modulation provides range control to “fly out” vehicle and environmental dispersions
- Bulk Atmospheric density impacts altitude capability
- Density structure directly impacts ability to fly out dispersions
- Nearly open loop in heading alignment; vulnerable to atmospheric dispersions

## Supersonic Parachute Deploy

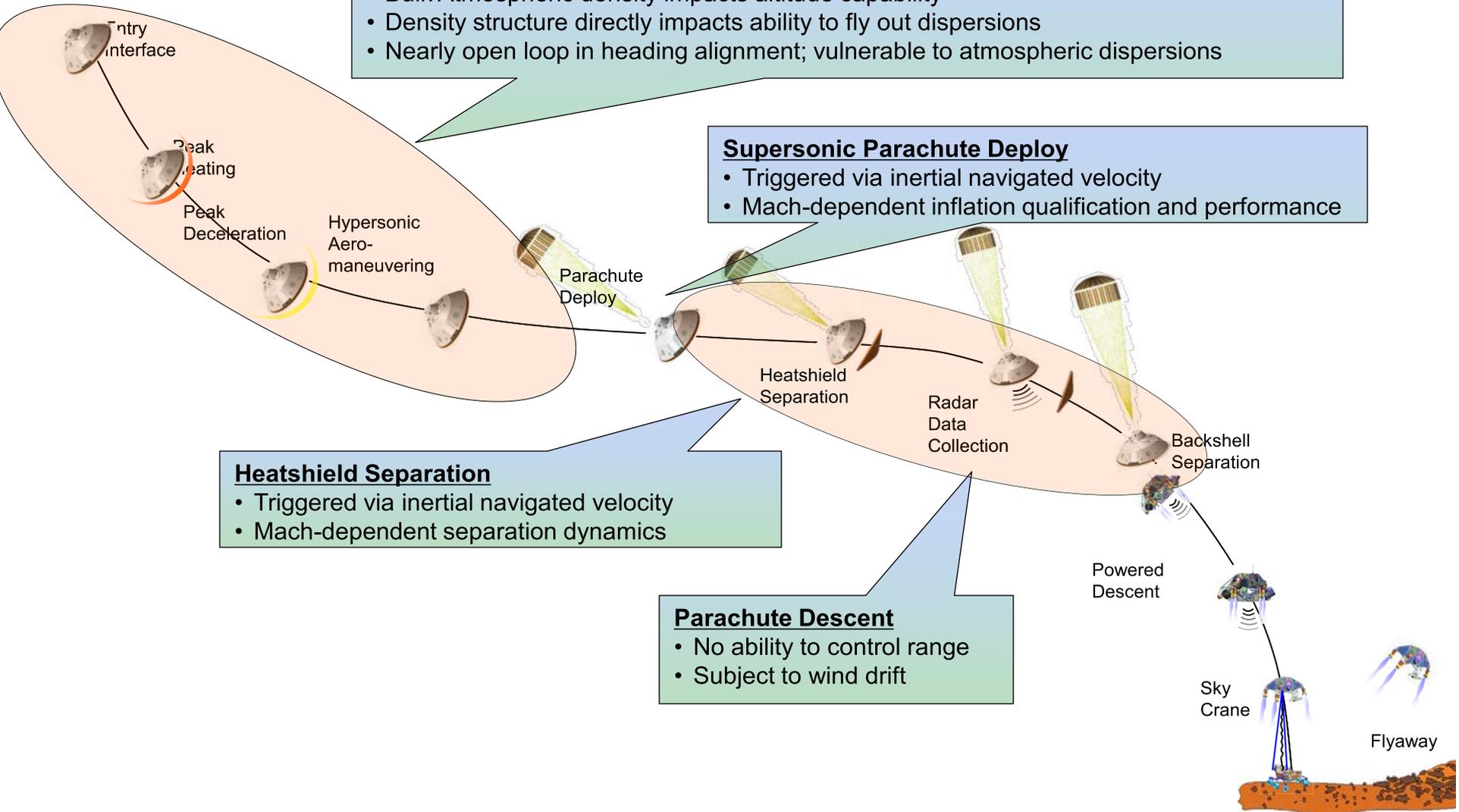
- Triggered via inertial navigated velocity
- Mach-dependent inflation qualification and performance

## Heatshield Separation

- Triggered via inertial navigated velocity
- Mach-dependent separation dynamics

## Parachute Descent

- No ability to control range
- Subject to wind drift





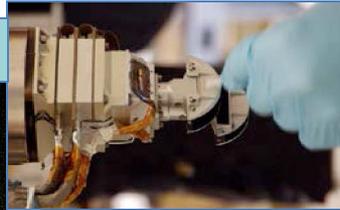
# What We Want



- The holy grail for atmosphere reconstruction: free stream temperature, pressure, density, and wind at every point along the as flown trajectory
- This has never been possible
  - Very little onboard data collection other than IMU data
  - Only a few post landing relevant data sets
  - Limited remote sensing data from orbiters
  - Extremely limited options for direct measurements of quantities of interest
- Don't have everything we want yet, but have more data available than ever before

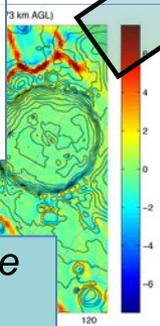
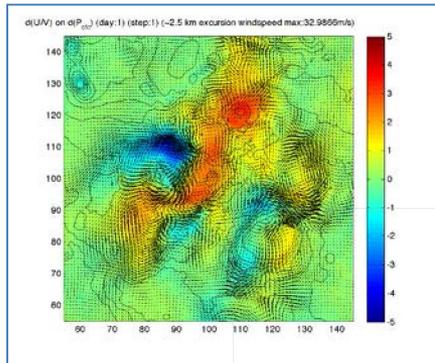
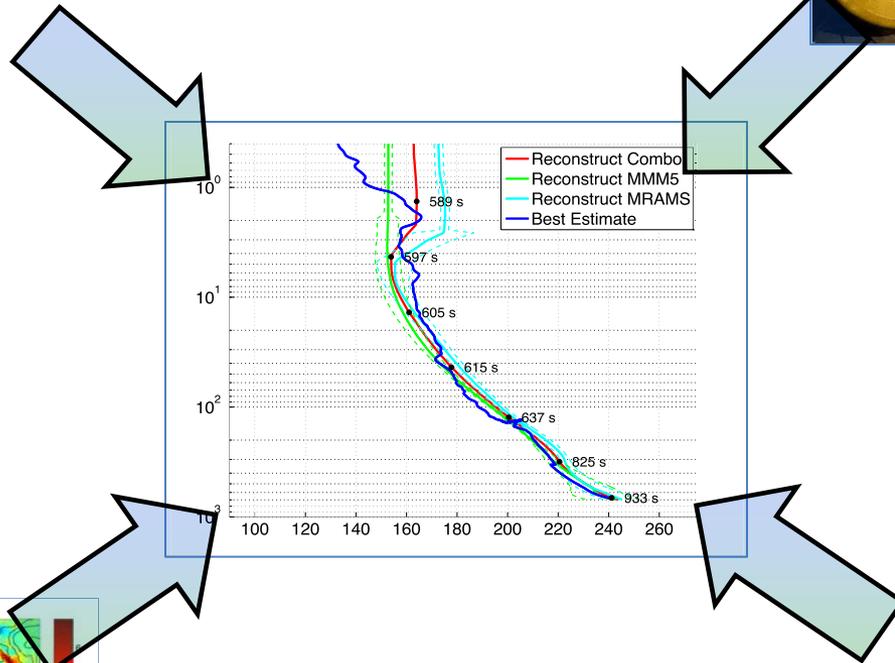
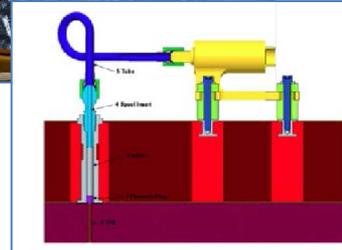
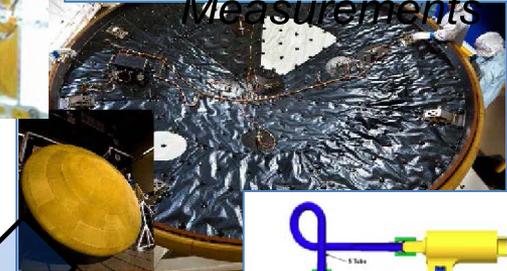
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## Remote Sensing

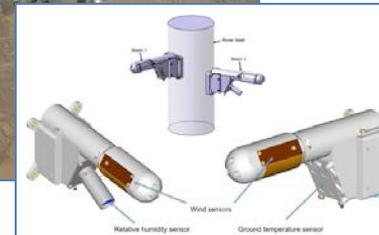
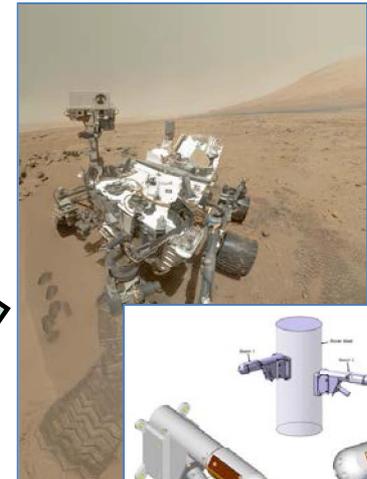


Mars Science Laboratory

## Onboard Measurements



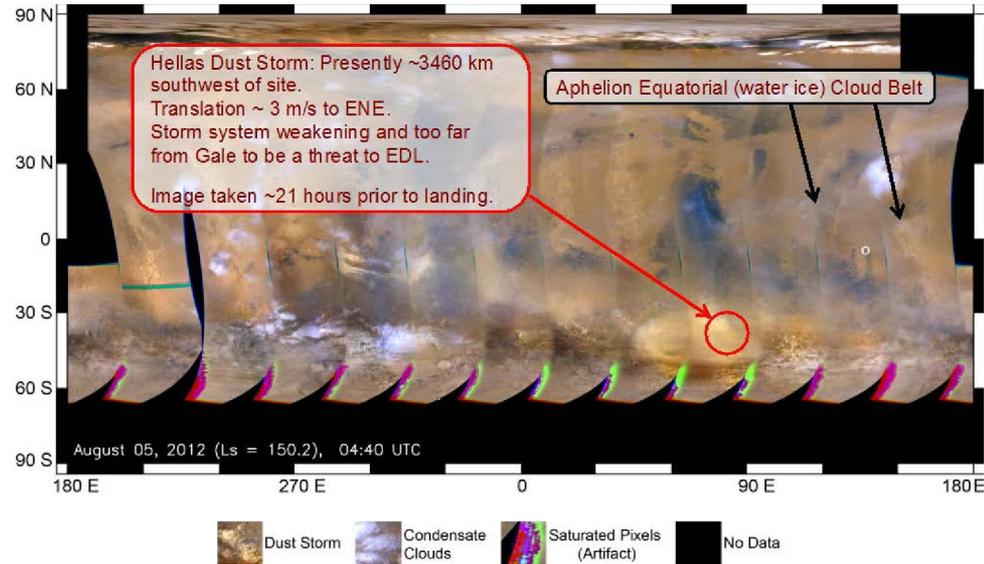
## Model Outputs Along the Flown Trajectory



## Post-Landing Measurements

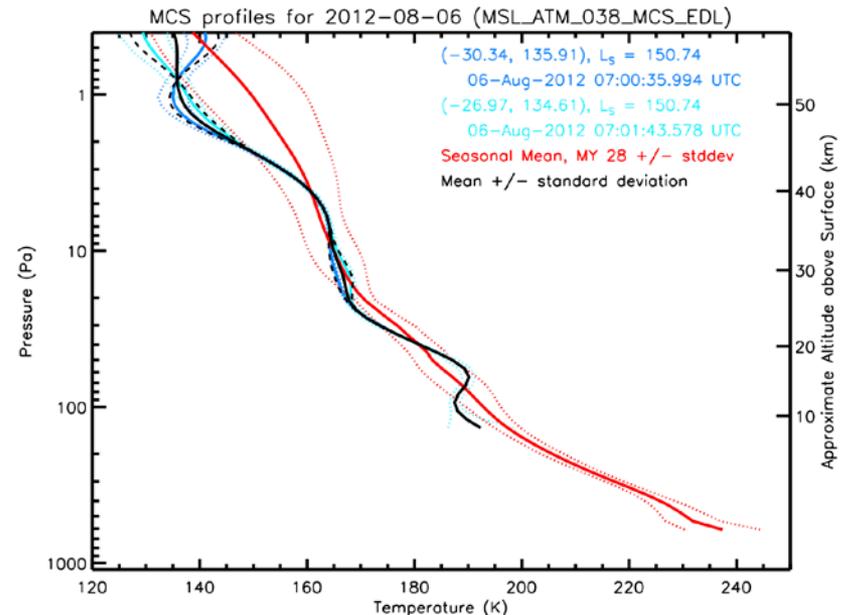
## MARCI

- Provided pre- and post-landing global imagery for observation of water ice clouds and dust activity
- Limitations
  - Resolution
  - No direct measurement of density or wind
  - No vertical structure information



## MCS

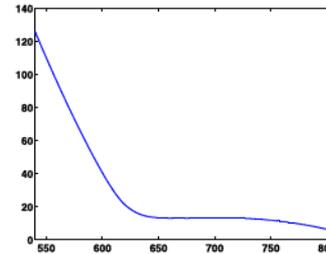
- Provided vertical structure for temperature and opacity
- Limitations
  - No direct measurements of density or wind
  - Unable to see to the ground
  - Limited spatial availability in landing season
  - Not along the trajectory flown



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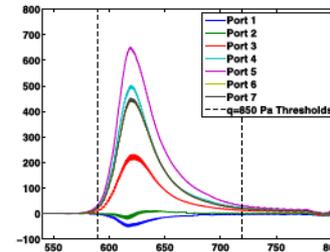
## IMU

- Provided high rate acceleration and body rates
- Enabled reconstruction of the trajectory flown and attitude history
- Limitations
  - Can't determine relative contribution of drag coefficient vs. atmosphere
  - Reconstruction limited by accuracy of drag predictions



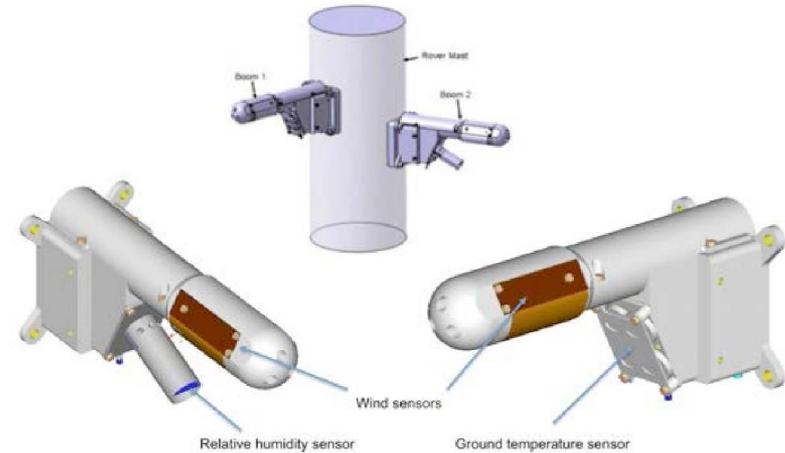
## MEADS

- Provided direct pressure measurements during flight along the trajectory flown
- When combined with IMU, allows separation of dynamic pressure and drag coefficient
  - Get estimate of free stream density and drag coefficient along the trajectory
- Limitations
  - Requires assumptions to reconstruct free stream conditions
  - Still sensitive to winds
  - Data quality degraded at low dynamic pressures

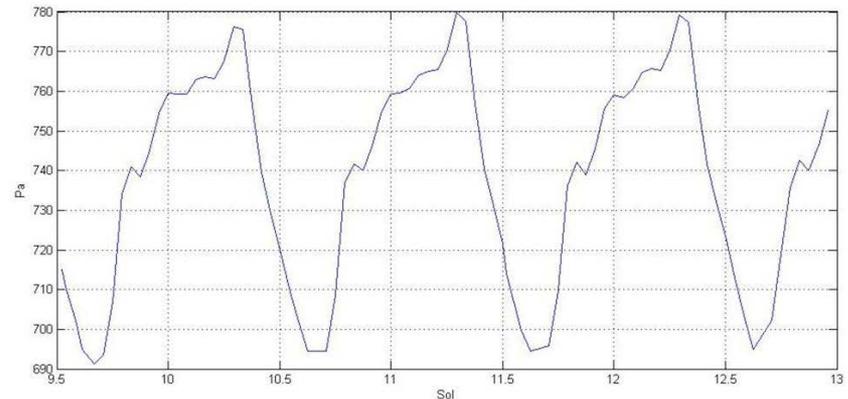


## REMS

- Provides surface pressure measurements for observation of diurnal and seasonal cycles
- Post landing measurements at same local time provide estimate of actual pressure during landing
- Anchors bulk atmospheric mass assumptions
- Limitations
  - No ability to see pressure or density structure along the trajectory flown
  - No useful wind information

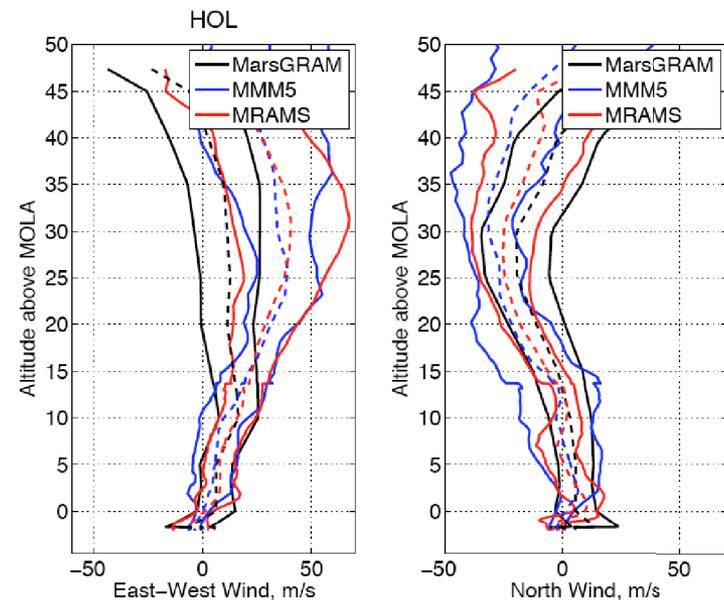
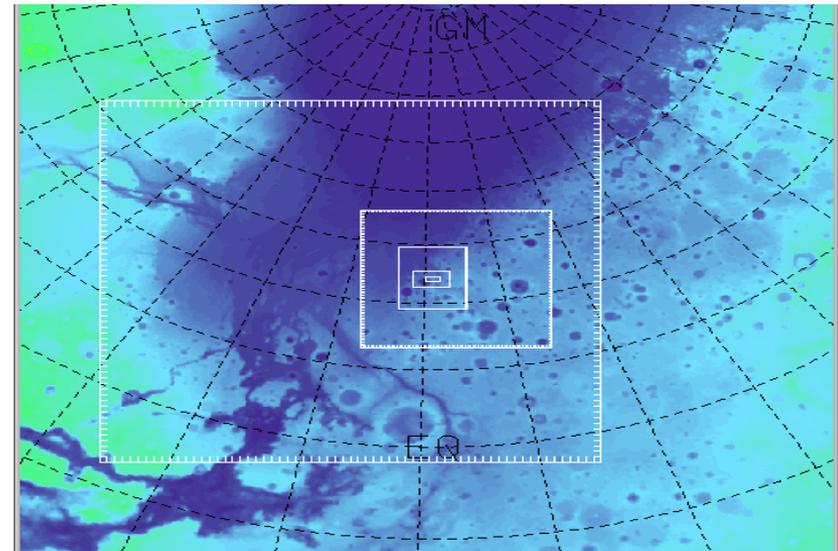


PRESSURE SENSOR

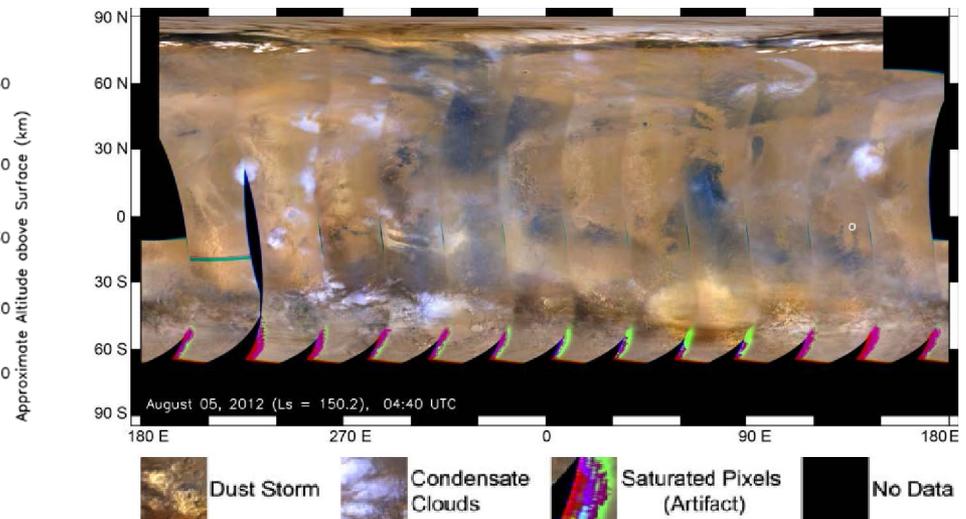
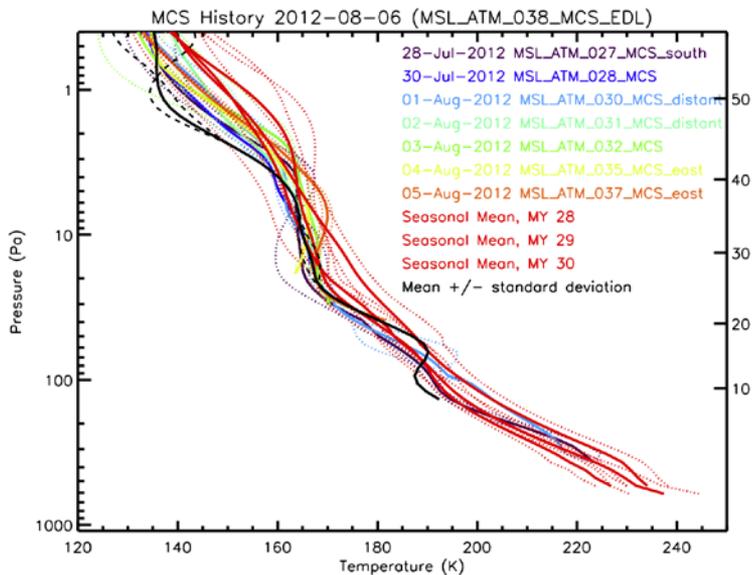


## Mesoscale Models

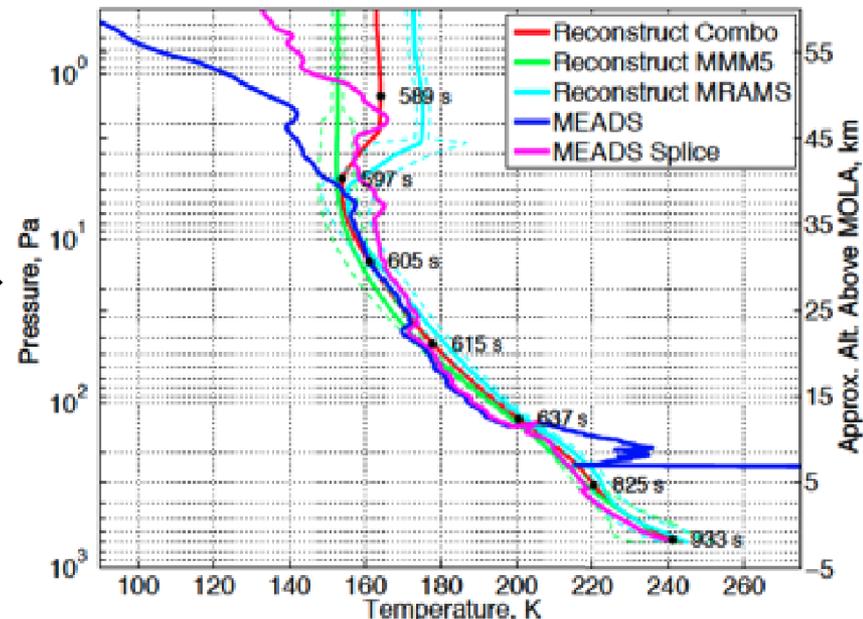
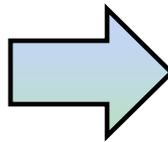
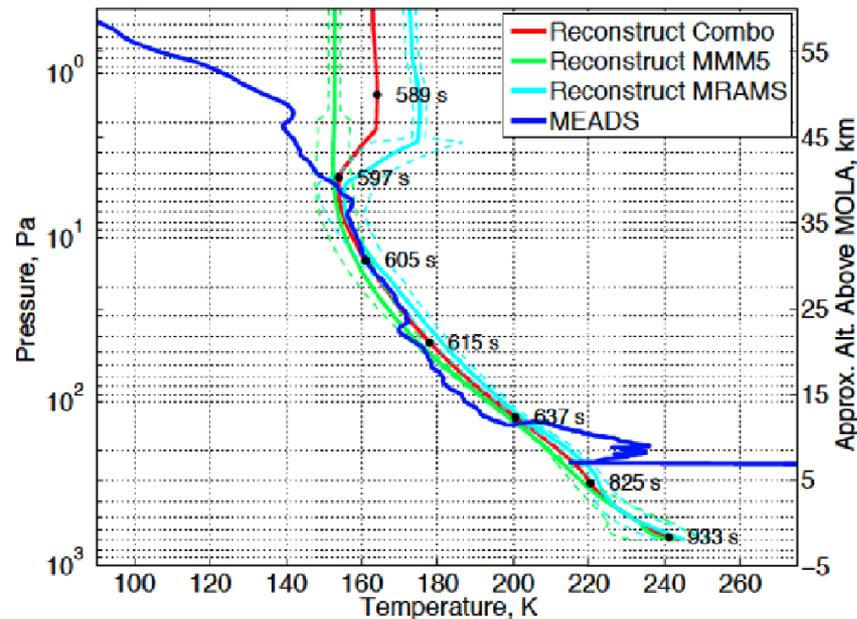
- Useful for characterizing density structure and wind fields
- Query model outputs along the reconstructed trajectory flown
- Anchor bulk atmosphere density based on surface pressure measurements taken
- Limitations
  - Density structure and wind field not based on any direct observations along the trajectory



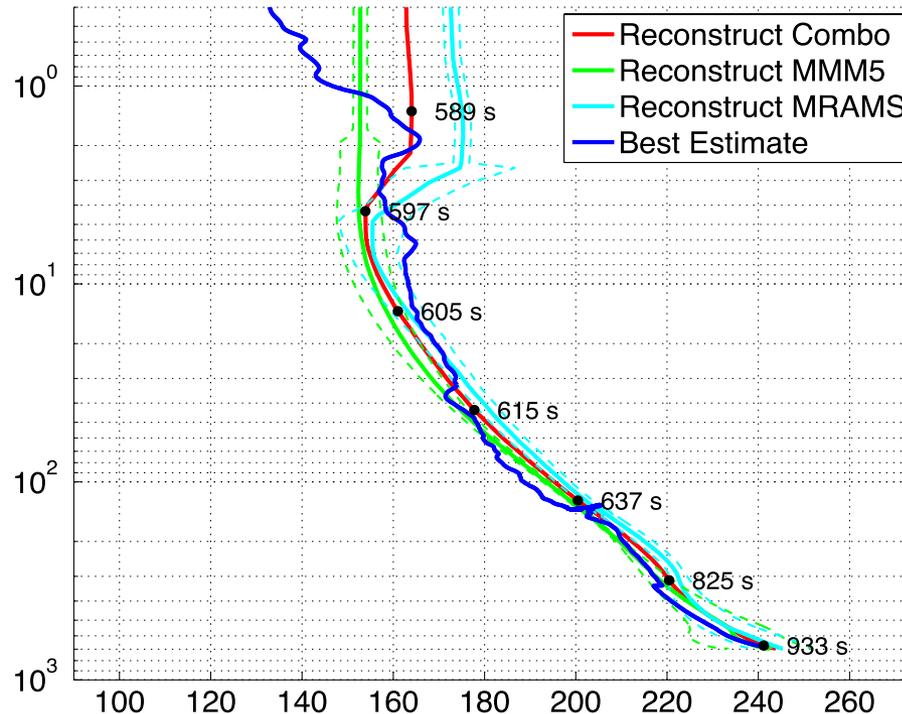
- Upper Atmosphere
  - Above 40-50 km altitude, MEADS data is suspect due to insufficient dynamic pressure
  - MCS temperature profiles are valid at high altitudes
    - Several regionally and temporally consistent profiles available from approach measurements
    - Profiles suggest cold and clear upper atmosphere
  - MARCI images during approach corroborate cold and clear assessment
  - Also corroborated by earlier than expected start of entry guidance



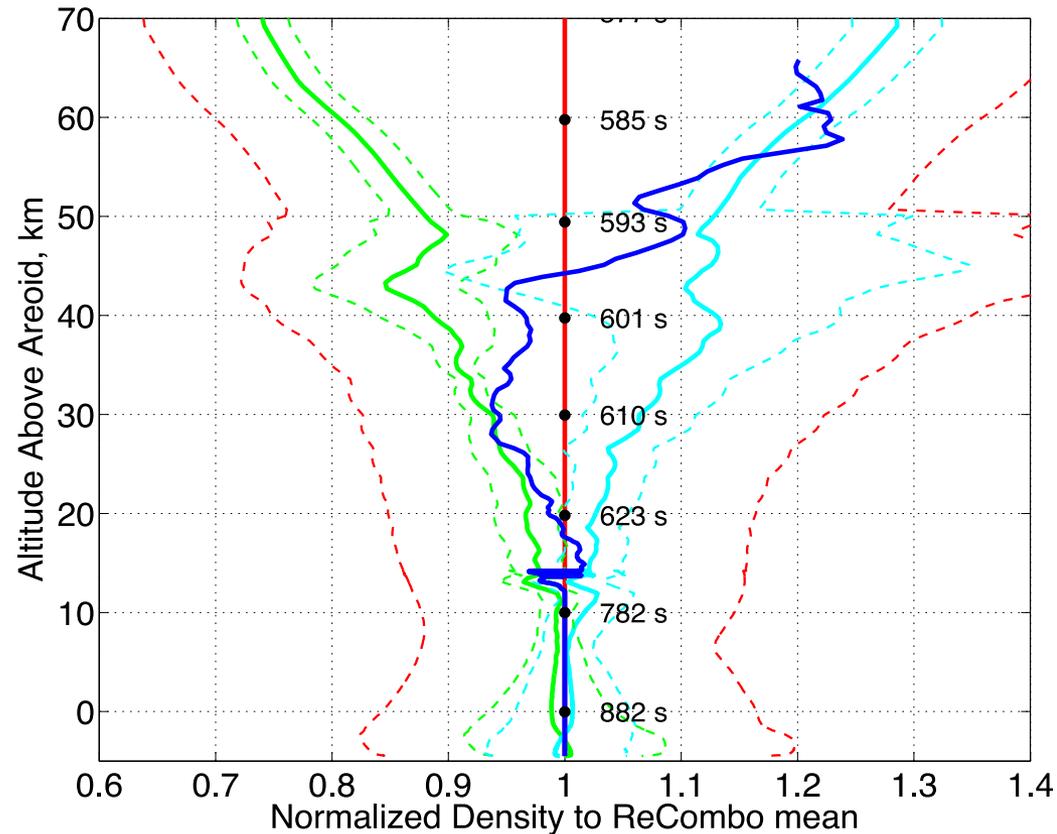
- Middle Atmosphere
  - Between 15 and 40 km altitude, vehicle is primarily in hypersonic flight
  - MEADS data is within valid dynamic pressure range
  - MEADS + IMU reconstruction provides most credible atmospheric information
    - MEADS profile is non-credible in upper atmosphere
  - Force MEADS based profile to match MCS retrievals at ~40 km altitude



- Lower Atmosphere
  - Still don't have any useful data!
    - MEADS below valid dynamic pressure range (and then gone)
  - The best we can do is update our mesoscale models
    - Query along the trajectory
    - Update the surface pressure assumption (<2% correction)
  - Transition gradually from MEADS based profile to mesoscale



- Resulting reconstructed atmosphere profile compares favorably to envelope of mesoscale model results
- Anchoring MEADS to MCS in upper atmosphere mitigates errors due to insufficient dynamic pressure
- MEADS based reconstruction provides near direct atmosphere measurements along the trajectory
- Transitioning to re-anchored mesoscale models in lower atmosphere removes invalid low dynamic pressure issues





# Conclusions



- Developed a best estimate atmosphere reconstruction using a variety of data sets, each with strengths and weaknesses
- In general, data sets reinforce one another and are corroborated by each other and inflight observations
- Approach still relies on a number of assumptions and doesn't yield everything we want
  - e.g. wind profiles
- Reconstructed atmosphere profile is in family with preflight model outputs and likely contributed to the overall nominal EDL performance