# GENERATING EMISSIONS AND METEOROLOGY TO MODEL THE IMPACTS OF BIOMASS BURNING EMISSIONS ON REGIONAL AIR QUALITY IN SOUTH AFRICA

Warren Carter[1] *, Mark Zunckel[2] and Roseanne Diab[3]

[1]CSIR, P O Box 17001, Congella, 4013, Durban, South Africa.

[2] uMoya-NILU Consulting (Pty) Ltd, PO Box 20622, Durban North, 4016, Durban, South Africa.

[3]School of Environmental Sciences, University of KwaZulu-Natal, Westville College Campus, Durban 4041, South Africa.

## Abstract

Biomass burning is a source category that is often ignored in pollution dispersion modelling simulations. This study presents a unique contribution to the quantification of emissions from biomass burning for high resolution modelling.

Previous work focussed on quantifying gaseous and aerosol particulate pollutants from vegetation fires for the main burning season (July – September) in the Kruger National Park (KNP), 2000. The current included the development of a spatially and temporally resolved emissions inventory using a bottom up approach in a GIS (Arc GIS vers. 9.1). Further to this, back and forward wind trajectories were computed for the domain of interest, in order to investigate the possible transport of pollutant emissions.

The bottom-up approach and sources of data and assumptions used to generate the emissions inventory are discussed. The domain of interest extends 600km from north to south and 600km west to east around the Kruger National Park. The grid cell resolution is 5km x 5km regular intervals. The quantification of high resolution emissions in this work will be used further as input for regional scale atmospheric modelling simulations, in order to determine the potential impacts of biomass burning emissions on air quality.

This study presents a unique contribution to the quantification and high resolution modelling of emissions from biomass burning and will present the methodology used to estimate emissions, the relevant emissions inventory, and results of air mass transport in the region

*Keywords*: Biomass burning, emissions inventory, trajectory analysis.

## 1. Introduction

The Kruger National Park (KNP), situated on the border of South Africa and Mozambique was intensively studied for its emission contributions and effects on the atmosphere during both the SAFARI-1992 and SAFARI-2000 campaigns. It is a region that is characterised by dry season biomass burning with more than 52% of its fires occurring throughout the winter months. As an initial step in this study, pyrogenic emissions from savanna and grassland biomass burning, specifically those in the dry season (main burning) within the KNP during 2000 are quantified. The emissions inventory resolved in both space and time, is developed for particulates pollutants of diameter less than 10 microns and less than 2.5 microns ($PM_{10}$ and $PM_{2.5}$ respectively), oxides of nitrogen (NOx) and sulphur dioxide ($SO_2$). The emissions inventory was developed in a GIS (ArcGIS vers. 9.1) format, which allowed for spatial representation and manipulation of the data. These emissions are used as input for regional scale modelling simulations, the objective of which is to determine the impacts on ambient air quality.

It is known and well documented in Africa (Yokelson *et al.*,2003, Sinha *et al.*, 2003, Hobbs *et al.*, 2003, Andrea and Merlet, 2001) that these fire events can emit substantial amounts of gaseous and particulate air pollutants in certain regions. Hence it is important to include the contribution of pyrogenic emissions from biomass burning in any model simulations. Few regional scale modelling studies in southern Africa have included the contribution from this source to examine the effects on regional air quality and atmospheric chemistry. This is largely due to the uncertainty in individual parameterisation estimation and subsequent regional emissions estimates.

The emissions data were spatially disaggregated over a modelling domain extending 600 km from north to south and east to west. Regular grid spacing of 5km x 5km intervals were used which amounted to 120 grid points. The grid originates at 675.278 km (x) and 7066.080 km (y) (UTM) which corresponds to the west and south projected boundary coordinates respectively. Figure 1 illustrates all fires identified in Kruger National Park. The inventory takes into account fires caused by malicious intent (i.e. arson) and management practices (i.e. scheduled burning and firebreaks).

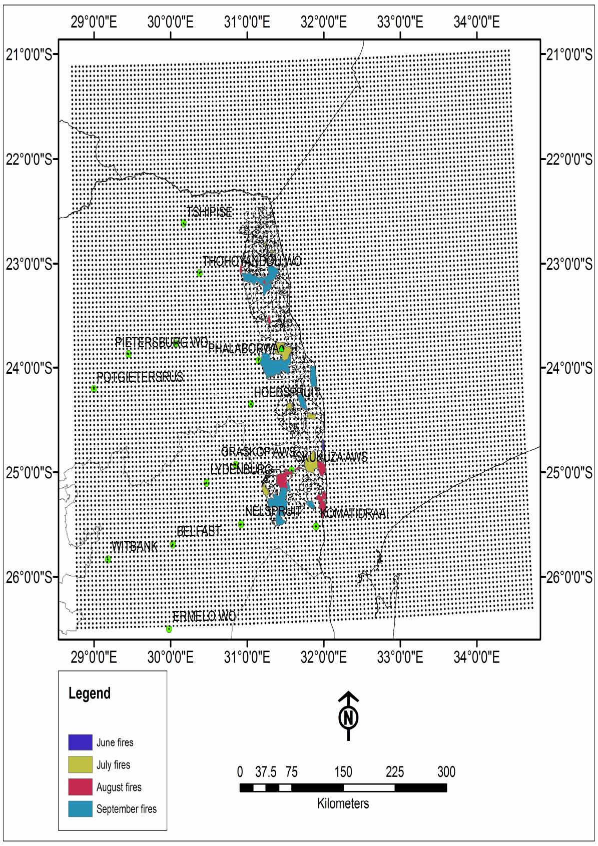


Figure 1. Kruger National Park Modelling Domain showing classification of fire polygons and SAWS meteorological stations used for meteorological modelling.

## 2. Development of Biomass Burning Emissions Inventory

### 2.1 Data sources

Generally two approaches are applied to estimate emissions from biomass burning. Satellite remote sensing is the most recently developed approach. This method is however often associated with a very course temporal resolution with measurements being captured at twice daily overpasses, e.g. TERRA and AQUA MODIS satellite. Although it is possible to observe fire events and quantify pollution measurements using this method, it is complicated by the variable nature of fire start and ending times. As such, this approach is associated with a high level of uncertainty.

An alternative approach to quantify emissions from biomass burning is to use a bottom-up approach, as used in this study. This method involves estimating and calculating different parameters to derive estimates of pollutant release. There is also a degree of uncertainty associated with individual parameterisations however.

Diurnal profiles from fire observations at fine temporal resolution, e.g. hourly measurements are better suited to distribute emissions data for atmospheric models as opposed to disaggregating emissions uniformly (i.e. throughout a 24 hour period). This allows for hourly impacts on air quality to be determined by atmospheric models.

The data (and their sources) required to calculate the gridded pollutant emissions were the total area burned (ha) and perimeter (km) of each individual fire event throughout a full burning season; the dynamic fuel load (kg/ha), vegetation specific emissions factors (g/kg) and combustion completeness. Fuel load information was taken from a study conducted as part of the SAFARI 2000 campaign (Hely *et al*, 2003). Vegetation species specific emission factors were allocated to the total fuel consumed. Emission factor data was taken from recently published studies by Andrea and Merlet (2001) and Ward (1996). Data from these studies are the most recent and reliable for late dry season fires in southern Africa (Hely *et al*, 2003). Information relating to the location and duration of each fire event, was acquired from the SAFARI 2000 literature (CD-ROM Series : Vol 3).

## 3. Emissions Estimation Procedures

Development of the GIS-based emissions inventory involves integration of fire polygon maps into ARC/Info. The irregular polygons were gridded to 5km resolution. Important metadata accompanying the polygon shapefile included fire start date, time, size and geo-location. . The biomass burning emissions inventory reports hourly emissions estimates of particulate ($PM_{10}$ and $PM_{2.5}$) and gaseous pollutants $NO_x$ and $SO_2$.

The emissions were calculated by multiplying fuel consumption estimates by the emission factor for each pollutant species (Equation 1). Fuel consumption was determined by applying a combustion completeness factor (0.95) to the available fuel load (Equation 2).

The basic calculation of quantifying aerosol and gaseous emissions (*M(X)*) from biomass burning, follows the methodology of Seiler and Crutzen (1980) :

$$M(X) = BL \times BE \times E \qquad \text{(Eq.1)}$$

where, $M(X)$ are the amount of emissions released (g of kg), $BL$ I the biomass fuel load (kg/$m^2$), BE is the combustion efficiency (unit-less fraction)and $E$ is the amount of pollutant emission released per unit of dry matter or plant material (g($i$)/kg).

This is a commonly used method for estimating emissions from biomass burning and the same approach was followed in this study. The total biomass in the area burned for each month was determined by multiplying the biomass density (fuel availability) (kg/ha) for each fire event in each month by the combustion completeness in order to determine the total area burned in each month (Figure 2, Equation 2).

$$A = B \times CC \qquad \text{(Eq.2)}$$

where, A = Area burned kg fuel / ($km^2$) or (ha) per month in, B= Biomass density (kg/$m^2$) / (kg/ha),and CC= Combination completeness (0.95).

## 4. Results

Most fires occurred in the dry winter season in KNP in 2000. Between 1 June and 30 September, 2000, a total of 45 fires were identified. This represented approximately 52% of the fire events throughout the year. The largest fire event occurred on 1 September, 2000, in which a total area of 64515 ha was burned, covering a perimeter of 155.43 km. The smallest fire (perimeter 0.95 km) in which 5 ha were burned, occurred on 19 August, 2000. In total, 351294 ha were burned from the beginning of June to the end of September (Figure 2). This covered a total perimeter of 1575 km.

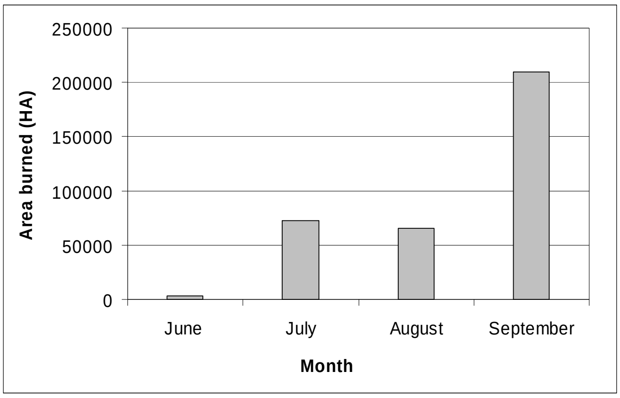


Figure 2. Total area burned by month in Kruger National Park, 2000.

Figure 2 presents the total area burned for each month in the period of interest. Most fires occurred later in the dry season (September) with fewer fires having occurred at the beginning of the dry season (June). Five fire events occurred in June, burning a total area of 2810 ha. In July, eleven large fire events burned a total area of 73054 ha. Although more fire events occurred in August, a smaller area burned (65536 ha) as a result of these being much smaller fires. Approximately ten fire events occurred in September with an estimated total burned area of 209894 ha. In total 351294 ha of area were burned.

The emissions estimates represent the contribution from all biomass burning fires from 1 June 2000 to 30 September, 2000. Only pyrogenic emissions from savanna and grassland biomass burning were considered. Vegetation maps in GIS indicted the underlying vegetation as predominantly savanna and grassland.

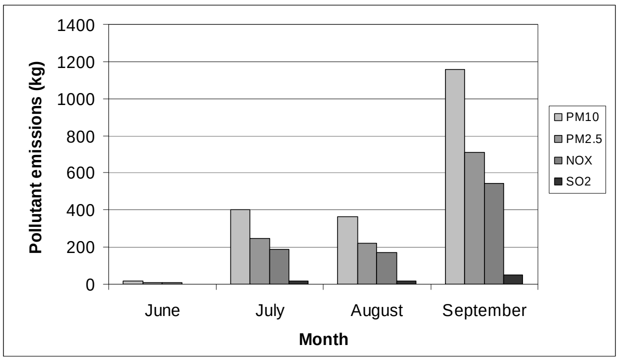
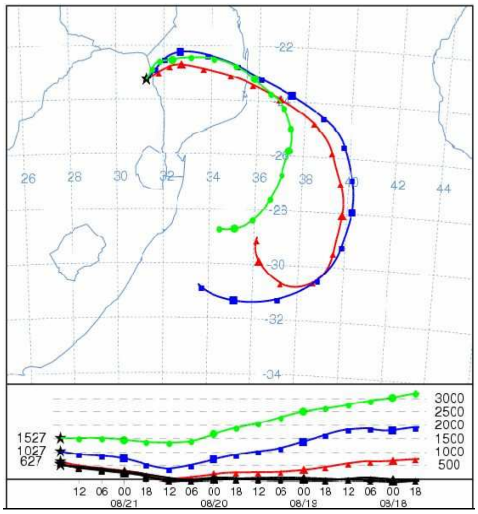


Figure 3.Monthly pollutant emissions from biomass burning in Kruger National Park, 2000.

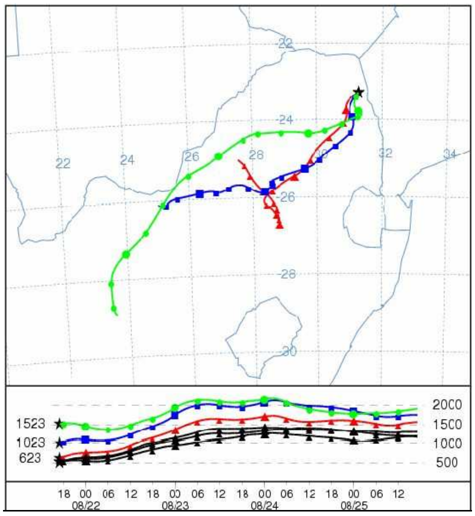
The greatest amount of pollutant emissions released from the biomass fires was for $PM_{10}$ (1938.97 kg). This was closely followed by fine fractions particulate emissions ($PM_{2.5}$), (1191.41 kg). Pollutant emissions from NOx and SOx were 911.08 kg and 81.76 kg respectively.

### 4.1 Air Mass Trajectory Analysis

Possible impacts to regional air quality from regional transport were investigated through computation of backward and forward trajectories. Prevailing wind patterns for the 21 August 2000 indicate east to west air mass transport. The Hybrid-Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model (http://www.arl.noaa.gov/ready/hysplit4.html) was used to generate back and forward wind trajectory simulations for the transport analysis.



(a)



(b)

Figure 4. Back (a) and forward (b) trajectory air parcels (100-m in red, 500-m in blue and 1-km in green) terminating and emanating near a fire event occurring on 21 August 2000.

Figure 4 shows 96 hour back and forward trajectory air parcels computed with NCEP global re-analysis meteorology using the HYSPLIT model. Anti-cyclonic flow of air masses from back trajectory air parcels at different vertical profiles are evident. The trajectories were computed for 100 m (red), 500 m (blue) and 1000 m (green) above ground level (AGL) for four days. The back trajectories indicate anticyclonic recirculation of winds off the South African east coast towards the Kruger National Park (Figure 4a). This has been identified as the dominant transport pattern in the southern Africa Winter (Tyson and Preston-Whyte, 2000) with up to 80% frequency of occurrence. It is also confirmed by an analysis of dominant synoptic scale systems occurring over southern Africa in 1992, which showed that anticyclonic conditions occurred 70%-80% of the time in midwinter months (Tyson *et al*., 1996). The vertical component of the back trajectories show the occurrence of subsiding air throughout the period. Forward trajectories show the transport of air masses from the Kruger National Park towards the interior in a south west direction. Additional computation of forward trajectory air parcels in September revealed similar transport patterns as well as anti-cyclonic recirculation of air from the interior, exiting the east coast.

## 5. Conclusions

Pollutant emission from vegetation fires can have significant impacts on air quality, both at the local and regional scale. The construction of an emissions inventory is the first step towards determining the contribution of emissions from fires and examining impacts to air quality. This work has discussed how an emissions inventory from fire events in the Kruger National Park in 2000 was generated.

The frequency of burning and the emissions data indicate that biomass burning is an important contributor to emissions in the region, which could potentially have impacts for air quality.

From 1 June to 30 September 2000, a total of 45 fires events occurred in the Kruger National Park. This resulted in a total of 351294 ha area burned and 1938.97 kg of $PM_{10}$ atmospheric emissions. Data used to construct the emission inventory were sourced mainly from the SAFARI 2000 study. The emissions inventory was built in a GIS, using a bottom-up approach.

Analysis of wind data using forward and backward air mass trajectories passing through a fire event in the central region of Kruger National Park indicate possible regional transport of pollutant emissions. The direction of prevailing winds at different vertical profiles suggests a possible influence of transport of emissions from surrounding cities to the region.

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