Death of Darkness: Artificial Sky Brightness in the Anthropocene

Charlie Zender <zender@uci.edu>, Departments of Earth System Science & Computer Science, UC Irvine

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Many species (including ours) need darkness to survive and thrive yet light pollution in the anthropocene has received scant attention in the media or in Earth System Models (ESMs). Anthropogenic aerosols can brighten background sky brightness and reduce the contrast between skylight and starlight. Previous studies (e.g., Falchi et al. at right) show that light pollution already prevents nearly half the world's population from seeing the Milky Way. Light pollution poses both aesthetic and health-related issues due to its accompanying disruption of circadian rhythms. We quantify aerosol contributions to light pollution using a single-column night sky model, NiteLite, suitable for implementation in ESMs. NiteLite accounts for physiological (photopic and scotopic vision, retinal diameter/age), anthropogenic (light and aerosol pollution properties), and natural (surface albedo, trace gases) effects on background brightness and threshold visibility. **We find that stratospheric aerosol injection contemplated as a stop-gap measure to counter global warming would increase urban night-sky brightness by ~25%.** If ESMs incorporate light pollution, then the associated societal impacts can be better quantified for inclusion in policy deliberations.

Methods

We assess light pollution due to Stratospheric Aerosol Injection (SAI) with a column radiation model (Zender, 1999). We spread sulfate aerosol throughout the 10-100 mb region of a standard mid-latitude summer atmosphere whose troposphere already contains the current global mean natural and anthropogenic background aerosol.

Assumptions:

Tropospheric aerosol (natural+anthro) boundary layer AOD = 0.12
Stratospheric sulphate AOD to counteract 2xCO2 = 0.17 (in 10-100 mb)
Sulphate effective radius, geometric standard deviation = 0.3 μm, 0.4
Color temperature of artificial light = 3000 K
Natural dark sky brightness = 177 μcd/m^2 ~ 55.83 nL ~ 22 mag/arcsec^2
Artificial light per capita = 1000 lm emitted isotropically at surface
Urban, Remote population density = 10^{-3}/m^2, 10^{-6}/m^2
Surface reflectance of land, ocean = 0.2, 0.05
NiteLite simulations employ clear sky (no clouds) conditions with 92 levels and four streams.

Photometric Units

Results are presented in photometric units and thus correspond to human-perceived light intensity rather than radiometric energy. Photometric luminance (brightness) and illuminance are derived by applying CIE photopic bandpass applied to model-computed radiometric intensity and irradiance, respectively.

Artificial brightness severity estimated by Falchi et al. (2016) from DMSP and model. Pristine sky is black (< 1% artificial).

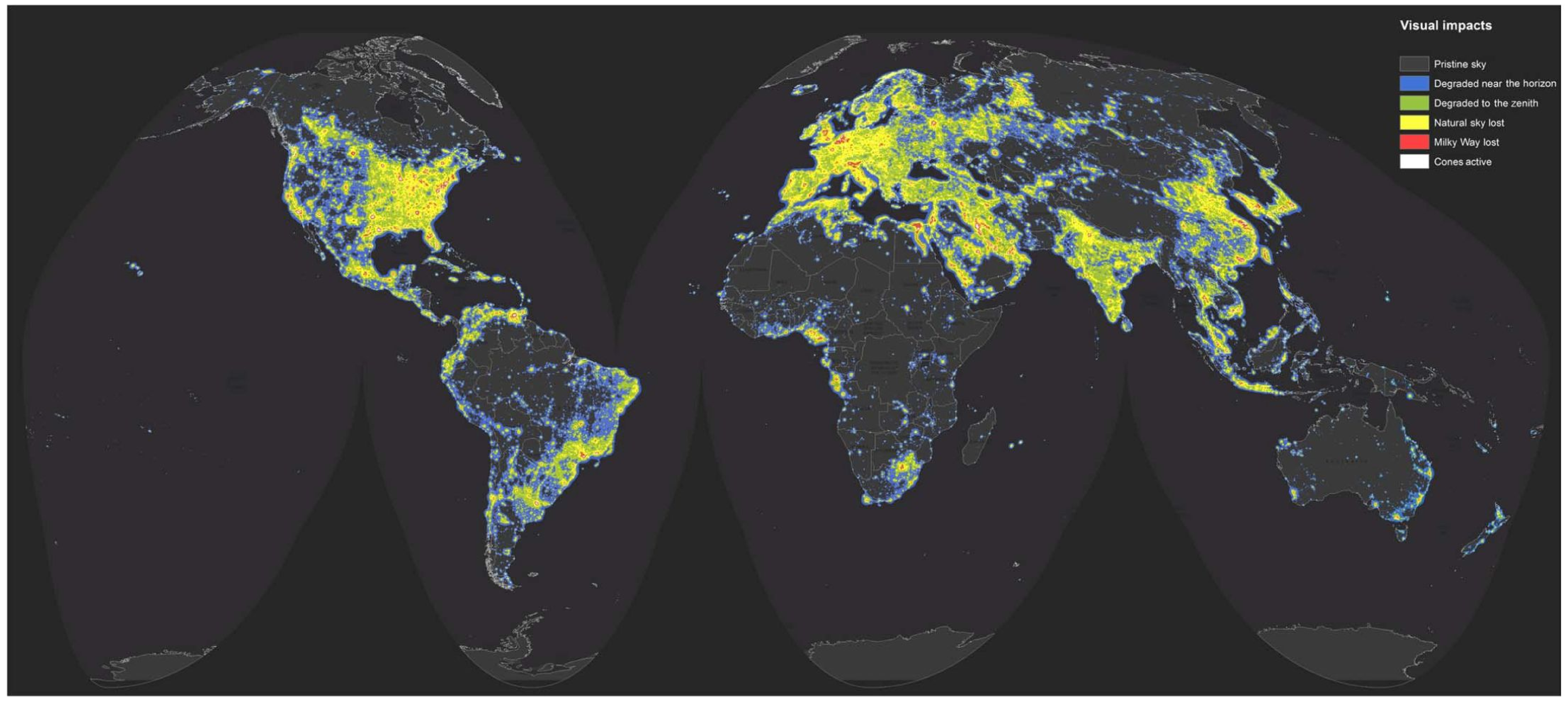

Fig. 10. Map of light pollution's visual impact on the night sky. The sky brightness levels are those used in the tables and indicate the following: up to 1% above the natural light (0 to 1.7 μcd/m^2; black); from 1 to 8% above the natural light (1.7 to 14 μcd/m^2; blue); from 8 to 50% above natural nighttime brightness (14 to 87 μcd/m^2; green); from 50% above natural to the level of light under which the Milky Way is no longer visible (87 to 688 μcd/m^2; yellow); from Milky Way loss to estimated cone stimulation (688 to 3000 μcd/m^2; red); and very high nighttime light intensities, with no dark adaption for human eyes (>3000 μcd/m^2; white).

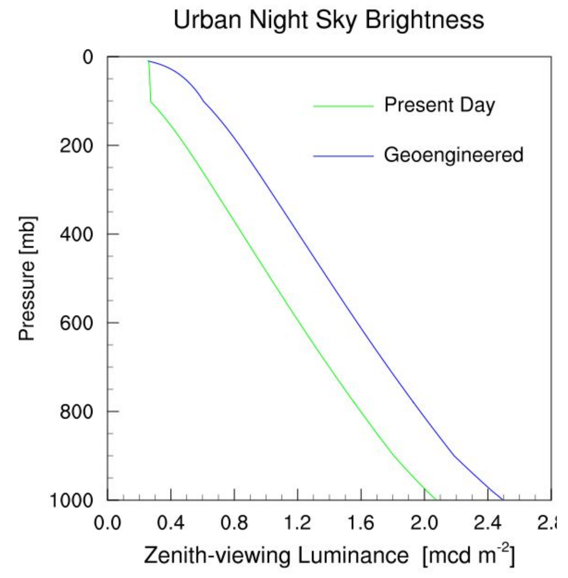

Figure 1: Night sky brightness in an urban setting with 10^6 people in 10^3 km^2. Present day aerosol (AOD = 0.1277) and Rayleigh cause substantial backscattering of artificial light sources. Artificial light backscattering from SAI increases total sky brightness by ~25%.

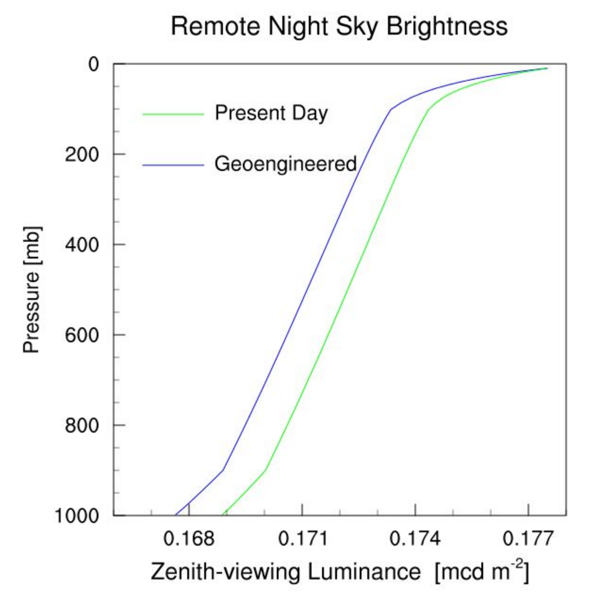

Figure 2: Same as Figure 1 but in a remote setting with 1 person per km^2, so the artificial source is 1000 times less, and is dimmer than the diffuse starlight of the night sky. Starlight backscattering from SAI reduces total sky brightness by ~1%.

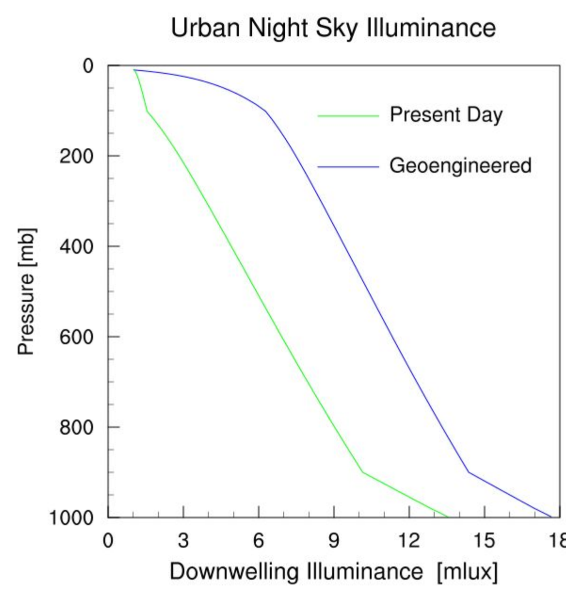

Figure 3: Same conditions as Figure 1 but showing total downwelling, cosine-weighted, photometric illuminance. Isotropically emitted artificial light side scatters from all aerosol. SAI increases hemispheric illuminance more than zenith brightness in Figure 1.

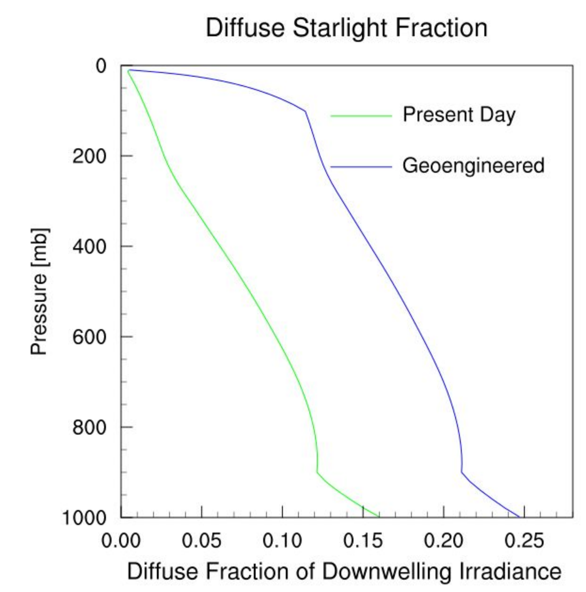

Figure 4: Same conditions as Figure 1 but showing change in fraction of diffuse to total radiometric irradiance due to SAI. SAI increases stratospheric AOD from present-day 0.008 to 0.178. Forward scattering by SAI dramatically increases diffuse fraction in stratosphere, upper troposphere, and (by ~50%) surface. Same figure applies to sunlight, whose diffuse increase would could significantly affect photosynthesis.

Conclusions

How would Stratospheric Aerosol Injection (SAI), the leading stopgap measure to slow or reverse global warming, affect light pollution?

1. Significantly increases (by ~25%) zenith-looking urban night sky brightness.
   a. Effects strengthen toward horizon so total downwelling illuminance increases more than zenith-looking brightness
   b. Insensitive to surface albedo (single scattering regime)
2. Slightly reduces remote zenith-looking night sky brightness (and stellar visibility) in remote regions due to backscattered starlight
3. Artificial night light, unlike sunlight, is all diffuse. However, SAI significantly increases (by ~50%) diffuse fraction of starlight.

Health Impacts

The IAU defines skies where artificial brightness exceeds 10% of natural above 45° as light-polluted. A review by Chepesiuk (2009) describes how light pollution 1) disorients turtle navigation, 2) disrupts bird migration, 3) inhibits frog mating, 4) alters bat feeding, 5) is suspect in declines of nocturnal mammal populations. Human studies show that light pollution disrupts circadian cycles and melatonin production, implicating it in increased depression, insomnia, shift-work sleep disorder, heart disease, and breast cancer.

Future Improvements

1. Replace isotropic with directional emission
2. Horizontal connectivity via successive orders of scattering
3. Stellar visibility

Citations

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Support

Inspired by Roy Garstang. Grants: DOE ACME DE-SC0012998, NASA ACCESS, NNX14AH55A, NSF AGS-1541031.