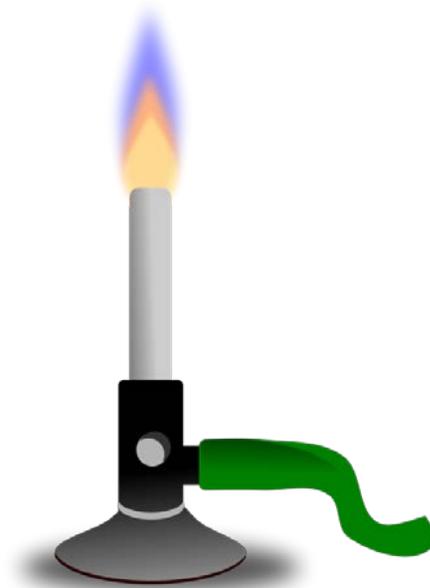


Is Global Warming Hot Air?



W. A. van Wijngaarden

Preface

The title of this book will no doubt attract controversy. Some may deem it provocative. But a discussion of the evidence supporting or inconsistent with global warming is timely and should not frighten anyone. All 7.3 billion inhabitants of this planet deserve to know what is going on.

As I was working on this manuscript, one of my children said; “Papa, this may make you popular in the U.S. Republican party”. That indeed is a concern, as some of the leading contenders in the 2016 presidential cycle are espousing truly loony ideas. However, scientists must be guided strictly by evidence and should never allow politics to govern their research.

William Arie van Wijngaarden, April, 2016

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1

Why Should We Care?

Barely a week passes without an article warning about humanity's adverse effect on the Earth's climate. Headlines mention historic droughts [1, 2], catastrophic floods [3, 4], record heat waves [5, 6, 7], rising sea levels [8], disappearing Arctic sea ice [9], increasing storm severity [10, 11], ocean acidification [12, 13] etc. Predicted consequences range from the whimsical such as the endangerment of Canada's hockey prowess because children can't skate on ponds that don't freeze [14, 15] to the possible extinction of iconic animal species such as polar bears [16, 17], the destruction of scenic underwater treasures such as Australia's Great Barrier Reef [18] and the spread of disease [19].

The basis for these concerns is mankind's increasing use of fossil fuels that began with the industrial revolution. Coal, oil and natural gas all produce carbon dioxide (CO_2) when burned. Careful measurements show a steadily increasing amount of CO_2 in the atmosphere that acts as a thickening blanket warming the Earth [20]. Beginning in

the 1990s, a group of international scientists established by the United Nations, the Intergovernmental Panel on Climate Change (IPCC), has issued voluminous reports [21, 22, 23, 24, 25]. Their most recent warning in 2013, states “Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia.” They conclude that “Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes.”

Political leaders have taken note. No less than the leader of the free world, President Obama of the United States, has proclaimed that “Climate Change is settled science”[26, 27]. We are told there is an overwhelming scientific consensus that mankind’s use of fossil fuels is changing the atmosphere resulting in a warmer climate with many negative side effects.

However, questions have been raised about the IPCC reports. The 1990 and 2001 reports presented graphs shown in Figure 1.1 that plot the change of the Earth’s average temperature over the past 1,000 years. The vertical axis of the 1990 graph does not have numeric labels which is not recommended scientific practice. It shows temperatures were warmer between 1000 and 1300 AD which is known as the Medieval Warm Period. This was followed by a colder period called the Little Ice Age and finally a temperature increase over the most recent century. In contrast, the 2001 graph does not show any Medieval Warm Period. Temperatures decreased slightly from 1000 to 1900 AD before beginning a steep rise [28]. The shape of this curve resembles a “Hockey Stick” and was prominently featured in the movie

“An Inconvenient Truth” starring former Vice President Albert Gore [29]. One doesn’t have to be religious to note that a continuation of the increasing 20th century temperature trend means the Earth is headed straight to hell. The obvious question to ask is why are the two graphs so different? Questions have been raised whether the hockey stick graph is correct [30, 31, 32, 33]. Indeed, the 2013 IPCC report showed that after 2000 the warming stopped even though the climate models all projected temperatures to increase sharply.

The IPCC does acknowledge some mistakes. The 2007 IPCC report was amended to withdraw the claim that the Himalayan glaciers would be completely melted by 2035 [34]. Similarly, the statement that 55% of the Netherlands lies below sea level was later corrected to the actual 26% [35]. Why weren’t these errors caught by the approximately 2,500 scientists and experts involved in producing the voluminous IPCC reports? Undoubtedly, the various chapters were written by small subcommittees and the entire report was only reviewed by a still smaller number of individuals.

The controversy over whether global warming is caused by humans or so called anthropogenic activities, is strange. Science is not normally associated with passionate argument. It is based on objective mathematics. There was only one correct answer when your Grade one teacher asked what was 8×6 . This book seeks to explain what the fuss is about. First, the basic science is reviewed. Next, the evidence is presented. Is the Earth experiencing changes in temperature, glaciers, sea level, oceans, precipitation etc. as predicted by the global warming theory? Finally, what should mankind do to ensure this world remains habitable for our descendants?

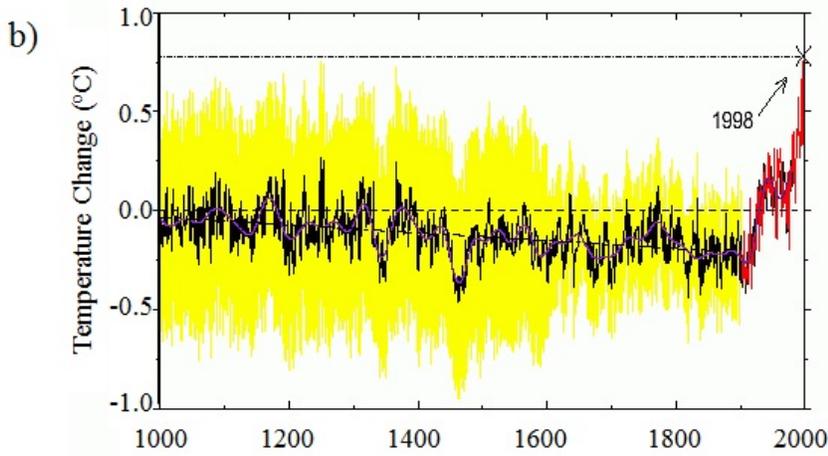
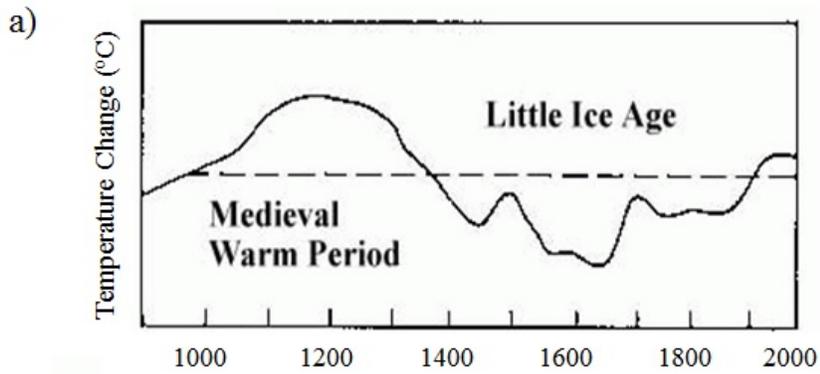


Figure 1.1: a) Change in Temperature according to the IPCC Reports in a) 1990 and b) 2001. Yellow indicates the range of temperature uncertainty about the average (black line). Red indicates temperatures measured by thermometers while the black data represents temperature inferred from the thickness of tree and coral rings [21, 23]. The dashed line shows the temperature in 1998 was 0.8 °C higher than 1,000 years ago.

2

Global Warming For Poets

¹The solar system is a harsh environment. One can admire the pretty photos of astronauts dancing on the Moon during the 1970s or be mesmerized by fascinating pictures taken by robotic spacecraft landing on Mars, Venus and other more distant heavenly bodies. However, only the Earth has an atmosphere that can support life. Without it, temperatures on the Earth would vary like those on the Moon. Lunar temperatures range from 100 °C during the day to -173 °C at night.

Figure 2.1 shows the sharp contrast between the Earth and the Moon. The atmosphere is the thin blue haze covering the Earth's surface. It looks especially fragile when compared to the harsh lunar

¹Poet is a somewhat derogatory term used by physicists to describe someone who is not a scientist nor even an engineer. The assignment to teach physics to non-scientists is a formidable tool in the arsenal of a departmental chair. That fate befell the author one summer. Fortunately, he quickly returned to the Chair's good graces and taught Solid State Physics the following semester. The temptation proved irresistible. At the first class, the Physics for Poets exam was given to the Solid State students. It was no contest. The first year poets creamed the senior physics majors.

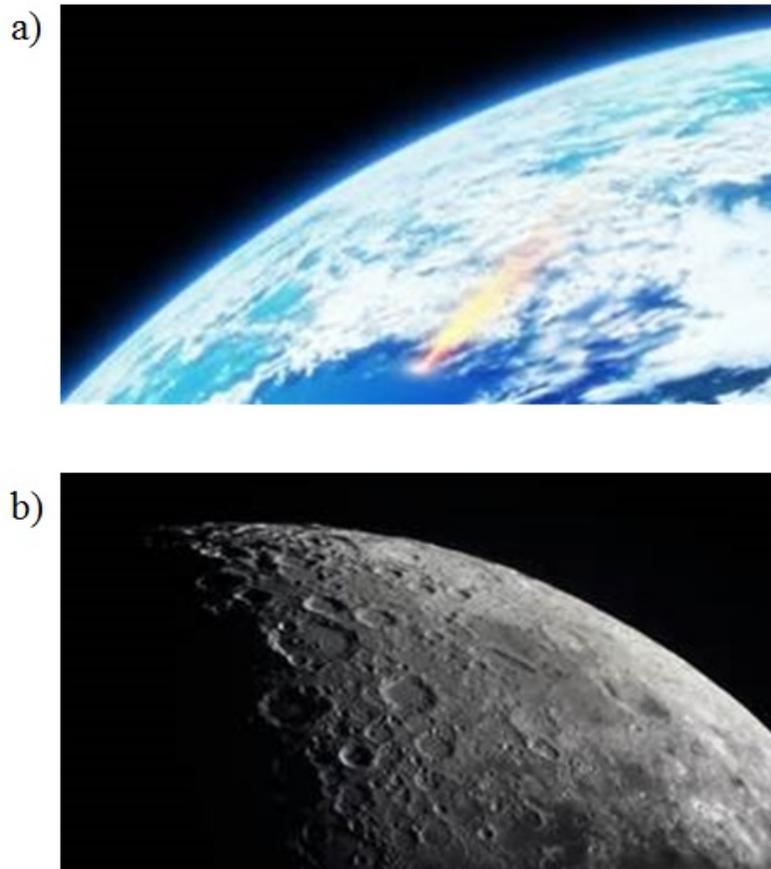


Figure 2.1: There is a remarkable contrast between the a) Earth and b) Moon as viewed from space. The major difference is due to the Earth's atmosphere which appears as a thin blue haze above the surface.

terrain. The atmosphere thins out rapidly as one increases in altitude. That explains why jets must be pressurized or passengers will die due to a lack of oxygen. The atmosphere has a thickness of only about 10 kilometers which is much less than the Earth's radius of 6,400 km. Yet, it is the atmosphere that supplies the essentials of life, from the air we breathe to the moisture plants and animals need to grow.

2.1 Historical Climate

The Earth's atmosphere generates the weather, a source of endless conversation as it changes from day to day. Forecasters can predict reasonably well tomorrow's weather or even two or three days hence. But ask them to predict the weather in one or two weeks, and even the best forecasters fail abysmally. Fortunately, the weather is stable when viewed on a longer term. Seasons come and go with regularity. In the Northern Hemisphere, winters are cold while summers are warm. It may be difficult to predict the weather next week but the long term weather patterns known as climate appear to be constant from year to year. Of course, the climate must be constant for how else would humans and other life have survived on this planet.

But is the climate constant? The answer over periods of tens of thousands of years is no! This can be stated emphatically because we all know about the Ice Ages. Ten thousand years ago the last Ice Age was ending. Glaciers had completely covered North America as shown in Figure 2.2 as well as large parts of Europe and South America. These large glaciers meant that the sea level was much lower. The modern shoreline was not recognizable. Britain was connected to Europe. Ice Ages are believed to have occurred because temperatures

were lower due to changes in the Earth's orbit around the sun [36, 37].



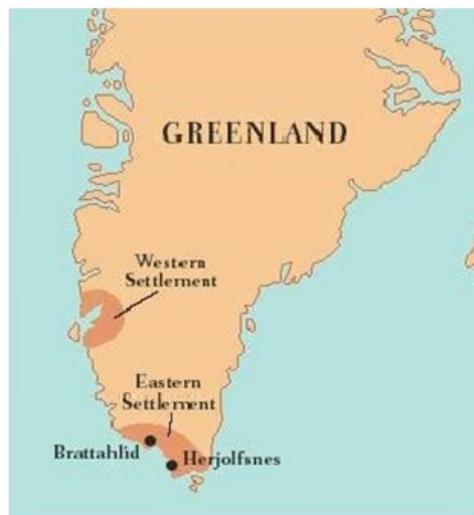
Figure 2.2: Glaciers covering North America during the Quaternary Ice Age from 100,000 to 10,000 B.C.

The Ice Age shows the Earth's climate is not constant on time scales longer than 10,000 years. That is a long time and not the subject of this book. We are interested in climate changes on shorter time scales, that will affect us or at least our grandchildren in 50 years. Has the climate been constant throughout recorded human history? The answer is no. Temperatures in the North Atlantic region were warmer during the so called Medieval Warm Period from 900 to about 1300 AD. This allowed the Vikings to settle in southern Greenland and farm!

Here, farming refers not to modern day aquaculture but traditional farming with sheep and cattle. Greenland was so named because parts of the south, at least during summer, were green. Two settlements shown in Figure 2.3 known as the Western and Eastern Settlements, were established which at their peak had a total population of several thousand inhabitants [38, 39]. Trade with Europe was brisk in such things as walrus ivory for several hundred years. The stone ruins of a Catholic Church at Hvalsey, Greenland are a striking remnant of Norse culture.

A visiting cleric, Ivar Bardarson, found the Western Settlement destroyed on a visit around 1350 [39]. There were wild horses, cattle and sheep, but no inhabitants. The reasons for the demise of the Western Settlement are not clear. There are some Norse accounts of fighting a small people they called the “Skraelings”. The Inuit are known to have settled northern Greenland at this time. The larger Eastern Settlement existed until the 15th century. In 1410, the crew of a visiting ship recorded the burning of a witch [40]. There also exists a contemporary Icelandic record of a couple who married in Greenland and later emigrated. Excavations of cemeteries in Greenland by Danish archaeologists in the 20th century have found evidence of malnourishment of the inhabitants. It appears there was a shift to a markedly cooler climate in the Northern Hemisphere in the 1300s that led to the demise of the Viking settlements. Radiocarbon dating of plant material found beneath glaciers on Baffin Island and Iceland shows glaciers began to grow in the late 1300s [41] although there has been a study that temperatures during the Medieval Warm period were not higher in Greenland as compared to today, but only in Europe [42].

a)



b)



Figure 2.3: a) Map showing the Western and Eastern Viking settlements in Greenland. b) Remains of Hvalsey Church located in the Eastern settlement.



Figure 2.4: Winter Dutch landscape painted by Hendrik Avercamp in 1608. A cursory examination of Avercamp's painting reveals several individuals with curved sticks chasing a puck. This is heresy in Canada which righteously regards itself as the birthplace of hockey. Canadian audiences are reassured when told these players are distant relatives of Wayne Gretzky and Bobby Orr.

The period from about 1400 to 1700 is known as the Little Ice Age. Temperatures in Europe were cooler. Swiss villagers even offered prayers to stop advancing glaciers from destroying their alpine villages [43, 44]. Rivers such as the Thames and Rhine regularly froze during winter, something that seldom occurs today. Famous paintings, such as the one by Hendrik Avercamp, shown in Figure 2.4, pictures the Dutch public enjoying a winter afternoon in 1608 on the ice. The Little Ice Age ended around 1700. Thereafter, the Earth warmed as indicated by the IPCC graphs in Figure 1.1.

2.2 Solar Intensity

Clearly, the Earth's climate has changed on time scales of centuries. Why did this occur? One possibility is that the sun's heat output changed over time. Satellite measurements of the solar intensity measured in watts per square meter exist from 1975 onwards as shown in Figure 2.5 [45]. These NASA data show the sun's intensity varies by about 0.1% in a cyclic fashion having a period of 11 years. This coincides very closely with the well known sunspot cycle. Sunspots are small dark spots on the sun's surface that astronomers have observed for hundreds of years. Modern science has shown they are as big as the Earth and are magnetic storms. The temperature is about 1,000 °C cooler than the average temperature of the sun's surface. Sunspots therefore produce less heat than other parts of the sun and appear darker. This is analogous to having a campfire. The most heat is generated by the parts of the fire that are also the brightest. It is therefore reasonable that the sun's intensity will be reduced if there are more sunspots.

However, an examination of Figure 2.5a shows that the exact opposite occurs, the sun's intensity increases as the number of sunspots increases! It turns out that in addition to dark sunspots there are bright spots called faculae. Faculae are not readily seen because the brightness of the sun saturates the eye. The increase in solar energy produced by the faculae outweighs the decrease caused by the sunspots producing a net increase in solar power.

Sunspots were first observed in about 1600. The number of sunspots has varied over time as is shown in Figure 2.5b. The sharp decreases in sunspot number in the 1600s and immediately after 1800 are known as the Maunder and Dalton Minima, respectively. It is not clear whether the Maunder Minimum occurred because the sun actually had fewer sunspots or because solar observations were intermittent during this time. The number of sunspots has varied cyclically with a period of 11 years for over the last 200 years. The average number of sunspots did increase during the 1900s. Figure 2.5 gives rise to the intriguing suggestion that the sun may indeed have had fewer sunspots during the 1600s which may have corresponded to a reduced solar intensity that contributed to the Little Ice Age.

Other evidence of small variations of the solar intensity exists [46]. The sun spews out a mess of elementary particles known as the solar wind. An incoming neutron can collide with nitrogen in the Earth's atmosphere to produce ^{14}C . This radioactive isotope of carbon has a half life of 5,760 years and is useful for carbon dating historical objects. This is done by comparing the ratio of ^{14}C to regular stable ^{12}C in an old object, to that of a recently grown biological specimen. The amount of ^{14}C in the atmosphere is not exactly constant. This was

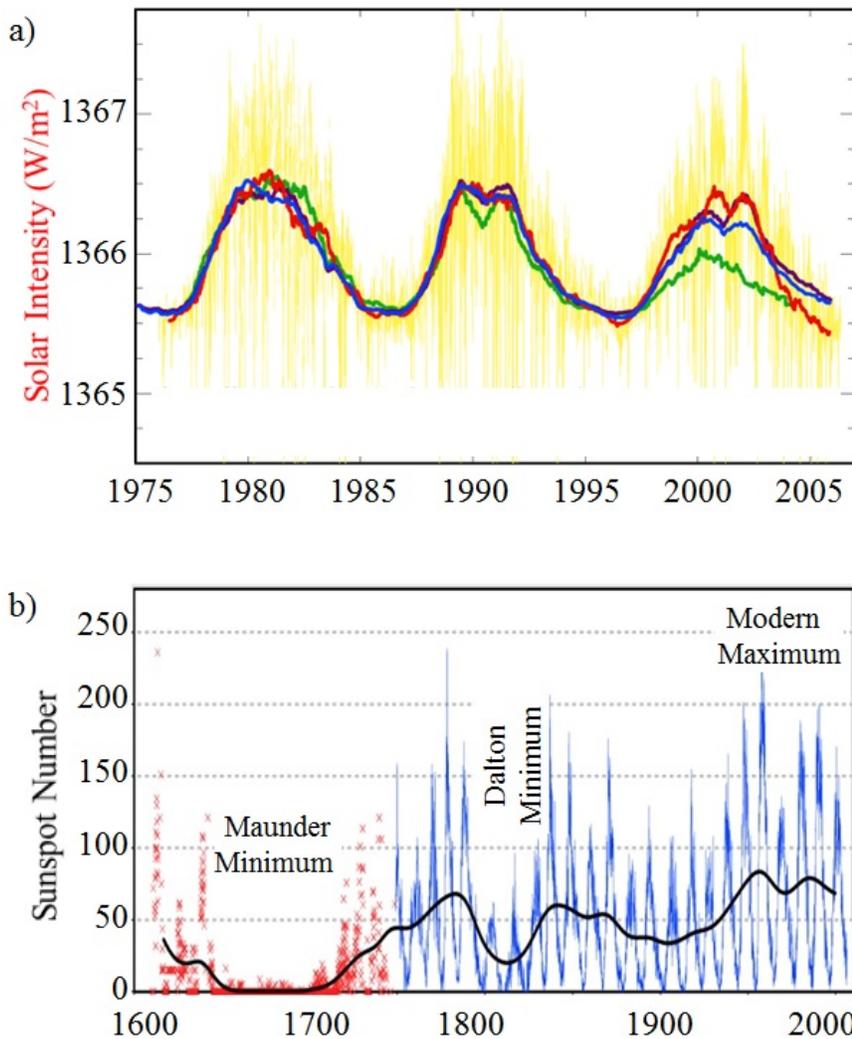


Figure 2.5: Variation of a) the solar intensity and b) the number of sunspots [45]. The red curve is the annual average of the daily (yellow) measurements of the solar intensity. The green curve shows the number of solar flares while the purple curve gives a measurement of the radio wave intensity. (b) shows the number of sunspots. The data in red may be unreliable as observations may have been taken intermittently as opposed to the later data in blue. The black curve is the sunspot number averaged over 10 years.

discovered by carbon dating the rings of Bristlecone pine trees that can live for several thousand years [28, 37].

It is reasonable to conclude that the sun's intensity has not been constant over time. This must be considered when creating a global computer model of the climate. There are no obvious signs that the Earth's temperature varies with a period coinciding with the sunspot cycle. Hence, it is unlikely that the observed variation of the solar intensity is solely responsible for climate change.

2.3 Atmosphere

Does the composition of the atmosphere affect the climate? Volcanic eruptions have shown this is the case. Figure 2.6 shows a picture of the eruption of Mount Pinatubo, Philippines in 1991. A volcano can shoot an enormous amount of gases and debris high into the atmosphere. The heavier ash material settles back to the Earth relatively quickly near the volcano. Finer particles remain in the atmosphere much longer. These particles ascend high into the atmosphere where the jet stream distributes them around the Earth. The particles scatter incoming sunlight reducing the sun's intensity at the Earth's surface. Blue light is scattered much more than red light resulting in strikingly beautiful red sunsets. A similar effect also occurs in large polluted cities such as Mumbai (formerly Bombay), India.

Some volcanoes generate sufficient debris in the upper atmosphere to noticeably affect the Earth's surface temperature. The year 1816 is known as the "Year Without a Summer". It followed the eruption of Mount Tambora, Indonesia the preceding year. This is believed to have been the largest volcanic eruption in over 1,000 years [48]. Tem-

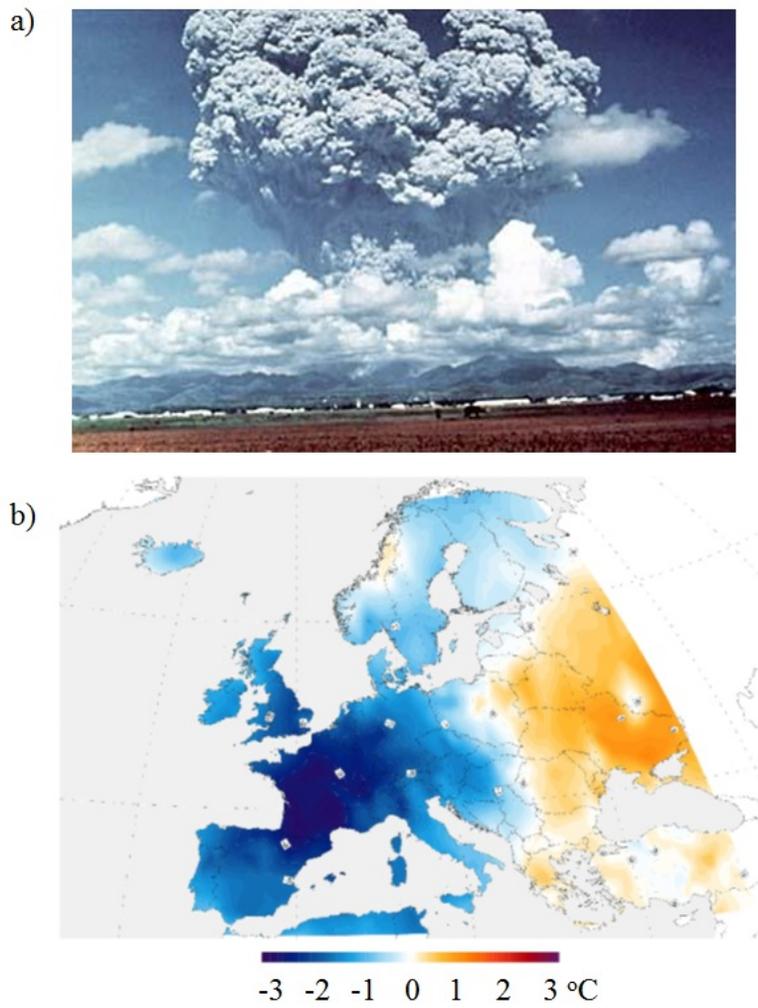


Figure 2.6: a) Eruption of Mount Pinatubo, Philippines in 1991 b) 1816 Summer Temperature Anomaly following the eruption of Mount Tambora, Indonesia the preceding year [47]. The anomaly is defined as the difference of the 1816 and the historically averaged summer temperature.

peratures during the summer of 1816 were noticeably lower as shown in Figure 2.6b. Snow fell on Albany, New York in June! Crops in North America and Western Europe failed. Fortunately, the climate returned to normal the following year as the volcanic particles precipitated out of the atmosphere. This shows that the composition of the atmosphere strongly affects the climate. It also illustrates how climate instability can adversely affect humans.

The components of dry air are shown in Figure 2.7. About 99% of the atmosphere consists of Nitrogen and Oxygen which are essential to animal and plant life. The inert gases Argon, Neon and Helium comprise about 1% of the total. Carbon dioxide (CO_2) and methane (CH_4) are only found in trace amounts. Water vapour is an important atmospheric constituent. Its concentration varies considerably, from as high as 4% in the warm tropics at high humidity to minuscule amounts in the polar regions during winter.

The present day concern about global warming is that mankind is changing the composition of the atmosphere by burning fossil fuels that generate carbon dioxide. The greatly expanded use of oil, coal and natural gas (methane) began with the onset of the industrial revolution as is shown in Figure 2.8 [49]. The use of these energy sources continues to expand as developing countries seek to improve their standard of living.

There are several significant other sources of these so called greenhouse gases. As much as nearly 20% of the annual anthropogenic production of carbon dioxide has been estimated to result from clearing forests by burning vegetation [50, 51]. The most notable deforestation has occurred in Brazil where about 10%, or 400,000 km^2 , of the

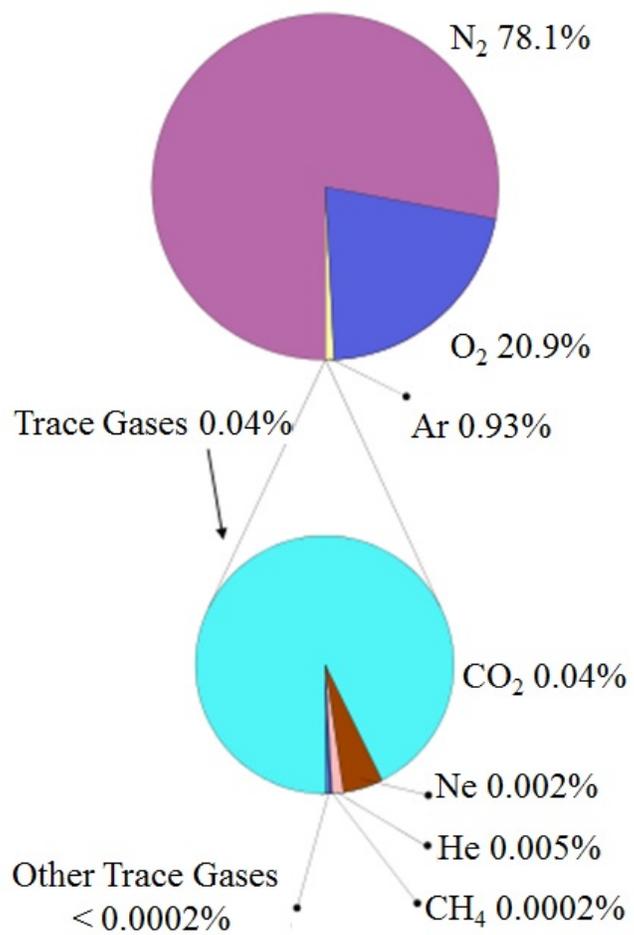


Figure 2.7: Composition of dry air by volume.

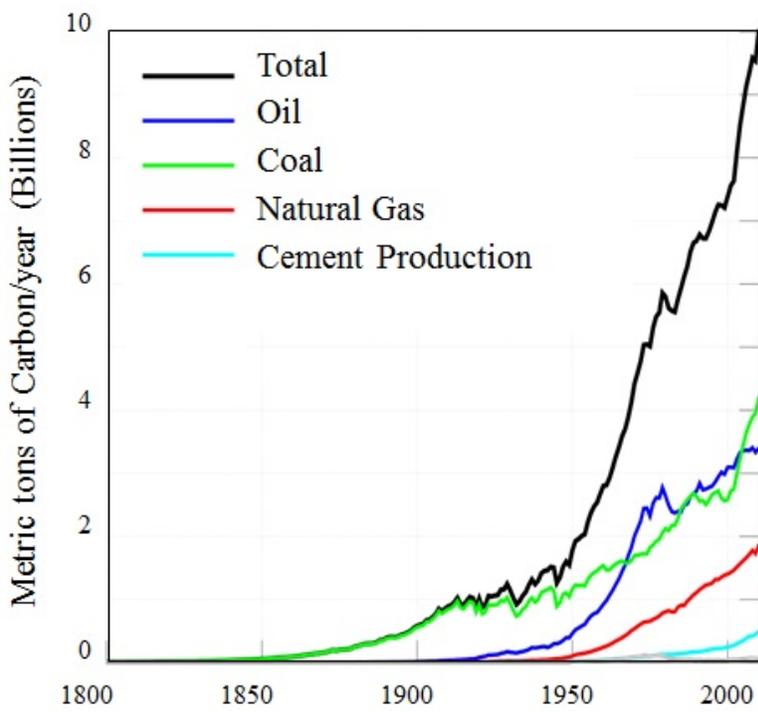


Figure 2.8: Increased use of fossil fuels over time [49]

Amazonian rainforest was destroyed during 1988-2013 [52]. Another large potential source of greenhouse gases is the Arctic permafrost which presently traps a great deal of carbon. Increased biological activity will produce a great deal of carbon dioxide and methane if warming temperatures melt the permafrost [53, 54]. This will add to the methane already inadvertently released during natural gas drilling and from leaky pipelines [55]. An enormous amount of methane is also trapped in the form of methane hydrates at low temperatures in ocean sediments which may be released if the oceans warm [56]. Inevitably, the popular media cannot refrain from writing titillating stories about methane generation by farting cows, kangaroos, etc. [57].

The amount of carbon dioxide in the atmosphere varies. It is relatively higher in heavily industrialized regions. Measurements of the atmospheric CO₂ concentration have been made at Mauna Loa, Hawaii since 1958 as shown in Figure 2.9 [20]. This location is distant from large cities and therefore more likely accurately reflects the average global carbon dioxide level. Over the past 67 years, the CO₂ concentration has risen from 315 to 400 parts per million (ppm) per volume of the atmosphere. The preindustrial CO₂ concentration before 1800 is estimated to have been 280 ppm. The measurements show the CO₂ level varies throughout the year. It goes down in spring and summer and increases during fall and winter by about 6 ppm. This is caused by biological activity. Most of the Earth's land mass is located in the Northern Hemisphere. Carbon dioxide is absorbed by plants during spring and summer. Correspondingly, vegetation decays in the fall and winter releasing carbon dioxide back into the atmosphere. Nevertheless, there has been a steady upward trend of over 1 ppm per year

since 1958.

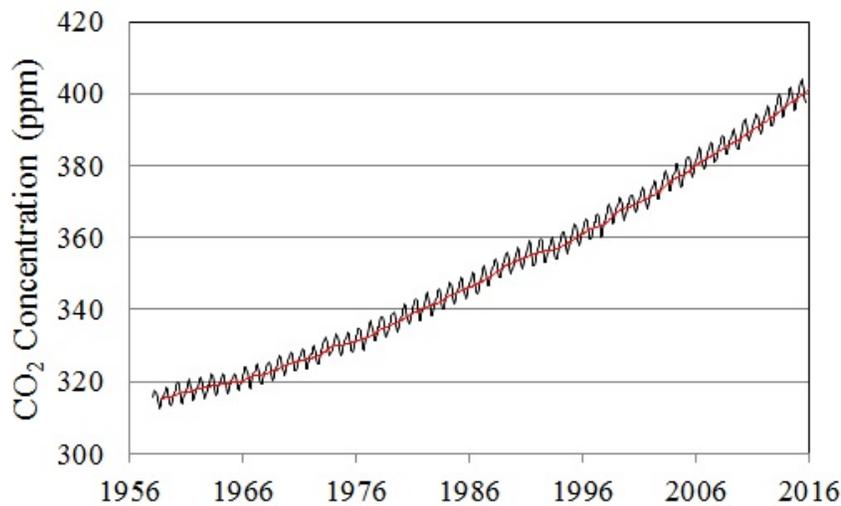


Figure 2.9: Change in atmospheric carbon dioxide recorded at Mauna Loa, Hawaii over time [20]. The red curve is the annual averaged CO₂ level.

A much longer record of carbon dioxide concentration has been found using ice cores obtained at Vostok, Antarctica [58]. Each year a layer of snow as well as dust falls onto the surface. The weight of succeeding layers compresses the snow which eventually turns to ice. Air is then no longer free to be exchanged with the atmosphere but is trapped in small bubbles. Figure 2.10 shows the concentration of CO₂ measured as a function of the depth of ice retrieved from a borehole at Vostok. The date of ice formation can be determined from measurements of the concentration of various radioactive isotopes. The temperature is determined by measuring the abundance of the heavier isotopes of oxygen and hydrogen in the ice [59]. Regular oxygen has

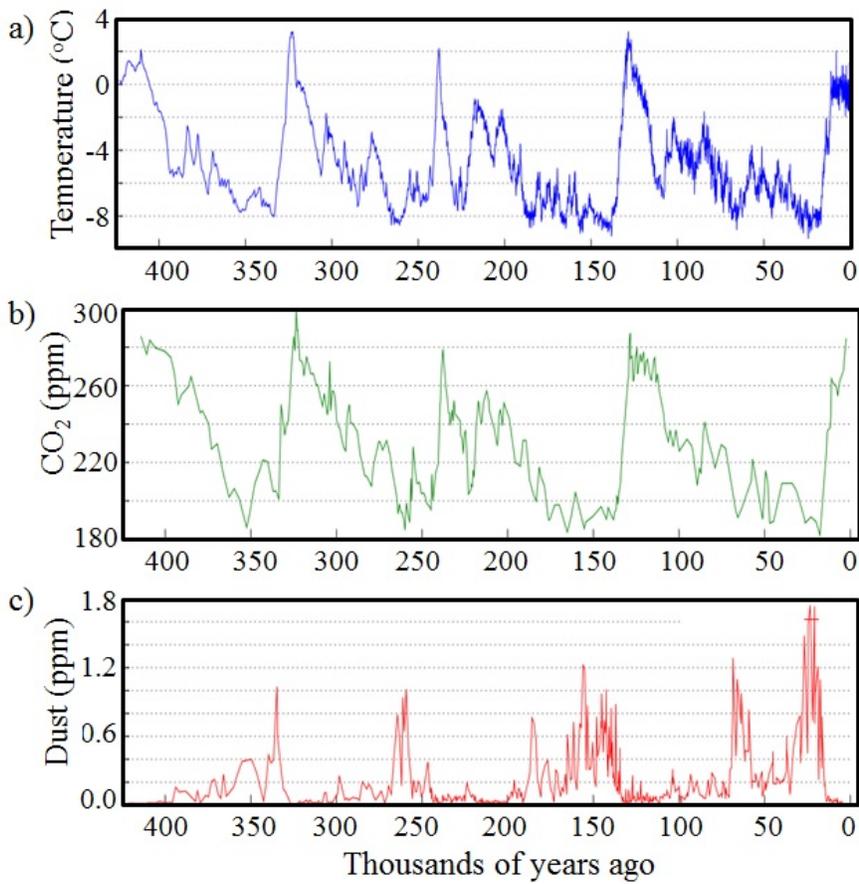


Figure 2.10: Vostok, Antarctica ice core determination of a) Temperature change relative to the present b) CO₂ concentration and c) Dust concentration for the last 400,000 years. [58]

eight protons and eight neutrons and is labelled ^{16}O . A few oxygen atoms have two additional neutrons and are thus labelled ^{18}O . Similarly, some hydrogen atoms have an additional neutron and are called deuterium. These heavier isotopes cause some water molecules to be slightly heavier. It has been observed that the concentration of these heavy water molecules in snow depends on the temperature. A heavier water molecule requires more energy to evaporate than a regular water molecule. Hence, at colder temperatures, the abundance of the heavier isotopes in water vapour is less, which in turn lowers their concentration in snow. This allows the temperature to be determined.

Figure 2.10 shows a very strong correlation between the temperature change and the carbon dioxide concentration although less so with dust that would be produced by volcanoes. It is especially noteworthy that the present CO_2 level of 400 ppm, is much higher than that occurring at any time in the past 400,000 years! The obvious question to ask is which happened first. A number of recent careful examinations have shown that the increase in CO_2 appears to have occurred about 800 years after the temperature began to increase [60]. The increase in CO_2 is believed to have been caused by the release of carbon dioxide by a warmer ocean. A similar effect happens when a bottle of coca cola is warmed producing bubbles of carbon dioxide. It does not appear that increasing atmospheric carbon dioxide was responsible for the initial rise in temperature. However, the possibility exists that increases in CO_2 levels caused additional temperature increases. The question remains as to what triggered the initial rise in temperature and why the temperature at a later date began to decrease even though the CO_2 concentration was elevated?

2.4 Interaction of Sunlight with Atmosphere

The theory of global warming necessitates understanding how sunlight interacts with the atmosphere. Sunlight consists of all colours of the spectrum. This is shown in Figure 2.11 where white light is separated into its component colours by a prism. The human eye is sensitive to visible colours ranging from blue to red that correspond to wavelengths from 0.4 to 0.6 microns. This is only a small part of the light or radiation that comprises sunlight. Wavelengths longer than red light are known as infrared radiation or heat. A thermometer placed beyond the red spectrum shows an increasing temperature due to absorption of this infrared radiation. Similarly, ultraviolet radiation has wavelengths shorter than blue light. Ultraviolet rays are of special concern because too much exposure can cause skin cancer.

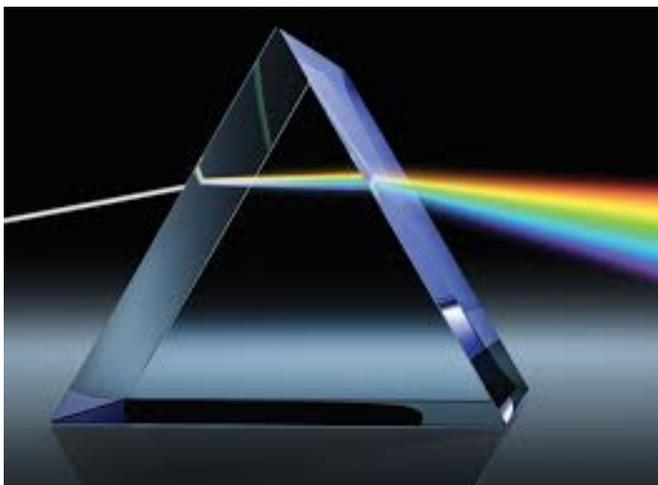


Figure 2.11: Separation of white sunlight into its colour components by a prism.

Figure 2.12 illustrates how incoming solar radiation interacts with the atmosphere. Here, radiation refers to all possible wavelengths of light comprising the infrared, visible and ultraviolet. It should come as no surprise that the human eye evolved to be sensitive to the visible part of the sun's spectrum that is not absorbed by the atmosphere. Radiation at wavelengths below 0.3 microns is scattered by a process called Rayleigh scattering which is a fancy name referring to the scattering of light by air molecules in all directions. Blue light scatters much more than red light which explains why the sky is blue.

Oxygen and ozone are important absorbers of light having wavelengths near 0.3 microns, blocking this UV light from reaching the Earth's surface. In the 1980s, the alarm was sounded that ozone high in the atmosphere was being destroyed due to the release of chemical compounds known as chlorofluorocarbons then commonly used in aerosol spray cans and in refrigeration [61]. These compounds break down releasing chlorine which can accumulate especially in clouds in the stratosphere, the part of the atmosphere between about 10 to 50 km above the Earth's surface. Chlorine acts as a catalyst breaking down ozone. The resulting ozone hole is particularly acute in polar regions during winter. Fortunately, atmospheric chlorofluorocarbon concentrations are slowly declining as a result of the 1986 Montreal Protocol, an international environmental treaty that sharply limited their use [62]. This history shows how unforeseen chemistry involving just one class of compounds can have a deleterious effect on the ability of the atmosphere to protect humans.

Many molecules absorb the sun's radiation at infrared wavelengths. Each molecule has its own fingerprint of wavelengths or spectrum that

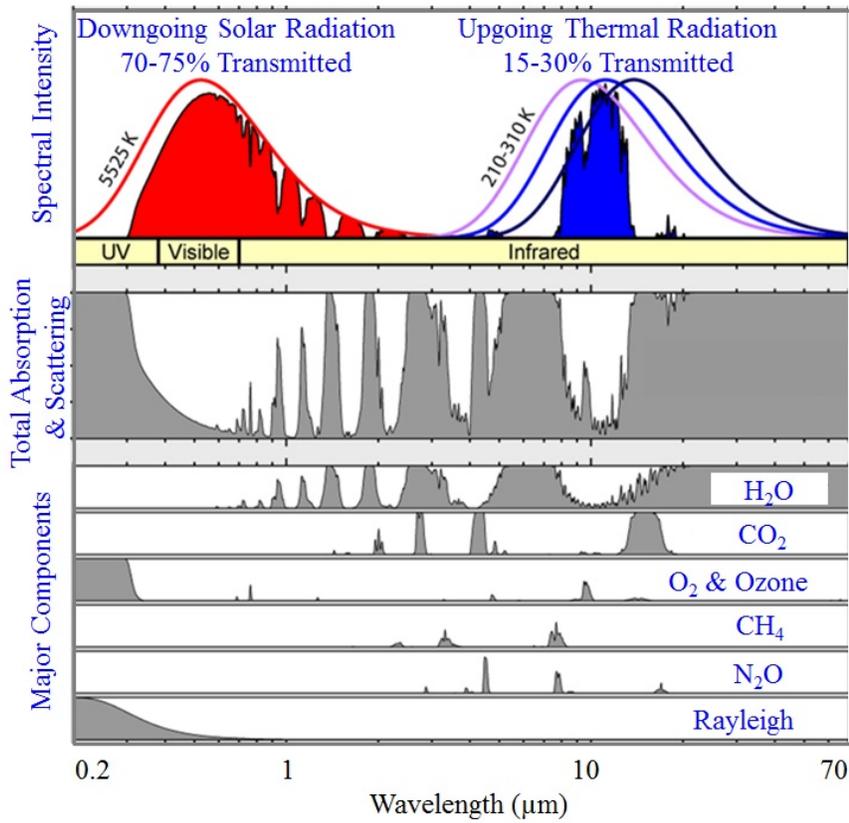


Figure 2.12: Interaction of the atmosphere with incoming solar radiation and outgoing thermal radiation produced by the Earth. Major greenhouse gases include water vapour H_2O , carbon dioxide CO_2 , oxygen O_2 , ozone O_3 , methane CH_4 and nitrogen oxide molecules such as N_2O .

it can absorb. It is by measuring these absorption wavelengths that astronomers determine the gas composition of planetary atmospheres. Figure 2.12 shows methane absorbs light at wavelengths of 1.7, 3.3 and 8 microns while carbon dioxide absorbs at 2.7, 4.3 and 15 microns. The exact wavelength and how strongly a molecule absorbs light depends on a number of factors including the temperature and air density. Some molecules absorb light more readily than others. A single methane molecule absorbs light about ten times more strongly than a carbon dioxide molecule. Hence, methane can significantly absorb radiation even though its atmospheric concentration is much lower than carbon dioxide.

The sun warms the Earth's surface. Every object emits radiation that depends on its temperature. The sun is very hot and therefore produces visible light. Cooler objects generate heat or infrared radiation. The Earth's surface radiates thermal radiation at infrared wavelengths. This outgoing radiation is strongly absorbed and scattered by the atmosphere. Hence, the atmosphere acts as a blanket trapping the Earth's heat which is known as the greenhouse effect. Increasing the concentration of gases such as carbon dioxide is likely to increase the thickness of the atmospheric blanket warming the Earth. This was first recognized by Svante Arrhenius, a Swedish scientist, who estimated in 1896 that doubling the CO_2 in the atmosphere would increase the average global temperature by about 2°C [63]². This estimate is remarkably close to recent estimates.

²Scientists are renowned for boring talks. Chemists wake up when told that Arrhenius was a very good physicist. Unfortunately, there were so many excellent physicists meriting the Nobel Prize in the early 1900s that he received the Nobel Prize for Chemistry as a consolation.

Water vapour is an especially strong absorber of infrared radiation. The ability of air to contain water vapour, increases strongly with temperature as we know from hot muggy summer days. Hence, the atmospheric water vapour concentration varies considerably with latitude and altitude. A rise in temperature would especially affect the Arctic. Reduced ice cover would expose open ocean, increasing evaporation. Models of global warming estimate that this increase in water vapour is responsible for about half of the forecast temperature increase [64]. A major uncertainty in predicting the effect of water vapour are clouds. It is possible, although it has not been observed, that an increase in water vapour increases the number and thickness of clouds. Clouds not only reflect incoming sunlight, but also scatter infrared light or heat, acting as a blanket. Cloudy nights are warmer than clear nights while the temperature drops when a cloud blocks the sun. It is difficult to determine whether clouds cause a net cooling or heating [65]. The various types of clouds; cumulus, cirrus or stratus may have different effects [66]. The 1997 IPCC report described clouds as “the largest source of uncertainty” in predictions of climate change.

Another critical factor when considering the interaction of the Earth with sunlight is the reflectivity or albedo of the Earth’s surface. It is much hotter on a summer day when walking across a black asphalt parking lot as opposed to strolling in a pleasant meadow. As the old saying goes, if you pave paradise to make a parking lot, you change the climate [67]. The surface covering can also vary considerably from season to season. Snow and ice reflect light much more strongly than open ocean or dark soil. Mankind has changed the Earth’s reflectivity not just by building sprawling urban centers but by ploughing mil-

lions of square kilometers of pristine prairie and clear cutting forests to make farmland.

2.5 Climate Model Projections

Beginning about 50 years ago, extensive efforts have been made to produce computer models of the global climate. These are massive undertakings done by large teams of scientists. Two of the most widely known are based at the National Center for Climate Research (NCAR) at Boulder, Colorado and the Hadley Centre for Climate Prediction and Research in the United Kingdom. The fundamental physical laws governing the behaviour of a gas are well understood. However, a model of the atmosphere must take into account a number of different gases whose concentrations vary with altitude, latitude and longitude. One also needs to consider temporal changes not just from day to night but due to the seasons. The response of each gas to the sun's radiation must be considered at different wavelengths. Clouds must be modelled, especially if one wishes to examine precipitation. The surface of the Earth must be considered. The albedo or surface reflectivity varies considerably over land. The oceans can exchange heat as well as gases with the atmosphere. Ocean and wind currents are complicated. It is impossible to consider all of these effects exactly as the power of even the world's fastest supercomputers is completely insufficient. Many simplifying approximations are essential. Typically, a global climate model is run with many parameters that are adjusted so that the model accurately predicts the climate observed during the 20th century. One then lets the model proceed into the future to make predictions.

Figure 2.13 shows the results of a number of different models that

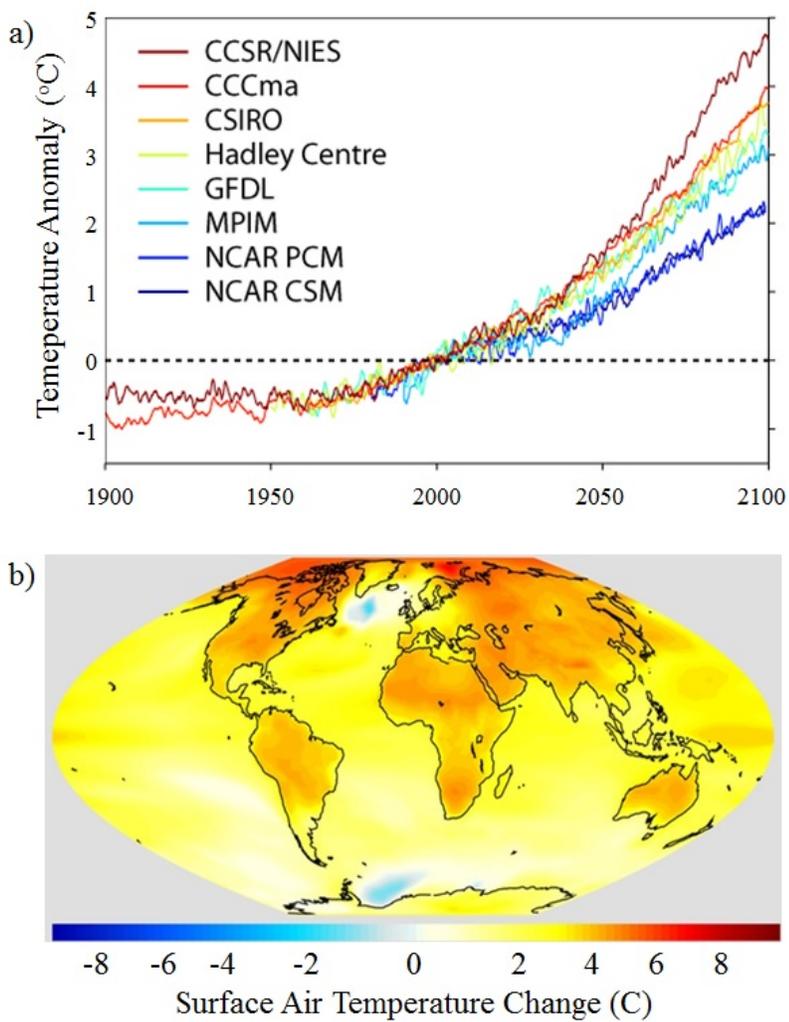


Figure 2.13: a) Predicted temperature change for various global climate models and b) Temperature change in 2050 relative to 1971-2000 [68].

consider various future climate scenarios. The temperature during the 21st century is predicted to increase at a rate between 2 and 5 °C per century. The higher estimate is obtained for the case of higher greenhouse gas concentrations. This warming is not predicted to occur uniformly over the Earth. The temperature increase over the Arctic is expected to be about five times larger than that experienced near the equator. The models also make predictions about precipitation, storms, sea levels, melting of the polar ice caps, etc.

Models are essential for scientific progress. It is important that they be tested by comparing their predictions to observed data. Inevitably, one finds discrepancies between models and observations that lead to a refinement of a model. That does not mean that the original model was total nonsense, merely our understanding was incomplete. In science, there are times when we believe something is well understood but a comparison with observations shows that is not the case. This can be frustrating. However, scientific progress requires that we be humble enough to recognize that human intuition is not infallible. This book looks at the evidence. How closely do the global warming theory predicted changes in temperature, precipitation, storms, etc. agree with observations?

3

Is The Earth Warmer?

Modern temperature measurement is easy. Digital thermometers in our cars and watches routinely display the temperature to one tenth of a degree. The inclusion of a decimal digit is pointless. It doesn't affect our decision to wear a coat but auto manufacturers believe it causes us to swoon over a new vehicle. Many thermometers measure the change of a material's volume due to a change in temperature. This effect has been known for thousands of years. A simple thermometer can be constructed by enclosing water in a glass tube. Adding a colour dye facilitates reading the water level. Finally, a numeric scale is added. The thermometer can be calibrated using convenient references such as freezing/boiling water or the body of a hopefully healthy human. An obvious complication arises at temperatures below the freezing point or above the boiling point of the thermometer fluid.

Daniel Fahrenheit (1686-1736) was the first to use thermometers with mercury which expands significantly when heated [69]. It has melting and boiling points of $-39\text{ }^{\circ}\text{C}$ and $357\text{ }^{\circ}\text{C}$ respectively, mak-

ing it ideal for measuring terrestrial temperatures. The Fahrenheit temperature scale is defined by setting the freezing and boiling points of water to 32 and 212 °F, respectively. It is no longer widely used except in a few undeveloped countries and the United States. It has been replaced by the Celsius or Centigrade scale which uses common sense to set the freezing and boiling points of water to 0 and 100 °C respectively, as measured at sea level pressure.

Thermometer readings have been recorded at some places in Europe for over 300 years. Longer records of temperature can be inferred using so called “proxy data”. An example is the thickness of a tree or coral ring. The assumption made is that trees grow more in a warm year than when it is cold. A comparison of rings grown during a recent period for which thermometer readings exist permits the temperature to be estimated for years extending back for up to 5,000 years in the case of the Bristlecone pine species [70]. Of course, other factors also govern growth. Most notably, proper tree nutrition includes sufficient moisture. This limits the accuracy of temperatures inferred using proxy data. In addition, aged biological specimens are not found everywhere on Earth. This chapter focusses on temperature data measured by thermometers.

3.1 Data Analysis

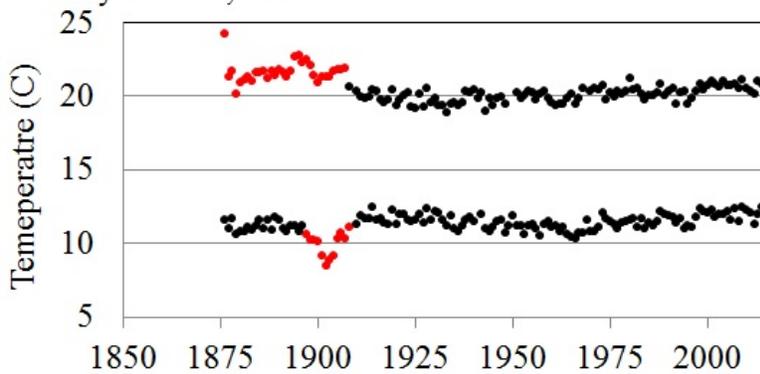
It is important to understand the limitations of any climate data. Every measurement has an uncertainty. Instruments sometimes fail or are improperly used. The result may have an impressive number of digits but is completely meaningless. For example, a dieter may proudly announce a decrease in weight from 60 to 55 kg (1 kilogram

= 2.54 pounds). However, if the scale operates incorrectly, no useful information is conveyed and the exuberance is premature.

Some examples of flawed data are shown in Figure 3.1. The first graph shows the average minimum and maximum daily temperature observed at Moruya Heads, Australia. The large change in maximum temperature during the first two years of the station's operation is unlikely to reflect an actual climate change. A more likely explanation is that the weather observer didn't quite have the hang of the job. Perhaps, she/he did not take measurements during winter when it was deemed too cold to venture outside. The maximum temperature data remained fairly stable until about 1910 when there was a sudden downwards step of about 2° C. This is much larger than the year to year temperature variation and therefore suspicious. Such sudden steps are called inhomogeneities. It is not clear what caused the abrupt downward shift in maximum temperature at Moruya Heads. This is commonly the case as documentation of station procedures let alone pictures of the instruments and station site are missing. Many of the original instruments may no longer exist. This explains why the World Meteorological Organization issues manuals to standardize observation procedures [71]. For the case of Australia, it is known that standardization of weather measurements was introduced around 1910 [72]. One stipulation was that thermometers be housed in a white wooden box called a Stevenson Screen. Regulations state the proper box height, the surrounding ground cover, distance from nearby trees, etc. It is reasonable to expect the maximum temperature inside such a box would be lower than that found by a thermometer directly exposed to the midday sun. This may account for the downward shift

in the maximum observed temperature in 1910. It is not known what caused the dip in the minimum temperature during 1895-1910 but is unlikely to have been a natural climatic effect.

a) Moruya Heads, Australia



b) The Pas, Canada

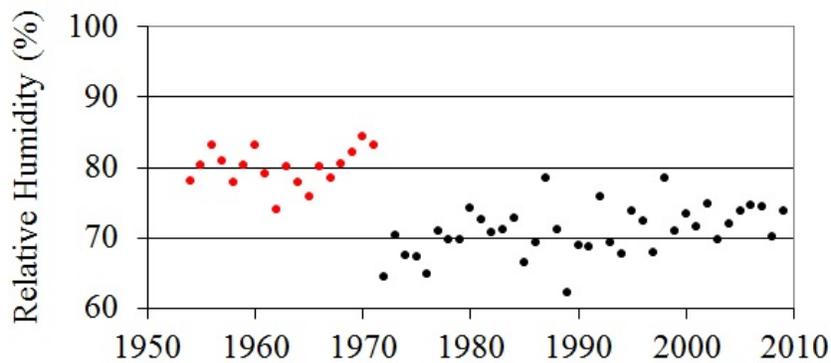


Figure 3.1: a) Minimum and maximum temperatures measured at Moruya Heads, Australia and b) winter relative humidity measured at The Pas, Manitoba in Canada. The red points are suspect as discussed in the text.

Figure 3.1b shows an inhomogeneity where the relative humidity abruptly decreased by over 10% from 1970 to 1971 at The Pas, Manitoba, Canada. Similar downward steps were found in relative humidity observations at many Canadian airports during winter [73]. Meteorological stations are frequently found at airports that monitor temperature and humidity. As air rises, the temperature falls. Eventually the altitude is reached where the relative humidity is 100% and clouds form. Hence, airports measure relative humidity to estimate cloud height. This information is conveyed to the pilot who then knows at what altitude the runway should be visible.

The dates of the inhomogeneities, similar to that shown in Figure 3.1b, coincided with a system wide replacement of the relative humidity sensor in the early 1970s. The new instrument called a dewcel replaced the psychrometer that consisted of so called wet and dry bulb thermometers. The wet bulb thermometer refers simply to a wet cloth wrapped around a standard thermometer. The psychrometer is operated by swinging the two thermometers in a circular fashion like a cowboy twirling a lasso at a rodeo. At low humidity, water readily evaporates from the wet rag and the wet bulb thermometer reads a lower temperature than the dry bulb thermometer. This is analogous to stepping out of the shower. One gets cold as water evaporates from one's skin. The relative humidity is determined by the temperature difference between the wet and dry bulb thermometers. A problem occurs at very low temperatures which at The Pas can reach $-40\text{ }^{\circ}\text{C}$ in winter. The wet rag freezes instantaneously and the psychrometer no longer works. The dewcel consists of a solution of lithium chloride that absorbs moisture which changes its electrical conductivity.

The electrical resistance therefore depends on the relative humidity. An important advantage is the dewcel can be monitored by either a computer or a human operator who remains in a warm building.

It is useful to examine a large number of stations when studying possible climate change. One then finds the average temperature change which is relatively insensitive to inhomogeneities or measurement errors unique to each station that occur in different years. However, systemic changes such as automation or the introduction of a new instrument such as the Stevenson screen or dewcel, can seriously affect average data. It is critical to check if data have inhomogeneities before evaluating climate change trends. Failure to do so may result in a conclusion of exaggerated climate change when in fact what is occurring is instrumental failure or human error.

Mathematicians have developed techniques to discover and correct for inhomogeneities. Typically, one averages data for periods of time immediately before and after a suspected inhomogeneity. One concludes an inhomogeneity exists if the difference of the two averages is larger than the year to year data scatter [74, 75]. Some researchers have corrected inhomogeneities using data at nearby surrounding stations that do not experience inhomogeneities. This is unrealistic in remote parts of the world such as the Arctic where the closest station may be over 1,000 km distant and experience a very different climate. Adjustments to data can be controversial. There have been instances where data were adjusted due to a change of instruments even though there was no apparent discontinuity [76].

It is kosher to check for a change in temperature over a period of a time only after data have been checked for inhomogeneities. Typically,

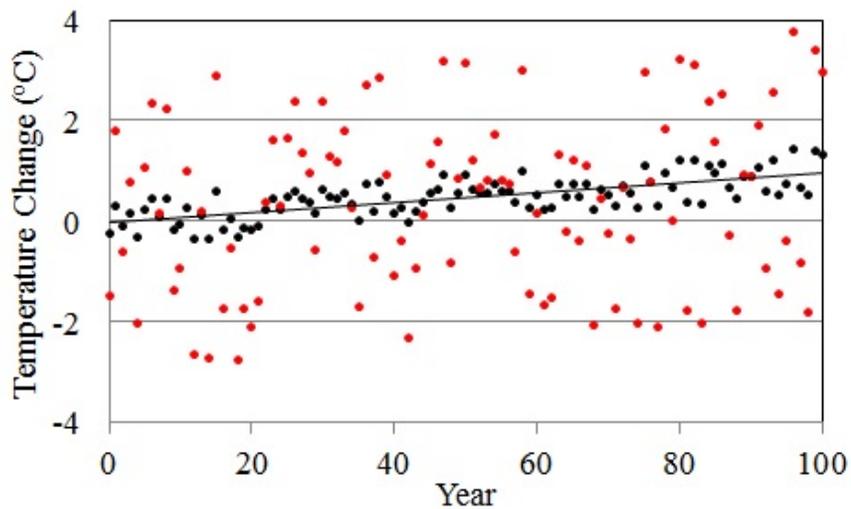


Figure 3.2: Effect of noise on the determination of a temperature trend. These data were generated by considering a line sloping upwards at a rate of $1.0\text{ }^{\circ}\text{C}$ per century to which was added random noise. The noise of the red time series has six times the amplitude as that of the black time series. The slope of the black (red) data is found to be 1.0 ± 0.2 (1.0 ± 1.2) $^{\circ}\text{C}$ per century. The uncertainty of the trend derived using the black data is less than the trend magnitude. The trend is then said to be statistically significant. Correspondingly, the uncertainty of the trend found using the red data exceeds the trend which is therefore not statistically significant.

one fits a straight line to the data. The data are scattered about this line which is not surprising because temperature varies slightly from year to year. One can conclude there is significant climate change if the year to year temperature fluctuation is small compared to the temperature change over the period in question. Figure 3.2 shows a sample of artificial data that illustrates this point. The slope of the line for the black and red dots is $1\text{ }^{\circ}\text{C}$ per century to which random noise has been added. The noise amplitude of the red points is six times larger than for the black points. Statisticians assign an uncertainty to the trend that takes into account the data scatter. In the example shown in Figure 3.2, the black (red) data trend is found to be 1.0 ± 0.2 (1.0 ± 1.2) $^{\circ}\text{C}$ per century. The trend is said to not be significant if the uncertainty exceeds the trend magnitude. The uncertainty is the same as the margin of error of a survey. A political poll stating party X has 40% support with a margin of error of 4% nineteen times out of twenty means there is a 95% probability that the real voter support of party X is between 36% and 44%. Similarly, a trend of 1.0 ± 0.2 $^{\circ}\text{C}$ per century means there is a 95% probability the actual trend is between 0.8 and 1.2 $^{\circ}\text{C}$ per century.

3.2 Surface Temperature Observations

The longest temperature observations exist for stations in Europe as shown in Figure 3.3. The station histories of some of these stations such as De Bilt, Netherlands have been carefully analyzed to take into account inevitable changes in the station siting, instruments, etc [77]. Nevertheless, uncertainties remain. Temperature data in the 1700s likely have an uncertainty of about $\pm 1\text{ }^{\circ}\text{C}$ while that of 1800s data is

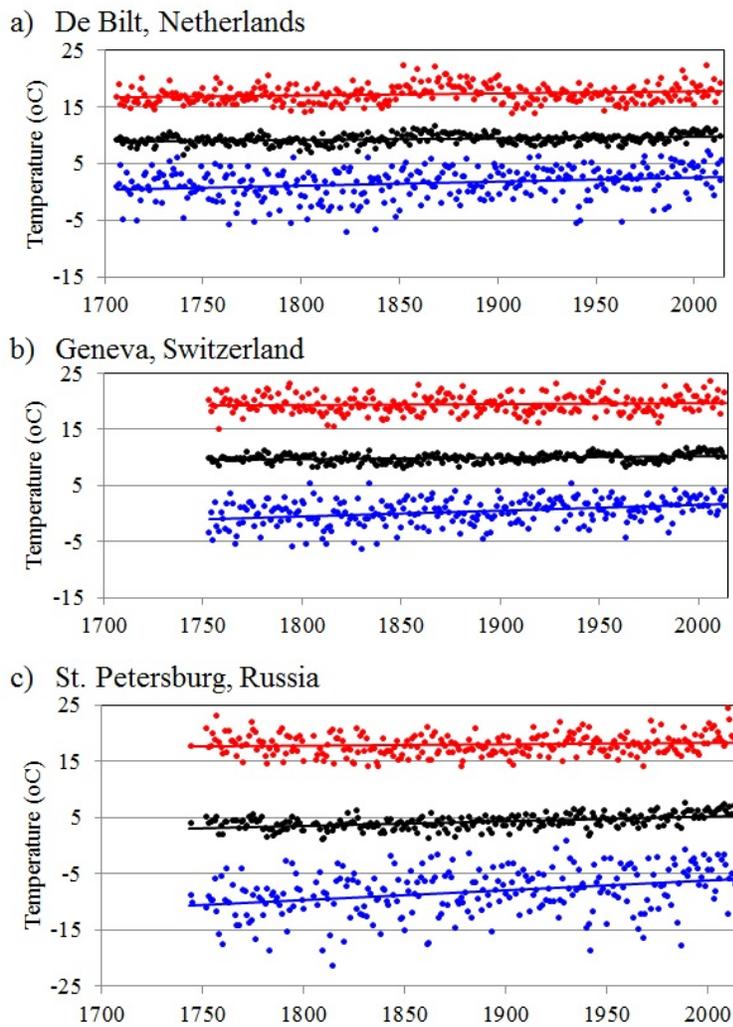


Figure 3.3: Average temperature for January (blue), July (red) and annual (black) at three European stations. The January, July and annual trends in units of $^{\circ}\text{C}$ per century are 0.8 ± 0.3 , 0.3 ± 0.2 and 0.3 ± 0.1 at De Bilt, Netherlands; 1.0 ± 0.4 , 0.2 ± 0.3 and 0.3 ± 0.1 at Geneva, Switzerland; and 1.7 ± 0.2 , 0.3 ± 0.3 and 0.8 ± 0.2 at St. Petersburg, Russia.

about ± 0.5 °C. Monthly averaged temperatures can be downloaded from the Global Historical Climate Network [78] or from national databases maintained by Environment Canada [79] and the Australian Bureau of Meteorology [80].

The annual average temperature was computed if data were available for each month of the year. The average January, July and annual temperatures are shown along with the fitted trendlines. Some years are colder than others. For St. Petersburg, Russia, January of 1813 following Napoleon's invasion, was one of the eleven coldest months ever recorded. Similarly, January of 1942, after Hitler invaded the Soviet Union, was the coldest January in 150 years with an average temperature of -10.9 °C. This not only proves God favoured Russia but illustrates how weather has affected human history.

Figure 3.4 shows the locations of stations for which data were retrieved. Nearly all of the stations having more than 150 years of observations are located in Europe. The continental United States and parts of Asia and Australia have data records extending for over a century. Stations do not exist for most of the globe. The absence of data is particularly striking for the less habitable parts of the continents such as the Sahara desert, Amazon basin, polar regions, etc. and especially for the oceans which comprise 71% of the Earth's surface. It was not until the advent of satellite monitoring beginning in the 1980s that data became available for the entire Earth.

The temperature trends were found for each station as shown in Figure 3.5 provided at least 80% of data were present for all years during the period in question. Most stations experienced significant warming as is shown in Table 3.1. The number of stations in Figure



Figure 3.4: Stations whose temperature observations were examined. 68 stations (blue dots) have more than 150 years of data, 379 (green dots) have 100-150 years of data and 429 (red dots) have less than 100 years of data.

3.5 is considerably less than that in Figure 3.4. The reason is that many stations did not operate continually. Data are missing during periods of severe civil strife. Notable such events include the American Civil War, the Russian Revolution, World War II and the postcolonial period in Africa when there was a great deal of political upheaval.

The plots of temperature trends in Figure 3.5 do not show how climate change is affecting all points on the Earth. Such a map would be desirable to compare to that predicted by the climate models as shown in Figure 2.13. It can be generated by interpolating the temperature between stations. For example, if one knows that New York

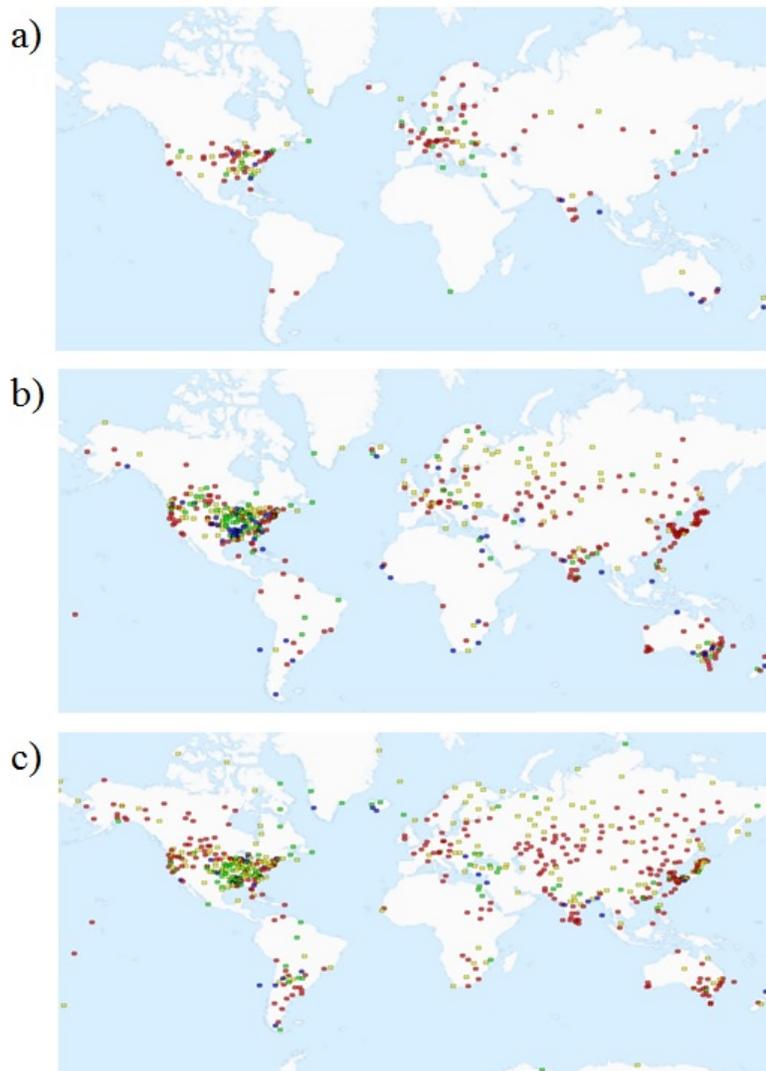


Figure 3.5: Map of station temperature trends for the periods of (a) 1850-2000, (b) 1900-2000 and (c) 1950-2000. Red (yellow) dots represent an increasing trend that is (not) statistically significant while blue (green) indicates a decreasing trend that is (not) statistically significant. Trends are plotted for stations having 80% of data for all years during the period in question.

Table 3.1: Number of stations having decreasing/increasing temperature trends for different intervals. The number of stations having statistically significant trends is in brackets. Trends were only found for stations having data for 80% of all years in the time period in question.

Interval	Number stations with decreasing trend	Number stations with increasing trend
1850-2000	30(10)	117(87)
1900-2000	149(68)	360(233)
1950-2000	145(38)	496(288)

City experienced a warming of $1.0\text{ }^{\circ}\text{C}$ per century while Philadelphia experienced a warming of only $0.45\text{ }^{\circ}\text{C}$ per century, then it is reasonable to assume that a place midway between the two cities like Princeton, New Jersey will experience the average of the two trends, which in this case would be $0.725\text{ }^{\circ}\text{C}$ per century. Such interpolation schemes become more sophisticated when one has data from hundreds of stations. Nevertheless, a huge limitation is estimating the temperature trend at places thousands of kilometers from the closest station which may experience a very different climate. For example, estimating temperature trends over a region such as the southern Indian or Pacific Oceans over the period 1850-2000 has a huge error. Sometimes, scientists become too impressed with computers which display a considerable number of decimal digits. In the case of averaging the New York City and Philadelphia temperatures, it would be silly to claim that Princeton

experiences a warming of $0.725\text{ }^{\circ}\text{C}$ per century. Archival temperatures are typically given to $0.1\text{ }^{\circ}\text{C}$ accuracy. Sophisticated data processing cannot yield data having higher accuracy! Serious caution should be exercised when seeing a map displaying temperature change everywhere on the globe. This conveys a false impression that data are available for every spot on the Earth and are highly accurate.

An alternative analysis uses data from all stations to calculate the change in temperature in a given region. The temperature change is calculated relative to a reference period which is commonly taken to be the 30 year period from 1961-1990. Figure 3.6 shows the temperature change that occurred for the continents located in the Northern and Southern Hemispheres. Using a different reference period such as 1971-2000 does not change the curve shape, but only shifts it slightly up or down.

There is considerable scatter of the data before 1850 when relatively few stations existed. The temperatures for the Northern Hemisphere continents exhibit greater year to year variability than is the case for the Southern Hemisphere continents. This is not altogether surprising given that Asia, Europe and North America have an approximately 50% greater area and the climate ranges from the polar to the tropical. Many of the stations in the southern continents are located near the coast where the oceans moderate the climate. All three northern continents exhibit a warming of about $0.5\text{ }^{\circ}\text{C}$ from 1850 to the 1940s. This was followed by a cooler period during the 1960s and 1970s. In contrast, temperatures remained relatively constant in the southern hemisphere. All continents show a marked increase in temperature of about $1\text{ }^{\circ}\text{C}$ during the 1990s followed by a levelling off

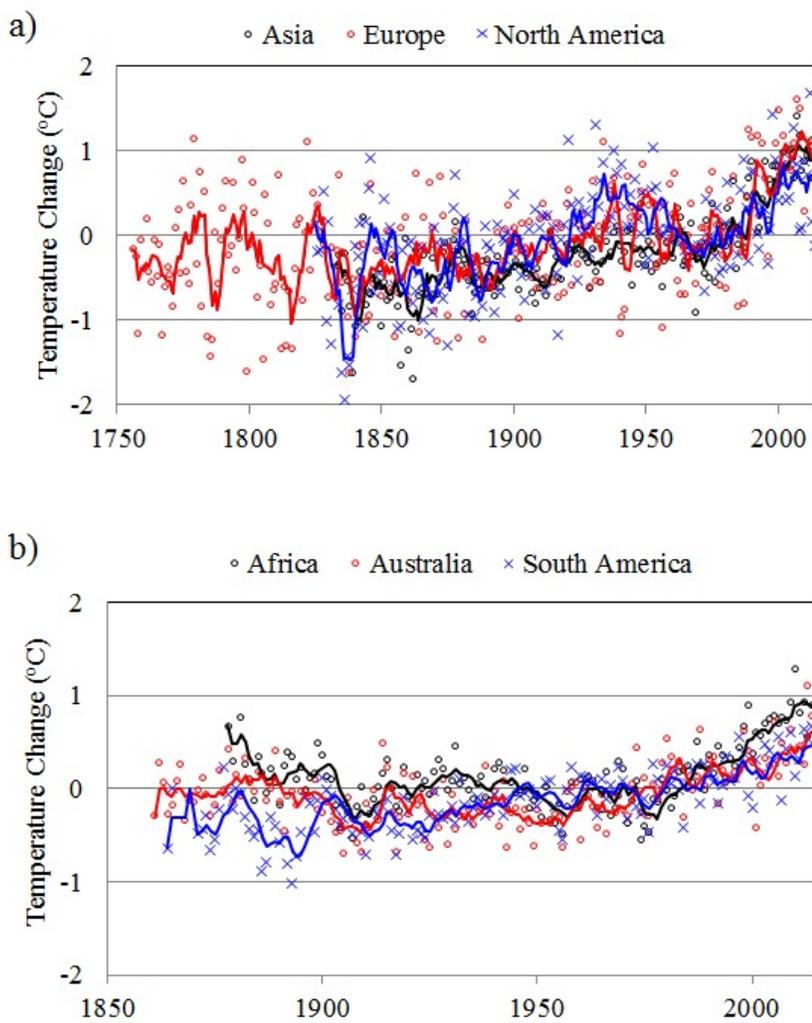


Figure 3.6: Temperature change relative to 1961-1990 in a) Northern and b) Southern Hemisphere. Solid lines are 5 year averages.

after 2000 which is known as the global warming hiatus.

The global temperature change is shown in Figure 3.7. This was calculated in two ways. First, an average of the station data was taken. This preferentially weights North America and Europe where nearly half of the stations are located. An alternative was to combine the time series for the continents excluding Antarctica, for which there are very little data, using weighting factors proportional to the continental areas. The resulting two curves do not differ significantly.

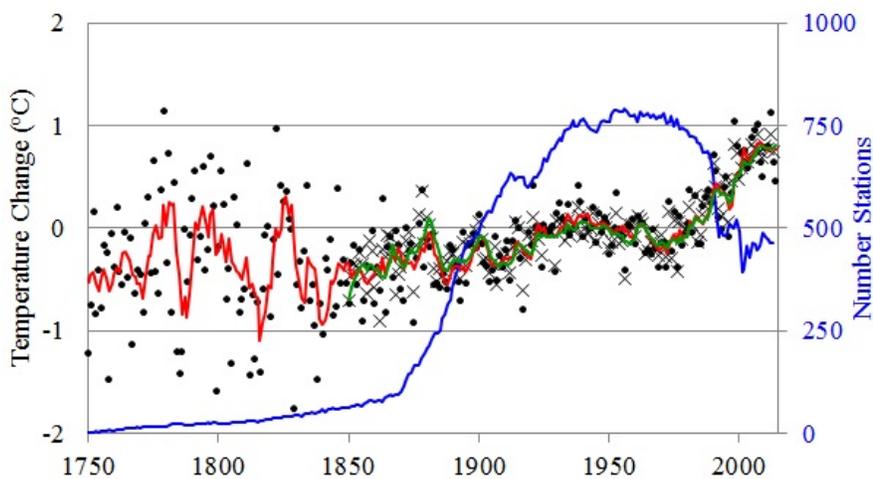


Figure 3.7: Global temperature change relative to 1961-1990. The black dots represent data found by averaging the data over all stations while the crosses were found by weighting the various continental time series by the continental area. The red and green curves are the 5 year moving averages while the blue curve indicates the number of stations. The green curve was only found for years where data exist for all continents excluding Antarctica.

Table 3.2 shows the trends depend strongly on the time period

considered. The calculation of the trends over an interval ending in 2014 instead of only the more aesthetically pleasing 2000, was done to avoid minimizing the effect of global warming. Exclusion of the years after 2000, reduces the trends as shown in Table 3.2. For example, the largest trend of 1.4 ± 0.3 °C per century was found for the interval 1950-2014 but a trend of 1.1 ± 0.5 °C per century occurred during 1950-2000. This highlights the effect of temperature variations on a decadal timescale. It should be noted that the most recent trends for 2000-2014 and 2005-2014 are not statistically significant which is not surprising as these intervals are relatively short.

Table 3.2: Global temperature trends were calculated for data shown in Fig. 3.7 for various time intervals.

Interval	Trend (°C/Century)	Interval	Trend (°C/Century)
1750-2014	0.3 ± 0.1	1750-2000	0.2 ± 0.1
1800-2014	0.4 ± 0.1	1800-2000	0.4 ± 0.1
1850-2014	0.6 ± 0.1	1850-2000	0.5 ± 0.1
1900-2014	0.7 ± 0.2	1900-2000	0.5 ± 0.2
1950-2014	1.5 ± 0.3	1950-2000	1.1 ± 0.5
2000-2014	1.1 ± 2.4		
2005-2014	-2.0 ± 5.1		

The surprising result of Figure 3.7 and the trends shown in Table 3.2 are that global warming has not occurred as predicted by the

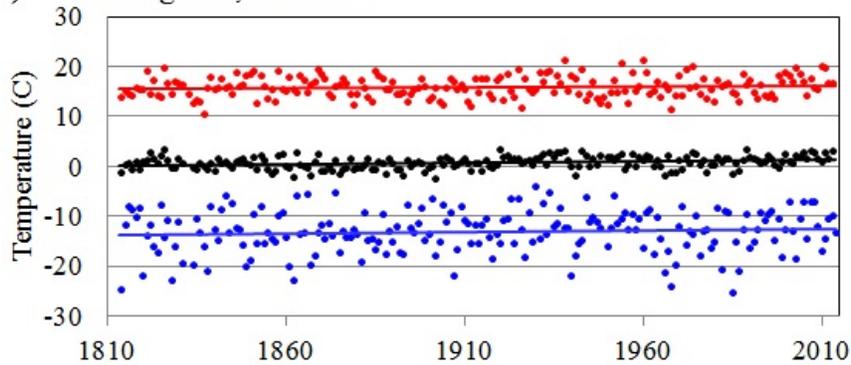
models in Figure 2.13 which forecast an uninterrupted exponential like warming. The slightly cooler temperatures in the 1950s, 1960s and 1970s relative to the 1940s were noted by scientists and a few articles even appeared in the popular press about a coming ice age [81, 82]. The sudden temperature increase in the 1990s is alarming and its arrest or hiatus following 2000 is mysterious. There was no decrease in fossil fuel use after 2000. Indeed, their use continued to increase. There has been discussion about oceans acting as a reservoir to absorb heat [83]. However, the oceans also existed in the 1990s. Why did they suddenly start to absorb heat after 2000? This behaviour was not predicted by any of the climate models and the reason(s) for it is as yet unknown. Recently, there was a claim that the hiatus is not found if ocean temperatures were corrected using buoy as opposed to ship observations [83]. It is not clear why the ocean surface would warm while the land temperatures remain unchanged.

3.3 Surface Arctic Temperature Observations

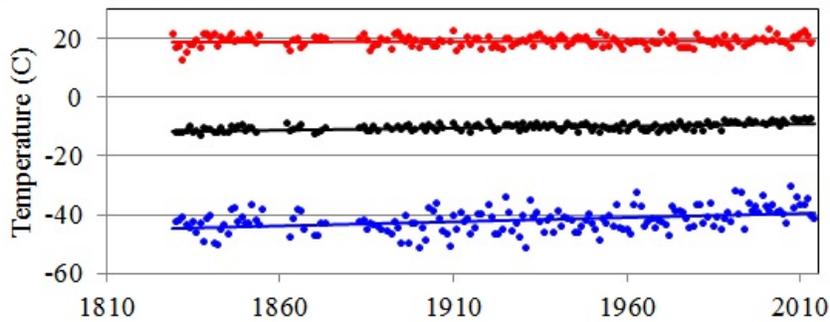
The Arctic is widely considered to be the “canary in the coal mine”¹ as all the models predict global warming should be much more pronounced in this region than for the Earth as a whole. It is therefore useful to examine the Arctic station temperatures separately [84]. Figure 3.8 shows observations taken at three Arctic stations that experience very different climates. Archangelsk is located in northern European Russia on the White Sea. Jakutsk is in Siberia and is one of the coldest places in the Northern Hemisphere in winter. Hay River is

¹Canaries were used in coal mines before the advent of animal rights to detect odourless methane which is highly explosive.

a) Archangelsk, Russia



b) Jakutsk, Russia



c) Hay River, Canada

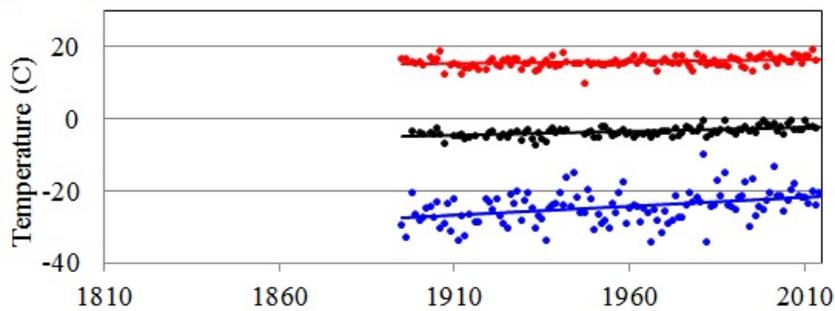


Figure 3.8: Average temperature for January (blue), July (red) and annual (black) at three Arctic stations. The January, July and annual trends in units of $^{\circ}\text{C}$ per century are 0.7 ± 1.0 , 0.4 ± 0.5 and 0.6 ± 0.3 at Archangelsk, Russia; 2.9 ± 1.1 , 0.1 ± 0.5 and 1.3 ± 0.3 at Jakutsk, Russia; and 4.9 ± 2.2 , 1.1 ± 0.8 and 2.4 ± 0.7 at Hay River, Canada.

in the Northwest Territories, Canada. The data record for these stations is much shorter than that for the European stations shown in Figure 3.3. The data for Yakutsk also show a number of years of missing data. This is a common occurrence for stations located in remote regions having inhospitable climates.

Figure 3.9 shows the locations of 118 Arctic stations and 50 European stations for which temperature observations were examined [85]. The temperature change relative to the average occurring during 1961-1990 was found for each station. The warming has been greater in January than in July. Siberia, Alaska and Western Canada appear to have warmed slightly more than Eastern Canada, Greenland, Iceland and Northern Europe. The warming has not occurred at a steady rate. Much of the warming indicated by the trends found during 1800-2014 occurred in the late 1990s, and the data show temperatures levelled off after 2000. The July temperature trend is even slightly negative for the period 1800-2014.

The change in annual Arctic and European temperatures relative to 1961-1990 is shown in Figure 3.9b. The European data in the 1700s and the Arctic data in the early 1800s show considerable scatter because data were present for relatively few stations. It is remarkable how closely the two curves track each other. This does not agree with the prediction of the global warming theory that Arctic temperatures are increasing much more than elsewhere on the planet. Temperatures appear to have been a bit cooler in the later 1800s, slightly warmer around 1940, cooler during the 1950s to the 1970s and warmer during the 1990s.

Table 3.3 shows the temperature trends for the European and Arc-

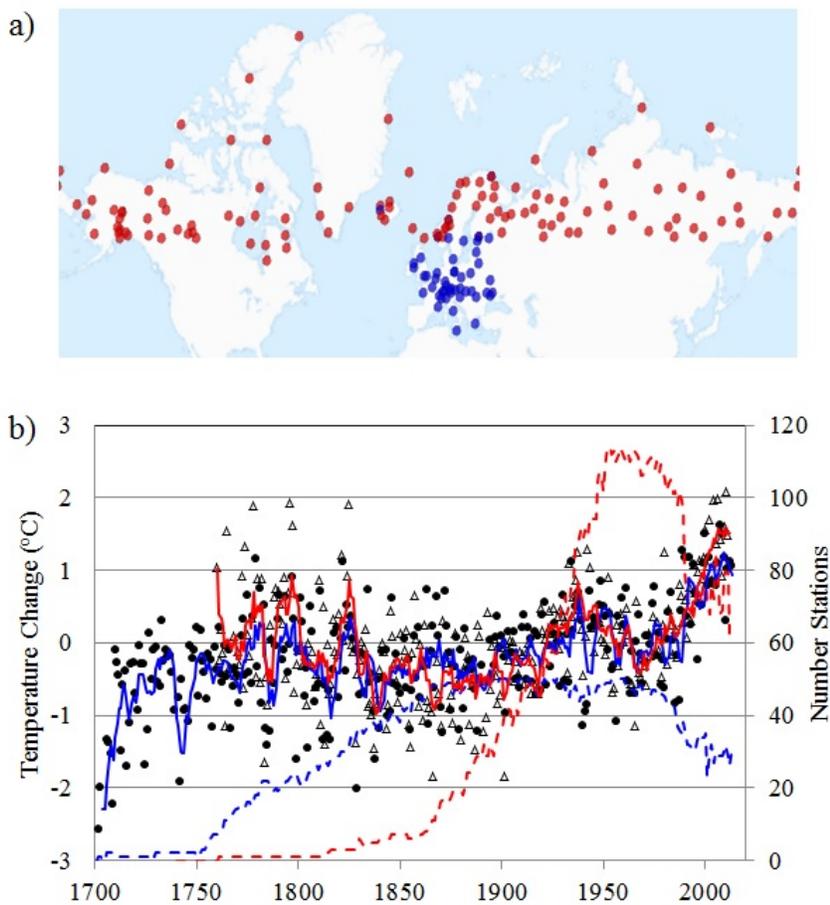


Figure 3.9: a) Map of 118 Arctic (Red) and 50 European (Blue) stations and b) Comparison of annual temperature change relative to that during 1961-1990 for European stations (black dots) and Arctic stations (open black triangles) [85]. The red (blue) curve is the moving 5 year average for the Arctic (European) data. The red (blue) dashed curve gives the number of stations for the Arctic (European) data.

tic stations computed for various time intervals. The two sets of trends agree remarkably well. Typically, the January temperatures exhibit greater warming than the July data. It is not clear why this is the case, although it could be evidence of a shift in global weather circulation patterns. There are well known changes in the jet stream that control the location of large high and low pressure systems. Measurements show a small decrease in winter surface air pressure occurred over northern Canada during the second half of the 20th century [86]. This is likely due to a shift in the position of the jet stream which in some winters brings relatively warm air to Alaska and Northern

Table 3.3: Comparison of European and Arctic temperature trends in units of $^{\circ}\text{C}$ per century calculated for various time intervals. The intervals for July and Annual temperatures end in 2013.

Dataset	Interval	January	July	Annual
Europe	1750-2014	1.0 ± 0.3	0.0 ± 0.2	0.3 ± 0.1
	1800-2014	1.1 ± 0.4	0.3 ± 0.2	0.5 ± 0.1
	1850-2014	1.0 ± 0.6	0.4 ± 0.3	0.7 ± 0.2
	1900-2014	1.1 ± 1.1	0.9 ± 0.5	0.9 ± 0.3
	1950-2014	3.6 ± 2.5	2.7 ± 1.3	2.1 ± 0.7
Arctic	1800-2014	0.9 ± 0.4	-0.2 ± 0.2	0.6 ± 0.1
	1850-2014	0.9 ± 0.5	0.2 ± 0.2	1.0 ± 0.2
	1900-2014	1.4 ± 0.9	0.8 ± 0.3	1.2 ± 0.3
	1950-2014	3.5 ± 2.0	1.9 ± 0.6	3.0 ± 0.7

Europe while frigid air reaches far south into the United States [87]. In other winters, the jet stream brings storms further north creating wetter weather in Alaska and Northern Europe. Cold winter air then does not extend as far into the middle of North America [88].

The close correlation of the Arctic and European temperatures is somewhat surprising since the European stations are nearly all located in large metropolitan areas that have expanded substantially during the past 250 years as their populations have greatly grown. Cities use energy and also change the surface reflectivity of the terrain. Studies have shown that this urban heat island effect has increased temperature by as much as 1 °C, although there is some evidence for cities such as London, England that it has levelled off since 1981 [89]. The urban heat island induced increase in minimum temperature also has been found to be twice that for the maximum temperature. This is consistent with the result that temperatures have increased more in January than in July.

Air masses in Europe, northern Asia and North America do not stop at the Arctic Circle. Hence, it is reasonable that if temperatures in Europe change, temperatures in the Arctic change similarly. The Southern Hemisphere has different weather systems and therefore experiences different temperature trends. Thus, the sudden increase in temperatures in the 1990s in the Northern Hemisphere is less pronounced in the Southern Hemisphere. As President Kennedy said, “We all breathe the same air”, at least in each hemisphere [90].

3.4 Troposphere Temperature Measurements

Satellites unlike stations, are ideal for monitoring the entire Earth. They also measure the temperature of the entire atmosphere not just at the Earth's surface. Global warming predicts increases to not just the surface air temperature but to all of the atmosphere. Beginning in 1979, scientists began to measure the temperature of the troposphere [91, 92]. This is the region of the atmosphere extending from the Earth's surface to the top level of clouds. Its thickness ranges from about 7 km in polar regions to as high as 20 km around the equator. The troposphere contains about 75% of the atmosphere's mass and is responsible for the weather.

The heat radiated by the troposphere is measured by detectors on satellites that are sensitive to various microwave frequencies. The relative sizes of the different microwave signals allows the atmospheric temperature to be determined. This is similar to measuring the intensities of different colours of light emitted by an object. In the case of the sun, more yellow light is produced than red or blue light. An object at a much lower temperature such as the troposphere, emits light not in the visible but in the microwave region of the spectrum. A comparison to measurements made using high altitude balloons was carried out to validate the satellite determined temperatures. Figure 3.10 compares the results to those predicted by climate models. The measured troposphere temperature has increased by less than 0.2 °C since 1978 which is below the predictions of all climate models. Indeed, the average increase predicted by 102 models was a temperature increase of 1 °C. This is a very large discrepancy that is not understood at all.

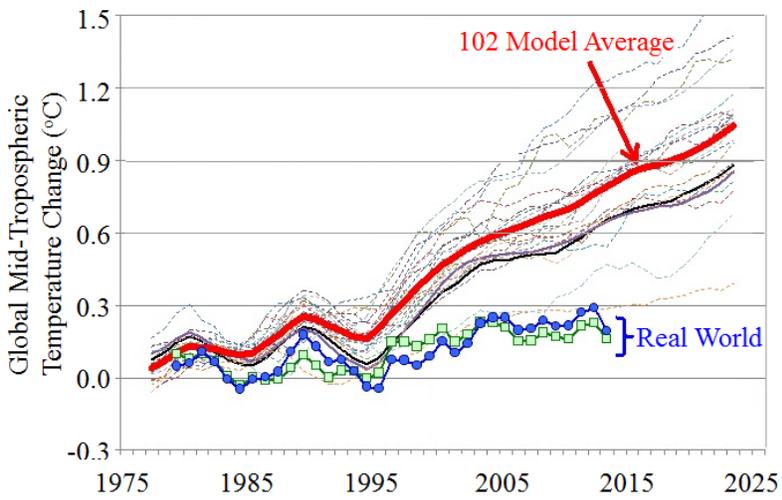


Figure 3.10: Comparison of climate model projected troposphere temperatures with satellite and balloon measurements [93]. Various climate model projections are given in dashed coloured light lines. The average of 102 climate model runs is shown by the thick red line. The balloon (satellite) measurements are given by the blue (green) data points.

4

Are Glaciers Shrinking?

A warmer Earth implies there will be less ice. However, it isn't necessarily that simple. A glacier typically melts during the summer and gains snow during winter. If winter precipitation decreases, glaciers can still retreat even if temperatures remain constant. Reports abound that most glaciers began shrinking in size after the end of the Little Ice Age [94]. The famous Athabasca Glacier, a part of the Columbia Ice Field in the Canadian Rocky Mountains, has retreated by 1.5 kilometers over the past 125 years [95]. This retreat rate of 12 meters per year is significant but less than what occurred at the end of the last ice age. The retreat rate of the North American ice sheet can be crudely estimated by dividing its size of about 5,000 kilometers by 10,000 years yielding 500 meters per year.

Glaciers are not just important scenic attractions but critical for modern civilization. Rivers such as the Ganges and Colorado originate from melting glaciers. They are the lifeblood of agriculture and supply drinking water for millions of people. Hence, the issue of shrinking

glaciers is of great concern.



Figure 4.1: Mount Kilimanjaro, Tanzania. Glaciers atop Africa's highest mountain have receded dramatically during the last 100 years.

One of the fastest glacial retreats has affected Africa's tallest mountain, Mount Kilimanjaro, Tanzania shown in Figure 4.1. It is one of the few places where Africans can experience snow. In 2002, Mount Kilimanjaro's glaciers were predicted to be completely gone between 2015 and 2020 [96]. A subsequent study compared pictures of the mountain from 1912 to 2011 and confirmed that Mount Kilimanjaro has lost 85% of its ice cover over the last 100 years [97]! However, the ice remains as of 2016. Interestingly, hikers have noted very little meltwater coming from Mount Kilimanjaro. It turns out that much of the ice doesn't melt but turns directly into water vapour or subli-

mates. The drier the air, the more sublimation occurs. It now appears that the dominant cause of ice retreat is not a warming temperature but decreasing humidity around the mountain due to deforestation of the surrounding area [98]. The reduction of Mount Kilimanjaro's ice is due to human activity but not in the way expected by the global warming theory. This cause of the retreat of Mount Kilimanjaro's glaciers is undoubtedly unique. It illustrates that things are not always as simple as they appear at first. Sometimes caution is called for before jumping to conclusions.

4.1 Arctic Ice Cap

The world's largest glaciers are of course located at the North and South Poles. The largest volume of Arctic ice is contained in the Greenland ice sheet. It has a volume of about 2.6 million km^3 and covers an area of about 1.7 million km^2 with a thickness ranging up to three kilometers [99]. The remaining Arctic ice is floating. So called multiyear ice has a typical thickness between three to four meters while single year ice is only about one meter thick [100]. The polar ice has its minimum extent in September and maximum in March when it extends south to the shores of Russia, Alaska and completely covers Hudson Bay, Canada.

The extent of the polar ice caps has been monitored since 1979 by satellites. Figure 4.2 shows the Arctic ice cap has been steadily shrinking. The reduction has been especially noticeable north of Siberia and near Greenland in recent years [101]. This is not surprising given that Arctic temperatures increased during that period. The minimum ice extent observed in September has been decreasing faster than the

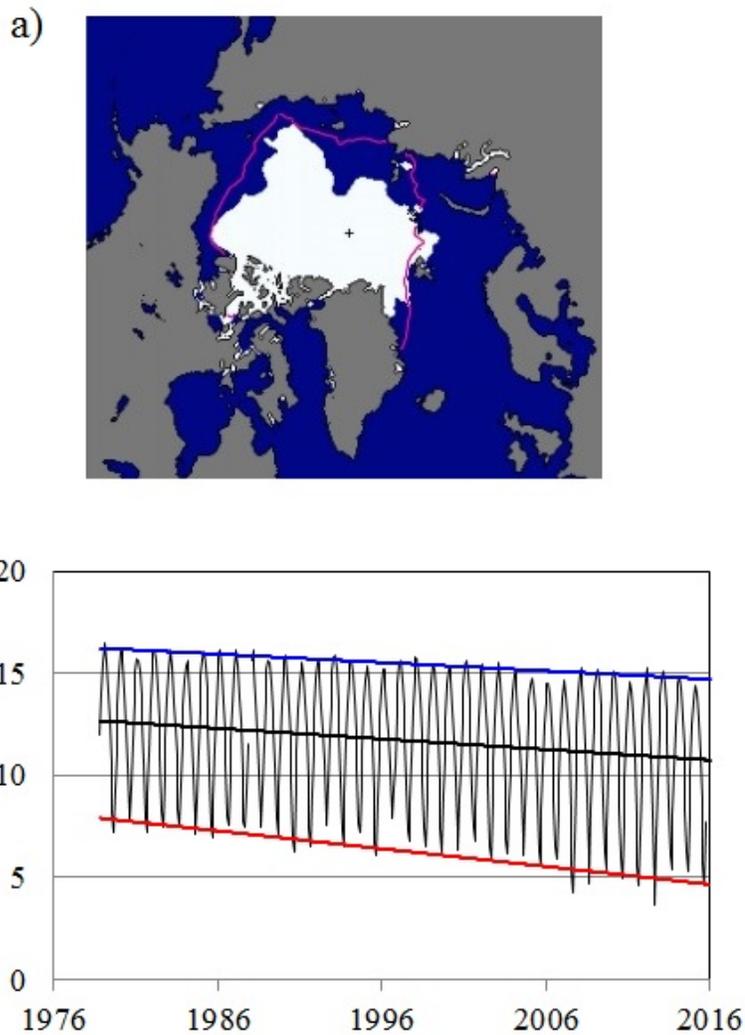


Figure 4.2: Arctic Ice Cap. a) Arctic Ice in Sept. 2014. The pink line shows the average extent during 1979-2014 and b) the area covered by at least 15% ice during 1978-2015. Slopes of red (September), blue (March) and black (annual) lines are -8.7 ± 1.7 , -4.1 ± 0.9 and -5.2 ± 0.7 million km^2 per century.

maximum ice extent which occurs in March. This can be explained as a decrease in the ice thickness which has been found by analyzing data recorded by submarines [100]. Extrapolation of the September trend, leads to a prediction of no summer Arctic ice by 2070. This has alarmed a number of countries as the prospect of expanded shipping in the Arctic ocean increases the risk of oil spills that would damage the fragile Arctic ecosystem [102]. Sailing between Europe and Asia via an ice free Arctic ocean would significantly shorten shipping times and thereby reduce costs, especially for large vessels that are too large to use either the Panama or Suez canals.

Records of winter ice cover for the Baltic Sea exist for nearly 300 years as shown in Figure 4.3 [103]. The Baltic Sea extends from a latitude of 53 °N to 66 °N and has an area of 420,000 km². Its ice coverage varies from year to year. Nearly the entire Baltic is ice covered in some years such as 1987. The average maximum extent of winter ice covered half of the Baltic during 1720 to 2013. The trend line slopes downward at a rate of -4.8% per century. There is noticeable variation of the ice coverage on decadal time scales. The maximum ice extent averaged 35% during 1988-2013 but was 54% during the preceding 25 year period. Another example are the periods 1868-1893 and 1894-1919 which had ice coverages of 55% and 43%, respectively. The ice coverage in recent decades is the lowest ever recorded but still not unduly so. The average maximum ice coverage for the winters between 1817 and 1826 was only 40%.

The trend in Baltic ice coverage is -56% per century for the period 1979-2013. Extrapolation of the 1979-2013 trendline leads to a prediction of zero Baltic ice cover in 2073. This closely matches the

a) Maximum Ice Extent

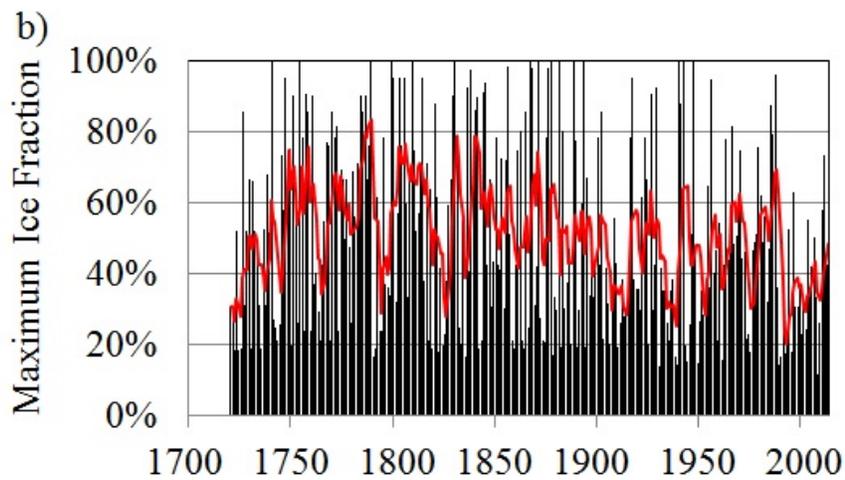
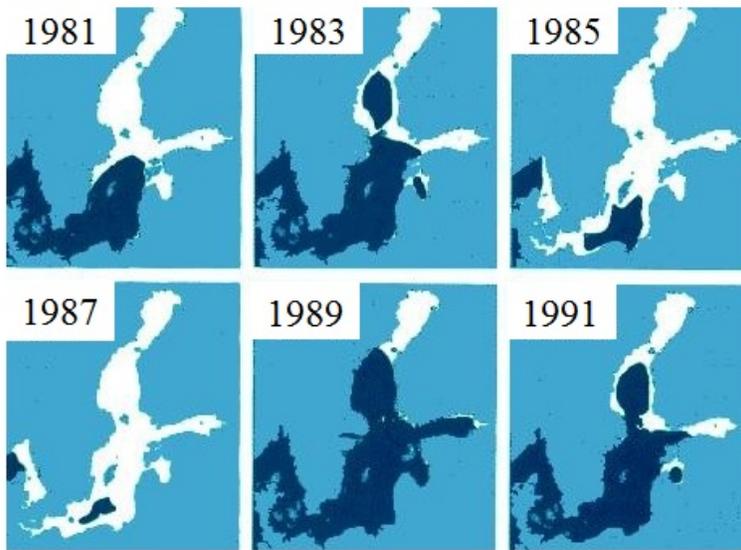


Figure 4.3: a) Variation of maximum extent of Baltic Sea ice during 1981-1991 and b) Maximum fraction of Baltic Sea ice covered in winter from 1720 to 2013 [103]. The red curve is the 5 year moving average of the data.

recent change in the Arctic ice coverage. This leads to the question of whether the last 35 years are truly representative of the Arctic climate? The Northern Hemisphere was cooler during the 1950s to 1970s as was discussed in the previous chapter. Unfortunately, the Arctic ice data record is too short to show the possible effects of decadal temperature variations.

Scientific investigations have been carried out in the Arctic for about a century. An interesting article describes a Norwegian expedition to Spitzbergen [104]. It states: “*The Arctic seems to be warming up. Reports from fishermen, seal hunters and explorers who sail the seas about Spitzbergen and the eastern Arctic all point to a radical change in climatic conditions, and hitherto unheard of high temperatures.*” It adds “*where formerly great masses of ice were found there are now often moraines, accumulations of earth and stones. At many points where glaciers formerly extended far into the sea, they have entirely disappeared. ... Great shoals of white fish have disappeared and seals are few in number.*” The waters formerly “*held an even summer temperature of about 3 °C; this year recorded temperatures up to 15 °C and last winter the ocean did not freeze over even on the north coast of Spitzbergen.*” The article was published in 1922 [104]. This indicates that some caution may be warranted before making predictions of an ice free Arctic in the near future.

4.1.1 Polar Bears

An important question is whether the reduction of Arctic ice during the last few decades has affected the ecosystem? The majestic polar bear has become the symbol of this concern. Figure 4.4 manifests the

effect of climate change as one sees a lonely polar bear clinging to a residual ice flow.

Seals are the primary staple of the natural polar bear diet. These are typically hunted at the edge of the ice pack. Polar bears have their young during winter on land. In spring, mothers gorge themselves on seal meat. The worry is that as the ice recedes, mommy polar bears must expend copious amounts of energy swimming to their food source. This may be especially hard on recently born cubs.

Mankind has had a devastating effect on polar bears principally by hunting. In the 1960s, over 1,000 were killed annually largely for sport. Legitimate concerns about possible extinction resulted in the International Agreement on the Conservation of Polar Bears in 1973, signed by Canada, Denmark, Norway, the Soviet Union and the United States [105]. Commercial hunting was sharply restricted. An exception was made for aboriginal peoples using traditional methods to hunt.

The number of polar bears seems to have rebounded since 1973 but the exact population is quite uncertain, especially in northern Russia. The best estimates provided by the Polar Bear Specialist Group indicate that the total population of about 15,000 bears in the 1970s increased to between 20,000 and 25,000 by 1990 [105]. There has not been a significant change since then. Nineteen subpopulations occupying different geographic areas of the Arctic are recognized. As of 2015, there are insufficient data to judge the populations of 9 regions, 6 areas appear to have a stable population while 3 (1) subpopulations are decreasing (increasing). The conclusion is that mankind has adversely impacted polar bear populations but it is not clear what role if any climate change has played. More accurate census data are needed.

a)



b)



Figure 4.4: a) Iconic picture of a polar bear clinging to a residual ice floe and b) Polar bears in their natural? habitat at the garbage dump in Churchill, Manitoba, Canada.

4.2 Antarctic Ice Cap

The Antarctic ice sheets are the world's largest with a volume of about 27 million km³ [106]. The Antarctic ice sheet is nearly all on land although part of it is below sea level. The ice thickness averages several kilometers with a maximum thickness of just under five kilometers. The Antarctic ice sheet appears to be growing somewhat as shown in Figure 4.5. The September 2014 ice area was the largest ever recorded since observations began in 1979. The ice sheet appears to be increasing at a rate of several million km² per century at all places around the continent with the exception of the Antarctic peninsula that juts northward toward South America.

Observational data from Antarctic stations are very sparse as shown in Figure 4.6. Less than a dozen stations have existed, operated by various nations. All but two stations are located on the coast. A station at the South Pole is run by the United States while the Russians have a station at Vostok, which is near the southern geomagnetic pole and is also the coldest place on the planet. Most stations only began operation after 1955.

Figure 4.6 shows the average annual temperature for nine stations. Only Faraday and Rothera, both on the Antarctic peninsula, have experienced a statistically significant warming during the period 1955-2014. This is consistent with the observed reduction of ice in this area shown in Figure 4.5. All other stations have not experienced a statistically significant temperature change. Faraday and Rothera are closest to some glaciers in the western Antarctic that have been reported in recent years to be increasing their flow toward the sea [107]. Interestingly, the region next to the Antarctic peninsula is one

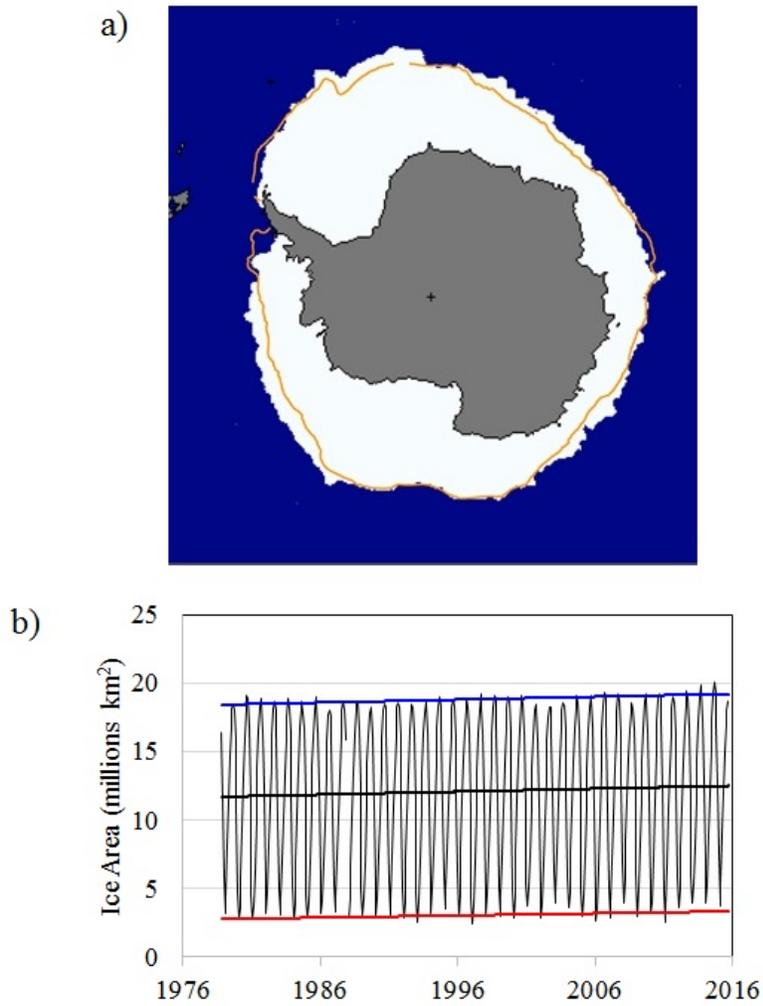
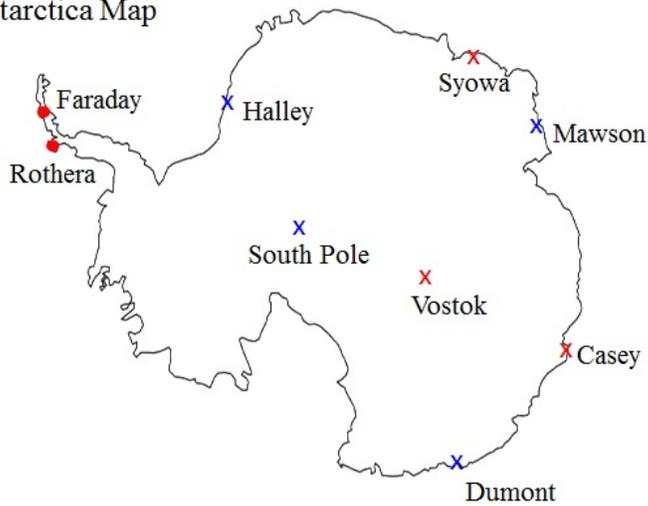


Figure 4.5: Antarctic Ice Sheet. a) Antarctic Ice sheet in July 2014. The orange line shows the average extent during 1979-2014. b) the area covered by at least 15% ice during 1978-2015. Slopes of red (February), blue (September) and black (annual) lines are 1.5 ± 1.2 , 2.1 ± 1.2 and 2.2 ± 0.9 million km^2 per century.

a) Antarctica Map



b) Station Temperatures

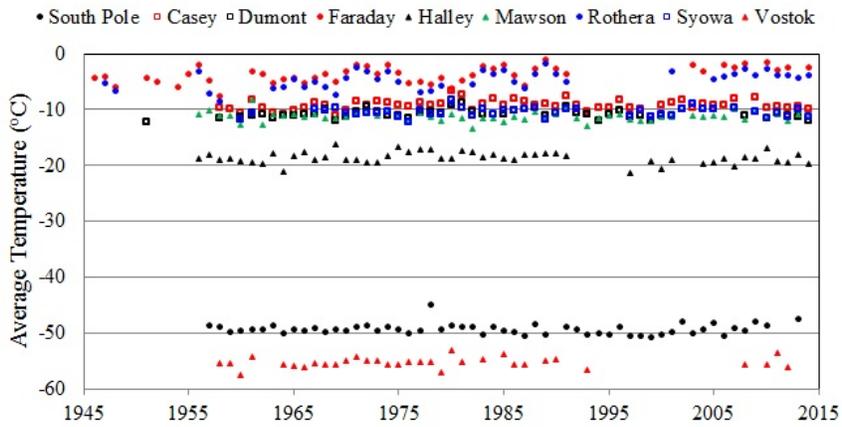


Figure 4.6: a) Location of Antarctic stations and b) Annual temperatures observed during 1945-2014. The trends were computed for the period 1955-2014. A red dot signifies a statistically significant warming trend while a red (blue) cross denotes an insignificant warming (cooling) trend.

of only two areas that are predicted by the climate models to cool by 2 °C as shown in Figure 2.13. It should be noted that the time series for Faraday, Rothera and several other stations have large amounts of missing data. The data that do exist do not show convincing evidence of a warming Antarctic climate.

There is a marked contrast between the Arctic and Antarctic. The Antarctic is surrounded by seas and interacts less with the weather of the rest of the Southern Hemisphere than does the Arctic with the more southern parts of the Northern Hemisphere. Water vapour increases in the Arctic also enhance the warming. It has also been suggested that pollution affects the Arctic more than the Antarctic. In recent decades, Arctic snow is not pristine white but sometimes is grey in colour. Many of the largest polluting countries such as China, which recently passed the United States to become the largest emitter of greenhouse gases, are located in the Northern Hemisphere. The largest sources of Arctic soot pollution in Greenland now appear to be South Asia [108]. This change in albedo means that less sunlight is reflected and can have a significant warming effect [109]. Finally, it is interesting that recent observations of melting glaciers in Greenland do not agree with the climate model result shown in Figure 2.13 which predicts less warming for Greenland than other areas of the Arctic.

4.3 Outdoor Skating

In Canada, every citizen learns to skate. It is the duty of fathers to make an ice rink in the backyard¹. Our family has pursued this tradi-

¹This comment is clearly sexist. Alas, Messrs. H. Clinton, B. Friedan et al haven't expressed any interest in joining this profession.

tion with vigour, undoubtedly enhanced by tales of ancestors skating on frozen canals in Holland. Growing up near Detroit, my father went out year after year in the middle of the night to water the backyard rink. I have inherited this ability and have made ice rinks for the last 20 years behind our house in Toronto as shown in Figure 4.7. It is always interesting to hear older colleagues wax nostalgically about their ice rink making days and lament that it is no longer possible due to the warmer winters. Not that winters in Toronto are balmy, but all of us “know” they are warmer. But what does the temperature record show?

Figure 4.7b shows a plot of the average January February temperature in Toronto and Detroit. There was a cluster of particularly cold winters in the late 1970s and early 1980s. One also sees that the Toronto winter temperature is increasing much more than for Detroit. That is somewhat mysterious. Toronto is located 350 kilometers east of Detroit. Surely, the air isn't warmed as it crosses the international border. Table 4.1 shows the temperature trends at Buffalo, New York and Erie, Pennsylvania, two stations much closer to Toronto than Detroit. Toronto's warming clearly is anomalous. This is likely an illustration of the urban heat island. Toronto's weather station originally was likely located in an area that was not heavily urbanized. As Toronto expanded, the land surface changed. Indeed, the difference between the winter trends for Toronto and Detroit entirely disappears if one considers the period after 1950.

The regional temperature data do not support the claim that winters in Toronto have become much warmer. This is a difficult rational argument for some to accept. I regularly get accosted about the im-

a)



b)

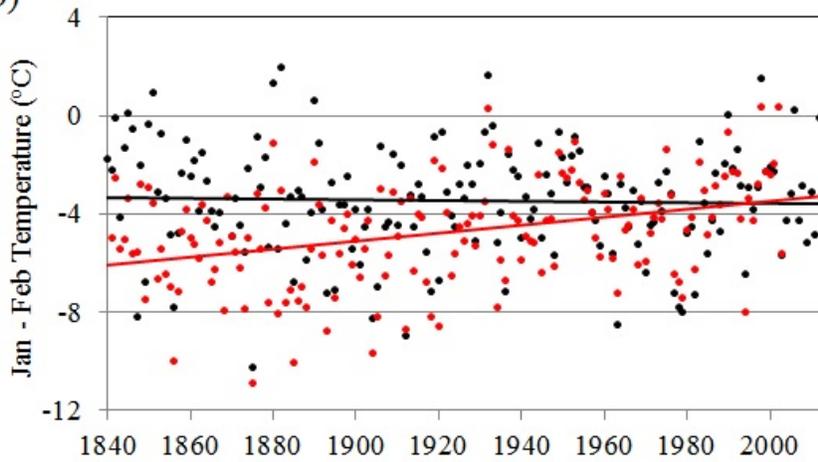


Figure 4.7: a) Ice rink in the author's Toronto backyard and b) average January February Temperature in Toronto (red) and Detroit (black) from 1840 to 2014. Solid lines are the trend lines.

Table 4.1: January February Temperature Trends.

Station	Period	Temperature Trend °C per century
Toronto	1840-2006	1.6 ± 0.7
Detroit	1840-2013	-0.2 ± 0.7
Erie	1874-2014	0.0 ± 0.9
Buffalo	1873-2014	0.3 ± 0.9

possibility of making outdoor ice rinks and have begun to suspect something other than science is going on. Inevitably, my greying male interlocutor claims he is much warmer in recent winters. The argument is strongly bolstered by his nearby spouse. Perhaps she recalls being woken up in the middle of the night by a husband returning to bed after watering the rink. His hug was not meant to initiate a romantic encounter but to dethaw. But, maybe the old chap is warmer. After all, he is likely inside his house chatting to grandchildren on the cell phone rather than playing with ten year olds in the snow.

Another country where warmer winter temperatures would affect cultural skating traditions is the Netherlands. The Avercamp painting, shown in Figure 2.4, illustrates that skating has been a national pastime for centuries. My Dutch cousins whine that the reason they skate poorly is not a lack of athletic prowess but that the canals seldom freeze. This is confirmed by many aged relatives who talk about skating on the Rhine River in March, 1929 and about the famously

cold winters during the Second World War. The last time the Rhine River completely froze over was 1963.

The validity of this folklore can be studied by considering the temperature data recorded for De Bilt, Netherlands which covers the period 1706-2014. The average temperature was found for the prime skating months of January and February. The histogram in Figure 4.8 shows only 49 years, or about one in six winters, had an average January February temperature below 0 °C. The norm for a Dutch winter is that it doesn't freeze for prolonged periods. There were only 14 winters with a January February temperature below -2.5 °C². Four of these winters occurred in the 1700s, and five each in the 1800s and 1900s. The two coldest winters occurred in 1942 and 1963 with average January February temperatures of -4.7 and -4.4 °C, respectively. Four cold winters occurred during the period 1929 to 1947 which likely accounts for the familial oral skating tales, whereas not a single cold winter occurred from 1856 to 1928.

One may ask how representative the Avercamp painting was of the Dutch winter climate. Avercamp made his painting during the Little Ice Age in 1608 when temperatures were a bit lower. A shift of -2 °C in the histogram given in Figure 4.8 would more than double the fraction of winters having January February temperature less than -2.5 °C, from 4.5% to 11%. Cold winters would have been more likely but still not a dependable annual occurrence. In all likelihood, Hendrik Avercamp was a poor artist, struggling to compete with contemporaries such as Rembrandt van Rijn. A painting showcasing the relatively unusual cold winter scene would be easier to sell than one

²These cold winter years were: 1709, 1740, 1784, 1795, 1803, 1814, 1823, 1838, 1855, 1929, 1940, 1942, 1947 and 1963.

documenting a typically drab dreary wet Dutch winter.

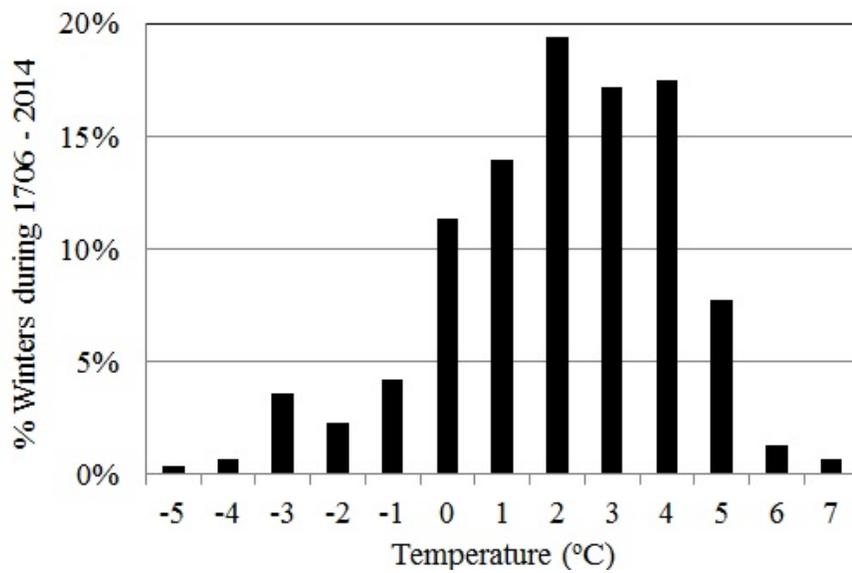


Figure 4.8: Histogram showing the percentage of winters with average January February temperatures in 1 °C increments for De Bilt, Netherlands during 1706-2014.

5

Are The Oceans Changing?

5.1 Sea Level

The obvious result of melting glaciers would be to increase sea level. An increase of about six meters would occur if the entire Greenland ice sheet were to melt while the demise of the Antarctic ice sheets would increase ocean levels by over 60 meters [99]. This would inundate coastal areas displacing hundreds of millions of people.

It is important to realize that sea levels only change if glaciers located on land melt. The melting of the entire floating Arctic ice cap would have no effect. The reason is that floating ice displaces a volume of water that exactly equals the volume it would occupy if the ice completely melted. This is readily demonstrated by putting an ice cube in a glass of coca cola. Draw a line at the water level. Then talk to your friend until the ice melts, without drinking! The coca cola

level with the ice fully melted will be unchanged.

Figure 5.1a shows sea level has risen over 100 meters since the end of the last ice age. The rate of sea level rise 10,000 years ago exceeded 10 mm per year. Ancient sea levels can be estimated using fossil coral reefs. Coral reefs grow vertically as sea level increases such that the distance to the ocean surface remains approximately constant. The age of successive levels of coral can be determined by measuring the concentration of various radioactive isotopes such as ^{14}C [111, 112].

Modern sea level measurements are determined by averaging the low and high tide levels. Figure 5.1b shows that sea level rose at an average rate of about 2 mm per year between 1870 and 2000 [113]. This has increased to 3.5 mm per year for the most recent data covering the period 1994-2008. This coincides with the temperature increase of nearly 1 °C that occurred in the Northern Hemisphere as was discussed in the previous chapter. A significant complication in this determination is the land may be subsiding or rebounding. The coastal area bordering Hudson Bay is rising at a rate of about 10 mm per year [114]. This so called isostatic rebound occurs because the land no longer is depressed by the weight of kilometer thick ice sheets that existed during the last Ice Age.

The increase in sea levels is caused not just by additional water supplied by melting glaciers but also by the water's thermal expansion. The maximum density of water occurs at 4 °C. This is approximately the ocean temperature at depths below 1000 m [115]. Most of the ocean's heat is contained in the top few hundred meters. A 200 meter column of water whose temperature changes from 20 to 21 °C would increase in height by 14 mm. Sea level should increase as the

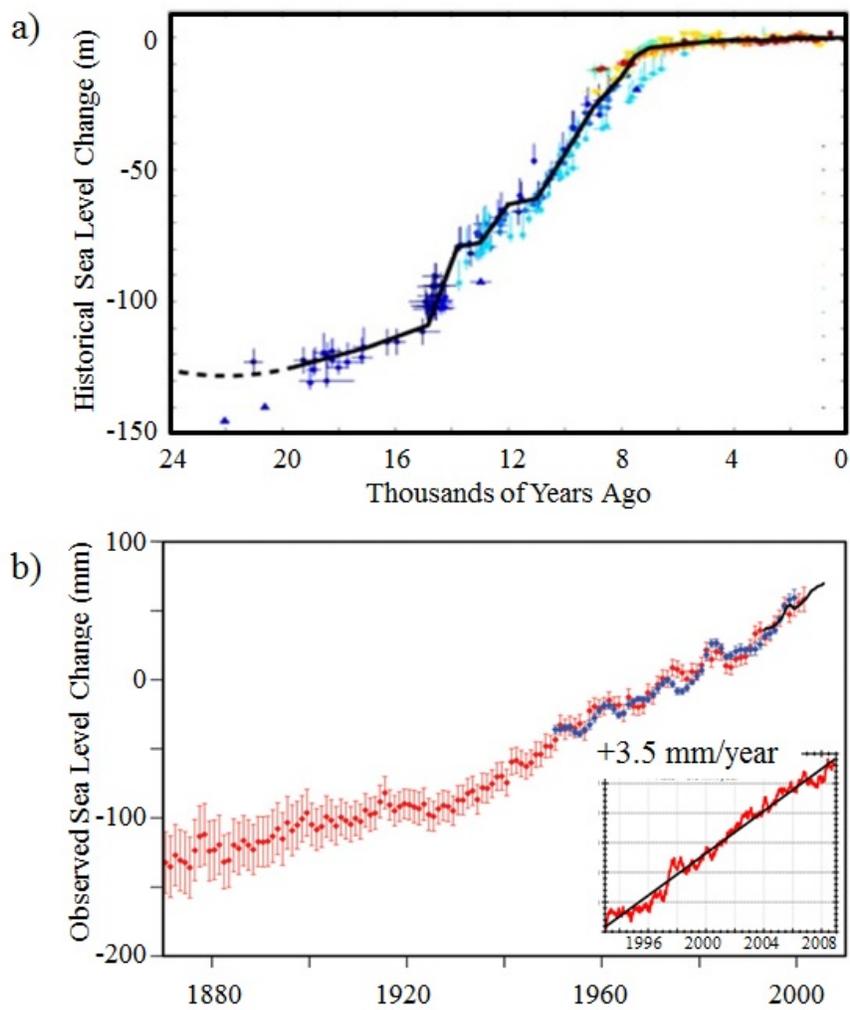


Figure 5.1: a) Sea level change since the last Ice Age and b) Observed sea level change from 1870-2010 [110].

ocean absorbs heat from a warming atmosphere. Estimates vary but it appears that this so called thermosteric contribution is responsible for an increase of sea level throughout the 20th century of about 1 mm per year [116]. This effect is difficult to estimate, in part because the transfer of heat via ocean currents is not well understood. It may take decades or even centuries before heat is transferred to the deep ocean depths [117]. Even if global warming stopped today, the temperature change that has been observed to be about 1 °C during the 20th century would be responsible for future thermosteric sea level increases.

Sea level rise is a significant concern and nowhere has the fight against the sea been as longstanding as in the Netherlands. A popular saying is that God created the world but humans made the Netherlands¹. Figures 5.2 and 5.3 show how the coastline has changed over time. Most notable has been the appearance of an inland sea known as the Zuyder Zee (Southern Sea) that had a depth of four to five meters before parts of it were reclaimed in the 20th century. In 500 B.C., this central area was a marshy region consisting of small lakes called Lacus Flevo by the Romans. There were several large floods in the 1100s and 1200s that are believed to have seriously breached the northern coastal sand dunes that acted as a dike. This in turn facilitated the inland flow of sea water which further eroded the peat rich soils. It was at this time that the name Zuyder Zee came into usage [119]. Figures 5.2 and 5.3 also show the northern sand dunes originally connected to the mainland are now a series of islands. Similarly, the sea has made

¹The struggle against the sea has shaped the Dutch character. Dutch people also tend to be rather tall. When asked why that is the case, my response is that the short ones drowned.

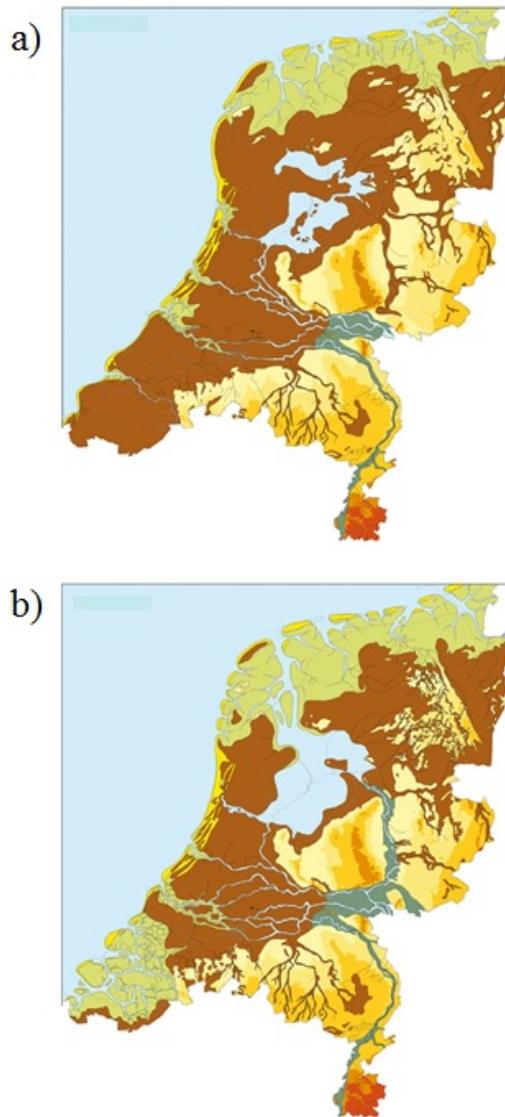


Figure 5.2: Changing coastline of the Netherlands a) 500 B.C. and b) 800 A. D. [118]

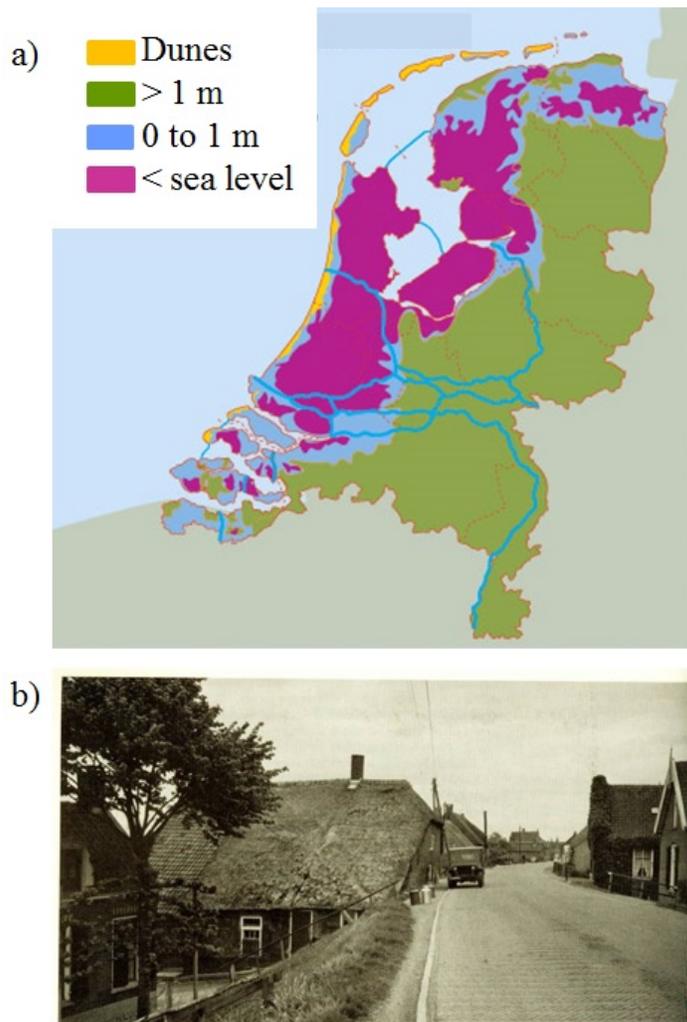


Figure 5.3: a) Topographical map of the Netherlands relative to sea level and b) Effect of successive dike raising. The farmhouse on the left side of the dike was built several hundred years ago. It has become embedded in the dike which was successively raised to prevent flooding.

major inroads in the southwestern Netherlands.

About a quarter of the Netherlands is several meters below sea level and would not exist without dikes. These have been progressively raised throughout the centuries as shown in Figure 5.3b. Dividing a sea level rise of two to four meters by 2,000 years implies sea level has risen between 1 and 2 mm per year. This estimate warrants caution as there has been notable land subsidence that occurs when soils are drained of water. In the case of the Rhine and Maas deltas, flooding is also more likely when land is reclaimed leaving less space for the Rivers. This increases the risk of river flooding in spring when meltwater from the Alps is at a maximum. Dikes have also been strengthened to provide a higher level of protection. After extensive flooding in 1953, the so called Delta plan resulted in dikes being raised to reduce the risk of flooding to less than once in a thousand years [120]. Nevertheless, it appears reasonable that a substantial part of present day sea level rise is the continuation of a natural process that began after the end of the last Ice Age.

Other low lying heavily populated areas of the world such as Florida, Louisiana and Bangladesh are also susceptible to rising sea levels. In the case of Louisiana, located at the mouth of the Mississippi, the damming of the River during the 20th century greatly reduced the amount of sediment deposited [121]. This has led to substantial loss of coastal wetlands which has enhanced flooding caused by hurricanes such as Katrina that struck Louisiana in August, 2005 [122].

One repeatedly made claim is that rising sea levels are increasing the amount of hurricane storm damage. Large hurricanes such as Katrina or Sandy that struck New York and New Jersey in October, 2012

produce storm surges that can reach heights of seven meters or more. The amount of sea level increase during the entire 20th century is less than 0.3 meters. There has however been a significant increase in insurance claims due to storm damage as coastal populations have increased dramatically. The U.S. population residing in coastal counties increased by 39% or 35 million from 1970 to 2010 [123]. Inadequate zoning has allowed homes to be built near beaches or in other flood prone areas. The effect of global warming is comparatively minuscule.

5.2 Storms

One prediction of global warming is that warmer temperatures will increase the severity and frequency of storms. This makes sense for hurricanes that develop in tropical regions and get their energy from the warm surface ocean water. Their strength dissipates quickly when they travel over land. This prediction may be simplistic. An important driver of the Earth's climate is the temperature difference between the equatorial and the polar regions. The weather systems transfer energy away from the tropics. Global warming predicts the largest temperature increases will occur in the Arctic. Hence, the temperature difference between the Arctic and the equator will be reduced, with presumably a subsequent weakening or shift of wind patterns such as the jet stream [124].

The greatest storm damage affecting the largest areas is caused by hurricanes, also known as cyclones in the northern Indian Ocean and typhoons in the western Pacific Ocean. The number of people killed can be enormous not just because the high winds cause buildings to collapse and create flying debris but due to storm surges into low

lying areas. The Bhola cyclone in Bangladesh in November, 1970 is estimated to have killed up to half a million people [125]. The amount of damage very strongly depends on the maximum sustained wind speed. Hurricanes are categorized using the “Saffir Simpson Wind Scale” given in Table 5.1 [126]. Damage to well constructed homes can be major even for a Category 1 hurricane. Large tree branches may break and broken power lines may result in power outages for up to several days. Category 5 hurricanes can make an area uninhabitable for months.

Table 5.1: Saffir Simpson Hurricane Wind Scale [126] and definitions of Tropical Storm/Depression.

Hurricane Category	Sustained Windspeed km/hour (mph in brackets)
Five	≥ 252 (157)
Four	209-251 (130-156)
Three	178-208 (111-129)
Two	154-177 (96-110)
One	119-153 (74-95)
Tropical Storm	63-118 (39-73)
Tropical Depression	≤ 62 (38)

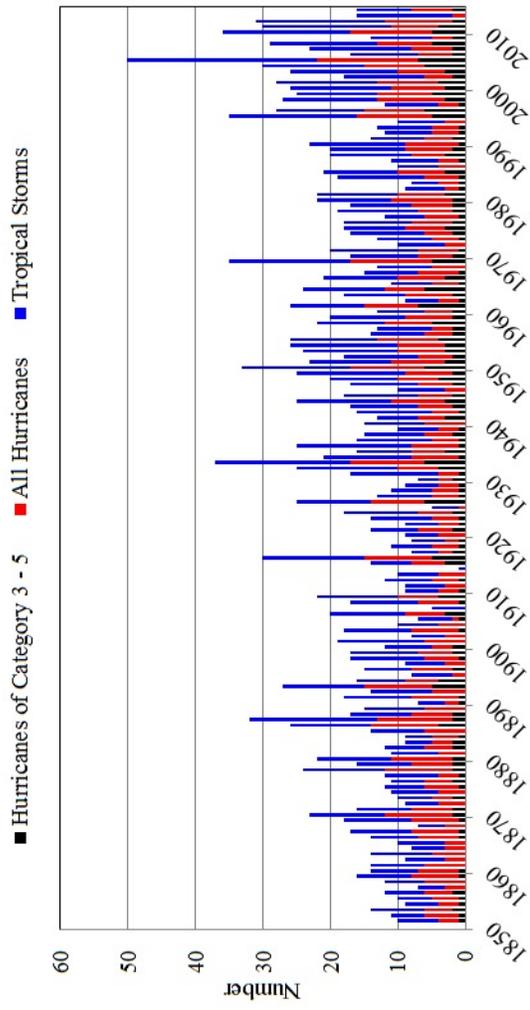


Figure 5.4: Number of Hurricanes and Tropical Storms in the Atlantic Ocean north of the equator during 1851-2014 [126].

Figure 5.4 shows the number of storms that have occurred in the Atlantic Ocean north of the equator from 1851-2014 [126]. Each of these storms was sufficiently large to merit a name that was assigned by the U.S. National Hurricane Centre. The number of storms varies significantly from year to year. The average number of tropical storms was only 7.4 during 1851-1930 and 11.4 for 1931-2014. This increase is undoubtedly due to better detection using planes and satellites. Indeed, not a single trend calculated for the two intervals 1851-1930 and 1931-2014 is statistically significant for tropical storms, all hurricanes or Category 3-5 hurricanes. For example, the trend of Category 3-5 hurricanes for the period 1931-2014 is $+0.7 \pm 1.6$ hurricanes per century. Figure 5.5 shows the total number of global hurricanes and tropical storms has decreased slightly between 1970-2014 [127]. The

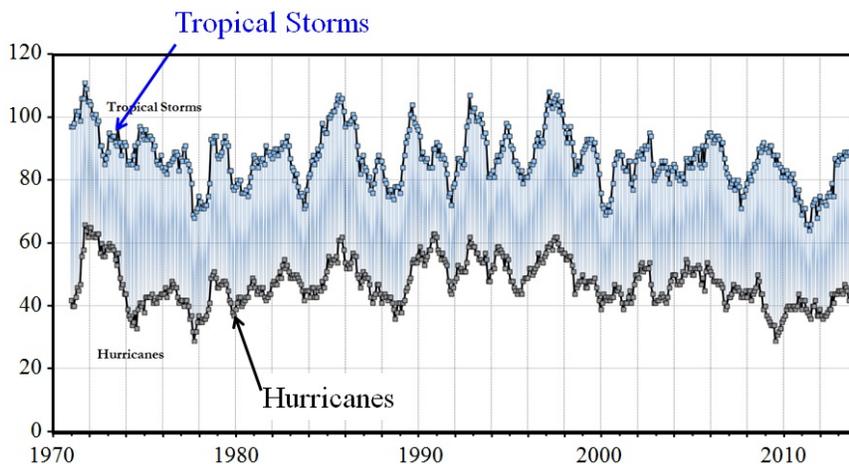


Figure 5.5: Total Number of Global Tropical Storms and Hurricanes during 1970-2014. Neither the number of Tropical Storms nor Hurricanes is increasing [127].

evidence does not support claims that either the number of hurricanes or their severity is increasing.

5.3 Ocean Acidification

An especially insidious result of climate change is ocean acidification. Acidity is measured using the so called pH scale illustrated in Figure 5.6. Distilled water is neutral and has a pH of 7. Substances such as baking soda, ammonia and bleach have a pH greater than 7 and are known as bases while coffee, orange juice and stomach acid have a pH less than 7 and are called acids. Sea water is slightly basic due to various impurities in the water, most notably salt.

The combustion of fossil fuels has increased the concentration of carbon dioxide in the atmosphere. About half of this carbon dioxide is believed to be absorbed into the oceans [128]. It is estimated that one in a thousand dissolved carbon dioxide molecules reacts with seawater to generate carbonic acid [129]. Carbonic acid is used to make carbonated beverages. The concern is that burning fossil fuels is slowly turning the ocean into pop. Estimates are that this has caused the pH of the surface ocean water to change from 8.25 in 1750 to 8.14 in 2004 [130]. It should be emphasized that this estimate is not based on any measurements of ocean water acidity but is a result of modelling ocean chemistry due to an increase in dissolved carbon dioxide which is inferred from the record of fossil fuel use. Actual observations of the amount of dissolved carbon dioxide and the acidity of seawater only began in the 1980s.

Ocean chemistry is complex. It cannot be simply modelled as a clean glass of water into which one dissolves carbon dioxide. There

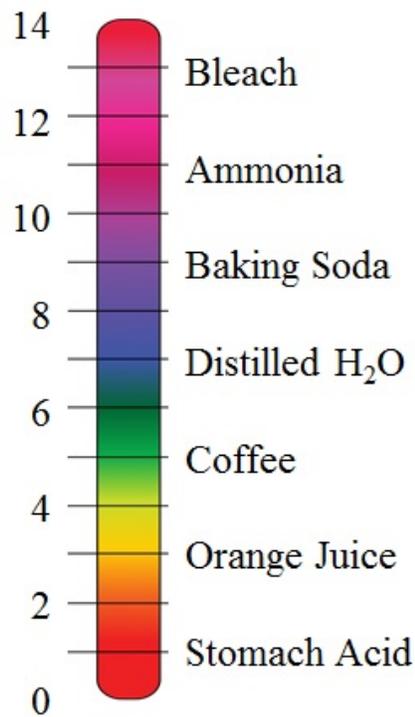


Figure 5.6: pH Acidity Scale

are reactions that buffer against a change in acidity. One of those reactions involves calcium carbonate. It is proposed that increasing ocean acidity may decrease the amount of calcium carbonate which will hinder the growth of various marine organisms such as corals, crustaceans, etc [131]. This has led to concern about the health of the marine ecosystem and claims that changes in acidity cause coral bleaching [132]. It would be a shame to damage spectacular treasures such as Australia's Great Barrier Reef shown in Figure 5.7.



Figure 5.7: Great Barrier Reef off the coast of Australia.

The estimated change of ocean acidity by 0.1 pH over the past 250 years is smaller than the change in pH observed on far shorter timescales in various parts of the oceans as shown in Figure 5.8 [133]. Changes of pH in coastal regions can be explained due to the influx of inland fresh water caused by the tides. The extremely large changes of 1 pH on time scales shorter than one day observed at Puerto Morelos, Mexico and Ischia, Italy are due to the presence of nearby submarine CO₂ vents. There is no apparent adverse impact on the ecosystem. The change of pH is observed to be much less in the open ocean, far from land.

It would be incorrect to assume that organisms that have adapted to daily acidity fluctuations as high as 1 pH can tolerate a comparable

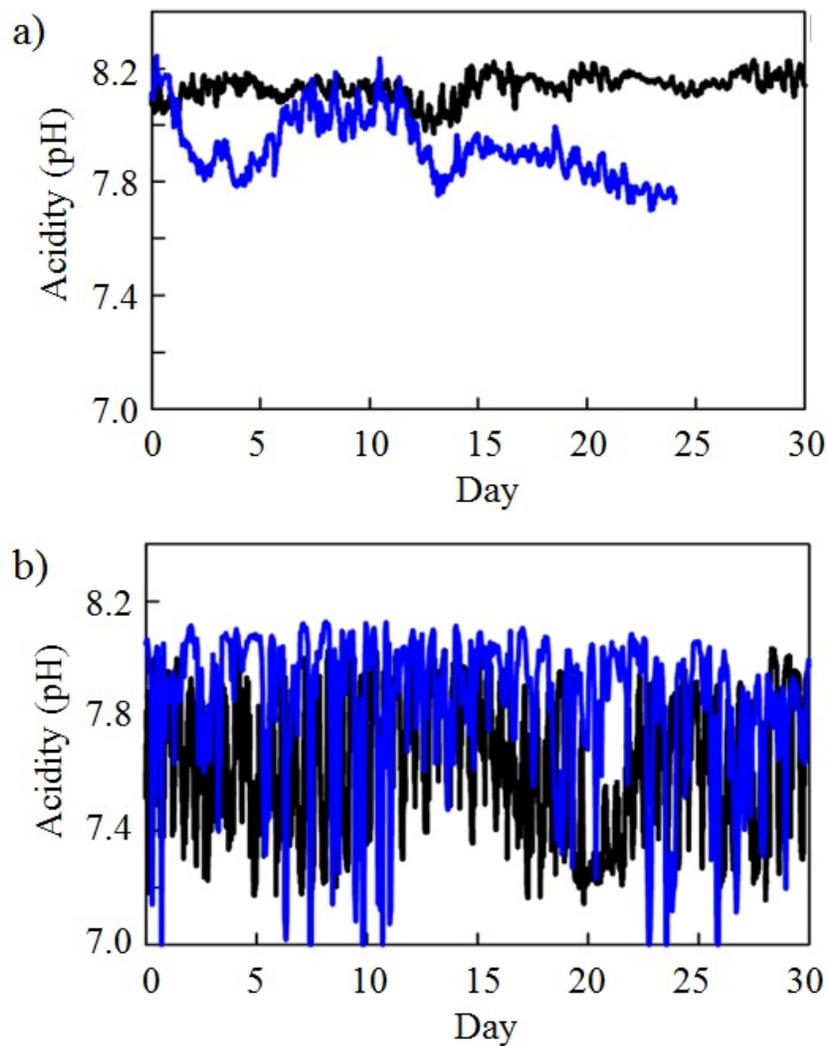


Figure 5.8: Ocean acidity measurements at a) (blue) Santa Barbara and (black) La Jolla, California and b) (blue) Ischia, Italy and (black) Puerto Morelos, Mexico [133].

long term pH change. For example, temperature varies by about 10 °C from day to night but a 10 °C annual temperature increase would have dire consequences to life. The long term response of the ecosystem to a change of 0.1 pH is unclear and is an important subject of further research. Any effect due to ocean acidification on marine life will not be easy to discern as mankind has certainly adversely affected ocean health. Overfishing has decimated many species. The oceans have been used as a sewer and a toxic waste dump. Modelling ocean chemistry to predict small changes in acidity is also no simple task. It is far from obvious if fossil fuels have caused the oceans to acidify and affected the global marine ecosystem.

6

Is It Wetter Or Drier?

The maximum amount of water vapour contained in air increases exponentially with the temperature. It is therefore reasonable that precipitation should increase in a warmer world [134]. Indeed, torrential downpours occur on hot humid summer days. One study claimed to have detected human influence on twentieth century precipitation trends [135]. The 2007 IPCC report stated that precipitation has increased in some regions by as much as 1% in each decade of the 20th century [24, 136]. These predictions assume that relative humidity remains constant. However, recent work has found that a small decrease in relative humidity, especially in inland areas remote from large bodies of water, has occurred during 1948-2010 in North America [75].

Several large studies examined precipitation records for decades in the last part of the 20th century. The results range from a globally averaged precipitation trend that has changed by: -1 [137]; +3.5 [138]; and +0.1 mm per year [139]. These differences are not entirely surprising given that precipitation varies considerably over time scales of

decades [140]. Data are also very sparse for large regions of the Earth including the Sahara, Amazon, Oceans etc. The resulting trends frequently are not statistically significant.

The need to be cautious about concluding precipitation has changed significantly is illustrated in Figure 6.1. This shows winter precipitation observed at Medicine Hat, Alberta. There is a sharply decreasing trend for the period 1952-2006, but the trend is much less if one considers data extending back to 1884. The 1930s were particularly dry. The central plains of North America were afflicted by a terrible drought and the region was known as the Dust Bowl. The large fluctuation of precipitation on timescales of years to decades is especially common in relatively dry areas.

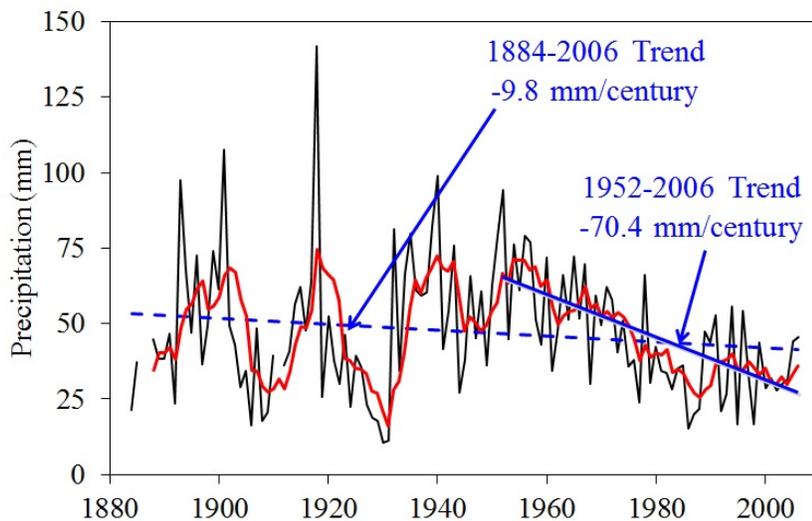
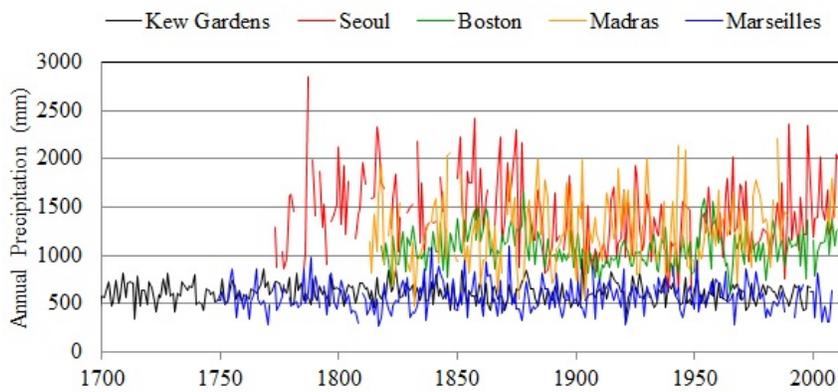


Figure 6.1: Winter precipitation in Medicine Hat, Alberta from 1880-2006.

a) Sample Northern Hemisphere Stations



b) Sample Southern Hemisphere Stations

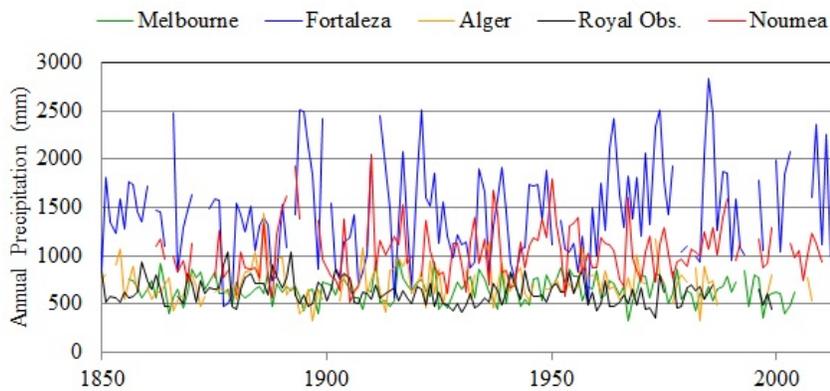


Figure 6.2: Sample annual precipitation for stations in a) Northern Hemisphere: Kew Gardens, United Kingdom; Seoul, South Korea; Boston, United States; Madras, India and Marseilles, France and b) Southern Hemisphere: Melbourne, Australia; Fortaleza, Brazil; Alger, Algeria; Royal Observatory, South Africa and Noumea, Caledonia.

6.1 Precipitation Observations

The longest precipitation records exist for European stations as was the case with the temperature data. All stations were located on land. Unfortunately, very little precipitation data are available over the oceans. Figure 6.2 shows observations made at stations located in the Northern and Southern Hemispheres. In general, stations in the Northern Hemisphere have a longer data record than those located in the Southern Hemisphere. The annual precipitation varied substantially for stations experiencing wet versus dry climates as did the year to year fluctuations.



Figure 6.3: Locations of stations examined. Red dots show the 776 stations having 100-149 years of data, green dots the 184 stations having 150-199 years of data and blue dots the 24 stations having more than 200 years of data.

Figure 6.3 shows the locations of stations for which data were retrieved from the Global Historical Climate Network [141]. Stations were only considered if over a century of observations had been recorded. The longest station record of 303 years was available for Kew Gardens, United Kingdom. Most station data were available beginning after 1850. The resulting dataset consisted of 984 stations located in 114 countries. The annual total precipitation was only computed for years in which no month had missing data. The number of years for which the annual precipitation could be computed was 116 years when averaged over all stations.

The percentage precipitation change relative to the average annual precipitation occurring during 1961-1990 was computed for each station. Figure 6.4 shows the location of stations experiencing either increasing or decreasing precipitation. Trends were only found for stations having observations for at least 80% of the years for the period in question. Table 6.1 lists the number of stations experiencing increasing/decreasing precipitation trends for the periods 1850-2000, 1900-2000 and 1950-2000. Most trends were not statistically significant during any of the time periods considered. Many stations experienced increased precipitation during one period but decreased precipitation during another time period. Only half of the 256 stations for which trends were found for all three intervals, experienced trends that either all increased or all decreased. About one third of the 684 stations had opposite trends during 1900-2000 and 1950-2000.

The percentage precipitation change was averaged over all stations in a given country or region as shown in Figure 6.5. Large variations of precipitation on time scales of years to decades are evident. Notably,

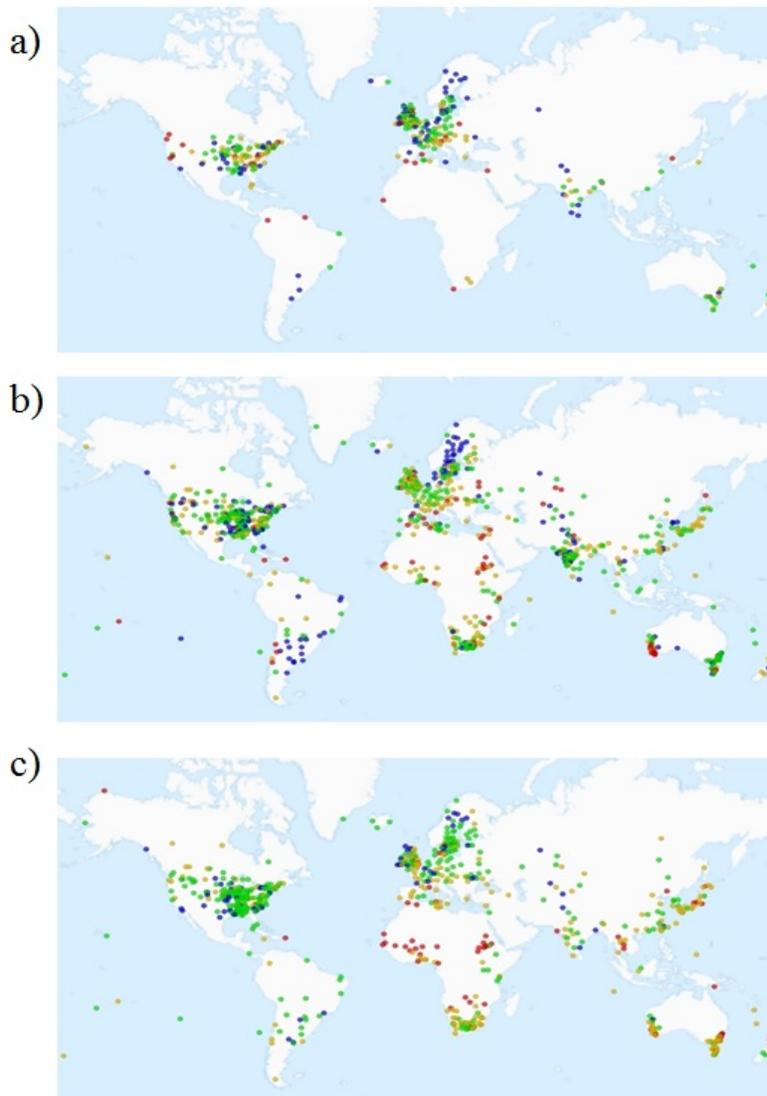


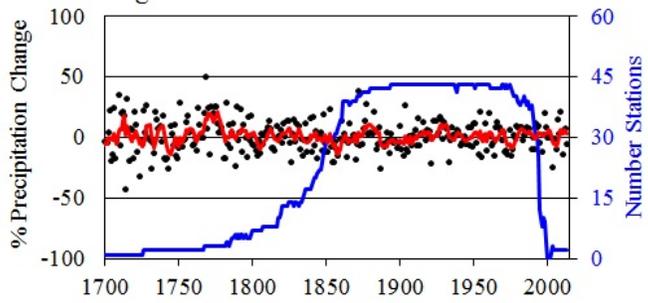
Figure 6.4: Maps of station precipitation trends for the periods of a) 1850-2000, b) 1900-2000 and c) 1950-2000. Blue (green) indicates an increasing trend that is (not) statistically significant while red (yellow) indicates a decreasing trend that is (not) statistically significant. Trends are plotted for stations having at least 80% of observations for all years during the period in question.

Table 6.1: Number of stations having decreasing/increasing precipitation trends for different time periods. The number of stations having statistically significant trends is in brackets. Trends were only found for stations having data for 80% of all years in the time period as is discussed in the text.

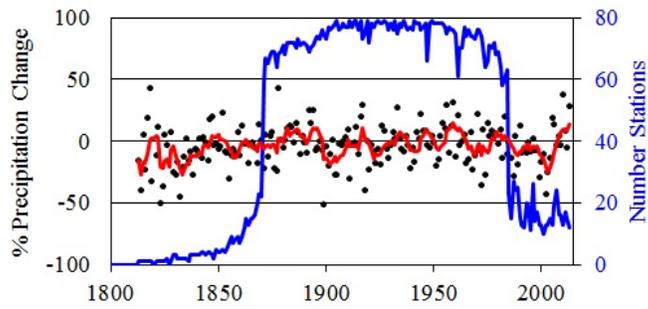
Interval	Number stations with decreasing trend	Number stations with increasing trend
1850-2000	113(28)	179(67)
1900-2000	323(71)	530(162)
1950-2000	328(66)	388(68)

countries such as India/Pakistan and South Africa as well as Africa north of the equator and California experience greater interannual variability than do either France, Japan or the United Kingdom. There are notable outlier points. For example, 1900 was an exceptionally dry year in India/Pakistan. This drought occurred when the monsoons failed to arrive and caused widespread starvation. Estimates of the number of deaths range as high as a few million [142]. One can well imagine that anthropogenic climate change would be held responsible if something similar were to happen today. Long term droughts arise due to a change of weather patterns caused by a shift in the position of high and low pressure systems [143, 144]. The best known of these shifts is perhaps El Nino, which is believed to be caused by a warming of the sea surface temperature of the eastern Pacific Ocean. It is difficult to forecast such events. This would be very desirable as El Nino is associated with increased precipitation in places like California.

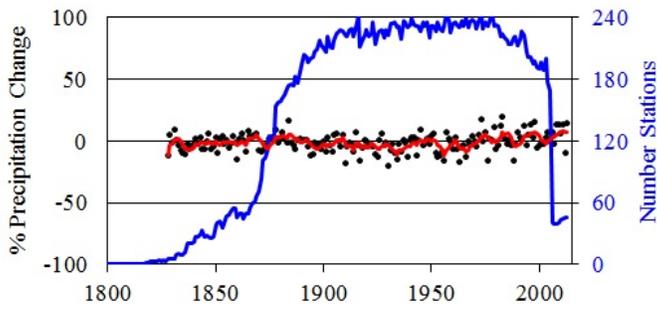
a) United Kingdom



b) India/Pakistan

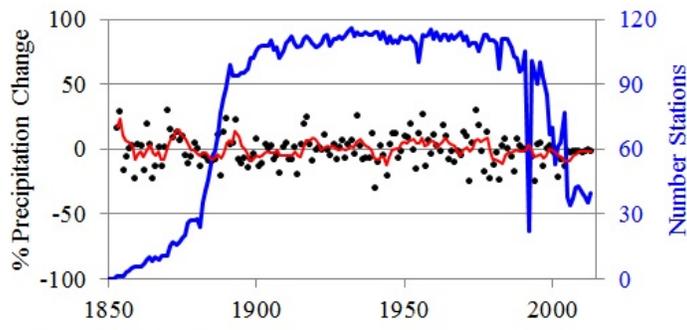


c) Lower 48 U.S. States

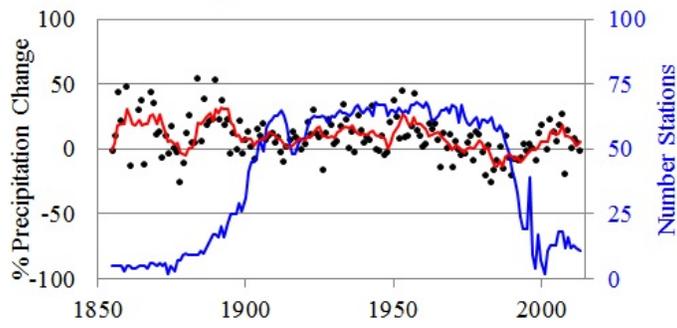


6. IS IT WETTER OR DRIER?

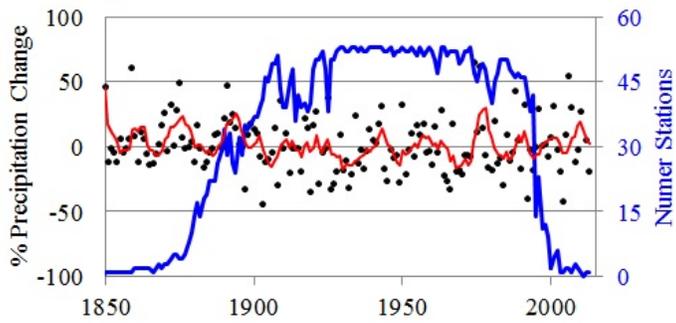
d) Australia



e) Africa north of Equator



f) Lesotho, Swaziland and South Africa



g) California

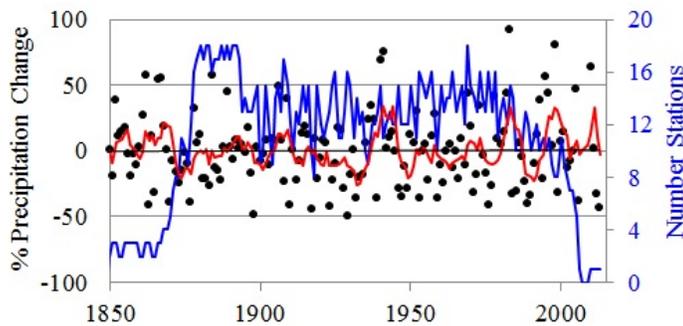


Figure 6.5: Percentage precipitation change relative to 1961-1990 for a) United Kingdom b) India/Pakistan and c) Lower 48 States of U.S. d) Australia e) Africa north of the Equator f) Lesotho, Swaziland and South Africa and g) California. The red curve is the 5 year moving average while the blue curve indicates the number of stations.

California experienced headline making droughts in the 1970s and again in 2014. The Governor has stated that the recent drought is caused by climate change [145]. The data shown in Figure 6.5 give some pause to that claim. Headlines of historic drought typically recede when rains resume what is considered a more “normal” pattern. The problem in places like California, is that they are naturally dry. Southern California is a desert and the tens of millions of inhabitants rely on imported water through a series of hundreds of miles of pipelines and canals to survive. Figure 6.5 shows that precipitation is far less dependable than in places like the United Kingdom. There also does not appear to be any change in the year to year or decadal variability of the precipitation to support claims that climate change

makes precipitation more erratic [146]. For each time series, the data points lie close to the horizontal line showing zero precipitation change.

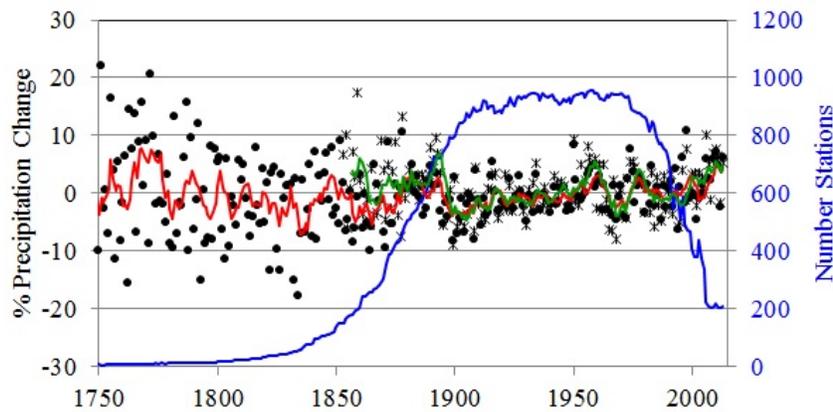


Figure 6.6: Global percentage precipitation change relative to 1961-1990. The black dots represent data found by averaging the data over all stations while the crosses were found by weighting the various continental time series using the continental areas. The red and green curves are the 5 year moving averages while the blue curve indicates the number of stations. The green curve was only found for years where data exist for all continents excluding Antarctica.

Figure 6.6 shows the global percentage precipitation change. This was computed in two ways. First, an average of the station data was taken. This preferentially weights North America and Europe where about half of the stations are located. An alternative was to combine the time series for the continents excluding Antarctica using weighting factors proportional to the continental areas. The resulting two curves do not differ significantly. Table 6.2 shows the trends depend strongly on the time period considered illustrating the effect of decadal variations. Most of the trends have uncertainties that overlap with no

precipitation change. The annual precipitation averaged over all stations was 850 mm. Therefore, a trend of 1% per century corresponds to a change of less than 0.1 mm per year. Such an annual change is difficult to measure using a simple rain gauge.

Table 6.2: Global precipitation trends were calculated for the data shown in Figure 6.6 for various time intervals.

Interval	Trend (%/Century)
1700-2013	-0.2 ± 1.1
1750-2013	-0.3 ± 1.0
1800-2013	1.2 ± 1.1
1850-2013	1.7 ± 1.4
1900-2013	3.1 ± 2.2
1950-2013	-1.1 ± 6.8

The percentage precipitation change was also found separately for stations located north of 20° N latitude, within $\pm 20^\circ$ of the equator and south of 20° S latitude. There was no substantial trend difference between the three curves. Similarly, no difference was found for stations experiencing low (annual precipitation < 500 mm), moderate (between 500 and 1000 mm) and heavy (annual precipitation > 1000 mm) precipitation. This indicates deserts and jungles are neither expanding nor shrinking. It is reasonable to conclude that large changes to global precipitation have not occurred during the last 150 years.

6.2 Extreme Rainfall Events

The preceding discussion does not consider whether extreme events, such as once in a century downpours, are becoming more common. It is difficult to study such events because they occur so rarely. One needs at least several centuries of data to make any meaningful conclusions about whether the frequency of a once in a century event is changing. Data for such extended times do not exist. That is not to say that heavy rainfall events do not produce greater flooding than in the past. Such flooding with extensive associated damage invariably occurs in urban settings where the land surface has been greatly modified to accommodate concrete roadways, parking lots, buildings, etc. that make the land surface impervious to water [147]. Whereas before it was developed the land was able to soak up much of the rainfall like a sponge, the water now runs off into creeks turning them into raging torrents.

6.3 Great Lakes

A signature of changing precipitation would be a change in the levels of large lakes. The five Great Lakes of North America contain over one fifth of the world's fresh water. Their surface area of nearly a quarter million square kilometers makes them vast inland seas. The maximum lake depths range from 406 meters for Lake Superior to 64 meters for Lake Erie. The Great Lakes watershed is shown in Figure 6.7 along with the water levels of the Lakes which have been carefully monitored since 1860.

The levels of the Great Lakes depend not only on the amount

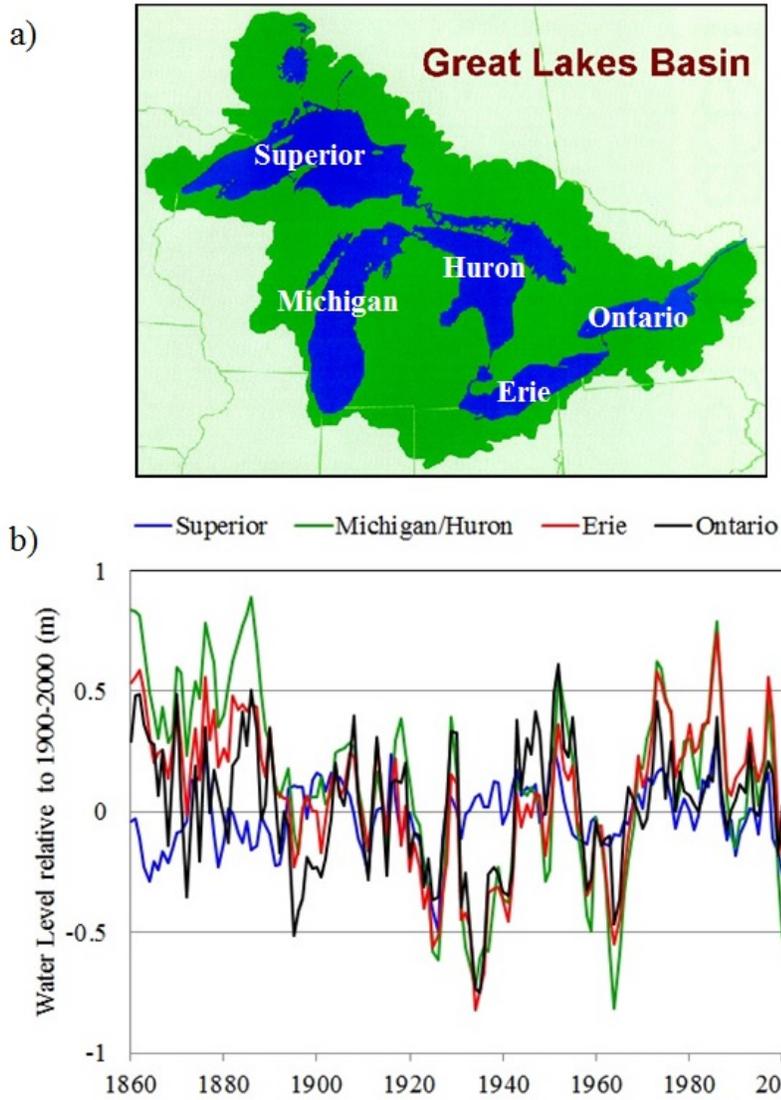


Figure 6.7: a) Great Lakes Basin and b) Water Levels from 1860-2014 [148].

of precipitation but also on the temperature. Warmer winter temperatures would decrease ice coverage. This would in turn increase evaporation reducing the water levels. The Great Lakes have also been affected by the St. Lawrence Seaway [149]. This consists of a series of locks, canals, and dredged shipping channels which allow ocean going freighters to navigate all the way to Chicago, Illinois and Duluth, Minnesota, a distance of 3,700 kilometers from the Atlantic Ocean. Shipping companies desire higher lake levels to enable larger ships that can carry more freight and are more economical.

The present St. Lawrence Seaway opened in 1959. Seven locks lift vessels 75 meters between Montreal and Lake Ontario. The level of Lake Ontario is also controlled by a hydroelectric dam. The 44 kilometer long Welland Canal connects Lake Ontario to Lake Erie, allowing ships to bypass Niagara Falls. The first Welland Canal was built in 1829. It has been progressively enlarged to accommodate larger ships and presently has eight locks which lift ships 100 meters. Lakes Erie and Huron are connected via the relatively shallow Lake St. Clair, Detroit and St. Clair Rivers. A shipping channel was dredged to a depth of eight meters through Lake St. Clair which has an average depth of just over three meters. Lakes Superior and Huron are connected via the St. Marys River. Locks bypass the rapids raising ships eight meters.

Figure 6.7b shows there is no clear trend of the Lake levels over the period from 1860-2014. There are significant variations from year to year and over decades. Water levels were particularly low in the 1960s. This resulted in the construction of many cottages near the waters edge. Widespread flooding occurred in the early 1970s as water levels

returned to more normal levels. Since 2000, the levels of Lakes Erie and Ontario have remained stable while the those of the other Lakes have decreased. This may be the result of dredging of the shipping channel through Lake St. Clair which acts similar to a drain in a bathtub. More water pours out if the drain opening is enlarged.

6.4 Forest Fires

A significant negative effect of decreasing precipitation would be an increased risk of forest fires due to extended droughts. The concern is that climate change is increasing the severity of droughts, making fires more numerous and larger. Large forest fires occur nearly every year especially during the summers in the western part of North America. Fire has always been a natural part of the ecosystem. Many fires are started by lightning.

The number of forest fires varies from year to year and between locales. The Canadian province of British Columbia may experience a large number of forest fires one year while the neighbouring province of Alberta may have few fires, and vice versa the next year. Figure 6.8 shows no obvious change in the number of wildfires in Canada during 1960-2013. There also is no clear change in the number of acres affected. The lack of any obvious signal is somewhat surprising given that mankind has strongly interfered in the forest ecosystem. Policies to extinguish fires have allowed a build up of flammable material to accumulate in North American forests during the 20th century. One would expect fires that do occur, to be much larger. In addition, humans have all too frequently and inadvertently started forest fires.

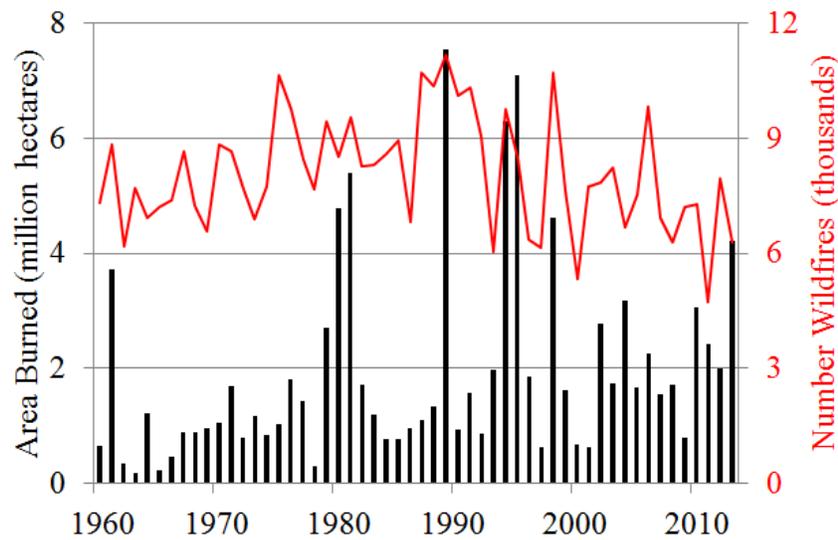


Figure 6.8: Wildfires in Canada during 1960-2013 showing affected area and the number of fires [150].

6.5 Final Precipitating Remark

Precipitation records, especially when considered over times of a century or more, do not show any significant changes. Similarly, there is no apparent change in the number of forest fires or changes to the Great Lake water levels to support such claims. Droughts have been occurring at least since the time of Elijah in the Old Testament. They have serious adverse consequences for modern civilization. Indeed, one presidential candidate recently suggested anthropogenic climate change was responsible for the drought in the Middle East that in turn contributed to the creation of the Islamic State of Iraq and Syria (ISIS), a particularly reprehensible terrorist group [151]. This is also

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not new. Genesis records the servants of Abraham and Lot fought over access to scarce water for their livestock.

7

Extraordinary Claims

Extraordinary claims about the consequences of climate change abound. There is nothing improper about making such a claim. That is how scientific breakthroughs occur. However, one should accept rigorous scientific scrutiny and realize the onus is on the person making the claim to provide the supporting evidence. It goes without saying that an extraordinary claim requires extraordinary proof. This has always been the scientific standard and should definitely be met by anyone urging the Earth's 7.3 billion people to drastically change their way of life. This chapter discusses the claim about 9/11 changing the climate and presents three especially dubious examples.

7.1 Did 9/11 change the climate?

About ten years ago, after a long day analyzing climate data, I turned on the television to relax. The American Public Broadcasting Service scientific show NOVA began with dramatic footage of the terrorist at-

tack on the World Trade Center on September 11, 2001 [152]. Three scientists realized the ensuing three day ban of all commercial flights across North America provided a unique opportunity to examine how airplane contrails affect the daily temperature [153, 154]. Contrails are the white exhaust trails sometimes produced by aircraft seen in the sky. The scientists found the diurnal temperature range, defined as the difference between the daily maximum minus the minimum temperature, increased over the continental United States excluding Alaska during the three days when commercial flights were suspended as compared to the three day periods before Sept. 11, 2001 and after flights resumed. The diurnal temperature range during Sept. 8-17, 2001 was compared to the average value occurring on those dates during 1971-2000. It increased by 1.1 °C for Sept. 11-14, 2001 as compared to the value for the previous 30 year period. The corresponding changes for Sept. 8-11 and Sept. 14-17 were -0.2 and -0.8 °C, respectively. This change was attributed to a lack of contrails which act like clouds reflecting sunlight during the day and radiation from the Earth's surface at night [155].

The supposed effect of the absence of contrails after the 9/11 tragedy was hailed as a major scientific discovery. The IPCC had previously pointed out that global warming of about 1 °C per century had occurred due to greenhouse gas emissions produced by hundreds of millions of vehicles and millions of factories. The 9/11 contrail study now revealed that a comparable temperature change occurred within hours after a few hundred jet engines had been turned off! If this were true, one could imagine a simple solution to global warming. An additive to airplane fuel would help generate contrails that would reflect

sunlight during the day. The additive would need to be carefully chosen so contrails would precipitate out of the atmosphere before sunset, eliminating any night time warming effect. It sounded too good to be true.

Several studies questioned the conclusions pointing out that the observations could be explained by a lack of cloudiness over North America in the three days following September 11, 2001 [156, 157, 158]. My group examined data observed at stations located throughout Canada where flights were also prohibited following 9/11 [159]. No change in the diurnal temperature range corresponding to the flight restrictions imposed after Sept. 11, 2001 was observed. These conclusions did not change when only stations near the U.S. border were considered.

Unfortunately, it took some time before the American data could be accessed¹. Eventually, data were received for 202 stations located

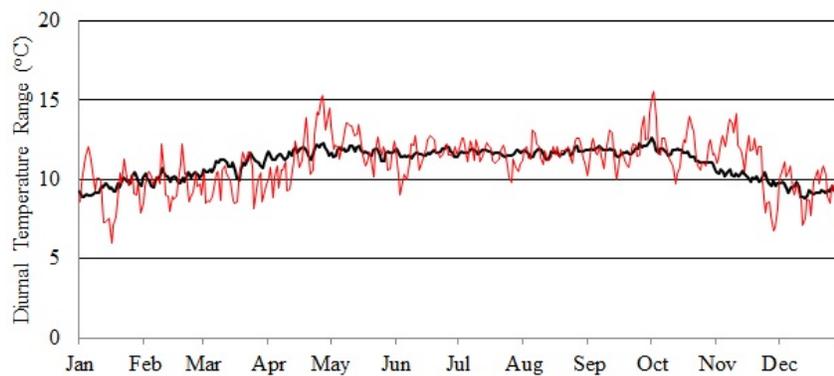


Figure 7.1: Diurnal temperature range averaged over the stations located in the lower 48 U.S. states as a function of time throughout the year. The black curve represents data averaged for 1975-2005 while the red curve is data for 2001.

in the lower 48 U.S. states for the period 1975-2005. The diurnal temperature range averaged over all stations was found for each day in 2001 and compared to the average value occurring during 1975-2005 as shown in Figure 7.1 [160]. The September, 2001 data are very close to the 31 year averaged values. The largest departures of the 2001 data from the 1975-2005 averaged values occur in months other than September.

Figure 7.2 shows the change of the diurnal temperature range for the period Sept. 8-17, 2001 relative to 1975-2005. The diurnal temperature range increased during each of the four days from Sept. 8-11, decreased until Sept. 14, whereafter it increased. This does not correlate well with the flight ban. Figure 7.2 also displays the three day averaged values. The changes in the diurnal temperature range averaged during Sept. 8-10, 11-13, 14-16 were -0.3, 0.6 and -0.5 °C, respectively. These results are comparable to those found in the original 9/11 contrail study [153].

The change in the diurnal temperature range during September 8-17, 2001 experienced by the different stations was also plotted on a map of North America. The results at a given station were found to be similar to those at surrounding stations. The maps show day to day changes consistent with the natural progression of weather systems across North America. This agrees with other studies that found September 11, 2001 to have been an unusually clear day [156, 157, 158].

It has been pointed out that Osama bin Laden was unfortunately not stupid. He realized his terrorist pilots were not entirely proficient

¹Climate observations are not always readily accessible. This author has been forced to pay over a \$1,000 for a few years of climate data recorded at publicly funded airports. This is most unfortunate as it seriously impedes scientific inquiry.

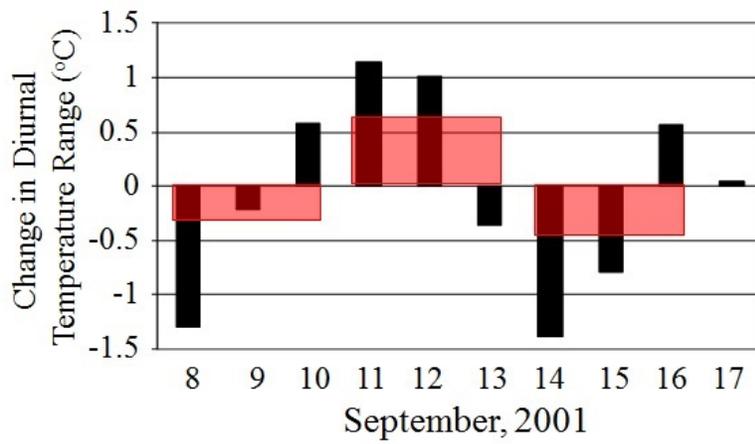


Figure 7.2: Change in diurnal temperature range. The three day averaged values shown in red are very close to those found in the original 9/11 contrail study that claimed the diurnal temperature range changed as a result of the flight ban following 9/11. The more likely explanation is that skies were clear immediately following 9/11 as is discussed in the text.

in flying in cloudy weather and would need clear skies to navigate the hijacked planes to their targets. The tragedy of 9/11 changed the world but not the climate.

7.2 Truly Extraordinary Claims

7.2.1 Ocean Wave Heights

²Some time ago, I attended a talk about the change of ocean wave heights from 1860 to the present day. The speaker was highly regarded and had published extensively in the refereed literature. Graphs were presented showing how wave heights had dramatically increased. The trend line was extended to 2100 to emphasize that waves would be much higher at that time. One was left wondering whether tsunamis would then be a common occurrence.

A scientific presentation normally begins by describing the apparatus and the procedure used to make the measurements or take the observations. In this talk, it was disconcerting that nothing was said about how wave heights were determined. Today, wave height measurement is relatively straight forward. One could place a global positioning transponder on a buoy. The precise vertical position of the bobbing buoy as a function of time is then transmitted to a satellite which in turn sends the information to the scientist. However, this technology has only been available for the last few decades. It was also odd that the data presented did not show an improved accuracy as technology has greatly improved over the past century and a half.

²The intent of this book is to enlighten the public, not to embarrass individuals. References are therefore omitted in this section.

After the talk, the obvious question was posed asking how wave heights were measured in 1860. The response was that logbook entries, made by captains sailing primarily between Europe and North America, had been studied. It is ludicrous to claim that meaningful quantitative information can be extracted from a comment such as “big waves observed today”.

7.2.2 Wind Speed

The implications of climate change are becoming popular with politicians. One concern is that the civil infrastructure is inadequate for a changed climate. This was the theme of an elected official serving in some hamlet north of Toronto. He began his presentation by mentioning that he was a corecipient, along with Al Gore, of the 2007 Nobel prize. He had not gone to Stockholm but apparently was one of the thousands of authors who had a paper referenced in one of the voluminous IPCC reports.

The speaker was concerned about increasing wind speeds. “Data” were presented showing how wind speed had increased during the 20th century in a county just north of Toronto. This in turn had substantially increased wind damage. After the talk, the question was asked how the average wind speed was measured in 1920. Today, each house could have an anemometer that is connected via the internet to a central computer at Environment Canada that calculates the average wind speed. The answer was that newspaper accounts of wind reported damage had been studied. It is silly to attempt to convert an archival account in an obscure county paper about “Farmer Joe’s barn losing its roof” into a meaningful accurate numerical value of the wind

speed. The speaker went on to vehemently claim that the increase in wind damage was not due to the huge increase in the county's population from a few hundred farmers a century ago to tens of thousands of Toronto suburbanites.

7.2.3 Hudson Bay Warming

The concern about rising Arctic temperatures is a popular topic. This was highlighted by an invited speaker at a workshop. He was introduced as a journal editor who had authored over 200 refereed publications. The speaker showed how the global climate models forecast temperatures will change over North America in the mid 21st century. The center of Hudson Bay is predicted to warm 8 °C by 2050. This would correspond to a warming trend of about 20 °C per century. When asked whether this was plausible, the speaker emphasized it was. The 8 °C estimate had been derived by averaging the predictions of several climate models. One model even predicted that Hudson Bay would be ice free during winter in 2050. This got the attention of even dozing members of the audience. How is this possible if the average January temperature at a place like Churchill, Manitoba is less than -20 °C? The speaker answered that he had done a careful statistical analysis. A particularly courageous audience member said he was certain that was the case. However, garbage in from a faulty climate model plus a perfect statistical analysis still produces garbage out. It is unlikely sane people will be water skiing throughout Hudson Bay in 2050 during winter.

8

What Should/Can Be Done?

8.1 Summary of Evidence

Table 8.1 summarizes the evidence. The Earth's average surface temperature has increased by about 1 °C since the start of the industrial revolution. However, the climate models are not able to account for substantial decadal variations. The most significant of these is the abrupt warming that occurred in the 1990s followed by the so called hiatus after 2000. Arctic temperatures for the past two centuries have not increased as predicted, but been strongly correlated with temperature changes observed elsewhere in the Northern Hemisphere such as Europe. It is especially disconcerting that the measurements of the troposphere do not show any significant temperature change, in sharp disagreement with all model forecasts.

There has been a significant reduction in glaciers, especially in the

Table 8.1: Evidence Summary.

Quantity	Status
Temperature	<ul style="list-style-type: none"> -Global average temperature increased by about 1 °C since 1850 -Climate models do not account for decadal temperature variations -Arctic and Europe have experienced similar warming, inconsistent with climate models -No change in troposphere temperatures inconsistent with climate models
Glaciers & Polar Ice Caps	<ul style="list-style-type: none"> -Reduction in Arctic ice cap during 1979-2013 consistent with warming in 1990s -Insufficient data to conclude polar bear populations are declining -Increase in Antarctic ice cap during 1979-2013 not predicted by climate models
Oceans	<ul style="list-style-type: none"> -Sea levels have increased since end of last Ice Age -Some evidence of accelerating sea level rise in 1990s consistent with temperature increase -Evidence does not indicate change in number or severity of hurricanes -Ocean acidification evidence not overwhelming -Claim of damage to marine ecosystems is tenuous
Precipitation	<ul style="list-style-type: none"> -Evidence does not support claims of any large precipitation change during the 20th century -Evidence of change in forest fire frequency or Great Lake levels due to climate change is weak

Arctic ice cap, that has been commensurate with the temperature increase in that region during the 1990s. This coincides with the reduced ice cover of the Baltic Sea. However, the latter record exists for three centuries and shows a much smaller trend over that extended time period. It is not possible to make any definitive conclusions about whether Arctic wildlife, most notably polar bears, have been affected as the census data are inadequate. Unlike the Arctic ice cap, the Antarctic ice cap increased from 1979-2014. Antarctica does not seem to have warmed as much as the Arctic, although observational data are sparse.

Sea levels have increased throughout the 20th century at a rate of about two mm per year. This is likely a continuation of a natural process that began near the end of the last Ice Age. There appears to be a small acceleration of the sea level rise which is consistent with the observed temperature increase in the 1990s and associated glacial melting. There is no evidence to support claims that storms have increased in either number or severity. It is also not obvious that ocean acidity, which is estimated to have increased by 0.1 pH since 1750, has had any impact on marine ecosystems. Mankind has, however, had a major negative impact on the oceans due to pollution and overfishing, which should stop immediately.

There has not been any major change in the amount of precipitation or precipitation patterns around the world since 1850. Extreme events such as droughts have occurred since time immemorial. Evidence that forest fires have increased in number or severity is very weak and masked by human interference in forest ecosystems during the past century. Major watersheds such as the Great Lakes do not

show significant change caused by climate change over times of a century or more.

In conclusion, the evidence does not validate the climate models. That does not mean that global warming due to increasing greenhouse gases is completely wrong. This author finds the temperature increase in the 1990s quite disconcerting, even though it does not coincide with any dramatic increase in fossil fuel use. Similarly, fossil fuel use did not stop after 2000 which would help explain the global warming hiatus. In fact, the production of oil, coal and natural gas increased to meet the rising energy demand in developing countries.

The failure of the climate models is universally recognized. The latest IPCC report contains Figure 8.1 that shows how the observed temperature is lower than that predicted by nearly all the models that consider various scenarios for increasing greenhouse gases [25]. It is not known what effects the models have inadequately considered. Possibilities include changes in: the sun's intensity, cloudiness, absorption of heat from the atmosphere by the oceans, carbon soot pollution in the Arctic, natural decadal variations, etc. This is frustrating. There may very well be no single cause but a combination of factors which will make the diagnosis as to how to fix the climate models more challenging.

The creation of a global climate model is no easy task. Highly competent computer programmers run complex code on the fastest supercomputers available. However, the models can only approximate the Earth atmosphere and ocean system. It may be too complicated to generate a model that is able to make reliable predictions in the foreseeable future. A model can only be validated by comparing pre-

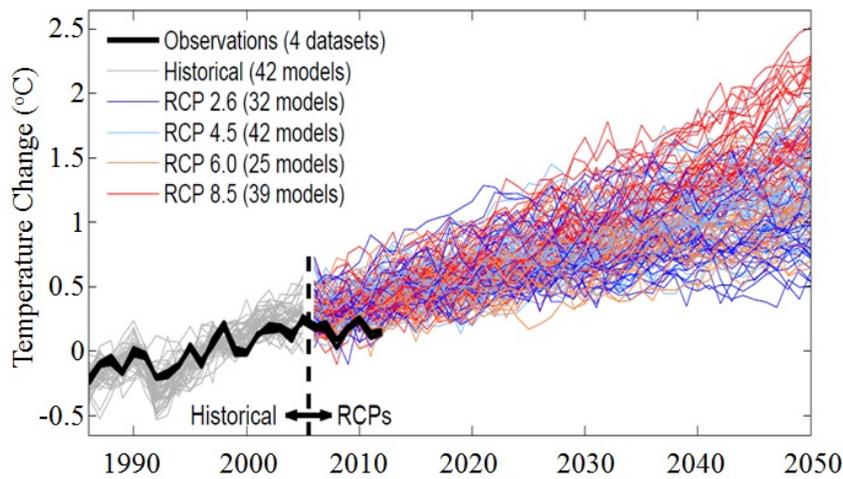


Figure 8.1: Comparison of global climate model temperature projections for the 21st century and observed data[25].

dictions of several decades to observations. This takes considerable time. The concern is that by the time a reliable climate model finally exists, unchecked greenhouse gas emissions would have set global warming into motion on such a scale that the Earth's climate will be unalterably changed for centuries to come. The proponents of the climate change agreement reached in December, 2015, argue that action is needed now to reduce and even stop greenhouse gas emissions. The agreement sets the goal to limit future global temperature increases to 2 °C. Each nation was left to decide its own greenhouse gas emissions target. The treaty does not have any enforcement mechanisms.

8.2 Energy Sustainability

There are many reasons to reduce or entirely eliminate the use of fossil fuels even if global warming due to increased greenhouse gas concentrations was completely wrong. Figure 8.2 shows the devastating consequences to wildlife of an oil spill. Mama seal does not like it when her pups come home covered in crude oil.



Figure 8.2: Oil covered duck as a result of a crude oil spill.

Just how easy would it be for the world to change its energy use? Figure 8.3 shows the sources and sector users of energy for the United States. As of 2009, only about 8% of the total energy was generated renewably. This refers largely to solar, wind and hydroelectric generation. It should be noted that these are not without environmental

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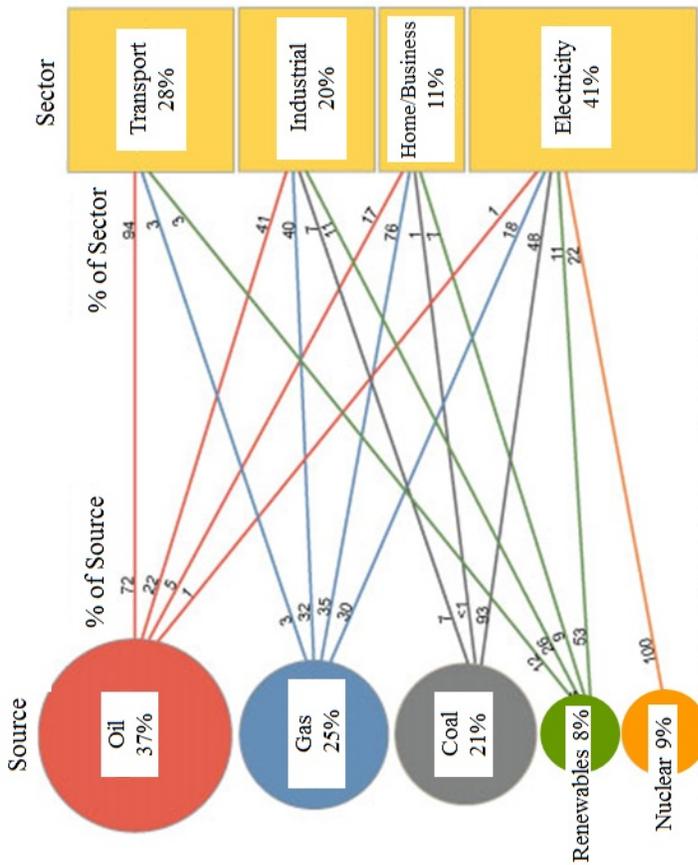


Figure 8.3: U.S. energy sources and use by sector in 2009 [161].

consequences. Salmon are not too amused by dams blocking their migratory routes. Similarly, windmills placed along bird migratory routes can kill birds, although the exact estimates of fatalities vary wildly [162, 163]. Many renewable energy sources are heavily subsidized to compete with cheaper fossil fuels. The province of Ontario, Canada pays solar energy suppliers over 50 cents per kilowatt hour whereas traditional plants that burn fossil fuels produce power about ten times more cheaply [164]. Solar and wind energy are also not reliable on cloudy or windless days. Nuclear power can generate energy without producing greenhouse gases but this is also not without concerns which are not the subject of this book. In short, there is no simple way to generate electricity without some adverse environmental consequences.

Figure 8.3 shows North Americans would need to reduce their energy use by about 90% to stop greenhouse gas emissions. This is impossible to do by conservation alone. Even such avant garde politicians as Canada's newly elected Prime Minister Justin Trudeau are not going to restrict Canadians to only heat their homes one day a week in winter, and prohibit driving to all but a few days each month. Conservation is nevertheless important. If Ms. Toyota can build a Prius that uses only 4.6 liters per 100 kilometers¹, why can't the traditional North American automakers do so? It should be pointed out that a Prius is no mere experimental bicycle, but comfortably seats four adults.

Other technological innovations also exist. Lighting efficiency can be substantially improved by replacing incandescent bulbs by light

¹This is equivalent to over 60 miles per imperial gallon or 50 miles per U.S. gallon.

emitting semiconductors. These devices generate light producing drastically less waste heat which in turn reduces the need for air conditioning. Cities also need to invest in mass transit to give commuters a realistic option to get out of their cars. These changes are not cheap and require political leadership. The Toronto city council has argued for decades about the location of a few subway stations. My Chinese graduate students point out that in the time it takes Toronto to build three subway stations, Chinese cities start and complete entire subway systems. Conservation measures and investments in energy reducing technologies will decrease our need for fossil fuel but do not come close to reducing our energy demand to the level that fossil fuels can be entirely eliminated.

Moreover, there is the developing world. People in India, Africa and elsewhere, see the European and North American standard of living and want it. A starving person in Bangladesh or Africa is concerned about their next meal and is relatively deaf to Western pleas regarding possible climate change a century from now. For that reason, even if developed countries drastically reduce their use of fossil fuels, global demand will continue to increase.

The hope is that future technological innovation will reduce or even eliminate the need for fossil fuels. Research progress can be painstakingly slow. Scientists have been working to enhance the power of light emitting semiconductors for about 50 years. It has taken 35 years to triple the average automotive fuel economy [165]. There were significant gains in the 1970s following the Arab oil embargo but this slowed substantially in the 1980s until relatively recently. The lesson is that technological innovations are not cheap and do not come quickly. A

sustained investment is required in a wide variety of research including fundamental science. This may not have the promise of an immediate technological dividend but is critical for future progress to develop strong lightweight materials, better batteries, high temperature superconductors, etc.

8.3 What should we do now?

The unlikelihood of significant reduction in fossil fuel use has led some scientists to propose massive geoengineering schemes. One is to spray small particles such as sulfur oxide compounds from a fleet of 747s high in the atmosphere [166, 167, 168]. These aerosol particles would reflect sunlight and cool the planet counteracting the effect of increasing greenhouse gases. This intervention would be massive and concerns have been raised about possible unintended adverse consequences. These aerosols would likely aggravate the effect of pollutant particles that are already estimated to cause more than half a million premature deaths per year worldwide [169]. Could such sulfur oxide molecules produce acid rain and contribute to ocean acidification? Our understanding of the Earth atmosphere system is woefully insufficient to contemplate such schemes.

It is not clear whether global warming due to increased greenhouse gases caused by burning fossil fuels is true. It is very possible that only part of the temperature increase observed especially in the 1990s was due to the anthropogenic increase of greenhouse gases. The public needs to be correctly informed about what is known and uncertain. Figure 8.4 shows a page from the National Oceanographic and Atmosphere Administration website that conveniently gives the monthly

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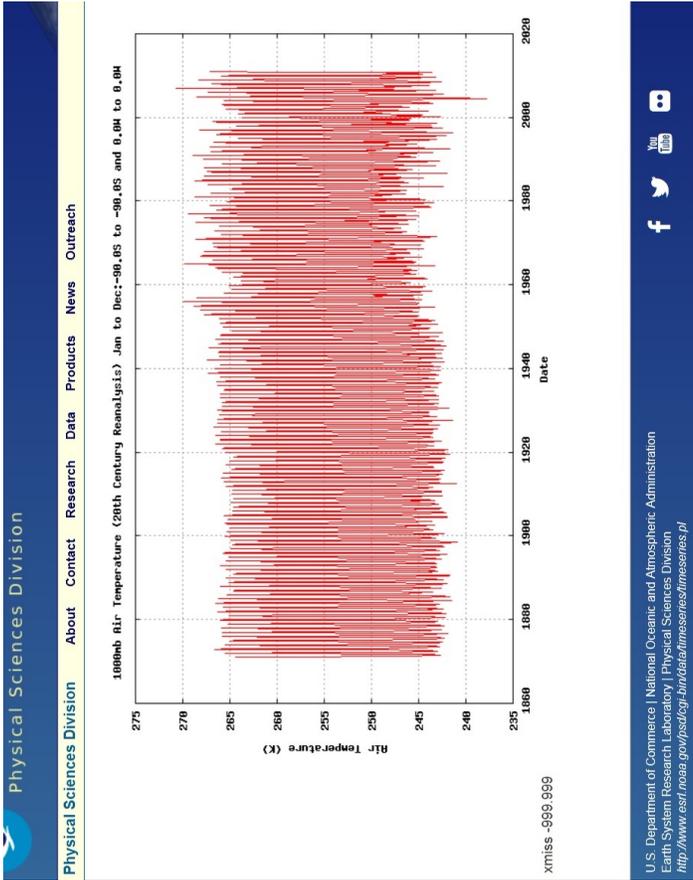


Figure 8.4: NOAA South Pole monthly reanalysis temperatures from 1871 to 2015. The temperature is expressed in units of Kelvins. The Kelvin scale sets the freezing point of water at 273 °K and one degree Kelvin equals one degree Celsius [115].

averaged temperature at any point on the Earth since 1871. The resulting temperature is given with an accuracy of one hundredth of a Celsius degree. “Data” are provided for all points on the Earth, even for temperatures at the South Pole in 1871! This is unbelievable as no human came within thousands of kilometers of the South Pole until several decades later. The South Pole temperature was undoubtedly extrapolated from observations made in South America, South Africa and Australia. However, temperatures in the 1800s were made using simple thermometers that had an accuracy of at best 0.1 °C. It is silly to claim that one can infer a temperature that has ten times better accuracy at a place thousands of kilometers distant. The public rightly becomes skeptical of science when they see such nonsense. That is dangerous. History shows there are instances when scientists point out a danger such as that posed by the chlorofluorocarbon compounds in the 1970s, and the public needs to listen and support urgent action.

Scientific literacy must improve to enable the general public to digest the nearly daily dose of news stories purporting to show the adverse consequences of global warming, particularly when the weather is unusual. Four questions may be helpful when considering a scientific study.

1. Does the study consider only a short span of time? The record of the past two centuries shows that temperature and precipitation trends have varied due to naturally occurring decadal fluctuations.

2. Is the accuracy of the results given or even discussed? Any 20th century temperature trend claiming an accuracy of 0.01 °C is likely incorrect as it is impossible to read a mercury thermometer to better than 0.1 °C.

3. Does the study have the inherent capability to obtain the purported result? For example, suppose one wanted to study the temperature of Lake Erie which covers an area of 25,000 km² and has an average depth of 19 meters². Placing a thermometer every 100 km² and at depths of every 5 meters, would require over 1,000 thermometers. The temperature would need to be monitored several times each day. This may be challenging in winter, when large parts of Lake Erie freeze, and the ice can crush a thermometer. This is no small undertaking and shows how challenging it will be to study ocean temperature.

4. Is the study based on modelled results which all too frequently and misleadingly are called data? Only measured observations constitute data and can test climate models.

What is needed is not more climate hysteria but quality scientific research. A high priority should be to improve our understanding of the world's oceans. Efforts to monitor not just the temperature at various depths but also the water salinity, acidity, currents, etc. only began after 2000 [170]. Scientific understanding has always emerged from an iterative process of trial and error. A model is proposed. It makes predictions which are compared to observations. Discrepancies between predictions and observations lead to model improvements. The process then repeats. In the case of climate studies, many researchers have stopped questioning whether the climate models are correct. Too many papers start with the premise of the infallible word of the climate models, and go on to forecast doom and gloom. That is religion not science.

Mankind faces great challenges in the coming century. The Global

²Satellites can determine the surface temperature of a body of water. This does require proper calibration checks using thermometer measurements.

Warming theory is far from being settled science. Indeed, after world temperatures ceased their dramatic increase in 2000, the favoured name became Climate Change. Changing the name does not affect the conflicting scientific evidence. It is not always easy for scientists to convey our understanding of the Earth's climate and the limits of our knowledge to the public. But, if scientists expect the entire world to drastically change its standard of living, a hardship which may be especially devastating for the world's poor, we owe everyone a detailed explanation. Indeed, the people should demand it.

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