Climate Change and its Impact on Ski Industry

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1 Introduction

As the world grapples with the consequences of climate change, few industries remain untouched by its effects. One of the most significantly impacted is the ski industry, which relies on a delicate balance of temperature and precipitation to create and maintain optimal snow conditions for recreational skiing. Global warming has led to a notable decrease in snow cover and reduced the overall reliability of ski seasons, leading to profound consequences for the economies and ecosystems dependent on this popular winter sport.

The ski industry is an important economic driver in many regions, particularly those with mountainous landscapes and colder climates. It generates billions of dollars in revenue each year, providing jobs and supporting local communities through tourism and infrastructure development. As such, the potential decline of the ski industry due to global warming poses serious socio-economic challenges for the communities that depend on it.

One of the most pressing concerns is the diminishing snowpack. Warming temperatures have led to shorter winters and a decrease in average snowfall, resulting in less snow cover and a shorter ski season. This, in turn, forces ski resorts to rely on artificial snowmaking, which has its own set of environmental and economic costs. Another critical issue is the changing precipitation patterns, which can result in more rain than snow during the winter months and impacts the quality of the ski slopes. Because of those issue, in some cases, resorts may have to close earlier or remain closed for entire seasons, causing financial strain for businesses and workers reliant on the ski industry. For consumers, it means the higher ticket price of the ski resorts.

In this project, we visualize the climate change related to the ski industry such as increasing temperature, shorter winters, reduced snowfall, and changing snow-to-precipitation ratio. We also visualize the evidence that the ski industry has indeed been affected by climate change, mainly through the change of ticket price which reflects the change of operation cost. It is crucial for the ski industry to recognize and address these challenges, investing in innovative strategies and technologies to mitigate the impact of global warming and ensure a sustainable future for both the industry and the environment.

The final visualization is deployed on Streamlit Cloud: https://ggleod-si649group-streamlit-publish-vteofm.streamlit.app/.

2 Related Work

Several studies have been conducted to examine the impacts of climate change on ski resorts and their surroundings. The article "Impact of climate change on ski industry" also highlights the vulnerability of the ski industry to climate changes. They indicated that climate changes has had a significant impact on the ski industry due to the reduction in natural snowfall and the shrinking duration of seasonal conditions suitable for skiing. For instance, between 1961 to 1990 in Sweden, the temperature rose by an average of 2°C and precipitation remained stable, but the snow decreased by 8cm in depth. This led to a reduction of 5 days in the underlying ski season, which was measured in days with a snow depth of at least 30cm (2).

Some research makes the prediction on the future ski industry under the influence of climate change. In the near future, a period coincident with the lifetime of the investments, snowmaking will probably remain feasible. However, in the long term, climate change will finally exceed technical thresholds meaning that in years when natural snowfalls are poor the ski season may be curtailed and without snowmaking technical improvements, warmer temperatures will make snowmaking increasingly expensive and ski resorts are likey to be shifted to higher elevation, shaded, more snow reliable runs (1).

Furthermore, some research also shows the complexity of analyzing the influence of climate change on ski industry. The implications of climate change for skiing will depend on many factors such as technical snow-making capabilities, location (latitude, elevation, proximity to markets), business models (resort size, diverse ownership structures and access to capital) (4). This indicates the complexity and difficulty of analyzing the influence of climate change on ski industry and we should consider such problems such different perspective, case by case.

3 Objectives

We want to create a narrative visualization (5) incorporating various visual elements, such as interactive maps, charts, and graphs, to present data on snowfall patterns, ski season lengths, the distribution of ski resorts, their price tickets and so on. We try to organize those contents in a linear way to guide our audience step by step to the learning objectives. Our target audience is anyone who care about skiing or environment.

By presenting complex data in a visually appealing and easily digestible format, this information visualization project aims to help audience develop a deeper understanding of the impact of global warming on the ski industry including the specific consequences of climate change on snowfall patterns, ski season length, and ski resort operations. In addition, we want audience to recognize the geographic distribution of ski resorts that are most vulnerable to the effects of global warming, and identify regional trends in climate change impacts.

What's more, we want to encourage informed decision-making and action among ski resort operators, related businesses, and policymakers. Ultimately, we hope that this project will contribute to the global effort to combat climate change and foster a more sustainable future for the ski industry and the environment.

4 Data

As collecting data worldwide is hard, for all data and visualization mentioned below, they are for the United States.

4.1 Climate Change

Climate data is essential to this project and though climate is a broad topic, we only care about data related to skiing resort, which is mainly snow data and temperature data. Snow data includes snow coverage, snow season length and snowfall. Snowfall is determined by the height of snow that accumulates each day. In order to see the change, we need their history data.

Temperature data is available in National Centers for Environmental Information. The database includes average temperature in each month in each state from 1895 to 2023.

Snowfall data is available in United States Environmental Protection Agency. It includes the snow season length calculated based on an average of all parts of the country that receive snow every year. In addition, it processes the snowfall data and shows the average yearly change of snowfall data and snowfall-to-precipitation data from 1930 to 2007 in 419 weather stations.

Snow cover data is available in Rutgers University Global Snow Lab. Its dataset contains daily snow coverage of multiple districts in Northern Hemisphere from 1966 to 2023. We will use its data of North America.

4.2 Ski Resorts

A comprehensive description of the data used in this research includes the process of gathering and visualizing data was collected on zRankings through web scraping. Initially, we considered various quantitative measures, including snow depth, snow score, and season length across various ski resorts, as they directly impact the economic benefits of these resorts. These factors are also dependent on climate change and the location of the ski area. To obtain this data, we conducted extensive research on the authority of zRankings, which is an online platform that provides information on ski resorts across the North America. The data provided by zRankings was carefully curated to determine the relevant data needed for our analysis.

The data collected from zRankings included detailed information on snowfall, snow score, and season length, as well as each ski resort's geographic coordinates. The data allowed us to draw meaningful insights on the economic benefits of ski resorts in the United States, and how they are impacted by various factors such as climate change and location.

Snow fall amount data within each ski resort is available in Snow Forecast & Report. The data include the average snow fall amount of ski resort with in 7 years, which also include the data of snow evaluation for each resort. The snow evaluation has four categories (table 1).Each day will be assigned to these four categories.Data has been collected as average number of days of quality categories in each week of month for 7 years.

Table 1: Snow quality evaluation categories description

Snow Quality Categories	Snow	Sunny	Wind
Bluebird Powder Day	Fresh	Sunny	Light
Powder Day	Fresh	Limited	Median
Bluebird Day	Average	Sunny	Light
Very Windy Day	N/A	N/A	Higher(30km/h)

4.3 Economy

When considering the economy of the ski industry, we first consider some direct elements such as the ski resort profits and tourist population. However, it is really difficult to find the historical record for these information, so we consider some indirect indicators like ticket price for each ski resort. We finally find the historical ticket price for each resort in the northeast region including Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont. The data is available on NewEnglandSkiHistory.com.

Besides, the ticket price, we also consider the potential factor that influences the ski economy such as temperature, inflation, consumer price index. We finally choose the temperature and consumer price index (CPI). We use the temperature data mentioned before and scrape the CPI data from U.S. BUREAU OF LABOR STATISTICS. We also focus on the northeast region based on the price ticket.

Ticket price of ski resort data is available in Ticket Price. The data include the ticket price for adult, child and senior with weekday and weekend in 2021-2022. The price data using in analysis is assume 70% adult, 20% children and 10% seniors. Therefore, weighted ticket price for weekend or weekday. After getting the average weekend price and average weekday price, then time weekend price with 2 (2 days of weekend) and time weekday price with 5 (5 days of weekday) and divide 7 to average the daily price.

In order to compare the ticket price between different state, cost index of state in US will be used to eliminate the cost difference between state, the cost index data is available in Cost Index of State in US. The data includes the cost index for each state in US.

5 Methods

5.1 Climate Change

Climate change mostly involves temporal data so line charts and linear regression are widely used in this section to show the change. Map chart is also used to show the relationship between climate change and geographical location.

5.1.1 Temperature Change of Four Seasons

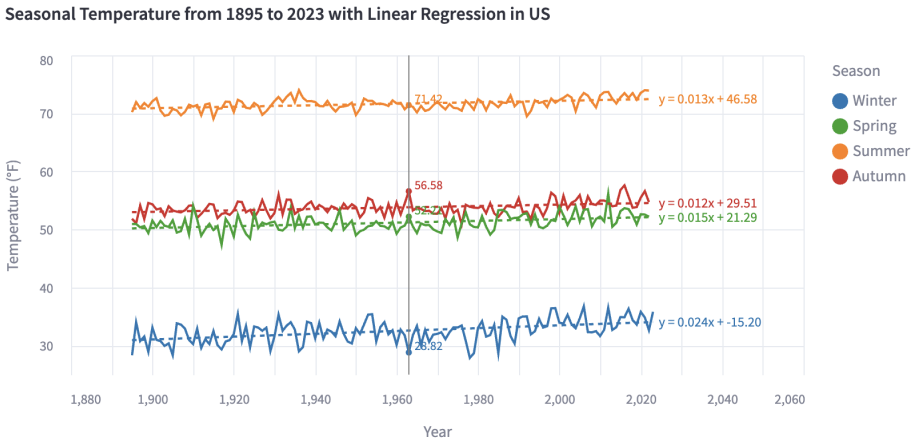

Figure 1: Temperature change of four seasons from 1895 to 2023.

Figure 1 shows the temperature change of four seasons from 1895 to 2023. We decide to show the change by season because skiing is mostly happens in winter and we find the change is the most significant in winter. However, it is not so obvious from the graph so we choose to add regression line and show the coefficient on the graph. Color of each line are carefully chosen to best representing four seasons. In addition, a rule can be moved with the user's mouse to show the temperature of four seasons at that year. We think this interaction can be helpful for users curious about the exact temperature value of a specific year.

5.1.2 Snow Season Length and Snow Cover

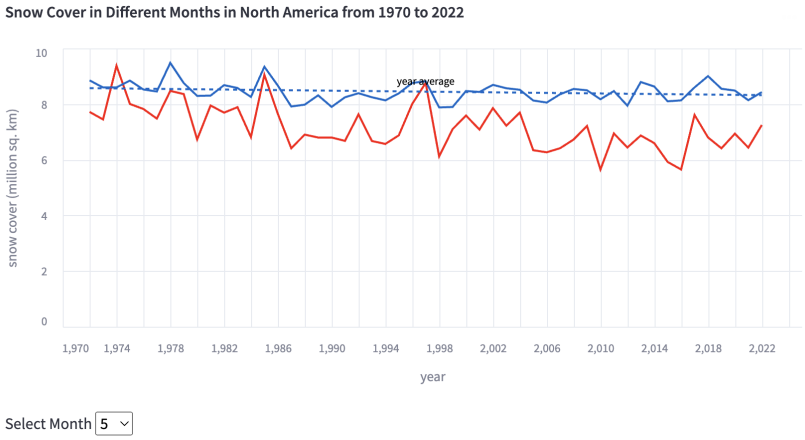

Figure 2: Change of yearly snow cover in different months (May is selected).

Figure 2 shows the change of snow cover. The blue line shows the change of year average data while the red line shows the the data of the selected month in each year. Like temperature, snow cover

varies a lot within a year so at first we want to visualize data by dividing them to seasons like figure 1. However, we find even within a season, snow cover varies a lot so we decide to show in month. Since showing 12 months in one graph is hard to read, so we add a drop down box for users to select. The year average line also serves as a criterion for users to compare data across different months more easily.

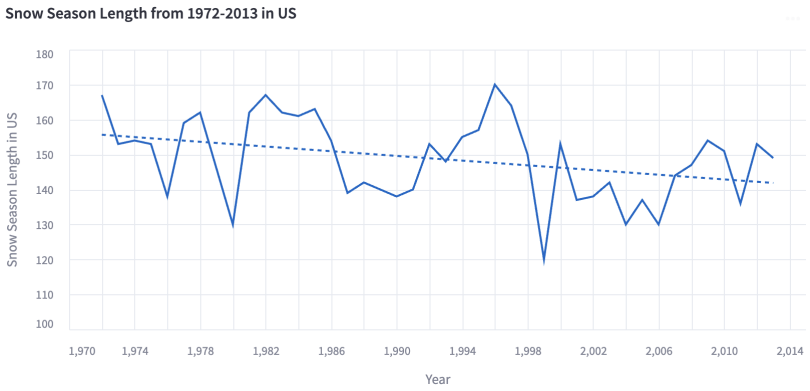

Figure 3: Change of yearly snow season length.

Figure 3 is a simple line chart showing the decreasing of snow season length. However, it is not obvious how fast it is decreasing so a regression line is added to show snow season length has decreased about two weeks from 1970.

5.1.3 Climate Change by Geographical Location

We also want to visualize the climate change in different locations because ski resorts do not distribute evenly across the country. Figure 4 has two layers. The first layer shows the winter temperature change in different states. The second layer uses dots to represented snowfall change in different weather stations. Here, we use absolute value of the change as the size of the dots and use color to encode whether it is decreasing or increasing. The reason we make this decision is that human are very sensitive to color and we can easily tell which part is decreasing and which part is increasing.

Some research suggests that global warming leads to higher evaporation and thus enable more global precipitation so snowfall increases as well (3). Thus, we also show a similar visualization about the change of snowfall-to-precipitation ratio in figure 5. However, one visualization problem since one has range [0,3], another has range [0,40], if they use the same scale, either one image will have small dots or one image will have very large dots. Therefore, we have to use different scales for each image but that could be misleading to the audience. We have to remind them in the text. Nonetheless, this issue does not prevent us from easily finding some general patterns of climate change in terms of geographical location, which will be explained later.

5.2 Geographic Visualization of Ski Resorts in the United States

The goal of this part data visualization is to provide a clear and informative way to visualize the snowfall data for ski resorts in North America. The data includes information on snow depth, snowfall score, and season length for each resort. We intended to present this data in a visual way that would allow viewers to easily compare and contrast different resorts based on these factors, and also highlight the theoretical impact of climate change on ski resorts.

The research started by exploring the data and thinking about the different factors that might be important for skiers and snowboarders when choosing a resort. The first iteration of the visualization was a basic map that showed the location of each ski resort in North America with interactive tool tips. We added circle marks to the map indicating resorts, with the size of the circle representing the average snow depth at each location. Yet, we soon recognized that this visualization was limited in conveying significant information about the amount of snowfall at the resort and the length of the season. Hence, in the second iteration, it was decided to focus on the combination of snow depth and snowfall fraction, using the size and color of the circles to stand for each of these two factors. A tool

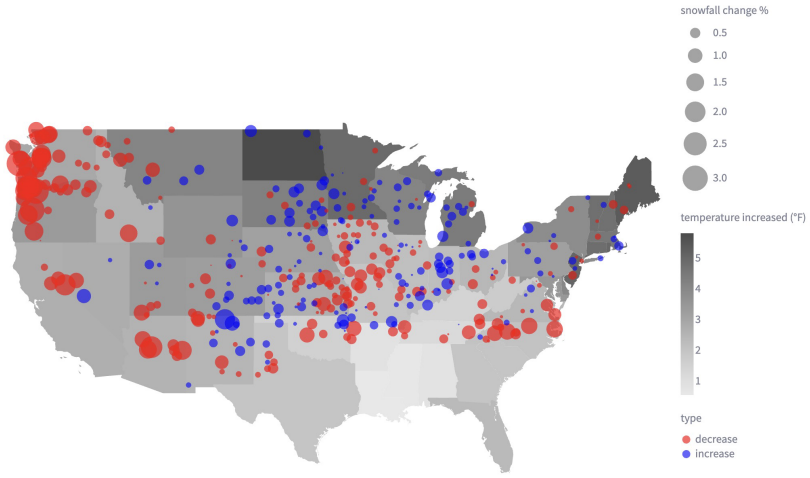

Figure 4: Winter temperature change in 48 states and snowfall change in 419 weather stations. The dot size encodes range [0,3].

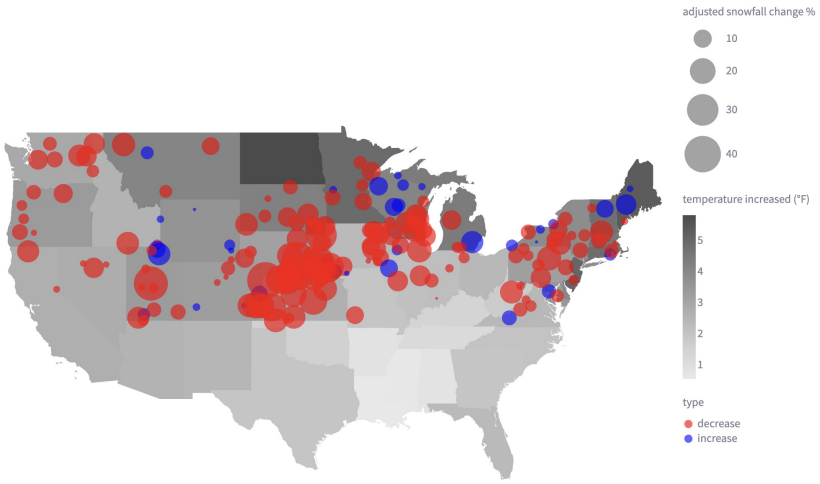

Figure 5: Winter temperature change in 48 states and snowfall-to-precipitation change in 177 weather stations. The dot size encodes range [0,40].

tip was also added so that the audience could see the name of each resort and its associated data. This visualization , which is shown in Figure 6, was more effective in conveying key information about the resorts.

In the final version, a histogram was added to allow the audience to filter resorts based on their snowfall scores. This feature enabled easier comparison of resorts with similar scores, while also giving the viewer the ability to observe how many resorts fall into different score ranges. Finally, along with the other parts of the data visualization, Streamlit was used to create an interactive version of this part that allows users to browse the data and narrow down the resorts based on their preferences.

5.3 Influence on Economy of Ski Industry

We have already found the general trend of temperature. In this section, we would like to find how does the temperature influences the ski industry, or specially, the economy of ski industry. At first, we design a line chart

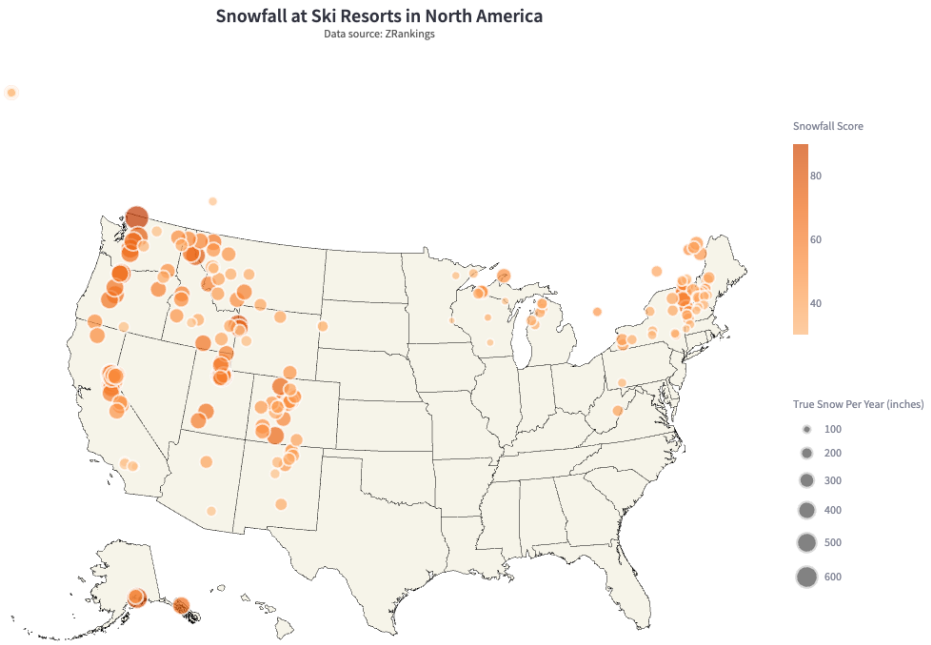

Figure 6: Geographic visualization of ski resorts in the U.S.

5.4 Correlation between Price and Snow

The goal of this part is to discover how the climate effect the price changing. Before exploring this correlation, the some other coefficient factors need to be filtered.

Therefore, four snow resorts with different height are taking example shown in figure 7. The distribution are taking weeks of months as x-axis and counting the number of days for each categories in each week as y-axis. Combining table 2 with figure 7, the higher ski resort(mountain) has better snow condition and higher ticket price. Therefore, height of the ski resort(mountain) will be consider as the crucial factors and be using to filter the data in visualization.

Table 2: Information of four example resorts with height and price

Resort Name	Height(m)	Price($)
Alpental	957	128
Arizona	576	49
Keystone	953	178
Mt holly	106	55

In order to discover the correlation between price and snow amount. We making an dashboard with price and price distribution in map. The upper corner map is average snow amount of ski resort in state and deeper color indicate less snow amount. Lower corner map is average price of ski resort with deeper color referring higher price in that state. However, the color comparison is hard, so the scatter plot with price as x-axis, snow amount as y-axis, each point indicate as ski resort. The ski resort are also categorised into 3 categories by height (table 3) and color the points of each resort in scatter plot.

The dashboard (figure 8) has interactive filter function with height. Therefore, the correlation and distribution could be discovered by different height categories.

Table 3: Height categories assigned to each resort

Category	Height(m)
Higher	Over 900
Median	(450, 900]
Lower	(0, 450]

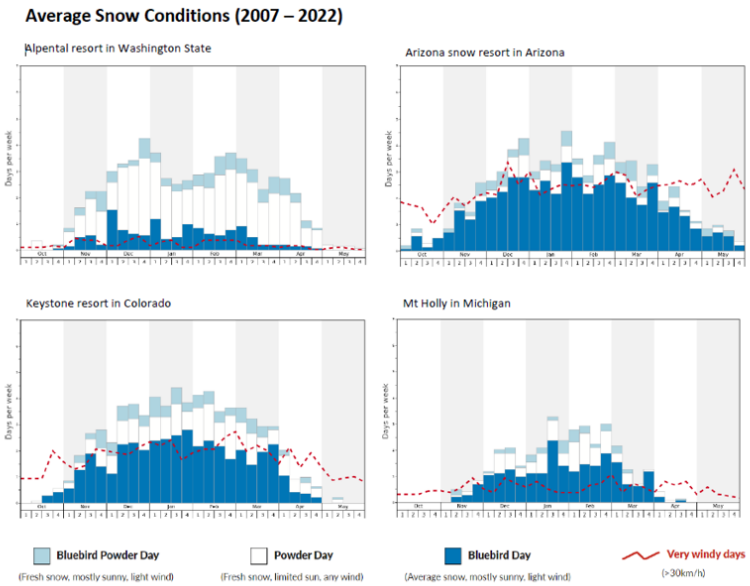

Figure 7: The snow quality conditions distributions in average 7 years with in four ski resorts (More label detail in table1

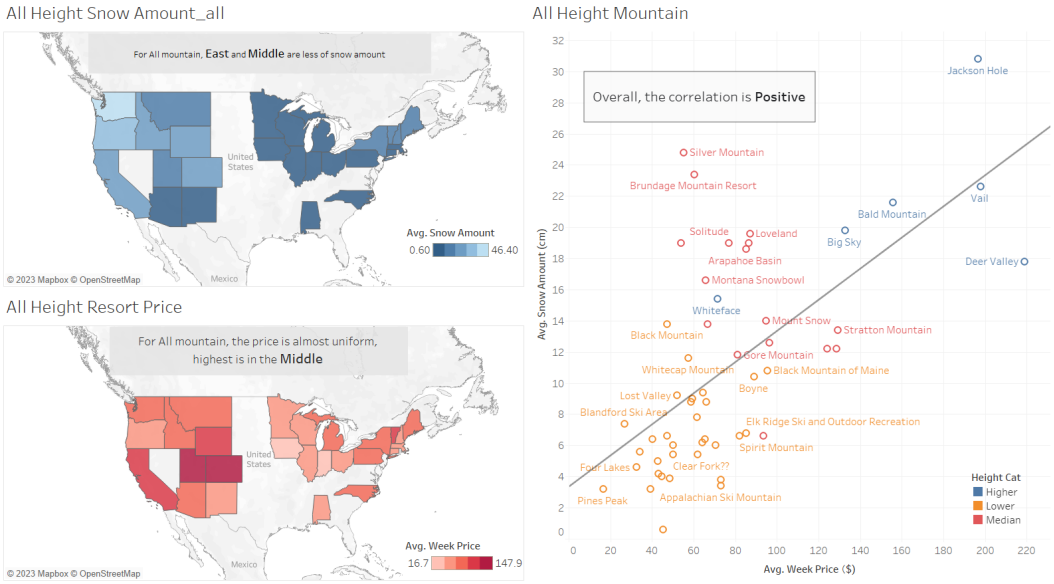

Figure 8: Snow amount and price distribution map & price-snow amount scatter plot

6 Results and Findings

Based on the data we obtained, we created several visualizations and organized them into a web application, aiming to engage people into the conversation of how climate change has affected ski resorts. We developed a web application to showcase our visualization and added explanations to be more engaing. There are mainly three findings we summarized from these visualizations and we will talk about them down below.

6.1 Finding 1: Increasing Temperature and Decreasing Snow Cover

Decling snow-pack levels and higher temperatures are shortening the ski season, making it more difficult for ski resorts to maintain adequate snow coverage. The winter temperature has increased significantly over the past decade in figure 1, while the snow season length has decreased significantly over the past decades in figure 3. It is obvious that the snow cover declined full year round over the past decades, especially significant starting from May, which is often considered as the end of snow season for many places, illustrated in figure 2.

6.2 Finding 2: Disproportionately Affected Resorts

Ski resorts on the West Coast have better snow conditions, particularly those near Canada, but are disproportionately affected by changes in temperature and snowfall. Snowfall score is devised to gauge the snow condition of a ski resort. By visualizing snow fall score and snowfall amount, 6 demonstrated clearly that ski resorts in states like Washington have better snow. However, we observed from figure 4 that weather stations in similar areas show significant drop in snowfall and moderate temperature rise, both adversarial to snow condition. Thus, this is a warning to us all that if we don't take measures necessary, the climate change might just ruin the best ski resorts we loved.

6.3 Finding 3: The Correlation between Ticket Price and Snow Amount by Mountain Height

Ticket price of a ski resort is related to many factors besides snow condition. One of the most important factors is height. A ski resort on a higher mountain typically has higher operation cost and favored by skiers. By choosing the height of mountains above, we can find the ticket price of ski resorts is highly related to the mountain height.

The interesting finding is that, the correlation between snow amount and price is negative relationship in median height mountain and the correlation is positive for higher mountain (figure 9). There is probability many reasons and factors lead to this interesting opposite correlation. One factor we consider is Artificial Snow Making and Customers Segments.

For snow making, the median height resort may have good snow making equipment, so when the snow condition is poor, they will be making snow with higher cost, which lead to higher ticket price; and if the snow amount is high, the cost of snow making is lower with lower price, which could attract more customers. The customers of lower height mountain resort are almost locally, and the snow making cost is too high to using, so when the snow condition is good, the resort will increasing the price and making more profit from the snow condition and customers.

6.4 Evaluation

To evaluate our web application, a google form was distributed encouraging people to give a score on a scale of one to five. We evaluated the application on both visualization and textual contents. We gauged our visualization from the perspective of expressiveness, clarity, interation and aesthetics, and our textual contents on interpretation and conclusions.

By the end of writing this report, there are 13 people filling this form. The link is available here. The evaluation result is summarized in table 4.

Based on the evaluation we received, it seems that we did a great job in drawing insights from the data and the visualization. However, it seems we focused more on being technical and clear rather than beautiful, as our team lacks talent in backgrounds of UX design. One way to improve the aesthetics is to include elements that only contribute to aesthetics. For example, we could substitute the circles with snow flakes, which would make the visualization more interesting.

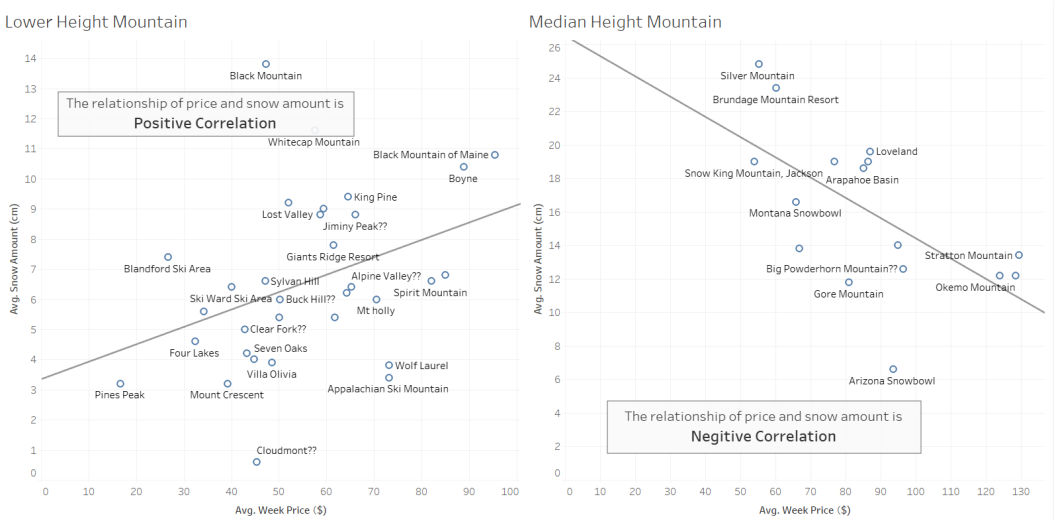

Figure 9: Compare the scatter plot between lower mountain and higher mountain

Table 4: Average score of each perspective from user feedback.

Perspective	Score
Expressiveness	4.54
Clarity	4.54
Interaction	4.54
Aesthetics	4.23
Interpretation	4.62
Conclusion	4.54

7 Future Work

7.1 Collecting and Analyzing more Industry-Related Data

As most of ski resorts are small private businesses, they do not record their data very often and precise, and they do not tend to share it online. Thus, many information we wanted to learn about ski resorts are not accessible to us. Some of possible data set we were interested in includes: yearly data on ski resorts revenue, snow making costs, number of employees. For those who has access to such data, it would be beneficial to use them and add insight to our analysis. For those who come outside US but from a country that also has a mature ski industry, it would be a great idea to conduct similar research in their home country, like Canada or some European countries.

7.2 How Ski Resorts Impact Climate

The impact of global warming on the ski industry also extends to the environmental footprint of the resorts themselves. As resorts scramble to adapt to the changing climate, they may be forced to expand their operations to higher altitudes or remote locations, increasing greenhouse gas emissions from energy production, transportation, and construction. This vicious cycle exacerbates the very issue that threatens the industry in the first place, amplifying the urgency to find sustainable solutions. Therefore, analyzing and visualizing how ski resorts impact climate can be an interesting and important topic.

7.3 Move beyond Present and Create Prediction Models

Our research mainly focused on unveiling the relationship between many indicators of climate change and the ski industry. However, those who have better knowledge background could develop models that would predict future climate and the ski industry prospect, making the topic and product more alarming and convincing.

7.4 Abnormality in Price-snowfall Relationship across Heights

As discussed in Finding 3, for ski resorts in different heights, the relationship between ticket price and snowfall varies drastically. Our guess is that low elevation resorts are often smaller businesses and rely less heavily on snow-makers. Thus, when the snowfall is poor, the overall snow condition would be poor and thus reducing its ticket price. On the contrary, high elevation resorts are often bigger businesses and rely more heavily on snow-makers. When the snowfall is poor, they will make artificial snow to keep the snow condition afloat while increasing costs, thus causing the ticket price to rise. However, those interested in this relationship can find further sources to either confirm or refute our guess.

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