STATEMENT

Synopsis of Research Report 167

HEALTH EFFECTS INSTITUTE

Assessment of the Relationship Between Satellite-Based Estimates and Measurements of $PM_{2.5}$ in the Eastern United States

INTRODUCTION

Over the past decade, satellite-based estimates of ground-level pollution have emerged as a potentially important source of information on human exposure to health-damaging pollutants such as nitrogen dioxide and fine particulate matter ($PM_{2.5}$; PM with an aerodynamic diameter of 2.5 µm or smaller). Estimates of the concentration of ground-level $PM_{2.5}$ can be made from satellite calculations of aerosol optical depth (AOD) — a measure of light extinction by aerosols in the total atmospheric column calculated from measurements of light scattering at various wavelengths. Health effects researchers have begun to use satellite-based estimates of $PM_{2.5}$ from AOD calculations in both epidemiologic research and risk assessment; however, the accuracy and precision of estimates provided by different satellite-based estimators and the circumstances in which such estimates might make the most important contributions remain uncertain.

Dr. Christopher J. Paciorek of the Harvard School of Public Health submitted an application under Request for Applications 05-2, "The Walter A. Rosenblith New Investigator Award," which was established to provide support for an outstanding investigator beginning his or her independent research career. In his proposed study, "Integrating Monitoring and Satellite Data to Estimate $PM_{2.5}$ Exposure and Its Chronic Health Effects in the Nurses' Health Study," Paciorek planned to reanalyze data on the chronic health effects of $PM_{2.5}$ in the Nurses' Health Study, a large epidemiologic cohort study, by integrating AOD measurements from satellite data with ground monitoring data to improve the exposure-assessment modeling. The HEI Health Research Committee urged Paciorek to focus on the estimates of exposure, rather than the epidemiologic analysis. Ultimately, HEI funded the current study, "Integrating Monitoring and Satellite Data to Retrospectively Estimate Monthly $PM_{2.5}$ Concentrations in the Eastern United States," which began in 2006.

The overall objective of Paciorek's study was to assess the ability of approaches that use satellite-based measurements of AOD from the National Aeronautics and Space Administration's (NASA's) multiangle imaging spectroradiometer (MISR) and moderate resolution imaging spectroradiometer (MODIS) satellites to fill spatial and temporal gaps in existing monitoring networks in the eastern United States. To accomplish this, the investigators developed statistical models for integrating monitoring, satellite, and geographic information system (GIS) data to estimate average monthly ambient $PM_{2.5}$ concentrations. They then applied those models across the eastern United States at various times during the period from 2000 to 2006 at a fine spatial resolution. Their goal was to better understand temporal and spatial variation in $PM_{2.5}$ and then determine how accurately it could be characterized based on satellite, monitoring, and GIS data. They developed and applied statistical methods to quantify (1) how uncertainties in exposure estimates based on ground-level monitoring data might be reduced by adding satellite-based monitoring data and (2) how systematic discrepancies between a proxy measure — such as AOD as a proxy for $PM_{2.5}$ — could be identified and accounted for. They also explored the potential for two additional sources of information, the Geostationary Operational Environmental Satellite (GOES) and the Community Multiscale Air Quality (CMAQ) atmospheric-chemistry model, to improve $PM_{2.5}$ exposure estimates for years in which satellite measurements from MISR and MODIS are unavailable.

This Statement, prepared by the Health Effects Institute, summarizes a research project funded by HEI and conducted by Dr. Christopher J. Paciorek at Harvard School of Public Health, Boston, Massachusetts, and Dr. Yang Liu at Rollins School of Public Health, Emory University, Atlanta, Georgia. The complete report, *Assessment and Statistical Modeling of the Relationship Between Remotely Sensed Aerosol Optical Depth and $PM_{2.5}$ in the Eastern United States* (© 2012 Health Effects Institute), can be obtained from HEI or our Web site (see last page).

APPROACH

The investigators assembled publicly available data for the eastern United States from satellites, ground-level air pollution monitors, meteorologic observations, and land-use databases; these included NASA's MODIS and MISR satellites for AOD measurements, the U.S. Environmental Protection Agency's (EPA's) Interagency Monitoring of Protected Visual Environments $PM_{2.5}$ monitoring network, GOES, the U.S. EPA's CMAQ model for emissions-based estimates of $PM_{2.5}$, the U.S. National Oceanic and Atmospheric Administration's North American Regional Reanalysis database, and the Multi-Resolution Land Characteristics Consortium.

They then analyzed the relationship between $PM_{2.5}$ monitoring data and AOD measurements in both space and time. First they estimated the correlation between $PM_{2.5}$ and AOD both before and after calibration with meteorologic factors and at different temporal and spatial scales in order to understand discrepancies between AOD and $PM_{2.5}$. Then they conducted analyses in which (1) AOD data were included as variables in statistical models to predict $PM_{2.5}$ concentrations, and (2) the discrepancies between proxies (such as AOD) and $PM_{2.5}$ were determined. They also explored the spatial relationship between AOD and $PM_{2.5}$ using new methods they had developed for this purpose.

RESULTS

The investigators report that satellite-based AOD estimates did not improve $PM_{2.5}$ predictions for the eastern United States as compared with predictions from other geospatial models. Although AOD data were temporally correlated with $PM_{2.5}$ measurements, correlations of long-term spatial averages were relatively weak unless they were adjusted statistically for the discrepancy between AOD and $PM_{2.5}$. Although statistical models that combined AOD, $PM_{2.5}$ observations, and land-use and meteorologic variables were highly predictive of $PM_{2.5}$, AOD itself contributed little to the predictive power of those models over and above the other variables.

Further, the investigators report that substituting $PM_{2.5}$ estimates from the U.S. EPA's CMAQ model for AOD data also did not improve the ability of the multivariable models to predict the measured $PM_{2.5}$ data, and that attempts to use data from the GOES satellite to correct for interference with AOD from surface reflectance (brightness), a factor that may affect the relationship of AOD with $PM_{2.5}$, were largely unsuccessful.

Using statistical models that accounted for potential discrepancies between AOD and $PM_{2.5}$ at both large and small spatial scales was an important determinant of predictive ability in this study. Models that did not account for discrepancies at small spatial scales had poor predictive ability for measured $PM_{2.5}$. The investigators attributed this lack of predictive ability to the fact that their analysis did not account for spatial differences in the vertical profile of the aerosol and to the effects of the variable degree of reflectance of the Earth's surface.

Paciorek and his colleague, Yang Liu, concluded that the inability of AOD data to improve the spatial prediction of monthly and yearly average $PM_{2.5}$ in the eastern United States is a result of the spatial discrepancy between AOD estimates and measured $PM_{2.5}$, particularly at smaller spatial scales. They stress the importance of explicitly accounting for such discrepancies in statistical models that use proxy estimates, such as AOD, in order to distinguish the $PM_{2.5}$ "signal" in the proxy measure (AOD) from the "noise" contributed by the discrepancy between the proxy and ground-level $PM_{2.5}$. They concluded that there is little evidence that current satellite-based estimates of AOD can improve the prediction of ground-level $PM_{2.5}$ at small-to-moderate scales in the eastern United States, and they argue that until more evidence regarding the reliability of satellite-derived AOD data is available, it is premature to use such data in epidemiologic studies as a proxy for $PM_{2.5}$. They note, however, that more promising results might be obtained in areas that have levels of ambient $PM_{2.5}$ higher than those in the eastern United States, such as some developing countries, because the AOD signal would be relatively stronger in such locales than the noise contributed by background surface reflectance.

INTERPRETATION AND CONCLUSIONS

On the basis of this report, several conclusions regarding the application of satellite-based estimates of $PM_{2.5}$ air pollution in health effects research seem warranted. First, the use of raw AOD estimates as a proxy for $PM_{2.5}$ measurements in health effects research should be avoided in general. Rather, approaches that combine information from multiple sources — remote sensing, model-based estimates, and ground-level measurements — may offer the most promise. Recent studies that have taken the latter approach have reported that satellite-based estimates can explain a fair amount of between-city variability in $PM_{2.5}$, but that the estimates need to be combined with other data to explain within-city variation.

Applications to health effects research should include, to the extent possible, evaluations of the relationship between satellite-based estimates and monitoring data; researchers should try to quantify the contribution of satellite-based estimates to the total exposure measurement error in epidemiologic effect estimates.

Satellite-based estimates can potentially play an important role in the evaluation of exposure to, and health effects of, short-term episodes of high levels of air pollution from vegetation fires or dust events, especially in areas with limited or no monitoring, where satellite-based estimates could help define the spatial extent of the exposure.

In areas of the world where ground-based measurements of air pollution are not likely to be collected for the foreseeable future, satellite-based data may help address the needs of epidemiologic research and public health–based risk assessment. Satellite remote sensing may offer promise for providing information on exposure to $PM_{2.5}$ at regional-to-global scales, especially in places with the highest levels of pollution and the greatest estimated burden of disease attributable to it. However, there are limitations to and outstanding questions about the accuracy and precision with which ground-level aerosol mass concentrations can be inferred from satellite remote sensing, including the level of global variation in the relationship between AOD and $PM_{2.5}$ at specific satellite overpass times during cloud-free conditions. Addressing these issues will require a systematic effort that includes measuring ground-level $PM_{2.5}$ in selected global regions to identify the factors that most affect the relationship between satellite-based and ground-level estimates.

Assessment and Statistical Modeling of the Relationship Between Remotely Sensed Aerosol Optical Depth and $PM_{2.5}$ in the Eastern United States

Investigators' Report

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