A REMOTE SENSING BASED SYSTEM TO PREDICT EARLY SPRING PHENOLOGY OVER BOREAL FOREST

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ABSTRACT:

"Snow gone" (SGN) stage is one of the spring phenological variables over the forested regions as it influences various forestry related activities. The objective here is to evaluate the potential of two MODIS-based indices in determining the SGN stage over the 5 forest-dominant natural subregions in the Canadian Province of Alberta for the period 2006-08. The indices of interest were normalized difference water index using shortwave infrared (SWIR) spectral band centred at 1.64 µm ($NDWI_{1.64µm}$) and 2.13 µm ($NDWI_{2.13µm}$); and were calculated at 8-day intervals with resolution of 500 m using MODIS-based composites of surface reflectance data. Temporal trends were generated by averaging the results of these indices over each of the natural subregions. In a similar way, we also calculated the average SGN days using ground-based lookout tower data obtained from the Department of Alberta Sustainable Resource Development. We then compared these ground-based average SGN days with the temporal trends of the both indices. The predictions from $NDWI_{1.64µm}$ were found in the range of 0 to +3 periods (i.e., 0 to +24 days); on the other hand $NDWI_{2.13µm}$ were found in the range of ±1 period or ±8 days in comparison to the ground-based SGN stages.

1. INTRODUCTION

The knowledge about early spring phenology over forested regions plays a critical role in understanding of the forest related activities, such as tree growth dynamics, carbon sequestration, forest fire, and many more (Linkosalo *et al*., 2006; Westerling *et al*., 2006; Richardson *et al*., 2009). The focus here is to understand the spring phenological event of snow gone stage (SGN: defined as the date when 25% or less of the surrounding area is covered by snow; Anonymous, 1999) over the boreal forested regions in the Canadian Province of Alberta. At present, there is an existing network of about 130 lookout towers, which are used to monitor our variable of interest among others. However, this dataset is point-specific and fails to capture the spatial variability. This limitation potentially could be addressed by using remote sensing-based techniques, as it has been a proven tool to delineate the spatial variability over forested regions (Hassan *et al*., 2006; Hassan and Bourque, 2010).

Among various remote sensing-based indices, the normalized difference wetness index [NDWI: a function of near infrared (NIR) and short wave infrared (SWIR); (Gao, 1996)] has shown relatively better significance in understanding various vegetation phenological stages (Picard *et al.* 2005; Delbart *et al.*, 2008). In literature, it is found that three different SWIR spectral bands are used in the calculations of NDWI. Those include: (i) 1.24 µm (Gao, 1996), (ii) 1.64 µm (Wilson and Sader, 2002; Frenshholt and Sandholt, 2003; Yilmaz, 2008), and (iii) 2.13 µm (Chen *et al.*, 2005; Gu *et al.*, 2007; Yi *et al.*, 2008).

In this paper, our objectives are: *(i)* calculating two indices of $NDWI_{1.64µm}$ and $NDWI_{2.13µm}$ using MODIS data for the period 2006-08 at 8-day intervals with 500 m resolution; *(ii)* averaging the indices of interest over each of the 5 forest-dominant natural subregions (as shown in Figure 1 with * mark beside the legend), and generating the temporal trends; *(iii)* calculating natural subregion-specific average SGN day over the natural subregions of interest; and *(iv)* comparing the MODIS-based indices with the SGN ground-based observations from lookout tower sites located across the natural subregions of interest (as shown in the Figure 1 with black hollow circles).

2. METHODS

2.1 General description of study area and data requirement

The Province of Alberta lies in between 49-60 ^{o}N latitude and 110-120 ^{o}W longitude. It experiences a continental climate; which is relatively humid climate, with cold winters and moderately warm summers. The range of mean annual temperature is from -3.6°C to 4.4°C; while the range of summer mean temperatures is from 8.7 °C to 18.5 °C, whereas the range of winter mean temperatures is from -25.1°C to -9.6°C (*Natural Regions Committee*, 2006). The average annual precipitation ranges between 333-989 mm (*Natural Regions Committee*, 2006). The Province is divided into 21 natural subregions on the basis of climatic variables, soil formation and type, topography,

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and vegetation (*Natural Regions Committee*, 2006). Out of 21, the 5 forest-dominant natural subregions have been considered, that occupy about 46% of the total land area in the province (see Figure 1 and Table 1 for greater details).

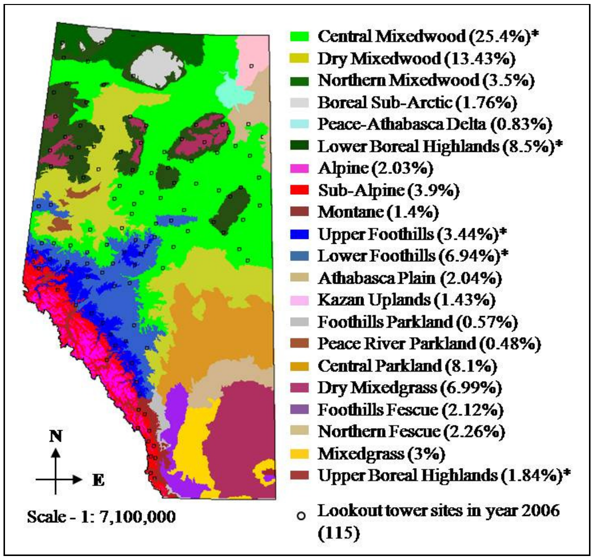

Figure 1. Study area, the Province of Alberta, showing 21 natural subregions. The locations of the "lookout towers" are also shown (black hollow circles). The forest-dominant subregions over which MODIS based NDWI were evaluated are marked with *.

In this study, we used MODIS-based 8-day composite surface reflectance data with a spatial resolution of 500 m for the period 2006-08 freely available from NASA. These data were used to calculate MODIS-based NDWI's as discussed in the next sub-section. We also acquired SGN observations made at ground level from the lookout tower sites from forest-dominant natural subregions of interest during the period 2006-08.

2.2 Data Processing

We re-projected the obtained surface reflectance images from SIN format into UTM Zone 12 NAD 83 projection system. The MODIS-based $NDWI_{1.64\mu m}$ (Wilson and Sader, 2002) and $NDWI_{2.13\mu m}$ (Chen *et al.*, 2005) were then computed using the following equations:

$$NDWI_{1.64\mu m} = \frac{\rho_{NIR} - \rho_{SWIR\text{ at }1.64\mu m}}{\rho_{NIR} + \rho_{SWIR\text{ at }1.64\mu m}} \quad (1)$$

$$NDWI_{2.13\mu m} = \frac{\rho_{NIR} - \rho_{SWIR\text{ at }2.13\mu m}}{\rho_{NIR} + \rho_{SWIR\text{ at }2.13\mu m}} \quad (2)$$

Where ρ is the surface reflectance for the spectral band in the suffix.

Natural subregion	Area (1000 Km^2)	Mean annual Temp. (°C)	Mean annual precip. (mm)	Dominant vegetation	No. of towers*
Central Mixed-wood	168	0.2	478	Deciduous leading mixed-wood	24
Lower Boreal High-lands	55.6	-1.0	495	Early to mid-seral, pure or mixed forests hybrids	21
Upper Boreal High-lands	11.85	-1.5	535	Conifer dominated	11
Upper Foothills	21.54	1.3	632	Conifer dominated	15
Lower Foothills	44.90	1.8	588	Conifer leading mixed wood	15

*N.B. These numbers are representing the operational ones in 2006.

Table 1. Description of 5 forested natural subregions (modified after *Natural Regions Committee*, 2006) over which potential of both NDWI were evaluated.

We then calculated regional-average for both indices over each of the 5 forest-dominant natural subregions. We calculated natural subregion-specific average SGN day for the year of interest by averaging the data from all the lookout towers within the subregion. We assumed that the natural subregion-specific average SGN would be representative for the region of interest. In order to compare the SGN day with MODIS-based indices, we transformed these days into respective 8 day period of the year in which the observed day was falling.

3. RESULTS AND DISCUSSION

We analyzed temporal trends for both of the indices that were averaged over each of the natural subregions for the period 2006-2008 at each 8 day intervals. Examples of such trends over the natural subregions of *central mixedwood* and *lower foothills* are illustrated in Figures 2-3 as a function of day of year (DOY).

The NDWI values maintained a high platform during the winter in the year beginning (between 1 to 73 DOY). The values then started to decrease (around 81 DOY). This decrease might be associated with the snow melt, as the melting away snow causes a decrease in the moisture content of the canopy (Delbart *et al.*, 2005; Delbart *et al.*, 2006). NDWI were observed to reach to a minimum value or a platform (about 109 to 135 DOY); and then started to increase again. The similar trends were also observed by others (Delbart *et al.*, 2005; Delbart *et al.*, 2006).

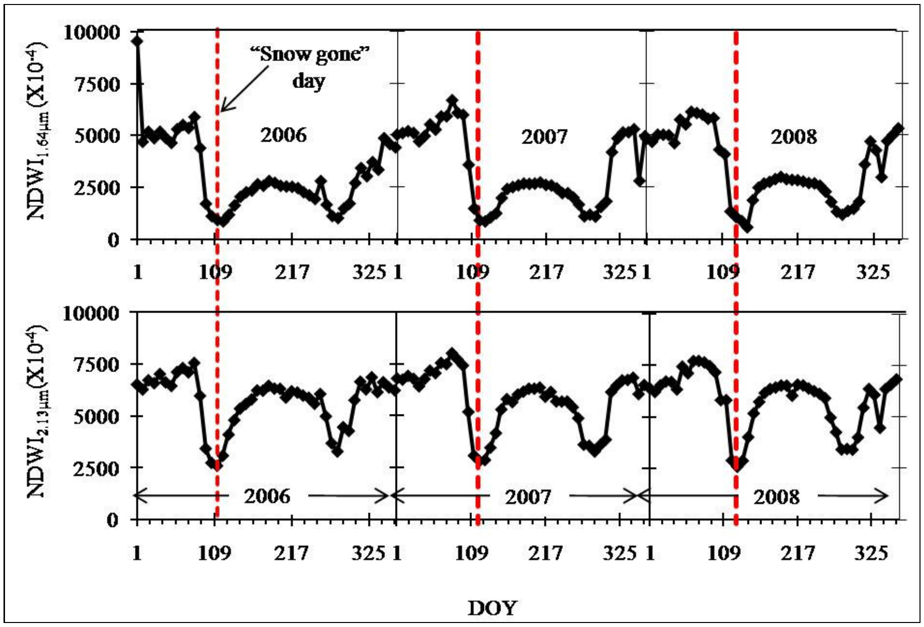

Figure 2. Temporal trends of regional-averaged values of $NDWI_{1.64\mu m}$ and $NDWI_{2.13\mu m}$ for the natural subregion of *central mixedwood* (i.e., occupies ~25.5% of the province, see Figure 1) for period of 2006-08. The ground-based observations of SGN periods for the same region are also shown by dotted line running vertically.

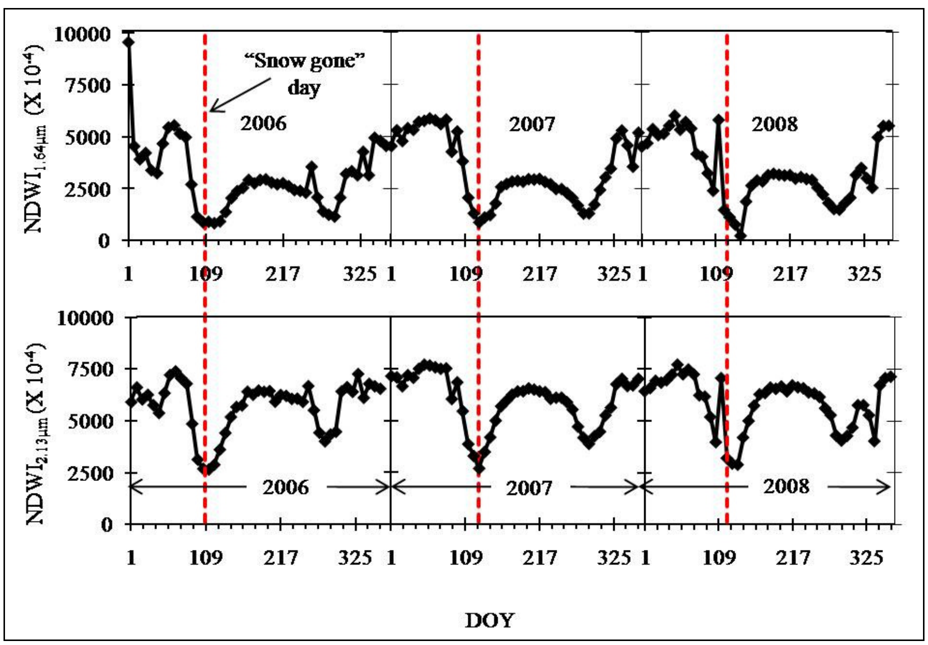

Figure 3. Temporal trends of regional-averaged values of $NDWI_{1.64\mu m}$ and $NDWI_{2.13\mu m}$ for the natural subregion of *lower foothills* (i.e., occupies ~6.9% of the province, see Figure 1) for period of 2006-08. The ground-based observations of SGN periods for the same region are also shown by dotted line running vertically

The rises in NDWI trends might be associated with greening up (Delbart *et al.*, 2005; Delbart *et al.*, 2006). As NDWI depicts the snow melting and greening up in opposite directions; the minimum values of NDWI might be considered as corresponding SGN stage (or onset of the growing season as well).

Due to the fact that both of the NDWI's showed distinct temporal pattern (i.e., the lowest values found in the early spring as shown as Figures 2-3) with the ground-based SGN periods, we opted to analyze it further by assuming that these values were the period of SGN. As such, Figures 4-5 shows the comparison between SGN periods measured at ground and also determined using both $NDWI_{1.64\mu m}$ and $NWDI_{2.13\mu m}$. It revealed that the deviation was in the range of 0 to +3 periods (i.e., 0 to +24 days) in case of $NDWI_{1.64\mu m}$-based calculations; and ±1 period (i.e., ±8 days) in case of $NDWI_{2.13\mu m}$-based calculations. The negative and positive deviations mean the early and delayed predictions respectively with compare to the ground observations.

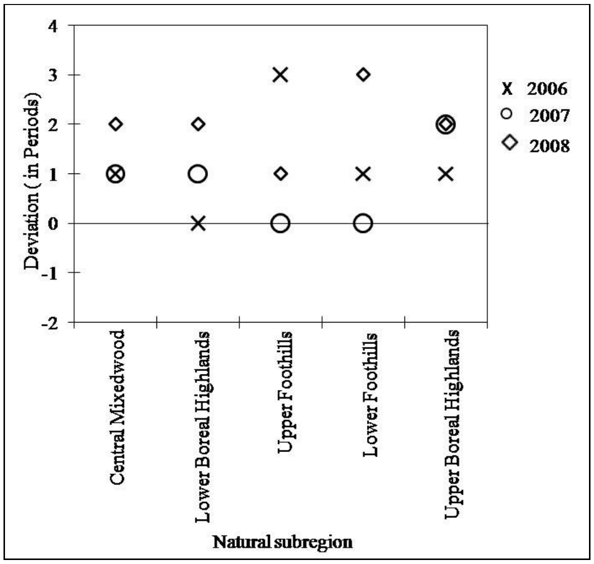

Figure 4. Comparison between the ground-based observations of SGN period and $NWDI_{1.64\mu m}$-based SGN period. The negative and positive deviation corresponds to the early and delayed prediction respectively.

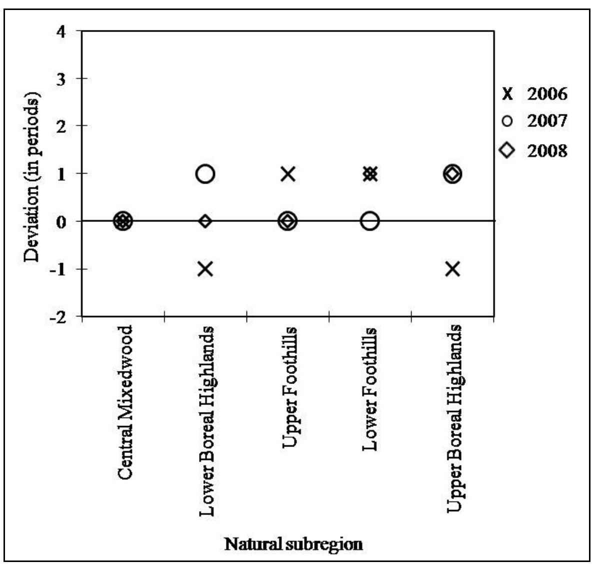

Figure 5. Comparison between the ground-based observations of SGN period and $NWDI_{2.13\mu m}$-based SGN period. The negative and positive deviation corresponds to the early and delayed prediction respectively.

4. CONCLUDING REMARKS

In this paper we evaluated the potential of two MODIS-based indices (i.e., $NDWI_{1.64\mu m}$ and $NDWI_{2.13\mu m}$) in determining SGN stages over the 5 forest-dominant natural subregions of Alberta for the period 2006-08. Temporal dynamics of the natural subregion-specific values of the indices were compared with the similar ground-based SGN data. Our analysis revealed that the best performances were observed by use of $NDWI_{2.13\mu m}$.

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