Project Report:

Fire monitoring and modelling of emissions from fires

Results for pilot areas in 2014 and recommended next steps

ZEBRIS

Author:	G. Rücker
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PREFACE

This report details results on consulting activities provided to the project "Prevention, Control and Monitoring of fires in the Cerrado". Views and opinions expressed herein are those of the consultant.

The author wishes to thank all people and institutions that provided support during this work, especially by providing data, and by supporting the work on site. Special thanks go to Paulo Adriano Dias of the Chapada das Mesas National Park for hosting us there and introducing us to his magnificent park and the great work on fire management implemented there. I also wish to thank Livia Carvalho Moura for the discussions on field sampling in PNCM, and for her support in translation, and thanks also to her and Clara Baringo Fonseca for providing the field data on fuel and fuel consumption. Thanks also to James Possap for his translation at the workshop in Palmas. Albero Setzer and his crew at INPE, especially Pietro de Almeida Cândido are thanked for providing the burned area data.

Thanks go also to Eckehard Lorenz and his crew at DLR in Berlin for their hospitality during our visit, as well as for tasking the TET-1 satellite and providing the data.

EXECUTIVE SUMMARY

Reducing greenhouse gas (GHG) emissions from fires in the project region is one of the main goals of the project “Prevention, Control and Monitoring of Fires in the Cerrado”. This report details results on consulting activities for estimating emissions from three pilot areas. These areas are the Jalapão State Park (PEJ), the Ecological Station of Serra Geral do Tocantins (ESEGT) in the State of Tocantins and the Chapada das Mesas National Park (PNCM) in the State of Maranhão.

The radiative heat released by a fire (termed fire radiative power, FRP) can be observed from space and is proportional to fuel consumption, thus providing a direct means to quantitatively assess biomass burning. Through a statistical model integrating burned area, FRP, weather observations and fuel loadings, we estimated biomass consumption by controlled and uncontrolled fires in the project area. Through the application of standard emission factors we converted these estimates to emissions of greenhouse gases.

Analysis of emissions in the three pilot areas results in a preliminary global warming potential estimate of an equivalent of 2.1 Mt of CO_2 (calculated for a 100 year time horizon) with a share of Non-CO_2 GHG’s (methane and carbon monoxide) between ~10 % and ~30 %. This corresponds to about 1.1 Mt of burned biomass. Preliminary uncertainty estimate of burned biomass is about +/- 30%, while preliminary estimate of uncertainty due to emission factors is between 10% on a 20 year time horizon, and 5% on a 100 year time horizon. About 60% of emissions are from ESEGT (the larges pilot area), about 30% from PEJ, and about 10% from PNCM. Uncertainty is high for PNCM (estimated +/- 60%), partly due to incomplete data, and lower for the other areas.

Uncertainties can be reduced through consolidation and expansion of burned area data, inclusion of data from additional satellites and sensors, and inclusion of higher accuracy fire weather data to better assess fire behaviour. To further constrain estimates, it is recommended to conduct systematic field studies on fuel load and combustion completeness for validation. It is further recommended to conduct fire experiments to better constrain emission factors as well as the conversion of radiative heat release to biomass burned, and to validate FRP measurements from different sensors.

To enhance monitoring capacities, use of the German FireBird satellites shall be increased through furthering the cooperation between DLR and INPE. To achieve this objective, INPE and DLR agreed to take measures for targeted data collection of FireBird data as well as for FireBird data reception at INPE’s receiving stations. Both parties also discussed opportunities to collaborate with the objective of flying a fire-enabled infrared sensor on a future Brazilian mission.

LIST OF ABBREVIATIONS

Abbreviation	Meaning
AEB	Agência Espacial Brasileira
AVHRR	Advanced Very High Resolution Radiometer
CH_4	Methane (chemical formula)
CO	Carbon Monoxide (chemical formula)
CO_2	Carbon Dioxide (chemical formula)
DLR	Deutsches Zentrum für Luft- und Raumfahrt
ENVI	Environment for Visualizing Images
EOC	Earth Observation Center
ESEGT	Estacão Ecologica da Serra Geral do Tocantins
FC	Fuel consumption
FRE	Fire Radiative Energy
FRP	Fire Radiative Power
FTP	File Transfer Protocol
GAM	Generalized Additive Modell
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für internationale Zusammenarbeit
GOES	Geostationary Operational Environmental Satellites
GPS	Global Positioning System
GWP	Global Warming Potential
HSRS	Hotspot Recognition System
INMET	Instituto Nacional do Meteorologia
INPE	Instituto Nacional de Pesquisas Espaciais
IPCC	Intergovernmental Panel on Climate Change
IR	Infrared
MODIS	Moderate Resolution Imaging Spectroradiometer
MPP	Multi-Purpose Platform
NASA	National Aeronautics and Space Agency
NASA	National Aeronautics and Space Agency
NOAA	National Oceanic and Atmospheric Administration
OLI	Optical Light Imager
PEJ	Parque Estadual do Jalapão
PNCM	Parque Nacional Chapada das Mesas
PoC	Program of Cooperation
RS	Remote Sensing
RSS	Remote Sensing Solutions
SAFIM	Satellite Fire Monitoring Program
SD	Standard deviation
SEVIRI	Spinning Enhanced Visible and Infrared Imager
S-NPP	Suomi National Polar Orbiting Partnership

Abbreviation	Meaning
TET	Technologie-Erprobungsträger
UNB	Universidade Nacional do Brasilia
USGS	United States Geological Service
UTC	Universal Time Coordinated
VIIRS	Visible and Infrared Imaging Radiometer

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1 INTRODUCTION

Reducing greenhouse gas emissions from fires in the project region is one of the main goals of the project "Prevention, Control and Monitoring of Fires in the Cerrado". In 2014, an integrated fire management (Manejo Integrado do Fogo, MIF) approach was tested in three pilot conservation areas with the objective to reduce adverse impacts of fires. Two of these areas – the Jalapão State Park (Parque Estadual de Jalapão, PEJ) and the Ecological Station of Serra Geral do Tocantins (Estacão Ecologica de Serra Geral do Tocantins, ESEGT) are located in the state of Tocantins and one – the Chapada das Mesas National Park (Parque Nacional da Chapada das Mesas, PNCM) is located in the state of Maranhão. One of the main activities implemented during the MIF pilot campaign was the implementation of early season prescribed burns in selected zones of the pilot areas. Prescribed burning in the early dry season aims at reducing fuel loads and create a landscape of patchy burns, thus decreasing the probability of large late season fires which tend to be more severe and more difficult to control. When applied on a larger area, integrated fire management is expected to reduce fire severity, create a more diverse landscape and reduce the emission of greenhouse gases and other pollutants into the atmosphere while at the same time helping to enhance carbon stocks, e.g. through enhanced tree growth. In order to verify and quantify these effects, a monitoring system needs to be established. Monitoring of greenhouse gas emissions is one key element of such a system, and remote sensing provides effective tools for this. Remote sensing of active fires can support estimates of fire intensity, biomass burned and greenhouse gas emissions through the observation of radiative heat (fire radiative power, FRP) released by the fire, which is proportional to fuel consumption. Through a statistical model integrating burned area, FRP, weather observations and fuel loadings, we estimated biomass consumption and emissions from controlled and uncontrolled fires in the project area. Using data from the MODIS sensor and the Landsat satellite series (among others), this method supports the establishment of a time series of emissions back to about 2002. Such a baseline is crucial to quantify the impact of integrated fire management on GHG emissions through comparison with historical emission levels present before the implementation of this new management approach.

This report describes the methodology used, and preliminary results for 2014. It is planned to update these results with a revised version including newly available data (on burned area, active fires, and fire weather information). The results also provides information on the co-operation between the Instituto Nacional de Pesquisas Espaciais (INPE) and the German Aerospace Centre (DLR) on improving fire monitoring from space through the incorporation of data from a German scientific mission, FireBird, as well as further technical cooperation.

2 METHODS

Calculation of emissions of gases and particulate matter is complicated due to the volatile and heterogeneous nature of fire, and therefore uncertainties are high. Moreover, the main parameters of interest are not easily obtained in the field for validation. In the following we present the two most common approaches to estimate emissions from fires.

2.1 Estimating fire emissions

Emissions from fire are commonly estimated from the amount of fuel burnt:

$$M_{s\,pecies} = M_{biomass} \times E_{species}$$ **eq. 1**

where $M_{species}$ is the mass emitted for a particular gas or particulate matter, $M_{biomass}$ is the fuel consumed and $E_{species}$ is the – often biome- or land cover specific emission factor (mass emitted / mass burned) specific for the emitted species (e.g. carbon dioxide or methane).

$M_{biomass}$ is often estimated from

$$M_{biomass} = A_{burned} \times M_{fuel} \times f$$ **eq. 2**

where A_{burned} is the Area burned (m^2), M_{Fuel} is the fuel load (kg/m^2) and f is the combustion efficiency (%).

Usually, burned area is derived from remote sensing data, while fuel loads need to be derived from biogeochemical models and remote sensing data (van der Werf, Morton et al. 2009) or from default values for different land cover classes and remote sensing data. Combustion efficiency and emission factors are commonly default values taken from literature studies. All terms in equation 1 and 2 have considerable uncertainty.

The direct measurement of the fire radiative energy (FRE, measured in MJ) released during burning offers an alternative way for the calculation of fuel consumed since it has been demonstrated that remotely sensed FRE is proportional to the biomass burned (Wooster, Zhukov et al. 2003, Wooster, Roberts et al. 2005):

$$M_{biomass} = s \times FRE$$ **eq. 3**

where s (kg/MJ) is a scaling factor, which is assumed to be +/- constant in time and for all locations due to the very similar heat content of vegetation across ecosystems. Fire radiative energy release rate can be observed from air- or space-borne infrared sensors. Continuous observation of the fire radiative energy would therefore potentially provide a much higher accuracy because actual measurements within a well-defined accuracy range would replace much of the estimation involved in emission calculations after the burned area approach. Furthermore, this approach has the great advantage that it permits near real time emission estimates and that it relies on measurement of physical properties directly related to combustion, while the indirect method presented above depends on estimates of various factors influencing combustion, and is hence potentially more error-prone. Therefore, this method is used by the European pre-operational service for monitoring trace gas emissions from fires on a global scale and for pollutant dispersion forecast (Kaiser, Heil et al. 2012).

Satellite remote sensing sensors, however, can only sample fire radiative energy during the burning process. The heat release rate at the instant of observation is commonly determined fire radiative power (FRP), and total FRE is the integral of all FRP measurements over the time of burning. FRP is expressed in units of power (W = J/s), while FRE is expressed in units of energy (J). In terms of biomass combustion, FRP is related to the combustion rate at the time of observation (kg/sec) while FRE is related to the total biomass combusted during a fire (kg). The lower the sampling intensity of a given fire, the higher is therefore the error in the FRE estimate for that fire. Sampling is not only hampered by limitations in observation frequency, but also when observation of the fire is obscured by clouds. A large number of fires are therefore missed when fire emissions are calculated from FRE estimates alone, and an even larger number of fires may not be adequately sampled for FRE estimation.

A combination of burned area and FRP measurements is therefore seen by some authors as a way of significantly improving estimates of fuel burned. Boschetti and Roy (2009) explored strategies for combining FRP and burned area measurements by temporally interpolating FRP and spatially extrapolating FRE over the burned area and found that results for an exemplary large grassland fire in Australia were within 30 % of estimates obtained with other methodologies. (Roberts, Wooster et al. 2011) present an approach for integrating geostationary Meteosat SEVIRI FRP measurements over Africa with MODIS burned area datasets to account for fires not observed by SEVIRI, and for savannah fires in Africa they observe fuel consumption rates that correspond well to those reported from field studies.

However, the MODIS burned area product is known to have high errors of omission especially in the tropics and for small fires, and Meteosat SEVIRI only detects the strongest fires due to its low spatial resolution, thus leading to understimation.

2.1.1 Uncertainty due to different emission factors for trace gases

Another source of error in emission estimates is the emission factor, which defines for each trace gas or particulate matter species the mass released per mass unit of fuel burned (e.g. kg CO_2/kg biomass burned). Emission factors are decisive in the estimation of radiative forcing from biomass burning emissions. The uncertainty regarding emission factors affects both methodologies. Emission factors depend to a varying extent on the condition at the time of burning. Under conditions of reduced availability of oxygen associated with smouldering combustion, combustion is less complete, and a higher proportion of reduced gas species (such as methane) is emitted.

Emission factors for most species are strongly related to combustion efficiency, which in turn is related to fuel characteristics and meteorological conditions at the time of burning and the amount of smouldering versus flaming combustion. This relates to the fact that during flaming combustion (characterized by temperatures over 1000 K), combustion rate is high and oxidation of combusted fuel is nearly complete, while during the smouldering stage (temperature between 600 and 800 k) biomass consumption rate is low, and combustion is incomplete. Therefore, Yokelson, Karl et al. (2007) found in field experiments that emission factors of NO_x, CH_4 and other trace gas species associated with incomplete oxidation in Amazonian fires are related to combustion efficiency (MCE, see Figure 1).

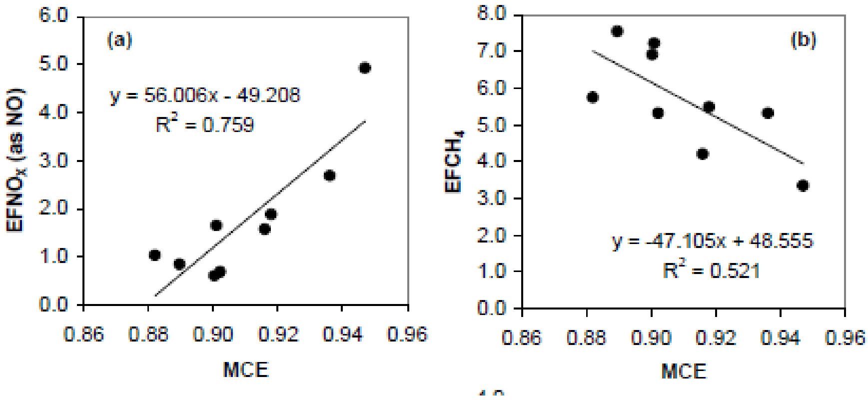

Figure 1 *Relationship of emission factors to combustion efficiency (Yokelson, Karl et al. 2007)*

2.2 Methods used in this study

Our approach is based on integrating FRP observations from various sensors and burned area, thus following the approaches of (Boschetti and Roy 2009) and (Roberts, Wooster et al. 2011). We amplify this approach through a statistical model integrating burned area, FRP, weather observations and land cover and other information to estimate FRE and thus biomass consumed. The main advantage of using a model is that estimates for FRP between satellite observations are expected to be better than those achieved with simple linear interpolation between available measurements. We then convert biomass consumed to emissions for different species using standard emission factors from (Akagi, Yokelson et al. 2011) (Figure 2).

The approach has been developed in close cooperation with the Statistics Department of the University of Munich and is based on a Generalized Additive Model (GAM). This model is used to predict FRP observations using input parameters that were found to have an effect on observed FRP values. A GAM has the advantage of integrating linear effects with non-linear, e.g. cyclical effects. It is therefore possible to model the influence of solar time as a cyclical spline effect. Since the diurnal fire cycle is very pronounced in the tropics (Giglio 2007), modeling of a cyclical effect is important for a satisfactory estimation of FRP.

The primary use of the GAM is to model FRP values for time steps without observations either due to cloud cover or due to lack of satellite observations. Therefore, in a second step, the model output was fitted to observed values.

We used burned area provided by INPE or from a global MODIS-based burned area dataset where no INPE data were available (Giglio, Loboda et al. 2009) to search for active fire detections over a specific burned area based on the approximate time of burning (derived from the Landsat acquisition time or the approximate day of burning information of the MODIS dataset, see following chapter). As a boundary condition, we estimated that a fire started three hours before the first detection over the burned area, and ended three hours after the last detection. To calculate FRE, we then estimated FRP based on the model described above for every hour (including the real fire detections with FRP values) and integrated FRP over the fire lifetime to calculate the total emitted energy, or FRE.

We then converted FRE to biomass burned using the conversion factor of 0.368 kg/MJ (+/-5%) provided by (Wooster, Roberts et al. 2005). Biomass burned was converted to estimated emission using standard emission factors provided by (Akagi, Yokelson et al. 2011).

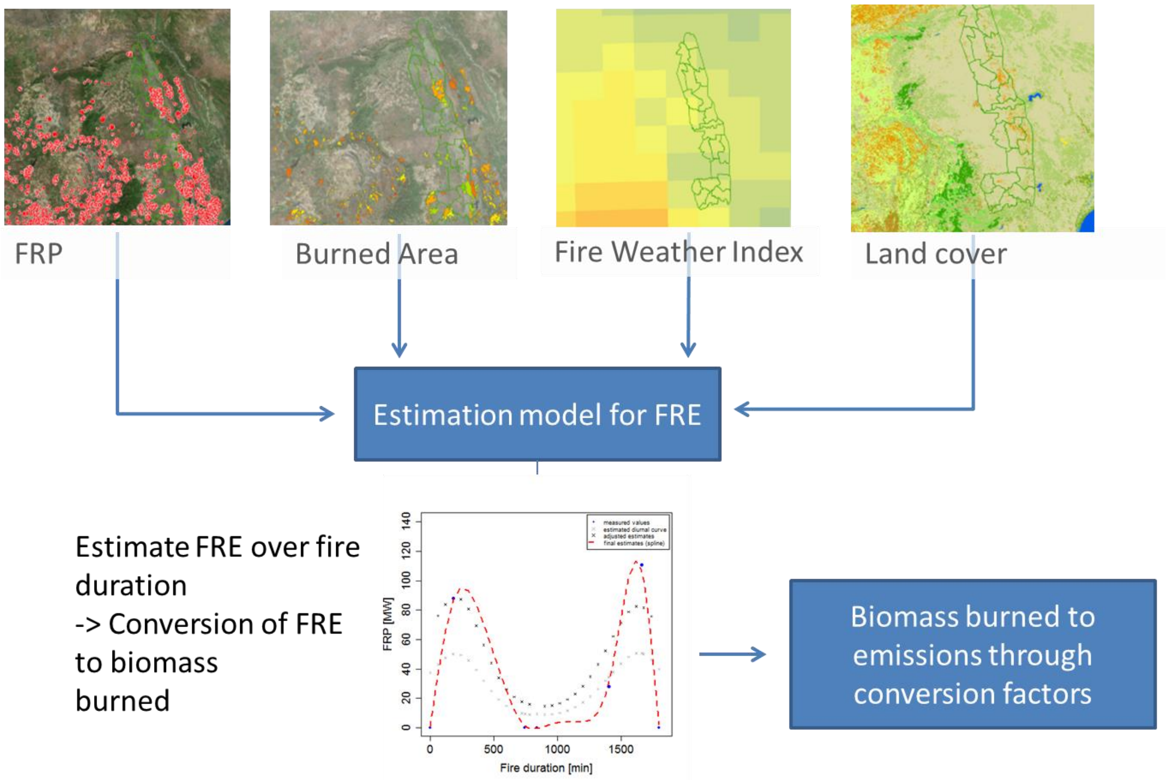

Figure 2: *Schematic graph of the process for estimating fire emissions in the project.*

2.3 Data

We used active fire detections from the MODIS instruments provided through NASA and USGS. This data set is known under the name MOD14 (for the MODIS instrument onboard of the Terra satellite) and MYD14 (for the MODIS sensor onboard the Aqua satellite). It consist of a list of pixel coordinates with ancillary information such as FRP and a fire mask indicating the location of active fire detections, clouds, clear land and water. The fire mask is used to identify cloudy or partially obscured observations.

For burned area we used the data provided by INPE, which have been developed using scene-to-scene change detection using Landsat-8 OLI observations from cloud-free or nearly cloud-free images (da Almeida Cândidio, 2014). Some images containing burned areas were not analyzed due to clouds, and we used the global MODIS burned area products provided by University of Maryland (product name MCD64, based on (Giglio, Loboda et al. 2009) to have information on some of the early season burns.

However, at the time of processing, for many late season fires, there were neither Landsat nor MODIS burned area data available, causing omission errors in the final data set.

For land cover (which is an input to our FRP estimation model) we used the global MODIS land cover dataset available through NASA and USGS (Friedl et al., 2010).

To estimate the Canadian Fire Weather Index, (FWI, another input for the FRP estimation model) we used a global dataset (DeGroot et al, 2010).

For the next release of the emissions estimate it is planned to replace these two datasets and the MODIS burned are product by higher resolution and higher accuracy data provided by project partners, such as meteorological data from INMET (see 3.4.4).

The MODIS active fire products obtained from NASA/USGS shall also be replaced by active fire data from INPE. INPE is currently receiving data from more than 10 satellites that can detect active fires, and some of them can also retrieve FRP. In 2015, INPE plans to provide FRP data for these satellites, and it is also planned to retrieve high resolution active fire data from the German FireBird constellation, which can be used to support fire monitoring in the project area (see chapter 4).

Also, a new algorithm using active fire detections from the NOAA VIIRS sensor flying on the S-NPP satellite has been implemented at INPE and will provide high resolution active fire detections, though no FRP (see 3.4.1).

During the fire experiments carried out by UNB with support of the Cerrado Jalapao project in June 2014, some of the prescribed burns could be made coincident with satellite overpasses so that ground and space based observations of fire intensity and fuel consumption could be linked (see 3.1.2).

3 RESULTS

We will present preliminary results of fire emission estimation for the year 2014 and the three MIF project areas Chapada das Mesas National Park (PNCM), Jalapão State Park (PEJ), and Ecological Station of Serra Geral do Tocantins (ESEGT). First, three exemplary fires are presented to further introduce the methodology, one prescribed burn in PEJ, and one in PNCM, and a large uncontrolled fire in PEJ. We will then proceed to present preliminary FRE estimates for the three parks as well as estimates of biomass burned and fire related emissions for the parks, and will discuss the results.

3.1 Example fires

3.1.1 Prescribed burn at PNCM, 2nd to 5th June, 2014

The first fire event discussed here is a prescribed burn started within MIF pilot implementation in PNCM. The fire was active over three days in Zone 1 of the park, and was detected first on 3rd June by MODIS Terra. The fire was still active on 5th June when Landsat 8 passed over. Fire fronts are clearly visible on that image, but no fire was detected by MODIS on that day. The fire was not mapped by the INPE burned area data because no scenes were analysed for PNCM before 24th July, 2014 due to cloud cover. We therefore used the 500m resolution data from the MODIS burned area product to analyse this fire.

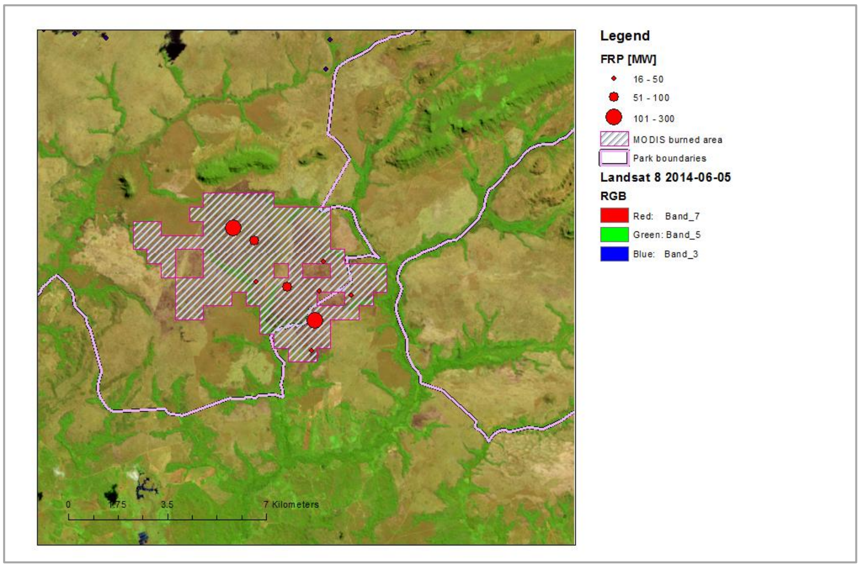

Figure 3: *Prescribed burn in PNCM, zone 1: MODIS burned area and active fire detections over Landsat 8 satellite image of 05/06/2014*

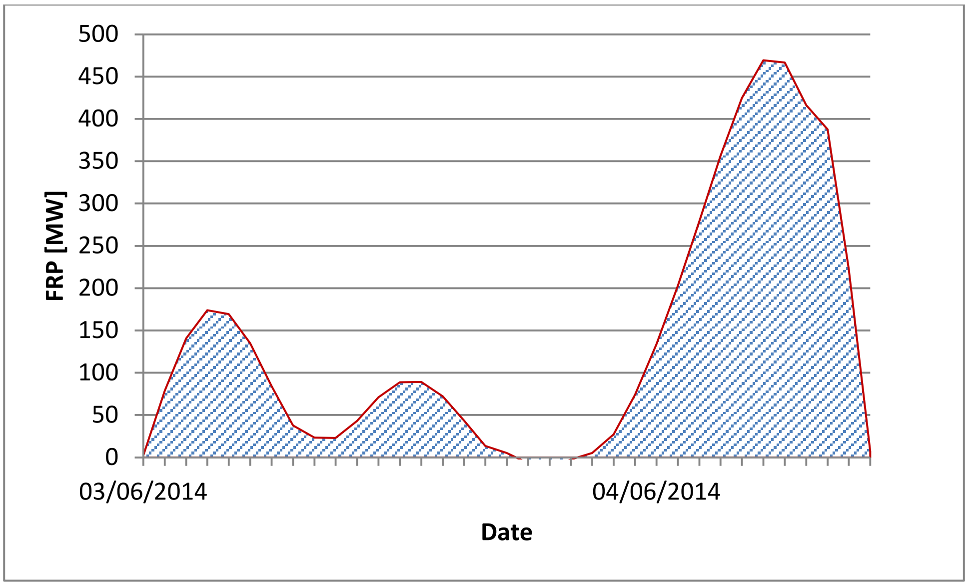

Figure 4: *estimated fire radiative power (FRP) for the fire in zone 1 of PNCM*

Figure 3 shows the estimated diurnal FRP curve for this fire derived from MODIS observations and our statistical model. The hatched area below the curve corresponds to the FRE (FRE being the integral of FRP over the fire duration).

According the coarse resolution MODIS data burned an area of 2700 ha. Following our estimate, the fire released a radiative energy of 38,400 GJ, corresponding to a burned biomass of about ~5,450 t. This translates to a fuel consumption of ~0.21 kg/m^2, estimated CO2 emissions: ~9,600 t and estimated methane emissions of ~ 1.1 t. Due to the low number of observations from MODIS - the fire was not detected by MODIS Aqua on 4th June, probably due to its low intensity - this estimate has a rather large uncertainty. Inclusion of additional satellites for observation would help improve accuracy for such fires (see 3.4.1).

A field measurement point of UNB was available for this burn at the northern edge of the burned area, and according to this estimate fuel consumption was 0.59 kg/m^2 and thus almost three times higher than our estimate. We will discuss error sources of both our and the UNB field estimates in chapter 3.3.

According to the description of the fire, it was started the evening of the 2nd June, and though it had difficulty to ignite that night and was described as very low intensity, it burned through the night and the following two days until it was put out by the fire brigade on the morning of 5th June (Carvalho Moura, 2014)

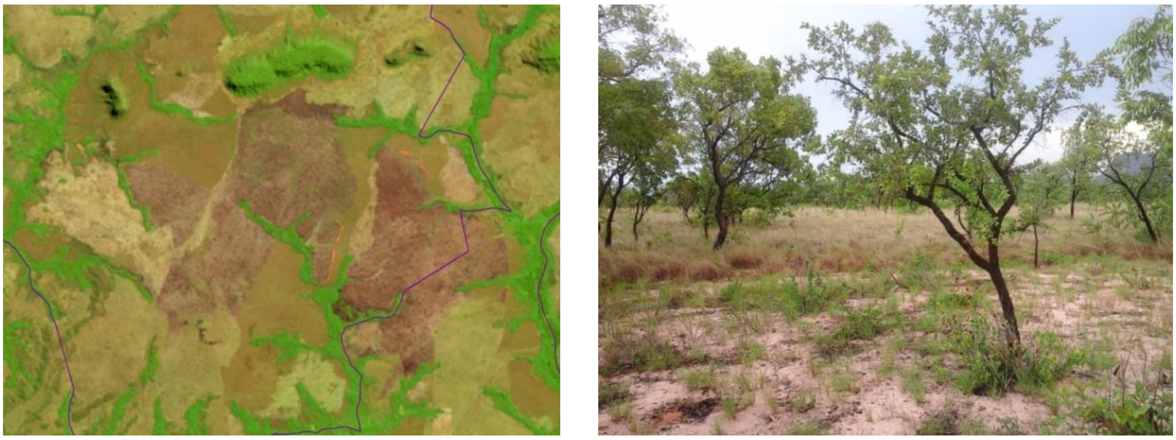

Figure 5: left: *Landsat 8 image of the burned area with active fire fronts (red) on 5th June, 2014.* **right:** *picture of the edge of the burned area taken in November 2014 showing the reduced fuel in the burned area, and the unburned fuel in the back, which gives an idea of the grass fuel loading in the area*

3.1.2 Prescribed burn and uncontrolled fires in PEJ, 14th to 17th June

The prescribed burn in PEJ was made coincident with the satellite overpasses, and field measurements by UNB were also conducted to determine fuel load, combustion completeness, and assess parameters related to fire behaviour (see Carvalho Moura, 2014).

Satellite overpasses were calculated using STK (Systems Tool Kit) software, which can compute overpass times, elevation and azimuth angles, as well as sensor coverages for target areas for a large number of satellites. Boundaries of the parks were imported into the software, and coverages for the satellites of interest calculated (see Figure 6 and Table 1).

FireBird data were received from DLR as calibrated radiance image files. They needed to be manually co-registered and georeferenced, and were analyzed for fires using a special program for fire detection running in the ENVI image analysis software (code provided by DLR).

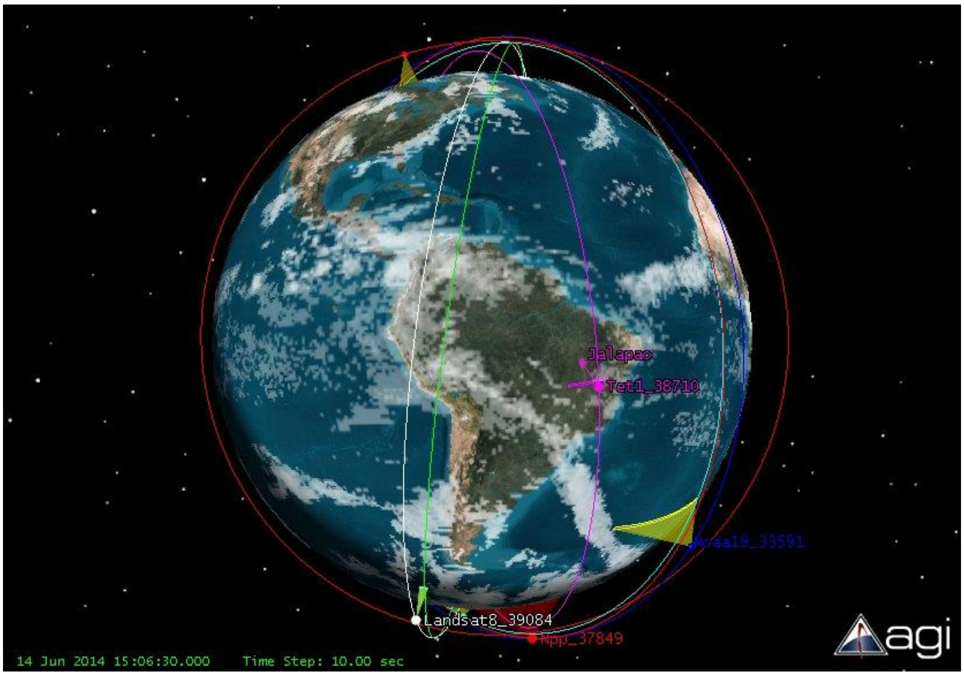

Figure 6: *Representation of polar orbiting satellites capable of fire detection on 14th June, 2014, 15:00 UTC (12:00 local time) TET-1 (in magenta) is approaching PEJ. Colored triangles indicate swath of each sensor, i.e. the part of Earth the sensor "sees" at that specific moment.*

Table 1*: Satellite overpass schedule for 14th/15th June over the PEJ (featured satellites: Terra, Aqua, Landsat, TET-1, S-NPP). Times have been converted from UTC to local time*

Date/Time	Azimuth	Elevation	Satellite
13/06/2014 22:53	85.774	-68.577	MODIS Terra
14/06/2014 01:33	271.532	-85.85	S-NPP VIIRS
14/06/2014 01:55	273.516	-55.445	MODIS Aqua
14/06/2014 10:13	259.207	-89.196	Landsat
14/06/2014 12:06	219.737	-71.854	FireBird TET-1
14/06/2014 14:08	85.955	-52.675	S-NPP VIIRS
14/06/2014 14:11	86.021	-50.526	MODIS Aqua
14/06/2014 22:29	84.221	-80.707	Landsat
14/06/2014 23:59	176.523	-72.377	FireBird TET-1
15/06/2014 01:00	93.912	-38.657	MODIS Aqua
15/06/2014 01:15	94.189	-62.225	S-NPP VIIRS
15/06/2014 10:25	111.757	-76.887	MODIS Terra
15/06/2014 13:16	269.802	-41.05	MODIS Aqua

The prescribed fires were followed by a series of fires that were lit by local villagers and not within the framework of MIF, thus making the final burned area much larger than originally intended (R. Beatty, pers. Comm.). The fires could be observed with INPE and NASA satellite data over three days. Figure 7 illustrates the satellite overpasses and fire detections over the area from 14th June through 17th June.

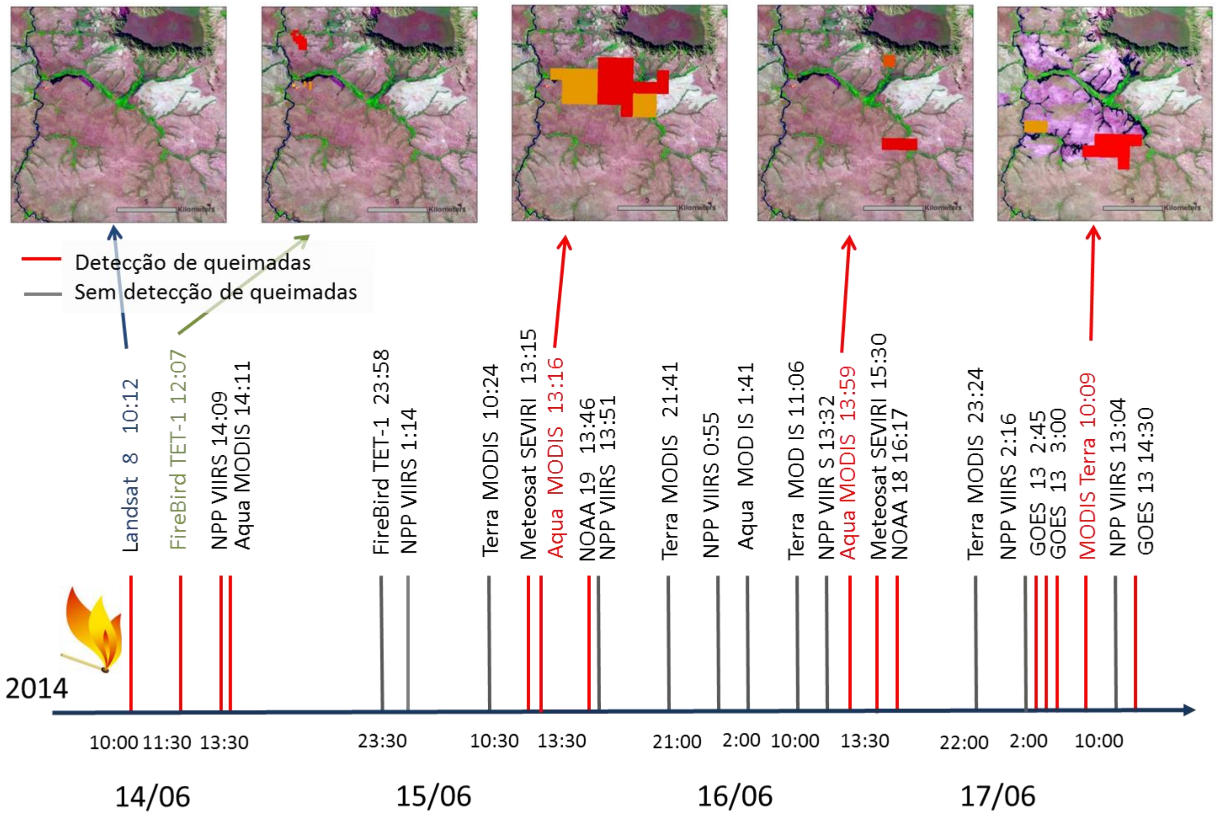

Figure 7: *graphical representation of the time series of fire detections over the area at Perna Corta fron 14th June to 17th June, 2014. Red are registered satellite overpasses with detections, black overpasses without detections. Panels on top (left to right): Landsat 8 image acquired at 14th June, 10:00, FireBird TET-1 active fire detections 14th June, 11:30, MODIS Aqua active fire detection footprint, 13:30 (note the coarse footprint when compared to FireBird), MODIS Aqua fire detections 16th June, 13:59, MODIS Terra detections 17th June, 10:09. Backdrop for this last picture is the Landsat 8 image of 30th June, showing the fire scar, background to the other pictures is the Landsat 8 image of 14th June.*

According to our FRE-based estimate, 0.33 kg/m^2 were consumed on this 4200 ha area, amounting in a total biomass burned of about 14,000 t, a CO_2 emission of close to 24,000 t, and a methane emission of 27 t.

A point measurement of UNB was available for the Northern edge of the fire. According to this sample, 0.72 kg/m^2 of fuel was consumed – again, the estimate is more than twice our estimate for the area.

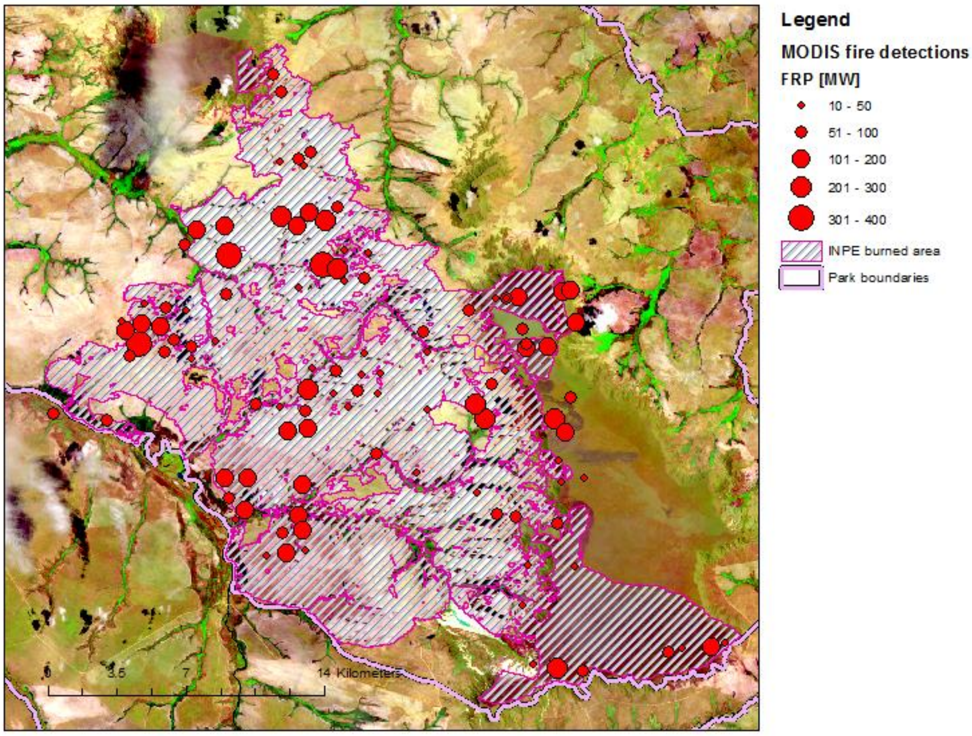

Figure 8: *Map of the burned area at PEJ (INPE burned area map derived from Landsat 8 data) overlayed with MODIS active fire detections. Active fire detections are pixel centre coordinates. Circles are scaled according to detected fire radiative power.*

3.1.3 Uncontrolled fire in PEJ, August/September

Our last example is from a large, and uncontrolled, fire burning in PEJ. Active fires were detected over this area between end of July and end of September, 2014, and the fire possibly consisted of several events/ignitions, and there was low or no activity during prolonged periods of time, and very high FRP – related to high fire intensity – during about one week at the end of August/beginning of September (figure).

The total area burned Area burned was 41,395 ha, with an estimated energy release of 489620 GJ, corresponding to a biomass consumption of ~172,800 t (0.42 kg/m^2) and associated CO_2 emissions of ~0.3 Mt, and methane emissions of ~ 335 t. There were no previous field measurements of UNB in the area.

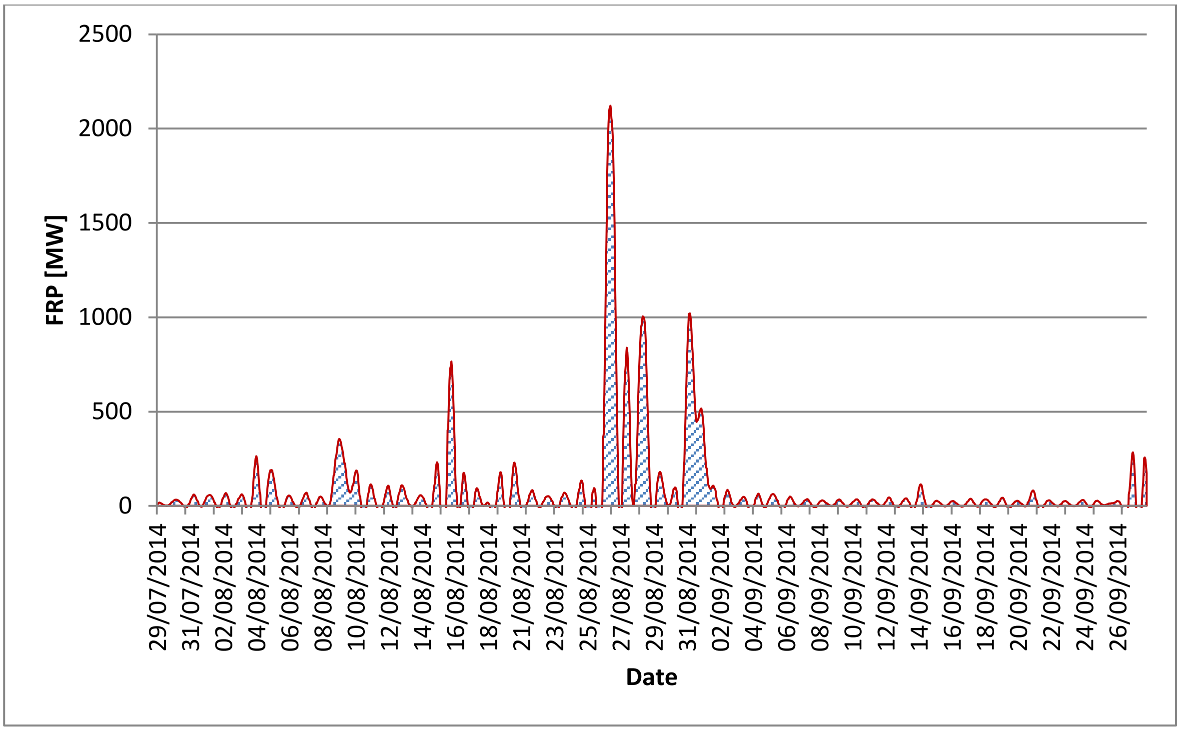

Figure 9: *estimated FRP curve for the fire in PEJ. The hatched area under the curve corresponds to the fire radiative energy (FRE)*

3.2 Preliminary emission estimates for the three pilot parks

According to the Landsat burned area data, 21,205 ha were burned in Chapada das Mesas (complemented by MODIS burned area for fires before 30th July), 186,465 ha in ESEGT, and 76,977 ha in PEJ.

Not all of the mapped fires had corresponding active fire detections for estimation of FRP. We calculated the percent area that did have fire detections, as well as the percent are that were sufficiently well observed to estimate confidence levels of the FRE-derived fuel consumption estimates. As a criterion for these fires we selected that there should be a minimum of three fire detections and three MODIS overpasses, meaning that the fire would at least be detectable for about 24 hours.

For the three target parks 88 % of the burned area had at least one detection and 79.5 percent had a minimum of three detections. The rates were similar for ESEGT (90.8% with detections and 83.7 % with a minimum of three detections) and PEJ (87.7/79.5) while for PNCM this number was substantially lower (70.2/56.2). In the case of PNCM this is partly due to the incomplete character of the Landsat burned area data, and subsequent problems with the search algorithm which lead to erroneous assignments of active fire detections.

This can be corrected for the next release of these estimates. Another reason may be the nature of the fires, which tended to be smaller in PNCM than in the two other areas, thus leading to less active fire detections. Results are summarized in table 2.

Table 2: *Burned area and fire detections over the three pilot areas. "Well observed areas" are defined as those that have at least three detections and three observations*

Park	Area [ha]	Area burned [ha]	Burned area with AF Detections [ha]	Well observed fires [ha]	Percent with detection	Percent well observed
PNCM	160047	21205	14876	11918	70.2%	56.2%
ESEGT	708272	186465	169240	156126	90.8%	83.7%
PEJ	158979	76977	67476	61233	87.7%	79.5%
Total	1027300	284647	251591	229278	88.4%	80.5%

We calculated the total and estimated daily fire radiative energy (FRE) for all fires with assigned detections following the method described in chapter 2.2. Using the daily FRE, monthly FRE for all parks was calculated (Figure 10)

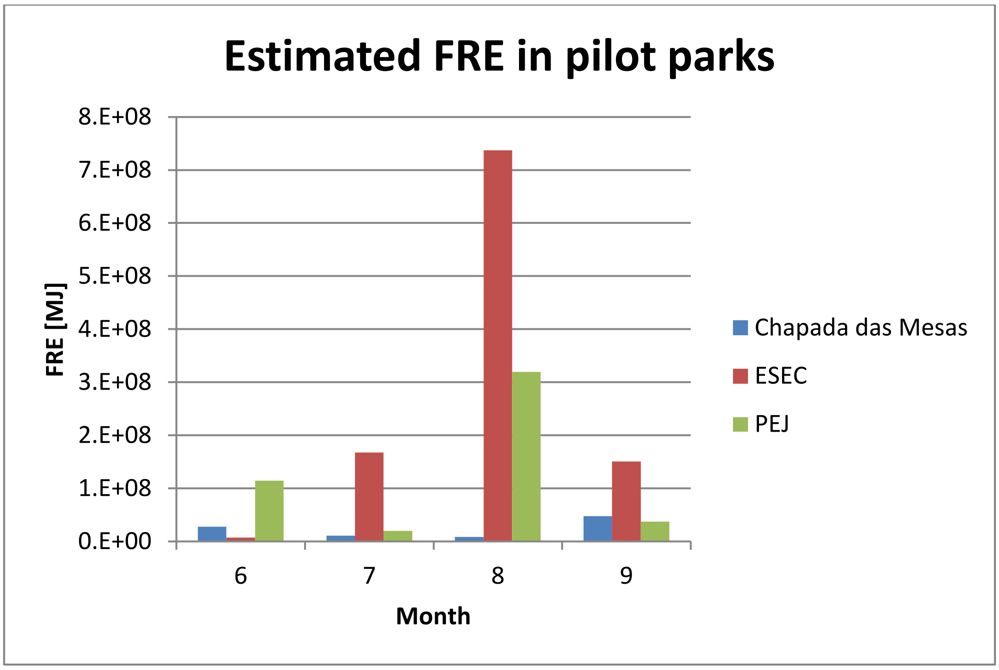

Figure 10: *Estimated monthly fire radiative energy (FRE) for the three pilot parks*

ESEGT, being the largest protected area, also has the largest share in FRE. To eliminate this effect, we divided FRE by park area to enhance the differences in monthly and total FRE.

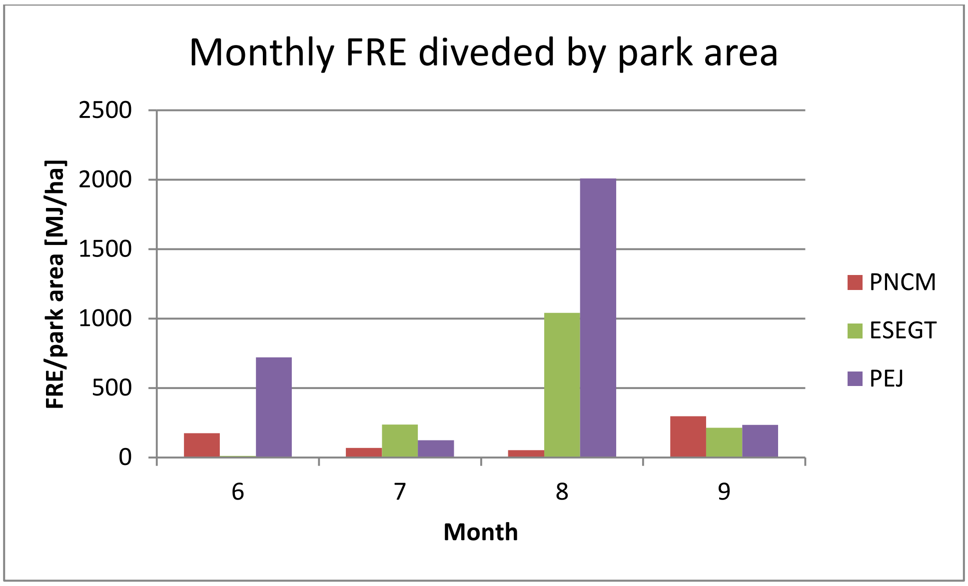

Figure 11: *Monthly FRE divided by area of conservation unit*

For all burned areas with active fire detections, we calculated fuel consumption from FRE.

As pointed out in Table 2, a certain percentage of each park's burned area did not have active fire detections. We multiplied the burned area of those areas with the area-weighted fuel consumption (t/ha) for each park to correct for these burned areas without fire detection. On the other hand, we also observe a number of active fire detections that do not have an associated burned area. While in PEJ and ESEGT, over 90% of the total sampled FRP could be associated with a burned area, in PNCM only 55% of the total detected FRP could associated with a burned area. This is due to the limited availability of burned area data in May, June and July (only MODIS burned area data), and the unavailability of burned area data from beginning of September onwards for this national park. Assuming that the percentage of the unassigned FRP equals the percentage of FRE and hence biomass consumption by these fires which is not accounted for in our estimates, we introduced an additional correction by multiplying the total biomass estimate with the percentage of undetected FRP. This our final biomass consumption estimate, from which we derive our estimate of fire emissions for the three protected areas for 2014. Results are summarized in Table 3 which also holds the area weighted averages of biomass consumption per unit area.

Emissions are derived from biomass consumed multiplied by the emission factor as described in chapter 2. The emission factors, and the amount of variation (high/low estimates) are taken from (Akagi, Yokelson et al. 2011). For the non-CO2 gases we also calculated the global warming potential on a timescale of 20, 50 and 100 years following the latest version of the Intergovernmental Panel on Climate Change (IPPC) reports (Myhre et al., 2013). The global warming potential is often called CO_2 equivalent, and describes the climate effect of one pulse of one kg of a greenhouse gas emitted in relation to the same quantity of CO_2 emitted (hence CO_2 equivalent). As gases (such as methane or CO) take part in chemical reactions in the atmosphere, their effect changes over different time scales. For instance methane, a potent GHG emitted during biomass burning, is depleted from the atmosphere over time, and thus its effect is lower when looking at a 100 year time scale than when looking at a 10 year time scale. The Kyoto protocol uses a 100 year time scale as a reference, but this choice is rather arbitrary, and hence we show the GWP over three different timescales.

Table 3: *Estimate of biomass burned for the three conservation areas*

Park	Final estimate (corrected for emission from fires with no mapped burned area) [t]	Estimated biomass burned for total mapped burned area area [t]	Estimated biomass burned for areas with detections	Mean area weighted fuel consumption [t/ha] (in well observed fires)
PNCM	95,179	65,752	44,258	3.10
ESEGT	682,582	634,658	580,994	3.40
PEJ	332,770	310,707	262,449	4.04
Total	1,110,530	1,012,452	887,700	3.56

Table 4: *Estimate of CO_2, CO, and CH_4 emissions for the three conservation units*[1]

		Emissions [t]		
Park	**Burned Biomass [t]**	**CO_2 emissions**	**CO emissions**	**CH_4 emissions**
PNCM	95179	160,471	5,996	185
ESEGT	682582	1,150,833	43,003	1324
PEJ	332770	561,050	20,965	646
Total	**1122035**	**1,891,751**	**70,688**	**2,177**

[1] Emission factors: Mass of species emitted per kg biomass burned: [g/kg] (Low bound/high bound): CO_2: 1,686 (1,648/1,724); CO: 63 (46/80), CH_4: 1.94 (1.09/2.79)

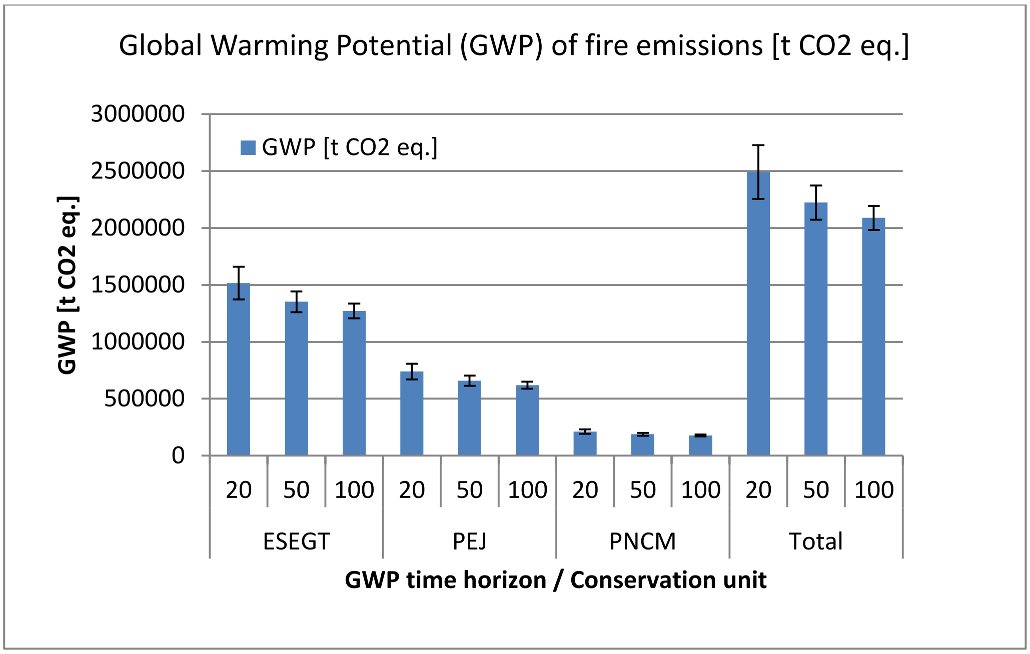

Figure 12: *Global warming potential of fire emissions over a 20, 50 and 100 year time horizon for the three conservation units. Error bars indicate approximate range of uncertainty introduced due to the variability of emission factors (conversion of biomass burned to emissions)*

Applying the emission factors of Akagi et al, and the GWP's of IPPC to our data, we find that fire emissions from all conservation areas have a global warming potential equivalent to about 2.5 Mt CO_2 on a 20 year time horizon, and about 2.1 Mt CO_2 on a 100 year horizon. GWP is lower for the longer time horizons since effects of methane and CO emissions in relation to CO_2 diminish over time. Uncertainties due to different emission factors will be between +/- 10% (20 yrs.) and +/- 5% (100 yrs.) based on the variability for savannah landscapes given by Akagi, Yokelson et al (2011). Depending on the GWP time horizon and the emission factors applied, we estimate that between 71% (20-year horizon) and 93% (100-year horizon) of the GWP can be attributed to CO_2.

3.3 Addressing uncertainty of biomass burned estimates

The uncertainty in the estimate of biomass burned is most probably higher than the uncertainty introduced through the application of emission factors and shall be discussed below. Any measurement has two components of uncertainty: bias and precision, which together define the overall accuracy of a measurement. Bias defines a systematic error, e.g. a low bias describes the tendency of a measurement/estimation to underestimate the true value. Precision describes variability of measurements and is usually described by the standard deviation of the mean from the true value. The concepts are illustrated in Figure 13.

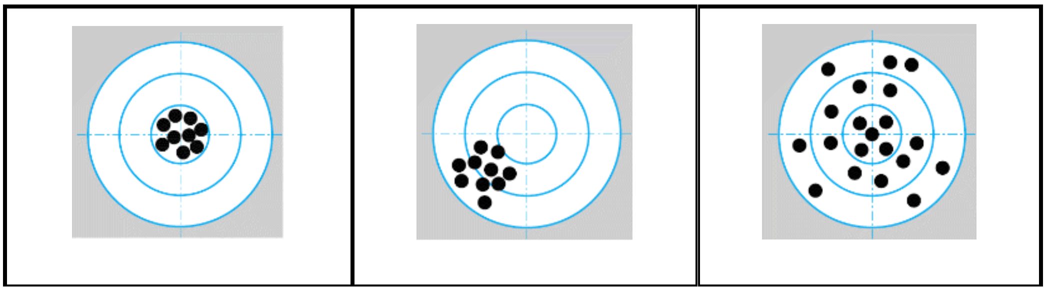

Figure 13: *Illustration of the concept of bias and precision: the true value is in the centre of the dart screen. The left panel indicates a measurement with high precision and low bias – the optimal case. The middle panel indicates a measurement with high precision but is also highly biased, while the right panel indicates a measurement with low precision which is rather unbiased.*

For our approach, the main sources of uncertainties of estimates of biomass burned are:

- Measurement precision of FRP in MODIS: this error depends mainly on the position of the fire front within a MODIS pixel. This uncertainty has been estimated by (Freeborn, Wooster et al. 2014) to be up to 26% of the true value for single MODIS pixels, while it is lower for larger clusters (and hence less important if FRP is aggregated over space and time).
- Error of omission (causing a low bias): Many fires will not be detected by MODIS, either because they are small and burn with less energy than the MODIS sensor can detect, or because they are short-lived and burn only between MODIS overpasses, or because the fire is obscured by clouds. As indicated in Table 2, about 10 % of the burned area does not have corresponding fire detections. We corrected for this by assigning these areas the average fuel consumption per hectare as described in 3.2. Also, for burned areas with fire detections, FRP may be underestimated. From previous work we can estimate this bias to be about 20% (Ruecker, Lorenz et al. 2011). The next version of the emissions estimate should include a correction fir this using FireBird and possibly VIIRS data.

- Error of commission (would cause a high bias): these are false alarms, i.e. erroneous fire detections. The false alarm rate of MODIS is very low, and from evaluation of the detections over the three conservation areas we can justify to neglect this error.
- Conversion of FRP to biomass burned: (Wooster, Roberts et al. 2005) provide an error of +/- 5% for this conversion based on measurements over a range of fuels in laboratory conditions. The error under field conditions will be higher and is currently under investigation based on larger scale burnings that were conducted in Kruger National Park, South Africa (see 3.4.7).
- Estimation of FRP when no observations are available (approximation of the diurnal cycle of FRP): temporal undersampling of FRP is probably one of the largest source of uncertainty, leading to a low precision of estimates. Our modelling approach tries to minimize this error. Due to the limited amount of reference data (FireBird TET-1 will provide reference data for the future), it is difficult to estimate this error. Together with the Institute of Statistics, we are currently developing a method to estimate FRE variability using a so called jackknife approach, which will be shortly described below.

3.3.1 Assessing FRE uncertainty through statistical resampling

The delete-1 jackknife method is a statistical resampling method. It is based on omitting, for each subsample (in our case each fire), one observation at a time (i.e. one MODIS FRP measurement). In our approach we thus derive an estimate of FRE (the total energy release) by purposefully omitting MODIS FRP observations, and recalculating the FRE value. We do this for each fire as many times as we have observations over the fire. The jackknife mean is then the mean of all of these calculations, and the jackknife variance the variance over all observations for this fire. We can then sum up the jackknife mean and the jackknife variances for all fires, and derive the jackknife standard deviation (square root of the variances). It is only feasible to calculate this measure for well observed areas, which make up about 80% of the total area (though only 56% of PNCM, see 3.2).

We then extrapolated these results to all burned areas with detections (Figure 14). In comparison to the mean, PNCM had the highest standard deviation (33% of the mean), meaning that the biomass burned estimates here are highly uncertain here, while PEJ had the lowest standard deviation (16%). For all three areas together, standard deviation was 15% of the mean, resulting in an uncertainty of +/- 30% of the mean at the 95% confidence level[2].

A final version of the jackknife approach and more complete error estimate for emissions will be developed with a new version of the emission estimates. Pathways to reduce uncertainty of biomass burned estimates are discussed in 3.4.

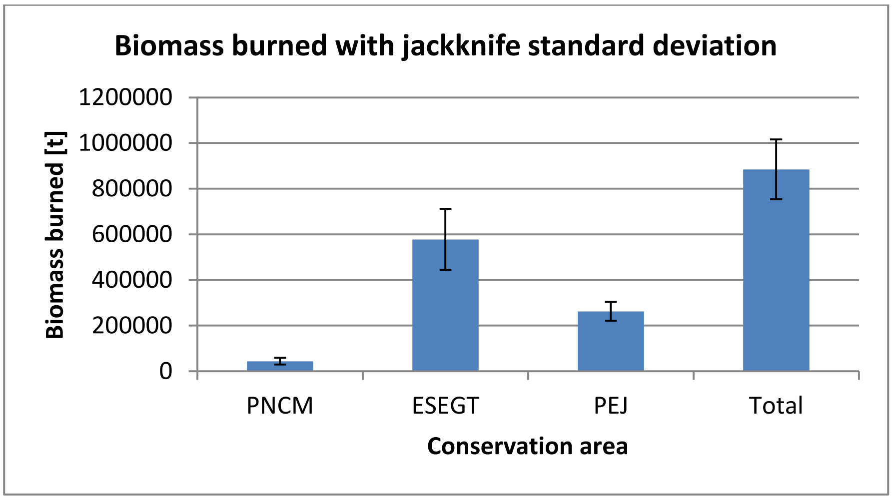

Figure 14: *Biomass burned with jackknife standard deviation estimates (error bars) for the three conservation areas*

3.3.2 Comparison with field and literature values

We received field data collected by UNB researches on fuel load, fuel consumption and fire behaviour that were collected at some of the prescribed burning sites. For those example fires described in 3.1, we also cited the field measurement results of fuel consumption. Due to the limited number of samples available, and the relatively large uncertainty regarding single fire events, as well as for reasons regarding the sampling design of the field samples collected, we compare averaged fuel consumption estimates instead of trying to do a correlation analysis.

[2] Confidence is higher for all areas together than for any individual area due to the increased sample size

Altogether, thirteen samples were available that had GPS coordinates and fuel consumption values attached. Fuel load was assessed collecting several (five to nine) disc pasture meter readings arbitrarily distributed about 20 m around a central point (the GPS coordinate, for some points only approximate location was available). Measurements were repeated after the burn (though not the exact same points could be found), and from the average of pre and post-burn measurements fuel consumption was calculated.

The sampling design was opportunistic, i.e. samples were taken at points were the integrated fire management prescribed burns were taken in such a manner that sampling did not interfere with the burning.

Potentially, a bias was introduced by the way the individual sampling points were collected: for the pre-burn measurement, only bunches with grasses were sampled (thus neglecting the unvegetated soil between clumps), while after the burn, predominantly burned patches were sampled, and neglecting unburned patches. Hence there may be an overestimate of the initial fuel and an underestimate of residual fuel, leading to a high bias of the fuel consumption estimate. It is not clear how relevant this bias is, but at least for the fuel loading it may not be negligible since the grasses (at least at PNCM, which we could visit) in the field grow in bunches with quite some empty space between bunches[3].

Table 5: *Fuel consumption (FC) from remote sensing (RS, our approach) and field data (UNB) (N: Number of samples, SD: Standard deviation). For this statistic, only well observed fires were used (more than three observations)*

Park	RS FC [kg/m²]	SD of RS FC [kg/m²]	N RS	Field FC [kg/m²]	SD of Field FC [kg/m²]	RS / Field data	N Field
PNCM	0.491	0.386	8	0.424	0.142	116%	4
ESEGT	0.534	0.488	20	0.364	0.124	147%	5
PEJ	0.606	0.387	10	0.489	0.231	124%	3
Average/Total	**0.544**	**0.434**	**38**	**0.415**	**0.153**	**131%**	**12**

Results are summarized in Table 5, indicating broad agreement between the field data averages and the remote sensing averages. The remote sensing averages are on average

[3] Information on field sampling is based on discussions with Livia Carvalho Moura during our field visit at PNCM

31% higher than the field data. This may be due to the fact that for most of the field data low intensity prescribed burns were investigated, which may have a lower fuel consumption. Also, for the field data, only grass fuel was sampled, leaving out fuel on leaves and twigs.

In order to use field data for a more extensive validation of remote sensing-derived biomass estimates, a protocol needs to be established detailing field validation requirements. Some baseline requirements will be outlined in the next chapter.

3.4 Next steps to improve the emission estimates

To further improve and consolidate the emission estimates, the following activities should be implemented:

- Add new sensors to the active fire data
- Consolidate and expand the burned area product
- Improve estimates of uncertainty
- Include improved data on fire weather to support statistical modelling
- Establish a field sampling protocol and define a field sampling strategy to reduce uncertainties of biomass burned estimates
- Cross-comparison and integration of Landsat-8 derived fuel load maps
- Conduct field experiments to improve knowledge on the relation between fire radiative power and fuel consumption, reduce uncertainty regarding emission factors for different greenhouse gases, and intercalibrate the different sensors available to estimate FRP.

We discuss details of the different steps below.

3.4.1 Add new sensors to the active fire data

INPE fire detections were available from nine different satellites: Aqua, Terra (operated by NASA), NOAA 15 – 19, S-NPP, GOES-13 (all operated by NOAA), and Meteosat SG 8 (operated by Eumetsat), delivering a total of 3583 fire detections over the three conservation units. The AVHRR sensor on board of the NOAA 15 -19 satellites cannot be used to estimate FRP due to saturation of the sensor. While only 52 detections came from NOAA 15 and 16, NOAA 18 and 19 provided 829 detections. For the remaining 2707 detections, FRP could be retrieved – however, this is not currently done by INPE, and hence

FRP for the emissions assessment was only used for the MODIS sensor on Terra and Aqua which were downloaded from USGS. The emission estimate was hence based on 1230 MODIS detections or 45% of all available detections that can have FRP retrievals.

The other detections that could have FRP retrievals are from S-NPP (771), GOES-13 (320) and Meteosat (381). The VIIRS sensor on board of the S-NPP satellite is similar to MODIS, but has a higher spatial resolution and hence has a better potential for fire detection than MODIS. The VIIRS fire products are declared to be at provisional stage (i.e. not extensively validated), and FRP retrievals are currently at beta stage. Progress is expected for 2015.

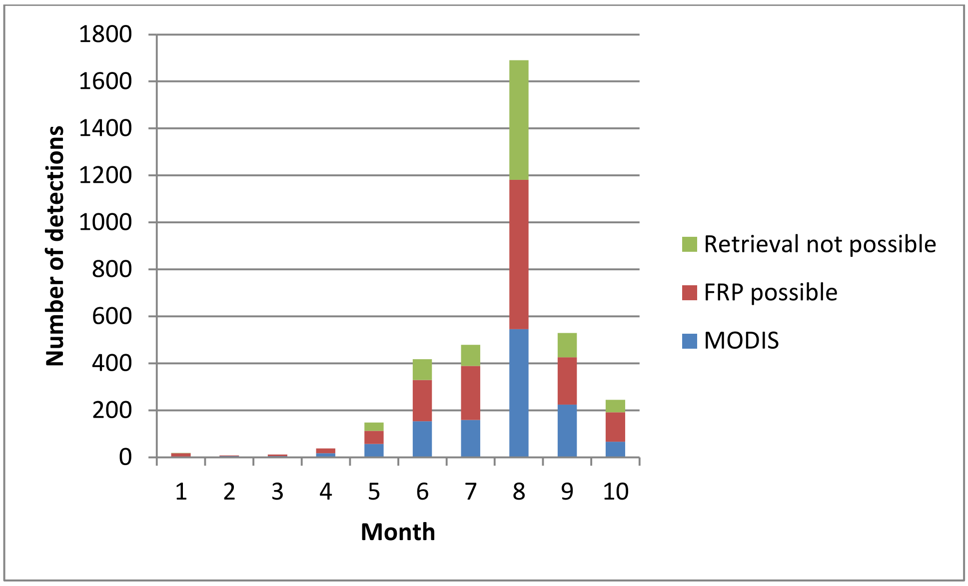

Figure 15: *INPE active fire detections grouped after detections for which FRP retrieval is possible*

A new VIIRS product is in the process of being set up at INPE, using a new 375 m infrared band not present at the MODIS sensor (Schroeder, Oliva et al. 2014). This band has a very good fire detection potential due to its high spatial resolution, but no FRP retrievals will be possible because the band saturates at high temperatures. Once the product is available routinely at the INPE website it can be used as an additional information, e.g. to constrain burn duration for the FRE model. An example is presented in Figure 16.

INPE is also about to add data from the German FireBird satellites, which provide 370 m resolution active fire data with FRP (see chapter 4). FireBird data were evaluated during the prescribed burning field campaign (see chapter 3.1.2). It was possible to even detect fires burning at low intensity (Carvalho Moura, 2014).

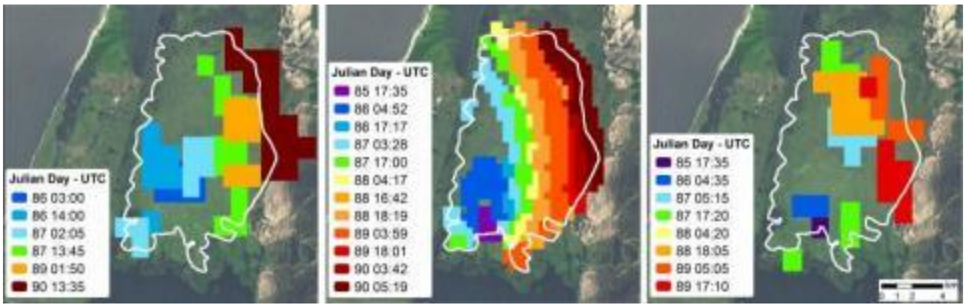

Figure 16: *Fire detected by 1 km Terra/MODIS (left), 375 m VIIRS (center), and 1 km Aqua/MODIS (right) over the Taim Ecological Reserve in Southern Brazil during 26-31 of March 2013 (Julian days 85-90)*[4].

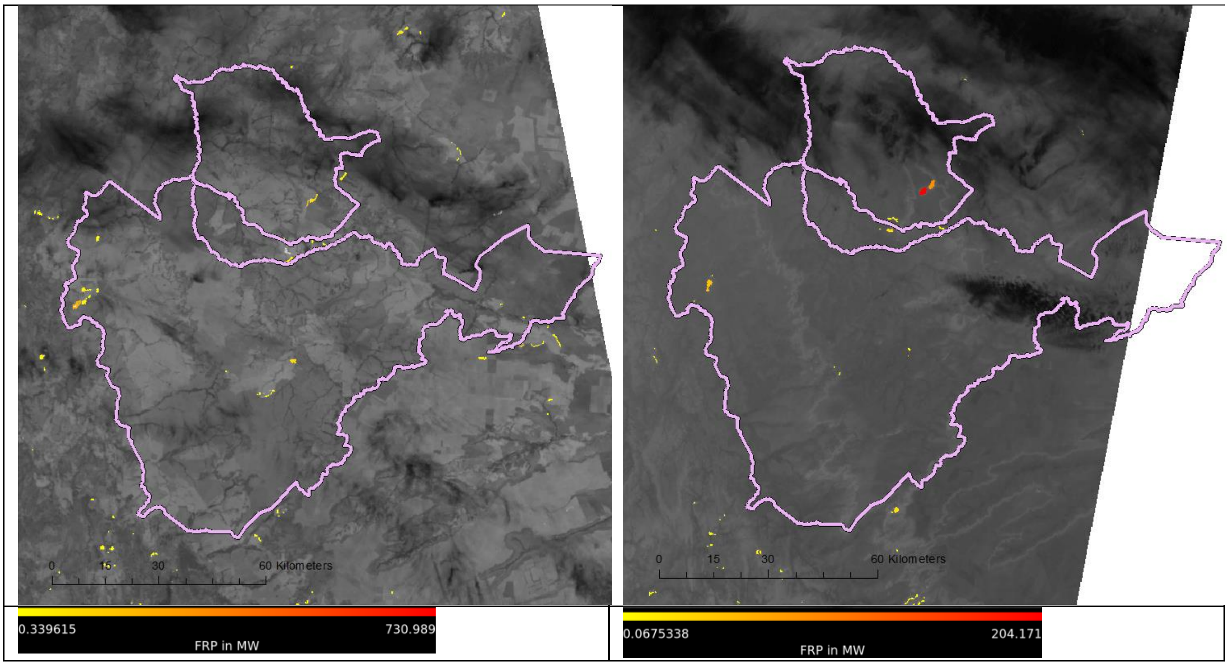

Figure 17: *FireBird TET-1 daytime (left) and nighttime (right) images of PEJ and ESGT for 18th October, 2014. Fire detections are colour coded (see scales). Background is the mid-infrared channel.*

During fire season, a number of TET-1 images were acquired, demonstrating the good fire detection capacity of the sensor.

FireBird data will enhance the fire monitoring capacities and support the further development of the emissions estimates especially through providing a high resolution active fire dataset for validation of coarse resolution data, as well as to support monitoring through the provision of two datatakes within 12 hours approximately every three days.

[4] Figure and caption from the VIIRS active fire website: http://viirsfire.geog.umd.edu/viirs-af-products

Finally, for Meteosat and GOES, algorithms for FRP have been described in the literature (Roberts and Wooster 2008, Xu, Wooster et al. 2010) and integration into the into the INPE processing chain should be relatively straightforward.

3.4.2 Consolidate and expand the burned area product

The INPE burned area product used for our analysis appears to have a high accuracy for burned area detection, and is an excellent basis for emissions estimation. To make processing more straightforward, it would be good to make some minor changes to how the data are delivered:

- Provide the start and end dates of each scene pair analysed
- In the final product remove boundaries between adjacent scenes to provide a seamless product (unremoved boundaries between scenes may cause artefacts in emission estimates)

A major enhancement to the current INPE method would be to not only process cloud-free or near cloud free Landsat scenes pairs. Excluding partly cloudy scenes causes a large error of omission in some areas – this was especially noted in Chapada das Mesas, were probably about half of the total burned area was not mapped. The implementation of a cloud mask, and inclusion of analysis of partially cloudy scenes would probably help to reduce this error.

3.4.3 Improve estimates of uncertainty

ZEBRIS continues work with the Institute of Statistics, University of Munich, to further improve the uncertainty estimates for our model. These will be implemented in the next version of our biomass burning emissions, and reprocessing will be done after input data have been further consolidated and improved.

3.4.4 Include improved data on fire weather to support statistical modelling

Currently, we use fire weather data from a recent global dataset, which has not yet been validated. In order to improve the model using good quality local data, additional analysis shall be conducted within the framework of a master's thesis. The thesis concept, presented by Carol Barradas from ESEGT, is currently under evaluation (within the ICMBio master's programme) and shall be decided upon in January, 2015.

Main tasks to be carried out for the thesis are:

- Collect and analyse time series data from available weather stations in Tocantins
- Derive the Canadian Fire Weather Index and its sub-indices
- Derive the modified Monte Alegre index
- Use statistical analysis to:
    - compare the data derived from local stations to a global gridded dataset of the Canadian FWI
    - assess the relationship of the Canadian FWI (and its subindices) and the (modified) Monte Alegre formula to:
        - fire occurrence in different land cover types
        - mid-day fire radiative power in different land cover types

Once a consolidated dataset is available, and relationship with FRP has been established, the FWI data shall be integrated into the model and replace the current global dataset.

3.4.5 Establish a field sampling protocol

Field data on fuel consumption have been collected along with the prescribed burning campaigns in the three parks (see 3.3.2), and have been very helpful to provide a general idea of the plausibility of our results. To do a proper quantitative validation however, a detailed sampling strategy needs to be defined and discussed with UNB researchers. Some major elements for such a strategy are described below:

- Sampling of all fuel categories: though grass is the main fuel and driving fire behaviour, other categories like tree leaves and woody debris, but also twigs or small branches can be consumed (see e.g. (van Leeuwen, van der Werf et al. 2014). The assessment should therefore consider these categories and devise a way on how to adequately sample them.
- Stratification of fuels after land cover categories: an adequate strategy for fuel loads in different land cover/land scape types needs to be devised.

- Spatial sampling design: for the location of samples, and the sampling scheme (transects, point samples etc.), as well as the necessary type and number of samples, a sampling design needs to be developed. It should take into account spatial variability of the sampled quantities, which decisively impact the uncertainty of the sampled parameter estimates.
- Assessment of combustion completeness: Calculating combustion completeness needs to be assessed through a pre- and a post fire sample. This is best obtained either from experimental plots of limited size, or from systematically sampling prescribed burn areas. In the latter case this needs to be coordinated with the prescribed burning schedules, and pre-fire sampling needs to be implemented sufficiently ahead of the burn in order to implement an adequate sampling scheme.

A field protocol shall be designed in close cooperation with UNB and the consultant on fuel maps in order to obtain the necessary samples with high accuracy. This would greatly help in the validation of the biomass consumption estimates.

3.4.6 Cross-comparison and integration of Landsat-8 derived fuel load maps

Qualitative fuel load maps have been produced to support planning for the 2014 fire season by RSS GmbH. These maps shall be calibrated with field samples (see previous paragraph). If calibration is possible, the fuel load maps would provide a quantitative estimate of dry phytomass and can be compared against the fuel consumption estimates to derive an additional indication on whether the fuel consumption estimates are plausible. In a second step, integration of the fuel load maps into the statistical model shall be evaluated. The maps can potentially help further improve the model for selected areas for which the maps are produced.

3.4.7 Field experiments to improve knowledge on biomass burning emissions

Field experiments can substantially help to improve knowledge on the relation between fire radiative power and fuel consumption, reduce uncertainty regarding emission factors for different greenhouse gases, and intercalibrate the different sensors available to estimate FRP. Such an experiment was conducted by an international crew and NASA funding support in the Kruger National Park (South Africa) in 2014. The experimental setup included a hand-held infrared camera operated from a helicopter, delivering continuous observations of FRP over the burn time, thus enabling the temporal integration of FRP and derivation of a fuel consumption estimate, which than can be compared to field samples taken before and after the fire. It was also planned to measure emission factors using a Fourier spectrometer, but unfortunately the equipment was damaged during transport and could not be repaired on site. Ten fires were implemented on established experimental plots in the park and made coincident with satellite overpasses of Aqua and Terra, S-NPP and TET-1.

It is recommended to implement such an experiment with the help of international collaborators in one of the pilot areas in 2015. This would greatly help to reduce uncertainty of emission estimates and build confidence in the derived products.

Figure 18: *experimental fire in Kruger National Park, and helicopter with thermal camera hovering over the fire.*

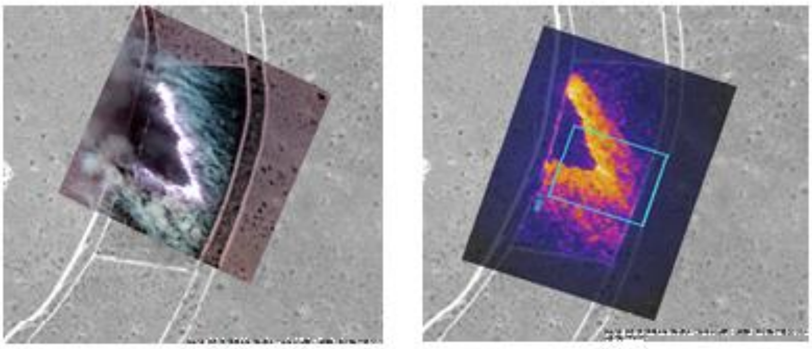

Figure 19: *left: georeferenced VIS/NIR image of the experimental fire taken from the helicopter overlaid over a high resolution satellite image. Right: georeferenced mid-infrared image showing the fire front and temperature (yellow to purple colours for hot to cool areas) – such an image can be evaluated quantitatively to derive FRP.*

4 MAIN RESULTS OF TALKS BETWEEN INPE AND DLR ON COOPERATION IN FIRE MONITORING

The Cerrado Jalapao project helps facilitate a closer cooperation between INPE and DLR in fire remote sensing with a special focus on the usage of the FireBird data. ZEBRIS provided input to the coordination of talks between INPE and DLR on satellite based fire monitoring held at DLR's premises in Berlin between 10th and 14th November, 2014. The talks followed up meetings between DLR and INPE representatives held in Sao Jose dos Campos at the end of 2013, as well as various telephone conference and email exchanges.

The main topics covered were:

1. Usage and distribution of FireBird data by INPE
2. Reception of FireBird data at INPE's ground station
3. Opportunity of flying a fire enabled infrared sensor on a future Brazilian mission
4. Programme of cooperation (PoC) AEB - INPE – DLR: SAFIM

1. Usage and distribution of FireBird data:

FireBird data shall be delivered to INPE in a routine way for usage in INPE's fire monitoring system. The specifics for the intended cooperation in this area are listed below:

- Type of product delivered by FireBird:
  - INPE will receive FireBird level 2 data consisting of georeferenced fire masks with tabular information containing the main fire cluster attributes: number of pixels, fire temperature, fire area, FRP. The fire masks are currently not produced, but shall be produced routinely starting in early 2015. Fire masks shall contain information on the background validity and cloud cover similar to the information provided in comparable fire products.
- Establish ordering and delivery procedure:
  - An ordering procedure shall be established, by which a designated person at INPE shall be able to order images following the DLR procedures used for ordering new FireBird acquisitions using the DLR Swath Preview and Ordering Tool (SWOT). Acquisition of images is subject to best effort as specified in the

FireBird data policy. It must be clarified if image ordering by INPE shall have precedence over routine monitoring as described below in case of conflicts.

- A delivery procedure shall be established between DLR and INPE enabling a fully automated chain for ingesting new FireBird images into INPE's fire monitoring system. The procedure could be based on offering an automated pick-up point via FTP for any new FireBird level 2 data.

- Routine monitoring of specific areas starting with Cerrado Jalapao project areas:
    - The Cerrado Jalapão project will deliver outlines of project monitoring areas (mainly protected areas where project activities in integrated fire management are implemented) to DLR as shapefiles for routine monitoring. DLR will propose a monitoring scheme and communicate back to the project. Data will be routinely delivered to INPE via the established procedure. Monitoring shall commence in early 2015 (March).
    - Further areas of interest (e.g. in Amazonia, Caatinga ecosystems) shall be specified by INPE.

2. Reception of FireBird data at INPE's ground stations

INPE shall receive FireBird data at its own ground stations as soon as possible – if feasible starting the first half of 2015.

The following steps that lead to the desired goal have been agreed upon:

- Exchange of specification documents: INPE sends specifications of its S-band stations to DLR, DLR delivers to INPE specification of the satellite transmitter
- DLR sends specifications for routine operations for downlink to INPE
- INPE and DLR will agree upon and perform a tracking test and experimental downlink
- After a successful experimental downlink, an „operational downlink" based on routine contact slots shall be established
- Downlinked data shall be delivered to DLR for further processing to level 1 and 2 products. Processed products will be returned to INPE based on the agreed upon procedures (see point 1). Processing is quick and will be performed within less than one hour after reception.

- INPE is aware of certain framework conditions:
    - TET-1 cannot downlink and acquire images at the same time. Image acquisition has priority over downlink
    - Downlink through INPE's ground station will free onboard-memory for TET-1 acquisitions. The downlinked data are not necessarily over Brazil or other areas of interest for INPE. Data are downlinked based on the principle "first in – first out".
    - A downlink through INPE's Southern ground station will have the advantage that the probability of data acquired over Brazil is higher in the descending node while the probability that memory will be freed for acquisition over Brazil is higher in the ascending node.
    - More detailed scenarios shall be developed between INPE and DLR over the coming months.

3. Opportunity of flying a fire enabled infrared sensor on a future Brazilian mission

INPE is interested in DLR's fire monitoring technology, and sees a potential opportunity to fly a fire enabled infrared sensor in a future Brazilian mission. The following points describe the rough technical (not institutional or financial) framework of such cooperation:

- Baseline would be the Brazilian Multi-Purpose Platform (MPP), such as to be flown in Amazon-1 mission
- Possible sensor concepts were discussed and it was agreed to do a definition study on flying a next-generation IR-sensor as a secondary payload on a future Brazilian mission. Such a definition study shall be based on a cooperation without exchange of funds, and shall be used to further define the following points:
    - Define spectral channels, swath and resolution
    - Define sensor baseline technology: different sensor technologies were discussed since the BIRD-type HSRS-sensors have been superseded by a new generation (offering a wider swath) and an optimal configuration needs to be defined.
    - Define possibilities to fit an infrared sensor as an additional payload on the Multi-Purpose Platform and define a possible mission (Amazon 1, Amazon 2)

- Define possible additional applications

4. Satellite Fire Monitoring Programme

A draft Programme of Cooperation (PoC) between the Brazilian Space Agency (AEB) and DLR has been prepared in advance of the meeting; the PoC is to be implemented by INPE. The PoC shall be amended or altered over the next weeks as necessary due to the outcomes of the meetings, and passed to DLR's legal department. The PoC document has already passed through INPE's department of international cooperation. The PoC shall be completed as soon as possible and cover mainly points 1 and 2 discussed during the meeting. Extendend cooperation such as flying a fire enabled infrared sensor on a future Brazilian mission should be subject to an amendment or a new PoC. The PoC is based on the principle that there will be no exchange of funds and no liabilities.

The PoC shall be complemented by a work plan which will cover the specifics of cooperation and timelines. This will make the PoC a living document. It is the task of each party to calculate and plan for work and costs regarding the PoC.

5. Next steps

The immediate next step for the cooperation is the drafting of a work plan. This will include the establishment of a timeline, and for each party, an (internal) estimation of workload and cost. The Cerrado Jalapão project can continue its support in facilitating the timely establishment of such a work plan.

Additionally, there is interest in fostering collaboration between DLR's Earth Observation Center (EOC) and INPE beyond FireBird. This cooperation should be furthered in a separate process/work plan.

5 MAIN FINDINGS AND RECOMMENDATIONS

- Analysis of emissions in the three pilot areas results in a preliminary global warming potential estimate of an equivalent of 2.1 Mt of CO_2 on a 100 year time horizon, and of 2.5 Mt of CO_2 on 20 year time horizon, with a share of Non-CO_2 GHG's (methane and carbon monoxide) between ~30 % (maximum estimate at 20 year time horizon) and ~10 % (minimum estimate at 100 year time horizon).
- This corresponds to about 1.1 Mt of burned biomass. Preliminary uncertainty estimate of burned biomass is about +/- 30%, while preliminary estimate of uncertainty due to emission factors is between 10% on a 20 year time horizon, and 5% on a 100 year time horizon.
- About 60% of emissions are from ESEGT, about 30% from PEJ, and about 10% from PNCM. Uncertainty is high for PNCM (estimated +/- 60%), partly due to incomplete data, and lower for the other areas.
- Uncertainties can be reduced through consolidation and expansion of burned area data, inclusion of data from additional satellites and sensors, and inclusion of improved fire weather data. Inclusion of fire weather data into modelling, and data validation, shall be supported through a master's thesis
- To further constrain estimates, it is recommended to conduct systematic field studies on fuel load and combustion completeness for validation. A protocol for the sampling activities shall be established in cooperation with UNB
- It is further recommended to conduct fire experiments to better constrain emission factors as well as the conversion of FRE to biomass burned, and to validate FRP measurements from different sensors
- To enhance monitoring capacities, use of the German FireBird satellites shall be increased through furthering the cooperation between DLR and INPE. To achieve this objective, INPE and DLR agreed to take measures for targeted data collection of FireBird data as well as FireBird data reception at INPE's receiving stations. Both parties also discussed opportunities to collaborate with the objective of flying a fire-enabled infrared sensor on future Brazilian mission.

- Besides further elaborating methods and technologies for emission estimation, the next steps for emissions estimation should aim at constructing a time series going back more than ten years to establish a longer term emissions baseline, against which to benchmark efforts to reduce emissions through integrated fire management.

6 LITERATURE

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7 APPENDIX

7.1 List of Deliverables

1. Program of visit of INPE delegation to DLR
2. Meeting notes of the INPE-DLR meeting
3. This report
4. Power point presentations of findings

7.2 Contact Information

Gernot Ruecker

ZEBRIS GbR

Lipowskystr. 26 D - 81373 München

Tel.: +49 - 89 - 1893789 - 30 (-36)

Fax: +49 - 89 - 1893789 - 39

Internet: www.zebris.com