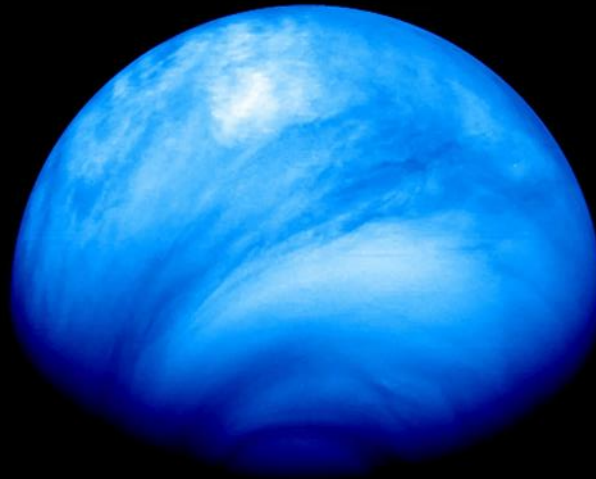# Venus Global Reference Atmospheric Model

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Venus-GRAM

- Venus Global Reference Atmospheric Model (Venus-GRAM) is an engineering-level atmospheric model developed by MSFC that is widely used for diverse mission applications including:
  - Systems design
  - Performance analysis
  - Operations planning for aerobraking, Entry, Descent and Landing, and aerocapture
- Is not a forecast model
- Outputs include density, temperature, pressure, wind components, and chemical composition
- Provides dispersions of thermodynamic parameters, winds, and density
- Optional trajectory and auxiliary profile input files
- Has been used in multiple studies and proposals including NASA Engineering and Safety Center (NESC) Autonomous Aerobraking and various Discovery proposals
- Released in 2005
- Available at: https://software.nasa.gov/software/MFS-32314-1

Venus-GRAM Atmosphere (0-250 km)

- From the surface to 250 km, Venus-GRAM atmosphere model is based on the Venus International Reference Atmosphere (VIRA)

- Lower atmosphere: 0 - 100 km

  - VIRA data depends on height and latitude

- Middle-atmosphere: 100 - 150 km

  - VIRA data depends on height and local solar time (LST = 0 or LST = 12 Venus hours)

- Upper-altitude: 150 - 250 km

  - VIRA data depends on height and solar zenith angle

- Venus-GRAM ensures smooth variation between height regions by averaging values at the two transition heights (100 km and 150 km)

- Version of VIRA in Venus-GRAM includes Pioneer Venus Orbiter and Probe data as well as Venera probe data

  - Does not include a solid planet model, nor a high resolution gravity model

Venus-GRAM Thermosphere (250–1000 km)

- The Venus-GRAM thermosphere (250 - 1000 km) is based on a MSFC-developed model
- Model assumptions:
  - VIRA conditions and constituents at 250 km are used as lower boundary values
  - Constant (exospheric) temperature is assumed above 250 km (exospheric temperature = local VIRA temperature at 250 km)
  - Hydrostatic conditions are computed separately for each constituent (diffusive separation)
  - Total pressure is computed from constituent partial pressures
  - Mass density is computed from constituent number densities

Venus-GRAM Thermosphere Model

- Exospheric temperature is highest (about 300K) for a few hours on either side of solar noon

- Normally, hydrostatic conditions mean that densities at high altitudes are larger for higher exospheric temperatures

  - Density increases as the entire atmospheric column expands, because of larger temperatures

- Above about 300 km altitude, density is at a relative minimum near solar noon, despite the higher values of exospheric temperature at this time of day

Log10(Density,kg/m^3) or Exospheric Temperature Ls=0 Lat=0
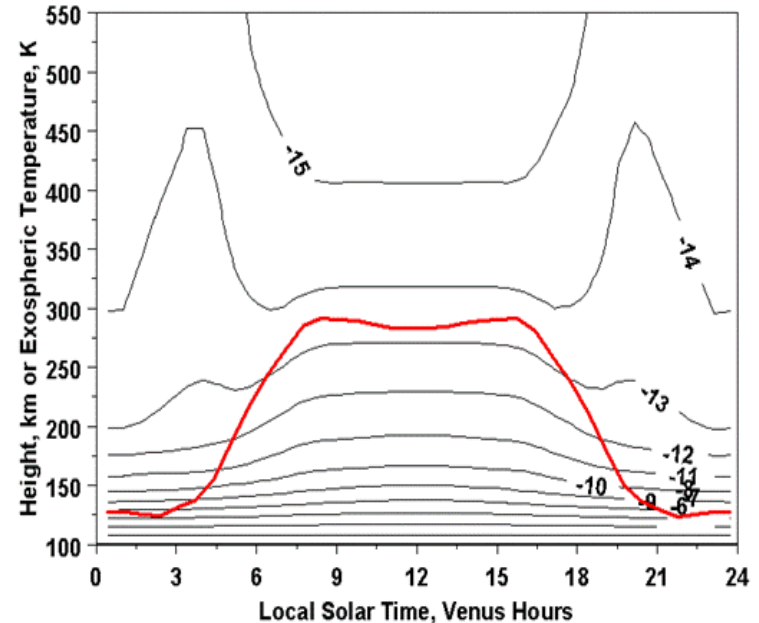
Contours of Venus thermospheric density versus altitude and time of day, and a plot of exospheric temperature (red line) versus time of day, at Latitude=0, Ls=0 (Spring equinox). Density contours are labeled in units of Log base-10 of density in kg/m^3
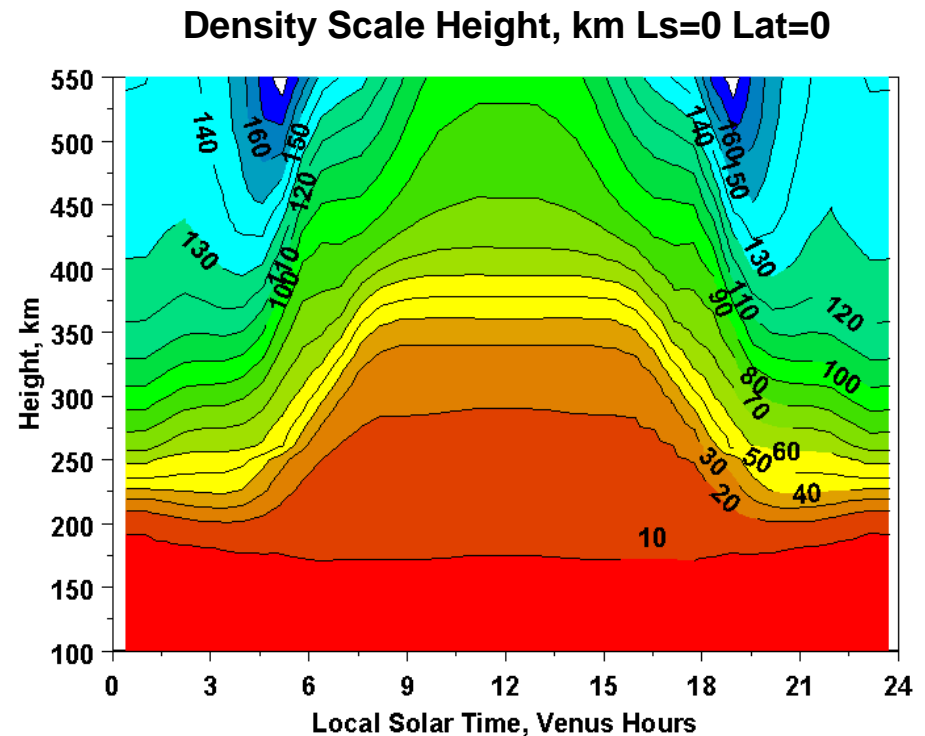
Venus-GRAM Thermosphere Model

- Anomaly can be explained by examining the relationship between the mean molecular weight (M) and density scale height (H) versus altitude and local time

- H is proportional to T / M, where T is temperature

- Higher exospheric temperature near noon would tend to make H larger near this time of day

- Higher values of M near noon would tend to make H smaller near this time of day

Molecular Weight Ls=0 Lat=0

Contours of Venus mean molecular weight (M) versus altitude and time of day
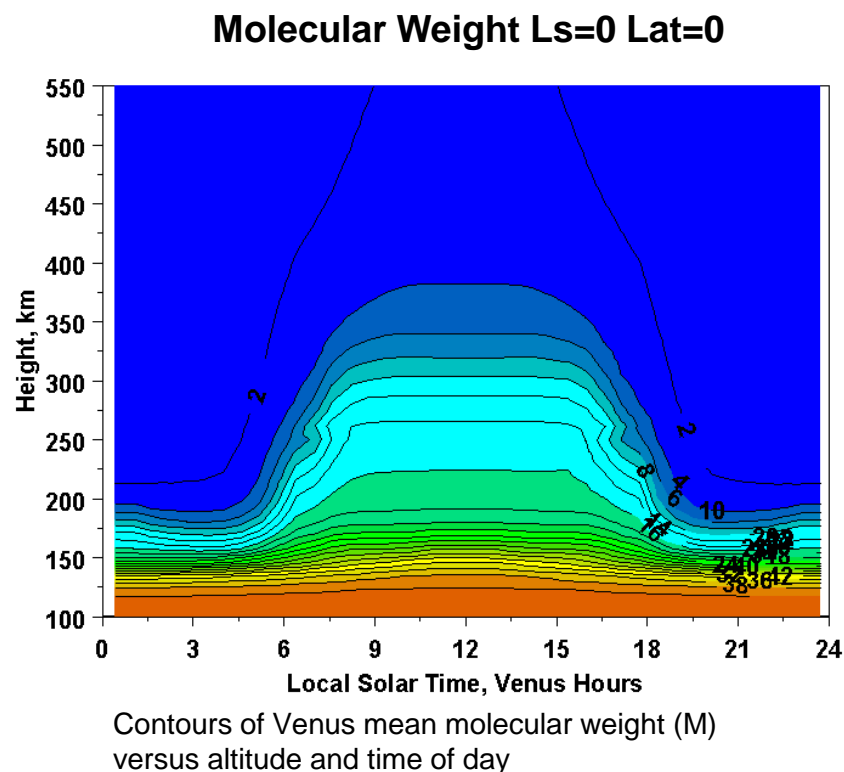
Venus-GRAM Thermosphere Model

- For conditions of Ls=0, Lat=0, the M effect dominates, making H smaller near noon
- Density varies with altitude z as $Exp(-z/H)$
  - Smaller H near noon means that density falls off more rapidly near noon than in morning or afternoon.
- Thus, above about 300 km altitude, density is at a relative minimum near solar noon

Density Scale Height, km Ls=0 Lat=0

Contours of Venus density scale height (H) versus altitude and time of day

Venus-GRAM Data Upgrades

- Evaluating several Venus atmosphere models and data sources that can be utilized to update Venus-GRAM:
  - Updated VIRA model in work (Sanjay Limaye et al.)
  - Earth observation data of Venus
  - Venus Express data
  - Magellan surface and gravity field data
  - Updated Venus Thermospheric General Circulation Model (VTGCM) and Venus General Circulation Models (VGCMs)
  - Development of a Venus Global Ionosphere-Thermosphere Model (V-GITM) (Steve Bougher (University of Michigan))
- Additional suggestions would be appreciated

Venus-GRAM Capability Upgrades

- Convert model code from Fortran to C++
  - Easier to incorporate in trajectory simulation software
- Identify high priority items that would enable mission modeling that are not currently available. Examples include:
  - Incorporating a higher resolution topography model for probe mission analysis
  - Utilizing Venus Express data to build sets of auxiliary profiles for representation of mean atmospheric conditions in Venus-GRAM
  - Characterizing observed atmospheric variability and update perturbation models for density, temperature, and winds in Venus-GRAM
- Additional suggestions would be appreciated