Status Of Outer Planet Global Reference Atmospheric Model (GRAM) Upgrades

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Background

The inability to test planetary spacecraft in the flight environment prior to a mission requires engineers to rely on ground-based testing and models of the vehicle and expected environments. One of the most widely used engineering models of the atmosphere is the Global Reference Atmospheric Model (GRAM) developed and maintained by the NASA Marshall Space Flight Center (MSFC). The NASA Science Mission Directorate (SMD) has provided funding support to upgrade the GRAMs.

GRAM Overview

- GRAMs are engineering-oriented atmospheric models that estimate mean values and statistical variations of atmospheric properties for numerous planetary destinations
  - Provide mean values and variability for any point in an atmosphere
  - Include seasonal, geographic, and altitude variations
  - Outputs include winds, thermodynamics, chemical composition, and in Mars-GRAM radiative fluxes
  - Rapidly integrates numerous data sets into a seamless composite climatology
  - Used by engineering community because of the need to simulate realistic dispersions; can be integrated into high fidelity flight dynamic simulations of launch, entry, descent, and landing (EDL), aerobraking, and aerocapture
  - GRAMs are not forecast models
  - Current GRAM models include: Earth, Mars, Venus, Neptune, and Titan-GRAM
  - GRAMs are available through the NASA Software Catalog https://software.nasa.gov/

Objectives

- The funding for the GRAM Upgrades aims to achieve three 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

Outer Planet GRAM Upgrades

- Focus of the model upgrade task is to improve the atmosphere models in the existing GRAMs and to establish a foundation for developing GRAMs for additional destinations
- GRAM ephemeris has been upgraded to the NASA Navigation and Ancillary Information Facility (NAIF) Spacecraft Planet Instrument C-matrix Events (SPICE) toolkit
- Providing funding in FY20 to Kunio Sayanagi (Hampton University) to develop empirical global models for Venus, Jupiter, Saturn, Uranus, Neptune, and Titan
  - Work is ongoing to develop models that will be used in future GRAM updates
  - Will incorporate latest data available for each destination
  - Working with Ralph Lorenz (JHUAPL) and Jared Bell (GSFC) (Titan model development) and Juilanne Moses (Space Science Institute) (Saturn model development)
- Identifying and obtaining planetary mission atmospheric data and analysis, that is available and appropriate, to use as the basis for verification and validation of the GRAMs
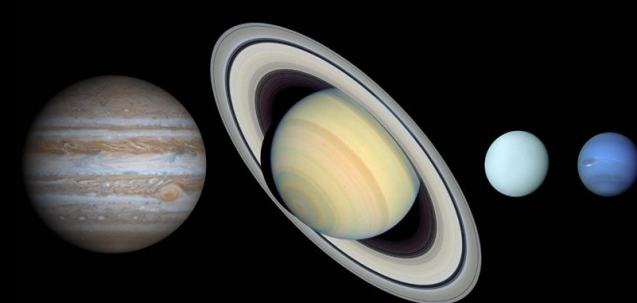
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Code Modernization - GRAM Suite

- Developed the GRAM Suite, a common C++ framework that simplifies model updates, integration, testing, and maintenance
  - Common framework that supports all solar system destination models
  - Provides a uniform user interface for all planetary GRAMs
  - Includes C++ library with C and Fortran interfaces that can be incorporated in a trajectory or orbit propagation code
  - All of the rearchitected and new GRAM models will be released as the new GRAM Suite
  - First C++ releases of existing planetary GRAMs in GRAM Suite will be a straight conversion from the latest Fortran version
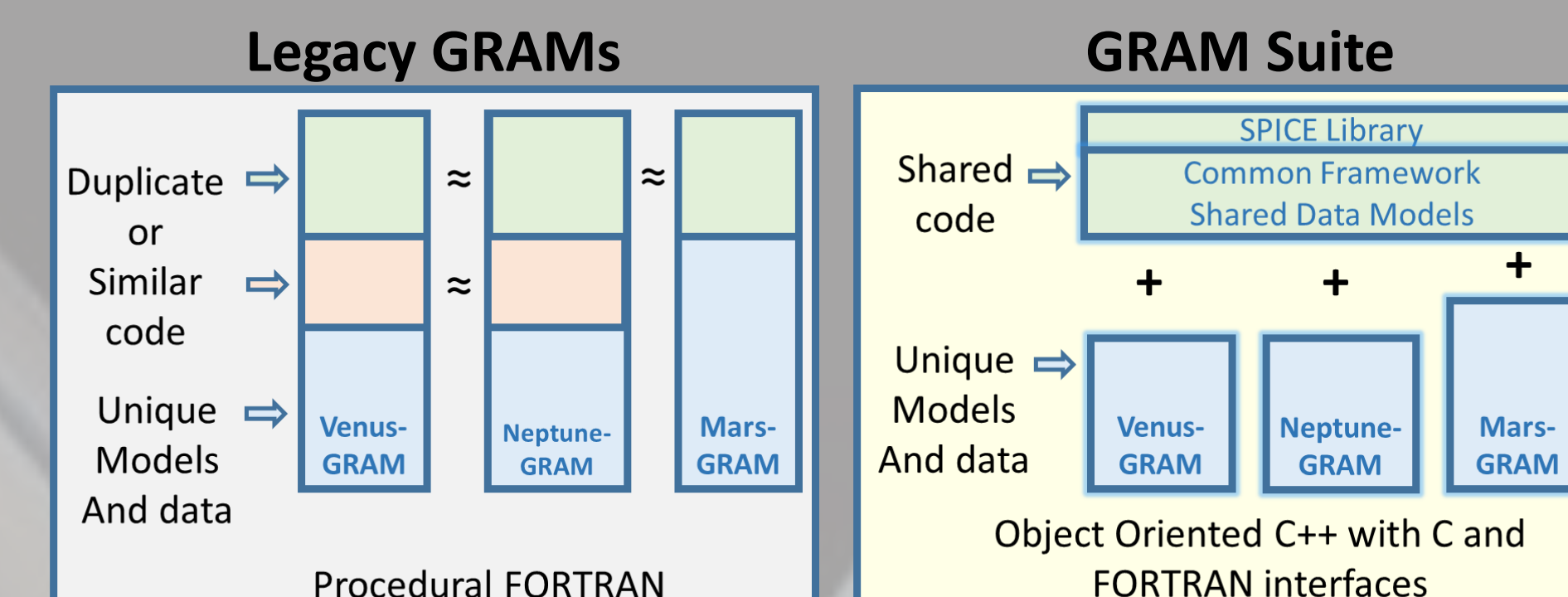
Upgraded Outer Planet GRAM Releases

- Neptune-GRAM will be the first upgraded planetary GRAM released in the GRAM Suite
  - Includes the new common C++ framework and SPICE
  - Beta test version now available
  - User's and Programmer's Guide will be included in the release
  - Releases of other upgraded existing planetary GRAMs (Titan, Venus, and Mars) will follow the release of Neptune-GRAM

New Outer Planet GRAM Releases

- Uranus-GRAM
  - Based on individual profile generated by Gary Allen (ARC) from Voyager 2 occultation data
  - Beta test version now available
- Jupiter-GRAM
  - Based on individual profile produced from Al Seiff's Jupiter model[1]
- Saturn-GRAM
  - Julianne Moses (Space Science Institute) has provided six individual profiles based on Cassini data at different latitudes (2° N, 23° N, 26° N, 6° S, 12° S, and 49° S latitude)

Conclusions

- GRAMs are a critical tool set that influence mission selection and decisions
- NASA SMD funding has been essential to addressing current limitations and accomplishing GRAM developmental goals
- Updates to the existing outer planet GRAMs and development of new outer planet GRAMs are ongoing

References

[1]Seiff, A., et al. (1998) *Journal of Geophysical Research*, Vol. 103, No. E10, pp. 22,857-22,889.

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