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REMOTE SENSING OF BIOMASS BURNING IN THE TROPICS

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ABSTRACT

A new method is developed for the global assessment of the contribution of biomass burning to climate change (trace gases and particulates emission). The method is based directly on remote sensing of the emitted products - particulates. The detected mass of emitted particulates is converted into the mass of the emitted trace gases using published relations between the particulates and trace gases emitted, for the flaming and smoldering phases. The NOAA-AVHRR 1km resolution images, in the visible, near IR, mid-IR and IR channels are used for this purpose. The analysis can be applied to regions where intensive biomass burning takes place.

Preliminary analysis of the 1987 burning season shows that in Brazil (between 6.5^{o}-15.5^{o} south and 55^{o}-67^{o} west), during the three months of the dry season, there may be up to 5000 fires a day, observed from space, each contributing 200 ton/hr of CO_2, 20 ton/hr of CO and 0.5 ton/hr of CH_4 to the atmosphere. During the dry season of 1987, it is estimated that 150,000 fires were burning, resulting in the emission of $6 \cdot 10^{12}$ g of particulates, $1.6 \cdot 10^{12}$ g of CH_4, 10^{14} g of CO and $7 \cdot 10^{14}$ g of CO_2. A comparison to estimates of global emission are given.

1.INTRODUCTION

The Global Tropospheric Chemistry program [13] set as its goal to understand the sources and sinks of the atmospheric trace gases and their variations in the atmosphere. The sinks of the gases is caused mainly by oxidation. Measurements of the emission rates of trace gases can show the potential of changes in the atmospheric balance. Comparison of the changes of the emission rates with the variations in the background concentration can teach us what is the ability of the atmosphere to take care of extra emission - the cleaning processes. For example methane (CH_4) concentration is increasing by 1% a year [2,13] and it doubled in the last 100-300 years after being constant for thousands of years [20]. It is not clear whether this increase is due to an increase in the emission of CH_4 or due to a reduction of its oxidation [13]. The present increase in the tropospheric concentration of ozone (an oxidant) suggest that the first reason is more likely to be true. The larger cycles in the CH_4 concentrations in the Northern Hemisphere than in the Southern Hemisphere also suggest the dependence of CH_4 concentration on the source variation.

During prescribed and natural fires large amounts of trace gases ($C0_2$, CO, CH_4, NO_x) and particulates (organic matter and Graphitic carbon) are released to the atmosphere. It is estimated that biomass burning contributes 5-30% of the global amounts of CH_3Cl, CH_4, NO_2 [13] and has a similar contribution to the atmospheric trace gases as fossil fuel burning [6,9]. It may increase the atmospheric greenhouse effect as well as it can affect the tropospheric chemistry [5]. Trace gases such as N_2O, that are inert in the troposphere, but are activated by UV radiation in the stratosphere, and are generated in the fires, may affect the chemistry of the stratosphere [6]. Note that most of the stratospheric NO, that serves as a catalyst in the ozone destruction, originates from tropospheric N_2O [25]. NO is expected to be responsible for about 70% of the annual global destruction of stratospheric ozone via the nitrogen oxide catalytic cycle [4,25]. The particulates emitted may affect the radiation budget and boundary layer meteorology by reflecting sunlight to space and absorbing solar radiation. The particulates also supply the condensation nuclei that form clouds. Therefore an increase in the aerosol concentration may cause an increase in the reflectance of thin to moderate clouds [3,26] and a decrease in the reflectance of thick clouds [22].

Present methods for the estimation of trace gases emission from biomass burning are based on measurements of the ratio of the trace gas concentration to the concentration of CO_2, and on a crude global estimate of the rate of emission of CO_2 during biomass burning. This estimate may suffer from uncertainty in the rate of deforestation [21], and uncertainty in the fraction of the burned material. Satellite imagery can show the spatial and temporal distribution of fires, provide a measure of the rate of deforestation, as well as measure the emission of particulates from the fires. Although satellite imagery cannot be used directly to sense the emitted trace gases, both the mass of emitted particulates and the mass of emitted trace gases are proportional to the mass of the burned biomass, or the mass of the released CO_2. Therefore, once the relation among the emitted particulates, trace gases and the burned biomass is established, measurement of the emitted particulates can be used to determine the mass of the emitted CO_2 and the mass of the emitted trace gases.

2. THE SMOKE AND ITS REMOTE SENSING

There are three major fire phases in which particulates and trace gases are emitted. During a moderate flaming phase the burning is relatively efficient releasing only small amounts of particulates or trace gases. Strong flaming results in release of unburned graphitic carbon but only moderate amount of trace gases [23]. Smoldering results in an inefficient burning and a release of large amounts of trace gases and organic particulates [28,29], but a much smaller amount of graphitic carbon. From satellite imagery it is possible to distinguish between smoldering and flaming conditions by deriving the single scattering albedo of the smoke [8,15,17] - the ratio of light scattering to light extinction by the smoke (ω_o) which is related to the amount of graphitic carbon in the smoke.

Ward and Hardy[28,29] studied the emission from prescribed open fires. Their data indicates that there is a relationship between particulates emission (M_{part}) and CH_4 emission (M_{CH4}). For flaming a least square fit of the data of Ward [24] results in $M_{CH4}=0.94+0.16M_{part}$. For smoldering conditions $M_{CH4}=2.1+0.41M_{part}$. Similar relations where found for CO). Therefore, remote sensing of the particulates in the smoke [10,16,17] can be used to derive their mass, and from it the mass of CH_4, CO and other trace gases.

These relations between particulates, trace gases and CO_2 measured by Ward [24] can be compared to measurements [4] of the emission from a prescribed fire in the Chaparral forest, and the measurements of Greenberg et al., in the Amazonas. The measurements of Coffer et al., [4] after conversation to mass ratio, are 0.0016 for CH_4/CO_2 and 0.036 for CO/CO_2. These results are similar to the results of Ward, for strong flaming conditions, as is the case of prescribed fires by the forest service. The measurements of Greenberg et al., [12] resulted in mass ratio of 0.003 for CH_4/CO_2 and 0.075 for CO/CO_2, which corresponds to mixed flaming and smoldering conditions, which is typical of the tropics.

Satellite imagery of the earth's surface in the visible and near IR part of the spectrum were used to derive the aerosol optical thickness (a measure of the aerosol mass loading in the atmosphere) its single scattering albedo (ratio between scattering and total extinction - a measure of the presence of graphitic carbon in the aerosol) and the particle mass median size. The remote sensing technique is based on the difference in the upward radiance, reaching the satellite sensor, between a hazy day and a clear day [8,10,15,17]. The aerosol optical thickness can be detected from the radiances above water or land, for almost every land cover (except bright soil or sand). The single scattering albedo can be detected over a sharp contrast in the surface reflectance, e.g. a sea-shore as well as over vegetated areas (here the contrast is between the low reflectance in the visible and the high reflectance in the near IR).

3. THE METHOD

The remote sensing technique is based on the analysis of NOAA-AVHRR 1km resolution imagery. The 3.7μm and the 11μm channels are used to detect fires and distinguish them from clouds and hot soil (that may also saturate the 3.7μm channel). The mass of particulates in the smoke and their single scattering albedo (ω_o) are determined from the visible and near IR channels (ω_o is used to distinguish between the relative contribution of smoldering and flaming to the smoke). Since fires are better defined in the image than smoke, first the average emission of particulates per fire (in a given area and season) is estimated and the corresponding total amount of fires (in the same season and area) are counted. The mass of the emitted particulates is converted to the mass of emitted trace gases and CO_2.

Remote sensing of fires and total emitted mass

The radiative temperature of the pixel from AVHRR channels at 3.7 and 11 μm can be used to identify fires. Although for some hot objects the use of the two channels can be used to identify the object temperature and its subpixel size, for fires (temperature>500°K) if 1% of the pixel is covered by a fire it is enough to saturate the 3.7μm channel, and have too small effect in the 11μm channel to be detected (see Fig. 3 in [7]). Both AVHRR channels saturate at 320°K [18]. The use of the 11μm channel is useful to distinguish between fires, reflective clouds and hot surface areas (all of them can saturate the 3.7μm channel). For a hot area the radiance in 11μm will be larger or similar to the radiance in 3.7μm channel. For fires the radiance in the 3.7μm channel will be much larger than in the 11μm channel and usually saturated. Clouds that saturate the 3.7μm channel, will usually result

in low radiances in the 11μm channel, and have an irregular shape. A computer program was written to determine the fires, based on these criteria. The total emission during the fire season is computed by multiplying the emission per fire by the number of fires. The emission is adjusted for the cloudiness, that covers some of the fires.

4. RESULTS

Remote sensing of the aerosol emission and the presence of fires was used to detect the rate of emission of particulates and trace gases from biomass burning. Remote sensing of the emitted aerosol and its conversion to the emitted trace gases (CO, CH_4, CO_2 etc.) shows (see table 1) that in average each fire in the tropics contributes 40 ton of particulates, 11 ton of CH_4, 700 ton of CO and 5,000 ton of CO_2. Analysis of AVHRR imagery, during 36 days in the dry season in Brazil, of the area between 6.5^o-15.5^o south and 55^o-67^o west, resulted in 60,000 fires (see Fig. 1). The cloudiness was also estimated from the satellite imagery for the same period. Clouds may hide part of the fires from the sensor, but they also may indicate the presence of rain and thus less fires (see Fig. 2). It was assumed in this analysis that the presence of fires is independent of the clouds. Accounting for the cloudiness and computing for 80 days of the burning season, we get 150,000 fires that correspond to the emission of $6{\cdot}10^{12}$ g of particulates, $1.6{\cdot}10^{12}$ g of CH_4, 10^{14} g of CO and $7{\cdot}10^{14}$ g of CO_2.

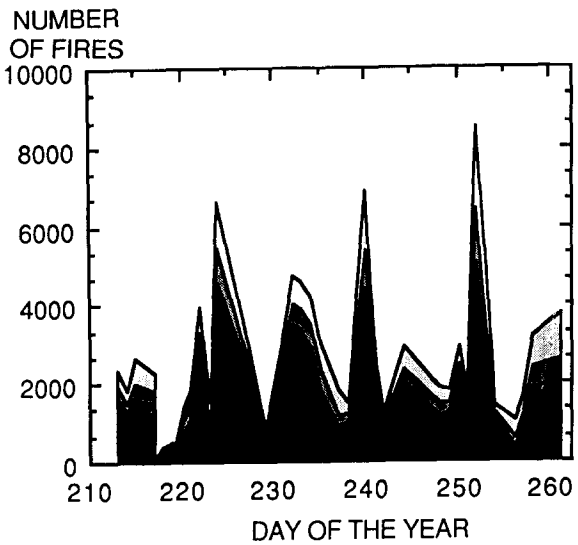

Fig. 1: number of fires as a function of the day of the year for 1987. The fires were counted, based on the radiance in the AVHRR 1km resolution imagery, in channels 3 and 4, over the area between 55^o-67^o west, and $55.^o$-15.5^o south. The black area represent fires that saturate channel 3 (3.7 μm), the gray area are additional fires that are 2^o colder, and the dotted area fires that are 4^o colder.

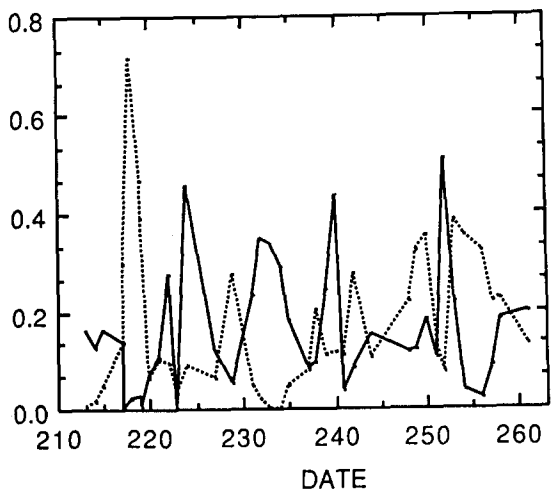

Fig.2 : The count of fires/10000 (——) and the cloud fraction (·····) during the dry season in 1987, for the area described in Fig. 1.

***Table 1:** Examples of the results for the smoke area (A), the number of fires (N), the aerosol single scattering albedo (ω_o), the aerosol mass per fire (M_{af}) and the corresponding CH_4 mass per fire (M_{cf}), for the state of Rondonia, Brazil.*

Date	A smoke area (km^2)	N number of fires	ω_o single scat. albedo	M_{af} aerosol mass /fire (ton)	M_{cf} CH_4 mass/ fire (ton)
7/31/87			0.95	60	24
8/22/87	22,000	1570	0.98	12	6
8/22/87	21,000		0.90	9	2.4
8/23/87	54,000	720	0.92	78	24
9/ 1/87	36,000	760	0.94	52	16
9/ 8/87	27,000	1830	0.93	26	8
9/ 9/87	40,000	2420	0.93	42	13

5. ONCLUSIONS

The results of the remote sensing analysis can be compared with Setzer [19] analysys of AVHRR imagery, taken over Brazil, of an area twice as large. He estimated the emitted trace gases and particulates, using estimates of the fire size, fuel density and published emission ratios.(see Table 2). In this state it is difficult to come with a reliable error analysis. Based on the measurements of Ward [24] of the emission from fires, and on the expected accuracy of remote sensing of particulates [17], it is estimated that the uncertainty in the emissions is around 50%. Comparison with the global estimates of biomass burning ([6] - Table 2), shows that the area presently analyzed should contain 1/10 of the global biomass burning, in order to fit the global estimates. Accounting for the additional fires in Brazil [19] as well as other south American, African and Asian countries, and accounting for wild fires [8], the global estimate is reasonable, though on the low side. This is mainly due to the expansion of deforestation and biomass burning in the Amazon[19].

TABLE 2: Emission from biomass burning

Source	CH_4 ($x10^{12}$gr)	CO ($x10^{12}$gr)	CO_2 ($x10^{12}$gr)
present results (limited area)	1.6	100	700
Setzer [19]	4.6	40	500
Crutzen ([6] - global estimate)	40.	800	10,000

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