1.3 UTILIZING MODIS SATELLITE OBSERVATIONS TO MONITOR AND ANALYZE FINE PARTICULATE MATTER, PM2.5, TRANSPORT EVENT

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1.0 INTRODUCTION

Under IDEA (Infusing satellite data into environmental applications), a project supported under NASA's Earth Science Enterprise Application Program and the US Environmental Protection Agencies Office of Air Quality Planning and Standards, we investigated the ability of MODIS derived aerosol optical depth (τ_a) to provide relevant information associated with the fate and transport of fine aerosols within the lower troposphere. The ultimate goal of this work is to identify existing NASA assets, scientific data, and modeling work developed for tropospheric chemistry research that can be used in the environmental decision support systems of the EPA, Regional Planning Organizations, and State and Local air quality management agencies. IDEA is directed toward improving the assessment, prediction, and real-time decision-making tools of the air quality management community for the protection of public health and the environment.

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2.0 MODIS AEROSOL OPTICAL DEPTH VS. IN-SITU CONTINUOUS PM2.5 MASS MEASUREMENTS – DATA AND METHODOLOGY

Satellite remote sensing has established long records of aerosol measurements since the late 1970s. However, most of the aerosol properties were derived over ocean (e.g., Advanced Very High Resolution Radiometer, AVHRR) until the discovery of TOMS (Total Ozone Mapping Spectrometer) new capabilities for detecting absorbing aerosols over land and ocean using ultraviolet spectrum (0.34 and 0.38 μm) (Hsu et al., 1996; Herman et al., 1997). Neither of these instruments was designed to retrieve aerosols. TOMS suffers from relatively coarse resolution of 50km, which makes it difficult to avoid cloud contamination. The restriction of AVHRR's spectral range to only 2 channels in the reflective solar spectrum makes it difficult to separate the observed signal into atmospheric and land components. Although TOMS does not have this separation (since the earth's surface is uniformly dark in the ultraviolet spectrum), the strong sensitivity of TOMS's detection of absorbing aerosols to aerosol height limits its applications. The MODIS (Moderate Resolution Imaging Spectroradiometer) sensors on EOS-Terra MODIS launched in 1999 and on EOS-Aqua in

2002 were designed to systematically retrieve aerosol properties over both land and ocean (Kaufman et al., 1997; Tanré et al., 1997). The success of MODIS aerosol retrieval is due to a unique set of seven well-calibrated channels (0.47, 0.55, 0.67, 0.87, 1.24, 1.64, 2.1 μm) from visible to shortwave infrared wavelengths. The ability of MODIS to derive aerosol optical depth (τ_a) over land and ocean, along with a characterization of uncertainty (Chu et al., 2002; Remer et al., 2002) has drastically increased the ability to look at aerosols on a regional scale, in both source and downwind regions.

The new $PM_{2.5}$ National Ambient Air Quality Standards (NAAQS) represent a major change from previous standards in terms of the size fraction being measured and monitoring methods. As a result of the new $PM_{2.5}$ standard, new monitoring regulations (US EPA, 1997) require continuous PM2.5 monitors to be operated across the US. New continuous PM2.5 monitors have been added to the State and Local Air Monitoring Stations (SLAMS) and National Ambient Monitoring Stations (NAMS) compliance monitoring for $PM_{2.5}$ which uses a variety of continuous monitoring technology. The continued deployment of the continuous $PM_{2.5}$ monitoring network since 1999 provided a robust set of measurements to evaluate the potential usefulness of the MODIS AOD with respect to $PM_{2.5}$ on large spatial scales.

MODIS-derived aerosol properties are reported at several different time and spatial scales (Kaufman et al., 1998). The MODIS aerosol product used for this study is the MOD04-L2 product and contains retrieved aerosol properties, including τ_a, at 10 x 10 km^2 spatial resolution within each granule, where each granule is a 5 minute segment of one orbit of data.

Comparisons between MODIS τ_a and $PM_{2.5}$ measurements were accomplished by deriving a combined coincidence data set. All $PM_{2.5}$ hourly measurements, typically reported in local time, where placed into GMT and geo-located. The MODIS data is given in 5-minute granules related to an orbital segment. All $PM_{2.5}$ hourly observations lying within the field of view for the 5 minute MODIS granule where matched with valid retrieved MODIS τ_a pixels coincident for the same hour. This was done on a continuous basis from June through September 2003. For these months the number of actual coincidence data points varied from site to site. This is primarily due to obstruction of a valid $\tau_{retrieval}$ due to clouds or sun glint (Chu et. al., 2002).

2.1 SEPTEMBER 2003 AEROSOL TRANSPORT EVENT CAPTURED BY MODIS AND IN-SITU PM2.5 MEASUREMENTS

It is well known that summer haze is responsible for producing bad air quality in the Midwest and Eastern US. However, the sources that contribute to the fate and transport of these aerosols are, to a large extend, unknown. On 4 September 2003 forest fires through the Northwestern US and British Columbia produced emissions that led to a large loading of aerosols in the troposphere (Fig. 1 and Fig. 2).

Figure 1 - Bear Butte Fire & Booth Fire wildfire complex in Northwest Oregon on 4 September 2003 (Image Courtesy of MODIS Land Rapid Response and Envirocast™ StormCenter Communications, Inc).

Figure 2 - WF_ABBA (Prins et al., 2003) daily composite fire locations in Pacific Northwest on 4 September 2003.

This initial loading of aerosol into the troposphere was captured by the MODIS derived-τ_a (Fig 3). On September 8 - 11, a high-pressure system stagnated to the east of the Ohio River Valley creating meteorological conditions conducive to the formation of a large pollution event. The formation and the development of this pollution event was captured by the MODIS sensor aboard the Terra Satellite, which showed the significant enhancement of the MODIS derived-τ_a level (τ_a =~1.1 in Chicago, IL and Milwaukee, WI) over the Midwest and the persistence of the level for a couple of days until frontal clouds washed out the aerosols on September 15 (Fig 5 and 6). The vGeo forward trajectory analysis (Fig 4) and the time sequence of the MODIS derived-τ_a images (Fig 3 – 6) strongly suggest that the formation of this large-scale pollution event was heavily influenced by the initial aerosol loading into the lower troposphere from the fires in the Northwest, the subsequent eastward transport and the subsidence associated with the high pressure system into the boundary layer.

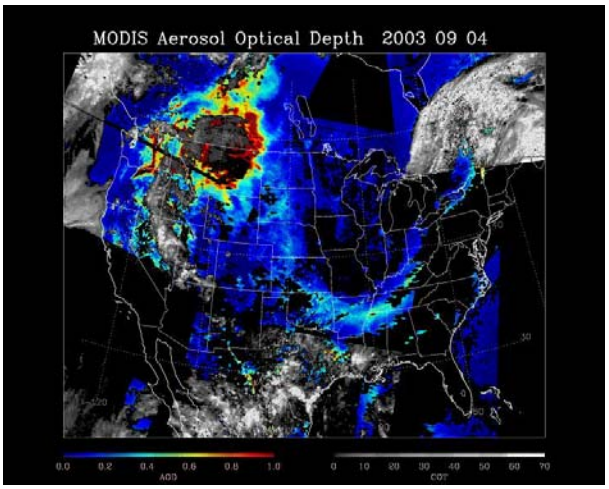

Figure 3 - The MODIS (Terra) derived-τ_a (colored) and derived-cloud optical depth (black/white) for September 4, when the MODIS on Terra captured heavy aerosol loadings in British Columbia and the Northwestern US.

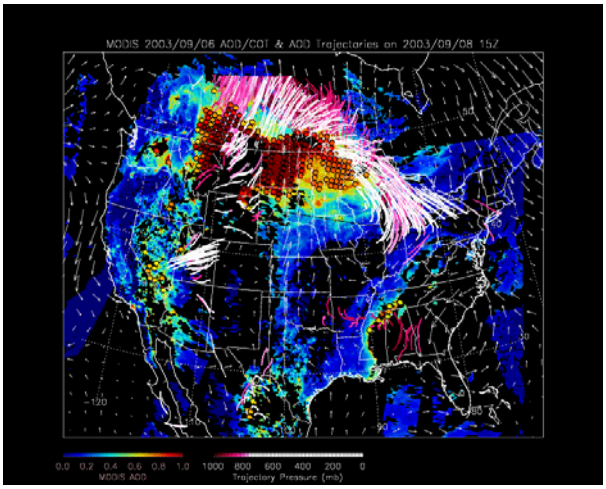

Figure 4 - The MODIS derived-τ_a for September 6 (colored background) and the vGeo forward trajectories initialized with MODIS derived-τ_a of higher than 0.6 at four vertical layers (a 50mb increment from the surface) at the MODIS overpass time on September 6. The trajectories are drawn for 8 September for the period 03Z to 15Z. The trajectories are color-coded with altitude.

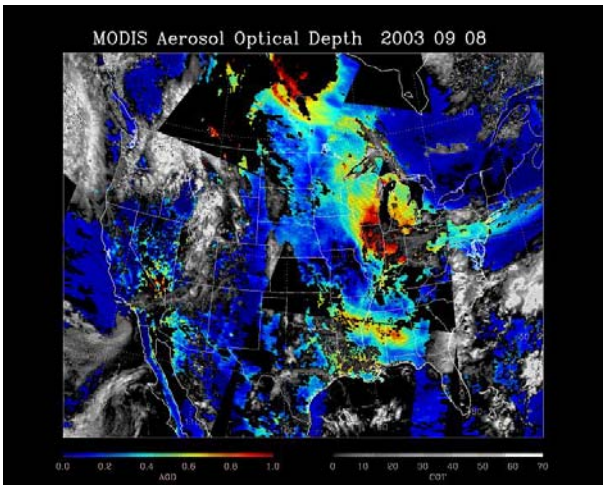

Figure 5 - Same as Fig. 3 except for September 8, when the elevated τ_a values were observed over the Midwest.

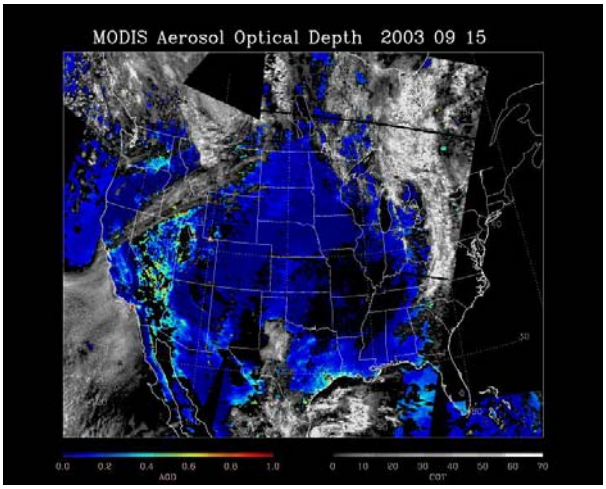

Figure 6 - Same as Fig. 3 except for September 15, when the τ_a values in the Midwest are lowered after the frontal clouds have passed.

On September 11, as well as subsequent days, elevated ground level 24 hour average $PM_{2.5}$ concentrations in excess of 40.5 µg/m^3 (Air Quality Index >100) were seen in many areas across the Midwest, including Chicago, IL and Duluth, MN (Fig. 7 and Fig. 8). At some monitoring sites during this time period coincident measurements of τ_a and in-situ hourly $PM_{2.5}$ mass concentrations where lacking, we believe this is primarily due to obstruction of a valid τ_a retrieval due to clouds or the optical depth was above a threshold value and not processed in the algorithm.

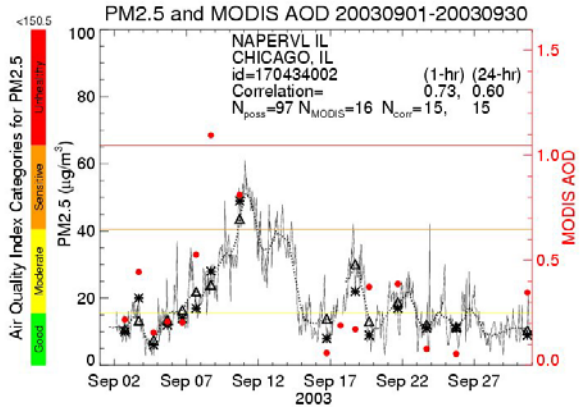

Figure 7 - Time-series and correlations between MODIS aerosol optical depth, τ_a, and hourly/24-hour average In-situ $PM_{2.5}$ mass concentrations Chicago, IL.

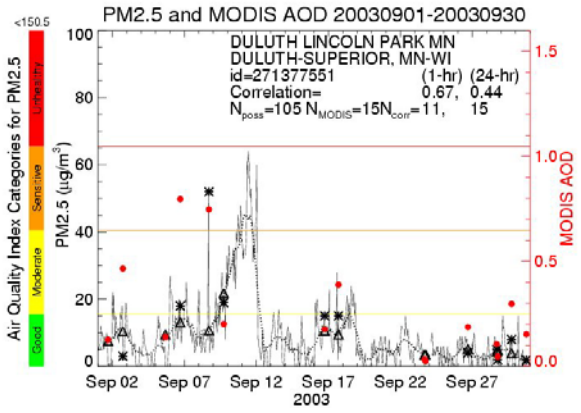

Figure 8 - Time-series and correlations between MODIS aerosol optical depth, τ_a, and hourly/24-hour average In-situ $PM_{2.5}$ mass concentrations Duluth, MN.

3.0 CONCLUSIONS

In general, results of this comparison showed similar spatial patterns between hourly $PM_{2.5}$ concentrations (Surface Monitor) and coincident MODIS derived-τ_a in the mid-Western US and central Ontario. This is supported by the high degree of correlation (e.g. correlation coefficient=0.73, 0.67 at Naperville, IL and Duluth, MN, respectively) between the surface and column-integrated quantities at a majority of the sites affected by this aerosol transport event. Additionally, time series of hourly $PM_{2.5}$ measurements and temporally co-located MODIS τ_a observations generally showed in-phase variations (similar maximums and minimums) indicating similar regional pollution sources and air mass control in the region. Such agreement shows the MODIS τ_a observations are indicative of $PM_{2.5}$ concentrations at or near the surface as measured by the in-situ monitor.

4.0 ACKNOWLEDGMENTS

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