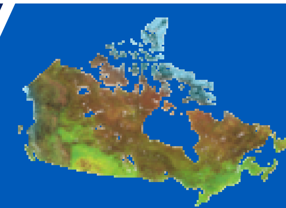
Remote Sensing of Burn Severity in the Canadian Boreal:



Results and Lessons Learned

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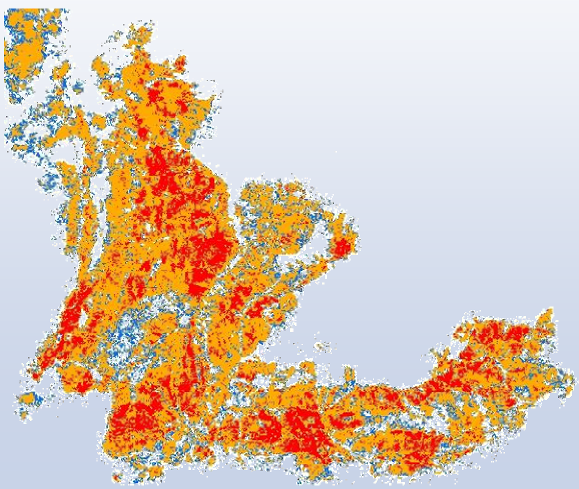

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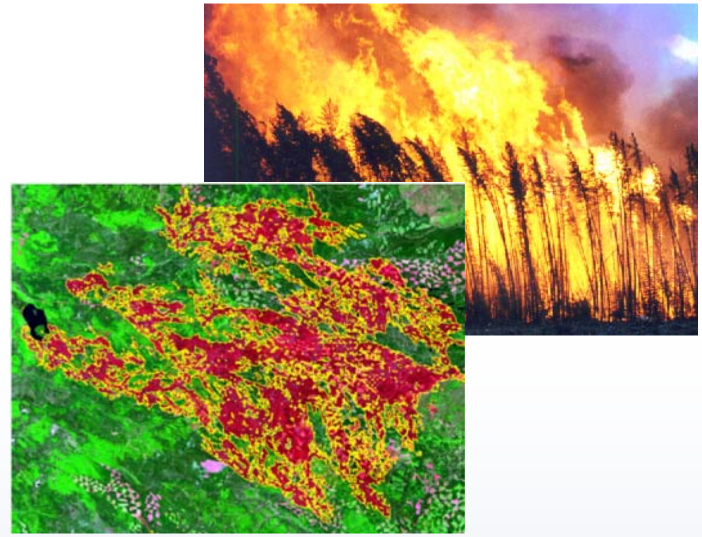
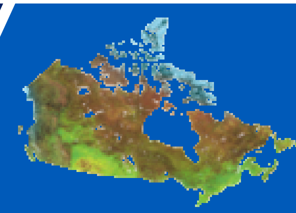
Presentation Outline

- CWFIS
- Background, Objectives
- Method flowchart
- Results
  - dNBR – CBI models
  - Influence of fuel type
  - Classifying/mapping burn severity
  - dNBR – fuel consumption
- Discussion & Summary: Lessons & Opportunities



Canadian Wildland Fire Information System



Purpose of CWFIS is to report national fire statistics by developing a reliable and defendable forest fire emissions reporting system to meet UNFCCC, Criteria & Indicators and Kyoto reporting obligations.

Approach:

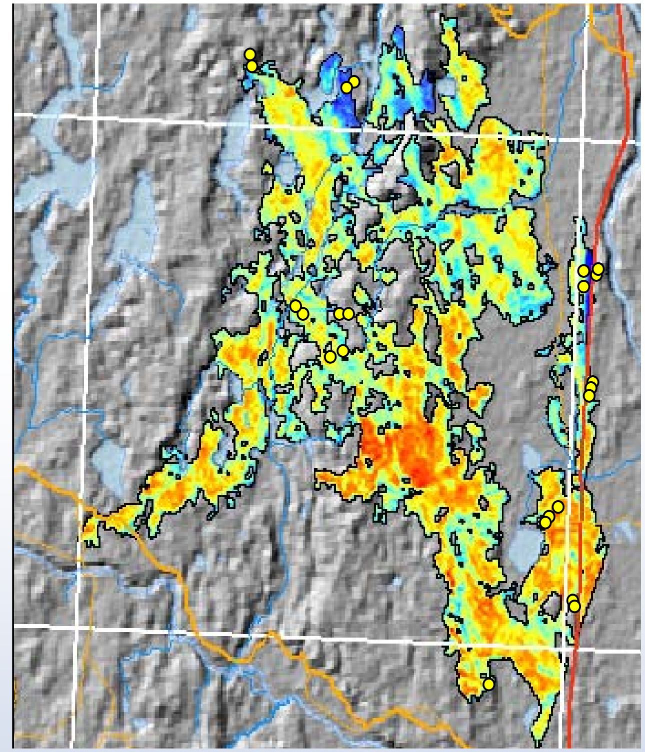
To generate national forest fire burn area products by combining satellite data products and ground-based weather information with fuel consumption and carbon budget models.

A small component of CWFIS was to investigate the possible influence of burn severity on fuel consumption.

http://cwfis.cfs.nrcan.gc.ca/en/index_e.php

Background

- There is often a considerable variation within boreal fires.
- Severity of the burn reportedly influenced by the amount of fuels consumed (Brewer et al. 2005, Roy et al. 2006).
- Considerable interest to quantify and relate the ecological effects of burn severity between field and image.
- Many papers report use of dNBR and CBI (Key, Benson)



How are these attributes related in Canadian boreal fires?

Objectives

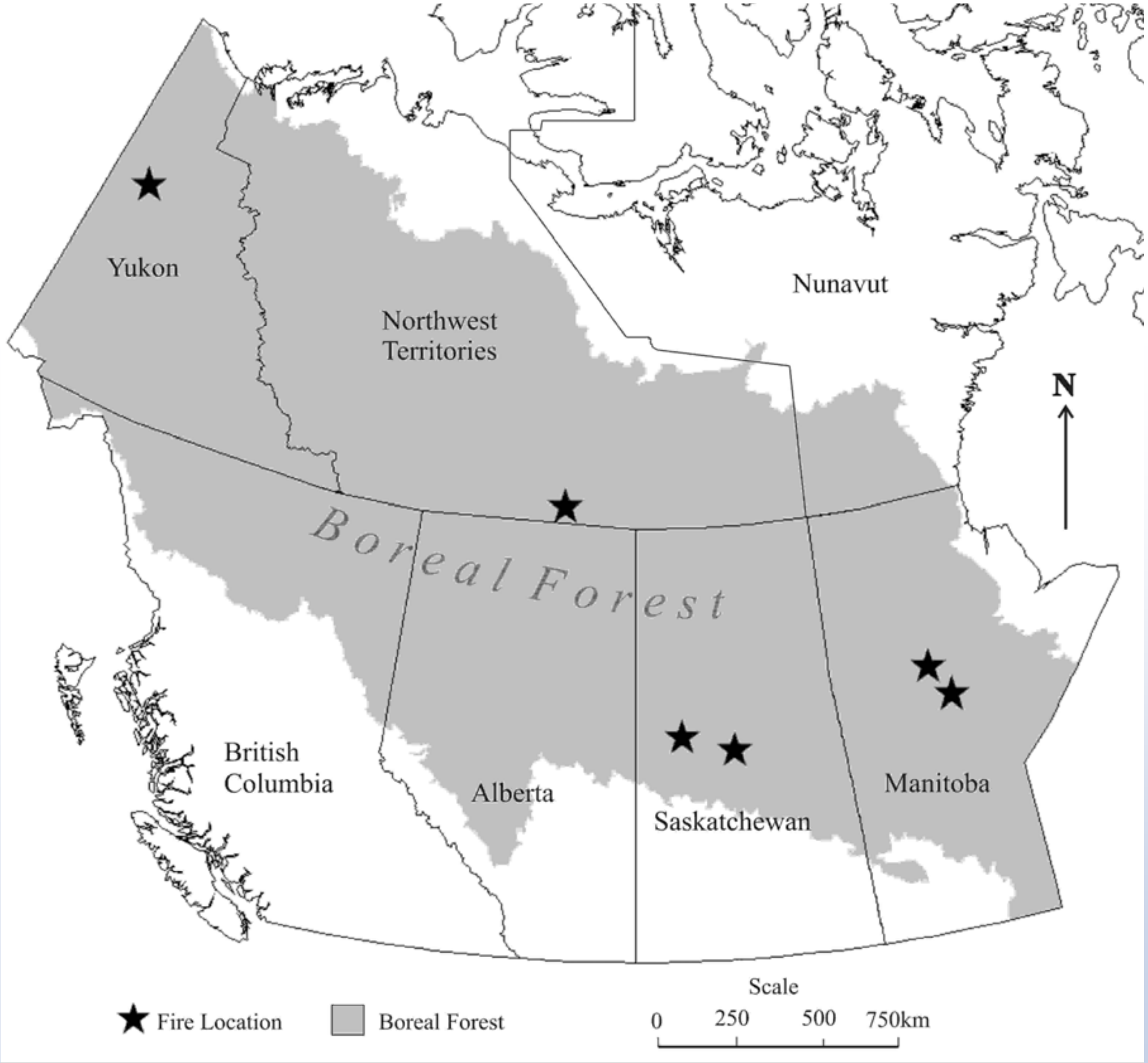
1) Are satellite image (dNBR) and field (CBI) indicators of burn severity related?

2) Are these indicators influenced by fuel type?

3) How may these associations be used to classify and map burn severity?

4) Are satellite image (dNBR) and field (CBI) indicators of burn severity related to fuel consumption?

Location of Fires

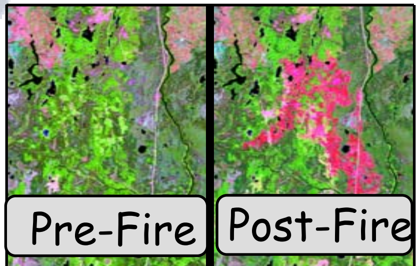


Landsat Image Acquisition

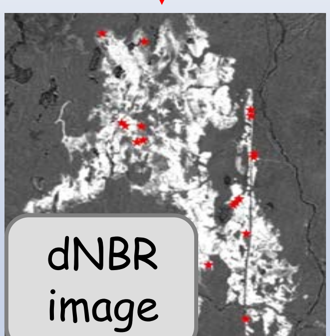
Fire	Temporal Period	Path/Row	Image Date
Green Lake	T1	39/22	Aug 2/01
Saskatchewan	T3	39/22	July 25/04
Montreal Lake	T1	37/22	Aug 12/01
Saskatchewan	T3	38/22	Aug 19/04
Dawson	T1	62/15	Aug 9/03
Yukon	T3	62/15	July 13/05
WBNP	T1	46/18	July 10/04
NWT	T3	45/18	Aug 23/05
Burntwood	T1	33/21	July 31/01
Manitoba	T2	33/21	Aug 14/03
Thompson	T1	33/21	July 31/01
Manitoba	T2	33/21	Aug 14/03

Method Overview

Landsat TM



Preprocessing:
- Atmospheric correction
- Orthorectification
- dNBR image created



Variables Collected:
- Composite Burn Index
- Fuel type, Plot Loc^{n}.
- Fuel consumption

Field Data Collection

Database Development

PLOT	dNBR	CBI	Fuel Type	Fuel Cons.
01-01	0.1423	1.55	D2	4.22
02-01	0.4677	2.29	D2	5.40
02-02	0.2373	0.82	D2	0.89
03-01	0.9367	3.00	C2	3.35
04-01	0.3995	1.49	D2	2.59
05-02	0.2128	1.65	C3	4.01
06-01	0.1661	1.34	D2	1.40

Modeling of burn severity and dNBR with CBI

Assess influence of fuel type on dNBR, burn severity

Produce classified maps of burn severity

Pooling Datasets

- Merged small datasets from fires occurring in the same Eco-Region
- Green Lake and Montreal Lake formed the Saskatchewan (Sask.) dataset

2-Sample T-test Results

Provincial Fires	Variable	Mean Diff.	p-value
Green Lake-Montreal Lake	dNBR	-0.42	0.22
	CBI	-0.07	0.43

Modeling Burn Severity with dNBR

Pearson's corr*	Sask.	Yukon	NWT	ALL
dNBR-CBI	0.87	0.85	0.87	0.87

*** All correlations significant, $p < 0.001$**

	Sask.		Yukon		NWT		ALL	
Data model	R^2	**RMSE**	R^2	**RMSE**	R^2	**RMSE**	R^2	**RMSE**
$Y = aX + b$	0.76	0.30	0.76	0.36	0.76	0.21	0.73	0.30
$Y = aX^2 + bX + c$	0.85	0.19	0.88	0.18	0.87	0.12	0.84	0.17
$Y = X / (aX + b)$	0.82	0.22	0.85	0.22	0.82	0.17	0.82	0.20

Modeling Burn Severity: T1 - T3

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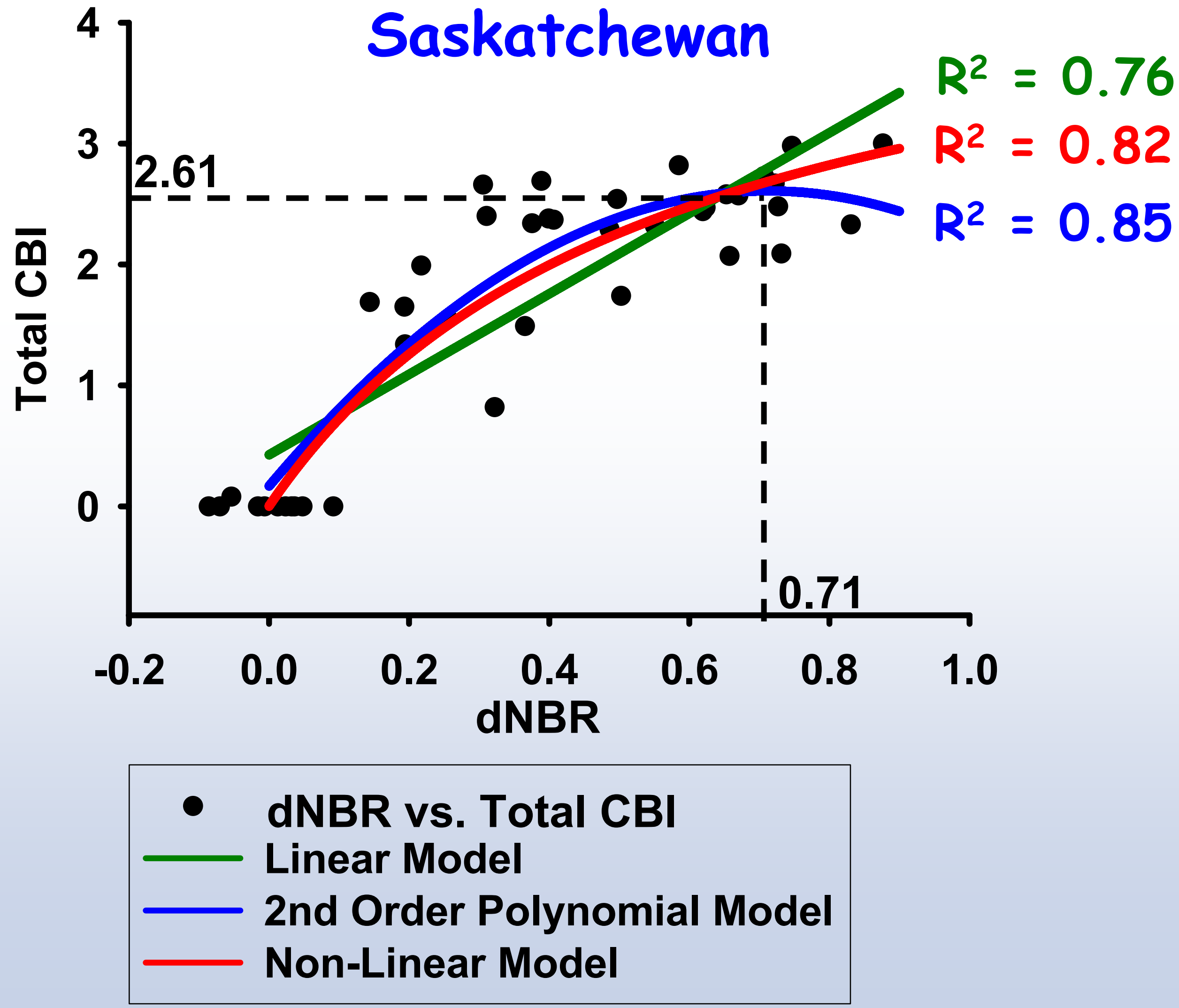

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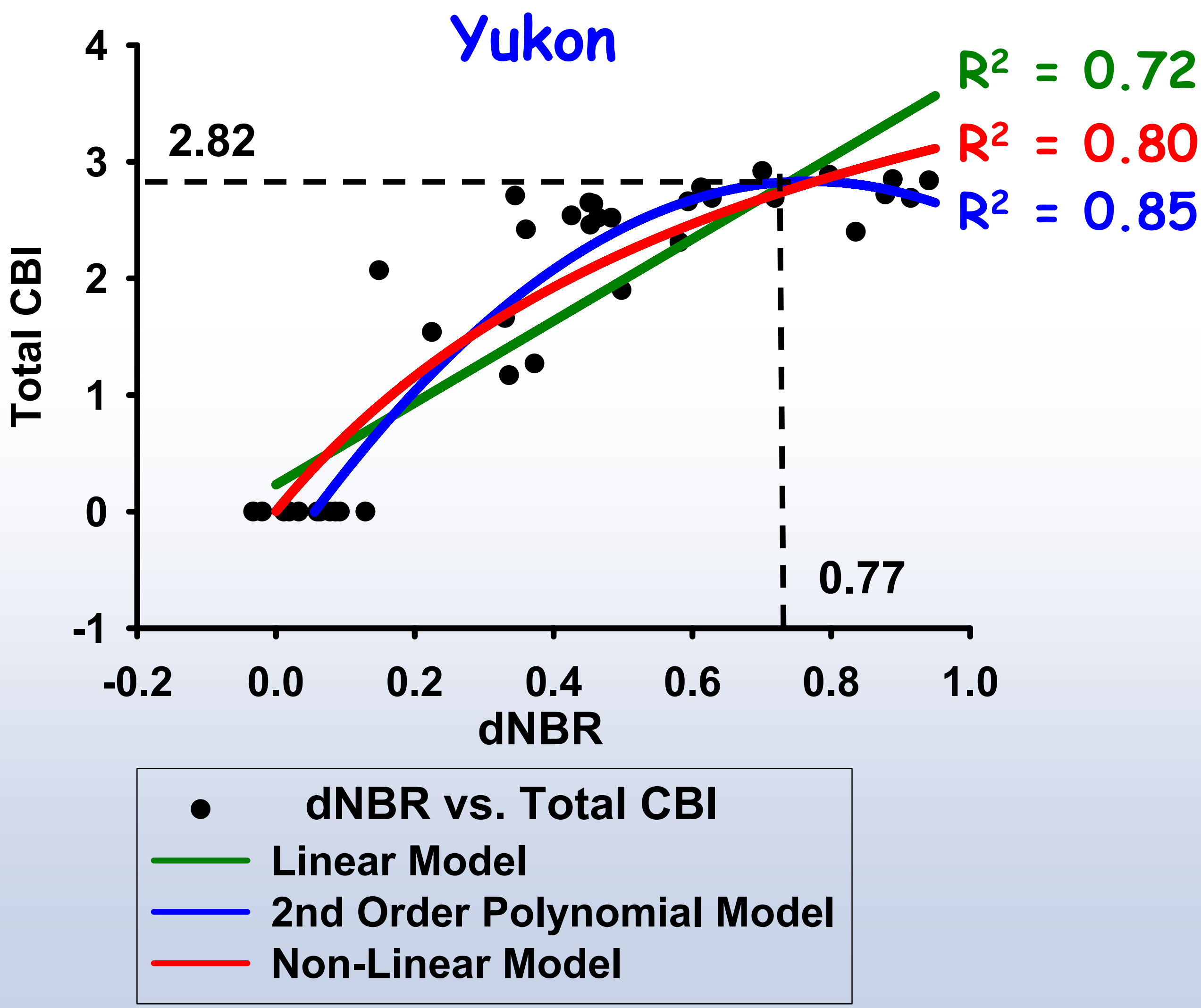
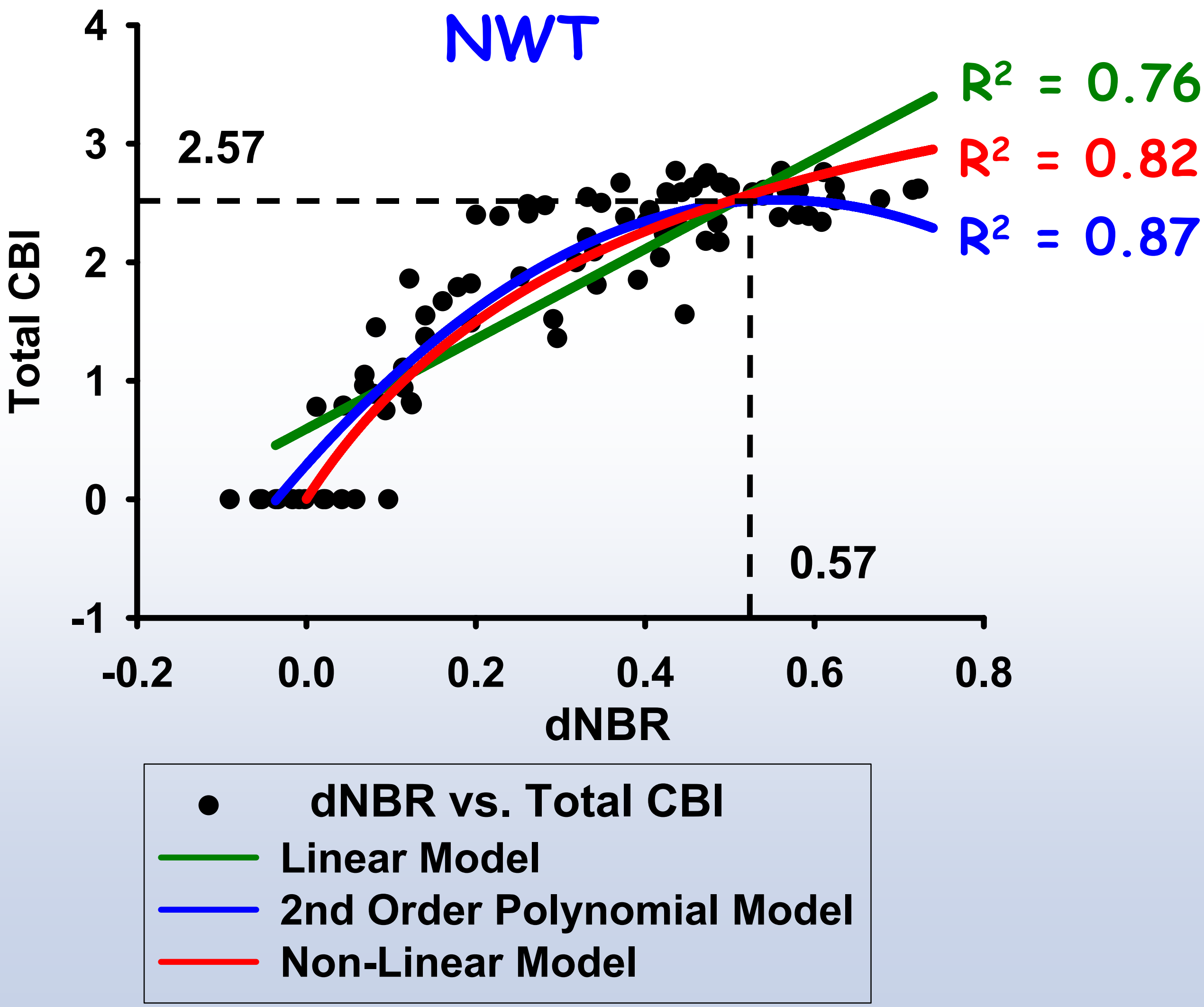
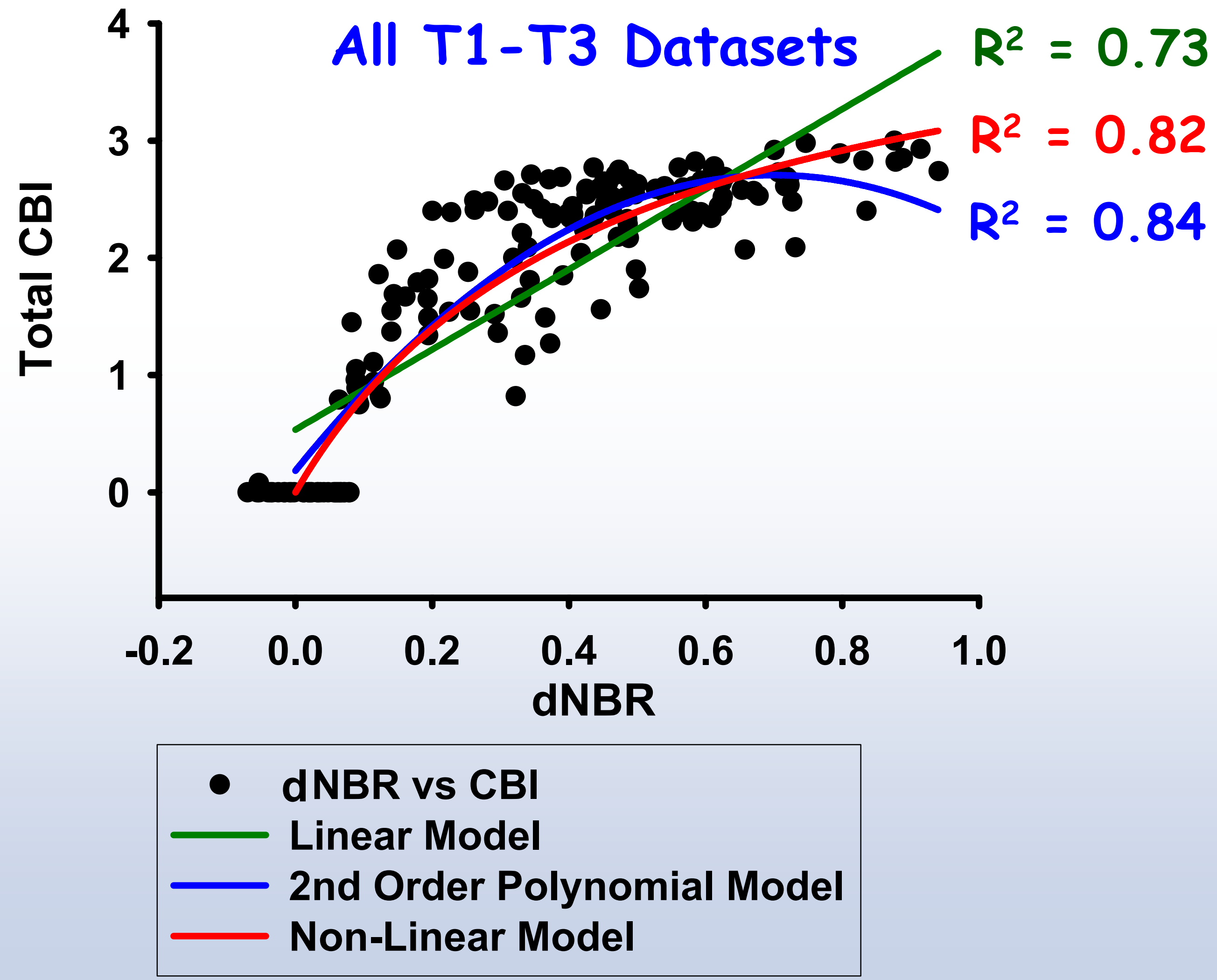
Modeling Burn Severity: T1 - T3



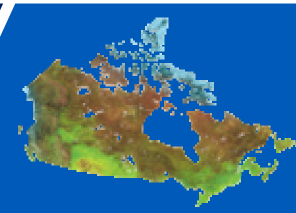
Modeling Burn Severity: T1 – T3



Modeling Burn Severity: T1 - T3



Temporal Analysis: T1-T2 vs. T1-T3

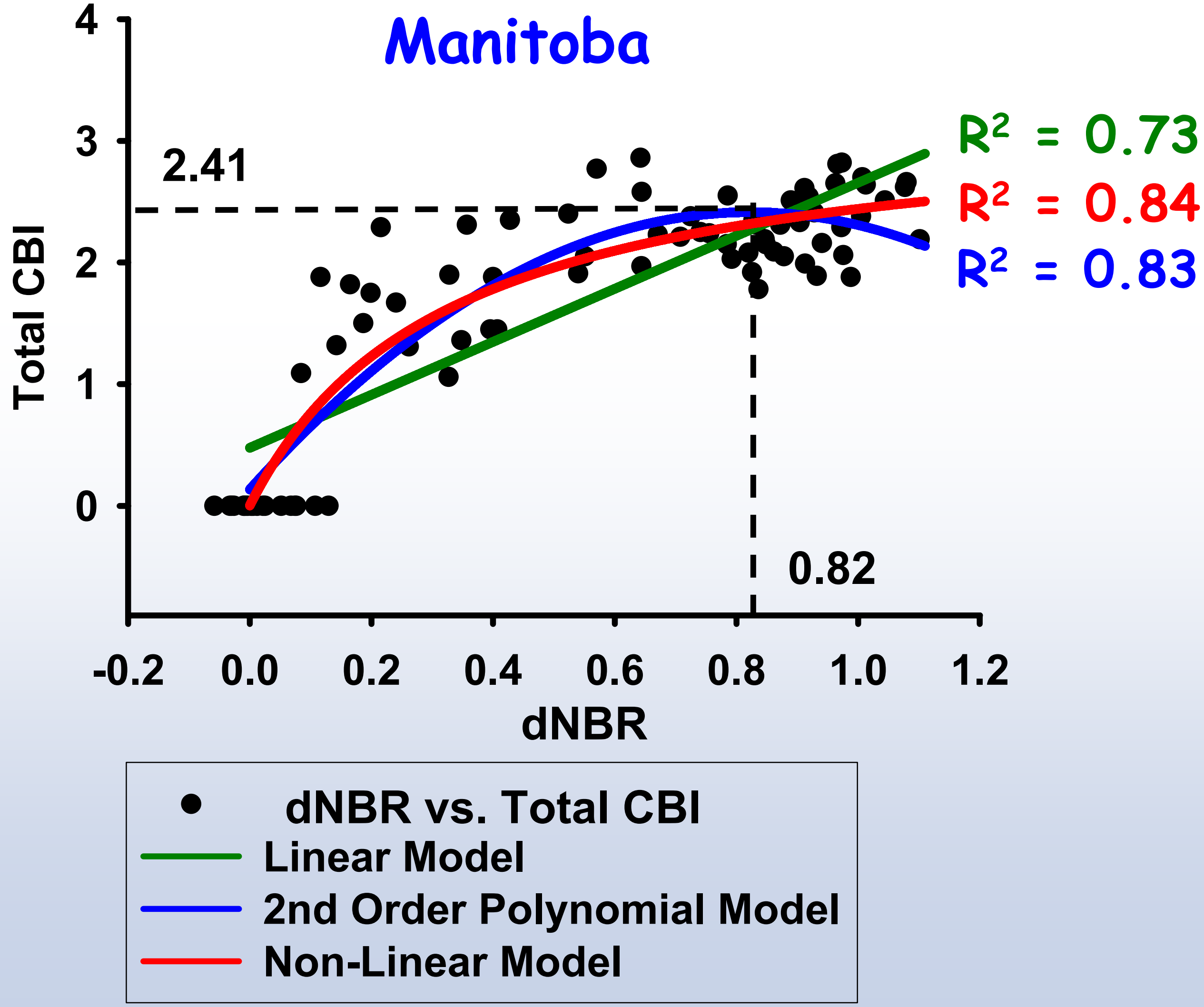


dNBR Descriptive Statistics

	Saskatchewan		NWT	
	T1-T2	T1-T3	T1-T2	T1-T3
N of plots	39	41	83	83
Mean	0.42	0.37	0.40	0.31
St. Dev.	0.31	0.29	0.25	0.22
Minimum	-0.04	-0.09	-0.06	-0.09
Maximum	0.97	0.88	0.85	0.72
Range	1.01	0.96	0.91	0.81

Fires mapped from T1-T2 appear more severe and variable than from T1-T3 although the differences are not large.

Modeling Burn Severity: T1 - T2



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Discussion: Modeling Burn Severity

1. Study completed on four datasets representing six fires. dNBR accounts for greater than 80% variability in CBI.
2. Statistically, the non-linear model form compared favorably to other models reported in the literature, and were remarkably similar among the burns studied.
3. Severity of a fire does appear higher in immediate (T1-T2) compared to extended (T1-T3) assessment images.
4. Replication over a larger number of fires in the boreal representing a range of vegetation fuel types and range of burn severities will help to verify if these results are consistent over the range of the boreal.

Effect of Fuel Types

Jack pine (C3)

Fire Intensity: 950 kW/m

Carbon Emissions: 7 t/ha

Fire Weather Index = 17 for both fires

Black Spruce (C2)

Fire Intensity: 13 400 kW/m

Carbon Emissions: 12 t/ha

Example: C2
Boreal Spruce

Fuel Type C2

dNBR 500
CBI 1.90
DOB 2.0 cm
FC 0.9 kg/m^2

Moderate

Fuel Type C2

dNBR 610
CBI 2.78
DOB 9.2 cm
FC 7.0 kg/m^2

High

Example: C3
Mature Jack Pine

Fuel Type C3

dNBR 300
CBI 1.67
DOB 1.3 cm
FC 0.8 kg/m^2

Moderate

Fuel Type C3

dNBR 590
CBI 2.82
DOB 5.0 cm
FC 1.4 kg/m^2

High

Example: M2
Mixedwood

Fuel Type M2

dNBR 200
CBI 1.32
DOB 6.7 cm
FC 5.2 kg/m^2

Low

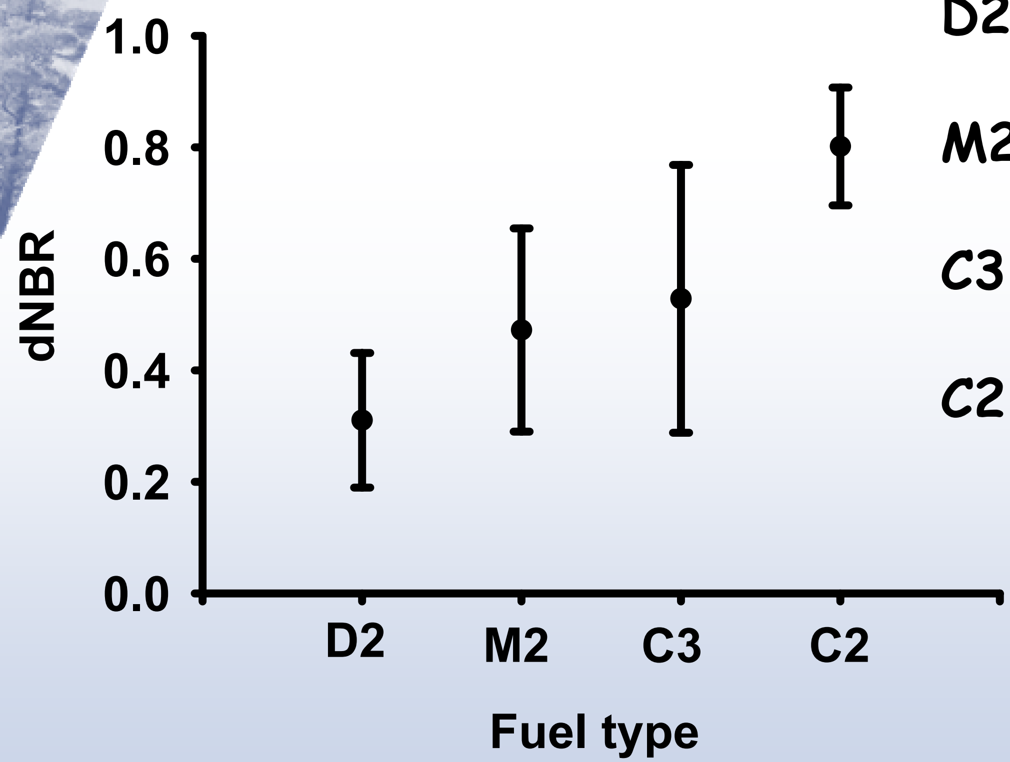
Fuel Type M2

dNBR 340
CBI 2.04
DOB 3.3 cm
FC 1.7 kg/m^2

Moderate

Effect of Fuel Type on dNBR

Saskatchewan



Fuel Types:

D2: Leaf-On Aspen Dominated

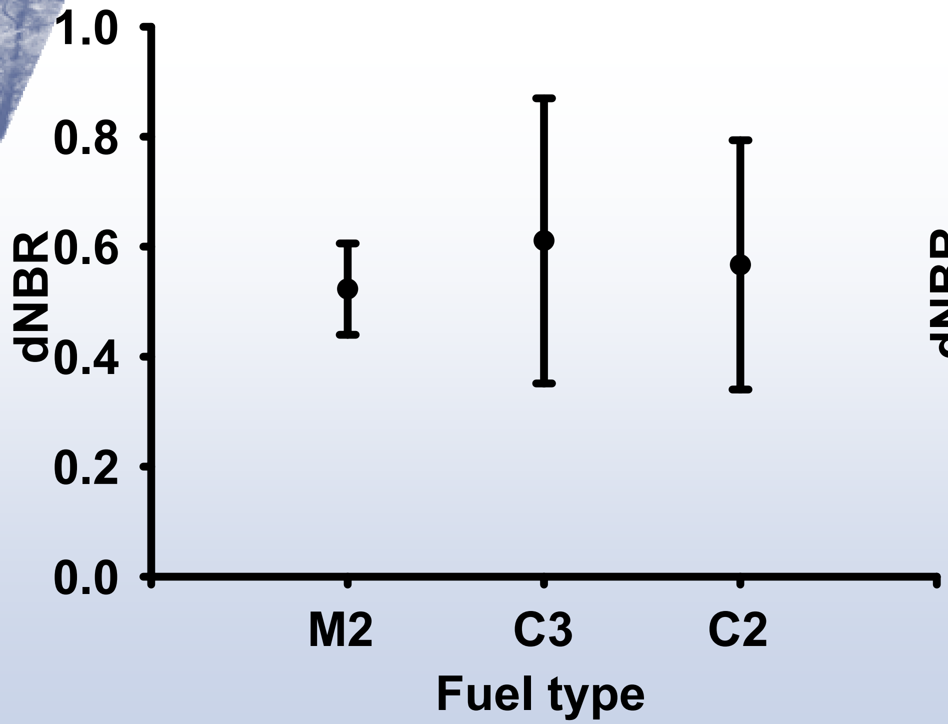
M2: Boreal Mixedwood-Green

C3: Mature Jack or Lodgepole Pine

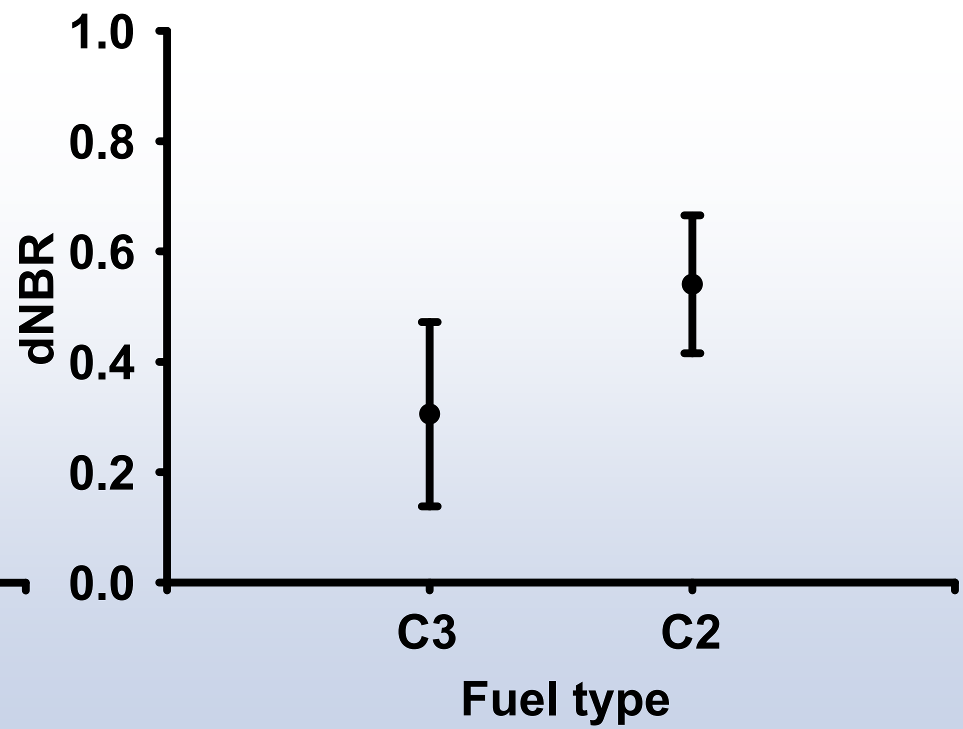
C2: Boreal Spruce

Effect of Fuel Type on dNBR

Yukon



NWT



Assessing the Effect of Fuel Type on dNBR

One-Way ANOVA: Testing difference in dNBR between fuel types

	Sask.	Man.	Yukon	NWT
N of cases	31	63	26	70
F-ratio	3.61	6.15	0.63	14.28
p-value	0.03	0.004	0.54	0.001

Multiple Means Comparison of Significant Differences in dNBR Between Fuel Types

Fire(s)	Fuel type pair	dNBR Mean difference	Tukey's p-Value
Sask.	C2-C3	-0.309	0.05
Sask.	C2-M2	-0.329	0.05
Sask.	C2-D2	-0.491	0.03
Man.	C2-C3	-0.268	0.001
NWT	C2-C3	-0.235	0.001

Discussion: dNBR and Fuel Type

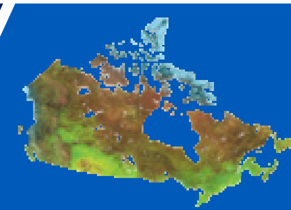
1. Degree of post-fire change varies, in part, by pre-burn vegetation type and fire weather.
2. Field sampling for burn severity typically strives to sample a full range of severity. Considerations for stratification by fuel type are not typically specified.
3. Fuel type influences dNBR response. Knowledge of fuel type may improve insights into the characterization of burn severity observed from field and image perspectives.
4. Use of pre-fire vegetation or fuel type maps could constitute an area for future improvement in the modeling of burn severity (eg., field sampling, model development).

Classifying Burn Severity with dNBR

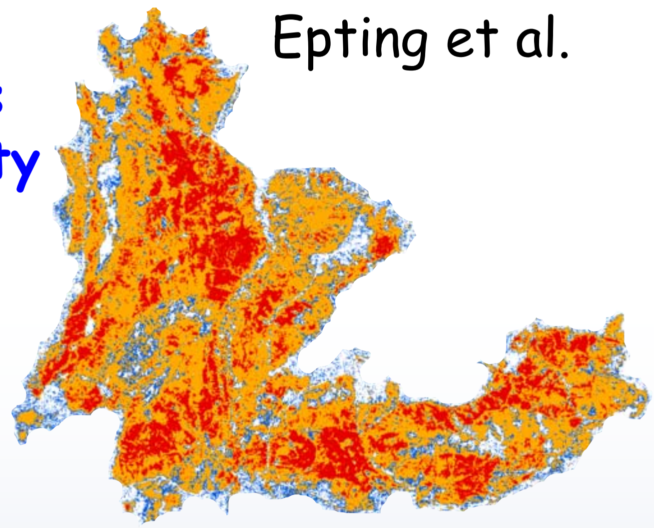
- dNBR often used to classify and map burn severity.
- Mapping burn severity with dNBR requires dNBR thresholds.

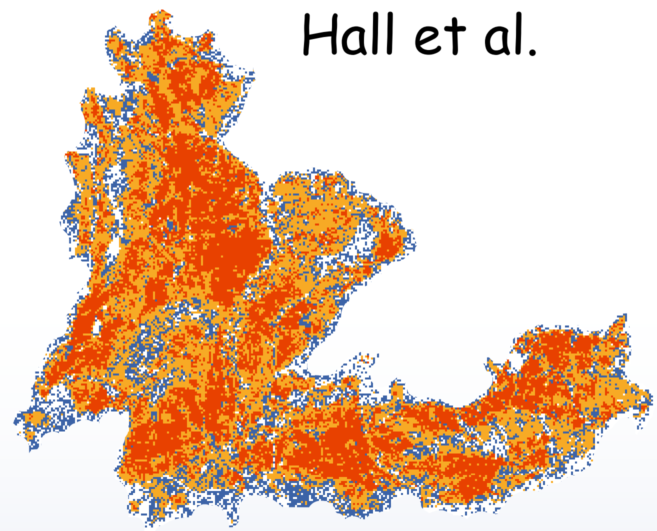
	Cocke et al.	Epting et al.	Key & Benson	Hall et al.
Unburned	≤50	≤89	≤99	<40
Low	51-240	90-274	100-269	41-283
Moderate	241-570	275-679	270-659	284-513
High	≥571	≥680	≥660	≥514

Classifying Burn Severity with dNBR

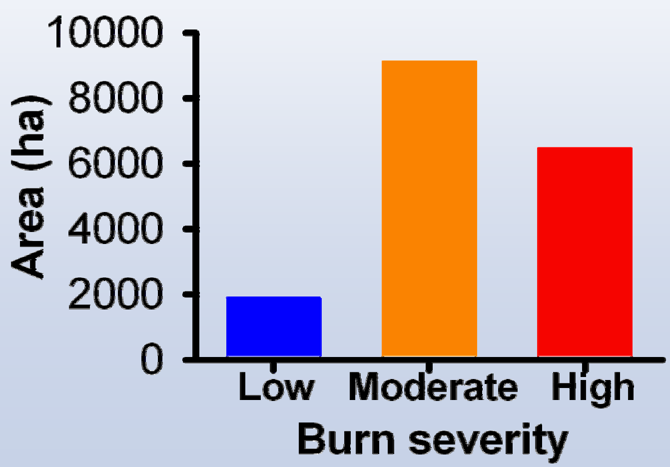


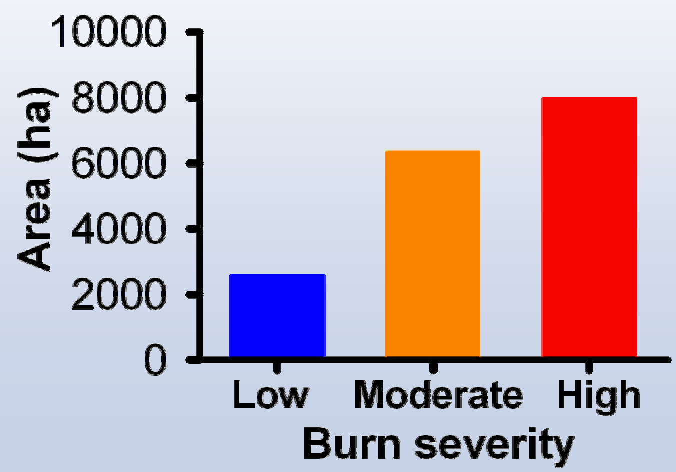
Thematic maps of burn severity depicts distribution of burn severity within a fire.





Differences in frequency distribution of burn severity by area.





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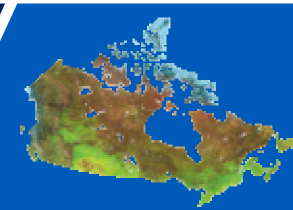
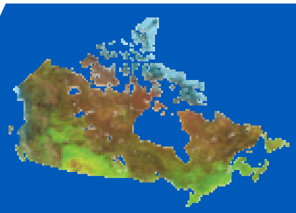
Discussion: Mapping Burn Severity



1. Burn severity varies continuously over the landscape but it is often partitioned into broad discrete classes for thematic display and practical application.
2. Definition of burn severity thresholds is subjective.
3. Defining class limits from a physical remote sensing value such as dNBR is challenging (eg., values, # of classes).
4. Defining these thresholds from the field such as through the CBI, and using the CBI – dNBR relationship provides a basis for defining locally meaningful dNBR thresholds. Supports recommendation by Lentile et al. (2006).

Fuel Consumption Estimates



In the field:

- based on combining depth of burn data, with changes in fuel load bulk density (kg/m^3), sampled at 2 cm intervals, down to 10cm (after removing litter)

In BORFIRE:

- Computes fuel consumption from species-specific models for consumption at different layers (litter, duff, dead and down, etc.) within a forest stand.
- Crown consumption depends on crown fire initiation which is generated from surface fire intensity (product of surface fuel consumption and rate of spread).

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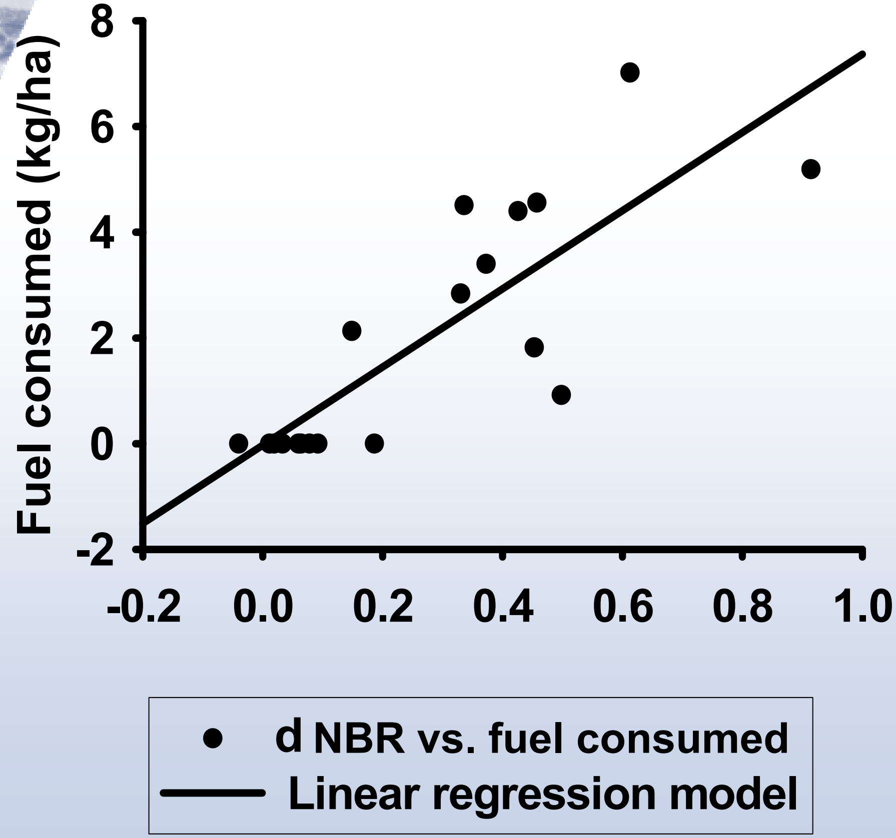
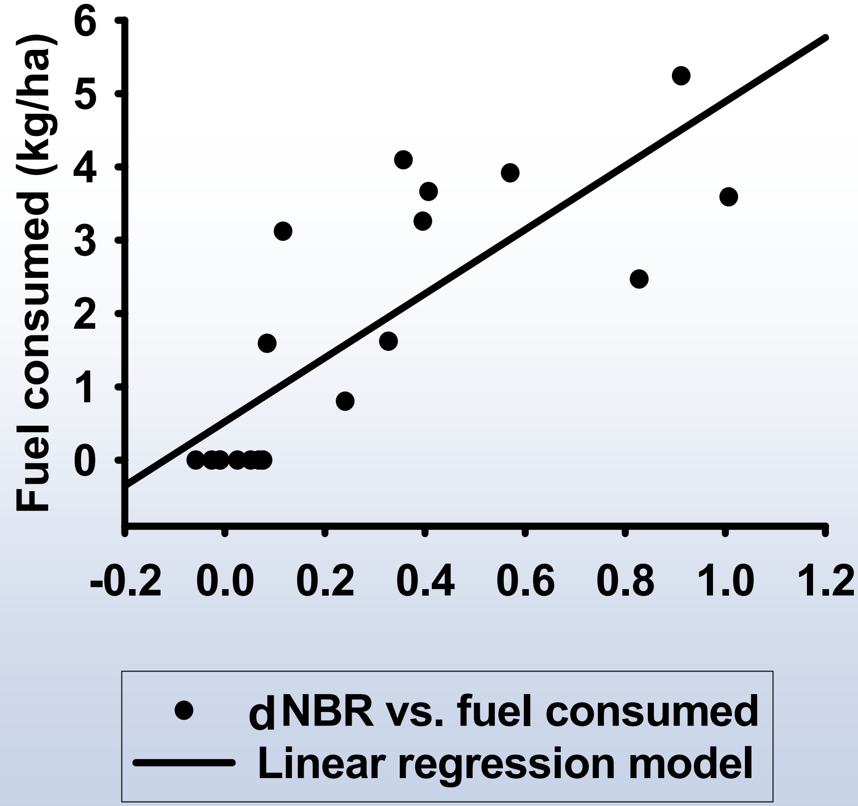
Modeling Fuel Consumption with Fuel Type and dNBR

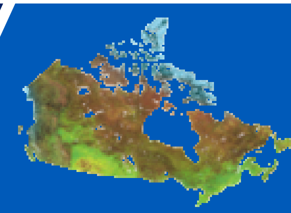
Yukon C2



NWT C3



Discussion: Fuel Consumption

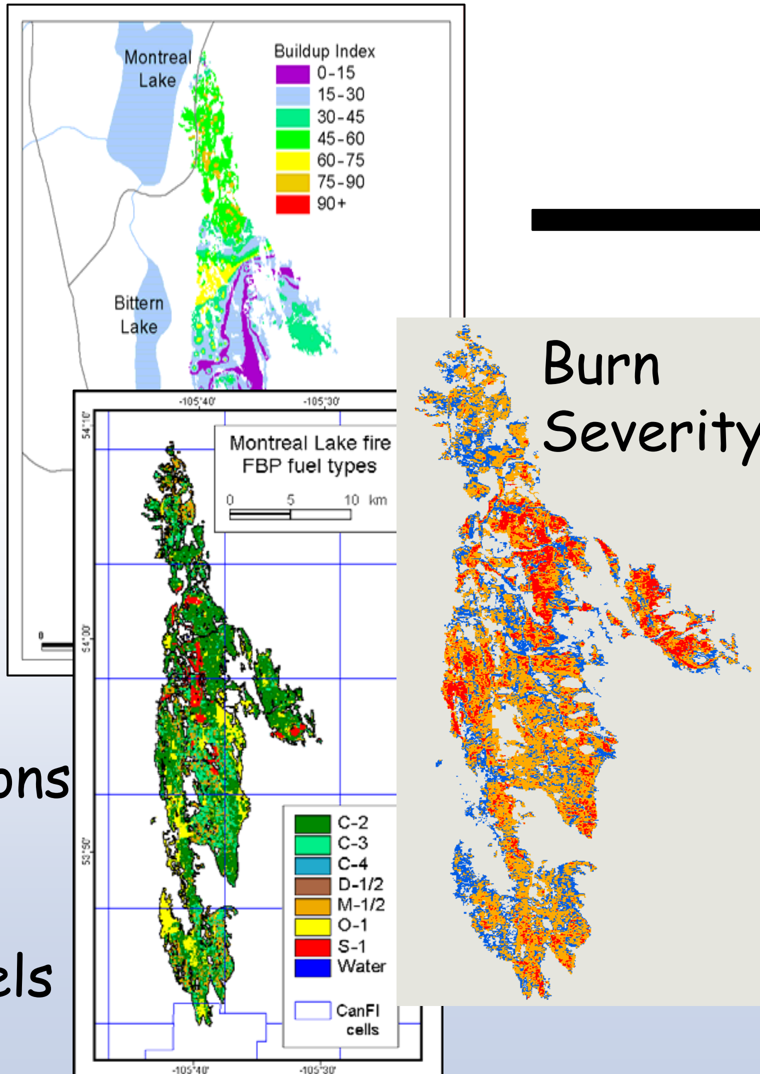


1. Image integrates response from the canopy and the ground.
2. There is an association between dNBR and field-measured fuel consumption but this varies by fuel type. Our results were limited by:
   a) small sample size, incorporation of burn conditions
   b) lack of measured surface vs. crown fuel consumption
3. To fully address this problem requires actual field measurements of total fuel consumption at a range of burn severities by fuel type.

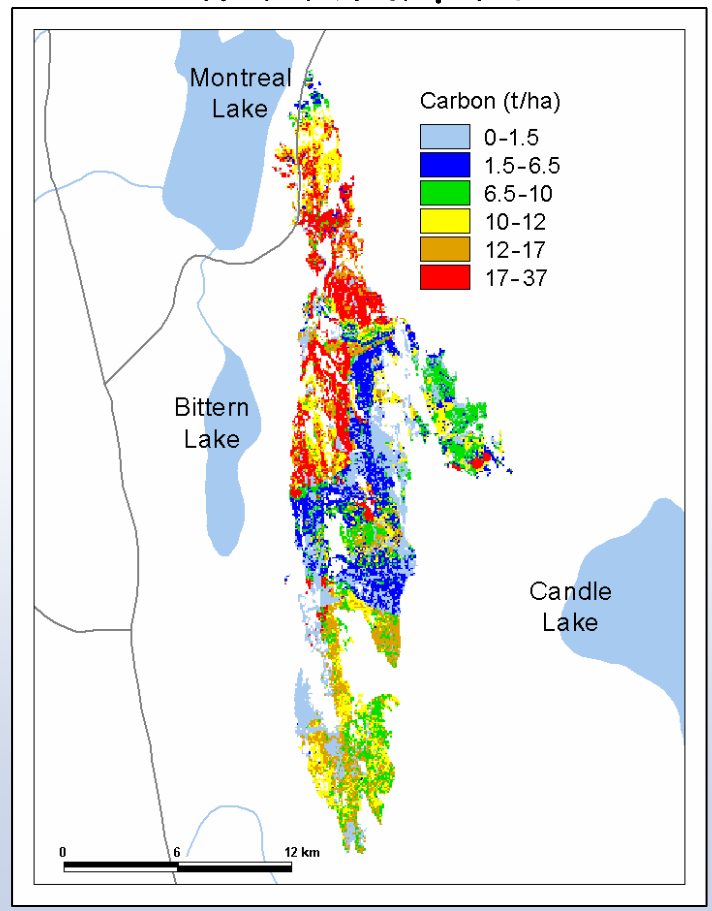
Where Would We Like To Be?

Burning Conditions

Fuels



Carbon emissions within a fire



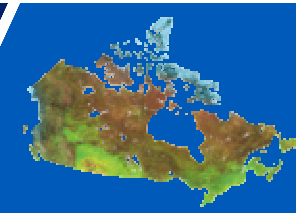
Summary: Lessons
What have we learned?

1. Burn severity observed across dNBR, CBI, DOB, FC attributes. Results similar to several US reports suggesting that these attributes can also be applied to boreal fires in Canada.
2. Reported non-linear dNBR-CBI models across T1-T2 and T1-T3 assessment time periods.
3. dNBR – CBI values influenced by fuel type.
4. Introduced definition of burn severity thresholds via CBI.
5. Association between fuel consumption and burn severity (defined by dNBR, CBI) when stratified by fuel type.

Opportunities

1. Analyze dNBR – CBI over more fires in the boreal.
2. Further assess influence of fuel type.
3. Define severity thresholds through field observations but tempered by application.
4. Address: Is the estimation of fuel consumption by remote sensing of burn severity integrated with other variables such as fire weather conditions and fuel type feasible?
5. Collaboration key for further advancement.

Acknowledgments



- This study is a component of a larger project directed at improved estimation of emissions from wildland fire in the Canadian Boreal. Funding support by the Canadian Space Agency and Natural Resources Canada is appreciated.
- Team members to this project include Jason Freeburn, Bill DeGroot, Janet Pritchard, Tim Lynham, Robert Landry.
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