USGS
science for a changing world

Modeling Boreal Forest Performance With MODIS, Site Characteristics, and Weather to Monitor Climate, Management, and Disturbance Impacts.

B43C-0388

B. K. Wylie[1], K. Murnaghan[2], J. A. Rover[1], L. L. Tieszen[1], B. Brisco[2]
[1]U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center, Sioux Falls, SD, USA.
[2]NRCan/ESS/CCRS/EOGD, Ottawa, ON, Canada.

Introduction

High-latitude ecosystems are experiencing the effects of climate change at higher rates than other regions of the globe (Corell 2006), making 30% of the terrestrial carbon in boreal forest vulnerable (Chapin et al. 2000). Increasing fire frequencies and intensities have reduced the productivity of boreal forests (Rupp et al. 2002), and declining productivity of these systems related to fire and other factors has been quantified with remote sensing (Goetz et al. 2005). By accounting for changes in boreal forest productivity related to interannual variations in weather, performance anomalies identified stressed boreal areas (Wylie et al. 2007). The performance anomaly approach is applied to boreal forests within the Yukon River Basin (Figure 1) using 250 m eMODIS data to assess boreal forest areas affected by disturbances or other stresses such as a wetting or drying system. Underperfroming anomalies were prevelant in fires which occurred in the previous decade. Older fires, prior to 1990, often had increasing trends in performance anomaly showing post fire succession and recovery.

Methods

The Normalized Difference Vegetation Index (NDVI) was used as a proxy for vegetation production. The eMODIS NDVI products (http://lca.usgs.gov/lca/emodisak/index.php) were temporally smoothed to remove residual effects of persistent clouds (Swets et al. 2000) from the 7-day NDVI maximum value composites. Growing season NDVI (GSN) was derived by averaging smoothed NDVI from May 1 to October 1.

A regression tree "boreal performance model" was developed to predict GSN from respective years from over 15,000 random boreal forest pixels which had not previously burned and were stratified across productivity gradients and across years. The regression tree model had the basic form

GSN = f(site potential, weather)

where GSN and weather were from specific years. Site potential was the long-term unburned NDVI as mapped by regression trees models (R^2 =0.49) from more temporally stable variables of permafrost, surface geology, elevation, slope/aspect, domain clusters (Saxon et al. 2005), compound terrain index, and other datasets (Wylie et al. 2008, Figure 1). Monthly weather maps (McKenny et al. 2006) for precipitation, maximum temperature, and minimum temperature were summarized into seasonal periods, winter, early summer, late summer, and fall for the specific years. Other weather data included growing degree days and precipitation for three months prior to the growing season, weeks 1-6 of the growing season, week 7 to the end of the growing season, and the total growing season.

Results

The boreal performance model confidence intervals were used to determine thresholds for anomalous pixel performance relative to weather-based expected values. GSN observations greater than the 90% confidence interval were considered overperforming anomalies, while those less than the 90% confidence interval were underperforming anomalies (Figure 2).

The performance anomalies were mapped for each year from 2000 to 2005 by comparing predicted boreal performance and actual GSN for each year. Persistent anomalies were indentified across the six years (Figure 3). Underperforming anomalies which persisted 6 or 5 years aligned well with fire perimeters before the study period (fires from 1991 to 2000).

Fires that occurred in 2004 and 2003 were dominated by underperforming anomalies which persisted two or three years between 2003 and 2005 (white color in Figure 3). The agreement between the Monitoring of Trends in Burn Severity (Landsat) fire perimeter for the Lower Mouth fire in the southern Yukon Flats in 2005 is striking (Figure 4). Apparently, this fire continued to expand in the late fall of 2004 when 2004 GSN would be minimally affected by late season disturbances.

At a 2003 fire, persistent underperforming for 3 years from 2003 to 2005 extended beyond the Bureau of Land Management fire database (http://agdc.usgs.gov/data/blm/fire) perimeter but was verified in 2005 Landsat imagery (Figure 5). The fire perimeters are sometimes mapped before the fire is entirely out, and in this case, the fire extended beyond the perimeter not only at the black oval in Figure 5 but also in areas west and north of the black oval.

Overperformance is harder to validate than underperformance, where fires often provide known stand replacing disturbances and dates. Postfire boreal succession often includes a deciduous shrub or tree phase dominated by birch or aspen. This deciduous phase may persist in more intense areas of burns where the soil organic layer was reduced or eliminated. The red circle in Figure 5 is an area which is not related to a known fire perimeter but appears to be deciduous dominated both in 2001 and 2005 from the Landsat imagery. This area was classified as a deciduous forest in the National Land Cover Database 2001 (http://www.mrlc.gov) and appears to be a historical fire scar.

Persistent overperforming anomalies also occur along bends in the Porcupine River (Figure 6) where they are offered some protection from fires.

De-trending for interannual weather effects on boreal forest systems provides a consistent dataset for trend analysis (Y = performance anomaly and X = years). Trends of performance anomalies should not reflect trends in weather (like droughts) but focus on trends related to disturbance and succession. The significant negative trends (negative slopes or ecosystem productivity declining over time) are associated with fires which occurred during the latter period of our analysis (2003 and 2004; Figure 7). Fires that occurred prior to the study period (< 2000) show scattered positive trends related to postfire succession.

Conclusions

The separation of weather-related effects of vegetation improves the understanding of the ecosystem over just GSN time series analysis. Not only can the trends and persistence of performance anomalies be investigated but also the trends and persistence of weather-driven vegetation impacts. This approach will identify areas vulnerable to transitioning to new steady state systems and can be applied (at least for weather-driven impacts) to future climate scenarios. This approach provides useful information on boreal forest resiliency needed to address climate change and changing permafrost in these systems.

References

Chapin, S. F., D. A. McGuire, J. Randerson, R. Pielke, D. Baldocchi, E. S. Hobbie, N. Roulet, W. Eugster, E. Kasischke, B. E. Rastetter, A. S. Zimov, and W. S. Running (2000), Arctic and boreal ecosystems of western North America as components of the climate system, *Global Change Biology*, 6, 211–223.

Corell, R. W. (2006), Challenges of climate change: an Arctic perspective, *Ambio*, 35, 148–152.

Goetz, S. J., A. G. Bunn, G. J. Fiske, and R. A. Houghton (2005), Satellite-observed photosynthetic trends across boreal North America associated with climate and fire disturbances, *Proceedings of the National Academy of Sciences*, 102, 13521–13525.

McKenny, D. W., J. H. Pedlar, P. Papadopol, and M. F. Hutchinson (2006), The development of 1901-2000 historical monthly climate models for Canada and the United States, *Agricultural and Forest Meteorology*, 138, 69–81.

Rupp, T. S., A. M. Starfield, F. S. Chapin, III, and P. Duffy (2002), Modeling the impact of black spruce on the fire regime of Alaskan boreal forest, *Climate Change*, 55, 213–233.

Saxon, E., B. Baker, W. Hargrove, F. Hoffman, and V. Zganjar (2005), Mapping environments at risk under different global climate change scenarios, *Ecological Letters*, 8, 53–60.

Swets, D. L., B. C. Reed, J. D. Rowland, and S. E. Marko (2000), A weighted least-squares approach to temporal NDVI smoothing, in Proceedings of the 1999 ASPRS Annual Conference, From Image to Information, Portland, Oregon, May 17–21, 1999 (Bethesda, MD: American Society for Photogrammetry and Remote Sensing, CD-ROM).

Wylie, B. K., L. Zhang, N. B. Bliss, L. Ji, L. L. Tieszen, and W. M. Jolly (2008), Integrating modelling and remote sensing to identify ecosystem performance anomalies in the boreal forest, Yukon River Basin, Alaska, *International Journal of Digital Earth*, 1, 196–220.

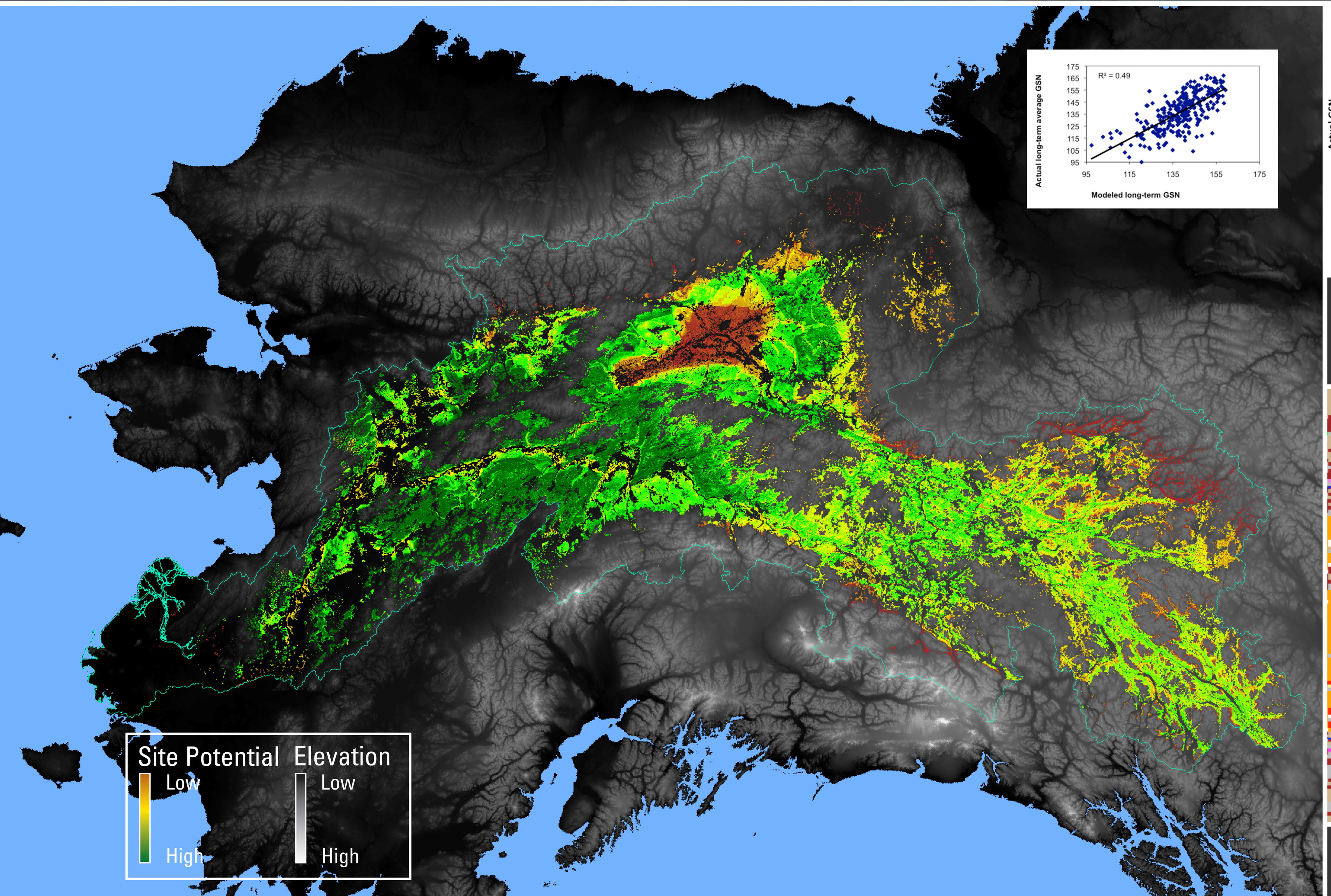

Figure 1. Long-term boreal forest site potential for the Yukon River Basin of Alaska and Canada.

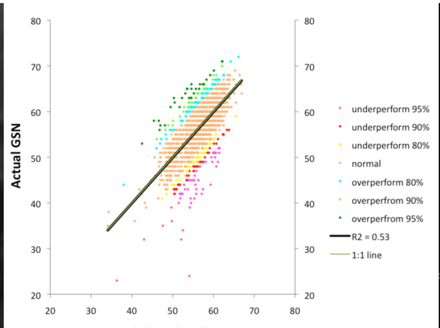

Figure 2. Boreal performance model: 2000–2005 (n = 15,049, every 10th observation shown).

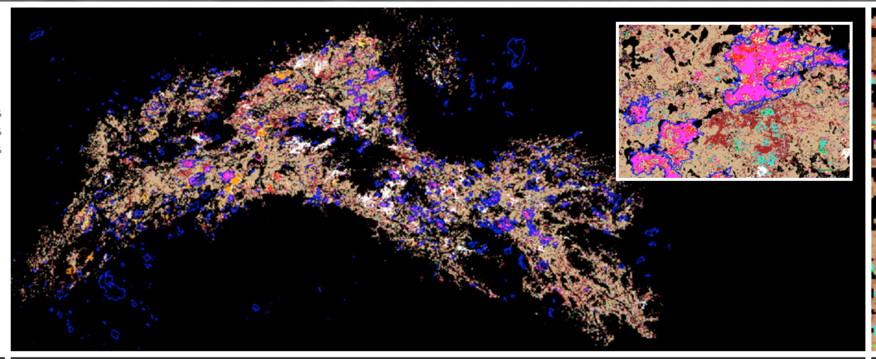

Figure 3. Persistent performance anomalies from 2000 to 2005 and from 1991 to 2000; fire perimeters are outlined in blue.

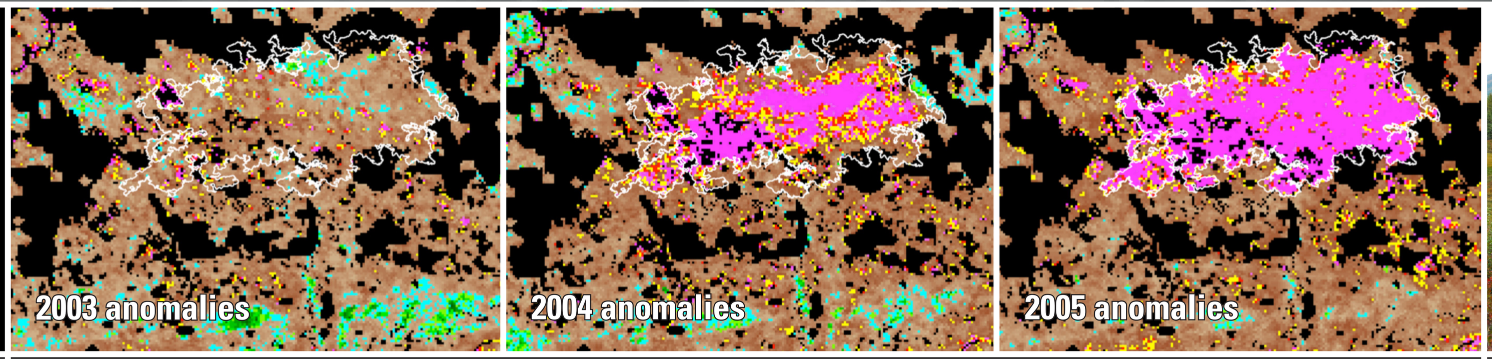

Figure 4. Performance anomalies align with fire effects for a 2004 fire (Lower Mouth).

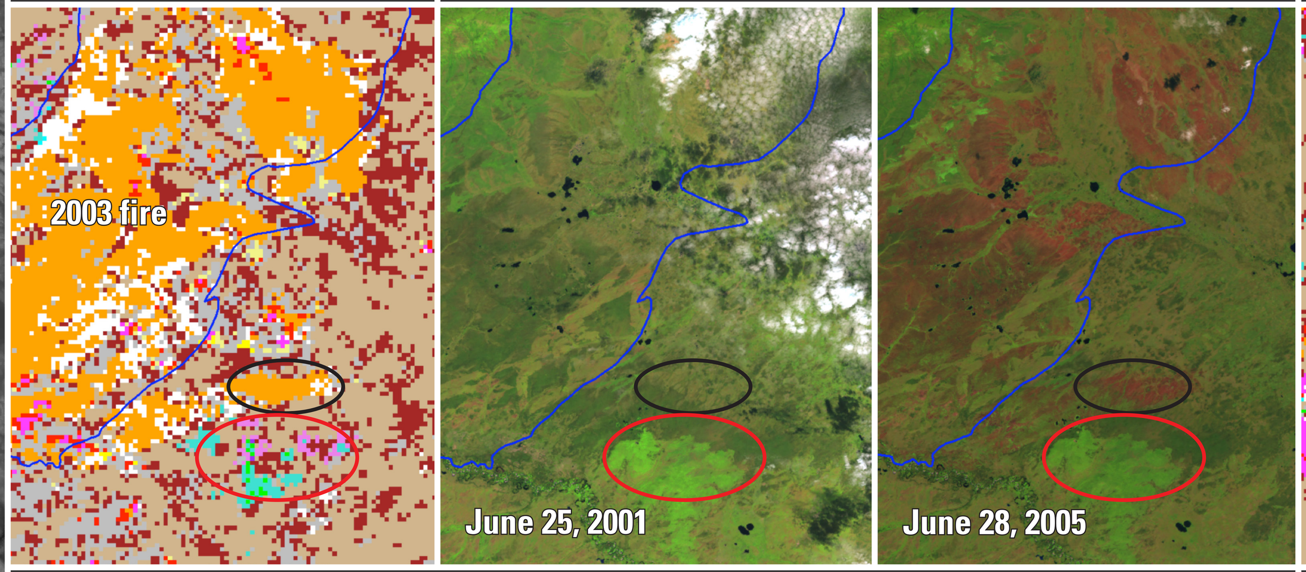

Figure 5. Burn extents beyond fire perimeter are identified by persistent underperforming anomalies (underperform all 3 years from 2000 to 2002) and Landsat imagery.

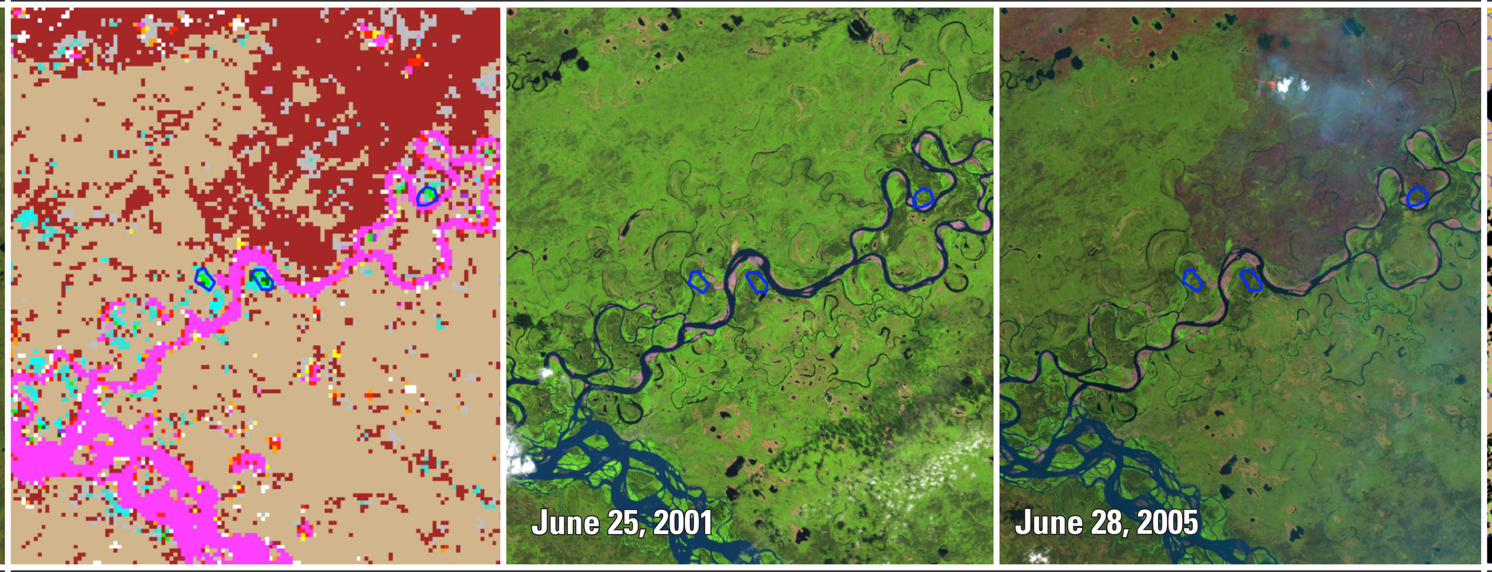

Figure 6. Persistent overperforming anomalies (outlined in dark blue) often occur in protected river bends, oxbows, winding tributary streams, and areas of moist soil.

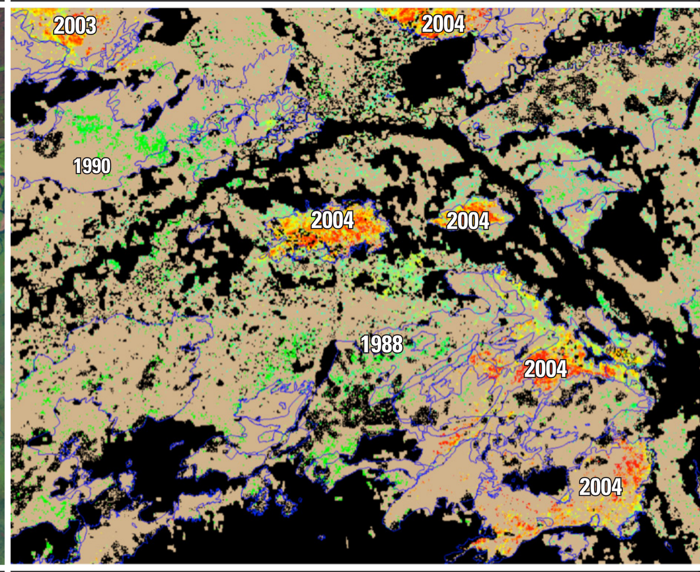

Figure 7. Declining performance anomalies linked to 2003 and 2004 fires, which occurred late in the time interval studied. Fires from 1965–2005 are outlined in blue.

U.S. Department of the Interior
U.S. Geological Survey

December 2009