

Global Reference Atmospheric Model (GRAM) Improvements and New Releases



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GRAM Overview

- Engineering-oriented atmospheric models that estimate mean values and statistical variations of atmospheric properties for numerous planetary destinations
- Currently available for Earth, Mars, Venus, Titan, Neptune, Uranus, and Jupiter
- Outputs include atmospheric density, temperature, pressure, chemical composition, radiative fluxes (for Mars-GRAM), and wind components along a user-defined path
 - Includes seasonal, diurnal, geographic, and altitude variations
- Widely used by the engineering community because of their 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

GRAM Overview (Continued)

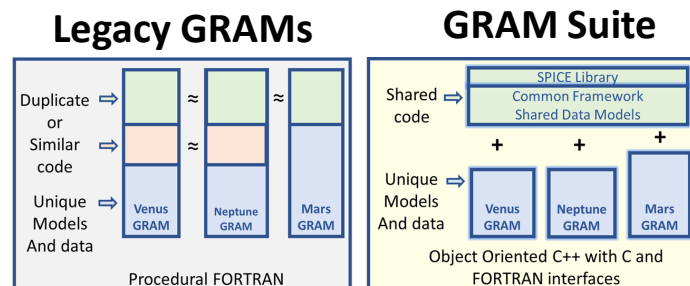
- Optional trajectory input file consisting of time, height, latitude, and longitude can be used to provide the GRAM trajectory path
- Optional auxiliary profile consisting of height, latitude, longitude, temperature, pressure, density, eastward wind, and northward wind may be used to replace model data in the GRAMs
- Not a forecast model
- Available through the NASA Software Catalog
<https://software.nasa.gov/software/MFS-33888-1>

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

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 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 GRAM versions
- Output files have been reformatted
 - Comma separated value file
 - Consolidates the column formatted output files from the legacy GRAMs 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

GRAM Suite 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 (NASA/TM–20205006805)
 - Examples and tests for successful implementation of Titan-GRAM

GRAM Suite Releases

- GRAM Suite Version 1.2 (Released July 2021) added:
 - New Uranus-GRAM (common GRAM framework and planet-specific code)
 - Uranus-GRAM atmospheric data is from the NASA Ames Research Center (ARC) Uranus Atmospheric Model^{1,2}
 - Based on Voyager radio science, Infrared Interferometer Spectrometer and Radiometer (IRIS), and Ultraviolet Spectrometer (UVS) data from the Voyager 2 fly-by of Uranus that occurred on January 24, 1986^{3,4,5}
 - Includes atmospheric density, pressure, temperature, and chemical composition (helium, hydrogen, and methane)
 - Does not include wind data
 - Uranus-GRAM User Guide (NASA/TM -20210017250)
 - Examples and tests for successful implementation of Uranus-GRAM

GRAM Suite Releases

- GRAM Suite Version 1.3 (Released October 2021) added:
 - New Jupiter-GRAM (common GRAM framework and planet-specific code)
 - Based on Galileo probe Atmospheric Structure Instrument (ASI) data from Seiff et al.⁶
 - Includes atmospheric density, pressure, and temperature
 - Does not include chemical composition or winds
 - Rearchitected Venus-GRAM (common GRAM framework and planet-specific code)
 - Jupiter-GRAM User Guide (NASA/TM-20210022058)
 - Venus-GRAM User Guide (NASA/TM-20210022168)
 - Examples and tests for successful implementation of Jupiter-GRAM and Venus-GRAM

GRAM Suite Releases

- GRAM Suite Version 1.4 (Released November 2021) added:
 - Rearchitected and Updated Earth-GRAM (common GRAM framework and planet-specific code)
 - Addition of the 2019 Range Reference Atmosphere database
 - Able to produce correlated atmospheric dispersions from a ballistic (up-down) trajectory
 - Able to correlate atmospheric dispersions originating from multiple atmosphere objects
 - Rearchitected Mars-GRAM (common GRAM framework and planet-specific code)
 - Updated Earth-GRAM User Guide (NASA/TM-20210022157)
 - Updated Mars-GRAM User Guide (NASA/TM-20210023957)
 - Examples and tests for successful implementation of Earth-GRAM and Mars-GRAM

GRAM Upgrade Team Funded Projects

- GRAM project has established several ongoing contracts to improve atmospheric data in the GRAMs
- Beginning Fiscal Year 2020
 - 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
 - Hampton University
 - Developing Venus, Jupiter, Saturn, Uranus, Neptune, and Titan global models
- Beginning Fiscal Year 2022
 - Johns Hopkins University Applied Physics Laboratory
 - Develop Dragonfly atmospheric profile for use in Titan-GRAM upgrade

Fiscal Year 2022 GRAM Suite Upgrade Activities

- Established GRAM Working Groups
 - Discuss potential GRAM upgrades and develop a forward plan
 - Includes Venus-GRAM and Titan-GRAM Working Groups
 - Mars-GRAM Working Group will be starting soon
- Earth-GRAM Upgrades to be released by end of 2022
- 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
- Venus-GRAM Upgrades – Currently Under Discussion
 - Improve zonal, meridional, and vertical winds
 - Incorporate Magellan high-resolution gravity datasets

Summary

- GRAMs are frequently used toolsets and vital in assessing effects of atmospheres on interplanetary spacecraft during the program life cycle process
- GRAM Suite Version 1.4 contains the legacy and new GRAMs and is available via the NASA Software Catalog
<https://software.nasa.gov/software/MFS-33888-1>
- Upgrades of GRAM Suite are continuing
 - Venus-GRAM and Titan-GRAM Working Groups have been established
 - Upgraded Earth-GRAM to be released by end of 2022
 - Ongoing discussions with:
 - Modeling groups within NASA and academia regarding status of their models
 - Planetary mission teams (VERITAS, DAVINCI, Dragonfly, MAVEN, etc.) to determine potential mission support by the GRAM team, utilization of collected atmospheric data, and needed GRAM upgrades
- Feedback regarding the GRAMs is encouraged and welcomed



References

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