“Will Ski Jumping Survive? Snowfall Patterns and the Future of the Sport”

By

Natasha Mattoon

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Project Advisor: Timothy Rawson

2nd Reader: Eeva Latosuo

3rd Reader: Karen Compton

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# Abstract

 The sport of ski jumping has made many adaptions over the last few decades due to changing weather conditions. My purpose through this project is to see how clubs throughout the world are adapting to these weather changes, what the weather data is showing and how clubs can be more prepared for future winters. The project consists of climate and ski jumping history, snow decline research, weather data on temperature, snowfall, and precipitation changes over the last 50 winter seasons; along with a questionnaire given to different clubs to learn about their changing weather perceptions and mitigation techniques. Temperature, snowfall, and precipitation are all interconnected.

This project specifically looking at the weather data in the locations of the club questionnaires received. The weather data shows that all studied ski jumping locations have seen an increase in temperature and the majority saw a decline in snowfall and an increase in precipitation. These overall trends have pushed clubs to pursue different mitigation techniques to keep the sport alive. The two major mitigation techniques are installing plastic onto the ski jumps for summer ski jumping, as well as winter snowmaking. Although these adaptations can be expensive projects, the amount of volunteer help, grants, sponsorships, and members keep the interest for these projects going. The best way to be prepared for future climate change and mitigation projects is keeping the interest high within the club, as well as having other clubs around for help and advice. In an effort to keep communication between clubs high, I have become a representative of the Local Environmental Observers (LEO) network to keep us all connected. The LEO network gives clubs a place to ask questions, post climate observations and post new mitigation techniques. Through this research I learned that rising temperatures has a major impact on ski jumping, snowfall, and precipitation patterns. Being well informed about these changes and potential mitigation techniques could be the key to keeping the sport of ski jumping alive for future generations to come.

# Introduction

 Since I was 5 years old I have been involved in the sport of ski jumping. Whether it be competing or coaching, ski jumping has been a big part of my life. It has been interesting to see the changes in the sport just over the last 15 years that I have been involved. Changes that I have seen are shorter winter seasons, more mid-winter melt downs and many clubs installing plastic on hills for jumping in the summer and/or snowmaking machinery for the winter. These observations and my involvement with the Karl Eid ski jumps in Anchorage has inspired my curiosity. I wondered if all ski clubs around the world are seeing the same trends and what is the best way of dealing with the changing trends to ensure future success in this sport. Therefore, I will be researching the impacts of climate change on winter sports, specifically ski jumping. I will address the following questions. What do studies show us about past and present snow decline? What does the future hold for winter sports and the industries connected to them? How will ski communities rise to the challenge of these trends to ensure the future of these winter sports, particularly ski jumping?

 My goal in this research project has been to find trends in seasonal winter weather patterns and mitigation techniques being used by ski clubs around the world. In the end I would like to share my finding with all ski jumping clubs to spread knowledge of weather changes and the best mitigation techniques used by others that they might not otherwise know about. My hope is to link this information through a network called the Local Environmental Observers (LEO). LEO was started in 2009 by the Alaska Native Tribal Health Consortium. LEO was originally created to follow how arctic regions are impacted by climate change. There are now organizations throughout the world that use LEO to post observation, raise awareness and ask questions about environmental changes (LEO, 2017). I have become the ski jumping representative for LEO and hope to raise awareness about declining snowfall trends, how it affects the sport of ski jumping and how we can preserve the sport through collaborative mitigation techniques.

# Literature Review

## Ski Jumping History

 Ski jumping is a sport that began in Norway in 1808 when Ole Rye first jumped 9.5 meters off a ski jump. The first official competition was held in Ofte, Høydalsmo, Norway in 1866 (Bach, 2016). Ski jumping has been included in the Olympics since its opening year in 1924 in Chamonix, France. This was one of the eight original winter Olympic events (Staff, 2015). Ever since then, ski jumping has been a sport that has brought many spectators to see this unique winter sport.

Up until the early 20th century, the primary ski jumping technique was to sit in a tuck down the in-run and jump straight up off the takeoff and hope to land. After WWI this technique was replaced by Thulin Thams and Sigmund Ruud’s idea of bending at the hips in the air, holding your arms out in front of you and keeping your skis parallel to each other in the air (Spector, 2014; Bach, 2016). In the 1950s Swiss ski jumper, Andreas Daescher, further improved the sport by keeping his arms at his side while in the air (Spector, 2014). This technique was dominant for many years; until in 1985, Jan Bokloev decided to try and make his skis into a V shape instead of keeping them parallel in the air (Bach, 2016). This proved to be a very successful technique and has been kept to this day.

 When competing, it is important to keep these techniques in mind because athletes are not just ranked by how far they jump, but also how well the skier executes the ideal flight technique. To win competitions athletes must be able to jump far, while also doing it stylishly (Board, 2014).

 Although the technique of ski jumping has changed quite a bit over the years, it is not the only major change that the sport has seen. The equipment has improved tremendously from wearing regular clothes, no helmet, stiff wooden skis and cable binding, to wearing suits made of a foamy, neoprene like material, highly regulated helmets, regulated ski lengths and having ski widths made with a more flexible wood, and boots that angle your knees forward and are attached to your skis through heel and toe clip bindings (Board, 2014; Tingley, 2016).

 Another major change has been in the architecture of the ski jumps themselves. The old ski jumps were made completely out of wood, whereas now they are often made of steel or concrete or a combination of the two (Tingley, 2016). Some smaller ski jumping clubs around the world still ski jump off of wooden structures, but larger hills that are many times used for international competition must build ski jumps to a certain safety standard and code.

## Debate on Climate Change

Throughout history there have been different periods when the earth has seen higher temperatures and lower temperatures. Studying these past time periods through ice cores, tree ring widths, glaciers, ocean and lake sediment cores, plant fossils and written records has helped scientists to see how the earth’s climate has changed and adapted over time (NIWA, 2016).

 Climate change has become a very controversial topic due to the fact that not everyone agrees that it is irregular or caused by humans. Studying the history of the Earth’s climate can prove that there have been warmer and colder periods, but never has there been a recorded time when greenhouse gases in the atmosphere have been so high (BBC, 2013; Archer & Rahmstorf, 2010). Some scientists believe that it is just a new climate cycle after the Little Ice Age but others believe that the heating up of the Earth is being caused by humans. The climate is always changing, and therefore, referring to this phenomenon, climate change, might not be the best term to use when discussing the new climatic period. Due to the fact that many that believe it is human induced, the better term would be anthropogenic climate change or climate forcing. Both refer to the amount of greenhouse gases that humans add to the atmosphere and how trends have shown there has been an increase in greenhouse gasses over the last hundred years of human existence (Loyola, 2016; UNEP, 2007).

The end of the Little Ice Age can mark the transition between those who believe in anthropogenic climate change and those that believe this is a natural warming cycle in earth’s history. The Little Ice Age refers to the time also known as the Maunder Minimum (UNEP, 2007). This is referred to as a time of minimum sun spots. Sunspots increase solar intensity so the less sun spots the sun has pointing towards Earth, the less radiation is received from the sun. Since the amount of sun spots has decreased since the end of the Little Ice Age, the earth has seen an increase in temperatures (Archer & Rahmstorf, 2010). On the other hand, those who believe in anthropogenic climate change argue that the Earth was pulled out of the Ice Age by an increase in greenhouse gases in the atmosphere.

In 1859, a scientist named John Tydall found that CO2, methane and water vapor were both greenhouse gases, being that they absorb the sun’s radiation in the atmosphere and convert it into heat (Archer & Rahmstorf, 2010). As the amount of greenhouse gases, especially CO2, increase in the atmosphere, the overall global temperature of the earth increases (Kellogg & Schware, 1981). Although many scientists believe that the rise in atmospheric greenhouse gases is the reason for the current global warming trend (Bagley, 2015; Kellogg & Schware, 1981; Archer & Rahmstorf; Scott, Steiger, Rutty, & Johnson, 2014), others believe this is just part of a natural cycle of Earth’s warming climate (Loyola, 2016; Staff, 2012). As Severinghaus states, “The warming between 1850 to 1950 was: ‘consistent with warming caused by increases in solar output and decreases in climate-cooling volcanism’.” (Staff, 2012).

Nonetheless, both sides of the climate change debate provide studies that show that the average global temperature is increasing, the amount of snow and ice is decreasing, sea level and temperatures are rising and the amount of unpredictable weather patterns are increasing (UNEP, 2007; Steiger & Mayer, 2008; Solomon, et al., 2007; Kunkel & NOAA, 2016; Loyola, 2016; Bagley, 2015) No matter how scientists believe it is happening, they all agree that the changing climate and future problems will come about because of it so it needs to be discussed and prepared for. Rising sea levels could displace millions from their homes, higher temperatures could change weather patterns in a way that will affect agricultural crops and change local weather patterns to be less suitable for growing and melting snow and ice could reduce the amount of water that feeds into rivers that provides millions of people and agricultural lands with water (UNEP, 2007; DeWalle, 2008). The climate is warming, and in each area of concern more studies are being done and people are trying to come up with solutions for everyone to be more prepared for the future of earth’s climate.

## Snow Decline

Since the end of the Little Ice Age, the global temperature has been rising at an increasing rate, which will disturb many aspects of the earth’s climate. Although temperature is a major driving force of earth’s climatic system, wind and precipitation are also major climate drivers. All three of these climate system drivers are affected by other outside factors, such as dust from volcanic eruptions, greenhouse gases and sun radiation variation. (UNEP, 2007). These outside factors can increase or decrease the driving forces and therefore create an unknown climate situation due to all of the different variables that go into producing a climate system (Archer & Rahmstorf, 2010).That being said, there are many variables to how the climate changes throughout history and the future. Therefore, many scientists who study different areas of the changing climate look back at historical patterns to predict patterns that may also be seen in the coming future of the planet.

When specifically studying precipitation patterns and the effects of increasing temperature on snow, there are many different ways to go about collecting snow quality and depth samples and keeping track of precipitation measurements. Measuring precipitation is much harder than temperature because the measurements are less precise and more variable, which is why multiple measurement tactics are used (Archer & Rahmstorf, 2010). Many times when determining a snow depth sample by a measuring rod, multiple measurements are taken in the same area to come up with an average depth (DeWalle & Rango, 2008). This kind of snow measurement can be affected by winds that create snow drifts and the surrounding environment, such as tall trees, that can intercept snow fall. Winds can sometimes remove up to 70% of snow cover in alpine areas, and trees can prevent up to 60% of snow from reaching the ground (UNEP, 2007). Trees can also be a problem for accurately measuring snow depth because they are an imperative part for snow retention. Trees can slow the process of snow melt up to threefold because they decrease the direct impact of radiation and wind speeds (UNEP, 2007; DeWalle & Rango, 2008). These additional variables are why multiple measurements are taken and human error is a factor in all studies (Kunkel & NOAA, 2016; UNEP, 2007).

Snowfall is dependent on multiple factors besides what has been discussed so far. For example, snowfall is highly dependent on the locations latitude, altitude, distance from a large body of water and regional air mass circulation patterns (DeWalle & Rango, 2008). As the climate changes, these factors are changing as well, and places that may have received large snowfalls in the past may not have them anymore. The average latitude and altitude for snow is increasing, meaning that a higher latitude and higher altitude is required for major snowfalls (Archer & Rahmstorf, 2010). This is important for ski areas to know because of the fact that many of them have runs below and above this increasing snow lines. One study found that at the highest of elevations snow precipitation remains the same, but an extreme decline has been seen below 1000m (Daly, 2012).

As the average temperature of the earth increases, the more moisture there is in the air, increasing evaporation. As stated in Archer and Rahmstorf’s book, *The Climate Crisis*, “An established law of the 19th century physics, the Clausius-Clapeyron relation, states that the amount of water vapor that fits into a given volume increases by 7% for each degree Celsius of warming,” (2010, p.47), meaning that, as temperature increases, water expands which increases the amount of water vapor an air parcel, being a standard volume of air, will be able to hold before it lets it out as precipitation (Archer & Rahmstorf, 2010).

Research has shown that as evaporation increases, so, too, will precipitation (Archer & Rahmstorf, 2010). This domino of effects will inversely lead to less snow cover at lower latitudes of the mountains, but an increasing amount of rain will affect permafrost, vegetation coverage and lake and river ice formation (Solomon, et al., 2007), as the amount of snow cover decreases the snow will begin to melt earlier in the spring. This melting will only add to the amount of warming in the atmosphere, due to the loss in the albedo effect. The albedo effect is the measurement of reflectivity of the Earth’s surface, reflecting radiation back towards space (UNEP, 2007). Snow is an important part of creating an insulated blanket on the ground as the temperature drops through the winter. Snowfall keeps the soil warm and unfrozen, protecting it from frost penetration, which can cause root damage to plants and protect small animals that live in the ground throughout the winter (DeWalle & Rango, 2008). Due to the fact that snowfall precipitation is decreasing soils, plants, and animals in these decreasing areas may suffer.

Multiple studies throughout the Northern Hemisphere have shown that as temperatures rise, precipitation will increase, but much of it will be in the form of rain instead of snow. The mean monthly snow cover extent in the Northern Hemisphere has decreased at a rate of 1.3% per decade over the last 40 years (UNEP, 2007). One study in the US, using 419 observation stations around the country, found that 57% of the stations saw a decline in the amount of snow precipitation measured. It also estimated an average decrease of 0.19% of snowfall per year throughout all stations. One pattern to note about these weather stations is that they are all at lower elevation. Snow decline will be more prevalent at lower elevations, due to the fact that the snow line or elevation needed for snow is increasing (Kunkel & NOAA, 2016). A new kind of weather station has been created that can take automatic measurements in remote areas or high up on mountain peaks, called an Automatic Weather Station (AWS). These weather stations have shown that even though there is a decline in snow precipitation at lower elevations, high mountain peaks are actually seeing more snow because of the increase of overall precipitation (DeWalle & Rango, 2008). Therefore, keeping track of where the snowline is and being aware of where winter sports are located will help people prepare for future winters at different elevations and also at different latitudes.

 The farther north you go from the equator, the worse the negative effects are on snow cover loss. While snow is on the decline and is melting earlier in the spring, sea ice is also beginning to melt earlier and quicker as it loses the reflectivity of the snow and the dark ocean waters absorb the suns heat. The NASA Earth Observatory shows that the rate of Arctic snow cover loss in June between 1979 and 2012 was 17.6% per decade (Gannon, 2013).

As the snow has melted and exposed glaciers and ice caps, they have begun to melt as well. Glaciers and ice caps began to retreat in the 1850s, leading to an average rise in sea level of 0.77 to 0.22mm per year between 1991 and 2004 (Solomon, et al., 2007). These measurements show that snow has melted significantly from glaciers and ice caps as the earth gets warmer, and sea levels will begin to rise even more than they already have. Even though snow melt will provide more water for humans temporarily, when the glaciers and ice caps melt completely, humans will have to find a new water source once they are gone.

Snow melt provides 1/3 of all irrigated waters in the US, and glacier fed rivers alone provide 1.5 to 2 billion people with clean drinking water (UNEP, 2016; DeWalle & Rango, 2008) Snow is also extremely important for reflecting radiation and cooling the Earth through the albedo effect (Archer & Rahmstorf, 2010). As snow melts, the amount of bare ground that is exposed and absorbs more of the suns radiation brings more heat into the global system, further increasing snow melt (Gannon, 2013; UNEP, 2016). On average, snow albedo will reflect 80% of the sun’s radiation, whereas vegetation can typically reflect 15% (DeWalle & Rango, 2008). Therefore, the earlier snow cover is removed, the more potential there is for vegetation and the oceans to absorb heat (Gannon, 2013). Knowing what snow levels have been in the past and what factors are currently affecting snow decline allows scientists to make calculated predictions on what is estimated in the future and how we as humans will be effected.

##

## Snow Decline Predictions

Many scientists have made predictions about different potential snowfall and precipitation charts that we may see in the coming future. All of these studies agree that temperatures are predicted to rise, snowfall is predicted to decrease and weather patterns are predicted to change drastically throughout many regions of the world.

Results of studies will differ depending on what region of the world the study takes place and the regional effects of the ocean or elevation, for example. Two different studies within the European Alps found that the reliable snowline will rise by about 150m per degree Celsius of warming (Steiger & Mayer, 2008; UNEP, 2016). That means, looking at projections of temperatures, a rise between 2 and 4.5 degrees Celsius is predicted to be seen by 2050. With greater warming being seen at higher elevations, the world could lose between 300m and 700m of snowline within the next 35 years (Archer & Rahmstorf, 2010; UNEP, 2016). Another study shows that when considering these reductions in snow and comparing them to the change in the snowline, it is predicted that by the 2040s at 1000m a reduction of 3-44% will be seen and at 2000m a reduction between 6-51% (Daly, 2012; Kellogg & Schware, 1981). These predictions could possible lead to a 60-80% reduction of snow by the end of the century, leading to more problems than loss of clean drinking water or advanced warming. The IPCC projects that there will be a 25% reduction in the North Atlantic Current during this century due to the weakening of deep water formation. As the ocean temperature rises, the water expands, referred to as thermal expansion. Add in the additional snow and ice melt to thermal expansion and oceans could potentially rise 0.5m before the end of the century (UNEP, 2007).

In *The Climate Crisis* by Archer and Rahmstorf, they predict the Arctic will be ice free in the summer by the middle of this century. Subtropical areas are expected to become drier while the deep tropics and the high latitudes are expected to become wetter. Mid-latitudes are expected to see drier summers, which will be bad for crop production, and see wetter winters, which will lead to more flooding in regions. Regions that are already seeing droughts are expected to see 30% more droughts by the end of this century. These long dry spells will also lead to worse flooding when they do see rain (Archer & Rahmstorf, 2010). In areas these droughts could lead to intense wildfires, pine beetle epidemics and intense storms that wipe out roads and buildings (Jacobson, 2013).

One recent study, headed by the International Olympic Committee (IOC), evaluated what past Olympic facilities would be able to hold the games again in the future. For this study they examined the natural snow depth on the first of February, the mean daily maximum and minimum temperature in February, the probability of exceeding the optimal temperature threshold, the snowmaking days in January and February, the probability of retaining snow base greater than 30-60cm and the number of rainy days at each Olympic location. With these indicators, they predicted that by the middle of the 21st century at a low emissions pathway, only 11 out of the 19 former Olympic venues would be suitable to host again. If looking at a high emissions pathway by the middle of the 21st century, only 10 would qualify. They then predicted the locations that would be suitable by the late 21st century and found that at a low emissions calculation, only half would have reliable conditions. The only thing that can make a less reliable location more reliable is the advancements in technology we have seen. Advancements, such as indoor ice surfaces, refrigerated ski tracks/jumps and snow making have become common in the last 30 years, whereas before the Olympics relied entirely on natural weather conditions (Scott, Steiger, Rutty, & Johnson, 2014). The implications of future weather patterns and snow decline could be detrimental to winter sports and the cultural, industrial and economic impacts that follow snow related activities.

## Industrial Impacts and Mitigation of Snow Decline

Within alpine towns, winter tourism is a significant part of the local economies and an important source of income for the local people (UNEP, 2007). As snow is on the decline, many areas that support recreational activities, or other related industries such as sporting goods stores, transportation services, hotels, restaurants and insurance services, will have to find other ways to produce revenue, not to mention the impact on the health and happiness of all of the people who love winter sports (Kellogg & Schware, 1981). For example, Australia’s winter tourism industries make up 4.5% of GNP revenue (UNEP, 2007). In the US snow sports industries support hundreds of thousands of jobs and contribute about $12.2 billion to the economy every year (Bagley, 2015). Just the ski resorts alone account for 36% of the employment of all winter tourism related employees in the US (Hansman, 2015). The recent and projected climate variability will greatly affect income distribution and the local people’s ability to afford any kind of recreation or vacation (Kellogg & Schware, 1981).

According to the National Ski Area Association, the US has lost about 20% of its ski resorts since 1992, dropping from 546 resorts to 470 by 2015 (Bagley, 2015). Even the resorts that have survived since then are seeing more problems and are having to come up with plans to keep the resorts running or shut them down because they are no longer equitable. Not only is snow melting sooner in the spring, but it also does not come until later in the fall. (Bagley, 2015; Steiger & Mayer, 2008). This makes the skiing seasons shorter for resorts and also pushes them to use other methods of snow making, such as snow guns, and has prompted resorts to become involved in summer tourist attractions, such as zip lines, rope courses, dirt biking tracks, frisbee golf and hiking trails (Bagley, 2015).

Snowmaking is currently the dominant way for ski resorts to cope with the effects of snow decline (Steiger & Mayer, 2008). For some resorts, snowmaking is essential for them to open at all. During the 4th warmest US winter in history (2011-2012), the number of skiers that visited resorts dropped by 15% nationwide (Jacobson, 2013). Although snowmaking has become extremely beneficial to resorts around world, the cost of making snow is very high. With the three biggest costs of snow making being energy, labor and equipment, resorts can easily spend between $500,000-$3.5 million annually (Flynn, 2013; Hansman, 2015), accounting for about 10-20% of a ski area’s total yearly expenses (Kittle, 2011).

Resorts can end up pumping thousands of gallons of water into the air every minute the guns are running (Jacobson, 2013), adding up to approximately 50-400 gallons of water per year during the time when water levels are the lowest (Flynn, 2013). Due to these extra costs to keep the resorts in action, the increases in functioning costs will be put on the consumers. The consumer’s reactions could, in the end, lead to less buying fewer ski passes, therefore not benefiting the extra cost to cover runs covered in man-made snow throughout the year (Steiger & Mayer, 2008).

Typically, days reaching -2 degrees Celsius are considered possible days for snow making, but as temperatures rise, there will be more moisture in the air requiring temperatures to be even colder for snow making to be possible. In places, such as Austria, where 59% of ski areas are covered by natural snow, the amount of days reaching below -2 or more is vital for them to be in operation (Steiger & Mayer, 2008). An important variable for ski resorts that make snow is that due to the fact that natural snow has more time to fall and create snowflakes, the snow will contain more air. This creates snow that is less dense compared to machine snow that has less time in the air making it a denser kind of snow (Jacobson, 2013). Considering the density of snow is important for ski resorts because the denser the snow is, the more snow that is required to cover rocks and vegetation on the slopes. Natural snow can sufficiently cover a run with between 20-40cm of snow, whereas man-made snow requires 30-50cm of snow (Steiger & Mayer, 2008). Another important consideration for snow making resorts is to figure out individually is how to stay on top of weather fluctuations and be prepared to begin snowing the runs on short notice if weather conditions suddenly present themselves (Kittle, 2011).

 As ski resorts require more energy and water to support themselves, they are having more of a negative effect on the environment. Schendler, vice president of the Sustainability for Aspen Ski Company, maintains, “In the end, snow making is not a viable solution to climate change. You’re using tons of energy and cannibalizing the climate you depend on to respond to warming” (Jacobson, 2013). Organizations, such as Mountain Pact and the National Ski Areas Association’s Climate Challenge, are encouraging resorts to cut back on greenhouse gases emissions, shrink their environmental impact and bring mountain communities together to lobby for environmental policies that will help alpine towns adapt to climate change (Hansman, 2015; Bagley, 2015). These changes are vital not just for the ski resorts, but for all those who want to be involved in winter sports in the future.

# Methods

With the help of Rick Thoman of the National Weather Service here in Anchorage, I accessed the Applied Climate Information System (ACIS) database, which is maintained by the National Oceanic Atmospheric Administration’s (NOAA) Regional Climate Centers (RCC). The RCC has created and kept this database updated to help make it easier for people to find weather data in local areas. The ACIS is a unique database because you can see the datasets and combine data from multiple data sources to help you find exactly what you are looking for (ACIS-RCC, 2016).

Using datasets from each localized city, I created temperature, snowfall and precipitation charts, and graphs for each of the US and Canada locations. I was looking for statistical patterns about each point separately and to see how the three charts interconnect.

## Temperature Data Collection

Using the average temperatures between the dates of October 1st and April 30st, I was able to look specifically at how the winter temperatures have changed over the last 50 winter seasons. This time period was chosen because this is when temperatures are lowest in the northern hemisphere and are more likely to receive snowfall. I started by taking the monthly temperatures in each study location during the winter season and took the average temperature of each selected month. From the averages from each winter month I was then able to calculate the average for the whole winter. I used this data to create a graph that would show the average winter temperature in each region over the studied time period. After charting these graphs, I was able to create a trend line that would allow me to see if the average winter temperature has increased or decreased. By looking at the temperature at the beginning and end of the trend line, the average temperature change over the last 50 years was calculated.

## Snowfall Data Collection

Snowfall data was organized through the help of the ACIS database. I began by finding the average monthly snowfall during the October 1st to April 30st winter time period. After that I was able to calculate the average snowfall for each winter season over the last 50 winters for each location. Inserting each of these seasons into a graph, I was able to see the snowfall trend over the last 50 years and create a trend line that would show me how much snowfall has increased or decreased over the last 50 winters in each location.

## Precipitation Data Collection

Using the ACIS database, I looked at the datasets for each location and found the average monthly precipitation over the October 1st to April 30st time period. In this database, precipitation is the water equivalent of rain and snowfall throughout the stated time period. After calculating the average precipitation for each year, a graph was created showing each yearly precipitation average. Using the graphs, I was then able to find a trend line to show if precipitation had increased or decreased within each area over the last 50 years.

## Questionnaire Data Collection

Through my research I have collected questionnaires from different clubs around the US, Canada and Europe to see what their perspective of change weather patterns has been over the past couple of decades. I sent questionnaires to clubs in Park City, Utah, Steamboat Springs, Colorado, Eau Claire, Wisconsin, Lake Placid, New York, Anchorage, Alaska, Calgary, Alberta, Dokka, Norway, and Hinterzarten, Germany. These questionnaires were sent out electronically and collected over the course of my project. I asked questions geared towards each club specifically, looking for their perspectives on weather changes and how they are modifying their programs because of it. I wanted to see if their responses to the questions showed similar trends throughout all participating ski clubs, as well as with the winter weather data.

Table 1 lays out a few key important facts about each location to keep in mind when looking through the results. Latitude, altitude and climate classification of each location is extremely important to remember when studying weather data in many different locations. Below is a table showing the location of each location included in the study, along with their latitude, altitude and the Koppen-Geiger climate classification.

Table 1: Key information for each ski club location

|  |  |  |  |
| --- | --- | --- | --- |
| Location  | Latitude  | Altitude  | Koppen-Geiger Climate Classification  |
| Eau Claire, WI | 45°N | 221-291m | Dfa: Snow climate, fully humid, hot summer |
| Steamboat Springs, CO  | 41°N | 2133m | Dfb: Snow climate, fully humid, warm summer |
| Park City, UT  | 41°N | 2100m | Dsb: Snow climate with dry summers, warm summer |
| Lake Placid, NY  | 44°N | 550m | Dfb: Snow climate, fully humid, warm summer |
| Anchorage, AK  | 61°N | 152m | Dsc: Snow climate with dry summers, cool summers |
| Calgary, AB | 51°N | 1000m | Dfb: Snow climate, fully humid, warm summer |
| Dokka, Norway | 61°N | 2788m | Dfc: Snow climate, fully humid, cool summers |
| Hinterzarten, Germany | 48°N | 800-900m | Cfb: Warm temperate climate, fully humid, warm summer |

Table Key information for each location

Note: Koppen-Geiger climate classification citation (Bugger, 2012).

# Results

## Temperature Data

 Below are each of the temperature graphs made for each US and Canada location that was used in this study, figure 1. Eau Claire, Steamboat, Park City, Anchorage, Lake Placid and Calgary have all seen some kind of temperature warming trend over the last 50 years. Looking at each location, Steamboat has seen a warming of 1.1° Fahrenheit (F), both Eau Claire and Lake Placid have seen a warming of 3.25 degrees F, Park City has seen a warming of 3.5° F, Anchorage has seen 4° F of warming and Calgary has seen 5° F of warming.

Figure Annual mean temperature data. Vertical axis is temperature in Fahrenheit and Horizontal axis is winter season.

Analyzing the differences in the US and Canada locations shows a close correlation relative to their latitudinal location. Steamboat is found at 40° North (N), Lake Placid and Eau Claire are both found between 44° and 45° N and Anchorage is at 61°. The two temperature outliers are Calgary at 51° N and Park City at 40° N. I consider these to be the outliers because they don’t follow the trend of increasing temperature as increasing in latitude. The overall trend goes to show that as you move farther north in latitude the temperature change is more drastic.

 The outliers show that different locations, climate, and altitudes can also play a part in the way an area is changing. Calgary is extremely continental compared to Anchorage, causing it to see more drastic temperature changes throughout the year. This continental climate biome would play a major part into why the temperature change is more extreme in Calgary than in Anchorage.

Park City, Utah, on the other hand, appears extremely different considering how close it is to Steamboat Springs, Colorado and the fact that they are both relatively at the same altitude (Park City-7000 ft and Steamboat -6732 ft.). This is where their location and climate biome come into play. Park City is located on the eastern or leeward side of the Wasatch mountain range, meaning that it sees less precipitation. Weather in this area moves over the mountains from west to east. Therefore, as weather systems move over the mountains, precipitation drops on the west side of the mountains and leaves the east side dry, arid and less cloudy. Steamboat, on the other hand, is on the west, or windward, side of the mountain that will see more precipitation and cloud cover as weather systems move west and up the mountains.

## Snowfall Data

 Below are each of the snowfall graphs from each US and Canada locations. Areas that showed a decline in snow over the last 50 winters are Eau Claire by 1”, Park City by 50”, Lake Placid by 34”, and Calgary by 1.5”. Areas that showed an increase in snowfall include Steamboat at 14” and Anchorage at 13.5”. By looking at the overall trends of all of the locations combined, there is an overall decrease of 59” of snow over the last 50 winters.

Figure Annual snowfall data

Vertical axis is snowfall in inches and horizontal axis is year.

Looking at the variations of increases and decreases of snowfall in the areas studied, it appears one must look at more than temperature and snowfall in analyzing overall weather patterns.

## Precipitation Data

Using the ACIS database, I looked at the datasets for each location and found the average monthly precipitation over the October 1st to April 30st time period. In this database, precipitation was the amount of water equivalent from rain and snowfall. After calculating the average precipitation for each year, a graph was created showing each yearly average precipitation. Using the graphs, I was then able to find a trend line to show if precipitation had increased or decreased within each area over the last 50 years.

 Precipitation at each location is shown in the graphs below (Figure 3). Contrary to the snowfall graph trends, there are a few locations that see a decrease in precipitation, but the majority have seen an increase in winter precipitation. Steamboat is the only location that has seen a decrease of precipitation at 0.4”. Locations that saw an increase in precipitation are Eau Claire at 0.4”, Lake Placid at 6.5”, Anchorage at 0.02”, Park City at 0.6” and Calgary at 0.2”. Overall, this shows a gain of 7.32” of winter precipitation throughout all locations over the last 50 years.

Figure Precipitation graphs

Vertical axis is precipitation in inches and horizontal axis is year.

Steamboat is the only outlier in the precipitation data. Looking at the individual data from Steamboat, the temperature has increased the least in average annual mean winter temperature. Steamboat has only increased 1° F where all of the other locations were above the 3° F change mark. This may not seem like a big deal, but when it comes to sensitive climate biomes, a change of 1° or 2° F can be significant.

 Another key piece of data that shows that Steamboat has seen less drastic changes so far, is the fact that they have had an increase of snow over the last 50 years. Research by Archer, D. & Rahmstorf, S. has shown that temperature increases will actually increase the amount of precipitation. This happens when water molecules expand with rising temperatures and end up moving through the water cycle at faster speeds (Archer & Rahmstorf, 2010). Since Steamboat is located in a high altitude area, it makes sense that they have been seeing an increase in snow precipitation when accounting for this phenomenon.

##

## Climate Trends of Club Locations

After putting each separate location into an excel spreadsheet with its perspective graphs of temperature, snowfall and precipitation, I was able to pin point the average of all three graphs at each location at the beginning and end of the 50 winters. This then gave me the trend line for each graph that I then compare with each factor to see if their data correlates with one another. I created a table with these trend lines to show how each location has been affected by temperature, snowfall and precipitation. Table 2 below shows how these factors have changed over the last 50 winters. The numbers in yellow show that the numbers have increased and the green shows that they have decreased.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Location | Average Temperature Change  | Average Snowfall Change | Average Precipitation Change |  |
| Eau Claire  | 27.75 to 31F  | 50 to 49”  | 11.9 to 12.3” |  |
| Park City  | 34 to 37.5F | 103.5 to 53.5” | 15.3 to 15.9”  | \*green=decrease |
| Steamboat  | 27 to 28.1F | 156 to 170”  | 15 to 14.6”  | \*yellow=increase |
| Lake Placid  | 27.25 to 30.5F | 127 to 93”  | 17 to 23.5”  |  |
| Anchorage  | 23 to 27F | 65 to 78.5”  | 6.85 to 6.87”  |  |
| Calgary | 25 to 30F |  48.5 to 47”  | 4.1 to 4.3” |  |

Table Data comparison table

By looking at each individual location, differences can be seen in each area that may seem similar in many ways. Latitude, altitude, water bodies and mountains play a huge part in how places see such different weather patterns.

Eau Claire has seen an increase in both the average temperature and precipitation between October 1st and April 1st, along with a decrease in the average amount of snowfall. As temperatures increase over the winters in Eau Claire, the amount of precipitation that is coming down as rain is increasing. Higher average temperatures produce winters with more rain and less snow.

 Similar to Eau Claire, Calgary and Lake Placid see this same trend of higher temperatures, less snow and more rain. These three locations are all at relatively low elevations, 3500ft in Calgary, 787ft in Eau Claire and 1800ft in Lake Placid. They are also all within 44° and 51° latitude, where they are affected by more humid continental weather patterns, explaining why they would see similar trends.

 Park City has seen the same trend of increasing temperature, decreasing snowfall and increasing precipitation. I had originally thought that I would see the same kind of weather trends in both Park City and Steamboat. However, weather trends show Steamboat has seen an increase in temperature and snowfall, with a decrease in precipitation, in contrast to Park City’s data. With Park City being at an elevation of 7000ft and Steamboat being at 6732ft, they are relatively close in elevation and latitude. The key difference is where these areas lie in relation to the mountains nearby; Park City is on the East side and Steamboat is on the West side of the mountains. This factor creates a substantial difference in the weather and precipitation they receive. Park City tends to see clear skies and dry conditions, whereas Steamboat will see more precipitation and cloud cover.

Anchorage is the only location within my study that saw an increase in all three categories. Anchorage saw increases in the average temperature, snowfall, and winter precipitation over the last 50 years. All three categories have seen many fluctuations throughout the time period, showing times of high and low temperatures, snowfall, and precipitation. Although Anchorage has been seeing more average snowfall over the years, the increasing average temperature increases the amount of rain that is also falling throughout the winter. This creates a trend of winters with more snow and rainfall, but also more mid-winter melting due to the higher temperatures.

## Results in Questionnaires

I sent questionnaires to every ski jumping region of the US and Canada, along with some very well-known ski clubs in Europe to compare information from each. I was hoping to see the answers of the questionnaires to line up with the weather data collected and find patterns in mitigation techniques across the board. 7 out of the 9 questionnaires were returned. Responding clubs are from Dokka, Norway, Hinterzarten, Germany, Eau Claire, Wisconsin, Anchorage, Alaska, Steamboat Springs, Colorado, Park City, Utah and Calgary, Alberta. Due to the fact that I was unable to get weather data from the European city areas, I am unable to compare the questionnaires to their regional weather data. The questionnaire answers from Europe do line up very closely with those of the US and Canada though.

The questionnaire contained 6 main categories: Jumping facility, weather changes – temperature, weather changes – precipitation, mitigation techniques, financial affects and participation. I started by gathering general information from each of them as to location, elevation, and how long each club has been in existence. Some clubs such those in Dokka, Norway, Eau Claire, Wisconsin and Steamboat Springs, Colorado have been around for over a hundred years, whereas places such as Park City, Utah and Calgary, Alberta have only been around for 25-30 years.

 Every club stated that they have seen an increase in temperature fluctuation over the last 15 years. As Paul Jastrow from Eau Claire, WI expands, “Looking back on our tournament weekends, we have seen major fluctuations. Some weekends it is in the 30s and others we have had it in the 20s.” With these fluctuations, snowmaking has become essential for all of these clubs. Snowmaking has become a very important part of keeping this sport alive throughout the winters across the board. Locations such as Dokka and Steamboat have had snowmaking for 30-35 years, whereas Anchorage started snowmaking this winter for the first time. One benefit of having a wide variety of snowmaking experience amongst different clubs is that the clubs are able to lean on each other for snowmaking advise and techniques. The best way to make this possible is to have a very open communication system throughout all clubs to increase the overall success for all winter ski jumping areas.

 Looking at the answers I received about snowfall precipitation, Steamboat is the only location that stated they have not seen a decrease in snow over the last 15 years. This correlates with the weather data collected, showing that Steamboat has been seeing an increase in snowfall over the last 50 years. When looking at rain precipitation, all of the participants stated that they have seen more rain over the last 15 years, except Calgary. The historical weather data shows that Calgary has experienced a 0.2” increase in precipitation; it would be extremely hard to tell that difference because it is so similar to the norm. These precipitation trends explain why all ski clubs have had to come up with a variety of mitigation techniques to ensure the livelihood of the sport.

 A major reason for the increase in the amount of precipitation throughout the winter is the increasing fluctuation of temperatures, leading to more rain, mid-season melt downs, and earlier spring warm ups. All locations stated that they have seen mid-season warm ups more often than they had 15 years ago. In addition to more mid-season melting, all but one location has stated that they have also seen earlier spring melting. The location that has not seen earlier spring melt is Hinterzarten, Germany. Due to the fact that I was unable to get the Germany weather data I am unable to compare this statement with the actual weather data.

One mitigation technique that has become more popular over the last few years is using steel or porcelain tracks in the winter instead of snow. Steel or porcelain tracks are used for summer ski jumping. In the summer, a watering system is used keep the track slippery so the skier is able to pick up speed on the way down the track. In the winter, when these tracks are used it is usually cold enough that water does not need to be run down the tracks and they are smooth because of cold temperatures. This technique has become extremely helpful for clubs such as Hinterzarten, Anchorage and Steamboat that have seen more mid-season warm ups and earlier spring melt. There is less snow that needs to be made at the beginning of the season and when mid-winter warm up happens, you don’t have to worry about the snow tracks melting away.

Due to higher average temperatures, more rain, and more melting, all clubs have stated that the winter season seems to be shorter than it was 15 years ago. Wesley Savill from Calgary, Canada states, “Bigger swings in temperature, quicker and longer lasting weather systems, volatile weather events, and unpredictable weather” could be what is driving these winter conditions. An important mitigation technique besides snowmaking for shorter winters are the instillation of summer ski jumping tracks. Besides Dokka, Norway, all other participating clubs have incorporated plastic on their hills to increase the times of the year that ski jumping is possible. Since we have so many ski jumping facilities that have plastic on their hills, summer has become a major training season for ski jumping. Due to the fact that Anchorage just finished putting plastic on their hills this past summer, travelling to other locations as another way to increase ski jumping participation was extremely important, as it still is to Dokka. Summer ski jumping has become essential for athletes to be able to train year round and stay prepped for the winter competition season. Travelling becomes a key training tool for clubs like Dokka since they do not have plastic on their hills yet.

 Although ski jumping seasons have changed, athlete and volunteer participation is being affected differently for each club. Some clubs may have seen worse winters over the past 15 years, but due to more recruiting tactics have actually increased participation. Others have seen a decrease in participation that correlates with either the shortened winter season or increased membership fees due to extra operational costs, such as snowmaking or plastic. The number of kids within a program directly correlates with the number of volunteer participation a club receives. Without a substantial amount of kids in the program, the amount of volunteers the club will receive is minimal.

 Funding new projects such as summer plastic, snowmaking or traveling, has become important for all of the clubs participating in the questionnaire. Places such as Hinterzarten, Eau Claire and Anchorage have used grants for partial funding. Locations such as Dokka, Eau Claire, Anchorage and Park City have had to increase the cost for members. Increasing costs can make it hard for some clubs to keep kids in the sport if the cost become too high to participate. Recruiting efforts in clubs such as Park City, Anchorage, Steamboat Springs, and Calgary have all seen an increase in athlete participation. Others have seen a decrease in participation that correlates with either the shortened winter season or increased membership fees due to extra operational costs, such as snowmaking or plastic.

# Conclusion

Through my research and data collection I found that all of my participating locations are seeing an increase in temperature to some degree. Rising temperatures have had a major effect on both snowfall and winter precipitation. All locations except for Steamboat and Anchorage have seen a decrease in snowfall, while Steamboat is the only place that saw a decrease in precipitation over the 50 year winter season study period but an overall increase in snowfall.

I found that the participants in my questionnaire had very accurate perceptions of the climate trends in their area. All the weather data shows that temperature, snowfall and precipitation are not independent of each other, but are connected. It is important to look at all three trends to be able to see how the weather is affecting winter conditions and how it might shape up for the future.

Due to the fact that temperatures are still on the rise, discussing mitigation techniques will be extremely important now and into the future. As seen from the questionnaire, many clubs already have techniques in place, but as winters become less filled with natural snow it will be important for each club to become efficient in mitigating these problems. Therefore, having access to equipment and funding for mitigation is essential to supporting winter sports such as ski jumping. Although it is important to keep environmental effects to a minimum, it is important for the health and happiness of past and future skiers to be able to keep participating in winter sports. As snow decline keeps increasing and the regional precipitation and temperature patterns change, it is important for all ski clubs to know what future possible winters could look like.

 Close communication with other clubs around the world will be extremely important to sharing information about different mitigation technique. I have become the LEO Network representative for ski jumping in hopes to have an easy form of mutual communication for all ski jumping clubs. This network will allow all clubs to become part of the network and share weather changes, new mitigation technologies and questions for other clubs. This project has encouraged me to try and connect all clubs more than they already are, and to improve communication to create a closer ski jumping community across the world.

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