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Land cover classification of active fire and burned area detections for Canadian provinces, 2001-2010.

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LAND COVER CLASSIFICATION OF ACTIVE FIRE AND

BURNED AREA DETECTIONS FOR CANADIAN

PROVINCES, 2001 - 2010

By

Tyler Kerr
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A Master's Thesis Approved

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DEDICATION

This Thesis is dedicated to my Parents

Jamie and Randy Martin and Terrence Kerr

Who provided me with the educational opportunity to complete this work.

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ABSTRACT

LAND COVER CLASSIFICATION OF ACTIVE FIRE AND BURNED AREA
DETECTIONS FOR CANADIAN PRVINCES, 2001 - 2010

Tyler Kerr

May 2012

This thesis is a methodological analysis of fire locations in Canadian provinces
from 2001 to 2010. The research presented in this thesis highlights the dominant fire
types for each province. Accurately locating active fires and burned area is critical to
improving emissions estimates of greenhouse gases and black carbon in northern
latitudes. Black carbon and emissions are climate changers. Continual release of
emissions from a source location has been shown to alter the atmosphere near the source.
Black carbon, or soot ash, deposited on arctic snow and ice leads to faster deterioration of
the snow and ice. Detected fires and burned areas are recorded by the MODIS satellite
sensor on-board the geo-synchronous orbiting Terra and Aqua satellite platforms.

The Introduction and Present Study sections introduce the topic. Satellite data and
imagery greatly increase accuracy of emissions estimates and aid emergency response
teams and hazard monitoring situations. Infrared sensors onboard the Aqua and Terra
satellites allow scientists, emergency planners, and citizens to monitor fires that may be
hazardous to their lives, property, and families. The MODIS sensor also allows us the
unique perspective of spatially locating fires and their areal extent.

The Data section describes the technological specifications of the three remote sensing products: MODIS Active Fire Product, MODIS Burned Area Product, and MODIS Land Cover Dataset.

The Literature Review section situates this thesis into its historical perspective. Remote sensing is a new science; new techniques are being developed daily. This exciting new science allows researchers to study the specific wavelengths of light that are not visible to the naked eye. The Methodology section justifies the use of the techniques used in this project and presents a past study that was conducted to test the various products available in order to produce the most accurate picture of what is occurring on the ground.

The Results and Conclusions present the spatial and temporal distributions of fires in Canadian Provinces from 2001 to 2010. Emergency response units and researchers can use this research to plan for future fire events. This research is also a first step in producing emissions estimates for the region.

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INTRODUCTION

Fire is a primary disturbance agent in Canadian ecosystems and has significant social,

environmental and economic consequences (Van de Werf et al. 2006, E. S. Kasischke et

al. 2006, and Soja et al. 2007). Accurate location and identification of open biomass

burning, especially in northern latitudes, are critical to understanding the transfer of gases

and particles into earth's atmosphere. It is also important as they aid atmospheric models

in estimating black carbon (BC) deposition on arctic snow (French et al. 2008, Bond-

Lamberty et al. 2007).

BC deposits alter the surface albedo and affect microclimates due to changes in

the local energy balance. Changes over time to local levels of insolation and reflection

are important for climate monitoring (Langman et al. 2009, Korontzi et al. 2006).

Previous research has shown that remote sensing products can be used to identify active

fire locations as well as post-burn scarring in surface vegetation and soil (Soja et al 2009,

Korontzi et al 2006, and French et al. 2008).

The purpose of this study is to gain insight into the distribution and occurrence

level of agricultural fires, and to set the groundwork for more specific analysis of

greenhouse gas estimates for specific crop and tree types in future papers.

This provincial study of Canada utilizes existing remote sensing products to relate

active fire locations, burned area and greenhouse gas emission estimations with land

cover and/or land use classes for years 2003 to 2010 (Soja et al. 2009). These remote

sensing products include the Moderate Resolution Imaging Spectroradiometer (MODIS) Active Fire Points (MOD/MYD14) and the Burned Area Product (MCD45A1),

Several complimentary questions will be addressed during the course of the research project. The first question to be addressed is where and when the most active fires and burned areas being detected are located. Upon completion of the study it will be known in which Canadian provinces the most burned area and active fires occur for each year. Year to year variability is being coupled with an assessment of concurrent meteorological history of the region. Analysis of the data will also show which months produce the most total fire detection. Months will also be grouped into four seasons (winter, spring, summer, and fall) to determine inter-seasonal variability of fire occurrences.

The second question to be addressed is what percentage of detected burning is located in agricultural land. The MODIS Land Cover Product (MODIS LCP) classifies land cover into 21 categories. The 21 original categories are resolute enough to distinguish between deciduous tree types. It is important to determine in which land cover category fires occur throughout the seasons. To acquire this information the 21 MODIS LCP categories are reclassified into seven broad groups (Cropland, Forest, Grassland, Urban area, Water bodies, Wetlands, and Barren soil). The purpose is to highlight agricultural fire and burned area detections. This is important because agricultural fires are human-sourced emissions unlike forest fires which are a mixture of naturally caused and human-caused combustion (French et al 2008).

LITERATURE REVIEW

Agricultural fires are important because their role in climate change is understudied compared to Canadian forest fire monitoring and records. Agricultural fires are almost always the product of human activity and are critical in estimating human-source greenhouse gas emissions (Korontzi et al. 2006). Cropland is intentionally burned for two reasons; to clear the field of residue in preparation of planting and to fertilize the soil.

In Canada, regulation of open burning is different per province, but wheat stubble is often removed with fire. Wheat is the most widely grown crop, accounting for an average of 10,000,000 hectares seeded per year (Ag Canada 2011).

It is important to understand that not all 'smoke' is created equally. Smoke and material that is emitted from fires bear the markers of what is actually being burnt. Corn, for example, will not only burn at a different rate of speed than say wheat, but will also release different percentages of chemical compounds such as sulfur dioxide, carbon monoxide, and BC soot ash (Korontzi et al. 2006, McCarty et al. 2010). Various plant species will also produce different percentages of combustion on a scale from 0 to 100%, with 100% being total combustion and thus no residue or large material left on the ground once the fire ceases to burn. Fire intensity and duration of the burn are also determining factors in whether vegetative material reaches complete combustion, or no large particles besides ash, soot, and small residuals (McCarty et al. 2009).

The location of fires is also important as it determines the soil composition, vegetation, moisture content, and will also impact the air humidity and temperatures throughout the four seasons. Soil also burns and plays a role in producing BC and other chemical emissions when vegetative layers are burnt (Gerard et al. 2003). Alfisols or soils rich in iron (Fe) and aluminum (Al) dominate the Canadian forest landscape and the hinter regions of the agricultural area of Canada (Ag Canada 2011). When woody biomass is cleared and burned it releases a chemical marker of the alfisols which can be traced from the black carbon depositions in the Arctic (Hegg et al 2010). When soil is burnt it loses amounts of organic material and change occurs to its chemical composition. Burnt alfisols typically see a reduction in Nitrogen (N), Phosphorus (P), and Potassium (K). Soil Ph levels change as well (Mokwunye 2000).

Fire intensity and levels of combustion are also dependent upon the fuel load and fire type. Wooster and Zhang (2004) observed that boreal forest fires burn less intensely in Russia than North America due to differences in dominant fire type. Dense ground pack, shrub, and brush combined with high crown fire capacity in North American forests are responsible for the intensity compared to the more spread out forest structures with less ground clutter seen in Russian forests (Wooster and Zhang 2004).

Northern boreal forests play an important role in the global carbon budget; these forests act as large carbon sinks and accounting for 49% of the total carbon pool in forested ecosystems (Gerard et al. 2003). From 1997 to 2009 Van der Werf (2010) conducted a study on global emissions. He concluded that the boreal region of North America accounted forest fires to be almost 96% of the total emissions. However,

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emission estimates in the boreal region had higher uncertainties due to difficulties in estimating fuel consumption in organic soils (Van der Werf 2010).

Increases in global warming are expected to extend the fire season, increasing the likelihood of more frequent large intensity forest fires (Wulder et al. 2009) and extending the season for farmers to perform agricultural residue burning in addition to field expansion/land cover conversion (McCarty et al. 2009). The dominant ecosystem coverage in Canada is shrub, boreal forest, sparse vegetation, other forest and agriculture (Ichoku et al. 2008).

Although Canada is the second-largest country in the world, approximately 90% of the population is concentrated within 160 km of the US border (CIA World Factbook 2010). The remoteness of the country has resulted in a limited inventory of agricultural fires and forest composition that makes the incorporation of remote sensing particularly useful in this region.

PRESENT STUDY

The objective of this thesis is to identify the spatial locations of fires in Canadian provinces. This study also identifies the time of year and the seasonal variances between the occurrences of fires. Lastly this thesis identifies the major land cover classifications that are being affected by fires; for example whether or not British Columbia is experiencing more fires in forests or in agricultural areas. The study covers a time period from 2001 to 2010.

DATA

The Moderate Resolution Imaging Spectrometer (MODIS) sensors are carried onboard

the sun-synchronous polar orbiting Aqua and Terra satellites, giving them the benefit of

covering the earth four times per day for 10+ years. The multispectral sensor has 36

bands total and was designed in part specifically for fire detection and comprehensive

terrestrial monitoring for improved global land cover mapping (Justice et al., 2002; Friedl

et al. 2002). Specific products used or this work include:

MODIS Active Fire Product (MOD14/MYD14)

This research includes active fire detections from MODIS Data Processing System

(MODAPS) Collection 5 (version 5.1) for the years 2001-2010 (NASA/University of

Maryland 2002). The MODIS Level 2 fire product collects daily hotspot/active fire

locations (latitude, longitude) at a 1 km resolution. Two satellites, MOD14 (Terra) and

MYD14 (Aqua), are integrated sun synchronous satellites whose images are stitched

together to form resolute images of Earth. The MODIS active-fire algorithm uses the

mid-infrared radiation from fires to examine each pixel and subsequently classify it as

either missing data, cloud, water, non-fire, fire or unknown (Justice et al. 2006).

MODIS Burned Area Product (MCD45A1)

The monthly MODIS Burned Area product (MCD45A1) was used for this study over the

years 2003-2010 and was provided by the University of Maryland FIRMS in a GEOTIFF

format (NASA/University of Maryland 2002). The year 2003 was used as the start year instead of 2001 to due improvements to the processing algorithm. MCD45A1 is visualized in a spatial resolution of 500 meters. The MCD45A1 product uses an algorithm trained to detect spectral, temporal and structural changes that characterize burned area by deposits of charcoal and ash, removal of vegetation and alteration of the vegetation structure (Boschetti et al. 2009). Thus the MODIS Burned Area product detects burned pixels, categorizes the intensity of fire and estimates the amount of burned area at a global scale (Giglio et al. 2003; Giglio et al. 2005).

MODIS 1 km Land Cover dataset (MOD12Q1)

The MODIS 1 km Land Cover data (MOD12Q1) product was used to identify the primary land cover where active fire and burned area were detected. The MOD12Q1 product uses a supervised decision-tree classification algorithm to assign land cover classes based on MODIS level 3 products. The primary land cover classification scheme is based on the International Geosphere Biosphere Programme (IGBP) and identifies 17 categories of land cover.

METHODOLOGY

In this study zonal statistics and/or raster calculator operations have been carried out on each of the fire identification products to assign Land Cover values to each detected pixel based on the MODIS Land Cover Product (MOD-12) (1000 m) land cover map. The zonal statistics and raster calculator operations classify each detected fire or burned area pixel into a specific land cover category such as "cultivated agricultural land" or "mixed forest." These specific categories will be further generalized and re-categorized for the purpose of highlighting agricultural land and vegetation burning in Canadian provinces. Descriptive statistic, graphs, and thematic mapping are useful to visually show the yearly and seasonal variability of fire detections.

All data processing was performed in a GIS environment using ESRI ArcGIS software versions 9.3.1 and 10. Active fire data points for the years 2001 - 2010 were assigned a MODIS land cover classification. The 16 MODIS land cover classes were aggregated into 7 new classifications that broadly reflected the dominant land cover type (Figure 1). Next, the attribute fields of 'month', 'year', 'season', 'province' and 'reclassified land cover' were added to the dataset. Scan failures by the sensor were identified on 4 dates and removed from analysis.
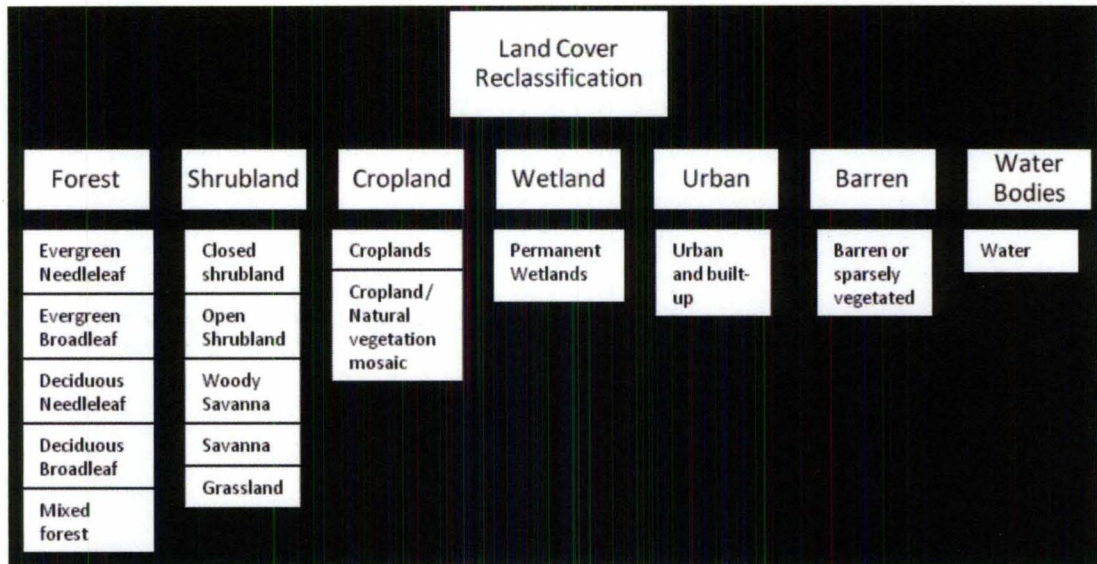
Figure 1. MODIS land cover classes aggregated for active fire classification.

The University of Maryland Fire Information for Resource Management System (FIRMS) was used to download Active Fire data points in a shapefile format for 2001 to 2010. Every hotspot detection (active fire) location is the centroid of an approximately 1 kilometer (km) pixel that was identified as containing one or more actively burning hotspot/fire within that pixel. The MODIS active-fire algorithm uses the mid-infrared radiation from fires to examine each 500m pixel and subsequently classify it as Missing data, Cloud, Water, Fire, Non-fire, or Unknown. Monthly Burned Area product from 2003 to 2010 was also acquired from the University of Maryland in a GEOTIFF format. Both the burned area product and the active fire points needed to be re-projected into WGS 1984 systems for mapping continuity when overlaid with the land cover products.

Preprocessing of the monthly Burned Area product (MCD45A1) was done according to the MCD45A1 user guide. Burned area pixels and their associated burn date

were selected and retained using raster calculator, while all other values were discarded. Next, the monthly burned area pixels were multiplied by the MODIS cropland land cover class, resulting in the number of burned area pixels that intersected cropland (Figure 2). A total of 12 months for 8 years in 7 provinces amounted to 672 processed MODIS burned area products. The results were broken down to the provincial level and summarized by season. The resolution of a MODIS burned area pixel is 463 m or 214,659 m^2, the area of which is multiplied by 0.0001 to obtain the area in hectares.

$$BAp \times MCr \ (LC12) = NC(b) \tag{1}$$

MODIS Burned Area Pixel x MODIS Cropland pixel (LC12) = Number of Cropland Pixels that Burned.

Initially three land cover products were considered: Globcover, Geobase, and MODIS. Each land cover product produced different spatial resolutions. A previous study of fire detection in British Columbia helped to verify the accuracy and reliability of each of the three land cover products (Kerr et al 2011). The comparison establishes a cross-validation for land cover classification at various resolutions and highlights differences between these three products. The MODIS Terra+Aqua Land Cover product MOD-12 (1000 m) incorporates five different land cover classification schemes, derived through a supervised decision-tree classification method. The scheme used for this study contains 17 classifications including 11 for vegetation.

GLOBCOVER (300 m) is a global land-cover map which was attained primarily from the MERIS sensor on-board the ENVISAT satellite. GLOBCOVER imagery was

acquired over all twelve months of 2005. International remote sensing experts interpret the local land cover characteristics and provide data for the statistical assessment of map accuracies and ground-confirmation (ground-truthing) analysis.

The GeoBase (30 m resolution) land cover product is the result of vectorization of raster thematic data originating from classified Landsat 5 and Landsat 7 Ortho-images. Image dating spans from 1996 to 2005. However, 80% of the land cover base comes from imagery taken from 1999 to 2001.

First, all of the data underwent preprocessing that allowed easy integration with each other and also limited their extent to British Columbia. From the MODIS Burned Area product only burned area pixels were retained and all other pixel classes eliminated. The Active Fire Product was divided into months so that it was comparable with the Burned Area product which is delivered in a monthly composite.

The land cover products were reclassified into 5 classes: Forest, Cropland, Grassland, Shrub land and Other (Figure 2). This aggregation of classes was necessary to simplify the comparison between the land cover products. Each product has a unique classification algorithm or methodology. Aggregating classes is a forced standardization process for comparing land cover products. All calculations were done in a GIS environment using ESRI ArcGIS 9.3.1 Spatial Analyst tools. Active Fires were designated to a land cover class based on their absolute location. The results were then summarized by month per year for every province.

Next, The Burned Area pixels were assigned to land cover classes based on each product. The raster format in the MODIS land cover product made it possible to utilize

the raster calculator tool to multiply the burned area pixels with the land cover class. The result is a total pixel count per class.

The GeoBase product was converted from its original shapefile format into a raster format, reducing the file size and making it possible to for raster calculator operations to be performed. The GLOBCOVER product used Zonal Statistics to summarize the Burned Area pixels within the land cover classes. Burned area pixels were summarized by month per year for every province.

The results of the reclassified burned area and land cover products (GeoBase, GLOBCOVER and MODIS) can be seen in figures two through four. Burned area and active fire results were similar, both showing forest fire as the preeminent type detected in British Columbia, Canada. MODIS and GEOBASE both show Cropland burning while GLOBCOVER does not. The comparison reveals that both GEOBASE and MODIS provide sufficient accuracy for comparing fire detections and classifying land cover type. GLOBCOVER is not as resolute in its final mapping capabilities and excludes cropland land cover types. MODIS is most easily integrated with Active Fire and Burned Area data because of the shared source satellite and sensor system (Ernst et al. 2011).

Figure two (2) lists the 21 original MODIS LCP classifications underneath their respective re-classified land cover categories. The re-classified land cover categories encompass the dominant land cover types in Canada.
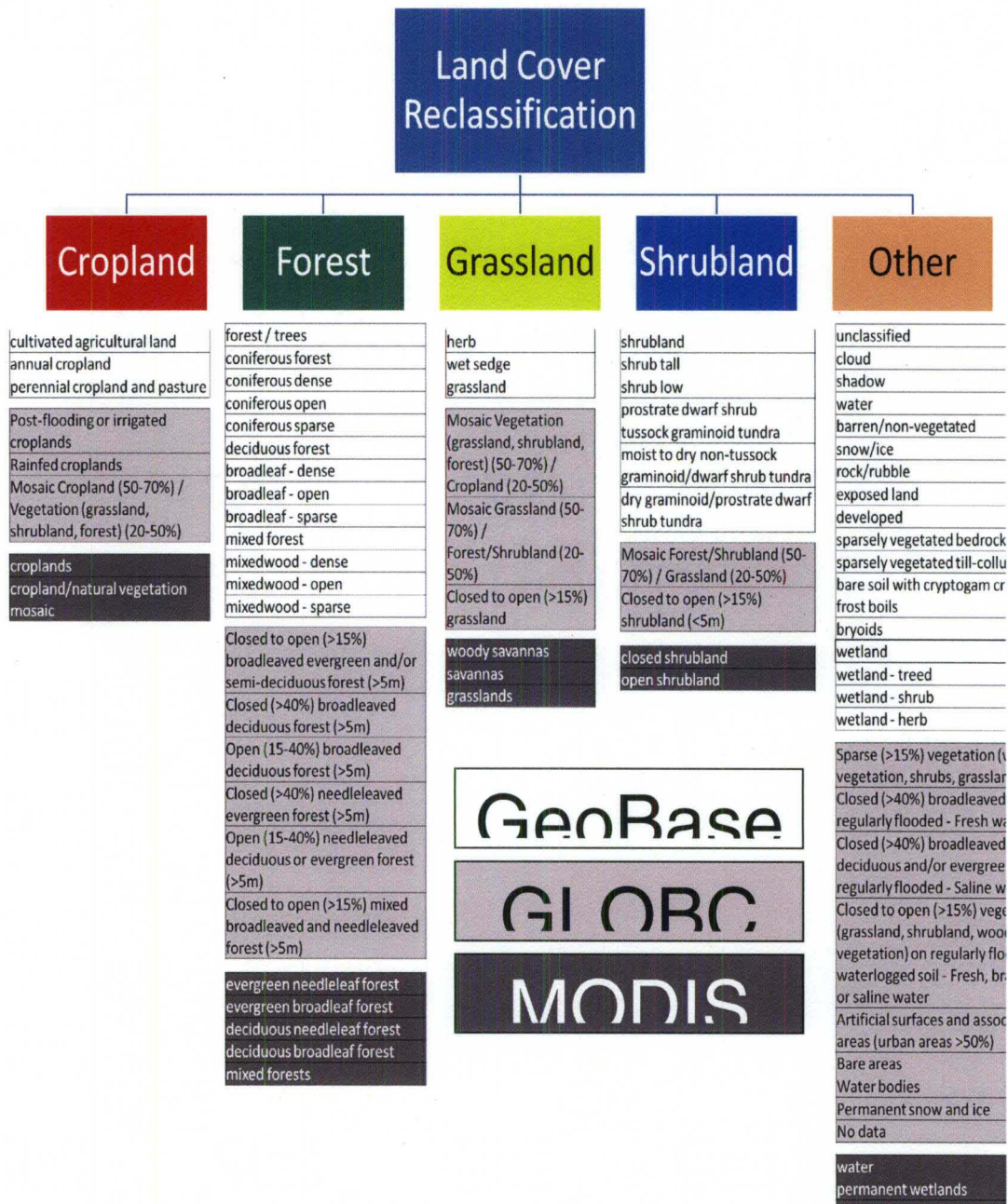
Figure 2. Original MODIS LCP classifications below their respective reclassified land cover type.
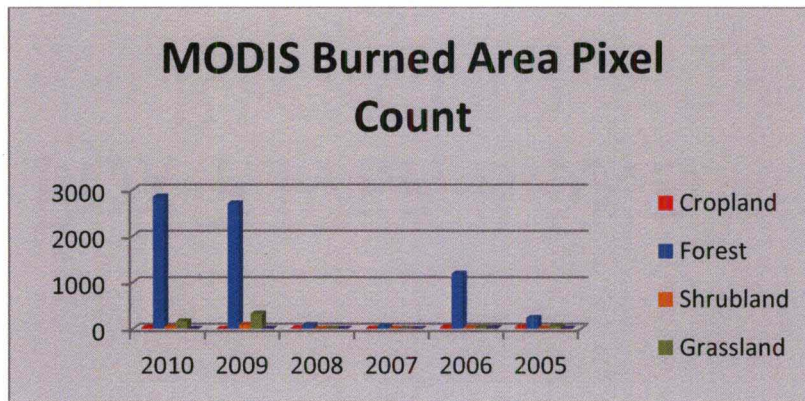
Figure 3. Count of MODIS Burned Area Pixels by re-classified land cover type.
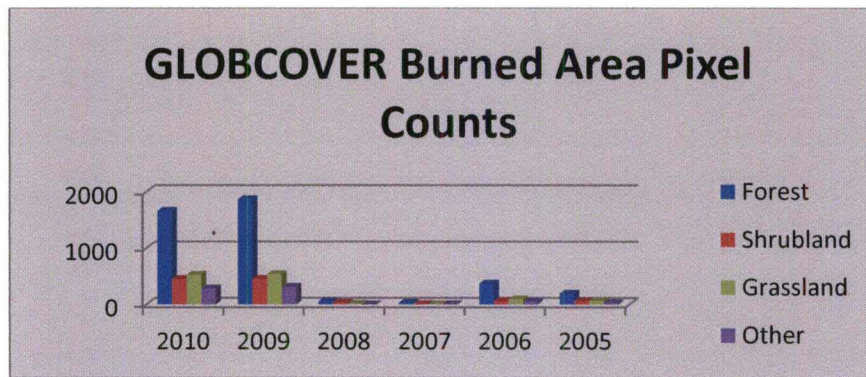
Figure 4. Count of GLOBCOVER Burned Area Pixels by re-classified land cover type.
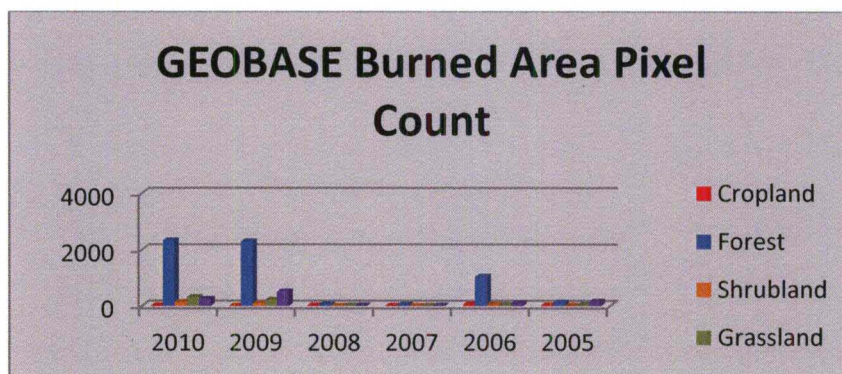
Figure 5. Count of MODIS Burned Area Pixels by re-classified land cover type.
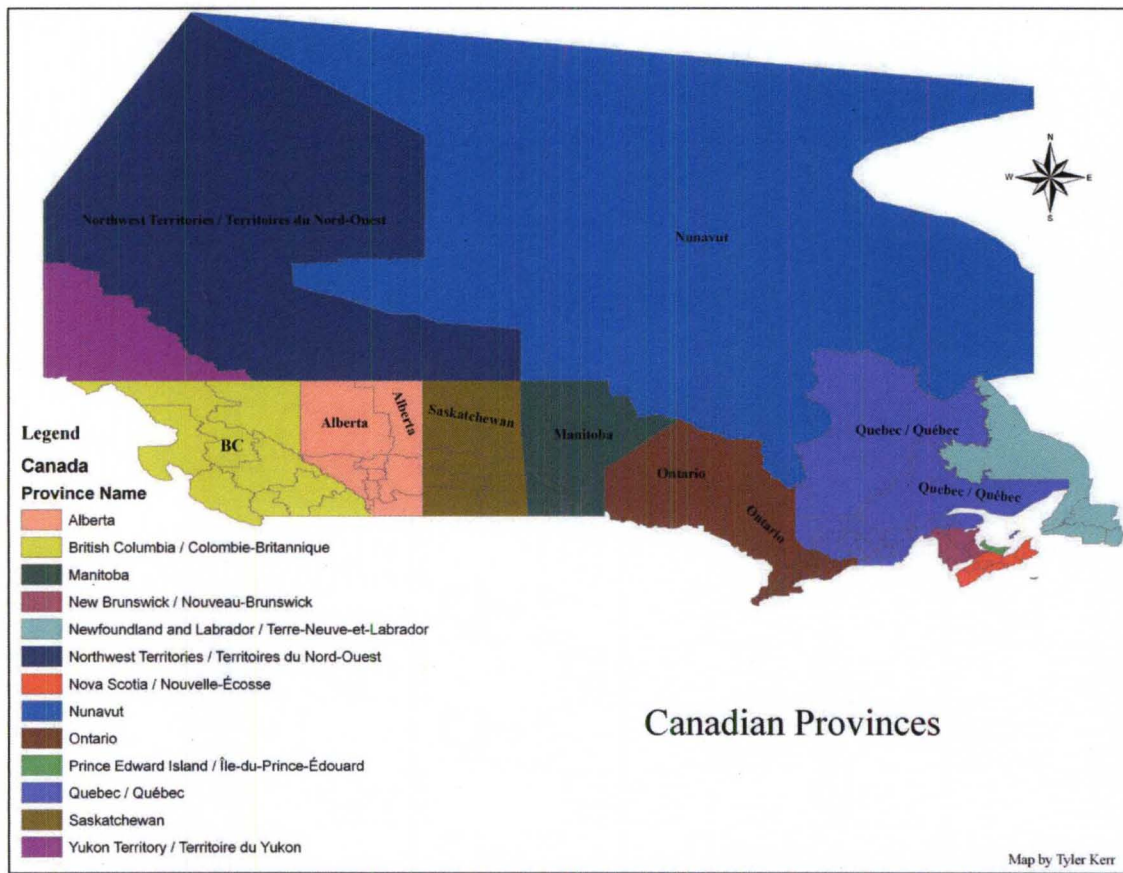
Figure 6. Map of Canadian Provinces.

ANALYSIS PLAN

Canadian fire detections by province for a time period of 2001 to 2010 will serve
as a framework analysis model for future fire monitoring and emissions inventory
estimates for local and international climate science and policy. As more data becomes
available from year to year more accurate and comprehensive estimates will be able to be
produced. This project serves as an addition to previous literature in analyzing methods
to scientifically examine satellite data for the purpose of environmental and hazards
monitoring.

RESULTS
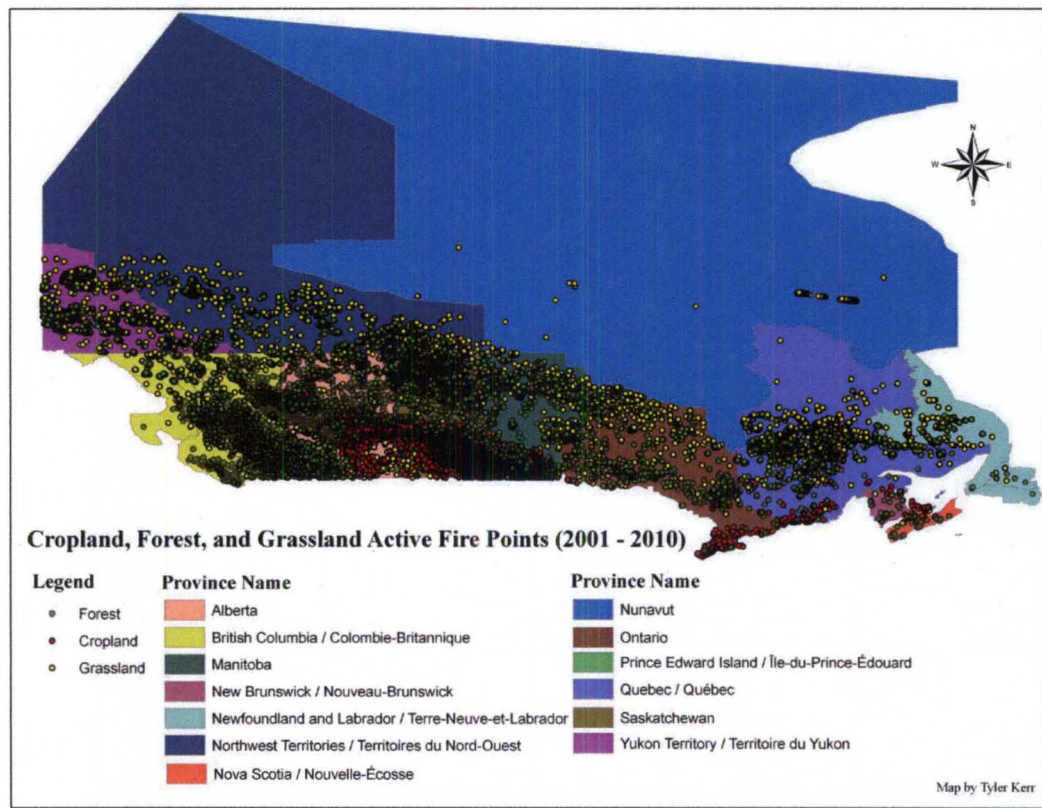
Figure 7. Cropland, Forest, and Grassland Active Fire points mapped to show general distribution over Canada.

The spatial distribution of fire is concentrated in the western provinces and especially in the prairie region (Figure 7). The results of the active fire land cover classification show that forest accounted for 65%, shrubland for 19% and cropland for 13% of fire in the study area from 2001 to 2010. Forest and shrubland burn across all of the provinces, but

cropland fires are clustered in agriculturally intense areas. Years 2003 and 2010 had the highest number of recorded fires while 2001 and 2009 were the lowest.

Forest and shrubland have similar annual fire activity, perhaps due to wildfires starting and spreading between these two land cover types. Forest and shrub fires have large fluctuations in the number of fires per year, which could be related to climatic conditions and fire management. On the other hand, cropland fires are anthropogenic in origin and show a fairly consistent level of burning over the years.

Cropland burning has a distinctly different seasonal pattern compared to forest and shrubland burning (Figure 8). Springtime burning accounts for 61% of cropland fires, 32% of shrubland fires and 29% of forest fires. Summer fires account for 19% of cropland fires, 65% of shrubland fires, and 52% of forest fires. During the fall, 20% of cropland fires, 3% of shrubland fires, and 17% of forest fires occurred. Less than 1% of cropland, shrubland, and forest fires occur in the winter.

Forest fire detections are concentrated in British Columbia and northern Saskatchewan. Cropland fire detections are located in Saskatchewan and Manitoba, and extend to the Peace River agricultural area in Alberta along the border with British Columbia. The cropland area is an extension of the same region of the United States known for large farms producing crops such as wheat, corn, soybean, and rye.
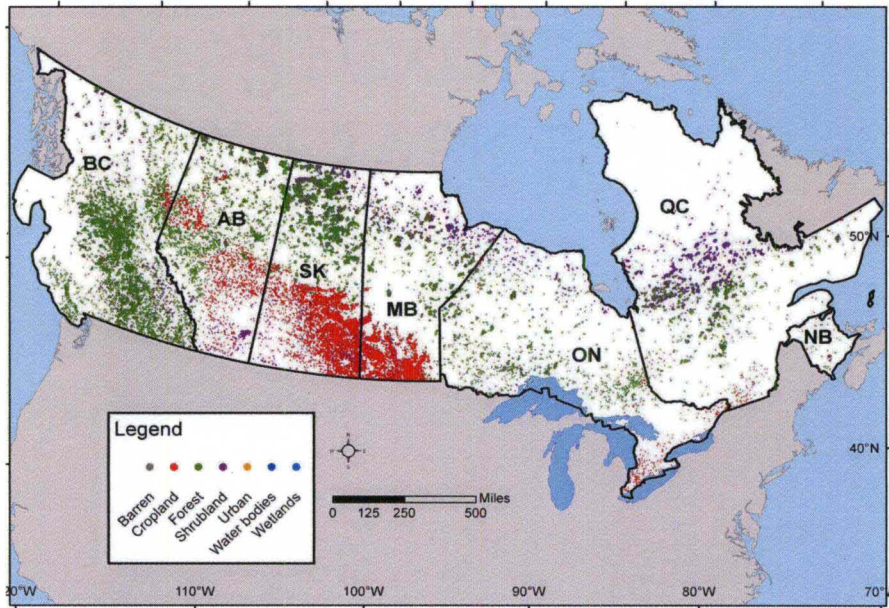
Figure 8. The location of active fires from 2001-10 identified by MODIS land cover type.

	winter	spring	summer	fall
forest	291	4,624	8,189	2,605
shrubland	12	1,488	3,010	146
cropland	15	1,880	570	599
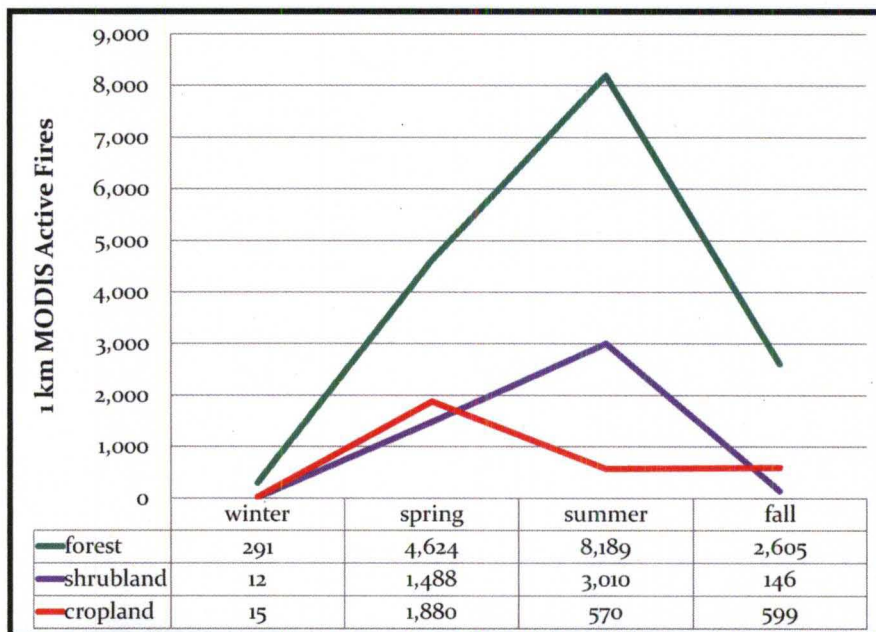
Figure 9. The average (2001-10) seasonality of the dominant land cover fires: cropland, forest, and shrubland. Seasons are winter (January - March); spring (April - June); summer (July - September); fall (October - December).

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A. Forest fire in British Columbia

B. Cropland fire in Saskatchewan

C. Shrubland fire in Alberta

Figure 10 a-c. Fires in forest, cropland, and shrubland.

On average from 2001-2010, the Prairie Provinces are the largest source of cropland active fire detections (Figure 8). Saskatchewan accounted for 46% of total cropland fires, followed by Manitoba 40% and Alberta 10% (Table 1). Spring is the season when all provinces burn the most cropland area. Fall burning occurs more frequently than summer, perhaps to clear the fields before fallowing them for the winter. The year 2004 had a low count of agricultural fire detections, followed by the highest number of agricultural fire detections in 2005.

Of the cropland detected active fires 91% were located in the original MODIS land cover class cropland (LC 12) and 8% in cropland/natural vegetation mosaic (LC 14). The MODIS burned area product was used to estimate the amount of cropland (LC 12) area that burned each season per province from 2003-2010 (Table 2). The results show that between 2003 and 2010, the top three provinces were on average Saskatchewan with 102,414 hectares, Manitoba with 77,858 hectares and Alberta with 35,823 hectares. The year 2005 experienced the most cropland burning, with 33% of all fires between 2003-2010 occurring. 2004 experienced the least, with 3% of total cropland burned area. The peak burned area months were May, September and October for all provinces.

Because of the concentrated nature of cropland burning it would seem that monitoring and regulation of agricultural emissions should be fairly manageable; however, it is a difficult and challenging task given the vast expanse of land that is Saskatchewan, Manitoba, and Alberta.
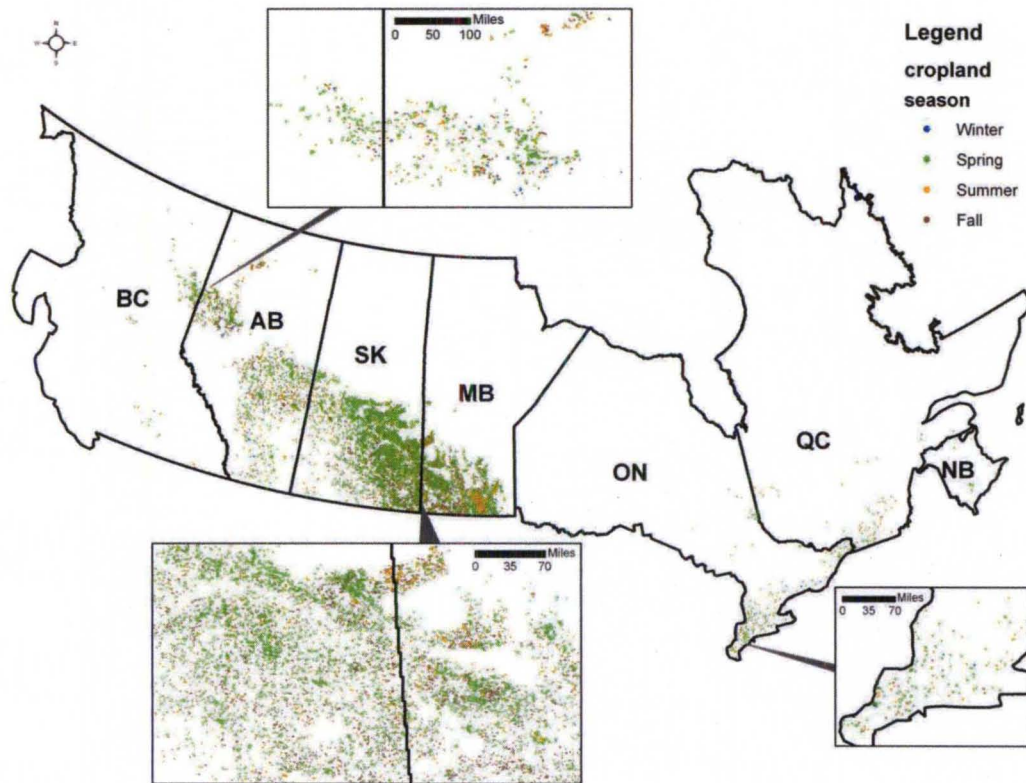
Figure 11. Seasonality of cropland active fires in Canada, 2001-10.

Table 1 below shows the raw count of AF detections in cropland (LC12 and LC14) by season for Canada and each province. Spring 2005 was the peak AF detection year in Canada (3,802 detections). Saskatchewan accounted for 2,093 of the 3,802 AF detections in spring 2005. This represents 55% of the spring 2005 AF detections. Saskatchewan produced the highest number of AF cropland detections of all provinces for every year except 2003, in which there were 839 AF detections compared to 935 AF detections in Manitoba. Alberta and Saskatchewan had their peak AF cropland detections in the spring season for every year while Manitoba shifted its peak AF cropland detections between spring and summer.

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Area	Season	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Average
Canada	Winter	13	6	19	11	8	29	4	7	2	53	15
	Spring	881	1,336	2,001	937	3,802	1,892	1,502	1,891	2,235	2,323	1,880
	Summer	668	805	601	137	448	767	744	484	602	443	570
	Fall	380	228	961	713	312	450	835	932	519	662	599
Alberta	Winter	8	4	14	10	7	22	4	7	1	11	9
	Spring	180	174	142	168	311	257	91	152	205	132	181
	Summer	92	173	11	38	34	44	41	43	91	60	63
	Fall	78	79	43	50	67	12	46	54	56	71	56
British Columbia	Winter	5	0	0	0	1	0	0	0	0	0	1
	Spring	7	14	32	0	16	18	14	11	17	16	15
	Summer	4	2	17	8	5	2	4	2	0	6	5
	Fall	0	13	5	8	7	8	4	1	2	5	5
Manitoba	Winter	0	0	5	0	0	0	0	0	0	28	3
	Spring	133	305	935	355	1,303	354	520	570	833	609	592
	Summer	350	462	404	41	259	454	576	317	388	238	349
	Fall	181	106	386	502	75	244	420	400	329	290	293
Saskatchewan	Winter	0	0	0	1	0	0	0	0	0	6	1
	Spring	547	829	839	390	2,093	1,211	826	1,121	1,116	1,529	1,050
	Summer	205	141	151	40	129	254	111	115	121	128	140
	Fall	119	24	523	150	157	179	358	475	131	292	241
Quebec	Winter	0	0	0	0	0	0	0	0	0	0	0
	Spring	3	3	12	4	7	10	6	10	10	11	8
	Summer	5	3	5	3	4	2	2	2	0	4	3
	Fall	0	5	1	1	0	1	1	1	0	0	1
Ontario	Winter	0	2	0	0	0	7	0	0	1	8	2
	Spring	11	11	34	13	70	36	43	23	50	26	32
	Summer	12	22	12	7	17	11	10	5	2	6	10
	Fall	2	1	3	2	6	6	6	1	1	4	3

Table 1. Active fires detected in cropland (LC12 and 14) by season: Winter (January-March), spring (April-June), summer (July-September) and fall (October-December) with seasonal high shown in bold.

Table 2 below shows calculated burned area in hectares of cropland BA detections (LC12) by season for Canada and each province. Spring 2005 was the peak AF detection year in Canada (3,802 detections), accounting for 494,681 hectares of burned area. Saskatchewan accounted for 2,093 of the 3,802 AF detections in spring 2005, equating to 268,774 hectares of burned area. For Canada, the maximum area in hectares burned occurred in the spring season for every year from 2003 to 2010 except in 2004 (fall) and 2007 (summer). Saskatchewan is the only province to see its maximum burned

area in the spring for every year from 2003 to 2010. The largest three areas of burned

area detections are: Saskatchewan in spring 2005 (268,774 hectares), Alberta in spring

2005 (145,989 hectares), and Saskatchewan in spring 2006 (106,728 hectares).

Area	Season	2003	2004	2005	2006	2007	2008	2009	2010	Average
Canada	Winter	129	0	0	0	0	43	0	193	46
	Spring	105,805	22,947	494,681	163,978	26,725	74,336	103,015	66,179	132,208
	Summer	71,116	4,422	71,932	127,765	56,541	26,575	10,647	53,429	52,803
	Fall	104,281	25,995	6,225	26,961	14,039	36,964	150	58,044	34,082
Alberta	Winter	0	0	0	0	0	21	0	21	5
	Spring	2,232	4,680	145,989	43,511	8,865	1,889	11,377	10,754	28,662
	Summer	9,209	1,352	2,919	11,463	1,073	8,415	258	1,610	4,537
	Fall	11,570	687	1,073	794	4,186	1,782	0	859	2,619
British Columbia	Winter	0	0	0	0	0	0	0	0	0
	Spring	43	64	730	343	0	0	0	0	148
	Summer	558	0	64	21	150	322	21	258	174
	Fall	107	21	0	0	0	0	0	301	54
Manitoba	Winter	129	0	0	0	0	0	0	172	38
	Spring	43,747	10,647	79,059	12,729	2,962	10,797	18,353	17,581	24,485
	Summer	41,086	1,266	64,805	37,222	51,046	11,119	2,597	35,590	30,592
	Fall	60,276	24,900	3,134	23,570	3,456	23,333	0	43,275	22,743
Saskatchewan	Winter	0	0	0	0	0	21	0	0	3
	Spring	59,353	7,170	268,774	106,728	14,811	61,521	72,877	37,737	78,621
	Summer	11,313	751	3,456	78,780	3,971	5,281	4,916	14,468	15,367
	Fall	31,898	365	1,975	2,447	6,204	11,055	0	13,438	8,423
Quebec	Winter	0	0	0	0	0	0	0	0	0
	Spring	0	0	0	0	0	0	0	0	0
	Summer	580	386	215	0	0	21	43	365	201
	Fall	150	21	21	86	21	0	21	0	40
Ontario	Winter	0	0	0	0	0	0	0	0	0
	Spring	429	386	129	408	43	0	408	64	233
	Summer	8,372	665	472	258	301	1,417	2,812	1,138	1,929
	Fall	279	0	21	64	172	794	129	172	204

Table 2. Burned area in hectares detected in cropland (LC 12) by season: Winter (January-March), spring (April-June), summer (July-September) and fall (October-December) with seasonal high shown in bold.
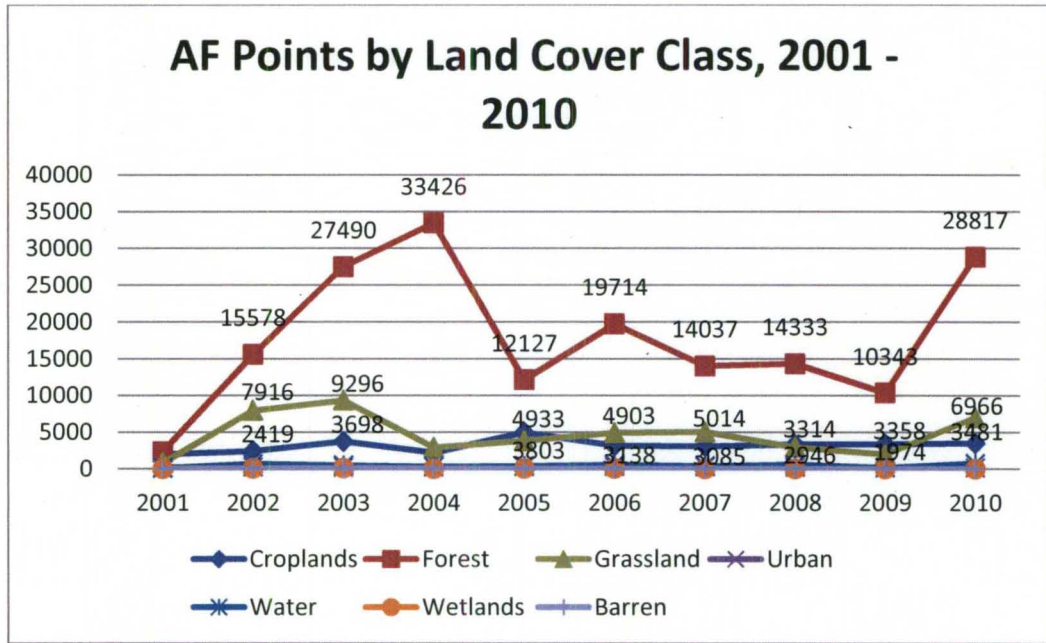
Figure 12. Canadian AF points by land cover classification for 2001 to 2010.

The Forest land cover class accounts for the greatest number of fires during any given year from 2001 to 2010. Grassland accounts for the second most numerous amounts of active fire detections for this time period. Grasslands serve as the boundary layer between agricultural and pastoral lands and forest regions.

Forest land cover types have an abundant fuel load to supply fires with the energy to spread across large tracts of land. Grasslands and Cropland land covers, however, offer significantly lower fuel load potentials. Active fire cropland detections outnumbered the Grassland detections in 2005 and 2009.

Active fire detections for Cropland land cover have been steady and consistent since 2006. This could be attributed to "repeat offending" farmers burning residue from

year to year; however, qualitative survey analysis would be necessary to confirm or deny this

postulation. Active fire detections in the Forest land cover class have been the most erratic, and are correlative to the number of forest fires and the ability of fire fighting response units to prevent, manage, and reduce the spread of each fire for any given year. Water, wetlands, barren land cover classes produced insignificant detections, and are most likely being classified as an Active Fire due to the reflectance of the surface at the time the sensor passes and scans the ground. Urban fires also produced a significantly lower number of Active Fire detections.
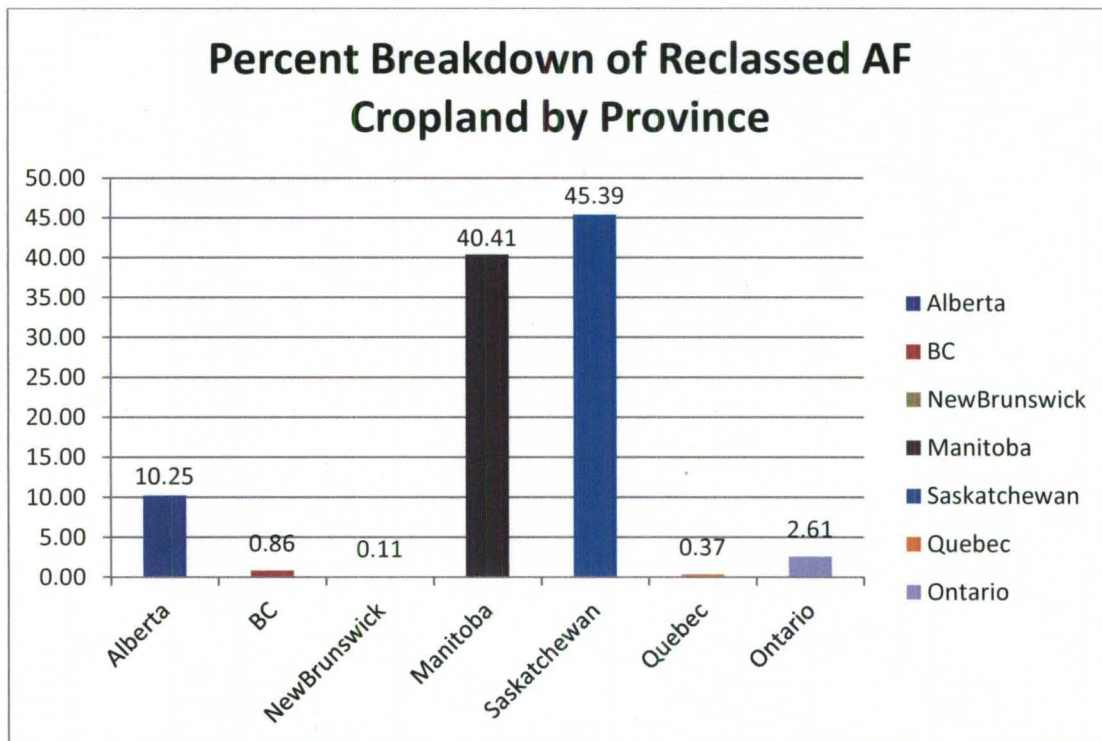
Figure 13. Percent of AF Cropland points by province.

The "Bread Basket" provinces of Saskatchewan, Manitoba, and Alberta produced

the greatest number of Active Fire detections in the cropland land cover category from

2001 to 2010. British Columbia, New Brunswick, Quebec, and Ontario produced

significantly lower

numbers of Active Fire detections for the period of 2001 to 2010. The Yukon Territories,

Prince Edward Island, Newfoundland, Nunavut, Nova Scotia, and the Northwest

Territories had no Cropland burning.
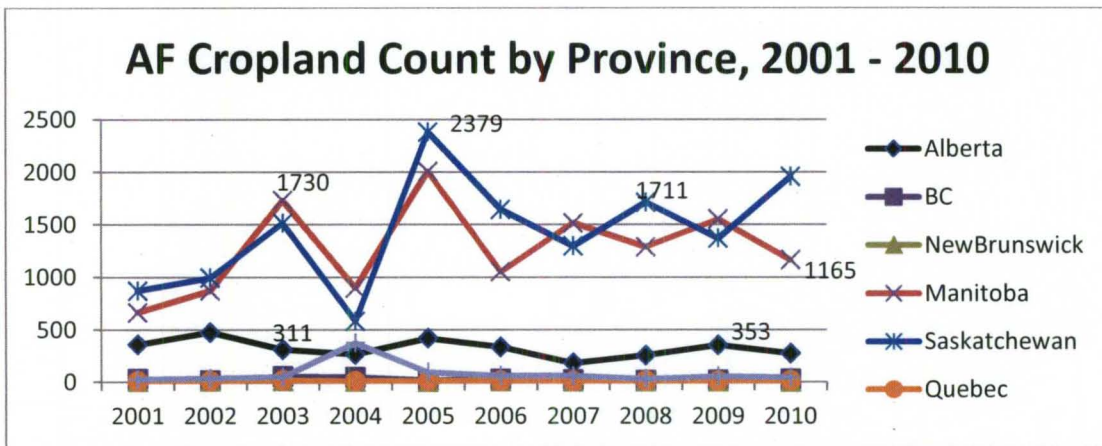
Figure 14. Number of AF detections cropland by province from 2001 to 2010.

Saskatchewan had its peak Cropland fires in 2005 with a count of 2,379 Active

Fire detections. Manitoba also peaked in 2005 with nearly 2,000 Active Fire detections

in the Cropland land cover category. Alberta peaked in 2002 with approximately 500

Active Fire detections in the Cropland land cover class.
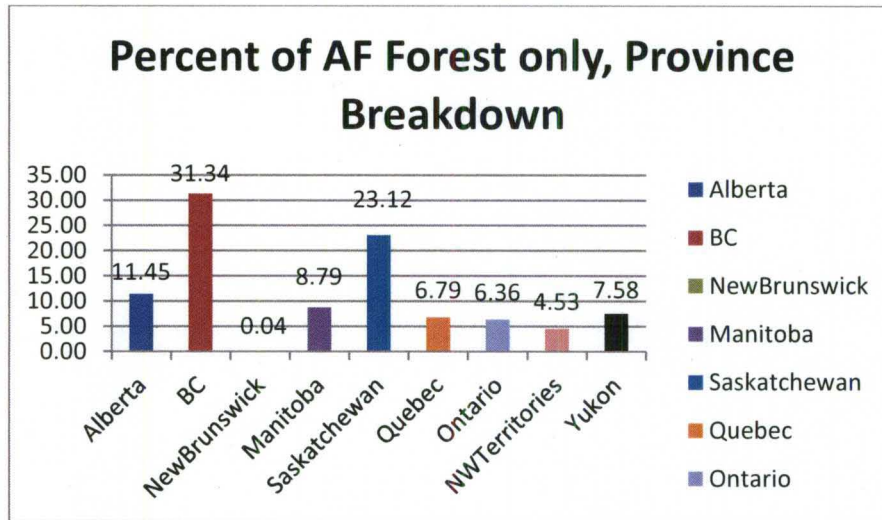
Figure 15. Percent of AF Forest points by province.

British Columbia and Saskatchewan account for the largest percentage of Active Fire detections in the Forest land cover category. Alberta accounts for the third most Forest class active fire detections. The rest of the Forest class AF detections are equally distributed amongst Manitoba, the Yukon, Quebec, and Ontario. The Northwest Territories and New Brunswick are the least significant contributors to AF Forest class detections amongst the provinces detecting AF Forest fires. Nova Scotia, Prince Edward Island, Nunavut, and Newfoundland had zero AF detections in the Forest land cover class. The large percentage of fires in British Columbia occurs in forest; this allows for specific planning for fire management teams in the province.
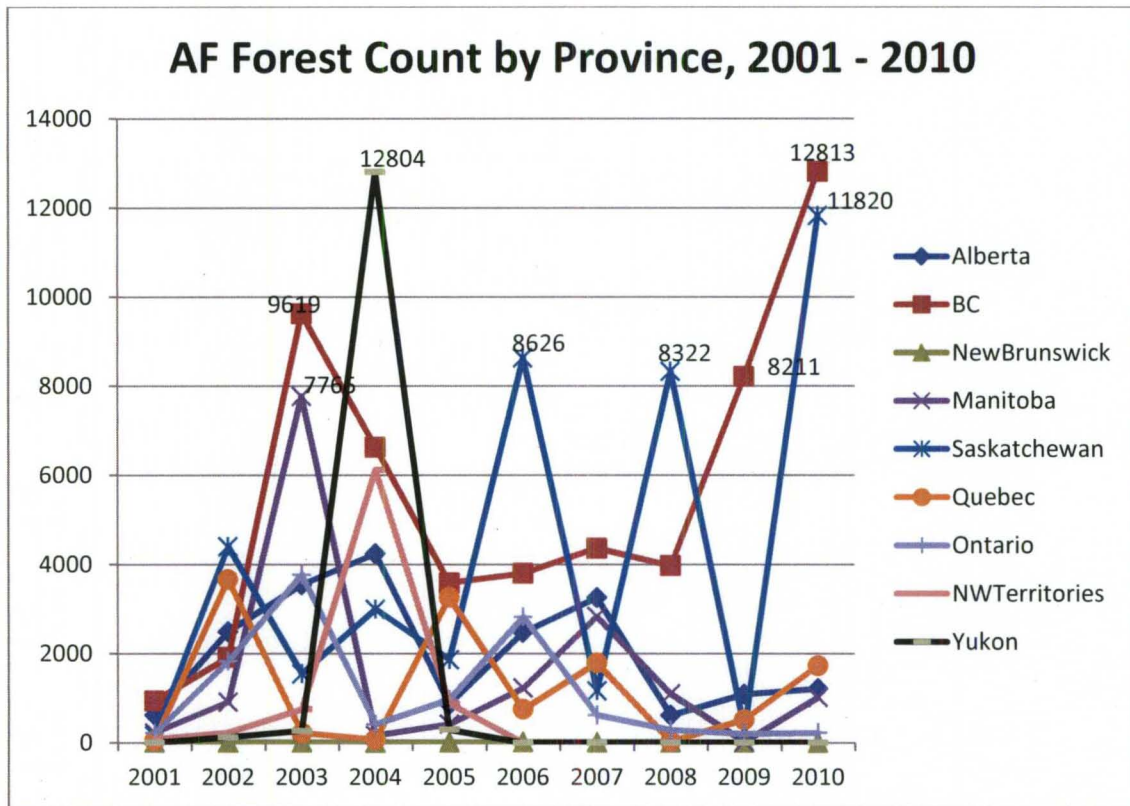
Figure 16. Number of AF detections forest by province from 2001 to 2010.

Despite only accounting for 7.58% of the total AF Forest detections, the Yukon

produced the second highest number of AF Forest detections of all provinces in any

single year in 2004 with 12,804 pings. 2004 was the only significant year of AF Forest

detections for the Yukon and the Northwest Territories. This can be attributed to a year

that has been recorded as one of the driest and warmest in the region spanning from

Northern Alaska into the Northwest Territories and the Yukon (Eamer 2004). British

Columbia (31.34%) recorded the highest number of AF Forest detections of all provinces

in any given year in 2010 with 12,813 pings. There is no consistent pattern in AF Forest

detections from year to year for any of the Provinces. This is attributable to the weather

conditions of each province in each year as well as to the ability of fire management teams to prevent, manage, and control the spread of fires on a year to year basis.
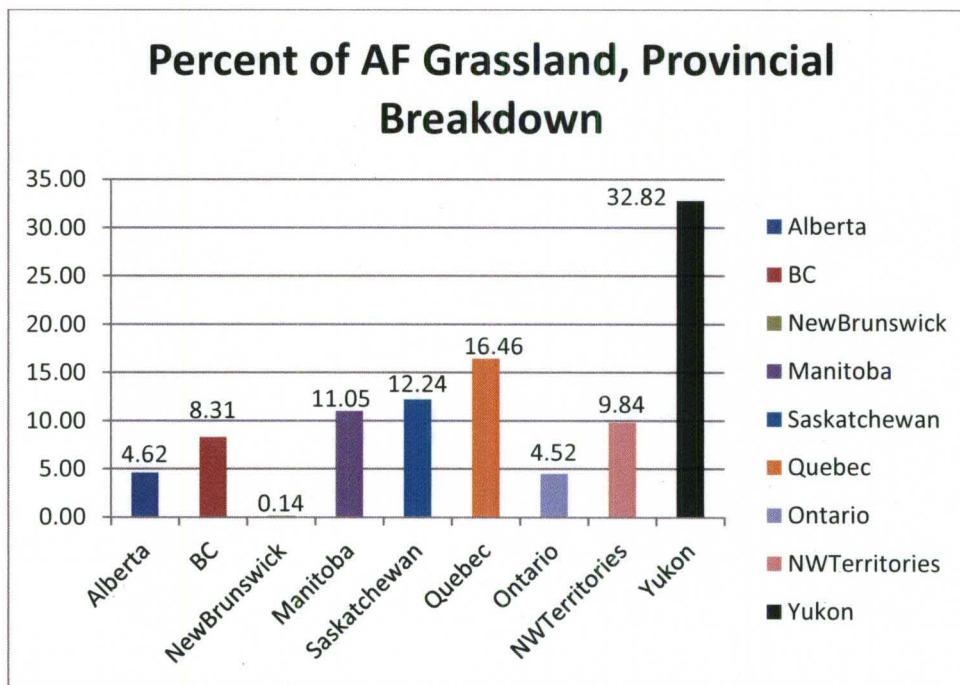
Figure 17. Percent of AF Grassland points by province.

The Yukon territories accounted for the largest percentage of AF grassland detections for the time period of 2001 – 2010, representing 32.82% of all AF pings in the Grassland land cover class. Quebec was the second largest contributor, accounting for 16.46%. Manitoba and Saskatchewan, located side by side, accounted for a collective total of 23.29% of total AF Grassland detections. Nova Scotia, Prince Edward Island, Nunavut, and Newfoundland did not contribute to the AF Grassland detections for 2001 – 2010.
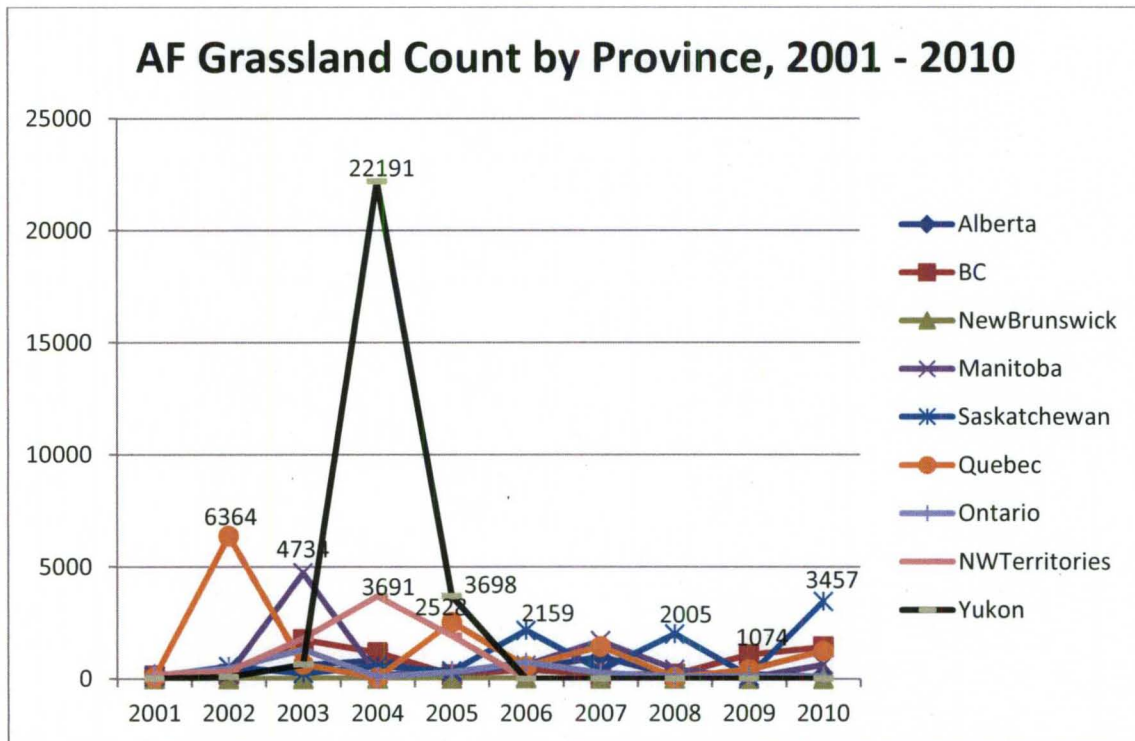
Figure 18. Number of AF detections grassland by province from 2001 to 2010.

2004 was a peak fire season in the Northwest corner of Canada comprising the

provincial areas of the Yukon and the Northwest Territories. These peaks attribute the

large percentage of AF grassland detections for the Yukon. The total number of AF

Grassland detections for 2001 to 2010 is 26,633; however, there were 22,191 AF

Grassland detections in 2004 alone. Similarly for the Northwest Territories there were a

total of 7,984 AF Grassland detections with 3,691 occurring in 2004 alone. This

represents 46.2% of the total AF Grasslands from 2001 to 2010 in the Northwest

Territories.

Much of the burning throughout the year in Canada occurs in the Western

provinces because of the extensive tracts of land. The Eastern Provinces have less forest

and agricultural lands and retain more of the population of Canada with exception of

large cities in the West such as Vancouver, Edmonton, and Calgary.
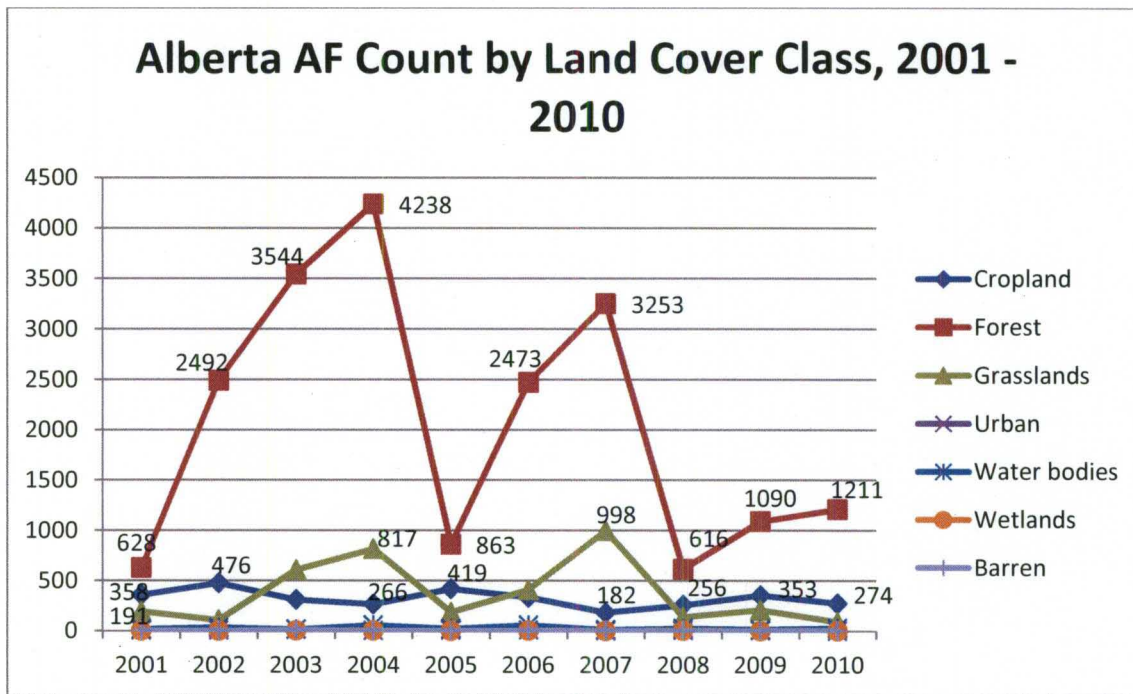
Figure 19. Number of AF detections by land cover class for Alberta from 2001 to 2010.

The Forest land cover class accounted for the largest number of AF detections in

Alberta from 2001 to 2010. There were 27,773 total AF detections in Alberta for the

study period, of which 20,408 were classified as Forest land cover. Forest land cover

accounted for 73.5% of the total AF detections in Alberta from 2001 to 2010. The peak

fire year in Alberta for forest fires was 2004 (4,238 detections), followed closely by 2003

(3,544 detections) and 2007 (3,253 detections). 2004 AF forest detections account for

15.3% of the total AF detections in Alberta from 2001 to 2010; 2003 AF forest detections

account for 12.8%, and 2007 AF forest detections account for 11.7% during the same

time span. The table below shows the total AF counts for Alberta broken down by land cover classification for each year in the study period.

Alberta	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	Total
Cropland	358	476	311	266	419	335	182	256	353	274	3230
Forest	628	2492	3544	4238	863	2473	3253	616	1090	1211	20408
Grasslands	191	108	608	817	186	408	998	138	208	90	3752
Urban	4	6	12	5	7	10	2	8	3	1	58
Water	18	34	16	57	22	57	13	26	14	28	285
Wetlands	0	0	3	3	0	3	0	4	0	0	13
Barren	7	0	11	0	0	3	2	0	3	1	27
	1206	3116	4505	5386	1497	3289	4450	1048	1671	1605	27773

Table 3. Raw number count of AF detections for Alberta from 2001 to 2010.

The Grassland classification accounted for 13.5% of the total AF detections in Alberta while the Cropland classification accounted for 11.6%. The peak AF year for Grassland detections in Alberta was 2007 (998 detections) followed by 2004 (816 detections) and 2003 (608 detections.

The peak AF year for Forest detections was 2004 (4238 detections) followed by 2003 (3544 detections) and 2007 (3253 detections). Cropland AF detections peaked in 2002 (476) followed by 2005 (419) and 2001 (358). Water bodies, Wetlands, and Barren land cover categories were most likely classified as such due to the reflectance values collected by the MODIS sensor being close to the programmed values for the presence of fire.
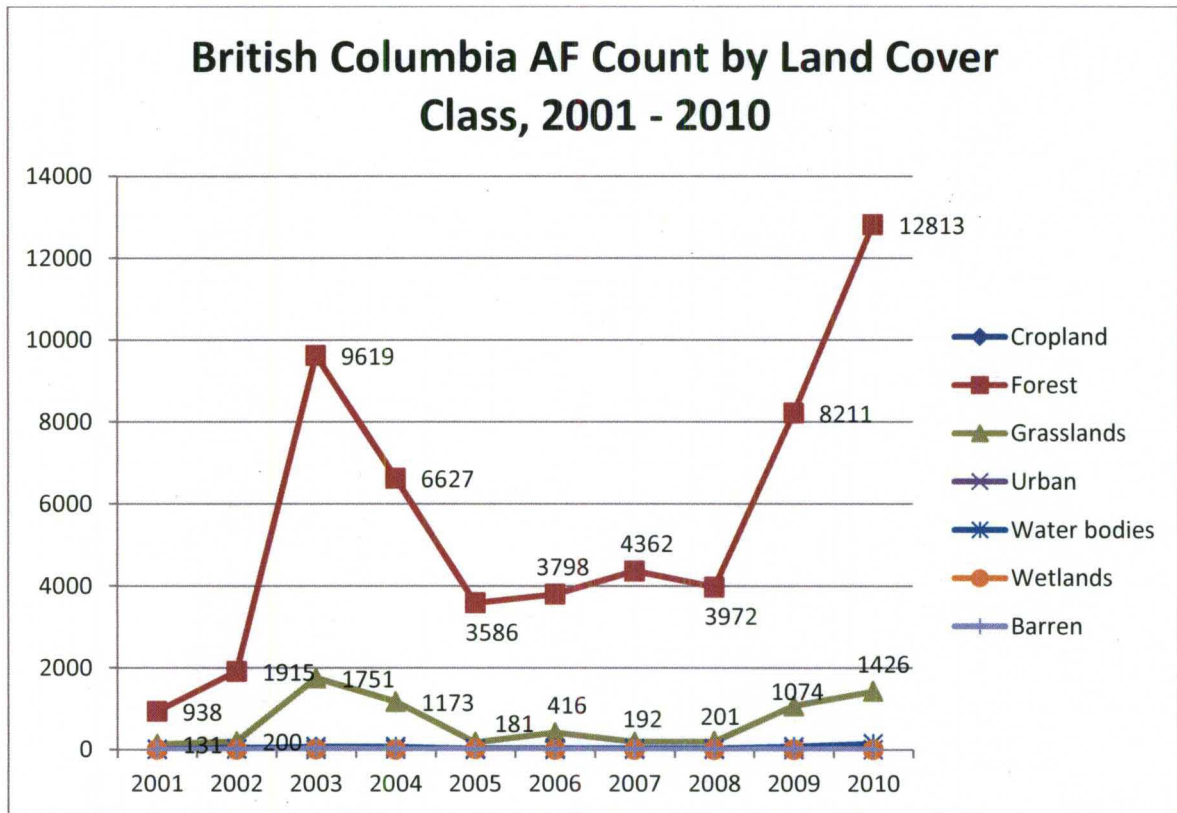
Figure 20. Number of AF detections by land cover class for British Columbia from 2001 to 2010.

There were a total of 63,477 AF detections in British Columbia from 2001 to 2010. British Columbia AF detections were most numerous for the Forest classification followed by Grasslands. Forest AF detections accounted for 88% of the total AF detections in British Columbia while Grasslands represents 10.6%. There was insignificant Cropland burning (271 detections) in British Columbia.

The peak AF year for the Forest classification was 2010 (12,813 detections) followed by 2003 (9,619 detections) and 2009 (8,211 detections). 2010 forest AF detections accounted for 20.2% of the total AF detections in British Columbia from 2001 to 2010. The peak AF fire year for the Grasslands classification was 2003 (1,751

detections) followed by 2010 (1,426 detections) and 2004 (1,173 detections). The 2003

grasslands AF detections accounted for 2.6% of the total AF detection in British

Columbia from 2001 to 2010. The peak fire year for Cropland was 2003 (54 detections).

BC	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	Total
Cropland	16	46	54	16	29	28	22	14	19	27	271
Forest	938	1915	9619	6627	3586	3798	4362	3972	8211	12813	55841
Grasslands	131	200	1751	1173	181	416	192	201	1074	1426	6745
Urban	0	6	3	6	3	2	4	0	4	0	28
Water	13	20	73	72	22	32	31	26	75	148	512
Wetlands	0	0	8	0	16	3	0	0	5	4	36
Barren	0	0	18	9	0	0	7	0	10	0	44
	1098	2187	11526	7903	3837	4279	4618	4213	9398	14418	63477

Table 4. Raw number count of AF detections for British Columbia from 2001 to 2010.
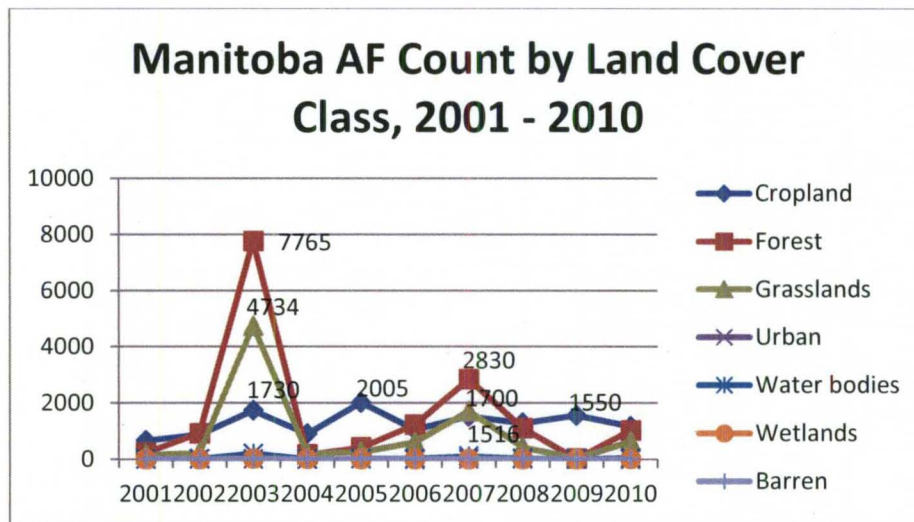
Figure 21. Number of AF detections by land cover class for Manitoba from 2001 to 2010.

There were a total of 37,923 AF detections in Manitoba. In Manitoba from 2001 to 2010, the most AF detections fell into the Forest classification (15,670) followed by Cropland (12,740) and Grasslands (8,968). Forest accounted for 41.3% of AF detections in Manitoba from 2001 to 2010; Cropland accounted for 33.6%, and Grasslands accounted for 23.6%. The peak AF year for the Forest classification was 2003 (7,765 detections) followed by 2007 (2,830 detections). The 2003 forest AF detections accounted for 20.5% of all of the AF detections in Manitoba from 2001 to 2010. The peak AF year for the Cropland classification was 2005 (2005 detections) followed by 2003 (1,730 detections) and 2009 (1,550 detections). The 2005 cropland AF detections accounted for 5.6% of the total AF detections in Manitoba from 2001 to 2010. The peak AF year for the Grasslands classification was 2003 (4,734 detections) followed by 2007 (1,400 detections). The 2003 Grasslands AF detections accounted for 12.5% of the total AF detections in Manitoba from 2001 to 2010.

Manitoba	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	Total
Cropland	664	873	1730	898	2005	1052	1516	1287	1550	1165	12740
Forest	224	915	7765	164	414	1224	2830	1098	19	1017	15670
Grasslands	166	222	4734	202	254	604	1700	423	37	626	8968
Urban	2	4	3	1	9	2	7	9	5	0	42
Water	4	16	202	3	15	31	109	31	6	51	468
Wetlands	0	0	25	3	0	1	1	0	0	5	35
Barren	0	0	0	0	0	0	0	0	0	0	0
	1060	2030	14459	1271	2697	2914	6163	2848	1617	2864	37923

Table 5. Raw number count of AF detections for Manitoba from 2001 to 2010.

There were 67,164 total AF detections in Saskatchewan from 2001 to 2010. The Forest land cover category accounted for the 61.3% of AF detections (41,191) in Saskatchewan from 2001 to 2010. Cropland (14,311) accounted for the second most (21.3%) and the Grassland (9,931) classification accounted for the third most, or 14.8% of the total AF detections in Saskatchewan from 2001 to 2010. The peak AF year for the Forest classification was 2010 (11,820 detections) followed by 2006 (8,626 detections) and 2008 (8,322 detections). The peak AF year for the Cropland classification was 2005 (2,379 detections) followed by 2010 (1,955 detections) and 2003 (1,513 detections.) The peak AF year for the Grasslands classification was 2010 (3,457 detections) followed by 2006 (2,159 detections) and 2008 (2,005 detections). Water bodies accounted for 2.4% of the total AF detections in Saskatchewan while Urban, Wetlands, and Barren land cover classes totaled less than 1% of the total AF counts for the province from 2001 to 2010.
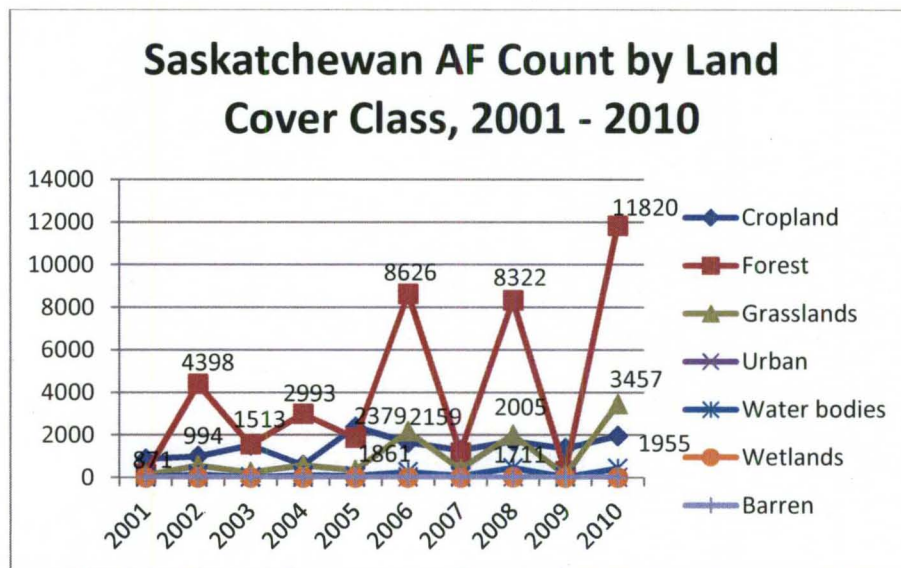
Figure 22. Number of AF detections by land cover class for Saskatchewan from 2001 to 2010.

Saskatchewan	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	Total
Cropland	871	994	1513	581	2379	1644	1295	1711	1368	1955	14311
Forest	162	4398	1545	2993	1861	8626	1166	8322	298	11820	41191
Grasslands	97	551	242	565	342	2159	394	2005	119	3457	9931
Urban	16	12	14	8	12	28	11	23	13	5	142
Water	12	138	24	106	74	262	78	446	13	427	1580
Wetlands	0	0	0	1	0	2	0	6	0	0	9
Barren	3	3	2	0	5	19	1	9	3	1	46
Total	1161	6096	3340	4254	4673	12740	2945	12522	1814	17665	67210

Table 6. Raw number count of AF detections for Saskatchewan from 2001 to 2010.

Burned area data reveals a more complete picture of seasonal variations in distribution of fires across land cover classifications for Canada. Burned area data was available from 2003 to 2010. For this study period of total of 74,909 BA pixels were classified by season and were detected for seven provinces.

Canada	2003	2004	2005	2006	2007	2008	2009	2010	Total
Spring (Jan-Mar)	6	0	0	0	0	2	0	9	17
Summer (Apr-June)	4,933	1,069	13,648	9,616	1,245	3,464	4,799	3,083	41,857
Fall (July-Sept)	3,313	206	3,351	6,486	2,634	1,298	496	2,489	20,273
Winter (Oct-Dec)	4,858	1,211	290	1,256	654	1,782	7	2,704	12,762
Total:	13,110	2,486	17,289	17,358	4,533	6,546	5,302	8,285	74,909

Table 7. Raw number count of BA detections for Canada from 2003 to 2010 by season.

Summer months accounted for the largest percentage of Burned Area pixels detected for the whole of Canada from 2003 to 2010. Summer accounted for 55.9% of total BA detections in Canada for the study period. Fall accounted for 27.1% of the BA detections while winter accounted for 17.0%. Spring accounted for less than 0.1% of the total BA detections in Canada from 2003 to 2010. The peak season for BA detection in Canada was the summer of 2005 (13,648 detections) followed by the summer of 2006 (9,616 detections) and fall 2006 (6,486 detections). The summer of 2005 accounted for 18.2% of the total BA detections in Canada from 2003 to 2010. The summer of 2006 accounted for 12.8% of the total BA detections in Canada from 2003 to 2010. The fall of 2005 accounted for 8.65% of the total BA detections in Canada from 2003 to 2010.

Forest fire season reaches its peak during the hottest months when fuel loads increase due to dry, combustible prone conditions. Brush clearing and crop residuals are also cleared and burned towards the end of the harvest season in order to prepare fields for the winter and certainly play a role in the larger number of BA detections in the Summer and Fall Seasons. Winter burned area detections can be misleading in the Northern Latitudes and field research was used to uncover what was occurring in the region from October to December. The results of the field research are discussed in the concluding section; however, it can be briefly noted that carbon rich soil and land cover conversion are significant players in pinging BA detections in Canadian provinces in winter and early springtime.
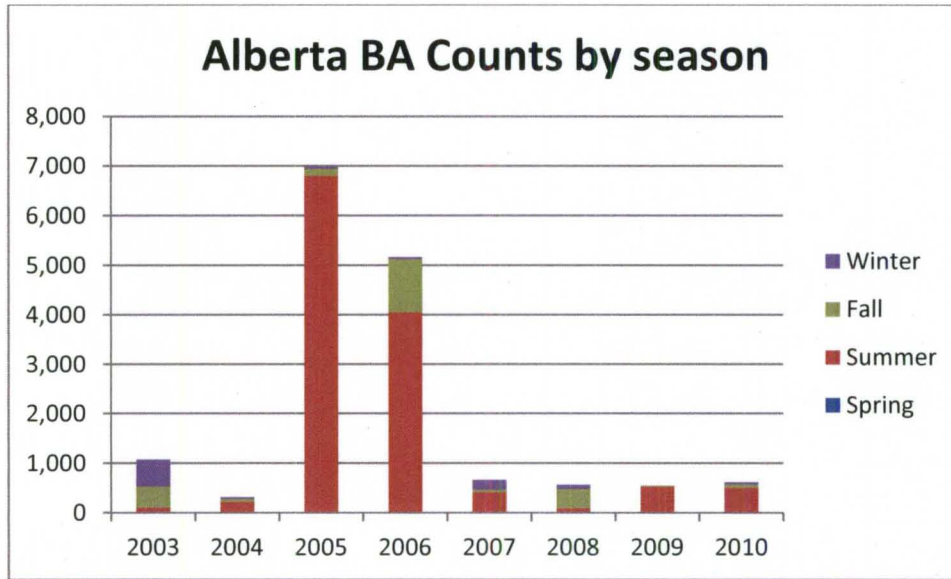
Figure 23. Seasonal BA detections from 2003 to 2010 in Alberta.

Alberta	'03	'04	'05	'06	'07	'08	'09	'10	Total
Spring (Jan-Mar)	0	0	0	0	0	1	0	1	2
Summer (Apr-June)	104	218	6,801	4,054	413	88	530	501	12,709
Fall (July-Sept)	429	63	136	1,068	50	392	12	75	2,225
Winter (Oct-Dec)	539	32	50	37	195	83	0	40	976
	1,072	313	6,987	5,159	658	564	542	617	15,912

Table 8. Raw number count of BA detections for Alberta from 2003 to 2010 by season.

There were 15,912 total BA detections from 2003 to 2010 in Alberta. Alberta accounted for 21.2% of the total BA detection in Canada for the study period. The peak BA detections in Alberta occurred in summer 2005 (6,801 detections) and 2006 (4,054 detections) and the fall of 2006 (1,068 detections). Summer 2005 accounted for 42.7% of

the BA detections in Alberta from 2003 to 2010; summer 2005 accounted for 25.5%, and

fall 2006 accounted for 6.7%.
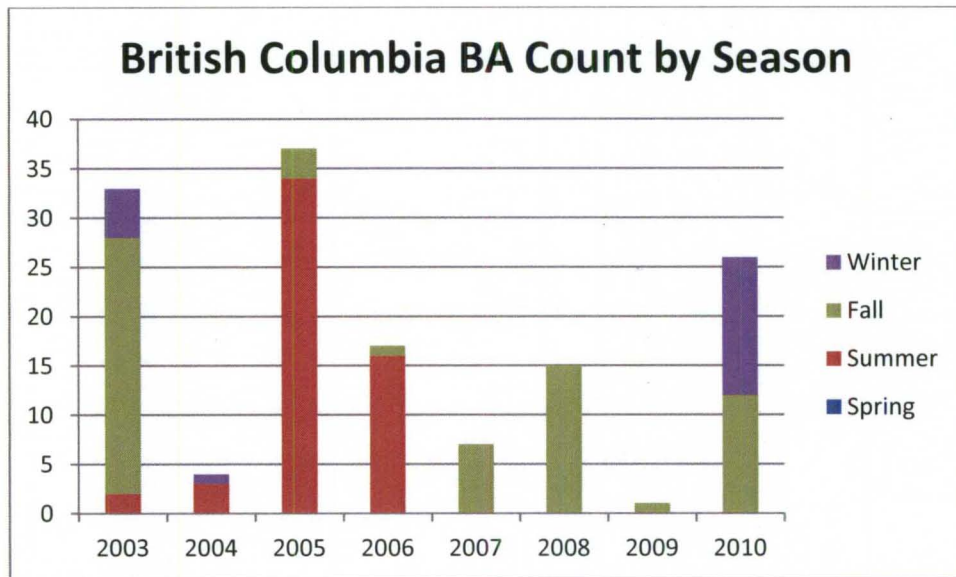
Figure 24. Seasonal BA detections from 2003 to 2010 in British Columbia.

British Columbia	'03	'04	'05	'06	'07	'08	'09	'10	Total
Spring (Jan-mar)	0	0	0	0	0	0	0	0	0
Summer (Apr-June)	2	3	34	16	0	0	0	0	55
Fall (July-Sept)	26	0	3	1	7	15	1	12	65
Winter (Oct-Dec)	5	1	0	0	0	0	0	14	20
	33	4	37	17	7	15	1	26	140

Table 9. Raw number count of BA detections for British Columbia from 2003 to
2010 by season.

There were 140 total BA detections from 2003 to 2010 in British Columbia.

British Columbia accounted for less than 1% of the total BA detection in Canada for the

study period. The peak BA detections in British Columbia occurred in summer 2005 (34 detections) and fall 2006 (26 detections). Summer 2005 accounted for 24.3% of the BA detections in British Columbia from 2003 to 2010. Fall 2006 accounted for 16.4%.

Figure 25. Seasonal BA detections from 2003 to 2010 in Manitoba.

Manitoba	'03	'04	'05	'06	'07	'08	'09	'10	Total
Spring (Jan-mar)	6	0	0	0	0	0	0	8	14
Summer (Apr-June)	2,038	496	3,683	593	138	503	855	819	9,125
Fall (July-Sept)	1,914	59	3,019	1,734	2,378	518	121	1,658	11,401
Winter (Oct-Dec)	2,808	1,160	146	1,098	161	1,087	0	2,016	8,476
	6,766	1,715	6,848	3,425	2,677	2,108	976	4,501	29,016

Table 10. Raw number count of BA detections for Manitoba from 2003 to 2010 by season.

There were 29,016 total BA detections from 2003 to 2010 in Manitoba. Manitoba accounted for 38.7% of the total BA detection in Canada for the study period. The peak

BA detections in Manitoba occurred in summer 2005 (3,683 detections), fall 2005 (3,019 detections), and winter 2003 (2,808 detections). Summer 2005 accounted for 12.7% of the BA detections in Manitoba from 2003 to 2010; fall 2005 accounted for 10.4%, and winter 2003 accounted for 9.7%.
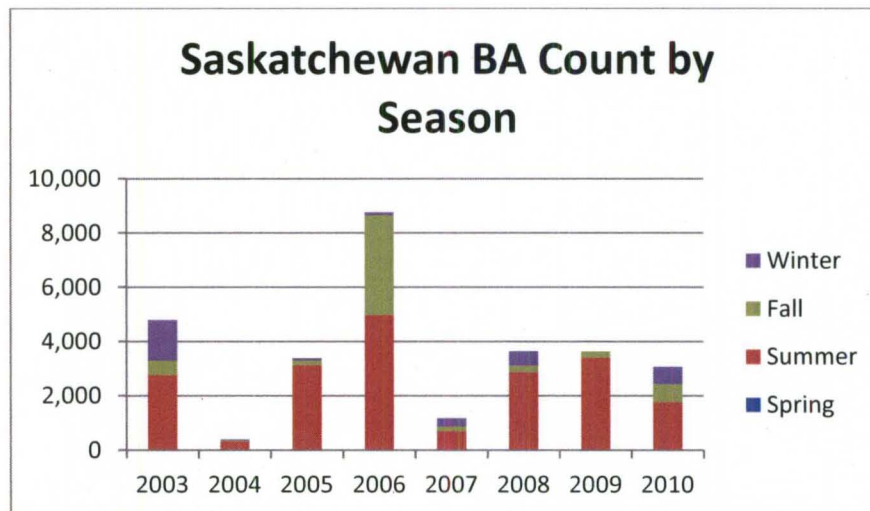
Figure 26. Seasonal BA detections from 2003 to 2010 in Saskatchewan.

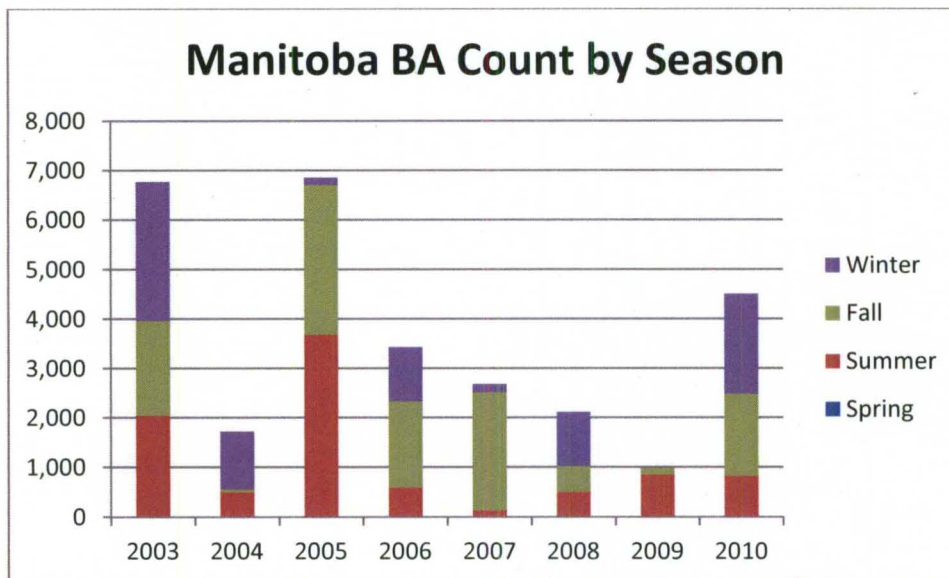| Saskatchewan	'03	'04	'05	'06	'07	'08	'09	'10	Total
Spring (Jan-mar)	0	0	0	0	0	1	0	0	1
Summer (Apr-June)	2,765	334	3,124	4,972	690	2,866	3,395	1,758	19,904
Fall (July-Sept)	527	35	161	3,670	185	246	229	674	5,727
Winter (Oct-Dec)	1,486	17	92	114	289	515	0	626	3,139
	4,778	386	3,377	8,756	1,164	3,628	3,624	3,058	28,771

Table 11. Raw number count of BA detections for Saskatchewan from 2003 to 2010 by season.

There were 28,771 total BA detections from 2003 to 2010 in Saskatchewan. Saskatchewan accounted for 38.4% of the total BA detection in Canada for the study

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period. The peak BA detections in Saskatchewan occurred in summer 2006 (4,972 detections), fall 2006 (3,670 detections), and summer 2009 (3,395 detections). Summer 2006 accounted for 17.3% of the BA detections in Saskatchewan from 2003 to 2010; fall 2006 accounted for 12.8%, and fall 2006 accounted for 11.8%.
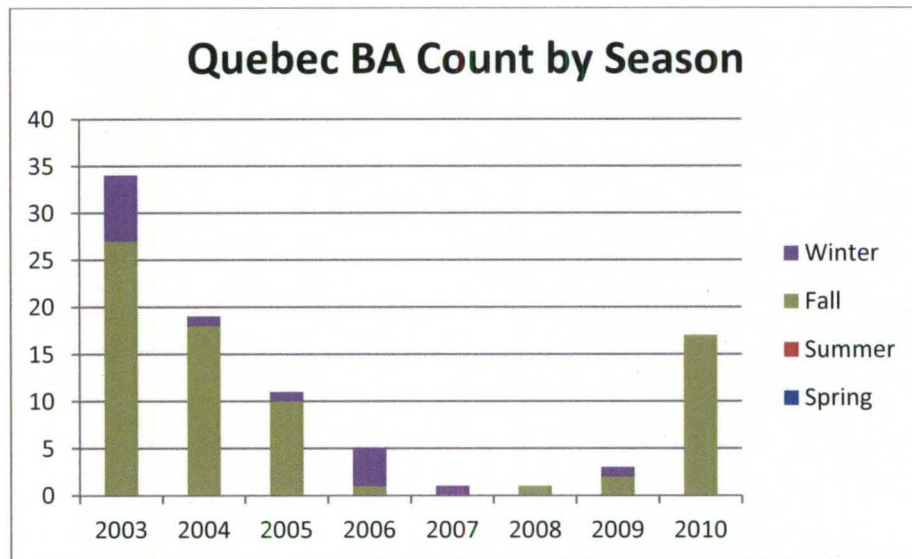
Figure 27. Seasonal BA detections from 2003 to 2010 in Quebec.

Quebec	'03	'04	'05	'06	'07	'08	'09	'10	Total
Spring (Jan-mar)	0	0	0	0	0	0	0	0	0
Summer (Apr-June)	0	0	0	0	0	0	0	0	0
Fall (July-Sept)	27	18	10	1	0	1	2	17	76
Winter (Oct-Dec)	7	1	1	4	1	0	1	0	15
	34	19	11	5	1	1	3	17	91

Table 12. Raw number count of BA detections for Quebec from 2003 to 2010 by season.

There were 91 total BA detections from 2003 to 2010 in Quebec. Quebec

accounted for less than 1% of the total BA detection in Canada for the study period. The

peak BA detections in Quebec occurred in fall 2003 and fall 2004. There were 27 BA

detections in fall 2003 accounting for 29.7% of the BA detections in Quebec from 2003

to 2010. The 18 BA detections in fall 2004 accounted for 19.8%.
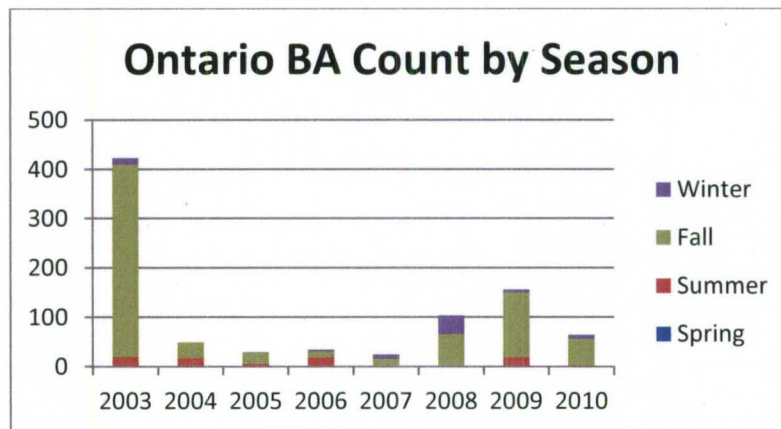
Figure 28. Graph of seasonal BA detections from 2003 to 2010 in Ontario.

Ontario	'03	'04	'05	'06	'07	'08	'09	'10	Total
Spring (Jan-mar)	0	0	0	0	0	0	0	0	0
Summer (Apr-June)	20	18	6	19	2	0	19	3	87
Fall (July-Sept)	390	31	22	12	14	66	131	53	719
Winter (Oct-Dec)	13	0	1	3	8	37	6	8	76
	423	49	29	34	24	103	156	64	882

Table 13. Raw number count of BA detections for Ontario from 2003 to 2010 by season.

There were 882 total BA detections from 2003 to 2010 in Ontario. Ontario

accounted for 1.2% of the total BA detection in Canada for the study period. The peak

BA detections in Ontario occurred in fall 2003 (390 detections) and fall 2009 (131 detections). Fall 2003 accounted for 44.2% of the BA detections in Ontario from 2003 to 2010; fall 2009 accounted for 14.9%.

New Brunswick BA Count by Season
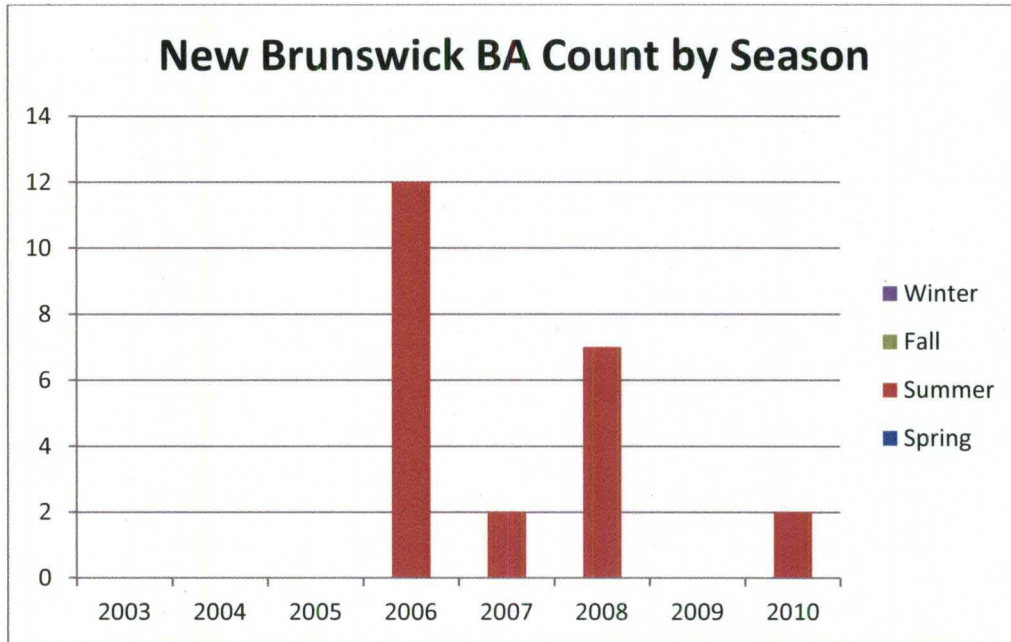
Figure 29. Seasonal BA detections from 2003 to 2010 in New Brunswick.

New Brunswick	'03	'04	'05	'06	'07	'08	'09	'10	Total
Spring (Jan-mar)	0	0	0	0	0	0	0	0	0
Summer (Apr-June)	0	0	0	12	2	7	0	2	23
Fall (July-Sept)	0	0	0	0	0	0	0	0	0
Winter (Oct-Dec)	0	0	0	0	0	0	0	0	0
	0	0	0	12	2	7	0	2	23

Table 14. Raw number count of BA detections for New Brunswick from 2003 to 2010 by season.

There were 23 total BA detections from 2003 to 2010 in New Brunswick. New Brunswick accounted for less than 1% of the total BA detection in Canada for the study period. The peak BA detections in New Brunswick occurred in summer 2006. Summer 2006 accounted for 52.2% of the BA detections in New Brunswick from 2003 to 2010.

Peace River Agricultural Area (PRAA) Field Work

The most northern agricultural region in North America is the PRAA, which straddles

the border of Northeastern British Columbia and Northwestern Alberta (Figure 30).
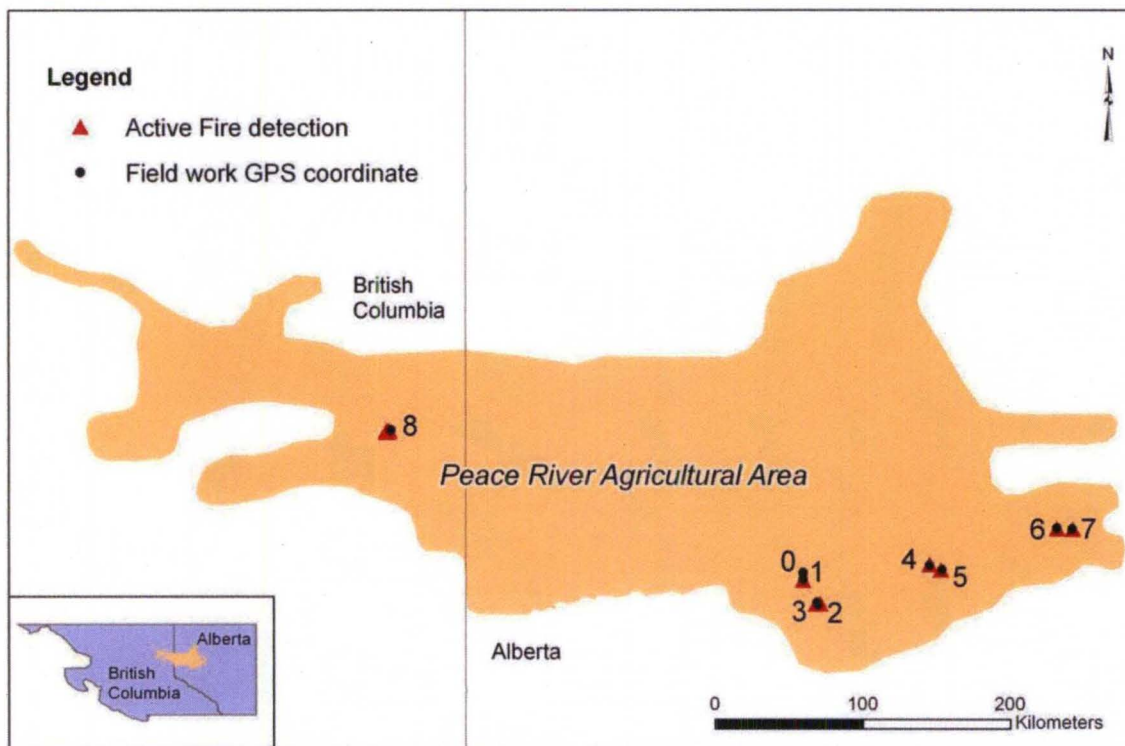
Figure 30. Location of field work GPS points collected and MODIS active fire detections in the Peace River agricultural area.

The British Columbia portion produces 77% of the provinces' grains and the

Alberta side grows canola, wheat and hay (British Columbia agriculture in the classroom

foundation 2008; Agriculture and Agri-Food Canada 2000). Field work was conducted

April 9-10th of 2011 on active fire points from the previous 6 months (October 2010 –

March 2011) that were supposedly located in croplands. The goal was to determine if any of the fires had been the result of crop residue burning, a practice commonly used to clear fields after harvest. Hegg et al. (2010) identified the region as being a source of black carbon in the Arctic due to cropland and grassland spring burning. The transport of aerosols from mid-latitudes to the Arctic is favored during the spring and has the most impact on snow melt.

The results of the field work showed that crop residue was not being burned during early April, nor was there evidence of fall burning. We found numerous large piles of trees and underbrush at all but one active fire point location. This indicated to us that the source of fire was from clearing the land and/or land conversion to maintain or expand agricultural fields (Figures 31 – 32a-f).

Figure 31. Picture taken at active fire location (field point number 6 in Figure 30 on page 46) with side comparison of field in Google Earth.

Figure 32a-b. Field points 0 and 2 as depicted in Figure 30 (page 46).

Figure 32c-d. Field points 4 and 5 as depicted in Figure 30 (page 46).

Figure 32e-f. Field points 7 and 8 as depicted in Figure 30 (page 46).

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CONCLUSION

Final conclusions from field work in the PRAA revealed several important conclusions about vegetation burning. Investigation of the Peace River agricultural area found active land use conversion from forest/shrubland to cropland/pasture. What seemed to be occurring in many instances was over the course of late fall, winter, and early spring farmers began to clear away to in-creeping brush and tree lines around the edges of their fields to maintain field lines or to expand the area of the field. Brush, thick weeds, and timbered trees were then stacked into large piles, some as tall as 3 meters or more and often lined out in even spread, grid like patterns across the field.

Talking to locals revealed that this was done for two main reasons. First, it prevented one large fire from having to be maintained. One large fire poses a threat to the soil and could spread to nearby forests if not managed properly. Fires of such large size can often draw unwanted attention from authorities; a positive for farmers, however, it undermines the ability to regulate emissions. The second reason was that the spread pattern of the burn piles helps to clear off snow cover when burned in the later spring time. Farm machinery can then more easily spread the charred residue over a larger area of the field for nutrient supplementation of the soil. There was, however, little evidence of fall and early spring field burning maintenance, suggesting that these piles were collected through the fall, winter, and early spring and burned sometime in late April or early May.

The large amount of prairie province cropland burning in the spring may contribute to black carbon deposition in the Arctic. Because the material was often shrub or forest material located in a field, some confusion can be created as to what is the source of the emissions. Forest material in Canada often grows in an alfisol, or iron and aluminum rich soil. Tracer alfisols detected in BC deposits suggest that forest fires are the source of major BC deposits in the Arctic. However field research in the PRAA revealed that the wooded/shrubby material was being cleared and burnt in fields and were not sourced from wide, forested areas as Hegg et al. 2010 had suggested. Field research also showed that the black, carbon rich soil, still mostly covered in mid April, could be pinging BA detections in the MODIS sensor for winter months. When snow melts off in patches and reveals the dark soil it has a strikingly similar appearance to burned area after a fire. Further field work and collaborative processing with the MODIS team could help to rectify the potential signal confusion in late winter for Northern latitudes.

Forest, grassland, and cropland are the dominant land cover types where active fires were detected from 2001 to 2010. Forest and grassland share a similar fire pattern over all of the years while cropland is distinct and has less inter-annual variability of fire activity. Cropland fires peak in the spring while forest and shrubland peak in the summer months and into the fall. Saskatchewan is the leading source of cropland active fires and burned area, followed by Manitoba and Alberta. British Columbia and Saskatchewan are the primary sources of forest fire detections.

Using the MODIS sensor it is possible to classify and quantify the location and source of fires in Canada. When coupled with field research we are able to complete a

more accurate picture of burning and fire emissions in Canada. This project can serve as a stepping stone for future research into quantifying the particular "greenhouse" gasses and BC deposition responsible for driving up temperatures in micro-climate regions of Canada as well as decreasing the albedo of the Arctic surface.

This study is also important as it can aid fire management and medical response teams in planning for emergency events. By reviewing the locations, times, and types of fires they will be dealing with fire emergency units will be better prepared to handle fires when they occur. British Columbia's fires occur almost exclusively in forested areas. As such specific training and protocols need to be followed in comparison to standards used in urban house fires or agricultural burns in farmland. Locating sources of water nearby the most fire prone areas with clear access for helicopter units can drastically reduce the time spent fighting forest fires. It can also aid in creating evacuation plans for at-risk communities susceptible to forest fire encroachment. Saskatchewan and Manitoba, however, experience the majority of agricultural fires. Local prescribed burn days and fire management and enforcement of cropland fires can aided by this research and the satellite data in that it reduces the in-the-field necessity to spot fires. Once fires are detected with the MODIS sensor a fire management specialist can be sent out to investigate the fire occurrence, greatly increasing the financial and human resources of the fire management office.

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CURRICULUM VITAE

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Tyler F. Kerr

Experience

December 2011 – Present   Department of Geography
Part-Time Faculty (Graduate Teaching Instructor)

- Serve as instructor of an Online Distance Learning Course, Geosciences 200 (The Global Environment), at the University of Louisville.
- Provide assignments and information relevant to each week's review of a Chapter from the assigned textbook. Respond and interact with student's discussion posts and lead in creating critical analysis of the material.
- Administrative management including responding to emails, grading, and rectifying online technical problems while ensuring a safe, fun, and beneficial learning environment.

August 2011 – Present, October 2009 – May 2010
Athletics Department, University of Louisville
Academic Tutor for Student Athletes

Meet with student athletes for weekly study sessions, reviews of material, homework assistance, and test preparation and review. I assisted them in learning course material, preparing for tests and quizzes, and reviewed their written or calculated coursework per NCAA Guidelines.

August 2010 – August 2011
Graduate Research Assistant for Dr. Jessica McCarty

Planned and conducted field research to ground truth the locations of Kentucky tobacco fields as identified by the U.S. Department of Agriculture's Cropland Data Layer (CDL). Training data was then created using collected GPS

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information and ArcGIS per contract requests from the Environmental Protection Agency (EPA).

Calculated high, average, and low emissions of selected greenhouse gases from agricultural fires for 2003 – 2008 in the United States as collected by the MODIS Fire Product. Emissions factors were calculated by a group of professors and EPA scientists. The results were used to help in the expansion of the EPA's emissions inventory.

Produced maps displaying areas within the continental United States comparing the overlap of two Fire Detection Products derived from satellite sensed imagery. Detected burn areas were classified by land cover type to highlight cropland and rangeland burning in agricultural areas of the US. Maps have been presented and discussed in several conference calls with EPA scientists.

Created image catalogs detailing major agricultural burn sites for regions throughout the United States, Canada, and Russia (near Moscow)

Served as a lab instructor for GEOG 355: Introduction to Remote Sensing. Labs moderated were "Analyzing Radar Signatures," "Supervised Classifications of LandSat TM Imagery," and "Multi-temporal Change Detection."

Presented work analyzing agricultural fire detections in Canada for the past decade at the Fall 2011 AGU Conference.

May 2005 – August 2005, May2006 – August 2006
Summer Safety Intern, PennDot District 10

Verify and Coordinate the location of road maintenance crews throughout a five (5) county jurisdiction.

Plan daily trips to intersect road crews for safety inspections.

Performed a drive-through and walk-through safety inspection per PennDot specifications and OSHA regulations with each crew's foreman.

Produced written reports for each inspection

Conducted two to three inspections for each foreman in each county. There were approximately 60 foremen in total.

Education

May 2010: B.S. Geography (Human/Environmental Interaction)
University of Louisville   Louisville, KY 40292

Currently: Completing M.S. in Applied Geography at the University of Louisville, anticipated graduation: May 2012

Presentations

December 2011: American Geophysical Union National Conference: ""Reclassified Cropland Active Fire and Burned Area Detections by the MODIS 1 km Sensor in Canadian Provinces by land cover type, 2001 - 2010"

October 2011: EPA Community Modeling and Analysis Conference (contributor): "Development of a Crop Residue Burning Emissions Inventory: Preliminary CMAQ Results"

April 2011: University of Louisville Graduate Research Symposium   Honorable Mention: "A Remote Sensing Analysis of Fire in British Columbia, CA" by Carie Ernst, Tyler Kerr, Jessica McCarty and Megan White

October 2010: Applied Geography Conference Undergraduate Research Poster Competition: "Spatial Correlation of Foreclosures and Crime: How Increasing Numbers of Foreclosed Homes have Affected Crime Distribution in Louisville, KY"

Skills

- Advanced experience with ArcGIS, Arc Catalog, and Geo-database design and management, and Microsoft Office.

- Experience performing GIS analysis, queries, searches and data manipulation to meet project needs on time.

- Experience planning and conducting field research excursions in the US and Canada.

- Field experience collecting environmental data (GPS, land cover analysis) and ground-truthing satellite information/imagery.

- Professional and academic experience in accurate data collection and analysis.

- Excel working in an environment promoting active team work and effective communication across all levels of employment.

- Familiar knowledge with 29 OSHA 1910, 1926 Regulations.

- Management and responsibility for the growth of knowledge in individuals while promoting increased independence in learning via interdependent communication.

- Classroom management and administration