Electronic Supplementary Material (ESI) for Photochemical & Photobiological Sciences.

Solar UV radiation and microbial life in the atmosphere

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SUPPLEMENTARY MATERIALS

S1. The Tropospheric Ultraviolet-Visible (TUV) Model

The Tropospheric Ultraviolet-Visible (TUV), version 5.3.1, was used for the calculation of spectral irradiances and fluence rates used in the main text. The model has been described in detail before (e.g. [1, 2]). Briefly, TUV calculates the transmission of shortwave (121-700 nm) through the atmosphere, including gaseous absorption by O_2, O_3, NO_3, and SO_2, Rayleigh scattering by air molecules, and Mie scattering and absorption by aerosols and clouds. Atmospheric composition is discretized in 1 km layers. The radiative transfer equation for multiple layers was solved using the 4-stream discrete ordinates method[3]. The spectral resolution was set to 1 nm for this study. Unless otherwise noted, the model was run with no aerosols, 5% ground albedo, and a latitude-dependent O_3 column of 250, 300, or 350 Dobson units for 0, 30, and 60 degrees, respectively.

The TUV model has been compared extensively to other models and measurements, and found to perform well (within a few percent) for both irradiances[4] and fluence rates[5]. The TUV fortran source code and web-based calculator are available at https://www2.acom.ucar.edu/modeling/tropospheric-ultraviolet-and-visible-tuv-radiation-model

S2. Empirical relation between UV-B and UV-DNA

The relationship between UV-B and DNA-weighted irradiances was deduced from monthly mean measurements derived from spectral irradiances at a subset of the sites shown in Fig. 4. The relationship is shown in Fig. S1. UV-B irradiances at all sites were converted to DNA-weighted irradiances using the cubic polynomial shown in the figure. The additional uncertainty associated with conversion is estimated to be less than ±10%. Further scale factors were applied in Fig. 4 to convert from monthly values to daily values, and to account for the normalization at 254 nm, rather than the usual normalization wavelength of 300 nm.

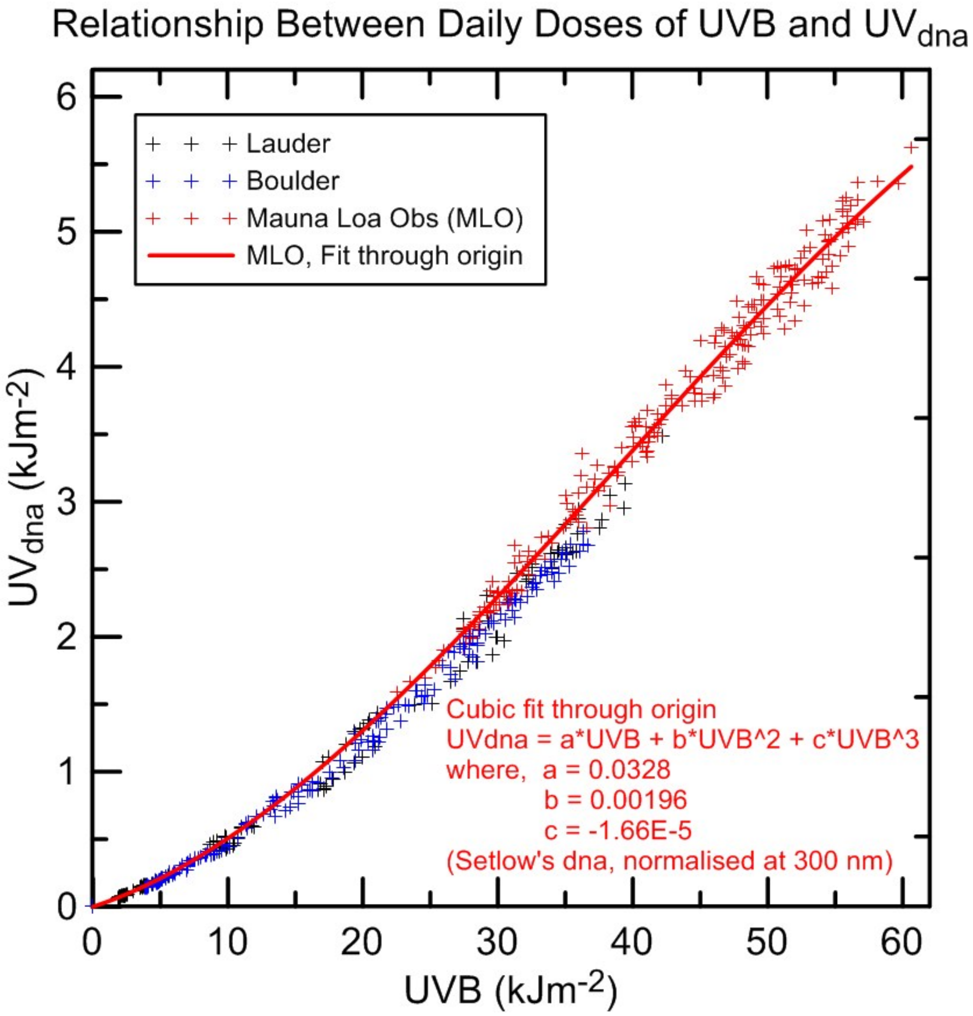

Figure S1. Relationship between UV-B and DNA-weighted UV

S3. Parameterization of fluence rate to irradiance ratio.

Figure 5 presented the ratio of fluence rate at any altitude, to the irradiance at ground level, calculated for several representative locations (Equator, 30°, and 60°) and representative days of the year (equinoxes and solstices). For these days, the solar zenith angle at noon is simply the latitude (at equinoxes), plus or minus the ecliptic tilt of 23.5° (at summer and winter solstices, respectively). The values from Fig. 5 are replotted as a function of the cosine of the solar noon zenith angle, for selected altitudes, as shown in Fig. S2. The ratios are seen to be good linear functions over a cosine range of 0.35 to 1.0. The linearity only fails for low sun, when the noon solar zenith angle is larger than about 70 degrees.

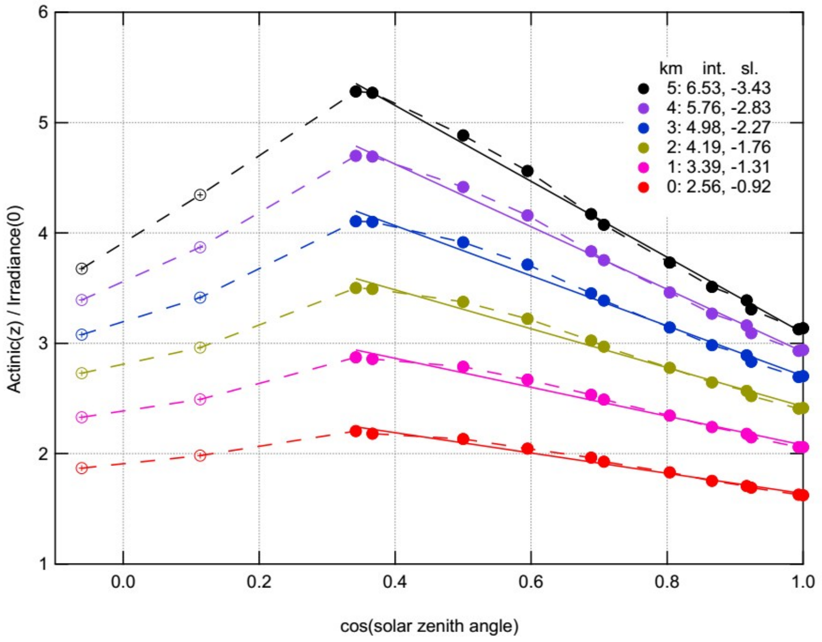

Figure S2: Ratio of fluence rate at any altitude z, to irradiance at ground level, for the points shown in Fig. 5. Calculated with the TUV model.

The slopes and intercepts of Fig. S2 are shown in Fig. S3, and are also seen to be simple linear functions.

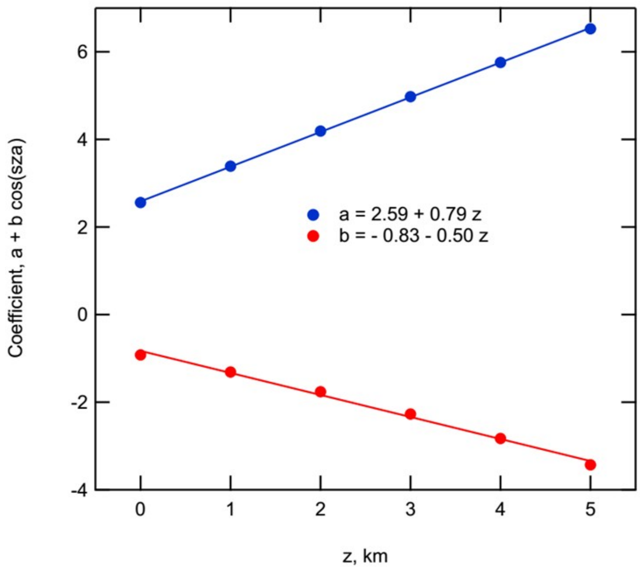

Figure S3: Intercepts (blue) and slopes (red) of the fitted lines of Fig. S2.

Simple linear fits through the two lines in Fig. S2 lead to the expression:

$$R \approx 2.6 + 0.8\,z - (0.8 + 0.5\,z)\cos\Theta_{\mathrm{N}}$$

R = Ratio of Fluence Rate (z) / Irradiance (0)

Θ_N = solar zenith angle at noon
z = altitude, km.

This expression was derived for clear skies and should be used with caution when clouds are relevant. Clouds usually decrease the irradiance at the surface, but significantly increase the fluence rates above clouds, and to some extent within them. Figure S4 shows the effect of clouds on the ratio R. Large enhancements, increasing with cloud thickness, are seen above cloud. Below cloud, factor of two enhancements are comparable to clear skies, and independent of cloud thickness. Note that this is for low ground albedo, and R would obviously be larger over, e.g., snow.

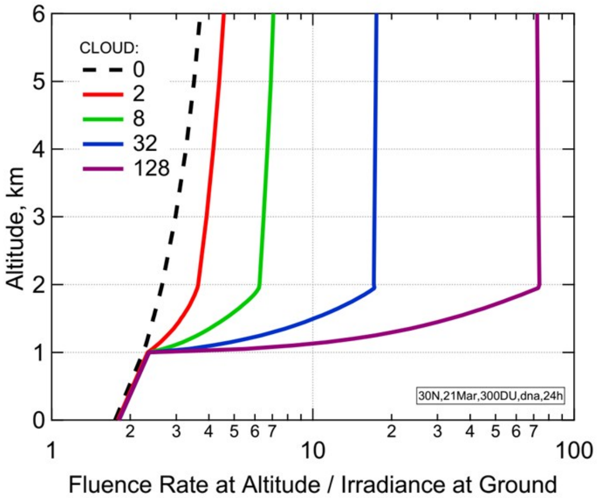

Figure S4: Relationship between Fluence Rate at any altitude, and Irradiance measured at ground-level, for a range of cloud optical depths.

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