

Periodicities of Solar Activity from Atmospheric Hydroxyl Radicals

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Abstract

The effects of solar activities in the atmospheric hydroxyl radicals were examined using data acquired over JPL's Table Mountain Facility. The observed variation due to the 27-day solar cycle was 6% during April-December 2002. The photochemical model, however, predicts a variation about half of the observations. Modeling the effects of solar cycles in the stratosphere and mesosphere thus provides a stringent test of the current models of photochemistry.

Introduction

Periodicities of solar activity have been observed for more than a century and are related to the dynamics of solar magnetic fields. Photolysis rates in the terrestrial atmosphere depend on the incident solar radiation, and should be sensitive to the periodicities in the solar spectrum, providing a stringent test of the current models of photochemistry. The column abundances of stratospheric hydroxyl radicals (OH) measured by the ground-based instrument at JPL's Table Mountain Facility (TMF) have been used for this study.

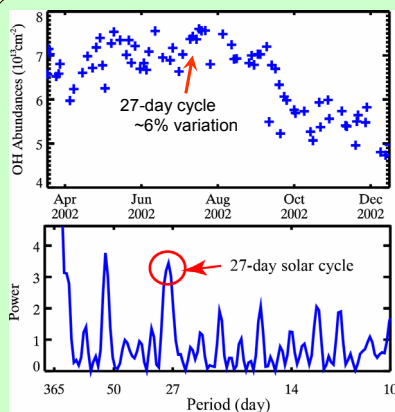


Figure 1 Observed daily maxima of OH column abundances over TMF during April - December 2002 (top). Also shown is the Lomb periodogram during the same period (bottom). The observed 27-day cycle in OH is about 6% (peak-to-peak).

Observations

The column abundances of stratospheric hydroxyl radicals (OH) has been measured by the Fourier-Transform ultraviolet spectrometer (FTUVS) at TMF near Los Angeles since July 1997 [Cageao *et al.*, 2001]. Year 2002 has the best data set for the 27-day solar cycle analysis. This year is also coincident with the peak of the 11-year solar cycle. Fig. 1 shows the Lomb periodogram [Scargle, 1972] of the daily maxima of the OH column abundances during April - December 2002. A relatively strong signal is seen at a period of 27 days.

Photochemical Model

- 1D Caltech/JPL photochemical model [Allen *et al.*, 1981] is used in this study. The model is simplified and the species involved include the HO_x family:
O, O(¹D), O₂, O₂(¹Δ), O₃,
H, OH, H₂, H₂O, H₂O₂.
The net loss of ozone by NO_x and ClO_x catalysts are parameterized as in Liang *et al.* (2006).
- Vertical transport mechanisms include eddy, molecular and thermal diffusion.
- The SOLAR/SOLSTICE [Woods *et al.*, 2006; McClintock *et al.*, private communication] daily observation of the solar spectral irradiance (SSI) has been used as the input of the 1D photochemical model to study the 27-day cycle in OH (Fig. 2). The irradiances are 1-nm spectrally resolved. A representative 27-day solar cycle was chosen from November 11 to December 11, 2003. The SSI data on these days are integrated and scaled to solar photon fluxes on wavelength grids appropriate for the photochemical model (Fig. 3).

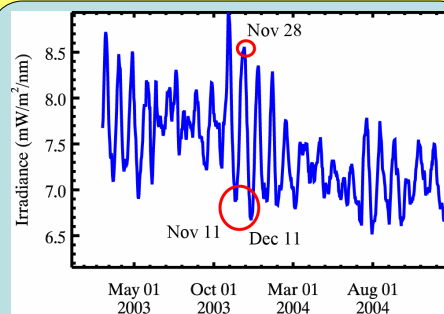


Figure 2 Solar spectral irradiance at 121.5 nm measured by SOLAR/SOLSTICE. Circled are defined as 27-day solar cycle minima (Nov 11 and Dec 11, 2003) and maximum (Nov 28, 2003).

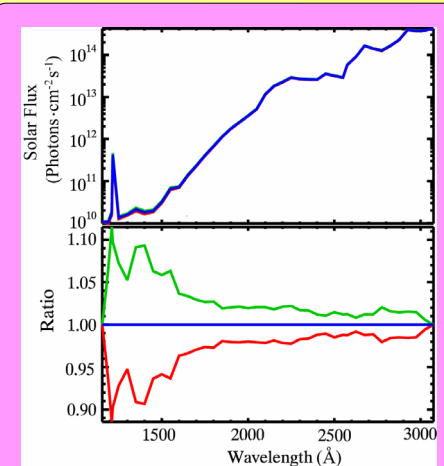


Figure 3 (Up) Solar flux input implied by SOLAR/SOLSTICE data. Green: Nov 28; Red: average of Nov 11 and Dec 11, 2003; Blue: mean of green and red. (Bottom) Ratios of changes of solar fluxes referenced to the blue line in the upper graph.

References

- Allen, M., *et al.* (1981), *J. Geophys. Res.*, **86**, 3617-3627;
Cageao, R. P., *et al.* (2001), *Applied Optics*, **40**, 2024-2030;
Liang, M.-C., *et al.* (2006), *J. Geophys. Res.*, **111**, D02302, doi:10.1029/2005JD006342; McClintock, B., *et al.* (private communication), SOLAR/SOLSTICE unreleased data;
Woods, T., *et al.* (2006), *The Earth Observer*, **18**(4), 8-14;
Scargle, J.D. (1982), *Astrophysical Journal*, **263**, 835-853.

Linear Response Analysis

The vertical structure of changes due to the 27-day cycle perturbation can be most easily understood by calculating the linear response functions (Green's functions) at each wavelength. The photon flux at each wavelength is perturbed and the difference between the resultant and the unperturbed OH vertical profile is calculated. Figure 4 shows the linear response functions corresponding to 1% photon flux perturbations, illustrating the important chemical reactions at each wavelength and altitude.

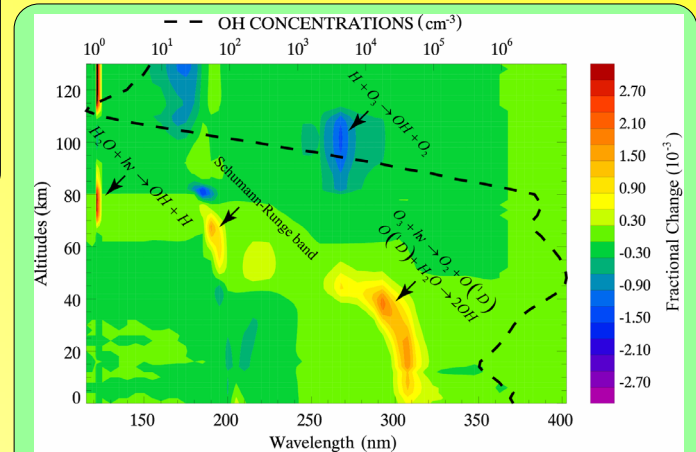


Figure 4 The positive response at 121.5 nm, 80 km is due to the photolysis of H₂O; similarly, the positive responses at about 200 nm near 60 km and about 290 nm below 50 km are due to the photolysis of O₂ in the Schumann-Runge bands and ozone in the Hartley bands respectively. The negative response at 270 nm near 100 km is due to the decrease in ozone because of photolysis, thereby reducing the budget for OH creation from the following reaction: H + O₃ → OH + O₂.

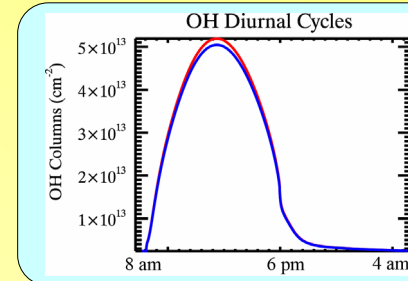


Figure 5 Simulated diurnal cycles of OH column abundances. Blue: 27-day solar minimum; Red: 27-day solar maximum. The daily maxima of differs by 2.6%.

Conclusions

The OH response on the 27-day solar cycle forcing can be estimated from the steady states of the diurnal cycles (Figure 5). At 8 am the sun rises and thus OH column abundance increases. A peak of about 6×10^{13} cm⁻² is reached about 30 minutes after the local noon. The sun sets at 6 pm and the OH column drops back to about 5×10^{12} cm⁻² at night. The daily maxima of OH column abundances at 27-day cycle maximum and minimum defined above differs by about 2.6%, which is about half of the observed value at TMF.