Two Articles by Peter Bunyard, Founder of *The Ecologist* magazine, U.K.

I have recently returned from Colombia where I gave talks on the Amazon, climate connection and in particular about the likely impact on the region in terms of diminished rainfall, hence droughts...etc... the social consequences will be gigantic... also if the Amazon forests should die-back there will a chain of consequences across the globe, including affecting the US Corn-belt... (*Teleconnections* to the Amazon Basin - *Teleconnections* means that weather changes at one location may be related to weather changes at other remote locations.).

SEQ CHAPTER \h \r 1Peter Bunyard, Lawellen Farm, Withiel, Bodmin, Cornwall PL30 5NW
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From the book Scientists Debate Gaia, published in 2004 by MIT Press. Also recommended is Bunyard's previous book on climate, The Breakdown of Climate, published by Floris Books (a few years old but still it's all basically there).

San Rossore: Gaia, Climate and the Amazon
30 June 2004

Let us start with the premise that the atmosphere is largely a construct of life and that climate as we know it is an emergent property of the interaction between life and the physical/chemical structure at the earth's surface, naturally in relation to the energy input from the Sun. Just think of the gases in the atmosphere: nitrogen, oxides of carbon and nitrogen, oxygen, methane and water vapour – with the exception of the noble gases, they are all part of life's metabolism. And, if you are a James Lovelock, you will look at the atmospheres of our flanking planets, Mars and Venus, compare their atmospheres with that of the Earth – and wonder!

Living processes affect the concentrations of greenhouse gases in the atmosphere; they affect cloud formation and whether the Earth's surface absorbs or reflects sunlight; they affect how the lower atmosphere is stratified; and they may even have prevented this planet from losing its water.

Why, for instance, does Earth have such a low concentration of carbon dioxide compared to its flanking planets; why does it have so much water; how come that it does not have extremes of temperature; how is it that the proportion of available nutrients such as phosphorus, nitrogen, carbon remains relatively constant in the surface waters of the ocean, despite fluctuations in the quantities being flushed in from the continents? How are oxygen concentrations in the atmosphere maintained at their current levels, at least over millennia, in coexistence with reducing gases such as methane, carbon monoxide and nitrous oxide? When we look more closely we find the hand of life heavily implicated in every one of such issues.

And is it pure coincidence that the proportions of greenhouse gases in the atmosphere, including water vapour, give us an overall climate and surface temperature that best suits life as a whole? Should we be thinking in pure neo-Darwinist terms, that life has done little more than adapt as best as it can to the conditions it finds? Or should we be thinking Gaia and accept the evidence that we cannot understand the processes of climate unless we bring life properly into the equation, even perhaps that life has helped generate those very conditions in its immediate surroundings that best suit it? If so, Panglossian notions of life having inherited the 'best of all possible worlds' turned deftly on its head!

Climatologists have for the most part ignored the dynamics of life's interactions with climate, that is aside from human-induced increases in greenhouse gases. And by ignoring 'life writ large' in their models, climatologists for the most part have generated half-baked models at best, although we might give them the benefit of the doubt in waking us up to the possible consequences on climate of accumulating greenhouse gases in the atmosphere.

The problem climatologists face is to encompass all the prime factors that make up climate and then somehow transform those same factors into heat budgets that drive mass circulation systems, ocean currents such as the Gulf Stream, that evaporate water and alter albedo – that is the reflectivity of the Earth's surface – as a result of changes to cloud, snow and ice cover and precipitation patterns. Not an easy task, and, quite aside from the question raised about the intervention of life in the formation of climate, big questions remain over the validity of the predictions of the GCMs — the general circulation models – and just how much the fluctuations in climate from year to year and changes in surface temperature may be the result of natural variability within an extremely complex system that has non-linear equations and chaos writ large as part of its defining principles.

Climatologists have long agreed on the notion of a 30-year moving averaging out of annual data so as to avoid statistical errors in ascribing climate change to what may be a 'one-off' result. However, that leads to a possible risk of underestimating bona fide changes by blurring them with the statistical weight of previous years, so that we may get wise to climate change only when we are well and truly in the midst of it, and therefore too late to act in time. For instance, much of the 0.6o C temperature rise seen over the past century occurred during the last decades of the century. It certainly should alarm us that we may be at the beginning of a steep upward trend in surface temperatures, without an easy going back.

Uncertainties about the causes of the current spate of global warming should not be used to justify the continuing emission of greenhouse gases at ever-increasing 'business-as-usual' rates. And surely those, such as Sally Baliunus of Harvard University, who persist in their claim that current global warming can be put down largely to changes in solar output, are giving us a story at 'half cock'. No self-respecting climatologist would deny the importance of solar input — it is the prime source of the Earth's surface energy — but it is the way that such energy is moderated and transformed through surface phenomena, such as varying albedo and the greenhouse effect, that gives us the climate that we live with. Indeed, although the Earth lies between Mars and Venus, its climate is not intermediate between the two — we would be boiling if it were — instead it is modulated in a remarkable fashion through the mass metabolism of life, such that the extremes that do exist are tempered through the transfer of energy from the tropics to the poles, whether in air mass movements or in ocean currents, such as the Gulf Stream. Without question the carbon cycle, the major part of it in the hands of life, plays a momentous role in the formation of climate, and any increase in atmospheric concentrations of the main greenhouse gases will necessarily lead to more heat being kept at the surface. (See Figure 1.)

And were we to get it wrong, Bush-like, and listen to Baliunus and her ilk, the costs would undoubtedly be greater than our western civilizations could cope with. Just remember that the 0.6o C rise in temperature from pre-industrial times, most of it since World War 2, is already the cause of considerable havoc. The unprecedented heat-waves in Europe last summer and storms like that which struck off the southern coast of Brazil earlier this year are worrying indications that global warming does not lead to linear changes but to abrupt, even unforeseen ones.

Global warming is also causing fundamental problems in agriculture, especially where it matters. According to the UN's Food and Agricultural Organization (FAO), global grain production per person in 2002, fell to its lowest level since 1970 and we have now had a spate of years in which the global grain harvest has fallen below demand, in the United States the shortfall being made up from stocks held in private and government stores. If relatively small fluctuations in climate can have a major effect on cereal crop production that does not bode well for a world population that is not only increasing but is increasing its demands for more and more animal protein, much of which is produced through feeding grains, such as maize and supplemented with protein from soya, the latter increasingly derived from Brazil's Amazonia.

As climate is essentially an emergent property of life's interaction with its immediate environment, we surely cannot accept uncritically those climate GCMs that treat life as little more than a black box that functions as an established unvarying constant irrespective of climatic events and the temperature changes that may be taking place around it. Based on such models, the IPCC's predictions are deficient at best; they may indeed be dangerously misleading in making us think we have more time than we actually have.

We must therefore applaud climatological institutes that have heralded the way to incorporate a dynamic terrestrial carbon cycle into their climate models. In true Gaian form, that relationship goes both ways: climate has its impact on vegetation, for instance through changes in temperature and rainfall, and changes to vegetation then feed back on the processes that bring about climate change, such as by increasing levels of carbon dioxide in the atmosphere from the decomposition of biomass within soils.

As we heard earlier, Peter Cox, Richard Betts and their colleagues at the UK Meteorological Office are now advancing climate models that make a valid attempt to incorporate relevant living processes, as expressed through biomass production and decay, in different ecosystems. Their shock results indicate that a 'business-as-usual' trend in greenhouse gas accumulations in the atmosphere may lead to a sharp transition from a world in which primary photosynthetic production is enhanced and encouraged to one in which decomposition, especially from soils, takes over, undermining the accumulation of biomass of the previous 200 years. 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, on the contrary we may have to face the consequences of an atmosphere with more than 600 gigatonnes of carbon over and above current levels. That so, without taking any account of current and future emissions, we will experience a nigh on doubling of the current atmospheric levels of greenhouse gases – a momentous change in the span of a few years. Conceivably atmospheric concentrations of greenhouse gases could rise to four times pre-industrial levels – a state of affairs not seen for millions of years.

There are ifs and buts about any climate models, no less so the Hadley Centre models, nevertheless we must take their predictions seriously, especially their prognosis of a world considerably warmer than that indicated in the models used by the IPCC in its Third Assessment Report of 2000 – which are undoubtedly bad enough. The Hadley Centre talks of surface terrestrial temperatures reaching nearly 9o C more compared with the late eighteenth century.

Of course, there is much we do not understand, such as the role that clouds are likely to play in a warmer world. Jim Lovelock has suggested that even though the atmosphere over the oceans may contain greater humidity because of warmer temperatures, cloud formation, especially of marine stratus clouds, may actually diminish. The reason, he suggests, is because of a likely sharp decline in the populations of coccolithophore-like algae. It is those algae that produce dimethylsulphide which, on oxidation to sulphur dioxide, generates cloud condensation nuclei. If Lovelock is right and marine clouds are primarily generated because of cloud condensation nuclei from living organisms, then a warmer clime, through the spread of nutrient deficient regions of the oceans, will lead to a decline in phytoplankton, a reduction in marine stratus clouds and therefore more warming through the oceans absorbing light. In addition, if clouds do form, they are likely to be higher clouds on account of a warmer lower atmosphere and therefore paradoxically cooler clouds. Such clouds radiate less heat back into space and the overall result will be a warming of the Earth's surface rather than a cooling.

Betts, Cox and their colleagues at the Hadley Centre have highlighted in particular what global warming may do to the Amazon Basin. From a Gaian point of view, the Basin is a remarkable climatic system that has emerged from a tight association of air mass movements and forest-driven evapotranspiration. In effect, the humid tropical rainforests of the Basin constantly recharge the air flowing above the canopy with water vapour, the net result being that several million square kilometres of forest receive sufficient rainfall for their survival. Without such a vapour-regenerating system, the forests to the west of the Atlantic Ocean may well not survive in their current form.

The process begins in the tropical Atlantic Ocean, off the coast of Africa, where dry, sinking air travels westwards either side of the equator towards the Brazilian coastline, picking up more and more moisture as it goes. The Trade Winds from the two hemispheres converge at the solar equator and finish up moving virtually as one body over the Atlantic forests of Brazil. Through a process known as 'convection' they then form giant cumulo-nimbus thunder clouds that may stretch for several hundred kilometres at a time.

By measuring the change in the ratio of oxygen isotopes — the less common isotope, oxygen-18 being one-eighth heavier than the common oxygen-16 — as water was first evaporated from the ocean and then precipitated as rain, Eneas Salati, a Brazilian physicist discovered that the proportion of the heavier oxygen-18 became substantially reduced in the rains that fell further to the west. That could only mean that clouds over the Amazon Basin had formed from evaporated rain arising from a previous downpour.

Salati's work has since been confirmed and extended. In effect, the process of downpour and then recharging takes place as much as six times as the air-mass moves over the Basin, from the Atlantic Ocean and all the way to the Andes. Furthermore, as much as three-quarters of the total volume of water that was originally picked up by the trade winds from the Atlantic Ocean, gets pumped back into the atmosphere, finally leaving the Basin altogether in the mass air circulation that climatologists name as the Hadley Cell after the famous 18th century English astronomer.

Water requires considerable energy to evaporate, some 600 calories per gram; equally when it condenses and falls as rain that same energy is released as heat and fuels the further expansion of the clouds so that they rise still further, ever releasing more water as rain. Meanwhile, the spin of the Earth — the Coriolis Force — draws the Hadley Cell air mass towards the northeast in the northern hemisphere and its mirror image, hence southeast, in the southern hemisphere. As it loses its water, air mass cools and becomes denser, sinking over East Africa as dry air. Put another way, the deserts of the Sahara and Kalahari are the other side of the coin of the wet, warm air of the Amazon.

The combined process of evaporation/transpiration just over the Legal Amazon of Brazil, puts back into the atmosphere more than 6 million million 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.

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. And in equal ignorance, the United States receives its share of the bounty, particularly over the Midwest.

The system of forest and rainfall may appear to be rugged and therefore resistant to perturbations, but the Hadley Centre finds otherwise. According to their models, global warming, if uncurbed, will result in a dramatic change in the air mass movement such that it switches from being driven across the Atlantic Ocean by the Trade Winds and hence across the Amazon Basin towards the Andes, 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.

Teleconnection

The Amazon rainforests play such a significant role in global climate and rainfall, that Brazilian climatologist Pedro Silva Dias lays claims to being able to predict rainfall in South Africa, six months after rainfall patterns over the Amazon. His work and that of Roni Avissar, at Duke University in the United States, indicate that what falls as rain over the Amazon Basin is paralleled, three to four months later, by rain falling over the US corn belt during its Spring and Summer.

Approximately 6.5 teratonnes of water (1012) get evapotranspired over the 5 million square kilometres of the Legal Amazon of Brazil each year, of which half gets exported out of the region and the other recycled within the Basin itself. In total that evapotranspiration takes up 1.63 x 1022 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. A sizeable proportion of that massive amount of energy gets teleconnected and consequently the Amazon Basin is responsible for a process of energy transfer across the planet that is equivalent to one half that now accumulated in the atmosphere because of 150 years of anthropogenic greenhouse gas emissions. At the same time, we must realise that even were there no forest, the water and energy transport would not be zero, because they are largely driven by the difference in the planetary energy balance between the equator and the poles. Nevertheless, it has become clear that the functioning of the Amazon Basin as a hydrological power engine is a critical component of contemporary climate.

Teleconnection and thunderstorms

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 them through the release of latent energy, so compensating for the cooling effect on rising air of expansion against reduced pressure, and as localised differences in warming and heat transfer bring about powerful convective up-draughts. 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, 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 effecting 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 teleconnect to middle and higher latitudes, which alters the weather in those regions. This effect appears to be most clearly defined in the Winter Hemisphere."

Teleconnection is the name given for such transfers of energy by means of rainfall to the United States, to South Africa and towards Europe from Amazonia and it comprises relatively slow-moving moist masses of air that, like a slowly moving train, 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, to Argentina, the Northeast of Brazil and even South Africa. Let the forests of the Amazon wither away, or just cut them down and burn them, as cattle ranchers and soya bean farmers are currently doing, and the US, let alone other parts of the world, will suffer like no-one had ever imagined they would.

During the drought of 1988, caused by a powerful El Niño event in the tropical Pacific, when the normal oceanic currents were overturned, the United States had a foretaste of what would happen were the Amazonian forests to disappear. Corn yields fell by more than a quarter, swallowing up the surpluses of previous years, and for the first time leaving production behind US consumption. The federal government was forced to pay out three billion dollars as debt relief to farmers.

Roni Avissar and Pedro Silva Dias point out that teleconnection processes between Amazonia and the United States depend on the humid tropical forests remaining largely intact over the Basin's 7 million square kilometres. The irony is that much of the recent deforestation in the Brazilian Amazon, particularly in the States of Mato Grosso and Para, is for cattle ranching and growing soya beans to meet the European demand for non-genetically modified produce, and in addition, to feed China's ever growing demands for soya-fed poultry and pigs. Around Santarem in the State of Para, for example, thousands upon thousands of acres of monoculture soya, stretch from horizon to horizon and the species-rich tropical forest has gone forever.

The other issue relates to the current frenzied destruction of the rainforest and its potential impact on climate. Thunderstorms are the key to the survival of the forest because they bring essential rain, in some parts of the Amazon, as in Colombia, to the tune of 40 feet a year. Cut the forest down and rainfall dwindles. That causes still more of the forest to die, so reducing rainfall still further and bringing about a vicious cycle of spreading degradation as fires begin to rage out of control.

To date climatologists 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 a higher resolution 'mesoscale' modelling – in other words focussing on a limited region, Roni Avissar has 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 100 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 process leads to massive thunderstorms. Under those circumstances rainfall will increase, perhaps by as much as 30 per cent. On the other hand, make the clearing relatively large, when the forest is no longer large enough to moisten the up-draught of air, and the convection process literally runs out of steam. Rainfall then declines sharply.

How close are we to that critical point when the forests are no longer big enough to sustain the sucking out of water over the clearings? It may be that we are perilously close in some regions of the Brazilian Amazon, such as in the southwest, on the border between Brazil and Bolivia, where rainfall has recently begun to increase. To some that may indicate that deforestation is not linked to rainfall: to Roni Avissar, such increases spell potential disaster and the remaining forest may be in grave danger of collapsing on account of an impending dramatic decline in rainfall.

World-granary countries such as the United States are threatened on both counts. First, when the Amazon self-destructs through being sucked dry by agro-industry. Second, because the accumulating impact of greenhouse gases in the atmosphere may lead within a few decades to a sudden switch in air mass movements over the Pacific and the Americas. Those El Niño-like changes will combine with the impact of massive agro-industrial clearings to the point when the humid rainforests of the Amazon can no longer sustain themselves. A climate disaster if ever there was one and certainly on the scale of cinema's The Day after Tomorrow.

In conclusion, it is becoming increasingly clear that we perturb climate, not simply because of greenhouse gas emissions from fossil fuel burning, but also because ecosystems such as those of the Amazon Basin play a massive role in the transport of energy from the equator to the more temperate regions of the planet. Our climate system, with its particular prevailing weather patterns, needs those energy transfers.

Consequently, we must do all in our power to prevent agro-industrial enterprises, whether for soyabean or cattle production, from destroying anymore of the Amazonian tropical rainforests.

At the same time as 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. It is a tall order, but one that we must urgently address, simultaneously to do all in our powers to conserve tropical rainforests, and worldwide to reduce greenhouse gas emissions. And should we prove unable to curb our greenhouse gas emissions, then 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.

As the ancient Greeks knew and no less traditional Amazonian peoples, the Earth Goddess Gaia will treat you well and bountifully if you respect her and the life that she represents. Treat her badly and she will reap death and destruction. Let us hope that we don't have to learn that lesson from our cavalier, ignorant and insensitive approach to the humid tropical rainforests of the Amazon Basin. They are a vital component of Gaia, one that stabilises climate and enables humanity as well as the rest of nature to flourish.

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SEQ CHAPTER \h \r 1

Why the United States Needs the Amazon: The 'Tele'connection
The US cornbelt will shrivel if the Amazon is destroyed.

By Peter Bunyard

During the 'Dust Bowl' years of the 1930s, yields of wheat and maize plummeted by 50 per cent as the soil blew away in choking clouds. Hindsight tells us that much of the horrors of those years resulted from putting the plough to wind-swept, vulnerable soils that had never before been tilled. Things have improved: soil conservation practices — contour ploughing and keeping soils covered with vegetation — have turned the corn belt into one of the main granaries of the world. Mind you, the cost of that production, in terms of fertilisers, machinery, transportation, has been immense, considering that between 1945 and 1970 energy inputs in the US corn belt rose 400 per cent, with just a 138 per cent increase in yield. Barely more energy comes out of the crop compared with that put in. Greenhouse gases emissions are part of the price we pay for that intensive and energy-expensive agriculture.

Today the United States produces a third or more of the global maize harvest, mostly for export. But even if the 'Dust Bowl' remains a distant, albeit traumatic memory, it doesn't take much for corn yields to drop — just a dry spell during the critical period of the growing season. In 2002 drought conditions across the Mid-West brought corn yields down by 8 per cent and wheat yields by 14 per cent. Those 'losses', when added to the 40 per cent drop in Australian wheat yields — also the result of severe drought — show how dependent we have become on a handful of seemingly bountiful agricultural regions of the world.

That vulnerability is becoming all too clear. According to the UN's FAO, global grain production per person in 2002, fell to its lowest level since 1970 and we have now had a spate of years in which the global grain harvest has fallen below demand, the shortfall in the United States being made up from stocks held in private and government stores. Consequently, by the end of 2002, world cereal stocks had fallen to their lowest level in 40 years since records began.

If relatively small fluctuations in climate can have a major effect on cereal crop production that does not bode well for a world population that is not only increasing but is increasing its demands for more and more animal protein, much of which is produced through feeding grains, such as maize. And what if climate change in some unforseen way were to bring about the conditions that led to the Dust Bowl? Just imagine how corn-belt farmers would react to being told that in the foreseeable future, a generation away at best, their sons and daughters would see their crops shrivel and die in the baking sun, the precious soil once again blown away? And, not just once, but year after year in devastating succession, turning what was the granary of the United States into near desert.

It may come as a surprise to most Midwestern farmers, let alone those who advise them, that essential crop-enhancing rains in the Spring and early Summer are a result of rainfall patterns thousands of miles down to the south, in the Amazon Basin. But why worry? Surely nothing is going to happen there that would affect rainfall over the United States?

Well, it looks as if farmers and the people who depend on them are in for a shock. That immense expanse of tropical forest, rivers and some of the world's greatest diversity of plants and animals, may not be as immune from global warming as we would like. And if we continue to chop it down at the rate of an area the size of Belgium in just one year, as happened in 2003 then, at a critical point, before we have even cleared half the forest, the whole system will collapse abruptly and irremediably. We would then be in dire straits because, as climatologists are now discovering, not only would rainfall patterns collapse over the entire Basin of some 7 million square kilometres, but the effect would ripple on in other parts of the world, such as the US Midwest, which stands to lose its rains just when it needs them most. In fact, at the rate we are going, and combining the impact of global warming with unchecked forest clearance over Amazonia, we may have less than 40 years before climate change makes life extremely uncomfortable for the majority of human beings on this planet.

How can that all come about? The process begins in the tropical Atlantic Ocean, off the coast of Africa, where dry, sinking air travels westwards either side of the equator towards the Brazilian coastline, picking up more and more moisture as it goes. The winds from the two hemispheres, known as trade winds because of their association with the tall ships of the past, converge at the solar equator and finish up moving virtually as one body over the Atlantic forests of Brazil. Through a process known as 'convection' they then form giant cumulo-nimbus thunder clouds that stretch for several hundred kilometres at a time.

By measuring the change in the ratio of oxygen isotopes — the less common isotope, oxygen-18 being one-eighth heavier than the common oxygen-16 — as water is first evaporated from the ocean and then precipitated as rain, physicists have unearthed just how important the Amazon forests are in keeping the air charged with water vapour as the converged winds move westwards over the Basin towards the Andes. Eneas Salati, a Brazilian physicist carried out the original study in the early 1980s and what intrigued him was the way in which the proportion of the heavier oxygen-18 became substantially reduced in the rains that fell further to the west. That could only mean that clouds over the Amazon Basin were forming leap-frog like from evaporated rain arising from a previous downpour.

His work has since been confirmed and extended. In effect, the process of downpour and then recharging takes place as much as six times as the air mass moves over the Basin, from the Atlantic Ocean and all the way to the Andes. Furthermore, as much as three-quarters of the total volume of water that was originally picked up by the trade winds from the Atlantic Ocean, gets pumped back into the atmosphere, finally leaving the Basin altogether in the mass air circulation that climatologists name as the Hadley Cell after the famous 18th century English astronomer. That process of precipitation and then recharging leaves no more than one quarter of the original quantity of water from the Atlantic Ocean to flow into and down the Amazon River to the coast. The Amazon River, augmented by a number of important rivers such as the Rio Negro, which flows down from Venezuela, as well as the Putumayo and Caqueta Rivers of Colombia, the Madeira River of Bolivia, nevertheless remains the largest freshwater river in the world.

Water requires considerable energy to evaporate, some 600 calories per gram; equally when it condenses and falls as rain that same energy is released as heat and fuels the further expansion of the clouds so that they rise still further, ever releasing more water as rain. Meanwhile, the spin of the Earth — the Coriolis Force — draws the Hadley Cell air mass towards the northeast in the northern hemisphere and its mirror image, hence southeast in the southern hemisphere. As it loses its water, it cools and becomes denser, sinking over East Africa as dry air. Put another way, the deserts of the Sahara and Kalahari are the other side of the coin of the wet, warm air of the Amazon.

Powerful dynamics are involved in driving the Hadley Cell circulation system. In fact, the forest itself pumps back as much as half the quantity of water that falls as rain through the process of transpiration. Transpiration involves the tree drawing water up through its roots and then pumping it out of millions of pores, known as stomata, in the leaves. Within the leaf the water gets split into oxygen and hydrogen during photosynthesis, the oxygen escaping into the atmosphere and regenerating it. The water, in leaving the surface of the leaf as vapour, also prevents the leaf from wilting and keeps it cool when exposed to direct sunlight. At the same time, some of the original rainfall never hits the ground, but in trickling down the trunk of the trees gets immediately evaporated back into the atmosphere.

The combined process of evaporation/transpiration puts back into the atmosphere more than 6 million million 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.

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. And in equal ignorance, the United States receives its share of the bounty, particularly over the Midwest.

The Amazon rainforests play such a significant role in global climate and rainfall, that Brazilian climatologist Pedro Silva Dias lays claims to being able to predict rainfall in South Africa, six months after rainfall patterns over the Amazon. His work and that of Roni Avissar, at Duke University in the United States, indicate that what falls as rain over the Amazon Basin is parallelled, three to four months later, by rain falling over the US corn belt during its Spring and Summer.

Teleconnection is the name given for such transfers of energy by means of rainfall to the United States, to South Africa and towards Europe from Amazonia and it comprises relatively slow-moving moist masses of air that, like a slowly moving train, 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. Let the forests of the Amazon wither away, or just cut them down and burn them, as cattle ranchers and soya bean farmers are currently doing, and the US will suffer like noone had ever imagined it would.

During the drought of 1988, caused by a powerful El Niño event in the tropical Pacific, when the normal oceanic currents were overturned, the United States had a foretaste of what would happen were the Amazonian forests to disappear. Corn yields fell by more than a quarter, swallowing up the surpluses of previous years, and for the first time leaving production behind US consumption. The federal government was forced to pay out three billion dollars as debt relief to farmers.

Roni Avissar and Pedro Silva Dias point out that teleconnection processes between Amazonia and the United States depend on the humid tropical forests remaining largely intact over the Basin's 7 million square kilometres. The irony is that much of the recent deforestation in the Brazilian Amazon, particularly in the States of Mato Grosso and Para, is for cattle ranching and growing soya beans to meet the European demand for non-genetically modified produce, and in addition, to feed China's ever growing demands for soya-fed poultry and pigs. Around Santarem in the State of Para, for example, thousands upon thousands of acres of monoculture soya, stretch from horizon to horizon and the species-rich tropical forest has gone forever.

[BOX] The big ills for the Amazon are cattle ranching, soya plantations, illegal timber extraction, mining and big, grossly inefficient dams that require enormous reservoirs to provide relatively little return. 2002 was one of the worst years ever for deforestation in the Amazon with more than 25 000 square kilometres of forest destroyed. Forest that would have covered a country the size of Belgium was wiped out by little more than a handful of agro-industrial enterprises, such as the one owned by the governor of Mato Grosso himself, Blairo Maggi.

A few years' back, Brazil produced 25 per cent of the world's soya, the United States 50 per cent. But Brazil is intent on becoming number one in soya production, surpassing the United States, and all at the expense of the rainforest. We in Western Europe are as responsible as any Brazilian for the mindless destruction of the Amazon rainforest, which, quite aside from its biological richness, functions as a vital stabiliser of global climate. The European Union now imports no less than 55 million tonnes of soya beans each year as cattle feed, increasingly from Brazil. With our intensive agriculture, our obsession with spurious productivity and cheap food, we in Europe could be responsible for destroying the future.[BOX ends]

Two issues are involved. One is global warming which, if the trend continues, will reach a critical point mid-century when the air currents bringing rain to the Amazon from the Atlantic suddenly switch to a climate regime that is much drier and warmer. That switch in climate will be akin to El Nino years, when South Pacific Ocean currents reverse their normal east to west direction. Indonesia and Australia, instead of enjoying the low-pressure system that brings tropical rains, will find themselves becoming tinder-dry and subject to raging forest fires. Meanwhile, on the other side of the Pacific, Peru will find itself suffering torrents of rain and a warming of coastal waters such that the nutrient-rich cold waters of the Humboldt Current are held at bay. The trade winds over the Atlantic and Pacific Oceans tend to wither away during strong El Ninos.

A succession of El Nino-like years, brought about through a global-warming-induced switch in climate, will permanently alter rainfall patterns and, with less rain and therefore a much reduced pumping back of water vapour into the air through evapo-transpiration, the survival of trees within the expanses of the Amazonian tropical humid rainforests will be seriously threatened. As it withers back, its mass of carbon, some 200 tonnes for each hectare, will decompose into carbon dioxide and methane, so building up still more the greenhouse gases in the atmosphere.

Once the Amazon forests, bar a few remnants, have all gone, more than 70 billion tonnes of carbon gases will find their way in a matter of years into the atmosphere, leading to ever more global warming. Taking the additional impact of the loss of Amazonian forests into account, Peter Cox, Richard Betts and their colleagues at the UK Met Office's Hadley Centre predict that land surface temperatures will likely rise by nearly 9 oC from pre-industrial levels. The last time temperatures were that high was more than 40 million years ago, when neither of the Poles had permanent ice and sea levels were scores of feet higher than today. At current greenhouse gas emissions, we have a few decades at most before the forest begins to wither and die.

The other issue relates to the current frenzied destruction of the rainforest and its potential impact on climate. Thunderstorms are the key to the survival of the forest because they bring essential rain, in some parts of the Amazon, as in Colombia, to the tune of 40 feet a year. Cut the forest down and rainfall dwindles. That causes still more of the forest to die, so reducing rainfall still further and bringing about a vicious cycle of spreading degradation as fires begin to rage out of control.

To date climatologists 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. Roni Avissar has 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, certainly no more than 100 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 process leads to massive thunderstorms. Under those circumstances rainfall will actually go up above 'normal'.

On the other hand, make the clearing relatively large, when the forest is no longer big enough to moisten the up-draught of air, and the convection process literally runs out of steam. Rainfall then declines sharply.

How close are we to that critical point when the forests are no longer big enough to sustain the sucking out of water over the clearings? It may be that we are perilously close in some regions of the Brazilian Amazon, such as Rondonia, and that any further loss of forest will lead to a dramatic collapse of rainfall.

The United States is threatened on both counts. First, because the Amazon is likely to self-destruct through being sucked dry by agro-industry. Second, because the accumulating impact of greenhouse gases in the atmosphere is likely to lead within a few decades to a sudden switch in air mass movements over the Pacific and the Americas. Those El Nino-like changes will add to the drying-out as a result of massive agro-industrial clearings.

We have a decade at best to get our greenhouse gas emissions in order. But, in no less measure we must all act to ensure that the greater part of the Amazon is conserved and not just for reasons of the extraordinary richness of its plant and animal life, but to safeguard the climate for all of us.