Atmospheric implications of Indonesian peat fires

by Angelika Heil & Baerbel Langmann

Introduction

Smoke-haze from vegetation fires has a long history in Indonesia. Traditionally, fire is used as a tool to clear forests for agricultural purposes. It has also been used to convert swallow peatlands into paddy rice fields (Andriesse 1988, Sorensen 1993). Indonesia possesses the largest reservoir of tropical peatlands worldwide (up to 27 million hectare Mha), most of them in Eastern Sumatra, Southern Kalimantan, and Irian Jaya. The peat layer may be 10 m in depth and more and is generally densely forested (Rieley et al. 1997).

Along with the dramatically increasing deforestation and forest degradation rates in the last decades (Archard et al. 2002, FWI/GFW 2002), vegetation fires in Indonesia increased in intensity and frequency (Siegert et al. 2001), including also fires in peatlands (Diemont et al. 2002). Vast peatland areas in Indonesia have been drained for land conversion purposes in the last decades (Sorensen 1993). A popular example is the 1-Million ha Mega-Rice Project in Central-Kalimantan initiated by the Indonesian government in 1995 (Boehm and Siegert 2001). Drainage, in turn, increases the ignitability of peatlands, particularly during extreme drought events such as those triggered by the El Nino Southern Oscillation (Siegert et al. 2001). In contrast to surface vegetation fires, fires in peat areas may burn underground, are more long-lasting, and are difficult to extinguish (Bowen et al. 2000).

Fires in peatlands are also more critical to cause smoke-haze pollution: Their biomass load and thus the potentially available fuel that can turn into emissions is much higher than that of other vegetation types. For instance, a peat layer of 2 m depth would result in a biomass load of 2000 kg dry matter (dm) per m^2 (when bulk density is ~ 0.1 g/cm^3 (Sorensen 1993)). In contrast, the above-ground biomass load of tropical forest ranges from 13 –36 kg dm/m^2 (Ogawa et al. 1965, Brown and Gaston 1996) and ~ 0.4 –1.2 kg dm/m^2 for *Imperata* grassland (Ariyadasa 1999). Moreover, while peat is mainly consumed by smouldering combustion, combustion emits larger amounts of incompletely oxidised compounds (e.g. CO, NH_3, CH_4 and other hydrocarbons) per unit amount biomass consumed (Lobert and Warnatz 1993, Ward et al. 1996, Einfield et al. 1991). This applies also to fine particles (with high OC and low EC content), which are largely responsible for causing strongly impaired visibility during smoke-haze episodes. The fine particle emissions are also by far the most important emissions from a public health standpoint (Sharkey 1997).

Vegetation fires in Indonesia have caused several transboundary smoke-haze episodes in the last decades. The largest reported before 1997 were in 1982/83 and 1994, in which an estimated area of 3.5 and 5.1 Mha was affected by the fires, respectively (Lennertz and Panzer 1984, Qadri 2001). However, the pre-1997 fire events remain largely anecdotal: Missing documentation hinders the reconstruction of the atmospheric impacts of these events and the estimate of the relative importance of peat fire emissions (Nichol 1997). The situation changed with the 1997 fire and smoke-haze event in South-East Asia that excited unprecedented levels of international concern. Since then, various research activities have been initiated to improve the understanding of the origin and characteristics of the smoke-haze and its impact on atmosphere, climate, air quality, and health (e.g. Duncan et al. 2003, Heil and Goldammer 2001, see also WHO Health Guidelines for Vegetation Fire Events (Goh et al. (1999)).

Recently, Langmann and Graf (2003) published the hypothesis that the increased sulfur content observed in the Indonesian fire aerosols could be due to volcanic sulfur deposited in Indonesian peat areas. The island arc volcanoes in and around Indonesia have been permanently degassing for thousands of years, releasing heavy metals and sulfur into the atmosphere. These volcanic compounds may accumulate in the Indonesian peat areas by wet deposition and be re-released with fire. Volcanic compounds may enforce the atmospheric

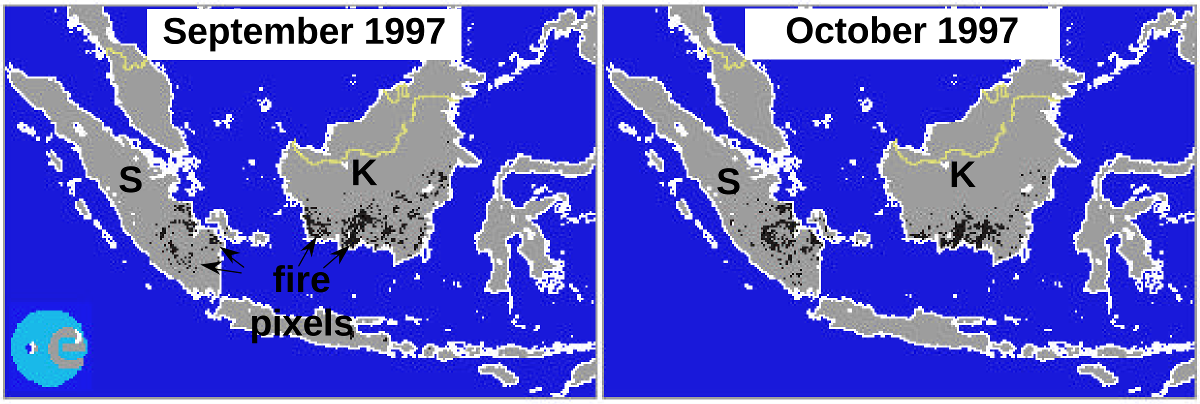

Figure 1a (left) and 1b (right): Monthly night time fire activity map of Kalimantan (K) and Sumatra (S) for September and October 1997 as depicted by the ATSR satellite instrument (adapted from Arino and Rosaz (1999)).

implications of peat fire aerosols. For instance, an increased heavy metal content would imply a higher toxicity and thus increased health impacts.

Emission estimates

The 1997 fire episode in Indonesia began in July and ended in November with the onset of the monsoonal rain. A second fire episode occurred in 1998. The temporal and spatial development of the fires was registered by several satellite systems as ‘hotspot’, i.e. pixels where temperature exceeded a certain threshold (e.g. Fig. 1a). However, a detected fire pixel does not provide direct evidence how much of the pixel burned hampering an estimate of the area burned. In addition, low-intensity, subsurface fires such as those occurring in peatlands, commonly elude satellite retrievals. Depending on the approach used, area burned estimates for the 1997/98 fires in Indonesia vary significantly (c.f. Levine et al. 1999). Furthermore, the attribution of a fire pixel to a specific vegetation type depends on the quality of vegetation maps. Both factors strongly determine the estimated emission production.

Levine (1999) estimated the emission production resulting from the 1997 fires in Kalimantan and Sumatra. For his calculation, he used both the estimate of the area burned and the estimate of the ecosystem burned of Liew et al. (1998), which suggests that 20% of the area burned consisted of peat swamp forests and the remainder of agricultural and plantation areas, forests and bushes (Table 1). Levine assumed that a 1.5 m peat layer was burned with a burning efficiency of 50% (i.e. effectively 0.75 m entirely burned). As a result of this and other assumptions, fires in peat swamp forests accounted for the largest part of the total emission production, with 91% (223 Tg C) for total C and 94% (15.6 Tg C) for particulate matter (TPM), respectively (Table 1). The same applies to the emission of trace gases.

Table 1: Estimated emissions produced from the 1997 vegetation fires in Indonesia based on Levine (1999) and the intermediate estimate by Page et al. (2002). Page et al. (2002) estimated the emissions from fires in peatlands solely.

Source	Land cover type affected by 1997 fires	Area burned [Mha]	% total area burned	Biomass Carbon [MgC/ha]	depth burned m	Carbon released [MgC/ha]	Total C released [TgC]	% of total C released	Total TPM [Tg C]	% of total TPM released
Levine (1999)	Agriculture&Plantations	2.3	50%	22.5	(a)	4.5	10.3	4%	0.5	3%
	Forests& bushes	1.4	30%	45.0	(a)	9.0	12.3	5%	0.5	3%
	Peat forest (1.5m deep) incl. aboveground vegetation	0.9	20%	487.5	0.75	243.8	222.3	91%	15.6	94%
	Total	4.6	100%				244.9	100%	16.6	100%
Intermediate estimate Pageetal.(2002)	Peat mean depth 2.3 m	2.4		1,311.0	0.51	290.7	709.6	81%	49.7 (d)	87%
	surface vegetation on peat (forest)	~ 1.4 (b)		250.0	(c)	125.0	170.0	19%	7.6 (d)	13%
	Total	2.4		1,561.0		415.7	879.6	100%	57.2	100%

(a) Burning efficiency 20% TPM= Total Particulate Matter

(b) Area of peat surface vegetation burned not explicitly given by Page et al. (2002)

(c) Burning efficiency of above-ground vegetation (pristine forest assumed) is 50%.

(d) Applying same emission ratios related to total C released as Levine (1999) for peat forest and forests&bushes, respectively

Page et al. (2002) estimated the amount of carbon released from fires in peatlands only. The inventory is based on satellite images of a 2.5 Mha study area in Central Kalimantan. From the 2.15 Mha of peatlands, 29.3 % were fire-damaged. Based on ground measurements, they assumed that a 0.51 m peat layer entirely burned on average. In addition, they took into account that the forest cover on the peat layer was also affected by the fire (Table 1). Compared to Levine (1999), the assumption of Page et al. (2002) for biomass load and depth burned resulted in much higher carbon emissions per ha (416 Mg C/ha versus 244 Mg C/ha). However, when comparing with the carbon emissions resulting from the peat layer solely (291 Mg C/ha), the numbers are relatively close. Levine (1999) did not explicitly consider the emissions from the aboveground vegetation burned, while Page et al. (2002) assumed a relatively high biomass density as typical for pristine peat swamp forests. When extrapolating the results on Indonesia as a whole, Page et al. (2002) set up 3 different scenarios for the total area of fire-damaged peatland: a) a lower estimate resulting in 0.52 (± 0.04) Gt C released from 1.45 Mha of fire-damaged peatland, b) an intermediate estimate with 0.88 (± 0.07) Gt C from 2.44 Mha of peatland burned (Table 1) and c) an upper estimate with 2.34 (± 0.19) Gt C from 6.8 Mha peatland released. The latter would mean that 34% of Indonesia’s peatland area (20 Mha) was fire damaged. Each of these scenarios result in higher

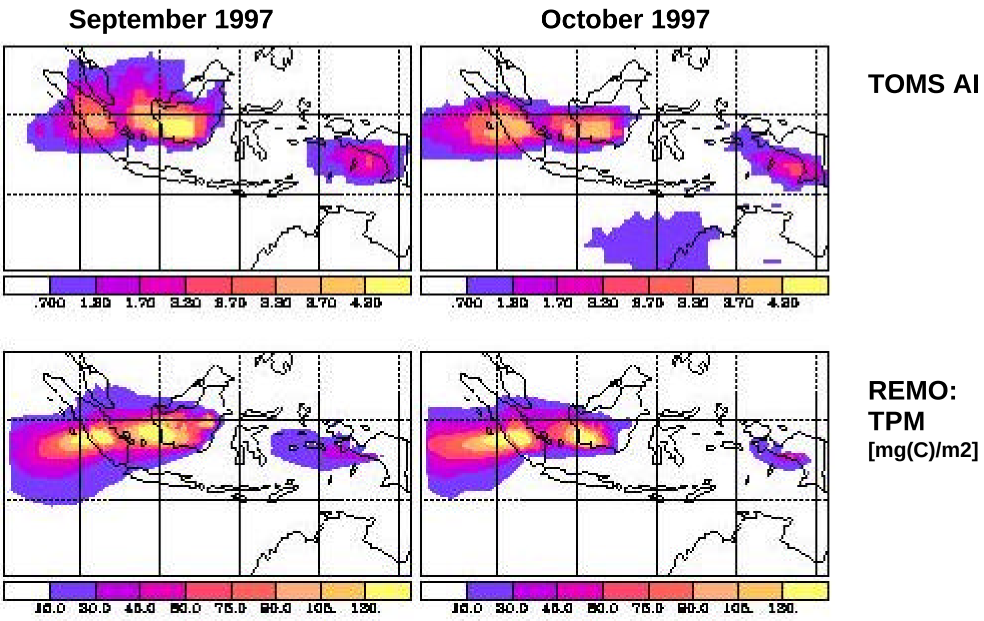

Figure 2: TOMS Aerosol Index (AI) versus REMO simulation of TPM column burden above 1.5 km height for September 1997 on the left and for October 1997 on the right.

total emissions than the one calculated by Levine (1999) for all land cover types affected by the fires. The range of these figures demonstrates clearly the uncertainties involved in emission estimates. Only very recently, pyrogenic emissions from combusting peat samples from Sumatra have been characterised within the framework of the EFEU-Project (Impact of Vegetation Fires on the Composition and Circulation of the Atmosphere, c.f. Wurzler et al. 2001). In the absence of specific emission characteristics for Indonesian peat fires, Levine (1999) used emission factors obtained from burning boreal peat. Despite all these uncertainties, the particular importance of peat fire emissions remains unquestioned. The estimated emissions of particulate matter (TPM) from the Indonesian fires by Levine (1999) and Page et al. (2002, intermediate estimate), respectively, are by about a factor of 25 and 89 larger than the estimated annual emissions of particulate matter from anthropogenic sources in Europe 1990 (0.65 TgC TPM/a, from Amman et al. 2001, C-content of 0.15 assumed).

Modelling atmospheric impacts

Due to the scarcity of air quality data and other observational information in Indonesia, it is particularly important to model transport and dispersion of fire emissions over Indonesia for impact assessments. For this purpose, the regional model REMO has recently been applied for simulations of particulate matter emissions from vegetation fire in Indonesia during 1997/98 (Langmann and Heil, in preparation). REMO (Langmann 2000) is an on-line atmospheric-chemistry model with a standard horizontal resolution of 0.5 degree. Vertically, 20 layers are used. For the model run, the area burned estimate for the 1997 fire episode given by ADB/BAPPENAS (1999) (similar to the lower estimate used by Page et al. 1999) has been redistributed spatiotemporally (1/2°, weekly intervals) using ATSR1 hot spots information (Along Track Scanning Radiometer, Arino and Rosaz 1999). The vegetation data by Loveland et al. (2000) were complemented with information on peat areas based on Rieley et al. (1995) and other sources. The emissions were calculated following the approach of Levine (1999). For a detailed methodology, we refer to Langmann and Heil (in preparation).

Figure 2 shows preliminary results from a qualitative comparison of REMO calculated Total Particulate Matter (TPM) (column burden above 1.5 km height in mg(C)/m2) with TOMS Aerosol Index (AI) (Herman et al. 1997) as monthly mean for September and October 1997. The space borne sensor TOMS measures the presence of aerosols in the whole atmospheric column with a height-dependent sensitivity. From the qualitative comparison (note that the absolute numbers differ) we conclude that REMO is able to reproduce the spatial and temporal distribution of the fire particles. Figure 2 also demonstrates the impressive extend of the smoke-haze layer that covered large parts of Indonesia, Malaysia, and Singapore. A preliminary comparison with ground-based measurements suggests that REMO may approximately predict the TPM concentration ranges observed, but requires further adaptations to reproduce the temporal TPM patterns. Further research will focus on the influence of the Indonesian fire aerosols on local and regional climate via modifications of clouds and precipitation and incoming solar radiation. In addition, health aspects will be considered. Dependent on the availability of corresponding satellite data and vegetation maps, the atmospheric impacts of the different fire episodes over the last decade (e.g. 1994, 2001) will be studied, too.

Conclusions

Modelling the atmospheric impacts of emissions from vegetation fires in Indonesia largely depends on the data base available to establish the emission inventory, i.e. spatio-temporal information on the area burned and the corresponding vegetation data. Due to the high potential emission rate, the inclusion of fires in peatlands is of particular importance. Improved data bases on peat areas and characteristics are urgently required. Given this apparent particular relevance of peat swamp fires to the development of transboundary smoke-haze, emission reduction and control strategies will have to focus on the prevention of fires in this type of vegetation as a matter of priority.

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Integrated river basin management in Air Hitam Laut River Basin, Sumatra

by Dua Klaas

Introduction

This paper focuses on the sustainable management especially of the peat swamp forests of Air Hitam Laut river basin, Sumatra – Indonesia. It presents findings from a literature review, discussions, interviews, and a one-day workshop conducted in Jambi – Indonesia with representatives from the Dutch partners, the local community, NGOs, government officials, and academic sectors.

A four month research (April – August 2002) was carried out at the International Agriculture Centre (IAC, Wageningen - the Netherlands) and by a fact-finding trip in the study area as part of the development of an inception report for the Water and Ecosystem Programme released by the Dutch government in accordance with the declaration of The Hague 2000 on Water Security in the 21st Century. The research aims to support the Water and Ecosystem programme through the compilation of data, identification of main Indonesian stakeholders, and support to the workshop in Indonesia, and by providing recommendations concerning the Air Hitam Laut river basin.

Study area

Air Hitam Laut River and Berbak National Park

The Air Hitam Laut River and Berbak National Park are located in Jambi Province, Sumatra – Indonesia. This river flows adjacent to South Sumatra province, through the centre of Berbak National Park and ends in the South China Sea. Upstream, freshwater swamps dominate the river basin. Downstream, the river is affected by tidal flow and saltwater swamps are found. Rich brackish and mangrove vegetation cover the coastline and estuarine area. Large areas of this river basin consist of peat soils. According to Diemont and van Reuler (1984), the formation of up to 10 metres thick peat layers of this 175,000 ha peat area started between 4,780 and 3,015 BP.

There are approximately 17,000,000 ha of lowland peatland in Indonesia (Andriesse 1988; Soil Research Institute 1976), of which 9.7 million ha lie in Sumatra (Soil Research Institute 1976). Most of the areas have shallow peat (0,5 – 1,5 m deep), and extensive parts are flooded during the wet season. Peatlands in this river basin are classified as ombrotrophic peatlands (Silvius et al. 1984; AWB 1992). They play an important hydrological role, absorbing and storing water from Air Hitam Laut River, and providing it to the whole Berbak ecosystem.

The river is of significant importance to the Berbak National Park, which has a total area of 162,300 hectares (AWB, 1992) and includes saltwater swamp, freshwater swamp, and coastline ecosystems. The Berbak National Park is the largest remaining undisturbed peat and freshwater swamp forest area in Sumatra, and comprises two-thirds of all visibly undisturbed peat-swamp forest of Sumatra (Asian Wetland Bureau, 1992). Thus, this national park might be considered as the best peat swamp reserve for flora and fauna in Asia. The National Park and the adjacent areas have an exceptionally high biodiversity and have been assigned Ramsar status. The vegetation species list currently contains over 260 species (Giesen, 1991), including 150 tree species and 23 palms (Arecaceae). This makes it the most palm-rich swamp forest yet known (Dransfield 1974).