Paulo Artaxo is a Professor of environmental physics at the University of São Paulo, Brazil. He has participated in several major research efforts of international organizations such as IGAC, CACGP, IPCC and WMO. He has acted as member of several scientific steering committees, for example IGAC, Deposition of Biologically Important Trace Species (DEBITS) project, Biomass Burning Experiment (BIBEX) project, Polar Atmospheric Snow Chemistry Committee (PASC), and the IPCC Panel on Global Aviation Effects. He is one of the coordinators and member of the Scientific Steering Committee of the Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA), member of the IPCC working group I, and also member of the iLEAPS scientific steering committee. He was general secretary of the CACGP, the IAMAS Commission on atmospheric chemistry and global pollution. His scientific experience is in radiative effects of aerosols, focusing on tropical aerosols, biogeochemical cycling in the Amazon basin, dry and wet deposition, biogenic and biomass burning aerosols. He also works with urban air pollution in megacities.

Biomass burning as a driver for atmospheric composition and ecosystem changes

Paulo Artaxo[1] and Meinrat O. Andreae[2]

[1] Institute of Physics, University of São Paulo, São Paulo, Brazil
[2] Max Planck Institute for Chemistry, Department of Biogeochemistry, Mainz, Germany

The composition of the atmosphere is controlled by several natural and anthropogenic processes, and emission from biomass burning is one of the strongest. For example, agricultural residues have been burnt for millennia, and the reduction in forest area in North America and Europe over the last centuries has evidently contributed to the changes in atmospheric composition. More recently, during the last 4–5 decades, the rapid and intensive land use change in the tropics has significantly enhanced attention to the issue.

It is important to emphasize that biomass burning is a major atmospheric driver not restricted only to the tropical areas. Two recent examples show the impacts of biomass burning emissions on ozone and $PM_{2.5}$ particles (particulate matter with an aerodynamic diameter of less than 2.5 μm) far from tropical areas. Even in megacities, with large emission of pollutants from industrial sources and vehicles, biomass burning contributes a significant proportion of the urban air pollution burden. Results from the MILAGRO (Megacity Initiative: Local and Global Research Observations) experiment, a detailed study of urban pollution in Mexico City, indicate that even in downtown Mexico City, biomass burning emissions are responsible for 20–50% of the $PM_{2.5}$ levels. In megacities around the world, inhabitants burn wood for a variety of reasons. Burning of fuelwood in large urban conglomerates leads to smoke that significantly contributes to urban air pollution levels. In Beijing, black carbon and potassium measurements indicate a high atmospheric impact of wood combustion. Similar emissions from biomass burning are expected in medium and large sized cities in Asia and Africa. In the western United States, forest fires during the past 10 years have been claimed as responsible for up to a 6 ppb increase in the regional ozone concentrations – a large proportion of the atmospheric concentration of the oxidant. The latest IPCC report [1] shows that the positive global radiative forcing of ozone is increasing rapidly and today is as high as 0.35 Watt per m². In regions downwind of biomass burning emissions, high ozone concentrations have been reported, particularly over the remote South Atlantic Ocean. In Amazonia, ozone con-

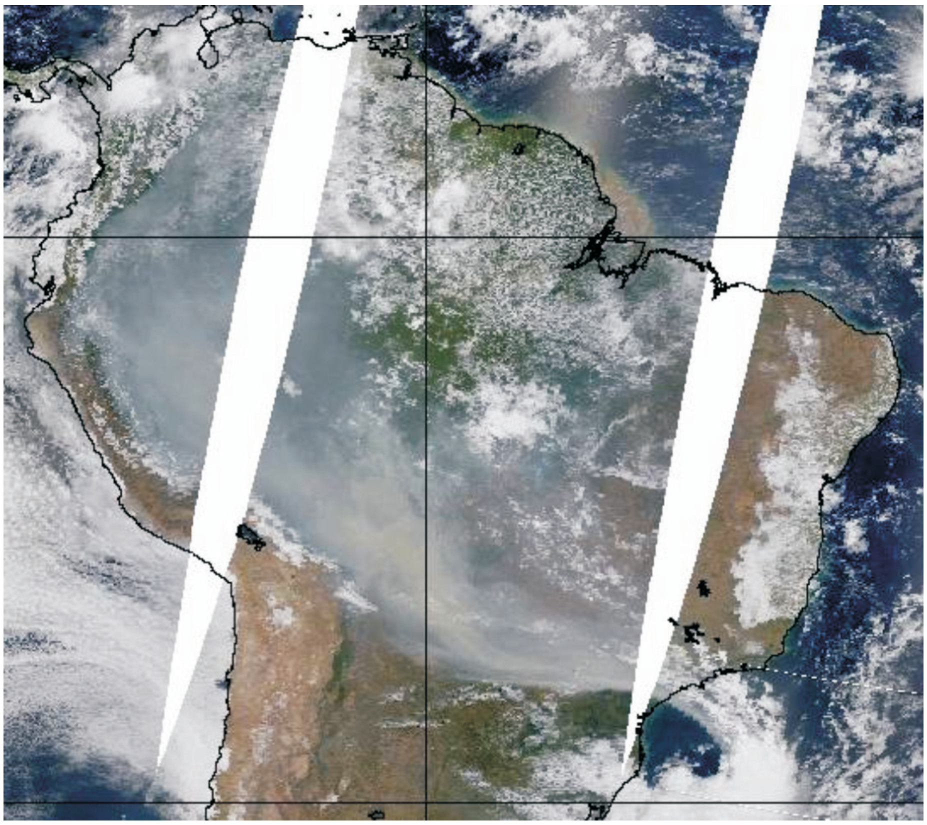

Figure 1. MODIS image of an aerosol plume from biomass burning, reaching continental scales and affecting a large area of South America.

Every year about 20.000 km² of primary tropical forests are cleared in Amazonia, with significant atmospheric emissions of aerosols and trace gases.

centrations as high as 100 ppb have been measured downwind of biomass burning plumes. These high ozone levels are harmful for vegetation over thousands of kilometers away from the sources of emission. In the southern hemisphere, biomass burning is one of the major factor affecting ozone concentrations. Fig.1 shows a MODIS image of aerosol plume from vegetation fires, reaching continental scales, and hence affecting a large area of South America.

Aerosol particles emitted from vegetation fires have profound impacts on the regional and global radiative forcing and on cloud properties. During seven years (1995–2002) of LBA (The Large Scale Biosphere-Atmosphere Experiment in Amazonia) measurements in Alta Floresta, the surface radiative forcing is calculated to be on average -37 Watt m^{-2}, significantly cooling the surface. Based on surface measurements in several locations impacted by biomass burning plumes, the radiative forcing is very significant regionally and has important impacts on several aspects of ecosystem functioning. Aerosols from vegetation fires contain high amounts of black carbon particles and thus the atmospheric absorption of heat is very significant, heating the top of the boundary layer by about 2–3 degrees and cooling the surface. This effect stabilizes the atmosphere and reduces the convection that pumps up water vapor to higher altitudes where it is available for cloud formation and development.

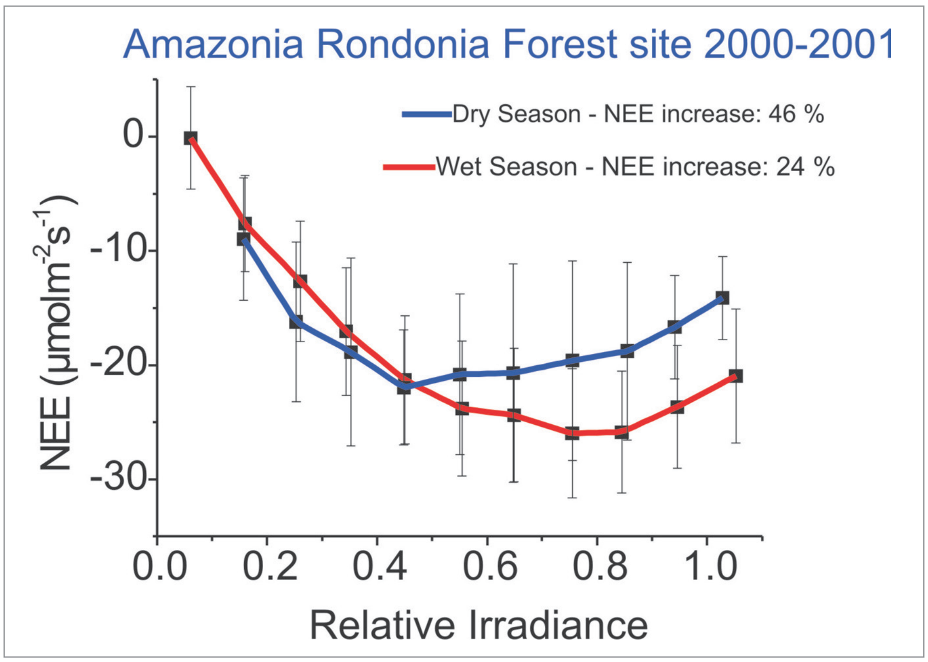

Figure 2. Net ecosystem exchange (carbon flux in μmol m^{-2} s^{-1}) as a function of aerosol loading in the atmosphere expressed as the relative irradiance index. Note that negative values of NEE correspond to net ecosystem uptake, and that relative irradiance index decreases with increasing AOT. For details, please refer to Oliveira et al. [6].

The large increase of aerosol loading in the Amazonian atmosphere due to biomass burning emissions has a strong effect on the photosynthetic rate over large areas. Fig. 2 shows the impact of the increase in aerosol loading in the atmosphere as a function of measured carbon fluxes in the Amazonian topical rain forest. A small increase in aerosol loading actually increases the fraction of diffuse versus direct radiation, and therefore the vegetation increases the efficiency of the use of solar radiation, increasing net primary productivity (NPP) (defined as the net flux of carbon from the atmosphere into green plants per unit time), up to a certain point. From clean conditions (aerosol optical thickness, AOT, around 0.1 at 500 nm) to an AOT of 1.2, NPP increases by 46% in the dry season and 24% in the wet season in Rondonia [6]. As soon as the aerosol optical thickness becomes larger than 1.2 at 500 nm, the reduction in the total flux starts to reduce carbon assimilation, and at an AOT of about 3-4, the vegetation basically stops assimilating carbon efficiently due to the low radiation flux. As the areas of the biomass burning plumes in South America, Africa and Southeast Asia are very large, the effect of aerosols from biomass burning on the carbon exchange is most important in the Southern Hemisphere.

The suppression of low cloud formation is another important climatic effect of aerosols from biomass burning. Results from the LBA Smoke, Aerosols, Clouds, Rainfall and Climate (LBA-SMOCC) experiment both from in-situ measurements and remote sensing show that the high number of cloud condensation nuclei suppress cloud formation and alter cloud microphysics affecting the hydrological cycle over large areas in the Southern Hemisphere [2, 3]. The high concentration of particles makes smaller cloud

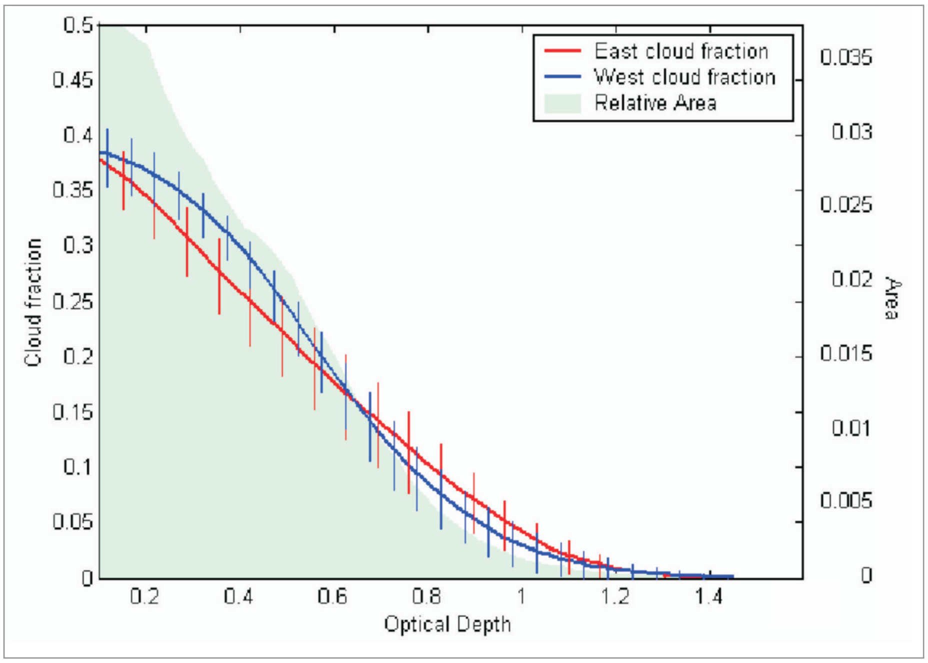

Figure 3. Reduction in low cloud fraction as a function of biomass burning aerosol loading in Amazonia. From Koren et al. [3].

droplets and inhibits droplet growth, reducing precipitation on the ground and increase cloud lifetime. This aerosol indirect effect has global climatic influences on the radiative forcing. Fig. 3 shows the cloud cover fraction for low clouds as a function of aerosol loading in the atmosphere. When aerosol optical thickness exceeds 1.0, cloud cover is strongly suppressed [3]. This mechanism was observed in Amazonia, but similar cloud suppression mechanisms that affect the hydrological cycle could be found in other tropical regions where biomass burning emissions are significant.

A recent review article by Fuzzi et al. [4] illustrates the complexities of aerosol particles emitted through biomass burning in tropical areas. Due to the complex organic composition and size distribution, modelling of transport processes of the aerosol particles to cloud droplets is quite difficult. We are also far from understanding the possible effects of aerosol particles on precipitation rate. Kaufman and Koren [5] showed that aerosol can either increase or decrease cloud cover, depending on the amount of absorbing particles. It appears that the absorbing properties and black carbon amount are among the key issues in aerosol-cloud-climate interactions. The balance between the effect on clouds from the dynamics of the atmosphere versus the aerosol effects on clouds is not yet solved.

The recent IPCC reports stated that it is urgent to significantly reduce tropical deforestation and biomass burning emissions and that the reduction has global and regional climate implications. Several modelling studies indicate that climate change will affect very intensively the extent of tropical forest area. Lower precipitation rates and higher temperatures in Amazonia could reduce the forest area up to 35% during this century. These climate effects will feed back to the carbon cycle injecting large amounts of carbon stored in the Amazonian forest into the atmosphere, since Amazonian rain forest has 200–350 tons of carbon per hectare. This possible reduction in forest area also will reduce tropical evapotranspiration, with important consequences for the global hydrological cycle.

Through research in the framework of LBA we found out that the Amazonian forest is much less robust than had been thought previously. The strong drought in 2005 in Amazonia showed that the equilibrium of the climatic system that sustains the Amazonian forest is actually quite fragile. If the current deforestation figures continue at the level we have been observing these last years, about 40% of the Amazon forests could disappear by 2050, and as a consequence, there could be an emission of 32 Pg of carbon to the atmosphere [7]. These possible emissions will increase CO_2 concentrations, aggravating the greenhouse effect. At the same time, water vapor fluxes from Amazonia will be reduced significantly. It is an important task to reduce tropical deforestation rapidly, and to implement conservation policies in Amazonia as well as tropical Africa and Southeast Asia.

artaxo@if.usp.br

1. IPCC: Climate Change 2007. The 4th Assessment Report of the Intergovernmental Panel on Climate Change, available at http://www.ipcc.ch
2. Andreae M.O., Rosenfeld D., Artaxo P., Costa A.A., Frank G.P., Longo K.M. and Silva-Dias M.A.F. 2004. Smoking rain clouds over the Amazon. Science 303, 1342-1345.
3. Koren I., Kaufman Y.J., Remer L.A. and Martins, J.V. 2004. Measurement of the effect of Amazon smoke on inhibition of cloud formation. Science 303, 1342-1345.
4. Fuzzi Sandro, Decesari S., Facchini M.C., Cavalli F. Emblico L., Mircea M., Andreae M.O., Trebs I., Hoffer A. Guyon P. et al. (in total 29 authors) 2007. Overview of the inorganic and organic composition of size-segregated aerosol in Rondônia, Brazil, from the biomass burning period to the onset of the wet season. Journal of Geophysical Research 112, 1201-1236, doi:10.1029/2005JD006741.
5. Kaufman Y. and Koren I. 2006. Smoke and Pollution Aerosol Effect on Cloud Cover. Science 313, 655-658.
6. Oliveira P.H.F., Artaxo P., Pires Jr C., de Lucca S., Procópio A., Holben B., Schafer J., Cardoso L.F., Wofsy S.C., Rocha H.R. 2007. The effects of biomass burning aerosols and clouds on the CO_2 flux in Amazonia. Tellus B 59B, 338–349. DOI: 10.1111/j.1600-0889.2007.00270.x.
7. Soares-Filho B.S., Nepstad D.C., Curran L.M., Cerqueira G.C., Garcia R.A., Ramos C.A., Voll E., McDonald A., Lefebvre P. and Schlesinger P. 2006. Modelling conservation in the Amazon basin. Nature 440, 520-523, doi:10.1038/nature04389.