EVALUATION OF SATELLITE MEASUREMENTS OF FIRE RADIATIVE POWER (FRP) USING AIRBORNE MEASUREMENTS

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1. INTRODUCTION

Wildfires and other types of open biomass burning occur seasonally in different vegetated landscapes throughout the world, and are ignited either by natural (e.g. lightening) or anthropogenic (accidental, agricultural, arson, experimental, or prescribed burning) processes. Irrespective of their origin or location, these large fires generate intense heat energy, burning up large amounts of biomass and emitting corresponding amounts of smoke plumes that comprise aerosols and trace gases, which include carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), non-methane hydrocarbons, and several other chemical compounds, most of which have adverse effects on human health and environmental processes. Accurate estimates of these emissions are required as model inputs to simulate and forecast smoke plume transport and impacts on air quality, human health, clouds, weather, radiation, and climate. However, accurate estimation of biomass consumption and smoke emissions has eluded the scientific research community for a long time, because it depends fundamentally on accurate quantitative determination of fire activity, which is not possible by *in situ* measurement methods.

Recent advancements in the capability of space-borne sensors have enabled routine quantitative measurement of active fire radiative energy (FRE) release rates or power (FRP) from advanced satellite sensors, such as the Moderate-resolution imaging spectro-radiometer (MODIS) aboard the Terra and Aqua polar-orbiting satellites [2], [4] and the Spinning Enhanced Visible and Infrared Imager (SEVIRI) aboard the Meteosat-8 geostationary satellite [5]. Presently, FRP is generally derived from radiance measurements at mid-infrared (MIR) wavelengths (typically, in the 3.7 to 4.0 μm wavelength range) [3], [4], [6], [8]. Fig. 1 shows an Aqua-MODIS true-color image acquired over the firestorm that occurred in Southern California, USA, during October 2007, showing the fire locations and smoke plumes, while Fig. 2 shows the fire pixel FRP values (in MW). FRP has been shown to be proportional to the rates of biomass combustion and smoke aerosol emissions, and its effectiveness in estimating these quantities has been demonstrated [1], [6], [7].

The objective of this paper is to quantitatively evaluate the FRP measurements from MODIS using airborne MIR measurements acquired with the Autonomous Modular Sensor (AMS) Wildfire instrument aboard the remotely piloted NASA Ikhana aircraft. This effort will help to reinforce the physical understanding and utilization of satellite FRP measurements to quantitatively characterize the spatio-temporal distribution of biomass burning and to derive smoke particulate and gaseous emissions in different regions of the world. It holds great promise in helping to advance scientific knowledge about the impacts of biomass fires and the associated smoke emissions on land-use changes, air quality, human health and safety, the water cycle, and climate.

Fig. 1: True color composite of MODIS visible image acquired aboard the Aqua satellite, at 2:40 p.m. Pacific Daylight Time on 23 October 2007 during the Southern California firestorm. The fire locations are delineated with red contours. The grayish thick smoke plumes from the fires are quite prominent. (Image courtesy of the NASA Earth Observatory team: http://earthobservatory.nasa.gov/).

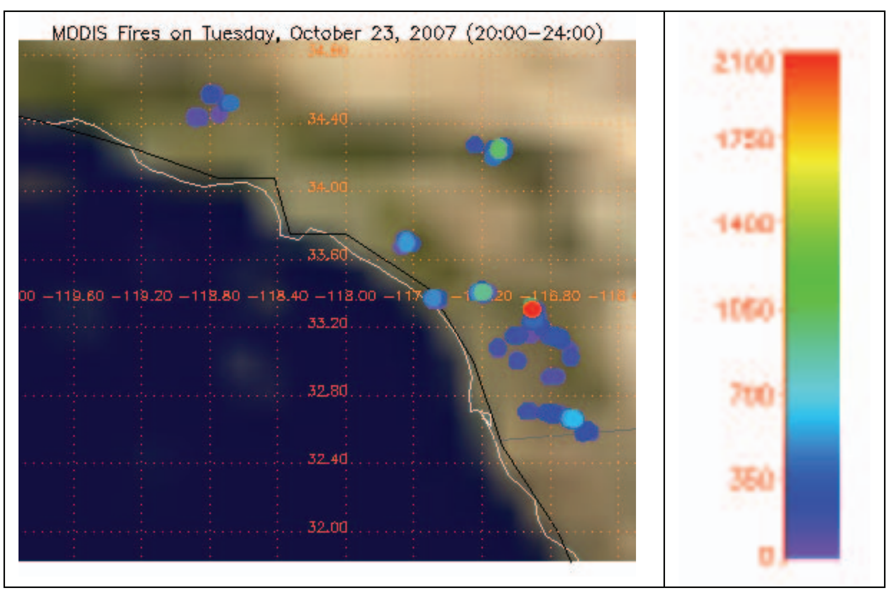

Fig. 2: Fire pixel FRP values (in MW) of the 23 October 2007 Aqua-MODIS fire scene in Fig. 1. The FRP values on this fire scene range from just above 0 to ~2000 MW, as represented on the color bar scale at right.

2. METHODOLOGY

The AMS datasets acquired over the severe firestorm that took place in southern California in October 2007 were processed and collocated with MODIS fire data products. The FRP measurements from MODIS have a 1-km nominal spatial resolution at nadir while the resolution of the data acquired by the AMS during that October 2007 airborne campaign was of the order of 10 m. Therefore, thousands of AMS pixels fit within each MODIS pixel. This has enabled the use of the higher-resolution AMS fire measurements to analyze the detailed sub-pixel characteristics of individual MODIS fire pixels. After the collocation of corresponding pixels from the two sensors, the AMS pixel radiance values within each MODIS pixel were averaged to obtain the equivalent AMS radiances at MODIS spatial resolution. Subsequently, the radiance measurements at the MIR fire channel of these two instruments were compared; bearing in mind the difference in their wavelengths: as the wavelength of the AMS fire channel is ~3.7 µm, while that of MODIS is ~3.96 µm. The AMS radiances were then used to calculate FRP, also taking into consideration the AMS wavelength difference with MODIS, and these FRP values were compared to corresponding MODIS FRP data, followed by detailed evaluation of the effects of the imaging conditions and specific scene geophysical characteristics.

3. RESULTS AND DISCUSSION

Although the data analysis were still in progress at the time of writing, preliminary results show very good agreement between the MIR radiance measurements from the AMS and MODIS, as well as their corresponding FRP values. More detailed analysis of specific discrepancies due to differences in fire-channel wavelengths and possible detector saturation, as well as the effects of measurement geometry and scene geophysical factors, will be completed in the near future and reported in a full technical paper. The results of this work show indeed that advancements in satellite remote sensing during the last decade have, not only facilitated fire detection from space, but have also enabled quantitative measurement of rates of radiative energy release from large forest fires and other open air biomass burning.

Indeed, remote sensing provides the only practical method of fire measurement, as it is impossible to measure large fires by *in situ* sampling techniques or even at close range. The advantages offered by satellite measurement of FRP are important for effective monitoring of the effects of fires and their emissions on the Earth's environmental and climate systems. No substitute is known at the present time for effective monitoring of active fire intensity from satellite. Furthermore, since the specific locations and times of fire occurrence are unpredictable, it is only reasonable that fire remote sensing be conducted from unmanned satellite systems that not only operate independently but also can cover very large regions within minutes, and in a repetitive fashion. Therefore, it is very important to seriously consider including FRP measurement capability in most future satellite remote-sensing missions. Since different remote sensing systems have different spatial and temporal resolutions, measurement of FRP from multiple sensors will provide the opportunity for inter-calibration of measurements to ensure robustness. Sub-orbital FRP measurements could then be used for more locally focused fire characterization and validation of the satellite measurements, as performed in this work. Large scale implementation of FRP measurement capability in future satellite missions will lead to significant improvement in global fire monitoring and characterization as well as accurate burned biomass and emissions estimation over extended regions even in near real time; an undertaking that was not possible before the advent of satellite remote sensing. The benefits of this development can be far reaching and will include significant improvement in the effectiveness of fire management and suppression activities as well as in the simulation, analysis, and forecasting of smoke impacts on air quality, human health, weather, and climate.

4. REFERENCES

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