The Effects of Ocean Freshening
on Marine and Atmospheric Circulation: Impacts and Solutions

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Abstract

Ocean freshening (the desalination of the oceans) is occurring, in part, due to increased terrestrial runoff and ice cap melting caused by rising carbon dioxide emissions. Ocean freshening causes a variety of problems on its own, independent of other variables of global climate change. What are the impacts of ocean freshening? Ocean freshening weakens thermohaline circulation, deepens the thermocline, and increases mean global oceanic temperatures. Additionally, ocean freshening increases tropopause temperatures, thus impacting Hadley cells which affect wind patterns and wind-driven upwelling. Changes in thermohaline circulation also impact productivity through stratification of the water column, producing decreased mixing which leads to a decrease in available nutrients. Ocean freshening then impacts human society by affecting fisheries and economics, human health (via temperature-dependent diseases), and technology via sonar accuracy and wind power. To tackle the conditions of ocean freshening, we suggest a monitoring plan, as well as a series of steps to combat carbon dioxide emissions.

Introduction

Global climate change is caused primarily by the increased greenhouse gas emissions (Rahmstorf 1999). One study found emissions have increased by 70% from 1970-2004 (IPCC 2007). This presents us with a reality: climate change is occurring with multiple repercussions. One such repercussion is ocean freshening. Warming global temperatures cause polar ice cap and increased glacial melting, increasing the freshwater content of the ocean by 36,055 km^3 annually (Syed et al. 2010). Ocean freshening, on the most basic level, is the decrease in the ocean's salinity due to the influx of freshwater.

In this paper, we delve into the impacts of ocean freshening on thermohaline circulation (THC), the ocean-air interface, and meridional overturning circulation (MOC). The difference between THC and MOC is THC is density-driven, whereas MOC includes THC, as well as encompassing the role of winds and tides (Rahmstorf 2006). Current predictions suggest a decreased THC, causing cooling in the northern hemisphere, and warming in the southern (Rahmstorf 2006). We will look at this scenario with a focus on THC, water and air temperature, and MOC through surface circulation and upwelling. We will conclude with a monitoring plan, and impacts to humans with possible solutions.

Thermohaline Circulation

Ocean circulation is driven by wind, tides, and THC. THC is driven by temperature (thermo-) and salinity (halo-) (Rahmstorf 2006). THC is the main driver of deep water masses around the globe because wind-driven currents only penetrate to depths of a few hundred meters (Rahmstorf 2006). Salinity is influenced by environmental factors; evaporation and ice formation increase salinity whereas ice melt, runoff, and precipitation decrease salinity. With increased proximity to the equator and increased solar radiation, water driven by THC will rise. With colder waters and increasing salinity, the water will sink in the ocean column (Rahmstorf 2006).

Significant deep water formation occurs in the North Atlantic, where sea ice forms and temperature decreases (Figure 1). This deep water pools in marginal seas (Price 1998). Marginal seas are underwater basins constrained by landmasses and seafloor topography (Price 1998). The water then spills out of the marginal seas and moves around the globe (Price 1998). Circulation patterns are largely influenced by the Coriolis effect, seafloor bathymetry, and the location of continents (Figure 1). In the Antarctic region, water sinking in the Weddell Sea flows toward India and in the Atlantic; water sinking in the Ross Sea flows toward the Pacific (Rahmstorf 2006).

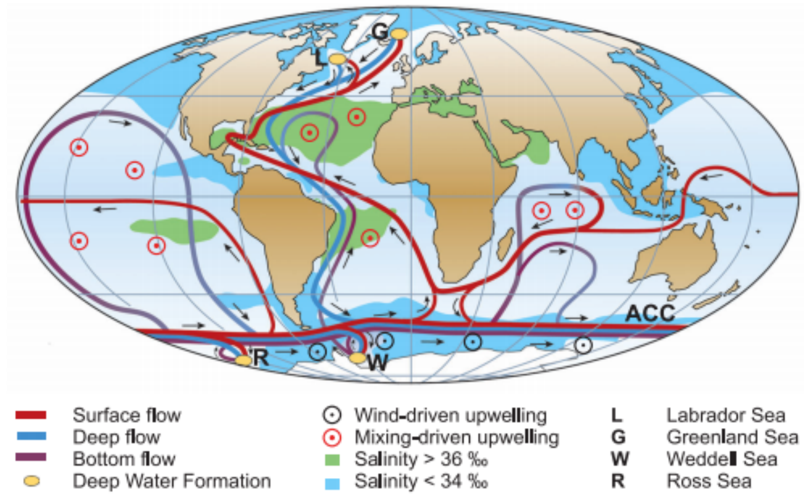

Figure 1: Representation of thermohaline circulation illustrating cold water sinks and global circulation patterns (Rahmstorf 2006).

According to Rahmstorf (2006), THC is influenced heavily by the bathymetry of the ocean. The dense water rises with elevation changes in the underwater landscape. THC bottom water circulates until it reaches warmer waters in the Indian and Pacific oceans (Figure 1). Here, bottom water decreases density and rises in the water column (Rahmstorf 2006).

THC is synonymous with the global conveyor belt, responsible for the movement of water and heat around the globe. The water in the Arctic increases in salinity and density, causing it to sink and be pulled towards the equator. The sinking and transfer of Arctic water forces the warm surface waters from the equatorial Atlantic Ocean to be pulled poleward to replace the Arctic water. This circulation of water transfers heat from the equator to the poles,

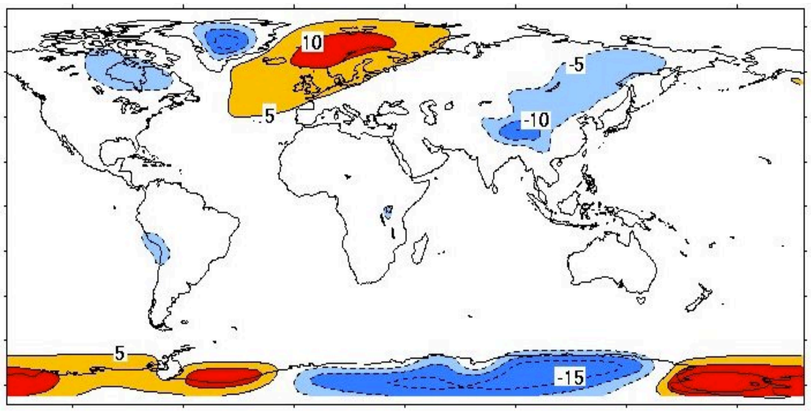

Figure 2: The 5-10˚ C temperature difference shown over western Europe is due to THC (Rahmstorf 2006).

maintaining temperatures around northern Europe above the average temperature found at similar latitudes (Figure 2). A molecule of water traveling in the THC takes approximately 1000 years to complete the cycle (Rahmstorf et al. 2006). THC converts approximately 13 Sverdrup (Sv) of the upper ocean to deep water in the North Atlantic (Brix 2001) and 4-5 Sv in the Antarctic (Toggweiler and Key 2003). One Sv is designated as 1,000,000 m^3/s (Kuhlbrodt et al. 2009).

<u>Effect of Ocean Freshening on Thermohaline Circulation</u>

THC is density-driven and depends on large differences in salinity between low and high latitude waters. Freshening causes the Arctic water to become less dense and no longer sink to the bottom, slowing or stopping the Arctic waters from being transferred towards the equator via THC. The lack of sinking would stop the warm equatorial waters from being pulled poleward. This causes permanent warm conditions in the tropics (Fedorov et al. 2006), where oceanic heat transport occurs (Barreiro et al. 2011). The lack of water transfer would create a domino effect as THC weakens and possibly shuts down

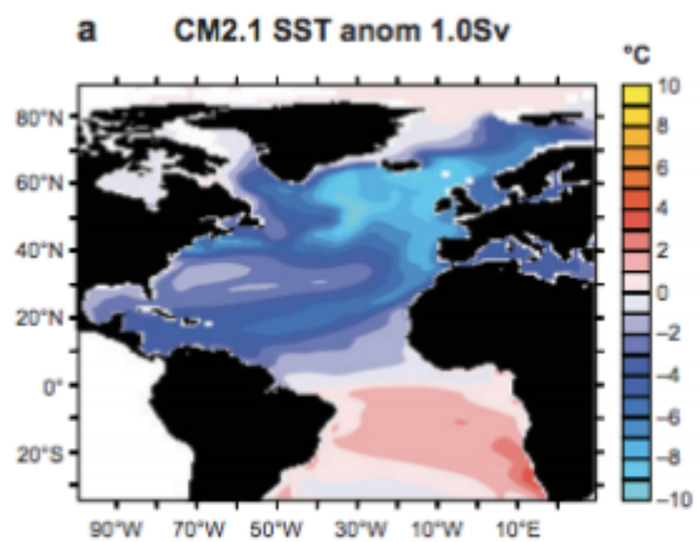

Figure 3: This shows the effects of 1 Sv of freshwater entering the Atlantic Ocean on SST (Stouffer et al. 2006).

(Fedorov et al. 2006, Teller et al. 2001). At present, "the sea ice acts as a bandage to protect THC" (Jayne et al. 1995) due to the albedo effect.

According to Barreiro's model (2007) (Figure 3), the addition of 1 Sv of freshwater between 50˚N and 70˚N in the North Atlantic would cause the entire circulation to stop. This results in a decrease in Sea Surface Temperature (SST) (Stouffer et al. 2006). By examining reconstructed historical data, scientists have concluded that a similar event occurred during the Younger Dryas (Rahmstorf 2006).

Historical Ocean Freshening Event: The Younger Dryas

Scientists have based much of their research regarding impacts to THC due to ocean freshening on an event during the Younger Dryas (Bluemle 2007). Approximately 12,000 years ago, Lake Agassiz experienced multiple jokulhlaups (ice dams breaking) in central North America. This large lake (with a surface area of 426,000 km^2) released thousands of cubic kilometers of freshwater into the ocean (Bluemle 2007; Murton et al. 2010). This caused a decrease in water density, leading to a slowing THC in the North Atlantic. Temperatures in the northern Atlantic and Western Europe dropped (Manabe et al. 1997). Because THC slowed down, the warmer waters that typically travel to the North Atlantic remained in the equatorial regions, and colder torpid waters were not driven from the North Atlantic (*The Younger Dryas* 2008). THC did eventually recover as a result of the negative feedback loop created when the cooler northern latitudes caused increased ice formation (Manabe et al. 1997), and freshwater influx abated (*The Younger Dryas* 2008). The Younger Dryas serves as an example of how THC could be impacted due to ocean freshening.

Water Temperature

The ocean loses heat through atmospheric convection, whereas the ocean gains heat through solar radiation. The amount of heat gained is influenced by the depth of the oceanic thermocline (Barreiro et al. 2007). The thermocline is a layer of rapidly changing temperature in the ocean located at an average depth of around 0-1000 meters (Trujillo 2005). Boccaletti et al. (2003) states, "the heat gain is large when the thermocline is shallow but is small when the thermocline is deep." Since there is low heat loss at the poles (in comparison to the heat the ocean gains), then we can hypothesize the thermocline will become deeper (Fedorov et al. 2006) because of ocean freshening. By measuring oceanic temperatures at different points across the globe, and correlating their data with past measurements (EPA 2013), scientists have deduced the ocean is absorbing more heat than it is expelling (Figure 4) (Kosaka et al. 2013, Levitus et al. 2012). This claim is supported by the observed increase in heat storage of $2x10^{23}$ J (or 0.06°C) globally from mid-1950 to mid-1990 (Levitus et al. 2000).

Figure 4: Global measurements of ocean temperature measured by different agencies (EPA 2013).

The effects of polar icecap melting and ocean freshening are already apparent, as shown by a change in water temperatures. Researchers found an 8 Sv loss in deep Southern Ocean water colder than 0°C, suggesting a decrease in Antarctic Bottom Water (AABW) (Purkey et al. 2012). This decrease causes ocean depths below 4 km to have a heat increase of 0.029±0.009 W/m^2 globally (Purkey et al. 2012). To put this in perspective, the ocean surface absorbs an average of 175W/m^2 annually in the form of solar radiation (Gill 1982). When extrapolated, this results in 34±14 TW (1 TW equals 1 trillion W) of energy entering the deep ocean from volume loss of

AABW (Purkey et al. 2010). In the Southern Ocean, warming below 1km is 1.2 W/m^2, 40 times the global average (Purkey et al. 2012). The rising water temperatures cause a decrease in contrasting density layers within THC, thus weakening THC and reducing poleward heat transport (Fedorov 2006). In addition, the weakened THC could possibly cause changes in surface air temperature in some areas (Manabe et al. 2007).

Fedorov et al. (2006) studied the relationship between the global heat budget and surface circulation as ocean freshening decreases or stops THC. The weakened THC leaves warm water in the tropics, and as a result the thermocline lowers. This increase of warm water at the equator drives changes in atmospheric circulation. As the oceanic heat transfer shuts down, the ocean relies on the atmosphere to convectively transfer heat toward the poles in its place. If the atmosphere were not present to circulate the heat, surface currents, such as the Gulf Stream, would not exist (Fedorov et al. 2006).

The result of the change in water temperature by a freshened THC will impact the atmosphere. The ocean temperature was rising by an average of 0.06°C from mid-1950 to mid-1990, but from 0-300m depth the increase in temperature was 0.31°C (Levitus et al. 2000). The average ocean temperatures now range from 26-32°C (Liou 2006). The changes in the SST impact wind patterns found in the troposphere, particularly Hadley cells (Piana n.d.).

Air Temperature, Hadley Cells, and Surface Circulation

A Hadley cell is a region of the troposphere ranging from 0°-30° latitude on either side of the equator (Figure 5) (Piana n.d.). According to Trujillo (2005), Hadley cells are a product of convection. The warm air found in the tropics absorbs heat from the ocean and rises, pulling cold polar air down towards the equator. The Hadley cells prevent the warmest air from reaching the poles because the warm air cools due to low pressure and falls to the surface of the Earth around 30° latitude (Trujillo 2005). These cells are responsible for the trade winds (Piana n.d.).

Temperature changes on the ocean's surface have potential effects for atmospheric Hadley cells. Two models were found to describe the possible impacts of temperature changes. The first is in relation to SST. As studied by Piana (n.d.), should the SST rise by 1°C, the tropopause's temperature would increase by around 7.5°C. If the equatorial SST were raised from the average 27°C to 32°C then the tropopause would be heated 37°C above average. A 5°C SST increase, combined with other factors, would hypothetically cause the Hadley cells to increase in height allowing them to reach the poles. This effect terminates Ferrel and Polar cell convection and replaces it with a large Hadley cell (Figure 5). This causes global climates to become more equable than previously existed as temperatures are more evenly distributed across the globe (Piana n.d.).

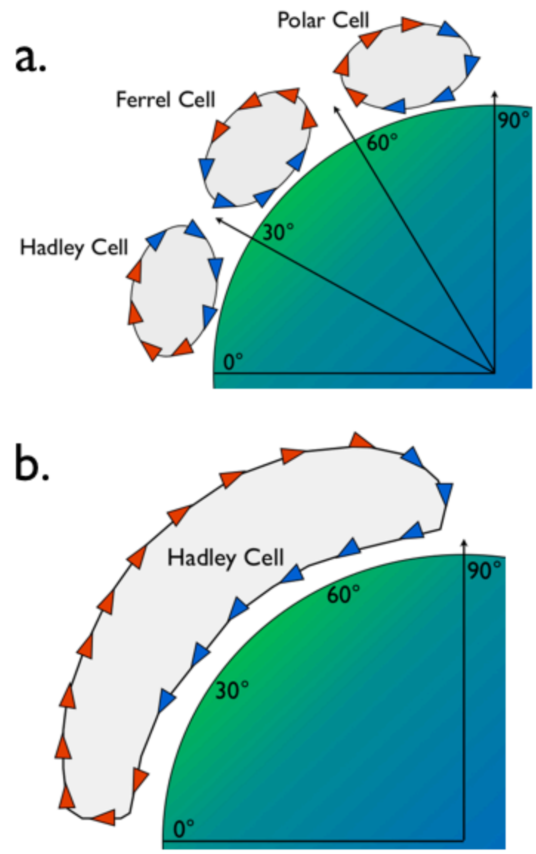

Figure 5: a. This shows the Hadley, Ferrel, and Polar Cells in the troposphere. For a Hadley cell warm air rises near the equator and falls after cooling at 30° latitude, creating a convection cell. b. This illustrates a single large Hadley cell due to increased SST (Hagerman design).

Wind currents are responsible for generating ocean surface currents. According to Trujillo (2005), surface currents occur within the first kilometer of ocean depth. Surface currents within this depth are generated by 2% of a wind's energy and affect only 10% of the ocean's volume. Currents now follow the coasts and the direction of wind in the Coriolis force. Winds generated from Hadley Cells, coupled with currents generated by the Coriolis force, form subtropical gyres. In the northern hemisphere, the trade winds create eastern boundary currents while prevailing westerlies create western boundary currents (Trujillo, 2005).

The Hadley cells are directly related to the surface currents. Greater temperature gradients generate stronger wind patterns. A greater wind creates a stronger current. Extrapolating from basic physical oceanography, if the Hadley cells were altered to extend up to the poles, the Ferrel cells would be gone, erasing the prevailing westerlies. Weak gyres may still exist because of the Coriolis effect.

All of these changes in surface circulation directly impact how wind-driven upwelling takes place. As these surface currents run into the shorelines they play an important role in upwelling of nutrients due to Ekman transport (Trujillo 2005). Ekman transport causes wind-driven upwelling along the shores of landmasses. In the northern hemisphere, a southerly wind blowing along the coast of the eastern seaboard causes water to move away from the beach. This creates a void that must be filled with the nutrient-rich deeper water creating upwelling. As long as the Coriolis force pulls water away from the shore, there will be a wind-driven upwelling event occurring (Trujillo 2005).

Induced El Niño Phase

The increased temperatures in the tropics produced by ocean freshening may cause a permanent El Niño effect in the Pacific Ocean (Fedorov et. al. 2006). The El Niño (EN) is a period of warmer water temperatures (Trujillo 2005). During these phases of EN, the trade winds are weakened and sometimes reversed due to atmospheric pressure changes (Trujillo 2005). Normal EN pressure changes cause warm equatorial SST but due to ocean freshening, this relationship is altered (Trujillo 2005). Ocean freshening causes warmer temperatures, and therefore weakens trade winds of the Hadley cells (Trujillo 2005). The winds may be weaker, but this is because the temperature gradient of the atmosphere is more equable than before ocean freshening occurred (Piana n.d.). The Hadley cells stretch to higher latitudes but are not greater in energy because the convection process is slowed due to the lesser gradient (Piana n.d.). The net result of this induced EN phase is weakened upwelling in the Pacific Ocean and altered weather patterns.

Productivity

The connection between ocean freshening and productivity is impacted by changes in density stratification, SST, and upwelling. At the basic physiological level, the importance of freshening in marine life is most marine animals have a particular tolerance level for salinities. If the salinity were to change, the animals would have to adapt to new salinity levels. Those that could not adapt would have to eventually migrate or perish, and biological communities could change as a result (Davey 2000).

Upwelling serves as the major mechanism for phytoplankton blooms and mixing of nutrients throughout the water column. Upwelling can be driven by wind, as described above, or density. Density-driven upwelling occurs when surface waters become more dense, through increased salinity or decreased temperature, and sink. This sinking of surface water pushes up bottom waters toward the surface. Density-driven upwelling can be caused by THC (Schewe 2009).

Effects of density stratification have been observed in the Arctic. With an increase in freshwater surface waters, the water column becomes much more

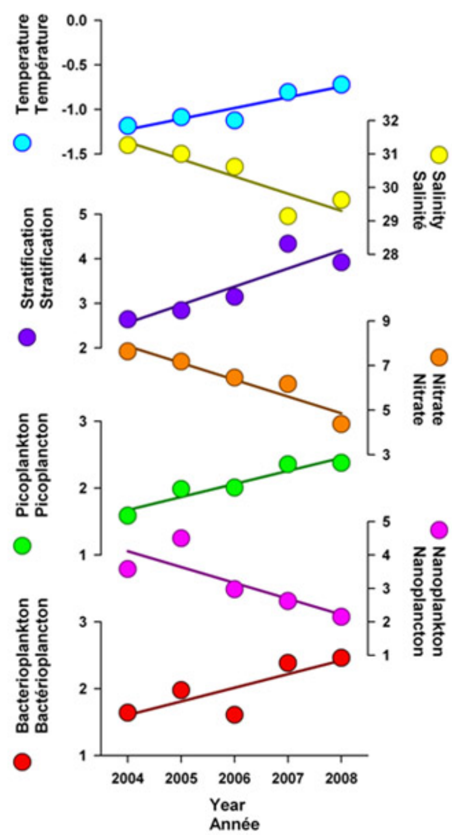

Figure 6: Effects of reduced salinity on productivity in the Arctic (Li 2009).

stable and increases overall stratification. By increasing stratification, the overall availability of nutrients, including nitrates, is reduced (Barreiro et al 2007, Li 2009, Ji et al. 2008). When available nitrates are reduced, the population sizes of other planktons (such as diatoms and dinoflagellates) are also reduced and community structure shifts (Figure 6). By removing larger plankton, smaller plankton, such as picoplankton and bacterioplankton, are less influenced by predation, causing an overall increase in smaller plankton population sizes (Li 2009).

Nutrient Availability and Primary Productivity: Off the coast of Nova Scotia, increased freshwater input has caused a change in timing of phytoplankton blooms (Ji et al. 2008). Due to lower surface salinity, there is less density-driven mixing of the water column. Because of this lower mixing, suspended nutrients decrease, which could alter the timing of phytoplankton blooms. If phytoplankton bloom timing were to change, it could disrupt the synchronization of systems (Ji et al. 2008). Off the coast of Nova Scotia the timing, however, varies by year (Ji et al. 2008). In 1998 and 2000, the spring blooms occurred later in the year; while in 1999, the spring blooms occurred earlier. In 1999, researchers found that the increased freshwater input caused a shallow and smaller mixing zone in the water column (Ji et al. 2008). This sudden mixing of nutrients (albeit smaller in size) caused an earlier and smaller phytoplankton bloom. The effects are compounded by the reduced availability of nutrients due to the increased stability of the water column that a lower surface salinity causes (Ji et al. 2008).

Fisheries: The cod fishery off the northern coast of Norway has been a main staple to European and world markets. With greater stratification as a result of a weaker THC, there will be less overall availability of nutrients. This will cause fewer juvenile Atlantic cod to survive to adulthood, decreasing overall population (Kuhlbrodt 2009). If cod were unable to acquire food off the coast of Norway, then one of two consequences would occur: either the cod would leave from Norwegian waters, or their overall population would be greatly reduced (Deutsch 2002).

Capelin are another example of a fish species potentially impacted by ocean freshening. According to Vilhjálmsson (2002), capelin are in the smelt family and provide the main food source in the northern Atlantic ecosystem. Capelin migration patterns are thought to be in direct correlation to ocean currents and any changes caused by ocean freshening may have an impact. If capelin, which provide a primary food source to whales (2190 tonnes annual consumption), cod (900 tonnes annually), and sea birds (350 tonnes consumed during summer months), were to suddenly change locations of activity, an important ecosystem could be impacted (Vilhjálmsson 2002).

THC Monitoring

THC will need to be monitored more closely to help predict any changes caused by ocean freshening. An autonomous underwater vehicle should be deployed with the capability to measure ocean salinity and chlorofluorocarbons (CFC's), similar to the THOR project in the North Atlantic. In this project, nine countries monitor THC with the goal of predicting future climate changes (Pohlmann et al. 2013). CFC's can efficiently track Deep Water masses. CFC's are measureable due to the previous high concentrations in the atmosphere that have been dissolved into the ocean and have stratified into separate deep water masses. The isotopes of CFC's can be tracked to define the movement of THC (Bullister et al. 1998). This submersible device should also be outfitted with GPS capabilities. Costs for this system can be decreased if we do not require the data to be sent simultaneously as collected.

THC collapse will also change SST, which can be monitored by weather satellites. NASA currently has Moderate Resolution Imaging Spectroradiometer (MODIS) satellites, which have been supplying SST global data since 2000. In addition to NASA, NOAA has

Geostationary Orbiting Earth Satellites (GOES) capable of relaying information on the current SST. Since these satellites already exist, this method of monitoring is relatively inexpensive.

In addition to these methods, a system is needed to monitor ice melt. Ice Mass Buoys (IMB's) placed on the ice caps will measure ice thickness. IMB's are fairly inexpensive compared to other Arctic platforms, costing 35,000 USD per buoy (Polashenski et al. 2011). Similar to the submersibles, the GPS systems on these IMB's do not need to relay data every minute, but daily. These IMB's can also be outfitted to measure salinity and SST under the ice caps, providing a cross-reference to analyze the correlation between the melting of the ice caps to the sea surface salinity and temperature. By using these systems, we will be able to more effectively predict the rate of ocean freshening and the regions likely to be most impacted.

Global Effects of Ocean Freshening

Fisheries: Possible changes to THC could have both economic benefits and deficits. When looking at negative impacts, the eastern North Atlantic cod and capelin fisheries serve as examples. The catch rate of cod could drop by 80%, thus affecting the price of Atlantic cod and profits of the North Atlantic cod fishery (Kuhlbrodt 2009). This could create a substantial economic blow since the Atlantic Cod fishery in Norway, Iceland and Russia was valued at 1.3 billion USD in 2007 (*World Cod Supply* 2007). The capelin fishery would also be affected by the collapse of THC. Based upon Link and Tol's model (2004), it would take 50 years for the capelin reproduction rates and catch rates to be affected, at which point the reproduction rates would decrease 10-50%. In a worst case scenario of a 50% decrease in reproduction rates, the time period of the first 15 years (after the initial 50 years) would cause a loss of 81,000 USD, and after 30 years it would cause a loss of 36.32 million USD (Link and Tol 2004). These figures correspond to specific fisheries and do not take into account other ecosystem effects.

Temperature changes: Data show that, with a collapse of THC, global warming will slow thus reducing climate change damages and associated costs (Link and Tol 2004). Tol and Link (2004) created a model and stated with the collapse of THC, the U.S. would save approximately 0.4% of its GNP (worth $63 billion). However, the costs of the effects of ocean freshening greatly outweigh the savings that result from the slowing of global climate change. For example, greater cooling in northern Europe and warming in southern Africa, as a result of changes in THC and wind-driven circulation (Fedorov et al. 2006), could have negative economic impacts.

Not only does ocean freshening affect the marine environment, but the atmospheric environment as well. If temperatures equalize globally due to the development of large Hadley Cells, the poles would become relatively warmer while the tropics would become relatively cooler (Piana n.d.). Temperature-dependent diseases, such as malaria (Link and Tol n.d.) would continue to follow warming temperatures.

These changes in atmospheric circulation have potential for some positive consequences. In the southern hemisphere, Hadley cells are likely to get warmer due to heat being trapped from a weakened or collapsed THC. Hypothetically, this would cause trade winds to become more prevalent and westerlies to have lesser magnitude due to smaller Ferrel cells (Piana n.d.). This provides opportunity for renewable energy sources where winds prevail.

Technology: The thermocline change originating from ocean freshening impacts groups such as the U.S. Navy, U.S. Coast Guard, and fishermen. Any of these entities that use SONAR will be impacted by changes in the thermocline (Trujillo 2005) because thermocline alters the route of the signals used by SONAR (Helgason 2002). Predictions show the thermocline will become deeper in the tropics (Boccaletti 2003). Fish closer to the surface may become easier to find if the thermocline descends deeper than where they swim. However, the fish may swim deeper to compensate for temperature. Submarines will have to dive lower to evade enemy SONAR, or risk being discovered. This also changes how oceanographers can map the ocean floor, as researchers will have to alter equipment based on thermocline depth (Trujillo 2005).

Local Effects of Ocean Freshening

Changes in global THC have lesser direct effects in the North Pacific than the Atlantic Ocean. However, models developed by Boccaletti (2003) and Fedorov et al. (2006) suggest that the North Pacific could develop permanent El Niño conditions. In Alaska, Papineau (n.d.) explains that the increased temperature at the equator causes increased cloud cover in the northern Gulf of Alaska, producing storms which are larger and more frequent. Due to the increased cloud cover, there is greater precipitation in the southern coast of Alaska ranging from the Aleutians to southeastern Alaska (Papineau n.d.). The temperatures caused by an EN phase are dependent on the strength of the phase (Papineau 2005). Average temperatures taken in Juneau, Alaska during El Niño years show there is a temperature anomaly ranging from -4˚C to +4˚C (Papineau 2005).

In addition to climate, ocean freshening poses economic change for Alaska. With the potential decrease in Atlantic cod, an opportunity arises for Pacific cod to replace its relative (Deutsch 2002, Kuhlbrodt 2009). The average cost for Pacific cod per pound is approximately 1.41 USD compared to the cost of Atlantic cod, which is 8 USD a pound (Friedrick 2010). The switch from Atlantic cod to Pacific cod would be an economic opportunity for Alaska and other northern states, such as Washington.

Solutions

The increase in carbon dioxide emissions is a global problem and the U.S. cannot fix it by itself; it will take collaboration among all nations. The U.S. should serve as an example for other nations and pave the way towards lowering emissions. Although the U.S. has been taking strides towards lowering emissions through programs such as the Energy Star tax credit, we believe more action should be taken. We suggest three solutions to apply to the U.S. to lower global emissions with the goal of other nations independently adopting similar practices as follows:

1. Charge an import tax based on the emissions produced when making a product, since 26% of global emissions come from producing goods for trade (Harrabin 2011). The tax acts as an incentive to entice oversea companies to lower their emissions and would support a shift toward greener manufacturing techniques. This same tax could be applied to companies within the U.S. as well. Hypothetically, this would lead to more efficient manufacturing globally. The revenue could then go into other emission-lowering solutions (such as greener infrastructure and research and development), as well as helping developing countries lower their emissions and become developed in a greener way. This follows the model set by the United Nations Framework Convention on Climate Change, known as the Clean Development Mechanism (*CDM* 2013).

2. To lower the U.S.'s emissions, encourage citizens to invest in greener infrastructure and energy since roughly 43% of greenhouse emissions in the U.S. are due to poor building infrastructure (Biello 2011). We suggest increasing existing tax credits for consumer energy efficiency and green energy (such as wind or solar). By decreasing our dependency on nonrenewable resources and increasing efficiency, the U.S. will not only be lowering our emissions, but will also be weaning ourselves off of fossil fuels. One example of increasing efficiency here in Alaska is shown by the Seward SeaLife Center, which uses an ocean heat exchange system (*AEA* 2012).

3. Require education about climate change and combating its effects in order to preserve Earth and its resources for future generations. This educational piece is suggested for inclusion into the nationwide Next Generation Science Standards (*Human Sustainability* n.d.), and we support this. By educating students, we heighten their awareness and motivate them to eliminate causes.

Conclusion

The impacts of ocean freshening are not easily understood due to the dynamic nature of the oceanic and atmospheric systems. THC impacts the ocean through global circulation, heat transfer and the resulting connections with the atmosphere. Similar effects of ocean freshening were seen during the Younger Dryas event (Rahmstorf 2006), although anthropogenic CO_2 levels are a variable not present at that time. Studies have suggested the North Atlantic Ocean could become cooler and the South Atlantic warmer for a period of time after an influx of freshwater (Manabe et al. 1997). This would impact Hadley cells, water temperatures, wind patterns, and upwelling, possibly inducing an EN phase (Fedorov et al. 2006). With a freshwater influx, the stratification of the water column would be increased and nutrient mixing reduced, which could have a negative impact on ocean-wide productivity. This in turn impacts cod and capelin fisheries, altering oceanic community structures.

The effects of ocean freshening span both the marine and atmospheric interface, and impact humans both locally and globally through fisheries, economics, and technology. In addition to a monitoring plan, we have proposed several solutions to combat this problem by decreasing CO_2 emissions. These solutions include an emissions tariff, education, and greener infrastructure both nationally and internationally. This is a serious global issue, but with the help of all nations and people working together, it can be addressed and alleviated to the benefit of all.

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