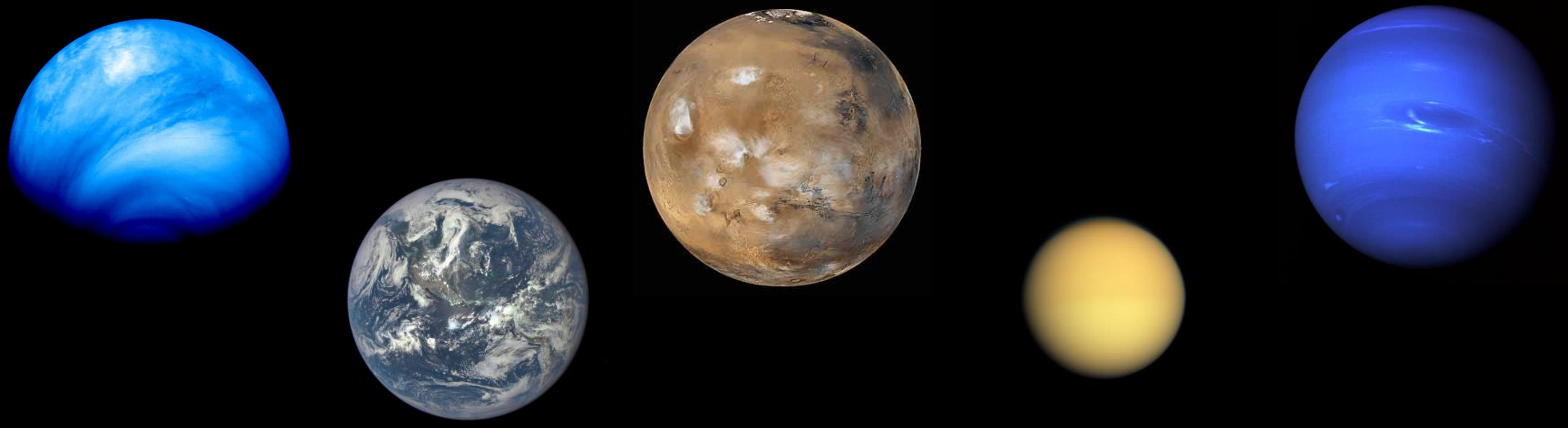
Global Reference Atmospheric Model (GRAM) Overview



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What are GRAMs?

- The Global Reference Atmospheric Models (GRAMs) are engineering-level atmospheric models applicable for engineering design analyses, mission planning, and operational decision making
  - Provides mean states and measures of variability for any point in atmosphere
  - Includes seasonal, geographic, and altitude variations
  - Outputs include winds, thermodynamics, chemical composition, and radiative fluxes
  - Integrates numerous data sets into a seamless composite climatology
  - Used by engineering community because of their ability to create 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

GRAM Perturbation Model

GRAM output value = Mean value + Large-scale perturbation + Small-scale perturbation

Function of latitude, longitude, height, and time.

Modeled as a wave

Modeled as a stochastic (random) process

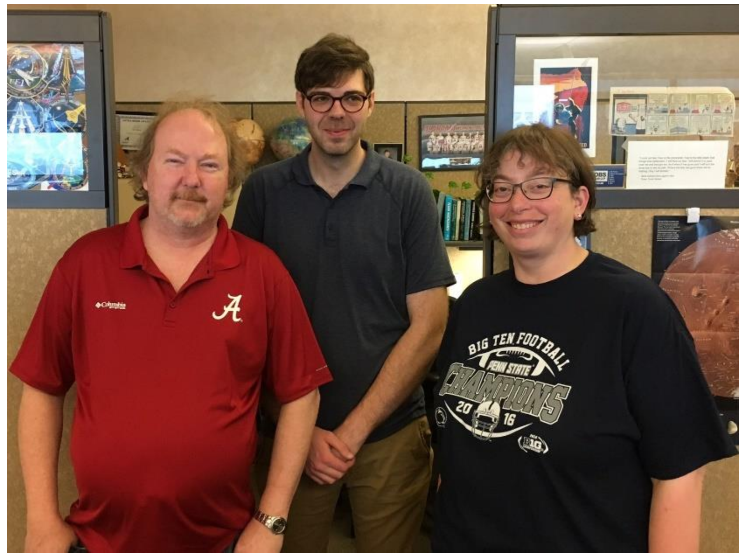
Driven by observed standard deviation

GRAMs can quickly compute dispersed profiles appropriately correlated in time and space for an input trajectory or flight path

Current GRAM Versions

- MSFC Natural Environments Branch has been developing and upgrading GRAMs since 1974
- GRAM was initially developed by Jere Justus at Georgia Tech with NASA funding
  - Jere joined MSFC in 1993 where he continued to develop and maintain the GRAMs until his retirement in 2011
- Earth-GRAM 2016 has been released in C++
- Current versions of the following GRAMs are written in Fortran:
  - Mars-GRAM 2010
  - Venus-GRAM 2005 Rel. Oct 2009
  - Titan-GRAM 2004
  - Neptune-GRAM 2004
- Available through the NASA Software Catalog https://software.nasa.gov/

GRAM Team



- GRAMs are maintained at MSFC by the GRAM Team
  - Hilary Justh – Planetary GRAM Lead (Mars, Venus, Neptune and Titan-GRAM)
  - Patrick White – Earth-GRAM
  - Lee Burns – Mars-GRAM

GRAM Analyses are Easily Customizable

- Includes user-selectable inputs specifying particular analysis scenarios
  - Scalable perturbations for analyzing dispersed environments
  - Individual scale parameters for density, wind, and boundary layer dynamics
  - Variable solar activity
- Provides flexibility through runtime options.
  - Auto-generated profiles with variable step sizes
  - Detailed perturbation model for applications in Monte Carlo simulations
  - User-defined trajectory files
  - User-specified auxiliary profile option for detailed analysis along an observed corridor
  - Range Reference Atmospheres for site-specific analysis (Earth-GRAM only)

GRAMs are a Critical Tool Set

- GRAMs influence mission selection and decisions as a result they need to be treated as a critical tool set to be maintained
- Examples include:
  - PrePhase A: (many landing sites, characterize trends)
    - EDL Architecture Study: Human Mars Missions
  - Phase A: Proposals: ROSES/Discovery/New Frontiers
  - Phase C&D: Space Launch System (SLS), Orion, Commercial Crew Program (CCP)
  - Phase E: Flight operations:
    - Used by Mars Atmosphere and Volatile Evolution mission (MAVEN) to develop maneuver strategies
    - Mars Science Laboratory (MSL) used Mars-GRAM perturbation models
  - Studies: Academia/ Industry/ International
    - Mars Aerocapture Systems Study
    - NASA Engineering and Safety Center (NESC) Autonomous Aerobraking Study
    - Neptune Aerocapture Study, etc.

Program Utilization of GRAMs

- Earth-GRAM
  - SLS, Orion, CCP (both SpaceX and Boeing), OSIRIS-Rex, Ares I-X, MLAS-2, Space Shuttle, Orbital ISS down mass, Stardust, Genesis, LDSD, and Exo-Break
- Mars-GRAM
  - MAVEN, MGS, Odyssey, MRO, MER, MSL, Human Architecture Team (HAT), InSight, and NASA Engineering Safety Center (NESC) Autonomous Aerobraking
- Venus-GRAM
  - Used in multiple studies and proposals and NESC Autonomous Aerobraking
- Titan-GRAM
  - Huygens (both NASA and ESA), Cassini and NESC Autonomous Aerobraking
- Neptune-GRAM
  - Used in various studies and proposals

Needed GRAM Investments

- Stable and sufficient funding source to address current limitations and accomplish near and long term goals for GRAM development
  - Current funding:
    - Earth-GRAM: 1.0 FTE (Single civil servant)
    - Planetary GRAMs: No dedicated funding source
  - Many projects, proposals, industry, academia use GRAMs, but no support is in place to maintain and update all versions consistently and regularly
- Dedicated GRAM team focused on specific areas of expertise
  - Robust user support to address both current implementations and future capability enhancements
  - Greater continuity of knowledge and expertise.
- Increased integration with the GRAM user communities
  - Attend conferences, analysis group meetings, etc. to gain a greater understanding of user needs and applications
  - Improved visibility to expand user base

Proposed Forward Work

- Maintain consistent support and maintenance across all GRAM versions
  - Establish formal communication between GRAM users and developers; monitor shortcomings, expand capability, and fix bugs
  - Establish formal and continuous relationship between GRAM developers and model providers to ensure regular model updates
  - Establish a process to obtain models developed outside of NASA
  - Incorporate surface and orbiting data, correlated where possible, into GRAM global circulation and dispersions models
- Work with planetary missions to obtain and incorporate the latest versions of atmosphere relevant data sets
- Incorporate MAVEN data and provide an upgraded Mars-GRAM to the project for evaluation during the extended mission
- Upgrade Mars-GRAM for industry, Mars 2026/28 studies, etc.
- Upgrade Venus-GRAM for New Frontiers and Discovery

Proposed Forward Work Continued

- Update Neptune and Titan-GRAM
- Develop Jupiter, Saturn and Uranus-GRAM for New Frontiers and mission studies
- Evaluate additional features (e.g. destination specific uncertainty models, mesoscale model accommodation and interfaces)
- Document and present updated GRAM comparisons to recently acquired data sets
- Attend atmosphere modeling conferences
- Convert GRAM codes to C++
- Test, validate and verify all new GRAM versions

Acknowledgement

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