1.2 UTILIZING MODIS SATELLITE OBSERVATIONS IN NEAR-REAL-TIME TO IMPROVE AIRNow NEXT DAY FORECAST OF FINE PARTICULATE MATTER, PM2.5

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1.0 INTRODUCTION

Over the past several years, the remote sensing of trace gases and aerosols from space has improved dramatically. The emergence and application of these measurements adds a new dimension to air quality forecasting by enabling consistent observations of pollutants over large spatial domains. Current instruments aboard NASA and European Space Agency satellites can provide derived measurements of trace gases and aerosols relating directly to most of the EPA's criteria pollutants: ozone, NO_2, SO_2, CO, and particulate matter (PM_{10} and $PM_{2.5}$) (Burrows J., 1999; King et al., 1999; Fishman J., 2000).

For decades, weather forecasters have used parameters derived from satellites to help forecast weather. Researchers are now showing that satellites can also help with forecasting air quality. In late summer 2003, NASA, NOAA, and US EPA prototyped a new forecast tool using satellite data to aid in EPA's AIRNow Air Quality Index (AQI) forecast tool.

The forecast tools involved the near-real-time data-fusion of aerosol optical depth, τ_a at 550 nm, derived from the MODIS sensor aboard the EOS-Terra Satellite (Kaufman et al., 1997; Tanré et al., 1997), combined with hourly in-situ $PM_{2.5}$ mass concentrations from the State and Local Air Monitoring Stations (SLAMS) and National Ambient Monitoring Stations (NAMS) continuous monitoring network, and NOAA/NCEP Eta 48 hour forecast data, to provide a pseudo-synoptic view of aerosol and aerosol transport across the North American continent. These data products were provided for evaluation and use by a group of State and Local Air Management Agencies and internally within EPA to help improve the accuracy in EPA's AIRNow AQI next-day $PM_{2.5}$ forecast which began on 1 October 2003.

2.0 FORECAST TOOLS

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The forecast tools were based on the following data sets:

1. Daily MODIS Aerosol Optical Depth, MOD04_L2, at 10 x 10 km^2 (Kaufman, 1998) and daily Cloud Optical Thickness MOD06_L2 at a 4 x 4 km^2 from the MODIS sensor aboard the Terra satellite which has a descending orbit and a 10:30 equatorial overpass time.

2. Hourly fine particulate ($PM_{2.5}$) mass concentrations from in-situ monitors (State and Local Air Monitoring Stations (SLAMS) and National Ambient Monitoring Stations (NAMS) network)

3. Surface and Upper Air Wind Fields (NOAA/NCEP-Eta forecast model, every 3 hours).

4. Air Parcel Trajectories (vGeo – EDAS forecast winds).

5. Daily Fire Locations GOES Wildfire Automated Biomass Burning Algorithm (WF_ABBA) (Prins et at., 2003) NOAA/NESDIS/ORA.

From these inputs, five products were generated: 48-hr forecast trajectories in regions of high MODIS τ_a; regional views of aerosol optical depth and cloud optical thickness; an animation of surface data, MODIS data, and 850 mbar winds; a national view of the correlation between surface observations and MODIS observations; and a site by site view of the correlation between surface observations and satellite observations.

2.1 DATA FLOW AND AVAILABILITY OF FORECAST PRODUCTS

The overall data flow is shown in Figure 1. The MODIS data were obtained from the Space Science and Engineering Center, Cooperative Institute for Meteorological Satellite Studies (SSEC/CIMSS) at the University of Wisconsin. Eta meteorological forecast data, used to produce the forecast trajectories, were obtained from NOAA/NCEP and EDAS meteorological data from NOAA/ORA/ALR. US EPA provided hourly fine aerosol $PM_{2.5}$ data produced by the surface based network operated by state and local agencies and by Canadian provinces and centrally reported into the AIRNow data management centers. The GOES WF_ABBA data is courtesy of NOAA/NESDIS/ORA and the University of Wisconsin CIMSS. The data fusion products were generated by the IDEA team at NASA Langley Research Center, and data services were provided by the NASA Langley Data Active Archive Center. The following products were provided to the forecasters to utilize in the development of next day local AQI $PM_{2.5}$ forecasts.

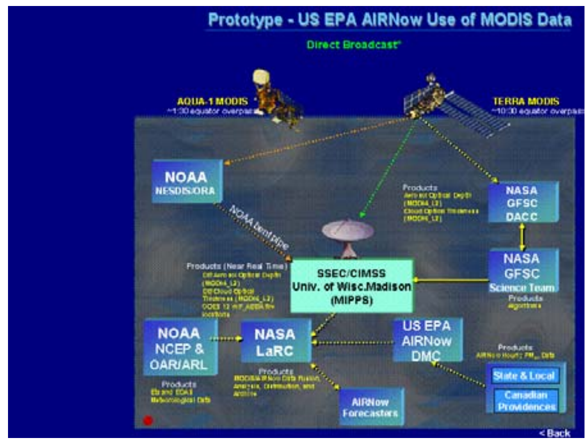

Figure 1 - Data Sources and Flow for Development of Forecast Products

Forecast Tool 1: Forecast trajectories for high MODIS aerosol optical depth, $\tau_a \geq 0.6$

The trajectory forecast animation (Fig. 2) plotted the latest available daily MODIS aerosol optical depth, daily MODIS cloud optical thickness, and an animated ~48 hour air parcel trajectory forecast.

This plot provided a North American view of high values of MODIS τ_a (>0.6) and were used to initialize starting locations for forecast trajectories. The high MODIS τ_a values were determined by calculating mean τ_a values on a 50 km x 50 km grid, or 5 pixels square. The τ_a value of 0.6 was based on data analysis which indicated aerosols located within a well mix boundary layer showed a τ_a of ~0.6 equating to ~40ug/m^3 or an ~AQI value of 100.

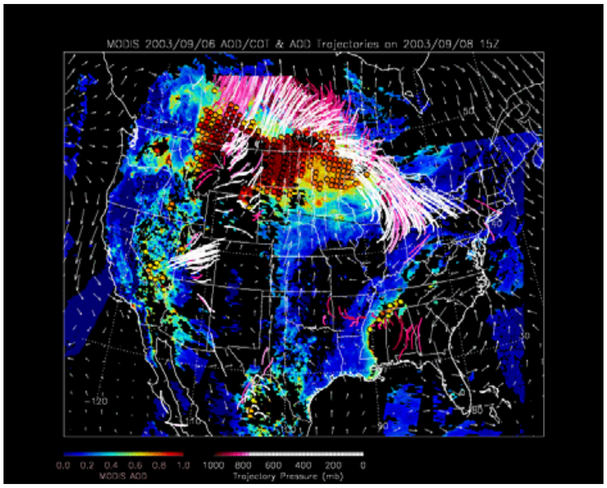

Figure 2 - The MODIS derived-τ_a for 6 September 2003 (colored background) and the vGeo forward trajectories initialized with MODIS derived-τ_a of higher than 0.6 at four vertical layers (a 50mb increment from the surface) at the MODIS overpass time on 6 September 2003. The trajectories are drawn for 8 September 2003, 03Z to 15Z. The trajectories are color-coded with altitude.

The trajectories were initialized at latitudes and longitudes of the high τ_a values at 50mb, 100mb, 150mb, and 200 mb above the surface level to capture boundary layer flow over the forecast period. The air parcel trajectories were run using the 12Z NOAA/NCEP Eta forecast data providing a ~48hr forecast via trajectories.

A forecast trajectory animation was provided to detail the potential vertical movement of air parcels in the area of high aerosol loads in the troposphere as captured by the MODIS derived τ_a. The darker colors on the trajectory pressure scale were limited to the 1000-800 mb pressure levels to help distinguish trajectories moving within the boundary layer.

Forecast Tool 2: 3-day composite MODIS aerosol optical depth (τ_a) cloud optical thickness, hourly in-situ $PM_{2.5}$ mass concentrations, EDAS 850mb wind vectors, and WF_ABBA fire locations

The data fusion animation (Fig. 3) plotted the past three days of available daily MODIS aerosol optical depth (in color contours), daily MODIS cloud optical thickness (in gray contours), hourly $PM_{2.5}$ concentrations for the in-situ continuous monitors (vertical color bars), EDAS 850mb wind field vectors, and half-hourly WF_ABBA fire locations (pink and purple triangle) . This data fusion product visualized the relationship between the MODIS τ_a, hourly $PM_{2.5}$ mass concentration and the air quality index, providing a pseudo-synoptic view of aerosol events across North America for the previous three days.

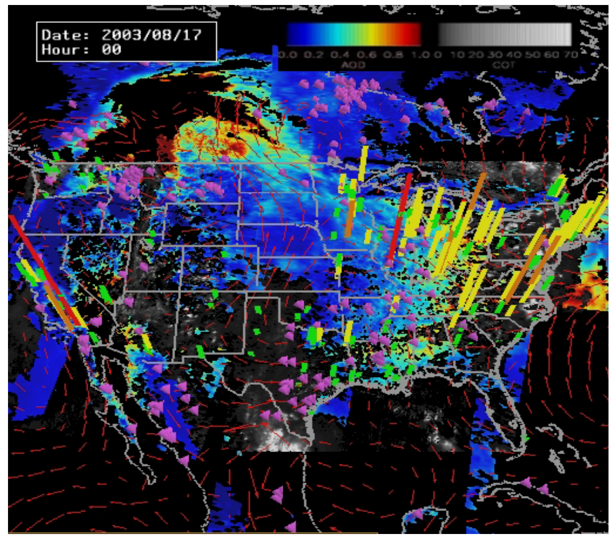

Figure 3 - Sample 3-day MODIS τ_a–hourly $PM_{2.5}$ mass concentration animation

The location of each continuous $PM_{2.5}$ monitor from the State and Local Air Monitoring Stations (SLAMS) and National Ambient Monitoring Stations (NAMS) is represented by a vertical color bar. The height of the bar represents the hourly $PM_{2.5}$ concentration (ug/m^3) and the color represents the associated US EPA Air Quality Index (AQI) level based on a 24 hour running average (see Table 1). An AQI above 100 (orange or red) means PM levels are unhealthy for sensitive groups.

Table 1 – US EPA AQI Index for Particulate Matter

Air Quality Index for Particles

Index Values	Category	Cautionary Statements	$PM_{2.5}$ (ug/m^3)	PM_{10} (ug/m^3)
0-50	Good	None	0-15.4	0-54
51-100	Moderate	Unusually sensitive people should consider reducing prolonged or heavy exertion	15.5-40.4	55-154
101-150	Unhealthy for Sensitive Groups	Sensitive groups should reduce prolonged or heavy exertion	40.5-65.4	155-254
151-200	Unhealthy	Sensitive groups should avoid prolonged or heavy exertion; everyone else should reduce prolonged or heavy exertion	65.5-150.4	255-354
201-300	Very Unhealthy	Sensitive groups should avoid all physical activity outdoors; everyone else should avoid prolonged or heavy exertion	150.5-250.4	355-424

Source: US EPA, 1997

The 850 mbar wind field vectors were plotted to show wind direction and speed. This was provided to qualitatively show areas of convergence and divergence, and can indicate downward or upward air motion, respectively.

Half-hourly fire locations as identified by the GOES 12 WF_ABBA were plotted to identify fire activity. The fire locations plotted were temporally filtered, reporting fire pixels that appeared more than once within the past 12 hours. The locations of the fire pixels were color coded by the assigned flags provided by the WF_ABBA algorithm, which is based on the probability that the pixel contained a fire.

Forecast Tool 3: - Regional summary plots of MODIS aerosol optical depth, τ_a, and cloud optical thickness

The Regional plots (Fig. 4) were defined by US EPA Regions, with Regions 1-3 combined into one view and Regions 4-10 as separate plots. The Regional plots showed four parameters: daily MODIS aerosol optical depth (in color contours), daily MODIS cloud optical thickness (in gray contours), EDAS forecast 850 mbar wind vectors, and locations of in-situ continuous $PM_{2.5}$ monitors.

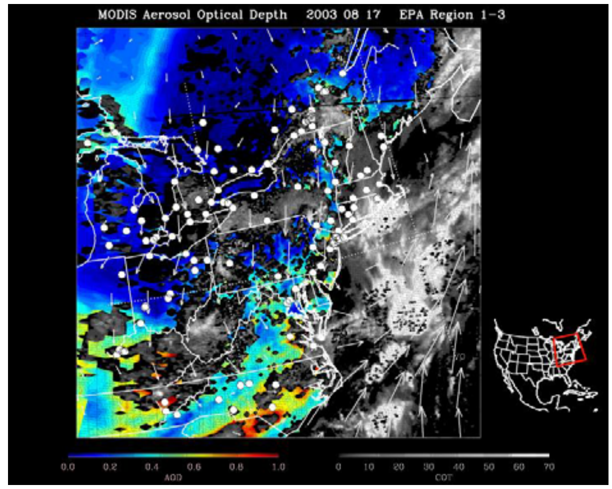

Figure 4 **-** Sample Regional Summary plot

Forecast Tool 4: National summary plots of correlations between MODIS aerosol optical depth, τ_a, and hourly in-situ $PM_{2.5}$ mass concentrations

The MODIS τ_a/In-situ PM2.5 correlation summary plot (Fig. 5) detailed correlation coefficients across the United States and parts of Canada. The correlation is based on spatially coincident MODIS τ_a pixels and hourly $PM_{2.5}$ concentrations for the in-situ continuous monitors. The parameters plotted were monitor site-specific running correlation coefficient for a 60-day minimum (in color scale). The size of the point plotted relates to the number of coincidences between MODIS τ_a pixels and hourly $PM_{2.5}$ concentrations for the given period.

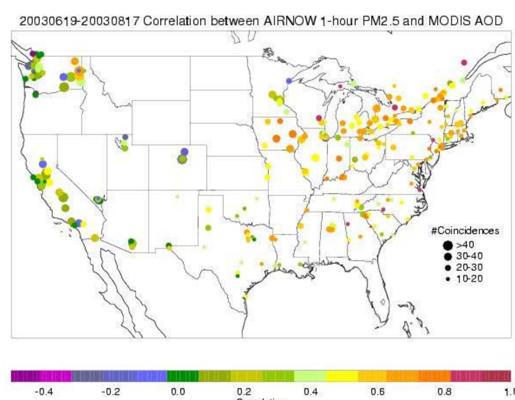

Figure 5 - Sample MODIS τ_a- in-situ $PM_{2.5}$ correlation summary

The correlation plot provided a site specific and regional intercomparison perspective on the utility of coincident MODIS τ_a pixels and hourly

$PM_{2.5}$ concentrations. Higher correlations suggested the $PM_{2.5}$ mass concentrations at the in-situ monitor are similar to the MODIS τ_a pixel, and that the observed aerosol may be near the surface.

Forecast Tool 5: Site specific plots of time-series and correlations between MODIS aerosol optical depth, τ_a, and hourly/24-hour average In-situ $PM_{2.5}$ mass concentrations

The site specific MODIS τ_a -In-situ $PM_{2.5}$ mass concentration plot (Fig. 6) detailed correlation coefficients at a specific monitoring site location. The correlations were reported for both a 1-hour and 24-hour in-situ mass concentrations values. The 1-hour correlation was based on coincident MODIS τ_a pixels and the closest hourly $PM_{2.5}$ concentrations for the in-situ continuous monitors. The 24-hour correlation was based on a running 24-hour average as compared to the coincident MODIS τ_a pixel. The time period used to generate the correlation was a 60-day minimum.

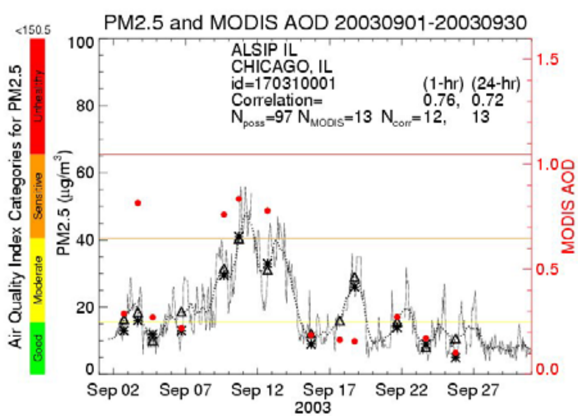

Figure 6 - Sample site specific MODIS τ_a-In-situ PM2.5 time series and correlation plot

The number of coincident MODIS pixels/ $PM_{2.5}$ concentrations data points used to determine the correlation were reported as Ncorr. The right vertical axis indicated mass concentration of $PM_{2.5}$ (scale 0-100) and the left vertical axis indicated MODIS aerosol optical depth (scale 0.0 – 1.6). The continuous line represented hourly $PM_{2.5}$ mass concentration and the dashed line the 24-hour average $PM_{2.5}$ mass concentration. Coincident values are represented by symbols:

• - MODIS AOD
* - hourly $PM_{2.5}$ mass concentration
triangle - 24 hour average $PM_{2.5}$ mass concentration.

The time-series/correlation plots provided site specific information important to help interpret if the MODIS AOD was indicative of PM concentrations at or near the surface as measured by the in-situ monitor. Higher correlations suggested the $PM_{2.5}$ mass concentrations at the in-situ monitor were in agreement with the daily MODIS τ_a pixel.

3.0 CONCLUSION

The IDEA AQI forecasting demonstration was successful in achieving its primary objective to enable or enhance the forecast of an AQI for particle pollution on a daily basis for the month of September 2003. The group of forecasters who participated indicated that they used the forecast tools and found them valuable in their daily forecasts. Perhaps equally important, the forecasters and partners identified multiple uses for the data products, and underlying data, that were not envisioned in the baseline planning. In general, the additional uses identified by the forecasters included: tracking of natural aerosol events (i.e., fires and dust storms) and associated impacts as related to US EPA's Regional Haze Regulations; retrospective analysis assessing regional and long-range transport impacts on $PM_{2.5}$, as related to US EPA's National Ambient Air Quality Standard; and performance evaluation of Chemical Transport Models (CTMs).

4.0 REFERENCES

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