Cauldron of Forces

Designing a Lightning Observatory on Lake Maracaibo

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

ABSTRACT

There are storms in the world, and the world is a storm, and we ourselves are weather. Earth and the universe are continually emerging and dissolving: geological, meteorological, and biological forces interact to create planets, storms, and living creatures, which cycle from one form to another. What seems static is simply moving slowly. Everything is weather.

As an example, take the Maracaibo Basin in western Venezuela, a 50,000 km^2 valley where wind, water, oil, and mountains are fused in a single turbulent system. The Catatumbo Lightning burns overhead, dominating the scene. Nearly every night for centuries there has been a thunderstorm over Lake Maracaibo – a persistent, recurring weatherform that has shaped cultural memory and mythology in the region. Below, the lake is the centre of Venezuela's oil extraction operation. Wellheads dot the surface of the lake, threaded by a labyrinth of leaky underwater pipelines. All these phenomena have their genesis in the geological processes that shaped the basin. The uplift of surrounding mountain ranges has depressed the valley, freeing deep reservoirs of oil and trapping them close to the surface. The same mountains funnel low-level winds sweeping south from the Caribbean and create favourable conditions for thunderstorms.

This thesis wrestles with the complexity of the Maracaibo Basin through storytelling and design. *Part One* is a cosmic history, tracking the spatial and cultural metamorphosis of the valley. *Part Two* is a design investigation into architecture's capacity to frame an encounter with wild weather. Through the speculative design of a thunderstorm observatory sited near the epicentre of the Catatumbo Lightning, it asks: what kind of architecture might participate in cycles of transience and change, rather than obscuring them? How might architecture extend sensory perception and become an instrument for connecting humans more completely to the storm that is our world?

ACKNOWLEDGEMENTS

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My family is amazing. Emma, Rosemary, and Elizabeth, you're all incredible sisters, and talking with you has returned me to sanity so many times. I'm so thankful for my parents, who have not only ferried me everywhere, but who long ago set the course for me and my siblings to be forever curious, always asking questions as we learn our way through the world.

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PROLOGUE

This thesis begins under a shadow of looming danger, under a storm. The Earth is in turmoil. *Figure 1.1 (overleaf)* is John Martin's painting "The Great Day of His Wrath" (1851-53). It portrays an apocalypse.

I want to deterritorialize this image.

Aesthetically, it shows a "cauldron of forces": a vortex of churning, ambiguous geology and weather. The crumbling structures that loom over the painting from the upper right: are they clouds or mountains? The world is destabilized, and made uncertain. What seemed solid before, is not. Ground is upended. There are human figures suffering in the foreground: figures adrift in a vortex, a landscape that no longer seems inhabitable for them, a world that seems full of storms.

The physical world is formed by forces that can be destructive, and into which we have often imagined judgement.

And one of our coping mechanisms is to try and become the judgmental deity, the promethean demiurge that can re-shape and order things as it pleases. But we find control sliding out of our grasp. As the world warms and the seas rise, we are caught in an apocalypse of our own making.

But the forces that lay waste also bring life: the world is continually being created. Holding off the apocalypse, trying to find a place to stand, we miss celebrating life in its incarnate wildness. This thesis is a celebration and a wrestling with the life of one particular storm. It makes no effort to 'solve' cataclysms but sits with them.

I want to invoke a different biblical image: Jacob and the angel. Here, we are invited to wrestle all night. From evening to morning, as lightning flashes in the sky.

The Maracaibo Basin
is

Figure 1.1 - "The Great Day of His Wrath" (John Martin)

A Cauldron of Forces

PART 1: EVERYTHING IS WEATHER

In 2014, the Maracaibo Basin in South America was recognized as the place on Earth that gets the most lightning. Specifically, that meant the 'flash rate' of nearly 250 lightning strikes per square kilometre per year, in the southwest corner of the basin, was higher than the rate in Kabare, Congo, which took second place.[1]

That gold medal finish wasn't a fluke. The Catatumbo Lightning *(Figure 1.2, overleaf)* is a permanent, recurring, nocturnal thunderstorm. It's a storm that keeps happening in the same place, at the same consistent time, over and over again. If you reach [9.5°N; 71.5°W] or [9°N; 73°W] between midnight and morning, you'll be right in the middle of it.[2]

The setting for this oxymoronic piece of predictable weather is a valley with a lake in the middle. At the northern end of South America, caught between two branches of the Andes, opening onto the Caribbean Sea, the Maracaibo Basin and its lake are both enormous. The basin is over 50,000 km^2, while the lake is 13,000 km^2, which is comparable to Lake Ontario.[3,4] Its surface is "a pincushion of oil wells"[5] – over 15,000 by some estimates. Politically, most of the basin is contained within the Venezuelan state of Zulia. It is densely populated on the north and east sides of the lake, while the south and west, including the watershed of the Catatumbo River, consist mainly of sparsely populated forest and wetlands.[6] The climate remains hot and humid for most of the year.[7]

What follows in the first half of this thesis is a story about the Catatumbo Lightning and the basin that gives it birth. By pulling apart and tugging at the scientific and historical data, we can begin to see the poetry inherent in it, and to sense the convulsions of rock, oil, life, and lightning as a single interconnected system. This system has undergone massive transformations through time; the storm is a rhythmic, rather than static, thing. Thus the writing is organized around three different time-scales: the 4.5 billion years of Earth's existence, the 200,000 years since anatomically modern humans evolved, and the daily cycles of changing weather.

I write as an architect, reading this place as an event in space and time. I also write as an outsider, re-telling and re-presenting what others have seen and know better. This land is the home of the Wayuu, Barí, Añu, and Yukpa peoples, who have been telling stories about this place from the beginning.

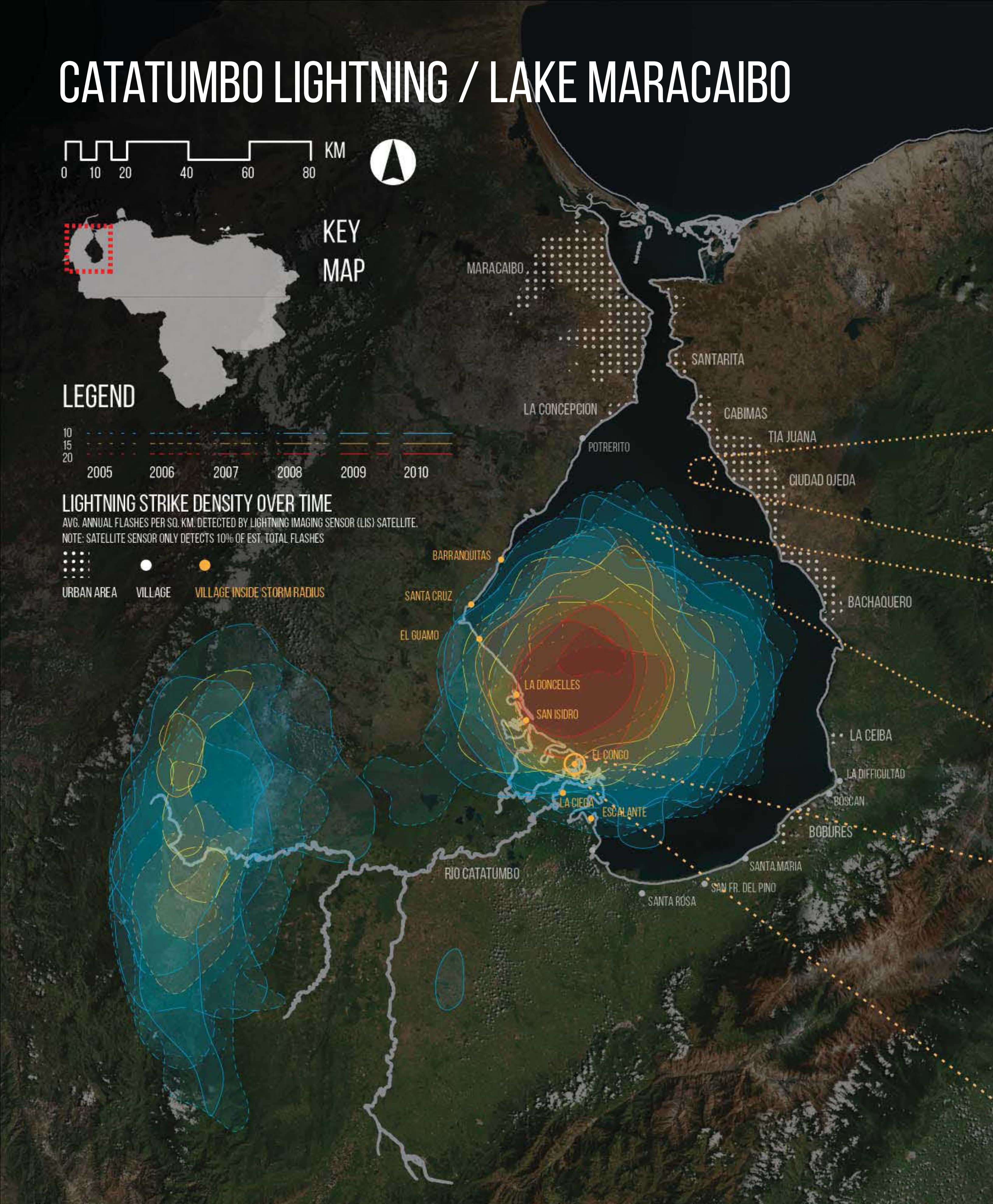


Figure 1.2 - The Maracaibo Basin.


SW ONTARIO
10 FL. / SQ. KM. / YR.
CENTRAL FLORIDA
60 FL. / SQ. KM. / YR.
KIFUKA, CONGO
160 FL. / SQ. KM. / YR.
CATATUMBO LIGHTNING
250 FL. / SQ. KM. / YR.
REGIONAL MAXIMUM LIGHTNING INTENSITY COMPARISONS { FLASHES / SQ. KM. / YEAR }
1 : 50 000
OFFSHORE OIL DERRICKS
1 : 10 000
GAS PROCESSING FACILITY
1 : 10 000
"PALAFITO" / STILT VILLAGE
LAKE ONTARIO
19 328 . 9 SQ. KM.
MARACAIBO {E}
13 210 SQ. KM.
ITAPARICA {R}
8 779 . 1 SQ. KM.
TITICACA
8 270 . 6 SQ. KM.
LARGEST BODIES OF WATER IN S. AMERICA
INCLUDING LAKE ONTARIO FOR COMPARISON. R = RESERVOIR. E = ESTUARY

GEOLOGICAL TIME

Figure 1.3 - The Tablelands, NL.


4.5 BILLION YEARS

begin

The Maracaibo Basin is a cauldron of forces. It contains a storm, but is also itself a storm. Churning slowly, cooked by temperature and pressure over time, it's a stew that reached its boiling point centuries ago, and has been kept simmering ever since.

Let's begin at the beginning. There was nothing. And then -

The infinitesimally small point containing all of reality cracked open, and the universe poured out. It didn't make a bang, because sound was still impossible, and there were no ears. *If a universe explodes in the forest and no one is around* – what happens next? Atoms formed. Space kept stretching. Stars condensed; galaxies and molecules stuck together. Planets were born by the billions.

One of them happened to be Earth, and throughout the Hadean Eon it was a very inhospitable place. Armadas of meteors crashed down and left no craters because they melted the crust. Whenever molten rock on the planet's surface showed any sign of solidifying, the space rocks came down and beat it to a pulp.[8] An inquisitive planetary body named Theia stopped by and collided with the Earth, and in their fairly sexual encounter, Theia and Earth were mixed together, their iron cores joining and becoming one. Out of this union was born the young Moon, coalescing from an escaping plume of rock and dust.[9]

In all the endless years of our world's ancient history, measured in billions, this is one of the moments when we zoom in. Time slows down. When Theia meets Earth, we are counting the minutes.

According to astrophysicist Robin Canup's model of the Giant Impact Hypothesis, Theia was moving at up to 4 km/s when it struck Earth at an oblique angle.[10] 50 minutes later, half of Theia had fragmented and was streaming sideways around the Earth. After 6 hours, most of the iron in this material sank down and struck the planet's surface again. The rest – material from Theia's mantle – continued into orbit.[11] The Moon formed in as little as a month, making possible the very idea of months, and it wasn't long before Earth had its first atmosphere: a boiling cloud of rock vapour thrown up by the collision.[12]

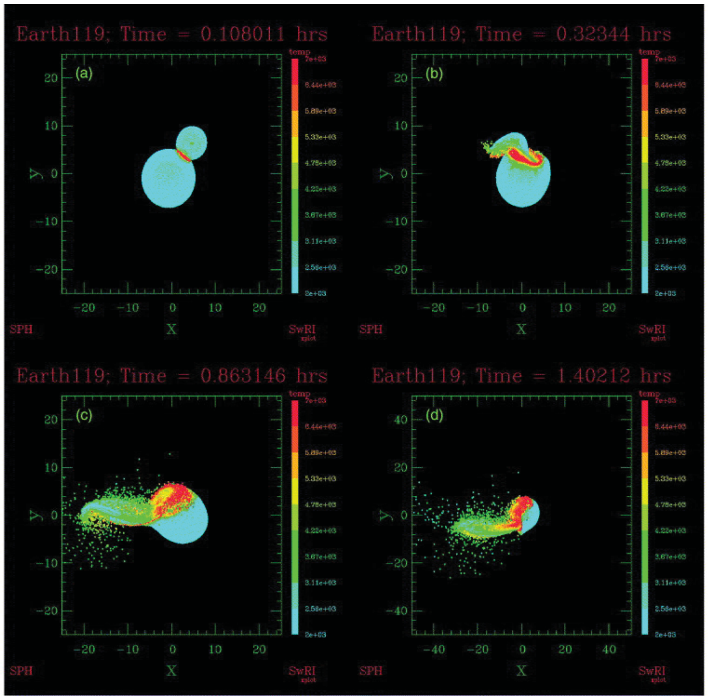


Figure 1.4 - Theia Meets Earth
Computer Model - Robin M. Canup

This is the beginning of Weather, but the line between weather and geology blurs because the first weather was made of rocks. Meteorology, at this point, really did consist of meteors. The Hadean Eon also concluded with the first rains ever,[13] which sounds lovely, but back then everything had to be big or fiery or explosive, so there was nothing gentle about this rain. Water vapour had been building up in the atmosphere for ages, and it was stuck there. It couldn't reach the ground: surface temperatures kept boiling it off midair. Thus, as Cynthia Barnett describes, "when the surface finally cooled enough for the rains to touch down, they poured in catastrophic torrents for thousands of years."[14] The air was also heavily charged with static, which makes for a lot of lightning.[15]

Endless rains? Storms lasting millennia? Perhaps our Catatumbo lightshow is not quite the world-aberration we thought. Perhaps the weather of the Maracaibo Basin somehow recapitulates the memory of earlier ages, elder storms.

deluge

The rain was like an Old Testament wall of water. The air was dense with vapour. I could barely breathe. Road-tripping with my family through Gros Morne National Park, we had driven to the foot of the Tablelands, jumped out of our van, and started walking. The rocks at this spot originated in the Earth's mantle under a now-vanished ocean, and were forced out during continental collisions in the Paleozoic Era.[16] Some people in my family are Creationists and don't believe this. They say the rocks got spit up during Noah's Flood. On this particular day I was more concerned about the actual flood being aimed at us by grumpy nimbostratus clouds.

Mist clung to the edges of the rock walls on our right. The wind howled and delivered rain into our faces. The trail flumed like a river: we would have gone faster in a canoe. After about half a kilometre, nearly ready to give up, we got a breather as the precipitation paused and the mist lifted. A gaping valley opened just in front of us, eroded out of humpbacked yellow stone. Most of the rock here was peridotite, laced with heavy metals which made the soil too toxic for plants to grow.[17] On the ground, we picked up scattered pieces of serpentinite, dark green and inlaid with a web of spidery lines. Then the weather closed back in.

We turned and raced to the car. Now the rain was at our backs, and it welled up behind, catapulting us to frantic speeds as though chasing us out of its territory. As we fought to keep our balance, a thought occurred to me. Or, rather, it didn't occur to me, but if I were clever enough, what I would have thought was that the rocks under my feet were not solid. They were liquid, if you looked long enough. The plateau rising beside us was once part of the mantle, so deeply buried that no human could ever have visited it – not in the deepest mine. But it *came to us*. In the slow twisting and turning and churning of crust over magma, and magma into crust, this part got sent up. And now, worn down again by wind, and channeling rain to beat in our faces, it sits on the western edge of Gros Morne in Newfoundland, naked and yellow. It participates in the grand metamorphosis of the whole world from one moment to the next, that continual process of change and re-formation in which *everything is weather.*

So I had this epiphany. Also I got completely soaked, and my clothes were damp for several geological ages.

tempus

Tim Ingold, quoting Michel Serres, reminds us that in French, the same word – *temps* – can be used for both *time* and *weather*.[18] Tracing the word's etymology to the Latin *tempus*, Ingold connects it to *tempo* and *tempest*, and states simply that "Time is weather."[19]

Weather is about change; weather is change. And change only occurs within time: time is the medium in which change takes place. Time is the space of change. Thus, to tell the story of a piece of weather, it is necessary to delve into the kind of time in which it exists. Most of the weather we're familiar with exists on a temporal scale of days or hours, with some monthly or yearly cycles. The Catatumbo Lightning does exist and fluctuate on this plane – but its persistent patterns have been repeating for thousands, and perhaps tens of thousands, of years. This places it firmly within the realm of deep time. Since its causes are as much geological as meteorological, the formation of the mountains that cradle the storm, and the pilgrimage of continents that built the mountains, become part of our story.

Ted Nield, in a remarkable book called *Supercontinent: Ten Billion Years in the Life of Our Planet,* tells us that the 'supercontinent cycle' is the longest cycle in

Figure 1.5 - Rocks on Wreck Island, Ontario. Photo by Graham Girard.

PERMIAN
299 - 252 MILLION YEARS AGO

TRIASSIC
252 - 201 MILLION YEARS AGO

nature[20] – the solar system orbited three times around the galaxy in the length it took for one mega-continent (Pangaea, or one of its predecessors) to form and break up.[21] 500 - 600 million years: that's how long it takes for Earth to change its facial expression. As Geoff Manaugh puts it, riffing on Nield,

> *The amazing thing is that this cycle will continue: long after North America is expected to reunite with Eurasia, which itself will have collided with North Africa, there will be yet another splintering, following more rifts, more bays and inland seas, in ever-more complicated rearrangements of the Earth's surface, breeding mountain ranges and exotic island chains. And so on and so on, for billions of years.*[22]

Everything is weather. Even supercontinental landmasses move like clouds across the sky-canvas of this planet. They break up and re-form in new shapes like the ones we dream when we stare at the sky.

Continents and oceans ride on plates like the cracked shell of an egg. Some shell-fragments are lower and wetter; others are high and dry. This is not by chance: the oceanic plates are heavier and mostly made of basalt, so they sink.[23] The continental plates are lighter (insofar as anything the size of *Africa* can be light) and also thicker, and like icebergs they look tall because they ride deep.[24]

Figure 1.6 (top) - Continental cloud patterns.

JURASSIC
201 - 145 MILLION YEARS AGO

CRETACEOUS
145 - 66 MILLION YEARS AGO

Continents seem solid. They seem like the most solid things imaginable. Bedrock, hard-as-rock: all our metaphors for stability come from geology. I bought into this idea until I visited Wreck Island, in the Massasauga Provincial Park, Ontario. There, on the wind-scraped edge of Georgian Bay, bare rock strata appear to bend and twist, to flow like lava, as fluid as the waves eddying over them.

The truth is that nothing is solid, and also, everything is solid.

It all depends on our perception of time: if you're impatient, then clouds are frozen in photographs; the ocean is solid in every instant. But if you're willing to wait, then continents crack, mountains fold, and planets die. The astonishing thing, really, is how much stability we are able to imagine into our environment. It's amazing that we can think of mountains as static, pointy things, when they are the wrecks and rumples and crash zones of continents in collision. At our lifetime-scale, it's almost as if we are interacting with a freeze-frame of the Earth, a single cell in a film strip. In fact, in a two hour movie, the existence of modern humans relative to the age of the earth (200,000 years out of 4.54 billion[25]) would occupy 7 frames, or 0.3 seconds. The time since the end of the last ice age and the beginning of agriculture (12,000 years[26]) would be half of a single frame, or 0.02 seconds. Our view of time is so instantaneous, perhaps because we are so intensely and briefly alive.

ingredients

The ingredients that go into cooking the dish of the Maracaibo Basin were simmering for centuries. Ángel Muñoz, and his team of scientists at the Centro de Modelado Cientifico (CMC) in Zulia, describe the recipe for lightning as follows:

> *Our research identified the role of what we're calling the Maracaibo Basin Low-Level Jet — an ebbing and flowing 'tide' of winds present between the ground and the base of the clouds that blow from the Caribbean to the southern part of the basin, and then in the opposite direction— as the main regulator of lightning activity at daily scale. The interaction of these winds with the mountain range surrounding the basin explains the location, timing and high frequency of events.*[27]

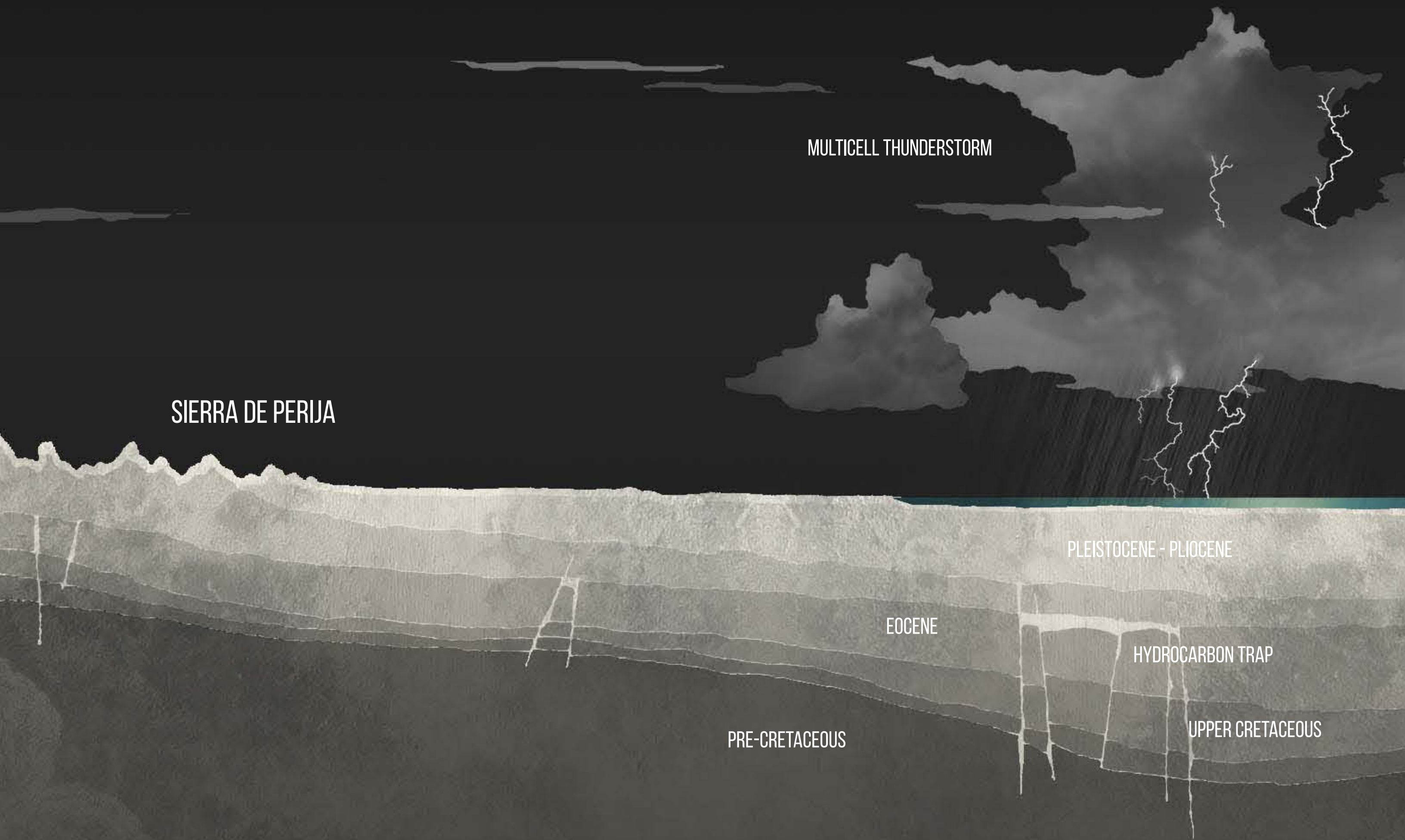
Local winds and the shape of the mountains thus drive the production of lightning over Lake Maracaibo. Other factors include the shallowness and warmth of the lake, which allows for rapid evaporation, and the larger-scale influence of weather patterns like the trade winds.[28] But how did these characteristics come to be, and how did the valley come to be one of the richest oil reserves in the world? When did the lightning begin?

We go back to deep time.

The later Cretaceous Period was a good time to be a Tyrannosaurus Rex, and a bad time to be a small prey animal. It was also a good time for oil-bearing rock formation. Long before this period, the supercontinent Pangaea had already split into two chunks: Laurasia and Gondwanaland.[29] As the Cretaceous drew to a close, these chunks were splitting into even smaller pieces,[30] and South America, having broken up with Africa, was steaming west as fast as the Mid-Atlantic Ridge could lay out new crust.[31] Continents move at the speed of fingernails growing, which gives some indication of the length of time needed for the adolescent growth of the young Atlantic Ocean.[32] One result of this slow turmoil was the deposition of western Venezuela's La Luna Formation: between 60 and 150 metres of sedimentary rock and organic material "deposited on a shelf-to-slope environment under anoxic conditions."[33]

Figure 1.7 - Lake Maracaibo seen from space, looking south

The future site of Lake Maracaibo scored front-row seats to the extinction of the dinosaurs when the Chicxulub Impact took place on the Yucatan Peninsula, partway around the Caribbean. A 10 km diameter asteroid struck the Earth and blasted out a 200 km impact crater, displacing sediment, vapourizing rock, and sending tsunamis out in all directions.[34] In a throwback to the Hadean Eon, global weather clouded over; dust and ash blocked the sun. It wasn't long before all non-avian dinosaurs were dead.[35] This marked the end of the Cretaceous Period, and the beginning of the Paleogene (66 - 23 MA) – notable to us for a collision between the Caribbean and South American tectonic plates which triggered a pulse of "voluminous hydrocarbon generation"[36] in the La Luna Formation. In the following Neogene Period (23 - 2.5 MA), things got even more interesting. The continuing plate collisions, and particularly the subduction of the Caribbean Plate as it started to *slide underneath* the coast of South America, compressed the land enough that it buckled and folded along a triangular set of fault-lines.[37] Two sets of mountain ranges – the Cordillera de Mérida and Sierra de Perijá – sprang up around a wide, shallow plain. This process "folded and depressed

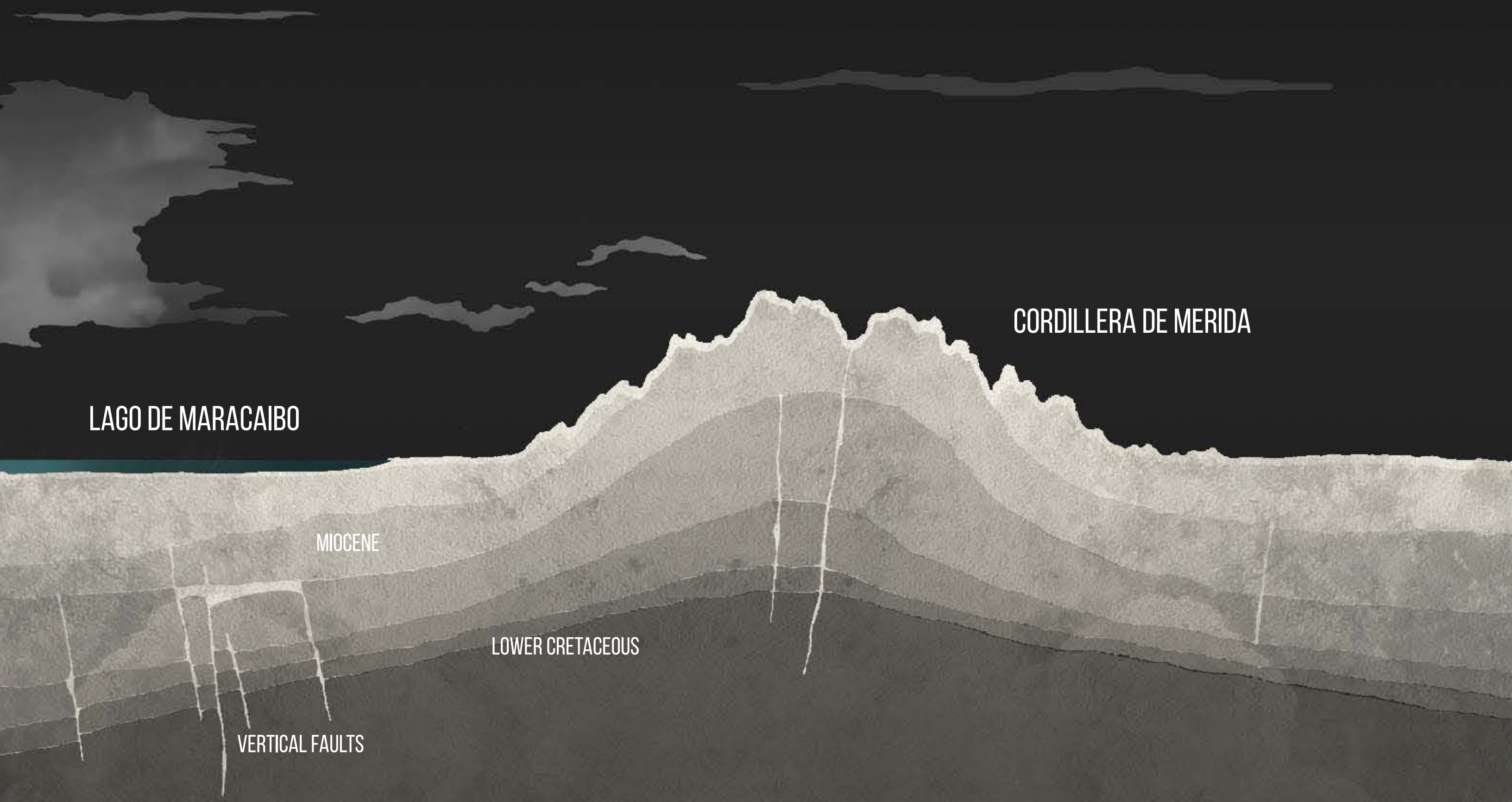


the interior of the basin to form the extensive Maracaibo syncline."[38] More oil formed. The valley filled up with water and became a lake. And possibly, just possibly, lightning was kindled and began to play over its surface.

But how and when, in all this mountain-building and basin-sculpting, did it begin? Because of the consistency of the trade winds, the answer may very well be 'as soon as there were mountains to get in their way.' Ted Nield points out that, purely based on latitude and the earth's rotation, global convection patterns are remarkably consistent:

> *If you want stability, look to the atmosphere. Here three huge, sausage-like convection cells sit around each hemisphere. . . They have existed for billions of years and continue their convection more or less irrespective of what the orbit is doing, or where the continents happen to lie on the shifting surface of the globe. Behind the fickle airs there is a dynamic stability that has easily outlasted the transient continents.*[39]

Figure 1.8 - Section through Maracaibo Basin.



In Venezuela, the relevant air circulation pattern is the Hadley Cell, which creates the northeast trade winds.[40] It may be impossible to reconstruct exactly what combination of continental position, height of cordillera, and size of lake first gave rise to the Maracaibo Low-Level Jet. But I imagine the storm must have arrived slowly – a few scattered thunderstorms, here and there, month to month, years later a few more. Or maybe it came all at once, in a single great burst – perhaps the landscape attunement was so precise as to be almost magical, giving rise to an explosion of electrical energy.

Regardless, in some fashion the lightning was kindled as the continents slid into place and the mountains rose and began to deflect the winds. This was the boiling point; this is when the stove turned to "on." And it stayed on for tens of thousands of years, perhaps burning and scarring the forests, leaving marks on the rocks. The pattern varied from year to year, shifted its epicentre from one place to another across the lake, but rarely faltered. The shape of the animals underneath might change as they evolved, but overhead, the storm persisted.

persistence

The peculiar condition of El Relámpago del Catatumbo is that it is a thunderstorm which takes place in the same location nearly every night of the year – a perpetual storm, a storm that becomes a permanent feature of a place. Is the conventional language of meteorology adequate for describing a permanent storm? Or would it be better to read the storm *as a landscape?*

Weather is produced by an attunement of environmental factors. In the case of the Catatumbo storm, the attunement is very persistent, and so the pattern of weather has changed very little for thousands of years. I believe we need new language in order to talk about this particular storm as a site, because it belongs in a category that has not been defined – or it crosses categories. It is too ephemeral for landscape, too permanent for weather. We are accustomed to language that refers to weather events recurring in time – El Nino, Monsoons, the Chinook. We even have a way of conceptualizing large geographical expanses, like Tornado Alley, by extreme weather events that occur often in those regions. And, oddly enough, we *are* familiar with the idea of permanent or long-term weather events, and they have a very particular setting: other planets. Jupiter's Great Red Spot, which we see simply as a dark smear on the marbled face of a gas giant, is a true perpetual storm.[41] But we can only observe it cartographically, from a distant orbit. How do we conceptualize a place like this on earth?

Weather is like a landscape changing extremely rapidly. We might coin a new term to describe a persistent piece of weather: weather that behaves like an amorphous landform might be called a *weatherform.* This term describes what happens when weather *hardens* or becomes persistent in a specific location. It's important to understand that this storm is not static but iterative: it is like a machine or a huge animal gathering energy and then releasing it, drawing breath and exhaling violently. It has inputs and outputs. It is a kind of massive landscape device, making visible the latent tensions in the physical environment, resolving an imbalance of potential energy. It is as if there is a continual tension in the Maracaibo valley that can only be resolved by thunder. The storm is a weatherform continually cycling through variable but related shapes – like copies of a printed book, or instances of a cast statue. It exists as multiple instantiations of a single environmental principle encoded in the landscape.

Figure 1.9 - Lightning on Lake Maracaibo.
Photograph by Jonas Piontek.

Figure 1.10 - Bonne Bay, NL.

CIRCA. 200,000 YEARS

Indígena

Out of the earth comes the oil. From continental movements and tectonic crushing, the weight of layers upon layers of time and sediment, organic matter thickens, collapses, oozes. The Caribbean Plate slams into future Latin America and slides underneath. Fault-lines open; strata crack. The Maracaibo Basin sinks and fills up with water. From underneath, Eocene-Miocene rock layers become saturated with bubbling crude, as the oil and gas rise under pressure and become trapped,[42] hovering suspended under newer rock, heavy and potent, a second lake hidden below the first.

A few million years later, perhaps 20,000 years ago, people get there.[43] And now a different kind of story begins. Entering this cauldron, this collection of strange landscapes and weathers, for the first time we have conscious actors – beings able to respond in self-awareness by choosing how they orient themselves within a landscape. They develop culture, a kind of collective self-directed evolution.

Anthropologists Stephen Beckerman and Roberto Lizarralde write of "two contrasting subsistence strategies, one lacustrine and one terrestrial,"[44] which came to define life in the Maracaibo Basin. Groups like the Añu and Quiriquiri lived in and around the lake, while the Barí and Yukpa lived in the surrounding rainforest, or on the slopes of the Andes.[45] Several of these groups still occupy at least part of their traditional territories.[46] Their ways of life, developed in careful choreography with the ecology of the basin, have remained resilient amid sustained oppression and massive social change.

The lakeshore itself was never very hospitable: it was hot, swampy, thickly forested, and swarming with mosquitoes.[47] So the Añu built on the water instead. Their *palafito* stilt-villages were and are located just offshore, carefully positioned on lagoons and at the mouths of rivers to take advantage of lake breezes.[48] The adjacent mangrove forests, with their aerial lattice of roots, helpfully provide both tectonic inspiration[49] and construction materials.[50] Venezuelan architect Andrés García describes structures ranging from triangular shelters meant only for sleeping to full-fledged rectangular houses with pitched roofs.[51] Originally clad in palm leaves and plant fibre textiles, most now use materials like corrugated

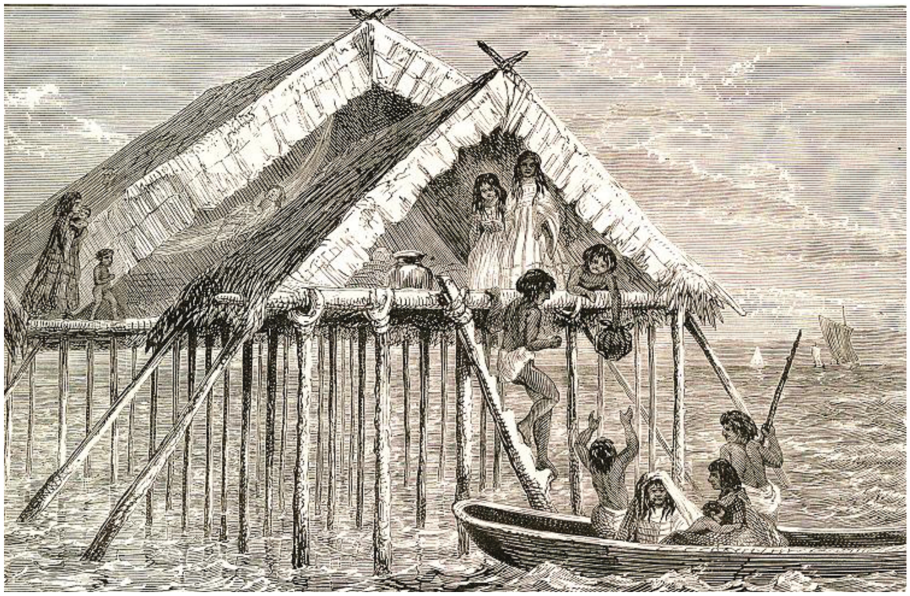


Figure 1.11 - Palafito shelter
Early Engraving

Figure 1.12 - Palafito village
with houses connected by boardwalks

metal.[52] Wooden boardwalks snake between deep porches, connecting the houses together.[53] Before industrial oil extraction began in the 20th century, the three main Añu towns each had about 400 people, with an average of 6.5 people per house.[54]

Oil itself was just another material that was conveniently available. The lacustrine peoples

> *used the tar that bubbled to the surface to waterproof their roofs, seal baskets, caulk their boats, light torches, trap animals, and in some cases cure various ailments.*[55]

The lake provided well. It also made a good highway for canoes. The Quiriquiri people, who lived around the swamps at the mouth of the Catatumbo river, carried on a brisk trade in fish and manioc with the Barí further inland.[56] However, once the Spanish arrived, their exposed palafito settlement pattern left them vulnerable. After decades of struggle and resistance, they were wiped out.[57] The Añu remain, though their habitat south of the Gulf of Venezuela is severely threatened.[58]

Harder for the Spanish to find were the longhouses of the Barí, who live deep in the rainforests of the upper Catatumbo watershed.[59] In contrast to the clustered single-family houses of the Añu, groups of 50 or more Barí traditionally lived together in "a large, internally undivided longhouse . . . built in the middle of a garden."[60] Inside the structure,

> *"People slept in clusters of hammocks slung between the sloping wall of the longhouse and an internal ring of stout outward-leaning posts that supported the wall. Enclosed by the ring of posts was a central area where people cooked. Each clump of hammocks around the rim of the longhouse was near a cooking place in its central area."*[61]

Each hammock cluster corresponded to a 'hearth group' of extended family members.[62] The interior territory of the hearth groups extended outward like spokes into the surrounding field, determining which plot each family would farm.[63] If someone died, they would even be buried in a spot further out in the forest aligned with their hammock.[64]

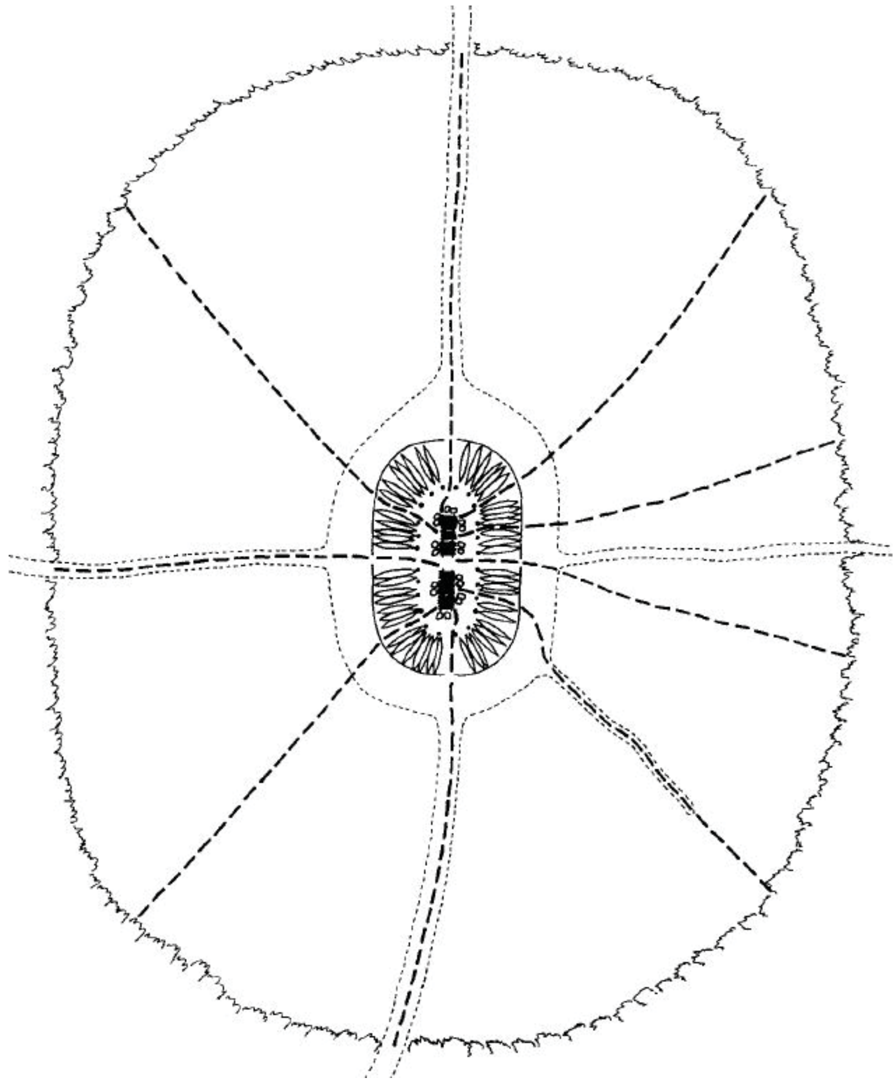


Figure 1.13 - Barí longhouse and garden plan arrangement
(Roberto Lizzeralde)

Figure 1.14 - Image withheld for copyright reasons;
see print copy in UW Musagetes Library for image.

A further twist: the Barí were semi-sedentary. This means that each local group had several longhouses in different places, and they moved between them. One reason has to do with defence. The Barí were constantly under threat from their neighbours – both Indigenous, like the Yukpa and Quiriquiri, and Europeans, along with European diseases. Living in a dispersed and mobile pattern helped the Barí survive both those threats.[65]

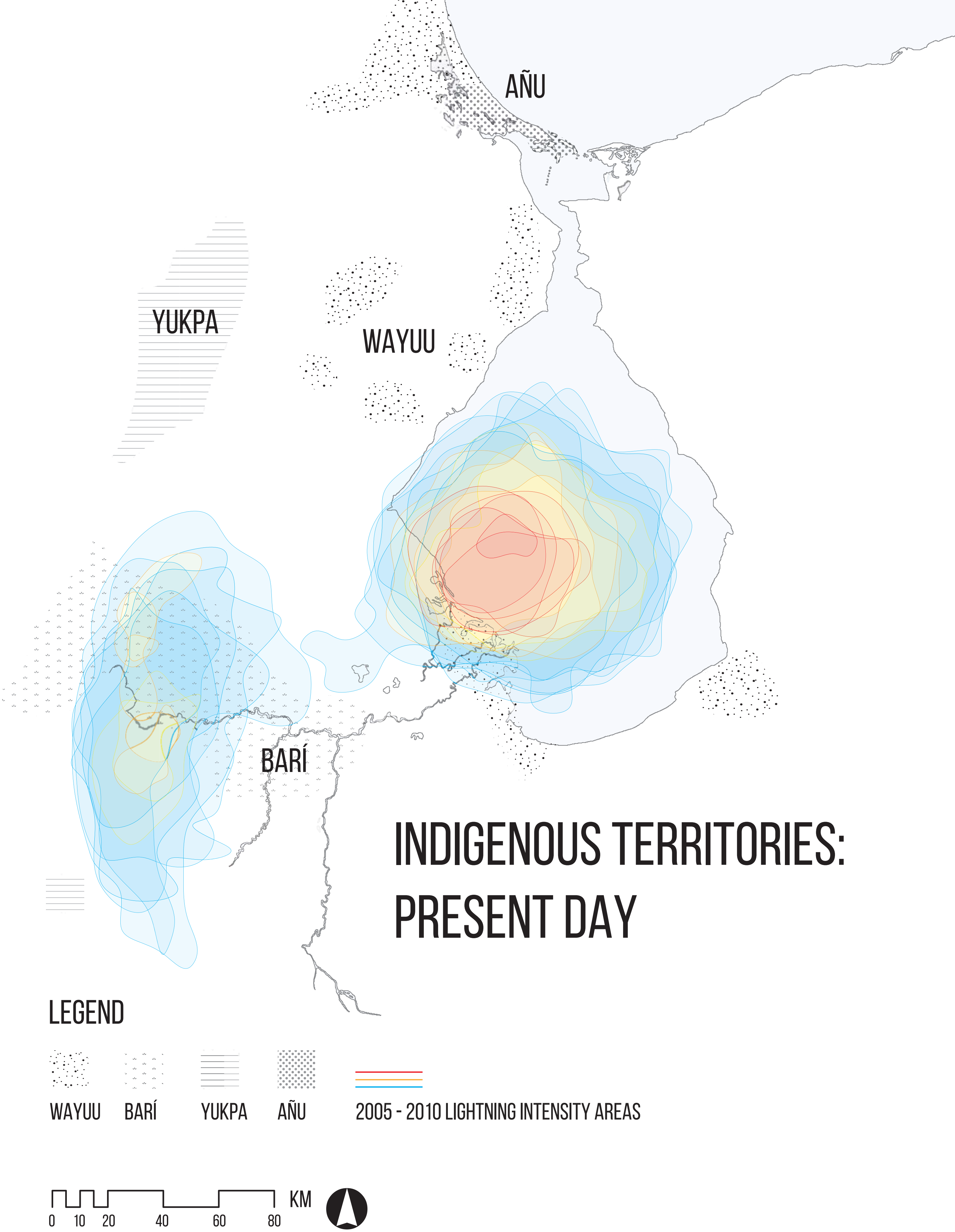
The other reason has to do with weather. In *The Ecology of the Barí*, Beckerman and Lizarralde write that "the clear-water rivers and creeks where the Barí fish with their long, graceful spears are the peripheral veins of a vast, complicated circulatory system whose heart is Lake Maracaibo."[66] This heart beats out a rhythm that the people follow. There are two rainy seasons each year, with peaks in May and November.[67] Heavy rain clouds the water. Spear-fishing, which relies on vision, becomes impossible in the wet season, and so the Barí travel upland to hunt instead.[68] During the dry season, the bocachico fish leave the swamps near Lake Maracaibo and swim up into the rivers[69] – and the Barí are there waiting for them. It's as though, with each rainy season, the landscape breathes in, and then out.

Rain, fish, people – and lightning. All follow the same cycle. It turns out that the Catatumbo Lightning peaks around the same time as the rain (May and October[70]) – and both, in this region, tend to happen at night.[71] They rise and fall together. From the map in *Figure 15*, it also becomes clear that Barí territory is directly under the western epicentre of the Catatumbo Lightning. The phenomenon is said to consist of "millions of cocuyos (fireflies) that meet to pay tribute to the parents of creation."[72] Remarkably, the Barí word for 'lightning' is reported to be *Ri'baba*, meaning 'river of the sky.'[73] I speculate that as a river people, living close enough underneath to see twisting, branching streams of fire scorching the air, while others more distant can only see a phosphorescent glow, the Barí perceive a sort of heavenly mirroring of the earth-bound rivers below.

Rain and lightning hold great significance for the Wayuu people as well. Originating from La Guajira peninsula, the most northerly piece of land in the continent of South America, many Wayuu have migrated south and settled around the Maracaibo Basin.[74] Their home territory, lashed by the northeast Trade Winds, is characterized by poor soil and pronounced droughts.[75]

Figure 1.15 (opposite) - Indigenous territories.

INDIGENOUS TERRITORIES: PRESENT DAY



Alberto Rivera Gutierrez writes that "Wayuu existence in the peninsula is immersed in a larger natural cycle where rains and droughts alternate bringing bounty and devastation."[76] In this setting, Wayuu religious belief is "permeated by the presence of two central characters: Juya and Pulowi."[77] Juya is a male figure whose "presence is signaled by the rains and lightening,"[78] while Pulowi, his wife, "is associated with the droughts and the dry season."[79] Gutierrez explains further:

> *[Pulowi] opposes Juya when he rains. The confrontation with Pulowi keeps Juya away from her home for a good part of the year. . . When Juya is joined with Pulowi the rainy season ensues and lasts until he leaves her."*[80]

Lightning has a special function as Juya's weapon, and in fact "individuals killed by lightening become associated with Juya."[81] There are stories of these persons appearing as messengers to warn that Juya cannot send the rains, because the people are not behaving appropriately as Wayuu.[82] Some sources say that lightning is "the manifestation of the fury of the [creator] god Maleiwa, made visible by the extraction of the blood of Mma'paa, or mother earth. . . an outbreak of the veins of the ancestral territory."[83] The Wayuu, like the Barí, perceive a link between earth and sky. And as Juya and Pulowi come together, the Wayuu "play the drums and stage dances before the arrival of the rains."[84]

Although La Guajira is likely beyond visibility range for the Catatumbo Lightning, many Wayuu would have experienced it as they migrated south. Many left as a result of drought and hunger, but labour recruiters exploited these conditions to trap thousands of people in indentured labour.[85] Slave trading and kidnappings on the peninsula continued well into the 20th century.[86] The Barí, meanwhile, skirmished back and forth with Spanish colonizers over the centuries, experienced devastating epidemics of disease, and suffered "frequent and increasingly brutal"[87] attacks after foreign oil companies arrived.[88] Despite all this, the Barí endured, and the Wayuu have grown to become the largest Indigenous group in Venezuela.[89] Wayuu, Barí, Añu, and Yukpa continue to demonstrate persistence and resilience, maintaining their cultures in the face of the colonial invasion and occupation that began, rupturing history, about five hundred years ago.

Figure 1.16 - The drought-prone landscape of La Guajira

Figure 1.17 - Wayuu dance celebration.

rupture

Like a second Chicxulub meteor, the Europeans arrived, and wreaked havoc. As elsewhere, disease, violence, land-theft, and enslavement followed them – though some groups, including the Barí, were able to resist incursions into their territory.[90] When stories of golden *El Dorado* didn't pan out, Spanish arrivals settled down to the dark business of administering the Venezuelan territories as a colonial backwater.[91] They enslaved some of the Indigenous peoples, fought with others, and brought in thousands of people from Africa as slave labourers to work plantations.[92] As centuries went by, people of Indigenous, African, and European descent became intermixed, but strong racial hierarchies persisted.[93]

In the midst of this rupture in history, the Catatumbo Lightning seems to have worked itself into the colonizers' consciousness as well. Many news articles about the phenomenon include the story of how Sir Francis Drake tried to invade the city of Maracaibo under cover of darkness, but was foiled when a flash of lightning exposed his fleet.[94,95,96] It's a remarkable story – and almost certainly false. The legend appears to be based on a misreading of the epic poem *La Dragontea*, which describes Drake's last voyage of 1595-96.[97] There is a line about "cursed flames" revealing "what the wings of night cover": but the lines refer to a burning ship, and the city in question is San Juan, Puerto Rico.[98]

True or false, the legend tells us about the way local people have seen the lightning – as an ally, as a guide, as an active force able to turn the compass of history.[99] The presence of the lightning in local consciousness is strong enough to lift an English pirate off the Caribbean and imagine his entire fleet into a different city.

This theme appears again in 1823. When Venezuela won its independence under Simón Bolívar, the final battle was fought on Lake Maracaibo.[100] Gun-smoke joined the clouds over the estuary. Once again, lightning is said to have played a role in the outcome,[101] and once again, evidence is lacking. But it does appear to be true that ships on the Caribbean regularly used the distant flashes as a lighthouse to guide them into port.[102] A piece of weather became a landmark. Zulia State later emblazoned a yellow bolt on its flag, laid over blue for the lake and black for oil.[103] All three things were important to culture and life in the province. But as the 20th century began, the black gold began to eclipse the bolt and the blue – and attracted another kind of invasion from elsewhere.

Figure 1.18 - Flag of Zulia State
(lightning bolt, sunburst, black for oil, blue for lake)

Figure 1.19 - Battle of Lake Maracaibo
(José María Espinosa Prieto, 1840)

Instant Utopia

Should I work in the oil industry?
In Venezuela?
With Creole?

These are important questions . . .

You should have the whole picture
well in mind
before making a decision
about a job with Creole.

Therefore, although this booklet is necessarily long
it is important that you read it all.[104]

So begins a remarkable document: an oddly poetic guidebook put together in 1956 by the Creole Petroleum Corporation (a subsidiary of Esso) for prospective overseas employees.[105] In seventy-seven pages, it overviews the operations of a company with 15,000 employees hard at work exploring, producing, refining, transporting, and marketing a million barrels of oil a day.[106] Should you work in the oil industry / in Venezuela / with Creole? In case you are tempted *not* to say yes, this book wants you to know about the income and benefits, language training, healthcare, housing, transportation, social activities, and vacation opportunities that will be available to you.[107] In fact, the book suggests, with a few adjustments, living in Venezuela as an employee of Creole is *not much different from living in a modern American suburb.*

In support of that implicit proposition, Creole includes not only photos of its corporate headquarters in Caracas (a "completely modern" city),[108] but also of its company towns. These "have the appearance of small residential developments"[109] – they look like postwar suburbs, with lawns, driveways, and shrubbery. Oh, and also thousands upon thousands of steel wellheads stretching out to the horizon, gridding Lake Maracaibo as far as the eye can see.

What is going on here?

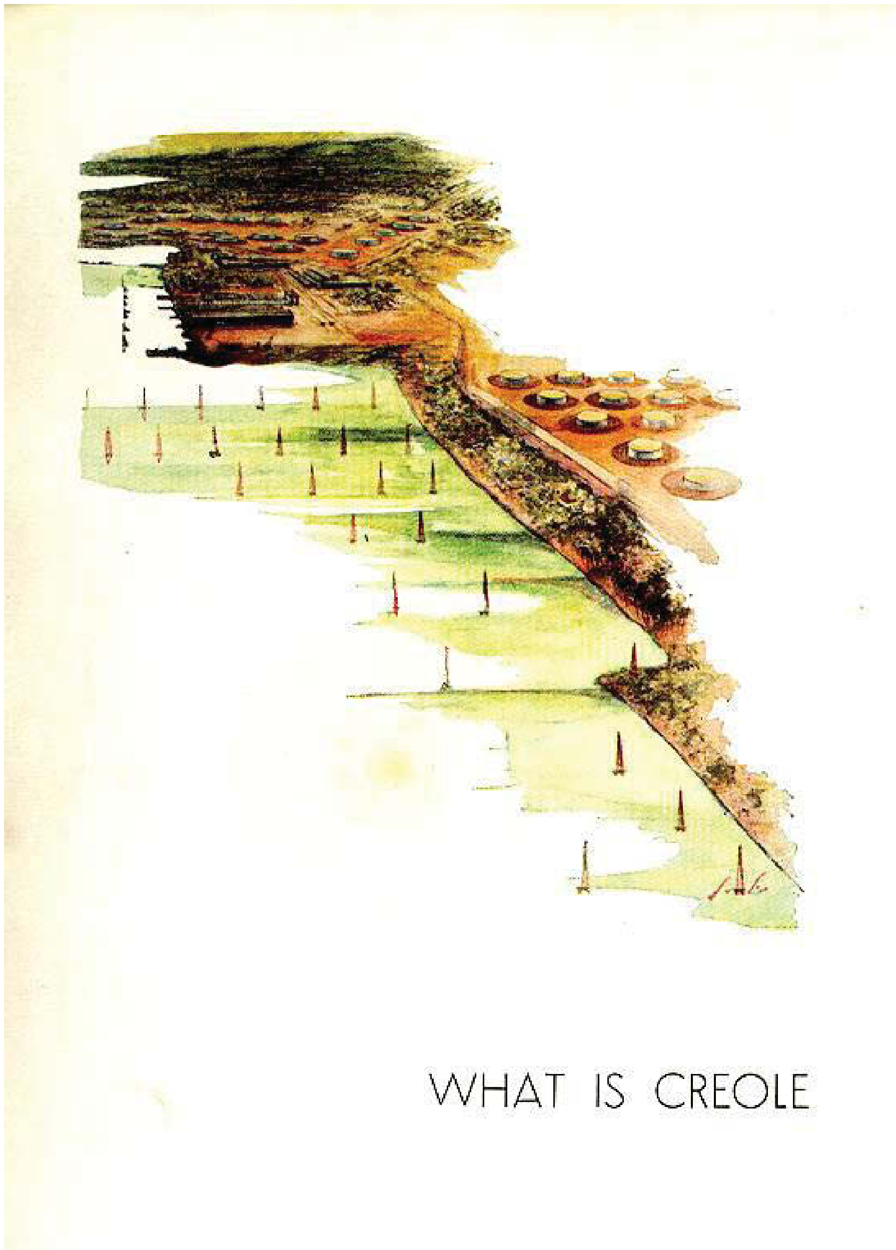


Figure 1.20 - page from Creole guidebook

There is a lot to unpack, underneath the smooth veneer of the Creole pamphlet. The book's utopian optimism projects a world up for grabs, a landscape for the taking. And, indeed, those clean suburbs, and the vast infrastructure of extraction they serve, were constructed by claiming and transforming the physical and social ground of an entire country.[110] We are hearing the sweet sound of corporate propaganda woven into a Venezuelan national myth. But beneath the storytelling is a complicated and violent reality. Essayist and historian Arturo Uslar Pietri, writing in 1972, says the following:

> *Petroleum is the most fundamental and basic fact of the Venezuelan destiny. It presents to Venezuela today the most serious national problems that the nation has known in its history. It is like the minotaur of ancient myths, in the depths of his labyrinth, ravenous and threatening.*
>
> *The vital historical theme for today's Venezuela can be no other than the productive combat with the minotaur of petroleum.*
>
> *Everything else loses significance.*[111]

How did this tangled labyrinth form, and who woke the minotaur? At the beginning of the 20th century, Venezuela was a loose collection of isolated and distinct regions. The presence of Lake Maracaibo meant that Zulia was better connected than most other provinces, but the population was small, and agriculture and trade were limited.[112] Caracas was weeks away, reachable only by a combination of sea voyage and rough overland journey.[113]

None of this was unusual. Most of South America was like this at the time.[114] However, the salvation-through-oil narrative requires the idea that Venezuela was still a left-behind backwater before oil extraction began, that oil was the only route to modernization, and that the foreign oil companies, specifically, were synonymous with the arrival of modernity. Miguel Tinker Salas, author of *The Enduring Legacy: Oil, Culture, and Society in Venezuela*, describes these beliefs as "self-sustaining myths."[115]

This is not to say that the arrival of the oil industry didn't produce massive changes. It did. But Tinker Salas argues that oil's pervasive influence allowed its practitioners to construct and sustain their own narrative.

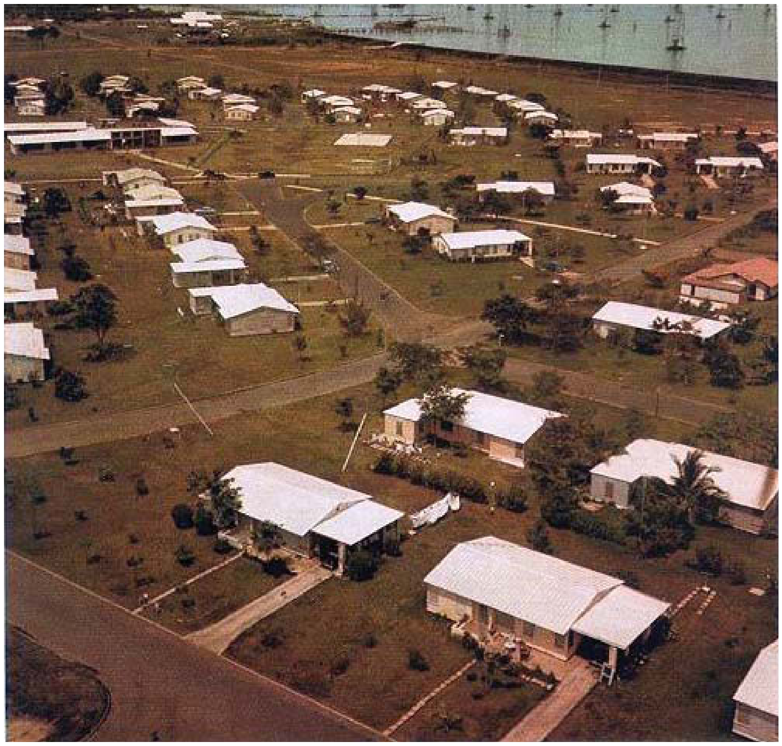


Figure 1.21 - Oil company housing (Creole booklet, 1956)

Figure 1.22 - Wellheads on Lake Maracaibo - contemporary photograph

Commercial extraction in Venezuela began in 1914, but the excitement didn't reach Klondike proportions until 1922. In December of that year, a well at La Rosa was dug beyond 450 metres in depth, and exploded like a volcano:

> *In the early hours of the morning the ground shook and the well made a noise that "sounded like the passage of a thousand freight trains." Working on the rig, Samuel Smith . . . remembers hearing the sound of thunder and seeking cover to avoid the rocks and other debris that descended on the laborers from all directions. Another witness recalled, "with a roar that froze the blood, oil leaped from the well in a spout that towered 200 feet above the derrick and fanned out in the air like a titan's umbrella."* [116]

In this moment of geological violence, lithospheric layers separated by millions of years came crashing together, and once again, as in Earth's childhood, the weather was made of rocks. Almost immediately the alienness of this oozing prehistoric substance was made clear when it "saturated not only the crew but the entire town of La Rosa . . . Oil soon impregnated nearly everything in the vicinity of the gusher and blackened the waters of the lake."[117] People in La Rosa had to figure out how to clean it up.

From then on it was a game of competing claims and shadowy land acquisitions. Three main companies, including Creole, eventually won out. The genius of Creole was to figure out that the money didn't stop at the water's edge, and to extend their operations far out onto the lake.[118]

Heavy industrial activity does not mesh well with mangrove forests and swamps. The companies soon found they wanted open and dry land near the eastern shore, and couldn't find any. So they created it:

> *The task of clearing the trees and undergrowth was grueling. Shifts of men worked twenty-four hours a day, performing all the backbreaking work with axes and machetes. They drained swamps, leveled the rainforest, constructed docks, laid railroad track, and built aqueducts, power plants, and roads. Behind them other laborers laid pipe and built tanks at a feverish pace . . .*[119]

Devastation to the ecology of the lake region occurred quickly, and was highly visible. Oil spills, filthy water, and deadly fires were among the complaints brought

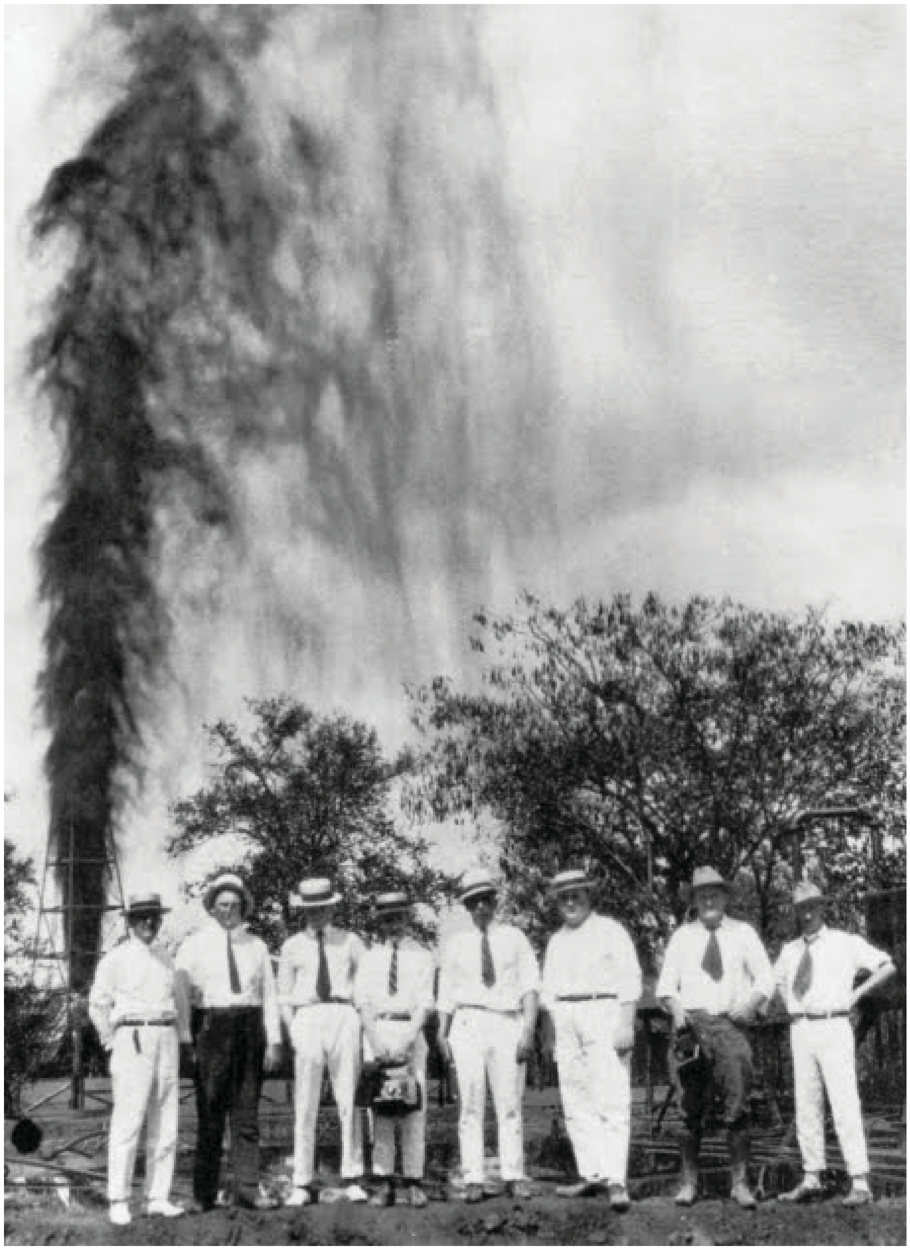


Figure 1.23 - Barroso II gusher, 1922

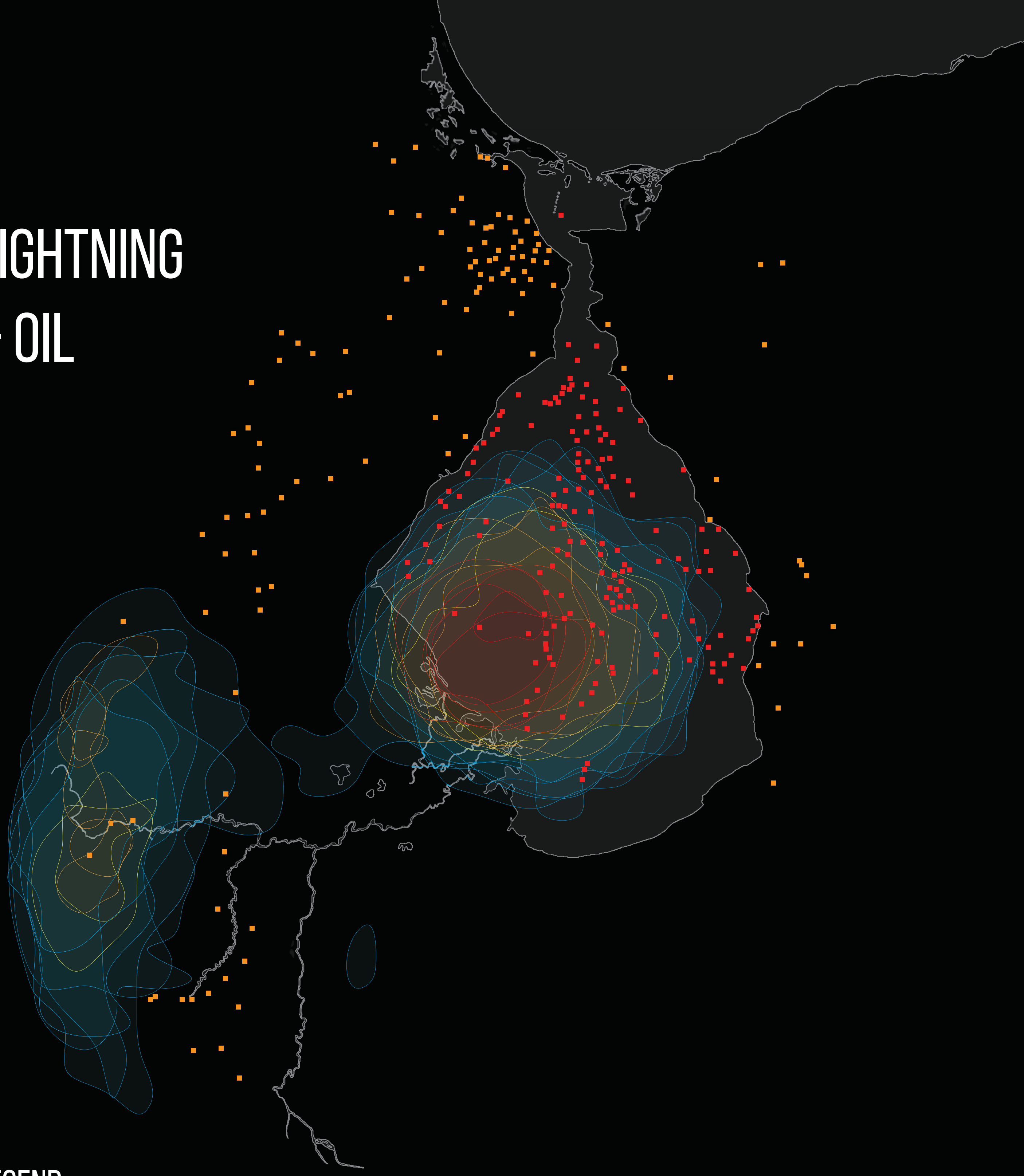
by local people in a petition to the country's autocratic president, Juan Vicente Gómez.[120] Corrective action didn't come: the oil interests were too important to restrict. In fact, given the limitations of the Venezuelan state, the oil companies gradually took on a massive role in the provision of services. Reluctant at first to do more than provide minimal shelter for their employees, they realized that they could overcome regional resentment by hiring local and carefully cultivating their image as the modernizers of Venezuela.[121]

This was the colonizing mission of Creole and the others: "both the environment and the people had to be transformed."[122] And the way to do this was through the company towns – the *campos petroleros*. These were set up to project an explicit contrast with most Venezuelan communities, and were characterized by a planned urban order, social and racial hierarchies, and centralized services.[123] Not only did the oil camps model urbanity, they were a major catalyst for urbanization. They induced mass migration away from rural areas, and brought Venezuelans from different regions together for the first time. This movement was so drastic that "by the 1960s upwards of 25 percent of the Venezuelan population lived in or near an oil camp."[124] Everyone wanted to work in the industry – but not everyone got to. The image of widespread new prosperity and modernity was a distortion: "a significant portion of the Venezuelan population existed on the margins of the oil economy."[125]

The parallel development of the Venezuelan state was a rocky road. After the death of Juan Vicente Gómez in 1935, two decades of gradual reforms culminated in the October Revolution of 1945, which briefly introduced universal suffrage.[126] However, at the moment when the Creole booklet was crowing about a 'completely modern' Caracas, the country was again living under a militaristic dictator. Marcos Pérez Jiménez, despite having overthrown elected leaders in a coup, had the full support of the United States for his anti-communist stance.[127] In 1958, an army-backed popular uprising ushered in a new democratic era.[128] The state flexed its muscles and took on some of the same roles once monopolized by the oil companies.[129] Massive foreign corporations now felt like a drag on the country, instead of a catalyst, and so in 1976, the high-riding government of Carlos Andrés Pérez nationalized the oil industry.[130] And the money gushed in.

Figure 1.24 (opposite) - Oil wells and lightning.

LIGHTNING & OIL



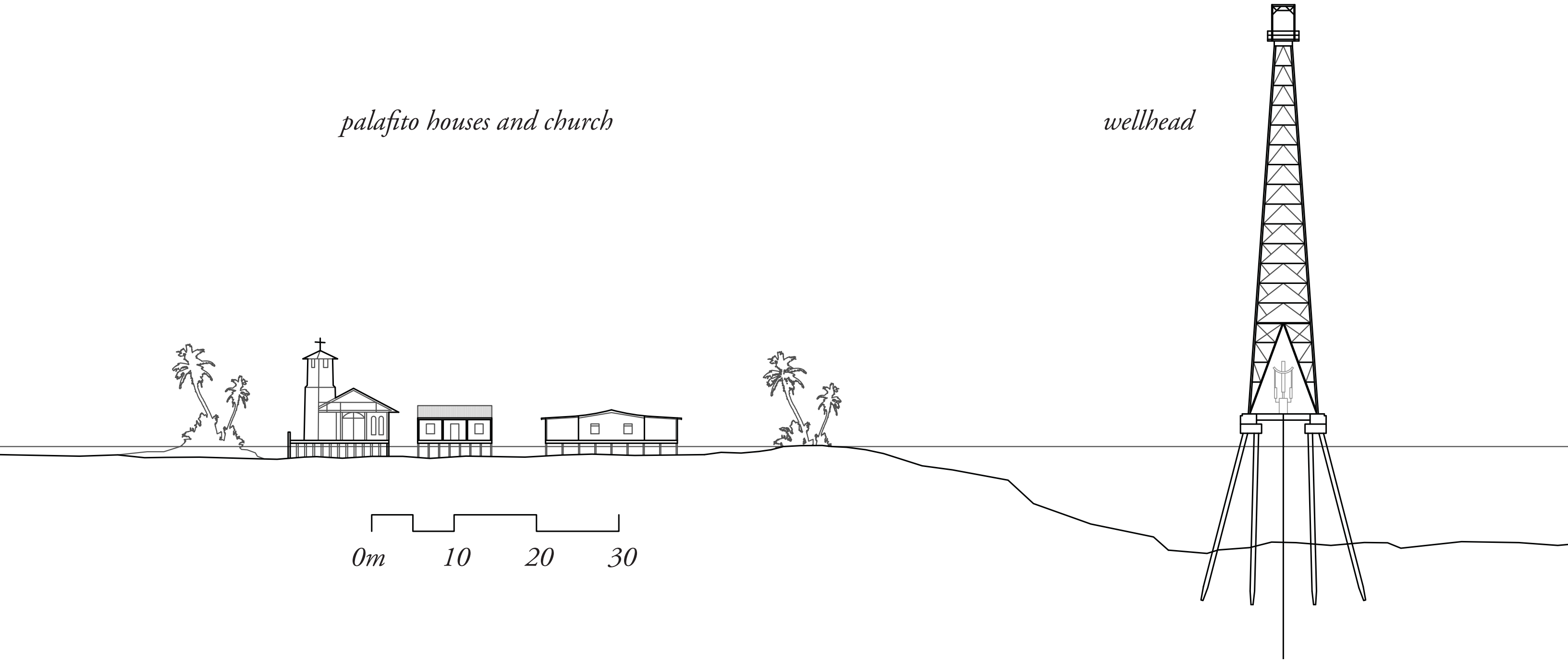
LEGEND

SELECTED LAKE-BASED OIL WELLS

SELECTED LAND-BASED OIL WELLS

LIGHTNING INTENSITY AREAS 2005 - 2010

0 10 20 40 60 80 KM



dream deferred

It's tiring being a lake, when utopian dreams end, and a crumbling spaghetti-tangle of pipelines is leaking constantly into you, bleeding internally. When a dredged channel to the sea is (predictably) raising salinity levels and killing off the fish that aren't already dying from petroleum poisoning or the rampant infestation of duckweed. When no one cares about fixing the lake because the country is in crisis after years of economic and political mismanagement. When, as one news report stated in 2010:

> *Dark oil slicks are spreading from the middle of Venezuela's Lake Maracaibo towards the shores – the wetlands, mangroves, beaches and docks. Oil is permeating fishing nets, coating the garbage dumped into the water, killing off wildlife and driving away residents and tourists.*[131]

Different sources quote wildly different numbers for the total length of pipeline on the lakebed – between 25,000 and 45,000 kilometres[132,133] – which may suggest that no one knows for sure. The number of active wells is around 6,000,

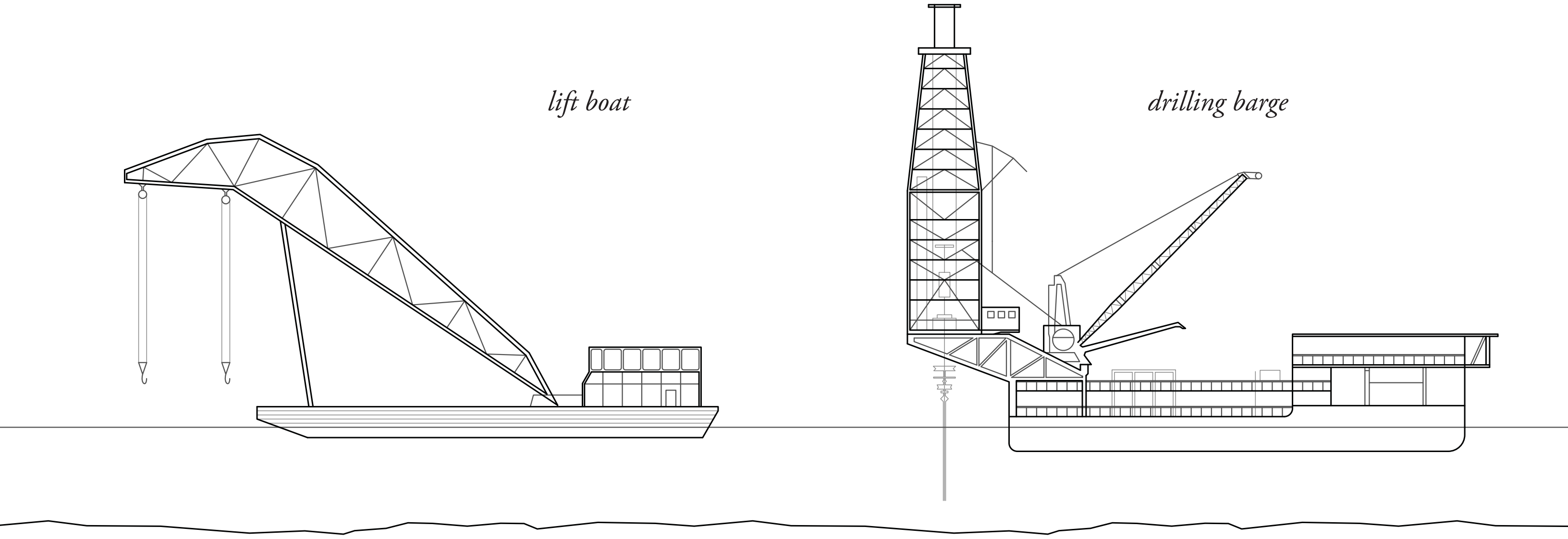


Figure 1.25 - Scale comparison of typical oil-drilling equipment with structures from Congo Mirador village.

with several thousand more lying abandoned.[134] Production has sunk from 700,000 barrels per day in 2015 to 350,000, and the oil workers are barely getting paid.[135] Venezuela has the world's largest crude reserves[136] – but can't even keep up production, much less address collateral damage.

From the very beginning, the extraction industry in Venezuela has been destroying villages, flattening forests, and polluting water. But something happened in the last 16 years which made it all much worse.

In response to a general strike in 2002, the government of Hugo Chávez fired thousands of oil workers and put military personnel in charge.[137] Routine maintenance of pipelines and equipment was one of the first things to suffer, and deteriorated further in 2009 when PDVSA, the national oil company, put the remaining repair contractors out of work.[138] A local politician remarked that "a few years ago, 135 boats were going out every day to monitor the installations. Now there are just 15 or so."[139]

What this looks like on the ground involves pipes that haven't been replaced in fifty years, daily spills, oil-coated shorelines, and dead fish. The volume of oil is too much for the lake's natural cleansing process to handle, and because water circulation is slow, it just sits there. Fertilizer runoff from farms, wastewater from urban areas, and blooms of duckweed add their own distinct flavours.[140,141]

The people most threatened are fishermen like those that live in the village of Congo Mirador, *(figures 1.26 & 1.27)* near the mouth of the Catatumbo River. Although distant from sites of the most intense pollution, they cannot escape the collapse of fish stocks. Species like the bocachico, whose migrations were so important to the lifestyle of the Barí, have almost disappeared. The remaining fish are often contaminated.[142]

There were, in 2010, about 13,000 fishermen working around the lake; that number has almost certainly changed.[143] PDVSA used to hire them to clean up oil spills, which would supplement their income, but now that has stopped too.[144]

The pattern for all this deterioration was set long before the current government came to power. It was built in from the start. Extractivism began as a second wave of colonialism, another El Dorado quest, and it was never interested in recognizing the lake as a complex organism, with its own internal forces and a carefully-balanced digestive system. It sees "nature as a large container that can be emptied."[145]

Lake Maracaibo is no longer a lake, no longer what Gilles Deleuze and Félix Guattari would call *smooth space*.[146] It has been striated almost completely: made into architecture. Defined by a grid of steel towers, dotted with immense gas plants, chemically altered to function as an infinite depsoitory for waste. Rather than framing a landscape, this kind of architecturalized infrastructure obscures, builds over, remakes, ignores entirely.

The lake is only one casualty, however, of a much larger, closely related disaster that has overtaken Venezuela.

Figure 1.26 - Congo Mirador palafito village.

Figure 1.27 - House in Congo Mirador.

Exodus

The Maracaibo region, like the rest of Venezuela, is facing an unprecedented economic crisis, with runaway inflation projected to reach 13,000% this year.[147]

Long supermarket lines in Maracaibo made international news in 2015 when falling oil prices began to hit the economy.[148] Now, standing in line for hours to purchase basic staples from near-empty shelves has become the national norm.

It's near impossible to overstate how bad things have gotten in Venezuela. Children are starving.[149] Infants die in hospitals for lack of basic medicines.[150] Venezuelans have lost weight – an average of 24 lbs per person.[151] Thousands of people are fleeing over the borders into Colombia, Brazil, and beyond.[152] The bridge leading to Cúcuta, Colombia, southwest of the Maracaibo Basin, has become a symbol of this exodus.[153]

Hundreds of thousands took to the streets of Caracas and other cities last year to protest; one hundred people were killed.[154] Little changed. Nicholas Maduro's government succeeded in sidelining the opposition-led congress by creating a new Constituent Assembly; it also avoided a presidential recall vote.[155] There are stories of food supplies withheld from families and communities who vote with the opposition.[156] Perhaps most damning of all: shipments of foreign aid have been blocked from entering the country.[157] This policy could be about saving face, but it's possible that there's another reason: hungry people have less energy to protest.[158] People standing in supermarket lines for hours have no time. If the buses are broken down, people can't get together and organize. It's not just that Maduro won't admit there's a problem; it's not just that he's afraid of American intervention, or ashamed to be seen accepting help. It may be more devious than that. He knows there's a problem, knows people are starving, and that *helps* him.

This situation is volatile, complex, and urgent. What I've written here will be out of date by the time you read it, and it's anyone's guess what will happen next.

Weather is much easier to predict.

Somehow, despite everything, the lake is still there, the wind still blows, the lightning still shines overhead.

Figure 1.28 - Empty supermarket shelves in Venezuela

Figure 1.29 - Opposition protesters in Caracas

METEOROLOGICAL TIME

Figure 1.30 - Cloud bank in Cambridge.

TWENTY-FOUR HOURS

Maracaibo speaks

I am a lake. I am surface and depth. I spread out over a deep land, with oil underneath me: black blood filling the cracks in the rock.

During my days, sunlight spreads from end to end over my surface. Photons strike the water and bend to get inside. Some are reflected away, zooming back up into space, but my dark colour, almost black, retains most of the heat. I swell, I ripple, I hum like a furnace. As the day goes on, the sun swings over and circles round and the light keeps growing. I drink it down, and I thrum with half-musical thermodynamic energy; my skin, stretched taut, is a drum. And when you sail over me, all you feel is the heat, and all you see is the stillness. Underneath, I am boiling over.

I am boiling, I am bubbling, my body is bursting to get free. Molecules on the surface vibrate and gyrate; soon, nothing can hold them in their liquid state and they change phase, break hydrostatic bonds, and rise. Becoming gas, they soar up. Everywhere, vapour is rising from the lake. You still can't see it; you only see a faint shimmering. A mirage, you think.

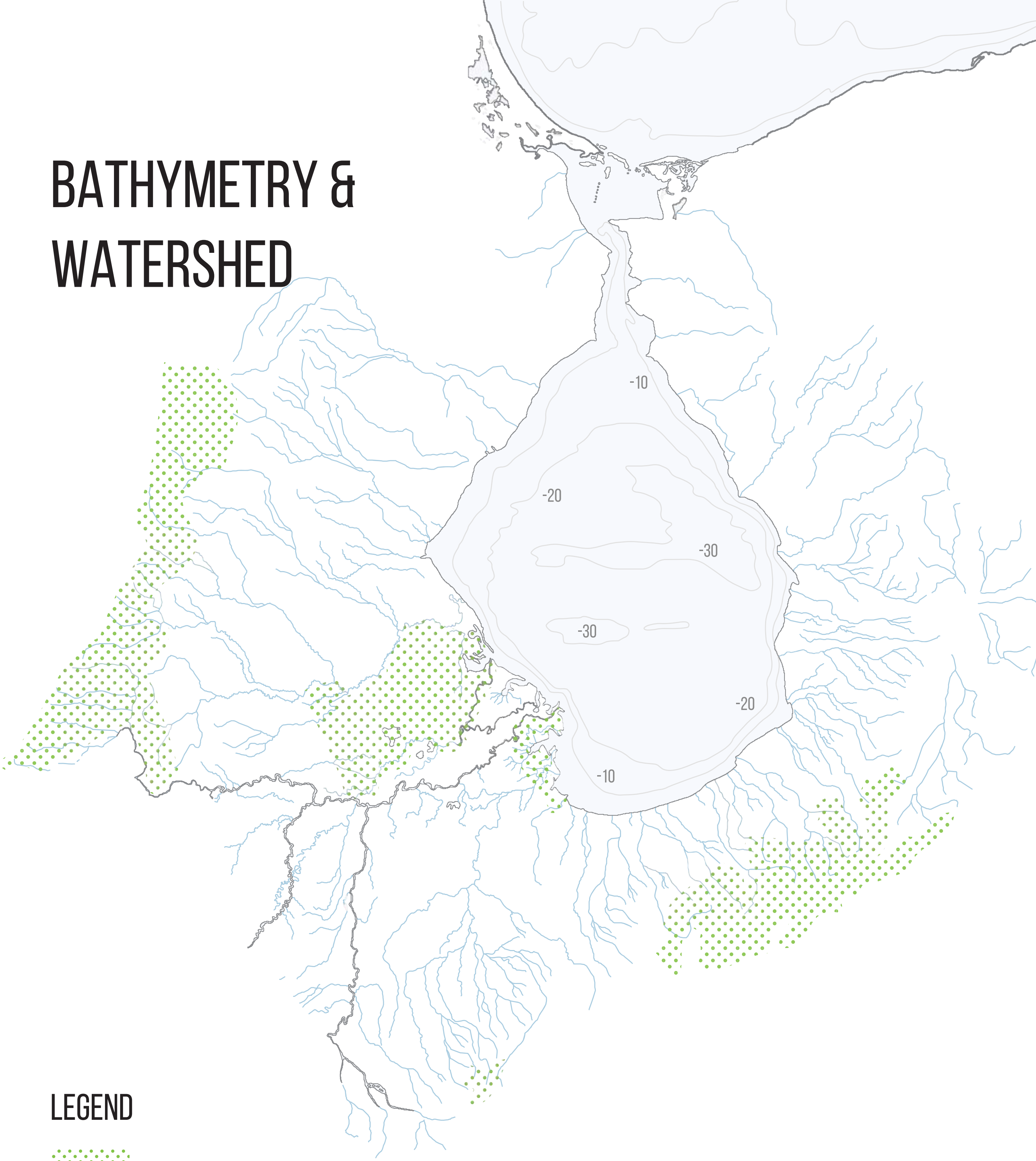
Meanwhile, high above, the water molecules rise like rockets to the top of the troposphere, and they get cold. Lethargy slows them down, draws them together. They fall, and rise, and fall. They begin clustering. They form a cloud. Today, the same molecules, the same matter, become in turn lake, vapour, cloud, and rain.

The newborn cumulus towers up and billows outward. As the sun sinks behind the Andes to the west, the one cloud becomes many clouds. But still, the energy in the basin of my valley is not free, not balanced. Electrostatic charge is growing inside the cumulonimbus towers and across my surface as well, as my electrons rush to respond to the call of those above. Soon nothing will be able to keep them apart. Not even the dense volume of intervening air will stop the strokes, the violating arcs of energy. As night deepens, the air between my body and the sky will be torn apart by lightning.

I am a lake. But a lake is never just a lake. A lake contains within it thousands of potential storms, each waiting for its chance to be born, to discover itself, to live.

Figure 1.31 (opposite) - watershed & protected areas.

BATHYMETRY & WATERSHED



LEGEND

PROTECTED AREAS

BATHYMETRY 10M CONTOURS

MARACAIBO WATERSHED

0 10 20 40 60 80 KM

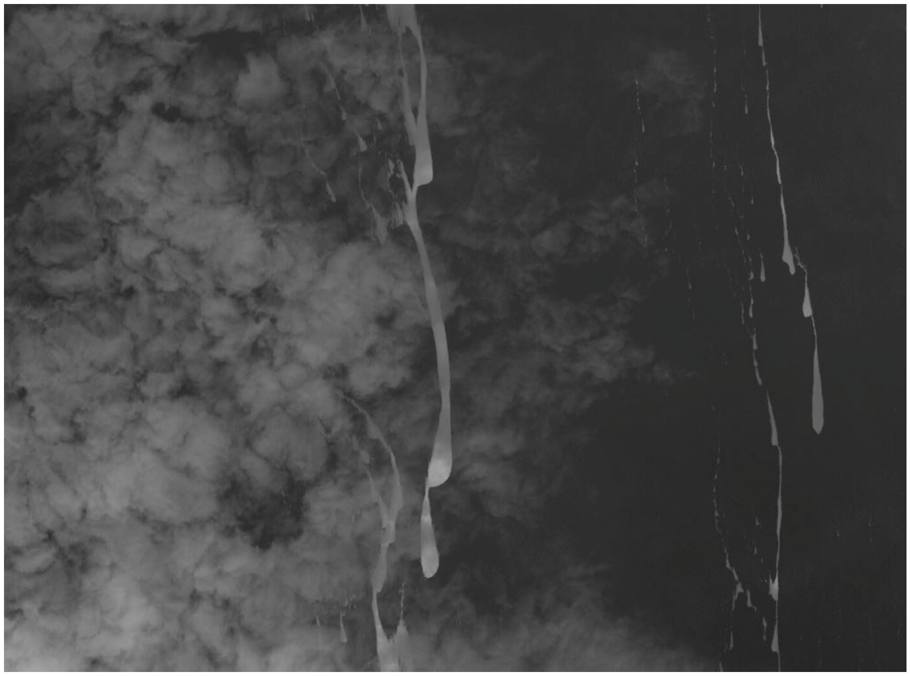


Figure 1.32 - Satellite capture: clouds and algae

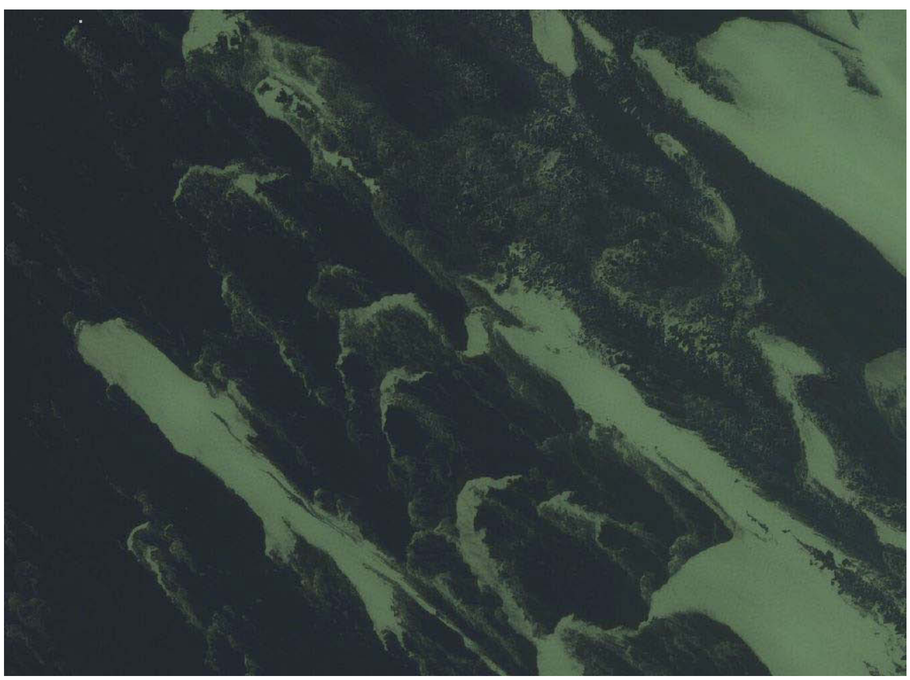
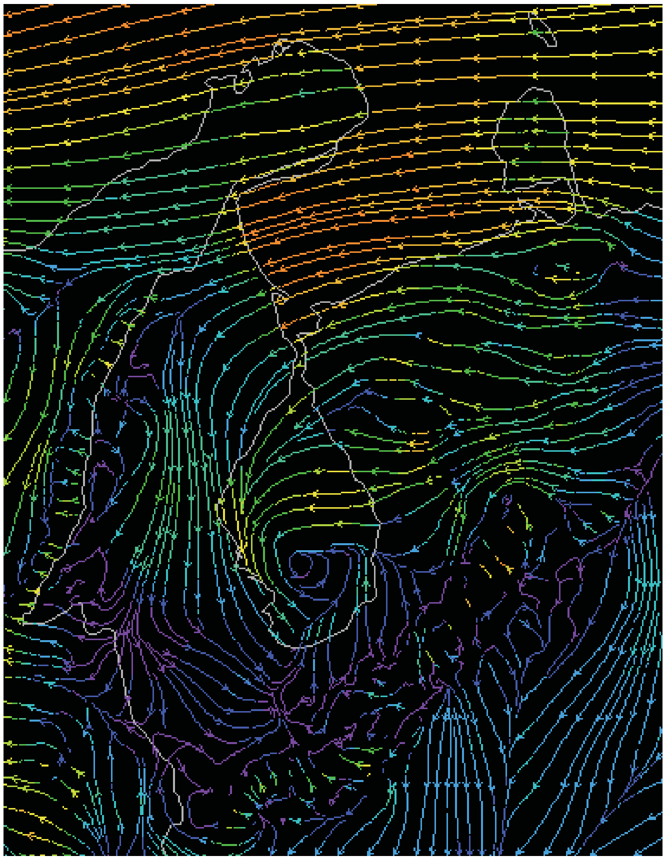


Figure 1.33 - Satellite capture: duckweed on the surface of Lake Maracaibo

Figure 1.34 - Satellite capture: clouds over Lake Maracaibo

Figure 1.35 - Silt and sediment at the mouth of the Catatumbo River



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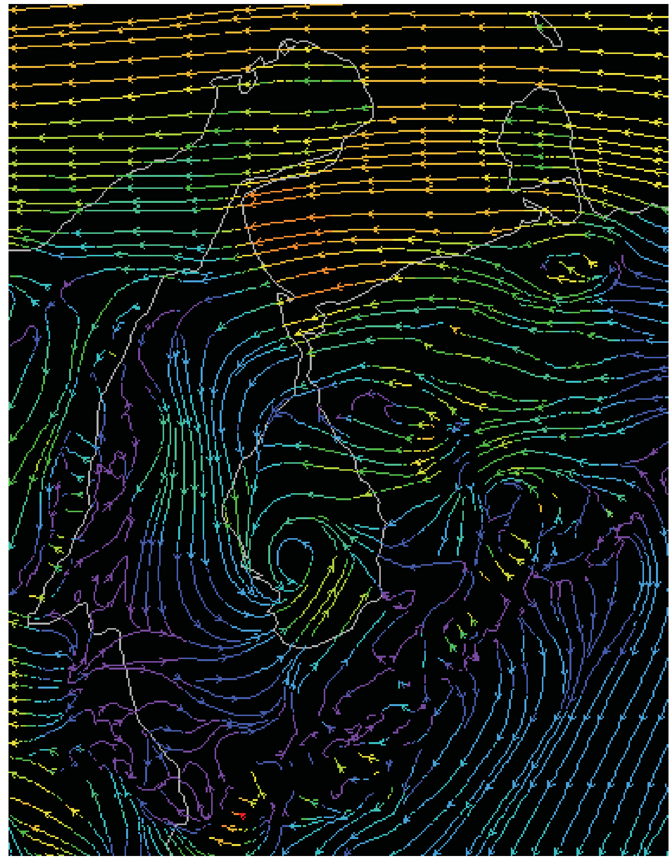

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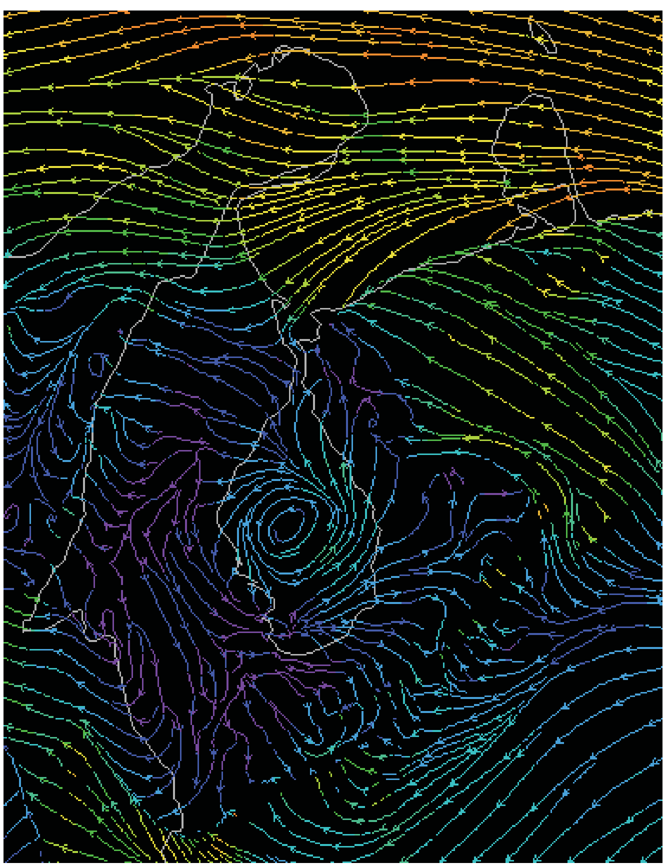

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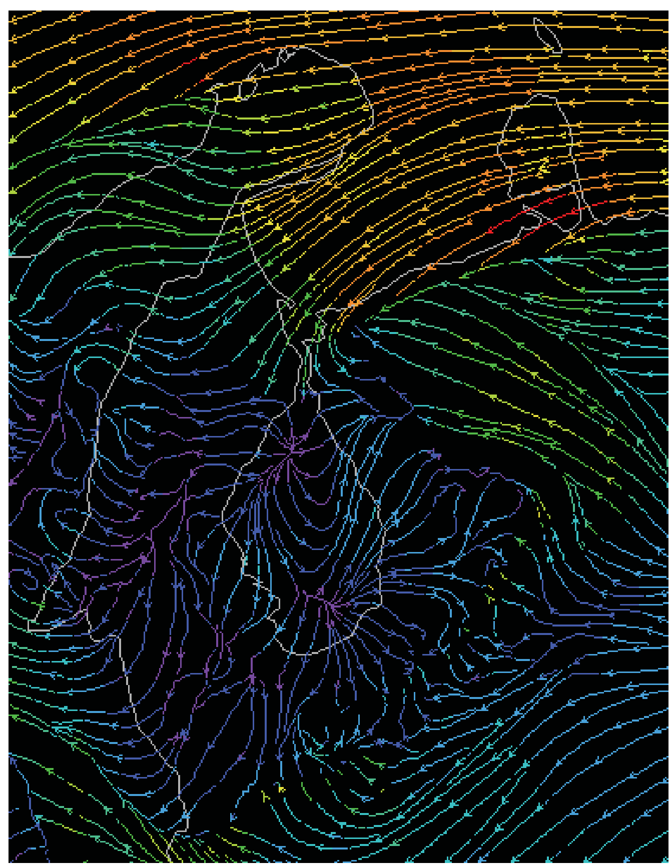

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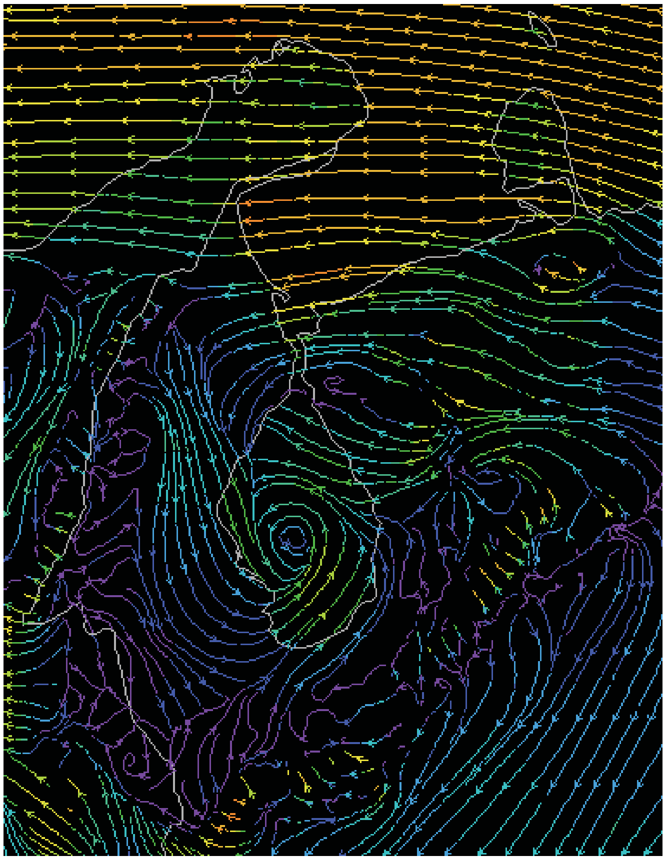
Figure 1.36 - wind patterns on January 10, 2010.



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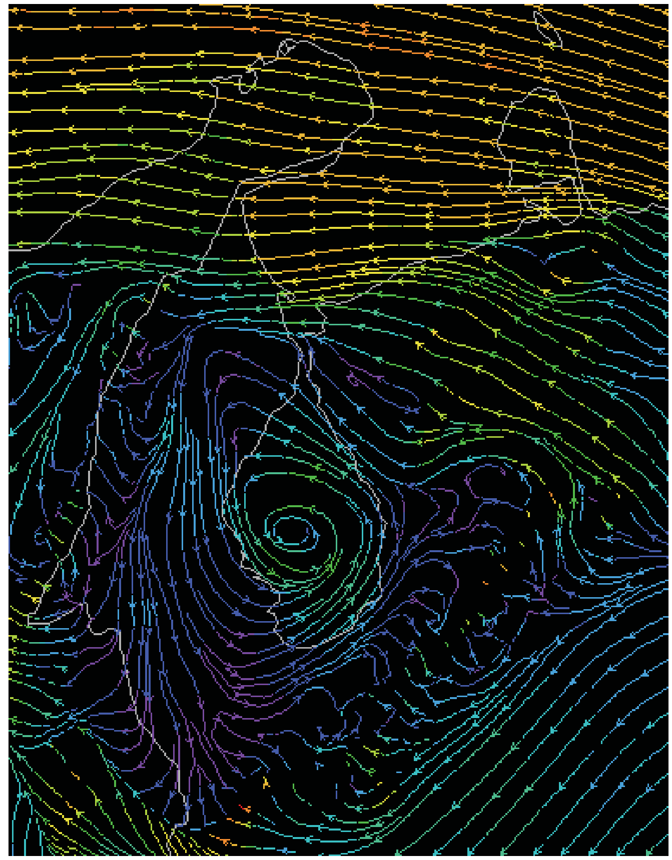
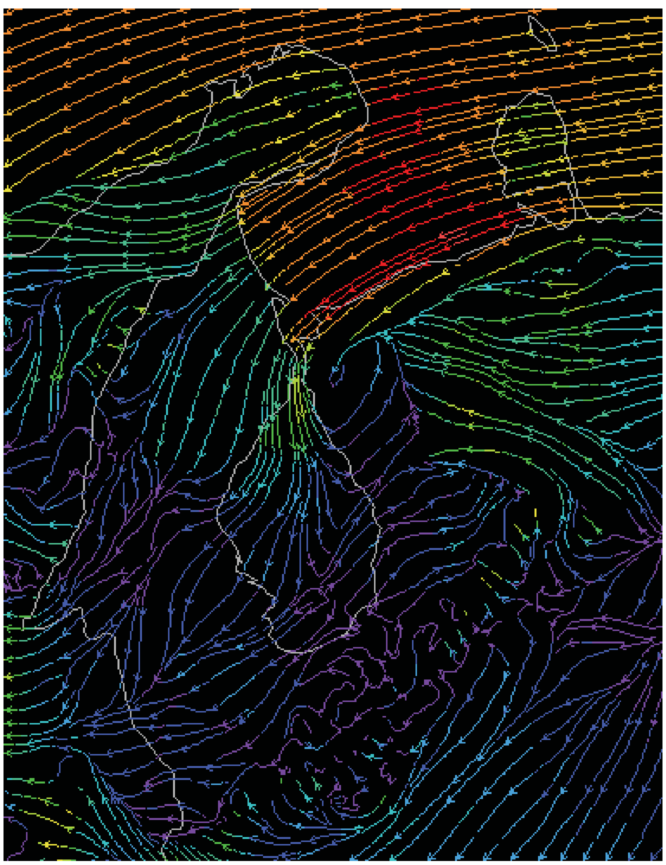
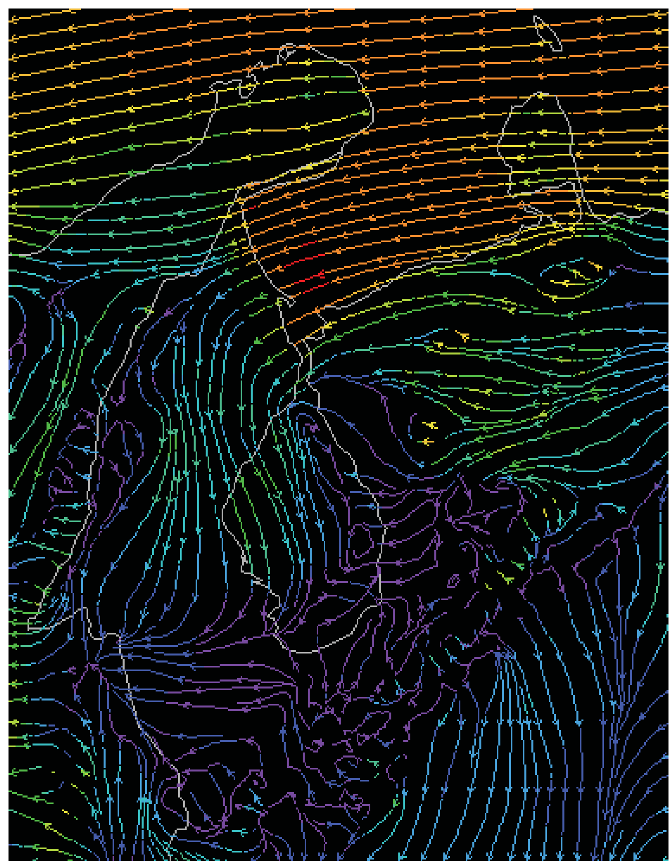


9:30 AM



6:30 PM



9:30 PM

Tide of Winds

There's always a wind blowing west across the southern Caribbean. Among persistent weatherforms, not much else can compare with the northeast trade winds. They're part of the "dynamic stability" of global convection currents which Ted Nield described as outlasting the continents.[159] Warm air rises, near the equator, and heads north. The air rushing to replace it gets twisted by the Coriolis Effect and bends southwest, blowing just above Earth's surface. Along the north coast of Venezuela, for much of the year it forms a sort of constant, flowing, tranquil band: the Caribbean Low-Level Jet.[160]

Being in Lake Maracaibo is like standing at a keyhole and listening to the wind howl outside. During the early part of each day, not much gets in through the narrow opening of Tablazo Strait. In the afternoon, this changes. An offshoot of the Caribbean winds, the Maracaibo Basin Nocturnal Low-Level Jet (MB-LLJ) "transports moisture from the Caribbean and Lake Maracaibo to the southwestern part of the basin. Around [4:30 pm] the meridional winds are so intense that they are capable of crossing the Andes and Perijá cordilleras. . ."[161] This moisture-laden air races south across the lake and up the mountains. As it rises, it begins to condense and form clouds and start raining. Some air and moisture escapes the cauldron of the basin, frothing over the edge of the peaks – but after sunset, the now-colder air flows back downhill toward the lake, which is still warm.[162]

This is a recipe for fast-rising clouds.

Throughout the rest of the night, the winds continue to shift. The centre of Lake Maracaibo becomes a vortex, as north and south winds spin around each other in turbulent lockstep until morning. Only when the northward flow becomes weak enough to unlock the door to the Caribbean can the cycle begin again.[163]

This sequence occurs almost every day of the year. The winds are constant; what changes is the moisture available. During the drier months, less convection occurs, and the lightning peters out. This can also happen at an inter-annual scale due to the influence of El Niño patterns.[164]

Cloud Construction

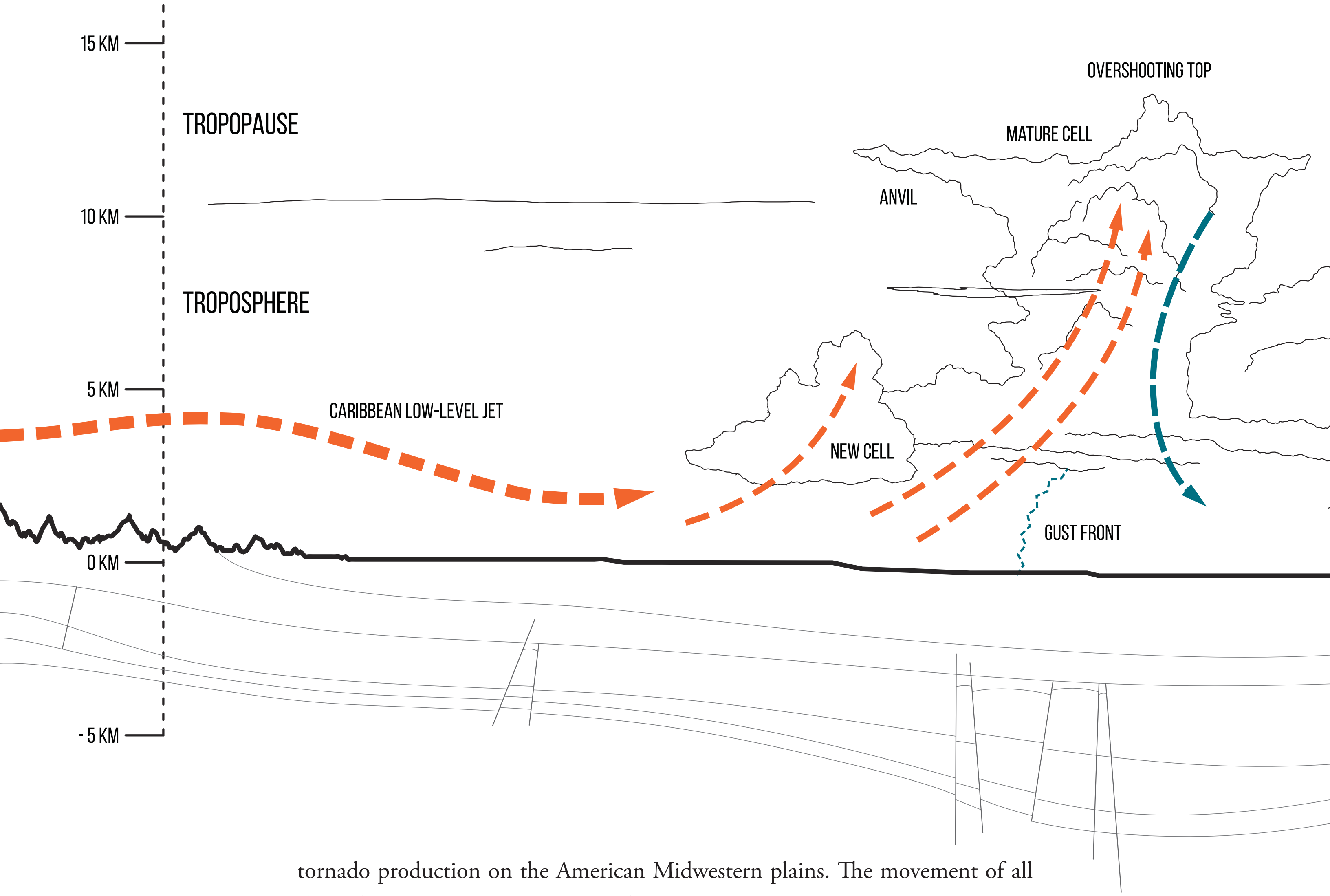
The first clouds form at the edge, by the mountains. These happen in a very simple way, with air forced up the slopes providing the necessary updrafts to fuel the creation of towering cumulonimbus. This area lights up with lightning around 8:00 pm, tapering off by 2:00 am. Then the river in the sky flows back above the course of the actual Rio Catatumbo, and ignites the second, more powerful hotspot, which peaks between midnight and 4:00 am.[165]

Long after sunset, the air above shallow Lake Maracaibo is still humming with energy. Specifically, it's alive with Convective Available Potential Energy (CAPE), a measure of atmospheric instability and a good predictor for the likelihood of thunderstorms.[166] When the pool of cold air hits it, and tries to slide underneath, a battle starts. The line of confrontation is called the *gust front*, and this becomes the storm's forward side. Robert Fovell describes it this way:

> *As the cold pool spreads, it collides with air that is warmer, more moist and less dense, and forces that air to rise up and over the cold pool. As the less dense air rises in the storm updraft, it saturates, forming the cloud.*[167]

What begins to form is a *multicellular thunderstorm*, a complex creature that exists at the intersection of two conflicting air masses. Rather than some great balloon carried along by the wind, a storm is more like a waterfall that exists at a certain point along a river[168] – continually flowing, but structured by the underlying 'topography' of the air. Each cell is a convective unit, almost a cloud in its own right, with its own updrafts and downdrafts. As a new cell grows at the gust front, it explodes upwards until it becomes a fully developed cumulonimbus tower, with an anvil top and torrents of rain at the bottom. Within an hour, its energy is exhausted, it gets squeezed toward the rear of the storm, and dies off in downdrafts. A new cell will have already taken its place. The process of repeated growth and replacement can go on for many hours.[169]

As complex as this is, it's too simple for Lake Maracaibo. The interaction of winds across the basin produces not one storm every night, but many. Observers have reported seeing five or six separate clusters at once, over the lake and the river.[170] *Multiple* multicellular thunderstorms. Or single-cell storms: giant amoebas, shape-shifting through the night. Even supercells[171] – usually associated with

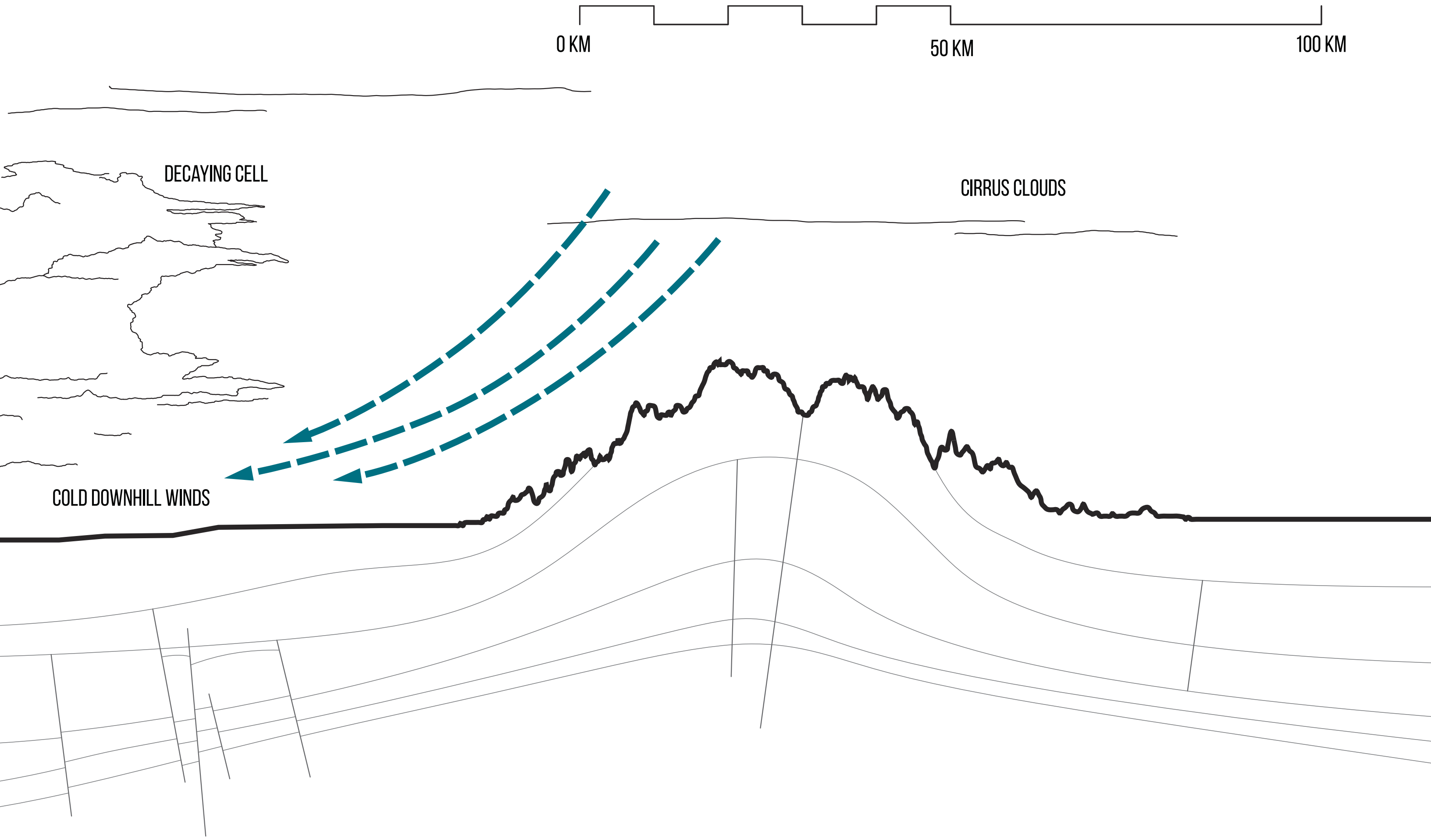


tornado production on the American Midwestern plains. The movement of all these clouds is variable: sometimes they come close to the shore; sometimes they don't. Within the constant rhythm of Catatumbo is a wild musical creativity. Each storm struggles into being. Each cloud is assembled differently. Every wind blows on its own intricate path.

But the leaping and falling choreography of rain being formed inside those clouds is even more intricate. Making even a single raindrop is challenging. The water which makes up the cloud itself has coalesced in droplets just 0.01 mm in diameter. Cloud droplets, on their own, do not fall. Raindrops have to grow a hundred times wider, to around 1 mm: they need to be heavy enough to overcome drag and avoid evaporating.[172]

The relationship between the liquid and gas phases of water is a funny thing. They're never static: it's not like water just condenses and stays like that. The border between a drop of liquid and the gas surrounding it is a porous gradient, with pieces flying away and touching down every moment.[173] Even the surface of ice is nearly always coated with a layer of looser molecules, making it feel

Figure 1.37 - Multicell thunderstorm formation.



wet.[174] For tiny droplets that form by simple collision of molecules, evaporation exceeds condensation, because surface tension is weaker in a small, highly curved surface. The only way for any droplets to form and sustain themselves is for water to condense onto particles already present in the air, which can act as *condensation nuclei*. This bumps the droplets up in size - or, in some cases, the particle dissolves, and the resulting solution is more resistant to evaporation.[175] Thus are cloud droplets made possible.

The clouds that form over Lake Maracaibo are mountainously tall, and much of their mass exists at levels above freezing altitude. The frozen upper reaches of cumulonimbus towers are said to be *glaciated* - composed of ice crystals which get feathered out by the wind.[176] The middle level is a churning mess. It's a mixed-phase zone, a kind of state of exception where supercooled water droplets exist alongside ice crystals and nascent hail, and give birth to both rain and lightning.[177] The rain manages to happen either by the collision and coalescence of larger liquid drops, or by the rapid growth of ice crystals which fall and then melt on their way down.[178] As for the lightning, well -

Lightning Phenomenology

The turmoil within the cloud is not just a matter of water droplets and ice crystals. At an even smaller scale, the component particles of these miniscule droplets are buzzing. Each atom is its own solar system – and even though we now understand that electrons do not orbit their nuclei in neat round circles, but zoom, untraceable, through probability clouds, they are still like wandering planets. Each one is susceptible to theft. The attraction of a passing nuclear 'star' is enough to lure them away. And by some not-entirely-understood process (there are lots of these in lightning science, or *fulminology*), the friction of rising crystals and falling drops is enough to induce electronic rebellion, en masse.[179]

The thunderhead assumes a tripartite structure: positively charged ice crystals fly up to the cloudy attic; negatively charged water drops and graupel collect in the seething, mixed-phase zone in the middle.[180] Around the base and edges, a thin layer of positive charge marks the boundaries of the cloud.[181]

The cloud, as we've seen, does not form or move in a vacuum. It sits on air and in air; it is shaped by currents of air. And the explosive energy of the updraft that formed the cloud, now partially converted into electrical potential energy, is building up and lying in wait, and beginning to affect the air and the ground beyond itself.

The magic of the cloud is that it can act at a distance, and like a sorcerer, transform the earth below at an atomic scale. The negative charge concentrated in the cloud-core begins to repel electrons from the surface of the ground,[182] forcing them down, deep into bedrock. The surface becomes heavily charged with positive energy.[183] Any object, any human standing nearby, experiences the same. We cannot escape the affect of the storm when we are underneath: it literally reaches into our bodies.[184]

And now the electrical field, the expanse of air between cloud and ground, crackles as it resists the eagerness of opposing charges to reunite.

But it can't resist for long. Air is an unwilling conductor, but it can be tortured into submission. And that is what the cloud is willing to risk to reach equilibrium. Somewhere in the cold depths of its lower charge centre, a pulse

Figure 1.38 - Photo by Jonas Piontek.

begins. A stampede of electrons surges in short bursts down a staircase which they make up as they go, an improvised Jacob's ladder. Each rung of this stepped leader is a twisting, 50 metre channel of ionized air, or plasma, 2-5 centimetres across.[185] In a single microsecond, the atoms in the channel are stripped of their electrons. These electrons hover and wait. After about 50 microseconds, the pulse continues.[186]

The stepped leader is a surveyor, a pathfinder. The air resists at every step, and the leader must find the path of least resistance.[187] This means its route is constantly bending and swerving; it remains tortuous no matter how much we magnify our photographs.[188] In the quest of lightning to find the ground, there are no straight lines. The air is a kind of maze, and there are numerous branchings and dead ends. The path of least resistance is rarely the most direct route: in extreme cases lightning has been observed to travel more than a hundred kilometres, reaching far beyond the boundaries of its own storm.[189] Lightning from a clear sky, as a phrase, did not come out of nowhere.

The stepped leader is never quite allowed to reach the ground.[190] The ground, in its eagerness, comes to meet it. By the time the pulse is about 100 metres away, mystical fire appears on tall, pointy objects nearby. St Elmo's Fire, sailors used to call it, when a corona discharge became visible on the masts of a ship.[191] Upward, positive streamers of charge tentatively reach toward the incoming stepped leader. The strongest one will cause the downward path to bend toward it, and, a few dozen metres from the ground, they connect.[192]

The long quest is over. Everything starts happening very fast. A new suspension bridge is open across the ocean, ground-seeking electrons no longer need to search for a path – one has already been made. The channel of ionized air is full to the brim with free electrons, and suddenly, beginning at the base, they drop.[193] As though a traffic light turned green, each little vehicle races forward. The ones in front accelerate first; those behind rev their engines and start moving when the way is clear. In fulminological terms, this initiates the return stroke, an upward-propagating wave of downward-moving electrons which moves at 1/3 the speed of light, and heats the air around it five times hotter than the surface of the sun.[194] This is the scandalously bright flash we observe, with our slow human

Figure 1.39 - Photo by Jonas Piontek.

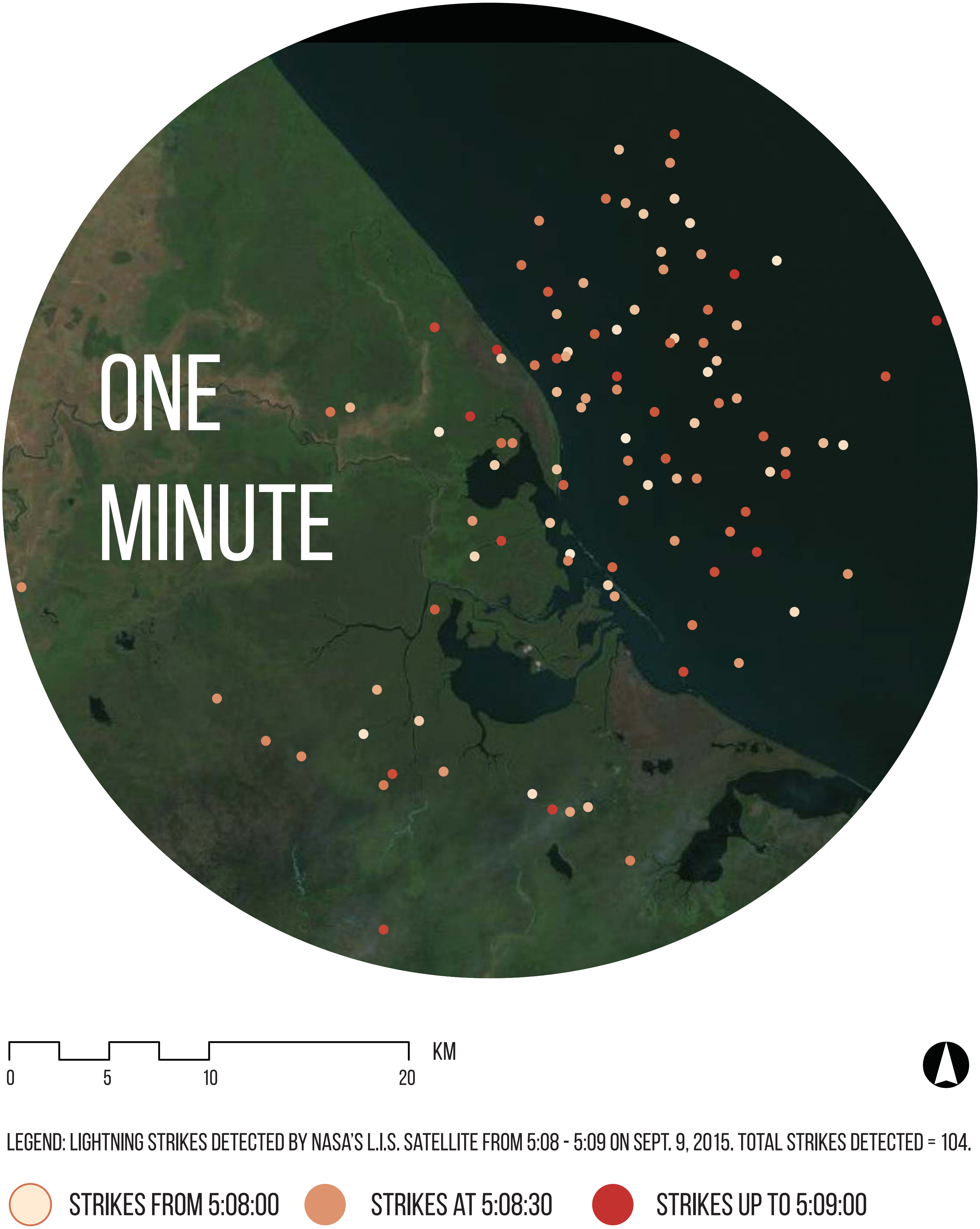
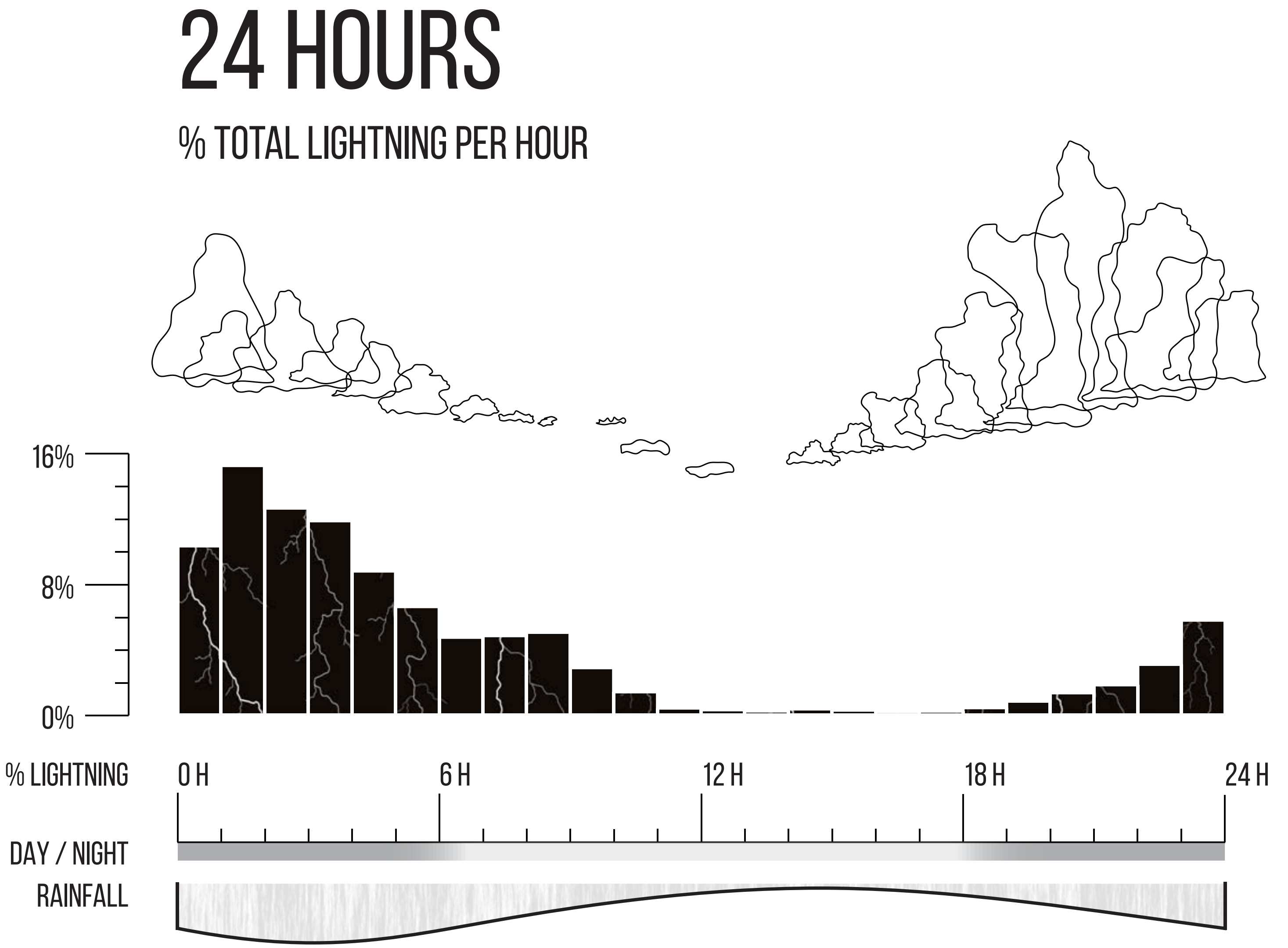


Figure 1.40 - One minute of Catatumbo lightning strikes.



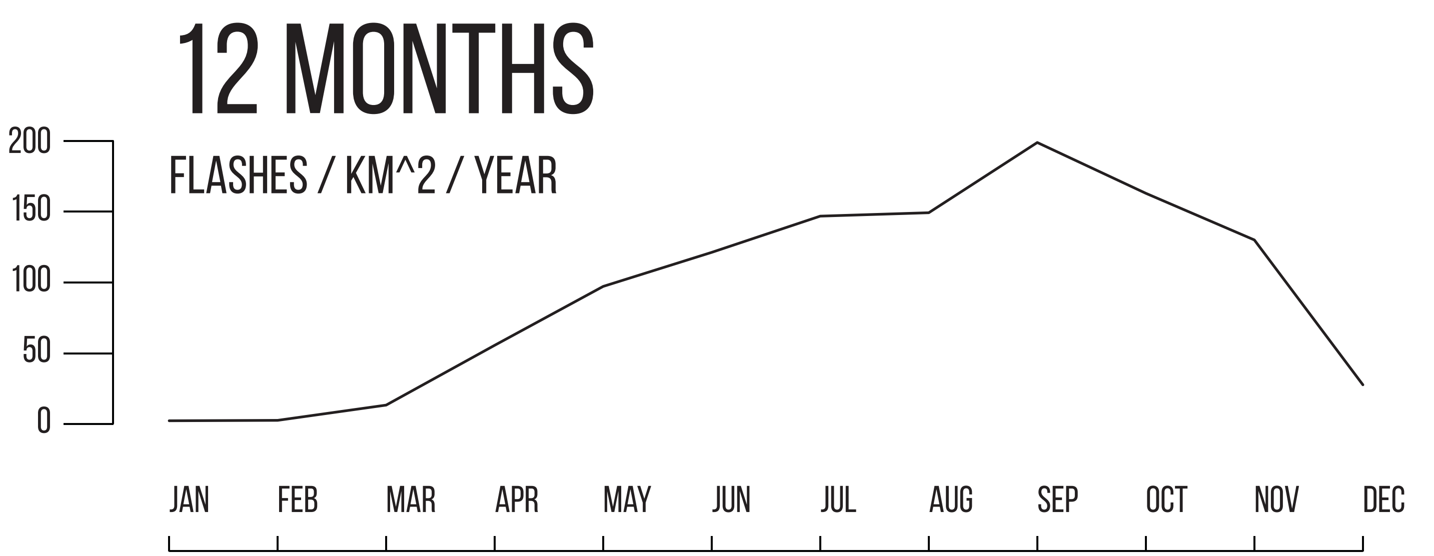


Figure 1.41 - Daily and monthly lightning cycles.

eyes, as lightning. The entire quest of the stepped leader has been invisible, but now it registers.[195] We see it. We hear it.

We hear it because this is the moment when thunder happens. Superheated air explodes away from the plasma channel in a shock wave. The wave decays; the air contracts.[196] As though a bent cylinder had blown up like a long balloon around the lightning channel, smoothing out its tortuosity, sound waves emanate outward.[197] Not every twist and turn of the lightning is registered; thunder is like a scratchy phonograph. It's a rough translation of light into sound. The way you hear it depends on where you're standing, as well as on what kind of 'acoustic room' the storm occupies.[198] Like the stepped leader of lightning, the peal of thunder must go on a quest through the unforgiving air, which does its best to dissipate the sound. But unlike lightning, with its violent shattering of electron bonds, thunder is almost gentle as it ripples along. Its medium is the air itself. After the initial shock wave, thunder drifts outward at a leisurely pace of 340 metres per second until it reaches your ears. Or until it doesn't. Lightning can be seen from hundreds of kilometres away, but thunder is only audible for about twenty – and this distance can be massively reduced by rain or wind.[199] The audio and visuals of a storm are oddly un-synced.

They can, nevertheless, be read together. Lightning is intensely spatial and spread-out; it is a kind of extended infrastructure in the air. And thunder records that structure sonically. If you practiced, you might be able to draw the shape of the lightning, and determine its trajectory, just from hearing thunder. It is not like a sound emitted from a single point; instead, it is a collection of compressions and rarefactions emitted almost simultaneously from multiple points. It's just the imprint, the shadow, the snow angel of the lightning left behind on the air – and we happen to have bodily organs that translate that imprint into a kind of acoustic seeing.

If you, as an unwary storm chaser, stand very close to a ground strike, you will hear the crackling sound of a positive streamer followed by a massive explosion as the return stroke begins.[200] And it may, at 120 dB, damage your eardrums.[201] This initial clap will be followed by a long rumble, as sounds created in the upper reaches of the channel wash over you in a rolling cadence. Generally, sounds emitted perpendicular to the lightning channel are much louder than sounds

Figure 1.42 - Photo by Jonas Piontek.

running parallel to it.[202] Even at a distance, you will pick up on a mixture of claps and rumbles, due to the endless switchbacks and sharp turns on the electron highway.[203]

In some cases, once the lightning channel is drained of charge by the return stroke, the story ends. A degree of balance has been achieved. But most of the time there is still more negative charge, waiting impatiently inside the cloud.[204] Next up: dart leaders.

The lightning channel remains open. As NOAA describes it, what happens next is that "the lightning channel branches out inside the cloud in a tree-like shape, and draws free electrons to it."[205] A dart leader heads downward, and unlike the original stepped leader, it tends to stick to the existing channel and meets no dead ends. Several sequences of dart leaders paired with return strokes may follow.[206] From an observer's perspective, the lightning appears to flicker. Sometimes it chooses a new path for part of its route; sometimes the wind even blows the channel sideways and spreads out the lightning in a kind of frayed ribbon.[207] These successive strikes reveal the electric architecture of clouds. Martin Uman describes how the storm cell gets cleaned out from bottom to top:

> *Each stroke in a multiple-stroke flash averages about a third of a mile longer than the preceding one. This is the case because, in order to obtain negative charge for a new stroke, J-streamers and K-streamers tap new areas . . . of the cloud during the time between strokes, and these tapped regions become part of the new stroke.*[208]

Eventually, the flow of charge along the plasma channel peters out, and the air is sewn back together. Cloud and ground, for the moment, have reached an understanding.

The entire process has taken less than half a second.[209]

Figure 1.43 - Lightning at sunrise. Photo by Jonas Piontek.

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PART 2: LIGHTNING FRAME

You can imagine this entire next chapter taking place in your mind at the moment of a lightning flash. It's a folly, a flight of fancy. But it needs some scaffolding to hold it up while you walk through it.

What I've done is this: designed a lightning observatory, and written a story to show it to you. It's not meant as a real-life prescription, or as a device to solve problems. Instead, it's a way of using design to reflect on this phenomenon of the recurrent storm.

What can architecture do, in a place like this?

The storm is wild, extreme, chaotic. It's a zone of great intensity, impossible to inhabit directly.[1] Human bodies weren't meant to be exposed to a hundred million volts, a hundred flashes in sixty seconds. You might survive for a few minutes in an open boat on Lake Maracaibo at midnight, but only by pure luck. You'd be even luckier to notice or feel anything beyond pure terror.

Architecture frames.[2] It filters the cosmos, making it sensible and inhabitable to us.[3] It might even succeed, for a little while, in carving out a house in the middle of the wildest lightning storm on earth.

That's the starting point.

But what kind of experience could be created, and what kind of architecture might do it?

Gilles Deleuze and Félix Guattari write that art creates percepts out of perceptions, extracting and preserving a set of sensations for as long as the supporting materials can last. Whenever anyone goes to look at Turner's *Snowstorm*, the sensation of the oceanic blizzard is there to be felt. It doesn't depend on the viewer; neither artist nor model need be present. The painting can "stand up on its own."[4]

The percept acts "to make perceptible the imperceptible forces that populate the world."[5] In a thunderstorm, the forces are imperceptible not through subtlety, but through ferocity. Architecture can be deployed as a translator, receiving and transforming lightning, thunder, wind, and rain like an outer skin, an exo-sensorium. The forces are not predictable: each oscillation of electric charge is newly invented.[6] The building is a screen through which to feel their fluctuations.

When I began, I envisioned some kind of lightning tower in the middle of the storm. As I worked through iterations, it seemed to migrate away from open water and toward the lake's edges - the tidal zones, the lagoons and the barrier islands – becoming part of the shore. Tim Ingold writes about "a zone of admixture and interchange between the more or less solid substances of the earth and the volatile medium of air."[7] He argues that life happens, not simply on the surface of the ground, but *within* this blurred and thickened boundary.[8] I began to consciously situate my building in the zone of transition. Opposing terms like aerial and earthy, dark and light, became gradients instead. The form sank down and sent out roots to join in the slow weather of sedimentation; it rose and redirected wind sweeping off the lake. Absent a solid and abstract ground plane, architecture is forced to grapple with the fundamental instability of its setting, orienting itself within a stream of interwoven forces.

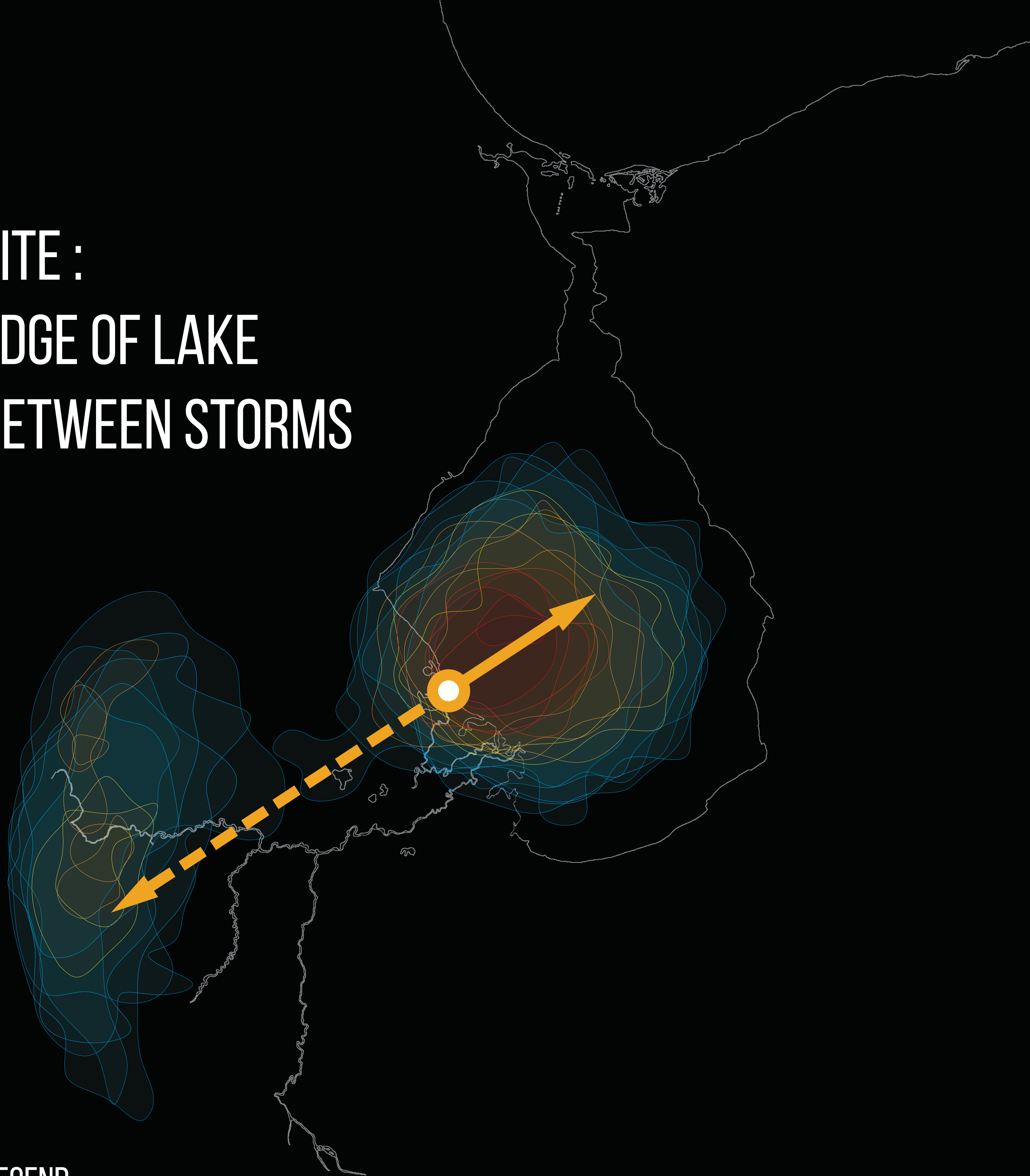
This orientation can be both defensive and responsive. As a specific example: I had assumed that, in order to keep its occupants safe from a direct strike, the observatory would have to be constructed from non-conductive materials. It would then require a lightning protection system with air terminals (lightning rods), down-conductors, and grounding rods.[9] The most critical thing is avoiding the build-up of differences in electrical potential between components, which can cause side-flashes of current that leap inside the structure, sometimes passing through its human occupants.[10] However, as Martin Uman writes in *The Art and Science of Lightning Protection,* "the ultimate air terminal is a solid metal roof."[11] An all-metal building, bonded together so as to be electrically continuous,[12] will avoid side flashes while providing multiple paths to ground along its outside skin. It turns out that rather than resisting or pushing back against the overwhelming force of a lightning strike, it is safest to embrace the current.

Lightning creates a very special and strange kind of light. It is discontinuous in time, and spatially local, rather than astronomical. The flash happens too fast for the human mind to think about it – the affect is immediate.[13] It induces our becoming-animal, becoming-storm.[14] It acts on us, as the storm acts on the building – and remember that the percept lasts only as long as the materials used to form it. It's not exactly *safe* to spend the night inside a thunderstorm.

Let's take a walk.

Figure 2.1 (opposite) - Design site and orientation.

SITE :
EDGE OF LAKE
BETWEEN STORMS



LEGEND

PRIMARY VIEW

SECONDARY VIEW

2005 - 2010 LIGHTNING INTENSITY AREAS

0 10 20 40 60 80 KM

Day and night, night and day, the circle of fire and light goes around.

Figure 2.2 - mangrove forest.

And on one of these days, in the dead heat of an October afternoon, you arrive.

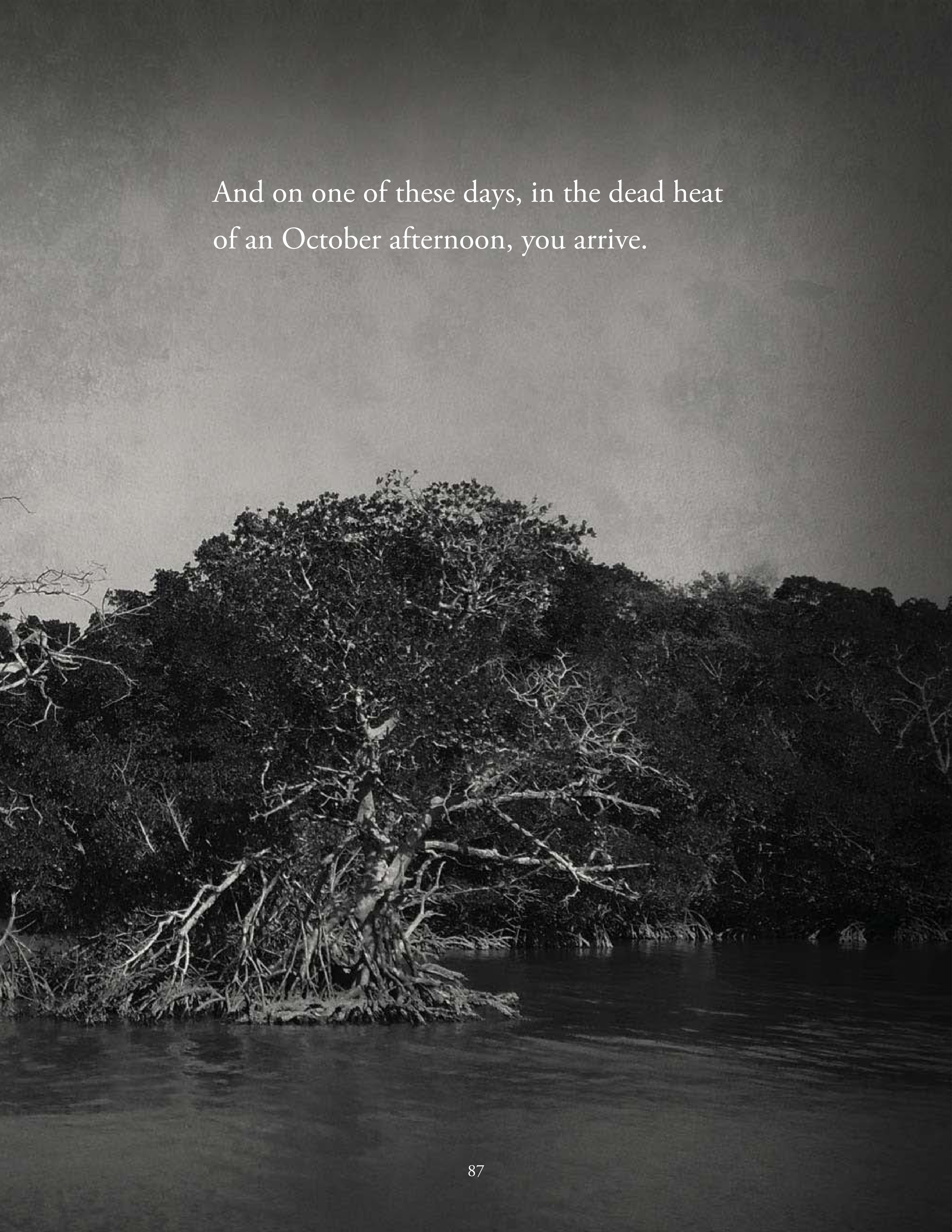
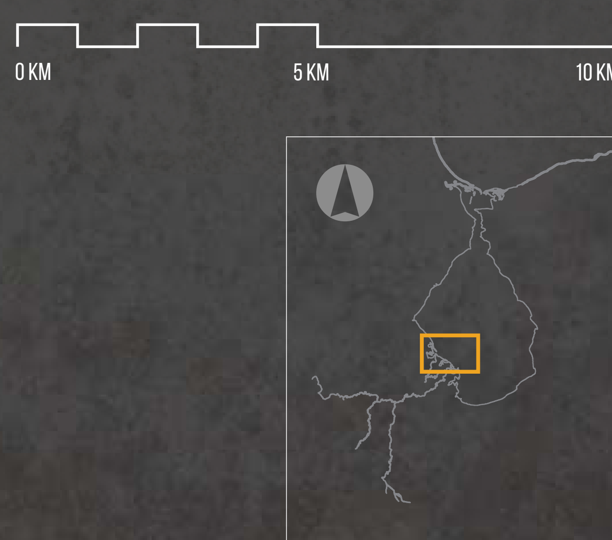
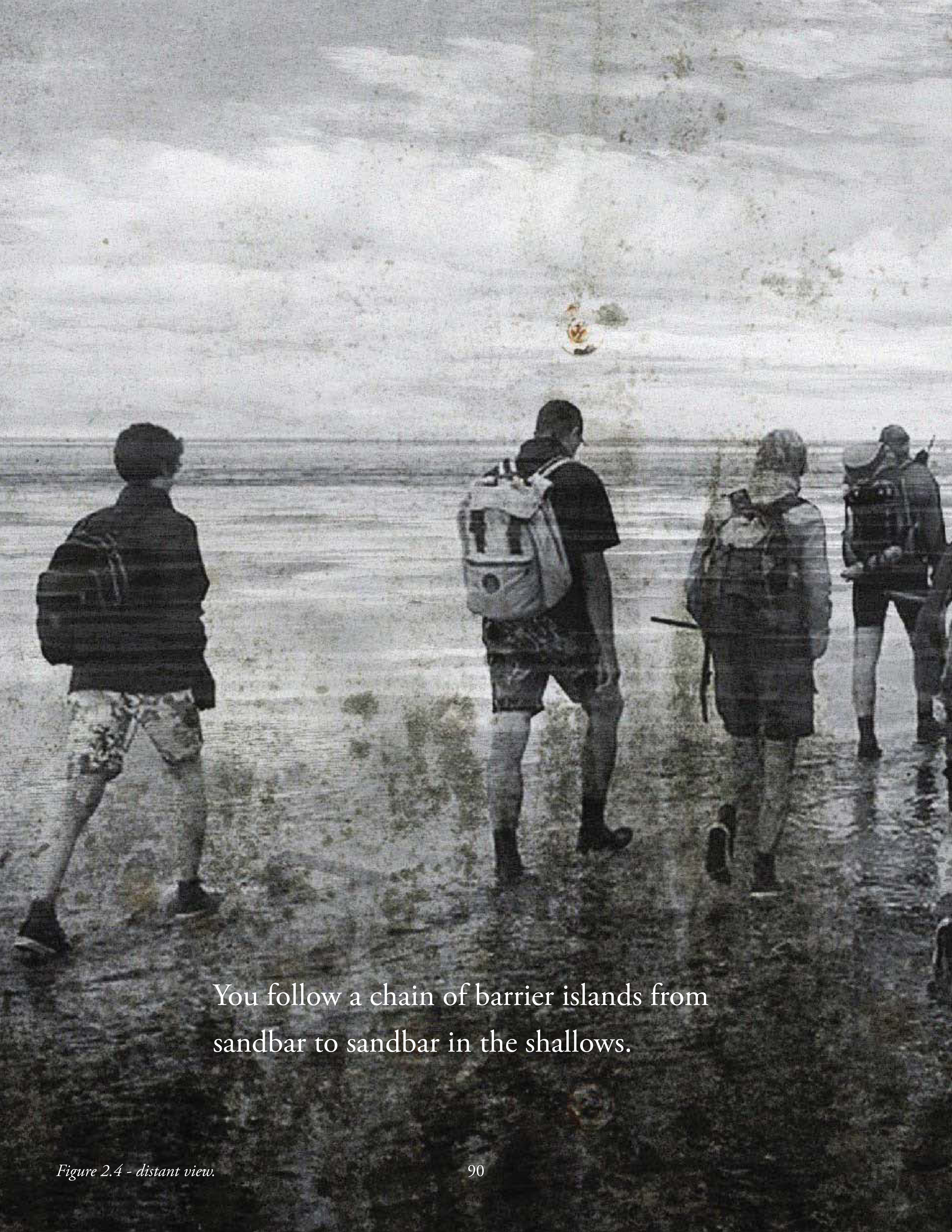


Figure 2.3 - regional site plan.

You've taken a boat across the lake from Maracaibo, threading the oilfields to the southwest shore. Around the mangrove forests and the stilt houses is a tidal world of shifting shores and twisted rivers: the nearest solid ground is miles toward the mountains.

Now your motley crew of scientists and tourists walks the last stretch from San Isidro, striking out along the sand.





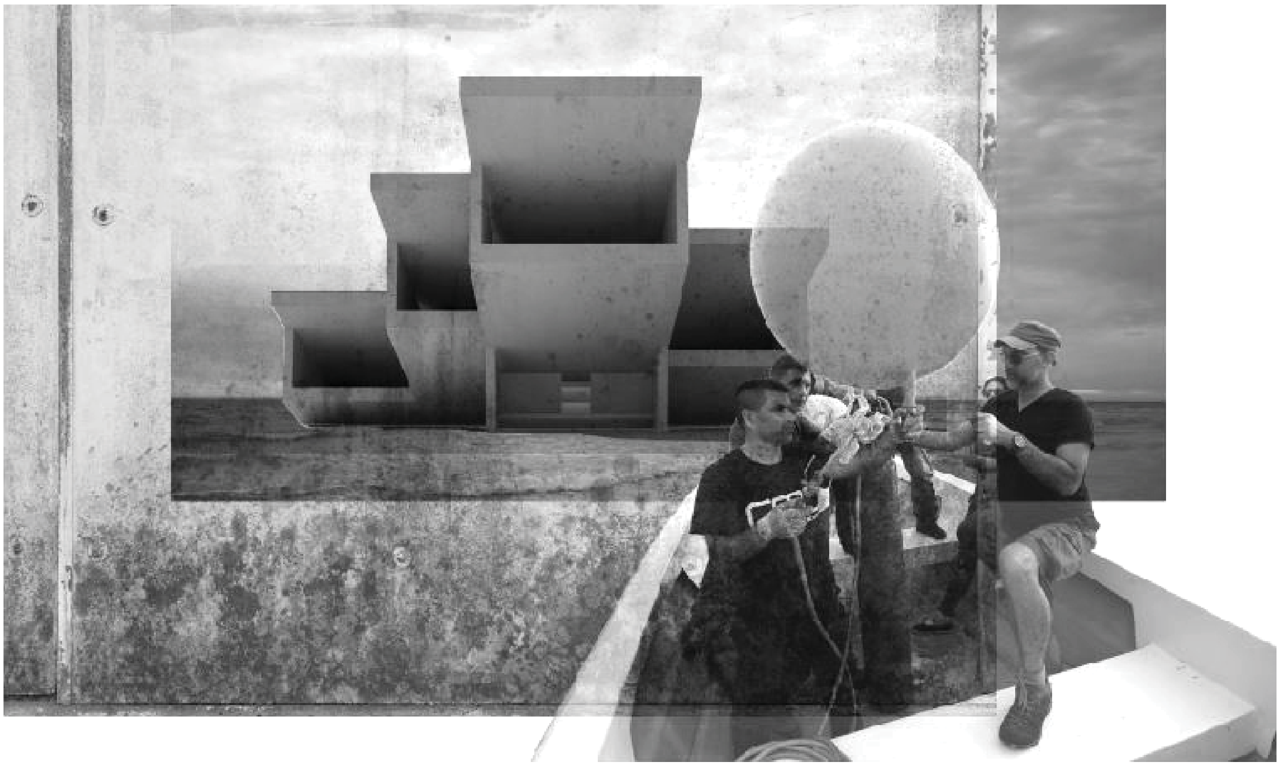
You follow a chain of barrier islands from sandbar to sandbar in the shallows.

Figure 2.4 - distant view.

A shape looms on the horizon. “That’s base camp,” they tell you. But what is it?

As you get closer, you see what looks like a doorway on the underside. Could this be a shipwreck? A misplaced wartime bunker?

Figure 2.5 - island chain.



Some meteorologists are launching a weather balloon from a nearby boat. Your own crew cheers as it soars up, a shrinking red smudge in a sultry sky.

Then you turn to go inside.

Figure 2.6 - rear entry.

Relief from the heat is palpable. In the sudden shade, you barely notice the dim outlines of a space that nosedives into the lake, yawning like the mouth of a tunnel.

Turning left, your team follows a narrow bridge into a room that faces southwest.

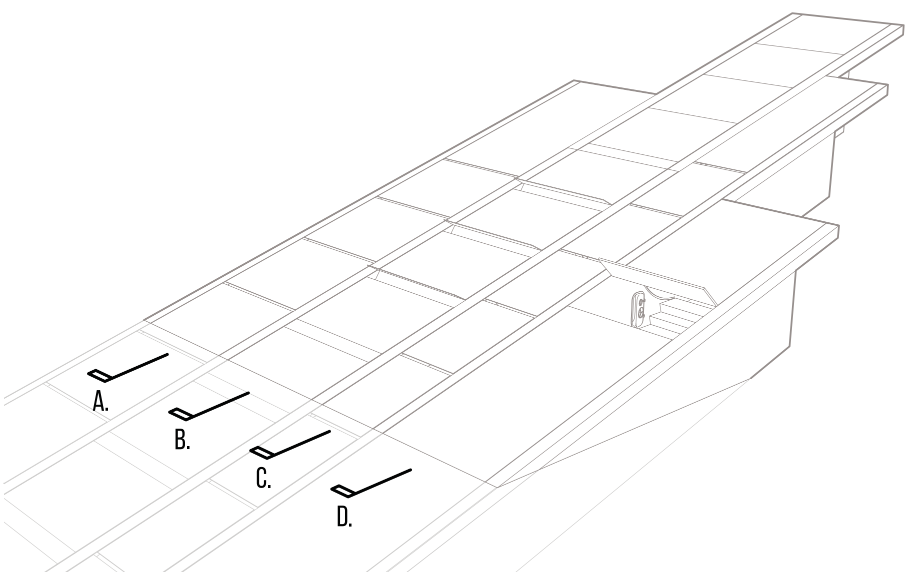
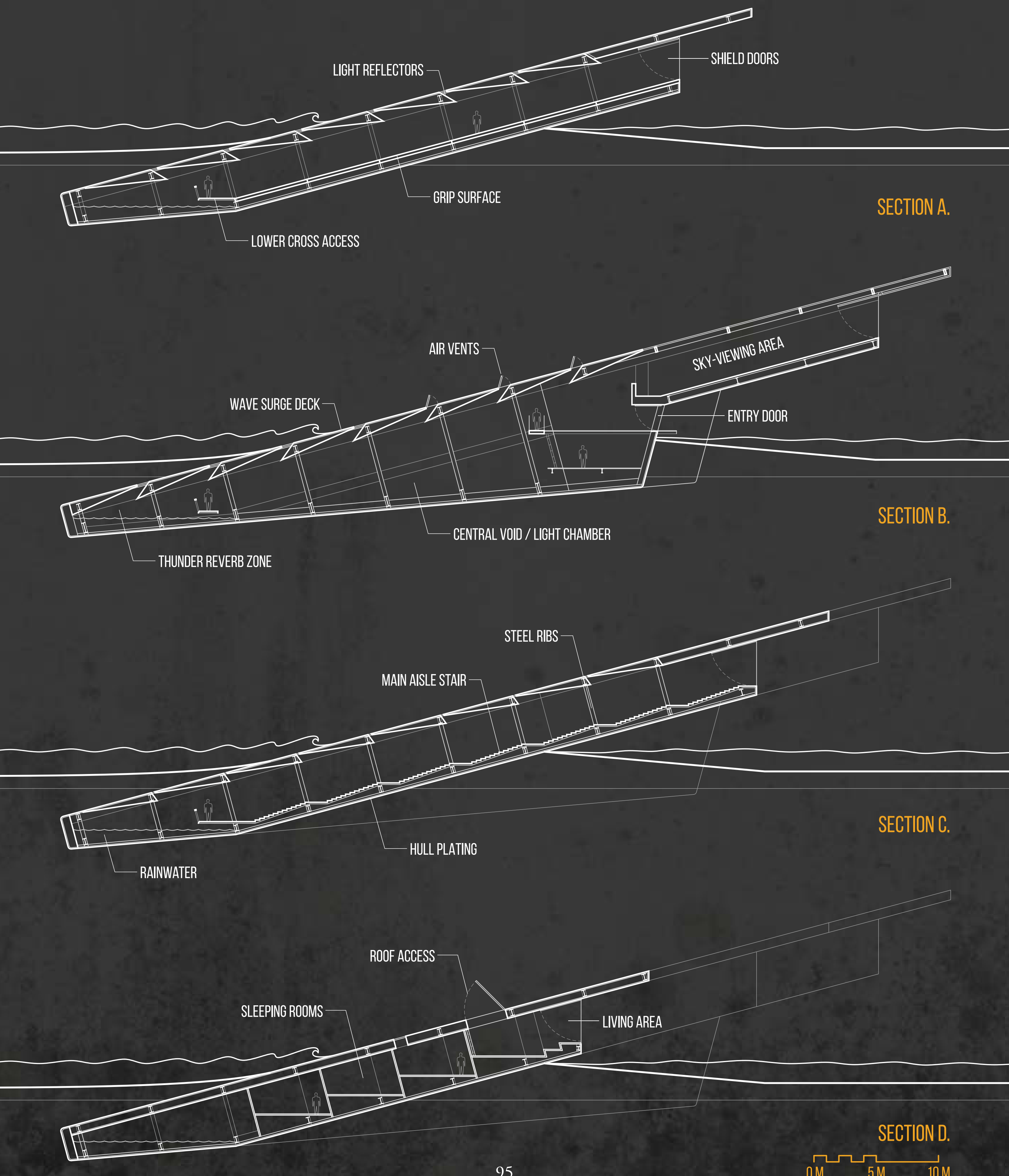


Figure 2.7 - aerial view & section key.

Getting out cooking equipment, the group shares a meal as the sun sinks lower.

Figure 2.8 (opposite) - Sections.


LIGHT REFLECTORS
SHIELD DOORS
GRIP SURFACE
LOWER CROSS ACCESS
SECTION A.
AIR VENTS
SKY-VIEWING AREA
WAVE SURGE DECK
ENTRY DOOR
CENTRAL VOID / LIGHT CHAMBER
THUNDER REVERB ZONE
SECTION B.
STEEL RIBS
MAIN AISLE STAIR
HULL PLATING
RAINWATER
SECTION C.
ROOF ACCESS
SLEEPING ROOMS
LIVING AREA
SECTION D.
0 M
5 M
10 M

You watch the jagged line of the mangroves
get dimmer and fade from sight.

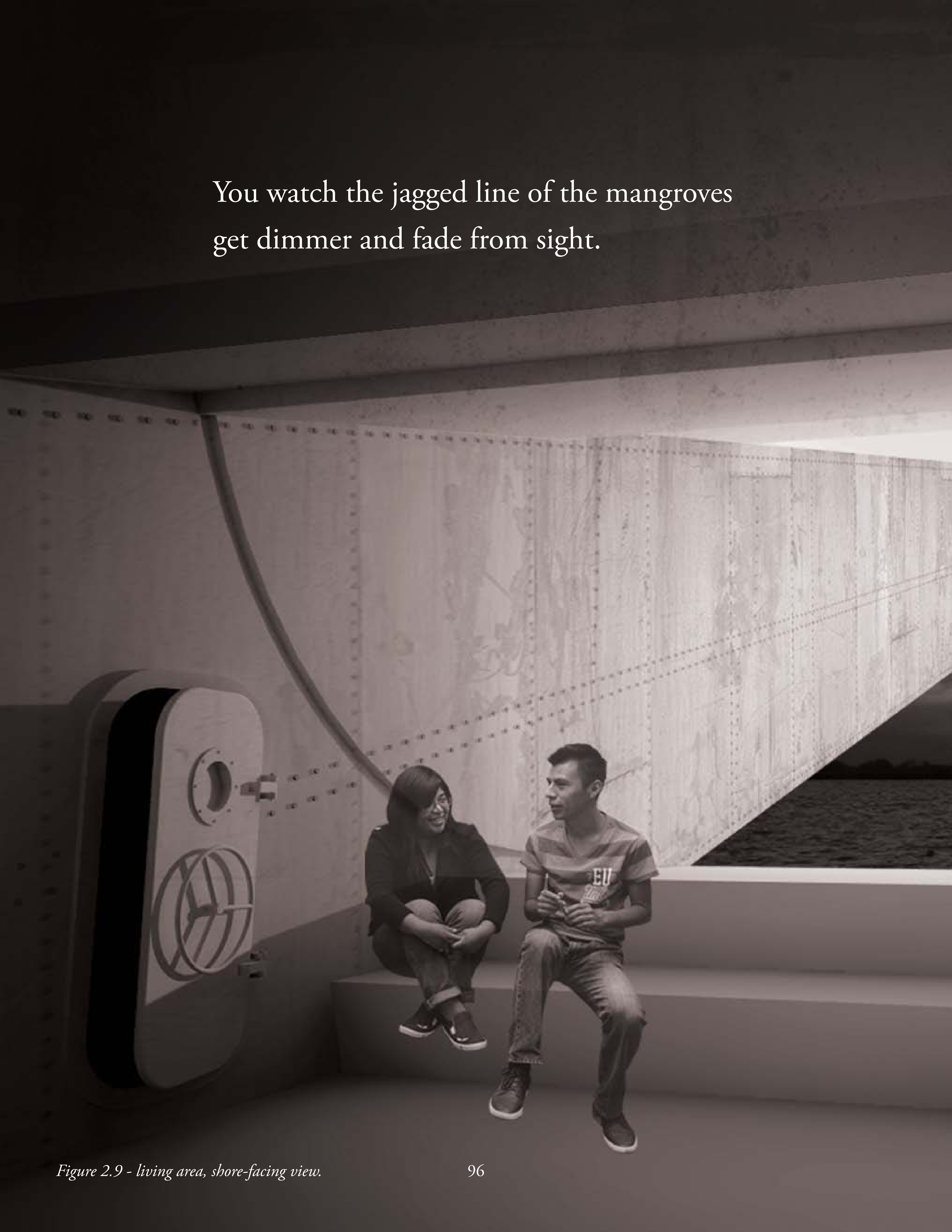
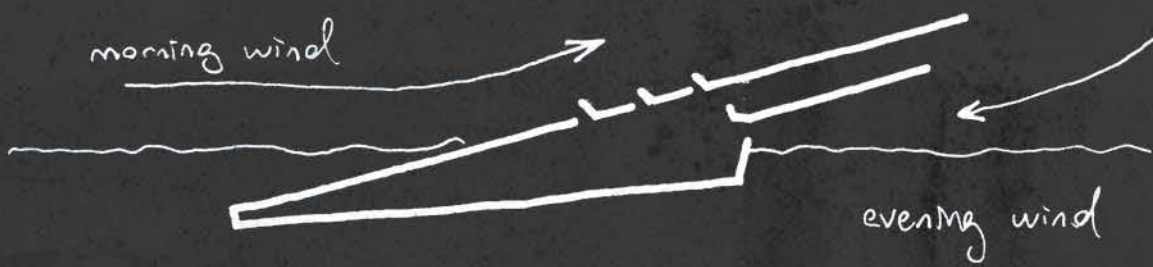


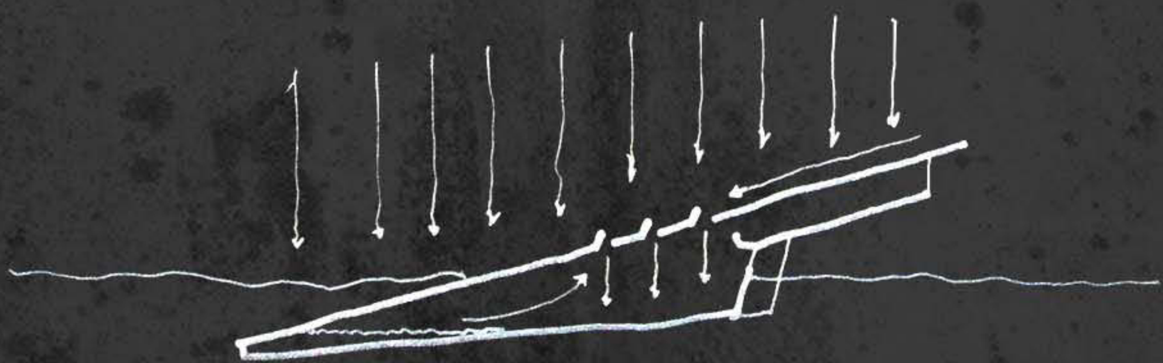
Figure 2.9 - living area, shore-facing view.

LIGHTNING RECEPTION

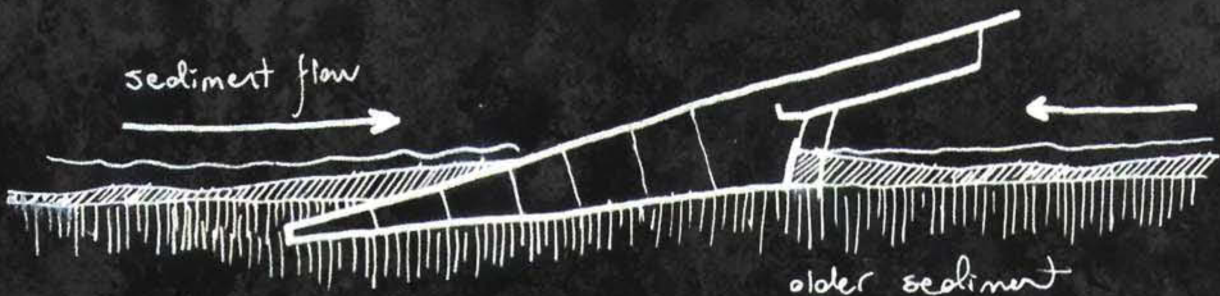
WIND CYCLE



RAIN + EVAPORATION



SHORELINE CHANGE



In growing darkness, a geologist unfolds a map.

She draws sketch after sketch on small pieces of paper, showing you the various forces affecting the station, and how it affects or absorbs them.

You get lost in her words, so you excuse yourself to go take a look around the ship.

Figure 2.10 (opposite) - force sketches.

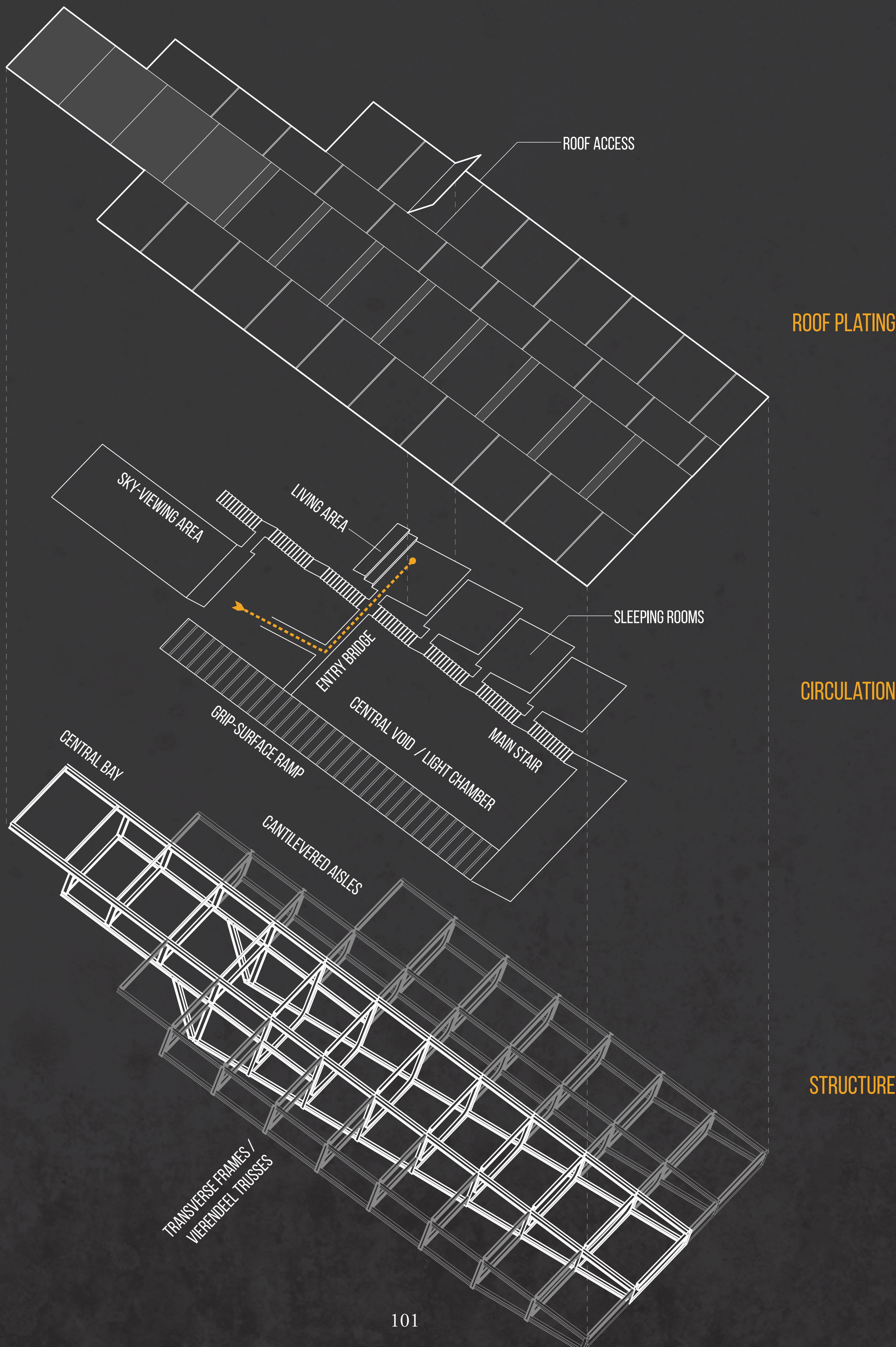
You do not find the steel structure entirely reassuring: there are spots of rust, patches of algae.

You move around its big metal bones. They seem to hum, slightly, resonating with the wind outside; waiting, like the strings of an instrument, to be struck.

One of the meteorologists goes topside and opens the vents to catch the evening breeze.

“Don’t worry,” he calls. “I’ll get ‘em closed long before midnight.”

Figure 2.11 (opposite) - exploded axonometric.


ROOF ACCESS
ROOF PLATING
SKY-VIEWING AREA
LIVING AREA
SLEEPING ROOMS
ENTRY BRIDGE
CIRCULATION
GRIP-SURFACE RAMP
CENTRAL VOID / LIGHT CHAMBER
MAIN STAIR
CENTRAL BAY
CANTILEVERED AISLES
STRUCTURE
TRANSVERSE FRAMES /
VIERENDEEL TRUSSES

Night sinks in like the weight of the lake above.

You're underwater, inside.

The slow rhythm of waves on the roof lulls you to sleep.

You wake in what feels like an earthquake.

You can see nothing, but your body and the metal underneath you are shaking, buzzing.

Slowly, your ears adjust, and can begin to distinguish sounds: drumming rain on the roof, waves crashing like cymbals, and rumbling peals of thunder.

Sitting up, you turn around, and now –
light.

A dim flash.
It must be after midnight.

Another flash: there's more light higher up. You stand, a little unsteadily, and step forward.

Navigation is difficult: wait for a strike, then walk till the after-image fades. You feel your way, falling into rhythm with the storm.

Seeing two people at the far end of the central void, you climb to join them, then follow their eyes upward.

Figure 2.12 - central void / light chamber.

The ceiling throbs with light. Strobing flashes catch the hanging profiles and kindle them.

This building, a wreck by day, at night becomes something else.

You begin to walk about from place to place, testing and feeling the different qualities of light, the colour of shadows.

You sit down at the lowest level and just listen to thunder. You climb slowly up and down the aisles, watching shards of light dance on the walls. The storm is being alchemized and atomized, and reassembled.

Figure 2.13 - sectional perspective.

This is a reef the storm can break over, a fortified lightning shrine.

As current strikes the roof, it flows around the body of the building, sticking close to the skin outside, leaving the internal organs alone.

Inside, you're safe, wearing the building like a crustacean's shell.

But any suit of armour has flaws.

The waves outside have gotten louder. Above their pounding, you pick up a new sound: a metallic rattle, repeated with each crest.

Another wave curls down. It crashes and breaks, surging up the slope.

Then the roof gives way.

Figure 2.14 - deluge.

Water explodes downward.

Having found a weak spot, the whole lake seems to be trying to pour through. You're suddenly drenched, up to your knees in murky water.

Clinging to the railings, you pull yourself out onto a stair landing.

Others are there, including the meteorologist who spoke to you earlier.

A muddy entomologist scrambles up beside you. “Didn’t all those vents get bolted down?” she splutters.

The meteorologist stares for a moment. Then he turns and rushes up the stairs.

He runs. You follow, shouting:

Figure 2.15 - the chase.

"Don't go out there! You'll be dead in seconds."

You catch up just as he throws open the access hatch. Rain pours down on both of you; the wind is screaming.

If lightning strikes now, it's over. But you pause to lift a bundle from a hook on the wall.

“Wait!” you say, climbing the ladder behind him. “At least hold onto this rope, so you don’t get swept off.”

He grabs one end and steps off the ladder.

You lean out of the opened hatch and grip the rope, blinking away rain.

He misses his footing, and then he just *leaps,* diving for the vent.

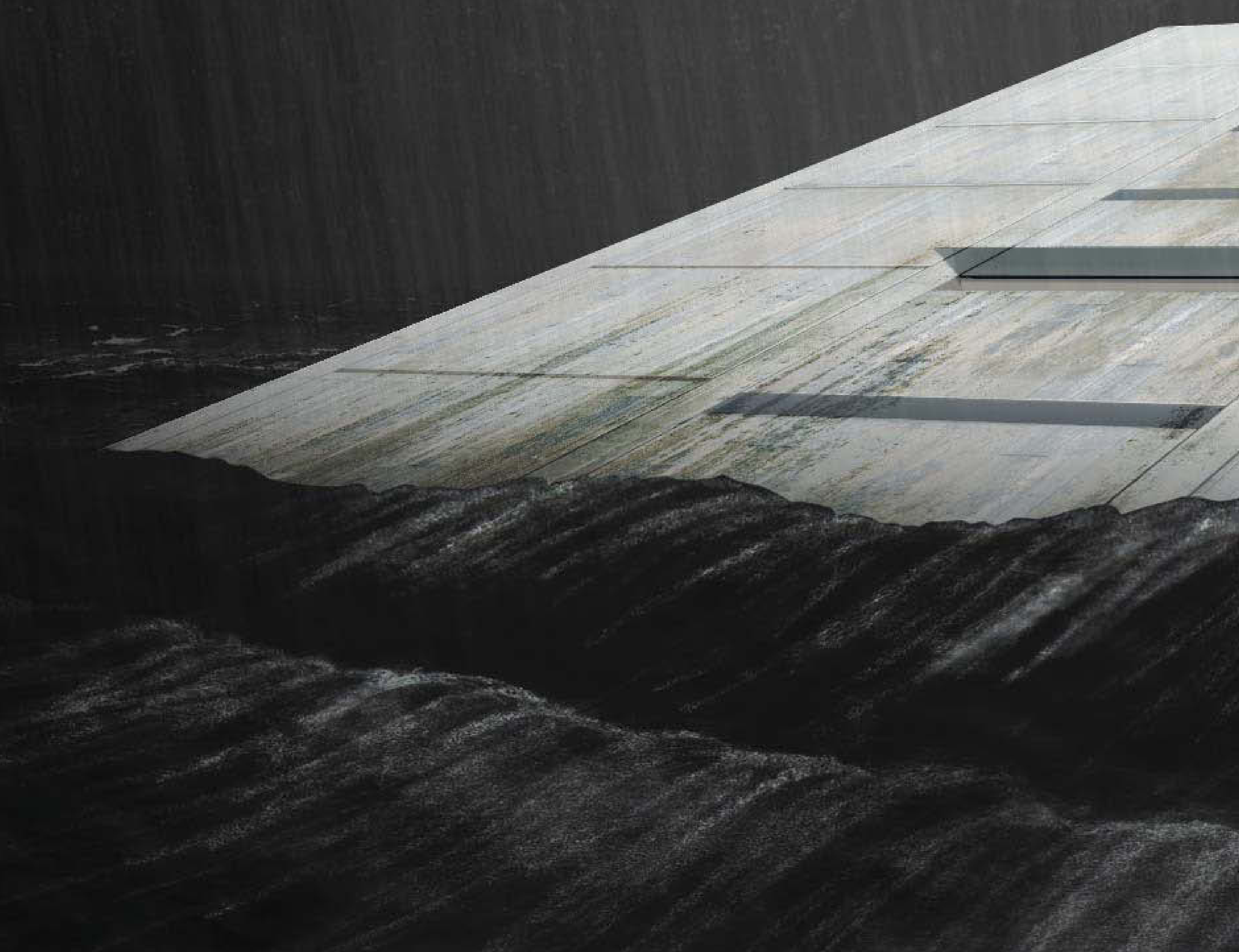


Figure 2.16 - the leap.

The sky seems to freeze.

The meteorologist wrenches down the vent cover and locks it. You hold your breath, holding back the lightning.

The storm is like another animal around you. There's nothing but empty air between.

Static charge rises in your body, pulled up by the clouds. The sky is coming to find you.

“Hey!” A tug on the rope. “Get me out of here!”

You’re back, just pulling. Now he’s back too. The hatch slams. It’s done.

Eager hands help you down and offer towels and blankets. Happy to be neither drowned nor electrified, the group sweeps you along to the observatory level. Some lie back against the slope; others jibe and praise the meteorologist.

Gradually the laughter fades. It’s impossible to look away from what the sky is doing.

It's the sunset of the lightning, the end of the fireworks show. Lightning tears open the skin of the sky, and then rain comes, and washes away the scars.

Tomorrow, some will leave, but not you. You're going to stay on inside the circle of storms, and it could be for one night or a thousand.

Figure 2.17 - sky-view level.

EPILOGUE

Figure 2.18 - Andromeda arrives.

Dance

6,378 kilometres. That's how deep the Earth is. That's how deep it is possible to go.[15]

100 kilometres. That's the height of the atmosphere – the Kármán line, which is one way of defining where the weather-ocean ends and outer space begins.[16]

46.6 billion light-years. That's the radius of the observable universe. That's how far it's possible for us to *see*.[17]

7.5 billion years. That's how long we have until our planet gets eaten by the sun.[18]

Earth, a strange word. E-A-R-T-H. The word itself means 'ground,' but we are not grounded – our location is not fixed. We are wanderers on a wandering planet. We do not stand still in the galaxy, and the galaxy does not stand still in the universe. After the Catatumbo Lightning ends and begins several times over, as South America shifts westward, and a new supercontinent forms and dissolves, the sun and its planets will race around the glowing core of the Milky Way three times. Then they'll do it again, and again, and still eleven times more.[19]

And then the Andromeda Galaxy will crash into the Milky Way.[20]

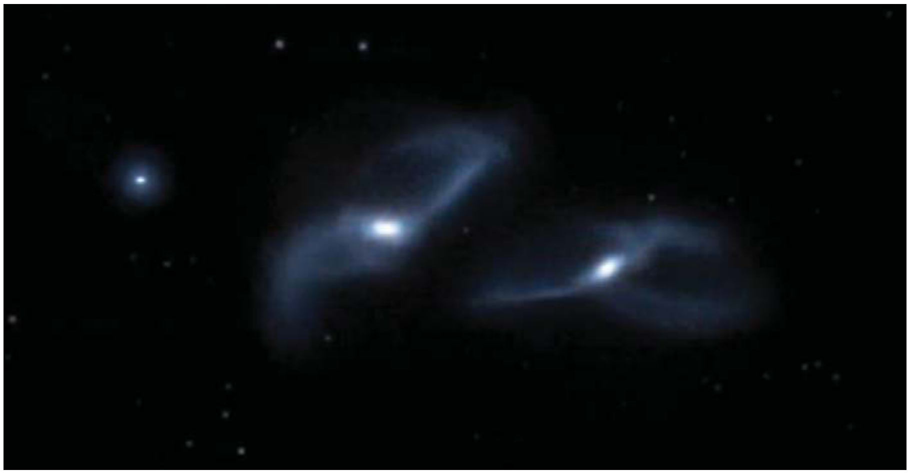


Figure 2.19 - Simulation of the Andromeda-Milky Way collision.

It won't hurt. It won't be a cataclysm. Earth will still be around, and any living creatures that have evolved to adapt to its higher temperatures will be able to watch the slow motion dance in peace and safety. Nadia Drake describes it:

> *The two galaxies will collide head-on and fly through one another, leaving gassy, starry tendrils in their wakes. For eons, the pair will continue to come together and fly apart, scrambling stars and redrawing constellations until eventually, after a billion or so years have passed, the two galaxies merge.*[21]
>
> *"Few if any stars in either galaxy will actually collide. Any life on the worlds of that far-off future should be safe, but they will be treated to an amazing, billion-year long light show."*[22]

Think about this: we can't possibly predict what the world will be like in a hundred years. Or a thousand years. Or a thousand thousand years.

But we know what's going to happen in four billion. There's going to be an extraordinary light show in the sky, night after night. It doesn't matter if anyone is around to see it. Like a future, cosmic echo of the Catatumbo Lightning, the two galactic partners will keep shining, keep circling back, until all their energy for dancing is exhausted, and they settle down for a quiet life, merged into one, every star ablaze.

ENDNOTES - PART 2

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2 Gilles Deleuze and Félix Guattari, *What is Philosophy?* trans. Hugh Tomlinson and Graham Burchell (New York: Columbia University Press, 1994), 187.

3 Ibid.,182.

4 Ibid.,163- 165.

5 Ibid.,182.

6 Manuel De Landa, "Deleuze, Diagrams, and the Genesis of Form," *American Studies* 45, no. 1 (2000): 33-34, accessed April 27, 2018, https://seansturm.files.wordpress.com/2011/06/delanda-deleuze-diagrams-and-the-genesis-of-form.pdf.

7 Tim Ingold, "Footprints through the weather-world: walking, breathing, knowing," *Journal of the Royal Anthropological Institute* 16, no. s1 (2010): 122, accessed April 27, 2018, https://doi.org/10.1111/j.1467-9655.2010.01613.x.

8 Ibid.

9 "Erico Lightning Protection Handbook," *Pentair,* 14, accessed April 27, 2018, https://www.erico.com/catalog/literature/E907W-WWEN.pdf.

10 Ibid.,15- 16.

11 Martin A. Uman, *The Art and Science of Lightning Protection* (New York: Cambridge University Press, 2008), 72.

12 "Erico Lightning Protection Handbook," *Pentair,* 28, accessed April 27, 2018, https://www.erico.com/catalog/literature/E907W-WWEN.pdf.

13 This comes from a point my supervisor, Dereck Revington, made in one of our conversations recently.

14 Gilles Deleuze and Félix Guattari, *What is Philosophy?* trans. Hugh Tomlinson and Graham Burchell (New York: Columbia University Press, 1994), 169.

15 "Earth Fact Sheet," *NASA,* accessed April 27, 2018, https://nssdc.gsfc.nasa.gov/planetary/factsheet/earthfact.html.

16 "100Km Altitude Boundary for Astronautics," *Fédération Aéronautique Internationale,* accessed April 27, 2018, https://www.fai.org/page/icare-boundary.

17 Paul Halpern, "How large is the observable universe?" The Nature of Reality, accessed April 27, 2018, http://www.pbs.org/wgbh/nova/blogs/physics/2012/10/how-large-is-the-observable-universe/.

18 David Appell, "The Sun Will Eventually Engulf Earth--Maybe," *Scientific American,* September 1, 2008, accessed April 27, 2018, https://www.scientificamerican.com/article/the-sun-will-eventually-engulf-earth-maybe/.

19 This is my calculation of the number of times the Milky Way will revolve before the Andromeda collision. Data source: Ted Nield, "Supercontinents Before Rodinia," *The Geological Society*, October 2009, accessed January 17, 2018, https://www.geolsoc.org.uk/Education-and-Careers/Ask-a-Geologist/Continents-Supercontinents-and-the-Earths-Crust/Supercontinents-Before-Rodinia.

20 Nadia Drake, "Milky Way Has 4 Billion Years to Live — But Our Sun Will Survive," *National Geographic,* March 24, 2014, accessed April 27, 2018, http://phenomena.nationalgeographic.com/2014/03/24/scientists-predict-our-galaxys-death/.

21 Ibid.

22 Neil DeGrasse Tyson, quoted in: Nadia Drake, "Milky Way Has 4 Billion Years to Live — But Our Sun Will Survive," *National Geographic,* March 24, 2014, accessed April 27, 2018, http://phenomena.nationalgeographic.com/2014/03/24/scientists-predict-our-galaxys-death/.

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1.4	11	**Theia Meets Earth.** Robin M. Canup, "Simulations of a Late Lunar-Forming Impact," *Icarus* 168, (2004): fig. 2, accessed March 25, 2017, https://www.sciencedirect.com/science/article/pii/S0019103503002999. Used with permission.

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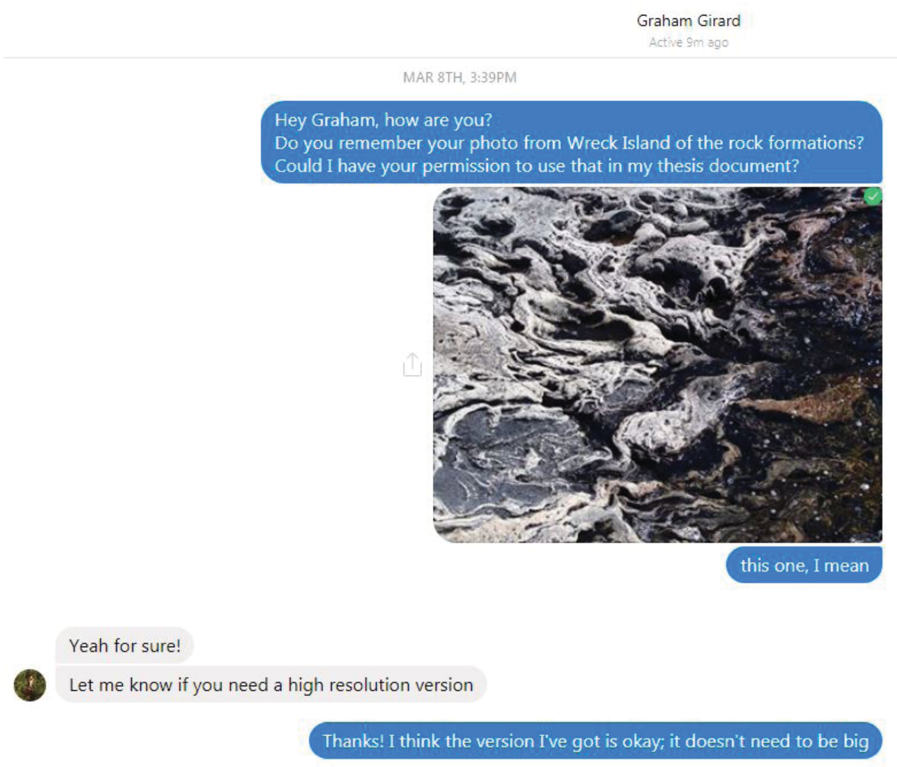
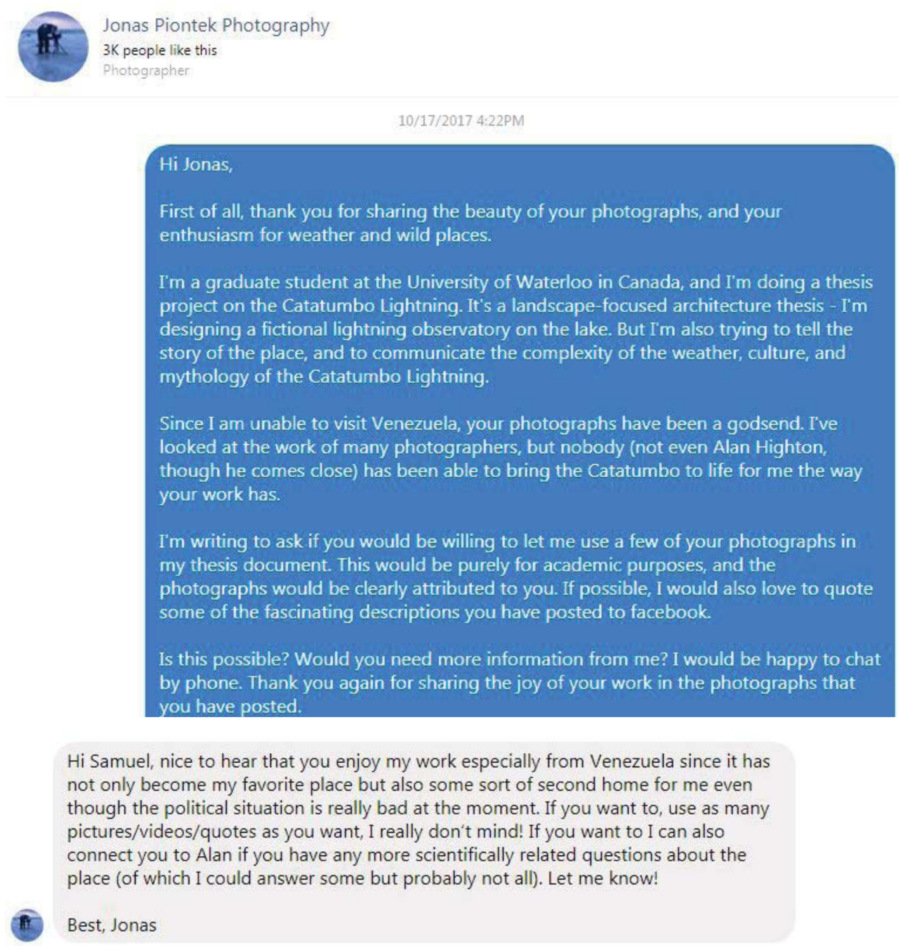


Fig.	*Pg.*	*Source:*
1.9	21	**Lightning on Lake Maracaibo.** Jonas Piontek, 2016. Available from: https://www.facebook.com/JonasPioPhotography/photos/a.931867743570955.1073741828.931857343571995/1155476261210101/?type=3&theater (accessed on April 26, 2018). Used with permission.

See also: Figures 1.38, 1.39, 1.42, 1.43.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10/17/2017 4:22PM

Hi Jonas,

First of all, thank you for sharing the beauty of your photographs, and your enthusiasm for weather and wild places.

I'm a graduate student at the University of Waterloo in Canada, and I'm doing a thesis project on the Catatumbo Lightning. It's a landscape-focused architecture thesis - I'm designing a fictional lightning observatory on the lake. But I'm also trying to tell the story of the place, and to communicate the complexity of the weather, culture, and mythology of the Catatumbo Lightning.

Since I am unable to visit Venezuela, your photographs have been a godsend. I've looked at the work of many photographers, but nobody (not even Alan Highton, though he comes close) has been able to bring the Catatumbo to life for me the way your work has.

I'm writing to ask if you would be willing to let me use a few of your photographs in my thesis document. This would be purely for academic purposes, and the photographs would be clearly attributed to you. If possible, I would also love to quote some of the fascinating descriptions you have posted to facebook.

Is this possible? Would you need more information from me? I would be happy to chat by phone. Thank you again for sharing the joy of your work in the photographs that you have posted.

Hi Samuel, nice to hear that you enjoy my work especially from Venezuela since it has not only become my favorite place but also some sort of second home for me even though the political situation is really bad at the moment. If you want to, use as many pictures/videos/quotes as you want, I really don't mind! If you want to I can also connect you to Alan if you have any more scientifically related questions about the place (of which I could answer some but probably not all). Let me know!

Best, Jonas

Fig.	*Pg.*	*Source:*
1.13	27	**Longhouse.** Roberto Lizarralde, "Barí Settlement Patterns," *Human Ecology* 19, no. 4 (1991): Fig. 1, accessed April 23, 2018, https://link.springer.com/content/pdf/10.1007%2FBF00889789.pdf. Used with permission.

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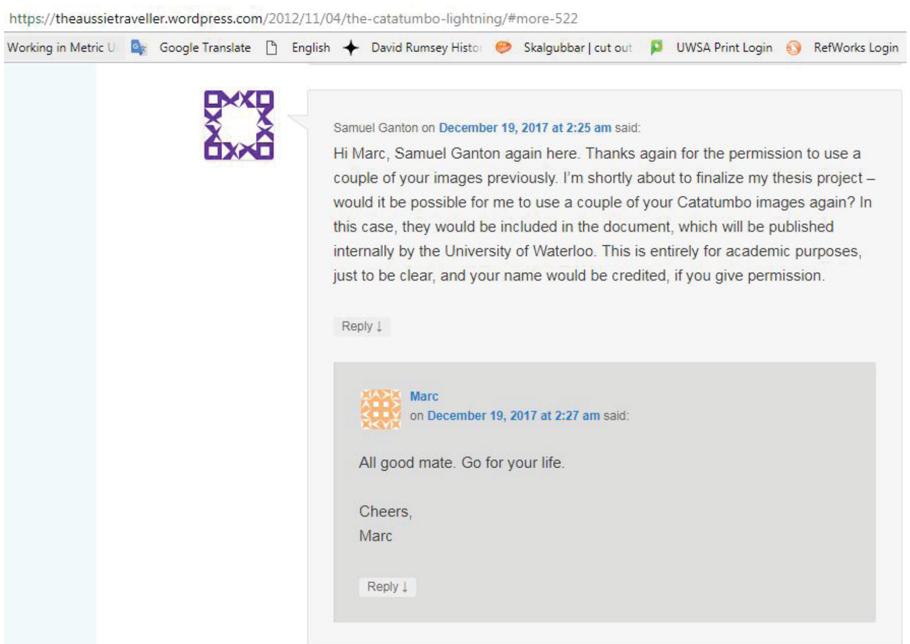
1.27	45	**House in Congo Mirador.** Marc "the Aussie Traveller," 2012. Available from: https://theaussietraveller.wordpress.com/2012/11/04/the-catatumbo-lightning/#more-522 (accessed April 26, 2018). Used with permission.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Samuel Ganton on December 19, 2017 at 2:25 am said:

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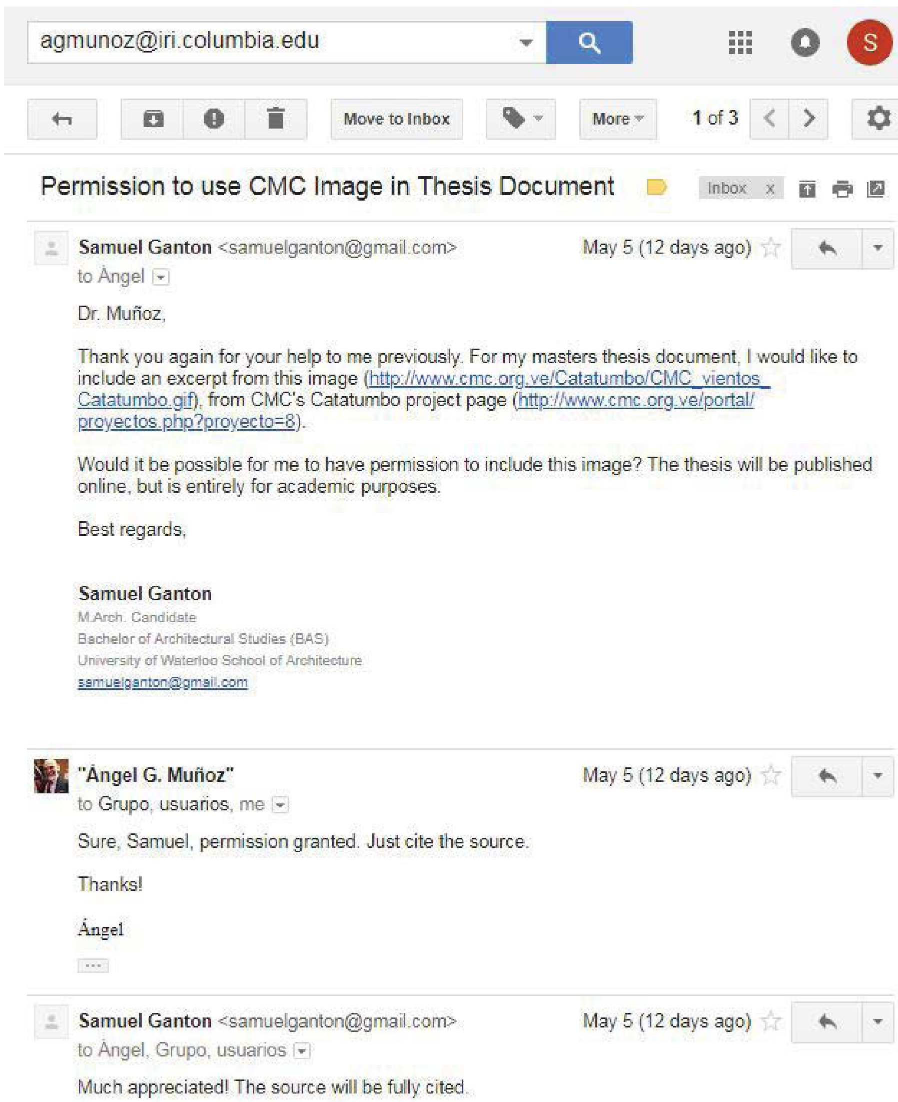
Marc
on December 19, 2017 at 2:27 am said:

All good mate. Go for your life.

Cheers,
Marc

Reply ↓

Fig.	*Pg.*	*Source:*
1.36	54	**Wind patterns.** Frames extracted from GIF available at: “Estudio Multidisciplinario de los Relámpagos del Catatumbo,” *Centro de Modelado Científico,* fig. 4, accessed April 26, 2018, http://cmc.org.ve/portal/proyectos.php?proyecto=8. Used with permission.



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Dr. Muñoz,

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Best regards,

Samuel Ganton
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Bachelor of Architectural Studies (BAS)
University of Waterloo School of Architecture
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Thanks!

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Much appreciated! The source will be fully cited.

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