EAZA Pole to Pole campaign- Climate change

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1. Introducing the cryosphere and its polar regions

1.1 The cryosphere and its polar regions

Figure1. Overview of the cryosphere and its larger components (UNEP/GRID-Arendal 2007a).

The cryosphere (derived from the Greek word for cold *"kryos"*) is the scientific term for the parts of the Earth's surface that are frozen. The cryosphere includes snow, permafrost, ice on rivers and lakes, glaciers, ice caps and sea ice (see Figure 1). It includes the great ice sheets of Antarctica and Greenland; the sea ice of the Arctic and Antarctic; frozen stretches of Canada, Siberia, and other lands within the Arctic Circle; and also mountain glaciers. Two major cryosphere elements are:

Polar ice – The great polar regions of the Arctic and Antarctica. Although very different in many respects, both of these regions are dominated by cold conditions and the presence of ice, snow, and water. A key difference is that the polar Arctic is a frozen ocean surrounded by continental landmasses and open oceans, whereas Antarctica is a frozen continent surrounded by oceans. (IPCC 2001).

Alpine glacier - Glaciers confined by surrounding mountain terrain. They are also called mountain glaciers (NSIDC, 2009) and include many outside of the polar regions (for example the extensive Himalayan and Andean glacier systems).

Why the cryosphere is so important to our climate

The cryosphere is an integral part of our global climate system. For example, the reflective (albedo) properties of white crystals of snow and ice, along with frozen ground or permafrost are very effective at bouncing most of the sun's energy that strikes them back into space. This greatly influences how much of the sun's energy is retained to heat our planet (IPCC 2007). The moisture content of the atmosphere along with cloud, rain and storm patterns are all greatly influenced by the cryosphere as are river, lake and other water dynamics. The freezing over of sea ice and the melting of ice sheets and glaciers is a major influence the global circulation of oceans by affecting the ratio of fresh water to salt (NCAR, 2009).

Other reasons to appreciate the cryosphere

In addition to providing a wide and diverse range of biodiversity supporting ecosystems and socio-economic benefits, the cryosphere locks up huge amounts of water that if returned to its liquid state would raise global average sea levels by at least 65 metres or 213 feet (UNEP 2007). This is a key consideration as, working in concert with other climate change impacts, even a metre or so of sea level rise is sufficient to threaten many of the world's coastal habitats and human settlements (World Bank 2010; Hallegatte *et al* 2013)

Find out more:

National Snow & Ice Data Center. State of the cryosphere http://nsidc.org/cryosphere/sotc/sea_level.html

Richard Z. Poore, Richard S. Williams, Jr., and Christopher Tracey Sea Level and Climate. Fact Sheet fs002–00 January 2000, rev. September 2011 Sea Level and Climate. US Geological Survey http://pubs.usgs.gov/fs/fs2-00/

EarthLabs: Future of the Cryosphere Part B: Sea Level Rise http://serc.carleton.edu/eslabs/cryosphere/6b.htm

UNEP (2009) Climate Change Science Compendium 2009. http://www.unep.org/pdf/ccScienceCompendium2009/cc_ScienceCompendium2009_full_en.pdf

World Bank (2010) Turn down the Heat. Why a 4 degree centigrade warmer world must be avoided. http://climatechange.worldbank.org/sites/default/files/Turn_Down_the_heat_Why_a_4_degree_centrigrade_warmer_world_must_be_avoided.pd

1.2 The Polar Regions

The polar regions are the extensive icy regions around the North and South Poles. In the north they are within an area called the Arctic Circle and in the south they are within an area called the Antarctic Convergence (see fig 2).

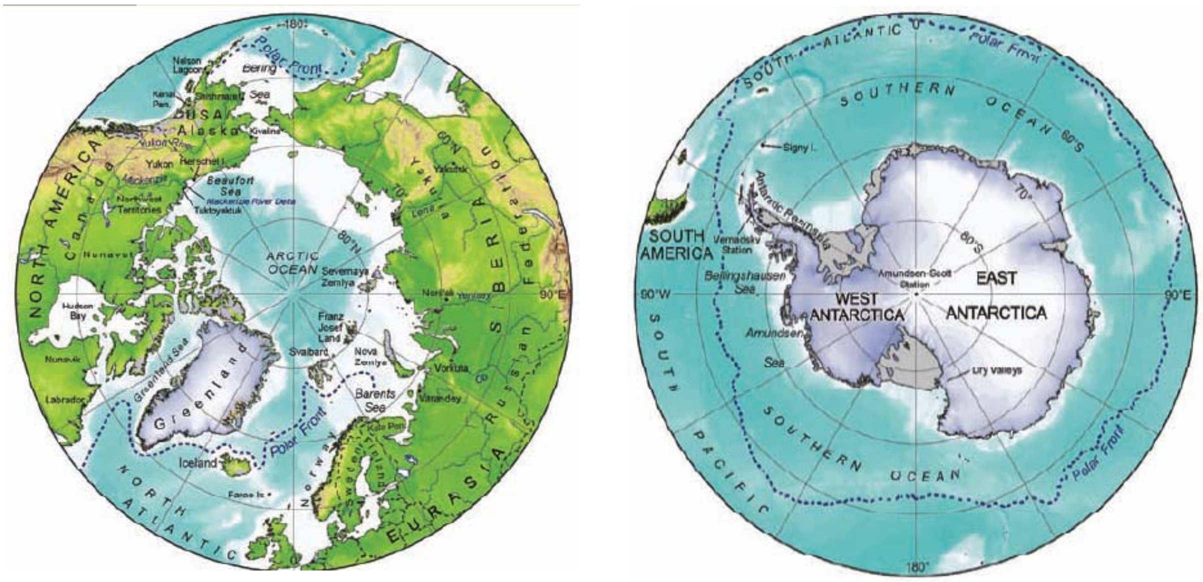

Figure 2. The left map shows the Arctic region that covers the area within the Arctic Circle, whilst the right map shows the southern polar region of Antarctica that covers the area within the Antarctic Convergence, including the Antarctic continent, the Southern Ocean and the sub-Antarctic islands. (IPCC 1997)

The polar regions are the coldest areas of the planet but the Arctic and Antarctica are quite different in character. While the majority of the Arctic region is ocean surrounded by landmasses, Antarctica is a frozen continent surrounded by ocean. (IPCC 1997). The climate system is also quite different in both regions;

Antarctica's climate is generally much colder and oceanic while the Arctic's climate is continental/sub-alpine. (WWF 2007a). Both the Arctic and Antarctic sea ice naturally partially melts and regrows in an annual cycle with sea ice reaching its maximum extent at the end of its winter cooling period after which it gradually shrinks back in response to the seasonally warmer environmental conditions.

The Arctic region includes the northern parts of Canada, Finland, Norway, Russia, Sweden, the United States (Alaska), and the whole of Greenland and Iceland. The ecosystems are varied, from the permanent ice cover on the more northern areas to taiga and boreal forest in the southern parts of the region. Tundra is the more extensive ecosystem but other ecosystems such as alpine and high mountain areas, broad-leaved forest in coastal areas, valleys and marshes also occur. (UNEP 1997). The Arctic supports many mammals and has an important role in the annual cycle of migratory birds. (CBD 2007). It also supports a large and diverse fish population.

Largely unchanged for the last 15 million years, Antarctica is the driest, coldest and windiest continent (NERC-BAS 2007b). The average annual temperature is –55°C (with -87°C being recorded at the Russian Vostic station) and wind speeds have been recorded to reach 250km per hour. 97.7% of the continent of Antarctica is covered by permanent ice, covering a total surface area of almost 14 million square kilometres (8,699,196 miles). This ice is distributed in two major ice sheets, the East Antarctic and the West Antarctic, and over ice shelves, extending over the sea water. (UNEP/GRID-Arendal 2003). The great thickness of the ice sheets (up to 2146m) makes Antarctica the world's highest continent.
Only a small number of species can contend with Antarctica's harsh terrestrial conditions with only the Marieland Tundra (which is free of permanent ice) having a relatively high biodiversity and biomass. (UNEP/GRID-Arendal 2008). However, the seas surrounding Antarctica are rich in plankton, which supports a rich and diverse marine food web. (CBD 2007).

2. Climate change threats to the polar regions

The polar regions are very vulnerable to a wide range of climate change impact factors, all of which interact to further increase the threat to these regions, and the wider world. The main impact considerations are:

2.1 Rising air and sea temperatures

Global average surface temperature has increased by 0.8°C since the late 19th century but in the polar regions the warming has been considerably greater. In the Arctic, temperatures have increased sharply over most of the region, especially in winter. Winter increases in Alaska and western Canada have been around 3-4°C over the last half century (ACIA 2006). Antarctic Peninsula average annual temperatures have risen above 2.5°C (as recorded at Vernadsky Station) since 1951 (IPCC 2007) Temperature increases are projected to be much greater in the polar regions than for the world as a whole (IPCC 2007; AMAP 2012). It's important to keep in mind that the warming oceans are a major additional temperature impact concern for the polar regions.

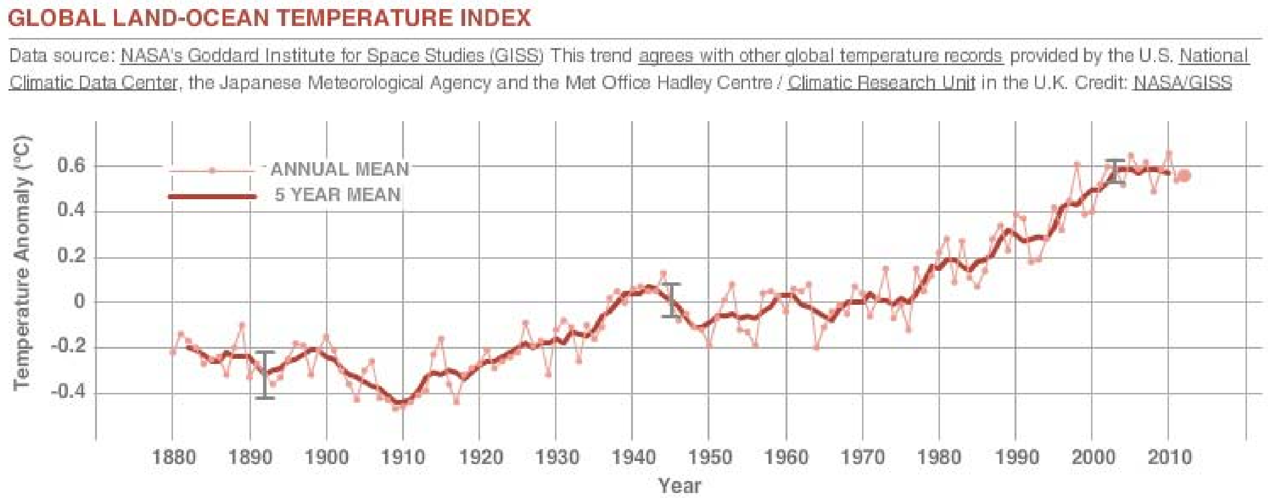

Figure 3. This NASA graph illustrates the change in global surface temperature relative to 1951-1980 average temperatures. Global surface temperatures in 2012 were the ninth warmest on record. (Source: NASA/GISS) The gray error bars represent the uncertainty on measurements. This research is broadly consistent with similar constructions prepared by the Climatic Research Unit and the National Atmospheric and Oceanic Administration. NASA http://climate.nasa.gov/key_indicators

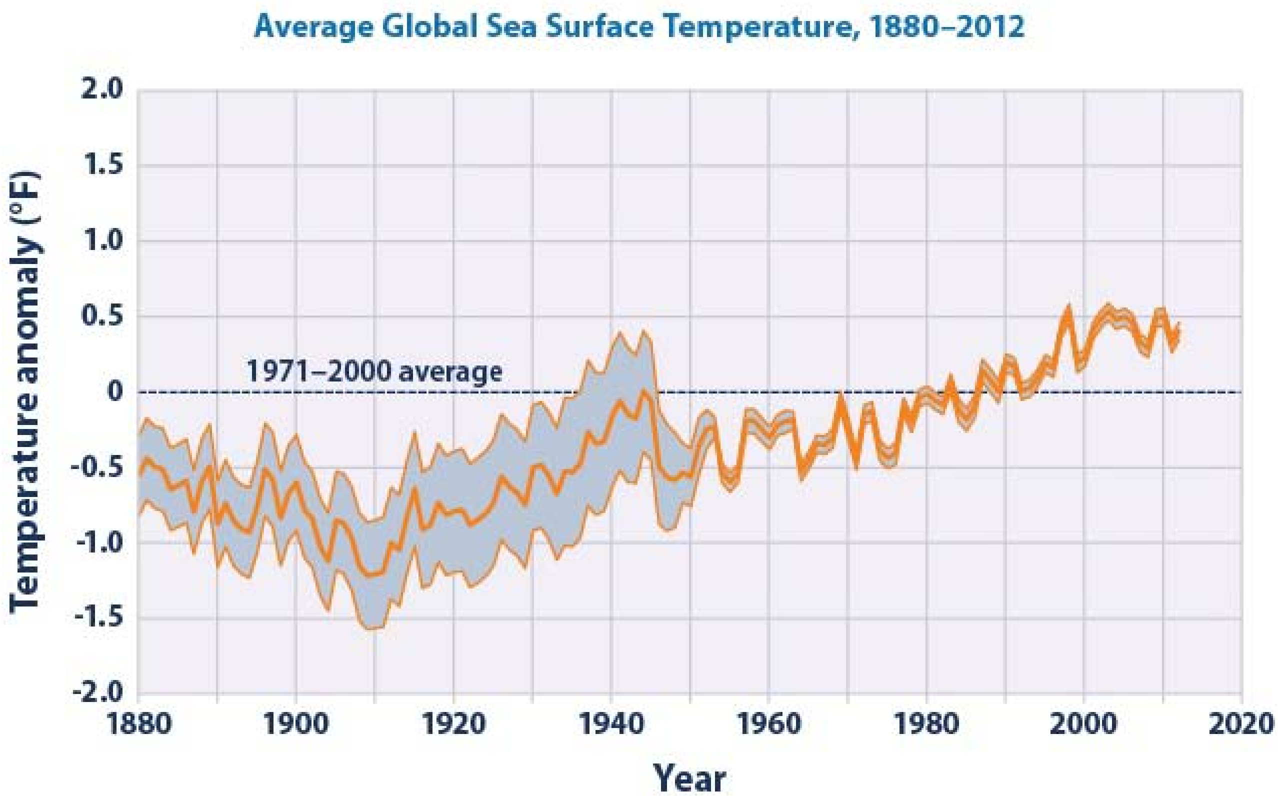

Figure 4. This US EPA graph shows how the average surface temperature of the world's oceans has changed since 1880. This graph uses the 1971 to 2000 average as a baseline for depicting change. Choosing a different baseline period would not change the shape of the data over time. The shaded band shows the range of uncertainty in the data, based on the number of measurements collected and the precision of the methods used. Data source: NOAA, 2013. http://www.epa.gov/climatechange/science/indicators/oceans/sea-surface-temp.html

Find out more:
IPPC: TS.3.1.1 Global Average Temperatures
http://www.knmi.nl/climatescenarios/monitoring/temperature.php

Major feedbacks on climate via the cryosphere: AMAP. (2011) Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. Xii + 538pp. http://amap.no/swipa/CombinedReport.pdf; Chapter 11.1.3; p 11- 14

National Academy of Sciences (2010). Advancing the Science of Climate Change. Accessed December 1, 2010.

National Academy of Sciences (2006, July 27). Testimony to U.S. House of Representatives -- Climate Change: Evidence and Future Projections. Accessed November 30, 2010.

NASA (2010, January 21). NASA Climatologist Gavin Schmidt Discusses the Surface Temperature Record. Accessed November 30, 2010.

NASA Earth Observatory (2010, June 3) Fact Sheet: Global Warming. November 30, 2010.

NOAA National Climatic Data Center (n.d.). Global Warming Frequently Asked Questions. Accessed December 1, 2010.

NOAA 2012 Arctic Report Card http://www.climate.gov/news-features/features/2012-arctic-report-card
NOAA State of the Climate in 2012 http://www.ncdc.noaa.gov/news/2012-state-climate-report-released

Romanovsky & Osterkamp 2001. Permafrost Response on Economic Development, Environmental Security and Natural Resources. Ch: Permafrost: Changes and impacts. Pp: 297-316 (Book)

World Bank (2010) Turn down the Heat. Why a 4 degree centigrade warmer world must be avoided. http://climatechange.worldbank.org/sites/default/files/Turn_Down_the_heat_Why_a_4_degree_centigrade_warmer_world_must_be_avoided.pd

2.2 Snow cover

Snow cover extent has declined about 10% over the past 30 years, (ACIA 2006) especially in spring and summer. Declines are mostly in the Northern Hemisphere (AMAP 2012). In the Southern Hemisphere, the few long records available show either decreases or no change in the past 40 years or more. (IPCC 2008) Spring peak river flows have been occurring 1-2 weeks earlier during the last 65 years and there is also evidence for an increase in winter base flow in northern Eurasia and North America. (IPCC 2007). Simulations project widespread reductions in snow cover throughout the 21st century, despite some projected increases at higher altitudes (Walsh 1995) which would lead to redistribution of ecosystems. (Daimaru and Taoda 2004). In general, the snow accumulation season is projected to begin later, the melting season to begin earlier, and the fractional snow coverage to decrease during the snow season. (IPCC 2008; AMAP 2012).

Find out more:
AMAP, 2012. Arctic Climate Issues 2011: Changes in Arctic Snow, Water, Ice and Permafrost. SWIPA 2011 Overview Report. AMAPs 2011 assessment of the Arctic Cryosphere (the SWIPA assessment) updates information presented in the 2004/5 Arctic Climate Impact Assessment. http://www.amap.no/swipa

IPCC Technical Paper VI – 2008: Climate Change and Water. Ch 2: Observed and projected changes in climate as they relate to water. (Report)

IPCC fourth assessment report: Climate Change 2007. Working Group I Report "The Physical Science Basis", Ch 4 Observations: Changes in Snow, Ice and Frozen Ground. (Report)

Walsh, J.E., 1995. Long-term observations for monitoring of the cryosphere, Climatic Change 31: 369-394. (Abstract)

Daimaru, H. and H. Taoda, 2004. Effect of Snow Pressure on the Distribution of Subalpine Abies mariesii Forests in Northern Honshu Island, Japan. Journal of Agricultural Meteorology 60: 253-261. (Abstract)

2.3 Glaciers and ice caps

Extensive studies (IPCC 2007; World Bank 2010; AMAP 2012) continue to document a general worldwide glacier degradation trend which has accelerated over the past two decades. Based on highly accurate satellite mass balance measurements of more than 300 glaciers (including glaciers in the Arctic) glaciers worldwide are estimated to have lost 219 ± 112 kg m^{-2} per year between 1961 -1990, which more than doubled to a loss of 510 ± 101 kg m^{-2} per year between 2001-2004. Large and accelerating mass loss from Alaskan glaciers with 98% of these glaciers thinning and/or retreating (Arendt et al., 2002).

It is projected that glaciers and ice caps, including those surrounding the ice sheets, will contribute 10-25 cm of sea level rise by 2100 (Meier et al. 2007). Glaciers in the Arctic, apart from those in Alaska, are not among the highest in terms of mass loss per unit area, although their large areas mean that they will be among the biggest contributors to sea-level rise (Romanovsky *et al.* 2007; WWF 2008). Observations of ocean-terminating outlet glaciers in Greenland and West Antarctica indicate that their contribution to sea level is accelerating as a result of increased velocity, thinning and retreat (Rignot et al 2008; Vieli et al 2009; King et al 2012; Shepherd et al 2012 and Zwally et al 2011). Thinning has also been reported along the margin of the much larger East Antarctic ice sheet (Pritchard et al 2009). The most recent study confirms significant East Antarctic glacier impacts, especially along the warmer western South Pacific coast and concludes that parts of the world's largest ice sheet may be more vulnerable to warming air and oceans than previously recognised (Miles et al 2013).

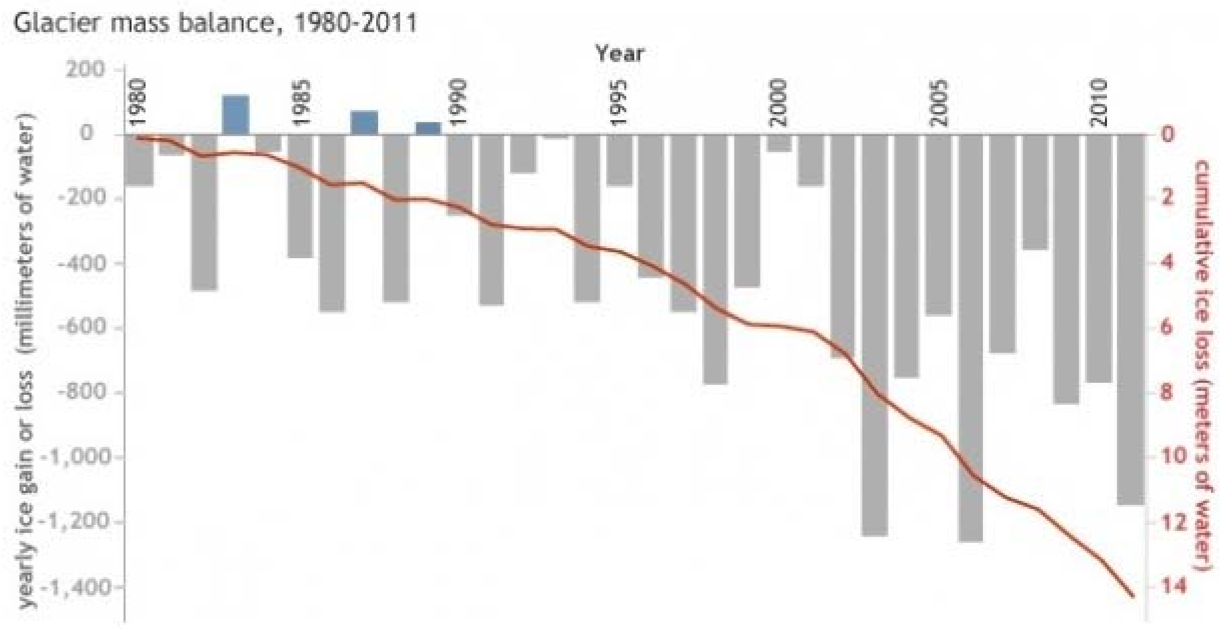

Figure 5. Glacier mass balance (snow gain minus melt loss) from 1980 through to 2011. Bars indicate positive (above the 0 line) and negative (below the 0 line) glacier mass balances each year, and the red line shows the cumulative annual balance. Only three years – 1983, 1987, and 1989 – experienced mass gains. All other years had negative mass balances with loses getting larger in more recent years. Source NOAA (adapted from the 2012 BAMS State of the Climate report) http://www.climate.gov/news-features/understanding-climate/2012-state-climate-glaciers

Find out more:

AMAP, 2012. Arctic Climate Issues 2011: Changes in Arctic Snow, Water, Ice and Permafrost. SWIPA 2011 Overview Report. AMAPs 2011 assessment of the Arctic Cryosphere (the SWIPA assessment) updates information presented in the 2004/5 Arctic Climate Impact Assessment. http://www.amap.no/swipa

Arendt et al. 2002. Rapid Wastage of Alaska Glaciers and Their Contribution to Rising Sea Level Science 297 no. 5580, pp. 382 – 386. (Abstract)

IPCC fourth assessment report: Climate Change 2007. Working Group I Report "The Physical Science Basis", Ch 4 Observations: Changes in Snow, Ice and Frozen Ground. (Report)

IPCC Fourth Assessment Report: Climate Change 2007. Working Group II Report "Impacts, Adaptation and Vulnerability" Ch 1: Assessment of Observed Changes and Responses in Natural and Managed Systems. (Report)

NASA http://climate.nasa.gov/

National Snow and Ice Data Centre (NISDC) http://nsidc.org/

World Bank (2010) Turn down the Heat. Why a 4 degree centigrade warmer world must be avoided. http://climatechange.worldbank.org/sites/default/files/Turn_Down_the_heat_Why_a_4_degree_centrigrade_warmer_world_must_be_avoided.pd

2.4 Ice sheets and ice shelves

Ice sheets are very vulnerable to global warming; the increase of the temperatures has enhanced glacier melting in Greenland and Antarctica. When melt-waters reach the bedrock, that the ice sheet rests upon, it, lubricates the ice sheet bottom and speeds up its movement (IPCC 2007). Regional warming in the Antarctic Peninsulatriggered ice shelf collapse, which lead to a 10 fold increase in glacier flow and rapid ice retreat (Rignot 2006). In the coming decades, significant changes in the Polar Regions will increase the contribution of ice sheets to global sea-level rise. (Bell R. 2008).

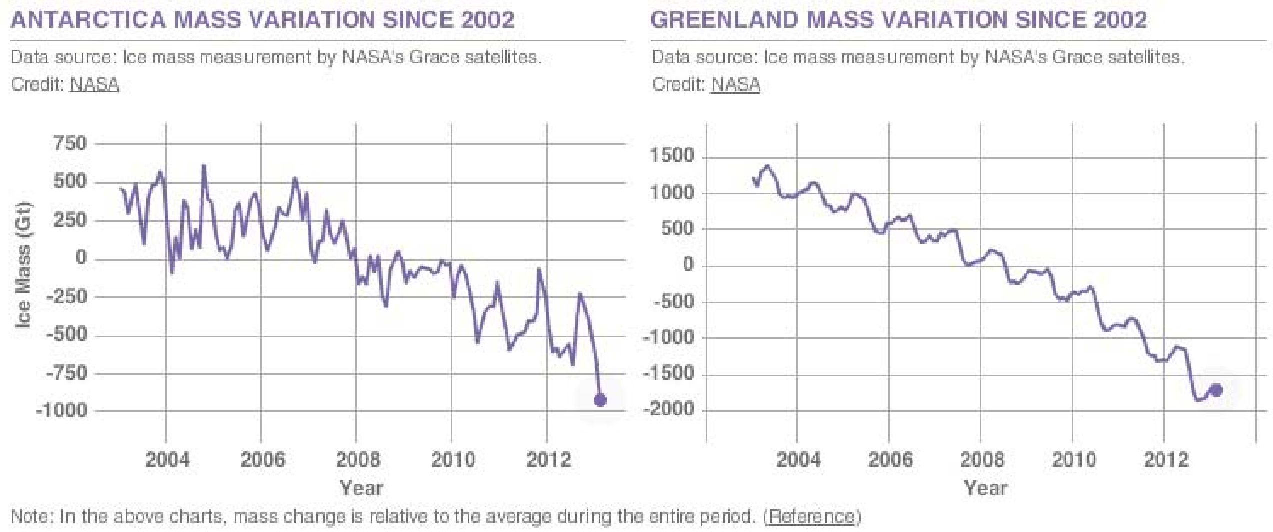

Figure 6. Data from NASA's GRACE satellites show that the land ice sheets in both Antarctica and Greenland are losing mass. The continent of Antarctica (left chart) has been losing more than 100 cubic kilometers (24 cubic miles) of ice per year since 2002. NASA http://climate.nasa.gov/key_indicators

Find out more:

AMAP, 2012. Arctic Climate Issues 2011: Changes in Arctic Snow, Water, Ice and Permafrost. SWIPA 2011 Overview Report. AMAPs 2011 assessment of the Arctic Cryosphere (the SWIPA assessment) updates information presented in the 2004/5 Arctic Climate Impact Assessment. http://www.amap.no/swipa

Rignot E. 2006, Changes in ice dynamics and mass balance of the Antarctic ice sheet. The Royal Society. Vol 364, No. 1844 p.1637-1655 (Abstract)
http://rsta.royalsocietypublishing.org/content/364/1844/1637.full.pdf

Rignot E. 2008. Changes in West Antarctic ice stream dynamics observed with ALOS PALSAR data. J. Geophys. Res, 35 http://www.ess.uci.edu/researchgrp/erignot/files/RignotGRL2008.pdf (Abstract)

Rignot, E. et al. (2008) Recent Antarctic mass loss from radar interferometry and regional climate modelling. Nature Geosci. 1, 106–110 http://www.nature.com/ngeo/journal/v1/n2/abs/ngeo102.html

2.5 Sea ice

Since 1979, winter Arctic ice extent has decreased about 3 to 4 percent per decade (Meier *et al.* 2006).. In 2007 the minimum ice sea extent was 39% less than the 1979-2000 average and this record was broken again in 2012 (NOOA 2013). Global warming is also affecting the thickness distribution of the Arctic sea ice, where the ice is getting younger and thinner. This means that, at the start of the melting season, open water areas develop earlier and become more extensive through summer. (Serreze & Stroeve 2008) The increased melting of the summer Arctic sea ice is accumulating heat in the ocean, raising the air temperatures in the region (referred to as Arctic amplification). As this was detected much earlier than expected it is thought that the Arctic may already have passed the climatic tipping-point towards ice-free summers. (Connor S. 2008 Lenton 2008; Lenton et al 2011) Projections suggest that an acceleration of the trend may be especially pronounced, appearing as an abrupt transition to ice-free summer conditions possibly in few decades (Serreze & Stroeve 2008;)

Meanwhile overall sea ice cover in Antarctica has grown which, as the National Snow and Ice Date Center (NISDC) explains, is due the fact that both global warming and ozone loss (i.e. the slowly repairing ozone hole over the Antarctic) act to strengthen the circumpolar winds in the south. This is due primarily to persistently cold conditions prevailing on Antarctica year-round, and a cold stratosphere above Antarctica due to the ozone hole. Stronger winds generally act to blow the sea ice outward, slightly increasing the extent, except in the Antarctic Peninsula region, where due to geography; winds from the north have also increased, pushing the ice southward. Thus, sea ice extent near the northwestern Antarctic Peninsula continues to decline rapidly, while areas in the Ross Sea and the southern Indian Ocean show significant increases (NISCC 2013 & Stammerjohn et al., 2012).

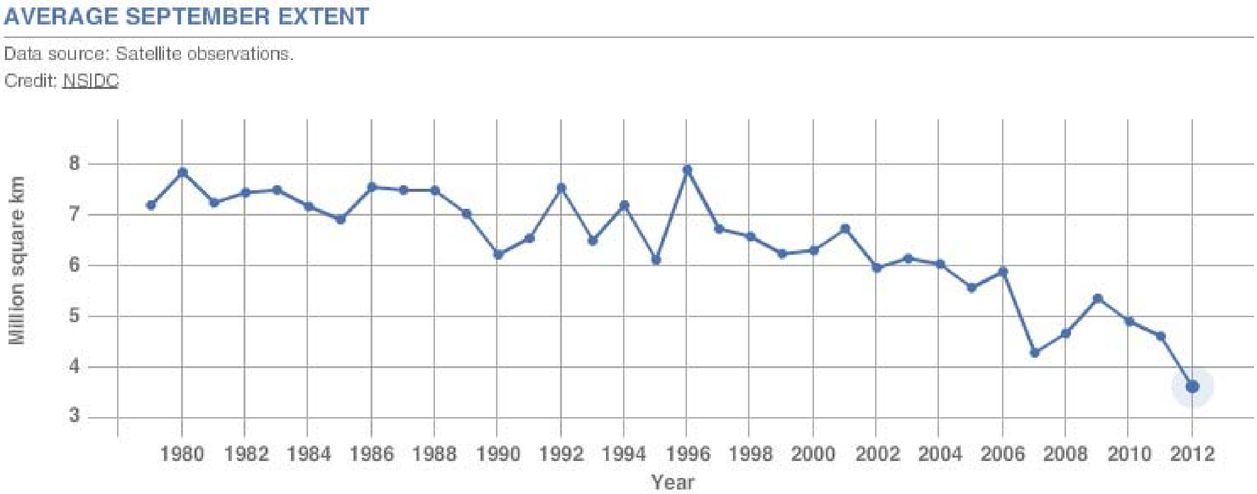

Figure 7. September Arctic sea ice is now declining at a rate of 11.5% per decade, relative to the 1979 to 2000 average. Arctic sea ice reaches its minimum each September. The graph above shows the average monthly Arctic sea ice extent in September from 1979 to 2012, derived from satellite observations. The September 2012 extent was the lowest in the satellite record. National Snow and Ice Data Centre http://nsidc.org/ and NASA http://climate.nasa.gov/key_indicators

Find out more:

AMAP. (2011) Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. Xii + 538pp.

AMAP, 2012. Arctic Climate Issues 2011: Changes in Arctic Snow, Water, Ice and Permafrost. SWIPA 2011 Overview Report. AMAPs 2011 assessment of the Arctic Cryosphere (the SWIPA assessment) updates information presented in the 2004/5 Arctic Climate Impact Assessment. http://www.amap.no/swipa

http://amap.no/swipa/CombinedReport.pdf NSIDC (National Snow and Ice Data Centre; http://nsidc.org/arcticseaicenews/2013/03/annual-maximum-extent-reached/)

Meier, W.N., J.C. Stroeve, and F. Fetterer. 2006. Whither Arctic sea ice? A clear signal of decline regionally, seasonally and extending beyond the satellite record. Annals of Glaciology 46: 428-434 http://www.the-cryosphere.net/7/699/2013/tc-7-699-2013.html

NASA http://climate.nasa.gov/

National Snow and Ice Data Centre (NISDC) http://nsidc.org/

NOOA (National Oceanic and Atmospheric Adminstration) State of the Climate in 2012: Highlights http://www.climate.gov/news-features/understanding-climate/state-climate-2012-highlights
Stammerjohn et al. (2012) Regions of rapid sea ice change: An inter-hemispheric seasonal comparison. Geophys. Res. Lett., 39, L06501, doi:10.1029/2012GL050874. http://pubs.giss.nasa.gov/abs/st06020o.html

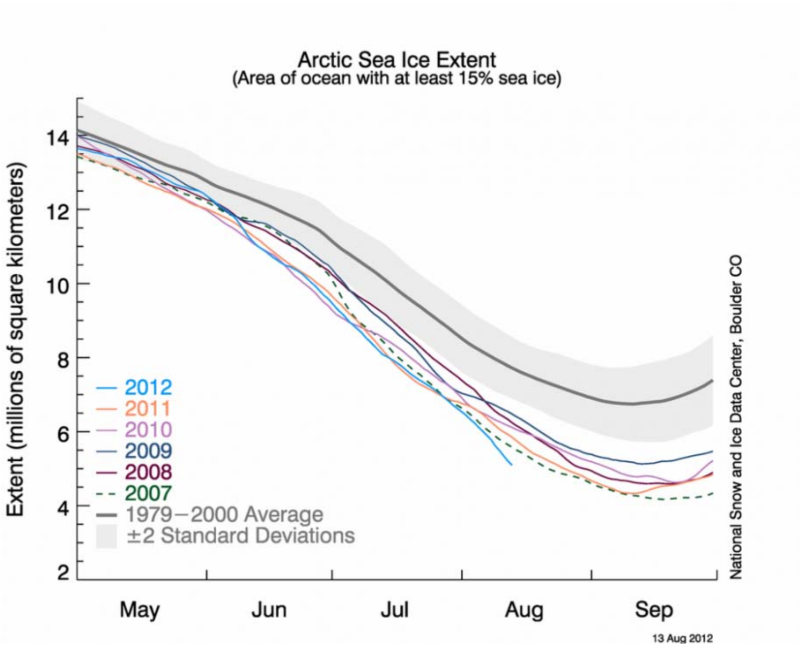

Figure 8. Sea ice extent reached a new record low on August 27, 2012 and continued to decline. The last six years have seen minimum sea ice extents below the two standard deviation range of the data. The graph above shows Arctic sea ice extent as of August 13, 2012, along with daily ice extent data for the previous five years. 2012 is shown in blue, 2011 in orange, 2010 in pink, 2009 in navy, 2008 in purple, and 2007 in green. The gray area around the average line shows the two standard deviation range of the data. National Snow and Ice Data Center http://nsidc.org/icelights/category/data-2/

2.6 Old thick sea ice versus young thin sea ice

Due to increasing temperatures ice of all ages declines. Since 1983, 5+ year old ice has declined sharply. The Arctic cover now mainly consists of First year ice which tends to melt rapidly in summer.

Newly developed estimates of sea-ice age, basin-scale sea-ice thickness, and sea-ice volume indicate thinning of the ice cover and loss of old ice types.

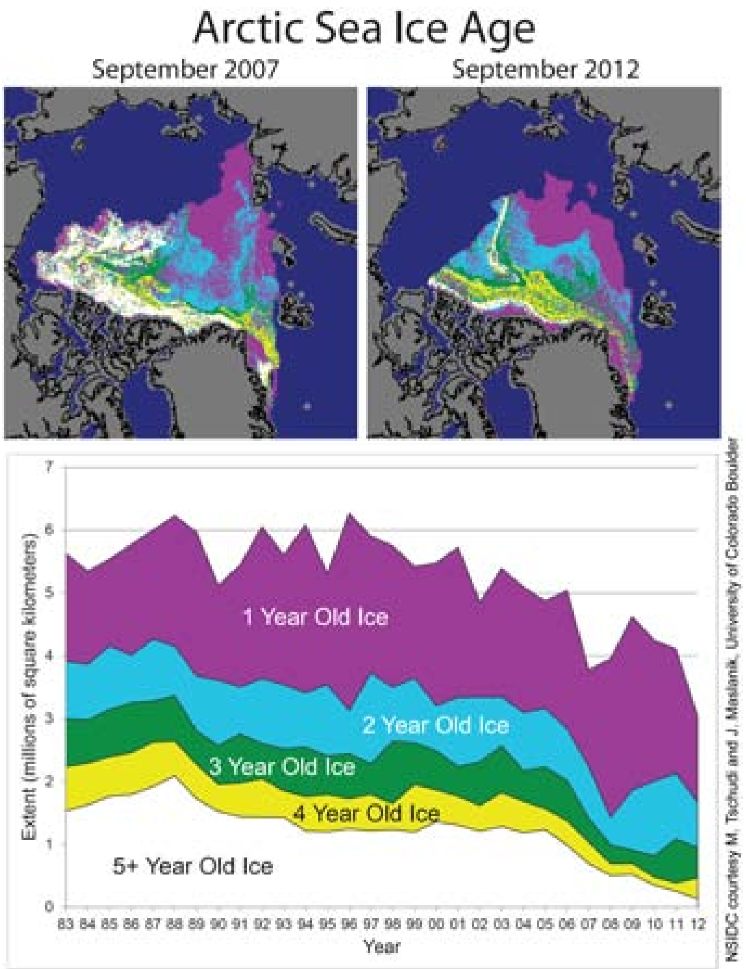

Figure 9: These images from September 2007 (top, left) and September 2012 (top, right) show the decline of multiyear ice since the previous record minimum extent was set in 2007. The chart at bottom shows the changes in multiyear ice from 1983 to 2012. NSIDC (National Snow and Ice Data Centre; http://nsidc.org/

Find out more:

AMAP. (2011) Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. Xii + 538pp. http://amap.no/swipa/CombinedReport.pdf

World Bank (2010) Turn down the Heat. Why a 4 degree centigrade warmer world must be avoided. http://climatechange.worldbank.org/sites/default/files/Turn_Down_the_heat_Why_a_4_degree_centrigrade_warmer_world_must_be_avoided.pd

2.7 Ocean freshening and circulation

River inflows to the Arctic Ocean have increased over the last 30 years due to ice melting and increased precipitation. Effects of increased freshwater input to the ocean include a greater absorption of heat, which in turn increases ice melt and glacier calving (ACIA 2004; IPCC 2007). Thermohaline circulation is also affected by these changes which may alter circulation patterns within the ocean. (Arnell N. 2005). Projected global warming during the 21st century will alter the wind and pressure patterns and the ocean circulation system. (International Arctic Science Committee 2010).

Find out more:

AMAP, 2012. Arctic Climate Issues 2011: Changes in Arctic Snow, Water, Ice and Permafrost. SWIPA 2011 Overview Report. AMAPs 2011 assessment of the Arctic Cryosphere (the SWIPA assessment) updates information presented in the 2004/5 Arctic Climate Impact Assessment. http://www.amap.no/swipa

International Arctic Science Committee (2010) Ocean processes of climatic importance in the Arctic http://www.eoearth.org/view/article/154991/

Arnell (2005) Implications of climate change for freshwater inflows to the Arctic Ocean. Journal of Geophysical Research: Atmospheres (1984–2012) http://onlinelibrary.wiley.com/doi/10.1029/2004JD005348/abstract

Arctic Climate Impact Assessment 2004 http://www.amap.no/arctic-climate-impact-assessment-acia

IPCC 2007 Polar regions (Arctic and Antarctic) http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-chapter15.pdf

2.8 Sea level rise

Sea level rise is caused by two factors related to global warming: the added water coming from the melting of land ice, and the expansion of sea water as it warms up (thermal expansion). During the period 2003-2008 the average rate of sea level rise has been 2.5 mm/yr, a smaller scale than the period 1993-2003 (3.1 mm/yr). The contribution of different factors involved in sea level rise has changed in the latest period, so for the period 2003-2008 80% of the sea level rise is due to the contribution of the polar ice sheets and mountain glaciers melting while thermal expansion contributed 50% of sea level rise for the period 1993-2003 (Cazenave et al. 2008). Future changes in the climate will accelerate the sea level rise. The IPCC did not include the full dynamic ice sheet responses in their projections, so its estimated sea level rise from 18-59 cm by 2100 is considered as conservative (WWF 2008). However, estimations from assessments and ice loss projections in Greenland and in West Antarctica suggest a sea level rise from 0.8 to 2 meters by 2100 (Pfeffer et al. 2008).

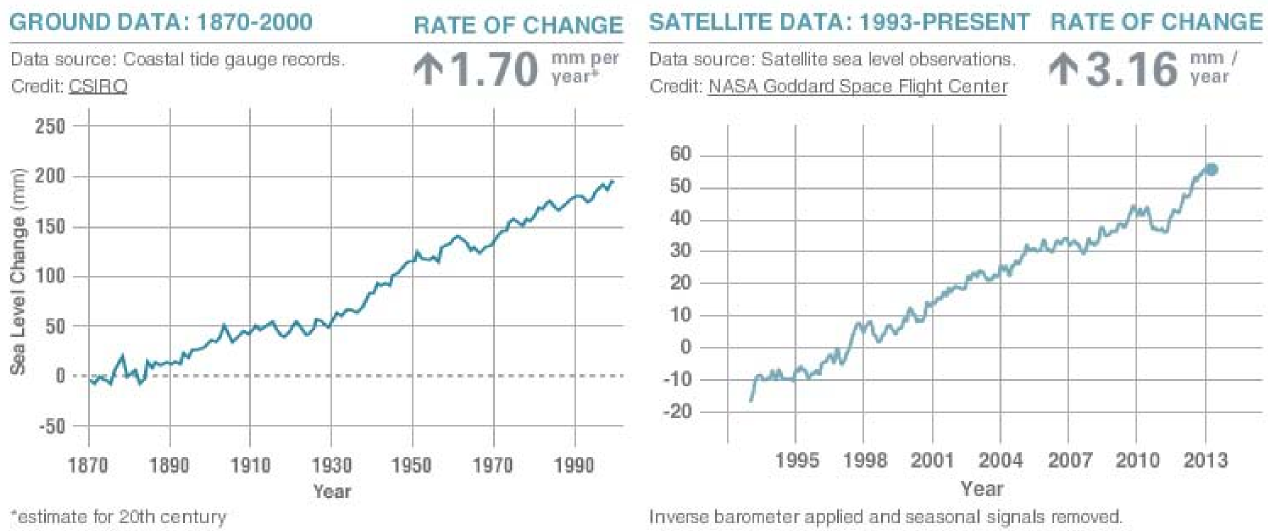

Figure 10. Sea level rise is caused by two factors related to global warming: the added water coming from the melting of land ice, and the expansion of sea water as it warms up. The above graphs show how much sea level has changed since 1993 (right, satellite data record) and about 1880 (left, coastal tide gauge data). NASA 2013 http://climate.nasa.gov/key_indicators

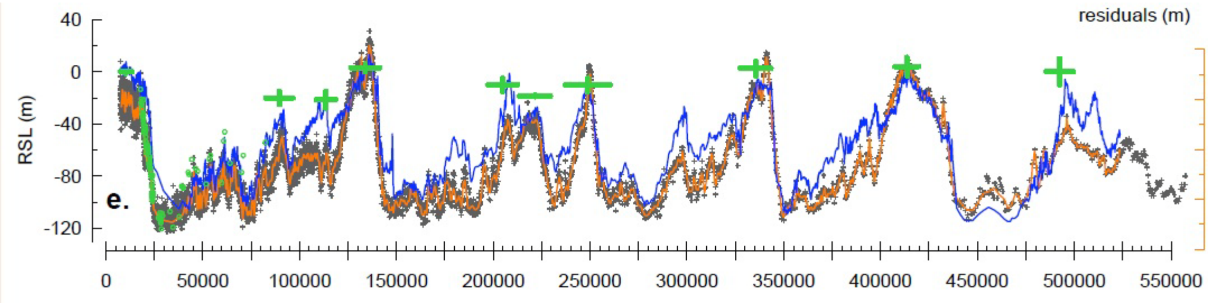

Figure 11. Sea level (blue, green: scale on the left) and Antarctic air temperature (orange, gray: scale on the right) over the last 550,000 years, from paleo-records (from right to left: present-day on the left). Sea level varied between about 110 m below and 10 m above present, while air temperature in Antarctica varied between about 10°C below and 4°C above present, with a very good correlation between both quantities. Variations in Antarctic air temperature are about two-fold those of global mean air temperature. From the World Bank Turn Down the Heat Report 2010.

Find out more:

AMAP. (2011) Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. Xii + 538pp. http://amap.no/swipa/CombinedReport.pdf

AMAP, 2012. Arctic Climate Issues 2011: Changes in Arctic Snow, Water, Ice and Permafrost. SWIPA 2011 Overview Report. AMAPs 2011 assessment of the Arctic Cryosphere (the SWIPA assessment) updates information presented in the 2004/5 Arctic Climate Impact Assessment. http://www.amap.no/swipa

Hallegatte, S., Green, C., Nicholls, R.J. and Corfee-Morlot, J. (2013) Future flood losses in major coastal cities. Nature Climate Change 3, 802–806 (2013) doi:10.1038/nclimate1979 http://www.nature.com/nclimate/journal/v3/n9/full/nclimate1979.html#ref3

NASA http://climate.nasa.gov/

National Snow and Ice Data Centre (NISDC) http://nsidc.org/

NOAA Sea Level Rise and Coastal Flooding Impacts Viewer http://csc.noaa.gov/digitalcoast/tools/slrviewer

Pfeffer W. et al. 2008. Kinematic Constraints on Glacier Contributions to 21st- Century Sea-Level http://www.sciencemag.org/content/321/5894/1340.full

Rahmstorf, S., Cazenave, A., Church, J. A., Hansen, J. E., Keeling, R. F., Parker, D. E. and Somerville, R. C. J. (2007) Recent climate observations compared to projections. Science 316: 709. http://pubs.giss.nasa.gov/abs/ra04500f.html

Rignot,E., Velicogna,I., van den Broeke,M.R., Monaghan, A. and Lenaerts, J. (2011) Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise http://igitur-archive.library.uu.nl/phys/2012-0315-200618/rignot_etal_grl2011.pdf

World Bank (2010) Turn down the Heat. Why a 4 degree centigrade warmer world must be avoided. http://climatechange.worldbank.org/sites/default/files/Turn_Down_the_heat_Why_a_4_degree_centrigrade_warmer_world_must_be_avoided.pd

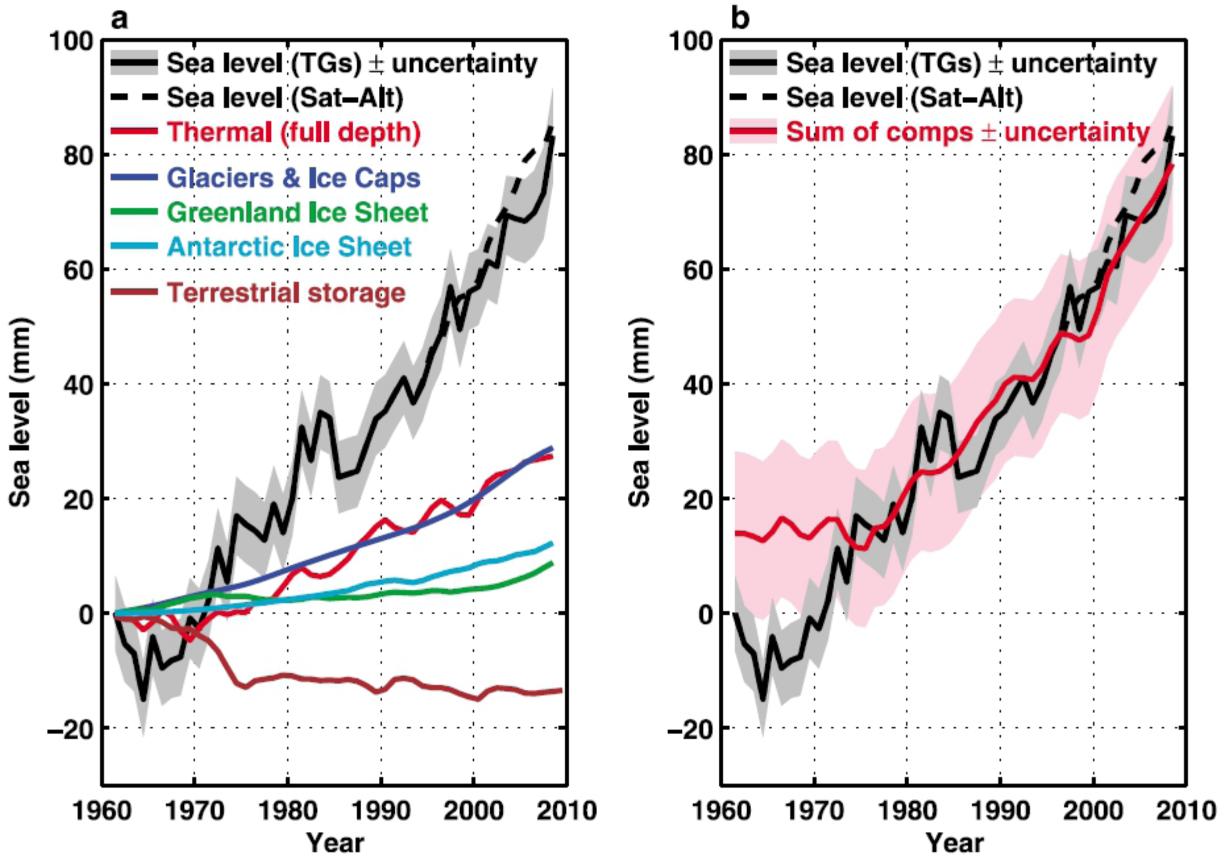

Figure 12: Left panel (a): The contributions of land ice (mountain glaciers and ice caps and Greenland and Antarctic ice sheets), thermosteric sea level rise, and terrestrial storage (the net effects of groundwater extraction and dam building), as well as observations from tide gauges (since 1961) and satellite observations (since 1993). Right panel (b): the sum of the individual contributions approximates the observed sea-level rise since the 1970s. The gaps in the earlier period could be caused by errors in observations. World Bank 2012 Turn Down the Heat http://climatechange.worldbank.org/sites/default/files/Turn_Down_the_heat_Why_a_4_degree_centrigrade_warmer_world_must_be_avoided.pdf

2.9 Permafrost

Permafrost is frozen ground (soil or rock including ice and organic material) that remains at or below 0°C for at least two consecutive years. They are almost exclusively associated with the Arctic region. It is natural for the topmost layer of permafrost soils to melt when absorbing sufficient heat during summer. In this layer (referred to as the active layer) plants can grow and animals find their food. However, in the absence of global warming, the soil underneath this layer always remains frozen, preserving the organic material including large amounts of carbon and methane. It is estimated that Arctic permafrost contains nearly 1,700 billion tons of carbon, about twice the carbon that is currently in the atmosphere. Paleoclimate studies show the land warming trend to be 3.5 times greater during rapid ice loss events and that extra warming by disappearing sea ice penetrates 1500 Km inland, covering almost the entire region of continuous permafrost. (Lawrence et al. 2008).

Over the last 30 years permafrost warming from 0.5 to 2 ºC has been observed depending on the location (Romanovsky et al. 2008) with the most sensitive regions being the areas exposed to the Arctic Ocean. Since 1900 seasonally frozen ground has declined by 7% in maximum extent. Observed rates of mean annual erosion vary from 2.5 to 3.0 m yr^{-1} for the ice-rich coasts to 1.0 m yr-1 for the ice-poor permafrost coasts along the Russian Arctic Coast. Over the Alaskan Beaufort Sea Coast, mean annual erosion rates range from 0.7 to 3.2 m yr^{-1} with maximum rates up to 16.7m yr^{-1} (IPCC 2007). Permafrost and frozen ground degradation affect the water surface causing retreating of ponds and drier soils in those areas with thin permafrost, whereas in those areas with thicker permafrost, new wetlands will come up. (WWF 2008) Is projected that permafrost's southern limit shift northward by several hundred km during this century. (ACIA 2006).

Vast amounts of methane hydrates (methane gas encased in ice) are stored in sediments in Arctic continental shelves and warmer temperatures (as in previous major warming periods of Earth's history) have the potential to bring about methane release. (IPCC 2007; Koven et al 2011; DeConto et al 2012;). In fact, very large scale methane emissions in several parts of the Arctic region have recently been observed (Anthony et al 2012; Kort et al 2012). Permafrost thawing is releasing CO_2 and methane to the atmosphere, which acts as a feedback, causing further global warming. It is estimated that by 2050 the permafrost area will have decreased by 20 to 35% in the Northern Hemisphere and the depth of active layer may increase by 15 to 25% and by 50% and more in the northernmost locations. (IPCC 2007). Permafrost degradation could mean a loss of 1 million Km^2 of frozen ground and the release of 900 million tons of carbon to the atmosphere by 2100 (Strom R. 2007).

Find out more:

Nafeez Ahmed (2013) Seven facts you need to know about the Arctic methane timebomb. Earth Insight hosted by the Guardian http://www.theguardian.com/environment/earth-insight/2013/aug/05/7-facts-need-to-know-arctic-methane-time-bomb

DeConto et al (2012) Past extreme warming events linked to massive carbon release from thawing permafrost. Nature 484: 87-91. http://www.nature.com/nature/journal/v484/n7392/full/nature10929.htm
KORT, E. A., WOFSY, S. C., DAUBE, B. C. & DIAO, M. (2012): Atmospheric observations of Arctic Ocean methane emissions up to 82° north. Nature Geoscience 5: 318–321.
http://www.nature.com/ngeo/journal/v5/n5/abs/ngeo1452.html

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Schuur, E.A.G., BockheimJ., Canadell.G., EuskirchenE., FieldC.B., GoryachkinS.V., Hagemann, S., KuhryP., Lafleur, P.M., Lee, H., Mazhitova, G., Nelson, F.E., Rinke, A., Romanovsky, V.E., Shiklomanov, N., Tarnocai, C., Venevsky, S., Vogel, J.G. & Zimov, S.A. (2008) Vulnerability of Permafrost Carbon to Climate Change: Implications for the Global Carbon Cycle. Bioscience 58 (8): 701-714 http://www.bioone.org/doi/abs/10.1641/B580807

World Bank (2010) Turn down the Heat. Why a 4 degree centigrade warmer world must be avoided. http://climatechange.worldbank.org/sites/default/files/Turn_Down_the_heat_Why_a_4_degree_centrigrade_warmer_world_must_be_avoided.pd

2.10 Shifting habitats and species impacts

Global warming affects both habitats and the species that rely on them (Foden et al 2013). Vegetation zones are projected to shift northward, (e.g. tundra will turn into forests and polar deserts will turn into tundra (ACIA 2006)) and it is predicted that forest will replace from half to two thirds of tundra. (University of Cambridge 2006). In Polar Regions, the sea ice is fundamental for species which rely on ice for resting, feeding and breeding. In a greenhouse future, the progressively earlier break-up of the Arctic sea ice, would increase starvation rates and decrease birth rates in marine mammals (CBD 2007). Mountain glaciers are expected to continue shrinking, causing habitat impacts for many species. Changes in rainfall and snowfall also affects streamflows and wetlands, affecting wildlife and possibly accelerating the invasion of non-native plants into streamside habitats (AMAP 2012). Projected sea level rise would inundate wetlands and lowlands and would increase the saltwater intrusion in marshes, estuaries and aquifers that would affect wildlife around the world (Pearce-Kelly et al 2013).

Find out more:

AMAP, 2012. Arctic Climate Issues 2011: Changes in Arctic Snow, Water, Ice and Permafrost. SWIPA 2011 Overview Report. AMAPs 2011 assessment of the Arctic Cryosphere (the SWIPA assessment) updates information presented in the 2004/5 Arctic Climate Impact Assessment. http://www.amap.no/swipa

BARNOSKY et al (2012): Approaching a state shift in Earth's biosphere. Nature 486: 52–58. http://www.nature.com/nature/journal/v486/n7401/full/nature11018.html

FODEN, W. B., MACE, G. M., VIÉ, J.-C., ANGULO, A.,BUTCHART, S. H. M., DEVANTIER, L., DUBLIN, H. T., GUTSCHE, A., STUART, S. N. & TURAK, E. (2008): Species and case studies. Conservation Biology 24: 63–69
Foden et al (2013) Identifying the World's Most Climate Change Vulnerable Species: A Systematic Trait-Based Assessment of all Birds, Amphibians and Corals. PLoS ONE 8(6): e65427. doi:10.1371. http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0065427

HOEGH-GULDBERG, O. & BRUNO, J. F. (2010): The impact of climate change on the world's marine ecosystems. Science 328: 1523–1528.

PARMESAN, C. & YOHE, G. (2003): A globally coherent fingerprint of climate change impacts across natural systems. Nature 421: 37–42.

Pearce-Kelly, P., Khela, S., Ferry, A.C. & Field, D. (2013) Climate-change impact considerations for freshwater-fish conservation, with special reference to the aquarium and zoo community. Int. Zoo Yb. (2013) 47: 81–92 DOI:10.1111/izy.12016 http://onlinelibrary.wiley.com/doi/10.1111/izy.12016/abstract

Titus J. and Barth M. 1984. Greenhouse effect and sea level rise: a challenge for this generation. Ch 1. An overview of the causes and effects of the sea level rise. EPA. (Book)

WALKER, B. (2001): Catastrophic shifts in ecosystems Nature 413: 591–596.

2.11 Extreme weather conditions

Reduced seasonal sea-ice presence is already leading to greater shoreline exposure to open water and storm waves. These changes expose greater wave and erosion hazards for shoreline, infrastructure, waterfront structures, and cultural heritage sites in some places.

Extreme climate events are likely to continue to have severe effects on many ecosystem types. The global warming impacts on the polar regions will increasingly affect us all because of the coastal damage, extreme weather and their socio-economic consequences.

Find out more:

AMAP. (2011) Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. Xii + 538pp. http://amap.no/swipa/CombinedReport.pdf Chapter 9.4.5.2.1; p 64-66; Chapter 11

Carter, P. (2012) Arctic Summer Sea Ice Tipping Point. Video posting featuring Ted Scambos, Robbie Macdonald, Don Perovich, Mark Serreze and Vladimir Romanovsky. http://vimeo.com/34547995

Hansen et al (Submitted) Scientific Case for Avoiding Dangerous Climate Change to Protect Young People and Nature. Proc. Natl. Acad. Sci. http://pubs.giss.nasa.gov/abs/ha08510t.html

World Bank (2010) Turn down the Heat. Why a 4 degree centigrade warmer world must be avoided. http://climatechange.worldbank.org/sites/default/files/Turn_Down_the_heat_Why_a_4_degree_centrigrade_warmer_world_must_be_avoided.pd

2.12 Ocean Acidification

Ocean Acidification (often referred to as OA) refers to an increase in the acidity of the ocean over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide from the atmosphere (IPCC 2007). It is a great concern as left unchecked and working in concert with the effects of global warming, OA will profoundly affect marine ecosystems and species (Hoegh-Guildberg & Bruno 2010; Veron 2010). For example the world's coral reef ecosystems will be functionally non-viable once the full effect of current atmospheric CO_2 levels take effect (Coral Crisis Working Group position statement 2009; Veron et al 2009, WAZA Position Statement 2010 and Veron 2012).

OA is a great threat to the polar region marine food chains and is already pronounced in these cold region oceans, due to the higher capacity of cold waters to absorb carbon dioxide. The Arctic Monitoring and Assessment Programme's Arctic Ocean Acidification Assessment report states that indirect OA effects include changes in food supply or other resources. For example, birds and mammals are not likely to be directly affected by acidification but may be indirectly affected if their food sources decline, expand, relocate, or otherwise change in response to ocean acidification. OA may alter the extent to which nutrients and essential trace elements in seawater are available to marine organisms. Some shell-building Arctic molluscs are likely to be negatively affected by OA, especially at early life stages. Juvenile and adult fishes are thought likely to cope with the acidification levels projected for the next century, but fish eggs and early larval stages may be more sensitive. In general, early life stages are more susceptible to direct effects of OA than later life stages (AMAP 2013). Critically important food web species such as pteropods and other calcium carbonate shell building animals are examples of directly vulnerable polar region species, the loss of which reduce the availability of nutrients and the ability of oceans to absorb atmospheric CO_2. (IPCC 2007) (Sommerkorn M. 2008).

Find out more:

Arctic Monitoring and Assessment Programme (2013) Arctic Ocean Acidification Assessment: Summary for Policymakers. Link to Arctic Council Web site

Fabry, V.J.; Seibel, B.A.; Feely, R.A.; Orr, J.C. Impacts of ocean acidification on marine fauna and ecosystem processes. J. Mar. Sci. 2008, 65, 414–423.

HOEGH-GULDBERG, O. & BRUNO, J. F. (2010): The impact of climate change on the world's marine ecosystems. Science 328: 1523–1528.

Veron, J.E.N.,(2008). Mass extinctions and ocean acidification: biological constraints on geological dilemmas. Coral Reefs 27, 459–472.

Veron, J.E.N., Hoegh-Guldberg, O, Lenton, T.M, Lough, J.M., Obura D.O., Pearce-Kelly, P., Sheppard, C., Spalding M., Stafford-Smith, M.G. and Rogers, A.D. (2009) The coral reef crisis: The critical importance of <350 ppm CO2. Marine Pollution Bulletin 58 (2009) 1428–1436

*Veron, E.N. (2011) Ocean Acidification and Coral Reefs: An Emerging Big Picture. Diversity **2011**, 3, 262-274; doi:10.3390/d3020262*

WAZA (2012): Resolution 67.2. Emergency resolution on avoiding disastrous and unmanageable climate change and ocean acidification impacts by returning atmospheric CO2 concentrations to below 350 parts per million while it is still possible to do so. Gland, Switzerland: World Association of Zoos and Aquariums. Available at http://www.waza.org/files/webcontent/1.public_site/5.conservation/climate_change/RES%2067.2%20Climate%20Change.pdf

2.13 Sea ice and industry

As the Arctic Ocean becomes increasingly ice free it is tempting for many countries to exploit the region for hitherto inaccessible resources like oil and natural gas. Energy companies apply for drilling permits and shipping companies are eagerly looking for newly opened routes through the Arctic.

Find out more:

NSIDC (National Snow and Ice Data Centre; http://nsidc.org/

What about the people living in the Arctic?

Human Societies living in the Arctic are already, and will increasingly be, severely affected by ice melting due to rapid climate change (AMAP 2012). Their traditional lifestyles and culture are wholly dependent on the on the Arctic environment.

AMAP. (2011) Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. Xii + 538pp. http://amap.no/swipa/CombinedReport.pdf Chapter 9.4; p 52-70; Chapter 12.3.6, p. 11-12

AMAP, 2012. Arctic Climate Issues 2011: Changes in Arctic Snow, Water, Ice and Permafrost. SWIPA 2011 Overview Report. AMAPs 2011 assessment of the Arctic Cryosphere (the SWIPA assessment) updates information presented in the 2004/5 Arctic Climate Impact Assessment. http://www.amap.no/swipa

2.14 The global warming threat to Antarctica

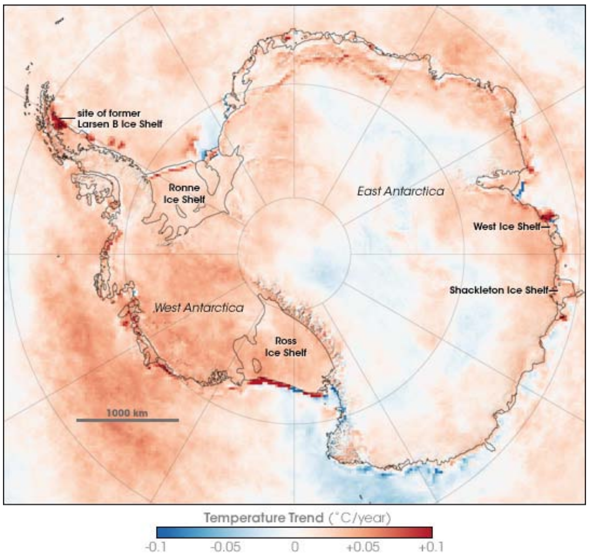

Figure 13.Temperature trends in Antarctica between 1981 and 2007, based on thermal infrared observations made by a series of NOAA satellite sensors. Author: Robert Simmon, NASA Earth Observatory.

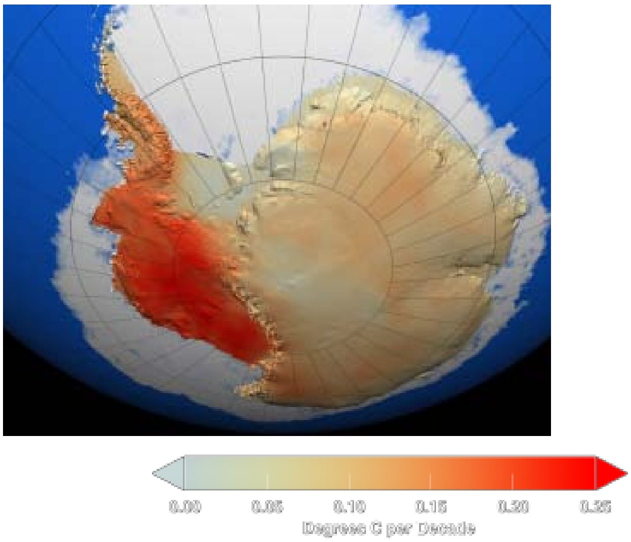

Figure 14. This NASA image shows the extensive warming of the West Antarctic ice-sheet surface inland of the Antarctic Peninsula. This warming is significantly higher than previously reported, exceeding 0.1 degree C per decade over the past 50 years, and is strongest in winter and spring. The image incorporates temperature data collected over a 50-year period from 1957 to 2006 (NASA/GSFC Scientific Visualization Studio 2008)

There is a remarkable difference in observed warming between the West Antarctic Ice Sheet (often referred to as the WAIS) and the East Antarctic Ice Sheet, which so far has remained relatively unaffected, largely due to the cooling effects of the ozone hole (Thompson A. 2009). However, the WAIS, which includes the Antarctic Peninsula, has experienced a significant warming trend, with average temperatures rising by nearly 3°C in the west coast of the Peninsula (approximately 10 times the average global warming rate). Also, in the last 50 years upper ocean temperatures to the west of the Antarctic Peninsula have increased by over 1°C and 87% of glaciers along the west coast of the Peninsula have retreated. (NERC-BAS 2007; IPCC 2007). In 2002 the Larsen ice shelf collapsed completely **(**NERC-BAS 2007**).**

The West Antarctic Ice Sheet is much less stable than East Antarctica because it sits on rock below sea level and observations that large areas of the WAIS are thinning fast may indicate the ice sheet's collapse. **(**NERC-BAS 2007a**).** Evidence that the WAIS is losing mass at an increasing rate comes from the Amundsen Sea sector and in particular from three glaciers: Pine Island, Thwaites and Smith. Total ice discharge from these glaciers increased 30% in 12 years and the net mass loss increased 170% (Rignot E. 2008). Ice shelf collapses could precede the West Antarctic Ice Sheet collapse which would eventually cause an average global sea level rise of about 5 meters (Bentley C.R. 1998) and would have profound ecological, social and economic impacts worldwide. Increased emissions of atmospheric CO_2 and projected intense winds and changes in stratification will alter rates of atmospheric CO_2 draw-down in the Southern Ocean (in the last 20 years it has dropped up to 30%).

The situation is very different for Antarctic sea ice which, due to the regional climate dynamics, is generally unchanged or actually increasing. For example, the NOAA 2012 state of the Climate report (NOAA 2013) confirmed that in 2012 Antarctica sea ice extent reached record high of 7.51 million square miles on September 26 2012. However, the longer term viability of Antarctic sea ice is linked to the fate of the ice sheets and wider global warming impacts (Hansen et al 2013).

3. What all this means for the rest of the world

The degradation of the cryosphere in general and the poles in particular will have increasingly severe repercussions over the rest of the world. Ice melting is leading to increasing amounts of CO_2 and methane being released from melting permafrost which in turn is further enhancing the greenhouse effect. The retreat of ice in the polar and other cryosphere regions, in addition to tree line shifts will greatly reduce albedo which will generate strong positive feedbacks causing further warming. Any changes in the ocean circulation system will have further consequences for further climate change in addition to potentially severe effects on marine ecosystems. Ice melting increases sea levels with repercussions on many low-land and coastal areas. Biodiverstiy will be threatened by loss of habitats and alien species invasion, involving significant changes in the abundance and distribution of species.

Projected sea level rise will increasingly impact coastal environments, including the salinity of estuaries and aquifers.(Titus J. 2008), with severe socio-economic and ecological implications. Although some of the most vulnerable regions in South, South-east and East Asia, Africa and low-land islands will be among the first affected (IPCC 2007) almost all costal environments and human settlements (including many of the world's major cities) will be increasingly threatened (World Bank 2012; Hallegatte et al 2013)

3.1 The take home message

The polar regions are critically important systems, both for their dependent biodiversity and for the key role they play in maintaining the stable climate and sea levels we all rely on. They also exemplify the highly interconnected nature of our planet's physical and living systems and how vulnerable we all are to even current levels of global warming (AMAP 2012; Whiteman *et al* 2013).

In the case of the Arctic there's increasing concern that the region may already be entering a state of committed change which would eventually cause all of its sea ice, ice sheets and permafrost to be lost. The same concern pertains to the West Antarctic Ice Sheet, although, as with Greenland, the huge amounts of ice involved means that complete collapse could take several centuries, and quite possibly millennia in the case of East Antarctica. However, once sufficient ice-melt momentum has been reached there would be no practical way for humanity to halt the disintegration process. Moreover, the impacts of even relatively modest levels of ice sheet disintegration on sea levels is such that well within this century the threat to marine and terrestrial ecosystems and our own coastal settlements, including many of the world's major cities, will become increasingly unmanageable.

The already observed impacts on the polar regions and the fact that a lot more 'committed' warming responses are in the pipeline, due to combined effects of climate system inertia and the delayed response of ice sheets (Hansen 2012; Hansen et al 2013) means that we are now faced with this critical threshold risk. Unless we act now to ensure that atmospheric concentrations of carbon dioxide are returned to below 350 parts per million in the short window of time remaining for this to be still possible, humanity will be committed to the fate of tens of meters of sea level rise and the plethora of extreme climate and ocean acidification conditions summarized in the Met Office $4^{o}C$ world map below.

The 2012 emergency resolution by the World Association of Zoos (included in full at the end of this chapter) highlights the threat to the Arctic and the associated global scale ramifications this has for disastrous and unmanageable climate change and ocean acidification. It also details the essential mitigation actions that must be taken if we are to avoid this fate. It's these realities that are the catalyst for our community's Pole2Pole campaign.

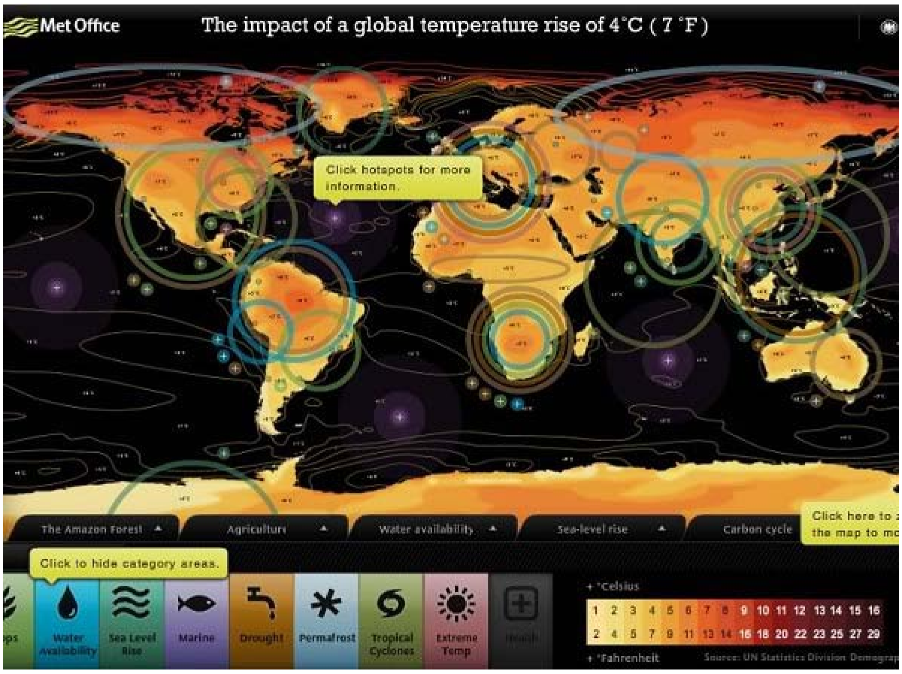

Figure 15. This 4°C average global warming map shows the far higher regional warming that the polar regions would be subjected to (AVOID 2009). High resolution and interactive versions of this map can be obtained from the UK Met Office www./climate-change/guide/impacts/high-end/map

3.2 Resolution 67.2 (WAZA Annual Conference, Melbourne 11 October 2012)

Emergency resolution on avoiding disastrous and unmanageable climate change and ocean acidification impacts by returning atmospheric CO_2 concentrations to below 350 parts per million while it is still possible to do so:

RECOGNIZING NASA's confirmation (27 August 2012) that Arctic sea ice has shrunk to a new low in the era of detailed satellite observations as further evidence that atmospheric concentrations of carbon dioxide (CO_2) have already exceeded their safe planetary boundary;

CONCERNED that climate system inertia is masking the true impact of current CO_2 levels and the amplifying feedback effects they are already starting to generate;

ALARMED that their combined impacts will include unstoppable disintegration of sea ice, ice-sheets and mountain glaciers with resultant dangerous sea level rise and greatly reduced freshwater supplies; thawing and release of frozen carbon and methane hydrates; ocean acidification; shifting climate zones; extreme weather events and mass biodiversity extinctions with profound consequences for humanity;

RECOGNISING that the essential mitigation actions are a linear phase-out of coal emissions by 2030; avoiding emissions from 'hard to reach' conventional oil and gas reserves, avoiding emissions of oil shale, tar sands and other unconventional fossil fuels and reducing current atmospheric CO_2 concentrations to below 350 parts per million (ppm), especially through reversing the destruction and degradation of natural habitats and the negative net impact of agricultural practices;

FURTHER RECOGNISING that the fate of biodiversity and humanity is dependent on these dangers and mitigation imperatives being acknowledged and effectively addressed;

Therefore
REQUESTS all WAZA members to:

- Actively reduce CO_2 emissions wherever possible and, where it is not possible, to compensate for via best practice habitat support initiatives.
- Call on world leaders to avoid disastrous and unmanageable climate change and ocean acidification impacts by implementing the essential mitigation actions detailed in this emergency resolution for curtailing further growth of CO_2 emissions and returning atmospheric CO_2 concentrations to below 350ppm while it is still possible to do so.
- Prioritise awareness raising and visitor engagement focus on these threat and response issues.

Supporting information to emergency WAZA resolution 67.2

WAZA statements and resolutions Climate change has been addressed principally by RES 49.1 at the 49th Annual Conference held in Sao Paulo, 1994, by RES 61.4 at the 61st Annual WAZA Conference, held in Leipzig, 2006 and the pre COP-15 communication to world leaders, via UN Secretary General in December 2009; WAZA Climate change position statement and supporting resolution 65.1 at the 65th annual WAZA conference, 22 October 2010 http://www.waza.org/en/site/conservation/climate-change

NASA (27 August 2012) Arctic sea ice shrinks to new low in satellite era http://www.nasa.gov/topics/earth/features/arctic-seaice-2012.html

National Snow and Ice Data Center (NISDC) August 27 2012 Arctic Sea Ice News & Analysis http://nsidc.org/arcticseaicenews/

AMAP, 2011. Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xii + 538 pp. http://amap.no/swipa/. With briefing video: http://www.youtube.com/watch?v=RTF2Ll9g_W4mm

Arctic summer sea ice tipping point. 2011 Video briefing featuring Dr's Ted Scambos, Robbie Macdonald, Don Perovich, Mark Serreze and Vladimir Romanovsky. http://vimeo.com/34547995

Anthony et al (2012) Geologic methane seeps along boundaries of Arctic permafrost thaw and melting glaciers. Nature Geoscience 5: 419-426. http://www.nature.com/ngeo/journal/v5/n6/full/ngeo1480.html

Barnosky et al (2012) Approaching a state shift in Earth's biosphere. Nature 486: 52-58. http://www.nature.com/nature /journal/v486/n7401/full/nature11018.html

DeConto et al (2012) Past extreme warming events linked to massive carbon release from thawing permafrost. Nature 484: 87-91. http://www.nature.com/nature/journal/v484/n7392/full/nature10929.htm

Duarte et al (2012) Abrupt Climate Change in the Arctic. Nature Climate Change 2: 60–62. http://www.nature.com/nclimate/journal/v2/n2/full/nclimate1386.html

Hansen et al (Submitted) Scientific Case for Avoiding Dangerous Climate Change to Protect young People and Nature. Proc. Natl. Acad. Sci. http://pubs.giss.nasa.gov/abs/ha08510t.html

Hansen et al (2011) Earth's energy imbalance and implications Atmos. Chem. Phys., 11, 13421-13449 http://www.atmos-chem-phys.net/11/13421/2011/acp-11-13421-2011.html

Kort et al (2012) Atmospheric observations of Arctic Ocean methane emissions up to 82° north. Nature Geoscience http://www.nature.com/ngeo/journal/vaop/ncurrent/full/ngeo1452.html

Koven et al (2011) Permafrost carbon-climate feedbacks accelerate global warming. PNAS http://www.pnas.org/content/early/2011/08/17/1103910108.full.pdf

Isaksen, et al (2011), Strong atmospheric chemistry feedback to climate warming from Arctic methane emissions, Global Biogeochem. Cycles, 25, GB2002,
http://www.atmos.washington.edu/academics/classes/2011Q2/558/IsaksenGB2011.pdfV

Veron, J.E.N. (2011) Ocean Acidification and coral reefs: An emerging big picture. Diversity 2011, 3, 262-274
http://www.mdpi.com/1424-2818/3/2/262/pdf

An Iterative Reference List of Climate Change Science, Policy & Related Information. World Association of Zoos and Aquariums, Botanic Gardens Conservation International, Zoological Society of London and IUCN's Conservation Breeding Specialist Group and Climate Change Specialist Group.
http://www.waza.org/en/site/conservation/climate-change

3. Definitions of technical terms used in this chapter or likely to be encountered when engaging with polar threat issues:

NB. Unless otherwise stated, have been taken from the IPCC Fourth Assessment Report.

Abrupt change: *The nonlinearity of the climate system may lead to abrupt climate change, sometimes called rapid climate change, abrupt events or even surprises. The term abrupt often refers to time scales faster than the typical time scale of the responsible forcing. However, not all abrupt climate changes need be externally forced. Some possible abrupt events that have been proposed include a dramatic reorganisation of the thermohaline circulation, rapid deglaciation and massive melting of permafrost or increases in soil respiration leading to fast changes in the carbon cycle. Others may be truly unexpected, resulting from a strong, rapidly changing forcing of a nonlinear system.*

Albedo: *The fraction of solar radiation reflected by a surface or object, often expressed as a percentage. Snow-covered surfaces have a high albedo, the surface albedo of soils ranges from high to low, and vegetation-covered surfaces and oceans have a low albedo. The Earth's planetary albedo varies mainly through varying cloudiness snow, ice, leaf area and land cover changes.*

Albedo feedback: *A climate feedback involving changes in the albedo (~0.3). In a warming climate, it is anticipated that the cryosphere would shrink, the Earth's overall alb Earth's albedo. It usually refers to changes in the cryosphere, which has an albedo much larger (~0.8) than the average planetary edo would decrease and more solar radiation would be absorbed to warm the Earth still further.*

Anthropogenic: *Resulting from or produced by human beings.*

Adaptation: *Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished including anticipatory, autonomous and planned adaptation.*

Biomass: *The total mass of living organisms in a given area or volume; dead plant material can be included as dead biomass.*

Carbon dioxide (CO2): *A naturally occurring gas, also a by-product of burning fossil fuels from fossil carbon deposits, such as oil, gas and coal, of burning biomass and of land use changes and other industrial processes. It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured and therefore has a Global Warming Potential of 1.*

Climate change: *Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for* *an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes. See also Climate variability; Detection and Attribution.*

Climate variability: *Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).*

Cryosphere: *The component of the climate system consisting of all snow, ice and frozen ground (including permafrost) on and beneath the surface of the Earth and ocean.*

Ecosystem: *A system of living organisms interacting with each other and their physical environment. The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of interest or study. Thus, the extent of an ecosystem may range from very small spatial scales to, ultimately, the entire Earth.*

Extreme weather: *An extreme weather event is an event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of the observed probability density function. By defi nition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. Single extreme events cannot be simply and directly attributed to anthropogenic climate change, as there is always a finite chance the event in question might have occurred naturally. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season).*

Equilibrium line *The boundary between the region on a glacier where there is a net annual loss of ice mass (ablation area) and that where there is a net annual gain (accumulation area). The altitude of this boundary is referred to as equilibrium line altitude.*

Feedback: *An interaction mechanism between processes is called a feedback. When the result of an initial process triggers changes in a second process that in turn influences the initial one. A positive feedback intensifies the original process, and a negative feedback reduces it.*

Food web: *A network of trophic relationships within an ecological community involving several interconnected food chains.*

Glacier: *A mass of land ice flowing downhill (by internal deformation and sliding at the base) and constrained by the surrounding topogaraphy (e.g. the sides of a valley or surrounding peaks). A glacier is maintained by accumulation of snow at high altitudes, balanced by melting at low altitudes or discharged into the sea.*

Global warming: *The gradual increase, observed or projected, in global surface temperature, as one of the consequences of radiative forcing caused by anthropogenic emissions.*

Greenhouse effect: *Greenhouse gases effectively absorb thermal infrared radiation, emitted by the Earth's surface, by the atmosphere itself due to the same gases, and by clouds. Atmospheric radiation is emitted to all sides, including downward to the Earth's surface. Thus, greenhouse gases trap heat within the surface-troposphere system. This is called the greenhouse effect. Thermal infrared radiation in the troposphere is strongly coupled to the temperature of the atmosphere at the altitude at which it is emitted. In the troposphere, the temperature generally decreases with height. Effectively, infrared radiation emitted to space originates from an altitude with a temperature of, on average, –19°C, in balance with the net incoming solar radiation, whereas the Earth's surface is kept at a much higher temperature of, on average, +14°C. An increase in the concentration of greenhouse gases leads to an increased infrared opacity of the atmosphere, and therefore to an effective radiation into space from a higher altitude at a lower temperature. This causes a radiative forcing that leads to an enhancement of the greenhouse effect, the so-called enhanced greenhouse effect.*

Habitat: The locality or natural home in a particular plant, animal, or group of closely associated organisms lives.

Hydrosphere: *The component of the climate system comprising liquid surface and subterranean water, such as oceans, seas, rivers, fresh water lakes, underground water, etc.*

Ice cap: *A dome shaped ice mass, usually covering a highland area, which is considerably smaller in extent than an ice sheet.*

Ice Sheet: *A mass of land ice that is sufficiently deep to cover most of the underlying bedrock topography, so that its shape is mainly determined by its dynamics (the flow of the ice as it deforms internally and/or slides at its base). An ice sheet flows outward from a high central ice plateau with a small average surface slope. The margins usually slope more steeply, and most ice is discharged through fast-fl owing ice streams or outlet glaciers, in some cases into the sea or into ice shelves floating on the sea. There are only three large ice sheets in the modern world, one on Greenland and two on Antarctica, the East and West Antarctic Ice Sheets, divided by the Transantarctic Mountains. During glacial periods there were others.*

Ice shelf: *A floating slab of ice of considerable thickness extending from the coast (usually of great horizontal extent with a level or gently sloping surface), often filling embayments in the coastline of the ice sheets. Nearly all ice shelves are in Antarctica, where most of the ice discharged seaward flows into ice shelves.*

Invasive species: *A species aggressively expanding its range and population density into a region in which it is not native, often through outcompeting or otherwise dominating native species.*

Mitigation: *An anthropogenic intervention to reduce the anthropogenic forcing of the climate system; it includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks.*

Mass balance (of glaciers, ice caps or ice sheets): *The balance between the mass input to the ice body (accumulation) and the mass loss (ablation, iceberg calving).*

Ocean acidification: *Increased concentrations of CO_2 in sea water causing a measurable increase in acidity (i.e., a reduction in ocean pH). This may lead to reduced calcification rates of calcifying organisms such as corals, mollusks, algae and crustacea.*

Permafrost: *Ground (soil or rock including ice and organic material) that remains at or below 0°C for at least two consecutive years (Van Everdingen, 1998).*

pH: *pH is a dimensionless measure of the acidity of water (or any solution) given by its concentration of hydrogen ions (H+). pH is measured on a logarithmic scale where pH = –log10(H+). Thus, a pH decrease of 1 unit corresponds to a 10-fold increase in the concentration of H+, or acidity.*

Relative sea level: *Sea level measured by a tide gauge with respect to the land upon which it is situated. Mean sea level is normally defined as the average relative sea level over a period, such as a month or a year, long enough to average out transients such as waves and tides.*

Sea Ice: *Any form of ice found at sea that has originated from the freezing of sea water. Sea ice may be discontinuous pieces (ice floes) moved on the ocean surface by wind and currents (pack ice), or a motionless sheet attached to the coast (land fast ice). Sea ice less than one year old is first year ice. Multiyear ice is sea ice that has survived one summer melt season.*

Sea level change: *Sea level can change, both globally and locally, due to (i) changes in the shape of the ocean basins, (ii) changes in the total mass of water and (iii) changes in water density. Sea level changes induced by changes in water density are called steric. Density changes induced by temperature changes only are called thermosteric, while density changes induced by salinity changes are called halosteric.*

Sea level equivalent: *The change in global average sea level that would occur if a given amount of water or ice were added to or removed from the oceans.*

Sea surface temperature: *The sea surface temperature is the temperature of the subsurface bulk temperature in the top few metres of the ocean, measured by ships, buoys and drifters. From ships, measurements of water samples in buckets were mostly switched in the 1940s to samples from engine intake water. Satellite measurements of skin temperature (uppermost layer; a fraction of a millimetre thick) in the infrared or the top centimetre or so in the microwave are also used, but must be adjusted to be compatible with the bulk temperature.*

Sea ice: *Any form of ice found at sea that has originated from the freezing of seawater. Sea ice may be discontinuous pieces (ice floes) moved on the ocean surface by wind and currents (pack ice), or a motionless sheet attached to the coast (land-fast ice). Sea ice less than one year old is called first-year ice. Multi-year ice is sea ice that has survived at least one summer melt season.*

Sensitivity: *The degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g. a change in crop yield in response to a change in the mean range or variability of temperature) or indirect (e.g. damages caused by an increase in frequency of coastal flooding due to sea-level rise).*

Snow line: *The lower limit of permanent snow cover, below which snow does not accumulate.*

Tipping point: *A climate tipping point occurs when a small change in forcing triggers a strongly nonlinear response in the internal dynamics of part of the climate system, qualitatively changing its future state (Lenton, 2011).*

Greenhouse gases:
Greenhouse gases act like a blanket. They absorb energy from the sun that is reflected by the Earth's surface and slow down or prevent the loss of heat to space. The result of this is that Earth gets warmer than it would otherwise be. This process is known as the "greenhouse effect". Without the natural Greenhouse effect live on Earth would not be possible. However, it's the additional greenhouse gases that humans have very rapidly added to the atmosphere that are responsible for increasing the natural warming effect of these gases out of balance. The main greenhouse gases emitted by human activity are:

Carbon dioxide (CO_2) *- Fossil fuel use is the primary source of CO_2. The way in which people use land is also an important source of CO_2, especially when it involves deforestation. Land can also remove CO_2 from the atmosphere through reforestation, improvement of soils, and other activities.*
Methane (CH_4) *- Agricultural activities, waste management, and energy use all contribute to CH_4 emissions.*
Nitrous oxide (N_2O) *- Agricultural activities, such as fertilizer use, are the primary source of N_2O emissions.*
Fluorinated gases (F-gases) *- Industrial processes, refrigeration, and the use of a variety of consumer products contribute to emissions of F-gases, which include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).*

Of these gasses it is the additional carbon dioxide levels since the Industrial Revolution that are responsible for the greatest amount of additional global warming.

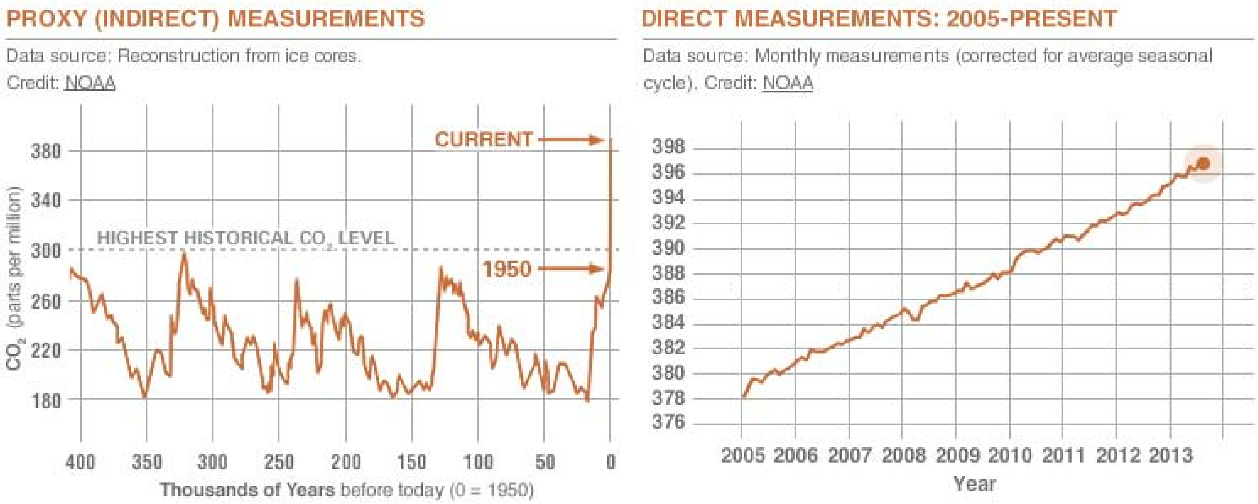

Figure 16. Carbon dioxide (CO2) is an important heat-trapping (greenhouse) gas, which is released through human activities such as deforestation and burning fossil fuels, as well as natural processes such as respiration and volcanic eruptions. The chart on the left shows the CO2 levels in the Earth's atmosphere during the last three glacial cycles, as reconstructed from ice cores. The chart on the right shows CO2 levels in recent years, corrected for average seasonal cycles. NASA http://climate.nasa.gov/key_indicators

Read more:
http://www.epa.gov/climatechange/ghgemissions/global.html
http://www.ipcc.ch/publications_and_data/ar4/syr/en/spm.html

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5. Helpful Web site resources

Climate Literacy Zoo Education Network (CliZEN) http://www.clizen.org/
Met Office Hadley Centre http://www.metoffice.gov.uk/climate-change/resources/hadley
NASA http://climate.nasa.gov/

National Snow and Ice Data Centre (NISDC) http://nsidc.org/

NOAA: The Essential Principles of Climate Literacy http://www.climate.gov/teaching/teaching-climate-literacy-and-energy-awareness

6. Helpful video briefings

Arctic summer sea ice tipping point. 2011 Video briefing featuring Dr's Ted Scambos, Robbie Macdonald, Don Perovich, Mark Serreze and Vladimir Romanovsky. http://vimeo.com/34547995

James Hansen: Why I must speak out about climate: http://www.ted.com/talks/james_hansen_why_i_must_speak_out_about_climate_change.html

Interview With Professor Peter Wadhams - Climate Change Series
http://www.youtube.com/watch?v=_biGUz6ACBg

Major feedbacks of Arctic Global Warming: Peter Carter (2011) Arctic global warming feedback briefing. Video posting http://vimeo.com/30474470

Major feedbacks on climate via the cryosphere: AMAP. (2011) Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. Xii + 538pp. http://amap.no/swipa/CombinedReport.pdf; Chapter 11.1.3; p 11- 14

NOAA Ocean Acidification - The Other Carbon Dioxide Problem http://www.youtube.com/watch?v=MgdlAt4CR-4

Richard Feely - Ocean Acidification: Trouble for Ocean Ecosystems http://www.youtube.com/watch?v=7WeeBgnuvag

Rob Dunbar: The threat of ocean acidification http://www.youtube.com/watch?v=evfgbVjb688