Analysis of whistler weather data

Snowfall patterns, related variables and odd behavior

by Nathan Esau, Ethan Sim, Benjamin Chan

Summary

Background

In this study we analyze daily weather data from Whistler, BC. The variables analyzed were the amount of snow on the ground and the average temperature during each day.

Our study was motivated by trying to answer the following questions:

1. When is the winter season? When does it start, peak and end?
2. How severe is the winter? How much snow is present at different points in the year?
3. What trends exist in the data? What odd behaviors have shown up over the past 9 years?

Methods

To answer our questions, we used the following techniques:

1. Regression, to determine whether there was a trend in the snowfall data
2. Time series techniques, such as average smoothing, to compare different winter seasons
3. Correlation, to determine how different variables were related

Results

We found that while temperature is very consistent year to year, the amount of snowfall has been showing a downward trend. In particular, the 2009–2010 winter in which Vancouver hosted the Olympics was far less severe, both in the amount of snow and the duration of snowfall, than typical winter seasons. This was shown by comparing the length, average snowfall and peak snow amount of the 2009–2010 winter to other winters.

By averaging different annual time series, we determined what a typical winter season is like in Whistler. In order to do so, we needed to make an assumption about what constitutes the start and end of winter. We classified winter as the period when the average snow on the ground over a week stayed above a given threshold. This contrasts the typical definition of winter as the period from December 21 to March 21.

We also analyzed whether cold winters also tend to have a lot of snow. While these variables do exhibit some negative correlation, we do not have too much evidence that this is necessarily the case.

Interpretation

Whistler weather typically ranges from . . .

Introduction

Whistler Blackcomb is a Canadian resort town in the province of British Columbia, one of the largest ski resorts in North America. Whistler's economy is highly dependent on the seasonality of snow as the main winter activities offered there are skiing and snowboarding. In July 2003, Whistler was selected to host the alpine skiing events for the 2010 Winter Olympics. However, 2010 was accompanied with an unusually mild winter. The lack of snow made it challenging to run some of the Winter Olympic activities. Given this kind of uncertainty, it would be helpful to have a rough estimate of the when the whistler winter season usually occurs and the peak time of snowfall.

Our weather data was obtained from http://climate.weather.gc.ca/. Data was recorded at an elevation of 657.80 metres, a longitude of 122°57'17.400" W and a latitude of 50° 07'44.001" N over the period 2006 – 2014. The data set contained the following variables

- Temperature – minimum, maximum and mean temperature during each day
- Snow on the ground
- Total precipitation
- Wind speed and direction

The variables most relevant to answering our questions were the snow on the ground and the temperature. For temperature, we decided to use the mean temperature during each day, as we felt this is the most robust measure. We didn't account for wind, due to the large number of missing and truncated values present, or for precipitation which we felt wasn't related to our question.

We needed to perform some imputation for our variables. In particular, the snow on the ground during the summer months was not recorded, so we made the assumption that these was no snow on the ground at this point. Also, during the winter period when snow was not recorded we imputed the snow value from the previous day. Similarly, when the temperature was not recorded we imputed the temperature value from the previous day. During the winter, only a small portion of values were missing for these variables ($< 5\%$) so this imputation shouldn't have a large impact on our analysis.

Our overall goal was to understand the time series shown in Figure 1. In this figure we have shown the two-week moving average for the amount of snow on the ground and the three-week moving average for the mean temperature.

Methods

Our methods are divided into the following sections. First, we analyze whether a downward trend exists in the amount of snow during our observation period. Second, we average the annual time series and to determine the minimum, maximum and average amount of snow present in Whistler at each day during the year. Finally, we compare the length and severity of each of the winter seasons. For the severity, we look at the average amount of snow and average temperature during the winter, and analyze whether these results are correlated in some way.

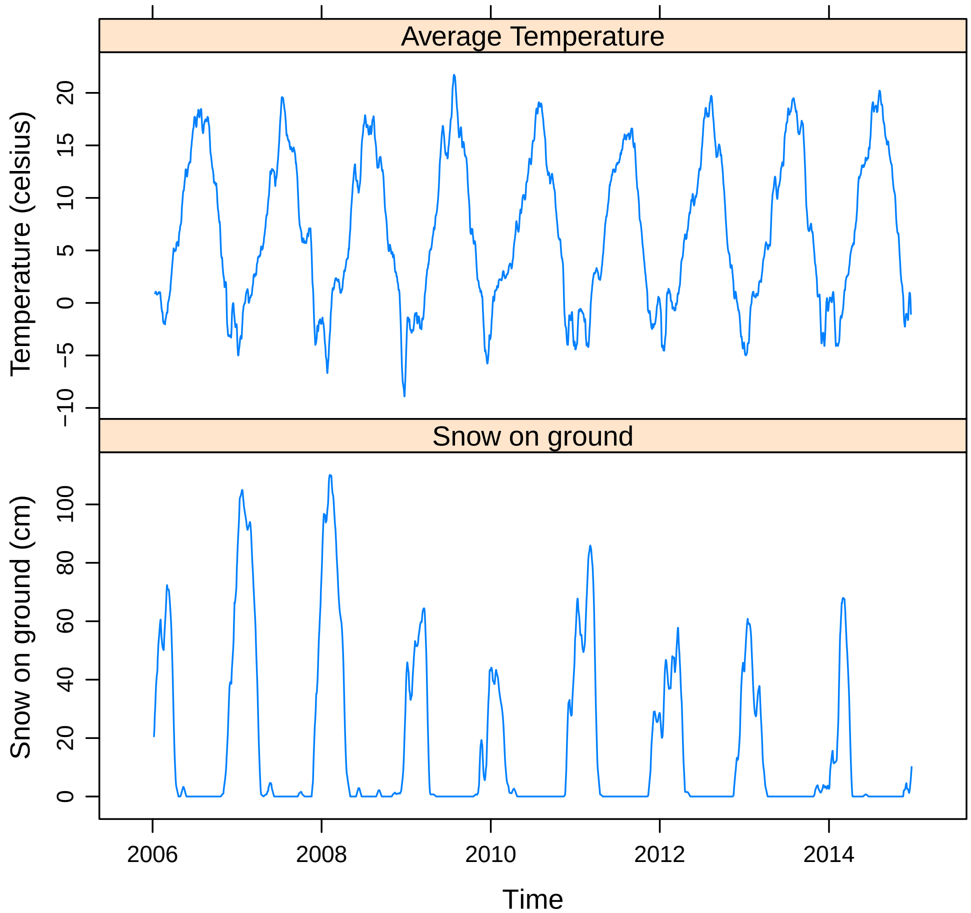

Figure 1: Whistler weather data from 2006 – 2014

Trend

Linear regression was used to fit a trend for snowfall, as shown in Figure 2. There is evidence that the amount of snow present in Whistler has been decreasing, as the slope coefficient is highly significant with p-value < 0.001. However, this downward trend is likely exaggerated due to the fact that we only have 9 years of weather data.

It is natural to wonder whether this downward trend is a result of rising temperatures (global warming). However, this is little evidence from our data to support this claim. For instance, the average temperatures (shown in Figure 1) don't appear to be increasing over time. When we tried fitting a trend line to these temperatures, the slope was 0.0003 with p-value > 0.01, which makes it difficult to infer causality between the temperature and declining amount of snow.

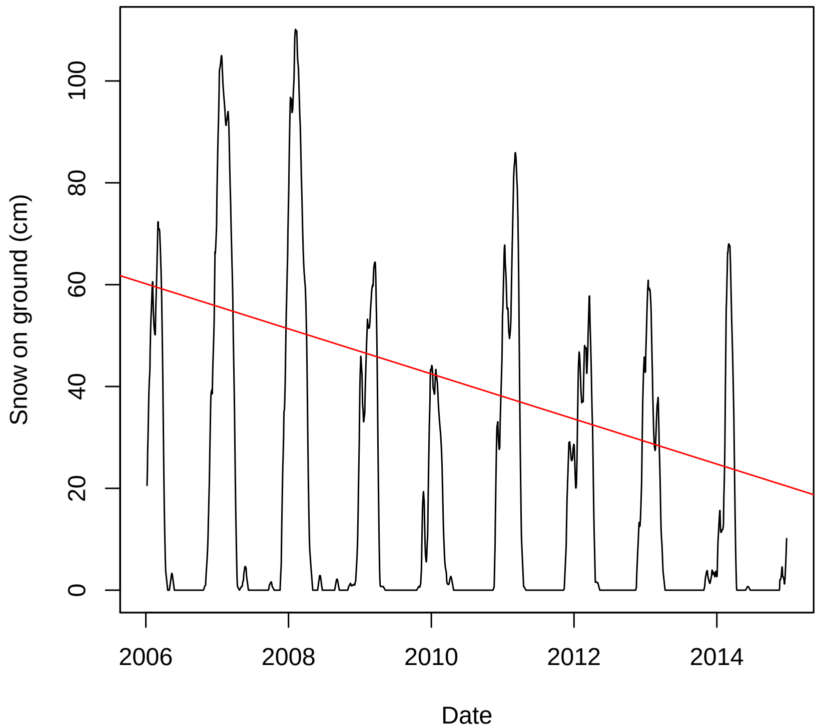

Figure 2: Snowfall trend with trend line $\mathit{Snow} = 219.4922 - 0.0121 \times \mathit{Date}$

Average smoothing

In order to determine how much snow is present at different points in the year, we averaged the 9 annual time series. One complication was that 2008 and 2012 were leap years. We needed the annual time series to be the same length in order to average them, so we removed February 29th of 2008 and 2012 from our data set.

The resulting minimum, maximum and average amount of snow at each day is shown in Figure 3. We have rearranged the dates to show the period July 1 – June 30 rather than Jan 1 – Dec 1. Notice that snowfall usually starts at the beginning of November and melts by the end of April. Since the amount of snow was recorded at the base of the mountain, at an elevation of 657.8 metres, it is quite a bit lower than one would expect at the top of the mountain at an elevation of 2,284 metres (*Whistler Blackcomb*, 2015).

Winter length and severity

One of goals was to compare the winter season of each of the years. Our criteria for the start of winter was based on a snow threshold as shown in the equation below.

$$Winter = \text{Period when 7 day moving average of snow} > \mathit{Threshold}\ \text{(cm)}$$

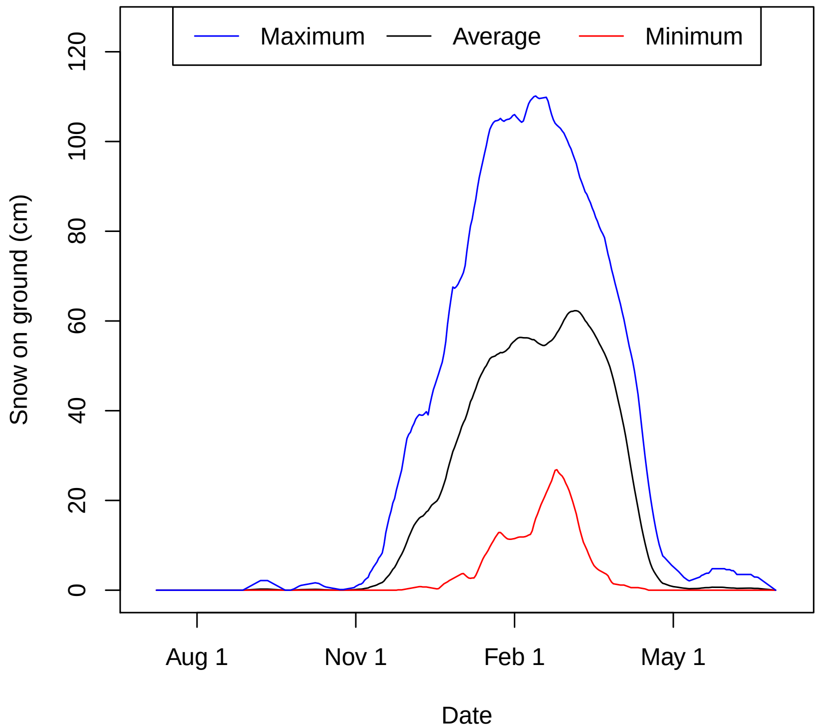

Figure 3: Average amount of snow present at each day during the year based on period from 2006 – 2014

We tried varying the threshold over different values. Regardless of the threshold, the results were quite similar as demonstrated in Table 1. The remainder of our report is based on a threshold of 15 cm.

Threshold (cm)	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14
10	145	138	108	93	136	143	121	87
15	137	135	103	85	128	136	99	87
20	134	132	101	78	125	126	94	55

Table 1: Length of winter under a variety of thresholds

The average snow is shown in Figure 5. Fusce mauris. Vestibulum luctus nibh at lectus. Sed bibendum, nulla a faucibus semper, leo velit ultricies tellus, ac venenatis arcu wisi vel nisl. Vestibulum diam. Aliquam pellentesque, augue quis sagittis posuere, turpis lacus congue quam, in hendrerit risus eros eget felis. Maecenas eget erat in sapien mattis porttitor. Vestibulum porttitor. Nulla facilisi. Sed a turpis eu lacus commodo facilisis. Morbi fringilla, wisi in dignissim interdum, justo lectus sagittis dui, et vehicula libero dui cursus dui. Mauris tempor ligula sed lacus. Duis cursus enim ut augue. Cras ac magna. Cras nulla. Nulla egestas. Curabitur a leo. Quisque egestas wisi eget nunc. Nam feugiat lacus vel est.

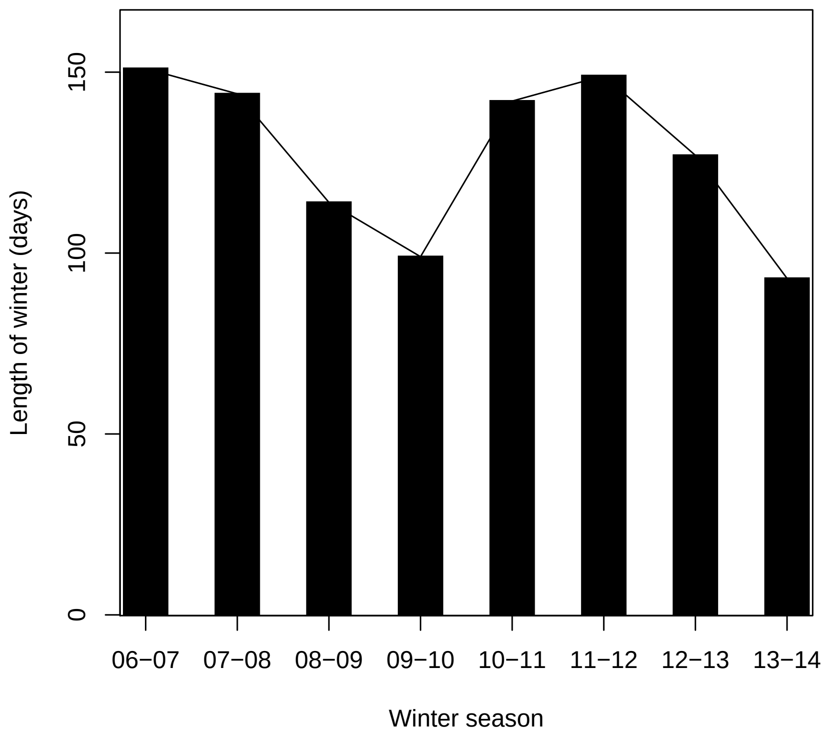

Figure 4: Length of whistler winter season 2006–2014

Curabitur consectetuer.

The average temperature is shown in Figure 6. Suspendisse vel felis. Ut lorem lorem, interdum eu, tincidunt sit amet, laoreet vitae, arcu. Aenean faucibus pede eu ante. Praesent enim elit, rutrum at, molestie non, nonummy vel, nisl. Ut lectus eros, malesuada sit amet, fermentum eu, sodales cursus, magna. Donec eu purus. Quisque vehicula, urna sed ultricies auctor, pede lorem egestas dui, et convallis elit erat sed nulla. Donec luctus. Curabitur et nunc. Aliquam dolor odio, commodo pretium, ultricies non, pharetra in, velit. Integer arcu est, nonummy in, fermentum faucibus, egestas vel, odio.

Results

The summary table is shown in Table 2. Sed commodo posuere pede. Mauris ut est. Ut quis purus. Sed ac odio. Sed vehicula hendrerit sem. Duis non odio. Morbi ut dui. Sed accumsan risus eget odio. In hac habitasse platea dictumst. Pellentesque non elit. Fusce sed justo eu urna porta tincidunt. Mauris felis odio, sollicitudin sed, volutpat a, ornare ac, erat. Morbi quis dolor. Donec pellentesque, erat ac sagittis semper, nunc dui lobortis purus, quis congue purus metus ultricies tellus. Proin et quam. Class aptent taciti sociosqu ad litora torquent

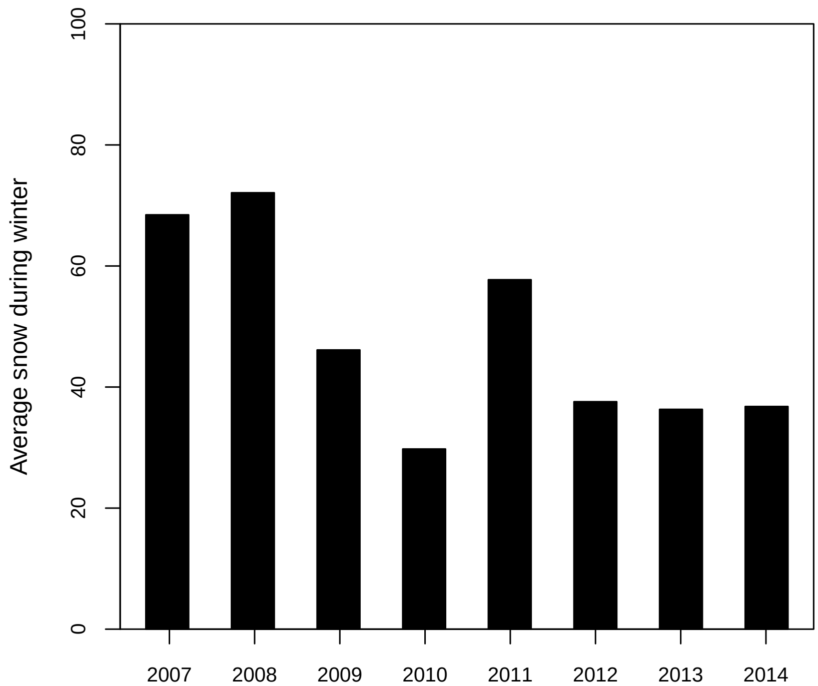

Figure 5: Length of winter

per conubia nostra, per inceptos hymenaeos. Praesent sapien turpis, fermentum vel, eleifend faucibus, vehicula eu, lacus.

.

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo. Cras viverra metus rhoncus sem. Nulla et lectus vestibulum urna fringilla ultrices. Phasellus eu tellus sit amet tortor gravida placerat. Integer sapien est, iaculis in, pretium quis, viverra ac, nunc. Praesent eget sem vel leo ultrices bibendum. Aenean faucibus. Morbi dolor nulla, malesuada eu, pulvinar at, mollis ac, nulla. Curabitur auctor semper nulla. Donec varius orci eget risus. Duis nibh mi, congue eu, accumsan eleifend, sagittis quis, diam. Duis eget orci sit amet orci dignissim rutrum.

Nam dui ligula, fringilla a, euismod sodales, sollicitudin vel, wisi. Morbi auctor lorem non justo. Nam lacus libero, pretium at, lobortis vitae, ultricies et, tellus. Donec aliquet, tortor sed accumsan bibendum, erat ligula aliquet magna, vitae ornare odio metus a mi. Morbi ac orci et nisl hendrerit mollis. Suspendisse ut massa. Cras nec ante. Pellentesque a nulla. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus

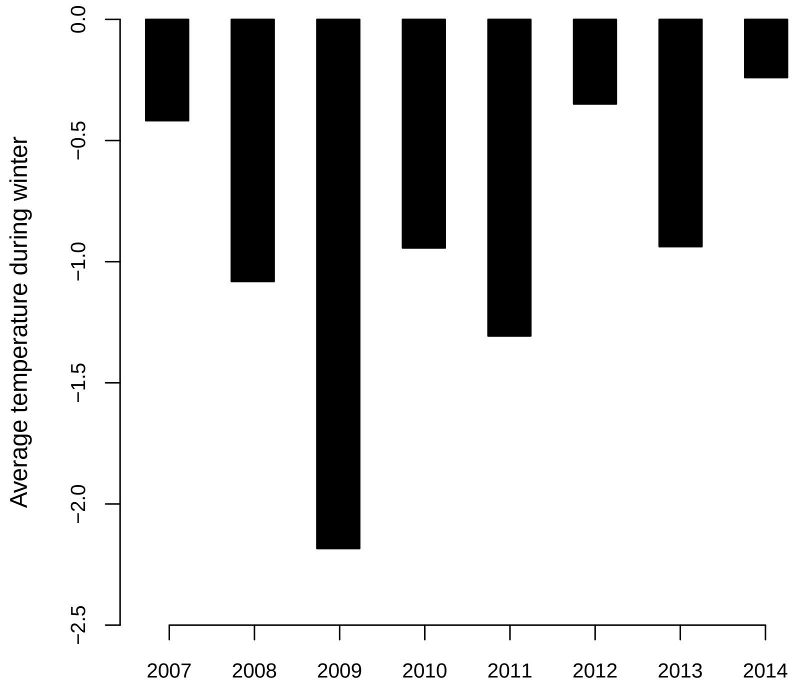

Figure 6: Length of winter

mus. Aliquam tincidunt urna. Nulla ullamcorper vestibulum turpis. Pellentesque cursus luctus mauris.

Nulla malesuada porttitor diam. Donec felis erat, congue non, volutpat at, tincidunt tristique, libero. Vivamus viverra fermentum felis. Donec nonummy pellentesque ante. Phasellus adipiscing semper elit. Proin fermentum massa ac quam. Sed diam turpis, molestie vitae, placerat a, molestie nec, leo. Maecenas lacinia. Nam ipsum ligula, eleifend at, accumsan nec, suscipit a, ipsum. Morbi blandit ligula feugiat magna. Nunc eleifend consequat lorem. Sed lacinia nulla vitae enim. Pellentesque tincidunt purus vel magna. Integer non enim. Praesent euismod nunc eu purus. Donec bibendum quam in tellus. Nullam cursus pulvinar lectus. Donec et mi. Nam vulputate metus eu enim. Vestibulum pellentesque felis eu massa.

Quisque ullamcorper placerat ipsum. Cras nibh. Morbi vel justo vitae lacus tincidunt ultrices. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. In hac habitasse platea dictumst. Integer tempus convallis augue. Etiam facilisis. Nunc elementum fermentum wisi. Aenean placerat. Ut imperdiet, enim sed gravida sollicitudin, felis odio placerat quam, ac pulvinar elit purus eget enim. Nunc vitae tortor. Proin tempus nibh sit amet nisl. Vivamus quis tortor vitae risus porta vehicula.

Fusce mauris. Vestibulum luctus nibh at lectus. Sed bibendum, nulla a faucibus semper, leo velit ultricies tellus, ac venenatis arcu wisi vel nisl. Vestibulum diam. Aliquam pellen-

Winter	Start	End	Peak	Length	Peak.Amount
2006-2007	Nov 11	Apr 5	Jan 19	145.00	113.00
2007-2008	Nov 26	Apr 13	Feb 7	139.00	125.00
2008-2009	Dec 18	Apr 5	Mar 17	108.00	75.00
2009-2010	Nov 13	Feb 14	Jan 2	93.00	58.00
2010-2011	Nov 22	Apr 7	Mar 5	136.00	94.00
2011-2012	Nov 19	Apr 11	Mar 15	144.00	68.00
2012-2013	Nov 21	Mar 22	Jan 9	121.00	81.00
2013-2014	Jan 6	Apr 3	Mar 6	87.00	78.00
Average	Nov 28	Mar 29	Feb 12	122.00	86.00

Table 2: Dates table

tesque, augue quis sagittis posuere, turpis lacus congue quam, in hendrerit risus eros eget felis. Maecenas eget erat in sapien mattis porttitor. Vestibulum porttitor. Nulla facilisi. Sed a turpis eu lacus commodo facilisis. Morbi fringilla, wisi in dignissim interdum, justo lectus sagittis dui, et vehicula libero dui cursus dui. Mauris tempor ligula sed lacus. Duis cursus enim ut augue. Cras ac magna. Cras nulla. Nulla egestas. Curabitur a leo. Quisque egestas wisi eget nunc. Nam feugiat lacus vel est. Curabitur consectetuer.

Suspendisse vel felis. Ut lorem lorem, interdum eu, tincidunt sit amet, laoreet vitae, arcu. Aenean faucibus pede eu ante. Praesent enim elit, rutrum at, molestie non, nonummy vel, nisl. Ut lectus eros, malesuada sit amet, fermentum eu, sodales cursus, magna. Donec eu purus. Quisque vehicula, urna sed ultricies auctor, pede lorem egestas dui, et convallis elit erat sed nulla. Donec luctus. Curabitur et nunc. Aliquam dolor odio, commodo pretium, ultricies non, pharetra in, velit. Integer arcu est, nonummy in, fermentum faucibus, egestas vel, odio.

Sed commodo posuere pede. Mauris ut est. Ut quis purus. Sed ac odio. Sed vehicula hendrerit sem. Duis non odio. Morbi ut dui. Sed accumsan risus eget odio. In hac habitasse platea dictumst. Pellentesque non elit. Fusce sed justo eu urna porta tincidunt. Mauris felis odio, sollicitudin sed, volutpat a, ornare ac, erat. Morbi quis dolor. Donec pellentesque, erat ac sagittis semper, nunc dui lobortis purus, quis congue purus metus ultricies tellus. Proin et quam. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Praesent sapien turpis, fermentum vel, eleifend faucibus, vehicula eu, lacus.

Conclusion

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo. Cras viverra metus rhoncus sem. Nulla et lectus vestibulum urna fringilla ultrices. Phasellus eu tellus sit amet tortor gravida placerat. Integer sapien est, iaculis in, pretium quis, viverra ac, nunc. Praesent eget sem vel leo ultrices bibendum. Aenean faucibus. Morbi dolor nulla, malesuada eu, pulvinar at, mollis ac, nulla. Curabitur auctor semper nulla. Donec varius orci eget risus. Duis nibh mi, congue eu, accumsan eleifend, sagittis quis, diam. Duis eget orci sit amet orci dignissim rutrum.

Nam dui ligula, fringilla a, euismod sodales, sollicitudin vel, wisi. Morbi auctor lorem non justo. Nam lacus libero, pretium at, lobortis vitae, ultricies et, tellus. Donec aliquet, tortor sed accumsan bibendum, erat ligula aliquet magna, vitae ornare odio metus a mi. Morbi ac orci et nisl hendrerit mollis. Suspendisse ut massa. Cras nec ante. Pellentesque a nulla. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Aliquam tincidunt urna. Nulla ullamcorper vestibulum turpis. Pellentesque cursus luctus mauris.

Nulla malesuada porttitor diam. Donec felis erat, congue non, volutpat at, tincidunt tristique, libero. Vivamus viverra fermentum felis. Donec nonummy pellentesque ante. Phasellus adipiscing semper elit. Proin fermentum massa ac quam. Sed diam turpis, molestie vitae, placerat a, molestie nec, leo. Maecenas lacinia. Nam ipsum ligula, eleifend at, accumsan nec, suscipit a, ipsum. Morbi blandit ligula feugiat magna. Nunc eleifend consequat lorem. Sed lacinia nulla vitae enim. Pellentesque tincidunt purus vel magna. Integer non enim. Praesent euismod nunc eu purus. Donec bibendum quam in tellus. Nullam cursus pulvinar lectus. Donec et mi. Nam vulputate metus eu enim. Vestibulum pellentesque felis eu massa.

Quisque ullamcorper placerat ipsum. Cras nibh. Morbi vel justo vitae lacus tincidunt ultrices. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. In hac habitasse platea dictumst. Integer tempus convallis augue. Etiam facilisis. Nunc elementum fermentum wisi. Aenean placerat. Ut imperdiet, enim sed gravida sollicitudin, felis odio placerat quam, ac pulvinar elit purus eget enim. Nunc vitae tortor. Proin tempus nibh sit amet nisl. Vivamus quis tortor vitae risus porta vehicula.

Fusce mauris. Vestibulum luctus nibh at lectus. Sed bibendum, nulla a faucibus semper, leo velit ultricies tellus, ac venenatis arcu wisi vel nisl. Vestibulum diam. Aliquam pellentesque, augue quis sagittis posuere, turpis lacus congue quam, in hendrerit risus eros eget felis. Maecenas eget erat in sapien mattis porttitor. Vestibulum porttitor. Nulla facilisi. Sed a turpis eu lacus commodo facilisis. Morbi fringilla, wisi in dignissim interdum, justo lectus sagittis dui, et vehicula libero dui cursus dui. Mauris tempor ligula sed lacus. Duis cursus enim ut augue. Cras ac magna. Cras nulla. Nulla egestas. Curabitur a leo. Quisque egestas wisi eget nunc. Nam feugiat lacus vel est. Curabitur consectetuer.

Suspendisse vel felis. Ut lorem lorem, interdum eu, tincidunt sit amet, laoreet vitae, arcu. Aenean faucibus pede eu ante. Praesent enim elit, rutrum at, molestie non, nonummy vel, nisl. Ut lectus eros, malesuada sit amet, fermentum eu, sodales cursus, magna. Donec eu purus. Quisque vehicula, urna sed ultricies auctor, pede lorem egestas dui, et convallis elit erat sed nulla. Donec luctus. Curabitur et nunc. Aliquam dolor odio, commodo pretium, ultricies non, pharetra in, velit. Integer arcu est, nonummy in, fermentum faucibus, egestas vel, odio.

Sed commodo posuere pede. Mauris ut est. Ut quis purus. Sed ac odio. Sed vehicula hendrerit sem. Duis non odio. Morbi ut dui. Sed accumsan risus eget odio. In hac habitasse platea dictumst. Pellentesque non elit. Fusce sed justo eu urna porta tincidunt. Mauris felis odio, sollicitudin sed, volutpat a, ornare ac, erat. Morbi quis dolor. Donec pellentesque, erat ac sagittis semper, nunc dui lobortis purus, quis congue purus metus ultricies tellus. Proin et quam. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Praesent sapien turpis, fermentum vel, eleifend faucibus, vehicula eu, lacus.

(Williams, 1997) and (Andrews, 2007)

References

Andrews, D. (2007). *A practitioner's observations on some innovative ideas for pension plan investment* (Tech. Rep.). University of Waterloo.

Whistler blackcomb. (2015). http://ww1.whistlerblackcomb.com/media/stats/mountains/.

Williams, A. (1997). Intergenerational equity: An exploration of the 'fair innings' argument. *Health Economics*, *6*(2), 117–132.