Global Reference Atmospheric Model (GRAM) Suite Upgrades

Hilary L. Justh

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

2023 GRAM Virtual Workshop
November 14, 2023

GRAM Upgrade Team

NASA Langley Research Center

Project Manager
Soumyo Dutta

Code Architect
James Hoffman
Analytical Mechanics Associates

Outer Planet GRAM Developer
Kunio Sayanagi

Implementation Expert
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

Data Implementation
Corey Walker
Jacobs Space Exploration Group

Paul Bremner

GRAM Suite 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 at a rapid runtime
- Can be integrated into high fidelity flight dynamic simulations of launch, entry, descent and landing (EDL), aerobraking and aerocapture

GRAM Suite 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
- Version History (details can be found in GRAM Suite Change Log included in the documentation folder within the GRAM Suite distribution files)
  - Version 1.0 - May 2020
  - Version 1.1 - September 2020
  - Version 1.2 - July 2021
  - Version 1.3 - October 2021
  - Version 1.4 - November 2021
  - Version 1.5 - April 2023
  - Version 2.0 - October 2023

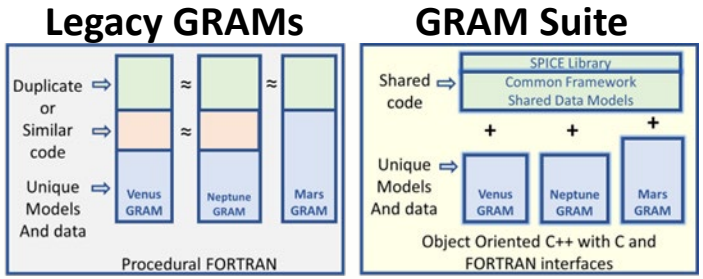
GRAM Upgrade Objectives

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



Initial GRAM Suite Upgrades

- GRAM ephemeris has been upgraded to the NASA Navigation and Ancillary Information Facility (NAIF) Spacecraft Planet Instrument C-matrix Events (SPICE) toolkit for increased accuracy
- Input parameters have been renamed to be more descriptive
- Output files have been reformatted into a comma-separated value file and a LIST file
- Improved speed of sound calculations
- Contains rearchitected legacy GRAMs (Mars, Venus, Neptune, and Titan-GRAM), rearchitected and updated Earth-GRAM, and new GRAMs (Uranus and Jupiter-GRAM)
- Details regarding these upgrades can be found in the GRAM User Guides included in the documentation folder within the GRAM Suite distribution files

Recent GRAM Suite Release

GRAM Suite Version 1.5 (released April 2023) added:

- SPICE file overrides
- SPICE kernel "starter pack“ to the release bundle
- Upgraded SPICE toolkit - Version N0067
- Venus-GRAM topography model based on Magellan data
- Earth-GRAM bug fixes:
  - Bug fix to low/high density outputs
  - Bug fix to memory management
  - Bug fix to error condition
- For distribution, the NCEP data files are now in a separate zip bundle - EarthGRAM_NCEP_Data.zip

SPICE Kernel Overrides

- For analytical purposes, it is important for each user of the GRAM Suite to choose and use the appropriate SPICE kernels for their application from the NAIF website
- SpicePath
  - Overrides the default path to the root folder of the SPICE data
  - All other SPICE file names are relative to this folder
- SpiceLsk
  - Overrides the default SPICE leapseconds LSK file name
- SpicePck
  - Overrides the default SPICE planetary constants PCK file name
- SpiceVenus, SpiceEarth, SpiceMars, SpiceJupiter, SpiceSaturn, SpiceUranus, SpiceNeptune, SpiceTitan
  - Overrides the default SPICE planet kernel file name
  - SpiceTitan should be a Saturn kernel

SPICE Kernels – Starter Pack

- A set of reduced size standard SPICE kernels
  - Created using **spkmerge**
  - BEGIN_TIME = 1 JAN 2000 00:00:00.000
  - END_TIME = 1 JAN 2100 00:00:00.000
  - No satellite(moon) data

GRAM Variable	Location in /GRAM/SPICE	Size	Original
SpiceLsk	/lsk/naif0012.tls		
SpicePck	/pck/pck00011.tpc		
SpiceVenus	/spk/planets/de440_GRAM.bsp	5MB	114MB
SpiceEarth	/spk/planets/de440_GRAM.bsp	5MB	114MB
SpiceMars	/spk/satellites/mar097_GRAM.bsp	60MB	448MB
SpiceJupiter	/spk/satellites/jup365_GRAM.bsp	11MB	1050MB
SpiceSaturn	/spk/satellites/sat441_GRAM.bsp	16MB	630MB
SpiceUranus	/spk/satellites/ura116_GRAM.bsp	8MB	97MB
SpiceNeptune	/spk/satellites/nep101_GRAM.bsp	6MB	395MB
SpiceTitan	/spk/satellites/sat441_GRAM.bsp	16MB	630MB
	Total	104MB	2700MB

Latest GRAM Suite Release

GRAM Suite Version 2.0 (released October 2023) added:

- Python Application Program Interface (API)
- Earth-GRAM Modern Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) Update
  - Multiple downloads are required to run Earth-GRAM with the MERRA-2 model
  - MERRA-2 data 2.0-degree files are divided into 9 separate zip files

GRAMpy

- In version 2.0, a new Python interface for the GRAM Suite has been included
  - Many thanks to NASA intern Zeb Becker
  - Includes a Jupyter Notebook with many examples
  - Assumption is made that the user has Python experience
  - Requires building the GRAM suite and GRAMpy using make
- Currently works on:
  - Linux using GCC
  - Windows with a MinGW64 build of the GRAM Suite
- Feedback and suggestions are welcome
  - Especially from Mac users

Upcoming GRAM Suite Releases

Future planned upgrades include:

- Venus-GRAM gravity data upgrades
- Update of the MOLA topography resolution within Mars-GRAM
- MATLAB API
- Earth-GRAM gridded forecast upgrade
- Gravity data upgrades to all GRAMs
- Uranus, Mars, Venus, and Titan-GRAM input model data upgrades
- Addition of Saturn-GRAM

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 2.0 is available via the NASA Software Catalog https://software.nasa.gov/software/MFS-33888-1
- Upgrades of GRAM Suite are continuing
  - Updating the inherent data in the GRAMs to reflect current best estimates
  - Next GRAM Suite release in Spring 2024
  - Ongoing discussions with:
    - Modeling groups within NASA and academia regarding status of their models
    - Planetary mission teams (VERITAS, DAVINCI, Dragonfly, MAV, 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