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AIRNOW SATELLITE DATA PROCESSOR: IMPROVING EPA'S AIRNOW AIR QUALITY INDEX MAPS USING NASA/NOAA SATELLITE DATA AND AIR QUALITY MODEL PREDICTIONS

Adam N. Pasch*, Patrick H. Zahn, Jennifer L. DeWinter, Michael D. Haderman, Tim S. Dye
Sonoma Technology, Inc., Petaluma, California, USA

James J. Szykman
NASA Langley Research Center, Hampton, VA, USA

John E. White and Phillip Dickerson
U.S. EPA, Research Triangle Park, USA

Aaron van Donkelaar and Randall V. Martin
Dalhousie University, Halifax, Nova Scotia, CA

1. INTRODUCTION

Exposure to elevated concentrations of ambient fine particulate matter ($PM_{2.5}$) is associated with adverse cardiovascular and respiratory health effects. Additionally, in a recent announcement of its classification of PM as carcinogenic to humans, the International Agency for Research on Cancer (IARC) cited a study in which $PM_{2.5}$ was estimated to have contributed 3.2 million premature deaths worldwide in 2010 (IARC, 2013). From a public health perspective, people who take protective action to avoid exposure to high levels of ambient air pollutants, including $PM_{2.5}$, will experience substantial health benefits.

To provide the public with easy access to national air quality information, the U.S. Environmental Protection Agency (EPA) AirNow program includes a website that reports daily air quality in terms of the Air Quality Index (AQI), which is a standardized metric based on health effects of air pollution. AQI levels are currently calculated from ground-based measurements submitted by state, local, and federal air quality agencies, and are then interpolated to a grid using kriging to create maps that cover national, regional, and local spatial scales. However, the real-time ambient air monitoring network from which the measured data are obtained does not cover all regions in the continental United States (see Fig. 1). Significant gaps in coverage of the network occur especially in the Intermountain West and Great Plains. These measurement gaps lead to high uncertainty of mapped AQI levels in monitor-sparse locations and a lack of accurate information on real-time exposure to $PM_{2.5}$ affecting more than 42 million people who reside in populated places farther than 40 km from the nearest $PM_{2.5}$ monitor.

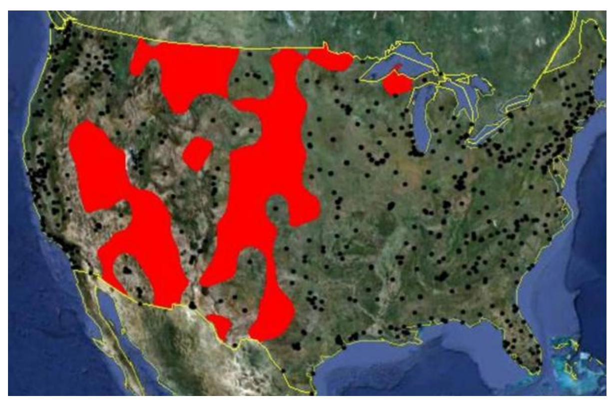

Fig. 1. Network of active fine particulate matter ($PM_{2.5}$) monitors reporting data to AirNow (black dots) and regions lacking sufficient monitoring (red areas), which are currently masked in AirNow data products, including contoured air quality index (AQI) maps.

One way to reduce the gaps in $PM_{2.5}$ information and improve the usefulness of AQI maps is to use $PM_{2.5}$ concentrations estimated from satellite aerosol optical depth (AOD) measurements. Under a recent NASA-funded project, we developed the AirNow Satellite Data Processor (ASDP), which is a system for routine estimation of surface $PM_{2.5}$ concentrations from satellite data and fusion of those estimates with routine surface $PM_{2.5}$ monitor observations within the AirNow data system. ASDP is flexible and

**Corresponding author:* Adam N. Pasch, Sonoma Technology, Inc., 1455 N. McDowell Blvd., Suite D, Petaluma, CA 94954-6503; e-mail: apasch@sonomatech.com

can fuse additional data sets, such as future satellite data products, data from other surface observation networks, and air quality model (AQM) predictions. In this paper, we focus on the general approach used to fuse multiple data sets in the ASDP, estimating data uncertainties that are required in the fusion program, and future work for evaluating ASDP through statistical analyses and case studies.

2. METHODOLOGY

2.1 Derivation of Satellite-Based Surface $PM_{2.5}$ Concentrations

The project team completed the development and documentation of an algorithm to estimate, in near-real time, surface $PM_{2.5}$ concentrations from satellite observations of AOD. Specifically, we improved the accuracy of daily ground-level $PM_{2.5}$ concentrations derived from satellite observations (Moderate Resolution Imaging Spectroradiometer [MODIS] and Multi-angle Imaging Spectroradiometer [MISR]) of AOD and chemical transport model (GEOS-Chem) calculations of the relationship between AOD and $PM_{2.5}$ (van Donkelaar et al., 2012). This improvement was achieved by

1. Applying climatological ground-based bias-correction factors based upon comparison with in situ $PM_{2.5}$; and
2. Applying spatial smoothing to reduce random uncertainty and extend coverage.

After the completion of this algorithm, we focused on developing a method to consistently relate the errors in satellite and in situ observations, as described below.

2.2 Combined Kriged and Satellite-Derived $PM_{2.5}$

We combined the kriged surface $PM_{2.5}$ observations with satellite-derived $PM_{2.5}$ data using a simple weighted average.

$$PM_{2.5,combined} = ((PM_{2.5} \times E^{-1})_{krig} + (PM_{2.5} \times E^{-1})_{sat}) / (E_{krig}^{-1} + E_{sat}^{-1})$$

$PM_{2.5}$ values are inversely weighted by their respective errors, E, thereby more heavily weighting combined estimates on the values of least uncertainty.

Successful application of this method requires a consistent representation of the error expected from each dataset. The error in the satellite-derived surfaces used by AirNow is described with a one-sigma error envelope (van Donkelaar et al., 2012), whereas the kriged surfaces presently generated by AirNow provide values of variance of prediction (VOP).

A relationship was developed to relate values of VOP from the kriged surface to a one-sigma error prior to weighting. This relationship was determine by comparing observed $PM_{2.5}$ concentrations at monitor locations with kriged values under a variety of different VOP values and $PM_{2.5}$ concentrations from June 2011 to May 2012. Kriged surfaces were created using “dead zones”, within which all observational values are removed and the local effect of VOP on kriged surface accuracy was evaluated. Optimal error estimates at each monitor location were determined by comparing the accuracy of the final, combined kriged and satellite $PM_{2.5}$ estimates with observations within a 90-day running window. Kriged errors were allowed to vary by VOP values and $PM_{2.5}$ concentrations, by grouping similar values within the bins given in **Table 2**. The local error estimates of each bin were then extended nationally using an inverse distance weighted average.

Table 1. Kriged surface VOP and $PM_{2.5}$ uncertainty bins.

Quantity	Uncertainty bins
VOP	0-1, 1-5, 5-10, 10-20, >20
$PM_{2.5}$ [µg/m^3]	0-5, 5-10, 10-20, >20

3. RESULTS

Figure 2 shows examples of kriged, combined, and satellite-derived $PM_{2.5}$ estimates for July 1, 2011. As expected, the combined AQI (first row) and $PM_{2.5}$ surfaces (second row) use values from both the kriged and satellite-derived values. The uncertainty in the kriged surface is generally lower than in the satellite-derived values (third row); however, the combined surface demonstrates improved agreement with observations at elevated $PM_{2.5}$ concentrations and increased VOP values (fourth row). The highest levels of VOP values (>20) showed the greatest improvement, but are rarely found under operational conditions, and are only present on this day due to the artificial use of dead zones surrounding monitor locations. The fourth row shows that error reductions of 10-30% are found for this day for the operationally-realistic VOP of 1-20, under high $PM_{2.5}$ concentrations of >20 μg/m^3.

Input files necessary for real-time implementation were provided to AirNow in formatted netCDF files using the Community Multiscale Air Quality model (CMAQ) grid, which matches the satellite-estimates. The netCDF files provide the absolute and percent error determined for each VOP and PM2.5 bin. Interpolation of these values, based upon the VOP and PM2.5 of any given kriged surface, will provide local error variables. Kriged error is provided by multiplying the kriged PM2.5 concentration prediction on a given day by the percent error and adding the absolute component.

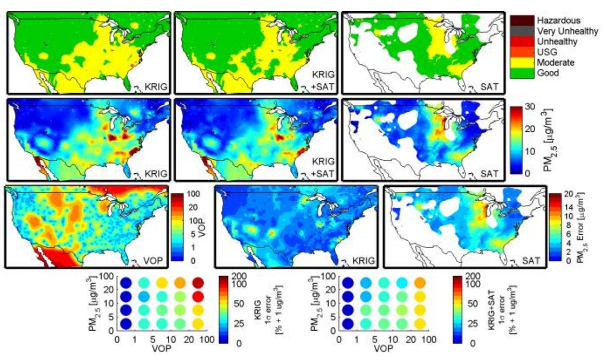

Fig. 2. Kriged (KRIG), combined (KRIG+SAT), and satellite-derived (SAT) values for July 1, 2011. The first and second rows show AQI values and $PM_{2.5}$ concentrations for each dataset. The third row shows the variance of prediction (VOP) and estimated error of the kriged and satellite-derived surfaces. The fourth row shows the observed error as a function of $PM_{2.5}$ and VOP for the kriged and combined surface.

4. CONCLUSIONS AND DISCUSSION

The combined $PM_{2.5}$ surface derived by fusing observed and satellite-based $PM_{2.5}$ data through ASDP demonstrates improved agreement with observations at elevated $PM_{2.5}$ concentrations, with error reductions of 10-30% found on a sample day under $PM_{2.5}$ concentrations in excess of 20 μg/m^3.

In addition, it should be noted that the ASDP approach is flexible and can be used to fuse additional data sets, such as future satellite data products, data from other surface observation networks, and air quality model (AQM) data. The flowchart in Figure 3 illustrates how AQM data can be included in the ASDP. Note that incorporating AQM predictions into the ASDP requires a consistent approach for estimating the corresponding uncertainty.

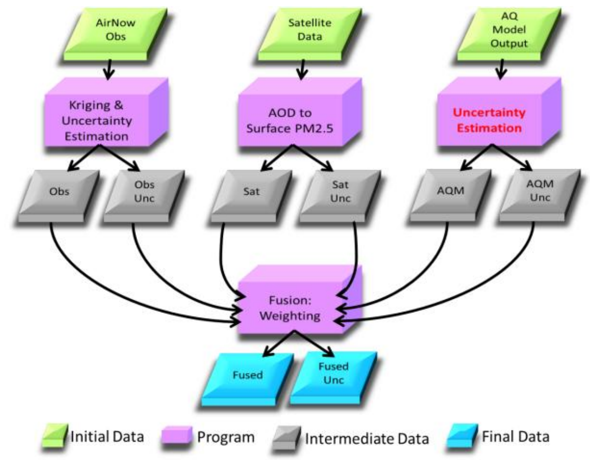

Fig. 3. Flowchart showing process steps for fusing data sets through ASDP.

5. REFERENCES

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