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Overview
In this study, we analyze long term (approximately 15-15 years depending on the site) observational records of total downwelling shortwave (SW) radiation, clear-sky downwelling SW radiation, cloud cover (CVR) fraction, clear-sky diffuse ratio (DF), and aerosol optical depth (AOD) together with aerosol concentrations from several networks (e.g. SURFRAD, CASTNET, IMPROVE and ACR). Observations from seven sites (i.e. Brooks, Montana; Mississippi, Colorado, Pennsylvania, Nevada and Oklahoma) with different climatology are selected in this assessment to better understand the spatial and temporal distributions of aerosols and clouds in conjunction with their direct, semi-direct, and indirect effects.

This analysis aims to test the hypothesis that the reductions in anthropogenic aerosol burden and cloud cover resulting from substantial reductions in emissions of sulfur dioxide (SO2) and nitrogen oxide (NOx) over the past 15 years has caused an increase in SW radiation near the surface. The results from these assessments are presented in two parts. The first part examines the “brightening” trend by using SW radiation and cloud cover observations. The second part examines the effect of the reduction in SO2 and NOx emissions on the radiation budget by using AOD and aerosol concentration measurements.

Table 1: Listing of site identification of each site for different networks and their measurement period.

Results and Discussion

- The trends in total SW and clear-sky SW radiation are 0.16 and 0.18 W/m²/year respectively while the AOD trends for different sites are similar for both years.
- The association between trends in clear-sky SW radiation and aerosol loading is also supported by the trend in the near surface aerosol concentration from CASTNET, IMPROVE and SURFRAD. During the analysis, surface aerosol concentrations from CASTNET, IMPROVE and SURFRAD decreased by 0.002 µgm⁻³/year and NOx decreased by 0.0039 per year respectively.
- The increasing trend in clear-sky SW radiation is confounded by trends in aerosol burden and cloud cover changes. Possible factors influencing the trends in radiation retrieval methodology which can potentially influence the results of SW SW sky diffuse ratio are often confounded by other factors and did not show a clear association with trends in aerosol burden over the US arising from the implementation of the CAA, but a consideration of cloud cover, aerosol vertical profiles and elevated plumes.
- At these sites, the changes in aerosol burden and direct aerosol effects cannot explain the observed changes in surface SW radiation, but other factors also need to be considered such as cloud cover, aerosol vertical profiles and elevated plumes.

- The trends in clear-sky SW diffuse ratio are consistent with increasing aerosol burden. Although the clear-sky diffuse ratio also exhibits an increasing trend, this may be caused by heavy air traffic or croplands which are the dominant types of surface in the eastern U.S. The increase in clear-sky SW diffuse ratio is consistent with increasing aerosol burden.
- Aerosol and OMC reflectance have an increasing trend of 2% and 30% respectively.
- The trends in total SW and clear-sky SW diffuse ratio are 0.16 and 0.2 µgm⁻³/year respectively while the AOD trends for different sites are similar for both years.
- The association between trends in clear-sky SW diffuse ratio and aerosol loading is also supported by the trend in the near surface aerosol concentration from CASTNET, IMPROVE and SURFRAD. During the analysis, surface aerosol concentrations from CASTNET, IMPROVE and SURFRAD decreased by 0.002 µgm⁻³/year and NOx decreased by 0.0039 per year respectively.

Summary
- The overall downwelling SW radiation and clear-sky SW radiation at major sites across the eastern U.S. exhibit an increasing trend over the 15 years.
- At locations where discrepancies in trends were noted, the apparent dimming can be explained by the site location, heavy air traffic, increasing cloud cover and aerosol burden.
- Trends in AOD retrievals from SeaWiFS at all locations of the SURFRAD sites agree with the in-situ AOD measurements at these locations (except at TBL). However, the difference (SURFRAD - SeaWiFS) is significant and may be due to the top of the atmosphere scattering (0.17 ± 0.07) of SURFRAD.
- The analyzed trends of SW radiation, AOD and aerosol concentration from three of the seven sites (i.e. BON, LGWT and SURFRAD) show a clear association between increasing clear-sky SW and decreasing surface and tropospheric (narrowed from AOD) aerosol burden.
- Three sites (i.e. TBL, KPP and DRA) show increasing trends in AOD associated with increasing trends in aerosol concentration at surface. At these sites, the changes in aerosol burden and direct aerosol effects cannot explain the observed changes in surface SW radiation, but other factors also need to be considered such as cloud cover, aerosol vertical profiles and elevated plumes.
- Trends in clear-sky diffuse ratio are often confounded by other factors and did not show a clear association with trends in aerosol burden.
- There are several possible interpretations to the trends in existing conduction such as heavy air traffic in the eastern US which can enhance the cirrus coverage and the classification of “clear-sky” conditions in the radiation retrieval methodology which can potentially influence the results of clear-sky radiation estimate.
- Future work: Multi-decadal model calculations with the coupled WRF-CAM5 model (Wang et al., 2012) is being setup for the 1980–2010 period to test the ability of the model to simulate not only the changes in aerosol burden over the US arising from the implementation of the CAA, but also the associated radiation brightening as analyzed in the present analysis.