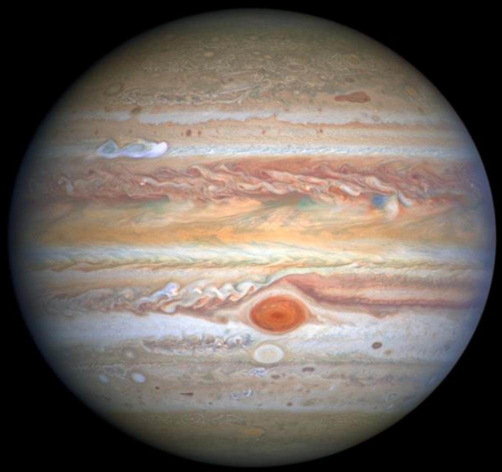
Jupiter Global Reference Atmospheric Model (Jupiter-GRAM)



Hilary L. Justh

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

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Jupiter-GRAM Overview

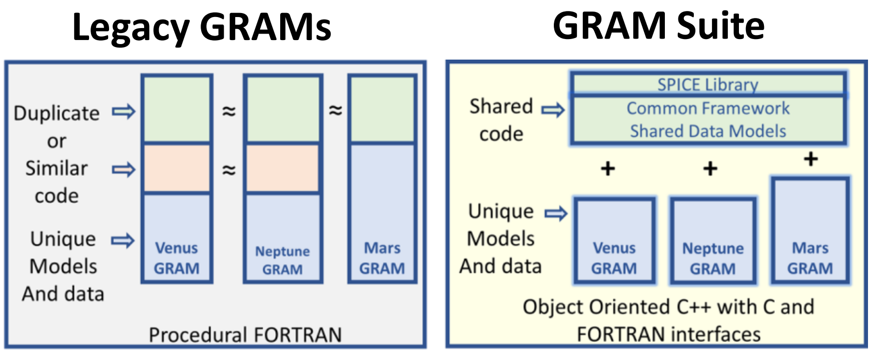
- Developed by the Natural Environments Branch at NASA Marshall Space Flight Center and the Atmospheric Flight and Entry Systems Branch at NASA Langley Research Center
- Engineering-oriented atmospheric model that estimates mean values of atmospheric properties for Jupiter
- Outputs include atmospheric density, temperature, and pressure along a user-defined path
- Can be integrated into high fidelity flight dynamic simulations of launch, entry, descent and landing (EDL), aerobraking and aerocapture
- Optional trajectory input file consisting of time, height, latitude, and longitude can be used to provide the Jupiter-GRAM trajectory path

Jupiter-GRAM Overview (Continued)

- Optional auxiliary profile consisting of height, latitude, longitude, temperature, pressure, density, eastward wind, and northward wind may be used to replace model data in Jupiter-GRAM
- Not a forecast model
- Part of the GRAM Suite and shares a common software core with the other planetary GRAMs while maintaining Jupiter specific models
- Software release package incudes Jupiter-GRAM User Guide, GRAM Programmer's Manual, and examples and tests for successful implementation of Jupiter-GRAM
- GRAM Suite is 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



Jupiter-GRAM Features

- Jupiter-GRAM takes advantage of major code modifications made to the GRAMs. Important features include:
  - 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
    - Use of the NAIF SPICE library requires the Jupiter-GRAM user to download the latest SPICE data before using Jupiter-GRAM
  - Output files are provided in two formats: a comma separated value file and a LIST file
  - Jupiter-GRAM computes speed of sound based on a thermodynamic parameterization using density, pressure, and γ, the ratio of specific heats, for a given constituent gas mixture
    - Jupiter-GRAM does not include a constituent gas model and as a result utilizes a default constant value for γ which is based on the value of γ for hydrogen

Jupiter-GRAM Atmospheric Data

- Atmospheric density, temperature, and pressure as a function of height are characterized by data from Seiff et al.[1]
- Data was measured from 1029.2 km above to 132.40 km below the 1-bar pressure level by the Galileo probe's Atmospheric Structure Instrument (ASI)[2] as it entered and descended through the atmosphere of Jupiter on December 7, 1995
- Does not include wind data
  - Seiff et al.[1] model did not include wind data due to the lack of understanding of the winds at these altitudes
- Does not include a perturbation or constituent gas model due to lack of data
- Values for winds, perturbations, and constituent gasses will be updated in future Jupiter-GRAM releases as they are available

Atmospheric Structure Instrument (ASI) Data

- ASI measurements occurred in two stages
- First set of ASI measurements - 1029.2 km to 23.3 km above the 1-bar level
  - Taken by on-board accelerometers of the decelerations occurring along and normal to the z axis (the probe axis of symmetry in the direction of the probe velocity) during the Galileo probe's high-speed entry into the upper atmosphere of Jupiter
- Second set of ASI measurements - 17.291 km above to 132.4 km below the 1-bar level
  – Began seconds prior to parachute deploy and captured pressure, temperature, and acceleration data for the lower atmosphere of Jupiter

Lower Atmosphere Jupiter-GRAM Data
17.291 km above to 132.4 km below the 1-bar level

- Altitudes and decent velocities in lower atmosphere of Jupiter were calculated by Seiff et al.[1] as functions of time from ASI measured temperature and pressure
- Atmospheric density in the lower atmosphere of Jupiter was calculated by Seiff et al.[1] through utilization of the equation of state
  - Gas composition and gas constant were allowed to vary with the pressure level if their values were consistent with:
    - Measured He/H_2 abundance ratio of 0.136/0.864 = 0.1574 from the Galileo probe Helium Abundance Detector (HAD)[3]
    - Minor constituent variations measured by the Galileo Probe Mass Spectrometer (GPMS)[4]
    - NH_3 abundance profile determined by radio science[5] and the Galileo probe Net Flux Radiometer (NFR)[6]
- Details of these calculations can be found in Jupiter-GRAM User Guide and Seiff et al.[1]

Upper Atmosphere Jupiter-GRAM Data
1029.2 km to 23.3 km above the 1-bar level

- Seiff et al.[1] derived atmospheric densities for the upper atmosphere of Jupiter from ASI measured accelerations based on Newton's second law of motion and the Galileo probe aerodynamics
- Galileo probe velocity and altitude calculated as functions of time by the Galileo probe trajectory reconstruction completed by Seiff et al.[1] based on the Galileo probe's measured accelerations and initial conditions
- Atmospheric pressures in the upper atmosphere were calculated by Seiff et al.[1]
- Atmospheric temperatures in the upper atmosphere were calculated by Seiff et al.[1] from the densities and pressures using the equation of state
- Details of these calculations can be found in Jupiter-GRAM User Guide and Seiff et al.[1]

Jupiter-GRAM Gravity Parameters

- Planetary constants used in Jupiter-GRAM are from the Planetary Data System "Standard Planetary Information, Formulae and Constants" web page: http://atmos.nmsu.edu/jsdap/encyclopediawork.html
- Gravitational parameter is from the JPL Solar System Dynamics Outer Planet Gravity Fields web page: https://ssd.jpl.nasa.gov/?gravity_fields_op

	Label	Units	Value
Gravitational Parameter	GM	km^3/s^2	126686534.1960128
Mean Equatorial Radius	R_e	km	71492.0
Mean Polar Radius	R_p	km	66854.0
J2 harmonic	J_2	km^5/s^2	0.014736
Period		s	35730.0

Summary

- GRAMs are frequently used toolsets and vital in assessing effects of atmospheres on interplanetary spacecraft during the program life cycle process
- Planned Jupiter-GRAM upgrades will occur in the near future
  - Addition of wind data, perturbation model, and constituent gas model will occur as this information is available
  - Ongoing discussions with Jupiter mission teams and modeling groups within NASA and academia regarding utilization of collected atmospheric data and the status of their Jupiter models
  - Aligning GRAM upgrades with planetary mission needs and priorities identified by the Planetary Science and Astrobiology Decadal Survey 2023-2032

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