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

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Research By: Jonathan C. Ruel
Mentor: Martin Snow
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Introduction

• National Center for Atmospheric Research
  – CCM2 and CAM3
• δ-Eddington approximation
  – Binning of the solar spectrum
  – 8 bins between 200 and 700 nm
• This analysis compares the solar irradiance penetration at 1nm wavelength resolution to the bin-averaged irradiance spectrum.
Basic Atmospheric Model

- Focus was specifically on absorption due to atmospheric ozone
- Required finding an accurate ozone density profile
- The SpectralCalc\(^1\) website provided:
  - Assumed an atmosphere in mid-latitude summer conditions
  - Temperature and pressure profiles
  - Mixing ratios of O\(_3\) with altitude
- Used these to create a 1-dimensional atmosphere
- Interpolation performed
  - Profile data in 1 km increments from 0 to 120 km
- Total atmospheric number density profile obtained using the ideal gas law:
  \[
  \frac{N}{V} = \frac{P(z)}{kT(z)}
  \]
- Ozone number density profile obtained by multiplying by the O\(_3\) mixing ratios
Basic Atmospheric Model

Atmospheric Temperature Profile

Altitude (km)

Temperature (K)
Basic Atmospheric Model
Basic Atmospheric Model

Ozone Number Density Profile

Altitude (km)

Number Density (#/cm³)
Solar Spectral Irradiance

- SOLSTICE instrument on the SORCE spacecraft
- Obtained through the LISIRD\(^5\) webpage
- SOLSTICE only sensitive up to 316 nm
  - Middle of the 7\(^{th}\) bin (305 – 350 nm)
  - Irradiance values taken between 200 and 305 nm
- Data was averaged over each of the bins
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Solar Spectral Irradiance

Spectral Irradiance for 19-Jul-2005
(Wavelength=200 - 305 nm)

Irradiance (W/m²/nm)

200 220 240 260 280 300

Wavelength (nm)
Optical Depth

- The amount of energy absorbed or transmitted through a medium is directly related to the optical depth, or opacity, of the medium.
- Optical depth is both a function of altitude and wavelength (via the absorption cross section).
- JPL\(^3\) gives the \(O_3\) spectral absorption cross section:
  - Reference temperature of 273 K
  - Another interpolation needed 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:
  \[
  \tau = \sigma \int_{z_0}^{\infty} n\,dz
  \]
- Each altitude and wavelength has its own optical depth value.
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Optical Depth

Absorption Cross Section of $O_3$

at 273 K

Cross Section ($\text{cm}^2$)

Wavelength (nm)
Optical Depth

Optical Depth as a Function of Wavelength and Altitude
Optical Depth

Spectral Altitudes for Optical Depth Unity ($\tau=1$)
Optical Depth

Comparison of 1nm Resolution and 6-bin Approximation
Optical Depth Unity Spectra
Solar Energy Penetration

• The Beer-Lambert Law
  – Relates pre- and post-absorption irradiances and the optical depth of the medium by:

\[ I = I_0 e^{-\tau} \]

• Solar irradiance values obtained from SORCE used as the values at 120 km
• Irradiance at each decreasing altitude value was then calculated
• The same was done using the bin-averaged irradiance values
  – all wavelengths in a bin have the same irradiance
• Irradiance values were integrated over wavelength for each altitude in both cases
Solar Energy Penetration

Total Penetrating Energy due to Ozone Extinction

Altitude (km)

Integrated Irradiance (W/m²)

- 1 nm
- 6-Bin
Solar Energy Penetration
Solar Energy Penetration

Difference in 6-bin Irradiance from 1nm Irradiance

Altitude (km)

Irradiance Difference: $I_{\text{nm}} - I_0 \text{ (W/m}^2\text{)}$
Solar Energy Penetration

Percent Difference of 6-bin Irradiance from 1nm Irradiance

Altitude (km)

% Difference
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/m² 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 than expected.
Future Research

- Expand to a plane-parallel atmospheric model
  - Includes 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
References


• With thanks to Marty Snow and Erik Richard
Questions