Monitoring of the Effects of Fire in North America Boreal Forests Using ERS SAR Imagery

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ABSTRACT

ERS SAR imagery collected over the boreal forest regions of North America (Alaska and Canada) have displayed a characteristic signature over regions which have recently been disturbed by fire. Studies have clearly shown that these signatures have a definite seasonal trend related to patterns of soil moisture originating from snow melt in the spring and precipitation during the growing season. At times, the fire-scar signatures are between 3 and 6 dB brighter than adjacent unburned forests. These signatures appear in all regions of the North American boreal forest, and remain visible for up to 13 years after a fire.

Keywords: fires, boreal forests, soil moisture, ERS SAR

INTRODUCTION

Fires in boreal forests disturb over 10 million ha/yr; thus they represent a major factor driving of CO_2 exchange between the atmosphere and terrestrial biome (Kasischke et al. 1995). Due to their large spatial extent and frequency, satellite remote sensor represent one of the only viable means to monitor the extent and effects of these fires (French et al. 1996a; Kasischke and French 1995).

Under the sponsorship of both NASA and ESA, investigations have been underway since 1992 to evaluate the utility of ERS SAR data to monitor boreal forests. Through these studies, we have demonstrated that: (1) ERS data can be used to monitor variations in above-ground biomass in black spruce forests (Harrell et al. 1995); (2) unique signatures associated with the effects of forest fires are present on ERS SAR imagery (Kasischke et al. 1992; 1994); (3) dominant factor responsible for these signatures is variation in soil moisture (French et al. 1996b); and (4) these signatures are persistent for at least 13 years after a fire, occur throughout the entire state of Alaska, and are present in areas covered by tundra (Bourgeau-Chavez et al. 1997). In addition to these published results, we have recently determined that these characteristic radar signatures are present in other forest types in North America and have begun to develop approaches to using the soil moisture information derived from ERS SAR data to monitor patterns of soil respiration and carbon dioxide flux from these forests.

This paper contains five sections, including this introduction. The next section of this paper illustrates fire-scar signatures which have been detected on ERS SAR imagery collected over Canada and Alaska. The following section illustrates the temporal variability exhibited throughout the growing season and presents evidence which shows these signatures are related to variations in soil moisture. The next section discusses why the ability of the ERS SAR to monitor variations in soil moisture is extremely important in monitoring carbon dynamics in the boreal forest. The final section summarizes the results.

FIRE-SCAR SIGNATURES ON ERS SAR IMAGERY

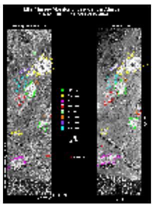

Figure 1. ERS-1 SAR Observations of Fire Scars in May and September of 1992 over the Tanana and Porcupine River Valleys, Alaska (Click Image for Larger JPEG).

Figure 1 presents a pair of ERS SAR image mosaics collected during the summer of 1992 near the confluence of the Porcupine and Yukon Rivers in interior Alaska (Bourgeau-Chavez et al. 1997). This region experienced numerous recent forest fires which depict the bright image intensities present in the ERS SAR imagery. The boundaries of all recent fires in this region were obtained from the Alaska Fire Service and overlaid onto the ERS-1 images using GIS software. These images illustrate that: (1) there is a seasonal variation in the radar signature; (2) the boundaries of the fires match the areal extent of the radar signatures quite closely; and (3) fires up to 12 years in age are detectable. Figure 2 presents ERS SAR imagery collected over different boreal forest regions in Canada showing that the characteristic fire scar signatures observed in Alaska are not idiosyncratic to this region. These signatures were compared with fire boundary records maintained by the Canadian Forest Service, and in all cases they closely correspond to recent forest fires.

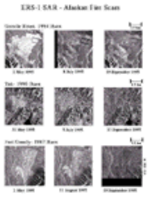

Figure 2. Seasonal Variation in Radar Image Intensities for Different Aged Fire Scars in Interior Alaska

SEASONAL VARIABILITY AND THE CAUSES OF FIRE SCAR SIGNATURES

Figure 3 presents a set of ERS SAR images collected over three different fire scars in the Tanana River Valley of Alaska. These scars resulted from fires in 1987, 1990, and 1994 in forests between Delta Junction and Tok, Alaska. Studies of data from these and other sites show that the radar image intensities are brightest in the early spring immediately after the melting of the winter snow pack. The image brightness decreases during the growing season as soil moisture decreases, but also increases immediately after significant precipitation events.

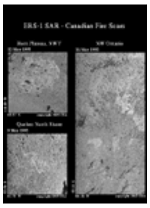

Figure 3. Scars Detected on ERS SAR Imagery Collected Over Fires in Canadian Boreal Forests

Beginning in 1992, a field campaign was carried out to monitor soil moisture in the Tok site, which burned in 1990. Figure 4 presents data from these studies clearly showing a strong correlation between radar image intensity and soil moisture (French et al. 1996b). Field studies to monitor soil moisture in the other two sites presented in Figure 3 were initiated during the summer of 1996.

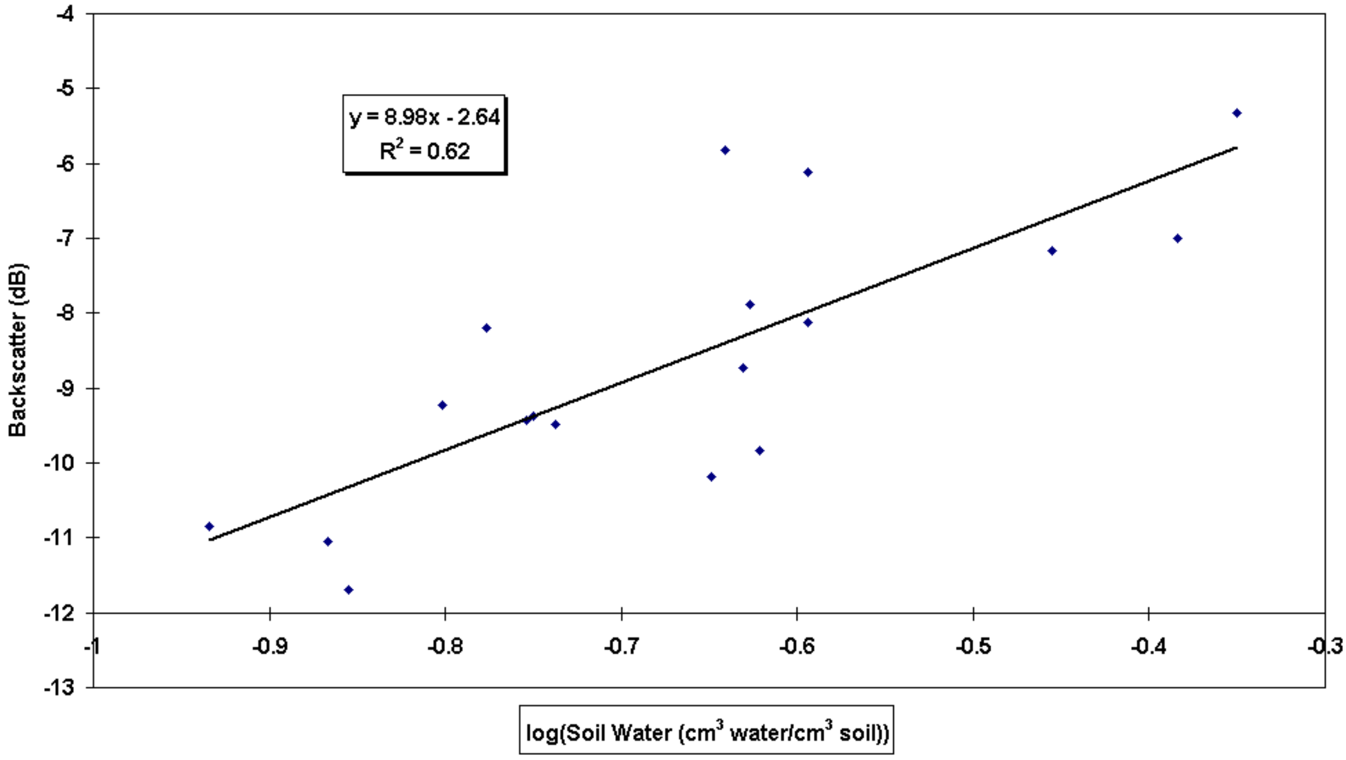

Figure 4. The Relationship Between Soil Moisture and ERS SAR Backscatter in a Fire-Disturbed Alaskan Boreal Forest

The increases in vegetation cover through regrowth after fire would affect the ERS signature in two ways. First, the increases in woody plant biomass would result in an increase in radar backscatter (Harrell et al. 1995). Second, the increase in biomass would also serve to attenuate the radar backscatter signature originating from the soil surface. Since forest regrowth is extremely slow in these forests, increases in biomass do not contribute greatly to the radar signature. For example, measurements collected at the Tok site in 1995 showed that living vegetation levels ranged between 15 and 100 grams per square meter. It is more likely that increases in vegetation will mask the soil moisture signature. This may, in fact, be the reason for the less bright signature observed in the 1987 fire scar.

USING ERS SAR DATA TO IMPROVE ESTIMATE OF CO_2 FLUXES FROM BOREAL FORESTS

The organic soils of boreal forests represent one of the largest terrestrial pools of carbon (Kasischke et al. 1995). The cycling of carbon in this pool is controlled mainly by soil temperature and moisture. Both of these factors change significantly after a fire, leading to significant increases in soil respiration and an overall net loss of carbon to the atmosphere.

The patterns of soil respiration leading to biogenic emissions of carbon dioxide are largely controlled by three factors: (1) the amount of organic matter present in the soil; (2) soil temperature; and (3) soil moisture.

Total soil respiration, R, (g CO_2– m^{-2} – h^{-1}) is calculated after (Schlentner and Van Cleve, 1985) as

$$R= \quad M/(a_1 + M) \quad a_2/(a_2 + M) \quad a_3\, a_4^{(T - 10)/10}$$

where M is the average forest floor moisture content (percent by dry weight), T is the soil temperature (C) at a depth of 15 cm, a_1 is the percent soil water at half-field capacity, a_2 is percent water at half retentive capacity, a_3 is the theoretically optimal respiration rate at 10 C, and a_4 is the temperature Q_{10} value.

Efforts are currently underway to collect field and laboratory measurements of carbon dioxide emissions from the three Alaskan test sites illustrated in Figure 3. These field measurements will be used to calibrate the soil respiration equation. Estimates of CO_2 emissions will be derived using seasonal/spatial variations in soil moisture derived from ERS SAR imagery and soil temperature data derived from AVHRR and ATSR data.

SUMMARY

Our studies have clearly demonstrated that ERS SAR imagery represents a unique tool to monitor the effects of fires in boreal regions. Not only do fires in these forests result in clear, unambiguous signatures on the ERS radar imagery, but the cause of these signatures (variations in soil moisture) is an extremely important parameter in studies of a key ecological process in this biome: soil respiration. Due to this relationship, ERS SAR data are critical to monitoring the carbon cycle in boreal forests.

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