ESTIMATING BURNED AREA FROM AVHRR AND MODIS: VALIDATION RESULTS AND SOURCES OF ERROR

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Fire impact on Russian boreal forests has been studied for several decades. However, only remote sensing can currently provide consistent and unbiased observations of fire activity over the entire territory. Burned area estimates provide a critical input for numerous fields of science and resource management such as carbon cycle, climate modeling, forestry and fire management. Coarse resolution satellite instruments (e.g. SPOT-VEGETATION, AVHRR, MODIS, and ATSR) provide daily global observations of fire activity. We evaluated a set of fire products from AVHRR (Advanced Very High Resolution Radiometer) and MODIS (Moderate Resolution Imaging Spectroradiometer). The validation of these products by fine resolution Landsat imagery has demonstrated that they provide consistent and realistic estimates of burned area with RMSE = 0.9. AVHRR derived products in general tend to overestimate burned area whereas MODIS products tend to slightly underestimate it. Georegistration error, fire spread, duration of fire events, season of burning and other parameters have been found to influence the differences in area estimates from the two instruments. Both active fire and burned area products are necessary for detailed characterization of fire activity and impact extent. In addition to the operational use of the burned area estimates, records of fire activity from AVHRR provide an opportunity to observe longer-time trends and cycles in fire occurrence. The intercomparison of the products is aimed at the development of a long-term consistent suite of fire products which will enable us to understand changes in fire regimes with climate and land use change.

Introduction

Wildland fire is a major ecological disturbance factor world wide. Fire impacts on various ecological communities are important in terms of ecological succession, changes in ecosystem sustainability, loss of economic resources, environmental impacts, and damage to human lives and property [1], [2], [3]. Wildland fires have both multi-spatial and multi-temporal impacts on the environment. They extend from the local scale watershed damage [3] to global scale climate change consequences associated with massive release of greenhouse gasses (and particularly carbon) in the atmosphere from large forest fires [4]. Forest fires often occur in remote areas with limited access and cover large areas making it difficult to provide accurate assessments of fire impact. Remote sensing presents the only viable source of timely and consistent data for burned area assessment and spatially explicit fire impact analyses [5]. The importance of burned area mapping is reflected in the numerous algorithms and approaches developed for this application in many parts of the world. The variety of approaches ranging from single date image classification to multi-temporal change detection to regression based modeling indicates that no single method has been sufficiently and consistently successful in achieving the mapping accuracy required by various users. Observations received from coarse resolution instruments (e.g. SPOT-VEGETATION, AVHRR, MODIS, and ATSR) are of particular importance because they provide daily observations of fire activity. Here we provide an evaluation of some fire products from AVHRR (Advanced Very High Resolution Radiometer) and MODIS (Moderate Resolution Imaging Spectroradiometer).

Project goals and objectives

In this project we are focusing on the evaluation of the near-real-time fire products, generated primarily for management purposes, in terms of their use for science applications. The primary fire products are locations of active fires, which are later processed into burned areas by spatial and temporal aggregation. Fire product validation has two major goals. First, we provide accuracy assessment for burned area mapped from MODIS and AVHRR operational fire products in support of scientific research conducted under the Northern Eurasia Earth Science Partnership Initiative (NEESPI). There is currently a suite of operational coarse resolution fire products available for Russia [6]. Although some of these products have already been applied for scientific studies [7], they have not undergone a complete validation and therefore, their accuracy has not been fully evaluated. Second, we aim at developing inter-calibration methodologies for MODIS and AVHRR fire products in order to insure a set of consistent observations. These inter-calibrated observations will allow for long-term evaluation of fire occurrence and its changes in Northern Eurasia.

Methodology

Coarse resolution data and validation area

We evaluated a number of active fire detection and burned area products from MODIS and AVHRR for the 2002 fire season. Within the scope of this project we evaluated: MODIS active fires [8], MODIS burned area (experimental algorithm; L. Giglio, personal communication), AVHRR active fires (Sukachev Forest Institute - SFI, Krasnoyarsk) [7], AVHRR active fires and AVHRR burned area (Center for Forest Ecology and Productivity - CFEP, Moscow) [6]. Due to differences in spatial and temporal coverage of individual products, there are variations in validation areas (Figure 1). The MODIS active fire product contained latitude/longitude point locations representing center of the pixels flagged as active fires. These points were used to reconstruct 1km MODIS nominal pixels in Sinusoidal projection. MODIS burned area product was converted from the binary image format in Sinusoidal projection to shapefile format. AVHRR active fires (SFI) were aggregated based on the daily fire polygons in shapefile format. AVHRR active fire and burned area products (CFEP) were assessed independently of each other as well as in combination with each other as complimentary datasets. In addition, active fire products and burned area CFEP products from NOAA-12 were compared to those from NOAA-14. The datasets were aggregated from daily observations available in shapefile format. All products were subsequently clipped to the spatial extent of available Landsat scenes and converted into the UTM projection of a relevant high resolution reference database.

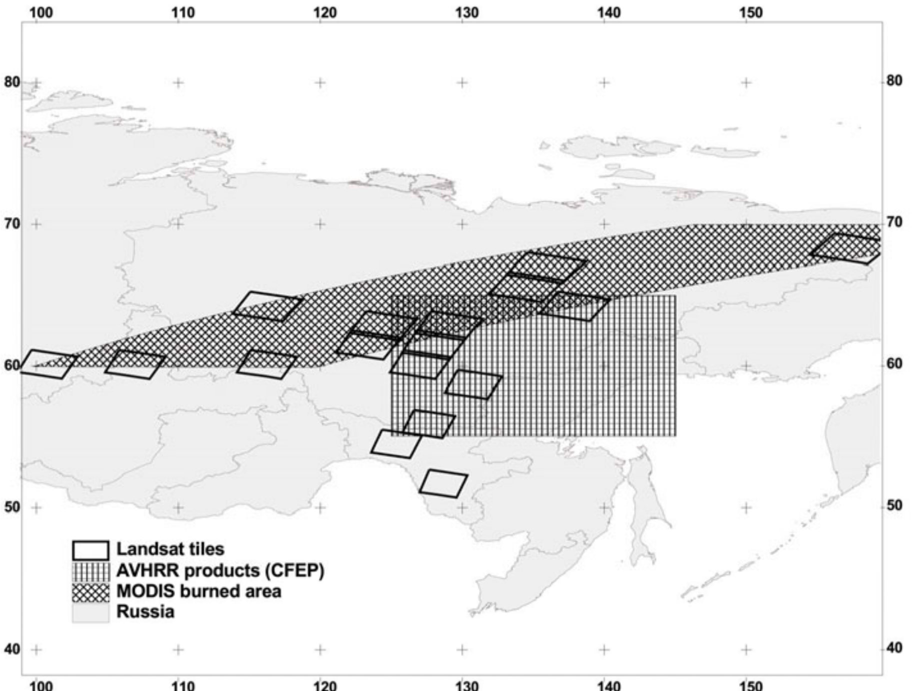

Figure 1. The spatial distribution of the evaluated coarse resolution products and the reference high resolution data

High resolution reference dataset

A high resolution dataset from Landsat/ETM+ imagery was created as a reference database for coarse resolution product evaluation. We included 22 Landsat scenes in the database. Although three of the available scenes did not have burned areas in them, they provided important information on the absence of false detections from AVHRR and MODIS. Several of the available images presented multi-temporal sequences of the same scene; however, the majority of scenes presented a single image.

In the course of the reference database development we evaluated an approach for single-image burned area mapping vs. multi-temporal change detection. For both cases raw digital number (DN) values of Landsat/ETM+ imagery were converted to top of atmosphere reflectance and the 30m nominal resolution pixels were aggregated to 100m to account for the modulation transfer function (MTF) effect [9]. Multi-temporal images were co-registered and they underwent atmospheric rectification using the Dark Object Subtraction method. Subsequently, map algebra was applied to subtract the later image from the earlier one. The resultant values were classified into burned and unburned area based on individually derived thresholds at an image scale. Separately, burned areas were mapped on a single image using the Spectral Angle Mapper supervised classification in ENVI image processing environment. The results of the former classifications were subtracted from the results of the latter classifications. The output presented burned areas mapped within a comparable time frame for the comparison of two approaches. The comparison showed that both approaches provide very close estimates of burned area (Figure 2). The single-image classification approach provides a considerable advantage. First, the limited availability of multi-temporal cloud-free Landsat imagery over Russia significantly constricts the spatial extent of potential validation area. Second, when multi-temporal images are available, single-image classification allows for several observations of burned area mapping progression throughout the burning season to assess burned area mapping accuracy over multiple dates.

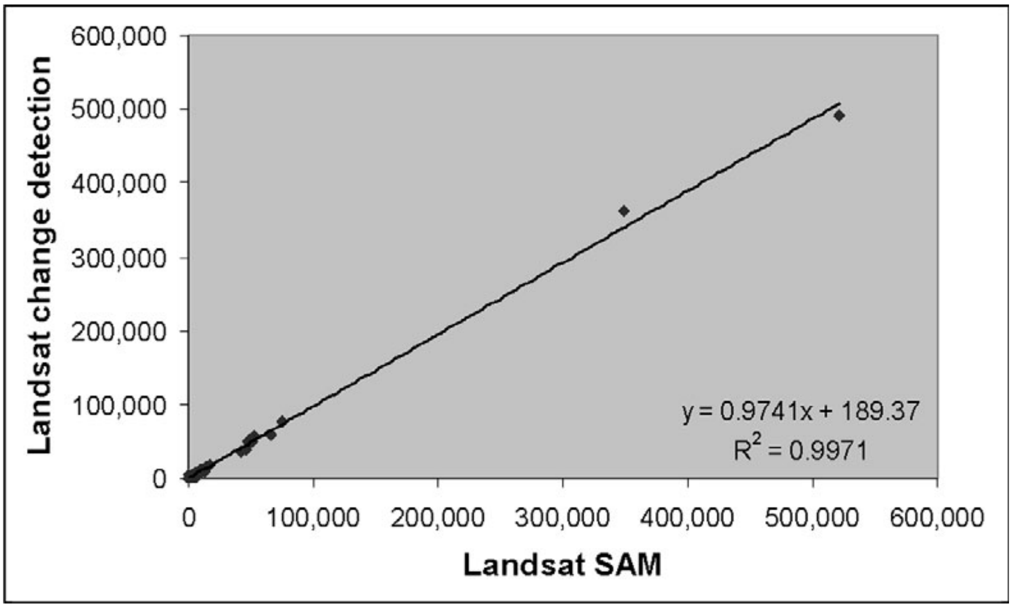

Figure 2. Intercomparison of burned area from single-date (Spectral Angle Mapper) and multi-date (change detection) mapping approaches

Results

Inventory assessment

Inventory assessment provides information about the accuracy of the amount of area burned regardless of the geographic accuracy of burned area mapping. The differences in spatial and temporal coverage of the evaluated products make the direct comparison between all products difficult. Therefore, we provide a separate inventory accuracy assessment of AVHRR (CFEP) products and then provide a comparison of MODIS products and AVHRR (SFI) product.

Inventory assessment was made at an individual burn scar scale. Burn scars in Landsat imagery were assigned identification numbers. The difference in product resolution and geolocational error of AVHRR products makes automated approaches to scar matching between the evaluated products and the reference base difficult. Therefore, reference Landsat burned areas were visually matched with burn scars mapped by MODIS and AVHRR from different products. The unmatched MODIS scars were further assigned identification numbers which were later compared against AVHRR products. The remaining unmatched AVHRR scars were also assigned identification numbers. The analysis was carried out based on the comparison of the matched reference dataset and the coarse resolution MODIS and AVHRR products.

AVHRR (CFEP) products derived from NOAA-12 proved to have higher general detection capability than those of NOAA-14. There is generally a significant discrepancy between area estimates provided by burned area and active fire products. Individually both the burned area and active fire products underestimate the amount of burned area. Although the combination “active fire/burned area” sets tend to overestimate the area burned, they provide closer estimates to the reference data. Overall the combination of all available AVHRR (CFEP) products, i.e. active fires and burned areas from both NOAA-12 and NOAA-14, give a general 25% overestimation of the amount of burned area with $R^2 = 0.95$ (Figure 3a).

Figure 3 (b and c) shows burned area estimates from AVHRR (SFI) and MODIS active fire products as compared to reference Landsat/ETM+ data. Although both products have very high R^2 value, MODIS slightly underestimates (~10%) burned area whereas AVHRR (SFI) product gives a ~37% burned area overestimation. MODIS burned area product (Figure 3d) also has a very high R^2 value (~0.98) but it underestimates the amount of area burned by roughly 14%.

This assessment allows for the evaluation of the accuracy of spatial mapping of burned areas by different products (Table1). Although explicit burned mapping accuracy is fairly low the overall mapping accuracy for burned and unburned area is around 99% for all products except AVHRR active fire product from NOAA-14 (CFEP). Specific burned area products have lower commission error than active fire products and the MODIS burned area product has the lowest commission error of ~27%. Subsequently, the MODIS burned area product has the highest user accuracy. Combined AVHRR (CFEP) products show a considerable improvement in geographic mapping accuracy over individual active fire and burned area products from NOAA-12 or NOAA-14. Kappa values, which provide the overall mapping accuracy rating, show that the MODIS burned area product has the highest mapping accuracy of 0.56 followed by the combination of all AVHRR (CFEP) products and then MODIS active fires and AVHRR active fires (SFI). This demonstrates that burned area products improve on burned area extent mapping compared to that of the active fire products.

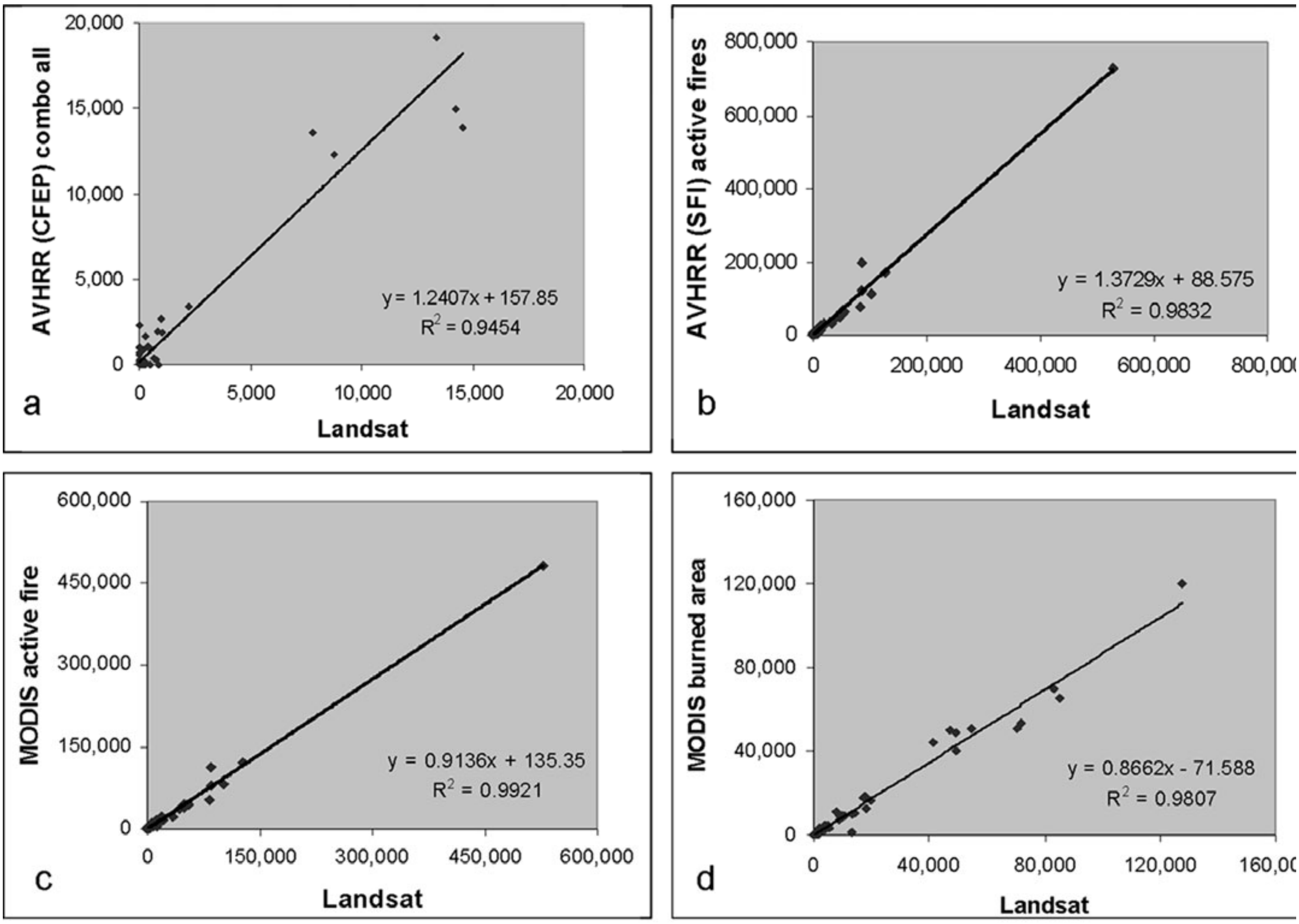

Figure 3. Comparison of burned area estimates (ha) from: a) AVHRR combination of burned area and aggregated hotspots (CFEP), b) AVHRR (SFI) aggregated hotspots; c) MODIS aggregated hotspots and d) MODIS burned area product

Table 1. Geospatial accuracy assessment for coarse resolution products.

Product	*Commission*	*Omission*	*Producer Accuracy*	*User Accuracy*	*Overall Accuracy*	*Kappa*
AVHRR (SFI) AF	61.62	45.38	54.62	38.38	98.58	0.43
AVHRR (CFEP) AF NOAA 12	67.33	80.43	19.57	32.67	97.85	0.22
AVHRR (CFEP) BA NOAA 12	56.76	76.45	23.55	43.24	97.94	0.26
AVHRR (CFEP) Combo NOAA 12	59.17	57.86	42.14	40.83	97.84	0.38
AVHRR (CFEP) AF NOAA 14	63.85	79.48	20.52	36.15	74.43	0.26
AVHRR (CFEP) BA NOAA 14	47.14	59.04	40.96	52.86	99.60	0.46
AVHRR (CFEP) Combo NOAA 14	49.02	46.25	53.75	50.98	99.59	0.52
AVHRR (CFEP) Combo AF	54.27	54.80	45.20	45.73	99.55	0.45
AVHRR (CFEP) Combo BA	51.45	56.73	43.27	48.55	99.58	0.45
AVHRR (CFEP) Combo All	55.94	36.06	63.94	44.06	99.52	0.52
MODIS AF	49.77	53.47	46.53	50.23	98.86	0.46
MODIS BA	27.09	49.40	50.60	72.91	99.34	0.56

Discussion: sources of error

Understanding the sources of error of the evaluated products is crucial for the inter-calibration of the products and the possibility of long-term observations. We identified five major sources of error in area estimates. The first source of error is presented by the missed fires and false detections. The false detections in the MODIS active fire product account for only 0.7% of total area burned detected by both MODIS and Landsat. Fires missed by MODIS account for 0.2% of the total burned area. The total area of fires missed and falsely detected by MODIS accounts for less than 1% of all burned area and therefore, they do not present a significant source of error.

Coarse spatial resolution of the instruments is the second source of error. Although there is a considerable number of fire scars with total area burned below MODIS or AVHRR resolution, the bulk of burned area is defined by a few very large scars which are well mapped by coarse resolution instruments.

Third, the geolocation accuracy of AVHRR needs to be corrected either manually or using sophisticated mapping algorithms [10]. These latter procedures have residual errors of their own, or cannot be performed at all due to time constraints. MODIS data, on the other hand, have reported geolocation accuracy less than the 1 km pixel size [11]. Thus, MODIS data can be used for a baseline of burned area estimates. The effect of geolocation errors on the accuracy of the aggregated AVHRR-based products was estimated by Monte Carlo simulation of the geolocation errors on MODIS data. We found that total area estimates increased with increasing geolocation errors (Figure 4).

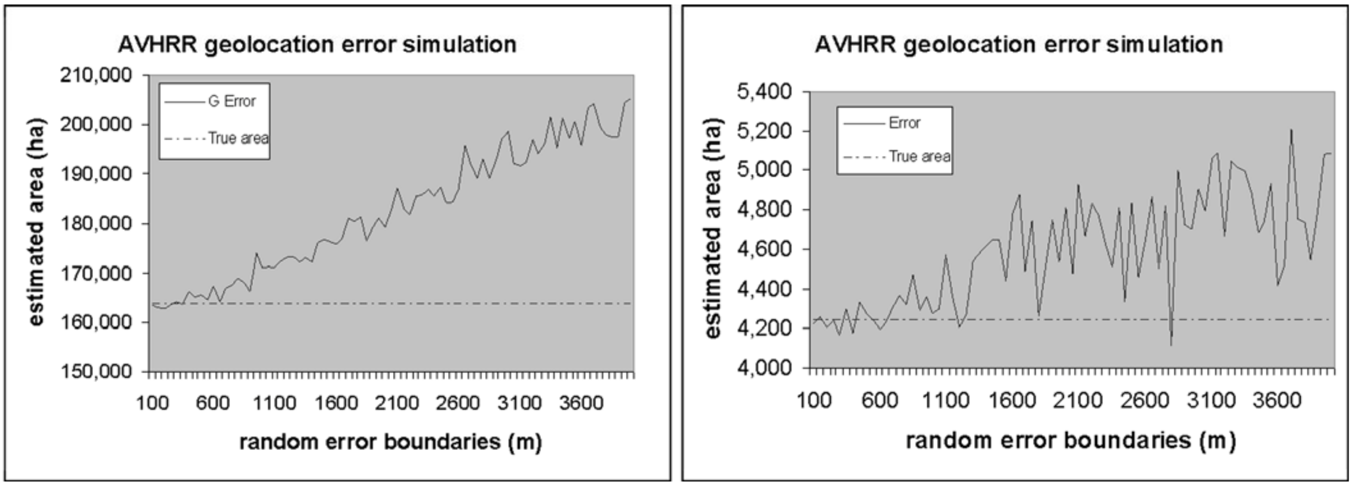

Figure 4. Growth of total burned area estimate as a function of geolocation error for a large scar on the left and a small scar on the right

Fourth, the accuracy of the burned area estimates from aggregated hotspots is also a strong function of spatial and temporal coverage. In particular, fire spread determines whether there are gaps between consecutive fire detections. To study this effect, fire clustering and spread rate retrieval algorithms were developed. As the variation in fire spread rates affect burned area estimates from aggregated hotspots from any sensor, this suggests that biases in burned area estimates need to be evaluated over the entire spatial and temporal domain of the fire product suite. Once fire spread rates are determined, errors of burned area estimates from AVHRR – where both geolocation errors and fire spread play a role - can be further evaluated. Figure 5 shows relative errors as a function of geolocation error for three values of fire spread rate. It can be seen that the rate of increase of the errors in area estimates with increasing geolocation errors decreases with increasing spread rate.

Fifth, the error in burned area estimates is also introduced through the heterogeneity of burn scars (Figure 6). The limitations arising from the instruments' spatial resolution are amplified by the heterogeneity of burned surface with numerous unburned inclusions within the scars. The example shows how the correctly mapped by AVHRR (SFI) burned area results in significant overestimation of area amount due to unevenly burned surface.

Conclusions

Coarse resolution fire products from MODIS and AVHRR evaluated within this project provide consistent and reliable estimates of burned area in Russia with $R^2 \sim 0.98$. Overall fire products derived from AVHRR data tend to overestimate burned area up to 35% over the reference data. Fire products from MODIS tend to slightly (10-15%) underestimate the amounts of burned area. While geospatial accuracy of burned area mapping is fairly low, the overall mapping accuracy of all burned and unburned areas is over 98%. Burned area products have higher geospatial accuracy of mapping burned areas with MODIS burned area product having the highest Kappa values. Each of the evaluated products had a number of strong points and therefore can be advantageous for particular applications. Consequently, inter-calibration of fire products for long-term observations of fire dynamics is an important issue for future research.

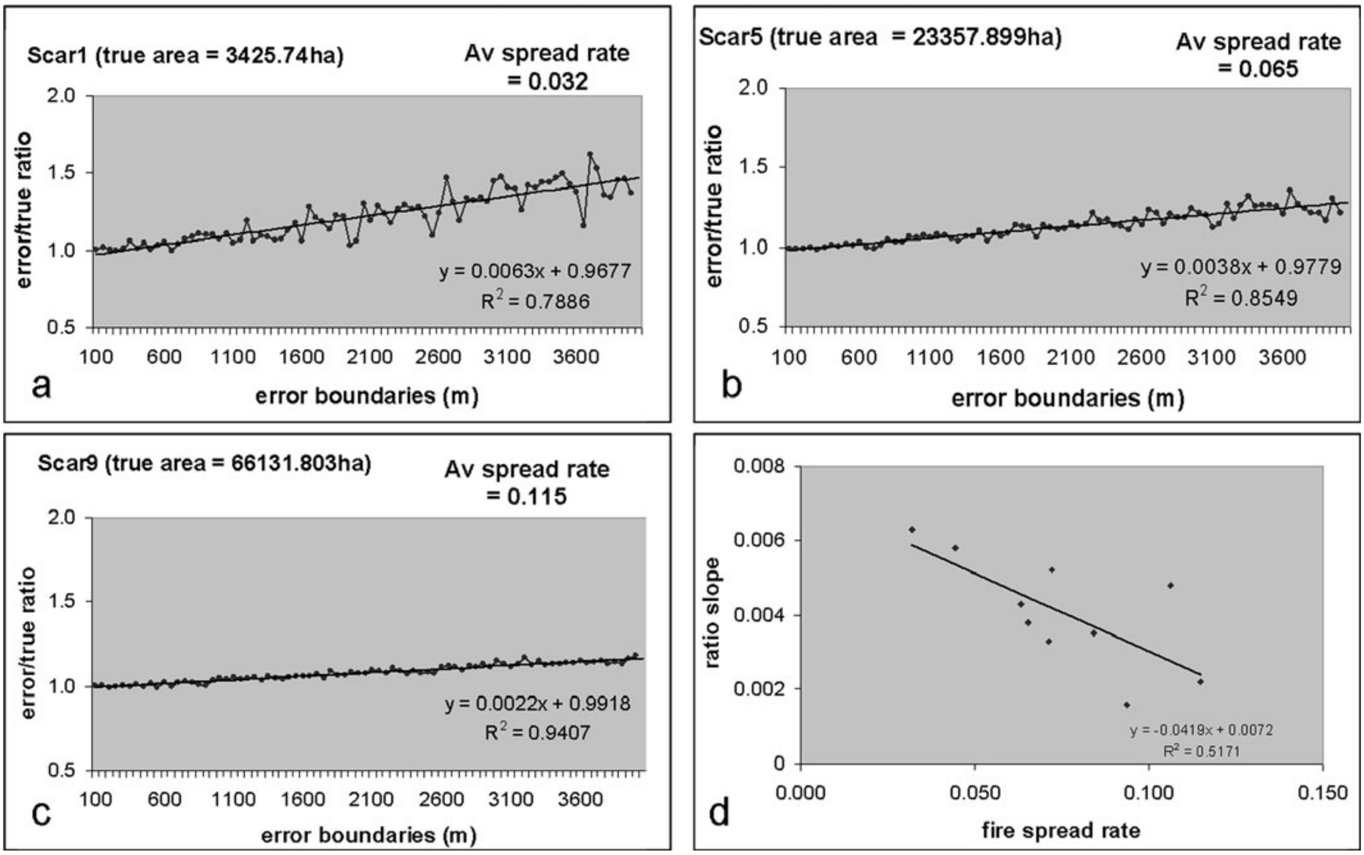

Figure 5. Relative errors in total burned area estimates as a function of pixel geolocation error.
The plot in 5d shows the change of the slope of the linear fit with average fire spread rate

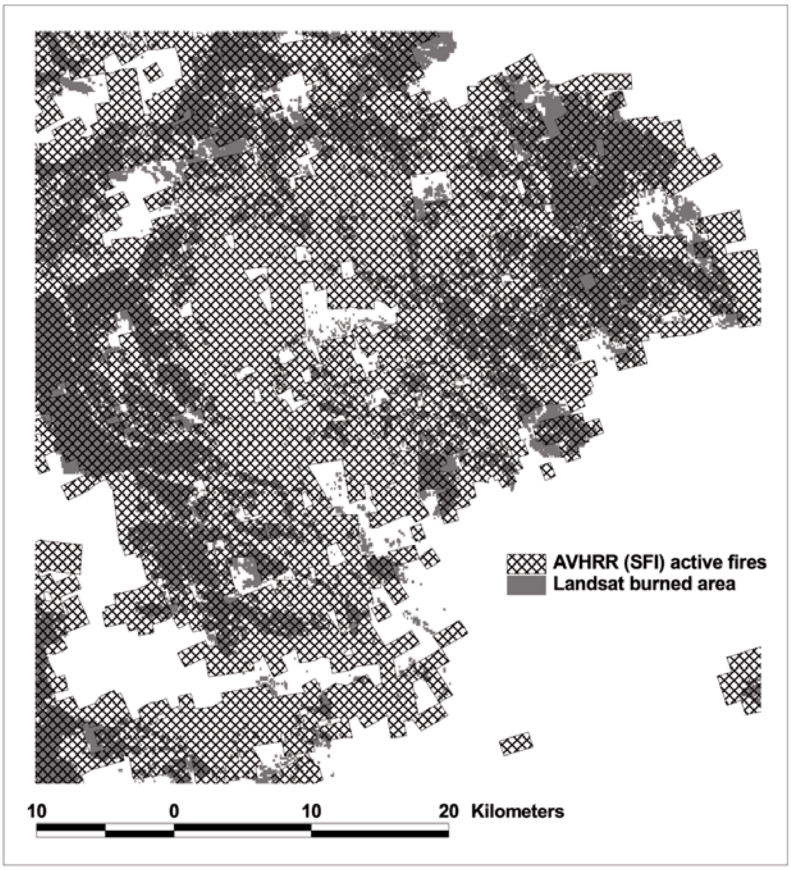

Figure 6. Heterogeneity of burned area as a source of error in burned area estimates from coarse resolution AVHRR (SFI)

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