SAFARI 2000 Emissions Estimates, MODIS Burned Area Product, Dry Season 2000

Abstract

The MODIS burned area product over southern Africa for the month of September 2000 was used to calculate regional biomass burning emissions from grassland and woodland fires for a number of trace gases and particulates at 1 km spatial resolution. A dynamic regional fuel load model developed for southern Africa in support of SAFARI 2000 fire emissions modeling is used to compute spatially explicit southern Africa fuel load data. Regional grassland and woodland emissions are estimated using ecosystem-specific emission factor algorithms for carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), non-methane hydrocarbons (NMHC), and particulate matter with diameter less than 2.5 μm ($PM_{2.5}$) for southern African savanna fires (Korontzi et al., 2004). We have expanded the emissions database for this region by incorporating emission factors for a variety of compounds, including oxygenated volatile organic compounds (OVOC), halocarbons, nitrogen oxides (NO_x), ammonia (NH_3), sulfur dioxide (SO_2), hydrogen cyanide (HCN), and particulate ionic components measured during the SAFARI 2000 dry season field campaign.

The data set archived by ORNL DAAC provides a MODIS-based estimate of CO (carbon monoxide) pyrogenic emissions (in kg) for southern Africa in September 2000 at 1 km. Emissions data for the other trace gases and particulates described in this documentation file will be archived by ORNL DAAC when they are finalized.

Background Information

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Project: SAFARI 2000

Data Set Title: SAFARI 2000 Emissions Estimates, MODIS Burned Area Product, Dry Season 2000

Site: Southern Africa
Westernmost Longitude: 9.673753° E
Easternmost Longitude: 46.647256° E
Northernmost Latitude: 0.338881° N
Southernmost Latitude: -34.142467° S

Data Set Citation:

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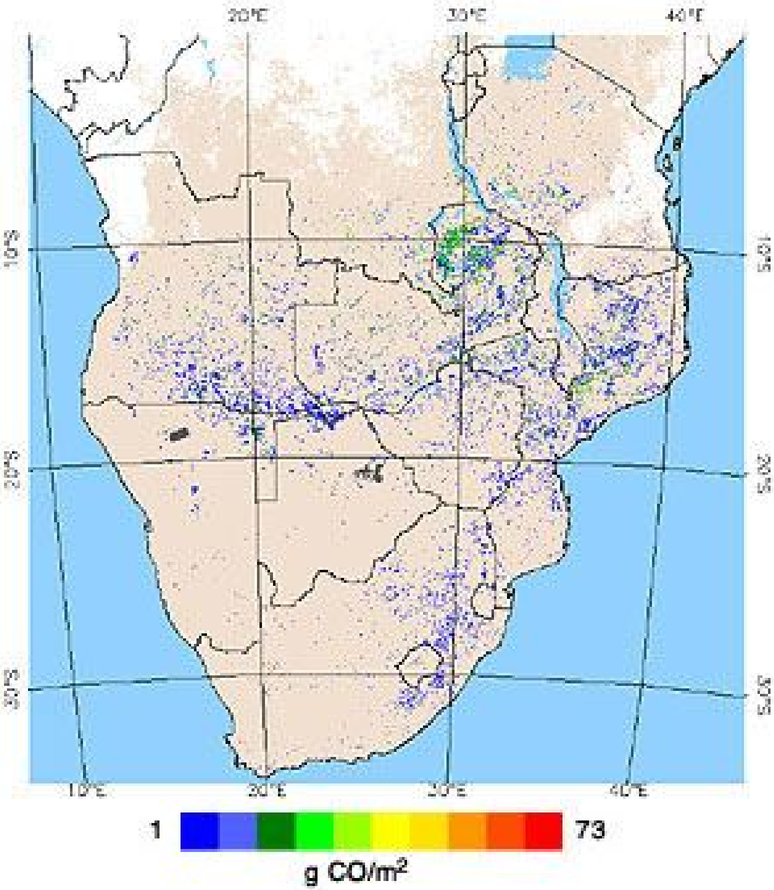
Data File Information

This data set provides a MODIS-based estimate of CO (carbon monoxide) pyrogenic emissions (in kg) for southern Africa in September 2000 at 1 km. The MODIS_SEP_2K _CO.tif image file is stored in GeoTIFF binary format. There is also an ENVI header file, named MODIS_SEP_2K _CO.hdr, that is an ASCII text file.

Emissions data for the other trace gases and particulates listed in Table 1 below will be archived by ORNL DAAC when they are finalized.

Please contact Stefania Korontzi (stef@hermes.geog.umd.edu) for information about the other emissions data sets generated during the SAFARI 2000 dry season field campaign.

MODIS_SEP_2K_CO.tif



MODIS CO emissions, southern Africa, September 2000.

White = not mapped due to insufficient cloud-free observations.
Dark grey = not considered due to ephemeral water or inland water.
Light blue = water

Image Data Format

file format	GeoTiff
data type	32-bit signed long integer
image size	3717 samples by 3906 lines
geographic projection	Lambert Azimuthal Equal Area, center of projection Longitude = 25.0 degrees, Latitude = -15.0 degrees
datum	none
sphere radius	6370997.0 m
upper left corner, x	9.673753° E
upper left corner, y	0.338881° N
x pixel size	1000 m
y pixel size	1000 m

Fire Emissions Modeling Methodology

Estimates of pyrogenic gas emissions require information on burned area, fuel load (the amount of fuel per unit area), completeness of combustion (the proportion of the fuel consumed during the fire), and emission factors (characteristic of the amount of the specific atmospheric species produced during the burning). Emissions are computed using spatially explicit input data following the well established Seiler and Crutzen (1980) model:

$$E_x = \sum_{i,j} A_{i,,j} * F_{i,j} * CC_{i,j} * (EF_x)_{i,j}$$

where: E_x	total pyrogenic emissions for compound x (g)
$A_{i,,j}$	burned area (km^2)

$F_{i,j}$	fuel load (kg km^{-2})
$CC_{i,j}$	the completeness of combustion (fraction)
$(EF_x)_{i,j}$	the emission factor for compound x (g kg^{-1})
i,j	spatial coordinates
x	compound for which emissions are estimated

We use the formula above to compute emissions of major and minor gaseous compounds and particulate species for September 2000 for all of Africa south of the equator (not including Madagascar) at a pixel size of 1 km^2. The region is stratified spatially into grassland and woodland areas and the emissions are computed independently for these two land covers. The relative proportions of woody, grass, and leaf litter fuels determine important aspects of fire behavior which impact factors including emission factors and the completeness of combustion (Shea et al., 1996; Hoffa et al., 1999). In grasslands, the fuel layer is relatively homogeneous, whereas in woodlands the woody and grass fuel components coexist with more restricted grass production in the more closed-canopy woodlands (Scholes et al., 2002). We apply different emission factors and combustion completeness estimates for woodland and grassland. The Intergovernmental Panel on Climate Change (IPCC) guidelines for greenhouse gas emissions reporting also suggest the division of these two savanna land covers (IPCC, 1997). We use the MODIS percent tree cover (PTC) product (Hansen et al., 2002) to distinguish between grasslands and woodlands and define areas with PTC less than or equal to 10% are grasslands and areas with PTC greater than 10% are woodlands. The 10% PTC threshold is based on the Food and Agricultural Organization of the United Nations (FAO) definition of forest for the Forest Resource Assessment 2000 (FRA 2000) (FAO, 2001).

Model Inputs

Burned Area

The MODIS burned area product maps the 500 m location and approximate day of burning using a change detection algorithm based on a bi-directional reflectance model-based expectation method applied to the MODIS near-infrared and shortwave infrared bands (Roy et al., 2002). The algorithm was applied to recently reprocessed 500 m daily MODIS land surface reflectance data to produce burned area data sets for all of southern Africa for 2000 onwards. The MODIS burned area data (Roy, 2004) used in this data set are archived at ORNL DAAC. In order to minimize geolocation errors associated with nearest neighbor resampling, the 500 m burned area data were reprojected into the Lambert Azimuthal Equal Area projection with an output pixel dimension of 500 m rather than 1 km. The reprojected data were then binned to 1 km pixels by counting how many burned 500 m pixels occur in each 1 km pixel (0 to 4) (i.e., in an 1 km^2 pixel with a count of 1 only 25% of the pixel is burned, whereas a 1 km^2 pixel with a count of 4 is assumed to be completely burned). This reduces nearest neighbor resampling pixel shifts (i.e., position errors) (Dikshit & Roy, 1996) and provides a more accurate burned area assessment for subsequent analysis. Pixels labeled by the MODIS burned area product as "not considered" (either an area of ephemeral or inland water) or "unmapped" (due to insufficient MODIS data associated with persistent cloud and/or missing MODIS data) were not counted. The precise day of burning may not be certain because of cloudy and missing data. We used a conservative estimate of the area burned in September 2000 by only considering pixels with burns occurring in September and on the last day of the previous month.

Fuel Load

Regional fuel load data sets of green grass, dry grass, leaf litter, and twigs fuel types generated by Hély et al. (2003) for southern Africa in support of SAFARI 2000 fire emissions modeling are used to compute spatially-explicit total fuel load amounts and fuel load type mixtures. The modeled fuel load type outputs used in this research are archived at ORNL DAAC (Hély et al., 2004). The production of green and dry grass, and leaf litter fuel types is calculated using a satellite-driven Net Primary Productivity (NPP) model that incorporates ecophysiological processes, such as respiration and potential evapotranspiration, in conjunction with empirical relationships. Herbivory reduction of the grass fuel is also included using established mammalian metabolic energy requirement statistics and regional livestock density maps (Hély et al., 2003). The twigs amount is not explicitly calculated by the NPP model but is determined empirically from the AVHRR derived PTC. Here, we improve the modeled twigs data layer using the MODIS PTC and the empirical relationship by Hély et al. (2003). Fuel amount for each fuel type is computed for each 1 km^2 pixel every 15 days for the preceding growing season from September 1, 1999 to August 31, 2000. The total fuel load available for burning in September 2000 is determined by accumulating fuel load throughout this period. The fuel load ranges predicted by the model are generally in agreement with the limited published field measurements (Shea et al., 1996; Trollope et al., 1996, Hély et al., 2003). We recognize several potential biases in the fuel load model, including: no modeling of fuel load reduction by people, fuel load accumulation and decay since the last fire occurrence, and that larger diameter woody fuels are not modeled, even though smoldering following fires on these fuel types may be highly emissive (Bertschi et al., 2003). The impact of these limitations on fuel load estimation is currently not possible since only this particular fuel load data set is publicly available. We hope that recognition of these issues will lead to the development of more robust fuel load models.

Combustion Completeness

Combustion completeness is defined as the fraction burned of the biomass fuel exposed to the fire (Shea et al., 1996; Scholes et al., 1996). Combustion completeness depends on the fuel loading, type, moisture content, packing, and meteorological parameters including wind speed, relative humidity, and temperature. Fine and/or drier fuels typically burn more completely than coarser and/or moister fuels. The combustion completeness of all fuel types is generally thought to increase as the southern Africa dry season progresses (Hoffa et al., 1999). In grasslands, the combustion completeness is determined from the percentage of green grass to total grass (PGREEN) for values of PGREEN equal or greater than 20%, to allow for the assessment of the effects of varied grass moisture content, and has a lower limit of 44% based on field measurements by Hoffa et al. (1999). For values of PGREEN below 20%, CC_{grass} is computed using an empirical relationship derived from the late dry season measurements by Shea et al., (1996) during SAFARI 92. In woodlands, the combustion completeness is determined from PGREEN for values of PGREEN equal or greater than 14%, and has a lower limit of 1% (Hoffa et al., 1999). The equations are given in Korontzi et al. (2004).

Emission Factors

An emission factor is the amount of a specific trace substance emitted by the combustion per unit mass of dry fuel consumed ($g\ kg^{-1}$) (Ward et al., 1996). Regional grassland and woodland emissions are estimated using ecosystem-specific emission factor algorithms for carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), non-methane hydrocarbons (NMHC), and particulate matter with diameter less than 2.5 μm ($PM_{2.5}$) for southern African savanna fires (Korontzi et al., 2004). Most modeling studies report emissions for these five key carbon-containing species. Here we expand the emissions database for this region by incorporating emission factors for a variety of compounds, including oxygenated volatile organic compounds (OVOC), halocarbons, nitrogen oxides (NO_x), ammonia (NH_3), sulfur dioxide (SO_2), hydrogen cyanide (HCN) and particulate ionic components measured during the SAFARI 2000 dry season field campaign (Yokelson et al., 2003; Sinha et al., 2003). A fuel carbon content of 50% is assumed in all emission factors calculations (Ward et al., 1996).

Results

Table 1 summarizes the regional September 2000 pyrogenic emissions for major and minor trace gases and particulate species computed using the MODIS burned area.

Table 1. MODIS-based regional fire emissions (in Gg = 10^9 g), southern Africa, September 2000.

Species	Woodland	Grassland	Regional
Carbon dioxide (CO_2)	93393	40387	133780
Carbon monoxide (CO)	5100	767	5867
Methane (CH_4)	174.8	13.3	188.1
Nonmethane hydrocarbons (NMHC)	137.9	20.5	158.4
Nitrogen oxides (as NO)	189.8	70.1	259.9
Dimethyl sulfide (CH_3SCH_3)	0.146	0.036	0.182
Methyl bromide (CH_3Br)	0.089	0.013	0.102
Methyl chloride (CH_3Cl)	4.6	1.3	5.9
Methyl iodide (CH_3I)	0.101	0.029	0.13
Methyl nitrate (CH_3ONO_2)	0.027	0.004	0.031
Ethane (C_2H_6)	12.9	1.9	14.8
Ethene (C_2H_4)	44.6	6.6	51.2
Propane (C_3H_8)	3.882	0.574	4.456
Propene (C_3H_6)	14.443	0.682	15.125
Acetylene (C_2H_2)	12.5	1.8	14.3
i-butane (*i*-C_4H_{10})	0.2321	0.0055	0.2376
n-butane (*n*-C_4H_{10})	1.249	0.185	1.434
t-2-butene (C_4H_8)	1.249	0.185	1.434
1-butene (C_4H_8)	3.005	0.299	3.304
c-2-butene (C_4H_8)	0.892	0.132	1.024
i-pentane (*i*-C_5H_{12})	0.134	0.02	0.154
n-pentane (*n*-C_5H_{12})	0.55	0.11	0.66

1, 3-butadiene (C_4H_6)	3.897	0.431	4.328
3-methyl-1-butene (C_5H_{10})	0.446	0.066	0.512
t-2-pentene (C_5H_{10})	0.2321	0.0055	0.2376
2-methyl-2-butene (C_5H_{10})	0.446	0.066	0.512
2-methyl-1-butene (C_5H_{10})	0.491	0.073	0.564
Isoprene (C_5H_8)	3.109	0.605	3.714
n-heptane (C_7H_{16})	0.937	0.139	1.076
Benzene (C_6H_6)	12.9	1.9	14.8
Toluene (C_7H_8)	9.4	1.4	10.8
Formaldehyde (HCHO)	75	14.4	89.4
Methanol (CH_3OH)	89	11.6	100.6
Acetic acid (CH_3COOH)	185.5	23.1	208.6
Formic Acid (HCOOH)	48.4	11	59.4
Ammonia (NH_3)	18.8	3.4	22.2
Hydrogen Cyanide (HCN)	33.4	10	43.4
Particulates with diameter < 2.5 µm (PM2.5)	586.9	44.4	631.3
Total particulate matter (TPM)	1077	101	1178
Organic carbon (OC)	221.6	47.3	268.9
Black Carbon (BC)	25.9	3.8	29.7
Chloride (Cl-)	117.5	2.9	120.4
Nitrate (NO3-)	16.4	3.9	20.3
Sulfate (SO_42-)	18.4	1.3	19.7
Potassium (K+)	71.4	10.6	82

Additional Sources of Information

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