GLOBAL REFERENCE ATMOSPHERIC MODEL (GRAM) ADVANCEMENTS AND ADDITIONS.

H. L. Justh[1], A. M. Dwyer Cianciolo[2], K. L. Burns[3], A. Diekmann[4], J. Hoffman[5], and R. W. Powell[6]. [1]NASA, Marshall Space Flight Center, Mail Code EV44, Marshall Space Flight Center, AL, 35812, hilary.l.justh@nasa.gov, [2]NASA, Langley Research Center, Mail Stop 489, Hampton, VA 23681, alicia.m.dwyercianciolo@nasa.gov, [3]Jacobs Space Exploration Group, 1500 Perimeter Pkwy., Suite 400, Huntsville, AL 35806, kerry.l.burns@nasa.gov, [4]Jacobs Space Exploration Group, 1500 Perimeter Pkwy., Suite 400, Huntsville, AL 35806, anne.m.diekmann@nasa.gov, [5]Analytical Mechanics Associates, 21 Enterprise Pkwy., Suite 300, Hampton, VA 23666, james.hoffman-1@nasa.gov, and [6]Analytical Mechanics Associates, 21 Enterprise Pkwy., Suite 300, Hampton, VA 23666, richard.w.powell@nasa.gov.

Brief Presenter Biography: Hilary L. Justh is a scientist with the Terrestrial and Planetary Environments team in the Natural Environments Branch of the Engineering Directorate at NASA's Marshall Space Flight Center (MSFC). As Planetary Global Reference Atmospheric Model (GRAM) Lead, she has utilized the MSFC developed planetary GRAMs for diverse mission applications including Mars Reconnaissance Orbiter (MRO), Mars Science Laboratory (MSL), Cassini, Mars Ascent Vehicle (MAV), and others. Hilary Justh is the Atmosphere Modeling Lead for the GRAM Upgrade task.

Introduction: The Global Reference Atmospheric Model (GRAM) is one of the most widely used engineering models of the atmosphere. GRAM development and maintenance has been led by NASA Marshall Space Flight Center (MSFC). The NASA Science Mission Directorate (SMD) has provided funding support to upgrade the GRAMs since Fiscal Year 2018. NASA Langley Research Center has been working with MSFC on the upgrades. This presentation will provide details regarding the upgrades that have been made to the existing GRAMs, the development of new GRAMs, as well as the ongoing objectives, tasks, and milestones related to the GRAM upgrades funded by NASA SMD.

GRAM: The GRAMs are engineering-oriented atmospheric models that estimate mean values and statistical variations of the atmospheric properties for numerous planetary destinations. They provide mean values and variability for any point in the atmosphere as well as seasonal, geographic, and altitude variations. GRAM outputs include atmospheric density, temperature, pressure, winds, and chemical composition along a user-defined path. They have been widely used by the engineering community because of their ability to create realistic dispersions. GRAMs have been integrated into high fidelity flight dynamic simulations of launch, entry, descent and landing (EDL), aerobraking and aerocapture. MSFC has been developing and updating GRAMs since 1974; GRAMs are currently available for Earth, Mars, Venus, Neptune, and Titan.

GRAM Upgrade Status:

Code Moderization. The planetary GRAMs are being rearchitected from Fortran to a common object-oriented C++ framework called the GRAM Suite. This new architecture creates a common GRAM library of data models and utilities. The first C++ releases of the existing planetary GRAMs (Mars, Venus, Neptune, and Titan-GRAM) in the GRAM Suite are straight conversions from the latest Fortran version.

Model Upgrades. The 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. The GRAM ephemeris has been upgraded to the NASA Navigation and Ancillary Information Facility (NAIF) SPICE toolkit (version N0066). The calculation of the speed of sound has also been improved in the GRAMs.

The GRAM team has received updated Mars General Circulation Model (MGCM) datasets from NASA Ames Research Center. Mars Global Ionosphere-Thermosphere Model (M-GITM) data is being obtained to replace the Mars Thermospheric General Circulation Model (MTGCM) data in legacy Mars-GRAM. M-GITM and updated MGCM data will be incorporated into a future GRAM Suite release.

Two projects that will improve the atmospheric model data in the GRAMs have been funded by the GRAM team since Fiscal Year 2020. Sanjay Limaye and Patrick Fry at the University of Wisconsin are reanalyzing the Venus Express radio occultation observations and analyzing the Akatsuki radio occultation observations. This will lead to the calculation of number density, temperature, and pressure profiles for the 40-90 km altitude range. Kunio Sayanagi, Justin Garland, and Ryan McCabe at Hampton University are developing empirical global models for Venus, Jupiter, Saturn, Uranus, Neptune, and Titan that incorporates the latest data available for each of these planetary destinations.

Upgraded GRAM Releases. GRAM Suite Version 1.0 was released in May 2020 and contains the rearchitected Neptune-GRAM, including the common GRAM framework and planet–specific code. GRAM Suite Version 1.1 was released in September 2020 and added the rearchitected Titan-GRAM to the GRAM Suite. A User Guide and Programmer's Manual are released with all GRAMs. The rearchitected Mars and Venus-GRAMs will be released in upcoming versions of the GRAM Suite.

New GRAM Releases. New GRAMs have been developed for Uranus and Jupiter. Uranus-GRAM is based on an individual profile generated by Gary Allen (ARC) from Voyager 2 occultation data and will be released in GRAM Suite Version 1.2. Jupiter-GRAM is based on individual profile produced from Al Seiff's Jupiter model [1]. Jupiter-GRAM will be released in GRAM Suite Version 1.3. Saturn-GRAM is currently under development and will be released in a future version of the GRAM Suite.

Conclusions: GRAMs are vital and frequently used toolsets. Releases of the GRAM Suite, upgrades of the existing planetary GRAMs, and development of new planetary GRAMs are ongoing. NASA SMD funding has been essential to addressing current limitations and accomplishing GRAM developmental goals. Continuation of SMD funding will ensure the development, upgrades, and maintenance of the GRAMs.

References: [1] Seiff, A., et al. (1998) *JGR*, 103, 22,857-22,889.

Acknowledgments: The authors gratefully acknowledge support from the NASA SMD.