Neptune Atmospheric Upgrade for Orbiter 2010

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Description

This atmospheric upgrade is designed for Orbonauts like myself who enjoy aerobraking, de-orbiting, or flights in the upper atmosphere of Neptune. As there is such a huge fuel price to pay for so little gain, there's likely not many of you. However if you tried this stunt you likely noticed the Surface MFD's thermal readout reading a constant 288K. Thus the vanilla orbiter config file defines the following for Neptune's atmosphere:

T=288K

P=414e3*e^(-z/h) in kPa, where z is a constant

Rho= 0.5093*e^-(g0/(R*T)*z) kg/m^3, where g0 and T are constant

The result is an atmosphere that is generic in orbiter. It takes only a few minutes to define, but is totally lacking distinct layers. This makes it much more difficult to recreate any future Neptune missions or demonstrate concepts of said missions with any reasonable accuracy. Such examples might include (but are not limited to) attempting aerocapture at 400 kilometers per a NASA design document only to find thyself incinerated, and attempting to re-enter with a delta glider and seeing higher than realistic heating due to a stratosphere at +15C. This is precisely what encouraged me to spend the hours involved in coding up a proper atmosphere.

Using the data remotely sampled, the Neptune GRAM, and several research papers, I was able to identify 8 unique layers, meaning this module does the work of 8 config files, each one also defining temperature.

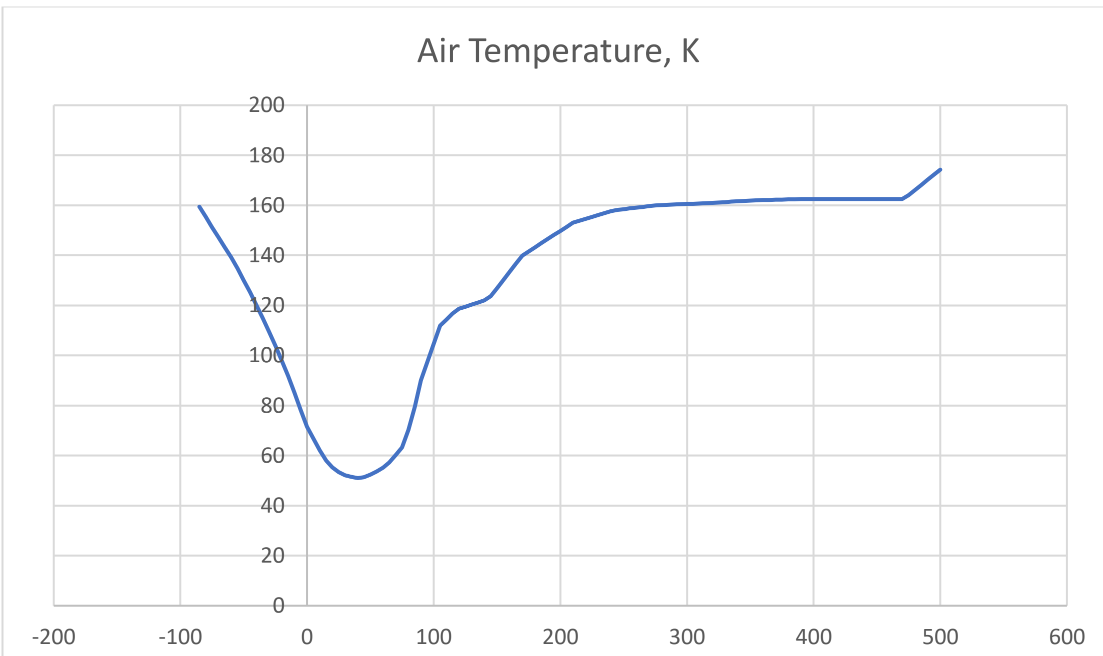
Process

Unlike Jupiter, Neptune did not have a probe directly sample the atmosphere (as of 2023). Instead data was collected based on Voyager 2 occupation experiments and large ground and space based telescopes that helped to create a Global Reference Model of the atmosphere.

The data was tabulated from the Neptune GRAM output graphs onto an excel spreadsheet using transfer functions and converted to an excel table.

At this point to keep things harder to make careless mistakes I translated the 0 altitude datum from the 1-bar level (1 bar true column) to the zero altitude (Cutoff true column) in Orbiter. This allowed me to work in Orbiter compliant altitudes, as altitudes below 0 km are not supported in code. The translation was exactly +208000m, which is the exact distance from the explicitly defined Neptune altitude-0 and the 7 Celsius isotherm which just about corresponds with the lowest condensing water ice clouds.

Next I needed to determine some data trends. This module runs fundamentally from specific gas constant, R, acceleration due to gravity, g, and measured temperature, T. All other parameters are calculated using these 3 base values. As there was no probe, we don't know precisely the R values of Neptune versus altitude. Therefore we only have the Voyager occultation data and Neptune GRAM output to go off of. Gravity calculates using the simple formula $g = Gm/(r+h)^2$, where m is the mass of Neptune, r the radius at 1 bar, and h the altitude relative to 1-bar (the "surface"). That just leaves T to be filled in by remote sensing observations. Shown below is the plot of T from the NeptuneGRAM output. All x axis values are in km. Note that the NeptuneGRAM model ends at -85km, and since we need to go to -208km, I had to extrapolate the temperature based on lapse rate trends towards the bottom of the sample from -85 to -208km.



The following equations represent R, G, and T:

$$For\ base\ to - 85km, R0(z) = 3208.09$$

$$-85km\ through\ tropopause, R1(z) = 2889.25$$

$$tropopause\ to\ stratopshere, R2(z) = 3070.9$$

$$stratosphere\ through\ lower\ stratopause, R3(z) = 3961.7$$

$$lower\ stratopause\ through\ upper\ stratopause, R4(z) = 3162.0$$

$$upper\ stratopause\ to\ thermosphere, R5(z) = 3545.6$$

$$thermosphere\ to\ exosphere, R6(z) = 4517.0$$

$$exosphere\ to\ the\ top\ of\ the\ atmosphere, R7(z) = 4124.4$$

g is the simple 1/r^2 law. For all altitudes:

$$g(z) = \frac{6.67E - 11 * 1.024E + 26}{24556000 + z^2}$$

For temperature, out comes 8 equations for the 8 layers:

$$For\ the\ deep\ troposphere, T0(z) = -0.000978453 * (z - 208000) + 76.2694$$

$$For\ troposphere, T1(z) = 9.8279E - 19 * z^4 - 6.3885E - 13 * z^3 +$$

$$1.5022E - 07 * z^2 - 1.6081E - 02 * z + 828.59$$

$$For\ tropopause, T2(z) = 9.0429E - 09 * z\text{^}2 - 4.4547E - 03 * z + 600.49$$

$$For\ stratosphere, T3(z) = 1.6637E - 03 * z - 406.78$$

$$For\ lower\ stratopause, T4(z) = 2.5771E - 13 * z^3 - 2.6205E - 07 * z^2 +$$

$$8.8986E - 02 * z - 9968.38$$

$$For\ upper\ stratopause, T5(z) = 3.8101E - 15 * z^3 - 6.5156E - 09 * z^2 +$$

$$3.6956E - 03 * z - 534.46$$

$$For\ thermosphere, T6(z) = 875.35/\left(1 + e^{-2E-6*(z-1E+6)}\right) - 137.921$$

$$For\ exosphere, T7(z) = 7.2727E - 5 * z + 417$$

And when graphed together, these produce the graph found above.

Here is the table mapping each equation to altitude:

Temperature Layers			
Deep Troposphere	0	123000	0
Troposphere	123000	248000	1
Tropopause	248000	283000	2
Stratosphere	283000	313000	3
Lower Stratopause	313000	353000	4

Upper Stratopause	353000	678000	5
Thermosphere	678000	4208000	6
Exosphere	4208000	8588000	7
	From	To	ID

From that point, we have what we need to determine p and rho.

For every altitude, the pressure equation was run for the entire layer, and the outputs at the top of the layer defined the equation coefficients for the next layer. Here is a table of coefficients used in the calculations:

Altitudes	
Z1	123000
Z2	248000
Z3	283000
Z4	313000
Z5	353000
Z6	678000
Z7	4208000
R’s	
R0	3208.09
R1	2889.25
R2	3070.9
R3	3961.7
R4	3162
R5	3545.6
R6	4517
R7	4124.2
Temperatures	
T0	279.7876
T1	159.438
T2	51.89892
T3	64.0471
T4	113.9575
T5	125.7792
T6	163.4996
T7	736
Pressures	
P0	8974318
P1	1324100
P2	8822.68

P3	992.9035
P4	300.37
P5	95.558
P6	0.10256
P7	4.41E-09
Lapse Rates	
L0	-0.00098
L1	-0.00086
L2	0.000347
L3	0.000405
L4	0.00039
L5	0.000116
L6	0.000162

For every altitude except the exosphere and deep troposphere,

$$p(z) = P\# * (1 + (z - Z\#) * L\#/T\#)^{-g(z)/(R*L\#)}$$

Where # represents 1-6 as shown in the table. Z represents a current altitude.

In the deep troposphere, pressure is always $p(z) = -5.5114E - 10 * z\hat{}3 + 4.1310E - 04 * z\hat{}2 - 1.0467E + 02 * z + 8974318$

In the exosphere, pressure is always $p(z) = P7 * e^{-\frac{(z-Z7)}{R7*T7/g(z)}}$

Density is a simple relationship between everything so far. At all altitudes, $\rho = \frac{p}{R0*T(z)}$

Now some changes I made to the Neptune.cfg file:

Mean Radius- biggest change of all. In a gas or ice giant planet, which lacks a distinct surface, the "height of 0 altitude" is defined as the radius from the center of the planet to where the ambient pressure of the atmosphere is 1 Earth Standard Atmosphere (101325 kPa). Orbiter defines 0 altitude as the height at which the atmosphere ends and the solid surface of the planet is drawn, and does not support negative altitudes. If we want to simulate the atmosphere down to 89 bar, then we need to decrease the radius from the center of the planet to the level the atmosphere reaches 89 bar. Otherwise, the planet will appear inflated (1 bar would be 265km too high, meaning the radius at 1 bar would be incorrectly represented as 24830km, making planet Neptune 208 km too large. I set the radius to 24,416km, which means the 1 bar altitude is 208 above that, at 24,624km which is the correct size.

AtmPressure0- adjusted to pressure at the 7C isotherm (water cloud deck base). Roughly 89 bar.

AtmDensity0- adjusted to rho0 density per the module.

AtmGasConstant- adjusted to R0 constant.

AtmAltLimit- raised to 8588 km to simulate the exosphere transition to space and enable atmospheric driftdown of low hanging orbits.

ATMColor0- Adjusted to match Spectra table parameters in *Hazy Blue Worlds: A Holistic Aerosol Model for Uranus and Neptune, Including Dark Spots*, P.G.J. Irwin, et al. This scientific paper discusses in great detail the color of Uranus and Neptune. Table 4 lists the transmission at various spectra for 3 layers of aerosol haze on Neptune. I normalized them for the human cone cell peaks (445nm, 535nm, 575nm) and combined them to get the new ATM color. This is as realistic as we can get without someone dropping a camera down there and snapping a picture.

AtmHazeColor- also adjusted to match the Table 4 parameters in the above referenced paper.

AtmHorizonAlt- Adjusted to 407km to improve the optical thickness of the atmosphere.

AtmHaxzeDensity- Adjusted to match clarity as found in P.G.J. Irwin et al.

AtmHazeShift- Adjusted to neatly overly the H2S cloud deck. This allows it to function as methane haze.

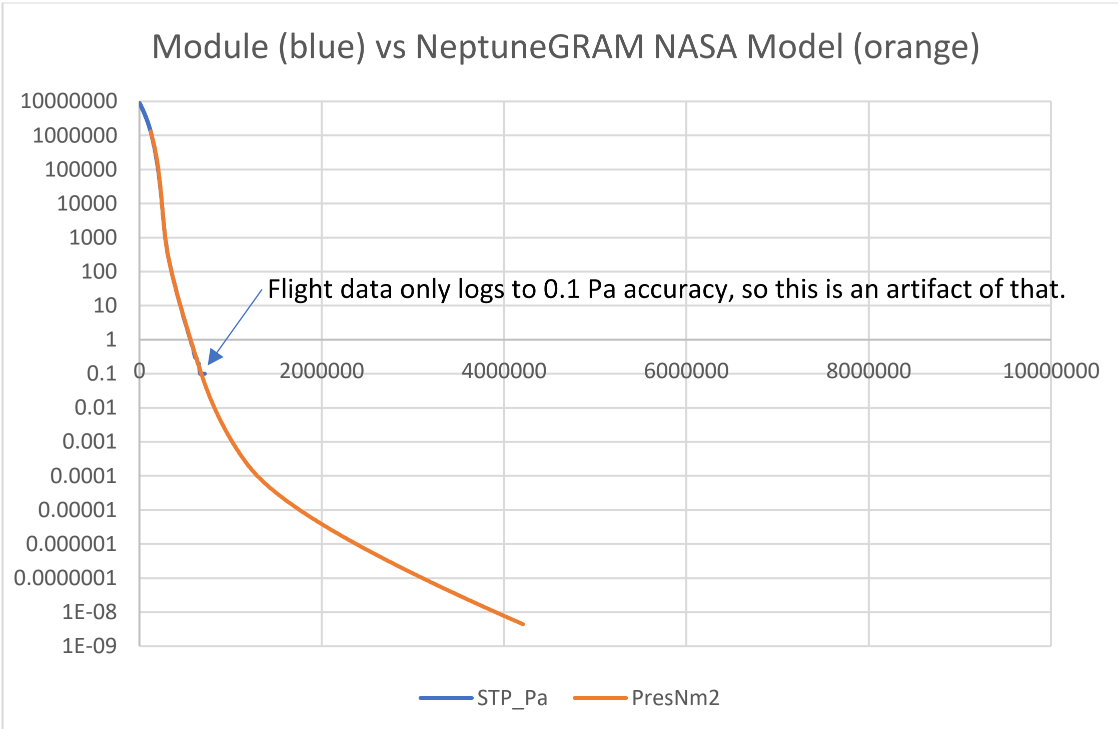
CloudAlt- adjusted to the base of the H2S cloud deck at 7 bar. This is the first optically thick cloud deck. The methane one is mostly transparent (except for the rare icebergs). This can be seen in Figure 3 in P.G.J. Irwin et al. figure 3 and figure 5, and is the “surface” we see.

CloudRotPeriod- adjusted so that it moves at 200 m/s relative to the rigid body of Neptune, simulating winds at that level. Note that because Neptune is NOT a rigid body, its cloud deck appearance evolves over time. So you’ll see a slightly different surface every day. In case you think that sounds slow for Neptune, it isn’t, at least here. The 2 km/s winds that everyone makes a big hoopla over are much higher up in the stratosphere.

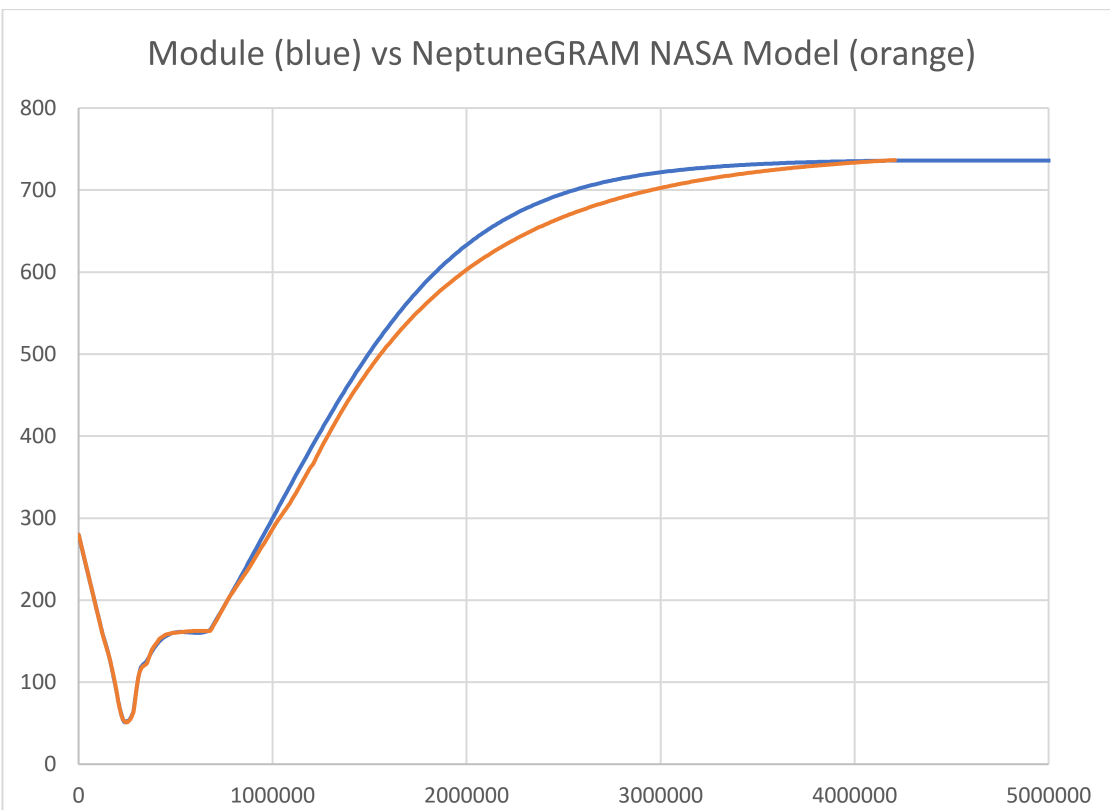
Results

Here are graphs of the module plotted against the NASA GRAM for pressure and temperature.

Pressure (NeptuneGRAM to Module at 85km to 683km)



Temperature (NeptuneGRAM to module at 85km to 4208km)



As you can see, pressure is spot-on, virtually no difference. There is a little difference in thermosphere temperature, but I am not concerned about that because the thermosphere is very dynamic and can vary widely depending on solar conditions. Thus, as you can see the module produces a very realistic atmosphere model of Neptune.

Well that about covers it. I hope you enjoy flying in your realistically upgraded Neptune.

If you have questions or want to learn more you can reach out on the forums.

Be sure to check out my Youtube Channel: https://www.youtube.com/user/4656nick/