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The Cloud Is Material: On the Environmental Impacts of Computation and Data Storage

Steven Gonzalez Monserrate¹

¹Program in History, Anthropology, and Science, Technology, and Society, MIT

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ABSTRACT

In the age of machine learning, cryptocurrency mining, and seemingly infinite data storage capacity enabled by cloud computing, the environmental costs of ubiquitous computing in modern life are obscured by the sheer complexity of infrastructures and supply chains involved in even the simplest of digital transactions. How does computation contribute to the warming of the planet? As information technology (IT) capacity demands continue to trend upward, what are some of the ecological obstacles that must be overcome to accommodate an ever-expanding, carbon-hungry Cloud? How do these material impacts play out in everyday life, behind the scenes, where servers, fiber optic cables, and technicians facilitate cloud services? This case study draws on firsthand ethnographic research in data centers—sprawling libraries of computer servers that facilitate everything from email to commerce—to identify some of the far-reaching and tangled environmental impacts of computation and data-storage infrastructures. It surveys a range of empirical accounts of server technicians to illustrate on-the-ground examples of material and ecological factors that permeate everyday life in the Cloud. These examples include air conditioning and thermal management, water cycling, and the disposal of e-waste. By attending to the culture of workplace practice and the behaviors and training of technicians in data centers, this case study reveals that the Cloud is not fully automated, nor is it hyperrational; emotion, instinct, and human judgment are enlisted to keep servers running. This case study closes with a speculative vignette that scales up from various local impacts to a planetary framework, sketching some of the particular ways that computation contributes to climate change and the Anthropocene.

Keywords: climate change, Anthropocene, data centers, data storage, digital ecology, materiality of computation, sustainable computing

Steven Gonzalez Monserrate

Program in History, Anthropology, and Science, Technology, and Society, MIT

Learning Objectives

- Learners will be able to identify the various material and ecological impacts of computation and digital data storage practices.

- Learners will recognize the environmental toll of digital life and the complexity of infrastructures involved in its operation.
- Learners will understand some of the ways that user behavior and cultures of computing influence efficiency and sustainability outcomes.
- Learners will be able to apply a holistic, humanistic approach to sociotechnical challenges.

Introduction: Materializing the Immaterial

Screens brighten with the flow of words. Perhaps they are emails, hastily scrawled on smart devices, or emoji-laden messages exchanged between friends or families. On this same river of the digital, millions flock to binge their favorite television programming, to stream pornography, or enter the sprawling worlds of massively multiplayer online roleplaying games (MMORPGs), or simply to look up the meaning of an obscure word or the location of the nearest COVID-19 testing center. Whatever your query, desire, or purpose, the internet provides, and all of the complexity of everything from unboxing videos to do-it-yourself blogs are contained within infinitely complex strings of bits. As they travel across time and space at the speed of light, beneath our oceans in fiber optic cables thinner than human hairs, these dense packets of information, instructions for pixels or characters or frames encoded in ones and zeros, unravel to create the digital veneer before you now. The words you are reading are a point of entry into an ethereal realm that many call the “Cloud.”

While in technical parlance the “Cloud” might refer to the pooling of computing resources over a network, in popular culture, “Cloud” has come to signify and encompass the full gamut of infrastructures that make online activity possible, everything from Instagram to Hulu to Google Drive.¹ Like a puffy cumulus drifting across a clear blue sky, refusing to maintain a solid shape or form, the Cloud of the digital is elusive, its inner workings largely mysterious to the wider public, an example of what MIT cybernetician Norbert Wiener once called a “black box.”² But just as the clouds above us, however formless or ethereal they may appear to be, are in fact made of matter—water molecules in various states of condensation and crystallization—the Cloud of the digital is also relentlessly material.

To get at the matter of the Cloud we must unravel the coils of coaxial cables, fiber optic tubes, cellular towers, air conditioners, power distribution units, transformers, water pipes, computer servers, and more.³ We must attend to its material flows of electricity, water, air, heat, metals, minerals, and rare earth elements that undergird our digital lives. In this way, the Cloud is not only material, but is also an ecological

force. As it continues to expand, its environmental impact increases, even as the engineers, technicians, and executives behind its infrastructures strive to balance profitability with sustainability. In my experience, nowhere is this dilemma more visible than in the walls of the infrastructures where the content of the Cloud lives: the factory-libraries where data is stored and computational power is pooled to keep our cloud applications afloat.⁴

In this case study, I bring you into the beating heart of the digital, into the blinking corridors of data centers (or server farms) that make digital industry possible. As an anthropologist, I approach the study of the Cloud holistically, taking seriously the technological and material aspects of computation and data storage, while also attending to the ways that the Cloud is a social and cultural formation. In what follows, I draw on five years of qualitative research and ethnographic fieldwork in North American data centers to illustrate some of the diverse ecological impacts of data storage and some of the sociocultural factors that influence the sustainability of digital infrastructures.⁵ I also provide a broad, introductory overview of some of the fast-moving and evolving literature on the material impacts of computation and data centers from a range of disciplines including computer science, engineering, media studies, and more.

Discussion Question: Where is the Cloud? Using the resources below, describe how you might “locate” the Cloud: What are the human and technological infrastructures that bring it about? What histories are relevant to narrating the “location” you sketch?

Undersea cable map	Interactive fiber optic cable map
Seeing Networks, city infrastructure website	What People Mean When They Talk About ‘The Cloud’

Cloud the Carbonivore

It is four in the morning when the incident occurs. At that moment, I am crouched on the floor of one of the containment aisles of the data center, computers arrayed like book stacks in a library on either side of me. The clamor of server fans makes it nearly impossible for me to hear Tom, the senior technician I am shadowing, explain to me how to pry open a faulty floor tile. With a specialized tool, I remove the white square tile from its hinges, noticing tiny perforations etched on its surface, points of ingress designed to help cool air rush up from a vast, pressurized cavity beneath us called a “plenum.” I set the tile aside, feeling a rush of cold tickle my nose as a gust of chill whips up from the exposed underfloor plenum. I go about replacing the tile, using one

with more notches to improve airflow to this particular cluster of dense computing equipment. That is when I hear the alarms go off. Amid a sea of blinking green and blue lights, an entire rack of computers suddenly scintillates yellow, and then, after a few seconds, a foreboding red. In that instant, panic sweeps over Tom's face, and he too is flush and crimson as he scrambles to contain the calamity unfolding around us. "They're overheating," Tom says, upon inspecting the thermal sensors, sweat dripping from his brow.

I feel the heat swarming the air. The flood of warmth seeps into the servers faster than the heat sinks printed onto their circuit boards can abate, faster than the fans can expel the hot air recycling in a runaway feedback loop of warming. The automatic shutdown sequence begins, and Tom curses, reminding me that every minute of downtime, of service interruption, may cost the company many thousands of dollars. Within two minutes, however, the three massive air conditioning units that had been idling in a standby state activate to full power, flooding the room with an arctic chill and restoring order to the chaotic scene.

In the vignette above, which draws on my ethnographic fieldnotes, I recount an episode that data center technicians refer to as a "thermal runaway event," a cascading failure of cooling systems that interrupts the functioning of the servers that process, store, and facilitate everything online ([Figure 1](#)) The molecular frictions of digital industry, as this example shows, proliferate as unruly heat. The flotsam and jetsam of our digital queries and transactions, the flurry of electrons flitting about, warm the medium of air.⁶ Heat is the waste product of computation, and if left unchecked, it becomes a foil to the workings of digital civilization.⁷ Heat must therefore be relentlessly abated to keep the engine of the digital thrumming in a constant state, twenty-four hours a day, every day.

Figure 1

A data center technician. (Original photograph by the author; artistic rendering applied by the author to preserve the technician's anonymity.)

To quell this thermodynamic threat, data centers overwhelmingly rely on air conditioning, a mechanical process that refrigerates the gaseous medium of air, so that it can displace or lift perilous heat away from computers.⁸ Today, power-hungry computer room air conditioners (CRACs) or computer room air handlers (CRAHs) are staples of even the most advanced data centers. In North America, most data centers draw power from [“dirty” electricity grids](#), especially in Virginia’s “data center alley,” the site of [70 percent](#) of the world’s internet traffic in 2019.⁹ To cool, the Cloud burns carbon, what Jeffrey Moro calls an [“elemental irony.”](#)¹⁰ In most data centers today, cooling accounts for greater than 40 percent of electricity usage.¹¹

While some of the most advanced, “hyperscale” data centers, like those maintained by Google, Facebook, and Amazon, have pledged to transition their sites to carbon-neutral via carbon offsetting and investment in renewable energy infrastructures like wind and solar, many of the smaller-scale data centers that I observed lack the resources and capital to pursue similar sustainability initiatives.¹² Smaller-scale, traditional data centers have often been set up within older buildings that are not optimized for ever-changing power, cooling, and data storage capacity needs. Since the emergence of hyperscale facilities, many companies, universities, and others who operate their own small-scale data centers have begun to transfer their data to hyperscalers or cloud

colocation facilities, citing energy cost reductions. According to a Lawrence Berkeley National Laboratory report, if the entire Cloud shifted to hyperscale facilities, energy usage might drop as much as 25 percent.¹³ Without any regulatory body or agency to incentivize or enforce such a shift in our infrastructural configuration, there are other solutions that have been proposed to curb the Cloud's carbon problem. Some have proposed relocating data centers to Nordic countries like Iceland or Sweden, in a bid to utilize ambient, cool air to minimize carbon footprint, a technique called "free cooling."¹⁴ However, network signal latency issues make this dream of a haven for green data centers largely untenable to meet the computing and data storage demands of the wider world.

As a result, the Cloud now has a greater carbon footprint than the airline industry.¹⁵ A single data center can consume the equivalent electricity of fifty thousand homes.¹⁶ At 200 terawatt hours (TWh) annually, data centers collectively devour more energy than some nation-states.¹⁷ Today, the electricity utilized by data centers accounts for 0.3 percent of overall carbon emissions, and if we extend our accounting to include networked devices like laptops, smartphones, and tablets, the total shifts to 2 percent of global carbon emissions.¹⁸

Why so much energy? Beyond cooling, the energy requirements of data centers are vast. To meet the pledge to customers that their data and cloud services will be available anytime, anywhere, data centers are designed to be hyper-redundant: if one system fails, another is ready to take its place at a moment's notice, to prevent a disruption in user experiences. Like Tom's air conditioners idling in a low-power state, ready to rev up when things get too hot, the data center is a Russian doll of redundancies: redundant power systems like diesel generators, redundant servers ready to take over computational processes should others become unexpectedly unavailable, and so forth. In some cases, only 6–12 percent of energy consumed is devoted to active computational processes.¹⁹ The remainder is allocated to cooling and maintaining chains upon chains of redundant fail-safes to prevent costly downtime.

That being said, there are two computational processes performed by servers that are particularly energy-intensive and are of increasing concern to scholars, activists, and data center industry professionals: 1) machine learning and 2) cryptocurrency mining. In a study conducted at the University of Massachusetts, Amherst, PhD candidate Emma Strubbel determined that training a handful of artificial intelligence models can emit over 626,000 pounds of carbon dioxide, as much as five American automobiles do over their lifespans.²⁰ In this way, computation is metabolic: to maximize returns on

computational processes, energy inputs must match intensity in the same way that tons of cooling (BTUs) must be matched to electricity curves (kwh) to prevent thermal runaway. Ironically, advances in machine learning have led to sustainability innovations in a number of industries and have advanced research to support environmentalist agendas.²¹ The question therefore becomes: how can AI reduce its ecological footprint? Can machine learning algorithms be designed to operate with greater energy efficiency? Some scholars and practitioners are working toward better understanding of precisely how machine learning contributes to greenhouse gas emissions, so that methods can be developed from a design and policy standpoint to mitigate those effects.²²

Like AI and machine learning, the mining of cryptocurrency is a computationally intensive process with a growing ecological impact.²³ Given the increasing computational complexity of blockchain operations, the average Bitcoin miner is no longer an MIT student experimenting with GPUs in a dorm room, but instead a person with enough resources to afford specialized, high-performance computers and the costly capital required to cool and host them.²⁴ The energy requirements for cryptocurrency production are so high that miners only stand to profit on returns if the cost of energy where their computers are located is sufficiently cheap.²⁵ For places like Iceland, with free cooling and a largely sustainable geothermal energy grid, high-performance computation is a “natural” fit.²⁶ However, cheap energy is also available in places like China, where over 73 percent of electricity consumed by data centers is sourced from coal.²⁷ Authorities on this matter debate the precise carbon footprint of cryptocurrency production, but estimates range anywhere from 20 to 115 TWh annually, around 0.33 percent of global electricity usage.²⁸ Framed differently: the equivalent of one US dollar in Bitcoin requires over seventeen megajoules of energy to produce, which is double the amount of energy required to mine copper, gold, or platinum.²⁹

Discussion Question: What are some of the challenges of scale (policy, design, culture) that stand in the way of bringing about a carbon-neutral Cloud? What kinds of interdisciplinary and practitioner conversations might bring about more sustainable machine learning or cryptocurrency production?

Precipitations

It is late July in Arizona. The sun is white and hot on this cloudless day. I feel it scorch the back of my neck as I follow Jeremy, a junior technician, to the backlot behind a data center, where dozens of shipping containers are arrayed in rows. Amid this 117-

degree heat wave, our task is to repair an evaporative cooling system that is failing. We unfasten the screws on one of the exterior panels before entering the shipping container, which I am surprised to learn is actually a modular server cluster. Pipes snake up from tiny channels in the lot, where potable water is pumped up from the ground, to seep up into a spongey, filter media. To my eyes, this foamy material resembles a honeycomb or a wasp's nest (Figure 2). The sediment-rich waters of the Colorado River have congealed to form an oozy soot on the porous surface that is not unlike honey. The wet tray of material evaporates quickly in the arid desert air; the roiling cloud of moisture gently cooling the loudly buzzing servers around us, Jeremy explains. This, I learn, is why the shipping container has the nickname, "The Mouth."

Figure 2

Adiabatic cooling filter media. (Original photograph and artistic rendering by the author.)

The Cloud may be a carbonivore, but as the example of "The Mouth" shows, the Cloud is also quite thirsty. Like a pasture, server farms are irrigated. In many data centers today, chilled water is piped through the latticework of server racks to more efficiently

cool the facility, liquid being a superior convective agent than air. This shift from cooling air to cooling water is an attempt to reduce carbon footprint, but it comes at a cost. Weathering historic drought and heat domes, communities in the western United States are increasingly strained for water resources. In Mesa, Arizona, where I spent six months researching the emergence of a desert data center hub, some politicians are now openly [opposing the construction of data centers](#), framing the centers' water usage as inessential and irresponsible given resource constraints.³⁰ In Bluffdale, Utah, residents are suffering from water shortages and power outages, as a result of the nearby Utah Data Center, a facility of the US National Security Agency (NSA) that guzzles seven million gallons of water daily to operate.³¹

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In response to increasing awareness of data centers' impact on water-stressed communities like Mesa and Bluffdale, companies like Google are pledging to go "[water-positive](#)" by 2030, committing to "replenish" 120 percent of the water they consume in their facilities and offices.³² By implementing costly "closed-loop" water cooling systems, companies like Google and Cyrus One are able to recycle some of the wastewater used in evaporative cooling, though much of the water escapes into the atmosphere during the evaporative process.³³ In addition to optimizing water utilization and minimizing "waste," Google and others pledge to invest in water infrastructure and community resources to enhance "water stewardship" and "water security."³⁴

Corporate pledges such as these, while laudable, are not enforceable, nor do they appear to be feasible given the explosive growth expected in data storage infrastructures over the next decade, a tripling by some estimates.³⁵ Media scholar Mél Hogan warns against entrusting "Big Tech" with its own regulation, given the companies' [financial ties to the fossil fuel industry](#) and failure to meet the deadlines of [previous pledges](#) to reduce carbon emissions or other kinds of waste.³⁶ Per the [2021 Emissions Gap Report](#) authored by the United Nations Environment Programme, global temperatures are projected to rise by 2.7°C by the end of the century. Planetary heating will melt glaciers and raise sea levels. The result will be the salinization of freshwater supplies, proliferation of pathogen growth in stagnant water reservoirs, and the intensification of ongoing processes of desertification, creating near-ubiquitous conditions of water scarcity by 2040 if governments and companies fail to

intensify their efforts to curb emissions.³⁷ While corporate pledges offer no guarantee that data centers will regulate, larger mechanisms of accountability like the recent [Climate Neutral Data Centre Pact](#), a consortium of European data center companies and infrastructure providers promising to become “climate neutral” by 2050, provide a model for larger-scale regulatory initiatives that could make a more substantial impact.³⁸

Discussion Question: How are farms and data centers alike? How does water scarcity impact clouds and publics? How are the carbon emissions of data centers related to their use of water to cool their facilities?

The Cloud Is Not Silent

2019. Brenda Hayward takes a stroll through her sunny neighborhood, past the lovely, green lawn of Chuparosa park in Chandler, Arizona, when she hears it—the noise that haunts her every night as she attempts to sleep. It is there every morning when she wakes up. It is there in the park where her children played when they were young, riffling through the boughs of the palo verde trees, stalking her as she tries to live her life quietly. It began as a dull boom, not unlike the racket of bass-frenzied teenagers partying late into the night. Later, it evolved into a continuous, mechanical whine. She tries not to notice it, she tries to unhear it, but it is there, behind everything, a hellish background track to her life. As a nurse, she knows that the sound is more than mere annoyance. She sees the signs of its toll—hypertension, cortisol—but she cannot stop it. No one can, because it does not sleep.

2020. Lockdown has forced urban residents to remain in their homes to minimize the transmission of COVID-19. For David Gray, cabin fever is the least of his worries. Instead, he and his neighbors at Printer’s Row in downtown Chicago must weather a scourge of a sonic variety. As he mills about his home, as he works, and eats, and bathes, it is there, a monotonal drone, a clatter unceasing, a constant, undesired companion to his life. It festers in his mind, clawing at his thoughts, probing his sanity, poisoning him with a constant spell of dread and anxiety. He cannot leave; he is not allowed to. He cannot escape. He is there, with it, a prisoner to its bewitching monotone.

2021. At Chuparosa Park, I hear it, too. Above the cries of children playing, dogs barking, cars racing by, it soars. My ears prick up with the music of the Cloud, a discordant symphony of text messages, emails, cat videos, and fake news, pulsing,

thrumming in my ears. Just past the basketball courts, the picnic tables, and the prickly pears, the source is visible for all to see: a CyrusOne data center ([Figure 3](#)).

Figure 3
A data center in Arizona. (Photograph by the author.)

Over vast distances, the sonic exhaust of our digital lives reverberates: the minute vibrations of hard disks, the rumbling of air chillers, the cranking of diesel generators, the mechanical spinning of fans. Data centers emit acoustic waste, what environmentalists call “noise pollution.” For communities like Brenda’s and David’s, the computational whirl of data centers is not merely an annoyance, but a source of mental and physical harm. Brenda, a nurse by training, reported an uptick in her blood pressure and cortisol levels with the onset of the noise. David, a twenty-something software engineer, was diagnosed with hypertension, and meets frequently with a

clinical therapist to manage the anxiety caused by the [data center's hum](#).³⁹ (See [Figure 4](#).)

Figure 4

Noise pollution experiences: A wordcloud by the author, sampled from the author's interview data with residents in Chandler, Arizona.

Their stories are cautionary tales; they are neither uncommon nor exceptional. The acute and longitudinal physiological effects of industrial noise pollution are [well-documented](#) to include hearing loss, elevated stress hormones like cortisol, hypertension, and insomnia.⁴⁰ Brenda and David met with other disaffected residents

in their respective communities to organize for change. Brenda soon joined the [Dobson Noise Coalition](#), helping to organize a community meeting with her neighbors, city officials, state and federal representatives, and employees of CyrusOne, the offending data center. David took a stand with others in his building, successfully mobilizing the Chicago Department of Public Health to file a [noise complaint](#) on their behalf and successfully obtain a hearing for a noise pollution violation.⁴¹ While the efforts of these communities to minimize the noise pollution harming them are ongoing, they are resigned to modest goals to improve rather than solve the problem. Unlike other industries, data centers are largely self-regulating: there is no sweeping federal agency to govern the siting and operation of new and existing facilities.

Because data center noise is unregulated by political authorities, facilities can be built in close proximity to residential communities. Given the subjective nature of hearing, the history of noise regulation might best be characterized by a series of contests over expertise and the “right” to quiet, as codified in liberal legal regimes. Over the course of my fieldwork with the communities of Chandler and Printer’s Row, I learned that the “noise” of the Cloud uniquely eludes regulatory schemes.⁴² In many cases, the loudness of the data centers, as measured in decibels (dB), falls below the threshold of intolerance as prescribed by local ordinances.⁴³ For this reason, when residents contacted the authorities to intervene, to attenuate or quiet their noise, no action was taken, because the data centers had not technically violated the law, and their properties were zoned for industrial purposes.⁴⁴ However, upon closer interrogation of the sound, some residents reported that the monotonal drone, a frequency hovering within the range of human speech, is particularly disturbing, given the attuned sensitivity of human ears to discern such frequencies above others. Even so, there were days when the data centers, running diesel generators, vastly exceeded permissible decibel-thresholds for noise. As with water and carbon, local companies like CyrusOne pledged in community meetings to take steps to attenuate their sound, though these were unenforceable promises that, to date, they have failed to keep.

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Discussion Question: What are some technological, legal, political, and societal pathways to ending the noise pollution caused by cloud storage facilities? What are some of the challenges to implementing or realizing these proposed solutions?

Immortal Waste

With both hands, I haul a pushcart across the server room floor, down six storeys on service elevators before depositing its contents—obsolete and decommissioned servers and equipment—into a haphazard pile labeled “decommissioned assets.” Under the supervision of senior technician Ricardo, I cut off the elastic asset tags from every piece of discarded equipment, and then scan them into a terminal to finalize the rendering of these valuable computing components as null and void.

“What happens to them, now?” I ask innocently.

“We recycle what we can, but most of it gets dumped to god knows where.” The technician grumbles, helping me lift the last of the heavy servers into the mountain of rubble before my feet.

Since the year 2007, when the first smartphone debuted on the marketplace, over [7 billion devices](#) of the sort have since been manufactured.^{[45](#)} Their lifespans average less than two years, a consequence of designed obsolescence and a thirst to profit from flashy new features and capabilities. Meanwhile, the material and political conditions of their manufacture, and the resources required for their production, remain obscured. Under grueling conditions, miners tirelessly plumb the earth for the rare metals required to make information and communications technology (ICT) devices. Then, in vast factories like Foxconn located in the Global South, where labor can be procured cheaply and legal protections for workers are scant, smartphones are assembled and shipped out to consumers, only to be discarded in a matter of months, to end up in e-waste graveyards like those of Agbogbloshie, Ghana ([Figure 5](#)).^{[46](#)} These metals, many of which are toxic and contain radioactive elements, take millennia to decay.^{[47](#)} The refuse of the digital is ecologically transformative.

Figure 5
Computer graveyard in Agbogbloshie, Ghana.
Source: Agbogbloshie Makerspace Platform. [CC BY-SA 2.0](#)

Historian Nathan Ensmenger writes that a single desktop computer requires 240 kilograms of fossil fuels, 22 kilograms of chemicals, and 1,500 kilograms of water to manufacture.⁴⁸ The servers that fill the halls of data centers are dense, specialized assets, with some units valued in the tens of thousands of US dollars. Cables, batteries, uninterruptible power supplies (UPS), air conditioners (CRACs and CRAHs), power distribution units (PDUs), and transformers are also periodically decommissioned and disposed of, when warranties expire and units fail to perform with the high standards of reliability and redundancy set by entities like the [Uptime Institute](#). Some of these components have toxic polychlorinated biphenyls (PCBs) and must be disposed of rather than reused. Efforts are underway in Europe and elsewhere to augment facility and equipment designs to extend the lifespan of units, more easily accommodate repair, and formalize a system of exchange to recycle old equipment using “[materials passports](#)” that precisely document unit histories, not unlike CARFAX.⁴⁹ Even with these sustainability initiatives in place, environmental organizations like Greenpeace estimate that less than 16 percent of the tons of e-waste generated annually is recycled.⁵⁰

Discussion Question: Why are ICTs (mobile phones, laptops, servers, etc.) designed for rapid obsolescence? In what ways do culture and behavior contribute to the rapid proliferation of e-waste, from a user perspective and from the perspective of a risk-averse cloud technician?

The Cloud Is Cultural

It has been a week since the overheating incident. Tom leads me down a corridor of server racks to the site of the thermal anomaly, rack C9. I notice that some of the racks do not contain servers. Instead, the empty sockets are bracketed off with blanking panels, which keep cool air from escaping the pressurized aisles. Without consulting his instruments or tablet, Tom starts ripping out the blanking panels, handing them to me to stack neatly ([Figure 6](#)).

“What are you doing?” I ask.

“I have a hunch this aisle is starved for air,” Tom says. “Can’t you hear it, the way the fans are groaning?”

I hear nothing unusual in the mechanical whir of the fans. “Not really.”

“Look, the fluid dynamics model says these racks are just fine,” Tom says, gesturing to the flashing green and yellow lights, “but you saw what happened last week. These models don’t capture everything. Sometimes, you just have to trust your gut.”

I put my hands in the empty sockets of the rack, feeling cold air tickle my fingertips.

“How do you know how many you need to take out? Do you have to measure the airflow or do some math or calculations?”

Tom shoots me a glare, eyebrows furled. “When you’ve been doing this as long as I have, you get a feel for things. Kinda hard to explain. It’s not all numbers and curves and ratios here. We’re caretakers, not robots.”

I set down the blanking panels. “Caretakers?”

“The servers need to breathe, they need fuel just like we do, and our job is to keep them running at whatever cost because ultimately the responsibility falls on us if they shut down. You see, our asses are on the line. If they go down, we go down.”

“That sounds stressful.”

“Fear is a constant part of the job. So much can go wrong here. Mechanical failure. Power failure. Human error. Our goal is to prevent all downtime but that’s not humanly

possible, so we do the best we can. We try to be as reliable as possible. 99.9 per cent uptime or whatever we can manage, but we're only human, after all."

Figure 6

Data center technician. (Original photograph by the author; artistic rendering by the author to preserve the technician's anonymity.)

When I first started working in data centers as an ethnographic observer, I expected that the experience might teach me how to think like an engineer, how to see the world through quantitative logics and thermodynamic principles. As an anthropologist, I have been trained to be sensitive to my own biases, to do my best to leave stereotypes at the door when researching a new community. Even so, I expected people like Tom to be more like “robots” than “caretakers.” I mistakenly assumed that the culture of the Cloud would mirror the technologies and artifacts that make it up. I expected to be immersed in cold mechanical rationality, not spending my days with fearful “caretakers” making decisions based on “gut feelings” rather than equations.

Over the last five years of ethnographic research and fieldwork, I have come to learn the various ways that the story of the data center is as much about humans as it is about air conditioners, servers, and the messy cables I spent hours untangling as part of my initiation into this niche world. The Cloud’s stewards have a culture of their own. As Tom puts it, he is not an automaton that can be easily replaced, he is, rather, a “caretaker.” Given the [enormous financial cost](#) for every minute of downtime in data centers, incidents attributable to human error are often “career-ending” for those

involved, as one industry veteran relayed to me in a virtual interview. As such, Tom's livelihood hinges on whether or not his servers are operational. In this way, Tom and his servers are linked: the demise of one foretells the demise of the other. *This* is where the fear comes in.

At an industry meetup in Boston, one data center manager shared with me that the overwhelming responsibility and constant fear of downtime in his data center had led his doctor to diagnose him with hypertension. Another, a senior technician in an Arizona data center, reported that he met with a therapist weekly to manage his "server stress." Wracked with fear, the data center managers I observed tended to rely on their own senses and instincts rather than cede too much ground to computational models or instruments. They preferred the "tried and true" over the abstracted readings and provisional models afforded by instruments and labyrinthine dashboards that display everything from network latency to power consumption at the rack level.

In the early 2000s, this same fear led many technicians to resort to the wasteful practice of "flood cooling" to eliminate hotspots and stop thermal runaway events from causing downtime. [Flood cooling](#) was about "making the room cold at whatever cost," as one technician characterized it to me, like "using a flamethrower to light a candle."⁵¹ These tales of what Tom calls the "Wild West era" in data center management demonstrate the role of culture and behavior as we strive to understand the material impacts of data storage more holistically. "Flood cooling" is an example of a practice or norm, not a limitation of design, that led to large amounts of unnecessary energy waste in the earlier days of the data center industry.

While more reliable technologies and heightened awareness to climate change have made "flood cooling" practices largely defunct today, I still observed behaviors in the data center that were similarly motivated by fear or "hunches," like the one Tom had about aisle C9. The behaviors and practices of technicians I observed in data centers suggest that the ecological impacts of the cloud must extend beyond the realm of design to consider practice. A holistic approach to environmental reforms in the data center industry requires consideration of the workplace culture and norms within data centers. How does culture impact energy-efficiency outcomes? How might attention to training and workplace operations shift the focus of sustainability efforts?

Discussion Question: If "instinct" as well as "logic" is required to keep the Cloud operating, how might the problem of the Cloud's sustainability be shifted to think about the role of behavior in affecting efficiency outcomes? Can Tom be blamed for his fear of downtime, an event that could cost him his job and his company thousands if

not millions of dollars in damage? How might the culture of the Cloud workplace shift to accommodate these realities and constraints?

Conclusion: Cloud Futures

Fireworks burst into the sky in bright, azure plumes. The neon clouds condense to form the outlines of the words, “Welcome to 2030!” Esmeralda screams with glee, inaugurating a new decade alongside her best friends, Tony and Ines. They look at the crowds gathered and all of the expletives emblazoned on their signs. Tony is wearing a festive avatar today, a crocodile with a New Year’s top hat, while Ines is donning a more youthful, airbrushed version of herself, without the crow’s feet and grays speckled about her black hair. Esmeralda is content to wear her usual panda skin, but with some new name-brand sunglasses from the digital bazaar she scored on a post-holiday discount.

“I can’t believe they are letting such large groups assemble today,” Tony says, his reptilian jowls synched perfectly to his speech.

“Maybe some of them are just bots,” Ines sighs, “though it feels real enough.”

“I’ve missed seeing you guys,” Esmerald says, using the best buds emote to wrap her arms around her pals. “Next run, I want to go bodysurfing on the shores of Titan.”

“Sounds like a blast!” Ines exclaims, her avatar jumping to embody her glee.

“Or you can just take off your headset and go outside,” Tony scowls, “there’s plenty of extra shoreline these days.”

“That’s not funny!” Esmerald says, but in that instant, an alarm blares, and the simulated masses and pixelated fireworks freeze.

Esmeralda tosses her headset into her lap with a loud sigh. “We are sorry to interrupt your experience. As you know, bandwidth rationing is in effect. We hope to see you again when your data allowance refills. Thank you for choosing Symphony™.”

Esmeralda sets the device aside and creeps over to the window, where she looks out at the Manhattan skyway, a new system of smart roads built to replace the many submerged and permanently flooded sections south of 51st Street. She wanted to return to the lush worlds of Symphony™, to escape the ruin that her world was becoming, but the Cloud was finite. Network activities had to be rationed, per government regulations, to minimize environmental impacts.

Sociologist Ruha Benjamin, whose research focuses on how science and technology can both entrench and help to address longstanding problems like systemic racism,

has used speculative fiction as a method to help envision more just futures. As she explains,

Fictions...are not falsehoods but refashionings through which analysts experiment with different scenarios, trajectories, and reversals, elaborating new values and testing different possibilities for creating more just and equitable societies. Such fictions are not meant to convince others of what is, but to expand our own visions of what is possible.⁵²

Other scholars have recently turned to speculative fiction to help identify potential harms that could arise from computing research practices, such as the collection of huge data sets compiled from publicly accessible social media sites.⁵³

In the speculative tale I fashion above, virtual reality constructs powered by machine learning with ultrahigh bandwidth (8k definition) have accelerated anthropogenic climate change. Demands for cloud services have outpaced sustainable growth, leading to cascading systemic failures, data rationing, and more. While this bleak future is unlikely to unfold as I describe it, it is nonetheless useful to spell out the dangers that lie ahead if the Cloud is allowed to perpetually expand, unchecked by governments or publics.

Some might read this world of bandwidth scarcity as the result of runaway desire, a culture of excess and unrestrained impulses. Such a reading might conveniently exculpate the large forces behind the dirty Cloud, shifting blame to individual users and their covetous behaviors. Indeed, readers might start to question the environmental impact of their Netflix binges or doomscrolling sessions, turning to applications like [Website Carbon](#) or [Neutral](#) to quantify their individual carbon footprints and modify their behaviors accordingly. Yet such individualized responses would not be enough to mitigate the crisis; individuals' digital abstinence would not likely exert enough market influence to stop or slow the expansion of the Cloud, with its servers and redundant chains of idling equipment designed to make the digital available anytime, anywhere. Instead, the scenario I envision above depicts a world in which tech companies continue to expand—seeking profits and remaining largely unregulated—until the cumulative effects of their industry so greatly disrupt a warming world that governments and publics have no other choice but to intervene, albeit too late.

In this warming epoch that earth scientists have named the “Anthropocene,” in which climate models anticipate cataclysmic climate futures, speculation is no longer the sole

province of fiction writers.⁵⁴ The survival of civilization now hinges on our collective capacities to envision and realize a sustainable future.⁵⁵ Speculation requires the imagination of worlds otherwise: worlds that might be or might have been.⁵⁶

In this case study, I introduce some of the material impacts of the Cloud, from carbon emissions to water usage, noise, and toxic e-waste. The case study illustrates that the ecological dynamics we find ourselves in are not entirely a consequence of design limits, but of human practices and choices—among individuals, communities, corporations, and governments—combined with a deficit of will and imagination to bring about a sustainable Cloud. The Cloud is *both* cultural and technological. Like any aspect of culture, the Cloud’s trajectory—and its ecological impacts—are not predetermined or unchangeable. Like any aspect of culture, they are mutable.

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Footnotes

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5. “Ethnography” is a research method for learning about a community via sustained immersion and engagement with members of the community. Participants are not considered research subjects per se, but are rather considered to be collaborators. Learning is often fostered by doing activities alongside members of the community: a method known as “participant observation.” In my case, participant observation meant working in data centers alongside technicians, much as an intern or new employee might do. [↵](#)
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16. Hu, *A Prehistory of the Cloud*. ↵
17. Ingrid Burrington, "The Environmental Toll of a Netflix Binge," *The Atlantic*, December 16, 2015, <https://www.theatlantic.com/technology/archive/2015/12/there-are-no-clean-clouds/420744/>; Jennifer Holt and Patrick Vonderau, "'Where the Internet Lives': Data Centers as Cloud Infrastructure," in *Signal Traffic: Critical Studies of Media Infrastructures*, ed. Lisa Parks and Nicole Starosielski (Champaign: University of Illinois Press), 71–93. ↵
18. Burrington, "The Environmental Toll of a Netflix Binge"; Cook et al., "#ClickClean"; Jones, "How to Stop Data Centres from Gobbling Up the World's Electricity." These figures are far from comprehensive. Given that the data required to calculate the carbon emissions is often proprietary, scholars and activists can only draw upon publicly available records, documents, and data provided voluntarily by companies like Amazon and Google. Compare with the discussion in Jonathan Koomey and Eric Masanet, "Does Not Compute: Avoiding Pitfalls Assessing the Internet's Energy and Carbon Impacts," *Joule* 5, no. 7 (2021): 1625–28, <https://doi.org/10.1016/j.joule.2021.05.007>. ↵
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