# The use of MODIS-derived Fire Radiative Power to characterise Siberian boreal forest fires

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**Abstract**

**When observed by the MODIS sensor, the mean radiative power of boreal forest fires in Siberia, compared with fires in North America, appears significantly lower. Here we explore possible reasons for this difference and we find that it is not a result of orbital parameters, detector effects or cross track illumination differences, but the effect appears to be due to a physical difference between the forests. The result agrees with independent modeling work assessing the plant functional types in each region, and their life cycle adaptation with respect to fire. We go on to analyse the variation of fire radiative power with latitude and time with respect to the fire diurnal cycle. Finally, we examine the relationship between fire radiative power and burnt area and demonstrate the development of "delayed" fire scars in Siberia, as a consequence of post-fire dieback after lower intensity fires.**

## 1 Introduction

The boreal forests of Eurasia account for between 5 and 20 million Hectares of the annual burned area in the worlds forests (Wooster and Zhang, 2004). This means that such fires may have a significant impact on the the global carbon cycle, both as a source during the fires themselves and as a potential sink during post-fire regrowth. However there remains a great deal of uncertainty about the behaviour of these forests under fire conditions. As most of the forest area is far beyond the direct influence of, or risk to, humans it remains largely wild and understudied. With the development of satellite remote sensing technology it has become possible to detect more of the fires in the wild-wood that would have otherwise gone unnoticed. In the past the intention has mostly been to develop maps of burned area post-fire which has lead to the strategy of statistically estimating the fuel load and combustion efficiency in order to derive a carbon emission estimate. This however suffers from of only being sensitive to changes in the canopy. Now the availability of data from MODIS (Justice et al., 2002) more simply allows the estimation of fire combustion power we are in a position to say something far more physical about the nature of these fires. However we do not yet know a great deal about how these fires behave in the context of these "new" parameters. Consequently we have set out to make an assessment of the responses of these new parameters to the behaviour of Siberian forest fires. The first complete fire season dataset available is from 2002 and was recorded at an approximate pass interval of 12 hours by the MODIS sensor on the NASA Terra spacecraft.

Wooster and Zhang (2004) found (based on an analysis of the of MODIS derived Fire Radiative Power (FRP)) that the relative frequency of fires in any intensity class, except the lowest, was less in Siberia than it was for the same period in North America.

## 2 Methodology

Because of the geometric peculiarities of the MODIS sensor it was necessary to process the data in order to form a valid synoptic picture of the behaviour of Siberian forest fires. The variation in across-track pixel width between the nadir and edge of swath is from ∼1 to ∼4 km (Nishihama et al., 1997). This expansion leads to a phenomenon known as the bow-tie effect, whereby the footprint of consecutive scans over lap at the edge of the swath.

### 2.1 Mapping

It is necessary to map the MODIS data on a per pixel basis as the bow-tie effect is still present in MOD14. But by mapping it is possible to remove the impact of this effect from the data to be analysed. In addition to the eradication of the bow-tie effect, mapping the data for analysis using an equal area projection puts the data in a format that allows the improved estimation of the FRP.

### 2.2 Scaling the FRP

The original FRP calculation (equation 1) comes from the NASA MODIS fire/thermal anomaly team (Justice et al., 2002).

$$FRP = 4.34 * 10^{-19}(T_4^8 - T_{4background}^8) \quad (1)$$

Where $T_4$ is the brightness temperature of the pixel in question and $T_{4background}$ is the mean brightness temperature of the pixels in the region. This original FRP calculation does not allow for pixel size variations. Whilst the detectors onboard MODIS are obviously identical, the surface footprint of the detectors varies with the scan angle of the target. Therefore the area over which the fire-emitted energy is integrated is variable. An alternative FRP derivation was developed by Wooster (Wooster et al., 2003)(equation 2), which re-scales the FRP on the basis of the area over which it was integrated. Equation 2 also has the significant advantage of being linear with respect to radiance and is consequently less susceptible to small errors in the data.

$$FRP = Area * 20.25 * (R_4 - R_{4background}) * 10^{-6} \quad (2)$$

Where $R_4$ is the radiance of the pixel in question, and $R_{4background}$ is the mean radiance of the neighbouring non-fire background pixels. As an alternative to adjusting the Area parameter across the imaging swath, we remapped the data to an Mollweide equal area projection. This means a fire pixel whose area was 2 $km^2$ in the original image became two equal area 1$km^2$ pixels in the remapped image, and the cumulative FRP for the fire in the original and remapped data are the same.

By mapping to a Mollweide equal area projection, it is possible to ensure that the area parameter is constant for all pixels.

### 2.3 Fire analysis

In order to analyse the fires from the MOD14 products the individual fire pixels are clustered together. The fires are clustered on the basis of spatial adjacency within the MOD14 fire mask. Once clustered, the fires are mapped to the final equal-area projection. This mapping removes any pixels duplicated due to the MODIS bow-tie effect (Nishihama et al., 1997), from the analysis. The radiance of these mapped fires is calculated from the Planck function and the radiance is used with equation 2 to derive a scaled FRP.

### 2.4 Burn-scar Map

The burn-scar map used in this analysis, was provided by the Center for Ecology and Hydrology (CEH) at Monks Wood (Balzter et al., 2004). This map was compiled as a part of the SIBERIA-2 project and covers the years 1990 to 2003. It was compiled using a multi-sensor strategy and includes data from AVHRR, ATSR (1 and 2) and NASA MODIS. The burn scars

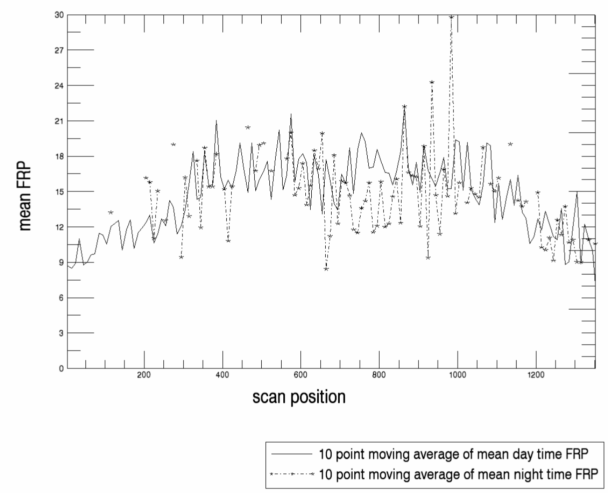


Figure 1: The mean daytime FRP (solid) and nighttime (dashed) FRP for each pixel location within the MODIS swath, compiled over April to August 2002

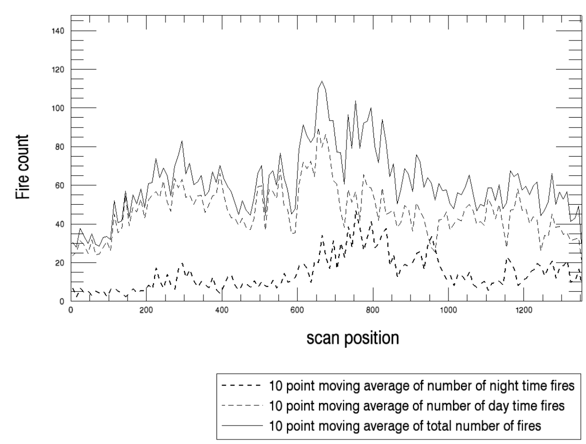


Figure 2: The fire count per detector for day (long dashed line), night (short dashed line) and total (solid line)

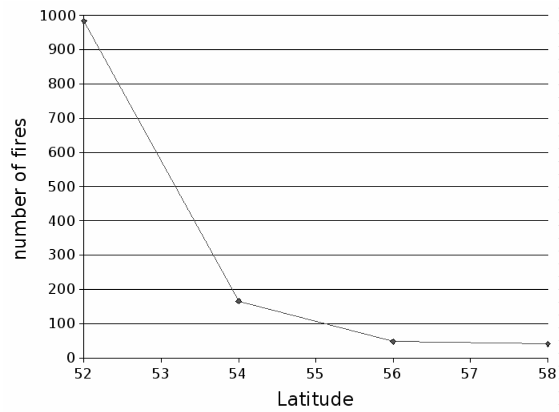


Figure 3: The change in the number of fire events with latitude

are detected using a contextural Normalised Difference Shortwave Infrared (NDSWIR) algorithm in order to identify areas of forest damage. These damaged areas are then compared to historical records of hotspots in order to date the scars and to eliminate areas of damage not resulting from, or linked to, fires from the dataset.

## 3 Data Analysis

Figures 1 and 2 show all the identified fire pixels in Siberia for April to august 2002. The pattern of these data shows greater cumulative FRP and fire count over the near nadir scan positions and a slight bias towards the high detector numbers. This bias to one edge of the swath is a result of the higher fire/background contrast achieved on the "dusk" side of the pass. This is a marginal effect which is mostly a concern at the very high latitudes, but does not contribute to a perceived difference between the Americas and Eurasia as both are prone to the same illumination differences. The number of fires detected decreases rapidly between $52^o$N and $54^o$N and continues to decrease at a reduced rate until there are very few indeed above $58^o$N. This is shown in figure 3

| Class | Power:area ratio (MW/Km$^2$) | $r^2$ |
|---|---|---|
| 1 | 0-9.9 | 0.95 |
| 2 | 10-25 | 0.96 |
| 3 | 25-49 | 0.94 |
| 4 | 50-74 | 0.98 |
| 5 | 75-99 | 0.98 |
| 6 | $> 100$ | 0.89 |

Table 1: The power-density classes identified and the $R^2$ fit for each class

Taking the individual fire clusters, derived from the processing of MOD14 data, it becomes clear that there are a number of different fire types. Analysing the ratio of total FRP to area yields evidence of 6 different fire classes (see Table 1). The lowest class, $< 10$MW/Km$^2$ seems to be rarely associated with immediately visible fire scars. This implies that these are most likely to be ground fires as they are not directly destructive to the tree stands. The highest fire power class appears always to be associated with immediate fire scars. This indicates that these fires are destroying the forest. In a few cases there seem to be fire scars coinciding with these low intensity fires in the year following the fire (2003). There are two probably interconnected reasons for this. Firstly the initial ground fire may have been sufficiently intense to scorch the root system of the trees without actually destroying the biomass. If this is the case then the tree is likely to die in the ensuing season and thus provide fuel for a further, secondary, fire. Alternatively the low intensity fire may have killed the trees and the scar becomes visible as a consequence of the post burn dieback. The nature of the CEH burn-scar map is such that it would favour the identification of the scar as fire related only if it did feature a 2003 secondary burn.

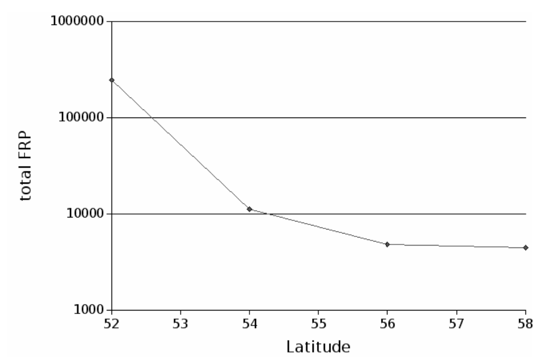


Figure 4: The variation in FRP summed by latitude

## 4 Discussion

The differences between the fire behaviour in the Americas and Eurasia were explained well by Wirth (2005) as a result of a combination of modelling and ecological studies. These showed that the species balance between Siberia and North America was such that the populations in Siberia are adapted for fire resistance while the North American populations are generally adapted to embrace fires as a part of their life cycle. A consequence of this, according to Wirth, is that the fraction of surface fires in Siberia is far higher than those in North America.

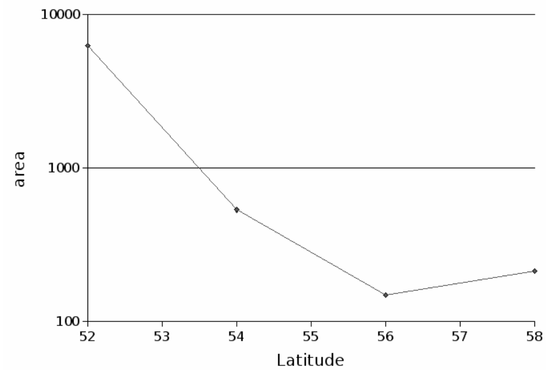


Figure 5: The variation in burning area summed by latitude

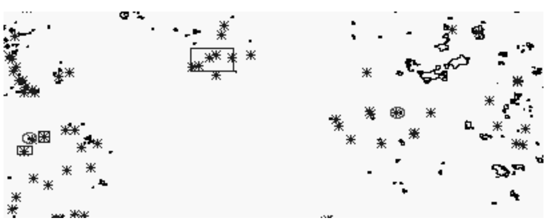

Figure 6: A subset of the study are showing: 2002 low power fires (asterisks), 2003 dated fire-scars from the CEH fire scar map (outlines), fires apparently unrelated to a scar (boxes) and fires apparently related to a 2003 fire-scar (ellipses)

Figure 4 shows that the FRP falls off very rapidly with increasing latitude. The fall off in FRP would be expected to be accompanied by a linearly deteriorating burning area. While the number of fires continues to decline north of $56^o$ (figure 3) the area actively burning increases at the highest latitudes (figure 5). This indicates that the individual fires north of $56^o$ are larger though fewer in number

The FRP data were compared to the map of fire-scars corresponding to the period of 2002-2003 (figure 6). The comparisons referred to here are descriptive and a full statistical analysis of the comparison will be carried out once the full FRP data for 2002/2003 fire seasons have been processed. A number of fires have been identified, falling into the low intensity class, which apparently match the location of fire scars which become visible during the following year. There are also a large number of low power fire events detected which do not appear to be associated with a fire scar from the dataset. These delayed and non-existent fire scars, associated with low intensity fires imply that the fires are not directly burning the tree boles or canopies and are therefore most likely to be associated with surface fires.

## 5 Conclusions

The number of active fires visible to MODIS in the 2002 fire season was affected by the diurnal cycle of the boreal region, though their intensity was not. The emitted power of fires apparently also drops off with increasing latitude. The evidence for this is visible but is quite limited so needs to be compared over a longer time series.

## 6 Further Work

The immediate intention is to extend this work to the 2003 and 2004 fire seasons, and increase the spatial resolution of the study. In addition to increased spatial resolution, the extension to 2003 and 2004 means that data from the Aqua MODIS sensor will be available giving an approximate 6 hour observation interval rather than the approximate 12 hour repeat time for this study. It would also be useful to extend the burn scar map beyond the range of the SIBERIA-2 project in order to find more matchups between the active fires and scars.

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