Saturn GRAM Planning

2022-11-18

Kunio M. Sayanagi (NASA LaRC E302)

Justin Garland (NASA LaRC E302 / AMA / Hampton U.)

Overview

- Saturn GRAM is the last of the PlanetGRAMs still to be released
- Saturn GRAM will follow the development roadmap of the other Giant Planet GRAMS (i.e. for Jupiter, Uranus and Neptune)
- General Development Phases for Giant Planet GRAMs:
    1. One-dimensional column data for Temperature, pressure and density vs. altitude
        a. Consider adding following variables
            - Eastward Wind Component
            - Composition
    2. Add latitudinal and/or seasonal dependence

Saturn GRAM Development Considerations

Opportunity is ripe to develop Saturn GRAM

- Cassini Mission's orbital tour of the Saturnian System collected a wealth of data
  - Especially, the Grand Finale phase of the mission collected data from a very close range
  - Cassini's Final Dive also took in-situ measurements of the Upper Atmosphere
- Saturn Probe is one of the solicited mission themes for the upcoming New Frontiers 5 AO
  - NF5 AO's current expectation is "No earlier than 2026"
  - Probe Design depends on atmospheric structure, and increases demand for Saturn GRAM

Cassini Mission Instrument/Data Overview

Upper Atmosphere / Thermosphere (pressure < 10^{-4} mbar)

- Ion and Neutral Mass Spectrometer (INMS)
  - Collected density and composition data during Grand Finale as function of spacecraft trajectory
- UV Imaging Spectrometer (UVIS)
  - Stellar Occultation measurements to measure atmospheric density as function of altitude

Middle Atmosphere / Stratosphere (10^{-4} mbar < pressure < 100 mbar)

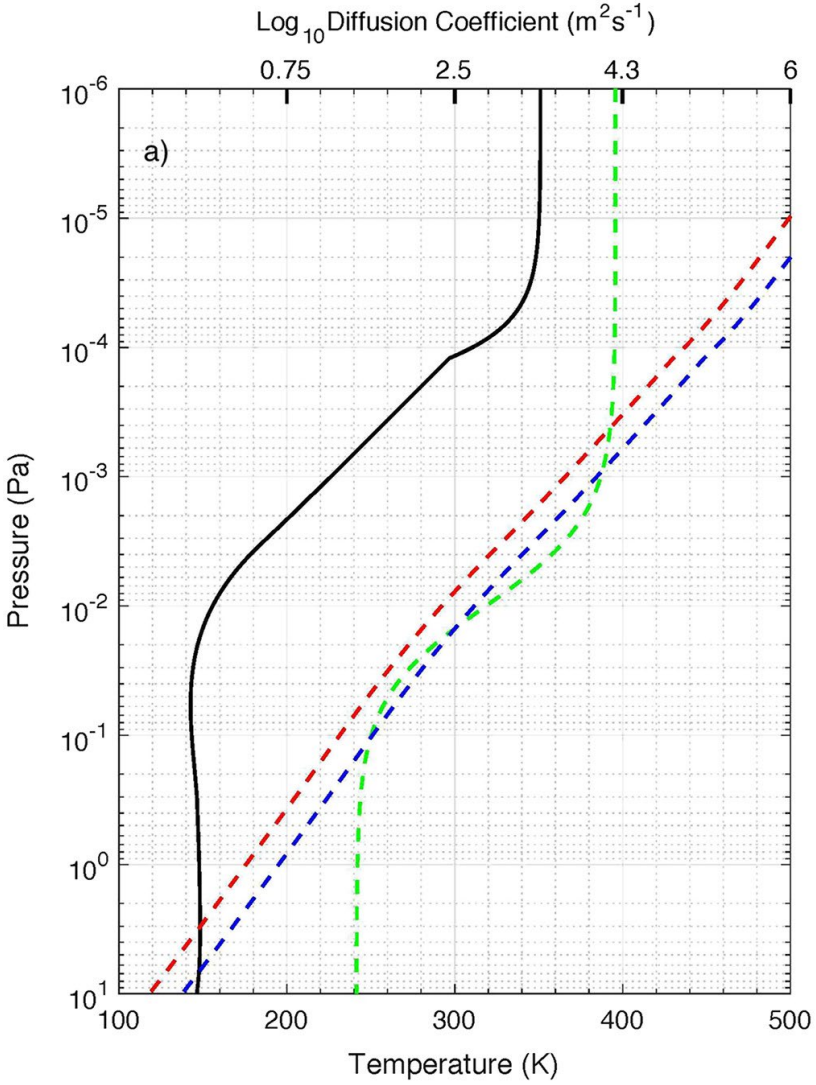
- Composite Infrared Spectrometer (CIRS)
  - Spectral sounding of to retrieve temperature and composition as function of latitude and altitude

Lower Atmosphere / Troposphere (pressure > 100 mbar)

- Radio Occultation
  - Measure density as function of altitude

Saturn GRAM: One-dimensional Column Model Upper Atmosphere Data Review

- INMS Measurements:
  - Yelle et al. (2018) “Thermal Structure and Composition of Saturn's Upper Atmosphere From Cassini/Ion Neutral Mass Spectrometer Measurements” Geophysical Research Letters, Volume 45, Issue 20, pp. 10,951-10,958, doi: 10.1029/2018GL078454
  - Brown et al. (2020) “A pole-to-pole pressure-temperature map of Saturn's thermosphere from Cassini Grand Finale data” Nature Astronomy, Volume 4, p. 872-879, doi: 10.1038/s41550-020-1060-0
- UVIS Measurements
  - Koskinen et al. (2021) “An empirical model of the Saturn thermosphere” Icarus, Volume 362, article id. 114396, doi: 10.1016/j.icarus.2021.114396
  - Vervack and Moses (2015) “Saturn's upper atmosphere during the Voyager era: Reanalysis and modeling of the UVS occultations” Icarus, Volume 258, p. 135-163. doi: 10.1016/j.icarus.2015.06.007
- Review Article
  - Strobel et al. (2018) “Saturn’s Variable Thermosphere” in book *Saturn in the 21st Century*, Cambridge University Press.



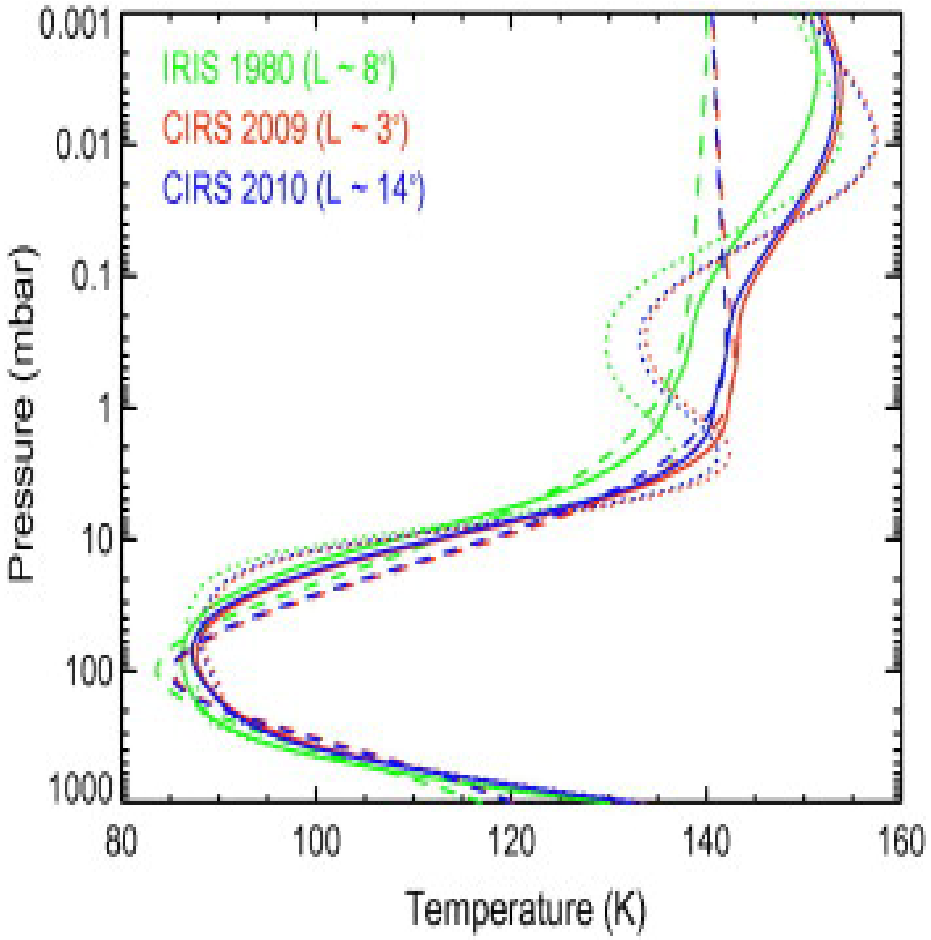
T vs p from INMS data (black line)
From Yelle et a. (2018)

Saturn GRAM: One-dimensional Column Model Stratosphere Data Review

- Sinclair et al. (2014) “From Voyager-IRIS to Cassini-CIRS: Interannual variability in Saturn’s stratosphere?” Icarus, Volume 233, p. 281-292. doi: 10.1016/j.icarus.2014.02.009
- Sinclair et al. (2013) “Seasonal variations of temperature, acetylene and ethane in Saturn's atmosphere from 2005 to 2010, as observed by Cassini-CIRS” Icarus, Volume 225, Issue 1, p. 257-271. doi: 10.1016/j.icarus.2013.03.011
- Fletcher et al. (2010) “Seasonal change on Saturn from Cassini/CIRS observations, 2004-2009” Icarus, Volume 208, Issue 1, p. 337-352. doi: 10.1016/j.icarus.2010.01.022

Review Article:

- Fletcher et al. (2018) “Saturn’s Seasonally Changing Atmsophere: Thermal Structure, Composition and Aerosols” in book *Saturn in the 21st Century*, Cambridge University Press



T vs p from CIRS data during different years
From Sinclair et a. (2014)

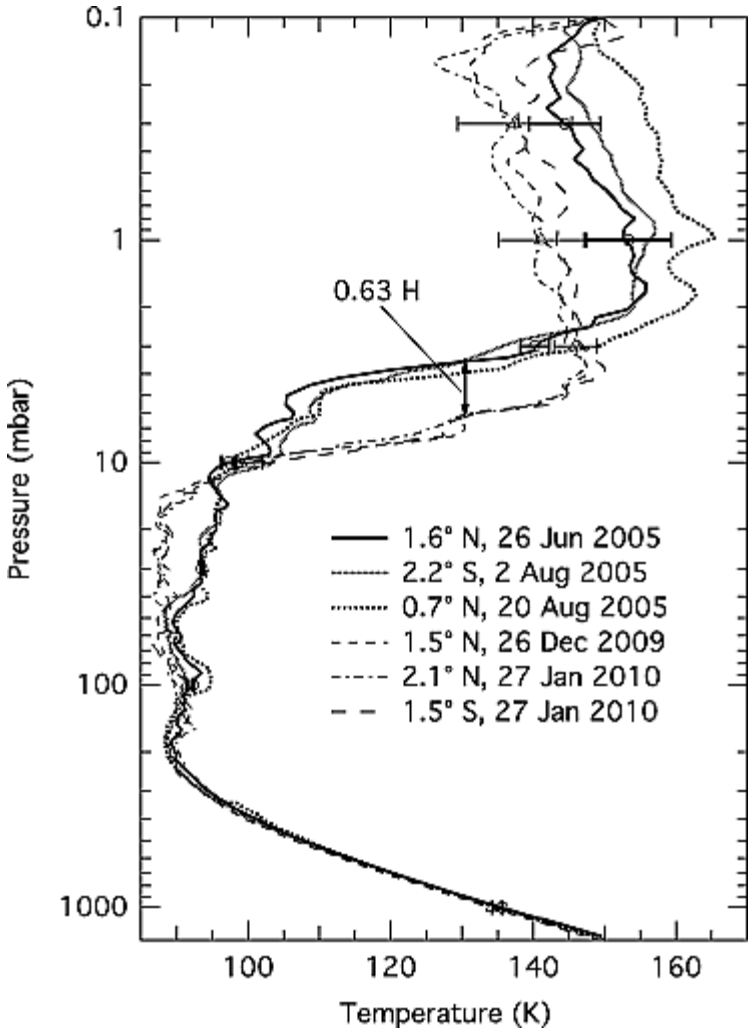
Saturn GRAM One-dimensional Column Model Troposphere Data Review

Much of Cassini Radio Occultation Data remain to be analyzed/published, but several profiles have been published:

- Schinder et al. (2011) “Saturn's equatorial oscillation: Evidence of descending thermal structure from Cassini radio occultations” Geophysical Research Letters, Volume 38, Issue 8, CiteID L08205, doi: 10.1029/2011GL047191
- Schinder et al. (2015) “A numerical technique for two-way radio occultations by oblate axisymmetric atmospheres with zonal winds” Radio Science, Volume 50, Issue 7, pp. 712-727, doi: 10.1002/2015RS005690

Given the dearth of data, Voyager Radio Occultation data are still relevant:

- Lindal et al. (1985) “The atmosphere of Saturn - an analysis of the Voyager radio occultation measurements” Astronomical Journal, vol. 90, June 1985, p. 1136-1146. doi: 10.1086/113820



From Schinder et al. (2011)

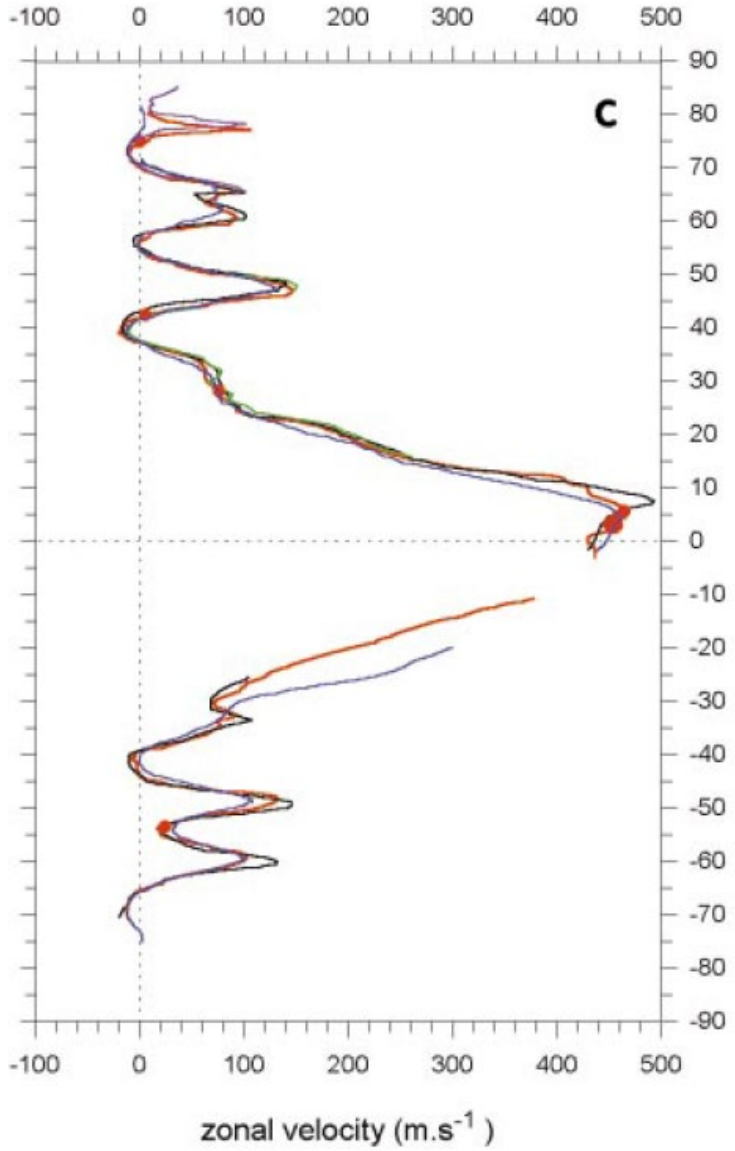
Saturn GRAM Wind Data

Numerous results are available for cloud-top Wind Speed as function of Latitude

- Classic Voyager Result:
  - Sanchez-Lavega et al. (2000) “Saturn's Zonal Winds at Cloud Level” Icarus, Volume 147, Issue 2, pp. 405-420, doi: 10.1006/icar.2000.6449
- Cassini results:
  - Garcia-Melendo et al. (2011) “Saturn's zonal wind profile in 2004-2009 from Cassini ISS images and its long-term variability” Icarus, Volume 215, Issue 1, p. 62-74. doi: 10.1016/j.icarus.2011.07.005
  - Studwell, e tal. (2018) “Saturn's Global Zonal Winds Explored by Cassini/VIMS 5-µm Images” Geophysical Research Letters, Volume 45, Issue 14, pp. 6823-6831, doi: 10.1029/2018GL078139

Considerations in Saturn GRAM:

- Wind speed as function of latitude is at ~500 mbar level.
  → How do we mesh it with the 1D vertical column data?



From Sanchez-Lavega et al. (2000)

Saturn GRAM: Outlook toward Latitude-Altitude 2D Model

Upper Atmosphere

- Observational Data are sparse and scarce. Limited sampling of stellar occultations have sensed several locations
- Latitudinal structure would need to be filled in from models, e.g.
  - Yates et al (2020) “Magnetosphere-Ionosphere-Thermosphere Coupling at Jupiter Using a Three-Dimensional Atmospheric General Circulation Model” Journal of Geophysical Research: Space Physics, Volume 125, Issue 1, article id. E26792, doi: 10.1029/2019JA026792
  - Muller-Wodarg et al (2006) “A global circulation model of Saturn's thermosphere” Icarus, Volume 180, Issue 1, p. 147-160. doi: 10.1016/j.icarus.2005.09.002

Stratosphere:

- CIRS papers (already listed) naturally sense latitudinal variabilities.

Troposphere:

- New results are needed to make predictions.
- Tropospheric structure shown in dynamical models are likely representative of parameter choice for convenience, and observational data is lacking
- Simple theoretical predictions (e.g. thermal wind extrapolation, equilibrium thermodynamics models etc) offer most promise

Saturn GRAM: Closing Thoughts

- Similar to the other GRAM efforts, Saturn GRAM will synthesize multiple data sets
- New/Recent data from Cassini mission makes Saturn a unique case
- Combining data from different datasets/instruments will have unique challenges (e.g. some quantities natively depend on altitude, while others prefer pressure coordinate, so hydrostatic approximation is required to mesh the datasets)
- Starting point: 1D column model similar to Jupiter/Uranus/Neptune GRAM
- Future Outlook: Introducing Latitudinal Dependence