Atmosphere and Climate Context of the MSL Landing Sites

Ashwin Vasavada

Allen Chen

Jet Propulsion Laboratory, California Institute of Technology

MSL Council of Atmospheres

September 29, 2010

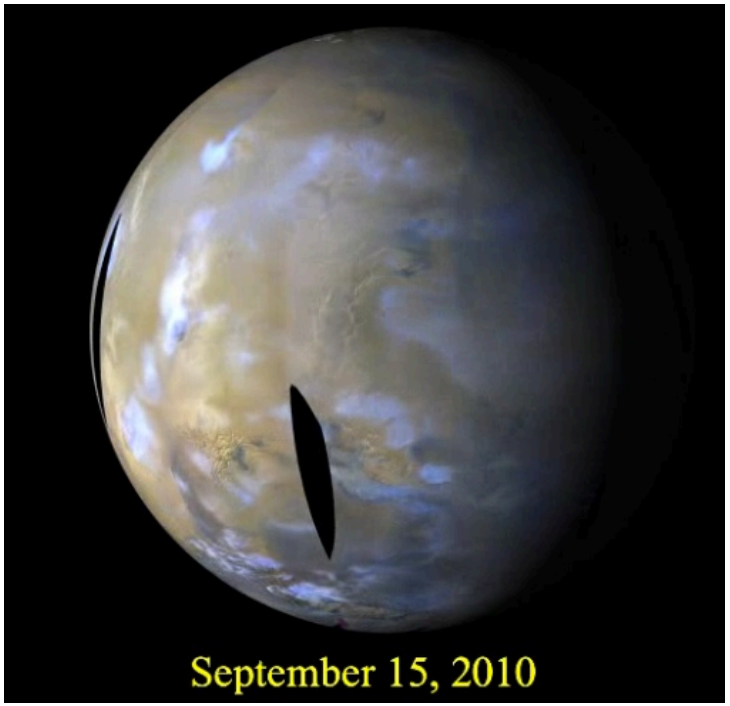
Arrival at Mars

Arrival Parameters

- L_s = 151-158 (right now it is L_s=155 on Mars!)
- Mars local time range = 2:38 to 4:04 PM
- August 6-20, 2012

Mars' Atmospheric Characteristics

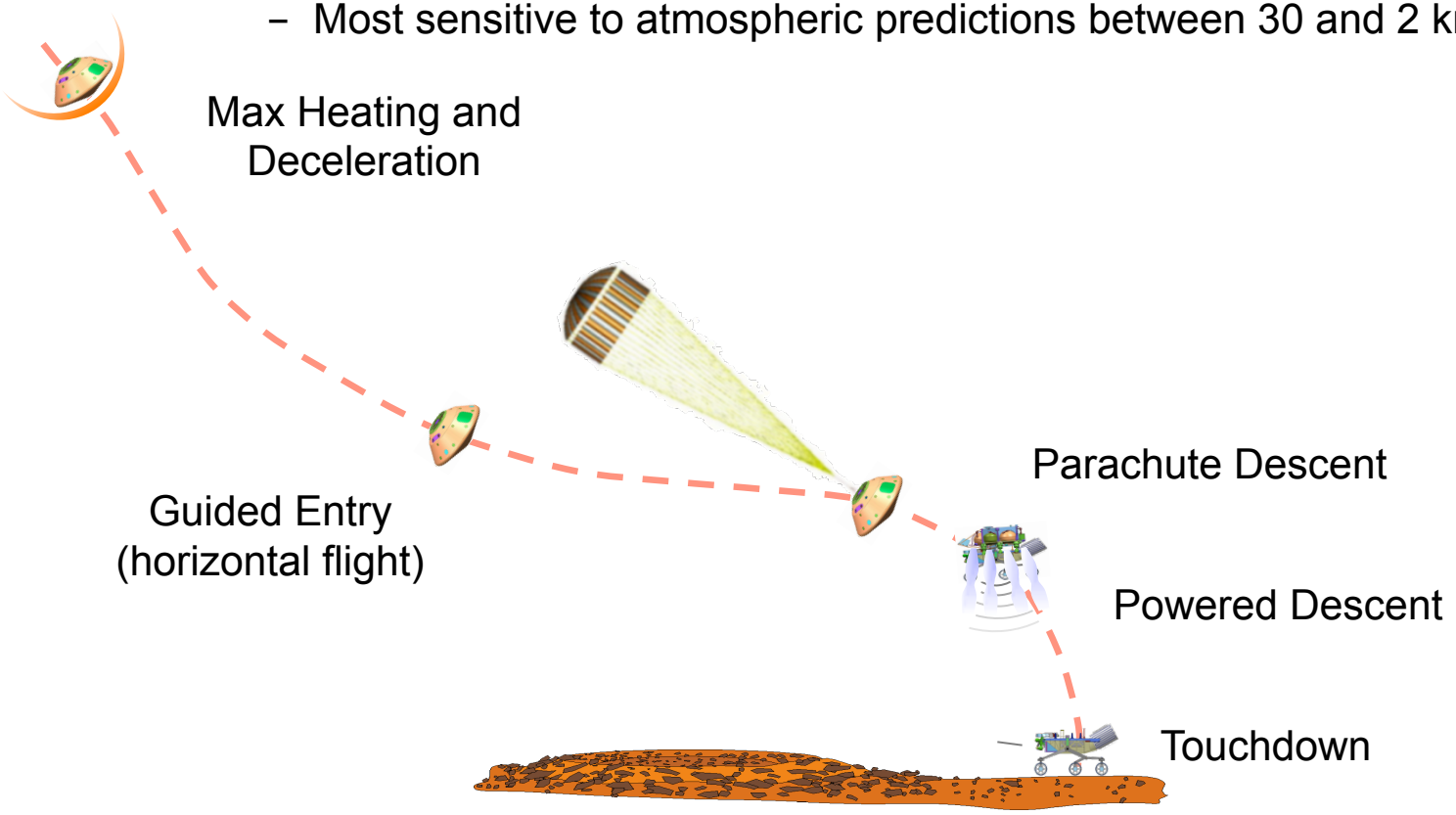
- "Labor Day" timeframe; late N. Summer (late S. Winter)
- Northern sites experience mild summer, but high sun results in active convection in the middle of the day
- Water ice clouds around the equator and southern mid-latitudes
- Southern winter is long and intense; southern baroclinic storm track is well south of landing sites. Many cap-edge dust storms occurring.



NASA/JPL-Caltech/MSSS

Overview of MSL EDL

- Primary differences from previous missions include:
  - Closed-loop, guided entry based on inertial measurements
  - Horizontal flight for ~100 km at 10-15 km above ground level
- Critical events are parachute deploy, heat shield separation, initiation of powered descent, and touchdown
  - Most sensitive to atmospheric predictions between 30 and 2 km altitude

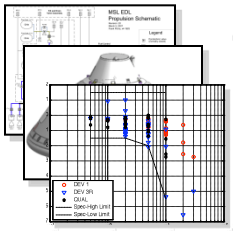


Atmospheric Component of EDL Safety Assessment

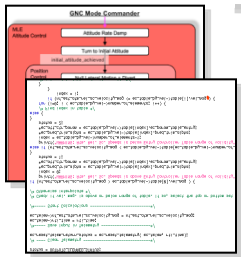
MSL EDL Safety Assessment

Council of Atmospheres

Hardware Models



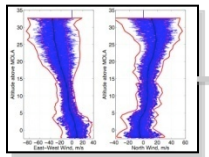
Flight Software



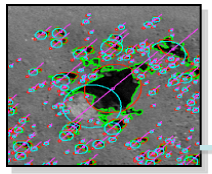
System/ Hardware Assessment

Fuel Budget

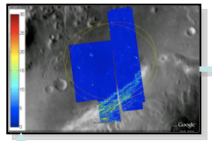
Atmosphere



Rock Map

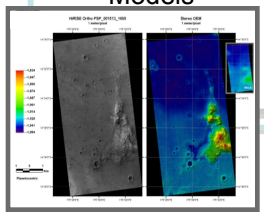


Slope Map

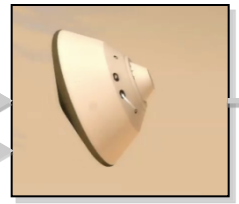


(Gap fill w/photoclinometry)

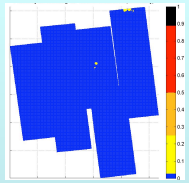
Digital Elevation Models



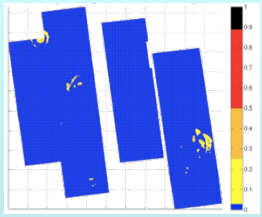
Closed Loop Flight Dynamics Simulation



Touchdown Hazard Map

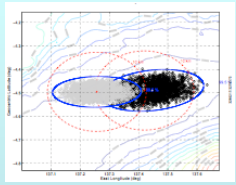


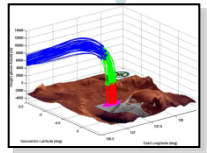
PD Accordion Hazard Map



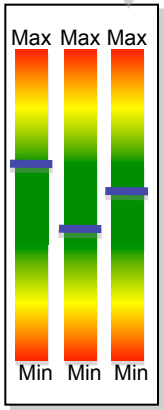
Margin Table

Landing Distribution





Probability of Terrain Failure



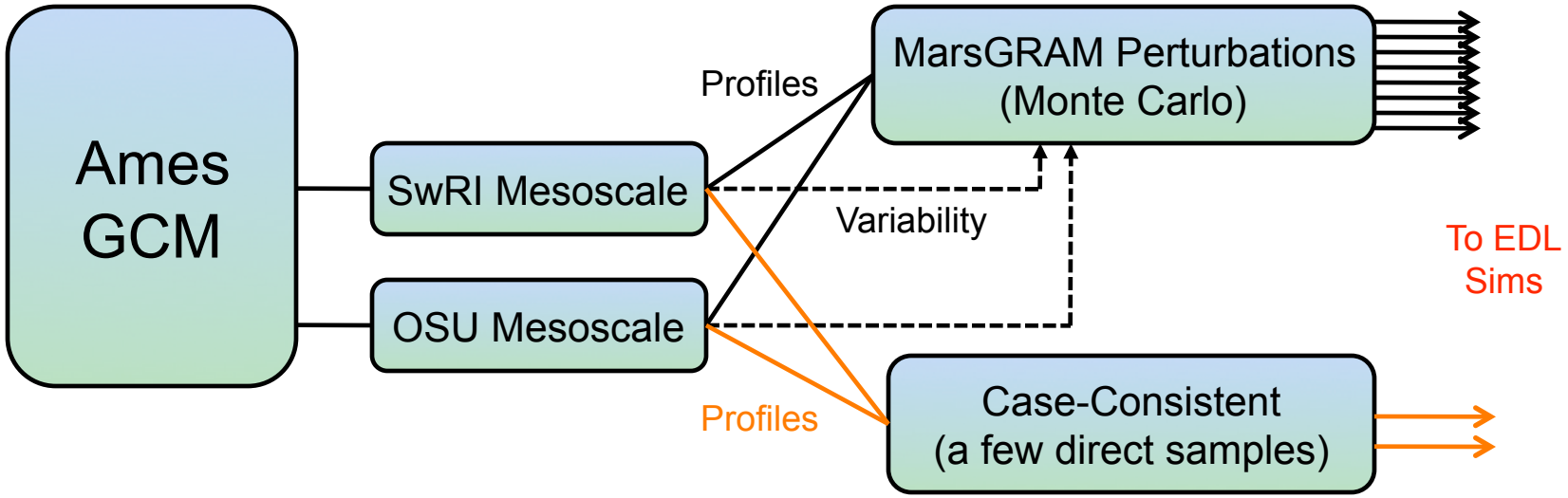
Margin Assessment

System Capability | Mars | Performance Maps | Performance @ Mars

Atmospheric Safety Assessment

- Generate the best prediction of the atmospheric state (i.e., wind and density fields) at the local time and season of MSL EDL
  - Include variability to represent uncertainty and normal weather
  - Include off-nominal cases to represent anomalous weather
- Validate these predictions
  - Use suite of independent numerical models
  - Test against observations where and when available
  - Conduct stand-alone studies (e.g., turbulence, storms, dust, tides, waves)
- Provide atmospheric numerical model results to EDL simulation team
  - Make sure data is relevant for MSL trajectory
  - Also provide advice for adding additional engineering margin
- Simulate EDL; compute success rate, surface “error ellipse”, and system margins

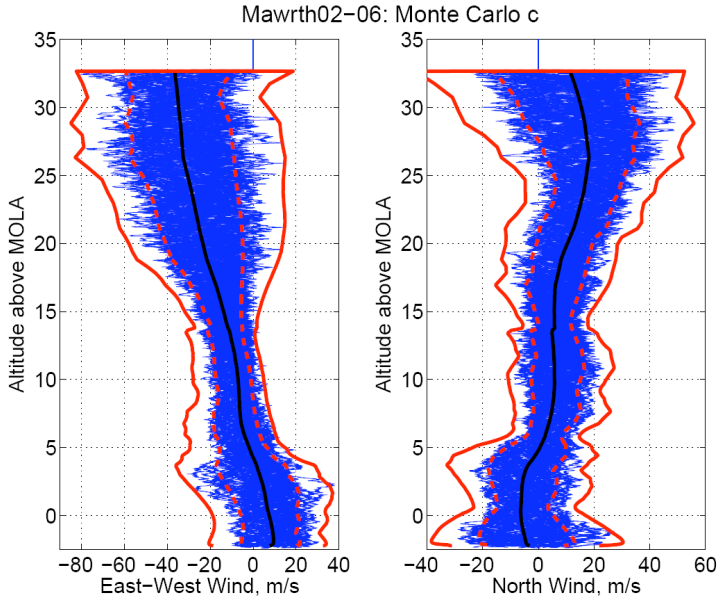
Atmospheric Model Usage

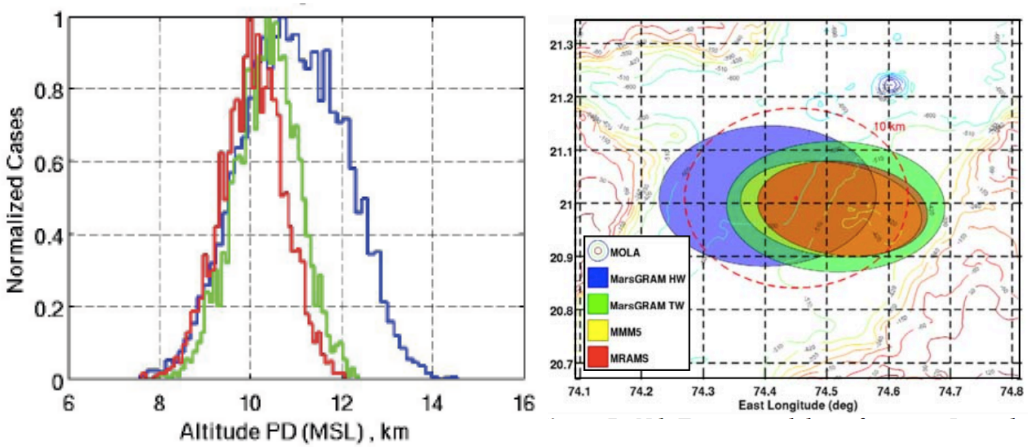


- Ames GCM used to generate global/seasonal boundary conditions
- Mesoscale models run and output passed to EDL simulations
  - SwRI and OSU models have independent lineage
  - Mesoscale models queried for ~20 sols / 4 hours spanning arrival time
- Simulations use mesoscale model fields (average and variability) to create large set of Monte Carlo runs; engineering margin added
- EDL also simulated using single model snapshots

EDL Monte Carlo Simulations

- Mesoscale models are sampled over 20 sols and 4 hours
  - Each Monte Carlo case flown through a “dispersed profile”
  - Mean profile is the model average
  - Perturbations are generated using model variability
- Dispersions from model results are enveloped and expanded
  - Can combine results from models into single Monte Carlo
  - Example: increase variability in steady state winds and wind perturbations
- Can separately interrogate resutls of each model, if desired



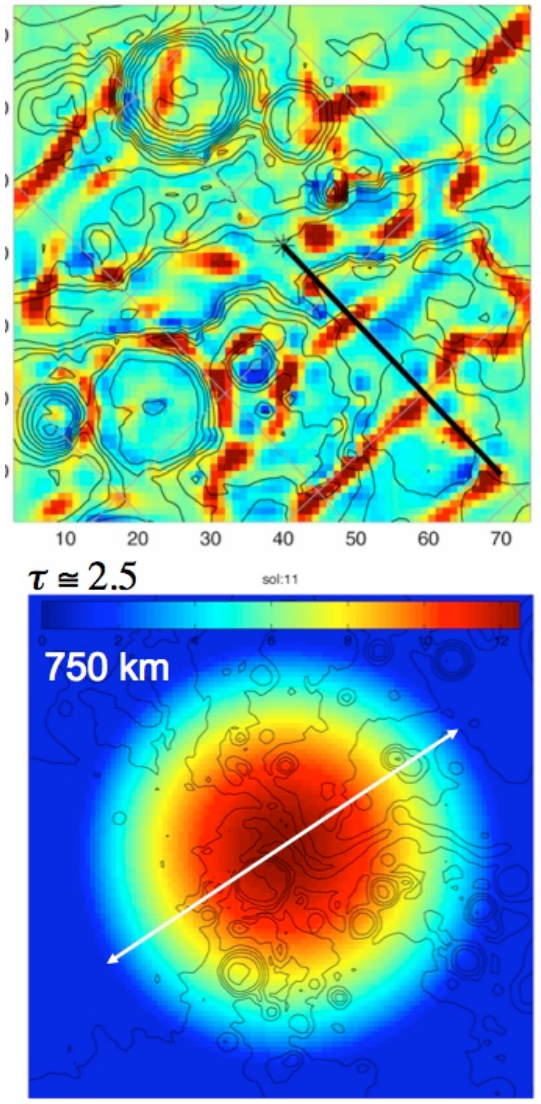


Atmospheric Stand-Alone Studies

- Great deal of work done to validate the Ames, OSU, and SwRI models as part of their scientific use
- Large eddy simulations run to simulate meter-scale turbulence within the planetary boundary layer
- Surface pressure derived from TES-assimilated UK Mars GCM, validated using radio occultation data and VL1/PHX
- Mesoscale models validated at MSL season against TES and MCS temperature fields
- Dust storm frequency and properties derived from MOC-WA and MARCI observations
- Effects of local dust storms simulated with mesoscale models
- Other studies include winter storm track, gravity waves, density variability at small scales

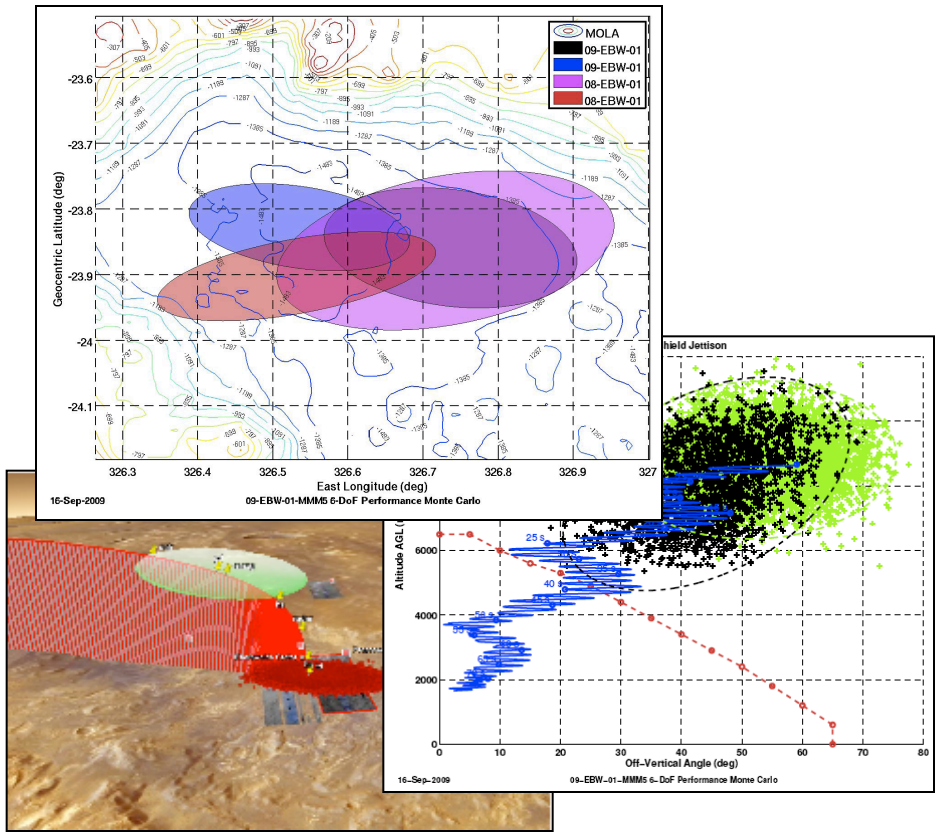
What We've Done to Date

- GCM-bounded mesoscale models have been run for all sites at 2012 arrival L_s, but not with latest versions of models
- End-to-end EDL simulations performed for all sites including some robustness testing
- Models with enhanced background dust and spatially discrete and time-variable dust events ('dust bombs') have been analyzed offline for 2010 arrival
- Focused studies of boundary layer convection, active dust lifting, southern storms to mitigate risk



2011 Performance Summary

- EDL performance analyses conducted using mesoscale model results
- Key performance metrics:
  - Altitude/timeline margin
  - Propellant margin
  - Landing precision
- More benign mesoscale winds (vs. engineering winds) help offset margin lost to pressure cycle effects
  - Performance similar to 2009 capability
- Preliminary results: all sites can be reached with acceptable margin
  - Pending model updates and additional atmosphere characterization work



Derived from Monte Carlo Results	Mawrth	Gale	Eberswalde	Holden
Altitude Margin (km, 0.5%-tile low)	1.7	2.3	0.5	1.1
Propellant Margin (kg, 0.5%-tile low)	23	30	17	20
Range Error at Touchdown (km, 99%-tile high)	8.2	9.3	8.0	8.1

EDL Results & Future Work

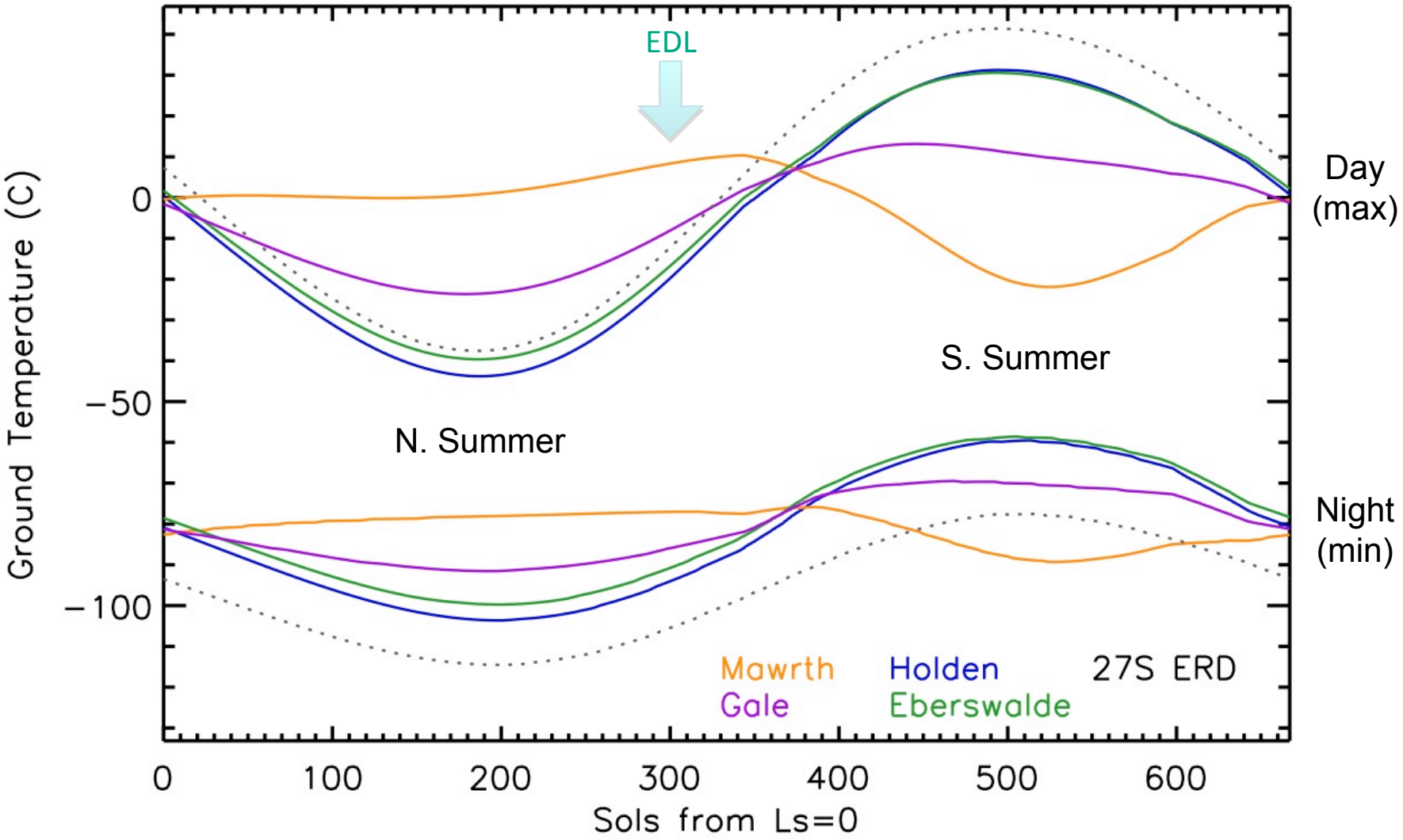
- Atmospheric safety is not likely to be a driver for site selection
- Risk of encountering local dust storms is << 1%
- Risk of encountering regional dust storm is higher than previously thought (based on 2008 event at MSL arrival season), but effect on EDL is likely to be small
- Still some risks that require additional work:
  - Zonal wind field may be significantly affected by regional dust storm
  - Large eddy simulations may reveal strong vertical winds that reduce robustness of powered descent phase
- Currently acquiring MCS and MARCI observations of dust events at MSL arrival season, one year prior to EDL
- Currently conducting final set of mesoscale model runs to be fed to EDL simulations
- Future: additional LES runs and off-nominal mesoscale cases

Climatology of Landing Sites for Mission Design & Performance

Climatology of the MSL Sites

- The mission performance of MSL is strongly coupled to environmental temperatures through the need for electrical survival heating and actuator heating
- Simulations of min/max ground temperature, air temperature, diurnal temperature range, solar flux, and dust opacity for various sites with the MSL-accessible region on Mars were conducted early in the Project to set requirements
- More recently, models were run at final candidate sites, along with a “stress test” fictitious site to represent the requirements-driven case

Climatology of Landing Sites



Climatology and Mission Performance

- The environmental model results will be used to assess mission performance (e.g., number of sols to drive a certain distance, or to acquire and process a sample) as a function of season at the different landing sites
- We are also compiling high-resolution albedo and thermal inertia data for final sites to aide predictions during the surface mission
- How these data discriminate among site candidates will be studied in detail between this workshop and site selection