

IDEA-I Air Quality Forecast Software Package: Aerosol, Ozone, and Carbon Monoxide Detection and Trajectories

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Introduction

The presence of trace gases and air borne particulates in the boundary layer can be harmful to human health and the local environment. Therefore, the Environmental Protection Agency (EPA) has put in place regulations on the amount of those pollutants allowable in the air near the surface, called the National Ambient Air Quality Standard (NAAQS). If the regulation thresholds are exceeded at a location several times, it will cause the location to be given non-attainment status and steps must be taken to reduce local emissions. If it can be shown that that exceedance was not due to locally controllable anthropogenic causes, the event does not count towards a location receiving a non-attainment status. It is therefore important to be able to determine if an event was due to the long-range transport of nonlocal pollution to a location that was locally unavoidable so that unnecessary and costly actions can be avoided when they are not needed.

Much of air pollution monitoring is done using surface observing stations. However, surface observing stations are not dense enough to give a complete picture of the distribution of aerosol and trace gases and are unable to measure the pollutants aloft that may descend to levels at which humans would be affected. Satellite observations can give a broader view of pollutants and so compliment surface observations to create a more complete picture of the air quality situation, making them a useful tool for analyzing the state of the atmosphere in a way that is otherwise impossible.

The Infusing Satellite Data into Environmental Applications – International (IDEA-I) air quality forecasting packages distributed through the International MODIS/AIRS Processing Package (IMAPP) uses aerosol and trace gas retrievals from polar orbiting satellite instruments to identify locations of high aerosol and trace gas concentration. Those locations are then used to initialize three-dimensional trajectories calculated using the NASA Langley trajectory code (Pierce and Fairlie 1993) to forecast where aerosols or trace gases may be transported in the next 48 hours in both the horizontal and the vertical dimensions. The trajectory movement is calculated using winds from Global Forecasting System (GFS) forecasts interpolated in space and time. Those trajectories can be used to forecast where harmful levels of aerosols or trace gases may be transported or, inversely, can be traced backwards to help determine the cause of poor air quality in a given location.

IDEA-I is based off of the Infusing Satellite Data into Environmental Applications (IDEA) project that was developed through a collaboration of NASA, NOAA, and EPA scientists in the early 2000's (Al-Saadi et al. 2005). The IDEA project produced five different daily aerosol forecast products from a synthesis of information on particulate matter at the surface, assimilated and forecast winds, satellite-derived wildfire locations, and air parcel trajectories. The objective of IDEA-I is to create easy-to-use, globally configurable, publicly available software based on IDEA that any user around the world with a direct broadcast receiving antenna could use for local air quality forecasting. Direct broadcast from a satellite

allows ground stations within the line-of-sight of the satellite to download its continuously transmitted data, enabling the creation of near real-time products from that data. Initially, the IDEA-I software only forecasted the movement of aerosols. It used MODIS aerosol optical depth retrievals to show where high aerosol concentrations would potentially travel. The software suite has been expanded to also include a separate software package that uses dual-regression retrievals from polar orbiting satellite sounders to forecast the movement of stratospheric intrusions of ozone. Supported satellite sounders include the Atmospheric Infrared Sounder (AIRS), Cross-track Infrared Sounder (CrIS), and Infrared Atmospheric Sounding Interferometer (IASI) instruments aboard the Aqua, Suomi National Polar-orbiting Partnership (NPP), and MetOp-A and MetOp-B satellites, respectively. Carbon monoxide retrievals are still in development and so are not yet included in the software suite. The IDEA-I aerosol and ozone software packages are available for anyone to use and can be freely downloaded from the IMAPP website at <http://cimss.ssec.wisc.edu/imapp>.

IDEA-I Aerosol Software

The IDEA-I aerosol software uses the MODIS MOD04 Aerosol Optical Depth (AOD) retrievals (Remer et al. 2005) to identify locations with high aerosol content. It then forecasts the horizontal and vertical movement of the aerosols within the next 48 hours using a trajectory model. The AOD retrievals are produced from data from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on board the Terra and Aqua polar orbiting satellites. Terra has a late morning equator crossing time of about 10:30am local time for the descending node and Aqua crosses the equator at about 1:30pm local time for the ascending node. The primary AOD product is produced at a 10 km x 10 km resolution. The updated MODIS Collection 6 processing also produces a 3km AOD product (Remer et al. 2013), but that resolution cannot yet be used with the IDEA-I software.

Two separate algorithms are now used for creating the MODIS AOD retrievals: the Dark Target algorithm over dark soil and vegetation and the Deep Blue algorithm over bright surfaces. The Dark Target aerosol retrieval algorithm is known to have problems where there is sun glint from water and over snow and ice and bright desert regions since the difference between the cloud and surface radiances becomes small. The Deep Blue update in the MODIS Collection 6 processing algorithm improves aerosol detection over those regions by using the band sensitive to blue radiances to better distinguish between cloud and bright land surface. The AOD products created with the Deep Blue algorithm are not yet used in the current IDEA-I software package, but simple variable name changes can be made to the current processing scripts to use the Deep Blue aerosol retrievals, or a combined product that uses Dark Target retrievals over ocean and dark land and vegetation and Deep Blue retrievals over bright land surfaces. The solely Dark Target product from the Collection 6 granules can be used without making any changes to the IDEA-I software.

Aerosol Case Study

Besides being harmful to human health and potentially damaging to the environment, the haze due to air pollution reduces visibility and harms the view of the natural scenic resources of our country. The Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring program was founded after the 1977 Clean Air Act required the EPA to set standards for visibility levels in national parks and wilderness areas in addition to creating national ambient

air quality standards for particulate matter, ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide, and lead.

During the early part of June 2011, the IMPROVE monitor at Bandelier National Monument in north central New Mexico recorded a drop in visibility to 30 deciviews, which is equal to a visual range of only about 20 km. Bosque del Apache to the southwest of Bandelier National Monument also recorded a steep decrease in visibility at about the same time. To help determine the cause of the dramatic reduction in visibility, the IDEA-I software is initialized with MODIS data from 1 June 2011 (Figure 1). One caveat of the IDEA-I system is that aerosol optical depth can only be retrieved in locations without clouds and so high aerosol concentrations will not always be captured and used in the trajectories if they are in cloudy regions. The Aqua satellite was able to pick up on some high aerosol concentrations in the southeastern part of Arizona, which is where the Wallow and Horseshoe Two wildfires were active at that time. Another location of high aerosol concentration was also identified over western Mexico, where fires were also ongoing. The trajectories initialized at those locations moved towards the north and east in the direction of New Mexico (Figure 2). Had there been no clouds, there would likely have been more trajectories initialized in the vicinity of the large fires in eastern Arizona. What trajectories were initialized there moved over northwestern New Mexico close to Bandelier National Monument. However, they did not appear as close to Bosque del Apache, which had also recorded low visibility. Trajectories initialized over the fires in Mexico were shown to approach nearer the ground and to cross near both locations. The IDEA-I trajectories from Aqua seem to show that the particulates from the Mexican fires were the likely cause of the low visibility in this situation.

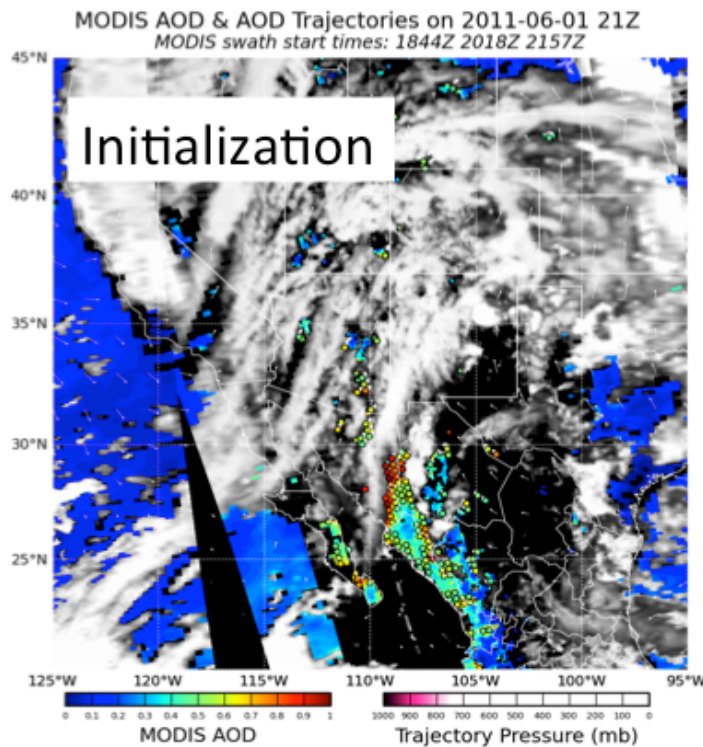


Figure 1. MODIS aerosol optical depth (AOD) from 1 June 2011 used to initialize trajectories. Cloud emissivity is also shown in regions where clouds did not allow for any AOD retrievals.

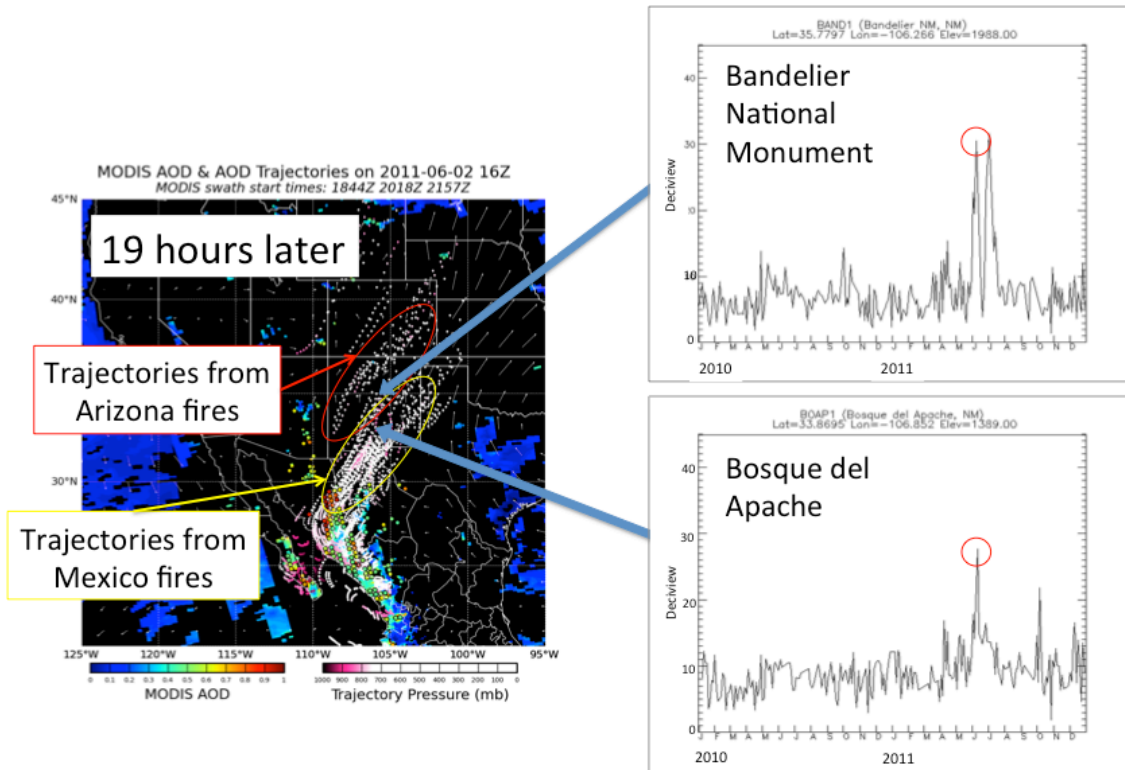


Figure 2. Trajectories 19 hours after the initialization along with the time series of visibility for 2010 and 2011 at Bandelier National Monument and Bosque del Apache. The low visibility event during June 2011 is circled in red.

Poor air quality was observed in southeastern South Carolina later that same month on 23 June 2011 (Figure 3a). The EPA deemed the levels of small particulate matter in that area unhealthy for everyone, not just sensitive groups of people. The MODIS AOD retrievals for the 21 June show high AOD in southeastern Georgia in the location of the ongoing Honey Prairie wildfire. Trajectories initialized with those retrievals move to the north towards South Carolina and maintain a pressure level near the surface, indicating that the aerosol particles from the wildfire in Georgia were a probable cause of the unhealthy air in South Carolina in the days following (Figure 3b).

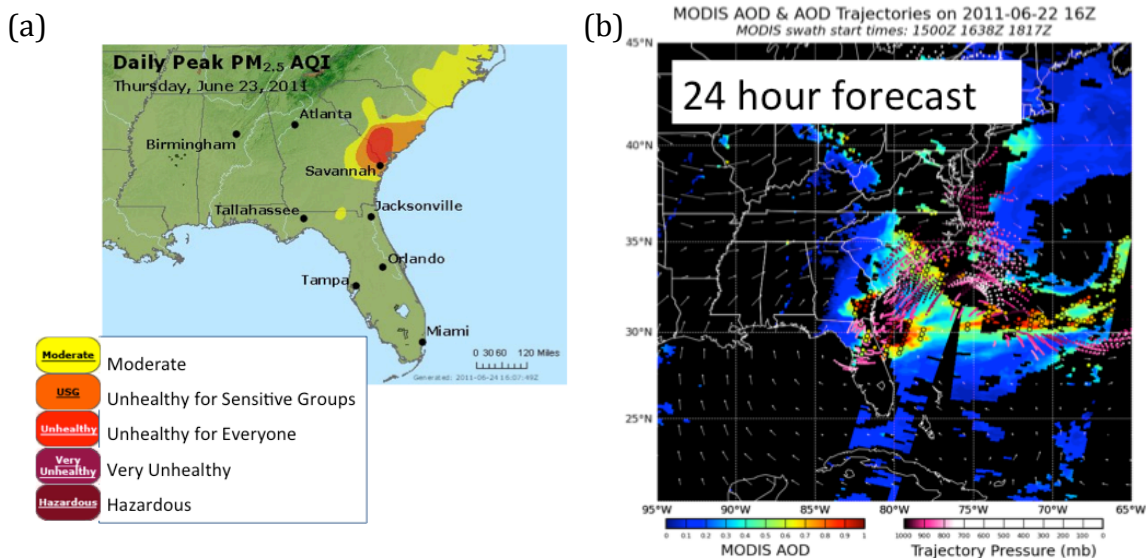


Figure 3. (a) Air quality index for 23 June 2011 and (b) IDEA-I aerosol trajectory forecast valid at 16 UTC on 22 June 2011 initialized with MODIS aerosol optical depth (AOD) from 21 June 2011.

IDEA-I Ozone Software

The IDEA-I ozone air quality forecasting software is intended to help forecast the movement of ozone from stratospheric intrusions and to help trace the origins of high levels of surface ozone. The EPA has established criteria for what levels of surface ozone are acceptable before a non-attainment status is declared and action must be taken. The current regulations state that when a location has 4 episodes of 8-hour average ozone above 75 ppb over a 3-year period, they are given a non-attainment status and are required to make plans for reducing emissions in their area. If an exceedance of the EPA’s standard of 75 ppb can be shown to be due to the long-range transport of naturally occurring ozone, such as with a stratospheric intrusion or wildfires, it is termed an “exceptional event” and does not count towards a location’s non-attainment status. IDEA-I ozone trajectories can be used to help determine if a stratospheric intrusion may have been the original cause of high levels of ozone in the planetary boundary layer at a location.

Ozone retrievals from the AIRS, CrIS, and IASI satellites are used by IDEA-I to determine locations with stratospheric ozone, which are then used to initialize trajectories for forecasting the movement of that ozone. The retrievals are produced by the University of Wisconsin Dual-Regression algorithm (Smith et al. 2012; Weisz et al. 2013) available as part of the Community Satellite Processing Package (CSPP) and available for download from <http://cimss.ssec.wisc.edu/imapp>. The algorithm creates single field-of-view products under both clear and cloudy conditions and can be run on direct broadcast or archived AIRS, CrIS, and IASI granules. Carbon monoxide retrievals are still under development and so are not yet a part of the Dual-Regression software and are not yet included in the IDEA-I trace gas software.

Ozone Case Study

The Wyoming Department of Environmental Quality’s Thunder Basin National Grasslands air quality monitoring site in northeastern Wyoming recorded a maximum surface ozone of 99 ppb with an 8-hour average of 88 ppb during 6 June 2012, which exceeds the threshold set by the EPA. To investigate if a stratospheric intrusion may have been the origin of the high surface ozone in Wyoming, the IDEA-I ozone software was initialized with satellite ozone retrievals from AIRS, CrIS, and IASI from 4 and 5 June 2012. Retrievals from all three sounders showed a region of high stratospheric ozone just off the western coast of California on June 4 that then moved eastward to where it was over the Great Basin on June 5. Trajectories initialized in that region of stratospheric ozone moved eastward towards and then over northeastern Wyoming by 1100 UTC on June 6. The trajectory color changed from white to pink as it moved over that region, indicating that the air from the stratospheric intrusion had descended to a level below 800 mb, which is typically a level at which it can affect the surface. That shows that the ozone exceedance at Thunder Basin was likely at least in part due to air descending from the stratospheric intrusion that was located off the west coast of California two days prior.

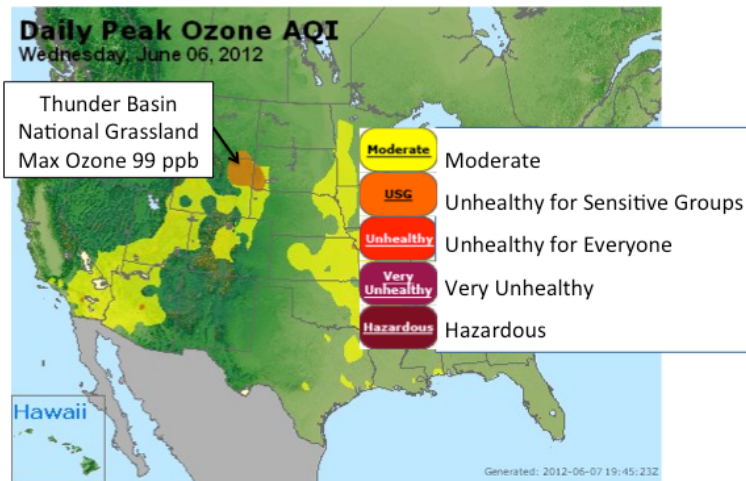


Figure 4. Air quality index for ozone 6 June 2012.

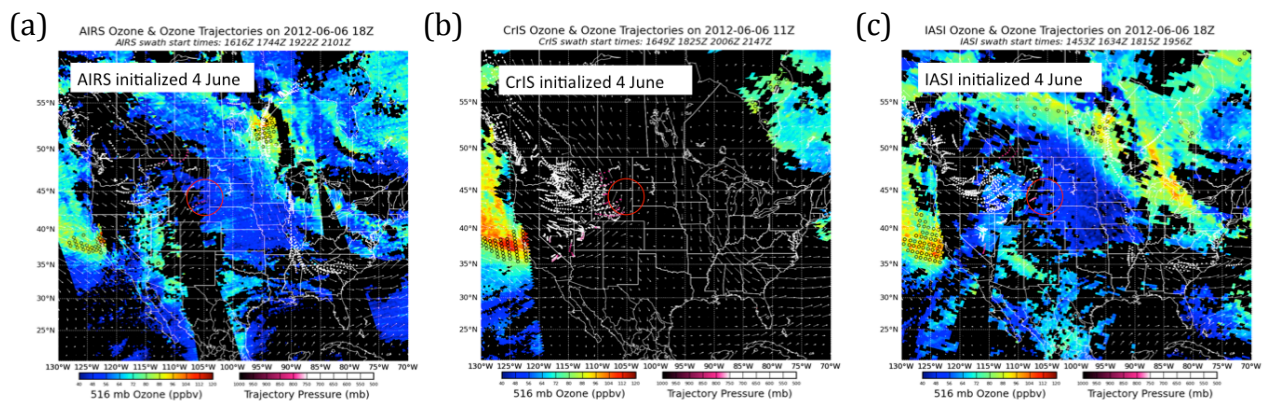


Figure 5. IDEA-I stratospheric ozone intrusion trajectory forecast valid 6 June 2012 initialized with (a) AIRS, (b) CrIS, and (c) IASI ozone retrievals from 4 June 2012.

Future Plans

The IDEA-I aerosol and stratospheric ozone intrusion software packages have been developed and released in support of air quality forecasting as a part of the IMAPP software suite. Possible future additions to the IDEA-I software suite include updating the IDEA-I aerosol package to use the MODIS Collection 6 Deep Blue and 3-km Dark Target algorithms and the creation of trajectory forecasts initialized with the MODIS fire detection product. In addition to the ozone retrievals, carbon monoxide retrievals from the University of Wisconsin dual-regression retrieval algorithm are under development and there are plans to include them in a future version of the IDEA-I air quality forecasting software.

References

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