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ABSTRACT

A hypothetical study of valley crosswinds

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Crosswinds can occur in locations where topography combined with summer temperatures can create air flows through a mountain pass. The circulation of wind in a given area depends not only on the landscape over which the wind is passing, but also on the geography of the surrounding mountains and how the wind flows through them. The crosswinds that occur in the U.S. intermountain west provide a clear example of how they can affect the surrounding areas. The difference in wind speed is taken into consideration with wind power and the effect thereof. This effect is also examined in detail during different times of the year to show the probability of crosswinds occurring and at what times. The paper is termed “hypothetical” because the data upon which the observations and results were based proved to be inaccurate. However, should parallel investigations on wind movement be performed, the steps used to determine these results would still be valid.
ACKNOWLEDGEMENTS

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Introduction

The following paper and results are based upon inaccurate data, which occurred because of a misunderstanding of weather terminology. When examining the wind speeds throughout the year, my understanding had been that the “wind direction” was the direction toward which the wind was blowing. However, upon concluding my research, I came to the understanding that wind direction is not measured in reference to its destination but to its source. I found this out with help from the National Weather Service. They describe the data this way,

“In the weather world, wind direction is always referenced by the direction from which it blows. This convention is based on how wind direction was determined before instruments were designed...the easiest way to determine wind direction was to stand with your face to the wind...so you would be looking the direction from which the wind blows.” [1]

In referring to the images that they displayed on their website they said the following:

“Think of an arrow...if you think of the wind barbs (speed ticks) as the feathers and the smooth end as the point or tip, then the arrow travels toward the tip and from the feathers.” [1] So, because of this piece of information, it should be recognized that the following results are invalid. The data and observations are flawed, so the results should only be examined from a hypothetical standpoint.

In certain areas such as Eastern Idaho, there are places where two mountains with a valley in between meet a larger valley. An example is shown here. A study of the wind in such regions shows that there is a significant difference in the wind speed due to what we will from here on out call valley crosswinds. That is when the wind from the valley comes down and meets the wind moving across the plain, a difference in wind speed will be seen in the areas directly following this collision of the wind. Now whether this difference is large enough to merit consideration depends upon many factors. However if the difference in wind speed is great enough it would indeed be prudent to consider the location of that difference in respect to the valley crosswinds. Through thorough study of the wind and valley crosswinds for specifically the Eastern Idaho area, we may find the effect and difference that is created from such a situation.

Most of the data for the following observations and hypothesis are taken from the two northern valley regions highlighted in green, from the specific locations of the Base of Howe
Peak anemometer and the Blue Dome anemometer which is further north. Other calculations are also included from other places such as the sand dune anemometer, the radioactive waste site anemometer as well as a few other central locations. Using these, we will attempt to determine whether there is a significant difference in wind speed based on the conditions and whether this difference is negligible or not.

It would be beneficial to introduce some new symbolism at this point so that the reader may understand each of the graphs more clearly. Most of the data for this study was taken from the National Weather Service, and their wind maps show notches and lines in certain directions which account for the speed and direction of the wind. This will be explained now so no confusion will follow. When there is a flag on the end of a line, it means that the wind speed is 50 miles per hour. These most likely won’t be seen in any of these observations because we are observing winds at around 20 miles per hour. The direction of the line shows the direction of the wind. When a line is accompanied by another line or a half line, it indicates the speed of the wind. One half-line is worth 5 miles per hour and one full line is worth 10 miles per hour. These lines will be stacked in a map to show the approximate speed of the wind. Although there will most likely be no calm wind data, it is beneficial to account for them here, and they are indicated.

Figure 2: Understanding Wind Map Symbols [1]
by a circle within a circle. Figure 2 shows how to read each of these wind lines with some examples as well. [1]

Eastern Idaho is a prime location for wind turbines because there is a constant flow of wind over the plain region. Because of this, it would be wise to consider the ideal locations for such wind turbines, and in considering locations one must look at all the possible factors which would affect the wind speed. The effect of valley crosswinds is one of those factors. However, there are a few factors that must be understood about valley crosswinds before an accurate representation of how they affect the surrounding areas can be taken into account. One of the most crucial issues with valley crosswinds has to do with the time of year in which these winds would have an effect. As will be shown, study of the wind speed and direction through the year shows that an interaction of wind will only make a difference in the summer months. Although a constant wind does occur throughout the year, only the wind crossing the plain in the summer is affected by the valley winds. This, as will be shown, is because the temperatures required to create a constant wind flow down the valleys (at least in the Eastern Idaho area) don’t occur until the spring and summer seasons. So, it is clear that this is one of the things that must be taken into considerations.

Another thing that is central to our understanding of the valley wind is the conditions required in the right season to make the valley crosswinds occur. The crosswinds only happen on days that I will later classify as fair weather days.[8] That is on days of specific temperature and cloud cover, while those days that are stormy days have been shown to be less predictable. Still, even if the ratio of fair weather days to stormy days was only 1 in 5, it would still be practical to consider the effect these crosswinds have as will be shown later on.

The majority of this study is because of the impact that it would have on the placement of wind turbines. A small difference in wind speed can be a very large difference in wind power and one should not consider the placement of a wind turbine without first considering the effect of the valley crosswinds. Most of the yearly data for a certain area will show that there is a considerable difference in wind speed, but we can’t know for sure whether that data would be repeated in an area without the same anemometer. However, if we can understand how the valley crosswinds affect an area, we can postulate the effect that would occur in areas that had similar characteristics. And so, we can shorten the wait for wind turbines in some areas if we simply understand a little bit more about how the wind moves and how those nearby valleys affect it.

Before beginning the observations of this study, it was hypothesized that there would be a significant difference in the wind speeds due to the valley crosswinds. The significance of valley crosswinds is something that may have been previously overlooked and if we are to completely describe the movement of the air then it is essential to our understanding. So we must look at all the factors that

Figure 3: Highlighted valleys/Topography of the Intermountain West Area [1]
concern valley crosswinds in detail to appropriately explain them.

Before we can pursue a study of the wind, we must understand something of the geography of the area. We have considered the topography to some extent, but it must be elucidated comprehensively to gain a solid foundation upon which we can build our conclusion. The Eastern Idaho area has three obvious valleys that lead into the plain. Two come from the north-westerly region of the plain and one smaller one comes from the south-easterly region. This valley is walled on every side with mountains except for the plains which continue out to the southwest. This barrier of mountains makes a cul-de-sac area which acts like a basin for the wind entering it. So the north eastern region of the vicinity has quite unpredictable wind caused by the barriers on every side. Still all the other areas apart from that section face a fairly constant wind speed and direction most of the year.

This constant wind comes from the southwest. \(^1\) Because of the constant wind in this region, it is an excellent place for wind turbines which can save millions of dollars in power to those living nearby. However, in the most northerly regions of the plain, the wind which is channeled from the valley will cross with the wind from the plain and this crossing of winds slows down the average speed of the wind. Here is an example of one such day in which this occurred. As you can see the majority of the anemometers show wind direction in the plain to the north east, but down each of the valleys the wind travels in a south east direction and at position 64 there is a crossing of the wind. This is what decreases the wind speed further north up the plain. \(^1\)

**Conditions that affect the wind speed**

Although the wind is not completely seasonal, most of the wind coming from the upper valley does not occur until the spring and summer months. From the end of April until the beginning of September, one can view a significant difference in wind speed. \(^1\) Because Eastern Idaho lies far north in the United States, it faces a colder climate than some other areas. The cold climate of this area does have an effect on the wind movement and is because of valley and mountain breezes. There is an effect that occurs because of the cooling and heating of the mountains, and this effect changes the air around it.

According to the Encyclopedia Britannica, “When the valley floor warms during the day, warm air rises up the slopes of surrounding mountains and hills to create a valley breeze. At
night, denser cool air slides down the slopes to settle in the valley, producing a mountain breeze.” [2] This image shows how the valley crosswinds are created in Idaho. As the warm air rises because of the mountain, the cool air travels down the valley.

Here is a concept that we must understand, because it is specifically for this reason that the valley crosswinds are seasonal. They don’t occur as often in the winter time, because the temperature, especially up in the mountains, doesn’t rise enough to get the cool air flowing down the valley. This was taken from a state site concerning the temperatures of the Snake River region: “In the basin of the Snake River and its tributaries, between Twin Falls and Idaho Falls, monthly mean temperatures of 32° F or lower persist from December through February.”[10] Seeing as this is only speaking specifically of the valley regions, it can be easily expected to find much colder temperatures up toward the mountains and the mountain valleys. Usually, only from April to September does the temperature rise enough to create these valley crosswinds.

In the study of the wind in this valley, it was necessary to define certain days as *fair weather days*. This was indispensable because it became evident that on days other than fair weather days, the wind became unpredictable. Figure 6 shows an example of one of those days when the wind became unpredictable. Instead of moving up the plain as was normal the weather of the day made the wind move in the opposite direction. [1] This day, which was the first of June, 2010, could not be classified as a fair weather day because of the cloud cover over it.
In figure 7, it shows the cloud cover from a satellite.\textsuperscript{[1]} As is evident, the clouds cover most of Utah and Wyoming but there is also cloud cover over the eastern Idaho area. Although this one day would not be a sufficient proof of the difference that cloud cover and cold weather make on the wind, various other days were shown to have the same affect. So, those things that need to be included in our definition of \textit{fair weather day} are cloud cover and temperature thus far.

Based on my observations, the pressure systems that circulate in the summer cause higher wind speeds than in the winter. One example occurred on May 25, 2010.\textsuperscript{[1]} Figure 3, a pressure map of USA Today, shows how the low pressure system is moving toward the east to meet the high pressure system.\textsuperscript{[3]} This causes cloud cover over Eastern Idaho. While wind speeds increase in the summer, these high and low pressure systems make the wind movement (i.e. direction) less predictable.
Understanding Pressure Systems

To better understand how high and low pressure systems affect the movement of wind, we must look at information from the University of Illinois. According to them.

“Winds flow clockwise around a high pressure center in the northern hemisphere. Temperatures are dependent upon the location relative to the high. Northerly winds associated with an approaching high are likely to result in colder temperatures while southerly winds found on the backside of a high, or once a high has passed through, typically result in a warming trend.”

“Winds flow counterclockwise around a low pressure center in the northern hemisphere and temperatures are dependent upon the location relative to the low. Southerly winds associated with an approaching cyclone are likely to result in warmer temperatures while northerly winds found on the backside of a low, or once a low has passed through, typically result in a cooling trend.”

So, when weather fronts cause circulation either clockwise or counter-clockwise, the predictability of the wind decreases so that it is futile to attempt to classify crosswinds under such conditions.

On the day of the 24th of May, a similar situation occurred. An extensive look at the whole surrounding area helped to create a clear picture of the air pressures. Figure 11 shows that the pressure system is causing a clockwise wind cycle through the Idaho Snake River plain area. These situations make crosswinds impossible not only because the temperatures in the mountain valleys don’t raise enough to create a crosswind but also because the wind is traveling in a direction that prevents it from coming down the valley.
So, from the previous examples it should be clearly noted that only on fair weather days can these crosswinds occur. Temperatures for most of the days in which it was observed to occur were above 45 degrees Fahrenheit. Now, one could look specifically at the temperature and vapor and humidity in a certain day, but such analysis has now been incorporated into our very definition of *fair weather days*. So, from this point onward, when we discuss the implications of wind crossing, it will only be on those days which are considered fair weather days.

Another component of this study that must be addressed at this point is the time of day that the change in wind speed occurs in. The crossing winds only occur in the morning hours because it is only during those hours that the mountains are heating up enough to create a flow of cool wind down through the valley. After 12:00 noon, the temperature of the mountain area begins to decrease and we cease to see a flow of air down the valleys. The optimal time to consider and observe the wind is from 8:00 a.m. to 11:00 a.m. Most of the time, crosswinds occurred during these hours. [1]

**Observations**

On average the ratio of fair weather days to stormy days was about 1 to 1 (though not usually every other day).[1] So, we can assume that for the summer months approximately half of those days can be considered fair weather days. In the next few pages, some examples of the observations and data that were collected to show these facts will be shown.

The first example is from June 14, 2010.[1] An account directly from my journal of observations that were made that day will help to best describe what occurred.
“9:00 – Fortunately, a crosswind did occur this morning that can be clearly seen coming from Howe canyon. Although Blue Dome Canyon does not show the same southeastern wind crossing as the Howe canyon does, it is enough that there is a big difference in some of the more northern stations. The infrared map of Idaho shows us that the skies are very clear today, unlike the previous days when we didn’t see any crosswinds. Perhaps the clear skies are a key ingredient in pushing these winds in the right direction and creating the perfect situation for crosswinds."

The best example of crosswinds occurring is evidenced from Howe and the Base of Howe sites. Although the wind is traveling north east at 11 mph further south, as soon as the wind crosses with the wind coming down the canyon it slows the flow a little. In fact by looking at the other sites further north, it is clear that it is slowing.

Another example is from May 17, 2010.[1] It indicates that there was a significant difference between the wind speed of the radioactive waste site and the sand dune site caused by the wind from the Howe canyon. Figure 15 shows the approximate locations of each of the sites from which the data from the anemometers is taken. The average speed from 10:00 a.m. to 12:00 a.m. for the radioactive waste site anemometer was 14 miles per hour. The wind traveling down the Howe canyon was on average 5 miles per hour during that two hour time period. And, the sand dunes anemometer showed an average wind speed of 9 miles per hour. [1]
Now this alone would not be enough to demonstrate accurately the affect of the valley crosswinds. However, combined with the direction of the wind, it is clear that the difference in wind speed is caused by the crosswinds. Table 1 shows the wind speed and the wind direction for each of these places for the two hour time period. Each piece of data was taken every five minutes from ten o’clock to twelve o’clock. Although the wind direction and speed does fluctuate from the one expected, the average shows clearly that it is traveling fairly constantly in each of these areas for the two hours. [1]

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<th>Direction</th>
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The final example is from May 17, 2010.[1] The same occurrence is witnessed here for the same areas. Here, a map has been devised to show multiple locations along the plain as well as through the valley to solidify the argument about the crosswinds. As the wind travels up the plain here, it is going approximately 15 miles per hour, but as this wind comes in contact with the wind from the valley, it slows so that toward the middle you can see it has slowed to a speed of 8 or 9 miles per hour. Yet, it still travels in the same direction. However, when the crosswind from the Blue dome area (which is in blue) interacts with this wind, it slows it to the point that the anemometer at the sand dunes showed a wind speed of 4 miles per hour from another direction. Most likely this is because the northerly wind at the sand dunes had slowed to a point that it was overtaken by other competing winds.

Figure 16: Wind Directions for May 17 [1]  
Figure 17: Wind Speeds for May 17 [1]

Had this been the only observational data taken, it would be insufficient to prove any conclusive results. However, the study was performed over many days throughout the season and was shown time and time again (on fair weather days) to be accurate through numerous concurring results. Even previous years were taken into consideration, and although day by day they differed from the results of 2010, the same things did occur on average throughout the year. The same data was compiled for the summer season and it proved that there was a difference in wind speed because of the valleys leading into the plains.
Results

In discussing the differences between the wind speed and how they would affect the power output, we must take into account the cube of wind speed formula. That is that the power output from the wind is directly related to the cube of the speed. According to the Danish Wind Industry Association, “The energy content of the wind varies with the cube (the third power) of the average wind speed, e.g. if the wind speed is twice as high it contains $2^3 = 2 \times 2 \times 2 = eight$ times as much energy.”[5] This is because of the momentum of the wind. While a car increasing to twice its average velocity would merely require twice the force to stop it because of the momentum, wind traveling at an increased speed is quite different. Wind has more of a fluid motion and so the momentum and inertia of such will increase dramatically more than that of an average object.

A good example of the difference wind speed can make in the amount of power it supplies is given from this same DWIA. “The graph shows that at a wind speed of 8 meters per second we get a power (amount of energy per second) of 314 Watts per square meter exposed to the wind (the wind is coming from a direction perpendicular to the swept rotor area). At 16 m/s we get eight times as much power, i.e. 2509 W/m².”[5] This is found from the Wind Power formula. It is the Density of Air multiplied by the Diameter of the Turbine blade cubed times the velocity of the wind cubed times a constant.

\[ d \times D^2 \times V^3 \times C = P_{wind} \] [5]

So, for the case of the East Idaho valley area, we can see that there would be a big difference due to the crosswinds. Taking even only one day at a time, we can see the difference it would make.
Figure 20 shows the difference in wind speed of the Radioactive waste site and the Sand Dune site caused by the crosswind from the Howe canyon and the Blue dome canyon for the day of May 17, 2010.\textsuperscript{[1]} These values are taken over a two hour time period in the morning from 10:00 to 12:00. There is a consistent average difference between them of about 5 miles per hour. Assuming that each of these wind turbines had an identical blade diameter, the one stationed at the Sand dune site would receive power approximately 16 times less than that in the Radioactive waste site.

Now, if we were to assume (from the above arguments) that this difference in wind speed occurred on every fair weather day during the morning hours of the summer solstice, then we could calculate the amount of power lost due to the position of the wind turbine by a simple formula. If we take the difference between the wind speeds caused by the crosswind, and multiply it by the other factors in the wind power formula, we can find the amount of power lost in a day.

If we know that the equation for the power from a wind turbine is

$$P = \rho \cdot \frac{1}{2} \pi r^2 \cdot V^3 \cdot (0.59) \quad [5]$$

Where $\rho$ is the air density and $r$ is the diameter of the turbine blade and $V$ is the velocity of the wind, then we can find the difference in power by taking the derivative with respect to the velocity.

$$\frac{dP}{dV} = \rho \cdot \frac{1}{2} \pi r^2 \cdot 3V^2 \cdot (0.59)$$

So,

$$dP = \rho \cdot \frac{1}{2} \pi r^2 \cdot 3V^2 \cdot (0.59) \cdot dV$$
Now the efficiency of the wind speed across a turbine is at a maximum 59% because of the Betz law.\[^9\] This law was discovered by a German physicist who showed that you could never harness the full power of the wind but harness a maximum 59% of its power.\[^9\]

As the average blade diameter is about 70 Meters\[^6\], we will use that as our diameter. The density of air based on our elevation and average temperature of that time of year is approximately 0.0625 kg/m\(^3\) give or take 0.0025 kg/m\(^3\). For estimating purposes, we will assume the average wind speed in the morning to be approximately 15 mph or 6.7 meters/second, with the difference being 5 mph or 2.23 meters/second. Also, for wind turbines in the area, the average cost is about 5.5 cents per kilowatt hour. Using this information, we can determine the amount of power lost in a year, and from that determine the cost deficiency of placing a wind turbine in such a location as described above. After some calculation, it was found that dP was approximately 1370000 Watts. So, if we assume on average 5 months in a year of summer weather, and approximately every other day producing fair weather conditions that would create the crosswinds, we can find the total number of hours by multiplying 75 days times the number of hours per day that the crosswind would occur. We will assume about 3 hours a day giving us a total of 225 hours that must be taken into account. This means that placing a wind turbine in a location such as the sand dunes would bring in approximately 17,000 dollars less than a location not affected by a crosswind.

Now we must ask ourselves if 17,000 dollars worth of power is worth the consideration of placement of the wind turbine. Regardless of the fact that wind turbines cost over 1 million dollars to manufacture and install, we must look at the loss in profit from its position. Using the same reasoning as above, we can determine the approximate profit that an average wind turbine makes in a year. This turns out to be around 700,000 dollars (assuming the 5.5 cents per kilowatt hour). Now although 17,000 is much smaller compared to 700,000 thousand, it is greater than the standard deviation of the amount and for that reason should be taken into consideration when setting up a wind turbine.

So, we can ask ourselves whether this evaluation of the wind speed is really worth it. Some could say that the difference is too small, but because the power of the wind is related to the cube of the speed, every little bit makes a difference. So those hours in which the turbine would be affected by crosswinds are equivalent to many dollars worth of electricity that could be provided to a community. Overall, they are receiving the majority of the wind power from the turbine, but a better position for the turbine could have been picked if there was an understanding of these crosswinds and their effect on these areas.
Other Results

Although this study was specific to the Howe canyon and sand dune areas, the principles are applicable in any such area that has the same kind of conditions. Another example is of Rexburg, Idaho. Rexburg, Idaho lies to the northeast in Snake River valley and on its south eastern side there runs a small valley. The valley creates a crosswind much like the one from Howe canyon except that this wind runs to the northwest. Idaho Falls lies further south from Rexburg and is not affected by this valley crosswind, so we should expect to see a difference in wind speed from time to time between these two cities caused by the crosswind. Sure enough, our predictions run true in this scenario as seen by the following data for Rexburg and Idaho falls through the year.

![Figure 20: Ririe Crosswind Direction](image1)

![Figure 21: Rexburg and Idaho Falls Wind Speed Difference](image2)
Figure 22 not only shows the difference in wind speeds between these two cities, but also shows the time of year when we can expect the wind flow to increase. It was from the spring to the summer. Also, upon closer inspection of the graph, it is clear that in the middle of this windy season, Rexburg’s averages for the wind dips down (point 4). This is most likely caused because of the crosswinds. The data from table 3 is taken from June 22, 2010.[1] It shows clear indications that a crosswind is occurring.

Table 2: Rexburg, Rigby, and Idaho Falls data for June 22 [1]

<table>
<thead>
<tr>
<th>Time - Ririe</th>
<th>Direction</th>
<th>Speed</th>
<th>Time - Rigby</th>
<th>Direction</th>
<th>Speed</th>
<th>Time - Rexburg</th>
<th>Direction</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/18/2010 15:53</td>
<td>NW</td>
<td>4G07</td>
<td>6/18/2010 16:00</td>
<td>NNE</td>
<td>5G06</td>
<td>6/18/2010 16:00</td>
<td>ENE</td>
<td>2G05</td>
</tr>
</tbody>
</table>
Conclusion

This study has concluded that although crosswinds only occur during various times throughout the year, the difference in wind speed is NOT negligible. When we take into account the conditions of the day and the time of year, we can see wind speeds that are affected by the topography. There is a significant difference in wind speed that must be taken into account especially when considering where to place a wind turbine, because that information could cost a company Tens of thousands of dollars.

This effect from the crosswinds is not local to only the Howe canyon area as well, but was also shown to be an accurate prediction for the Ririe canyon and Rexburg in Idaho.\[1\] This effect would plausibly occur in any area where there is a valley hidden in the mountains met by a plain. It is clearer in Idaho because of the constant wind speed that occurs, but it is not secluded in that place. Many places around the world likely experience the same effect from crosswinds, and this effect though mild cannot be ignored completely.

As we look to the future and study our environment around us, much of what we see is unpredictable, such as the wind. However, if we make careful observations, we can see changes occurring and we can learn to theorize about those changes. So it is with the crosswinds. We now know that they can be predictable insofar as the weather is predictable and that they do have an effect on the movement of the wind. The wind cannot be accurately described in some places without also describing the wind from other places. And so crosswinds have a crucial place in the study of the wind.

Once again, it should be recognized that the results achieved through this research are invalid. Because of the misinterpretation of the data signs and symbols, the observations recorded are inaccurate. However, the steps followed in this research should prove an effective method of understanding more about the wind and if another study was undertaken in the future it may be of some use to follow the same routine. Researching wind circulation is an important step in harnessing its power, and through careful observations, we can increase our understanding about wind movement in certain areas.
Bibliography


