SURFACE ENERGY BALANCES OF CANADIAN BOREAL FORESTS FOLLOWING FIRE

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1. INTRODUCTION

In boreal forests, one of the most important stand-renewing events is fire. Fire results in drastic changes in the species composition and the ecosystem function of the forest. During the stages of succession that take place following fire, changes in surface characteristics will have significant impacts on the forest's surface energy and water budgets. Researchers have studied energy balances of boreal forests over short time periods and within the growing season (e.g., Amiro et al. 2005, Amiro et al. 2003, Chambers et al. 2005, Liu et al. 2005). This study examines the differences in the energy balance at three boreal forest sites in central Saskatchewan over a period of five years. Changes in the energy balance that take place with time following fire were examined.

2. MATERIALS AND METHODS

2.1 *Site Characteristics*

Three boreal forests in central Saskatchewan, Canada were selected for monitoring based on their relatively flat terrain, relative proximity to one another, and their age. The sites were located in close proximity so that they experience similar climate conditions. Fire occurred in 1977 (F77), 1989 (F89), and 1998 (F98). All three sites have Dystric brunisol soils with a sandy loam texture.

Tree species present at the sites include black spruce (*Picea mariana*), jack pine (*Pinus banksiana*), and trembling aspen (*Populus tremuloides*). More trembling aspen is present at F89 than at the other two sites. There are many standing dead trees at F98, whereas most dead trees have fallen at F77 and F89.

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2.2 *Energy Balance Measurements*

Triangular flux towers were erected at F89 and F98 in the spring of 2001. The heights of the towers were dependent on the canopy height at each site. In the summer of 2002, the 7.7 m tower at F98 was replaced with a 20 m scaffold tower. A 7.4 m tower was constructed at F77 in the spring of 2003. Instruments for all flux and most meteorological measurements were mounted at the top of the towers. A Kipp and Zonen CNR1 radiometer was used at all sites to measure net radiation (Rn). Sensible heat flux density (H) was calculated using temperature and wind measurements obtained from a CSAT3 sonic anemometer/thermometer. Latent heat flux density (LE) was calculated using eddy covariance measurements from an open-path LI7500 (LICOR, Lincoln, NE) infrared gas analyzer (IRGA) at all sites. Before August 2002, a closed-path LI6262 (LICOR) IRGA was used at F98. Thornthwaite (Model 610, Pittsgrove, NJ) soil heat flux plates were placed in the soil at a depth of 0.05 m to measure soil heat flux density (G). Three soil heat flux plates were installed at each site and soil heat storage above the plates was measured with thermocouples. Soil moisture, soil temperature, rainfall and snow depth were also measured. Data were recorded using a 23X data logger (Campbell Scientific Inc., Edmonton, Canada). Sites were powered using solar power and batteries.

2.3 *Data Filtering and Gap-filling*

Data were filtered using friction velocity (u_*) thresholds as filtering criteria. Data that were obtained under conditions with friction velocity values below the threshold were rejected. Data were also rejected if collected during precipitation events or if there was an instrument malfunction. . Friction velocity thresholds that were used were 0.3 m/s, 0.25 m/s, and 0.25 m/s at F77, F89 and F98 respectively. LE values obtained during the night were set to zero to calculate daily totals. Gaps covering less than four half-hour periods that occurred as a result of obviously wrong data or these filtering criteria were filled using interpolation. Larger gaps were filled using 48-point moving windows. For more gap-filling procedures, see Amiro et al. (2005).

3. RESULTS AND DISCUSSION

3.1 *Net Radiation*

Net radiation was highest at F89 for the years 2001 and 2002 (Fig.1). Rn at F89 then decreased in 2003 and 2004. Rn values for 2003 were approximately the same at all three sites, varying by less than 1 MJ/m^2/day. In 2004, net radiation was slightly higher at F77 than at F89 and F98, the latter of which were very similar. The Rn was higher at all sites in 2005 than in 2004. The decrease in Rn at the more mature sites is likely an indication of the drought that occurred during 2003. Drought conditions may have stressed the vegetation which caused the plant stomata to close in an effort to conserve water. The closure of the stomata would cause the plant surface to warm and would thus cause an increase in longwave radiation being emitted from the vegetation. By 2005, the increase in net radiation can likely be explained by the improvement in moisture conditions and cooler plant canopies during that year.

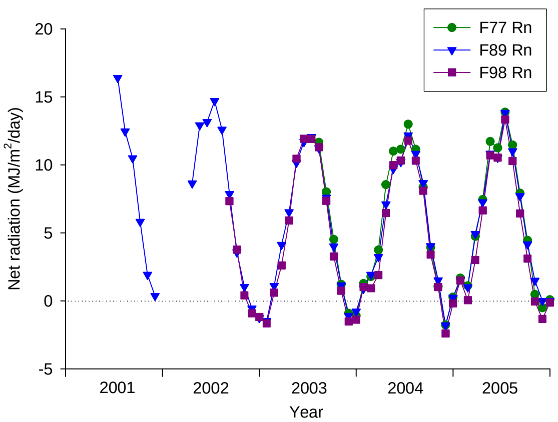


Fig. 1: Net radiation (Rn) at three southern boreal forest sites in central Saskatchewan from 2001 to 2005. Sites were burned in 1977 (F77), 1989 (F89), and 1998 (F98). Results are 4-week averages.

3.2 *Sensible Heat Flux Density*

Sensible heat flux was the highest during 2002 at F89. H then showed a clear decrease at F89 over the years until 2005 (Fig. 2). In 2003, the sensible heat flux at F98 increased to the point where it approached the same magnitude as F89. The sensible heat flux at all sites during 2004 and 2005 were very similar to each other with a small separation among sites. The magnitude of H at a given site is highly dependent on the effects that vegetation will have on the LE flux at the same site. This dependency occurs because the partitioning of energy is mostly determined by the H and LE fluxes.

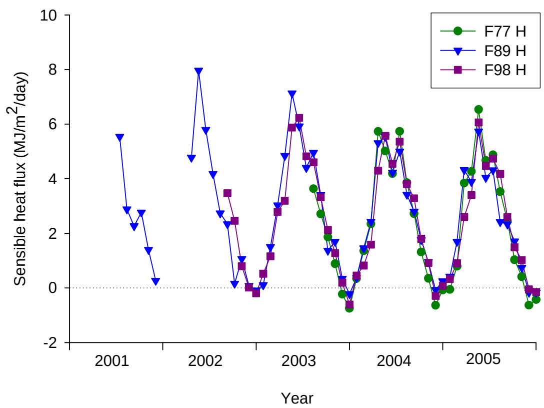
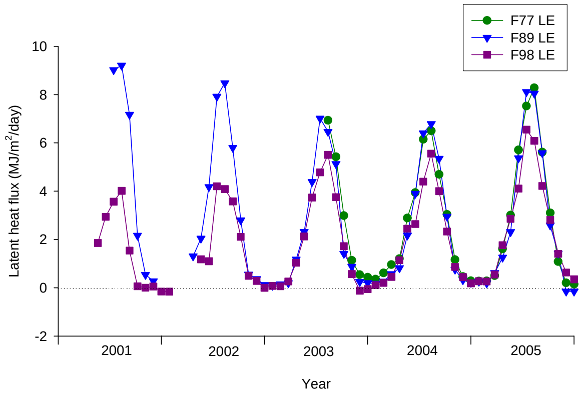


Fig. 2: Sensible heat flux (H) at three southern boreal forest sites in central Saskatchewan from 2001 to 2005. Sites were burned in 1977 (F77), 1989 (F89), and 1998 (F98). Results are 4-week averages.

3.3 *Latent Heat Flux Density*

Latent heat flux is the energy component that best illustrates how vegetation dynamics impact the energy balance of a forest following fire. LE at F77 and F89 were very similar during 2003 (Fig. 3). The older sites had a peak LE value that exceeded the peak value at F98 by approximately 1.5 MJ/m^2/day. The gaps between the older sites and F98 are smaller in 2004. The decrease in LE at F77 and F89 in 2003 is likely due to the drought that occurred in the summer of 2003. This decrease carried over into 2004 because it is likely that the vegetation was unable to recover from the drought stress in the span of one year. In 2005, higher values of LE were observed at all sites. This is due to the increased precipitation events that took place at all sites during that summer. Increased precipitation will lead to an increase in transpiration and evaporation. The increase in LE at F98 over time is likely caused by the progressive development of the vegetation over the years.



Fig, 3: Latent heat flux (LE) at three southern boreal forest sites in central Saskatchewan from 2001 to 2005. Sites were burned in 1977 (F77), 1989 (F89), and 1998 (F98). Results are 4-week averages.

3.4 *Soil Heat Flux Density*

Soil heat flux illustrates the differences in vegetation and snow cover at the sites of different ages. G is the highest at F98 in both the summer and winter (Fig. 4). This is likely due to the lack of vegetation at this site compared to the more mature sites. At F98, there is no tall tree canopy to intercept snow during winter. The snow then accumulates more on the ground and provides an insulating layer on the soil surface. During the summer, there is less vegetation at F98 to shade the ground from sunlight. The bare ground is also dark colored which will decrease the albedo of the site and will therefore absorb more solar radiation and will gain more energy than the older sites. The more mature sites have similar G because their vegetation characteristics are very comparable. By 2005, the summer G at all sites was similar, likely because of similar vegetation ground cover.

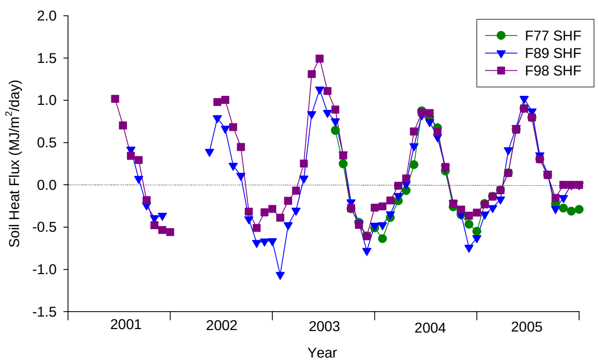


Fig. 4: Soil heat flux (G) at three southern boreal forest sites in central Saskatchewan from 2001 to 2005. Sites were burned in 1977 (F77), 1989 (F89), and 1998 (F98). Results are 4-week averages.

4.0 CONCLUSION

Changes in the surface energy budget of the forest following fire give a good indication of the changes that occur in the surface characteristics of a forest as it recovers from disturbance. By observing sites for multiple years, we can also observe the impacts that climate will have on the energy balance in years of drought and in extremely wet conditions. As forests recover from fire and as they progress through the different stages of succession, it is clear, through the changes in the distribution of energy fluxes that ecological processes are also changing. Latent heat flux illustrates how recovering vegetation affects the energy balance by controlling how much water is transpired from the plants. Soil heat flux is also a good indicator of how vegetation cover and ground type have a significant impact on the energy budget during both the winter and summer periods. The frequency of forest fires is expected to increase as climate change increases warm, dry conditions (Flannigan et al. 2005). Understanding how the energy balance of a forest changes with time following disturbance is also important for predicting the effects that the possible increase in forest fires that may accompany climate change could have on local, regional, and global climates.

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