THE LATEST ON THE VENUS THERMOSPHERIC GENERAL CIRCULATION MODEL: CAPABILITIES AND SIMULATIONS

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Introduction:
Venus has a complex and dynamic upper atmosphere. This has been observed many times by ground-based, orbiters, probes, and fly-by missions going to other planets. Two over-arching questions are generally asked when examining the Venus upper atmosphere: (1) what creates the complex structure in the atmosphere, and (2) what drives the varying dynamics. A great way to interpret and connect observations to address these questions utilizes numerical modeling; and in the case of the middle and upper atmosphere (above the cloud tops), a 3D hydrodynamic numerical model called the Venus Thermospheric General Circulation Model (VTGCM) can be used. The VTGCM can produce climatological averages of key features in comparison to observations (i.e. nightside temperature, O_2 IR nightglow emission) ([1]). More recently, the VTGCM has been expanded to include new chemical constituents and airglow emissions, as well as new parameterizations to address waves and their impact on the varying global circulation and corresponding airglow distributions.

Recent VTGCM vs Measurement Comparisons:
Recently, the VTGCM has been compared to the ESA Venus Express (VEX) observations. These studies mainly addressed the thermal structure and tracer density profiles.

SOIR.
VEX SOIR terminator temperature and CO_2 density profiles (in the northern hemisphere) have been collected and compared to the VTGCM ([2]), see figure 1. The overall outcome is the VTGCM simulates the temperature minimum near 125 km and the stronger temperature maximum over ~130-150 km as observed and at the pressure/altitude levels at low latitudes. However, the magnitudes of the simulated and measured temperatures are different as a function of latitude. The model also produces an asymmetry between the two terminators which the SOIR observations do not show. From this work it was determined that both radiative and dynamical processes are responsible for maintaining averaged temperatures at the terminator.

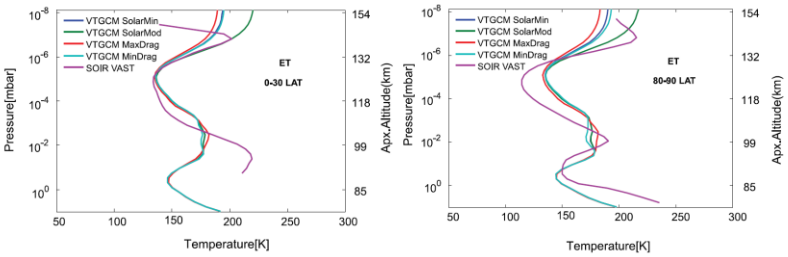

Figure 1: Temperature profiles with respect to pressure (approximate altitude); VEX SOIR and VTGCM. Left plot is evening terminator (ET) at 0-30 latitude. Right plot is ET at 80 – 90 latitude. The purple line represents SOIR observations. The other profiles represent two different scenarios based within the VTGCM regarding the solar flux input and Rayleigh Friction drag. See [2] for more details.

VIRTIS.
VEX VIRTIS instrument provided temperature and CO density profiles covering mainly the northern hemisphere and dayside with an altitude range from ~100 km to 150 km. These observations were originally compared with the VTGCM simulations by [3], see figure 2. The VTGCM reproduced the CO density profiles reasonably above ~125 km and below ~125 km the model under produces the CO density. Preliminary work has shown that by including aerosol heating in the VTGCM the CO density increases in the altitude range of ~90 km to ~130 km due to increasing scale heights. As for the temperature profiles, the model overestimates sub-solar temperatures near the equator from ~100km to 130 km altitude. However, the VTGCM is in better agreement with observations at higher latitudes (noontime meridian) and at the terminators (near the equator). The temperature discrepancy could be related to the observations having large error bars or the VTGCM is not capturing all the physics necessary to simulate the circulation.

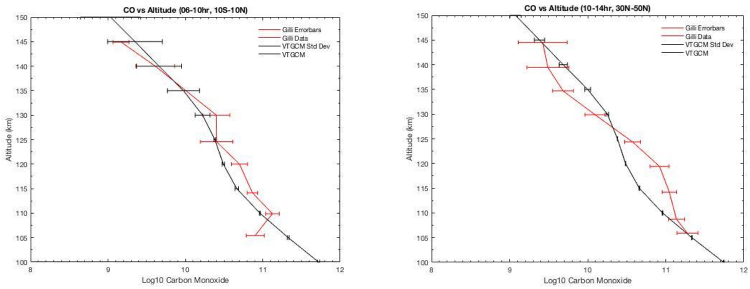

Figure 2: CO log density profiles as a function of altitude; VEX VIRTIS observations vs VTGCM simulation. Left plot is for 06 – 10 Local Time (LT) and 10S – 10N latitude. Right plot is for 10-14 LT and 30N – 50N latitude. The red line represents VIRTIS observations [3] and the black line represents the VTGCM simulation.

Improvements:
The latest improvements to the VTGCM enable the model to address the driving forces in Venus' upper atmosphere and its' variability.

Chemistry.
The SOx chemistry has been included (e.g. SO_2 and SO) and also the necessary OH chemistry to model the OH nightglow emission. The inclusion of these chemical species (and nightglow emission) provides tracers of the global circulation at different altitudes in the upper atmosphere.

Aerosol Heating.
The VTGCM lower boundary is at ~70 km, which is near the cloud tops. Near this level, aerosols provide heat to the middle atmosphere. A parameterization guided by [4] has been incorporated and tested. The additional heating increases the scale heights in this altitude range (~75-90 km) and therefore augments density profiles (~100-130 km) and modifies wave propagation.

Planetary Waves.
Due to observations of waves near the cloud tops, Kelvin and Rossby planetary waves have been implemented as part of the VTGCM lower boundary. But most importantly, they have been implemented with a self-consistent moving lower boundary (winds are not equal to zero and temperature is not constant). This lower boundary is taken from the Oxford

Venus GCM; 5 day time averaged fields (T, U, V, Z) were provided ([5] [6]). The combination of the moving lower boundary and Kelvin waves produces variability which impacts the intensity and local time location of the O_2 IR nightglow emission. These variations in the nightglow emission (as much as ~1-3 MR) are of a similar magnitude as observations. Waves are important to understand because of their impact on the varying dynamics of Venus' upper atmosphere.

Conclusion:

The work to be presented will include a reference VTGCM simulation showing the impacts the latest improvements make upon the upper atmosphere and how the results compare to observations. The comparative work relating modeling and observations is very important to improving our understanding of the underlying processes driving the complex and dynamical structure of the upper atmosphere of Venus.

References:

[1] Brecht A. S., Bougher S. W. Gerard J. C. Parkinson C. D. Rafkin S. Foster B. Understanding the Variability of Nightside Temperatures, NO UV and O_2 IR Nightglow Emissions in the Venus Upper Atmosphere // Journal of Geophysical Research. 2011. V. 116. E08004.

[2] Bougher S. W., Brecht A. S., Schulte R., Fischer J., Parkinson C. D. Mahieux A., Wilquet V., Vandaele A. Upper Atmosphere Temperature Structure at the Venusian Terminators: A Comparison of SOIR and VTGCM Results // Planetary and Space Science. 2015. V. 113-114. P. 336-346.

[3] Gilli G., Lopez-Valverde M. A., Peralta J., Bougher S., Brecht A., Drossart P., Piccioni G. Carbon Monoxide and temperature in the Upper Atmosphere of Venus from VIRTIS/Venus Express non-LTE Limb Measurements // Icarus. 2015. V. 248. P. 478-498.

[4] Haus R., Kappel D., Arnold G. Radiative Heating and Cooling in the Middle and Lower Atmosphere of Venus and Responses to Atmospheric and Spectroscopic Parameter // Planetary and Space Science. 2015. V. 117. P. 262-294.

[5] Lee C. and Richardson M. I. A General Circulation Model Ensemble Study of the Atmospheric Circulation of Venus // Journal of Geophysical Research. 2010. V. 115. E04002.

[6] Lee C. and Richardson M. I. A Discrete Ordinate, Multiple Scattering, Radiative Transfer Model of the Venus Atmosphere from 0.1 to 260 μm // Journal of the Atmospheric Sciences. 2011. V. 68. P. 1323-1339.