Evidence of Clear-Sky Daylight Whitening: Are we already conducting geoengineering?

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Original US Brightening paper:


- Used data from 6 SURFRAD sites and ARM SGP
  - 1996 - 2007
US Sites All-Sky Brightening

Average = +8 Wm$^{-2}$/decade
US Clear-Sky Brightening

• US average total SW increase of 4.6 Wm$^{-2}$/decade
• Direct SW shows no trend over the study years
• Trend in clear-sky total SW was virtually all in the diffuse SW

• This is NOT what is expected for aerosol direct effect!
  – For decreased aerosols: Expect increase in direct SW (less attenuation), decrease in diffuse SW (less scattering)
• Total SW changes not correlated with aerosol optical depth changes!
Clear-Sky Total Brightening

US Sites Yearly Clear-Sky SWdn Anomalies

Clear-sky SWdn slope: 4.6 Wm⁻²/decade
Clear-Sky SW Components

US Sites Yearly Clear-Sky Diffuse and Direct SW Anomalies

Clear-sky Dif slope: +4.5 Wm^{-2}/decade

Clear-sky Dir slope: 0.08 Wm^{-2}/decade

Year

Correlation of Aerosol versus Clear-sky SW Anomalies

US Sites Seasonal AOD vs Clear-sky SWdn Anomalies

Slope = -40 Wm^{-2}/unit_AOD

R^2 = 0.05
Puzzling!

- The clear-sky total SW increased
- Documented aerosol optical depths decreased
- But clear-sky direct and diffuse components did not change as expected for direct aerosol effect...
- All confirmed by more recent study spanning 1995-2010
Why is the sky blue and a cloud white?

Blue light scattered 4X more than red light

Sky Imager classification of cloud and cloud-free pixels uses a ratio of red over blue: Ratio is small for blue sky, but approaches 1 for cloud. So the red/blue ratio increases for increasing “whiteness”…

Molecular scattering

Rayleigh Scattering

Larger particle scattering

Visible light scattered about equally

Cloud droplets scatter all wavelengths of visible light creating the appearance of white clouds.
Scattering phase function

Molecules scatter equally forward and backward

Larger particles scatter more in forward direction
The Hypothesis

- Decreasing aerosol optical depth increased the downwelling clear-sky SW.
- But at the same time there was a shift from smaller mode somewhat absorbing scatterers to a larger mode mostly non-absorbing scatterers.
- This resulted in the increased direct SW being scattered out of the direct component into the diffuse.
  - Large mode scattering still in forward direction, but less backscatter.

Also scattering more of the longer wavelengths!
So where did the larger mode come from?

- Radiative transfer modeling shows the hypothesis is feasible for small sized ice crystal amounts increasing while aerosols loading is decreasing.
- Records show that US commercial air traffic increased over the study period.
- Jet exhaust results in aerosol particles and water vapor → contrails → moistening → contrail cirrus → cirrus haze.
Clear-sky Whitening

• We allow some amount of condensed water in the column still to be traditionally classified as “clear-sky”
  – Dupont et al. (2008) show up to 0.15-0.2 optical depth of typically ice haze to be classified as “clear-sky” in the traditional definition
• So the “clear-sky” brightening results could be due to a “whitening” of the conditions we classify as “cloud-free”
• Indicated in Long et al. (2009) by increase in the clear-sky diffuse over direct SW ratio, which is related to increased atmospheric turbidity

• How can we further test this “whitening” hypothesis?
MFRSR diffuse spectral SW Measurements

- The SURFRAD and ARM sites all have collocated Multi-Frequency Rotating Shadowband Radiometers (MFRSRs)
  - Include spectral channels at 415, 500, 615, 673, 870, 940 nm
  - Spectral total, direct, and diffuse components

- Use diffuse 870 nm as “red”, and 415/500 nm as “blue”
- Use same methodology as for broadband SW in original study
  - Use SW detected clear-sky periods and fit functions for the MFRSR spectral channels, interpolate coefficients for cloudy periods same as broadband in original study
  - Produce yearly averages of clear-sky diffuse 870, 500, and 415 nm using same averaging methodology as original study

- If clear-sky whitening is occurring, there should be an increasing tendency in the 870/415 nm and 870/500 nm ratio (red/blue like TSI) through the study years
Yearly Average 870/415 & 870/500 nm Ratio for ARM SGP

Both trends statistically significant

95% Conf Level: -0.0005, 0.0028

y = 0.0011x + 0.2365

95% Conf Level: 0.0003, 0.0019

y = 0.0011x + 0.151
Questions!

• Tendency of Diffuse/Direct and 870/415 and 870/500 nm ratios compatible with hypothesis of clear-sky whitening…for SGP
  – Is this due to increased “ice haze” from increased jet air traffic?
  – Are the results that same for other (SURFRAD) sites? Are the 870/415 nm ratio slopes greater for the sites with greater clear-sky trends as one would expect?
  – Is the “whitening” occurring with same magnitude but more frequently, or as often but greater whitening?

• Long et al. (2009) study showed greater SGP clear-sky brightening Summer and Fall, very little for Winter and Spring
  – What are the seasonal differences causing these trend differences?
  – Are these seasonal trends the same for other geographic areas?

• If indeed caused by air traffic moistening and adding IN to the upper troposphere, then there should be a diurnal signature with increased whitening in the afternoon. Is there?

Thank You…

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Ice crystals are not spherical...
• SGP 1996-2007 clear-sky SW slope 3 W/m^2/decade
  – Clear-sky direct SW slope -0.3 W/m^2/decade
  – Clear-sky diffuse SW slope 3.2 W/m^2/decade

• Model sensitivity test: SHDOM radiative transfer model [Evans, 1998] in 1D mode, and average the SW over a 24-h period

• Hofmann et al (1998) Wyoming study of thin aerosol layers from jet exhaust, not spread over 1-2 km model layers!
  • 8.6 - 12.7 km (29 to 41 kft), 1973-1997
  • Thin layers of highly concentrated CN.
  • Frequency of occurrence of the CN layers approximately doubled from 1980 to 1992.

Correlation of All-Sky Brightening with Sky Cover Anomalies

US Sites Seasonal Sky Cover vs All-sky SWdn Anomalies

Slope = -13.5 W/m²/10%Scv

$R^2 = 0.62$