Can stratospheric ozone observations tell us anything about solar spectral irradiance?

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Abstract

Heating within the stratosphere mainly results from the absorption of solar ultraviolet (UV) radiation by ozone. Variations of incoming solar UV modulate stratospheric ozone concentration and heating rates and can lead to a dynamical response throughout the middle and lower atmosphere. Despite three decades of ozone and spectral solar irradiance (SSI) observations, the magnitude of SSI cycle variations is still to be accurately determined and, therefore, so is the Sun's effect on ozone. Observations from the SORCE[1] satellite suggest much larger solar cycle UV variations compared to SSI models based on previous data. The solar signal in ozone derived from observational data shows some similarity with that found in atmospheric models in response to SSI from SORCE and solar models, but the uncertainty in both SSI and ozone observations makes comparisons difficult. We show that the response in the tropical ozone profile to variations in the solar spectrum can be reconstructed from a linear combination of individual responses to separate spectral bands. Based on this, we use a Bayesian statistical approach to show that it is possible, in principle, to combine SSI and ozone observations to better determine variations in both, but that the large observational uncertainties in both make it difficult to make any claims about solar variability from current ozone data.

Background

Ozone concentration is largely determined by the ratio of solar irradiance from wavelengths below 242 and 310 nm, respectively initiating production and destruction processes (Fig. 1). Thus, the response of ozone to solar variability is sensitive to changes in SSI.

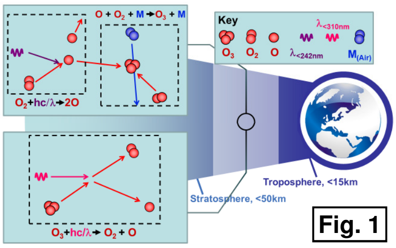

Fig. 1

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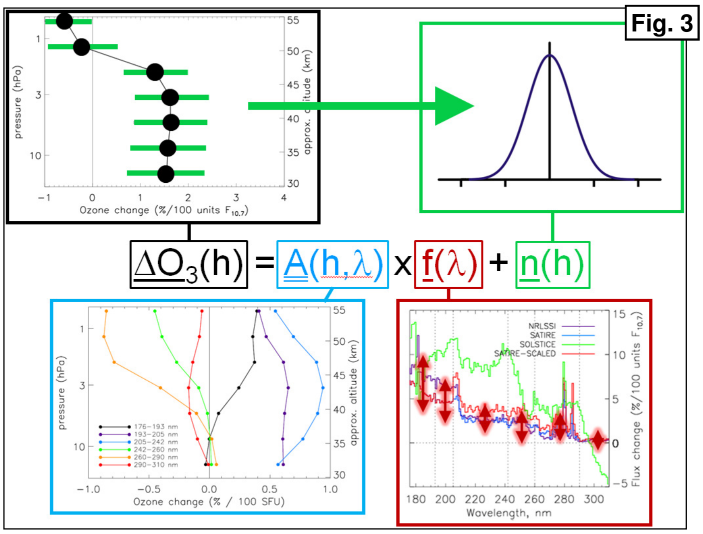
The linear model ozone profile, $\Delta O_3(h)$ profile is encoded in the matrix, $\mathbf{A}(h,\lambda)$, giving the weightings of each spectral band, $\mathbf{f}(\lambda)$, while taking account of the noise, $\mathbf{n}(h)$. By inverting the equation in Fig. 3, $\mathbf{f}(\lambda)$ can be determined for any $\Delta O_3(h)$ profile. However, the large error bars on the observations allow many combinations of $\mathbf{f}(\lambda)$ that produce similar $\Delta O_3(h)$. We therefore apply priors (see below right) and use Bayesian inference to calculate the most likely $\mathbf{f}(\lambda)$.



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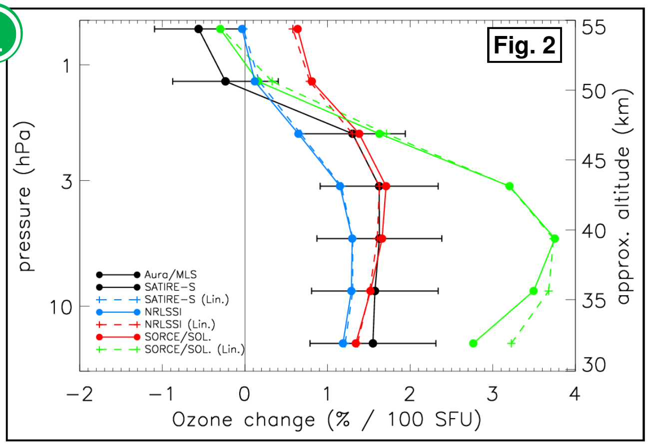

We use a 2D photochemical dynamical model[2] of the middle atmosphere to deduce the response in tropical ozone, ΔO_3, to the changes in UV suggested by the SATIRE-S[3,4] solar model in six spectral bands between 176 and 310 nm (Fig. 3, lower left). We find that the full response (as determined by the 2D model) to any prescribed change in SSI can be accurately represented by a linear combination of the six profiles. An example for three different SSI datasets is shown in Fig. 2 (full 2D model response in solid lines, linear model in dashed lines) The profile in black is derived from Aura/MLS observations between 2004 and 2012.

Priors

1) maximum SC change in each f(λ) is limited to 5 x SATIRE-S, ~50% larger than any observations

2) minimum changes below 242 nm must not be less than zero

3) minimum changes over 242-310 nm must not be less than -1 x SATIRE-S

4) SC changes below 242 nm must be larger than the largest change above 242 nm

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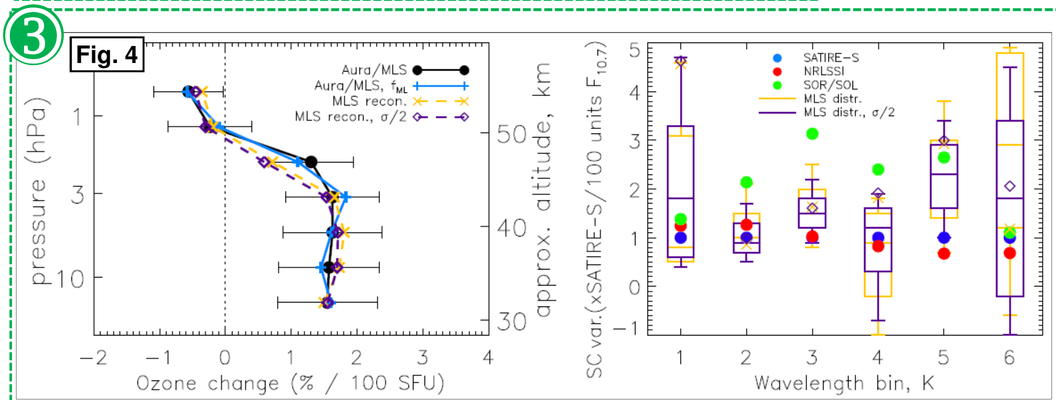

We make one million random samples within the priors to produce a distribution of the most likely SSI SC changes $\mathbf{f}(\lambda)$, relative to SATIRE-S (blue dots), that can produce the observed ozone profile. Fig. 4, right: the box and whisker plots give the mode, 68% and 95% ranges for standard (yellow) and halved (purple) errors in the Aura/MLS ΔO_3 profile in each spectral band. The diamonds indicate the best fit values. SC changes of NRLSSI[5] and SOLSTICE[6] are red and green dots in the right plot. Fig. 4, right: maximum likelihood (no priors, light blue) and best profile fits (from the priors, yellow/purple from diamonds in right plot).

Conclusion

We present a new statistical approach to investigate the relationship between SC SSI changes and ozone using Bayesian inference to incorporate uncertainty in ozone and prior knowledge in SSI. Similar ΔO_3 SC changes can be produced with different SC SSI changes. The current data are not sufficient to distinguish between competing SSI datasets. We do, however, consider this approach to be more robust than single profile comparisons and suggest that it may provide significant advances in analysis of longer datasets.

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References

[1] Rottman, G., 2005, Solar Physics, 230,7–25; [2] Harwood, R. S., & J. A. Pyle (1975), Quart. Journal of the Royal Met. Soc., 101, 723–747; [3] Fligge, M., Solanki, S. K., & Unruh, Y.C. 2000, A&A, 353, 380; [4] Krivova, N. A., Solanki, S. K., & Unruh, Y. C. 2009, J. Atmos. Solar-Terr. Phys; [5] Lean, J., 2000, Geophys. Res. Lett., 27, 2425–2428; [7] McClintock, W. E., G. J. Rottman, and T. N. Woods (2005), Solar Physics, 230, 225–258