Satellite/NDVI data for CWFIS/fire danger rating in Canada

The Canadian Forest Fire Behavior Prediction (FBP) System uses weather, topography, and vegetation (fuel type) data to estimate potential rate of spread, fuel consumption, and fire intensity (Forestry Canada Fire Danger Group 1992, Wotton et al 2009). These estimates support fire management preparedness and decision-making, prescribed burn planning, fire growth modelling, smoke forecasting, and other applications.

The Canadian Wildland Fire Information System (CWFIS) uses the FBP system to produce daily national maps of fire behavior components, which are presented on the CWFIS web site (Lee et al 2002; see cwfis.cfs.nrcan.gc.ca). Gridded weather inputs are produced by interpolating current observed or forecasted weather from weather station locations. Obtaining and processing weather data from an array of federal and provincial sources is a major function of the CWFIS. Elevation at grid cell locations is taken from GTOPO30, a 30-arcsecond global digital elevation model assembled by the US Geological Survey in 1996 (see lta.cr.usgs.gov/GTOPO30).

The current (2015) CWFIS fuels grid was developed at NoFC by Brian Simpson and is based on a 2012 MODIS land cover classification and Canadian Forest Inventory (CanFI) data. It is updated annually by taking into account burned areas from previous years. Areas burned last year (2014) are considered non-fuel, and areas burned in the previous two years are mapped as grass. Needless to say vegetation succession after fire is far more complex than this, and depends on pre-fire fuels, fire severity and size, post-fire climate, and other factors. A completely new fuels map is made approximately every 5 years using the latest available data.

Some fuel types change during the course of the year. These are deciduous trees, whose fire behavior potential varies depending on leaf phenology, and grass, which burns readily when dry (cured) but not when green. When the CWFIS began producing and disseminating fire danger maps in 1995, these changes were dealt with in a simplistic manner by assuming a constant spring greenup (leafout) date and a constant grass curing value.

Subsequently in 2005 Jin Ji-zhong at GLFC produced a greenup date map, which gave the date of deciduous greenup for every location (grid cell) in Canada based on climate normals and greenup observations. This replaced and improved on the single spring greenup date, but was still unresponsive to variation between years. Meanwhile, curing was still set to a constant value of 90%, across the country, for the entire year. A high value was used to avoid predicting low spread rates when high rates can occur.

The CWFIS spread rate and fire intensity maps reflected this overestimation, which was clearly visible in the prairies, during the summer months. In the summer, grass is typically green. When the curing falls below 50%, fire spread as predicted by the FBP System drops to near zero, even when the weather is warm and dry. The high moisture content of live green grass is high enough to prevent almost all fire spread. In contrast, in the spring the previous year's dead grass may dry after snow melt and can burn easily; in the fall, before snowfall, this year's grass is dry and still standing which makes it even more flammable. These two "habits" of grass are represented by different fuel types in the FBP system, O1a (matted grass) and O1b (standing grass).

There was therefore a need to improve the grass curing input to the CWFIS. Fires can spread more quickly in dry grass than forest. In Alberta, most grass fires occur outside the province's fire management zone, which includes the boreal forest in the north and and alpine forests in the west. These fires are therefore managed by municipalities, and suppressed by municipal fire departments staffed largely with volunteer firefighters. The agricultural zone in southern Alberta is not included in the provincial fire danger rating maps, though some components of the Fire Weather Index (FWI) System are provided by Alberta Agriculture and Forestry's AgroClimatic Information Service (ACIS; see agriculture.alberta.ca/acis). This makes it more likely that the CWFIS maps would be referred to by firefighters and the public. As an example, in November 2011, a grass fire in southern Alberta spread 12 km in 1½ hours, burning two residences and entering the Lethbridge city limits (Alexander et al 2013).

In 2013, we started looking at NDVI (Normalized Difference Vegetation Index) data to estimate and map grass curing in near(er) real time. NDVI is a widely-used satellite-based measure of vegetation greenness. When grass is green, or deciduous trees are leafed out, the NDVI is high. When the grass is cured, or the trees are leafless, the NDVI is low. When snow is present, the NDVI is very low. NDVI was the most widely and successfully used index for this purpose in Australia, where extensive efforts have been made to monitor grass curing (Newham et al. 2010, Allan et al. 2003).

NDVI formula: NDVI = (NIR - VIS) / (NIR + VIS)
where NIR is near-infrared, and VIS is visible brightness.

NDVI distinguishes between live vegetation; dead vegetation and bare ground; and cloud, snow and ice. Green vegetation absorbs visible light and reflects infrared, resulting in high NDVI values. Snow, in contrast, absorbs infrared and reflects visible, resulting in very low or negative NDVI values.

In evaluating NDVI for estimating grass curing, 14 years of NDVI data was obtained for 45 grassland sites in Canada (figure 1). These included both natural grasslands and croplands. The NDVI data was derived from MODIS (MOD13Q1 product) and provided by the Oak Ridge National Laboratory (ORNL 2008). The data included NDVI values at 16-day intervals. At each site, an area of 9x9 pixels was sampled (2.25x2.25 km). Grassland sites were determined using 2010 North America MODIS land cover (http://cec.org/tools-and-resources/map-files/land-cover-2010). However, at some sites, within the 9x9 pixel area, there were some pixels that were not classified as grassland. To prevent these from impacting the results significantly, the median NDVI value was used in the analysis.

Figure 1. Grassland test/data sites

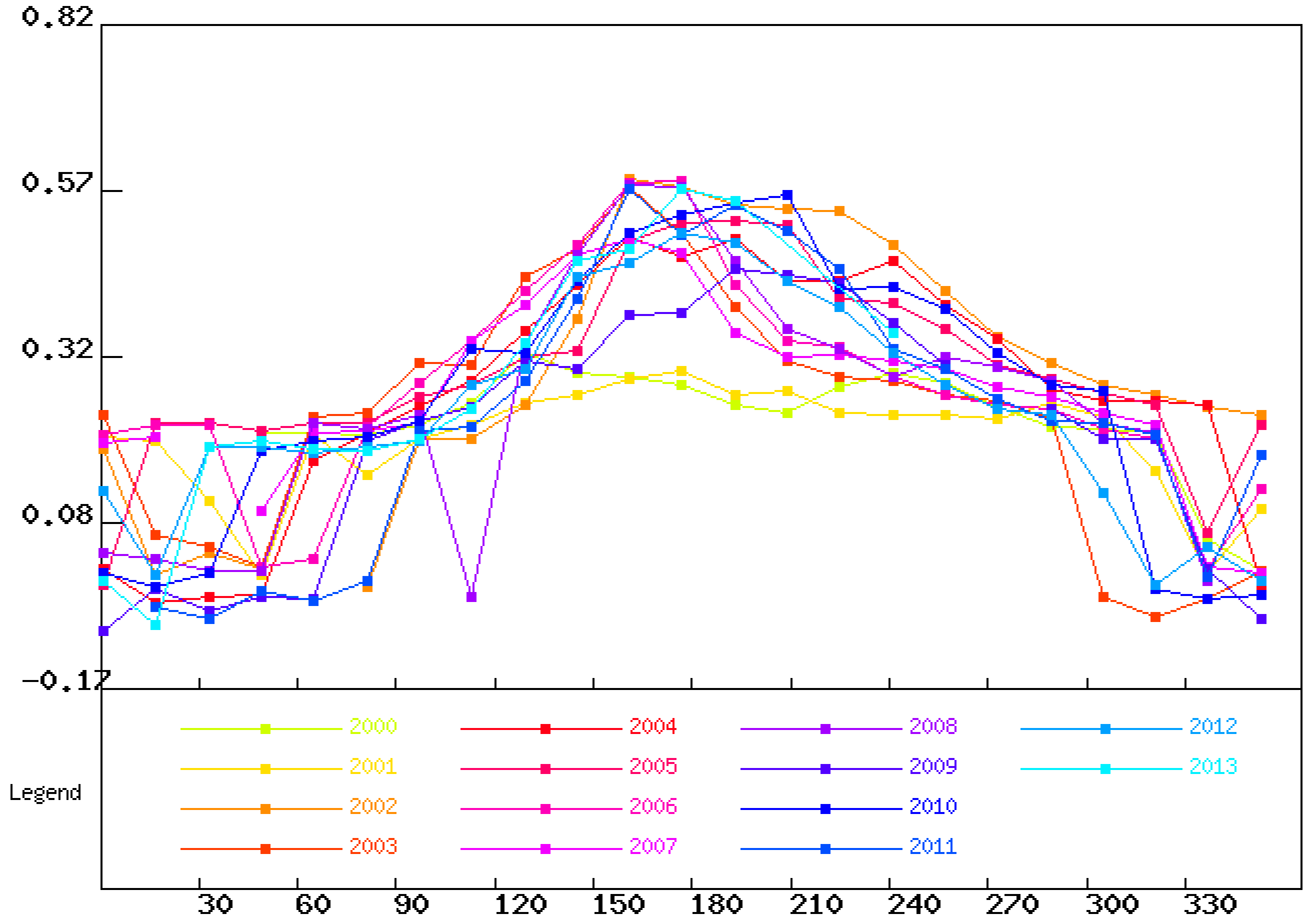

Figure 2. Chart courtesy of ORNL. The X axis is the julian/ordinal day/day of the year. The Y axis is the NDVI value. Each color represents a different year. Each point represents the most recent available cloud-free pixel within a 16-day period. This data came from a natural grassland site near Medicine Hat, Alberta. The values follow a similar pattern each year, with the exception of 2000 and 2001 which were drought years. In 2008 there was a late spring snow fall. Winter values alternate between cured grass (around 0.2) and snow (around 0). Summer values increase as the new green grass grows through and over the previous year's dead grass, and then decrease as the grass cures.

Examination of this and many other NDVI time series charts provided background and context for selecting a model to derive curing from NDVI. We tried to get actual ground-based curing observations, but these were essentially unavailable. Alberta and BC have some data, but not in a usable format, and anyway not available for this project. Nevertheless, the NDVI data seemed to provide a clear picture of what was happening at each site. For example, this site in Ontario appeared from a recent land cover map to be grassland, but the time series below (figure 3) shows that it was a coniferous stand that burned in 2011. Because it is coniferous, it lacks the spring and fall "shoulders" that are common in deciduous and grassland sites. Note that after the fire, both the summer and winter NDVI values are much lower. Also note that over the two years following the fire, the site is recovering and the greenness increases each year.

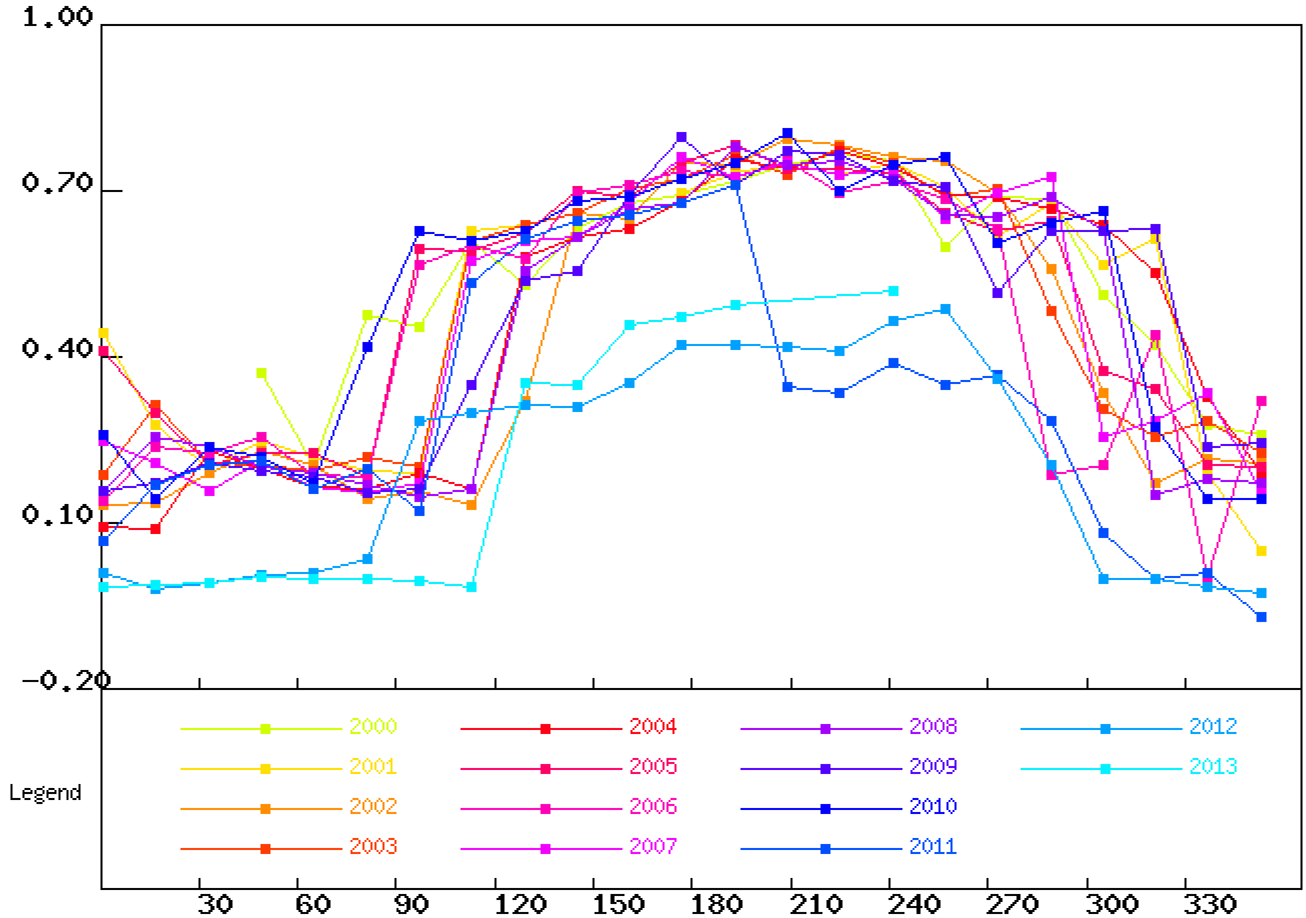

Figure 3. Chart courtesy of ORNL. NDVI from a coniferous forested site that burned in 2011.

For the CWFIS in 2014 we used an Australian formula (Newnham et al. 2010) to derive grass curing from NDVI values.

$$GC = 124.71 - 121.4 \times NDVI \qquad \text{(Equation 1)}$$

This formula seemed to fit the NDVI observations well. We downloaded MODIS NDVI for all of Canada from the USGS (250m resolution). A new set of NDVI tiles is available every 8 days, each based on a 16-day composite. There are two MODIS satellites, Aqua and Terra, imagery from which is used alternately to provide composites every 8 days. Within each composite, the most recent cloud-free pixel is used.

However, Newnham et al. recommended another formula, one that included historical maximum and minimum NDVI values. It therefore took into account the degree of vegetation coverage, as well as the type of vegetation. That formula didn't work well in Canada, primarily because the minimum NDVI in Canada is much lower due to snow cover.

We therefore assumed a minimum NDVI of 0.2 and came up with this formula, which we started using in 2015.

$$\% \text{ curing} = (1 - (NDVI - 0.2) / (MaxNDVI - 0.2)) * 100\% \qquad \text{(Equation 2)}$$

in which the maximum NDVI for each pixel was determined from 5 years of MODIS NDVI values (Kross et al. 2011). The assumptions here are that the maximum NDVI over the last 5 years represents 0% cured, or fully green, grass, while an NDVI of 0.2 indicates 100% cured (dry) grass. The grass curing varies linearly with the NDVI between these values. This switch to a site-relative formula addresses the problem with sparse grass never appearing fully green under the previous formula.

For the CWFIS FWI and FBP maps, we mask out snow-covered areas. But just in case there's an area that's covered in snow and we don't know about it, I didn't want to leave the curing at 100% because then we would show high ROS values where they should actually be 0. So, at very low NDVI values the curing is set to 0, not because the grass is green but because we want the ROS to be 0.

Also in 2015, we began using a combination of observed and modelled NDVI values. The modelled values were derived using a weather-based model developed by Dan Thompson. The idea was to bridge the gap between satellite observation date and current date, which can be as much as 23 days. A 23-day gap would result when the value in the composite is from the first day of the 16 days, and the current day is day 7 after the composite was produced, i.e. the day before a new composite is produced. (The new composite is available one day after the 16th day.)

The model was developed using the 14-year NDVI time series from 45 plots across Canada, along with the corresponding historical weather and Fire Weather Index (FWI) data.

The model uses 64-day average temperature (T64) and 16-day total precipitation (PCP16) in the spring, and 16-day average RH (RH16), 16-day average temperature (T16), and 64-day total precipitation (PCP64) in the fall, to estimate current NDVI (equations 3 and 4). Here "spring" consists of all days before July 19, and "fall" is on or after July 19. Many other variables were tested for inclusion in the model, including PCP32, T32, growing degree-days above 10°C, freezing degree-days, BUI16, DMC16, elevation, latitude, longitude, and grassland/cropland composition.

The previous (16-day-old) NDVI value was also tested as an input, but wasn't significant. This implies that after 16 days, the previous NDVI should no longer be used to estimate the current NDVI. The final equations are:

$$\text{Spring: } NDVI2K = 1104.4 + 189.8(T64) + 7.5(PCP16) \qquad \text{(Equation 3)}$$

$$\text{Fall: } NDVI2K = -4214.3 + 203.6(T16) + 4.5(PCP64) + 63.8(RH16) \qquad \text{(Equation 4)}$$

where

$$NDVI2K = (NDVI * 10000) - 2000$$

The observed and modelled NDVI values are therefore combined as follows:

$$current\_NDVI = NDVI\_obs * (1 - mod\_weight) + NDVI\_mod * mod\_weight \qquad \text{(Equation 5)}$$

where

$$mod\_weight = days\_old / 16$$

where days_old is the number of days since observation, up to a maximum of 16. The number of days since observation can be determined because the observation date for each pixel is included with the NDVI composite.

The final NDVI is not allowed to be below the observed NDVI in the spring, or above the observed NDVI in the fall.

The final NDVI is used to estimate the grass curing for each pixel using equation 2, producing a daily grass curing map which is used by the CWFIS to predict spread rate and fire intensity in grasslands and croplands according to the FBP system.

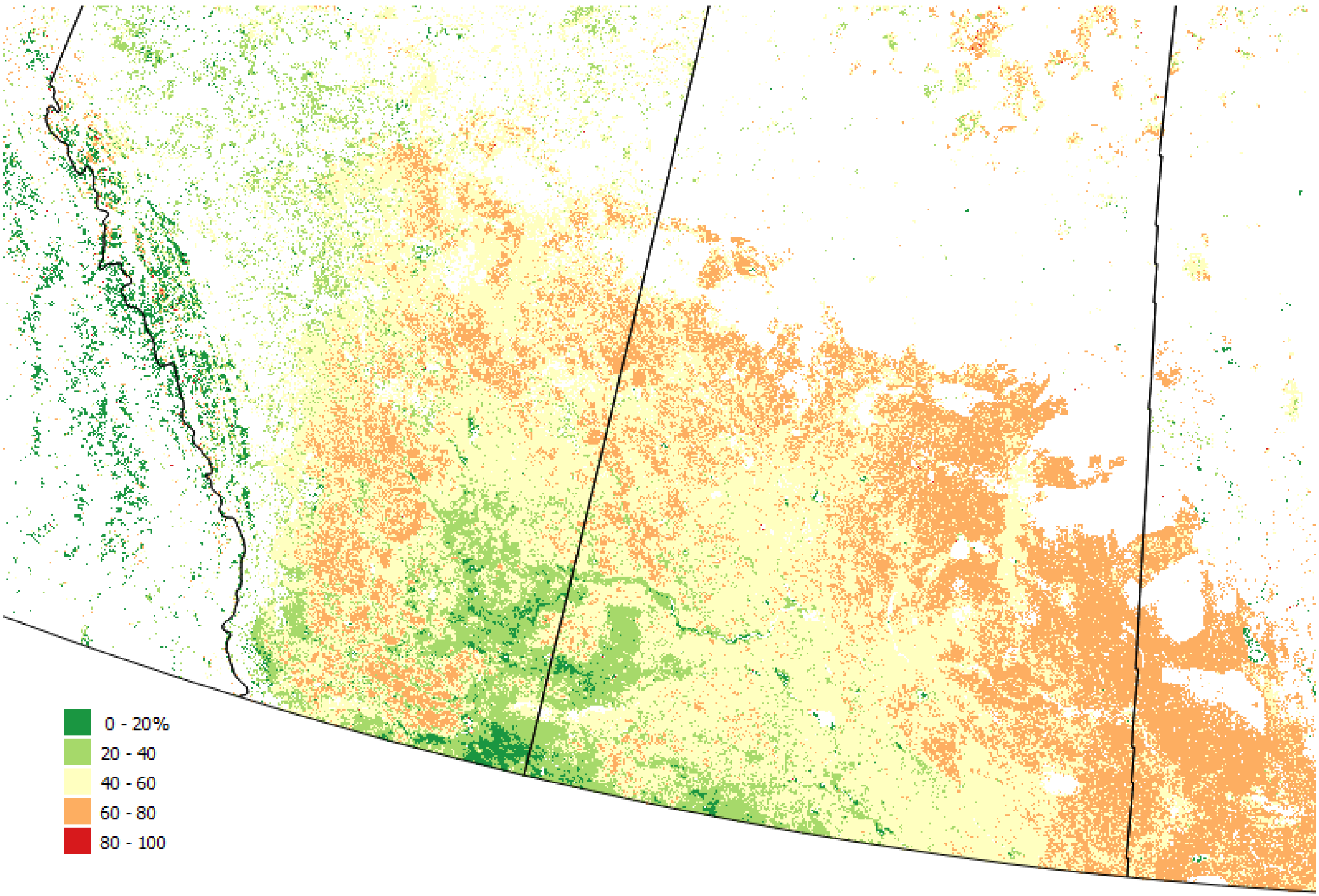

Figure 4. Percent curing in grassland, cropland, and alpine areas on May 15, 2016 in southern BC, Alberta, Saskatchewan, and Manitoba. Alpine areas have low values not because they are green, but because they are snow-covered and set to zero.

Greenup (leafout)

A similar process is used to produce greenup maps indicating the phenological state of deciduous and mixedwood stands. Again, in the absence of ground-based observations, NDVI time series plots were examined to determine whether the NDVI values contain enough information to provide a reasonable estimate of greenness. NDVI has been used successfully to estimate greenness in deciduous stands (Beaubien & Hall-Beyer 2003, Li et al. 2010, Kross et al. 2011).

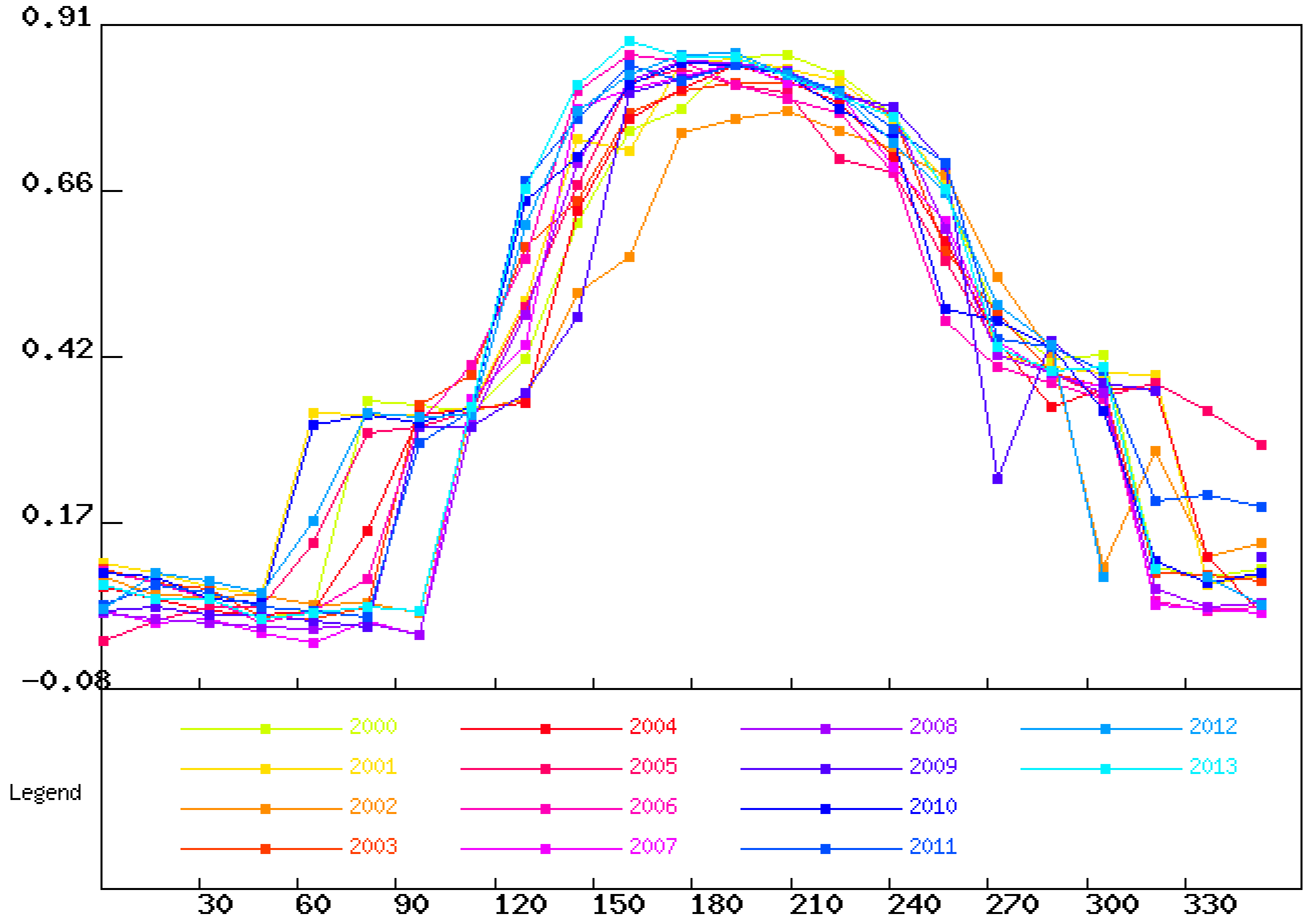

Figure 5. Chart courtesy of ORNL. NDVI time series for a deciduous stand in western Saskatchewan.

As suggested in Kross et al (2011), a very simple formula is used. Greenup (leafout) is assumed to have occurred when the NDVI reaches 70% of its 5-year maximum. Maximum NDVI was determined using MODIS NDVI data obtained from the US Geological Survey (USGS 2014). Leaf fall is assumed to have occurred when the NDVI drops below 70% of the maximum. The greenup map indicates either leafless or green; no intermediate states are considered. The CWFIS uses this map to distinguish between D-1 (leafless aspen) and D-2 (leafed out aspen), and between M1 (leafless mixedwood) and M-2 (green mixedwood). In both cases, spread rates (and fuel consumption) and therefore fire intensity are much reduced in green stands. D-2 is not an official FBP System fuel type, as leafed-out deciduous stands rarely burn. However, they do burn under extreme conditions (Alexander 2010).

Dan Thompson has developed a weather-based model for greenup based on 25 deciduous stands (figure 6).

Spring: NDVI2K = 2636.8 + 204.7(T64) – 1.96(GDD10) + 10.3(RH16) (Equation 6)

Fall: NDVI2K = 5891.5 + 202.0(T32) – 1.44(GDD10) -1.41(DC16) – 50.1(LAT) (Equation 7)

where

NDVI2K = (NDVI * 10000) - 2000
T32 = 32-day average temperature
T64 = 64-day average temperature
GDD10 = growing degree-days over 10°C
DC16 = 16-day average Drought Code
LAT = latitude

Figure 6. Deciduous test/data sites.

As with the curing model, this model estimates NDVI, which is then used to predict greenup. This model was implemented in the CWFIS starting in 2016, using the same modelled/observed weighting approach (equation 5).

The model was developed using data from pure deciduous stands. However, it is also applied to mixedwood stands. Depending on their coniferous content, mixedwood stands reach the 70% of maximum threshold sooner than pure deciduous stands. This discrepancy remains unaddressed at this time.

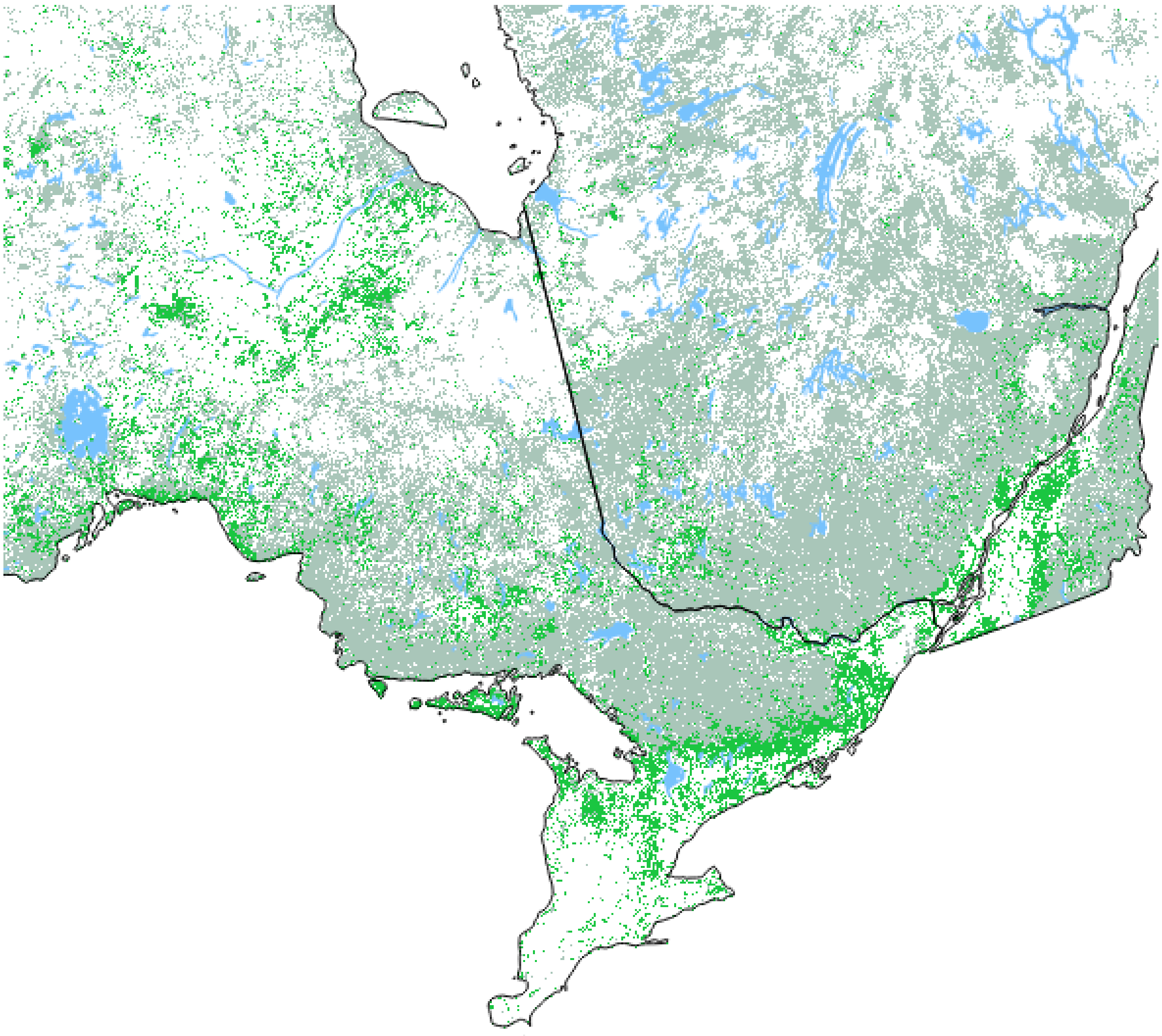

Figure 7. Greenup (leafout) in deciduous and mixedwood, May 15, 2016, for part of southern Ontario and Quebec. Green indicates leafed out; gray indicates leafless; white indicates other land cover types; blue is water.

The daily curing and greenup maps are both intended to improve the accuracy of the CWFIS FBP maps, in order to provide the best information to the public, fire managers, and fire researchers, and GIS junkies.

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