How much are glaciers and ice sheets contributing to global sea-level rise?

From measurements made by the IPCC it is clear that global sea level is rising, however the direct cause of this rise is not yet fully certain, although there is strong evidence that glacier melt is a strong causal factor. Global sea level rose by about 120 meters during the several millennia that followed the end of the last ice age (approximately 21,000 years ago), and stabilized between 3,000 and 2,000 years ago. Global sea level did not then change significantly until the late 19th century when the record of sea level change shows evidence for an onset of sea level rise. Estimates for the 20th century show that global average sea level rose at a rate of about 1.7 millimetres per year. Satellite altimetry observations provide more accurate sea level data with nearly global coverage and indicate that since 1993 sea level has been rising at a rate of about 3 millimetres per year. Climate models based on the current rate of increase in greenhouse gases, however, indicate that sea level may rise dramatically more than this, at about 4 millimetres per year by the period 2090-2099 (IPCC).

Several factors directly related to the state of the Cryosphere have the potential to contribute to a rising sea level during a warming climate (presently being experienced by the Earth). How related to the Cryosphere these evident changes in sea level are is a contested issue, with some feeling that the Cryosphere plays an extremely important role and others arguing that changes are merely cyclical and hence any direct effects are counteracted by the following change in season, or over a longer period of time, for example ice ages followed by long periods of a much warmer climate.

Initially it would be assumed that all melting ice and snow – as a direct result of global warming – contributes to sea level rise, this however is not the case. Firstly, seasonal ice and snow cover (found predominantly in mountainous regions) melts during the spring and summer months; much of this runoff falls into drainage basins and, hence, will eventually filter through the hydrological system and into the sea. However, as this is a process with a seasonal hydrologic cycle with no net increase in seasonal snowfall over time - and no significant increase has occurred in recent decades - melting snow cannot then be considered as a factor that contributes to long term annual net sea level rise. A further point is that the melting back of off land sea ice and ice shelves (in the Arctic) will not directly contribute to sea level rise because this ice is already floating on the ocean, and so already displacing its mass of water; hence this ice does not have any further significant influence on sea level after it melts – their weight has already displaced a significant amount of water. As these ice shelves melt they contract; the increase in thermal energy causes the hydrogen bonds to be shaken out of position. This weakens the hydrogen bonding and allows for less space in the liquid structure. Hence, melted ice sheets and shelves will not have any further effect after melting has taken place. However, the melting back of this ice can lead to indirect contributions on sea level. For example, the melting of sea ice leads to a reduction in albedo...
and allows for greater absorption of solar radiation. More solar radiation being absorbed will accelerate warming, thus increasing the melting back of snow and ice on land – a self feeding cycle. In addition, ongoing breakup of the floating ice shelves will allow a faster flow of ice on land into the oceans, thereby providing an additional contribution to sea level rise.

Another issue (although less commonly thought to aid sea level rise) is that in the summer months permafrost thaws and the ice within the soil melts, adding an additional amount of liquid to the water table, raising ground water levels and increasing the saturation level of the soil. However, whether this melting frost has any significant effect on sea level is not yet clear. It would seem unlikely that this relatively small amount of increased moisture would affect sea level by any measurable degree.

Global sea level is currently rising as a result of both ocean thermal expansion and glacier melt, with each accounting for about half of the current observed sea level rise, caused by recent increases in global mean temperature. For the recent modern period 1961-2003, the observed sea level rise was 0.69 millimetres per year due to total glacier melt (small glaciers, ice caps, ice sheets). Between 1993 and 2003, the contribution to sea level rise increased to 1.19 millimetres per year (IPCC), a marked increase.

One of the most pronounced effects of climate change has been melting of masses of ice around the world, predominantly glaciers. Glaciers and ice sheets are the world’s largest reservoir of fresh water, holding approximately 75% of the global supply, and so are extremely important to the global hydrological balance between fresh and salt water. Over the past century, most of the world’s mountain glaciers and the ice sheets in both Greenland and Antarctica have lost mass. Retreat of this ice occurs when the mass balance is negative, such that more ice melts each year than is replaced (net ablation). By affecting the temperature and precipitation of a particular area (both of which are key factors in the ability of a glacier to replenish its volume of ice) climate change affects the mass balance of glaciers and ice sheets. When the temperature exceeds a particular level or warm temperatures last for a long enough period, combined with or separately to insufficient precipitation, glaciers and ice sheets will lose mass through melting.

One of the best-documented examples of glacial retreat has been on Mount Kilimanjaro in Africa. It is the tallest peak on the continent, and so, despite being located in the tropics, it is high enough that glacial ice has been present for at least many centuries. However, over the past century, the volume of Mount Kilimanjaro’s glacial ice has decreased by about 80%. If this rate of loss continues, its glaciers will likely disappear within the next decade. Similar glacial melt backs are occurring in Alaska, the Himalayas, and the Andes.

Antarctica and Greenland, the world’s largest ice sheets, make up the vast majority of the Earth’s ice. It has been modelled and concluded that if these ice sheets melted entirely, sea level would rise by more than 70 meters. However, current estimates indicate that mass...
balance for the Antarctic ice sheet is in approximate equilibrium and may represent only about 10 percent of the current contribution to sea level rise with a source from glaciers. However, some localized areas of the Antarctic have recently shown significant negative balance, for example Pine Island and Thwaites Glaciers, and glaciers on the Antarctic Peninsula. There is still much uncertainty about accumulation rates in Antarctica, especially on the East Antarctic Plateau. The Greenland Ice Sheet however may be contributing about 30 percent of all glacier melt to rising sea level – a large amount of melt water from a single ice mass. Furthermore, recent observations show evidence for increased ice flow rates in some regions of the Greenland Ice Sheet, suggesting that ice dynamics may be a key factor in the response of coastal glaciers and ice sheets to climate change and their role in sea level rise. In contrast to the polar regions, the network of lower latitude small glaciers and ice caps, although making up only about four percent of the total land ice area may have provided as much as 60 percent of the total glacier contribution to sea level change since 1990s (Meier et al., 2007). The Greenland and Antarctic ice sheets are losing mass at an accelerating pace (NASA). The findings of this study by NASA, the longest to date of changes in polar ice sheet mass - suggest these ice sheets are overtaking ice loss from Earth's mountain glaciers and ice caps to become the dominant contributor to global sea level rise, much sooner than model forecasts have predicted. Were all the ice on Greenland to melt, a process that would likely take many centuries to millennia, sea level would rise by around 7 meters. The West Antarctic ice sheet holds about 5 m of sea level equivalent and is particularly vulnerable as much of it is grounded below sea level; the East Antarctic ice sheet, which is less vulnerable, holds about 55 m of sea level equivalent. The models used to estimate potential changes in ice mass are, so far, only capable of estimating the changes in mass due to surface processes leading to evaporation/sublimation and snowfall and conversion to ice. In summarizing the results of model simulations for the 21st century, IPCC reported that the central estimates projected that Greenland would induce about a 2 cm rise in sea level whereas Antarctica would, because of increased snow accumulation, induce about a 2 cm fall in sea level. That there are likely to be problems with these estimates, however, has become clear with recent satellite observations, which indicate that both Greenland and Antarctica are currently losing ice mass, and we are only in the first decade of a century that is projected to become much warmer over its course.

Not only the net measured ice loss should be considered, but also the speed at which ablation is occurring. Recent studies show that the movement of ice towards the ocean from both of the major ice sheets has increased significantly. As the speed increases, the ice streams flow more rapidly into the ocean, too quickly to be replenished by snowfall near their heads. The speed of movement of some of the ice streams draining the Greenland Ice Sheet, for example, has doubled in just a few years. Using various methods to estimate how much ice is being lost (such as creating a ‘before and after’ image of the ice sheet to
estimate the change in shape and therefore volume, or using satellites to ‘weigh’ the ice sheet by computing its gravitational pull), scientists have discovered that the mass balance of the Greenland Ice Sheet has become negative in the past few years. Estimates put the net loss of ice at anywhere between 82 and 224 cubic kilometres per year – a huge deficit.

In Antarctica, recent estimates show a sharp contrast between what is occurring in the East and West Antarctic Ice Sheets. The acceleration of ice loss from the West Antarctic Ice Sheet has doubled in recent years - similar to the effects in Greenland. In West Antarctica, as well as in Greenland, the main reason for this increase is the quickening pace at which glacial streams are flowing into the ocean. Scientists estimate the loss of ice from the West Antarctic ice sheet to be from 47 to 148 cubic kilometres per year. However, recent measurements indicate that the East Antarctic ice sheet (which is much larger than the West) is in fact gaining mass because of increased precipitation. Despite this gain in mass by the East Antarctic ice sheet, this does not equal the net ablation from the West Antarctic ice sheet. Therefore, the mass balance of the Antarctic Ice Sheet as a whole remains negative.

In conclusion, it is clear that the melting of the glaciers and ice sheets will consistently add water to the oceans, steadily contributing to sea level rise. Projections suggest that the rate of sea level rise is likely to increase during the 21st century, although there is considerable controversy about the likely size of the increase; this controversy arises mainly due to uncertainties about the contributions to expect from the melting of glaciers and ice caps, and the loss of ice from the Greenland and West Antarctic ice sheets. For the 21st century, an IPCC assessment projected that melting of glaciers and ice caps will contribute roughly 10-12 cm to sea level rise, with an uncertainty of roughly a third. This would represent a melting of roughly a quarter of the total amount of ice tied up in mountain glaciers and small ice caps. Because model simulations underestimate the sea level rise observed during the 20th century, significant debate has developed within the scientific community about IPCC’s projections of sea level rise for the 21st century. The accuracy of the projections has been questioned for a variety of reasons, particularly relating to limitations of the model representations of the ice sheets, which do not account for the increase in ice sheet movement (dynamics) that occurs as ice sheets warm, perhaps because the physics are not well understood. There are also problems projecting how rapidly and how much global temperature will increase during the 21st century, in part due to the range of possible emissions - doubts surrounding projections of global warming lead to uncertainties in projections of sea level rise. Uncertainties relating to the potential loss of ice from the Greenland and West Antarctic ice sheets are also common. The dynamics of ice sheet movement are incredibly complex - some ice streams are moving very rapidly, suggesting the potential for contributions to sea level rise of order 10 mm/year or even larger, a rate that is far larger than any of the other terms. There seems even the possibility of a collapse of
one or both ice sheets, especially if there is rapid loss of buttressing ice shelves that would reduce the resistance to ice stream flows. Capturing these processes accurately in climate models is extremely difficult, while omitting the process that is likely the most important contributor to sea level rise presents a significant issue - the result being that IPCC’s projections of sea level rise during the 21st century and beyond may be significantly too low.

As CO2 emissions and climate change continue, risks to the health of the ocean will become a more prominent concern. With accelerated melting back of glaciers and ice sheets and the subsequent rise in sea level, with further decreases in oceanic pH, and with deceleration of the thermohaline circulation, there are many ways in which the delicate balance of ocean dynamics and ecosystems are being put at risk. These factors, combined with the uncertainty in predicting exactly how these impacts will interact, are causing changes in the ocean: an increasingly problematic issue for future generations.

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**Supervisor’s feedback** – the annotated comments on this essay fall into two categories: Firstly, it is important to state the sources of information used. This applies to both the arguments themselves and also to any supporting evidence. Secondly, it is important to express your ideas clearly. This means that you have to pay attention to how your arguments are structured, ensuring that there is a logical progression of ideas or information. This also means paying attention to the structure of sentences. Shorter sentences are generally more effective than more complex ones. If you choose to write longer sentences you need to be confident in your use of punctuation, so that the reader does not get lost half way through. Remember that spoken English, which often includes use of conditional or subordinate clauses, is different from more formal, academic written English.

This essay has not been marked for its factual content, i.e. to assess whether the writer demonstrates knowledge and understanding of the topic and the relevant processes linking glaciers and ice sheets to global sea-level rise.