P1.9 **ANALYSIS OF AIR POLLUTANT TRANSPORT TO CLASS I AREAS USING MULTIPLE SATELLITE PRODUCTS AND IN SITU GROUND BASED MEASUREMENTS**

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1. INTRODUCTION

Visibility has been historically defined as "the greatest distance at which an observer can just see a black object viewed against the horizon sky" (Malm, 1999). A more general definition of visibility involves how well one can appreciate and differentiate colors, forms, and textures of an object from a distance.

Congress realized the importance of visual air quality and passed the Clean Air Act (CAA) in 1977. Class I areas, described as parks or wilderness areas greater than 5,000 acres were labeled "protected environments," where visibility is a critical resource for human appreciation of the natural area. The Regional Haze Rule, a product of the 1990 CAA amendments, followed (Environmental Protection Agency, Emissions Monitoring and Analysis Division, June 1999). "The Interagency Monitoring of PROtected Visual Environments (IMPROVE) program was established in 1985 to aid the creation of Federal and State implementation plans for the protection of visibility in Class I areas. The program is a collaborative effort governed by a steering committee composed of representatives from Federal and regional-state organizations" (IMPROVE-CIRA, 2005).

Visibility studies are important to determine the sources and effects of pollutants on protected areas. Ground based *in-situ* measurements are typically used to analyze visibility impacts. We show in this paper that satellite data can also be useful in visibility-related studies. The ability of satellites to make observations over large areas makes the data well suited for visibility studies. Satellites can provide a better understanding of the pollutant source and, potentially, its concentration in protected sites. This paper aims at using both *in-situ* measurements and spaceborne data to analyze visibility impairment to a specific Class I area.

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2. METHODOLOGY

Suites of spaceborne and *in-situ* ground based measurements were analyzed to determine the transport of pollutants to Dolly Sods Wilderness, West Virginia. This site was chosen to get an enhanced understanding of particulates that affected visibility on the East coast in the summer of 2004. Dolly Sods Wilderness is 39.107°N, 79.426°W.

2.1 Measuring Visibility Impairment

In-Situ Sources of Data

In-situ measurements from the IMPROVE monitoring program have been used for visibility analysis. The program uses several measurements to adequately analyze visibility-related characteristics. Those measurements typically consist of optical, scenic, and aerosol data " (IMPROVE-CIRA, 2005).

United States Department of Agriculture (USDA) Forest Service (USDA, 2005) scenic data was then analyzed to estimate observer visual range, clarity, color, contrast, and texture of the object being viewed. Scenic views provided a better understanding of visibility characteristics.

Environmental Protection Agency (EPA) Metropolitan Statistical Area (MSA) $PM_{2.5}$ data was used in addition to IMPROVE aerosol data. EPA AIRNow produces fine particulate matter maps to monitor air quality, which were useful to determine the quality of air at protected sites (EPA, 2005).

Trajectory data was subsequently used to determine the actual source of pollutants to each protected area. The National Oceanic Atmospheric Administration (NOAA) Air Resources Laboratory (ARL) (HYbrid Single-Particle Lagrangian Integrated Trajectory)

HYSPLIT model was important to assess potential pollutant source directions. HYSPLIT computes the advection of a single pollutant particle or its trajectory. The on-line (Internet-based) HYSPLIT model was run using FNL archived meteorological data. Five-day air trajectories with start heights at 1, 2, and 3 km were produced to evaluate transport of pollutants (HYSPLIT, 2005).

Spaceborne Sensors

The MODerate Resolution Imaging Spectroradiometer (MODIS) instrument aboard the AQUA and TERRA satellites proved particularly useful in this study of protected areas. TERRA MODIS and AQUA MODIS view the surface of the entire Earth every day. Data is acquired in 36 spectral bands, with up to 250m x 250m spatial resolution. Forty-four products are produced from the spectral data collected by the MODIS instrument. NASA provides MODIS satellite data in a format known as Hierarchical Data Format (HDF); (Kaufman, 2005). MOD02QKM-Level 1B and MYD02QKM-Level 1B from the TERRA and AQUA platforms, respectively, were used in the cases studied. This data was essential to produce quarter kilometer (QKM) resolution true color red-green-blue (RGB) images from the calibrated geolocated radiances.

The MODIS Aerosol Optical Depth (AOD) product was also used. AOD data products are MOD04_L2 for the TERRA platform and MYD04_L2 for the AQUA platform. All images were processed using HDFLook (Gonzalez & Deroo, 2005).

MODIS true color images were used to help provide a better understanding of smog and haze distribution over land. Haze and smog appear gray, which in most cases is clearly identifiable in true color images. MODIS AOD values, which indicate the extinction from aerosols in a vertical column, typically range from 0.0 to 5.0. Values greater than one indicate significant haze and greater than two indicate extremely intense haze or smoke events. One limitation is that MODIS AOD shows no data under clouds and in areas where extreme pollution, such as large intense smoke plumes, are present. Previous research has also shown that MODIS AOD has better correlation with ground based fine particulate matter ($PM_{2.5}$) in the East and Midwest (Engel-Cox, 2004). However, MODIS AOD can still be useful in identifying the intensity of aerosols at sites in the West. Thus, MODIS AOD was used in conjunction with NOAA GOES (or Geostationary Operational Environmental Satellite) Aerosol Smoke Product (GASP) data to provide a better understanding of the intensity of aerosols over a particular site (GASP, 2005). The GOES satellites are a series of geostationary satellites that continuously monitor the United States.

The Hazard Mapping System (HMS) fire and smoke product, when available, was then used to determine the locations of significant fires and smoke plumes (HMS, 2005). The HMS product integrates fire detection data from MODIS, GOES, and polar satellites (Advanced Very High Resolution Radiometer (AVHRR), and Defense Meteorological Satellite Program/Operational Linescan System (DMSP/OLS)).

The Naval Research Laboratory (NRL) NAAPS aerosol model was used to further understand the sources of pollutants to Class I areas (NRL, 2005). The model uses meteorological data from the Navy Operational Global Atmospheric Prediction System (NOGAPS). NRL also compares NAAPS Aerosol data to satellite observations. Comparison of the model and satellite data help validate and provide clear analysis of pollutant source.

3. RESULTS AND DISCUSSION

3.1 Dolly Sods Wilderness

Dolly Sods Wilderness located in West Virginia is an area of high elevation wind swept plains on the Allegheny Plateau. It is a unique island of wild country surrounded by Appalachian hardwood forests (Outdoor Travels, 2005).

Fires were discovered in Alaska and northwestern Canada in early June 2004. Lightning was responsible for triggering the fires and the damage was extensive. "As a matter of scale, Alaska had 25,000 km^2 in fire this year and the Taylor Complex fire alone was 5,260 km^2 in area, twice the area of all the 2003 Southern California fires combined. The Alaska fires comprised 86% the fire area of the US up to September 1" (Hoff, 2004).

Midwest aerosols and smoke from the Alaska/Canadian fires impaired visibility at Dolly Sods Wilderness on June 30, 2004. Scenic imagery from the USDA Forest Service shows the hazy/smoky conditions. [Figure 1]

April 28th 2004: Clear
b_{ext} – 10 Mm^{-1}

June 30th:Hazy/Smoky
b_{ext} – 86 Mm^{-1}

Figure 1: Clear Day vs. Hazy/Smoky Day at Dolly Sods on June 30, 2004

Data from the Dolly Sods IMPROVE nephelometer estimated a light scattering coefficient of 100 Mm^{-1} indicating hazy conditions, which is identified as a light gray mass over the park in the AQUA MODIS image; [Figure 2]. The IMPROVE aerosol monitor measured a reconstructed total aerosol extinction of 86 Mm^{-1}, indicating extremely hazy/smoky conditions. MODIS AOD values were elevated ranging from 0.3 to 0.6. [Figure 3] and GOES GASP estimated 0.5 [Figure 4].

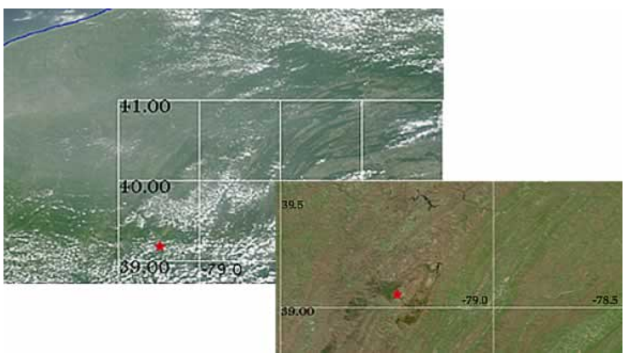

Figure 2: MODIS True Color Image of DOSO1 June 30, 2004 Smoky/Hazy day vs. Clear day April 28, 2004. Processed by Nikisa S. Jordan

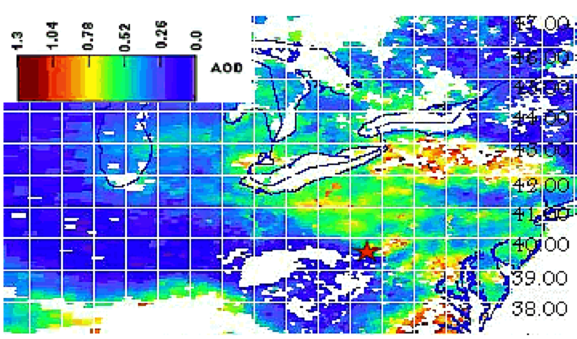

Figure 3: MODIS AOD June 30, 2004 Processed by Nikisa S. Jordan

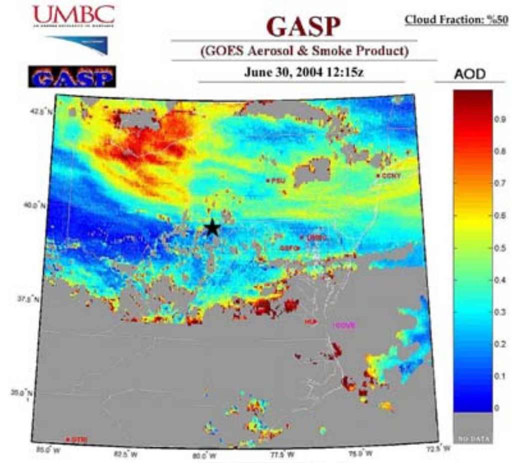

Figure 4: GOES GASP AOD June 30, 2004. Processed by Kevin McCann, UMBC

EPA Fine Particulate Mass Monitors north of Dolly Sods Wilderness estimated 25 to 32$\mu g/m^3$ of total $PM_{2.5}$ (IDEA, March 2005). Data from EPA AIRNow indicated that the air quality was moderate to unhealthy for sensitive groups. A measure of total fine particular matter calculated from MODIS AOD, sourced from the IDEA website, revealed a measurement of 24 $\mu g/m^3$ of PM 2.5 for Dolly Sods Wilderness on June 30, 2004 (IDEA, September 2005).

NRL NAPPS maps showed elevated sulfate concentrations to the west of Dolly Sods just a few days prior to June 30, 2004. Satellite data also showed a midwestern haze plume earlier in the week west of Dolly Sods.

Figure 5 is a pie diagram for June, 30 2004 that displays the percentage of IMPROVE estimated light extinction for various aerosol components, which include Ammonium Sulfate, Soil, Organic Carbon, Ammonium Nitrate, and Elemental Carbon. Extinction values were relative to that of an extremely hazy day at Dolly Sods Wilderness. It is clear that the primary cause for visibility impairment was due to sulfates.

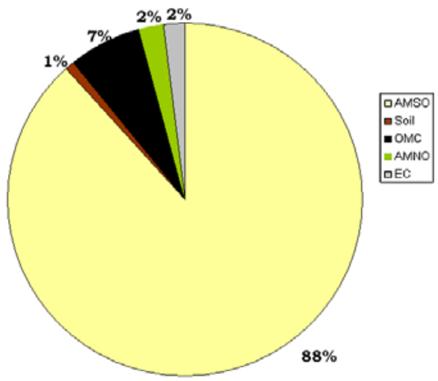

Figure 5: Dolly Sods Wilderness Extinction Fraction for June 30th 2004

Figure 5 also indicates that the role of organics on visibility impairment was secondary. The HMS product, which identifies fires and smoke by combining suites of satellite data indicate that some smoke (shown as a gray plume) reached the wilderness. NOAA HYSPLIT backward trajectories indicated pollutants came from the Midwest and Canada [Figure 6].

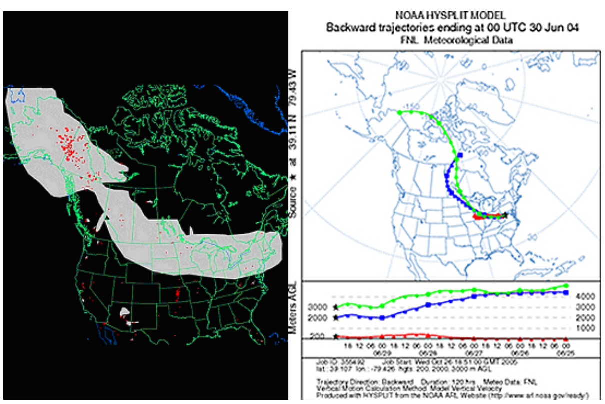

Figure 6: HMS (left) & HYSPLIT showing pollutant transport to Dolly Sods Wilderness on June 30th 2004

4. CONCLUSIONS

It is complex to determine visibility impairment to Class I areas. However, satellite data in conjunction with ground-based measurements provide additional information over ground sensors. Suites of spaceborne and *in-situ* ground based measurements were analyzed to determine the transport of pollutants to a protected Class I site. A case study of Dolly Sods revealed that a Midwestern sulfate event primarily impaired visibility on June 30, 2004. Smoke from fires in Alaska and Canada were secondary in impairing visibility at Dolly Sods. Future goals involve analysis of additional Class I sites, using the multi-sensor technique described to determine fluxes of fine particulate matter (PM 2.5) to Class I areas.

5. ACKNOWLEDGEMENTS

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