Feeling the Heat: The Effects of the Changing Oceans

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The Situation

Global warming is a term used regularly by people, especially when discussing strange weather patterns. Most educated people are aware of what global warming entails. Global warming refers to the process of the greenhouse gases in the atmosphere trapping the heat that was supposed to be radiated back out to space. Since the Industrial Revolution, the amount of CO_2 and other green house gases have been increasing steadily until the 1990's where there was a sharp increase. Between 1933 and 2000 the amount of CO_2 in the atmosphere has increased by 33%[15]. Average Temperatures have already increased 0.7^{o}C from 1860 to 2000[15]. Nowadays, the effects of global warming are beginning to become more pronounced. Droughts have become more frequent and intense. For instance, the 1999-2002 drought in the US was the most extensive drought in the past 40 years[4]. While in other places more intense rain storms have become more frequent[4]. Also, in the past 35 years there have been more category 4 and 5 hurricanes worldwide[4].

People have now begun to realize that they need to reduce pollution in an attempt to reduce the effects of global warming. The movement to become more environmentally friendly is slowly gaining popularity, but not at a fast enough rate. Global warming affects more than just the weather; it has profound effects on the ocean as well. Few people understand these conditions. If people realized the impact of global warming on the ocean, they would know how serious the situation is and the effort to slow down global warming would be much stronger.

The oceans cover about 70% of our world, so they impact the world significantly in many ways. They play a huge role in weather and climate regulation and how it absorbs and redistributes heat worldwide. Aside from affecting the weather, the ocean directly affects millions of people. Millions of people's lives are centered around the ocean. Thousands of

people work each year as fishermen. Millions of other people make their living benefitting from the ocean's attractions. Coral reefs for scuba diving, gorgeous beaches for swimming and relaxing, and big waves for surfing are major attractions for tourists. Tourism involving the ocean is responsible for over 200 million jobs worldwide and is the most important industry in 38% of the countries[1]. There are villages that would collapse without the money that tourism brings. Many other villages depend on the ocean for food and other raw material. Each year, roughly 200 billion pounds of food are extracted from the oceans[1]. Not only are the oceans a major source of food, but are also a source of raw material like various minerals such as gold. The food and raw material extracted from marine ecosystems provided to the US are worth over 14 trillion dollars[11]. Plus, the ocean is used for transportation for that raw material and the final products. Thousands of tonnes of cargo are shipped across oceans each year. With so many functions the ocean has, any changes to the ocean will have a major global impact.

Three primary effects that global warming will have on the ocean include increases in water temperature, increases in sea levels, and a weakening or even a shutdown of the thermohaline circulation. The consequences of those events will have substantial consequences felt worldwide.

As Temperatures Rise so do the Risks.

As the earth begins to warm up, the oceans will heat up as well because water readily absorbs heat. Surface temperature has already increased 0.7^{o}C over the twentieth century[15] and is projected to increase between 1.4-5.8^{o}C before 2100[14]. Most of the warming will occur within the first 300m of the ocean[14]. The temperature increase will affect all marine life and humanity whether it is directly or indirectly.

Species distribution and the health of animals are all affected by sea temperature so any changes will have a significant impact. The animals that live within a specific temperature range will suffer the biggest effects[14]. They will have to relocate or they will not survive. Corals are an example of an organism that cannot survive temperature increases. Most live close to their upper thermal tolerances so a temperature increase would cause them to overheat and perish. A considerable amount of coral death and bleaching have already been observed with water warming[11]. They cannot avoid the warmer waters because of their sessile lifestyle. Other animals may be able to migrate to colder waters but at the expense of their range. Bowhead whales are an example of an animal that will be restricted to a smaller area because these whales only live in polar conditions. Animals that normally experience large temperature differences, like the blue and humpback whales that migrate between the poles and the tropics, will be less affected by the increased water temperature[14]. Unlike the animals that prefer cold water, the ranges of the animals that prefer warmer water will expand, thereby increasing the amount of invasive species. Studies in the New England area have already shown that as water temperatures increased so did the population of an invasive species[17]. Personal temperature tolerance is not the only reason for a shift in range or distribution. Shifts in certain species can be caused because their prey is affected by temperature. For example, plankton, a popular food source, is negatively affected by increasing temperatures[3]. Plankton blooms are already being found in regions farther north than their normal range in an attempt to escape the warmer waters[3]. In Scotland this plankton migration is causing a food shortage for arctic terns and skuas. The birds eat plankton-eating fish, but these fish have followed the plankton. So the amount of fish in Scottish waters has greatly decreased causing many birds to starve to death.

The decrease in food supply, whether it is from a shift in the location of food sources or from the prey dying due to increased temperatures, will ultimately affect the breeding success of the animals. Animals need abundant food supplies in order to breed, so if the food supplies are being reduced due to warming, the breeding rates will drop. Female fin whales will only produce a calf in times where plankton is in abundance[14].This means that if the plankton moves out of the breeding zone of fin whales, the fin whales will not breed and their numbers will go down. In recent summers the largest colony of skuas found in Scotland has only produced a couple of chicks due to the lack of fish[3].

Animal populations are at risk of declining not only because of lowered breeding rates, but because warmer waters affects the overall health of the animals. The heat causes them stress, therefore making them more susceptible to disease[14]. Also, warmer waters lead to increased toxic algae blooms that have poisoned many animals like dolphins and manatees[14]. Over 190 manatees have died from the toxic algae called the Florida red tide[18].

Rising ocean temperatures will also indirectly have enormous consequences for humans worldwide. A big concern, more so for countries that suffer from hurricanes and monsoons, is how tropical storms and hurricanes will be affected by the rising temperature. Hurricanes have been observed increasing in frequency and intensity as the North Atlantic has been increasing in temperature[16]. Models have shown the increasing sea surface temperature will increase wind speed by 8.7%[16]. That increase in wind speed will worsen the damages caused and that will cause a large economic stress on countries that are frequently hit by hurricanes such as the United States. In 2005, hurricanes caused approximately 12.4 billion dollars of damage to the United States. With a 2.5^{o}C increase in sea temperature it is estimated that a hurricane year similar to 2005 it would cost the United States 27 billion[16]. For developing countries, they can't

afford to deal with millions of dollars in damage, so many people will become homeless and suffer from poverty. Increased hurricane frequency and intensity is a large concern, but even more so are the inevitable changes the in precipitation patterns.

Precipitation patterns are dictated by differences in air pressures and evaporation rates which are all ultimately affected by water temperatures. In order to predict the new precipitation patterns, computer models are used. There are two types of models: one that assumes that the worldwide warming will not be uniform and the other that assumes that it will be uniform. Models assuming non-uniformity show that in the North Pacific and the North Atlantic precipitation increased with warming while the south showed decreased precipitation[8]. Meanwhile, the other models show that as temperature rises, the areas with plenty of rainfall will have more precipitation while the edges of those areas will become dryer[8]. In both cases, there are areas with more precipitation and areas with less. This will affect the food and water supply in the respective regions. The areas suffering less precipitation will be able to support less plant life and farmers will have less success farming. This will cause a potential food shortage. Also, less precipitation means less available water for drinking and a water shortage.

Food shortages can also occur on the areas of the coast that mainly rely on fish and other sea food for sustenance if the fish have moved to new water either to follow prey or to find cooler waters. In addition to the food shortages, the careers of fishermen will be destroyed because the fish population have now shifted. The loss of the income for those families will have devastating financial consequences placing the family below the poverty line. Along with raising the risk of food and water shortages, warmer water raises the risk of contracting a water born disease. Warm water is an ideal growing environment for many harmful bacteria and other pathogens. In Asia and South America, a noticeable increase in water temperature is observed

before increased outbreaks of cholera[13]. High water temperatures are necessary for many algae blooms including toxic algae like cyanobacteria[13]. Cyanobacteria can cause dermatitis, hepatitis, and respiratory problems by coming into contact with the contaminated water[13]. The increased risk of contracting a water borne caused by increasing water temperature is quite serious. If the world is not prepared, the global consequences will have devastating outcomes.

The Aftermath of an Ocean Conveyor Belt Shutdown

The thermohaline circulation (THC), otherwise known as the ocean conveyor belt, is a giant loop of currents, spanning across all the oceans[12]. It is based on the principle that warmer, fresher water is lighter than cold, salty water so the warm water will float on top of the colder water. Water warms up in the tropical regions and flows up to the Northern Atlantic where it cools and becomes heavier therefore sinking to the bottom and is now called deep water. This deep water flows to the Indian Ocean and the Northern Pacific where it warms and upwells to the surface[12]. The warm water then travels back to the Northern Atlantic to continue the giant loop. The THC plays a massive role in climates around the world. The THC transports and redistributes heat from the equator and tropics to the poles[12]. The reason why the United Kingdom has much warmer winters than Canada is because the Gulf Stream, which is a warm water current part of the THC, flows much closer to the United Kingdom. It warms those countries more than it does Canada. The THC also helps bring up nutrients from the deep with its upwelling, nourishing fish and other organisms. Since the THC does play important roles in the world, any disruption will have a considerable impact.

The THC is at risk of shutting down if the surface waters become too warm or too light to sink, causing the circulation to be cut off. An increase of freshwater released into the Northern Atlantic by either precipitation or glaciers melting could cause the shutdown. As the world

warms, the evaporation rates will increase therefore increasing the precipitation rates. Most models predict that the increased high latitude precipitation will only weaken the THC. However, large amounts of freshwater released by the melting of glaciers, specifically Greenland's glaciers, will be able to completely shut down the circulation[14]. Present day models do not show the THC shutting down before 2100 but weakening by at least 25%[14]. But there is always the possibility of a complete shutdown if climate continues to change with its current pace[14]. The one fact guaranteed is that dramatic changes in the THC will have a significantly impact the global climate negatively.

The repercussions of a weakened THC or a complete shutdown are not easy to predict because there are many other factors that could also affect the outcome. This could include such things as the amount of the greenhouse gas and the extent of the weakening of the atmosphere. Computer models are used to run simulations with various background conditions to predict what the impacts would be. The effects of the THC weakening or shutting down will have the biggest impact on the climate of the Northern Hemisphere, but more so on Western Europe's climate. After a complete shutdown, heat will be no longer be redistributed normally, so the Northern Hemisphere will cool while the Southern Hemisphere will warm up slightly[23]. Average cooling will be approximately 1.7^{o}C but Western Europe will observe the strongest cooling of about 2-5^{o}C[22]. Due to the cooling, snow cover in Western Europe is expected to last 1-2 months longer than usual[22]. A THC shutdown will also cause alterations in the precipitation pattern of regions across the world. The Northern Hemisphere will suffer a loss of 6cm/year of precipitation which can be partly explained by the fact that less water evaporates from cooler water[21].The areas around India will also observe precipitation reductions which, in their case, is slightly beneficial because it lessens monsoon intensities [23]. However in Brazil, the wet season

will observe an increase in rain and no significant changes in the dry season[23]. A weakened THC is predicted to cause the same consequences, only less severe. However, due to the complex nature of the THC, the consequences are difficult to predict so there may be other unforeseeable effects caused by a weakening or a shutdown.

The changes in temperature and precipitation will have a significant impact on marine and terrestrial life, especially plants. Some models estimate a 5% reduction in the amount of vegetation produced each year. There will be areas that will not receive enough precipitation to support all the plants that it previously could[23]. Western Europe's growing season will be shortened because snow cover and colder temperatures will last longer. Also, some plants that are more sensitive to the temperature will not be able to adjust to the temperature changes and become extinct if their seeds cannot be transported to a warmer climate. If the change in precipitation patterns is large enough, it will also greatly affect humans and other animals. Some regions will suffer droughts and severe water shortages. If other sources of freshwater cannot be found, many animals and possibly humans will die if they cannot relocate in time. Other places will suffer too much precipitation that leads to floods. Marine life will also be greatly affected by a THC shutdown because the THC is responsible for bringing up important nutrients through upwellings. If the upwellings shutoff, it is estimated that the production of plankton will decrease 40% in the Indian Ocean and 25-50% in the South Atlantic[20]. Plankton is the primary food source for many other marine species, such as herring and smelt. These are the food source of other species like tuna, squid, and humans. This reduction of a primary food source will have a ripple effect throughout the food chain leading to food shortages and starvation for many organisms. A shutdown of the THC could also cause food shortages by shifting the ranges of certain species. The location of algae and plankton blooms rely on the currents and without the

currents caused by the THC the blooms will not be in the usual range. Therefore, many fish species will not be in the normal range either because they follow the blooms. The consequences of shifting fish populations due to the shutdown of the THC will be the same as a shift due to increased temperatures. Clearly the THC has a strong effect on life worldwide, so the world should be alarmed when any situation threatens this circulation.

Higher the water, higher the stakes

As global warming continues to increase, the melting rate of glaciers continues to increase as well. The glaciers are releasing tonnes of freshwater into the oceans causing a large rise in sea levels. Data from tide gauges have already shown a global increase between 0.1-0.2m in the twentieth century and it is predicted that it could rise another 0.88-0.99m before 2100[14]. However, the sea levels have the potential to rise much higher. The levels depends on the melting rate and how much of the glaciers will melt. If the melting rate increases, the water levels will rise higher and faster. Glaciers worldwide have already begun to melt more rapidly. For example, the melting rate of Greenland's glaciers has increased to five times faster than its rate in the 1990's[2]. This means sea levels rising higher and faster than predicted is quite possible. It is estimated that if all Greenland glaciers melted completely it would raise sea levels 7m and if all the land glaciers melted, the sea level would raise more than 70m[6]. Any substantial sea level rise (SLR), especially one of 70m, will have devastating consequences on animal and human life.

Rising sea levels endangers the existence of many animals that rely on the unique ecosystems that are found along the coastline. The endangered Lower Keys Marsh Rabbit (LKMR) is a species of rabbit, unique to the low lying Florida Keys, which has already seen 48% of their habitat destroyed by SLR[19]. LKMR is only one example of species that will not survive if sea levels continue to rise because their unique habitat would have been completely

destroyed. With other species SLR will not greatly affect their everyday lives but will have a significant impact on their breeding. Beaches and coves serve as excellent breeding grounds for many species, such as the green sea turtle and the northern elephant seal, but those areas are at risk of destruction. At Point Reyes, California, which is the location of many northern elephant seal rookeries, studies have shown that by 2050 most of their prime breeding grounds will be submerged[5]. Other studies of the green sea turtle rookeries in regions in Australia predict that 11 to 36% of turtle nests will be inundated with a half a meter water level rise[10]. In parts of the Caribbean 26 to 36% nests will be destroyed. With a one meter rise some entire nesting regions in Australia and the Caribbean will become inundated[10]. Both green sea turtles and the northern elephant seals will have to find a different place to breed. If there are no other places to live their populations will suffer a massive decrease in numbers because females cannot produce more offspring without a suitable habitat. A decrease in population places the animals at risk of extinction. Unfortunately, there are hundreds of species in the same situation as LKMR, the northern elephant seal, and the green sea turtle. Many will not be able to cope with substantial SLR and will become extinct.

SLR may not directly threaten the survival of the human race but it will have a tremendous negative impact on humanity worldwide. Approximately 10% of the world's population or over 634 million people, live in low lying regions that are 10m or less above sea level[9]. In Bangladesh alone a one and a half water level rise would displace 17 million people[9]. As sea levels begin to increase, millions of people will have to move inwards creating cramped living conditions in cities and taking up land that could be used for agriculture. Attempting to provide for millions of extra people will create economic stress on the cities trying to provide supplies and create jobs for the refugees. The other option is to erect structures that hold back

the water and/or elevate roads and buildings, but that would also require millions if not billions of dollars. In the US alone, the cost to protect the land from a one meter sea level rise would be over 425 billion dollars[7]. Another consideration is that economies will decline from the lack of tourists within many developing countries. These countries thrive off the thousands of tourists coming to visit their beaches[9]. However, a SLR increases long term beach erosion leading to the destruction of those beaches[9]. Another economic burden is the cost of repairing damages after a natural disaster. Higher sea levels lead to taller and stronger storm surges and larger floods simply because there is more water at a higher level. These storm surges and floods will destroy more property and affect more people[9]. More damaged property means a higher cleanup cost. If a country does not have enough economic resources to cope with these things, thousands of people will fall into poverty and malnourishment. The prices for land or even just to rent a room will sharply increase forcing families into the streets or unaffordable housing. Additionally, thousands will not be able to find a job because of the excess of people. Poverty will be at critical levels.

The economic issues are serious, but the more significant issue about SLR is how it will affect food and water supplies. As sea levels rise higher, the seawater will slowly start contaminating valuable freshwater aquifers[9]. SLR will also destroy valuable crop land. For example, a one meter increase in the Nile river will destroy 4500km^2 of fertile land[9].There are over seven billion people in the world and many already suffer a lack of food and water. Therefore the destruction of land and aquifers can only lead to an increase of people that lack food and water unless the world's population falls to a number that the world can support. As previously mentioned, SLR has very serious and potentially deadly consequences for humanity worldwide and methods to cope with SLR should be thoroughly investigated.

The Reality of the Situation

Since so many plants and animals including humans rely on the ocean, any significant changes, specifically with temperature, sea levels and the ocean circulation, will have drastic negative effects. Temperature increases will affect ranges and distributions of animals that have specific thermal tolerances. Plus it warmer waters favour more toxic algae blooms that have harmful effects to animals and humans. Precipitation patterns will change. Those effects will cause other consequences such as increasing the risk of food and water shortages in regions. Increased water levels will destroy thousands of square kilometers of land therefore endangering many species that depend on the coast line ecosystems and displacing millions of people. A shutdown of the THC will cause food shortages of the primary food sources, like plankton, because of the lack of nutrients being brought up with the upwelling which in turns causes food shortages throughout the food change. THC heavily influences the temperature and precipitation patterns. So any change in the THC will cause change in these patterns. Considering that all these changes to the ocean will be occurring in the same time period, the consequences on marine and terrestrial life will even more devastating. Dramatic climate change, extreme loss of biodiversity, increased poverty and food and water shortages are realistic possibilities of what could happen. The effects of global warming on the ocean present serious problems with no simple solutions. Dealing with the consequences will be difficult. The world will not ever be the same if global warming continues to go unchecked. People need to realize the seriousness of the situation at hand, change their habits, and take precautions. After all, the increased CO_2 in the atmosphere is primarily due to humanity's lifestyle. Global warming is a result of the immense amounts of fossil fuels that are used every day for transportation, manufacturing, heating, and

more. Those fossil fuels release tonnes of carbon dioxide into the atmosphere. Alternative renewal fuels need to be created to reduce the consumption of fossil fuels. Individuals need to work diligently to reduce their carbon footprint and help reduce global warming before it is too late.

References

1. Ocean Resources-MarineBio.org [Internet]United States: MarineBio Conservation Society; c2013 [cited 2013 02/21]. Available from: http://marinebio.org/oceans/ocean-resources.asp.

2. Greenland glacier melting 5 times faster than in 1990s [Internet]Canada: cbcnews; c2012 [cited 2013 02/19]. Available from: http://www.cbc.ca/news/politics/story/2012/11/29/pol-ice-sheets-melting-greenland.html.

3. Plankton: doing more than drifiting through [Internet]: Bamfield Marine Sciences Center; c2007 [cited 2013 02/21]. Available from: http://oceanlink.island.net/ONews/ONews7/plankton.html.

4. Consequences of Global Warming On Weather Patterns [Internet]: Natural Resources Defense Council [cited 2013 02/22]. Available from: http://www.nrdc.org/globalwarming/fcons/fcons1.asp.

5. Allen S, Davis J, Funayama K, Hines E. Effects of sea-level rise on northern elephant seal breeding habitat at point reyes peninsula, california. Aquatic Conserv: Mar Freshw Ecosyst [Internet]. [revised 2012 12/06;:2013/02/20. Available from http://onlinelibrary.wiley.com/doi/10.1002/aqc.2318/full.

6. Alley RB. Abrupt climate changes, oceans, ice, and us. Oceanography 2005;17:194-206.

7. Brown S, Gaunt C, Greene M, Leatherman S, Mausel P, Titus J, Trehan M, Park R, Weggle JR, Yohe G. Greenhouse effect and sea level rise: The cost of holding back the sea. Coastal Management 1991;19(2):171-204.

8. Deser C, Ma J, Teng H, Vecchi G, Wittenburg A, Xie S. Global warming pattern formation: Sea surface temperature and rainfall. J Climate 2010;23:966-86.

9. FitzGerald DM, Fenster MS, Argow BA, Buynevich IV. Coastal impacts due to sea-level rise. Annu Rev Earth Planet Sci 2008 02/04;36:601-47.

10. Fuentes M, Limpus C, Hamann M, Dawson J. Potential impacts of projected sea-level rise on sea turtle rookeries. Aquatic Conserv: Mar Freshw Ecosyst 2010 12/03;20:132-9.

11. Harley CDG, Randall Hughes A, Hultgren KM, Miner BG, Sorte CJB, Thornber CS, Rodriguez LF, Tomanek L, Williams SL. The impacts of climate change in coastal marine systems. Ecology Letters 2006 01/2012;9:228-41.

12. Haupt BJ, Kelly MC. Ensuring the future of the oceans. Companion Encyclopedia of Geography: From Local to Global 2007;2:767.

13. Hunter PR. Climate change and waterborne and vector-borne disease. Journal of Applied Microbiology 2003 04/03;94:37-46.

14. Learmonth LR, Macleod CD, Santos MB, Pierce GJ, Crick HQP, Robinson RA. Potential effects of climate change on marine mammals. Oceanography and Marine Biology: An Annual Review 2006;44:431-64.

15. Lowe J, Mitchell J, Vellinga M, Wood R. Extreme events due to human induced climate change. Phil Trans R Soc A 2006 08/15;364:2117-33.

16. Nordhaus W. Clim Change Econ 2010;1:1-20.

17. Osman R, Stachowicz J, Terwin J, Whitlatch R. Linking climate change and biological invasions: Ocean warming facilitates nonindigenous species invasions. PNAS 2006 11/26;99:15497-500.

18. Manatee deaths call attention to the rise of toxic algal blooms [Internet]: E&E Publishing; c2013 [cited 2013 06/04]. Available from: http://www.eenews.net/public/Greenwire/2013/03/26/8.

19. Schmidt JA, McCleery R, Seavey JR, Cameron Devitt SE, Schmidt PM. Impacts of a half century of sea-level rise and development on an endangered mammal. Global Change Biology 2012 07/18;18(12):3536-42.

20. Schmittner A. Decline of marine ecosystem caused by reduction in the atlantic overturning circulation. Nature 2005;434:628-32.

21. Thorpe R, Vellinga M, Wood R. Global warming and thermohaline circulation stability. Phil Trans R Soc Lond A 2003 09/15;361:1961-75.

22. Vellinga M, Wood R. Impacts of thermohaline circulation shutdown in the twenty-first centuary. Climatic Change 2008 01/13/2007;91(1):43-63.

23. Vellinga M, Wood R. Global climatic impacts of a collaspe of the atlantic thermohaline circulation. Climatic Change 2002;54(3):251-67.