Final report

Glaciers

A Survival Guide for Climate Conversation

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Figure 1: Alaskan Glacier calving into the Ocean. [Robert H. Zakon, 2003]
1 Introduction

The climate and therefore earth’s temperatures have always varied significantly in the past. Ice ages and warm phases have followed each other for hundred thousands of years. Therefore, ice coverage of the earth has varied a lot as well. While during the last ice age, the earth was covered with kilometers of ice sheets down to nowadays moderate climate zones such as the U.S. and central Europe, today only about 10% of the earth’s surface is covered with ice - and its melting even more. This time, the melting is not due to natural variations in the climate, but due to an anthropogenic warming.

2 Overview

Various different kinds of glaciers exist. They are largely divided into two subgroups: alpine glaciers, which are found in mountainous regions and move downwards due to gravity, and continental glaciers, which cover large areas of continents at high latitudes. The largest glaciers on earth are continental glaciers located around the poles. Around the South Pole, the landmass of the Antarctica is covered with kilometers of ice and snow, while at the North Pole, there is no land mass, but the ocean is covered with a layer of ice. However large ice covers on land masses such as Greenland and Alaska account for the largest glaciers in the northern hemisphere. Additionally, high mountains all over the earth are still covered with the typically smaller kind of glaciers, the mountain glacier. These kinds of glaciers can be found on all the continents except for Australia. They can be subdivided into valley glaciers (glaciers covering mountain valleys), ice caps which cover entire mountains, plateau glaciers which cover plateaus at high altitudes and tidewater glaciers (glaciers that flow into the sea and create flows of icebergs).

Glaciers are of great benefit to humans: in the temperate regions, they are used as a source and storage of drinking water. During the warm season, when the rivers generally provide less water due to less rainfall, the enhanced melting of the glaciers regulates the water supply. Glaciers are - due to their impressive appearance - a large source of income for many countries in terms of tourism and all year long ski industry. Glaciers also provide benefit to natural science: ice cores can be drilled from glaciers and earth’s history can be reconstructed thousands of years back in time.

However, glaciers are melting due to climate change.

3 Evidences and future scenarios

3.1 Meltdown of Artic sea ice cover

Figure 2: Comparison of two views of the Arctic in 1979 and in 2003. The two figures show September sea ice area, which corresponds to the annual sea ice minimum after summer melting. Over this 24-year period, sea ice has retreated and thinned significantly. [ACIA report, 2004, p.25]

Using satellite data, scientists have observed unusually warm wintertime temperatures in the Artic and a resulting decline in the length of the Arctic ice season (Comiso, 2006). The maximum amount of
sea ice cover in the Arctic winter has fallen by six percent over each of the last two winters, as compared to a loss of merely 1.5 percent per decade on average annually since the earliest satellite monitoring in 1979. This is happening as summer sea ice continues its retreat at an average of ten percent per decade. In the past, sea ice reduction in winter was significantly lower per decade compared to summer sea ice retreat (Comiso, 2006).

### 3.2 Greenland and Antarctica

These two regions are covered by the only continental glaciers on earth. Also for these large ice sheets, there is scientific evidence for their meltdown. The total volume of the Antarctic and Greenland ice sheets adds up to 33 million cubic kilometers of ice, which corresponds to about 70m of sea level rise. A sensitive balance between snowfall and runoff of melt water has established and any disturbance of this balance can lead to major changes. While Greenland is affected by nearby land masses and the Gulf stream in the Atlantic ocean, the Antarctica is not much influenced by its surroundings. A mass balance for such large amounts of ice as in the Antarctica are difficult to perform, but scientists concluded by methods of remote sensing, that the total ice volume loss in West Antarctica is about $-48\text{km}^3/\text{year}$, while East Antarctica gains about $22\text{km}^3/\text{year}$. Greenland managed to accumulate enough mass in its center from 1992 to 2002 so it could account for its mass loss at the edges (Figure 2). However during the last few years, even the mass balance of the glacier covering Greenland is negative due to the massive thinning at the coasts, accounting for an annual sea level rise of at least 0.13mm/year (Rignot and Thomas, 2002). Other estimates lead to values of $0.3 \pm 0.15 \text{mm year}^{-1} \text{K}^{-1}$ (Gregory and Oerlemans, 1998).

![Figure 3: Comparison of two views of Greenland in 1992 and in 2002. The red area shows the ice sheet area at the edges which has melted during this period. [ACIA report, 2004, p.40]](image)

### 3.3 Two examples of mountain glacier retreat

#### 3.3.1 Switzerland

Glacier mountains are prone to melting since they are located in relatively warm climate zones. Although they grow due to snowfall in their accumulation zones and they flow downwards due to gravity, almost all of them shrink in length and mass every year. It is estimated that all alpine glaciers will have melted within 70 to 100 years. As an example, Figure 3 shows Grosser Aletschgletscher in the Swiss alps. This glacier has been of scientific interest for a long time as it is the largest alpine glacier. Measurements of
Figure 4: Comparison of two views of *Grosser Aletschgletscher* in the Swiss Alps around 1900 and in 2005. An extreme loss in length and mass can be seen. The glacier loses around 50m in length and more than 2m in thickness per year. [gletscherarchiv.de]
length and mass reduction have been performed for more than 100 years on about 120 glaciers located within the Alps. Figure 3 shows a comparison of a view around 1900 and one in 2005, which shows the massive reduction in length during this period. The glacier retreats at a rate of about 50 m per year and loses in thickness by about 2 to 2.5 m/year, which are average values compared to other mountain glaciers within the next 10 years, 20% of all alpine glaciers will have melted, even, melt water from glaciers does not immediately flow down into the valleys, but builds lakes within the mountains, which can result in sudden outbreaks of large amounts of water into the valley. The function as a water regulating system, which the glaciers fulfilled for many years, has turned into a potential danger for people downstream.

3.3.2 Colombia

Colombian mountain glaciers are vanishing. Even though this country is responsible for only 0.25% of the total global emissions of carbon dioxide to the atmosphere, it has been considered as one of those nations particularly vulnerable to the negative impacts of global climate change (Colombian Institute of Hydrology, Meteorology and Environmental Studies -IDEAM-, 2002). By 2050 it is expected that 78% of Colombian glaciers will be seriously affected by increases in temperature. The Nevado del Ruiz (5,321 m, Andes Central mountain range), for instance, has experienced a dramatic loss of its cap since 1850, reaching almost 70% of the ice-covered area. In 1976, the El Ruiz supported an ice cap that had an area of 21.3 km² according to LANDSAT images. The snowline was by then at an altitude of 4,900 m on its west flank and 4,800 m on the east flank. By comparison between 19th century paintings of the west flank and recent photographs, it was estimated that the retreat of the margins of the ice cap was almost 150 m, equivalent to shrinkage of 64% from the area in 1845. Between 1986 and 1995, the average retreat rate of the glacier reached 3-4 m/year, which amounts to 20-30 m in elevation, even though faster retreat was noted on individual glaciers. In 2002, the IDEAM estimated that the ice cap was reduced to 9.3 km². In early 2006, the snowline of El Ruiz reached an altitude of 5,128 m on its west flank (Ruiz et al., 2006).

The Nevado de Santa Isabel (5,110 m, also located in the Andes Central mountain range) had in 1976 an ice-cap of 10.8 km², with a snowline at 4,800 m on its W flank and 4,700 m on its E flank. Since 1986 the Santa Isabel has undergone a similar but more moderate increase in loss of its snowfield area compared to the El Ruiz. The snowline has risen 10-15 m in the period 1986-1994. In 2002, the Santa Isabel supported an ice cap of 5.3 km² (IDEAM, 2002). Based on fixed points deployed by the IDEAM, Ruiz et al. (2006) suggested that the average retreat rate has increased dramatically over the past 15 years. From Feb/1990 through Nov/2001, the retreat rate reached 1.3 m/month; from Nov/2001 through Feb/2003, it reached 1.7 m/month; from Feb/2003 through Mar/2006 it was 2.1 m/month. Presumably, recent retreat rate exceeds 2.7 m/month. The snow-and-ice cover area is now less than 5 km² (Ruiz et al., 2006).

As a concomitant/coupling consequence, increases of 0.3°C and decreases in monthly rainfall of 2-3 mm have been observed in the area per decade (WBG, 2006). The major concern regards the future impacts on high mountain ecosystems. The central mountain range of the Andes in this country is host to the largest stretch of moorland habitats in the planet. These fragile ecosystems have unique endemic flora, and serve as important reservoirs of water. In the future, it is expected that 56

4 Potential impacts

Perhaps the most important potential impact of the reduction of continental glaciers is sea level rise, even though some authors suggest that marine animals are becoming now seriously affected. The most significant effect of the retreat of mountain glaciers is possibly the dramatic loss of environmental goods and services.

4.1 Sea level rise

The two processes responsible for global sea level rise (GSLR) are volume increase and mass change (Miller and Douglas, 2004). Indirect estimates based on the volume increase due to ocean warming suggest a
rate of the twentieth-century GSLR of about 0.5 mm/yr. The rate due to mass change, primarily from the melting of continental ice, was initially thought to be smaller. However, direct estimates from tide gauges, which include both volume and mass changes, suggested a GSLR equal to 1.5-2.0 mm/yr (1.0-1.5 mm/yr greater than rates due to volume increase). Combined analysis of sea level measurements at tide gauges and observations of temperature and salinity in the Pacific and Atlantic oceans supported the 1.5-2.0 mm/yr rate, and suggested that mass increase plays a larger role than ocean warming in twentieth-century GSLR. Antonov et al. (2002) calculated that the oceans are freshening at a rate equivalent to the addition of 1.4 mm/yr of fresh water. There is now ample evidence that changes in ocean volume due to temperature and salinity account for only a fraction of sea level change, and that mass change plays a dominant role in twentieth-century GSLR (Miller and Douglas, 2004). Several evidences support this conclusion:

- Linear regression on smoothed dynamic heights, which reflect only volume changes, indicates an upward trend of 0.5 mm/yr between 1932 and 1997 in the Eastern Pacific region, and of 0.2 mm/yr between 1911 and 1998 in the Eastern North Atlantic (Miller and Douglas, 2004).

- Gauge records in Honolulu, San Francisco, San Diego, and Balboa (Panama) in the Eastern Pacific region show trends of 2 mm/yr during the twentieth century. Gauge records in Cascais (Portugal) and Tenerife (Canary Islands) in the Eastern North Atlantic show sea level trends of 2.1 and 1.9 mm/yr, respectively (Miller and Douglas, 2004). Finally, gauge records in the SlopeWater region, Western North Atlantic, north of the Gulf Stream and East of the tide gauge sites at Boston, Portland and Halifax, exhibit sea level trends of 1.9 mm/yr from 19311996.

- Results from each local area in the Eastern Pacific support the conclusion that twentieth-century sea level rose at a rate several times higher than can be accounted for by volume (temperature and salinity) changes alone (Miller and Douglas, 2004).

- Finally, results are consistent with ongoing satellite altimeter determinations of sea level variability (Ducet et al., 2002).

4.2 Loss of marine biodiversity

Seasonal ice regions in the Arctic are among the most biologically productive places in the world. If the retreat of the Arctic winter ice cover continues, marine animals will be profoundly affected (Volpi and Miller, 2006). Sea ice provides melt-water in spring that constitutes an ideal layer for phytoplankton growth, because it does not sink and there is plenty of sunlight reaching it to enable photosynthesis. If the concentration of plankton goes down, animals at all trophic levels would be deprived of a basic source of food.

4.3 Loss of environmental goods and services, and impact on human health

The health of a population, if is to be maintained in a sustainable state (King, 1990; Martens, 1997), requires the continued support of, among others, safe water and high levels of biodiversity. Unfortunately, it has not been properly recognized that biodiversity influences human well-being through its effects on the ecosystem processes that lay at the core of the Earth’s most vital life support systems (Diaz et al., 2006). The well-being of human societies is based on the sustained delivery of fundamental ecosystem services, such as the regulation of the quality and quantity of water supply, and the security in the face of future environmental change (Diaz et al., 2006). Regrettably, the consequences of biodiversity loss will be felt disproportionately by the poor, who are the most vulnerable to the loss of ecosystem services (WRI, 2005).

The icecaps of mountain glaciers feed high altitude lagoons and permanent water-reservoir habitats, which contribute to the headwaters that are currently used by lowland populations to satisfy the water demand. As an example, Central Europe was profiting from glacial melt water during the drought in Summer 2003 which due to an increase in melting. Additionally, the retreat of mountain glaciers would result in a dramatic loss of biodiversity and environmental goods and services provided by these habitats, especially water supply and basin regulation (Ruiz, 2006). Turberas are mainly colonized
by mountain species with narrow habitat tolerance and low dispersal capacity, and are likely to be at high risk from the environmental effects of climate change. Agriculture, livestock grazing, and local climate anomalies related to land use changes are also threatening the existence of these fragile reservoirs.

Figure 5: Photographs of permanent water-reservoir habitats (turberas) in the headwaters of Alfombrales Creek (top left), Claro River (top right and bottom left), and Sietecuerales Creek (bottom right), in the Los Nevados Natural Park, Andean central mountain range, Colombia. The first three turberas still receive water supply from mountain ice caps and high altitude lagoons. The Sietecuerales turbera used to receive supply from El Cisne ice-capped mountain, which disappeared in the last decade. The abovementioned streams are funneled into one major river, the Claro River, in which the mean daily discharge has decreased from almost 6.7 m³/s in early 1990 to less than 1.0 m³/s by the end of 1993 (increasing water use must be also considered) (Ruiz et al., 2006).
5 Take home points

- Glaciers and ice sheets are located in the polar regions and high mountainous areas.
- Glaciers all over the world are in a process of accelerated meltdown, which can be fully attributed to human impacts.
- Consequences of glacial melting are most importantly sea level rise, but also loss of marine biodiversity as well as the environmental services that are provided by glaciers such as storage of water.

Figure 6: Glacier in Alaska calving, where pieces of the glacier break away and fall into the ocean. [princewilliamsoundcruises.com]
6 References

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