Application of MODIS to Resolve the Effects of Global Change on Boreal Forest C Dynamics: Disturbance versus Climate Warming?

Shawn P. Serbin
Douglas E. Ahl
Stith T. Gower

Department of Forest Ecology and Management
University of Wisconsin-Madison
http://forestecology.forest.wisc.edu
contact: stgower@wisc.edu

SUMMARY

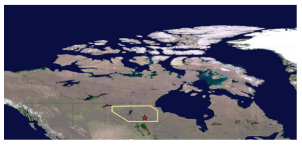
This study builds on Gower's 10 years of boreal forest carbon research in the BOREAS northern Study Area (NSA) that includes the BOREAS, BigFoot, BEx-FIRE, and BEx-WARM project. Gower is the PI of BEx-FIRE, a NSF Integrated Research Challenges in Environmental Biology grant ($3,000,000) that is examining changes in species composition, structure, and function for well- and poorly-drained, boreal forest wildfire chronosequences. BEx-FIRE provides all the necessary field measurements of vegetation canopy dynamics, including the labor-intensive site and species-specific allometric equations required to directly estimate leaf area and net primary production. The objective of this study is to use MODIS to quantify three critical vegetation canopy parameters that influence CO_2 exchange between boreal forests and the atmosphere, and are strongly affected by two dominant aspects of global change of boreal forests: wildfire and climate warming. The three research questions, and their scientific importance, are:

- Can MODIS accurately measure (i) early growing season "green-up" or phenology; (ii) inter-annual changes of vegetation composition and LAI of aggrading boreal forest stands following disturbance; and (iii) vegetation composition and LAI of different-aged and contrasting drainage?

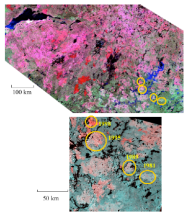
- Does light use efficiency change during boreal forest stages of succession, and if so, can it be correlated to changes in forest canopy structure and chemistry? We will quantify the relationships between changes in overstory and ground cover vegetation composition to changes in chemistry. These data will be used to provide a physiological basis for our hypothesized differences in (i) canopy reflectance and (ii) light use efficiency among the different-aged stands.

- Can MODIS reflectance data be used in combination with historic AVHRR data to quantify the contribution of the recent increase of NDVI for boreal regions (Zhou et al. 2001, Tucker et al. 2001) to the direct effect of climate warming on early green-up versus the indirect effects of increased fire frequency and canopy reflectance.

STUDY AREAS



The study sites will include eight stands comprising well- and poorly drained boreal forest chronosequences located near Thompson, MB (red). The stand ages include 1, 6, 10, 15, 23, 40, 74 and 154 years. A regional analysis will cover much of northern Saskatchewan and Manitoba (yellow).



MODIS surface reflectance image from July 2002. Much of the red/magenta areas are young regenerating stands from past forest fires

July 2002 Landsat ETM+ showing 4 of the 8 proposed sites of the forest fire chronosequence.

APPROACH

The sampling design is based upon a variogram analysis completed for each chronosequence. The analysis, which proved effective during the BigFoot project for the NOBS study site (Burrows et al. 2002, 2003), producing a compromise between optimal spectral characteristics and feasibility. The design consists of two 3km transects in each chronosequence; installed pre-growing season 2004. The transects run parallel to each other 100m apart in a spectrally representative region of the burn. Plots in each transect are 150m apart for a total of 40 plots per chronosequence site.

We will measure LAI using standard direct and indirect optical methods at each plot within the transects located installed in the study stands. Maximum LAI of the overstory and understory will be measured directly using site- and species specific allometric equations, developed for the trees and shrubs at the chronosequences. FAPAR and LAI will also be estimated indirectly using the Li-Cor LAI-2000 Plant Canopy Analyzer, and LI-191SA radiation sensors.

We will measure NPP of all vegetation strata (overstory, understory and ground cover) at the well- and poorly drained stands comprising the chronosequences using well-tested methods for these boreal forests.

Hypothesis: Light use efficiency decreases in boreal forests as the overstory forest composition changes from predominantly deciduous to evergreen conifer.

Hypothesis: MODIS can accurately measure changes in FAPAR and LAI (i) across different-aged and drainage classes of boreal forest stands in the wildfire chronosequences and (ii) year-to-year increases in FAPAR and LAI of young stands as they aggrade.

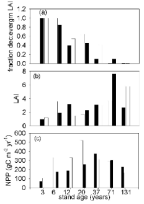


Figure 1. a) Comparison of the ratio of LAI comprised by deciduous:evergreen conifers, b) total LAI and c) total net primary production (NPP) for seven stands comprising the well drained (dark bars) and poorly drained (open bars) wildfire chronosequences for BEx-Fire.

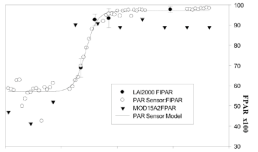


Figure 2. Leaf expansion of a northern hardwood forest in Wisconsin as captured by MODIS, LAI-2000, and a single quantum sensor (Ahl et al., in prep)

Our previous work in northern Wisconsin (Figure 2) demonstrated how difficult it is to capture the short duration, and relatively unpredictable "green-up" periods. We will use an automated system to capture phenology along with indirect LAI-2000 and direct methods to measure FAPAR and LAI to test our hypotheses.

Hypothesis: Leaf budburst or "green-up" will occur earlier in the deciduous-dominated early successional forests than in the evergreen conifer dominated late successional forests.

A regional analysis will be conducted by extending our results from the intensive field measurements within the chronosequences in order to examine burn phenology across northern Manitoba and Saskatchewan. In addition, we will use burn information from existing databases and extract spectral signatures of historical burns from MOD09 and MOD43 surface reflectance products and MOD15 LAI and FAPAR products. Data will be compiled for each day or period quality data are available for the study area.

Hypothesis: Wildfire is the dominant factor influencing phenological changes as observed by satellite for the past 20 years across northern Manitoba and Saskatchewan

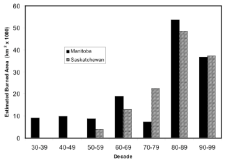


Figure 3. Estimated forest fire burn area by decade for Manitoba and Saskatchewan (Rapalee and Nickeson 2001). Data for Saskatchewan include only years 1950-1996.

PRELIMINARY RESULTS

- Normalized Difference Vegetation Index (NDVI) data measured by MODIS in 2004 show the general phenology patterns for four of the chronosequence sites, burned in the years 1964, 1981, 1989, and 2003.
- The 1964 burn exhibited the highest initial NDVI values, however both this burn at that from 1981 show a less distinct spring transition likely due to the advanced conifer regeneration.
- Onset of greenness can be unpredictable and appears to vary considerably, backed by our preliminary field measurements, which may indicate the influence of spatial heterogeneity and species variability.

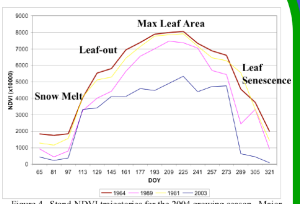


Figure 4. Stand NDVI trajectories for the 2004 growing season. Major phenologic periods are indicated and each line represents a different aged burn showing the variation between early and later successional stands.

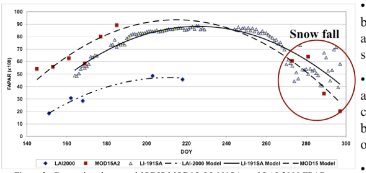


Figure 5. Comparison between MODIS MOD15, LI-191SA, and LAI-2000 FPAR values for a 16 year old stand.

- Generally, we found a good agreement between the LI-191SA radiation sensors and MOD15 FPAR values for the study sites.
- Significant understory development and temporal compositing may contribute to the discrepancies found between the MOD15 product and optically field measured FPAR and LAI.
- MODIS MOD09 NDVI data appear to successfully capture the increase in plant biomass throughout the growing season (Fig. 6).

Field Season 2005 Tasks

- Adjust sampling transects, increasing spatial extent and reducing issues of autocorrelation.
- Increasing spatial and temporal coverage of the radiation sensors; improving FAPAR estimates.
- Measure Net Primary Production (NPP) of all vegetation strata at the well- and poorly drained stands.
- Estimate Light Use Efficiency (LUE) for the different aged burn classes.
- Measure foliage nitrogen and chlorophyll content for the dominant over- and understory species.

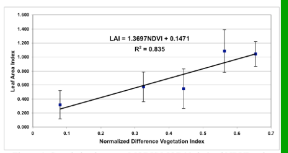


Figure 6. Correlation between MODIS MOD09 derived NDVI and optically measured LAI within a 16 year old stand. Error bars represent the average variation in measured LAI for each sampling period.

More Information

On the web @ http://forestecology.forest.wisc.edu/

Selected References

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