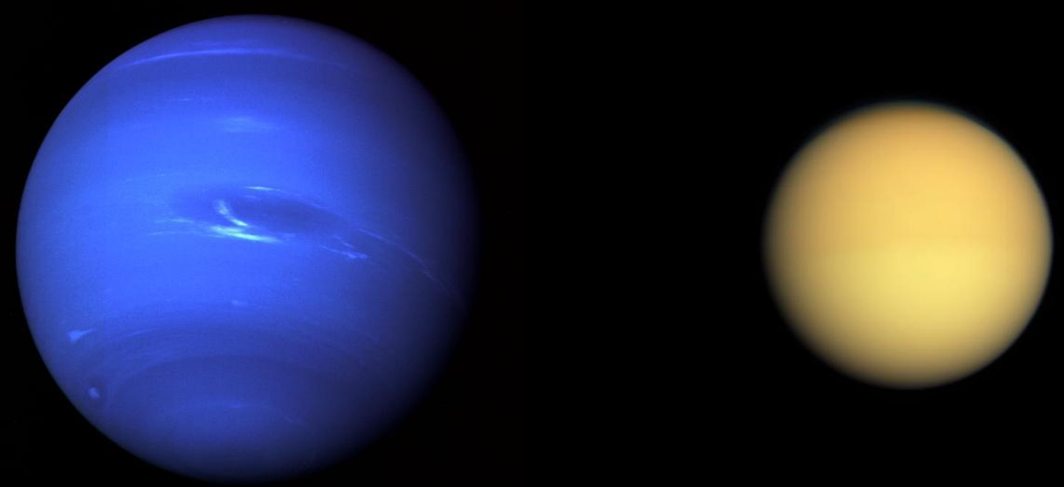
Neptune and Titan Global Reference Atmospheric Models



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GRAM Virtual Workshop, September 21, 2017

Neptune and Titan-GRAM

- Neptune and Titan Global Reference Atmospheric Model (Neptune-GRAM and Titan-GRAM) are engineering-level atmospheric models developed by MSFC that are widely used for diverse mission applications including:
  - Systems design
  - Performance analysis
  - Operations planning for aerobraking, Entry, Descent and Landing, and aerocapture
- Are not forecast models
- Outputs include density, temperature, pressure, wind components, and chemical composition
- Provides dispersions of thermodynamic parameters, winds, and density
- Optional trajectory and auxiliary profile input files
- Neptune-GRAM has been used in multiple studies and proposals
- Titan-GRAM has been used in Titan aerocapture systems analysis studies, pre-entry re-analysis studies of Huygens systems, NASA Engineering and Safety Center (NESC) technical assessment of the Huygens probe entry, descent and landing, and atmospheric estimates for the Cassini T70 flyby
- Both were originally released in 2004
- Available at: https://software.nasa.gov/software/MFS-32296-1 (Neptune) and https://software.nasa.gov/software/MFS-32297-1 (Titan)

Neptune-GRAM Atmospheric Data

- Input atmospheric data files for Neptune-GRAM are from figures in "Neptune and Triton", Univ. Arizona Press, 1995, D.P. Cruikshank, editor
  - Profiles of average, minimum, and maximum values are used for atmospheric parameters
  - Includes height above reference ellipsoid, total number density, number densities for hydrogen, helium, and methane, mass density, air pressure, air temperature, and the compressibility effect (Zeta)
  - Data have been extended in altitude with a simple thermospheric model that includes diffusive separation
- Contained within Neptune-GRAM is a basic zonal wind model which includes latitude variations
- Based on observations from Voyager radio science, infrared interferometer-spectrometer (IRIS), and ultraviolet spectrometer (UVS) which provide an adequate fit to all three sources of variations and uncertainty:
  - Uncertainties in the analysis of the Voyager data
  - Estimated range of latitudinal variations in atmospheric structure
  - Temporal changes in the atmosphere due to seasonal and diurnal variations

Titan-GRAM Atmospheric Data

- Atmospheric density, temperature and pressure as a function of height are characterized by engineering model profile envelopes from Yelle et al. (1997) representing expected minimum, average and maximum conditions
  - Includes height above reference ellipsoid, total number density, number densities for nitrogen, methane, and argon, mass density, air pressure, air temperature, and correction factor for the perfect gas law equation
  - Data in these three files has been extended above 1300 km by a simple thermosphere model with diffusive separation
  - A small amount of Argon has been added to the minimum case profile, to avoid problems caused by assuming zero Argon
- Similar to Neptune-GRAM, the Yelle model is based on observations from Voyager radio science, IRIS, and UVS
- Includes an option that estimates thermodynamics and winds using output data from a Titan General Circulation Model (GCM) (Hourdin et al., 1995), combined with output from a Titan thermospheric GCM (Müller-Wodarg, et al., 2000)
- Includes Huygens Atmospheric Structure Instrument (HASI)/Doppler Wind Experiment (DWE) and Cassini Composite InfraRed Spectrometer (CIRS) auxiliary profiles produced by a Titan-GRAM Comparison Study (Justh and Justus 2007)

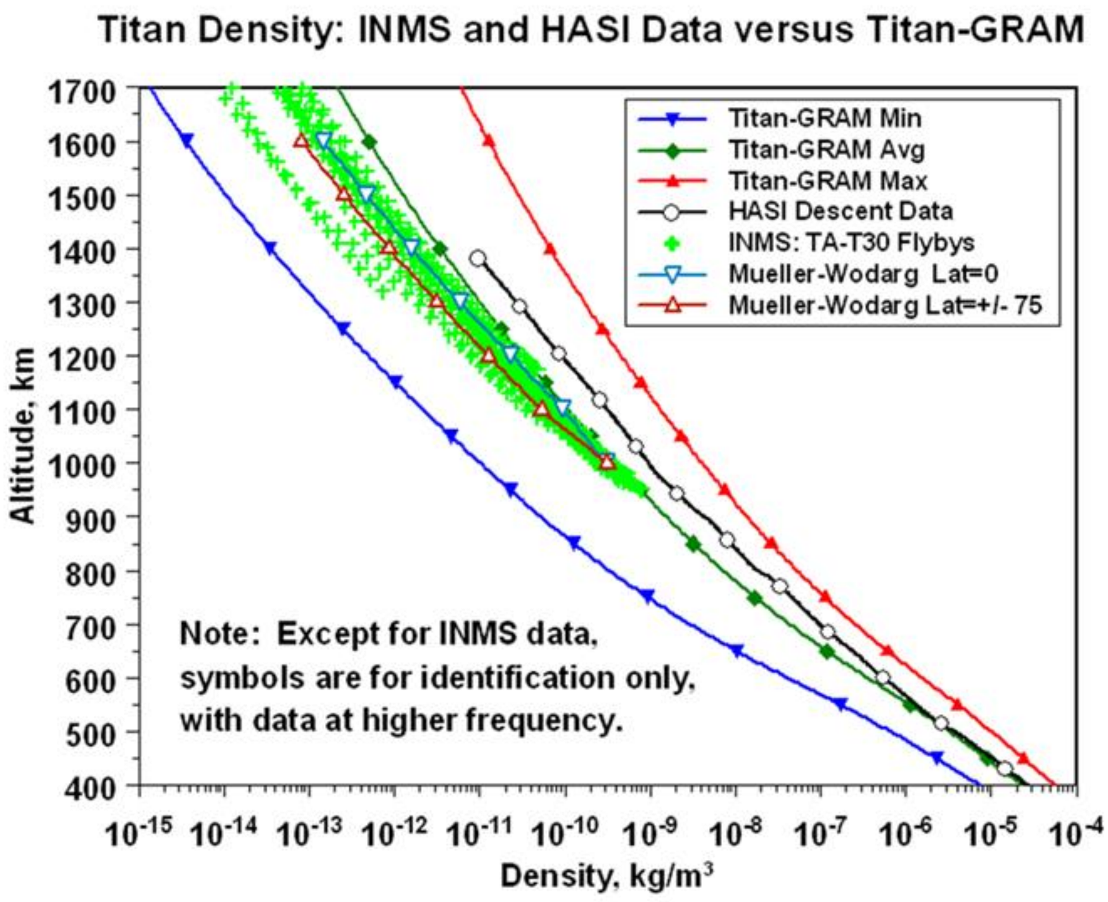
Neptune and Titan-GRAM Atmospheres

- Neptune and Titan-GRAMs do not explicitly compute time-dependent or latitude-dependent atmospheric values
  - Three data files are used and provide average, minimum and, maximum atmospheric data properties
  - This minimum-to-maximum envelope of data includes effects of variations with latitude, season, and time of day
- Vertical profiles may be selected using input parameter Fminmax from anywhere within the minimum-to-maximum envelope
  - Fminmax can be any real number between -1 (minimum) and +1 (maximum). Fminmax = 0 gives the average (recommended) profile
  - Fminmax values between -1.0 and 0.0 are automatically interpolated between minimum and average conditions
  - Fminmax values between 0.0 and +1.0 are automatically interpolated between average and maximum conditions
- Input parameter IFMM may be utilized to automatically adjust Fminmax for seasonal, latitude, and time-of-day effects

Titan-GRAM Comparison Study

- Comparison study (Justh and Justus 2007) of Titan-GRAM with:
  - Atmospheric density and wind measured during Huygens descent through Titan's atmosphere
    - Huygens Atmospheric Structure Instrument (HASI) data
    - Huygens Doppler Wind Experiment (DWE) data
  - Atmospheric density data measured by the Composite InfraRed Spectrometer (CIRS) instrument and the Ion and Neutral Mass Spectrometer (INMS) system during the Cassini flybys of Titan
- Up to an altitude of about 600 km, observed densities are fairly near the Titan-GRAM average expected value, and at all observed altitudes are well within the envelope of expected minimum and maximum values
- Winds from the Huygens DWE average near Titan-GRAM values
  - Substantial wind oscillations, within +/- two standard deviations are seen in observed winds.
- Results showed that Titan-GRAM is doing a reasonable job of representing Titan's atmosphere
- HASI/DWE and CIRS auxiliary profiles produced from this study allow Titan-GRAM to better replicate this observational data

Comparison Study Results

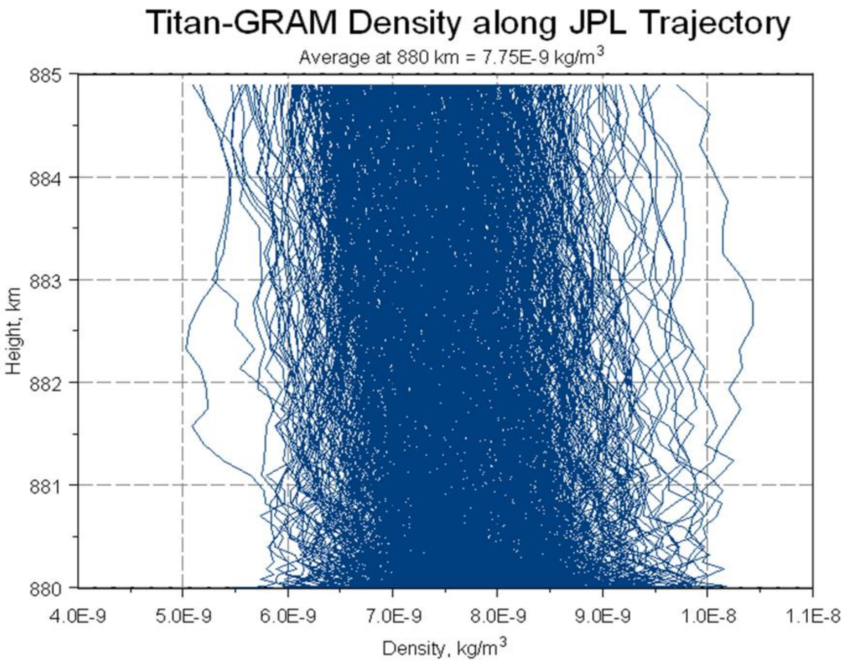


Titan-GRAM Auxiliary Profiles

- HASI/DWE and CIRS auxiliary profiles produced from the comparison study allow Titan-GRAM to better replicate the Huygens/Cassini observational data
  - The HASI data profile has been combined with Huygens DWE winds and formatted into an auxiliary profile
  - CIRS instrument data from the Cassini flybys of Titan for three latitudes (75S, 10S, and 75N) have also been formatted into Titan-GRAM auxiliary profiles
- Auxiliary profiles were not generated from the Cassini Ion and Neutral Mass Spectrometer (INMS) (Waite et al., 2005) data
  - Uncertainty in their absolute calibration, as evidenced by systematic differences observed between INMS densities and densities inferred from Cassini drag measurements and torque measurements for attitude control (Lee and Hanover, 2005)

Titan-GRAM Density along T70 Flyby

- Results of an 800-profile Monte-Carlo simulation (Justus and Justh, 2010) along the expected T70 flyby trajectory using Fminmax = 0.6 in Titan-GRAM
- Density values at 880 km average a value of 7.75E-9 kg/m^3, as prescribed by the latitude trend that was determined
- Individual profiles of perturbed density have values of about 10.0E-9 kg/m^3, verifying that as a reasonable expected maximum density value at 880 km



Neptune-GRAM Capability and Data Upgrades

- Convert model code from Fortran to C++
- Seeking input from the planetary science and GRAM community regarding:
  - Neptune atmosphere models and data sources that are available that can be utilized to update Neptune-GRAM
  - High priority items that would enable mission modeling that is not currently available
    - The expansion of the maximum depth of Neptune-GRAM
      - Current maximum depth is - 85 km (10 bars)

Titan-GRAM Capability and Data Upgrades

- Convert model code from Fortran to C++
- Several Titan atmosphere models and data sources are available that can be utilized to update Titan-GRAM:
  - Incorporate all of the CIRS data from the Cassini flybys of Titan
    - Covers the altitude range from about 100 km to near 450 km
    - Important altitude region for aerocapture into Titan's atmosphere (Lockwood, 2006)
    - In addition to providing data for auxiliary profiles for use in Titan-GRAM, CIRS can be used to update the built-in latitudinal, seasonal, and time-of-day variations in Titan-GRAM
  - INMS data can be used in a similar fashion to upgrade Titan-GRAM from about 1000 to 1800 km altitude
    - Important for possible science orbit maintenance and station keeping analyses
  - Recent Titan GCM output data
- Additional suggestions would be appreciated