

# The Effect of Wavelength Binning on Solar Irradiance Extinction Altitude by Atmospheric Ozone Absorption



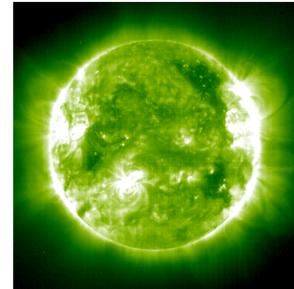
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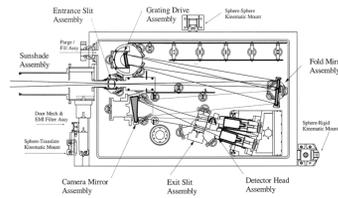
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Table 1: Wavelength Binning in the  $\delta$ -Eddington Approximation<sup>2</sup>

Bin	$\lambda$ min (nm)	$\lambda$ max (nm)
1	200	245
2	245	265
3	265	275
4	275	285
5	285	295
6	295	305



**Introduction:**  
Current atmosphere and climate models designed by the National Center for Atmospheric Research (CCM2 and CAM3) employ the  $\delta$ -Eddington approximation which includes a binning of the solar spectrum to 8 bins between 200 and 700 nm (see Table 1). This analysis compares the solar irradiance penetration at 1nm wavelength resolution to the bin-averaged irradiance spectrum.

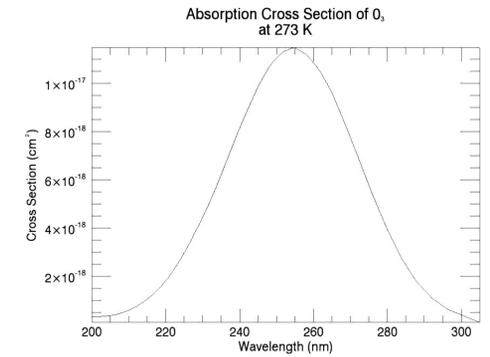


### Optical Depth:

The amount of energy absorbed or transmitted through a medium is directly related to the optical depth, or opacity, of the medium. The optical depth is both a function of altitude and wavelength (via the absorption cross section). JPL<sup>3</sup> gives the O<sub>3</sub> spectral absorption cross section at a reference temperature of 273 K (shown in plot to right) however, another interpolation needed to be performed in order to achieve cross section values at 1 nm intervals between 200 and 305 nm. With the appropriate absorption cross section and number density profiles, the optical depth was calculated using the equation:

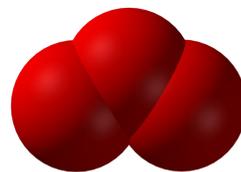
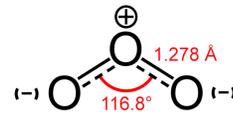
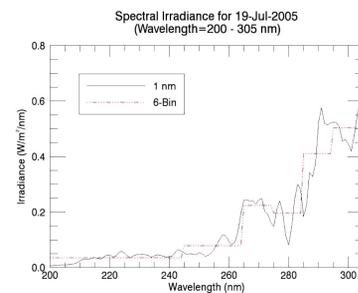
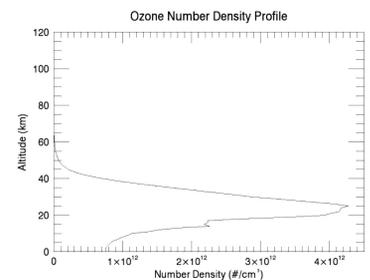
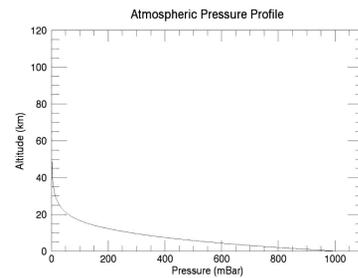
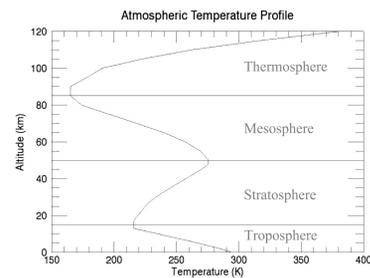
$$\tau = \sigma \int_0^{120} n dz$$

These optical depth values are also shown in a plot to the right where each point corresponds to the optical depth at a specific wavelength and altitude.



### Basic Atmospheric Model:

One of the main objectives of this research was to focus specifically on the absorption due to atmospheric ozone. This required finding an accurate ozone density profile. The SpectralCalc<sup>1</sup> website provided not only the mixing ratios of O<sub>3</sub> with altitude but also the temperature and pressure profiles used to create the 1-dimensional atmosphere. All data obtained from the Atmospheric Browser assumed an atmosphere in mid-latitude summer conditions. Since there was no constant altitude separation between each data point, an interpolation was performed to create profiles with temperature, pressure and mixing ratio values every 1 km from 0 to 120 km. The total atmospheric number density profile was obtained using the ideal gas law,  $\rho = \frac{P}{kT}$ , where P and T are the pressure and temperature profiles and k is Boltzmann's constant. By multiplying this by the O<sub>3</sub> mixing ratios, the ozone number density profile was finally obtained. The plots below illustrate the three atmospheric profiles that were created.

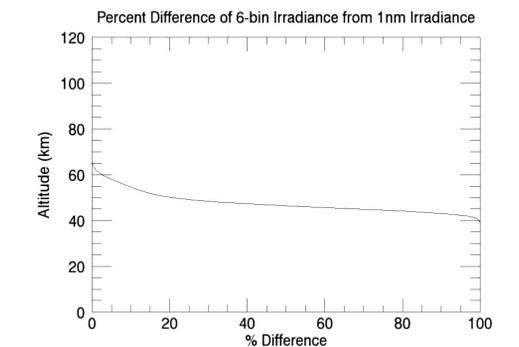
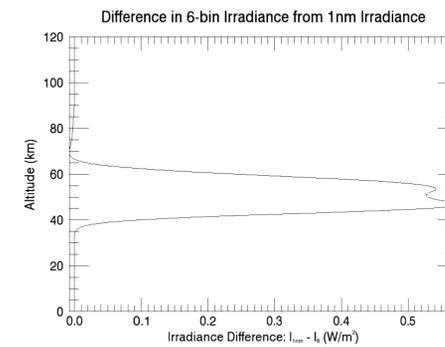
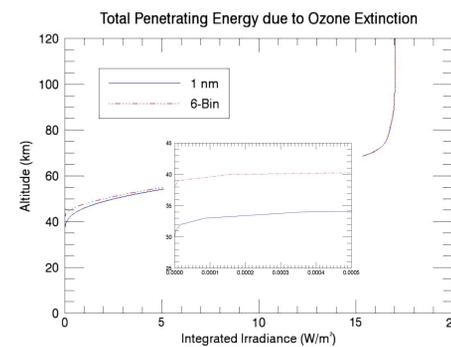


### Solar Energy Penetration:

The Beer-Lambert law relates the pre- and post-absorption intensities and the optical depth of the medium by:

$$I = I_0 e^{-\tau}$$

Using the solar irradiance values obtained from SORCE as the values at 120 km altitude, the irradiance at each decreasing altitude value was calculated. The same was done using the bin-averaged irradiance values (all wavelengths in a bin have the same irradiance). Finally, in each set, the irradiance values were integrated over wavelength for each altitude. Below are the plots comparing the intensities of the 1 nm and bin-averaged cases as they vary with altitude.



### Solar Spectral Irradiance Data:

The solar spectral irradiance data from the SOLSTICE instrument on the SORCE spacecraft was obtained through the LISIRD<sup>5</sup> webpage. The SOLSTICE instrument is only sensitive to wavelengths up to 316 nm (the middle of the 7<sup>th</sup> bin) so, in order to ensure the integrity of all bins in the binned experiment, irradiance values were taken between 200 and 305 nm. Finally, this data was averaged over each of the wavelength bins. The plot above shows both the 1 nm resolution original data as well as the bin-averaged irradiance values.

### References:

- "Atmospheric Browser." SpectralCalc.com. GATS Inc. 16 July 2007 <http://www.spectralcalc.com/spectralcalc.php>.
- Briegleb, Bruce P. "Delta-Eddington Approximation for Solar Radiation in the NCAR Community Climate Model". Journal of Geophysical Research, Vol. 97, Pg: 7603-7612. May 20, 1992.
- "Chemical Kinetics and Photochemical Data for Use in Stratospheric Modeling". JPL Publication 94-26, Evaluation Number 11, Pg: 114-116. Nov. 15, 1994.
- Rybicki, George B. and Lightman, Alan P. Radiative Processes in Astrophysics. New York: John Wiley & Sons, Inc., 1979.
- "Spectra Measurements" LASP Interactive Solar Irradiance Datacenter. LASP, University of Colorado. 16 July 2007 <http://lasp.colorado.edu/cgi-bin/ion-p?page=lisird\_spectra\_input.ion >.

### Results and Conclusions:

- The optical depth at small wavelengths of the 6-bin approximation is almost 5 times that of the 1 nm model
- The extinction altitude of the 1 nm resolution spectrum is approximately 29 km
- The extinction altitude of the 6 bin spectrum is approximately 38 km
- The difference in altitudes results in a maximum irradiance difference of almost 0.6 W/m<sup>2</sup> at 47 km
- The 6-bin model approaches 100% difference from the 1 nm resolution model at 40 km
- By employing wavelength binning, solar irradiance energy is deposited higher in the atmosphere that should be expected

### Future Research:

- Expand to a plane-parallel atmospheric model so to include scattering of the solar photons (not just absorption)
- Include more atomic and molecular species to get a more realistic simulation of the atmosphere
- Do the same analysis for different atmospheric conditions (seasonal and regional) to see if there is a change in result

