Climate change, forest disturbance and carbon retention

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Carbon retention is an important aspect of sustainable forest management and mitigating future climate change. Forest ecosystems contain 1146 Pg C. Various large scale naturally occurring disturbances can have large impacts on forest ecosystems and their carbon cycles. Fire results in global CO2 emissions of 2 to 4 Pg C y-1. As forest ecosystems respond to climate change, changes in disturbance regimes are likely to impact carbon management in a non-linear manner. Failure to include analytical approaches for quantifying and forecasting the impact of disturbances, such as fire, in planning for sustainable forest carbon management will significantly lessen the utility of that planning.

Remote Sensing (RS) technologies are a critical component of the needed analytical approaches, since climate change impacts and seasonal through inter-annual variability of disturbance regimes should be monitored on a global basis. Additionally, Geographic Information System (GIS) technologies that focus on tracking forest carbon cycles and carbon projects will be central to successful monitoring and cataloging changes in forest carbon stocks.

Key Words: Climate; Forests; Carbon; Disturbance; Response

Introduction

Climate change and Sustainable Forest Management share many areas of common interest. Carbon retention in forest ecosystems is a particularly important one. Forest ecosystems contain (vegetation and soil) 1146 Pg C, cover approximately 4 Billion ha of land, with a net flux to the atmosphere estimated as 1 Pg C y-1 (Dixon et al. 1994). Maintenance of forest contributions to global carbon cycles is a key criterion for Sustainable Forest Management (SFM) (Montreal Process, 2007). Forest carbon is likely to assume a much more important role in the 2009 United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties (COP) 15 (Copenhagen) than it did in the 1997 COP 3 (Kyoto). Natural Resource managers will need to monitor and report changes in forest carbon retention to account for forest contributions (positive and negative) to reduce Greenhouse Gas (GHG) emissions (Brown et al., 2008). These same managers can also expect climate change related increases in wildland fires and other ecosystem disturbances (IPCC WG II, 2007). Disturbances resulting from fire, insect and disease outbreaks, wind damage, salt water penetration and other climate change influenced environmental variables are recognized as agents that modify forest carbon cycling. Improved knowledge of how ecosystem disturbance regimes will be altered by climate change (Dale et al., 2001) is important for improved forest carbon monitoring over time. Carbon loss from disturbance risk should be included in all UNFCCC carbon accounting methodolgies.

Carbon accounting methodolgies will increasingly incorporate remote sensing (RS) technologies in order to provide global, regional and national coverage and to rapidly update after disturbance occurrences (Brown et al., 2008). RS data utility and acceptance are enhanced when complemented by in situ observations based on both inventory and flux approaches. Goals for increased forest carbon sequestration are more realistic when supported by historic inventory analyses of national forest stocking trends (Birdsey et al. 2006). These national forest inventories can then be aggregated with supplemental data sets to produce hemispheric estimates (Goodale et al., 2002). Incorporation of multiple time varying data sources that are

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geographically referenceable requires application of GIS technologies (Falloon et al., 1998) to support carbon retention efforts.

Material and Methods

The 1992 United Nations Conference on Environment and Development (UNCED) (UNCED, 1992) produced both a Statement of Forest Principles and the UNFCCC as part of an agenda to ensure sustainable development. Canada convened a 1993 International Seminar of Experts on Sustainable Development of Boreal and Temperate Forests, which, in turn, lead in 1994 to the first meeting of the Montreal Process Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests (SFM C&I) (Montreal Process, 2009). While the climate change and sustainable forest management communities have not worked in close association in the 17 years since UNCED, carbon has remained a common link and one that is drawing the environmental siblings together as mitigative and adaptive responses to climate change are receiving heightened attention. Maintenance of forest contribution to global carbon cycles is Criterion 5 of SFM C&I, with three associated Indicators: 5.22 Total forest ecosystem carbon pools and fluxes; 5.23 Total forest product carbon pools and fluxes; 5.24 Avoided fossil fuel carbon emissions by using forest biomass for energy. These three indicators are somewhat modified from the earlier Criterion 5 Indicators (26, 27, and 28) and better reflect that forests exist within a context of the global environment and the world's economic and social activities. Indicator 5.22 covers the role that forest disturbance plays in relation to climate change and carbon retention. Forest ecosystem carbon stocks in the United States are estimated, based on Forest Inventory data, at over 165 Pg C (Fig. 1), with live trees and soil organic carbon accounting for the majority of this stock (USDA Forest Service, 2008).

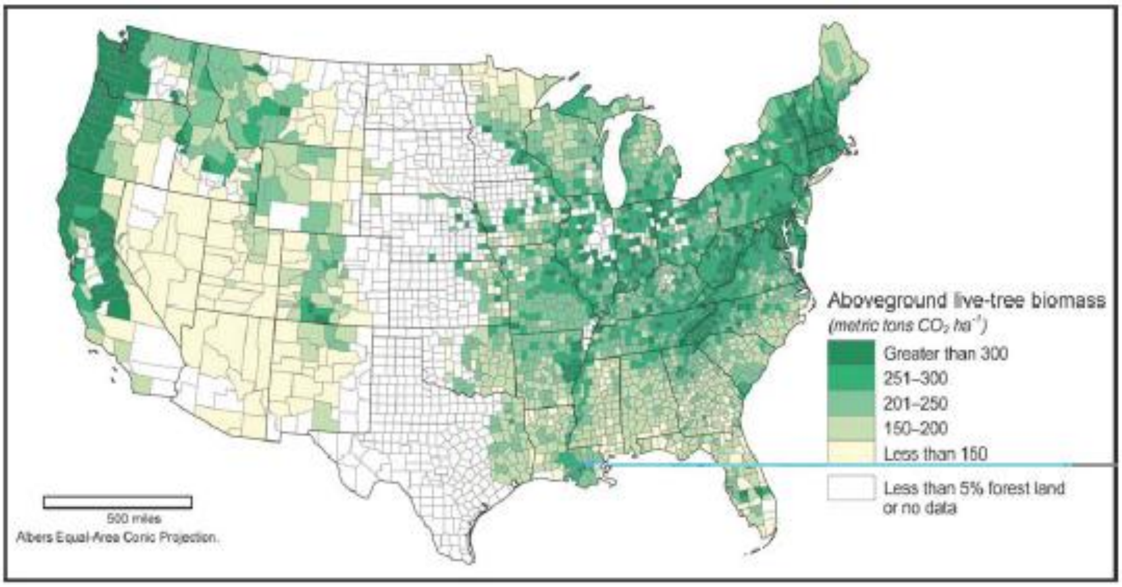

Figure 1. Forest aboveground live biomass carbon stocks by county for United States, 2006. (USDA Forest Service, 2008)

Various large scale naturally occurring disturbances (fire, insect and disease, wind, flood, volcanic eruptions) can have large impacts on forest ecosystems (Foster et al., 1998), being fundamental to the development of their structure and function (Attiwill, 1994). Direct human intervention disturbances, lumped under the land use, land use change and forests (LULUCF), while also of importance, are not directly considered in this paper.

Results and Discussion

Fire is the most globally ubiquitous natural disturbance . Today, only 15% of the World's terrestrial ecoregions are considered fire independent (The Nature Conservancy, 2007). Fire results in global CO2 emissions of 2 to 4 Pg C y-1, which at the high end equates to about 50% of annual emissions attributed to fossil fuels (IPCC WG I, 2007). Carbon retention may become a more accurate measure of fire management peformance than acreage burned or number of fires. Fire has played an important role in Earth history since terrestrial vegetation appeared and must be better represented in global models (Bowman et al., 2009). Fire has shaped postglacial forest development under climate change and human intervention, with fire regimes in turn being modulated by post-fire vegetation succession (Higuera et al., 2009). A strong nonlinear relationship between climate and fire is evident (van der Werf, 2008) meaning it is probable that fire can act as a nonlinear accelerator of climate driven forest change in the years ahead. The geographic distribution of fire can be better understood on a global basis using quantitative techniques (Krawchuk et al., 2009) that emphasize the importance of climate conditions and fuel availability in determining the tendency of current ecosystems to be fire prone or not. Extension of these statistical results using climate model outputs indicates a future with potentially widespread impacts of climate change on fire and severely altered fire regimes, albeit with significant regional variability. Increased fire activity has already been statistically attributed to warmer winter temperatures and earlier snowmelt (Westerling et al., 2006)

Warmer winter temperatures are also expected to increase insect damage to forests in many areas as a result of changed insect population dynamics (Tran et al., 2006). On other areas, significant recent outbreaks appear to be related to extremely high summer temperatures (Berg et al., 2006). While global counts of CO2 emissions directly associated with forest insect and disease outbreaks are not available, a recent mountain pine beetle outbreak in British Columbia, Canada is estimated will cause a two decade cumulative effect of .27 Pg C from 374,000 km2 of affected forest (Kurz et al., 2008). Whether insect and disease outbreaks pre-condition forest fuels for greater susceptability to large fires is a long standing area of interest that takes on more urgency in view of climate change. Analyses of areas suffering spruce budworm caused tree mortality in eastern Canada (Fleming et al., 2004) indicate significant temporal and spatial variability in subsequent fire activity.

While global counts of CO2 emissions associated with forest damage from wind, ice and other storm effects are not currently available, a recent study of tropical cyclone (hurricane) damage to U.S. forests resulted in 53 Tg C annual biomass loss on average with an average carbon release of 25 Tg C year-1 (Zeng et al., 2009). The impacts of tropical cyclones on coastal ecosystems are of particular importance because almost half of the World's population depends on those areas for livelihood (Stanturf et al., 2007). In addition to direct wind damage, storm surge and salt water intrusion impact coastal forests. Each of these factors may increase in severity with climate change induced sea level rise and tropical storm pattern change. Wind events other than tropical cyclones, are also known to impact large areas of forest through blow down events. A convective storm event in 1999 affected up to 150,000 ha of forest in northern Minnesota, USA (Woodall and Nagel, 2007), increasing the amount of dead fuel on the forest floor ten fold (Frelich and Carlton, 2000).

The impact of most forest disturbance regimes and/or events is modified by management actions, with fire management and pre and post disturbance timber removal being among the most signiifcant. Fire management includes actions such as hazard reduction thinning, prescribed burning and fire incident suppression. If successful, all of these fire management actions are intended to increase the retention of carbon, especially in the form of merchantible timber, over time. However, long term fire suppression has been shown to alter forest ecosystems (Shang et al. 2007) and is held responsible (USDA Forest Service, 2009), as a result of hazardous fuel accumulations, for a significant increase in fire activity in the United States in the last decade of so (Fig. 2). This major increase in fire activity has occurred at a time when receipts from National Forest timber sales and demographic factors categorized under the Wildland Urban Interface (WUI) terminology have greatly increased the economic burden of fire suppression (Sommers, 2008). The relative importance of climate change and ecosystem modification from years of fire suppression is a topic of considerable interest. Post disturbance interventions after fire, insect outbreaks, and wind storm damage to remove downed timber in order to salvage its commercial value and reduce fuel availability for future forest fires are significant management actions that affect carbon stocks both in terms of immediate removal, with potential long term sequestration in wood products or landfills, and the reduced likelihood of future carbon emissions from fire.

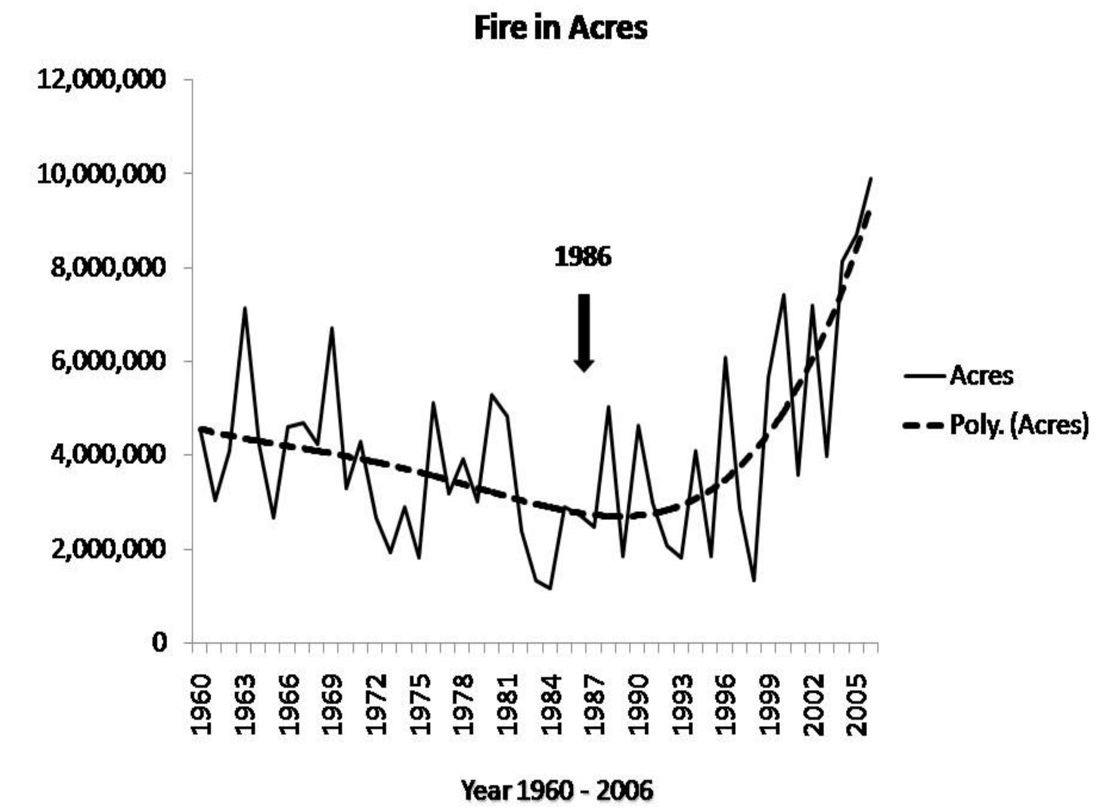

Figure 2. Annual acres burned totals have increased significantly in the United States during the last decade. (Sommers, 2008)

Source: NIFC
http://www.nifc.gov/fire_info/fires_acres.htm

Forest disturbances are known to be prime factors in shaping forest ecosystems, with clear but complex impacts on forest carbon retention, and with demonstrated links to weather and climate.

All major ecosystem classification systems, such as Holdridge Life Zones (Holdridge, 1947), relate forest and other terrestrial ecosystems to climate variables. They also serve as the major link for interpreting General Circulation Model (GCM) outputs in terms of future ecosystem responses. Simply put, for any geographic location where future climate differs from present climate future ecosystems will differ from present ecosystems. However, since both GCMs and ecosystem classifications represent hypothetical equilibrium conditions, they shed little direct light on how current ecosystems will transition to future conditions. Fire and other disturbances are known to have influenced past changes in forest ecosystems subject to climate stress (Bowman et al., 2009).

Forest disturbances, with the exception of insect outbreaks, are usually the direct result of weather events. There are some indications that weather events associated with some forest dusturbances will be become more frequent and/or of greater magintude with climate change (IPCC WG I, 2007). Convective storms and tropical cyclones are the most frequently cited possibilities. Insect population dynnamics are related to climate variations (Tran, 2007) and large fires to seasonal through multi-year drought (van der Werf, 2008). All major fires, certainly those of ecosystem altering magnitude, occur in conjunction with synoptic scale weather events that bring mositure, temperature and wind readings at the extreme tail end of meteorological variable distributions (Moritz, 1997). Fire is an ecosystem process that is global in nature, impacts most forest ecosystems, has been studied in terms of both climate and weather, and is likely to be the most significant disturbance consideration in regard carbon sequestration (Kashian et al., 2006). Fire is likely to be an agent of change as forests convert under new climate conditions to different forest types or to non-forest ecosystems. Under certain regional warming and drying scenarios, savanification of some forest ecosystems is likely. As changing climate results in changing forest ecosystems carbon retention will be affected both in terms of release during disturbance events and in terms of the carbon retention potential of the new ecosystems. Evidence is mounting (Krawchuk et al., 2009) that climate change is likely to result in severly altered fire regimes with consequent carbon retention impacts.

Responses to climate change are usually categorzed under mitigation and adaptation, the former roughly referring to ways to limit or reduce future climate change and the latter to ways to adapt to, or cope with, already programmed (due to climate system inertia) and additional future climate change. Mitigation dialogue is largely subsumed by energy sector options, but forest sector contributions remain under discussion with likely greater inclusion in future internationally agreed to efforts. Increased retention of forest carbon is seen as an important aspect of climate mitigation options, with the potential to both limit the estimated 20 to 25% of total global greenhouse gas emissions attributed to deforestation and degradation and to increase sequestration through afforestation funded by carbon offset trading. A potential to sequester an additional 87 Pg C by 2050 in global forests has been proposed (Watson et al., 2007). Methologies for more accurate assessment of carbon sequestration potential in forest plantations has been developed (van Minnen et al., 2008). The Reducing greenhouse gas Emissions from Deforestation and Dedgradation in developing countries (REDD) Sourcebook (Brown et al., 2008) offers a comprehensive treatise on the opportunities and complexities for mitigation potential through forestry management in developing countries. Fire is cited as a degradation component in REDD terminology. Forest carbon management in developed countries (Birdsey et al., 2006; Piao et al., 2009) also offers several opportunities for both retaining existing carbon stocking levels and for modest enhancement of carbon stocks, as well as for use of forest products to sequester carbon and/or offset non-renewable fossil fuel uses with bioenergy.

In all of these potential efforts, monitoring and accounting provide sizable hurdles both in terms of technology and policy. Consider a figurative example of a forest carbon project bounded in space and time by an accounting and monitoring box. When the project is initiated it receives certain projected carbon credits based on projected carbon sequestration and retention attributes, growth rate and sequential harvesting for example, that will aggregate over several decades or longer. Monitoring in space is mostly focused on "leakage", the concern that a given project claiming carbon credits will be paired with a nearby unaccounted for activity that negates the subject project carbon benefits. Afforesting a plot of farmland for carbon credit while deforesting adjacent acreages would be an unsophisticated example of leakage.

Much greater complexity is involved with the temporal aspects of carbon retention accounting and monitoring. Monitoring in time is mostly focused on "permanence". A reasonable expectation for a carbon retention project would be tracking periods of 10, 25 and 50 years. Growth and yield models based a large amounts of data have been an empirical mainstay for predicting forest growth but are not considered reliable predictors of future carbon retention in view of climate change, land use change and fire (Peng et al., 2002). Although sophisticated land use models are adding valuable insight in regard to potential gains from enhanced forest carbon sequestration, permanence remains uncertain due to expected increases in land use change and disturbance regimes (van Minnen et al., 2008). The REDD Sourcebook (Brown et al., 2008) notes that degradation of carbon stocks by forest fires could be more difficult to monitor with existing satellite imagery and little to no data exist on the changes in carbon stocks. The impact on the carbon stocks could vary widely depending on fire characteristics. In the absence of climate change, net carbon balance over a fire cycle should be zero given enough time (in some cases several centuries) for full ecosystem recovery (Kashian et al., 2006). With climate change altering fire regimes (Kasischke and Turetsky, 2006) the likelihood of the likelihood of achieving zero carbon balance in complete fire cycles is greatly diminished. As ecosystems and people seek to adapt to climate change (Seppälä et al., 2009), attempts to alter changing disturbance regimes (Blate et al., 2009) are likely to further complicate projections of future carbon retention.

Satellite and other RS platforms are capable of providing global coverage of insect (Fig. 3a), fire (Fig 3b) and other forest disturbance regimes. RS is being used to measure burned area and quickly assess damage from large forest fires (Gitasa et al., 2004), record major multi-fire events (Cahoon et al.,1994) and assess carbon impacts (Conard et al., 2002). LiDAR is proving to be particularly useful in carbon quantification (Patenaudea et al., 2004). Blowdown from tropical cyclones (Chambers et al., 2007) and other disturbance events are ammenable to observation using RS. The REDD Sourcebook (Brown et al., 2008) offers a very useful current synopsis of RS technologies available for estimating changes in forest carbon stocks. Since all disturbance events, that are of importance to carbon retention, are marked by measurable changes in vegetation cover and vigor, applying coordinated RS approaches in an all disturbance framework will offer substantial efficiencies.

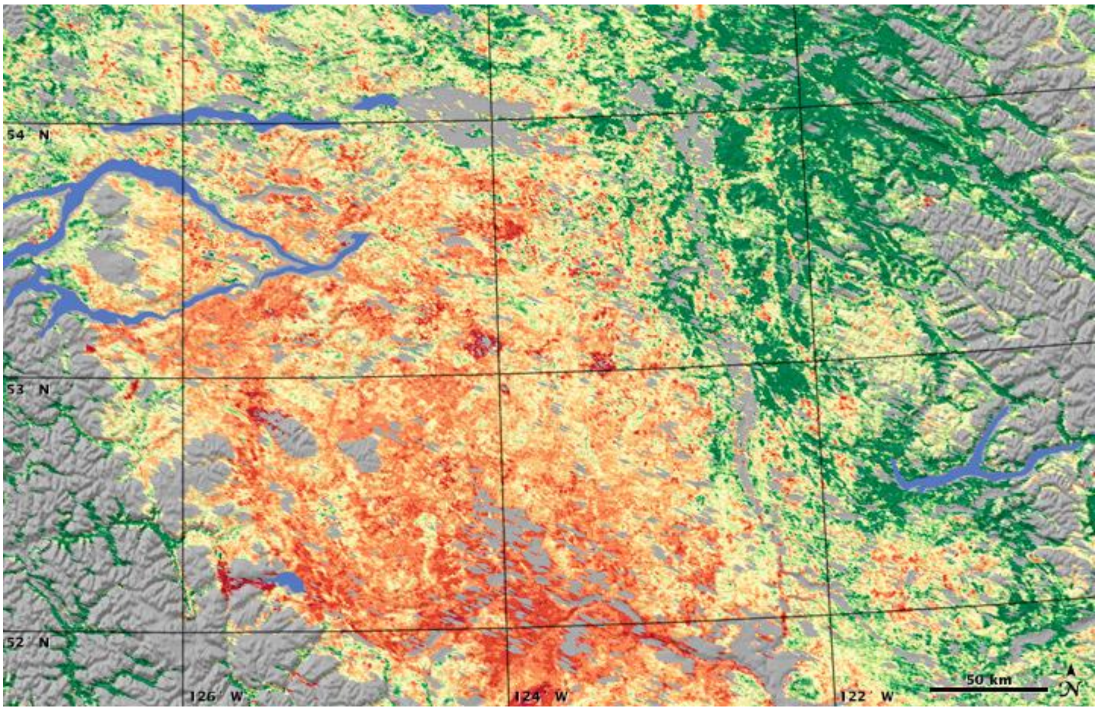

Figure 3a. Insect Damage in British Columbia Forests. NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) acquired June 26, 2006 - July 11, 2006. NASA map by Robert Simmon, based on data from Paul Montesano, Jon Ranson, and the MODIS land team.

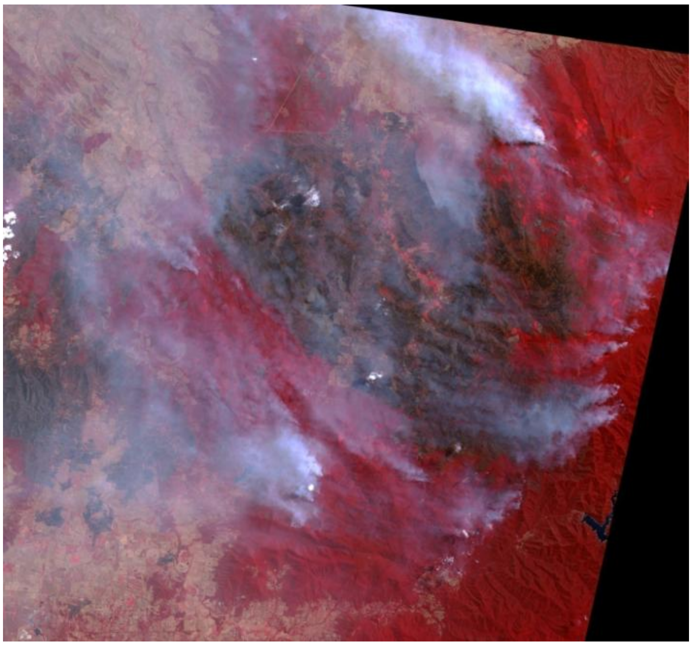

Figure 3b. False-color image from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on NASA's Terra satellite from February 17, 2009 of the Killmore East-Murrindindi Complex North Fire. Unburned vegetation is red, while burned areas are charcoal.
NASA image created by Jesse Allen, using data provided courtesy of: NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team.

Combining RS observational capabilities with Geographic Information System (GIS) technologies provides the near term opportunity for monitoring forest disturbance on a global basis. GIS is already used for fire risk mapping (Jaiswal et al., 2002), fire damage assessment (Sunar and Ozkan, 2001), post-fire ecosystem change (Mast et al., 1997), and estimating the potential for fire feed back loops with climate change (Randerson et al., 2006), as just a few examples. Forestry professionals are now very well versed in applying GIS for various forest resource uses.

Conclusions

The contribution of forest carbon is an important factor in sustainable forest management and climate change mitigation. Climate change will alter fire and other forest disturbance regimes. These altered disturbance regimes are likely to result in changes to forest carbon retention. Climate mitigation options that rely on maintaining or enhancing forest carbon sequestration and retention need to incorporate forest disturbance monitoring to add assurance to the permanence of the carbon budget gains. Since forest disturbances serve as non-linear agents of climate change, neglecting disturbance regimes in carbon sequestration calculations that target retention for multiple decades into the future will call those projections into question. Adaptive responses to climate change are also likely to alter forest disturbance regimes and carbon retention should be included as a factor in all adaptive response approaches.

A specific task of monitoring carbon in response to both SFM C&I 5.22 and climate change related forest carbon goals deriving from the UNFCCC process will be achievable if sufficient budgetary resources are provided. Sufficient technology and expertise are available to provide monitoring based on RS observations and GIS cataloging that will meet sustainable forest management and climate change needs.

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