Bursting the Atmosphere

what happens when
rain falls up

the book by
Robert Ben Mitchell

you will never look at the sky
the same way again

First Edition

Library of Congress Control Number: 2014917122
CreateSpace Independent Publishing Platform
North Charleston, SC

ISBN-13: 978-1502452443
ISBN-10: 1502452448

Book Industry Subject and Category (BISAC)
Science / Global Warming & Climate Change

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DEDICATION

This book is dedicated to John Clarke, the once spiritual counterpart to my hypothetical Lewis.

ACKNOWLEDGMENTS

I want to thank Kathy Bailey for having a spell checker better than mine. May the powers that be save her some extra oxygen.

I also want to thank Alex Dobuzinskis for finding the missing link.

No snowflake in an avalanche ever feels responsible.

- Baron Stanislaw Jerzy de Tusch-Letz (1909 - 1966)

When you are one hundred percent certain is when you are most likely one hundred percent wrong.

- Robert Ben Mitchell (1958 - ?)

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Introduction

There is an old saying in medicine which still applies to all sciences today. It states that fifty percent of what we know is wrong, but we do not know which half is incorrect. In other words, though we know a lot, we are far from knowing everything, and we still have so much more to learn. That is why this is a very difficult book to write. For how can anyone begin to talk about the end of all life on Earth, given there are still countless unknown species right beneath our feet and oceans?

This book is based upon an article I wrote in 2009 when my then boyfriend, John, insisted I do so after he endured too many agonizing months of listening to me drone on and on about this subject. Upon completion, I immediately sent copies of the paper to dozens of experts in the fields of geology, climatology and astronomy. The response was immediate and deafening: absolute silence. So, I took that vacuous reaction as an indication that more study was required on my part, and that is what I have been doing for the past five years.

One of the difficulties in writing something like this is that you have to know a lot to make it credible. After all, if the Sagans and Hawkins of the world have not already written such a tome, then who am I to scribe such a text? I often asked myself that question, and I have finally come to understand the answer. This kind of book is usually written by someone who specializes in a relevant area of study: astronomers write books on planets, doctors write books on medicine, and so on. Yet, to become so learned, these authority figures must limit their knowledge to a very narrow field of study. In the end, they often learn so much about so little that, taken to the absurd, it could be said that they know everything about nothing. I am just the opposite.

While I do have an osteopathic medical degree and teaching certification in multiple fields of science (chemistry, physics, biology, general science and basic mathematics), I never earned certification in any medical specialty, even though I have given continuing medical education lectures to large groups of specialty-certified physicians. Instead, my lifelong specialty has been to not specialize in anything at all. Whenever I began to learn too much about a subject, it would raise so many questions for me in other areas that I had to leap outside the box. Chasing a speciality was too myopic and mentally claustrophobic for me. Consequently, I have learned a moderate amount about so many things that, taken to the extreme, one could say that I know nothing about everything.

Being an academic generalist, it has been somewhat easy for me to look at this question about the end of all life on Earth without getting lost in the details. I am able to distinguish the forest from the trees, simply because I am able to walk through and around the woods without tying myself to any one particular trunk or limb. That is what makes me the perfect person to write this kind of book, which seeks an impossible answer while, hopefully, raising innumerable questions. I can show you the big picture while talking about the details, and I can explain the seemingly insignificant minutia without losing sight of the larger scenario.

Given the complexity of this book's topic, one of my main goals has been to write it in a way that is easily understandable by those with modest, as well as advanced, levels of education. For if it is to have any impact, this is one of those books that needs to be understood by the masses and not reserved for the elite. My original thought was to make it so simple that it would not need any references: so easy to understand that everything in it would be common knowledge. After completing the first draft, I realized this was not possible. So, on a friend's advice, I have compromised.

Rather than fill this text with lots of obscure citations to academic articles and writings no one has read in over a decade, I decided to only reference information sources that most people can readily access. While I could cite data from Sir Vivian Ernest Fuchs' classic 1962 British Antarctic Survey [1], few people would know where to find it or even how to interpret it. In my younger days when we had questions, the library was the only place to go. Today, when you want to know something, you go on the internet, and that usually means Google or Wikipedia.

Wikipedia has some nice features as a research tool. Though it is open access and anyone can rightly or wrongly contribute to it, the people behind the curtain there do make an effort to assure that historical and scientific listings are kept up-to-date, accurate and well-referenced. While by no means a highly-detailed and all-encompassing dissertation on any subject, Wikipedia is an every-person's portal to our ever-expanding database of human knowledge. It is also a living document which, unlike single edition academic texts, is constantly being updated and renewed as new information is being discovered. That way, even though, as in medicine, half of it may be wrong, at least they practice reasonable due diligence to sustain, expand and improve the half that is right.

These pages explore the end of all life on Earth, but its real goal is to be the starting point for your journey into this subject. As such, it must be easy to understand, easy to verify, and easy to use as a tool to begin answering the uncountable questions it will hopefully raise. That is why I have used online links to Wikipedia as my main reference source for most of the facts and data which I will be discussing in this book. In addition, the book's reference notes section will include many of the calculations I performed to interpret this data.

Though this book was very hard to write, once begun, I was able to complete it fairly quickly. Given I had five years to mull it over, the entire process from beginning to end had an almost Genesis-like quality, as I wrote the six chapters - one per day - in six consecutive days and then at least tried to rest on the seventh. While that is one of the few theologic references you will find in this text, for my own posterity, I have left the original inscription dates at the top of each chapter.

Now that it is done, the only thing left is to see what you think.

Good luck!

Robert Ben Mitchell
September 14th, 2014

Chapter 1 - Coffee

September 7th, 2014

"Thank you. Black, no cream or sugar, please," I reply.

So here goes. Yet another end of the world scenario which many critics will likely, and hastily sweep aside. Yet, I would state in its defense that this one is unique as, unlike most of its predecessors, it is not based on religious philosophy or texts. Instead, its entire argument rests upon two principles of physics: thermodynamics and the Ideal Gas Law. More precisely, this book, instead of using theology, will describe the end of the world in terms of phase change leading to an expanding and depleted atmosphere.

For those who seem a little intimidated at this point by words like thermodynamics and phase change, do not run to find your high school or college physics books just yet. In some ways, I fully understand your trepidation in engaging in an ivory-tower discussion about such a lofty topic. That fear notwithstanding, I was once told by a professor of mine that if you can't explain your ideas at eleven o'clock in the evening to the graveyard shift waitress who is serving you coffee at an all-night diner, then no one is ever going to understand what you are talking about. So drop your books and pick up your aprons, because I am going to try and make this explanation easy to understand.

Personally, I knew we were in serious trouble way back in 1970. It was the year Richard Nixon was President of the United States, Paul McCartney announced the official split-up of the Beatles, Linus Pauling declared that large doses of Vitamin C could ward off colds, and I was in the sixth grade. My epiphany came during a general science class while we were studying the part of our books labeled "The Universe." We were at the end of this chapter where everyone gets hit by the traditional bad news and good news regarding our solar system's finale. The bad news was that one day the Sun will expand from its current size so dramatically that it will engulf and incinerate the Earth. The good news was that the scheduled incineration date was some five billion years away.

Right after explaining this gargantuan, doomsday event, our teacher stated, "All right class, let's turn our pages to the next chapter and begin reading about photosynthesis." My hand immediately shot up. "Yes, Mr. Mitchell?" inquired the teacher.

"Well, you just said the Earth is going to end. Could we talk about that some more?" I asked.

"No, it's time to talk about photosynthesis," he replied demurely.

"But, the end of the Earth is important!" I insisted.

"Not for another five billion years it isn't," he responded, "so turn your page to the next chapter and read the first paragraph for us." And with that, our attention shifted from planetary Armageddon to agricultural photochemistry.

I was dumbfounded. It was not that I did not understand that this Earth-ending moment was far off in the future, because I did. What was shocking to me was the nonchalant manner in which this topic was cast aside. I had never heard of this pending catastrophe before, yet in the coming days I would realize that almost everyone older than me was well aware of it and, for the most part, could care less. How could this be?

Okay, so five billion years is a long time away. Even if you put in a healthy fudge factor for things like planetary-sized plasma spit balls that the Sun might hurtle at us during its transition from a yellow dwarf into an Earth-devouring red giant, that would whittle the game clock to perhaps just two or three billion years left and counting: still a long way off. But despite the fact that I did have an obsessive-compulsive-disorder-like tendency to prepare for things far in advance, hard as I tried, I could not wrap my brain around everyone's indifference. There was so much packing to be done, so many flashlights and batteries to hand out, and so many rockets that needed to be built to shuttle us off to some yet unknown destination in a safer part of the universe.

Over the years, I have learned to mellow my apprehension about our solar-based doom. During my later teen years and twenties, I also began to come out of my middle-class American cocoon to see the larger world and all the misery it perpetually emanates. After some time I began to wonder if maybe incineration was a fitting end for such a pain-ridden place. But a few weeks ago, my own indifference was swept away and my dormant school-day trepidations were reignited by an online news report about near-Earth object 1950 DA. It turns out that this particular object is an asteroid that astronomers have been tracking for over half a century, and it seems that it has a slight, but significant, chance of colliding with our planet somewhere around the year 2880. Given its size, 1950 DA is so large that the consequences of this impact, if it happens, range from life-changing to life-ending. [1] So it seems we may have recently moved the countdown clock from a few billions years and counting to just a few centuries and ticking. Samsonite anyone?

While titillating as it may seem, the 1950 DA news is still not enough to get most people excited. Even the grandchildren factor ("Do it for your grandchildren, for God's sake!") is not enough to motivate most parents, as their grandchildren, like themselves, will be long gone before this supposed near-Earth object impact occurs. And therein lies the chill, for few people are focused on next year, let alone the next century or millennium. On the evolutionary time scale, we are short-lived as a species and even more so as individuals. That is why it is hard to get people who are lucky to live for eighty years to worry about things that might happen eight hundred years from now, let alone a few billion years in the future. Yet, what would happen if that countdown clock were moved even closer? What would it mean if, instead of millennia or centuries away, the two-minute warning was a few decades away? How would you react if, instead of the world ending in some distant great-grandchildren's lifetime, it ended in yours?

I already said that I have often contemplated about the fairness of ending life on this planet, given the misery-go-round Earth always seems to be. Having restated that judgement, there is also something to be said for fair warning, and that is why I am writing this book. Asteroid 1950 DA may hit Earth in 2880, and the Sun will likely envelop and incinerate our planet some five billion years from now. But neither of these events or any other will end life on this planet. For life on Earth - all life on Earth - will have vanished well before the end of this century. Now, as I order my second cup of coffee at the all-night diner, I will try to explain why.

Summary:

1. Generally speaking, people are not concerned about long-term consequences.

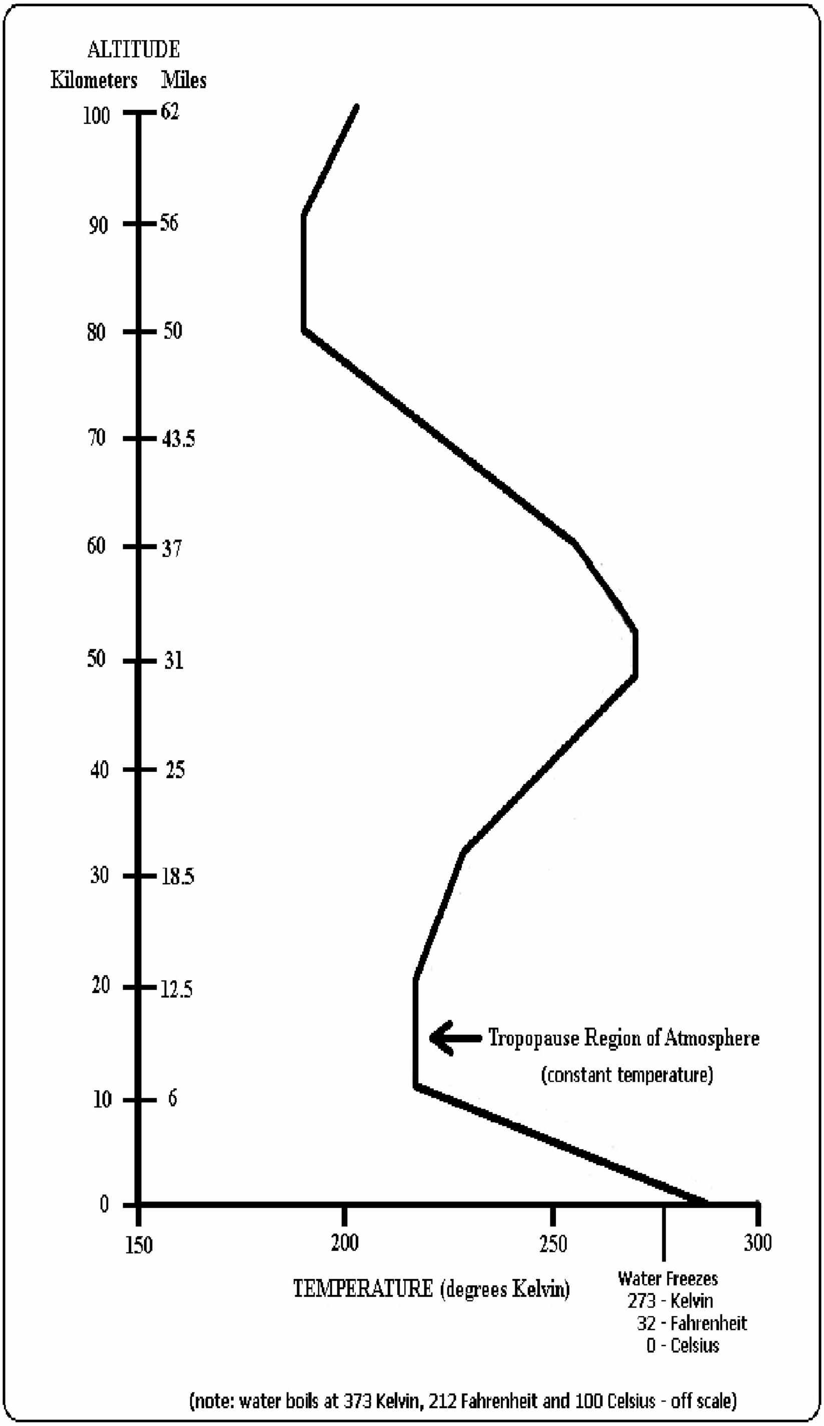
2. There is something to be said for fair warning.

Chapter 2 - Iced Tea

September 8th, 2014

On the following page is a very important graph which we will get to in a moment. But first, I want to turn our attention to iced tea. Now I am going to assume that everyone is familiar with cold tea that has ice floating in it, which is a very nice drink to have on a hot summer day. When we start enjoying our iced tea, usually the glass is full of ice and feels cold in our hands. But as we continue drinking, the ice begins to melt, slowly at first and then more rapidly as time passes. Initially, we do not notice the change in temperature as the ice liquefies. Yet, near the end, when the ice is nearly gone, suddenly the tea begins to warm up. Remember this, and let's now turn our attention back to the graph on the next page.

In 2009, I began researching global warming effects on atmospheric temperature. This was when many people on both sides of the greenhouse gas argument were focusing on why we had seen so little rise in our planet's temperature. While surfing the internet, I came across the graph on the next page. It was originally made in 1962 from NASA data [1] comparing atmospheric altitude against temperature, plotting kilometers for altitude vertically and the Kelvin scale [2] for temperature horizontally. Just like Fahrenheit and Celsius, the Kelvin scale is another way of looking at the heat energy of a substance. To make the graph a bit easier to read, I have added mile, Fahrenheit, and Celsius reference points.


ALTITUDE
Kilometers Miles
100 62
90 56
80 50
70 43.5
60 37
50 31
40 25
30 18.5
20 12.5
10 6
0
150
200
250
300
Tropopause Region of Atmosphere
(constant temperature)
TEMPERATURE (degrees Kelvin)
Water Freezes
273 - Kelvin
32 - Fahrenheit
0 - Celsius
(note: water boils at 373 Kelvin, 212 Fahrenheit and 100 Celsius - off scale)

I remembered first seeing this graph some thirty years ago in my undergraduate Astronomy 101 class, and my first impressions were not remarkable. But on this second go around, I was immediately struck by something I had not previously noticed. Most people probably assume that the higher up you go in altitude, the colder it gets, and this is true for about the first five or six miles. After that, however, the temperature begins to rise, then drop, and then rise again the farther out you go. Yet, it was not these heat fluctuations that fascinated me. Instead, I focused on the regions where the temperature line went perfectly vertical, representing areas of the atmosphere where the temperature remained constant. There are three such regions shown in this graph, and we are concerned with the lower one that is marked "Tropopause Region of Atmosphere."

Depending on your location and the local weather, the tropopause [3] can be several miles thick and is usually found somewhere between six and twelve miles above the Earth's surface. It is a very special region of our atmosphere because, while rain can form below this level, the tops of towering cumulonimbus clouds and devastating hurricanes climb into the tropopause as they generate lightening, thunder and torrential downpours. So, it is in the tropopause that water vapor reaches its highest altitude before returning to us as either rain, sleet, snow or hail. For those of you yearning for a theological metaphor, think of the tropopause as the atmospheric ceiling where the Water Gods grab hold of rising vapor and throw it back down to us in liquid or solid forms so that the water does not escape into outer space.

Keeping in mind that I had seen this graph several decades earlier, it suddenly dawned upon me why those isolated temperature lines were vertical. Heat transfers are constantly occurring throughout the atmosphere. In some areas, heat is being gained and the temperature is rising. In others, heat is being lost as the temperature falls. Yet, in those three regions of the graph where the temperatures are constant, something very special is occurring: phase change. [4] Under certain conditions, when heat is gained or absorbed, phase change can happen as solids turn into liquids (ice melting) or liquids turn into gases (water boiling). In reverse circumstances, when heat is lost or released, phase change happens as gases turn into liquids (water vapor condensation) or liquids turn into solids (water freezing).

The Laws of Thermodynamics determine when and how phase changes occur, and the fascinating thing about these warming and cooling transformations is that, while they are happening, the substance's temperature remains unchanged. In thermodynamics, this process is known as the absorption (warming) or release (cooling) of latent heat. [5] However, to avoid getting too technical, let's get back to your iced tea.

When you first started reading this book, we imagined that it was a hot summer day and you had made some iced tea. Remember how cold it was when you first picked it up? Over time, as you continued to hold it, heat was transferred from both your hand and the surrounding air into the tea and ice, warming them to the ice's melting point. But once that melting point was reached, before either the tea or the water in the ice could warm any further, the ice had to fully liquify.

You may not have noticed it, but as they continued to absorb heat from your hand and the air during the phase change, the temperature of the ice and tea surrounding it remained constant throughout this transformation. Finally, once the ice had fully melted into liquid water, then the tea could continue to warm. So, if it did not go into raising the temperature, where did all that absorbed heat energy go during the phase change? It went into altering the water's physical form from a solid into a liquid. Now, for anyone who found this description of phase change a bit too complex, the take home message is this: while there is still ice left, things will not warm up.

Getting back to the atmospheric temperature graph, upon seeing it for a second time, I realized that like ice in iced tea, the vertical graph lines were areas of phase change. The lowest of these three regions - the tropopause - is the highest region where water vapor transforms into liquid rain, and that liquid then sometimes transforms into solid snow. It occurred to me how important this tropopausic function was to our well being. For if the gasified matter did not phase change into the denser and heavier liquid or solid forms which gravity could pull back down to us, that vapor would continue rising upward and never return to Earth. Now, that would be bad.

Upon further reflection about phase change and the tropopause, I suddenly understood why there had not been any dramatic rise in our global temperature, even though the concept of global warming had been around for some time. The culprit was ice. There were still huge amounts of frozen water covering our planet in the forms of snow, glaciers, floating polar ice sheets and land ensconced polar caps. Though our planet is continually absorbing and holding onto more and more solar energy as we pump more and more greenhouse gases into the atmosphere, just like your iced tea, the Earth cannot warm up significantly until all that ice is gone.

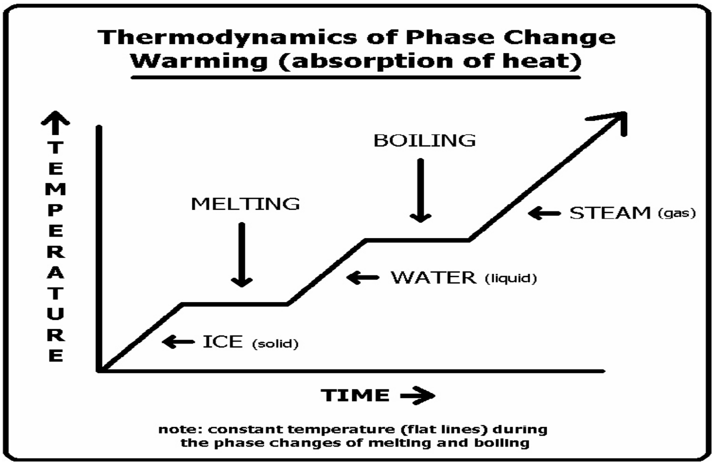
Here is where I made a crucial conclusion: global warming is a misnomer. Instead, what we are currently going through is global phase change. Earth and its atmosphere cannot begin to warm dramatically until the ice on the planet has all melted and phase changed into water. Even though more solar energy is being trapped day-by-day, and local weather is fluctuating more intensely, the long-term planetary climate will show only incremental movement towards warming as long as there are large areas of ice still left to melt. Until then, the frozen water will continue to absorb the vast majority of that incoming heat for its own phase change. And that is why we must now change directions and head south to the coldest place on Earth: Antarctica.

Summary:

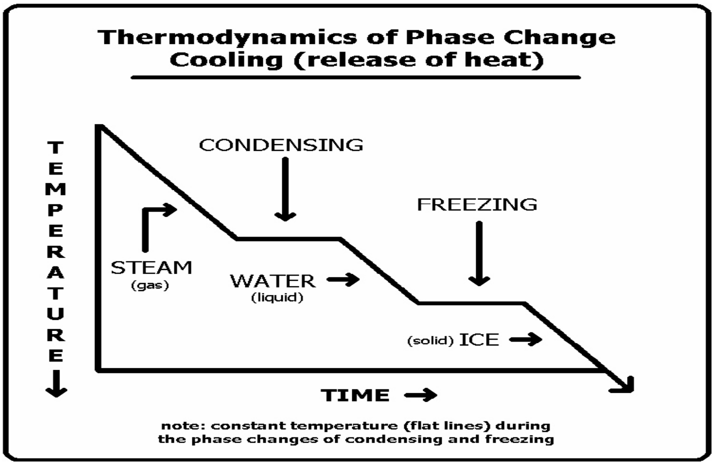
1. The temperature cannot go up until all the ice has melted.

2. We are currently going through global phase change, not global warming.

3.



4.



I am always a tad bemused whenever I hear people discussing Greenland in terms of global warming. First, we are not yet experiencing significant global warming. What we are experiencing is global phase change in which the increasing amounts of greenhouse gases in our atmosphere are trapping increasing amounts of solar heat energy that are, in turn, melting the ice on Earth at an alarming rate. Secondly, if you are concerned about planetary ice, then Greenland is not the place to go. What is Greenland, then? Well, if you squint slightly while looking at a map and do not mind taking a slight jog to the north, then Greenland is about halfway between Chicago and Berlin. This means it is easy to get to, which makes it easy to study. However, if you want to see the mother load of all earthly ice, then there is really only one place to go: Antarctica.

While it may not be as easy to get to as Greenland, Antarctica is to ice what Disney World is to childhood entertainment: the holy land. Around ninety percent of all ice on Earth resides in Antarctica [1], so there is about ten times as much ice at the planet's southern pole as there is in Greenland. In fact, if you had a flat surface in the same shape and size as the borders of the continental United States and you packed all of Antarctica's ice on it to a uniform level height, that USA size block of ice would rise over two miles into the air. [2] Now that is a lot of ice, and to understand how it all got there, we must turn back the hands on the clock of time.

The universe began approximately fifteen billion years ago in the deafening, lifeless silence of the big bang. Some ten billion years later, the Earth made its debut. A billion years or so after that, the first one-celled organisms began our dance of life. That was nearly four billion years ago.

As the Earth's crust cooled, it settled into continental shapes somewhat similar to those we know today. Under the influence of tectonic forces, these elevated fragments were periodically forced together to form supercontinents. [3] These supercontinents remained intact for a few hundred millions years and then broke apart into their constituent continental fragments.

Over time, this process of congregating and dissociating repeated itself over and over again. Though its existence is debatable, a proto-supercontinent, Yilgarn, may have formed as early as four and a half billion years ago, shortly after Earth's formation. However, the first recognized supercontinent was Vaalbara, which coalesced around three billion years ago while single-celled organisms still ruled the planet. After Vaalbara's breakup, the second supercontinent Kenorland formed some two and a half billion years ago when multicellular organisms first appeared. Kenorland, in turn, broke apart and was succeeded by the third supercontinent, Nuna (also called Columbia), around one and a half billion years ago. It then separated and reformed about one billion years ago as the fourth supercontinent Rodinia, which, in turn, lasted for some two hundred and fifty million years before its dissolution. Pannotia, also known as the Vendian supercontinent, may have briefly appeared around six hundred million years ago, but its existence, like Yilgarn's, is also disputed. Either way, from Yilgarn to Kenorland, life was strictly unicellular, while from Kenorland through Pannotia it remained close to the rudimentary multicellular stage.

It was not until Pangea, the fifth and final official supercontinent, which formed around three hundred million years ago, that organisms began to evolve rapidly. Trilobites, arthropods with large exoskeletons that bear a striking resemblance to today's horseshoe crabs dominated the land. While early versions of these extinct creatures were less than a millimeter long, later varieties grew up to twenty-eight inches in length. Of note, some trilobites had eyes with upwards of fifteen thousand microscopic lenses in each one. But even with that good sight, they still disappeared around the time that Pangea broke up into the sub-supercontinents of Laurasia and Gondwana, around two hundred million years ago. By then, evolution had unveiled fish, small reptiles, and a wide spectrum of plant life which covered both land masses. Amongst these reptiles were the theriodontias, our pre-mammalian ancestors.

As Laurasia and Gondwana moved apart, the former heading north and the latter moving south, dinosaurs ruled the Earth until their extinction some sixty-five million years ago. By that time, Laurasia had divided into the major northern continents we know today: North America, Mexico, Central America, Europe and Asia (minus India). Gondwana, on the other hand, would take another sixty million years or so to regress into the southern hemisphere's major land masses: South America, Africa, Australia and Antarctica. About half way through the dinosaurs' age of domination, India, originally part of Gondwana, broke apart from Antarctica and headed toward the northern hemisphere. Along the way, about ninety million years ago, it dropped off Madagascar by the southeastern edge of Africa before slamming itself into Asia. During India’s journey, the six mile wide Chicxulub Meteor landed near the Yucatan Peninsula, bringing the dinosaurs' reign to and end. Thus began the age of mammals.

In the absence of dinosaurs, mammals proliferated from small reptile-like creatures into a wide variety of shapes and forms. Some, like the creodonts, voracious carnivores that included the bison sized megistotheriums, would only last a few million years before their own extinction. Others, like the primates, would appear early on and evolve into modern day rulers of this planet. The first of these primates, the lemurs, arose around forty five million years ago just as India was making its final approach toward Asia. Lemurs, in turn, would give rise to the first modern monkeys and apes nearly twenty-five million years ago. About this time, the last great Gondwanian shift began, as South America broke off from Antarctica and also headed north. During its transit toward Central America, our direct ancestors genetic line sprang from the great apes approximately seven million years ago. As South America crashed into its final resting place, dredging up the Panamanian Isthmus some three million years ago, the final branches of homo sapiens' evolution were underway. In contrast, the de-evolution of Antarctica was also nearing its completion.

Antarctica, the world's fifth largest continent, traveled through the Vaalbara, Kenorland, Nuna, Rodinia and Pangea supercontinents, ending up as part of the sub-supercontinent Gondwana about two hundred million years ago. Having been originally located at the equator during the Pangean era, it released its final companion, South America, around twenty-five million years ago. Without any other land masses to guide warmer tropic waters southward toward it, Antarctica and its inhabitants found themselves totally encircled by the Southern Ocean, cut off from warmer air and water currents to the north. With nothing to counteract the increasingly severe winters, this orphaned continent regressed into an isolated ice age that would claim the lives of nearly every inhabitant upon it.

To this day, though it holds ninety percent of the world's fresh water in the form of ice and snow, it is considered to be the planet's largest desert, as average annual rainfall is less than one quarter of an inch. [4] Not only is it the least rainy place on Earth, it is also the coldest. During the dead of winter, temperatures at the

South Pole can drop to minus one hundred and thirty degrees Fahrenheit, while in the summer they can reach a balmy minus ninety degrees Fahrenheit. Snowfalls of four feet in two days are not uncommon. Oddly, sunburns are of great concern in Antarctica, as the white ground covering reflects ninety percent of the Sun's energy.

Alone and at the bottom of the Earth, Antarctica has spent the past twenty-five million years being buried under snow. With little means of removing this accumulation, the continent was permanently blanketed in layer upon layer of frozen water. As these strata built up, their sheer weight compacted the individual flakes into sheets of dense ice which also accumulated one on top of the other. As the millennia passed, this frozen mass grew into an astounding volume, with the ice itself totaling between six and seven million cubic miles. [5]

Today this polar cap covers the entire continent to an average depth of slightly over one mile. If that same amount of ice and snow were to be evenly distributed over a flat surface the same size as the continental United States, it would rise to a uniform average height of 2.1 miles. [6] That is nearly equal to the 2.35 miles at which the Titanic rests below the surface of the Atlantic Ocean. The stupefying weight from this amount of frozen water has caused some parts of the Antarctic continent to sink down into the Southern Ocean over three thousand feet below its normal elevation [7], both crushing the land and deforming the planet's profile.

Water expands when it freezes, so that frozen ice occupies more space than its liquid water counterpart. The thick polar cap is so heavy that it actually crushes the bottommost ice into a more compact super-cooled (below freezing) liquid form. Contrary to what one would expect, there are over one hundred giant pools of super-cooled liquid water trapped beneath the polar ice, some in pockets with volumes greater than that of Lake Michigan. [8]

While the rest of the planet was progressing through the evolutionary stages from dinosaurs to suburbia, Antarctica was moving backwards. Trapped in the farthest frozen south, all of its highly developed plants and animals were completely wiped out except along isolated parts of the coastline. Now, aside from a few transient research scientists, over ninety-nine percent of Antarctica's surface has no permanent residents that walk on two or more legs. However, the interior of the continent is not entirely devoid of life. Within those sub-glacial, super-cooled lakes, there exist billions upon billions of single-celled organisms trapped in time. Retrieved from ice cores drilled deep into the ice cap [9], these biological misfits beneath Antarctica's glacial ice might represent a diverse cross-section of prehistoric life.

While the rest of the world jaunted off to seasonal habitats, these lost sub-glacial souls adapted to an environment that would crush the average unprotected adult person into the size of a soccer ball. Never seeing sunlight, never breathing air, and never finding water above the freezing point, their evolution slowed to a crawl during the twenty-five million years that their counterpart's were evolving at an exponential rate. Living and procreating at a pace that would make Hugh Hefner [10] shiver in horror, these microscopic organisms traveled in an isolated space and time that was within, yet separate from, our own. For all practical purposes, they and their genomes might as well have been on Jupiter or Mars. For that very reason, living in one of the most extreme environments on Earth, these life forms are of great interest to NASA in its search to understand how life might thrive under the harsh conditions found on other planets. [11]

So what happens when all that ice melts under the influences of man-made greenhouse gases? Well, getting back to our Greenland enthusiasts, if all of that northern ice did melt, then global sea levels would be expected to rise nearly twenty-four feet, or about the height of a third floor balcony railing. However, if all the ice on Antarctica were to melt, then global sea levels would rise an astounding two hundred feet, or about the height of a twenty story building. [12] Take that, Greenland! Contrary to popular belief, though, later on we will see how this rise in sea level should not be our major concern. For if these ocean-wide elevations do occur, they will most likely be less than predicted, temporary, and rapidly reversed. But more on that later, as there are some other more worrisome things to consider when talking about melting away all that Antarctic ice: namely earthquakes and pathogens.

Remember when I stated how the colossal weight of ice resting on Antarctica had pushed some parts of the continent over three thousand feet down into the Earth? Well, guess what happens when all that ice melts? The continent will probably come back up. To place some perspective on this, consider Alex Dobuzinskis' August 21st, 2014, Reuter's news piece titled, "*Drought is slightly elevating ground in U.S. West, study finds.*" [13] In this article, the author explains that the sixty-three trillion gallons of water recently lost to drought there have caused an average land uplift of four millimeters (0.15 inch). More incredible and unexpected was the fact that California's mountainous regions in the affected areas rose up to an astounding fifteen millimeters (0.6 inch), roughly four times the overall average.

If sixty-three trillion gallons of lost water resulted in a four to fifteen millimeter rise in the western United States' terrain, how far could Antarctica rise when the weight of all its ice melts and runs off into the ocean? To get a rough idea, consider the fact that there is about one hundred-thousand times more water still frozen in the south pole as has been lost in America's far west: some seven million-trillion gallons of southern ice to be more precise. [14] So, using this rounded off ratio, we find that one hundred-thousand times the average 0.15 inch of western rise results in an estimated average 1,250 foot up-lift for Antarctica from its present position. If we use the more impressive 0.6 inch extreme rise seen in some

Californian mountain ranges, then we can expect some parts of the south pole to elevate an eye-popping five thousand feet from their current location. [15] Now, that would be a problem.

Along with a host of other factors, the ice age sinking of Antarctica was likely one of the forces that helped the final breakup of Gondwana, sending both South America and Antarctica to their current resting places. If the reverse were to happen and Antarctica rose once again from the depths, would that process be reversed? Could South America be drawn back - even partially - towards its Gondwanian counterpart? Today, science measures the most fearsome earthquakes based upon the planet's tectonic plates shifting a fraction of an inch. What kind of earthquakes can we expect if the fifth largest continent on this planet rises up over a thousand feet? It is nearly impossible to imagine.

As if that earth shattering possibility is not enough to make you want to stop reading, consider this gruesome fact. Remember all those sub-glacial lakes I mentioned earlier in this chapter? Remember all those microbes lost in time that are floating around in those sub-glacial lakes? Well guess what happens to them when all the ice on Antarctica melts? They run off into the Southern Ocean. Now, keep in mind that small amounts of these micro-organisms have probably always been leaching into the sea for eons. However, these microbes are trapped in fresh water sub-glacial pockets, and they are most likely killed off by exposure to the high salinity (salt content) of the sea water.

The problem arises, however, when several million-trillion gallons of fresh water run into and dilute the saline surrounding Antarctica. As we will see in the fifth chapter, this runoff could possibly occur over decades, rather than millennia. While there is not enough ice in the south pole to turn the Southern Ocean into a body of fresh water, there probably is enough to turn large regions around the coastline into brackish water that has lower levels of salt. This is what waters in river delta regions around the globe are like because of the fresh water that runs into the sea. These delta areas can be particularly prone to algae blooms when too many organisms populate the brackish waters. [16] Antarctica's Onyx River, the continent's largest, is already prone to such blooms, but luckily it flows away from the ocean. [17] So what if the brackish waters surrounding Antarctica became fertile grounds for sub-glacial microbial blooms?

The answer to this question might simply be nothing. Yet, it is important to consider that these countless numbers of sub-glacial organisms have not seen us, and we have never seen them. What are the chances that at least one of them may have evolved into something that is highly pathogenic to us, capable of causing an incurable disease? What would happen if that organism escaped into the brackish Antarctic waters and began infecting birds and fish that later ended up on our tables? Again, the answer might be nothing. Or it could be everything we do not want to think about.

So there you have it, ladies and gentleman. Antarctica, under the influence of man-made phase change, is poised to leap up from the depths with Earth-shaking results as it pours microbial Armageddon into our planet's oceans. And when all that ice is finally gone, can we finally move away from global phase change and return to our beloved global warming? Well, not just yet. For the rising of Antarctica is merely stage one in the phase change puzzle. Once this melt-off inspired rise-up is completed and its full consequences are known, we will then shift into stage two of global phase change: atmospheric expansion.

Summary:

1. Ninety percent of the Earth's ice, some seven million-trillion gallons of frozen water, rests upon the continent of Antarctica.

2. The weight of all the accumulated ice on Antarctica has pushed some parts of the continent over three thousand feet into the Earth.

3. When all the ice melts off of Antarctica, the continent might rise up over one thousand feet causing catastrophic earthquakes.

4. When all the ice melts off of Antarctica, an untold number of unknown micro-organisms will invade the newly-formed brackish waters that line the edges of the continent. Some of these micro-organisms might challenge our capacity to survive on Earth.

In the prior chapter, I established that we are not going through significant global warming because the Earth's melting frozen water is absorbing the solar energy that is being trapped by greenhouse gases. Given that there are still millions of trillions of gallons of frozen water left to liquify on the planet, and that the temperature will remain relatively constant during this melting phase change, we cannot expect to see substantial global climate warming until the vast majority of this ice has transformed into liquid water. But once that has happened, will global warming finally ensue? Probably not, and here's why.

If you look back at the summary section of Chapter Two, you will notice that there are four different types of phase change depicted in the graphs. Two of these, condensing and freezing, occur when a substance is cooling and changes from a gas to a liquid, or from a liquid to a solid. We can ignore these two types of phase changes, as today's environmental concerns are focused upon warming. For the purpose of this text, we are focusing primarily on phase changes that happen during melting and boiling. These transformations take place when a substance changes from a solid to a liquid or from a liquid to a gas.

We already talked extensively about the melting process in both the second and third chapter. I will now introduce another kind of phase change that is very similar to boiling: evaporation. [1] Evaporation and boiling are both examples of vaporization phase changes where a liquid turns into a gas or vapor. Now I do not want to get into all the sticky details about their similarities and differences, but the major distinction between the two is that evaporation can occur below the boiling point. In other words, liquid water can evaporate into a gas at any temperature, or it can quickly change into steam once its boiling point is reached. Your body takes advantage of this fact when you sweat. The water on your skin absorbs your body heat, evaporates into a gas and then carries the energy away so that you do not boil inside.

Like melting, both boiling and evaporation are temperature-neutral phase changes. The temperature of the water does not rise as it changes from a liquid into a gas, regardless of whether it does so by evaporation or boiling. And this is the reason that even after all the ice on Earth has melted, there will still be no significant global warming. Why? Because, once that melting is completed, there will be over three hundred-million cubic miles of liquid water laying on the Earth. To give you a better idea of how much that is, if you bundled it all up into a single ball, you would have a sphere that is eight hundred and sixty miles wide and eight hundred and sixty miles tall. [2] For reference, Birmingham, Alabama, is eight hundred and sixty-six miles from New York City. Try bouncing that around for awhile.

So how can an eight hundred and sixty mile wide water ball impede global warming? After all, once the ice is gone, we will still be spewing out oodles of greenhouse gases, and increasing amounts of solar energy will continue to be trapped in the atmosphere. Before all the melting occurred, this heat energy was absorbed by the ice whose phase change into liquid water prevented our planet's overall temperature from rising. Now with the ice gone, the liquid water itself becomes the major heat sink for all that trapped solar energy.

Just like solid ice, liquid water can also absorb trapped solar heat in the atmosphere and use that energy to undergo yet another phase change: from a liquid to a gas. By evaporating into the atmosphere from the surfaces of oceans, seas, lakes, rivers, ponds, streams and swamps, liquid water can phase change into water vapor that helps to counteract global warming, just like your body evaporates sweat off of its surface to cool you.

Even though evaporation is always happening, including while the planet's ice is liquifying, once all the solid water has completely transformed, the evaporative process will become the major regulatory mechanism that inhibits global warming. In essence, vaporization through evaporation will replace melting as the key temperature regulator in stage two of global phase change. For just as people get heat stroke when they cannot sweat effectively, without global evaporation, the temperature of our iceless planet's atmosphere would increase until the next phase change occurred at the boiling point of water (212 degrees Fahrenheit, 100 degrees Celsius). That would be very bad, as there are few known life forms that can survive such high temperatures. So, post-ice evaporative phase change is a very good thing, but there will be a heavy price to pay for this stage two safety mechanism.

Greenhouse gases come in many forms. The one we are most familiar with today is carbon dioxide - CO2 - because it is the one we commonly create through man-made pollution, usually by burning fossil fuels. It turns out, however, that any gas in the atmosphere can be a greenhouse gas, and water vapor is one of the most powerful greenhouse gases known. [3] So through evaporation, increasing amounts of water vapor in our atmosphere will capture increasing amounts of solar energy from the sun. These increasing amounts of trapped solar energy will then be absorbed even faster by the remaining liquid water still resting on the planet's surface, which, in turn, will further increase the rate of evaporation.

In the end, this will become a viscous positive-feedback cycle, where increasing atmospheric water vapor from evaporation will increase the levels of trapped solar heat whose energy will then be transferred into the remaining surface water to increase evaporation, once again. Without planetary ice to dampen this process, as time progresses, evaporation and solar energy trapping will repeatedly accelerate one another, each pushing the other onward faster and faster. That is why, even if the sea levels do initially rise after the ice is gone, that rise will be temporary and then quickly reversed through rapidly progressing evaporative phase change. Also, keep in mind that evaporative phase change is always happening, even now. If it did not, then there would be no clouds in the sky. Therefore, the onset and intensity of sea level rise might be delayed and even less than we expect due to the current rate of evaporation.

Either way, whether it affects sea level rise or not, where is all that water vapor going to go? Currently, only a tiny fraction of the Earth's water resides in the atmosphere, or about thirty-one hundred cubic miles of water. [4] But as stage two global phase change continues, increasing amounts of that water will end up in the atmosphere due to evaporation. Yet, even at one hundred percent humidity, or full saturation, our current atmosphere is not likely able to hold even one percent of all Earth's water. [5] So, if our present atmosphere lacks the capacity to hold that much water vapor, how can stage two evaporation prevent global warming?

In Chapter One, I mentioned two principles of physics that will guide this discussion: thermodynamics and the Ideal Gas Law. [6] Chapters Two and Three were focused primarily on the former, and now we will discuss the latter. The Ideal Gas Law in equation form goes like this:

$$\mathbf{PV=nrT}$$

where: P = pressure
V = volume
n = the number of gas molecules
r = the gas constant
T = temperature

Given this equation has four variables (P, V, n, and T) and one constant (r), there are many complex relationships that it can be used to explore. As with all equations, it is paramount that both sides remain equal, so that whenever we multiply "P" by "V" we get the same result as when we multiply "n" by "r" and then "T." So, if one side of the equation decreases, then, to balance it out, the other side must decrease as well. And if one side of the equation increases, then the other side must increase as well. With this in mind, let's apply the Ideal Gas Law to stage two of global phase change.

Once all of the Earth's ice has melted and surface water evaporation accelerates in stage two global phase change, the number of water vapor (gas) molecules in the atmosphere will increase. On the right side of our equation, this is represented by an increase in the value of "n." As this evaporation is a temperature neutral process that is absorbing excess trapped solar heat energy, it prevents the overall average temperature of our planet from showing any significant increase. So, beyond some modest and minimal fluctuations, temperature (T) remains relatively stable on the same side of our equation. Finally, "r" by definition is a constant that never changes.

Thus, in stage two of global phase change, the right side of the Ideal Gas Law ends up with "n" increasing, "r" remaining constant, and "T" staying relatively unchanged. The result is that the right side of the Ideal Gas Law will increase with, and due to "n" during stage two of global phase change.

Remembering that if one side of an equation increases, then the other side must increase as well, we must now decide how pressure (P) and volume (V) will react in response to the increase in their "n" counterpart. Now, since "n" has increased on the "nrT" side of this equation, then either pressure and/or volume must also increase to keep both sides of the Ideal Gal Law equal. In the case of our atmosphere, it is the volume that will mostly increase.

Unlike a gas tank, our atmosphere has no hard outer shell. Instead, it expands outward from the planet's surface in all directions until it dissipates into nothingness. Currently, the outer reaches of our measurable atmosphere can be found about sixty-two miles above Earth's surface. Beyond that distance, little if any free floating gas molecules can be detected. Though sixty-two miles sounds like a lot, if the Earth were the size of a basketball, then our atmosphere would be an outer layer less than one-tenth of an inch thick. [7]

As more water vapor rises into the atmosphere through surface evaporation, without a hard outer shell to contain it, the atmosphere will expand like a balloon, moving farther upward and away from the Earth's surface. This expansion will produce an increase in atmospheric volume while acting as a relief valve to prevent any major increase in average atmospheric pressure. If our atmosphere were contained inside a hard shell, the volume of the atmosphere would not be able to increase, and then the pressure would rise dramatically, just like it does when you pump air into your car's tires. Luckily, no such outer shell exists, as in the planet-within-a-planet scenario, that pressure increase would crush us.

Putting this all together, we find in stage two global phase change that the amount of water in the atmosphere (n) will increase due to accelerated surface water evaporation from continued solar energy trapping by greenhouse gases. Just like the melting did in stage one global phase change, this positive feedback cycle between evaporation and solar heat trapping will prevent atmospheric temperature (T) from significantly changing. But, to counteract this rise of "n", atmospheric volume (V) will increase. Given our planet's atmosphere is not contained within a hard outer shell, its pressure (P), like temperature, will remain relatively constant. So, during stage two global phase change, atmospheric water vapor and volume will increase, while its overall temperature and pressure will stay about the same.

At first, this will be a good thing, as increased atmospheric volume will balance out the increased amounts of evaporated water molecules in the atmosphere, allowing both atmospheric pressure and temperature to remain relatively constant. Also, through this expansion the atmosphere will accomplish one other important thing: like an expanding sponge, it will be able to hold vastly greater quantities of water than can our current atmosphere. Why then is there a problem?

Everyone is concerned about global warming and the destructive impact it can have on our planet. So far, we have discussed how phase change - first through melting of planetary ice and then through surface water evaporation accompanied by atmospheric expansion - will ultimately absorb the vast quantities of solar energy that are continually being trapped by our greenhouse gases. For the hedonistic amongst us, the only foreseeable problems at this point will be the absence of snow skiing in the winter and the temporary submersion of their beach-side homes. Even if evaporation and greenhouse gases do act in a positive-feedback cycle to accelerate each other, the atmosphere will just expand farther to accommodate the increasing accumulation of water vapor. All in all, the temperature will not rise significantly in this scenario, and after awhile the sea levels will fall back to normal through evaporative reduction.

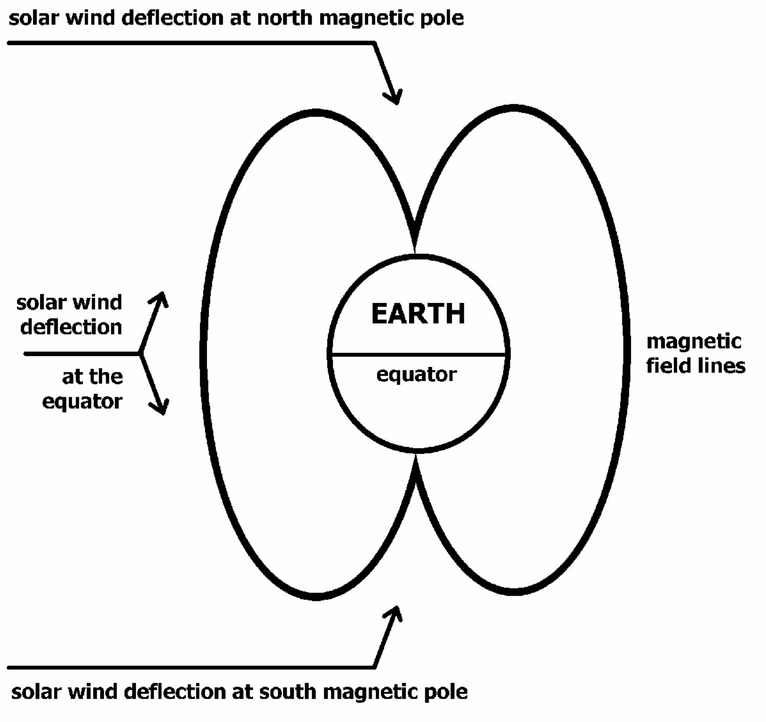
If only it were that simple. Yes, as per the laws of thermodynamics, increasing solar energy trapped by man-made greenhouse gases are causing all the ice on Earth to melt, and the seas will rise as that ice disappears. And yes, after all the ice is gone, surface evaporation will kick in and become the main replacement for melting as a means to keep the planet's temperature relatively stable. And yes again, the atmosphere will expand as predicted by the Ideal Gas Law to accommodate the ever increasing amounts of evaporative water vapor needed to absorb the continually increased amounts of solar energy being trapped in our atmosphere. But gravity can only take so much.

Recall the graph at the beginning of Chapter Two that had a special area marked "Tropopause Region of Atmosphere." The tropopause is a key layer of our atmosphere, because that is the highest altitude where water vapor finally condenses into more compact forms like rain and snow that gravity can then pull back down to us at the surface. Today, that region of our water cycle can usually be found anywhere from six to twelve miles above the Earth's surface, depending on your location's elevation and weather. However, what happens in stage two of global phase change when the atmosphere begins to expand from the increased amount of evaporated surface water it must accommodate? If we are lucky, nothing. It will remain at the same average heights.

Unfortunately, as the atmosphere expands, it is more likely that the tropopause will, also. But so too will the part of the atmosphere just below the tropopause. This layer is known as the troposphere [8], and like the tropopause, it will probably expand as the overall atmosphere increases in volume in response to evaporative phase change. The problem occurs when the lower-level expanding troposphere pushes the upper-level tropopause higher up in altitude and farther away from the Earth's surface. In the next chapter we will see how gases can expand very rapidly, so that as trapped solar energy and evaporated water vapor work together to accelerate one another, this synergistic positive feedback process may push the tropopause rapidly away from us. Once the tropopause reaches six hundred and twenty miles above our planet, something very bad might start to happen: solar wind stripping.

Solar winds are high energy plasma streams made up mostly of electrons and protons that are constantly being ejected from the Sun's surface and then bombard all the planets in our solar system. [9] The Earth's magnetic field, also known as the magnetosphere [10], deflects most of these particles, but due to complex interactions like Kelvin-Helmholtz instabilities [11], the solar winds can be driven down along the magnetic lines of the magnetosphere and end up in lower levels of our atmosphere. This occurs predominantly around the Earth's magnetic poles, producing the Aurora Borealis [12], also known as the Northern and Southern Lights.

To better understand this process, you must realize that the Earth's magnetosphere is an invisible magnetic field whose shape, instead of being a perfectly round ball, resembles the skin of an apple: it is spherical around the equator, but dimpled inward at the top and bottom toward the core. When the charged electrons and protons of the solar winds encounter a strong enough magnetic field like our planet's magnetosphere, their path is altered to make them travel parallel to the lines of that field. So at the equator, these solar winds are predominantly deflected north and south around the Earth by what is called a bow shock effect. [13] But as they pass by the planet's northern and southern poles, these same magnetic fields funnel the winds inward toward the planet's surface. I call this the apple core funnel effect (see diagram). Even though this funneling process can cause spectacular light shows in the northern- and southern-most regions of our skies, it can also facilitate unwanted solar wind stripping.



The Apple Core Funnel Effect

Solar wind stripping happens when the particles of the solar winds collide with molecules in our upper atmosphere. [14] This impact transfers energy from the solar wind particles to the atmospheric molecules and, if that energy transfer is strong enough, the atmospheric molecules can then overcome gravity and escape into outer space. Even though the solar winds can reach into the Earth's lower atmosphere, the stripping effect usually occurs higher up in a region known as the exosphere [15] which begins about six hundred and twenty miles above the planet's surface.

Six hundred and twenty miles seems far away. However, returning to our previous basketball scenario, if today's atmosphere is represented by a thin layer less than one-tenth of an inch thick, then six hundred and twenty miles up would be less than three-quarters of an inch above the surface of that same basketball. [16] In planetary terms, six hundred and twenty miles up is just a hop, skip and a jump away. So why worry? Because, due to solar wind stripping in stage two of global phase change, gravity begins to reach the limits of its ability to hold onto rising water vapor.

Earth's gravity extends outward infinitely in all directions, so that if you could measure it, you would still find some infinitesimal residual millions of miles away. Yet, in stage two of global phase change, when the rising tropopause passes the six hundred and twenty mile mark, it will bring vast quantities of water vapor with it. Around the planet's magnetic poles, these elevated water molecules will be exposed to the solar winds. The process of solar wind stripping can then knock this high altitude vapor, like pool balls, into outer space where gravity can no longer retrieve it. In other words, once the tropopause and its water molecules pass the six hundred and twenty mile mark, the Earth's gravity will no longer be strong enough to keep the solar winds from sweeping that water into outer space. Our rain water will fall up, but never down again.

Now, take a deep breath, then let's recap. Man-made greenhouse gases are trapping solar energy in our atmosphere. As a result, Earth's ice is starting to melt, which will prevent the planet's temperature from rising. Once all the ice is gone, surface water evaporation will take over and keep the planet cool, just like your body sweats to keep you from overheating. As the evaporative-cooling process continues, the atmosphere will expand to accommodate the increasing volume of evaporating water vapor. The atmosphere is not contained within a hard shell, so it can expand indefinitely. As it expands, all the layers of the atmosphere will elevate, including the tropopause which will be pushed into higher altitudes by the expanding troposphere below it. The tropopause is the highest region where water vapor finally condenses into heavier forms like rain and snow that gravity can pull back to the planet's surface. However, once the tropopause is pushed above the six hundred and twenty mile mark, solar winds can overcome gravity's pull and sweep our water into outer space.

The upshot of all of this is that, in the very near future, all of Earth's water might evaporate up and then off of our planet. Finally, when the water is all gone, there will be nothing to phase change, and temperatures will soar as true global warming begins. But without water, there will also be no life of any kind left here, and a once-vibrant blue ball will become as hot and dead as Mars.

Summary:

1. Global phase change comes in two stages: melting of planetary ice followed by evaporation of liquid planetary water.

2. As long as they last, both stages of global phase change will prevent any significant global warming.

3. Water vapor is a very powerful greenhouse gas.

4. In stage two of global phase change, a positive feedback cycle will evolve where increased amounts of evaporated water vapor will trap increased amounts of solar heat whose energy will further increase the rate of evaporation, and so on.

5. Accelerated surface water evaporation during stage two of global phase change will reverse the rise in sea levels seen from the melted ice during phase one of global phase change.

6. Evaporative phase change is always happening, and it may delay and/or dampen the amount of sea level rise seen in stage one of global phase change.

7. As predicted by the Ideal Gas Law, Earth's atmosphere will expand in response to increased amounts of water vapor being produced in the second stage of global phase change.

8. The expanding atmosphere will cause all layers of the atmosphere to swell and rise in altitude, including the tropopause: the highest layer of our atmosphere where water vapor condenses into heavier forms (rain, snow) that gravity can pull back to the planet's surface.

9. Once the tropopause rises farther than six hundred and twenty miles above the Earth's surface, solar winds can overcome gravity's pull and sweep our water into outer space.

10. After all of our planet's water has been swept into outer space, global warming will ensue, and Earth will end up as dead and hot as Mars.

If you have made it this far and are still reading, then you are probably wondering how fast this will all happen. Even by current predictions, in the not too distant future, the northern Arctic polar cap will completely vanish in the summertime [1], and the southern Antarctic polar cap is already beginning to deteriorate. Do we have centuries left, do we have decades left, or should we just go to dinner and try not to think about it?

While it is impossible to say when it will all end, I can tell you the exact date, and place where, global phase change began. It was on January 10th, 1901, when the Lucas oil well on Spindletop Hill just south of Beaumont, Texas, finally reached a depth of one thousand, one hundred and thirty-nine feet. A geyser shot out sending one hundred-thousand barrels of oil per day over one hundred and fifty feet into the air. Nicknamed the Lucas Gusher, by 1903 production boomed, and over two hundred and eighty active wells dotted the area. As a result, hundreds of new oil companies sprang up overnight. [2]

Marking the beginning of the end here does not mean that we were not polluting the atmosphere prior to 1901. The great change that came with Spindletop was the domination of oil as a global energy source. Before then, coal was king and it blackened many a sky on a daily basis. But coal was more suited to land and sea based mass transportation in the form of trains and ships.

Oil begat gasoline, diesel and other petroleum fuels that helped us to turn away from coal-based forms of mass transportation in favor of personal automobiles, trucks and airplanes. Today, trains burn diesel instead of coal, and there are over one billion cars and trucks running along the globe's roadways [3], each one containing a gas-burning engine that spews environmentally toxic carbon dioxide into the atmosphere. If you combine this with the industrial pollution and the thousands of ships and planes that traverse our seas and airways, we have headed down a road that makes global phase change inevitable. The only question now is how long do we have left?

The answer to this question is, in my best guestimate, about sixty to seventy years, and here is why. Given that most people do not yet understand the difference between global warming and global phase change, most of the time when you hear someone talking about how fast global warming is progressing, they will say something like, "At the current rate, blah-blah-blah will blah-blah-blah." What they are doing is predicting when something is going to happen - the ice will all melt, the sea levels will rise, etc. - if things continue to happen at their current rate of change, without that amount of change going faster or slower.

In science, this type of rate change is called uniform, or linear acceleration: where something changes by the same amount during each uniform time period. [4]

For example, let's say you are going to start traveling down a road from a stopped position and you decide to increase your speed by one mile per hour (1 mph) every minute for five minutes. A chart of your car's speed would look like this:

LINEAR ACCELERATION

Time (minutes)	Speed (mph)
1	1
2	2
3	3
4	4
5	5

This is linear acceleration. You are increasing something (your car's speed) by the exact same amount (1 mph) during each uniform time period (every minute), and at the end of five minutes you would be going five miles per hour.

There is, however, another way that things can change, and it is called exponential acceleration. [5] To give an example of this, let's say that instead of increasing your car's speed by one mile per hour each minute, that you decide to double your speed every minute. After five minutes under these conditions, a chart of your car's speed would look like this:

EXPONENTIAL ACCELERATION

Time (minutes)	Speed (mph)
1	1
2	2
3	4
4	8
5	16

In the case of linear acceleration, you added one mile per hour every minute. But in exponential acceleration, the amount of change itself changes as time passes. In this second example, though you only added one mile per hour at two minutes, at three minutes you had added two more miles per hour, at four minutes you added yet another four miles per hour, and at five minutes you added eight more miles per hour to your speed.

You can see that by using exponential acceleration instead of linear acceleration that you would be traveling at sixteen miles per hour after five minutes had passed: over three times faster than you would have been traveling had you used linear acceleration. If you continued these two examples for a full thirty minutes instead of five, then at the end of the first half hour, your car would be going thirty miles per hour using linear acceleration. But if you had used exponential acceleration, then at the end of that same thirty minutes, you would be going over five hundred-million miles per hour (check for yourself - start with one and then double it twenty-nine times). Now that is fast!

This is why I think global phase change is going to happen much faster than anyone expects: because it will undergo exponential acceleration instead of linear change. The rate of this change will happen slowly at first, but over time it will speed up at an ever quickening pace. In a way, it is not unlike a slow snow slide that rapidly builds into an avalanche.

In the two-stage model of global phase change that I outlined in the previous chapters, the first stage will likely be the slowest. Given that exponential acceleration only shows modest increases at first, melting away all of the planet's ice might take a few decades. However, after that, things should start to pick up markedly. With the expected rise in sea level, more land will be submerged and there will be an even greater surface area of ocean water for the evaporative process to work on during stage two. In addition, the evaporated water itself will become a greenhouse gas, further accelerating the trapping of solar energy in our atmosphere. When this positive feedback mechanism kicks in between evaporation and solar energy trapping, exponential acceleration will likely shift into high gear.

Another factor that will further accelerate the global phase change process is that the two stages will probably overlap. In other words, the second stage will start in earnest even before all of the ice in stage one has completely melted away. Though the planet's overall temperature will likely undergo only minor fluctuations until we near the end of the second stage, this overlap will cause paradoxical events to occur that seem to contradict the direction in which we are truly headed. For example, as more water vapor enters the atmosphere during the later portion of stage one, winter storms will become more fierce and drop even greater amounts of snow. But as time moves forward and phase change progresses, we can expect the cooler seasons to shorten and these type of gargantuan snow storms to become less and less frequent.

So how fast will all of this happen, and when will the last drop of water leave Earth? I cannot tell you exactly, for we have no precise records of how these kinds of events have occurred in the past. Even though we are reasonably sure that something similar to this did happen on Mars - a desert planet that once held water - we are still uncertain of how or when it all transpired. So we are left with little evidence to guide us, except our own best guesstimates. In my defense, however, I do have some experience in these kinds of matter.

I belong to the modern smog generation: those born after World War Two who lived to see our cities choked by car emissions. You can easily recognize us by our irritated eyes and respiratory tract, chest pain, cough, nausea and headache. So, as far back as I can remember, I have always driven down the highway of life with the omen of global warming looming in the rear-view mirror. It took me quite some time to tether out the differences between this back-seat monster and global phase change, and even more time after that to appreciate the consequences of exponential acceleration. Yet, that extended period of study has made me aware that exponential acceleration could make Earth and Mars identical twins much sooner than we think: in decades rather than centuries, millennia, or eons. Unfortunately, having never witnessed such a globacidal event before, we have no accurate models upon which to base such predictions. However, we can still outline possible trends based upon what we do know.

The trends that I am emphasizing here are exponential, not linear. They are the kind of changes that in thirty minutes can leave you going five hundred-million miles per hour instead of thirty miles per hour. They are the kind of changes that make the difference between something burning slowly like a candle, or something exploding like a bomb. These are the kind of forces I see acting upon our planet, not the slow linear change that most researchers assume. And even though we are still in the first, slower stage of global phase change, once we pass the tipping point of no return, things will happen explosively, not linearly.

Moving forward during both stages of global phase change, reinforcing mechanisms will play a large role in this exponential process. In the previous chapter, I outlined how evaporated water in a positive feedback cycle will increase the levels of atmospheric greenhouse gas concentrations that will then trap even more solar energy, which, in turn, will evaporate the surface water even faster. But stage one will also be similarly effected: rising man-made CO2 greenhouse gas levels will trap solar energy ever faster which will then melt the planet's ice faster. These types of mechanisms can be truly vicious. That is why I believe it will only take a matter of decades for each key component of the global phase change model to occur: not centuries, millennia, or eons. So, for all of you interested in my best forecasts, and keeping in mind that I am writing this in the latter part of 2014, here goes.

Stage one of global phase change - the melting of all planetary ice - will probably take another twenty years or so to complete. Other than moving to higher ground from the coastlines, putting up with fiercer earthquakes, dealing with some unexpected sub-glacial pathogens, and living through stronger and deadlier seasonal weather patterns, a majority of people should survive these decades.

Stage two of global phase change will probably make itself known some time around when stage one passes the five-years-left mark, or about fifteen years from now. Even before stage one is completed, the first noticeable effects from stage two might be atmospheric expansion in the form of clouds rising to significantly higher altitudes than before. This will likely be followed a decade or two later by a reduction in stage one swollen sea levels due to evaporative phase change acceleration. As this progresses and the oceans recede even below their current levels, a few decades later the tropopause will probably reach the dreaded six hundred and twenty mile ceiling, and the final exodus of water will begin. Once our rain starts to fall up instead of down, the impact of exponential acceleration will be so great that it will seem like our atmosphere has literally burst, showering water into outer space. Once the atmosphere has burst, Earth will be bone dry in less than twenty years. But do not worry. No one will be around to see that happen.

One of the unexpected things I realized about our stage two expanding atmosphere is that it will cause a dilution in oxygen concentration. It is not that there will be more, or less oxygen in our atmosphere. It is just that it will be spread out over a greater volume of space as the atmosphere expands.

Think of it this way. If you put a blind person and a ball in a small closet, then it is not too hard for the blind person to find the ball. But if you place that ball and the blind person far apart in a huge, one room warehouse, then it is a bit trickier for the blind person to find the ball. The same thing will happen with your lungs. Our current atmosphere is like a small closet full of oxygen balls that are easy to find. But as it expands in size, those balls will spread farther and farther apart, making it harder for your lungs to find them. This is what happens when people move from sea level to higher altitudes. The air is thinner there and contains less oxygen, making it harder to breath. When the atmosphere expands, the air will become thinner everywhere, including sea level.

A rapidly expanding atmosphere would not only change oxygen concentrations, it might also change the kinds of airborne pathogens we encounter. While we consider them bad things, disease-causing organisms are just doing what comes naturally to them: living. Unfortunately for us, the way they live their lives can sometimes end ours. Yet, like us, these microbes proliferate better in certain environments than others. An expanding atmosphere could alter that airborne world both in, and against our favor. While some current respiratory pathogens might be less of a threat in a revised atmosphere, others that are now benign might become problematic. Could the early processes of phase change have already altered our atmosphere enough for this to start happening? Could diseases like the previously rare breakout of EV-D68 infections in the United States, that is currently being tracked by the CDC, be one of these early warning signs? [6]

In some ways, the expanding atmosphere and its consequences might spare any of us from ever seeing dramatic global warming. By the time the tropopause passes the six hundred and twenty mile mark and starts tossing water into outer space, we could already be overwhelmed by a host of new and unexpected respiratory illnesses. In addition, oxygen concentrations on Earth may have dipped well below the levels necessary to support life, leaving this planet lifeless long before it dries out.

Summary:

1. Exponential acceleration starts out slowly, but then quickly accelerates at mind boggling speeds.

2. Global phase change will likely be ruled by exponential acceleration instead of linear (uniform) acceleration, with stage one happening during the initial slower periods of change, while stage two dominates the latter more rapid periods of change.

3. Exponential acceleration in stage one of global phase change will be driven by a mechanism where rising man-made CO_2 greenhouse gas levels will trap solar energy ever faster, which will then melt the planet's ice faster.

4. Exponential acceleration in stage two of global phase change will be driven by a positive feedback cycle where evaporated water will increase the atmospheric concentration of greenhouse gases, thereby trapping even more solar energy, which, in turn, will evaporate the surface water even faster.

5. We have never witnessed exponentially-accelerated phase change ejecting planetary water into outer space, so we have no accurate models upon which to base predictions, but we can still outline possible trends based on what we do know.

6. Stage one global phase change - the melting of all planetary ice - will likely be complete by 2035, with rising sea levels, and Antarctica-related earthquakes and sub-glacial pathogens being the main concerns.

7. The initial effects of stage two global phase change - clouds at markedly higher altitudes - will likely be noticeable by 2030, even before all the planetary ice has melted.

8. As stage two global phase change continues, sea levels that rose during stage one will recede backwards even below today's levels, somewhere around 2050 or 2060.

9. Due to stage two atmospheric expansion, the tropopause will probably reach the six hundred and twenty mile mark in altitude somewhere between 2070 to 2080.

10. Once begun, the ejection of water into outer space will probably take little more than a decade to

complete, with Earth being completely dry like Mars by 2090. At this point, global phase change will be finished, and global warming will finally be the dominant factor affecting our environment.

11. Most oxygen-based life forms will disappear from this planet by 2080 as continued atmospheric expansion lowers oxygen concentrations below the survival level. All life, oxygen based or not, will be gone from Earth by 2090, when all the water has left.

12. An expanding atmosphere might allow new respiratory pathogens to evolve.

Let's review binary (two stage) phase change one more time. In Chapter One I explained how people do not usually plan long term, but that fair warning was still warranted. I followed this in Chapter Two by explaining the concept of phase change. In Chapter Three, I applied phase change to the melting ice in Antarctica, and then I followed this up in Chapter Four by showing how - once all the planetary ice has melted - evaporative phase change will then expand our atmosphere. Finally, in Chapter Five, I outlined how this atmospheric expansion will cause the tropopause to pass the six hundred and twenty mile mark in altitude, after which Earth's water will be ejected into outer space, and this planet will become as dry and dead as Mars.

Before I go any further, I would like to answer those who have chosen to confront global warming through denial. Albeit phase change postpones global warming for many decades, their rejectionist arguments come in four flavors, which I will address as follows:

1. *Even with increasing CO2 levels, there has been no significant rise in planetary temperature.*

   As predicted by the binary phase change model, global warming cannot occur until all of the ice has melted and the liquid surface water then evaporates. While they are still happening, these two transformative processes will absorb most of the excess solar heat energy trapped in our atmosphere by greenhouse gases, preventing any significant increases in temperature.

2. *So far, elevation in sea levels has been much less than expected.*

   Evaporative phase change is always happening. The current level of surface water evaporation may be sufficient to delay and/or dampen the amount of sea level rise anticipated by the current early-stage melting rate of planetary ice.

3. *There is more sea ice surrounding Antarctica than at any time since space-based measurements began in 1979.*

   As ice on the Antarctic continent melts, considerable amounts of it slide off into the surrounding sea in a process known as iceberg calving. A similar thing happens when you hold a melting ice cream cone and it runs down your hand. Even though the ice cream is now spread over a greater area (your hand), the overall amount of ice cream has not increased.

4. *There has been no significant increase in the*

> *frequency or intensity of present-day weather patterns.*
>
> Given exponential acceleration in the binary phase change model, weather events will only show relatively modest fluctuations in the first stage, followed by rapidly increasing changes during the second stage. We are still in the first stage.

Denial and skepticism can be healthy perspectives from which to approach a problem. But now that I have described the concept of globacidal, binary phase change and shown how it can explain these objections, it is time to propose some solutions to this dilemma. Specifically, I will present three preventive measures we can employ, but keep in mind that this is an all-or-nothing package. Doing just one or two of them will accomplish little, if anything, towards keeping Earth populated past 2100. I have set 2060 - a little over halfway between when I am writing this and the year 2100 - as the deadline for accomplishing them all, globally. If we can not whole-heartedly and fully implement these goals by the time all the rise in our oceans' heights have evaporated away and the planet's seas have begun receding below their current levels, then I hold little hope for us. As impossible as this may seem, none of these are new ideas. However, given our overall prior enthusiasm for them, I am not holding my breath until they are unilaterally embraced around the world. Yet, for what it is worth, here they are.

POPULATION CONTROL: I am sorry to burst your bubble, but even though their implementation backfired, the Chinese were right. We need to decrease the population of this planet, and quickly, back down to a level that will not overtax global renewable resources. It took over one hundred years of linear growth to double the Earth's population from one billion in 1804 to two billion in 1927. Less than one hundred years later, by 2012, exponential growth had more than tripled the number of people alive to seven billion. [1] While I have not yet seen numbers showing the best fit between renewable resources and our planetary population size, if linear acceleration had continued after 1927, then there would be less than three billion people alive on Earth today. Therefore, my best guestimate is that we need to rapidly reduce our planet's population, or at least its carbon footprint, by at least half before 2060. To be done thoroughly and peacefully, it will take a worldwide voluntary effort. The Chinese have already demonstrated - via female infanticide - how people will resist such a process if they are forced to comply. [2]

SOLAR BASED ENERGY: I am sorry to burst your bubble for a second time, but if you are a republican, the democrats got it right. At 1:31 p.m. on June 20, 1979, then United States President Jimmy Carter gave his "Solar Energy Remarks Announcing Administration Proposals" from the West Terrace of the nation's White House. In this speech, he set a goal for the United States to derive twenty percent of its total energy needs from solar-based energy by the year 2000. [3] This proposal, like much of his presidency, was laughed into obscurity. Yet, while Carter did have the right idea, I think his benchmark was far too low for what we need to do. In order to stop life-ending binary phase change on a planetary scale, I guestimate that we will need to obtain eighty percent of our global energy needs from solar sources by the time we reach 2060. To achieve this will require the equivalent of a third-world-war-like effort whose goal is wiping out man-made greenhouse gases. This might be feasible if we took the trillions of military dollars we spend annually to kill one another and reinvested it toward saving the planet. Unfortunately, I question our overall willingness and determination to exchange guns for calculators.

RECYCLE: I am sorry to burst your bubble for a third time, but if you like disposable goods, the industrialists were wrong: throw-away items are a bad idea. We need to refocus our manufacturing energies on reusable, repurposable, and renewable goods, with one-time use becoming a veritable crime against nature. [4] We can no longer afford to make products that drain the planet's resources. Instead, we must learn to emulate, and thereby integrate ourselves and our lives into the natural cycles that exist within planet Earth's current limitations. And we need to do it fast, which means by 2060 or bust. However, whether we can exchange avaricious, greed-based capitalism for capitalism with a conscience is an entirely different question.

So there you have it: a three-part answer to a two-part problem. None of these would be hard to do if they did not go against our entrenched and ingrained propensity to make babies, burn oil, and throw everything away. Ever since we adopted this pattern of behavior around 1800 when the industrial revolution began to take hold, we have repeatedly demonstrated ever new and ingenious methods of using, abusing, and then destroying the world around us, rather than living in an integrated, symbiotic nature within it.

Can we change? Even if we could, will we? Well, if you disagree with everything that is in this text, then I have not done my job. But, if you agree with everything that is in this text, then I have also not done my job. Given we have never witnessed these kinds of global phase change events before and have no experience-based data to rely upon, many unanswered questions remain before us. Hopefully you will use this book as a starting point to answer some of them. Yet, how long do we wait before acting? Should we postpone action for years or decades to search for definitive proof supporting or denying this thesis, or do we begin changing now? That decision is ultimately yours, but every minute wasted is one minute closer to the tipping point of no return. Sadly for us, you can only play Russian roulette for so long. Sooner or later you draw the bullet, and the worst part is that we live in the barrel of the gun.

Summary:

1. To stop binary-phase-change globacide, by 2060 we must voluntarily reduce our global population, or at least its carbon footprint equivalent, to around three billion.

2 To stop binary-phase-change globacide, by 2060 we must get eighty percent of our global energy needs from solar-based resources.

3. To stop binary-phase-change globacide, by 2060 we must almost exclusively manufacture reusable, repurposable, and recyclable goods.

Reference Notes

Author's note: As previously explained in the book's introduction, to make this text easy to understand, easy to verify, and easy to use as a research tool to begin answering the uncountable questions it will hopefully raise, I have used online links to Wikipedia as the main reference source for the majority of facts and data which I will be discussing. To that end, most of the following citations will contain online website references. Over time, the content of these links might change and the link addresses themselves might be altered or removed from the internet. Therefore, to avoid losing these citations to the ever-evolving nature of online, living documents, I have quoted relevant tracts from these links as they currently exist in the latter part of 2014.

To facilitate ease of reading, these reference notes have been indexed so that "2-3" means chapter 2, reference 3.

Introduction

I-1 Sir Vivian Ernest Fuchs' classic 1962 British Antarctic Survey:

"Operation Tabarin was a small British expedition in 1943 to establish permanently occupied bases in the Antarctic. It was a joint undertaking by the Admiralty and the Colonial Office. At the end of the war it was renamed the Falkland Islands Dependencies Survey (FIDS) and full control passed to the Colonial Office. At this time there were four stations, three occupied and one unoccupied. By the time FIDS was renamed British Antarctic Survey in 1962, 19 stations and three refuges had been established. From 1958 to 1973, the Antarctic explorer Sir Vivian Fuchs was Director of FIDS/BAS."

source:
http://en.wikipedia.org/wiki/British_Antarctic_Survey

Chapter 1 - Coffee

1-1 Near-Earth Object 1950 DA:

> *"1950 DA is a near-Earth asteroid. Among asteroids more than 1 km in diameter, it is notable for having the highest known probability of impacting Earth. In 2002, it had the highest Palermo rating with a value of 0.17 for a possible collision in 2880. In 2013, the odds of an Earth impact in 2880 were estimated as 1 in 4,000 (0.025%) with a Palermo rating of -0.83."*

source:
http://en.wikipedia.org/wiki/%2829075%29_1950_DA

Chapter 2 - Iced Tea

2-1 The graph was originally made in 1962 from NASA data:

"The U.S. Standard Atmosphere is a series of models that define values for atmospheric temperature, density, pressure and other properties over a wide range of altitudes. The first model, based on an existing international standard, was published in 1958 by the U.S. Committee on Extension to the Standard Atmosphere, and was updated in 1962, 1966, and 1976."

source:
http://en.wikipedia.org/wiki/U.S._Standard_Atmosphere

2-2 Kelvin Temperature Scale:

"The kelvin is a unit of measurement for temperature. It is one of the seven base units in the International System of Units (SI) and is assigned the unit symbol K. The Kelvin scale is an absolute, thermodynamic temperature scale using as its null point absolute zero, the temperature at which all thermal motion ceases in the classical description of thermodynamics."

source:
http://en.wikipedia.org/wiki/Kelvin

2-3 Tropopause:

> *"The tropopause is the boundary in the Earth's atmosphere between the troposphere and the stratosphere. Going upward from the surface, it is the point where air ceases to cool with height, and becomes almost completely dry."*

source:
http://en.wikipedia.org/wiki/Tropopause

2-4 Phase Change (a.k.a. phase transition):

> *"A phase transition* [change] *is the transformation of a thermodynamic system from one phase or state of matter to another one by heat transfer. The term is most commonly used to describe transitions between solid, liquid and gaseous states of matter, and, in rare cases, plasma."*

source:
http://en.wikipedia.org/wiki/Phase_transition

2-5 Latent Heat:

> *"Latent heat is the energy released or absorbed by a body or a thermodynamic system during a constant-temperature process. A typical example is a change of state of matter, meaning a phase transition* [change] *such as the melting of ice or the boiling of water."*

source:
http://en.wikipedia.org/wiki/Latent_heat

Chapter 3 - Antarctica

3-1 Around ninety percent of all ice on Earth resides in Antarctica:

"Nearly all of Antarctica is covered by a sheet of ice that is, on average, a mile thick or more (1.6 km). Antarctica contains 90% of the world's ice and more than 70% of its fresh water."

source:
http://en.wikipedia.org/wiki/Climate_of_Antarctica#Ice_cover

3-2 That USA size block of ice would rise over two miles into the air:

"About 98% of Antarctica is covered by ice that averages at least 1.9 kilometers (1.2 mi) in thickness."

source:
http://en.wikipedia.org/wiki/Antarctica

"At 14.0 million km2 (5.4 million sq mi), it [Antarctica] *is the fifth-largest continent in area after Asia, Africa, North America, and South America."*

source:
http://en.wikipedia.org/wiki/Antarctica

> *"Together, the 48 contiguous states and Washington, DC, occupy a combined area of 3,119,884.69 square miles (8,080,464.3 sq km), which is 1.58% of the total surface area of the Earth."*

source:
http://en.wikipedia.org/wiki/Contiguous_United_States

> Note: rounding off and then dividing 3.1 million (the area of the USA) by 5.4 million (the area of Antarctica), we find that the contiguous United States cover an area approximately 0.57 the size of Antarctica. Dividing 1.2 miles (the average depth of ice on most of Antarctica) by 0.57 yields an estimated height of 2.1 miles if that ice were transferred to the contiguous United States.

3-3 Supercontinents:

> *"In geology, a supercontinent is the assembly of most or all of the Earth's continental blocks or cratons to form a single large landmass."*

> source:
> http://en.wikipedia.org/wiki/Supercontinent

3-4 Antarctica is considered to be the planet's largest desert, as average annual rain fall is less than one quarter of an inch:

"The total precipitation on Antarctica, averaged over the entire continent, is about 166 mm (6.5 in) per year (Vaughan et al., J Climate, 1999). The actual rates vary widely, from high values over the Peninsula (meters/yards per year) to very low values (as little as 50 mm (2 in) per year) in the high interior. Areas that receive less than 250 mm (10 in) of precipitation per year are classified as deserts. Almost all Antarctic precipitation falls as snow."

source:
http://en.wikipedia.org/wiki/Climate_of_Antarctica#Precipitation

3-5 As the millennia passed, this frozen mass grew into an astounding volume, with the ice itself totaling between six and seven million cubic miles:

"The Antarctic ice sheet is one of the two polar ice caps of the Earth. It covers about 98% of the Antarctic continent and is the largest single mass of ice on Earth. It covers an area of almost 14 million square km (5.4 million sq. miles) and contains 26.5 million cubic km of ice (6.36 million

cubic miles).”

source:
http://en.wikipedia.org/wiki/Antarctic_ice_sheet

3-6 If that same amount of ice and snow were to be evenly distributed over a flat surface the same size as the continental United States, it would rise to a uniform average height of 2.1 miles:

Note: see reference 2 of this chapter.

3-7 The stupefying weight from this amount of frozen water has caused some parts of the Antarctic continent to sink down into the Southern Ocean over three thousand feet below its normal elevation:

“It is estimated that the volume of the Antarctic ice sheet is about 25.4 million cu km, and the WAIS [Western Antarctic Ice Sheet] *contains just under 10% of this, or 2.2 million cu km. The weight of the ice has caused the underlying rock to sink by between 0.5 and 1 kilometers* [1640.42 to 3280.84 feet] *in a process known as isostatic depression.*”

source:
http://en.wikipedia.org/wiki/West_Antarctic_Ice_Sheet

3-8 Contrary to what one would expect, there are over one hundred giant pools of super-cooled liquid water trapped beneath the polar ice, some in pockets with volumes greater than that of Lake Michigan:

“Lake Vostok (Russian: Ozero Vostok, lit. "Lake East") is the largest of Antarctica's almost 400 known subglacial lakes. Lake Vostok is located at the southern Pole of Cold, beneath Russia's Vostok Station under the surface of the central East Antarctic Ice Sheet, which is at 3,488 m (11,444 ft) above mean sea level. The surface of this fresh water lake is approximately 4,000 m (13,100 ft) under the surface of the ice, which places it at approximately 500 m (1,600 ft) below sea level. Measuring 250 km (160 mi) long by 50 km (30 mi) wide at its widest point, and covering an area of 12,500 sq km (4,830 sq mi) and an average depth of 432 m (1,417 ft), it has an estimated volume of 5,400 cu km (1,300 cu mi),”

source:
http://en.wikipedia.org/wiki/Lake_Vostok

"Lake Michigan is the only one of the Great Lakes wholly within the borders of the United States; the others are shared with Canada. It has a surface area of 22,400 square miles (58,000 sq km), making it the largest lake entirely within one country by surface area (Lake Baikal, in Russia, is larger by water volume), and the fifth largest lake in the world. It is 307 miles (494 km) long by 118 miles (190 km) wide with a shoreline 1,640 miles (2,640 km) long. The lake's average depth is 46 fathoms 3 feet (279 ft; 85 m), while its greatest depth is 153 fathoms 5 feet (923 ft; 281 m). It contains a volume of 1,180 cubic miles (4,918 cu km) of water."

source:
http://en.wikipedia.org/wiki/Lake_Michigan

3-9 Within those sub-glacial, super-cooled lakes, there exist billions upon billions of single-celled organisms trapped in time [which have been] retrieved from ice cores drilled deep into the ice cap:

"Living Hydrogenophilus thermoluteolus micro-organisms have been found in Lake Vostok's deep ice core drillings; they are an extant [existing] *surface-dwelling species. This suggests the presence of a deep biosphere utilizing a geothermal system of the bedrock encircling the subglacial lake."*

source:
http://en.wikipedia.org/wiki/Lake_Vostok#Traits

3-10 Hugh Hefner:

“Hugh Marston Hefner (born April 9, 1926) is an American adult magazine publisher and businessman, the founder and chief creative officer of Playboy Enterprises.”

source:
http://en.wikipedia.org/wiki/Hugh_Hefner

3-11 These life forms are of great interest to NASA in its search to understand how life might thrive under the harsh conditions found on other planets:

“This discovery of life existing in [Antarctica] *one of Earth's darkest, saltiest and coldest habitats is significant because it helps increase our limited knowledge of how life can sustain itself in these extreme environments on our own planet and beyond.”*

source:
http://www.jpl.nasa.gov/news/news.php?release=2012-382

3-12 How much sea levels will rise if all the ice melts off of Greenland and Antarctica:

"Melting of the Greenland ice sheet or the Antarctic ice sheet would produce 7.2 m [24 ft] *and 61.1 m* [200 ft] *of sea-level rise, respectively."*

source:
http://en.wikipedia.org/wiki/Current_sea_level_rise

3-13 ***Drought is slightly elevating ground in U.S. West, study finds***; by Alex Dobuzinskis; Reuters, Los Angeles; Aug 21, 2014.

"The 63 trillion gallons of water missing in the U.S. West is the equivalent of a 4-inch (10-cm) layer of water spread across the entire region, researchers found. On average, the loss of water resulted in an average uplift of the land in the West of 4 millimeters (0.15 inch), with up to 15 millimeters (0.6 inch) of uplift seen in California's mountains, according to Scripps."

source:
http://www.reuters.com/article/2014/08/21/us-usa-drought-west-idUSKBN0GL2AY20140821

3-14 To get a rough idea, consider the fact that there is about one hundred-thousand times more water still frozen in the south pole as has been lost in America's far west:

Due to expansion while freezing, ice occupies about a ten percent greater volume than liquid water. There are about 1.1 trillion gallons in a cubic mile. Given there are an estimated 6.36 million cubic miles of ice on Antarctica (see reference 5 of this chapter), that translates to about 6.996 million-trillion gallons of solid ice, or 6.36 million-trillion gallons of liquid water. To keep the comparison the same between the Western United States' drought and Antarctica, the 100,000 ratio was obtained using the conversion to liquid water instead of ice as follows:

6.36 million-trillion / 63 trillion = 100,952.38

3-15 The estimated 1,250 average, and 5,000 maximal foot up-lifts for Antarctica were derived by the following calculations:

0.15 = average inch rise in American West
0.6 = maximal inch rise in American West
100,000 = water ratio Antarctic to American West
12 = inches in one foot

0.15 x 100,000 = 15,000
inch average rise estimated in Antarctica

15,000 / 12 = 1,250
foot average up-lift estimated for Antarctica

0.6 x 100,000 = 60,000
inch maximal rise estimated in Antarctica

60,000 / 12 = 5,000
foot maximal up-lift estimated for Antarctica

3-16 These delta areas can be particularly prone to algae blooms when too many organisms populate the brackish waters:

"An algal bloom is a rapid increase or accumulation in the population of algae (typically microscopic) in an aquatic system. Cyanobacteria blooms are often called blue-green algae. Algal blooms may occur in freshwater as well as marine environments. Typically, only one or a small number of phytoplankton species are involved, and some blooms may be recognized by discoloration of the water resulting from the high density of pigmented cells."

source:
http://en.wikipedia.org/wiki/Algal_bloom

3-17 Antarctica's Onyx River, the continent's largest, is already prone to such blooms, but luckily it flows away from the ocean:

"The Onyx River is an Antarctic meltwater stream which flows westward through the Wright Valley from Wright Lower Glacier and Lake Brownworth at the foot of the glacier to Lake Vanda, during the few months of the Antarctic summer. Despite being only 32 kilometers (20 mi) in length it is the longest river in Antarctica. The river flow is away from the ocean, an example of endorheic drainage, as the Wright Glacier blocks the entrance to the valley. It has several tributaries, and there are multiple meteorological stations along the length of the river. Flow levels are highly variable, both during the day and between summers, with the river failing to reach the lake some years. In contrast, it can cause significant erosion in flood years, and was rafted in 1984 by New Zealand researchers. While there are no fish in Onyx River, it does support microscopic life, and the algal blooms can be quite extensive."

source:
http://en.wikipedia.org/wiki/Onyx_River

Chapter 4 - Balloons

4-1 Evaporation:

"Evaporation is a type of vaporization of a liquid that occurs from the surface of a liquid into a gaseous phase that is not saturated with the evaporating substance. The other type of vaporization is boiling, which is characterized by bubbles of saturated vapor forming in the liquid phase."

source:
http://en.wikipedia.org/wiki/Evaporation

4-2 All the liquid water on Earth after the ice has melted:

"The volume of the largest sphere, representing all water on, in, and above the Earth, would be about 332,500,000 cubic miles (1,386,000,000 cubic kilometers), and be about 860 miles (about 1,385 kilometers) in diameter."

source:
http://water.usgs.gov/edu/earthhowmuch.html

Note: even though the water *"above the Earth"* is included in this quote, atmospheric vapor represents only around 0.001 percent of the total, or about 3,100 cubic miles (see reference 4 of this chapter).

4-3 Water vapor is one of the most powerful greenhouse gases known:

"Water vapor accounts for the largest percentage of the greenhouse effect, between 36% and 66% for clear sky conditions and between 66% and 85% when including clouds."

source:
http://en.wikipedia.org/wiki/Greenhouse_gas#Role_of_water_vapor

4-4 Currently, only a tiny fraction of the Earth's water resides in the atmosphere, or about thirty-one hundred cubic miles of water:

"There is always water in the atmosphere. Clouds are, of course, the most visible manifestation of atmospheric water, but even clear air contains water - water in particles that are too small to be seen. One estimate of the volume of water in the atmosphere at any one time is about 3,100 cubic miles or 12,900 cubic

kilometers. That may sound like a lot, but it is only about 0.001 percent of the total Earth's water volume of about 332,500,000 cubic miles (1,385,000,000 cubic kilometers).”

source:
http://water.usgs.gov/edu/watercycleatmosphere.html

4-5 Yet, even at one hundred percent humidity, or full saturation, our current atmosphere is not likely able to hold even one percent of all Earth’s water:

The volume of water that Earth’s air contains varies from almost no water at times in Antarctica (zero percent) to full saturation elsewhere on a rainy day (one hundred percent). Given this wide range, even if the planetary average for saturation was only one percent, meaning it could hold one hundred times more water, then using the current saturation level of 0.001 percent from the preceding reference, that would still mean the atmosphere could only hold 0.1 percent of the Earth’s total water (0.001% x 100 = 0.1%)

4-6 The Ideal Gas Law:

“The ideal gas law is the equation of state of a hypothetical ideal gas. It is a good approximation to the behaviour of many gases under many conditions, although it has several limitations. It was first stated by Émile Clapeyron in 1834 as a combination of Boyle's law and Charles's law.”

source:
http://en.wikipedia.org/wiki/Ideal_gas_law

4-7 If the Earth were the size of a basketball, then our atmosphere would be an outer layer less than one-tenth of an inch thick:

“The Kármán line, located within the thermosphere at an altitude of 100 km [62 miles]*, is commonly used to define the boundary between the Earth's atmosphere and outer space.”*

source:
http://en.wikipedia.org/wiki/Atmosphere#Earth

Note: Earth’s atmosphere is 62 miles tall, the planet’s diameter is 7,918 miles wide, a NBA regulation basketball has a diameter of 9 inches, and there are 63,360 inches in one mile. So in a basketball sized Earth, the atmosphere would be

0.07 inches tall, calculated as follows:

(62 x 63360) x (9 / [7918 x 63360]) = 0.07

4-8 Troposphere:

"The troposphere is the lowest portion of Earth's atmosphere. It contains approximately 80% of the atmosphere's mass and 99% of its water vapour and aerosols. The average depth of the troposphere is approximately 17 km (11 mi) in the middle latitudes. It is deeper in the tropics, up to 20 km (12 mi), and shallower near the polar regions, approximately 7 km (4.3 mi) in winter. The lowest part of the troposphere, where friction with the Earth's surface influences air flow, is the planetary boundary layer. This layer is typically a few hundred meters to 2 km (1.2 mi) deep depending on the landform and time of day. The border between the troposphere and stratosphere, called the tropopause, is a temperature inversion."

source:
http://en.wikipedia.org/wiki/Troposphere

4-9 Solar Winds:

> *"The solar wind is a stream of plasma released from the upper atmosphere of the Sun. It consists of mostly electrons and protons with energies usually between 1.5 and 10 keV."*

source:
http://en.wikipedia.org/wiki/Solar_wind

4-10 Magnetosphere:

> *"A magnetosphere is the area of space near an astronomical object* [Earth] *in which charged particles are controlled by that object's magnetic field."*

source:
http://en.wikipedia.org/wiki/Magnetosphere

4-11 Kelvin–Helmholtz Instabilities:

> *"The magnetopause exists at a distance of several hundred kilometers off earth's surface. Earth's magnetopause has been compared to a sieve because it allows solar wind particles to enter. Kelvin–Helmholtz instabilities occur when large swirls of plasma travel along the edge of the*

magnetosphere at a different velocity from the magnetosphere, causing the plasma to slip past.”

source:
http://en.wikipedia.org/wiki/Magnetosphere#Structure

4-12 Aurora Borealis:

“An aurora is a natural light display in the sky (from the Latin word aurora, "sunrise" or the Roman goddess of dawn), especially in the high latitude (Arctic and Antarctic) regions, caused by the collision of solar wind and magnetospheric charged particles with the high altitude atmosphere (thermosphere).”

source:
http://en.wikipedia.org/wiki/Aurora

Note: the thermosphere is the layer of the atmosphere just below the exosphere, which means it is below six hundred and twenty miles in altitude (see reference 15 of this chapter).

4-13 So at the equator, these solar winds are predominantly deflected north and south around the Earth by what is called a bow shock effect:

"In astrophysics, a bow shock is the area between a magnetosphere and an ambient medium. For stars, this boundary is typically the edge of the astrosphere, where the stellar wind meets the interstellar medium. For a planetary magnetosphere, the bow shock is the boundary at which the speed of the stellar wind abruptly drops as a result of its approach to the magnetopause. The best-studied example of a bow shock is that occurring where the Sun's wind encounters Earth's magnetopause, although bow shocks occur around all magnetized planets, such as Jupiter or Saturn. Earth's bow shock is about 17 kilometers (11 mi) thick and located about 90,000 kilometers (56,000 mi) from the planet."

source:
http://en.wikipedia.org/wiki/Bow_shock

4-14 Solar Wind Stripping:

"Excess kinetic energy from solar winds can impart sufficient energy to the atmospheric particles to allow them to reach escape velocity,

causing atmospheric escape. The solar wind, composed of ions, is deflected by magnetic fields because the charged particles within the wind flow along magnetic field lines. The presence of a magnetic field thus deflects solar winds, preventing the loss of atmosphere. On Earth, for instance, the interaction between the solar wind and earth's magnetic field deflects the solar wind about the planet, with near total deflection at a distance of 10 Earth radii. This region of deflection is called a bow shock."

source: http://en.wikipedia.org/wiki/Atmospheric_escape#Significance_of_solar_winds

Note: not all of science is uniformly agreed upon. In contrast to the above quote, see reference 11 of this chapter which discusses Kelvin–Helmholtz instabilities that allow solar winds to penetrate the magnetosphere around the Earth's poles.

4-15 Exosphere:

"The lower boundary of the exosphere is known as exopause; it is also called the exobase, as in Earth's atmosphere the atmospheric temperature becomes nearly a constant above this altitude. Before the term exobase was established the

boundary was also called the critical altitude where barometric conditions no longer apply. The altitude of the exobase [the lower boundary of the exosphere] *ranges from about 500 to 1,000 kilometers (310 to 620 mi) depending on solar activity."*

source:
http://en.wikipedia.org/wiki/Exosphere#Lower_boundary

4-16 Returning to our previous basketball scenario, if today's atmosphere is represented by a thin layer less than one-tenth of an inch thick, then six hundred and twenty miles up would be less than three-quarters of an inch above the surface of that same basketball:

If we substitute 620 miles for the 62 miles used in the equation from reference 7 of this chapter, then we get 0.70 inches as follows:

(620 x 63360) x (9 / [7918 x 63360]) = 0.70

5-1 Even by current predictions, in the not too distant future, the northern Arctic polar cap will completely vanish in the summertime:

"The climate models on which the IPCC report Nr.4 is based give a range of predictions of Arctic sea ice loss, showing near-complete to complete loss in September anywhere from 2040 to some time well beyond 2100. About half of the analyzed models show near-complete to complete sea ice loss in September by the year 2100. More recently, the Catlin Arctic Survey concluded that summer ice loss would occur around 2029. It has been apparent though since 2007, that those models grossly underestimate sea ice loss."

source:
http://en.wikipedia.org/wiki/Arctic#Climate_change

5-2 Spindletop Hill:

"On January 10, 1901, at a depth of 1,139 ft (347 m), what is known as the Lucas Gusher or the Lucas Geyser blew oil over 150 feet (50 m) in the air at a rate of 100,000 barrels per day. It took nine days before the well was brought under

control. Spindletop was the largest gusher the world had seen and catapulted Beaumont into an oil-fueled boomtown. Beaumont's population of 10,000 tripled in three months and eventually rose to 50,000. Speculation led land prices to increase rapidly. By the end of 1902, more than 500 companies had been formed and 285 wells were in operation."

source:
http://en.wikipedia.org/wiki/Spindletop#History

5-3 Today, trains burn diesel instead of coal, and there are over one billion cars and trucks running along the globe's roadways:

"The number of vehicles in operation worldwide surpassed the 1 billion-unit mark in 2010 for the first time ever."

source:
http://wardsauto.com/ar/world_vehicle_population_110815

5-4 Linear (Uniform) Acceleration:

"Uniform [linear] *or constant acceleration is a type of motion in which the velocity of an object changes by an equal amount in every equal time*

period.”

source:
http://en.wikipedia.org/wiki/Acceleration#Special_cases

5-5 Exponential Acceleration (Growth):

“Exponential growth [acceleration] *occurs when the growth rate of the value of a mathematical function is proportional to the function's current value.”*

source:
http://en.wikipedia.org/wiki/Exponential_growth

Note: the idea here is that unlike linear acceleration where you add a fixed amount to the current value each time, in exponential acceleration (growth) you multiply the current value by a fixed amount each time.

5-6 Could diseases like the previously rare breakout of EV-D68 infections in the United States, that is currently being tracked by the CDC, be one of these early warning signs?

“Q: How many people have been confirmed to have EV-D68 infection?

A: From mid-August to September 19, 2014, a total of 160 people in 22 states were confirmed to have respiratory illness caused by EV-D68. (See States with Lab-confirmed Enterovirus D68.) The cases of EV-D68 infection were confirmed by the CDC or state public health laboratories that notified CDC.

Q: How common are EV-D68 infections in the United States?

A: EV-D68 infections are thought to occur less commonly than infections with other enteroviruses. However, CDC does not know how many infections and deaths from EV-D68 occur each year in the United States. Healthcare professionals are not required to report this information to health departments. Also, CDC does not have a surveillance system that specifically collects information on EV-D68 infections."

source:
http://www.cdc.gov/non-polio-enterovirus/about/EV-D68.html

Note: this is an example of a pathogen, EV-D68, that was previously so uncommon that it was not routinely tracked by the CDC.

Chapter 6 - Solutions

6-1 Earth's Population:

"It is estimated that the world population reached one billion for the first time in 1804. It was another 123 years before it reached two billion in 1927, but it took only 33 years to reach three billion in 1960. Thereafter, the global population reached four billion in 1974, five billion in 1987, six billion in 1999 and, according to the United States Census Bureau, seven billion in March 2012. The United Nations, however, estimated that the world population reached seven billion in October 2011."

source:
http://en.wikipedia.org/wiki/World_population#Milestones_by_the_billions

6-2 Female Infanticide:

"Sex-selected abortion, abandonment, and infanticide are illegal in China. Nevertheless, the US State Department, the Parliament of the United Kingdom, and the human rights organization Amnesty International have all declared that China's family planning programs

contribute to infanticide. The 'one-child' policy has also led to what Amartya Sen first called "Missing Women," or the 100 million girls "missing" from the populations of China (and other developing countries) as a result of female infanticide, abandonment, and neglect."

source:
http://en.wikipedia.org/wiki/One-child_policy#Alleged_effect_on_infanticide_rates

6-3 President Carter set a goal for the United States to derive twenty percent of its total energy needs from solar based energy by 2000:

"By the end of this century, I want our Nation to derive 20 percent of all the energy we use from the Sun..."

source:
http://www.presidency.ucsb.edu/ws/?pid=32500

6-4 Reuse versus Repurpose:

Reuse is using something for its original purpose more than once, instead of one time. Repurpose means to reuse something for a different purpose other than for what it was originally designed.