Comparison of MODIS-Derived Burned Area Algorithm with Landsat Images in Eastern Siberia, Russia

Wei Min Hao, Bryce Nordgren, Alex Petkov, Rachel E. Corley, Shawn P. Urbanski
US Forest Service, RMRS Fire Sciences Laboratory, Missoula, MT 59808
whao@fs.fed.us, bnordgren@fs.fed.us, apetkov@fs.fed.us, rcorley@fs.fed.us, surbanski@fs.fed.us

ABSTRACT

Considerable efforts were made to verify our MODIS algorithms for mapping burned areas in Siberia. We compared the MODIS-derived burned areas with the Landsat-derived burn scars over eastern Siberia in 2002. The MODIS burned area to Landsat burned area ratio of 1.0 and the minimal standard errors of the slope and intercept of the linear regression equation clearly indicate our MODIS burned area algorithms are reliable for determining burned areas in boreal ecosystems at continental, annual scales. The algorithms are being used to map daily burned areas at a 500 m x 500 m resolution in Northern Eurasia from 2002 to 2011. Emissions of trace gases and aerosol particles (including black carbon) from biomass burning then will be estimated with the same spatial and temporal resolution in Northern Eurasia for the same 10-year period.

1. INTRODUCTION

Global and regional climate has become warmer in the past 160 years, especially since the 1950's [IPCC, 2007]. Global warming is most pronounced in northern high latitude regions. The temperatures have increased in winter and summer seasons in Northern Eurasia between 1881 and 2004 [Groisman et al., 2007]. Northern Eurasia covers 20% of the global land mass and contains 70% of the boreal forest. High latitude temperate and boreal ecosystems are also particularly sensitive to climate changes [Goetz et al, 2007]. Warmer temperatures in these regions have led to less snowfall, an earlier spring season, higher rainfall and river runoff in the spring, and less moisture for soil and vegetation in the summer [Trenberth et al., 2007; Groisman et al., 2007].

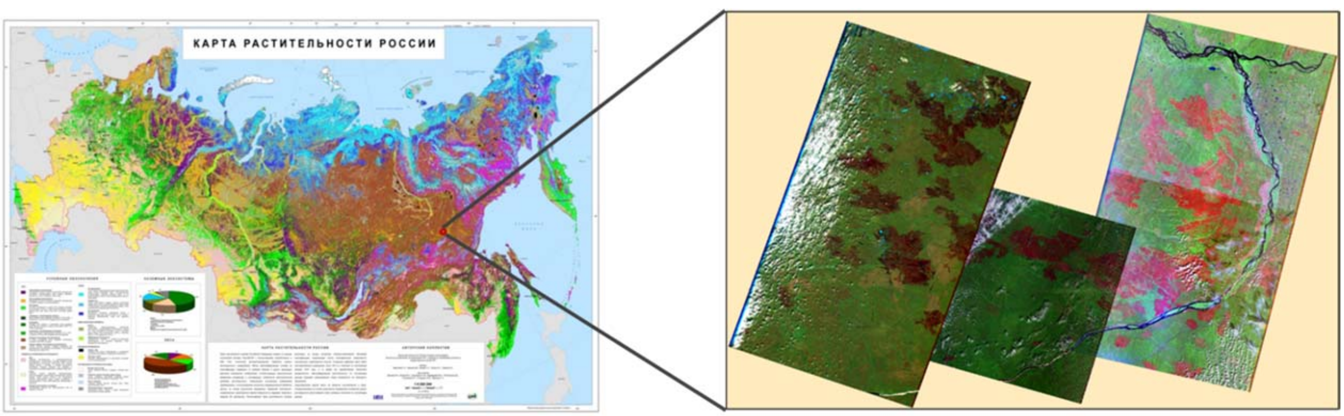
Changing weather and hydrological conditions have created an environment favorable for forest and grassland fires in northern high latitudes. Biomass burning is a significant source of atmospheric trace gases and aerosols [van der Werf et al., 2010], and these emissions significantly influence the chemical composition of the atmosphere [Simpson et al., 2006] and the Earth's climate [Naik et al., 2007]. Biomass burning in Northern Eurasia also may be a significant source of atmospheric black carbon that deposits on Arctic ice and accelerates ice melting.

One of the biggest uncertainties in assessing the impacts of emissions from biomass burning on regional and global atmosphere is the spatial and temporal extent of the location and size of burned areas. Two global burned area datasets were developed based on NASA's MODIS (**Mod**erate Resolution **I**maging **S**pectroradiometer) instruments on the Terra and Aqua satellites [Roy et al., 2008; Giglio et al., 2010]. However, only limited efforts were made to validate the MODIS algorithms for mapping burned areas in Northern Eurasia. We will present the results for comparison of our MODIS-derived burned areas (500 m resolution) with burn scars on high-resolution Landsat images (30 m resolution). This MODIS-derived burned area dataset will be used to develop the 10-year trend on the emissions of trace gasses and aerosols from biomass burning in Northern Eurasia. The results also will be used to study the impacts of biomass burning on black carbon emissions and on ice melting in the Arctic.

2. METHODOLOGY

We selected the area inside the four coordinates (63.9°N, 119.1°E; 63.7°N, 131.6°E; 60.3°N, 119.5°E; 60.1°N, 130.7°E) in eastern Siberia (red dot in Figure 1) for comparison. The area was selected because a severe fire season occurred in 2002 and large areas were burned from May to early October. Only limited relatively cloud-free Landsat images were available over this region. Five Landsat scenes on July 11 (path 126, row 16 and 17), August 30 (path 124, row 17), and October 3, 2001 (path 122, row 16 and 17) were selected as the references for the burn scars prior to 2002. Five Landsat scenes on May 30 (path 126, row 16 and 17), July 19 (path 124, row 17), and July 21 (path 122, row 16 and 17), 2003 were acquired for validation of MODIS-derived burned areas. Landsat burn scars were categorized by computing the normalized burn ratio (NBR) for each scene. The threshold of separating “burned” from “unburned” area was determined by using the Jenks natural breaks algorithm (Jenks, 1967) with 5 classes in these scenes in ArcGIS. The division between the first and second classes was taken to be the normalized burn ratio threshold. Burn scars from a 2001 scene were spatially subtracted from burns scars derived from a 2003 scene to yield the burned areas during the 2002 fire season. It was not feasible to acquire pairs of cloud-free Landsat images at the same time of the year to generate the differenced normalized burn ratio, as was done in the United States.

Figure 1. The land cover map of Russian Federation (provided by the Space Research Institute of the Russian Academy of Sciences) and the Landsat images on May 30, July 19 and 21, 2003 used for validation.



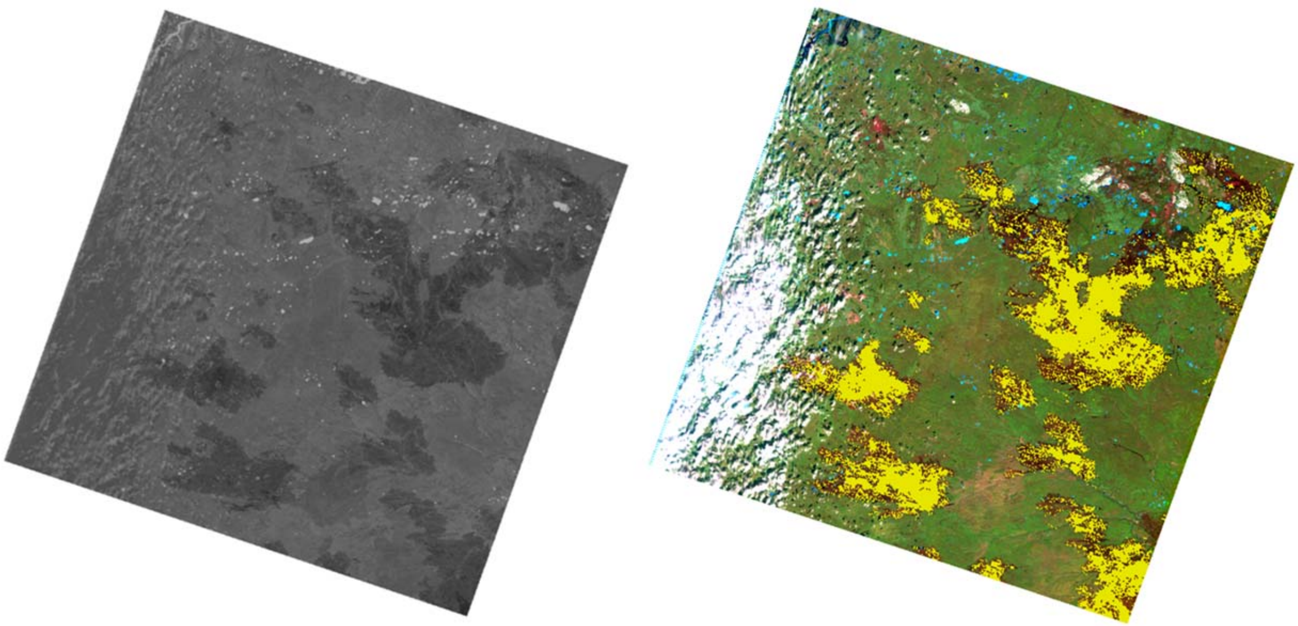
The burned areas (500 m resolution) derived from the MODIS instruments were compared with Landsat images (30 m resolution). The MODIS-derived burned area algorithms were originally developed by the Forest Service, RMRS Fire Sciences Laboratory for the direct broadcast system to map burned areas in near real-time over most of the United States. The methodology has been described in detail [Urbanski et al., 2009; Urbanski et al., 2011]. The methodology is quite different from the approaches of the global burned products [Roy et al., 2008; Giglio et al., 2010]. The mapping of burned areas was based on active fire detections, the surface reflectance in a single MODIS image, and a set of algorithms to remove false alarms (e.g., water, cloud shadow). The burned areas had to be within 5 km and 10 days of detected active fires in order to minimize false identifications of burned areas for boreal ecosystems. The criteria for the distance and the timing between active fire and burned area detections depend on the ecosystems. For the boreal ecosystems dominated by forests, shrubland, and grassland, we found the optimum conditions were 5 km and 10 days. However, the optimized conditions were 3 km and 5 days over the western United States [Urbanski et al., 2011].

The MODIS-derived burned areas and the burn scars of Landsat images were compared in each 3 km x 3 km grid cell. A statistical analysis was performed to understand the correlation of the two datasets.

3. RESULTS

The Forest Service MODIS-derived burned areas were compared with burn scars on the Landsat image (Figure 2b). The burned areas mapped by the MODIS algorithms were mostly consistent with the Landsat burn scars. The burn scars on the upper right corner were detected by Landsat but not by MODIS and the AVHRR satellite [Ponomarev, personal communication]. The area was most likely burned in the late summer of 2001.

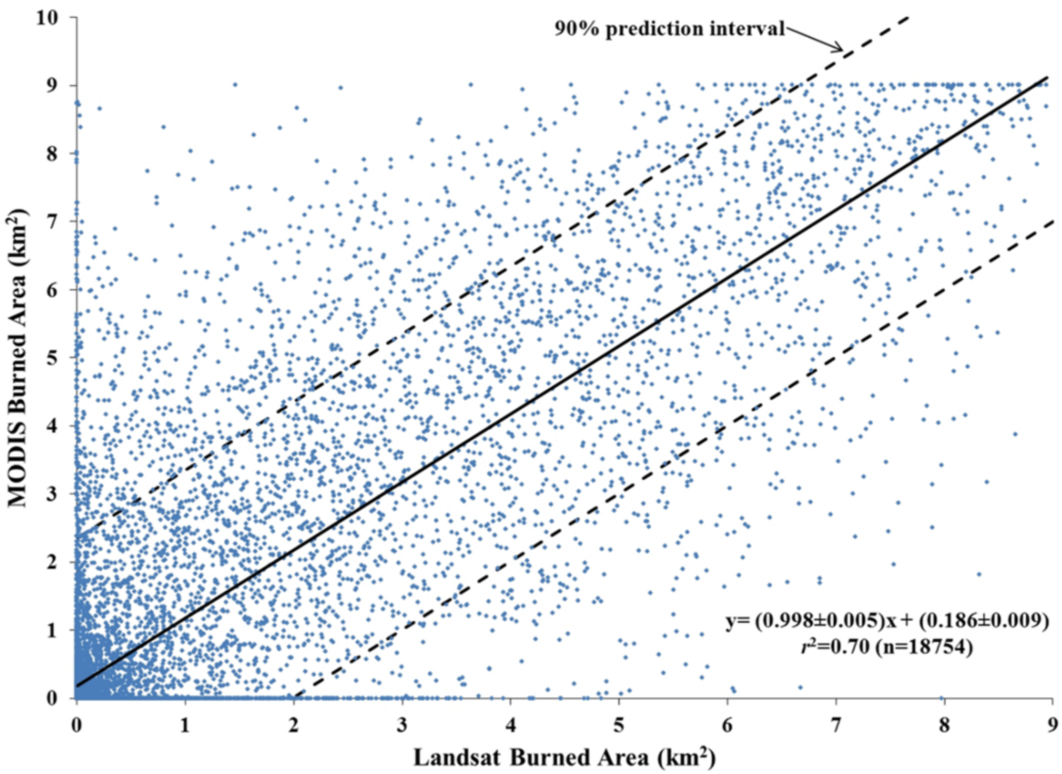
Figure 2. (a) Landsat image on May 30, 2003 (path 126, row 16), (b) overlay of the MODIS-derived burned areas (yellow) with the Landsat scars (dark brown).



(a) (b)

The MODIS-derived burned areas were compared extensively with the burn scars on the Landsat images in 3 km x 3 km grid cells over the area of five Landsat images. The results are shown in Figure 3.The burned areas derived by the two methods are linearly correlated with a slope of 1.0 and a coefficient of determination (r^2) of 0.7 over 18754 grid cells. The slope of 1, the small intercept of 0.186 km^2, the small relative standard errors of the slope (0.5%) and the intercept (4.8%), and the high coefficient of determination clearly indicate our MODIS-derived burned area algorithms can be used confidently for determining burned areas in the forests, grassland, and shrubland in Siberia at continental scales and for time intervals approximately one to two years.

Figure 3. Comparison of MODIS and Landsat detected burned areas.



4. CONCLUSIONS

Extensive research was conducted to ensure the best possible accuracy of our MODIS algorithms for mapping burned areas in Northern Eurasia. We compared the MODIS-derived burned areas (500 m resolution) with the burn scars on the Landsat scenes (30 m resolution) over eastern Siberia in 2002. The results of the comparison with the MODIS burned area to Landsat burned area ratio of 1.0 and the small standard errors of the slope and intercept of the linear regression equation strongly indicate our MODIS burned area algorithms are appropriate for determining burned areas in boreal ecosystems at continental, annual scales. The algorithms will be used to map daily burned areas at a 500 m x 500 m resolution in Northern Eurasia from 2002 to 2011. Emissions of trace gases, aerosol particles, and black carbon from biomass burning then will be estimated with the same spatial and temporal resolution as the burned areas in Northern Eurasia for the same 10-year period.

5. REFERENCES

Giglio, L., J.T. Randerson, G.R. van der Werf, P.S. Kasibhatla, G.J. Collatz, DC. Morton, and R.S. DeFries, "Assessing variability and long-term trends in burned area by merging multiple satellite fire products," Biogeosciences, 2010, 7, 1171-1186.

Goetz, S.J., M.C. Mack, K.R. Gurney, J.T. Randerson, and R.A. Houghton, "Ecosystem responses to recent climate change and fire disturbance at northern high latitudes: observations and model results contrasting northern Eurasia and North America," Environmental Research Letters, 2007, 2, doi:10.1088/1748-9326/2/4/045031.

Groisman, P.Ya., B.G. Sherstyukov, V.N. Razuvaev, R.W. Knight, J.G. Enloe, N.S. Stroumentova, P.H. Whitfield, E. Førland, I. Hannsen-Bauer, H. Tuomenvirta, H. Aleksandersson, A.V. Mescherskaya, and T.R. Karl, "Potential forest fire danger over Northern Eurasia: Changes during the 20th century," Global Planet. Change, 2007, 56, 371-386.

IPCC, "Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change" [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007, 996 pp.

Jenks, G.F., "The data model concept in statistical mapping," International Yearbook of Cartography, 1967, 7, 186-190

Naik, V., D.L. Mauzerall, L.W. Horowitz, M.D. Schwarzkopf, V. Ramaswamy, and M. Oppenheimer, "On the sensitivity of radiative forcing from biomass burning aerosols and ozone to emission location," Geophys. Res. Lett., 2007, 34, L03818, doi:10.1029/2006GL028149.

Roy, D.P., L. Boschetti, C.O. Justice, and J. Ju., "The collection 5 MODIS burned area product – Global evaluation by comparison with the MODIS active fire product," Remote Sensing of Environment, 2008, 112, 3690-3707.

Simpson, I.J., F.S. Rowland, S. Meinardi, and D.R. Blake, "Influence of biomass burning during recent fluctuations in the slow growth of global tropospheric methane," Geophys. Res. Lett., 2006, 33, L22808, doi:10.1029/2006GL027330.

Trenberth, K.E., P.D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A. Klein Tank, D. Parker, F. Rahimzadeh, J.A. Renwick, M. Rusticucci, B. Soden, and P. Zhai, "Observations: Surface and Atmospheric Climate Change. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change" [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007.

Urbanski, S.P., J.M. Salmon, B.L. Nordgren, and W.M. Hao, "A MODIS direct broadcast algorithm for mapping wildfire burned area in the western United States," Remote Sensing of Environment, 2009, 113, 2511-2526.

Urbanski, S.P., W.M. Hao, and B. Nordgren,"The wildland fire emission inventory: western United States emission estimates and an evaluation of uncertainty," Atmos. Chem. Phys., 2011, 11, 12973-13000. doi:10.5194/acp-11-12973-2011.

van der Werf, G.R., J.T. Randerson, L. Giglio, G.J. Collatz, M. Mu, P.S. Kasibhatla, D.C. Morton, R.S. DeFries, Y. Jin, and T.T. van Leeuwen, "Global fire emissions and the contribution of deforestation, savanna, forest, agricultural, and peat fires (1997-2009)," Atmospheric Chemistry and Physics, 2010, 10, 11707-11735.

KEY WORDS

Biomass Burning

Burned Areas

Landsat

MODIS

Northern Eurasia

Emissions

Black Carbon