Climate Change and the Skiing Industry: Impacts and Potential Responses

by Stefan Walter

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Abstract

The global climate is expected to change significantly within a few decades, exemplified by a temperature increase and change in precipitation patterns. The resulting alterations in glacier mass balance and snow cover depth, distribution, and length of snow season have large effects on regional economies in alpine areas that have specialised in the provision of services for tourists exercising winter sports. Most glaciers worldwide are subject to retreat. Reasons for retreat include anthropogenic global warming and natural climatic variability. Some maritime glaciers are in advance due to favourable precipitation trends. It is projected that half of the alpine glaciers will have disappeared at the end of the century. This and the increasing unreliability of snow cover may lead to a decrease in visitors and to increased costs to maintain the existing ski runs artificially. A decreasing number of visitors may benefit mountain ecosystems, which suffer large impact from skiing. It also opens up possibilities for ecological recovery. Primary impacts of skiing include destruction of vegetation and alteration of soil properties. Secondary impacts include the amount of traffic and increasing urbanisation due to housing and infrastructure development. Considering the economic importance of tourism and winter sports it is possible that the industry will attempt to adapt to changing conditions and also search for new destinations that provide climatic reliability in the long term.

1.0 Introduction

There is growing consensus among scientists that the climate is likely to change in the decades to come. The earth's cryosphere is anticipated to be among the areas most impacted by climate change through global warming in the next century. This is due to the expected change of two of the major elements of the climate that determine extent and characteristic of the cryosphere's system components, temperature and precipitation. According to the latest Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) the increase in temperature is projected to be between 1.4° C and 5.8° C over the period 1990 to 2100. This temperature increase is much larger than the increase during the 20th century and palaeoclimatic data suggests that this increase is without any precedent in the last 10000 years of earth history (IPCC, 2001b). The increase in temperature exceeds even the change caused by changes in the thermohaline circulation, which is projected to weaken and to reduce the heat transported to northern latitudes, in Europe via the North Atlantic Drift. Simulations further suggest that the global amount of water vapour and precipitation will increase. For the second half of the 21th century it is likely that winter precipitation will increase in northern high latitudes and in Antarctica (IPCC, 2001b). Nevertheless, glacial snow cover is likely to retreat further in the next 100 years due to the fact that runoff from glaciers and ice sheets, e.g. Greenland, is higher than the increase in precipitation.

Declining glacier mass and snow cover length have tremendous socio-economic impacts, on local, regional, as well as on national level. Tourism, besides having a significant ecological impact potential, is on a global scale one of the most important industries. It accounts for a total turnover of about $478 billion in 2000 and appears, thus, in the top five industries of 68 per cent of all countries and is the top industry in 38 per cent (United Nations Environment Programme (UNEP), 2001). Tourism is expected to grow by four per cent per annum over the next five years (UNEP, 1999). The Alpine share of global tourism is estimated to be around ten per cent, i.e. 120 million visitors a year (British Broadcasting Corporation, 2001). The large economic output of winter tourism and skiing activities forms consequently an incentive to develop new possibilities and to possibly search for new alternative locations for skiing tourism on a larger scale. Sport activities can be described as belonging to both, tourism and recreation, as sport can be the main purpose of a holiday, for example skiing. For simplicity, recreation is defined here as being associated with activities that have no cash value, and is therefore not considered in the analysis of socio-economic impacts. However, concerning environmental impacts no differences are made between skiing exercised as part of a holiday or leisure time since the overall environmental impacts from skiing can be considered the same.

The paper aims to show the relationship between tourism and the environment, and the impacts of skiing on the natural environment. Moreover, it reviews the impact of global warming on glaciers and snow cover. Finally, the paper analyses the socio-economic impact of global warming on alpine communities concerned with skiing activities and shows potential adaptations and responses of the skiing industry.

2.0 Impacts of skiing on the natural environment

2.1 Relationship of tourism with the environment

Tourism has environmental impacts that are similar to any other industry. Considering its importance on a global scale, the impacts on the environment can be tremendous. These impacts include the exploitation of natural resources, the pressures on wildlife and habitats, the creation of pollution and wastes and pressures on the local population due to overuse of local resources.

2.1.1 Systems approach

From an environmental system's perspective negative impacts occur when the number of visitors is larger than the carrying capacity of the system, i.e. the ability of the system to cope with its use. Therefore, uncontrolled tourism poses the major potential threat to nature (UNEP, 2001).

2.1.2 Natural resources

The increased construction of infrastructure and housing for tourism creates pressure on both, renewable and non-renewable resources, which include fossil fuels, minerals, fertile soil, or forests. Water, in particular freshwater, belongs to the most critical resources. There is often an overuse of water for hotels and personal consumption due to the tendency of tourists to use more water when on holiday than at home. Tourism can also create pressure on local resources that may be already in short supply, including energy, food or certain raw materials. The high demand of such resources is due to meet the often high expectations of tourists, for example proper heating (UNEP, 2001).

2.1.3 Biological resources

Any kind of outdoor activity may bring about stress to animals and may even alter their behaviour, for example, neglecting their young (UNEP, 2001). Developments that take place for tourism result in large clearances of vegetation. In some areas there might be a higher demand for fuelwood due to tourism, which in turn results in forest clearances. Trampling may result in a decrease of soil organic matter, increased permeability and, consequently, higher runoff, and accelerated soil erosion. This eventually leads to a loss of biodiversity. Impacts are largest in ecosystems that are very fragile to which the mountain environment also belongs.

2.1.4 Pollution and wastes

Where there are many tourists waste generation and proper disposal is a significant problem. In areas where there is no way of waste disposal nature can be misused as a waste dump, and, consequently, this may lead to distraction of scenery and habitats. The high consumption of freshwater results in large amounts of wastewater being generated. Air pollution is, for instance, the result of extensive tourist transportation systems on local and global level. The generated carbon dioxide that contributes to global warming also stems from widely used air conditioning and heating systems. Stress to wildlife as well as to humans is caused by increasing noise pollution generated by modern transport systems, including cars, airplanes, and snowmobiles (UNEP, 2001).

2.1.5 Environmental threats to tourism

A change in climate alters eventually the landscape, e.g. snow cover may decrease, new ecosystems may establish with a loss or shift in biodiversity, which in turn may change the attractiveness of an area for tourism (Weller and Lange, 1999). Water and air pollution can additionally alter the amenity of a certain area and at least part of this impact might be due to tourism itself.

2.1.6 Positive aspects of tourism

Tourism can directly contribute to efforts made in conserving the environment. Park entrance fees and similar sources can be allocated to finance the management of environmentally sensitive areas. In a similar way, licenses for hunting and fishing can increase the government's revenue to finance environmental management. Environmentally sound management of tourist facilities can also benefit the natural and, thus, economic value of an area. Finally, tourism brings people close to nature and, therefore, can increase the awareness for environmental problems, which may eventually lead to an environmentally conscious behaviour (UNEP, 2001).

2.2 Impacts of large scale skiing in mountain regions

It is difficult to quantify impacts from specific sport activities. In general, activities related to sport cause impacts in fields such as soil erosion and change in nutritional status of soil, vegetational destruction, disturbance to wildlife and humans, pollution, and alteration of land and scenery.

2.2.1 Complexity of ecosystem

Haslett (1997) writes that mountain environments have been traditionally seen as simple ecosystems because their complexity, i.e. the number of species supported, decreases with height. Although, due to the spatial complexity, it is suggested that mountain ecosystem are complicated. This argument is supported by a case study of flies of the Syrphidae family. Impacts on these flies resulting from different types of human land use, including skiing tracks, are not reflected by species diversity but rather by survival strategies, i.e. specialist or generalist, of the flies (Haslett, 1997). Further, the definition of spatial borders for ecosystem communities is much better expressed on a so-called mosaic patch scale, i.e. a scale that is relevant for a particular species, rather than on a human defined scale. Also, the complexity of borders between patches of a mosaic may be equally important in defining species diversity. Finally, it is argued, that the vulnerability of a mountain ecosystem is likely to be due to changes in microclimate of these mosaic patches as well as to changes in overall climatic conditions.

2.2.2 Impacts of traffic

Whenever people change their location they have to use some kind of transport. Depending on the mode of transport it consequently generates a certain degree of impact, of which the types have been described earlier already. According to a study carried out in Switzerland (Swiss Federal Statistical Office (SFSO) / Swiss Agency for the Environment, Forestry and Landscapes (SAEFL), 1997) 24 per cent of total leisure related traffic is attributable to sport. This traffic encompasses the transport of people who participate in a sport activity, and spectators, officials and support personnel at sport events. The total traffic amounts to around twelve billion passenger kilometres per year. Of this the largest share, i.e. 79 per cent, can be attributed to transport by car or motorbike, 17 per cent to public transport and four per cent to walking and cycling. Skiing accounts for almost 14 per cent of leisure related traffic and, thus, shows the significant potential environmental impact. The figures only indicate traffic within Switzerland, not traffic to and from the country for the purpose of skiing. Hence, the percentage indicating the share of skiing related traffic is likely to be much higher.

2.2.3 Impacts of buildings and infrastructure

The number of hotels in Switzerland was around 6300 in 1993. Although this number has fallen by 1800 since 1970, the amount of private accommodation not used for permanent living has more than doubled in the same period to about 300000. Private accommodation includes holiday cottages, apartments, and bed-and-breakfast type accommodation. Of these dwellings 80 per cent or around 720000 beds are available for tourists. Together, the mentioned accommodation types make up almost 57 per cent of all types available. Others include caravans, camp sites, or club houses. Depending on the region the occupancy of the dwellings may be highest in summer or in winter. For hotels it varies from 14.5 per cent o 51.8 per cent in winter (SFSO / SAEFL, 1997). There are no figures available for the other accommodation types showing the occupancy related to the seasons or specifically to skiing. The figures in general may provide indication for the potential numbers of tourists that can be accommodated. It is clear that such an accommodation infrastructure has large impacts. Apart from the areas occupied by buildings, water supply and waste disposal are big problems in the high season when the numbers of tourists increase. When facilities are sufficient to cope with large numbers in peak times, they may be too elaborate for the rest of the year (SFSO / SAEFL, 1997).

Further infrastructure that is needed for large scale skiing are ski runs and ski lifts. Switzerland has around 1200 ski lifts and, thus, one of the densest networks of such transport facilities in the world. The appearance of these facilities impairs the landscape and disturbs the countryside experience. The mechanical preparation of ski runs results in large scale soil erosion and eventually in a decrease of biodiversity (SFSO / SAEFL, 1997). A study presented by Ruth-Balaganskaya and Myllynen-Malinen (2000) reports that the construction of ski runs is one of the major anthropogenic impacts in mountain areas in Finnish Lapland. At Mount Yllas the use of machines for grading and levelling ski slopes since 1992 resulted in the damage of the vegetation and soils. The study further showed that of several types of soils not all were suitable for unassisted ecosystem recovery in regard to the soils' organic matter and nutrient content.

2.2.4 Direct impacts of skiing activities

A survey undertaken by Englisch and Starlinger (1996) showed the impacts of anthropogenic activities on woodland communities. The survey area, situated in Tyrol, Austria at the northern edge of the Alps, is dominated by Rendzic Leptosols and Chromic Cambisols that have developed from dolomite and limestone parent material and are mainly resistant against anthropogenic impacts. Of the nine woodland communities found, montane spruce-fir-beech and subalpine woodland communities were dominant. The elevational treeline, situated at a height of about 1700 m, is consisting of Norway spruce. The treeline is widely depressed due to a number of anthropogenic and edaphic factors, including use of the forests for mining purposes that started already in medieval times. Recent impacts include use of the forests by tourists, especially for skiing. The factors are responsible for changes in the tree species composition and dynamics of soil development. Immediate effects of skiing and other sports are soil compaction, leading to surfaces that are more impermeable and, thus, generating higher surface runoff. It is argued that skiing as a major anthropogenic factor is able to have similar profound impacts on woodland communities and soils if exercised in areas that have not yet experienced any major anthropogenic activities.

There are considerable environmental effects from waste pollution and energy consumption by skiing and other sport activities. In Switzerland, there are about 4300 tonnes of skiing articles, 2800 tonnes of sports footwear, and 4000 tonnes of sports clothing disposed every year. About 65 per cent of these articles consists of plastic materials and the majority of the waste ends up in waste incinerators, while the remainder is disposed at landfill sites. There are concepts for recycling these kind of articles but are not fully implemented yet (SFSO / SAEFL, 1997).

Leisure activities on the ground (for instance skiing) as well as in the air (for example hang-gliding) can have negative effects on animals that have their habitats in the higher mountain regions. Studies have shown that disturbed animals, including chamois and mountain goats, are caused to leave the open grasslands for the forests. The forests, in turn, are usually providing less food than the grasslands, which can have adverse effects on the woods. Especially young trees can be expected to be damaged by browsing (SFSO / SAEFL, 1997). Noise pollution by mass participation sport activities can also affect other people. For instance, those who want to avoid crowds can create impacts in areas more remote, thus putting areas under pressure that are still more sensitive.

3.0 Impacts of climate change on the cryosphere

The cryosphere comprises all snow and ice within the Earth system. It involves important processes and feedback effects that can have impacts on the amplification of climatic variability and changes of climate. Among the significant effects are the dependence of surface albedo on the temperature, depth and age of ice and snow, and the influence on melt and freeze processes that can affect the salinity of the sea surface and deep water formation, thus affecting the thermohaline circulation and associated heat transport (IPCC, 2001b). The paper concentrates on glaciated areas and snow cover depth and length as they are both of significance for commercial skiing, the latter for winter skiing and the former especially for summer skiing.

3.1 Glacier mass balance

A glacier forms where the annual accumulation of snow exceeds the melting or evaporating of snow. Accumulation is related to temperature, which in turn is dependant on the altitude. Other factors may include local wind patterns and topography, e.g. shady sides of mountains retain more snow. Under the pressure of its own weight the snow gradually turns into ice. This process of transformation is fastest in temperate regions, e.g. Alps, and slow in cold regions, such as Antarctica and Greenland. If the ice is thick and heavy enough it starts to flow under the influence of gravity. The change from snow to ice, the movement downslope and the melting at the bottom can be seen in terms of a balance between accumulation and ablation, i.e. loss or melting. This concept is referred to as mass balance (Hambrey and Alean, 1992).

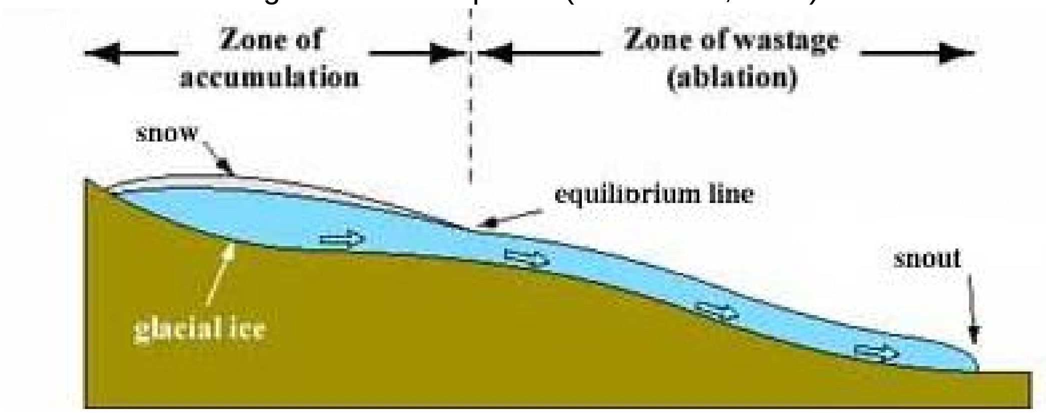
Depending on the season, e.g. late summer, snow accumulation exceeds melting at the top of the glacier. This area is called the accumulation area (Fig. 1). High altitude or polar glaciers may not experience any melting at all at the top. Downwards, there is a zone where there might be some melting. The melting water will usually freeze again, especially in winter, creating ice layers below the surface and on the surface. The glacier, nevertheless, still gains considerable mass in this zone. Further downwards, a glacier is characterised by a wet snow zone. The temperature in this zone is above the freezing point and the snow gains have been mostly lost. In this zone the losses of ice and snow through melting exceed the gains. This zone is also referred to as the ablation area. The boundary between the zone where the glacier accumulates mass and the wet snow zone is known as the equilibrium line. At this point gain equals loss (Hambrey and Alean, 1992).

3.2 Glacier fluctuations

The annual net balance between gain and loss of mass is reflected by the glacier's extent downwards. The lower end of a glacier is referred to as snout and will remain at the same position if the accumulation of glacier mass at the top will be equalled by the loss of mass in the ablation area. If the gain of mass exceeds the loss, the snout will advance. In the case of a net loss, i.e. loss of mass exceeds gain, the snout will retreat (Hambrey and Alean, 1992).

Small glaciers tend to respond faster to climatic fluctuations in terms of mass balance, possibly within a few years, whereas large glaciers may need several decades to respond. Consequently, short term variations in climate will not be reflected by a change of snout of a large glacier. Hambrey and Alean (1992) argue, that climatic changes over a period of several decades will supersede short term variations. Therefore, global warming since the end of the Little Ice Age 100 to 300 years ago has lead to a retreat of most glaciers in North and South America, Europe, and the tropics (IPCC, 2001a).

Figure 1: Glacier profile (after Cheel, 2001)



Glaciers, in spite the fact that they make up only a few percent of the worlds ice cover, are consequently much more susceptible to climate change than the large ice sheets of Greenland and Antarctica (IPCC, 2001b). This is also due to the ice sheets being located in areas much colder than most of the glaciers. This results in lower precipitation and lower melting rates. Changes in mass balance respond very slowly to climatic changes and may need hundreds or thousands of years to respond. The timescale for this process is, thus, beyond the most studies undertaken to assess the likely implications of melting ice sheets, for example to a rising sea level, in the next hundred years.

3.3 Observed changes

Around 90 per cent of the glacier, ice and snow cover sites examined in studies used by the IPCC (2001a) exhibited a trend expected under consideration of known physical processes that change the characteristics of the site in increasing temperatures (Table 1). There is, therefore, high confidence that the observation of widespread accelerated glacier retreat and shifts in the timing of associated hydrological events, i.e. streamflow from spring to winter, can be linked to the observed increases in temperature.

Table 1: Glaciers, snow cover and melt, lake and stream ice (IPCC, 2001a)

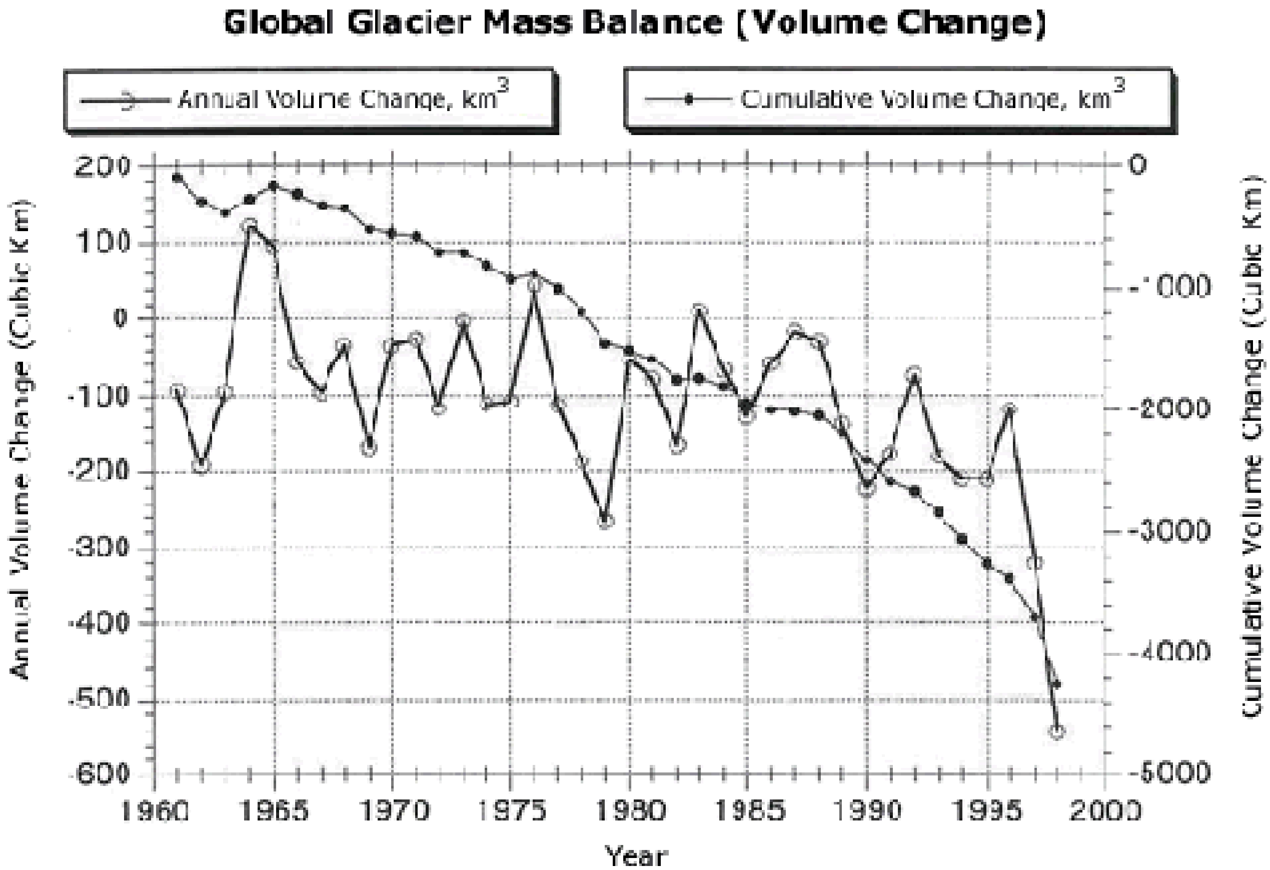
Region	**Changes predicted by climate change**	**Changes contradictory to climate change**
Africa	1	0
Antarctica	3	2
Asia	14	0
Australia	1	0
Europe	29	4
North America	36	4
Latin America	3	0
Total	**87**	**10**

Table 1 shows number of processes in each region associated with regional temperature change. The first number shows processes, whose changes are in accordance with the global warming. The second number indicates processes that are in opposition to the predicted changes.

The World Glacier Monitoring Service (WGMS) reports that mass balances of 33 reference glaciers continued to decrease at an accelerated rate. The retreat of the glaciers in the years 1990/91 to 1994/95 corresponds to an increase in energy flux (2 - 3 W / m^2) during the same time. This additional energy flux is considered to be of anthropogenic origin and equals the estimated anthropogenic greenhouse forcing. The decrease of the mass balance of the reference glaciers, distributed over eleven mountain ranges, is 287 mm and is, thus, slightly higher than the decadal mean 1980 - 1990, which was 277 mm (WGMS, 1998). Natural climatic variability should not be neglected as a cause for glacier retreat. In regard to the glaciers in the European Alps, there has been a reduction in glacier area by 50 per cent between 1850 and the mid 1970's. Most of this changes occurred during the second half of the 19^{th} century and the first half of the 20^{th} century and, thus, during a time of relatively weak anthropogenic forcing (WGMS, 1998).

In some coastal/maritime regions (e.g. Norway), there have been increases in precipitation due to changes in the regional atmospheric circulation patterns. These changes are, in turn, due to changes in the thermohaline circulation, that compensated for the warming trend and resulted in advancing glaciers in these maritime areas (IPCC, 2001b). Reichert et al. (2001) found an interesting relationship between glaciers in Norway and in Switzerland based on the thermohaline circulation. To simulate the mass balance of the Nigardsbreen glacier in Norway and the Rhonegletscher in Switzerland, Reichert et al. (2001) used a statistically downscaled general circulation model (GCM) where they applied glacier-specific characteristics based on seasonal sensitivity. The simulations showed a high correlation between glacier mass balance and the North Atlantic oscillation (NAO). The dominant factor for the correlation is the high impact of winter precipitation associated with the NAO. A so-called high phase of the NAO means increased winter precipitation for the glacier in Norway, resulting in a positive net mass balance, i.e. higher than the normal annual mass balance. In contrast, a high NAO phase results in reduced winter precipitation for the Rhonegletscher, leading to a negative net mass balance compared to the normal annual mass balance. Reichert et al. (2001) concluded that this mechanism, which is completely due to internal variations in the climate system, can explain the advance of Nigardsbreen and other maritime Norwegian glaciers during 1980 - 1995. In turn, the mechanism can partly be responsible for the strong negative mass balances resulting in recent retreat of Alpine glaciers.

Figure 2: Global glacier mass balance (NSIDC, 2001)



The overall extent of snow cover has been reduced in the Northern Hemisphere by about 10 per cent since 1972. This is largely due to deficits in spring and summer seasons (Weller and Lange, 1999). The depth of snow cover is a function of the temperature of an area, in turn depending on altitude and its precipitation. For every 100 m of altitude, the temperature decreases by some 0.75° C. In the European Alps, the temperature has increased by 0.8° C between 1962 and 1992 at a particular station (Komat, Carinthia, 1050 m a.s.l.). Other climate stations in the Alps can confirm this trend. However, the deviation still lies within the natural climatic variability, compared to climatic data collected over the last 200 years (Breiling, 1993). Compared to the importance of temperature fluctuations, variations in precipitation are of minor significance for snow cover.

3.4 Projected changes in the future

Regarding mean surface air temperature, model experiments show that the high latitudes of the Northern Hemisphere will experience the maximum warming, while the Southern Ocean will have a minimum warming due to ocean heat uptake. This minimum warming is also projected for the North Atlantic, although the land areas will warm faster than oceans. The warming in the Northern Hemisphere is closely connected with the accelerated retreat of snow and ice (IPCC, 2001b). It should be added that warming at different altitudes will be different. Warming is expected to be highest in cold areas, i.e. high elevations.

It is suggested that glacier mass balance is determined by temperature changes rather than precipitation, on the global average (IPCC, 2001b). Therefore, the future impacts of climate change on glaciers depends on whether an increase in temperature can be offset by an increase in winter accumulation. Simulations show, however, a general decline of glacier mass, indicating that temperature has a higher significance for mass balance changes than precipitation. Increasing winter accumulation may be responsible for increases in the exchange of glacier mass and, thus, rates of movement. Glaciers in the tropics are particularly vulnerable to global warming as their equilibrium line is more sensitive to air temperature. This is due to the lack of seasons in the tropics and the ongoing ablation of mass (IPCC, 2001a). The IPCC (2001b) further projects those areas that are only marginally glaciated to become totally free of ice and half of Europe's glaciers could disappear by the end of this century. Ice sheets, i.e. Greenland and Antarctica, will continue to react to climatic changes for several thousand years to come, even if the warming trend would be stabilised (IPCC, 2001a).

As a result of an increase in greenhouse gasses the thermohaline circulation is expected to weaken, both in the Northern and Southern Hemisphere. The thermohaline circulation is responsible for heat to be transported polewards in the Atlantic. The amount of heat is projected to be reduced, although there is still an overall warming in Europe. Nevertheless, a complete shutdown of the thermohaline circulation could have serious implications for the long term climate (IPCC, 2001b).

Table 2: Number of days with mean temperature below 0° C in eastern Alps (Breiling, 1993)

Altitude	**Mean 1851 - 1950**	**0.75° C increase**	**1.5° C increase**	**3° C increase**
400 m	77	68	60	27
600 m	90	84	77	60
800 m	101	95	90	77
1000 m	110	106	101	90
1200 m	120	115	110	101
1400 m	130	125	120	110
1600 m	144	137	130	120
1800 m	163	155	144	130
2000 m	178	170	163	144

Table 2 shows the potential days suitable for winter sport activities. However, there is a minimum snow depth necessary to be suitable for alpine skiing (30 cm). Depending on the local climate of the area, between 25 and 40 days have, therefore, to be subtracted from the days estimated in the scenarios (Breiling, 1993). Apart from an increase in mean annual temperature, there are expected changes in the amplitudanal extent of temperatures of seasons, month or days. Even more important than the change in precipitation is the distribution of it. There might be increases in extreme events like droughts or strong precipitation (Breiling, 1993).

4.0 Global warming and the skiing industry

A system of resources can be vulnerable and fragile to environmental changes. Therefore, changes induced by natural climatic variability and/or anthropogenic causes can have serious implications for socio-economic systems, since dependency on resources can be considered as a way of life (Weller and Lange, 1999). As a consequence, there could be demands on other areas and their resources. This is especially true for regional economies where different economic sectors are very much dependant on the same resources as in the case of winter tourism and skiing.

4.1 Socio-economic impacts

4.1.1 Economics in the context of climate change

Economics can be defined as the decision process for the allocation of scarce resources. A resource in nature is anything, which is of value and use for humans. Essential for this statement is the cultural perception of the environment and its resources. What is a resource in one society might be none in another. Increasing knowledge and technological inventions also influence the perception and the use of commodities as environmental resources. Natural resources can, therefore, be seen as subjective and depending on a functional use for humans. These resources are transformed into goods and services by economic activity (Weller and Lange, 1999). A relationship between climate change and economics can, thus, be established. Changes in the environment that affect a system of resources that is of importance for humans eventually change economic activity. There are social and cultural linkages to resources and climate change could be responsible for limitations in lifeway options. This may, for example, lead to population migration and put pressure on the social and economic system of a country as a whole.

The vulnerability of an economy can be described as operating on four levels (Weller and Lange, 1999). Level 1 is characterised through the physical parameters of the climate that influences the responses of an ecosystem to the climate at level 2. These responses of the ecological system, in turn, affect management decisions on human resource use at level 3. The sensitivity of economic systems to natural resources and climatic changes at level 4 is a direct result of the resource management policies. Weller and Lange (1999) point out that there are impacts on economies that are independent of climatic changes due to the effects of resource management policies.

4.1.2 Effects on the regional economy: the case of Austria

Until the 1950's agriculture was still the most important economic sector in Austrian alpine districts. Since the 1960's tourism developed rapidly and the capacities for winter sport activities have been built out. In 1991, 9 per cent of the Gross National Product (GNP) in Austria was directly derived from tourism, whereas winter tourism has a 50 per cent share of this figure (Breiling, 1998). The facilities for skiing were built according to the variations in temperature. The period 1965 - 1985 was relatively cold leading to an expansion of ski lifts. The period 1985 - 1995 saw an increase in temperature of 0.8° C and many communities had serious problems to manage the situation. Adaptation measures like artificial snow became popular (Breiling and Charamza, 1999).

The sensitivity of the Austrian economy to climatic changes varies. In the lowlands were 56 per cent of the population live, the regional economy is less dependant than in higher regions (Table 3). In Austria 400 m are considered the minimum altitude for profitable skiing. High alpine zones with peaks are currently excluded from skiing mainly due to safety reasons or unpleasant climatic conditions. Therefore, the snow conditions between 400 m and 2800 m are relevant for the skiing industry (Breiling and Charamza, 1999). Skiing districts can be divided into three elevational zones, low, medium, and high. Low zones are suitable for cross-country skiing. Most of the residential areas are in these zones. Ski centres start usually at medium altitude zones and end at high altitude. The requirements concerning snow depth are about 10 cm for cross-country skiing and 30 cm for alpine skiing. The required depth increases above the tree line in rocky terrain. For socio-economic analysis the zones at low and medium altitude are most interesting as they are the most critical. 74 per cent of all ski lifts in Austria are located below 1000 m and 69 per cent of winter tourist nights are spent below 1000 m (Breiling, 1998).

Table 3: Climatic sensitivity of Austrian regional economy (Breiling, 1998)

Altitude	**Communities**	**Population**	**Climate impact on regional economy**
117 - 400 m	950	56 %	no
401 - 800 m	1026	38 %	yes: income losses
801 - 1780 m	379	6 %	yes: income gains

At higher altitudes the impacts of climatic warming on snow are less than at lower altitudes. There are speculations about a possible increase of precipitation above 2000 m (Breiling and Charamza, 1999). However, the seasonal snow cover at lower altitudes will decline by a relatively large percentage. Income gains at higher altitudes are partly due to the climatic conditions at lower altitudes since visitors will shift to the areas with better snow conditions. In a model, Breiling and Charamza (1999) predict that at a warming of 2° C, half of the mean annual temperature values will remain in the temperature range of the period 1965 - 1995, which saw the emergence of commercial skiing and was particularly successful in increasing revenues. Thus, occasionally good winter seasons can be expected but not regularly. The future of most resorts in the Alps will, therefore, be determined by the frequency of good and bad seasons. The ski areas located on glaciers did not meet their economic expectations, either. These had been developed to open up new opportunities for skiing during the summer season. Since glaciers in the Alps are in general retreat, the areas may, nevertheless, have significance for future winter skiing (Breiling, 1993).

With an increase of 1.5° C Breiling (1998) estimates that some 15 days of the season are lost, depending on the altitude (see Table 2). In most cases the most profitable Christmas and Easter periods would be affected. The direct loss of revenues would be about 10 per cent of revenues. Including various economic multipliers the loss amounts to 30 per cent, equal to roughly 1.5 per cent of the Austrian GNP. On a local scale losses might be higher since many communities are particularly dependant on good climatic conditions. The change in income has implications on the employment structure. More people are forced out of the service industry, possibly to stay within the agricultural sector.

There are growing economic disparities between alpine communities. The ones that are already richer are those, which are located at higher altitudes (Breiling, 1993). Climate change will increase the debt burden as more than 50 per cent of Austrian tourism companies, around 80000 in total, borrowed money heavily. A decrease in revenues will lead to problems in paying back these loans, eventually leading to the economic ruin for many companies (Breiling, 1998). Thus, communities situated at higher altitudes have a competitive advantage. However, Breiling (1998) adds that a possible overuse of high alpine areas could lead to more environmental damage and make the areas less attractive. As a consequence, tourists could choose other destinations with an ultimate decrease in economic profits for high alpine areas.

4.2 Adaptations to changing conditions

Facilities for snow making are already in use. In 1991 there were 127 communities in Austria equipped with 250 snowmaking units. These units cover 20 per cent of all skiing tracks. To cover all skiing tracks in Austria, some US$ 10 billion are needed, of which US$ 2 billion have been invested so far. This is considerably more than the total income of one winter season, which is US$ 8 billion (Breiling, 1998). To be a worthwile investment the snowmaking units need to generate at least 10 per cent more income annually over 10 years (Breiling, 1993). However, snowmaking units are only useful with mean daily temperatures of -2° C. Low altitude communities have particularly unfavourable conditions for their use. For them, these units will cost more in relation to their income and do not necessarily guarantee to increase revenues (Breiling, 1998).

The rapid urbanisation of mountain regions after the Second World War and the rise in tourism required to increase protection measures to prevent natural catastrophes. Such threats include avalanches, unstable slopes, wild rivers, floods, and storms. A by-product of global warming in mountain areas is the increase in catastrophes, including avalanches and river floods due to higher glacier runoff. On average, Austria had to invest 0.4 per cent of its Gross Domestic Product per year into protective measures for the past 40 years. It is estimated that a doubling of carbon dioxide in the atmosphere would lead to a tenfold increase of catastrophes. The investments to prevent such events increase the earlier the 2 x CO_2 scenario is reached (Breiling, 1993).

The emerging economic disparities between lower alpine areas and those located at higher altitudes will lead to conflicts over resources. These conflicts can only be solved if the rural alpine economies are made less dependant on the climate. For local problems to be solved it is especially important to incorporate local knowledge and develop individual concepts (Breiling, 1998). Such an achievement has to be planned over a longer term of several decades and requires policymakers to develop a favourable policy framework.

4.3 Ecological restoration of former ski areas

As environmental change in mountain regions progresses, many communities that are involved in the winter tourism will be forced out of business. Abandoned ski tracks may open up possibilities for ecological recovery. Natural recovery is often connected to the expansion of resilient plant species into the disturbed areas. This recovery occurs in time spans of several decades. Changes in soil characteristics are common and include alterations of soil nutrients and decreases of organic matter due to fluvial erosion of exposed soil. For unassisted recovery only few soils may be suitable. The capacity for recovery depends on soil nutrient status and soil organic matter, and to which extend this has been destroyed or reduced due to anthropogenic activity (Ruth-Balaganskaya and Myllynen-Malinen, 2000). If the restoration goal is not to recreate the original vegetation, assisted recovery may be an option. The restoration process can then be accelerated. Ruth-Balaganskaya and Myllynen-Malinen (2000) propose the implementation of a substrate composed of the upper layer of initial soil. Such a soil can be collected during the construction work of the ski run, or from other sites with a similar soil composition. Klug-Pumpel and Krampitz (1996) point out the importance of breeding autochthon seeds. These species have proven in experiments at altitudes above 2000 m to be able to cope with the extreme conditions on ski runs are emphasised as a basis for re-vegetation. In an attempt to analyse the suitability of bioremediation as an option for diesel-oil polluted soils in a glacier area, Margesin and Schinner (2001) monitored the hydrocarbon concentrations and the soil microbial activity in unfertilised and fertilised soil. The fertilised soil was treated with Sodium, Phosphorus and Potassium. The contamination decreased significantly already after three years of monitoring. The initial level of contamination had been reduced by 50 per cent for the unfertilised soil and 70 per cent for the fertilised soil. The biological parameters, including microbial activity and soil respiration, in the fertilised soil were significantly enhanced and the effects of biostimulation on the original soil microorganisms declined over time. Bioremediation could, therefore, serve as a viable treatment for chronically polluted soils.

4.4 Future locations for commercial skiing

If factors other than climatic remain stable than winter sport communities at lower alpine regions will disappear first (Breiling and Charamza, 1999). Glaciated areas that have been developed for summer skiing might become more important for winter skiing when winter accumulation of glacier mass is still sufficient. It is likely that the pressure will increase on areas located at higher altitudes that have not yet been opened up for skiing due to legal restrictions. At the moment, there are still nature protection interests that prevent these areas from being developed. However, such areas may still offer significant economic revenues during the winter season, putting pressure on the government to relax environmental protection. The time scale for such a development might be several decades. However, considering that the IPCC (2001b) predicts half the glaciers in the European Alps to disappear by the end of the century, this is probably not an option for the time beyond 2100, perhaps not even for the second half of this century.

Rather exclusive skiing areas, situated at high altitudes, are likely to get increases in ordinary guests when snow conditions become unfavourable for skiing in lower areas. When the numbers of unwanted guests increase, the provision of quality tourism is not possible anymore. Tourists who are willing and able to afford expensive areas may seek even more exclusive destinations (Breiling, 1993). For commercial skiing in the second half of this century and beyond there are several locations that could provide the climatic conditions favourable for skiing. The Andes mountain range in South America already offers some winter sports, although at relatively high altitudes, up to 5000 m above sea level (Hambrey and Alean, 1992). However, even there glaciers are in retreat. This is especially true for glaciers located in tropical latitudes as they are not subject to seasonal fluctuations regarding accumulation and ablation. The Himalayas may offer favourable climatic conditions but are likely to be far too high for serious winter sport, apart from trekking and hiking. Adapting tourists to these atmospheric conditions would probably take too long time, costs too much money and is, therefore, not interesting for mass participation sport activities. The IPCC (2001a) reports that glaciers in the south of Alaska are in retreat, while in the north they are in advance. North America's highest mountains are located there and may offer snow and ice security for a space of time that could attract investments to develop ski centres. In addition, as it is located in the Northern Hemisphere it is still in relatively easy reach for wealthy European as well as North American ski tourists. The glaciers in the Scandinavian Mountains are advancing currently. This is due to a recently favourable phase of the North Atlantic Oscillation. However, as reported by Reichert et al. (2001) the current NAO phase is subject to natural variation, can therefore change in a relatively short time. This makes financial investments to expand the facilities needed for skiing in these mountains unlikely if the glacier expansion or equilibrium is unreliable. Antarctica provides security for stable glaciers possibly for centuries to come. The response to a rising temperature is very slow. In fact, the temperature increase that accompanied the end of the last glacial 10000 years ago has not yet fully penetrated the East

Antarctic Ice Sheet (Hambrey and Alean, 1992). For Europeans and North Americans the large distance might be the obstacle. It might be too inconvenient for a skiing holiday. Also, food, energy etc. would need to be either produced and generated locally on the Antarctic continent or supplied from outside. This would mean intensive costs that the tourist has to pay. Greenland, located within North America and Europe, is in relatively close distance to both, Europeans and Americans. Greenland offers similar advantages in terms of reliability than Antarctica. A further advantage is that there is already some tourism infrastructure available, including possibilities for skiing. Greenland provides also already a good standard concerning health care or communication, factors that can influence tourists' decisions. An expansion of winter sport activities is likely and it might be a worthwile venture for investors.

5.0 Discussion

Without doubt tourism and skiing activities have significant environmental impacts that are able to alter whole landscapes and ecosystems. With the expected increase in tourism these impacts are likely to become worse. Global warming, in addition, will change the ability and capacity of ecosystems to buffer physical changes of the climate. These issues lead to a multiple impact on the environment. Limiting the effects from skiing can possibly be done by applying a landscape-ecological approach (Hrnciarova, 1995). It involves biotic and abiotic factors of the area concerned as well as socio-economic considerations. Areas that might be suitable for the development of skiing tracks are selected on the base of their ecological limits. The analysis yields the fields where the largest conflicts over resources could originate.

There are still particular uncertainties in the areas of temperature and precipitation development in the decades to come. The socio-economic impact analysis, for example, is based on the assumption that the lower alpine areas have disadvantages as these areas are expected to suffer from precipitation deficiencies earlier than higher areas. However, if, in accordance with the IPCC, cold regions will warm up faster this would mean an earlier warming in the higher alpine regions. This would then even accelerate changes in glacier mass balances and snow cover patterns in higher regions. It is, therefore, difficult to predict any likely development. Although the outcome should be similar, that is the alpine regions become increasingly unsuitable for winter sport activities on a larger scale. The development will be accompanied by rising transport and maintenance costs and the numbers of tourists will decrease. Only people that are able to pay higher prices will be able to afford winter sports. On the other hand, in regions that are influenced by a polar climate, such as Scandinavia, temperature increases could have the opposite effect on visitor behaviour. In the northern provinces of Scandinavia temperatures easily reach -30° C during the winter season, with short time maximums at beyond -50° C. It can be argued that increases in temperature might result in these areas becoming more popular since temperatures become more comfortable. The consequences would be that the infrastructure serving visitors expands, more traffic, and heavier direct impacts from skiing.

The opening of new locations for skiing, e.g. Greenland, may provide adequate alternatives in the long term for winter tourists. However, winter sports will be more expensive as transport costs are higher. Similarly, the provision with food, water, energy, and other necessary supplies will be more expensive. It is therefore likely that skiing at the turn of the 22nd century is restricted to an exclusive circle of people. It is clear that such a development would lead to environmental impacts several magnitudes higher since the environments in remote areas have not yet experienced any large anthropogenic impact. They are, consequently, not very resilient. When tourist destinations shift, the economic benefits shift. The communities in the alpine regions will have to develop concepts to diversify their economic base and to decrease their economy's dependency on the climate. The success of this development will prevent the migration of large populations into larger towns and cities in the lowlands.

6.0 Conclusion

The paper has reviewed the environmental impact potential that tourism and winter sport activities possess. It has furthermore analysed the impacts of global warming on glaciers and snow cover and the resulting socio-economic impacts. Climate change implies a large threat both to ecosystems that are already under pressure and to socio-economic systems in mountain regions. Improvements in the models, which analyse socio-economic impacts and predict the likely development concerning temperature and precipitation could lead to more accurate information and better understanding how the change in climate will be transformed to affect regional economies. A decline in visitors and, thus, skiing activities can be beneficial for the environment and may lead to a use of the resources snow and ice that does not exceed the capacity of the system to manage its use, and, hence, could be more sustainable than today.

7.0 References

Breiling M (1998). The Role of Snow Cover in Austrian Economy During 1965 and 1995 and Possible Consequences Under a Situation of Temperature Change, Paper presented at Conference of Japanese Snow and Ice Society, 10/1998, Niigata

Breiling M (1993). 'Klimaveraenderung, Wintertourismus und Umwelt' (engl. Climate change, winter tourism and the environment) in Pillmann W A, Wolz A (eds.) Conference Proceedings Envirotour II Report, International Society for Environmental Protection, Vienna

Breiling M, Charamza P (1999). 'The impact of global warming on winter tourism and skiing: a regionalised model for Austrian snow conditions' in Regional Environmental Change, Vol. 1, 4 - 14, Springer, Berlin

British Broadcasting Corporation (BBC) (2001-11-08). Tourist's heavy Alpine toll, URL http://news.bbc.co.uk/hi/english/sci/tech/newsid_1515000/1515276.stm

Cheel R (2001-11-26). Course information: Geology and the Environment, Earth Sciences, Brock University, URL http://craton.geol.brocku.ca/faculty/rc/teaching/1F90/figures/figure143.html

Englisch M, Starlinger F (1996). 'Woodland communities and sites at two altitude profiles near Achenkirch (the Tyrol)' in Phyton-Annales Rei Botanicae, Vol. 36, 33 - 54, Ferdinand Berger & Soehne, Horn, Austria

Intergovernmental Panel on Climate Change (IPCC) (2001a). Climate Change 2001: Impacts, Adaptation, and Vulnerability, Cambridge University Press, New York

Intergovernmental Panel on Climate Change (IPCC) (2001b). Climate Change 2001: The Scientific Base, Cambridge University Press, New York

Intergovernmental Panel on Climate Change (IPCC) (1998). The Regional Impacts of Climate Change, Cambridge University Press, New York

Hambrey M J, Alean J C (1992). Glaciers, Cambridge University Press, Cambridge

Haslett J R (1997). 'Insect Communities and the Spatial Complexity of Mountain Habitats' in Global Ecology and Biogeography Letters, Vol. 6, 49 - 56, Blackwell, Oxford

Hrnciarova T (1995). 'Landscape-Ecological Bases for Proposal of Skiing Tracks' in Ekologia-Bratislava, Vol. 14, □285 - 302, Slovakian Academic Press, Bratislava

Klug-Pumpel B, Krampitz C (1996). 'Conservation in Alpine Ecosystems: The plant cover of ski runs reflects natural as well as anthropogenic environmental factors' in Bodenkultur, Vol. 47, 97 - 117, Oesterreichischer Agrarverlag, Vienna

Margesin R, Schinner F (2001). 'Bioremediation (natural attenuation and biostimulation) of diesel-oil-contaminated soil in an alpine glacier skiing area' in Applied and Environmental Microbiology, Vol. 67, 3127 - 3133, American Society of Microbiology, Washington

National Snow and Ice Data Centre (NSIDC) (2001-11-08). The State of the cryosphere, URL http://nsidc.org/sotc/glacier_balance.html

Reichert B K, Bengtsson L, Oerlemans J (2001). 'Midlatitude forcing mechanisms for glacier mass balance investigated using general circulation models' in Journal of Climate, Vol. 14, 3767 - 3784, American Meteorological Society, Boston

Ruth-Balaganskaya E, Myllynen-Malinen K (2000). 'Soil nutrient status and re-vegetation practices of downhill skiing areas in Finnish Lapland - a case study of Mt. Yllas' in Landscape and Urban Planning, Vol. 50, 259 - 286, Elsevier, Amsterdam

Swiss Federal Statistical Office (SFSO) / Swiss Agency for the Environment, Forests and Landscape (SAEFL) (1997). The Environment in Switzerland 1997: Facts, Figures, Perspectives, Neuchâtel/Bern

United Nations Environment Programme (UNEP) (2001-11-08). Environmental Impacts of Tourism, URL http://www.unepie.org/ps/tourism/sust-tourism/environment.htm

United Nations Environment Programme (UNEP) (1999). 'Addendum C: Tourism and Environmental Protection' in Report on Industry and Sustainable Tourism, Commission for Sustainable Development; also URL http://www.unepie.org./pc/tourism/documents/csd.pdf

Weller G, Lange M (eds.) (1999). Impacts of Global Climate Change in the Arctic Region, Report from a Workshop on the Impacts of Global Change, 25 - 26 April 1999, Tromsø, Norway, International Arctic Science Committee

World Glacier Monitoring Service (WGMS) (1998). Fluctuations of Glaciers 1990 - 1995 (Vol. VII), International Institute of Hydrological Sciences/United Nations Environment Programme/ United Nations Educational, Scientific and Cultural Organisation, Wallingford/Nairobi/Paris