The Impact of Climate Change on Ski Resort Operations and Development: Opportunities and Threats

By

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Submitted to the Department of Urban Studies and Planning in partial fulfillment of the requirements for the degree of

Master of Science in Real Estate Development

at the

Massachusetts Institute of Technology

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ABSTRACT

This thesis serves as a pedagogical guide to the ski resort industry, and presents a broad overview of the unique issues that accompany climate change. The paper also provides recommendations to resort developers as to which regions of North America will likely become desirable destination for skiers in light of such changes.

The ski resort industry is on the cutting edge with respect to sustainable building techniques and adoption of innovative "green" principles in day-to-day operations. But while these efforts are admirable and set an important precedent, in the global context they do little to stem the tide of global warming which penalizes indiscriminately. It is therefore necessary for stakeholders within the ski industry to not only embrace adoption strategies, but also to consider what preemptive actions can be taken to capitalize on global warming.

Using historical annual total snowfall records and "skier visit" data, this study intends to quantify the extent to which climate change has impacted resort operations in different regions of the United States over the last several decades. In addition, the paper provides an overview of current and future effects of climate change on North America's ski resort industry and provides recommendations as to how these operators can adapt to ever changing conditions over the next 30 – 50 years. This is followed by a review of climate adaptation practices currently employed by resort operators and stakeholders.

With few exceptions, existing literature on this topic has neglected to consider what opportunities might emerge as a result of climate change. While the field of climatology is an ever evolving science, the ski industry would be wise to take note as global warming is likely to prove one of those tectonic forces that gradually – but powerfully – changes the economic landscape in which they operate.

Thesis Supervisor: William C. Wheaton
Title: Professor of Economics

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1. Introduction

With approximately 720 ski areas in North America, 475 falling within the United States, the ski resort industry is in the midst of a veritable "Golden Age", as a confluence of positive circumstances has combined to advance the sport and boost revenues for entrenched operators. These resorts range from small scale operations that service local day skiers to large destination resorts that attract patrons from all over the world in search of the complete vacation experience. Skiing is estimated to be a $4 billion annual industry in the U.S. and with ever increasing interest in the sport, this figure is sure to grow.[1]

While professionals within the industry tend to credit this success to new innovations and clever marketing campaigns, there are several exogenous factors outside these operators' sphere of influence which have propagated this good fortune.

First, demographic trends heavily favor the ski industry as the baby-boom generation transitions into their prime leisure years. In addition the popularity of the sport continues to grow with the echo-boomer generation (10 – 24 year olds). Additionally, with no new major resorts opened in the last twenty-five years, the existing operators can unilaterally profit from the continued growth. The barriers to entries are significant for new entrants, due largely to the dearth of private lands on which to build and the challenges of obtaining government approvals to develop on public lands. In fact, some 90% of resorts in the Pacific West and 85% of resorts in the Rocky Mountains operate under permits administered by the United States Forest Service (USFS), procurement of which often involves a lengthy and bureaucratic approval process.[2] The absence of new entrants enables existing operators to increase lift ticket prices with little concern of losing their competitive advantage.

Although the future looks promising for the ski industry, there are long term threats which have the potential to dramatically impact the business. This thesis will explore one such issue: climate change or global warming.

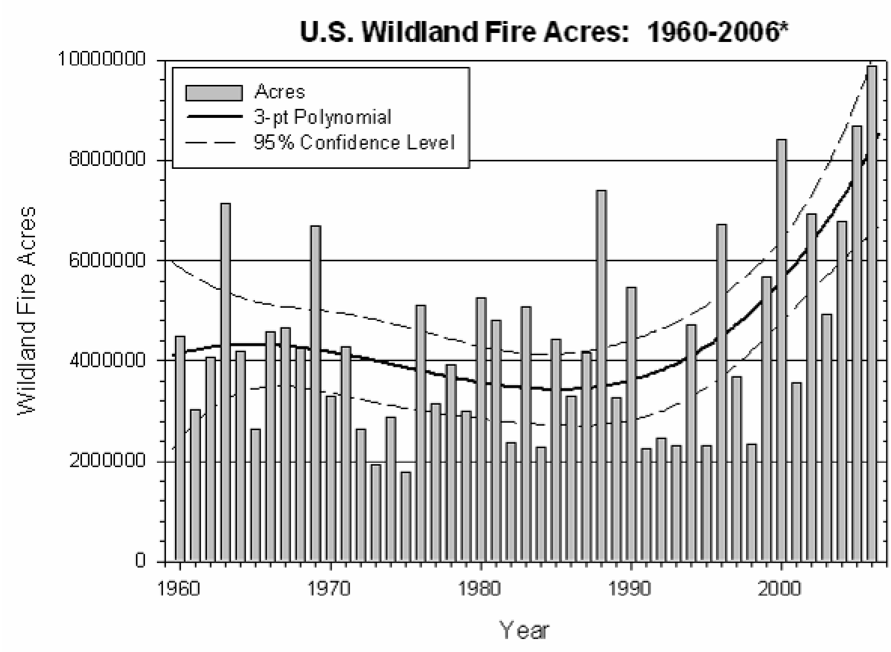
In principle it is basic to understand why climate change and its resultant warming would have a substantive impact on the ski resort industry: warmer temperatures result in shorter winters and less snow, which directly impact the bottom line. In addition, the higher frequency of extreme weather events, such as draughts and forest fires, increase the risk of costly damage to land, infrastructure, and facilities.

Scientists' widespread contention that global warming increases the volume of such climatic events is supported by seemingly daily reports of weather anomalies, ranging from forest fires in the West, to draughts in the West, and to heat waves in the Northeast. Headlines depicting Mother Nature on a rampage have become commonplace.

To illustrate this observable fact, consider both wild fires and droughts. Wild fires pose an acute threat to the skiing industry as ever dryer conditions continue to fuel more powerful fires which have the potential of enveloping a resort's carefully manicured ski slopes in a matter of days. In addition recent studies suggest that the resulting soot released into the air lands on mountain snowpack and leads to faster snowmelt.[3]

Last year alone a record 9,871,863 acres[4] of forest land burned nationwide, an area greater than the land areas of Massachusetts, Connecticut, and Rhode Island combined.[5] Graph 1.1 below illustrates the large scale of damage cause by forest fires in the U.S. over the last fifty years.

Graph 1.1: Historic Impact of Wildfires



Source: http://www.ncdc.noaa.gov/img/climate/research/2006/dec/us-wildfires-1960to2006-pg.png

Similarly, according to a recent study, wind-blown dust from drought-stricken and disturbed lands can shorten the duration of mountain snow cover hundreds of miles away by up to a month.[6]

1.1. <u>Background</u>

Recognized as one of the most significant threats to the ski resort industry, the reality of Climate Change is no longer in doubt. While the discourse continues regarding the magnitude and the implications for future generations, Time Magazine recently published an article entitled "*Climate Change: Case Closed*" which declares that the global warming debate is over.[7] The World Economic Forum also released a report entitled *Global Risks 2007* citing Climate Change as one of the five greatest threats to our planet.

Following are several recent examples from around the globe which highlight the timeliness of this research:

- The globally averaged combined land and sea surface temperature for December 2006 to February 2007 was the highest since records began in 1880;[8]

- 10 of the warmest winters globally since 1880 have occurred since 1995;[9]

- A resort in the Alps, Abondance, at 3,051 feet, closed in July 2007 due to the chronic absence of snow, representing the first ski resort casualty of global warming;[10]

- Mountain glaciers and snow cover continue their declined in both hemispheres, leading to sea level rise;[11]

- Warming trends in Europe this winter (2006/07) prompted officials to cancel races on the World Cup circuit;[12]

- Average spring temperatures in California's Sierra Nevada range have increased more that 2^{o}F degrees since 1950 and if spring temperatures rise by a mere 5^{o}F degrees on average, California is predicted to lose 89% of its natural snow pack.[13]

Although global warming predictions vary, current weather trends in mountainous regions indicate that appreciable effects are only just beginning to emerge. “Nationwide this year, there were huge disparities in winter weather conditions,” said Michael Berry, president of the Colorado-based National Ski Areas Association (NSAA), an organization which represents most of the nation's estimated 475 ski areas.

NSAA, who publishes an annual assessment of each season entitled the *Kottke National End of Season Survey*, issued the following ominous summation of the 2006/07 season in their preliminary report:

> “Estimates indicate that 2006/07 was indeed a challenging year for the ski industry. Abnormally warm temperatures and below average snowfall impacted most areas of the country, delaying planned openings, interrupting the season with periodic resort closures, and otherwise shortening the effective length of the season in all regions except the Rocky Mountains.”[14]

“Skier visits”, the group's measure of volume, were down by an estimated 6.9% during the 2006/07 season from the previous year,[15] which amounts to a reduction of just over four (4) million visits.

Downhill skiing is an industry that is highly dependant on particular weather variables necessary to ensure favorable skiing conditions. Temperature and precipitation need both comply to realize adequate snowpack and enable artificial snowmaking. Should these warming patterns persist, many of the world's existing ski resorts may not have adequate snowpack to sustain business operations over the next 30 – 40 years.

1.2. Future Implications

Reviewing the latest research reports on climate change, this study will forecast which geographic regions hold particular promise as future locations for ski operations in light of climate change. Could Canada and/or Alaska emerge as the new hotspots for the sport’s enthusiasts?

In addition the paper will underscore strategies entrenched operators can employ today to mitigate the risk of global warming.

This paper will serve as a primer for forward thinking resort developers who are considering proactive strategies in the face of this growing concern. For example, developers should consider taking calculated risks and place educated bets on specific promising new markets, by optioning land in untapped areas. Owners/operators must plan for the future and think about where these as-of-yet unidentified opportunities will emerge.

2. Literature Review

To date, there have been few studies completed which specifically examine the future impacts of climate change on the North American downhill ski industry. The literature review did reveal a myriad of reports on climate change generally, as well as studies examining potential effects of climate change on various weather sensitive industries throughout the United States and Canada.

Following is a review of numerous professional and academic papers assessing both the socioeconomic and ecological impacts of climate change, with concentrations on specific geographic regions of the U.S.

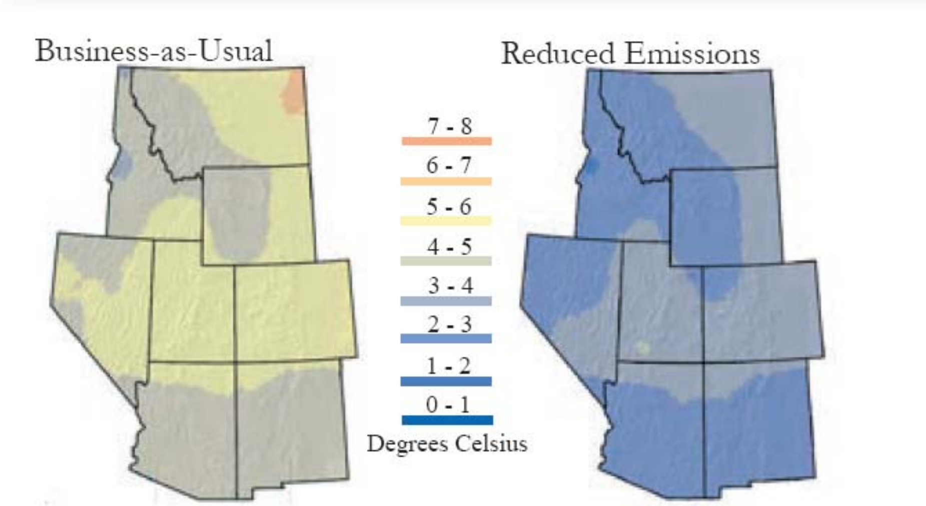
The Michigan Journal of Economics published a paper entitled *The Economic Impact of Climate Change on the Mid-Atlantic Region's Downhill Skiing Industry* which investigates climate change's long-term impact on the ski industry in the Mid-Atlantic region. This report concluded that by 2095 resort operators in this region will no longer find it financially viable to offer skiing to their clientele. The study credits the gradual increase in temperature which will both shorten the ski season and significantly increase operating costs, such as snowmaking.

This study went on to predict that savvy resort operators will gradually differentiate their recreational offerings and shift to a summer/fall oriented business model focused on golf, biking, rafting, and hiking.[16]

Colorado College released a report in 2006 entitled *The 2006 Colorado College State of the Rockies Report Card,* which sought to predict the effect of climate change generally on the Rockies region; including the impact on both the ecosystem and the economy. This report based its results primarily on two discrete models, one which assumed the rise in greenhouse gas emissions would continue unabated as they have for the past forty (40) years and another which considers a future in which emissions are reduced considerably. While there is a clear variance in the results between the models, both indicate upward trends in temperature, reduced snowpack, and variations in precipitation throughout the region.[17]

Figure 2.1, adapted from the report, illustrates the predicted change in winter temperatures under both scenarios. The report predicts temperatures to rise anywhere from 1.5^{o} to 7^{o}C depending on the emissions output in the next eighty (80) years.

Figure 2.1: Winter Temperature Increase, 1976 to 2085* (Degrees Celsius)

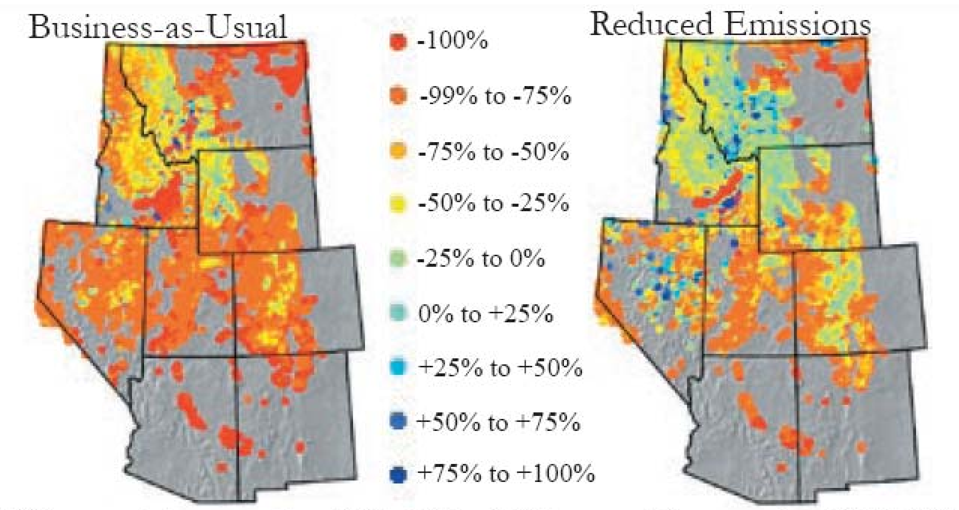


*1976 represents the average from 1961 to 1990, and 2085 represents the average from 2070 to 2099.

Source: The 2006 Colorado College State Of The Rockies Report Card

Figure 2.2 reflects the anticipated loss of snowpack under both scenarios. Again, while there is a sharp contrast between the two scenarios, both depict a future in which snowfall is diminished.

Figure 2.2: April 1 Snowpack Change, 1976 to 2085* (centimeters of Snow Water Equivalence)

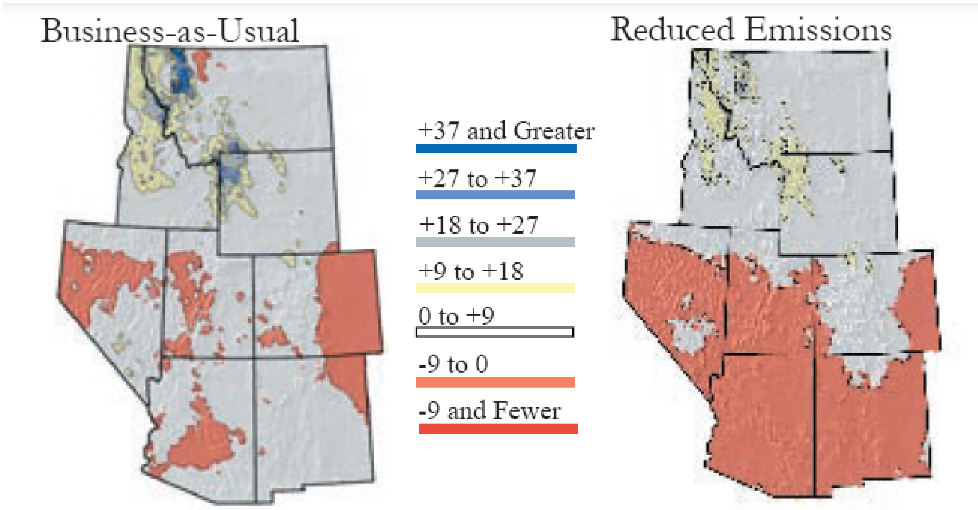


*1976 represents the average from 1961 to 1990, and 2085 represents the average from 2070 to 2099.

Source: The 2006 Colorado College State Of The Rockies Report Card

Finally, Figure 2.3 shows the forecast change in precipitation under both scenarios. The report predicts an increase throughout much of the Rockies in higher latitude regions. Much of this increase will manifest itself as rain however, negatively impacting ski resorts in those regions.

Figure 2.3: Annual Precipitation Change, 1976 to 2085* (Centimeters Per Year)



*1976 represents the average from 1961 to 1990, and 2085 represents the average from 2070 to 2099.

Source: The 2006 Colorado College State Of The Rockies Report Card

The report went on to summarize the predicted impact on tourism stating that "a change in climate will undoubtedly impact the tourism industry in the Rockies, a region often seen as the nation's playground."

The *State Of The Rockies Report* forecasts dramatic reductions in snowpack in counties which house some of the Rockies' largest ski areas. Most ski counties in Colorado are predicted to lose around 50%. The report identifies the northern region of the Rockies, such as Teton County, home to Jackson Hole, as the least impacted, with only 26% projected reduction in spring snowpack. [18]

An additional paper which is uniquely apropos considering today's headlines, is entitled *Wildfires in the West* (S.W. Running et. al., 2006) and chronicles the ever growing risk of fire in the western United States. This report finds that although land-use history is an important factor in wildfire risk, the broad-scale increase in wildfire frequency across the western United States is primarily driven by increased spring and summer temperatures coupled with earlier spring snowmelt which leads to extended fire seasons. The team also discussed how increased biomass burning will result in a carbon release from forest ecosystems thereby potentially turning western forests from net users of carbon dioxide to net contributors of the gas. This could have large scale implications for the terrestrial carbon cycle in the United States, since western forests are currently responsible for 20 to 40% of total U.S. carbon sequestration.[19]

Another comprehensive report is Aspen Global Change Institute's *Climate Change and Aspen: An Assessment of Impacts and Potential Responses.* The City of Aspen has consistently been on the forefront of the "Green Movement" and this 2006 assessment is the result of their extensive efforts to draw attention to climate change. The report begins with a thorough review of current trends in climate and then goes on to consider possible future climates. The institute took a three-pronged approach which modeled future scenarios with low, medium, and high levels of future greenhouse gas.

Climate models from several major climate centers were utilized to project changes in monthly temperature and precipitation by 2030 (near term) and 2100 (long term).[20] The results of the climate modeling were then used to examine how variations in climate will affect both Aspen's socioeconomic well being and the diverse ecosystem. The report concludes with a discussion of the primary regional stakeholders and actions they can undertake in response to forecast changes.

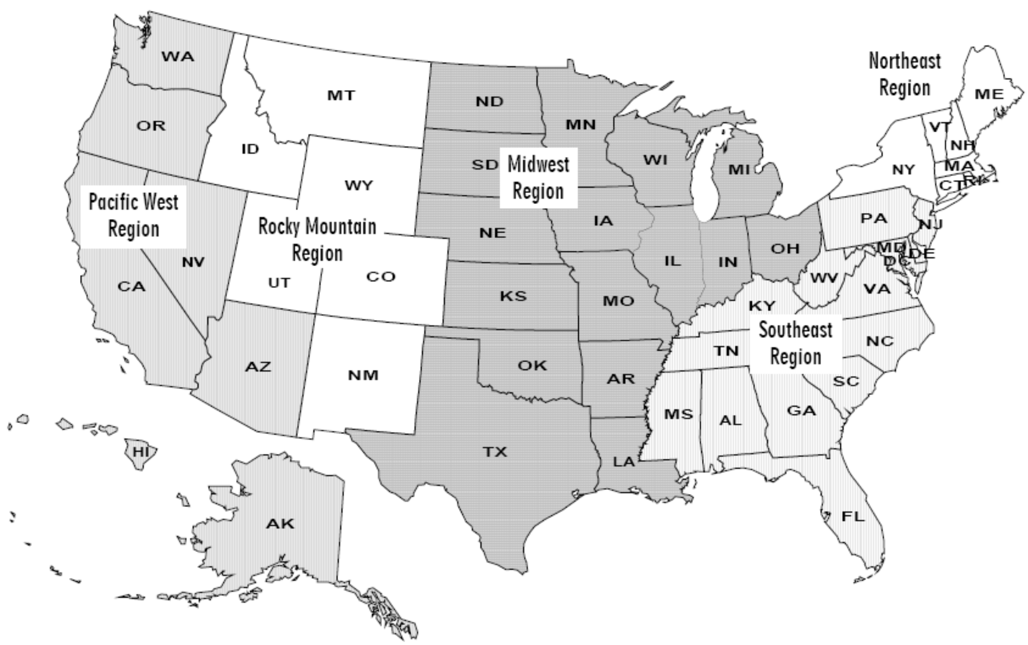
3. <u>Methodology</u>

This dissertation intends to quantify the extent to which climate change has impacted resort operations in different regions of the United States over the last several decades, using both historical annual total snowfall data and "skier visit" data to evaluate the impact.

The term "skier visit", is defined as "one person visiting a ski area for all or any part of a day or night for the purpose of skiing, snowboarding, or other downhill sliding. Skier visits include full-day, half-day, night, complimentary, adult, child, season pass, and any other type of ticket that gives a skier/snowboarder the use of an area's facilities."[21]

For this paper, the thesis will consider five (5) primary ski regions: Pacific West, Rocky Mountain, Midwest, Northeast, and Southeast. These regions are illustrated in Exhibit 3.1 below.

Figure 3.1: United States Ski Regions



Source: NSAA: National Ski Areas Association

3.1. Historic Climate Data Collection

Data was collected on both historic annual mean temperatures and historic annual snowfall accumulation. This data was sourced from numerous representative weather stations in each of the five predefined geographic regions. These stations were selected on the basis of their general proximity to ski areas, their elevation, and the quality of the data available. To ensure the integrity of the data, there were numerous stations evaluated and subsequently eliminated from the study due to incomplete data or to their locations exhibiting different climatological characteristics. Only stations with $\geq$95% complete records of snowfall were used.

The weather stations are a part of the United States Historical Climatology Network (USHCN), an organization which maintains a high quality data set of basic meteorological variables from over 1,000 observing stations across the 48 contiguous states. The data aggregated by USHCN includes observations of maximum and minimum temperature, precipitation amount, snowfall amount, and snow depth. Data records extend through 2005 and are essentially complete for at least 50 years; the latest beginning year of record is 1948.[22]

The temperature data was derived using monthly averages collected from stations across the country. Annual snowfall data, on the other hand, is not provided as monthly figures, rather as daily records. Therefore the thesis collected and summed these daily records - often spanning 100+ years – for each USHNC station.

3.2. Skier Visits Data

Next, in order to analyze and compare the average annual performance of resorts; “skier visit” data was collected from each region. “Skier visit” figures are a widely accepted measure of ex-post demand and business success in any given year.

There are two methods whereby to secure this data; (1) by reaching out to each resort on an individual basis or (2) by turning to one of the ski trade associations that aggregate these figures and statistics. Preliminary attempts to secure this data directly from a number of resorts proved time consuming and ineffective as privately owned resorts are uniformly guarded with these figures. Meanwhile publicly held ski resorts report lift ticket sales in their Annual Report as a percentage of revenue rather than as discrete “skier visits” figures.

Consequently the second method was used and the study employed statistics as reported by the National Ski Area Association (NSAA), an association consisting of ski area owners and operators. NSAA is the principle ski trade association which collects and published a wide series of industry information collected from members accounting for more than 90% of the skier/snowboarder visits nationwide.[23]

3.3. Data Synthesis

Upon completion of data collection, the thesis employed a diagnostic VAR model designed to interpolate the correlation between weather in any given year and the performance of resorts in that region, as measured by skier visits in the corresponding year. The intent is to determine whether there is a tendency for regions to struggle during low snowfall seasons and, if so, determine the magnitude of this response.

Clearly there are a wide variety of variables that influence skier decision making patterns in any given season. This study will attempt to establish a relatively simple correlation between snowfall and skier visits, which will support the proposition that this industry is uniquely susceptible to climate change and the resultant loss of snowpack.

Using the model, the thesis will determine the future impacts and change in skier visits based on forecasts reductions in snowfall in each region.

3.4. Future Opportunities

Next the thesis takes a broad-brush perspective on the North American ski industry by concentrating on high-level climate forecasts for the continent. While there are statistical downscaling techniques available to draw relationships between large-scale global climate model (GCM) data and smaller scale climate variables at a specific location, there are significant shortfalls to these techniques as they assume that the statistical relationship between the climate variables in a GCM and observed climate at a specific location will not change with climate change. This assumption of a constant statistical relationship has been challenged and is likely to yield inaccurate results; therefore the thesis will not employ these techniques.[24]

To accomplish this, the study identified geographic regions which will likely emerge as attractive locations for resort development due to climate change. These predictions will be based primarily on the latest report issued by the Intergovernmental Panel on Climate Change (IPCC), released in February 2007.

Established in 1988 by two UN agencies, the IPCC is widely recognized as the world's foremost authority on climate change. The IPCC issued comprehensive assessments in 1990, 1996, and 2001; and its Fourth Assessment Report (AR4) is the most comprehensive synthesis of climate change science to date. The report aggregates studies contributed by the world's foremost climatologists from over 130 countries and represents six years worth of work. More than 450 lead authors have received input in excess of 800 contributing authors, and an additional 2,500 experts reviewed the draft documents.

The thesis will evaluate the conclusions from the AR4 report and extrapolate from the North America climate change projections which areas are likely going to become more temperate and/or benefit from an increase in overall annual snowfall levels.

To date, nearly all rigorous research has centered on measuring the effects of global warming and strategies to stem the tide. This section will put a new – *positive* – slant on global warming and survey what new regions might benefit and become attractive resort destinations. Research could pinpoint Canada and/or Alaska as locales which will realize significant booms to their tourist industries.

4. Global Warming Demystified

While the scope of this thesis is fundamentally regional in natural and focused on a specific graphic area, it is necessary to understand the anatomy of global climate change. What follows in this section is a brief yet concise explanation of the global warming phenomenon.

4.1. Overview

Historically speaking it is not unusual for temperatures to vary widely year to year, week to week or even day to day. By utilizing a variety of techniques, such as observing marine sediments and drilling polar ice cores, historic weather records going back hundreds of thousands of years can be collected and analyzed.

These natural data warehouses confirm that long-term variations of climate conditions are a completely natural. These variations occur in accordance with the variation, distribution and magnitude of solar radiation, which are further amplified by ocean-land-atmosphere interactions.[25] However, the swift temperature increase observed in the past half century cannot be fully explained by these natural influences.

The latest report released by the Intergovernmental Panel on Climate Change (IPCC) concludes that "it is extremely unlikely (<5%) that the global pattern of warming during the past half century can be explained without external forcing, and very unlikely that it is due to known natural external causes alone. The warming occurred in both the ocean and the atmosphere and took place at a time when natural external forcing factors would likely have produced cooling. Greenhouse gas forcing has very likely caused most of the observed global warming over the last 50 years."[26] In other words, mankind has caused global warming.

4.2. Climate Defined

Vital to any discussion of global warming (climate change) is developing a working knowledge of the sophisticated system that comprises the earth's climate. IPCC defines climate as "a complex, interactive system consisting of the atmosphere, land surface, snow and ice, oceans and other bodies of water, and living things. The atmospheric component of the climate system most obviously characterizes climate; climate is often defined as 'average weather'. Climate is usually described in terms of the mean and variability of temperature, precipitation and wind over a period of time, ranging from months to millions of years (the classical period is 30 years)."[27]

The climate system evolves over time in response to both its own internal dynamics as well as external factors known in the scientific community as 'forcings'.[28] These 'forcings' can occur naturally such as volcanic eruptions and solar variations and can also be the result of anthropogenic actions, particularly through the creation of greenhouse gases.

The Earth's climate is powered by solar radiation and can be altered in three basic ways. First and most basic is a change in the magnitude of incoming solar radiation by either change in Earth's orbit or variation in the Sun itself. Next is by a reduction in the "albedo" effect, or the fraction of solar radiation that is reflected back into space by the planet's numerous reflective surfaces, such as glaciers and bodies of water.[29] And finally, climate is vulnerable to the introduction of new pollutants, or greenhouse gases, into the atmosphere which traps heat emitted by the planet.

4.3. Greenhouse Warming

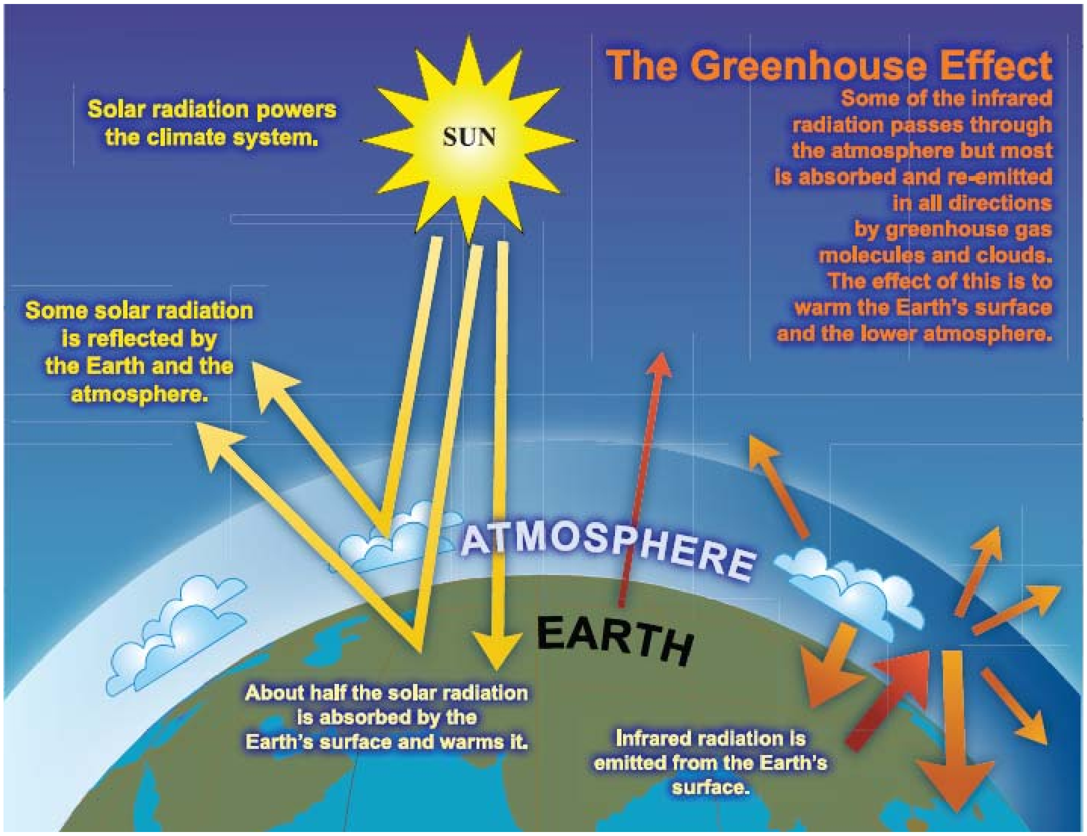
"Greenhouse warming" and the resulting "greenhouse effect" are terms used to explain the rise in global temperatures over the last many decades. Following is a short explanation of the phenomena.

As the principal source of warmth on Earth, the sun emits approximately 340 watts per square meter (w/m^2) of radiant energy (the precise figure varies over time, by +/- 0.1%)[30]. As it enters the Earth's atmosphere, this energy, transferred via "short wavelength" radiation, is not appreciably hindered by greenhouse gases, which are mostly translucent to "short wavelength" radiation. However, of the 340 w/m^2 the sun emits, only about 240 w/m^2 is absorbed by the Earth's surface. The remaining 100 w/m^2 is reflected off clouds, assorted aerosols, and various reflective features of the planet such as snow and ice.

To balance this incoming energy, the Earth itself must radiate, on average, the same amount of energy back into space. However, the radiation emitted from the earth is less energetic and transferred via "long wavelength" radiation, or "terrestrial radiation".[31] Everything on Earth emits terrestrial radiation continuously. That is the heat energy one feels radiating out from a fire; the warmer an object, the more heat energy it radiates. To emit 240 w/m^2, a surface would have to have a temperature of around -19°C (-2°F). This is much colder than the conditions that actually exist at the Earth's surface (the global mean surface temperature is about 14°C or 57°F). Instead, the necessary (-19°C) is found at an altitude about 5 km above the surface.[32]

The reason the Earth is not unbearably cold (-19°C) is the presence of "greenhouse gases" in the atmosphere which, although transparent to the sun's short wavelength energy, are somewhat opaque to long wavelength radiation and serve to prevent terrestrial radiation from escaping the atmosphere, redirecting nearly half of it, roughly 180w/m^2, back down to Earth. This redirection of energy is what is commonly known as the "natural greenhouse effect". (see Figure 4.1)

Figure 4.1: Illustration of the Greenhouse Effect

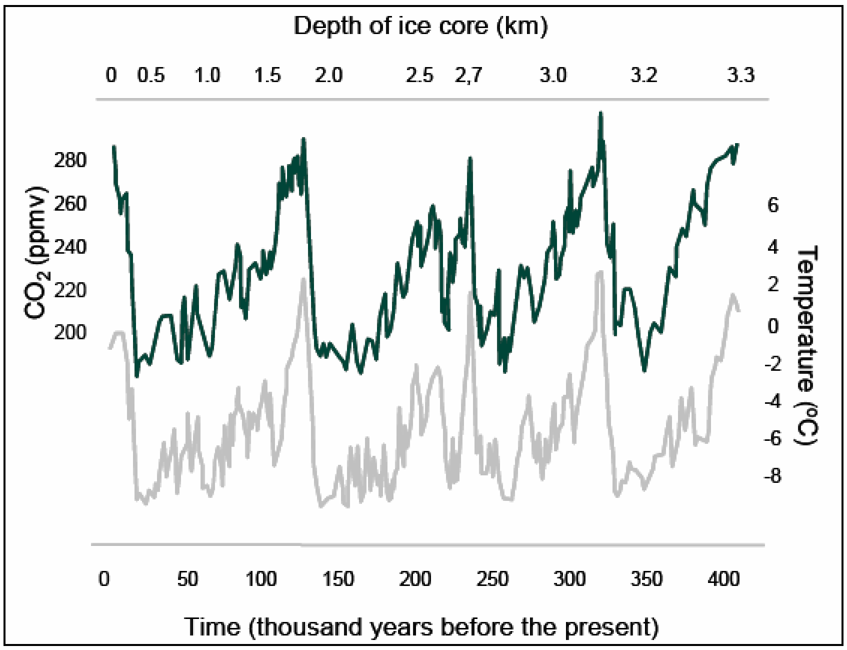


Source: IPCC, Fourth Assessment Report "Climate Change 2007", pg. 115

This greenhouse effect is both a natural and beneficial process. The earth emits greenhouse gases in large number of ways: such as through volcanoes, the decay and respiration of plant material, forest fires, animal digestive processes, wetlands, and natural soil and ocean processes. These gases work to regulate the world's temperature and keep the planet inhabitable by human beings who can only tolerate a relatively narrow range of temperatures.

The most important greenhouse gases present in the Earth's atmosphere are water vapor and carbon dioxide. (Nitrogen and oxygen, the most prevalent gases, have no such impact on terrestrial radiation).[33] As Figure 4.2 illustrates, the correlation over the past 400,000 years between CO_2 and temperature is striking and undeniable, the two trend lines are virtual reflections of one another providing clear evidence of the direct relationship.

Figure 4.2: Historic Carbon Records and Temperature Records



Source: Petit, J.R. et al. (1999), 'Climate and Atmospheric History of the past 420,000 Years from the Vostok Ice Core, Antarctica', *Nature*, 399, pp. 429-436.

Over the past 150 years, however, the "natural" rate and quantity of greenhouse gases cycling from the Earth, into the atmosphere, and back to the Earth has been greatly exacerbated by humankind. Since the Industrial Revolution, excessive levels of these gases have been produced and released into the atmosphere at a level far exceeding any "naturally occurring" rate. In recent decades, stemming from the Industrial Revolution, humankind has dramatically altered the chemical composition of the atmosphere with the introduction of manufactured pollutants which have served to intensify the greenhouse effect. Activities, including fossil fuel combustion, fertilizer and manure application, biomass burning, and soil cultivation have resulted in increased concentrations of carbon dioxide by about 30% (Table 4.1). Methane concentrations have risen by nearly 150% and nitrous oxide concentrations have increased about 15%.

Table 4.1: Historic Concentrations

Greenhouse Gas	Preindustrial Atmosheric Concentrations	1998 Atmosheric Concentrations
Carbon Dioxide (ppm)	278	365
Methane (ppm)	0.7	1.745
Nitrous Oxide (ppm)	0.27	0.314

Source: U.S. Greenhouse Gas Inventory Program, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000. U.S. Environmental Protection Agency (2002)

4.4. Reinforcing Global Warming Mechanisms

What has been observed in the past 50+ years is the genesis of a "self-reinforcing cycle" of warming. While scientists continue to debate the extent of this phenomenon, recent studies strongly suggest that global warming does feed on and sustain itself.

Although the long run history of Earth's mean temperature is indicative of a system that is mean-reverting, when excessive amounts of terrestrial radiation is captured in the Earth's atmosphere artificially, the climate system adjusts accordingly. Many scientists postulate that the now warmer Earth responds by emitting even more terrestrial radiation. This, in turn, increases the amount of radiation remaining in the earth's atmosphere and continues the warming cycle.

Below are several examples of this "positive feedback" mechanism:[34]

1. Melting of the permafrost, which exposes organic matter that then decays, releasing the greenhouse gases methane and carbon dioxide;[35]

2. As the atmosphere warms, the amount of water vapor it can hold rises. Because water vapor is an active greenhouse gas, this multiplies the effect of warming;

3. Rising temperatures and changes in weather patterns, particularly rainfall, are thought to damage the ability of the Earth's natural "sinks" – the oceans and soil – to absorb CO_2;[36]

4. As snow and ice gradually melt and dissipate the leave behind darker land and surfaces which absorb more of the Sun's heat, causing more warming, which causes more melting, and so on, in a self-reinforcing cycle;[37]

5. Furthermore, ocean acidification, the result of dissolved CO_2, weakens the CO_2 absorption organisms.

While debate in the scientific community continues over the "feedback mechanism" theory, these events likely play a significantly larger role in global warming than previously estimated. These revelations have prompted many scientists to revisit previous studies and adjust their estimates.[38]

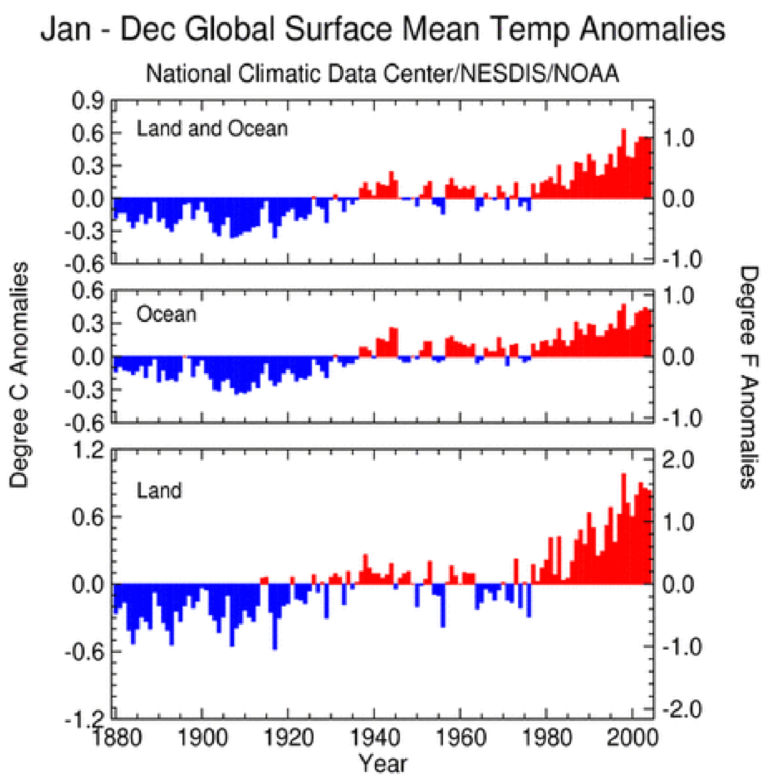
4.5. *Recent Observed Warming Trends*

Today, there is widespread consensus that near-surface air temperatures are increasing. According to the IPCC, over the 20th century, the global average surface temperature has increased by about 0.6ºC (1.08^{o}F). The year 2005 was reported as having been the warmest year in several thousand years and 2007 is expected to break that record.[39] It's worth noting that the record warmth recorded in 2005 is even more unusual as it was not aided by a tropical El Niño incident. Whereas the prior record year, 1998, was enhance 0.2°C above the trend line by the strongest El Niño of the past century.[40]

The Center for Climate Change and Environmental Forecasting performed a study that tracked warming over the past 100+ years. The results of this study are illustrated below (Figure 4.3) on the globally-averaged mean annual temperature time series which includes both land and ocean data point for 1880-2000. Although yearly and decadal variations are clearly visible, the 1901-2004 long-term trend in combined land and ocean temperatures is consistent with IPCC's conclusion at approximately +0.6°C/century.[41]

The study concludes that land surface temperatures have increased at a rate of +0.8°C/century while ocean surface temperatures have risen +0.6°C/century during the same time period. The trend has increased to +0.17°*C/decade (.17^{o}F)* during the past 25 year period (1979-2004) when considering combined land and ocean temperatures.

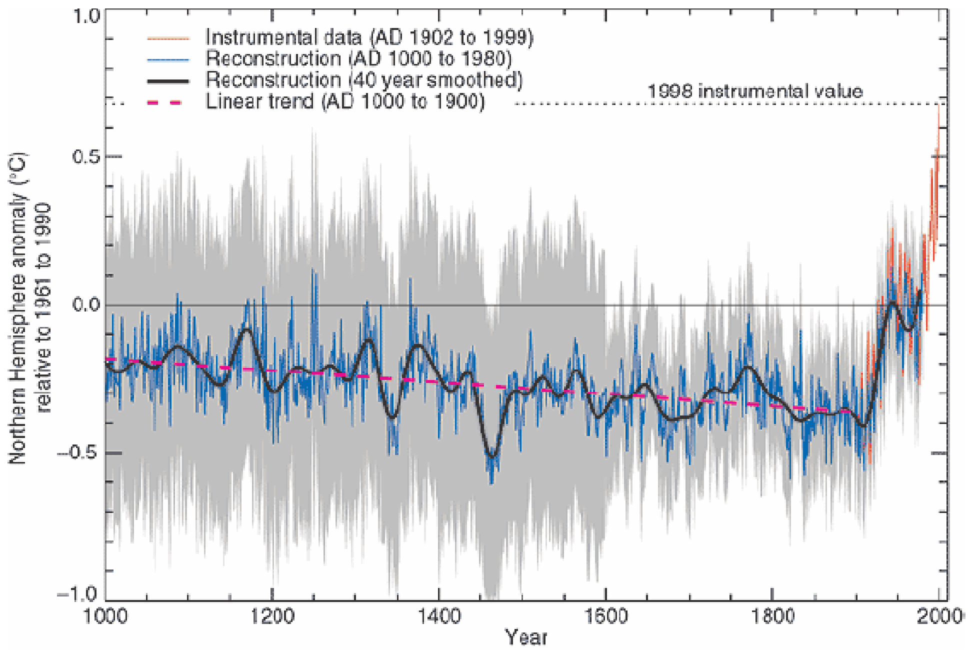
Figure 4.3. Global near-surface temperatures for land, ocean, and combined land and ocean



Source: http://www.ncdc.noaa.gov/oa/climate/research/trends.html

In another large-scale exercise, Mann et al. (1998, 1999) used historical data from tree rings, ice cores, and other 'proxies' to reconstruct the northern hemisphere's mean temperature over the past 1,000 years. This resulted in the 'hockey stick' chart (Figure 4.4) which reflects a dramatic positive shift in temperatures over the last 30 years or so.

Figure 4.4: Northern Hemisphere's Mean Temperature over the past 1,000 years

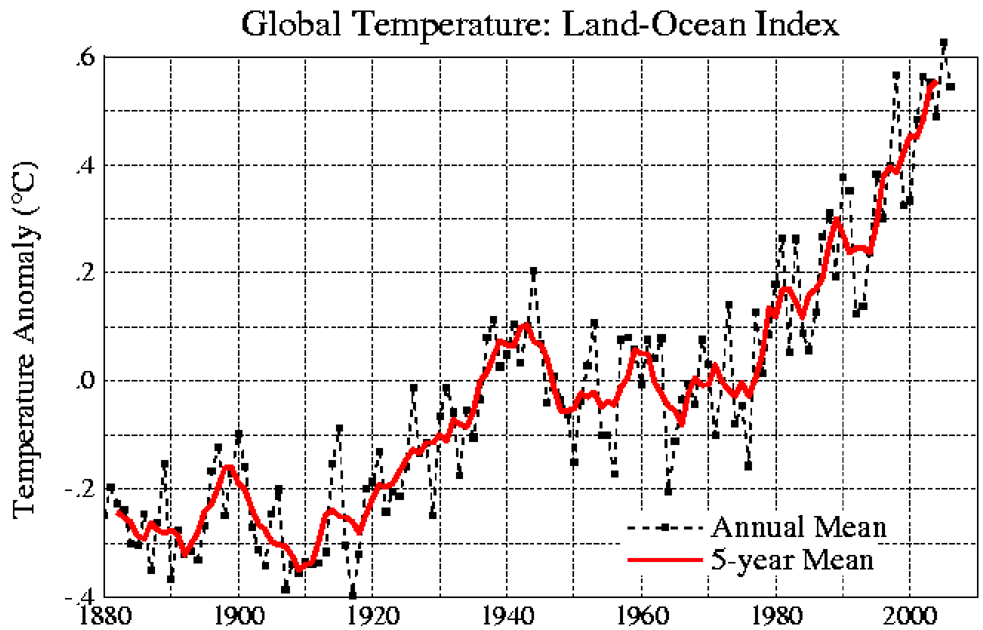


Source: Intergovernmental Panel on Climate Change (2001), vol.II, Summary for Policy Makers.

While this study and its results prompted heated debates when it was released, the conclusions are now widely accepted by most scientists, including, importantly, by a specially convened committee of the US National Academy of Sciences. The committee's chair is reported as saying that it has a "high level of confidence" that the second half of the 20th century was warmer than any other period in the past four centuries.[42]

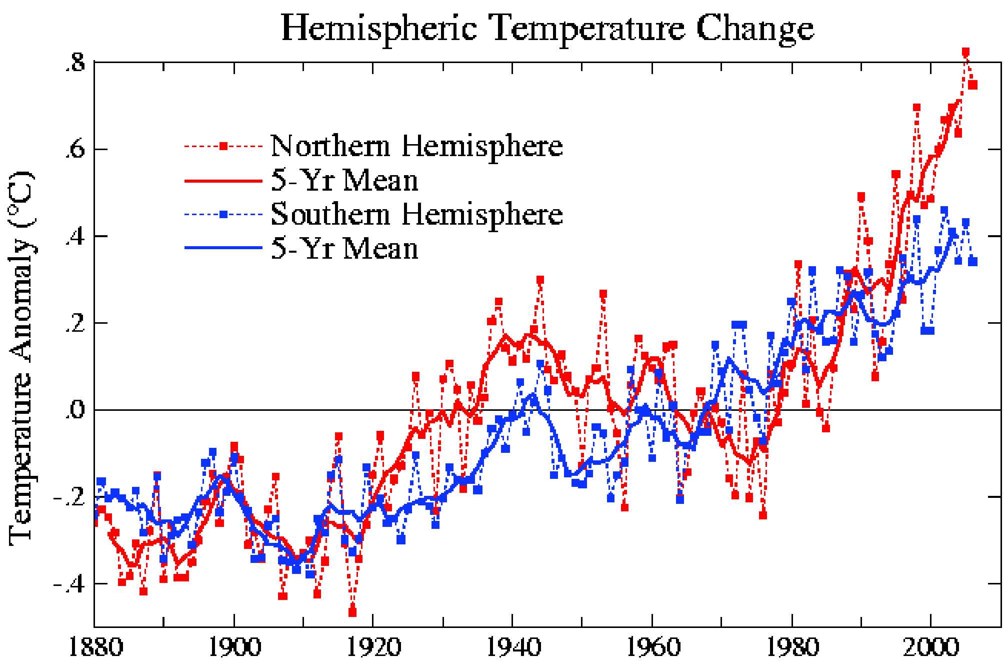
Another study, completed by NASA, focused on the past 125 years relied mainly on instrumental data to evaluate global warming. Below are graphs from this study which reflect both general global warming trends (Figure 4.5) and further localizes the results to graphically illustrate both Northern and Southern Hemispheres independently over the period (Figure 4.6).

Figure 4.5: Global Annual Mean Surface Air Temperature Change



Source: NASA Goddard Institute for Space Studies website, Jan. 2007

Figure 4.6: Annual Mean Temperature Change for Hemispheres



Source: NASA Goddard Institute for Space Studies website, Jan. 2007

5. Model Results

In order to determine whether ski resort returns have generally suffered as a result of climate change historically, econometric analyses were engineered to run a "skier visit" series for each of the five regions: Pacific West, Rocky Mountain, Midwest, Northeast, and Southeast.

These series considered annual skier visits in each region and quantified their correlation to annual snowfall accumulation, the independent variable used to signify climate change in the model. The variables are defined below:

Variable	Definition:
SV:	Skier Visits
SF:	Snowfall

The results were fairly predictable. First, resorts which depend on heavy weekend traffic from dense urban areas, predominately areas along both coasts exhibit more sensitivity to natural snowfall accumulation than those resorts in central regions of the country. This is consistent with prior studies which conclude that the Northeast and the Pacific West regions are more susceptible to varied conditions due to their reliance on weekend visits by patrons who can spontaneously change/cancel plans in the event of marginal conditions.

Meanwhile, ski vacations booked in the Rocky Mountain region, for instance, customarily require planning and investment long before any snowfall forecasts can be issued. This fact coupled with visitors' propensity to align ski vacations with inflexible work and school schedules, results in skiers proceeding with scheduled trips, conditions notwithstanding.

5.1. The Regional Series Outcome:

5.1.1. Northeast

The weather stations selected to represent snowfall in this region were both located in Vermont. The decision to use two (2) stations was predicated on the quality and consistency of data available for both, coupled with their proximity to ski resorts. The first, *Cavendish*, is located approximately 6.5 miles from both *Okemo Resort* and *Ascutney Mountain*. The next station, *Cornwall,* is approximately 20 miles from both *Mad River Glen* and *Sugerbush* and exhibits consistent geographic characteristics.

The results from the Northeast time-series (Table 5.1) reflect a modest (positive) correlation regionally between total annual snowfall and skier visits. For every one hundred (100) additional inches of snowfall, an additional 1.52 million skier visits are anticipated, resulting in a 14% increase. While this is a notable percentage increase, it's important to keep in mind that the regional average snowfall is only 98 inches; hence an additional 100 inches of snow would constitute a record breaking year.

Table 5.1: Northeast – Skier Visits and Annual Snowfall Totals

Northeast Skier Visits vs. Annual Snowfall

Skier Visits = 10.68 + 0.0152 SF

Regression Statistics	
Multiple R	0.455493557
R Square	0.207474381
Adjusted R Square	0.175773356
Standard Error	1.404501447
Observations	27

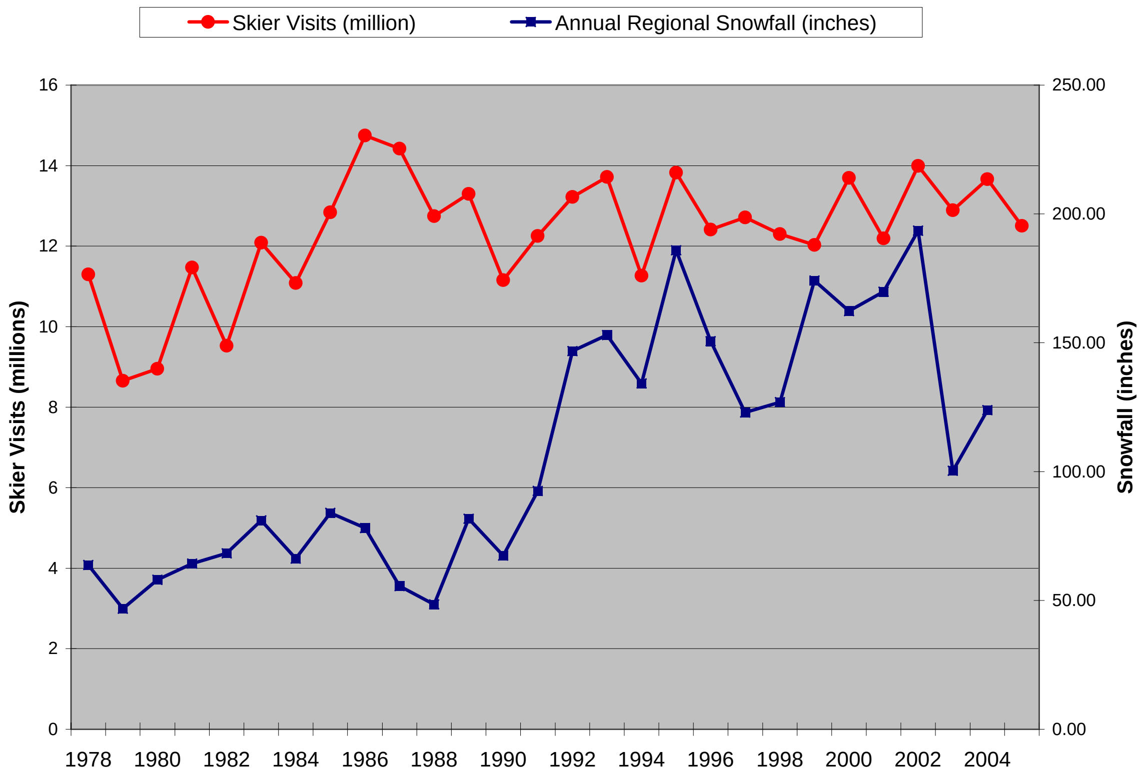
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	12.9102769	12.9102769	6.544721572	0.016960755
Residual	25	49.31560784	1.972624314		
Total	26	62.22588474			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	10.68002051	0.692639119	15.41931464	2.80879E-14	9.253503555
Annual Regional Snowfall (inches)	0.015189988	0.005937612	2.558265344	0.016960755	0.002961246

Figure 5.1 is a graphical depiction of natural snowfall against skier visits for the period 1978 - 2005. During the early 90's there was a dramatic increase in snowfall, to which skier visits respond in kind. However there is a stark disconnect between total snowfall and visits occurring between 1985 and 1988. With the exception of this anomaly, the trend in skier visits corresponds with plentiful snowfall as is discernible during the seasons of 1993, 1995, and 2002.

Figure 5.1: Northeast Data



5.1.2. Southeast

To approximate snowfall for the Southeast region, annual data was averaged from four (4) stations which returned complete data sets and were within close proximity of local resorts. Two stations were located close to *Ski Denton* in northwestern Pennsylvania, with one located in western Maryland, very close to western Maryland's *Wisp* resort. The last station is located in West Virginia and is within 15 miles of both *Canaan Valley* and *Timberline Four Seasons.*

The results of the regression analysis are below (Table 5.2):

Table 5.2: Southeast – Skier Visits and Annual Snowfall Totals

Southeast Skier Visits vs. Annual Snowfall

Regression Statistics	
Multiple R	0.286986494
R Square	0.082361248
Adjusted R Square	0.045655698
Standard Error	0.631884335
Observations	27

Skier Visits = 4.22 + 0.0107 SF

ANOVA

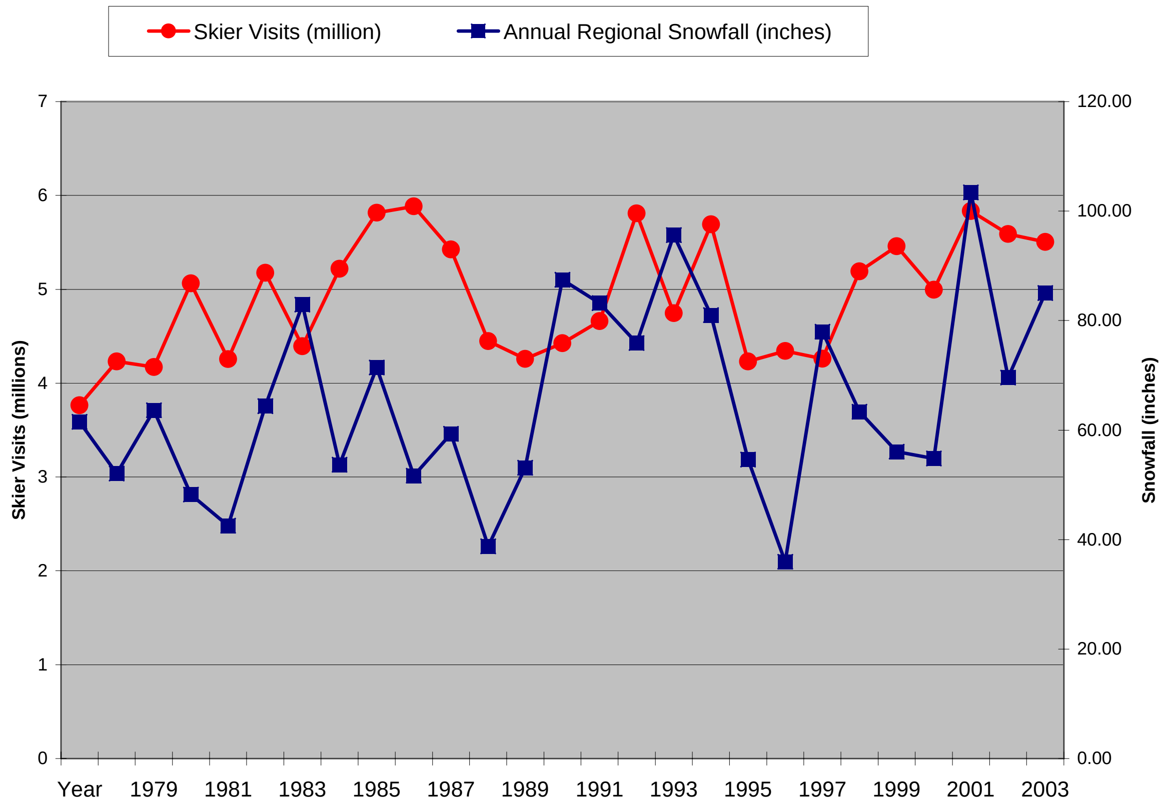
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.895914076	0.895914076	2.243836363	0.14666899
Residual	25	9.981945331	0.399277813		
Total	26	10.87785941			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	4.22040915	0.482510606	8.746769698	4.44645E-09	3.226659963
Annual Regional Snowfall (inches)	0.01068637	0.007134025	1.497944045	0.14666899	-0.004006429

Although slight, the model reveals a positive correlation between snowfall and skier visits. Per these results, an additional fifty (50) inches of snowfall would translate to approximately 534,000 additional skier visits, which represent a 12.7% bump in expected business. Again, it's necessary to point out that the average snowfall for the Southeast if only 66 inches, therefore an increase of 50 inches would be a banner year for this region.

Figure 5.2 shows natural snowfall against skier visits for the Southeast during the period 1978 - 2004. Here the endogenous variable does not appear to mirror snowfall data, as there is a clear disparity in both 1980 and 2000 when increases in snowfall result in *reductions* in skier visits. Resorts in this region are characterized by their strong dependence on artificial snowmaking, which allows them to offer reliable conditions in spite of lackluster snowfall, insulating them against dry seasons.

Figure 5.2: Southeast Data



5.1.3. Midwest

The Midwest region was represented by two (2) stations which were again proximate to local ski resorts and had rich data sets available. *Minocqua Dam* is located in northern Wisconsin and is approximately 20 miles north of *Camp 10*, a small scale resort serving northeast Wisconsin. The other station, *Ironwood*, is located in the northwest panhandle of Michigan roughly 6 miles from *Whitecap Mountain*, a resort in northern Wisconsin.

The Midwest regression analysis (Table 5.3) results denote a statistically insignificant correlation between snowfall and skier visits. This lack of connection is not entirely unexpected for this region which is characterized by small family oriented resorts. One hypothesis is that the weather conditions which deliver such heavy snowfall are harsh and serve to dissuade families that are in search of more inviting conditions. The numbers of would-be patrons that opt to stay home serve to offset the gains in visits one would expect due to heavy snowfall.

Another explanation could be that the region effectively shuts down in response to large amounts of snowfall, as local infrastructure is simply not able to handle the burden, thus stymieing transportation.

Table 5.3: Midwest Data

Midwest Skier Visits vs. Annual Snowfall

Skier Visits = 7.41 - 0.00132 SF

Regression Statistics	
Multiple R	0.0602204
R Square	0.0036265
Adjusted R Square	-0.0362284
Standard Error	0.7907522
Observations	27

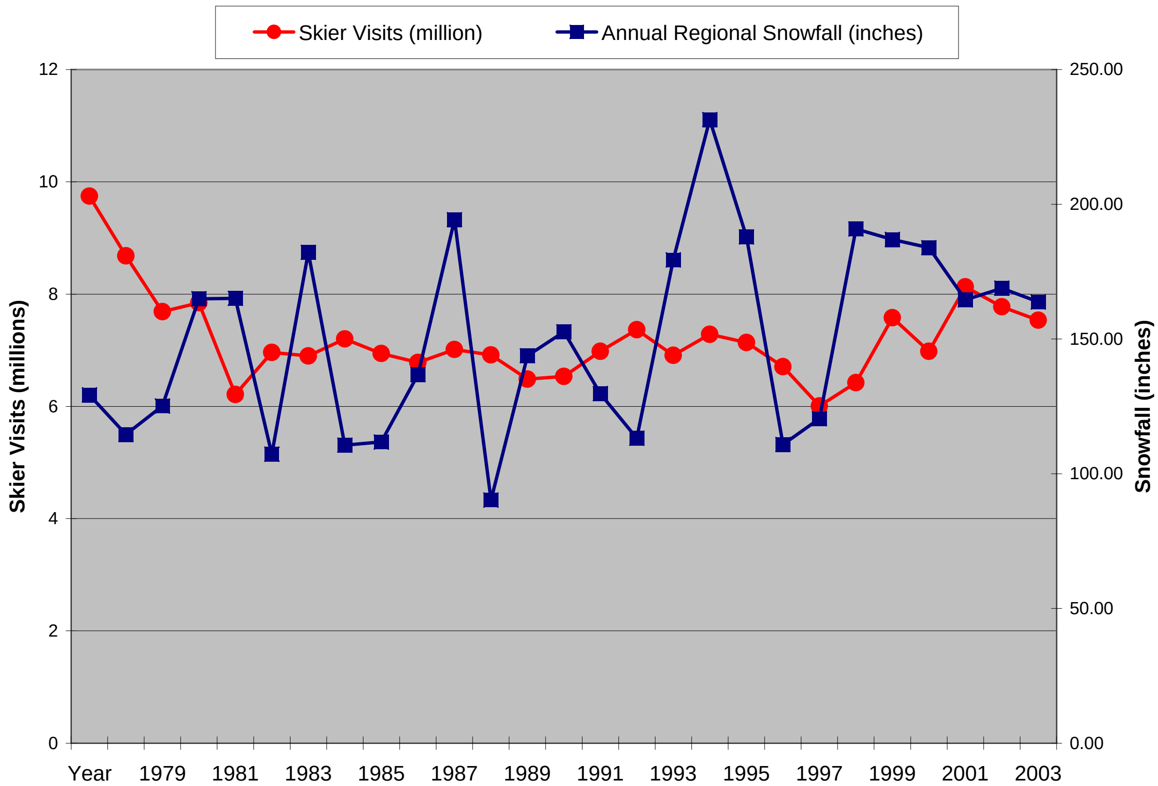
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.056896577	0.056896577	0.090992443	0.765414239
Residual	25	15.63222594	0.625289038		
Total	26	15.68912252			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*
Intercept	7.410625	0.677733847	10.93441777	5.13034E-11	6.014806044	8.806444	6.014806044
Annual Regional Snowfall (inches)	-0.0013248	0.004391842	-0.301649537	0.765414239	-0.01036997	0.0077204	-0.01036997

Figure 5.3 provides an illustration of Midwest skier visits and snowfall totals data. This chart displays the absence of really any contemporaneous relationship between the two. The endogenous variable simply does not respond to relatively dramatic swings in the exogenous variable. These results are indicative of a region in which snowpack is dependable and ski operators are less vulnerable to variations in snowfall.

Figure 5.3: Midwest – Skier Visits and Annual Snowfall Totals



5.1.4. Rocky Mountains

As the preeminent ski destination in the United States, if not all of North America, the Rocky Mountain region has earned an international reputation for its steep vertical drops and deep snowpack. Resorts in this region are also more challenging to reach, a characteristic which works to the local ski industry's advantage.

After evaluating weather station data from Montana, Wyoming, and Utah, two (2) representative stations in Colorado were selected. The *Dillon* and *Steamboat Springs* stations both provided the best data and closely proximate the regional snowfall trends. The *Dillon* station is roughly 15 miles from *Vail/Beavercreek*, while the *Steamboat Springs* station is located at the resort which bears its name.

As the results below indicate (Table 5.44), snowfall does not determine the magnitude of demand in the Rockies. If in a given year the region received a hundred (100) additional inches of snow, the model predicts no concomitant shift in skier demand. This is a consequence of the significant time and capital investment required to arrange travel to the Rocky Mountain region. Also, these resorts are fully prepared for periods of marginal snowfall and therefore visits do not diminish.

Table 4: Rocky Mountain Data

Rocky Mountain Skier Visits vs. Annual Snowfall

Skier Visits = 17.94 - 0.0048 SF

Regression Statistics	
Multiple R	0.109248093
R Square	0.011935146
Adjusted R Square	-0.027587448
Standard Error	1.876175563
Observations	27

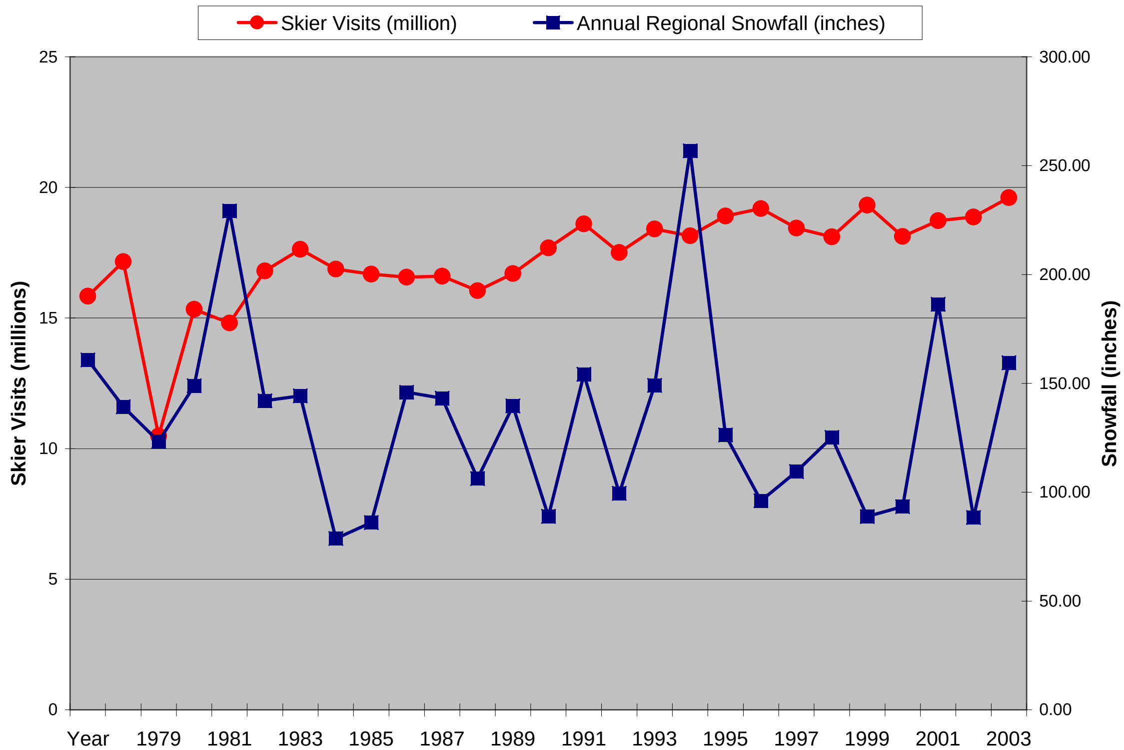
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.062990141	1.062990141	0.301982855	0.587517895
Residual	25	88.0008686	3.520034744		
Total	26	89.06385874			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	17.93843527	1.212224319	14.79795034	7.12232E-14	15.44181257
Annual Regional Snowfall (inches)	-0.004757218	0.008656891	-0.549529667	0.587517895	-0.022586418

Figure 5.4 illustrated these results with a graph depicting a trend of steadily increasing skier visits that is segregate from the effects of snowfall. This was evident in Utah this year, where the state reported a record-breaking year for business in spite of lackluster snowfall. Carolyn Daniels, spokeswoman for *Powder Mountain*, reported that while a relatively lean year for snow prevented some locals from coming to the mountain, visitors from out of state more than made up for the shortfall.[43]

Figure 4: Rocky Mountains – Skier Visits and Annual Snowfall Totals



5.1.5. *Pacific West*

The Pacific West is the final region considered in this study and encompasses California, Washington, Oregon, Nevada, as well as other states. Gathering complete data for this region proved challenging as numerous weather stations with complete data sets were situated at lower elevations and therefore reported extended periods of insignificant snow accumulation. Consequently, after consulting with various industry professionals, the data utilized here is from one station, *Tahoe City*, which is proximate to several renowned California resorts and serves as an appropriate proxy for the region.

While the correlation between visits and snowfall is relatively minor, the model (Table 5.5) does generate a positive response to increased snowfall. This supports the theory that skiers in this region are more apt to spontaneously travel to the resorts during periods of superior snowfall. Specifically, the model calculates an approximately 850,000 uptick in skier visits in response to an additional hundred (100) inches of snowfall during a given season.

Table 5.5: Pacific West Data

Pacific West Skier Visits vs. Annual Snowfall

Skier Visits = 8.97 + 0.0081 SF

Regression Statistics	
Multiple R	0.460015621
R Square	0.211614372
Adjusted R Square	0.180078947
Standard Error	0.970828735
Observations	27

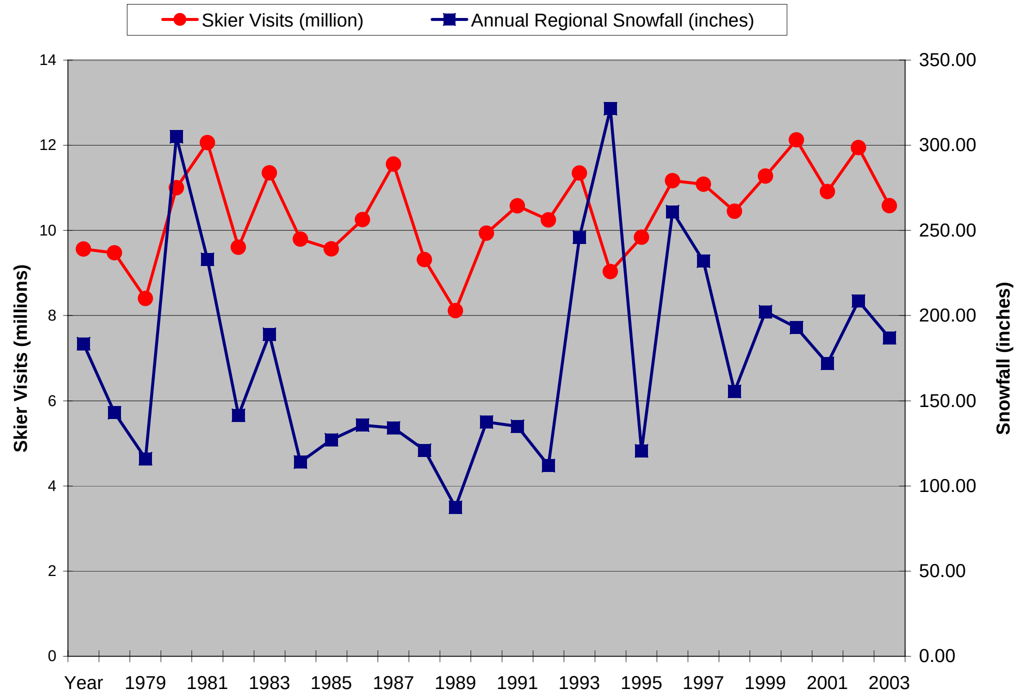
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	6.324580347	6.324580347	6.710370032	0.015765177
Residual	25	23.56271084	0.942508434		
Total	26	29.88729119			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	8.97301622	0.578669407	15.50629101	2.47182E-14	7.781224277	10.164808
Annual Regional Snowfall (inches)	0.008125742	0.003136822	2.590438193	0.015765177	0.001665337	0.0145861

Figure 5.5 is the chart reflecting the data trends for Pacific West. A trend is observable over the thirty year period in which skier visits relate to snowfall totals. This relationship is most pronounced in the years between 1981 and 1984 where the variation in the endogenous variable, skier visit, closely mirror the patterns of snowfall. One can also observe a similar pattern over the last decade, with skier visits lagging snowfall ever so slightly.

Figure 5.5: Pacific West – Skier Visits and Annual Snowfall Totals



5.2. Implications for the Future

While the limited VAR model used in this study does not attempt to account for the many unique variables that come into consideration when decisions whether to ski are made, it is important to recognize the straightforward relationship between resorts' success and climate conditions. Coupled with today's most advanced climate modeling technology, a greater understanding of future consequences for the ski industry will help guide mitigation strategies and encourage developers to look towards the future and begin considering where new opportunities will surface.

6. Forecast Climate Change: North America

Over the next 30 to 50 years, as the global climate continues to warm, many people and nations will find themselves in possession of land and resources of rising value, while others will suffer dire losses and be left with desiccated property unfit for everyday life. Economic change means winners as well as losers. Huge sums will be made and lost as the global climate changes.[44]

The natural question arises of exactly *which* regions of North America will benefit from milder winters and which areas will lose. Using the most sophisticated models available, this section will provide a broad-brush summary of the forecast climate changes in the United States and discuss the implications of a warming world.

6.1. *Summary of IPCC Results*

The IPCC report offers a sobering assessment of the impacts of climate change in North America during the coming century. As the summation of twenty-one (21) distinct models from scientists around the world, the report provides a range of potential future outcomes, each with varying degrees of confidence.

By closely examining the effective illustrations – maps and graphics – within the report, the thesis extrapolated conclusions about future changes.

Globally, all 21 models represented in the IPCC report, project a steady increase in mean surface air temperature (SAT) throughout the 21st century. This change is caused by increases in anthropogenic greenhouse gas emissions and the associated radiative heating that follows.

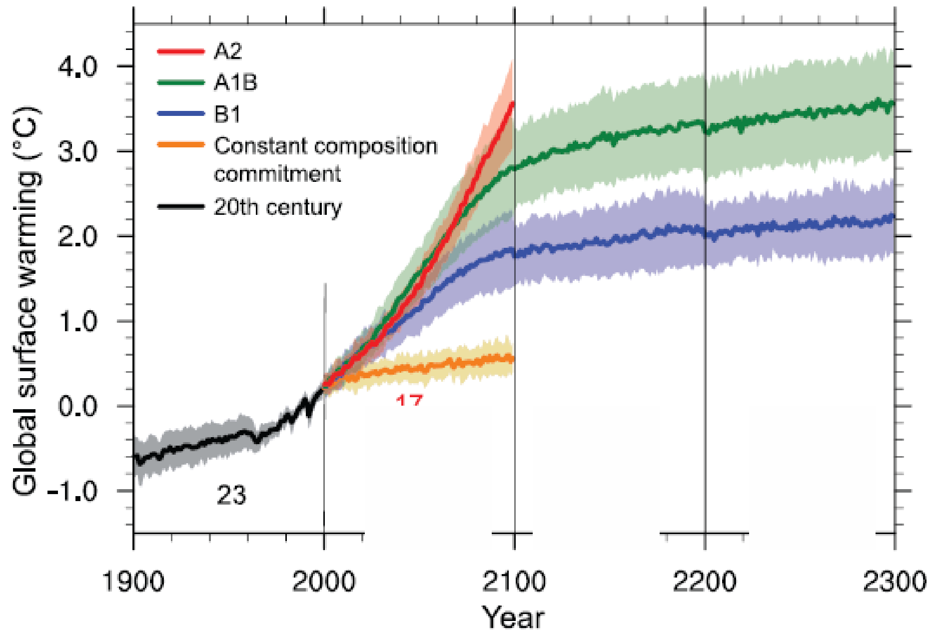
The 21 IPCC models take into account varying levels of future greenhouse gas (GHG) emissions. Therefore different conclusions are drawn. The author of this thesis consulted with Professor Peter Stone, a Harvard Ph.D. in Applied Mathematics (1964) and, most recently, Director of the MIT Climate Modeling Initiative (1995-2004), to determine upon which model the study should base its conclusions. Based on Professor Stone’s feedback, the thesis will focus on model “A1B”, which uses moderate levels of GHG emissions as its input. This is considered by Professor Stone to be the most accurate depiction of future climate change.

Additionally Professor Stone and his team provided their forecast of global increases over a 30 year timeframe. The projected increases in global mean surface temperature from the decade 2002-2011 to the decade 2032-2041 and their respective confidence intervals follows:[45]

- 80% confidence interval: 0.78°C to 1.06°C (1.4°F – 1.91°F)
- 90% confidence interval: 0.72°C to 1.18°C (1.33°F – 2.12°F

Figure 6.2 below shows the forecast increases in global temperatures relative to the average temps of 1980 to 1999. Observe that the A1B model calculates a range of 1.8°C - 2.0°C (2.25°F – 2.6° F) increase over the next half century.[46]

Figure 6.2: Forecast surface warming for scenarios A2, A1B and B1. Lines show the multi-model means, shading denotes the ±1 standard deviation range of individual model annual means.



Source: IPCC Fourth Assessment, 2007. pg. 762

6.2. North America Climate Change Projections

6.2.1. North American Temperature

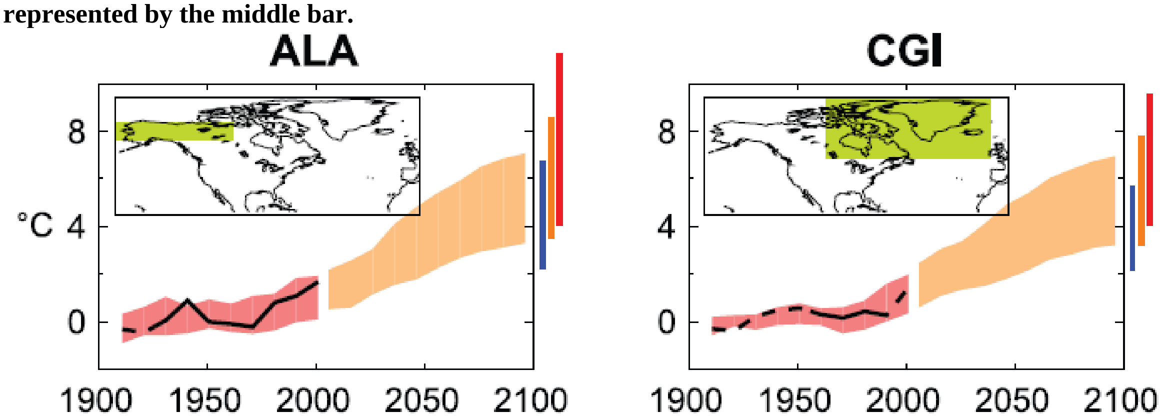
The IPCC report deduces that all of North America is *very likely* to warm during this century and states that the annual mean warming is going to exceed the global mean.[47]

In northern regions of the continent, warming is likely to be most pronounced during the winter months, which will have a direct and negative impact on winter snowpack.[48]

The report goes on to state that the lowest winter temperatures are likely to increase more than the average winter temperature in northern North America; in other words, the coldest and harshest days of winter will realize the most change, which could be a positive by reducing the number of unskiable days due to adverse conditions.

Figure 6.3 below displays Alaska and Northern Canada respectively. The are the regions where the largest warming trends are projected to occur. The simulations reports as much as a 10°C (18°F) temperature increases in these regions by 2100 due primarily to the positive feedback resulting from a reduction in snow cover, or ablation.

Figure 6.3: Temperature trends in Alaska and Northern Canada for 1906 to 2005 (black line); and as projected for 2001 to 2100 by models for the A1B scenario (orange envelope). The bars at the end of the orange envelope represent the range of projected changes for 2091 to 2100. The A1B scenario is represented by the middle bar.



Source: IPCC, Fourth Assessment, 2007. pg. 889

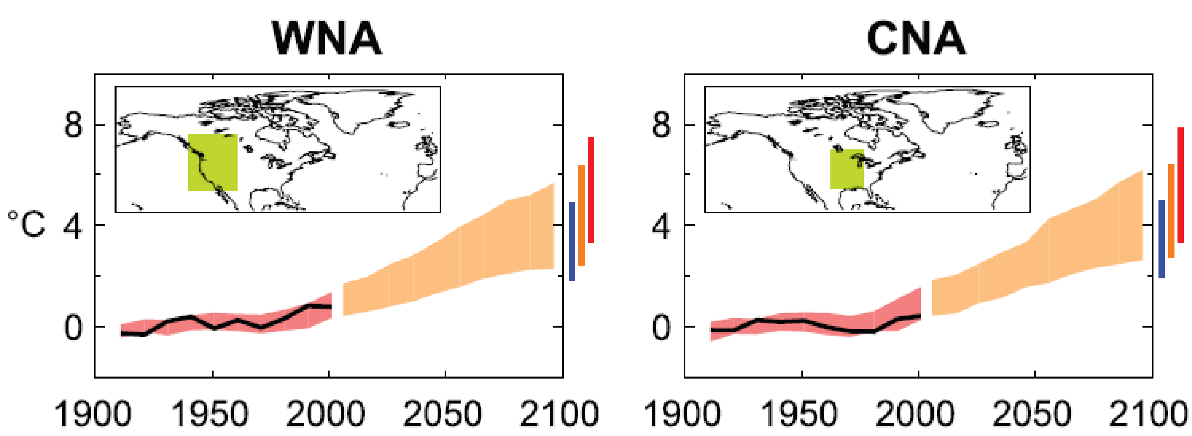
This prediction of considerable warming in those areas characterized today by harsh and frigid weather, carries with it great promise for future ski resort development opportunities. Alaska, British Columbia, and Alberta all lay claim to promising peaks which will benefit from warmer temperature and increased snowfall. Several examples follow.

Today, Alaska's largest ski mountain, *Alyeska*, located some 40 miles southeast of Anchorage boosts on average some 782 inches of snow a year. The summit is 4,000 feet, with a rise of 2,500 feet. There are 1,000 skiable acres; 89 % of which is for intermediate or advanced use. The popularity of this area will continue to gain as climate change makes conditions more desirable.[49]

In January 2007, Intrawest Corporation announced plans to develop Mt. Mackenzie, a remote peak about 175 miles (5 hours) east of Calgary. "*Revelstoke*", as it's known, will have 115 runs, 21 lifts, and a vertical drop of 1,829 meters (2,719 ft), the longest in North America. Capital investment is expected to surpass $1 billion[50].

Figure 6.4 represent Western and Central North America respectively and reflects warming trends which will impact the majority of ski resorts in the United States and Canada. On an annual-mean basis, surface air temperature are projected to warm from 2°C to 3°C (3.6°F to 5.4°F) along the western, southern and eastern borders of the continental over the next century. The northern regions are expected to realize an increase of more than 5°C (9°F).

Figure 6.4: Temperature trends for Western and Central North America for 1906 to 2005 (black line); and as projected for 2001 to 2100 by models for the A1B scenario (orange envelope). The bars at the end of the orange envelope represent the range of projected changes for 2091 to 2100. The A1B scenario is represented by the middle bar.



Source: IPCC, Fourth Assessment, 2007. pg. 889

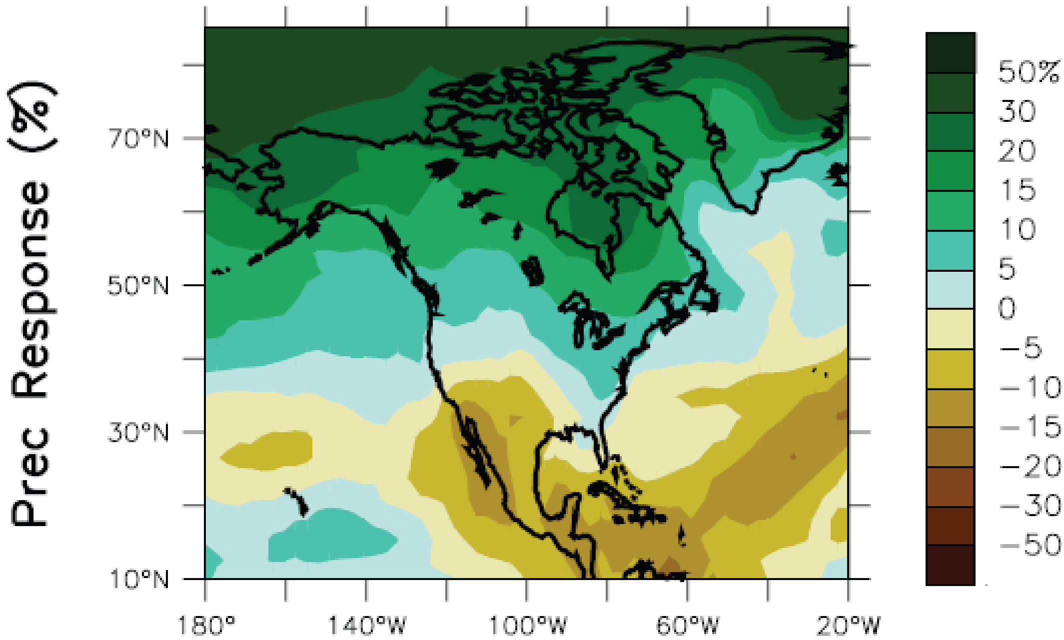
6.2.2. Precipitation

When considering precipitation, the report envisages varied changes across North America. Generally global warming is expected to be accompanied by an increase in annual mean precipitation over much of the continent with the largest increase believed to occur during the winter months in the greater Northeast regions. The increase is projected to be as much as 30%

(Figure 6.5) which will effect the ski operations in Canada and those located in the northeastern region of the United States.

IPCC does indicate likely decreases in precipitation in the southwestern region of the United States, specifically Arizona, New Mexico and Nevada.

Figure 6.5: Annual precipitation changes over North America from the A1B simulations.



Source: IPCC, Fourth Assessment, 2007. pg. 890

In southern Canada, precipitation is likely to increase in winter and spring, but decrease in summer.

Although there will be greater volume of winter precipitation, much of this will fall as rain, which naturally degrades ski conditions. Snow season length and snowpack depth are "very likely" expected to decrease in most of North America, with the exception of northern Canada, an area expected to realize both average temperature increases and an escalation in snow depths. This bodes well for future prospects of ski resorts in these northern mountainous regions.

The primary factor leading to North America's increasing temperatures and increasing precipitation is the influence of mid-latitude cyclones. These are large traveling atmospheric cyclonic storms up to 2000 kilometers in diameter with centers of low atmospheric pressure.[51] As the storm tracks shift poleward, the atmospheric moisture transport and convergence is projected to increase, resulting in a widespread increase in annual precipitation over most of the continent except the south and south-western part of the USA and Mexico.[52]

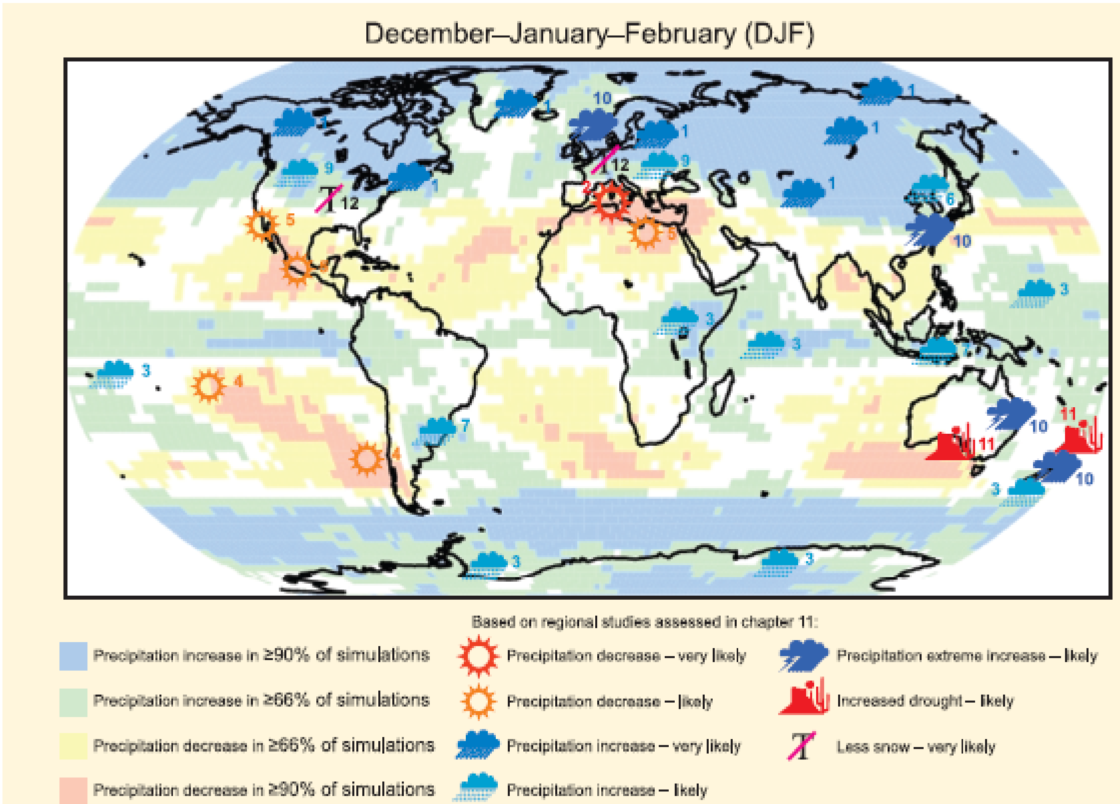
6.2.3. Snowfall, Snowpack

Snow accumulations are projected to decrease overall due to delayed autumn snowfall and earlier spring snowmelt. However in northern regions where winter precipitation is projected to increase, the additional snowfall could more than make up for the shorter snow season and yield increased snow accumulation in the next 20 – 30 years.

A similar scenario could unfold in the Rocky Mountains, although most models project a widespread decrease of snow depth in this region.[53]

The graphic on the following page was adapted from the IPCC report and provides a snapshot of long run trends affecting the globe during winter months. The blue shading in the background signifies the expected increase in precipitation over much of North America, with the exception being the southern latitudes regions of the Southwest and Mexico. The icons over North America denote less snow and warmer temperatures in the Midwest and Rock Mountains, while increases in precipitation in Canada.

Figure 6.6: Winter Trends Resulting from Warming



(1) Very likely annual mean increase in most of northern Europe and the Arctic (largest in cold season), Canada, and the North-East USA; and winter (DJF) mean increase in Northern Asia and the Tibetan Plateau.

(2) Very likely annual mean decrease in most of the Mediterranean area, and winter (JJA) decrease in southwestern Australia.

(3) Likely annual mean increase in tropical and East Africa, Northern Pacific, the northern Indian Ocean, the South Pacific (slight, mainly equatorial regions), the west of the South Island of New Zealand, Antarctica and winter (JJA) increase in Tierra del Fuego.

(4) Likely annual mean decrease in and along the southern Andes, summer (DJF) decrease in eastern French Polynesia, winter (JJA) decrease for Southern Africa and in the vicinity of Mauritius, and winter and spring decrease in southern Australia.

(5) Likely annual mean decrease in North Africa, northern Sahara, Central America (and in the vicinity of the Greater Antilles in JJA) and in South-West USA.

(6) Likely summer (JJA) mean increase in Northern Asia, East Asia, South Asia and most of Southeast Asia, and likely winter (DJF) increase in East Asia.

(7) Likely summer (DJF) mean increase in southern Southeast Asia and southeastern South America

(8) Likely summer (JJA) mean decrease in Central Asia, Central Europe and Southern Canada.

(9) Likely winter (DJF) mean increase in central Europe, and southern Canada

(10) Likely increase in extremes of daily precipitation in northern Europe, South Asia, East Asia, Australia and New Zealand.

(11) Likely increase in risk of drought in Australia and eastern New Zealand; the Mediterranean, central Europe (summer drought); in Central America (boreal spring and dry periods of the annual cycle).

(12) Very likely decrease in snow season length and likely to very likely decrease in snow depth in most of Europe and North America.

Source: IPCC, Fourth Assessment, 2007

7. Future Change In Regional Snowfall

While the efficiency of climate models continues to evolve, yielding ever more detailed predictions, the GCM's remain limited in their ability to forecast seasonal changes in specific locations. It's under this pretense that the paper will consider potential changes in snowfall and the ensuing impact on the five (5) primary US ski regions. For these forecast the study relied on a 2000 report released by US Global Change Research Program (USGCRP), which bases conclusions on the projections from the Hadley Centre in the United Kingdom and the Canadian Centre for Climate Modeling and Analysis. This USGCRP study focuses on North America and serves as a comprehensive resource for localized climate change forecasts.

Inputting these localized snowfall forecasts into the models elucidated in Chapter 5.0, the study will interpolate future impacts to each region's ski industry.

7.1. Northeast

For the region as a whole, the period between the first and last dates with snow on the ground has decreased by 7 days over the last 50 years, resulting in a shorter snow season.[54] This observable fact was clearly on display during the 2006/2007 season which did not realize appreciable snowfall in the Northeast until mid-January.

Over the next 30+ years, USGCRP predicts increases in winter precipitation of upwards of 10%, which will lead to increased snowfall during that timeframe. However as temperatures continue to rise more of this precipitation will occur in the form of rain hampering ski conditions.

Using the Northeast model (Section 5.1.1) developed for this study, an increase in snowfall of 10% would result in approximately 170,000 additional annual skier visits. While statistically speaking this figure is immaterial, the fact that there is a predicted increase is noteworthy for the Northeast region. The formula follows below:

Formula 7.1: $SV_{NE} = 10.68 + 0.0152\ SF_{NE}$

The Northeast also features numerous microclimates which experience different changes. For instance, the Great Lakes are very likely to experience decreased ice cover as warming progresses. This reduction in ice cover will add significant moisture to southbound winter cold fronts coming from Canada thereby fueling the "lake effect" snow storms that dump significant amounts of snow on the Buffalo, NY area. Eventually, it's expected that warming will turn this precipitation into rain, but over the next 30+ years snowfall records are set to fall.[55]

7.2. Southeast:

The Southeast will likely experience a high degree of warming. Here there is also an expectation for increased precipitation. However this precipitation is expected to manifest itself as rain since the average mean temperature is the highest of the five regions.

The USGCRP report predicts an increase in annual precipitation of 10 – 15%; however the concurrent rise in temperatures will dramatically impact snowfall accumulation, resulting in a loss of approximately 40%. Although the model (Formula 7.2) only projects an approximately 280,000 reduction in visits when this figure is input, there's little doubt that severe reduction will bring with it serious implication for all but the largest operators. We anticipate many closures over the next three to four decades.

Formula 7.2: $SV_{SE} = 4.22 + 0.0107\ SF_{SE}$

7.3. Midwest

Throughout the 20th century, the northern portion of the Midwest, where the majority of resorts are located, has warmed by almost 2.3^{o}C (4.1°F). Annual precipitation has increased, up some 20% in areas, with much of this coming from singular heavy precipitation events.[56]

The length of the snow season over the last 50 years has increased by about 6 days per year in the northern Great Lakes area. This trend is expected to continue over the next 30 years as the "lake effect" on snowfall becomes more pronounced in this region, with an estimated 20% increase in precipitation. Although counter intuitive, plugging this estimate into Midwest model (Formula 7.3) results in a negative impact on skier visits.

Formula 7.3: $SV_{MW} = 7.41 - 0.00132\ SF_{MW}$

While statistically this result is irrelevant, it does serve to reinforce the argument posed in Section 5.1.3 that skier visits are negatively impacted by increases in snowfall due to skiers' proclivity towards more manageable conditions.

7.4. Rocky Mountains

When considering the complex mountainous regions defining the landscape of the Rocky Mountain region, studies point to a decline in winter snowpack and a hastening of snowmelt due to regional warming[57]. This region has generally become wetter over the last century with observed increases in precipitation in some areas greater than 50%.

Looking to the future, the temperature in the Rocky Mountain region is predicted to increase, with a forecast decrease in precipitation. This recipe of warming combined with decreased precipitation will result in shorter ski seasons. Resorts at lower elevations will experience the most severe impact to their business.

The two models employed by USGCRP project a 3.8°F (2.1°C) winter warming and 4.8°F (2.7°C) warming, respectively by the year 2030. While is there is generally dissention as to the magnitude of change in snowfall, for the purposes of this study, the thesis will assume a 10% decrease (Formula 7.4). This amount of decrease in snowfall would results in only a roughly 3% impact to skier visits.

Formula 7.4: $SV_{RM} = 17.94 - 0.0048\ SF_{RM}$

It is the author's contention however; that there will be an observed *increase* in skier visits in 30+ years, as a high percentage of skiers from the enfeebled Southeast region will elect to travel west to find superior conditions. The Rocky Mountain region stands to gain from this displaced segment of the market.

7.5. Pacific West

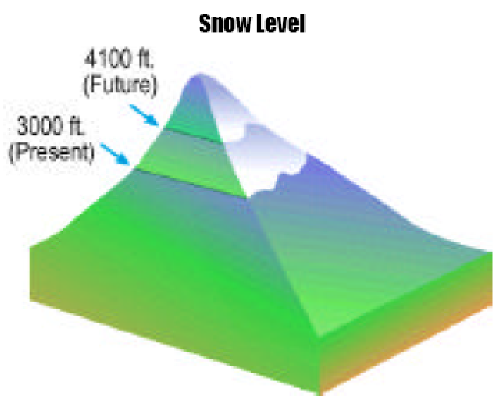
The Pacific West region has experienced warming of approximately 3°F (1.7°C) over much of the region, with nearly equal warming in summer as has occurred in winter. The length of the snow season in California and Nevada has decreased some 16 days from 1961 – 1996.[58]

Annual temperatures are projected to increase nearly 4°F by the year 2030, which will be accompanied by considerable increases in winter precipitation. The greatest increase is expected over California, where USGCRP reports as much as a 40% boost. Per the model (Formula 7.5), this only nets a 6% increase in skier visits however, as much of this gain will come in the form of rain, degrading skiing conditions.

Formula 7.5: $SV_{PW} = 8.97 + 0.0081\ SF_{PW}$

Figure 7.1 illustrates the impact warming will have on the snow line, which will shift vertically over 1,000 s.f. This will not have an immediate effect on resorts in the region, but serves as a harbinger of things to come.

Figure 7.1: Estimated snowline shift by 2050, assuming about 4ºF warming.



Source: R. Leung, Pacific Northwest National Laboratory.

8. Adaptation and Risk Mitigations

Global warming will have an increasingly severe affect on the ski industry in the coming decades. Although accurate weather forecasts are not available more than a week or so in advance, the fact that there will be greater variability from year to year is indisputable. Recognizing this fact will enable operators to plan accordingly and adopt strategies designed to minimize the negative corollaries that follow. This section will examine the various tools available to stakeholders in the winter recreation business and discuss the merits of each.

8.1. Artificial Snowmaking

The most ubiquitous strategy to mitigate climate change risk is the installation of snowmaking equipment. First implemented in 1953 at Grossinger's Resort in New York,[59] snowmaking has become a principle fixture in the industry, with an estimated 95% of resorts worldwide engaged in snowmaking to some degree.[60]

While snowmaking offers an invaluable – some would argue superior – substitute to natural snow during extended dry periods, the application of this technology is governed temperatures. Even after advances that permit artificial snow creation at ever higher temperatures, Mother Nature must still cooperate with both temperature and low humidity.[61]

Technological advances in snowmaking are reducing labor costs by enabling resorts to automate the process. *Keystone Resort* recently installed snow guns operated by computers which adjust air and water flows and automatically engages the system when weather conditions warrant. This automation is increasingly valuable as warmer temperatures may only dip below freezing for short spells and every moment available to make snow should be put to use.[62]

In a 2006 study, snowmaking was found to extend the average ski season in the Northeast by between 55 – 120 days.[63]

There are concerns, in that the practice requires a considerable amount of water. Blanketing a large resort can use millions of gallons of water each year.[64] Therefore resorts must acquire legal rights to water sources and/or install retention basins to collect and store runoff. As the industry's largest consumer of water, *Vail Resorts* has rights to more than 1 billion gallons of water held in four reservoirs, as well as rights to water from creeks and streams near each of its four Colorado ski areas[65]. This strategy has paid dividends for Vail, as they have been able to sustain their snowmaking program in the driest of years.

8.2. Weather Derivatives

Weather derivatives are a relatively new class of weather risk management tool that are structured like classic put options, call options, and swaps in the capital markets. Today the capital markets have an appetite for weather-related risk because it is, in principle, completely uncorrelated with other market sectors.[66]

Reportedly the over-the-counter market began in 1996 when Koch Energy (now Entergy-Koch) and Enron completed a swap for the winter of 1997 in Milwaukee, WI based on heating degree days (HDD). Since this contract the industry has expanded rapidly, with an estimated $19.2 billion of contracts traded on the Chicago Mercantile Exchange during 2007, as reported buy the Weather Risk Management Association (WRMA).[67]

The application of such derivatives is straightforward. In a typical temperature transaction if the average temperature over a predefined time period exceeds a certain threshold, the buyer of the contract is entitled to receive a payment from the seller based on the extent to which the average temperature exceeds the aforementioned threshold. The amount of payment is determined at the time the contract is executed and is predicated on the buyer’s sensitivity to adverse changes in temperature – for example increased costs of artificial snow making.

In the context of a ski area operator, derivative agreements can be structured based on snowfall and/or temperature. For instance, to protect against a dry snow season, a ski area might buy a snowfall put option, which is structurally equivalent to snowfall insurance. Additionally the resort operator might sell a snowfall call option or buy a swap, which would effectively provide a “revenue backstop” in the event of low snowfall.

Another application would be to use weather derivatives to finance marketing promotions intended to increase patronage (see 8.5 below). For instance a ski area could structure an advertising campaign in which a refund would be paid if snowfall over a 5-7 day period is below a predefined minimum. For a fixed price, the resort could completely hedge this exposure using weather derivatives.

Weather derivatives serve as a more cost effective hedge against weather risk than insurance policies, which have become increasingly expensive in light of recent poor snowfall seasons. In 1999-2000, Vail Resorts bought "reduced skier-day" insurance that paid $13.9 million when the resort didn't get much snow and lift ticket sales were down substantially. After that, insurance prices rose and Vail no longer carries such insurance.[68]

8.3. Revenue Diversification

As the skiing industry continues to grow and broaden its customer base, one of the key strategies is to develop new compelling entertainment offerings which cater to the non-skiing consumer. There are wide varieties of offerings available to engage and delight customers with all preferences. For examples, many resorts offer snowmobiling or cross-country skiing to the active non-downhill skier. While more passive activities involve high-end day spas, indoor pools, retail shopping alternatives, and fine dining establishments.

Another method of diversification available to large scale operators is the acquisition/development of resorts in dissimilar geographic locations. While in any given year snow conditions could be poor in specific regions, the risk to operators is greatly assuaged by owning operations in disparate areas that are exposed to completely different weather patterns. For example, during the 2004/2005 season Booth Creek, the fourth largest ski resort owner in North America, was able to relieve some of the financial stress felt at *Summit at Snoqualmie*, due to exceptionally poor conditions in the Pacific Northwest. The company relocated employees to their two California resorts and honored *Summit at Snoqualmie* season passes at other resorts in their portfolio. In another goodwill gesture, Booth Creek allowed season pass holders, who account for approximately half of skier visits, to extend their passes through the next season at no cost.[69]

8.4. Cloud Seeding

Employed by a handful of resorts in a bid to cause bountiful snowfall, cloud seeding is a process by which either dry ice or, more commonly, silver iodide aerosols are released into the upper part of clouds in order to fuel the precipitation process. Since most rainfall starts through the growth of ice crystals from super-cooled cloud droplets (droplets colder than the freezing point, 32 deg. F) in the upper parts of clouds, the silver iodide particles are meant to encourage the growth of new ice particles.[70]

A recent study from the Bureau of Reclamation estimates that in an average precipitation year, about one million acre-feet of additional snowpack water could be produced by seeding.[71] However the practice is expensive and a large majority of resorts remain skeptical as to its merits.

8.5. Marketing

There are a wide variety of marketing initiatives available to assuage growing concerns over conditions, specifically during the early and late stages of each season. Resorts often cater to a stratified audience, namely local day visitors as well as destination travelers, therefore it's imperative for resorts to tailor marketing efforts to both groups.

Marketing season passes to locals is a basic means to insulate against losses resulting from short-term fluctuations in weather, as locals are the most likely to cancel plans in response to marginal conditions. Vail, for instance, realized a quarter of their FY06 lift ticket revenue from season pass sales.

There are also a variety of marketing incentives intended to give customers comfort around booking early. For instance, during the 1999/2000 season, the American Ski Company guaranteed visitors to several of their New England resorts a 25% reduction on their next vacation in the event less than 70% of the skiable terrain was open during the Christmas/New Year holiday. Three of the resorts ended up having to provide these rebates due to warm temperatures.[72]

While these rebates can be costly, there are strategies to hedge this exposure, such as using weather derivatives as discussed in Section 8.2.

Finally, good old fashion luck can often serve as effective marketing. It's been reported than when Denver hosts Monday Night Football and snow is falling, Colorado resorts receive a surge in advance reservations. This is not backed up by hard statistics; but empirics strongly suggest it is true.[73]

9. Conclusion

Although the study confirms that claims of the imminent demise of the United States' ski industry at the hands of climate change are overstated, it is evident that this phenomenon poses a continuing long term threat the business.

The simple model employed for this paper demonstrates that the level of snowfall is only one of many variables that drive skiers' decisions whether to visit a particular resort. Savvy operators should be able to withstand poor snow seasons through a calculation application of any one or more of the techniques chronicled in this study.
While those resorts that rely on weekend skier visits, namely the Northeast, Southeast, and Pacific West, are most susceptible to the vicissitudes of snowfall, these resorts can counteract this risk through snowmaking, weather derivatives, or by diversifying their entertainment offerings.

Even with these new innovations however, there will come a time when daily temperatures simply will not support the creation of artificial snow and the preference of customer base will permanently adjust. Therefore it is imperative for today's resort developers to look beyond the classic short term business planning and investment time horizons and commit resources to address these long run concerns.

A well founded investment in regions that today perhaps are considered too frigid and uninviting might well hold the promise of considerable returns should conditions shift as forecast. This presents the ideal scenario to attract skiing enthusiasts, an audience that is not deterred by travel. This is supported by a survey of skiers which shows that this group will respond flexibly to changing snow conditions. During a period of snow-poor seasons, a 2003 study found that 49% of skiers would change to a ski resort that is more snow-reliable. 32% of skiers would ski less often and only 4% of respondents would chose not to ski.[74] This represents a paradigm shift in the industry and an opportunity for savvy resort developers to capture this displaced market.

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