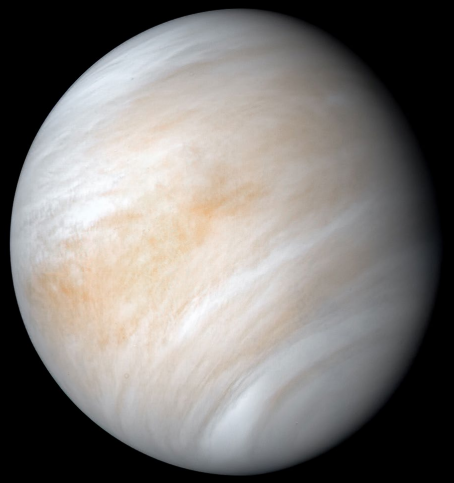
Venus Global Reference Atmospheric Model (Venus-GRAM) Upgrade Status



Hilary L. Justh

Planetary GRAM Lead
Natural Environments Branch (EV44)
NASA Marshall Space Flight Center
Hilary.L.Justh@nasa.gov

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GRAM Upgrade Team

NASA Langley Research Center

Project Manager
Soumyo Dutta

Code Architect
James Hoffman
Analytical Mechanics Associates

Implementation Experts
John Aguirre
Analytical Mechanics Associates

NASA Marshall Space Flight Center

Planetary Atmosphere Specialist
Hilary Justh

Earth-GRAM Developer
Patrick White

GRAM Developer
Lee Burns
Jacobs Space Exploration Group

Venus-GRAM Overview

- Engineering-oriented atmospheric model 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, Neptune, Uranus, and Jupiter
- Available through the NASA Software Catalog https://software.nasa.gov/software/MFS-33888-1

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)

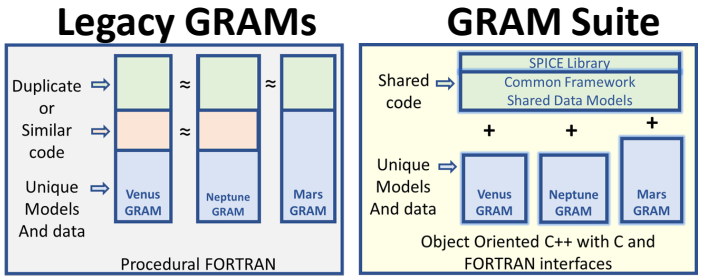
- From 250 - 1000 km, input atmospheric data files are from a MSFC-developed model containing the following assumptions:
  - VIRA conditions and constituents at 250 km are used as lower boundary values
  - Constant (exospheric) temperature is assumed above 250 km (exospheric temperature = local VIRA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

GRAM Suite

- Common object-oriented C++ framework
- Includes a common GRAM library of data models and utilities
  - Reduces duplicated code
  - Ensures consistent constants across all GRAMs
  - Simplifies bug fixes
  - Streamlines the interface with trajectory codes
- Includes C++ library with C and Fortran interfaces which can be incorporated in a trajectory (or orbit propagation) code
- All future Venus-GRAM Upgrades will be released in the GRAM Suite



Upgrades contained within the GRAM Suite

- GRAM ephemeris has been upgraded to the NASA Navigation and Ancillary Information Facility (NAIF) Spacecraft Planet Instrument C-matrix Events (SPICE) toolkit (version N0066) for increased accuracy
  - Requires the GRAM user to download the latest SPICE data before using the GRAM Suite
- Input parameters have been renamed to be more descriptive
  - Legacy input parameter names are still accepted to maintain compatibility with existing NAMELIST input files from prior Venus-GRAM versions
- Output files have been reformatted
  - Comma separated value file
    - Consolidates the column formatted output files from the prior Venus-GRAM versions into a single file that can easily be loaded into data centric programs
  - LIST file
    - Can be read using an American Standard Code for Information Interchange (ASCII) reader or a Markdown syntax for enhanced rendering in a web browser

GRAM Suite Improvements in Speed of Sound Calculations

- GRAMs compute speed of sound based on a thermodynamic parameterization using density, pressure, and γ, the ratio of specific heats $\frac{C_p}{C_v}$, for a given constituent gas mixture
  - C_p is the specific heat capacity of a gaseous mixture for isobaric processes
  - C_v is the specific heat capacity of a gaseous mixture for isochoric processes
- 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 includes an improved methodology for computing γ, involving temperature and pressure dependent tables of C_p and C_v evaluated in run-time for the current constituent combination

Upgraded Venus-GRAM Release

- Rearchitected Venus-GRAM released in GRAM Suite Version 1.3 in October 2021 includes:
  - Common GRAM framework and Venus–specific code
  - Makefile and Visual Studio solutions for building the GRAM Suite
  - Venus-GRAM User Guide (NASA/TM-20210022168)
  - GRAM Programmer's Manual
  - Examples and tests for successful implementation of Venus-GRAM

Venus-GRAM Upgrade Funded Projects

- GRAM project established in Fiscal Year 2020 several ongoing contracts to improve atmospheric data in Venus-GRAM
- University of Wisconsin
  - Reanalysis of the Venus Express radio occultation observations
    - Calculating number density, temperature, and pressure profiles (40-90 km altitude)
  - Analysis of Akatsuki thermal imaging data
    - Calculating temperature values at the limb altitudes as a function of solar time
  - "Updating Venus-GRAM with Recent Atmospheric Structure data (40-80 km)" will be presented during COSPAR Session C3.1
- Hampton University
  - Developing Venus global model

Fiscal Year 2022 Venus-GRAM Upgrade Activities

- Established Venus-GRAM Working Group
  - Discuss potential Venus-GRAM upgrades and develop a forward plan
- Venus-GRAM Upgrades - Currently Under Review
  - Incorporate Magellan and Akatsuki datasets to provide alternative atmospheric profiles in the lower atmosphere region (30-100 km)
    - Includes temperature, pressure, and density profiles based on radio occultation measurements
  - Incorporate Magellan topographic datasets to increase the resolution of topographic data in Venus-GRAM
- Venus-GRAM Upgrades – Currently Under Discussion
  - Improve zonal, meridional, and vertical winds
  - Incorporate Magellan high-resolution gravity datasets

Summary

- Venus-GRAM is a frequently used toolset and vital in assessing effects of atmospheres on interplanetary spacecraft during the program life cycle process
- Venus-GRAM is included in GRAM Suite Version 1.4 and is available via the NASA Software Catalog https://software.nasa.gov/software/MFS-33888-1
- Upgrades of Venus-GRAM in the GRAM Suite are continuing
  - Venus-GRAM Working Group has been established
  - Venus-GRAM upgrades under review
  - Ongoing discussions with:
    - Modeling groups within NASA and academia regarding status of their Venus models
    - VERITAS and DAVINCI mission teams to determine potential mission support by the GRAM team, utilization of collected atmospheric data, and needed Venus-GRAM upgrades

References

1. Kliore, A.J.; Moroz, V.I.; and Keating, G.M. (editors): "The Venus International Reference Atmosphere", *Advances in Space Research*, Vol. 5, No. 11, pp. 1-305, 1985.