Use of optical, thermal infrared and radar remote sensing for monitoring fuel moisture conditions

B. Leblon, K. Abbott, L. Gallant & G. Strickland
Faculty of Forestry and Environment Management, University of New Brunswick, Canada
bleblon@unb.ca or Brigitte.leblon@agrorennes.educagri.fr

M. Alexander
Northern Forestry Complex, Canadian Forest Service, Edmonton, Canada

Keywords: optical, thermal infrared, radar, fuel moisture, NOAA-AVHRR, ERS-1, RADARSAT-1

ABSTRACT: Our study presents results acquired over boreal coniferous forests located in the Mackenzie River basin, Northwest Territories, Canada. NOAA-AVHRR optical and thermal infrared images and SAR images from ERS-1 and RADARSAT were correlated to the Canadian Forest Fire Danger Rating System (CFFDRS) Fire Weather Index (FWI) codes and indices, which were used here as a surrogate of fuel moisture. Results showed that FWI codes and indices were related to optical and thermal infrared NOAA-AVHRR data or SAR data, but the relationship was more or less strong with either fast-drying fuel codes or slow-drying fuel codes and indices, depending on the case The study suggests that the most promising use of satellite images for fire danger monitoring is through the combination of optical and thermal infrared images to radar images.

1. INTRODUCTION

As reviewed in Leblon (2001, 2003), fuel moisture studies using remote sensing have been primarily used indices derived from NOAA-AVHRR NDVI images like the relative greenness (RG) (e.g., Burgan et al; 1998). Leblon (2001, 2003) also listed several problems related to the use of NDVI images in fuel moisture mapping, namely the saturation of relationships, the influence of site wetness on relationships and the difficulty of using NDVI over forests, due to the spectral mixture of the overstory with the understory, both being different in nature and in moisture content. In fact, NDVI and associated vegetation indices are only indirectly related to fuel moisture, because it rather measures the greenness and the chlorophylleous activity of the vegetation. Thermal infrared data are more related to moisture variables, since surface temperatures (T_s) increase with droughtness levels (e.g., Pierce et al., 1990). NOAA-AVHRR surface temperature data were correlated to fuel moisture variables (e.g., Dominguez et al., 1994; Chuvieco et al., 1999; Strickland et al., 2001). Indices combining NDVI and thermal infrared NOAA-AVHRR images, like the Vegetation and Temperature Condition Index (VT) of Kogan (2001) and the index of Chuvieco et al. (2001), were also proposed. The one primary disadvantage of the optical or thermal infrared-derived information is that coverage is restricted to cloud-free conditions, a limitation that can be overcome using data acquired by active microwave sensors, like those onboard the ERS and RADARSAT satellites. For northern Alaskan boreal forests, Canadian Forest Fire Danger Rating System (CFFDRS) Fire Weather Index (FWI) codes and indices, which were used as a surrogate of fuel moisture, were correlated to σ^o derived from SAR images (Bourgeau-Chavez et al. 1999, 2001).

Our study presents results gathered over northern boreal coniferous forests located in the Mackenzie River basin, Northwest Territories, Canada. NOAA-AVHRR optical and thermal infrared images and SAR images from ERS-1 and RADARSAT were correlated to the CFFDRS FWI codes and indices, which were used here as a surrogate of fuel moisture. Details of the study on NOAA-AVHRR images can be found in Leblon et al. (2001) and in Strickland et al (2001). The one on RADARSAT images is detailed in Abbott et al. (2002) and on ERS-1, in Leblon et al. (2002).

2. MATERIALS AND METHODS

NOAA-AVHRR optical and thermal infrared images and ERS-1 SAR images were acquired during the 1994 fire season over 18 stands of jack pine, black spruce and white spruce distributed among 6 sites located in the Mackenzie River basin, Northwest Territories, Canada (57°36' Lat. N. to 71°27' Lat. N. and 110°39' Long. W to 135°18' Long. W). NOAA-11 AVHRR images consisted of NDVI and surface temperature (T_s) images acquired, from snowmelt to snowfall. The time of acquisition was between 22 and 24 UT, which means that the corresponding local time was afternoon. Each image has a ground spatial resolution of 1 km and was georeferenced to a Lambert conic conformal projection. They were corrected for radiometric and atmospheric effects following the method described in Strickland *et al.* (2001). On each corrected image, a 3-by-3 pixel window was extracted for each stand based on its geographical coordinates and mean NDVI and T_s values were computed. They were used as follows: (i) estimation of NDVI for cloudy days using polynomial interpolations and computation of the accumulated NDVI over the fire season (ΣNDVI) and (ii) estimation of daily ratios between actual and potential evapotranspiration (AET/PET) following the method of Vidal et al. (1994) developed for Mediterranean forests. In the method, AET is calculated from T_s-T_a, through an analytical model derived from the energy budget equation, while PET is calculated by the Penman-Monteith equation. In both AET and PET computations, NDVI is used to account for the effect of ground cover on some model parameters.

The second spectral data set acquired over the 18 stands consisted of twenty-two ERS-1 SAR images which have a nominal ground resolution of 30 m. Only daytime ERS-1 SAR images (descending orbit) were considered because they were acquired closed to the time of FWI indices estimation. SAR images were georeferenced and radar backscatters (σ^o) were extracted to compute mean backscatters of each stand. In this study, data from Alaska sites were also used (see Bourgeau-Chavez *et al.* 1999). In addition to these 1994 data sets, the study used 11 descending orbit RADARSAT-1 SAR images acquired in 2000 over black spruce and jack pine forests located at the International Crown Fire Modelling Experiment (ICFME) site, Northwest Territories (61°35'Lat.N., 117°10'Long.W). The images were acquired almost daily, over a 15 day period in June 2000, between 6h30 and 7h45 am (LST), but at different incidence angles and different spatial resolutions. For both SAR image types, selected sites were ideal, because they do not have significant topography which may affect radar backscatter. Fuel moisture conditions were assessed through the FWI codes and indices. They were computed using the WeatherPro™ package of Remsoft Inc. based on the CFFDRS equations from weather stations records located close to the stands.

3. RESULTS

3.1 Optical images

The correlation between NDVI or ΣNDVI and FWI codes and indices was positive, and was better with CFFDRS variables corresponding to slow-drying fuels, like the duff moisture code (DMC), the drought code (DC) (Fig. 1) and the buildup index (BUI), than to CFFDRS variables related to fast-drying fuels, like the fine fuel moisture code (FFMC) and the fire weather index (FWI)). Strong correlations have previously been observed with DC, but they were negative, because NDVI data were acquired not only on forests, but also on grasslands, for which drought reduces vegetation greenness and thus NDVI, while in the same time, it increases FWI variables. In our case, NDVI images were acquired solely on coniferous stands, for which NDVI increases until mid-summer and then decreases, because of understory deciduous phenology. Thereby, the seasonal variation of NDVI did not reflect possible drought increasing throughout the season, as shown by the seasonal trends of FWI variables. These results suggest that red and near-infrared-based vegetation indices, like ΣNDVI, are better indicators of chlorophyll activity of vegetation rather than indicators of actual drought. For this reason, a better use of NDVI images over boreal forests in fire management will be to map timing of deciduous leaf flushing, which is critical for fires in mixed deciduous-boreal forests.

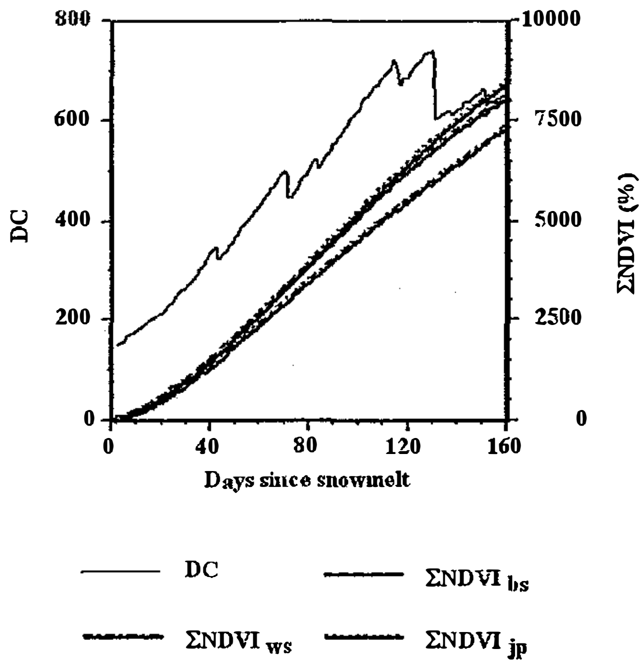

Figure 1. An example of seasonal variation for DC and ΣNDVI for the three stands of Hay River (bs: black spruce, ws: white spruce and jp: jack pine) (after Leblon et al. 2001)

3.2 Thermal infrared images

Thermal infrared AVHRR bands are possible better drought indicators than the red and near-infrared ones, because the difference between surface and air temperatures (T_s-T_a) is analytically related to AET. Because a better indicator of drought levels and thus of fire potentials is the ratio between actual and potential evapotranspiration (AET/PET), correlations between AET/PET and each FWI code and index were computed for each stand, each species, each site and for all the cases. FFMC and FWI were most correlated with AET/PET, except in the northern site, where DC, DMC, and BUI were the most correlated. The difference at this site may be related to the sparser and shorter forest canopy occurring at this site, which makes satellite signals sensitive not only to the surface level, but also to the forest floor level. To define a fire danger index based on the AET/PET ratio, AET/PET values were categorized into classes ranging from 0.0 to 1.0 by steps of 0.1. For each class of AET/PET, a mean value for each FWI index and code was estimated. These categorized ratios were plotted against mean FWI index or code. AET/PET was well related to FWI in most of the sites, but it was related to fast-drying fuel codes or to slow-drying fuel codes and indices, depending on the site. A negative trend was also found when pooling all the mean values for the different sites (Fig. 2). However, there was some variability around the trend, which means that other fire danger factors should be considered, like the wind. Also, since AET/PET can be computed only under clear sky, the use of SAR images has also been investigated.

3.3 SAR images

Mean radar backscatters (σ^o) extracted from the ERS-1 images were first correlated to weather variables which was measured at the time of satellite overpasses over the study sites. σ^o exhibits a decreasing trend with increasing air temperatures, probably because high air temperatures induces plant water stress that can lower radar backscatter from the canopy. In each case, σ^o increases with the rainfall, as already shown in other studies. The good correlation σ^o and weather variables, which are used to compute the various FWI codes and indices, may expect that these indices and codes are also well related to σ^o. For each site, there was no systematic relationship between the FWI codes and observed radar backscatter, except in the site where the cumulative precipitation before image acquisition was the highest. When one examines correlation coefficients when specific forest types are considered across all regions, some significant patterns do emerge. Within black spruce stands, there does appear to be statistically significant negative correlations between radar backscatter and DMC, DC (Fig. 3), and BUI. Indeed, northern boreal black spruce stands have open canopies, with much of the ground layer exposed to the incoming microwave radiation. Therefore, variations in the moisture conditions of the ground layer (DC and DMC) would be expected to alter the amount of energy scattered from these surfaces. A significant negative correlation was also found with FFMC for the white spruce stands and with FWI for the jack pine stands. A similar trend was observed over the ICFME site with the RADARSAT-1 images (Abbott et al. 2002).

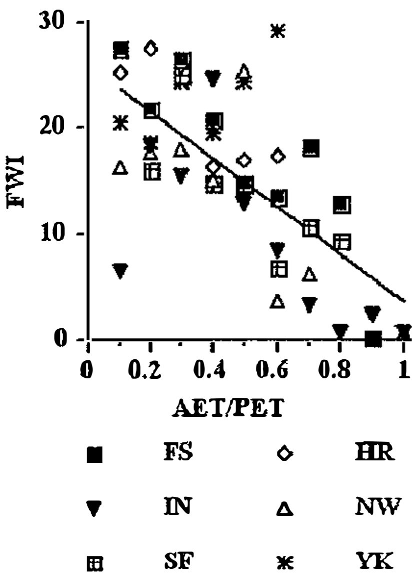

Figure 2. Relationships between the AET/PET ratio and FWI for all the sites together. Each site is marked by a different symbol. The trend is indicated by a solid line (after Strickland et al. 2001)

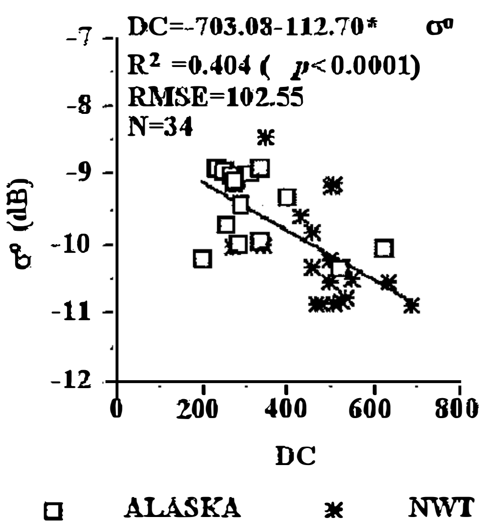

Figure 3. Relationship between σ^O and slow-drying fuel moisture (DC) for the black spruce stands located both in Alaska and in Northwest Territories. Data from Alaska stands are from Bourgeau-Chavez *et al.* (1999). Data from Northwest Territories stands are from Leblon *et al.* (2002).

4. CONCLUSIONS

Our study over northern boreal forests showed that FWI codes and indices were correlated to optical and thermal infrared NOAA-AVHRR images or SAR images, but the relationship was more or less strong with either fast-drying fuel codes (FFMC) or slow-drying fuel codes and indices (DMC, DC and BUI), depending on the case. Because of the inherent operational limitations of each kind of images (image availability due to either poor weather conditions or long revisiting periods), the study suggests that the most promising use of satellite images for fire danger monitoring is through the combination of optical and thermal infrared images to radar images, the first kind of images being acquired by the same satellite in the same time, whereas the second kind can be seen as a complementary data source.

5. REFERENCES

Abbott, K., Leblon, B., Staples, G., Alexander, M.E., & MacLean, D. 2002. Use of RADARSAT-1 images to map forest fuel moisture over boreal forests. 24th Canadian Remote Sensing Symposium, Toronto,Canada, June 2002.

Bourgeau-Chavez, L.L., Kasischke, E.S., & Rutherford, M.D. 1999. Evaluation of ERS SAR data for prediction of fire danger in a boreal region. International Journal of Wildland Fire 9(3): 183-194.

Bourgeau-Chavez, L. L., Brunzell,S., Nolan, M., & Hyer, Ed.: 2001. Analysis of SAR data for fire danger prediction in boreal Alaska. Final Report, ASF-IARC Grant NAS-98-129, 59 pages.

Burgan, R.E., Klaver, R. W., & Klaver, J.M. 1998. Fuel models and fire potential from satellite and surface observations. International Journal of Wildland Fire 8(3): 159-170.

Chuvieco, E., Aguado, I., Cocero, D. & Riaño, D. 2001, Design of an empirical index to estimate fuel moisture content from NOAA-AVHRR analysis in forest fire danger studies, 3rd International Workshop of the European Association of Remote Sensing Laboratories (EARSel) on Remote Sensing and GIS applications to Forest Fire Management, Paris, France, pp. 36-39.

Kogan, F.N. 2001. Operational space technology for global vegetation assessment. Bulletin of the American Meteorological Society 82(9): 1949-1964.

Leblon, B. 2001. Forest wildfire hazard monitoring using remote sensing. Remote Sensing Reviews 20(1): 1-43.

Leblon, B. 2003. Using remote sensing for fire danger monitoring Natural Hazards (in press)

Leblon, B., Chen, J., Alexander, M.E., & White, S. 2001. Fire danger monitoring using NOAA-AVHRR NDVI images in the case of northern boreal forests. International Journal of Remote Sensing 22(14): 2839-2846.

Leblon, B., Kaschike, E.S., Alexander, M.E., Doyle, M, & Abbott M. 2002. Fire danger monitoring using ERS-1 SAR images over northern boreal forests. Natural Hazards 27: 231-255.

Strickland, G, Leblon, B., Chen, J., & Alexander, M. 2001. A model to assess fire danger using NOAA-AVHRR images in the case of northern boreal forests, 23th Canadian Remote Sensing Symposium, Québec, Canada, August 2001, pp. 667-676.

Vidal, A., Pinglo, F., Durand, H., Devaux-Ros, C. & Maillet, A. 1994. Evaluation of a temporal fire risk index in Mediterranean forests from NOAA thermal IR. Remote Sensing of Environment 49: 296-303.

Leblon, B.; Oldford, S.; Abbott, K.; Strickland, G.; Gallant, L.; Alexander, M.E. 2003. Use of optical, therma infrared and radar remote sensing for monitoring fuel moisture conditions. Pages 33-37 *in* E. Chuvieco, P. Martin and C. Justice (eds.). Proc. 4th Interl. Workshop Remote Sensing and GIS Applications For. Fire Management: Innovate Concepts and Methods in Fire Danger Estimation (June 5-7, 2003, Ghent, Belgium). EARSeL, GOFC, Ghent Univ., Ghent, Belgium.