Venus Global Reference Atmospheric Model (Venus-GRAM) Overview and Future Upgrades

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2023 GRAM Virtual Workshop
November 14, 2023

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 Study and various Discovery proposals
- From the surface to 250 km, input atmospheric data files are from the Venus International Reference Atmosphere (VIRA)[1]

Venus-GRAM Overview (Continued)

- From 250 - 1000 km, input atmospheric data files are from a MSFC-developed model[2]
- 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
- Contained in the GRAM Suite which is available through the NASA Software Catalog https://software.nasa.gov/software/MFS-33888-1

Upgraded Venus-GRAM Releases

- Rearchitected Venus-GRAM released in GRAM Suite Version 1.3 in October 2021 included:
  - Common GRAM Suite C++ 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
- 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
  - Includes an improved methodology for computing speed of sound
  - Input parameters have been renamed to be more descriptive
  - Output files have been reformatted

Upgraded Venus-GRAM Releases (Continued)

- GRAM Suite Version 1.5 released in April 2023 added the following to Venus-GRAM:
  - Topography model based on Magellan data[3] to correctly capture atmospheric properties with respect to altitude above ground level
  - Changes in implementation of the SPICE files
    - SPICE toolkit was upgraded to version N0067.
    - SPICE files needed for solar longitude calculations were previously prescribed by the GRAM team
      - Added SPICE file override capability and smaller SPICE kernel starter pack

Venus-GRAM Upgrade Funded Projects

- GRAM project has established several ongoing contracts to improve atmospheric data in Venus-GRAM
- Established a contract in Fiscal Year 2020 with 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
  - Compare VIRA with Venus Express and Magellan radio occultation data.
- Established a contract in Fiscal Year 2022 with Johns Hopkins University Applied Physics Laboratory
  - Develop a Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI) atmospheric profile for Venus-GRAM that will be delivered in Fiscal Year 2024

Future Venus-GRAM Upgrades

- 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
- Add a zonal wind model
- 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 and 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 upgrades of lower atmosphere region (30-100 km) profiles and gravity data will be included in a future GRAM Suite Release
  - Ongoing discussions with:
    - Modeling groups within NASA and academia regarding status of Venus models
    - Venus Emissivity, Radio science, InSAR, Topography, And Spectroscopy (VERITAS) and DAVINCI mission teams to determine potential mission support by the GRAM team, utilization of collected atmospheric data, and needed Venus-GRAM upgrades
- Feedback regarding Venus-GRAM encouraged and welcomed

References

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3. Ford, P.G. and Pettengill, G.H.: "Venus Topography and Kilometer-Scale Slopes", *Journal of Geophysical Research: Planets*, Vol. 97, No. E8, pp. 13103-13114,1992.