Appendix S

Implementation of a Mars thermal environment model using standard spacecraft analysis tools

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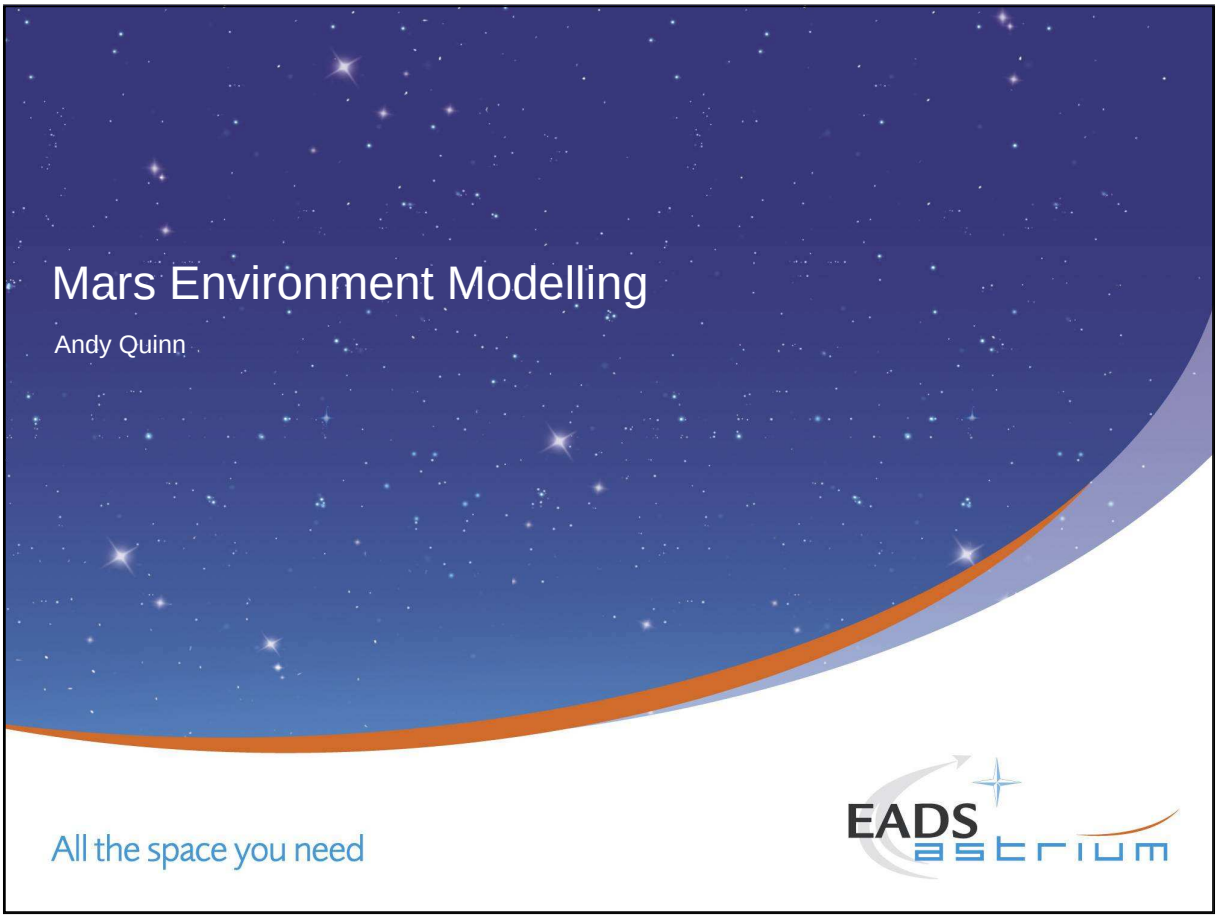
Abstract

A number of models of the surface of Mars exist which can be used as inputs to thermal analysis. On ExoMars ESATAN and ESARAD have been used along with a simplified one dimensional Mars climate model supplied by the Laboratoire de Météororologie Dynamique in Paris. These tools can be used to generate flux profiles including diffuse load due to atmospheric dust, dynamic ground temperatures which take into account shadowing and soil thermal response, and representative diurnal cycles. The methods for achieving these are presented here.


Mars Environment Modelling
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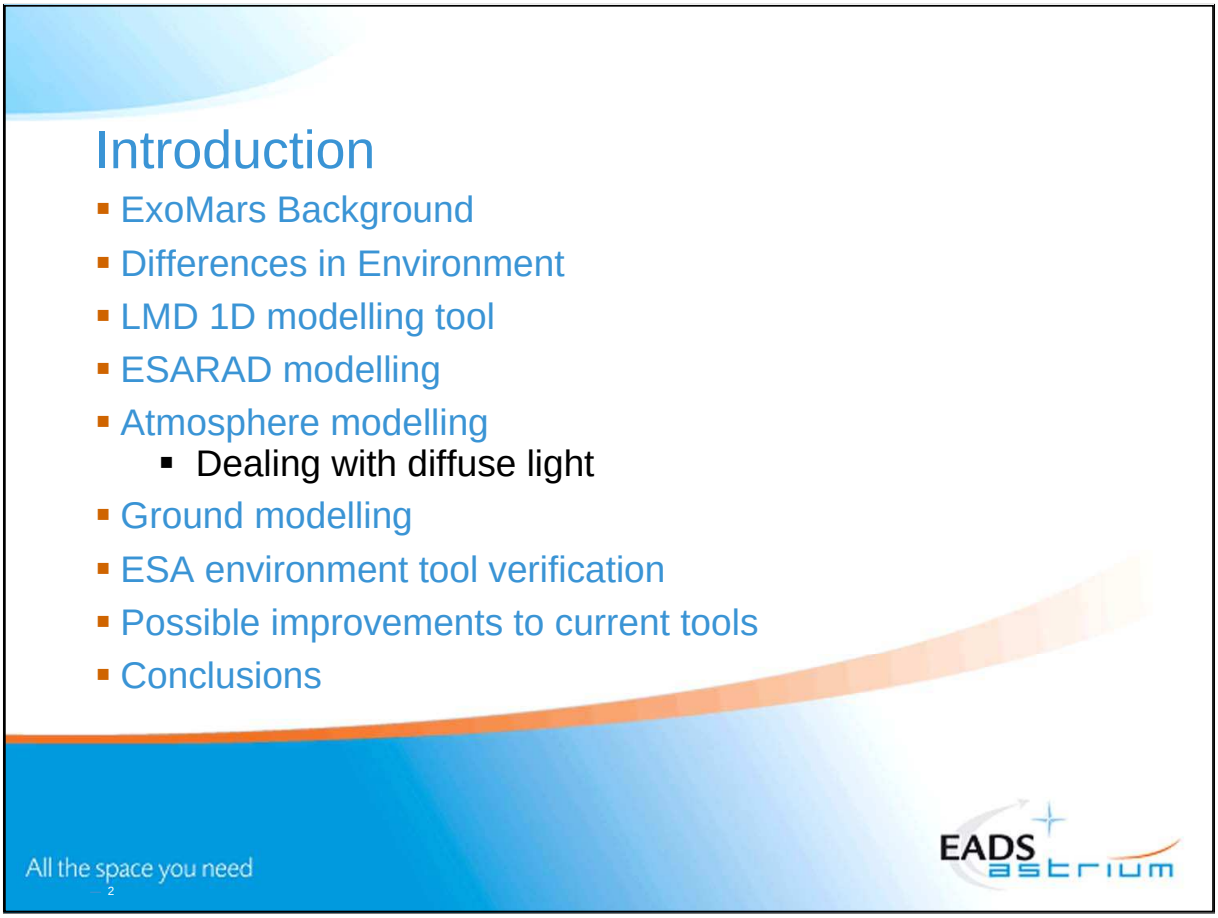
Introduction
ExoMars Background
Differences in Environment
LMD 1D modelling tool
ESARAD modelling
Atmosphere modelling
Dealing with diffuse light
Ground modelling
ESA environment tool verification
Possible improvements to current tools
Conclusions
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ExoMars Background

- Prime Contractor Thales Alenia Space in Turin
- Astrium UK Rover Vehicle lead
- Nominal launch in 2013 with backup in 2015
- Landing in 2015/16
- Recently completed phase B2
- PDR held in September

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Environment Differences

- Atmosphere
  - Primarily CO_2
  - Pressure range 570-700 Pa
  - Temperature range -125 to 5 °C
- Variation in suspended dust
  - Affects how flux reaches rover
  - Varies over year and over short periods
- Diffuse light
- Planet surface, not an orbit

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LMD Modeling tool

- Tool created at the Laboratoire de Météororologie Dynamique in Paris under ESA contract
- Based on European Mars Climate Database
- Builds on previous power analysis tool
- Includes surface temperature, solar flux, diffuse flux and effective sky temperature as outputs.
- Outputs such as sky temperature and diffuse flux used directly in model
- Other parameters used to verify model outputs

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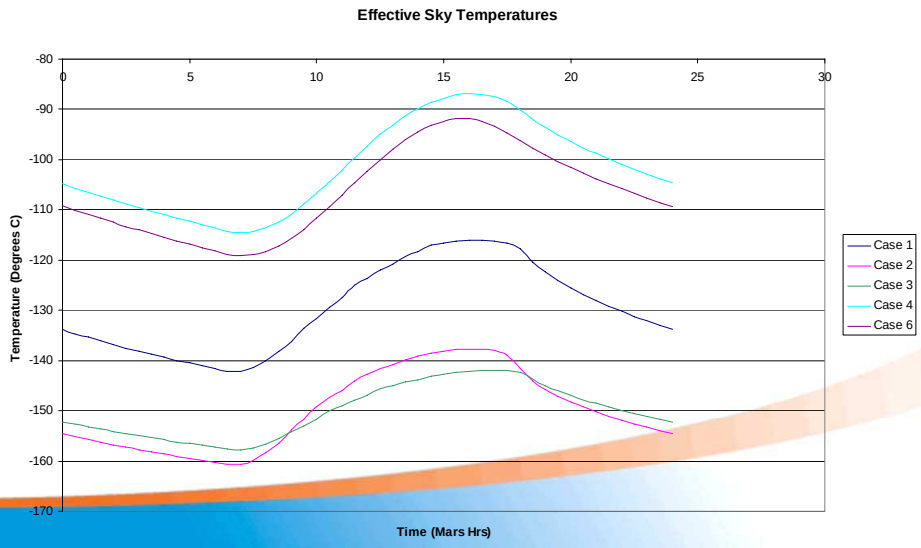
Sky temperatures from LMD tool



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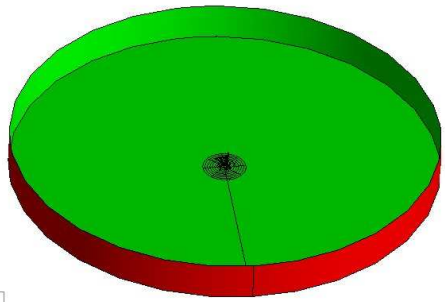
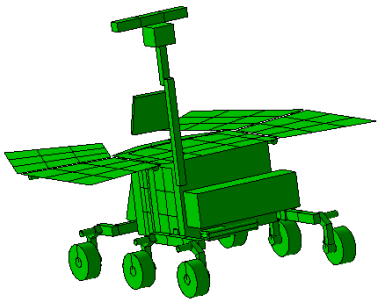
ESARAD Modelling

- Modelled as surface in orbit about sun with mars orbit parameters
- Large sunshade including cylinder for horizon at 10°
- 1 day orbit arc considered
- Geometry model rotated to angle of latitude
- Geometry reference axes rotated in line with axial tilt
- Planet rotation introduced around tilted axis





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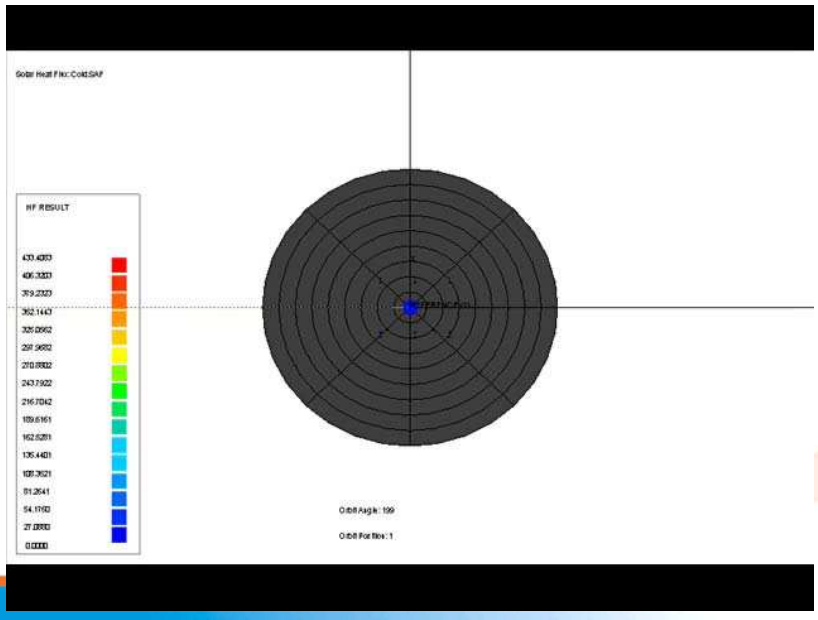

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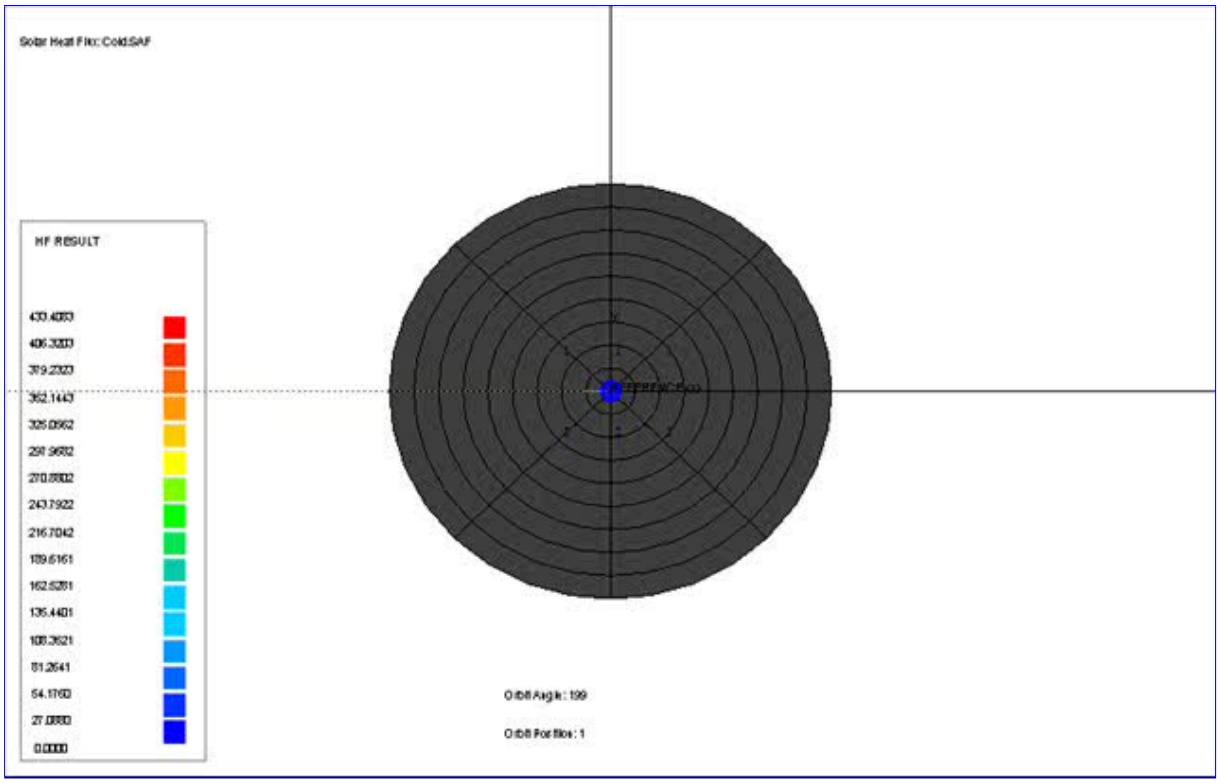
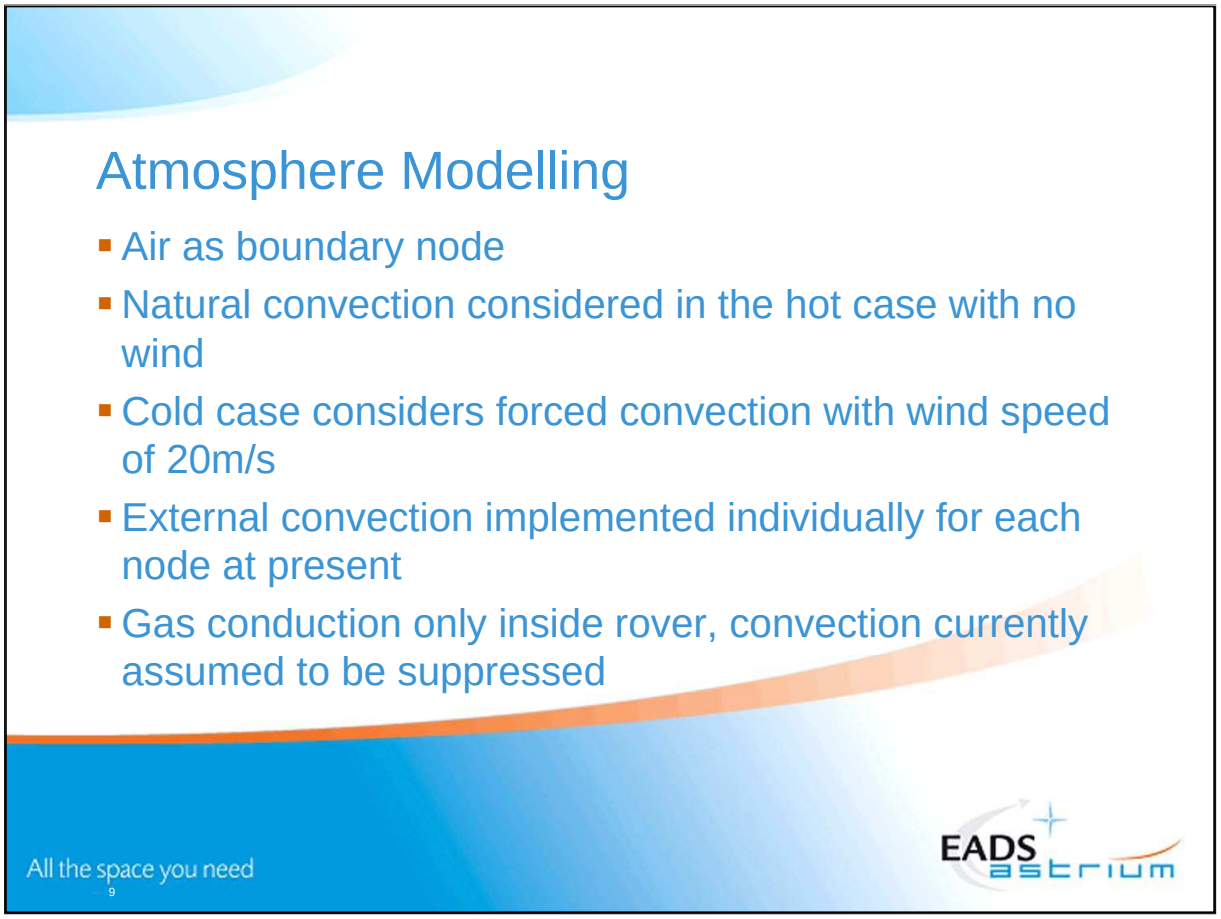


If clicking on the picture above does not run the movie then try opening the file ‘movies/ewtes-flux-anim.html’ manually.



Handling Solar Flux

- Can't be handled entirely in ESARAD
- Dust optical depth major parameter
  - Affects effective Sky temperature
  - Proportion of direct/diffuse light
- Sky temperature determined from external tool
- Tool cannot handle shadowing and reflections
- Optical depth factor applied to ESARAD generated direct flux
- Diffuse flux applied using model GR's to space

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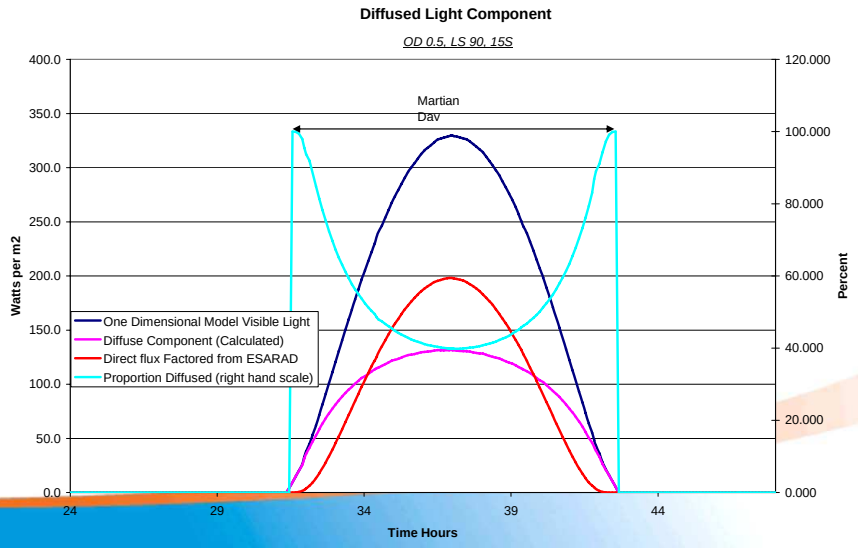
Diffuse light



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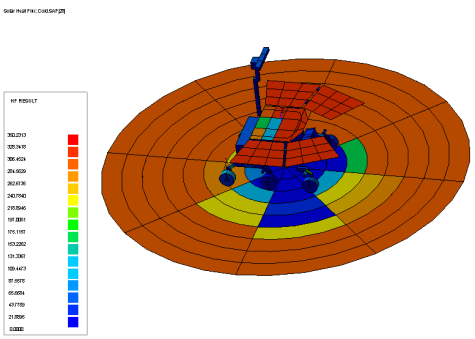
Ground Modelling

- Dynamic ground model local to rover
- Large boundary remote from rover
- 72 nodes at surface in detailed ground
- 5 nodes deep under surface
  - Simplified version of ESA model
- All coupled through to a subsurface boundary node



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Ground variation

- Ground parameters vary across surface
- Major parameter is ground thermal inertia

$$I = \sqrt{\lambda C}$$

- Light dusty surface means large daily temperature variation
- Solid hard rock means smaller daily temperature variation
- Diurnal T^4 average temp unaffected by thermal inertia.

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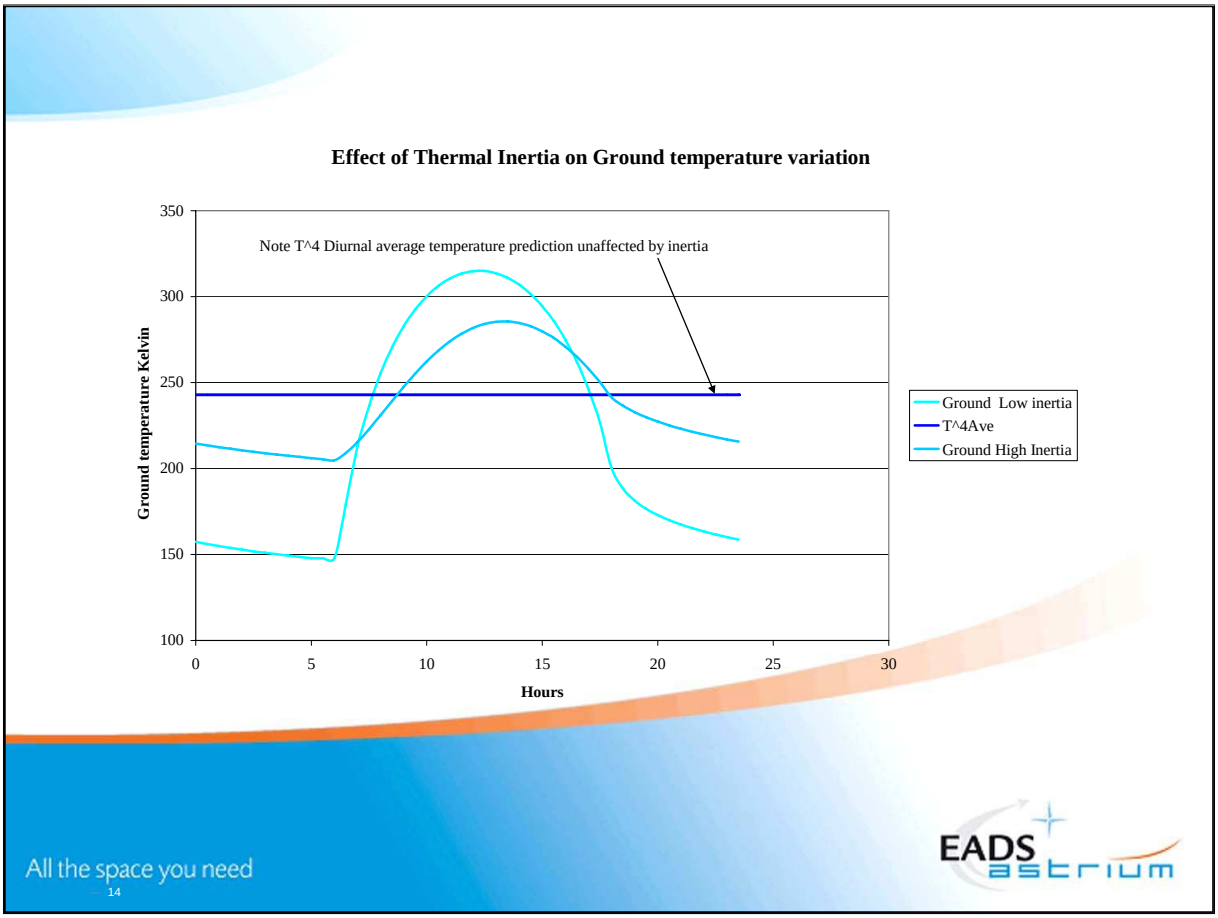
Effect of Thermal Inertia on Ground temperature variation
Note T^4 Diurnal average temperature prediction unaffected by inertia
Ground temperature Kelvin
350
300
250
200
150
100
0
5
10
15
20
25
30
Hours
Ground Low inertia
T^4Ave
Ground High Inertia
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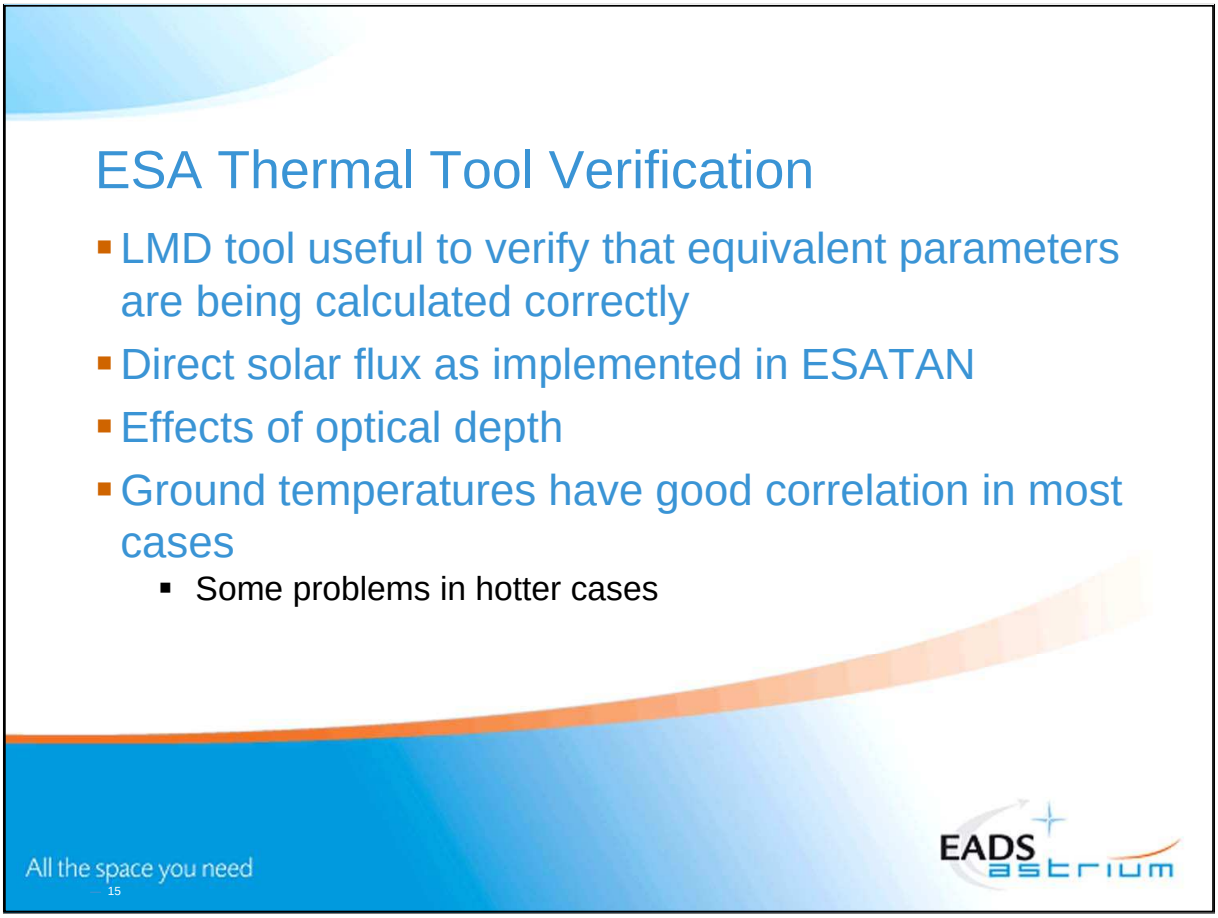
ESA Thermal Tool Verification
LMD tool useful to verify that equivalent parameters are being calculated correctly
Direct solar flux as implemented in ESATAN
Effects of optical depth
Ground temperatures have good correlation in most cases
Some problems in hotter cases
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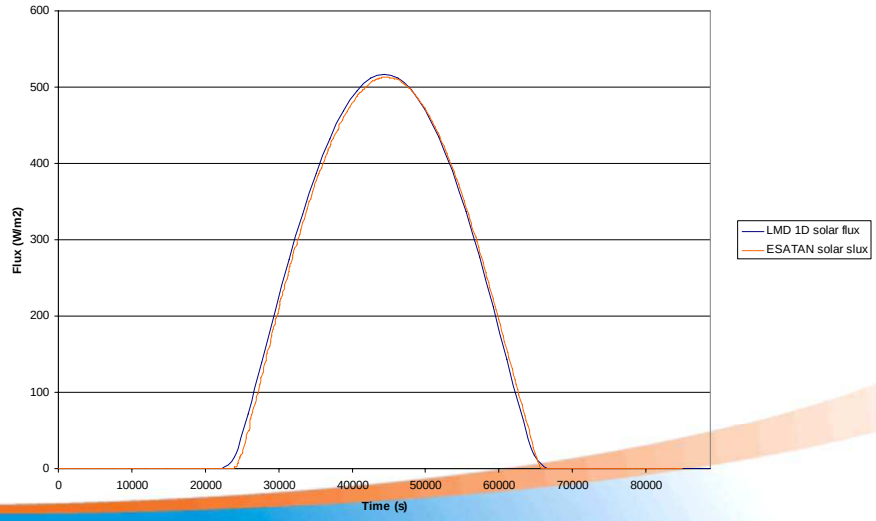
Solar flux comparison



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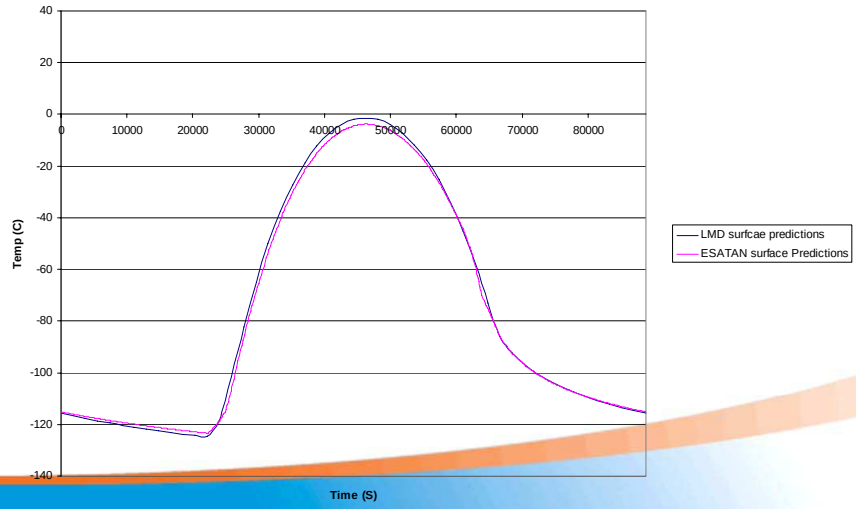
Ground temperature comparison



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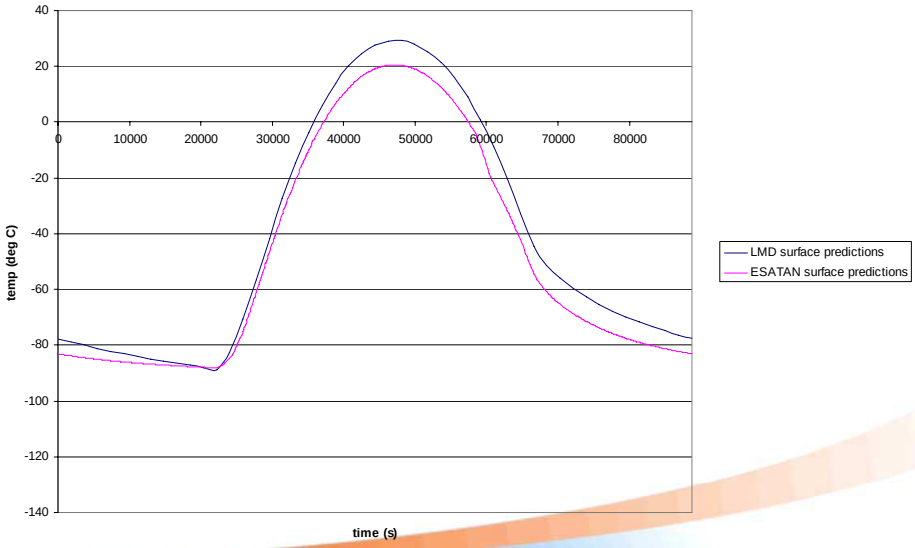

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Tool Improvement Suggestions

- Not possible to place model on planet surface in ESARAD
- Night time calculated like eclipse periods
- Optical depth inclusion for solar flux calculations
  - Straightforward for direct flux
  - More complex for diffuse flux
- Better method for calculating external convection
  - Have considered using TMG as a pre-processor

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Conclusions

- Determined good method of using esarad for planetary surface analysis
- Solar and IR radiation modeling considering suspended dust implemented
  - Including diffuse light
- Dynamic ground model created including local shadowing effects
- Ground model only verified in certain cases

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