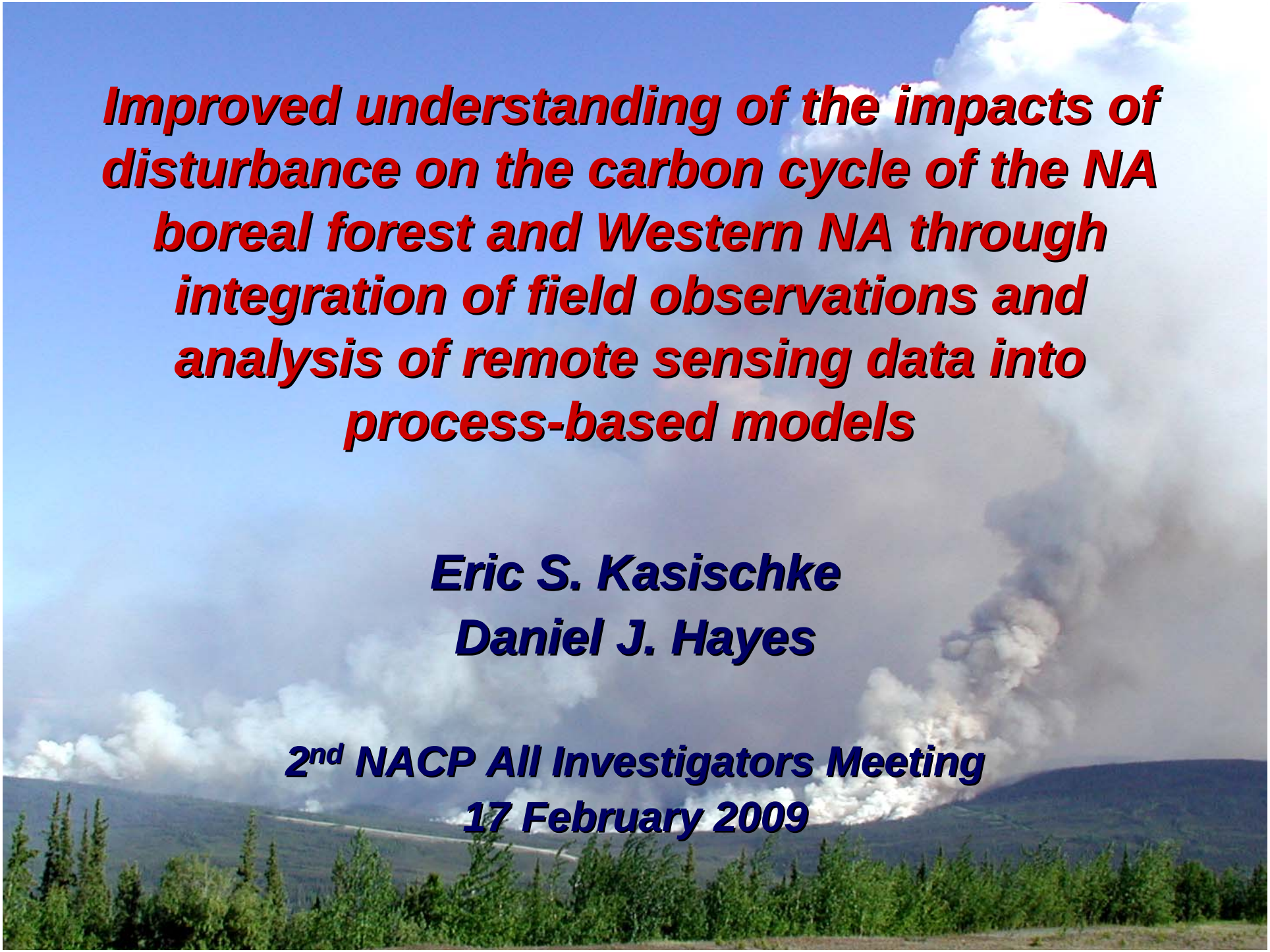


# Improved understanding of the impacts of disturbance on the carbon cycle of the NA boreal forest and Western NA through integration of field observations and analysis of remote sensing data into process-based models


**Eric S. Kasischke**

**Daniel J. Hayes**


**2nd NACP All Investigators Meeting**

**17 February 2009**

***E.S. Kasischke,*** E. Hoy, M. Borr, T. Loboda, A. Schmid (Univ. MD)

***M.R. Turetsky***, E.S. Kane, B. Benscoter, C. Treat (Michigan State Univ., Univ. Geulph)

***A.D. McGuire, K. Keilland,*** D.J. Hayes, S. Yi, F. Yuan, A. Shenoy, T.S. Rupp, T.J. Burnside (Univ. of AK)

*N.H.F. French,* ***L.L. Bourgeau-Chavez*** (Mich Tech Res. Inst.)

*J. H. Harden, K.Barrett, K. Manies* (U.S. Geological Survey)

*R.D. Ottmar, D. MacKenzie* (U.S. Forest Service)

*W. Kurz, M. Flannigan, W. de Groot, R. Hall, G. Stinson* (Canadian Forest Service)

***J.F. Johnstone*** (Univ. of AK, Univ. of SK)

*M. Waddington* (McMaster Univ.)

*D.W. Kicklighter*, *J.M. Melillo* (Marine Biological Laboratory)

*K.R. Gurney* (Purdue Univ.)

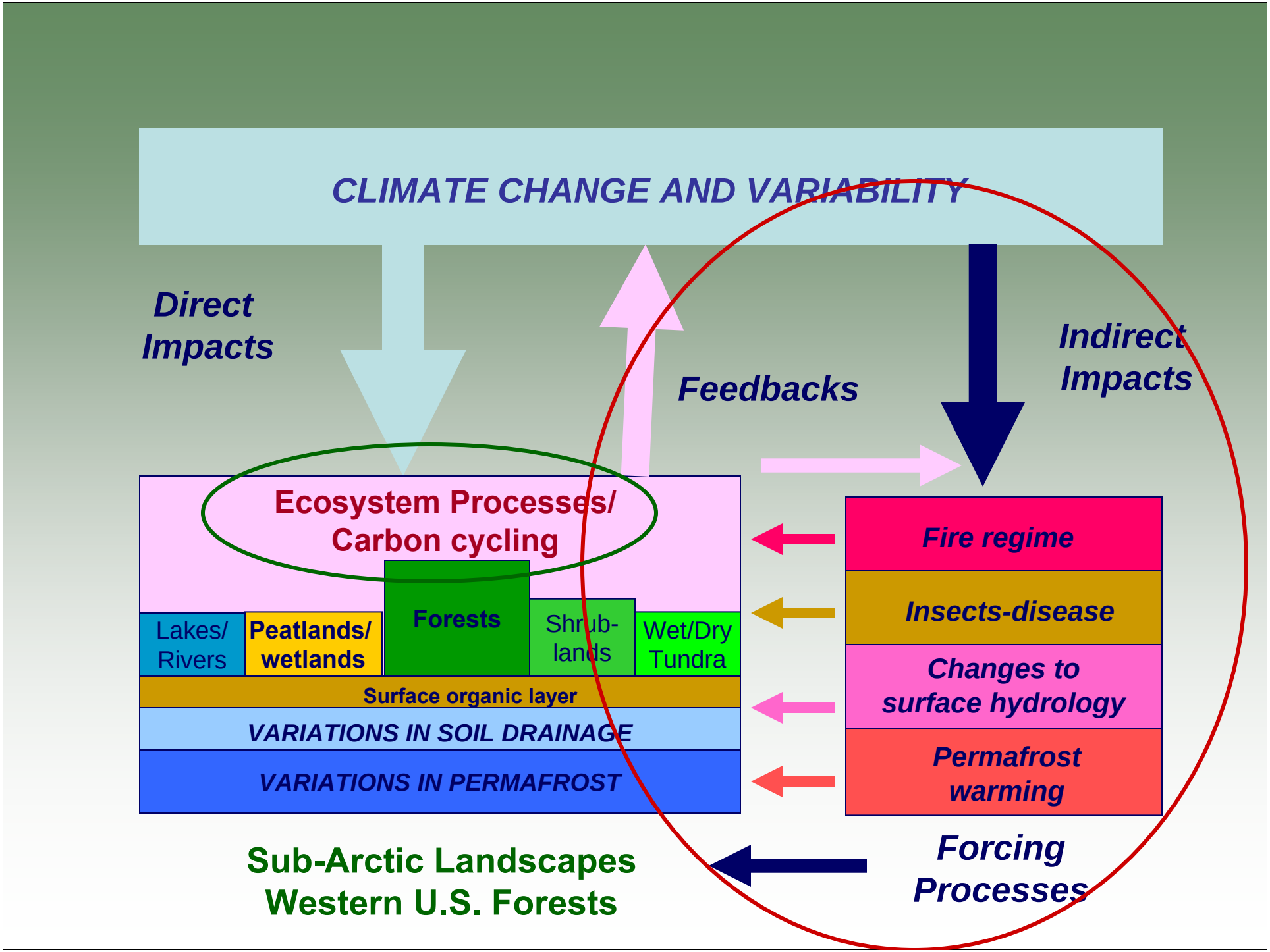
# Disturbance Presentations

*ASSOCIATED WITH THIS PROJECT*

- Kurz – Friday 10 am
- Kasischke et al. Poster 50, 150
- Hayes – Poster 12
- French – Poster 77
- McKenzie et al. – Poster 123
- Johnson et al. – Poster 49

*OTHER PROJECTS*

- Birdsey et al. – Poster 108
- Boulden et al. – Poster 33
- Cohen et al. – Poster 138
- Coursolle et al. – Poster 36
- Goetz et al. – Poster 31
- Goward et al. – Poster 144
- Grosse et al. – Poster 92
- Healy et al. – Poster 116
- Hicke et al. – Poster 43
- Hudiburg et al. Poster 93
- Huang et al. – Poster 13
- Kennedy et al. – Poster 51
- Margolis/Grant – Tues 2 pm
- Masek et al. – Poster 55
- Matamala et al. – Poster 120, 122
- Moisen et al. – Poster 60
- Neigh et al. – Poster 97
- Potter/Klooster – Poster 124
- Schroeder et al. – Poster 24
- Sierra/Harmon – Poster 66
- Thomas et al. – Poster 102
- Tian et al. – Poster 70
- Wang et al. – Poster 72
- Williams et al. - Poster 104


CLIMATE CHANGE AND VARIABILITY
Direct Impacts
Feedbacks
Indirect Impacts
Ecosystem Processes/ Carbon cycling
Lakes/ Rivers
Peatlands/ wetlands
Forests
Shrub-lands
Wet/Dry Tundra
Surface organic layer
VARIATIONS IN SOIL DRAINAGE
VARIATIONS IN PERMAFROST
Fire regime
Insects-disease
Changes to surface hydrology
Permafrost warming
Forcing Processes
Sub-Arctic Landscapes
Western U.S. Forests

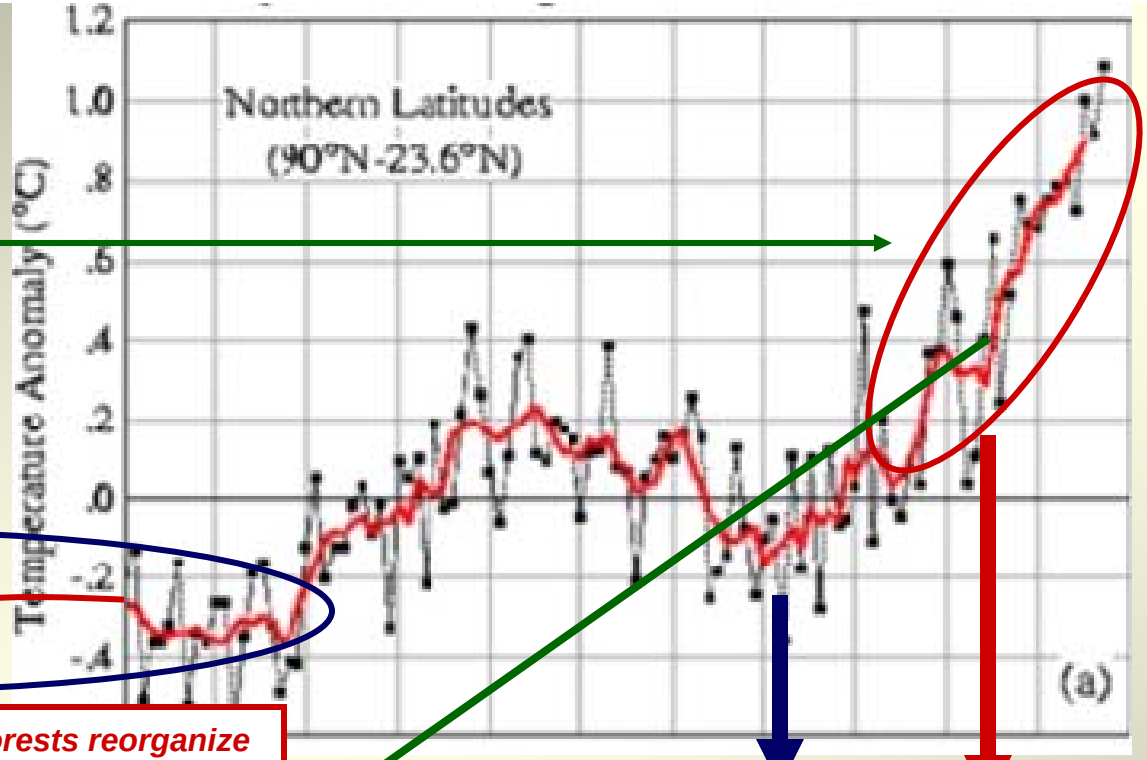
## Typical mature black spruce forests found in Interior Alaska
## 60% of vegetation cover, 78% of forest cover

**Black spruce/lichen forest**
**Organic layer = 9 - 12 cm**

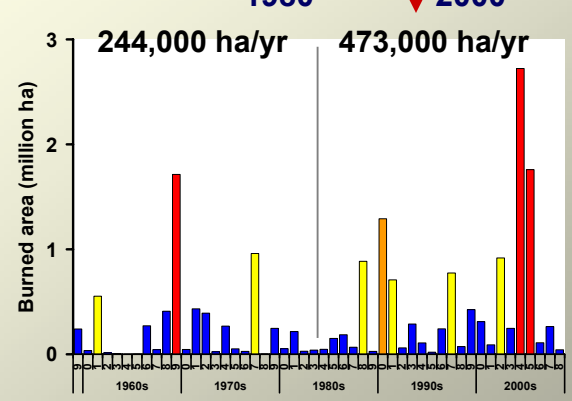
**Black spruce/feathermoss forest**
**Organic layer = 16 – 28 cm**

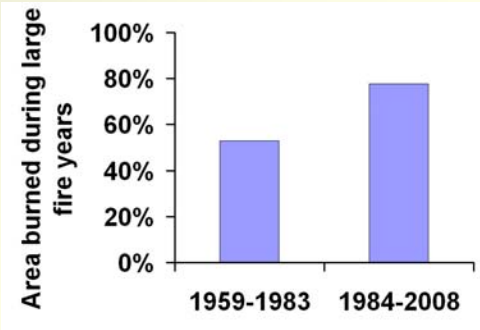
**Black spruce/sphagnum moss forest**
**Organic layer = 35 to > 40 cm**

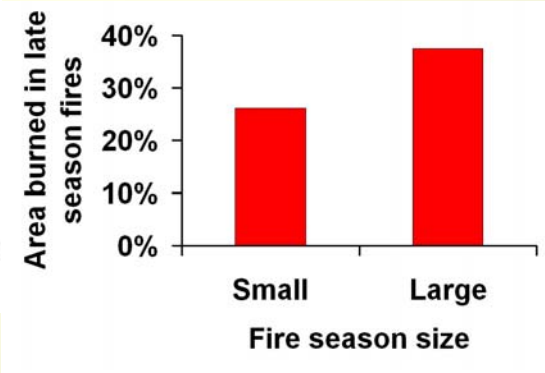
**Black spruce forests that have burned over the past 25 years were formed ~80 to 200 years ago under much different climatic conditions**




*1. To what extent will black spruce forests reorganize themselves in response to the changes in the fire regime and climate?*
*2. What processes will control this re-organization?*
*3. How will carbon cycling be impacted by this reorganization?*



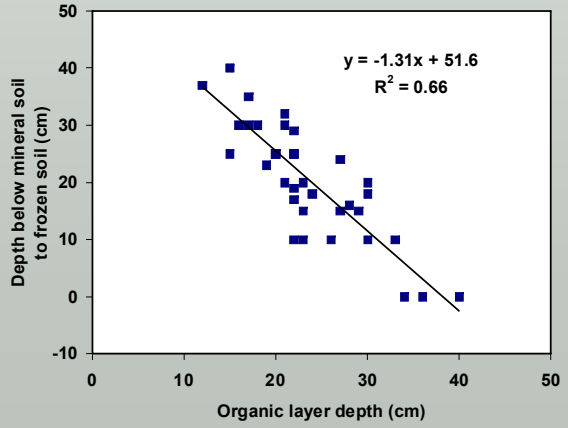

***Significant changes in the fire regime have occurred over the past 25 years***

# *Highlights of New Findings*

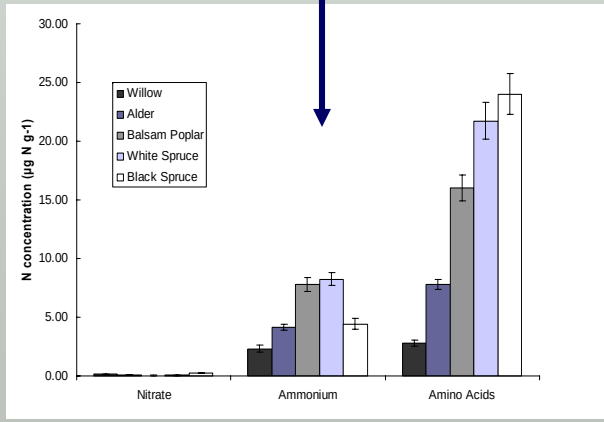
1. Field-based observations
   a. Burning of organic soils
   b. Impacts of fire severity on post-fire conditions and regeneration
2. Analysis of the fire regime using moderate resolution (30 m) remotely-sensed data - Controls on spatial/temporal patterns of fires
3. Modeling results
   a. Pyrogenic emissions during the 2004 Alaska fires
   b. Impacts of disturbance on the terrestrial carbon budget in HNH regions

# *Why organic soils?*

1. Large carbon reservoir (>85% of carbon above mineral soil, burning impacts C reservoir)
2. Insulation of ground layer (regulates permafrost formation/deformation)
3. Medium where plant propagules reside (controls post-fire vegetative reproduction)
4. Variations in water retention capacity between organic/mineral soils (influences seed germination and survival)
5. Variations in nutrient cycling between organic and mineral soil environments (regulates plant growth)




***(E. Kane, E. Kasischke)***




***(K. Kieland)***

**Our research is based on data collected in plots in 36 fire events and unburned stands**
**• Used to measure fire severity and surface fuel consumption in black spruce forests**

**Studies by researchers at ERIM, UMD, MSU, UAF, USFS, USGS, USFWS**

**284 plots in unburned stands, 465 plots in burned stands**
**8,447 organic layer depth measurements in unburned stands, 10,140 in burned stands**
**>2,000 organic layer samples collected for lab analysis to determine bulk density and % C**

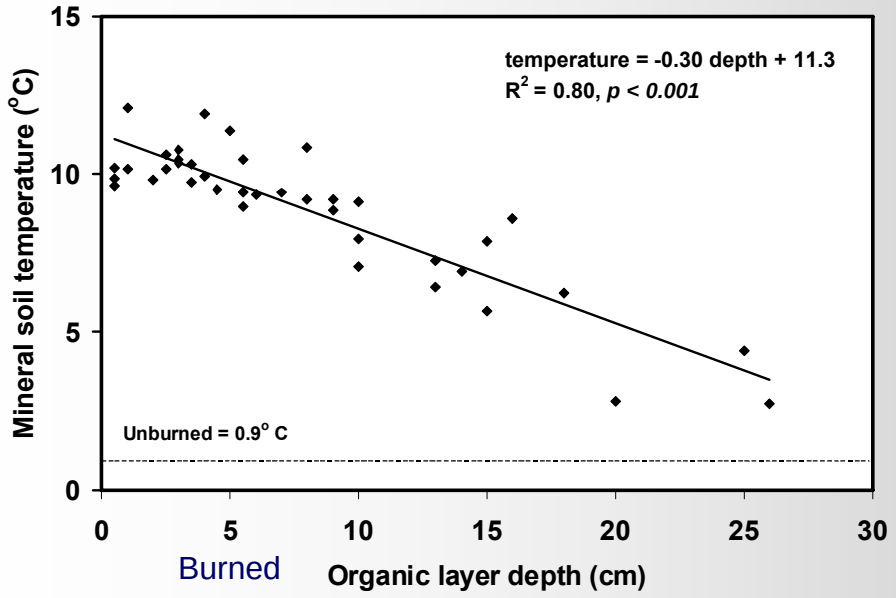
***Primary sampling device**

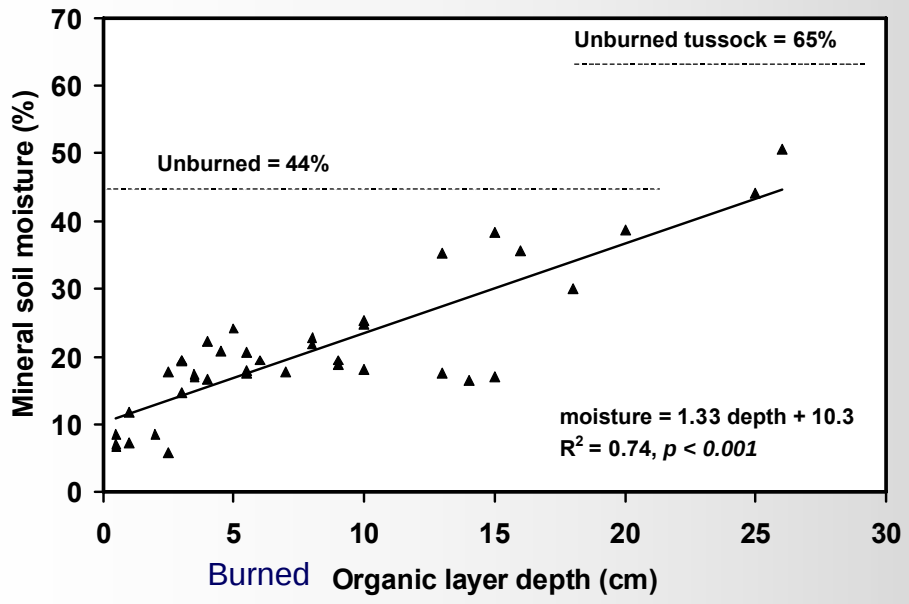
# Organic Soil Burning
# (M. Turetsky, E. Kane, J. Harden, E. Kasischke)

1. Depth of burning/C loss is controlled by a combination of factors that control duff moisture, including seasonal and inter-annual variations in temperature and precipitation, topography, and seasonal thawing of permafrost

2. Much more organic soil in BS forests is consumed during fires than previously estimated (~4.9 kg C $m^{-2}$ over past 25 years)

## 8 years post-fire




*(E. Kasischke, J. Johnstone)*

**Depth of burning in a black spruce forest controls post-fire patterns of soil moisture and temperature**

→ **S. Yi, D. McGuire, and J. Harden have focused on modifying the Terrestrial Ecosystem Model (TEM) to account for the impacts of variations in depth of burning on permafrost in boreal forests**

# Impacts of fire severity and site moisture on tree recruitment and growth

***(J. Johnstone, A. Shenoy, E. Kasischke)***

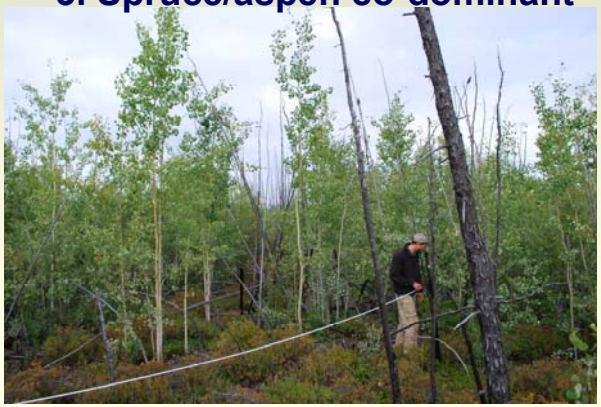
### 1. Spruce-shrub dominated

a. Deep residual organic layer (7-11 cm)
b. High spruce recruitment and growth (recruitment >> pre-burn stand density)
c. Shrub layer established via vegetative reproduction of species present prior to fire

### 2. Open black spruce

a. Shallow to deep residual organic layer (2 - 8 cm)
b. Spruce recruitment < < pre-burn stand density
c. Low aspen recruitment and growth
d. Shrubs established mainly through vegetative reproduction
e. Soil moisture limits seedling recruitment and growth

### 3. Spruce/aspen co-dominant



a. Deep residual organic layer (9 cm)
b. Spruce recruitment high enough to support recovery to near pre-fire stand density
c. Aspen recruitment moderate, with moderate level of biomass accumulation
d. Shrubs dominated by species established via vegetative reproduction

***Our studies have found 5 distinct patterns of post-fire succession in Alaskan black spruce forests***

# Impacts of fire severity and site moisture on tree recruitment and growth

### 4. Aspen/spruce co-dominant

a. Moderately deep residual organic layer (3-6 cm)
b. Spruce recruitment high enough to support recovery to near pre-fire stand density
c. Aspen and willow recruitment high, but biomass accumulation low, herbivory may have a role
d. Source of shrubs (seedlings vs. vegetation reproduction) TBD

### 5. Aspen dominant

a. Shallow residual organic layer (< 3 cm)
b. High aspen growth
c. Spruce recruitment < pre-burn stand density
d. Shrubs established through seeding

***See poster #150***

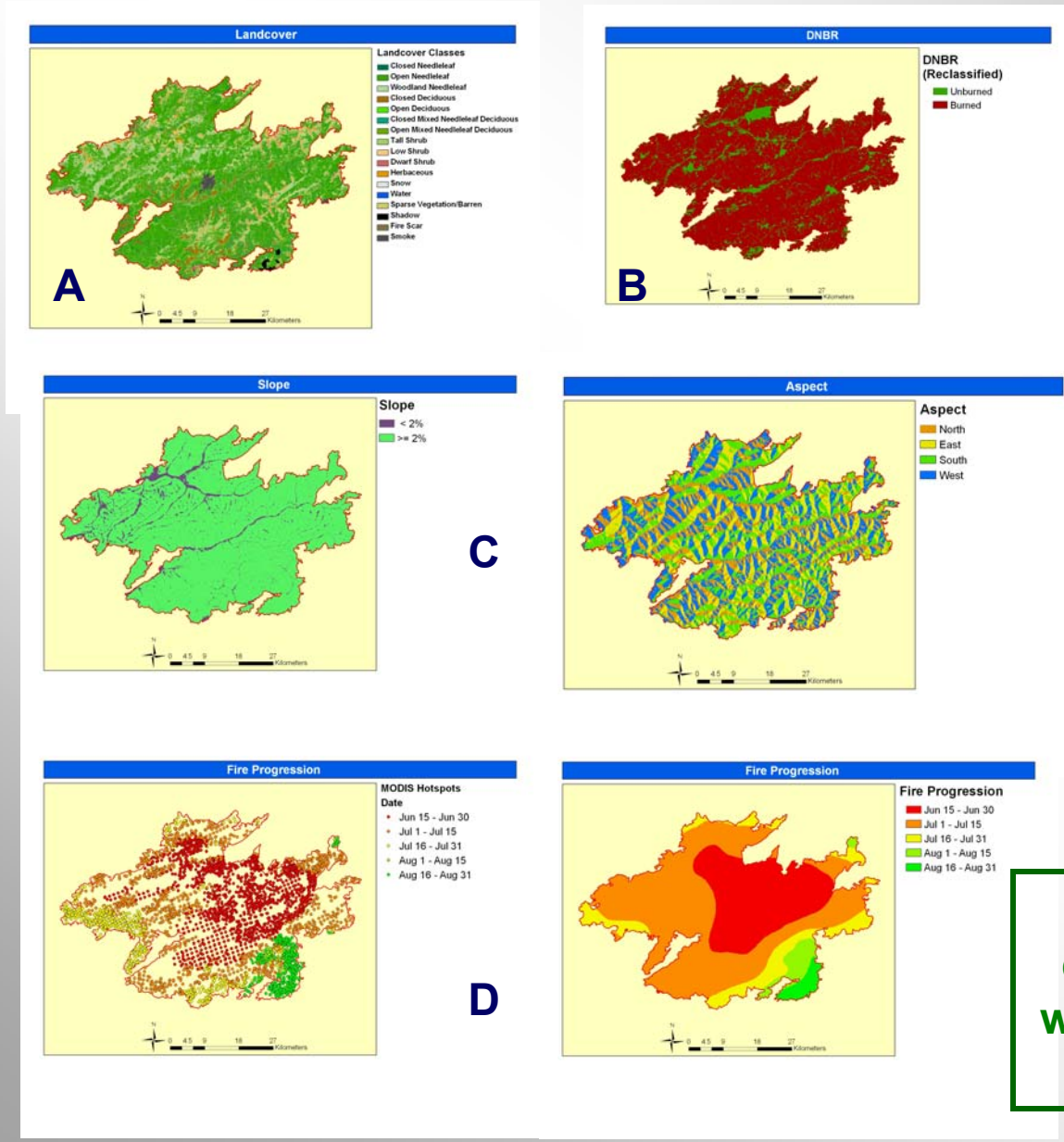
***K. Barrett is working with S. Rupp and D. McGuire to model the impacts of variations in fire severity on post-fire succession and C cycling***

## *Does weather or fuel type control susceptibility to burning at landscape scales?*

- ***Fuel hypothesis:*** Under wet to moderately-dry conditions, fuel type and fuel load control patterns of burning across the landscape, with site drainage also being important

- ***Weather hypothesis:*** Under dry conditions that result in intense fire activity, fuel type, fuel load, and site drainage do not limit the spread of fire across the landscape

## *Data integration approach developed by L. Hoy*




**Seasonal patterns of burning of 6 fuel types on two topographic positions (uplands/ lowlands) were examined for 41 fire events from the 2004 Alaska fire season (95% of all area burned)**

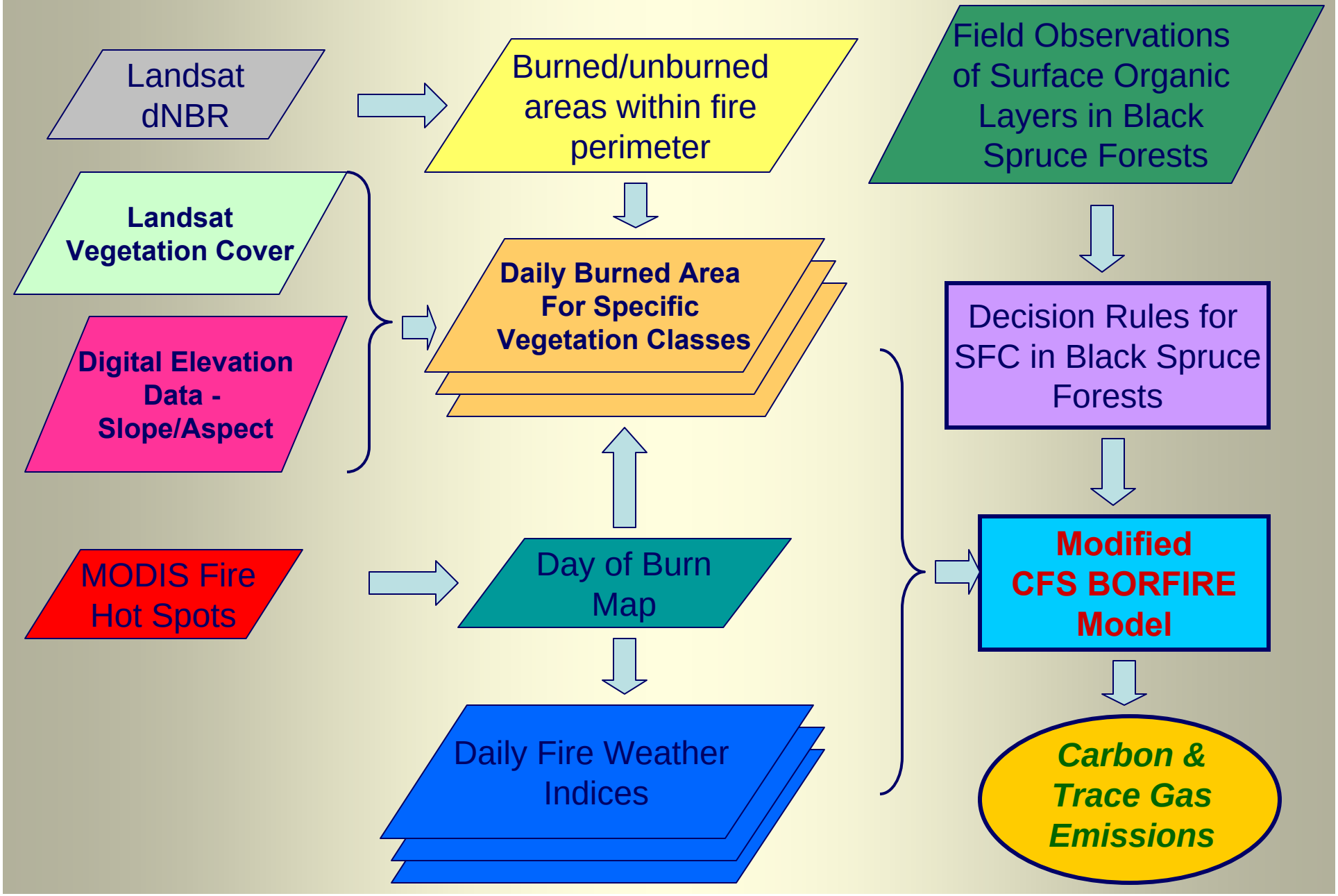
**Burned areas were then correlated with seasonal fire weather indices obtained from 36 stations**

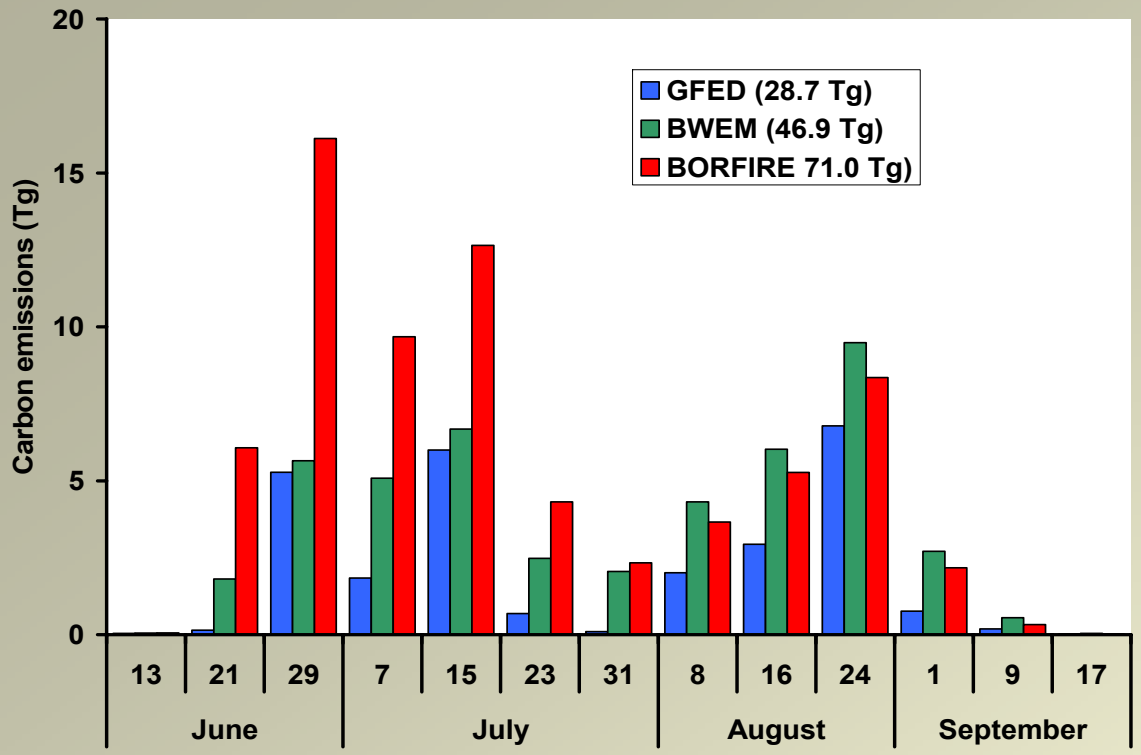
## *Climate/vegetation/topographic interact to control on patterns of burning at landscape scales*

**Our study showed**

1. **20% of the area within fire perimeters did not burn**
2. **Upland sites burned more frequently than lowland sites**
3. **Coniferous forests burned more frequently than deciduous forests**
4. **Forests burned more frequently than non-forests**
5. **Across all forest types, fraction of area burned during the growing season was controlled by weather, with a higher fraction of area burned occurring during drier, windier conditions**

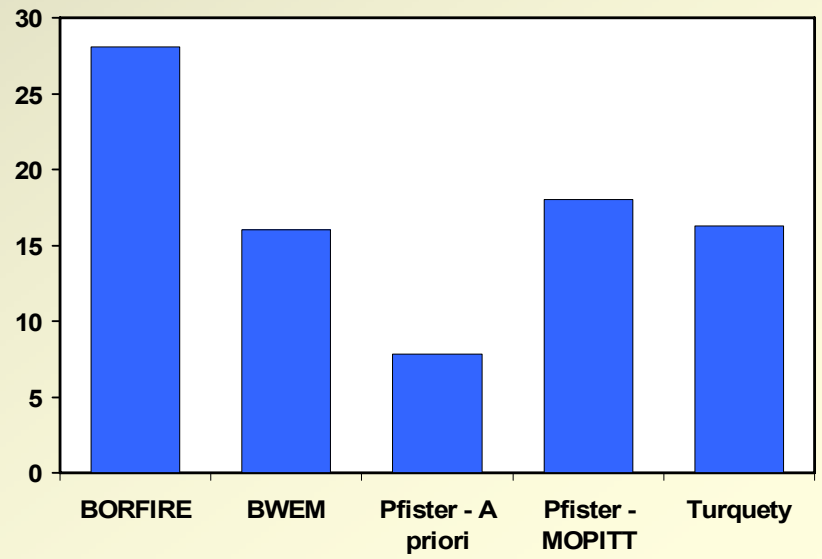
# *Fire Emissions Estimation in the Alaskan Boreal Forest*
## *(Kasischke, de Groot, Hoy, French, Turetsky)*





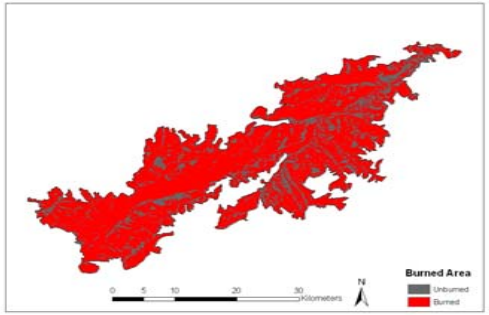

*See poster #50*

CO Emissions from the 2004 Alaskan Fires

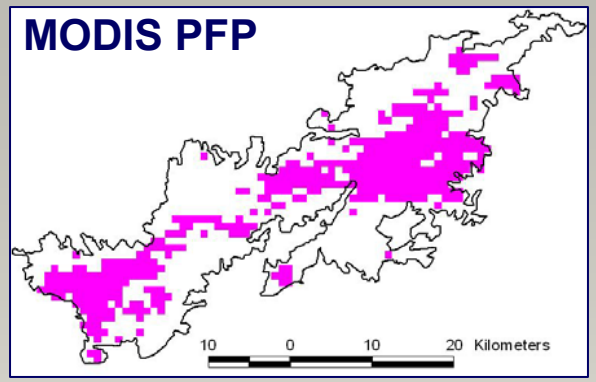



***Emission estimates for the 2004 Alaskan Wildfires***

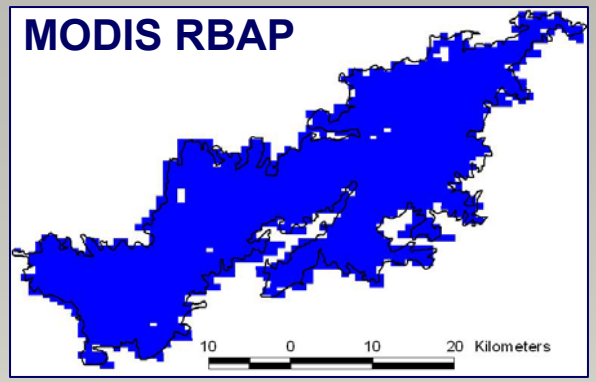
## *Estimates of burned/unburned area - Wolf Creek Fire (T. Loboda)*




**Landsat TM: burned 79%**
**Unburned 21%**




**MODIS Product: 35% burned**
**65% unburned**

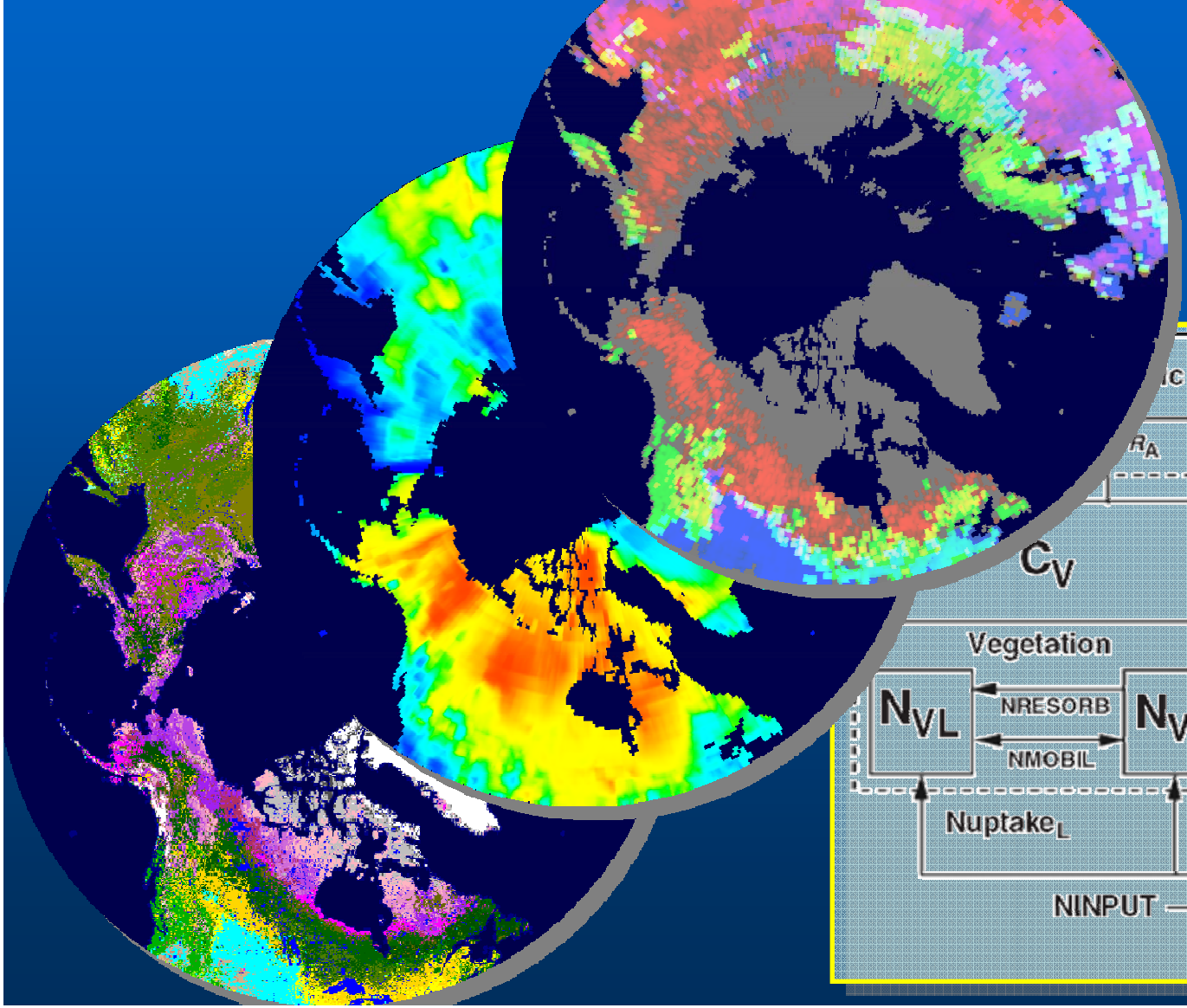


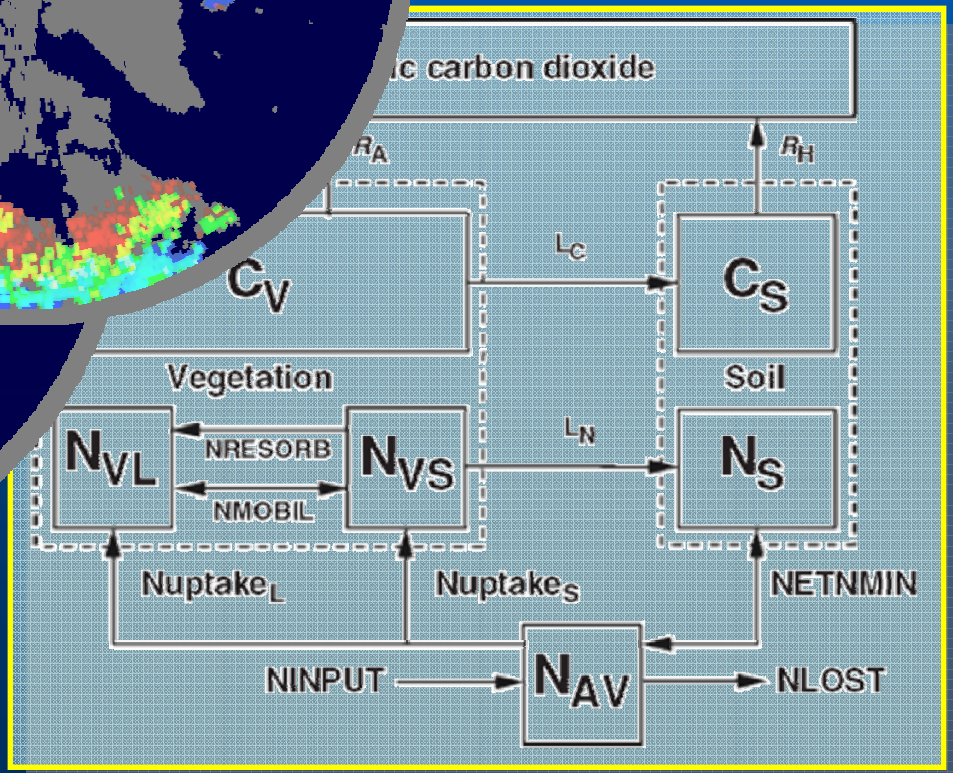

**Loboda Product: 96% burned**
**4% unburned**

## *Vegetation Cover within 5 burn perimeters (A. Schmid)*
## *Fire impacted area = 824,000 ha*

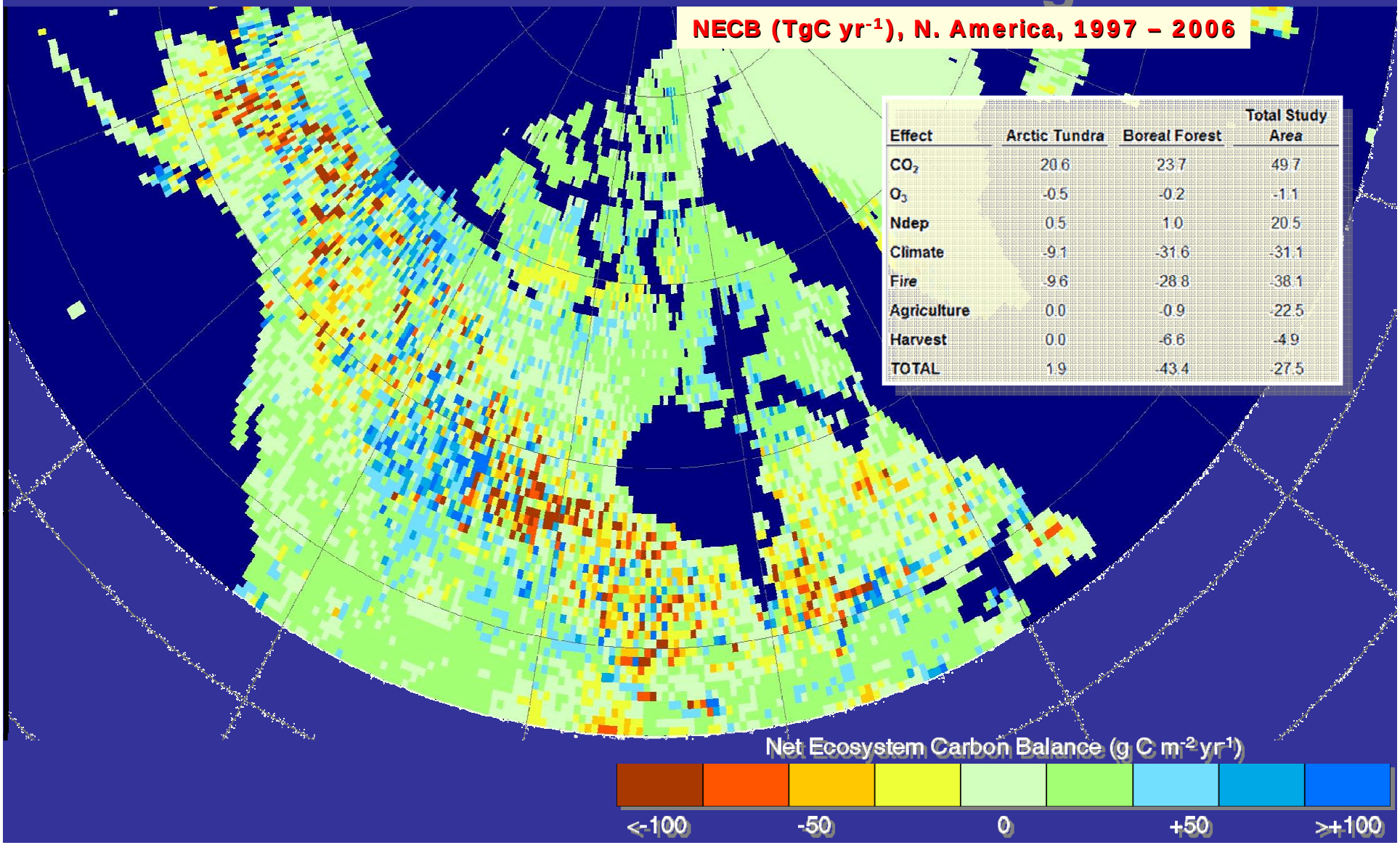
| Landsat TM | | MODIS | |
|---|---|---|---|
| Spruce Forest | 59% | Evergreen/deciduous needleleaf forest | 21% |
| Deciduous forest | 5% | Deciduous/Evergreen broadleaf forest | 0% |
| Mixed | 9% | Mixed forests | 3% |
| Tall Shrub | 6% | Closed shrublands | 0% |
| Low Shrub | 13% | Open shrublands | 27% |
| Herbaceous | 3% | Savannas/grasslands | 4% |
| | 4% | | |
| Other | 2% | | |
| | | Woody Savannas | 44% |

# Modeling the impacts of disturbance on the terrestrial carbon budget





# Modeling the impacts of disturbance on the terrestrial carbon budget

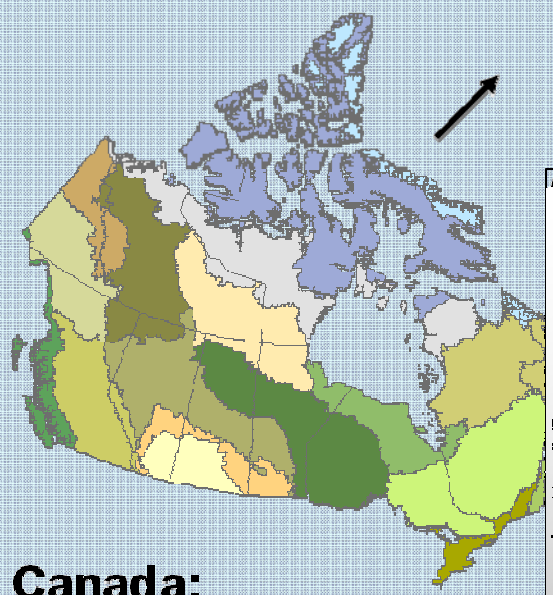



| Effect | Arctic Tundra | Boreal Forest | Total Study Area |
|---|---|---|---|
| $CO_2$ | 20.6 | 23.7 | 49.7 |
| $O_3$ | -0.5 | -0.2 | -1.1 |
| Ndep | 0.5 | 1.0 | 20.5 |
| Climate | -9.1 | -31.6 | -31.1 |
| Fire | -9.6 | -28.8 | -38.1 |
| Agriculture | 0.0 | -0.9 | -22.5 |
| Harvest | 0.0 | -6.6 | -4.9 |
| TOTAL | 1.9 | -43.4 | -27.5 |

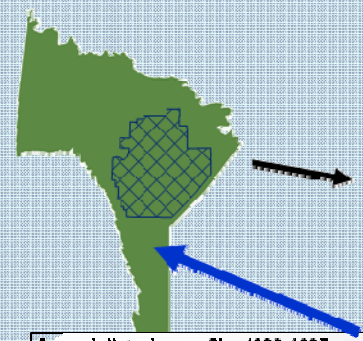
# Modeling the impacts of disturbance on the terrestrial carbon budget

Canada Data Sets:
Multiple Disturbances at Hierarchical Spa

**60 Reconciliation Units**



**Canada;**
**18 Reporting Zones**



**Annual disturbance file: 1920-1995**

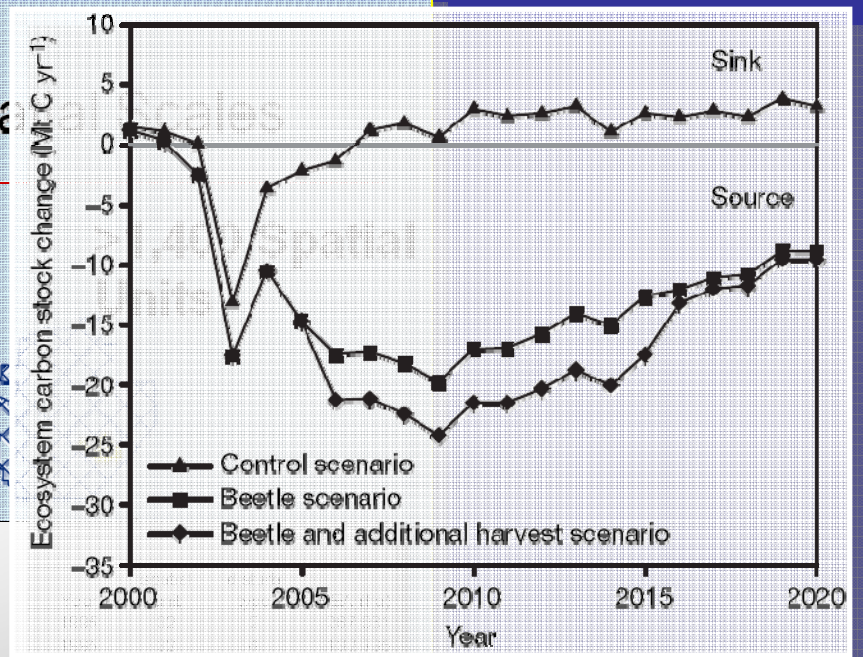
| Year | spatial unit | disturb type | AREA (ha) |
|---|---|---|---|
| 1920 | 1 | [illegible] | 3,047 |
| 1920 | 3 | [illegible] | 10,377 |
| 1920 | 4 | [illegible] | 5,305 |
| 1920 | 5 | [illegible] | 4,491 |
| 1920 | 6 | [illegible] | 212,331 |
| ... | | | |
| 1995 | 32 | 5 | 3,123 |
| 1995 | 32 | 8 | 2,898 |
| 1995 | 32 | 10 | 3,348 |
| ... | | | |

**Disturbance types**

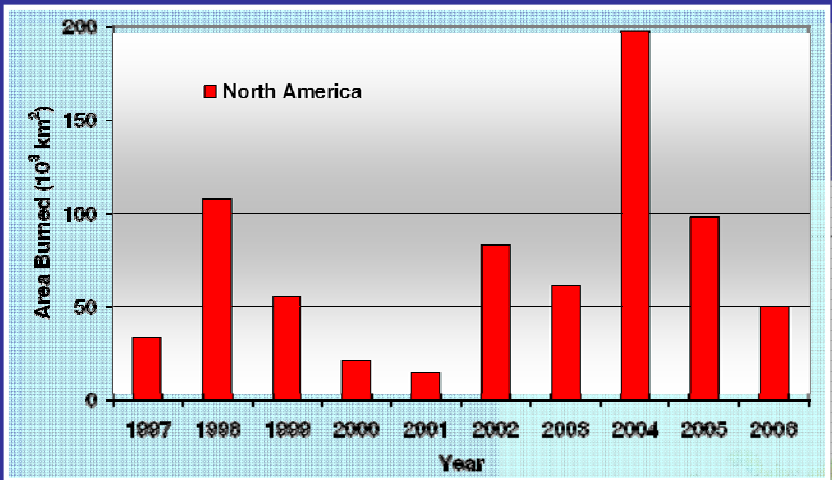
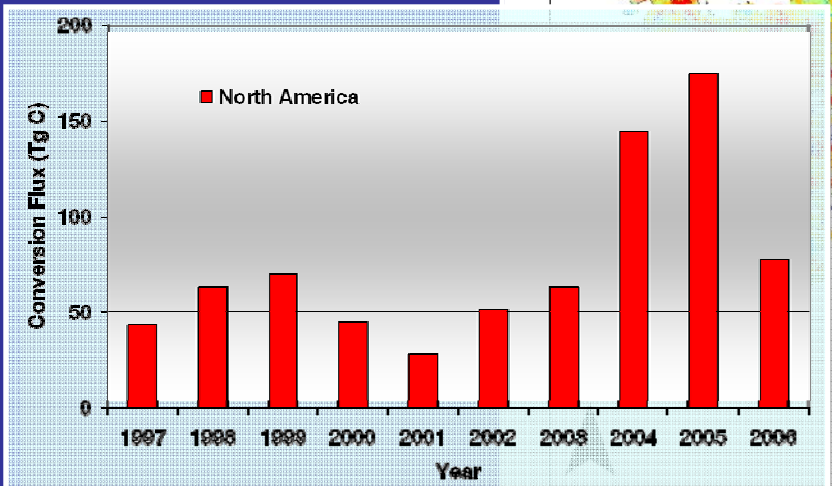
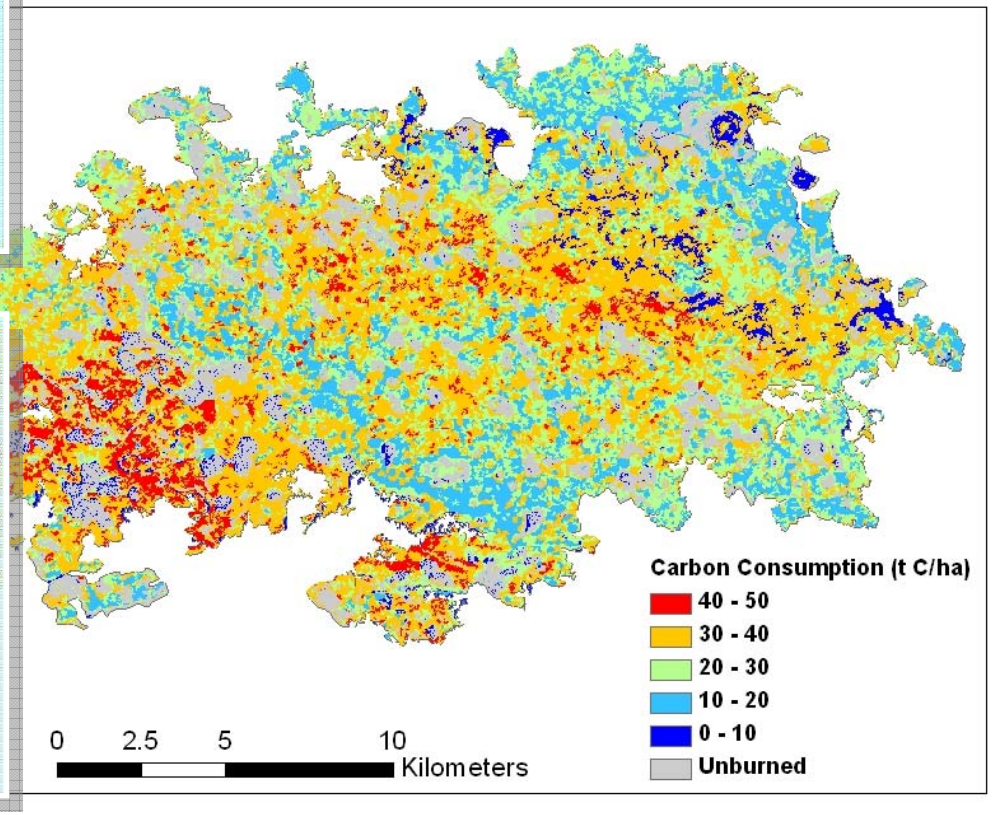
| Code | Disturbance |
|---|---|
| 1 | Fire |
| 2 | Insects |
| 3 | Clear-cut and burn |
| 4 | Clear-cut |
| 5 | Post fire salvage |
| 6 | Post insects salvage |
| 10 | Partial cut |

**Spatial units**

| spatial unit | Ecoclimati | administrative unit |
|---|---|---|
| 1 | Arctic | N/W Territories |
| 2 | Arctic | Yukon Territory |
| 3 | Sub-Arctic | Yukon Territory |
| 4 | Sub Arctic | Yukon Territory |
| 5 | Sub-Arctic | N/W Territories |
| 6 | Sub Arctic | N/W Territories |
| 7 | Cordillera | Yukon Territory |
| ... | | |




(Kurz et al., 2008)

# Modeling the impacts of disturbance on the terrestrial carbon budget

See poster #12