SAFARI 2000 Biomass Burning Emissions, Selected Sites, Dry Season 2000

Abstract

Biomass burning is a major source for atmospheric pollution over southern Africa and globally (e.g. Crutzen et al, 1979; Crutzen and Andreae, 1990). Biomass burning from the African continent currently accounts for about 35% of the global total (Logan and Yevich, unpublished) and is expected to rise. Biomass burning emits a large variety of gaseous and particulate compounds with significant implications to atmospheric and biogeochemical cycles. Consequently, quantification of biomass burning emissions is essential for understanding and predicting associated environmental impacts. However, despite intense scientific study over the past two decades, global and regional emissions of some compounds are still poorly constrained.

A total of 60 biomass burning experiments were carried out between November 2000 and January 2001 in three regions of southern Africa that are representative of major ecosystem types in the region: Etosha National Park in northern Namibia, Kruger National Park in north-east South Africa, and woodland sites in Zambia and Malawi. A suite of organic halogen-containing gases (CH_3Cl, CH_3Br, CH_3I, CH_2Cl_2, CH_2Br_2, CH_2I_2 and others) were measured in the exhaust of these fires as well as the smoke mixing ratios of CO, CO_2, NO_x, CH_4 and N_2O. Samples of fuel and ash were collected and processed for subsequent analysis of elemental composition of carbon, chlorine, bromine, iodine, nitrogen, and sulfur. These data allow investigators to assess the elemental mass balance for each experimental burn as well as the corresponding emission factors for individual compounds as functions of the biofuel composition.

Background Information

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Project: SAFARI 2000

Data Set Title: SAFARI 2000 Biomass Burning Emissions, Selected Sites, Dry Season 2000

Site: Southern Africa

Data Set Citation:

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Web Site: http://jurgenlobert.net/projects/mpi_safari/

Data File Information

A total of 60 biomass burning experiments were carried out between November 2000 and January 2001. A suite of organic halogen-containing gases (CH_3Cl, CH_3Br, CH_3I, CH_2Cl_2, CH_2Br_2, CH_2I_2 and others) were measured in the exhaust of these fires as well as the smoke mixing ratios of CO, CO_2, NO_x, CH_4 and N_2O.

Data File Types	File Name	Ver.	Ver. Date	Contact Person
Base data for individ- ual fires (time series of engineering data, CO_2, CO, NO_x fluxes)	Multiple. See "Base Data for Individual Fires" section below.			
Fuel and ash elemental analyses (C, N, S, P, Cl, Br, I, K, Ca, Na, and Mg)	s2k_CNX_analysis _5.csv	5	05-Nov-2003	Bill Keene
Overview of experiments sorted by date. Integrated mass fluxes of CO, CO_2, NO_x and total mass of burned elements relative to the fuel element (not complete yet). Also contains above fuel analyses.	integrated_emissions_ CNX_4.csv	4	17-Feb-2003	Jürgen Lobert
Emissions of soluble, gaseous compounds: (NH_3, SO_2, CH_3COOH, HCOOH, HCl, HONO, and HNO_3). Emissions of total inorganic Cl and Br; ionic and elemental compositions of particles.	s2k_elemental_emiss_ factors.csv s2k_standard_emiss_ factors.csv s2k_molar_emiss_ ratios_CO.csv s2k_molar_emiss_ ratios_CO2.csv	2	12-Jun-2003	Bill Keene

Base Data for Individual Fires

The files contain engineering data (weight, temperatures, flows, pressures, etc.) as well as the mixing ratios and mass fluxes of CO, CO_2 and NO_x at 1 to 3 second resolution. The file naming convention is the date on which the experiment took place, followed by an "a", "b", "c"... for multiple experiments performed on each day. The temporal range of the data files are from 24-November 2000 to 16-January-2001.

The tables are stored as tab-delimited text files. If the field contains NAN (not a number), this indicates an invalid data point, unless otherwise specified in the the table below. Each file has four header lines followed by two rows of column descriptors with column names and units. A sample file header and field descriptions are found below.

Sample File Header:

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SAFARI 2000 Collaborative Research: Biomass Burning Emissions Over Southern
Africa
J.M. Lobert, W.C. Keene, P.J. Crutzen, unpublished and preliminary data, 2000
http://JurgenLobert.net/projects/mpi_safari/
20010111b Version2 Time step is 1 second Text file only.
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NOTE: The phrase "unpublished and preliminary data, 2000" means that this data has not been formally published yet. ORNL DAAC is archiving the data set with the authors' permission. Please see the SAFARI 2000 Data Policy (http://mercury.ornl.gov/safari2K/Data_Policy.htm) regarding Data Sharing, Authorship, and Acknowledgments.

The bottom line of the header is in the format "Date of experiment, Version#, Date of this version, length of time step; addtl. comments:". The next line (line 5) the headers is the column names and line 6 is the units (see the table below).

Column Header	Description	Units
DateTime	The number of days since 01-Jan-1900 in spreadsheet format. 1.0 is 01-January-1900, 00:00 midnight. The decimal is the fractional day, hence 1.5 is 12:00 noon on 01-Jan-1900.	spreadsheet
ExpTime	Expired experiment time expressed as a fractional day. 0.0 is the start of the experiment, negative numbers are pre-run data before the fire started (typically the first 2 or more minutes).	fract_day
Remarks	**NAN** - designates an empty field **start daq** - start data acquisition **start pumps** - aerosol, filter, and mist chamber pumps started drawing air	text

	re-ignition - fuel was ignited again using the torch (COx was usually adjusted for that if visible) **percent value** - a visual observation of the approximate amount of fuel that was ignited at that point **flame out** - no more significant flames, only smoldering burn **pumps off** - stop of aerosol, filter, and mist chamber sampling **defined end of fire (run, or experiment)** - indicates end of data set (even though the DAQ may have continued to run)	
Marker1	A digital marker to mark certain events explained in "remarks"	numeric
T1	Temperature 1 measured at the sampling point, near the top of the stack.	°C
CO2pressure	Pressure inside the CO_2 instrument. Close but not equal to ambient pressure. In very long experiments (more than 30 minutes), this pressure drops due to the water traps slowly freezing up. The CO_x mixing ratio is corrected for pressure and (internal to the instruments) also corrected for temperature.	hPa
T3	Temperature 3 measured in the fuel bed (not always measured)	°C
AirSpeed	Air speed inside the stack, measured at the sampling point, top of the stack	m/s
T2	Temperature 2 measured at a mid-point, middle of the stack (not always measured)	°C
Weight	Fuel mass	g
Flowrate1	Volumetric flow rate calculated from the airspeed and the cross-section of the stack.	$m^3\ s^{-1}$
Flowrate1corrected	Volumetric flow rate corrected to 0 degrees C. No pressure correction was applied, since the pressure did not change significantly in the stack and was always equal to ambient pressure.	$m^3\ s^{-1}$
CO2	CO_2 mixing ratio in the stack	Mixing_Ratio
CO	CO mixing ratio in the stack	Mixing_Ratio
NOx	NO_x mixing ratio in the stack	Mixing_Ratio
CO2flux	CO_2 mass flux per delta time. Note that delta time is not always 1.0 second and is stated in the file header!	gC/dt
COflux	CO mass flux per delta time. Note that delta time is not always 1.0 second and is stated in the file header!	gC/dt
NOxflux	NO_x mass flux per delta time. Note that delta time is not always 1.0 second and is stated in the file header!	gN/dt

Description of the **s2k_CNX_analysis_5.csv** file

Column Name	Description	Units

Code	3 letter designator (ENP = Etosha Nationa Park; KNP = Kruger National Park; MAL = Malawi; ZAM = Zambia)	ASCII
Sample_ID	Unique number identifier for each biofuel and corresponding ash sample	ASCII
Sample_type	'B' designates biofuel and 'A' ash	ASCII
Biofuel_Ash_num	**for biofuel** - Designate paired analyses (1 and 2) of independently processed (i.e., bagged, ground, weighed, dried, reweighed, and analyzed) subsamples of the same sample **for ash** - Designates number (1 or 2) of experiments during which the biofuel was burned; because burn conditions varied, these are not considered replicates	ASCII
split_field	1, 2, and 3 designate paired analyses of separate subsamples from the same batch of ground sample (splits were taken immediately after grinding)	ASCII
split_lab	1 and 2 designate paired analyses of lab splits from the same subsample	ASCII
burn_id	Designates the ID number (mmdd followed by a, b, c, or d) of the experiment during which the sample was burned	ASCII
C_content	Carbon content - Average of three independent measurements of separate subsamples of each sample	kg/kg dry weight
C_sd	Carbon content standard deviation of replicate analyses	kg/kg dry weight
N_content	Nitrogen content - Average of three independent measurements of separate subsamples of each sample	g/kg dry weight
N_sd	Nitrogen content standard deviation of replicate analyses	g/kg dry weight
S_content	Sulfur content - Individual digest and analysis	mg/kg dry weight
P_content	Phosphorus content - Individual digest and analysis	mg/kg dry weight
Cl_content	Chlorine content - Individual digest and analysis	mg/kg dry weight
Br_content	Bromine content - Individual digest and analysis	mg/kg dry weight
I_content	Iodine content - Individual digest and analysis	mg/kg dry weight
K_content	Potassium content - Average of three independent measurements of individual digests	mg/kg dry

		weight
Ca_content	Calcium content - Average of three independent measurements of individual digests	mg/kg dry weight
Na_content	Sodium content - Average of three independent measurements of individual digests	mg/kg dry weight
Mg_content	Magnesium content - Average of three independent measurements of individual digests	mg/kg dry weight
Comments	Data comments, if any	ASCII

Description of the **integrated_emissions_CNX_4.csv** file.

Column	Description	Units/Format
Experiment #	Unique experiment ID (date and indentifier)	YYYYMMDD (a,b,c)
Site Code	Location and site from which sample was extracted	Code
Site & fuel & type	Sample site, fuel type, fire type	ASCII
Date	Date of experiment	DD-Mon-YY
PTR/MS	If experiment # is indicated in this column, then the PTR-MS system participated (MPI Lelieveld) in this experiment.	YYYYMMDD (a,b,c)
AP-CIMS SO2	If experiment # is indicated in this column, then the AP-CIMS system participated (MPI Andreae) in this experiment.	YYYYMMDD (a,b,c)
Aerosols	If experiment # is indicated in this column, then the aerosol sampling (MPI Andreae) was part of this experiment.	YYYYMMDD (a,b,c)
Sample Type	Type of biofuel	ASCII
Sampling Location Comments	Comments on Sampling Location	ASCII
Fire Type	Type of fire (unless otherwise noted, the burn table was positioned at a 30° angle and fuel loosly arranged)	ASCII
Sample wet weight in field	sample weight after sampling	kg
Sample air dry weight in field	sample weight after drying on location	kg
Moisture content (wet-dry)/dry	ppm moisture after sampling and on-location drying	g H_2O/kg dry
Sample air dry weight in Mainz	sample weight after arrival at destination	kg
H2O added before burn	moisture added before the fire	g/kg air-dry wt

Moisture factor for air-dry fuel	combined moisture factor	dimensionless
Total moisture at burn	final moisture of fuel at experiment	% fraction
Peak temperature in stack	Max temperature in the stack during fire, if > 250°. (blank indicates temperature <250°)	°C
Comments on experiment	Special comments	ASCII string
Unburnt fuel	Amount of fuel left unburned after fire, if any	g
Biofuel net weight (less unburnt)	Difference amount of actually volatilized fuel	g
Fuel net weight at burn g dry matter	Fuel weight in g dry matter	g dry matter
Ash weight (less unburnt) g dry matter	Ash weight in g dry matter (assumes ash was dry)	g dry matter
Fuel C fraction	Amount of fuel carbon as a percentage of dry weight fuel	%
Ash C fraction	Amount of ash carbon as a percentage of dry weight ash	%
Fuel C	Weight of fuel carbon	g C
Ash C	Weight of ash carbon	g C
TBC	Total burned carbon, the volatilized carbon (Fuel C - Ash C)	g C
TBC fraction	Total burned carbon, the volatilized carbon as percentage of Fuel C	%
Fuel N fraction	Amount of fuel nitrogen as a percentage of dry weight fuel	%
Ash N fraction	Amount of ash nitrogen as a percentage of dry weight ash	%
Fuel N	Weight of fuel nitrogen	g N
Ash N	Weight of ash nitrogen	g N
TBN	Total burned nitrogen, the volatilized nitrogen (Fuel N - Ash N)	g N
TBN fraction	Total burned nitrogen, the volatilized nitrogen as percentage of Fuel N	%
Fuel Cl fraction	Amount of fuel chlorine as a percentage of dry weight fuel	%
Ash Cl fraction	Amount of ash chlorine as a percentage of dry weight fuel	%
Fuel Cl	Weight of fuel chlorine	g Cl
Ash Cl	Weight of ash chlorine	g Cl
TBCl	Total burned chlorine, the volatilized chlorine (Fuel Cl - Ash Cl)	g Cl
TBCl fraction	Total burned chlorine, the volatilized chlorine as percentage of Fuel Cl	%
Fuel Ratio Cl/Br	Ratio of fuel chlorine to fuel bromine	unitless
Fuel Br fraction	Amount of fuel bromine as a percentage of dry weight fuel	%

Ash Br fraction	Amount of ash bromine as a percentage of dry weight fuel	%
Fuel Br Wt	Weight of fuel bromine (lower detection limit is 4.3e-6)	g Br
Ash Br Wt	Weight of ash bromine (lower detection limit is 4.3e-6)	g Br
TBBr	Total burned bromine, the volatilized bromine (Fuel Br - Ash Br)	g Br
TBBr fraction	Total burned bromine, the volatilized bromine as percentage of Fuel Br	%
Fuel I fraction	Amount of fuel iodine as a percentage of dry weight fuel	%
Ash I fraction	Amount of ash iodine as a percentage of dry weight fuel (lower detection limit is 3e-5)	%
Fuel I Wt	Weight of fuel iodine (lower detection limit is 3e-5)	g I
Ash I Wt	Weight of ash iodine (lower detection limit is 3e-5)	g I
TBI	Total burned iodine, the volatilized iodine (Fuel I - Ash I)	g I
TBI fraction	Total burned iodine, the volatilized iodine as percentage of Fuel I	%
Fuel S fraction	Amount of fuel sulfur as a percentage of dry weight fuel	%
Ash S fraction	Amount of ash sulfur as a percentage of dry weight fuel	%
Fuel S	Weight of fuel sulfur as a fraction of dry weight fuel	g S
Ash S	Weight of ash sulfur as a fraction of dry weight fuel	g S
TBS	Total burned sulfur, the volatilized sulfur (Fuel S - Ash S)	g S
TBS fraction	Total burned sulfur, the volatilized sulfur as percentage of Fuel S	%
Fuel P fraction	Amount of fuel phosphorus as a percentage of dry weight fuel	%
Ash P fraction	Amount of ash phosphorus as a percentage of dry weight fuel	%
Fuel P	Weight of fuel phosphorus (lower detection limit is 7E-6)	g P
Ash P	Weight of ash phosphorus (lower detection limit is 7E-6)	g P
TBP	Total burned phosphorus, the volatilized phosphorus (Fuel P - Ash P)	%
TBP fraction	Total burned phosphorus, the volatilized phosphorus as percentage of Fuel P	%
CO2 emissions	CO_2 emissions as grams of carbon	g C
CO emissions	CO emissions as grams of carbon	g C
NOx emissions	NO_x emissions as grams of nitrogen	g N
CO2 emissions/TBC	CO_2 emissions as percentage of total burned carbon	%
CO emissions/TBC	CO emissions as percentage of total burned carbon	%
NOx emissions/TBN	NO_x emissions as percentage of total burned nitrogen	%
CO emissions+CO2 emissions/TBC	Sum of CO emissions and CO_2 emissions as a % of total burned carbon	%
CO emissions/CO2 emissions	CO emissions as a percentage of CO_2 emissions (indicator of burning efficiency)	%

Description of the files:

s2k_elemental_emiss_factors.csv
s2k_standard_emiss_factors.csv
s2k_molar_emiss_ratios_CO.csv
s2k_molar_emiss_ratios_CO2.csv

Blank indicates 'not measured'.

Columns (in white)	Definition		Units	
Experiment #	Unique experiment ID (date and indentifier)		YYYYMMDD (a,b,c)	
Site code	Identifier for site.		ASCII	
Sample Type	Biomass sample type (i.e., grass, twigs).		ASCII	
Fire Type	Type of fire (unless otherwise noted, the burn table was positioned at a 30° angle and fuel loosly arranged)		ASCII	
Soluble, gaseous compounds, total inorganic Cl and Br, ionic and elemental compositions of particles.	**Units for elemental emission factors**	**Units for standard emission factors**	**Units for molar emission ratios relative**	**Units for molar emission ratios relative**

			to CO	**to CO_2**
CO/kg dry fuel	not included in emission factor files	not included in emission factor files	mol/kg	mol/kg
CO2/(CO2+CO)	g C/ g C	g C/ g C	g C/ g C	g C/ g C
CO2	g C/kg C fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
CO	g C/kg C fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
CH3COOHg	g C/kg C fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
HCOOHg	g C/kg C fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
Particulate CH3COO-	g C/kg C fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
Particulate HCOO-	g C/kg C fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
Particulate C2O42-	g C/kg C fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
Total Particulate C	g C/kg C fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
NOx (as NO)	g N/kg N fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
NH3	g N/kg N fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
HONO	g N/kg N fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
Particulate NH4+	g N/kg N fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2

Particulate NO3-	g N/kg N fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
Total Particulate Nl	g N/kg N fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
HCl	g Cl/kg Cl fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
Total Vol. Cl	g Cl/kg Cl fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
Particulate Cl-	g Cl/kg Cl fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
Total Vol. Br	g Br/kg Br fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
Particulate Br-	g Br/kg Br fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
SO2	g S/kg S fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
Particulate SO42-	g S/kg S fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
Particulate PO43-	g P/kg P fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
Particulate K+	g K/kg K fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
Particulate Ca2+	g Ca/kg Ca fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
Particulate Na+	g Na/kg Na fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2
Particulate Mg2+	g Mg/kg Mg fuel	g/kg dry fuel	mol/mol CO	mol/mol CO_2

Research Activities

A total of 60 biomass burning experiments were carried out between November 2000 and January 2001. A suite of organic halogen-containing gases (CH_3Cl, CH_3Br, CH_3I, CH_2Cl_2, CH_2Br_2, CH_2I_2 and others) were measured in the exhaust of these fires as well as the smoke mixing ratios of CO, CO_2, NO_x, CH_4 and N_2O. Samples of fuel and ash were collected and processed for subsequent analysis of elemental composition of carbon, chlorine, bromine, iodine, nitrogen, and sulfur. These data allow us to assess the elemental mass balance for each experimental burn as well as the corresponding emission factors for individual compounds as functions of the biofuel composition.

Sample Collection and Processing Methods

During the dry season (August to October) of 2000, representative biofuels were sampled in the Etosha National Park, Namibia, the Kruger National Park, South Africa, and in the Miombo woodlands of Malawi and Zambia. Samples were weighed, air dried, and reweighed on site. These samples were shipped to Germany in loosely packed cardboard boxes, reweighed, subsampled for elemental analysis, and then burned at the Max Planck Institute for Chemistry (MPI) in Mainz.

Site	Site Code	Experiments/Fuels	Vegetation Type
Kruger National Park, South Africa	KNP	23 experiments with: 17 savannah grasses 8 twigs and branches 1 litter	semi-arid woodland and savannah
Etosha National Park, Namibia	ENP	11 experiments with: 5 savannah grasses 3 shrubs 2 branches 1 litter	grasslands and mopane woodlands
Zambia (Miombo Network)	ZAM	6 experiments with savannah grasses	Miombo woodland (woodlands and dambos)
Malawi (Miombo Network)	MAL	11 experiments with: 5 savannah grasses 3 shrubs 2 branches 1 litter	Miombo woodland (woodlands and dambos)

A photo library of biofuel sampling sites, burn experiments, and instrumentation can be found at the project web site link: http://jurgenlobert.net/projects/mpi_safari/images/index.html.

Most samples were rehydrated with deionized water (DIW) before burning. Typically, 0.5 to 0.6 kg subsamples of grass and 1 to 4 kg subsamples of branches were burned for a given experiment. Burn durations ranged from several minutes for grasses to >1 hour for large branches, charcoal, and dung.

Subsamples of biofuels and ash were ground in a Wiley mill, weighed, dried at 72° C for 48 hours, cooled in a desiccator, and reweighed. C and N contents were measured with a Carlo-Erba Elemental Analyzer. Halogens, S, P, Ca, and K were measured by ion chromatography (IC) following digest of subsamples via Parr Bomb (Butler et al.,1979).

Measurement Techniques for Soluble Gases

NH_3, HONO, HNO_3, HCl, SO_2, CH_3, COOH, and HCOOH in ambient air and burn exhaust were sampled at 18 standard liters per minute (SLPM) with tandem mist chambers (Keene and Savoie, 1998) containing DIW and analyzed by IC. A 45-mm quartz fiber filter (Pallflex QAT-UP 2500) removed particles at the stack. Analytes condensed onto inlet walls (1.2 m insulated 3/16 inch internal diameter Teflon line) were extracted, analyzed, and included in calculating total concentrations. Inorganic volatile Cl, Br, and I were sampled at 100 SLPM on tandem 90-mm Rayon filters (Schleicher and Schuell 8S) impregnated with 10% $K_2CO_3$and 10% glycerol (Bardwell et al., 1990) and positioned immediately downstream of a 142-mm quartz fiber filter (Pallflex QAT-UP 2500) that removed particles at the stack.

Additional Sources of Information

Additional information regarding these ongoing studies can be found in the data directory of the project web site link: http://jurgenlobert.net/projects/mpi_safari/images/index.html. Included there are PDF files of a presentation and a poster from the 2001 AGU Fall meeting, with overview information, images, graphs, and results.

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