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A Study About Realities of Climate Change: Glacier Melting and Growing Crises

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Additional information is available at the end of the chapter

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1. Introduction

Climate change has ceased to be a scientific curiosity since long, and is no longer just one of many environmental and regulatory concerns. As the Secretary General of United Nations has said, it is the major, overriding environmental issue of our time, and the single greatest challenge faced by environmental regulators. It is a growing crisis with economic, health and safety, food production, security, and other dimensions.

Climate change is expected to hit developing countries the hardest. Its effects; higher temperatures, changes in precipitation patterns, rising sea levels, and more frequent weather-related disasters- pose risks for agriculture, food, and water supplies. The fight against poverty, hunger and disease, and the lives and livelihoods of billions of people in developing countries are at stake. Tackling this immense challenge must involve both mitigation- to avoid the unmanageable and adaptation- to manage the unavoidable while maintaining a focus on its social dimensions.

1.1. What is weather and climate?

The weather, as we experience it, is the fluctuating state of the atmosphere around us, characterised by the temperature, wind, precipitation, clouds and other weather elements. This weather is the result of rapidly developing and decaying weather systems such as mid-latitude low and high pressure systems with their associated frontal zones, showers and tropical cyclones. Weather has only limited predictability. Mesoscale convective systems are predictable over a period of hours only; synoptic scale cyclones may be predictable over a period of several days to a week. Beyond a week or two individual weather systems are unpredictable.

Climate- It refers to the average weather in terms of the mean and its variability over a certain time-span and a certain area. Classical climatology provides a classification and

description of the various climate regimes found on the Earth. It varies from place to place, depending on latitude, distance to the sea, vegetation, presence or absence of mountains or other geographical factors. Climate also varies with time; from season to season, year to year, decade to decade or on much longer time-scales, such as the Ice Ages. Statistically significant variations of the mean state of the climate or of its variability, typically persisting for decades or longer, are referred to as "climate change".

Climate variations and change, caused by external factors, may be partly predictable, particularly on the larger, continental and global, spatial scales. Because human activities, such as the emission of greenhouse gases or change in land-use, do result in external forces, it is believed that the large-scale aspects of human-induced climate change are also partly predictable. However the ability to actually do so is limited because we cannot accurately predict population change, economic change, technological development, and other relevant characteristics of future human activity. Therefore, one has to rely on carefully constructed scenarios of human behaviour and determine climate projections on the basis of such scenarios.

Climate variables-The traditional knowledge of weather and climate focuses on those variables that affect daily life directly i.e.; average, maximum and minimum temperature, wind near the surface of the Earth, precipitation in its various forms, humidity, cloud type and amount, and solar radiation. These are the variables observed hourly by a large number of weather stations around the globe.

However, this is only part of the reality that determines weather and climate. The growth, movement and decay of weather systems also depend on the vertical structure of the atmosphere, the influence of the underlying land and sea and many other factors not directly experienced by human beings. Climate is determined by the atmospheric circulation and by its interactions with the large-scale ocean currents and the land with its features such as albedo, vegetation and soil moisture. The climate of the Earth as a whole depends on factors that influence the radiative balance, such as for example, the atmospheric composition, solar radiation or volcanic eruptions. To understand the climate of our planet Earth and its variations and to predict the changes of the climate brought about by human activities, one cannot ignore any of these many factors and components that determine the climate. We must understand the climate system, the complicated system consisting of various components, including the dynamics and composition of the atmosphere, the ocean, the ice and snow cover, the land surface and its features, the many mutual interactions between them, and the large variety of physical, chemical and biological processes taking place in and among these components. "Climate" in a wider sense refers to the state of the climate system as a whole, including a statistical description of its variations.

1.2. What is greenhouse effect?

A natural system known as the "greenhouse effect" regulates temperature on the Earth. Just as glass in a greenhouse keeps heat in, our atmosphere traps the sun's heat near earth's surface, primarily through heat-trapping properties of certain "greenhouse gases". Earth is

heated by sunlight and most of the sun's energy passes through the atmosphere, to warm the earth's surface, oceans and atmosphere. However, in order to keep the atmosphere's energy budget in balance, the warmed earth also emits heat energy back to space as infrared radiation. As this energy radiates upward, most is absorbed by clouds and molecules of greenhouse gases in the lower atmosphere. These re-radiate the energy in all directions, some back towards the surface and some upward, where other molecules higher up can absorb the energy again. This process of absorption and re-emission is repeated until; finally, the energy does escape from the atmosphere to space. However, because much of the energy has been recycled downward, surface temperatures become much warmer than if the greenhouse gases were absent from the atmosphere. This natural process is known as the greenhouse effect. Without greenhouse gases, Earth's average temperature would be -19°C instead of $+14^{\circ}\text{C}$, or 33°C colder. Over the past 10,000 years, the amount of greenhouse gases in our atmosphere has been relatively stable. Then a few centuries ago, their concentrations began to increase due to the increasing demand for energy caused by industrialization and rising populations, and due to changing land use and human settlement patterns.

1.3. What are greenhouse gases?

Water vapour is the most common constituent of greenhouse gases. But others are equally important and some occur naturally while some come from human activity. Carbon Dioxide or CO_2 is the significant greenhouse gas released by human activities, mostly through the burning of fossil fuels. It is the main contributor to climate change.

Methane is produced when vegetation is burned, digested or rotted with no oxygen present. Garbage dumps, rice paddies, and grazing cows and other livestock release lots of methane.

Nitrous oxide can be found naturally in the environment but human activities are increasing the amounts. Nitrous oxide is released when chemical fertilizers and manure are used in agriculture.

Halocarbons are a family of chemicals that include CFCs (which also damage the ozone layer), and other human-made chemicals that contain chlorine and fluorine. Since greenhouse gases make up such a small percentage of the atmosphere, why do changes in their concentrations have such a big effect on climate?

Most greenhouse gases are extremely effective at absorbing heat escaping from the earth and keeping it trapped. In other words, it takes only small amounts of these gases to significantly change the properties of the atmosphere. 99% of the dry atmosphere consists of nitrogen and oxygen, which are relatively transparent to the sunlight and infrared energy, and have little effect on the flow of the sunlight and heat energy through the air. By comparison, the atmospheric greenhouse gases that cause the earth's natural greenhouse effect total less than 1% of the atmosphere. But that tiny amount increases the earth's average surface temperature from -19°C to $+14^{\circ}\text{C}$ - a difference of about 3°C . A little bit of greenhouse gas goes a long way. Because the concentration of greenhouse gases in the atmosphere is so low, human emissions can have a significant effect. For example, human emissions of carbon dioxide (CO_2)

currently amount to roughly 28 billion tonnes per year. Over the next century human emissions will increase the concentration of carbon dioxide in the atmosphere from about 0.03% today to almost certainly 0.06% (a doubling), and possibly to 0.09% (a tripling).

1.4. What causes climate change?

Earth's climate changes naturally and such changes in the intensity of sunlight reaching the earth cause cycles of warming and cooling that have been a regular feature of the Earth's climatic history. Some of these solar cycles - like the four glacial-interglacial swings during the past 400,000 years - extend over very long time scales and can have large amplitudes of 5 to 6°C. For the past 10,000 years, the earth has been in the warm interglacial phase of such a cycle. Other solar cycles are much shorter, with the shortest being the 11 year sunspot cycle. Other natural causes of climate change include variations in ocean currents (which can alter the distribution of heat and precipitation) and large eruptions of volcanoes (which can sporadically increase the concentration of atmospheric particles, blocking out more sunlight). Still, for thousands of years, the Earth's atmosphere has changed very little. Temperature and the balance of heat-trapping greenhouse gases have remained just right for humans, animals and plants to survive. But today we're having problems keeping this balance, because we burn fossil fuels to heat our homes, run our cars, produce electricity, and manufacture all sorts of products, we're adding more greenhouse gases to the atmosphere. By increasing the amount of these gases, the warming capability of the natural greenhouse effect is enhanced. It's the human-induced enhanced greenhouse effect that causes environmental concern, because it has the potential to warm the planet at a rate that has never been experienced in human history.

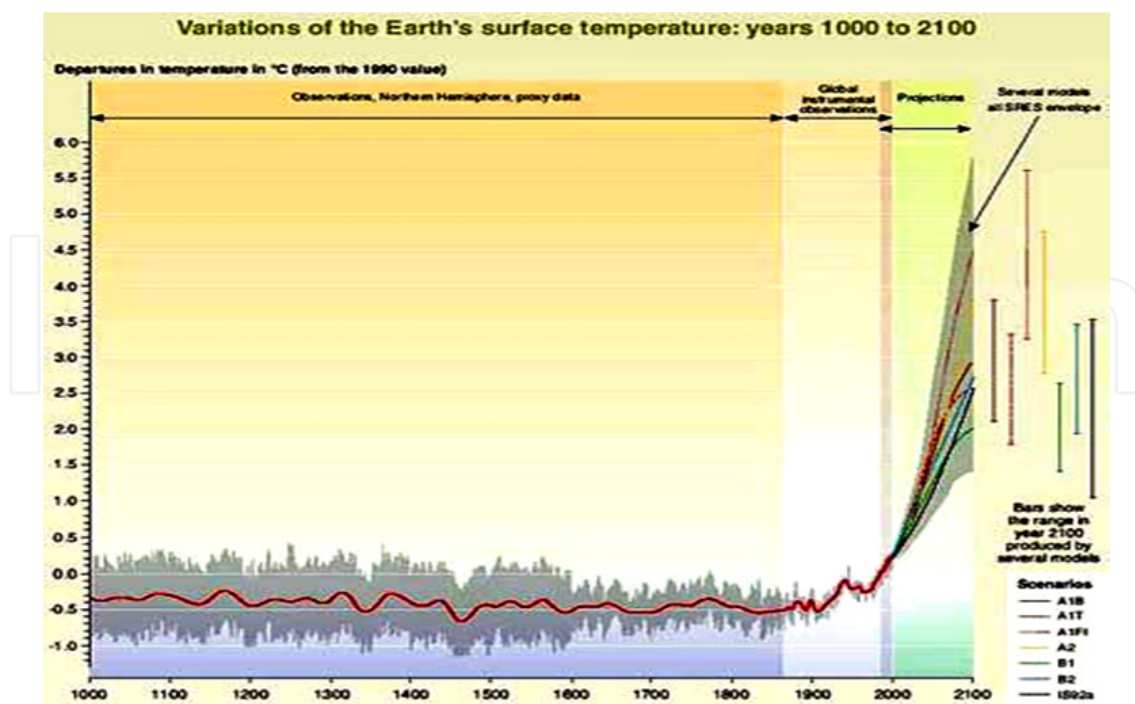


Figure 1. Variations in average surface temperature from year 1000 to year 1860; year 1860 to 2000 annually averaged and year 2000-2100 projected average temperature

From year 1000 to year 1860 variations in average surface temperature of the Northern Hemisphere are shown in **Fig. 1**, but corresponding data from the Southern Hemisphere was not available and hence it was reconstructed from proxy data (tree rings, corals, ice cores, and historical records). The line shows the 50-year average, the grey region the 95% confidence limit in the annual data. From years 1860 to 2000 are shown variations in observations of globally and annually averaged surface temperature from the instrumental record; the line shows the decadal average. From years 2000 to 2100 projections of globally averaged surface temperature are shown for the six illustrative SRES scenarios and IS92a using a model with average climate sensitivity. The grey region marked "several models all SRES envelope" shows the range of results from the full range of 35 SRES scenarios in addition to those from a range of models with different climate sensitivities. The temperature scale is departure from the 1990 value.

1.5. What happens due to climate change?

Shifting weather patterns, threaten food production through increased unpredictability of precipitation, rising sea levels contaminate coastal freshwater reserves and increase the risk of catastrophic flooding, and a warming atmosphere aids the pole-ward spread of pests and diseases once limited to the tropics. Ice-loss from glaciers and ice sheets has continued, leading, for example, to the second straight year with an ice-free passage through Canada's Arctic islands, and accelerating rates of ice-loss from ice sheets in Greenland and Antarctica. Combined with thermal expansion—warm water occupies more volume than cold—the melting of ice sheets and glaciers around the world is contributing and an ultimate extent of sea-level rise that could far outstrip those anticipated in the most recent global scientific assessment.

2. Alarming evidences due to climate change

There is alarming evidence that important tipping points, leading to irreversible changes in major ecosystems and the planetary climate system, may already have been reached or passed. Ecosystems as diverse as the Amazon rainforest and the Arctic tundra, for example, may be approaching thresholds of dramatic change through warming and drying. Mountain glaciers are in alarming retreat and the downstream effects of reduced water supply in the driest months will have repercussions that transcend generations. Climate feedback systems and environmental cumulative effects are building across Earth systems demonstrating behaviours we cannot anticipate.

2.1. Deforestation and climate change

Forests are vital for life, home to millions of species, they protect soil from erosion, produce oxygen, store carbon dioxide, and help control climate. Forests are also vital for us to live as they provide us with food, shelter and medicines as well as many other useful things. They also purify the air we breathe and water that we need to survive. Deforestation by humans

is causing reduction in all of these necessary functions, and hence damaging the atmosphere even further.

Forests play a huge role in the carbon cycle on our planet. When forests are cut down, not only does carbon absorption cease, but also the carbon stored in the trees is released into the atmosphere as CO₂ if the wood is burned or even if it is left to rot after the deforestation process. Smaller crops e.g. plants and agricultural crops also draw in carbon dioxide and release oxygen, however forests store up to 100 times more carbon than agricultural fields of the same area. Deforestation is an important factor in global climate change. Climate change is because of a buildup of carbon dioxide in our atmosphere and if we carry on cutting down the main tool we have to diminish this CO₂ build up, we can expect the climate of our planet to change dramatically over the next decades.

It is estimated that more than 1.5 billion tons of carbon dioxide is released to the atmosphere due to deforestation, mainly the cutting and burning of forests, every year. Over 30 million acres of forests and woodlands are lost every year due to deforestation; causing a massive loss of income to poor people living in remote areas who depend on the forest to survive.

3. Risk due to climate change

Climate vulnerability and risk management is a part of dialogue and work with developing countries. Key sectors affected by climate change include health, water supply and sanitation, energy, transport, industry, mining, construction, trade, tourism, agriculture, forestry, fisheries, environmental protection, and disaster management as detailed ahead.

3.1. Potential health impact due to climate change

Change in world climate would influence the functioning of many ecosystems and their member species. Likewise, there would be impacts on human health. Some of these health impacts would be beneficial. For example, milder winters would reduce the seasonal winter-time peak in deaths that occurs in temperate countries, while in currently hot regions a further increase in temperatures might reduce the viability of disease-transmitting mosquito populations. Overall, however, scientists consider that most of the health impacts of climate change would be adverse.

Climatic changes over recent decades have probably already affected some health outcomes. Indeed, the World Health Organisation estimated, in its "World Health Report 2002", that climate change was estimated to be responsible in 2000 for approximately 2.4% of worldwide diarrhoea, and 6% of malaria in some middle-income countries. However, small changes, against a noisy background of ongoing changes in other causal factors, are hard to identify. Once spotted causal attribution is strengthened; if there are similar observations in different population settings.

The first detectable changes in human health may well be alterations in the geographic range (latitude and altitude) and seasonality of certain infectious diseases – including

vector-borne infections such as malaria and dengue fever, and food-borne infections (e.g. salmonellosis) which peak in the warmer months. Warmer average temperatures combined with increased climatic variability would alter the pattern of exposure to thermal extremes and resultant health impacts, in both summer and winter. By contrast, the public health consequences of the disturbance of natural and managed food-producing ecosystems, rising sea-levels and population displacement for reasons of physical hazard, land loss, economic disruption and civil strife, may not become evident for up to several decades.

3.2. Glacier melting

3.2.1. Greenland ice sheet may melt completely with 1.6 degrees of global warming¹

The Greenland ice sheet is likely to be more vulnerable to global warming than previously thought. The temperature threshold for melting the ice sheet completely is in the range of 0.8 to 3.2 degrees Celsius of global warming, with a best estimate of 1.6 degrees above pre-industrial levels, shows a new study by scientists from the Potsdam Institute for Climate Impact Research (PIK) and the Universidad Complutense de Madrid. Today, already 0.8 degrees of global warming has been observed. Substantial melting of land ice could contribute to long-term sea-level rise of several meters and therefore it potentially affects the lives of many millions of people.

The time it takes before most of the ice in Greenland is lost strongly depends on the level of warming. "The more we exceed the threshold, the faster it melts," says Alexander Robinson, lead-author of the study now published in *Nature Climate Change*. In a business-as-usual scenario of greenhouse-gas emissions, in the long run humanity might be aiming at 8 degrees Celsius of global warming. This would result in one fifth of the ice sheet melting within 500 years and a complete loss in 2000 years, according to the study. "This is not what one would call a rapid collapse," says Robinson. "However, compared to what has happened in our planet's history, it is fast. And we might already be approaching the critical threshold."

In contrast, if global warming would be limited to 2 degrees Celsius, complete melting would happen on a timescale of 50.000 years. Still, even within this temperature range often considered a global guardrail, the Greenland ice sheet is not secure. Previous research suggested a threshold in global temperature increase for melting the Greenland ice sheet of a best estimate of 3.1 degrees, with a range of 1.9 to 5.1 degrees. The new study's best estimate indicates about half as much.

"Our study shows that under certain conditions the melting of the Greenland ice sheet becomes irreversible. This supports the notion that the ice sheet is a tipping element in the Earth system," says team-leader Andrey Ganopolski of PIK. "If the global temperature significantly overshoots the threshold for a long time, the ice will continue melting and not

¹ Science Daily (Mar. 11, 2012)

regrow -- even if the climate would, after many thousand years, return to its preindustrial state." This is related to feedbacks between the climate and the ice sheet: The ice sheet is over 3000 meters thick and thus elevated into cooler altitudes as shown in **Fig. 2(a)**. When it melts its surface comes down to lower altitudes with higher temperatures, which accelerates the melting. Also, the ice reflects a large part of solar radiation back into space. When the area covered by ice decreases, more radiation is absorbed and this adds to regional warming.

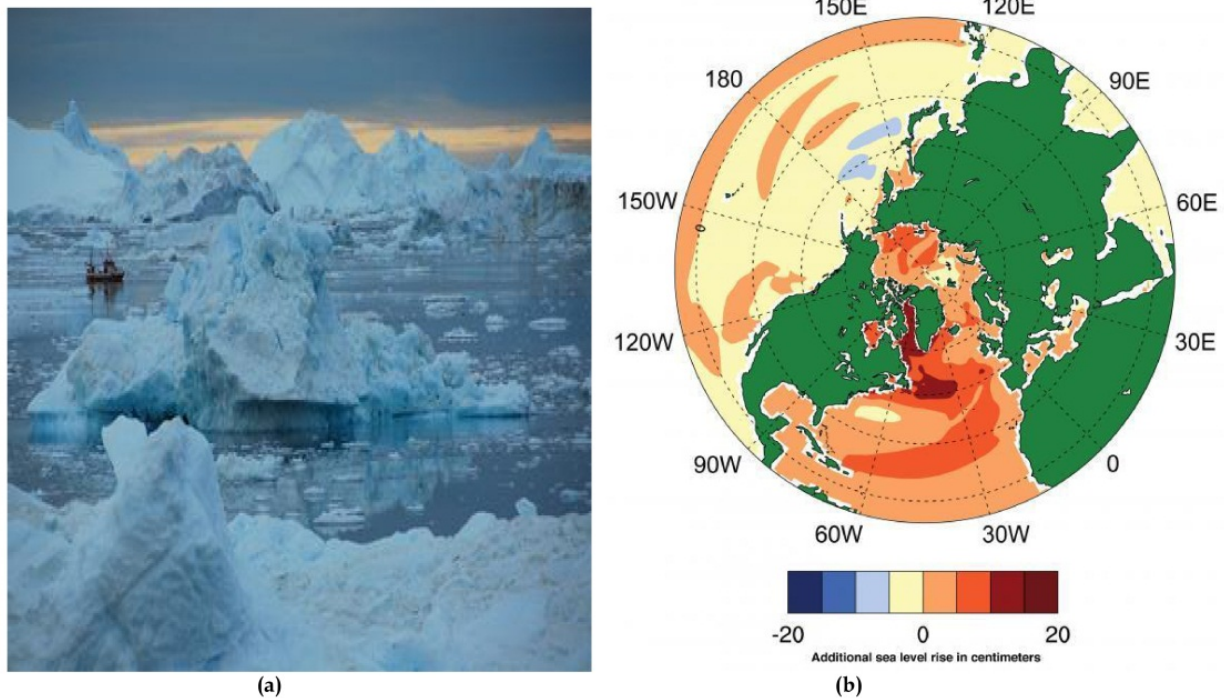


Figure 2. (a) The Greenland ice sheet is likely to be more vulnerable to global warming than previously thought. The temperature threshold for melting the ice sheet completely is in the range of 0.8 to 3.2 degrees Celsius of global warming, with a best estimate of 1.6 degrees above pre-industrial levels, shows a new study. Today, already 0.8 degrees global warming has been observed. (Credit: © Martin Schwan / Fotolia);

(b) This visualization, based on new computer modeling, shows that sea level rise may be an additional 10 centimeters (4 inches) higher by populated areas in northeastern North America than previously thought. Extreme northeastern North America and Greenland may experience even higher sea level rise. (Credit: Graphic courtesy Geophysical Research Letters, modified by UCAR)

The scientists achieved insights by using a novel computer simulation of the Greenland ice sheet and the regional climate. This model performs calculations of these physical systems including the most important processes, for instance climate feedbacks associated with changes in snowfall and melt under global warming. The simulation proved able to correctly calculate both the observed ice-sheet of today and its evolution over previous glacial cycles, thus increasing the confidence that it can properly assess the future. All this makes the new estimate of Greenland temperature threshold more reliable than previous ones as shown in **Fig. 2(b)**.

3.2.2. Arctic sea ice shrinks to smallest extent ever recorded

Sea ice in the Arctic has shrunk to its smallest extent ever recorded, smashing the previous record minimum and prompting warnings of accelerated climate change. Satellite images show that the rapid summer melt has reduced the area of frozen sea to less than 3.5 million square kilometres this week from 27 August 2012 – less than half the area typically occupied four decades ago. Arctic sea ice cover has been shrinking since the 1970s when it averaged around 8m sq km a year, but such a dramatic collapse in ice cover in one year is highly unusual.

A record low in 2007 of 4.17 million sq km was broken on Monday, 27 August 2012; further melting has since amounted to more than 500,000 sq km. The record, which is based on a five-day average, is expected to be officially declared in the next few days by the National Snow and Ice Data Centre (NSIDC) in Colorado. The NSIDC's data shows the sea ice extent is bumping along the bottom, with a new low of 3.421m sq km on Tuesday, which rose very slightly to 3.429m sq km on Wednesday and 3.45m sq km on Thursday as seen in Fig. 3.

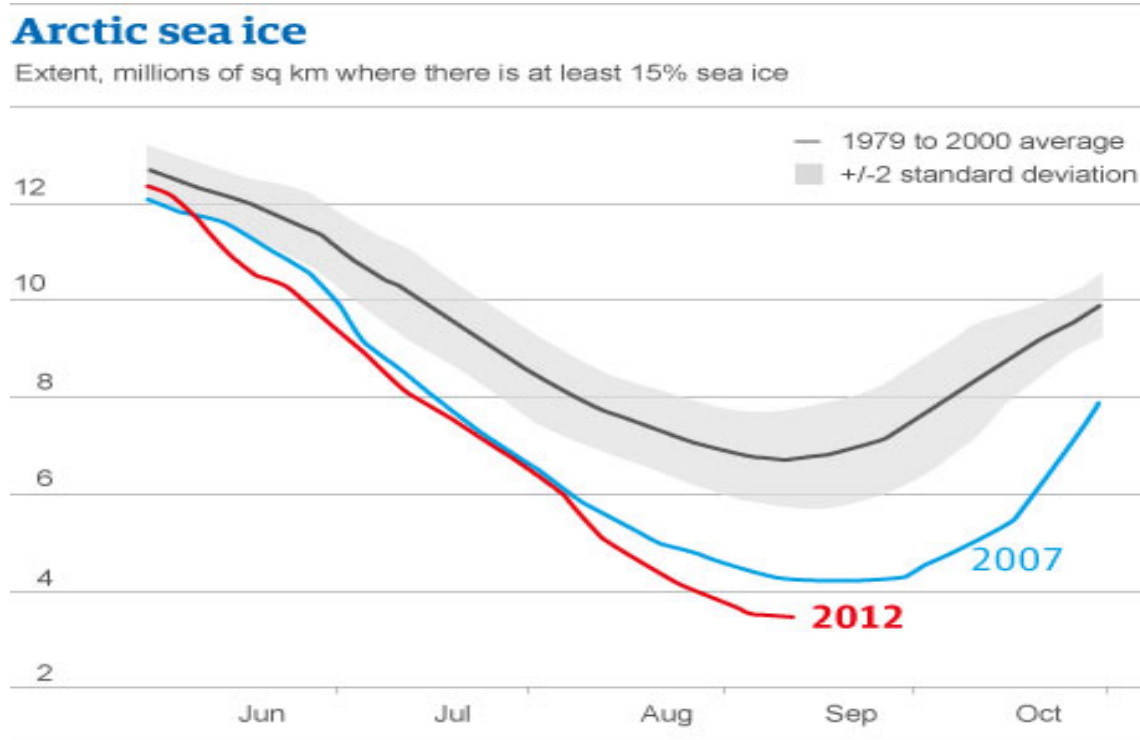


Figure 3. The shrinking of the ice cap was interpreted by environment groups as a signal of long-term global warming caused by man-made greenhouse gas emissions. A study published in July in the journal *Environmental Research Letters*, that compared model projections with observations, estimated that the radical decline in Arctic sea ice has been between 70-95% due to human activities.

Scientists have predicted on 31st August 2012 that the Arctic Ocean could be ice-free in summer months within 20 years, leading to possibly major climate impacts. "I am surprised. This is an indication that the Arctic sea ice cover is fundamentally changing. The trends all show less ice and thinner ice," said Julienne Stroeve, a research scientist with the NSIDC.

"We are on the edge of one of the most significant moments in environmental history as sea ice heads towards a new record low. The loss of sea ice will be devastating, raising global temperatures that will impact on our ability to grow food and causing extreme weather around the world," said John Sauven, director of Greenpeace UK.

Sea ice experts said that they were surprised by the collapse because weather conditions were not conducive to a major melt this year. The ice is now believed to be much thinner than it used to be and easier to melt.

Arctic sea ice follows an annual cycle of melting through the warm summer months and refreezing in the winter. The sea ice plays a critical role in regulating climate, acting as a giant mirror that reflects much of the Sun's energy, helping to cool the Earth.

David Nussbaum, chief executive of WWF-UK, said: "The disappearance of Arctic ice is the most visible warning sign of the need to tackle climate change and ensure we have a world fit to pass on to the next generation. The sheer scale of ice loss is shocking and unprecedented. This alarm call from the Arctic needs to reverberate across Whitehall and boardrooms. We can all take action to cut carbon emissions and move towards a 100% renewable economy."

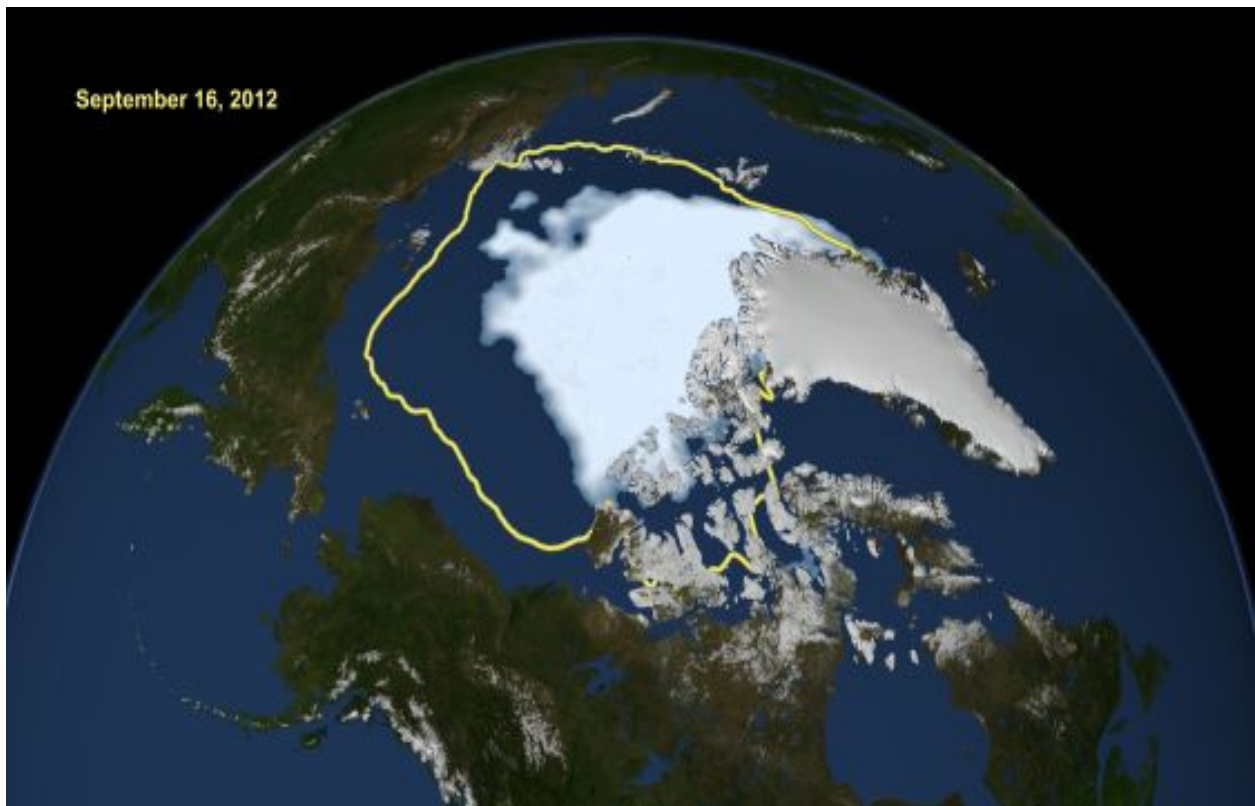


Figure 4. Arctic sea ice extent on 16 September 2012, in white, compared with the, Satellite data reveal how the new record low Arctic sea ice extent, from Sept. 16, 2012, compares to the average minimum extent over the past 30 years (in yellow) with reference to 1979, NASA/Goddard Scientific Visualization Studio

Ed Davey, the UK climate and energy secretary, said: "These findings highlight the urgency for the international community to act. We understand that Arctic sea-ice decline has accelerated over recent years as global warming continues to increase Arctic temperatures at a faster rate than the global average.

"This Government is working hard to tackle climate change and we are working closely with our international partners not to exceed 2 degrees above pre industrial levels. I am calling for the EU to increase its emission target from 20% to 30% and will be taking an active lead at the UNFCCC Climate change talks in Doha later this year, where I will push for further progress towards a new global deal on climate change and for more mitigation action now. The fact is that we cannot afford to wait".

Canadian scientists said that the record melt this year could lead to a cold winter in the UK and Europe, as the heat in the Arctic water will be released into the atmosphere this autumn, potentially affecting the all-important jet stream. While the science is still developing in this area, the Met Office said in May that the reduction in Arctic sea ice was contributing in part to the colder, drier winters the UK has been experiencing in recent years as shown in **Fig. 4**.

3.2.3. Loss of Arctic sea ice '70% man-made'

Study finds only 30% of radical loss of summer sea ice is due to natural variability in Atlantic – and it will probably get worse. Since the 1970s, there has been a 40% decrease in the extent of summer sea ice. Photograph: Alaska Stock/Corbis. The radical decline in sea ice around the Arctic is at least 70% due to human-induced climate change, according to a new study, and may even be up to 95% down to humans – rather higher than scientists had previously thought. The loss of ice around the Arctic has adverse effects on wildlife and also opens up new northern sea routes and opportunities to drill for oil and gas under the newly accessible sea bed as shown in **Fig. 5**. The reduction has been accelerating since the 1990s and many scientists believe the Arctic may become ice-free in the summers later this century, possibly as early as the late 2020s.

"Since the 1970s, there's been a 40% decrease in the summer sea ice extent," said Jonny Day, a climate scientist at the National Centre for Atmospheric Science at the University of Reading, who led the latest study.

"We were trying to determine how much of this was due to natural variability and therefore imply what aspect is due to man-made climate change as well."

To test the ideas, Day carried out several computer-based simulations of how the climate around the Arctic might have fluctuated since 1979 without the input of greenhouse gases from human activity.

He found that a climate system called the Atlantic multi-decadal oscillation (AMO) was a dominant source of variability in ice extent. The AMO is a cycle of warming and cooling in the North Atlantic that repeats every 65 to 80 years – it has been in a warming phase since the mid-1970s.



Figure 5. Science correspondent The Guardian, Thursday 26 July 2012 by Alok Jha,

Comparing the models with actual observations, Day was able to work out what contribution the natural systems had made to what researchers have observed from satellite data.

"We could only attribute as much as 30% [of the Arctic ice loss] to the AMO," he said. "Which implies that the rest is due to something else, and this is most likely going to be man-made global change?"

Previous studies had indicated that around half of the loss was due to man-made climate change and that the other half was due to natural variability. Looking across all his simulations, Day found that the 30% figure was an upper limit – the AMO could have contributed as little as 5% to the overall loss of Arctic ice in recent decades.

The research is published online in the journal *Environmental Research Letters*. Day said that there are a number of feedback effects that could see the Arctic ice loss continue in the coming years, as the Earth warms up. "[There is] something called the ice-albedo feedback, which means that when you have less ice, it means there's more open water and therefore the ocean absorbs more radiation and will continue to warm," he said.

"It's unclear what will happen – it definitely seems like it's going in that direction."

3.3. Sea level rise due to global warming

3.3.1. Sea level rise poses threat to New York City²

Global warming is expected to cause the sea level along the northeastern U.S. coast to rise almost twice as fast as global sea levels during this century, putting New York City at

² Science Daily (Mar. 16, 2009)

greater risk for damage from hurricanes and winter storm surge, according to a new study led by a Florida State University researcher as shown in **Fig. 6**.



Figure 6. New York Skyline. Global warming is expected to cause the sea level along the northeastern U.S. coast to rise almost twice as fast as global sea levels during this century, putting New York City at greater risk for damage from hurricanes and winter storm surge. (Credit: iStockphoto/Klaas Lingbeek-Van Kranen)

Jianjun Yin, a climate modeler at the Center for Ocean-Atmospheric Prediction Studies (COAPS) at Florida State, said there is a better than 90 percent chance that the sea level rise along this heavily populated coast will exceed the mean global sea level rise by the year 2100. The rising waters in this region -- perhaps by as much as 18 inches or more -- can be attributed to thermal expansion and the slowing of the North Atlantic Ocean circulation because of warmer ocean surface temperatures.

Yin and colleagues Michael Schlesinger of the University of Illinois at Urbana-Champaign and Ronald Stouffer of Geophysical Fluid Dynamics Laboratory at Princeton University are the first to reach that conclusion after analyzing data from 10 state-of-the-art climate models, which have been used for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. Yin's study is published in the journal *Nature Geoscience*.

"The northeast coast of the United States is among the most vulnerable regions to future changes in sea level and ocean circulation, especially when considering its population density and the potential socioeconomic consequences of such changes," Yin said. "The most populous states and cities of the United States and centers of economy, politics, culture and education are located along that coast."

The researchers found that the rapid sea-level rise occurred in all climate models whether they depicted low, medium or high rates of greenhouse-gas emissions. In a medium greenhouse-gas emission scenario, the New York City coastal area would see an additional rise of about 8.3 inches above the mean sea level rise that is expected around the globe because of human-induced climate change.

Thermal expansion and the melting of land ice, such as the Greenland ice sheet, are expected to cause the global sea-level rise. The researchers projected the global sea-level rise of 10.2 inches based on thermal expansion alone. The contribution from the land ice melting was not assessed in this study due to uncertainty.

Considering that much of the metropolitan region of New York City is less than 16 feet above the mean sea level, with some parts of lower Manhattan only about 5 feet above the mean sea level, a rise of 8.3 inches in addition to the global mean rise would pose a threat to this region, especially if a hurricane or winter storm surge occurs, Yin said.

Potential flooding is just one example of coastal hazards associated with sea-level rise, Yin said, but there are other concerns as well. The submersion of low-lying land, erosion of beaches, conversion of wetlands to open water and increase in the salinity of estuaries all can affect ecosystems and damage existing coastal development.

Although low-lying Florida and Western Europe are often considered the most vulnerable to sea level changes, the northeast U.S. coast is particularly vulnerable because the Atlantic meridional overturning circulation (AMOC) is susceptible to global warming. The AMOC is the giant circulation in the Atlantic with warm and salty seawater flowing northward in the upper ocean and cold seawater flowing southward at depth. Global warming could cause an ocean surface warming and freshening in the high-latitude North Atlantic, preventing the sinking of the surface water, which would slow the AMOC.

3.3.2. Significant sea-level rise in a two-degree warmer World³

Sea levels around the world can be expected to rise by several metres in coming centuries, if global warming carries on. Even if global warming is limited to 2 degrees Celsius, global-mean sea level could continue to rise, reaching between 1.5 and 4 metres above present-day levels by the year 2300, with the best estimate being at 2.7 metres, according to a study just published in **Nature Climate Change**. However, emissions reductions that allow warming to drop below 1.5 degrees Celsius could limit the rise strongly.

The study is the first to give a comprehensive projection for this long perspective, based on observed sea-level rise over the past millennium, as well as on scenarios for future greenhouse-gas emissions.

"Sea-level rise is a hard to quantify, yet critical risk of climate change," says Michiel Schaeffer of Climate Analytics and Wageningen University, lead author of the study. "Due

³ Science Daily (June 24, 2012)

to the long time it takes for the world's ice and water masses to react to global warming, our emissions today determine sea levels for centuries to come."

Limiting global warming could considerably reduce sea-level rise

While the findings suggest that even at relatively low levels of global warming the world will have to face significant sea-level rise, the study also demonstrates the benefits of reducing greenhouse-gas emissions. Limiting global warming to below 1.5 degrees Celsius and subsequent temperature reductions could halve sea-level rise by 2300, compared to a 2-degree scenario. If temperatures are allowed to rise by 3 degrees, the expected sea-level rise could range between 2 and 5 metres, with the best estimate being at 3.5 metres.

The potential impacts are significant. "As an example, for New York City it has been shown that one metre of sea level rise could raise the frequency of severe flooding from once per century to once every three years," says Stefan Rahmstorf of the Potsdam Institute for Climate Impact Research, co-author of the study. Also, low lying deltaic countries like Bangladesh and many small island states are likely to be severely affected.

Sea-level rise rate defines the time for adaptation

The scientists further assessed the rate of sea-level rise. The warmer the climate gets, the faster the sea level climbs. "Coastal communities have less time to adapt if sea-levels rise faster," Rahmstorf says.

"In our projections, a constant level of 2-degree warming will sustain rates of sea-level rise twice as high as observed today, until well after 2300" as shown in **Fig. 7**, adds Schaeffer, "but much deeper emission reductions seem able to achieve a strong slow-down, or even a stabilization of sea level over that time frame".

Building on data from the past

Previous multi-century projections of sea-level rise reviewed by the Intergovernmental Panel on Climate Change (IPCC) were limited to the rise caused by thermal expansion of the ocean water as it heats up, which the IPCC found could reach up to a metre by 2300. However, this estimate did not include the potentially larger effect of melting ice, and research exploring this effect has considerably advanced in the last few years. The new study is using a complementary approach, called semi-empirical, that is based on using the connection between observed temperature and sea level during past centuries in order to estimate sea-level rise for scenarios of future global warming.

"Of course it remains open how far the close link between temperature and global sea level found for the past will carry on into the future," says Rahmstorf. "Despite the uncertainty we still have about future sea level, from a risk perspective our approach provides at least plausible, and relevant, estimates."



Figure 7. Flooded dock. Sea levels around the world can be expected to rise by several metres in coming centuries, if global warming carries on. Even if global warming is limited to 2 degrees Celsius, global-mean sea level could continue to rise, reaching between 1.5 and 4 metres above present-day levels by the year 2300, with the best estimate being at 2.7 metres. (Credit: © knuderik / Fotolia)

3.4. Hurricanes and global warming⁴

Debate over climate change frequently conflates issues of science and politics. “There’s a push on climatologists to say something about extremes, because they are so important. But that can be very dangerous if we really don’t know the answer” (Henson 2005). In this article we focus on a particular type of extreme event—the tropical cyclone—in the context of global warming (tropical cyclones are better known in the United States as hurricanes, i.e., tropical cyclones that form in the waters of the Atlantic and eastern Pacific oceans with maximum 1-min-averaged surface winds that exceeds 32 m s^{-1}). We follow distinctions between event risk and outcome risk presented by Sarewitz et al. (2003). “Event risk” refers to the occurrence of a particular phenomenon, and in the context of hurricanes we focus on trends and projections of storm frequencies and intensities. “Vulnerability” refers to “the

⁴ American Metrology Society; November 2005

inherent characteristics of a system that create the potential for harm,” but are independent from event risk. In the context of the economic impacts of tropical cyclones vulnerability has been characterized in terms of trends in population and wealth that set the stage for storms to cause damage. “Outcome risk” integrates considerations of vulnerability with event risk to characterize an event that causes losses. An example of outcome risk is the occurrence of a \$100 billion hurricane in the United States. To calculate such a probability requires consideration of both vulnerability and event risk. This article discusses hurricanes and global warming from both of these perspectives.

3.4.1. *Event risk*

At the end of the 2004 Atlantic hurricane season, many scientists, reporters, and policymakers looked for simple answers to explain the extent of the devastation, which totaled more than \$40 billion according to the National Hurricane Center. Some prominent scientists proposed that the intense 2004 hurricane season and its considerable impacts, particularly in Florida, could be linked to global warming resulting from the emissions of greenhouse gases into the atmosphere (e.g., Harvard Medical School 2004; NCAR 2004). But the current state of climate science does not support so close a linkage (Trenberth 2005).

Tropical cyclones can be thought of to a first approximation as a natural heat engine or Carnot cycle (Emanuel 1987). From this perspective global warming can theoretically influence the maximum potential intensity of tropical cyclones through alterations of the surface energy flux and/or the upper-level cold exhaust (Emanuel 1987; Lighthill et al. 1994; Henderson-Sellers et al. 1998). But no theoretical basis yet exists for projecting changes in tropical cyclone frequency, though empirical studies do provide some guidance as to the necessary thermodynamical and dynamical ingredients for tropical cyclogenesis (Gray 1968, 1979).

Since 1995 there has been an increase in the number of storms, and in particular the number of major hurricanes (categories 3, 4, and 5) in the Atlantic. But the changes of the past decade in these metrics are not so large as to clearly indicate that anything is going on other than the multidecadal variability that has been well documented since at least 1900 (Gray et al. 1997; Landsea et al. 1999; Goldenberg et al. 2001). Consequently, in the absence of large or unprecedented trends, any effect of greenhouse gases on the frequency of storms or major hurricanes is necessarily very difficult to detect in the context of this documented variability. Perspectives on hurricanes are no doubt shaped by recent history, with relatively few major hurricanes observed in the 1970s, 1980s, and early 1990s, compared with considerable activity during the 1940s, 1950s, and early 1960s. The period from 1944 to 1950 was particularly active for Florida. During that period 11 hurricanes hit the state, at least one per year, resulting in the equivalent of billions of dollars in damage in each of those years (Pielke and Landsea 1998).

Globally there has been no increase in tropical cyclone frequency over at least the past several decades (Webster et al. 2005; Lander and Guard 1998; Elsner and Kocher 2000). In addition to a lack of theory for future changes in storm frequencies, the few global modeling

results are contradictory (Henderson Sellers et al. 1998; Houghton et al. 2001). Because historical and observational data on hurricanes and tropical cyclones are relatively robust, it is clear that storm frequency has not tracked recent tropical climate trends. Research on possible future changes in hurricane frequency due to global warming is ambiguous, with most studies suggesting that future changes will be regionally dependent, and showing a lack of consistency in projecting an increase or decrease in the total global number of storms (Henderson-Sellers et al. 1998; Royer et al. 1998; Sugi et al. 2002). These studies give such contradictory results as to suggest that the state of understanding of tropical cyclogenesis provides too poor a foundation to base any projections about the future. While there is always some degree of uncertainty about the future and model-based results are often fickle, the state of current understanding is such that we should expect hurricane frequencies in the future to have a great deal of year-to-year and decade-to-decade variation as has been observed over the past decades and longer.

The issue of trends in tropical cyclone intensity is more complicated, simply because there are many possible metrics of intensity (e.g., maximum potential intensity, average intensity, average storm lifetime, maximum storm lifetime, average wind speed, maximum sustained wind speed, maximum wind gust, accumulated cyclone energy, power dissipation, and so on), and not all such metrics have been closely studied from the standpoint of historical trends, due to data limitations among other reasons. Statistical analysis of historical tropical cyclone intensity shows a robust relationship to the thermodynamic potential intensity (Emanuel 2000), suggesting that increasing potential intensity should lead to an increase in the actual intensity of storms. The increasing potential intensity associated with global warming as predicted by global climate models (Emanuel 1987) is consistent with the increase in modeled storm intensities in a warmer climate, as might be expected (Knutson and Tuleya 2004). But while observations of tropical and subtropical sea surface temperature have shown an overall increase of about 0.2°C over the past ~50 years, there is only weak evidence of a systematic increase in potential intensity (Bister and Emanuel 2002; Free et al. 2004).

Emanuel (2005) reports a very substantial upward trend in power dissipation (i.e., the sum over the lifetime of the storm of the maximum wind speed cubed) in the North Atlantic and western North Pacific, with a near doubling over the past 50 years (Webster et al. 2005). The precise causation for this trend is not yet clear. Moreover, in the North Atlantic, much of the recent upward trend in Atlantic storm frequency and intensity can be attributed to large multidecadal fluctuations. Emanuel (2005) has just been published as of this writing and is certain to motivate a healthy and robust debate in the community. Other studies that have addressed tropical cyclone intensity variations (Landsea et al. 1999; Chan and Liu 2004) show no significant secular trends during the decades of reliable records.

Because the global earth system is highly complicated, until a relationship between actual storm intensity and tropical climate change is clearly demonstrated and accepted by the broader community, it would be premature to conclude with certainty that such a link exists or is significant (from the standpoints of either event or outcome risk) in the context of variability. Additionally, any such relationship between trends in sea surface temperature and various measures of tropical cyclone intensity would not necessarily mean that the

storms of 2004 or 2005 or their associated damages could be attributed directly or indirectly to increasing greenhouse gas emissions.

Looking to the future, global modeling studies suggest the potential for relatively small changes in tropical cyclone intensities related to global warming. Early theoretical work suggested an increase of about 10% in wind speed for a 2°C increase in tropical sea surface temperature (Emanuel 1987). A 2004 study from the Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey, that utilized a mesoscale model downscaled from coupled global climate model runs indicated the possibility of a 5% increase in the wind speeds of hurricanes by 2080 (Knutson and Tuleya 2004; cf. Houghton et al. 2001). Michaels et al. (2005) suggest that even this 5% increase may be overstated, and that a more realistic projection is on the order of only half of that amount. Even if one accepts that the Knutson and Tuleya results are in the right ballpark, these would imply that changes to hurricane wind speeds on the order of 0.5–1.0 m s⁻¹ may be occurring today. This value is exceedingly small in the context of, for example, the more than doubling in numbers of major hurricanes between quiet and active decadal periods in the Atlantic (Goldenberg et al. 2001). Moreover, such a change in intensities would not be observable with today's combination of aircraft reconnaissance and satellite-based intensity estimates, which only resolves wind speeds of individual tropical cyclones to at best 2.5 m s⁻¹ increments.

3.4.2. *Vulnerability and outcome risk*

Understanding of trends and projections in tropical cyclone frequencies and intensities takes on a different perspective when considered in the context of rapidly growing societal vulnerability to storm impacts (Pielke and Pielke 1997; Pulwarty and Riebsame 1997). There is overwhelming evidence that the most significant factor underlying trends and projections associated with hurricane impacts on society is societal vulnerability to those impacts, and not the trends or variation in the storms themselves (Pielke and Landsea 1998). Growing population and wealth in exposed coastal locations guarantee increased economic damage in coming years, regardless of the details of future patterns of intensity or frequency (Pielke et al. 2000). Tropical cyclones will also result in death and suffering, in less developed countries in particular, as seen in Haiti during Hurricane Jeanne (cf. Pielke et al. 2003).

Over the long term the effects of changes in society dwarf the effects of any projected changes in tropical cyclones according to research based on assumptions of the Intergovernmental Panel on Climate Change (IPCC), the scientific organization convened to report on the science of climate change. By 2050, for every additional dollar in damage that the IPCC expects to result from the effects of global warming on tropical cyclones, we should expect between \$22 and \$60 of increase in damage due to population growth and wealth (Pielke et al. 2000). The primary factors that govern the magnitude and patterns of future damages and casualties are how society develops and prepares for storms rather than any presently conceivable future changes in the frequency and intensity of the storms (see **Fig. 8**).



Figure 8. Flooding at costal area

Consider that if per capita wealth and population grow at a combined 5% per year, this implies a doubling in the real costs of hurricanes about every 15 years. In such a context, any climate trend would have to be quite large to be discernible in the impacts record.

With no trend identified in various metrics of hurricane damage over the twentieth century (Pielke and Landsea 1998), it is exceedingly unlikely that scientists will identify large changes in historical storm behavior that have significant societal implications. In addition, looking to the future, until scientists conclude:

- a. that there will be changes to storms that are significantly larger than observed in the past,
- b. that such changes are correlated to measures of societal impact, and
- c. that the effects of such changes are significant in the context of inexorable growth in population and property at risk, then it is reasonable to conclude that the significance of any connection of human-caused climate change to hurricane impacts necessarily has been and will continue to be exceedingly small.

Thus a great irony here is that invoking the modulation of future hurricanes to justify energy policies to mitigate climate change may prove counterproductive. Not only does this provide a great opening for criticism of the underlying scientific reasoning, it leads to advocacy of policies that simply will not be effective with respect to addressing future hurricane impacts. There are much, much better ways; to deal with the threat of hurricanes than with energy policies (e.g., Pielke and Pielke 1997). There are also much, much better ways to justify climate mitigation policies than with hurricanes (e.g., Rayner 2004), with energy policies (e.g., Pielke and Pielke 1997) and to justify climate mitigation policies than with hurricanes (e.g., Rayner 2004).

3.4.3. Worrying beyond hurricane Sandy

With the last hurricane to directly hit New York City dating back to the 1800's, residents have so far lacked the impetus to demand concrete strategies for dealing with the potential devastation to housing, the subway system and the electrical infrastructure from a major modern-day storm. Now Hurricane Sandy threatens major flooding from a storm surge that could reach up to 14 feet above the average sea level here.

Some scientists suggested on Monday 29th October' 2012 that once New Yorkers have moved to higher ground and weathered the hurricane, they should begin to take more decisive steps to adapt to more of the same. As it was reported last month, pressure has been growing for aggressive action as shown in **Fig. 9**.



Figure 9. Awaiting an onslaught: wave activity at Rockaway Beach on Monday morning, when Hurricane Sandy was 425 miles southeast of New York City (Oct 29' 2012).

It is small comfort to sodden and stranded New Yorkers that Hurricane Sandy's flooding of the city's infrastructure, from power lines to subways to low-lying communities, was predicted in grimly precise detail by scientists in the latest state and city climate studies. Deeper and more frequent flooding from Rockaway to Lower Manhattan and the city's transit tunnels has been a repeated warning that largely went unnoticed by the public and most politicians.

But now, with the floods from Sandy and Tropical Storm Irene last year on his watch, Gov. Andrew Cuomo is pointedly stressing what he considers the inevitability of more such disasters. "Climate change is reality," the governor said on Wednesday, 31st Oct' 2012, estimating Sandy's economic damage up to \$6 billion. "Given the frequency of these extreme weather situations that we've had-and I believe that it's an increasing frequency - for us to sit here today and say this is a once-in-a-generation and it's not going to happen again, I think would be shortsighted." Mr. Cuomo admits that he does not have all the answers nor enough government money for all the proposed solutions. And we can all hope that he is wrong in his forecast. But the urgency of his warning is rooted in a basic fact of nature underpinning the government studies: New York's coastal waters, which rose an inch per decade in the last century, are heading toward rates of 6 inches per decade as the oceans warm and expand. That would be a disastrous rise of 2 feet across the next 40 years, for anyone planning ahead. And there aren't many in government planning ahead as the postrecession political debate grinds along the question of how to slash government improvements, not expand them.

Just last September, Klaus Jacob, an adviser to the city on climate change, warned of the certainty of flooded Manhattan highways and tunnels and of stranded subway riders and subway commuters if the next storm surge topped Irene's. "I'm disappointed that the political process hasn't recognized that we're playing Russian roulette," said Mr. Jacob, a research scientist at Columbia University's Earth Institute and an author of a 2011 state study that predicted tens of billions in economic losses from worsening floods.

This is why the problem underlined by Mr. Cuomo deserves heightened public debate. Mayor Michael Bloomberg agreed. "What's clear is that the storms that we've experienced in the last year or so around this country and around the world are much more severe than before," the mayor said. "Whether that's global warming or what, I don't know. But we'll have to address those issues."

Mr. Cuomo proposed consideration of the sort of storm surge barriers in use in Europe. Gates like those guarding London's riverfront could be closed in disastrous weather at three main points of ocean inflow — the Verrazano-Narrows Bridge, the upper East River and the mouth of the Arthur Kill between Staten Island and New Jersey. This idea and others involve billions of dollars, which could be a bargain if Sandy and Irene truly are harbingers of more frequent disasters eating deeper into the city's heart.

(Source: The New York edition; Worrying Beyond Hurricane Sandy, October 31, 2012.)

4. How to prevent climate change?

The potential for runaway greenhouse warming is real and has never been more prominent as now. The most dangerous climate changes may still be avoided if we transform our hydrocarbon based energy systems and if we initiate rational and adequately financed adaptation programmes to forestall disasters and migrations at unprecedented scales. The tools are available, but they must be applied immediately and aggressively.

4.1. What can I do to help prevent climate change?

In the United States, approximately 6.6 tons (almost 15,000 pounds carbon equivalent) of greenhouse gases are emitted per person every year. And emissions per person have increased about 3.4% between 1990 and 1997. Most of these emissions, about 82%, are from burning fossil fuels to generate electricity and power our cars. The remaining emissions are from methane from wastes in our landfills, raising livestock, natural gas pipelines, and coal, as well as from industrial chemicals and other sources. (Source: US EPA).

With this said, also keep in mind that emissions vary based on the country and state in which you live. At the present time, the United States emits more greenhouse gasses per person than any other country. Emissions also vary by state as they are based on the many factors such as the types of fuel used to generate electricity, the total population of a state, and the amount of (and distance traveled by) commuters.

As an individual there are three areas where we can make the most impact in reducing carbon emissions:

- the electricity we use in our homes,
- the waste we produce, and
- the transportation we choose to use.

According to the U.S. EPA, you can affect the emissions of about 4,800 pounds of carbon equivalent, or nearly 32% of the total emissions per person by the choices we make in these three areas. The other 68% of emissions are affected more by the types of industries in the U.S. the types of offices we use, how our food is grown and other factors (source: U.S. EPA). Below are tips on how to reduce carbon emissions and help stop climate change.

4.2. How can I do to help prevent climate change?

When people talk about Climate Change, they are talking about the temperature and weather on the **Planet Earth** changing. In the last one hundred years the temperature on our planet has gone up by a little bit, about 1 degree. The reason it's getting warmer is because too much heat is getting trapped in earth's atmosphere and making the planet too hot. Every time we use energy, we send more heat (Carbon Dioxide) into the atmosphere. Carbon Dioxide, or Mr. Carbon as we call him, is created when humans drive cars and make electricity for things like lights and computers. But, if we are all more careful and don't waste energy or use more than we need, we can help to cool off the earth!

Here are some great ideas to get you started:

- **Use less energy at home-** In winter, wear a sweater and turn the thermostat down. In summer, turn off the lights and use the natural light of the sun!
- **Take shorter showers-** Heating shower water uses energy. Even just a few minutes can add up to a big difference over time!
- **Ride your bike!** -If you live close enough to school, hop on your bike or walk. Replace car rides whenever possible.

- **Carry a reusable water bottle-** Picture how many disposable water bottles pile up after a week, a month, or a year. Skip all that waste by getting a cool reusable one!
- **Power down-** Even when they're "off," many appliances like computers continue to use energy. Ask your family to unplug these items when they're not in use, or to turn off the power strip they're attached to.
- **Eat Your Veggies-** Livestock like cows create carbon on farms. Even just one day a week of vegetarian meals can make a big difference!

4.3. Ten basic tips to help stop climate change

Don't have a lot of time, but want to take action? Here are ten, simple, everyday things each of us can do to help stop climate change. Pick one, some, or all. Every little effort helps and adds up to a whole lot of good.

- a. **Change a light-** Replacing a regular light bulb with a compact fluorescent one saves 150 pounds of carbon dioxide each year.*
- b. **Drive less-**Walk, bike, carpool; take mass transit, and/or trip chain. All of these things can help reduce gas consumption and one pound of carbon dioxide for each mile you do not drive.
- c. **Recycle more and buy recycled-** Save up to 2,400 pounds of carbon dioxide each year just by recycling half of your household waste. By recycling and buying products with recycled content you also save energy, resources and landfill space!
- d. **Check your tyres-** Properly inflated tyres mean good gas mileage. For each gallon of gas saved, 20 pounds of carbon dioxide are also never produced.
- e. **Use less hot water-** It takes a lot of energy to heat water. Reducing the amount used means big savings in not only your energy bills, but also in carbon dioxide emissions. Using cold water for your wash saves 500 pounds of carbon dioxide a year, and using a low flow showerhead reduces 350 pounds of carbon dioxide. Make the most of your hot water by insulating your tank and keeping the temperature at or below 120.
- f. **Avoid products with a lot of packaging-** Preventing waste from being created in the first place means that there is less energy wasted and fewer resources consumed. When you purchase products with the least amount of packaging, not only do you save money, but you also help the environment! Reducing your garbage by 10% reduces carbon dioxide emissions by 1,200 pounds.
- g. **Adjust your thermostat-** Keeping your thermostat at 68 degrees in winter and 78 degrees in summer not only helps with your energy bills, but it can reduce carbon dioxide emissions as well. No matter where you set your dial, two degrees cooler in the winter or warmer in the summer can mean a reduction of 2,000 pounds of carbon dioxide a year.
- h. **Plant a tree-** A single tree can absorb one ton of carbon dioxide over its lifetime.
- i. **Turn off electronic devices when not in use-** Simply turning off your TV, VCR, computer and other electronic devices can save each household thousands of pounds of carbon dioxide each year.
- j. **Stay informed-** Use the Earth 911 Web site to help stay informed about environmental issues, and share your knowledge with others. Together, we can and do Make Every Day Earth Day!

5. Conclusion

From the studies and reports, it is evident that the potential for runaway greenhouse warming due to release of carbon dioxide and other gases in the atmosphere which is the cause of potential increase of the global temperature, and subsequent melting of ice cap, rise in sea level, and it triggers the disasters. The following major issues are noticed:

- Emissions from human activities are increasing the frequency of extreme weather events.
- Due to climate change there are likely to be many more heatwaves, droughts and changes in rainfall patterns.
- By the mid-2020s, sea level rise around Manhattan and Long Island could be up to 10 inches, if the rapid melting of polar sea ice continues at same pace. By 2050, sea-rise could reach 2.5ft and more than 4.5ft by 2080 under the same conditions.
- Global warming threatens the planet in a new and unexpected way – by triggering earthquakes, tsunamis, avalanches and volcanic eruptions.
- Irene-like storms of the future would put a third of New York City streets under water and flood many of the tunnels leading into Manhattan in under an hour because of climate change.

Climate changes may still be avoided if we transform our hydrocarbon based energy systems and if we initiate rational and adequately financed adaptation programmes to forestall disasters and migrations at unprecedented scales.

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