A multi-sensor approach to fine-scale fire characterization

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Abstract – Recent improvements in sensor capabilities have enabled fire characterization from satellites. Instantaneous intensities of active fires have been characterized by the Fire Radiative Power (FRP), while burn severity has been assessed from the evaluation of Normalized Burn Ratios (NBR) derived from pre- and post-fire multispectral imagery. MODIS on the Terra and Aqua satellites enables FRP retrievals at a global scale. However, the 1km^2 sub-satellite resolution is too coarse to account for fine scale spatial heterogeneities that are often typical of the burning process. The high resolution (15-90m) ASTER is flown on the Terra satellite, and can be used to determine the location of the active fire front within the MODIS footprint. In this study several fire events in North America were analyzed. MODIS FRP values, localized using ASTER, were combined with burn severity data derived from collocated 30m Landsat TM (Thematic Mapper) and ETM+ (Enhanced Thematic Mapper) imagery for a more complete characterization of the burning process

FIRE CHARACTERIZATION FROM SATELLITES

Fire Radiative Power (FRP): total integrated *instantaneous* rate of radiative energy emitted by all fires within the satellite pixel (Kaufman et al., 1998; Wooster et al. 2003):

$$FRP = A_{sa}\,\varepsilon\sigma\sum_{i=1}^{n} f_i T_i^4$$

A = the total area of the satellite pixel [m^2]
ε = fire emissivity
σ = Stephan-Boltzmann constant [5.67x10^{-8} J^{-1}m^{-2}K^{-4}]
f_i = fractional area of the i^{th} thermal component
T_i = temperature of the i^{th} thermal component [K].

FRP has been shown to correlate with instantaneous biomass consumption rate (Wooster, 2002).

The MODIS (Moderate Resolution Imaging Spectroradiometer) on the experimental polar orbiting Terra and Aqua satellites is the first sensor to enable systematic retrievals of the Fire Radiative Power at a global scale (Justice et al., 2002).

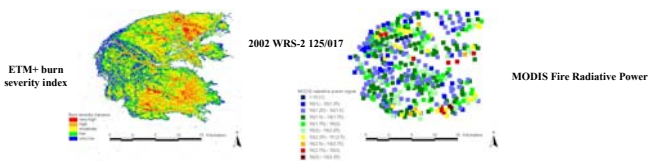
Normalized Burn Ratio (NBR): developed for Landsat Thematic Mapper (TM) or Enhanced Thematic Mapper (ETM+),

$$NBR = \frac{R_4 - R_7}{R_4 + R_7}$$

R_4 = band 4 (0.76-0.90 µm) reflectance
R_7 = band 7 (2.08-2.35 µm) reflectance.

The difference between pre-and post-burn NBR (dNBR) has been related to levels of *burn severity for the entire burn* (Key and Benson, 2004).

What information do FRP and dNBR provide about the burning process?

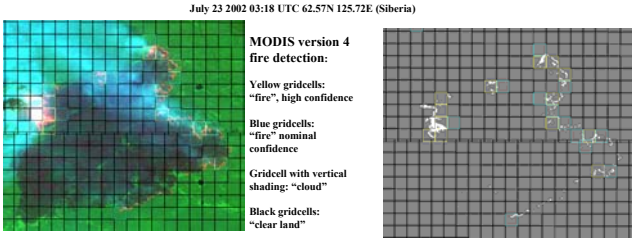


Observations of a large fire complex in Siberia.

The MODIS pixel size is too large compared to the spatial heterogeneity of dNBR from 30 m Landsat data. In this study we used of 30 m ASTER data to localize burning at finer spatial scale

ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer; Yamaguchi et al., 1998) is flown on the same Terra satellite and therefore can provide observations coincident with MODIS. The low saturation of ASTER bands does not allow for the retrieval of FRP at the full range of fire intensities, but it can be used to determine the location of the active fire front within the MODIS pixel.

July 23 2002 03:18 UTC 62.57N 125.72E (Siberia)



ASTER image of a large fire complex in Siberia. The gridcells are 1 km MODIS pixels.

ASTER fire mask of the same fire complex

DATA

- database of coincident MODIS/ASTER and Landsat-based dNBR data in North America
  - MODIS and ASTER from NASA's Earth Observing System (EOS) Land Processes Distributed Active Archive Center (LPDAAC)
  - Landsat/ETM+/dNBR from NPS (National Park Service) and USGS (US Geological Survey) National Burn Severity Mapping Project; and several independently selected sites

WRS-2 path/row	Pre-burn date	Post-burn date	ASTER date	Number of MODIS fire pixels
38/29	7/15/00	7/5/02	8/28/01	5
72/15	6/23/01	6/17/02	7/9/01	1
34/27	7/6/01	7/9/02	5/13/02	2
24/34	8/14/00	8/28/02	4/5/02	1
66/15	9/12/99	9/8/04	6/21/04	14

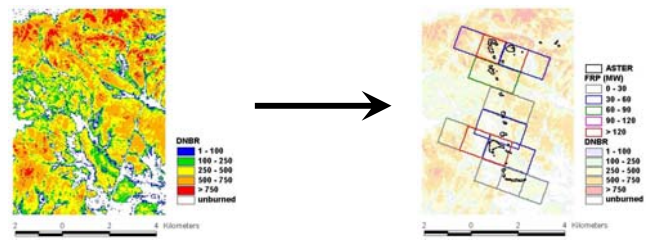
Summary of Landsat and ASTER imagery used in this study

APPROACH

- extract MODIS FRP from standard MOD14 fire product (Giglio et al., 2003)
- generate ASTER fire mask
- map ASTER fire pixels into true 2x1 km MODIS footprint
- normalize MODIS FRP to a hypothetical rectangular point spread function (PSF) using the true triangular MODIS PSF

$$FRP = A_{sa}\,\varepsilon\sigma\sum_{i=1}^{n} f_i k_i T_i^4 \quad \text{(assuming constant } f \text{ and uniform } T\text{)} \quad FRP_a = FRP \times n / \sum_{i=1}^{n} k_i$$

- co-register ASTER and Landsat imagery and map ASTER fire mask on dNBR product

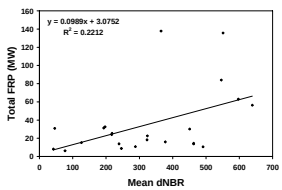


dNBR map of a section of a fire complex in Alaska (WRS-2 path/row 66/15)

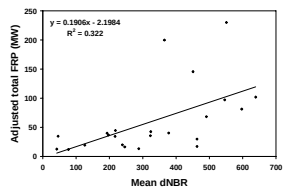
ASTER active fire masks over the same fire complex, with FRP values from MODIS. Active fire data are from 6/21/2004.

RESULTS

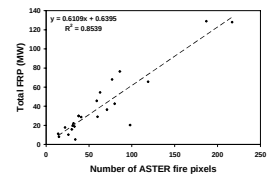
Weak statistical relationship between FRP and dNBR



Total Fire Radiative Power against differential Normalized Burn Ratio averaged over the ASTER fire masks



Adjusted total Fire Radiative Power against differential Normalized Burn Ratio and averaged over the ASTER fire masks



Total Fire Radiative Power against the number of ASTER fire pixels within MODIS pixels

Strong statistical relationship between FRP and fire size

CONCLUSIONS

- instantaneous FRP from MODIS is insufficient for the direct evaluation of burn severity
- FRP is a good indicator of the spatial extent of burning and the integrated biomass consumption rate
- for full fine scale instantaneous fire characterization higher resolution sensors with proper specifications are needed
- multiple observations are necessary to observe smoldering, which accounts for a large proportion of mass consumption, emissions and resultant burn severity
  - moderate resolution sensors (i.e. MODIS) carry inherent uncertainties regarding the location of burning and varying pixel sizes
  - higher resolution sensors on single platforms do not provide observations with necessary frequency -> a constellation of multiple satellites is necessary
- post-fire assessment is necessary for full evaluation of fire severity and impacts

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