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Climate Change Is in the Air: Investigating Climate and Air Quality in Atlanta

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a thesis submitted to the Faculty of Emory College of Arts and Sciences
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Abstract

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This thesis investigates how climate change is affecting air quality, pollution, and health with a focus on Atlanta, Georgia in the United States. Inspired by the latest in climate and science communications, "Climate Change Is in the Air" explores how shifting global weather patterns affect respiratory health. Specifically, the project analyzes ground-level ozone, wildfire emissions, and aeroallergens through two interdisciplinary methods: (1) unpacking the science behind both the atmospheric and natural processes that affect air quality, and how air pollutants enter and affect our bodies and (2) offering solutions on what the world is currently doing, what it should be doing going forward, and what the everyday individual can be doing to help address these issues. Finally, the paper also includes a comprehensive explanation of the motivation behind the project and the science communications theories that helped shape its development.

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Ground-Level Ozone

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Humankind has mixed feelings above ozone, and with good reason. Think of this pale blue gas as a long-distance lover who's a bit too smothering in-person, or that one friend with the super clingy cousin.

On one hand, stratospheric ozone prevents most of the sun's harmful ultraviolet (UV) rays from reaching us, essentially forming a shield of sunscreen 6 to 31 miles above the Earth's surface (Gleason). You might have remembered stratospheric ozone (or, more accurately, its concerning lack thereof) making headlines about 20 years ago, when a team of British scientists discovered of a huge hole in the ozone layer above Antarctica (Newman and Nash). Luckily for our skin and continued existence, the international community came together in response to phase out the use of chlorofluorocarbons (CFCs): synthetic chemicals used in aerosol sprays and refrigerants that break up ozone by "stealing" its oxygen atoms (Handwerk). Now, some scientists are predicting that by 2080, global ozone will recover to its 1950s levels—assuming greenhouse gas emissions don't get in the way before then (Masters).

And that's all good and well for the ozone layer, but now we're the ones we might need to worry about surviving until then in one piece. Stratospheric ozone's evil twin, tropospheric ozone, has become partners in crime with global climate change (Applying or Implementing Ozone Standards). Tropospheric ozone also goes by ground-level or ambient ozone, but no matter what you call it, it's bad news for us. A key component of smog, tropospheric ozone is the lovechild of sunlight and some of our (least) favorite pollutants—namely, nitrogen oxides (NO_x), carbon monoxide (CO) and volatile organic compounds (VOCs). VOCs refer to a compound of carbon, excluding some varieties, which participate in atmospheric photochemical reactions ("Volatile Organic Compounds" Definition per 40 CFR Part 51.100(s)). And while there are some natural sources of these emissions—particularly VOCs, which are released by some plants in a form of self-defense against insects—we supply our own fair share through fossil fuel combustion and industrial processes (Sutherland). On rare occasions, stratospheric ozone itself will convert to the dark side, and contribute to ground-level ozone levels near the surface.

These ingredients are bad enough on their own, even if you're one of those weird people that likes the smell of gasoline. NO_x is one multitasking molecule; besides contributing to ozone, it's also a big component of acid rain and destroys good stratospheric ozone. Not to mention, both NO_x and VOCs exacerbate respiratory conditions on their own. Add a little sun to the mix, and the solar energy separates the nitrogen oxide from one of its oxygen molecules. Desperate for companionship, the lone oxygen will quickly bind with one of our friends, O_2 (breathable oxygen), to create one of our enemies: ground-level ozone (O_3). Who needs soap operas when you're keeping up with the drama of atmospheric chemical processes, right? And in a cruel twist of fate, the more sun, the more tropospheric ozone. In other words, the days that you're probably more likely to be outside (think higher temperatures, sunnier skies, and lighter winds) are characterized by same conditions that ground-level ozone thrives in, meaning you may want to rethink how much time you're outside (although ground-level ozone has a nasty habit of getting inside, too). Plus, it's not like you could try just avoiding this gas like you would a clingy cousin; it's both odorless and colorless. Unfortunately, its effects on the human body are quite noticeable.

An Inside Job

That's not to say that our bodies don't have any defenses against outdoor air pollutants. Most of the time, your upper respiratory tract—including your larynx (which holds your voice box), pharynx (which connects your nose and mouth to your esophagus), and nose (you're probably familiar with this organ)—are pretty good at "scrubbing" air pollutants out of the oxygen we breathe, purely because the relatively extensive, slimy surface area in there gives your body more chances to snag it.

Unfortunately, our respiratory systems aren't really doing us any good when it comes to ground-level ozone. The "scrubbing" effect of the upper respiratory tract works best with water-soluble gasses like sulfur dioxide and chlorine gas and, you guessed it, ozone has very limited solubility in water. That means that the majority of inhaled ground-level ozone is able to infiltrate deep into the lower respiratory tract. Once there, the ozone dissolves in the thin layer of epithelial lining fluid (ELF) throughout the lungs: the very barrier designed to protect the airways from infection (United States, Environmental Protection Agency).

Here, deep in the lungs and several steps past the body's best defenses, the ground-level ozone begins to unleash pure chaos as it targets the proteins and lipids on the surface of the cells in the lung lining fluid. The result is oxidation, where many of the body's biomolecules are forced to take on an extra oxygen molecule after interacting with the invading ozone.

Depending on the substrate, this chemical process either protects the underlying epithelium from interference, or, most frequently, does the exact opposite: creating highly reactive compounds such as lipid hydroperoxides, cholesterol ozonization products, ozonides, and aldehydes (Amann et al.). In other words: bad guys. In response to this new threat, the body is forced to fall on the defensive, sending an army of white blood cells (leukocytes) and alveolar macrophages (or “dust cells,” which swallow any threats) to the front lines (United States, Environmental Protection Agency). This surge in activity is also known as inflammation, as the body orders leukocyte-rich blood to flood to the lungs.

In small doses, inflammation is an important and instinctive immune reaction. You might notice the distinctive train of blood as a warm, pink-red outline thinly encircling a healing wound. But if the lungs are continually exposed to stress, like ground-level ozone, and not given the chance to properly heal, the lining of the lungs can become irritated and chronically inflamed (“Higher Temperatures”). Think of it as if you began to constantly skin the same knee in the same exact spot, day in and day out. Many experts compare the effects over time to something like a sunburn on the lungs—it’s the same story of continuous exposure, insufficient biological defense, cell damage, and increased health risks (Cox). And when it comes down to inhaled ozone exposure, the story doesn’t end very well for us: inflammation also causes your airways to constrict, making it much harder to inhale to total lung capacity (“Health Effects of Ozone Pollution”).

In the best-case scenario, this leads to coughing, throat irritation, chest pain while breathing, and shortness of breath (United States, Environmental Protection Agency, Office of Air and Radiation). But in the worst cases, ozone inhalation can aggravate existing lung conditions (asthma, emphysema, and chronic bronchitis), and increase the chance of lung infection and disease. In fact, being exposed to high levels of ozone can continue to permanently damage the lungs, even when symptoms have subsided. In adults, it can cause chronic obstructive pulmonary disease—a permanent side effect of ozone exposure that's more commonly associated with cigarette smoking, which makes it increasingly hard to breathe as the airways narrow ("What is COPD?"). In children, breathing ozone early on can lead to abnormal lung development—a health cost they'll carry for the rest of their lives. Together, these health effects have serious and tangible consequences for society, from school absences, to medication use, doctor's visits, emergency room admissions—and graveyards ("Health Effects of Ozone Pollution").

I don't mean to be a downer, but it's about to get worse. Take a deep breath—but maybe check the daily ozone levels first.

Climate Change's Atmospheric Cocktail

Here's the explanation in a nutshell: as climate change gets comfortable on Earth, rising greenhouse gas emissions also making our planet's surface increasingly inviting for ozone to move in. So unless humankind wants to permanently room with lung inflammation and irritation, we're going to have to kick out both, preferably as soon as humanly possible.

The long story actually starts off on a good note. Believe it or not, most people have realized over time that ground-level ozone does very little good for us (read: none whatsoever). Essentially, this means that ozone-creating emissions (or ozone "precursors") from humanoriginating sources have been decreasing fairly steadily in the United States. Nitrogen oxide emissions have decreased by more than 60 percent between 1970 and 2016, no thanks at all to industrial processes, which are only rising (“Air Pollutant Emissions Trends Data”). Instead, the reduction is mostly due to stricter environmental regulations that are hitting down hard on car emissions, including nitrogen oxides, as well as the other major ozone precursor, VOCs. In fact, national total estimated VOC emissions from anthropogenic sources (excluding natural wildfires) decreased by an impressive 47 percent between 1990 and 2011 (from 23.0 million tons to 12.3 million tons) (United States, Environmental Protection Agency, Office of Research and Development).

We wouldn’t start celebrating quite yet, though. Despite these decreasing emissions, climate change, which remains as inconvenient since Al Gore first pointed it out, encourages the development of meteorological conditions that are more favorable to ozone formation. In other words, climate change is doing its darndest to make sure that ground-level ozone levels continue to rise, with or without the support of human emissions. This means that reaching national air quality standards for ground-level ozone will be increasingly difficult as climate change offsets some of the improvements that would otherwise be made from reducing emissions. This effect is called the “climate penalty,” or otherwise known as, “Why life isn’t fair” or “Why climate change sucks” (Rasmussen et al.).

Sticking with the theme of injustice, it’s also becoming increasingly evident that climate change has a number of tricks up its sleeve when it comes to giving tropospheric ozone a helping hand. The main tool in its arsenal, unsurprisingly, is higher global temperature. Global temperatures have been accelerating upward in the past 30 years; 2001 to 2010 was the warmest temperature ever recorded in history ("Higher Temperatures"). Already, average U.S. temperatures have increased more than two degrees Fahrenheit during the past century. Besides fanning heat waves, melting polar ice caps, and significantly altering delicate ecosystems (as if those aren't bad enough in and of themselves), increased temperatures also aid in ground-level ozone formation by increasing the chemical rates at which ambient ozone develops. Basically, higher temperature makes molecules in the atmosphere less stable, so they're more likely to separate, bounce around, collide, and ultimately end up combining into ozone ("Climate Change and Your Health: Rising Temperatures, Worsening Ozone Pollution").

And that's not all, folks. Besides accelerating the chemical formation of ground-level ozone, higher temperatures can increase the emissions from anthropogenic and vegetative sources. Plants, for example, may create more emissions in a warmer world, since some of them are produced in response to heat stress (Galbraith). Not to mention, as the temperature increases, the warmer air, which is less dense, becomes capable of holding more water, and the percent of water in the air falls ("Humidity | Climate Education Modules for K-12"). In other words, relative humidity—the percent of water in the air relative to the amount of water the air can hold—drops. This reduces the main arsenal for cloud cover, promoting ozone formation (Fann et al.). (Full disclosure: there's been some argument over this. For a long time, the status quo was that relative humidity would stay constant as climate changed, because while warmer air can hold more water, increased temperature also means more evaporation, and thus more water in the atmosphere. A new analysis by NASA, however, has found that while more water will indeed evaporate as well as temperatures increase, it won't be enough to keep relative humidity levels from falling a bit [Przyborski and Ichoku; "2013 State of the Climate: Humidity | NOAA Climate.Gov"].)

And while climate change and higher temperatures are probably best known for speeding things up, in certain cases, they're all about slowing down. Increasing temperatures are at least partly responsible for slowing global wind patterns. A comprehensive study by atmospheric scientists at Indiana University found that in most of the United States, wind speeds appear to be slowing down by more than 1 percent a year (Moyer). The stagnant atmosphere will allow ozone and ozone precursors to stagnate and accumulate over time, choking unlucky regions—and not to mention, making it that much harder to get renewable wind energy off the ground and into our power grids.

Here's what's happening on an atmospheric level: winds are driven by pressure gradients, because air flows from high-pressure to low-pressure settings (Briney). Think of the average college student, who also prefers resting in lower-pressure environments. The bigger the difference in pressure is, the larger the incentive for the student to get from study time to nap time as quickly as he or she possibly can. In our scenario with climate change, as the temperature increases, so does the air pressure. Imagine, for example, heating a container full of gas. As the temperature increases, the gas molecules inside have more energy and hit the container walls more often and with more force, increasing the pressure from the inside out ("How are temperature and pressure related?"). On a global scale, as the polar regions warm significantly more quickly than the tropics, the temperature difference between the two areas falls, slowing air circulation between them and minimizing any breezy reprieve for areas plagued by ground-level ozone (Galbraith). In other words, if naptime was just as much pressure for a college student as study time—thanks to a noisy roommate, for example—they're more likely to stay in the library. You've probably heard of global warming, but global stilling's been avoiding the spotlight.

And ozone concentrations near the ground aren't just influenced by horizontal wind patterns. They're also strongly affected by the upward and downward movement of air (also known as "vertical mixing"). Normally, temperatures are warmer closer to the Earth's surface than further from it. This fact makes intuitive sense—most people think of outer space to be pretty cold—but is also backed by science. As the sunlight warms the ground, the ground in turn warms the layer of atmosphere directly above it. Under certain conditions, however—like on calm, clear nights, when the Earth's surface cools very quickly—the air near the ground becomes cooler than the air above it. This phenomenon is referred to as a temperature inversion, where a sandwich of warm air forms that acts like a lid on the Earth's surface (Service, NOAAs National Weather). It traps emitted air pollutants near the ground, preventing them from diluting or mixing in the atmosphere and deteriorating the air quality. There's evidence that these kinds of high-pressure systems are both contributing to and exacerbated by climate change in some regions, like Greenland and the larger Arctic region: the kind of vicious feedback loop that reminds us of how we got catapulted into climate change in the first place ("Climate change, extreme weather linked to high pressure over Greenland").

Location, Location, Location

That being said, when it comes to Atlanta, we're happy to start with some good news. Ground-level ozone levels have decreased significantly since 1999, dropping from 120 parts per billion to the upper 70s ("Ozone"). The scary thing is, nobody is sure if climate change will cooperate with Atlanta's efforts to keep that trend going downhill. Despite the overall pattern of decline thanks to increasingly stringent regulation, spikes in tropospheric ozone aren't exactly unheard of. In fact, the city has only been consistently decreasing in annual average ozone levels since 2012, and there's one county in Georgia that has actually been on the rise. And that's not the only ominous sign. Despite consistent ozone precursor emissions reductions, the sun-dependent ozone season is beginning to extend into the fall, peaking in October rather than July (Toon). Is climate change behind it? What's its end game?

Unfortunately, climate change is fickle—basically, a fake friend (acquaintance? enemy? frenemy?) that acts completely differently depending on the setting it's in. It's one of the reasons why most scientists and organizations increasingly prefer referring to the global phenomenon as "climate change" rather than "global warming," since increased surface temperatures is just one tick on a laundry list of symptoms that actually includes cooling in certain places—like snow in the Sahara Desert last December for the first time in decades (O'Hare).

What almost all research scientists *can* agree on right now is that the Southeastern United States, which includes Atlanta, Georgia, is a highly contested region when it comes to the effects of climate change on local tropospheric ozone levels. Here's just a taste of that uncertainty: Hogrefe et al found an increase in projected summertime ozone concentrations in the 2050s but a decrease in the 2080s relative to the 1990s; then Racherla and Adams showed the Southeast to be the U.S. region with the largest ozone increase nationwide in response to the effects of climate change between 1990 and 2050 (2004; 2006). Murazaki and Hess also found fairly large ozone increases in the Southeast, while Wu et al found little effect at all, with some potential for a "climate benefit"—as in, climate change could actually help reduce ground-level ozone levels (more on this later) (2006; 2008). Lin et al discovered the chance of exceeding 85 parts per billion as an average daily maximum concentration increases with temperature across the U.S., although the increase in the Southeast is much weaker compared to the northeast (2001).

In other words, nobody is 100 percent sure what climate change will do to ground-level ozone here in Atlanta.

That isn't to say, however, that all these people have no idea what's happening at all. Almost all studies studying ground-level ozone projections in the Southeastern U.S. found and incorporated climate-change driven increases in isoprene. Remember earlier, when we mentioned vegetative sources of ground-level ozone precursors? In fact, the largest source of VOCs by far is naturally emitted by vegetation, and is more often than not in the form of isoprene ("4.2.3.2 Volatile organic compounds [VOC]"). This common organic compound is produced by many species of trees, including oaks, poplars, eucalyptus, and some legumes. Plants use isoprene to combat different stresses, particularly in response to moderate heat stress in order to protect against large fluctuations in leaf temperatures or destabilized cell membranes. As the world warms, it's widely agreed that isoprene emissions will rise with surface temperatures, especially in forested regions like the Southeastern United States.

The debate starts when we try to determine what effect increased levels of isoprene will have on the formation of ground-level ozone. The problem, of course, is in the chemistry. You might remember when we talked through the basic chemical reactions behind ground-level ozone formation. To quickly recap, solar energy cleaves nitrogen oxide from one of its oxygen molecules, which then does a complete 180^o turn to bind with breathable oxygen (O_2) to ultimately create O_3: ground-level ozone. This is still the main idea behind how carbon monoxide, NO_x, and VOCs become pressured by sunlight to form tropospheric ozone. But in order to understand why increasing isoprene emissions have thwarted our attempts to predict the future of tropospheric ozone levels, we need to take a few chemical steps back in the ground-level ozone formation process.

The whole thing starts with the hydroxyl radical OH, a highly reactive and consequently short-lived marriage between oxygen and hydrogen. When OH bumps into carbon monoxide, or some kind of VOC (hint: like isoprene!), a new radical chemical compound forms, which immediately oxidizes in the presence of breathable oxygen (O_2). This leads to the creation of carbon dioxide (CO_2) and an intermediate peroxy radical, which we'll refer to as RO_2*. Now, here's where things get a bit trickier. When RO_2* inevitably reacts with nitrogen oxide (NO), one of two things can occur. In the first scenario, the chemical reaction leads to the formation of nitrogen dioxide NO_2, which then loses an oxygen molecule to breathable oxygen thanks to the power of solar energy and ultimately creates a trio of notorious oxygen molecules better known as ground-level ozone.

But in the second story, RO_2* and nitrogen oxide produce a stable organic nitrate that has nothing whatsoever to do with ozone and actually ends up taking some NO_x out of the picture. In this case, increasing ground surface temperatures thanks to climate change, which ramp up isoprene emissions from heat-stressed trees, would actually end up reducing ground-level ozone emissions—that weird climate benefit we were talking about earlier (Chen et al.). But even then, there's still debate on how the story ultimately ends, because scientists are still trying to determine if isoprene nitrates represent a temporary or permanent sink for NO_x. Either way, understanding the chemistry behind how isoprene interacts with ozone precursors sheds light on the range of predictions on future ground-level ozone trends in the Southeast. According to one estimate, if isoprene nitrate is treated as a terminal sink for NO_x, ozone over the Southeastern U.S. will stay constant or even decline in the 2050s. On the other hand, if isoprene nitrate is allowed to recycle in the atmosphere and therefore contribute to ground-level ozone formation, ozone levels are predicted to increase by as much as 7 parts per billion in the same region (Mickley et al.).

So here's the takeaway on how climate change will affect ground-level ozone formation in Atlanta: an incredibly unsatisfying, "We're not sure." We definitely have hope and encourage you to stay optimistic, considering recent declining annual trends in tropospheric ozone near the city. But between mixed interpretations of rising isoprene emissions, and not to mention shifts in wind patterns and pressure systems, precipitation and water vapor levels, wildfire incidents, and government priorities, all we can confidently say that we do know at this point is that we don't entirely know how ozone levels are going to react going forward. Climate change, you win this round, but the fight is far from over.

Solutions: On Ozone's Case: Confronting Ozone in Atlanta

A Moving Regulatory Target

Not including climate change, ground-level ozone doesn't have a lot of fans. In addition to the myriad of negative respiratory health effects this pollutant unleashes on the lungs, it also wreaks havoc on sensitive vegetation and ecosystems and contributes to smog. (Fun fact: one supporter that it did have was Claude Monet, the founder of French Impressionist painting. He loved documenting scenes of heavily-polluted London in the early 1900s and went so far as to claim that without the smog, "London would not be beautiful." Coincidentally, the guy also died of lung cancer, so take that as you will [Brown].)

Considering all that negative press, it's not surprising that many countries, regions, and states have taken steps to combat or minimize ground-level ozone formation. On American soil—or rather, air—ozone pollution is controlled through the Clean Air Act (CAA), a comprehensive federal law designed to control and regulate air pollution on a national level from both stationary and mobile sources ("Summary of the Clean Air Act"). Among other things, the law requires the EPA to establish National Ambient Air Quality Standards (NAAQS) for six common air pollutants in the name of protecting public health and welfare ("Criteria Air Pollutants"). Ozone (O_3) has the distinctive (dis)honor of being identified as one of these toxins, along with sulfur dioxide (SO_2), particulate matter (PM), carbon monoxide (MO), lead (Pb), and nitrogen dioxide (NO_2). Altogether, members of this troublesome squad are better known as "criteria air pollutants," because the EPA deems that their levels in outdoor air need to be limited based on health criteria. We might be a little biased, but we can't help but agree.

Once the EPA has determined a maximum allowed measurement level for ozone to be present in outdoor air, the agency works with states and tribes, reviews recent data from air quality monitors, and gathers other relevant technical information to size everybody up against the standard. Then, following Title I of the CAA, the EPA designates areas as either “attainment” or “nonattainment” with national ambient air quality standards, like ground-level ozone, within two years after the NAAQS are first issued. Attainment areas either meet, or in some cases go above and beyond (lookin’ at you, California) the national standard; nonattainment areas fail to meet the benchmark (“Learn About Ozone Designations”).

Once these attainment labels are agreed on, state and local governments and air quality management agencies have three years to develop State Implementation Plans (SIPs). The proposals detail a general strategy for attaining as well as maintaining standards in their region, and include a specific plan for reaching those standards for any areas that were designated as nonattainment. Generally, they include programs like air quality monitoring, air quality modeling, emissions inventories, emission control strategies, and documents like policies and rules that the state can use to attain and maintain the NAAQS. And it’s not just policymakers and researchers that get a say; states are required to engage the public, through notices and public hearings, before finalizing the SIP (“Applying or Implementing Ozone Standards”).

Once finished, the SIPs are formally adopted by the state and submitted to the EPA for approval. Upon review, the EPA proposes to approve or disapprove all or part of each SIP. Here, the public has another opportunity to comment on the EPA’s proposed action, which the EPA factors into consideration before taking any final action on a state’s plan. If the EPA approves any part of a SIP, those control measures become enforceable in federal court—essentially giving the law "teeth." But if a state fails to submit an approvable plan or the EPA disapproves of it entirely, it's back to the drawing board, and the EPA is required to develop a federal implementation plan (FIP) on the state's behalf ("Air Quality Implementation Plans"). Usually, that's not the best option for states, which prefer crafting strategies that take into account their own circumstances and preferences ("Q&A: EPA's Federal Implementation Plan").

If this sounds like a lot of work, that's because it is. Part of that is because thanks to sections 108 and 109 of the CAA, that work never ends. The EPA is required to continuously and periodically review their air quality standards every five years, as well as the science on which they're based, for each criteria air pollutant and revise them as appropriate—all to keep the people and environment as healthy as possible ("Process of Reviewing the National Ambient Air Quality Standards"). Taking into consideration recommendations from a group of independent scientific advisors called the Clean Air Scientific Advisory Committee (CASAC), the EPA has already revised the NAAQS for ozone three times: once in 1997, from a 1-hour standard of 120 parts per billion to an 8-hour standard of 80 parts per billion; in 2008, to 75 parts per billion; and most recently in October 2015, to 70 parts per billion (McCarthy and Lattanzio). By lowering the acceptable standard, the EPA is raising the bar for air quality control and respiratory health.

The good thing is, policymakers know that regulation like this works. Air quality was a major concern leading up to the 1996 Olympics in Atlanta; event organizers wanted to see athletes choke on pressure, not on smog. Given vehicle emissions are the largest contributing factor to NO_x, they went to great measures to reduce the amount of traffic downtown and encouraged people who didn't need to be downtown to not commute or take transit at all

(Paul). Epidemiological studies have shown that these efforts paid off: traffic went down by 22 percent, and with it went ozone concentrations (by 28 percent) and emergency room trips for asthma attacks (42 percent) (Friedman et al.). Unfortunately, these clear conditions didn't last; ozone shot back up in the next several years, peaking in 1999 when Atlanta suffered its worst summer on record for air pollution. Air pollution monitors showed violations for 69 out of the 150 total days of ozone season (Oser). The Sierra Club went so far as to sue the state and the EPA on behalf of Georgia's citizens in the late 1990s as the air conditions worsened, leading to deep cuts in Atlanta's federal highway budget (Paul).

Of course, that's when Georgia starting getting serious about reducing its air pollution emissions, especially in the metro Atlanta area. Programs like Georgia's Vehicle Emissions Inspection and Maintenance (I/M) Program were implemented, which ensure that vehicles on the road are periodically tested to make sure their engine pollutant emissions are in line ("Georgia's Clean Air Force"). Lower pollution gasoline was brought to the metro area, and more than 40 counties were forced to sell this cleaner gasoline (Wall). Dozens of polluters, including Georgia Power, were hit with new rules requiring them to install emission controls for their Atlanta-area coal-fired plants. Outdoor homeowners were banned from burning their yard trimmings and land-clearing debris during ozone season ("Open burning ban set for 54 Georgia counties"). Another program mandates that any new sources of air pollution find an existing source of air pollution willing to simultaneously reduce their emissions, ensuring that atmospheric room is made for developers and ideally, the air quality won't get worse. These local programs are enforced by a variety of supplementary federal requirements, like the current Cross-State Air Pollution Rule (CSAPR), which helps facilitate the CAA's "good neighbor provision" requiring the EPA and states to address interstate transport of air pollution that affects downwind states' abilities to attain and maintain NAAQS ("Cross-State Air Pollution Rule").

From the average Georgia citizen's point of view, of course, more air pollution control programs and increasingly stringent regulation, the merrier—especially for those of us that might suffer from any preexisting respiratory conditions that ground-level ozone loves psyching out. But for the industries and fields that actively contribute to ozone pollution by emitting precursors like nitrogen oxide (NO_x) and VOCs, these increasingly stringent benchmarks couldn't be more of a hassle. Even though the general trend of Georgia's air quality is steadily decreasing, many counties are still struggling to consistently meet the 2008 standards, with some occasionally straying back into 1997 territory in some years (Paul). In fact, Atlanta has struggled to meet federal health-based air quality standards for ground-level ozone ever since they were first established in 1991.

But federal policy is federal policy. Plus, the health problems that go hand in hand with rising ground-level ozone emissions don't really care about the economic costs of controlling it.

Demission and Drive

For anyone that's lived and worked in Atlanta, the answer to limiting local ground-level ozone emissions might seem blatantly clear: the city needs to provide more consistent, dependable, and robust means of public transportation. Since city officials and local policymakers also tend to be locals, this is something that they've been trying to work on,

especially when they're considering the influx of people the city is expected to see in the coming years. If you think rush hour traffic is bad now, imagine how much worse the roads will be when projected 2.5 million new residents move into town over the next 25 years.
And according to Planning Commissioner Tim Keane at a public meeting in Buckhead last February, it's very important that many, most, or perhaps all of those people drive a lot less than we do now, or congestion will be "unbearable." According to Keane, "We will not grow and the city will not thrive if we don't ensure a lot of the people coming here do not drive" (Saunders).

Rhyming aside, local air quality control officials like the sound of Keane's statement, and the positive effects it might have on their commute and the city's ground-level ozone levels. And even though there's some fear that Atlanta government officials are just talking the talk, this time it looks like they're planning to walk the walk (or maybe ride the bus) as well. Right now, the city is in the process of updating the Connect Atlanta Plan, its first comprehensive transportation plan that was adopted in 2008 ("Connect Atlanta Plan"). A lot has changed since then, like growing by 10 percent between 2010 and 2015 alone, and topping national charts for average commute times ("Ten Ways to Look at Metro Atlanta's Population Growth"; Albright). According to its website, Atlanta's new and improved Transportation Plan will "provide policy and project recommendations to build a world class, sustainable transportation system that addresses congestion in our growing and evolving city" and work to "guide Atlanta's transportation decisions to make Atlanta one of the most livable cities in the country" ("Atlanta's Transportation Plan").

The main focus of the proposed plan so far is to reduce the reliance on cars as people's primary form of transportation around the city. Not only are cars a much less efficient use of Atlanta's limited space compared to public transportation or biking, but it also emits far more ozone precursors compared to ride-sharing or more environmentally friendly commute options. The priority on making buses and the Metropolitan Atlanta Rapid Transit Authority (MARTA)—the principal public transport operator in the Atlanta metropolitan area—more convenient would help keep more cars off the road and more ozone precursors out of the atmosphere. In addition, the plan will also adapt to and anticipate new ride-sharing services like Uber and Lyft (not like they could ignore the trend at this point if they tried). Of course, the strategy of improve bike paths and add needed sidewalks to encourage walking is the best option from an environmental standpoint, since people not only don't add to ozone formation, but actually help take it out of the air for everybody else (just kidding!). Other incentive-driven options the city might be toying with include reduced prices of public transportation passes, benefits for working from home, and convenient and secure bicycle parking, in addition to discouraging people from driving through increased gas prices, decreased parking opportunities and increased rates, and reduced speeds ("Atlanta's Transportation Plan").

The Atlanta Transportation Plan in the works wouldn't just be wishful thinking, either—it has the financial and social power to enact real change. Last November, voters approved sales tax increases that would provide an opportunity for infrastructure improvement that could revolutionize Atlanta. Anticipating approval of the referendums, Mayor Kasim Reed said it's the "biggest expansion of MARTA in the city's history" (Kass). The 0.5 percent hike in the existing MARTA funding tax could raise an estimated $2.5 billion over 40 years, while a 0.4 percent increase in the five-year transportation local special option sales tax (TSPLOST) could bring in $300 million for infrastructure improvements, like streets and sidewalks (Andrews). Coupled with the city's ambitious new transportation plan, MARTA's potential new fleet of electric buses, and the rising interest in metro Atlanta to live near public transit, there's a good chance Atlanta's public transportation system could get a nice makeover while also making a dent in the city's ambient ozone levels (Baldowski; Tegna).

While the Atlanta Transportation Plan might be a win-win for everybody in this case, generally speaking, state air quality control officials aren't happy about the new ozone standards. But they're more than willing to suggest where they think future ozone regulations should come from: the federal government. Last March, the Georgia Department of Natural Resources wrote a tense letter to the EPA to dispute the new 8-hour 70 parts per billion ozone level standard was being debated and ultimately passed. Keith Bentley, Chief of the Air Protection Branch at the Georgia Environmental Protection Division, wrote, "Any future reductions in measured ozone concentrations will come from federal control measures that reduce NO_x emissions from on-road mobile sources, off-road mobile sources, locomotives, aircrafts, and shipping." He continued, "There are no effective control measures left available to the state, beyond those already identified and being implemented, to reduce ozone levels in the Atlanta nonattainment area" ("EPA's Proposed National Ambient Air Quality Standards for Ozone, Georgia's Environmental Protection Division Comments").

It's not just state governments that like pointing fingers when it comes to environmental regulations—it happens on an even larger scale as well. Most of this is ground-level ozone's fault. Because it's gaseous in nature and an outdoor air pollutant, ozone doesn't tend to listen very well to local, state, or national boundaries. These qualities make it that much more difficult for localized regions to control and reach their environmental standards successfully, since they also have to factor in ozone that's drifting in from the a neighboring country or state. But humans have to take some of the blame for the confusion as well. Ozone precursor emissions from international aviation and shipping are rapidly increasing; aviation emissions contribute an estimated 2 percent and international shipping an estimated 15 percent of global NO_x emissions respectively, and who knows where they'll end up. That's why when the Royal Society, the United Kingdom's national academy of science, discussed ground-level ozone in the 21st century, their first recommendation was to explore "options for an international mechanism to provide a globally coordinated approach to air pollution issues, and O_3 specifically, should be identified and evaluated" ("Ground-Level ozone in the 21st century: future trends, impacts, and policy implications").

Even so, people can point fingers all day, and that won't change the air quality a bit. At a certain point, it boils down to individual decisions.

Hold Your Breath

At the end of the day, the fact that the city of Atlanta—and indeed, the world—is choosing to focus their efforts on vehicle emissions to control ground-level ozone pollution provides a natural starting point for an individual looking to do the same. The most straightforward way to help reduce air pollution on a personal level, of course, is to limit relying heavily on the driving habits that emit those pollutants in the first place. In everyday practice, this strategy might look very different depending on a person's lifestyle and priorities. For some people, it could be combining errand-running trips to cut down on time in the car, or carpooling to work. For others, it could mean cutting out the commute entirely by exploring the option of telecommuting. As the workforce shifts, employers are increasingly exploring other flexible work options. Under the right circumstances, setting up virtual workspaces can result in a win-win situation for employer, employee, and environment. For instance, Emory University manager Mark Wilson told the *Emory Report* that one of his employees was "exceptional" about working under minimal supervision. He continued, "Telecommuting seemed like a perfect fit, saving her hours in commute time and helping the environment by not burning fossil fuels" (Williams).

If you still need to get around the city, another way to cut back on emissions is to explore other transportation options. Depending on where you live, mass transit might be a feasible option. In the Atlanta area, there are a variety of public transportation options that you could use. MARTA, which serves Fulton and DeKalb counties through a bus and rail system, might be the most well-known alternative to driving, but it's not the only one. Just in the metro Atlanta area, there's also the Atlanta Streetcar, a 2.7 mile East-West route that connects the Centennial Olympic Park area to the Martin Luther King Jr. Historic Site; the Cherokee Area Transportation System (CATS), which provides countywide transportation services for residents of Cherokee County; and Emory University's Cliff shuttles, which provide shuttle services for students, staff, and the local community surrounding the university and the Clifton corridor, to name just a few options. There are also resources for out of state for residents in Athens, Augusta, Macon, Rome, and other neighboring counties. Consider spending your commute reading, napping, or getting some work in, while saving money on the way. A monthly MARTA Breeze Card, for instance, is only $95, compared to the approximately $335 a month that it costs to drive alone ("Don't Text and Drive, Text and Ride!").

And while it's easy to, try not to forget the power of your own body to get you places that you need to be. After all, more than 25 percent of all auto trips are less than a mile, which should hopefully be within your range of motion (Congressional record, 109ADAD). Not only does commuting by bike or foot completely slash your own personal air pollutant emissions, it also promotes a more active lifestyle and offers significant health benefits. To get started, check out the Atlanta Bicycle Coalition, a member-based nonprofit advocate for better bicycling in Atlanta. They offer a variety of resources for those looking to incorporate biking into their transportation habits, from finding the perfect route, to financial assistance in renting or purchasing a starter bike, to offering classes about Atlanta's new bike share program or fostering urban confidence in beginning cyclers.

There's also other programs in the area works towards the same end. PEDS, a small advocacy group, works with transportation agencies, neighborhood organizations, and local law enforcement to bring about pedestrian-friendly policies, plans, and street designs in Georgia. The Georgia Department of Transportation (DOT) Bike and Pedestrian Program offers technical assistance, engineering, and planning guidance, public information, and educational materials and programs for cyclists and walkers. Cycle Atlanta, a smartphone app developed by Georgia Tech, uses your phone's GPS to record your bike routes in real-time, giving transportation planners with the City of Atlanta the data they need to make Atlanta a better place to ride. This is the kind of positive feedback loop (or cycle!) sustainable city planners love.

If you insist on continuing to use your car, however, there are still steps you can take to minimize engine emissions contributing to air pollution problems in your city. Some of the emissions, in fact, are directly under your control based on the way you drive and care for your car. Remember your first driving lessons: not only are these tips better for your safety on the road, and the safety for those around you, but they're also valuable strategies from an ozone emissions standpoint. Small habits like limiting idling, avoiding jackrabbit starts, and driving within the speed limit are all ways you can begin to limit your ground-level ozone footprint. This mentality can also translate into routine maintenance and caring for the vehicle itself. Keep your tires properly inflated to ensure that you get the most bang for your buck (and ozone precursor emissions) out of every ounce of gasoline. And while you're at the gas tank, stop short of topping off your gas tank, and try visiting in the evening on "Smog Alert Days" to refuel. Make sure you have your car emissions tested as required by law at a certified testing location.

Transportation, while one of the most important sectors when it comes to ozone precursor emissions, isn't the only aspect of ground-level ozone pollution that ordinary citizens can help in. Besides your cars, keep your lawn equipment and boats periodically checked and tuned up, to make sure that emissions standards are within their limits. Try using electric or natural gas grills instead of charcoal and lighter fluid. Using environmentally-safe paints and cleaning products to cut down on VOC emissions from your home. Keep your thermostats high in the summer and low in the winter. And if you're serious about reducing ground-level ozone pollution in your city, get involved with preexisting programs with the same vision. If you're in Atlanta, get involved in the city's new Transportation Plan by attending a pop-up meeting to give your two cents on the future of public transit in metro Atlanta, or take a couple minutes to fill out their publicly available survey. Check out Georgia Commute Options, a program from Georgia's DOT that helps provide incentives and resources to help "commuters, employers and property managers take advantage of commute alternatives" ("Georgia Commute Options").

Even if you're taking all these actions and going to lengths to reduce your own ozone precursor emissions, keep in mind that air pollutants aren't exactly fair, and you and your family are still susceptible to the ground-level ozone that forms due to other's emissions. To that end, make sure that you're minimizing your own exposure, especially if any respiratory health condition makes you especially sensitive to the pollutant. Make it a habit to check daily Air Quality Index (AQI) forecasts for ground-level ozone ("AIRNow – Atlanta, GA Air Quality"). Even better, convince your organization to partner with AirNow's Air Quality Flag Program and raise a flag corresponding to how clean or polluted the air is to help raise awareness of local air quality conditions for others. Think about spending more time indoors and choosing less strenuous outdoor activities so you don't breathe as hard when ozone levels are high, or just planning outdoor activities at times when ozone levels are forecasted to be lower (usually in the morning and evening).

At the end of the day, we're all in this together, because the air belongs to all of us. We're all partly responsible for local air quality. Even if we don't want to hold ourselves accountable, our health will.

Wildfire Emissions

Science: In Climate Change's Line of Fire: Too Hot to Handle?

One moment, you might be enjoying a peaceful morning, surrounded by songbird and sunlight. Then, the trees begin to blush orange (Prado). Sunlight filters weakly through the rising smoke, embers glowing like small eyes in the underbrush. A wave of earthworms, slugs, mites and other invertebrates crawl through the dry soil, trying to stay ahead of the heat (Zielinski). As the winds pick up, the fire starts to come alive in earnest, licking up the sides of trees and leaping from branch to branch ("Fighting Wildfires"). The next thing you know, it can be dancing through the forest sounding like a freight train, lighting the canopies of 150 foot trees in crowns of flame. A powerful fire can engulf millions of acres of forest at a time, leaving a thin coat of white ash—like snow—in its wake (Turturici).

Even if you've been lucky enough to have never met a wildfire in person, you're probably familiar with the concept. Maybe you grew up with Smokey the Bear, who for some reason insisted that only you could stop forest fires. Or you've seen portrayals of wildfires in movies—from watching Spirit in Dreamwork's Stallion of the Cimarron galloping from a fiery train explosion in the woods, to witnessing "the red flower" snap at your favorite characters' heels in Disney's Jungle Book. Or maybe you just recently claimed that a viral meme "spread like wildfire" around the Internet—or, if you're being honest, just your immediate social circle. But Smokey the Bear, animated movies, and expressions never really get to the science behind wildfires—how exactly do they start, and how do they spread? Are they always bad? What do animals do during a wildfire, and what kind of health effects do they have on people? Not to mention, does climate change change (pun intended) any of that? (Hint: yes, it does!)

This, my friends, is where we come in.

What's in a Wildfire?

The birth of a wildfire can start with a bang or a fizzle: a bolt of lightning, an arsonist torch, a stray power line, or even a nearby volcano (Byrd et al.). But even if it begins with a discarded cigarette on the forest floor, things can heat up very quickly. Once wood is heated to about 300 degrees Fahrenheit, it begins to emit biogenic volatile organic gasses, or BVOCs for short (Loreto et al.). For reference, the temperature of the tip of a lit cigarette when smoldering is nearly 1300 degrees Fahrenheit, so it really doesn't take that much relative heat to induce this stress response in wood (Ewart and Skorucak). (But before you start thinking of wood as weak, consider that your pansy skin could start to burn at a mere 109 degrees Fahrenheit—just to put that into perspective for you ["General data about burns"].)

In any case, BVOCs—including our ozone precursor friend, isoprene—were designed to protect against large fluctuations in leaf temperatures and destabilized cell membranes ("Isoprene emission from plants – a volatile answer to heat stress"). Unfortunately, in an ironic twist of fate, BVOCs are also pretty flammable (Loreto et al.). In fact, BVOCs are technically non-methane hydrocarbons—the very same compounds that make up gasoline ("What is Gasoline?"). Like gasoline—you know, that compound with enough power to run our thousand-pound vehicles—BVOCs have a lot of energy. So does another group of compounds commonly found in forests where wildfires begin: oxygen. But because both BVOCs and oxygen molecules want to be in a reduced energy state, they form a partnership and decide to rearrange themselves into carbon dioxide and water, two relatively low-energy compounds. But that energy can't just disappear; the newly formed molecules have to deal with it in some way. Here, they use two strategies: 1) they take off after the reaction with extremely high speed and rotation, which we feel in the form of heat, and 2) as they spin off, they emit visible and infrared light. Together, this heat and light form a force that is both familiar and frightening: fire (Crash Chemistry Academy).

Just because the stars align to create one drop of fire in a forest, however, doesn't necessarily mean that conditions are prepped for a full-blown wildfire. Every fire requires three ingredients to keep burning: heat, oxygen, and fuel. Together, these components make up the fire triangle, a simple model for understanding how any fire works ("The Fire Triangle"). In general, a wildfire will spread in the direction that has the most abundant resources for each of these three elements. Of course, in the real world fire is anything but simple, partly because these unpredictable forces of nature have their own means of securing at least some of their own necessities (a pretty frightening concept, if you ask us).

For one, as soon as hydrocarbons and oxygen combust, the heat that the newly-formed flame generates induces more BVOC to be emitted from nearby wood, which then combusts to generate more heat and more gasses: a built-in positive feedback loop that allows for fire to spread very easily under the right conditions, consuming larger and larger vegetation (SciShow). Not to mention, a wildfire can also replenish its own source of new oxygen, known more commonly as wind. As a fire heats up the air around it, the hot air rises quickly, allowing fresh, oxygen-filled air to fill the vacuum left behind. As a bonus, this influx of air can pick up ashes from the ground, which has the potential to be reignited. On a large enough scale, this self-sustaining whirlwind of air can produce a teetering, spinning vortex of flame that goes by a variety of names, each as terrifying as the last—fire whirls, fire devils, fire tornados, fire twisters, or (our personal favorite) firenados (Leberfinger).

Clearly, wildfires have a pretty destructive reputation, but they also have a soft side that people don't usually mention. In the wild, fires provide really important natural services to a bunch of environments that have come to depend on fire for renewal, maintenance, and balance. For example, in many grasslands, like the Little Bighorn Battlefield National Monument in southeastern Montana, fires prevent larger trees, woody plants, and invasive species from crowding out native herbs and grasses. Without them, these rolling plains of windswept grasses would be quickly replaced by forests, much to the chagrin of the many animal species that call these grasslands home (United States, Dept. of the Interior, National Park Services; "Wildlife").

In forest ecosystems that evolved with fire, many plant species have adapted to and even come to rely on fire. Jack pine trees of the Great Lake state forests, for instance, will only release its seeds in the presence of intense heat ("Jack Pine: Great Lakes States"). This adaptation to fire gives Jack pine seedlings a great shot at life, as they can take advantage of the ash-enriched soil and reduced competition. In general, fires often stimulate the flowering and fruiting of many plants, since wood ash is such a great fertilizer—it contains all the nutrients that plants need to grow, including calcium, potassium, and magnesium (Griffin). Not to mention, because of these elements (particularly calcium), wood ash also acts as a liming agent: a calcium- and magnesium- rich soil additive that neutralizes soil acidity and increases activity of soil bacteria. From the forests of British Columbia, to California shrublands, to South Africa's savannas, to the longleaf pine forests of the Southeastern U.S. and even wetlands, ecosystems around the world play with fire—and instead of getting burnt, they flourish (Bunnell; Keeley and Fotheringham; Reid and Gamble; Means et al.; Watts et al.).

But before you start going around your neighborhood committing arson in the name of nature's best interests, consider finishing this section of the site. From the unfortunate human health impacts of wildfire emissions, to how climate change is meddling in the size and severity of wildfires (and why wildfires are becoming increasingly less "wild"), to exploring what this force of nature is up to in the Southeastern U.S. near Atlanta, GA, the role of wildfires today is anything but black and white. And the future, of course, is an even more ambiguous shade of grey.

Devil in the Details

You might be thinking that you have a pretty solid understanding of how wildfires can affect human health in general. After all, you're probably human, and so you've likely had some experience with fire (you know, like your ancestors have for literally millions of years [Miller]). And the public health burdens that you immediately think of wildfires having on the healthcare system and public health infrastructure are absolutely valid: large-scale evacuations, temporary shelters, and treatment of individuals for burn injuries, for instance. Other negative effects, like mental health impacts and soil erosion, which can lead to potential contamination of water reservoirs and drinking supplies, and possibly increased flooding, don't come to mind at first but seem relatively intuitive. Air quality might fall into that last category, since the dark, billowing grey smoke above the treetops doesn't look particularly designed to be inhaled (Fann et al.).

But if air quality is an afterthought, you might want to reconsider your priorities a bit. But, to be completely honest, we’re not surprised if it were. Wildfires are such a dramatic force of nature, and they leave some very distinct trails of damage in their path: blackened trees, fleeing animals, burnt homes. But when it comes to arguably the most severe health effect from wildfires, these roaring natural disasters are much more subtle. The real danger, more specifically, comes from inhaling particulate matter (PM): a catch-all term for a mixture of solid particles and liquid droplets found in the air. Some of these particles, like dust, dirt, soot, or smoke, are big or dark enough for you to see with just your naked eye. Others are so tiny that they’re pretty much invisible, and can only really be detected with an electron microscope (“Particulate Matter [PM] Basics”).

These tiny pollutants might not sound so bad to you, but your respiratory system begs to differ. In fact, when it comes to PM, the bigger, the better. Ideally, of course, PM is large enough that your upper respiratory tract will try its best to eject it from entering into your body at all. For example, you might choke and cough out a stray ember (hey, nobody said the ejection process was graceful). It’s when particles get small enough to inhale that the trouble starts. PM_{10} are one such category of inhalable particles, which are 10 micrometers and smaller in diameter. $PM_{2.5}$, as you might be able to guess, refer to particulate matter with diameters that are 2.5 micrometers and smaller. To put that into perspective, the average human hair is about 70 micrometers in diameter, or 30 times thicker than the largest fine particle (Australia, Department of the Environment and Energy). $PM_{2.5}$ are referred to as “fine” inhalable particles, but just so we’re clear, that adjective is only accurate when it comes to describing their size, not their positive qualities. Because really, once they get inside your body, it’s far from fine.

PM, particularly $PM_{2.5}$, has two major methods of attack once it's gotten inside you. (You've already helped it get there by breathing it deep inside your lungs, and basically giving it a golden ticket into your bloodstream. Great job [Xing, Yu-Fei et al.].) First,$PM_{2.5}$ can wreak havoc on your body through free radical peroxidation (Donaldson). Since that only seems to be a loose interpretation of English—I mean, you probably recognize the first two words but also realize we're likely not talking about a liberating social movement—we're going to break that down for you. Free radicals simply refer to any kind of atom, molecule, or ion—so think of a tiny, chemical building block—with an unpaired electron in its outer orbit, otherwise known as a valence electron (James). Electrons, you see, don't like to be alone; they liked to be paired with other electrons. They're hopeless romantics. So basically, an unpaired electron is an unhappy, reactive electron that is vigilantly on the look-out for an opportunity to find some love.

In this case, free radicals begin to proliferate in the lungs due to $PM_{2.5}$ exposure, mostly thanks to the fact that the $PM_{2.5}$ surface is rich in iron, copper, zinc, manganese, and other metals (Xing, Yu-Fei et al.). Usually, like you'd probably expect, these metals are fairly well-regulated inside your body. For example, transerrin proteins bind to iron and help you to control the amount of iron inside your bloodstream (Bridges). That's good, because when metals aren't bound inside the body, they'll start to initiate free radical production through a really inconvenient process called the Fenton reaction ("Water Treatment Solutions"). Of course, this isn't good news for your body. Unless you're Wolverine, and that doesn't count because he could control the metal in his system anyway.

And here's where we get to that scary word we mentioned above: peroxidation. Basically, that's a really scientific way of saying that free radicals, once turned loose in your body, will start to initiate a specific chain of events that ultimately cause a whole bunch of problems for your cells. Because free radicals are, by definition, single and ready to mingle, they jump at the chance to buddy up with another electron—even if this electron is already taken. It's not unusual for free radicals to "steal" an electron from one of the membrane lipids that form the surface of all your cells. Because of this greedy, home-wrecking free radical, now that membrane lipid becomes a free radical itself, desperate to find a partner for its unpaired electron. It starts to flirt with its neighboring lipid's electrons, steals one, and ultimately starts a domino effect of cellular damage (Osmosis). And this doesn't just happen at the cell membrane level. Free radicals can also do their destruction inside the cell, to proteins and DNA, which can lead to cancer (Xing, Yu-Fei et al.). Basically, everybody loses, including you. Everybody, that is, except that free radical in the beginning, which got the electron it wanted in the end (Osmosis).

But in case that wasn't enough damage for you, there's a second strategy particulate matter likes to use that turns the body against itself through inflammation. PM plays a mean waiting game, though. First, it flirts with scavenger receptors, which are partnered with alveolar macrophages. (Translation, working backwards: macrophages are a type of white blood cell that get rid of anything the body is suspicious of—cellular debris, foreign substances, microbes, cancer cells, and the like—through a process called phagocytosis, which is a fancy way of saying "swallowing the thing whole." Think Kirby from Super Smash Bros. Alveolar macrophages specifically refer to the macrophages that live in any of the small air spaces in the lungs where carbon dioxide leaves the blood and oxygen enters. As you can imagine, traffic here is pretty high, considering the alveoli are one of the major boundaries between the body and the outside world. And finally, scavenger receptors help their phagocyte identify molecular patterns in the name of deciding what material to digest [Zani et al.]. So basically, if you'll eat anything, you wouldn't make a good macrophage without the help of a picky scavenger receptor.)

Under normal circumstances, scavenger receptors help the phagocyte they're associated with be selective of the material that is phagocytized, so as to not compromise the normal cells and structures of the body. But when under the spell of PM, scavenger receptors give the green light for the macrophage to ingest the particles, even though unfolding events quickly reveal it's not in the best interests of the body's overall health (Obot et al.). Upon ingesting the PM, the phagocyte immediately commits suicide to protect the body, which is more scientifically known as "programmed cell death" or apoptosis, from a Greek word meaning "falling off," as in leaves from a tree (Horvitz). Obviously, massive die-offs of the body's first line of defense isn't exactly a sign that things are going well. So, in response to widespread alveolar macrophage apoptosis, blood-traffic-control proteins called cytokines signal a variety of immune cells, from more macrophages to other types of white blood cells, to travel to the site of infection. Once there, the cytokines activate the cells, and stimulate them to produce more cytokines.

There isn't anything wrong with this in and of itself. Normally, the body is able to keep this feedback loop in check. However, in some circumstances, like when PM is involved, the reaction spirals out of control and way too many immune cells are activated in a single place:

another name for inflammation. In small doses, of course, this rush of blood—rich in white blood cells, the body's first line of soldiers—is an important and lifesaving instinct. You might notice this response as a warm outline encircling a skin wound, a deep pink color from the influx of red blood cells. Unfortunately, however, sometimes (like in this case) this impulse ends up backfiring on the body. This particular positive feedback loop is called a cytokine storm, and it's basically inflammation on steroids (Tisoncik). PM might have taken a while to get to this point, but that's why people talk about the calm before a storm.

Together, the double whammy health effects of particulate matter from wildfire emissions that penetrate deeply into the lungs—specifically, free radical peroxidation and inflammation—irritate and corrode the alveolar wall, and can ultimately lead or at least make you more susceptible to a really depressingly long laundry list of respiratory health problems. In fact, during times of peak fire PM concentrations, the chances that a person will seek emergency care increases by 50 percent when compared to non-fire conditions (Thelen et al.). We'll go through as many resulting health conditions as we can, as quickly as we can:
lung cancer, chronic obstructive pulmonary disease (COPD) (causes airflow blockage and breathing problems), general cardiopulmonary issues (which generally refers to the heart and lungs), asthma development and exacerbation, pneumonia, influenza, acute respiratory tract infection, cardiovascular disease, low birth weight, and, of course, early death (Pope et al.; United States, Environmental Protection Agency; Pope et al.; Lewis et al.; Katanoda et al.; Yadav et al.; Yadav et al.; United States, Environmental Protection Agency; Holstius et al.; B and ST).

And now that we have all that good stuff out of the way, let's learn about how climate change is going to make everything even worse! (In case you can't tell, we're making a joke. If you get sad, feel free to take a break and skip ahead to the solutions section. There are solutions people are working on, we promise!)

Why Climate Change and Wildfire are BFFLS

If the public health effects of wildfires came easily to you, you probably at least have a couple of guesses when it comes to the effects of climate change on the size and severity of wildfires, present and projected. As we reviewed earlier, wildfires need three things to survive and flourish, according to the fire triangle diagram: heat, oxygen, and fuel. And climate change, as you might have already figured out, is happy to deliver on both heat and fuel (oxygen is a bit out of its pay grade). In return, wildfires add an estimated 3.5×10^{15} grams of carbon to atmospheric emissions each year, or roughly a whopping 40 percent of fossil fuel carbon emissions, making this partnership good for both of them but bad for us—as most of climate change's deals tend to be (Van der Werf et al.).

First of all, climate change helps lengthen fire season, or the period of time when fires are actually burning, giving wildfires a larger window of time and opportunity. More specifically, one study found that the length of the active wildfire season in the Western United States has increased by 78 days (64 percent), and that the average burn duration of large fires has increased from 7.5 to 37.1 days, when comparing 1970 to 1986 with 1987 to 2003 (Westerling). One of the main reasons for this is that the fire season is starting much earlier, giving wildfires a head start. In parts of the country with substantial snowmelt, winter-spring runoff is happening at least five days earlier than it did in the mid-20th century, with the largest changes occurring in the Pacific Northwest and Northeast ("Climate Change Indicators: Streamflow"). Other scientists see the changes as more severe, reporting that mountain snowpacks are melting 1- to 4- weeks earlier than usual, with snow-dominated forests at elevations of about 2100 meters showing the greatest historical difference (Westerling). Either way, all trends are looking pessimistic when it comes to the longevity of snowmelt in a changed climate. But this snowmelt is important; the moisture from snowpacks keeps wildfires at bay in colder months. Once the snowmelt is complete, these forests become easily combustible within a month (Running). Summer heat builds up more quickly, and warm conditions extend further into the fall, ensuring wildfires can stick around for longer. In fact, in the 34 years studied, years with earlier snowmelt had five times as many wildfires as years with late snowmelt (Westerling).

Not only will the fire season be longer, but it will also be much drier, which is to every wildfire's liking. As you probably know by now, climate change is increasing ground surface temperatures at a fairly alarming rate. Summertime temperatures in western North America are projected to be 3.6 to 9 degrees Fahrenheit higher by the middle of the century, for example (Staudt). In general, global temperatures have been accelerating upwards in the past 30 years; average U.S. temperatures as a whole have increased by more than two degrees Fahrenheit in the last century ("Climate Change and Your Health: Rising Temperatures, Worsening Ozone Pollution"). Higher temperatures, in turn, lead to higher rates of evaporation. The heat energy from the warmer air is transferred to the surface of a liquid, which makes the molecules in the liquid begin to move faster. (Think of you, on caffeine, feeling like you can run a marathon.) This means that the molecules also begin to collide with one another at an increasing rate, until some of the molecules are able to escape into the atmosphere in the form of water vapor: a process that's more commonly known as evaporation. More evaporation means drier vegetation, or the perfect snack for a wildfire looking for a promotion.

And it's not just rising evaporation rates that's creating tastier fuel for wildfires. Warmer and drier conditions exacerbated by climate change are conducive to widespread beetle and other insect infestations. More infestations mean more dead trees, and more dead trees means more fuel for fires (SciShow, "The Science of Wildfires"). For instance, bark beetles have been culling sickly trees in North American forests for a while (Oatman). But thanks to climate change, these tiny winged insects have been working overtime. Prolonged droughts and shorter winters have allowed them to kill billions of trees in what may be the largest forest insect outbreak ever recorded—about 10 times the size of past eruptions. Plus, they're enjoying the warmer temperatures as well. In 2008, a team of biologists at the University of Colorado observed some beetles attacking trees in June, a month earlier than previously recorded (Mitton and Ferrenberg). Not to mention, climate change also weakens trees through heat and drought, making it difficult for them to fight back the way a healthy tree usually would with chemical defenses and sticky resin. From 2000 to 2012, bark beetles killed enough trees to cover the entire state of Colorado, leaving behind broad ranges of dead and highly combustible trees (Jason et al.).

Finally, climate change is expected to lead to increased lightning strikes. More specifically, new findings suggest that lightning rates will increase 12 percent for every 2 degrees of Fahrenheit rise in global temperatures, which comes to a 50 percent increase by the end of the century across the continental United States (Romps, et al.). That would mean some

30 million lightning strikes per year by 2100. And because lightning triggers about half of those wildfires, this increase in lightning could dramatically accelerate wildfire proliferation. The reason behind this lies in the moisture. At the air warms, it becomes less dense and capable of holding more water. A more moist atmosphere means more vigorous thunderstorms, and more severe thunderstorm means more lightning strikes (Lee). Ultimately, climate change is going to provide more lightning to start wildfires, stockpile a plentiful supply of dry vegetation for them with the help of invasive species, and lengthen the fire season to give wildfires more time to burn. It's a package deal wildfires appreciate with a burning passion.

The Smoky Southeast

Honestly, if we told you a year ago that the Southeastern United States was particularly vulnerable to threats from wildfires because of the accelerating effects of climate change, you might not have believed us. Maybe the Southwestern United States, with their cacti, and Death Valley, and all those lightning storms east of the Rockies. But the Southeast? With our intense bouts of rain and our wet, old growth forests? No way.

But you're probably much more inclined to believe us now. In October and November 2016, a series of large wildfires raged across the Southeastern United States, including Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia. They left a dramatic wake of destruction in their path: burning more than 150,000 acres, injuring nearly a hundred, and killing more than a dozen people (Bever et al.). For some of the wildfires, we know exactly what sparked that first flame. For instance, in the Great Smoky Mountains National Park, two arson-committing juveniles are to blame, and were charged with aggravated arson ("Two juveniles charged with arson in deadly Tennessee fire"). But for others, like the fires in western North Carolina or North Georgia, the actual causes are a bit murkier. There's speculation it might have been accidental human activity, like campfires, or a lightning strike (United States, National Wildfire Coordinating Group, Incident Information System). But lightning has been striking and people have been stupid with fires in the Southeast for almost all of history, and these states haven't gone up in flames, at least not like this, until just recently. So what's changed?

The biggest culprit is drought. California and the Southwest have stolen the spotlight for drought in the United States (at least until 20 inches of rain and 12 feet of snow hit this winter [Rice]. And even so, not everybody is convinced enough to celebrate the end of the dry season [Griggs]). But while these seasonal dramas are playing out on the West Coast, America has been largely ignoring the same issues taking place in the Southeastern United States—ones that have remained a bit more resilient. According to the U.S. Drought Monitor, two-thirds of the Southeastern United States is experiencing some form of drought today; in Georgia, about 20 percent of the state, almost exclusively in the North, is classified under severe, extreme, and exceptional drought ("U.S. Drought Monitor Southeast"; "U.S. Drought Monitor Georgia"). These drought conditions are significantly worse than what is now occurring in the West, which is now only considered to be experiencing "abnormally dry" intensity characteristics ("U.S. Drought Monitor").

The major driving factors behind drought in the Southeast are the usual suspects: climate change, rising surface temperatures and increased evaporation. Since the 1970s, the

Southeast's average temperatures have steadily increased, breaking all the worst records (Erdman). And tropical storms and hurricanes, which are usually responsible for bringing in tropical moistures from off the Gulf of Mexico, have been recently skipping over the region, probably thanks to climate change ("Why wildfires are suddenly ravaging the Southeast"). Cyclones harvest energy from the atmosphere when masses of warm and cold air interact along the polar front, or the boundary between cooler polar air and warmer subtropical air. As the temperature between the poles and the topics decreases, there may be less energy for these storms to absorb (Voiland). It doesn't help that the trees, bushes, and understory in the Eastern United States dry out much more quickly than their counterparts in the West, because they're not adapted to the same arid conditions (Walsh). Basically, Western vegetation is used to dealing with lack of rain, but Eastern vegetation isn't. Stressed trees means dead trees, and you know how much a wildfire loves dead trees. All together, these newly emerging weather patterns are creating the perfect tinder to breed and feed wildfires.

If you've been keeping up with the wildfires in northern Georgia and the Southeastern United States, either by choice or necessity, you might have been struggling to hold your tongue through this section. "But drought season is over," you might be wanting to blurt out. "I saw it on the news. Water conditions are improving here, and states are beginning to lift their water restrictions" (Bluestein). And you'd be absolutely right. But the pessimists that are cautious to celebrate the downpours in the West are the same ones giving the wet winter in the Southeast a critical eye. One of these scientists—Mark Svoboda, a climatologist who directs the National Drought Mitigation Center—told *Popular Science* that even if it does rain in the Southeastern United States, it's not likely to solve the region's water woes. He and his team have seen early indications that the Southeast might see more rain over time, but more time in-between rain events ("Why wildfires are suddenly ravaging the Southeast"). This sentiment has been echoed in other sources, like NASA's Earth Observatory, which predicts fewer but stronger storms (Voiland).

As the research compiles, a tentative picture of the future Southeastern United States is starting to form: one characterized by drought and interrupted by the occasional extreme weather event, which will bring only temporary water relief to the region. To be sure, the final verdict on the region's developing weather and climate patterns is clouded by a degree of scientific uncertainty. But it might just be hazy because of the wildfire smoke that's sure to follow us forward.

Solutions: Fighting Fire: Past, Present, Future

Burn, Baby, Burn

Science astrophysicist and communicator Carl Sagan said, "You have to know the past to understand the present" ("Carl Sagan Quotable Quote"). That's especially true when it comes to wildfire control and regulation policy in the United States.

From a first glance at the data, one might conclude that United States policy on wildfires has been more or less reasonable. In the past twenty years, the average number of wildfires that have broke out per year has remained relatively consistent, waffling in the 50,000 to 100,000 range. When looking at data for acres burned, though, the situation takes a turn for the worse: even controlling for interannual variability, there's steep incline between 1984, when 1,148,409 acres were consumed by wildfires, and 2015, when 10,125,149 acres were burned. But things get even more confusing when factoring in historical data. According to the National Interagency Fire Center, the average number of fires that breaks out now is significantly fewer than the number that scorched the nation in the 1960s, 70s, and 80s. In fact, 1981 holds the record for most number of wildfires in a year, at nearly 250,000 compared to 2016's 68,000. Between 1981 and 1984, the number of annual wildfires in the US took a nosedive, even as their severity increased ("Total Wildland Fires and Acres [1960-2015]").

These statistical patterns beg several questions: what was the United States doing to control and manage wildfires in the past? What changed in the 1980s, and why? And what are we doing now?

The main events that set the original course for fire policy in the United States occurred in the late 1800s and early 1900s, when a series of catastrophic wildfires led to high fatalities and sent ripples of shock and fear throughout the developing nation. On October 8, 1871, the Peshtigo Fire ravaged forests in and around Peshtigo, Wisconsin, killing as many as 2,500 people to take its place as the deadliest wildfire in recorded history (Rosenfeld). A severe drought and high temperatures allowed the Santiago Canyon Fire of 1889 to burn through large parts of Orange County and San Diego County in California (Keeley and Zedler). The Great Fire of 1910 scorched about three million acres in northeastern Washington, northern Idaho, and western Montana, destroying a number of communities and killing 87 people over the course of two days. Also known as the Big Blowup, the Big Burn, or the Devil's Broom fire, the human health costs of this historic wildfire are often credited with defining fire management policies for decades afterwards (“The Great Fire of 1910”).

Specifically, these giant fires supported the “fire exclusion” mentality in fire policy: the simple idea that every single fire should be immediately suppressed at all times (Tidwell). In fact, by 1935, the U.S. Forest Service’s official fire management policy mandated that all wildfires were to be put out by 10:00 AM the next morning after they were first spotted. It didn’t matter if the fire started from lightning or from traditional human practices, like for use in foraging, herding, or farming (as the Native Americans had done for hundreds of years) (Anderson). It didn’t matter if the fire threatened human civilization or helped enhance land and ecological quality. If there was a fire, it had to be put out. This mentality was promoted by an extremely effective U.S. Forest Service advertising campaign to help educate the public that all fires were detrimental: a cartoon black bear named Smokey the Bear, whose iconic catchphrase “Only you can prevent forest fires” can still be found on posters.

In some ways, the total wildfire suppression policy of the early- and mid-90s was a success. The annual average area burned by wildfires fell from 30,000,000 acres in the 1930s, to between 2,000,000 acres and 5,000,000 acres by the 1960s (United States, City of Fort Collins, Natural Areas Department). During World War II, the increased demand for lumber perpetuated the idea that forests need to be preserved, since a burnt forest is not a commercially profitable one. But while the fire-exclusion strategy seemed to be in the public’s best interest, by eliminating fire entirely, forest ecosystems and national parks that evolved with fire began to choke on the thick layer of highly flammable underbrush, which freely developed without fire to keep it in check. Forests became ticking time bombs, ready to explode at the hint of heat.

Starting in 1962, protests from the burgeoning American fire community began to challenge this assumption of fire suppression policy. That year, the Tall Timber Research Station and Land Conservancy in northern Leon County, Florida hosted its first fire ecology conference, sowing the seeds of fire acting as an important ecological force (Nijhuis). The Nature Conservancy put academic theory in practice, conducting a controlled burn in a prairie in Minnesota (Pyne). At some point in the 1960s, ecologists realized that no new giant sequoia had grown in the forests of California since the fire exclusion policy was enacted. That's because these trees rely on fire to release seeds from their cones, expose bare mineral soil their seedlings can take root in, recycle nutrients into that soil, and open holes in forest canopy so sunlight can reach the young seedlings (United States, Department of the Interior, National Park Service, Sequoia and King Canyon National Parks California). Altogether, these shifts and realizations sparked a new revolution on good fire: that maybe, this formidable force of nature is a bit misunderstood. Or maybe, it's a necessary evil natural ecosystems learned to deal with. Either way, it was beginning to become clear that forests that evolved with fire continued to rely on it.

So, in 1968, the National Park Service changed its national policy to recognize fire as an ecological process (Wagtendonk). Fires were to be allowed to run their natural course, provided they could be contained within fire managements units and accomplished approved management objectives. In other words, by 1972, naturally-caused fires were allowed to more or less burn themselves out ("When to Let the Forest Burn"). Several national parks established their own fire use programs (United States, Dept. of the Interior, National Park Service, Yellowstone National Park). The U.S. Forest Service followed suit with its own comprehensive overhaul of historic fire regulation in the 1970s and by abandoning their 10:00 AM policy (United States, Department of the Interior and Department of Agriculture). Fire management replaced fire suppression, and controlled fires were tolerated as long as they stayed within their predetermined boundaries.

In theory, these new regulations should have helped control wildfires by periodically limiting their access to fuel. And on small, limited scales, there's evidence that they worked. Specifically, the new fire management mentality took off successfully in Florida, where controlled fire became general practice (Pyne). But overall, in reality, these policies fizzled out as soon as they were implemented. The 1980s were great for cable television and country music, but they were pretty rough from an environmentalist's perspective, who often refer to the eight years of Ronald Reagan's presidency as "the lost years" (Shabecoff). After all, his 1981 appointment of James G. Watt as Secretary of the Interior and Anne M. Burford as Administrator of the EPA were two well-known and aggressive champions of industry. As the U.S. Forest Service became increasingly dysfunctional and urban sprawl began colonizing the countryside, fire suppression became the default setting once more. By 1988, only about 30,000 acres of Yellowstone National Park's 2.2 million acres had been burned. According to one official, by not controlling large swathes of the park through controlled burning, park officials essentially poured 300 gallons of gasoline on every acre every year ("The Story Behind the Yellowstone Fires of 1988 | Retro Report | The New York Times").

Tons of untouched underbrush, drought conditions, an extremely dry summer, high winds, and lightning were an explosive combination in the late 1980s, culminating in the Yellowstone fires of 1988 ("The Story Behind the Yellowstone Fires of 1988 | Retro Report | The New York Times"). Together, the many smaller individual fires formed the largest wildfire in the recorded history of Yellowstone National Park, ravaging nearly a third of the park's total area and forcing park officials to close the entire park to all non-emergency personnel for the first time in its history (Schullery). At first, in response to wildfire on such a large scale, the American public reacted in fear and anger. They blamed Yellowstone park officials for letting wildfires burn freely, which the media coined as a "let it burn" policy. But after a quarter-inch of snow quenched the flames in September, the media offered a new angle as the park quickly bounced back from the flames: one of natural renewal as the ecosystem flourished, thanks to wildfire ("The Story Behind the Yellowstone Fires of 1988 | Retro Report | The New York Times").

In many ways, the widely publicized Yellowstone fires of 1988 ushered in a new era of fire management, where fires were properly recognized for the necessary ecological functions. Since 1995, federal fire policy has been significantly modified to recognize and embrace the role of fire as an essential natural process. Federal wildland fire management policy has stated since then that, "Fire, as a critical natural process, will be integrated into land and resource management plans and activities on a landscape scale, and across agency boundaries. Response to wildland fire is based on ecological, social, and legal consequences of fire." Today, national and local wildfire policy continues to incorporate this priority into their management strategies. The most recent Guidance for Implementation of Federal Wildland Fire Management

Policy published by the National Interagency Fire Center in 2009 writes under its guiding principles that, “The role of wildland fire as an essential ecological process and natural change agent will be incorporated into the planning process” (United States, National Interagency Fire Center, Wildland Fire Executive Council).

Of course, as convincing as the environmental argument is, it’s one of many oftentimes-conflicting priorities when it comes to wildfire management. Under the guiding principles, the point about wildland’s ecological role is second; the primary concern, of course, is firefighter and public safety (United States, National Interagency Fire Center, Wildland Fire Executive Council). But as people build closer and closer to wildfire-prone areas, the two principles become increasingly difficult to balance without someone getting burnt (“The Story Behind the Yellowstone Fires of 1988 | Retro Report | The New York Times”).

Mastering Firebending

Fire management, not fire suppression, is still the backbone for controlling wildfires in the US today. Just because national fire policy is more progressive and ecologically accurate than it was 50 years ago, though, doesn’t mean our work is done. In fact, the truth is far from it. Given the ongoing threats from climate change, and the fact that burned acreage is on the rise despite the significant resources we’re investing in the issue, clearly there’s something that we can be doing better. According to many first responders that work directly with fires, as well as policymakers and researchers that have seen wildfires on the rise, the wildfire-urban interface (WUI) is to blame.

The WUI is the scientific way of saying people are living close to nature. Technically, it refers to the zone of transition where houses or human settlements are intermingling with wildland vegetation. Thanks to urbanization, American citizens are moving farther into natural areas to take advantage of the privacy, natural beauty and scenery, recreational opportunities and usually more affordable living ("Wildland Urban Interface"). The WUI in the continental United States covers more than 720,000 square kilometers (9 percent of the total land area) and contains 44.8 million housing units (39 percent of all houses) (Radeloff et al.). And while that seems like a good deal for suburban homeowners, it's also a trend that wildfires love. The benefits for wildland fires are two-fold: first, having people so close to natural ecosystems means there's a much higher chance that a stray source of heat will have the opportunity to spark a fire. And second, besides actually starting fires in the first place, the WUI also provides the fuel as well.

"You have homes being built in a wildland setting, which basically makes the homes fuel during a wild land fire," said one fire department chief. "And because you do have those homes out in the wildland or a forest setting, you get people who are more often doing things like cleaning ashes out of their fireplace, having electrical malfunctions, and other different activities that can cause a short and cause fires outside."

The WUI isn't a new concept, and relevant federal agencies have been factoring the trend into consideration when thinking about wildfire management strategies. For instance, the National Park Service's 2015-2019 Wildland Fire Strategic Plan says, "Wildland-urban interface (WUI) fire issues will continue to impact the work NPS accomplishes" (United States, Department of the Interior, National Park Service, Branch of Wildland Fire Division of Fire and

Aviation). Similarly, in the National Interagency Fire Center's 2009 Guidance for Implementation of Federal Wildland Fire Management Policy, the document outlines the extra risks that an expanding WUI creates. It states the WUI is "more complex and extensive than previously considered in the 1995 and 2001 Federal Fire Policy reviews. Fire management activities affecting WUI areas require closer coordination and more engagement between with federal, state, local and tribal land and fire managers." Later, it specifically identifies one of the organization's key implementation goals to be "prevent[ing] the movement of wildfires from the wildlands into the WUI area, out of the WUI area into the wildlands, and improve efficiency of wildfire suppression in WUI situations" (United States, National Interagency Fire Center, Wildland Fire Executive Council).

While heightened awareness of how the expansion of the WUI can affect fire management and control is a good sentiment, without complementary policy recommendations, it becomes difficult to translate theory into practice. In a heavily cited academic journal article on federal forest-fire policy in the United States, two researchers from the University of California, Berkeley similarly identify the WUI as a major concern. They write, "Continued growth of human populations in the urban–wildland interface is one of the reduces management options" (Stephens and Ruth).

But they don't just stop there. One of their concrete recommendations for fire management agencies moving forward is to place defensible fuel profile zones (DFPZs) near areas with a high potential for human-caused ignitions. DFPZs are a kind of fuel break or gap in combustible material that act as barriers to slow or stop the progress of a wildfire. Installation and maintenance of this kind of structure would make it easier for fire managers to get ahead of the flames while reducing the severity of the fire. This fire management method was once put to the test in Lassen National Forest in northeastern California—and passed! When a small wildfire burned through both the treated and untreated sections of a DFPZ, the study found that fire that went through the completed DFPZ exhibited lower intensity fire behavior, with lower flame lengths and reduced rates of spread. In turn, this resulted in much lower scorch heights and mortality compared to surrounding areas (Hood). Think of DFPZs as opportunities to trip the fire; they might not stop the wildfire entirely, but by breaking up its continuous fuel source, they help take the wind out of the fire's sails.

One of the main problems when it comes to making recommendations to fire management strategies is that there aren't really enforced policies or laws. The logic is that local communities, states, and regions work with wildfires under very different conditions, so it's best to give them the freedom to make the best decisions for their specific circumstances. And while preserving a degree of independence is important, doing so can sometimes sacrifice enforcement. For instance, it's commonly understood that one of the most effective ways to minimize unnaturally severe wildfires is to reduce the potential fire's access to fuels in the form of leaf litter and dead vegetation. To this end, many current fire policies treat at-risk forests through controlled or prescribed burning. However, because fire managers are given so much leeway, there is little, if any, evaluation of the treatment effectiveness. In fact, most fuel treatments on U.S. Forest Service lands do not even measure the level of fuels before and after treatment to see if the fuels-management program works at all (Stephens and Ruth). Increased monitoring and evaluation is necessary to explore if our current strategies are effective.

It's not just levels of fuel that fire managers don't know, however. Despite how much we've learned since the 1930s, when it comes to wildfires, there is still a lot of uncertainty involved—especially when it comes to global climate change. Predicting future high-fire risk areas by developing new climate models could help prevent damage or destruction in those areas. On a smaller scale, we also need more information on wildfires and their effects in more localized, regional situations. Being more knowledgeable about wildfires as a whole could help inform effective wildfire management policy, and analysis of those policies, in turn, would ensure that policymakers are exploring all possible strategies and constantly reevaluating for improvement. Basically, like Fergie says, a little more research never killed nobody. (Unless it's on radioactive materials. Or wildfires, actually.)

Like Smokey Said

It's easy to feel helpless in the face of a wildfire. In some ways, humans have always sought out nature to make us feel small. There's something calming about stargazing and contemplating the infinite vastness of the universe, or standing at the edge of the Grand Canyon trying to wrap your mind around the roaring Colorado River. But there's a time and a place for that, and it's certainly not in the midst of a natural disaster. If you're confronting a wildfire head-on, fascinated by the sheet of flames, it might be too late for you. (Unless it's a controlled, prescribed burn, in which case, good for your local fire management agency!). But either way, you're definitely not reading this, so this section isn't written with you in mind anyway. Because when it comes to the everyday citizen and wildfires, the name of the game is prevention.

In some ways, the best thing you can do to prevent the spread of severe wildfires is to not start them, intentionally or unintentionally. Even though natural and controlled fires help nourish ecosystems that evolved with fires, as many as 90 percent of wildland fires in the United States are started by people, whether they result from unattended campfires, debris burning, negligently discarded cigarettes, or intentional acts of arson (United States, Dept. of the Interior, National Park Service, Fire and Aviation Management). This burden of responsibility on average people is part of what makes wildfires unique; try as one might, it's not really possible to set off a hurricane or whirl up a sand storm on your own. But it can be really easy to spark a wildfire.

Most strategies for reducing your risk of igniting a large-scale wildfire is to use your common sense when you're working with fire. First and foremost, in general, never leave a fire unattended. It only takes one stray ember to fall on some dead leaves before you have a situation on your hands. Make sure that you have completely extinguished the fire before sleeping or leaving the campsite, by dousing it with water and stirring the ashes until they're cold. Trust us, it's never fun to wake up to the smell of acrid smoke inside your tent. In the same vein, when camping, be careful if you're using and fueling lanterns, stoves, heaters, or any other devices that contain some kind of light or heat source. Always make sure that these devices are cool before refueling them, and avoid spilling any flammable liquids and store fuel near your appliances. Remember, this isn't fifth grade science lab—this is nature.

Even though your risk for starting a wildfire is probably higher when you're camping, continue to stay vigilant in your local community. Don't discard cigarettes, matches, or any smoking materials from moving vehicles, and feel free to yell at your friends if you notice them doing so. Before disposing of cigarettes, make sure that they are completely extinguished, especially if you are in a natural setting. If you're in the city, you should still completely extinguish it, unless you want to accidentally light a dumpster on fire and ruin a garbage collector's day. If you want to burn your yard waste, make sure you follow local ordinances. In Georgia, you'd need a permit, and there's almost always an open burning ban every summer when ozone levels are at their highest. If or when you do burn, try to avoid doing so in windy conditions that might let embers hitch a ride to your neighboring forest, and keep a shovel, water, and some fire retardant handy just in case. This probably goes without saying, but make sure to remove all flammables from the yard during burning.

If you're hungry to make wildfire prevention a larger part of your local community, consider partnering with like-minded organizations. The National Fire Protection Association is a global nonprofit organization that's devoted to minimizing death, injury, and property and economic loss due to fire, as well as electrical and related hazards. Their Firewise Communities Program, co-sponsored by big names like the U.S. Forest Service, the U.S. Department of the Interior, and the National Association of State Foresters, works to develop local solutions for fire safety by teaching people to adapt to living with wildfire, and encouraging communities to work together to take action. Their site says, "We all have a role to play in protecting ourselves and each other from the risk of wildfire." Their USA Recognition Program encourages communities to develop an action plan for their neighborhood based on a wildfire risk assessment, and join the organization's growing network of more than 1300 recognized Firewise communities across the country. They also offer educational materials, online courses, and other resources to help homeowners protect themselves and their property from damage ("Firewise Communities Program").

Of course, sometimes, prevention isn't enough. If you're advised to evacuate, do so immediately. Develop an evacuation route ahead of time, and prepare an evacuation checklist and emergency supplies. That way, if the fire is at your door, you're ready (to run away from it). If you have time, wear protective clothing and footwear to protect yourself from any flying sparks, embers, or ashes. Should you ever be in a situation where the wildfire has caught up to you, don't panic and don't try to outrun the blaze. Instead, find a body of water, like a pond or river, that you can crouch in. If there's no water nearby, look for a depressed, cleared area with little vegetation that could look like a snack for a hungry wildfire. Lie low to the ground, and cover your body with wet clothing, a blanket, or soil to look as unappealing as possible to the flames. Stay covered until the fire passes, and breath air as close to the ground and through some kind of cloth filter, if possible, to avoid inhaling smoke and to protect your lungs. Wait it out. You're playing a game of incentives that you can't afford to lose (Pant).

Hopefully, you never find yourself in a situation like that. If everybody stays alert and prepared for wildfire, more researchers study the links between wildfire, local situations, and its effects, and policymakers create enforceable mechanisms for wildfire management, there's a good chance you never will. But it never hurts to be prepared.

Aeroallergens

Science: Unpacking the Overreaction: Why Climate Change is Nothing to Sneeze at

We've honestly never yet met somebody who hated winter, but we know that everybody has their own favorite moments of the season. Maybe it's just witnessing the quiet magic of a white Christmas through frosted windowpanes. Maybe it's enjoying a warm cup of hot chocolate and a good book, wrapped up in front of a fireplace. Maybe it's the satisfaction of creating the perfect snowman on the front lawn, indulging in a good old-fashioned snowball fight on the quad with some roommates, or running to take the cross-country skis out of the garage at the first sight of snow.

Or maybe, it's that you suffer from severe pollen allergies. If so, we're not surprised that winter is your ultimate MVP. Ragweed persists through the fall, and isn't checked until winter's first touch of frost. From then on, the cold of the winter months is able to mostly keep vegetation that is eager to reproduce at bay, until the onset of spring allows for golden grass and tree pollen to take over the skies (Irfan). And so if you're a winter-loving allergy-sufferer, you probably also have a bone—or several—to pick with climate change. You're not the only one that's noticed what the changing climate is doing to "winter"—in quotations, since winter lovers barely recognize the new season. After all, for the first time in nearly 150 years, Chicago didn't receive any snow in January or February (Wong). And trust us in saying that you're definitely not alone if you can't help but notice (read: it's becoming impossible to ignore) what new changes to the climate—specifically, pollen counts, as well as other allergens—are doing to your body.

The Anatomy of an Allergy

If you have seasonal allergies, you're closely aware of what that means for you, your body, and your living habits. It means checking the pollen count in the morning when late March starts to roll around. It means always remembering your allergy pills in the morning or paying for it in the afternoon. It might even mean not being able to enjoy a nice spring picnic or running barefoot in the grass. And you jump through all these hoops because you know what happens if you let down your guard and your allergies catch up to you: an exhausting list of symptoms that you know (literally) inside and out. A stuffy and runny nose. Itchy and watery eyes. Sneezing, of course. Sore throat. Cough. Hives and itching. Fatigue. Nausea and vomiting ("Symptoms & Types"). In some cases, a severe allergic reaction can lead to anaphylactic shock due to throat swelling and difficulties breathing, which can be fatal (Hansen). But like we said, you might already know this. After all, nobody knows the effects of allergies better than the 30-40 percent (and rising!) of the world's population that suffer from them (SciShow, "All About Allergies").

There's no debating that allergies are, at best, a nuisance, and at worst, life-threatening. But the question remains: why do they exist at all? Why do so many people's bodies react so violently to things that seem so harmless? The problem lies in the fact that while your brain might recognize that allergies are usually caused by innocent stimuli, your immune system just doesn't get it. After all, we all know that there's nothing inherently dangerous about pollen, animal dander, dust mites, or peanut butter ("How do allergies work?"). And most of the time, your body is pretty good at telling the difference between what's a threat and what's not. Not only does your immune system draw on a built-in toolbox of nonspecific defense strategies like your skin and your stomach's highly acidic pH level (innate immunity), but it's also able to learn and improvise as it develops a "memory" and creates specialized responses to specific threats (adaptive immunity) ("Innate Immunity"; "Introduction to Immunology Tutorial"). All together, your immune system's network of cells, tissues, and organs works together effectively like a well-oiled machine to defend your body around the clock from foreign invaders.

The problem with allergies starts when your adaptive immune system begins to pick up the wrong habits. The blame almost universally falls to the lymphocytes, more commonly known as white blood cells (United States, National Institutes of Health, National Library of Medicine). Even though lymphocytes are usually your body's most vigilant soldiers, they can also make the occasional (costly) mistake. They are the cells responsible for moving freely through the body and acting as customs agents, checking the passport of every cell they encounter (Beach). If they run into a cell that seems suspicious or threatening, like some kind of new bacteria, virus, or fungi, they'll immediately begin to initiate countermeasures against the antigen, even if that antigen is nothing but an allergen! Because your immune system doesn't know that, it orders the white blood cells to begin mass-producing antibodies: Y-shaped proteins that are specifically engineered to bind to and fight a specific threat (Mandal). In the case of an allergy sufferer, a specific kind of antibody—immunoglobulin E, or IgE for short—is overproduced ("Immunoglobin E"). IgE then attach themselves to receptors on the surface of mast cells and basophils throughout the body in a process known as sensitizing exposure (Beach).

From then on, every time you are exposed to the allergen, these IgE-coated mast cells and basophils bind to the them and trigger that all-too-familiar, memorized domino effect of allergy symptoms in the body. Both mast cells and basophils are a specific type of white blood cell called a granulocyte, which simply means that they contain small particles or granules within their cell bodies ("Medical Definition of Granulocyte"). Every mast cell and basophil is filled with 500 to 1,500 granules that contain more than thirty different allergy-causing chemicals, which are released when multiple allergens begin to bind to the cell surface receptors (Chandler and Sadtmauer). One of the released chemicals that you might be most familiar with is histamine, but these Pandora's Boxes are goody bags filled to the brim with a variety of other biological mediators guaranteed to make your life difficult, like proteases, chemokines, heparins, cytokines, and leukotrienes (Amin).

To be fair, the intentions are good. The idea is to essentially send out a cry for help and make it easier for reinforcements to get to the war zone. In reality, however, the effects—like vasodilation, or the expansion of the blood vessels, or increased permeability of the capillaries—have far more negative effects than positive (Pal et al.; Chandler and Stadtmauer). Depending on where the mast cells and basophils are located, the reactions can range from swelling in the skin, to sneezing, itching, and continuous mucus production in the nose, to shortness of breath, wheezing, and coughing in the lungs. Considering that this whole mess was caused by an overprotective immune system sticking to a "better safe than sorry" philosophy, it's hard not to want to kick yourself when the symptoms kick in.

This explanation is a relatively simplified, crash-course version of the chaos that occurs in your body when it encounters an allergen. We had to skip over some of the more complex ideas (like differentiating different types of lymphocytes, to the specifics of mast cell and basophil degranulation) in the name of refraining from making this website a biology class (but there's always Khan Academy if that's the kind of information that you're looking for. Feel free to explore their sessions and come back when you're satisfied!). But even so, it's important to consider not only what scientists do know about allergic reactions, but also what we don't—and that category is a lot more robust than you might think. We don't know precisely why lymphocytes get tripped up by certain allergens in the first place, considering that structurally they don't even resemble bacteria or viruses (although there's some speculation that some people's immune systems may mistake the protein sequence in allergens as similar to those of parasites) (SciShow, "All About Allergies"; Little). And we don't even know why humans evolved to have allergies at all, although there are a couple of hypotheses floating around like pollen: that people happened to be exposed to an allergen while fighting off an actual pathogen, for example, or the hygiene hypothesis, which suggests that kids these days aren't being exposed to enough bacteria and viruses during early childhood, so their hypersensitized bodies turn to fighting harmless allergens (Wolchover; Meller).

But while we're still figuring out the details of our response to allergens in our evolutionary past, thanks to climate change, we have a pretty good idea of what our future relationship with allergies will look like. Here's a hint: it might be smart to invest in Kleenex.

Climate Change and Allergies: Harder, Stronger, Faster, not Better

If you suffer from severe seasonal allergies, you may already have firsthand experience of how climate change is making them worse—but even if you're one of the lucky ones that won the genetic lottery, you could probably make a good guess (if you didn't pick up on the heavy-handed clues we dropped in the introduction of this section, or the hints from the natural world around you. We don't know for you, but at least in Atlanta, some trees seemed to have decided against the whole lose-my-leaves-every-winter thing altogether this year) (Sifferlin).

Think way back to fourth grade science class. All photosynthesizing plants require some fundamental ingredients in order to properly grow, right? Things like sunlight, warmth, carbon dioxide, and water ("What Plants Need in Order to Survive and Grow: Light"). And climate change, for the most part, has been happy to deliver on some of these key components (the water one is a bit trickier, since climate change is also a big fan of drought. Read our last section on climate change and wildfires for more information!). For example, warmth, as you might know, is a pretty fundamental piece of climate change's platform, and it's something pollen-bearing plants are totally on board for since rising temperatures extend their growing season. Already, satellite images of land cover in the Northern Hemisphere have shown an ominous advancement in spring by up to 19 days over the past 30 years (United States, Global Change Research Program). But according to one study from the Harvard School of Public Health, allowing spring to arrive 30 days earlier resulted in a 54.8 percent increase in ragweed pollen production (Rogers et al.). So whether you're relying on scientist or groundhog (you already know what we recommend), the fact that growing season goes hand in hand with allergy season means you might not necessarily want to be celebrating predictions of an earlier—and longer—spring (“A Changing Climate Worsens Allergy Symptoms”).

And increasing temperatures don’t just lengthen the growing season across regions. They’re also making it possible for trees and grasses to expand into entirely new territories that used to be too cold for them. And unfortunately, it appears that climate change will favor the expansion of habitat for trees that happen to have more allergenic pollen. Specifically, habitat that highly allergenic oak and hickory tree species can work with may expand northward at the expense of habitat where much less allergenic pine, spruce, and fir trees currently dominate, as the climate becomes too warm for them. These shifts look like they’ll be most dramatic along the Appalachian Mountains, the Northeastern states from Pennsylvania to Maine, in the Upper Midwest, and along the lower Mississippi River (Staudt et al.). And it should come as no surprise that in a high emissions world, the projected distributions of annual allergenic potential from tree pollen in the United States looks even worse. That said, unfortunately, even in a low emissions scenario, some states won’t be able to avoid the heightened risk for allergen hotspots (we’re so sorry, Iowa).

Besides warmth, climate change is also a happy provider of carbon dioxide. After all, it totally understands the need for it. Not only does climate change love a little (or a lot of) carbon dioxide and other greenhouse gases, but it itself also helps to keep the cycle going. For example, in the Arctic, more than 1 trillion tons of carbon are locked in the region’s frozen soil. As the climate warms and the permafrost begins to thaw, this carbon could be released into the atmosphere in the form of methane, which perpetuates global warming and in turn thaws more permafrost (Magill). Vegetation around the world, however, isn’t complaining about the excess carbon dioxide in the air. As we mentioned earlier, the gas is necessary for all plants that conduct photosynthesis; it's absorbed, along with water, and transformed into glucose, oxygen, and ultimately chemical energy ("Photosynthesis"). So it shouldn't come as a surprise that plants aren't complaining. For instance, a study by the U.S. Department of Agriculture grew common ragweed in chambers and controlled the atmospheric carbon dioxide levels that the plants were exposed to. The researchers found that not only does ragweed grow faster as carbon dioxide in the atmosphere increases, but it also produces significantly more pollen. In fact, if fossil fuel emissions continue unabated, they estimated that pollen production is projected to increase by 60 to 100 percent by around 2085 from this carbon dioxide effect alone (Ziska and Caulfield).

Not to mention, rising carbon dioxide levels not only enhance plant growth and pollen counts, they also seem to be using the extra chemical energy to boost other processes and activities within the plant that weren't of high priority when carbon dioxide was scarce. For instance, not only will common ragweed grow faster and produce more pollen in a carbon dioxide-saturated atmosphere, but the pollen itself may become even more allergenic than it already is if carbon dioxide continues to increase. One study found that production of Amb a 1, the main allergenic protein in ragweed that triggers an allergic reaction, increased by 70 percent when dioxide levels were increased from the current level of about 385 parts per million to 600 parts per million, the levels that we can expect by mid-century if emissions aren't reduced (Singer et al.).

And even if you're not allergic to pollen, you still have cause to worry if you're part of the 85 percent of Americans that are allergic to poison ivy, or more accurately, the plant oil urushiol found in its leaves, stems, and roots ("Poison Ivy, Oak, and Sumac – the Basics"; Gilbert and Primomo). A study by Duke University found that not only does poison ivy grow faster as carbon dioxide in the atmosphere increased, but the plants also produced a more allergenic form of urushiol (Mohan et al.). These changes are great for plants, but clearly don't always align in our best interests.

Plants aren't the only natural allergens that climate change is working to help intensify. Fungus—which are neither plant nor animal, and so have their own unique kingdom—are responsible for more than 200,000 cases of allergic reaction in the United States every year (Wu; "Allergy to mold"). These rebels not only refuse traditional taxonomical classification, they also reject most seasonal limitations, mostly because they're happy to move into your basement when winter sets in ("Mold Allergy"). Whether fungal spores are infiltrating your lungs outdoors or inside, they're benefiting from the side effects of climate change just as much as their plant cousins. One experimental study published in the Canadian Journal of Botany, for instance, found that doubling atmospheric carbon dioxide levels led to a 4-fold increase in airborne fungal spores released from leaf litter (Klironomos et al.). Plus, the simultaneous increases in plant growth associated with higher carbon dioxide levels provide a helping hand: the higher amounts of plant biomass provide more fodder for decomposition and nutrient absorption for fungi (Sackett).

And true to their adaptable reputation, fungus will benefit from both extreme drought and flood, both of which are expected to become more common as the climate continues to change. Following Hurricane Katrina, hospitals in New Orleans reported an increase in patients with allergy symptoms and childhood asthma from fungal spores enjoying the dampness (Reid and Gamble). And as heavy rainfall and hurricanes are projected to increase and become more severe, we'll probably see a lot more fungus singing, and reproducing, in the rain. At the same time, the rise of hot and dry conditions might also exacerbate fungal allergies as people increasingly rely on air conditioning, since improper management of these systems can create perfect mold-growing conditions (Hamada and Fujita).

Finally, as some of the unluckiest members of the population know, allergies aren't just for plant (and psuedo-plant) species: some allergens can chase you. And yes, we're talking about insect stings. For most people, a bee sting is a terrifying but relatively unremarkable occasion; the area that was stung hurts for a few hours and then gets better (Robinson). But if you're allergic to the venom, technically referred to as "apitoxin" or "apis virus," then a quick kiss from a bee, wasp, or yellow jacket becomes a much more serious affair (Madell). One sting could lead to a range of reactions, from hives all over the body, to swelling in the face, throat, or tongue, to nausea or diarrhea, dizziness, and trouble breathing. In America's northernmost state, people are finding out the hard way if they're deathly allergic to these insect stings. Over the past 50 years, the Allergy, Asthma, & Immunology Center of Alaska found that the state saw a 46 percent increase in insect stings, with some parts of the state suffering from increases as high as 626 percent (Irfan). In 2006, Alaska saw two unprecedented cases of fatal allergy reactions to yellow jacket stings in Fairbanks (Staudt et al.).

The culprit is climate change; higher average winter temperatures are helping more yellow jacket queens to survive. Significant increases in the number of insect stings across Alaska were seen in regions where the average annual temperature increased 3.4 degrees

Fahrenheit or the average winter temperature has risen by at least 6 degrees Fahrenheit over the past 50 years (Demain et al.). More specifically, what some scientists think is happening is that it's becoming warm enough to snow. Yes, you read that right: Alaskan winters usually reach the point where it actually becomes too cold to snow, since very cold air can't hold enough moisture (Peroutka). Warmer winter temperatures allow for more snowfall, which helps insulate insect dwellings (Irfan). Ultimately, more stinging insects survive the winter and are able to expand their ranges, which increasingly interferes with human habitats. Basically, if you're an allergen—pollen, mold, poison ivy, or insect venom—climate change could probably do you a couple favors. (And if you really are an allergen, from the allergy sufferers of the world: please reconsider!)

The City in a Forest

If you're living in Atlanta and struggling with allergies, you might feel like you've been getting mixed signals. On the one hand, the city in a forest has been breaking records for soaring particles of pollen per cubic meter within the last five years ("Atlanta sets all-time pollen count record"). On the other hand, according to the Asthma and Allergy Foundation of America, Atlanta should start becoming more attractive for allergy sufferers. The foundation releases an annual Spring Allergy Capitals list to publicly shame and raise awareness for cities that struggle with spring allergies. And while Atlanta topped the entire list in 2004, it's been steadily falling in the ranks ever since—from #61 in 2015, to #70 in 2016 (DeNoon; "Spring Allergy Capitals 2016"). Soon, it seems that we might not even get featured at all. But then again, on the other hand, you've been living here for a few years and you swear you've been investing more and more on Zyrtec and tissues. If your allergies are supposed to be getting better, your immune system doesn't seem to have gotten the memo. So what's up with that?

You're not the only one that's confused. Experts that have been recording and researching pollen counts in the metro Atlanta area for decades also aren't sure why national rankings don't reflect the numbers they've been seeing. Allergist Stanley Fineman MD, who works for the Atlanta Allergy & Asthma Clinic, told Atlanta Magazine he was just as taken aback by the drop in rankings as local allergy sufferers. "I don't know why we're so far down there on the list," he told them. "In terms of pollen count per se, we're probably up there with anybody. If you're the patient struggling with their allergy symptoms, it doesn't matter where Atlanta ranks on that list. If it happens to you, it's major" (DiLonardo). But this insistence on Atlanta's allergenic attributes isn't just speculation; it's rooted in fact. The Atlanta Allergy & Asthma Clinic is not only the largest allergy practice in Georgia; they're also metro Atlanta's official pollen count keepers. Their Pollen Counting Station is the only one in the local Atlanta area that's certified for accuracy by the National Allergy Bureau. And despite interannual variability, they've been seeing a very clear, upward trend in pollen counts since they first started measuring in 1992: from an average of less than two extremely high pollen count days in March and April in 1992, 1993, and 1994, to consistently reaching around a dozen of them every year starting in 2013 ("Pollen Count").

Part of the reason for the inconsistency in its reporting may be due to the fact that not only is Atlanta's pollen season getting more intense, it's also shifting its timeline. Brad Nitz, a meteorologist at WSB-TV in Atlanta, pointed out on Twitter early last month that the metro

Atlanta area reached 1,298 particles of pollen per cubic meter on February 20th of this year. The first time the pollen count got above 1,000 last year was March 17; in 2015, it was March 18, and in 2014, it wasn't until April 3rd. Basically, the pollen is running more than a month ahead of schedule (Foreman). Because the first day of spring for the Northern Hemisphere always falls on March 20th or 21st, it's possible that these earlier peaks in pollen levels are bypassing the Asthma and Allergy Foundation of America's algorithms for calculating annual Spring Allergy Capitals (Duncan).

But for allergy sufferers in Atlanta, falling in the notorious ranks are nothing to celebrate. It just means bracing yourself for pollen season to begin as early as February, thanks to climate change pushing spring earlier. And as temperatures continue to stay high into the fall, seasonal allergies will likely overextend their stay. (To be fair, not all of this is climate change's fault. Heightened aeroallergen counts in the fall are at least partly attributed to the increasing prevalence of Chinese elm trees, which are prized by landscapers and gardeners for their shade, low maintenance, and beauty (McEwen). And on that note, we know we've been talking about climate change like it's become its own entity, and while in many ways it has taken on a life of its own thanks to feedback loops, here's your friendly reminder of who got those loops going in the first place: us.)

It might make you feel better to know that you're not the only one suffering from allergies in Atlanta. After all, misery loves company. But you might be surprised to know that the very fact you *can* relate to so many people in such a large city helps to contribute to the problem itself. The phenomenon makes Atlanta an "urban heat island": the scientific term behind why so many Atlantans affectionately refer to the city and her heat as "Hotlanta." As the population of a city rises, along with urban development and industrialization, so do environmental risk factors that exacerbate climate change and its threats. The most noticeable one of these patterns is temperature. The annual mean air temperature of a city with a million or more people can be 1.8 to 5.4 degrees Fahrenheit warmer than its more rural or suburban surroundings; in the evening, this difference can skyrocket to as high as 22 degrees Fahrenheit ("Heat Island Effect"). The metropolitan Atlanta area has nearly six million people, but we won't make you do the math (Niesse). A study sponsored by NASA's Earth Observing System Program found that metro Atlanta, on average, sees temperatures up to 10 degrees hotter than surrounding areas, much to the joy of pollen-bearing vegetation in the city limits (United States, National Aeronautics and Space Administration, Goddard Space Flight Center Scientific Visualization Studio). There are a lot of reasons for this discrepancy, like the insulating effect of skyscrapers, the "waste energy" from millions of businesses and people going about their daily lives, or the heat-absorbing nature of asphalt and cement compared to lighter, more organic materials (Rutledge et al.; Samuel).

The end result, however, is pretty simple: cities create and absorb more heat than their less-populated counterparts. And it's not just heat that gets trapped in there. Invisible local "domes" of high carbon dioxide levels can often hover over urban areas (Hiskes). Together, these higher temperatures and carbon dioxide levels create the perfect conditions for pollen-producing plants (save that five times fast) to thrive. We're already seeing this, both in reality and in research. Lewis Ziska, Ph.D., a weed ecologist at the Agriculture Research Service division of the U.S. Department of Agriculture, has experienced both. He's been studying weeds under future climate scenarios in Baltimore, which is already seeing higher local emissions and temperatures compared to rural areas of Maryland. He ran experiments on weeds to mimic climate conditions we'll likely experience by mid-century if heat-trapping emissions continue as usual: a temperature increase of three to four degrees Fahrenheit, and a concentration of heat-trapping gases of 450 parts per million. The results seemed like they were straight from a sci-fi novel: weeds that grew five and six feet tall in the countryside had counterparts in the city up to 20 feet tall ("A Changing Climate Worsens Allergy Symptoms"). Can you imagine how much pollen these giants can produce?

Even though the fact Atlanta is a city goes against those of us that suffer from allergies however, the very same allergy producers are the ones that help limit the urban heat island effect: plants. WABE 90.1 reported in 2015 that out of the 50 biggest cities in the country, Atlanta ranked a modest 31st in terms of how intense the heat island effect was. This low score was probably thanks to all the trees (Samuel). As Atlanta continues to develop, how will events play out? Which one has a greater effect on allergy sufferers: the effects of the urban heat island phenomenon, or the vegetation itself? Will trees give way to concrete and asphalt, or will the push for replanting green the city? Not to mention, normally, climate change and trees don't really get along, since trees remove carbon dioxide from the air. How do we strike a balance between minimizing pollen allergies, and encouraging carbon sinks?

Forget what we said earlier about the end result being simple: rarely anything about climate change is, especially when it's centered in a city as confusing as Atlanta (have you tried navigating without your GPS?). But when it comes to allergies in the city in a forest, the bottom line is that you can prepare for them to get worse. The only question is, by how much?

Solutions: Attacking Allergies: Our Own Worst Enemy

Myths and Madness

A hundred years ago, the deserts of the American West were imagined to be a dry, clean haven for allergy sufferers. In the years after World War II, thousands of people who suffered from asthma and allergies flocked to Arizona, seeking—and at first, finding—relief from their symptoms (McGinley).

According to Gregg Mitman, a medical historian, Tucson in particular aggressively described itself as a health utopia in the 1920s. In his book *Breathing Space: How Allergies Shape Our Lives and Landscapes,* he discusses how Tucson's Board of Trade marketed the city's "pure, dry, invigorating air" and "treasures of health [unlike] anywhere in North America." Mitman described how John A. Black, Arizona's commissioner of immigration, said Arizona was a land "where health welcomes the afflicted, and where strength awaits the weak and the suffering." Approximately half of all people who moved to Tucson in the two decades following World War II did so for health reasons, bringing more than $7 million in annual income to the state from the health and tourist trade (Mitman 104).

And yet, by the 1970s, pollen levels in Tucson had increased by a factor of 10 (Staudt et al.). The culprits? Urbanization and nostalgia. After millions of new residents made their way to the sunny southwest, they found themselves missing the "civilized" look of many eastern cities from where they came. And so, allergy-prone landscaping and gardening preferences quickly began to colonize the so-called health capital of the United States. For instance, Bermuda grass, a highly reactive allergen, was planted in front lawns. Quickly, it took over town lots and mobile homes, made its way to retirement parks on the city's edge, and wove along watercourses, all while releasing potent grass pollen. But Bermuda grass wasn't the only major landscaping change; Eastern tastes for large, shady trees led to the creation of a booming nursery business in exotic ornamental trees. Two particularly allergenic species—mulberry and Russian olive trees—led to the demise of the health-seeking allergy sufferer in Arizona.

When Tuscon's newly planted tree population reached maturity in the 1970s, Mitman wrote, "The ecological haven had become an ecological hell" (128). In little more than twenty years, the atmospheric pollen emissions of allergenic plant species in Tuscon had increased tenfold, created by a domino affect that started with landscaping tastes. At the same time, the rapid urbanization of the area created a distinct urban heat island effect, which further exacerbated pollen production and trapped unhealthy levels of air pollution (Staudt et al.). Altogether, as a result, statistics show that the incidence of asthma in the city became twice the national average at the time, while the incidence of hay fever became six to nine times greater. Some, like Phoenix allergist Dr. William Rieck, believe that genetic factors are partly responsible for the rise in allergy conditions. Because people have traditionally moved to the Arizona area in order to alleviate or escape their allergies, they argue a higher percentage of the population is inherently allergy prone (Laughlin). But this migration alone can not fully explain the increase; environmental factors were also at play.

This situation wasn't unique to Tuscon, Arizona. The same story was playing out in different cities across the Southwestern United States at this time: Eastern immigrants suffering from allergies come to seek healthy air, end up in a dry southwestern city, are joined by thousands of other health seekers that exacerbate the urban heat island effect, plant a variety of allergenic species in their backyards, and then complain when their allergies begin to immediately worsen. It was happening in Pheonix, Arizona and Albuquerque, New Mexico; in El Paso, Texas and Las Vegas, Nevada. And even if their own actions were at fault, allergic citizens at the time were understandably upset by what they perceived as a rip-off. But they didn't want a refund or an apology. They wanted a solution.

What followed was a whirlwind of government regulation that remains, to this day, some of the only instances of pollen allergen management in the United States. There were three primary strategies that local government officials adopted to keep seasonal allergies in check for their residents: zoning, nuisance, and police power (Sawers).

Zoning describes the control by which an authority, in this case the local government, has the power to establish districts that are restricted to specific types of land uses. Zoning laws might specify a variety of conditional uses of the land, or indicate the dimensions of land area or the scale of buildings ("Land Use and Zoning Basics"). It's an urban planning technique that helps the government guide urban growth and development so that cities don't haphazardly sprawl without deliberate direction. (For instance, Houston's famous lack of zoning laws means long commute times and poor public transit options, which leads to serious health consequences. It also results in some interesting eyesores, like an adult bookstore next to a department store next to a skyscraper [Gentile].) In the 1970s and 1980s, as residents' allergies began to act up in earnest, southwestern cities began to take advantage of these laws. By 1970, the city of Tempe in metropolitan Phoenix, Arizona created a zoning ordinance that did not allow developers to plant pollen-producing olive of mulberry trees (although individual landowners were permitted to do so [Sawers]). Similarly, in Tuscon, in order to get zoning approval for new developments, builders are required to use no pollen-producing plants (Reinhold).

The second strategy governments used was identifying public nuisances. In general, a nuisance simply refers to any person, thing, or circumstance that causes inconvenience or annoyance. Your mother might have told you to “stop being such a nuisance” when you were misbehaving in a grocery store. When something inconveniences or annoys the government, however, it becomes a pubic nuisance: an art, condition, or thing that is illegal because it interferes with the rights of the general public. For instance, the city of Atlanta lists poison ivy and poison sumac as public nuisances, in addition to “obnoxious gases or odors,” being intoxicated in an airport, and graffiti, to list a few (United States, Georgia State Government, City of Atlanta).

To many people, airborne allergens certainly fell into this category. In October of 1975, retired postal worker Herman Berlowe led frustrated, sneezing citizens in lobbying the Tuscon City Council to ban the sale of non-native pollen-inducing trees within city limits. In 1994, against the objection of some nursery owners and developers, the cities of Tuscon and Pheonix responded and officially declared allergenic plants to be public nuisances (Sawers). Specifically, in both cities, the planting or sale of male mulberry or olive trees was deemed a nuisance, although in 1995, the Tuscon ordinance was amended slightly to allow the planting or two varieties of olive tree that produce less pollen. In addition, Tuscon literally cut back on Bermuda grass. Allowing Bermuda grass to excessively pollinate became a nuisance; residents were essentially required to consistently mow their lawns or face a fine of up to $300 as punishment (Reinhold).

Other local governments have relied on police power in order to limit the amount of allergens that infiltrates their cities. Although that might sound severe, crimes related to exacerbating allergy conditions are usually considered to be misdemeanors, or lesser crimes that are tried in the lowest local court. Typical misdemeanors include petty theft, public intoxications, and various traffic violations. In Albuquerque, New Mexico, planting or selling certain trees joins that list of small crimes. And although the punishment might be light, in Albuquerque residents might want to double check their local ordinances before they landscape, considering that the city bans the largest number of plants in the U.S., like male cypress, juniper, mulberry, most poplars and cottonwoods, and most male elms. Certain less allergenic trees are allowed to be sold, but each plant must have an individual label warning of the trees' pollen production (Sawers).

While zoning, nuisances, and police power are the most common ways that cities in the American Southwest have been controlling local allergens, some regions are toying with other methods of management. For instance, in Las Vegas, Nevada, the government restricts certain allergenic trees as part of its air quality regulation. Clearly, the city wants to be known for sin, not sneezing and sniffling. Since 1991, nobody is allowed to plant or sell male mulberry or European olive trees within the city limits. Commercial growers, however, are allowed to apply for an exemption from the Air Pollution Control Board for low-pollen cultivated plant species (Sawers).

Besides air quality regulation, some private citizens take it upon themselves to establish community pollen regulations. For instance, if you purchased a condominium, townhouse, or other type of property in a planned development like a leased land property or a gated community, you would be obligated to join that community's homeowner's association (HOA) and fees to upkeep. In addition, the HOA has rules and regulations pertaining to the use of land and the look of the neighborhood as a whole. As early as 1975 and even earlier, deed restrictions from an HOA existed against the planting of Bermuda grass, catering to wealthy homeowners that wanted a private "pollen-free, dust-free" zone (Sawers). In the face of a sickening population and deflating reputations, these were the regulatory tools at the American Southwest's disposal.

Scientific Sidekicks

Unfortunately, despite these measures, risks from aeroallergens haven't significantly decreased since these policies were implemented in the 1970s and 1980s. Southwestern states still suffer from some of the highest pollen counts in the nation. Even though Albuquerque added a pollen-control ordinance banning entire categories of trees in 1994, with violators facing a hefty $500 fine, the city's Air Quality Division hasn't seen any major improvements (Brady). To be fair, these regions are very proactive (out of necessity) in combatting severe seasonal allergies when compared to the rest of the United States; in many regions, allergens are rarely discussed as an air quality issue, much less implemented or regulated through policy. And between urbanization and climate change, it's been an uphill battle from the beginning.

Still, it's never a bad idea to identify areas in which policy can be improved, or just introduced at all in places that lack any regulation. The first call to action there, unsurprisingly, would be to implement government policies that regulate highly allergenic plants, like mulberry and olive trees. Ideally, these species would be banned altogether, either by being named as a public nuisance or making it a crime to sell or plant them, to take a couple leaves out of Arizona's book.

But some people believe one of the main reasons that progress stalled on the southwest front in terms of pollen counts is because of the number of highly allergenic plant species that were getting grandfathered in each year. In other words, even though it's a misdemeanor to plant or sell a certain plant, there's much less regulation against a specific plant that's already planted in someone's backyard. In fact, whatever form regulation currently takes, no local government has required landowners to actively *remove* allergenic plants. Usually, if they exist, they just restrict new plantings. In some cases, this isn't a big issue. For instance, mulberry trees will die after about 30 years. But olive trees can live for as long as 500 years, emitting pollen the whole time for multiple generations of allergy sufferers to enjoy (Reinhold). With such long-lived allergen producers, the amount of pollen in the air will decline very slowly, if at all.

"We have to wait for those trees to grow to their mature age and die," Albuquerque City Forester Nick Kuhn told the National Public Radio in an interview for a story on Albuquerque's decades-long struggle with pollen in 2010 (Brady).

For a more effective approach, regulating bodies should mandate the active removal of highly allergenic plant species, in addition to controlling new plantings. If possible, local governments should try to compensate landowners to either incentivize or reward this proactive behavior. Obviously, money is always a good motivator in these cases (and in general, actually). Another option is to offer to replace those highly allergenic species with more allergy-friendly plants, where possible, like the tulip poplar, dawn redwood, or hawthorn. Cities' best bets are plants that are insect- rather than wind-pollinated, since trees that rely on as fickle a force as wind often produce massive amounts of pollen just in case. Also, using plants that have shorter bloom periods and emit "sticky" pollen, which doesn't travel as easily through the air, would also help.

In addition, promoting greater gender equality isn't just a social issue; in plant and tree nurseries, it could seriously help tip the scales for allergy sufferers. Again, the culprit here is landscaping and gardening preferences, with a pinch of human laziness thrown in: people like plants that aren't messy. In other words, trees that produce fewer nuts and fruits to clean up. In other words, males. Unfortunately, while male trees might appear to be less maintenance because they are supposedly "litter-free," they're also the ones that produce the highest abundance of allergenic pollen (Sawers). This preference means that most cities are dominated by pollen-spreading male trees. To help combat this, local governments should consider actively buying female trees, since not only do they not produce pollen, female plants also trap and remove pollen from the air. If cities are concerned about street little and clean-up, they can plant sterile female trees, which won't produce any fruit. And making the switch doesn't have to be an inconvenient process: according to horticulturalist Thomas Ogren, urban landscapers can simply perform "sex changes" by pruning or grafting male trees into female trees.

The easily-addressed gender imbalance of plants in our cities isn't the only case where science could help out the nation's pollen allergy capitals. Something as simple as spacing trees out slightly could have major differences on annual average pollen counts. In close quarters, tightly-packed communities of trees or shrubs become capable of producing massive amounts of pollen that can't easily be dispersed by air currents (Gan). Everybody loses, especially people with allergies. Instead, researchers from the University of Granada suggest keeping a certain minimum distance between trees (Cariñanos and Casares-Porcel).

More scientific studies could also help correct misconceptions in pollen management. For instance, one go-to strategy for city officials is to mandate occasional mowing of allergenic plants, under the assumption that keeping them trimmed will reduce its ability to release pollen. But a recent study of Detroit's more than 6,000 vacant lots proves this theory wrong. Researchers from the University of Michigan found that the city's spotty mowing routine—about every one to two years—actually *encouraged* the growth of ragweed, including its nasty pollen-producing habits. That's because in undisturbed lots, other plants will quickly outcompete ragweed, but in occasionally managed lots, they never got a chance. In other words, in this case, not mowing at all is preferred over mowing irregularly (Metcalfe).

But in order to suggest these kinds of science-backed policy changes, city officials and researchers need relevant data. One city is already making moves to collect information from its residents to better guide and inform air quality policy. In Louisville, Kentucky's groundbreaking Asthmapolis project uses a comprehensive mobile network of "smart inhalers" that can track exactly when and where asthma attacks are occurring throughout the city. Government officials can use that information, especially if it's cross-referenced with other data: maps of Louisville's tree cover, air quality, and localized heat island effects. This way, the city can identify the asthma and allergy hotspots to focus their public health efforts (Runyon).

Although Asthmapolis is the first of its kind worldwide, hopefully it can inspire other cities to think about how they can collaborate with their citizens to bring them allergy relief.

Allergies Blow

The hard truth is, there's no getting away from allergy problems anymore. In other words, everybody is stuck with their own city's unique set of allergy issues. And that means that everybody has to pitch in and work to reduce the number of allergens in the air, although it may seem fruitless at first to think about ways to limit how an individual personally contributes to their city's allergy problem. If pollen can just drift in on the next wind, you might wonder, what effect am I really having on my city, and the health of my family?

You would have to consider, however, how gravity applies to pollen. In 1972, Gilbert Raynor, a meteorologist from New York, set up an experiment to determine how allergens organized themselves spatially. He put pollen traps at intervals next to a large stand of timothy grass. And while he was still able to trap some timothy pollen at a mile away from the field, he found the greatest concentration of pollen closest to the field (Ogren). The bottom line is, the closer you are to a source of allergens, the more pollen you're exposed to. So if your yard is full of pollen-producing trees and shrubs, you and your family will be the ones that suffer most from them. If the schoolyard your children play in is surrounded by allergenic trees, your children will be the most affected.

In other words, addressing pollen sources near your home isn't just about doing what's best for the allergy sufferers in your city: it's also doing what's best for you and your family. But it doesn't hurt that you're helping to keep pollen out of your neighbor's lungs too, right?

For most people, that effort starts with the backyard and garden. If you are landscaping your garden from scratch, or if there's some room in your backyard that you'd like to fill, consider making it a priority to buy allergy-free plants. One useful tool for incorporating the most allergy-friendly species near your home is the Ogren Plant Allergy Scale (OPALS), an allergy rating system for plants that measures the potential of a plant to cause an allergic reaction in humans. The comprehensive strategy analyzes well over 3,000 common trees, shrubs, flowers, and grasses, taking into account not only pollen allergies, but also contact allergies and odor allergies. Within the United States, OPALS has been adopted for use by the American Lung Association and the U.S. Department of Agriculture Urban and Community Forest Service. State governments, like the California Public Health Department, have also endorsed this allergy scale in city landscape planning with the intention of reducing asthma. If governments are taking advantage of it, there's no reason the average allergy sufferer and homeowner can't as well ("OPALS—The World's First Plant-Allergy Scale").

If you're not starting from scratch, chances are either you or someone in your family is already feeling the effects of an allergy-rich garden. In that case, short of uprooting your entire landscape, prioritize replacing your biggest culprits—pollen-producing male plants and flowers—with pollen-absorbing female ones. The female plants are usually identifiable because they produce fruits, nuts, seeds, or seedpods, while the male ones produce pollen. If replacing all your male plants with female ones seems like too much work, you can also hire a landscaping professional to perform a variety of "sex changes" on male plants so you don't have to replace them. For mulberry trees, one of the worst allergy offenders, it's easy to top-graft part of a female tree onto a male one in order to change its sex and pollination habits (Ogren). You could also plant a tall, allergy-free hedge on the windward side of your property could help block not only pollen grains from the neighbors, but also dust, smoke, and other forms of air pollution that are often responsible for exacerbating respiratory conditions (Ogren 147).

Besides these strategies, however, the best bet for anybody that suffers from allergies is to simply try to avoid their triggers. Medical specialists call this behavior "allergen avoidance"; you might refer to it as common sense. Start by checking the daily pollen counts in your area through a reputable source. In Atlanta, the authority on the matter is undoubtedly the folks at Atlanta Allergy & Asthma, who run a certified daily allergy pollen count for the metro Atlanta area. On high count days, try to avoid going outside for extended periods of time, or interacting with allergenic plant species. Rolling around in the grass with your dog, having a picnic, or climbing trees might be a no-go, depending on how severe the allergy symptoms are. If you're inside, keep windows and screens closed, especially during the day when plants are especially active. If you have gone outside, remember to take a shower and change your clothing when you come inside.

These might not seem like the most sustainable solutions, especially when considering the worrisome global trends for allergy precedence, and the effects of climate change on highly allergenic environmental triggers. Still, until the condition is taken more seriously and the government takes a more active role in managing allergens and other chronic respiratory irritants, allergy sufferers are mostly on their own in navigating an increasingly pollen-congested world. Try pressuring your local representatives into taking the matter more seriously, and following Southwestern cities by adopting a pollen control ordinance. Talk to your local plant nurseries to start buying more female- and allergy-friendly plant species. Discuss options with your doctors. Everybody should be able to live to their greatest potential year-round—not just when the pollen counts are low.

The Story Behind the Stories

About the Author

Hello there! Thank you so much for stopping by. I'm Emily Sun Li, an Emory University alumna studying Creative Writing/English and Environmental Sciences. "Climate Change Is in the Air" is my undergraduate honors thesis project, inspired by my experience in science journalism and communications—from interning for the Smithsonian Environmental Research Center, to writing for various university sustainability office publications, to covering the United Nations Framework Convention on Climate Change (UNFCC) 22nd Conference of the Parties (COP22) in Marrakesh, Morocco.

A Little Background

Nowadays, communicating climate science is a tricky thing. Science writing and journalism certainly didn't used to be so complicated. In fact, it was rather straightforward: scientists conducted their research and published peer-reviewed studies. Journalists and news media organizations broke down this new information and presented it in an engaging way, while helping to explain the broader impacts. For the most part, the general public absorbed and accepted these findings and interpretations without question.

This, of course, is no longer the case. Contentious scientific issues, like climate change, have become increasingly emotionally charged. Over time, they've riven the public and have lead to unprecedented skepticism of both science and scientists, even in the face of overwhelming research evidence. As an interdisciplinary issue necessarily fraught with some elements of uncertainty, with some very real consequences that have the potential to rearrange society as we know it, climate change has become "center stage in this new dynamic between science and the public," according to Emory University senior lecturer Sheila Tefft, who directed the university's Journalism Department from 2000 to 2009.

Not only is climate change becoming more and more of a partisan issue, it's also being misinterpreted by people across the board. Some of this, to be sure, is climate change's fault (which is actually our fault, so really I guess everything is our fault). But we couldn't have designed a more severe threat to our existence as we know it if we wanted to: a problem with enormous consequences over the long term, but little that is immediately visible on a personal level. A global concern with far-reaching, and sometimes subtle, effects across all fields and sectors. An issue without an apparent antagonist, because we all share in that responsibility together.

And no matter who's to blame, public opinion polls show that there's some serious miscommunication between scientists and citizens. You've probably already heard the figure that 97 percent or more of actively publishing climate scientists agree that climate-warming trends over the past century extremely likely due to human activities (United States, National Aeronautics and Space Administration, Jet Propulsion Laboratory's Earth Science Communications Team). And yet, according to most recent data from the Yale Program on Climate Change Communication, only 49 percent of Americans in 2016 think that most scientists believe in global warming. Based on this same data, 58 percent of participants thought that global warming will harm people in the U.S., but only 40 percent believed that climate change would harm them personally (Marlon et al.).

There are a lot of theories out there about why public opinion just isn't matching up with the science. But it's pretty inarguable that it's (literally) the job of journalists and communicators to serve as an effective middleman between the two divides, in order for politicians to pay attention to the problem and for any sustainable solutions to develop. More and more people are certainly reporting increasingly often on climate change, but from the data, it's not clear how much good that's doing. What *is* crystal clear is that as public perception of scientific issues begins to shift, the old paradigm for reporting on climate science needs to as well. The question I needed to answer before I got started with my own project was, how?

How, Indeed?

Before I could even brainstorm what I wanted my project to focus on besides climate change, an impossibly large topic, I did a lot of research on what the best way to talk about climate change with the public is. I pored over opinion polls. I read academic journal articles in sociology and psychology. And I especially looked for blogs, articles, and studies from communications specialists who were in the same boat as I am, and who were trying and testing new techniques to get their messages across to a skeptical audience.

After all, even though climate change is unprecedented in a variety of ways, miscommunication between the public, the media, scientists, and lobbyists isn't new. Settlers heading to colonize the dry west believed that "the rain followed the plow" (Burns et al.). Even though ancient Grecian Dioscorides knew by 200 BC that "lead makes the mind give way," it didn't stop the National Lead Society from embarking on a successful child-aimed advertising campaign to encourage children to decorate their rooms with lead paint in the 1920s (Gilbert; Write_light). Tobacco companies lauded the health benefits of cigarettes for decades. It made me feel better to know that in some ways, I'm following the footsteps of the journalists before me.

Here are nine major points that I found for communicating with the public, particularly young adults that poised to become leaders in their fields, based on my readings and research.

(1) **The science is not enough**—Journalists are increasingly realizing that presenting scientific evidence is not enough to convince or change people's minds on climate change anymore. In other words, the facts are not sufficient. This is known as the "knowledge-action gap" or the "awareness-action gap." That being said, it can moderately help to increase public

awareness and concern when it's presented in a way that's easily digestible, visually and emotionally engaging, and accessible rather than condescending. Also, raising awareness of scientific consensus can be helpful. Don't focus on fighting climate skepticism.

(2) **Stay aware of audience values**—People have different values, sometimes to the point that they are polarizing. And whether a journalist is explicit about it or not, every article or message carries with it the values that an author imbues into it. It's important to be aware of this, so that communicators can frame their messages in a way that is more consistent with the values of their viewers. This way, people are more likely to absorb and engage with the issues discussed.

(3) **Tell a story**—Everybody loves a good story. And people not only like stories, they engage with and remember them. After all, we're highly social creatures, and we relate to other people. As Nels Nelson, a Boston planner, writes, "After all, Martin Luther King Jr. had a dream, not a five-point plan." For communications specialists, storytelling is a powerful tool that leads with values and builds credibility. Going forward, it's vital to communicate climate change and science through the use highly personal stories and narratives, with characters and conflicts. The stories must be real and relatable, and avoid trivializing the issue.

(4) **Use a positive message**—People respond to and engage with hope and victory, not fear and guilt-based messaged based on alarmism. If somebody feels helpless, they're like to simply shut down and not respond. This is a tactic that many communicators first adopted when talking about climate change, and it's a habit that's easy to fall into because it can seem so accurate at time (i.e. if we don't do something now, there's going to be worldwide catastrophe). Even if that's the way it is, from a public engagement angle, it's simply not

productive. What's the point of taking public transit, one might think, if the world is doomed anyway?

(5) **Focus on bridging emotional distance**—Climate change is perceived as abstract and otherworldly; even if people see it as an issue, they tend not to think of it as *their* issue. Journalists and communicators can work to combat this attitude by focusing on local, close-to-home issues that people care about, concepts that familiar and relevant to most people (i.e. public health), and the bigger picture. They should stay away from vague terminology like "climate risks" or "ambitious policy"—anything that makes people feel like this problem doesn't belong to them as much as it belongs to any of us.

(6) **Stress the urgent nature of climate change**—We can't just talk about what might happen two hundreds years into the future; in order for people to care, which is the end goal of every journalist, it's vital to hone in on the "here and now" aspect. Communicators need to move climate change from a future problem to present day concern, which luckily for us, it absolutely is. To do so, journalists should only sparingly use language about "future generations" and "our children and grandchildren."

(7) **Communicate from a friendly source—**There's a weird paradox going on where people expect the government to lead on climate change and the media to tell them about it, but also don't trust either of them. And while they do trust scientists, scientists aren't usually the ones explaining their science to the public; they're usually out there doing more science. One of the most effective sources for disseminating climate science is actually a peer. People trust peer-to-peer interaction and communication, because it seems normal and natural and low-stakes.

(8) **Focus specifically on the issue—**It's important for journalists to always consider the bigger picture, not just one policy or one extreme weather event. What kind of effects is climate change having on local communities as a whole? You have to do that for climate change. One of the main problems in communicating climate change and science is that even if people understand that climate change is happening and people are causing it, they don't think that anything terrible will happen as a result. Communicators should focus on highlighting those end results. And while doing so, stay away from jargon and inaccessible language.

My Project

After gathering all this information, it was time to hone on (1) a specific research topic on climate change to look into, and (2) an effective medium to share it through. Ultimately, I decided to focus on how climate change affects public health, which researchers have identified to be one of the most potentially powerful and effective strategies for inspiring change and countering climate skepticism, while bridging differences through a unified goal of climate action and mitigation. I was drawn to the topic because I learned that health often transcends political differences and sociocultural divides, since everybody values their health. It also helps to bridge the emotional distance that many communicators talk about, because human health is something that is very close to each and every one of us. It's something that everybody can relate to and care about. In other words, I saw an opening.

More specifically, I decided to focus on public health in Atlanta, Georgia after reading about the importance of localization and personal relevance. Because I go to Emory University in Atlanta, Georgia, the geographic limitation gave me the chance to take a lot of my own pictures and meet the people I wanted to interview in-person. I wanted one of the main foci of the project to help unpack climate science in a way that the average person can understand and engage with. But I knew that the science alone wasn't enough. It was therefore also important for me that I share the stories of people in Atlanta who have been affected by some facet of climate change, in order to make the project more relatable, bridge more emotional distance, and utilize the power of storytelling as a communications tool. And finally, I wanted to discuss solutions, in order to avoid losing my audience in the hopelessness of doom-and-gloom scenarios.

At first, I wanted to focus on five public health sectors—extreme weather events, air quality, water quality, vector-borne disease, food security, and mental health. Obviously, based on the title of the website, I ended up only picking one. And thank goodness for that, considering that "just one public health sector" somehow turned into the equivalent of more than 115 pages of a traditional academic paper. That being said, I'm interested in returning back to these other sectors in the future. I think each one is as important as the last, but ultimately I realized I needed to set a priority for my content in order to ensure I was giving it the attention and quality that the topic deserved.

Now I had my topic ironed out: the effects of climate change on air pollution, quality, and health-related issues in Atlanta, Georgia. But as I began to do my research, I started to realize that even though I was focusing on air quality specifically, there was still a nearly infinitely comprehensive amount of information I could look into. One resource that I relied on to help me focus my project even further is a document published by the United States Global Change Research Program in 2016 titled, “The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment.” I decided to focus on the three key findings they outline in their air quality impacts section: (1) exacerbated ground-level ozone health impacts, from weather conditions being increasingly conducive to ambient ozone formation and leading to rising respiratory health conditions; (2) increased health impacts from wildfires and their emissions, specifically particulate matter (PM); and (3) worsened allergy and asthma conditions due to increasing levels of airborne allergens and other respiratory or biological irritants.

And so, “Climate Change Is in the Air” was born.

Technically

I still had to figure out how I wanted to share my project with the world, however. Clearly, I decided to go with a website, inspired by long-form multimedia journalism pieces like *The New York Times'* “Snow Fall” and *The Chicago Tribunes'* “Saving Grace.” Especially when focusing on such a large and complex project, adopting a single-page format for a long-form piece lends itself to a sense of continuation and fluidity for the reader. I also combined this idea with my favorite aspect of traditional websites: the clarity that comes with a nested, well-organized primary menu. In this way, I was able to create a hybrid of a website inspired by two different digital design elements that I think is the best of both worlds: fluid and accessible, while still maintaining a sense of coherency and structure.

This is the type of viewer experience I was only able to create because of the digital format of the project. In today's digitalized world, creating a website is one of the most effective ways to reach the widest possible audience. And because I was especially interested in reaching young adults and millennials—inarguably the most plugged-in generation ever—it made sense to create a digital resource to share my work on (DeJesus). I was also attracted to the potential for multimedia engagement and interaction that a website offers, especially as they are becoming increasingly accessible in turn to the average user. Studies show that visual aides are extremely effective in getting a message across, and digital interfaces are bringing that to the next level.

Because I've had some experience with WordPress and found it an effective and accessible platform, I decided to go with it for the purposes of website development and design for this project. I hosted the domain http://climatechangeisintheair.com through InMotion Hosting, although any other hosting option would have worked equally well. The first step that WordPress encourages you to take is to pick a theme, which essentially sets up the basic structural design elements of the site. From there, you can customize on your own, add pages, change menus, and otherwise edit the default settings and take more or less full control of the site. While WordPress offers a great variety of free themes, I decided to purchase one that was especially geared toward journalism. The theme that this site is on, Myth, was developed by WordPress designer MeanThemes. I particularly liked how visually-centric the settings were, and the consistently and constantly available options for a viewer to share the content through their social media platforms.

In addition, another major selling point of the theme is that it was designed to be compatible with Aesop Story Engine (ASE), a WordPress plugin that describes itself as "a collection of thirteen unique components wrapped in a plugin that can be used to present rich, interactive stories or articles in any WordPress theme." Plugins are codes that act as built-in toolkit for a website design platform like WordPress, which allows users who download them to use a specific setting the plugin has designed but WordPress does not include by default. In the case of Aesop Story Engine, which is a free plugin, the code vastly simplified and streamlined the process multimedia storytelling process and developing an engaging long-form journalistic style. Among its features, the plugin allows the writer to easily insert elegant images, videos, audio clips, and chapter headings, among other options. Plus, did I mention it's free? It's a really handy little tool that I'd highly recommend.

Aesop Story Engine also creates their own complementary WordPress themes that are very attractive, but they're also expensive (usually about $100). I'm guessing that's how they make enough money to work on and upgrade the plugin itself. Whether or not you're comfortable paying for a WordPress theme, however, there are definitely other options for using an Aesop Story Engine-compatible themes. Two great paid ones are Literatum, another visually-focused, elegant theme with a clean design for $35, and Lore, another MeanThemes' product that is very similar to Myth, for $49.

For free options, there's Longform, which features a stunning gridlock of stories on the homepage, and Cover, a minimalist content-driven blogging theme. I like all of these because they have built-in compatibility with Aesop Story Engine, but if there's another theme that catches your eye, you can always download Snowball. Clearly inspired by NYT's Snowfall, Snowball is an ASE-like plugin that describes itself as "a block-based editor for authoring modern, immersive longform web articles." It's a bit simpler, and there aren't as many features as ASE, but it's more compatible across WordPress themes (and includes an image comparison slider, which is really neat!)

Like I mentioned, the multimedia component of a digital platform like WordPress was a factor that made the idea of a digital website so appealing to me. As such, it's a major focus of the project. Not only do I incorporate a variety of visual aides, from photographs, to comics, to graphs and charts, but I also made it a point to include audio and video clips in order to further draw the viewer into the world and lives of people I'm writing about. An immersive experience, after all, is the most relatable experience. Aesop Story Engine makes this very easy, but WordPress also offers great built-in tools for uploading and captioning images, customizing appearances, etc. And for what WordPress can't do, there are always more plugins to help you keep things the way you like. WordPress plugins allow you to customize nearly every aspect of your website, from creating drop-cap letters for your titles, to disabling comments, to accessing a wider variety of fonts.

And while WordPress and its army of plugins makes including a variety of multimedia content extraordinarily easy, as a journalist it's important from a ethical standpoint to always give credit where it's due. Almost all of what I was able to add in terms of images and videos is thanks to Creative Commons, an honestly amazing organization that makes copyright law accessible for anyone with an Internet connection. Basically, they create simple, easy-to-use copyright licenses so anyone can share anything with the rest of the world.

To use a Creative Commons image, video, or any other medium, you just have to follow the instructions on the license. For example, for a CC BY 2.0 license (you probably noticed this at the bottom of nearly all of my images), I just have to give appropriate credit, link back to the license, and indicate if changes were made. Because I never made any changes, I just credited the author and license information. It's a bit of extra work to uphold the ethical standards of Creative Commons, but it's absolutely worth it. Plus, sometimes you'll hit a freebie with a "public domain" image or video (hint: all government media is!), which doesn't have any rules for citation at all.

Spread the Word

If you're interested in this project, which I'm going to take a stab and guess you are, at least a little bit, since you bothered to read this entire paper, I'd love to hear from you! Maybe you'd like to take "Climate Change Is in the Air" to your own city, or there's someone you think I should speak with. Maybe you'd like to adopt a different public health issue to focus on, like food security, or maybe you're embarking on a similar kind of communications quest and you'd like to talk to someone who (mostly) made it out in one piece. Maybe you've noticed that I made a mistake and you'd like to correct me!

No matter what your reason, I'd highly encourage you to send me an email at li.emilysun@gmail.com. I look forward to hearing from you, and thank you so much for reading. I hope you enjoyed it as much as I enjoyed putting it together!

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