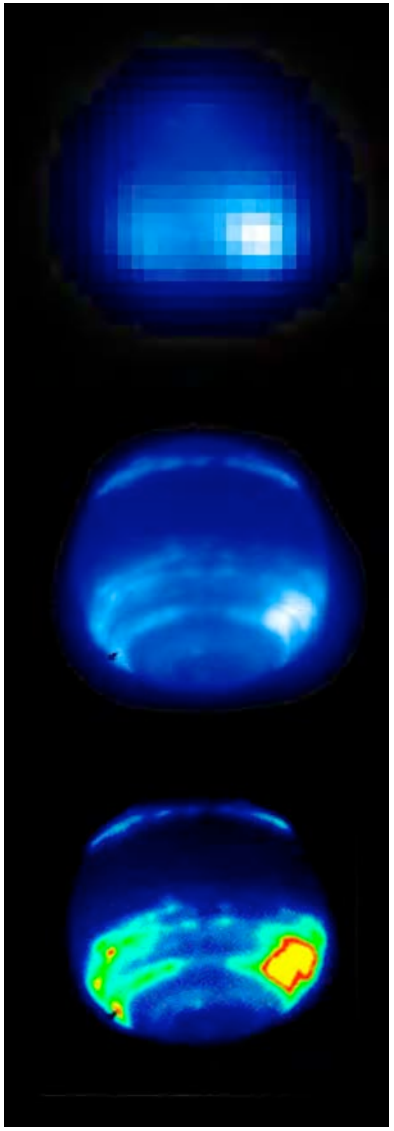

Session 7 "Cross-Cutting Technologies for Probe Missions"

Global Reference Atmospheric Models for Aeroassist Applications

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3rd International Planetary Probe Workshop
Anavyssos, Attiki, Greece
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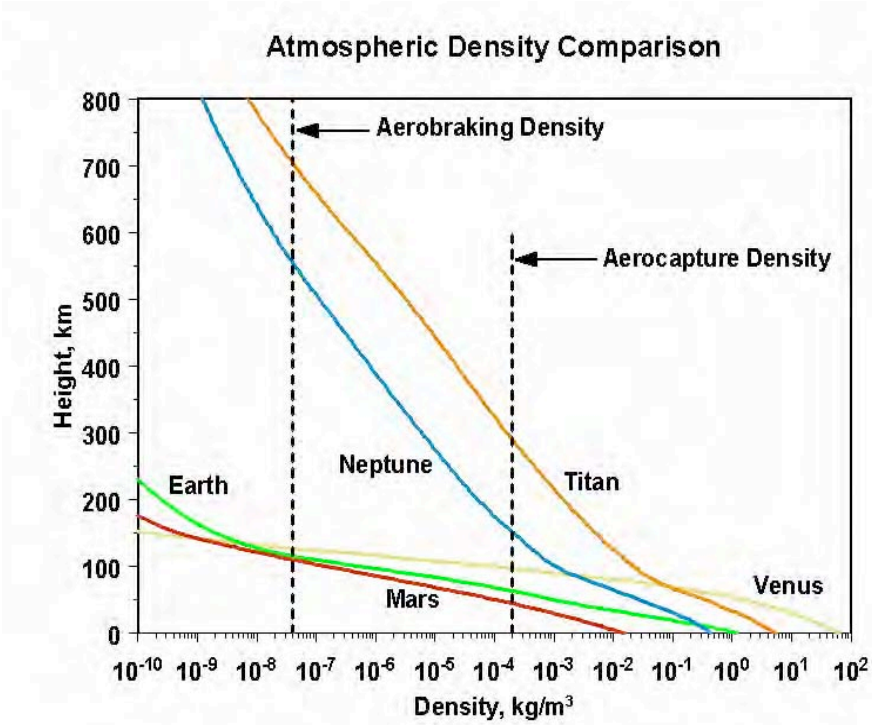
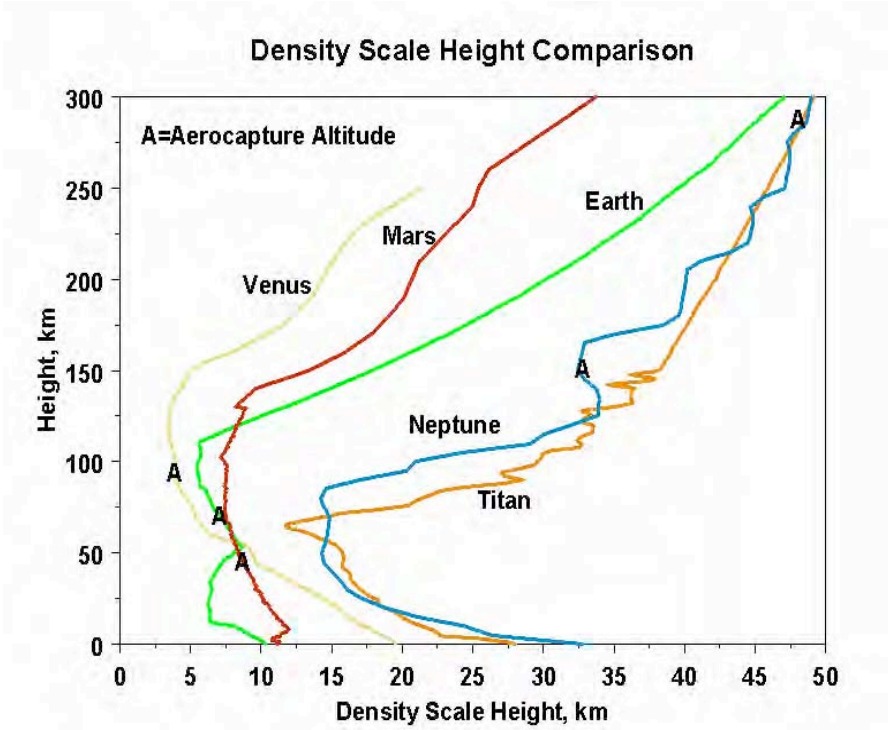
What is the Global Reference Atmospheric Model (GRAM) series?

- Series of engineering reference atmospheric models for aeroassist targets within the Solar System: engineering tool set.
- Originally conceived as electronic version of COSPAR International Reference Atmospheres (e.g., CIRA, MIRA, VIRA)
- Incorporate observational data - probe, satellite, ground-based - and climatology - GUACA, GGUAS, RRA for Earth, General Circulation Model output for other targets - to characterize global mean atmospheric state.
- Some large-scale variability is inherent in observations (e.g. gravity wave effects). Additional considerations for global coverage include seasonal and time-of-day variability and measurement uncertainty.
- GRAM series addresses these considerations via user-tunable parameters.
- Small-scale variability (e.g., density fluctuations) also user-tunable.
- Portable, computationally efficient, general release FORTRAN software.
- Current GRAM series comprises GRAM-99, Titan-GRAM 2004, Neptune-GRAM 2004, Mars-GRAM 2005, Venus-GRAM 2005.
- Complete GRAM series to include Jupiter-GRAM, Saturn-GRAM, Uranus-GRAM, subject to directed funding!

Global Reference Atmospheric Models for Aeroassist Applications





Models in the GRAM series have been utilized in:

Aerobraking operations (Mars Global Surveyor, Mars Reconnaissance Orbiter)

Aerocapture systems analysis studies (Titan, Neptune, Venus, Mars)

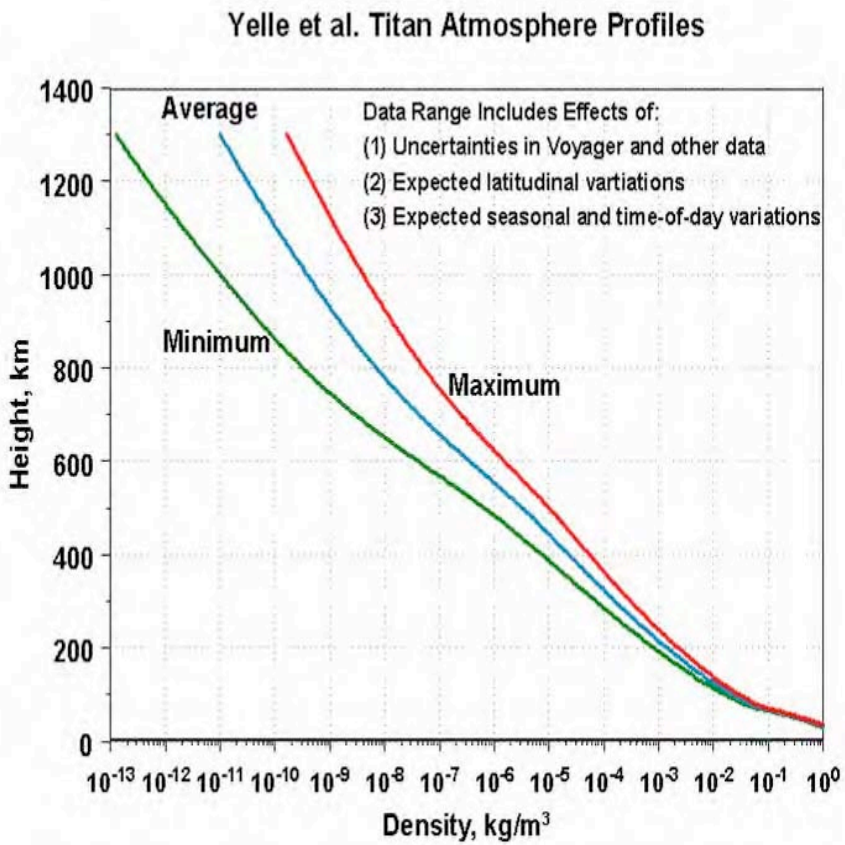
- LaRC POST Monte Carlo trajectory simulations

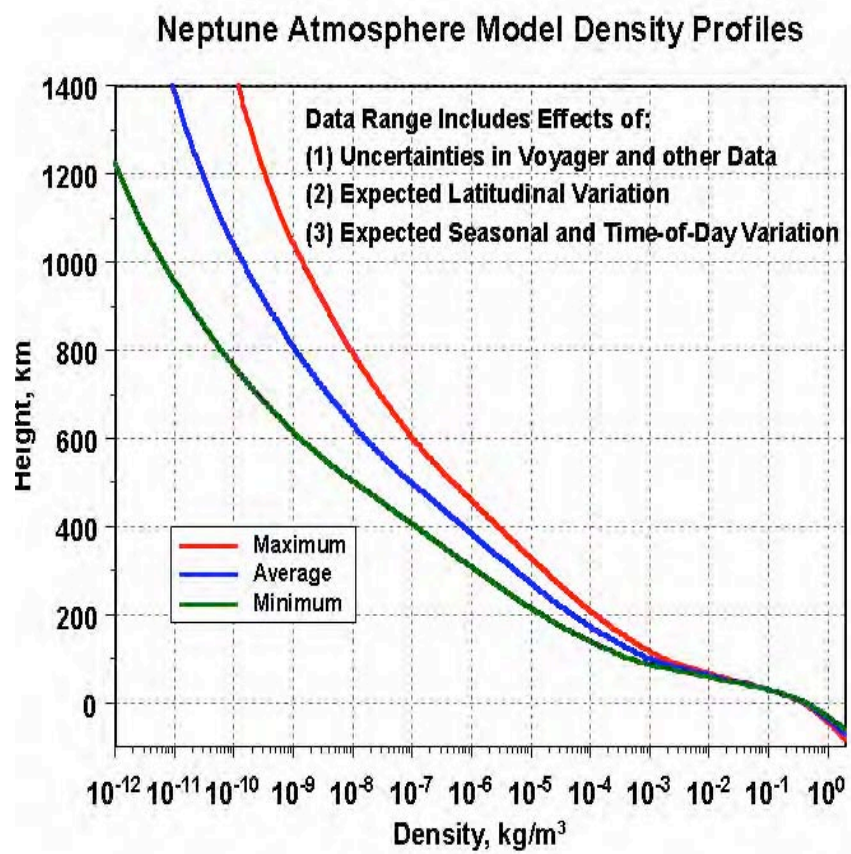
Direct aeroentry operations and analysis (Earth, Mars, Titan)

- Earth Orbiter operations, Genesis wind sensitivity study

- Mars Ascent Vehicle design study

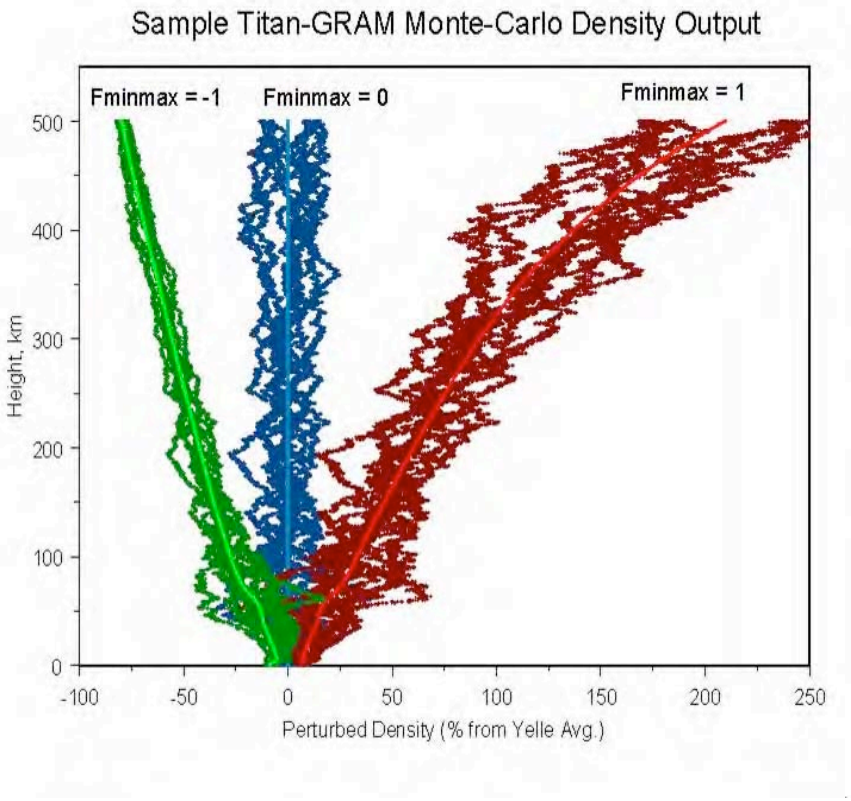
- NESC-sponsored Cassini-Huygens ITA/I

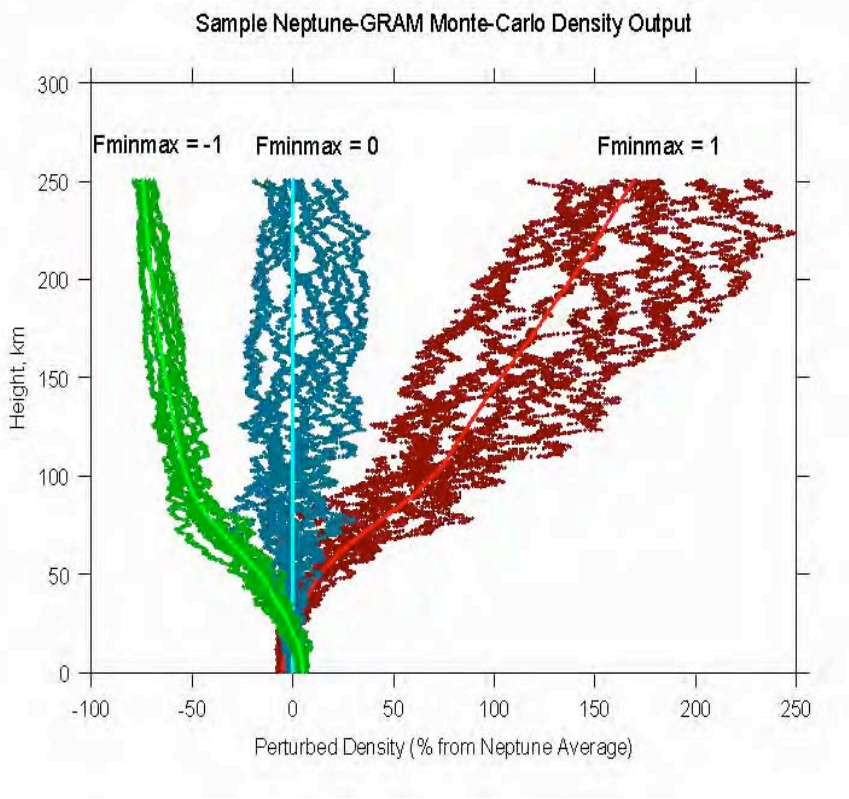




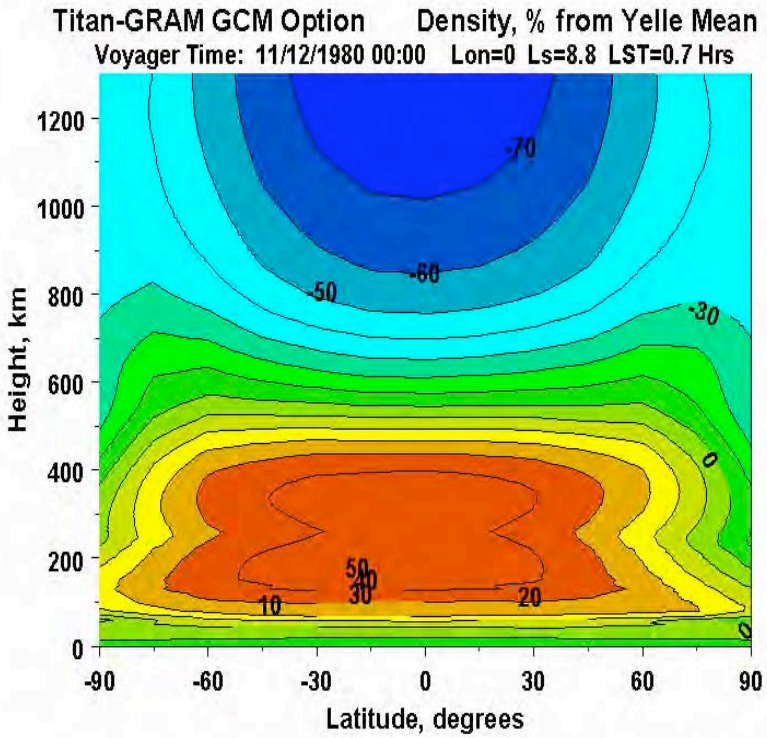
Titan-GRAM and Neptune-GRAM representations of minimum (fminmax = -1), average (fminmax = 0), and maximum (fminmax = 1) atmospheric density profiles. Here, random perturbation scale factor (rpscale) = 0.

Titan-GRAM (from [1]) and Neptune-GRAM (from [2]) released for general distribution in September, 2004. Titan-GRAM undergoing updates based on Cassini flyby and HASI findings.

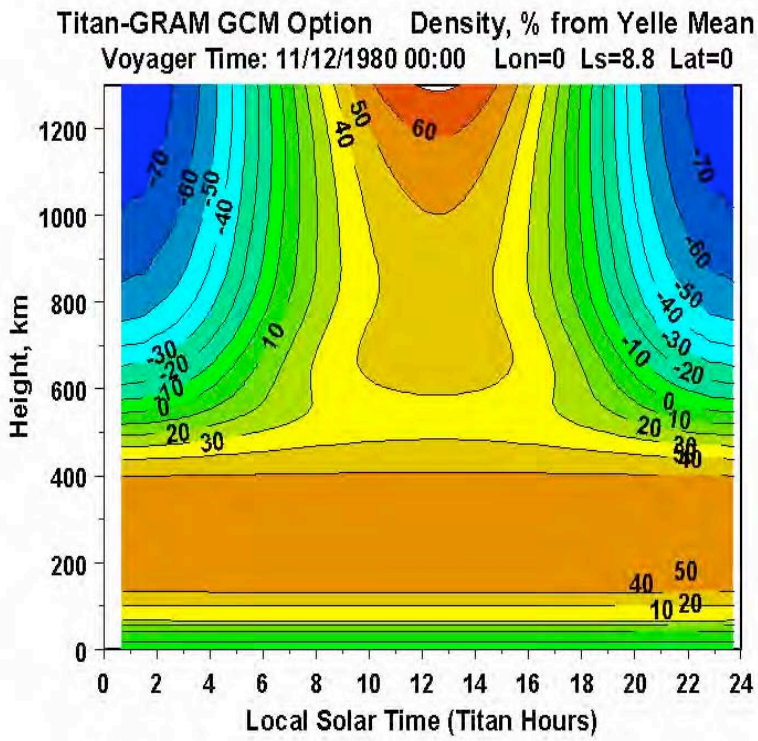




Titan-GRAM and Neptune-GRAM representations of small-scale variability in atmospheric density (rpscale = 1) as superimposed on minimum (fminmax = -1), average (fminmax = 0), and maximum (fminmax = 1) density deviations from average.

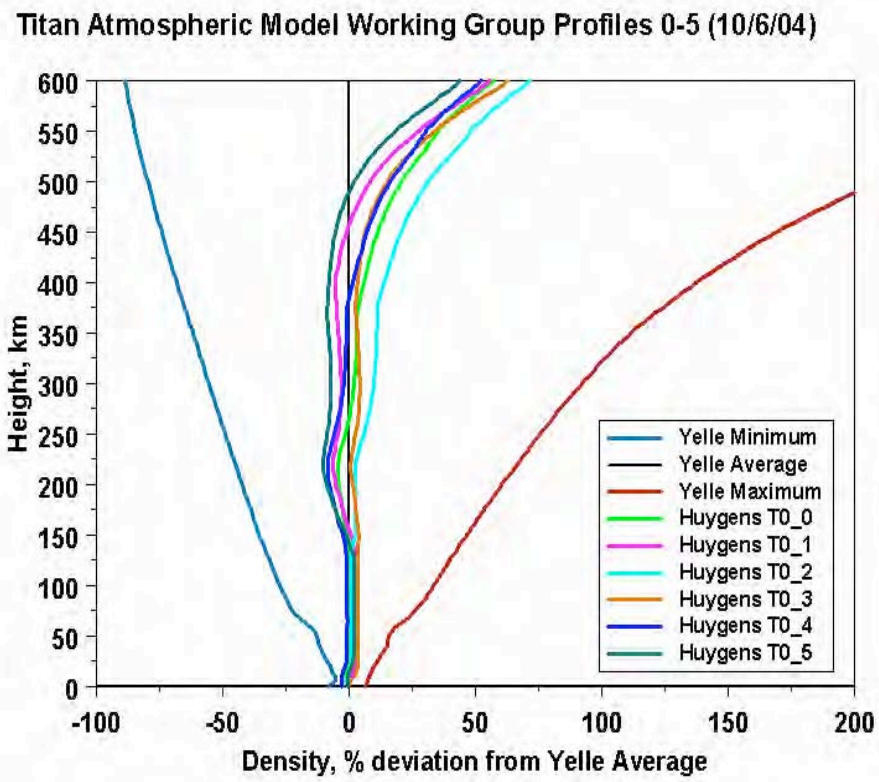


Height vs latitude cross-section of density percent deviation from average.

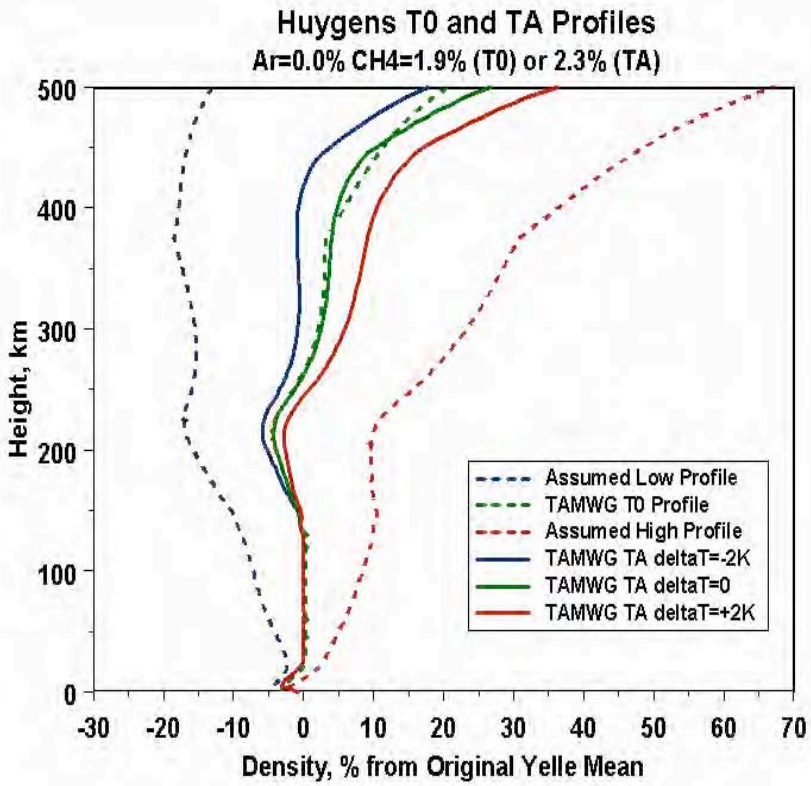


Height vs Local Solar Time cross-section of density percent deviation from average.

Titan-GRAM GCM Option (from [3]) density comparisons with Yelle average.

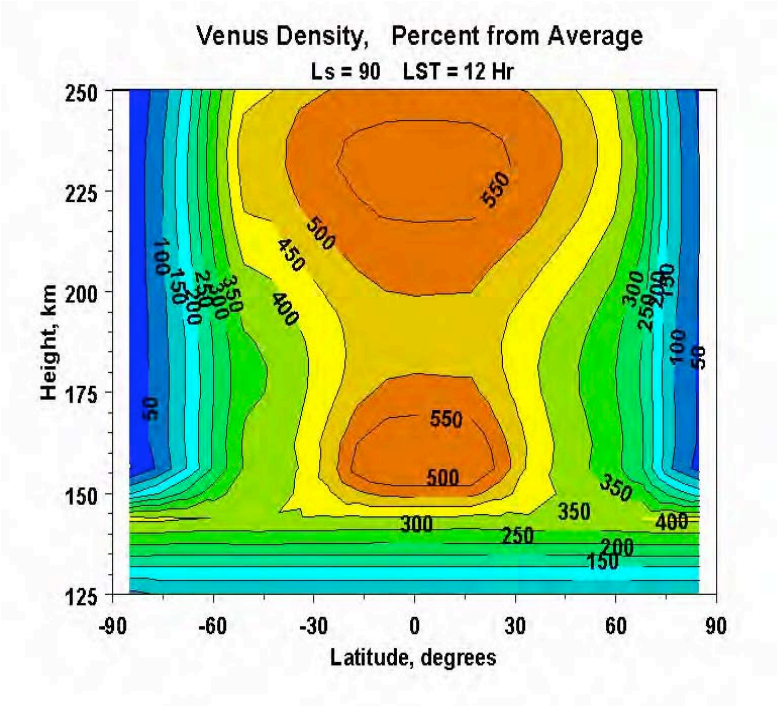


Comparison of Yelle minimum (fminmax = -1), average (fminmax = 0), and maximum (fminmax = 1) density profiles with TAMWG Cassini T0 flyby estimates.

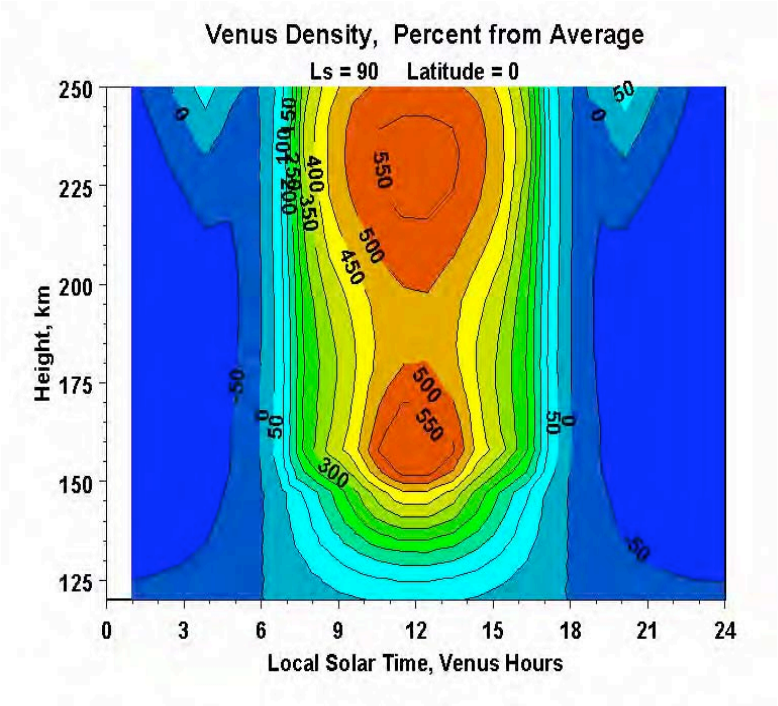


Comparison of Cassini T0 density estimates with TAMWG Cassini TA flyby estimates.

Comparison of pre-Cassini/Huygens density profiles with Cassini T0 and TA flyby estimates.



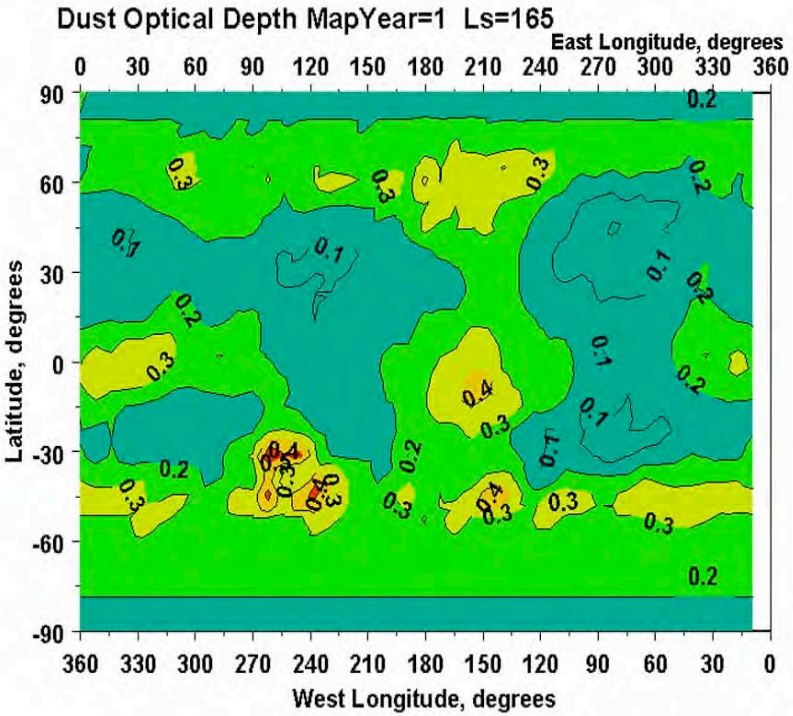
Height vs latitude cross-section of density percent deviation from average.

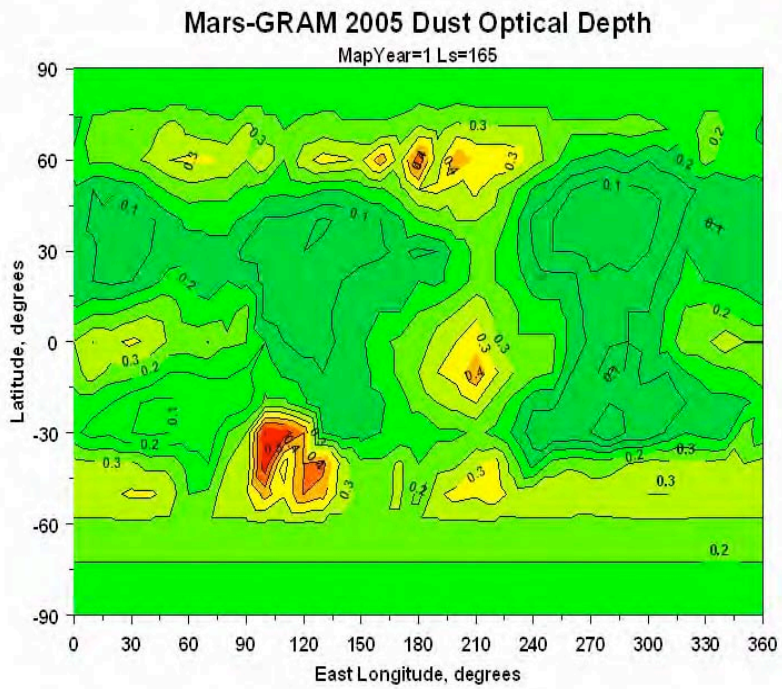


Height vs Local Solar Time cross-section of density percent deviation from average.

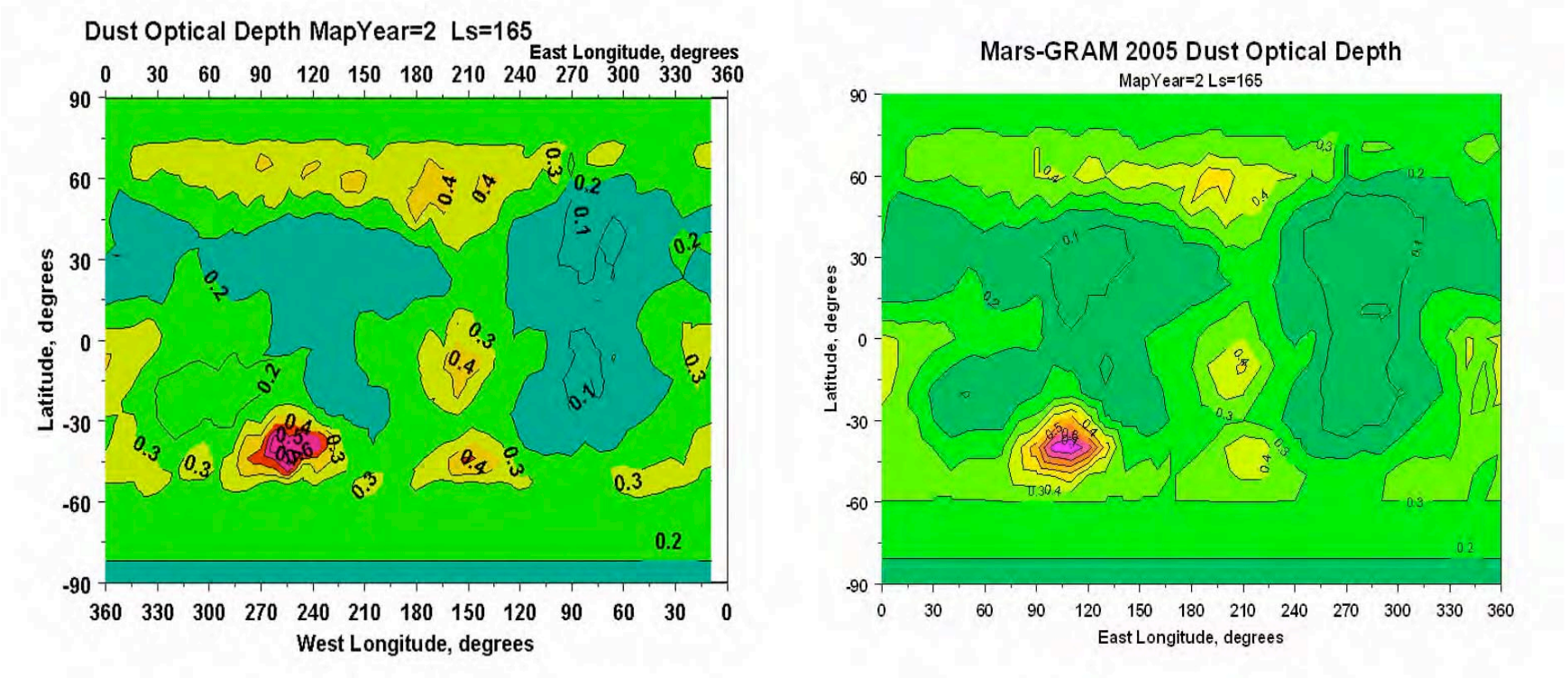
Venus-GRAM (from [4]) density comparisons with VIRA average.

- **Mars-GRAM 2005 released for general distribution in March, 2005**
- **Global climatologies at "monthly" (30 deg of Ls) resolution**
  - **NASA Ames Mars General Circulation Model (MGCM)**
    - **Surface to 80 km altitude**
    - **Original (Mars-GRAM 2001) global data from MGCM driven by uniform dust optical depth (tau) values of 0.3, 1.0, and 3.0**
    - **New global data from MGCM driven by tau distribution observed by Mars Global Surveyor Thermal Emission Spectrometer (TES) during mapping years 1 (no global dust storm) and 2 (major global dust storm peaking at Ls = 210 deg)**
      - **Mars-GRAM 2001 uniform dust optical depth ⇔ MapYear = 0**
      - **TES Mapping Year 1 ⇔ Apr, 1999 – Jan, 2001 ⇔ MapYear = 1**
      - **TES Mapping Year 2 ⇔ Feb, 2001 – Dec, 2002 ⇔ MapYear = 2**
  - **University of Michigan Mars Thermospheric GCM (MTGCM) Data**
    - **80 to 170 km (80 to 240 km for new MTGCM climatologies)**
    - **Same climatologies as for MGCM (original uniform dust cases and new TES observed dust cases)**
    - **MGCM values at 80 km used as lower boundary conditions for MTGCM**
    - **MTGCM extended upward with modified Stewart thermosphere model**
- **New Auxiliary Profiles Option**

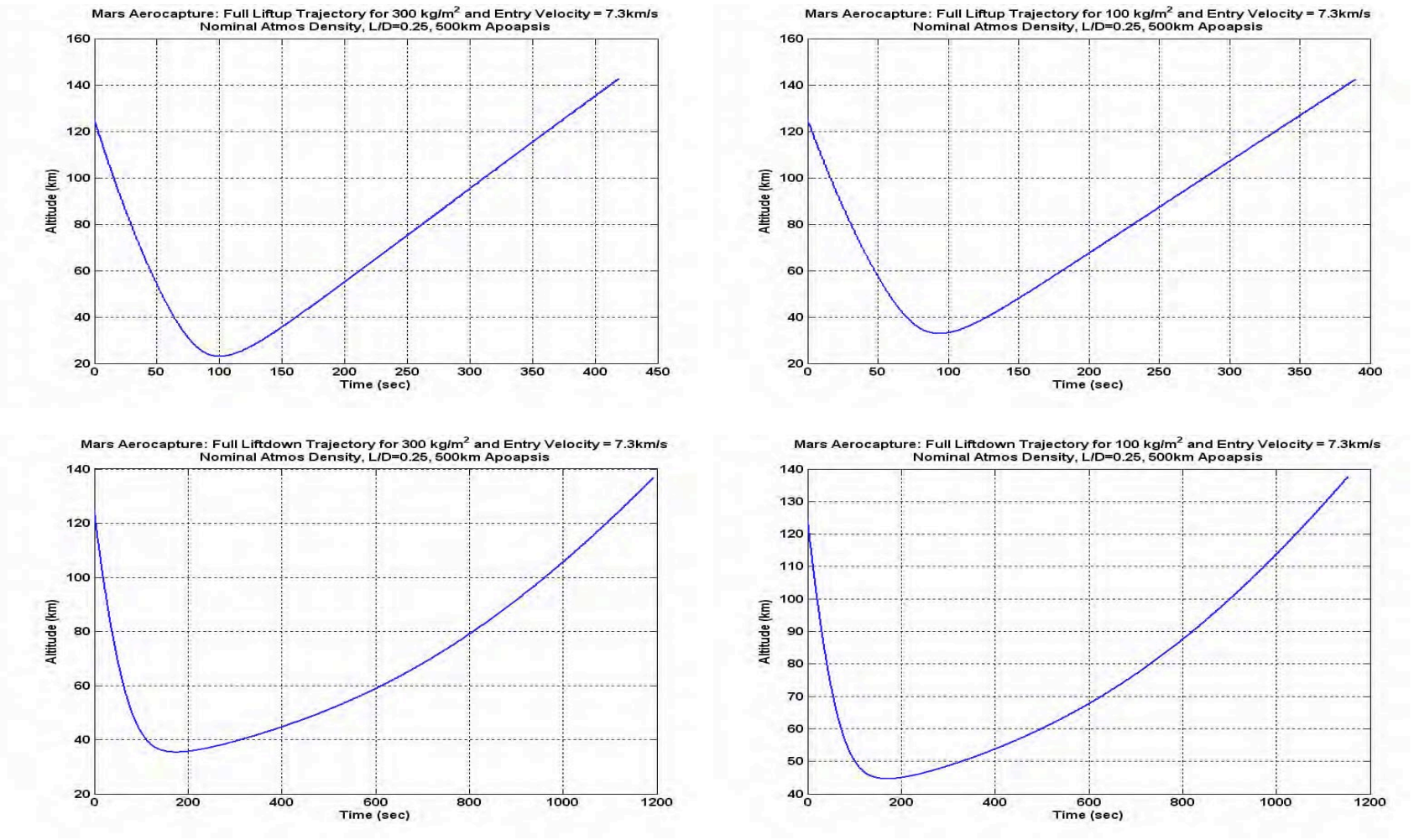




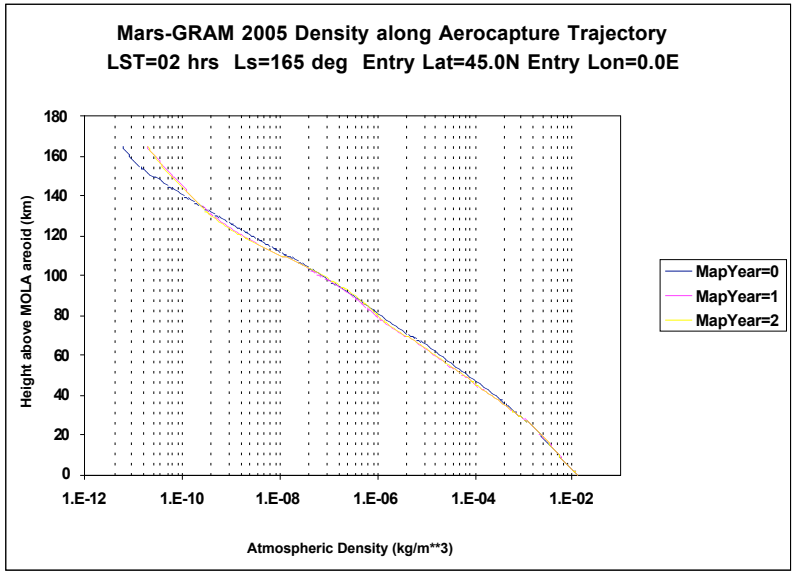
Comparison of latitude-longitude distributions of dust optical depth: TES observed (left) vs Mars-GRAM climatology, MapYear = 1 (right). Mars arrival date: 07/23/2014.

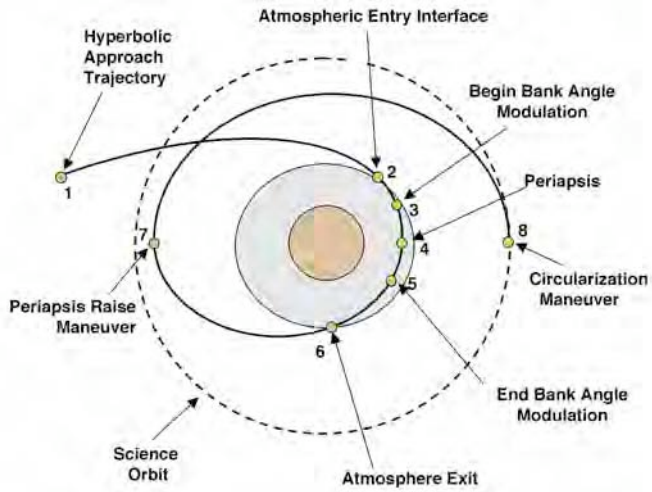


Comparison of latitude-longitude distributions of dust optical depth: TES observed (left) vs Mars-GRAM climatology, MapYear = 2 (right). Mars arrival date: 07/23/2014

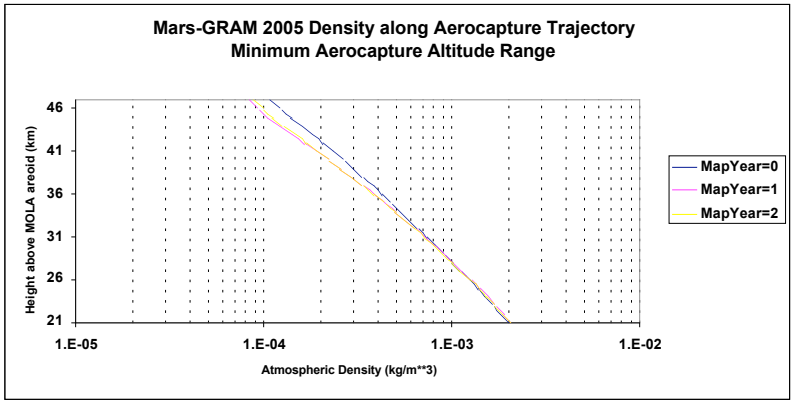


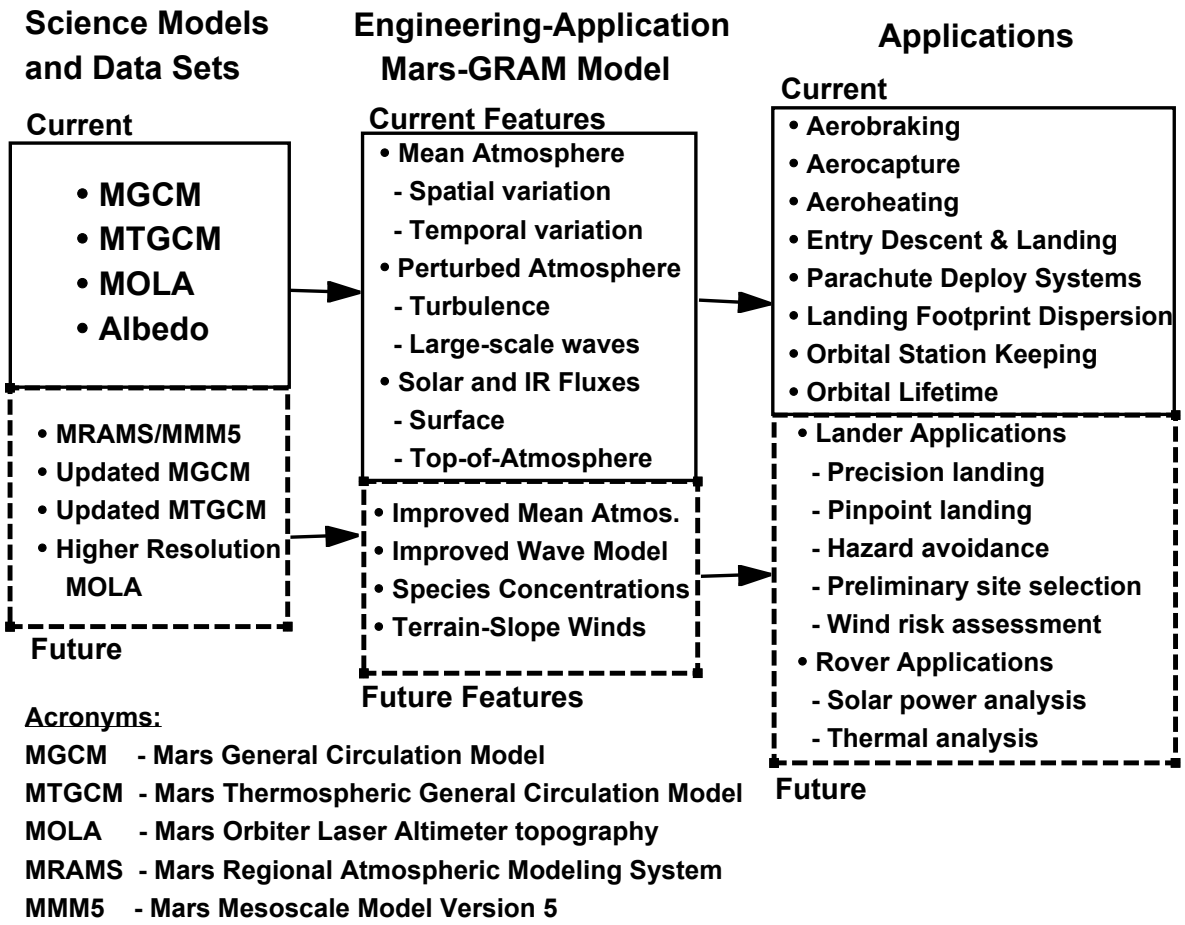
Mars Aerocapture Systems Analysis Theoretical Corridor Definition Trajectories (C. Westhelle, 02 June 2005)





Atmospheric Entry Conditions:
Lat/Lon/Azimuth = 5.0/0.0/0.0
Entry Altitude = 125 km
L/D = 0.25
Inertial Entry Velocity = 7.3 km/s
Ballistic Coefficient = 100-300 kg/m^2





Acronyms:

MGCM - Mars General Circulation Model
MTGCM - Mars Thermospheric General Circulation Model
MOLA - Mars Orbiter Laser Altimeter topography
MRAMS - Mars Regional Atmospheric Modeling System
MMM5 - Mars Mesoscale Model Version 5

Mars-GRAM Current and Future Applications

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[1]Yelle, R. V., Strobel, D. F., Lellouch, E., and Gautier, D., "Engineering Models for Titan's Atmosphere", in *Huygens: Science, Payload, and Mission*, ESA SP-1177, August, 1997.

[2]Cruikshank, D. P. (ed.), *Neptune and Triton*, University of Arizona Press, Tucson, 1995.

[3]Hourdin, F., Talagrand, O., Sadourny, R., Courtin, R., Gautier, D., and McKay, C. P., "Numerical Simulation of the General Circulation of the Atmosphere of Titan", *Icarus*, Vol. 117, No. 2, October 1995, pp. 358-374.

[4]Kliore, A. J., Moroz, V. I., and Keating, G. M. (eds.), "The Venus International Reference Atmosphere", Advances in Space Research, Vol. 5, No. 11, 1985, Pergamon Press, Oxford, 1986, pp. 1-304.