Intervening In Complexity:
A developmental theory of climate change
by
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Introduction

We have become accustomed in biology to creating and then believing in powerful and discrete objects that act and are acted upon in a direct causal manner. For example, we speak and conduct research as though genes directly control phenotype, even though it is our experimental design that first assumes the dominant causality of genetic factors and then constructs it by not testing for other casual types. It is our intervention then, which creates the causality we perceive. Intervention is part of science’s quiet meaning, it is the unmeasured dimension which invisibly dominates all scientific knowledge. We know because we intervene and we know in order to intervene.

The topic of intervention gives me a place to explain how the boundaries of biology and climate change became as slippery as they did during the course of this thesis. When we intervene in molecular biology, such as by using double stranded mRNA to silence protein expression, the point of the intervention is to take away one system aspect in order to monitor the resultant functioning of the whole. However, we cannot see the whole, we do not even know how to see it. This type of intervention results in a (sometimes) discernible phenotypic effect that may be significant on its own, or useful in future research. However, as researchers well know, reproducing that effect reliably in vivo is difficult and often requires some tricks of the trade, or extensive procedural tweaking. Part of the need for tweaking comes from the fact that even though we envision ourselves acting in a simple causal chain, we are instead intervening in a complex system. It is one of the hallmarks of
complex systems that single actions and single interventions are impossible. Finally, this method of intervention may tell us about how causality exists between a specific cause and effect under a number of conditions, but it does not tell us very much about how the system functions as a whole. We choose to highlight one type of causal mechanism at the expense of others. In research, we destabilize systems in order to determine how system components function. The goal is to control a specific cause and effect without needing to understand the entire system.

In my opinion, intervention is not only a long-standing issue of scientific importance, but also intimately related to many aspects of the modern condition. Most particularly, I am referring to how I feel when I reflect upon the quantity of information we possess, and yet how much we have failed to accomplish. The alchemy that changes acting into knowing is substantially more attainable than the magic we need for changing knowing into acting. I confess that at my darkest times, climate change seems like just another example of the human failure to act upon knowledge in time to prevent inequitable harm. And yet, eventually I return to the opinion that even though we are unskilled at the transformation, knowledge holds the potential for action inside of it, and that knowing how to think is a prerequisite for knowing how to act. The great scientific and social question of our time may well become, how can we intervene and what is it that we are intervening in?

It is in this spirit that I turn to climate change, a scientific-political issue which inhabits the boundary between knowing and intervening. More is at stake with intervention in climate change than in the molecular silencing of a gene and yet the two have substantial areas of overlap. In both cases, humans have destabilized
system functioning and produced an effect that is mistakenly assumed to be the direct result of a single intervention. In both cases, the continuous role of human intervention and of human systems is down played. Finally, as shall be expanded upon later, both an organism and the climate are developmental systems.

Climate literature recognizes two general responses to climate change, mitigation and adaptation. Mitigation refers to policy responses that attempt to cut down on greenhouse gas emissions or to sequester carbon and thus prevent it from entering the atmosphere. Adaptation on the other hand generally refers to policy that attempts to mitigate or capitalize upon climate change impacts, rather than seeking to avoid those impacts all together. As the likelihood that we are already facing climate change impacts has permeated the public consciousness, scientists and policy-makers have begun paying more attention to the possibility of adaptation. However, mitigation has historically been the policy of choice, and remains the most widely researched and implemented policy option.

Although an ideal solution to climate change will likely include generous dosages of both, adaptation and mitigation represent two very different approaches to climate change. Mitigation is a response to a global commons problem, meaning the idea that a ton of carbon dioxide emitted anywhere in the world will produce the same polluting effect. For this reason, when studying mitigation it makes sense to use models which focus on global, rather than local emissions and effects. On the other hand, my own interpretation of the current state of adaptation research suggests that adaptation is an intervention which attempts to make a system as a whole more resilient and robust. In other words, it
seeks to do the opposite of most research, it seeks to intervene in order to stabilize, rather than destabilize a system. Adaptation therefore leads us to our fundamental, modern epistemological problem, namely how to create complexity rather than reduce it. Interestingly, the process of creating complexity is known as development and it is currently the subject of considerable rekindled interest in biology. Thus, adaptation policy depends upon a strengthened understanding of development, and biology is the discipline with the most comprehensive treatment of this subject.

This thesis attempts to make headway on certain of these issues. However, I admit from the beginning that throughout this project, I have been made acutely aware of my own ignorance. Thus, one of my main purposes is not to inform, but to question. As I shall argue, asking the right questions is part of building the bridge between knowing and acting. I began asking my questions by formulating the most basic one, namely, what is climate change? The answer may seem obvious, but I found during my research that although a dominant climate change paradigm exists, many people are currently formulating different challenges to this conception. Part of my thesis is a similar and more outspoken challenge, as I attempt to both make the current climate change narrative explicit and also to argue persuasively why it is no longer useful. In addition, I believe that complex biological phenomena are developmental in nature, meaning that they are systemic and made up of regular and interacting processes. I therefore argue throughout this thesis that climate change, like an organism, is developmental and will best be addressed with system level solutions.
Part I: Developing Climate Change

So was I once myself a swinger of birches.

And so I dream of going back to be.

It's when I'm weary of considerations,

And life is too much like a pathless wood

Where your face burns and tickles with the cobwebs

Broken across it, and one eye is weeping

From a twig’s having lashed it open.

I’d like to get away from earth awhile

And then come back to it and begin over.

From Robert Frost, “Birches”
The Celebrity Status of Climate Change

In 2007, the Norwegian Nobel Committee awarded the Nobel Peace Prize jointly to the International Governmental Panel on Climate Change (IPCC) and Al Gore, “for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change.”\(^1\) In their website statement, the Panel explains that it awarded this year’s prize with the aim of highlighting the connections between climate change and the risk of war and conflict. Elaborating further on this theme in his presentation speech, Professor Ole Danbolt Mjøs, the Chairman of the Committee, argued that intra-national security is fast becoming more of a threat to worldwide peace than conflicts between nations. Furthermore, Mjøs asserted that climate change has and will continue to worsen civil conflicts, such as sovereignty claims in the Arctic and political unrest in areas such as Darfur. The Committee’s decision was therefore both a philosophical statement on the role of climate in peace and also a call to arms. He concluded his speech with the observation that, “The Norwegian Nobel Committee rarely raises its voice. Our style is largely sober. But it is a long time since the committee was concerned with such fundamental questions as this year. . .Action is needed now. Climate changes are already moving beyond human control.”\(^2\)

This bit of contemporary history highlights the extreme recognition and importance that society now awards to climate change. In the past few years, climate

change has expanded as a concept and now claims causality in a wide range of issues, such as violence, world hunger, and disease. The popular media now regularly implicates climate change not only in natural disasters and sea level rise, but also in problems of disease and global inequity. However, the choice of prize recipients also juxtaposes two different notions of what climate change actually is. Presumably, the Committee divided the prize in this manner in order to recognize the concurrent scientific and political struggles to give climate change the recognition it deserves. However, as I hope to show in a few pages, the IPCC has begun formulate a conception of climate change that diverges significantly from the one promoted by Gore.

Due to the fact that any debate surrounding the subject of climate change has historically been taken as evidence against its existence, discussion pertaining to climate change impacts and solutions remains sadly limited in the United States. Outside of academia (and perhaps even within it), the only issue of “debate” which arises is whether climate change is happening at all, a discussion that most of us would agree is now obsolete. This paper hopes to re-stimulate debate by exposing the way in which the current paradigmatic thinking on climate change is inadequate at answering or posing new and important questions. In addition, I have uncovered three alternative conceptions of climate change, partially in order to begin articulating how people who all agree that climate change exists can still productively disagree over *how* it is exists and what to do about it.
Articulating The Common Sense of Climate Change: The Pollution Paradigm

Throughout this paper I refer to the dominant set of assumptions about climate change as the pollution paradigm. This largely undisputed framework is the one espoused by Al Gore, most environmental groups and the popular press. The posited causality of the pollution paradigm is as follows: carbon dioxide and other greenhouse gases keep the world warm by retaining solar radiation. Humans have exacerbated the warming effect by burning fossil fuels and thus emitting unnatural amounts of carbon dioxide into the atmosphere. The extent to which global temperature will increase is a function of the amount of CO2 we emit and the sensitivity of the climate. Notice that although this understanding allows for some feedback between global mean temperature and water vapor, the main causal chain is linear. In other words, increases in carbon dioxide lead to increases in global mean temperature and then directly to climate change impacts (for a visual representation, see figure 1). Thus, the damages caused by impacts are assumed to be dependent on the extent of temperature increase. Underlying this whole conception is the idea that without human influence the climate would be a stable and natural process. In addition, the pollution paradigm holds that the source of global warming is carbon dioxide, a pollutant released when we use fossil fuels. Carbon dioxide is a pollutant because it is directly responsible (in a causal sense) for climate change, in the same way that sulfur dioxide is responsible for acid rain. Following this internal logic, it
appears that the best solution to climate change is mitigation (as much and as early as possible) and carbon sequestration.

Figure 1: The underlying causality of the pollution paradigm.

Whether or not one believes that this paradigm is correct, it is crucial to notice that these ideas imply a constituent morality. Because the causality of climate change is located so specifically in fossil fuels and the Industrial Revolution, it is clear that Western society is overwhelmingly responsible for global carbon emissions. There was a long period of time around last year when the phrase “addiction to oil” pervaded language surrounding climate change. The use of the word “addiction” implies that emitting carbon dioxide is a costly, socially damaging and selfish indulgence of Western nations. The term is also able to tap into a cultural disdain for addiction, particularly the lack of control that is the trademark of the condition. In my opinion, comparing one complex phenomenon that we don’t completely
understand to another one that exhibits the same characteristics does not advance us either scientifically or ethically. Despite the fact that the remainder of this thesis protests this way of thinking, I write with the caveat that emotionally, I find the pollution paradigm almost overwhelmingly convincing. However, I think that the narrative appeals to me because of some aspect of my human condition, and is largely unrelated to how I understand climate change. In other words, there are useful reasons believing in the pollution paradigm, but its popularity is due to its resonance with a Western zeitgeist. Greenhouse gases do trap solar radiation, but perhaps we would not think about climate change in this same way without the Western environmental and colonial legacies of guilt and geography, without September 11th, without interracial violence, urbanization, monoculture, or existentialism. The pollution paradigm ultimately preaches that since carbon dioxide is pollution, we must control carbon emissions and limit further interference in natural systems. The unspoken desire is to return to some point in the past, to erase our carbon emissions and our sins of interference completely.

Both morally and scientifically, the pollution paradigm teaches us that the only response to climate change is mitigation. After all, the appropriate response to a pollutant is to stop emitting it as quickly as possible and to clean it up. Strong believers in the pollution paradigm feel that if only we could stop emitting carbon dioxide immediately, damages from climate change would never happen.³ Mitigation makes sense scientifically because the paradigm envisions climate change as a causal

³ This logic seems to make sense, unless one considers the enormous cost that society would bear if all fossil-fuel emitting activities ceased immediately. In my opinion, the cost of that decision would surely have just as great of an impact as climate damages themselves.
chain leading straight from carbon dioxide to impacts. It also makes sense morally, because the need for mitigation on a national and personal level represents the desire for Western atonement.

The 2006 film, *An Inconvenient Truth*, was an overwhelming hit and placed climate change at the forefront of the American environmental conscious. In the movie, Al Gore presents a fully fleshed out version of the pollution conception of climate change. The movie begins and ends with images of a muddy river flowing slowly through a heavily forested area. A voice-over entreats us to relax by the side of the river and to revel in the beauty and power of nature. There are no signs of human habitation anywhere near by. The film exerts much of its power by showing the audience similar images of beautiful spaces that appear to be untouched by humans. Juxtaposed beside these images of pristine nature are ones of huge factories exuding dark smoke clouds. If this visual message were not clear enough, Gore refers to greenhouse gases as “global warming pollution” during the film. In order to help explain the science of climate change, he shows a humorous cartoon depicting carbon dioxide molecules as green, thug-like genies who beat up sunrays and deposit the bodies in earth’s atmosphere.

It is clear, even without the appearance of green carbon dioxide thugs, that Gore’s approach is that of the pollution paradigm. In addition to assuming the dominant causality of carbon dioxide, the film also illustrates the division that this paradigm assumes between natural and artificial systems. The paradigmatic thinking holds that unnatural human behavior, such as a reliance on coal and oil, leads to disruptions in natural systems. All human action is unnatural and most of it upsets
the balance of nature. Nature here is defined as the way that things would be in the absence of human interference. Why does the story of human disruption, human outcast status among the beautiful, fragile perfection of nature appeal so much to the modern West? Certain religious overtones, bloody historical occurrences and other aspects of historically contingent thought are not, in my own opinion, unrelated to the appeal of this narrative. However, for the purposes of this paper, it is enough to make the pollution narrative explicit in order to understand how useful it may be.

As it happens, the division between natural and artificial systems, if it ever existed, is becoming increasingly dubious. As Peter Vitousek first formulated in his seminal 1994 paper, “any clear dichotomy between pristine ecosystems and human-altered areas that may have existed in the past has vanished, and ecological research should account for this reality.” In other words, that riverbank in *An Inconvenient Truth* almost certainly included some introduced species. The river itself may have been carrying additional sediment from upstream farms. The human influence, even when it seems invisible, is still prevalent. I mean this in a physical sense, such as the widespread land use changes of urbanization and agriculture, the changes in soil chemistry, or the use of antibiotics. However, to apply Ian Hacking’s notions concerning the formative capacities of categories, I also mean that when we categorize nature, the categories themselves often influence the thing they are supposed to contain. Our language is part of how we begin to intervene.

In the end, I am forced to dispute two aspects of the pollution paradigm. First, carbon dioxide is not the sole cause of global warming, nor does it act in a manner

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similar to most other pollutants. As I will describe later on, climate change impacts are usually dependent on systemic causality of which carbon dioxide emissions are only a part. Climate change becomes real through interactions between temperature and carbon dioxide concentrations and other types of human modified systems. It may have been useful to think about climate change as a pollution problem when the main issue at stake was whether or not it was happening and anthropogenic in origin. However, at this point the more relevant questions are systemic in nature. For example, we should ask ourselves, how can we attempt to craft climate change policy that will be both politically feasible and also accomplish developmentally relevant goals? How can we improve upon the relevant human-nature systems in order to make them more adaptive and resilient in the face of specific risks? How will climate change policy affect other, related types of development? The pollution paradigm cannot really answer these questions because it does not provide a way for thinking about the systemic causality at issue. The rigid separation of human and natural systems is the second aspect of the pollution paradigm that I dispute. As I stated earlier, these two types of systems can no longer be considered separate in many contexts, meaning that it is impossible to try and “undo” human influence. Instead, we must continue research to determine how these hybrid systems function and how we can use developmental pathways to strengthen resilience.

Decisions where to allocate scientific and political effort are fast becoming more important as the reality that climate change is already occurring sets in. In light of this, part of the work of this thesis is to fully articulate a conception of climate change that can provide a framework for posing important, developmental questions.
As I hinted earlier, certain policy makers and academics (largely members of the IPCC and the German Advisory Council on Global Change) have already begun using a developmentally oriented vision of climate change. However, I want to highlight the importance of the work they do, and to expand upon it. Finally, I use this developmental perspective to push the importance of policy and research that explicitly acknowledges system level causality and the importance of adaptation.

**The Geoengineering Challenge**

Before delving into more modern conceptions of climate change, including my own, I want to begin by examining an older paradigm. Interestingly, before the prominence of the pollution paradigm, there was another conceptual framework concerning human intervention in climate and weather, namely weather modification. The idea that it is possible to purposefully control the weather seems alien to us now, as we are faced with climate change, or, as it used to be called, ‘inadvertent weather modification.’ However, from the late 1940s through the 1960s, climate modification enjoyed legitimacy in both the scientific establishment and popular culture. The spirit of weather modification lives on in geoengineering, one of the existing challenges to the pollution paradigm.

The frenzy surrounding weather modification began in 1946, when Vincent Schaefer discovered that adding dry ice to a freezer of super cooled water droplets

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5 By developmental here, I mean mostly the systemic aspects of the word.
resulted in ice crystals that strongly resembled snowflakes.\(^6\) Schaefer was working under the direction of Irving Langmuir at the general Electric Research laboratory during this time, and both men were interested in super-cooled cloud structures.\(^7\) The purpose behind this research was to induce and control cloud precipitation. In 1946, GE and the United States Army signed a contract launching Project Cirrus, an endeavor devoted to researching and implementing weather modification. Soon after, they succeeded in ‘seeding’ the first cloud by dropping three pounds of dry ice pellets into a stratus cloud and witnessing the cloud produce snow less than five minutes later.\(^8\) As Project Cirrus began to publish its experimental results, a weather modification industry grew up, particularly in the United States. The alleged successes of cloud seeding and other weather modification experiments are still hotly contested because it is difficult to prove that the resultant weather patterns were the result of human experimentation and not just simply part of normal weather variation.\(^9\)

In the 1950s and 60s, weather modification was regarded, particularly by the meteorology community, as a legitimate and emerging science, although in retrospect some of that excitement was related to the success of space age technology and fears


\(^7\) Pg. 27, Ibid.


\(^9\) This continues to be the major scientific problem with weather modification, it is largely impossible to discern the anthropogenic signal from the possibilities of normal weather variation. See, Cotton, W. R. and R. A. Pielke (2007). *The rise and fall of the science of weather modification by cloud seeding*. *Human Impacts on Weather and Climate*. W. R. Cotton and R. A. Pielke. Cambridge, Cambridge University Press.
regarding the cold war. George Breuer, a proponent of weather modification in the 1970s, wrote that, “it is the secret hope of many a meteorologist that the atmospheric sciences will, one day, also attain a degree of exactitude comparable to that reached by celestial mechanics several centuries ago. . .meteorology is still awaiting the birth of its Kepler.” Breuer’s desire to see the science of weather modification eventually reach the status of astronomy is linked to the ascendance of space exploration. In addition, meteorology, unlike most biological sciences, is missing that element of human intervention in real systems. Therefore, the scientific goal of control or at least prediction is much harder to achieve. Although few of the scientific findings from weather modification have been included or acknowledged in modern science research, weather modification reveals a few basic lessons about climate. For example, in an attempt to explain the sporadic nature of weather modification experiments, Breur wrote, “The relatively short history of weather modification already seems to provide examples which show that the effects aspired to – increase of rainfall or suppression of hail – do not come about only as the result of a mechanism predicted by the theory. . .but, at least partly, through another originally unforeseen mechanism.”

The 1950s and 60s saw a multitude of weather modification projects, but beginning in the late 1960s, concerned citizens began to speak out. For example, in 1970 a group of farmers in the San Luis Valley of Southern Colorado formed a group in opposition to the weather modification attempts (to suppress hail) that were occurring in the region.10 The farmers argued that the attempts to suppress hail were

10 Kwa.
also causing other types of damaging weather patterns. In 1972, the Colorado legislature heard the case and responded with a law regulating weather modification in the state. This type of situation repeated in Montana and the Washington, D.C. area. Chunglin Kwa notes in her chapter of *Changing the Atmosphere*, that this change in attitude was not due to a belief that weather modification was unsound science, but rather that it posed serious and unknown risks to the environment.

Additionally, it was during the 1960s and 70s that a group of people began worrying about “inadvertent weather modification.” In 1966, the National Academy of the Sciences reported that there were several possible types of inadvertent weather modification including carbon dioxide emissions, urbanization, forestation, deforestation, supersonic transport aircraft and contamination of the very high atmosphere. The fears about problems with weather modification were closely linked with emerging fears about inadvertent weather modification. In this way, the weather modification scheme rapidly lost both interest and funding. In addition, most attempts to purposefully interfere with the climate system halted despite the fact that the main stream meteorology societies continued to support weather modification until the mid-1970s or later. Chunglin Kwa ends her chapter by noting that, “out of weather and climate modification emerged continuing concerns about anthropogenic climate change and an increasing demand for computer simulation models of the climate.” In an important sense, fears over inadvertent climate modification emerged as a backlash to purposeful climate modification. This historical transition partially explains why purposeful modifications to prevent climate change are viewed with

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11 Ibid.
faint wariness. Although these measures might ease the situation, they still represent purposeful interference with the climate system, something we moderns remain nervous of.

Geoengineering is the modern inheritor of the weather modification legacy, albeit in slightly different guise. Whereas most weather modification schemes in the 1950s aimed to influence precipitation or storm frequencies, the goal of geoengineering schemes is to directly prevent global warming, often by increasing carbon sequestration or by modifying the radiation budget of the earth’s surface. Geoengineering holds in common with weather modification the idea that human intervention in natural systems is not inherently dangerous or immoral. For example in 2007, the Planktos corporation publicized plans to begin seeding experimental ocean areas with iron dust particles. Iron is often the limiting nutrient for plankton species, so adding more iron to the ocean results in algae blooms. The algae usually die quickly after an intense period of photosynthesizing and decompose or sink to the bottom of the ocean, becoming sediment. As they decompose, most of the carbon dioxide they used in photosynthesis is returned to the atmosphere as carbon dioxide. However, some portion of it remains trapped in the ocean and is therefore semi-permanently removed from the atmosphere. Plankton’s business plan was to sell carbon offsets to governments and corporations. In other words, the client would continue to emit carbon dioxide, while paying Planktos to sequester the same amount of carbon dioxide in the ocean.\textsuperscript{12} However, worldwide outcry from environmental groups forced Planktos to indefinitely postpone the project in February of 2008. As is

clear from this example, mainstream environmentalism finds geoengineering to be dangerous and even blasphemous. However, as more and more scientists have become frustrated with the slow pace of mitigation policy, it has gained some recognition. For example, scientists such as Nobel Prize winner Paul Crutzen have published controversial papers which detail geoengineering schemes.\textsuperscript{13}

Despite the impractical nature of most geo-engineering schemes, I find myself occasionally sympathetic to the geoengineers for two reasons. First, it is usually the geoengineers in the field of climate policy who are most ready to grasp the significance of human modified systems. Of course, the reasons for this are clear, by discipline geoengineers believe that further direct and purposeful human interference is the most efficient and rational way to solve climate change. Second, geoengineers are often stigmatized and discouraged from pursuing or publishing their research. Part of the reason for this reaction in mainstream science may stem from the fact that many scientists distrust the “quick fix” aspect of geoengineering, feeling that emission reductions are the only true climate solution. As Cicerone et al write, “There is a widespread, perhaps universal belief that humans must first attempt to limit these emissions”\textsuperscript{14} rather than to find other solutions. Even though I think mitigation is necessary, I dislike this moral rationalization that fears multiple types of problem solving.

\textsuperscript{13} Crutzen’s paper analyzed a possible scheme of injecting sulfur particles into the earth’s stratosphere in order to increase albedo, similar to the effects of a volcanic eruption. Cicerone, R. J. (2006). "Geoengineering: Encouraging Research and Overseeing Implementation." \textit{Climatic Change} 77: 221-226.

\textsuperscript{14} Ibid.
Geoengineering is not at present considered seriously by the IPCC or any other major scientific body concerned with climate change. The geoengineering framework takes as its starting point the assumption that humans have already extensively interfered and modified earth systems. They also recognize that this interference is not widely acknowledged for cultural and moral reasons. For example, Braden R. Allen, currently a professor at Arizona State University and a well-known proponent of geoengineering writes,

First, if we admit that we have designed Earth for our own purposes, we must also admit that we have some moral responsibility for what we have done – and that is really frightening. Second, many of us, for reasons that can be traced by in history, have learned to regard “Nature” as sacred. Thus, if we accept that we have terraformed the Earth, we will feel as if we have blasphemed – disturbing a powerful feeling, largely on an unconscious level. . .Earth is a highly complex, self-organizing, interactive system with components, from agricultural systems to genetic structures, that are increasingly anthropogenic.”

Allen uses anthropogenic here to mean that humans have reconstructed natural system functioning through interference. He is a Marxist thinker who believes that the main mechanism of anthropogenic system expansion is the human commodization of nature. Marx believed that the market structure of capitalism would continue to grow and Allen states that the new frontier of the capitalist system is nature.

The work of Alan Carlin, another well-known proponent of geoengineering, is even more significant for our purposes. In addition to taking human co-construction of earth systems for granted, he goes on to argue that climate change is not a single environmental issue, but four. The first of these is the rising global mean temperature

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and subsequent sea level rise, Arctic thawing and increases in storm intensities. The second issue is the increase in greenhouse gas concentrations and the contingent impacts associated with those increases, such as ocean acidification. The third is abrupt climate changes due to feed forward responses in the climate system and the fourth is the possibility of short term cooling episodes due to volcanic eruptions or nuclear conflicts. Carlin is a strong proponent of adding sulfur-like particles to the earth’s atmosphere in order to rectify the earth’s radiation balance. He writes, “SRM (solar radiation management) would control temperatures by reducing the radiation reaching the earth from the sun. . .This could be most easily and reliably accomplished by adding particles to the stratosphere to scatter a small, carefully calculated portion of selected wavelengths of incoming sunlight back into space.”

The problem with SRM, according to Carlin, is that it would not address the ocean acidification impact, which is cased by increased carbon dioxide concentrations rather than increased temperatures.

The distinction between the increased global mean temperature and the increased carbon dioxide concentrations is a worthwhile one to make. In dividing up climate change, Carlin illustrates that causality in climate change is multiple. However, he does not go far enough. Although in the context of mitigation policy it may make sense to conceptualize climate change as a homogenous and unified phenomena, this is an idealization. In fact, climate change will have different effects in different areas due to sets of causal feedbacks which interact differently with local

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systems. Climate change will be one thing in one place, and an entirely different thing somewhere else. If we think about it this way, there is not one type of climate change, but many. Carlin imagines that adding reflective particles to the atmosphere will allow humans to manage the solar radiation budget of the earth. However, just as he acknowledges the inability of these particles to solve ocean acidification, so I would argue that adding particles would leave untreated many related climate changes. Carlin still considers climate change to be a unicausal phenomena created by the interaction between additional carbon dioxide and the sun’s incoming radiation. I consider climate change to be developmental, meaning that it is the equal result of many causal elements. Therefore, addressing a single factor will not “cure” the condition, only change it.  

Our own lack of knowledge about the systemic affects of the complexity we inhabit limits the utility of the geoengineering paradigm from the beginning. However, the geoengineering perspective moves us beyond the pollution paradigm in a few important respects. Most importantly, geoengineering makes visible the deep influence that human interference has on earth systems. The perspective acknowledges the fear that this acknowledgement brings and then turns to address the question of responsibility for interference. In addition, the geoengineering framework implicitly argues that additional human interference will help solve issues caused by human interference. Taking this silent logic one step further, it is not human

17 This proposal to purposefully emit reflective particles does not acknowledge that the emissions of the particles would have to continue indefinitely, and even increase if carbon dioxide emissions continued unabated. This is part of what I mean when I say that geoengineering schemes will not cure the condition, they will only change it into another type of environmental problem.
interference that is dangerous, but how that interference happens. Unfortunately, most geoengineering projects do not think systemically. In other words, the main problem with geoengineering is that the type of human interference it champions is short-sighted and blind to the causality of system functioning. More dangerously, most geoengineers do not fully consider the possible side effects, feedback effects and long-term effects of their projects. In that way, geoengineering does not advance us any further past the pollution paradigm.

The Missing Piece: Development

I chose to start out with the pollution paradigm and geoengineering in order to show how two opposing ideologies are still missing a crucial insight as to the nature of climate change. In this next section, I use Developmental Systems Theory (DST) to articulate my own conception of climate change as a systemic and developmental phenomenon. DST is a body of writing that places developmental processes at the center of biological understanding. I choose developmental systems theory because I am convinced that climate change is not a pollution problem, but a developmental one. Perhaps it seems trivial to quibble over ideology when the phenomenon in question is so urgent. However, I worry that if we treat climate change as a pollution problem it will limit our ability to devise workable solutions. Most of the legislation passed on this issue has enacted only mitigation solutions, many of which are international or national. However, given that we are already committed to a few degrees of warming, it makes sense to research and implement a wider variety of
mechanisms. In particular, incorporating development into climate change has implications for evaluations of adaptation research and the integration of mitigation with adaptation.

This paper includes quite a bit of slippage between biology and climate science. This haziness is deliberate, as I believe that climate is a biological phenomenon and subject to many of the same tropes that persist through biology. For example, many of the informational and unicausal notions of causality that have dominated biological thought also plague conceptions of climate change. My hope is that, just as the burgeoning developmental challenge to mainstream biology has opened up new avenues for research, a similar challenge to climate change might perform a comparable service.

Having argued that climate change is not a monocausal phenomenon, I turn to my proposition that it is developmental by using Developmental Systems Theory. In DST, the cycle of contingency is the fundamental unit of development and therefore of biology. Most other theories of biological unification, such as molecular biology, see discrete particles, or objects, as being the originators of action. However, in DST, processes have agencies rather than discrete objects. Another way to say this would be that in molecular biology, particles produce processes whereas in DST, processes produce particles. Additionally, molecular biology remains informational on an epistemological level. Even though the central dogma is largely defunct and the concept of a gene has become riddled with difficulties, the Platonic ideal of the information content of stationary particles remains strong. As Susan Oyama writes in

her introduction to *The Ontogeny of Information*, “In an increasingly technological, computerized world, information is a prime commodity, and when it is used in biological theorizing it is granted a kind of atomistic autonomy as it moves from place to place, is gathered, stored, imprinted or translated. It has a history only insofar as it is accumulated or transferred. Information. . .(is) the modern source of form. . .”

In contrast, DST teaches that the regularity of developmental processes is not due to any information content of a particular actor, but rather to the interaction of material elements. The two words in this term, cycle and contingency each express one of the fundamental aspects of development. The cycle term refers to a belief that developmental processes are cyclic on a micro and macro level. The sense in which the lifespan of an individual is cyclic consists in the tidal use of material resources and the reliable interactions of many physical pieces. The contingency term reminds the reader that each cycle is dependent on the previous cycle for the renewal of resources, and therefore that the cycle is historically constructed and context specific.

Developmental systems theory (DST) first emerged out of the conviction that privileging genetic causality as the primary explanatory mechanism of biology is deeply flawed. Although different DST thinkers address different types of questions, many of them are interested in the following six themes, helpfully stated by Oyama, Griffiths and Gray in their introduction to *Cycles of Contingency*. First, DST is interested in joint determination by multiple causes. Traits in the evolutionary sense are therefore the result of complex, system-wide interactions. Although this statement seems self-explanatory, it is in opposition to the often unspoken assumption

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that most phenotypic traits are genetically determined and adaptive. Secondly, for DST thinkers, causal processes are context specific and contingent upon a wider set of premises. Again, this statement opposes the idea that a single cause, such as genetics or natural selection, drives phenotype. Instead, DST reminds us that genes are incapable of “acting” without the cooperation of the surrounding developmental system, which can extend well beyond the organism.

The construction theme continues in the third aspect of DST, the idea that the organism reconstructs itself from heterogeneous resources. In other words, DST comprehends the form of the organism as something that is constructed over and over again in cycles using available resources. Fourth, DST thinkers believe that it is misleading to define inheritance as the passing down of traits from generation to generation. Instead, the developmental cycle reconstructs traits from available resources and the reliability of the interaction creates similar forms. Each cycle is historical in that the resources available are the result of the previous cycles. Fifth, in DST thinking, there is distributed control during development, meaning that no one interactant is dominant in all developmental cycles. Finally, as has been adequately described previous to this, the DST theorist sees evolution itself as construction, an attitude which complicates traditionally understood causal boundaries\(^\text{20}\). In summation, when I refer to climate change as developmental, I mean that it is created by interactions of many causal factors, some of which seem quite weak in isolation.

Genetic Determinism in Biology and Carbon Dioxide Determinism in Climate Change

Developmental systems theory is formulated directly against the notion of genetic determinism, or the idea that genes are the most important causal determinant of phenotype. Part of the reason that genetic determinism persists in research is that scientists are often looking for differences between genotypes in the same laboratory environment, rather than the phenotypic differences of genetically identical organisms exposed to different environments. In many cases, this obscures the multitude of effects that the environment has on phenotype and the complex, developmental processes that lead to phenotype. Consider the figure below. On the left side, two genotypes are represented which exhibit a constant phenotype through a high variety of environmental extremes. Many scientific projects assume that the genotypes they test behave in this manner, even though such incredibly consistency seems extremely unlikely. To the right in the figure below is a depiction of two genotypes that vary nonlinearly across a variety of environments. Due to differing responses, genotype 1 is higher in some environments, and genotype 2 is higher in others. Norm of reaction graphs like these remind us that the appearance of phenotype is not linearly caused by a single factor, such as genes or environment.

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21 It is important to remember that although each of these variants is referred to below and in the literature as a “genotype,” this does not mean that genes are responsible for the patterns below. These two norms of reaction are not indicative of the roles of genes play in creating phenotypic expression. Although it is beyond the scope of the paper, such patterns could easily be due to developmental noise, maternal effects or interactions between a variety of factors.
Figure 2: The graph to the left shows a flat norm of reaction, where the phenotypes of two genotypes are constant across all environments. To the right is a different representation, where the phenotypes of two different genotypes vary non-linearly across environments.

This biological point helps me to make a similar one about the nature of causality in climate change. To begin, consider the following thought experiment. Let’s say that an exact replication of earth exists, except that it is devoid of any human presence. A divine programmer controls this experimental model of the earth, and she decides to inject it with a certain amount of carbon dioxide so that its atmospheric levels mirror those of the real earth through time. Does this produce what we would call climate change? Even beyond certain scientific inconsistencies, I would argue that it does not. For example, the sea level might rise, but since this planet has no cities or human coastal development, the meaning of sea level rise loses significance. The same is true for increases in the frequencies of hurricanes or coastal storms. In the experimental earth, certain species may migrate north and the biological advent of spring might occur earlier, as has been documented on our planet. Furthermore, we should expect some changes in the make up of organism
communities and ecosystem functioning. However, species migration will occur in quite different patterns because it will be unhindered by roads, agriculture, irrigation and other human impediments. Furthermore, biodiversity will have developed without human intervention and species will react to these local weather changes without being as inbred, as fragmented, or as widespread and invasive, as they are in a planet modified by humans. The ecology of this planet will probably have settled into its own type of development, and it is very difficult to predict the effects of additional carbon because it is so alien to the causal processes of the planet. My point is that climate change is not merely the result of burning fossil fuels or of an atmosphere enriched with carbon dioxide. It is the legacy of certain types of cycles of contingency which humanity has interacted in through time. It is a complex process that results not only from burning fossil fuels, but also from employing monoculture, from over-fishing, deforestation, coastal settlement, from population growth and a myriad of other factors. A change in global mean temperature is dangerous to life largely because it interacts with other extensive modifications of the planet. Under consideration, this idea is obvious and almost trivial. However, the fact that climate change is the result of many types of human intervention, rather than one, is hardly ever mentioned. One reason for this might be that acknowledging the complicated causality of climate change allows ethical shades of grey into our deliberations. It forces us to acknowledge the extent to which climate change is embedded in civilization, in types of modification which are beneficial in some ways. The

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developmental conception forces us to ask, which types of human modifications are the most dangerous, and is it feasible to change them?

Drawing norms of reaction, similar to the biological ones above, can make the same point about the multiple causation of climate change. If climate change is a non-developmental process where carbon dioxide behaves similarly to genes under the assumption of genetic causality, we might expect impacts to remain constant across environmental conditions. If, on the other hand, climate change were developmental, we would expect that the behavior of the ‘impact phenotype’ would vary not only according to carbon dioxide emissions but also to environmental effects. The figure below illustrates what both of these options would look like under different degrees of human development and expansion. Keep in mind that there are really three dimensions on such norm of reaction graphs, but that the fourth dimension, carbon dioxide emissions, is kept constant.

In my opinion, the impact that carbon dioxide emissions have is extremely dependent upon the functioning of earth systems. In fact, just as we cannot say that two biological variants are genotypes, we cannot say that the two impact trajectories shown above are purely due to carbon dioxide emissions. Instead, they are trajectories associated with, but not directly caused by, certain carbon emissions. The association may be due to the direct causal influences of carbon dioxide, but it is just as likely to be due to other concurrent developmental factors that vary along with carbon dioxide, such as degree of agriculture, industrialization and coastal development. In figure 3, the different environmental variations are representations of the earth and different time shots of human expansion and development.
Figure 3: The top panel of this figure (a) illustrates a non-developmental conception of climate change, in which the impacts of carbon dioxide remain constant despite changes in earth systems. In the lower panel (b), the effect the consistently high trajectory of carbon dioxide has exponentially increasing impacts due to the additional influence of changes in earth system functioning due to human influence.

However, it would also be possible to create a similar diagram where each step was a different nation. The reason that each nation will experience a different level and set of impacts is that its own development will mediate and create different climate
change effects. For example, the risk of sea level rise or of tsunamis is not likely to be a part of climate change in landlocked areas.

**A DST Account of Human and Climate Change Origins**

Many DST writers use the cycle of contingency to refer to the life cycle of an organism in an extended sense. For example, human development requires the union of egg and sperm, which are resources carried by two adults embedded in complex social structures. Traditional biological thought has tended to focus more on the informational content of the egg and sperm than on their material existence. DST wants to refocus on the materiality of the process and the extent to which genetic information simply does not exist without the material processes that construct it. For example, at the moment of fertilization the egg and sperm fuse together and the newly created proto-embryo gathers together the DNA from both parental sources. The cytochrome, which prevents the parental chromosomes from getting lost in the egg, originates with the sperm\(^{23}\). Similarly, the egg supplies the zygote with mitochondria, mRNA and proteins to aid in various aspects of early development. Even the inherited DNA, which we tend to think of as pure informational content, is riddled with protein complexes that change over time. In other words, we do not inherit information or any other intangible from our parents. We inherit a heterogeneous collection of physical resources that continue to interact in relatively reliable ways. As we develop, become born, and continue to develop, we slowly

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acquire the resources that will allow us to reproduce. I find it useful to picture the starting cycle as small and extremely materialistic. It consists of genetic material, the proteins which organize it, and various cellular material contributed by the gametes. However, the cycle inevitably expands over time because the products of development (proteins, for instance) begin to interact with each other and with the physical structure of DNA. As the number of interactions grows, certain reliable patterns of physical interaction emerge. Eventually the part of the pattern becomes what we would recognize as a human child.

It makes sense that material objects existing in a world limited by certain physical stipulations might form a system of regular causal interactions. However, this regularity does not exactly address the causal mechanism of development, or why systems change over time. In my opinion, Lewontin formulated an important answer to this question in his *Triple Helix*, although he himself used this concept to address the notion of adaptation. He writes, “the phenomenon of the weed is a manifestation of a general principle of historical development of any system: that the conditions which make possible the coming into being of a state of the system are abolished by

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24 I began this chapter with the simple intent of paraphrasing the basics of Developmental Systems Theory (DST) and then applying the theory to climate change. However, as I began to work through the concepts of DST on my own, always relating them in the back of mind to issues of climate change and adaptation, the DST that I ended up with was subtly different from what I had read about. Upon reflection, this is just as it should be. Part of the excitement (and exasperation) of DST is its innate flexibility, the way that it changes when one uses it to view a particular subject. Accordingly, I should warn the reader that when I turned to DST, I found a materialist and utility-oriented theory that was ultimately concerned with the physicality of pattern and the utility of concepts. Others have looked in the same places I did, and found quite different exciting and lovely thoughts.
that state." In other words, system functioning leads to causal mechanisms which act upon the very processes which created them. These growing sets of feed forwards and feedbacks increase in complexity and the system develops. The cycle of contingency necessarily changes through time because it acts upon itself. From a developmental perspective, feed-forward and feedback mechanisms are the most important causal determinants of system function or of the origin of phenomena.

We now turn to formulating a developmental conception of climate change that can challenge the still prevalent pollution oriented one. As we saw above, the hall-marks of a developmental process are systemic effects and the causal dominance of feed forward and feedback mechanisms. Earlier, we examined the early development of a human embryo in order to see the fundamental cycle of contingency which leads to an ever larger pattern. Now, we will “read” the origin of climate change in similar developmental ways in order to determine the fundamental causal mechanisms at work. As it turns out, there are two competing theories as to the origin of climate change. One of them superficially functions as part of the pollution paradigm and the other is a much more explicitly developmental account.

In the first narrative, the causal processes that led to climate change began with the Industrial Revolution. The literature defines the Industrial Revolution as a period of time around the turn of the 19th century when many Western economies made the transition to fossil fuel based energy sources. This period of time was characterized by a change in energy supplies from wood to coal, the rise of the factory system of production, increased mechanization in several industries and the

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rapid innovation of certain basic technologies, such as the steam engine.\textsuperscript{26} The changes in land use that occurred during this period of time did not happen in a vacuum, as the word revolution might suggest. Instead, they depended on existing economies, the amount of wood and hydropower available in various nations and other historically contingent patterns.

The Industrial Revolution is perhaps most truly a revolution in hindsight, since it caused many of the long-term changes that would shape environmental activity, policy and thought for the century to come. These include obvious examples such as sulfur dioxide emissions and acid rain, but also more subtle effects, such as a perception of the alienation of artificial, human modified systems from the natural world. When scientists trace the origins of climate change to the Industrial Revolution, they are referring merely to the beginning of increased levels of carbon dioxide emissions during that time. However, the carbon dioxide emissions were part of a larger historical context, which future generations would inherit and enlarge upon. With this in mind, it is not so much the carbon dioxide that has caused climate change, but the underlying systems that sustain the emission of carbon dioxide and the stable inheritance of those systems. The underlying origin of climate change is a complex system, part artificial and part natural, which replicates itself and in so doing emits carbon dioxide.

The hockey graph shown above is the best visual illustration of the way in which many scientists believe human intervention in the climate looks like through time. That is, until the Industrial Revolution, humans influenced climate very little. However, beginning in 2003, William Ruddiman, a prominent paleoclimatologist, began circulating a new theory that human influence on climate began with the advent of agriculture\textsuperscript{28}. Ruddiman believes that anthropogenic climate modification activity began when humans disrupted the normal global cycle of carbon dioxide and


methane fluctuations through farming activities, an idea known as the “early anthropocene” hypothesis. He also believes that this warming deflected the onset of an overdue ice age, an idea known as the overdue-glaciation hypothesis. Ruddiman’s main set of evidence are ice cores which have preserved concentrations of methane and carbon dioxide (two important greenhouse gases) through the previous three inter-glaciation periods. The work of J.C. Varekamp, a lesser-known climate scientist, supports the idea that local human actions could have influenced local and maybe even global climate much earlier than the Industrial Revolution. He posits the existence of a feedback between temperature and the beaver fur trade. However, Varekamp also points out that the world-wide decrease in beaver ponds may have decreased methane and carbon dioxide emissions from standing water, thus diminishing the greenhouse effect. He ends his article with the sentence, “Industrial society often is blamed for severe environmental damage, but the ideas presented here suggest that even during colonial times human actions may have strongly affected local environments and possibly even global climate.”

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29 Ruddiman’s findings have been subject to controversy since their publication. To follow some criticism, see Siegenthaler, U., T. F. Stocker, et al. (2005). "Stable Carbon Cycle-Climate Relationship During the Late Pleistocene." Science 310(5752): 1313-1317.


31 Ibid.
An Introduction to Adaptation

The vulnerability and adaptive capacity conception of climate change is currently undergoing considerable refinement in the IPCC umbrella of scientists and researchers. However, this change of interest away from the pollution paradigm is largely the result of the recognition that we are committed to a certain amount of warming and therefore to adaptation policy. Before directly addressing the vulnerability concept, I will illustrate how the serious consideration of adaptation measures leads straight to a systemic, and perhaps even developmental, conception of climate change. Adaptation and mitigation policy are the two main risk management policy options for addressing climate change. It is possible for the two policies to overlap, but the main difference between the two is that mitigation policy attempts to prevent increases in the global mean temperature while adaptation attempts to avoid the damage caused by climate change impacts.

Adaptation is a complicated term with a long history in multiple disciplines, including earth sciences, biology and economics. Smit et al. define adaptation as involving, “adjustments to enhance the viability of social and economic activities and to reduce their vulnerability to climate, including its current variability and extreme events as well as longer term climate change.” Notice that this definition includes both adaptation to variability as well as to changes in the mean. It also ignores the role of natural systems in adaptation completely. The IPCC, in the Fourth Assessment Report, defines adaptation as an
“adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.” This definition represents the current consensus from the most recent economic and biological literature surrounding climate change. This definition chooses to emphasize the ability of adaptation to anticipate future climatic events and includes a role for natural systems as separate from human ones.

In evolutionary biology, a textbook definition of adaptation refers to genetic or phenotypic changes that increase the fitness of a population or organism in a given environment. Under this definition, natural selection is a function of the environment and creates adapted organisms that fit the environment, much the way that a key fits into the lock. Common examples include the various adaptations to cold environments, including brown fat deposits in fish and thicker fur in mammals. In other words, the organisms are differently shaped keys which, in order to survive and reproduce, must fit into the unchanging lock of the environment. Although the economic and scientific definitions of adaptation seem diverse, they all include the idea of non-random change as the result of a one-way interaction between two systems. For example, both economics oriented definitions define adaptation as “adjustments” made by human systems to the external climate. The traditional biological definition defines adaptation as changes made by the organism in response to natural selection, which is a function of the external environment. Therefore, these
definitions assume a distinction between internal and external systems, with the internal system reacting to exogenous changes in the external.

Most research divides adaptation into at least two types, reactive and anticipatory. Reactive adaptation is a reaction to a climate change impact that minimizes damage or capitalizes upon a new opportunity. For example, when the weather begins to get colder humans reactively adapt by heating their homes and wearing warmer clothing. Some of them even capitalize upon the situation by opening ski lodges and making money. These behaviors and structural solutions allow us to avoid damage, and best of all, they are mostly reversible solutions with little short-term cost.

Some recent model simulations have suggested that adaptation may be a way of avoiding short-term, but not long-term, costs. Most studies mean this in the sense that eventually environmental variation will move outside of the human coping range, even as expanded by adaptive responses, and therefore mitigation is required. However, Robert Kates has greatly refined the notion of adaptation costs by arguing that there are three different types of costs concerning adaptation. The first is the cost of not adapting at all, and it is clear that the resultant damages and costs associated with such a move might be. For example, Kates describes the Green Revolution in Asia as being an adaptive response to massive population growth. If the Green Revolution or a similar technology had not been adopted, starvation and death would

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likely have occurred. The second cost of adaptation is the cost of adopting and maintaining the adaptation measure, in this case the new irrigation systems and the costs of fertilizer. The Green Revolution in Asia had several intended effects, such as the fact that food became cheaper and therefore more affordable to a larger number of people. However, it also had a number of unintended effects, such as increases in pest species and therefore in the requirements for pesticides and the intensive need for water. Therefore, the third type of cost that Kates posited is the most important – the unforeseen effects of a given adaptation. As Kates writes, “the costs of adapting to adaptations continue to be high.” What interests me here is that the economic term ‘cost’ begins to refer not simply to cost in a monetary sense, but also to the fact that any action we take will have complex downstream effects. This leads to the crucial realization that it is not enough merely to adapt or to mitigate. What will matter is how we choose to adapt and mitigate, and the way in which we recognize and act in accordance to downstream effects.

The notion of cost allows us to draw a much-needed distinction between reactions and reactive adaptation. Most models do not incorporate either, and the criticisms of that lack often do not distinguish between the two. However, in general, reactions to climate change have a much greater cost than adaptations to climate change. For example, various reactions to climate change are already occurring, particularly in natural systems. One of the most pronounced of these are changes in phenology, meaning the timing of plant and animal responses to seasonality. For example, certain bird and butterfly species have started breeding or migrating earlier

34 Ibid.
and some plants have begun to flower earlier in response to changes in temperature extremes, the length of freeze-free periods and precipitation.\footnote{Walther, Post, et al.} The problem is that these reactions are almost never beneficial. The classic example is that climate change is likely to change environmental variation and to decouple aspects of weather and climate that have historically occurred together. The importance of this is that many organisms rely on signal thresholds to determine when to undergo phenology events, and encounter serious survival problems when the signal is no longer correlated to an expected change in climate. A more serious problem is that organisms will respond in different ways to the new changes, and that therefore the previous life cycle connections between organisms will be disrupted. In other words, the differing reactions will cause a system-level collapse as the traditional relationships between organisms breaks down. As technology improves, humanity may be able to predict climate change and to choose adaptations that avoid the first of these two pitfalls. In other words, we have the ability to choose anticipatory adaptations, which react in advance to predicted climate changes. Unlike many of our organism peers, we will have the chance to make our immediate adaptations reactive. However, we are still incredibly vulnerable to the second problem, namely that our reactions combined with the stresses of climate change will disrupt system functioning. The success of adaptation will exist in its details and our knowledge of the complexity we inhabit.

There has been a lot of thoughtful work on adaptation to climate change, particularly on how to conceptualize such a complex phenomenon. Because early
climate change work focused on reducing carbon emissions, for many years even adaptation studies were conceptualized in regards to mitigation. For example, many economists and scientists tested adaptation in a fixed carbon emissions scenario ignoring the interrelationship between carbon emissions and economy. Even currently, most models which attempt to integrate human and earth systems limit the adaptation options to a few technological choices that are made at specific time intervals in response to changes in the mean. Part of the problem is that how one models adaptation vastly influences what the expected damages of climate change will be. So far, it is proven very difficult to formulate general rules about how adaptation will happen and what its effects will be. However, the important part is that the recent interest in adaptation, or at very least, responses to climate change, deeply challenge certain aspects of the pollution paradigm. Most importantly, while the pollution paradigm assumes a linear causal relationship between carbon dioxide emissions and climate change impacts, it is clear after considering the possibility of adaptation policy that impacts are caused by a wide array of causal influences. In addition, because the success or failure of adaptation policy depends on feedback mechanisms, adaptation-oriented perspectives turn our gaze to system level analysis and the question of development.

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The Vulnerability Model Challenge

There is growing recognition within scientific circles of the emerging vulnerability and adaptive capacity paradigm. However, the exact constituents of this conception remain ill-defined and contested. For example, social scientists tend to define vulnerability in terms of socio-economic factors that determine people’s ability to deal with the exposure to an environmental stressor. On the other hand, climate scientists tend to see vulnerability as the statistical likelihood of a natural disaster or climate related variability.\(^{37}\) This paper will consider the vulnerability of a system to be a function of its exposure to a specific stress, its sensitivity and its adaptive capacity.\(^{38}\) A more recent paper written by several experts in the field expands upon this further by defining vulnerability as, “represented by a suite of socio-economic, political and environmental variables that represent the sensitivity and exposure of national populations to climate hazards. Key indicators of vulnerability are identified by examining the statistical relationships between a large number of potential proxies for vulnerability and measure of mortality outcome.”\(^{39}\) Notice that vulnerability is decisively a system level attribute, and furthermore that it is not the direct causal result of a single element, but rather statistically indicated by the concurrent presence


of certain factors. The other term that the vulnerability model frequently uses is adaptive capacity, defined by the IPCC as the ability of a system to minimize damage due to external stressors or take advantage of external change. Additional literature has subsequently refined the notion of adaptive capacity further. For example, Richard Tol and Gary Yohe note that adaptive capacity is context specific and depends on a myriad of factors, such as the range of available technological options, the availability of resources, education, the dissemination of information and the public’s sense of risk. However, the two authors note that the strength of the relative components is unclear.

As Smit points out in a 2006 paper, the problem with this vulnerability model is how to apply it in a useful manner. Recent research has partially resolved this dilemma by first identifying factors that might predict vulnerability to local climate related stressors. These factors must be chosen based on studies of adaptive capacity and vulnerability to previous and similar environmental stressors. This assumes the ability to predict local effects of climate change and also to rely upon statistical indicators based on historical precedents. Luckily, many climate change effects will be very similar or identical to environmental stressors experienced in the past. For example, increased frequencies of storms, sea level rise and disease spreading are all disaster areas with a rich history and literature. The past history of emergency response to environmental disasters is therefore a valuable and still underused resource in climate change studies.

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The most immediate conclusion from the vulnerability approach is that areas that are already vulnerable to stress are likely to be hit harder by climate change. One of the primary reasons for local vulnerability is poverty, and consequently poverty reduction is one of the most often cited adaptive solutions in the vulnerability literature.\textsuperscript{41} The irony here is that the solutions to many risk factors, such as poverty reduction, are intimately connected to economic processes which fuel climate change. The main advantage of the vulnerability model is that it allows researchers to identify areas that will be particularly at risk for climate change damage. Current studies using the vulnerability model seek to develop national-level indicators of vulnerability and adaptive capacity. For example, Brooks et al. begin their investigation of vulnerability by acknowledging that it is context specific, meaning that,

the factors that make a rural community in semi-arid Africa vulnerable to drought will not be identical to those that make areas of a wealthy industrialized nation such as Norway vulnerable to flooding. . .Isolation and income diversity might be important determinants in Africa, whereas the dominant factors mediating vulnerability to storms and floods in Norway might be the quality of physical infrastructure and the efficacy of land use planning.\textsuperscript{42}

Continuing with the study, they used statistical methods to find correlations between different indices of vulnerability and the mortality levels of climate-related disasters in the past. They found 11 indicators which empirically co-occur with high levels of climate related damage across the world: population with access to sanitation, literacy rate (15-24 year olds), maternal mortality, literacy rate (over 15 years), caloric intake, civil liberties, political rights, governmental effectiveness, literacy ratio (male to

\textsuperscript{41} Kelly and Adger.
\textsuperscript{42} Ibid.
female), voice and accountability and life expectancy at birth. The use of these types of regression analysis is useful because it allows us to dodge the causality question.

It is clear that the vulnerability model is more developmental than that of the geoengineering paradigm. Although it does not go so far as to argue that climate change itself is multi-causal, it acknowledges that the adaptive ability of systems to avoid climate damage is. In addition, there is less interest here in what factor is most responsible for increasing adaptive capacity, since it is most likely caused by an interaction between multiple factors, many of which are invisible. For example, one of the best indicators that a climate disaster will be very damaging is that the population in the area afflicted has little access to sanitation. Obviously, the access to sanitation is not a direct cause of climate change damage. However, it is the symptom of a certain kind of systemic setup that is vulnerable to climate damages.

The Third Challenge to the Pollution Paradigm: The Syndrome Approach

The German Advisory Council on Global Change holds up a similar conception which places climate change in a wider context of global changes. The institute relies nearly exclusively on the work of Gerhard Petschel-Held, a scholar who specialized in approaching climate change from an interdisciplinary perspective at the Potsdam Institute for Climate Impact Research. In 1999 and again in 2004, Petschel-Held et al argued that one could conceptualize “global change” as consisting
of many syndromes. The term syndrome is purposefully taken from medical literature. In medicine, the term syndrome refers to a set of symptoms or conditions that often occur together and therefore suggest the presence of a certain disease. One of the interesting things about this term is its inductive nature, meaning that the diagnosis of a syndrome is based entirely on correlations of sets of observations with one another. In their research paper, Petschel-Held et al. define a syndrome tentatively as an “archetypal pattern of civilization-nature interaction.” However, the important part is that although syndromes cannot necessarily be defined objectively, they can be recognized by performing statistical analyses, such as cluster analysis, of data relevant to global change. The point is not to identify the underlying processes, which Petschel-Held admits as a weakness, but simply to diagnose the syndrome. Personally, I feel that in the matter of climate change the search for an underlying causal mechanism is misguided. What I am interested in is not so much why things have happened, but how they have happened. In addition, in cases of historically contingent complexity, these two things are likely to be one and the same.

A syndrome is composed of symptoms, and the paper states that they currently have identified 80 symptoms, including urban sprawl, accumulation of waste, increasing mobility, and tropospheric pollution. According to Petschel-Held, these phenomena are symptoms of larger macro-phenomena such as individualization or increases in international disparities. Additionally, the symptoms are spatially (and

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presumably, temporally) dependent. The most complex part of the paper is the attempt to link various symptoms together in patterns of interaction that reproduce reliably over time (called syndromes). This attempt is extremely similar to my own incorporation of developmental systems theory into climate change thought. For example, the relation between impoverishment and extension/intensification of agriculture (both symptoms) is also linked with population growth (symptom) and all four are characteristic of an underlying syndrome. The next step is to “diagnose” the global change syndrome.

One example of a global change syndrome is the Sahel Syndrome, which Petschel-Held et al. explain as follows,

The key characteristic of the Sahel Syndrome is described as the use of agriculturally marginal land by a poor rural population living in a context offering few or not alternative means of livelihood – thus leading to an ever increasing degradation of their environment. This syndrome typically occurs in countries at a low level of socio-economic development and in regions that are vulnerable to human impacts because of their relatively weak agricultural production potential. This production potential can either be limited as a result of aridity or temperature constrains or due to insufficient soil-fertility conditions. The main driving forces and effects are inherent in all forms of the Sahel Syndrome, regardless of the types of production limitations given by natural environmental conditions.44

As seen in figure 5, the central mechanisms of the syndrome relate to agricultural activity, poverty and soil degradation. In fact, poverty is a function of soil fertility and agricultural productivity.

There is one final analogy that is pivotal to understanding the Petschel-Held approach. They define “disposition” as the inverse of immunity, meaning the natural and social components of a region that might predispose it towards certain

44 Petschel-Held, Block, et al.
syndromes. The authors propose using “disposition” as an early warning indicator towards the types of regions and suites of problems that might co-occur. The Petschel-Held article closes by outlining a theoretical mathematical model for the Sahel Syndrome. One of the problems that they encountered was deciding how to apply the syndrome model to a specific space and time. The model that they created ends up with a “solution tree” that includes multiple pathways leading to multiple symptom expressions. The revolutionary paper concludes by stating, “The most important novel aspect of our approach is to employ dynamic patterns as the primary units of analysis, as such patterns seem to best match the heuristic granularity of the issues dealt with and the human ability to classify even weakly separable perceptions.” This statement is identical with the DST wish to place processes rather than objects at the heart of causal relevancy.

The syndrome approach greatly appeals to my own conceptions of climate change. However, there are a number of problems with utilizing this bottom-up method. First, the syndrome designation is dependent on a vast amount of very local data, very little of which exists or is readily accessible by researchers. Second, the medical analogy assumes the presence of a doctor who decides what qualifies as a symptom and what the appropriate political response might be. It seems pretentious to “diagnose” the world’s problems, especially from the ivory tower of western scientific thought. Finally, Petschel-Held does not explicitly consider climate change as a separate syndrome, presumably because he sees it as an underlying part of different systems and syndromes across the world. Notice how he includes the “enhanced greenhouse effect” and “regional climate change” among the system
components of the Sahel syndrome. The problem here is that there is no political motivation right now to address the Sahel Syndrome, whereas climate change on the other hand enjoys power and popularity. Therefore, although this viewpoint is the most developmentally accurate one we have seen, it is also politically impotent.

Figure 5: The Sahel Syndrome, as represented in the Petschel-Held (1999) paper

Another, more serious difficulty comes from problems developing assessment approaches and models which adequately depict syndrome dynamics in regards to climate change. Petschel-Held and other proponents of the syndrome approach often use a quantitative mode of analysis known as the Tolerable Windows approach in order to analyze mitigation scenarios. Generally speaking, this is the idea that
working backwards from an imagined scenario of non-dangerous interference in the climate system will reveal a range of emissions and policy scenarios which can then be whittled down by normative considerations. For example, the German Advisory Council on Global Change has chosen the syndrome approach and uses the Tolerable Windows Approach to dispense advice concerning climate change. However, the Council seems to take the concept one step further. Under its “mission and concepts” page, the Council writes, “The Council’s analyses show that humankind can only progress within the boundaries of a so-called ‘development corridor’. If these boundaries are violated, then development is no longer sustainable, since it imposes excessive demands on the environment or on social and economic systems.”

I find this appropriation of the evolutionary notion of developmental corridors to be premature. Perhaps it is possible that multiple corridors exist (after all, there is not only one kind of development), but I do not believe we possess a refined enough sense of what sustainability is in order to say what is inside a corridor and what is not.

Merging aspects of the syndrome and vulnerability models might alleviate some of their collective limitations. Most likely, this process would involve incorporating aspects of the syndrome model into the vulnerability model, since the latter is better established. It is important to notice that both the syndrome and vulnerability approaches are largely inductive, meaning that they rely on statistically analyzing the co-occurrence of predictive factors. However, the syndrome approach

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has a better theoretical basis for suggesting why certain factors (or symptoms) might co-occur in various regions throughout the world. In other words, while the vulnerability model only examines indicators that co-occur with climate related damages, the syndrome model examines the co-occurrence of indicators that coexist in the presence of a global change syndrome. It is therefore better able to deal with relevant questions such as what the dual effects of urbanization and climate change will be on a specific area. It may also be able to better predict the existence of complex socio-natural feedback chains that will reflect and amplify indirect climate change impacts. Finally, the syndrome model treats natural and human related symptoms as equally causally relevant in the formation of a syndrome. The vulnerability model on the other hand, still attempts to externalize the hazard in question and most environmental aspects of the situation. However, the vulnerability model considers the sensitivity of a system to particular climate related exposures, and the past history of responses to such exposures. It would be worthwhile to research the history of climate-related syndromes in response to particular stresses.

In the introduction to this thesis, I wrote that one of science’s best methods for understanding is reduction and interference in biological systems. We are now at the point where we understand the developmental and systemic nature of climate change processes. However, the problem now becomes how to understand complex processes and how to act within the climate-human system. Ultimately, like the organism responding only to its selective environment, we react to specific factors rather than in response to the whole. However, the true developmental question is how to conceptualize the complexity, how to reduce it in order to properly interfere.
In climate science, actual interference into biological systems is, as we have seen, discouraged. However, climate models stand in as tools for conceptualizing anthropogenic influence on earth systems. This thesis will therefore turn to the consideration of how models have created virtual interference, and the ways in which models embody conceptions of climate change.
Part II: Intervening in Climate Change

You don’t see something until you have the right metaphor to perceive it.

*Thomas Kuhn, “The Structure of Scientific Revolutions”*
Intervening

Despite the dream of weather modification, experimentation in climate is rare. Instead, a plethora of climate models exist, allowing scientists to perform virtual experiments on a virtual earth system. This paper exclusively considers general circulation models (GCMs) and Integrated Assessment Models (IAMs) because these models best represent the systems level analysis that I am interested in. In the previous section of this thesis, we considered both the dominant paradigm of climate change and also several challenges to this paradigm. This section of the paper turns to the question of how models embody these paradigms and the subsequent consequences of that embodiment for thought and policy. To begin with, I explain how the systemic structure of most GCMs assumes the direct causality and the systemic isolation of the pollution paradigm. In order to do this, I use general systems theory to articulate the difference between a system and a developmental system. My aim is to assert that models are systemic, whereas climate change is developmentally systemic. My hope is to use both discussions of general circulation models and developmental systems theory to refine what we are saying when we assert that climate change is, or behaves like, a complex system.

General circulation models represent the holistic Earth as a set of interacting systems, called modules in modeling jargon. Often times, a project that sets out to model something specific using general circulation models will compile a model from various modules developed across the world. General circulation models are a bit like bicycles, in that the modelers tweak their models by trading parts and then
upgrading certain elements to form a particular GCM. This cultural exchange is aided by the fact that relatively few labs in the world have the computational power necessary to run a fully coupled general circulation model.47

Generally, when we think about system functioning, the structure of a GCM as described above makes perfect sense. For example, the philosopher John Haugeland defines a system as consisting of components which interact at interfaces. In this definition, a component is “a relatively independent and self-contained portion of a system in the sense that it relevantly interacts with other components only through interfaces between them.”48 In our example of climate change for instance, the system components might be crop species, cars or aerosols. Notice that depending upon the level of relevant resolution, nearly all components of the climate system can also be defined as ‘systems.’ Haugeland goes on to define an interface as, “a point of interactive ‘contact’ between components such that the relevant interactions are well-defined, reliable and relatively simple.” This set of descriptions near exactly describes how GCMs and other types of technology function. However, in my own opinion, it is unlikely that the holism mimicked by the climate model actually functions in this way. As is obvious from the preceding chapter, climate change strikes me as a developmental system with a material basis for its development.

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What is the difference then, between a developmental system and a system? Although the concept of a system has a much longer history, I begin my own description with a biologist named Ludwig von Bertalanffy who launched the general systems program in the early 1930s. Von Bertalanffy sought to unify the sciences by arguing that systemic processes involved in many different phenomena behaved in similar, mathematically describable ways. In other words, although an ecosystem and a government might be made up of quite different components, certain aspects of their behavior might be identical, simply due to the fact that they are both systems, according to a Haugeland definition. As Von Bertalanffy wrote,

There exist models, principles, and laws that apply to generalized systems or their subclasses, irrespective of their particular kind, the nature of their subcomponent elements and the relations or ‘forces’ between them. It seems legitimate to ask for a theory, not of systems of a more or less special kind, but of universal principles applying to systems in general.  

Part of the inference is that it is the interactions between components and their interfaces that determine the main structure of the system. Thus, the causality of the components is not nearly as important as the causality of the interfaces. In addition, interfaces exist in similar structures across a variety of media.

There are three issues of some importance here. First, notice that this abstract conception of the term ‘system’ allows for the expanded role of models. If systemic behavior is universal, then when a model mimics real world system functioning, it is not merely mimicking, it is producing. General systems theory holds that the same laws causing a model to exhibit systemic behavior also govern the systemic behavior of the phenomena in question. Second, notice that the system becomes the universal

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unit of scientific practice, irrespective of the nature of the material that makes up the system. This leads me to my third observation, namely that in order for this supposition to be true, the material of the systemic factors must not affect system functioning at all. Therefore, general systems theory is almost informational in the way that it prioritizes abstract interactions over interactants. In systems theory, it is the relation between factors, not the nature of the factors themselves, which brings about the regular patterns of systemic functioning.

General systems theory is interested in all types of systems, from the most simple to the most complex. However, recent thinkers who have built upon the ideas of systems theory have been interested almost exclusively in complex systems. Part of the trouble with using complexity to refer to a specific, systemic trait is that the term is often used technically and colloquially to mean different things. For example, the most basic technical definition for complexity is that of algorithmic complexity. To understand this, assume that the basic unit of information is a bit, which can tell a pixel to be either black or white, in a state of 0 or 1. Then, assume that there is a program which creates an output of black and white pixels, or 0s and 1s. The program is of a certain size and contains a certain number of directing bits. If the sequence of pixels is relatively simple, say 00000000, or 01010101, or even 100101010, then the program controlling this output does not have to be very big. Even if the output is random, it is easy to develop a relatively short program to output random 1’s or 0’s, such as a program based around π. However, if a complicated rule orders the output, then the program controlling the output must become larger. The larger the program must become to create the output, the more complex the pattern of
the output is. This definition is a measure of regularity, because any easily discerned
regularity could be described in a brief program. The final teaching of this definition
is that an extremely complex system cannot be described by anything less than itself.

Beyond its technical definition, people often describe a complex system as being
‘more than the sum of its parts’. In order to give a little more substance to this
colloquial expression, my own definition is that a complex system is a system that
exhibits some type of organized emergent phenomena that cannot easily be predicted
by examining its basic components. The emergent phenomenon, a self-organizing
pattern, emerges as the result of complicated interfacing at hierarchical levels of the
system.

The thinker most famous for theorizing about self-organizing, complex
systems is Stuart Kauffman, who formulated his ideas in his popular book, *At Home
in the Universe*. In this book, Kauffman argues that, “self organization is the root
source of order. The order of the biological world, I have come to believe, is not
merely tinkered, but arises naturally and spontaneously because of these principles of
self-organization – laws of complexity which are we just beginning to uncover and
understand.”50 Kauffman’s basic argument is that natural selection cannot explain the
origin of life, or more importantly, the origin of self-organization. He eventually
concludes that life itself is an emergent property of the natural ability of complex
systems to spontaneous self-organize. In other words, natural selection tinkers with
previously existing forms rather than generating forms itself. One of Kauffman’s
most provocative examples of a complex system is that of Jupiter’s red spot, a storm

system that has been in existence for several centuries. Kauffman argues that this storm system is similar to a living organism in the fact that many different particles pass through it, but its fundamental organization remains the same.

Nearly all living systems and living subsystems are considered to be irreducibly complex in the sense that they cannot be modeled exactly accurately, hence the need for some reduction. Another, more elegant way of saying this is that a living system is the simplest algorithm that will produce it. Nevertheless, in a move that echoes general systems theory, complexity theory holds that despite significant variance, all complex systems have certain elements in common. The hope of complexity theory is that it will be able to help solve a number of modern problems that seem to exist on a higher organization level than other biological phenomena do. As Holland writes,

We have noted that several perplexing problems of contemporary society – inner city decay, AIDS, mental disease and deterioration, biological sustainability, are likely to persist until we develop an understanding of the dynamics of these systems. Even though these complex systems differ in detail, the question of coherence under change is the central enigma for each. This common factor is so important that at Santa Fe Institute we collect these systems under a common heading, referring to them as complex adaptive systems. This is more than terminology. It signals our intuition that general principles rule CAS (complex adaptive system) behavior, principles that point to ways of solving attendant problems.\textsuperscript{51}

One of Holland’s hopes is that studying CAS’s will reveal how to find complex system levers, a means of successful intervention into complexity. His example is that of a vaccine, a simple action that allows us to drastically influence the immune

system and also the organism. Another, less optimistic example might be that of carbon dioxide emissions, which seem to act as a lever in the climate-human system.

The words ‘complexity’ and ‘system’ are often used in very imprecise ways to refer to aspects of science that are not easily reducible to their constituent parts. However, as the above (brief) introduction to complexity theory and general systems theory has shown, these words carry technical and specific definitions with them. At first blush, it may seem as though the word system is employed in a similar way by developmental systems theory and general systems theory. However, in fact DST argues against the traditional definition of system, and even attacks the key vulnerability of general systems theory by focusing on internalized systemic change. General systems theory is most interested in how systems achieve their incredible regularity; therefore, much less time is spent describing how the system changes over time. In addition, Von Bertalanffy, Holland and Kauffman assume that complexity arises as the result of the structure of interfaces. Kauffman even believes that this complexity arises spontaneously, in a process analogous to oil forming a micelle in water. In my opinion, it is development itself that creates and maintains complexity, and therefore complex systems are constantly in a state of development. If they appear to remain constant, it is only because matter is moving through the cycle of contingency in a reliable way. If there are similarities between complex systems, they are due to the processes of development rather than to an idealized ‘structure.’ This difference seems trivial, but might become relevant in how we visualize our interventions in complexity. If complexity is a system, it is possible to pull a lever once to impact system functioning. If complexity is a developmental system, pulling
a lever will gently, or not so gently, change the developmental pathways of the system.

**Modeled Complexity and Climate Complexity**

General circulation models are structured as a number of interfacing systems that behave as complex systems according to general systems theory, or sometimes as complex adaptive systems. In other words, modelers almost always assume traditional, pollution paradigmatic boundaries between different systems and different system components. The perceived complexity arises due to interfacing between component systems. This type of modeling has been and will continue to be extremely useful for asking a set of non-developmental questions, most importantly attempts to fingerprint anthropogenic influence. Therefore, part of this chapter will trace the co-development of general circulation models with global theories of environmentalism and the pollution paradigm. Then we will turn to the challenge that the adaptation research has presented to the modeling community. This thesis therefore holds that there are (at least) two different types of complexity. The first is the developmental complexity of the real world, and the second is the general systemic complexity of the models the mimic that real world. It is unlikely that we need to perfectly mimic developmental complexity in models in order to learn how to intervene. However, it is important to question what type of systemic simplification best represents important developmental processes, such as carbon system feedbacks. Developmental Systems Theory responds to concerns over complexity by suggesting
a kind of utility-oriented reductionism. This method will suggest relevant causal relationships that are useful in building and analyzing models of climate change. It may also reveal causal relationships that will be useful in designing adaptation policy seeking to increase the resilience of human-nature systems.

Lewontin is one of the thinkers who alerted me to the idea that the way in which we conceptually reduce holistic processes informs our notions of causality. Lewontin does not focus on the importance of how we ask questions quite the way I do, but he leads me in my direction by calling a chapter of his The Triple Helix “Parts and Wholes, Causes and Effects.” In this appropriately named chapter, he writes that, “The problem of how to determine the appropriate ways of cutting up an organism and its functions lies at the base of many of the most contentious disagreements in biology.” His purpose in this chapter is to dismiss the ability of the reductionist or mechanist interpretation of the organism to correctly represent causality. He does so on four different grounds. First, he argues that there is no single way to divide up an organism into separate systems or functioning units of analysis. Second, he asserts that the organism exists at the intersection of a number of weakly determinate causal forces. Experimental design that seeks to find a gene “for” a phenotypic effect assumes that the gene is the most important causal element in the development. However, Lewontin writes that most systems are characterized by a plurality of causes. For instance he writes,

To be ill is precisely to be dominated by a single causal chain. . .Indeed, we may define ‘normality’ as the condition in which no single causal pathway controls the organism. The multiplicity of causal chains, all of weak

52 Pg 76 of Lewontin.
individual influence in their normal condition, present a special difficulty for the attempt to understand life processes. 53

Third, Lewontin claims that it is difficult to separate causes from effects due to feedback loops and multiple causal pathways. Finally, he suggests that the processes functioning in natural systems are historically and contextually situated.

Many DST thinkers, who are interested in how conceptual boundaries influence scientific practice, echo this type of approach. In her introduction to developmental systems theory, Susan Oyama writes that,

There are many kinds of influences on development, and there are many ways to group these interactants together. DST does not claim that all these sources of causal influence play the same role, nor that all are equally important (whatever that might mean). Rather, different groupings of developmental factors are valuable when addressing different questions. . .Many developmentally constructive interactions do not fit traditional categories, and for this reason have largely been overlooked or marginalized. . .DST emphasizes crucial but often overlooked similarities among resources that are usually contrasted.”54

In other words, when we model we need to choose the types of reduction that are most useful and relevant to our studies, not the types that we group together for other (perhaps historic) reasons.

Neither Lewontin nor Oyama make quite the further jump that interests me. The choice of a research question implicitly designates conceptual categories and therefore begins the process of revealing causal connections. When I push this notion further, I find that the causal connection is an artifact of conceptualization. If this sounds like a constructivist claim in a strong sense, then let me restate it. I believe

53 Pg 94 of Ibid. As will come up in my discussion of sickle cell anemia, I disagree that illness is characterized by a single causality. However, I found this quote to be provocative and interesting, and so decided to include it despite the plethora of equivalent Lewontin quotations that I do agree with.
that climate change originates from and affects systems which are extremely complex, especially when considered together. Despite the recent advances in certain theories of complexity, in computer science, ecology and biology, I believe we still know very little about how complexity originates and maintains itself, or how we alter it or create it. Thus, my point is that our reductionist science is often successful not because the simple causes we reveal are true, but because our experiments and the concepts we hold make it the partial causal relation relevant.

**Why Asking Questions Matters: Sickle Cell Anemia**

The DST desire to question how conceptions are designated and therefore how causality is made visible to us does not, to my knowledge, have a name in the literature. In this thesis, I will refer to it as utility-oriented reductionism because DST seeks to reduce wholes to parts that are relevant to the research question at hand. A DST theorist does not assume that any particular casual set-up is universal or that conceptual divisions should remain constant from project to project. In other words, it is not always appropriate to consider genetic effects, or to assume that organisms are fundamentally separate from the environment they inhabit. For this reason, DST thinkers analyze research topics very differently, with the knowledge that the subject is not oblivious to our needs, our interests or our questions. This relationship between ourselves and our categories places an enormous importance on the kinds of questions that we (as individuals, or as a society) ask. Often times, at their heart, questions are politically or ethically motivated, rather than drawn strictly from previous scientific
findings. This intimacy, especially when revealed in its gory detail as often happens during investigations into climate change, can make some people squeamish. Truth be told, it sometimes makes me feel squeamish too, but we can no longer afford to pretend that science is divorced from other human interferences. All we can do is hope that the questions we ask will reveal complexity in a most useful way. Thus, in my opinion, the DST indictment against stagnant concepts and stagnant questions becomes a moral stance against the same when applied outside of the biological realm.

In the discussion below, I will use utility-oriented reductionism to address two complex systems of development, a human disease and climate change. Part of my point is to show how concepts, questions and causality are interrelated. In a sense, when we ask a question we create a way for a certain type of causality to reveal itself. Causality is only visualized once acting concepts have been identified. This relationship explains why non-DST thinking, or historically contingent reduction in science, has been so successful. It appears that when we ask certain types of questions, we get an extremely useful answer by assuming that genes function as information. In order to articulate how genetic causality can be relevant, I am borrowing an example that Kitcher uses for a similar purpose. Sickle cell disease is a textbook example of how genetic causality can determine phenotype. In addition, this example carries a moral weight, because genetic causality has a direct effect on human health. The classic explanation of sickle cell anemia is that it afflicts individuals who are homozygous for a mutant allele. This allele codes for a part of

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the hemoglobin complex, and when both copies of the allele contain a single
mutation, the resultant protein folds differently and forms aberrant hemoglobin.
These strand-like hemoglobins cause the entire red blood cell to morph into a sickle
shape which blocks blood flow through capillaries. Kitcher uses this example to
argue that although some cases of reductionist science are fallible, others, such as the
logic used to deduce the causality of sickle cell, are more than justified.

If we agree that sickle-shaped red blood cells are the defining trait of sickle
cell disease and, furthermore, if we are interested in uncovering why some individuals
have this trait while others do not, then it is justifiable to conclude that genetic
causality reigns supreme in this case. However, at this historical moment, we know
the answers to those questions already. Now, we are interested in knowing a whole
different set of questions, like, why is it that some people with the disease suffer more
than others, or die earlier? We might also want to know how to best alleviate pain
and suffering. As we ask these public health questions, we become transported to a
different realm of biology.

Infants born with sickle cell anemia often have body pains, paleness and
jaundice. They may also experience a pneumococcal infection or an acute splenic
sequestration, both life-threatening conditions.⁵⁶ Today, most infants born with the
disease in the United States survive and are able to live with the disease for years.
Surviving adults with sickle cell often suffer vaso-occlusive crises, or sickle cell
crises, during which they experience intense body pains. Vaso-occlusion is the

number one reason why patients with the disease are admitted into hospitals. It is nearly impossible to predict when a pain crisis will occur, and the type of pain that the patient perceives differs from patient to patient. For example, patients who have sickle cell anemia and a relatively high amount of hemoglobin are more likely to experience increased numbers of individual crises. Additionally, it is likely that stress can also trigger the onset of the pain crisis. Current theory holds that there are two phases to the intense pain crises that sickle cell patients endure. In the first phase, the patient experiences intense pain, a decrease in red blood cell deformability, an increase in the number of dense cells and a number of other effects. In the second phase, these phenotypic traits decrease and the patient feels less pain. In many patients during this time, platelet count, fibrinogen and blood viscosity all increase, which may help induce the occurrence of a second pain crisis soon after the first. In addition, the following actions may help the patient reduce his/her experience of pain crises, the elimination or reduction of alcohol/smoking consumption, light and regular exercise, drinking plenty of water, and dressing warmly.

Based on the above information, it becomes clear that in some sense, the phenotype of sickle cell anemia is quite varied and complicated. Furthermore, if we are interested in preventing or diminishing the occurrence of pain crises, genetic

58 Ibid.
59 Deformability refers to the ability of the red blood cell to change shape slightly as it passes through narrow capillaries, a necessary and healthy attribute.
60 Ballas.
causality is no longer relevant. Certainly, the genetic causality is real, but the more important causality from the treatment angle is the interaction between misformed blood cells and a number of other material factors interacting on a local scale. I find this argument persuasive and interesting, because it illustrates my point earlier concerning how causal conceptions should be flexible based on moral, scientific and political needs. The question should shape what is relevant and what is real. However, even for those who disagree with this particular instance, it is easy to make the same point in the cases of most of the diseases wracking the United States today, including heart disease, cancer, obesity, and addiction. All of these diseases are biological, but none of them have been linked to a specific gene or even to a haplotype. The lack of a genetic correlation is likely to be due to the fact that these diseases are the products of complicated cycles involving disparate, heterogeneous forces which interact, develop and feedback upon themselves continuously.62

**Asking Developmental Questions About Climate Change**

If the most important question is how to determine who has sickle cell anemia or who is likely to get it, then it makes sense to use the genetic conceptual identity of the disease. However, as we saw above, as our questions become more concerned with aspects of pain management, the genetic causality ceases to become applicable

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62 It seems to me that in the case of these diseases, as with climate change (as I show later), the human desire to determine a single source of causality is related on a deep level to moral concerns about assigning responsibility and obligation. A genetic cause of a disease means that the individual is not to blame, but environmental causality can implicate society or the individual herself.
or relevant. It is thus clear that the questions we ask use specific concepts that in turn affect the causality of the system in question. This same idea is true for climate change. For example, a considerable amount of climate change research has been directed towards establishing an anthropogenic fingerprint of causality. In order to establish this fingerprint, scientists collect data on atmospheric and oceans temperatures at different depths, carbon dioxide concentrations and other indications of climate change. They then compare this data to numbers generated by a climate model, which is run under scenarios with varying levels of carbon dioxide emissions. If the model output which includes both human forcings (usually meaning carbon dioxide emissions) and natural forcings (such as pre-Industrial levels of greenhouse gases and the sun’s radiation) matches better with the data than the model output that only includes natural forcings, then an anthropogenic fingerprint has been detected.

Reading this description in this context should make it obvious that the attempt to find an anthropogenic fingerprint assumes the ‘pollution paradigm’ causality. In other words, the collected data is usually compared to output from a general circulation model in which the only source of anthropogenic forcing is the emission of carbon dioxide and aerosols. Missing from the analysis are the interactions between different human modified systems which will eventually create impacts. However, if we are interested in determining whether climate change is anthropogenic, or of human origin, then it is useful to use the pollution paradigm and to conduct fingerprint analysis in this way. In fact, it would be impossible to include all the interaction effects of other human modified systems and still detect a carbon dioxide fingerprint. The analysis and the question of anthropogenic fingerprinting
assumes that human forcing can exist separately from natural forcing. However, if this anthropogenic fingerprint had never been found, then it is likely that little work on climate change as a whole would be accomplished. Thus, the use of the pollution paradigm to find fingerprints is immeasurably useful.

Adaptation Challenges the Traditional Means of World Building

Just as the necessity for adaptation has endangered the academic acceptance of the pollution paradigm, it is also beginning to shift emphasis in modeling and assessment towards systemic analysis. At its heart, modeling depends on our ability to mimic systems accurately. In turn, this mimicry assumes basic rules about what a system is and how it functions. Models mediate between data and theories of causality. This is particularly true in climate models, because modelers often work without knowledge of direct causal laws. Much effort is therefore directed towards how well a climate model is able to resemble historical data. This section will take us briefly through a history of modern climate modeling in order to illuminate some of the underlying assumptions which are built into models and assessment techniques.

Paul Edwards refers to climate modeling as “world building” in his thoughtful essay, Representing the Global Atmosphere. In his work, he does not elaborate upon this term, using it to refer to the ways in which models create unified global

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63 This chapter comes from a book entitled, Changing the Atmosphere, which is altogether exceptionally bold and original. It is bold because it dares to think critically about the social and epistemological issues of an important environmental concern, and does so without downplaying the importance of political action. Edwards.
phenomena out of local and limited data sets. However, it is relevant to my work because GCMs are world-building in several larger senses as well. First of all, GCMs are often the models most highly valued by policy-makers, even though the modeling community often disagrees.\(^6\) Thus, policy-makers use GCM results to make decisions, and construct our world. Secondly, GCMs are world builders because they include and exclude certain aspects of the systems they represent. Of course, this is completely necessary as an indiscriminate holism leaves us with nothing. The model therefore chooses how to reduce the world to make it most useful to us – and in doing so it constructs a new world. Therefore, the types of reduction that we deem important have direct bearing on our understanding in a myriad of ways. It also speaks to the benefits of reducing complexity in multiple ways (leading to the modern climate model hierarchy).

Despite occasional reminders that the climate model hierarchy is more important than the results of any one model, general circulation models (GCMs) tend to steal the limelight in public discourses on climate science. However, GCMs do not exist in a cultural vacuum and the extent to which they are useful depends on the kinds of questions that policy-makers and scientists are interested in answering. During the modern global warming debate, policy has tended to focus on questions such as, “Is the global mean temperature rising,” “is this trend the result of human activity,” and “what levels of carbon dioxide emissions will prevent dangerous interference with the climate system?” In other words, since the seventies and eighties, mainstream concern has been over fingerprinting anthropogenic influence in

\(^6\) See pages 44-45 of Ibid.
climate and modeling different mitigation trajectories. As has been previously stated, global circulation models are most useful when answering these types of questions. However, as the IPCC and other organizations have begun to realize, the climate change issue contains a huge variety of piggybacked issues, such as economic development, globalization, deforestation and pollution. In fact, climate change will be most visible through a series of interacting effects and its amplification of existing vulnerabilities in the human-nature system. As is clear from the algorithmic definition of complexity, complex processes take up large amounts of computational resources. Edwards and several other thinkers on this issue have commented that this limitation forces modelers to choose between complexity and resolution. This explains the frequently expressed hope that more computational power will greatly increase the accuracy of GCMs. The mistake here is in assuming that the basic complexity of the model, which consists in attaching new modules which interface with each other by exchanging data, is the same type of complexity that exists in the human-climate system. Models must therefore make decisions not only about the tradeoff between complexity and resolution, but also between types of complexity.

The History of the Global Bias in GCMs

General circulation models have traditionally chosen to use a general systemic view of complexity and have focused on representing the world as a connected number of global sub-systems. Up until the 1960s, climate change was

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65 Edwards writes that he is using complexity to refer to two things “the number of phenomena simulated and the level of detail at which they are modeled.” Pg 55, Ibid.
conceptualized as occurring locally, perhaps because of the local nature of weather and weather data. However, during the decade of 1965-1975, global modeling began to dominate over localized weather models. Edwards notes in his *Representing the Global Atmosphere*, that this discipline shift reflected a wider paradigm shift towards global-driven climate science. And the new climate models, rather than weather models, were integral to the new paradigm. For example, in the early 1970s, a group of scientists appropriated the statistical dynamical models used in numerical weather prediction to create climate models for investigating traveling weather patterns over time. As models have grown in complexity, much emphasis has been placed on making models with larger domains, higher resolution and longer time periods.

During this period of time, the Massachusetts Institute of Technology sponsored a report that emphasized interest in global rather than local environmental issues. The purpose of the Report of the Study of Man’s Impact on Climate (SMIC) was to document the many types of inadvertent climate modification wrought by humanity on the planet. For example, in the summary section of the report, it lists urbanization, pollution of the atmosphere, aerosols, greenhouse gases, agriculture, desertification, dam building activities, and river diversion all as examples of inadvertent climate modification. The authors wrote, “We have spoken of some of the effects of industrial activity, but for thousands of years before the Industrial Revolution, agricultural and animal grazing practices have had a profound influence on large regions of the world, and it seems very likely that these have already resulted

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66 Ibid.
in changes of climate in those regions." Notice how heterogeneous SMIC’s understanding of inadvertent climate modification is. The authors included nearly every type of land cover change that humanity has created upon the planet. It is also interesting that the SMIC report, really the premier report on these global environmental concerns at the time, does not include a section specifically on GCM modeling. This is because in 1971, GCM models had not yet risen to become the favored type of model in policy analysis. Despite this, SMIC maintained an interest in global environmental problems. The report reads,

The following scientific objectives were adopted for SMIC: to review SCEP findings critically, to point to global environmental problems that were slighted or overlooked; to obtain a more complete assessment of present knowledge. . .and to point to questions requiring international policy decisions.  

The report focused on global environmental issues that required coordinated international responses. It also called for young scientists to engage with global climate issues, driving the focus away from local ones. Thus, as general circulation modeling began to come of age, it did so during a time when global environmental problems were prioritized over local ones. Remember that this was also the time when people were just beginning to fear rather than embrace inadvertent weather modification. General circulation models fit the mood of that time period perfectly, namely the desire for international cooperation and the assumptions that gradual mitigation would be a competent stand-alone solution to climate change.

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68 Ibid.
69 See page xv of preface, Ibid.
The State of the Art in GCM Modeling

Contemporary GCMs consist of a three dimensional grid with a resolution surface of about 4-5° latitude by 7-8° longitude. In addition, most modern GCMs are a compilation of land, ocean, atmosphere and sea ice modules coupled together.⁷⁰ For example, ocean general circulation models exchange heat, salinity and motion at the boundary layer data with the atmospheric and sea ice modules.⁷¹ The atmosphere grid generally has about eight to twenty layers, with multiple thin layers at lower altitudes. Similar to former models, each grid box completes its own series of equations of state and communicates to other grid boxes via equations of motion. Despite the high resolution, meaning the large number of small grid boxes, current atmospheric theory holds that many important processes occur at sub-grid levels. For example, cloud formation begins with tiny particles much smaller than the modeled grid boxes. However, most GCMs derive cloud activity from average grid box temperature and humidity.⁷² This is a good example of how model causality does not match theoretical causality. Parameterizations, the abstraction of complex processes to exogenously imputed numbers or simple equations is (at present) an indispensable part of climate modeling. The most important processes, which are represented by

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⁷¹ Ibid.

parameters, include ones involving cirrus and stratus cloud processes, cumulus convection and sub-grid mixing.  

Researchers use climate models to run several different types of simulations, including control runs, idealized climate simulations and time-dependent climate-forcing simulations. In control runs, modelers keep the variables thought to control global mean temperature, namely solar activity and atmospheric concentrations of greenhouse gases, at constant values. The value at which these forcing variables are set is equal to present day levels, and therefore a control run should mirror present day climate conditions. Idealized climate simulations include the well-known carbon dioxide doubling experiment. The experiment continues until the climate reaches a new steady state under conditions of increased global mean temperature. Time-dependent climate forcing scenarios are considered the most accurate. They include forcing variables that change over time, including volcanic eruptions.

The limitations of modern GCMs are acknowledged by scientists, but often believed to be intrinsic to the project. From the viewpoint of this paper the three largest weaknesses of GCMs are that they lack regional detail, fail to include adaptation measures and attempt to isolate physical and social processes.

The next part of this thesis will examine the last of these issues, particularly by focusing first of the GCM land use module and then on the more modern carbon cycle module. The penultimate draft of the U.S. Climate Change Science Program and the Subcommittee on Global Change Research notes that the land model is both highly important and also particularly difficult to model because, “the land surface is

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73 Climate Models: An Assessment of Strengths and Limitations.
very heterogeneous and biological mechanisms in plants are important. Climate model simulations are very sensitive to the choice of land model.” Figure 6 shows some types of variables and processes that the typical GCM land module might include. Although the level of detail considered in these physical processes is admirable, we might ask, where is this idyllic landscape visualized here? Obviously, it is somewhere far away from widespread agriculture or urbanization. There are no impervious surfaces, no wheat monocultures, no sign that this planet is in fact continuously being manipulated by our own species. According to the penultimate draft of the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, land models may include ecosystems but usually do not attempt to model human changes such as deforestation or reforestation. The report also does not address whether modeling of these human activities is critical to the future of land modeling in general.\footnote{Ibid.} \footnote{Ibid.} \footnote{Gruber, N., P. Friedlingstein, et al. (2004). The vulnerability of the carbon Cycle in the 21st Century: An Assessment of Carbon-Climate-Human Interactions. The Global Carbon Cycle: Integrating Humans, Climate and the Natural World. C. B. Field and M. R. Raupach. Washington, Covelo, London, Island Press. 62.}

Accurately representing the carbon cycle is a second example of the importance of human integration into natural systems. Even including the carbon cycle into models is a recent development and in many current models it is still not fully integrated, meaning that fossil fuel emissions are given exogenously and the model calculates atmospheric CO2 as the difference between emissions and land and ocean absorption.\footnote{Ibid.}
including accurate and complete feedback mechanisms in climate models is of the utmost importance because it is through this inclusion that the models will be able to generate useful results. However, focusing on the feedbacks and patterns in the climate system also forces one to recognize the prevalence of such cycles and their inter-systemic nature. The best example is the carbon cycle, which is intimately involved in both physical and human systems. For example, increased global concentrations of carbon dioxide lead to a higher temperature in some areas. In turn, the temperature increase causes increases in the rates of soil respiration which results

77 Figure from, Climate Models: An Assessment of Strengths and Limitations.
in more carbon dioxide being released into the atmosphere. Other examples of possible positive feedback mechanisms include carbon stored in frozen soil, in wetland soil and in forests at risk of fires. Each of these terrestrial carbon sinks may be affected by climate change impacts, and will in turn increase the magnitude of climate change. As we shall see, carbon cycling is also a part of numerous human feedbacks as well.

**GCMs Isolate Human Interactions: The Human-Nature-Carbon Cycle**

The atmosphere and the land exchange carbon continuously in several different ways. First, biotic elements, especially plants, store a great deal of terrestrial carbon. There is an annual cycle during which biotic elements decompose and the respiration of consumer species returns some of that oxygen to the atmosphere. As could be expected, the net gain or loss of carbon from the land varies from year to year based on variables such as reforestation or deforestation, wildfire, and land clearing. Tropical forest is the largest terrestrial sink for carbon, although different types of soils also contain large amounts of the element. During the past two hundred years, land use has favored increases in carbon emissions from these biotic sources. For example, the expansion of cropland and pasture into previously

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78 Gruber, Friedlingstein, et al.
79 A carbon sink is a area or process that retains carbon, thus preventing or at least drastically slowing its release into the atmosphere.
forested land has caused net increases in atmospheric carbon. The ocean is a vast carbon sink and it also exchanges carbon with both the land and the atmosphere. Most of the carbon found in the ocean is inorganic carbon.\textsuperscript{81}

In an illuminating piece on the carbon cycle, Sabine et al point out two areas where the carbon cycle is still not well understood, regional budgets and variability. In a way, these two weaknesses reflect some of the same problems of global climate change modeling. Although we cannot be sure how important these two weaknesses are, it is certain that the carbon cycle is not modeled very accurately because it is not modeled as integrated. For example, industrialized countries emit most of their carbon dioxide through the combustion of fossil fuels, whereas many developing countries are emitting carbon by changes in land use. This difference will cause regional feedbacks which are specific to that area, and may affect the carbon cycle in those areas. Additionally, carbon-rich products are traded throughout the world, such as fossil fuels, but also cereals and other agricultural products. Therefore, the global market plays a not-insubstantial role in how the global carbon cycle is materialized.\textsuperscript{82}

The second weakness in our understanding of carbon is the variability of carbon cycle processes. This type of knowledge is important for modeling the future impact of forest fires, the release of carbon from marine deep sediment, and other processes which are highly variable, poorly understood and perhaps influential in the carbon cycle. The carbon cycle is an example of the tension between old methods of

categorization and newer ones because it is a process that cuts across the boundaries of traditional module distinctions. Developmental systems theory would dream of a general circulation model which places processes, such as the carbon cycle, at the center of modeling efforts rather than modules.

The IPCC’s Fourth Assessment Report emphasized the need to develop better modeling of the carbon cycle, in particular the response of the terrestrial and oceanic carbon sinks to increases in temperature. However, it is clear that the writers of the report are envisioning further detail and resolution of the figure above, rather than the long overdue incorporation of the human carbon cycle into models. As can be concluded from figure 6, the most advanced and fully coupled GCMs have a fairly accurate representation of what is known about the carbon cycle. However, the only human modified interaction that this module allows for are fossil fuel emissions and a representation of land-cover change. Models which fully couple human and physical components of the carbon cycle do not exist. However, preliminary studies have shown that these types of feedbacks may lead to an acceleration of carbon emissions from terrestrial and oceanic sources.\textsuperscript{83}

Despite knowledge that the carbon cycle has been altered in significant ways by human intervention, many GCMs still use a simplified representation of the carbon cycle which excludes human influence. Different aspects of the human-carbon cycle include agriculture, forestry, urbanization, industrialization and commerce. Patricia Lankao argues that carbon-relevant social actions exist in certain patterns both

\textsuperscript{83} Field, Raupach, et al.
globally and regionally. In her perspective, human activities have transformed the carbon cycle. For example, humans have grown croplands and cleared forests, burned biomass and held large populations of livestock. Each of these activities changes the balance between terrestrial and atmospheric carbon, and each activity is also part of a larger set of social and developmental feedbacks. Urbanization is also an important spatial and temporal trend for the distribution of the carbon cycle.

Figure 7: The typical global carbon cycle incorporated into atmospheric-ocean general circulation models (AOGCMs)
Internalizing Change: Adaptation

The above information describes how dominant forms of modeling are still missing the needed developmental interactions between human and natural system components, particularly in regards to the carbon cycle. However, if we were only interested in modeling the effects of internationally coordinated mitigation policy, it is possible that this type of systemic representation would be adequate. However, the urgent need for models of adaptation has meant that the inability of these models to realistically stimulate endogenous change or local interaction effects has become readily apparent. In 2000, when interest in adaptation first surfaced, Smit et al. raised three crucial questions that continue to define debates surrounding adaptation. These questions are, who or what adapts, what does it adapt to and how does that adaptation take place? The paper formulated a partial answer by noting that the adaptation is locally dependent on characteristics of the system in question and the hazard. Additionally, adaptation to climate change is rarely a direct reaction to an increase in mean global temperature, and even less often a reaction to an increase in carbon dioxide concentrations. Instead, adaptation responds to interacting factors, such as the topography of coastline, insurance rates, the thermal capacity of the ocean and perceived risk of flooding.\textsuperscript{86} This final point begins to reveal the fact that a myriad of factors, both human and natural, interact to create the phenomenon of climate change and to shape our available responses.

\textsuperscript{86} Smit, Burton, et al. "An anatomy of adaptation to climate change and variability."
In the first half of this thesis, I illustrated how varying definitions of adaptation taken from across disciplines all assume that adaptation is the response of the internal system to an external stress. However, upon reflection in both biology and in climate change science, it is clear that adaptation is not strictly a response of one system to another. For starters, in climate change, the ‘external’ stressor that human systems must adapt to is a result of human intervention. Therefore, there is a hint, even from the beginning, that adaptation results in multiple causal processes that feed off of each other. The IPCC is the international body producing most of the theoretical work on climate change. Its most recent report introduced some novel ideas concerning adaptation and system interaction. For example, part of the executive summary states,

Both climate and non-climate drivers affect systems, making analysis of the role of climate in observed changes challenging. Non-climate drivers such as urbanization and pollution can influence systems directly and indirectly through their effects on climate variables. . .socioeconomic processes. . .also affect multiple systems.  

Although in that case the division between various ill-defined systems persists, the report recognizes a multiplicity of causal influences on climate change. Additionally, the report points out that non-climatic drivers can have large influences on climate change processes.

Current thought about adaptation recognizes that the ability to adapt is a characteristic of a system under a number of local conditions. Therefore, the policy goal is to have adaptation continuously improve the internal system (social or biological) over time, as the external (environment) remains independent of these

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87 Page 83, Working Group II, FAR.
machinations. However, even a shallow consideration of climate change reveals that social and natural systems do not become increasingly adapted to a stable and external environment over time. For example, the burning of fossil fuels could be considered a historical adaptation, and yet it changed the “external” climate in fundamental ways that will now shape our future adaptation efforts. In other words, the internal system creates the external system and therefore the conditions for its own path of development. The most novel and relevant research in adaptation is done by thinkers who relax the boundary between the external and internal (or humans and climate) and research adaptation as non-random action that responds to the historical nature of a system and a complex causality. For example, the FAR mentioned that adaptations (like mitigation plans) will have costs and externalities associated with them. They will also interact in feedback chains between different drivers. The concept of a cost of adaptation is a very important one, since it recognizes that change is temporally situated – and that all adaptations or actions have consequences. In the end, the real distinction to be made is not between external and internal systems, but around different feedback and feed-forward causal chains. As the first half of this thesis recognized, serious consideration of adaptation policy therefore requires thinking at the systemic level and even focuses attention on the role of developmental processes.
Assessment Challenges to the Pollution Paradigm

The IPCC is frequently one of the first organizations to pick up upon emerging conceptual changes and novel methodologies. In late 2007, the organization released their Fourth Assessment Report, which included a chapter on new assessment and modeling approaches to climate change. The report implicitly acknowledges that the driving force behind the need for new types of assessment is the recognition of necessary adaptation policy. In particular, the report includes descriptions of new assessment methods such as “assessments of current and future adaptations to climate, adaptive capacity, social vulnerability, multiple stresses, and adaptation in the context of sustainable development.”88 The inclusion of this chapter is merely one indication of rising interest in systemic thinking about climate change.

The IPCC designates several substantial challenges to the traditional (pollution paradigmatic) impact assessments, the most relevant of which are adaptive capacity and risk, vulnerability and integrated assessment models.89 To consider the latter of these first, vulnerability and adaptation research has been growing in popularity. One of the key breakthroughs in adaptation research has been the inclusion of historic emergency response data in order to better model response to climate related

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89 The report acknowledges that the vulnerability and adaptive capacity approaches are very similar, but chooses to distinguish them. In my opinion, both the concepts of adaptive capacity and vulnerability are attempts to get at the idea of system resilience and development and eventually should be part of the same theory.
disasters. For example, the mortality and morbidity correlated to flooding in Europe can be used to predict future responses and adaptations that will result from analogous climate change impacts.  

Using similar techniques scientists are now finding indicators of system-level vulnerabilities to specific exposures. This new approach moves towards a DST perspective by treating human and natural factors as equal types of causes. In other words, social factors, such as poverty, can drastically affect the supposedly physical phenomenon of climate change. Finally, both of these new assessment approaches direct attention away from global causality and back towards the regional level of impacts. This move will eventually have strong reverberations in modeling communities, as the state of regional modeling research is currently less sophisticated than the state of global modeling research. In addition, components such as carbon dioxide concentrations function differently when considered globally rather than locally. Carbon emissions enjoy primary causality when considering global causal processes (via their effect on global mean temperature), but only an indirect local causality. The eventual aim of the vulnerability and adaptive capacity approaches is to map the risks of damage from specific exposures onto particular areas using a combination of social and natural predicting factors. Taking a step further back, one of the most important systems affecting system resilience across the world will be the communication of relevant, local information to the regional actors and the ability of those actors to act upon that knowledge.

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Figure 8: This figure depicts the many types of components which a typical Integrated Assessment Model (IAM) might include.\footnote{Schneider, S. and J. Lane (2005). "Integrated Assessment Modeling of Global Climate Change: Much Has Been Learned - Still a Long and Bumpy Road Ahead." The Integrated Assessment Journal 5(1): 41-75.}

The other assessment type that has been steadily gaining influence and prestige is integrated assessment. Integrated assessment modeling attempts to represent complex interactions between heterogeneous systems over time.\footnote{Carter, Jones, et al.} Economists design integrated assessment models (IAMs) with decision makers in mind, and are therefore often much less computationally expensive than general circulation models or even earth system models of intermediate complexity.\footnote{Edwards Representing the Global Atmosphere.} As a result, modelers will often use the data output from a GCM for certain climatic
variables, and then plug the relevant numbers into other system functions. In addition, IAMs often estimate the carbon emissions from a given scenario of economic development and then convert those numbers into partial pressures which control global mean temperature output.

Integrated assessment modeling has important roots in economics, a discipline that picked up early on the idea of feedback processes. Many economists realized immediately that mitigation, like any other policy measure, will have costs as well as benefits associated with it, and that therefore the questions of when and how are extremely important. For example, William D. Nordhaus, a climate change economist, designed one of the first IAMs, called the Dynamic Integrated Model of Climate and the Economy, or DICE. The basic idea of DICE is that a society must weigh the benefits and costs of mitigation, taking into account future damages at some discounted rate. The costs of mitigation are often costs to energy and industry, whereas the benefits are to agriculture, coastlines, ecosystem and health (among others). DICE assumes that emissions reductions behave like societal investments in a Ramsey model. The model is designed to maximize the discounted value of utility, as subject to several economic and geographic constraints. In the model, each identical nation maximizes its own inter-temporal utility function as the sum of the discounted utilities of per capita consumption multiplied by the size of the population. Climate change impacts are limited to the global mean temperature.

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94 Discounting means that utility in the future is worth less than utility now.
96 Ibid.
The model assumes a direct relationship between global temperature and income loss in order to model climate change damages.

Integrated assessment models retain the systemic structure of the general circulation model while including certain sub-systems of human economic activity. Therefore, although they are systemic, IAMs are not developmental because they do not focus on human-natural cycles of contingency, such as agricultural development or the carbon cycle. Additionally, similar to general circulation models, many IAMs such as DICE choose not to spend computational resources on modeling specific impacts beyond temperature rise. As adaptation policy becomes increasingly important, this lack will become highly problematic.

**Intervening in Nature:**

As can be seen, all of the most prestigious modeling approaches are systemic in the sense of general systems theory. In other words, they do not really include any notion of development, or how internal change might occur in a system. In addition, there is no model that I know of which attempts to build human-nature system functioning in a fully integrated way. The drawback of using a systems based, rather than developmental systems approach, is that it is hard to predict what the long-term, structural changes of our decisions might be. If we decide to rely largely on mitigation measures in order to control risk, how will that decision affect downstream global politics and economies? Perhaps it will move us into a world where globally-located control and regulation is more accepted. Or, perhaps it will eventually be a
failure due to the inability of nations to cooperate. On the other hand, the consequences of the adaptation measures we choose will also have large structural impacts on the future. As the political theorist Robert Jervis once wrote, “In a system, the chains of consequence extend over time and many areas, the effects of actions are always multiple.”  

When we model, we create a way for virtual selves to interfere in virtual complexity. However, there are a limited number of fields (geoengineering being one) which propose actual intervention in realistic complexity. One of the most well-developed fields which already attempts to intervene in complexity in order to restore system functioning is ecosystem restoration. For example, policy makers decided to spend $8 billion on the 20-year restoration project in order to restore former water overflow patterns in the region of the Everglades in southern Florida. Restoration ecology can be defined as “the return of an ecosystem to a close approximation of its condition prior to disturbance.” Ecological engineering and restoration depend upon theories as to how ecosystems function and which parts of the ecosystems are most important to restore. For example, ecosystems are visualized as systems through which matter and energy pass and cycle. Ecosystems are open, meaning that they exchange matter and energy with the external environment. In addition, they are dependent on constant inputs of energy from external sources. Ecosystem terminology often uses Haugeland’s terms of components and interfaces. For

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99 Ibid.
100 Ibid.
example, it is a common convenience in the field to think of the components of an ecosystem as being interconnected, meaning that most actions result in both direct and indirect effects. In addition, indirect effects can be more important than direct effects due to accumulation. Ecosystems, like general systems, are envisioned as hierarchical and homeostatic. One of the greatest controversies in ecosystem restoration is whether the complexity and resilience of an ecosystem arises from the number of components interacting, or the number of interactions, or interface structure. For example, it has been long observed that there are certain keystone species in ecosystems which seem to play a very central role in the functioning of the whole system. In addition, there are indicator species whose populations can indicate the existence of a variety of correlated conditions.

Restoration ecology, and the related field of sustainable development, are much concerned with the concept of resilience. These disciplines have already recognized that social and ecological systems cannot be separated and therefore they define the resilience of social-ecological systems to be related to, “the magnitude of shock that the system can absorb and remain within a given state; the degree to which the system is capable of self-organization; and the degree to which the system can build capacity for learning and adaptation.” Folke, C., S. R. Carpenter, et al.

Although it is much too early to posit a relationship between complexity and resilience, notice that both concepts employ the notion of self-organization. One future path of hybrid research into complex systems may be whether complexity necessarily means higher resilience to stress. Developmental systems theory would probably dispute that living systems exhibit

\[\text{Folke, C., S. R. Carpenter, et al.}\]
spontaneous self-organization principles. However, there is no denying that natural systems and even human-nature hybrid systems (to a lesser extent) exhibit complicated regularities. If it could be possible, understanding how these universal or semi-universal regularities develop would be useful in both restoration ecology and climate change research. Although there is little direct research into the matter, restoration ecology tends to assume that the capacity of systems to develop into patterns of self-organization is healthy, whereas the human transformation of most hybrid systems into simplified monocultures is not. In my opinion, this is true for many systems such as agriculture, but it would be interesting to investigate whether diversity (and of what kind) is a prerequisite for resiliency. Climate change policy could use this type of research to decide how to implement adaptation policy, since the best types of adaptation will improve system resiliency. There is no reason to assume that the principles that indicate resiliency or complexity in a natural system will indicate the same things in a human system. However, it is possible that resiliency demonstrated by human managed or human modified systems might exhibit similarities, or at least provides clues as to the relative successes of management strategies.

The resilience perspective changes the emphasis from policies that attempt to control change in a “stable” ecosystem, to those attempting to manage the adaptive capacity of the system. According to these disciplines, resilience is often associated with diversity and with resources that regenerate slowly over time, such as soil banks and genetic diversity. Restoration ecology also teaches us the surprising revelation that attempting to rigidly control development can decrease resilience. For example,
different management styles of forest fires have often been too rigid and have resulted in disasters. Resilience management is therefore concerned with building systems which are flexible and able to adapt, “it attends to slowly-changing, fundamental variables that create memory, legacy, diversity and the capacity to innovate in both social and ecological components of the system.”\textsuperscript{102}

Restoration ecology suffers and benefits from the same legacy of general systems theory. Although recognition of the growth of “emerging ecosystems”\textsuperscript{103} is growing, restoration ecology remains stymied in debates over what it is trying to restore. However, the plethora of actual projects and interventions into complexity provides insight on the following aspects of complex systems. First of all, restoration ecology provides important research on the subject of levers, or keystone species, meaning the areas of systems that might be more easily manipulated in order to influence system functioning. It is my opinion that long term adaptation measures will require deeper systems building, but it is possible that in the short term there are certain levels, or at least certain systems which are more important than others. For example, perhaps making the process of urbanization more sustainable would be more economically manageable and have more downstream effects than attempting to do the same with agriculture. Second, restoration ecology has an intuitive sense of how to engage communities. Third, restoration ecology seriously considers the notion of resilience. Fourth, ecosystem restoration pays attention to multiple thresholds and stable states that ecosystems can inhabit. For example, Arctic

\textsuperscript{102} Ibid.

\textsuperscript{103} Meaning ecosystems, like urban parks, that have adapting to substantial human influence. Folke, C. (2006). "Resilience: The emergence of a perspective for social-ecological systems analyses." Global Environmental Change 16: 253-267.
ecosystems can be either grass dominated or moss dominated, while freshwater systems can be either characterized by clear water, benthic vegetation and game fish, or by turbid water, blue-green algae and game fish absent. What types of stabilities and thresholds might human-modified systems exhibit, and how can we decide to move from one stable state to another?

We humans widely consider ourselves to be the most adaptable species in existence. Our physical structures, our irrigations, agriculture and vaccines protect us from the environmental impacts that other species must endure with high mortality. However, as I wrote this thesis I began to wonder whether most of our adaptations were merely reactive, rather than truly anticipatory. In other words, if all of our adaptations have a cost, in the sense of downstream structural and developmental reverberations, how adaptive are they actually? Thus, the hardest part of system-oriented adaptation research and policy will be the attempt to enhance the resilience of the socio-ecosystems, such as agriculture, on which we depend. Why has human influence on systems tended to reduce, rather than enhance complexity and resilience? The extent to which human, short term adaptation measures degrade the resilience of holistic systemic functioning and therefore create long-term feedbacks, which may not be addressed by mitigation, is also important. What does it mean for a hybrid human-natural system to be resilient? In addition, the question of development will become of increasing importance as more research becomes more systemic and adaptation-oriented.
References


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