Uranus-GRAM Update Plans

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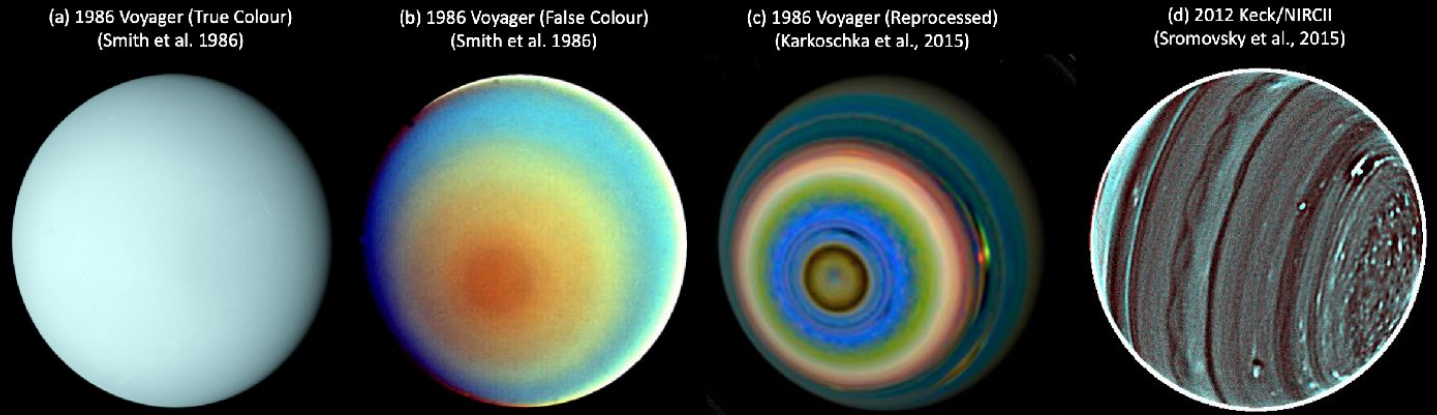

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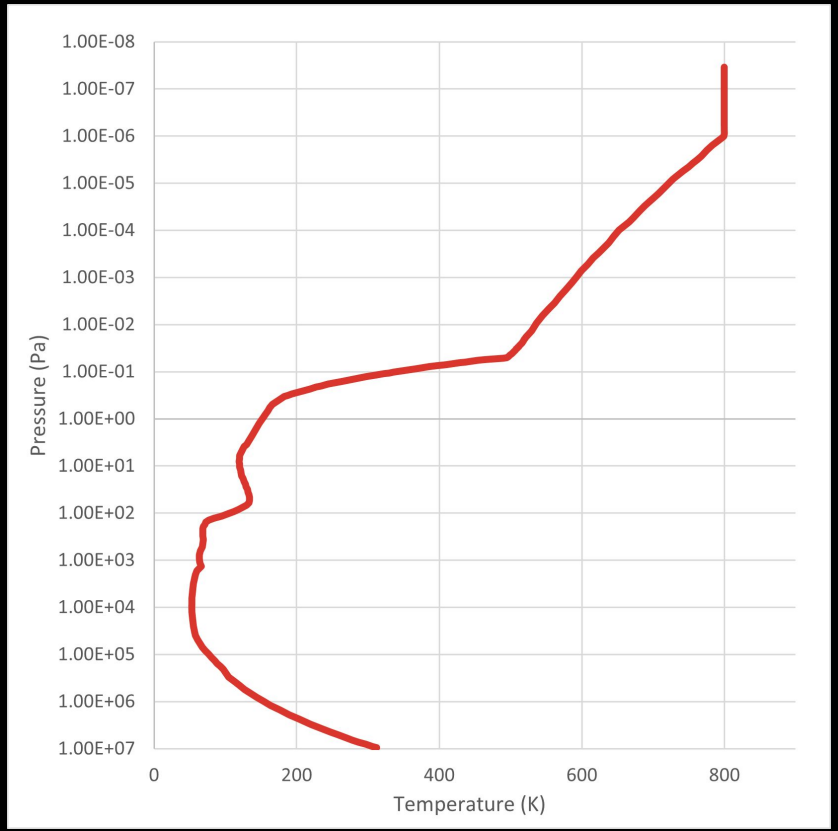
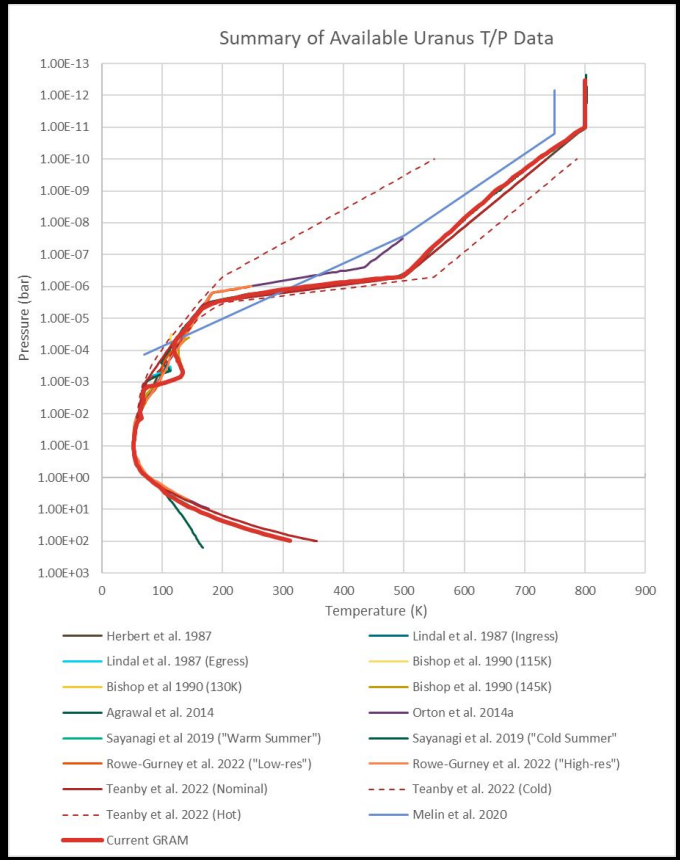
Current GRAM Release

- Current UranusGRAM atmospheric input is based on three papers:
  - Herbert et al. 1987
  - Lindal et al. 1987
  - Bishop et al. 1990
- No winds
- Voyager UV and radio occultations
- All have been superseded



TP Profiles in the Literature

- Reviewed the last ~40 years of Uranian TP profile retrievals
- Results from:
  - Voyager reanalyses
  - Spitzer Space Telescope
  - Theory-based extrapolations
- General agreement in the troposphere, wide spread in the thermosphere



New 1D Models

- UranusGRAM currently requires 1D arrays of:
  - Temperature
  - Altitude
  - Pressure
  - Density
  - Wind (zonal and meridional; optional)
- Most literature data are reported as TP profiles
- Need to convert pressures to altitudes and calculate density

Methods

- Convert pressures to altitudes using the barometric equation:

$$P = P_o \, exp\left[-\int_0^z \frac{dz}{H}\right] = P_o \, exp\left[-\int_0^z \frac{g(z)}{R(z)T(z)} dz\right]$$

P_0: pressure at z = 0 (1 bar)

g(z), R(z), T(z): altitudinally-dependant gravity, specific gas constant, and temperature, respectively

Methods

- Local gravity calculation:

$$g_r(r,\phi) = \frac{GM}{r^2}\left(1 - \frac{9}{2}\left(\frac{R}{r}\right)^2 J_2 \sin^2\phi + \frac{3}{2}\left(\frac{R}{r}\right)^2 J_2\right) - \omega^2 r\cos^2\phi$$

$g_r(r, \phi)$: local gravity at radius r and latitude ϕ

G: universal gravitational constant

M: mass of the planet

R: radius at which the zonal harmonic coefficients (J2) have been normalized

ω: the planet's angular velocity

Methods

- Specific gas constant calculation:

$$R(z) = \frac{k_B}{\bar{m}(z)}$$

R(z): specific gas constant at altitude z

k_B: Boltzmann constant

m-bar(z): mean molecular weight at altitude z

Methods

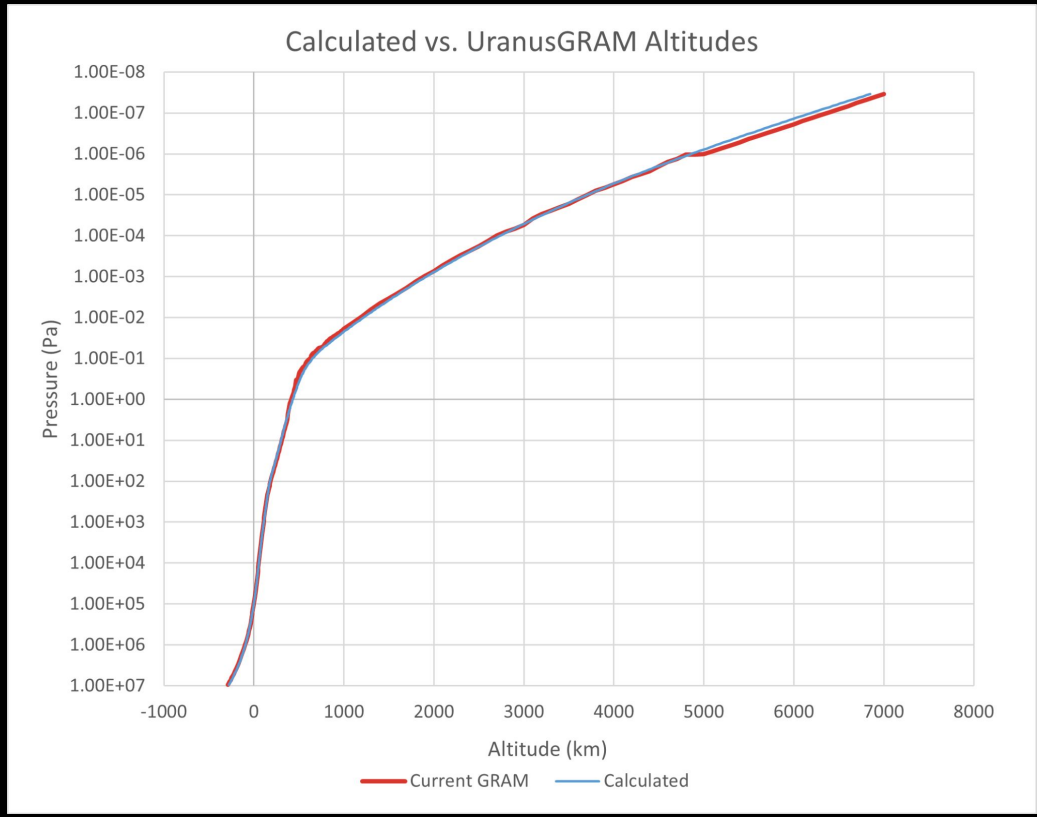
- Density calculation:

$$\rho(z) = \frac{p\bar{m}(z)}{k_B T}$$

Ideal gas law, with z-dependant mean molecular weight as before

Method Validation

- Validated against the current UranusGRAM model
- Fairly close agreement in both calculated altitudes and densities



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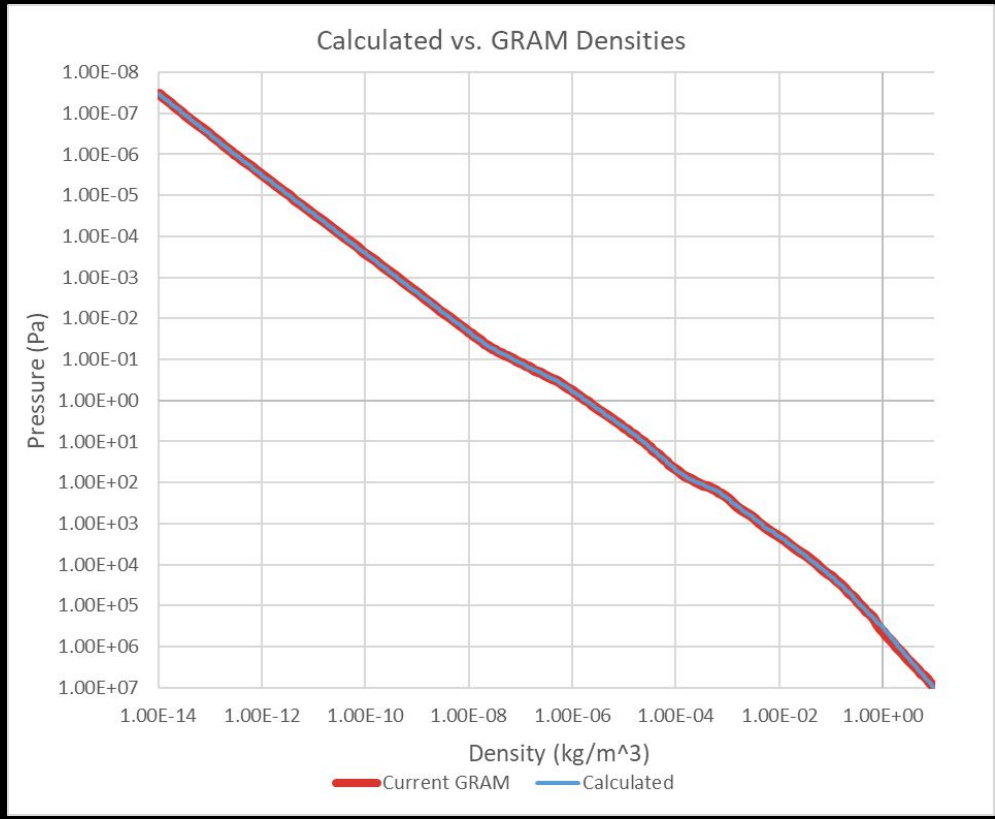
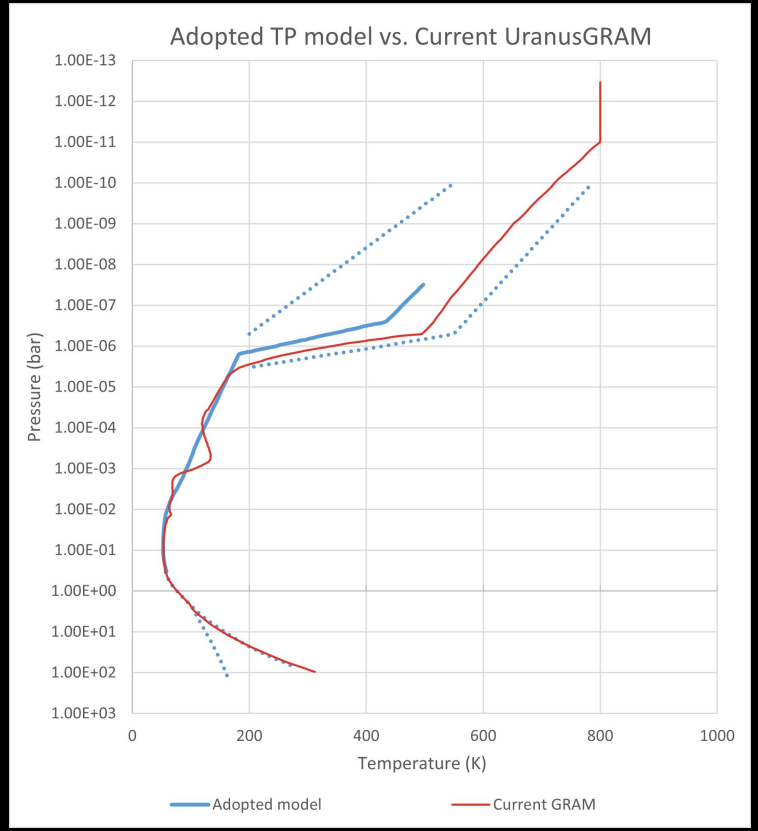


New 1D Models: Thermosphere

- Thermosphere: connect to the lower atmosphere via the hydrostatic equation for a constant lapse rate atmosphere:

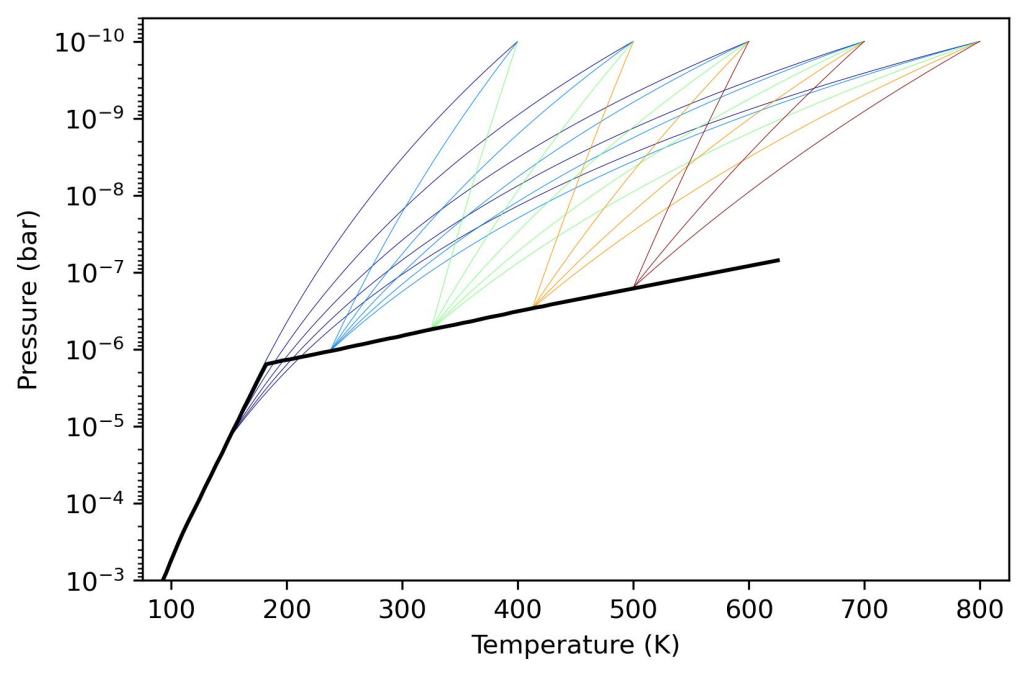
$$p(z) = p_o \left(\frac{T(z)}{To} \right)^{\frac{g}{R\Gamma}}$$

- "Families" of profiles connecting different upper, isothermal temperatures. Bounds from Teanby et al. 2022



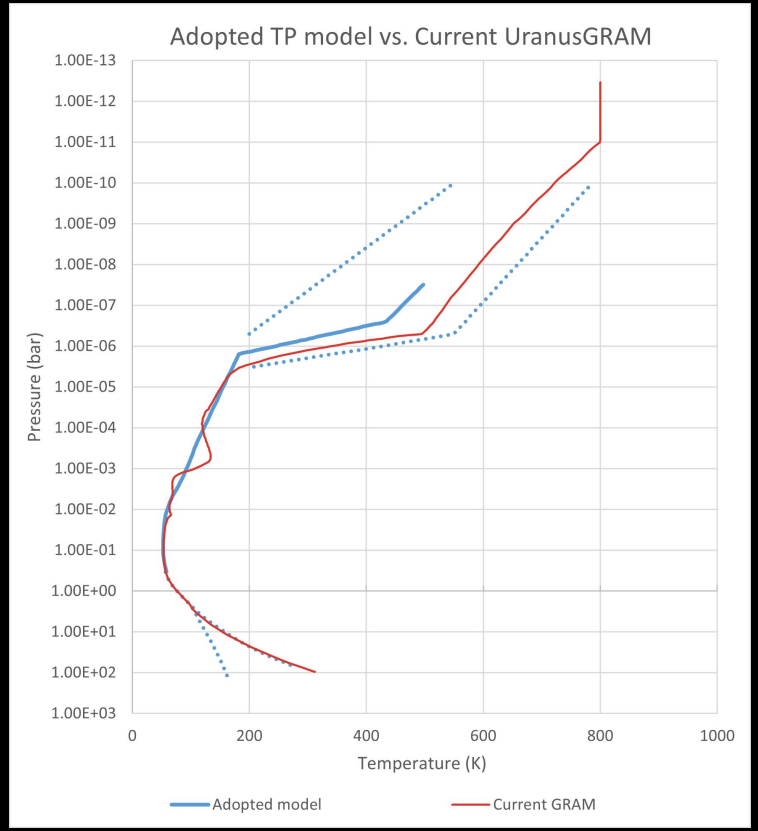
Thermosphere in Detail

- Example of thermospheric profile “families”
- Work with Jared Bell (Goddard): Profiles will be run through his thermospheric models to further test stability
- Work with Will Saunders (Boston U.): Incorporate his ground-based Uranus occultations; set sensitivity limits for future space-based occultation measurements



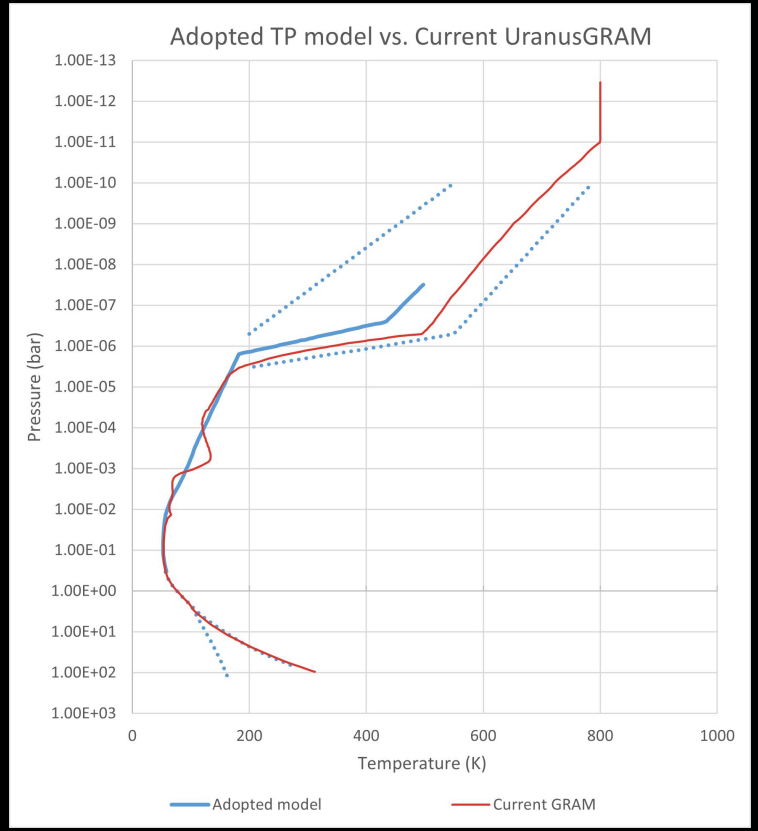
New 1D Models: Troposphere

- Troposphere: adopt the profile of Orton et al. 2014
- Voyager reanalysis and new Spitzer measurements
- Smooths high-altitude oscillations thought to be a result of vertically propagating waves or haze layers.



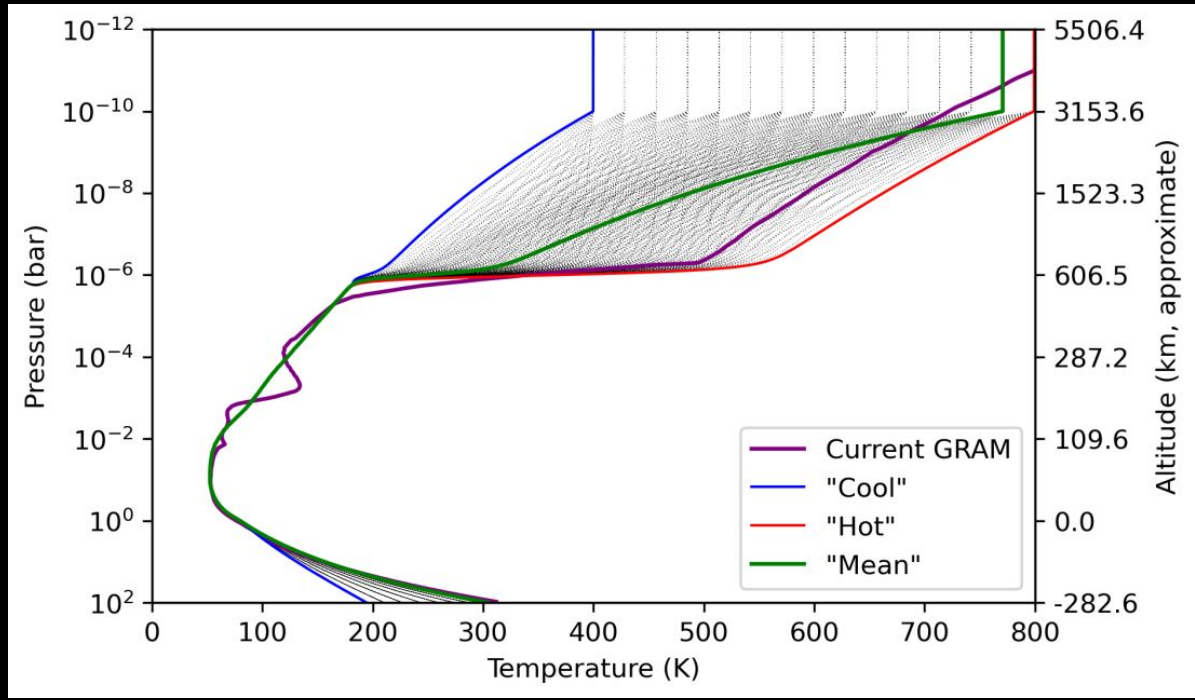
New 1D Models: Deep

- Deep atmosphere: adopt the range from Sayanagi et al. 2019
- Developed for the Small Next-generation Atmospheric Probe (SNAP) study
- Warmest profile follows the dry adiabatic lapse rate
- Coldest profile assumes a high static stability, using an assumed Brunt–Väisälä frequency of 0.005 s^{-1}



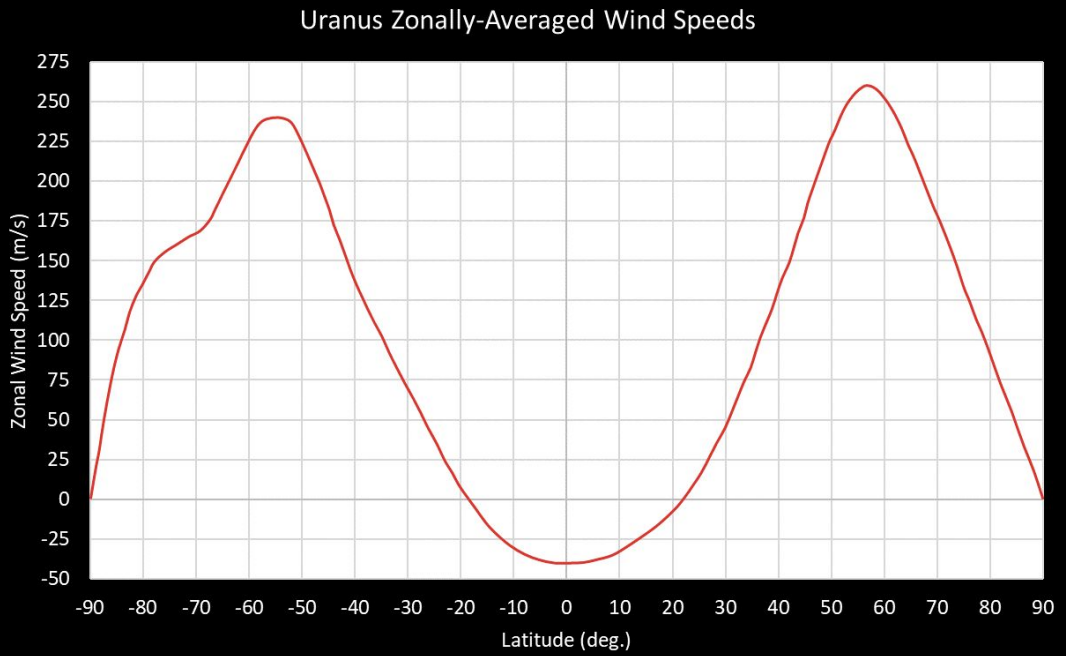
Atmospheric Profile Ensemble

- Beta atmospheric profiles under evaluation
- ~200 profiles which cover the spread of thermospheric observations. 15 temperature steps
- 10 assumed BV frequencies for the deep atmosphere



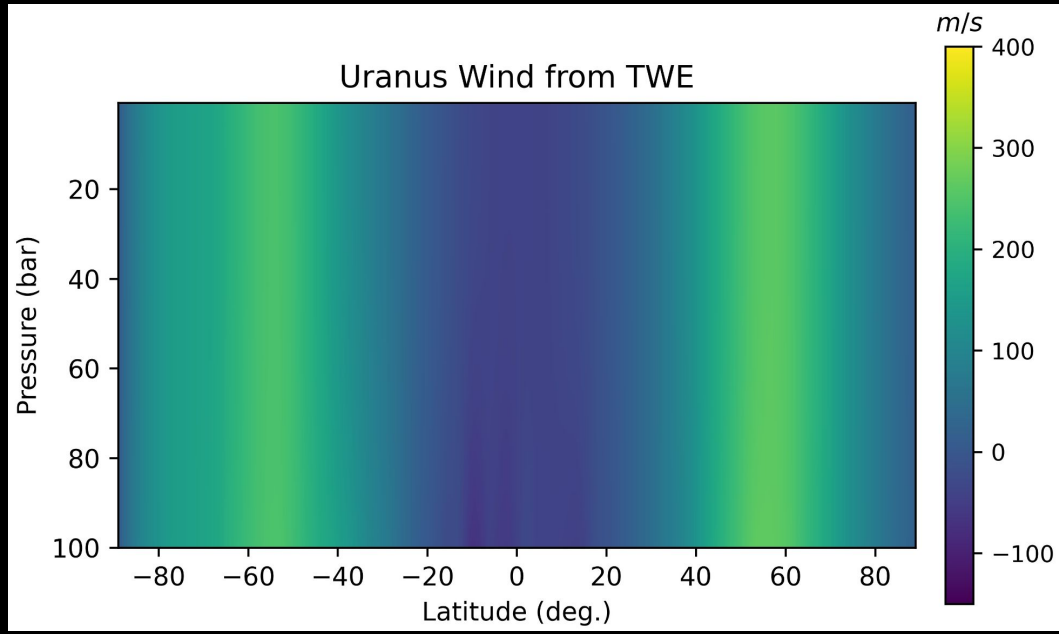
Wind Model

- 1-bar, zonally-averaged winds by latitude
- Initial model will assume a decay with altitude based on Jupiter Galileo vertical wind shear



Wind Model

- 1-bar, zonally-averaged winds by latitude
- Initial model will assume a decay with altitude based on Jupiter Galileo vertical wind shear
- In the future: winds will decay according to the thermal wind equation



Next Steps

- Introduce error and variability estimates on constituent gas species (H, He, CH_4)
- Assess tropospheric variabilities
  - Error range from Voyager measurements
  - Inject energy from waves (MarsGRAM has a similar routine)
- Work with Jim Hoffman to implement calculations directly into UranusGRAM
- Begin work on fully-2D Uranian temperature, pressure, altitude, density, and wind models

Questions?