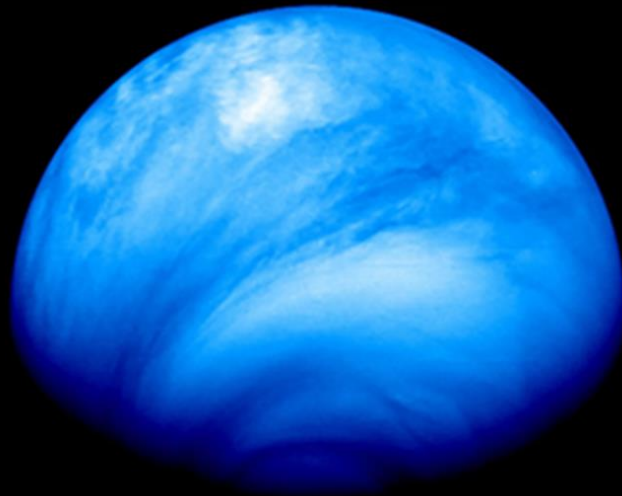


Venus Global Reference Atmospheric Model (Venus-GRAM) Updates



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**43rd COSPAR Scientific Assembly
January 28 - February 4, 2021**

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Venus-GRAM Overview

- Engineering-oriented atmospheric model developed by NASA Marshall Space Flight Center (MSFC) that estimates mean values and statistical variations of Venus atmospheric properties
- Outputs include atmospheric density, temperature, pressure, chemical composition, and wind components along a user-defined path
- Widely used by the engineering community because of its ability to create realistic atmospheric dispersions
- Can be integrated into high fidelity flight dynamic simulations of launch, entry, descent and landing (EDL), aerobraking and aerocapture
- Has been used in multiple studies and proposals including NASA Engineering and Safety Center (NESC) Autonomous Aerobraking and various Discovery proposals

Venus-GRAM Overview (Continued)

- Optional trajectory input file consisting of time, height, latitude, and longitude can be used to provide the Venus-GRAM trajectory path
- Optional auxiliary profile consisting of height, latitude, longitude, temperature, pressure, density, eastward wind, and northward wind may be used to replace model data in Venus-GRAM
- Not a forecast model
- GRAMs are also available for Earth, Mars, Titan, and Neptune
- GRAMs can be requested through the NASA Software Catalog <https://software.nasa.gov/>

Venus-GRAM Model Data Input (0 - 250 km)

- From the surface to 250 km, input atmospheric data files are from the Venus International Reference Atmosphere (VIRA)¹
- Lower atmosphere: 0 - 100 km
 - VIRA data depend on height and latitude
- Middle atmosphere: 100 - 150 km
 - VIRA data depend on height and local solar time (LST = 0 or LST = 12 Venus hours)
- Upper altitude: 150 - 250 km
 - VIRA data depend on height and solar zenith angle
- Insures 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 Model Data Input (250 - 1000 km)

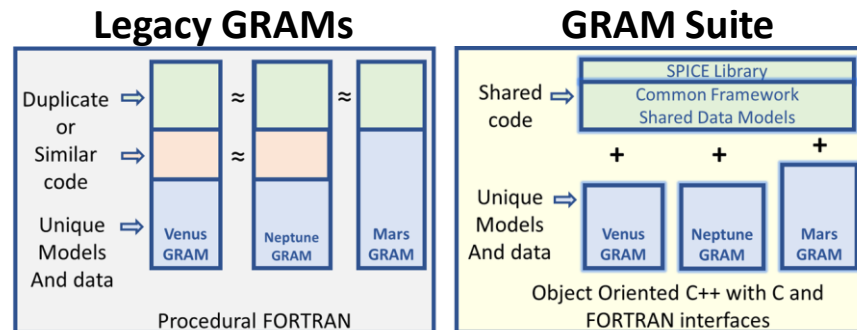
- From 250 - 1000 km, input atmospheric data files are from a MSFC-developed model containing the following assumptions:
 - VIRA conditions and constituents at 250 km are used as lower boundary values
 - Constant (exospheric) temperature is assumed above 250 km (exospheric temperature = local VIRA temperature 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

GRAM Upgrades

- NASA Science Mission Directorate (SMD) has provided funding support to upgrade the GRAMs since Fiscal Year 2018
- GRAM Upgrade Primary Objectives:
 - Modernize the code
 - Develop a new framework that transitions the original Fortran code to C++
 - Take advantage of the object-oriented capabilities of C++
 - Upgrade atmosphere models
 - Update the atmosphere models in the existing GRAMs
 - Establish a foundation for developing GRAMs for additional destinations (Saturn, Uranus, and Jupiter)
 - Socialize plans and status to improve communication between users, modelers, and developers
- This presentation focuses on the code modernization and model updates specific to the GRAM Suite and Venus-GRAM

Code Modernization – GRAM Suite

- Developed a common C++ framework that simplifies model updates, integration, testing, and maintenance
- Common framework supports all solar system destination models
- Provides a uniform user interface for all planetary GRAMs
- Includes C++ library with C and Fortran interfaces which can be incorporated in a trajectory (or orbit propagation) code



- Release of the rearchitected existing planetary GRAMs will contain the original atmosphere models; new model updates are being developed as part of future GRAM upgrades

Model Upgrades – GRAM Suite

Ephemeris Update

- GRAM ephemeris has been upgraded to the NASA Navigation and Ancillary Information Facility (NAIF) Spacecraft Planet Instrument C-matrix Events (SPICE) toolkit (version N0066)
- Venus ephemeris values, such as Ls and solar time, will be computed using the NAIF SPICE library for greater accuracy
- The values generated by SPICE are slightly different from those generated in the original custom Venus-GRAM ephemeris engine
- Overall, values produced by the new and legacy Venus-GRAMs compare favorably
- Use of NAIF SPICE requires the GRAM Suite user to download the latest SPICE data before using the GRAM Suite

Model Upgrades – GRAM Suite

Improvements in Speed of Sound Calculations

- GRAMs compute speed of sound based on a thermodynamic parameterization using temperature and γ , the ratio of specific heats for a given constituent gas mixture
- GRAM legacy codes use a constant γ , which is physically unrealistic
 - Analyses have shown this formulation to over-estimate speed of sound by as much as 10%
- GRAM Suite uses an improved methodology for computing γ , involving evaluation of Shomate coefficients in run-time for the current constituent combination
- Future development will replace the Shomate coefficients with high-precision specific heat values derived from detailed quantum-mechanical computations

Model Upgrades – GRAM Suite

New Venus Model Data

- GRAM team has distributed funding since Fiscal Year 2020 for two ongoing projects that will improve the atmospheric model data input into Venus-GRAM
- Reanalysis of the Venus Express radio occultation observations
 - Sanjay Limaye and Patrick Fry at the University of Wisconsin
 - Will result in number density, temperature, and pressure profiles for 40-90 km altitude
- Development of an empirical global model for Venus
 - Kunio Sayanagi, Justin Garland, and Ryan McCabe at Hampton University
 - Will include three-dimensional arrays of temperature, pressure, density and wind

Upgraded GRAM Releases

- GRAM Suite Version 1.0 (Released May 2020) includes:
 - Rearchitected Neptune-GRAM (common GRAM framework and planet-specific code)
 - Makefile and Visual Studio solutions for building the GRAM Suite
 - Neptune-GRAM User Guide (NASA/TM–20205001193)
 - GRAM Programmer’s Manual
 - Examples and tests for successful implementation of Neptune-GRAM
- GRAM Suite Version 1.1 (Released September 2020) added:
 - Rearchitected Titan-GRAM (common GRAM framework and planet-specific code)
 - Titan-GRAM User Guide
 - Examples and tests for successful implementation of Titan-GRAM
- Rearchitected Venus-GRAM will be released in a future version of the GRAM Suite

Additional GRAM Presentations at COSPAR

- Global Reference Atmospheric Model (GRAM) Upgrades and New Releases will be presented during COSPAR Session C3.1
 - Provides details regarding the upgrades that are being made to the existing GRAMs, the development of new GRAMs, as well as the ongoing objectives, tasks, and milestones related to the GRAM upgrades funded by NASA SMD
- Earth-GRAM Overview and Future Improvements will be presented during COSPAR Session C4.2
 - Includes Earth-GRAM overview, future updates, recent comparison analysis results, and our role in the working group to support International Standard Organization (ISO) 14222

Summary

- Venus-GRAM is a critical tool set that influences mission selection and decisions
- Upgrades of Venus-GRAM and the other existing GRAMs, as well as the development of new GRAMs are ongoing
 - GRAM Suite Version 1.1 has been released and is available via the NASA Software Catalog <https://software.nasa.gov/>
 - Future GRAM Suite version will contain the rearchitected Venus-GRAM
 - Data profiles resulting from the reanalysis of the Venus Express radio occultation observations and an empirical global model for Venus will be included in a subsequent GRAM Suite release
- NASA SMD funding has been essential to addressing current limitations and accomplishing GRAM developmental goals

References

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