Interpreting Satellite Observations of the Ultraviolet Aerosol Index to Understand Aerosol Scattering and Absorption

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Aerosols are particles suspended in Earth's atmosphere. They are emitted from a variety of sources, such as motor vehicles, industry, biomass burning, uplifted desert dust, and ocean spray. These particles impact climate through their interactions with solar radiation. Aerosols with scattering properties have a cooling effect on climate as they reflect incoming solar radiation back to outer-space, while aerosols with absorbing properties absorb the incoming solar radiation, which warms the atmosphere and cools the surface. The climate impacts of aerosols are known to be significant; it is estimated that the cooling effect of aerosols has masked approximately one third of the warming due to greenhouse gases [1], while aerosol absorption is estimated to possibly be the second largest source of atmospheric warming after carbon dioxide [2,3]. However, the overall magnitude of the climate effects of aerosols remains highly uncertain, due to the large uncertainties associated with the aerosol particles themselves. Global observations of aerosol scattering and absorption would improve our understanding of how aerosols interact with solar radiation and therefore also improve our understanding of their climate impacts.

We used NASA's Ultraviolet Aerosol Index (UVAI) dataset, which is a product of the Ozone Monitoring Instrument (OMI), to improve understanding of changes in aerosol scattering and absorption over time and space. Satellite remote sensing is a valuable tool which provides atmospheric composition information on a global scale. The UVAI is a method of detecting aerosol optical effects from satellite measurements in the ultraviolet.

Summary

We use the Ultraviolet Aerosol Index, a method of detecting aerosol optical properties from satellite measurements, to understand changes in aerosol scattering and absorption over time and space.

The UVAI is calculated as the ratio of the radiance measured by the satellite with the radiance that would be measured by the satellite if the atmosphere were completely free of aerosol. Positive UVAI values indicate aerosol absorption, and the sources of positive UVAI values are biomass burning and desert dust aerosol. Negative UVAI values indicate aerosol scattering, and the sources of negative UVAI values are inorganic and scattering organic aerosol. We examined trends in the UVAI for 2005-2015 to learn about changes in aerosol scattering and absorption over time.

To interpret the observed UVAI trends, we developed a simulation of the UVAI using the global chemical transport model GEOS-Chem coupled with the radiative transfer model VLIDORT. We used GEOS-Chem to split the atmosphere into about a million grid boxes, then in each grid box the meteorological and emissions inputs are given to the physical and chemical equations necessary to simulate the chemical composition of the atmosphere. From this simulation, we provided the aerosol information to VLIDORT necessary for the calculation of the atmospheric radiances used in the calculation of the simulated UVAI. We then used this simulation with known aerosol composition to interpret the trends in the satellite observed UVAI values.

We found that compared to the OMI UVAI, the UVAI simulation captured the aerosol absorption over desert regions, but failed to capture the absorption over biomass burning regions [4]. This was because chemical transport models, including GEOS-Chem, typically treat black carbon as the sole absorbing carbonaceous aerosol. However, over the past number of years there has been a growing amount of evidence for the existence of an additional absorbing carbonaceous aerosol species known as brown carbon, which absorbs strongly in the ultraviolet and is emitted through low-temperature, incomplete combustion of biomass and biofuel. By adding brown carbon to the

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GEOS-Chem simulation, the UVAI simulation was then able to reproduce the absorption over biomass burning regions compared to OMI.

We then used this improved simulation with known aerosol composition to interpret the 2005-2015 trends in observed UVAI values to learn about changes in aerosol scattering and absorption over time [5]. We found that decreasing levels of scattering aerosols, due to pollution controls, explained positive trends in the UVAI over the south-eastern U.S. A decline in absorbing biomass burning aerosol due to cropland expansion explained negative trends in the UVAI over West Africa. An increase in scattering aerosol due to industrial activity explained negative trends in the UVAI over India. Over the Middle-East there was a small region of positive trends in the OMI UVAI values that was not captured by the simulation. This feature was located near the Aral Sea, which has been drying up for several years due to land use changes. As the sea bed becomes more exposed, there would be increased emissions of absorbing desert dust and the surface reflectance would increase, which are both factors that would increase the UVAI. Therefore the satellite UVAI is capturing these effects as they happen, but they are not yet modeled in GEOS-Chem, which is why the feature is not captured in our UVAI simulation. This indicates an area for future model development.

CONCLUSION

In summary, interpretation of satellite UVAI observations with the GEOS-Chem chemical transport model is yielding new insight into scattering and absorption by atmospheric aerosols.

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