

Satellite monitoring and
assessment of fire –
Where are we and where do we go
from here?

E. S. Kasischke
for the Remote Sensing
Fire Science Community

*NASA Carbon Cycle & Ecosystems Joint Science Workshop
28-30 April 2008*

Contributors/Fire Science Researchers

- S. Conard, W. Hao, D. McKenzie, R. Ottmar, B. Schwind: **USFS**
- J. Eidenshink, J. Harden: **USGS**
- J. Allen, B. Sorbel: **NPS**
- K. Murphy: **FWS**
- S. Trigg: **Cranfield Univ., England**
- W. de Groot, R. Hall, D. McRae: **Canadian Forest Service**
- G. van der Werf: **Vrije Univ., Neth.**
- A. Sukhinin, G. Ivanova: **Sukachev Forest Institute, Russia**
- A. Setzer, K. Longo: **INPE, Brazil**
- Hicke, Asner: **Stanford**
- J. Johnstone –**USK, UAF**
- L. Curran: **Yale**
- N. French, L. Bourgeau-Chavez: **MRTI**
- S. Goetz, D. Nepstad, F. Brown: **WHRC**
- P. Gong, R. Pu: **UC-Berkeley**

- D. McGuire, D. Verbyla, S. Yi, M. Balshi: **Univ. AK**
- D. Mildrexler, S. Running: **UMT**
- D. Munroe: **Ohio State**
- D. Morton, C. Justice, I. Csiszar, T. Loboda, W. Schroeder, S. Korontzi, R. DeFries, J. McCarthy, E. Vermotte, J. Townshend, E. Hoy, Z. Li, G. Sun: **UMD**
- C. Neigh, C. Tucker, L. Giglio, J. Collatz, J. Morrisette: **GSFC/SSAI**
- C. Potter: **NASA ARC**
- K. O'Connell, S. Mitchell, M. Harmon: O. Krankina: **Oregon State Univ.**
- J. Randerson, E. Lyons, Y. Jin: **UC-Irvine**
- D. Roy, M. Cochrane: **SDSU**
- H. Shugart, N. Sherman: **Univ. VA**
- A. Soja, A. Westberg: **NASA LRC**
- M. Turetsky, E. Kane: **Mich State**

Presentation Outline

1. Summary of Results
2. Fire information products
3. Characterization of the fire regime
4. Improvement of biomass burning emission estimates and models of terrestrial carbon cycling
5. Assessment of post-fire environmental conditions and ecosystem processes
6. Recommendations and future directions

Summary of Results

(represents > 35 projects)

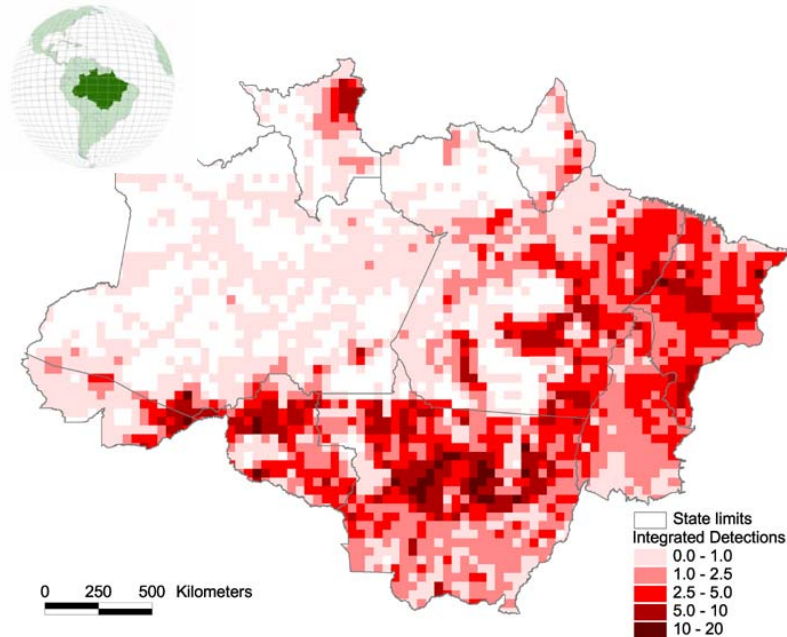
1. The development of new fire products from satellite remote sensing data continues, especially at regional scales
2. Integrated analyses of multiple remote sensing information products are leading to a clearer understanding of key characteristics of the fire regime at regional scales
3. Regional-scale studies have reduced uncertainties in estimates of biomass burning emissions, particularly in Brazil, Borneo, the Boreal Forest, the Western US, and from Agricultural Burning in the U.S.
4. Based upon integrated studies using field and satellite observations, new approaches are being developed to improve models that account for the impacts of fire on ecosystem processes and carbon cycling
5. Efforts are underway to develop new remote sensing products to assess and monitor the post-fire environment

Fire Information Products – Hot Spots, Burn Scars, Fire Intensity

1. MODIS Global Fire Products (Justice, Roy, Giglio, Csiszar et al. UMD)
2. TRMM VIRS Fire Products (Giglio, et al. SSAI)
3. Global MODIS Disturbance Product (Townshend, UMD **53**)
4. MODIS Global Fire Radiative Power Products (Vermotte et al., UMD **378**)
5. ASTER Fire Temperature Retrieval (Eckman, UCSB)
6. 12 year AVHRR Product for NA (Pu et al. UCB, UMD)
7. Regional MODIS Burn Scar Mapping - Russian Far East (Loboda, UMD: **159**)
8. US Agriculture Fire Products-MODIS (McCarthy, UMD)
9. MODIS Disturbance Index (Running et al. UMT **198**)
10. MODIS/GOES Regional Fire Monitoring – Brazil (Schroeder, Csiszar et al. UMD **234**)
11. AVHRR/MODIS Mapping of Fire Activity in Russia (Sukhinin, Soja, Kasischke et al. SFI **359, 360**)
12. Landsat Burned Area Product for the U.S. (MTBS Program - Eidsenink, USGS; Schwind, USFS)

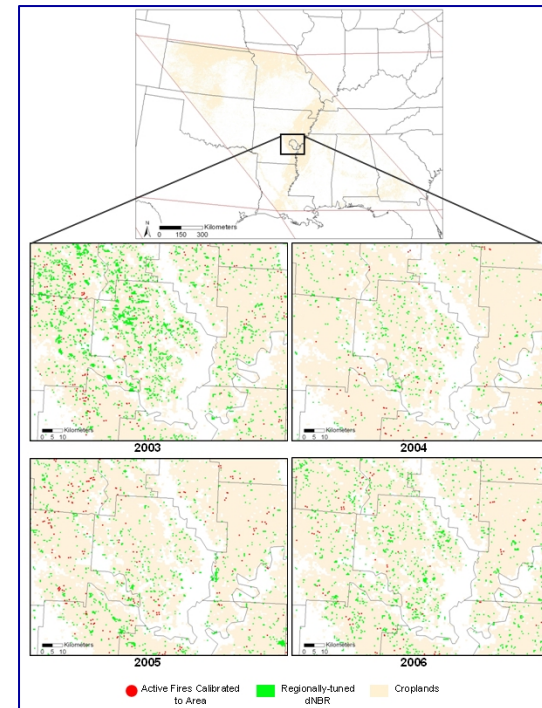
Regional Scale Fire Products

Schroeder et al. 234



Integrated fire product for Brazilian Amazonia using 2005 MODIS and GOES data showing average number of detection days per year.

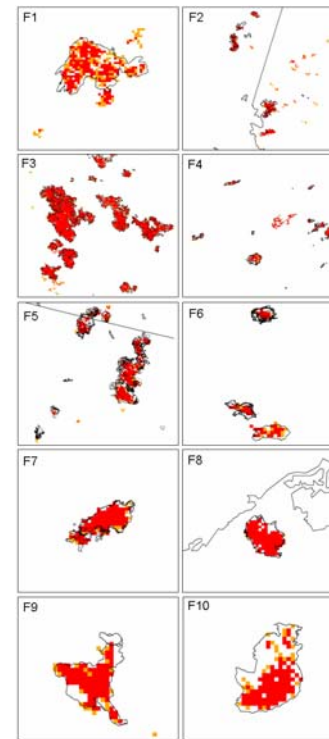
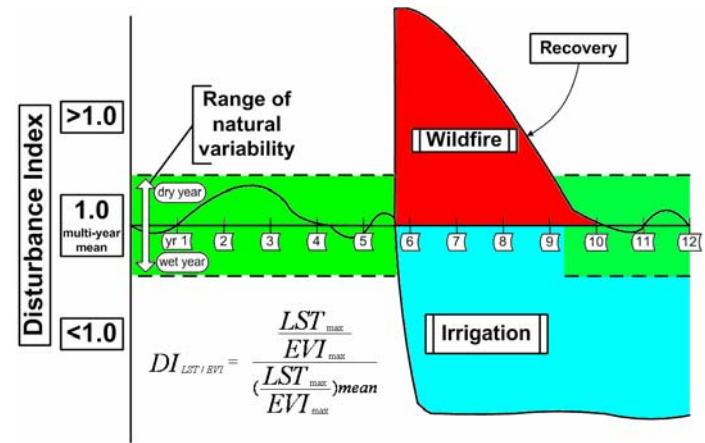
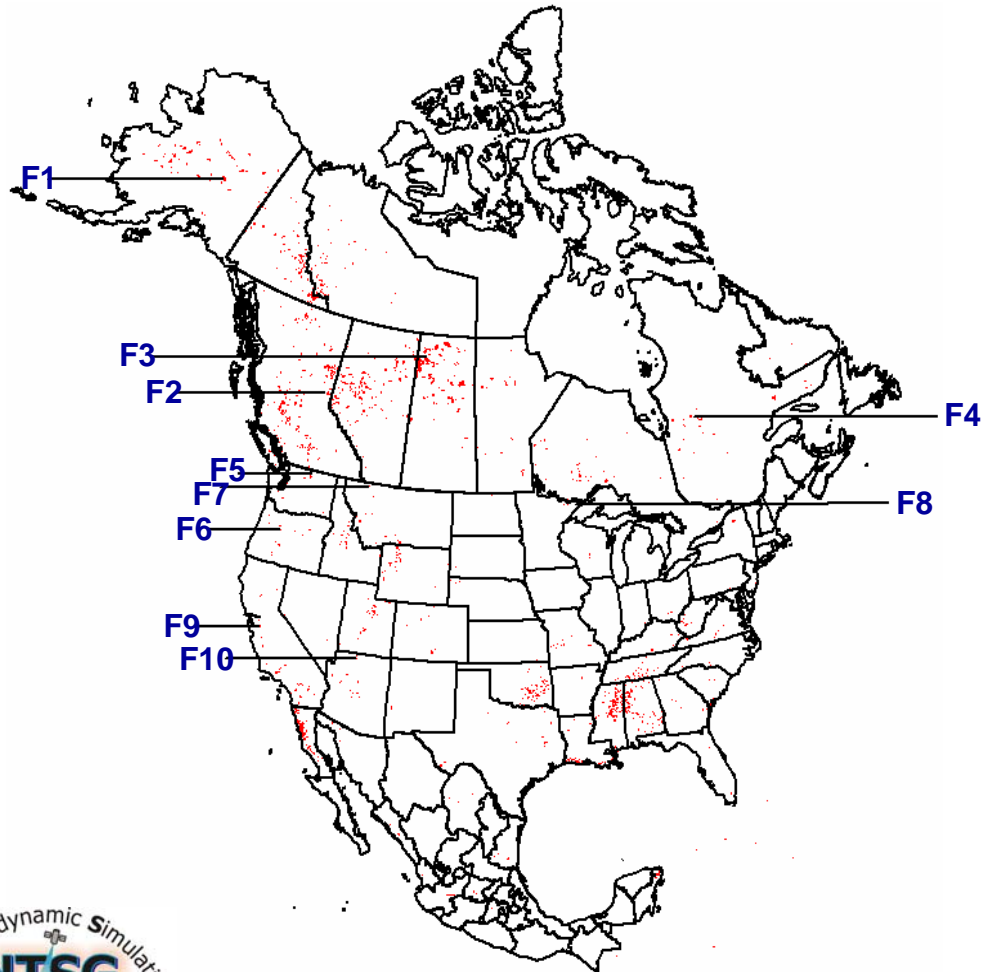
McCarthy et al.



Example of hybrid approach to burned area estimation for crop residue burning: Fall harvest for Arkansas County, Arkansas.

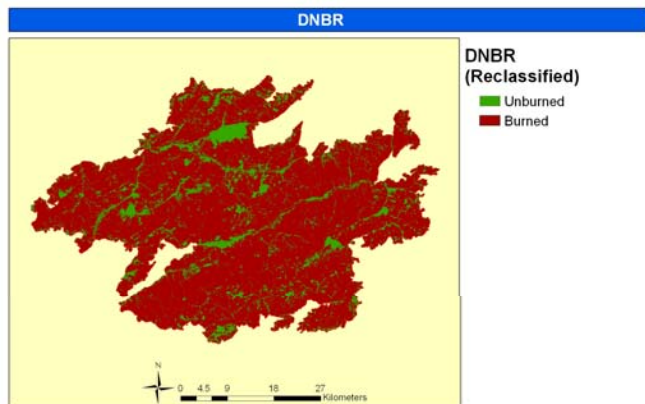
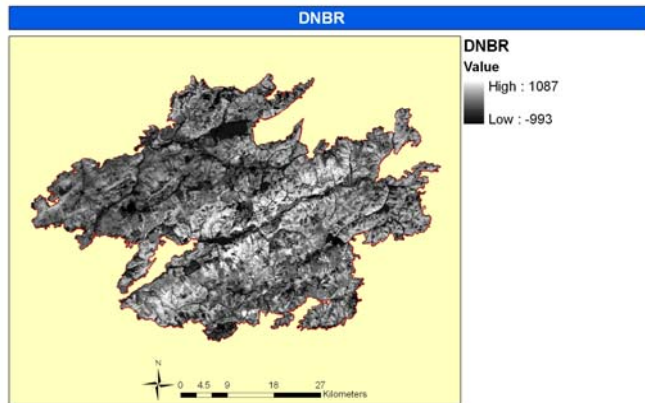
MODIS Disturbance Index 2006 wildfire detection across NACP domain

Mildrexler, Running et al. 198

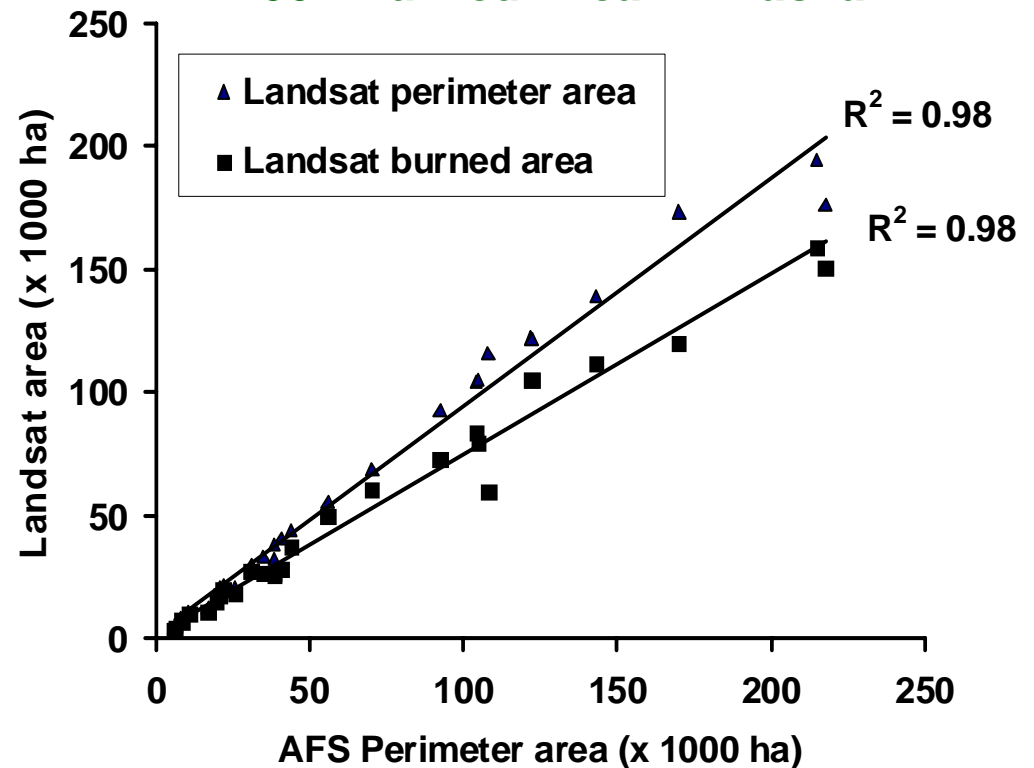


Monitoring Trend in Burn Severity (MTBS) Program – USGS/USFS

The MTBS Program is using Landsat TM/ETM+ data to generate burn severity products for all large fires in the U.S. between 1984 and 2000



2004 Burned Area in Alaska



Characterization of the Fire Regime

1. Diurnal Fire Patterns from TRMM VIRS Data (L. Giglio et al., GSFC/SSAI)
2. Climate-Fire Relationships in the Russian Far East (Soja, Westberg, LRC; Sukhinin, SFI; et al. **359, 360**)
3. Fire Danger, Fire Risk, and Fire/Landscape Relationships in the Russian Far East (Loboda and Csiszar, UMD **159**)
4. Landsat Mapping of Burn Severity Across the U.S. (MTBS Program - Eidenshink, USGS; Schwind, USFS)
5. Assessment of Satellite Fire Severity Products (Hoy, Kasischke, UMD; French, MTRI; Hall, CFS; Verbyla, UAF; Allen, Sorbel, NPS; Murphy, NPS **24**)
6. Analysis of Agricultural Fires Across the U.S. (McCarthy, UMD)
7. Spatial/Temporal Analysis of the 2004 Fires in Alaska (Kasischke, Hoy et al.; UMD **151**)
8. Fire and Land Use Change in Borneo (van der Werf, Randerson, DeFries, Curran et al.: Vrije Univ.)

Characterizing the Diurnal Fire Cycle

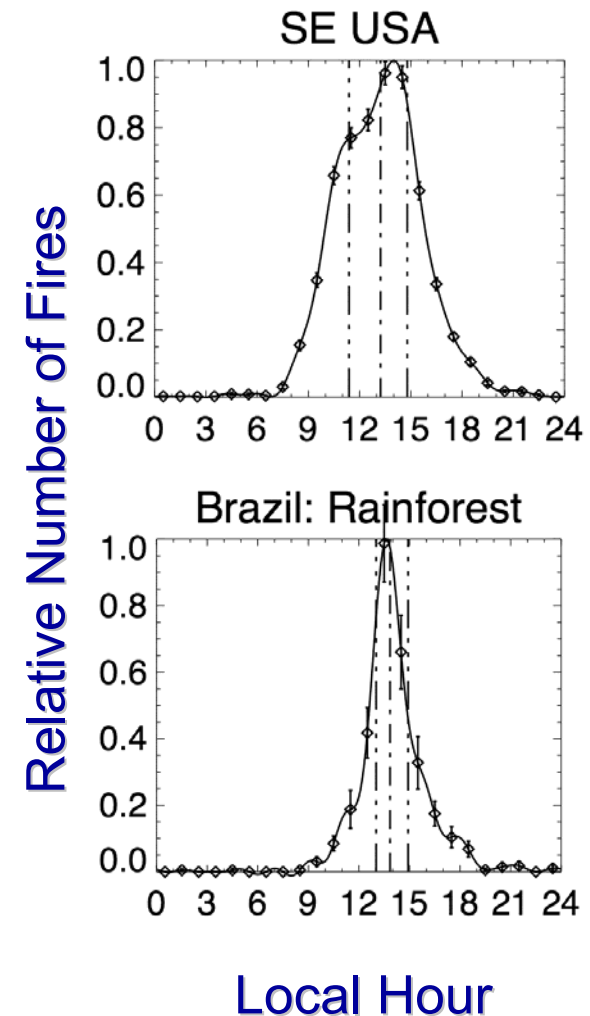
Approach

- Detect fires with TRMM VIRS sensor
- Exploit precessing TRMM orbit to sample diurnal fire cycle over time

Results

- Strong diurnal cycle in the tropics and sub-tropics
- Peak local time 13:00 to 18:30
- Peak width 1.3 h to 5.5 h
 - Higher tree cover → narrower peak

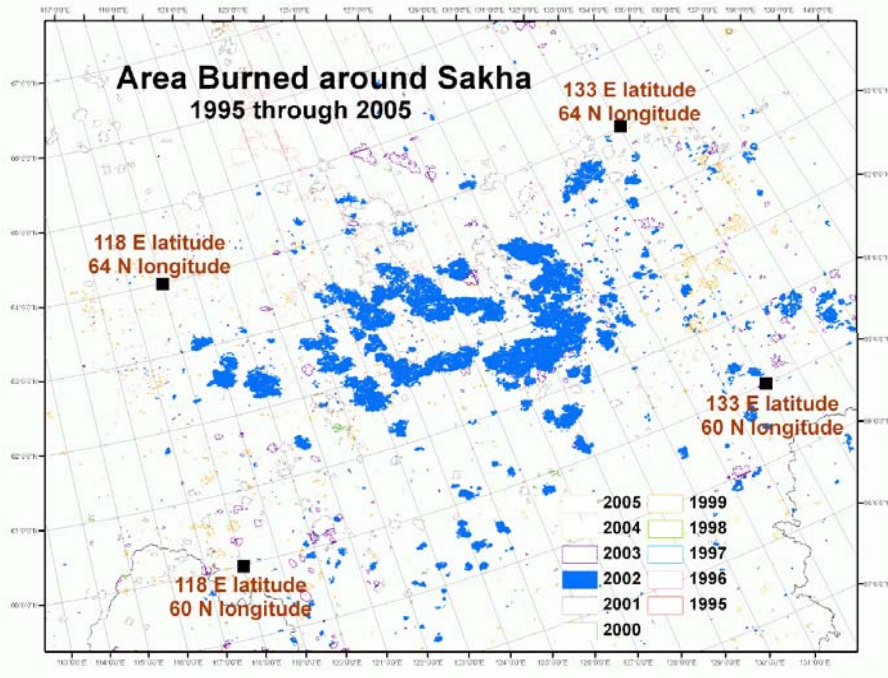
Giglio et al.



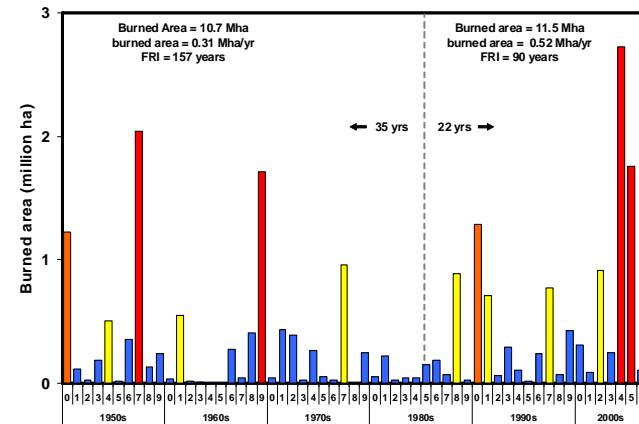
Episodic Fire Events at Sub-Continental Scales in the Boreal Forest

Soja, Sukhinin et al. 359,360

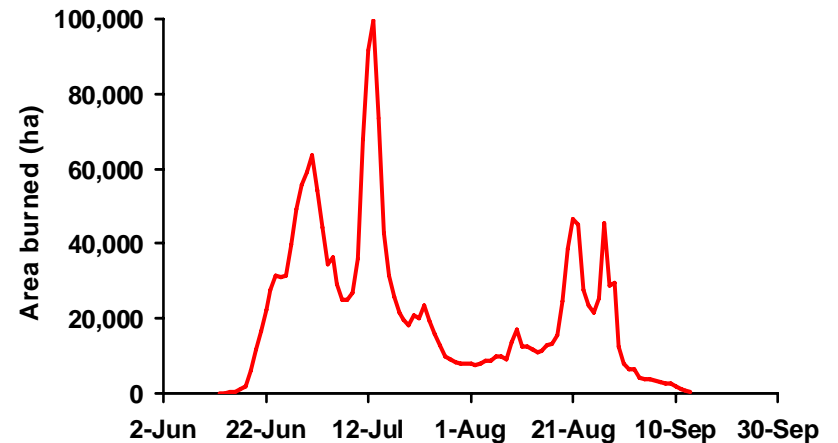
Kasischke et al. 151



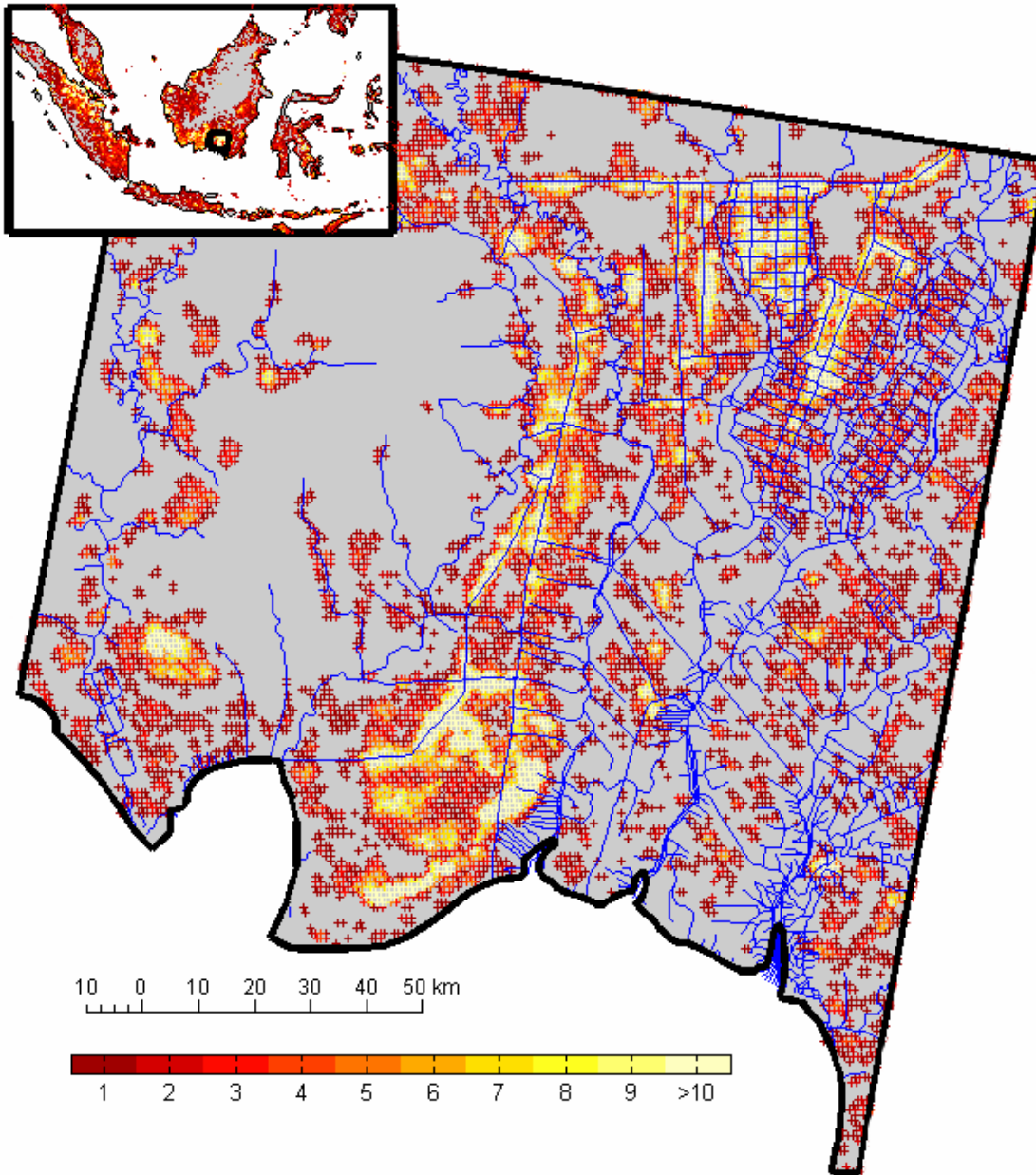
Fire activity in Northeastern Russia based on AVHRR/MODIS Fire Products



2004 Daily Burned Area in Alaska via Integration of Landsat and MODIS Data



Fire impacted area in Alaska

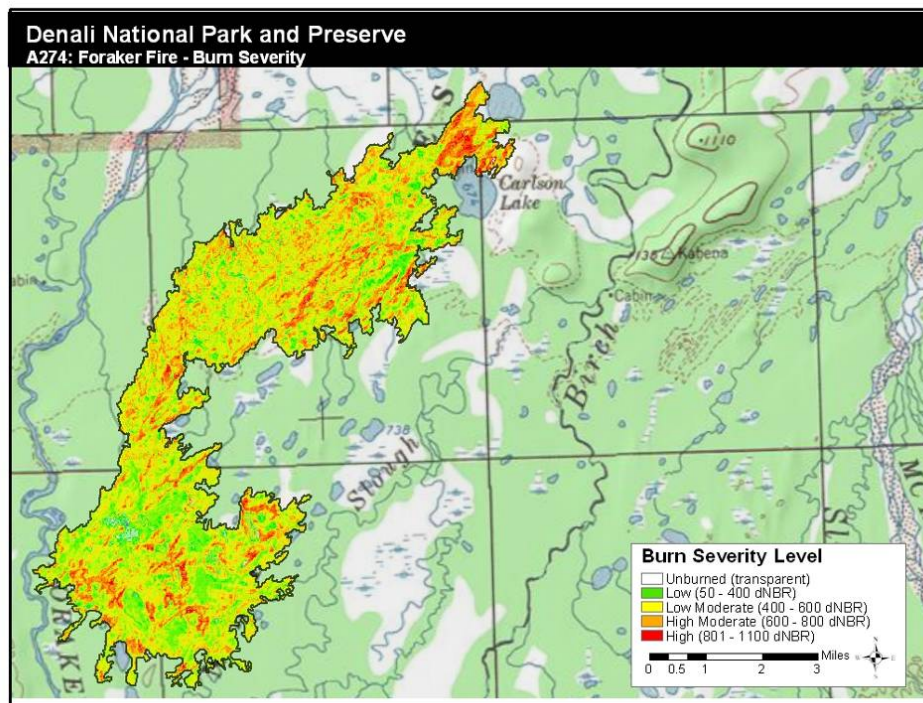


- Southern Borneo mega rice project area (or just south of that)
- Blue: drainage based on Landsat data
- Red-orange: number of MODIS fire counts (2000-2006)
- Repeat fires (yellow) occur frequently in drained areas
- Van der Werf et al., in review

Curran, Randerson, and DeFries Projects

Monitoring Trend in Burn Severity (MTBS) Program – USGS/USFS

The MTBS Program is using Landsat TM/ETM+ data to generate burn severity products for all large fires in the U.S. between 1984 and 2000



While numerous studies have shown that maps of burn severity can be generated from Landsat TM/ETM+ data for individual fire events, significant questions exist about using the dNBR/CBI approach to operationally map burn severity

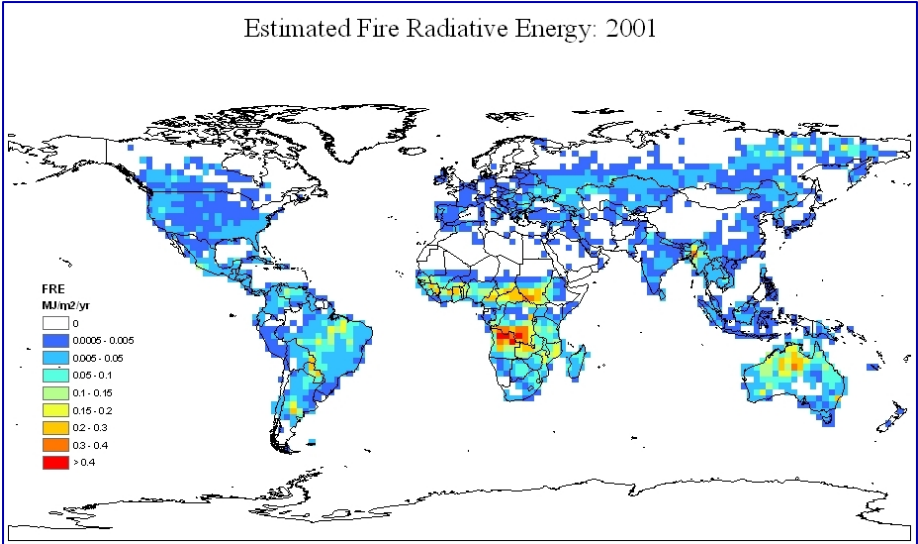
Allen, Sorbel: NPS

Biomass Burning Emission Estimates and Carbon Cycling

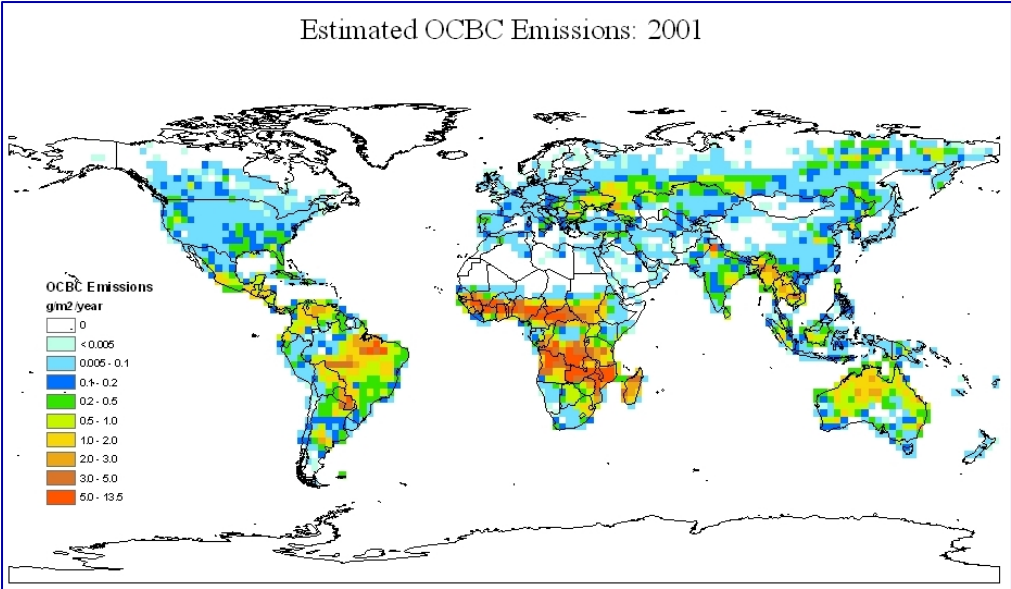
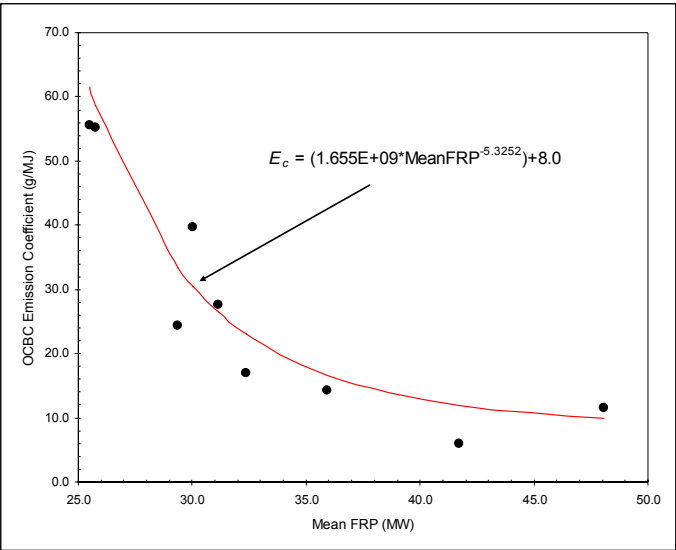
July 2002 NASA – GOF/GOLD – BIBEX Workshop on Improving Estimates of Emissions from Biomass Burning

1. Global BB Emissions - GFED (van der Werf, Randerson, et al., UCI, Vrije Univ)
2. Global Estimates of BB Emissions using MODIS FRP (Vermotte et al., UMD **378**)
3. *BB Estimates for the Conterminous US (Hao et al., USFS)*
4. *Improved BB estimates for the NA Boreal Region (Kasischke, Hoy, UMD; de Groot, CFS; Turetsky, Kane, MSU et al. **150**)*
5. *Estimates of BB Emissions for the W.U.S. (French, MTRI; McKenzie, USFS **24, 271**)*
6. *Improved Estimates of BB Emissions from Deforestation in Brazil (DeFries, Morton, UMD **231**)*
7. *Improved Estimates of BB Emissions in African Savannas (Korontzi et al., UMD)*
8. *Estimates of BB Burning from US Agricultural Fires (McCarthy et al., UMD)*
9. *Fuel consumption/fire weather relationships in Russian forests (Conard, USFS; McRae, CFS; Sukhinin, Sukachev Forest Institute)*
10. *Impacts of Peatland Fires in Borneo on BB emissions: (van der Werf, Vrije Univ; Randerson UCI; Curran, Yale; Trigg, Cranfield Univ.; DeFries, Dempewolf, UMD)*
11. *BB Emissions in Indonesia (Monroe et al. OSU **271**)*
12. *Effects of Fire Management on Fuels Along Fire Regime and Forest Productivity Gradients in Oregon: Implications for Long-Term Carbon Dynamics (Mitchell, O'Connell, Harmon, Oregon State)*
13. *Impacts of Fire on the Carbon Budget of the Boreal Forest (McGuire, Yi, Balshi, et al. UAF **358**)*
14. *Impacts of Disturbance on Boreal Carbon Cycling (Neigh, Tucker, Collatz, GSFC/SSAI **287**)*
15. *Impacts of Disturbance on Terrestrial Carbon Storage in Russia (Krankina et al. OSU)*
16. *Fire and Biomass Mapping in NE Asia (Sun et al., UMD **278**)*

Emission Estimates Based on MODIS FRP Measurements



Vermotte et al. 378



Collection of Additional Field Data to Reduce Uncertainties in Fuel Loads and Fuel Consumption

Ottmar et al. (Boreal)

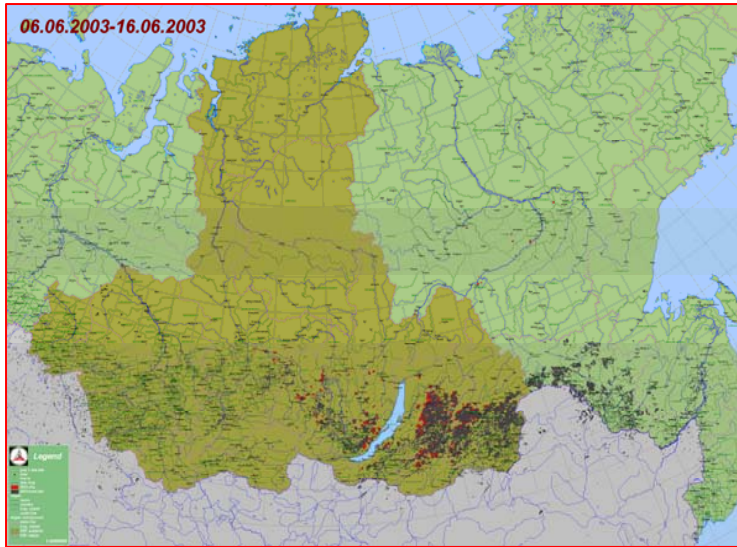


Turetsky, Harden, et al. (Boreal) 150



DeFries et al. (Tropical) 231

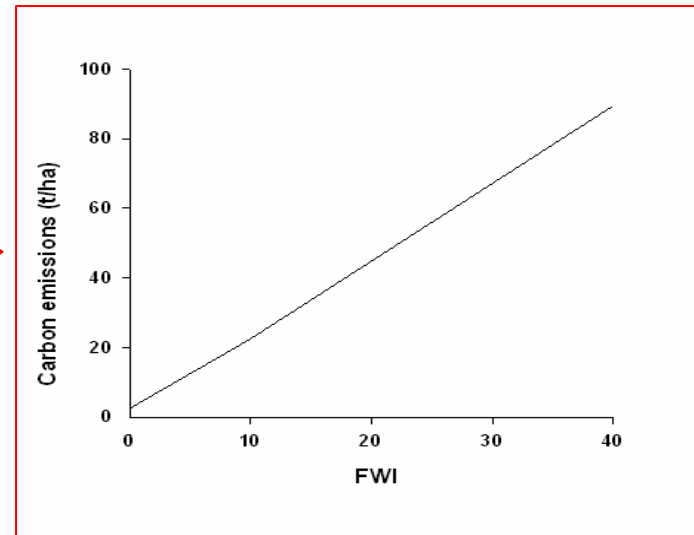




Satellite Mapping of fire activity

Conard et al. USFS/SFI

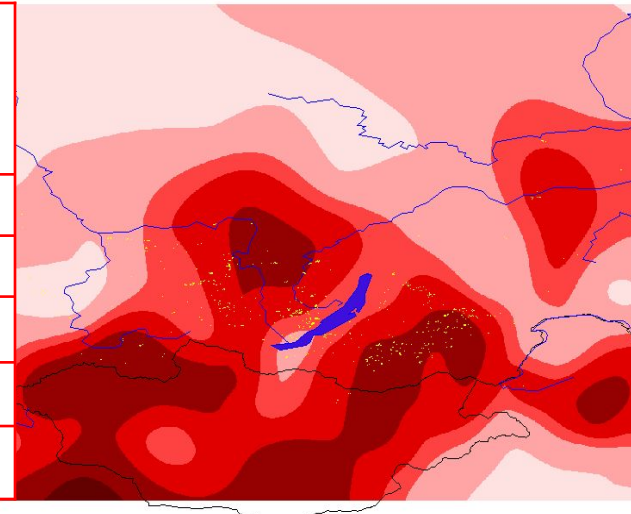
Driving fuel consumption based on temporal/spatial variations in climate (fire weather)



Field-based data relating fire weather indices and fuel consumption



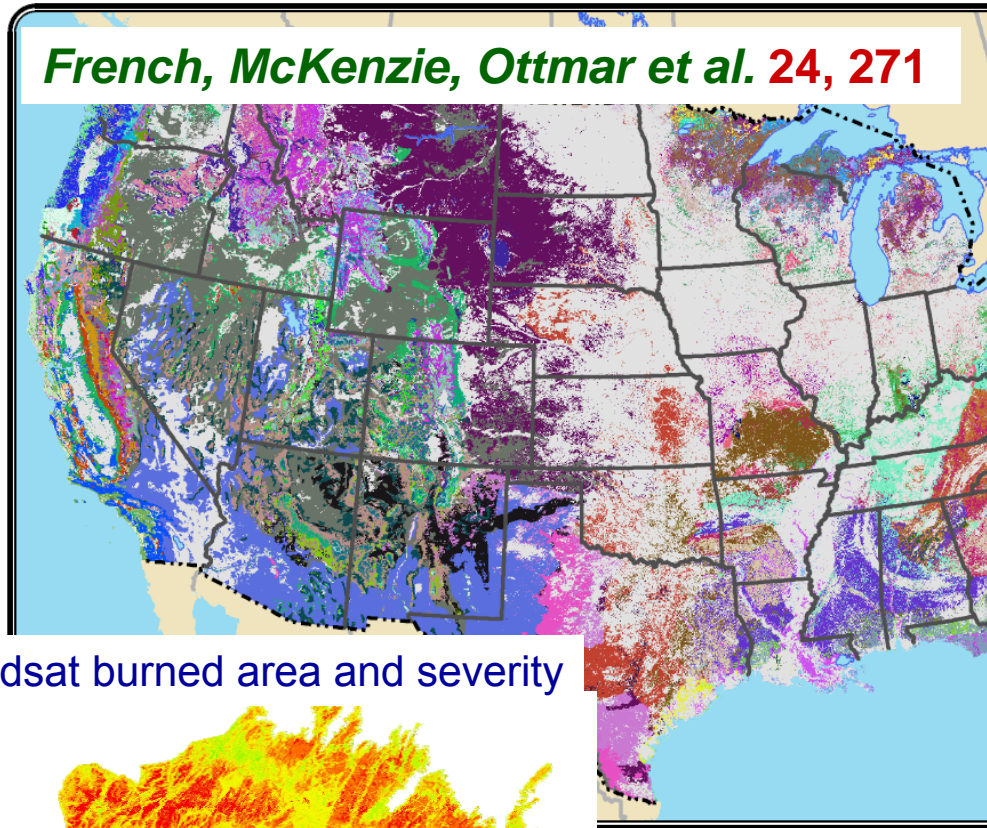
Fire Weather Index	Carbon emissions (t/ha)
0-2	2.2-3.3
2-10	3.3-7.8
10-15	7.8-10.5
15-23	10.5-15.0
23-40	15.0-24.0



500 0 500 1000 Kilometers

Estimating fuel consumption at regional scales

Integrated analysis of fuel consumption during fires



Landsat burned area and severity

FCCS Fuelbeds

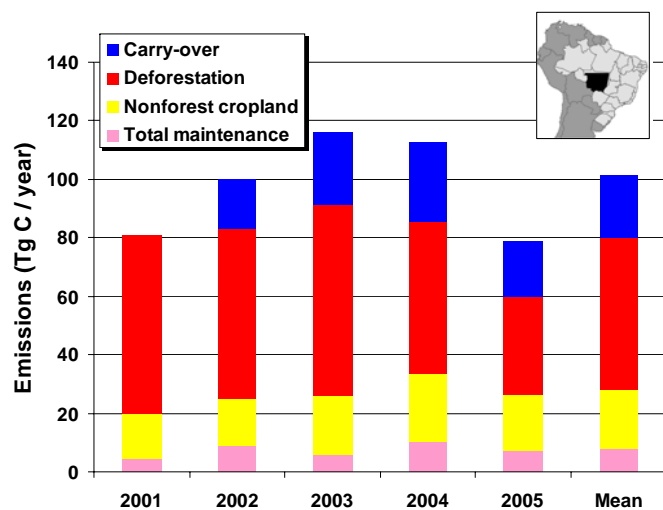
01 Agriculture - barren - urban	41 Pacific ponderosa pine forest
02 American beech - Sugar maple forest	42 Pacific silver fir - Mountain hemlock forest
03 American beech - Yellow birch - Sugar maple - Eastern hemlock	43 Pine - Oak forest
04 American beech - Yellow birch - Sugar maple - Red spruce forest	44 Pinon - Juniper forest
05 American beech - Yellow birch - Sugar maple forest	45 Pitch pine / Scrub oak forest
06 Arizona white oak - Silverleaf oak - Emory oak woodland	46 Pond pine forest
07 Bald-cypress - Water tupelo forest	47 Pond-cypress / Muhlenbergia - Seagrass savanna
08 Balsam fir - White spruce - Mixed Hardwoods forest	48 Ponderosa pine - Jeffrey pine forest
09 Black cottonwood - Douglas-fir - Quaking aspen	49 Ponderosa pine - Two-needle pine - Juniper forest
10 Black oak woodland	50 Ponderosa pine savanna
11 Black spruce - Northern white cedar - Larch forest	51 Post oak - Blackjack oak forest
12 Bluebunch wheatgrass - Bluegrass grassland	52 Red fescue - Catclaw grassland
13 Bluestem - Gulf cordgrass grassland	53 Red fir forest
14 Bluestem - Indian grass - Switchgrass grassland	54 Red mangrove - Black mangrove forest
15 Bur oak savanna	55 Red maple - Oak - Hickory - Sweetgum forest
16 Chamise chaparral shrubland	56 Red pine - White pine forest
17 Chestnut oak - White oak - Red oak forest	57 Red spruce - Balsam fir forest
18 Coastal sage shrubland	58 Red spruce - Fraser fir / Rhododendron forest
19 Crowsfoot bush shrubland	59 Redwood - Tanoak forest
20 Douglas-fir - Madrone / Tanoak forest	60 Rhododendron - Blueberry - Mountain laurel shrubland
21 Douglas-fir - ponderosa pine forest	61 Sagebrush shrubland
22 Douglas-fir - Sugar pine - Tanoak forest	62 Sand pine - Oak forest
23 Douglas-fir - White fir - Interior ponderosa pine forest	63 Sand pine forest
24 Douglas-fir - White fir forest	64 Saw palmetto / Three-armed grass shrubland
25 Douglas-fir / Ocean spray forest	65 Sawgrass - Muhlenbergia grassland
26 Eastern redcedar - Oak / Bluestem savanna	66 Scrub oak - Chaparral shrubland
27 Eastern white pine - Eastern hemlock forest	67 Shortleaf pine - Post oak - Black oak forest
28 Eastern white pine - Northern red oak - Red maple forest	68 Showy sedge - Alpine black sedge grassland
29 Engelmann spruce - Douglas-fir - White fir - Interior ponderosa	69 Smooth cordgrass - Black needletush grassland
30 Gambel oak / Sagebrush shrubland	70 Subalpine fir - Engelmann spruce - Douglas-fir - Lodgepole pine
31 Grand fir - Douglas-fir forest	71 Subalpine fir - Lodgepole pine - Whitebark pine - Engelmann spruce
32 Green ash - American elm - Silver maple - Cottonwood forest	72 Sugar maple - Basswood forest
33 Idaho fescue - Bluebunch wheatgrass grassland	73 Sugar maple - Yellow poplar - American beech - Oak forest
34 Interior Douglas-fir - Ponderosa pine / Gambel oak forest	74 Sugar pine - Douglas-fir - Ponderosa pine - Oak forest
35 Interior ponderosa pine forest	75 Tall fescue - Fodder - Purple bluestem grassland
36 Jack pine / Black spruce forest	76 Tanoak - California bay - Madrone forest
37 Jack pine savanna	77 Tobacco - Grease grassland
38 Jeffrey pine - Ponderosa pine - Douglas-fir - Black oak forest	78 Trembling aspen - Paper birch - White spruce - Balsam fir forest
39 Little galberry - Fetterbush shrubland	79 Trembling aspen - Paper birch forest
40 Live oak - Blue oak woodland	80 Trembling aspen / Engelmann spruce forest
41 Live oak - Sabal palm forest	81 Trembling aspen forest
42 Live oak / Sea oats savanna	82 Turbinella oak - Ceanothus - Mountain mahogany shrubland
43 Loblolly pine - Shortleaf pine - Mixed hardwoods forest	83 Turkey oak - Bluejack oak forest
44 Loblolly pine forest	84 Vaccinium - Heather shrublands
45 Lodgepole pine forest	85 Virginia pine - Pitch pine - Shortleaf pine forest
46 Longleaf pine - Slash pine / Saw palmetto - Galberry forest	86 Western hemlock - Douglas-fir - Sitka spruce forest
47 Longleaf pine / Three-awed grass - Pitcher plant grassland	87 Western hemlock - Douglas-fir - Western redcedar / Vine maple forest
48 Longleaf pine / Three-awed grass - Pitcher plant savanna	88 Western hemlock - Western redcedar - Douglas-fir forest
49 Longleaf pine / Turkey oak forest	89 Western juniper / Huckleberry oak forest
50 Longleaf pine / Yaupon forest	90 Western juniper / Sagebrush - Bitterbrush shrubland
51 Mesquite savanna	91 Western juniper / Sagebrush savanna
52 Mountain hemlock - Red fir - Lodgepole pine - White pine forest	92 Wheatgrass - Cheatgrass grassland
53 Oak - Hickory - Pine - Eastern hemlock forest	93 White oak - Northern red oak - Black oak - Hickory forest
54 Oak - Pine - Magnolia forest	94 White oak - Northern red oak forest
55 Oregon white oak - Douglas-fir forest	95 Whitebark pine / Subalpine fir forest
56 Pacific ponderosa pine - Douglas-fir forest	96 Willow oak - Laurel oak - Water oak forest

Fuel consumption:

- USFS CONSUME 3.0 for specific fuelbeds in fire sites
- Fire severity maps from MTBS program
- Assign consumption levels for specific fuelbeds from CONSUME 3.0 to remote sensing-derived severity maps

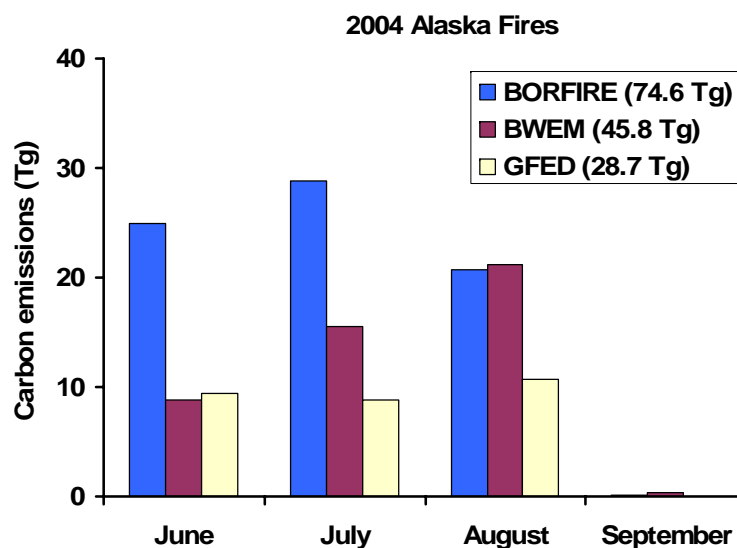
Integrated Regional-Scale Estimates of Biomass Burning Emissions

DECAF: DEforestation CARbon Fluxes in Brazil – *DeFries et al. 231*



- *Deforestation results in 73% of BB burning emissions*
- *Combustion completeness and duration of the deforestation process vary by land use.*
- *Carry-over emissions from deforestation in other years can be large (>20%).*

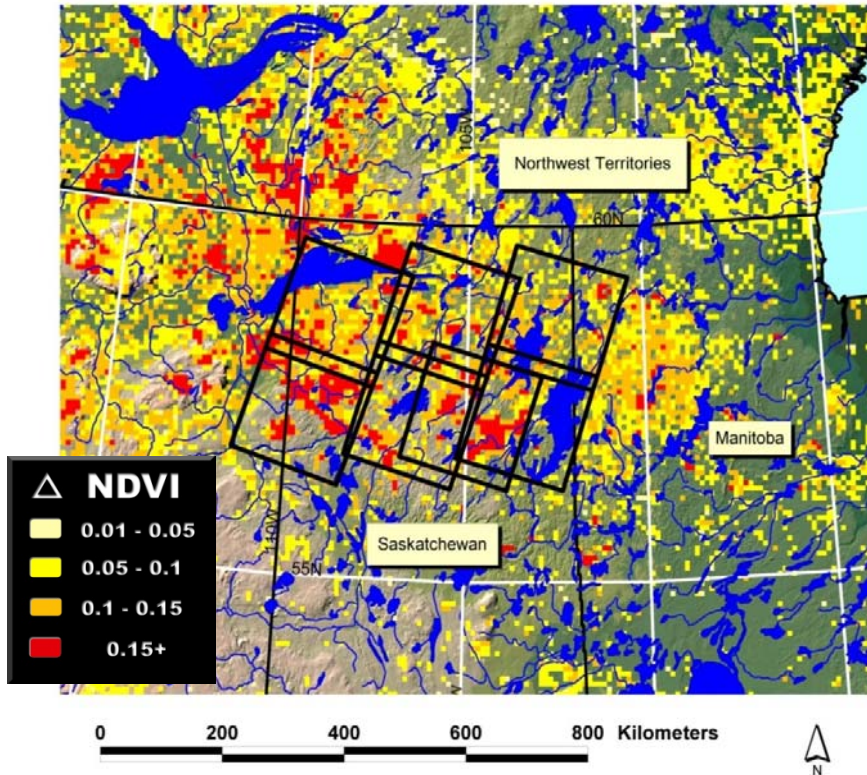
BORFIRE – AK *Kasischke, de Groot et al. 150*



- *Previous models did not account for deep organic layer burning in black spruce forests*
- *Surface organic layer in BS forests accounts for 72% of emissions*

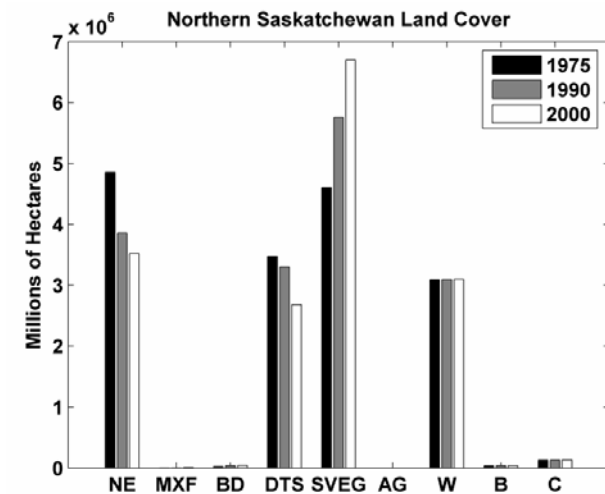
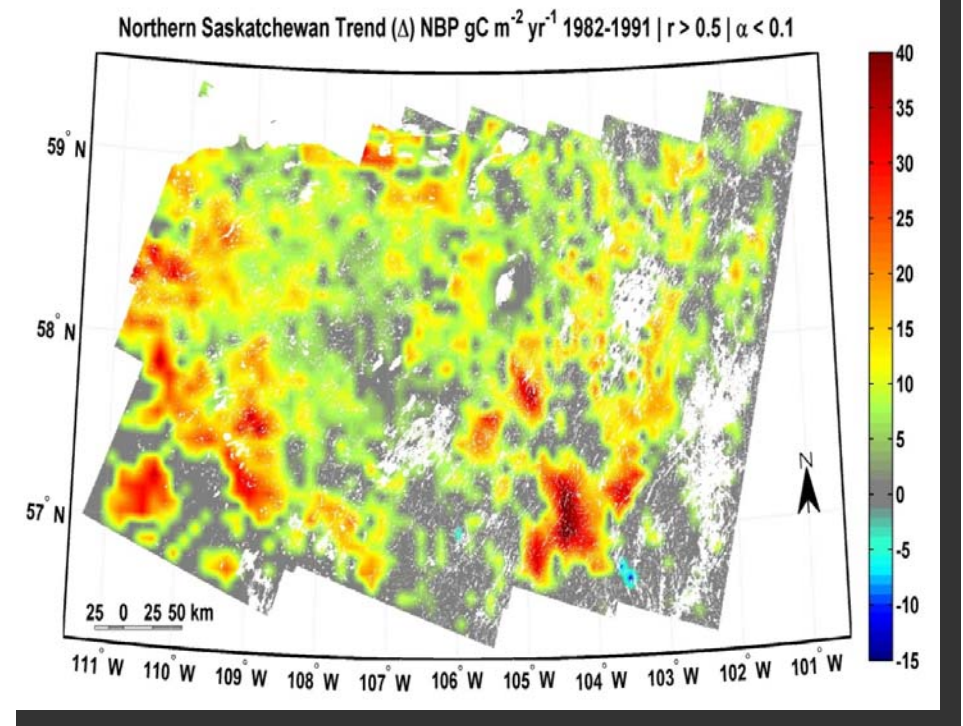
Northern Saskatchewan Post-fire Recovery

Landsat Land Cover Change
Integrated in a Fire Module of CASA
 Δ NDVI 1982-1991



Identifying & Understanding Carbon Cycle Implications of North American Natural and Anthropogenic Disturbances: 1982-2005

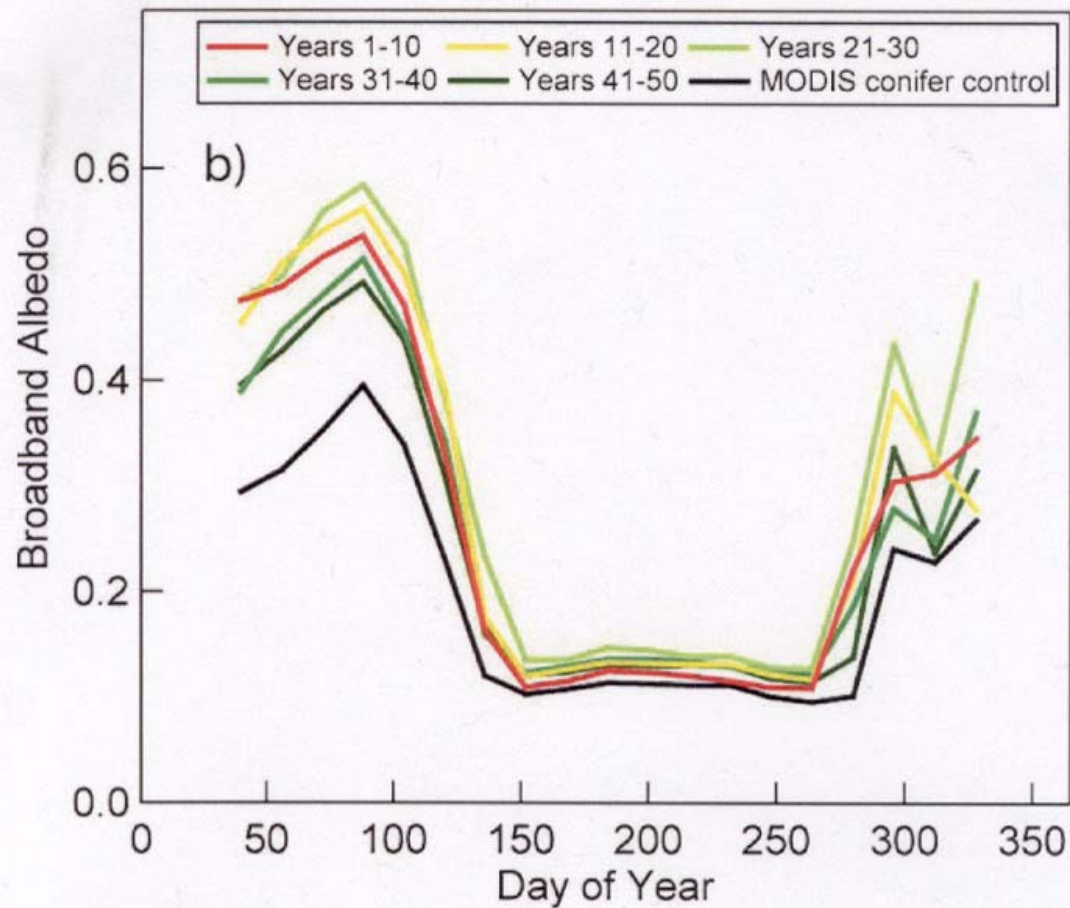
Tucker, Neigh, Collatz NASA/GSFC 287



Assessment of post-fire environmental conditions and ecosystem processes

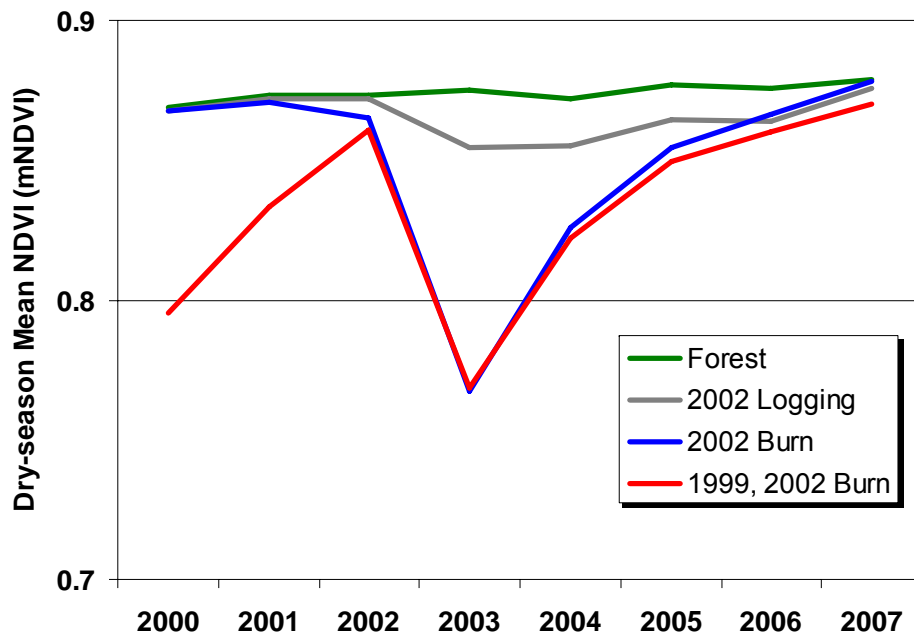
1. Effects of Fire on Vegetation Indices and GPP in Boreal NA (2 studies: Hicke et al. Stanford; Goetz et al., WHRC 28)
2. MODIS Observed Post-Fire Regeneration in Tropical Forests (Morton, DeFries, UMD)
3. Analysis of the Effects of Fire Severity, Forest Type, and Soil Moisture on Post-Fire MODIS VI Signatures (Kasischke, UMD, Bourgeau Chavez, MRTI, Johnstone, USask 151)
4. Post-fire regeneration in Canadian boreal forests (Gower et al., UW)
5. Post-fire Monitoring of Surface Albedo in Boreal Forests (Lyons, Randerson, UCI)
6. Effects of Fire on Forests in the Russian Far East (Sherman, Shugart et al. et al. UVA 160)
7. Variations in Post-Fire Soil Moisture in Boreal Forests (Bourgeau-Chavez, MRTI; Kasischke, UMD; Johnstone UAF)

Post-fire variations in albedo in boreal forests



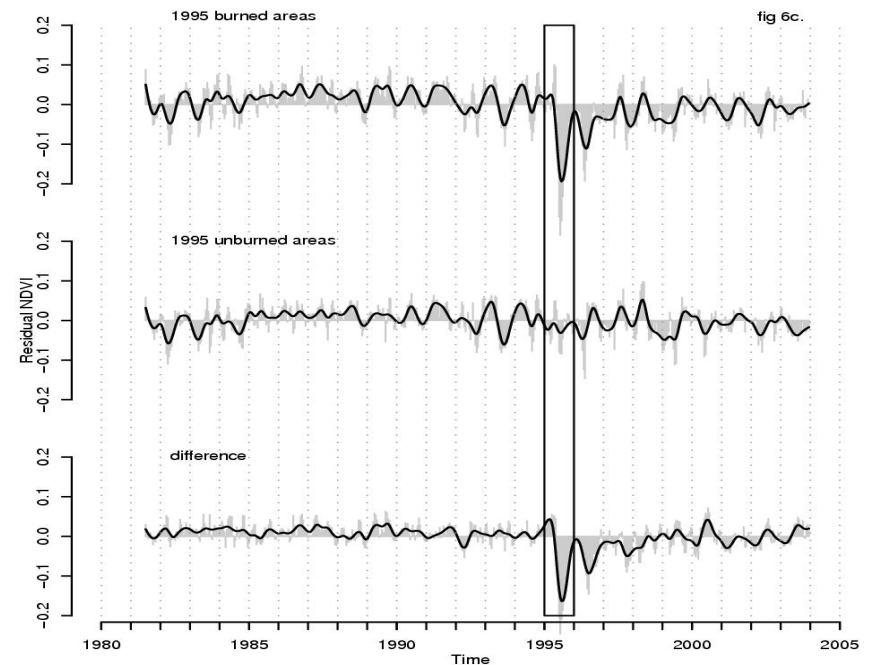
(Lyons, Randerson, Jin)

Satellite Monitoring of Forest Re-growth Following Fire



Brazilian Tropical Forests

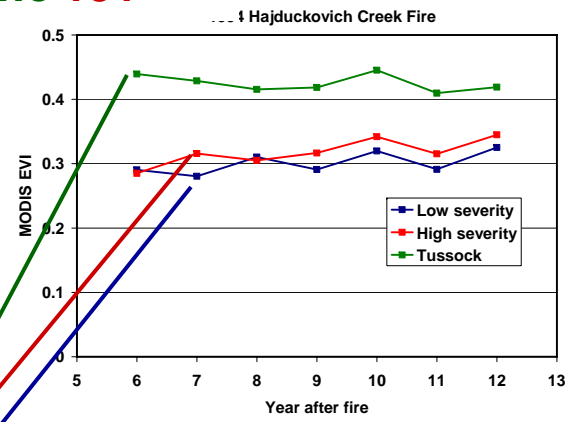
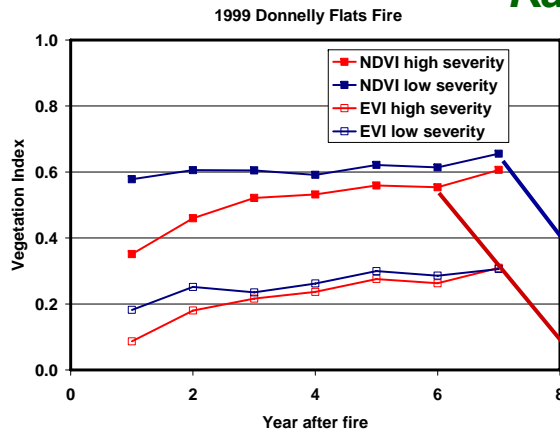
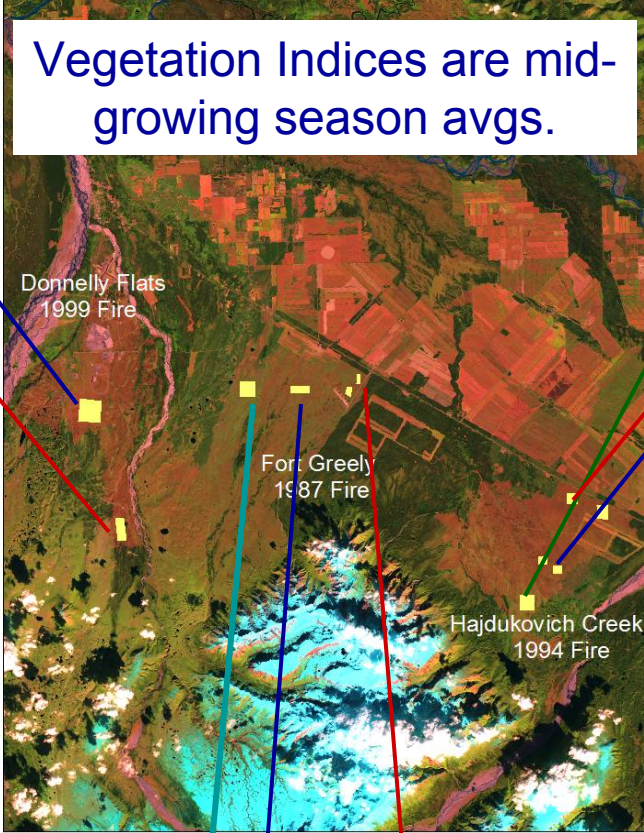
Morton



NA Boreal Forests

Goetz et al. 28

Kasischke, Bourgeau-Chavez, Johstone 151



1987 Fire
18 years post-fire



Low Severity



High Severity

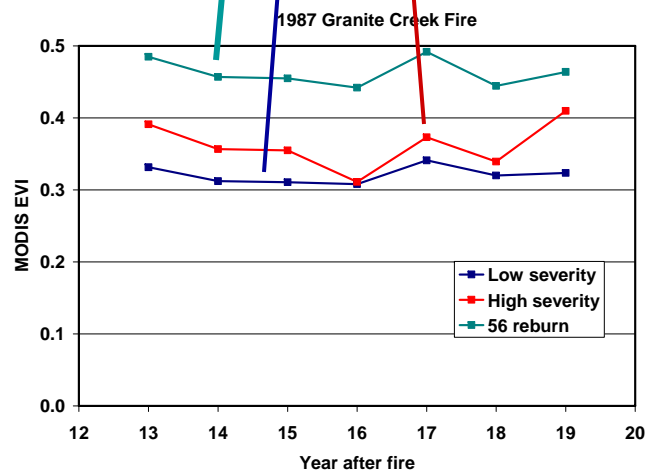
1994 Fire
9 years post-fire



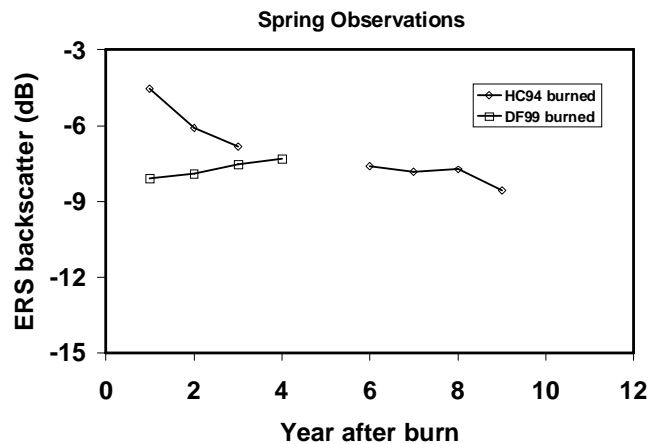
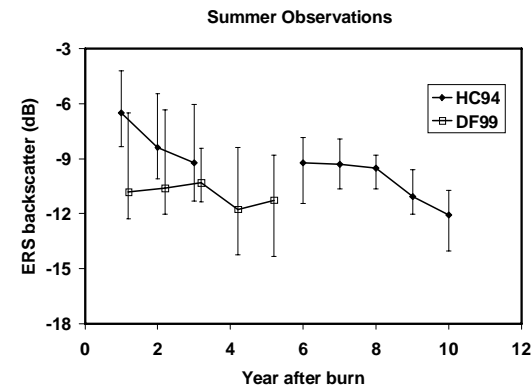
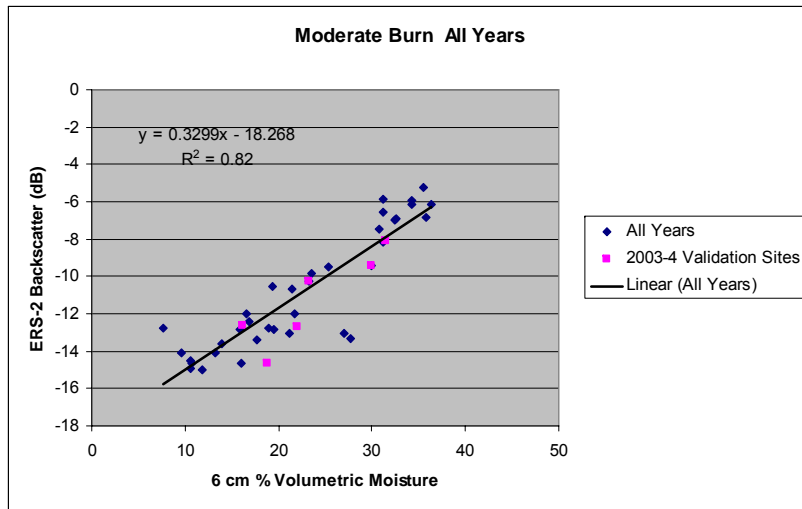
Low Severity



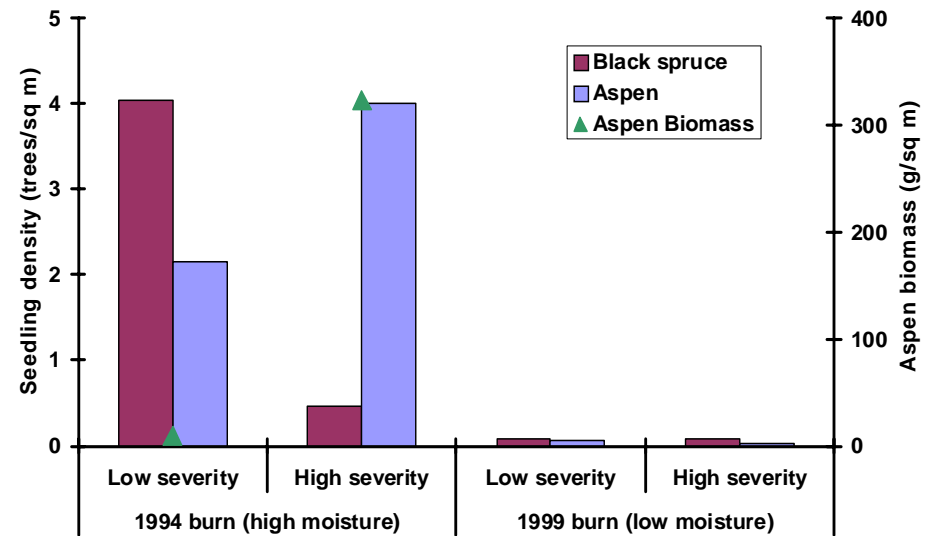
High Severity



Effects of fire severity and soil moisture on post-fire tree recruitment in boreal forests



Post-Fire seedling recruitment and aspen biomass



Bourgeau-Chavez, Johnstone, Kasischke et al.

Future Directions

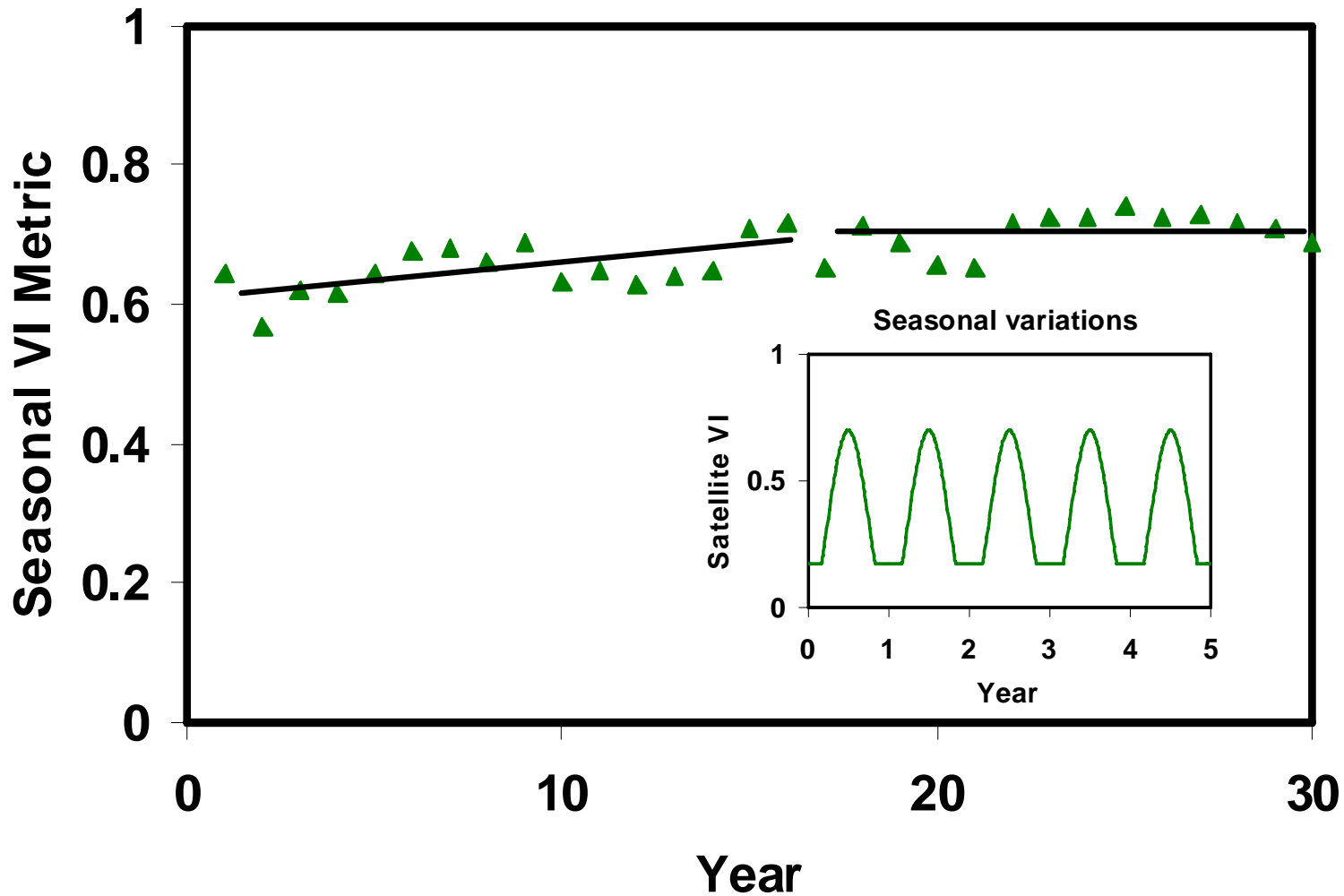
1. Recommendations from the NASA Fire Science Workshop – 20-22 Feb. 2008
2. The role of fire science in climate change and carbon cycle research
3. Integration of results from regional-scale studies into global-scale models (emissions and terrestrial carbon cycling)

Recommendations from the NASA Fire Science Workshop: 20-22 February 2008

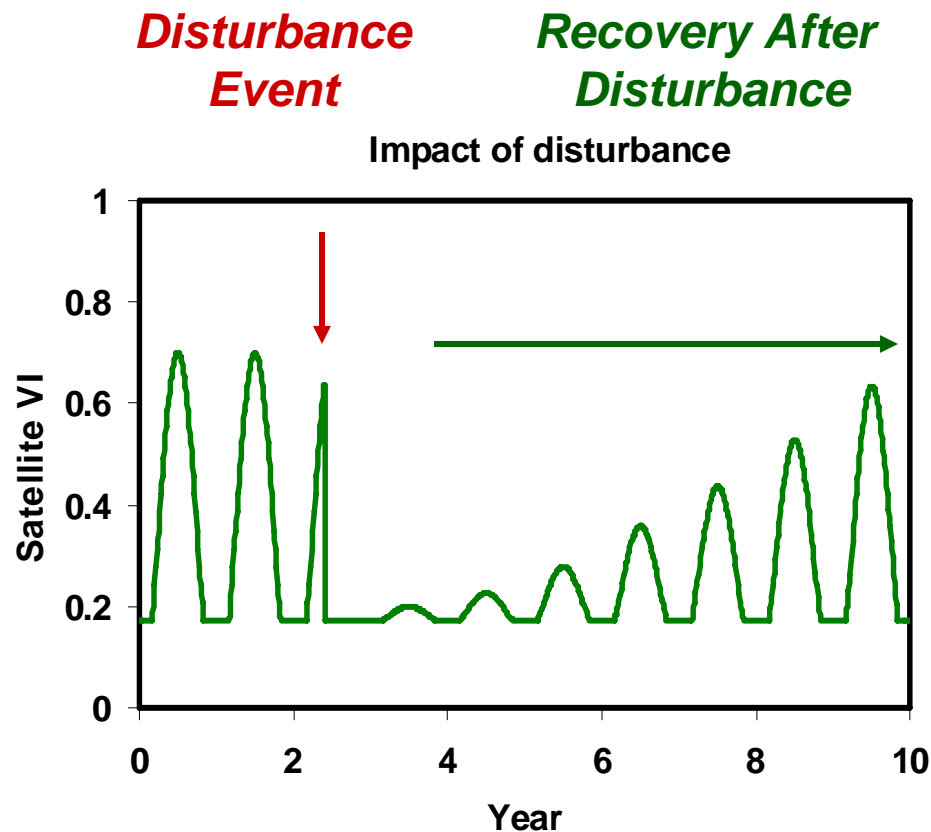
1. Improve the availability, standardization, and utility of multi-resolution spaceborne, airborne, and surface data sets
2. Conduct a global remote sensing assessment of current fire regimes (over the existing satellite record), providing a baseline for monitoring future changes in fire regimes and their impacts.
3. Develop new airborne and space-based remote sensing capabilities that provide improved products and information on fuel structure and condition, fire and emissions characterization, burn severity, and post-fire impacts
4. Continue and accelerate approaches to include fire characteristics within dynamic vegetation, ecosystem, biogeochemical cycling, and land-surface energy/water exchange models
5. Form a more cohesive, unified fire science community with better interaction between discipline sub-groups (e.g., fire danger, air quality, ecosystem effects, land use, and fire management) to provide a more holistic view of fire science.

Remote sensing of vegetation phenology: Monitoring effects of the climate continuum on characteristics of vegetation

Inter-annual and decadal variations



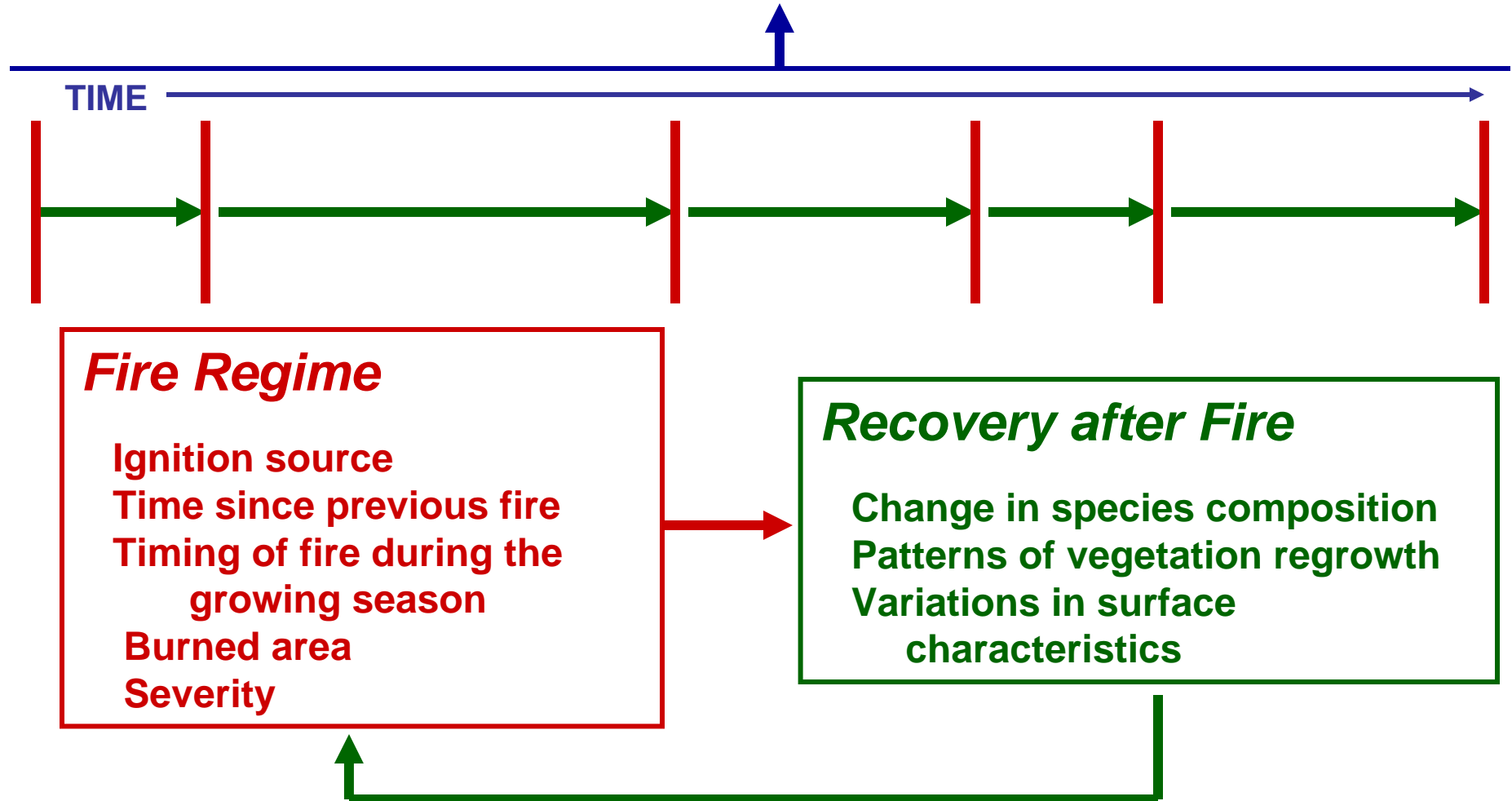
Importance of disturbance in carbon cycling



1. Disturbances cause significant short- and long-term variations of C flux to the atmosphere that are not captured through flux/ phenology measurements
2. The disturbance regime of a region (including human modifications to the regime) results in important short and long-term legacy effects
3. The frequency and severity of many disturbances (fire, insects, storm damage) are climate driven – likely to change in the future

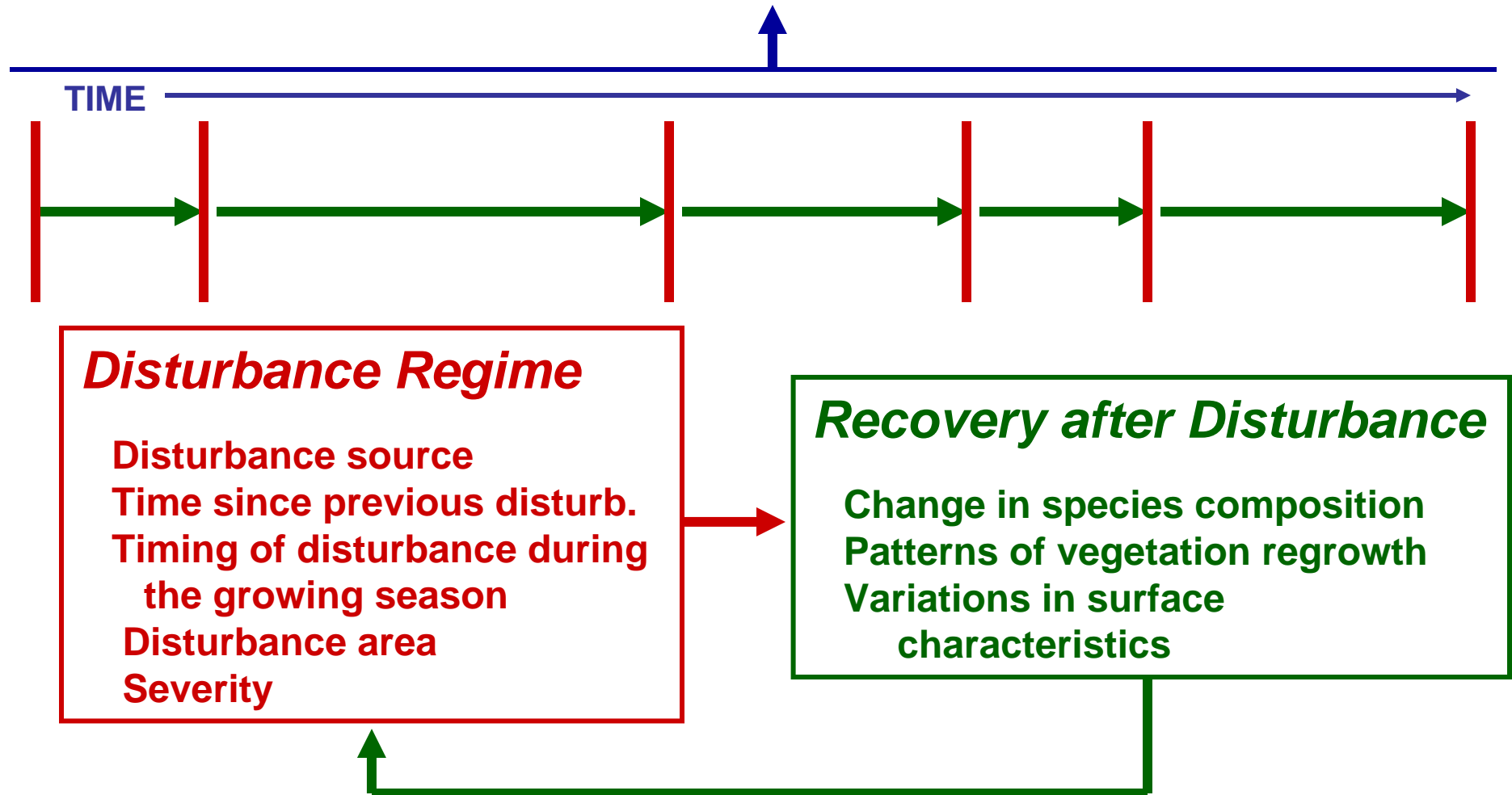
Monitoring and Assessing the Fire Disturbance Continuum

Understanding/Modeling the Impacts of Fire: succession, ecosystem composition, atmospheric emissions, carbon cycling, hydrology, land/atmosphere energy exchange, human dimensions (incl. fire management), ecosystem services



Monitoring and Assessing the Land Disturbance Continuum

Understanding/Modeling the Impacts of Disturbance: succession, ecosystem composition, carbon cycling, hydrology, land/ atmosphere energy exchange, human dimensions (land management), ecosystem services



Integration of Ongoing Efforts

1. Integration of regional scale studies of biomass burning emissions into global-scale models and Carbon Tracker –
 - Would support both carbon and atmospheric science communities
2. Integration of ongoing NACP/NASA projects (at least 12) that
 - a. Continue to develop new approaches to document and monitor fire and disturbance
 - b. Analyze the impacts of fire and disturbance on ecosystem processes and terrestrial carbon cycling



Any Questions??