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Climate Change

Kaufui Vincent Wong

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Abstract

Climate Change is a collection of a number of papers as well as chapters about the science of the subject. This collection is meant to inflame and excite conversation among engineers, scientists, and society at large. It would serve as a catalyst for a three-credit course, as a relatively new engineering subject, for both engineering and nonengineering university students. As university education develops to better prepare future leaders to appreciate science, technology, engineering, and mathematics, engineering courses for a mix of engineering and nonengineering majors are essential and so is the requirement for worthy textbooks. This monograph intends to be one of the useful tools available on this timely topic. The wide range of topics includes climate change and theories, the second law of thermodynamics, the global greenhouse effect, anthropogenic heat release, evidence around us owing to environmental change, sea level rise, jungles and forests, heat islands, atmospheric carbon dioxide removal via technology, nanotechnology, other innovations in response to climate change, and the energy–water–food nexus.

KEYWORDS

air, anthropogenic heat release, carbon dioxide, energy-water-food nexus, environment, greenhouse effect, heat islands, jungles, nanotechnology, sea level rise, sun, technology, thermodynamics, water, weather

Contents

List of Figures **xiii**
List of Tables **xv**
Acknowledgments **xvii**

1 Introduction **1**

2 Climate Change and Theories **5**
- 2.1 Introduction 5
- 2.2 Milankovitch Theory 6
- 2.3 Sunspot Cycle 7
- 2.4 Sea Surface Temperature and Pressure Oscillations in the Pacific Ocean 10
- 2.5 Sea Surface Temperature and Pressure Oscillations in the Atlantic Ocean 15
- 2.6 Discussion and Conclusion 20
- References 21

3 The Second Law of Thermodynamics and Heat Discharge to the Environment by Human Activities **27**
- 3.1 Background 27
- 3.2 Discussion and Proof 29
- 3.3 Conclusion 31
- References 31

4 Greenhouse Effect and Climate Change **33**
- 4.1 Background 33
- 4.2 Understanding Electromagnetic Radiation 33
- 4.3 Planck's Law and Radiated Energy 36
- 4.4 Greenhouse Effect 38

4.5 Characteristics of a Greenhouse Gas 39
4.6 Evidence of Global Climate Changes 41
References 43

5 Anthropogenic Heat Release into the Environment 45
5.1 Introduction and Statement 45
5.2 Hypothesis of Method and the Method 46
5.3 Heat Based on World Energy Consumption 47
5.4 Heat From Net Electricity Generation 49
5.5 Heat From Oil Refineries 51
5.6 Heat From Garbage Incineration 54
5.7 World Output of Carbon Dioxide 55
5.8 Heat From Formation of Sulfur Dioxide From Combustion 55
5.9 Heat From Animal Bodies 55
5.10 Discussion and Conclusion 57
5.11 Nomenclature 58
References 58

6 Climate Change and All Evidences of Global Warming 61
6.1 Introduction 61
6.2 Mean Temperature Changes 62
6.3 Arctic Ice Caps 63
6.4 Wildlife and Extinction 65
6.5 Weather Patterns 68
6.6 Solutions 71
References 72

7 Mitigation and Adaptation Responses to Sea Level Rise 75
7.1 Introduction 75
7.2 Literature About Rising Seas 75
7.3 Mitigation Responses 77
7.4 Adaptation Responses 79
7.5 Discussion and Conclusion 80
References 81

8 Freshwater Discharges into the Oceans 83
8.1 Background 83
8.2 Lower and Higher Latitudes 85
8.3 Groundwater Discharge and Anthropogenic Contributions 87
References 90

9 Wealth of the Oceans 91
9.1 Introduction 91
9.2 Current Status 91
9.3 Literature Survey 92
9.4 Research and Development 93
9.5 Discussion and Conclusion 95
References 96

10 Forests and Jungles Brake Climate Change 99
10.1 Photosynthesis 99
10.2 Costa Rica 100
10.3 Nicaragua 101
10.4 Haiti 101
10.5 The Amazon Jungle 102
10.6 Indonesia 102
10.7 Discussion and Conclusion 103
References 104

11 Atmospheric Carbon Dioxide Removal via Technology 107
11.1 Introduction 107
11.2 Carbon Dioxide Removal 110
11.3 Biochar 110
11.4 Artificial Trees 112
11.5 Enhanced Weathering 113
11.6 Bio-Energy with Carbon Capture and Storage 115
11.7 Carbon Dioxide Capture “Trapping” Procedures 116
11.8 Carbon Dioxide Sequestration Procedures 117
11.9 Media for Biological Systems 118

11.10 Production of Biofuel 119
11.11 Discussion and Conclusion 121
References 122

12 USE OF SATELLITE IMAGES FOR OBSERVATIONAL AND QUANTITATIVE ANALYSIS OF URBAN HEAT ISLANDS AROUND THE WORLD **127**
12.1 Introduction 127
12.2 Urban Heat Island Effect 128
12.3 Landsat 129
12.4 Image Selection 132
12.5 Thermal Images 132
12.6 Quantitative Differentiation 135
12.7 Discussion and Conclusion 138
References 139
Thermal Images of Cities Analyzed 143
Urban-Rural Differential Images of Cities Analyzed 147

13 CLIMATE CHANGE AGGRAVATES THE ENERGY–WATER–FOOD NEXUS **151**
13.1 Introduction 151
13.2 Energy–Water–Food Nexus 152
13.3 The Himalayas 153
13.4 The Effect of Climate Change on Glaciers 155
13.5 The Effect of Climate Change on the Indus River 158
13.6 The Effect of Climate Change on the South Asian Monsoons 162
13.7 Recommendations to Enhance Energy, Water, Food Security 163
13.8 Discussion and Conclusion 164
References 165

14 INNOVATIONS RELATED TO HYDROLOGY IN RESPONSE TO CLIMATE CHANGE—A REVIEW **169**
14.1 Introduction 169
14.2 Agricultural Demands 170
14.3 Solar Drip Irrigation 171

14.4 Wastewater Reuse 171
14.5 Optimal Resource Management 172
14.6 Nanotechnology 174
14.7 Conventional Wastewater Treatment 175
14.8 Membrane Bioreactors 176
14.9 Biofilters 178
14.10 Groundwater 178
14.11 Comparison of MBRs and AS Plants 179
14.12 Discussion and Conclusion 180
References 180

15 A Balanced View 183

Index 187

List of Figures

Figure 2.1.	Sunspot numbers 2008 to 2015 [14].	10
Figure 2.2.	Current Sunspot cycles versus Dalton Minimum [14].	10
Figure 2.3.	ONI and SOI 1960 to 2015 [23, 24].	13
Figure 2.4.	PDO index and ONI 1950 to 2015 [23, 31].	15
Figure 2.5.	AO index 1995 to 2015 [39].	17
Figure 2.6.	NAO index 2001 to 2015 [44].	18
Figure 2.7.	AMO index 1948 to 2015 [50].	19
Figure 2.8.	Correlation between all climate cycles.	20
Figure 4.1.	Plot of radiance versus wavelength (axis at top) and corresponding wave number (axis at bottom).	39
Figure 4.2.	Cumulative annual global carbon dioxide emissions.	42
Figure 5.1.	The global energy consumption [4].	46
Figure 5.2.	Energy conversion [14].	49
Figure 5.3.	Oil refining process [24].	54
Figure 5.4.	Caloric intake necessary to maintain the human body.	56
Figure 6.1.	10-year average (2000 to 2009) global mean temperature anomaly relative to 1951 to 1980 mean [2].	63
Figure 6.2.	Polar ice cap in 2003 compared to 1979 [4].	64
Figure 6.3.	Species richness of native rainforest vertebrates at various temperature scenarios [8].	67
Figure 6.4.	Regions vulnerable to coastal flooding [12].	70
Figure 12.1.	The temperature image of Seoul, South Korea, on the left, along with the corresponding true color image, on the right. The units of the temperature scale are in degrees Fahrenheit.	133
Figure 12.2.	The temperature image of Tokyo, Japan, on the left, along with the corresponding true color image, on the right. The units of the temperature scale are in degrees Fahrenheit.	134

Figure 12.3. The temperature image of South Florida, United States, on the left, along with the corresponding true color image, on the right. The units of the temperature scale are in degrees Fahrenheit. 134
Figure 12.4. The true color image of South Florida, Florida, United States. The urban area is shaded in red, while the surrounding rural area is shaded in green. 136
Figure 12.5. The true color image of Chicago, Illinois, United States. The urban area is shaded in red, while the surrounding rural area is shaded in green. 137
Figure 13.1. A diagram depicting the energy–water–food nexus [6]. 153
Figure 13.2. Depiction of the Indus River (dark line) and the basin area (dark area), with respect to the countries in South Asia [29]. 161

List of Tables

Table 4.1. Various greenhouse gases and the range of their impact on the greenhouse effect [9] 41

Table 5.1. The data for fossils fuel and biofuel consumption 48

Table 5.2. The data for the actual world energy consumption from 2005 to 2012 [15] 49

Table 5.3. Data and calculation of combustion 50

Table 5.4. Total electricity net generation 52

Table 5.5. Power produced by the top 10 nuclear-power-producing nations 53

Table 5.6. World refining capacity in thousand barrels per day [23] 53

Table 8.1. Mean annual freshwater discharge into the Arctic Ocean for the years 1921 to 2000 [3] 86

Table 8.2. Variations in air temperature, precipitation, and calculated runoff in the Arctic river basins from 1936 till 1996, obtained via a straight-line relationship 88

Table 11.1. Options in the five stages of microalgae production and product processing 121

Table 12.1. Temperature differences between the urban and rural areas of cities 137

Table 14.1. Percentage of collected wastewater treated 173

Table 14.2. Percentage reduction of TSSs, COD, and total nitrogen (tn) 176

Table 14.3. Percentage reduction of biological oxygen demand (BOD), COD, ammonia-nitrogen, and turbidity 177

Table 14.4. g/ml of BOD, COD, ammonia-nitrogen and TSS in inflow streams 177

Table 14.5. Percentage reduction of TSS, COD, ammonium 179

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CHAPTER 1

INTRODUCTION

This is the introductory material to a monograph on *Climate Change*. More than in any other developed country in the world, the phenomena happening throughout the globe, and documented by the Intergovernmental Panel on Climate Change (IPCC), a body under the patronage of the United Nations, have been denied by many in the United States.

After graduation from Case Western Reserve University, Cleveland, Ohio, with a PhD in mechanical engineering, I obtained a position as assistant professor at the University of Miami in 1979, and started research in an environmental topic immediately. I also became a member of the American Geophysical Union (AGU) in 1980 and continue to be a life member of the respected institution. Even though I personally did not perform climate change research in the 1980s, I kept up with the AGU weekly newsletter, which did include articles about climate change, starting at least from this early date. Hence, when the debate about climate change heated up in the United States in recent years, it was natural for me to fall in line more with one group owing to scientific evidence rather than the other.

As a precaution to prevent the current monograph from being biased, many of the chapters of the book are published papers. Academic journal papers are peer-reviewed and have any partiality removed from the text. The many and varied reviewers require that. Six of the chapters in this book are academic papers already published elsewhere.

The book starts with this Introduction, followed by the theories of climate change, in Chapter 2. This background information allows the critical thinking reader to evaluate whether the theories tell us anything real about climate change, and whether any of their predictive capabilities will be helpful or not. The third chapter is about the Second Law of Thermodynamics, and how this law essentially tells us that all human activities are eventually dissipated as heat into the global environment.

The fourth chapter explains the greenhouse effect based on the molecular theory of matter. Quantitative tabulation and discussion of all the major heat contributions from human activities are presented in the next chapter. Cattle and other livestock are considered as sourced by humans. Chapter 5 is a reproduction of a journal paper published in the December 2012 issue of the American Society of Mechanical Engineer's (ASME) *Journal of Energy Resources Technology*. Chapter 6, by an invited author, is an interesting account of the various phenomena recognizable as a consequence of climate change.

Sea level rise is one of the many consequences of climate change, as documented by the IPCC. The seventh chapter is a discussion about the mitigation and adaptation responses to sea level rise. The Netherlands and Singapore have taken exemplary steps. Even the local authorities in South Florida, United States have carried out initial steps toward meeting this challenge.

Chapter 7 is a reproduction of an academic journal article published in June 2015 in the *Open Hydrology Journal*, Bentham Science Open. Chapter 8 is about freshwater discharges into the oceans. Nature's reservoirs of freshwater are the ice glaciers in the two Polar regions, and the Third Pole, the Himalayas. When these reservoirs of freshwater melt, what could be done has to be planned and engineered in place. If the freshwater escapes unchecked into the salty sea, fresh water reserves are going to be lost. In Chapter 9, the wealth of the oceans is discussed. In the scenario of ever-increasing human population and diminishing natural resources, the oceans remain as a relatively untapped resource. This chapter is also a reproduction of an academic journal article published in June 2015 in the *Open Hydrology Journal*, Bentham Science Open.

The tenth chapter is an ode to forests and jungles, and explains their importance and role in the health of the environment. Chapter 11 details the various engineering processes and systems that are being employed and studied for abatement of atmospheric carbon dioxide. There is a review and discussion of technologies, including new ones, effective ones as well as not so effective ones. Chapter 12 deals with the use of satellite images for observational and quantitative analysis of urban heat islands around the world. "Heat islands" are urban areas all over the world, for example, Miami, Florida, which become significantly hotter than the surrounding countryside in the summer because of all the waste heat discharged by the air-conditioners. Long before there was "climate change" recognition, ordinary people knew that cities were warmer than the countryside. A simple and innovative way to confirm that such a heat island does exist at any one time for any big city, so that the government may warn the public to save lives, for example, by reducing the mortality rate among the elderly. Enough details are given to carry out this analysis by local municipal authorities. This chapter is a reproduction of a juried conference paper presented at the International Mechanical Engineering Congress and Exposition (IMECE), held in Houston, Texas, in November 2012. This annual congress is run by the ASME.

Chapter 13 is about how climate change aggravates the energy–water–food nexus. Because of extreme weather conditions and calamities caused by weather, the water–food nexus rears its ugly head as problems including food shortages. The energy connection in the energy–water–food nexus is a more permanent one produced by the fact that about 90 percent of the world's electric power is being generated via the classical thermodynamic Rankine cycle that requires much waste heat to be removed by water (and more recently by air). A brief historical view is also presented about what happened in the Indus River valley of India and Pakistan. This chapter is a reproduction of a juried conference paper presented at the ASME IMECE 2014 in Montreal, Quebec, Canada.

The fourteenth chapter is regarding innovations related to hydrology in response to climate change. This is the third academic journal article published in June 2015 in the *Open Hydrology Journal*, Bentham Science Open. The last, but hardly the least, chapter is to urge all students and the public in general to keep an open mind, and listen to all the information presented, and critically evaluate whether climate change is a happening phenomenon.

CHAPTER 2

Climate Change and Theories

Kaufui V. Wong and M. Jacqueline Pape

2.1 INTRODUCTION

Natural climate variability causes the Earth's climate to change on all time scales, both long term and short term. Naturally occurring fluctuations have always existed and have caused temporary and cyclical regional and global changes in temperature, average precipitation, and other weather phenomena. It is very likely that the interglacial and glacial events that occurred hundreds of thousands of years ago occurred due to natural climate change cycles. Throughout several millennia, the Earth's climate has been fluctuating between extreme periods of cold and extreme periods of warmth. However, the question now being posed is whether the recent trends toward a warmer period are the results of these naturally occurring cycles or whether anthropogenic factors have overwhelmed the environment and thus become another contributing factor.

It is well known that the climate in recent years has turned toward a steep warming trend. It has been well documented by many renowned organizations such as the Intergovernmental Panel on Climate Change (IPCC), the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and many others that the warming trend is being seen globally. However, it is still unknown whether these changes in climate are due to natural cycles.

This discussion analyzes several of the most influential global and regional natural cycles and correlates them to observed data on climate change. Each of these cycles is explained through known theories that have developed over years of scientific and data analysis. It is very satisfying when field data support theories and this is what the following discussion attempts to reinforce. Two cycles responding to external causes—Milankovitch cycle and the sunspot cycle—as well as several other cycles due to pattern changes in the Earth's systems—the El Niño Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), the Arctic Oscillation (AO), the North Atlantic Oscillation (NAO), and the Atlantic Multidecadal Oscillation (AMO)—are closely analyzed and discussed with their relative impacts on climate. Some of these cycles are much more influential to long-term global temperature change, while others mainly affect short-term weather patterns and have no implications on long-term climate change. It is heartening, however, that these theories are not controversial, and have not been rejected by the majority of experts in the field.

2.2 MILANKOVITCH THEORY

In the late 19th century and early 20th century, Serbian engineer Milutin Milankovitch studied the orbital variations of Earth and their influence on long-term climate change. He developed what is now known as the Milankovitch Theory, which states that "as the Earth travels through space around the sun, cyclical variations in three elements of Earth-sun geometry combine to produce variations in the amount of solar energy that reaches Earth" [1]. The three varying elements are the Earth's orbital eccentricity, the Earth's axial inclination, and the direction of the Earth's axis of rotation. Through many observations and astronomical calculations, Milankovitch determined the length of each of these variations. The Earth's orbital eccentricity has a period of approximately 100,000 years, the changes in obliquity of Earth's axis has a period of roughly 41,000 years, and cycle of precession has a period of roughly 21,000 years [1].

The cycle of orbital eccentricity influences the amount of sunlight that the Earth receives. The shape of Earth's orbit can be more elliptical with higher eccentricities or more circular with lower eccentricities. At higher eccentricities, Earth is much closer to the Sun at the perihelion and thus receives more radiation, which causes an increase of the temperature of the planet. At the aphelion, Earth would be at its farthest point in the orbit and thus receives a lesser amount of solar radiation [1]. This cycle appeared to have reached a maximum about 11,000 years ago when the last ice age occurred [2]. Earth's orbital eccentricity can range anywhere from 0 to 0.07. Earth's current eccentricity is 0.017, which means that there is a difference of about 6 percent between the amount of solar radiation during the perihelion and the aphelion. This percent difference is low compared to a difference in radiation of approximately 20 to 30 percent when the Earth is at its maximum orbital eccentricity [1]. This means that at present, the Earth is very nearly at the beginning of the 100,000-year cycle. In fact, due to this low level of eccentricity, the Earth is in an interglacial period [3]. Changes in climate over the past few decades are clearly not of the same order of magnitude as the 100,000-year Milankovitch cycle [4]. As a result, it is unlikely that the orbital eccentricity cycle is greatly significant in any currently observed climate changes, except to tell us that we are in a "variable warming period."

The cyclical variation in the tilt of the Earth's axis and the precession of Earth's axis affect the strength of the seasons and the seasonal contrast [5]. These cycles do not affect the amount of sunlight that the Earth receives, but rather the intensity of sunlight that one region at a certain latitude would receive in a particular season [5]. The inclination of Earth's axis varies from 22.1° to 24.5°. With less of a tilt, there are warmer winters and cooler summers. As the tilt increases, there are cooler winters and warmer summers. The Earth's axial tilt is currently at 23.5°. This means that the planet is in middle, nearing the latter half of the 40,000-year cycle [1]. This would account for more extreme seasons because there is a greater contrast between the winter and the summer. The paper by Hansen, Sato, and Ruedy [6] confirms via statistical data that there is more extreme seasons in recent years, on a global scale. The increase in extreme seasons and natural climatic "disasters" could be contributed by the tilt of the Earth's axis as well as to anthropogenic climate change causes.

2.3 SUNSPOT CYCLE

The first sunspot was observed in 1610 by astronomer Galileo Galilei. In 1843, astronomer Samuel H. Schwabe determined that sunspots followed an 11-year cycle of waxing and waning [7]. The correlation between the sunspot cycle and the climate became apparent looking at early records from well-known periods of more intense sunspot cycles and cycles with less activity. In the 17th and 18th centuries, records show that very few sunspots were observed from 1645 to 1715 [8]. This reduced number of sunspots was a period of solar inactivity known as the Maunder Minimum, which corresponds to the period, known as the "Little Ice Age," during which many regions around the planet experienced very low temperatures [8].

With these well-documented correlations between solar activity and global temperatures, scientists concluded that Earth's temperatures rise with an increase in solar activity and temperatures fall with a decrease in solar activity. More recent studies even show that sunspot cycles can also greatly influence regional weather patterns. Based on data collected by the Goddard Institute of Space Studies, an increase in solar activity was consistent with an increase in precipitation in the Northern Hemisphere [9]. Weather events such as the South Asian monsoons and 15 to 20 percent of local rainfalls around the world were also partly attributed to the solar activity [9].

Sunspots affect climate by influencing solar emissions as well as ultraviolet and x-ray emissions from the Sun to Earth [8]. Sunspots are regions where the temperature drops nearly 1,500°C from the surrounding surface of the Sun. When the sunspot regions are centered on the "solar disk," studies have shown that the Sun has a reduced amount of solar radiation. Based on data from space satellites, solar radiation is reduced by nearly 0.1 percent when the sunspot regions are located at the center of the Sun as observed from Earth [10]. The more striking effect that sunspots have on Earth's climate comes from the magnetic nature of the dark spots. The sunspot regions have a "spectral radiance" that can influence certain layers in the Earth's atmosphere, which have a direct impact on climate and weather patterns. The spectral radiance refers to the level of UV and x-ray radiation that is emitted from the sunspots and can vary by 10 percent [10]. Ongoing studies are trying to determine which of the two impacts that sunspot activity have on the Earth's climate, total solar irradiance or spectral radiance, is more influential. However, it is certain that they definitely affect short-term weather patterns and long-term climate change.

Space satellite data collected over several decades show that the 0.1 percent change in solar irradiation between the minimum and maximum periods of the sunspot cycle has an effect 0.2 W/m^2 at the ocean surface [11]. This corresponds to a change in ocean temperature by about 0.02°C to 0.06°C [11]. This is a substantial temperature difference considering the magnitude of the ocean and the amount of heat that is required to increase the temperature of the ocean by 1°. Additionally, the total solar irradiation data showed that an increased amount of irradiation over land could intensify local natural weather events such as monsoon and other wind and ocean responses that are directly associated with La Niña. Furthermore, an increased amount of total solar irradiation over ocean regions could increase evaporation and moisture levels in the atmosphere, leading to more rainfall [11].

The second mechanism associated with sunspot cycles is the increase or decrease in spectral radiance. During a solar maximum, there is an increase in incident UV rays into the atmosphere. The increase in incident UV rays causes an increase in mid level ozone in the atmosphere. The increase in ozone warms the region because more heat is absorbed via short- and long-wave absorption [9]. The increased level of ozone during solar maximum conditions leads to a larger temperature gradient between the higher and lower latitudes, resulting in stronger stratospheric west winds [9]. This causes upwelling in the Southern Hemisphere outside of the tropics and downwelling in the Northern Hemisphere outside of the tropics [9]. Downwelling in the Northern Hemisphere causes limited convection and rainfall, meaning that the Northern Hemisphere summer would be drier [9]. Based on experiments and calculations conducted by NASA, it was determined that UV radiation exceeded 12.27 W/m^2 during solar maximum years and was less than 12.15 W/m^2 during solar minimum years [11]. This led to an annual difference in total solar radiation of 0.2 W/m^2 between solar maxima and minima [11]. This effect is about the same as that of solar irradiation; therefore, it is unclear which of the two effects has a greater influence on the Earth's climate.

The parallels between the consequences of the sunspot cycles and the climate on Earth are undeniable. As a result, it would be useful to use predictions of future sunspot cycles to forecast their effect on climate for years to come. Sunspot cycles are numbered starting at Cycle 1, which began in 1755 [12]. The current sunspot cycle is Cycle 24, which began in November or December 2008 [7]. Figure 2.1 shows the monthly average of sunspot numbers plotted against time during Cycle 24. This sunspot cycle reached its peak in April 2014 as determined by NOAA [13]. Thus, this would follow with Hansen's statistical data showing more extreme seasons and weather events in recent years [6]. However, using the sunspot cycles as the only determining factor in climate change, the extreme-season and increased number of severe weather patterns should be decreasing in the upcoming years following the decline of Cycle 24. As shown in Figure 2.1, Cycle 24 seems to already have passed its peak and, therefore, should be in decline following a slower period of solar activity.

Not only is Cycle 24 in decline, but also the past few cycles have exhibited characteristics of the well-documented Dalton Minimum [15]. The monthly averages of sunspot numbers during the Dalton Minimum and during the past few sunspot cycles are shown in Figure 2.1. As shown in Figure 2.2, when the most recent sunspot cycles from 1970 to the present time are overlaid over the sunspot cycles from 1770 to 1830, the cycles are very similar. This has led many to believe that the Sun is experiencing a

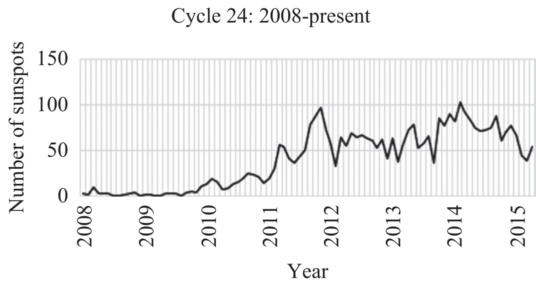

Figure 2.1. Sunspot numbers 2008 to 2015 [14].

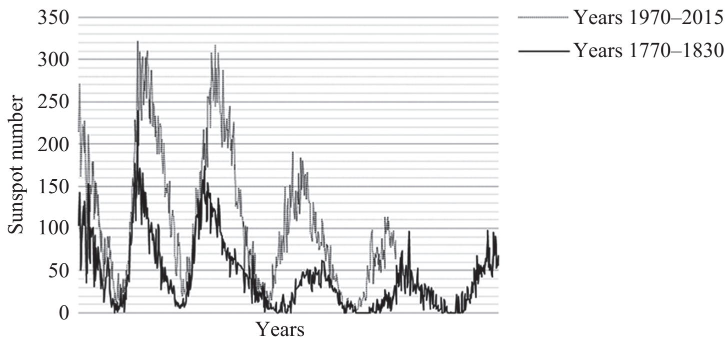

Figure 2.2. Current sunspot cycles versus Dalton Minimum [14].

period of inactivity and weaker sunspot cycles [16]. Based on predictions of future sunspot cycles, the current cycles are said to continue to be in a minimum state for another 30 years [16]. Although the effects of the sunspot cycles are not necessarily strong enough to overcome any anthropogenic impacts, the sunspot cycles are in decline which should lead to some global cooling.

2.4 SEA SURFACE TEMPERATURE AND PRESSURE OSCILLATIONS IN THE PACIFIC OCEAN

2.4.1 EL NIÑO SOUTHERN OSCILLATION

The ENSO refers to the variation of sea surface temperatures, wind patterns, and surface air pressures over the equatorial Pacific Ocean [17].

The cycle has an average period of three to five years; however, it can range anywhere between two and seven years [18]. Normally, trade winds blow in the westerly direction around the equator and create warmer waters on the western half of the Pacific Ocean known as a “warm pool” and colder conditions in the eastern half of the Pacific Ocean [18]. Throughout the cycle, the trade winds weaken and strengthen, causing the warm pool to extend beyond its normal boundaries into the eastern half of the Pacific Ocean or remain confined to the western half of the Pacific Ocean [17]. This oscillation causes the phenomena of the El Niño at one extreme or the La Niña at the other [17]. The effects of El Niño and La Niña are also accompanied by fluctuations in surface air pressure over the Pacific Ocean. This is known as the Southern Oscillation [18]. The Southern Oscillation describes the shift between below-average and above-average air pressures in the western part of the Pacific Ocean around Indonesia and the eastern tropical region of the Pacific Ocean [18].

There are normally warmer sea surface temperatures in the western half of the Pacific Ocean near Australia and Indonesia due to the east–west trade winds that blow across the ocean [19]. The warm sea temperatures force heat and moisture to evaporate into the atmosphere [19]. With enough moisture in the air, clouds and rain form over the region, leading to wet and stormy conditions. The rain and storms over the region leave dry air to move to the eastern regions of the Pacific Ocean due to convection patterns over the Southern Hemisphere [19]. However, every few years the easterly trade winds weaken and in some cases even reverse for reasons still unknown [17]. This allows the warm pool of water normally confined to the western region of the ocean to flow and spread throughout, causing rising sea temperatures in the eastern half of the ocean near the coast of South America [19]. As a result, hotter air with more moisture evaporates and causes wetter and stormier conditions in the eastern half of the Pacific Ocean. This event is known as El Niño and is characterized by above-average temperatures and above-average amounts of precipitation in the places like the coast of South America [19]. If the opposite occurs and the easterly trade winds strengthen, then the warm pool of water is confined even more to the western half of the Pacific Ocean, causing stormier conditions near Australia and even cooler temperatures and drier conditions near South America [19]. This is the La Niña.

The warming effects from the El Niño begin in December of the first year of the cycle and peak during late fall of the following year [18]. During a strong El Niño cycle, the weather effects are felt globally, causing torrential downpours and mudslides in places like Peru and southern California, and extreme droughts and dry conditions in Indonesia, Africa, and Australia [20]. After the peak of the natural phenomena, the waters cool down slowly but naturally over the next year [20]. During the period from 1950 to 1998, ENSO accounted for a 0.06°C increase in global temperatures [21]. The warming associated with ENSO usually occurs three months after the peak of the sea surface temperatures in the Niño region 3.4 and the warming can extend up to a ±30° latitude around the region several months after [21]. During periods of El Niño, this can account for rising ocean temperatures in the center and tropical regions of the Pacific Ocean extending from the subtropical latitudes of North America all the way down to the western coast of South America [21]. Moreover, the warm episodes of ENSO affect atmospheric circulation and cause the jet stream over the Pacific Ocean to strengthen. This in turn impacts storm paths and can even cause extratropical storms in the Northern Hemisphere allowing mid latitude low-pressure systems to increase in strength in the Northern Hemisphere, which causes milder conditions in Canada and the northern United States year-round [21]. Storms also increase in frequency due to the low-pressure systems around the Gulf of Mexico, causing wetter conditions in the United States [21].

Two indices, namely the Southern Oscillation Index (SOI) and the Oceanic Niño Index (ONI), are used as indicators of the ENSO [22]. The ONI is a measure of sea surface temperature anomalies in degrees Celsius in four different regions along the Pacific Ocean [22]. The four regions are known as Niño 1, Niño 2, Niño 3, and Niño 4. The ONI values are normally taken at the El Niño 3.4, which is in between region 3 and 4. According to established regression and statistical analysis made by NOAA, the ONI values need to exceed +0.5 or −0.5 for a full effect of the Southern Oscillation [22]. In an event that the ONI value exceeds +0.5, then there is an El Niño; when the ONI values exceed less than −0.5, then there is a La Niña episode [22]. The SOI, on the other hand, measures the difference between air pressure at sea level in Tahiti, to the east, and Darwin, to the west [22]. Negative values of SOI mean that the pressure in the eastern region of the Pacific Ocean is above average and below average in the western region of the Pacific Ocean, while positive values of SOI mean the opposite [22].

In Figure 2.3 is shown both ONI values and SOI values overlaid on the same graph. As this graph indicates, negative values of SOI correspond to positive values of ONI. This means that negative values of SOI showing higher pressure in the eastern region of the Pacific Ocean than in the western region of the Pacific Ocean correspond to above-average sea surface temperatures as shown through positive ONI values [23].

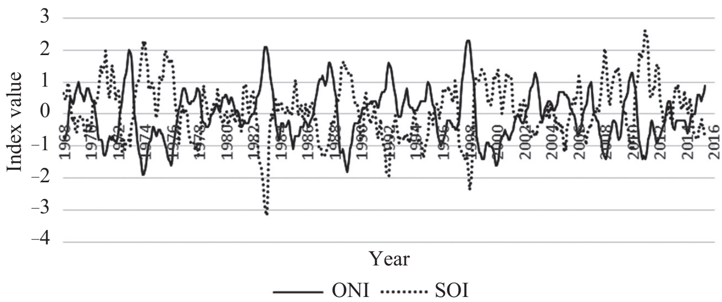

Figure 2.3. ONI and SOI 1960 to 2015 [23, 24].

El Niño episodes normally last 9 to 12 months, but in some cases they can last several years [17]. The longest recorded El Niño occurred during 1990 to 1995 where the ONI values exceeded +0.5 for five years as shown in Figure 2.3 [25]. La Niña episodes usually last a little longer, around one to three years [17]. However, as shown in Figure 2.3, the cycle is very irregular [17]. Thus, ENSO is very difficult to predict long term with certainty and accuracy. As a result, only short-term predictions can be made affecting the very near future.

Looking very closely at Figure 2.3, the most recent readings of both ONI and SOI values show that an El Niño episode is very likely to occur [25]. The ONI values have been consistently above 0, meaning that sea surface temperatures are above average. Likewise, SOI values have been negative, which show that air pressure is below average on the eastern region of the Pacific Ocean [25]. The positive ONI values combined with negative SOI values indicate that a period of El Niño is beginning to appear. This may have been the cause of increased storm weather patterns over the United States and warmer temperatures in the past few years. Additionally, it will account for any future wetter and warmer periods over the United States until the normal conditions return. According to NOAA, the El Niño conditions are supposed to continue through until the winter of 2015 or the spring of 2016 [25].

2.4.2 PACIFIC DECADAL OSCILLATION

The PDO is usually described as the long-term fluctuations of the ENSO variability [26]. The PDO pattern is characterized by periodic fluctuations in sea temperatures in the northeastern and tropical Pacific Ocean regions, resulting in a warm and cool phase much like that of ENSO [26]. However, one of the main differences between the PDO and ENSO is that while ENSO lasts only for 6 to 18 months, PDO can last anywhere from 20 to 30 years [27]. The implications that PDO has on the climate are very similar to that of ENSO, leading many to believe that the two are interrelated.

During a warm phase of the PDO, the sea surface temperatures in the central Pacific Ocean are below average and above average along the Pacific coasts and the North Pacific experiences below-average sea level pressures [26]. This leads to climate conditions very similar to that of El Niño with above-average air temperatures in the northwestern North American region and below-average temperatures in the Southeastern North American region [28]. In addition, there is above-average precipitation recorded in the southern North American region and below-average precipitation in the northwestern North American region around the Great Lakes [28]. During a cool phase of the PDO, the sea surface pressures in the central Pacific Ocean are above average, while those along the coast are below average and the North Pacific experiences above-average sea level pressures. As a result, conditions are the reverse of those seen during a PDO warm phase and resemble that of the La Niña [28].

The PDO index is used to measure the phases of the PDO. A positive index value corresponds to a warm phase and a negative index value corresponds to a cool phase. In Figure 2.4 is shown the PDO index values plotted against time from 1950 to the present overlaid with ONI values from 1950 to the present. From this figure it is clear that the two oscillations seem to be in phase. It has been observed that when the PDO is in warm phase, the effects of El Niño on climate and weather patterns are stronger and more frequent [29]. In contrast, when the PDO is in a cold phase, the effects of El Niño are weakened [29]. As a result, it can be concluded that the strength of ENSO is dependent on the PDO phase [28]. If the PDO and ENSO are in phase, then their combined effect causes much stronger climate effects during periods of El Niño and La Niña. However, if the two cycles are out of phase during a particular period, then they can somewhat cancel each other out and the effects from El Niño and La Niña are much lighter and weakened. During the winter of 1997 to 1998, as Figure 2.4 indicates, both the PDO and the ONI indices showed very positive values. This would mean that the PDO and ONI were very much in phase and would likely work together to produce a very strong El Niño event. Consequently, the El Niño event during the winter of 1997 to 1998 was the strongest El Niño on record in the 20th century [30].

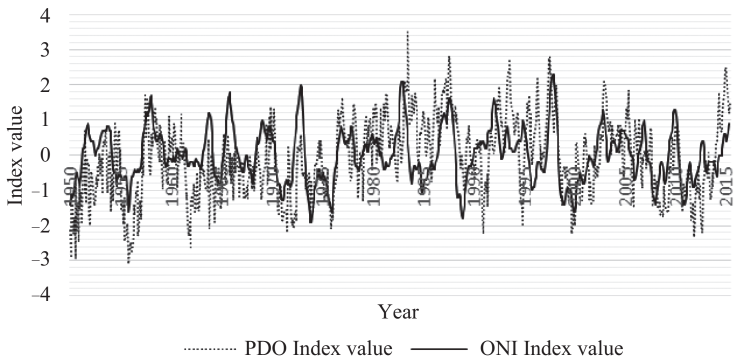

Figure 2.4. PDO index and ONI 1950 to 2015 [23, 31].

Currently, as Figure 2.4 indicates, the PDO has recently shifted to a warm phase, and the ONI shows that there is an El Niño occurring soon [32]. Additionally, neither the ONI nor the PDO seem to have very positive values, meaning that both are in a strong warm phase. Since both cycles seem to be in phase with each other, the effects of El Niño will probably be much stronger than in past periods. As a result, the combination of a warm phase in the PDO and the ENSO will lead to a milder winter and wetter conditions in the winter of 2015 to 2016 in the western region of the United States near California and northern Mexico [32]. Additionally, the current PDO warm phase seems to have begun very recently, meaning that it could last for a couple of decades.

2.5 SEA SURFACE TEMPERATURE AND PRESSURE OSCILLATIONS IN THE ATLANTIC OCEAN

2.5.1 ARCTIC OSCILLATION

The AO refers to natural fluctuations in mean sea level pressure north of 20°N [33]. The AO measures differences in sea level pressures between the Arctic region and the Northern Pacific and Atlantic regions [33]. The AO experiences two phases: a positive phase associated with warmer temperatures, and a negative phase associated with colder temperatures [33]. The AO can change phases anywhere from days to months [33]. As a result, it is a better indicator of short-term weather patterns rather than long-term climate change. The AO does show, however, climate changes in its effect on the sea ice in the North Pole [34].

Normally, an area of low pressure sits over the higher latitudes of the Northern Hemisphere known as the "polar vortex." During the positive phase of the AO, the sea level pressures in the northern latitudes of the Arctic are lower than in the lower latitudes, causing stronger westerly winds [35]. The stronger westerlies work to confine the permanent low-pressure system to the Arctic regions and allow the polar vortex to strengthen [35]. With a stronger polar vortex, there are below-average geopotential heights, meaning that there is dense cold air in the atmosphere causing the pressure surfaces to lower [36]. As a result, during a positive phase with below-average geopotential heights, cold air masses are restricted to the Arctic region. Consequently, there are below-average temperatures in northern latitude regions such as Greenland and Newfoundland and above-average temperatures in the eastern United States [36]. The strengthened low-pressure system also creates strong winds blowing toward northwestern Europe, which bring warm, humid air and storms over the Atlantic toward Europe [37].

At the other extreme, during a negative phase of the AO, the sea level pressure differences in the Northern Hemisphere are smaller [35]. As a result, the westerlies are much weaker, allowing the polar vortex to extend further south [37]. The negative phase of the AO has also been correlated to above-average geopotential heights in the northern latitudes and below-average geopotential heights in the mid latitudes [37]. As a result of this, there are warmer temperatures in the northern regions of Greenland and Newfoundland and colder temperatures in the United States and Europe [36].

The AO index is used to measure the extent of the arctic oscillation. The AO index was established by D. Thompson and M. Wallace and comprised monthly mean sea level pressure in the Northern Hemisphere for each year [38]. A positive AO index value corresponds to a positive phase, and a negative index value corresponds to a negative phase. In Figure 2.5 is shown the recorded AO index values from 1995 to the present. In the winter of 2010, the AO was extremely negative, as can be seen in the graph. The negative phase accounts for the extreme cold snap that hit the United States in the winter of 2010 [36]. The negative phase of the AO allowed for the weather and cold masses of air in the poles to move southward and enter Canada and the eastern United States. Thus, due to the AO, the United States experienced several winters of colder and wetter than normal conditions.

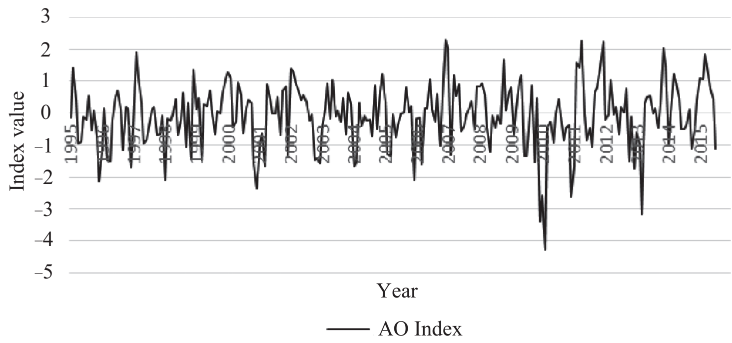

Figure 2.5. AO index 1995 to 2015 [39].

2.5.2 NORTH ATLANTIC OSCILLATION

The NAO describes variations in air pressure between regions in the Northern Atlantic that have implications on climate around the Northern Hemisphere [40]. The NAO causes shifts in weather patterns and conditions between the Greenland region and Northwestern Europe [41]. Normally, there is lower air pressure in the northern latitudes of the Atlantic Ocean near Iceland and Greenland known as the “sub-polar low” with air flowing counterclockwise and there is a zone of higher air pressure in the central latitudes of the Atlantic Ocean near the Azores known as the “subtropical high” with air flowing clockwise [41]. This naturally creates a north–south pressure gradient and causes westerly flow of wind through the Northern Atlantic region [42].

The NAO alternates between a positive and negative phase. During a positive phase, both the sub polar low and the subtropical high are stronger than normal, meaning that regions near Iceland experience lower than average air pressure and regions near the Azores experience higher than average air pressure [41]. The extreme subpolar low favors cold advection over the Greenland region, moving masses of mild and humid air to northwestern Europe [40]. Consequently, there are below-average temperatures in the Greenland region and above-average temperatures in Northwestern Europe and the eastern United States [40]. The eastern United States and northwestern Europe also experience increased stormy weather due to the increased winds in the upper levels of the atmosphere [40]. During a negative phase the exact opposite occurs. The sub polar low and the subtropical high are both weaker and thus the pressure gradient

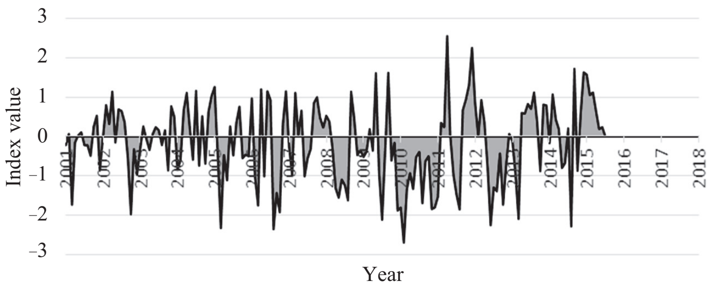

Figure 2.6. NAO index 2001 to 2015 [44].

between the two regions is smaller [41]. As a result of the reduced pressure gradient, the westerlies weaken allowing cold air to build up over Canada [40]. This causes below-average temperatures and drier conditions in the eastern United States and in northwestern Europe [41]. On the other hand, the Greenland region and the Mediterranean region experience wetter conditions [41].

The NAO index is used to measure the exact intensity of the oscillation each month of the year [43]. When the NAO index is below 0, the oscillation is experiencing a negative phase, and when the NAO index is above 0, it is in a positive phase. In Figure 2.6 is shown monthly NAO index values from 1950 to the present based on data from NOAA [44]. As seen from this graph, the NAO does not have a defined pattern. However, several conclusions can be made—the oscillation usually changes phase at least once within a decade, making the cycle an interdecadal oscillation [45]. As it is shown in Figure 2.6, the NAO seems to be in a positive phase with positive NAO index values dominating in recent years. As a result, the eastern United States and northwestern Europe may be seeing milder and wetter conditions in the upcoming years.

2.5.3 ATLANTIC MULTIDECADAL OSCILLATION

The AMO refers to the variation in sea surface temperatures in the Atlantic Ocean that has implications on climate around the world. Based on historical data, the North Atlantic sea surface temperatures change by 0.4°C over a 65- to 80-year period [46]. The AMO describes the change in the circulation of water and heat in the Atlantic Ocean [47]. This cycle was only recently established as the AMO by Kerr in 2000 [46]. However, based on reconstructions of past data, the AMO cycle has been occurring for the past 1,000 years [47].

As with the AO and the NAO, the AMO experiences a warm phase and a cool phase. Each phase could last for about 20 to 40 years [48]. During a warm phase, moist air is displaced northward over the tropical Atlantic Ocean and the westerlies strengthen, causing a reduction in rainfall over the United States and the northeastern regions of Brazil and an increase in precipitation over the Sahel region in Africa and northwestern Europe [48]. Additionally, the circulation of air in the atmosphere changes in such a way, thus allowing more hurricanes to form over the Sahel region in Africa [48]. During a cold phase, the opposite occurs and the United States and northeastern regions of Brazil experience increased amounts of precipitation and the Sahel region experiences lower amounts of rainfall and hurricane formations [48].

The AMO accounted for the droughts during the 1930s, the 1950 to 1960s, and 1996 to 2004 when the cycle was in a warm phase and the decades of increased rainfall during the 1940s and 1976 to 1995 when the cycle was in a cold phase [49]. The AMO has been in a warm phase for almost 20 years since the mid-1990s as shown in Figure 2.7 [47]. This means that there has been a warm phase for just about 20 years. Since the AMO still cannot be predicted accurately, it is unknown how much longer the warm phase will last [47]. However, looking at the graph and previous cycles, the warm phase is most likely nearing its end. Consequently, the cool phase of the AMO should take place within the next couple of decades. This means that, currently, there is below-average US precipitation; however, this will likely change with the cold phase leading to an increase in precipitation over the United States and a reduction in hurricane formations.

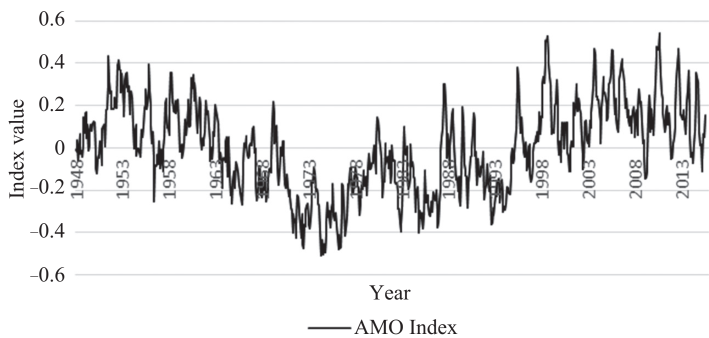

Figure 2.7. AMO index 1948 to 2015 [50].

2.6 DISCUSSION AND CONCLUSION

The question of whether these naturally occurring cycles play a dominant role in climate change has many complexities. In Figure 2.8 is shown the historical concurrent effects of the natural cycles discussed. When their quantifiable impacts are considered together, they clearly yield a net warming trend for the short term. As seen in the figure, majority of the cycle indices correlate and are above zero and, thus, are in a warming phase. This could be used to explain current climate change trends. However, several of the cycles have only recently entered their warming phase and some show that the current cycle activity is much lower compared to previous years.

As previously discussed, the two cycles known to impact long-term climate change are the Milankovitch Cycle and the Sunspot Cycle. The Milankovitch cycle shows that the climate should be currently in the interglacial period. The sunspot cycle, on the other hand, shows that the Sun is entering a period of inactivity with low sunspot numbers and solar radiation much like what happened during the Dalton Minimum, which led to colder global land temperatures. These two cycles show contrasting opinions. However, the Milankovitch cycle is a longer cycle and is likely the major cause of the last glacier periods. This means that the effects of the Milankovitch cycle are still important in terms of long-term climate change, while the other cycles with smaller periods affect climate for a shorter period. Therefore, the Milankovitch cycle shows a period of variable warming trend, while the minimum of the sunspot cycle could mean below-average temperatures for a few more decades.

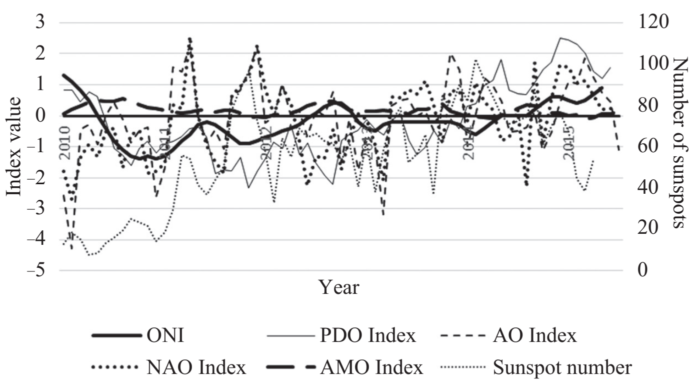

Figure 2.8. Correlation between all climate cycles.

The regional oscillations interact with each other and affect weather patterns. The ENSO and NAO are currently in their warm phases, while the AO is in a cool phase. As a result, there should be more rainfall in the United States accompanied by some below-average temperatures. However, these trends are only in the short term and not global but a more regional or local nature. These cannot explain large-scale, more expansive warming trends. Additionally, neither of these cycles has defined periods or durations. Consequently, they are very difficult to predict, making it problematic to use them to forecast any future trends. The AMO and PDO, however, are regional oscillations that are multi decadal, meaning that their phases can last several decades. These two trends also have more defined cycles and durations for each of their events, making them more effective in determining long-term trends. The AMO has been currently in a warm phase for the past two decades, which could in part explain the recent warming trends due to the far-reaching effects of the AMO. The PDO is also in a warm phase, which could also explain the recent and future warming trends. The cause of both of these cycles is still unknown, however. While they are well defined and observed, it is still unknown why either of them occurs. This makes forecasting difficult. As a result, these regional oscillations would not be sufficient to warrant the determination of a climate change state due to lack of information on the exact nature of their variations.

While the combined impact of the trends do seem to be causing above-average temperatures and greater amounts of rainfall in certain areas of the Earth, they are merely phases that could last anywhere for a few months, to a couple of years, to thousands of years. Consequently, it is unlikely that these cycles can explain the warming trend that has occurred over the past several decades since many of the natural climate cycles change phases on a very short-term basis. As a result, in addition to the natural climate variations, there are anthropogenic factors that need to be studied and quantified further to be able to determine their regional or local impact and their short- and long-term consequences. Only then would it be possible to introduce their quantifiable mark with the rest of the natural cycles and measure their true materiality in the overall discussion of climate change impacts.

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CHAPTER 3

The Second Law of Thermodynamics and Heat Discharge to the Environment by Human Activities

3.1 BACKGROUND

There is both a thermodynamic as well as statistical mechanics definition for entropy. The thermodynamic definition was proposed in the 1850s by Rudolf Clausius. Clausius recounted the method to measure the entropy of an isolated system in thermodynamic equilibrium. The statistical definition is attributed to Ludwig Boltzmann in the 1870s [1]. He studied the statistical behavior of the microscopic components of the system. He showed that his definition was identical to the thermodynamic entropy to within a constant number. This number is the Boltzmann's constant. The thermodynamic definition of entropy is the fundamental one. The statistical definition extends the notion and provides a more profound insight to its character.

The second law of thermodynamics stipulates that the total entropy of any system cannot drop but to raise the entropy of another system. Therefore, the entropy of a system isolated from its environment cannot drop. As a natural result, heat cannot be transferred from a cold mass to a less cold mass without work performed on the less cold mass. As a second principle, equipment undergoing a cycle cannot deliver net or take-away work from one reservoir at uniform temperature; the delivery of work demands heat transfer from a warm reservoir to a cool reservoir. Another essential principle is that a reduction in the upward change in entropy in a specified process shows that it is energetically more efficient than another.

From the second law of thermodynamics, the entropy of a system that can interact with its environment may drop. For instance, an air conditioner may reduce the air temperature of an office, thus cutting the entropy of the air. For comprehension purposes, the office is defined as the system. With the air conditioner on, the increment in the environmental entropy will be bigger than the decrement in the entropy of the system. Hence, the sum of the system entropy and the environmental entropy increases, in line with the second law of thermodynamics.

In classical thermodynamics, entropy is described as a state function of a thermodynamic system. It is a property that is dependent only on the current state of the system. The product of this state function and a reference temperature is that portion of energy, which cannot be converted into thermodynamic work. Consider a system undergoing a process where a quantity of energy equal to ΔE is employed. If the system entropy drops by ΔS, a minimum amount $T_0\Delta S$ must be dissipated to the environs (T_0 is the temperature of the system's environs). If not, the process will not occur.

In general, when a system's energy is tagged as its "useful" energy (energy that can be used, for example, to raise a weight), and as its "useless energy" (that energy that cannot be used to do external work), then entropy can be used to assess the "useless" or "lost" energy, which is based on the entropy of the system and the absolute temperature of the environs. Since the "useful" and "useless" energy are functions of the surroundings also, neither is a function of the state of the system alone. This can be contrasted with the system's Helmholtz free energy and temperature, which are well-defined state properties. Exergy is a well-defined function of state of the system with respect to the environment, that is employed to measure the "useful" energy.

When heat is transferred to a system at high temperature, the entropy upsurge is not much. Compare this to heat transferred to a system at low temperature, where the entropy proliferation is more. This can be quantified. In thermal systems, entropy variations can be evaluated by measuring the temperature and variations in energy. This holds true where thermal conduction is the one method of energy transfer (as contrasted to frictional)

$$\Delta S = \frac{q}{T}$$

where "q is the heat picked up by the system undergoing an isentropic or reversible isothermal process wherein the system transforms from state 1 to state 2 at an absolute temperature T [2].” When the temperature of the system temperature does not remain the same, the equation turns into a differential one:

$$dS = \frac{\delta q}{T}$$

The entropy change is $\Delta S = \int \frac{\delta q}{T}$.

This thermodynamic approach to compute the entropy is governed by several restrictions that must be obeyed without exception.

> In contrast, the fundamental statistical definition of entropy applies to any system, including systems not near equilibrium, and ones where “heat” and “temperature” are not easy to define. Where the thermodynamic approach is valid, it can be shown to be consistent with the basic statistical definition [2].

3.2 DISCUSSION AND PROOF

The hypothesis of the current work is that all human activities add heat to the global environment. In the following discussion, “global environment” is sometimes referred to as the total environment. Without any qualifications, the “environment” just refers to the area or space surrounding the system.

Two major classes of man-made engineering systems are the heat engine and the refrigerator/heat pump. The heat engine system includes the power plant cycle, the internal combustion engine—both gasoline and diesel, any system that employs the gas Brayton cycle, the Stirling cycle, and the Ericsson cycle. For heat engines, the heat is added at high temperatures (usually with the combustion of a fuel), work is done by the system and a portion of the heat is rejected to the environment. The fact is that all heat engine systems add heat to the total environment.

For a refrigerator or an air-conditioning system, the heat is removed from a cold space and transferred to the hot environment with the addition of work, usually in the form of electricity. By the first law of thermodynamics or the conservation of energy, the heat transferred to the hot environment is equal to the heat removed from the cold space plus the work added. The point here is that all refrigerator or air-conditioning systems add heat to the environment. In summer time, it is a familiar phenomenon that a city is like a heat island (higher temperature) in the middle of the surrounding rural area.

For a heat pump system, the heat is added to the hot space and removed from the environment with the addition of work (usually in the form of electricity). The system is principally the same as the refrigerator, except for a difference in size and capacity. There is net heat added by a heat pump in winter to the heated space, typically a home or small office building. Since the home or office building is part of the global environment, there is heat added to the global environment by all heat pump systems. In winter too, a city behaves like a heat island (higher temperature) compared with the surrounding countryside.

Human beings, as well as other warm-blooded animals, may be simply modeled as heat engines when analyzed in the thermodynamics sense [3]. By digesting the food and drinks we consume, we obtain our heat input. We perform work in our various activities and by just moving around, and dissipate heat via our excretions and feces, as well as through our body surface, which is most of the time at a higher temperature than the surrounding environmental temperatures. When the environmental temperature is higher than our body temperatures, human beings perspire, and heat is removed from the bodies as latent heat of vaporization for the perspiration. Hence, human beings and other warm-blooded animals add heat to the environment by just living as well as when they die and decay.

Plants, particularly the food items grown for consumption, do absorb energy from the sun and store it as internal energy. These are consumed by human beings and other animals, and a part of that internal energy is rejected as waste heat. The net result is that a part of the useful energy absorbed or otherwise utilized from the sun by all food crops, fruits, and vegetables are given up as waste heat to the global environment.

The laws of thermodynamics allow for all work to be converted into heat. A classic example is the use of friction work to make a fire from dried twigs. There is also the common example of all electricity generating heat when a current flows through a resistance. The electric heater would be the classic simple example for converting all work into heat.

All actual processes increase entropy, according to the second law, when the system is taken together with its environment. In a process where the system releases an amount of energy ΔE, and its entropy drops by ΔS, a minimum amount equal to $T_0\Delta S$ of that energy should be dissipated as unusable heat to the system's environs. Hence, any process in the real world either dissipates at least $T_0\Delta S_1$ of unusable heat to the system's surroundings when its entropy decreases by ΔS_1, or that the system's own entropy will go up by ΔS_2. As all systems on earth are parts of the global environment, all actual processes lead to increase in heat in the global environment.

The foregoing discussions have logically led to the inference that human activities add heat to the global environment. The proof has been shown by discussing all processes and major classes of systems. Mitigation of the effects of large heat additions can be realized by conservation practices as well as the exclusion of avoidable happenings that produce large heat releases.

3.3 CONCLUSION

The discussion above has led to the deduction that all human activities release heat to the environment. No significant category of human-related activity has been omitted in the deliberation, and hence the proof and inference. The means employed is observational and empirical.

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CHAPTER 4

Greenhouse Effect and Climate Change

4.1 BACKGROUND

If one is to scientifically verify global climate change, one must first understand its causes. Inbound sunlight passes through the earth's atmosphere and reaches the surface of the earth. Some of that light is absorbed as heat to be re-emitted later, while some of it is immediately reflected from the earth's surface back into the atmosphere. When the outbound energy reaches the atmosphere, the atmosphere acts like a gaseous lens by reflecting the major portion of the outbound energy back toward the earth's surface. The result is that extra energy is trapped. Let us consider the incoming radiation. As the distance of the sun is known (93,000,000 miles or 149,668,992 km) the angle of incidence of sunlight on the earth's atmosphere may be calculated. Since the radius of the earth is negligible in comparison to its distance from the sun, the sun's rays that come into contact with the atmosphere are all virtually parallel. The atmosphere behaves like a spherical lens and mirror, refracting and reflecting the inbound rays.

4.2 UNDERSTANDING ELECTROMAGNETIC RADIATION

Energy from the sun is transferred in the form of electromagnetic radiation or light waves. Electromagnetic radiation is the only form of energy that can be transferred through a vacuum. When electromagnetic radiation comes across a boundary, which is an interface comprising two different substances, some of the light is reflected from the interface, while some of the light is transmitted through the interface. Electromagnetic radiation comprises combined electric and magnetic fields, which fluctuate in space and time. Maxwell's equations are the governing equations for electromagnetism, and they are as follows:

$$\vec{\nabla} \cdot \vec{E} = \frac{\rho}{\in} \tag{4.1}$$

$$\vec{\nabla} \cdot \vec{B} = 0 \tag{4.2}$$

$$\vec{\nabla} \times \vec{E} = \frac{\partial \vec{B}}{\partial t} \tag{4.3}$$

$$\vec{\nabla} \times \vec{B} = \mu \left(\vec{J} + \in \frac{\partial \vec{E}}{\partial t} \right) \tag{4.4}$$

Where E is the electric field, B is the magnetic field, ρ is the free charge density, J is the free current density, and ε and μ are the permittivity and permeability of free space, respectively [1]. Employing these four equations, the boundary conditions for electromagnetic radiation incident on the earth's atmosphere can be described mathematically. Since the earth–atmosphere system is, statistically speaking, electrically neutral, the boundary conditions can be streamlined such that, at any interface between materials A and B, these conditions may be expressed as

$$E_{A,Parallel} = E_{B,Parallel}; \tag{4.5}$$

$$B_{A,Perpendicular} = B_{B,Perpendicular} \cdot [2] \tag{4.6}$$

Incoming radiation can be decomposed into two distinct categories, depending on the direction of its electric field. The electric field vector defines the "polarization" of the radiation, which comprises s-polarized and p-polarized light. Owing to the nature of light, the incident, reflected, and transmitted waves form a two-dimensional plane. S-polarized light is made up of radiation with its electric field direction perpendicular to the aforementioned two-dimensional plane; p-polarized light is made up of radiation with its electric field direction parallel to the plane. Any nonpolarized radiation may be considered as s-polarized light combined with an equal part of p-polarized light. The reflection coefficient, R, is described as the ratio of amplitudes of the reflected wave compared to the initial incident wave. Similarly, the transmission coefficient is described mathematically as the ratio of amplitudes of the transmitted wave compared to the incident wave. The equations governing the reflection and transmission coefficients at non-normal angles of incidence are given by Equations 4.7 to 4.10, according to the polarization of the incident light.

$$R_s = \left| \frac{n_1 \cos\theta_i - n_2 \sqrt{1 - \left(\frac{n_1}{n_2} \sin\theta_i \right)^2}}{n_1 \cos\theta_i + n_2 \sqrt{1 - \left(\frac{n_1}{n_2} \sin\theta_i \right)^2}} \right|^2 \tag{4.7}$$

$$T_s = 1 - R_s \tag{4.8}$$

$$R_P = \frac{n_1 \sqrt{1 - \left(\frac{n_1}{n_2} \sin\theta_i \right)^2} - n_2 \cos\theta_i}{n_1 \sqrt{1 - \left(\frac{n_1}{n_2} \sin\theta_i \right)^2} + n_2 \cos\theta_i} \tag{4.9}$$

$$T_P = 1 - R_P \tag{4.10}$$

θ_i is the angular deviation of the incident light away from normal incidence. Specifically, at normal incidence, θ_i is 0°, whereas a θ_i of 90° describes a wave, which will not affect the interface.

Since the reflection and transmission coefficients are functions of the wavelength of the incident light, these equations have restrictions. These equations were derived with the assumption that the atmosphere acts like a thin film under the circumstances [1]. To justify this assumption, the thickness of the atmosphere must be shown to be relatively small in relation to its radius of curvature. The outermost layer of the atmosphere, the Exosphere, has scarcely any particles, and really behaves like a vacuum for inbound radiation. The earliest layer met by this inbound radiation, which is not a vacuum, and hence behaves as a boundary, is the thermosphere. The thermosphere encompasses up to 600 km away from the earth's surface, but its variations in density cause the greater part of it to be located toward its lower end [3]. If one is to use the earth's radius as a basis of comparison, the largest estimate of the atmosphere is still less than 10 percent the radius of the earth. Thus, the justification of the thin film approximations of Equations 4.7 to 4.10.

Since the atmosphere is concentric with the earth's surface, outbound radiation from the earth's surface must be emitted at normal incidence to the atmosphere. Using a value of 0° for θ_i in Equations 4.7 and 4.9, the total reflection coefficient simplifies to

$$R_{outgoing} = \frac{R_S + R_T}{2} = \frac{n_{air} - n_{vacuum}}{n_{air} + n_{vacuum}} + \frac{1.000293 - 1.000000}{2.000293} \cong 0$$

This shows that while the inbound light has a reflection coefficient that differs a lot, depending on the angle of incidence—the reflection coefficient is 1 at the poles, where the angle of incidence is 90°, and almost zero at the equator—the outbound light is hardly reflected back inward. The greenhouse effect is the process by which incoming radiation is allowed to pass through the atmosphere and reach the earth's surface, but much less of the outbound radiation is transferred back out into space. Up to this point, refraction, the geometry, and the nature of electromagnetic radiation apparently predict a scenario that is contrary to the greenhouse effect. This provides motivation to continue examining further.

4.3 PLANCK'S LAW AND RADIATED ENERGY

The average index of refraction of the atmosphere is commonly taken to be 1.000293. However, some chemical molecular structures in the atmosphere allow more absorption of particular wavelengths of light than others. This is a quantum mechanical phenomenon and may be described scientifically, together with laws governing thermal radiation. According to data, the average temperature at the earth's surface is about 288 K. If one were to use power radiation equations, [4, 5], where

$$P = \in \sigma T^4 \tag{4.11}$$

the quantity of energy radiated from the sun to the earth may be computed. The energy absorbed depends on the solid angle, which an object supports within a radiating body's "field of vision." This solid angle describes an actual looking volume, and from the perspective of the sun, the earth subtends a solid angle caused by a disk with area πR_{3P}^2, where R_{3P} is the radius of Earth, the third planet from the Sun. The energy incident on the earth is calculated by the product of the total power multiplied by the ratio of the emitting surface area to the absorbing surface area multiplied by the effective viewing area of the earth. The emitting surface area is the whole surface of the sun, while the absorbing surface area is the area of the imaginary sphere with a radius equal to the distance from the sun to the earth [6]. When the earth radiates energy, it behaves like a blackbody, and its effective viewing area corresponds to a solid angle of 4π. From this, Equation 4.11 can be used to compute the theoretical mean temperature of the earth:

$$E_{Absorbed} = \frac{\in \sigma T_{Sun}^4 \cdot 4\pi R_S^2 \cdot \pi R_{3P}^2}{4\pi R_0^2} = E_{Radiated} = \in \sigma T_E^4 \cdot 4\pi R_{3P}^2 \quad (4.12)$$

From this, the temperature of the earth can be computed as

$$T_E^4 = \frac{T_{Sun}^4 R_S^2}{4R_0^2} \rightarrow T_E = T_{Sun}\sqrt{\frac{R_S}{2R_0}} = 278.3\text{K}$$

This result is somewhat dissimilar from measured values, but when it is realized that the earth is not a perfect blackbody, the result is even more disparate from real values. The albedo of Earth, a measure of its reflectivity toward incoming radiation, is about 30 percent. The import is that only 70 percent of the absorbed energy computed in Equation 4.12 penetrates the atmosphere to arrive at the Earth's surface [7]. This reduces the theoretical computation of Earth's average temperature to 255 K. At this juncture, it is good to look at this discrepancy.

The reason is that implicit in the above equations is the assumption that radiation behaves according to the Rayleigh–Jeans law, in that the energy density of radiation across wavelengths for a given temperature is given by

$$\frac{\partial R}{\partial \lambda} = \frac{2cKT}{\lambda^4} \quad (4.13)$$

which, if used to govern the total radiated energy, yields an infinite value [8]. The correct form of this law was developed by Max Planck, and is

$$\frac{\partial R}{\partial \lambda} = \frac{2hc^2}{\lambda^5\left(\frac{hc}{e\lambda KT - 1}\right)} \tag{4.14}$$

Equation 4.14 predicts that a blackbody will radiate energy, which has a peak value conforming to a particular, finite wavelength. This is the basic piece of information required to understand the greenhouse effect. The greenhouse effect in a glass greenhouse is due to the way the glass walls behave. The glass allows the transmission of radiation from the sun (mostly in the visible spectrum) but reflects any outbound radiation, which is mostly in the longer wavelength, lower temperature, infrared radiation spectrum [9]. The atmosphere behaves like a greenhouse. The atmosphere allows light in the visible spectrum at high temperatures, but its molecular composition thwarts the much longer wavelengths of light (at lower temperatures) from escaping the atmosphere. From Equation 4.14, the Wien displacement law foretells a peak wavelength radiated from the Earth's surface:

$$\lambda T = b \cong 0.0028977 \text{ m} \cdot \text{K} \tag{4.15}$$

4.4 GREENHOUSE EFFECT

With the temperature of Earth around 288 K, the radiation spectrum is focused on a wavelength of about 10^{-5} m. In comparison to the spectrum emitted from the sun, which is centered on 500 nm, the Earth's spectrum is a lot longer. In addition, the absorption spectrum for the molecules in the Earth's atmosphere is also focused on about 10^{-5} m. Figure 4.1 shows the radiance at various wavelengths and related wave numbers. Radiance is a form of energy density, given in terms of the power radiated per wavelength per solid angle. This measure of the radiance was perceived from the outermost layer of the Earth's atmosphere, viewing inward toward the surface of the Earth.

Original Source: IRIS data courtesy of the Goddard EOS Distributed Active Archive Center (DAAC) and instrument team leader Dr. Rudolf A. Hanel.

It is clear that there are a couple of dips in the radiance at wavelengths around 15 and 9.5 μm. These agree to the primary wavelengths, which are reflected by the greenhouse effect. Since this is a graph of received radiance from outside the atmosphere looking inward, there is a marked

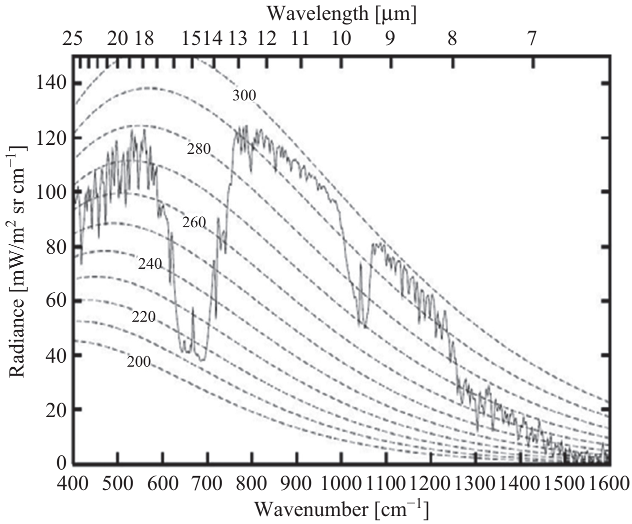

Figure 4.1. Plot of radiance versus wavelength (axis at top) and corresponding wave number (axis at bottom).

Source: Glickstein, I. Visualizing the "Greenhouse Effect"—Emission Spectra. http://wattsupwiththat.com/2011/03/10/visualizing-the-greenhouse-effect-emission-spectra/

drop in the radiance of specific wavelengths, which are reflected by the greenhouse gases.

4.5 CHARACTERISTICS OF A GREENHOUSE GAS

The best-known greenhouse gas is the most durable one, which is carbon dioxide. Carbon dioxide is a triatomic molecule, which, other than its contribution to the greenhouse effect, is rather inoffensive. Water vapor, methane, ozone, sulfur hexafluoride, nitrous oxide, and others are also greenhouse gases.

One characteristic that these molecules have in common is their relative size. Compared to monoatomic or even diatomic atoms, these triatomic and larger molecules have a much larger size. In addition, their molecular geometry is unlike. In a diatomic molecule, the two atoms are constrained to be located along a line, and since diatomic gases usually comprise two of the same atoms, there is no net polarization. For example, in nitrogen gas, two nitrogen molecules share two common electrons. Because each of the pair is identical to the other, there is no logic for the shared electrons to be located more often around one rather than the other. Hence, the molecule is electrically neutral both locally and universally.

In contrast to this, the atoms of triatomic molecules are usually in a plane rather than along a line. The reason is that the shared electrons and those of the central atom tend to ward off each other. In the case of greenhouse gases, such as water vapor, carbon dioxide, ozone (O_3), and nitrogen dioxide, all the molecules tend to exhibit a planar bent molecular geometry. If water vapor (H_2O) is taken as the example, it is not difficult to reason that the molecule is electrically neutral in a global sense. However, on the atomic scale, the two shared electrons of the oxygen atom with each of the hydrogen atoms have a larger probability density of being located near the oxygen atom. The reason is that the oxygen atom has many more protons than either hydrogen atom, resulting in a greater potential to attract. This unbalanced sharing generates a net local charge, in spite of the global neutrality. This polarization makes water to be a good solvent. The polarity of water is able to separate molecules. In the understanding of the greenhouse effect, the planar bent geometry and the uneven sharing of electrons result in a much larger number of degrees of freedom for each molecule [9]. Contrasted to a diatomic molecule, which has five degrees of freedom, three translational and two rotational, triatomic molecules have an additional three normal modes of oscillation. The result is a larger number of energy-level degeneracies for molecules with three atoms or more, which also drops the ground-state energy level. The overall consequence is that the bigger, more uneven molecules can be elevated into an excited energy state by radiation with less energy.

Quantum mechanics foretells that the possible energy quantity of any system is discrete, and not a continuous spectrum. Only discrete amounts of energies in a system are permitted, with the import that only specific “quanta” of energy can be taken up. When applied to the greenhouse effect, one can see that if triatomic (and more) molecules have lesser increments between their energy levels, it will not take as much energy to stimulate them. The energy of an electromagnetic wave is inversely related to its wavelength. Since infrared radiation possesses longer wavelengths than visible light and also less energy, it is this manner of increased intermolecular interaction with more degrees of freedom that permits the greenhouse gases to take up infrared radiation emanated by the earth.

At this juncture, the greenhouse effect has been placed on a scientific footing. A short review follows of the data that have been gathered as evidence of this global climate change.

4.6 EVIDENCE OF GLOBAL CLIMATE CHANGES

Data have been compiled from the National Oceanic and Atmospheric Administration (NOAA) that may be shown as the mean temperature anomaly each year from 1880 to 2013 [10]. The mean temperature anomaly is an amount of the deviance of the current annual average from some selected reference point. This standard reference is the average temperature during the time interval of 1900 to 2000. In 1880, the mean temperature anomaly is negative [10]. From that year to the present, the mean annual temperature anomaly steadily became larger, until in 2013 it is positively large. This confirms the expected trend. The mean temperature of the earth has been progressively going up from the industrial revolution to the current time.

The relative composition of greenhouse gases in the atmosphere is displayed in Table 4.1 [9]. The range of each greenhouse gas contribution is listed.

Although water vapor contributes a high percentage of greenhouse gases in the atmosphere, mankind is not worried with anthropogenic water vapor production, as the half-life of water vapor in the atmosphere is only several days. The rate at which water vapor leaves the atmosphere to reenter the water cycle is so quick that any human effort to reduce water vapor content would not be perceptible. "Methane takes about 12 years to disappear from the atmosphere, whereas carbon dioxide takes centuries" [9]. The presence of carbon dioxide in the atmosphere appears to be principally anthropogenic, from the industrial and transportation sectors. Before the industrial revolution, the average atmospheric carbon dioxide concentration was about 280 parts per million [11]. In an effort to measure and understand the effects of human activities on the planet, NOAA has a site at Mauna Loa in Hawaii to measure carbon dioxide levels. This location was selected since it is deemed not to be influenced by the nearby presence of a sizeable number of industrial equipment. From the Mauna

Table 4.1. Various greenhouse gases and the range of their impact on the greenhouse effect [9]

Greenhouse gas	Relative percentage of effect
Carbon Dioxide (CO_2)	9 to 26
Water Vapor and Clouds (H_2O)	66 to 85
Methane (CH_4)	4 to 9
Ozone (O_3)	3 to 7

Loa laboratory, the average concentration of carbon dioxide in the Earth's atmosphere as of 2013 is 393.82 parts per million [10]. This concentration is over 40 percent increase in carbon dioxide levels since the industrial revolution. In addition, this carbon dioxide concentration is the highest in over 800,000 years [11]. However, only in the most recent 50 years of the 800,000 years, 68 percent of this increase in carbon dioxide levels has taken place.

At the current time, the net quantity of carbon dioxide in the atmosphere is growing and the rate of production is too. In Figure 4.2 is shown the total global carbon dioxide emissions. The unmistakable rise from after World War II to the present day may be attributable to worldwide development and prosperity based on hydrocarbon energy.

The phenomenon of continually increasing amounts of carbon dioxide and other greenhouse gases can be correlated to a myriad of consequences resulting from global climate change. For example, the sea level has been unfailingly rising, but not at a fixed rate. The rate of sea level rise in the past 10 years is twice that for the previous 100 years [12]. The volume of sea water increases with temperature; hence, the rise of the seas. The mean ocean temperature has risen 0.17°C (0.3°F) in the past 40 years. This fact

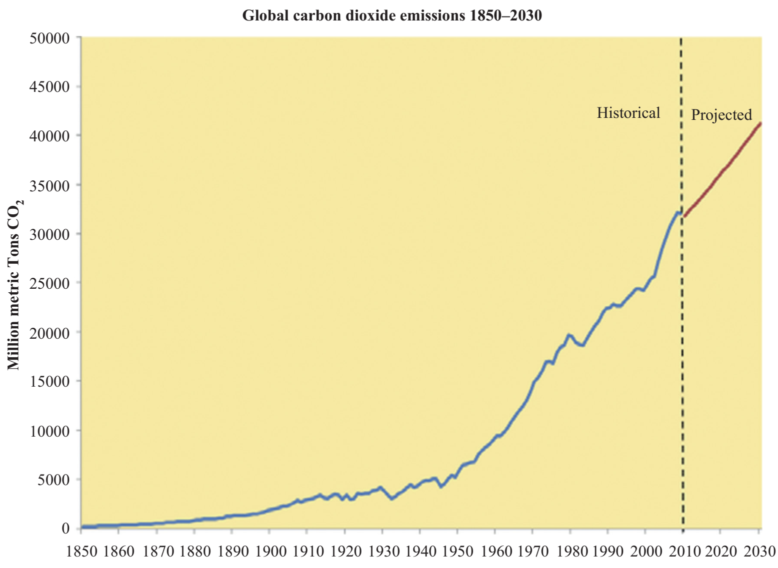

Figure 4.2. Cumulative annual global carbon dioxide emissions.

Source: Carbon Dioxide Information Analysis Center, Oak Ridge Nation Laboratory (2012). International Energy Agency, World Energy Outlook (2012).

is significant considering that 71 percent of the Earth is covered by oceans, and water has high specific heat compared to the air above. The transfer of heat from the atmosphere to the oceans is significant.

Global climate change does not only impact the temperature. The Earth's climate is always in a balance, and disturbing that balance everyday has led to an upward swing in the number of extreme weather events since the 1950s. These events include heat waves, droughts, hurricanes, super storms, tornadoes, and other adverse weather phenomena [13, 14].

In addition, glaciers, ice sheets, and Arctic and Antarctic sea ice have all decreased a lot, all within the past 30 years, and they continue to lose mass at increasing rates. The glaciers of the "Third Pole," or the Himalayas, [15], should not be forgotten. They too are showing increased heat stress and melting. The Third Pole is the source of water for about 40 percent of the Earth's seven billion plus persons. It has been so called because of the frozen glaciers in this region, like the other two Poles.

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CHAPTER 5

Anthropogenic Heat Release into the Environment

Kaufui V. Wong, Yading Dai, and Brian Paul

5.1 INTRODUCTION AND STATEMENT

In terms of humanity's energy consumption rate, 13 TW is a widely recognized number based on many scientific researches [1, 2]. This number is typically compared to 78,300 TW [1], the absorbed part of the primary solar radiation reaching the Earth's surface. Then, the consequence is that anthropogenic heat is typically neglected because it is only 0.017 percent. The energy flow of the primary solar radiation reaching the Earth's surface is 87,000 TW [3]. If this later figure is used in comparison, the anthropogenic heat of 13 TW is only 0.015 percent and hence neglected. In this work, "anthropogenic heat" refers to energy transfer via heat interaction caused by humans. According to Ref. [4], the energy consumption mainly comes from the burning of fuel, renewable sources, and nuclear energy generation, as shown in Figure 5.1. Additionally, nearly 85 percent energy mainly comes from fossil fuel, namely coal, natural gas, and oil. Many significant factors involved with energy usage or consumption and energy dissipation via heat interactions have been missed.

Besides the heat generated from fuel combustion, renewable energy development, and nuclear reactors for power, the processes and events such as heat produced from oil refineries, forest fires, and incineration of garbage can have a significant influence on the total amount of heat released to the earth every year. Therefore, in terms of those processes

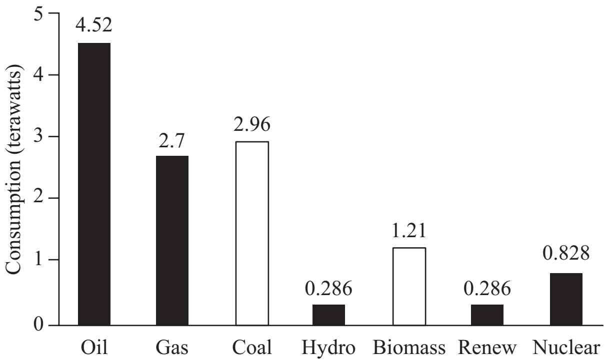

Figure 5.1. The global energy consumption [4].

and events that happen frequently, the claim of 13 TW human consumption rate needs to be examined thoroughly. In addition, it is important to compare the anthropogenic heat to the energy balance at the top of atmosphere (TOA). Because the TOA net energy flux was found to be 0.85 ± 0.15 W/m^2 the planet is out of energy balance [5]. The Earth is estimated to gain 431 TW from this.

5.2 HYPOTHESIS OF METHOD AND THE METHOD

Owing to the complexity of research for various kinds of ways to generate heat, the model for estimating the total heat released by humanity needs to be functional, logical, and systematic. Based on this point, the primary step is to control how many observational objects to select. The heat released from fuel consumption can be treated as an important contributor to total heat. Additionally, given that the majority of the electricity is eventually manifested as heat via various processes [6], the energy of net electricity can be converted into energy release via heat dissipation. The use of "exergy release" or "exergy consumption" is appropriate in this case [7–9]. Moreover, the significant processes and events involving humans and large quantities of heat should be taken into account. In this paper, categories that will be considered are total world energy (exergy) consumption, electricity production, oil refineries, garbage incineration, heat of formation of key gases like carbon dioxide and sulfur oxides, and heat produced by the human bodies and their domestic animals. It will be shown by our calculations that at least four of these categories will not be major contributors.

This would be in line with our hypothesis that better precision will be obtained by minimizing the number of observations (categories examined).

Basically, the calculations in this paper should be grounded on sound thermodynamics. The correct control volume for the Earth has to be selected and the first law of thermodynamics correctly applied. Finally, compared to the magnitude of the results, the estimation errors should be small enough to be negligible. In addition, from the first law of thermodynamics, energy cannot be consumed or destroyed, but exergy can. However, to be consistent with the U.S. Energy Information Agency (EIA), the phrase "energy consumption" is used when referring to exergy consumption.

5.3 HEAT BASED ON WORLD ENERGY CONSUMPTION

As the heat gain from fuel combustion is the main contributor to total heat release, the total amount of fuel (as shown in Table 5.1 [10–13]) needs to be found in order to figure out the total amount of energy.

Generally, given the total amount of fuel consumption of those four fuels, as shown in Table 5.3, the total energy of those fuels can be calculated based on the energy conversion formula, shown in Figure 5.2 [14].

According to U.S. EIA, the total energy consumed by the whole world is shown in Table 5.2 [15].

Taking all these information into consideration, the total energy from combustion of all those four fuel equals to $4{:}09 \times 10^{17}$ Btu per year, which is $4{:}31 \times 10^{20}$ J per year or 13.68 TW (Table 5.3).

Considering the latest 2010 estimated world energy consumption is 522 Quad Btu per year, the amount of heat associated is $5{:}51 \times 10^{20}$ J per year or 17.46 TW. Since only representative fossil fuels and biofuels are used, the heat stored in the fuels provides an estimated total, which is less than the world energy consumption. The world energy consumption is then a more inclusive and better estimate of anthropogenic heat generated from this category. The difference in the two figures should include the fuels consumed in the transportation sector. According to U.S. EIA, the total energy consumed by the whole world is shown in Table 5.2.

Table 5.1. The data for fossils fuel and biofuel consumption

Year	2007	2008	2009	2010	Average
World oil supply production (thousand barrel per day) [10]	84,571.57	85,563.67	84,414.92	86,837.77	85,346.9825
Dry natural gas production (10^9 ft.^{3}) [11]	104,161.6583	108,049.6711	104,786.591	112,089.855	107,271.9439
Total coal consumption (thousand short tons) [12]	7,014,933.612	7,327,553.886	7,318,283.125	7,994,703.198	7,413,868.455
Total biofuels production (thousand barrels per day) [13]	1,103.10749	1,476.22083	1,633.06158	1,855.64882	1,517.00968

a. 1 Therm of natural gas is 100,000 Btu
b. 1 Barrel of crude oil is 5,848,000 Btu
c. 1 Barrel of distillate oil is 5,825,000 Btu
d. 1 Barrel of residual oil is 6,287,000 Btu
e. 1 Quadrillion Btu = 1.0551 exa-joule=10^15 Btu
f. 1 Ton of wood pallets is 16,000,000 Btu
g. 1 Kilowatt-hour (kwh) of electricity is 3,412 Btu
h. 1 British thermal unit (Btu) = 0.252 kcal or 252 cal or 1.055 kj or 1055 joules
i. 1 Calorie = 2.54 joules
j. 1 Gallon of biofuel = 114,283 Btu
k. 1 Barrel = 42 gallon
o. Density of crude oil at 60 degree = 830 kg/m^3

Figure 5.2. Energy conversion [14].

Table 5.2. The data for the actual world energy consumption from 2005 to 2012 [15]

Year	2005	2006	2007	2008	2009	2010
Total world energy consumption (Quad Btu)	471	481.3	492.6	504.7	503.8	522

5.4 HEAT FROM NET ELECTRICITY GENERATION

The global energy or exergy consumption rate has been estimated to be 13 TW in Ref. [1] and 12 TW in Ref. [2]. In Table 5.4, the quantity is 2.32 TW [16, 17] for the total electricity net generation. The reason for the difference between 12 and 13 TW estimate and the amount of electricity generated, 2.32 TW, is due principally to the irreversibilities of

Table 5.3. Data and calculation of combustion

Year	Average	Energy stored	Formula	Total energy (Btu)
World oil supply production (thousand barrel per day) [10]	85,148.0792	1 barrel of crude oil is 5,986,667 Btu	World oil supply × energy stored × unit conversion	1.86×10^{17}
Dry natural gas production (10^9 ft.^{3} per year) [11]	107,271.9439	a. 1 therm of natural gas is 100,000 Btu	Dry natural gas production × energy stored × unit conversion	1.11×10^{17}
Total coal production (thousand short tons per year) [12]	7,510,795.678	1 ton of wood pellets is 16,000,000 Btu	Total coal consumption × energy stored × unit conversion	1.09×10^{17}
Total biofuels production (thousand barrels per day) [13]	1517.00968	1 gal of biofuel ¼ 114,283 Btu	Total biofuel production × energy stored × unit conversion	2.66×10^{15}
			Sum	4.09×10^{17}

the Rankine cycle, which is the cycle used to produce about 90 percent of the electricity used in the world. It includes only the heat produced from energy sources such as nuclear material, electricity, and fossil fuels. In a fossil fuel power plant, which accounts for the vast majority of the world capacity to generate electricity, the efficiency is typically around 33 percent, meaning that the available heat output is only one-third of the amount of total heat produced [18].

Nuclear reactors are becoming increasingly large sources of energy production throughout the world, as the global demand for energy continually grows. Over 30 countries currently employ the use of nuclear energy, with the United States near the forefront [19]. It is useful to study the global portion of energy supplied by nuclear reactors; the nuclear energy statistics for the top 10 nuclear-power-producing nations has been provided in Table 5.5 [20].

The total supplied in Table 5.5 is representative of the magnitude of the total amount of nuclear power produced, which is 0.395 TW. Because the efficiency of a nuclear reactor is generally slightly higher than that of a fossil fuel power plant—nuclear reactors typically operate between 40 percent and 45 percent efficiency—the overall estimate of the associated anthropogenic heat will be slightly less [21]. The new estimate is to be found by summing the power produced by fossil fuels and nuclear reactors, accounting for their respective efficiencies. The result is

$$P_T = \frac{P_f}{\eta_f} + \frac{P_n}{\eta_n} \tag{5.1}$$

with $P_f = 2.5 - P_n$ TW; $P_n = 0.395$ TW; $\eta_f = 0.33$; $\eta_n = 0.40$; overall efficiencies of utility boilers at about 60 percent, and the total electricity net generation throughout the world estimated at 2.5 TW, 24 hours a day, 365 days a year. The value for the anthropogenic heat from power generation with the correction for nuclear power plants is still about 13 TW—or, as far as our precision is concerned, the same as before.

The heat from world energy consumption of 18.14 TW logically includes this 13 TW related to electric power.

5.5 HEAT FROM OIL REFINERIES

An oil refinery mainly refers to the industrial process that refines crude materials into products of value via some chemical and physical means.

Table 5.4. Total electricity net generation

Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Total electricity net generation (10^9 kWh) [16]	17,334.07	18,009.27	18,794.68	19,104.27	19,287.01	20,318.75
Total electricity net generation index [17]	1.00	1.04	1.08	1.10	1.11	1.17

Table 5.5. Power produced by the top 10 nuclear-power-producing nations

Country	Annual nuclear energy production (GWh/yr)	Power output (GW)
United States	790,225	111.86
France	421,100	59.61
Japan	156,182	22.11
Russia	161,708	22.89
Republic of Korea	147,677	20.90
India	785,941	111.25
China	87,400	12.37
United Kingdom	62,700	8.88
Canada	90,034	12.74
Ukraine	84,845	12.01
Total	2,787,812	394.61

During the refinery process, industrial excess heat will be released into the environment. In Goteborg and Lysekil, Sweden, engineers have conducted a project of converting waste excess heat into practical usage since 1970 [22]. Based on their statistics, those two oil refineries with production capacity of 17 Mton (10^6 tons) per year can produce 543.8 GWh waste heat. Given the world refinery capacity shown in Table 5.6 [23], the excess heat of world refinery industry can be approximately estimated.

Figure 5.3 shows the schematic of an oil refining process. The crude oil is that which first enters the plant. Based on Figure 5.3 [24] and Table 5.6, the capacity of refining crude oil is chosen in that it represents the initial amount of oil into the refining system. The capacity of crude oil refinery

Table 5.6. World refining capacity in thousand barrels per day [23]

Year	2005	2006	2007	2008	2009	2010
World refining capacity (thousand barrels per day)	86,027	87,347	88,495	89,324	90,946	91,616

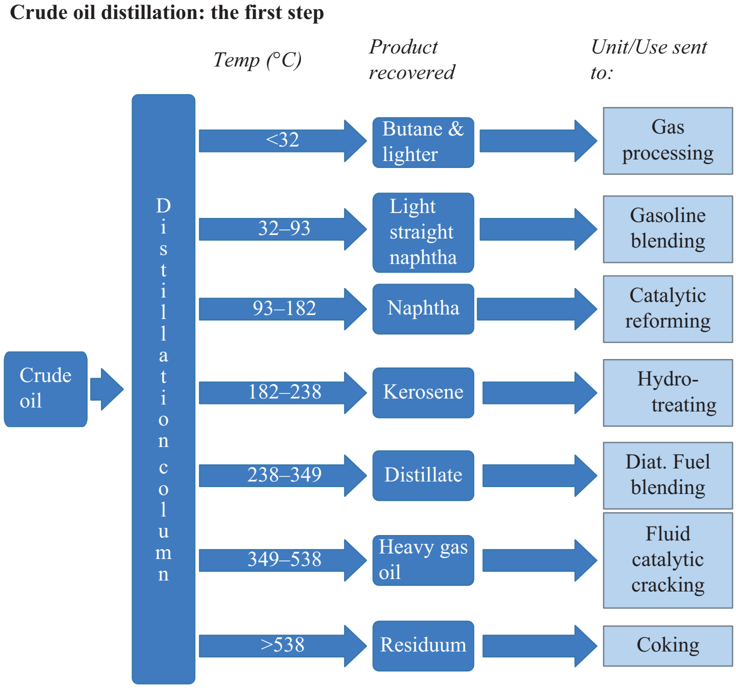

Figure 5.3. Oil refining process [24].

can be treated as the average capacity of whole facility. From Table 5.6, the world oil refinery capacity is approximately 91,616 thousand barrels per calendar day in 2010, corresponding to a production of 0.017 TW waste heat.

5.6 HEAT FROM GARBAGE INCINERATION

Specifically, the incineration of garbage refers to the combustion of biomass in current waste-to-energy plants. By definition, biomass refers to those wastes that can be a renewable resource, and biofuel is one of the subset products of biomass. Therefore, since the heat generated from biofuel is already calculated, only heat from burning biomass should be taken into account. Additionally, combustion of biomass is mainly used for generating electricity and this amount of electricity is already counted in the total amount of net electricity generation. Therefore, the heat production from the incineration of garbage has been included in the foregoing discussion.

5.7 WORLD OUTPUT OF CARBON DIOXIDE

Another category that deserves to be investigated is the fact that carbon dioxide releases heat upon its formation. While this may not initially seem as though it would contribute much heat toward the 13 TW, the sheer amount of carbon dioxide produced by human activities—approximately 35 Gton, or 3.18×10^{13} kg, annually—suggests that the actual numerical value is worth computing [25]. The standard enthalpy of formation of carbon dioxide is given as −393.5 kJ/mol, which, in terms of mass, is −8.94 kJ/kg [26]. The negative sign of this value indicates that heat is emitted in the process of combining carbon and oxygen to form carbon dioxide. So, knowing these two values, the total heat emitted due to carbon dioxide production in a given year can be calculated as

$$H = \left(\frac{8.94\,\text{kJ}}{\text{kg}}\right)\left(3.18 \times 10^{13}\,\text{kg}\right) = 2.84 \times 10^{17}\,\text{J}$$

The resulting heat output due to carbon dioxide formation is 0.009 TW.

5.8 HEAT FROM FORMATION OF SULFUR DIOXIDE FROM COMBUSTION

In addition to the heat of formation of carbon dioxide from human activity, the heat from generation of sulfur dioxide is also a factor in estimating total anthropogenic heat generation. Reference [27] provides a table showing the amount of sulfur dioxide worldwide if its levels are kept stable.

Based on this sulfur dioxide generation table from Ref. [27], the amount of emission of sulfur dioxide is taken as 69 TgS, which is 1.38×10^{14} g in sulfur dioxide. However, as most of the sulfur dioxide is generated with the production of electricity, the heat of formation of sulfur dioxide has already been included in the 13 TW exergy consumed in the generation of electricity.

5.9 HEAT FROM ANIMAL BODIES

One source of anthropogenic heat is very easy to overlook, but is essentially unavoidable and ever increasing as time passes: it is the very existence of humanity. One of the most complex engines in the universe is the human body, as it converts the chemical potential energy of food into energy usable for work or otherwise maintaining itself. Just as with any other engine, all of the energy input into the human body eventually manifests itself as thermal energy. This power output by the human body may seem—and, in fact, is—miniscule in magnitude compared to that of natural sources, but when it is considered that there are over seven billion human bodies producing this power, the need to calculate an exact figure for comparison seems important.

The straightforward means of determining the heat output of humanity itself seems to be through gathering information on the amount of energy necessary to maintain the human body on a daily basis, and then use this information to calculate the average power output. Figure 5.4 shows the data regarding the caloric intake for maintaining the human body across a variety of ages, as well as on average [28].

For males, an average of 2,475 kcal is necessary, while for females, it is a slightly lower 1,833 kcal. In order to determine the average number of calories necessary per person, however, these values must be averaged to the population distribution. As of 2010, the United Nations has the earth's population as 50.4 percent male, and 49.6 percent female [29]. Compiling the caloric intake with the weighted population, the necessary amount of energy per human body per day is 2,157 kcal. In SI units, the power output per human body is 104.4 watts. As of March 2012, the United States

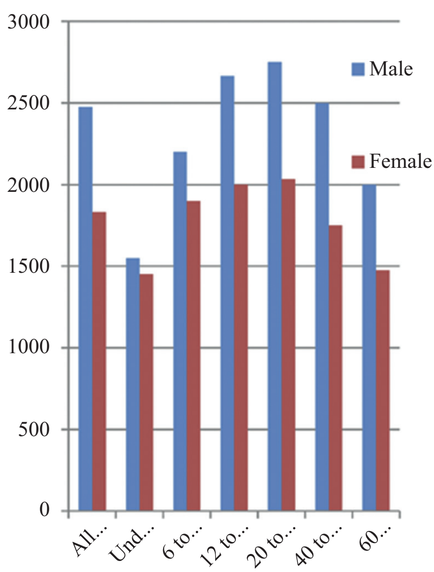

Figure 5.4. Caloric intake necessary to maintain the human body.

Census Bureau places the global population at 7.001457×10^9 people [30]. Multiplying this by the power output per person places the heat output of humanity at 0.731 TW, hardly negligible in its magnitude. Using the 2010 estimate for human population to be consistent with all other major data in the current work, 6.5×10^9, gives a heat output of about 0.7 TW.

Another remaining issue is that the foregoing simply does not account for some of the largest sources of heat that humans had a hand in releasing to the environment. In addition to humankind, there exist all the domestic animals that live as pets, livestock, and animals in captivity that are used for companionship, food, materials, study, and so on. Billions of such animals exist, but the exact number is unknown. In 1990 though, the amount of waste heat that was attributed to domestic animals was estimated to be about 1 TW [31]. If the increase of the waste heat from domestic animals is directly proportional to the increase of the human population through the same time period, a conservative estimate that about 1.5 TW of heat was added to the global energy equation in 2010 by domestic animals.

5.10 DISCUSSION AND CONCLUSION

The amount of heat associated with the exothermic anthropogenic production of carbon dioxide is about 0.01 TW and the waste heat produced by refineries is 0.017 TW. Based on these factors and the heat supplied to the boilers (in the Rankine cycle) of at least 13 TW, heat generated by 7×10^9 people and their animals, the value of the total world anthropogenic heat production rate is 15.26 TW. The relationship between the Earth and the Sun's energy has been studied carefully in reference to the energy balance at the TOA. Because the TOA net energy flux was found to be 0.85 ± 0.15 W/m^2 the planet is out of energy balance [5]. The Earth is estimated to gain 431 TW from this. It is this figure that is crucial in the global climate change discussion. It is found that the oceans are the primary location for stored energy, and the 15.26 TW is about 3.5 percent of this value.

Accounting for the anthropogenic heat given off by humanity's existence and associated domestic animals and using the conservative estimate of the heat produced by world energy consumption, the total heat from humanity is approximately 19.7 TW. To determine the relative size and impact of this value, it must be compared to the amount of heat gained by the Earth from all sources, such as the Sun and the interior of Earth itself. If this second option for summation is used instead of the one above, anthropogenic heat accounts for about 5 percent of the heat imbalance (gained) by planet Earth.

This comparison shows that the cause of global climate change is greatly affected by anthropogenic heat. In addition, an important fact is the amount of total heat retained by earth's atmosphere depends on the concentration of various greenhouse gases within the atmosphere—particularly carbon dioxide—of which humans are the main contributors. According to Terry Gerlach's article "Volcanic Versus Anthropogenic Carbon Dioxide," anthropogenic emissions of carbon dioxide surpass those of the nearest competitor, volcanic emissions, by two orders of magnitude [25]. In this way, not only is the amount of heat released into the earth's atmosphere through human means significant, 19.7 TW calculated in the current work instead of the previously calculated 13 TW, man plays a very active role in the process of global climate change. Previous conclusions regarding the 13 TW being only 0.017 percent of the absorbed part of the principal solar radiation reaching Earth needs to revised, when considering climate change.

The discussion of global climate change in all its aspects, besides just energy and engineering, is treated in Ref. [32].

5.11 NOMENCLATURE

P_T is the total value of the power created through human activities.
P_f is the value of the power generated through the burning of fossil fuels.
P_n is the value of the power generated through nuclear reactors.
η_f is the value for the typical efficiency of a cycle that operates through the burning of fossil fuels.
η_n is the value for the typical efficiency of a cycle in a nuclear reactor.

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CHAPTER 6

Climate Change and All Evidences of Global Warming

Brian Jozefat

6.1 INTRODUCTION

There has been a great amount of talk about “global warming” and “climate change” over the past few decades. However, many people do not completely understand what is happening to the planet. Additionally, others do not believe that global warming is really an imperative issue, if an issue at all. These beliefs come mostly from a lack of information on the issue at hand. It may be shown with various evidences that climate change is affecting the Earth, and there will be devastating consequences if humans do not make strong efforts to be more conscious of how the actions made today will affect the future.

The most important first question is: what exactly is global warming? In simple terms, global warming is the gradual increase in temperature of the Earth’s atmosphere, usually attributed to the greenhouse effect. Before this may be fully understood, one must be aware of the factors that affect the Earth’s temperature. The climate is a very complex system, consisting of land surface, bodies of water, the atmosphere, and living creatures. The atmosphere is part of the system that allows climate to be characterized, and is very often interpreted as the average of all of the weather patterns over time, which can be taken as the variations of temperature, wind conditions, and precipitation over a chosen time period [1].

Earth’s climate is driven by solar radiation, and a change in the amount of solar radiation has the potential to drastically change the climate system. This change can occur in several different ways. First, the incoming solar radiation can be altered if the distance between the Earth and Sun is changed or if the Sun began emitting more radiation. Secondly, the amount of solar radiation reflected off the Earth back out to space, or albedo, could change. The reflection may be influenced by the amount of cloud coverage and atmospheric particles. Finally, the infrared radiation from Earth out to space may be varied with a change in the concentration of greenhouse gas in the atmosphere [1].

The second and third methods are the reasons for the rising warmth of the planet. The greenhouse gases act as a blanket for the Earth, preventing infrared radiation from escaping to space. Clouds exhibit a similar effect, but they also reflect portions of the incoming solar radiation; this offsets the "blanket effect." While nitrogen and oxygen are the most prevalent elements in our atmosphere, these two gases do not contribute to the greenhouse effect. Instead, the most important greenhouse gases are carbon dioxide and water vapor. As mankind has industrialized, the vehicles, buildings, and energy generation processes have required the combustion of fossil fuels for the most part. The burning of fossil fuels releases carbon dioxide into the air, and thus builds upon the blanket of greenhouse gases. Additionally, foliage is a large factor in the amount of greenhouse gases in the environment because trees consume carbon dioxide. In turn, the greenhouse effect increases when forests are destroyed and cleared. As stated earlier, an increase in the amount of greenhouse gases prevents more of Earth's radiation from emitting to outer space. As this radiant heat stays within the atmosphere, the temperature of the planet will naturally increase. Global warming is an imminent problem and will drastically affect the future of the Earth if action is not taken. There have been an immense number of studies performed to determine exactly how an increase in greenhouse gases and mean global temperature affects the rest of the world. A wide variety of evidences of this phenomenon will be discussed.

6.2 MEAN TEMPERATURE CHANGES

One of the most basic methods to demonstrate that there has been a change in our climate is to compare the mean temperatures of the land and oceans over the years. Earth has been in a warming period for approximately the last 300 years. There is more emphasis on the past century, where the mean global temperature has risen between 0.56°C and 0.92°C [2]. Currently, the Earth is experiencing the warmest temperature period within the past 1,000 years [2]. This can be seen visually in Figure 6.1.

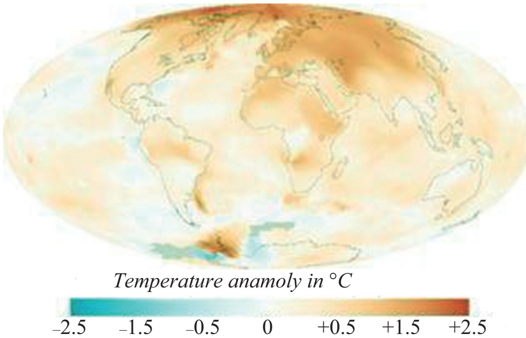

Figure 6.1. 10-year average (2000 to 2009) global mean temperature anomaly relative to 1951 to 1980 mean [2].

In this plot it is shown that a large part of the earth experienced an increase in average temperature during 2000 to 2009 compared to 1951 to 1980. It may be seen that there are large regional differences between the severities of global warming that has occurred. In general, land surfaces have increased temperature more than ocean surfaces. Additionally, the warming rates are much larger in the northernmost latitudes. This rise in temperature stems from an increase in the amount of energy stored on our planet, since the greenhouse gases hold it in. Even though the land temperatures have increased more than oceanic temperatures, it may be noted that approximately 90 percent of the extra stored energy since 1971 can be traced to the shallow ocean regions [3]. This occurs because water has a large heat capacity. Even though it is more difficult to heat up the oceans, the bodies of water are much more difficult to cool down once they have absorbed energy.

6.3 ARCTIC ICE CAPS

The combination of warmer shallow water temperatures and severe climate change in the northernmost latitudes has been devastating to the Arctic snow caps. As shown in Figure 6.1, the temperature rise has been as large as 2.5°C in certain Arctic regions. The change has been drastically melting the Arctic ice cap. This statement can be backed by observing the progression of the Ward Hunt Ice Shelf, the largest single ice block in the Arctic. After being around for approximately 3,000 years, the shelf began cracking in the year 2000 and eventually split all the way through two years after [4]. However, it is not just this ice shelf that is being affected. The polar ice cap as a whole has been melting and disappearing. According to NASA satellite information, “the area of permanent ice cover is contracting at a rate of 9 percent each decade" [4]. In order to understand how significant the damage is on this polar cap, a visual comparison is necessary.

Figure 6.2 shows a definitive change in the summer Arctic ice boundary in only 24 years. In fact, the ice cap has shrunk more than 20 percent over this time period [4]. If the polar ice cap continues to disappear at this rate, it would be completely melted by the end of the 21st century, or even as early as the summer of 2050. The Arctic temperatures are increasing at a rate of two to three times that of the mean global temperature. This can again be supported by Figure 6.1. In addition to the completely melted ice, the ice that remains has decreased in thickness, making it more vulnerable to cracking. Smaller pieces of ice broken off the large shelves make them easier to melt.

To make matters worse, there has been no indication of global warming slowing down or stopping, especially with minimal efforts put in by society as a whole. In fact, the melting of the ice caps accelerates the climate change. As stated earlier, one factor that affects climate change is Earth's albedo, or the amount of solar radiation that the Earth reflects back to outer space. One massive benefit of having the ice caps is that they have a very high albedo (50 to 70 percent), where they reflect the majority of the incoming radiation. Snow has an even higher albedo, reaching values of 70 to 90 percent [5]. On the contrary, when the ice has melted into water, the albedo is immensely lower (approx. 6 percent for open ocean) and the Earth absorbs much more radiation energy [5]. With more water in the Arctic and more solar radiation absorbed, this builds upon the present issue by warming the water to a greater extent. Additionally, a large benefit of the ice caps is that these masses keep the water temperature down. As a whole, the climate change is accelerating in the Arctic both because there is less ice to reflect solar radiation and keep water temperatures down, and because there is more water to absorb radiant energy. While it is

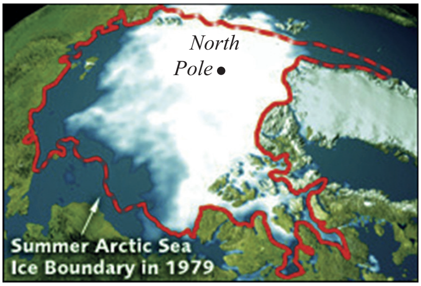

Figure 6.2. Polar ice cap in 2003 compared to 1979 [4].

unfortunate that the Arctic polar ice caps are melting, how does this affect the planet? What other implications does this trend have?

The melting of the ice caps causes both immediate and long-term issues. First, the immediate implications need to be discussed. This behavior is already affecting native people living around the area, wildlife, and plants. As stated earlier, the Ward Hunt Ice Shelf was split in the early 2000s as a warmer climate began melting the giant cap. What many do not know is that this shelf housed a freshwater lake, which itself had an entire ecosystem [4]. When the shelf was split, the lake and everything it supported was spent into the ocean. Without the freshwater lake and all of the smaller creatures it supported, the larger animals were forced to relocate and find new feeding supplies. These included whales, walrus, polar bears, and seals. Additionally, many villages along the Arctic coastline rely on hunting these animals for survival. The animal migration makes them much more difficult to track.

6.4 WILDLIFE AND EXTINCTION

There has been much more in-depth research and analysis performed to determine exactly how this rapid climate change has been affecting wildlife. Fifty-one different documented changes were observed in the Arctic marine life, and with the results shown in Tables 1–4 in the report by Wassmann, Duarte, Agusti, and Sejr [6]. Most of the reports dealt with marine mammals, especially polar bears. The physical changes to their environment that forced the new behavior included prevalent changes such as increased temperatures of seawater, increased overlap of warmer Atlantic and Pacific water with the much colder Arctic, and reduction in the amount of ice coverage [6]. The waters of the Hudson Bay in the arctic currently are absent of ice for three weeks longer than they were only 30 years go. This change affects the polar bears that thrive while hunting on the ice. The footprint of these changes is devastating, and has been found on polar bears all over the Arctic: Hudson Bay, North Alaska, Beaufort Sea, and White Sea, to name a few. The footprint that Global Warming has placed this species is tragic, and includes decline in population, altered conditions, landward shifting, declining rate of cub survival, drowned bears, decline in female conditions, and reduced birth rates [6]. While people may not want to admit it, these newfound problems and issues have come about because of the global warming that humans have accelerated. It becomes difficult to ignore our footprint on the Earth’s environment when studies and observations are performed, and the results found are as ominous as those of the polar bears.

While only the impact of climate change on the polar bears was discussed in detail, rapid warming of the planet significantly affects nearly every animal species type, both marine and terrestrial. Many animal species have adapted throughout history to meet the demands of the environment. This trait is necessary for long-term survival. However, there is a significant difference between those periods and the current climate change: the current change is occurring much more rapidly.

One particular study by Root, Price, and Hall [5] did an excellent job demonstrating evidence that there are species currently being affected. For this study, thousands of articles regarding biological changes from climate change were reviewed, and the ones chosen had to fit a few criteria. The observed period had to be at least 10 years (even though most experiments were more than 30 years), at least one species had to show a trait change in that period, and a temperature change over the period had to be observed. Vote counting and regression slope analysis was used to determine how probable it was that the results found were all a result of global warming, and not of outside factors. Taking a wide variety of factors into account, it was determined how much a temperature-related trait changed. This was measured in number of days per 10 years. It was found that birds exhibited the largest mean number of days changed per decade at 5.9 ± 0.3, where trees had the smallest change at 3.0 ± 0.1 days. Amphibians had a very large variation between the days changed from their temperature-related trait being affected, at a value of 4.9 ± 0.6 days per decade. This is an interesting find, because mean water temperatures vary based on location. It may have been that bodies of water that have experienced the most climate change brought upon the largest schedule change for the amphibians. All of the species combined for a value of 5.1 ± 0.1 mean days changed per decade [5].

These findings demonstrate how much weather is affecting wildlife. While five days per decade may not seem like a long time, this schedule change adds up quick. Over a time span of 60 years, a species may partake in a weather-related activity over a month earlier than usual. For example, flocks of birds could drastically alter their migration schedules. As the mean temperatures affect animal traits and natural scheduling, the connectedness among species is disrupted and communities are forced to redevelop. These changes could bring upon local extinction, or even global extinction.

There is a significant amount of fear that the current levels of climate change will lead to extinction for many species of animals and plants. One specific study was performed on this possibility regarding the Australian tropical rainforests. The prediction is that increasing the mean temperature would result in a significant reduction or complete destruction of the core environment [7]. The core environment was defined as 10 parameters that were significant in explaining the biological diversity within the region, and the areas considered had to exhibit values within the 5th and 95th percentile of those parameters. The experimental procedure consisted of modeling how climate changes would affect the biological diversity of native rainforest vertebrates. Sixty-five different species were considered, with 7,123 total unique records of these 65 vertebrates. The results found were severe and dramatic, as shown in Figure 6.3.

In Figure 6.3 is shown the Wet Tropics region in northeast Australia, as well as the current distribution of species throughout the region [8]. It can be seen that the current climate provides a strong environment for species diversity and richness. The vital spots are the ones shaded between the fifth and the tenth ranked dark areas. However, rising temperatures tell a completely different story. Based on current greenhouse gas emissions, it has been estimated that Earth may reach a mean temperature increase of 1°C within the next few decades. The predicted plot after this climate change already shows a difference in species richness. There is a noticeable decrease in the amount of area with very high species richness; various low species areas can be seen disappearing. Statistically, it was found that of the 65 species that were modeled, the core environment area would decrease for 63 of the species.

At 3.5°C above the current mean temperature in Figure 6.3, it has been modeled that there would be an immense decline in the overall richness in the Wet Tropics. The decline in biodiversity is apparent. There would no longer be any area with high species richness (30 species or greater), and native vertebrates will have disappeared from the low and mid-elevation

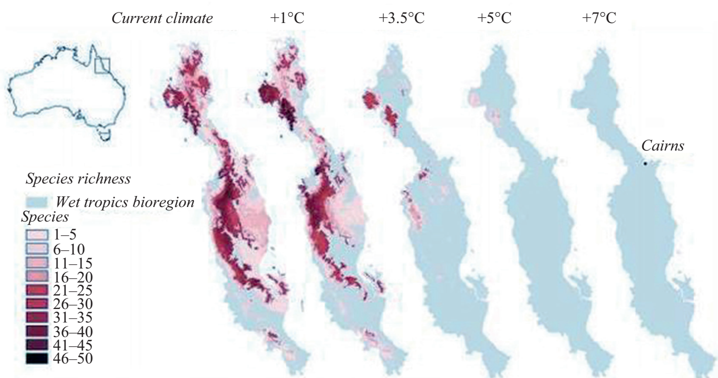

Figure 6.3. Species richness of native rainforest vertebrates at various temperature scenarios [8].

regions. Additionally, 30 of the 65 species would completely lose their core environment, and put them on the brink of extinction in this region [7]. This climate change is very possible within the next century, and the effect on such a thriving ecosystem is appalling.

When the climate change is exaggerated even further to 5°C, it may be seen that there are only a very few number of species that would be able to survive. Finally, at a temperature anomaly of 7°C, none of the 65 species would find areas that supported their core environment needs. While some of these increases in temperature may seem extreme, greenhouse gases are still being produced at an alarming rate and the climate is changing very rapidly. It may be noted that throughout history, species have become extinct even from very slow, gradual climate changes. With the current accelerated rate of warming, it will be difficult for animals to adapt quickly enough and many species globally may face extinction.

6.5 WEATHER PATTERNS

Further evidence that global warming is affecting us is the change in weather patterns over the past few decades. This has become apparent with extreme weather and storms. As stated earlier, the largest mean temperature increases are occurring closer to the North and South Poles. With these warmer temperatures, there is also more water vapor entering the atmosphere, resulting in a hotter and more humid environment. With this, areas closer the equator are already warm and humid, and do not experience as large a change. Overall, the temperature difference between the equator and poles is becoming smaller. With a smaller temperature difference between these regions, the strength of storms is intensified. More water vapor is being evaporated into the atmosphere, and this water vapor is what fuels storms [8].

The North Atlantic hurricane record is the longest among any record, starting in 1851, and with data determined to be most reliable after the early 1970s. It was found that relative to a 1981 to 2000 base period, every Atlantic hurricane season since 1995 (except two El Nino years) have had above-normal activity. "During 1995 to 2004, hurricane seasons averaged 13.6 tropical storms, 7.8 hurricanes and 3.8 major hurricanes …. In contrast, during the preceding 1970 to 1994 period, hurricane seasons averaged 8.6 tropical storms, 5 hurricanes and 1.5 major hurricanes" [9]. From these statistics, it can be clearly seen that there has been an increase in large storm activity. Additionally, these numbers excluded the record-breaking hurricane season in 2005, the most active season ever.

There are a few factors that have led to this increase in strong tropical storm activity, with one of the major factors being higher sea surface temperatures across the tropical Atlantic. As shown throughout the paper, water absorbs a lot of solar radiation and is being warmed from the current climate change. Hurricanes form when water evaporating from the oceans feed the swirling clouds; with warmer water, more available energy form the stronger storms. In terms of quantity of storms, the warmer sea surface temperatures create more favorable conditions for tropical storms to develop [9].

Along with stronger tropical storms, another by-product of global warming is widespread droughts. Droughts can be some of the most troublesome events, where they affect millions around the world each year agriculturally, economically, and ecologically. Droughts can be quantified with three criteria: the intensity, duration, and area affected. Intensity can be defined by soil moisture, precipitation, or water storage deficit. One of the most widely used indexes that take these criteria into account is the Palmer Drought Severity Index (PDSI), where lower values mean more severe droughts. Several studies have found the recent Sahel droughts in West Africa to be linked to a shift in the warmest tropical Atlantic sea surface temperatures and continuous warming of the Indian Ocean. Since 1960, the PDSI, overall precipitation, and soil moisture levels in Sahel have begun to decline [10]. The warmer Indian Ocean temperatures can be attributed back to climate change caused by the increase in greenhouse gases from human activity.

Since global warming has only recently begun to accelerate significantly, there is not an excessive amount of data available. As a result, it can be difficult to prove that certain weather behaviors are a result of climate change. However, models can be made to predict how certain phenomenon will affect the Earth in the future. This modeling is important in determining how global warming will affect sea level rise. As discussed earlier, ice caps are being severely affected by rising air and water temperatures from increases in solar radiation levels. The melting ice caps have led to a rise in global sea levels throughout the 20th century. Additionally, it is believed that the sea level rises will accelerate as global warming continues to become more prevalent. Since the late 19th century, tide gauge measurements have indicated that the ocean level has risen an average of 1.7 ± 0.3 mm/year until 1950 [11]. Since then, sea level measurements have become much more accurate using high-precision altimeter satellites. It has been measured that from 1993 to 2009, the sea level rising has increased to 3.3 ± 0.4 mm/year [11]; this phenomenon appears to be accelerating.

There are two factors that largely contribute to the rising sea levels. The first is thermal expansion of the water due to the increasing ocean temperatures. The second is the melting of major land ice reservoirs, including glaciers and ice sheets. The contribution of the melting glaciers and ice sheets in sea level rise has become much larger recently because of the significant increase in mean global temperature. From 1993 to 2003, less than 15 percent of the sea level rise was caused by melting ice. However, since 2003, it has been estimated that the contribution of melting ice has nearly doubled [11]. There is a large amount of uncertainty as to how the sea levels will rise in the future. For many future predictions, a large amount of factors have been taken into account to make better estimates outside of simple air and water temperatures. These factors include future social and economic developments that may influence greenhouse gas emissions, such as population levels and economic growth. With these models, it has been predicted the sea level may rise anywhere between 30 and 180 cm (~1 to 6 ft.) by 2100 [11]. These sea level increases could be potentially catastrophic for coastal communities. Land on the coast would be subject to large flooding and potentially complete submergence. Additionally, saltwater would intrude and contaminate bodies of fresh water.

In Figure 6.4 is shown many of the low elevation island and coastal regions that are vulnerable to flooding. Certain areas would be more devastated with excessive flooding. The areas that would be most devastated are ones with very dense populations since it would be difficult to move large amounts of people to dry land. Additionally, regions that do not have resources for flooding prevention would be in more danger. In Figure 6.4 is shown that most countries in South, East, and Southeast Asia

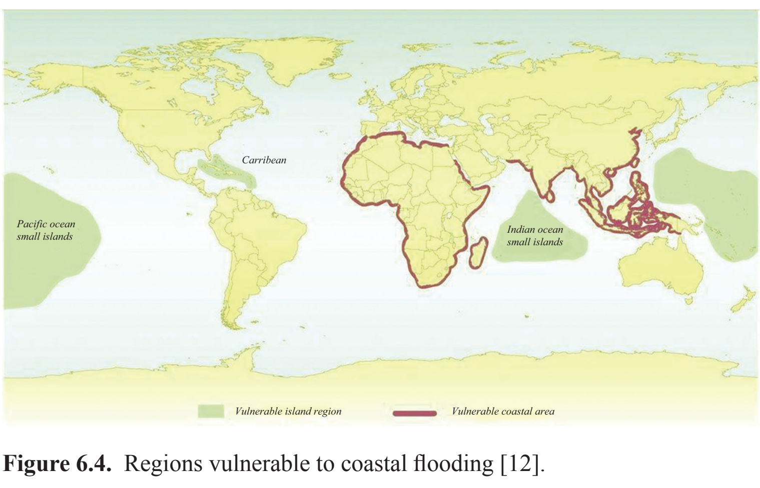

Figure 6.4. Regions vulnerable to coastal flooding [12].

would be threatened because of their large growing cities. Even so, the largest impact would be found in the small islands. Some of the low-lying islands (Maldives, Tuvalu) face the potential of complete submergence, whereas the lands would have to be abandoned [11]. People who live near the coast may not consider this problem because it would not affect them directly. However, this is not true. If a large amount of coastal regions become flooded, these areas will no longer be easily livable in. The large number of people who occupy these regions would be forced to move, and other large cities would become even more crowded. Additionally, the shoreline and beaches are some of the most beautiful and peaceful destinations in both the United States and throughout the world. A very important part of nature would be lost if the coastal regions were overrun by sea waters.

6.6 SOLUTIONS

While it may appear that there is no end to global warming, there are numerous ways that humans may help to slow climate change and save the Earth's environment. The largest contributor to the global climate change is the release of carbon dioxide from the burning of fossil fuels for energy. In turn, the most fundamental way to lessen the amount of carbon dioxide released is to reduce energy consumption. This can be accomplished on both a large and small scale, with the responsibility falling on energy companies and each individual person.

For energy suppliers to help reduce the burning of fossil fuels, it is imperative that they implement technologies that utilize renewable energy sources. One large energy source that can be utilized is solar power. Solar energy can be collected using various methods. First, solar photovoltaics can be used to convert radiation into direct current electricity. There are arrays of cells made of specific semiconductors that form a junction that allows for electricity generation when the cells are illuminated by the Sun [12]. Additionally, concentrated solar power may be utilized. This technology uses mirrors or reflective lenses to concentrate sunlight at a collector to heat a fluid to very high temperatures. The hot fluid flows from the collector to a heat engine, and a portion of the heat is then converted to electricity [12]. Along with solar power, wind is another very useful renewable energy source. Wind turbines utilize the rotational energy of the blades caused by winds to create mechanical energy, which can then be converted to electricity for a generator. While not the most talked about, the largest installed renewable energy source is hydroelectric power, supplying approximately 17.4 percent of the world's total energy in 2005 [12]. Water falling from dams and flowing down rivers is able to drive a turbine and generator and create electricity. Other renewable energy sources that are available include extracting the power of ocean waves, ocean tides, and nuclear power, to name a few. As a whole, energy companies need to make a much stronger effort to expand their renewable energy departments and begin to implement significantly more of these technologies. In doing so, humans will not need to continuously be burning fossil fuels to meet their energy needs. This will make a large impact in the effort to slow the global climate change.

On the note of energy needs, it is as much the responsibility of individuals as the energy suppliers to become smarter with energy-related decisions. Each person needs to reduce the amount of energy they consume, so renewable energy will be able to account for a larger portion of total consumption and less fossil fuel will have to be burned. There are many ways that an individual can work to fight global warming.

One may choose to change their energy supplier. Green-e-certified suppliers generate at least half of their power from clean sources, and meet strict environmental standards [13]. Additionally, consumers must be aware of the products they buy. This becomes important when choosing vehicles, appliances, and other products that consume a large amount of energy or produce hydrocarbons. An alternative to reduce vehicle emissions is simply to drive less. This can be accomplished with public transportation or using an alternative mode of transportation such as biking. Heating and cooling consumes a large portion of residential energy, so limiting heating and air conditioning, as well as weatherizing a home, can have a large impact on energy consumption. Finally, society as a whole has to raise their voice and push the government to put stricter carbon emission laws into effect. While it may not seem as if an individual person may contribute to solving the climate change issue, every person making a conscious effort to contribute to the cause can bring upon massive changes. This is the best way that humans may reduce their effects of global warming on their precious planet.

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CHAPTER 7

Mitigation and Adaptation Responses to Sea Level Rise

7.1 INTRODUCTION

The Netherlands is known throughout the world as one nation that has held back the sea successfully. The knowledge and expertise of their engineers as well as their urban and regional planners need to be respected. Certain countries like the Netherlands and Singapore are more advanced than others in taking steps because their citizens have witnessed the land slowly disappearing under water. Others like the United States, where climate change has been mired in politics, have been slow to react.

One publication opines that if the seas rise by 9 m, as early as 2100, and certainly by 2200 or 2300 [1], the glamorous cities of Dubai and Abu Dhabi, of the wealthy United Arab Emirates, will be under water. In our modern times, electrical infrastructure is at ground level or below. It will not be possible to inhabit or use a skyscraper that is flooded to the first or second story. Another such city with low areas and relatively new, tall skyscrapers is Shanghai, China.

The responses to sea level rise broadly fall into two categories: mitigation and adaptation. There are synergistic effects between some of these responses, even from two different categories, and their positive effects should be recognized and valued.

7.2 LITERATURE ABOUT RISING SEAS

The Intergovernmental Panel on Climate Change (IPCC) reports [2–4] have in recent times repeatedly predicted substantial sea level rise owing to climate change. There is little, if any literature, repudiating the fact about rising seas. The IPCC was awarded with great honor the Nobel Peace Prize in 2007.

There is an unverified estimate that between 1991 and 2011, there were more than 4,000 papers on climate change, with conclusions that were clear regarding whether climate change is taking place, and if humans were significantly responsible. Apparently, over 97 percent of the publications are in agreement that climate change is here, and that mankind is a significant contributor. The fact is that the literature is replete with publications about rising seas owing to climate change. In [5], Pielke et al. are calling for policy change and action to respond to this challenge. Nicholls and his group of researchers have been studying rising seas for years [6–12]. According to Nicholls, Hoozemans, and Marchand [8], the areas threatened by coastal flooding are the southern Mediterranean, parts of Africa, and most definitely, South and Southeast Asia, where there are a number of dense human population deltas. The regions with the top-most flood-risk increment relative to others in the world would be in the Caribbean, the islands of the Indian Ocean, and the relatively tiny islands of the Pacific. Baker, Littnan, and Johnston [13] studied the vulnerability of the northwestern Hawaiian islands because of their value for natural resources, including endangered species.

Wanless of the University of Miami in the United States has been studying the geology, seas, and oceans of the world and observing their characteristics with respect to time for several decades. Wanless, Parkinson, and Tedesco [14] wrote on this subject in 1994. A review has been performed by Yanez-Espinosa and Flores [15] about the consequences of rising seas on the mangrove forest.

In reference [16], Barnett, Adam, and Lettenmaier performed a review of the body of work related to water availability in areas that have a lot of snow throughout the year. This review confirms that there is a change in the season or months when the runoff from mountain glaciers is a maximum, owing to the warming climate. In many areas where water management has not been adjusted for this fact, the runoff goes directly to contribute to the rising waters in the immediate marine vicinity. Raper and Braithwaite [17] discussed the sea level rise from glaciers and polar caps due to global warming. This included the "Three Poles" that is the Arctic, Antarctica, and the Tibetan Plateau.

Other works include Rahmstorf [18], who predicted the sea level rise in the future using a semi-empirical method. He connects the rising seas with the average temperature rise of the Earth's surface. Rahmstorf claimed a 0.5 to 1.4 m range rise by 2100, relative to the 1990 sea levels across the globe. Fish et al. [19] studied the mitigation of sea turtle beach loss. Their work was mostly concentrated on 11 sea turtle beaches in the island nation of Barbados. Crooks et al. [20] produced a Vice Presidency (of Sustainable Development) paper for the World Bank in 2011. They focused on the course of actions to promote nature-based mitigating climate change by employing coastal wetlands and marine ecosystems.

7.3 MITIGATION RESPONSES

In areas near the mouth of small rivers, the Netherlands is showing a fascinating way of using hydrology to mitigate the effects of rising seas. The Dutch are creating a reservoir between the river, the river's mouth, and the harbor to create a large fresh water containment area in their country, near Amsterdam. This strategic placement of the reservoir will help in flood control. This is an innovative approach, and a recognition that creative water management is essential to live in the era of climate change.

A practice that has been done for a long time is the building of sea walls or barriers, both below and above the sea level. The sea walls can be raised in height for the immediate future, and designed to accommodate future increases in height. The Singapore government stated that 70 to 80 percent of the island nation has some kind of coastal protection. A rise of 2 m or more in the sea level would transform Singapore into some kind of a fortified island.

The level of the threatened coastal regions could be raised. This can be done by importing gravel and sand from the interior. Another option, recommended by the current work, is to use municipal solid waste from the community, as in a sanitary landfill. Of course, the lower layers will be imported rocks, gravel, sand, and clay, while the upper layers would be imported gravel and sand and clay. There will be no interaction between the municipal solid waste and the sea water, because the waste will be placed higher than the sea level. Moreover, an impervious plastic liner would be used, as in a sanitary landfill.

More resources and costs are involved in trucking in or shipping in imported gravel, sand, and clay. Municipal solid waste destined for landfills elsewhere in the interior can be routed to these coastal areas. A synergistic effect of this plan is that interior land could then be used for habitation, agriculture, or other uses. That the community's solid waste is being used to help the community live with climate change is good philosophical thinking and strategizing.

On the other hand, if the municipal solid waste was previously being incinerated, the landfilling of sinking coastal areas will help to reduce carbon dioxide emissions. The synergistic effect is that one of the main causes of climate change, carbon dioxide, is being reduced instead of constantly being pumped into the air from burning. In mitigating the rising seas, this landfilling of solid waste will also help to cut down on one of the root causes of the rising seas.

The establishment of offshore barrier islands has been done by several countries, for example, Singapore. Old barrier islands have to be made higher in elevation, and new high ones planned to strategically help protect the low-lying coastal areas. Traditionally, these islands have been made from imported rocks, gravel, and sand. In addition, the shallow sea bed has been dredged, and the dredged material used for these barrier islands. In addition, the current work suggests the use of municipal solid waste, with the accompanying environmental safety measures.

From [21],

> the average air emission rates in the United States from municipal solid waste-fired generation are: 3685 lbs/MWh of carbon dioxide, (it is estimated that the fossil fuel-derived portion of carbon dioxide emissions represent approximately one-half of the total carbon emissions) 1.2 lbs/MWh of sulfur dioxide, and 6.7 lbs/MWh of nitrogen oxides.

It is obvious that the usage of municipal solid wastes for building offshore barrier islands would help in reducing the production rate of carbon dioxide and the other two gases mentioned.

The dredging procedure presumably allows for a larger capacity for sea water to flow. It is the suggestion here that the design and engineering of the whole region needs to be taken into consideration. Not only should the flow through be considered, but also the complex shape and size of the underwater volume should provide less opportunity for the sea water to collect and rise. In other words, the underwater mechanics have to be simulated correctly and planned right.

Model simulation and analysis, both physical and digital, should be employed to study the segment of the ocean basin adjacent to the threatened low-lying coastal area. The effect of the redesign of the ocean floor with barrier islands should take into account the ocean currents and tides of the region. With the simulated results for a few, well-selected probable scenarios in hand, the hydrology of the near shore should be planned and designed to accommodate the potential increased volume of sea water flow. There should be an initial mapping of the regional seabed with historical data regarding currents and tides. The ultimate objective is to design and engineer a hydrological system that would allow an increased volume of flow through the shallow water region, without a noticeable sea level rise on the low-lying coastal area. Oceanographers, marine scientists, engineers, and regional planners should be involved in this significant task. Digital software packages for such simulation are readily available; some of them are open access.

The digital software should strive to be a complete simulation of fully three-dimensional (3D) flow, which is time dependent, with morphology and sediment transport, water quality, waves, and ecology. It should be possible to simulate interactions between the processes mentioned using parameters that are standard and not too difficult to measure for different parts of the world. Since domain experts and non-domain experts are expected to use the simulation software package, it should allow for collaborative use without too much difficulty. One successful structure of such a package comprises tested and validated programs that are linked to or dovetailed into one another. The interface for the user and the result processing portion of the package should, needless to say, be similarly user-friendly and compatible with established geographical information systems, and so on. Having the facility to enable the user to visualize the 3D data as a time series and animations is a much desired feature.

7.4 ADAPTATION RESPONSES

One of the first adaptation type responses to be suggested would be to use salt-resistant cultivars for sea water-intruded areas. This is well and good if the area is originally for agricultural use. Since the worst damage and most expensive ones from sea water rise will occur in urban areas, responses that address urban issues will be discussed in greater detail.

In the realm of sea plants and sea weeds, some cultures in the world have consumed certain plants from the sea for centuries. The Japanese and Chinese people come to mind as examples. There are even some highly priced, special plant species in the gourmet menu. Use of flooded coastal areas for consumable sea plants would be put forward as a suggestion.

The cultivation of various sea plants as a source for biofuel can be studied and considered. This will certainly increase the number of plants that are suitable for biofuels. On the negative side, the increased use of biofuels from plants (whether land or sea plants) will not reduce the carbon dioxide in the atmosphere.

Newly flooded areas may be used for aquaculture. Sustainable aquaculture includes that for different types of fishes and shell-fish. The upside is that the acreage for renewable bioresources could be increased with increased sea level rise.

The use of flooded coastal areas for desalination plants seems like a natural and ecologically friendly act. There is less pumping work required to be done to use the incoming sea water as the source. Most efficient and least energy-intensive methods of desalination should be used. The fresh water obtained would certainly help to mitigate the energy-nexus problems arising in many places around the world.

In urban areas, flooded water-front areas with some of the most expensive homes should be replaced by multiple-story expensive homes, with the first couple of stories used for purposes other than living. Transport to and from dry land should be done by boat, preferably the ones powered by solar power or human-powered.

In the same vein of living, luxury resorts can be built on stilts over the shallow water, as has been done in many tourist islands throughout the world. The ones in the Asia-Pacific region come to mind [22]. This would attract more tourists to the area. Cities threatened by rising seas, for example, Miami, will be well served with this adaptation to increase tourism and business.

In less-affluent areas, the floating villages of Thailand and China have shown the way. Families that live off fishing, and the sale of cultivated produce, could live in boats or floating houses.

Flooded areas can be adapted as extended wetlands. Mangroves and others can be planted to prevent further encroachment by the sea. These mangroves will also help to reduce erosion and damage caused by hurricanes in areas that are prone to these natural phenomena, for example, New Orleans and the Mississippi delta region, Florida.

7.5 DISCUSSION AND CONCLUSION

A number of mitigation and adaptation responses have been discussed in the current work. Some of these responses have synergistic effects that would improve environmental quality and even help reverse the amount of carbon dioxide in the atmosphere.

A rather innovative recommendation here is the use of municipal solid wastes to augment the landfilling of low-lying coastal areas, barrier islands, and so on, as long as sanitary environmental considerations are taken into account. This beneficial use of municipal solid wastes would certainly help to stop the growing size of wondering gyros of garbage in the oceans of the world. The flotsam and jetsam discarded by us humans worldwide were an inspiration for the current article.

The effectiveness of the response or responses selected will depend on the will and cooperation of regional authorities. In many places throughout the world, this might not be a problem. In island nations, forward-thinking governments would not be hindered by this at all because of their size, for example, Singapore. However, where local authorities have autonomy, for example, in the United States, it is important that the local authorities of affected neighboring areas be united in a concerted effort to meet this rising seas problem. There is much to be benefitted from mitigating rising seas and to live adaptively with the challenge. The only other option, not discussed here, is abandonment. This last choice should be viewed as unacceptable.

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CHAPTER 8

FRESHWATER DISCHARGES INTO THE OCEANS

8.1 BACKGROUND

Under non-time-dependent analyses, the precipitation P exceeds the evaporation or evapotranspiration E over land. The remaining water runs off the land and accounts for the continental freshwater discharge into the oceans. When one considers the oceans, the resultant freshwater transfer into the air above is balanced by the water runoff from the land and transfers between regions in the oceans. The excess of E over P over the oceans is transferred over the land and precipitated as rain, dew, snow, ice diamonds, and so on thereby completing the land–ocean water cycle. While E and P changes depending on the location, the runoff from the land into the oceans is mostly taking place at the mouths of the world's major rivers. This freshwater influx into the ocean is very important locally and changes the density of the oceans regionally. Groundwater flowrates are considered orders of magnitude lower than river flows.

In [1], a study was made of annual and monthly mean values of continental freshwater discharge into the oceans, using streamflow data from 921 of the world's largest rivers. This study was aided with estimates of discharge from areas, which were not instrumented based on the ratios of runoff and drainage area between the instrumented regions and those that were not. A river transport model (RTM) was used. The driving agent was a runoff field that was used to calculate the river mouth outflow. Three distinct calculations were performed using RTM computational studies driven by

different runoff fields: 1) based on observed streamflow and a water balance model, and from calculations of precipitation P minus evaporation E computed as remainders from the atmospheric moisture budget using atmospheric re-calculations from 2) the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) and 3) the European Centre for Medium-Range Weather Forecasts (ECMWF) [1].

Wherever they could, the researchers stretched the estimated discharge to the river mouth, included streamflow that were not instrumented, and completed an annual cycle of continental discharge. In other words, a water cycle balance was performed. As contrasted to simply using the streamflow from the farthest downstream stations, the study in [1] found increases of 19 percent when the river mouth outflow was used. The river-based estimate of global continental discharge was "37,288 ± 661 km^3yr^{-1}, which is approximately 7.6 percent of global P or 35 percent of terrestrial P" [1]. While this number was comparable to earlier results obtained by other studies, the findings of [2] were more precise. The highest discharges into the Pacific, the Arctic, and global oceans took place in June. The corresponding month was August for the Indian Ocean and May for the Atlantic. Additionally, it was a finding that snow build-up and melt had extensive consequences on the yearly cycle of freshwater discharge into oceans but the Mediterranean and Black Seas and the Indian Ocean.

In [2], the study discovered big fluctuations in yearly streamflow for most of world's big rivers and thus for freshwater outflow from continents. About 33 percent of the biggest 200 rivers (including the Mississippi, Ganges, Congo, Columbia, Niger, and Uruguay) showed significant drifts during the 56-year period starting from 1948. Forty-five of the rivers have decreased streamflow and only 19 had increased values for streamflow. The inter-annual fluctuations were matched with the El Nino-Southern Oscillation (ENSO) occurrences for discharge into several of the ocean basin profiles. These profiles were the Atlantic, Pacific, Indian, and global ocean as a single entity. For oceans not including the Arctic, and for the global ocean as a single entity, the freshwater outflows show decreasing amounts. For the Pacific Ocean basin, the amount dropped by 9.4 km^3yr^{-1}. Precipitation is a major driver for the discharge trends and, also, a big factor that influences inter-annual to 10-year variations. This study also concluded that human activities did not affect annual streamflow as much when contrasted to climate-driving factors during 1948 to 2004 for most of world's biggest rivers. For the Arctic Ocean basin, increased streamflow were not correlated with increasing precipitation. There was certainly no increased precipitation for Siberia. It was concluded that "recent surface warming and related downward trends in snow cover and soil-ice content over the northern high-latitudes are responsible for increased runoff in these regions" [2].

8.2 LOWER AND HIGHER LATITUDES

It is a fact that climatic change effects tend to be more visible and observable in the higher latitudes near the poles than in the lower latitudes around the Equator. Most of the world's peoples live in cities. One of the contributing reasons is that the average urban human person, especially one who works in an air-conditioned environment most of their lives, as in most cities, cannot differentiate temperatures fluctuations that are less than about 2.7°C (5°F). This is about the precision of the average liquid mercury or alcohol thermometer found in households who have them. Hence, we humans depend on our other senses, like sight, to clue us into the status of our environment.

For discussion purposes, if one lives in an area where the winter frost line occurs, one can literally see the movement of this frost line from one year to the next, by noticing what happens to the vegetation and the surrounding environment. These observations have been reported to the author by locals and tour guides in Iceland. This is true also for persons who live near rivers where the ice forms over the river in winter, and the location where there is ice and no ice formation keeps moving toward the north in the Northern Hemisphere. Unfortunately, nature does not provide such convenient indicators in the tropics. It is for this reason that the discussion in this essay turns to focus on the Arctic Ocean basin. The measurable differences in temperature and freshwater discharge in this ocean basin north of the Atlantic and Pacific Oceans, owing to climate change, provide good data for discussion.

Arctic Ocean Basin

From [3], the streamflow from the Arctic Ocean basin (excluding the Bering Strait) is 5250 km^3yr^{-1}. The percentage contributions from the surrounding land are 13 percent Europe, 41 percent North America and Greenland and 46 percent from Asia. In Table 8.1 are listed the annual discharge to the ocean from the various areas that drain into it. These give a good picture of the amount of freshwater that is discharged to the oceans in the water cycle.

N.B. The variation in river runoff is obtained from the equation: precipitation minus evapotranspiration, which is nothing more than the basin runoff divided by the drainage basin area [5].

Table 8.1. Mean annual freshwater discharge into the Arctic Ocean for the years 1921 to 2000 [3]

Basin	Discharge km^3yr^{-1}	Maximum km^3	Discharge year	Minimum km^3	Discharge year
Hudson Bay and Strait	946	1,140	1966	733	1989
Bering Strait	301	362	1990	259	1999
North America (Arctic Ocean drainage basin only)	1,187	1,510	1996	990	1953
North America (inc. Hudson Bay)	2,133	2,475	1996	1,800	1998
Europe	697	884	1938	504	1960
Asia (Arctic Ocean drainage basin only)	2,430	2,890	1974	2,100	1953
Arctic Ocean drainage basin	4,314	4,870	1974	3,820	1953
Arctic Ocean drainage basin and Hudson Bay basin	5,250	5,950	1974	4,700	1953

In Table 8.2 is shown that fluctuations in river discharge take place because of fluctuations in atmospheric driving parameters, especially precipitation and air temperature [5]. The 10 biggest river basins experience air temperature rises during the past 30 years [4], as tabulated in Table 8.2. Naturally, the big river valleys in Europe, which have seen big jumps in precipitation, also had the highest magnitude runoff. There is a lot of permafrost in the biggest Siberian river basins. They appear to have a rise in runoff even with the precipitation dropping. There are several factors that may have caused this rise in outflow. The winter was not as long for instance. There was quicker snowmelt in spring (decreasing evaporation and infiltration losses), melting permafrost, and soils being water-logged as a consequence of greater groundwater storage. It should be noted that there are great uncertainties in the variations in precipitation. The equation between precipitation fluctuations and river discharge obviously needs to be studied more. These values have been obtained because of using the simple formula stipulated in the note under the table, which does not include some of the other factors mentioned in this paragraph. It is clear that the effects of climate change cannot be repudiated.

8.3 GROUNDWATER DISCHARGE AND ANTHROPOGENIC CONTRIBUTIONS

It is commonly accepted that groundwater flow and thus discharges are orders of magnitude less than the discharges of rivers. However, we would like to investigate whether that is the case of some of the more high-profile anthropogenic activities that lead to freshwater discharges into the oceans.

One anthropogenic activity that fits the bill, which is worth a look, is the short-cut that has been engineered between the two coasts of the Americas. The Panama Canal has a system of locks to help vessels rise and fall to different levels along its length. The Panamax is the maximum size of the ship that could cross the Panama Canal. The New Panamax is the new maximum size of the ship that could cross with the completion of the Panama Canal Expansion Project. It is a fact that a Panamax-size ship causes a discharge of about 8.4546×10^{-5} km^3 of freshwater with each crossing of the Panama Canal [6]. To be of the same order of magnitude as the minimum discharge of the Bering Strait of 259 km^3/yr, there should be at least 3,063,421 Panamax-size ships crossing a year. From [7], there were only 14,721 vessels crossing in 2007. This would cause only about 0.5 percent of the freshwater outflow of the Bering Strait in 1999. Hence, even though the freshwater discharge owing to the Panama Canal

Table 8.2. Variations in air temperature, precipitation, and calculated runoff in the Arctic river basins from 1936 till 1996, obtained via a straight-line relationship

Basin	Period	Variable air temperature °C	Change for the precipitation mm/yr	Period river runoff mm/yr	Permafrost extent in percentage of total area
Severnaya Dvina	1936–1996	0.3	24	37	0
	1966–1996	1.3	62	44	
Ob	1936–1996	1.2	3.8	6	19
	1966–1996	2.2	−4	1	
Pechora	1936–1996	0.5	60	53	31
	1966–1996	1.7	27	30	
Yenisey	1936–1996	1.2	−11	13	71
	1966–1996	2.5	0	27	
Lena	1936–1996	1.1	−5	22	94
	1996–1996	2.1	−24	10	
Indigirka	1936–1966	0.0	−34	17	100
	1966–1996	1.0	−42	1	
Kolyma	1936–1966	0.0	−29	−5	100
	1966–1996	0.6	−36	15	

Yukon	1936–1966	1.6	19	6	90
	1966–1996	2.2	43	13	
Mackenzie	1936–1966	1.4	−6	−5	55
Back	1966–1996	1.7	6	6	100

Source: Shiklomanov utilizing data from [3].

and its locks are not very significant on an ocean basin level, it does cause freshwater shortage problems locally in Panama.

It is a good development in 2015 that it appears that the Nicaragua Canal, being constructed in the Central American country of Nicaragua, is planned to have minimum impact with regard to the freshwater discharge into the ocean. The freshwater for the locks built will be obtained from a very large artificial lake, and not from Lake Nicaragua [8]. The Nicaragua Canal will help relieve congestion buildup in the Panama Canal. The Nicaragua Canal will help make more efficient the trade routes between East Asia and Southeast Asia and the eastern coasts of North and South America, the Caribbean nations, and Western Europe.

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CHAPTER 9

Wealth of the Oceans

9.1 INTRODUCTION

"If you look at the increasing world population, we essentially have to double [meat] production by 2050," said Murray, professor at the University of California, Davis [1]. "And we have to do that with less land, less water, and in an environmentally sustainable manner." Murray suggested using genetic engineering of animals, which started about 30 years ago, but none of the genetically modified (GM) animals has been approved by the United States Food and Drug Administration (USFDA). It is the suggestion of the current work to turn to the wealth of the oceans for solutions.

We can look to the seas and oceans for energy, water, and food. The resources here will help in solving the problems brought on by the energy–water–food nexus. Energy from water can come both from the potential, kinetic, and thermal energies of water, and the magma of the Earth through geothermal energy. Solar energy collection is available without hindrance from forests or buildings.

It is a primeval call. Living organisms could have started near hydrothermal vents in the sea. As sea water level rises, we humans should also return to the sea for answers and solutions. We can respond by adapting and using the bounty provided by the oceans to survive and flourish. After all, our blood density is still pretty close to that of the sea water.

9.2 CURRENT STATUS

About 95 percent of the oceans has not been explored yet [2]. We need to look at our whole planet, including the deep oceans, to help us support the booming human population.

Oil and gas industry is already exploiting resources offshore, many of them in deep water. The ocean floor needs to be mapped in great detail. Machinery and equipment that operate under high pressures should be researched and developed [3].

The fat of sea mammals like whales and dolphins are very good sources of vitamins A, D, and E. The people of Faroe Islands have been hunting and eating cetacean species for years. The species from the order Cetacea include the bottlenose dolphin, white-beaked dolphin, Atlantic whitesided dolphin, and harbor porpoise [4].

Whale meat has been consumed in Japan since 12,000 BC [5]. Modern factory ships were used since the 1930s by the Japanese. They continue to consume whale meat. If proper count is kept of the number of whales surviving and monitoring is undertaken so that the numbers are not being depleted, culling the whale population for food in a sustainable manner should be a consideration.

Desalination of the salty water pumped from the seas has been utilized in countries that can afford them. Innovation is ongoing to try to bring down the costs, including operational costs, of these desalination facilities.

9.3 LITERATURE SURVEY

Bathymetry is the measurement of the ocean depths. Recent works include [6–10]. Courtney and Shaw used multibeam bathymetry and back-scatter imaging to map the Canadian continental shelf [6]. A new grid for Arctic bathymetry was presented in [7]. The objective was to get a better map of the ocean floor north of latitude 64 N. Kostylev et al. [8] reported their work with multibeam bathymetry. In [9], high-resolution airborne imagery was used in the Bahamas Banks. Global bathymetry is discussed in [10].

In 2001, Naylor, Williams, and Strong [11] predicted that there would be five times increase in domestic aquaculture products by 2025. The researchers [11] reported that the global aquaculture had increased output by more than twice in value and volume for the decade prior to 2001, and supplied one-third of the seafood worldwide. In [12], Liu and Cordes discussed the use of deoxyribonucleic acid marker technologies in aquaculture genetics. The researchers in [13] deplored the loss of stock in mollusk production owing to disease. None of these academic articles on aquaculture refers to aquaculture in deeper waters. The work in [11] refers to inland and coastal waters.

The place of deep water science and engineering is important if mankind is to use the deep waters more. Webster [14] wrote a review about the part played by the processes in hydrology with respect to the interactions between the oceans and the atmosphere. Chahine [15] wrote about the hydrological cycle and its impact on climate. Pierrehumbert [16] studied the hydrologic cycle in deep-time climate problems. The researchers in [17] published about sea level and deep water temperature changes. In [18], the scientists studied the variations in the circulation of the depths of the east Atlantic Ocean in the previous 30,000 years. The researchers in [19] studied the total hydrology (both surface and deep water) of the North Atlantic Ocean for the past 150,000 years.

Ocean Thermal Energy Conversion (OTEC) has been developed, but has yet to find widespread adoption. Finney [20] concluded that OTEC could be viable in tropical areas where the shipping costs of fuels and goods are high. The researchers in [21] studied an OTEC plant boosted by solar energy. In [22], they published about an OTEC—Offshore Solar Pond design.

9.4 RESEARCH AND DEVELOPMENT

A complete and detailed map of the ocean floors would be needed to properly use the resources there. In addition, the principal life forms living at the various levels need to be noted and recorded. It is expected that greater detail needs to be found for the deep trenches around the world, for example, Mariana Trench, Java Trench. The Mariana Trench in the western Pacific is the deepest trench in the world. It has a depth of 10.911 km (10,911 ± 40 m) or 6.831 mi (36,069 ± 131 ft.) [23].

Not only the trenches, but the ridges of the oceans can be rather deep also. The Mid-Indian Ridge has an average depth of 10.0 km or 6.2 miles. The Mid-Atlantic ridge has a deep rift valley in conformity to its crest [24]. The canyon is about 1 to 3 km deep. For instance, greater details need to be found if this is an area to be investigated for deep water aquaculture.

With the objective of supplying food to the teeming billions of the world, a master plan for the oceans should be discussed and agreed upon. The wild creatures of the sea should be all identified and recorded. Their migratory routes should be known. Animal and plant life suitable for food should be considered for aquaculture. Areas for these aquaculture projects should be designated, monitored, and verified to be environmentally friendly and sustainable before very large-scale aquaculture is allowed.

Possible food species should be explored and recognized. New food sources are required, especially protein sources, to supplement meat production on land for the teeming billions. Research and development should be done to make unusual sea foods more palatable, harmless, and nutritious.

In the present day, hydrothermal vents are natural occurrences underwater, which teem with life that can withstand the toxic chemicals present. The field of human knowledge would benefit by studying living organisms there. For example, one objective could be to learn what features and (or) genes they have that allow them to survive under those harsh conditions.

An innovative method has been proposed by the authors in [25] for sail boats to produce hydrogen. This is energy from the wind, deployed in the open seas where the winds are stronger than on land. The researchers in [26] proposed exploiting the West Wind Drift to generate electric power. The West Wind Drift refers to the westerly winds blowing in the region between the continent of Antarctica and the other southern continents. Beneath them, the water currents are also moving in the same direction. These incessant movements of the water and the wind would be an excellent source of energy to produce electric power if the engineering problems are solved, or existing technologies made less expensive and practical. Hydraulic turbines could be placed in the powerful currents, closer rather than farther from land, and the electricity generated can be transmitted to populated areas *via* cables.

One recent publication about using the winds over the oceans as a source of energy is [27]. In [27], the proposal is to generate electric power for the whole world. For practical and political reasons, modification of the power energy generation and storage for individual nations would be more acceptable. The hydraulic turbine is used to facilitate the success of the system in [27]. It would seem that under ideal conditions, the hydraulic turbines would generate power well by the ship driven by the wind, but only prototyping and tests would indicate whether the parawing would pull the ship (and hence the hydraulic turbines) off the water often enough to make the system very inefficient. The innovative article about land-sail vehicle to generate electricity [28] may be modified for use over the sea. The encouraging message in [28] is that there could be a significant jump in wind-generated electric power if scientists and engineers looked outside Betz's law.

Desalination plants should be made more efficient and less expensive to operate. The researchers in [29] wrote about the advances in desalination technologies, and the costs of operation. They came up with some suggestions for how the price of desalination might go down.

Karagiannis and Soldatos [30] performed a cost literature review. It seems that the significant factors in desalination costs are the desalting method, the level of salinity in the feedwater, the capacity of the desalination plant, and the energy supply. In [29], solar energy costs the most, but with the least environmental impact. However, solar energy costs have come down owing to affordable organic solar collectors, so the costs of desalination can also be driven downward.

9.5 DISCUSSION AND CONCLUSION

Aquaculture should be encouraged and increased to meet the rising food demand in the world. Deep water aquaculture should be explored and initiated. The whale is a denizen of the deep, however temporary, that seems to have satisfied the palate of the Japanese people.

Wind and water power generation technologies should be increased and implemented. Solar energy collection in the open oceans should be considered. Hydraulic turbines seem to be rather promising, and work should continue.

Desalting the sea water should definitely be a priority to make present technologies more affordable to poorer nations. Solar energy should be used as much as possible with respect to the desalination processes.

People have lived successfully for short periods underwater, for example, an underwater hotel in the Florida Keys, United States. The sailors in submarines do regular duty underwater for extended periods of time. Underwater built environments have been used to simulate outer space environments with respect to space exploration. It should be a consideration to research human beings living "permanently" in communities under deep water conditions.

In the discussion about climate change and global warming, it is a popular thought that the oceans are the world's heat sink. In other words, the oceans are reservoirs for Nature's heat sequestration. If this is indeed the case, we need to know whether life forms in the depths are being adversely affected by this added thermal load. The onus is on us to know what lives there, and to make sure that climate change is not hurting life forms in the ocean depths. We, humans, are after all, custodians of the world.

It is clear that the problems brought on by the energy–water–food nexus would be solved by tapping more into the resources of the oceans. Engineering and science research and development will be needed to help human kind move forward. Nature has given the world for us humans to use, as long as we do not abuse the resources.

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CHAPTER 10

Forests and Jungles Brake Climate Change

10.1 PHOTOSYNTHESIS

Photosynthesis is a natural process by which plants and trees pull carbon dioxide from the air to make carbohydrates as food for themselves. Light is necessary for the reaction to take place. Photosynthesis can be written as a chemical equation. The overall equation is as follows:

$$6CO_2 + 6H_2O \xrightarrow[\text{Sunlight energy}]{} C_6H_{12}O_6 + 6O_2$$

where

CO_2 is carbon dioxide, H_2O is water.
Light energy is required.
$C_6H_{12}O_6$ is glucose.
O_2 is oxygen.

As light energy (in the form of photons) reaches a plant, chlorophyll molecules forming a light-harvesting complex absorb that energy, thus exciting electrons. These electrons move along an electron transport chain, eventually transferring their energy into the bonds of ATP and NADPH. ATP is the acronym for Adnosine TriPhosphate. NADPH is the acronym for Nicotinamide Adenine Dinucleotide Phosphate. The NADPH is used in cells for energy. ATP and NADPH play the role of highly charged energy carriers ready to supply energy to continue photosynthesis in the dark reactions, that is, reactions that do not require light energy. By using the energy of the ATP and NADPH, and some other molecules, including carbon dioxide and water, a carbohydrate named glucose can be made.

Humans eat vegetables and plants, thus getting some of their stored energy (in the form of carbohydrates) from them. Photosynthesis involves one of the essential cycles of life. This cycle of life is the basis on which it is known that forests, trees, and plants are essential for one of the natural energy balances in the world.

The United Nations Department of Economic and Social Affairs proclaimed that reforestation is the simplest route to fight climate change. Concentrating on the tropical forests around the world is one of the best near-term strategies for putting brakes on climate change. Trees and plants make use of carbon dioxide, the main greenhouse gas, from the air and lock the carbon as a solid in their leaves and stems, and in their roots. Burning these plants and trees causes these solid forms, which contain carbon, to convert to a volatile form, that is, carbon dioxide. The triatomic molecule structure of carbon dioxide is large enough to hinder low-temperature, long-wavelength radiation from the earth's surface, thus helping to trap heat within the earth rather than being lost into outer space.

10.2 COSTA RICA

Before the Second World War, about 75 percent of Costa Rica was blanketed by tropical jungle. In the following 40 years, the national forest dropped to 21 percent. From about 1950 to 1983 [1], more than 46 percent of jungle land was cleared without re-treeing efforts. Between 1983 and 2010, a big reversal and a big move to re-forest the land took place. More than a quarter of the lost jungle land was restored. As of 2010, Costa Rica boasts of over 50 percent in jungle coverage.

The numbers mentioned above, quoted of Amelia Rueda's online website Nuestra Voz (Our Voice), are obtained from research undertaken by the Costa Rican Ministry of the Environment (MINAE in Spanish) and the National Forestry Financial Fund (FONAFIFO). The clearing of the jungle from the 1950s to the early 1980s was done to carry out large-scale farming of sugar cane, palm for cooking oil, and coffee. These crops were readily marketable in the world commodities market. A principal cause of deforestation was the irresponsible behavior of the timber industry. By 1987, it was obvious that without public action, Costa Rica's jungles would be in as dire a state as those in Nicaragua and Haiti.

The jungle lands in Costa Rica have been successfully reclaimed. MINAE and FONAFIFO have used programs like Payment for Environmental Services Program (PSE in Spanish) and the Strategy to Reduce Carbon Emissions Caused by Deforestation and Forest Degradation (REDD + in Spanish). Land owners are especially incentivized by the PSE program because it stimulates their industry when they take part.

There is a claim in Costa Rica that reforestation on a very large scale continues to take place, with the fundamental objective of achieving a jungle coverage of 60 percent. This is in keeping with the Costa Rica—Carbon Neutral initiative that shall take place in 2021.

10.3 NICARAGUA

From 1990 to 2005, 21 percent of Nicaragua's jungle was cleared away. The rate of clearing has decreased 17 percent since the end of the last millennium [2]. Human activity included agriculture, the timber industry, and the raising of cattle [2]. Forest fires also contributed to the decrease of forest acreage.

From around 1995 to the end of the millennium, the government gave logging licenses that caused the clearing of the forest. By 1998, the extent of deforestation was so great that Nicaragua's president banned the logging of cedar, mahogany, and bombox trees for a five-year period. Nowadays, unlawful logging exists as about half of the timber production [2]. Another threat to Nicaragua's rainforests is mining. Open-pit mines cause the river valley of the San Juan to be a region that has clearly suffered environmental degradation.

After Hurricane Mitch hit in 1998, it was pointed out that deforestation aggravated the damage that occurred in the path of the hurricane. Aerial surveys showed that landslides took place more frequently on hillsides that had been cleared of their natural plant life by human activities. Naturally vegetated hillsides experienced fewer mudslides or slow-moving mudflow down the hill.

Nicaragua's government has incentivized the cultivation of forest plantations, which have expanded from the acreage in 1990 to more than 12 times that by 2005. About 6 percent of the country is protected by legislation from exploitation by would-be timber merchants.

10.4 HAITI

Deforestation in Haiti is a critical environmental problem. In 1923, over 60 percent of Haiti's land was blanketed by forests [3]. In 2006, less than 2 percent of the land was covered with forests [4]. Beginning around 1954, timber merchants increased their logging operations in response to the island nation's capital's increased demand for charcoal. High birth rates, unsustainable agriculture, and intensified rivalry for land were the principal reasons for deforestation [4].

The most severe consequence of deforestation is soil erosion [5]. An estimated 15,000 acres (61 km^2) of topsoil are lost annually via erosion. Erosion also damaged other productive infrastructure such as roads, irrigation systems, coastal marine ecosystems, and dams. Soil erosion also lowers the productivity of the land, makes droughts worse, and ultimately leads to desertification. All of these contribute to mounting pressure on the land and trees left standing.

When the author flew over the island of Hispaniola, he obtained a very clear bird's eye view of the deforestation that had occurred in Haiti. In the common border of Haiti and the Dominican Republic, the land in Haiti is bare and uncovered, while the land in the Dominican side is green and covered with trees.

10.5 THE AMAZON JUNGLE

The Amazon jungle is the most expansive tropical jungle in the world. It blankets more than 5.5 million km^2 (1.4 billion acres). Over 50 percent of the Amazon jungle is in Brazil. The rest of it spreads into neighboring countries of Venezuela, Colombia, Ecuador, Peru, Bolivia, Guyana, French Guiana, and Suriname.

It is estimated that about 10 percent of the world's known species reside in the Amazon jungle [6]. Additionally, about 20 percent of the world's bird species call the Amazon jungle home. It is the natural habitat of about 2.5 million insect species and more than 40,000 plant species.

While the conservation of the Amazon jungle is still a point of contention, deforestation rates have been decreasing, whereas areas of preserved land have been on the rise over the past decade. In the recent years of 2005 and 2010, the Amazon rainforest experienced devastating droughts that caused large quantities of vegetation in the worst blighted parts to perish.

10.6 INDONESIA

In Indonesia, deforestation persists even though there is a presidential ruling against land concessions for the paper industry [7]. The program called Reducing Emissions from Deforestation and forest Degradation (REDD), sponsored by the United Nations, strives to conserve forests by employing financial incentives and markets. During the four years since its inception in Indonesia in the year 2009, the program has only initiated a weak start.

A couple of large Australian paper companies were called out for the clearing of large tracts of the Indonesian jungle areas [7]. The Greenpeace report states that the Australian firms are causing critically endangered animals, for example, the orangutan and the Sumatran tiger to go toward extinction by importing products from an Indonesian palm oil and paper giant, controlled by one of Indonesia's richest families. The palm oil and paper from this Indonesian company is popular in a wide variety of global consumables.

The Greenpeace report states that the Indonesian company relentlessly destroys tropical forests and causes environmental problems to supply its two pulp mills in the Indonesian island of Sumatra. "Today in Indonesia, an area of forest the size of a football field is cut down every 20 seconds" [7], said Greenpeace Forest Campaigner, Reece Turner. "The pulp and paper is ending up on our desks and in our toilets." Turner also stated that the Australian government must follow through with its 2007 promise to not allow the purchase of unlawfully cut timber products.

Greenpeace also focused on a well-known multinational company. Greenpeace aired a satirical imitation video of the company's advertisement that went viral on the World Wide Web. The multinational company immediately removed the Indonesian company from being a source of palm oil supply. This is a good example of the power of the Internet.

10.7 DISCUSSION AND CONCLUSION

In their time until the present day, humans have deforested some 75 percent of the natural forests around the globe. This has contributed significantly to the volatile carbon (carbon dioxide) side of the balance equation.

There are popular environmental movements in countries that are natural habitats to tropical forests. In addition, Western consumers care about sustainable practices. Government and corporate leaders have no choice but to energize a renewed effort to decelerate the felling of trees. Additionally, plans are being formulated by those same leaders to incentivize forest regrowth on a massive scale so as to reduce anthropogenic carbon dioxide in the air and transform it into solid form for the long term.

Throughout the world, trees are often cut before agriculture can take place. The single biggest threat to forests is the need to feed multiplying populations. An added problem is the growing global middle class with the means to eat better. Stopping deforestation will necessitate growing food more efficiently, on less land and water.

"For thousands of years, the march of civilization has been associated with converting natural ecosystems to crops that serve only man," said

Glenn Hurowitz, an executive of Climate Advisers, a Washington DC group [8]. "What's happening now is that we are trying to break that paradigm. If that succeeds, it's going to be a major development in human history." The paradigm here is to increase the land devoted to trees and forests, and to produce agricultural crops more efficiently with less land and water.

Scientists, engineers, and technologists are in somewhat agreement that deforestation should be stopped. On the other hand, reforestation will control climate change and conserve biodiversity. These days, they are also coming to the realization that there is a possibility of new or recovering forests to help remove carbon dioxide from the atmosphere, thus lowering its concentration in it.

"Every time I hear about a government program that is going to spend billions of dollars on some carbon capture and storage program, I just laugh and think, what is wrong with a tree?" said Nigel Sizer, a director at the World Resources Institute, a think tank in Washington DC, United States [8]. It is unfortunate that leaders of important programs tend to marginalize the problem of carbon dioxide increase and climate change by such careless statements. The processes of nature are relatively slow, as one can easily observe by planting a tree and waiting for it to mature and grow to the size they do in the forests. Combustion of fossil fuels in power plants and transportation vehicles, on the other hand, are human designed, and carbon dioxide formation takes place at much faster rates than that of nature removing carbon dioxide via photosynthesis. The living natural process of photosynthesis that uses up carbon dioxide is very slow compared to the burning process of organic matter, which produces carbon dioxide. On top of natural burning, we humans have engineered and used combustion processes using fossil fuels that go on continually every single minute of the day, all over the world. In other words, it is not possible to fight a raging fire by using a hose with a supply of dripping water.

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CHAPTER 11

ATMOSPHERIC CARBON DIOXIDE REMOVAL VIA TECHNOLOGY

11.1 INTRODUCTION

It is becoming popularly known that climate change is taking place worldwide. The Intergovernmental Panel on Climate Change (IPCC) has recognized these variable climatic conditions around the world owing to the evidences that were scientifically collected. They warned that the peoples of the world need to work together to put brakes on climate change. The report stated that during the years 1880 to 2012, the average temperatures of the land and sea have increased by 0.85°C; almost the whole Earth has seen this surface warming. The ocean levels have also built up, principally from the loss of glacier mass. From the conservation of mass, which is actually a physical law, whatever is lost in solid form (in glaciers) flows as liquid into the oceans. Between 1901 and 2010, the global sea level has built up an average of 0.019 m. Additionally, greenhouse gases in the air have built up.

> The concentrations of carbon dioxide has gone up to 390 ppm, methane to 1803 ppb, and nitrous oxide to 324 ppb. When looking at these numbers and their values before the Industrial Revolution in Europe, the values have risen by approximately 40 percent, 150 percent, and 20 percent, respectively [1].

Nomenclature

C	carbon atom
H	hydrogen atom

Mg	magnesium atom
O	oxygen atom
Si	silicon atom

Superscripts

−	anion or negatively charged particle
+	cation or positively charged particle

The study of IPCC World Group I discovered that mankind is responsible for climate change, proven by the large increase in greenhouse gas emissions and surface warming. If greenhouse gases are not cut, further global warming and climate change will accelerate. Significant reductions in greenhouse gases must be realized in order to put the brakes on climate change [2]. In addition, scientists have modeled and announced that oceanic warming will take place for the rest of this century. When enough heat has penetrated into the depths of the ocean, circulation will also be affected. It is also predicted that with the continued persistence of climate change forcing factors, the carbon cycle will compound and continue to raise the carbon concentration, and the problems will trend toward perpetuity.

The phenomenon of climate change has come to the consciousness of most of the lay people, but its impact and difficulties have not been fully realized, as discovered by Lorenzoni and Pidgeon [1]. Surveys were used to gather the views of the different communities on climate change in the United States and in the Europe Union. Even though a worldwide call to cut emissions was a priority at the Kyoto Protocol in 2001, policy requires peoples to "buy-in." If the policy is not supported by people, implementation may be neglected, which would sabotage the effort and thus produce no change. It was also discovered that the communities had a difficulty comprehending climate change and joining the dots to their everyday activities. Particularly in the United States, personal and social goals tend to grab peoples' attention as compared to broader, worldwide issues, like climate change. Moreover, issues regarding high-voltage power lines and more traditional environmental problems spark more concern in people than does the concept of climate change. This last phenomenon could be blamed on biased media coverage over the recent past. Even in countries with a culture of great environmental respect, such as Greece, this point arises. Few people were able to realize that the burning of fossil fuels is the main anthropogenic activity that goes toward causing climate change. Thus, it was discovered that the general peoples' understanding of climate change is not in line with the current scientific realization [1].

It was also discovered in [1] that people tend to see climate change as more of a threat to their progeny rather than to themselves. Hence, the public tend to favor mitigation procedures that can be performed without difficulty and cost practically nothing to them as individuals. While they are willing to take baby steps in this direction, they are not ready to give up high-energy-use technologies that they have been accustomed to. There is a conclusion that the deceleration of climate change cannot be accomplished with drastic changes to the way of life in developed countries; thus, individuals must select to modify their lifestyles (typically, in a minor way). Besides that, other actions must be carried out in order to reduce climate change effects without inciting political opposition [1].

One way to mitigate climate change is to use carbon removal technologies. Kriegler, Edenhofer, and Reuster [3] studied about how carbon dioxide concentration in the atmosphere affected overall climate change. The model employed by the researchers was named ReMIND; this model included energy, climate, and economy to predict the value of technologies that remove carbon. They began by realizing that the reduction of carbon emissions will take a long time, therefore reversal is necessary. There is a level of carbon dioxide in the atmosphere that causes climate change, and a higher level that causes accelerated climate change. Obviously, the world is at this higher level of carbon dioxide concentration at the current time. Carbon dioxide removal (CDR) technologies have recently become popular in reducing carbon dioxide from the air and the oceans.

Bio-energy with carbon capture and storage, or BECCS, has been examined; the aim is to contain carbon dioxide concentration to 450 ppm or below in the air. The study discovered that these technologies are essential because they contribute negative emissions to the whole scenario. Although the study in [3] focused on the impact of BECCS, the deductions were assumed to apply to CDR technologies taken as a unit. Additionally, these technologies may become more reliable for their being able to negate the effects of emissions. The transportation vehicles seem to be the most problematic to convert from using fossil fuels. The study also considered situations where BECCS is out of the consideration. In this scenario, high-cost emission control technologies had to be employed to arrive at almost zero emission level so as to produce an outcome that is less than the target atmospheric concentration. The inclusiveness of CDR technologies has the capability to reduce future costs of emissions.

The study ended with a confident perspective on CDR technologies taken together. CDR technologies may not be the main mitigation procedures used, but they do help to reduce carbon dioxide levels by sectors that will have the most problems in cutting their emission levels. The study concluded that carbon removal technologies can be considered as viable supplemental technologies. Corrective steps by the guilty sectors themselves did the most to cut emission levels [3].

11.2 CARBON DIOXIDE REMOVAL

Carbon dioxide is dissolved in the oceans as a natural process, forming carbonic acid. The forcing function is the dissimilarities in carbon dioxide concentrations between the oceans and the atmosphere. The higher the concentration, the more carbon dioxide will dissolve into the water from the air. This process creates carbonic acid. With increased carbon dioxide concentrations due to anthropogenic activities, the oceans reach higher levels of ocean acidification [4].

Carbon dioxide in the air is also fixed as solid matter (containing carbon) forming stems, branches, and decaying organic matter. In the study, it was found that juvenile plants exposed to twice the regular atmospheric carbon concentration grew faster. With this higher carbon concentration, the plants increased their rate of dry matter production by one-fifth to six-fifths; this demonstrated that higher atmospheric concentrations result in plants that utilize the carbon better [5]. Trees and vegetation in general play an essential role in braking the acceleration of carbon dioxide concentration in the air. However, the rate of increase of carbon dioxide is such that naturally occurring carbon removal is not enough to brake climate change.

11.3 BIOCHAR

Biochar and charcoal are the same materially. They only differ in their end use. One has been used by the natives of South America to help enrich their soils, while the other has been used by cultures all over the world as fuel. Charcoal or biochar are made in a pyrolysis procedure, where organic matter is brought up to 350°C to 700°C in an environment starved of oxygen. In this process, oxygen, volatile hydrocarbons, and hydrogen are driven out by the heat, and the end product is carbon-rich material that does not degrade chemically or microbially [6]. Carbon in charcoal or biochar is more stable than that in the initial organic matter [7]. The current procedure cuts down on the carbon emissions during the forming stage [6]. There are a variety of ways for producing charcoal or biochar. Quick pyrolysis takes place at high temperatures; the process manufactures a lower percentage of biochar, but a higher percentage of bio-oil and syngas that could be sold. Pyrolysis procedures, which are not as fast, produce a higher percentage of biochar and a smaller percentage of by-products. Bio-oil can be used for manufacturing electricity and as fuel in the transportation sector [8]. The noncondensable by-products of the pyrolysis process can be combusted again in the pyrolysis chamber or can be fuel for producing electricity [6]. Compared to the small amount of carbon emissions in the forming of charcoal or Biochar, the ability to reduce carbon dioxide in the air makes biochar usage carbon negative. Charcoal on the average has 20 to 50 percent of the carbon present in the original organic matter, which would typically be waste or discarded material. Wood is not used in modern methods of producing Biochar, even though it was the main source for producing charcoal traditionally.

The earth around the world binds more than 330 percent carbon dioxide than the air, and a variety of soils have the ability to fix several hundred billion more tons of carbon. Biochar is a very good absorbent of carbon dioxide. When the charcoal is then laid in the ground, it is fixed for up to thousands of years [6]. In [9], it was found that if the Earth's cultivable land is treated with charcoal, it would be possible to fix all of the carbon in the air that is attributable to anthropogenic activity [9]. The entity formed for the research and development of biochar technologies has calculated that 0.5 billion metrics tons of carbon could be taken out of the air annually. With the energy recovered from the pyrolysis process, which could compensate for some energy saved from not burning the equivalent amount of fossil fuels, the result would be the same as reducing the quantity of carbon by 1.2 billion metric tons each year [6].

Various organic matter and pyrolysis procedures produce biochars with an enormous range of properties. For the purpose of the fixation of carbon from the air, the biochar should have the following properties: "an oxygen to carbon ratio less than 0.4, a hydrogen to carbon ratio less than 0.6, and a black carbon content greater than 15 percent of the total carbon" [7]. The ratios of oxygen and hydrogen to the carbon are a measure of carbonization in the biochar, which controls how stable it is. Black carbon is the carbon that does not decompose, which is a very good property. It was found that plants, for example, barley stover, produced better biochars than manure. The reason is that manure has high levels of nitrogen, which will aggravate greenhouse gases in the atmosphere. In addition, high-temperature biochars can fix more carbon than low-temperature ones; this latter type is better at improving the soil [7].

There are indirect effects of adding biochar to the soil, which result in reduced greenhouse emissions. Biochar is rather porous and thus have a high surface-to-volume ratio. This property encourages the growth of bacteria and fungi. These beneficial organisms are essential for the plants to uptake nutrients. Biochar addition to the soil has been demonstrated to augment nitrogen absorption by 2.8 to 4 times. Soil aeration is improved and pathogens are limited by the biochar in the soil. Even though biochar does not increase agricultural outputs, it does allow the reduction of the use of fertilizers [6]. The side effect of biochar is that the emissions of methane and nitrous oxide are reduced. The methane molecule CH_4 is larger than the CO_2 molecule, and potentially can worsen the greenhouse effect locally near the sites of emissions. Biochar could help abate some of the pressing environmental problems: chronic food shortages, soil degradation, water contamination through fertilizer overuse, greenhouse gases, and thus climate change [9].

One of the biggest advantages of biochar is that it is simple. Biochar should only be made from plant waste, rather than felling trees, if this technology is to be carbon reducing [6]. Biochar can be made in a range of quantities, from small to large, which makes it suitable over a large range of economic scenarios. From a statistically averaged viewpoint, the amount of carbon decreased by using biochar is 25 percent more than the decrease achieved if the initial waste biomass were burned for fuel. In Asia and South America, where carbon prices are higher, biochar methodology could be cost advantageous when compared to other climate change mitigation methods and procedures [8].

11.4 ARTIFICIAL TREES

In [10], the researchers checked into the technical and economic viability of reacting carbon dioxide out of the air. Their numerical model demonstrated that carbon capture from the air has the potential of being more efficient than tapping energy using a wind turbine. In particular, for a specified quantity of electricity, a wind turbine would need to be hundreds of times bigger in size than a CDR equipment required to remove the gaseous pollutants from a diesel prime-mover producing the same amount of electricity as the wind turbine. On this basis [10], a CDR device could occupy an area of less than 1 m^2 to make up for one person's production.

In recent years, Lackner, Grimes, and Ziock have arrived at a concept called an "artificial tree," which is made of a beige polypropylene plastic. The "tree leaves" are streamlined tufts of material that are embedded with 25 μm sized particles of a resin [11, 12]. When the leaves come into contact with air, the carbon dioxide present goes into a chemical reaction with the resin to create sodium bicarbonate. The quantity of carbon dioxide that can be absorbed by the tree is inversely proportional to the water content of the leaves [11]. To release the absorbed carbon dioxide, the leaves may be drenched in water as a step in the recycling of these leaves [13]. These artificial trees absorb carbon dioxide from the air as real trees do. However, unlike natural trees, the "leaves" of these artificial trees can be bunched tightly as sunlight is not necessary [13]. Thus, these trees can remove atmospheric carbon dioxide better than real trees [12].

It is estimated that these artificial trees could be a thousand times better than real trees [13]. In the prototype form, a Lackner's "tree" can absorb about 700 kg of carbon dioxide, which is the quantity of carbon dioxide 13 persons will produce in a day [11]. These units are scalable; the quantity of carbon dioxide removed is dependent on the tree's surface area and the air speed over the leaves. Lackner figures that the units would be about car-size; for each kilogram of resin the cost would be about $2.5. The units are estimated to run approximately $20,000 each upon initial production [12, 13]. With the size of a car, the units could remove over one ton of carbon per day, thus making up for the carbon dioxide pollution of 36 cars. With this estimate [12], 10 million units have the capability of removing 12 percent of the carbon expelled into the air annually by humans.

If used extensively as planned, this technology would be able to remove carbon dioxide produced by the transportation sector because fossil fuels are still being used. It is a pipe dream to imagine that the world will quickly adopt clean energy sources to stop carbon emissions, and that "artificial trees" could be the solution to decrease carbon dioxide in the air. The biggest problem to the extensive adoption of artificial trees is economic. If the economic stimulants for reducing carbon dioxide in the air are not greater than the stimulants for the current use of fossil fuels and air pollution, then the technology will not be adopted [12].

11.5 ENHANCED WEATHERING

Weathering is an important natural method in which the level of carbon dioxide in the atmosphere is limited. Different minerals have varying rates of weathering. Olivine weathers fast and quartz weathers at a more sluggish pace [14]. Water is necessary for rocks to react with carbon dioxide in the air, forming bicarbonate ions. These then proceed to become solid carbonates, dolomites, and limestones, which are a couple of the ultimate stable states of carbon [15]. Natural weathering and photosynthesis have not been able to restrict carbon dioxide in the air since the start of the industrial revolution [15]. The objective of enhanced weathering is to employ quick-reacting silicates to fix massive quantities of carbon in the air. Magnesium and calcium silicates are probably the best for enhanced weathering technologies [16].

Enhanced weathering to reduce atmospheric carbon dioxide happens in three steps. This technology requires a lot of material that weathers without any problems; this material would be pulverized, and then spread over big tracks of land to react with the atmospheric carbon dioxide [15]. Olivine has been shown to be one of the more suitable substances for this enhanced weathering technology. Olivine is one of the most common substances in our planet's upper mantle. The carbonation reaction takes place readily, and is represented by Equation 11.1. This method and the other two discussed previously (biochar and artificial trees) fix carbon dioxide as solids, and hence are stable and immobile, compared to sequestering the gas in liquids like water. Philosophically speaking, carbon in solids is not mobile, but carbon dioxide in liquids is still mobile and thus potentially able to cause environmental problems. The action of olivine in enhanced weathering technology is as follows [15]:

$$Mg_2SiO_4 + 4H_2O + 4CO_2 \rightarrow 2Mg^{2+} + 4HCO_3^- + H_4SiO_4 \quad (11.1)$$

Olivine is favored as an enhanced weathering material since it reacts readily with carbon dioxide with a manufacturing and delivery cost per ton in the \$4 to \$5 range [17]. When crushed and in the presence of catalysts, olivine reacts with atmospheric carbon dioxide within a couple of hours. "The products of this reaction are magnesium carbonate, amorphous silica, and sometimes iron oxide" [14]; these compounds are marketable and, being solid, not potentially harmful to the environment. The carbonate ions cause alkalinity in the water and the corresponding pH to rise, which tends to balance the drop in alkalinity and pH owing to increased carbon dioxide levels in the air. Phosphorus, silicon, and potassium can also be produced in these reactions; they encourage plant and phytoplankton growth. The additional biomass because of greater growth rates will contribute to the cutting of carbon dioxide levels [16]. Additionally, spreading olivine on the ground in the forests and farms has the secondary advantage of mitigating acid rain, and thus bettering the soil [14].

From [14], with “25 billion tons of olivine, a likely 30 billion tons of carbon dioxide could be fixed, which is equivalent to 7 to 8 km^3 of dunites, the rocks created when this carbon is stored naturally.” A number of immense (about 30 to 50 in total) open-pit olivine mines could do the trick, if the application area is nearby to the mine. With minimal transportation costs, “the outlay of this technology could be brought down to 10 euros per ton” [14], which is more affordable than other technologies used to brake climate change. In developing countries, this technology could be employed as they surge forward in industrialization and thus air pollution. Many thousands of jobs would be created via the necessary mines [15].

Enhanced weathering could be economically viable, but one should also look at the downside. Distributing dust (from rock) over great tracks of land increases airborne dust, a large portion of which could harm human beings. The area selected for effective enhanced weathering should also be a consideration. It has been found to be most efficacious in lands within the tropics. In limited locations, because of feasibility concerns, the extent to which the technology must be used may be relatively too much to be an option. Transferring the pulverized olivine from the mines is an inherent issue. Since transportation forms a major cost and transportation is still dependent on fossil fuels, the advantage of enhanced weathering technology may be decreased significantly, if not brought to naught [16]. However, enhanced weathering is a promising mitigation technology. It should definitely be considered in concert with other technologies to form an arsenal to combat anthropogenic carbon dioxide emissions.

11.6 BIO-ENERGY WITH CARBON CAPTURE AND STORAGE

Another technology that is employed is the trapping of carbon dioxide that has been produced by the burning or the transformation of biomass. Biomass can generally be classified into two categories: wastes and residual materials, and specially grown agricultural crops [18]. Bio-energy is energy produced from burning biomass or from the liquid or gaseous fuel obtained after conversion of the original biomass. Bio-energy constituted 10 percent of the world’s energy use in 2009; the major contribution came from less developed nations where biomass is combusted for cooking and heating [19]. Bio-energy constitutes 1.5 percent of the world’s electricity generation and heat production industries [19]. Another form of bio-energy is to combust biomass with a fossil fuel, commonly called co-firing. Biomass percentage in co-firing fuel nowadays is about 10 to 15, although improvements could raise this percentage [20].

BECCS is the class of procedures that unite bio-energy and the reduction of atmospheric carbon dioxide via trapping and fixation. Suitable places for this trapped carbon dioxide include defunct gas and oil wells, still producing enhanced oil recovery fields, abandoned coal mines, and brine aquifers [18]. These non-freshwater aquifers are suitable for trapping carbon dioxide, and they exist around the world. Typically, the aquifers are found in between layers of impervious bed rock, on top of or below such a layer. For instance, the pervious sandstone can be filled with saline water or brine. If the aquifer is sandwiched between impervious rock layers, or is under such a layer, the impermeable rock acts as a seal on the carbon dioxide reservoir. After many millennia, the carbon dioxide transforms into solid carbonate and is fixed [21].

At the present time, a Swedish company called Biorecro is collaborating with other companies and research entities to improve this technology. Three of the collaborative ventures are in the United States. The Illinois State Geological Survey at the University of Illinois (U. of I.), sponsored by the U.S. Department of Energy (USDOE), takes carbon dioxide from ethanol production and puts it into the Mount Simon aquifer, which is salty water trapped within sandstone. “This BECCS project (one of the first in the world) has a record of removing carbon dioxide at the 300,000-ton level annually, but could potentially top 1 million tons per year” [22]. The present governmental funding comes to an end in 2016, and the project might halt then too. In the Energy and Environmental Research Center at the University of North Dakota, there is work being pursued to turn the biomass into gas prior to burning. An ethanol plant in Kansas emits carbon dioxide in the third project, which is headed by the Kansas Geological Survey. This project is sponsored by the U.S. federal government to study the potential of carbon trapping or capture procedures [22].

11.7 CARBON DIOXIDE CAPTURE “TRAPPING” PROCEDURES

This section describes the capture or trapping of the carbon dioxide. As a practical matter, carbon dioxide stores best in its supercritical state. In its supercritical state, carbon dioxide is denser than in its ordinary gaseous state so it occupies a smaller volume for a particular mass. The popular procedures fall under four classes. In no particular order, hydrodynamic trapping is considered first. In this procedure, carbon dioxide is trapped under a rock formation with low absorbance. “Because the carbon dioxide introduced is less dense than the supercritical fluid, it will rise to the cap rock, which has a capillary entry pressure larger than the hydrodynamic or buoyancy force” [23]. The supercritical carbon dioxide and the carbon dioxide will accumulate in a manner that completely secures the reservoir. Such traps can be seen in reservoirs that previously held oil and gas for millennia. Carbon dioxide in these traps is estimated to take over a million years to escape into the environmental air [23]. The second procedure of carbon trapping is residual trapping. In this trapping procedure, carbon dioxide is injected into the reservoir, and it displaces non-freshwater (brine) in the direction of the inward flow. Once the inward flow is halted, the two fluids start to flow in opposing directions, permitting downward flow of the brine and upward flow of carbon dioxide since it is less dense. Consequently, the brine permeates into the pores in the reservoir floor. In this procedure, the brine replaces the carbon dioxide, producing a considerable amount of the gas, which is then trapped in the tiny pores of the reservoir. This trapped gas is in a stable phase. The third procedure is solubility trapping. In this procedure, the infused carbon dioxide drifts upward and flows in conformity with the cap rock. As the carbon dioxide accumulates, there is diffusion into the salt-water present. “The solubility of the gas is a function of the salt content, pressure, and temperature of the water” [23]. Molecular diffusion is the natural physical mechanism in this process. The diffusion process occurs over a long time since the diffusion coefficient is small [23]. The fourth procedure for capture is mineral trapping. In this procedure, carbon dioxide is absorbed by the minerals by reacting with them. In time the infused carbon dioxide interacts with the salt-water causing chain reactions. This method is rather doubtful because some reactions trap the gas, while others permit the free movement of carbon dioxide. “The reaction rate of the minerals with carbon dioxide is a function of the pressure, temperature, pH, and concentration” [23].

11.8 CARBON DIOXIDE SEQUESTRATION PROCEDURES

Carbon dioxide should be fixed for the gas to be really sequestered. The best form will be in a stable solid state because a stable liquid state will still be mobile. The conversion to carbonates is one approach and be utilized as materials for buildings [24]. Direct carbon capture and sequestration is popularly interpreted as the procedure in which carbon dioxide is engineered out of the flue gas and stored in a number of reservoirs. It is essential that the carbon is held for a very long time. Indirect carbon sequestration includes natural processes that remove the carbon dioxide via absorption, like the ocean. "Fifty-five to sixty percent of all anthropogenic carbon dioxide are removed by natural processes. These processes include the ocean, photosynthesis, and weathering" [25]. Carbon dioxide reacts with sea water to form carbonic acid, causing ocean acidification. It has been found that there is a 30 percent increase in ocean acidity [25]. It is a well-known fact that marine life is adversely affected by ocean acidification. In addition, ocean sequestration of carbon is temporary. A calculated 15 to 20 percent of the carbon dioxide will be released back into the air within a few hundred years. In contrast, the injection of carbon dioxide into geological formations below ground is estimated to be good for periods of more than a thousand years.

Pre-combustion carbon dioxide capture is the procedure of converting the carbon in the fuel via gasification before burning occurs. The synthesis gas produced consists principally of carbon monoxide and hydrogen. In the next step, the carbon monoxide is converted to additional carbon dioxide and hydrogen using steam; the carbon dioxide then is captured by a post-combustion method. Hydrogen is a marketable commodity. Carbon dioxide is removed in post-combustion by one of the popular methods. Absorption and desiccant adsorption are two of these methods, while cryogenic separation and membrane separation are the other two. Carbon dioxide emissions are removed chemically via amine solvents in the absorption process. This method is the best in terms of energy and finance. Monoethanolamine (MAE) is the solvent of choice [25].

11.9 MEDIA FOR BIOLOGICAL SYSTEMS

Biological carbon mitigation (BCM) is an engineered procedure in which plant life transforms carbon dioxide into organic carbon. This occurs via natural photosynthesis, and the procedure engineers big quantities of biomass to be produced.

It has been found that microalgae fixed the carbon in fossil fuels. These microalgae grow very quickly during the photosynthesis process, usually doubling in volume daily. Microalgae feed on carbon dioxide, and use the gas for the formation of their basic units. Many studies have been made on these algae. It has been found that the amount of carbon dioxide absorbed is proportional to the cell density as well as the efficiency of light utilization. The growth rate of the microalgae goes up with this efficiency of light usage. Desirable characteristics include good growth rates, easily harvested, and generation of biomass. These microalgae have the potential in the manufacture of energy, chemicals, and food. The algae may be employed for the following: “(1) energy: for burning, hydrogen production, and hydrocarbons for biofuels, (2) chemicals: perfumes, colorants, vitamins, physiologically-active products, (3) foods: proteins, fats, oil, carbohydrates, sugars or alcohols” [25].

11.10 PRODUCTION OF BIOFUEL

Some researchers claimed that it is possible to reach the target set by the Energy Independence and Security Act of 2007 (EISA) and Renewable Fuel Standard (RFS) mandates. These mandates dictate that by 2022, the fuel sold in the United States should consist of at least 36 billion gallons of renewable fuels. The researchers found that the algae are not seasonal like the soybean or corncob. It was calculated that oil from the algae will have “at least 60 times more product and 15 times more than that of jatropha, and 5 times more than oil palm” [26]. There are important forcing functions for this claim.

> These factors include: (1) high productivity of biomass yields per acre of cultivation, (2) use of nonproductive land, (3) non- food based feed, (4) reduced competition for limited freshwater supplies by utilizing waste water, produced water, and salt water, (5) potential recycling of carbon from carbon dioxide emissions [26].

The area of biofuel production is considered to be in the research and developmental stage. The algae can be grown in open ponds (OPs) or with the help of photobioreactors (PBRs). A PBR is a closed system that gives good yields because the environment can be optimized [27]. The initial stage of biofuel production is carbon trapping or capture. The second stage that is critical is that of algae growth. The algae are cultivated in bioreactors. This work will describe the four categories of bioreactors: the OP, tubular photobioreactor (TPBR), bubble column photobioreactor (BPBR), and flat plate photobioreactor (FPBR) [28, 29].

In general, bioreactors are either open or closed systems. The OP is a water pond that is in communication with the external environment [30]. Bioreactors of this kind are used to provide experience with the harvesting of algae. Since it is affected by changes in the environment, optimization for performance is difficult. External uncontrollable conditions are undesirable since viral or bacterial infection can affect the algae [30]. The closed system can be engineered for better efficiency, but comes with a higher start-up and operational costs [31]. A closed PBR system does save space. The BPBR is an example of a simple bioreactor. It has not been tested on a large scale. Its simplicity implies affordability. In this PBR, light passes through the round, transparent tubes of the device and fosters photosynthesis within. Care has to be taken to design the tube to allow the light to reach the center of the tube. Since light is critical in photosynthesis, it is also paramount in the selection of the PBR.

TPBRs use a lot of energy. The FPBR, as its name implies, is similar in shape to a flat plate solar collector. The growing conditions of the microalgae in both these categories of PBRs may be engineered and controlled. Light is critical for photosynthesis. It is advantageous for the algae to also grow during the night hours. A solution for the night is to use artificial lighting like LEDs [26]. Before the algae can be processed, a variety of procedures have been designed to remove excess water. This stage is the dewatering process [31]. The algae concentration has to be increased by three orders of magnitude, and that can be problematic due to the fact that microalgae are really small [26]. There are three dewatering methods used. The first is flotation thickening; this method is not highly priced but needs additional drying time compared to other methods. The second dewatering method is filtration. This method only produces a 40 percent dry, solid product. Centrifugation produces 32 percent algae concentration, but takes up great quantities of energy [26]. After the algae have been dried, the lipids (oil, proteins, and carbohydrates) need to be harvested from the algae. Hexane is the solvent used to pull algal oil from the dry microalgae biomass. After pulling the lipids and algal oil, the biomass is refined to be transformed into hydrocarbon biofuels. The algal oil has to be refined to biodiesel. The procedures employed include "trans esterification, hydroprocessing, supercritical methanol transesterification, sodium methoxide-catalyzed transesterification, and super critical heterogeneneous, and enzyme catalyzed transesterification" [30]. The transesterification technologies result in fatty acid methyl esters, or "biodiesel." Hydroprocessing produces saturated hydrocarbons like renewable diesel that can take the place of fossil fuels. These procedures consume more energy and hydrogen.

In Table 11.1 is shown the various stages of the superstructure for microalgae-based hydrocarbon biorefinery superstructure [30]. It can be seen that multiple options are available for carbon capture and sequestration.

Table 11.1. Options in the five stages of microalgae production and product processing

Stages	Options
First stage: Carbon dioxide capture	Amine absorption; Direct flue gas.
Second stage: Light source	Only sunlight; Plus artificial lighting; Gas storage.
Third stage: Growth methods	OP; BPBR. TPBR; FPBR.
Fourth stage: Dewatering	Flotation; Filtration; Centrifuging.
Fifth stage: Algal oil processing	Hydroprocessing; Supercritical methanol transesterification. Sodium methoxide transesterification; Enzyme catalyzed transesterification; Heterogeneous catalyzed transesterification.

11.11 DISCUSSION AND CONCLUSION

The need for action to mitigate climate change has become more urgent with each new publication of the IPCC annual report. Irreversible climate change is in the offing. However, the general public's understanding of climate change and the part played by carbon dioxide is such that the call for action is not strong enough. While the majority recognizes carbon dioxide emissions and climate change as environmental problems that would be coming, they cannot visualize all that could happen and how their daily activities are continuing to drive climate change. CDR technologies could be used extensively to "buy time." Reduction of carbon dioxide in the atmosphere would slow climate change, but not stop it. Immediate and continuous CDR will provide the world more time as it changes from fossil fuels to renewable and clean energy sources.

Since the start of the industrial revolution, natural methods of carbon removal cannot cope with the great quantities of carbon dioxide produced by the activities of mankind. Biochar is the foremost carbon removal technology described. Biochar and charcoal are produced in a similar fashion. The biochar can store large quantities of carbon dioxide and enrich the soil to allow multiplication of crop yields. Formerly barren land can be made fertile with biochar. Another tool in the arsenal is artificial trees. Enhanced weathering is yet another promising technology. Enhanced weathering uses the natural compound olivine to bind the carbon dioxide. BECCS is then discussed in detail. This technology comprises two technologies. One technology is to utilize biomass to produce electricity and heat and the second is to remove and store carbon dioxide in brine aquifers. Biomass is cleaner than fossil fuels, and helps remove atmospheric carbon dioxide, while the carbon capture portion of the technology offsets current carbon emissions and can compensate for some previous carbon concentrations already in the air.

Combining carbon dioxide capture and storage is a good strategy to cut the cost and stress of achieving atmospheric carbon targets. BECCS could facilitate the achieving of targets in atmospheric concentrations [18]. As the objective ppm decreases, this technology becomes more important since it is capable of negative emissions. BECCS can be used to offset emissions from current and past sources [20].

In spite of the fact that there are advantages to this technology, it is missing the finances required to be a widely acceptable option for mitigating climate change [20]. There also needs to be financial stimulations to make up for price disparities between using bio-energy and fossil fuels for the production of electricity and heat [18]. Note that the biomass utilized may not be grown in an unsustainable way, causing water exhaustion for instance.

While each of these technologies has its own merits, not one technology can mitigate climate change by itself. Many need permanent fixation of the carbon dioxide somewhere, which is in itself a controversial issue. These technologies should be used to start the reduction of carbon dioxide in the atmosphere as science and engineering upgrades from fossil fuels to clean energy sources. To stimulate the research and development of CDR technologies, the Virgin Earth Challenge was instituted. Sir Richard Branson, the man who established the Virgin Group, sponsored this $25 million prize. Although there are exacting standards for the entrants, the prize will be awarded to an entity or group that possesses technology that sustainably and inexpensively reduces greenhouse gases in the air. In 2014, there is as yet no winner, but there are promising finalists. This kind of financial incentive will drive the scientific community to research and develop new, viable technologies for carbon reduction in our atmosphere. It also requires governmental or public subsidies to get the promising technologies off the ground, and for these new technologies to be competitive in the marketplace.

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CHAPTER 12

Use of Satellite Images for Observational and Quantitative Analysis of Urban Heat Islands Around the World

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12.1 INTRODUCTION

Anthropogenic heat generation is a significant by-product of today's society. By virtue of the laws of thermodynamics, all energy consumed by humans inevitably degenerates into this heat [1], where it is dissipated into the surrounding environment. This can have a profound impact on the environment, affecting wildlife populations as well as the very industries that are reliant on a healthy environment. Human beings are placed at risk by this heat stress, while the widespread use of air conditioning only exacerbates the problem outdoors where there is no air conditioning [2].

In large urban areas, the concentration of energy is sufficient to cause a significant rise in temperature. Anthropogenic heat in urban areas can be mitigated most effectively by altering the surface albedo of the city through reflective rooftops and other surfaces, thereby reflecting solar radiation harmlessly into space. Introducing more vegetation, which can serve to absorb more heat and absorb pollutants, is also another effective mitigating strategy. Increase in planetary albedo through reflective surfaces has been found to have the potential to reduce absorbed solar energy.

12.2 URBAN HEAT ISLAND EFFECT

Anthropogenic heat is defined by the American Meteorological Association as "Heat released to the atmosphere as a result of human activities, often involving combustion of fuels. Sources include industrial plants, space heating and cooling, human metabolism, and vehicle exhausts." This heat energy can have significant effects on nearby environments and weather patterns near cities, and can cause health problems in human beings as well [2].

The urban heat island (UHI) effect refers to the increased temperatures of urban areas in comparison with their rural and suburban surroundings [3]. Both the surface and the atmosphere are affected by UHI [4]. While many factors contribute to UHI, there are two main causes. First, because of material properties and color, roads, paved surfaces, and buildings absorb at least 80 percent of incoming sunlight and release this trapped energy throughout the night. Second, the heat produced by humans and their activities, also known as anthropogenic heat, such as the operation of motor vehicles and air conditioning units, is released into the atmosphere [5, 6].

UHI is particularly significant in sprawling cities, where miles of paved roads replace the vegetation that used to be present. Vegetation is closely linked with the cooling of environments. According to climatologist R. Pielke of the Cooperative Institute for Research in Environmental Sciences at the University of Colorado, "if landscape change in a region results in less vegetation, the maximum surface temperatures are expected to be hotter" [7]. In fact, during the hottest times of the year, forested areas are much cooler than cleared land [7]. As a matter of fact, forests and vegetation must be cleared and developed to make way for growing cities, contributing to UHI.

According to the U.S. Environmental Protection Agency (EPA), for an average city with a population of 1 million, the annual mean air temperature in the city can be 1°C to 3°C higher than that of the surrounding areas. At night, this effect can be magnified to as much as 12°C [3]. One dangerous consequence of UHI is the increased energy use. Because temperatures in the city are warmer, there is an increased use of air conditioning systems to cool buildings [2, 6]. Air conditioning units do cool buildings, but they release more heat and emit greenhouse gases into the atmosphere [4]. The heat released by AC units consequently increases the local temperature, and further contributes to the UHI in a cyclic manner.

Heat island is not only dependent on the population of a city. According to biologist and remote sensing specialist at NASA's Goddard

Space Flight Center in Greenbelt, MD, M. Imhoff, a city in a naturally forested area, such as Atlanta and Baltimore, will have greater UHI than a city in a semi-arid area with less vegetation, such as Phoenix or Las Vegas [8]. In fact, in many arid and semi-arid places, the city and suburbs are actually cooler than the surrounding desert landscape. Las Vegas is an example of this effect [8].

Using advanced imaging sensors on satellites, the land skin temperature (LST) can be determined from space. The LST provides a good estimation of the UHI in cities [7]. LST can also be used to monitor land usage over time, as the deforestation, urban sprawl, and agricultural irrigation all influence LST [7].

Weng [9, 10] studied LST data and its relationship with land cover in Guangzhou and in the Zhujiang Delta urban areas in China. Studies using satellite-derived radiant temperature, as is the current study, have been called the surface temperature heat islands [11]. LST is perceived to be related more closely with the UCL (urban canopy layer) heat islands than other recognized forms.

12.3 LANDSAT

To calculate LST, a satellite with advanced optics and high-resolution, multi-spectral imaging sensors must be used. The Landsat program has been fulfilling these needs for 38 years [12]. Operated by NASA, there are currently two satellites in orbit: Landsat 5 and Landsat 7. Landsat 5 was launched in 1984, with a design life of five years. It is still operating today, 28 years later [12]. Landsat 7 was launched in 1999 and is the most advanced of the Landsat series. Landsat 6, an upgrade of Landsat 5, was launched in 1993, but never made it to orbit [12]. The Landsat 5 and 7 satellites are able to image the entire Earth in 16 days [13].

Landsat 5 is equipped with the thematic mapper sensor that is able to image seven different bands of wavelengths of light, both visible and invisible. The Landsat 7 features an upgraded enhanced thematic mapper sensor, capable of imaging eight bands of the electromagnetic spectrum [13].

For both satellites, the sixth band represents the thermal infrared portion of the spectrum [13]. This is the band of interest when the objective is to observe LST. This band is capable of capturing the 10.40 to 12.50 μm wavelength portion of the electromagnetic spectrum, with a center wavelength of 11.435 μm, which resides in the infrared region [14]. Because of this, each pixel in the image formed by the sixth band sensor represents the thermal energy of that location. Because the camera is pointed at the surface of the Earth, each pixel represents the thermal energy at the surface of the Earth.

However, the conversion between pixel values and surface temperatures is not straight forward as many different variables and constants need to be taken account of. These include the sensor gain information, calibrated pixel values and constants, scaled spectral radiance, and rescaled bias. Fortunately, the information for all of these is available through NASA's Landsat Handbook [12], and further through Chandler, Markham, and Helder [14].

The first calculation that needs to be made is of the spectral radiance received by the sensor. This is done by the following equation:

$$L_{\lambda} = \text{Grescale} * \text{QCAL} + \text{Brescale} \tag{12.1}$$

where L_{λ} is the spectral radiance in watts/(meter squared * ster * μm); Grescale is the rescaled gain in watts/(meter squared * ster * μm)/DN; Brescale is the rescaled bias (in watts/(meter squared * ster * μm); and QCAL is the quantized calibrated pixel value in DN. QCAL essentially is the pixel value, from 0 to 255. The Grescale and Brescale can be found as described by Chandler, Markham, and Helder [14].

The spectral radiance at the sensor may not be equivalent to the surface leaving radiance [15]. The radiance leaving the surface is affected by the atmosphere. The atmospheric transmittance and radiance contribute to the spectral radiance that is ultimately received by the sensor. This process is illustrated by the following equation:

$$L_{\lambda} = t_{\lambda} * L_{\lambda 0} + d_{\lambda} \tag{12.2}$$

where t_{λ} is the atmospheric transmittance; $L_{\lambda 0}$ is the surface leaving radiance; and d_{λ} is the atmospheric radiance [15]. In essence, the true objective in finding the radiance is not determining L_{λ} but $L_{\lambda 0}$.

For this study, unfortunately, resources were not available to calculate these added effects. The uncertainty created by the atmospheric transmittance and radiance and continuing the study with $L_{\lambda 0}$ equal to L_{λ} is decreased, however, by the fact that these unknown effects are applied to the whole scene and all radiance values in the scene are affected. Because the objective of this study is to compare urban and rural environments from within the same scene, the impact of these unknowns is slightly diminished.

The spectral radiance, whether or not affected by atmospheric effects, is influenced by surface emissivity [15]. Because all real objects have emissivities less than unity, their radiance is not equal to that which would be radiated from a theoretical blackbody at the same temperature, as illustrated by the following equation:

$$L_{\lambda 0} = L_{\lambda}^{b}\left(T_{b}\right) = \varepsilon_{\lambda} * L_{\lambda}^{b}\left(T_{s}\right) + \left(1 - \varepsilon_{\lambda}\right) * L_{d\lambda} \qquad (12.3)$$

where $L^{b}_{\lambda}(T_{b})$ is the radiance that would be emitted by a blackbody at T_{b}, the brightness temperature seen by the sensor, $L^{b}_{\lambda}(T_{s})$ is the radiance that would be emitted by a blackbody at T_{s}, the true surface temperature, ε_{λ} is the emissivity of the object being observed, and $L_{d\lambda}$ is the down-welling sky radiance from the atmosphere [15]. This equation shows that the radiance seen by the sensor represents a temperature that can only be attributed to a blackbody. If the sensor is observing something that is not a blackbody, then the temperature corresponding to the radiance seen will not be the true temperature of the thing being seen.

Like the other two atmospheric effects, the down-welling sky radiance from the atmosphere was not calculated in this study. However, in the study by Li et al. [15], this variable had a miniscule effect on the data.

Emissivity values were not calculated in this study. Instead, using land cover data from the MODIS program [16], the surrounding land cover classifications for each of the regions observed were obtained. Combining the land cover classification with emissive data from NASA [17], the approximate emissivites of the rural land were determined. These emissivities were used when calculating the true surface radiance of the rural areas surrounding the subject urban regions. For urban areas, the emissivity was assigned the blackbody value of 1 [17], as done in many studies.

Once the surface radiance is calculated, it can be converted into temperature values, using the following equation:

$$T = \frac{K_{2}}{\mathrm{In}\left(\left(\frac{K_{1}}{L_{\lambda 0}}\right) + 1\right)} \qquad (12.4)$$

where T is the temperature in kelvin, K_{1} and K_{2} are constants contained in the image documentation, and $L_{\lambda 0}$ is the calculated and adjusted surface radiance at that point.

Using this equation, the temperature of every pixel in the image can be calculated. This is the LST.

12.4 IMAGE SELECTION

For this study, large urban areas where there was limited or no published research on UHI were selected. For accurate calculations, images from Landsat are needed where the cloud cover is at a minimum. Cloud cover as low as 2 percent can render a scene unsuitable for calculation. Therefore, despite Landsat's two-week orbit, the time between usable scenes may be months, or even years. For example, due to Miami's subtropical or monsoon climate [18], inclement weather and the wet season can disqualify many potential scenes, resulting in less than one usable scene per year, on average.

As illustrated by Imhoff et al. [19], UHI is not homogeneous throughout the year. In fact, there is about a 3°C greater UHI effect during summer time as compared to winter season. However, due to the relatively diminished pool of potential scenes, it is not always possible to choose scenes from a particular part of the year. In fact, for many regions, the selected scene was chosen because it was the only scene usable in recent years.

Oke et al. [20] point out a difference between daytime and nighttime UHI, stating that the UHI of "of the nearsurface air layer reaches its maximum a few hours after sunset on calm, cloudless summer nights." Unfortunately, most Landsat scenes are taken during the daylight hours of the scene locality, and only volcanoes are shot routinely during the nighttime [12].

With these limitations in mind, it is important to note that the data extracted from individual scenes are not meant to be representative average of the cities and regions captured in the image. Rather, all observations from this study should be considered estimates and representative only of the conditions present during the time and date of capture of the images.

In a literature-based study, Stewart [21] provided recommendations to aspiring UHI researchers. One of his recommendations is to disclose all possible limitations of data, and it is our objective in this study to present information transparently and with all necessary qualifications.

12.5 THERMAL IMAGES

Shown in Figure 12.1 is a plot of the temperature image of Seoul, South Korea, along with the respective true color image.

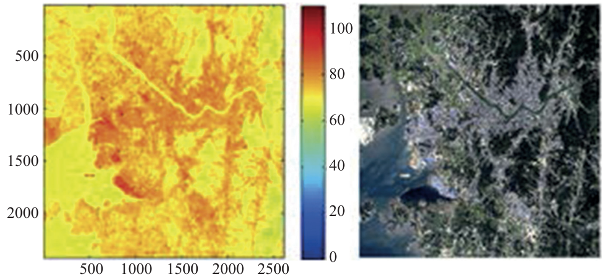

Figure 12.1. The temperature image of Seoul, South Korea, on the left, along with the corresponding true color image, on the right. The units of the temperature scale are in degrees Fahrenheit.

Using the scale bar on the right of the temperature image, one can see the relationship between color and temperature. The units are in degrees Fahrenheit. As shown, most of the image is in the blue-green color, representing a temperature in the upper 60s to lower 70s. The true color image shows the geography of the location. There is a body of water on the lower left side, and large areas of green vegetation along the right side. On the temperature map, these areas are almost unilaterally in yellow color.

Between the water and the vegetation is the urban area. This is where the majority of the population lives and works. From the true color image, it can be seen that the urban and developed area starts near the coast and then sprawls out over the vegetation. The temperature image points out the stark contrast between the urban and nonurban areas. The color in the urban areas ranges from orange to red, representing temperatures from the 80s to the low 100s. In the true color image, it is hard to notice any sort of unusual concentration in the urban areas. But using the temperature image, one can clearly see the increased temperatures near the coast. This may be where the most activity in the city takes place.

The mean temperature of all the pixels in this image was calculated to be 73.02°F (22.79°C). Looking closer, the mean of the maximum temperature for each column of pixels was 89.40°F (31.90°C). While the average temperature for the area may have been in the low 70s, some places consistently experienced temperatures nearing 90°F (32.22°C).

In addition, there is Tokyo, Japan, in Asia. Tokyo is one of the most populated cities on the planet Earth. Shown in Figure 12.2 is its temperature and true color images.

Tokyo is an interesting city because it is located very close to a mountainous region. Therefore, most of the population is concentrated within the urban area. Another interesting effect of the mountains is that

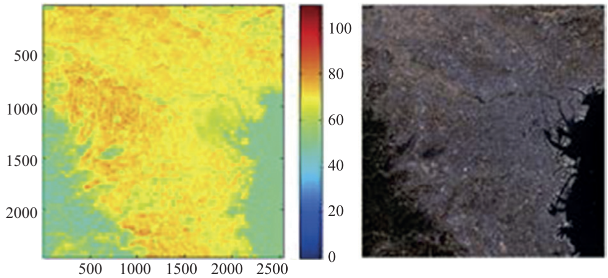

Figure 12.2. The temperature image of Tokyo, Japan, on the left, along with the corresponding true color image, on the right. The units of the temperature scale are in degrees Fahrenheit.

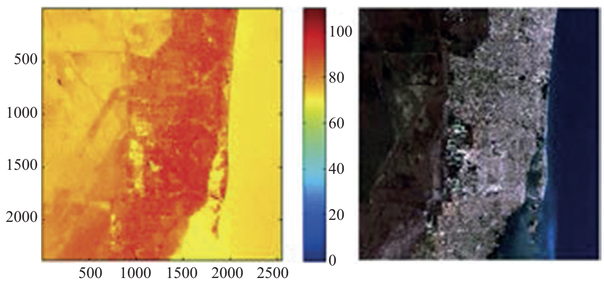

Figure 12.3. The temperature image of South Florida, United States, on the left, along with the corresponding true color image, on the right. The units of the temperature scale are in degrees Fahrenheit.

the temperature in elevated regions is generally much cooler than that of land at sea level. The temperature image confirms both of these effects.

It is shown that the temperature in the mountainous regions is very similar to the temperature of the ocean water, in the 40s to 50s range. The temperature of the land where most of the population lives, however, is almost 20°F higher. It is interesting to note, though, that, unlike Seoul, the hottest area is not on the coast. Instead, it is closer to the urban area near the base of the mountainous region. There could be many reasons for this, two being that the city near the ocean is cooled by the water and ocean breezes, and that the part of the city near the mountain is blocked from large wind patterns and is essentially a stagnant area where energy may be accumulated, resulting in higher temperatures.

The image shown in Figure 12.3 is the Gold Coast of Florida, United States, which includes Miami, Ft. Lauderdale, and West Palm Beach.

In Figure 12.3 is shown the study area of South Florida. This region has an interesting lay, where the urban area is surrounded by water. On the right of the urban area is the Atlantic Ocean. To the left are the Everglades and undeveloped land. The contrast between the urban area and these two borders is visible very clearly in both the true color image and the thermal image.

12.6 QUANTITATIVE DIFFERENTIATION

From a purely visual standpoint, it seems as if the UHI is greater in South Florida than it is in the previous two cities studied. However, the images themselves cannot quantify the actual heat island effect, and only a qualitative estimate can be ascertained by looking at them. In order to quantify the effect, the images must be split into two parts: urban and rural. Then the average temperature calculations can be applied to each part separately, and a difference can be obtained.

There are many ways to separate the rural and urban areas. Some, such as the Normalized Difference Vegetation Index and Impervious Surface Area, utilize the power of remote sensing [22]. The method used in this paper, however, is based on purely visual processes, and is meant to be a simpler alternative to the remote sensing methods.

While the true color image usually shows a discrepancy between urban and rural regions, there is not always a clearly defined border. Therefore, any separation attempts must be considered as estimates, and their corresponding results approximate.

Some cities, like Miami, are easier to differentiate than others. This is because the South Florida urban area is effectively surrounded by two resistive regions: the Everglades and the Atlantic. Obviously, the urban area will not sprawl out into the Atlantic. If the urban area does expand into the Everglades, it does so in contiguous areas first, as the land must first be developed and become suitable for building. Therefore, as shown in Figure 12.4, Miami's urban area is relatively easy to distinguish.

Using the image editing software Photoshop, the urban area of South Florida was selected and shaded in red. The corresponding selection was taken out of the thermal image of the same scene and saved as a separate file. Then, the inverse of the selection was taken, without the Atlantic Ocean, and was shaded in green. This section was also taken out of the thermal image and saved as a separate file.

Using this method, the thermal images of the rural and urban areas were obtained as separate files. Using the same procedure used to analyze

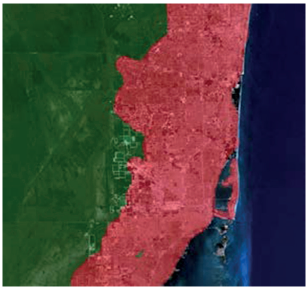

Figure 12.4. The true color image of South Florida, Florida, United States. The urban area is shaded in red, while the surrounding rural area is shaded in green.

the entire scene as prescribed already, the average temperature of the rural and urban areas was obtained. The results for a many selected cities are shown in Table 12.1.

In Table 12.1 is shown the data for temperature differences between urban and rural areas around the cities studied. Of the cities shown, Mexico City had the greatest temperature discrepancy, at over 5°C. A glance at the temperature image of Mexico City in Annex A would confirm the reasonableness of these results.

All of the regions studied showed significant increases in temperature between the urban and rural areas. Chicago only has a temperature difference of 0.44°C. This is less than the other cities, and could be due to various reasons. Shown in Figure 12.5 is the fragmented image of Chicago.

Like Figure 12.4 of Miami, in Figure 12.5 of Chicago is shown the urban area centered on the body of water. Unlike Miami, Chicago is not surrounded by a protected environmental zone like the Everglades. Because of this, the city sprawls out and fragments into localized suburban areas.

To aid with the differentiation, other satellite images were used. Using Google's mapping tools, data from satellites with either enhanced resolution or closer zoom were used. These images were much clearer at closer ranges, and allowed better differentiation between rural and urban land.

There are expensive software to aid in the differentiation between rural and urban environments. In keeping with the objective to aid municipalities without the extra resources to recognize days where precautionary measures need to be taken by their feeble or sick or old, or any combination of the three, because of increased thermal stresses, we have limited our work to using only free software or software commonly used by most

Table 12.1. Temperature differences between the urban and rural areas of cities

City	Average urban temperature (°C)	Average rural temperature (°C)	Temperature difference (urban–rural) (°C)
Miami, FL, U.S. (4/23/08)	30.793	26.279	4.514
Seoul, KR (9/13/06)	25.431	23.387	2.044
Tokyo, JP (4/05/11)	21.835	19.343	2.498
Chicago, IL, U.S. (9/12/10)	25.431	24.986	0.444
Madrid, ES (5/09/11)	27.283	26.933	0.351
Berlin, DE (6/02/11)	25.472	22.412	3.060
Moscow, RU (8/28/11)	23.593	22.276	1.317
Istanbul, TK (9/11/2011)	28.497	25.030	3.467
Mumbai, IN (11/14/11)	30.111	28.893	1.217
Mexico City, MX (9/25/07)	27.595	22.473	5.122
Shenzen, CN (11/02/09)	27.303	24.965	2.338

Figure 12.5. The true color image of Chicago, Illinois, United States. The urban area is shaded in red, while the surrounding rural area is shaded in green.

governmental offices (not specialized). Additionally, the municipal workers who might employ the method demonstrated here will likely know their built-up areas well and should not have a problem distinguishing them from the surrounding countryside.

12.7 DISCUSSION AND CONCLUSION

Urban Heat Island Intensity (UHII) is calculated as the spatially averaged temperature difference between an urban and its surrounding rural area (Magee, Curtis, and Wendler [23], Kim and Baik [24]). This concept, however, covers a range of diversified ideas that include the temperature difference between the densely developed urban area and least developed area or between two different built-up areas [25]. For instance, Wong and Yu [26] reported a maximum UHII of 4°C in between the well-planted and the most built-up region of central business district in Singapore. Giridharan, Ganesan, and Lau [27, 28] reported UHII as low as 0.4°C and as high as 1.5°C within and in between three housing estates in Hong Kong.

The aim of this work was to quantitatively analyze UHIs using satellite images, observationally and numerically, for cities around the world, several of which do not seem to have published data regarding this topic. The data collected and calculated showed the increased temperatures of urban environments with respect to their rural surroundings. This may be viewed as a relatively straightforward way of calculating the UHII.

For comparison purposes, Kim and Baik [24], using weather station data, reported maximum air temperature-based UHII of 3.4°C in Seoul, while Hung et al. [29] reported the surface-temperature-based UHII of 8°C in Seoul using satellite data. This is compared to the surface-temperature UHII of the current work calculated as 2°C. This variable is a very strong function of the exact date and time, as well as the definition of the UHII employed.

In [30], again for comparative purposes, the afternoon or evening heat islands around Mexico City were found to have an intensity of 4°C to 5°C. The straightforward method in the current work showed a single day UHII of about 5.1°C. The funding for [30] is considerable compared to that for the current method, which is basically data-mining of available satellite data. Hence, a rather straightforward response method has been demonstrated for calculating UHII in the current work, which is useful if necessary actions are required to prevent human health problems or mortality in the event of an unexpected heat island occurrence that lasts longer than two weeks, for instance. Even when UHII is significant but not unusually large because it is an average, the probability of pockets of very large heat stress increases with any event of a UHI. It is these pockets of extreme large heat stress (broken air conditioner, or power bill not paid) where human mortality occurs or increases. The delay of two weeks or so for the availability of Landsat data is small compared to the usual duration of typical UHI studies. The present work demonstrates the viability of a response method about which unprepared cities are not aware, so that these municipalities may be better able to help the disadvantaged segment of their communities. The method does not require much pre-budgeted resources, which typically take considerable time and effort to obtain.

Rizwan, Leung, and Liu [25, 31] essentially provided reviews about UHI and UHII. There is a table in [31] that provides the maximum UHIIs in different areas of the world. There was none reported for the major metropolitan areas of Chicago, Madrid, Berlin, Moscow, Istanbul, Mumbai, Miami, and Shenzen. A UHII of about 3°C in Madrid has been reported by [32], as compared to about 0.35°C seen on the image date in this work. Regions around Miami in South Florida and Shenzen, China, have very limited literature about them in the specialized topic of heat island effect, so the current work has filled this vacuum.

Using the method demonstrated in the current work, the differences in temperature between the urban and rural regions were obtained for 11 cities around the world. For these cities studied, the urban area was from 0.3°C to 5.1°C warmer than the surrounding rural area.

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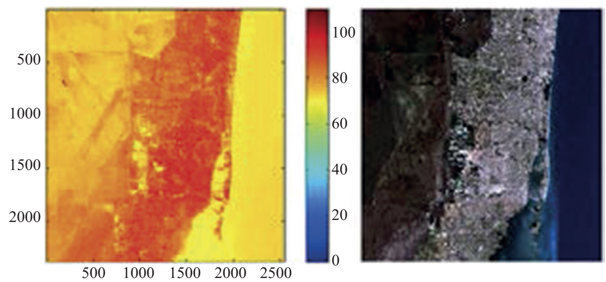
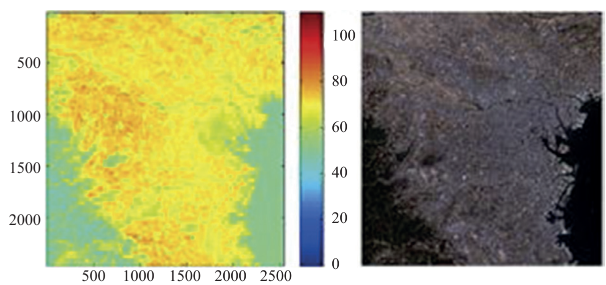
Annex A

THERMAL IMAGES OF CITIES ANALYZED

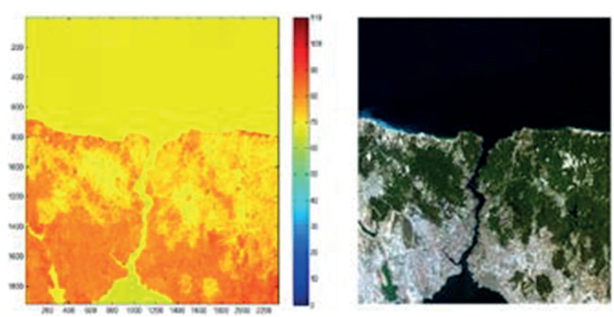
Miami, FL, U.S.



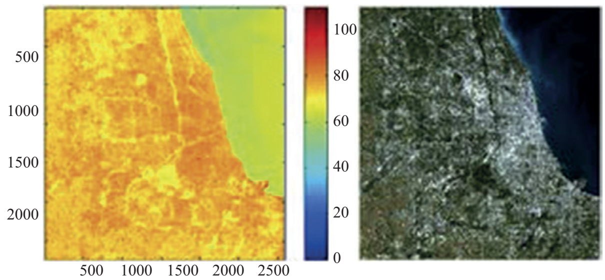
Tokyo, JP



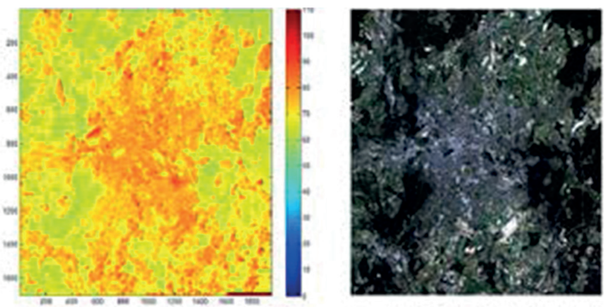
Istanbul, TK



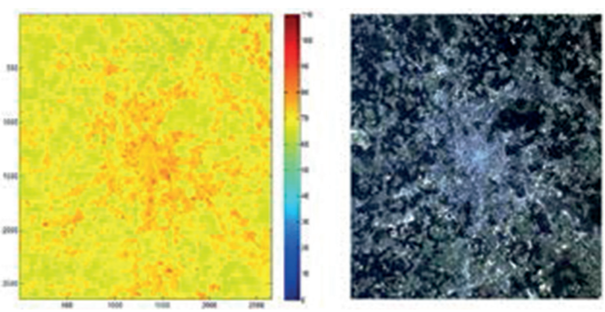
Chicago, IL, US



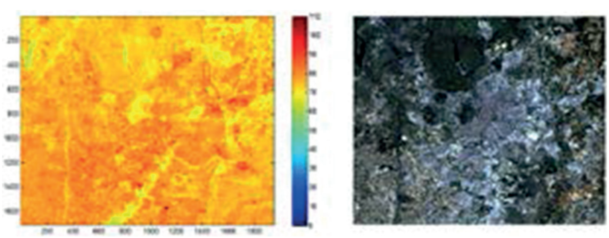
Berlin, DE



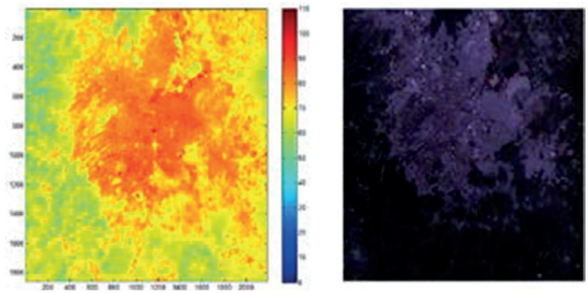
Moscow, RU



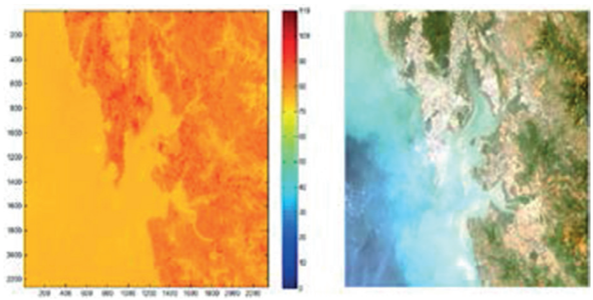
Madrid, ES



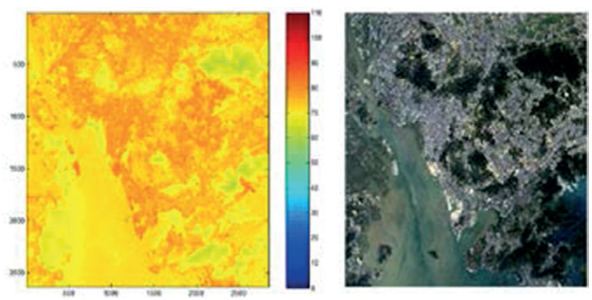
Mexico City, MX



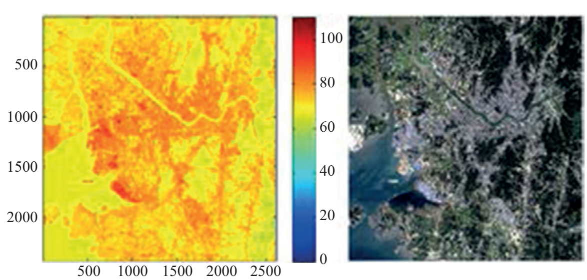
Mumbai, IN



Shenzen, CN



Seoul, KR

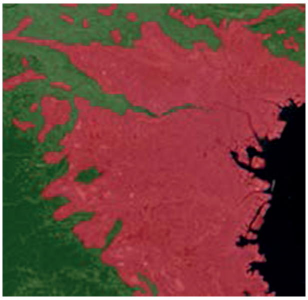


Annex B

URBAN-RURAL DIFFERENTIAL IMAGES OF CITIES ANALYZED

Miami, FL, U.S.

Tokyo, JP

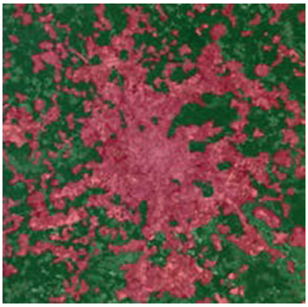


Istanbul, TK

Chicago, IL, U.S.

Berlin, DE

Moscow, RU

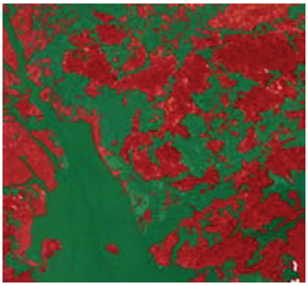


Madrid, ES

Mexico City, MX

Mumbai, IN

Shenzen, CN



Seoul, KR

CHAPTER 13

Climate Change Aggravates the Energy–Water–Food Nexus

Kaufui V. Wong and Sarmad Chaudhry

13.1 INTRODUCTION

The Indus River is a river running through four countries in East Asia and South Asia: China, India, Afghanistan, and Pakistan. It spans 3,000 km, with a basin that covers over 1 million km^2 [1]. The river forms the backbone of the Indus River Valley, which has for millennia been home for countless civilizations. The river serves as the source of water for the life that blossomed and continues to thrive in the valley [2]. The Indus River basin is critical to the continued survival of nearly 180 million people living in its vicinity, and about 80 percent of Pakistan's agricultural land is irrigated by the river.

The largest premodern civilization to flourish in this region was the Indus Valley Civilization. They are commonly referred to as the Harappan Civilization, after their largest city. The Harappan Civilization extended over a million square kilometers at its peak, from modern-day Pakistan to Afghanistan and India [3].

The Harappan civilization developed over 5,200 years ago, but peaked around 4,000 years ago, before slowly diminishing and disintegrating around 3,900 years ago. Because of their technical and social prowess, the demise of the Harappans was originally considered a mystery. New studies have shed some light on their unexpected disappearance, suggesting that climate change was a key component in their collapse [3, 4].

Like most civilizations of that time, the Harappans heavily depended on their river, the Indus, for continued existence. Prone to frequent flooding due to heavy rains during the monsoon seasons, the Indus River and Valley was not always the most suitable location for the development of agriculture. Therefore, sustained civilization did not blossom until around 4,200 years ago, when the dry seasons became dryer and the floods became less dramatic [4].

However, the dryness continued, and soon the aridity of the landscape was no longer suitable for agriculture. The river became dryer and less fruitful, many were forced to migrate, and the collapse of the civilization began [5].

13.2 ENERGY–WATER–FOOD NEXUS

Today, the energy–food–water nexus in the region is highly dependent on the flow of the Indus River. Water, of course, is needed for agriculture to produce food. Energy is required to obtain, treat, and transport the water to the point of use. Further, energy is needed directly in the agricultural process. More water is then used to generate more energy. The food that is produced during the agricultural process is consumed by the workers who create and maintain the processes for generating energy for the whole system [6].

In Figure 13.1 is depicted the relationships in the energy–water–food nexus. As water is one of the key resources in the energy–water–food nexus, it should be noted the reliance of the region on the water of the Indus River. Nearly 180 million people live in its vicinity, and about 80 percent of Pakistan's agricultural land is irrigated by it [1]. Pakistan's Aquastat Profile from the United Nations noted that water is a "critical and limiting resource" for its sustained economic development [7]. As food production falls short of population growth, water use is predicted to increase by 55 percent by 2030 [6]. The complex interactions between the three resources may be represented by springs between the three items, if the three items are modeled by thin slabs that can slide up and down on three vertical shafts, and where the relative heights represent the relative availabilities of the resources. It is assumed that at some time in the recent past, the three slabs representing water, energy, and food were all even and at an acceptable level of availability. Because of recent problems with the climate, the availability of food has caused this slab to reside at a lower level. This causes tension in the interconnections with water and energy, with pressure for both to drop below its acceptable level of availability. In

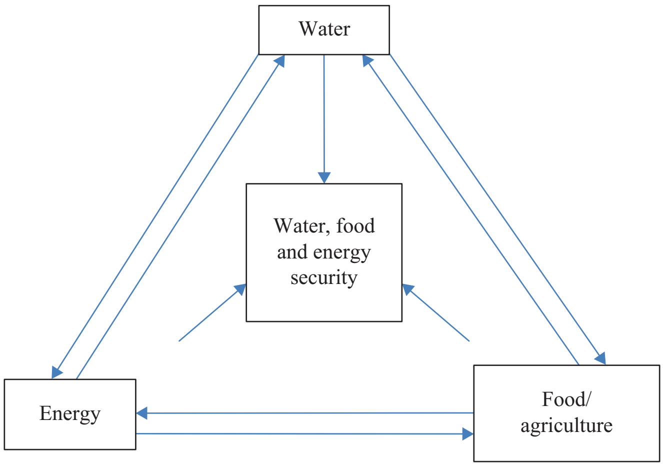


Figure 13.1. A diagram depicting the energy–water–food nexus [6].

other words, using Figure 13.1, when water falls short owing to drought or decrease in glacier melt, the other two, "Energy" and "Food," will fall short. If food falls short further owing to increased population, the other two, "Water" and "Energy," will follow suit.

Notwithstanding normal food stress due to population growth, agriculture is particularly vulnerable to global climate change, and developing countries such as Pakistan will bear the brunt of the adverse consequences due to these changes [8]. About 51 percent of the region is already food–energy deficient, a rate almost as high as that of sub-Saharan Africa [6].

To understand the role of climate change in the demise of the Indus Valley Civilization, and the potential effect of climate change on current civilization in the Indus River Valley, the Indus River's source high in the Himalayan Mountain Range must be examined.

13.3 THE HIMALAYAS

The Himalayas are home to the tallest mountain peaks on Earth, including the famous Mt. Everest and K2. Spanning over 1,500 miles, the Himalayas contain over 110 mountain peaks exceeding 24,000 ft. In total, the Himalayas cover 3 percent of the Earth's land area [9].

Most of the world's major rivers have headwaters, or sources, in mountains [10]. This is natural, as the potential energy due to gravity allows the water to flow from the upstream reservoir downstream and throughout the course of the river, where it exits at the mouth, typically at sea level [11–13]. Nineteen major rivers originate from the Himalayas [9]. The Indus River rises from the Himalayas, specifically from the Tibetan Plateau, at an altitude of 18,000 ft. [14].

Over half of the human population relies on the freshwaters that flow downstream from mountains, using it for drinking, cooking, and other industrial needs [10]. The Himalayas provide fresh water for the 210 million people living within them, and close to 1.3 billion people living downstream of its rivers [15].

This supply of fresh water is stored in a combination of snow, glaciers, and permafrost [15]. Some of these are seasonal, while others are perennial. For instance, much but not all, of the snow cover melts during the warmer summer months [16]. On the other hand, without taking into account global warming, only some of the glacier area melts during the summer months.

The Himalayas are rich in glacier ice. In fact, there is so much ice in the mountain range that it is often referred to as the "Third Pole," because the only two places on Earth containing more ice are the two actual poles, North and South [1, 6]. In total, about 17 percent of the Himalayas are covered in glaciers or ice, an area of nearly 44,000 square miles [17].

Illustrating the longevity of glacial ice in the Himalayas is difficult owing to a lack of reliable data, and gaps in the data that are available [15]. However, because of the similarities between the Himalayas and the Polar Regions, information regarding the Polar Regions can be useful to describe a phenomenon. In this case, it is useful to understand that in 1980, 62 percent of the glacial ice in the Arctic was older than one year [16]. This means that only 38 percent of the ice in that region had melted and refrozen during the summer months.

These numbers can show how glacial ice provides fresh water for those living downstream during dry seasons. While the rivers in South Asia are replenished by monsoons during the rainy seasons (and snow in the upstream regions), melt waters from glacial stores during the dry season are essential to the lives of millions of people in the region [15].

Due to geography, though, the Indus Valley experiences much weaker monsoon storms during the rainy season. Further, the dry season in the region is more arid than that of the neighboring regions to the east [15].

Because of the decreased water supply through precipitation, the Indus River is much more reliant on melt waters from the Himalayan glaciers. The percentage of river flow that is attributed to glacial melt is put at 70 to 80 percent [1].

This fact underscores the absolute importance of the Himalayan glaciers to the continued survival of the people who live in the Indus Valley. As shown by the historical example of the ancient Harappans, a change in the discharge and flow of the Indus River can signal the end of a civilization. The preservation of glacial ice stores is crucial to the 1.3 billion people who depend on the stores for water.

13.4 THE EFFECT OF CLIMATE CHANGE ON GLACIERS

The concentrations of carbon dioxide, methane, and nitrous oxide in the atmosphere are higher than they have ever been in at least 800,000 years. These are all primary greenhouse gases, which contribute greatly to the global warming effect [18].

The results of this effect are already visible. Some studies show that the average surface temperature of the Earth has risen between 0.3°C and 0.6°C in the last 100 years [19]. While the exact value of the temperature increase is widely contested, and widely varied depending on region, the consensus is that there is a distinct change in surface temperatures, in the plus direction.

Mountainous regions are more prone to the effects of global warming. Ice- and snow-covered areas are particularly sensitive [17]. The Himalayan Mountain Range is believed to be one of the climate change hotspots. In the past 30 years, the average temperature in the Western Himalayas, where the Indus River is sourced, increased between 0.6°C and 1.3°C [15].

This increase in temperature in the past 30 years is more than double the average temperature increase throughout the Earth over the past 100 years. The effects of global warming are much more severe in the Himalayas than they are elsewhere, which is alarming because of the number of people and livelihoods that depend on the mountain range as a source of fresh water.

To understand the effect of global warming on glaciers, predict future effects on glaciers, and, ultimately, take proactive measures, one must understand the glacial mechanics. Glaciers are a body of ice and snow. Their composition is a delicate balance of snowfall and snowmelt. The snowfall accumulates in the accumulation zone of the glacier. Likewise, the snowmelt melts from the ablation zone of the glacier. The simple mass balance of a glacier is the difference between the snowfall in the accumulation zone and the snowmelt in the ablation zone [15].

The terminus of a glacier is, quite simply, the spatial end of the glacier. While a glacier may appear motionless for small enough time steps, it is in fact either advancing or retreating. The measurement of the terminus after substantial time steps shows the advancement or retreat of a glacier [15].

It is relatively simple to calculate the change in terminus of a glacier, as it is just the difference between two successive spatial measurements. With the advent of satellite imagery, this process was made even easier. By measuring the position of the terminus in one image and then comparing the position in a later image, the advance or retreat of a glacier can be determined.

On the other hand, it is much more difficult to measure the mass balance of a glacier. Many times, it is not possible to make any measurement at all, and, if a measurement is made, it is usually an estimate. The mass balance is dependent on many more factors than are currently documented for most glaciers. In fact, of more than 50,000 glaciers in the Himalayas, less than 20 have had measurements taken of mass balance [15].

For glaciers that have had measurements made on the change in terminus, the average values are between 10 and 30 m per year of retreat. Some glaciers had retreat rates of upward of 60 m per year [19]. Of the limited number of glaciers studied for mass balance, the general trend showed a negative mass balance. This indicates that more ice is melting from the glaciers than is accumulating in the accumulation zone. After a long enough time, a negative mass balance will result in the disappearance of a glacier [15].

These results follow logically as effects of global warming. As temperatures rise, glaciers will melt at a faster rate. Then, when the winter is warmer than previous winters, the snowfall that re-accumulates is not as much as previous years. Both of these effects compound, so an overall negative mass balance is achieved, and the glacier is expected to retreat.

There is another compounding factor at play, called the “ice-albedo feedback” effect. Essentially, snow, particularly fresh snow, has a high albedo. This means that much of the sun’s incident radiation will reflect back off of the surface, as opposed to surfaces with low albedos (the lowest albedo, 0, represents a blackbody. A blackbody will absorb all incident radiation).

When the weather is relatively cool, the snow fall helps keep it that way, reflecting solar radiation and keeping the surface and local air temperature from rising. This is an unstable system, and can be illustrated in the example described in the following text. Imagine a snow-covered surface at some ambient, cool temperature. Now, if the temperature is increased, some of the snow covering on the surface will melt. This will reduce the albedo of the surface. Further radiation from the sun (which is assumed to be constant in this example) will now have a greater heating effect on the surface, which will in turn melt more snow and raise the local air temperature. This is a negative feedback loop that can dramatically increase local surface temperatures and covering conditions [20].

In order to disrupt the equilibrium of this unstable system, an initial increase of temperature is required. As has been shown, this temperature increase has been caused by global warming. The result of the ice-albedo feedback has been an accelerating rate of glacier decay.

Of the glaciers that have had mass balance measurements done, many showed signs of the accelerating rate of decay. For a particular set of glaciers, the initial measurement of the mass balance was −250 kg/m^2/year from 1980 to 2000. From 1996 to 2005, that same set of glaciers shows a decay of −596 kg/m^2/year [15]. The accelerating rate of decay is not insignificant for these glaciers.

To add some substance to this incidence of accelerated decay, the Arctic ice region will once again be visited. The observed rate of sea-ice retreat in the Arctic is greater than those predicted by current climate models [21]. In addition, measured at the Arctic was the amount of ice that was reformed within the past year compared to the amount of ice that has survived multiple seasons of warming/melting and cooling/freezing. In 1980, only 62 percent of the ice in the sea-ice had persisted through multiple cycles of warming/cooling.

In addition, data from 2012 show the amount of the ice that is first year or younger has increased to 55 percent. Now only 45 percent of the ice has persisted through cycles [21]. While this does lend weight to the data obtained for accelerating glacier decay in the Himalayas, it also sheds more light on another issue.

A commonly cited explanation of the current climate models' inability to predict retreat of sea-ice in the Arctic is lack of information. The Arctic, although popularized in media and entertainment as a highly studied region, is still relatively data-sparse, and significant data gaps are present. Further, the data available are constantly changing. Owing to the remoteness of the location and environmental challenges, not all information is fully reliable [21].

This causes the models that are built on the available data to be inaccurate and often made obsolete by newer models. For the Himalayas, this effect is even more pronounced [15]. Like the Arctic, the Himalayas are sparsely represented with data sources. Unlike the Arctic, however, the Himalayas are more remote and difficult to access. The high mountains make the building of observatory and meteorological stations difficult [15].

Projections of global temperature increases range anywhere from 1.4°C to over 6°C the next 100 years. These projections are based on various factors, including different climate models and greenhouse gases emission scenarios [19].

Currently, the concentration of carbon dioxide is about 400 parts per million. Of the aforementioned projections, the most conservative ones predict a concentration of carbon dioxide closer to 500 ppm in 100 years. This would represent a huge improvement in current greenhouse emissions, and a rate of concentration increase that is much lower than current rates [18].

While this decreased rate of concentration increase may be unlikely, more experts would agree that the most aggressive of the models, assuming a concentration of close to a 1,000 parts per million of carbon dioxide in 100 years are even more unlikely [18].

Instead, it would seem that the most likely model and projection of greenhouse gas emission and global temperature increase would lie somewhere in between the current most conservative and most aggressive models. Furthermore, as time passes, the collective knowledge of the complex physical processes that affect future conditions will increase, refining models and increasing their reliability and accuracy.

As for glaciers themselves, the projections are even more difficult to make. The complete science behind glacier formation and decay is not known, and this, coupled with the previously mentioned uncertainty with future climatic conditions, leads to an uncertain future, at least quantitatively. However, some predictive models have been made, and one estimates that a global increase in temperature of just 1°C can cause as much as 40 percent decrease in glacial area, and up to a 50 percent decrease in glacial volume [19].

13.5 THE EFFECT OF CLIMATE CHANGE ON THE INDUS RIVER

The fact that 151 percent more of the water inflow into the Indus River is due to glacial and snowfall melting upstream than downstream precipitation [15] necessitated the previous part of the current work. This echoes the previously discussed fact that 70 percent to 80 percent of the Indus's water is from the Himalayan glaciers [1].

As previously found, the effect of global warming is to decrease the area and volume of Himalayan glaciers. What remains now is to determine an accurate estimate of the melting of glaciers on the Indus River.

While it may appear initially that loss of the glaciers will immediately spell doom for the Indus River, this is not entirely the case. In fact, a decrease in the volume of glaciers in the Himalayas would result in a larger discharge of water downstream, at least temporarily.

Glaciers act as water storage devices that can retain water through seasons and even yearly cycles [19]. Under "normal" conditions, when the seasons become dryer, and the effect of monsoon precipitation on river discharge is diminished, the melt waters from the glaciers sustain the river and agriculture.

When the glacier melts, it not only discharges its water supply, but it also loses the ability to store water through seasons. The melt waters, which are increased in quantity due to increased temperatures and therefore increased melt rates, flow into the river downstream and increase discharge [15].

The Indus Valley region features the largest irrigation system in the world, which takes advantage of the nearly constant discharge of the Indus River [3, 4]. Because the river is so heavily dependent on the glaciers, which previously provided consistent melt waters, the river did not have as much variation in discharge as other nearby rivers, which had higher tendencies to flood dramatically during their heavier monsoon season.

The current irrigation system operates by "immobilizing the river" behind dams and channels. This is only possible because of the "tamed" state of the Indus River [3, 4], which is now at risk.

Another aspect of the climate model that needs to be considered is the change in precipitation due to global warming. Currently, precipitation is unevenly distributed, from 100 mm/year in some of the more arid regions, to over 1,500 mm/year in the northern regions. About 60 percent of the rainfall occurs during the three-month period between July and September [7]. The Indus Valley region is normally prone to relatively weak summer monsoon storms [15]. Research that considers climate change and precipitation includes reference [22].

The large irrigation system based on a "tamed" river, temporarily increased glacial melt waters due to higher glacial melt rates, and increased monsoon rains due to elevated temperatures could signal disaster for the region. In fact, this is what happened during the devastating floods of 2010 in Pakistan [3, 4].

If current conditions continue, more dramatic flooding is possible. In fact, widespread flooding could prove catastrophic for the Pakistan's massive irrigation system. It is possible that another heavy monsoon season due to elevated temperatures could render the irrigation system greatly "obsolete" [3, 4].

Another potential danger is the loss of riparian forest along the river. Riparian forest buffers, as they are known, are natural groups of woodlands that grow adjacent and along a river. While they serve a multifaceted role, their most important attribute in the case of the Indus would be their flood damping effect [23].

The buffer serves as a natural dam running parallel to the river. Fast-moving floodwater is slowed down by the root system, keeping the erosive powers of the flood at a minimum [23]. Unfortunately, in the Indus River Valley, due to deforestation, 90 percent of the original riparian buffer has been removed [1].

Without the natural buffer zone, the Indus and the surrounding land are more susceptible to catastrophic damage from flooding. Not only will flooding be more pervasive, but it also will be more ferocious, spreading at a higher speed.

The destruction of the Indus River-based irrigation system would be a critical failure for Pakistan's current infrastructure. Currently, 80 percent of Pakistan's agricultural land is irrigated by the system [1]. Further, 21.4 percent of the country's gross domestic product is produced through the agriculture industry, which also employs between 40 and 45 percent of the country's workforce [7, 24].

In projections where total glacial loss is not predicted, it is not expected that rainfall makes up for the missing melt waters runoff. In the Indus catchment, the mean annual rainfall is only 0.3 m/year. This is less than a fifth of the mean rainfall at the other 26 Southern Himalayan catchments [25].

Therefore, it is expected that the flow and discharge of the Indus River to be dramatically reduced in the case of partial glacial loss. If there is total glacial loss, which is not impossible [15], the River will be crippled and will be unable to provide for the 180 million people who depend on it for all of their needs [1].

Even without the continued effects of global warming, the people who live in the region are in danger. The water from the Indus has been over extracted for agriculture and industry, and this has caused salt water intrusion, reducing the usefulness of the water [1].

The United Nations Water program defines a scarcity of freshwater supply to exist when there is less than 1,000 m^3/person/year of freshwater [26]. Because the Indus is the only source of water for many of the people in the region, its water supply greatly affects the scarcity of freshwater for the people living there.

The World Resources Institute found that in 1995 the water supply per person in the region was only 830 m^3/person/year [26]. This would be classified as a freshwater scarcity [26].

The data for scarcity are from 1995, when the population of Pakistan was 127 million. Today, the population is closer to 180 million, which is almost a 50 percent increase in about 20 years [27]. It can therefore be assumed that the scarcity of water has actually increased in recent years. Currently, about 20 percent of the population lacks access to safe drinking water [6]. There are in existence models that predict the future scarcity of water in the region. In 2025, the situation is bleaker, and there is a projected supply of less than 500 m^3/person/year [1]. This is classified as absolute scarcity [26].

Currently, the irrigation system, which is the largest in the world [3, 4], is complex enough to handle a 10 to 13 percent decrease in river flow. However, if the scarcity continues, and the river discharge is decreased by approximately 15 to 20 percent of normal flow, there will be widespread shortages in the irrigation system [1].

A loss of the irrigation system would be catastrophic for Pakistan's economy and its people's well-being, as 92.76 percent of the nearly 20 million hectares of cultivated land is irrigated [28]. Irrigation is especially significant because most of the arable land is cultivated, so increased production is required from the already cultivated land [6].

In Figure 13.2 is shown the Indus River basin [29]. Its obvious importance to Pakistan cannot be denied. Surrounding countries in the basin include China, India, and Afghanistan.

A detailed study of how the river Indus is recharged by surface water and other water delivery systems has been done in [30]. Work on food, water, and energy security in South Asia include reference [31].

The water dependency is further stressed by the types of crops that are grown. The five most popular crops—wheat, rice, sugarcane, cotton,

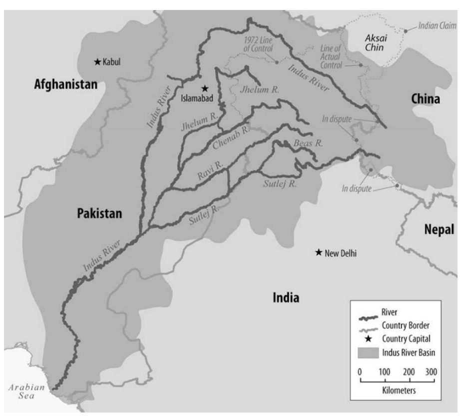


Figure 13.2. Depiction of the Indus River (dark line) and the basin area (dark area), with respect to the countries in South Asia [29].

and fodder—account for 82 percent of total available water resources [7]. Of these, wheat is the most cultivated crop, and it is considered a heavy water usage crop. Another crop, rice, is also a heavy water usage crop [6]. The rice industry has experienced a remarkable growth recently, accounting for 60 percent of total food export, a growth of 28.5 percent [7]. Rice needs more water than wheat, for instance, and its production has to be adjusted accordingly when the excess glacial melt (owing to global warming) ceases.

Currently, food production is falling short of population growth. The percentage of the population that is undernourished in Pakistan grew from 20.04 percent in 1996 to 26.39 percent in 2006 [7]. The percentage of the population considered severely food-insecure also grew from 23 percent in 2005 to 28 percent in 2008 [7]. To meet the nutritional needs of the people living in the Indus Valley region, food production will need to double in the next 25 years [6].

13.6 THE EFFECT OF CLIMATE CHANGE ON THE SOUTH ASIAN MONSOONS

The effect of climate change on the South Asian monsoons in Sri Lanka, India, Pakistan, and Bangladesh is decreased rainfall [32]. This prediction of the decrease in summer rainfall is supported by the work in references [33–35].

There may be some increases in some irrigated agricultural crops [36] because of increased carbon dioxide and higher average temperatures of the air owing to anthropogenic activities. However, there seems to be an agreement that there will be a drop in agricultural crop production generally, especially in areas that are already water deficient [37–39]. Since the Pakistani provinces in the Indus River valley fall into these water-stressed areas, it is expected that the overall agricultural crop production will fall owing to the effects of climate change. The Indian provinces in the Indus River valley to the east will not fare as badly, as has been stated previously in the present article.

As discussed in the section on the energy–water–food nexus, the drop of food production is modeled by a drop in level of the thin slab representing "Food" along the vertical shaft. This causes immediate additional stress in the springs connecting it to the other slabs representing "Water" and "Energy." The beauty of these nexus problems is that providing solutions to mitigate the shortage in one will also raise the level of availability of this resource, which then lessens the stress in the springs, and hence the stresses on the other two resources.

13.7 RECOMMENDATIONS TO ENHANCE ENERGY, WATER, FOOD SECURITY

Energy, water, and food security should be the objective when faced with problems associated with the energy–water–food nexus. The recommendations in this section strive to provide suggestions for developmental actions to be undertaken to help mitigate the problems.

The accelerated glacier melt from the Himalayas should be saved for current and future use of the people of the Indus River basin. Dams and lakes are essential for the proper management of floods, like the big one in 2010. The building of hydroelectric dams, which are carefully planned [40], would provide the much needed electricity and water for living and agricultural purposes.

Outdated electric power plants should be replaced with modern, more efficient power plants. These would include the supercritical coal-fired power plants with proper carbon-capture pollution prevention equipment, and combined cycle natural gas power plants that can reach 60 percent thermal efficiency. Seawater for condenser cooling in the Rankine cycle should also be considered, even for inland plants wherever nonarable land is available. Such seawater cooling canals would exchange enough heat with the surrounding earth and air to be closed systems, so that they may operate well inland from the distant coast. The use of seawater for cooling purposes only will alleviate further pressure on the freshwater supply.

The clean, renewable energy sources of wind, water, and solar energy should be developed in a systematic and well-planned manner. There are mountain passes in the foothills region, which are preferred pathways of the channeled wind. These are good places to locate windmill farms to generate electricity, and perhaps for irrigation purposes.

Inexpensive solar panels could be used to capture solar radiation to generate electricity for individual farms and provide hot water. As the sun shines equally on all living things in a given area, it is best to use its thermal and visual energy in a distributed manner. Research and development of concentrated solar energy should be left to richer nations with far more ambitious plans. Organic solar panels have been commercialized that are much less expensive than the silicon crystal variety, though with a shorter life. Much of the costs involved in installation and re-installation of organic solar panels in urban areas of Western nations may not be as prohibitive when translated to local conditions in the Indus River basin. The farmers there could be trained in the installation of these lower-cost solar panels, and adequate area for sun exposure should not be a problem.

Widespread use of solar energy, including solar cookers, would help decouple the energy–water linkage. This linkage would then weaken the energy–water–food nexus, and hopefully minimize rising problems. For a place full of sunshine, this bright source should be used widely to help ensure energy security.

The drinking water supply can be increased with increase in desalination of seawater. Since desalination is an energy-intensive process, technology that uses more renewable sources should be favored over others.

A low-profile irrigation method could be adopted in suburban lawns, rather than the overhead sprinkler method. Studies in California have shown a vast improvement in recharging underground aquifers using this method and best management practices [41].

In agriculture, appropriate food crops should be used in the transition from adequate water to much more stressed water resources. The crops have also to be picked and planted so that the changing months for peak water supply and minimal water supply are taken into consideration.

Any practices that are wasteful in terms of energy, be it in the urban areas or in the countryside, should be changed. Good energy conservation practices should be propagated throughout the land. Recycling should be carried out, and composting of organic waste materials in the agricultural lands should be universal.

13.8 DISCUSSION AND CONCLUSION

The future of the Indus River and the people who live in the surrounding is at risk. Although local leaders, mainly from the Pakistani provinces that are in the Indus Valley, have signed a water accord to better manage their natural resources, the accord has not been enforced, and many of the same problems that existed at the time of the signing persist today [1].

In the global economy, it is imperative that all countries and world leaders come together to provide solutions to the today's challenges. In particular, India and Pakistan need to cooperate over the fair and practical usage of the Indus River.

Anymore power plants to generate electricity for the increased demand by the growing population need to not use freshwater for cooling purposes. If they do, there will be an immediate conflict with agriculture, and hence food production will be impacted. Drinking water for the people will also be adversely impacted. This conflict will set off a chain of events like a downward spiral, degrading the livelihood and conditions of living of the people.

There is overwhelming evidence in the literature that the global climate change is decreasing the glacial ice coverage in the Himalayas. With these freshwater stores continuing to be diminished, there is real short-term and long-term threat to the region. In the short term, increased water discharge is dangerous to the fragile irrigation system supplying much of Pakistan's agricultural industry. In the long term, the loss of fresh water stores will dry out the river and increase water scarcity to abysmal levels.

In addition, the summer rainfall totals are decreasing owing to climate change.

These threats are real, and their effects are already being seen. The Intergovernmental Panel on Climate Change (IPCC) has essentially issued a warning about the effects of climate change to the governmental leaders of the world [42]. Unless appropriate action is taken, it is possible that the projected collapse of the Indus River system is inevitable. History will then have been allowed to repeat itself.

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CHAPTER 14

Innovations Related to Hydrology in Response to Climate Change—A Review

Kaufui V. Wong and Craig Lennon

14.1 INTRODUCTION

Water is becoming an ever more precious resource. Climate change only exacerbates what is already becoming an ever more pressing issue. Dry climates are faced with even more uncertainty and dwindling water supplies. In response to this rapidly increasing demand, careful water management is more crucial than ever. Because it is difficult to find new sources of potable water, the challenge in fact reduces to effectively utilize current water sources. This can be accomplished in several different ways. Current applications, ranging from irrigation to personal hygiene, can be improved in order to minimize water use. Current water sources like ground water can be gathered and utilized more effectively, to maintain their viability as a renewable resource.

In addition, it becomes ever more important to recycle the water we already use. Especially in developing, arid countries, wastewater is a largely untapped resource that will become absolutely crucial in the coming years. These countries are where it is absolutely crucial to maximize available water resources, as these countries expend as much as 90 percent of their water for irrigation, compared to 70 percent worldwide [1]. In these countries there is far less frivolous water consumption that could theoretically be cut back, just a pressing need for water. One such region, the Middle East and Northern Africa (MENA), collects the equivalent of 29.7 percent of their total water consumption as wastewater, showing that wastewater alone could make a massive impact on water resource sustainability [2]. The decentralization of wastewater treatment could also prove to be a boon to developing countries. This strategy helps to minimize the extra costs associated with the transport of water both to and from treatment facilities. Instead, smaller, localized plants can be used.

14.2 AGRICULTURAL DEMANDS

With droughts becoming more and more prevalent, the agricultural community must find ways to thrive in drought conditions. In the case of maize production, farmers are combating drought through low and no tilling systems. This process eschews tilling the top layer of soil in favor of drilling narrow holes for the seeds to be planted. The main advantage of this method, especially when considering droughts, is the increased carbon dioxide retention of the soil. When the soil retains a higher concentration of carbon dioxide, the plants will use water more efficiently. Minimizing the water required to produce crops is one of the great challenges droughts provide, and enabling plants to utilize the precious available water more efficiently is a key improvement. Agriculture is often the primary consumer of a cultivated area's water resources, and as such even marginal gains in this field can have substantial effects. In addition, the process of conventional tilling often leaves the land vulnerable to erosion. No or low till farming has also the benefit of greatly reducing erosion, due to the better packed fields it creates.

No till farming is a relatively new development, but its core philosophy does not explicitly require advanced technology. It is quite probable that no till farming could have been implemented a long time ago. Tilling provides the advantages of killing weeds and creating primitive irrigation tracts, as well as organizing fields into orderly lines. No till farming simply requires a hole to be drilled in the ground, which is aided by modern technology, though the same end can be accomplished with simpler means. Modern herbicides also help to combat the weed problem, the most significant obstacle to no till farming, but weeds have always been a problem for farmers. This "old" method of tilling that has been reintroduced in dry climes is discussed here as an innovation in hydrology because it does produce favorable results by decreasing erosion. Erosion is a hydrological phenomenon when water flows through the earth that needs to be curbed in many places or situations.

Many advances in farming technology have allowed farmers to vastly increase their raw yield over previous years. Yet, despite the numerous technological discoveries, the yields of some crops, such as maize, are more sensitive to droughts than ever. Many other variables have been able to be controlled more effectively than in the past, especially when compared to drought. Although the absolute yield may be higher, even when considering drought conditions, the ability to control and overcome these conditions is still unsatisfactory. Another condition that exacerbates this condition is the increased crop density. From 1992 to 2012, crop density increased a staggering 25 percent [3]. Holding all other factors equal, drought stress has a far greater impact on the yield of more densely planted crops than those that are less dense, making crops more vulnerable to drought stress.

Though this data shows that the raw total yields may increase, the real problem is one of wasted potential. As droughts make it more difficult to grow crops in many regions, it is becoming increasingly important to maximize the available production. With drought stresses potentially accounting for a 30 percent loss in yield, it is crucial to find solutions for this specific problem.

14.3 SOLAR DRIP IRRIGATION

An innovative irrigation procedure has been engineered and carried out in Benin, Africa. Solar Electric Light Fund (SELF) is a corporation which supplies the resources to help spread the use of solar energy in areas around the world. SELF funded this solar drip irrigation method in Benin. It uses solar panels to power a very efficient drip irrigation system. It has been shown that drip irrigation is ideally suited to agriculture under dry conditions [4, 5].

SELF has also successfully implemented solar-powered community water wells, and the Solar Market Gardens for community workers, the later using solar drip irrigation [5]. This same innovative procedure in hydrology has been repeated with success in Haiti. SELF has made inroads into South America, with projects in Colombia. It is conceivable that the solar drip irrigation process would also be used there also.

14.4 WASTEWATER REUSE

One of the main areas that society may be able to improve upon in the face of drought is the reuse of wastewater. The proper treatment and recycling of previously used water can greatly expand the pool of available water to any society.

It can be clearly seen from Table 14.1 that massive amounts of wastewater are being squandered. The region being considered is the MENA. This region produces 13.2 km^3 of wastewater annually while only treating 5.7 km^3, or 43 percent. Hence, 7.5 km^3, or 7,500,000,000,000 L, are untreated. The total quantity of water utilized by the domestic and industrial sectors in this region is 44.4 km^3 annually, so the untreated wastewater is significant when compared with the total water demands of the area [2].

14.5 OPTIMAL RESOURCE MANAGEMENT

Though water is becoming increasingly precious, our use of it continues to be suboptimal. Using the wealth of information currently available, it is possible to more efficiently use current water resources without improved technology.

Currently, many sources of usable agricultural water, such as the Nile River Basin, are being polluted beyond healthy rates. The ability to notice these trends and enact policy on a larger scale is relatively new, thanks to increased availability and understanding of data. Properly treating wastewater before reintroducing it into potentially useful water is absolutely key in areas where water is already scarce. For example, raising and enforcing the standards for wastewater runoff into the El-Qalaa basin could reduce violations of total suspended solids (TSSs) by 50 percent and eliminate chemical oxygen demand (COD) violations [6]. Models such as the one featured in [6] are a hugely valuable tool for determining the root causes of pollution, as well as suggesting paths toward a solution that can be enacted through policy.

Jordan is an excellent example of a country with limited water resources attempting to maximize their potential through policy. The Wastewater Management Plan of 1998 outlines several key points:

- Wastewater will not be disposed of, but is instead included in the water budget.
- Planning of water reuse will take place on a basin-wide scale.
- Use of recycled water will be encouraged.
- Fees for wastewater treatment may be collected from those who utilize the water.
- Crops irrigated with wastewater will be recorded and controlled [7].

Table 14.1. Percentage of collected wastewater treated

Country	Wastewater treatment rate (% collected)
Algeria	73
Bahrain	100
Djibouti	0
Egypt	79
Iran	4
Iraq	N/A
Israel	79
Jordan	88
Kuwait	87
Lebanon	2
Libya	7
Morocco	6–8
Oman	13
Palestine	34–54
Quatar	N/A
Saudi Arabia	75
Syria	57–67
Tunisia	79
UAE	22
Yemen	62

Source: Data from [2].

These policies promote what should be considered an essential resource in recycled wastewater, while also making it more economically feasible. In addition, many developing countries are somewhat inefficient at reprocessing wastewater, so it is important to monitor crops irrigated with such water, to ensure that poorly filtered water does not negatively affect the environment or the local population. These policies have contributed to Jordan treating 88 percent of its wastewater [2]. If other MENA countries began to treat 88 percent of their wastewater, there would be an additional 5.9 km^3 of processed wastewater available for use, which covers 13.3 percent of the region's total water demand [2].

The willingness of many farmers in these water-scarce regions toward using wastewater could also benefit from policy decisions. For example, Tunisian farmers have the option of paying 0.02 US$/$m^3$ for reclaimed water versus 0.08 US$/$m^3$ for conventional water, yet the demand for reclaimed water remains low [2]. This is in part due to the unreliable quality of reclaimed water in the area, and the alternative of free untreated wastewater. This pricing only reflects the current state of the water, without an eye toward long-term water resources. An increase in the price of conventional water that reflected its future rarity is most likely in order. A combination of taxation and subsidies that shifted demand toward more sustainable sources of water would be ideal.

14.6 NANOTECHNOLOGY

The adaptation of nanotechnology toward water filtration and purification can greatly improve the efficiency and effectiveness of water treatment.

Nanoabsorbers provide a vastly increased absorption surface area over conventional absorbers such as activated carbon. This increased ratio of surface area to particle volume allows for both a higher rate of absorption and a higher absorption capacity per unit volume. Nanoabsorbers have the ability to remove both organic and metallic contaminates. Their small size also allows them to diffuse rapidly, as the intraparticle distance required to effectively diffuse is much smaller than that of a larger absorbent.

Carbon nanotubes (CNTs) are one of the most effective options currently available, though the cost prohibits wider adaptation. Their primary use today is to filter out particles that cannot be removed using standard methods, such as antibiotics and polar aromatics [8]. Graphite oxide nanosheets may be produced fairly cheaply, and are therefore an interesting potential absorbent.

Metals can be absorbed through the use of metal oxide nanomaterials, such as nanomagnetite. Nanomagnetite's superparamagnetic properties allow it to easily separate from water when in the presence of even a weak magnetic field.

Nanotechnology has also excellent results when utilized as a membrane. This method allows for a low-energy, low-cost filtration system with excellent efficiency. This low-energy approach is especially necessary in many of the areas hit hardest by drought. The African continent is particularly affected by drought, due to a comparative lack of natural water and subpar infrastructure. Yet, despite this, only 1 percent of the wastewater generated in Africa is treated [9]. A filtration system with low energy demands would be particularly helpful in this sort of environment. Membranes also allow the process of filtration to be largely automated, as they passively filter water. This method also permits a variety of water sources to be treated in addition to wastewater, such as sea water. Membranes are subjected to fouling and blockage, especially when considering nano-channels, so care must be taken to reduce the harm of these obstacles. There are currently three main varieties of membranes utilizing nanotechnology: the CNT, the biomimetic membrane, and thin film nanocomposite membranes.

Nanotechnology use has also proven adept in sensing and disinfecting water. Because contaminants are often still harmful at extremely low concentrations, swiftly detecting and inactivating them is crucial for potable water. Quantum dots are extremely effective dye markers owing to their wide absorption bands and narrow emission spectrum.

Traditional disinfectants, such as chlorine, often leave behind harmful by-products. Nanomaterials have the potential to effectively disinfect water without leaving behind by-products that are toxic to humans. These disinfectants work by releasing metal ions that disrupt the integrity of the membranes of various microorganisms on contact. Nano-Ag is particularly effective because the various components of DNA are attracted to Ag^{+}. These microorganisms can also be made inactive when hit with a short electrical pulse if trapped in a CNT membrane.

The main issue of nanotechnologies is that of cost. Until the scale of production is greatly increased, the price will remain prohibitively expensive. However, compromises in quality can be made. Using fullerene soot instead of pure C60 in aminofullerene photocatalysts reduces the price by 90 percent, while hurting the effectiveness by only 10 percent [8]. Such sacrifices must be considered when thinking of implementation in impoverished areas of the world.

14.7 CONVENTIONAL WASTEWATER TREATMENT

The most common variety of wastewater treatment plant is the AS method. Bacteria are introduced into the wastewater to create a floc with the pollutants. This floc, the "sludge," can be filtered out far more easily than untreated pollutants. This system is widely implemented throughout the world due to its low energy demands and low capital cost. However, it is not a standalone process, as wastewater is not immediately potable without several additional treatments.

Table 14.2 shows the effectiveness of AS as compared to several other widely used methods. It differs from the latter three methods in that they are primarily passive treatments, whereas AS treatment requires more active treatment, and thus has higher operational costs.

In the case of Free Water Surface (FWS), constructed wetlands versus a traditional AS plant, the initial development costs for the FWS plant

Table 14.2. Percentage reduction of TSSs, COD, and total nitrogen (tn)

	% Reduction		
Treatment type	**TSS**	**COD**	**TN**
Activated sludge (AS)	97	92	32
Tricking filter beds	53	41	12
Lagooning	54	38	62
Constructed wetlands	86	92	75
Anaerobic Membrane Bioreactor (AnMBR)		>90	

Source: Data from [10, 11].

were found to be roughly eight-fold higher than that of the traditional plant. This was offset by the lower operational costs of the FWS plant, which were about eight-fold lower than its counterpart. It was found that the lower operational costs would allow the FWS plant to equal the costs of the AS plant after three years of operation [12].

14.8 MEMBRANE BIOREACTORS

Membrane bioreactors (MBRs) are an effective treatment option with a wide variety of uses. They can be used to treat waste from potentially dangerous sources ranging from petrochemical waste [13] to pharmaceutical waste [14]. There are a wide variety of MBRs with many different filters, pumps, and chemical treatments. Some of the ways they vary include membrane pore size, membrane configuration (vertical or horizontal), membrane classification (microfiltration or ultrafiltration), membrane material, fiber density and size, and the type of air scouring used. These plants currently use a comparable amount of energy to an AS plant, of about 3 kWh m^{-3}. Much of the energy used in the MBR plants is devoted toward the air blowers necessary to prevent fouling and concentration polarization known as air scouring. These blowers are often found to use over 60 percent of the total energy used in the reactor [15]. Whereas these reactors do not yet provide an energy advantage over traditional methods, they do provide significantly cleaner water. Water from AS plants must undergo further sand and ultra-violet UV filtration before it is acceptable to be used in irrigation, while the MBR provides water that is instantly usable.

It can also be helpful to combine AS treatment techniques with an MBR, by way of pretreating the effluent. To test this theory, four varieties of MBR were tested with both raw wastewater and advanced primary effluent (pretreated wastewater).

In Table 14.3, it is shown that all four varieties of MBR were incredibly effective using raw wastewater as feed water, removing almost all pollutants present. Standards for turbidity, which measure similar to that of TSS, generally require values of less than 1.0 for drinking water, which all four easily meet.

The amount of various pollutants in both the raw wastewater and the advanced primary effluent and the two candidates to be fed into the MBR are shown in Table 14.4. The advanced treatment clearly aids in the process, as it does a significant amount of treatment on its own. The raw amount of ammonia-nitrogen, BOD, COD, and TSSs are very similar whether raw wastewater or advanced primary effluent is used. The difference concerns the operation of the reactor. When pretreatment is used, less primary air needs to be used during operation, allowing overall energy needs to be drastically decreased, as the blowers consume more energy than any other component. The danger from using pretreated water

Table 14.3. Percentage reduction of biological oxygen demand (BOD), COD, ammonia-nitrogen, and turbidity

	MBR type			
% Removed	**U.S. filter**	**Kubota**	**Zenon**	**Mitsubhishi**
Ammonia-nirogen	98.9	97.3	96.8	85.9
BOD	99	>99	>99	>99
COD	95.8	96.2	96.4	95.2
Additional water quality measure				
Turbidity (NTU)	0.04	0.08	0.06	0.07

Source: Data calculated from [16].

Table 14.4. g/ml of BOD, COD, ammonia-nitrogen and TSS in inflow streams

(g/ml)	Raw wastewater	Advanced primary effluent	Reduction (%)
Ammonia-nitrogen	26.7	26.1	2.2
BOD	249.3	39.4	84.2
COD	200	106	47.0
TSS	484	224	53.7

Source: Data calculated from [16].

comes in the form of increased fouling, as the sludge can clog the narrow membrane. This problem is especially prevalent at high flux values, and requires more frequent cleaning.

A popular variety is the AnMBR. These reactors are able to effectively process wastewater at a high rate, with minimal effect from varying hydraulic retention time. They can also tolerate significantly higher solid retention times in the reactors [11]. The anaerobic treatment, by its nature, offers increased ability to eliminate biological pollutants.

14.9 BIOFILTERS

Biofilters are an incredibly promising field for developing countries, owing to their low operational and start-up costs, and variable size. Biofilters can be implemented in a variety of ways, through green roofs, living walls, and constructed wetlands. All of these methods involve using living organisms to filter out pollutants from wastewater.

One interesting potential application of these systems is small-scale domestic filtration. A combination of these three methods can be used to create a very low cost filtration system for domestic use with almost no maintenance costs or energy requirements. It was found that this type of system results in over a 92 percent reduction in BOD and nitrogen content. A system that can process 50 gallons/day of wastewater can be constructed for less than $300 [17]. The downside of this method is that a large percentage of the water can be lost to evapotranspiration during treatment. This concern is somewhat mitigated if this method is implemented in areas where wastewater goes untreated, as it results in a net positive.

14.10 GROUNDWATER

In addition to wastewater, groundwater is a key resource in drought-prone areas. For example, in Syria with an arid climate, groundwater accounts for over 50 percent of the water used for irrigation [18, 19]. However, many regions are overusing this precious resource. If enough time is not given for aquifer recharge, then these are no longer sustainable resources. In addition, the continued use of groundwater for irrigation causes nitrogen and salinization buildups within the soil. This practice results in 1 to 2 percent of global irrigated lands to become nonarable each year [20]. This can be combated through increased use of surface water in irrigation, which can refresh the groundwater sources. However, many areas reliant on groundwater do so because of insufficient surface water resources. In these cases, recycling wastewater again becomes key. Recycling and properly treating wastewater can counteract the salinization and nitrogen buildups in both soil and groundwater reservoirs.

The continuous reuse of groundwater without treatment serves as a positively reinforcing cycle in terms of salinization and nitrogen buildup. The water becomes increasingly salinized and gains a higher nitrogen concentration when used for irrigation before seeping back into the groundwater. This increases the equilibrium salinization and nitrogen content of the groundwater, before it is again raised by the next cycle of irrigation. In many cases, this high nitrogen content is not accounted for by farmers, who over fertilize their crops as a result.

14.11 COMPARISON OF MBRs AND AS PLANTS

A more direct comparison of the AS plants and the MBR plants shows that both are viable options.

In Table 14.5, the effectiveness of both systems is illustrated. Though the AS plant lags behind in TSS removal, it comes at a cheaper energy cost than an MBR plant, and as such can be supplemented with additional treatment. However, MBR plants are shown to be a one-step treatment option. They require little supervision, and if blower costs can be brought down, these plans can have minimal power requirements. They remove all kinds of pollutants, and can work with a wide variety of effluent sources. The effluent of the MBR also lacked enzymes, which were present in the AS effluent, which is another advantage for the MBR [21]. Both systems show effective nitrification, which is key for fertilization.

Table 14.5. Percentage reduction of TSS, COD, ammonium

Performance of AS and MBR plants			
Pollutant	**Amount in wastewater (mg/L)**	**MBR % removed**	**AS % removed**
TSS	64 + −22	99.9	60.9
COD	58 + −18	99.0	94.5
Ammonium (mg*N/L)	20.2 + −1.7	99.2	98.9

Source: Data from [19].

14.12 DISCUSSION AND CONCLUSION

The objective of this review is to look at innovations that have occurred in hydrology owing to climate change. One of the most important immediate impacts of climate change is the frequency of droughts. Droughts affect agriculture, and hence create water–food nexus problems wherever they occur. Hence, the review has focused on hydrological processes associated with agriculture.

While both of the AS and MBR systems that have been discussed can be effective, they must be widely used to see a real benefit. Both options can be deployed on smaller scales and used in a decentralized fashion, which is key in spread-out, sparsely populated areas. This small scale is an advantage over methods such as lagooning and manufactured wetlands, which generally must be deployed in a larger scale to become cost-effective.

Overall, carefully planned wastewater treatment can mean an enormous difference in places such as Africa, where only 1 percent of wastewater is treated. Through smart governmental policy encouraging the collection, treatment, and reuse of wastewater, along with increased treatment capacity, can lead to substantial gains in making potable water a more sustainable resource.

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CHAPTER 15

A Balanced View

This is the winding-up material to the monograph, *Climate Change*. This chapter outlines most of the highlights that should have been learned in going through all the chapters. Because of the strength, power, and influence of the deniers of climate change in the United States, there is greater need for readers to be convinced that such a phenomenon is taking place. Once convinced, it is hoped that such readers would use their energy and resources to do their part to mitigate the adverse effects. Even for the not fully converted, there are obvious practices that are not good for the environment and conservation of resources as well as waste reduction are praiseworthy practices regardless.

For most of the world, climate change brings with it mostly adverse effects. On the surface, it would seem that countries with frigid climates, for example, Canada, Russia, and Scandinavia, would probably benefit from the positive effects of climate change like temperature warming. The obvious immediate advantage is the lengthening of the growing season for agriculture in these countries. The savings in fuel for heating in winter is another. Yet, it may be difficult to find an abundance of academic literature on this unsung bounty from nature. Can Scandinavia be the next great wine growing region? Historians have stated that the Vikings before Columbus kept North America a secret because they did not want to share that newly found vast vineland they "discovered." Columbus learned about America through sailor gossip, and employed guile with the King and Queen of Spain to attain research and venture funds to sail westward to Asia. Columbus has been and should continue to be celebrated as the leader who enabled the opening up of the Americas, because he shared the information with the world and was instrumental in opening up new sea routes westward from Europe. He demonstrated that sea routes westward would reach land eventually, and that the round-trip journey from Europe could be done with success using the prevailing winds and ocean currents.

As stated in the Introduction, a cautionary step taken by me to prevent the current book from displaying partiality is to incorporate six published academic articles as chapters of this book. Academic journal papers are peer-reviewed and have any prejudice eliminated.

In the review of climate change theories, it was presented that the two cycles expected to influence long-term climate change are the Milankovitch Cycle and the Sunspot Cycle. The Milankovitch cycle predicts an age of warming expected to last over many thousand years, whereas the minimum of the sunspot cycle could mean below-average temperatures for a few more decades. While the joint influence of the many climate change theories do seem to be causing above-average temperatures and larger rainfall quantities in specific areas of the world, they are just phases that could last from a few months to a couple of years in most of these theories. Therefore, it is doubtful that these cycles can enlighten us about the warming trend that has taken place in recent decades because many of the natural climate cycles alter phases rather quickly. As a result, in addition to the natural climate variations, there are anthropogenic factors that must be further researched and studied to find out their global, regional, or local impact and their short- and long-term effects.

The greenhouse effect of the atmosphere is also explained in a chapter of this book. Carbon dioxide is the most long-lasting of all the greenhouse gases since its half-life in the atmosphere is in the order of a century longer than the next ranked greenhouse gas. Even though water vapor does constitute a high portion of the atmospheric greenhouse gases, we are not worried about anthropogenic water vapor production, as the half-life of water vapor is only several days.

Anthropogenic factors are discussed in the quantitative tabulation and discussion of all the major heat contributions from human activities, presented in one chapter. In another chapter is outlined an innovative method that starts from the basics, and is used to tabulate and account for the heat generated by all human activities in the globe. It is a good happenstance that these heat quantities are largely contributed by a few categories. Otherwise, the tabulation work would be untenable. Yet another chapter deals with the various results of climate change. Since all of these can be sensed by at least one of the five human senses, not much controversy is expected. These two chapters are presented as evidences of the occurrence of climate change and the factors are largely intuitive.

Sustainable science (natural, social, and medical sciences) and sustainable engineering are what we human beings are using to help us face and mitigate the problems brought on by climate change and an ever-increasing human population. Since research shows that pesticides and artificial preservatives are causing chronic diseases in the masses, it is logical that agricultural methods and food production now have become public health issues. It is a fact that some pesticides have greatly enhanced our ability to feed each other, to permit people to rise out of poverty, and to allow for a better quality of life for humankind. Nonetheless, agricultural practices and food production should be subjected to more public examination and policies. This natural sequence of events is a consequence of the human instinct to strive for betterment.

Themes in sustainable science range from atmospheric chemistry to climate change management and policy to latest agricultural and food processes to sustainable social systems to various medical and health science topics. Topics in sustainable engineering range from innovative planning and design for natural and built environments to conservation of energy to waste minimization to sustainable electric power generation to renewable fuels.

This concluding chapter is an appeal to all readers to maintain a critical but open mind, and consider all the information presented to evaluate whether climate change is a current phenomenon. One needs much proof to shut the lips of gainsayers. Experiencing first-hand the adverse effects of climate change has converted many a naysayer. Action is required from all, but only can be expected by those who have been convinced. Does that not mean that those who have been convinced need to do more and should do more?

If one were to subscribe to the notion that the human experience is a local experience for universal beings, then there is much to transform to improve the current world situation. It requires each human to transform itself from fragmented thinking to universal thinking. The sustainability of humans on Earth needs transformation of fear and distrust into love.

INDEX

A

Activated sludge (AS), 176, 179
Adaptation responses, sea level rise, 79–80
Adenosine triphosphate (ATP), 99
Agricultural demands, 170–171
AGU. *See* American Geophysical Union
Air scouring, 176
Amazon jungle, 102
American Geophysical Union (AGU), 1
American Society of Mechanical Engineers (ASME), 2
AMO. *See* Atlantic Multidecadal Oscillation
Amphibians, 66
Anaerobic membrane bioreactor (AnMBR), 176, 178
AnMBR. *See* Anaerobic membrane bioreactor
Anthropogenic heat generation, 127, 128
Anthropogenic heat release
- animal bodies, 55–57
- carbon dioxide output, 55
- electricity generation, 49, 51–53
- garbage incineration, 54
- global energy consumption, 45–46
- method, 46–47
- oil refineries, 51, 53–54
- outcomes, 57–58
- sulfur dioxide, 55
- world energy consumption
  - combustion, 47, 50
  - energy conversion, 47, 49
  - fossils fuel and biofuel consumption, 47–48

AO. *See* Arctic Oscillation
Aquaculture projects, 93
Arctic ice caps, 63–65
Arctic Ocean Basin, 85–86
Arctic Oscillation (AO), 15–17
Artificial trees, 112–113
AS. *See* Activated sludge
ASME. *See* American Society of Mechanical Engineers
Atlantic Multidecadal Oscillation (AMO), 18–19
Atlantic Ocean
- Arctic Oscillation (AO), 15–17
- Atlantic Multidecadal Oscillation (AMO), 18–19
- North Atlantic Oscillation (NAO), 17–18

Atmospheric CDR via technology. *See* Carbon dioxide removal (CDR) technologies
ATP. *See* Adenosine triphosphate

B

Bathymetry, 92
BCM. *See* Biological carbon mitigation
BECCS. *See* Bio-energy with carbon capture and storage

Bio-energy with carbon capture and storage (BECCS), 109, 115–116
Biochar, 110–112
Biofilters, 178
Biofuel, 79–80
Biofuel consumption, 47–48
Biofuel production
  factors, 119
  photobioreactors, 119–120
  stages, 120–121
Biological carbon mitigation (BCM), 118–119
Biological oxygen demand (BOD), 177
Biorecro, 116
Black carbon, 111
Blanket effect, 62
BOD. *See* Biological oxygen demand
BPBR. *See* Bubble column photobioreactor
Bubble column photobioreactor (BPBR), 119, 120

C

Carbon dioxide, 55
Carbon dioxide emissions, 42–43
Carbon dioxide removal (CDR) technologies
  artificial trees, 112–113
  BCM, 118–119
  BECCS, 115–116
  biochar, 110–112
  biofuel production
    factors, 119
    photobioreactors, 119–120
    stages, 120–121
  capture or trapping procedures, 116–117
  enhanced weathering, 113–115
  IPCC, 107–108
  Kyoto Protocol, 108
  mitigation procedures, 109
  outcomes, 121–122
  process, 110
  ReMIND, 109
  sequestration procedures, 117–118
Carbon emission laws, 72
Carbon nanotubes (CNTs), 174, 175
CDR. *See* Carbon dioxide removal technologies
Cetacea, 92
Chemical oxygen demand (COD), 172, 177
Climate change
  AGU, 1
  anthropogenic heat release (*see* Anthropogenic heat release)
  balanced view, 183–185
  CDR (*see* Carbon dioxide removal (CDR) technologies)
  energy–water–food nexus, 3 (*see* Energy–water–food nexus)
  forests and jungles, 2 (*see also* Forests and jungles)
  freshwater discharges, 2 (*see also* Freshwater discharges)
  global warming (*see* Global warming)
  greenhouse effect, 2 (*see also* Greenhouse effect)
  heat islands, 2–3
  hydrology innovations (*see* Hydrology)
  IPCC, 1
  oceans, 2 (*see also* Oceans)
  sea level rise, 2 (*see also* Sea level rise)
  second law of thermodynamics and heat discharge
    entropy definition, 27–29
    heat engine system, 29–31
    refrigerator/heat pump system, 29–30
  theories
    Atlantic Ocean (*see* Atlantic Ocean)

background, 1
fluctuations in, 5
historical concurrent effects, 20–21
Milankovitch theory, 6–7
natural cycles, types, 5–6
organizations, 5
Pacific Ocean (*see* Pacific Ocean)
sunspot cycle (*see* Sunspot cycle)
UHI (*see* Urban heat island)
CNTs. *See* Carbon nanotubes
Co-firing, 115–116
Coastal flooding, 70–71
COD. *See* Chemical oxygen demand
Conventional wastewater treatment, 175–176
Costa Rica, 100–101
Costa Rican Ministry of the Environment (MINAE), 100

D
Deforestation, 103–104
Desalination, 92–94
Disinfectants, 175
Droughts, 69

E
ECMWF. *See* European Centre for Medium-Range Weather Forecasts
EIA. *See* Energy Information Agency
El Niño Southern Oscillation (ENSO)
definition, 10
ONI and SOI, 12–13
Southern Oscillation, 11
warm pool, 11–12
El-Qalaa basin, 172
Electromagnetic radiation
Maxwell’s equations, 34
reflection coefficient, 35–36
s-polarized and p-polarized light, 34–35
transmission coefficient, 35
Energy Information Agency (EIA), 47
Energy–water–food nexus
glaciers
Arctic, 157
greenhouse gas emission and global temperature, 158
Himalayas, 155
ice-albedo feedback effect, 156–157
mass balance measurements, 157
mechanics, 155–156
Harappan civilization, 151–152
Himalayas, 153–155
Indus River
change in precipitation, 159
crops cultivated, 161–162
depiction, 161
food production, 162
freshwater scarcity, 160–161
glaciers melting estimation, 158–159
riparian forest loss, 160
outcomes, 164–165
recommendations, 163–164
schematic representation, 152–153
South Asian monsoons, 162–163
ENSO. *See* El Niño Southern Oscillation
Environmental Protection Agency (EPA), 128
European Centre for Medium-Range Weather Forecasts (ECMWF), 84

F
Flat plate photobioreactor (FPBR), 119, 120
FONAFIFO. *See* National Forestry Financial Fund

Forests and jungles
  Amazon jungle, 102
  Costa Rica, 100–101
  deforestation, 103–104
  fossil fuels combustion, 104
  Haiti, 101–102
  Indonesia, 102–103
  Nicaragua, 101
  photosynthesis, 99–100
  reforestation, 104
Fossil fuels combustion, 104
Fossils fuel consumption, 47–48
FPBR. *See* Flat plate photobioreactor
Free Water Surface (FWS), 175–176
Freshwater discharges
  Arctic Ocean basin, 85–86
  fluctuations and atmospheric driving parameters, 87–89
  groundwater discharge and anthropogenic contributions, 87, 90
  land–ocean water cycle, 83
  RTM, 83–84
  streamflow fluctuations, 84–85
FWS. *See* Free Water Surface

G

Garbage incineration, 54
Genetically modified (GM) animals, 91
Glaciers
  Arctic, 157
  greenhouse gas emission and global temperature, 158
  Himalayas, 155
  ice-albedo feedback effect, 156–157
  mass balance measurements, 157
  mechanics, 155–156
Global energy consumption, 45–46
Global warming
  Arctic ice caps, 63–65
  carbon emission laws, 72
  description, 61–62
  green-e-certified energy suppliers, 72
  hydroelectric power, 71–72
  mean temperature changes, 62–63
  renewable energy sources, 72
  solar power, 71
  weather patterns
    coastal flooding, 70–71
    droughts, 69
    modeling of, 69
    North Atlantic hurricane record, 68–69
    sea level rising factors, 70
  wild life and extinction
    amphibians, 66
    native rainforest vertebrates, 66–68
    polar bears, 65
  wind power, 71
GM. *See* Genetically modified animals
Green-e-certified energy suppliers, 72
Greenhouse effect
  causes, 33
  electromagnetic radiation
    Maxwell's equations, 34
    reflection and transmission coefficient, 35–36
    s-polarized and p-polarized light, 34–35
  global climate changes evidences
    annual global carbon dioxide emissions, 42–43
    gases and effects, 41–42
    National Oceanic and Atmospheric Administration (NOAA), 41
    Third Pole, 43
  greenhouse gas characteristics, 39–40
  Planck's law and radiated energy
    earth theoretical mean temperature, 37
    power radiation equations, 36

Rayleigh–Jeans law, 37
Wien displacement law, 38
radiance *vs.* wavelength, 38–39
Greenpeace, 103
Groundwater, 178–179
Groundwater discharge and anthropogenic contributions, 87, 90

H
Haiti, 101–102
Harappan civilization, 151–152
Heat engine system, 29–31
Heat pump system, 29–30
High-precision altimeter satellites, 69
Himalayas, 153–155
Hydraulic turbines, 94
Hydrodynamic trapping, 116–117
Hydroelectric power, 71–72
Hydrology
agricultural demands, 170–171
biofilters, 178
conventional wastewater treatment, 175–176
groundwater, 178–179
MBRs (*see* Membrane bioreactors)
nanotechnology, 174–175
optimal resource management, 172–174
outcomes, 180
solar drip irrigation, 171
wastewater reuse, 171–173
Hydrothermal vents, 94

I
Ice-albedo feedback effect, 156–157
IMECE. *See* International Mechanical Engineering Congress and Exposition
Impervious Surface Area, 135
Indonesia, 102–103
Indus River
change in precipitation, 159
crops cultivated, 161–162
depiction, 161
food production, 162
freshwater scarcity, 160–161
glaciers melting estimation, 158–159
riparian forest loss, 160
Intergovernmental Panel on Climate Change (IPCC), 1, 75–76, 107–108, 165
International Mechanical Engineering Congress and Exposition (IMECE), 3
IPCC. *See* Intergovernmental Panel on Climate Change

J
Jungles. *See* Forests and jungles

K
Kyoto Protocol, 108

L
Lackner's tree, 113
Land skin temperature (LST), 129
Land–ocean water cycle, 83
Landsat
emissivity values, 131
Landsat 5 and Landsat 7, 129
spectral radiance, 130–131
temperature values, 131–132
thermal infrared portion, 129–130
LST. *See* Land skin temperature

M
Man-made engineering systems, 29–31
Mangroves, 80
Mariana trench, 93
Maxwell's equations, 34
MBRs. *See* Membrane bioreactors
Membrane bioreactors (MBRs)
air scouring, 176
AnMBR, 178

BOD, COD, ammonia-nitrogen and turbidity reduction, 177
AS plants *vs.,* 179
types, 176
MENA. *See* Middle East and Northern Africa (MENA)
Microalgae
BCM, 118–119
biofuel production, 120–121
Mid-Atlantic ridge, 93
Mid-Indian ridge, 93
Middle East and Northern Africa (MENA), 169–170
wastewater reuse, 172, 173
Milankovitch theory, 6–7
MINAE. *See* Costa Rican Ministry of the Environment
Mineral trapping, 117
Mitigation responses, sea level rise
digital software packages, 79
model simulation and analysis, 78–79
municipal solid waste use in, 77–78
offshore barrier islands, 78
reservoir placement, 77
sea walls or barriers, 77
Municipal solid waste, 77–78

N

NADPH. *See* Nicotinamide adenine dinucleotide phosphate
Nano-Ag, 175
Nanoabsorbers, 174
Nanotechnology, 174–175
NAO. *See* North Atlantic Oscillation
National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR), 84
National Forestry Financial Fund (FONAFIFO), 100
National Oceanic and Atmospheric Administration (NOAA), 41
Native rainforest vertebrates, 66–68
NCEP-NCAR. *See* National Centers for Environmental Prediction-National Center for Atmospheric Research
Nicaragua, 101
Nicaragua Canal, 90
Nicotinamide adenine dinucleotide phosphate (NADPH), 99
NOAA. *See* National Oceanic and Atmospheric Administration
Normalized Difference Vegetation Index, 135
North Atlantic hurricane record, 68–69
North Atlantic Oscillation (NAO), 17–18

O

Ocean Thermal Energy Conversion (OTEC), 93
Oceanic Niño Index (ONI), 12–13
Oceans
climate change and global warming, 95
current status, 91–92
freshwater discharges
Arctic Ocean basin, 85–86
fluctuations and atmospheric driving parameters, 87–89
groundwater discharge and anthropogenic contributions, 87, 90
land–ocean water cycle, 83
RTM, 83–84
streamflow fluctuations, 84–85
literature survey, 92–93
research and development
aquaculture projects, 93
desalination, 93–94
electricity generation, 94
hydrothermal vents, 94
trenches and ridges, 93
underwater built environments, 95

USFDA, 91
Offshore barrier islands, 78
Oil refineries, 51, 53–54
Olivine weathers, 114–115
ONI. *See* Oceanic Niño Index
Open Hydrology Journal, 2
Open ponds (OPs), 119–120
OPs. *See* Open ponds
Optimal resource management, 172–174
OTEC. *See* Ocean Thermal Energy Conversion

P

P-polarized light, 34–35
Pacific Decadal Oscillation (PDO), 13–15
Pacific Ocean
ENSO
definition, 10
ONI and SOI, 12–13
Southern Oscillation, 11
warm pool, 11–12
PDO, 13–15
Pakistan's Aquastat Profile, 152
Palmer Drought Severity Index (PDSI), 69
Panama Canal, 87, 90
Panamax, 87
Payment for Environmental Services Program (PSE), 100
PBRs. *See* Photobioreactors
PDO. *See* Pacific Decadal Oscillation
PDSI. *See* Palmer Drought Severity Index
Photobioreactors (PBRs), 119–120
Photosynthesis, 99–100
Planck's law and radiated energy
earth theoretical mean temperature, 37
power radiation equations, 36
Rayleigh–Jeans law, 37
Wien displacement law, 38
Polar bears, 65
Polar ice cap, 62
Polar vortex, 16
PSE. *See* Payment for Environmental Services Program
Pyrolysis, 110–111

Q

Quantum dots, 175
Quantum mechanics, 40
Quartz weathers, 114

R

Rayleigh–Jeans law, 37
REDD. *See* Reducing Emissions from Deforestation and forest Degradation
Reducing Emissions from Deforestation and forest Degradation (REDD), 100, 102
Reflection coefficient, 35–36
Reforestation, 104
Refrigerator/heat pump system, 29–30
ReMIND, 109
Renewable energy sources, 72
Residual trapping, 117
River transport model (RTM), 83–84
RTM. *See* River transport model

S

S-polarized light, 34
Sahel droughts, 69
Sea level rise
adaptation responses, 79–80
Dubai and Abu Dhabi, 75
literature, 75–77
mitigation responses
digital software packages, 79
model simulation and analysis, 78–79
municipal solid waste use, 77–78
offshore barrier islands, 78
reservoir placement, 77
sea walls or barriers, 77

Netherlands and Singapore, 75
regional authorities cooperation, 81
Second law of thermodynamics and heat discharge
entropy definition, 27–29
heat engine system, 29–31
refrigerator/heat pump system, 29–30
SELF. *See* Solar Electric Light Fund
SOI. *See* Southern Oscillation Index
Soil erosion, 102
Solar drip irrigation, 171
Solar Electric Light Fund (SELF), 171
Solar power, 71
Solubility trapping, 117
South Asian monsoons, 162–163
Southern Oscillation Index (SOI), 12–13
Spectral radiance, 130–131
Sub-polar low zone, 17
Subtropical high zone, 17
Sulfur dioxide, 55
Sunspot cycle
"Little Ice Age," 7
Dalton Minimum, 9–10
solar activity and, 8
spectral radiance, 8–9
sunspot numbers, 9, 10

T

Thermal images
Seoul, South Korea, 132–133
South Florida, United States, 134–135
Tokyo, Japan, 133–134
Third Pole, 43
TOA. *See* Top of atmosphere
Top of atmosphere (TOA), 46
TPBR. *See* Tubular photobioreactor
Transmission coefficient, 35–36
Tubular photobioreactor (TPBR), 119, 120

U

UHI. *See* Urban heat island
UHII. *See* Urban Heat Island Intensity
Underwater built environments, 95
United Nations Department of Economic and Social Affairs, 100
United States Food and Drug Administration (USFDA), 91
Urban heat island (UHI)
anthropogenic heat generation, 127
effect, 128–129
image selection, 132
Landsat
emissivity values, 131
Landsat 5 and Landsat 7, 129
spectral radiance, 130–131
temperature values, 131–132
thermal infrared portion, 129–130
quantitative differentiation
Chicago, Illinois, United States, 136–137
South Florida, United States, 135–136
temperature differences, 136, 137
thermal images
Seoul, South Korea, 132–133
South Florida, United States, 134–135
Tokyo, Japan, 133–134
Urban Heat Island Intensity (UHII), 138–139
USFDA. *See* United States Food and Drug Administration

V

Variable warming period, 7
Virgin Earth Challenge, 122

W

Ward Hunt Ice Shelf, 63–65
Wastewater reuse, 171–173
Weather patterns
  coastal flooding, 70–71
  droughts, 69
  modeling of, 69
  North Atlantic hurricane record, 68–69
  sea level rising factors, 70
Weathering, 113–115
West Wind Drift, 94
Wien displacement law, 38
Wild life and extinction
  amphibians, 66
  native rainforest vertebrates, 66–68
  polar bears, 65
Wind power, 71
World energy consumption
  combustion, 47, 50
  energy conversion, 47, 49
  fossils fuel and biofuel consumption, 47–48

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Kaufui Vincent Wong grew up in Malaysia and came to the United States in 1973. As a young man, he had four parts of a wish. He accomplished the third part of his wish when he started as a professor at the University of Miami, Florida, in 1979, and that was to teach young men and women from all over the world to become engineers. He started having the fourth part of his wish come true when in the year 2000 he published his book for students studying to be engineers. By 2012, he had published four textbooks. His 2015 book projects with Momentum Press represent his fifth and sixth books and he is working on his seventh.

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