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The Role of Ecosystems in Determining Climate: The Special Case of The Amazon Rainforests

La Importancia de los Ecosistemas en la Determinación del Clima: Caso Especial los Bosques de la Amazonia

Peter Bunyard
Lawellen Farm, Withiel, Bodmin, Cornwall, PL30 5NW
Tel: (44) 1208831205/1208810417; email:
peter.bunyard@btinternet.com

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The summer floods in England, following deluges of rain more resonant of the Amazon, the searing, deadly heat in Southern Europe, with temperatures at times exceeding 45°C, should be enough to silence those who stalwartly maintain that we are experiencing no more than natural swings in climate. Those sceptics, who have insisted that long term changes in the Earth's orbit as well as in the flux of sunlight are accountable for the extreme weather and global warming, have basically been routed.

But have we got it right? Should we be concerned solely with greenhouse gases? Or is our obsession with carbon emissions a dangerous diversion from what we are doing rapaciously to our planet's natural ecosystems, in particular to the remaining tropical and boreal forests? Is the extreme weather we have been facing during the past decade simply a consequence of the accumulation of greenhouse gases in the atmosphere as a result of fossil fuel burning and forest clearing? Or could there be a connection to landscape and land-use changes?

Fuelled by cheap petroleum we have destroyed a staggering proportion of the world's tropical forests in the 50 years since the end of World War 2, with an average 20,000 square kilometres a year going up in smoke. Indonesia alone has destroyed the majority of its biodiverse-rich forests to make way for plantations of African Palm, as has Malaysia and increasingly Colombia in its Chocó region along the Pacific, while Brazil is now adding sugar cane to soya as its Amazonian crops, with the plan to sow 30,000 hectares of the crop alongside the BR-317 road in Acre. The bitter irony is that palm oil is now being touted as the biodiesel fuel of the future. But that has to be put in perspective in as much as 180 tonnes of carbon are lost to the atmosphere in destroying and burning just one hectare of tropical rainforest. Even with its yield of much as 4 tonnes of refined oil per hectare, a palm oil plantation would be hard put to make up for the original carbon losses. Under such circumstances, that hardly makes it an ecologically green fuel.

If the aim is business-as-usual and we keep our motor vehicles and aircraft running at all costs, we may well find that fuelling our motor vehicles with petroleum products, while they last, is a marginally better option than converting millions of hectares of the tropics to biofuels. As to biofuels produced outside the tropics, it hardly adds up. Compare the 120 kilograms of ethanol that can be produced from one hectare of maize grown in the Midwest with two or more tonnes of fuel oil that can be obtained from tropical crops and one can see why President Bush was so keen in March 2007,to discuss biofuels with President Lula of Brazil and President Uribe of Colombia.

We must also take into account the land requirements such as to permit the United States to substitute 20 per cent and the European Union 10 per cent of its gasoline consumption with biofuels by 2020. Even with high yielding oil crops an area larger than India would be required. Nor does that take into account the ecological and social damage caused by such a massive investment in energy crops, not least those involved in land use changes, with the inevitable loss of biomass carbon in the form of greenhouse gases.

Climate: an emergent property of life

Most climatologists — and not just those sceptics who deny the human impact on climate — appear to have little idea of the seminal role that life plays in generating a climate that we can live with. Voltaire got it wrong; Pangloss in *Candide* did not inherit the best of all possible worlds — life just made it so! That failure to include life is reflected in the models that the IPCC (Intergovernmental Panel on Climate Change) refers to in its Fourth Assessment Report (FAR) of 2007, which, nonetheless, attributes current climate change to human activities. In fact, the Stern Report is more enlightened than the IPCC in making life a relatively important factor in climate change, with particular emphasis on the need to protect and conserve remaining tropical rainforests.

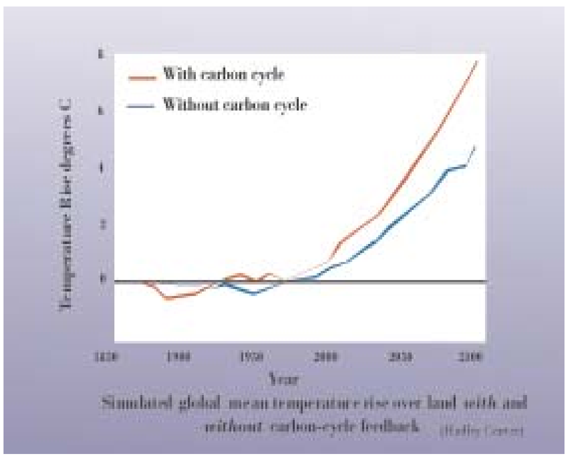
Models that do attempt to incorporate life as a dynamic factor in determining outcome, such as those of the UK Met Office's Hadley Centre for Climate Prediction, come up with substantially greater impacts on the climate system than when life is treated simply as an unvarying constant in the uptake and output of carbon dioxide. With rare exception, do they include a 'living' carbon cycle. The 'living' models show surface temperatures over the land masses increasing on average over the course of the current century by 9°C or more degrees compared with the maximum 6°C of the 'dead' models.

Some sceptical climatologists have claimed that, when generating their climate models, climatologists fail to take increases in solar short wave radiation, as during sunspot activity, into account. However, having failed in their claim that enhanced solar activity is sufficient in itself to explain the greater part of recent global warming, the sceptics, as shown in the UK Channel 4 controversial documentary, *The Great Global Warming Swindle*, have come up with a 'new' variation on the theme in order to explain why small changes in solar radiation would get amplified to the point of accounting for the surface temperature rise.

The idea is that the Sun's radiation keeps cosmic rays from getting through to the Earth's atmosphere and since cosmic rays contribute to the formation of clouds and since clouds reflect sunlight back into space, more solar radiation means clearer skies and greater warming. Vice versa, a cooler Sun will allow more cosmic rays to get through, so that more clouds form and the Earth cools significantly. Even were that theory of cloud formation correct, the idea that the Earth is now warmer because the Sun is more active simply does not stand up to scientific scrutiny. Mike Lockwood, of the Rutherford Appleton Laboratory in Oxfordshire, has carried out a new analysis of solar flux over the past 25 years. His results are unassailable, the Sun's magnetic field, which shields the Earth from cosmic rays, has been in decline since 1985, despite the earth heating up by an average 0.2°C every decade. That would mean that the Earth should be cooler now rather than warmer.

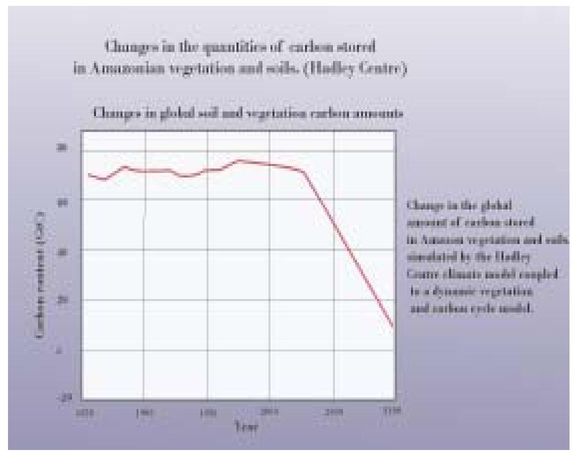
If the Hadley Centre models are reasonably correct, then it would appear that up until the year 2000 the inclusion or exclusion of a dynamic terrestrial carbon cycle shows little divergence between the two curves. Both curves track fairly accurately the observed curve of changes in surface temperature with time. After 2000, the models move into prediction rather than verification and that is when they move increasingly apart. Figure 1.

Figure 1. Simulated global mean temperature rise land With ans without carbon-cycle feedback (Hadley Centre)



could add at least 10 per cent to the current carbon content of the atmosphere. Conceivably atmospheric concentrations of greenhouse gases could rise to four times pre-industrial levels – a state of affairs not seen for millions of years. Figure 2.

Figure 2. Changes in the quantities of carbon stored in Amaonian vegetation and soil:(Hadley Centre)



Why the divergence? Richard Betts and his colleagues, at the Hadley Centre, as well as Peter Cox, of Exeter University, invoke plant physiology in their models, and it emerges that global warming, once it kicks in, pushes up soil respiration while simultaneously reducing net primary productivity from photosynthesis, thereby undermining the accumulation of biomass of the previous 200 years and probably much longer. Before the end of this century, if the models are anywhere near correct, then instead of soils, terrestrial vegetation and the oceans accumulating more than an atmosphere's worth of carbon, namely 1000 gigatonnes, and keeping all that potential carbon dioxide out of the atmosphere, we may, on the contrary, have to face the consequences of emissions totalling 600 gigatonnes of carbon, so pushing levels up on today's by 80 per cent, while simultaneously having lost the sinks.

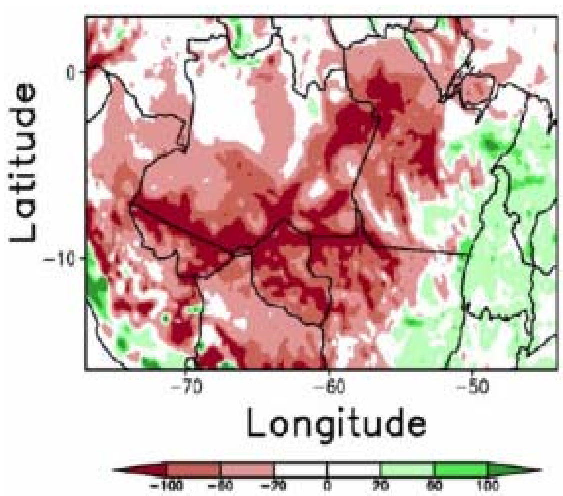
A double whammy if ever there were one and all that is without accounting for the emissions from fossil fuel burning. One consequence could be the fatal die-back of the Amazon's humid tropical rainforests. The loss of carbon from the Amazon Basin alone

Such a prognostic for the Amazon Basin is at loggerheads with the consensus Fourth Assessment Report of the IPCC, which sees the eastern part of the Amazon Basin being more vulnerable to rising temperatures than the central or western part. However, the general circulation models (GCMs), used by the IPCC to inform governments of climate change predictions, are incapable of simulating cloud formation. The mesoscale modelling of Roni Avissar and his colleagues, in which vegetation physiology and structure are taken into account, comes up with a drastically different picture. Avissar's modelling, based on relatively good simulations of real meteorological events over parts of the Amazon Basin, namely Rondonia, indicates a severe reduction in rainfall as a result of global warming. And that is without taking into account deforestation caused by humans.

Deforestation in Brazil

According to Philip Fearnside, of the National Institute of Amazonian Research (INPA) in Manaus, by 1998, the area of forest cleared in the Brazilian Amazon had reached some 549,000 square kilometres, about the size of France out of a total area as large as Western Europe. We must add another 200,000 square kilometres to the tally for deforestation carried out since then. In a few decades, Brazil has managed to deforest an area far greater than that lost over the preceding five centuries of European colonization. Figure 3.

Figure 3. Rainfall anomaly (mm) relativa to the "control" simulation for the land-use scenario of 2050



Losing the remaining Brazilian Amazon forests, remarks Fearnside, would add 10 per cent more carbon into the atmosphere than could be gained from the full implementation of the Kyoto Protocol together with a one per cent compounded reduction per year in the emissions of developed countries from fossil fuel burning between 2010 and 2100.

How worrying, therefore, what is happening today to the Amazon Basin. In 2005, the Amazon Basin suffered a drought as bad as had ever been, with river levels well down from the lowest ever recorded. Thousands upon thousands of fish died, suffocated for lack of oxygen, and smoke from countless fires in the western part of Brazil's Amazon and from Bolivia drifted northwestwards into the Colombian Amazon, preventing planes from landing and making life pretty uncomfortable for the populations of towns like Leticia in Colombia and Tabatinga in Brazil. The smoke hung there, filling the sky with a yellowish haze, and it kept the rains away. Further to the north, along Colombia´s Carribean coast, the heavens opened and the rain poured down, the flood waters in the Magdalena region surpassing in their intensity anything that England suffered in July, 2007. That was the time too of the biggest ever hurricane season, with Katrina and Wilma hammering the US shoreline and wreaking destruction in New Orleans, quite aside from the destruction of more than one hundred petroleum installations in the Gulf of Mexico.

Yet, how many people made the connection between the Amazon drought, the hurricane season and the floods that caused havoc in Rumania, Austria, Germany, Bulgaria and Switzerland? Scientists now have good evidence that a warmer than normal Caribbean coincides with stronger and more numerous hurricanes, and 2005 was no exception. New in the story is our better understanding of the role of the Amazonian rainforests in sucking in the mighty trade winds that traverse the ocean between Africa and South America. Meanwhile, by evaporating water off the ocean as they traverse the Atlantic, the trade winds leave the surface waters off the coast of Brazil more saline and somewhat cooler than they would otherwise be. The surface waters therefore become more dense and they sink, being replaced by cooler surface waters from the North.

With reduced convection over the Basin, the trade winds (vientos alisios) dwindle and the surface waters of the tropical Atlantic remain too diluted (in terms of salinity) and too warm to sink. The net result is above normal temperatures in the surface waters and correspondingly all the right ingredients for generating powerful and numerous hurricanes. Just as occurred in 2005.

Evapotranspiration from the rainforests fuels the air currents passing over the Amazon with water vapour. As the air rises the vapour condenses, so freeing latent energy and helping to generate a massive convection system which essentially carries water from the Atlantic Ocean all the way to the Andes. The same drop of evaporated water may therefore get recycled six times or more as the air mass passes over the Brazilian rainforest.

Were anything to prevent the flow of air coming in over the Basin from the Atlantic Ocean, the forests would be unable to sustain the level of evapotranspiration and, in turn, that would bring about a significant reduction in air mass convection. Less convection results in less energy being imparted to the trade winds. That in turn leads to a decline in the circulation of the air mass — the Hadley Air Mass Circulation — and consequently to warmer surface waters in the northern and southern tropics. Warmer waters, at least in the northern tropics, are equated with stronger, more numerous hurricanes, which provide an effective, even though destructive, way to get energy out from the tropics to the higher latitudes. Nor should it be forgotten that southern Brazil suffered its first ever hurricane in 2004.

Dr Greg Holland, from the United States National Centre for Atmospheric Research in Colorado, finds that hurricanes are now twice as frequent as they were one hundred years ago. In his study, published in Philosophical Transactions of the Royal Society in London, Holland was able to disentangle all the possible forcing factors and it became evident that man-made climate change, through global warming, had increased the temperature of the sea surface such as to promote more hurricanes and cyclonic tropical storms. Natural variability contributes less than 50 per cent of the actual increase in hurricanes, he claims, rather "Approximately 60 per cent, and possibly even 70 per cent of what we are seeing in the last decade can be attributed directly to greenhouse warming."

The forecast is that 2007 will be a very active season with nine hurricanes, of which five are expected to be intense.

What Holland did not say was that the faltering of the air currents over the Amazon, with subsequent drought, could be a major contributing factor to ocean warming in the Caribbean, by altering energy flows. The question then, is whether changes in the composition of ecosystems in the Basin could bear some relation to unprecedented droughts in the region. We now know from the studies of Lucy Hutrya and Steven Wofsy at Harvard that rainfall is declining in a stretch of the Brazilian Amazon between Tocantins and Guyana and, as a result, the forest is converting to dry season forest and savannah. Some 11 per cent of the region has been deforested.

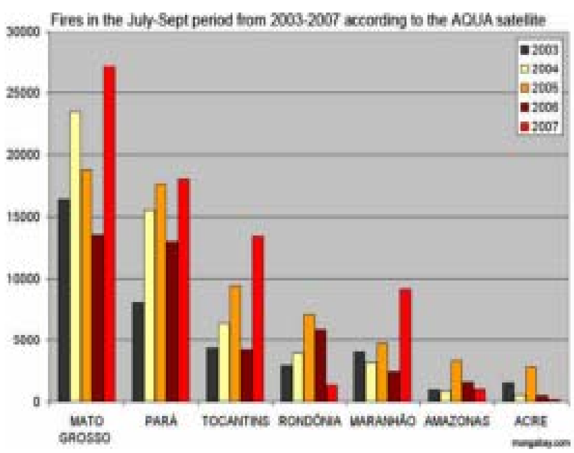
In 2005, the intertropical convergent zone (ITCZ) — where the trade winds from both hemispheres meet over the Amazon Basin — was way up to the North, hence the Caribbean rains and the warmer waters. At the same time, the Azores, in the mid Atlantic, had become a zone of low pressure rather than the high which normally would be expected at that time of the year, and just as happened in the summer of 2007, the jet stream was further South than normal.

As in 2005, the signs are that the Amazon Basin will suffer drought during 2007. The year began badly with fires raging in the Venezuelan Amazon during March and filling the air with smoke. For lack of rain, which also affected the whole of Colombia, many rivers became unnavigable. Meanwhile, in Brazil, a few months later, the burnings had begun, the number of fires, totalling 12,000, and 25 per cent up on the 9,340 fires noted up to the end of June in the year 2006. Just in one day, remote sensing detected 148 new fires of more than 30 square metres in size across the entire country, but with the greatest number proportionally in the Amazonian states of Tocantins, with 31 and 26 in Mato Grosso.

Meanwhile, in contradiction to President Lula´s pronouncement in August 2007 that deforestation and forest destruction was at least 30 per cent down on 2006, itself down on 2005, the evidence is that over parts of the Amazon Basin, mostly in the eastern sector, fires and forest destruction were at unprecedently high levels. Increases in the recorded number of fires in the Bolivian Amazon during September 2007 added to the destruction, as evidenced by carbon monoxide levels over the South American Continent. With the smoke flowing in a northwest direction, Leticia and Tabatinga once again found themselves inaccessible from the air.

In both 2005 and 2006 the combination of drought and forest fires, the latter covering thousands of square kilometres of the Brazilian Amazon, resulted in the emissions that might have reached 10 per cent of the total carbon emissions from all human activities worldwide. With 2007 showing signs of a 2005 repeat or even worse, the emissions could be as bad again and in *per capita* terms put Brazil into the same bracket as the United States. Meanwhile, from their field studies, Daniel Nepstad and his colleagues at the Massachusetts-based Woods Hole Research Center, conclude that Amazon forest ecosystems can withstand no more than two consecutive years of drought without becoming extremely vulnerable to forest fires, whether as a result of runaway burnings or because of lightning strikes.Figure 4.

Figure 4. 2007: Big jump in Amazon fires



“Undisturbed forests are resistant to burning because their dense leaf canopy prevents all but a tiny portion of incoming solar radiation from reaching the forest interior, keeping the litter layer too moist to sustain a fire.” says Nepstad. “Now large areas of forest are selectively logged prior to being settled, leaving holes in the canopy; longer, more intense dry seasons provoke leaf thinning; and both of these changes allow the litter to become dry enough to sustain a fire. Once a forest has burned a first time, the combination of a more damaged forest canopy and a stock of larger fuel from trees killed by prior fires make it even more vulnerable to subsequent fires.”

The Amazon rainforest acts an enormous energy pump, the fuel being the conversion of water to water vapour. Of some 12 million million tonnes of water vapour deposited as rain over the 5 million square kilometres of Brazil each year, between half and two-thirds gets evapotranspired, the evaporation occurring as the rain trickles down the trunk through the branches and leaves, and the transpiration through water brought up through the roots and transported by capillary action to the canopy and out through the stomata of the leaves. Recent research also indicates that the rainforest maintains a humid soil by bringing groundwater up to the surface. That dampening of the soil will enhance evaporation during the summer, dry season.

The combined process of evaporation/transpiration just over the Legal Amazon of Brazil, therefore puts back into the atmosphere more than 6 million million (1012 or tera) tonnes of water vapour every year — equivalent in energy terms to many times more than the total currently used by all human beings for all their activities. In fact, more than three quarters of the Sun’s energy over the Amazon Basin is taken up in the evapo-transpiration process, and since the sun delivers some 6 million atomic bombs worth of solar energy every day over the Brazilian Amazon, we are talking big energy. Indeed, if hurricane Katrina liberated the energy equivalent to one atomic bomb every second of its relatively short existence, the energy released over the Brazilian Amazon alone is equivalent to 70 atomic bombs a second over the entire year.

Over the Brazilian Amazon evapotranspiration takes up 1.63 x 10^{22} joules per year of the Sun’s energy, which is equivalent to nearly 520 terawatts and therefore 40 times the total energy used by humanity. The transfer of energy from the Amazon region to the higher latitudes may be equivalent to half the warming attributed to more than a century’s accumulated anthropogenic greenhouse gas emissions. For stabilizing climate, we need the forest mechanism to distribute heat from the tropics to the higher latitudes, whereas the accumulated heat from global warming is destabilizing climate and likely to put paid to vital ecological services, such as are provided by the rainforests of the tropics.

Antonio Nobre, in a personal communication, informs me that 20,000 million tonnes of water are evaporated and transpired every day over the 5 million km2 of the Legal Amazon of Brazil, an amount that exceeds the 17,000 million tonne flush of water each day into the Atlantic Ocean via the Amazon River. To put that into another perspective, the energy required to bring about that evapotranspiration is equivalent to the summed output of Itaipú, the largest hydro-electric dam in the world, for a period of 135 years.

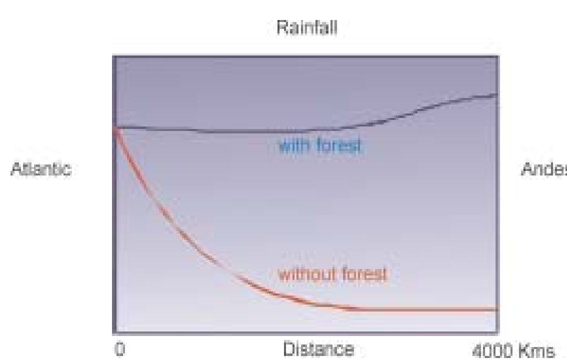
The forest, as a gigantic, irreplaceable water pump, is therefore an essential part of the Hadley mass air circulation system. And it is that system which takes energy in the form of masses of humid air out and away from the Amazon Basin to the higher latitudes, to the more temperate parts of the planet. Argentina, thousands of miles away from the Amazon Basin gets no less than half of its rain, courtesy of the rainforest, a fact that few, if any of the Argentinian landowners are aware of.

Although we have behaved as though the system of forest and rainfall is resistant to perturbations, the UK Met Office's Hadley Centre finds otherwise. According to their models, global warming, if uncurbed, will result in a dramatic change in both oceanic and air mass movements, with a switch to a more El-Niño like pattern, in which the air mass movement passes eastwards across the Pacific Ocean, then to be deflected by the Andes. The net result is a much diminished rainfall regime over the Amazon Basin and the consequences, according to the models, are forest die-back and death, given the vulnerability of the trees to drought-like conditions in successive years. In a matter of decades, decomposition over the Basin may well lead to more than 70 gigatonnes of carbon escaping as carbon dioxide into the atmosphere.

The unavoidable conclusion is that, unless the world acts swiftly to prevent further deforestation in the Amazon, we could find that the impact of global warming would be far worse than, anticipated in the IPCC's fourth report. What should worry us is whether the changes that occurred in 2005 across the tropical Atlantic could become a regular feature. Were that to be the case, then we could see the demise of the great tropical rainforests across the Amazon Basin.

As Makarieva and Gorshkov from St Petersburg have shown in a climate model that looks specifically at the relationship between rainforests and rainfall, natural forest cover is critically important in maintaining rainfall over a large continent, such as South America. Without inland forests to pump water vapour back into the atmosphere, the water vapour picked up from the ocean and deposited as rain will decline exponentially as the air currents move inland. The natural, broad-leafed, forest carries out transpiration through the stomata of their leaves at a rate that compensates for the exponential decline in rainfall and so maintains soil moisture and rates of evapotranspiration in a self-feeding, highly selected system.

The Russian scientists conclude that the mean distance to which the passive geophysical air fluxes can transport moisture over non-forested areas, does not exceed several hundred kilometres. Moreover, replacement of the natural forest cover by a low leaf index vegetation leads to an up to tenfold reduction in mean continental precipitation and runoff. Figure 5.



Indeed, without forests, precipitation decreases exponentially with distance from the ocean.

Alternative vegetation cannot do the job and, if inland natural forests are replaced by agro-industrial enterprises on a sufficiently large scale, the consequences must be a drying out of the entire system to the point when agricultural crops can no longer be grown. The Amazon Basin could turn into a Sahel, since, according to the Russian scientists, the Hadley Cell airflow over the tropics depends essentially on the forests to provide the necessary convective gradient. Hence, a swathe of forest destruction up to several hundred kilometres from the Atlantic Ocean could put paid to the forests further inland and lead to dramatic changes in the Hadley Circulation.

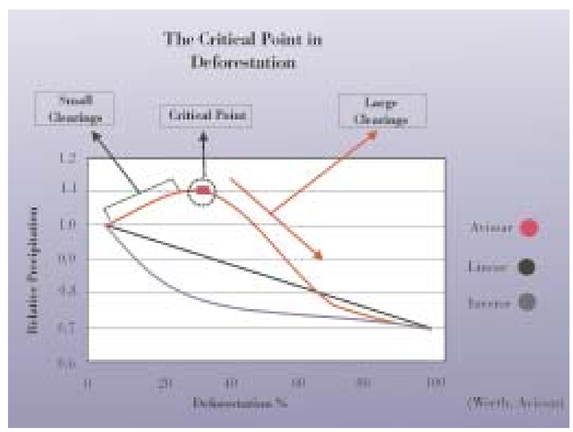
The more scientists delve into cloud-forming activities, the more they find life's ever ubiquitous presence. Life, whether photosynthesizing algae such as the coccolithophores that, in their billions, roam the oceans, whether epiphytic bromeliads clinging on to the great skyscraper trees of the rainforests of Central and South America, or indeed, whether sphagnum moss in the vast expanses of the high latitudes, all release dimethyl sulphide, which, on oxidation, transforms to cloud forming aerosols of sulphur dioxide. In varying degrees, depending on what kind of forest and where, trees also release cloud-condensation nuclei, the main ones in the Amazon Basin being terpenes and isoprenes, the latter related to rubber latex.

In all, as Stephan Harding points out in *Animate Earth: Science, Intuition and Gaia*, life on Earth may currently be responsible for forming clouds that cool the Earth overall by10º C. Climate is clearly affected by the amount of sunlight reaching the Earth's surface, but life, in its manifest alterations of the Earth's surface and albedo, in its production of cloud generating chemicals such as dimethyl sulphide and the isoprenes and terpenes, is the manager.

The physics, as far as modelling goes, may be relatively sound, whatever else is lacking in the models. Some evidence of that comes from meso-scale modelling, such as has been developed by Roger Pielke, Roni Avissar, Pedro Silva Dias and others. Here, the physics, maths and computing power used to obtain climate predictions for the entire planet are focussed down to relatively small regions of the terrestrial environment, like focussing the sun with a magnifying glass and setting twigs on fire.

To date climatologists, and therefore conservationists, have assumed that the amount of rainfall is dependent on the amount of forest and that as more and more of the forest goes, so rainfall will decline proportionately. By using'mesoscale' resolution, Roni Avissar and Pedro Silva Dias have uncovered a very different picture, with rainfall actually increasing when clearings are not too big, but then after a critical point, dwindling away rapidly and causing the remaining forest to crash. When a clearing is no more than a certain size, probably no more than a few kilometres across, and if the forest around is relatively intact, then the mass of warm air that rises over the clearing, will suck in cooler, more humid, air from the surrounding forest. That convection process leads to the formation of thunderstorms. Under those circumstances rainfall will increase, perhaps by as much as 10 per cent. On the other hand, make the clearing relatively large, when the forest is no longer large enough or close enough to moisten the updraft of air, and the convection process literally runs out of steam. Rainfall then declines sharply. Figure 6.

Figure 6. The Critical Point in Deforestation



The rainforests to the North and South of the equatorial divide of the Amazon Basin show just how intimate is their relationship to sunlight and the atmosphere and whether or not clouds are present. During the rainy season, which occurs during the winter months of December and January in the northern Amazon and in June and July in the southern Amazon, clouds shield the trees from the sun and, as a result, photosynthesis and net primary production of photosynthetic products, such as carbohydrates, declines. The leaf area covering the region also declines.

That situation switches dramatically during the dry season. Now the skies are cloudless and sunlight can penetrate through the canopy down to the forest floor. The trees, in response, as shown by Ranga Myneni and his team of scientists at Boston University, increase the leaf area by as much as 25 per cent, and evapotranspiration goes up accordingly. The increase in atmospheric water vapour, combined with the cloud condensation nuclei from the forest, kick-starts a convection process and hence the formation of the first thunderclouds. As the convection process gets underway, so the clouds once again mask the sun and the leaf area, in relationship to exposed soil, goes down.

Another surprising discovery is that during the dry season, the trees bring water up through their roots and, instead of it all being carried up the tree trunk and out to the leaves, a significant fraction is pushed out through side roots, thereby keeping the surrounding soil moist and therefore productive.

"In the Amazon Basin the only way to inject heat into higher altitudes of the atmosphere is convection, or thunderstorms... But how," asks Rong Fu of the School of Earth and Atmospheric Sciences, at Georgia Tech Fu, "can you have a thunderstorm before you have moisture being transported into the basin?" with her colleagues, she was able to show that once the thunderstorm season comes into effect, the winds dramatically change direction. During January and the northern hemisphere winter, when the ITCZ is South of the equator, the winds flow in a North to South direction. That reverses in July when southerly winds are drawn into the convection process, fuelling it with water vapour. The rainforests of the Amazon, by increasing and diminishing the rate of evapotranspiration, are effectively managing their local climate. Indeed, with such a powerful process going in the South American tropics and the tropical Atlantic Ocean, it should be of no surprise that our weather, and no less climate, are being profoundly affected by what we are doing to the Amazon. In blaming greenhouse gases emitted from our factories, transportation systems, electricity production, agriculture and our non-sustainable consumer life-style as a cause of climate change, we are neglecting at our peril the role that life plays. In fact, we are failing to understand that the Earth's climate is an emergent property of life's interaction with its environment. On that score, we must remember that the composition of the lower atmosphere is essentially the result of life's metabolism.

Teleconnection and Rossby Waves

The energies transferred through the air mass circulation system of the Hadley Cell are immense, as we have shown. However, that does not include energy and therefore heat — again in the form of water vapour — that travels large distances through a process of 'teleconnection.

Teleconnection comprises relatively slow-moving moist masses of air that push their way northwards and southwards out of the Basin, carrying their precious cargo of water in the form of water vapour. In effect, we are talking of water that is absolutely essential for the growth and survival of crops fundamental to the needs of the United States. Thunderstorms are the key to teleconnection. Most thunderstorms occur in a narrow band around the equator, some 1500 to 5000 a day, rising to a considerable height as precipitating water fuels their upward motion through the release of latent energy. Perhaps as much as two-thirds of precipitation around the planet is affected by the formation of cumulonimbus and stratiform cloud systems generated within the tropics. Scientists now believe that the heat, moisture and kinetic energy, which get carried from the tropics to the middle and higher latitudes in the mass circulation system, have a profound impact on the ridge and trough pattern associated with the polar jet stream. Changes in land-use and in land cover over the humid tropics are therefore affecting climate simply by altering and transforming the dynamics of cloud formation. As Professor Roger Pielke of Colorado State University, points out: "These alterations in cumulus convection are teleconnected to middle and higher latitudes, which alters the weather in those regions. This effect appears to be most clearly defined in the Winter Hemisphere."

Rossby wave teleconnection at risk from deforestation Nicola Gedney and Paul Valdes, from the Department of Meteorology, University of Reading, and Bristol University show from their models that, independent of global warming, deforestation of the Amazon would lead to considerable disturbances to climate over the north east Atlantic and western Europe as well as the eastern seaboard of the United States, especially during the northern hemisphere winter months, which would consequently become considerably wetter.

Normally, during those winter months, convection is at its strongest over the northern Amazon Basin. Such convection, based on the lifting of considerable quantities of vapour, then propagates strong Rossby waves some of which head out in a north-westerly direction across the Atlantic towards West Europe. The Rossby waves emanating from the Amazon tend to be suppressed by strong easterlies aloft; nevertheless, under normal circumstances, with the forest intact, the latent heat source for the Rossby waves is strong enough to override the easterlies. That situation reverses when the forest is replaced by grassland, because of a reduced precipitation over the Basin, which itself leads to a generalised weakening of the tropical air mass circulation - the Walker and Hadley cells. Under those circumstances the easterlies aloft bring about a suppression of the now weakened Rossby waves.

As Gedney and Valdes point out: "Our results strongly suggest that there is a relatively direct physical link between changes over the deforested region and the climate of the North Atlantic and western Europe. Changes in Amazonian land cover result in less heating of the atmosphere above. This then weakens the local Hadley Circulation resulting in reduced descent and increased rainfall over the south eastern US. The result of this is a modification to the Rossby wave source which causes subsequent changes in the circulation at mid and high latitudes in the northern hemisphere winter. This in turn causes changes in precipitation, namely an increase over the North Atlantic and a suggestion of some change over Western Europe." Many studies have shown the sharp differences in daily temperature between a natural forest and cleared land. In Nigeria, for example, the day-time temperature just above the soil in a clearing was 5°C higher than in the nearby forest and humidity was 49 per cent compared to the forest's 87 per cent. Clearings are also far more likely to flood and consequently erode. Carlos Molion, at the State University in Alagoas, points out that the forest canopy in the Amazon intercepts on average about 15 per cent of the rainfall, a large proportion of which then evaporates directly back into the atmosphere. The removal of the canopy leads to as much as 4000 tonnes of water per hectare hitting the ground each year , causing selective erosion of finer clay particles and leaving behind increasingly coarse sand. Soil under intact forest absorbs ten times more water compared with pasture, where erosion rates may be 1000 times greater.

Biodiversity

Biodiversity in Amazonia is not just a phenomenon of chaotic evolution, but is rather a vital, integral part of how the rainforest maintains itself. The forest simply would not survive without its accompanying suite of evolutionary forms, from bacteria, fungus to the ´higher' organisms such as primates and jaguar. In the 1980s, Harold Sioli was director of the Max Planck Institute for Limnology in Germany. As he then pointed out in *The Ecologist*, the Amazon rainforest, especially over the unflooded terra firma, was a remarkable self-contained system that depended crucially on the integrity of the whole to sustain itself. Even though the soils are among the poorest on the planet — washed out after millennia of heavy rains — yet the vegetation and the unparalleled richness of living organisms would seem to suggest a luxuriance that derives from plenty rather than from deprivation. That paradox is the miracle of the rainforest. Indeed, the entire system serves to retain virtually all the nutrients within the biomass. Leaks of vital nutrients, such as are common in temperate ecosystems would spell disaster. A dense root mat system, combined with fungal mycorrhiza bridges, literally sucks up any decomposing matter from the forest litter.

Most of the fauna live in the canopy and the system of tall trees, with their extraordinary profusion of epiphytes — the ferns, orchids and bromeliads that have attached themselves to the stems and branches of the great trees — take up any nutrients that are flushed down with the heavy rains. The fauna too are therefore perfectly integrated into the nutrient recycling system by providing the sustenance for the lateral extension of the forest. As a result, says Sioli, “the greatest number of plant and animal species we are aware of (estimated at between 1.5 and 2 million species) divides the general nutrient cycle into an immense number of sub-cycles.”

Soya - the environmental and social implications

The pressures on the Amazon’s rainforests, especially in Brazil, Peru and Bolivia, have intensified over the last decade. As Philip Fearnside points out, soya growing in Brazil spread initially from the states of Paraná and Rio Grande do Sul in the south, to the *cerrado* (savanna) region in Mato Grosso. Meanwhile, all along the way peasants have been displaced, either those in the South who were living off subsistence maize, beans and coffee, or those who had already cleared land in the *cerrado* and parts of the Amazon, as in Rondônia. Since soya production employs only one person on the ground for every 11 subsistence farmers, the peasants have little choice either to move to the city or to move the colonisation frontier ever onwards and outwards. In 1996, for instance, Rondônia had 1,800 hectares down to soya; in 1998, the area had expanded to 4,700 hectares and one year later to 14,000 hectares. In Maranhâo the soy area increased from 89,100 hectares to 140,000 over the same period.

More recent data, gleaned from the Brazilian government, show, after Cargill had constructed its soya storage and shipping facility in Santarém, in the western part of the state of Pará, that, between 2002 and 2004, the annual rate of deforestation in the region for the production of soya jumped from 15,000 to 28,000 hectares (Greenpeace). Meanwhile, in 2005, some 787,000 tonnes were exported, most destined for Europe. Clearly our need for dairy products, for chicken and for pork is fuelling the destruction of Amazon rainforest. According to Britaldo Silveira Soares-Filho, from the University of Minas Gerais, “By 2050, current trends in agricultural expansion will eliminate a total of 40 per cent of Amazon rainforests, including at least two-thirds of the forest cover of six major watersheds and 12 eco-regions.”

But, with 40 per cent of the Amazon gone just on such projects, without taking logging or cattle ranching into account, the rainforests would not survive. Curiously, the Brazilian hydroelectric industry, which supples the nation with some 80 per cent of its electricity has not been active in pushing for the remaining forests to be protected.

The advancing front of industrial soybean production is the leading driver of all major new transportation projects, including the creation of new highways, the channelisation of rivers for navigation, and the construction of new railroads, which will penetrate from the centre of Brazil into the heart of the Amazon. What is therefore no less than a massive government subsidy is intended to get cheap soya transported by ship to Europe, and particularly to Holland for fattening pigs and milk production, and to China, where much of the imported soya is pressed for oil.

But the destruction of rainforest is not just limited to soybean production and the need to get the soya exported out of the country. The very penetration of the Amazon leads to other ‘dragging effects’ in which more forest is cleared for cattle ranching and for illegal timber extraction than would otherwise occur. Meanwhile, a Dutch agribusiness company is talking of establishing industrial-scale pig farming in Mato Grosso, based on feeding them on local soya. There has also been talk of shipping pig manure from the Netherlands back to Brazil in the same boats that are now used for exporting soya from there.

The ‘development’ of the Amazon is also closely associated with hydroelectric schemes. Projects such as the Tucuruí and Balbina dams have come under heavy criticism for their failure to meet with expectations and their disastrous impacts on their surroundings. Balbina, for instance, despite causing the flooding and destruction of around 3,000 square kilometres of forest, is incapable of meeting the electricity needs of the nearby city of Manaus. Far from being benign sources of energy with regard to emissions, such hydroelectric plants bring about the release over their lifetimes of at least as much greenhouse gases as from a coal-fired plant generating the same amount of electricity, mainly in the form of methane gas.

The Amazon rainforests are rapidly approaching the point of collapse. Other tropical rainforests are being savagely deforested, as in Indonesia and Africa. The opening up of any tropical rainforest increases the vulnerability to fires caused through lightning strikes. The peatlands of Kalimantan in Indonesia have also started burning, with small chance of extinguishing all the fires because of their burning underground. The thousands of simultaneous fires that occur annually in Southeast Asia are making life miserable for millions of people living in Singapore and other highly populated areas in the region. Clearly local climate is seriously disturbed.

What to do?

While putting all our energies into preventing massive tropical forest destruction, we must be aware that humid tropical rainforests everywhere will be threatened by global warming bringing about a drastic switch in ocean currents and air mass movements. Consequently, we must simultaneously do all in our power to conserve tropical rainforests, and, worldwide, to reduce greenhouse gas emissions. And should we prove unable to curb our greenhouse gas emissions, it may be that the forests of Amazonia are anyway doomed.

Conservationists must take these issues on board, because if they fail to take the relationship between Amazonian forests and climate into account, then all those worthy projects in which they have managed to conserve isolated patches of forest, connected through ecological corridors, will be as dust. From Avissar's work, we may well need at least 60 per cent of the humid tropical rainforest intact – certainly no less.

But is any government going to forgo the quick returns on exploiting the natural resources of an area as large as the Amazon? As Bill Laurance, Philip Fearnside and Brazilian environmentalists point out, one way of persuading governments to leave well alone would be through a carbon credit system that realised the value of *avoided* deforestation, rather than just a value for new forest projects. The first commitment period of the Kyoto Protocol, largely because of vigorous campaigning by environmentalists against the notion of credits for existing forests, will allow credits only for land-use change when that leads to verifiable carbon uptake. Maybe, by the second commitment period of the Kyoto Protocol, post 2010, those campaigners, as well as governments, will have realised just how essential it is to find ways to avoid deforestation if the aim is to stabilise climate.

Kyoto Protocol misses the point

Indeed, the problem with the Kyoto Protocol is that while *Article 2* establishes that developed countries should 'protect and enhance sinks and reserves, promote sustainable forest management practices, aforestation and reforestation', *Article 12* ensures that existing forests are not included. The Protocol therefore reflects the wishes of environmentalists, and in particular those of western Europe and the United States, who have been strongly opposed to the notion that CDMs (Clean Development Mechanisms) include *avoided deforestation* on the understandable grounds that the carbon is already contained in the forest and soil.

Such environmentalists were justifiably worried that industrialised countries such as the US would wriggle out of their responsibilities to cut greenhouse gas emissions through claims that the existence and expansion of natural forests within state boundaries were doing the job for them. Hence, the environmentalists have argued that if *avoided deforestation* were to be legitimised in the CDMs, those countries (and companies) benefiting from any carbon trading on forest conservation would need to do little more than look around for the cheapest carbon offsets and count those against their own emissions.

To date the Brazilian government has also expressed its opposition to the inclusion of forest conservation and its corollary, a reduction in the rate of deforestation, as being legitimate opportunities for CDMs. Clearly the Brazilian government has believed that it will gain more through inviting in external investment in exploiting the land beneath the forests than it ever would through gaining carbon credits. That view is valid only if the true ecological and climatological services of the Amazon Basin are ignored.

The issue is not simply one of biodiversity. The relationship between tropical forests and climate must be our first consideration when justifying the need for conservation. Biodiversity conservation then falls naturally in place as the means by which a tropical forest can maintain itself. The means to ensure the conservation of the remaining tropical forests and the rehabilitation of those that have recently been destroyed is therefore a priority and one that should have equal status as concerns over the emissions of greenhouse gases in the deliberations and recommended actions from bodies such as the Intergovernmental Panel on Climate Change (IPCC).

It is therefore a matter of urgency that we value the rainforest primarily for its ecological and climatological services and for that reason a mechanism or better a multifaceted approach, including a complete revamp of the Clean Development Mechanism of Kyoto, must be developed that recognises that the value of the forest as a natural carbon sink is only one side of the vital role which the forest plays in determining climate processes while sustaining itself.

A system of carbon credits may be one mechanism, but it can easily be abused and lead to corrupt practices. Another way would be to find resources to fund indigenous communities and others who are now connected to the rainforest, to care for and protect rainforests in their vicinity. The funds would need absolutely to target the forest protectors, while simultaneously giving the opportunity for sustainable silviculture and agroforestry projects that will both provide subsistence crops, plus some revenue for the sale of any surplus products, and will provide a buffer zone at the margins of the forest. That buffer zone is essential to prevent loss of forests through edge effects.

Despite all the concern about the future of the Amazon, an international process that values the forest as a natural carbon sink and for its climate services has yet to be developed. Fortunately Amazon countries are beginning to realise that the further loss of this vast moisture reserve could cause great damage to farming across much of South America. Let us trust that those concerns will become a priority in the decision-making of all countries in the world, whether with or without tropical forests, in the process of preventing irremediable climate change: in addition, that countries specifically with vast expanses of humid tropical forests will take the initiative in getting global agreements in place that will result in protection of those same forests. Obviously, processes of compensation for maintaining the essential ecological services of such forests will need to be thrashed out.

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Note:
We have the extraodinary phenomenon of a generalised cooling of the planet over the past 100 million years or more. How? CO_2 levels brought down by orders of magnitude. Could it be that life, with all its evolving and rich biodiversity, had become a *force majeure* in regulating climate. Clearly, the conquest of the continents by life played a major role in pulling down carbon dioxide through photosynthesis, despite the Sun, as main sequence star, becoming more luminous over that stretch of time.