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Global Biomass Burning: Atmospheric, Climatic and Biospheric Implications

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regions during the 1985 NASA Global Tropospheric Experiment (GTE)-Amazon Boundary Layer Experiment (ABLE-2A) over the rain forest of Brazil and during the 1988 NASA/GTE Arctic Boundary Layer Experiment (ABLE-3A) over Alaska. Ozone profiles were obtained using the differential absorption lidar (DIAL) technique at 286 and 300 nm, and aerosol backscattering was measured simultaneously at 300, 600, and 1064 nm. The lidar system was operated in a nadir mode from the NASA Wallops Electra aircraft on long-range flights over the Amazon and Arctic.

Since the ABLE-2A was conducted during the dry season over the Amazon Basin, biomass burning plumes were observed on most of the flights, and they were generally found between the top of the mixing layer and below the trade wind inversion (TWI). The ABLE-3A field experiment was conducted over the Arctic during the summer, and while the number of biomass burning plumes was less than during ABLE-2A, several plumes were observed over Alaska from fires in that state. The plumes observed during these experiments contained significant enhancements in ozone and aerosol scattering compared to the background levels. Over the Amazon, the amount of photochemically produced ozone was found to significantly increase the total ozone below the TWI. The multiple-wavelength aerosol backscatter data for these plumes have been used to derive information on their optical properties and to examine the potential for remotely discriminating these plumes from other sources of aerosols. This paper discusses the spatial distribution and observed properties of the biomass burning plumes encountered during these field experiments, and these results are related to the large-scale impact of biomass burning on the lower troposphere.

Overview of the BASE-A Experiment

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ABSTRACT

Biomass burning in tropical region is a major source of trace gases (CO_2, CO, CH_4, NO_x) and organic particles. Due to the high spatial and temporal variation of the burning, spaceborne remote sensing methods are required in order to assess the extent of these emissions. The remote sensing methods depend on detailed relations between the occurrence of fires and the emitted trace gases and particulates. The BASE-A experiment (Biomass burning Airborne and Spaceborne Experiment - Amazonas), involving an INPE, instrumented aircraft and a research group, was conducted in Sept. 1989 over the Brazilian Amazon Basin to measure these relations. In the experiment, airborne measurements of the emitted trace gases (CO_2, CO, CH_4) and O_3 were conducted simultaneously with measurements of the emitted particles and their chemical composition. The aerosol particle size and vertical distribution were deduced from optical measurements. Profiles of water vapor and temperature were also recorded. The application of the collected data for the analysis of biomass burning from the NOAA/AVHRR and the GOES satellite imagery is discussed.

Characteristics of Smoke Emissions from Biomass Fires of the Amazon Region - BASE-A Experiment

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ABSTRACT

Estimates of smoke emissions from fires in the Brazilian Amazon have been difficult to obtain because of the uncertainty of estimates of biomass consumption ant the relations of emissions to particulate matter. Satellite imagery have been used for estimating total emissions but these estimates depend on, among other things, knowledge concerning the ratio of gases to particulates in the atmosphere. One purpose of the BASE-A experiment (Biomass burning Airborne and Spaceborne Experiment - Amazonas), involving an INPE instrumented aircraft and a research group, was to measure some of the important "greenhouse gases", ozone concentration, and the relation of gases to particulate matter for specific fires. This paper examines results for the BASE-A experiment with those for biomass burning in North America. Measurements were made for 3 different deforestation fires and one savannah fire from INPE's instrumented aircraft. Results of the experiment include emission factors for particulates less than 2.5μm in diameter, percent composition of the inorganic component of the particles, and percent composition of organic and graphitic carbon of the particles. Other correlations are made between the trace gas composition and the ozone concentration. A correlation matrix including the ratio of various gases to particles is presented for the results from the BASE-A experiment.

Deforestation in Brazilian Amazonia as a Source of Greenhouse Gases

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Cumulative area of forest cleared through 1988 is estimated to be 234 X 10^3 km^2 (including old clearings), or 8.2% of the 4 X 10^6 km^2 forested portion of Brazil's 5 X 10^6 km^2 Legal Amazon region. Recent (Post-1960) clearing of primary and old secondary forest totaled 268 X 10^3 km^2, or 6.4%. Including the cerrado (scrubland) increases the total of recent clearing to 460 X 10^3 km^2 (9.6%). Forest loss in 1988 was proceeding at 20 X 10^3 km^2/year.

Mean dry weight biomass (above and below ground) is estimated at 211 metric tons (MT)/ha for forest areas being cleared in 1988 and 247 MT/ha for the forest as a whole (carbon (C) content = 50%). Pasture biomass averages 10.7 MT/ha. Conversion releases 3.92 MT/ha of C from the top 20 cm of soil. Conversion of all forest and cerrado to pasture would release 51 gigatons (GT) of C. The annual rate of forest and cerrado loss in 1988 was releasing 270 X 10^6 MT of C on conversion to pasture. Considering the quantities of CO_2 and CH_4 released, this represents 262-282 X 10^6 MT/year of CO_2 equivalent C. This is almost 3 times the annual C release from Brazil's use of fossil fuels, but brings little benefit to the country.

Uncertainties in Tropical Forest Biomass. An Example from Rondonia, Brazil

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One critical factor in estimating the contribution of tropical deforestation to CO_2 buildup in the atmosphere is the amount of biomass available to burn. The biomass data for Brazil, which is the site of the highest deforestation rates, are few and of uncertain accuracy. To provide additional information from western Amazonia, we measured in 1988 the dbh, bole and canopy heights of nearly 500 trees covering 1 ha (10,000 m^2) in the Ecological Station of the Samuel Hydroelectric Reservoir in Rondonia (8 45'S, 63 23'W). Using calibration curves based on destructively sampled trees, we estimated the total aboveground living biomass as 300 t(dry weight)/ha. Fallen trunks and litter were 30 and 10 t/ha, respectively. The uncertainty in these values is about 20%, making the total biomass value good to less than one significant figure.

The biomass distribution is highly skewed: 3% of the trees contribute 50% of the biomass. For forests of similar distributions, plots typically used for biomass estimates (225 to 2,000 m^2) will usually produce biomass estimates significantly different from those of larger plots. Based on subsamples of our data, plots of 250 m^2 had an 80% chance of being outside the range of the global mean (240-360 t/ha). Plots of 2,000 m^2 had a 45% chance of being outside this range. For more constrained estimates of biomass in similar forests a sampling program should focus on emergent and large canopy trees, the dominant contributors to biomass.

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Biomass Burning in Brazilian Tropical Dry Forest: Carbon and Nitrogen Emissions

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Tropical dry forests (sensu Holdridge) cover 22% of the land area of South America. Most of these forests are located in northeastern Brazil where very high density non-urban population (>25 persons/km^2) utilizes slash and burn agricultural techniques. We examined biomass burning in these forests to determine rates of biomass consumption, heat flux into soils, and atmospheric nutrient emissions from slashed areas. Fires were set at three intervals during the dry season to cover a range of burning conditions (fuel moisture, day since last precipitation, microclimate) with the objective of determining biomass consumption as well as nitrogen and phosphorus loss.

We show that during the dry season, the biomass moisture content and microclimate conditions strongly affect carbon emissions to the atmosphere. Importantly, in addition to C release from slashed biomass, these very hot fires (>600°C at the soil surface) also result in high initial C emissions from the surface soils. Nitrogen emission follows a pattern similar to carbon except that proportionally larger amounts are volatilized by burning. Our results demonstrate that a wide range of biomass consumption values should be incorporated into estimates of tropical dry forest emissions and that these estimates should be based on regional climatic conditions.

Biomass Burning in Africa

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Africa has long been considered as a non polluted continent owing to the very low level of industrialization in most countries. Recent studies based on satellite data and field experiments have shown that large scale pollution associated with biomass burning occurs throughout the year in the african tropics.

This paper describes, first, general aspects of biomass burning in Africa, i.e., types of burnings-including bushfires in savanna zones, forest fires due to shifting agriculture and deforestation, use of wood as fuel - types of vegetation and associated biomass, burning periods and burnt areas. Estimate of burnt areas is still difficult, data bases for Africa are very poor. Studies using satellite imagery from SPOT, NOAA and Landsat are undertaken by several laboratories.

A brief overview of the most recent results on this topic is then given. The influence of biomass burning on the chemical composition of the atmosphere in Africa was evidenced for the first time through satellite data (TOMS) which showed significant photochemical ozone formation over the african continent and the tropical Atlantic. Surface and aircraft O3 measurements in central Africa confirmed this hypothesis. An aircraft experiment (TROPOZ I, 1987) showed the existence of polluted layers enriched in ozone over west africa during the fire period. This phenomenon was also observed during the DECAFE experiment in Northern Congo (1988).

Rainwater analysis carried out on yearly cycles in Ivory Coast and Congo indicate the presence of a pollution background due to biomass burning which induces acidification of rain water by nitric and organic acids derived from combustion products.

Methane Emission from Combustions in Equatorial Africa

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Methane and CO2 emissions from combustion of savanna plants and wood are studied by both field experiments and laboratory experiments using a combustion chamber. For savanna plants most of the carbon (85 %) contained in the biomaterial is volatilized as CO2 and 0.1 to 0.25% as methane. For graminaceous like loudetia simplex the ratio C-CH4/C-CO2 is of 0.11% ; it is of 0.28% for hyparrhenia the other main type of savanna plants and it reaches 1.4% for the combustion of wood. In natural fire plumes this ratio is around 0.26% for savanna fires and 0.56 to 2.22% for forest fires. These results show that methane release is highly dependant on the type of combustion. Since it is linked to the pyrolysis of the biomaterial, slow combustions such as burning of wood as fuel or in forest fires