# Millan Millan and the Mystery of the Missing Mediterranean Storms

By Rob Lewis, originally published by Resilence.org

Ed.note: Due to some editorial confusion, this piece was originally published as if it was Part 1 of a 3-part series. This is instead the entire piece.

I'd like to introduce this piece with a scenario. Suppose someone pointed out that you'd been looking at the climate through a pair of glasses with only one lens? Lifting them off your nose, they then provide you a new pair of glasses with two lenses. Suddenly, parts of the climate you couldn't see before appear. In addition to the atmosphere, you now see the landscapes around you and the soil beneath your feet, not as helpless victims, but as active drivers of this thing we call climate. Not only that, but you see that at one point, not too long ago, science looked at the climate in just such a manner. It was only later, in the 1980's, that the glasses with the single lens was put before our eyes and declared the official scientific view.

These are some of the insights gained when you follow the path of Millan's career and scientific work, though Millan uses different metaphors, referring to a "two-legged" climate understanding versus the one-legged, CO2-only view, the current orthodoxy. He also shows us that water, which lies at the heart of Earth's climate, "begets water," that soil is like a "womb" for rain and climate, and vegetation acts as a "midwife."

I realize I'm throwing out a lot of metaphors here, but with today's data-driven orthodoxy, metaphors are needed to help us see through the numerical fog. In any case, read on and things will become clear.

## Millan Millan and the Mystery of the Missing Mediterranean Storms

When Mediterranean climate expert Millan M. Millan was a boy, his father brought him along on his frequent partridge hunting forays through the dry scrubland of southern Spain known as the maqui, often stopping to show him how to read the surrounding weather, pointing out how a "cloud in a certain place in the morning would move somewhere else by afternoon, triggering a rainstorm." They'd watch the storms form across the landscape and plan their route home to avoid getting wet. Little could Millan know that 40 years hence he'd be asked by the European Commission to figure out why those afternoon storms, which he and his father so enjoyed tracking across the hillsides, were disappearing throughout the Western Mediterranean Basin, with rivers drying up in their wake.

The future Dr. Millan, Head of the Center for the Mediterranean Environment, degreed in Fluid Mechanics, Industrial Engineering, Aerospace Science, Atmospheric Physics and Spectroscopy, Synoptic Meteorology and Weather Forecasting, would indeed figure out why the summer storms were failing. "Land-use perturbations (mining, industrial expansion, deforestation, paving) that accumulated over historical time and greatly accelerated in the last 30 years" had rendered the land incapable of supporting the region's climate. The storms were vanishing because the land was vanishing, Millan showed, with far reaching implications for our understanding of the human causes of climate change and how we should respond.

Though hailed by Nobel laureate Paul Crutzen as the most significant finding for climate change in twenty years and published in the American Meteorological Association's Journal of Climate and others,1,2 his work was effectively ignored by mainstream climate science, proving as Millan put it, "incommodious." The CO2-oriented, global computer models that came to dominate climate science couldn't see the local, land-level processes Millan uncovered. Politicians, with their pet building projects and "growth" mandate, ran from them.

Millan isn't the only scientist raising the alarm about "land change" as a human cause of climate change,3,4 but at 82 he has been around the longest, long enough to remember a time when science held what he terms a "two-legged" view of climate, with a leg for atmospheric carbon and the greenhouse effect, and a leg for land disturbance and hydrologic effects (water cycles.) By researching past climate reports, I've been able to verify this,5,6 leading to another mystery: what happened to the two-legged understanding of climate? As it turns out, Millan's story answers this mystery also, as we will see.

The boy, whose father pointed to his destiny and who went on to deftly met it, nonetheless feels defeated. "I failed, for all of us," he wrote me once. And indeed, today's climate narrative completely leaves out Millan's work. But I don't think the story is over. The wheel of science is moving toward Millan's understanding, not away, and the scientific case for a two-legged view of climate just keeps building. Now, in fact, is the perfect time to tell his story.

Millan didn't set out to solve the mystery of the disappearing summer storms of the Western Mediterranean Basin. Like much of his story, the key developments were happenstance.

In 1966 the universities in Spain were erupting in student protests and he wanted to focus on his studies. And so, at the age of 24, he departed for Canada to continue his graduate work at the University of Toronto. With months ahead awaiting academic approvals, he sought employment and quickly found it with a Canadian corporation called Barringer Research Limited. There he distinguished himself early on by refining the technology that would eventually equip the metal detectors found in the world's airports, for which he now jokingly apologizes. But it was another instrument, called COSPEC, that would lead him to key scientific and professional insights, and eventual return to Spain.

His instrument, still in use, enables scientists to map plumes of pollutants as they move through the atmosphere, which had become quite necessary as rapid industrialization began choking cities with pollution. Millan felt he could improve on his instrument's application with a deeper understanding of meteorology, particularly the ground level, in-the-field insights concerning how land surfaces affect the flows of air, moisture and heat, for which Ted Munn, a professor at the university, was renowned. Munn was an important figure in the World Meteorological Organization and an expert in a field called biometeorology, which examines not only the effects of climate on living systems  but the effects of living systems on climate. The focus is on the atmosphere's lowest layer, what's called the "boundary layer," the layer in contact with and directly affected by Earth's surface. Munn founded and for twenty years edited the scientific journal, Boundary Layer Meteorology. His books Descriptive Micrometeorology (1964) and Biometeorological Methods (1970) are classics in the field.

Part of Munn's fame was the remarkable skill he demonstrated during WWII, forecasting weather for allied forces from the island of Newfoundland, never losing a plane or ship. Millan speculates that "he had moved from the large-scale systems he worked with during WWII to find out how those large meteorological processes were driven from the surface upwards." This is a key insight. Climate change is generally portrayed as having a downward pointing arrow of causation, from the atmosphere down, with the land acting as a passive receiver of climate change. But the arrow also points upward, from the land, with the land behaving not only as climate receiver, but climate driver as well.

Munn quickly took notice of his new student who seemed to already possess an intuitive understanding of the lecture material. "He was giving me the scientific explanations for my father's observations," Millan writes. For his part, Millan, who also loves the outdoors, was thrilled to be able to take his talents out of the laboratory into the natural world where, as it had for Munn, meteorology came alive for him. They soon became colleagues and friends in a 45 year long "tutorial and cooperation."

By 1969, Millan was fully engaged in his studies, plowing through a syllabus which Munn had custom designed for him, while at the same time taking Munn's courses in biometeorology. One day Munn handed him the draft for a book called Inadvertent Climate Modification: Study of Man's Impact on Climate, a joint production of MIT and the Royal Swedish Academy of Sciences. It was the first broad scientific assessment of anthropogenic climate change in the modern climate age, and Munn was the coordinating author for a chapter entitled Climatic Effects of Man-made Surface Change. He asked Millan to check the concurrences between text, references and figures, an assignment which crystallized the two-legged concept for Millan, for it was clearly laid out in the book. Its opening paragraph, for instance, lists "Climatic effect of manmade surface change" and "Modification of the troposphere and stratosphere" as "major areas" for consideration. Under the heading "Man's Activities Influencing Climate" there's roughly equal treatment for subsections concerning both "Atmospheric Contamination," and "Land-Surface Alteration." Under "Major Conclusions and Recommendations" is Munn's chapter "Climatic Effects of Man-Made Surface Change," as well as chapters concerning atmospheric greenhouse gasses.

"The idea was that both greenhouse gases and land use contribute to climate change, but at different rates," writes Millan. "Land-use changes the hydrologic cycle immediately, at a small or larger scale, depending on the perturbation. Greenhouse gases are already there," meaning they spread out globally and don't change day to day. He speaks of "two rates of climate interaction and two basic mechanisms."

For land change, the mechanism is hydrological, the water cycle; it occurs quickly and at local to regional scales. If you clearcut a forest you immediately destroy the water cycle in that place, and with it the cooling mechanism of the forest. Water vapor (along with carbon) begins burning out of the soil, and within a few hours the temperature can rise upwards of 20oC.

For greenhouse gases, the mechanism is the global spread and increase of gases that absorb outgoing long wave radiation, the greenhouse effect, steadily heating the planet. It's a slow process; the person sweating in the clearcut won't feel it, but it's relentless. The concentration of the gases just keeps building, subjecting the entire planet to geological scales of change that are difficult to contemplate.

The point is, it's not one or the other, but both. "Two legs is just a concept that implies an atmospheric (greenhouse gases) component and a surface (land change) component." A concept which, he writes in his book, "lingered in my mind for years, coming back to me twenty years later when I was asked to look into the matter of a perceived decline in summer storms around the Western Mediterranean Basin."

Demand for Millan's Instrument continued to grow, and in 1974 he was asked by officials of the European Commission (EC), operational body of the European Union, to bring his instrument and expertise to Spain to help them track the spread of industrial pollutants in the rapidly industrializing southern coast. He wasted no time accepting, and was soon back home, a few valleys over from where he and his father had trekked. It was while in the maqui setting up field instruments that he began to hear about the summer storms. Locals would come around and make comments like "what you are trying to do seems interesting, but the real problem in this place is that it does not rain as much as before." Remembering Munn's advice to treat the observations of locals as critical field data, he always took careful notes, which would later prove invaluable. But he was dealing with air pollution at the time, not climate, so there wasn't much he could do but bring the comments up at meetings with higher officials.

Eventually, in 1992, the issue caught the attention of the European Commission's Unit Head for Environment, Dr. Heinrich Ott. By then Millan was director of CEAM, Mediterranean Center for Environmental Studies, a large scientific research organization. In a meeting over general matters, the summer storms came up, and Ott asked Millan to apply his nearly two decades of field notes and data to the problem. And so began Millan's transition from science director to science detective.

Millan is a highly technical and practical scientist, steeped in physics and with an engineer's stamp. Yet he turns poet when describing how soil, water and plants all work together to recycle water, employing the tercet: water begets water, soil is the womb, vegetation is the midwife.

What he means by water begets water is that healthy landscapes seem to grow water. Of course, water just can't be created. There's a set amount on earth, and though we think of it as spread amongst oceans, lakes, rivers and glaciers, it is also inside living things. Humans are 60% water, birds 75%, fish 70 to 84%. A typical cat weighs in at 67%, while plants and trees are almost entirely water, 80 to 90%. How much water a landscape can hold is therefore proportional to how much life is in the landscape and soil to hold what arrives in periodic pulses from major water bodies, like oceans and lakes, via atmospheric currents. This water, once held, is transpired by vegetation back into the atmosphere as vapor to make clouds and future rain. Like this, the same water is recycled over and over, up and down, across landscapes. Though it used to be thought that virtually all inland water came from large water bodies and atmospheric circulations, it's now realized that 40-60% of most rain comes via this recycling, increasing the farther inland you go. It's called the small water cycle, and in some places, like the Amazon, it is responsible for 80% of the rain. The more life in a landscape, the more water it can "milk" from ocean flows. It's a self-amplifying circle: water, through life, begetting more water, begetting yet more life, gathering yet more water, and around it goes, the result being increased climate cooling and moderation.

Soil is the womb because it holds the water. But here again it is really life holding the water, the rich below-ground microbial community which makes the difference between compacted, water-repellent dirt and clumpy absorptive soil. Picture soil as a sponge, held together but full of tiny cavities. There are grains of sand, clay, and minerals within that matrix, but what binds them into a sponge is life, an astounding plethora of the invisible and nearly invisible: protists and bacteria, nematodes and soil mites, and up to eight miles per square inch of fungal hyphae. It is their exudates and decaying bodies which not only glue the particles together, but hold them apart, making room for the water so crucial to all life. When it's all working together, a very fortuitous feedback loop appears—the more carbon in the soil, the more water the soil can hold. The more water in the soil, the more vegetation it can grow. The more vegetation it can grow, the more moisture it feed the sky and the more carbon it draws down into life and soil. It's a virtuous cycle, "begetting" water, sequestering carbon, unseen and underground, womb-like.

Vegetation is the midwife because it delivers the water to the atmosphere as vapor, where it rises, condenses, and falls again as rain. But vegetation doesn't only send up water vapor, it also delivers the seeds of future rain drops, called cloud condensation nuclei. These are microscopic grains of various biota, such as bacteria, fungal spores, and released vapors, all of which have uniquely low freeze thresholds, hastening the vapor's condensation from vapor to water and its subsequent return to land as rain. The vegetation sending up the water is also bringing it back down in another virtuous, self-amplifying cycle.

You've probably noticed water features prominently in this analysis. That's because from the standpoint of climate, water is elemental. For one thing, it has the highest heat capacity of any common earthly substance and can therefore move massive amounts of heat around. It's why ocean currents are so critical to global weather. The oceans have been absorbing huge amounts of heat and are now moving that heat around, supercharging storms and droughts alike. But as previously mentioned, water also has an additional ability:

to phase-change, to go from water to vapor and back again, exchanging heat at each juncture.

Here's how it works. When water goes from liquid to vapor (evaporates) there is a cooling, no different from what we feel when we sweat in a breeze. That's because the phase-change from water to vapor uses heat, drawing it from the surroundings, which is felt as cooling. The heat required to turn liquid water into gaseous vapor, 540 calories per gram water, enters the vapor as a chemical potential called latent heat, like a spring pulled back. When the vapor rises and condenses back to liquid, the equation reverses, the spring rebounds and the same heat is released, only higher in the atmosphere. Though most of that heat will return to earth miles, even thousands of miles away, some will escape.

Scientists use the term transpiration for this ability of plants to turn water into vapor, but it can also be thought of as a kind of sweating. Since green is a darkish color, the tree or plant is not only absorbing sunlight for photosynthesis but is also absorbing a good bit of heat. To get rid of that heat, it basically sweats. Under each leaf and needle are thousands of microscopic pores called stomata, which release moisture during the daytime, keeping both the plant, or tree, and its surroundings cool. Tremendous volumes of water are involved in this process; 100 liters per day for a typical tree. A gram of water requires 540 calories to evaporate. At 100 liters/per day for a typical tree, that translates to a cooling equivalent of 54,000 kcal, or 2 hotel air conditioners running all day. Add the evaporative cooling of soils and you have a sense of just how powerful a forest or woodland is at cooling its surroundings.

With Millan's tercet in mind, let's look at what happened in the Western Mediterranean Basin, that portion of the Mediterranean west of Italy, particular the area around southeast Spain, where we humans have been, well, changing things for a while.

The Western Mediterranean Basin was once lush, with vast oak forests, springs and extensive coastal marshlands. Early Romans said a squirrel could travel limb to limb from the Pyrenees to the Strait of Gibraltar and never touch the ground. Two thousand years ago, that began to change in earnest with the steady spread of the Roman Empire. Marshes were drained first to counter endemic malaria, then for agriculture, with widespread deforestation and mining in the mountains. By the 16th century much of the oak forests were cut and lowland agriculture was spreading higher into the mountains, along with grazing and further land clearing. Then came the industrial revolution, followed by modernity. In the 1950's, mass urbanization sealed yet more land as Spain industrialized. A booming tourism industry was particularly devastating for Spain's coastal marshes, covering key links in the water cycle with parking lots and hotels. Then, in the early 1970's, due to unrest in the Middle East, petroleum infrastructure was moved across the Mediterranean Sea from the Middle East to the shores of Spain, France and Italy, resulting in "intense industrialization of the coasts."

Millan confronted a basin-wide hydrologic system in the final stages of collapse. The midwives had not only been cut, but the climatological regime by which the oaks of old could live had long passed. In its place was a much dryer climate, supporting mostly pinyon and scrub, the maqui. The soil womb was mostly eroded away, stretched in places over bare stone. A classic example of how badly things can go wrong is found in the nearby province of Almeria. In the 1850's its dense oak forests were clearcut to stoke the furnaces of lead smelters. The collapse to desert was so profound that the area eventually became a film locale for spaghetti westerns. Millan has come to believe the entire Western Mediterranean Basin is at such a tipping point, on its way to becoming an Almeria style desert, a point from which it is very difficult to return. "Once you hit rock," he says, "you're done."

Remembering Munn's advice to listen carefully to the observations of locals, he recalled a day when an old-timer told him of a local saying: "Cierzo a las siete, Solano a las diez, agua a las tres." Roughly, sea breeze in the morning at ten, rain in the afternoon at three. He thought about the tracks of the clouds he had watched as a boy moving up higher and higher into the mountains, gaining mass, dropping rain by afternoon. The refrain was revealing. For the sea breezes still came in off the sea each morning around ten, yet come afternoon, around three, the storms failed to materialize. The collapse, he reasoned, occurred in between.

Using traditional meteorological data, he uncovered a key detail. When the morning winds came in, their water content was 14 grams per cubic meter of air, not enough to form clouds, which under those specific conditions would require a moisture level of 21 grams water per cubic meter. The rest of the moisture, 7 grams per cubic meter, would have to come from somewhere else, which brings us back to the land.

At one time, that same sea breeze passed over vast coastal wetlands stretching miles inland, gathering the water vapor rising off of them. Then, proceeding toward the mountains, it would gain even more moisture from the great oaks, each a water tower in its own right. By the time it was climbing up the last high ridges it was saturated not only with moisture but cloud condensation nuclei. One can imagine the thunderheads billowing up, stacked plumes rising two miles in the air, the afternoon storm all but guaranteed, dropping cold rain back on the land, rehydrating the vegetation, recharging the aquifers and marshes, and releasing their latent heat to dissipate high over the mountains.

Now, however, rather than marshes and oaks, the sea breeze encounters concrete, steel and glass. Not only is it deprived of the moisture it needs to make storms, it's buffeted by the heat rising off the man-made materials, gaining 16oC before reaching the mountains. What finally reaches the hills finds shrubs and scattered pinions, skeletal remains of the ancient oak forests. Not only is there too little evaporative (respiring) life to provide the missing 7 grams water per cubic meter air to make the rain cloud, but the intense heating of the air mass means it requires even more moisture to do so. The pattern now is a few clouds gather in the late afternoon, rise, spread, then wisp away. The warm, moist, now-polluted air, instead of releasing its gathered heat and dropping rain on the land to replenish the system, merely flows back over the Mediterranean Sea.

This roughly explains the loss of summer storms, but the process doesn't end there. The moist, polluted layers of air pile up over the Mediterranean Sea, layer upon layer, day by day, three to five days at a time. Those layers, soupy with powerful greenhouse gases like water vapor and ozone, steadily warm the sea below, so that by the end of summer the warmed sea begins supercharging coastal storms, as well as storm tracks that curve down over the Mediterranean on their way back up to central Europe. These storm tracks gather up the warm, moist layers and become supercharged as well, contributing to the devastating floods in Eastern Europe.

Where did the summer storms go? They left with the forests, soils and wetlands. Why are the coastal storms getting worse? In part from a sea-body warmed by the hydrological effects of ruined forests, soils and wetlands. Where are the drenching central European rains coming from? In part from moisture picked up over the Mediterranean that should have emptied out as rain over the inland mountains. What to do about it? One, stop ruining forests, soils and wetlands. And two, start restoring forests, soils and wetlands. Or as Millan puts it in his own imaginative way, start "cultivating storms."

By 1995 Millan had finished his analysis and began publishing his work and making presentations. It was a heady time. Nobel laureate Paul Crutzen reportedly considered it the most important climate science in twenty years. His mentor, Ted Munn referred to his use of traditional meteorological charts as proof, a "smoking gun." High level officials within the European Commission were excited as well, and soon asked him to contribute chapters to their climate reports explaining how climate models were missing land effects, and to talk to the modelling community about the problems with their models. This, though, is when the troubles began. The modelers didn't appreciate his insights as to how their models were off. Many simply refused to believe what he was telling them, their argument being essentially that their models didn't see what his research revealed, and therefore it didn't exist. These were not pleasant assignments for him, and it was about to get worse.

He was soon invited by the IPCC to contribute to their Third Assessment Report, scheduled for publication in 2002. But he ran into the same conflict. The modelers there "questioned every result we presented," he said, describing a time of endless argument and report generation, which he eventually grew impatient with, leaving the IPCC. "I had 80 mouths to feed at CEAM and no time to argue," he recalls.

The political environment didn't help. Politicians much preferred the news of the modelers to what Millan was telling them. The last thing a politician wants to hear is that wherever they develop the land, whether for a school or a factory, they damage the climate. They preferred what the modelers offered, a globally dispersed problem for which they had no specific local or regional responsibility. All the better if it allows them to promote growth and burnish their job-making credentials. Indeed, the solution framework being presented to them— "green" energy—allowed them to not only promote development, but at the same time claim to be green, a politician's dream-come-true.

It's important to consider here the two sides of this scientific argument.

On one side we have Millan, whose conclusions are based on eighteen years of physical data utilizing over 50 meteorological towers, assorted air balloons, gauges and instrumental aircraft. Further, it incorporates and is informed by the lived experience of locals, particularly the elders who observed the changes the longest. And it relies on a minimum of computer modelling. That is, it is empirical, based on physical evidence not theoretical equations, using standard, long-tested meteorological methods. Lastly, it's from his own homeland which, thanks to his father, he's been peering at with a meteorological eye since he was boy.

On the other side you have individuals sitting behind computer screens, in the placeless place of a computer model, consulting what is ultimately a simulation.

How did we get here? One might ask. How did the climate end up inside a computer? What happened to the land leg and why don't we know about it? And why don't we get to make our own judgements about "the science."

These questions take us to the second part of Millan's story, the scientific drama playing out behind it.

After I first heard Millan speak in 2017, I immediately retrieved a copy of the MIT report he referred to and confirmed for myself the existence of a two-legged climate understanding within its covers. So what happened? I wondered. How did the land change leg vanish from the narrative, with the CO2 leg becoming the sole human cause of climate change? Beginning with the MT report, I began reading the texts of various climate reports, working my way forward in time, looking for clues. Eventually, a discernable picture emerged showing just how land change got left out of the climate narrative.

The key year was 1979, when two very different climate reports came out.

The first report was produced by the World Meteorological Organization in conjunction with its first World Climate Congress: A Conference of Experts on Climate and Mankind. Though employing some archaic language, the title shows a scientific attempt of broad scope and scale. From the forward: “this publication may safely be considered as the most profound and comprehensive review of climate in relation to mankind yet published.” It’s a reasonable claim for a report containing 28 Overview Papers and totaling over 700 pages, providing something of a textbook on scientific thinking about climate at that time.

As in the SMIC report, the two legs are seen side by side, with the conference’s keynote address neatly summing them up: “We now change the radiative processes of the atmosphere and perhaps its circulation by emission of the products of our industrial and agricultural society. We now change the boundary processes between earth and atmosphere by our use of the land.”

From there we encounter repeated references to land change as a human cause of climate change. The first paper, under a discussion of “the impacts that are of the most relevance to the subject of climate,” places “the transformation of the land surface of the planet by forest clearance, the ploughing up of the steppes and great plains, land reclamation, etc.” at the top of the list.

The report’s next section, Influences of Mankind on the Climate System, includes a paper coauthored by none other than Ted Munn. Munn’s paper, Human Activities that Affect Climate, begins: “Mankind has been modifying the environment for several thousand years, and some of these modifications affect climate. For example, whenever a forest is cleared or a road is built, the local heat and water budgets are changed.” He goes on to lay out, as in the MIT book eight years earlier, what is clearly a two-legged approach. “The subject of this paper is clearly of very wide scope and accordingly presented in two main parts as follows: Part I, By Munn, covers the main human impacts on climate, excluding mankind’s interference in the atmospheric carbon dioxide (C02) balance; and Part II by Machta (his coauthor,) deals comprehensively with those aspects of climatic change which are related to the carbon dioxide balance.”

There they are, the two legs of climate change, plain as day. He then makes a startling observation concerning the land’s role in climate: we have no baseline, no “reference state with which to compare current conditions.” In other words, we’ve so “changed” the earth’s surface we don’t even know how our climates are supposed to function, what their natural state would or should be. It’s a question with wide ranging implications depending on where you live.

For me here in the Pacific Northwest, it means comparing a climate regime in which the regional hydrology was once powered by 8-foot-thick, three-hundred-foot-tall giants spread sea to mountain, to the patchwork of clearcuts and tree plantations, cut on forty-year rotations, that currently masquerade as forests in this region, particularly in the hydrologically critical lowlands. It means acknowledging that most of the coastal marshes and estuaries, along with their hydrologic function, have been covered in highways, urban and suburban sprawl, and soil-killing industrial agriculture. It means, in addition to the background warming of the globe due to greenhouse emissions, we also must consider how these land transformations are contributing to the desiccation and heating of our local and regional forests.

Here in the northwest, we are lucky. Despite what we’ve done to the landscape, our particular proximity to the Pacific Ocean means its steady supply of moisture continues anyways, keeping things green, at least by appearance. Other geographies face very different circumstances, particularly those that rely on their indigenous soils and vegetation to maintain their moisture. Those places, such as in the Western Mediterranean Basin, face a more challenging circumstance.

One of the more intriguing papers in the report concerns climate change in the Sahara. Though climate change has been portrayed as a modern, oil-age phenomenon, the authors, Kenyan and Sudanese scientists

Julius S. Oguntoyinbo and Richard S. Odingo, reach a bit farther back, to between 6000 and 4700 years ago, when "the Sahara experienced a moister climate." "Desiccation of the climate possibly began well before 4700 BP, but the impact was apparently delayed due to higher water tables and extensive oases. Such sites provided adequate habitats for wildlife, domesticated animals, human beings and their crops."

Though some form of land change via farming and herding had already been present in the region, for perhaps thousands of years, the authors suggest that the region, by virtue of its extensive oases and aquifers, was ecologically resilient enough to tolerate it, but only up to a point. Eventually human modification of the landscape could have tipped the balance, which later research corroborates. "The period between 4700 and 3700 BP was arid" they note, with "the region becoming successively drier, particularly during the Roman occupation, and in more recent times."

It's interesting they note the Roman occupation. If the experience of the Western Mediterranean Basin is any guide, it would have been a time of intensified land use, with marshes drained, hills mined, forests cut. And as noted, it was a drier time.

The reference to "more recent times" is even more interesting. After noting that the traditional peoples of the area—the Tuareg nomads, the Haussaand farmers and Fulani pastoralists— "had developed social, economic, political, and land use systems which enabled their survival within the constraints imposed by the environment of the area," they describe how "European colonization introduced and imposed a variety of social and economic changes, which…disrupted the symbiotic relationships which had developed between socio-economic groups of the region. Among the measures introduced were the encouragement of the pastoralists to lead sedentary lives and the introduction of the cash crop economy. The expansion of cultivated areas took place at the expense of the more southerly and thus better watered grazing lands; fallow land was reduced; while much of the bushland, which was traditionally part of the pastoralists grazing land, was incorporated into the agricultural area."

Today's climate narrative typically blames Saharan droughts on CO2 emissions, but these authors clearly had land-use in their sites, pointing to "overgrazing of the deserts and their margins," and "the driving back of the nomads from parts of the steppes (leading) to degradation of the sparse vegetation cover in the surrounding semi-deserts on the one hand, and to disturbance of the ecological balance of the cultivated steppes on the other. Serious consequences also resulted from the ploughing of dry soils in particular."

There's much more that could be said about the WMO's report, and it should be noted that it also devotes considerable attention to carbon emissions, including an Overview Paper on the physical basis, detailing what it is and how it works. But there is another report to consider, one that soon followed and which proved far more consequential to the trajectory of climate science. It's called Carbon Dioxide and Climate: A Scientific Assessment, otherwise known as the "Charney Report."

Jules Charney was the brilliant mathematician credited with bringing weather forecasting into the computer age, working out the mathematics behind the computer modelling that revolutionized modern weather prediction. Number crunching that would've once required stadiums full of mathematicians could be done by increasingly sophisticated computers, and he was the matchmaker, vastly increasing the capability of weather forecasting and laying the groundwork for the flowing computer simulations we now take for granted on the nightly weather report.

In the mid 1970's, rising CO2 emissions caught the attention of the US Office of Science and Technology Policy, which made a formal request of the National Research Council—the century-old, private non-partisan institution set up by congress to serve as "scientific advisor to the nation,"—to look into the matter. The NRC turned the request over to its in-house Climate Research Group, which put together an Ad Hoc Study Group of scientists, led by Jules Charney. The Ad Hoc Group sequestered in Woods Hole, Massachusetts and began reviewing all the modelling on CO2 to date, reassessing weak spots and somewhat averaging the results. The outcome was a slim, 22-page report, with the closest thing yet to a definitive statement on CO2. Unlike the WMO report, which though comprehensive, offered no clear prediction regarding CO2, other than to say more research is needed, this report provided the closest thing yet to a firm prediction. If CO2 concentrations double, it said, global temperatures will increase 3 degrees centigrade.

It was a bombshell. Media had an attention-grabbing headline and grabbed it, with petroleum interests and environmentalists lining up on either side of its conclusion, one attacking, the other defending. As a result, a kind of social feedback loop developed. The more CO2 was denied as a cause of climate change, the more it was declared by its defenders, cementing in place the public sense that carbon gases were the sole matter of climate change. Suddenly the CO2 leg stood in the spotlight, with the land-change leg hidden in shadow, lost in the uproar.

Did Charney and his associates intend to portray CO2 as the only cause of climate change? Likely not. They point out in their Summary and Conclusions, "we have limited our considerations to the direct climatic effects of steadily rising concentrations of CO2." Like most scientists, they understood there is more to climate than CO2, but felt confident, despite the complexity of the subject, to make their prediction, "all other things being equal."

It's this "all other things being equal" where things get tricky. For within "all other things being equal" lies the land leg and the living processes around it, far too complex at the time for modelling. To simply leave those processes out, which is what the Charney Report essentially did, seems artificial, yet an attempt to predict the possible effects of rising CO2 concentrations was clearly needed, and waiting until all uncertainties were resolved before confronting the CO2 problem would likely mean waiting until it was too late to do anything about it. Further, setting aside uncertainties is a common practice in computer modelling, and can run both ways. For instance, in trying to model land-change effects, a modeler might tune out CO2 effects to get a clearer picture. It's part of the modeling process and shouldn't be seen as underhanded. It does, however, require a certain amount of explanation, which the Charney Report failed to provide, and which hasn't been provided since.

In any case, you can imagine where this left the WMO and the other international organizations. The Americans had come out with a strong statement on CO2, while they were far from such scientific consensus. The wide scope of their analysis, which they were so proud of, was suddenly a leaden liability. The CO2 train had pulled out of the station and there they were still sorting through the luggage of various uncertainties, often related to land change. What to do?

In a series of workshops and conferences held between 1980 and 1988, leading international climate organizations, such as the WMO (World Meteorological Associate) UNEP (United Nations Environmental Program) and ICSU (International Society of Scientific Unions) attempted to resolve their uncertainties around the CO2 leg and articulate their own consensus. Meanwhile, an organizational structure for international climate cooperation was needed, out of which two organizations were created.

One we're all familiar with: the Intergovernmental Panel on Climate Change, or IPCC. The other, the International Geosphere Biosphere Program, or IGBP, hardly anyone has heard of. The pesky land leg, with all its complex, difficult-to-model processes, was filed there, but in the context of different language. Rather than dealing with "climate change," this group's work was referred to as concerning "global change." Further, it received one tenth the funding of the IPCC, was largely ignored by the climate press and in 2015 was shuttered, turned into a private organization called Future Earth.

What happened to the two-legged approach to climate? It's really kind of simple. The land leg proved "incommodious," as Millan puts, so the two were split. The CO2 leg, championed by the IPCC, strode into the climate spotlight to save humanity, while the land-change leg, housed under the IGBP, remained behind for further research having vaguely to do with "global change," for a little while at least.

While these machinations were occurring, Millan was apart. He had his hands full dealing with severe pollution in the Mediterranean's coastal cities and valleys, and then the mystery of the collapsing summer storms. Of such political goings-on in climate science, he was largely unaware. His encounter was instead at the two opposite ends of the process. He was there at the beginning, when modern science began its first broad inquiries into the human impact on climate, exemplified by the MIT/Swedish Academy of Sciences report, where he picked up the two-legged concept which served him so well in the Mediterranean. Then, in 1995, when he began to share his results, he encountered the other end of the process, after the two legs had been administratively split, and CO2 had risen as the official cause of climate change, with land and vegetation demoted to carbon-sink and mitigation-agent.

It didn't really matter how convincing or important his observations were. The narrative was already established. CO2 as cause. Global Circulation Models as the ocular. Physics (math) as the basis. He had occasional backers high in the EC, and I'm sure he had many people nodding their heads at his presentations, but the scientific and political architecture could no longer fit his insights. It was like he brought a round answer to a square question.

Not surprisingly, it was a long and frustrating battle for Millan. And dispiriting. "I lost," he wrote me once, "for all of us." He knows well the implications of his work around the globe, the amount of good it could do, but feels it most acutely in his homeland. For Millan, the satisfaction that came with solving the summer storm mystery came along with the sadness of knowing the true state of his surroundings, what they should be, could be, and where they were headed. What Millan fears most are the feedbacks. Every unrealized summer storm, every failure of the system to eject its heat and release its water to the life below, not only diminishes that life, but leads to more powerful storms in fall, winter and spring. Those storms then further erode what's left of the land, deepening the cycle, as the land drifts ever closer to the critical threshold at which it collapses to desert.

I sometimes try to imagine how different things might be had the two two-legged conception of climate not been split. It's hard to imagine CO2 emissions being any higher. Despite the laser-focus on the CO2 problem, emissions have risen almost 20 percent since the formation of the IPCC in 1988. In that time how many midwives have gone under the saw that might have been saved had they been seen for their full hydrological importance? How much soil womb has been covered in concrete or eroded by land abuse without anyone realizing the climatic consequences? How much land would have been protected, and how much restored, if the public had known just how critical their local and regional landscapes are to their own, lived-in climates? At one point Millan had 100 million Euro of EC funding for land restoration efforts but could find no takers.

Now the boy, whose father literally pointed to his destiny, and as we've seen, met it with such scientific elan, feels defeated. Once, when we were communicating about Ted Munn's 2013 death, he wrote, "I just realized I may be the last living representative of the two-legged theory of climate." But the story isn't over. As mentioned, the scientific understanding of Earth's climate is moving toward Millan's understanding, not away. Already the term biophysical (the two-legged concept in a single word) is becoming commonplace in scientific literature. Scientists, for their part, are becoming increasingly pointed in their analyses. The World Resources Institute, for example, recently published a report declaring that, regarding "non-carbon effects of deforestation, the direction and size of those impacts are sufficiently clear to merit urgent action now." It's title: Not Just Carbon, Capturing All the Benefits of Forests for Stabilizing the Climate from Local to Global Scales." Emphasis theirs.

Meanwhile, scientists and citizens are joining forces and charting paths beyond the CO2-only narrative. Organizations such as Climate Landscapes are convening conferences to bring scientists, citizens and journalists together around the hydrological, landscape perspective. Citizen organizations, like Biodiversity for a Livable Climate, are compiling and synthesizing the scientific literature and providing courses for the general public, who are learning the science for themselves. Millan may have failed to alter the course of the scientific bureaucracy, but he succeeded in inspiring a new, still-emerging climate narrative.

Speaking personally, it was the elegance of his two-legged concept and the poetry of water begets water, soil is the womb, vegetation the midwife, that drew me into this exploration. And in my more hopeful moments, I think we may well be poised at the edge of a new movement, which if I had to saddle with a name, I would call a living climate movement.

**Rob Lewis**

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