Review Article

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Restoring the earth's damaged temperature regulation is the fastest way out of the climate crisis. Cooling the planet with plants

Abstract

Reversal of global warming is accepted as an urgent necessity. Atmospheric CO2 concentration is widely used as a proxy and predictive indicator for global warming. Scientific calculation of the cooling efficiency of carbon sequestration options provides a rational basis for optimising climate investment. Based on evapotranspiration data and average rainfall over the Amazon Basin, we determine the cooling power of latent heat transport over the tropical rainforest. A healthy rainforest acts as a heat pump, cooling the Earth's surface and releasing heat into space. Because of the heat pump, the cooling engendered by evapotranspiration and subsequent cloud-forming is two orders of magnitude greater than the cooling brought about by carbon sequestration in forming biomass. In rainforests situated far inland, the levels of rainfall, evapotranspiration, and latent heat release during cloud formation remain as high, or even higher, than near those near the coast. Whether the coastal forests attract ocean clouds through a biological pump mechanism, or are nourished by on-shore winds, the net result is the amplification of the Amazon's heat pump effect across millions of square kilometres and, therefore, deep into the interior of South-America.

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Introduction

Greenhouse gases heat up the planet, but they are not the only driver of climate change. While carbon gets all the attention, another factor is largely overlooked. It is water in its movements and changes of state (ice, liquid water and vapour) as it interacts with plant life and the atmosphere. This interaction has enormous stabilizing and cooling effects. Once we understand the full force of plants and the water cycle, we can actually confront the climate crisis with a whole new set of measures. Plants, healthy soils and healthy ecosystems stabilize weather, the climate and bring cooling. We can leverage these qualities to fight the climate crisis. If the damage to the biosphere is reversed, the planet will regain its capacity to regulate its own temperature.[1]

Global warming

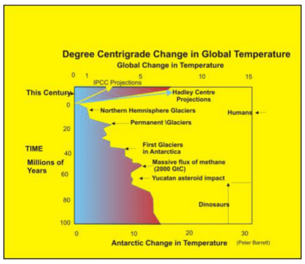
We know from NASA that the planet is increasingly warming, with peak values found at 1.81 watts per square metre in 2023. Taking the entire Earth's surface into account that means the extra warming since pre-industrial times is equivalent to roughly 0.75 per cent of the solar energy received on average at the Earth's surface. At first sight, that does not seem a great increase, at least not until we take account of extreme climate events, be they massive floods, powerful storms, devastating droughts, wildfires, all of which have increased both in frequency and severity. Concurrent with our emissions of greenhouse gases, primarily from the burning of fossil fuels, we have been degrading the ecosystems that play a crucial role in maintaining the Earth's temperature within a range conducive to human agriculture and prosperity.[1]

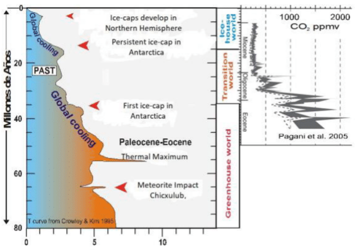
In particular, at the urgings of the IPCC, (the Intergovernmental Panel on Climate Change) and the Paris Agreement, the focus is on reducing our emissions of greenhouse gases such as to keep average surface temperatures from rising up to 1.5ºC above pre-industrial levels when CO_2 concentrations amounted to some 280 parts per million by volume. Above 1.5ºC, according to IPCC, we will be at a threshold, beyond which it may prove nigh impossible to return to cooler temperatures. We believe that carbon reduction is best achieved by restoring ecosystems and especially rainforests. Such restoration will go hand-in-hand with the cooling derived from the export of energy out to Space from latent heat transport up to cloud-forming altitudes, where it is released on condensation.

Some 100 million years ago, when the continents were forming their current layout, came the evolution of angiosperm vegetation, with broad, veined leaves. Boyce and his colleagues, at the Missouri Botanical Garden, point out that, because of such vascularisation and access to water via their roots, angiosperm trees could transpire at a rate at least four times higher than conifers and more primordial species of trees. With contiguous, closed-canopy forests that increase in transpiration enabled a higher rate of photosynthesis and consequently a significant increase in biomass, boosted no less by the expansion of forests deep into the hinterland of continents. The author's state: "Climate modelling of the impact of this physiological revolution indicates that the tropics would be hotter, drier and more seasonal in the absence of angiosperms and the overall area of tropical rainforest would decline substantially. Because angiosperm diversity is influenced by rainforest area and by precipitation abundance and evenness the high diversity of angiosperms is partially a product of a positive feedback loop with the climate modifications initiated by the angiosperms themselves."[2,3]

The evidence for the efficacy of the tropical rainforest species to pump water vapour into the atmosphere, despite the relatively high humidity, is there for all to see in the high rate of evapotranspiration, namely 1.37 metres annually on average over the forested regions of the Brazilian Amazon.[4] Furthermore, the isotopic studies of Eneas Salati and his colleagues indicate that more than 50 per cent and even as much as 75 per cent of rainfall is recycled over the Brazilian Amazon by means of evapotranspiration. Even during rainfall, clouds of vapour can be seen rising from Amazon vegetation. If it were not for such recycling, the forests to the far west of the oceanic source, as in the equatorial Colombian Amazon, would not exist.[5,6]

That important angiosperm evolutionary step helped bring down the carbon dioxide levels from more than 3,000 parts per million (by volume) to their pre-industrial concentration of 280 parts per million (ppmv). Meanwhile, the biomass converted to coal, which we have been burning indiscriminately once industrialisation got underway. In general terms, over the course of 100 million years, the temperature fell *linearly* from 7ºC above pre-industrial global-average levels to that at the beginning of the industrial revolution some 250 years ago. Over the same period, carbon dioxide levels fell *exponentially*, with the greatest change occurring all those millions of years back. From the diagram we see that over the past 20 million years the temperature trajectory is more or less linear with bumps, but the CO_2 atmospheric concentration shows the tail end of an exponential decline, with relatively little change. Yet, the cooling continued over those 20 million years from 2ºC above pre-industrial levels (280 ppmv) to zero by the turn of the 19th century.[7,8]

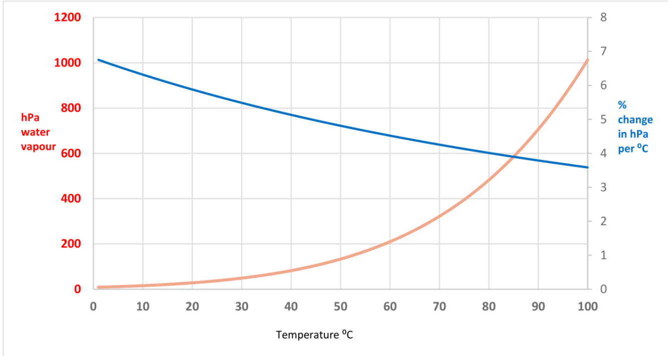




The obvious interpretation of the increase in biomass and the associated cooling was that it was the result of CO_2 uptake and the reduction in greenhouse gas concentration. Undoubtedly, such a conclusion is in part correct. However, it does not take account of the cooling brought about by a significant increase in evapotranspiration as a result of the evolution of angiosperm-dominated tropical rainforests which, over time, covered much of the continental surface. We calculate that the water-vapour transport of evapotranspired latent heat from the forest canopy to the upper troposphere and its subsequent irradiation to Space as infrared electromagnetic radiation may have brought about a cooling at least 100 times and possibly as much as 200 times greater than the cooling from biomass-forming and its role as a carbon sink. Indeed, if it were not for that transport of latent heat energy to Space, the upper atmosphere would have accumulated more and more heat, which is clearly not the case.[9]

More than 50 per cent of greenhouse gas warming, including that from carbon dioxide, methane, nitrous oxide and trace substances like the chlorofluorocarbons (CFCs), comes from water vapour carried in the atmosphere. Unquestionably, the amount of water vapour in the air depends on the air's temperature. Global warming happens through a self-reinforcing cycle: increased temperatures from greenhouse gases, like those from burning fossil fuels, cause more water to evaporate. This additional water vapour then further raises the temperature, leading to even more evaporation. This cycle continues until a new balance is reached, characterized by higher temperatures and more precipitation.

The process, according to the Clausius-Clapeyron equation of water vapour saturation with temperature, is exponential in the sense that the higher the temperature, the increasing capacity to absorb water vapour to achieve the same relative humidity. In effect, for each degree rise in temperature, the increase in water vapour to the point of saturation will be approximately 6 (+/- 1.5) per cent per degree Celsius, in a process akin to compound interest.



Clausius-Clapeyron equation. log P_2 - $(Q*(T_2-T_1))/(R*T_2*T_1*2.302)$ = *log* P_1 *with Q, latent heat of evaporation 40.65 kJ* mol^{-1}*, R, the ideal gas constant, 8.31 J* K^{-1} mol^{-1}. P_2 = *1013.25 hPa,* T_2 = *373 K.*

The brown curve (left-hand axis) is the hPa at saturation. The right-hand axis shows the percentage increment in saturation per degree temperature change. The X-axis is the temperature in Celsius.

Precipitation depends in great part on aerosols which capture the tiny drops of condensed water and, by amassing a multitude of such drops together, forms drops of rain with sufficient mass to overcome air-resistance and fall to Earth. Without those aerosols, especially those emitted from many plant and tree species in the form of organic compounds such as terpenes and bacteria (species of *Pseudomonas*), the water vapour would not form large enough rain drops on condensation and the droplets would re-evaporate, heating the atmosphere still further by water vapour's greenhouse effect. Owing to the high leaf-area-index and, consequently, the multi-layered density of evaporative surfaces, forest-led evapotranspiration is an order of magnitude greater per area covered than evaporation over the same latitude ocean. On that basis, the evolution of angiosperm forests, those 100 million years ago, will have resulted in rain-precipitating clouds and in the export of solar energy out to Space in the form of latent heat.[5,10–12]

The terrible droughts of 2005, 2010 and, now again, in 2023 over the Amazon Basin tell us that the deforestation and forest degradation which has been taking place over the past 70 years is having dire consequences on the flow of humid air from the tropical Atlantic Ocean. The reduction in evapotranspiration in the Eastern part of the Basin will result in less cloud-forming which, in turn, will have two consequences, namely a significant reduction in the power of the biotic pump and, with the resulting reduction in rainfall, a drying out of the forest and a decline in evapotranspiration. Dieback of the forest and its decomposition turns the Amazon Basin into a source rather than sink for atmospheric carbon, adding to greenhouse gas warming. Worse still, with the failure of the biotic pump and the forest die-back, the cooling from the export of latent heat energy will be much reduced.[5,13,14]

In effect, the forest-generated hydrological cycle, from evapotranspiration to cloud-forming, acts like a vast, natural air-conditioning heat pump. Avogadro's Law tells us that at standard temperature and pressure, one gram-mol of water vapour (18 grams) will take up a volume of 22.4 litres, hence a volume-expansion of 1,200 times as liquid water transforms to vapour. That expansion, involving the breaking of hydrogen bonds between one water molecule and another, needs energy in the form of latent heat. The vapour, so formed, percolates upwards in the atmosphere until reaching an altitude where the reduction in temperature permits water vapour saturation and cloud-forming. Water vapour condensation releases the latent heat simultaneous with the sharp reduction in volume as vapour transforms to liquid. In effect, the latent heat of some 540 calories per gram of water, has been transported from the leaf surface to cloud-forming at an altitude of several kilometres, thereby moving upwards to an altitude where the air is much thinner and the greenhouse effect significantly reduced. The latent heat transported in this manner from the forests of the Amazon Basin, based on the 1.37 metres on average of evapotranspiration, amounts to as much as 41 per cent of the total solar input to the surface, namely 240 watts.

The full importance of how the Earth naturally cooled itself millions of years ago should not escape us. With the current global warming, soon set to exceed the 1.5 ºC threshold, we need to prioritize reforesting areas that have been cleared since the industrial revolution began around 250 years ago. This restoration has its greatest impact in the tropical regions. This will restore the atmospheric hydrology over the landmasses sufficiently to stop the planet from heating up while the global economy is being decarbonized. This dual approach is essential for tackling the current climate challenges.

Further evidence of the cooling brought about by the spread of forests comes from the recent study of the cause of the mini-ice age during the 17th and 18th centuries, when, for example, the Thames in London froze over sufficiently for ice-skating. Alexander Koch and colleagues showed that the global carbon budget of the 1500s cannot be balanced until large-scale vegetation regeneration in the Americas was included. The Great Dying of the Indigenous Peoples of the Americas resulted in a human-driven global impact on the Earth System in the two centuries prior to the Industrial Revolution. Koch and his colleagues estimated that 55 million indigenous people died following the European conquest of the Americas beginning in 1492. Deadly disease therefore led to the abandonment and secondary succession of 56 million hectares of land which led to an additional 7.4 Pg C (7.4 gigatonnes of carbon) being removed from the atmosphere and stored on the land surface in the 1500s. Overall, including feedback processes, forest grow-back contributed between 47 per cent and 67 per cent of the 15–22 Pg C (15 -22 gigatonnes of carbon and equivalent to 7–10 ppm of atmospheric CO_2) decline in atmospheric CO_2 between 1520 CE and 1610 CE seen in Antarctic ice core records. Koch and colleagues conclude that the Great Dying of the Indigenous Peoples of the Americas led to the abandonment of enough cleared land in the Americas that the resulting terrestrial carbon uptake had a detectable impact on both atmospheric CO_2 and global surface air temperatures in the two centuries prior to the Industrial Revolution.[15]

Koch and colleagues, in their excellent analysis, did not take into account the potentially much more effective cooling from latent heat transport as the regenerating forest restored the condensation/biotic pump function and enhanced its evapotranspiration.

An important and largely overlooked factor in rainforest hydrology is the biotic pump. The evapotranspiration followed by condensation of water, from liquid to vapour and back to liquid, causes abrupt changes in atmospheric pressure, especially at the altitude where large cloud-masses are forming. An annual rainfall of 2.25 metres is equivalent to 2.25 million grams of water per square metre and the latent heat in joules for that quantity amounts to 580 kWh throughout the year per square metre of forest. Meanwhile, the implosion energy per square metre amounts to 40 kWh.[16] That's not a meagre amount when considering the force that is unleashed in the cloud-forming part of the atmosphere over the Amazon rainforests. If we take into consideration the surface area of the forested part of the Amazon Basin, amounting to some 5.2 million square kilometres, the total implosion energy is equivalent to 1 atomic bomb going off every second. (Bunyard, Peter, simple calculations if we assume 4.18 thousand joules per gram TNT).[4]

Assuming an environmental lapse rate of 6.5ºC per kilometre rise in altitude and an average surface temperature of 25ºC, at 4 kilometres altitude the temperature will be close to 0ºC. At that temperature the saturation pressure of water vapour is approximately 8 hectopascals (hPa) and the atmospheric pressure is 800 hPa. Condensation now takes place and, given that the average annual rainfall over the Amazon Basin is 2.25 metres, per day on average, precipitation will deliver 6.165 kilograms of water per square metre. If we assume that such delivery takes place over 4 hours during cloud-formation, then per second the delivery amounts to 0.43 grams of rainfall which generates an implosion energy of 66 joules per second per square metre and a reduction in atmospheric pressure of 0.66 hectopascals per second per cubic metre, as water vapour condenses into clouds. That significant pressure reduction will immediately cause the air from below to flow upwards to fill the partial vacuum at a rate approaching 10 metres per second. The newly arrived air will feed the process and, again, condensation will take place. That process will continue during rainfall and, importantly, will draw in the surface humid air from the tropical Atlantic Ocean.

We appreciate that precipitation levels over this continent-sized forest differ considerably from averages of 1500 mm on the South Eastern parts of the Basin to values beyond 3000 mm per year in some parts of the Western Amazon and the foothills of the Andes Mountains. In part, the differences are the result of deforestation. Our expectation is that regeneration of forests where they have been decimated, as in the South-East, will bring about an improved rainfall regime. Therefore, we have used the average precipitation value, namely 2.25 metres annually, in order to obtain values, which reflect better the functioning of contiguous closed-canopy biodiverse Amazon rainforests. When clouds form over rainforests, the air column above rapidly ascends to fill the created partial vacuum, caused by the imploding water vapour turning into liquid water, pulling in surface air from the ocean at the same latitude. This dynamic, fuelled by the forest's heat-pump effect and the air contracting as vapour condenses into liquid, is what, together with the Coriolis force, drives the Trade Winds. These moisture-laden winds converge in the Intertropical Convergent Zone (ITCZ) above the Amazon Basin, leading to the formation of the Walker Circulation.

In 2007, Anastassia Makarieva and Victor Gorshkov of the Peterburg Nuclear Physics Institute elaborated the original theory for the functioning of a biotic pump which, according to them, would enable the watering of contiguous rainforest, even thousands of kilometres from the oceanic source of humidity, such as is the case in the Colombian Amazon, some 3,000 kilometres distant from the tropical Atlantic Ocean of the same equatorial latitude.[10] Since the initial elaboration of the biotic pump theory, in 2019, Peter Bunyard, together with Martin Hodnett and others, confirmed from a large series of physical experiments that water vapour condensation must lead to air flow and its circulation. From their experimental results and fundamental physics, using a dedicated chamber in which they could cool a small portion of the contained air, they determined that the abrupt reduction in partial pressure from water vapour condensation, as the air passed over cooling coils, was one thousand times more powerful than the change in air density brought about by the cooling. That buoyancy change, therefore, had no more than a small effect on the airflow, as could be seen when condensation caused an updraught against the gravitational sinking of colder and therefore denser air.[5,14,16] But how much will reafforestation actually cool the Earth? In fact, we have discerned that forests cool the Earth's surface and the lower atmosphere in *seven distinct* but interconnected ways, as elaborated below.

Forests, especially tropical rain forests, play a crucial role in cooling the Earth and countering global warming through at least seven mechanisms:

I. Evapotranspiration: Trees release water vapour through their leaves, which requires energy and cools the surrounding area, by 98 Watts per square metre per second.

II. Shade and Soil Moisture: Forest canopies provide shade and maintain high humidity levels, preventing the soil from drying out. This keeps temperatures lower below the canopy by at least 10ºC and helps biological activity including photosynthesis.

III. Condensation-Driven Airflow: As water vapour condenses into clouds, it releases latent heat energy which radiates into space, cooling the atmosphere. It also causes air to rise, contributing to cooling at ground level.[9]

IV. Biotic Pump: Large forests draw in humid air from oceans, maintaining rainfall even far inland, creating more cooling biomass.

V. Cloud Formation: Forests create dense clouds, which reflect sunlight back into space, increasing albedo and reducing heat absorption.

VI. Reduced Sensible Heat: Sensible heat amplifies global warming. Forests diminish the amount of sensible heat, absorbing it as latent heat (released during evapotranspiration) diminishing the effects of greenhouse gases.[17]

VII. Forests act as carbon sinks, absorbing carbon dioxide (CO_2) from the atmosphere, which helps reduce greenhouse gas levels.

Transpiration at the surface cools the leaves as liquid water vaporises. Each gram of water requires 540 calories of solar energy (2,257 joules) to break the hydrogen bonds holding the water molecules together. Over the 5.2 million square kilometres of the Legal Amazon of Brazil, evapotranspiration absorbs 41 per cent of the sun's energy with 98 watts absorbed per square metre versus 239 watts of sunlight received on average per square metre of the forest surface.

The closed-canopy rainforest shades the surface below from direct sunlight. The humidity remains high under those circumstances, preventing the surface soil from drying out excessively. Temperatures remain several degrees (Celsius) below those above the canopy. As Hodnett and his associates have shown from their research in the Brazilian Amazon, during the dry season, the soil under the rain forest dries significantly, but not usually to the point when the forest suffers. That finding indicates that the forest continues its evapotranspiration using its deep roots to tap at least down to the unsaturated zone, if not to groundwater, which close to Manaus maybe as much as 30 metres down. As a result, after a long dry season, the soil profile shows greater drying beneath the forest than beneath pasture, largely because trees have deeper roots than grasses. In fact, in order to protect its low albedo leaves from direct sunlight during the dry season, the forest must transpire or the leaf temperature will rise to the point of scorching. In drought conditions, as during the unprecedented ones of 2005, 2010 and 2023, the forest trees may suffer severe die-back and even death. Under those circumstances, evapotranspiration will be severely reduced over the affected forest and the biotic pump from that region will also fail.[18]

The water vapour from evapotranspiration (18 grams per gram-molecule) is lighter than the nitrogen (28 per gram-molecule) and oxygen (32 per gram-molecule), which make up the bulk of air, and the vapour therefore rises through the column of air, spurred on by the warmth of the Sun over the forest canopy. The energy, encapsulated by the vapour in the form of latent heat, gets carried up to altitudes several kilometres above the Earth's surface, where colder temperatures cause the vapour to condense into clouds (an environmental lapse rate of 6.5ºC reduction per km rise in altitude). In fact, the further from the Earth's surface the colder it gets and the more rapid the rate of condensation. Water-vapour saturation, according to Clausius-Clapeyron, increases exponentially with temperature and colder air holds exponentially less vapour than warmer air.[16,19] At cloud-forming altitudes, the air is thinner and the greenhouse gases (CO_2, CH_4, N_2O) are less effective than close to the surface where the air is considerably denser. The latent heat energy released, as the water vapour condenses into liquid water and ice, takes the form of sensible heat, which, on losing its heat to its surroundings by convection and conduction will become electromagnetic radiation. A proportion of that infrared radiation will immediately (and at the speed of light) pass out to Space through a radiation window. The remaining latent heat energy will warm one kilogram of the surrounding air by 2.5ºC for every gram of condensed vapour. At the altitude of the jet stream the warmed-up air will get carried away, out of the Amazon Basin and towards Africa and during its passage will cool down and send the radiation released out to Space. When we take into account the average precipitation over the rainforest, including that from evapotranspiration and the humidity borne in by the Trade Winds, as much as 70 per cent of the sun's energy, received at the surface of the rainforest, will be radiated to Space over time.[9]

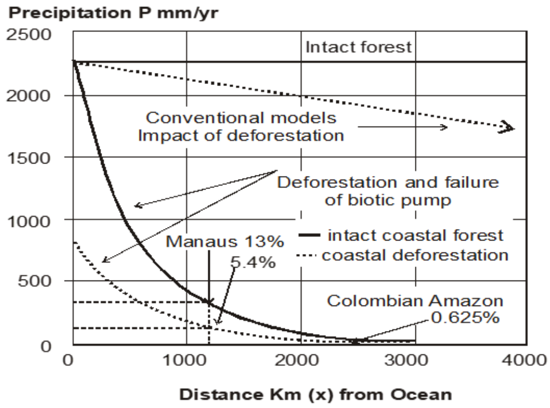
The biotic pump, as elaborated by Anastassia Makarieva and Victor Gorshkov, is a critical component of the Earth-cooling by closed-canopy forests. In their biotic pump theory, published in 2007, the two physicist/mathematicians claimed that the high rate of evapotranspiration generated over the rainforest and the subsequent cloud formation led to a partial pressure change, as vapour transformed to liquid, such as to pull the column of air upwards. In fact, the H_2O volume reduces by more than 1,200 times as each molecule of water vapour transforms to liquid water. The abrupt change in water volume causes an implosion of sufficient force to draw in a horizontal current of surface air all the way from the same latitude ocean. The combination of ocean-derived humid air and the recycling of evapotranspired water vapour maintains the coastal level of rainfall several thousand kilometres from the coast, but only as long as the entire area is well-forested and a high rate of evapotranspiration is maintained.[5,14,20] The process, the biotic pump, which draws in the humid air from the ocean, is a critical factor in the watering of the continent. From studying the proportion of deuterium and oxygen-18 isotopes in rainwater carried by the airflows from the tropical Atlantic Ocean to the western reaches of the Amazon Basin, some 3,000 kilometres inland, Eneas Salati and his colleagues determined that the rain was recycled at least five times across the expanse of the Amazon

Basin, the distance from evaporation to precipitation covering on average some 600 kilometres. Salati, as has been confirmed since, also found that as much as 60 per cent of rainfall was re-evaporated by forest transpiration and that such evapotranspiration contributed to the watering of the rainforests further to the West.[6]

In their original paper, Anastassia and Victor challenged the idea that the Trades Winds flowing from Africa to the Amazon Basin were the result of latitudinal heat differences. They pointed out that the air directly above the ocean was warmer during the day than the air above the rainforest, especially once clouds had formed, and that, if it were not for the biotic pump, the air would flow from the land to the ocean and not the other way round. In their 2007 article, *Biotic pump of atmospheric moisture as driver of the hydrological cycle on land*, Marakieva and Gorshkov state that precipitation at a particular distance from the oceanic source of humidity (P_x) is equal to the precipitation at the coast (P_0) multiplied by the minus exponential of the distance (*x)* in kilometres from the coast divided by the average fallout length (*l)* of a water molecule from its evaporation to precipitation, the latter being given as 600 kilometres in accordance with Salati's isotope measurements:

$$p_x = p_o \exp\left[-x/l\right]$$

If there is good forest cover all the way to the coast, then the biotic pump ensures sufficient rainfall by means both of evapotranspiration and by the cloud-forming implosion force, the latter drawing in the humid surface flow of air (the Trade Winds). Those twin processes ensure that the supply of humid air above the forest is sustained, with the consequence that the distance a molecule of evaporated water remains in the air appears to extend towards infinity. In fact, if the virtual length of the precipitation pathway of a water molecule extends to 5000 kilometres, the loss in precipitation, even thousands of kilometres distant from the coast, is negligible. If take the Amazon Basin as an example, the above formula indicates that, following deforestation, the closer to the coast the more rapid the reduction in precipitation. That simple finding tells us that first and foremost we should take good care to protect the forests close to the shore. Indeed, the curve of precipitation loss for a deforested Amazon Basin is exponential with the most rapid decline close to the coast and a levelling off several thousand kilometres later, when the annual rainfall would be no better than that we can expect for a desert as dry as the Negev in Israel.



Widespread deforestation in the Amazon Basin would lead, according to the biotic pump theory of A. Makarieva and V. Gorshkov, to an exponential reduction in rainfall as one passed from the coast to the deep interior. The net result would be desert conditions and not the savannah-like conditions indicated by conventional (without biotic pump) climate models. ©Peter Bunyard

The biotic pump, as a physical reality, is likely to have manifested itself in full-force, once the rate of evapotranspiration had increased as a consequence of angiosperm evolution and the spread of broad-leafed trees. As to the claim by climatologists that the biotic pump theory was an incorrect explanation for the flow of surface air from the oceans to the land, Peter Bunyard and his colleagues showed experimentally that, on the contrary, the physics of condensation would invariably result in just such a flow, thereby elevating the biotic pump from theory to principle.[5,10]

Experiments confirm Biotic Pump Theory

The scepticism that the spread of forests inland depended on a biotic pump to provide the necessary rainfall led Peter Bunyard to devise experiments to determine whether water vapour condensation would lead to a measurable circulating airflow. He therefore designed a 5-metre square 1-metre-wide donut-shaped structure in which he could enclose local air. An industrial refrigerator attached to a 12-millimetre diameter double-layer of copper piping was used to cool a portion of the enclosed 20 kilograms of air (see below).

The experimental structure for measuring airflow in relation to the rate of partial pressure change as a small portion of air passed over the cooling coils and the contained water vapour condensed. The cooling coils seen from looking up the right-hand column. How much air was cooled per second depended on the rate of condensation and the resulting airflow. With no condensation there was no measurable airflow, even though the air at the cooling coils showed a temperature reduction of 10ºC and a gain in density of 0.05 kilograms per m3. ©Peter Bunyard

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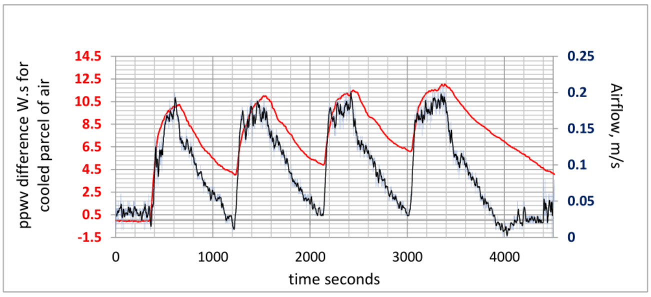


Experiment June 27th, 2016. The graph shows 4 refrigeration cycles. The left-hand axis shows the partial pressure change in water vapour in watt.seconds during the refrigeration cycle and the right-hand axis shows the anemometer readings in metres per second. The airflow was measured using a 2D- anemometer ©Peter Bunyard

The results of more than 100 experiments under different external weather conditions, ranging from temperatures as high as 25ºC and low as 5ºC, with different relative humidities, indicated that condensation caused by the refrigeration at the coils of a small parcel of air inevitably led to measurable airflow. Should the relative humidity be low, for instance below 60 per cent, such that cooling of the air parcel failed to bring about saturation and condensation, then no airflow could be detected even though the parcel of air had cooled by 10ºC relative to the average air temperature in other parts of the structure. That finding, in contrast to experiments where condensation was detected by ensuing rainfall and its collection, indicated that unidirectional airflow was a necessary correlation of condensation.

From the physics, using sensors to provide temperature (in kelvin), barometric pressure (in hectopascals) and relative humidity, the partial pressure change (in hectopascals and watts) according to the rate of condensation, could be determined. Under the physical conditions of the experiments, gravitational changes in air density of the cooled parcel of air were compared with the energy associated with the implosion of air, as condensation took place. The gravitational energy associated with air density was found to be at least 1,000 times weaker than the implosion energy associated with condensation, such that the air density change could not account for the measured airflow around the chamber.[5,13,14]

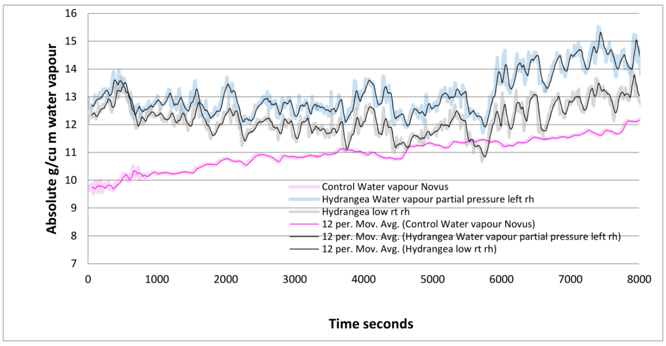
Meanwhile, physics tells us that:

$J\, or\, ws = \frac{\Delta Pa}{\Delta t} m^3 = 1000 \Delta T_v$ where $\Delta Tv = 0.621\ \Delta qT$, q being the specific humidity of the air parcel in kilograms of water vapour for each kilogram of moist air, with q being derived from the equation $q = 0.621 \frac{p_{wv}}{p_{atmos}}$ where p_{wv} is the partial pressure of water vapour and p_{atmos} is atmospheric pressure.

Multiplying the small temperature reduction, ΔTv by Cp, the heat capacity of dry air at constant pressure, 1,000 J kg^{-1} K^{-1}, the negative kinetic energy in Joules of watt.seconds can be calculated. As shown in the above calculation, the change in Tv relates to the net negative kinetic energy derived from the rate of change in the partial pressure of water vapour (*ppwv*) and the subsequent expansion of the surrounding air (from below) to fill the partial vacuum.

The temperature change from the partial pressure implosion, when one gram of water vapour condenses, leads to one kilogram of air cooling by 0.17ºC. The temperature change when the latent heat is released from one gram of water vapour leads to one kilogram of air warming by 2.5ºC. In effect, the energy of latent heat is approximately 15 times greater than the implosion energy of condensation. Nevertheless, the two are wholly different phenomena, one being mechanical and the other electromagnetic, and the temptation to subtract the 0.17ºC from the 2.5ºC must be resisted, otherwise, the implosion energy will be ignored and not taken into account when considering the validity of the biotic pump.[16]

The energies involved in condensation-implosion are considerable. Over the Brazilian Amazon (5.2 million square kilometres) they amount to 66 watts per square metre if delivered over four hours in the mid- to late-afternoon. That is sufficient energy to cause an air current of 10.5 metres per second, strong enough to account for the Trade Winds.[5,16] Further experiments were carried out, using the same sensors for relative humidity, barometric pressure and temperature (thermocouples) to determine the response of different plant angiosperm species, such as hydrangea and roses, to sunlight. In terms of absolute humidity and therefore evapotranspiration, as determined from the physics of ideal gases, a high degree of synchrony was found for leaves in different parts of the plant, some more in shade than others, and between species.



The absolute humidity directly above and in close proximity to the leaves of Hydrangea, one leaf in direct sunlight and the other in shade, compared with a control, show an extraordinary degree of synchronisation. It would appear that the stomata in different parts of the plant with different exposures to sunlight are responding simultaneously. ©Peter Bunyard.[21]

The dense cumulo-nimbus clouds which form, mostly in the mid to late afternoon, over the tropical rainforest have a relatively high albedo and will reflect a considerable proportion of the incoming sunlight back out to Space. If such clouds were to reflect up to three-quarters of the incoming sunlight back to Space during the time of their formation and dissipation, some 4 hours from midday to late afternoon, that would add an average cooling effect of some 30 watts per square metre and would amount to an average 12.5 per cent cooling of the total surface sunlight received during 24 hours. The forming of clouds over the tropical rainforest, plus the export of latent heat energy from evapotranspiration, could result in as much as 80 per cent of the total daily solar input to the Earth's surface being returned to Space, hence close to some 200 watts per square metre of the average 240 watts per square metre received from the Sun.[22]

As regeneration takes place and the forest grows back into degraded areas, the ratio between sensible heat and latent heat (the Bowen Ratio) will be greatly reduced. The sensible heat fraction is the fraction affected by the greenhouse gases and, in the main, is the cause of the global warming which is now taking place. Therefore, the reduction in the Bowen Ratio, as evapotranspiration kicks in, will have an important cooling effect over and above the forming of reflective clouds and the transport of latent heat to cloud-forming altitudes.[17]

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Clearly the regeneration and growth of the rainforest would act as a biomass sink for CO_2. The Amazon rainforest absorbs one-fourth of the CO_2 absorbed by all the land on Earth. Degradation and deforestation have resulted in the Amazon Basin becoming a source of greenhouse gas emissions rather than a sink.[23] Nevertheless, regrowth has to result in biomass-forming and CO_2 uptake. In terms of cooling, hydrology is far more important, by means of latent heat transfer and reflective cloud-forming than is CO_2 uptake. However, once a forest spreads and matures, the uptake has the effect of sustaining long-term cooling by reducing significantly the CO_2 concentration in the atmosphere.

According to Jan Pokorny and his colleagues, the growth of vegetation in the temperate zone adds 1 kilogram of dry matter per year per square metre. The photosynthetic energy required to produce that 1 kg of biomass is 4.4 kilowatt-hours (kWh), equivalent to 16.1 million joules and 0.5 Watts per square metre. Meanwhile, the energy required for transpiration amounts to approximately 98 joules per square metre, or close to 200 times as much. On the basis that at least 75 per cent of that Latent heat transpiration energy is radiated outwards to Space when the water vapour condenses, we conclude that, for global cooling, transpiration is far more effective than the biomass-sink for CO_2. However, the point is that the two processes, namely biomass growth and transpiration, act together and in addition to each other. It would be truly synergistic in the sense that more biomass translates into an expanded leaf area and, hence, to more evapotranspiration.[24]

Forest cooling

How much more forest would we need to cool the planet? We know from NASA that the current extra warming amounts to 1.81 Watts per square metre of the Earth's surface. The Earth's surface in square metres amounts to 510 million million square metres ($5.1x10^{14}$). Therefore, the additional global warming of the total Earth surface over the course of a year amounts to the seemingly gigantic number of $2.91109x10^{22}$ watts. Taking just the latent heat capture of the Amazon rainforest encompassing 5.75 million square kilometres and assuming all that energy is dissipated to Space, we obtain the number $2.92025x10^{22}$ watts. That number is remarkably close to the extra warming. Theoretically, and adding in the cloud-cooling effect described in 5), by reforestation we could cool the planet within a matter of decades. That process would be helped by reductions in greenhouse gas emissions.

For the time being we might want to reduce the additional global warming of 1.81 Watts per square metre by close to half, thereby reducing the average surface temperature by 0.9ºC. We could achieve that by restoring an area of tropical rainforest by 2.8 million square kilometres. Already more than one quarter of the Amazon rainforests have been destroyed during the last half century to make way for soya, cattle, palm oil, hydroelectricity schemes and mining. If we add in the uptake of carbon dioxide in reafforestation, then just the restoration of forests to those regions which have been cleared, would, in all probability, meet our target of cooling the planet and thereby reducing the number and severity of extreme weather events, like droughts, floods and scorching temperatures, or even bitter cold, as when the circumpolar air currents push their way to lower latitudes. In conclusion, the restoration of forests in areas that have been cleared could likely achieve our goal of stopping the planet from heating up further, while reducing extreme weather events such as droughts, floods, and heatwaves. In addition, forest regeneration would mitigate the long-term warming effects of carbon dioxide by biomass-absorption, thereby adding to the global benefits from phasing out fossil fuels.

Regeneration of forests to counter global warming from petroleum use

The daily, global consumption of oil is some 100 million barrels. With a density of 0.86 kilograms per litre and 159 million litres in 1 million barrels of oil, we obtain the quantity 136 million kilograms. The heat released by burning one kilogram of oil is 42 megajoules. The carbon content on average is 85 per cent, such that burning 1 kg will put close to 20 gram-molecules of carbon dioxide into the atmosphere.

The heat, released by burning 100 million barrels of oil each day for a year, amounts to $2.096 \text{ x } 10^{20}$ joules. On the basis of latent heat release from an annual precipitation of 2.25 metres and, assuming 75 per cent of solar energy received gets irradiated to Space by the mechanism described above, then, for each square kilometre of rainforest, the total release and consequent cooling amounts to $3.809 \text{ x } 10^{15}$ joules. That being the case, the area of rainforest required for the biotic pump cooling of a year's petroleum oil use amounts to some 55,000 square kilometres, equivalent approximately to one percent of the remaining forest in the Amazon Basin. Meanwhile, the carbon uptake of that area of regenerating forest at a rate of 0.41 kg of carbon-uptake per square metre per year, amounts to $2.25 \text{ x}10^{10}$ kilograms of carbon. That quantity needs to be compared to the carbon released in burning 100 million barrels of oil each day for a year, namely $4.2 \text{ x } 10^{12}$ kilograms. The forest carbon uptake is just 0.5 per cent of the carbon emissions from burning 100 million barrels of oil each day, all of which emphasises the role of the latent heat export of energy out to Space.

Action

Where would we put one more Amazon? We could begin by restoring the Amazon forests that were deforested in the past 200 years. That area is approximately 50 per cent of the land we need. The remaining half-Amazon could easily be restored by revegetating other parts of the world, such as Northern Africa or the North American Southwest. Methodologies of accelerated ecosystem restoration are now readily available. We believe that these methodologies could reverse global warming in a matter of decades. For sure, it will take more than a few decades for these methodologies to bring greenhouse gases back to pre-industrial level, but, once we start revegetating the planet, we will have initiated the process of cooling the planet, earning us time to reduce fossil fuel emissions of greenhouse gases before we reach the 1.5ºC threshold. In that respect, we need to make it clear that efforts and the commitment to reduce fossil fuel emissions of CO_2 to net zero must be adhered to. However, the planned reduction in greenhouse gas emissions will not be enough on its own. We urgently need to restore ecosystems and especially those which contribute to the re-establishment of plant-generated hydrological cycles. Ecological restoration is key both to carbon uptake and to latent heat cooling. Without such restoration, we will likely fail to cool the planet at the rate required. Ecological restoration is a win-win situation, first by contributing to a cooling of the planet and second by providing a sustainable means of living for those millions of people involved in such restoration.[25–27]

Solar energy and rainforest cooling plus clouds and winds

ET average 1.37m/yr across Amazon Basin

Rainfall 2.25 m/yr across Amazon Basin

Solar at Earth's surface is $3.85x10^{24}$ joules

Earth surface square metres = $5.1x10^{14}$

NASA overheating (radiation imbalance/sq m = 1.81 W/m^2

NASA overheating per Earth's surface/yr = $2.91109x10^{22}$ watts

5.2 million square kilometres Brazil Amazon

1 cm^3 (cc) = 1 gram water

Latent heat = 540 calories/g water = 2,257.2 joules

Implosion condensation energy per gram water = 153.5 joules

Sunlight received per sec per sq m over Amazon = 239 watts

ET @1.37 m/yr per sec per sq m over Amazon = 98 watts = 41% sunlight

Adding on 0.88 m/yr imported humidity (2.25-1.37), total latent heat/sec/sq m = 161 watts

Total latent heat of 2.25m/yr in proportion to solar = 67% sunlight

If all latent heat over legal Amazon irradiated to space the cooling effect = $2.6409x10^{22}$ i.e. The total overheating is practically equal to the cooling effect of 5.5 million square km of tropical closed canopy rainforest.

To reduce the overwarming by half or 0.9ºC would require the latent heat transport to Space of 2.25 million square km of tropical closed canopy rainforest.

Implosion energy per sq m (Amazon Basin) if delivered over 4 hours = 66 watts

Airflow resulting from the implosion energy (W = 0.5 airmass*v^2) = 10.5 m/s

Airflow = Trade Winds flow = Biotic Pump surface airmass ocean-to-continent.

Cloud cooling over Amazon per square metre average = 30 watts per square metre

Percentage cloud cooling if 75% cooling over 4 hours each day = 12.5%

Latent heat cooling @160 watts per square metre percentage = 67%

Total cooling on average = 80% or equivalent to 190 watts per square metre.

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None.

Conflicts of interest

The authors declare there is no conflict of interest.

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