

Integration of MODIS Aerosol Products for Estimating Impact of the Russian Wildfires over Europe and Asia during August 2010

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Abstract - A series of wildfires broke out in western Russia starting in late July, 2010. Detrimental particulates and gases released into the local Russian atmosphere and possible impact to the global atmosphere environment during this period have been reported. In this paper, an extremely hazy area and its transport trajectory were observed using Moderate Resolution Imaging Spectroradiometer (MODIS) colour composite image, integrated MODIS aerosol products based on Kalman filtering, HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model and Second Simulation of the Satellite Signal in the Solar Spectrum (6S) model. The advection and dispersion of the plume causing by Russian wildfires and its effect to local, regional and global atmospheric environment were analysed according to AOD, visibility and PM data. The result showed that the wildfires had an extremely bad influence to western Russia; however, little impact was obtained to most European and Asian parts except some neighboring countries.

Key words: Wildfire, Aerosol, Assimilation, Kalman filtering, MODIS

1. INTRODUCTION

Several hundred wildfires broke out across Russia, primarily in the west, starting in late July 2010, due to record temperatures and drought in the region (http://en.wikipedia.org/wiki/2010_Russian_wildfires) and hundreds of reports described the cause and possible effect since biomass burning has a direct influence to the atmospheric environment and indirect effect to human health, ecosystems as well as the science research. Many researches show that remote sensing is the most practical means of measuring energy release from large open-air biomass burning (Palacios-Orueta et al., 2004; Bradley and Millington, 2006) because satellite observations may detect unknown global or regional patterns, daily variations and seasonality that are not reproduced by models (Hoelzemann et al., 2009). Actually, integrating available products from multiple sources creates a picture of aerosol characteristics and transport that is not readily discernible from satellite data products alone (Liu et al., 2009).

It was found that different algorithms/instruments produce somewhat different results for aerosol optical depth (AOD) absolute values and spatial distributions even if the same location at the same time is observed because of cloud masking, instrument calibration; treatment of the underlying surface; assumptions on the aerosol model (Kokhanovsky *et al.*, 2007; Li *et al.*, 2009), which can be confusing to users of the products and policy makers, with damaging consequences. Therefore, it is critical to integrate data from multiple platforms and techniques to derive a consistent and accurate AOD product. Data assimilation methods such as Kalman filtering are designed to merge measurements of any different remote sensing observation (Reichle, 2008), which provides a new method for integrating different remote sensing products, either different sensor or different algorithm, to obtain a larger coverage and higher accuracy remote sensing products.

There exists, however, an outstanding problem that no single product, even a high quantity one after assimilation, is capable of providing totally unambiguous information about our quantitative understanding of atmospheric events. In order to detect the advection and dispersion of atmospheric event causing by biomass burning and its effect to local, regional or global atmospheric environment, MODIS composite images, visibility and PM data are all reliable information because the composite images can directly show the smoke or plume trajectory, and visibility and particulate matter (PM) are good indicators for atmospheric environment, especially during extreme events. Actually, understanding influences of biomass burning on the atmospheric visibility and PM is important because low visibilities can have disastrous impacts on transportation, and especially air traffic (Baumer et al., 2008), and high PM can pose serious health risks, especially to individuals with asthma and other respiratory problems. There are numerous previous publications that dealt with the correlation between visibility, PM and aerosol properties, especially AOD.

In this paper, an extremely hazy area and its transport trajectory were observed using Moderate Resolution Imaging Spectroradiometer (MODIS) colour composite image, integrated MODIS aerosol products based on Kalman filtering, HYSPLIT model and Second Simulation of the Satellite Signal in the Solar Spectrum (6S) model. Firstly, PM concentration

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and visibility retrieved based on assimilation aerosol products and 6S model were used to estimate impact of the wildfires to the local Russian environment. The results showed that the PM₁₀ concentration are three times than normal condition and the visibility of many part ,even Moscow, were less than 100m, some even less than 50m. What's more, the possible impact to the neighbouring countries due to the long-transport effect was also described using MODIS colour composite image based on HYSPLIT model during 1st and 15th August, 2010. The satellite aerosol products and HYSPLIT mode suggests that wildfires in western Russian had little impact to most European and Asian parts except Finland and Kazakhstan, however, the possible impact to the Arctic region was also found which may had serious influence to the polar atmospheric environment and creatures such as polar bear.

2. MODELS

The suite of MODIS dark-target algorithms (DDV) were originally formulated by Kaufman et al. (1997) over land and by Tanre et al. (1997) over water and it had been continuously evaluated for self-consistency and comparability to other datasets, including AERONET (Remer et al, 2005), the uncertainty is about $\pm 0.015 \pm 0.15\tau$. Since the limitation of dark-target algorithm, Hsu et al. (2004) proposed a new approach (DeepBlue) to retrieve aerosol properties over bright-reflectance source regions and good agreement results (i.e., within 30%) are indicated from their validation with ground-based AERONET sun/sky radiometer measurements. The integration of DDV and DeepBlue can produce a higher accuracy and larger coverage of AOD product. The Kalman filtering is effective for data fusion to provide uniform results from different sensor or algorithm. An integration AOD product was produced using Kalman filtering as following:

$$\tau_{\text{integration}} = \text{Kalman}(\tau_{DDV}, \Delta_{DDV}, \tau_{\text{DeepBlue}}, \Delta_{\text{DeepBlue}}) \quad (1)$$

where Δ_{DDV} is the deviation of DDV and Δ_{DeepBlue} stands for the deviation of DeepBlue.

Since there is a good relationship between PM, visibility and AOD, then a high accuracy and large coverage integration AOD product provide a believable PM and visibility value. And the visibility (V_0) in this paper was retrieved using 6S model. The PM data was retrieved using simple statistical method based on the integrated AOD products.

$$V_0 = \exp(-\log(\tau_{550} / 2.7628) / 0.79902) \quad (2)$$

The MODIS Rapid Response System was developed to provide daily satellite images of the Earth's landmasses in near real time, and it provides True-colour, photo-like imagery and false-colour imagery to track fires (<http://rapidfire.sci.gsfc.nasa.gov/>). The MODIS Aerosol Product monitors the ambient aerosol optical thickness over the oceans globally and over portion of the continents. Daily Level 2 data are produced at the spatial resolution of a 10x10km (at nadir) pixel array (http://modis-atmos.gsfc.nasa.gov/MOD04_L2/index.html), including DDV algorithm datasets and DeepBlue algorithm datasets.

The HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model is a complete system for computing simple air parcel trajectories to complex dispersion and deposition simulations. Hysplit computes the advection of a single pollutant particle, or its trajectory and so on (http://www.arl.noaa.gov/HYSPLIT_info.php). The Hysplit was used to characterize the transport pattern of air-mass flow over the study area. Some studies on aerosol transport tend to depict transport as if it occurred all at one level. The fact that air pollution in general is a low-level phenomenon, which make trajectories based on surface wind data especially useful (Rosenthal et al., 1998), especially for the prediction of the trajectory of dust event.

3. RESULTS AND ANALYSIS

Figure 1 demonstrated the MODIS composite images and Figure 2 showed the AOD distribution in the study area at some specify time, that is the beginning of the fire on 1st August, 2010; the fire began to effect the Asian area on 5th August, 2010; the fire began to effect the European area on 8th August, 2010 and the epilogue of the episode, with resolution of 10km. The MODIS composite images were downloaded from <http://rapidfire.sci.gsfc.nasa.gov/gallery/?search=Russia> including both Terra and Aqua composite image. And both the DDV product and DeepBlue product were from Aqua (Collection 5.1). In fact, the fire started in late July, 2010 and four periods were divided for further analysis. The beginning period of the fire ranged from late July to 3rd August; the fires began to affect the Asian area from 4th August to 7th August; the third period from 8th August to 10th August and the epilogue of the fire ranged from 11th August to 20th August. Four days, that is, 1st August; 5th August; 8th August (composite image was 9th August since there was no data on 8th August) and 15th August were chosen for analysis. The NOAA/ARL HYSPLIT model was used to calculate forward trajectories of air masses with a starting time of 00:00UTC. The forward trajectories at Moscow (37.35°E, 55.45°N) of three heights of 500 (red), 2000(pink) and 5000m (green) were also plotted in Figure 2.

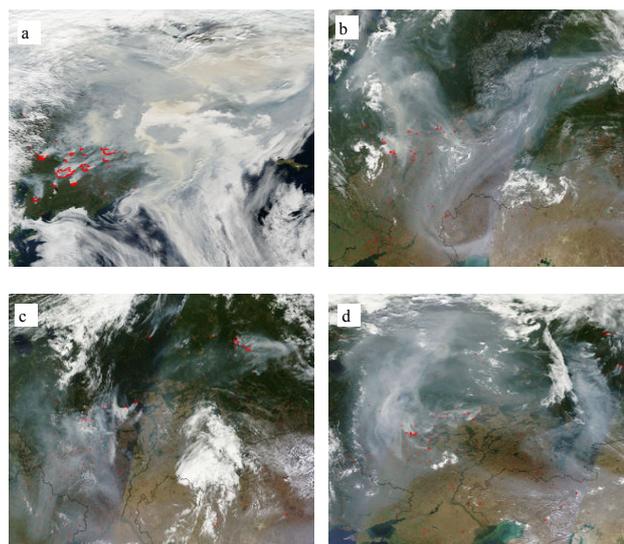


Figure 1. The MODIS composite image during the episode (The red points stand for the fire points)(a) 1st August, 2010-Aqua;(b) 5th August, 2010-Terra;(c) 9th August, 2010-Aqua;(d) 15th August, 2010-Terra.

As seen in Figure 1 (a), significant smoke aerosol plume from the Russian forest fires was observed over western Russia on 1st August, 2010. The AOD values (Figure 2(a)) of the burning area is around 1.0, which means, although there were many fire points detected, fires were not so fierce. And the 120h forward trajectory started at 0:00UTC 1st, August showed that the fire had an extremely bad influence to local western Russia at the beginning. Figure 1 (b) shows that this hazy area has a relatively high AOD (>1.0) with a maximum exceeding 1.5, even 2.0, indicating a higher aerosol concentration in the western Russia on 5th August, 2010.

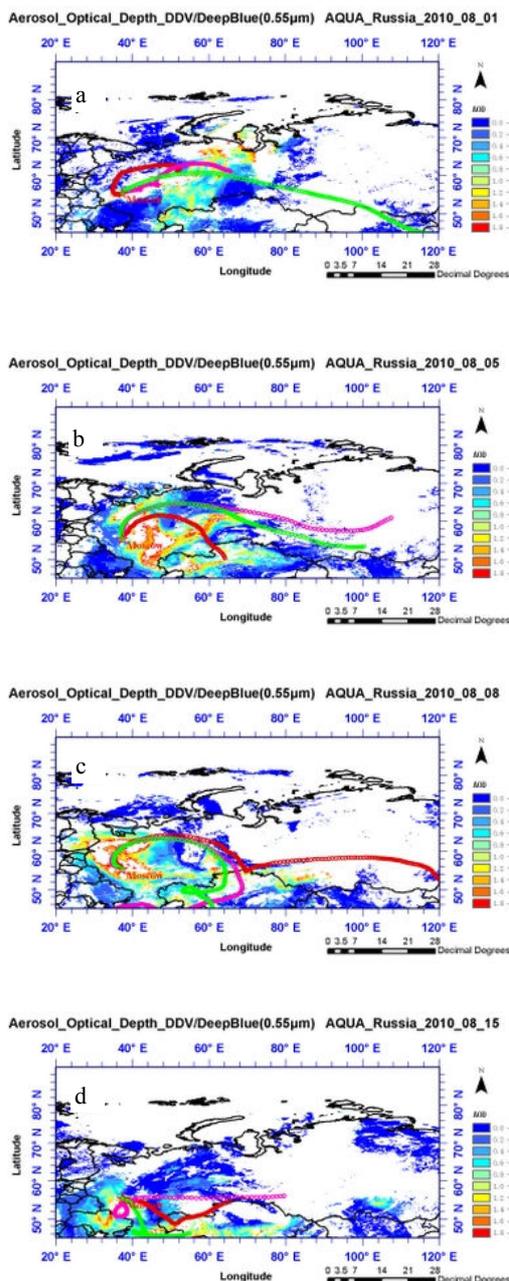


Figure 2. The assimilation AOD distribution and its trajectory in the study area during the episode: (a) 1st August, 2010-beginning of the fire; (b) 5th August, 2010-some effect to Asian area; (c) 8th August, 2010-effect Western Europe; (d) 15th August, 2010-epilogue of the fire. (Red trajectory stands for 500m height; Pink is 2000m height and Green is 5000m height)

What's more, the PM concentration was three times than normal condition, and the west-northern and northern Kazakhstan began to be effect by the transport phenomena, although the AOD in Kazakhstan was not so high (less than 0.6) as Moscow (larger than 2.0), it was twice than the clear day. The obvious transport effect in low height attributes to the increase of AOD and PM concentration since large particles transport to Kazakhstan because of meteorological condition. The composite image of Figure 2(b) show the plume moved southward on 5th, August. The Arctic area was seemed to be affected by the fire on 5th August since AOD value was extremely high and the meteorological condition during 1st August and 5th August help the particle transport to this area. Finland was affected by the fire on 8th August according to the composite image and AOD distribution map. And ground observation and retrieval results showed that the PM concentration was 60 μm^3 over the capital of Finland (Figure 1(c) and Figure 2(c)), Helsinki. The interesting thing was that Finland was effect by the fire on 8th August; however, the south-westerly winds have managed to improve the air quality and reduce the health risk of the smoke. MODIS AOD in Kuopio, as inferred from AERONET site, was approximately 0.4 because the site located in the middle of Finland, which was little affected by the Russian wildfires plume. The influence of the fire was decrease since 15th August. The plume faded (Figure 1(d)) and AOD values decrease into about 0.6. It was reported that the air quality of Moscow was improved since 11th August.

4. CONCLUSION

Extensive fire activities occurred during late July of 2010 over Western Russia and its effect to local atmospheric environment as well as regional particle pollution transport to Asia and Europe area were analyzed by assimilating remote sensing DDV and DeepBlue AOD products and surface observations (AERONET AOD and PM), together with meteorological data (wind direction as well as wind speed). The heavy smoke plume had a great effect to local atmospheric environment, especially western and middle Russia. The smoke plumes from the Russian forest fires extended far to Moscow, and moved out to the Eastern Europe, such as Finland by 8th August, 2010. Moscow was severity influenced by the wildfires in August 7, 2010, and the AOD was greater than 4.5, and the visibility in many parts were less than 100m, even 50m. The smoke aerosol contributed to an hourly averaged surface PM₁₀ concentration of Moscow up to 3 times than normal. However, other European and Asian countries were little affected by the fire except Finland and Kazakhstan, and both Finland and Kazakhstan were affected by the dust event in several during the whole event because of the metrological condition. The paper shows that the integrated of multiple remote sensing AOD products and ground-based data, together with metrology data provides a powerful tool for characterizing and plume transport.

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