

환경 및 응용기상 분과 [P-060]

Observational and Modeling Analysis of Drivers of Increasing Surface Solar Radiation over East Asia

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Recent decades have witnessed a significant decline in anthropogenic aerosol emissions across East Asia, largely attributable to stringent air quality regulations such as China's 2013 Clean Air Action Plan. This has led to a notable increase in surface solar radiation (SSR), a phenomenon known as 'solar brightening,' with substantial implications for the regional energy budget. This study investigates the trends and drivers of this brightening over East Asia from 2003 to 2024 using satellite observations from the Clouds and the Earth's Radiant Energy System (CERES), reanalysis products from the fifth-generation ECMWF atmospheric reanalysis (ERA5) and the Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2), and a fully-coupled meteorology-chemistry model, the Weather Research and Forecasting model with Chemistry (WRF-Chem). Our analysis of CERES data reveals a robust brightening trend, especially post-2013. Over eastern China (105–120°E, 20–40°N), the all-sky SSR increased at a rate of $+1.293 \text{ W m}^{-2} \text{ yr}^{-1}$. Crucially, the trend in clear-sky SSR was even stronger ($+1.504 \text{ W m}^{-2} \text{ yr}^{-1}$), which suggests that the reduction in aerosol loading is a dominant contributor to the observed brightening. This brightening exhibits a distinct north-to-south gradient, with the most pronounced trends in heavily industrialized regions: North China ($+2.340 \text{ W m}^{-2} \text{ yr}^{-1}$), followed by the Yangtze River Delta ($+1.470 \text{ W m}^{-2} \text{ yr}^{-1}$) and the Pearl River Delta ($+1.062 \text{ W m}^{-2} \text{ yr}^{-1}$), a pattern reflecting the pronounced impact of emission reductions in regions with historically high aerosol concentrations. Furthermore, the composition of incoming radiation has shifted, with a significant increase in direct radiation ($+1.764 \text{ W m}^{-2} \text{ yr}^{-1}$) and a corresponding decrease in diffuse radiation ($-0.319 \text{ W m}^{-2} \text{ yr}^{-1}$), which is consistent with reduced atmospheric scattering from a lower aerosol burden. In contrast, reanalysis datasets like MERRA-2 ($+0.551 \text{ W m}^{-2} \text{ yr}^{-1}$) and ERA5 ($+0.147 \text{ W m}^{-2} \text{ yr}^{-1}$) substantially underestimate these trends, likely due to incomplete aerosol process representations. WRF-Chem sensitivity experiments indicate that while the aerosol direct effect is the principal mechanism in regions with high aerosol loading, significant indirect effects from aerosol-cloud interactions are also prominent in cloud-rich environments, driven by decreased cloud cover and optical thickness. These findings quantify the profound impact of emission control policies on the regional radiation budget and highlight significant co-benefits, such as enhanced solar energy potential.

Keywords: Surface Solar Radiation, Aerosol Reduction, Aerosol–Cloud Interactions, East Asia, WRF-Chem and Reanalysis data Evaluation