Use of Environmental Satellite Imagery for Smoke Depiction and Transport Model Initialization

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ABSTRACT

The National Oceanic and Atmospheric Administration (NOAA) produces a daily satellite based smoke and fire analysis for the US. The capability to specify smoke concentration levels and to identify the start time, duration and areal extent of a particular fire which is producing smoke emissions has recently been added.

Smoke concentration values are obtained from visual inspection of animated Geostationary Operational Environmental Satellite (GOES) visible band imagery in conjunction with output from the automated GOES Aerosol and Smoke Product (GASP). There are three categories of smoke concentration utilized: 5, 16 and 27 μg/m3, which correspond to light, medium, and dense smoke respectively. The smoke concentration values are available for air quality managers and other users to download and/or view as GIS shapefiles.

The initial time and duration of smoke emissions are also obtained through inspection of animated GOES visible imagery by an analyst. This information is incorporated into the HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model which produces a 48 hour forecast of smoke dispersion and transport. In addition to approximating smoke emissions and the diurnal variations observed in wildfires the specification of emission duration allows for the representation of short duration agricultural and prescribed burns as well.

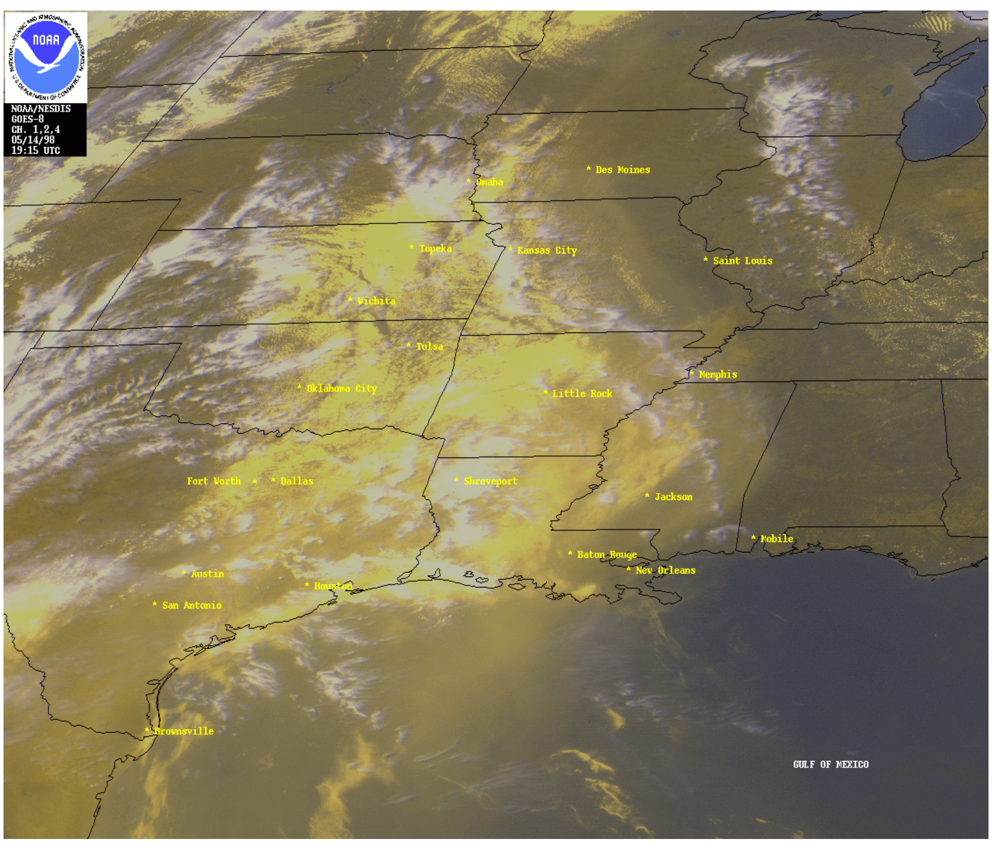
A number of examples depicting various smoke concentrations, including fires of different size and duration, will be shown. HYSPLIT performance in depicting the observed smoke will also be presented.

INTRODUCTION

NOAA/NESDIS has been producing an operational, daily fire and smoke analysis since the Spring of 1998. At that time tremendous smoke transport was occurring from Central America across Texas, the Southeast and as far north as the Mid-Atlantic States as seen in Figure 1. This occurred as the burn season was at its height in Central America and Mexico and an amplified weather pattern enabled the transport of the smoke northward. It created a health hazard across large areas of Texas and reduced visibility at the surface and aloft. The initial analyses (pre HMS) were quite rudimentary and only regionally based (covering a couple of states), with the region being analyzed changing as conditions warranted. While the analyses primarily supported National Weather Service (NWS) needs, their applicability to wildfire and air quality managers allowed for the development of the HMS.

The HMS was developed to provide coverage for all of North America. It incorporates multiple environmental satellites (NOAA and NASA) by remapping the data from each of the sensors to a common projection to allow for easy comparison between the different data sources. Currently the HMS analysis domain is adjusted seasonally, covering the coterminous US - including adjacent areas of Mexico and Canada - and Hawaii from October through March, expanding northward to include Alaska and Canada from Spring into early Fall and including Central America in the Spring during each region's respective prime wildfire and burning season. Any of the regions can be analyzed during off-peak periods as conditions warrant. The HMS integrates satellite based (NOAA and NASA) automatically derived fire points with the satellite imagery. Analysts perform quality control procedures on the automated points to arrive at the final product.

Figure 1. GOES-East visible image from May 14, 1998 showing extensive smoke area extending from the Gulf of Mexico into the western Gulf States and points north.

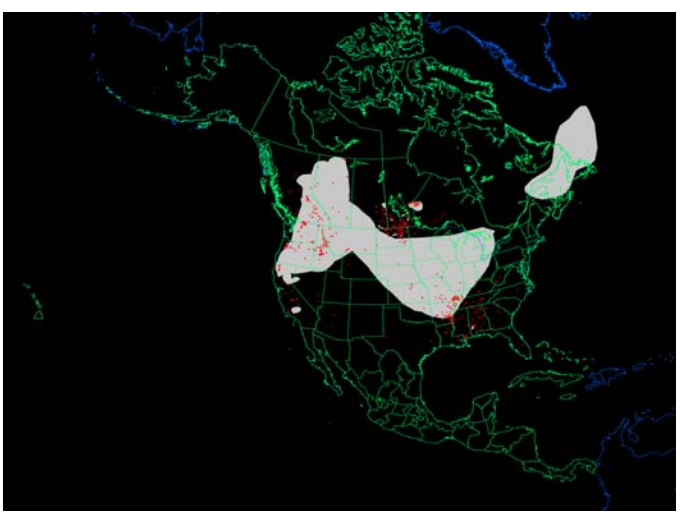


As the HMS has evolved, air quality concerns have increased, in part due to congressional mandate that NOAA provide air quality forecasts for the US which include PM2.5. Since fires (wildfires, agricultural and prescribe burns) can be a significant source of 2.5 μm Particulate Matter (PM2.5) and the smoke generated can remain airborne for extended periods of time and travel thousands of miles the HMS was seen as a tool that can quickly depict areas of smoke and identify the fires that are producing the emissions for inclusion in air quality transport and dispersion forecast models. The smoke outlines, which indicate the extent of smoke at a given time, are produced manually, primarily utilizing animated visible band satellite imagery. A quantitative estimate of the smoke concentration is provided with each outline that is drawn. The locations of fires that are producing smoke emissions that can be detected in the satellite imagery are specified and incorporated into the HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model, developed by NOAA's Air Resources Laboratory (ARL). The HYSPLIT is run once per day by the NWS and provides a forecast of smoke emissions and dispersion through 48 hours.

There are several limitations to the current procedures for detection and depiction of smoke emissions using satellite data. Since visible band imagery is employed for smoke detection it is useless at night. The presence of clouds may hinder or completely eliminate the capability to detect smoke. During large fire outbreaks when the smoke becomes lofted and can remain suspended for many days it can mix with anthropogenic sources such that only a best subjective estimate of a smoke demarcation is possible. Additional satellite data and algorithms may alleviate some of these limitations.

The fire and smoke analyses are available in several standard formats (Figure 2 shows jpeg and Geographic Information System (GIS)) at http://gp16.ssd.nesdis.noaa.gov/FIRE/fire.html. Fire detections from the automated algorithms are placed on the site as they become available. The quality controlled product is updated on an irregular basis. The products are also archived by the National Geophysical Data Center (NGDC) at http://map.ngdc.noaa.gov/website/firedetects/viewer.htm. A twice daily satellite based smoke text product is also generated which provides a brief description of the areal extent, an indication of smoke density and direction of movement for fire generated smoke plumes. It also provides a mechanism to identify long lived smoke events that travel far from their source regions. In addition to areas of smoke, blowing dust episodes are also discussed in the text message. The message is posted at http://www.ssd.noaa.gov/PS/FIRE/smoke.html .

Figure 2. Graphic depictions of fire and smoke analysis in jpeg (left) and GIS (right) format.



An important feature of the air quality aspect of the HMS is the analysis over Central America which can be the source of huge palls of smoke in the US. The US State Department, through the Partners of the Americas, American Fellows Program funded the transfer of the HMS system to Mexico in 2006. The analysis is performed at the Servicio Meteorologico Nacional in Mexico City and then transferred and merged with the NOAA analysis to create a comprehensive product covering all of North and Central America. The HMS is also currently in the process of being transferred to Thailand for fire and air quality monitoring over Southeast Asia.

DATA

The HMS incorporates imagery from seven NOAA and NASA satellites which allows for continuous monitoring. Geostationary data are obtained from GOES-11 and GOES-12 and offer high temporal resolution (data refresh of 15 minutes) and a nominal spatial resolution at satellite subpoint of 1 km for visible imagery (which is used for smoke detection) and 4 km for the 3.9µm band (which is employed for hotspot detection). Polar orbiting data are currently provided by the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on both the NASA Terra and Aqua spacecraft as well as the Advanced Very High Resolution Radiometer (AVHRR) on NOAA-15/17/18. The polar data provide a higher nominal resolution of 1 km for the 3.9µm band but at lower temporal refresh rates. Low and mid latitude locations are scanned twice per day by each of the polar orbiting satellites while higher latitudes receive more frequent coverage (up to 6 orbits per day in Alaska and northern Canada). The MODIS Terra and NOAA-17 spacecraft have similar equator crossing times near 1030 AM/PM local standard time (however, the NOAA-17 3.9µm band does not operate during daylight) while MODIS Aqua and NOAA-18 have similar crossing times near 130 AM/PM local standard time. NOAA-15 provides coverage near 600 AM/PM local standard time. This data integration allows for the strengths of each of the instruments to overcome their individual limitations.

Smoke detection is achieved exclusively with visible band imagery. Owing to the nature of smoke plumes for active fires (the source remains at a fixed location) and the need to often discriminate between smoke and clouds, the primary platform used for smoke detection is GOES. The satellite viewing angle in conjunction with the solar zenith angle is such that optimal smoke detection is achieved for the contiguous US with GOES-11 (centered over the equator at 135W) in the morning and with GOES-12 (centered over the equator at 75W) in the evening. Occasionally, polar imagery from the evening NOAA-15 pass is employed due to it's crossing near sunset which allows for enhanced smoke discrimination. Polar imagery is also used more frequently in polar regions of Alaska and northern Canada due to the more frequent coverage which allows for animation of the imagery with a shorter time interval than at lower latitudes.

The GOES Aerosol and Smoke Product (GASP) is an automated product derived from GOES visible imagery that the analysts can use to aid in the specification of smoke concentration. This will be discussed in more detail later.

SMOKE CONCENTRATION

While the focus of this paper is smoke detection and model initialization for emission transport and dispersion, the source of smoke emissions are the underlying fires. Considerable time and effort is expended to generate the most comprehensive fire analysis possible. This process involves inspecting each of the automated detections and evaluating it for accuracy and also inspecting the raw satellite imagery for additional fires that the automated algorithms may not have detected. Additional details on this phase of the analysis may be found at Ruminski et al.[1]

When smoke is identified the analyst draws contours that depict its concentration (thickness) and areal extent at a given time or time interval. As noted earlier, one of the methods used to identify smoke plumes is to locate a feature that has a fixed source. This can then be verified by noting whether a hotspot is also present at the source of the plume – although occasionally a smoke plume is the only indication of a fire and there is no corresponding hotspot detected. An additional means to differentiate between smoke and clouds (cirrus clouds, especially mountain induced cirrus, can look very similar to a smoke plume in visible imagery) is to compare the visible imagery to infrared. Clouds can be seen in infrared imagery while smoke normally is not discernable owing to the radiative properties of each.

Initially, the HMS only allowed for outlines of smoke extent to be drawn by the analyst. The capability to draw contours of smoke concentration, and therefore include an estimate of the smoke density over the entire atmospheric column, was added in November 2006. There are three categories of smoke concentration utilized: 5, 16 and 27 µg/m3, which correspond to light, medium, and dense smoke respectively. The values represent the midpoint of a range of values that the contours encompass. For example, a smoke concentration contour of 16 µg/m3 encompasses concentrations between 10.5 and 21.5 µg/m3. These values are an estimate and should not be used as a precise indication of the smoke concentration for the entire area of the contour. A graphic example of the concentration contours is shown in Figure 3.

GASP, described by Knapp et al[2], is used to assist the analysts in assigning a smoke concentration to an area of smoke and is seen in Figure 4. GASP is also available online at www.ssd.noaa.gov/PS/FIRE/GASP/gasp.html. GASP is derived using the concept that higher reflectance at a given location in visible imagery that isn't due to clouds may be caused by aerosols. Therefore, a clear sky composite reflectance reference image is generated for each location for each observation time by using the second darkest pixel from the previous 28 days. The current image is screened for clouds and the surface reflectance is obtained from the background image, using look-up tables calculated with the 6S radiative transfer model. The output from GASP is Aerosol Optical Depth (AOD) which is estimated using the look-up tables from the radiative transfer model and the calculated surface reflectance. Normally, the larger the difference between the calculated reflectance and the reference image from the previous 28 days the higher the AOD.

Figure 3. Visible image showing smoke over southeast Georgia on the left. Analyst annotation of smoke concentration on the right. Green shading represents dense, red denotes medium and yellow denotes light concentrations. The purple dots are locations of analyzed fires.

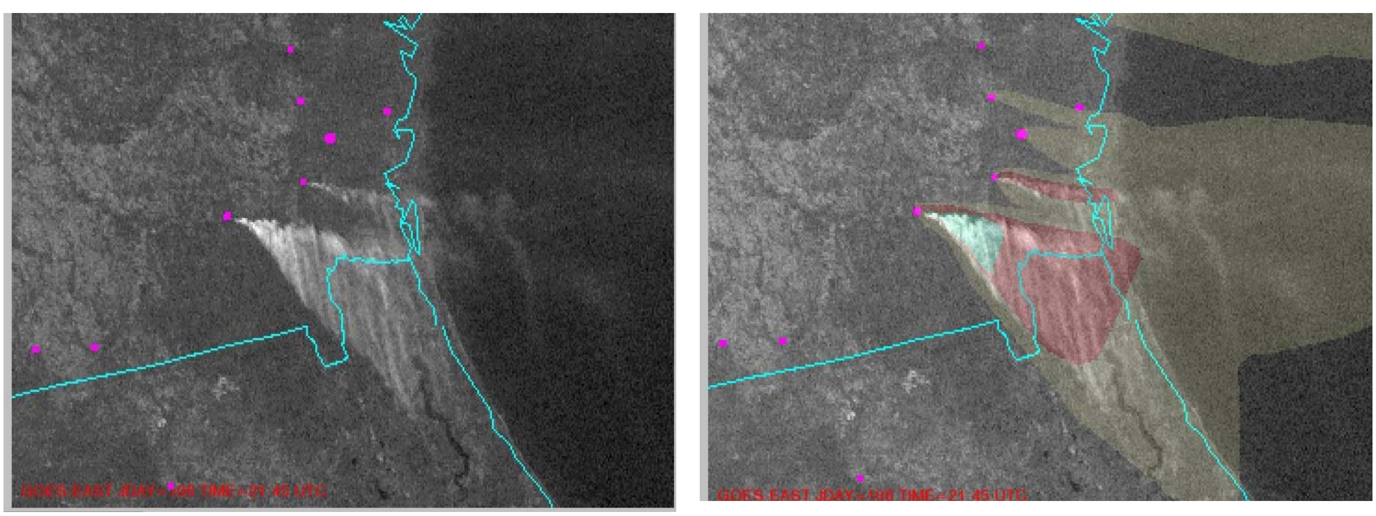
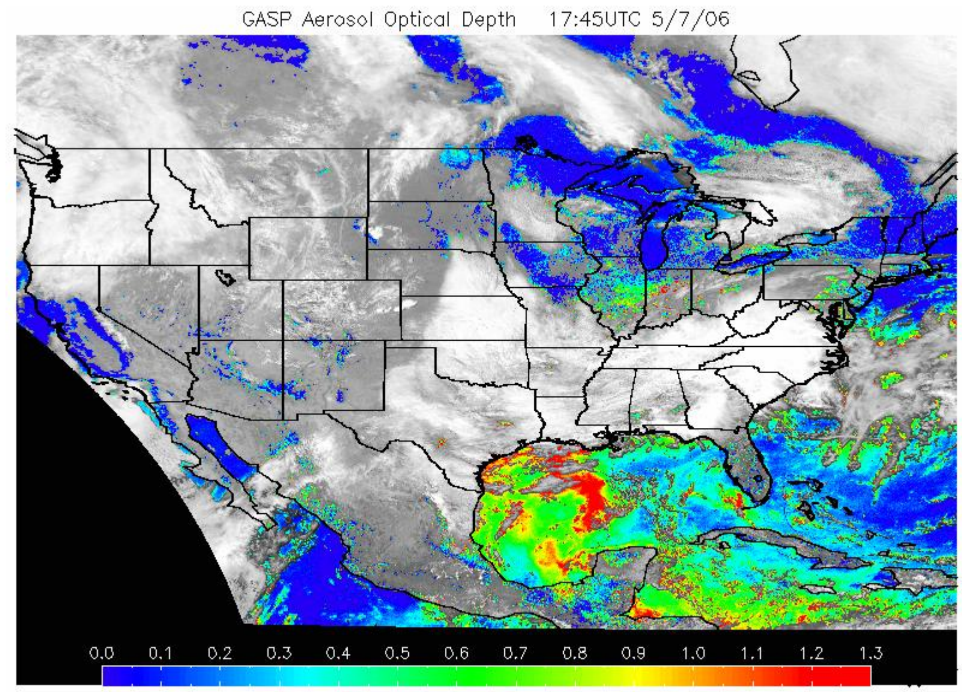


Figure 4. GASP image depicting aerosol optical depth for late afternoon 7 May 2006. The high values seen across the western Gulf of Mexico correspond to smoke originating from fires in the Yucatan.



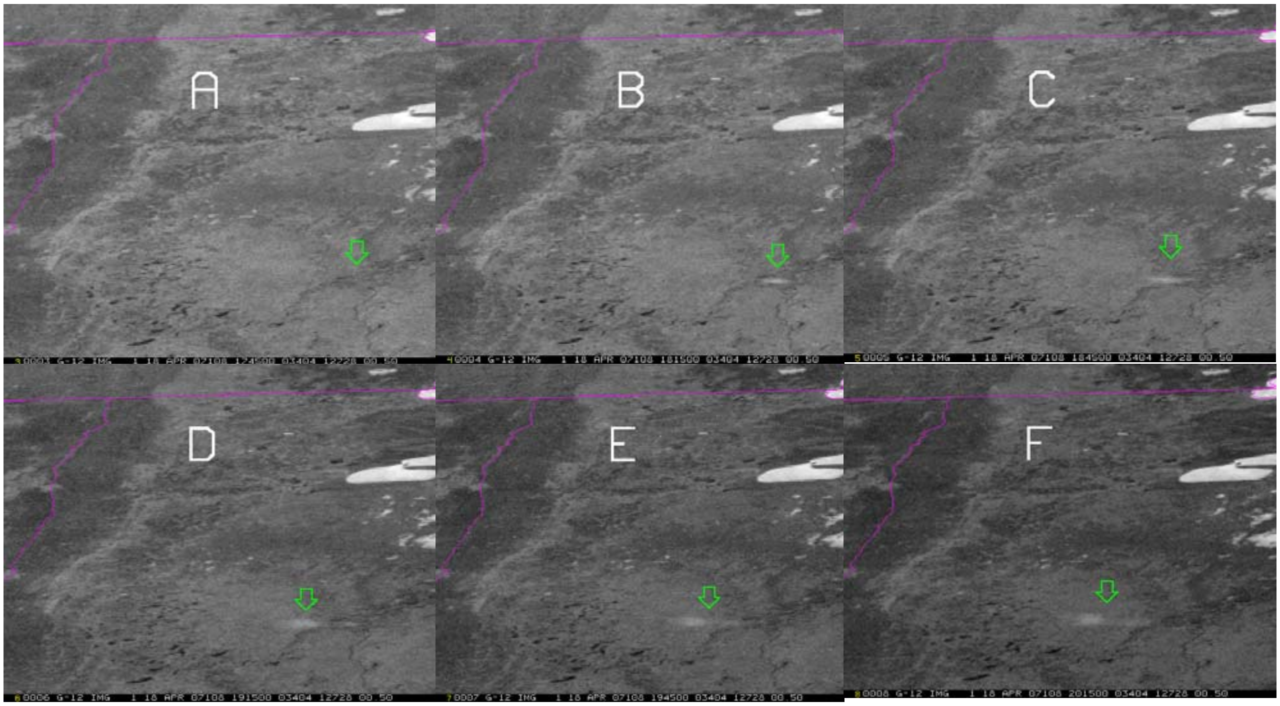
Since the HMS analysis is for smoke (as opposed to haze, blowing dust or other aerosols), the GOES AOD, which is derived using a continental aerosol model, is scaled for a smoke aerosol model. The AODs are then converted to smoke concentrations assuming a mass extinction coefficient of 7.9 +/- 4.5 m2/g with the smoke confined to the lowest 5 km. The conversion from an AOD to a smoke concentration allows for validation with the output from HYSPLIT, which is also smoke concentration.

GASP has 2 desirable properties for use with the HMS – it is derived routinely (every half hour over sunlit portions of the GOES domain) and provides an objective, quantitative estimate of smoke concentration. However, there are some deficiencies. As with other satellite based estimates of aerosol content using visible channels GASP performs better over darker surface backgrounds (ocean and moist continental areas) as opposed to over semi-arid regions (such as portions of the western and central US). While GASP employs GOES visible band imagery it only uses 4 km resolution compared to the 1 km imagery used in the HMS. Thus some of the smaller smoke plumes are either not depicted or may have smoke concentration values that are diminished due to averaging with adjoining non-smoke pixels. There is also no distinction made between smoke, dust or other aerosols, so it is the responsibility of the analyst to distinguish smoke from other types of aerosol. Retrievals are not performed for high solar zenith angles due to a known high bias. This is unfortunate because it is at the higher solar zenith angles that smoke is most discernable to the analyst.

FIRE DURATION

Analysts denote which fires are producing smoke for inclusion in the HYSPLIT model. Initially, all fires were modeled to emit smoke for at least 24 hours, which is generally representative for large wildfires. However, this is not appropriate for the large number of agricultural and prescribed

Figure 5. Series of GOES-12 half hourly visible images between 1745Z (A) and 2015Z (F) on 18 April 2007. The green arrows indicate a smoke plume that is first observed at 1815Z (B) and becomes detached from the source at 2015Z (F).



burns observed. This is apparent in the series of images depicted in Figure 5. Therefore, since May 2006 analysts have specified the time of initiation and the duration of smoke emissions for each fire for which emissions are observed. In addition to more accurately representing the amount of emissions, the dispersion accuracy can also be improved through a more accurate representation of the time of emission due to wind shifts and vertical temperature/wind profile changes that occur during the course of the day. This input to HYSPLIT is based on interrogation of visible imagery from GOES as well as 3.9µm from all of the satellites. Typically, GOES imagery is used to determine initiation and duration. If polar imagery from MODIS or NOAA spacecraft is available for a particular emitting fire, the fire is not near the limb of the image swath, the fire is not covered by clouds and the depiction is representative of the fire, it is preferred for use in determining the number of points to represent the areal extent of the fire over GOES due to the higher nominal spatial resolution. However, since the objective is to provide the most up to date information a polar satellite depiction of a fire would not be considered representative if, for example, a MODIS image from 1830Z captured the fire in question but subsequent GOES imagery indicated a marked increase in the size and intensity of the fire and a corresponding increase in the amount of smoke emissions.

An internal study was performed to determine whether the start/end time of emissions could be determined automatically using the WF-ABBA detections used by the HMS. However, the results were not favorable. The study was conducted over 8 days in January and February 2006. Of the 95 smoke plumes that were detected in GOES imagery 46 did not have a corresponding WF-ABBA detection. For those that were detected by WF-ABBA the average emission duration utilizing WF-ABBA was 1.4 hours while the average duration using manual inspection was 3.1 hours. There are several factors that should be noted: most of these fires are assumed to have been agricultural/prescribed; most (55) of the fires were still emitting smoke at sunset, precluding an accurate emission termination; since the study period occurred in the cold season it is possible that the number of WF-ABBA fire detections would be greater in the warm season.

HYSPLIT TRANSPORT AND DISPERSION MODEL

Smoke Forecast System

As noted earlier smoke forecasts are produced daily by NOAA/NWS using the HYSPLIT dispersion model. Detailed descriptions of the model can be found in Draxler and Hess[3,4]. HYSPLIT is configured to run over North and Central America once-a-day using the 0600 UTC North American Mesoscale (NAM) model and Global Forecast System (GFS) meteorological forecasts. Hourly-average air concentrations in the layers 0 to 100 m and 0 to 5000 m of primary PM2.5 are produced using the actual smoke emitting fire locations observed by satellite from the previous day. The dispersion simulation consists of two parts: 1) a 24 hr analysis simulation run for the previous day, and 2) a 48 hr forecast simulation. The smoke particle positions at the end of each analysis period are used to initialize the next day's analysis simulation. Particle age is limited to 72 hours after release, although much longer durations have been observed with large fires outbreaks allowing for very long range transport.

A preprocessor aggregates the individual fire pixel position data obtained from the HMS onto a 20 km resolution grid. Each fire location pixel is assumed to represent one km^2 and 60% of that area (10 ha) is assumed to be burning at any one time. The PM2.5 emission rate is based on the U.S. Forest Service (USFS) BlueSky (http://www.airfire.org/bluesky) emission algorithm, which includes a fuel type database and consumption and emissions models. The total grid cell emission rate and area is computed from the sum of the number of fire locations within the aggregated grid cell. Smoke particles are released from the center of each grid cell that contains one or more fire locations. Based upon the fire's location and area, the BlueSky algorithm uses a land-use database to determine the average PM2.5 emission rate and the heat released at each fire location. The heat release, in conjunction with the analysis/forecast meteorology, is used to compute a final plume rise (Briggs[5]). In the fire detection process all fire locations have a starting time and are identified as either continuous or non-continuous. Fires identified as continuous (24 h duration - the entire analysis period) will emit from their starting time through the end of the forecast. Non-continuous fires, mostly associated with agricultural land-clearing and prescribe burns, only emit for the duration specified.

The aggregated, gridded emissions file is saved each day and then loaded the next day by the preprocessor to be used as the new fire location file if a grid cell has no new emissions. However, the previous day's emissions are assumed to decay at a rate of 75% per day until the emission cell has less than 1 pixel burning. At that point, the cell emission is set to zero. The decay rate is not applied to the forecast period. This process was set up to account for periods where cloud cover or other factors may restrict fire detections.

Model Evaluation

The official NWS graphical output for each forecast hour over the CONUS is posted daily (Figure 6) as part of the Air Quality Forecast Guidance from the NWS National Digital Guidance Database (http://www.weather.gov/aq/). The current forecast maps, as well as a 30-day archive, are also available from NOAA/ARL's smoke product web page at (http://www.arl.noaa.gov/smoke/forecast.html). In addition, a "real-time" verification page is posted to the ARL website each day that includes model graphics, HMS smoke images and narratives, statistical graphs, and the ability to manually overlay the HYSPLIT and HMS smoke plumes on a map with the fire locations (Figure 7). The intent of the "real-time" verification is to permit air quality forecasters to judge the applicability of the current forecast based upon how well the fire locations and model predicted smoke compare with the actual smoke detection from the day before.

Figure 6. Surface smoke forecast guidance from the NWS Air Quality Forecast Guidance website as of 10 a.m. EST on March 7, 2007.

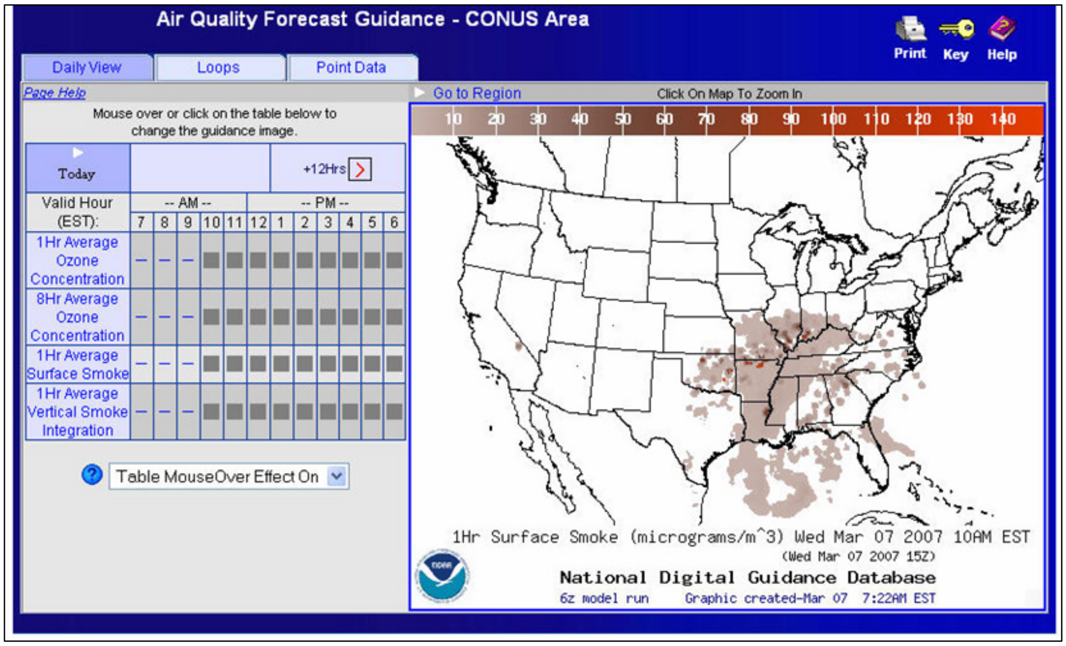
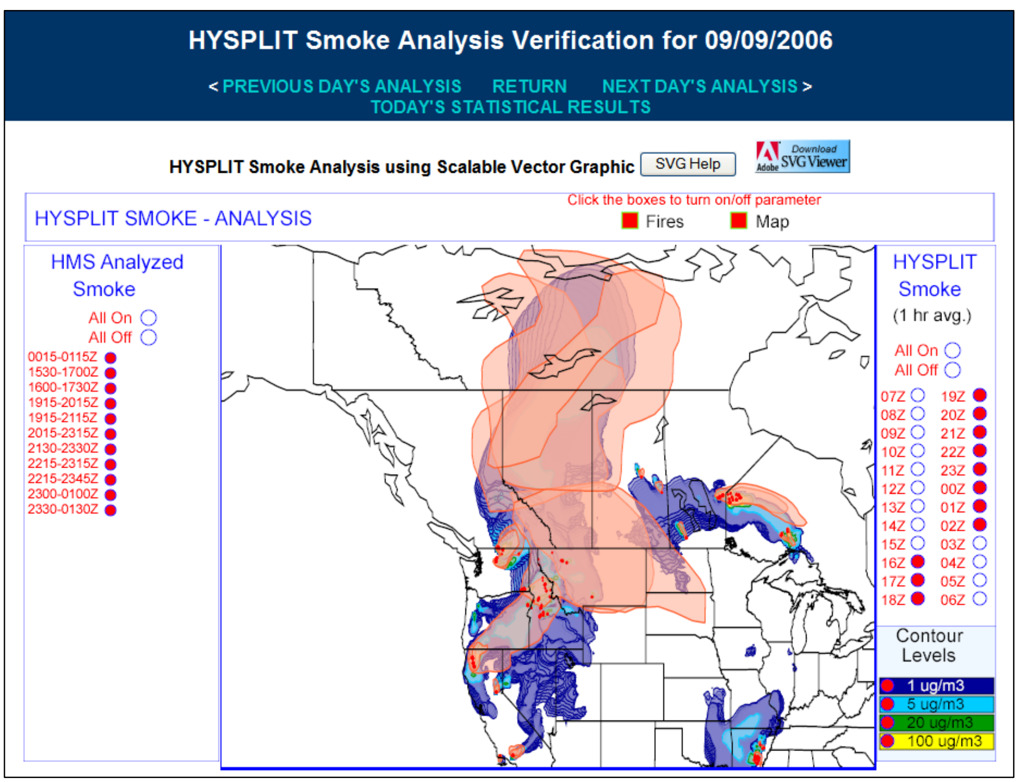


Figure 7. Scalable Vector Graphical (SVG) display of HYSPLIT smoke overlaid with HMS (orange shading) smoke for September 9, 2006.



One unique feature of the ARL web page is that the HYSPLIT output (0-5000m) of the current analysis period is shown alongside the HMS smoke graphic (http://www.arl.noaa.gov/ready-bin/smokevrf.pl) and that verification statistics are computed with each forecast. Two basic verification products are available – one for the analysis period and one for the forecast period. Naturally for today's forecast the verification is only available for the first 24 hour analysis period of the 72 hour simulation – yesterday's smoke plumes and fires which are used to initialize the forecast simulation. However, the current verification is also computed for the +24 hour period of yesterday's forecast, which corresponds to today's analysis period.

In order to produce the products needed for verification, HYSPLIT outputs the latitude and longitude positions of four select smoke concentration contours with intervals of 1, 5, 20 and 100 $\mu g/m^3$ each hour for the 72 hour period of the prior day's analysis and current forecast. The contours are converted to the GIS shapefile format for ready comparison to the HMS smoke plumes which are also in shapefile format (ftp://gp16.ssd.nesdis.noaa.gov/pub/FIRE/HMS/GIS/). Owing to limitations of satellite detection of smoke plumes indicated previously and personnel workload considerations the shapefiles are produced for different locations at various times throughout the day.

In the verification system, hourly HYSPLIT (0-5000m) plume shapefiles for each contour level are compared to the HMS shapefiles by producing the Figure of Merit in Space (FMS) statistic (Mosca et al.[6], Boybeyi et al.[7]) for each matched shape at a fixed concentration level. The FMS is defined as the ratio of the intersection area to the union area of the plume shapes:

Equation (1)
$$FMS(\%) = \frac{A_{HMS} \cap A_{HYS}}{A_{HMS} \cup A_{HYS}} \bullet 100$$

where

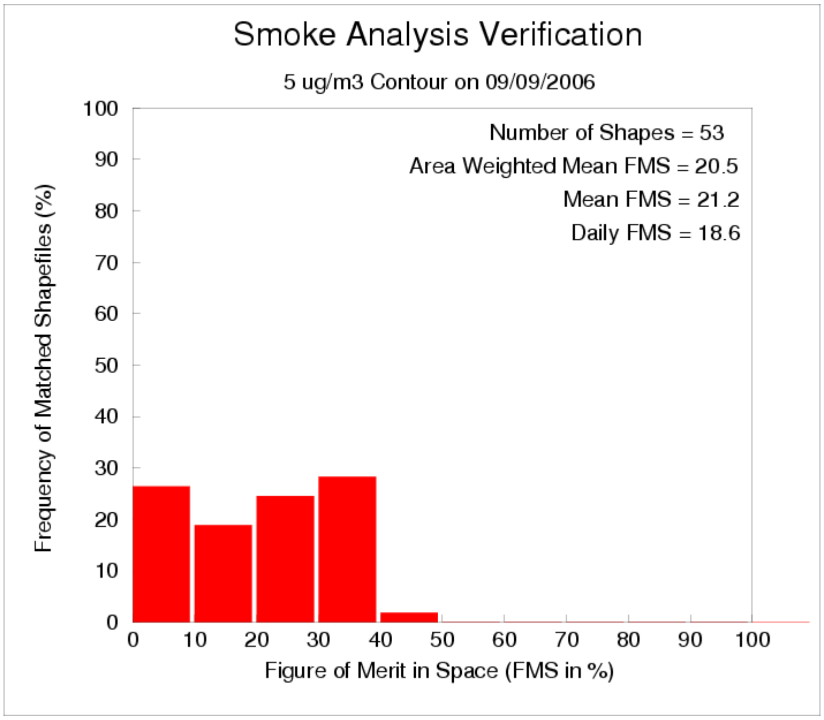
A_{HMS} = HMS plume area
A_{HYS} = HYSPLIT plume area

In general a high value of FMS indicates good model performance; however a low value does not necessarily indicate poor model performance. If the HYSPLIT and HMS plumes are very similar in shape but are shifted in space, possibly due to errors in the forecast wind direction or the modeled plume height, the result would be a low FMS score. For this reason, the satellite and HYSPLIT plume intersections should also be viewed on a map such as that provided on the ARL web page.

To compute the FMS statistics, multiple HYSPLIT shapefiles intersecting the same HMS shapefile are first merged into one shapefile before producing the FMS statistic. This is to account for the possibility of the modeled plume being depleted by deposition or the model having too few particles to adequately represent the full plume shape. In other words, the smoke plume can become depleted and begin to break up into many small shapes due to wet deposition and dispersion over time, and therefore we must assume that the smaller HYSPLIT shapes that overlap an HMS shape are part of the same plume. HYSPLIT shapefiles that do not intersect HMS shapefiles are not included in the analysis because of uncertainties in fire detections and the possibility that some of the detected smoke is not due to the fire locations represented in the model. Furthermore, the FMS statistic is computed for four concentration levels (1, 5, 20, and 100 $\mu g/m^3$) due to uncertainties in the emissions and the threshold concentrations representing the visible edge of the analyzed smoke plume.

Typical FMS scores range from 1 to 70%, with the higher numbers generally achieved during active fire periods. Figure 8 shows a histogram of the 5 $\mu g/m^3$ FMS scores for September 9, 2006, which represents a typical result during an active fire period. Figure 9 shows the FMS scores for the four contours during the month of September 2006 for the analysis and forecast periods, respectively.

Figure 8. Histogram of FMS scores for the 5 μg/m^3 September 9, 2006 HYSPLIT analysis



September 2006 was very active with large fires in the northwestern United States and southwestern Canada. During this period and throughout the second half of 2006 the 5 μg/m^3 contour tended to provide the best fit to the HMS plumes based on the resulting daily and monthly (Figure 10) FMS scores. A correction to the method of calculating the area burned was made in August 2006 that increased the amount of smoke emitted, the result of which is visible in the FMS statistics with the best scores switching from the 1 to the 5 μg/m^3 contour.

Another statistical method used to measure the overlap area of two shapes was developed by Warner et al.[8]. The two-dimensional Measure of Effectiveness (MOE) differs from the FMS in that the MOE includes in the results areas of under- and over-prediction (areas of false-negative (A_{FN}) and false-positive (A_{FP}), respectively). The MOE has two dimensions with the x axis corresponding to the ratio of the area of intersection to the HMS area, and the y axis corresponding to the ratio of the area of intersection to the HYSPLIT area. Simplification leads to the x axis corresponding to 1 minus the false-negative fraction and the y axis corresponding to 1 minus the false-positive fraction:

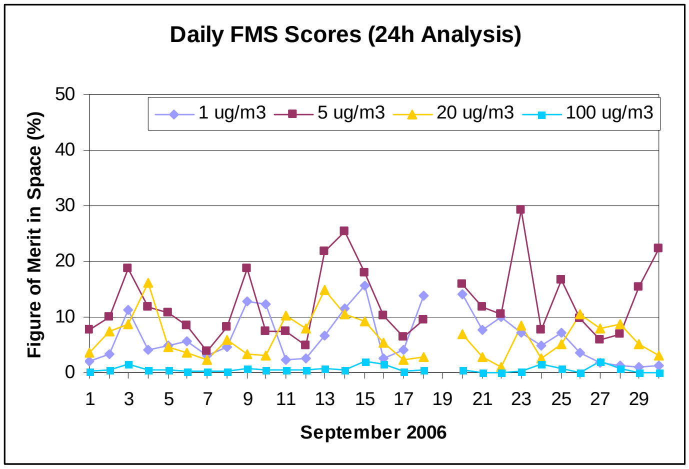
Equation (2)

$$MOE = (x, y) = \left(1 - \frac{A_{FN}}{A_{HMS}}, 1 - \frac{A_{FP}}{A_{HYS}}\right) * 100$$

where

A_{HMS} = HMS plume area
A_{HYS} = HYSPLIT plume area
A_{FM} = area of false-negative
A_{FP} = area of false-positive

Figure 9. Daily FMS scores for the 24 h analysis (left) and forecast (right) periods during the active fire month of September 2006.



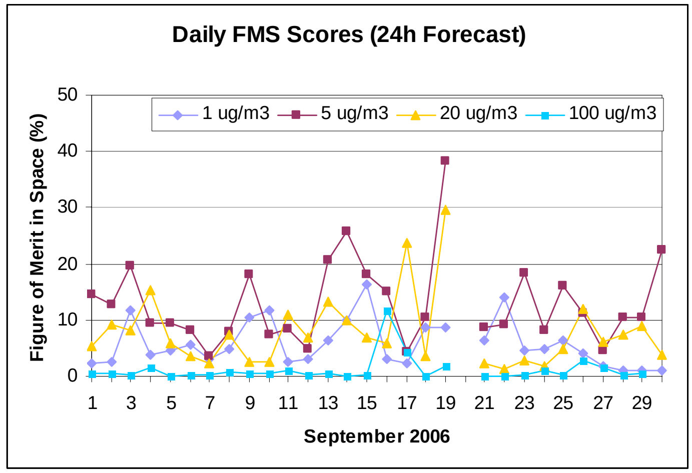
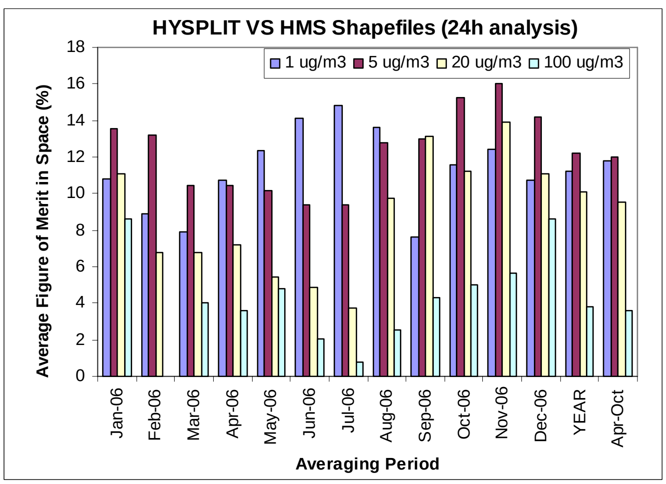


Figure 10. 2006 monthly average Figure of Merit (FMS) scores for the 24 hour analysis (left) and forecast (right) periods.



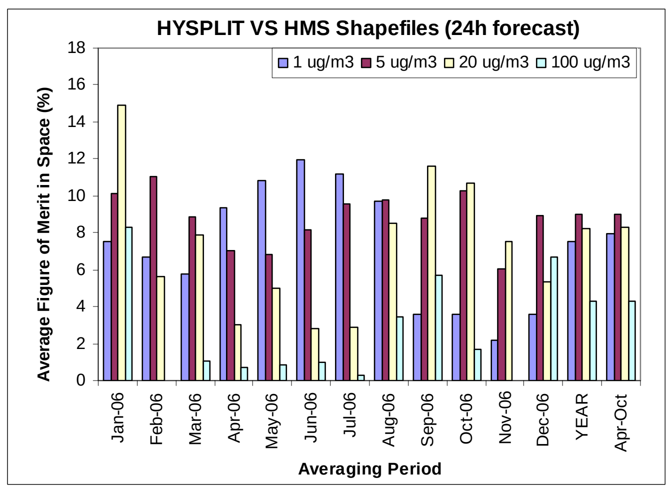
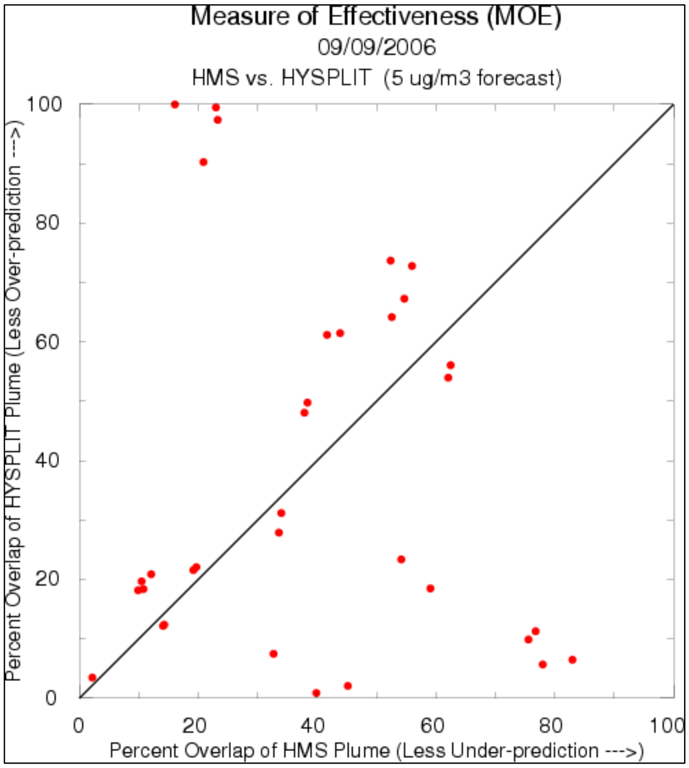


Figure 11 shows the MOE plot on September 9, 2006, for the 5 μg/m^3 HYSPLIT +24h forecast contour. The point (100,100) represents a perfect match between HYSPLIT and HMS plumes, ie., both shapes have identical overlapping areas. Points along the 1:1 line represent HYSPLIT and HMS shapes that are identical in plume area but are shifted in space, so that a point at (0:0) signifies no overlap. Points in the upper-left portion of the plot are cases where the HYSPLIT plume is nearly covered by the HMS plume, however the HMS plume is much larger than the HYSPLIT plume (under-prediction). Points in the lower-right portion of the plot are cases where the HMS plume is nearly covered by the

Figure 11. Measure of Effectiveness (MOE) for the 5 μg/m^3 HYSPLIT forecast contour as predicted for September 9, 2006.



the HYSPLIT plume, however the HYSPLIT plume is much larger than the HMS plume (over-prediction). On this day there were about equal cases with over- and under-prediction with many cases having similar areas but slightly shifted in orientation. These plots vary day-to-day, however very rarely do points fall in the far upper-right region of the plot, ie. 1:1 correspondence.

The most visible limitation of the existing verification system using the shape matching approach is that the statistics tend to show much poorer performance than what might be suggested by a qualitative examination of the graphical smoke plume products. This is due in large part to the nature of the FMS and MOE ratios. For instance, given all the potential directions (360 degrees) that a smoke plume, both measured and calculated, may show for any given verification time, only for those angular directions where there is some overlap between measured and calculated will result in a positive FMS and MOE. Even for those cases where there is complete overlap, if the measured or calculated plume is much larger than the other, the FMS will be reduced in magnitude and the MOE will be shifted left or right. Differences in plume area can be due to errors in the emissions as well as problems with detection of the smoke plume. One approach under consideration is to use the verification approach in an assimilative manner to improve the forecast. For instance, different plume-rise values could affect directional verification, suggesting the FMS could be used to determine the best value appropriate for the current simulation. In a similar vein, the model calculated contour that had the best fit with measured contour values could suggest an emission rate calibration factor valid for the forecast. These adjustments would be computed for the analysis period and then applied for the forecast duration.

RECENT AND PLANNED CHANGES

Future Plans

Single channel visible imagery used for smoke depiction has its limits. One of the deficiencies is the inability to readily distinguish between different types of aerosols (smoke, blowing dust, sulfates, etc). It becomes increasingly difficult to distinguish smoke from other constituents for long lived smoke events that are carried far from their source region. Another drawback is the challenge posed when clouds are present. Using visible band imagery it can be difficult to impossible to identify smoke. The recent availability of the Ozone Monitoring Instrument (OMI) on NASA's Aura spacecraft will help address these deficiencies by utilizing its hyperspectral imaging capability in the visible and ultraviolet wavelengths and applying specialized retrieval techniques. Additionally, OMI can provide better measurements over bright land surfaces than can GASP. It is hoped to include aerosol products from OMI into the HMSevaluate for evaluation.

A limited validation of the HMS fire product was performed using high resolution (30m) data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument on NASA's Terra spacecraft. However, additional validation utilizing ground truth reports are planned in order to provide a more complete validation. Validation of the HYSPLIT smoke products utilizing the GASP product has also been performed. Methods to isolate aerosol signatures in the imagery have been developed that select only those features that are correlated with fire detections (either automated or analyst detects) in order to develop a high level of certainty that the depiction is indeed smoke. This effort may be utilized to generate an automated smoke analysis.

A longer term goal is to achieve more robust, automated data fusion. Currently, the various satellite sources are incorporated into the HMS to be viewed by the analyst in a common projection for ease of manual comparison. However, better utilization can be achieved by automating a process to use all of the data sources in combination with the quality controlled fire locations to obtain improved estimates of fire and smoke emission duration and attach confidence levels to all analyzed fires (only automatically derived MODIS points currently have assigned confidence factors).

CONCLUSIONS

The HMS has evolved since it's inception in 2001. It's most recent and planned enhancements are focused on improving the detection, depiction and forecasting of the smoke emissions generated from wildfires, and agricultural/prescribed burns. One of the advantages of the system is that the detection and specification of smoke areas and smoke producing fires is performed in near real-time using constantly updating environmental satellite data and covers all of North America.

The ability to specify smoke concentrations in the analysis as well as the initiation and duration of emissions has allowed for a more realistic modeling capability. Validation results utilizing the FMS statistic have shown daily values as high as 70% with monthly averages around 12%. The best results are typically obtained during active fire periods with large areas of smoke being generated.

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KEYWORDS

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PM2.5