



# New Releases and Upgrades of Giant Planet Global Reference Atmospheric Models (GRAMs)

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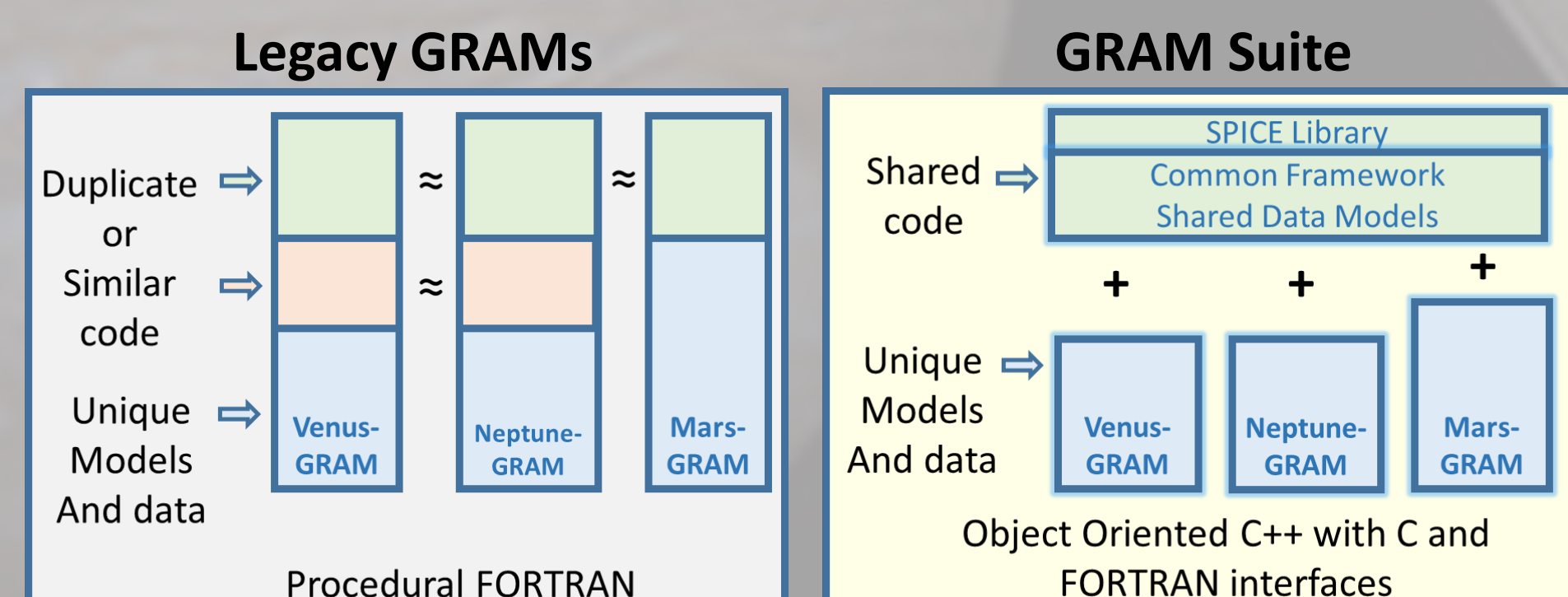
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## GRAM Overview

- GRAMs are engineering-oriented atmospheric models that estimate mean values and statistical variations of atmospheric properties for numerous planetary destinations
  - Outputs atmospheric density, temperature, pressure, winds, and chemical composition along a user-defined path
  - Provide mean values and variability for any point in an atmosphere
  - Includes seasonal, geographic, and altitude variations
  - Used by 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
- GRAMs are not forecast models
- GRAMs are available for: Earth, Mars, Venus, Neptune, Titan, Jupiter, and Uranus
- Available through the NASA Software Catalog <https://software.nasa.gov/software/MFS-33888-1>

## 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 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
- Calculation of the speed of sound has been improved in the GRAM Suite
  - GRAMs compute speed of sound based on a thermodynamic parameterization using density, pressure, and  $\gamma$ , the ratio of specific heats,  $\frac{C_p}{C_v}$ , for a given constituent gas mixture where  $C_p$  is specific heat capacity of a gaseous mixture for isobaric processes and  $C_v$  is specific heat capacity of a gaseous mixture for isochoric processes
  - GRAM legacy codes use a constant  $\gamma$ , which is physically unrealistic
  - GRAM Suite includes an improved methodology for computing  $\gamma$ , involving temperature and pressure dependent tables of  $C_p$  and  $C_v$  evaluated in run-time for the current constituent combination

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## Upgraded Giant Planet GRAM Releases

- Rearchitected Neptune-GRAM and Titan-GRAM have been released in the GRAM Suite and include:
  - Common GRAM framework and Neptune and Titan-specific code
  - Makefile and Visual Studio solutions for building the GRAM Suite
  - Neptune-GRAM User Guide (NASA/TM-20205001193) and Titan-GRAM User Guide (NASA/TM-20205006805)
  - GRAM Programmer's Manual
  - Examples and tests for successful implementation of Neptune and Titan-GRAMs

## New Giant Planet GRAM Releases

- New GRAMs for Uranus and Jupiter have been developed and released in the GRAM Suite adding:
  - Common GRAM framework and Uranus and Jupiter-specific code
  - Uranus-GRAM User-Guide (NASA/TM-20210017250) and Jupiter-GRAM User Guide (NASA/TM-20210022058)
  - Examples and tests for successful implementation of Uranus and Jupiter-GRAMs
- Uranus-GRAM atmospheric data is from the NASA Ames Research Center (ARC) Uranus Atmospheric Model<sup>1,2</sup>
  - 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<sup>3,4,5</sup>
  - Includes atmospheric density, pressure, temperature, and chemical composition (helium, hydrogen, and methane)
  - Does not include wind data
- Jupiter-GRAM atmospheric data is based on Galileo probe Atmospheric Structure Instrument (ASI) data from Seiff et al.<sup>6</sup>
  - Includes atmospheric density, pressure, and temperature
  - Does not include chemical composition or winds

## Giant Planet GRAM Upgrade Activities

- GRAM project has established several ongoing contracts to improve atmospheric data in the giant planet GRAMs
- Hampton University – Beginning Fiscal Year 2020
  - Developing Jupiter, Saturn, Uranus, Neptune, and Titan global models
- Johns Hopkins University Applied Physics Laboratory – Beginning Fiscal Year 2022
  - Developing Dragonfly atmospheric profile for use in Titan-GRAM upgrade
- Established Titan-GRAM Working Group
  - Discuss potential Titan-GRAM upgrades and develop a forward plan
- Saturn-GRAM currently under initial stages of development
- Ongoing discussions with:
  - Modeling groups within NASA and academia regarding status of their models
  - Planetary mission teams to determine potential mission support by the GRAM team, utilization of collected atmospheric data, and needed GRAM upgrades

## Conclusions

- GRAMs are frequently used toolsets and vital in assessing effects of atmospheres on interplanetary spacecraft during the program life cycle process
- Releases of the GRAM Suite, upgrades of the existing giant planet GRAMs, and development of new giant planet GRAMs are continuing

## References

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