Using radiative transport modeling to investigate Balmer-alpha line width derived exospheric temperatures

Anissa R. Zacharias [1], Edwin J. Mierkiewicz [1], Margaret A. Gallant [1], Liying Qian [2], Alan G. Burns [2], Susan M. Nossal [3], Derek D. Gardner [4], Fred L. Roesler [3]

[1] Embry Riddle Aeronautical University, Daytona Beach, FL; [2] National Center for Atmospheric Research, Boulder, CO; [3] University of Wisconsin-Madison, Madison, WI; [4] University of Arizona, Tucson, AZ

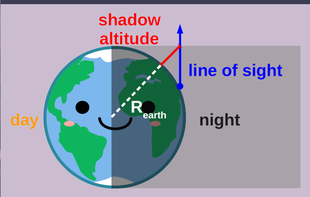
ABSTRACT

High spectral resolution line profile observations by Mierkiewicz et al. [2012] indicate a reproducible semi-annual variation in the geocoronal hydrogen Balmer-alpha line width derived effective temperature, with maxima near day numbers 100 and 300 and minima near day numbers 1 and 200. Temperatures ranged from approximately 710 to 975 K. Average MSIS model exobase temperatures for similar conditions were found to be approximately 1.5 times higher than those derived from the Balmer-alpha observations, a difference possibly due to a combination of contributions to the observed Balmer-alpha column emission. These contributions include those from higher, cooler regions of the exosphere (an observed decrease in effective temperature with increasing shadow altitude was found to be a persistent feature for every night in which a wide range of shadow altitudes were sampled) as well as multiple scattering of Lyman-beta illuminating the cooler regions of the lower thermosphere below. This poster will explore the magnitude of these contributions using the LYAO_RT radiative transport code of Bishop [1999]. Model line profiles will be generated using the best fit LYAO_RT parametric data-model results of Bishop et al. [2004], which uses a grid of radiative transport model input parameters to map out bounds for forward-model retrieved nighttime atomic hydrogen density distributions from same-night ground-based Balmer-alpha and geocoronal Lyman-beta intensity measurements (the latter from the EURD instrument on the Spanish satellite MINISAT-1). Here a detailed comparison of the Balmer-alpha line width will be considered. LYAO_RT generated geocoronal Balmer-alpha line widths will also be constructed using temperature and density altitude profiles obtained from WACCM-X; this work will explore possible future uses of ground-based Balmer-alpha datasets in model validation. This work is supported by NSF CAREER award AGS135231.

SCIENTIFIC MOTIVATION

- Investigate hydrogen and temperatures in the highest regions of the atmosphere
- Further explore the 1.5 times discrepancy between model exobase temperatures and those derived from Balmer-alpha observations
- Explore differences in modeled Balmer-alpha line widths derived from WACCM-X and NRLMSISE-00 model atmospheres

HYDROGEN OBSERVATION



Visual representation of shadow height measurements

By looking through the Earth's shadow into the illuminated atmosphere, Hydrogen observations can be made for different shadow altitudes.

Here, we are looking at Balmer-alpha emissions, which occur following a Lyman-beta excitation

EFFECTIVE TEMPERATURE

Full-width half-max wavelength is proportional to the square root of temperature:

$$\Delta\lambda_{fwhm} = 2\lambda_o\sqrt{\frac{2kT\ln(2)}{mc^2}}$$

Using values corresponding to atomic hydrogen, that equation becomes:

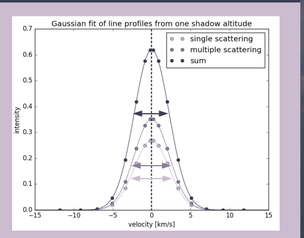
$$\Delta\lambda_{fwhm} = 7.14\times10^{-7}\lambda_o\sqrt{T}$$

From that, it can be seen that an "effective temperature", T_{eff}, in units of Kelvin can be determined using $\Delta\lambda_{fwhm}$

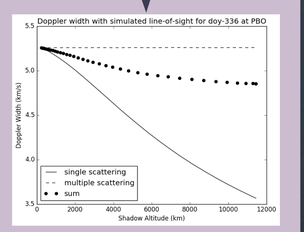
$$T_{eff} = 1.96\times10^{12}\left(\frac{\Delta\lambda_{fwhm}}{\lambda_o}\right)^2$$

By fitting Gaussian distributions to observation (or model) data, values of $\Delta\lambda_{fwhm}$ can be obtained and used to look at Doppler width.

Here, Doppler width will be used as a proxy to investigate temperature.



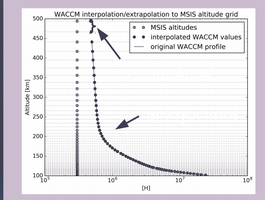
Repeated over range of shadow altitudes

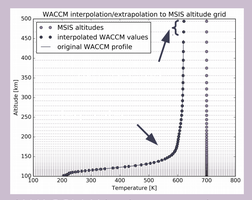


LYAO_RT MODELING WITH WACCM-X & NRLMSISE-00

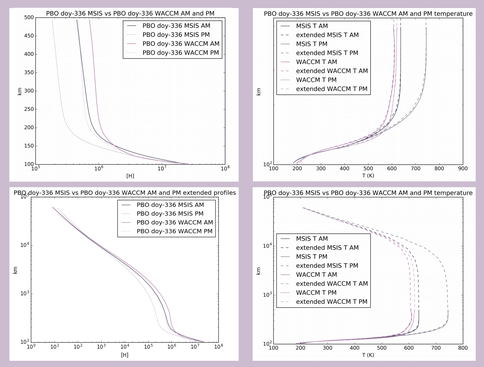
LYAO_RT

Bishop's LYAO_RT radiative transport code computes hydrogen volume emissions and line of sight radiances through a model atmosphere, which is extended using an evaporative model (Jean's escape) [Gardner et al. 2012]





Interpolated and extrapolated WACCM-X hydrogen and temperature profiles to preset LYAO_RT NRLMSISE-00 altitudes for direct substitution



Preliminary WACCM-X and NRLMSISE-00 generated hydrogen and temperature profies for matching environmental conditions

USING WACCM-X IN LYAO_RT

We are exploring the use of WACCM-X temperature and hydrogen profile in in the LYAO_RT code of Bishop. Here we compare LYAO_RT generated line width data using a preliminary WACCM-X run and MSIS-00 with roughly the same viewing conditions.

To do this, modifications were made to Bishop's LYAO_RT code to make it capable of accepting hydrogen and temperature profile data that we interpolated to match the existing altitude viewing geometry that then overwrote the NRLMSISE-00 data.

NRLMSISE-00

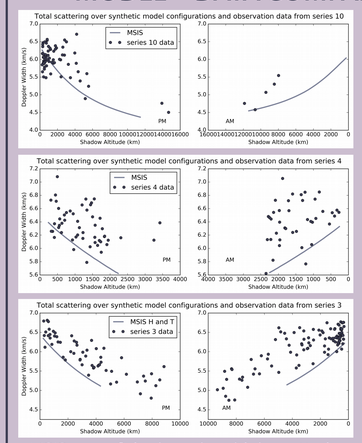
Released in 2000 and developed by the Naval Research Laboratory, MSIS (mass spectrometer and incoherent scatter radar) that extends through the exosphere is considered the standard in space science research. Bishop's LYAO_RT code was originally configured to accept MSIS model data

WACCM-X

The Whole Atmosphere Community Climate Model with thermosphere and ionosphere extensions is being developed by NCAR. It is part of the Community Earth System Model (CESM) which aims to model components of Earth's environment including the atmosphere, sea-ice, land, rivers, the ocean, land-ice, and the ocean.

MODEL AND DATA COMPARISON

MODEL – DATA COMPARISON



SERIES 10
F10.7 = 178
AP = 9.5
DOY = 332

SERIES 4
F10.7 = 194.2
AP = 28.9
DOY = 94

SERIES 3
F10.7 = 210
AP = 8
DOY = 64

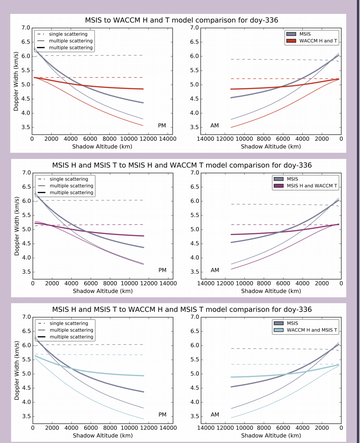
MSIS sum of single and multiple scattering runs corresponding to series 10 data [Mierkiewicz et al. 2012]. Solar condition variables were run to match the solar conditions at the time of observation for each observation

MODEL – MODEL COMPARISON

WACCM HT

WACCM T

WACCM H



Model comparisons using configurations of MSIS hydrogen and temperature profiles to WACCM hydrogen and temperature profiles. MSIS solar condition variables were run with F10.7 = 70 and an AP = 4.

RESULTS

NRLMSISE-00 AND DATA

Mierkiewicz et al. [2012] reported an offset between Balmer-alpha line width derived effective temperatures and representative MSIS-90 temperatures for similar geophysical conditions.

Here we are using MSIS-00 to explore this offset in terms of contributions to the observed Balmer-alpha column emission. These contributions to the observed emission arise from a combination of single scattering of higher, cooler regions of the exosphere, as well from multiple scattering from the cooler regions of the thermosphere below the base of the observed column. This work is the first step in the detailed radiative transport modeling, incorporating realistic hydrogen density and velocity distributions.

NRLMSISE-00 AND WACCM-X COMPARISON

We are preparing to compare a number of NRLMSISE-00 and WACCM-X runs sampling similar geophysical conditions.

Model line profiles will also be generated using the best fit LYAO_RT parametric data-model results of Bishop et al. [2004]; these results will be compared to NRLMSISE-00 and WACCM-X generated profiles.

FUTURE WORK

- Get more WACCM-X model runs that correspond with observed data
- Continue model-series and model-model comparisons
- Grid run of NRLMSISE-00 over F10.7 values to evaluate its effect on Doppler width

ACKNOWLEDGEMENTS

This work is funded with NSF CAREER award AGS135231. We thank the late James Bishop for his work on the LYAO_RT modeling tool, Jeff Percival for his shadow altitude computation program, and Embry-Riddle Aeronautical University and the University of Wisconsin-Madison for their resources and lab space to conduct this research. We also give special thanks to our collaborators at the National Center for Atmospheric Research for providing us with WACCM-X runs and invaluable insight.

REFERENCES

Gardner, D. D., Mierkiewicz, E. J., Roesler, F. L., Nossal, S. M., & Haffner, L. M. (2017). Constraining Balmer alpha fine structure excitation measured in geocoronal hydrogen observations. *Journal of Geophysical Research: Space Physics*, 122, 10,727 10,747. doi.org/10.1002/2017JA024055

Liu, J., Liu, H., Wang, W., Burns, A. G., Wu, Q., Gan, Q., et al. (2018), First results from the ionospheric extension of WACCM-X during the deep solar minimum year of 2008. *Journal of Geophysical Research: Space Physics*, 123, 1534–1553. doi.org/10.1002/2017JA02501.

Liu, H. -L., C. G. Bardeen, B. T. Foster, P. Lauritzen, J. Liu, G. Lu, D. R. Marsh, A. Maute, J. M. McInerney, N. M. Pedatella, L. Qian, A. D. Richmond, R. G. Roble, S. C. Solomon, F. M. Vitt, W. Wang (2018), Development and validation of the Whole Atmosphere Community Climate Model with thermosphere and ionosphere extension (WACCM-X v. 2.0). *Journal of Advances in Modeling Earth Systems*, 10, doi:10.1002/2017MS001232.

Mierkiewicz, E. J., F. L. Roesler, and S. M. Nossal (2012), Observed seasonal variations in exospheric effective temperatures, *J. Geophys. Res.*, 117, A06313, doi:10.1029/2011JA017123.

Nossal, S. M., F. L. Roesler, E. J. Mierkiewicz, and R. J. Reynolds. (2004). Observations of solar cyclical variations in geocoronal Hα column emission intensities, Geophys. Res. Lett., 31, L06110. doi: 10.1029/2003GL018729.

Qian, L., Burns, A. G., Solomon, S. S., Smith, A. K., McInerney, J. M., Hunt, L. A., Marsh, D. R., Liu, H., Mlynczak, M. G., Vitt, F. M. (2018). Temporal variability of atomic hydrogen from the mesopause to the upper thermosphere. *Journal of Geophysical Research: Space Physics*. doi:2017JA024998.