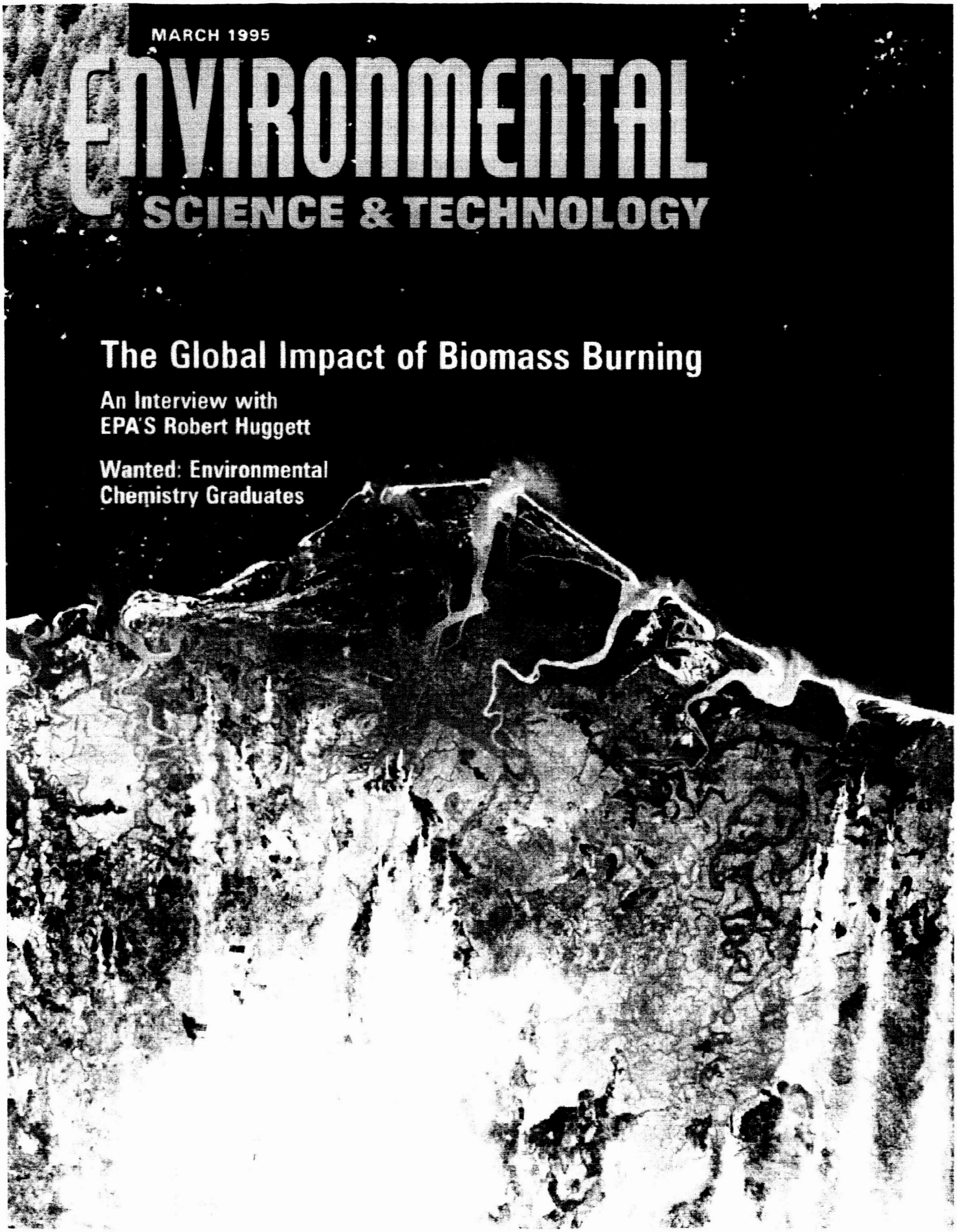

MARCH 1995
ENVIRONMENTAL
SCIENCE & TECHNOLOGY
The Global Impact of Biomass Burning
An Interview with
EPA'S Robert Huggett
Wanted: Environmental
Chemistry Graduates

Throughout the 4.5-billion-year history of the Earth, the composition and chemistry of the atmosphere as well as the climate of our planet have been shaped by the production of atmospheric gases within the biosphere. In the biosphere, atmospheric gases are produced by various biological processes, including photosynthesis, respiration-decay, nitrification, denitrification, and methanogenesis. Recent research has identified another biospheric process that has instantaneous and longer term effects on the production of atmospheric gases: biomass burning.

Biomass burning includes the burning of the world's vegetation--forests, savannas, and agricultural lands--to clear the land and change its use. Only in the past decade have researchers realized the important contributions of biomass burning to the global budgets of many radiatively and chemically active gases--carbon dioxide, methane, nitric oxide, tropospheric ozone, methyl chloride--and elemental carbon particulates.

The extent of biomass burning has increased significantly over the past 100 years because of human activities, and such burning is much more frequent and widespread than was previously believed. Biomass burning is now recognized as a significant global source of emissions, contributing as much as 40% of gross carbon dioxide and 38% of tropospheric ozone. Most of the world's burned biomass matter is from the savannas, and because two-thirds of the Earth's savannas are located in Africa, that continent is now recognized as the "burn center" of the planet.

In the past few years the international scientific community has conducted field experiments using ground-based and airborne measurements in Africa, South America, and Siberia to better assess the global production of gases and particulates by biomass burning. Researchers are gathering this month in Williamsburg, VA, to discuss the results of these and other investigations at the Second Chapman Conference on Biomass Burning and Global Change, sponsored by the American Geophysical Union. The first international biomass burning conference, held in 1990 (1), was attended by atmospheric chemists, climatologists, ecologists, forest and soil scientists, fire researchers, remote-sensing specialists, and environmental planners and managers from more than 25 countries.

When we hear about biomass burning, we usually think of the burning of the world's tropical forests for permanent land clearing. However, biomass burning serves a variety of land-use changes, including the clearing of forests and savannas for agricultural and grazing use; shifting agriculture

BIOMASS BURNING

A DRIVER FOR GLOBAL CHANGE

International field experiments and satellite data are yielding a clearer understanding of this important global source of atmospheric gases and particulates.

JOEL S. LEVINE

WESLEY R. COFER III

practices; the control of grass, weeds, and litter on agricultural and grazing lands; the elimination of stubble and waste on agricultural lands after the harvest; and the domestic use of biomass matter.

The contribution of boreal forest fires, such as this 1986 blaze in northwestern Ontario, to global emissions from biomass burning is not as well understood as are emissions from tropical forests.

Savannas the primary source

The major components of biomass burning are forests (tropical, temperate, and boreal); savannas; agricultural lands after the harvest; and wood for cooking, heating, and the production of charcoal. The burning of tropical savannas is estimated to destroy three times as much dry matter per year as the burning of tropical forests (2). The vast majority of the world's burning is human-initiated, with lightning-induced natural fires accounting for only a small percentage of the total.

The immediate effect of burning is the production and release into the atmosphere of gases and particulates that result from the combustion of biomass matter. The instantaneous combustion products of burning vegetation include carbon dioxide, carbon monoxide, methane, nonmethane hydrocarbons, nitric oxide, methyl chloride, and various particulates. During the burning of a forest, carbon dioxide that was sequestered for periods ranging from decades to centuries is suddenly released and returned to the atmosphere in a matter of hours. The new vegetative growth. Other gaseous emissions, however, remain in the atmosphere.

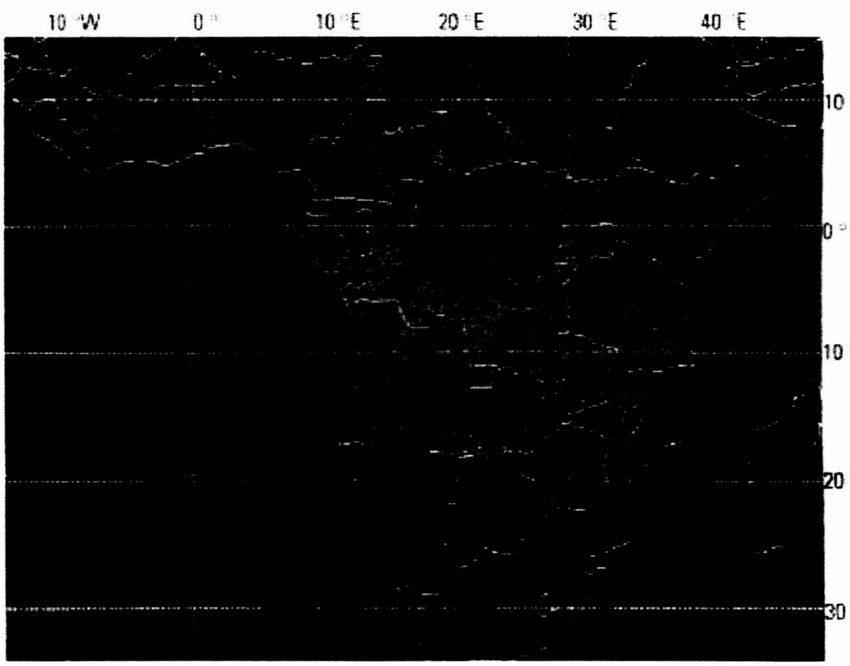
The gases produced by biomass burning are environmentally significant. The greenhouse gases carbon dioxide and methane influence global climate. Combustion particulates affect the global radiation budget and climate. Carbon monoxide, methane, nonmethane hydrocarbons, and nitric oxide are all chemically active gases that affect the oxidizing capacity of the atmosphere and lead to the photo-chemical production of ozone in the troposphere. Methyl chloride is a source of chlorine to the atmosphere, which leads to the chemical destruction of stratospheric ozone. Recently it was discovered that biomass burning is also an important global source of atmospheric bromine in the form of methyl bromine (3). Bromine leads to the chemical destruction of ozone in the stratosphere and is about 40 times more efficient in that process than is chlorine on a molecule-for-molecule basis.

Measurements have shown that in addition to the instantaneous production of trace gases and particulates burning of forests also destroys an important sink for atmospheric carbon dioxide. Hence, burning has both short- and long-term impacts on the global carbon dioxide budget.

If the burned vegetation is not regrown, the liberated carbon dioxide remains in the atmosphere. If the burned ecosystem regrows, as the savannas do, the carbon dioxide is eventually removed from the atmosphere via photosynthesis and is incorporated into the

resulting from the combustion of biomass matter, burning also enhances the biogenic emissions of nitric oxide and nitrous oxide from soil (4-6). It is believed that these emissions are related to increased concentrations of ammonium found in soil following burning. Ammonium, a major nitrogen component of the burn ash, is the substrate in nitrification, which is the microbial process believed

The burning of tropical savannas is estimated to release nearly three times as much carbon to the atmosphere as does the burning of tropical forests. The extensive burning of African savannas is mapped over an entire year (1987) using nighttime images from the Defense Mete orological Satellite Program (right. The absence of fires (red dots) near the equator is the result of the presence of rain forest, where fire is not as common as in the savanna grasslands. In addition to releasing gases and particulates fro mthe combustion of vegetation, burning appears to enhance the productio n of biogenic soil emissions of nitric oxide and nitrous oxide after the burn. A closed chamber flux box (below) is used to measure emissions after a controller burn in Kruger National Part, South Afri ca, in 1992.



responsible for the production of nitric oxide and nitrous oxide (5, 6). The

measurements from various Earth-orbiting satellites, including the Advanced Very High Resolution Radiometer (AVHRR) on the National Oceanic and Atmospheric Adininistration (NOAA) operational meteorological satellites and the nighttime imagery obtained from the Defense Meteorological Satellite Program (DMSP) Block 5 satellites.

Astronaut observations of fires and their accompanying smoke plumes provide only a rough indication of the geographical and temporal extent of burning. Most of these observations are of burning in the tropics because of the low orbital inclination of most space shuttle flights. Mthough these observations do not provide continuous coverage in space and time, they have provided some important information (7, 8). DMSP images provide useful information on the frequency and geographical distribuflon of active fires around the world (9). Unfortunately, DMSP images do not provide information on the area burned. AVHRR images can be used to study the distribution of fires by measuring fire hot spots using the 3.7-pm thermal channel and tracing the accompanying smoke plumes with the visible channels. Re cently, a technique was developed that uses AVHRR images to study forest fire "scars" and to quantify the actual area of burning within the forest (10, 11).

Satellite measurements of fire scars are important new tools with which to enhanced hiogenic soil emissions of nitric oxide and nitrous oxide may be comparable to or even surpass the instantaneous production of these gases during biomass burning.

By combining estimates for the global annual amounts of biomass burning (Table 1) with information on the emission ratios for various compounds produced during burning, we can estimate the global emissions of various gaseous and particulate combustion products and compare the source strength of these emissions with their production by all sources, including biomass burning (Table 2). These estimates indicate that biomass burning is a major global source of many environmentally significant radiatively and chemically active species.

Space-based measurements

The new insights on the importance of biomass burning as a source of atmospheric gases and particulates are directly related to the large geographical area that burning encompasses on our planet. Space observations have provided the first global perspective on the spatial and temporal distribution of biomass burning. These observations include photographs of burning and smoke taken by space shuttle astronauts and

more accurately quantify the area burned in the world's forests. To date, most of our information on the geographical and spatial distribution of biomass burning has been derived from space-based platforms designed for purposes other than studying fires. Each of these instruments has its own limitations and problems. For example, clouds obscure active fires and fire scars. The AVHRR detectors become saturated at temperatures significantly below those of fires, making positive detection of fires ambiguous at times.

Other space measurements provide additional information relevant to the importance of biomass burning as a source of trace gases to the atmosphere. The first measurements obtained in October 1981 with the Measurement of Air Pollution from

Space instrument on the space shuttle indicated that maximum tropospheric carbon monoxide concentrations were associated with areas of widespread biomass burning in South America and Africa (12). Measurements of tropospheric ozone obtained by subtracting the stratospheric component of ozone (in the Stratospheric Aerosol and Gas Experiment) from the total atmospheric column of ozone (by use of the Total Ozone Measurement Spectrometer) indicated that enhanced levels of tropospheric ozone are associated with regions of biomass burning in the tropics (13). Although ozone is not a direct product ofbiomass burning, its chemical precursors (carbon monoxide, methane, nonmethane hydrocarbons, and nitric oxide) are produced in large concentrations during biomass burning.

Determining emission levels

International field experiments

For the past 10 years, scientists from several institutions, including the Max Planck Institute for Chemistry (Mainz, Germany), the University of Freiburg (Germany), the National Center for Atmospheric Research (Boulder, CO), the U.S. Forest Service (Missoula, MT), and NASA's Langley Research Center (Hampton, VA), have used ground-based and airborne instrumentation to determine the emission ratios for various carbon, nitrogen, sulfur, and

Knowledge of the geographical and temporal distribution of burning is critical for assessing the emissions of gases and particulates to the atmosphere. As a first approximation, the total amount of biomass burned in a particular ecosystem can be calculated from measurements of the total land area burned annually, the average organic matter per unit area in the ecosystem, the fraction of the above-ground biomass relative to the total average biomass, and the burning efficiency of the above-ground biomass (see sidebar "Calculating biomass burn emissions"). Once the total amount of burned biomass is known, the total mass of carbon released to the atmosphere during burning can be estimated, because about 45% of biomass by weight is made up of carbon.

The carbon released during burning takes the form of several gaseous compounds-including carbon dioxide, carbon monoxide, methane, and nonmethane hydrocarbons-and particulate or elemental carbon. The ratio of any carbon compound to C02 produced in burning can be determined by knowledge of the "emission ratio." Recently, we have learned that the emission ratio for a particular compound varies with both the particular ecosystem burned and the phase of burning (e.g., flaming or smoldering).

Biomass matter is mostly carbon. Estimates for the release of carbon (in units of teragrams of carbon, TgC/year, where 1 teragram equals 1012 grams or 106 metric tons) into the atmosphere from biomass burning for different ecosystems are summarized in Table 1. Most of the remainder of the biomass matter is water. Biomass matter also contains trace amounts of several other elements, including nitrogen, sulfur, chlorine, and bromine. During burning, these elements are volatilized and released into the atmosphere in the form of molecular nitrogen, nitric oxide, nitrous oxide, sulfur dioxide, methyl chloride, and methyl bromide.

One of the impontant discoveries in biomass burning research over the past five years, based on a series of field experiments, is that fires in diverse ecosystems are very different in the production of gaseous and particulate emissions. Emissions depend on the type of ecosystem; the moisture content of the vegetation; and the nature, behavior, and characteristics of the fire. It is no longer correct to assume constant emission ratios for all fires and for the entire lifetime of a particular fire (14, 15).

TABLE 1

Types of biomass burned

Global estimates of annual amounts of biomass burning and of the resulting release of carbon into the atmosphere *(2)*.

Source of burning	Biomass burned (Tg dry matter/ year)	Carbon released (Tg carbon/ year)
Savannas	3690	1660
Agricultural waste	2020	910
Tropical forests	1260	570
Fuel wood	1430	640
Temperate and boreal forests	280	130
Charcoal	21	30
World total	**8700**	**3940**

TABLE 2

Burning's contribution to global emissions

Comparison of global emissions from biomass burning with emissions from all sources, including biomass burning *(2)*.

Species	Biomass burning (Tg element/ year)	All sources (Tg element/ year)	Biomass burning, %
Carbon dioxide (gross)	3500	8700	40
Carbon dioxide (net)	1800	7000	26
Carbon monoxide	350	1100	32
Methane	38	380	10
Nonmethane hydrocarbons[a]	24	100	24
Nitric oxide	8.5	40	21
Ammonia	5.3	44	12
Sulfur gases	2.8	150	2
Methyl chloride	0.51	2.3	22
Hydrogen	19	75	25
Tropospheric ozone	420	1100	38
Total particulate matter	104	1530	7
Particulate organic carbon	69	180	39
Elemental carbon (black soot)	19	<22	>86

[a]Excluding isoprene and terpenes.

The STARF/TRACE-A/SAFARI-92 experiment was the first international, intercontinental, and interdisciplinary fire-atmosphere experiment (16). The effects of forest and savanna fires in South America and South Africa on the atmosphere over and between

Calculating biomass burn emissions

More than a decade ago, Seiler and Crutzen (17) showed that as a first approximation, the total amount of biomass (M) burned in a particular ecosystem may be given by the equation

$$M = A \times B \times a \times b \text{ [grams dry matter per year (gdm/year)]} \quad (1)$$

where A = total land area burned annually (m^2/year), B = the average organic matter per unit area in the individual ecosystem (gdm/m^2), a = fraction of the above-ground biomass relative to the total average biomass B, and b = the burning efficiency of the above-ground biomass. The determination of A is based on new satellite remote-sensing techniques and procedures, such as fire scars. Parameters B, a, and b are determined during biomass burn field measurements in diverse ecosystems. Determination of these parameters requires measurements before, during, and after burning.

Once M is known, the total mass of carbon [$M(C)$] in grams released to the atmosphere during burning may be estimated using the equation

$$M(C) = 0.45\, M \quad (2)$$

because about 45% of biomass by weight is composed of carbon. The carbon released during burning takes the form of several gaseous and particulate compounds. The ratio of any carbon or nitrogen compound to CO_2 produced in burning can be determined by knowledge of the emission ratio (ER). The ER is the amount of any compound X produced during burning normalized with respect to the amount of CO_2 produced during burning. The ER is usually normalized with respect to CO_2 because CO_2 is overwhelmingly the carbon species produced during biomass burning and it is a relatively easy gas to measure. The ER is defined as

$$ER = \Delta X / \Delta CO_2 \quad (3)$$

where ΔX is the concentration of the species X produced by biomass burning. In addition, $\Delta X = X^* - X$, where X^* is the measured concentration of X in the biomass burn smoke and X is the back ground (out-of-plume) atmospheric concentration of the species; and ΔCO_2 is the concentration of CO_2 produced by biomass burning; $\Delta CO_2 = CO_2^* - CO_2$, where CO_2^* is the measured concentration in the biomass burn plume and CO_2 is the background (out-of-plume) atmospheric concentration of CO_2.

halogen compounds produced during biomass burning in diverse ecosystems. Information on compound emission ratios in different ecosystems and on the evolution of the fire is critical to assess the contribution of biomass burning to the global production of these compounds.

NASA Langley researchers have obtained gaseous and particulate emission ratios from fires in the tropical rain forest in Mexico's Yucatan Peninsula, savannas in southern Africa, chaparral in southern California, wetlands in Florida, and boreal forests in Canada and Siberia (14, 15). Two recent biomass burn experiments were organized by the Biomass Burning Experiment (BIBEX), a research activity of the International GeosphereBiosphere Program's International Global Atmospheric Chemistry (IGAC) Project. BIBEX assisted with the coordination of the the two continents were studied. More than 150 scientists from 13 nations participated in the experiment. SAFARI-92 involved researchers in atmospheric chemistry, biogeochemistry, fire ecology, forestry, meteorology, climatology, soil science, pasture science, microbiology; and remote sensing. These researchers obtained ground-based measurements in Kruger National Park, South Africa, and Etosha National Park, Namibia. Two controlled savanna fires, each about 2000 hectares (1 hectare = 2.47 acres), and a series of smaller controlled fires were observed in Kruger National Park. Airborne measurements of gases and particulates produced from savanna burning all over southern Africa were obtained by researchers in fixed-wing aircraft and helicopters.

TRACE-A, part of the NASA Global Tropospheric Experiment, centered around the NASA DC-8 instrumented aircraft and studied the large-scale atmospheric structure of the region extending from Brazil over the South Atlantic to southern Africa.

In samples of smoke obtained from burning savannas in southern Africa during the SAFARI-92 experiment and from a burning boreal forest in Siberia during the FIRFStAN-93 experiment, methyl bromide was measured by Mann and Andreae (3). Methyl bromide is the single largest source of stratospheric bromine. Mann and Andreae estimate the global emissions of methyl bromide from biomass burning to be in the range of 10-50 Gg/year (1 gigagram - 10^9 g), comparable to the other two known sources of methyl bromide, ocean emission and pesticide use. Hence, biomass burning is a major contributor to the stratospheric bromine budget.

Burning in boreal forests

Biomass burning is generally believed to be a uniquely tropical phenomenon because most of the information we have on its geographical and temporal distribution is based on observations of the tropics. Because of poor satellite coverage, among other things, there is little information available on biomass burning in boreal forests, which represent about 25% of the world's forests.

One of the largest fires ever measured occurred in the boreal forests of Heilongjiang Province, north eastern China, in May 1987. In less than four weeks, more than 1.3 million hectares were burned (6, 11). At the same time, extensive fire activity occurred across the border in Russia, particularly east of Lake Baikal between the

TRACE-A (Transport and Atmospheric Chemistry near the EquatorAtlantic) aircraft flights over Africa and organized SAFARI-92 (South African Fire-Atmosphere Research Initiative), a component of the Southern Tropical Atlantic Region Experiment (STARE) in SeptemberOctober 1992, and the Fire Research Campalgn AsiaNorth (FIRESCAN) Bor Forest Island Experiment in Krasnoyarsk, Siberia, in July 1993.

Amur and Lena rivers (11). Estimates based on NOAA AVHRR imagery indicate that 14.4 million hectares in China and Siberia were burned in 1987.

To illustrate how our knowledge of the geographical extent of burning in the world's boreal forests has increased in recent years, consider the following. Early estimates based on surface fire records and statistics suggested that as much as 1.5 million hectares of boreal forests burned annually (1;,). Follow-on studies, based on more comprehensive data, indicated that the extent of burning had been underestimated;

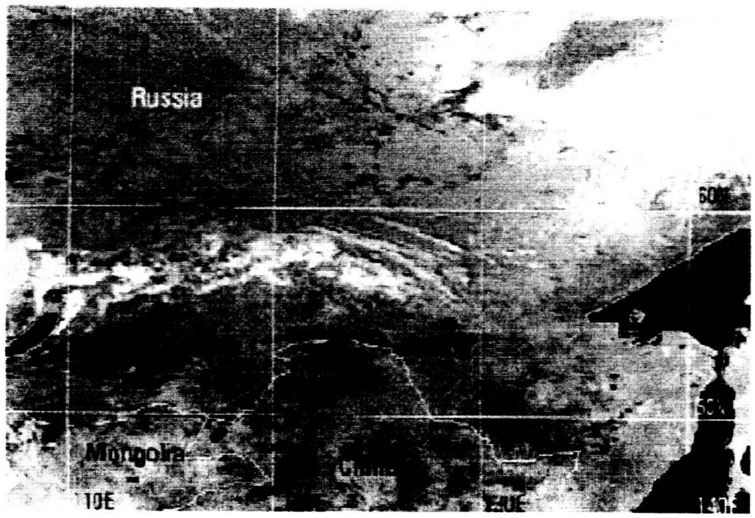
it was reported that an average of 8 million hectares burned annually during the 1980s, with great year-to-year fluctuations (18). The most recent study, this time based solely on satellite measurements, provided the approximate 14.4-millionhectare figure for the 1987 fires in eastern Asia (11).

Although 1987 represents an extreme year for fires in eastern Asia, the sparse database may suggest a fire trend. Is burning in the boreal forests increasing with time, or are satellite measurements providing more accurate data? We believe that satellite measurements are providing a more accurate assessment of the extent and frequency of burning in the world's boreal forests. Also, should global warming become a reality, predicted warmer and dryer conditions in these forests will result in more frequent and larger fires. Thus, increased burning will amplify global warming and vice versa.

Calculations using the satellite-derived burn area (11) and measured emission ratios of gases for boreal forest fires (14) indicate that the Chinese and Siberian fires in 1987 contributed about 20% of the total carbon dioxide, 36% of the total carbon monoxide, and 69% of the total methane produced by savanna burning (11). Because savannas represent the largest component of tropical burning in terms of the vegetation consumed by fire, it is apparent that the atmospheric emissions from boreal forest burning must be included in global species budgets.

Future research directions

International biomass burn research activities are being planned for two research activities of the IGAC Project. BIBEX is planning a series of field experiments in different ecosystems over the next few years, including the Experiment for Regional Sources and Sinks of Oxidants, Fire Research Campaign AsiaNorth, Fire Information Systems Research in the Ecology, Socio-culture and History of the Mediterranean Environment,



The extensive forest fires that occurred in China and Siberia during the summer of 1987 have been studied using satellite images and imageenhancement techniques. This false-color composite of several images from a National Oceanic and Atmospheric Administration satellite has been processed to eliminate clouds and delineate the burned forest (blackened regions). Land color ranges from yellow to green depending on vegetation cover; water appears blue and clouds white.

written (2), "We are uniquely fire creatures on a uniquely fire planet, and through fire the destiny of humans has bound itself to the destiny of the planet."

References

1. *Global Biomass Burning: Atmospheric, Climatic, and Bjospheric Implications; Levine, J. S., Ed.; The MIT Press: Cambridge, MA, 1991.*
2. *Andreae, M. 0. In Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications; Levine, J. S., Ed.; The MIT Press: Cambridge, MA, 1991.*
3. *Mann, S.; Andreae, M. 0. Science 1994, 263, 1255-57.*
4. *Anderson, I. C. et at. J. Geophys. Res. 1988, 93, 3893-98.*

and the South east Asian Fire Experiment.

In addition, the IGAC Global Emissions Inventory Activity has an important biomass burn component, the Global Emissions Inventory on Biomass Burning (19). Scientists involved in this international research activity are developing a global inventory of the geographical and temporal distribution of biomass burning and the gaseous and particulate emissions from burning for use in atmospheric models and as a database for environmental policy specialists. The development of a global database is a complex activity requiring global and temporal information on the occurrence of binmass burning, the distribution of vegetation by ecosystem, and the ratios for gaseous and particulate emissions as a function of both ecosystem and the evolution of the fire in each ecosystem.

In addition to being a significant instantaneous global source of atmospheric gases and particulates, burning enhances the biogenic emissions ofnitric oxide and nitrous oxide from the world's soils. Biomass burning affects the reflectivity and emissivity of the Earth's surface as well as the hydrological cycle by changing rates of land evaporation and water runoff. For these reasons, it appears that biomass burning is a significant driver of global change. As fire historian Stephen Pyne has

5. *Levine, 1.S. et at. Global Biogeochem. Cycles 1988,2,445- 49.*
6. *Levine, J. S. et at. In Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications; Levine, J. S., Ed.; The MIT Press: Cambridge, MA, 1991.*
7. *Wood, C. A.; Nelson II. In Global Biomass Burning' Atmo spheric, Climatic, and Biospheric Implications; Levine, I. S., Ed.; The MIT Press: Cambridge, MA, 1991.*
8. *Andreae, M. 0. Eos. Trans. Am. Geophys. Union 1993, 74, 129-35.*
9. *Cahoon, 0.11. et at. Nature 1992, 359, 812-15.*
10. *Cahoon, 0.11. et at. J. Geophys. Res. 1992, 97, 3805-14.*
11. *Cahoon, DR. er at.]. Geophys. Res. 1994,99,18,627-38.*
12. *Reichle, H. 6. et at.]. Geophys. Res. 1990, 95, 9845-56.*
13. *Pishman, J. et at. Science 1991, 252,1693-96.*
14. *Cofer, W 11. et at. Atmos. Environ., PartA 1990,24,1653- 59.*
15. *Cofer, W. 11. er at. In Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications; Levine, J. S., Ed.; MIT Press; Cambridge, MA, 1991.*
16. *Andreae, M.D. et at. In Global Atmospheric-Biospheric Chemistry: Prino, II. 6., Ed.; Plenum Press: New York, 1994.*
17. *Seiler, W; Crutzen, P J. Clim. Change 1980, 2, 407 27.*
18. *Stocks, B. J. In Global Biomass BurningAtmospheric, Climatic, and Bios pheric Implications; Levine, I. S., Ed.; The MIT Press: Cambridge, MA, 1991.*
19. *Graedel, T. E. Ens, Trans. Am. Geophys. Union 1994, 75, 585, 591.*
20. *Pyne, S. J. In Global Biomass Burning: Atmospheric, Clima tic, and Biospheric Implications; Levine, J. S., Ed.; The MIT Press: Cambridge, MA, 1991.*

Return Home

Last Updated: 10/01/2002 12:41:41
Web Curator: P. Kay Costulis (p.k.costulis@larc.nasa.gov)
Responsible NASA Official: Dr. Joel S. Levine, Atmospheric Sciences Competency

Feedback on Langley Products and Services