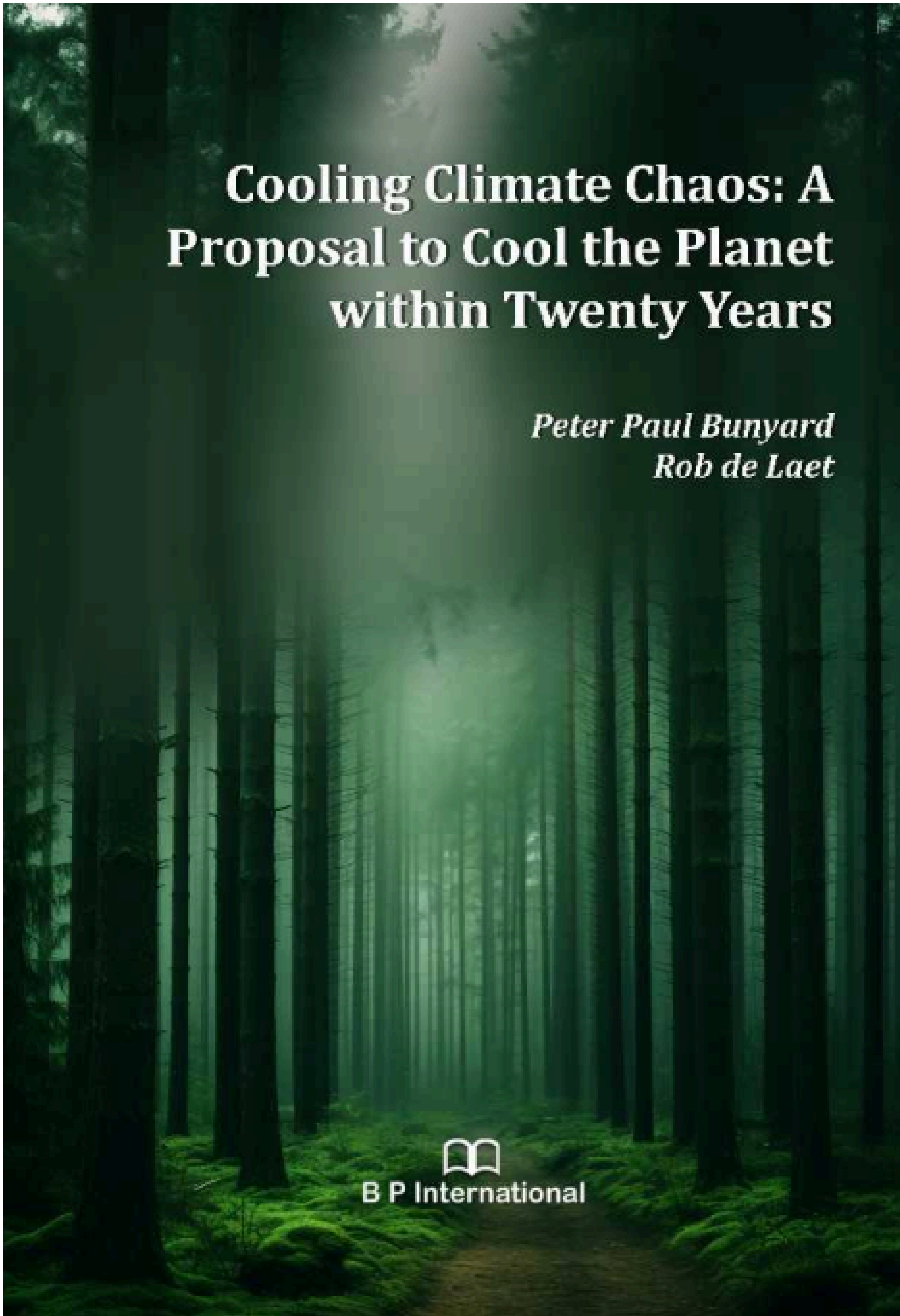

Cooling Climate Chaos: A Proposal to Cool the Planet within Twenty Years

Peter Paul Bunyard
Rob de Laet

B P International

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India ▪ United Kingdom

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FIRST EDITION 2024

ISBN 978-81-976932-2-9 (Print)
ISBN 978-81-976932-0-5 (eBook)
DOI: https://doi.org/10.9734/bpi/mono/978-81-976932-2-9

Peer-Review Policy: Advanced Open Peer Review policy has been followed for review. This book was thoroughly checked to prevent plagiarism. As per editorial policy, a minimum of two peer-reviewers reviewed the manuscript. After review and revision of the manuscript, the Book Editor approved the manuscript for final publication.

Approved by

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PREFACE

To address the climate crisis, now demonstrably causing havoc with life-killing extreme events, we must not only transform our economic and societal models towards sustainability and resilience, we must have a more holistic understanding on what climate really is.

Based on James Lovelock's Gaia Theory, a world view also prevalent in many Indigenous cosmologies, we operate from the hypothesis that the Earth functions as a living organism, with ecosystems maintaining conditions for life to thrive. This book presents an in-depth look at the workings of the atmosphere in the context of a living planet and particularly the role of water, based on an earlier book written by Peter Bunyard, called Climate Chaos, published in Spanish in 2010.

The biosphere interacts with soils, water and the atmosphere to stabilize weather and cool the planet. The destruction of ecosystems disrupts these metabolisms and cycles, significantly contributing to global warming. Restoring the damaged biosphere and transitioning to sustainable food production and land use can stabilize weather and cool the planet remarkably quickly. The approach in *Cooling Climate Chaos* offers effective climate solutions. We have seen climate restoration in smaller areas. If implemented wholesale by people everywhere based on local context, it will resolve most of the climate crises worst effects within decades, while benefitting society in many ways, including the protection of biodiversity, and correcting the gross inequity of our times. It may even open the possibility of slowing down partly inevitable sea-level rise.

While reducing emissions is crucial, repairing nature and water cycles is every bit as important. Regenerative agriculture, agroforestry, and ecosystem restoration can help achieve a balanced climate, mitigate extreme weather, and sequester CO_2. By leveraging these strategies, we can restore the planet's natural balance, creating a sustainable and abundant future.

Onward to a livable planet!

> "Look closely at nature. Every species is a masterpiece, exquisitely adapted to the particular environment in which it has survived."
>
> — Edward O. Wilson

ACKNOWLEDGEMENTS

This book is the culmination of years of research, and countless conversations about the most pressing challenge of our time, namely the existential crisis now facing humanity because of climate change. The concern for humanity's destructive impact on the natural world began in the 1960's for Peter and for Rob in the 1970's. This book was written by Peter Bunyard and Rob de Laet based on a publication that Peter wrote in 2010, while he was in Colombia, called *Climate Chaos*.

We are standing on the shoulders of many brilliant and passionate people, some of whom hover over this book in spirit, such as the great scientist James Lovelock, who still has to be acknowledged as one of the greatest of all times and the Aborigine leader Guboo Ted Thomas, a crucial mentor for Rob.

A special thank you goes to the founders of *Climate Change and Consciousness*, Stephanie Mines, the chairperson of *Biology for a Livable Climate*, Philip Bogdonoff and the co-founder of *EcoRestoration Alliance*, Jon Schull and finally, Eliza Collin, who helped with research for this book, with editing and getting it published. The second part of this book emerged from a writing group within the *EcoRestoration Alliance*, a global network of scientists, earth stewards, storytellers and grassroots leaders dedicated to restoring degraded lands and waters, to promoting biodiversity, and to cooling the planet. Contributing authors have been mentioned where applicable.

Many thanks to the following people who have added their knowledge and wisdom to the emergence of this book in conversations, publications and in some cases as co-authors of some of the chapters.

In no particular order, many thanks to: Ed Huling, Jim Laurie, Walter Jehne, Michael Pilarski, Russ Speer, Stephanie Mines, Charles Eisenstein, Daniel Pinchbeck, Ousmane Pame, Rodger Savory, Antonio Nobre, Carlos Nobre, Germán Poveda, Anastassia Makarieva, Douglas Sheil, Jim Laurie, Alan Savory, David Ellison, Douglas Sheil, Zuzka Mulkerin, Michal Kravčík, Jan Pokorny, Judy Schwartz, Alpha Lo, Erica Geis, Duane Norris, Sue Butler, Ananda Fitzsimmons, Elizabeth Herald, Howard Dryden, Colin Grant, Bru Pearce, Brian von Herzen, Anamaria Frankic, Tom Goreau, Stefan Schwarzer, Christopher Haines, Richard Betts, Zac Goldsmith, Ben Goldsmith, Alexander Goldsmith, Martin Hodnett, Rafael Mantilla, Martin von Hildebrand, Phoebe Barnard and Atossa Soltani.

We thank you, the reader, for your interest and willingness to engage with this critical topic, we need all of you to step into leadership and lead the way to a sustainable future on this amazing planet.

Last and not least, we want to express deep gratitude to Nature and Mother Earth, for giving us the greatest gift of all, Life. What a Wonderful Journey it is! ‘’You may say I'm a dreamer, But I'm not the only one. I hope someday you'll join us, And the world will live as one’’ John Lennon, Imagine.

Together, we can make a difference and we must, because we are running out of time.

Print ISBN: 978-81-976932-2-9, eBook ISBN: 978-81-976932-0-5

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Peer-Review History:
This book was reviewed by following the Advanced Open Peer Review policy. This book was thoroughly checked to prevent plagiarism. As per editorial policy, a minimum of two peer-reviewers reviewed the manuscript. After review and revision of the manuscript, the Book Editor approved the manuscript for final publication. Peer review comments, comments of the editor(s), etc. are available here: https://peerreviewarchive.com/review-history/7727C

INTRODUCTION

Greenhouse gases heat up the planet, but they are not the major driver of climate change. While carbon gets all the attention, there is another huge factor which 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 confront the climate crisis with a whole new set of powerful, additional measures. Plants, healthy soils, and healthy ecosystems stabilize weather, and the climate and bring about cooling.

Life, through its co-evolution with the surface of the planet, has evolved strategies over the course of 3.8 billion years to create the conditions for life to thrive, even though that has meant overcoming five great mass extinctions. Life has altered the composition of the atmosphere, constantly producing the oxygen we breathe and recycling carbon into the ground. The shells of microscopic skeletons of plankton have even formed whole landscapes! Life, with all its different ecosystems, has been balancing the climate for aeons and now, given all the destruction we humans have wreaked, we must help it to do so again. In fact, the whole planetary climate regulation has all the hallmarks of a self-regulating supra-being which, in a nutshell, is what James Lovelock called the Gaia Theory. Frontloading vigorous protection and regeneration of nature around the world, together with massive increases in regenerative agricultural practices and agroforestry, will restore a balanced climate, calm the weather and cool the planet!

We can leverage these qualities to fight the climate crisis.

The book will show how we can stabilize the climate and even get on a trajectory of cooling. It shows that if we intervene with Nature's intelligent methods, we may avoid average global temperatures exceeding the 1.5 degrees C limit of rising

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temperatures, set by the IPCC as the point beyond which climate change and the extremes will become unmanageable.

Regeneration of essential ecosystems, and in particular forests, will have enormous beneficial impacts, including fundamental changes to the flows of energy implicit in the restoration of nature, such that the beneficial changes will result in the Earth cooling, while simultaneously countering a great extent the global warming caused by anthropocentric emissions of greenhouse gases. The shortest way to describe what we need to do is to stimulate the increase of biomass in the coming two decades in a strategic way to stabilize the climate. The book will also touch on the strategies that are meant for humanity to undertake this largest endeavour in history at the speed and scale needed for it to be successful.

There will be in-depth chapters based on Peter Bunyard's amazing 2010 book *Climate Chaos: Threat to Life on Earth*, to explain the scientific underpinning of the solutions the book wants to offer. (*Caos Climático: Calentamiento global, efecto invernadero y otros factores que amenazan la vida*. Grupo Editorial Educar, 2nd edition 2011. ISBN: 978-958-05-1306-3).

The second part of the book came out of a six-month writing group of the *EcoRestoration Alliance*. The group came together to write a blueprint for a complete regeneration of the Earth's biology to restore its metabolisms, and temperature regulation. All biomes can be restored fast. Collectively we have the knowledge. Part II is a summary of that blueprint. You will find the contributing authors at the top of every chapter where applicable. Many of them are renowned authors, scientists and practitioners in their own right.

But we are running out of time. When fluctuations become too extreme, they break through the barriers of balancing that are key to the survival of all life. The authors are all too conscious that we are already at the tipping point of the cascading collapse of the life systems upon which humanity is completely dependent. At the same time, we share the hope that nature is incredibly resilient and can bounce back from destruction in remarkably vigorous ways when given a chance and strategic support.

We start with an opening poem, sung by a chorus of children in the Mezquita of Córdoba during a live performance of Paco Peña's *Requiem for the Earth*, which expresses the heartfelt pain and anguish of the young upcoming generation, who unwittingly have inherited a terribly damaged Earth. So, do listen! We hope that the knowledge in this book will contribute to reversing the existential threat now facing all mankind.

Requiem for the Earth, the Children's Song, *Paco Peña and Peter Bunyard*

https://youtu.be/boUu4pPfR6w

ALABANZA: RÉQUIEM POR LA TIERRA

Ay! de tí, hombre villano, *What of you, uncaring Man* ¿Qué has hecho con la tierra? *What have you done with the Earth?* ¿Dónde están las florestas, *Where are the forests,* Los límpidos arroyos, *The limpid streams,* el transparente mar? *The transparent sea?* Has truncado la vida *You have truncated the life* al árbol que, *of the tree which,* orgulloso, *With pride, rose up* de la tierra salía. *from the Earth*.

Has pelado montañas; *You have laid bare mountains,* y los ríos majestuosos *And the majestic rivers* hoy ciénagas serán. Today become *unpalatable swamps.* Ahora llegan torrentes *Now, we bear the brunt of torrents* que desbordan el río *Which burst the banks of rivers* y arrasan la ciudad. *And wipe out the city,* Las casas, *Houses, cattle, men, women,* el ganado, *children.* hombres, mujeres, niños *If we don't take care of our* todo perecerá.
Sacred Mother, all will perish.

Chapter 1

How to Uncook Our Planet!

"If you want to make major changes, you have to change the way you SEE things."

"I speak as a planetary physician whose patient, the living Earth, complains of fever; I see the Earth's declining health as our most important concern, our very lives depending upon a healthy Earth. Our concern for it must come first, because the welfare of the burgeoning mass of humanity demands a healthy planet"

''We live on a live planet that can respond to the changes we make, either by cancelling the changes or by cancelling us."

— James E. Lovelock, *The Revenge of Gaia*

The main message of our book is that we are both much closer to sudden collapse than almost anybody thinks because of planetary organ failure, and with that the wholesale collapse of human societies. The good news is that nature is incredibly resilient and with the right treatment, we might still be able to revive our planet's vitality fast. Our focus is entirely on nurturing the living planet back to health and saving our societies in the process. If the damage to the biosphere is reversed, the planet will regain its capacity to regulate its own temperature. Ecological restoration can and must be done by everyone everywhere.

Fig. 1. Rob de Laet & Dall-E

1.1 YOU AND I ARE PART OF A LIVING PLANET

We actually have an even more important message and that is that we operate from the knowledge that our planet is alive. Indigenous cultures across the globe, including Native Americans, Aboriginal Australians, Andean and Amazonian peoples, as well as the Māori of New Zealand, share a profound belief in the Earth
as a living, sacred entity. From the Native American concept of "Mother Earth" to the Andean "Pachamama" and the Aboriginal "Dreamtime," these cultures view the planet as a nurturing, spiritual mother figure deeply interconnected with all forms of life. This perspective fosters a strong sense of respect and stewardship for the environment, emphasising harmony and balance with the natural world. These beliefs are central to their cultural identity, spirituality, and environmental practices, underscoring a deep-rooted kinship with the Earth.

The authors have embraced James Lovelock's Gaia Theory, which revolutionises our perception of Earth within the Western body of science. We see the planet as a living, self- regulating entity. This ground breaking concept suggests that our planet functions like a single supra-organism, with its diverse biological processes intricately interconnected and working in unison to maintain and sustain life. Through this lens, Earth's atmosphere, biosphere, oceans, and soil are not just separate entities but components of a larger, living system.

Lovelock shows that the planet has vitality through the interdependence of all species and biomes in the biosphere, highlighting the delicate balance required to sustain life. Like the Indigenous people and the authors of this book, we acknowledge that we are part of a living being that needs care and respect. This makes us both offspring and stewards of our planet as we have a clear role to play in preserving this wonderful, living organism and the future generation of humans and other species, with which we have the honour to share this miraculous place in the universe. But, back to the reality of where we are today, because we are running out of time and much work has to be done fast to avert the worst- case scenarios of a dark future to where are now heading.

1.2 HOW MUCH DO WE HAVE TO DO TO REVERSE CLIMATE CHAOS?

Through a strategic plan, involving large parts of the global population to act locally with place-based solutions, we may still be able to reverse most damage fast. We call on people to organise themselves to restore their areas focusing on natural boundaries: bioregions and watersheds and cooperate with communities in those areas to improve the situation quickly, involving as many people in the region as possible.

1.3 RESTORATION ALONG BIOREGIONS

''If nature were to draw a map of the world, what would it look like? We've grown accustomed to seeing the world divided into countries but there is another way to see, and better understand, the planet we call home. One Earth presents a novel

biogeographical framework defined by 185 unique bioregions, which helps reveal the underlying ecological fabric of life that surrounds us.''

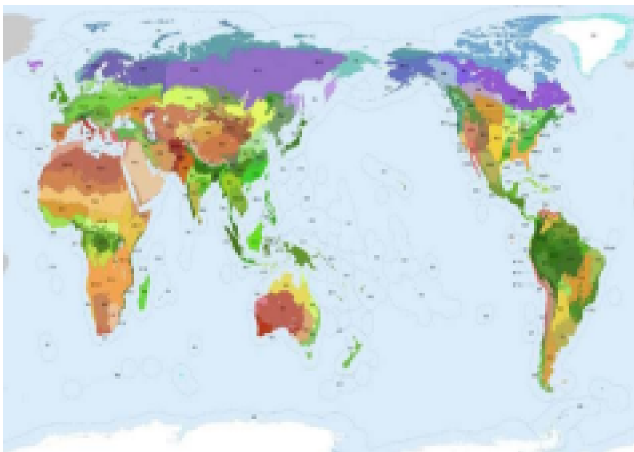

Fig. 2. Bioregion map of the World Courtesy One Earth
https://www.oneearth.org/bioregion

1.4 ECOLOGICAL RESTORATION BASED ON WATERSHEDS

Ecological restoration founded on the concept of watersheds represents a holistic approach to environmental conservation and ecosystem rehabilitation. It revolves around the idea that ecosystems within a given watershed are intricately interconnected, emphasising the need to consider the entire system as opposed to isolated components. Restoration will then contribute simultaneously to the well being of both the environment and the community.

Fig. 3. Water – Photo of Trutta/Shutterstock

One of the primary advantages of watershed-based restoration efforts is the significant improvement in water quality. By addressing the sources of pollution and runoff within a watershed, restoration projects lead to cleaner and healthier water bodies. This, in turn, has a positive impact on aquatic life and the communities that rely on these water resources for drinking water, recreation, and economic activities. All the diverse ecosystems within the watershed boundaries profit from this improvement, which can start at the level of alpine pastures and may include wetlands, forests, streams, rivers, deltas, coastal lagoons and marine ecosystems.

Watershed restoration projects include plans for biodiversity protection and regeneration, flood control, common water use and common infrastructure. Healthy watersheds are better equipped to face droughts for instance.

Community engagement is a fundamental aspect of watershed-based restoration. A great example is the Subak system in Bali, Indonesia, where Watership councils have formed communities to protect sources, forests, biodiversity, and water management together based on a cooperative organisation structure, involving everyone in a sense of ownership and stewardship. This engagement not only empowers communities but also builds a long-term commitment to the sustainable conservation of the watershed. Well-managed watersheds improve agricultural and fish production. They also build community cohesion and resilience.

While all people everywhere can become part of a regenerative movement, the damage is too large to leave it just to local forms of citizen action. For global needed actions, we need global organisations and finance.

1.5 THE LARGE EMERGENCY PRIORITIES TO REVERSE CLIMATE CHAOS FAST

This is the list of points we think need to be addressed immediately and at the size that fits the challenges:

- Avert the **tipping point of die-back of the Amazon rainforest** and strategically reforest the biome to restore the full vigour of the biotic pump function over the area, leading to fast regrowth of vast forest areas in the Americas. This rescue project must include probably more than a million workers getting paid to do the restoration and the finance must come from the whole world as the whole world will be affected if this cooling organ of the planet dies back.
- Plan for the **fast revival of ocean biology** including the fertilisation of ocean deserts to sequester carbon, restore the ocean food chain, increase vertical mixing of the water column, and increase planetary albedo through increased cloud formation. As this has to happen simultaneously in hundreds of places in the world's coastal marine ecosystems and deep oceans, this must be an internationally coordinated and financed effort.

Fig. 4. Healthy Amazon Rainforest – Photo of Theo Tarras/Shutterstock

- Plan to **green the desert areas** from the Thar desert to the Sahara and the fast drying out of the Mediterranean through strategic ecosystem regeneration, with the aim of drawing the Indian monsoon moisture streams all the way to the Mediterranean while simultaneously connecting them with the West-African monsoon. This will also increase precipitation on the Third Pole as the Himalayas and nearby mountain ranges are called because of the thousands of glaciers and snow-clad mountains they hold. Countries from India all the way to Senegal and around the Mediterranean must have a coordinated plan to bring back the atmospheric moisture streams over the areas, rehydrating the lands, regenerating soils and vegetation and cleaning up degraded coastal systems both above and below the water line.

Fig. 5. Permaculture food production in India – Photo of Dr. Chandrashekar Biradar

- Organise the best minds around the world to **reverse polar amplification** by reversing the melt of polar sea ice on both sides of the planet. We do not know how best to do that but the idea is to use *nature-based-solutions* combined with technical interventions.

Fig. 6. Sea Ice in the Weddell Sea – Photo of Steve Allen/Shutterstock

1.6 GLOBAL ACTION

While restoration can and must be done everywhere by everyone, these large projects we described above need support from powerful organisations like states, armies and large companies. By such means, we can stop the Earth from warming up within decades. Furthermore, such restoration actions will swiftly bring the number of weather extremes to drop significantly.

Here are the global priorities that cannot be done without international cooperation:

1. To bring finance, information, organisation and tools to the 500 million smallholder families around the world to restore their lands and transition to regenerative agroforestry food production. This will restore the small water cycles, regenerate degraded soils and substantially increase living biomass. A plan for this has been written. Estimate cost 0.3-0.5% of Global GDP per year for a period of twenty years.
2. As such, we invite large networks of organisations such as the Rotaries, WVF (World Veterans Federation), Red Cross, CARE, The Nature Conservancy, Oxfam, WWF, Peace Corps, climate action groups and so on to support communities everywhere to regenerate the ecosystems in their area and improve their own economy and well- being.
3. To bring about a programme of ocean and coastal marine ecosystem restoration. The cost of the total programme is in the tens of billions of dollars with almost immediate results.
4. We call for support to assemble in a very short time a Digital Gaia to support all these restoration processes. An outline has been written, and almost all

parts already exist. The cost to launch the first viable product is 5 million USD. Let's build this fast!
5. The planetary restoration project will be financed through several revenue streams from governments, philanthropy, investment programmes, green bonds and carbon credit finance.

Reducing emissions must continue but the main focus needs to shift to the repair of nature and water cycles around the world together with massive increases in regenerative agricultural practices and agroforestry to make landscapes climate resilient. Combined with reviving ocean biology, such efforts will restore a balanced climate, calm the weather and cool the planet! Tens of gigatons of CO_2 per year will be sequestered in the fast-increasing living biomass around the world. As we describe in a later chapter, the transition of an area of 2.5 million square kilometres in the tropical belt from what was once a closed-canopy forest back to forest, combined with strategically-sited agroforestry, will increase the cooling capacity through the atmospheric water cycle sufficient to stop the planet from heating up further.

Frontloading vigorous protection and repair of nature around the world together with massive increases in regenerative agricultural practices and agroforestry will make landscapes climate resilient. Combined with reviving ocean biology, land based initiatives will restore a balanced climate, calm the weather and cool the planet! This action, involving large parts of the global population in all kinds of different roles, is the only possible way out of the clear path leading to the collapse we are on now. If you resonate with these words, step into leadership and find your role in the greatest endeavour ever undertaken by humanity.

This book, *Cooling Climate Chaos*, is a proposal to restore the health of our planet fast and with that restore the future of the generations that want to live a happy life on a benign planet that provides enough for everybody's needs (but not everybody's greed!). But first, we start with a comprehensive overview of Earth's intricate living systems. The following chapters delve into the science of our living planet, atmosphere, biosphere, climate, and weather, laying a solid foundation for understanding how we can get ourselves out of the climate mess fast.

The initial chapters are dedicated to taking a look at 3.8 billion years of evolving life and unravelling the interconnections between these systems and how human activities have disrupted the natural balance. As the book progresses, it shifts focus to practical solutions, presenting practical strategies, from local actions to large-scale initiatives, to reverse the damage caused by our destructive economies. Packed with actionable tips, innovative ideas, and inspiring case studies, this guide empowers readers to become active participants in restoring Earth's climate. Whether you're a student, a policy maker, a company CEO or a concerned citizen, "*Cooling Climate Chaos*" offers a full proposal to restore the future. So, let's first dive into the science of the living planet to understand the roots of our proposals.

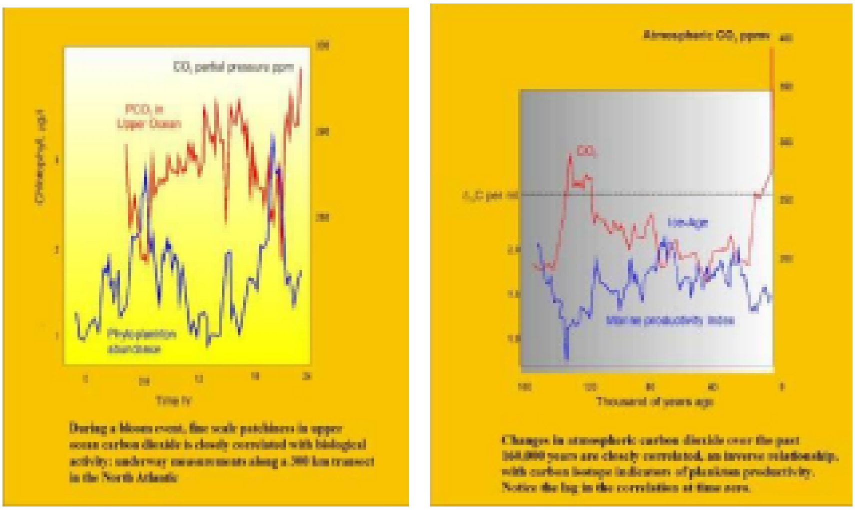

Fig. 7. Atmospheric and Ocean CO_2 values over time, indicate inverse correlations between phytoplankton and CO_2 – Graphs by Peter Bunyard from the Plymouth Marine Biological Laboratory.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Part I: The Science

Chapter 2

Honouring the Earth's Protective Shield

> *"We have a choice. Collective action or collective suicide. It is in our hands."*

Quote from the Secretary General of the UN Antonio Guterres, talking to a group of ministers from 40 countries on 18 July 2022.

Fig. 8. Sunrise over the planet showing how thin is our protective atmosphere. Courtesy: NASA

The Earth is the only place we know where life thrives in the cosmos. The incredibly beautiful biosphere has been responsible for creating the atmosphere as it currently is, with its composite of nitrogen, oxygen, water vapour and greenhouse gases. If life had never been and had not transformed the atmosphere into what it is today, living forms such as ourselves could never have evolved and survived. Without question, we humans inherited the best of all possible worlds, because life, prior to our hominid evolution, had made it so. The layer of atmospheric gases, carefully managed by Nature and which we inherited, plays a critical role in safeguarding the planet and its multifarious inhabitants, day and night.

2.1 A Bit of Astrophysics and Planetary Science

The atmosphere regulates the energy that comes in from our Sun, that immensely powerful star which, by transforming hydrogen into helium, gives us the fusion radiation energy that fuels life processes on Earth. Much of that radiation is lethal to life and we have to thank the stratosphere for giving us a protective layer against the Sun's detrimental ultraviolet radiation. The oxygen, provided by life through photosynthesis, percolates into the stratosphere and interacts with ultraviolet-C,

the most powerful in the spectrum of UVs, thereby preventing the UV-C from radiating down to the surface, where it would make it extremely uncomfortable for life such as ourselves. Meanwhile, ozone, resulting from the interaction of UV-C with oxygen, does its bit of interacting with UV-B, thereby lessening the amount of such radiation that can penetrate to the surface. Hence our concern about the 'ozone hole'.

In addition, the ionosphere, a layer of the atmosphere populated with charged particles, interacts with the magnetic field and solar wind and aids in the deflection of these potentially harmful particles. Without such mechanisms in place, and the protective effects of the Earth's magnetic field, these harmful rays could dramatically affect living organisms and certainly would not allow for such abundance of life including ourselves. The Auroras, whether in the high latitudes of both hemispheres, give us a spectacular view of the interaction of solar and cosmic radiation with our protective atmosphere. Apart from all this, the atmosphere forms an effective barrier against incoming space debris, such as small meteors, which, upon entry into the Earth's atmosphere, burn up because of their high velocities and the friction generated as they pass through the air. The outcome of this process, visible as shooting stars, protects the Earth's surface from continuous impact. That said, the atmosphere does not protect against the rare event of being struck by very large meteors. The last mass extinction on Earth was caused by the impact of a large meteor, the size of Mt Everest, which famously led to the extinction of large dinosaurs some 66 million years ago during the Cretaceous period. The event happened near the current town of Chicxulub in the Yucatan Peninsula, Mexico. It had a devastating impact the world over. The Moon, too, is the result of a planetary collision, more than 4,000 million years ago, which caused the fledging Earth to spew it out. We are indeed fortunate to have the Moon, for the very reason that it acts like a gyroscope, keeping the Earth from tumbling in its orbit around the Sun, which, were it to do so, would result in wholly chaotic seasons and would have prevented the evolution of life as we now know it.

For the most part, the atmosphere is a wonderful blanket of protection that lets through the right amount and right type of energy from the Sun for Life, as we know it, to be sustained. In addition, the atmosphere, with its greenhouse gases and especially water vapour, is a fundamental regulator of temperature on our planet. Water, as vapour, is the most potent of the atmosphere's greenhouse gases yet, when it condenses into dense white clouds, it becomes an agent of cooling by reflecting sunlight back to Space. What is happening to the water-cycle because of deforestation and human-induced environmental transformation is undoubtedly one of the key issues related to what we are experiencing as climate chaos, with horrifying increases in the frequency and intensity of extreme weather events.

Meanwhile, we must be grateful that life, by means of its metabolism, has put into the atmosphere just the right concentrations of greenhouse gases for capturing and retaining an appropriate amount of the Sun's heat to maintain a stable and liveable climate on Earth.

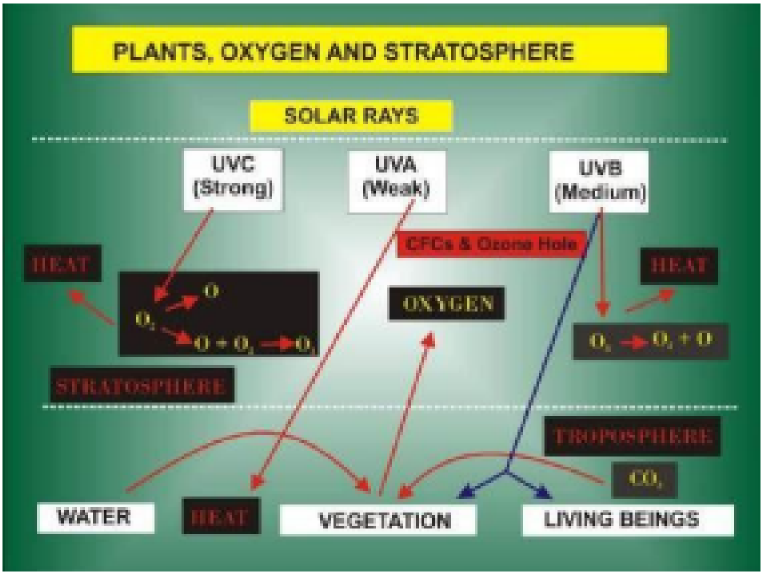

Fig. 9. Schematic overview of the interaction between sunlight, the atmosphere and the biosphere. Oxygen generated by plants protects life on the surface from harmful ultraviolet Sun rays – Peter Bunyard.

Without the atmosphere and its greenhouse gases, temperatures would swing from being excessively hot to excessively cold. Quite aside from there being no air to breathe, the planet would hardly be habitable. On the Moon, the temperatures on the side facing the Sun can peak at approximately 127 degrees Celsius (260 degrees Fahrenheit), while on the lunar night-side temperatures as low as minus 173 degrees Celsius (minus 279 degrees Fahrenheit) have been observed. As we saw earlier, if life did not keep the current mix of gases more or less constant, temperatures on Earth would either become lethally high, as on Venus or lethally low as on Mars. We can see how much the atmosphere regulates the Earth's
temperature from the following graph. Imagine the Earth without an atmosphere, like what scientists call a 'black body' and imagine that it is January when Antarctica is having its summer and the North Pole its winter. The temperature at the North Poles would be -140℃ and in Antarctica +40℃. With the atmosphere, that sharp contrast between the two Poles is smoothed out and the temperature is not so different from one to the other, despite the seasonal shifts in exposure to the Sun.

In essence, the Earth's atmosphere, through all these functions, works continuously to protect the planet and its abundance of life from external threats and to maintain conditions suitable for life. Many of these functions have been developed by life during the billions of years of evolution and it is life itself that carefully calibrates the temperature through the power of photosynthesis, evapotranspiration, cloud, rain and wind production with clear differences

depending on how much solar energy reaches the surface. Much more energy, approximately double, is received at the equator during the course of a year, than at the poles.

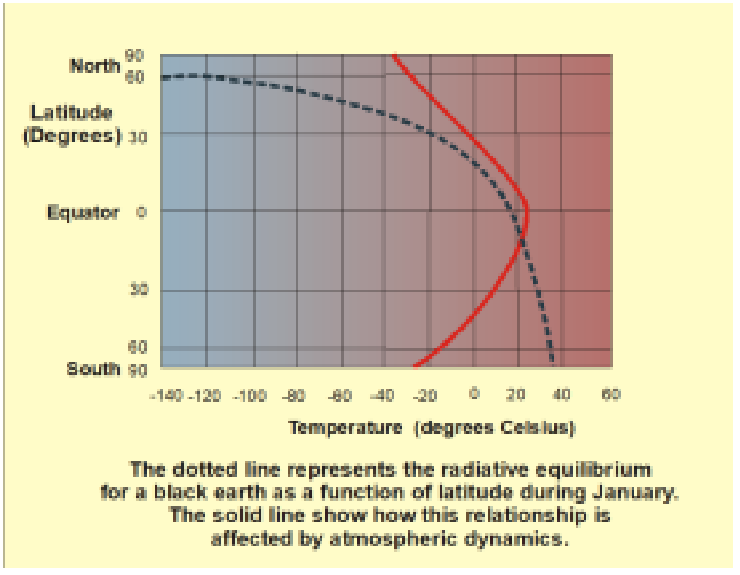

Fig. 10. Actual and calculated temperature if there was no atmosphere – Graph Peter Bunyard

2.2 HOW HUMANS CHANGED THE ATMOSPHERE

Human civilizations have developed in the last ten thousand years or so during a period of very stable climate just after the Last Ice Age. It is known as the Holocene epoch. During this time, favourable conditions allowed for agriculture, settlement, the rise of complex societies with surplus food production, and the increasing division of labour. One result was the creation of more and more specialised forms of expertise and with that the wonders of technology which we experience daily throughout the world.

However, our use of natural resources, as if nature was expendable and exploitable, has had severe consequences which we are now beginning to experience with a vengeance and which have come under the seemingly benign guise of 'climate change'. Climate change now poses significant threats to various aspects of human life. They include risks to food security, water resources, all ecosystems, human health, and the economy. In essence, changes in temperature, precipitation patterns, and extreme weather events disrupt agriculture, lead to water scarcity, intensify natural disasters, disrupt ecosystems and biodiversity, contribute to the spread of diseases, and have economic implications.

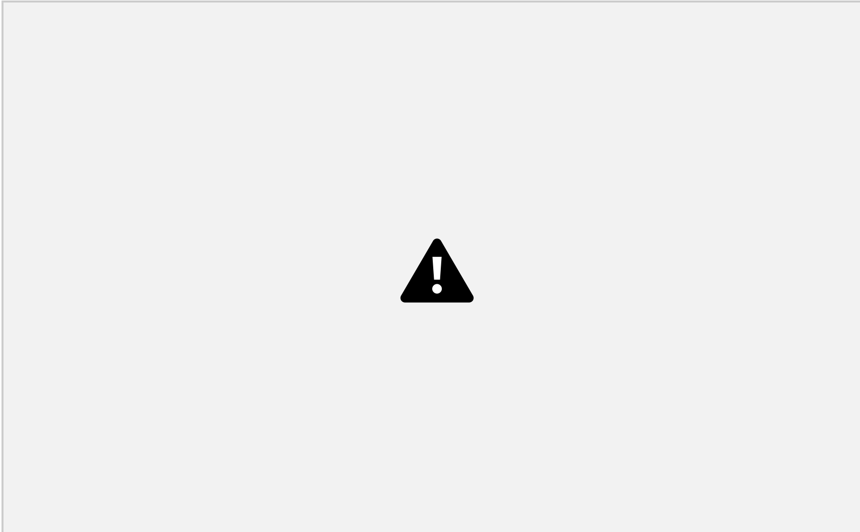

Fig. 11. Overview of interacting factors that increasingly triggered the climate chaos, we experience today – Graph Peter Bunyard.

But while humans and many species with which we are familiar, like the big mammals, may not be able to adapt to the changes on the planet, if given time, meaning thousands of years, and left to its own evolutionary devices, Nature as a whole will recover and grow anew. Only a hundred million years ago, the temperature on Earth was 7℃ higher on average than now. Moreover, the planet had no ice caps, sea levels were 70 metres higher and life, thank you, was doing pretty well. So, let us be clear, human-induced climate change does not pose a significant threat to life as a whole, in fact the authors of this book believe that Nature will probably bounce back within a matter of decades should global human societies collapse under the global deterioration of life-conditions on Earth. Indeed, we have some circumstantial evidence that points in that direction: the short cold period in the 16th and early 17th century in Europe, also known as the Little Ice Age, was in all likelihood in part triggered by events on the other side of the planet, in the so-called New World. As we all know, the population of North America collapsed because of the bacteria and viruses which the early European colonists
brought to the continent. This collapse caused the death of 90 percent of the indigenous population of some 50 to 60 million people, who largely depended on agriculture. With a much reduced and sick population, agriculture was largely abandoned and the forests grew back, triggering a cooling of the climate. (Koch, Alexander., Brierly, Chris., Maslin, Mark M., Lewis, Simon. L. *Earth system impacts of the European arrival and Great Dying in the Americas after 1492***.** Quaternary Science Reviews Volume 207, 1 March 2019, Pages 13-36.)

The same negative ‘cooling’ feedback will kick in should our numbers drop dramatically as a result of the collapse of our societies because of climate change

wiping out the means to grow sufficient food, whether from excess heat, lack of water, loss of fertile soils and a COVID-like disease for which we fail to find the cure.

So, while humans may be able to adapt to some extent to different climatic conditions it is especially our globally interconnected complex and highly technological societies that are at risk. To protect both our highly technologically complex human societies and the environment, it is crucial to mitigate climate change and adapt to its impacts. This is necessary to ensure a sustainable and resilient future. We hope to make the case that the move to a sustainable future may well be possible and achievable within a relatively fast timeline if we wake up to how the climate works and act accordingly.

While the world is currently obsessed with the increasing amounts of carbon dioxide in the atmosphere, our activities have impacted the atmosphere in many ways, including greenhouse gas emissions other than carbon dioxide, aerosol pollution from industry, agriculture and our transport systems, ozone depletion because of emissions of the CFCs, air pollution from changes to land-use creating more dust and diminishing humidity. All these diverse activities, taken together, are affecting the health of ecosystems, animals and humans alike.

With our concern about the rising levels of greenhouse gases in the atmosphere, we must be aware that we need sufficient greenhouse gases to make our planet comfortable for the plethora of species which make up the biota. The warming of the atmosphere, because of the greenhouse gases, including the important greenhouse characteristics of water vapour, has taken the planet's average surface temperature from minus 18℃ to plus 15℃ (the average of 200 years ago), a warming of 33ºC on average. That is the average surface temperature we inherited at the beginning of the industrial revolution. We have now increased the global temperature by just 1.4℃, which is the combined result of greenhouse gas emissions from fossil fuel burning and from our destruction and degradation of essential ecosystems, especially forests, and just that seemingly small rise in temperature has led to the spate of extreme climate events which we are currently experiencing, including the heat waves and outbreaks of fires that devastated Greece and elsewhere across the Northern Hemisphere during July 2023.

Given from our point of view that our greenhouse gas emissions are warming the planet excessively, we endorse initiatives to phase out the burning of fossil fuels, whether used in electricity generation, in transport or heating houses. However, the notion that we can solve the climate crisis simply by reducing CO_2 emissions while capturing carbon from smoke-stacks is missing the point that natural ecosystems are absolutely critical in giving us a climate which is beneficial to us and life in general. If, in averting climate chaos, we do not widen our minds and actions to the wider story of how climate chaos and the heating up of the planet have come about, we will be responsible for the collapse of our societies simply because our diagnosis was only right to a small extent.

By far the largest impact on climate, for which we are responsible, has resulted from extreme land-use change and the destruction of ecosystems. That worldwide

destruction has altered drastically the flow of water vapour from its evaporation and precipitation, all of which has had a profound effect on atmospheric hydrology and the flow of water locally and globally from ocean to land and back to ocean. The transformation of water through its phases from ice and liquid to vapour and back to liquid is the Earth's major transporter of the Sun's energy from the Earth's surface to outer Space, and we have to thank this fundamental role of water in cooling the planet. And, that cooling has taken place despite the Sun being 30 percent more luminous and energetic than it was 4.5 billion years ago when the Earth first formed. The increased luminosity of the Sun is the result of the retention of solar heat as helium accumulates from the thermonuclear fusion of hydrogen, with helium acting as a greenhouse gas blanket.

Life, during its long history on Earth, evolved photosynthesising-vegetation,

whether trees on land or phytoplankton in the ocean. Cloud-forming over both land and ocean has been significantly enhanced because of transpiration and because of the emission of aerosols, such as dimethyl sulphide and terpenes, all of which
are excellent cloud-condensation nuclei. In effect, the evolution of life on Earth has gone hand-in-hand with the regulation of the Earth's surface temperature, both by regulating the flow of water and by forming biomass from atmospheric CO_2 such that it has never become too hot or too cold, even taking account of cataclysmic events like the Chicxulub meteor strike 66 million years ago.

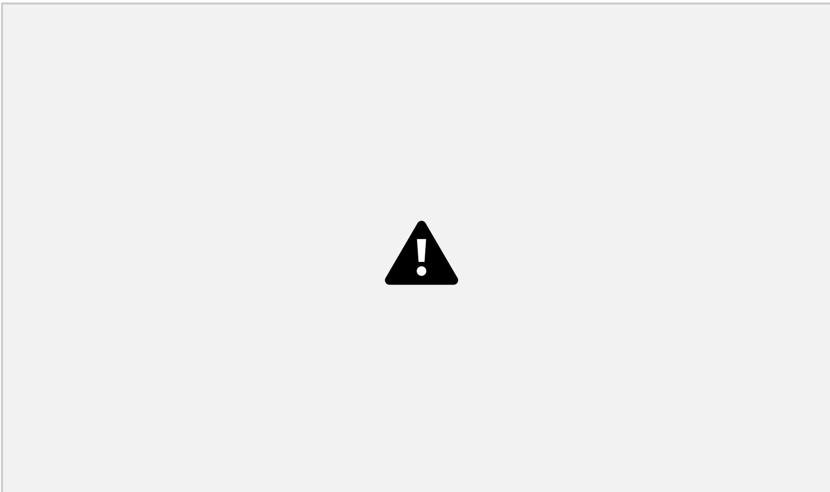

Fig. 12. Without rainforests we cannot cool the Earth. Ricardo Moraes | Credit: REUTERS

We have come to the conclusion that Nature has been the key regulator of the Earth's temperature and climate mainly through the movement of water in its various forms (liquid, solid, and vapour) through the atmosphere. Atmospheric hydrology, therefore, plays a critical role in weather and climate systems. When

we take into account the relationship between water and sunlight energy, we find that as much as 90 percent of the temperature regulation of the atmosphere is done by water, and just 10 percent by CO_2 and other greenhouse gases. In fact, the flow of water vapour in the atmosphere has contrasting effects on surface temperature. Atmospheric warming comes from water vapour in the atmosphere being the most important greenhouse gas; atmospheric cooling from the forming of dense, white clouds which reflect sunlight back to Space and, most importantly, from the release of latent heat energy at cloud-forming altitude, especially from high-altitude, towering cumulo-nimbus clouds, with their anvil-like shape.

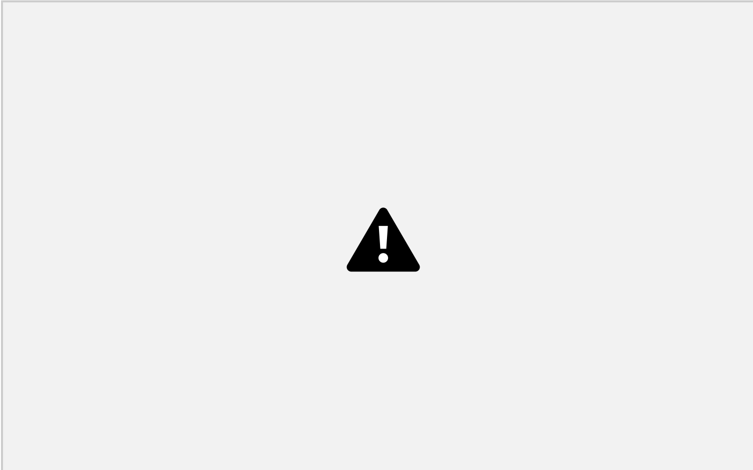

Fig. 13. From McIlveen's book on Climate and Weather. The diagram shows the radiation released from the anvil-shaped, cumulo-nimbus cloud at 15 km altitude over the Tropics. More radiation is released to Space as the jet stream carries the air from the Equator to the higher latitudes. The forests send their transpired vapour upwards to where they form clouds on condensation.

From the time of the neolithic revolution some 12,000 years ago, when we started farming and creating long-term settlements which became ever more grandiose cities, we humans have disturbed the flow of water across the surface. This disruption has happened primarily because of our destruction of natural ecosystems and, in particular, of forests. An early-on consequence of land clearances for agriculture and animal husbandry may well have been the desertification of the grasslands and savannas of places like the Gobi, the Arabian Peninsula and the Sahara. In a feedback loop of diminished forests leading to less evapotranspiration and therefore to less clouds and precipitation, natural vegetation had nowhere to go but to retreat under the increasing heat of the Sun and lack of water.

Agricultural practices also led to changes in the water cycle by redirecting and storing water for irrigation, often leading to soil salinization, and altering

precipitation patterns through the removal of natural vegetation. In urban settings, the removal of vegetation and the replacement of permeable land with impermeable surfaces, prevented natural water infiltration, increased runoff, and aggravated the local risk of floods. Cities also create "heat islands" with higher temperatures, especially when devoid of vegetation and the cooling effect of evapotranspiration.

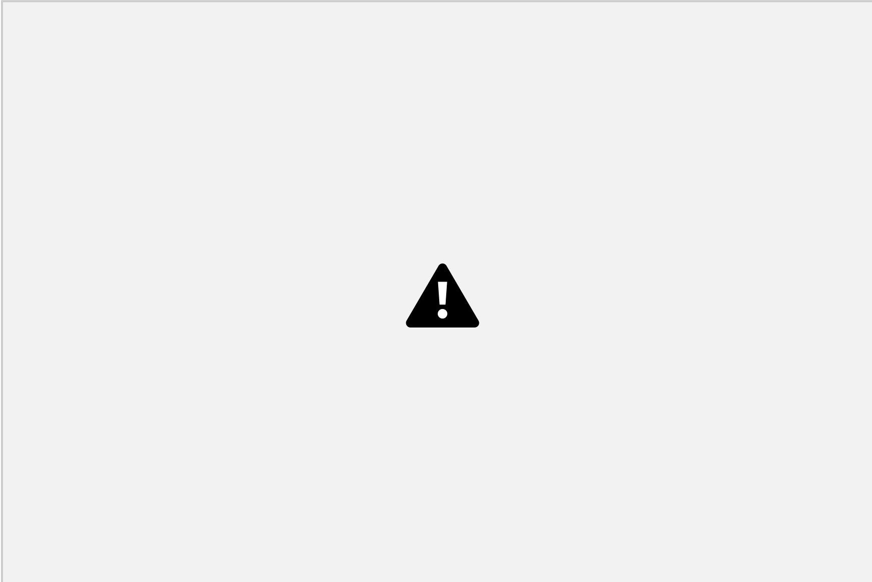

Fig. 14. Sand and Rocks in the Algerian Sahara – what happened to the vegetation? credit: Shutterstock

A reduction in evapotranspiration means a significant reduction in the total amount of sunlight-energy taken up as latent heat in the transformation of liquid water to water vapour. The ratio, the Bowen Ratio, between the amount of solar energy which can directly heat the surface and the amount of solar energy which is carried away in the transpired water vapour increases significantly and results in the heat of the Sun remaining trapped at the surface rather than cooling the surface as water is evaporated. Even when exposed to direct sunlight, we can perceive the temperature difference between a vegetated, transpiring surface and a hard surface free of all vegetation. The temperature difference can be as much as 20℃. Due to the disruption of natural water cycles, land-use change has been the most important factor in causing climate chaos and surface temperatures to rise. Greenhouse gas emissions are also important, but, with deforestation rampant, the warming which accompanies such emissions can go unchecked. A well vegetated surface and a healthy ocean, with its cloud- forming phytoplankton, will act together to temper and moderate the energy flows from the Sun. Under those

circumstances, the intensity and frequency of extreme weather events will be significantly reduced.

2.3 THE BIOTIC PUMP – EARTH'S IRRIGATION MECHANISM

Crucial in this respect is the biotic pump phenomenon, which plays a crucial role in generating atmospheric circulation patterns when the water vapour at saturation point condenses into dense clouds which release their moisture as rain. Over a tropical humid rainforest, the condensation into clouds results in a sharp, instantaneous implosion of air to fill the space left as vapour condenses into liquid water, a volume reduction of more than a thousandfold for each gram molecule of H_2O. That implosive reduction causes the move upwards and that movement, in consequence, draws in the humid surface air from the same latitude ocean. That in essence is the biotic pump and, combined with the recycling of evapotranspired water, the twin processes irrigate the forests deep inland, creating rainfall patterns thousands of kilometres from the oceans. In addition, the flow of air provides an extremely important mechanism for tempering the surface winds which flow from the ocean to land, thereby reducing the power and frequency of tropical storms and even hurricanes. Over an area the size of the Amazon Basin, some 7 million square kilometres, and assuming it is still largely forested, the implosion energy, as water vapour from evapotranspiration condenses into thick clouds, amounts to as much as the equivalent energy of one atomic bomb per second!

Following the industrial revolution of some 250 years ago, the ever-growing world population, now more than 8 billion people, has become increasingly urbanised and materialistically demanding. For the most part, the energy embedded in fossil fuels has enabled industrialisation and materialistic-living to penetrate apace to virtually every corner of the Earth. Concurrent economic activity has become a major and aggressive factor in the exploitation and destruction of natural ecosystems. An area larger than China has since been deforested and even larger areas have been degraded. Fifty-eight percent of habitable land (excluding the ice sheets and deserts) has now been substantially changed.

The consequences of widespread environmental destruction are now beginning to reveal themselves with impacts on food production and water availability in vulnerable parts of the world. Increasing numbers of refugees are fleeing for their lives from conflicts and extreme weather events. Countries like El Salvador, Nicaragua, Venezuela, several Sahelian countries, Somalia, Yemen, Syria, Lebanon and others have suffered difficult-to-reverse collapse of governing structures which were caused by a whole complex of social, economic and political factors but which all had problems with food and water security as one of its main roots. This food and water insecurity was in many cases caused by excessive land use change, with reductions in the biological capacity to grow plants for food. The green revolution, based on crops that required massive application of chemical fertilisers and pesticides, for their added growth, may have temporarily reversed this trend but wholly at the cost of ruining the fertile soils upon which life on land has depended for tens of millions of years. The increasing blows to harvests caused by a combination of weather events like droughts, and the destruction of

ecosystems, has for a large part been caused by modern industrial- type food production, often replacing small-scale, labour-intensive but productive food production based on local resources. Large-scale industrial-type monoculture production of grains, soy beans, sugar cane, and cotton has been at the expense of natural ecosystems, including forests, and without doubt, has led regionally and globally to further climate chaos.

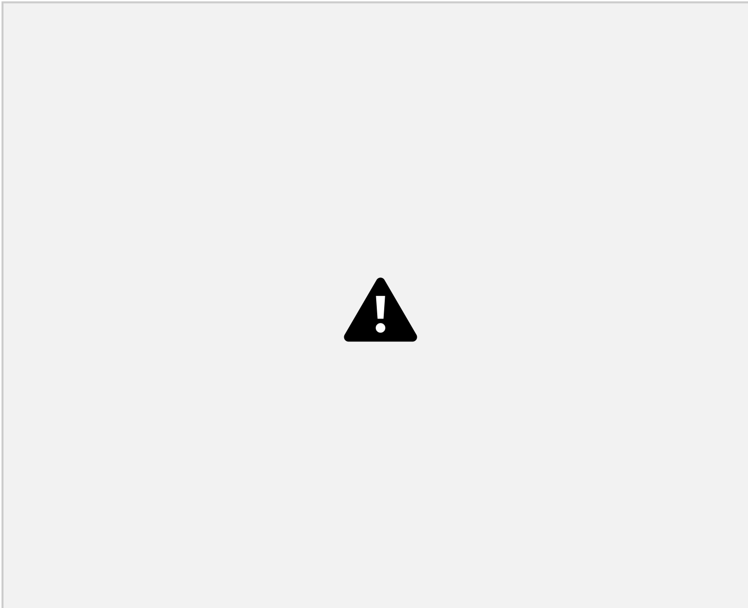

Fig. 15. Physics of energy flows creating latent heat, clouds, rain and wind. Latent heat from evapotranspiration (1370 mm/year) takes up 42% of the solar input, i.e. approx. 100 watts of 240 Watts input. The Trade Winds (the Biotic Pump component), is on average 880 mm/year and, therefore, adds 64 watts to the 100. The total Latent heat over the rainforest is 70% of solar input. That latent heat is exported to Space and is a significant means of surface cooling. –by Andrew Ayres from a discussion with Peter Bunyard.

2.4 CREATING THE CONDITIONS FOR THE GREAT TURNING

''If you do not change direction, you might end up where you are heading", Lao Tzu The opportunity we have to avoid the wholesale collapse of global human society is small and shrinking by the day, but there is an outside chance that we can still turn it around once we understand that we are an integral part of a living planet and
that, with such understanding, comes the responsibility of caring for a biosphere which has created the conditions for life and ourselves to thrive. Care and good husbandry for the natural world, with its essential ecosystems, needs to become our highest priority.

Just as our wellbeing is in good measure determined by the bacterial flora in our gut, our future welfare is directly linked to the health of the whole planet. Imagine that you are part of a much larger living being, an organism that has been alive for hundreds of millions of years and in that time has been working constantly to improve conditions for life on Earth, including the regulation of temperature, moisture, and the necessary recycling of nutrients. This amazing web of life, with its countless species and mind-boggling interactions, has co- evolved with the surface of the Earth to make a living planet. We are now at a threshold where any further destruction of essential ecosystems, like the remaining forests, will take us over the edge and into the abyss of climate chaos, leading to a fast and sudden collapse of societies.

Caring for the Earth, the land, the soils, the plant life and biodiversity everywhere, while drastically reforming our life-styles and food production methods could get us out of the mess we are in within years rather than decades. Only by that can we avoid the worst genocide in the history of our species, or as the UN Secretary General Antonio Guterres calls it, *our collective suicide*. The causes of the deterioration of the weather, climate, food and water security are relatively simple to understand and must be reversed fast.

Therefore, we absolutely need a widespread planetary movement to enable the Great Turn-Around. That movement must operate from a planetary perspective in the short -term before the wholesale collapse of human societies becomes irreversible.
Luckily, we have developed tools that come in very handy to avert collapse: the internet and social media have now created a web of collective interaction, knowledge and action that can make change go viral. We need to capture social media to incentivise and make the Great Turn-Around happen within a short time frame. It can go very fast because the largest investors in the world, such as pension funds, re-insurers and sovereign wealth funds have already found out that their asset base will be degraded fast with the accelerated onslaught of climate change destabilising whole regions. Also, once a new regenerative asset class comes off the ground, it will become the largest investment proposition ever. What project is larger than restoring our planet?

Tied in with the networking of the internet, we should employ Artificial Intelligence to speed up project design and management for generating climate-resilient landscape restoration across the planet. Ultimately, the aim would be to provide local people with optimised plans for their particular bioregion to create wellbeing for all in sync with local nature.

How can we create a global movement for regeneration that captures the hearts, minds and hands of the young who right now see their future destroyed?

2.5 THE STORY OF A NEW WORLD OF SIMPLE ABUNDANCE

Large human movements have been driven by powerful stories, with some of the most impactful ones derived from religious sources. Such stories were successful

because they promised a better world and a radical improvement in living conditions. Let's create a new powerful story where we trust the intelligence of the Earth, and Nature and embrace and stimulate her revival for the emergence of a liveable future with simple abundance for all. The new story describes an exciting world which is at peace with itself, takes care of all life and is based on great cultural virtues such as justice, kindness, honesty, generosity, humility, wisdom and fun. Let us come together and tell that new story that is created by vibrant, young multi
coloured, multi-cultured people celebrating the gift of life. Together we have the power to heal our beautiful living but wounded planet and with that create that beautiful world for all life to thrive for many generations to come.

2.6 THROUGH THE EYE OF THE NEEDLE

This is the famous moment where we have to get through the eye of the needle to overcome our current existential challenge. The expression comes from the Bible, where a wealthy man asks Jesus what he must do to inherit eternal life. Jesus tells him to sell his possessions and give the money to the poor. In that vein, we will need to redirect the unevenly-accumulated wealth, held by few, to regenerate our planet fast and invest in the habitable world of tomorrow, based on sustainability, circularity, and vibrant ecosystems while taking care of the basic needs of all.

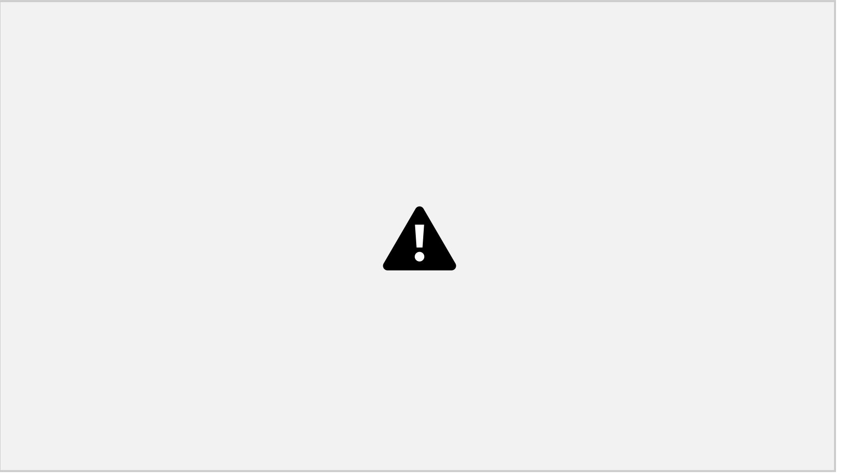

Fig. 16. Syntropic farming was developed in Brazil, where there are now large-scale profitable multi-crop plantations. (courtesy: Life in Syntropy)

Traditional Indigenous cultures have much to teach us with respect to societies and communities living sustainably within the capacity of their local environment to provide them with the bulk of their needs. In those cultures, as exemplified by traditional Amazonian peoples, communal well-being is prioritised over the individual accumulation of wealth and the wealthiest person is he or she who is most generous, distributing the abundance of what they have to other members of

the community. The economy of such communities is based on the notion of reciprocity and exchange, not only within their communities but in dealings with other, even ethnically distinct communities. And, what is critical for the survival of such communities, is that they apply the same principles of reciprocity and exchange with the natural world around them. For example, the Tanimuca of the Colombian Amazon believe that the Sun, passing overhead, bathes the forest and all its creatures with an element which can be translated as ‘thought’, and which is shared right across the biological spectrum. Therefore, it is the duty of the community, when hunting and gathering or when creating their slash-and-burn gardens (chagras) to maintain and respect the equilibrium which the Sun has provided. Such peoples are ecologists by culture and it is part of their cosmology. (Martin von Hildebrand, 1996).

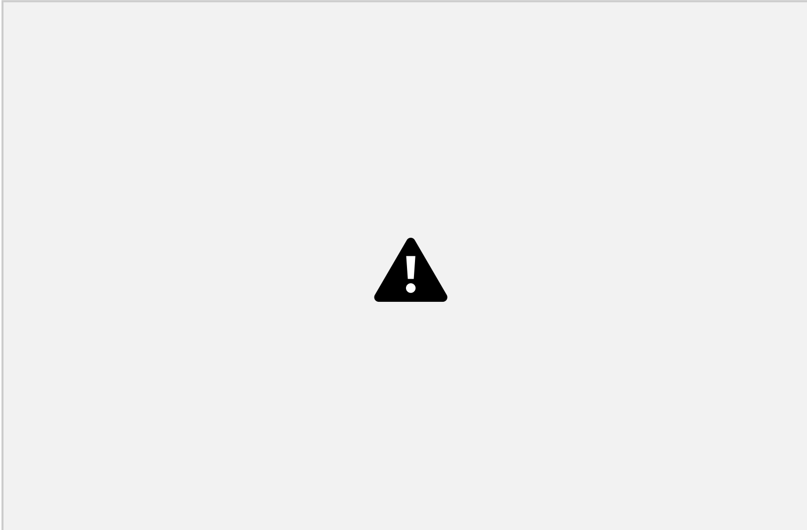

Fig. 17. A traditional house called a maloca, built by members of an isolated, semi-nomadic group, is pictured in 2011 near the Jandiatuba River in western Brazil. (CNS photo/Peetsa/Acervo CTI, courtesy ORPIO)

Greed in our industrialised and materialist culture is currently one of the great causes of the destruction of our living planet. Given the urgency of what is needed to restore equilibrium and balance to our planet, we should hope for those with excessive wealth to help fund the fast transition of our societies and help regenerate our world with future generations in mind. We will soon realise that the imagination of humans and the life force of new generations can overcome our current challenges. Once we wake up from our bad dream that the future is impossible to save, our agency to act will come about and we can heed the call of the United Nations leader, Antonio Guterres, and take collective action to avert collective suicide and open the windows to that beautiful future our hearts know is possible. It will be a great time to live and to be part of the most remarkable

transformation humans have so far achieved on our short journey as a young, juvenile but promising species, a journey that has only just begun.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Chapter 3

What is Climate, Really?

Our climate is changing, but climate, by its very nature, is always changing, and it cannot be otherwise. The Sun as a main sequence star is now some 30% brighter and more luminous than it was when the Earth formed some 4,500 million years ago on account of the thermonuclear reaction speeding up, all of which would mean a warmer Earth, were that the sole factor involved, which it is not. In addition, the Earth's orbit around the Sun never precisely repeats its rotation and sometimes the Earth is nearer, and at others further away than would be delineated by a
perfectly circular orbit. That means that different parts of the planet, in the north and south, get more or less sunlight during their respective winters and summers than they would if the orbit was a perfect one.

Nearly one century ago, the Serbian mathematician, Milankovitch, suggested that such variations in the Earth's orbit were responsible for triggering the ice ages and interglacial periods to which the planet has been subjected over the past few million years. The evidence appears to suggest that with regard to past episodes, he may well have been right, at least partially, the other, main factor, being the role of life in regulating the impact of greenhouse gases in the atmosphere. Nevertheless, nothing ever remains the same and the impact of human beings on the Earth is distorting what otherwise might well have been the trajectory of global temperature had humans not been around.

Indeed, on top of all those physical and unavoidable changes in how much sunlight the Earth receives and exactly which part of the planet is receiving it, we human beings are accelerating the process of change through our actions. In order to understand that change – anthropogenic change or man-induced change – we need to know as best as we can what it is that gives us our climate over and above the Sun's rays and the Earth's orbit, albeit that these two factors are undoubtedly critical ones.

3.1 THE SUN

The Sun derives its energy from hydrogen, the most common atom to be found in the Sun, being squeezed so forcibly together that it fuses at extremely high temperatures and pressures in a thermonuclear reaction to form helium and in so doing loses a little bit of mass which converts instantly into enormous quantities of energy. Here, Einstein's famous equation of mass transforming into energy and vice versa comes into play: E (energy) = mc^2, where m is mass and c is the velocity of light. As the helium builds up at the surface of the Sun, it acts like a greenhouse gas, making the Sun get hotter such that the thermonuclear reaction gradually and almost imperceptibly speeds up.

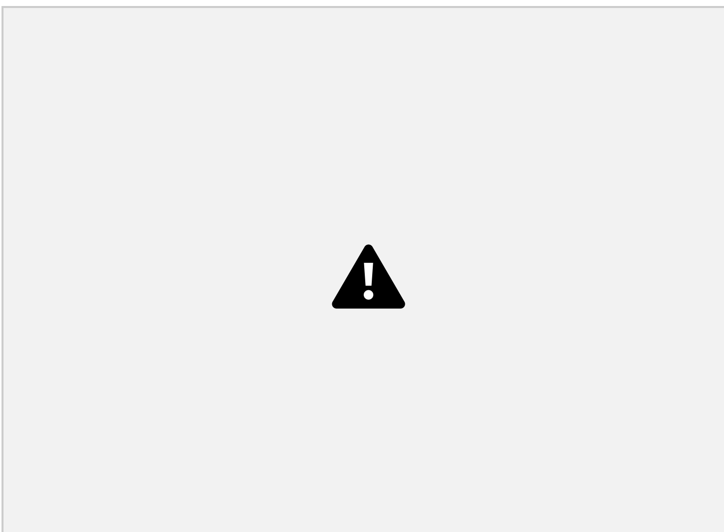


Fig. 18. Solar Input changes of seasons and the Milankovitch cycles changing weather and climate – Graph by Peter Bunyard

3.2 DISTRIBUTION OF SOLAR ENERGY

Sunlight is the main driver of climatic processes on Earth, providing light and heat which, in passing down to the surface of the Earth, generates currents in the oceans and movements of the air in the atmosphere and, most importantly, causes water to evaporate from the oceans such that clouds form and bring rain to the continents. The Sun also provides the energy in the form of light for photosynthesis which enables plants and algae to synthesise carbohydrates,

such as glucose, from carbon dioxide and water. The resulting, energy-rich carbon-based building blocks can then be used in the synthesis of proteins and other compounds
essential in the metabolism of living cells. As we shall see, life has long played a significant part in regulating the temperature of the Earth's surface and therefore has helped form what is today's climate. We can truly say that life and the Earth have co-evolved over the past 4,000 million years, taking into account cataclysmic events, such as the Earth being struck by an asteroid, like the one some 66 million years ago, which brought about the extinction of the dinosaurs.

In addition to accumulative changes in the Sun over its history as a star, how much energy gets sent out to space at any one moment of time depends on variations in solar activity, such as during sunspot cycles. Such cycles have a periodicity of around 11 years, with sunspots appearing and then vanishing. Some four centuries ago, in the early 17th century, the famous Italian scientist, Galileo Galilei, was able to observe sunspots, just as had Chinese astronomers many centuries before; we now know that when sunspots become more numerous the amount of energy reaching the Earth goes up, perhaps by as much as 0.1% and vice versa, declines

during periods of low sunspot activity, as happened during the Mini Ice Age of the 18th century. Then, Europe froze over during its winters, as is shown in paintings of the river Thames, with people skating happily over the surface.

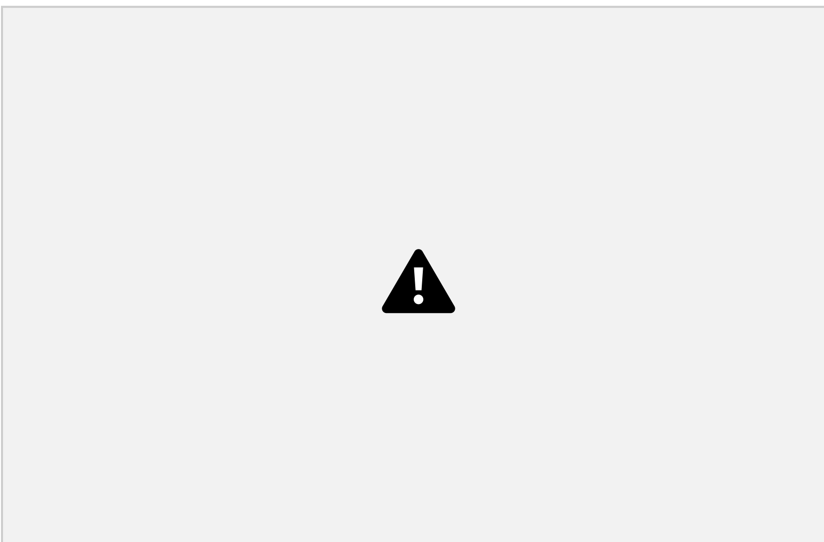


Fig. 19. Sunspots

In reality, there was an additional factor, all to do with the regeneration of forests over an area of 55 million hectares. That regeneration was a consequence of the European invasion of the Americas which brought death and destruction on a massive scale to the indigenous populations. The abandoned lands grew back as forests, the net result being a reduction in greenhouse gases as the forests laid down biomass. In addition to the reduction in atmospheric carbon dioxide, the forest increased the rate of evapotranspiration significantly above that pertaining to when the Europeans first arrived. As we have mentioned before, the enhanced evapotranspiration from the spread of forests led to an average surface cooling of as much as 1°C. (Koch, Alexander., Brierly, Chris., Maslin, Mark M., Lewis, Simon. L. *Earth system impacts of the European arrival and Great Dying in the Americas after 1492***.** Quaternary Science Reviews Volume 207, 1 March 2019, Pages 13- 36.)

The picture below, with St Paul's Cathedral in London, as it was before the Great Fire of 1666, shows us the consequence of even a small change in surface temperature.

Back to the Sun, some of the hydrogen atoms around the Sun's surface gain sufficient energy to escape the intense gravitational field, and, as atoms dissociate into protons and electrons, stream out to form the *solar wind*, a portion of which

reaches the outer atmosphere of the Earth. Physicists originally thought that the *solar wind* increased in strength during the peak of sunspot activity, but, recent observations suggest that the relationship between sunspots and the solar wind may not necessarily hold. The solar wind interacts with the stream of cosmic rays coming from outer space and the stronger the wind, the weaker the bombardment of the Earth's atmosphere by cosmic rays.

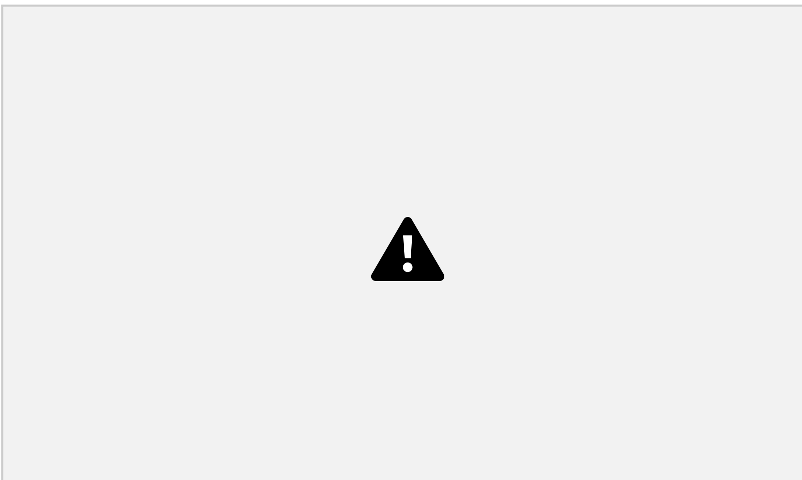


Fig. 20. Winter during the ''Little Ice Age" – photo credit Museum of London

It is becoming clear that our planet's climate is not simply the result of how much energy the Earth receives from the Sun, but is affected by other factors, including that the Earth is a watery planet, and that when clouds form from water vapour in the lower atmosphere, they mask the Earth's surface and cause some of the Sun's rays to be reflected back into space.

Water vapour, because of the latent heat associated with evaporation (some 540 calories per gram to turn liquid water into vapour), acts to transfer energy from one place to another, as when it condenses back into liquid and releases the equivalent energy of vaporisation.

We will know the importance of surface colour as to whether more or less heat is retained under the midday Sun at the height of the summer. Try walking barefoot across a beach with dark volcanic sands when the Sun is beating down; it can be a truly painful experience. Compare that with sitting on a light-coloured, or white painted surface. In fact, changes in the reflectivity of the Earth's surface – in the Earth's *albedo* – illustrate full well the principle of *feedback* in accelerating or damping down change. When the ice caps develop, both thickening and spreading, more of the Sun's rays are reflected back to Space and the general effect is for the temperature to remain low and for the ice and snow to spread ever more towards the lower latitudes, as indeed happened during the last glacial maximum some 40,000 years ago. That spreading and chilling of the surface temperature will reach some limit where the Sun's rays over those lower latitudes will be sufficiently strong to melt the ice as fast as it forms.

A slight change in the power of the Sun to melt the ice could mean that the ice melts faster than it can reform and instead of a reflective surface, the one which is exposed, be it dark rock or the open sea, now absorbs rather than reflects such that the warming and melting spreads back again towards the polar region. With regard to freezing and thawing cycles, the type of vegetation in the boreal, northern regions, can provide its own feedback and accelerate or restrain climate change. Pine trees, with their dark needles and Christmas tree shape, can grow up to the Arctic Circle, but from there northwards to the North Pole, the long, dark winter months and the low temperatures, prevent their colonisation of the frozen wastelands. However, such trees, by their conical shape, are ideally formed for shedding snow. Thus, in springtime, when the first rays of the Sun rise up over the horizon, the conifers expose their dark green needles, capturing certain wavelengths for photosynthesis and simultaneously warming up as light is absorbed and converted to heat. That way, a boreal forest of conifers will actually warm up its environment, the benefits being faster growth than would otherwise be the case and giving such trees an advantage compared to leaf-shedding deciduous trees, like birch, trembling aspen and poplar. Contrast that with the climate conditions beyond where the forest can grow. There, not only will the snow stay longer, having no conifers to warm up their local environment, but we will find permafrost, where the ground just below the surface is permanently frozen.

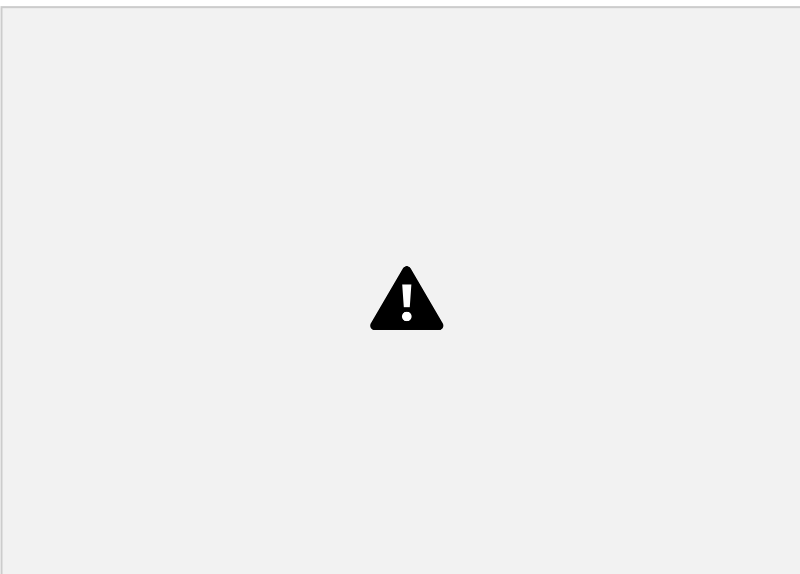


Fig. 21. Different Albedo values on the planet – Graph: Peter Bunyard

Albedo is an important factor in determining the Earth's surface temperature and, according to NASA (National Aeronautics and Space Administration of the United States) if albedo were to reduce on average by 1% (0.01) that would be equivalent in energy terms to doubling the concentration of greenhouse gases in the atmosphere and therefore adding several degrees centigrade to the surface temperature of the Earth. Could that happen? In some respects, the process is already happening, for as glaciers melt and sea ice disappears what is exposed, bare rock and ocean, for example, have much lower albedos than the ice which was there before. A surface which reflects most of the sunlight, sending the rays back towards space, is considered to have a high *albedo,* while one which absorbs sunlight has a low *albedo*, the *albedo* ismeasured on a scale of 0 to 1, or 0% to 100%. For instance, ice, snow and dense clouds, all have high albedo, while the open oceans, vegetation and bare rock have a low albedo.

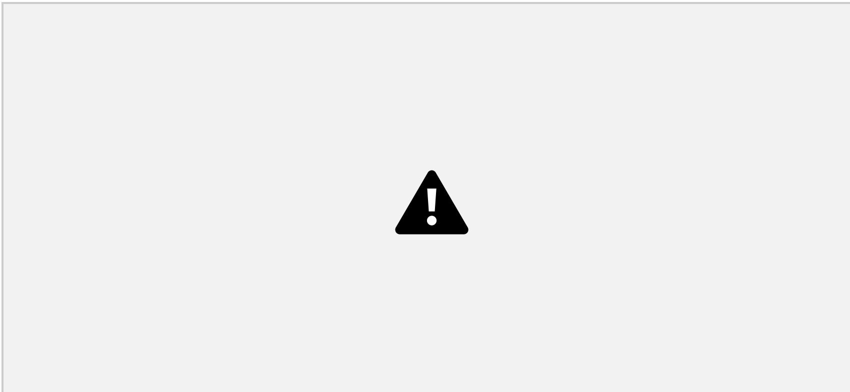


Fig. 22. High Albedo snow cover in majestic winter landscape – photo Andrew Mayovskyy/Shutterstock

3.3 EARTH'S ROTATION

As we have pointed out, the Earth's orbit around the Sun is not constant but varies from year to year in a long-term cycle of some 100,000 years, which takes it from being nearly circular to one that is more elliptical. The Earth's axis is also tilted from the perpendicular and, because the planet spins rather like a spinning top, it shifts from side to side every 25,000 years or so. Consequently, each hemisphere in turn is more exposed to the Sun during its summer or winter months simply because of the shift in orbit. When the orbit takes the Earth closest to the Sun, the facing hemisphere, enjoying its summer months, may receive as much as 3% more solar energy compared to the other hemisphere during its summer because it faces the Sun when the Earth is furthest away. Such shifts in the Earth's orbit are known as *Milankovitch Wobbles*, named after the Serbian mathematician who first described such distortions in the Earth's orbit, and who suggested that the 100,000-year- cycle might coincide with times of ice age.

3.4 GASEOUS COMPOSITION OF THE ATMOSPHERE

The composition of the atmosphere is made up of gases which, with rare exceptions, are all part of life's metabolism. As we have discovered as a result of scientific research over the past century, life has played a hand in regulating the concentrations of gases in the atmosphere, whether they be nitrogen, oxygen, carbon dioxide, methane and nitrous oxide and, equally, plays a massive role in the way in which water gets distributed across continents. Some of those gases, carbon dioxide, methane and nitrous oxide, as well as others, like the CFCs – chlorofluorocarbons – which we have manufactured, have properties which cause the infrared waves of heat to be trapped at the Earth's surface, rather than easily passing back into space. That way, the Earth's surface warms up, as it happens

by an average increase in temperature of some 34°C, taking the surface temperature to an average 16°C instead of a chilling -18°C. Remember that those are average temperatures over the planet's surface and therefore they incorporate
the extremes of temperature which we associate with the polar and tropical

regions. **3.5 GREENHOUSE GASES**

Typically, carbon dioxide (CO_2), water vapour (H_2O), methane (CH_4) and nitrous oxide (N_2O), have the potential to resonate with infrared photons, and since each molecular species has its own resonance frequency, the greenhouse gases cover a considerable range of the infrared spectrum. Satellites orbiting above the atmosphere indicate the extent to which the different greenhouse gases absorb thermal radiation and at what frequencies. Certain frequencies are unaffected by the presence of greenhouse gases, and those frequencies pass through the atmosphere without hindrance. Water vapour is seen to absorb infrared at each end of the thermal spectrum, with carbon dioxide making a big dent in the wavelength spectrum from about 15 to 19 micrometres (μm). The resonances of methane (CH_4) and nitrous oxide overlap between wavelengths of 7.75 to 8.25μm and ozone has a strong resonance between 9.5 and 10μm. Altogether, the different greenhouse gases complement each other, covering a good part of the full infra red spectrum. The extent to which the atmosphere warms up depends on the concentrations of the greenhouse gases, at least up to the point of saturation, beyond which the infra-red of a particular wavelength passes out to space relatively unhampered.

Our planet is a watery planet, with two-thirds of the surface covered by the oceans. On account of the greenhouse gases, like carbon dioxide, which warms the surface through trapping infrared radiation, water evaporates, thus providing the all essential rainfall for life on the continents. Water vapour has a powerful greenhouse effect, in its totality much more because of its concentration in the atmosphere than that of all the other greenhouse gases combined. Consequently, as we add greenhouse gases to the atmosphere, from the burning of fossil fuels and deforestation, we are causing the rise in surface temperatures to bring about more evaporation of water, in particular from the oceans. That increase in evaporation will enhance the greenhouse effect, such that temperatures will rise

still further and so on, until a new balance is reached; that is assuming that we have stopped emitting more greenhouse gases.

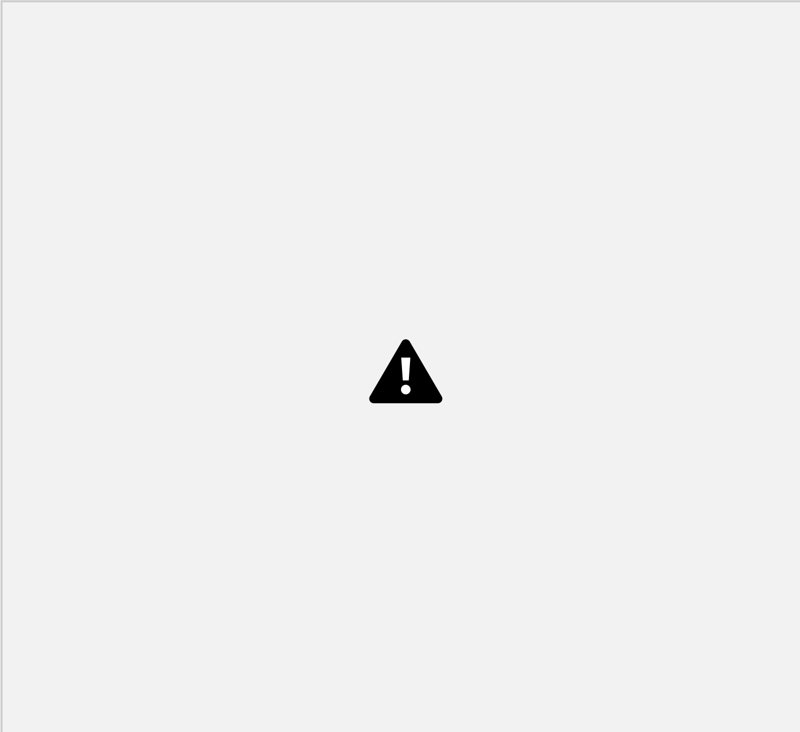


Fig. 23. Feedback loops in the atmosphere created by increasing water and CO_2 – Peter Bunyard

We are all aware of the Sun's power to burn our skins, dry out lakes and leave soil cracked and baked. If we add up the total of the energy delivered to the Earth it gives us prodigiously large numbers. In fact, the amount of solar energy getting to the Earth's surface in just one hour is equivalent to more energy than all human beings in the world use in the course of a year. In thinking of capturing that energy instead of our current reliance on fossil fuels, we have to take into account that the Sun's energy is not easily concentrated but is relatively diffuse and dispersed over a wide area. Furthermore, the amount of energy which the Sun delivers to any one place on the Earth is not constant; it varies with the seasons and the length of the day, whether it be day or night, and whether the skies are clear or covered in clouds. Yet, it would be wrong to think that the Sun does no more than shine down on us. The energy it gives to the Earth helps generate the winds and the circulation of seawater in the oceans. Wind and wave machines, in point of fact, use the Sun's energy, but at one step removed from direct sunlight, and of course, the wind

may be strong during night-time or the waves bigger and more powerful. The spinning of the Earth, in an anticlockwise direction – the Coriolis Force – contributes to air and ocean currents.

3.6 LUNAR ENERGY

The Moon also adds gravitational power to the Earth, causing the tides, which in some selected spots in the World, can vary by as much as 15 or more metres. Tidal energy, especially where large tides are experienced, as in Rance in Brittany, in the Bristol Channel in the UK, or Fundy Bay in Nova Scotia are therefore possible sources of power. The Rance tidal barrage has been operating since 1966 and it generates some 240 megawatts of electric power (one megawatt is one million watts) from a tidal difference which can amount to 13 metres.

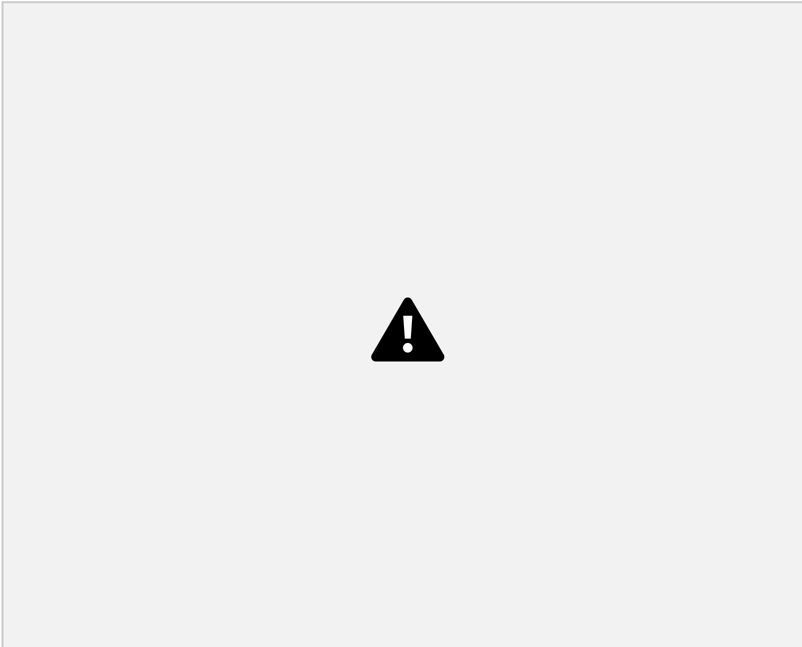


Fig. 24. Tidal Energy Power Station in France – Peter Bunyard

Venus has an orbit around the Sun which takes it within 108 million kilometres, and which results in an average surface temperature of some 457°C. That is the temperature of a really hot, red-glowing, oven. Then we have Mars, the other flanking planet to the Earth. Mars, with its thin atmosphere, has an orbit which takes 205 million kilometres at its closest and 249 million kilometres at its furthest. The average surface temperature on that inhospitable planet is some 55°C below zero: therefore, bitterly cold. So, we have the Earth, with just the right amount of

surface heat, between its two flanking and inhospitable planets, Venus and Mars. Like Goldilocks choosing the right bowl of porridge, life appears to have selected the right planet for its well-being and indeed survival. It took the perception and scientific acumen of James Lovelock, in the 1960s, to realise that Life, or as he described it *Gaia*, at its inception, had not just inherited the perfect medium for its survival but had then adapted the Earth such that Life, in all its manifest appearances, could spread to every nook and cranny, all the while maintaining just the right conditions of temperature and surface conditions, in a dynamic interplay of positive and negative feedbacks. (Bunyard, 2022).

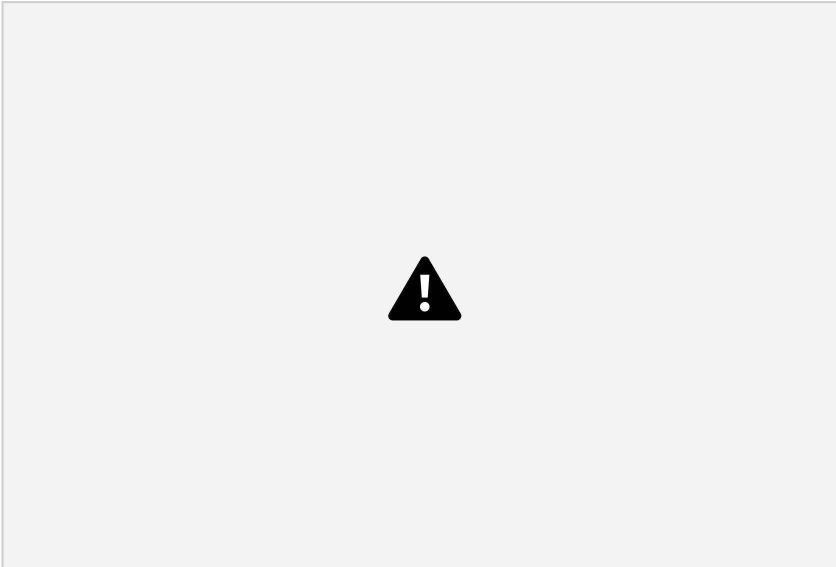


Fig. 25. Comparison of planetary atmospheres of Mars, Venus and the Earth with and without Life – Lynn Margulis, *Gaia in Action: Science of the Living Earth*. Floris Books 1996)

Nitrogen: Some 78% of the atmosphere is made up of molecules of nitrogen, N_2. Nitrogen is an essential element for life as we can see when we look at the composition of amino acids, proteins, DNA, and RNA. It is fortunate for life on the continents that so much nitrogen is in the atmosphere rather than washed out into the oceans in the form of nitrous and nitric acid. In fact, denitrifying bacteria in the oceans and on land send free molecular nitrogen into the atmosphere, in contrast to the nitrogen fixers, such as the rhizobacteria found in the root nodules of leguminous plants, which capture the nitrogen so that it can be synthesised into essential compounds for the living cell. The fixing of nitrogen needs energy – it is an endothermic reaction – and is helped by the high concentration of nitrogen gas in the atmosphere. In fact, the nitrogen-fixing bacteria, such as are found in the root nodules of leguminous plants (peas, beans, soya, peanuts), can operate only

when oxygen levels are low to vanishingly small and so the host plant manufactures a type of haemoglobin which mops up the oxygen in the root nodules, so giving them their characteristic rusty red colour. That relationship between the denitrifying bacteria and the nitrogen fixers helps regulate the balance of essential nutrients in the ocean, thereby keeping them in circulation for much longer than if they were to get caught up in the sediments. And what happens biologically in the oceans helps determine oxygen levels in the atmosphere. Moreover, the high concentration of nitrogen in the atmosphere helps dampen down the incendiary nature of oxygen, preventing conflagrations which would prevent trees from growing.

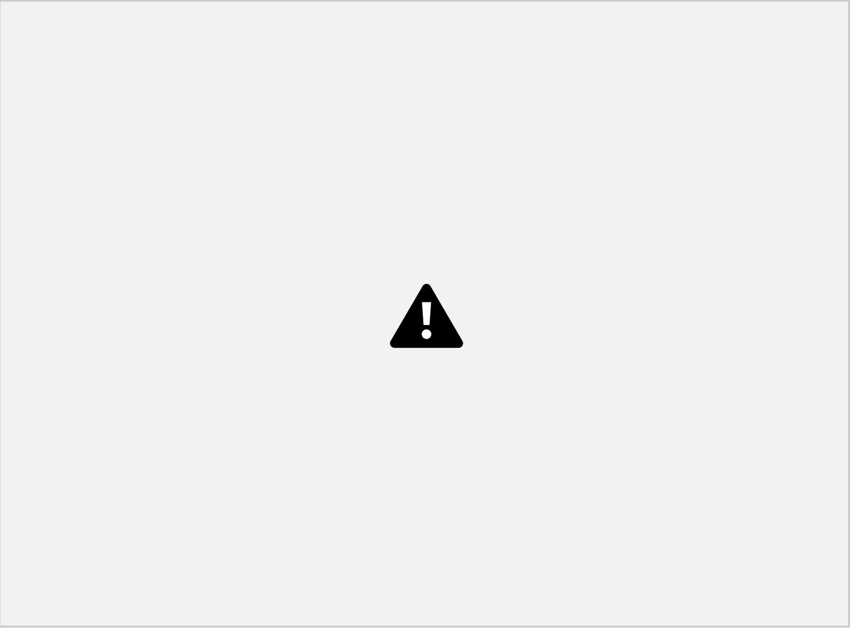


Fig. 26. Bacterial regulation of ocean nutrients - taken from Timothy Lenton and Andrew Watson, now at Exeter University. Peter Bunyard

Decomposition is the other side of the coin from synthesis and, as a cell dies and its components decay, some of the nitrogen gets oxidised to nitrous oxide, N_2O. Nitrous oxide weight per weight is some 300 times more powerful as a greenhouse gas compared to carbon dioxide. However, the concentration of N_2O is more than 1000 times less than that of CO_2, and it makes up around 9% of total greenhouse gases (not taking water vapour into account), while CO_2 accounts for 72% and methane 18%.

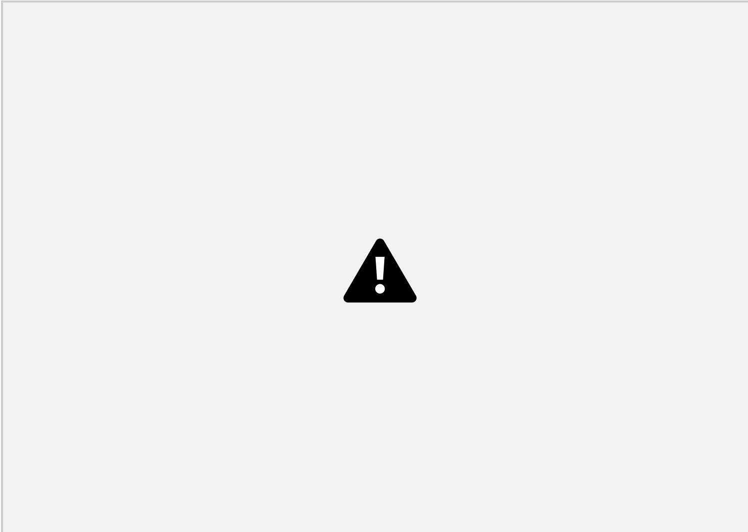


Fig. 27. Nitrogen cycle – for it to function well, life needs a high atmospheric concentration. Graph by Peter Bunyard

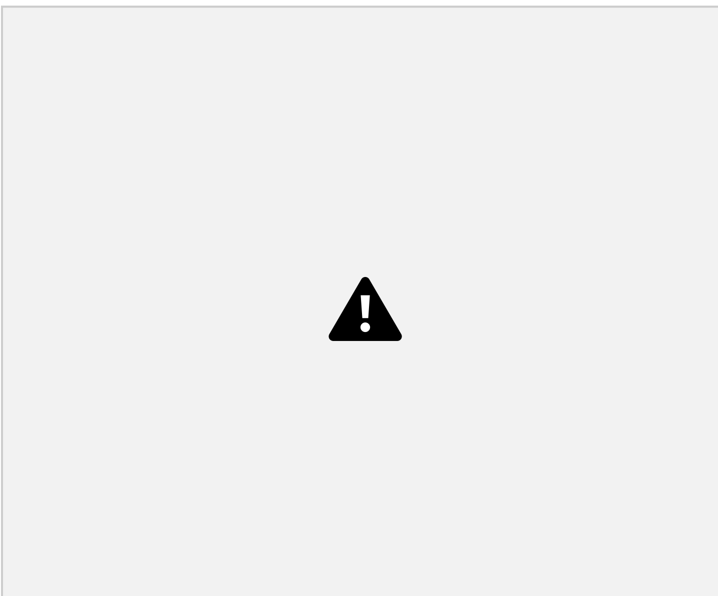


Fig. 28. Nitrogen Cycle at plant level – Artist unknown, courtesy QCE Biology Revision

Oxygen: O_2 is the next most abundant gas in the atmosphere. Over time the content of the atmosphere has changed and oxygen levels have varied greatly during different periods of the Earth's history. We must attribute the current oxygen concentration of 21% in the atmosphere to Life and in particular to photosynthesis which, through the energy derived from the Sun, results in carbohydrates being formed from carbon dioxide and water ($6\ CO_2 + 6\ H_2O = 6\ O_2 + C_6H_{12}O_6$). Oxygen, in common with nitrogen, is not a greenhouse gas.

Methane: CH_4, is mostly generated by methanogenic bacteria which survive well where there is little or no oxygen, such as in waterlogged soils and marshes and not least in the guts of invertebrates, such as termites. Ruminants, which include cattle, with their multiple stomach chambers for digesting cellulose-rich substances such as grass, are also prolific producers of methane, particularly when the vegetation is poor, as is generally the case with pasture grown on the poor soils of what once was a tropical rainforest. Cattle can be thought of as mobile 40-gallon methane generators, with each animal producing as much as several hundred kilograms of the gas each year.

After water vapour and carbon dioxide, methane is the next most important greenhouse gas. Methanogenic bacteria, with their need for oxygen-free places, such as bogs, swamps, irrigated rice paddies or the guts of animals, recall a time, more than 2 billion years ago, when the Earth's atmosphere lacked oxygen and methanogenic bacteria happily exposed themselves to the atmosphere. Once photosynthesizers had evolved and oxygen began to build up in the atmosphere, the methanogen's vulnerability to oxygen forced them into hiding.

Methanogens survive by pulling the oxygen atoms off carbon dioxide and then directing the oxygen to recombine with hydrogen or other hydrogen-rich chemicals, releasing energy in the process and fuelling their metabolism. They can also survive on acetate, methanol (wood alcohol) or trimethylamine. Methanogens therefore convert buried organic matter into the gas methane. Methane, when in the atmosphere, tends to interact with oxidising molecules, of which the most important is hydroxyl (OH). Hydroxyl derives primarily from the interaction between ozone and water. By oxidising methane, hydroxyl converts to water and in essence therefore methane removes oxygen from the atmosphere.

In what is one of the strange paradoxes of life on Earth, bacteria that shun oxygen actually help regulate oxygen levels in the atmosphere. Without methanogens, it might well be that oxygen levels would begin rising to the point when soaking-wet organic matter would be in grave danger of spontaneous combustion. Even the wettest forests in the world, like the Chocó rainforests lying off the Pacific Coast in Colombia and Ecuador, with their 12 metres of rain each year, would likely burn, were it not for those ancient Archean bacteria. Climatologists ascribe 60% of methane emissions — close to 300 million tonnes — to man-made sources. Currently, some 60 million tonnes a year of methane are accumulating in the atmosphere.

Methane was present as a greenhouse gas in the pre-industrial atmosphere of 1750, but at a relatively low concentration of 0.8 parts per million in volume (ppmv)

and its contribution to surface warmth was relatively small. With an annual rate of increase of nearly one per cent, the gas has now more than doubled its concentration in the atmosphere to 1.9 ppmv from 1.8 ppmv in 2011, and 0.7 in pre-industrial times, some 200 years ago, thus exceeding its highest-ever concentration in the past 160,000 years. The methane sequence, derived from the Vostok ice core, shows interesting parallels with carbon dioxide, in that it also follows the ups and downs of temperature shifts. Warmer spells are associated with concentrations of methane of up to 0.7 ppmv and cold spells with concentrations that fall down as low as 0.3 ppmv.

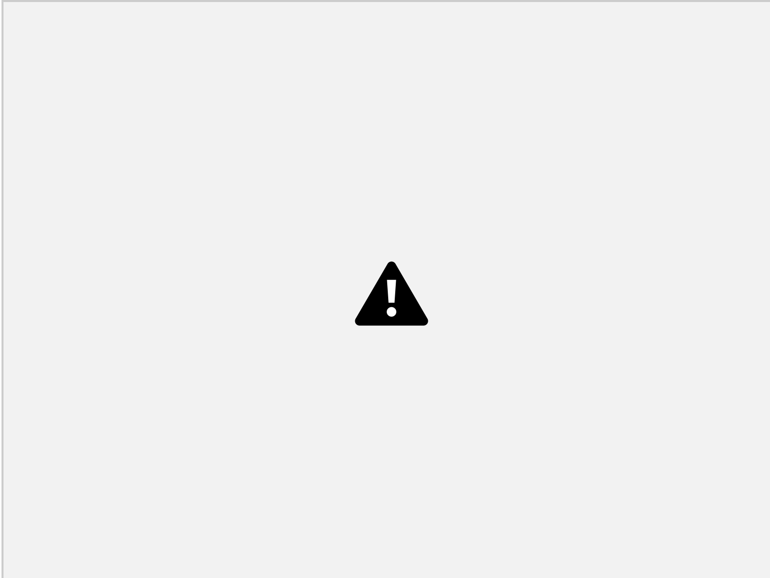


Fig. 29. Atmospheric Methane increase over time in parts per billion – courtesy NOAA

3.7 GLOBAL WARMING POTENTIALS

The warming effect of an emission of 1 kg of each gas relative to that of carbon dioxide

20 Years 100 Years 500 Years

Carbon dioxide 1 1 1 Methane 63 21 9 Nitrous Oxide 270 290 190 CFC-11 4500 3500 1500 CFC-12 7100 7300 4500 HCFC-22 4100 1500 510

While water vapour is by far the most abundant GHG in the atmosphere and responsible for most of the GHG effect overall, the per kilo measurement cannot be applied because the substance has a different impact depending on where it is in the atmosphere, how warm the surrounding air is and because it changes state from gas to liquid and ice and back again.

Each greenhouse gas makes its own particular contribution to global warming, which it continues to do until washed out of the atmosphere by rain, absorbed into soils and oceans or broken down through chemical interactions, some powered by sunlight. Sometimes those interactions lead to the production of other greenhouse gases — for instance, methane oxidises to carbon dioxide and water. Meanwhile, a gas, like a CFC, may be present in the atmosphere in very low quantities but still have a significant effect. Climatologists therefore invoke the idea of *Global Warming Potentials* in which the impact of emitting 1 kg of a gas over a stretch of time, such as 100 years, is compared with that of carbon dioxide.

The global warming potential therefore takes into account the disappearance of the gas from the atmosphere over time. Global warming potentials are likely to increase in the future when carbon dioxide builds up in the atmosphere. The increase comes because of saturation effects. Thus, relative to carbon dioxide the effects of other greenhouse gases will become proportionately greater.

Potential Catastrophic Releases: Considerable quantities of methane are trapped under permafrost in boreal regions close to the Arctic Circle. Rising temperatures, resulting in the melting of permafrost, could bring about the release of as much as 450 Gt of carbon in the form of carbon dioxide and methane. Such a release would be a powerful, runaway self-reinforcing feedback since it would entail more temperature rise, further permafrost melting and hence further releases. We already have considerable cause for concern. Siberia, much of which is covered in permafrost, is warming faster than almost anywhere on the planet.

But that is not all: according to the US Geographical Survey, 10,000 billion tonnes (GT) of methane are currently trapped under pressure in crystal structures — methane hydrates — on the edges of continental shelves, making them the Earth's largest fossil-fuel reservoir.

Should the temperature in the surrounding water or sediment be increased to the point where methane hydrate becomes unstable, methane gas could be released overnight. Hence, where water is relatively shallow and thus easier to heat, as in the Arctic (which is already warming at a rate two to three times the global average), tens if not hundreds of billions of tonnes of methane could be released. It happened before, some 55 million years ago and even more dramatically during the Permian/Triassic extinction of 251.4 million years ago when 96% of all marine species went extinct and 70% of terrestrial vertebrate species. Such massive emissions of greenhouse gases would have given rise to rapid global warming.

Methanogens and Hydroxyl Radicals: The life span of gases in the atmosphere, such as methane, depends on chemical reactions involving oxidising substances

and energy from the sun. The hydroxyl radical is generated when ultraviolet light splits ozone into oxygen gas (O_2) and an excited oxygen atom that immediately reacts with water. For every ozone molecule that splits two hydroxyl radicals are created. Much of this generation takes place in tropical skies simply because the ultraviolet of the right wavelength is better able to penetrate there, owing to low ozone levels high up in the stratosphere above equatorial regions. The quantities of hydroxyl produced by such photochemical reactions are extremely small, yet they are sufficient to account for the oxidation of methane, carbon monoxide (CO), nitrous oxide, hydrogen sulphide as well as traces of organic gases such as methyl chloroform, emitted by industry. The hydroxyl radical (OH^-) therefore plays a seminal role in cleansing the atmosphere of substances that might otherwise accumulate.

Gaia Thesis and Oxygen: In 1969, James Lovelock came up with a hypothesis in which he proposed that life in all its forms and variations acted with its immediate surroundings to generate optimum conditions for life to flourish. He named the hypothesis *Gaia* after the Greek Goddess of the Earth, and we use that name when we talk of *Geo*-graphy or *Geo*-logy or *Geo*-physics. Now, a half-century later, many have investigated the tenets of the original hypothesis and have upgraded it to be the *Gaia Thesis*.

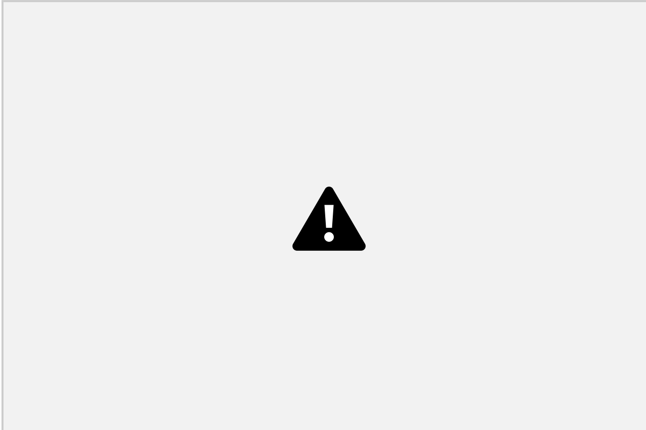


Fig. 30. Stromatolites are rock-like structures built by cyanobacteria colonies - Photo Ikonya/Shutterstock.

In the early 1970s, Lovelock teamed up with Lynn Margulis, a biologist renowned for her studies of symbiotic relationships between species and for the phenomenon of *endosymbiosis* in which ancient bacteria had incorporated themselves into the nucleated cells of *higher organisms.* We now know that the mitochondria, essential for respiratory processes in cells and the chloroplasts, which are the sites of photosynthesis in the stomata of leaves, were originally free-living bacteria. Lovelock and Margulis have suggested that the production of oxygen by

cyanobacteria as long ago as 3,800 million years (3.8 GA) may have prevented the loss of water from the Earth as the result of the oxygen reacting with hydrogen which would otherwise have percolated upwards from the Earth's surface and escaped into space. Certainly, Venus, with a surface temperature on average close to 500^{o}C has lost virtually all its water, and it is debated how much water still remains on Mars, where the thin atmosphere, mostly composed of carbon dioxide, gives the planet an average surface temperature of -60^{o}C.

James Lovelock, who died on his 103rd birthday, 26th July 2022, was a trail-blazing scientist who changed our thinking on the relationship between life in its broadest sense, as the sum of the biota, and the environment through interactions and collaborations with scientists from many fields. Lovelock accepted the Darwinian 'survival of the fittest' as an explanation for the evolution of species, but with a telling difference, namely that life in all its forms so modified its immediate environment that the transformations it engendered to the Earth's physical/chemical surface, including the crust, oceans and atmosphere, optimised the environmental conditions for survival for a host of different species, from bacteria to the tallest sequoia. Such life-caused changes to the environment then fed back on the process of evolution in a tight co-evolving and coupled relationship. The biosphere, therefore stretched, as far as Lovelock was concerned, all the way from the Earth's crust to the outer edges of the atmosphere. (*Lovelock, J.E.*

2000).

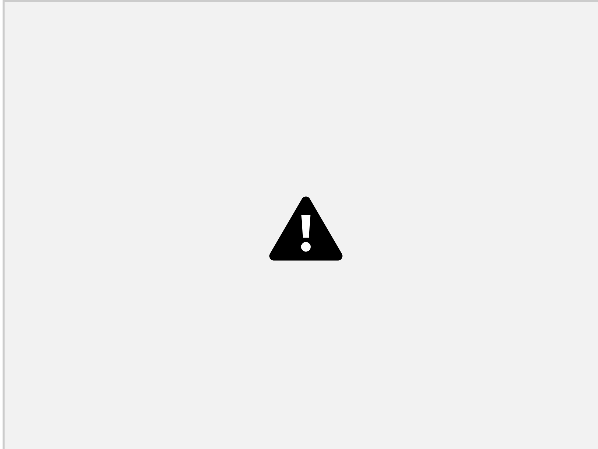


Fig. 31. James Lovelock in 2005 – scientist and author of the Gaia hypothesis next to the Earth Goddess, Gaia – Photo Courtesy Bruno Comby under Creative Commons license

In 1957, Lovelock invented the Electron Capture Detector (ECD), a clever tool for measuring trace contaminants such as chlorofluorocarbons which, as refrigerants and propellants for aerosol sprays, were beginning to become widely used in the industrialised world. The device used a radioactive isotope of nickel to provide electrons as beta radiation which then interacted with nitrogen gas to generate a

measurable current. The nitrogen acted as a carrier gas for the sample which, by means of the attached gas chromatograph, contained the separated traces of the volatile substance to be measured, in particular halogenated compounds such as the CFCs. The presence of such substances resulted in the absorption of electrons, thus reducing the flow of electrons and the current. The ECD, now widely used, is extraordinarily sensitive and can measure the quantities of a volatile substance even to as low as one part per trillion (Bunyard PP.,2022).

In 1971, Lovelock was in the South Atlantic on board the research vessel, RRS Shackleton, with his ECD and a homemade gas chromatograph and to his astonishment he found traces of the CFCs which had permeated there from the industrial North. That discovery then led to concern that the CFCs, by percolating upwards into the stratosphere, were responsible for the chemical/photolytic destruction of the ozone cap which, when properly intact, interacted with ultraviolet B radiation and thereby acted as a shield in preventing harmful UV-B radiation from reaching the Earth's surface.

Based on Lovelock's discovery of the prevalence of CFCs in the lower atmosphere, in 1974, Mario Molina and Sherwood Rowland expressed their concern on scientific grounds that the CFCs were damaging the stratospheric ozone cap and 10 years later the United Nations, under what was termed the Montreal Protocol, introduced a ban on the use of CFCs. In 1995, Rowland, Molina and the atmospheric chemist, Paul Crutzen, received the Nobel Prize in Chemistry. Lovelock's crucial contribution was ignored. (Molina, M. & Rowland, S., 1974).

Once the atmospheric gas spectra of both Venus and Mars became known, with both planets having atmospheres composed predominantly of carbon dioxide and just trace amounts of oxygen, with little to no nitrogen, that finding confirmed Lovelock's scepticism on scientific grounds, that NASA would find life on Mars. In effect, the atmospheres of Mars and Venus were close to a chemical equilibrium, which would have come about over time as the gases interacted with each other through the processes of oxidation and reduction as well as escapes of hydrogen into space from the photolytic decomposition of water. The contrast with the Earth's 0.03% of carbon dioxide (the 1960s), 78% nitrogen and 21% oxygen was telling. Meanwhile, the presence of 0.003% of the reducing gas methane, whereas Mars and Venus had none, indicated that the Earth's atmosphere was orders of magnitude away from chemical equilibrium and, according to Lovelock, kept in that state by living processes, such as by the activities of bacterial methanogens. He also surmised that methane in the atmosphere helped to regulate oxygen levels, atmospheric oxygen itself being a product of biotic photosynthesis (Bunyard PP.,2022).

Moreover, with the evolution of eukaryotes from prokaryotes, metabolic activities, such as photosynthesis and consequently respiration, could be vastly scaled up. The evolution of the angiosperm trees with their vascularised leaves and stems, and the high rates of transpiration and photosynthesis is a good example of the scaling up that resulted from cyanobacteria becoming incorporated, with their own separate DNA, by symbiogenesis into the eukaryotic cells of plants to form the

chloroplasts. The spread of forests, the evolution of grasses and the evolution of phytoplankton led simultaneously to oxygen levels rising to their current value of 21% and the deposition of carbon dioxide as fossil fuels and, associated with calcium, as deposits of carbonate.

In developing the Gaia Hypothesis, Lovelock realised that for life to be responsible for generating the current composition of the atmosphere, its metabolic activities would have to be global in extent. The handprint of life was in the atmosphere. Lovelock then asked what the Earth's atmosphere would be like were the planet never to have had life? If similar processes of outgassing, as has occurred during the past 4.5 thousand million years on Venus and Mars, had taken place on an Earth without life, then the composition of the atmosphere would be 98% carbon dioxide, a trace of oxygen, no methane and an atmospheric pressure 60 times that current today. The average surface temperature would be a life-killing 240ºC compared to the actual 15ºC of today's Earth.

But, how could life have a role in controlling surface temperatures? When he was in the South Atlantic, Lovelock noticed the ubiquitous presence of the volatile substance dimethyl sulphide (DMS). Together with Robert Charlson, Meinrat Andreae and Stephen Warren, he developed what became known as the CLAW Hypothesis using the surname initials of its proponents. The essence of the theory involved the release of DMS by phytoplankton such as the coccolithophores which are single-celled photosynthesising algae with a calcified shell. The DMS is rapidly oxidised to sulphur dioxide, sulphuric acid or methane sulphonic acid, with any one of such compounds acting as cloud-condensation nuclei. The coccolithophore metabolism and therefore the growth of the algal bloom are best served by warmer oceanic temperatures. So, right here, we have negative feedback in the sense that the surface sea temperature depends on how clear the skies are and the more DMS that is emitted, the cloudier the skies become and the cooler the surface waters beneath.

For their growth the coccolithophores need upwellings of nutrients, the rate of upwelling in turn depends on the surface temperature. Warm surface temperatures generate a thermocline layer which is impenetrable to nutrients coming from below. For that reason, the coccolithophores do best when surface temperatures are no higher than 8ºC. Above 12ºC, a thermocline layer forms, impeding the growth of phytoplankton. Thus, warmer sea temperatures are likely to leave the surface waters barren. Consequently, the negative feedback

relationship at lower
temperatures, when the sea surface is turbulent and mixing, *becomes a positive one* as the sea-surface temperatures rise above a critical point. The net result is a lack of cloud-forming nuclei. (Charlson, R. J., Lovelock, J. E., Andreae, M. O. and Warren, S. G. 1987).

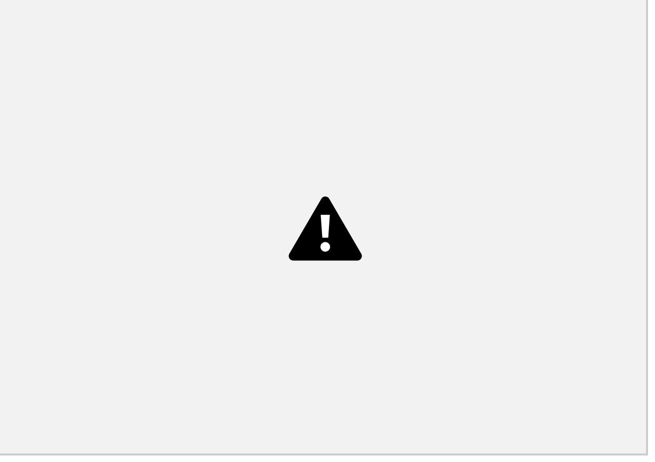
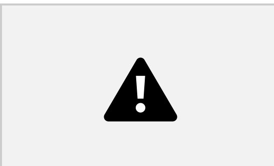
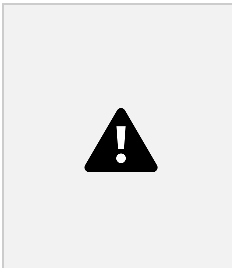
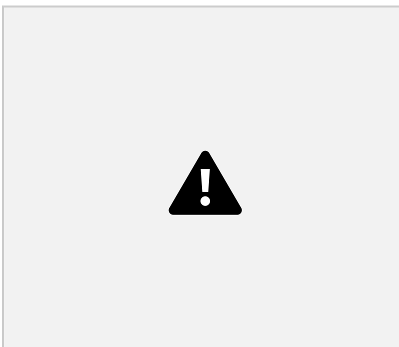
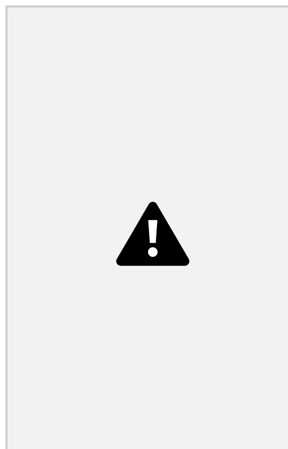


Fig. 32. Self-limiting negative-feedback loop between phytoplankton, temperature and clouds contrasting with a positive-feedback when the surface water temperature exceeds 12°C – Image by Peter Bunyard.









Coccolithophore blooms off the coasts of Ireland, Cornwall and the Bering Straits. [10]

Fig. 33. Images of coccolithophore blooms and the amazing design of their skeletons – Peter Bunyard

In conclusion, we are extremely fortunate that Lovelock was invited to join NASA in devising experiments and technologies to test for life on Mars because it induced him to reflect on the extraordinary phenomenon of life on Earth and how it came to be that life had persisted for close to 4,000 million years, even surviving a number of extinction events. His contribution to our understanding of the processes underpinning the success of life in transforming the Earth, such that it can host the panoply of nature, must surely place him amongst the great scientists of the world. For those who listened to him and studied his revolutionary ideas, including the science behind them, Lovelock fundamentally

changed their outlook on what should be humanity's responsibility towards nature. He made it clear that the climate of the Earth is not just a consequence of physical forces beyond our control, such as the Milankovitch wobbles as the Earth orbits the Sun, but that it is transformed by biotic physiology and metabolism (Bunyard PP.,2022). Evidence
for this is provided by phenomena such as seasonal changes to greenhouse gases, and the changes to albedo as vegetation deciduously sheds leaves. The climate, indeed, the atmosphere, are carefully calibrated products of the biosphere shaping the conditions for life to thrive in its interaction with the high-powered energy from the sun and the freezing cold of the universe, both of which by themselves make the existence of life near impossible.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Chapter 4

The Magic of Life, Photosynthesis and our Future

4.1 THE PHYSICS OF LIFE

Living organisms, with their ability to maintain and increase order within their structures, reverse entropy. Through metabolic processes, energy is harnessed and utilised to fuel the maintenance, growth, and reproduction of living systems. Cells, for instance, constantly engage in molecular and biochemical reactions that maintain their organisation and functionality.

Life's smartest invention so far has been photosynthesis, in which chlorophyll molecules shaped like antennae, their magnesium atoms suspended in space and fine-tuned by the tweaking of the enclosing protein structure, are able to capture photons and stream them down to activation centres. There, a concerted effort by between 8-12 photons of the right wavelengths, brings about the necessary cascade of electrons that leads to the splitting of water. One amazing finding is that the numbers of aligned chlorophyll molecules in a leaf — more than a trillion for every square centimetre — are at the right density to pick up most of the right wavelength photons of daylight hours.

How to Catch a Falling Electron: The ultimate source of all our energy and negative entropy or syntropy is the radiation from the sun. When a photon interacts with a material particle on our globe it lifts one electron from an electron pair to a higher level. This excited state as a rule has but a short lifetime and the electron drops back 10^{-7} to 10^{-8} seconds to the ground state giving off its excess energy in one way or another. Life has learned to catch the electron in the excited state, uncouple it from its partner, and let it drop back to the ground state through its biological machinery utilising its excess energy for life processes.

This process is magnificently efficient, although the net result is determined by other factors as well, such as the availability of water, essential nutrients, carbon dioxide levels, how much oxygen is present, whether clouds are obscuring the sun, what season it is, and what the temperature is. The net result is that of $240W/m^2$ received at the Earth's surface barely $0.7W/m^2$ worth of energy gets through for the production of new biomass.

The fundamental difference between man-made machines and life is the exquisite efficiency with which energy is employed in living processes. The eye, for example, can detect a single photon and through a cascade of molecular transformations, generate an electrical impulse to the brain that may be one million times more powerful than the original signal — and all in no more than one-hundredth of a

second. If life were as inefficient as our emulations of its processes, then cells would soon overheat and coagulate, like a boiled egg.

Energy in the living cell is further held and partitioned by life through the intricate web of different interacting forms. Primary producers — bacteria and plants — are consumed by a range of different grazers and herbivores that themselves fall victim to predators. Finally, in death, virtually all life's forms decay and decompose, helped on their way by fungi, bacteria, and even scavenging creatures such as hyenas and vultures. Overall, the more varied and diverse the system is, the greater its efficiency. The flip side — a degraded life system — is inherently much less efficient and, given its potential to alter the Earth's surface properties, including atmospheric chemistry and climate, in all probability non-sustainable.

Approximately one-third of the Earth's energy is absorbed by the hydrological cycle, while another third drives the convective forces responsible for moving air masses that carry the moisture essential for watering the land. At each step of this intricate process, energy is seemingly "lost," although we must not perceive it as such, as this energy fuels the very dynamics that have shaped our planet.

The extraordinary efficiency displayed in living organisms distinguishes them from man-made machines.

While this story may seem complex, the central message is this: we are part of a living organism, called Earth. The brilliantly designed architecture and metabolism, tweaked over hundreds of millions of years of evolution have created the exact conditions for life to thrive, despite the huge influx of potentially lethal energy from the sun and the deep freeze state of the universe that surrounds us.

The atmosphere, the climate, you, and I are the results of the life force itself designing lifeforms and processes beneficial for the whole of the planet, from the humble bacteria all the way to the mighty blue whale and the giant sequoia. But in order to see the wonder that is our planet, we must look much further and recognise the amazing concert of interactions between all species in an ecosystem, all ecosystems interacting together, all moisture streams in the sky, and all ocean currents working as one great body for life to thrive and evolve as it has done for billions of years.

In the first part of the book, we want to take a much deeper dive into the intricacies of how the climate works as a function of this living organism called Earth of which we are a part. This is not an academic exercise because it is the foundation for the second part of the book where we propose radical action to reverse the damage we have inflicted on our Planet, which is now starting to spiral down into a situation best described as multi-organ failure. Make no mistake, the current scientific warnings about the climate are serious underestimations of the danger we are in. Collapse can come fast and furious.

The goal of this book is to offer a path out of the climate chaos we are in and with that tackle a whole series of connected problems that are already overwhelming

many societies and will soon overwhelm all globally interconnected complex human societies unless we start the great work of our time which is restoring the planet to its former health and vigour and with that shape the conditions for all humans to thrive in sync with nature and graced with the dazzling beauty and abundance of the myriad of species that surround us. Like our next of kin, they give deep meaning to our lives and we are all related. When we succeed in restoring the planet's health, we will simultaneously take on the challenges of food and water security, extreme poverty, and excessive wealth. Equity is not just a human value to be pursued, it belongs to the internal logic of a well-functioning, healthy organism, such as our planet. Together we will be able to restore lands, increase their degraded fertility, and increase the well-being of communities, especially in the Global South. Should some politicians from the Global North read this page, then listen up! If you want to protect our flagging democracies, embrace the recommendations in this book, for they will slow, stop, and reverse the migrations of the millions that no longer find a way to live in their areas. Let us grant them the tools and finance to regenerate their degraded landscapes and communities and with that calm the weather and cool our planet to avert the collapse of all our societies. A lot of the damage caused to the planet has been by the voracious and parasitical excursions of the people in the Global North to confiscate and impound wealth from other regions. Whether it is colonialism or capitalism, these systems have dangerously degraded the living organism we are part of. It is high time to reverse the damage for the sake of the young and those who still want to be born.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Chapter 5

Climate Chaos Will Curse your Future

Every day of our lives we experience climate. Whether we look out of the window and see cascades of rain falling from the heavens; whether we are out in the blazing Sun; whether we are watching the fury of the seas as massive waves hurl themselves against the shore; or, if we are unfortunate enough to experience the devastating power of hurricanes and typhoons, the bitter cold of a blizzard, the Sun-baked, cracked soil of a crop-killing drought, or floods with water rising up to the eaves, roof and beyond; all these are aspects of climate which in different parts of the world and at different times may manifest themselves.

All such phenomena are normal: they are part of life on Earth. Yet, it is with considerable concern that we are now experiencing changes in climate which, right now, are having a devastating impact on our well-being and health. Devastating forest fires, violent downpours, sea surges associated with tropical storms, and long-lasting droughts are not only more severe than half a century ago but have become far more frequent.

Scientists from all over the world have now gathered sufficient unequivocal evidence to show that recent climate change, as evidenced by an overall warming of the surface of the Earth during the last few decades and which includes an increasing number and intensity of extreme events, is primarily the result of our industrialised way of life, including our systems of transportation, the industrialisation of agriculture, our destruction of rainforests, particularly in the tropics, our living increasingly in megacities, with populations running into the millions, and, not least, our dependence on energy from coal, petroleum and natural gas – the so-called fossil fuels because they were formed from once-living plant matter some 300 hundred million years ago, during the period known as the *Carboniferous*.

Dr. James Hansen, a climatologist who worked for NASA – the National Aeronautics and Space Administration of the United States – at the Goddard Space Institute in New York, is deeply concerned about what might be the consequences to the Earth's were temperatures to rise by 2^{o}C (Celsius) before the end of the century. He believes we can avoid such temperature rise only if we reduce the concentrations of greenhouse gases in the atmosphere to 350 parts per million (ppm by volume), while currently, we have exceeded 420 ppm, which is some 50 percent higher than the concentrations of pre-industrial times, some 200 years ago.

During the *Carboniferous* period of some 300 million years ago, carbon dioxide levels dropped dramatically in the atmosphere, as the gas was transformed into buried organic matter while, simultaneously, oxygen levels rose to as high as 35 per cent, compared with the 21 percent of oxygen today. Since carbon dioxide is

a greenhouse gas, which holds heat back at the Earth's surface – in the form of infrared radiation – in comparison to oxygen which is not a greenhouse gas, the production of oxygen, at the expense of carbon dioxide, would have caused the Earth's surface to cool and allow the formation of glaciers and polar ice. That glaciation, by killing the pre-gymnosperm trees of that era, helped form the coal seams which have become the main feature of the carboniferous era. And shallow seas, penetrating the landmass of Pangea, with their rich, diverse, calcareous creatures, were the sites where limestone deposits formed. Together, the carbonisation of the forests and the deposition of calcium carbonate would have significantly reduced the concentrations of CO_2 in the atmosphere. That fact alone tells us how much the concentration of greenhouse gases in the atmosphere depends on the activities of living organisms at any one moment in time. In time that cooling would have balanced out because of massive forest fires brought on by the high levels of oxygen, which would have caused damp forests and vegetation to burn if set off by lightning or a spark from a nearby volcano, with the net result that carbon dioxide concentrations would again have begun to rise, adding to the greenhouse effect and generating the balance of gases in the atmosphere to the kind of levels we find today.

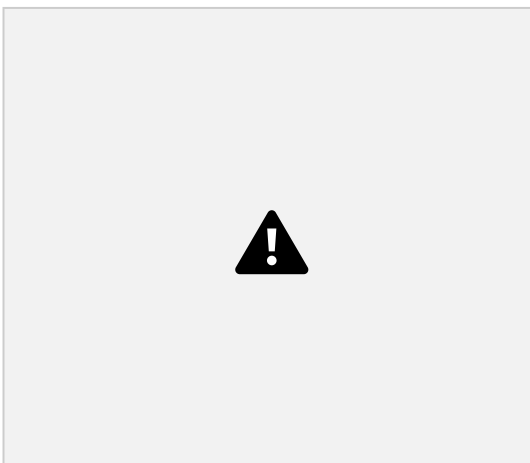


Fig. 34. Increasing atmospheric CO2 content over time – Courtesy NOAA

5.1 CLIMATE CHANGE CONSEQUENCES

Scientists now predict that extreme weather events caused by future climate change, particularly as they manifest themselves during the latter part of this century, could lead to many millions of refugees, maybe more than 100 million a year, who will be forced to leave their homes and may even have to flee for their very lives. In particular, sea level rise, caused by the expansion of water as it warms and by glaciers melting in the Polar regions, is likely to cause the flooding of low-lying land with saline seawater, especially in the wake of powerful storms.

The concern that sea-level rise will cause islands to flood and so have to be abandoned was made graphically clear by the prime minister and his cabinet of ministers of the Maldives in the Indian Ocean. In October 2009, they held a symbolic cabinet meeting underwater, off the shore of the Maldives, with the ministers using scuba-diving masks to enable them to breathe. It may have seemed a crazy gimmick, but the idea was to remind the governments of other countries that they must do all in their power to agree to a significant reduction in emissions of greenhouse gases before what was to be the forthcoming climate meeting in Copenhagen, Denmark, in December 2009; otherwise, islands such as the Maldives might well be doomed before the century is out.

Nor is that idle speculation on behalf of climatologists; in 2005 some 500,000 people from the island of Bhola in Bangladesh had to abandon their homes because the rising sea level brought about by the expansion of the surface waters from global warming had flooded more than half the land area.

By 2050, sea level along contiguous U.S. coastlines could rise as much as 12 inches (30 centimetres) above today's waterline, according to researchers who analysed nearly three decades of satellite observations.

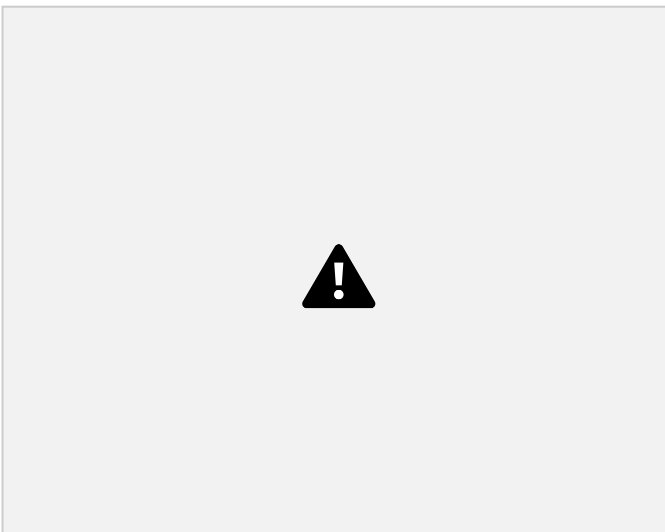


Fig. 35. Satellite image of the largest river delta in the world in India and Banglesh – courtesy NASA

It will not just be the fear of drowning that will drive people away, but the failure of their crops because of the intrusion of salt water into the soil and fresh drinking water. Again, in Bangladesh, as many as 20 million people are at risk on account of rising sea levels.

Monitoring over the past 30 years shows that the sea has risen by 5 millimetres a year and could well rise by one metre before the end of the 21st century. Where will all those people go once they can no longer carry on living in the vulnerable delta region, which actually covers a good third of Bangladesh? Will the rest of the world help, especially when the impact of climate change will not be limited to just one region?

Since it is we human beings, with our growing population and needs, who are in all probability upsetting the balance and causing dangerous climate change, it is up to us to do something about it. But what? One way is to try and reduce our impact on the environment, by cutting back substantially on our use of fossil fuels with the purpose of reducing the emissions of greenhouse gases, while still attempting to maintain or, in the case of developing countries, to achieve a comfortable consumer lifestyle; another way is to adapt, for instance, by building ramparts and dykes to keep the sea out; a third way is to try and offset the global warming now taking place by what is called *geo-engineering*, for example, by erecting enormous mirrors in space so as to reflect sunlight away from the Earth, in the hope of keeping the surface cooler.

Were we collectively to cut back on our consumption of fossil fuels, what would we replace them? Do we have to find an exact equivalent in energy terms to substitute for our growing energy needs, watt for watt so to speak? Or can we reduce our energy demands by improving energy efficiency all the way from production to end use – that point in the home, factory, vehicle, or public building, where we actually switch on our appliances? And what about forms of energy production, that emit far less greenhouse gases per unit of energy consumed and which are renewable, such as wind turbines, wave machines, photovoltaic devices, solar thermal plants, the growing of special energy crops, like sugar cane, or African palm, geothermal plants, like those currently used in New Zealand and Iceland, and tidal barrages, like the mega one proposed for the Severn Estuary in England? Will they add up to providing us with an adequate and sufficient substitute for fossil fuels? While all those technologies are either in use or being developed, it must be remembered that fundamental limits exist as to how much we can tap. The Sun is not just there to power our machines but actually generates the movement of oceans, the formation of clouds which bring rain, the movement of the air mass, such that we have winds, allows plants to grow through photosynthesis, keep us warm and gives the Earth its seasons such that it does not freeze over.

It may be that the only way we can properly substitute for fossil fuels is through international cooperation on a scale never seen before, such as the construction of a direct current super electricity grid that can efficiently and conveniently bring energy into our homes and workplace from thousands of kilometres away, indeed from different countries in the world, some blessed with clear skies and direct sunlight, such as North Africa, others with an excellent wind regime such as the United Kingdom, others with large tidal ebbs and flows, such as Fundy Bay in Newfoundland.

The concern is that global warming will cause more violent extremes of weather than those which we currently experience and which can be absolutely

devastating, as happened with the horrendous mudslides in Venezuela in mid December 1999, when over two days, Caracas and the neighbouring region received the rain it would normally get in an entire year. Then some 23,000 people lost their lives and 150,000 lost their homes. Late in September 2009, the Philippines too suffered unprecedented floods which left as much as 80 per cent of the Capital City, Manila, under 2 metres of water and caused hundreds of thousands to have to flee from their homes. Meanwhile, Hurricane Katrina, designated as category 5, which struck the Louisiana coast in August 2005, and devastated the city of New Orleans, gives us some idea of the power of single extreme weather events to change the course of history. Many failed to escape the city in time or decided to stick it out, and more than a thousand died. Twelve years later, in 2017, Hurricane Harvey, a category 4 hurricane, made landfall in Houston, Texas, and caused damage exceeding $125 billion.

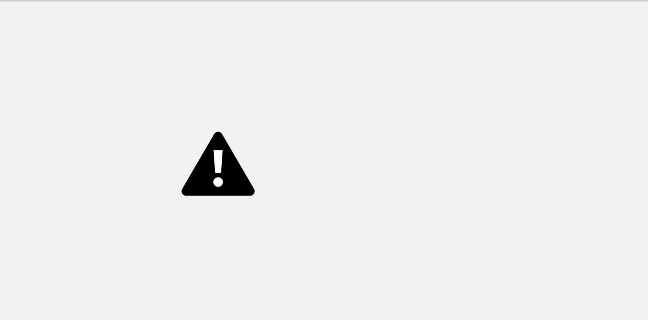
Climate policy has been an unwieldy beast. In the USA, under George Bush's tenure as president, the U.S. administration was sceptical of human contributions to climate change, attributing potential changes to natural climate variability. This scepticism led to the U.S. withdrawing from the Kyoto Protocol, an international agreement aiming to reduce greenhouse gas emissions by 5% below 1990 levels by 2012.

In contrast, President Obama acknowledged the reality of human-induced climate change, notably due to the surge in greenhouse gas emissions since the Industrial Revolution. His administration's recognition of this issue was marked by a pivotal agreement with Ban Ki-moon, the then Secretary-General of the United Nations, at the G8 summit in Italy in 2009. They concurred on the necessity for global action to limit the rise in global surface temperatures to no more than 2°C over the century, calling for an 80% reduction in greenhouse gas emissions by 2050. This objective underscored the challenge of balancing the energy demands of both developed and developing countries with the need for sustainable development and minimal greenhouse gas emissions. Based on what we see happening, the feasibility of reducing greenhouse gases, while resource consumption levels globally remain high, is very unlikely. The year 2023 saw a record increase of 5 ppm of CO_2 emitted into the atmosphere.

A key moment in to fight against climate change came with the Paris Climate Accord, formally known as the Paris Agreement. It was adopted on December 12, 2015, by 196 parties at the 21st Conference of the Parties (COP 21) to the United Nations Framework Convention on Climate Change (UNFCCC) held in Paris, France. It marked a historic turning point in global efforts to combat climate change, with the central aim of keeping the increase in global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase even further to 1.5°C, a value we are now beginning to exceed. The agreement requires all participating countries to submit nationally determined contributions (NDCs) and to pursue domestic measures aimed at achieving their targets, with the intent of increasing ambition over time. Furthermore, it established mechanisms for financial, technical, and capacity-building support to help developing countries adapt to climate change and transition to clean energy.

The adoption of the Paris Agreement has had profound consequences for global climate policy and action. It has galvanized international momentum, with countries, cities, businesses, and civil society groups taking unprecedented steps to reduce greenhouse gas emissions and invest in renewable energy and sustainable practices. The accord has also spurred innovations in climate finance and the development of low-carbon technologies. But all of this has not resulted in less emissions of CO_2. On the contrary, in 2023 we saw record temperatures and a sudden acceleration of ocean surface temperatures in several parts of the world. Indeed, the challenges have only become greater, including disparities in the capacities and contributions of developed and developing countries, the need for increased financial support for climate adaptation and mitigation, and the urgency of enhancing the ability of Newly Developing Countries (NDCs) to meet the accord's temperature goals. Despite these hurdles, the Paris Agreement remains a cornerstone of international efforts to address climate change, reflecting a collective commitment to a sustainable, low-carbon future. But as we shall see, that is leaving out half of the story on climate change: carbon emissions heat up the atmosphere, but water, in its interactions with the biosphere and the atmosphere actually functions as a cooling device.

Climate change, global warming and the impacts on Colombia:



Páramos: Water Soakers and River-makers

Frailejónes *(Espoletia)* Páramo (Colombia), Foto: Carolina Figueroa

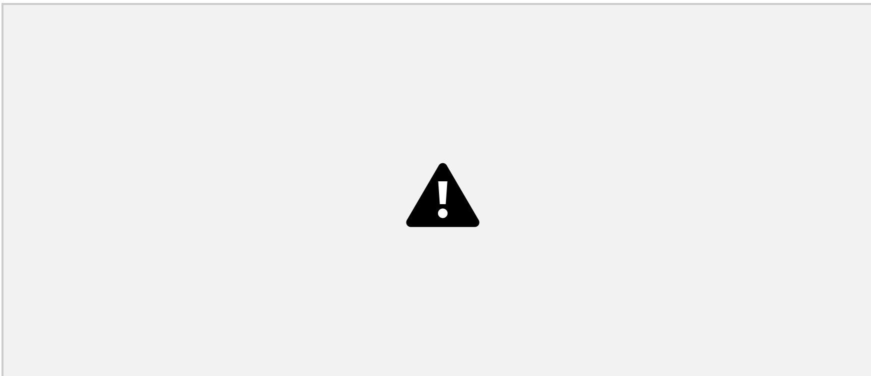


Fig. 36. Paramos in the high Andes, the sponges that soak up Amazonian rains - Photo Carolina Figueroa

If anywhere in the world were to be a litmus test that climate change and global warming were a reality, it would be Colombia. *First and foremost*, Colombia is an equatorial country with a foot in both hemispheres; *second*, it has a coastline which stretches from the Pacific Ocean to the Atlantic, with the two oceans separated by the Isthmus of Panama and the Darien Gap; *third*, in Colombia the Andes divides

into three distinct chains or cordillera, each with its own range of microclimates and ecosystems; *fourth*, it has the highest mountain massif, the Sierra Nevada de Santa Marta next to the sea of anywhere in the world; *fifth*, it has the highest biodiversity for its size compared to any other country, with more bird species, butterflies and orchids than can be found elsewhere; moreover, because of the Isthmus Colombia has been the gateway throughout evolution for species to move from Central America to South America and vice versa; *sixth*, and not least, Colombia has a biodiversity-rich part of the Amazon Basin, through which important rivers flow that have been generated in the Colombian highlands. In fact, Colombia has every imaginable ecosystem, from the coral reefs of the islands such as San Andres and Providencia in the Caribbean, the deserts of La Guajira along the coastline between Colombia and Venezuela, the cloud forests of the Andes, the wettest tropical forests in the world in the Chocó aligned along the Pacific coast; the swamps (Cienegas) of the north; and not least an extraordinary portion of the Amazon, with its rivers, indigenous communities and spectacular remnants of the Guiana Shield, which is severed apart by the Caquetá River at Araracuara.

Some 500 years ago, before the arrival of the Spanish conquistadores, Colombia was a country supremely well provided for with water resources, whether on account of the extensive high Andean glaciers, the Cienaga swamp regions in the northern part, and the upper moorlands, the páramos, which soaked up rain that had arrived with the prevailing winds over the Amazon Basin. Still today, the climate of Bogotá in terms of rainfall is very much an Amazonian one and more than half the rainfall of Colombia is derived from that same source. How important for Colombia is that the hydrological, and climate system of Amazonia remains intact. Consequently, we must look very carefully at the threats to the Amazon's climate brought about through climate change and in particular global warming.

Today, Colombia is threatened as never before with water shortages on an ever spreading scale, and it must be remembered that water is used in irrigation, especially in the Cauca, Magdalena and Tolima Valleys and for electricity generation, quite aside from the intensive use of water in the industrial and domestic sector. Gravity irrigation systems are used for the most part to water some 900,000 hectares and the efficiency of use is low with the result that Colombia is suffering from salts brought up from the subsoil and left as crystals on the soil surface. The high use of fertilisers and pesticides is contaminating water courses and having a deleterious impact on the environment.

In general, climate change and global warming threaten to cause:

1. A rise in surface temperature across Colombia;
2. Rapid and unexpected loss of glaciers;
3. Degradation of the páramos, with loss of ability to retain water; 4. Sea level rise, thereby threatening the coastal region and islands such as San Andrés;
5. Changes in the pattern of precipitation;
6. Loss of CO_2 from soils and biomass;
7. Soil degradation and erosion (Valle de Cauca);

8. Dramatic decline in the rains derived from the Amazon Basin;
9. Severe impacts on agriculture;
10. Increase in tropical diseases such as malaria, dengue and yellow fever:
11. Serious, irreversible loss in biodiversity;
12. Thousands of environmental refugees each year from a deteriorating environment.

Laguna de la Cocha in the High Putumayo (9,500 ft), The lake is fed by the air circulation over the Amazon. It then drains back into the Amazon, completing the cycle

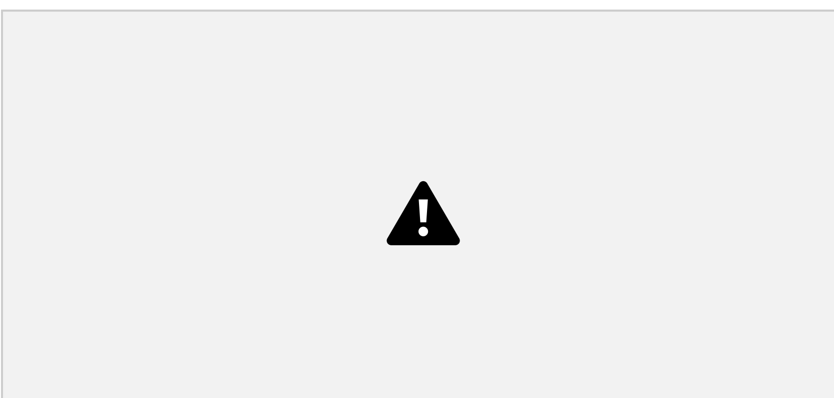


Fig. 37. Lake de La Cocha in Colombia and huge moisture clouds overhead,

carried in by the Walker Circulation from the Amazon Basin - Photo Peter Bunyard

Glaciers all over the Andes mountains have melted considerably. For example, the Colombian Sierra Nevada Santa Marta lost more than half of its glacier surface compared to 1990 when it had about 10 km^2. In 2022, just 5.3 km^2 are left. In Colombia alone, according to IDEAM (Institute of Hydrology, Meteorology and Environmental Studies of Colombia) Colombian glaciers have lost 92% of their glacier area since the end of the 19^{th} century. Furthermore, in the last 50 years, it is estimated that they have lost 3 to 5% of their glacier area per year.

Glacier melt is widespread across the globe, in Latin America, North America, Asia and Africa with enormous consequences for drinking water and agriculture in these areas. Approximately 2 billion people rely on rivers originating from what has been called the ''Third Pole''. The Hindu Kush-Karakoram-Himalayan mountain ranges together with the Tibetan highlands span over 4.2 million square kilometres across nine countries in High-Mountain Asia, bordering ten nations. This vast region, housing the world's highest peaks, including all 14 above 8,000 metres, earns its nickname due to its significant ice reserves, second only to the polar regions. This

area serves as the water tower for much of Asia. Ten major rivers originate from this area, including the Yangtze, Yellow River, Mekong, Ganges, Indus, Brahmaputra, Salween, Karnali, Sutlej, and Amu Darya. The Third Pole Region, which includes the Tibetan Plateau and surrounding areas, is home to approximately 95,536 glaciers. These glaciers cover an area of about 97,606 square kilometres, according to the Randolph Glacier Inventory Consortium 2017. It plays a crucial ecological role as well as supporting about 2 billion people with water resources. These rivers are vital for drinking water, agriculture, and hydropower in several countries across Asia, including China, India, Thailand and Vietnam. The melting of these glaciers would be an unimaginable catastrophe.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Chapter 6

The Amazon: Its Vital Role in Moderating the Climate

Over the Amazon Basin, 2005 was a year without precedence. Never before in recorded history had the region, especially in Brazil, suffered such an extensive and devastating drought, not even in the years of strong El Niños, when the Tropical Pacific Currents switch direction, and the trade winds, skimming over the surface from Africa to South America, falter and die away. 2005 should have been a normal, non-El Niño year, with strong trade winds picking up enormous volumes of water vapour from a warm tropical ocean, and dumping their load over the humid tropical Amazonian forests of Brazil.

But that is not what happened. Instead, the weather systems of the North Atlantic had transformed dramatically, with the Azores, normally a region of high pressure and sinking air, becoming a region of low pressure, with warm, moist air convecting upwards. Such a turn-around could explain in part why southwest Spain had its first-ever tropical storm; why the hurricane track hit further south than normal, striking well within the Gulf of Mexico and washing out New Orleans into the bargain; it could also explain why the Caribbean coast of Colombia was subjected to unprecedented rains in November, causing widespread flooding and deaths; and why the central and western Amazon Basin was left high and dry.

During the Amazonian drought, river levels fell to their lowest ever, and Brazilian authorities declared four municipalities 'disaster areas' and another 14 in a 'state of alert'. Fish died in their millions for lack of oxygen in the turgid waters of the myriad of tributaries that feed into the Amazon River. A heavy layer of cold, dry air had formed close to the ground, encompassing hundreds of thousands of square kilometres, reaching right up into the Colombian Putumayo, and effectively preventing the convection process that leads to thunderstorms and rain. Held down by that layer, the smoke from more than 30,000 forest-clearance fires in Brazil and some thousands of fires in the Bolivian Amazon had nowhere to go, except to make life extremely uncomfortable for people in Brazil, Peru and Colombia, who had to put up with a burning throat and smarting eyes for days on end. Aircraft were unable to land in Leticia and Tabatinga, the latter just across the border from Colombia, and when the smog was at its thickest, no one dared make the crossing to the other side of the Amazon River for fear of colliding with a floating log, or worse still another boat.

Was global warming to blame? Certainly, sea surface temperatures across the Caribbean were at their highest recorded, not just spawning more hurricanes than ever before, but leaving coral reefs bleached of algae and dying. The loss of the reefs, and the loss of mangrove swamps, all led to the coastline becoming ever more vulnerable to sea level rise and storm surges.

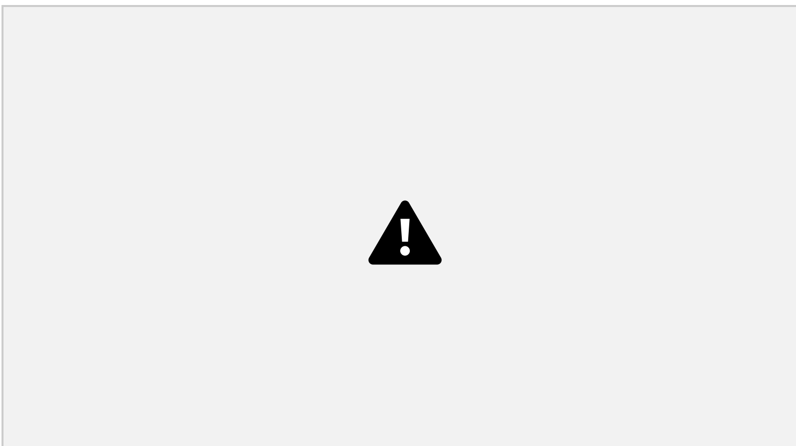

Fig. 38. Manaus, Amazonas, Brazil 09.29.23 View of what's left of the river at Marina do David in Manaus – Photo Jesper Sohof/Shutterstock.

But, what about deforestation across the Latin American tropics and in particular across the Amazon Basin? Could deforestation, with resulting alterations in the transport out of the tropics of latent heat in the form of water vapour, have played a role? The answer is we do not know, not precisely. However, as we are being made increasingly aware, even small changes in heat transfer from the equator to the high latitudes, can have a profound effect on weather systems. What should worry us is whether the changes that occurred in 2005 across the tropical Atlantic could become a permanent feature. Were that to be the case, then we could see the demise of the great tropical rainforests that currently cover vast expanses of the Amazon Basin. Under those conditions, South America's agriculture may well not survive in its current form. And where would Brazil get its water to feed its hydroelectric dams that now supply some 80 per cent of the country's electricity?

In 2023, this time during an El Niño year, the Amazon Basin suffered a far worse drought than in 2005, with the same symptoms of large rivers drying out and not just fish, dying by their millions, but river dolphins too. Emergencies were declared throughout the southern part of the Amazon in Brazil. Drought, too, affected Uruguay, Chile and Paraguay.

Already, from Tocantins right up to Guyana, we are seeing the Amazon Basin drying out and forming a savanna, with its mixture of drought-tolerant shrubs and grasses. That may well be the beginnings of desertification, indicating that the natural watering system over South America is breaking down; and that the forests are no longer able to sustain themselves. Without the forests, all the countries in South America would suffer dramatic changes to their climate and rainfall. In essence, it would be catastrophic, and the rest of the planet escape.

All tropical rainforests affect climate, either locally or regionally, but the Amazon Basin stands out because of its size and therefore its role in using water captured

by the Trade Winds of the tropical Atlantic Ocean to provide essential rain to much of the rest of South America. The corollary, that without the tropical rainforests of the Basin, much of South America would suffer a fearful water shortage, is in all likelihood true. The Amazon Basin is also linked to North America, Europe, and South Africa by standing waves of humid air that travel outwards from the Basin in a process described as 'teleconnection'. Months after winter rains over the rainforests of the Basin, rain brought in by teleconnection gets to the Corn Belt of the United States, just in time for the Spring spurt in growth. Another teleconnection gets rain to South Africa six months after the winter rains over the Amazon. We are beginning to discover just how important the Amazon rainforests are for the world's climate, once we have worked out the time lags between an event somewhere and its consequences months later.

In Brazil, large areas have been cleared in order to plant soybeans, particularly in the State of Mato Grosso which flanks the State of Amazonas. Subsistence farmers, too often have little idea how to farm in the heart of the tropics, where soils are often fragile and depleted of nutrients. For lack of opportunity, such colonists may be forced to occupy the least fertile areas, where their actions rapidly deplete the soil. The net result is a cancer-like need to clear more forest, just for subsistence.

Governments and corporations tend to blame rainforest destruction on the actions of subsistence farmers and settlers. However, in countries such as Brazil and Indonesia, government schemes have deliberately encouraged the 'colonisation' of rainforests and, throughout the Tropics, small-scale farmers have been forced off their own lands and into poorer forest areas by large agricultural companies, as during the 1970s and 80s when small-scale tenant farmers had to leave the rich fertile lands of Rio Grande do Sul in the southern part of Brazil. In point of fact, in Latin America and no less in the Brazilian Amazon, extensive cattle ranching has become the major cause of deforestation, both in bringing about primary deforestation and in taking over land which had been colonized, but because of a rapid decline in soil fertility and hence production, had been abandoned or in reality sold on.

6.1 AMAZON DESTRUCTION

Going back at least 50 years, Brazil has unleashed a process of development in its Amazon Basin that is leaving vast areas shorn of trees. A combination of satellite imagery and verification on the ground suggests that, by 1998, the area of forest cleared in the Brazilian Amazon had reached some 549,000 square kilometres, hence about the size of France out of a total area as large as Western Europe. In the ten years since, another 150,000 square kilometres have gone, with 24,000 square kilometres alone being destroyed in 2004 – an area larger than Belgium. In 2004, remote satellite sensing picked up more than 35,000 separate fires in the Brazilian Amazon and the situation was only marginally

better in 2005.
Meanwhile, because of government intervention in controlling deforestation and in no small measure because of the downturn in global economy, the year between 2008 and 2009 saw the annual deforestation fall to some 8,000 square kilometres.

In no more than a few decades, Brazil has managed to deforest an area far greater than that lost over the preceding five centuries of European colonization.

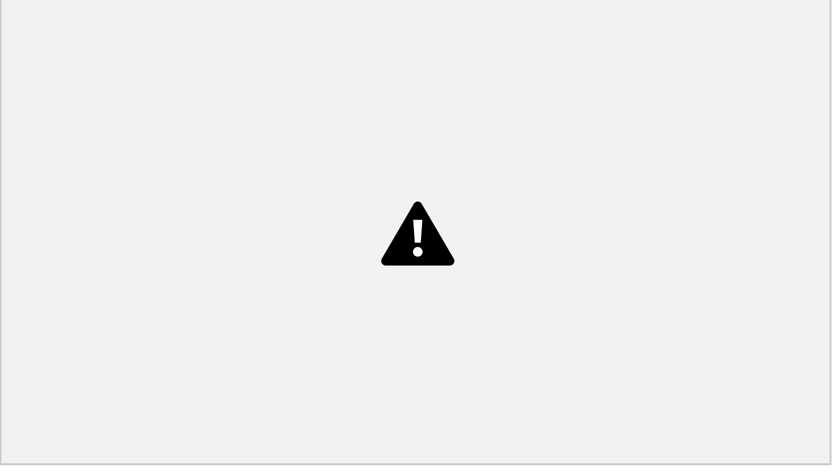

Fig. 39. Huge Soy Bean plantation after original vegetation was removed. - Photo Marcus Mesquita /Shutterstock

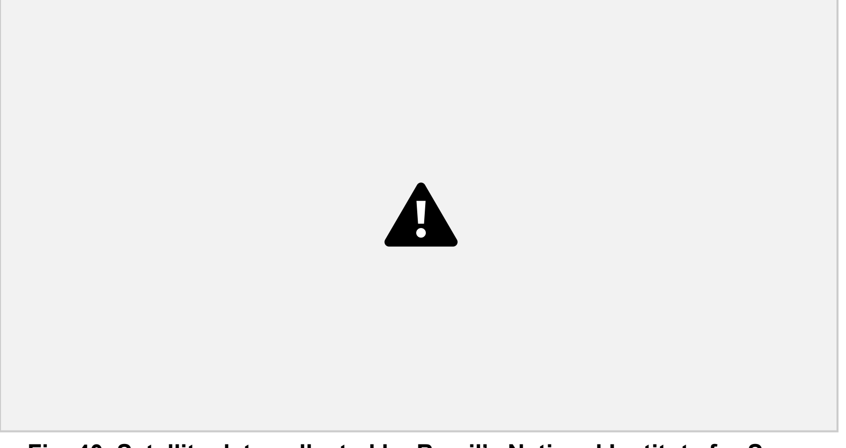

Fig. 40. Satellite data collected by Brazil's National Institute for Space Research (INPE) from August 22, 2019. Around 75,000 fires across the Amazon since the start of that year – Courtesy NASA Worldview

Climatologists are now discovering just how important the forests of the Amazon Basin are for regulating climate across the globe. The usual idea of the Amazon Basin is as the lungs of the world, somehow allowing the rest of the world to breathe. But wouldn't savannah or grassland do the job just as well as tropical rainforests and what about the rolling green hills of England? A much better analogy would be that the rainforests of the Amazon Basin are the 'heart' of the world because of all the water vapour and energy that gets pumped out of the region. In fact, tens of times more energy is pumped out than all the energy used by human beings in the world today.

That being the case — that the Amazon Basin is a gigantic irreplaceable pump that gets heat out of the tropics to the higher latitudes and out to Space — perhaps we should start worrying about what will happen to the climate if we insist on cutting down great swathes of trees.

Certainly, what happened in 2005 and 2023 throughout the Amazon Basin, not just in Brazil, but in Colombia and Peru, should be a stark warning that we may be close to the limits if we haven't gone beyond them.

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, akin to a straight line on a graph until all the forest has one. By using a higher resolution 'mesoscale' modelling – therefore focus on a limited region, in this instance, Rondônia in Brazil's western Amazonia — Roni Avissar, previously at Duke University in North Carolina and now at the University of Florida, and Pedro Silva Dias, from São Paulo have uncovered a very different picture, with rainfall actually increasing when clearings are not too big, but then after a critical point, dwindling away rapidly and causing the remaining forest to crash.

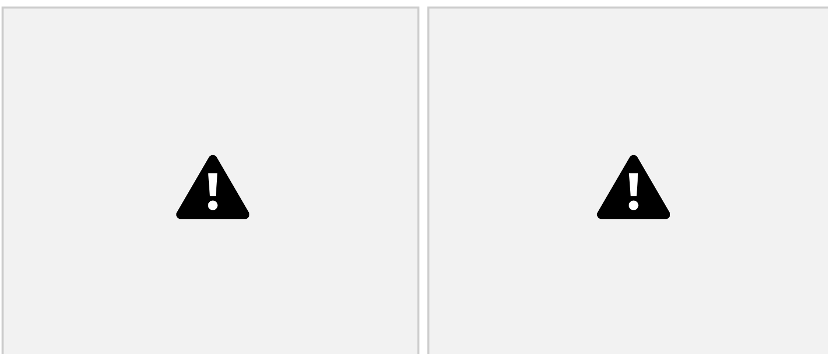

Fig. 41. Graph showing the relation between precipitation and size of forest clearing. Smaller ones increase precipitation, large one dry out and the forest dies back. – taken from discussions with Roni Avissar by Peter Bunyard

When a clearing is no more than a certain size, probably no more than a few kilometres across, and if the forest around is relatively intact, then the mass of

warm air that rises over the clearing, will suck in cooler, more humid, air from the surrounding forest. That convection process leads to the formation of thunderstorms. Under those circumstances, rainfall will increase, perhaps by as much as 10 per cent. On the other hand, make the clearing relatively large, when the forest is no longer large enough to moisten the up- draught of air, and the convection process literally runs out of steam. Rainfall then declines sharply.

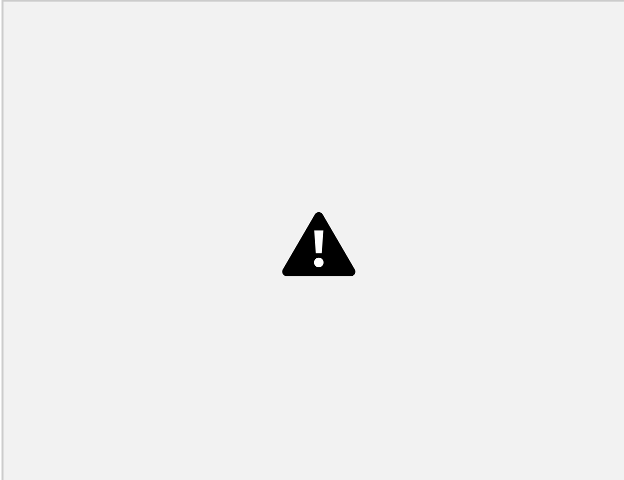

Fig. 42. Relation between size of clearing and precipitation – Graph Courtesy Dr Werth and Dr Avissar

6.2 DEFORESTATION AND FIRES

Thunderstorms and lightning strikes have been blamed for starting fires. Yet, according to Mark Cochrane of Michigan State University and Daniel Nepstad, of the Woods Hole Oceanographic Institute, the chances of fires taking hold in the natural forest as a result of lightning are minimal. Fires in the Amazon are a consequence of deforestation and land-use change. Indeed, Nepstad and his colleagues find that forests that have been subjected at least once to fires are far more vulnerable to successive fires in terms of tree mortality.

Initial fires may cause up to 45 per cent mortality in trees over 20 dbh (diameter breast height) and subsequent fires up to 98 per cent mortality. Meanwhile, during observations of fires in December 1997 fires in the eastern part of the Amazon, in Tailândia, they found that initial fires led to the immediate release of 15 tonnes of carbon per hectare and recurrent burns, up to 140 tonnes of carbon per hectare. Charcoal studies indicate that in lowland tropical rainforests natural fires are rare events, perhaps involving a rotation of hundreds if not thousands of years. According to recent research by Cochrane and Laurance, “Fire-return intervals of less than 90 years can eliminate rain forest tree species, whereas intervals of less than 20 years may eradicate trees entirely. Fragmented forests in the eastern

Amazon are currently experiencing fire rotations of between 7 and 14 years. Previously burned forests are even more prone to burning, with calculated fire rotations of less than 5 years.”

Successive dry years, such as a succession of El Niño years, will also make the forest extremely vulnerable to drying out and fires. During the exceedingly strong El Niño of 1998, says Nepstad, one third of Brazil’s Amazon rainforest experienced the soil drying out down to 5 metres, close to the limits of water uptake through the roots. Consequently, 3.5 million square kilometres were at risk, with some trees having to pull water up from as deep as 8 metres. During that period of stress, Nepstad noted that tree growth went down practically to zero as evidenced by canopy thinning rather than leaf-shedding.

How close are we to that critical point when the forests are no longer widespread and dense enough to sustain their humidity and that of the surrounding air? 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.

The Amazon Basin, as it is now, 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. In addition, just as phytoplankton coccolithophores release cloud-forming substances over the fertile parts of the ocean, so too do the tropical humid forests of the Amazon release terpenes and isoprenes that, on oxidation, form cloud condensation nuclei. Without such a vapour-cloud regenerating system, those rich forests far to the west of the Basin would in all probability vanish. In effect, the process of downpour and then recharging takes place as much as seven times as the air mass moves over the Basin, from the Atlantic Ocean and all the way to the Andes.

This tightly coupled climate system of air currents and forest-driven evapotranspiration is far more vulnerable to deforestation than we believed 30 years ago. The work of Roni Avissar and Pedro Silva Dias and others indicates that expanding the size of a clearing for agro-industry in the Amazon Basin, at least in the southwestern part, will lead to a sharp decline in rainfall and with that the die-back of the surrounding forest. And once the process of die-back begins, like cancer, it will spread deeper and deeper into the remaining forest as a result of the sun baking down on an ever-increasing area. Consequently, day-time temperatures over the cleared areas will rise by 10°C or more compared to the forested area.

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 that 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.

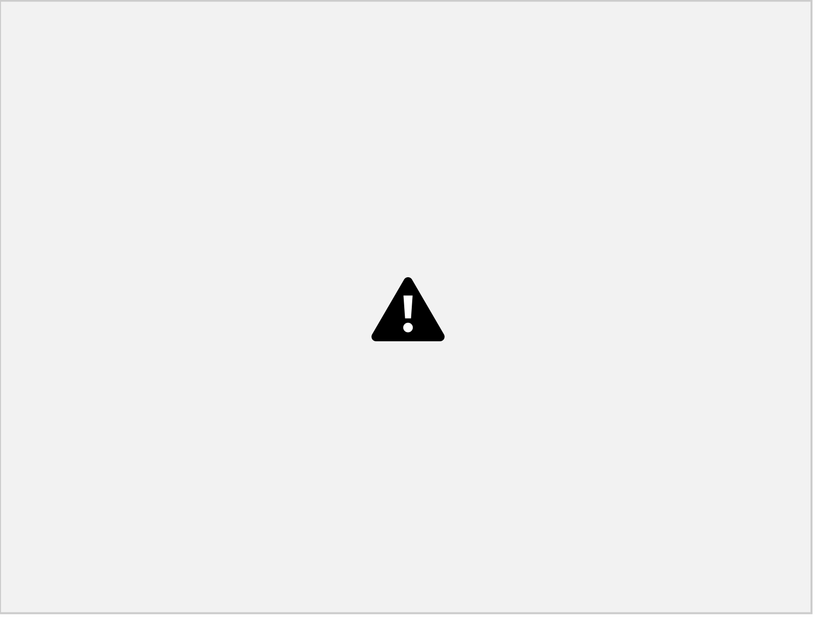

Fig. 43. The high rate of evapotranspiration in proportion to the rainfall, combined with the moist air brought into the Amazon Basin from the tropical Atlantic Ocean, leads to more than 50% of the rainfall being recycled some 6 times over the Basin. Recycling by means of evapotranspiration enables the forest to flourish even thousands of kilometres inland from the oceanic source of the moist air. – graphic Peter Bunyard. (Salati, E., The forest and the hydrological cycle. In: Dickinson, R., Geophysiology of Amazonia, pp. 273-296. New York: W & Sons, 1987.)

The ultimate result of that drying out may well be the desertification of vast areas of the central and western Amazon Basin. But first, we would expect 'savannisation' and that is precisely what appears to be happening, as Lucy Hutrya and Steven Wofsy at Harvard have recently discovered. Changes in hydrology as a result of deforestation within the Amazon Basin will have a massive impact on rainfall patterns over the tropical Andes.

Were it to be so, deforestation and soil drying out would lead to diminished rainfall over the eastern and mid part of the Andes (in Colombia the Andes divide into