Shadows

Forest clearing fires (*red dots*) in Mato Grosso: smoke creates a sunshade for the forest

IMAGES BY NASA

over the forest

Clouds of smoke from forest clearing fires block out 20% of the light from the sun, reduce rainfall and cool down the Amazon Forest

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Almost everyone has already seen this scene, either live or on the television: clouds of smoke stain gray the sky of the Amazon at the peak of the forest clearing fire season, between August and October, the driest time of the year in the region. In this period, for lack of visibility, the airports of capital cities such as Rio Branco and Porto Velho close all the time for take-offs and landings, as microscopic particles – called aerosols – arising from the combustion of the vegetation, cloud the firmament in a striking manner. On a particularly murky day, a false, slow – and beautiful – sunset can begin at midday and drag on for hours. All because of the shadow of the aerosols that hangs over significant parts of the Amazon when man uses fire, one of the most primitive and polluting ways of clearing and preparing the land for cultivation. The untimely darkness, as if over the forest there were a giant manmade sunshade, can be the most visible effect of an atmosphere saturated with suspended particles, but it is far from being the only one.

It is only now that science is beginning to have some elements to see that these forest clearing fires, the main source of aerosols during the dry season in the northern region, disturb the climate and the vegetation in even more subtle and perverse ways. Unleashing a chain of physico-chemical events a few kilometers above the forest, the startling concentration of aerosols at the height of the fire season reaches peaks of 30,000 particles per cubic centimeter of air, a level some 100 times greater than found in the polluted city of São Paulo in deepest winter. This alters the environment immediately beneath the cloud of smoke. It reduces by an average of one-fifth the

sunlight that hits the ground, and has the potential for cooling the surface by up to 2º Celsius and for reducing by from 15% to 30% the rainfall in the region. The reduction in solar radiation on the surface, caused by the excess of particles in suspension, can also pull down the photosynthesis rate of trees. "As the particles sometimes travel thousands of kilometers in the atmosphere before falling to earth, the aerosols can show their effects at spots that are distant from where the forest clearing fires occur", explains Paulo Artaxo, from the Physics Institute of the University of São Paulo (IF/USP), one of the researchers taking part in the Large Scale Biosphere-Atmosphere Experiment in theAmazon (LBA). "Particles coming from the Amazon have now been found in the Andes and in São Paulo."

This does not mean that, due to the cooling down and the dry season, associated with the action of the aerosols, the sales of sweaters have shot up or that umbrellas have fallen into disuse in sectors of the Amazon between August and October. Neither is there unequivocal evidence that the trees are suffering from lower photosynthesis in this period of the year. For the time being, except for the measurable fall in the light intensity that hits the surface at the time of the forest clearing fires, the other consequences attributed to the mantle of dust suspended over the forest still hold a considerable degree of uncertainty. They appear more in theory, in the calculations and mathematical models run on computers than in the daily reality. But one should not forget that the models are, in good measure, the laboratories of the climate scientists, and they would otherwise have no way of studying the impact of some of nature's phenomena. The good news is that the amount of information that is beginning to arise about the climate of Amazonia with the LBA – an international US$ 80 million mega-project that since 1999 has gathered together over 300 researchers from Latin America, Europe and the United States, under Brazilian leadership – has no parallel, and is already helping the effect of the aerosols in this ecosystem to be understood. "Now, we have amount of information that had never been available", says researcher Maria Assunção Faus da Silva Dias, from USP's Astronomy, Geophysics and Atmospheric Sciences Institute, who is also participating in the project.

Action of the aerosols - When one talks about the forest clearing fires in Amazonia, the first environmental villain that comes to mind is carbon dioxide (CO_2), one of the byproducts of the combustion of vegetation. The main compound associated with the increase in the greenhouse effect, a phenomenon responsible for heating the atmosphere all over the planet and that can alter the condition of life on Earth drastically, carbon dioxide is a recurrent theme. Aerosols, though, which have a diameter varying from 0.01 to 20 micrometers (1 micrometer is a millionth part of a meter), are a theme that is newer and less understood. Not for this reason less important. "This field of study is still in full spate of development", comments Carlos Nobre, of the National Institute for Space Research (Inpe) in São José dos Campos, the LBA scientific coordinator. "It is more difficult to understand the impact of the aerosols."

The hypothesis that aerosols have a deacreasing temparature effect is not an unprecedented one, nor is it used only in the context of Amazonia. When it broke out in eruption in 1991, the Philippine volcano Pinatubo expelled large quantities of lava and ash and led to a significant reduction in the average temperature of the planet throughout one year. In this context, a hasty thinker could conclude that mankind ought to increase deliberately the levels of production of aerosols, to combat the global warming caused by the increase in the greenhouse effect. Besides nobody knowing for sure wether this solution would really be effective, there is a sort of craziness within this line of thinking: aerosols are a form of air pollution, and it makes no sense to fight global warming with more dirt. "They are harmful to human health and carry toxic elements that affect ecosystems", Artaxo warns.

Everything that produces smoke in a large quantity can originate aerosols. These particles may be produced by industrial activities, volcanoes eruptions, automobile engines, pollen grains, bacteria, and soil dust. In the north of Brazil, during the dry season, it is the ashes from the forest clearing fires that cause a steep increase in the levels of aerosols. As they are short lived, with about one week in the atmosphere, aerosols produce effects more at the local or regional level. They are not like carbon dioxide, a gas that takes over 100 years to vanish from the atmosphere and which has a much more cumulative and global action on the climate of the Earth. But as every year, during at least three months, the particles launched into the air by the forest clearing fires are incorporated into the Amazonian ecosystem with an impressive intensity, their repercussions should not be all that temporary in the northern region of the country.

Sunblocker - With the help of satellite images, instruments set up at fixed points of the forest that record without inter-

THE PROJECTS

Chemical and Physical Interactions between the Biosphere and the Atmosphere in Amazonia in the LBA Experiment

COORDINATOR
Paulo Eduardo Artaxo Netto – IF/USP

MODALITY
Thematic project

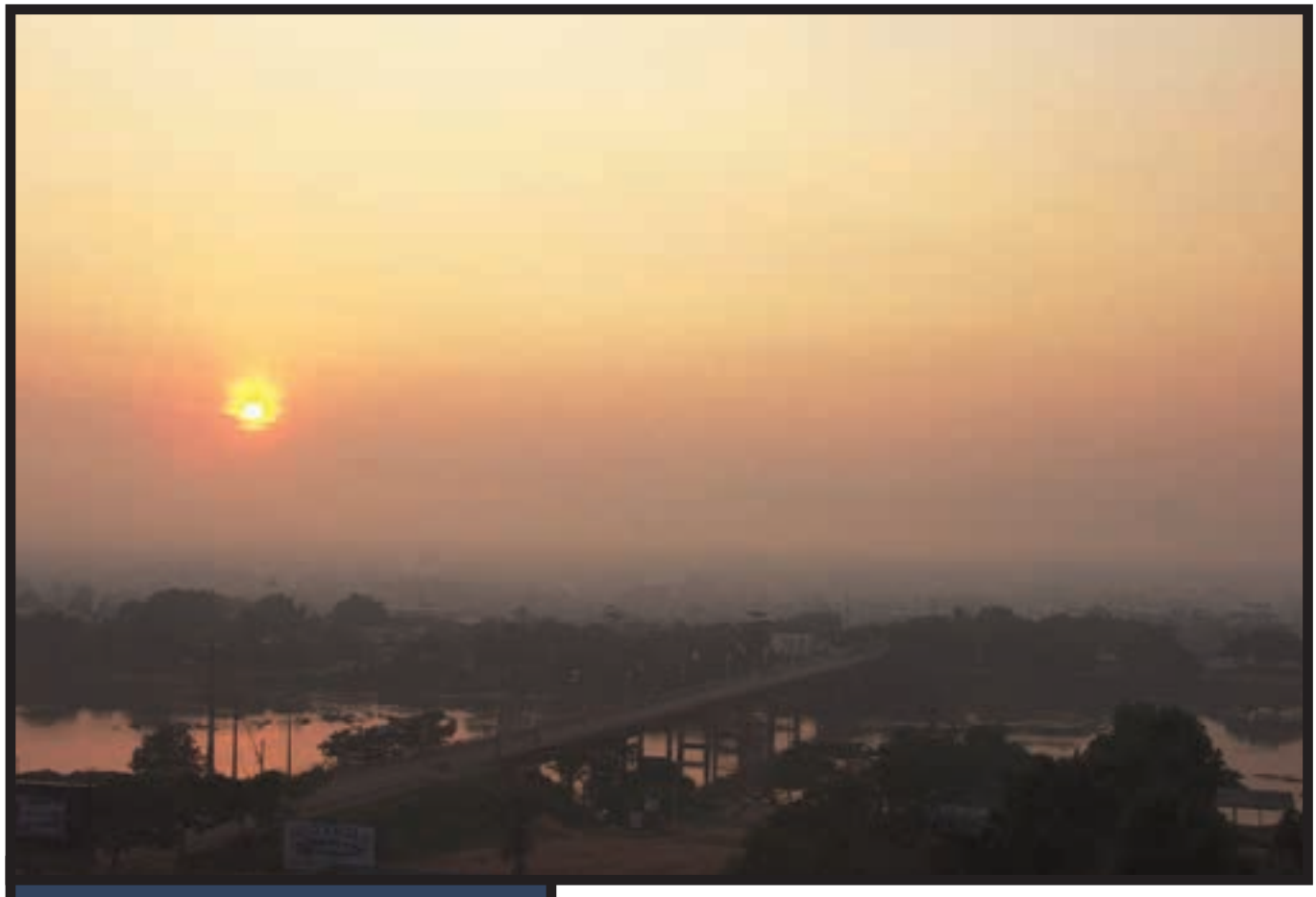
INVESTMENT
R$ 1,814,179.30

Interactions between Radiation, Clouds and Climate in the Transition between the Dry and Rainy Seasons/LBA

COORDINATOR
Maria Assunção Faus da Silva Dias – IAG/USP

MODALITY
Thematic project

INVESTMENT
R$ 1,538,922.32



PHOTOGRAPH BY PAULO ARTAXO/IF-USP

Sunset at 10 a.m. in Ji-Paraná: the atmosphere saturated with particles

ruption the temperature, the solar radiation and the flow of gases, and measurements made with the help of an aircraft, mainly during the two major campaigns carried out by the mega-project (one in the in the humid season, between January and February 1999, and another at the time of transition between drought and the beginning of the rains, from August to November last year), the action of the aerosols on the climate of Amazonia struck the eyes of the researchers in the LBA. There are many uncertainties about the impact of the particles in suspension, but one thing is certain: they are really very efficient in blocking out the sun during the forest clearing fires in Amazonia, as the smoke cover can extend over an area of from 2 to 4 million square kilometers, something between 40% and 80% of the total territory of this ecosystem.

It is true that to see this, one does not have to be a scientist, one just has to look at the sky on a smoky day. But the researchers have just quantified this decrease in solar radiation on the surface in detail. Calculations done at two points of the northern region – at Alta Floresta, in the north of Mato Grosso, and in Ji-Paraná, in Rondônia – show that, on average, from August to October, 20% of the solar radiation is absorbed by the aerosols or reflected and sent back to space. In extreme cases, peaks occur when the retention or reflection of the rays of the Sun can reach 50%. Even the light that is able to cross through the thick layer of smoke reaches the surface altered to a large extent: the quantity of direct radiation frequently falls to one third of the normal, and the diffused radiation (which does not strike the eyes directly) may increase up to sevenfold.

To obtain these results, the researcher Aline Sarmento Procópio, from Paulo Artaxo's team, of USP's Physics Institute, analyzed the data referring to four years of observation in Ji-Paraná and Alta Floresta. "It is interesting to point out that despite being separated by roughly 700 kilometers, these two towns show similar patterns of alterations to the flow of solar radiation caused by aerosols. This indicates that the problem is of a regional nature and affects a major part of Amazon", Aline comments.

Cooling down - If dust in suspension works as a sort of opaque sunshade over the forest, preventing a considerable part of light to arrive at the surface, it is reasonalbe to think that these particles induce a cooling effect at ground level during the dry season. It may seem ironical to say that a byproduct of plant combustion – a process that, at the first moment, logically heats up the place where the forest clearing fire occurs – may bring about, at a second moment, a fall in the temperature. But, by the researchers' reasoning, the concentration of particles coming from the forest clearing fires has, theoretically, the

capacity for lowering the temperature on the surface immediately beneath the cloud of smoke by around 2º C (Celsius). In a region like the Amazon, where daily averages easily reach 35º C, a reduction like this in the temperature may seem modest. But these values are, on the contrary, extremely high, even more so when one knows that significant changes in the world's climate can be caused by oscillations in the order a mere half degree Celsius.

There are, however, a few flaws in this story of looking at particles in suspension as an air conditioner installed above the Amazon. This concept is valid for the probable effects of aerosols at ground level – but not a few kilometers above the forest, where these particles of pollution are to be found. If they cool down the surface of the land by blocking the passage of part of the sunlight that reaches the planet, aerosols produce precisely the opposite effect in the troposphere, the layer of the atmosphere that extends to roughly 15 kilometers above the surface of the Earth. A portion of this blocked solar radiation is absorbed by the aerosols themselves, which set about raising the temperature of the atmosphere by the emission of thermal radiation.

In this case, the warmed up air transmits some heat to what is underneath, to the ground, as a fireplace warms a person not very far away from it. "By convection, a part of the extra heat in the atmosphere passes to the surface, and so it diminishes the cooling action of the aerosols on the ground", says Carlos Nobre, from Inpe. In this case, instead of reducing the temperature on the surface by 2º C, aerosols, in practice, end up bringing the temperature down by only 0.5° C at the ground, according to Nobre. This is because the fall in the temperature produced by the aerosols at the surface is of a magnitude that is a little greater than the warming up brought about in the troposphere.

Do you get it? Do you want more complexity in this picture? The scarcity of historical data on the climate in the northern region makes any more long-term comparison difficult of the current impact of aerosols on the temperatures. No one, for example, knows what the average temperature in Alta Floresta used to be in the 60s during the dry months, before the beginning of the projects for colonizing Amazonia. It is therefore impossible to compare data from the past, which does not exist, with those of today. Indeed, 40 years ago, the town had not even been founded and its current territory was no more than an untouched piece of jungle. One more complicating factor ? As the presence of aerosols is far from being the only factor that determines the real measured temperature in a place, the cooling action of the ashes may not be so intense . Other climatic variants may soften or even offset its effect. For example, in the years when the El Niño phenomenon occurs, bringing alterations to the pluviometric levels at several spots on the globe, it usually rains less in the north of Amazonia. "For all these conditioning factors, we still cannot see clearly the action that aerosols have on the surface temperature in the Amazon", explains Artaxo, who coordinates one of FAPESP's thematic projects within the LBA.

PHOTOGRAPH BY ARLAN NAEG/AFP

Delayed rainfall - That poses the question about rainfall. What is the impact of aerosols on the pluviometric levels in Amazonia? Nobody knows for sure, but, generally speaking, there is evidence that rainfall can be delayed or reduced by up to 30% as a result of the presence of aerosols in the atmosphere. Following a logical line of thought, the researchers believe that if the high concentrations of aerosols lower the surface temperatures, the rate of cloud formation in the region is also reduced. As there is less heat at ground level, less rising currents, the so-called thermals, are formed. On the basis of the fact that it is precisely these bubbles of heat that are responsible for carrying water vapor from the Earth's surface to the skies – as everyone knows, hot air rises –, the quantity of raw material available for rainfall to occur in the atmosphere also becomes lower.

The excess of aerosols may even influence the formation of clouds in the Amazon by means of another mechanism. About two thirds of the particles of smoke in suspension in the atmosphere are capable of retaining water and carrying out the role of cloud condensation nuclei (CCN). The water vapor builds up around these nuclei and form drops of cloud that grow to the point where the drops become big and heavy and fall in the form of rain. When there are few aerosol particles in the atmosphere of Amazonia, outside the period for forest clearing fires, the evaporated water is concentrated in a few CCNs, which are quicker to reach the size necessary to go back to the ground as rain. It is a very efficient mechanism for precipitation.

There are times when just in one hour the drop, supported by a condensation nucleus, grows a million times in size and falls to the ground. In this case, the clouds, typical of an environment with clean air, are of the maritime kind,

Eruption of Pinatubo: an impact on the climate of the planet during one year

for their low altitude, small number of CCNs and large size of the drops. They reach up to 5 kilometers in height and produce constant and regular rainfall. This is the predominant pattern in the natural cloud formation in the Amazon during the greater part of the year, when the number of condensation nuclei in the atmosphere oscillates between 300 and 800 particles per cubic centimeter.

At the height of the forest clearing fires, the skies become so laden with aerosols that the peaks of CCN concentration can reach 30,000 particles per cubic centimeter. This high level of pollution changes the whole scenario of cloud formation and rainfall in the Amazon. "When there is an excess of aerosols, the water vapor is spread over more condensation nuclei and takes more time to turn into rain", explains Maria Assunção, from the IAG-USP, the coordinator of another of FAPESP's thematic projects within in the LBA. In this situation, the clouds are of the continental kind, commonly found in polluted places, and they can be as much as 15 kilometers in height. The growth of the drops is so slow that, in some cases, the water does not fall in the form of rain but evaporates once again into the atmosphere and is taken by the currents of wind to other regions. What happens then is a geographical displacement of pluviosity: the rain that ought to fall in one area is displaced to another.

Storms - If the water from the continental clouds does not evaporate and this formation goes beyond 5 kilometers in height, it solidifies and turns into ice, since in this portion of the atmosphere the temperature is lower than 0º C. The result is a cumulo-nimbus, a storm cloud, which produces thunder and lightning. In this case, the rain takes longer to occur, but when it does happen, it is heavier and is concentrated in just one period. "During the campaign of the LBA last year in Rondônia, we were hoping for the rains to start in mid-October, but they only came in November", recalls Maria Assunção. "There is no way of guaranteeing that this delay is due to the aerosols launched into the atmosphere by the forest clearing fires, although this is what we suspect."

As it can be seen, the high levels of aerosols, as was observed in at least three months of the year in the Amazon, can make a mess of three major variants of climate: the levels of solar radiation, the temperature at the surface (and in the atmosphere) and the pattern of rainfall. Considering that the impact of these changes in the dynamics of the climate itself is still not well known, what is there to be said of its consequences in the ecosystem itself, in the forest and its inhabitants? At the first moment, the decrease of light in the forest strengthens the hypothesis that the photosynthesis of the plants should diminish in this dimmed environment created by the smoke from the forest clearing fires. But plant physiology does not respond in such a simple and direct manner. "It may even be that the effect of the aerosols is greater on ecology than on the physics of the atmosphere, but we still need to carry out studies along these lines", comments Carlos Nobre, from Inpe.

The disarray in the climate of the Amazon caused by the emission of aerosols is also of direct interest to other regions in Brazil and other countries. If it comes to be proved that the high concentrations of smoke lessens the rainfall in the northern region of Brazil, the becomes important for the international agenda. This is because the Amazonian rainforest is, after the oceans, the largest source of water vapor on the planet. If the rainfall in Amazonia changes, the rainfall in other regions of the globe is probably altered. In a study published last October in *Journal of Geophysical Research*, researchers from Duke University, in the US, simulated on a computer the climatic effects at a few points on the planet that could result from the deforestation of the Amazon. In this work, they observed significant reductions in the levels of rainfall and evaporation, above all during the wettest season, at spots on Earth as far away as South Dakota and North Dakota, states close to the border with Canada. •