The Relationship Between Upslope Flow and Relative Humidity

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ABSTRACT

During the week of 7-14 March 2006, observations of winds and relative humidity were taken at various points along the mountain at Storm Peaks Laboratory in Steamboat Springs, CO. These observations were used to determine the relationship between slope flow and relative humidity. Slope flow is defined as the dot product of the wind vector and the gradient in elevation. The charts show details about the relationship between relative humidity and slope flow, and under what conditions it is likely that slope flow is significant.

1. Introduction

One of the most basic statements about our general understanding of how weather works is up-moist, down-dry. This stems from our basic knowledge that when a parcel of air is rising, it will generally be cooling toward it's dewpoint, while a sinking parcel of air will generally be warming away from it's dewpoint. It has been documented that relative humidity varied directly with rising motion, with upward motion most commonly leading to a higher RH, and downward motion most commonly leading to a lower RH.

Vertical motion, however, can occur for various reasons. The three most common reasons for vertical motion are conservation of mass, including convergence and divergence patterns, convection, and orographically forced lifting. Convergence and divergence usually occur due to synoptic scale weather systems, cyclones and fronts. These systems are the dominant forcing behind changes in weather patterns over many places, including the mid-latitudes in the winter. Convection is often an enhancement of vertical motion already provided by surface convergence zones, and tends to occur more often in summertime and in tropics. Orographic lift is caused by a mountain, hill, or some form of topography simply getting in the way of the flow. Mountains can cause both rising and sinking motion depending on what direction the wind is flowing relative to the topography gradient.

Slope flow is determined by taking the dot product of the wind vector and the elevation gradient. This particular product determines the actual degree at which a parcel of air is being forced to rise due to the orographical features below it. It is dependent on the speed of the wind, the steepness of the gradient, as well as the cosine of the angle between the gradient and the wind direction. Any vertical motion driven by conservation of mass, or buoyancy will occur independently, and not be represented by this slope flow parameter.

Over an area like northern Colorado in early March, it is reasonable to believe that orographically forced rising and sinking will be the most significant component of the vertical motion. This would lead to a strong relationship between relative humidity and slope flow for early March in Colorado. This study will examine the relationship between slope flow and relative humidity for two purposes. Firstly, to examine the validity of the idea that the most important forcing behind vertical motion is indeed slope flow, and secondly to determine if there are any non-linearities, or other special aspects to the relationship between slope flow and relative humidity not previously understood.

2. Observations

This study uses the period of 7-14 March 2006 at the DRI-Storm Peak Labaratory in order to determine a more precise relationship between slope flow and relative humidity. For this, the Storm Peak Laboratory mesonet is used to determine wind speed, wind direction, as well as relative humidity. Precise measurements using a GPS were taken from the locations of the mesonet data points in order to determine the elevation gradient.

By multiplying the magnitude of the wind measured by the instruments by the magnitude of the elevation gradient measured at that location by the GPS and then multiplying that product by the cosine of the difference between the wind direction and the direction of the elevation gradient, the value of slope flow can be determined. This was done for three different stations on the mountain for the entire week, taking measurements every fifteen minutes. These three stations had different characteristics, and different elevations.

The first station was at the top of the Four Points Hut, which is just below 9800 feet in elevation. This station is characterized by the weakest elevation gradient of the three, and is also the northernmost of the three stations. The elevation gradient of this station points due east, meaning a westerly wind is straight upslope, and an easterly wind is downslope. This station also tends to have very weak winds, with many of the observations recording no wind at all. This made it difficult to get any upslope or down slope flow.

The second station is at the top of Storm Peaks, which is located just above 10,400 feet above sea level. This station had a slightly stronger elevation gradient, which also pointed due east. Due to the fact that this station is near the top of the mountain, there is a lot more wind at this particular station. In fact, this station is the windiest of the three selected for this study. However, this station has also many observations with near 100% or 100% relative humidity, as fog was commonly persistent at the top of the mountain at times when the base was clear.

The third station is located at the top of the Gondola, which is slightly farther south than the other two stations. This station is located at a somewhat lower elevation of around 9100 feet. However, this particular station had the widest range observations, with windy and calm, upslope and downslope, moist and dry events all occurring at this station during the course of the week. This station had the steepest elevation gradient, as well as an elevation gradient that pointed north of due east.

Observations taken at these three stations will provide a diverse series of observations taken in various situations at various elevations. This will give a general idea of how relative humidity is affected by upslope flow with a bias toward more upslope events, as westerly winds are more likely in the mid-latitudes in March, as Stemaboat Springs, CO is located just north of 40 degrees latitude.

3. Data

For all three stations, relative humidity vs. slope flow is plotted. Figure 1 shows relative humidity vs. upslope follow for the Four Points Hut. It is clear that although there is a general trend toward higher relative humidity with increased slope flow, this relationship is weak, with a correlation coefficient of 0.0229. These findings are similar to those found in Figure 2 for the Storm Peak station. Although these two stations are quite different, with one being commonly calmer and dryer than the other, they both tell nearly the same story. The correlation between relative humidity and slope flow for Storm Peak is 0.0621.

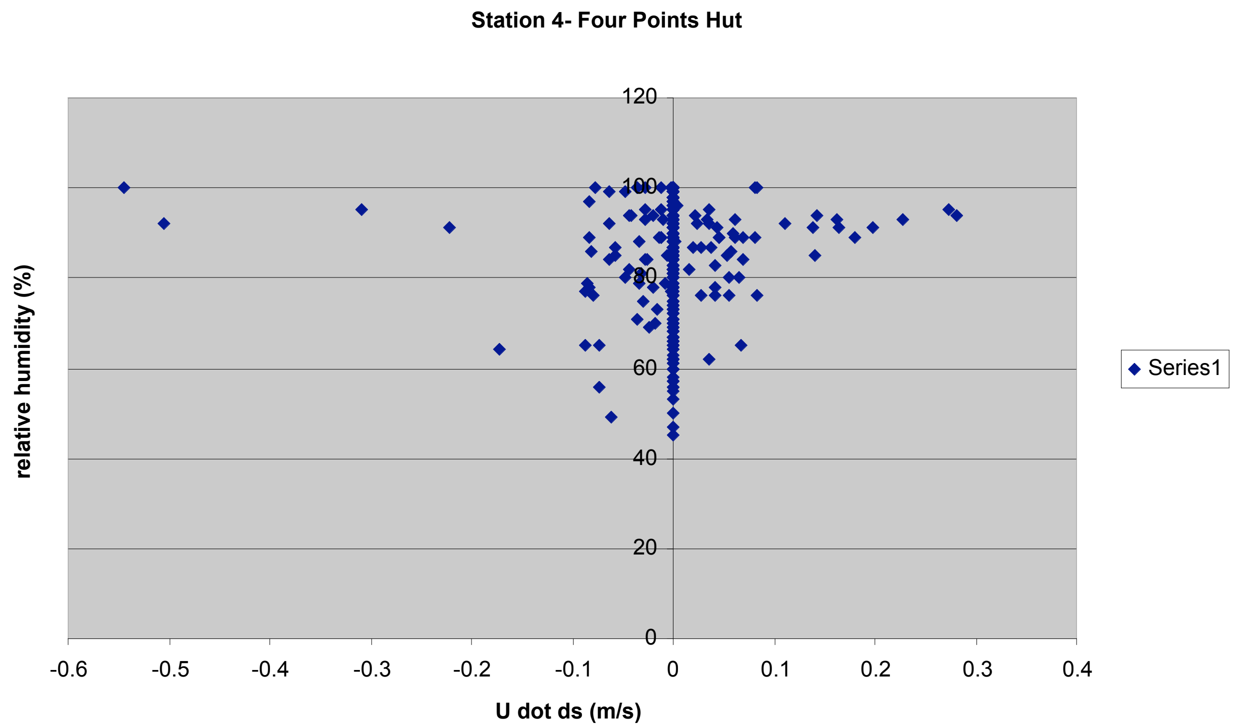

Fig.1 Relative humidity vs. Slope flow for the Four Points Hut

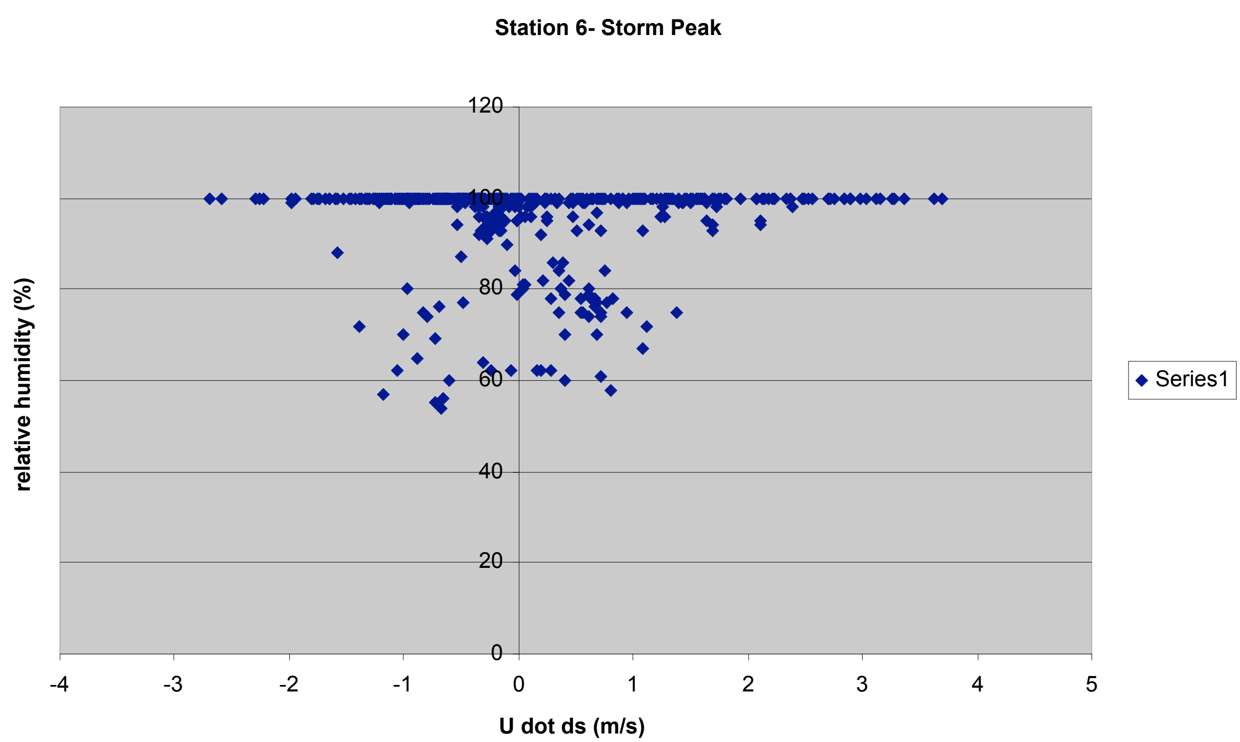

Fig 2. Relative humidity vs. Slope flow for Storm Peak

It also appears that although high relative humidity, near or at 100%, can occur with any type of slope flow, upward or downward. However, both of these charts lack observations of low relative humidity with a strong upslope flow. This leads to the idea that there could be a lower cutoff to how dry it can become, which is dependent on the slope flow.

Figure 3 further supports this notion of a lower cutoff for relative humidity based on the degree of slope flow. This figure, for the Top of the Gondola, shows only a slightly more definitive relationship between slope flow and relative humidity, with a correlation coefficient of 0.0645. This clear relationship between RH and slope flow seems only to be true for values of stronger slope flow, which is interesting because the values of slope flow achieved at this station are much higher than those of the other stations. For weak or no slope flow, relative humidity shows little, if any dependence on slope flow.

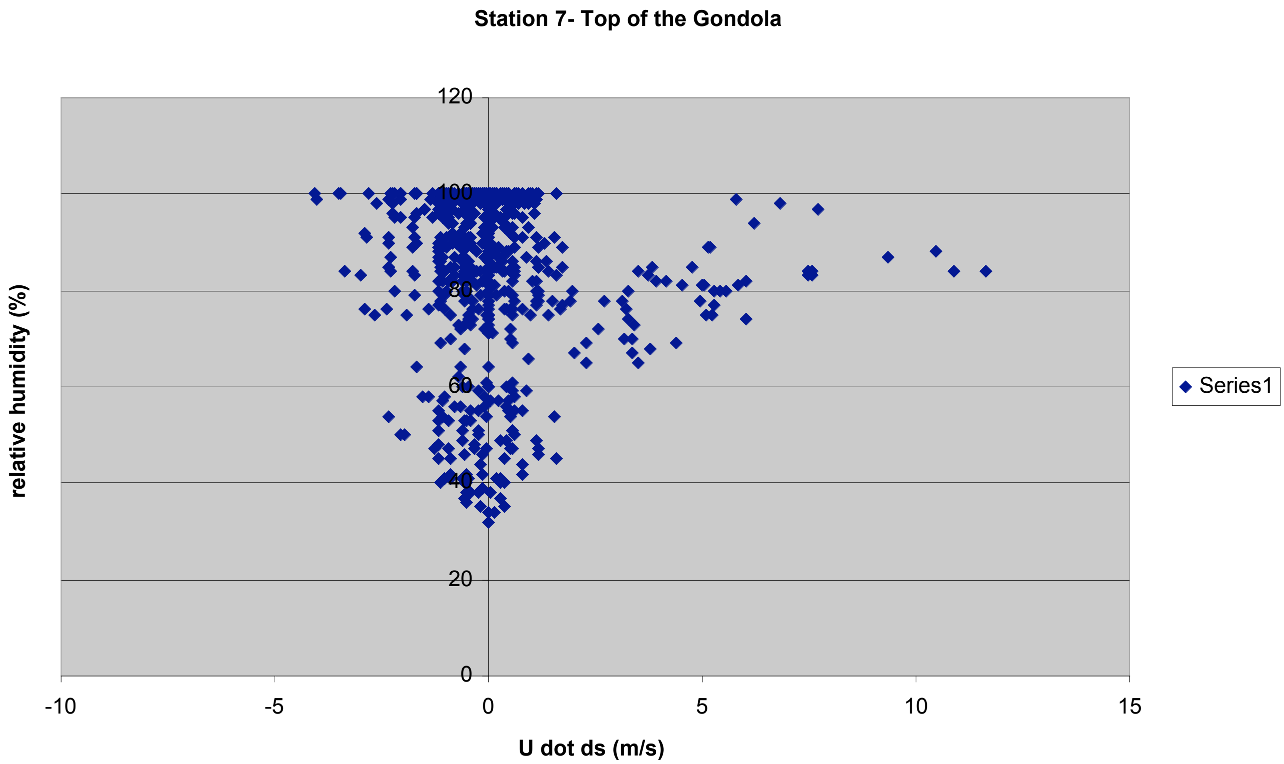

Fig. 3 Relative humidity vs. Slope flow for the Top of the Gondola

4. Analysis

As seen from the charts for relative humidity vs. slope flow, relative humidity is more likely to be high if there is a higher value of slope flow. However, it is still quite possible for relative humidity to be high with little slope flow, or even downslope flow. The only combination that seems not to be possible is strong upslope flow with lower relative humidity.

The most likely explanation for this is that there are multiple mechanisms in which high relative humidities are achieved in the Rocky Mountains at this time of year. One of those mechanisms is through upslope flow, as is demonstrated by the right side of the three figures, especially figure 3. However, another mechanism is responsible for the high relative humidities seen at all three stations with little slope flow, or even downsloping. Since convection is very unlikely in early March at this latitude, especially at elevations above 9000 feet, synoptic convergence zones must be responsible for these observations.

Figure 4 demonstrates the importance of synoptic scale convergence on relative humidity. Here, relative humidity vs. temperature is plotted only for station 7. Here lies a strong negative correlation of -0.645 between temperature and relative humidity. Since temperature is almost always higher at the surface under sinking motion than rising motion, it is likely that synoptic scale rising motion are leading to observations of high relative humidity with little upslope flow.

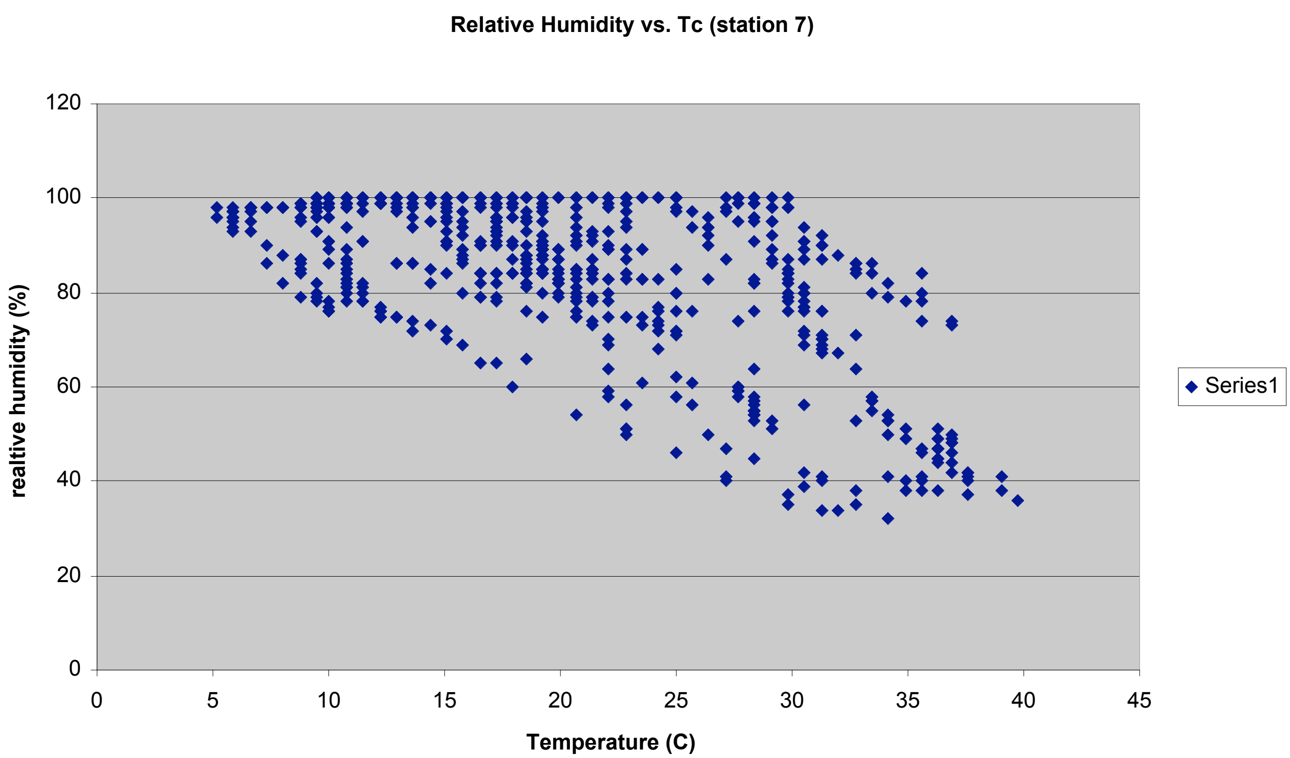

Fig. 4 Relative humidity vs. temperature

5. Conclusions

Relative humidity can be high in Rocky Mountain winters for two general reasons. Firstly, upslope flow can force high relative humidities, especially if this upslope is fairly strong. Secondly, lower level convergence, characterized by lower surface temperatures, can also lead to higher relative humidities under little slope flow, or even downslope flow. However, if there is little upslope flow, or downslope flow, and synoptic forcing is not convergent, it is likely that lower relative humidities will be observed.

The relationship between relative humidity and slope flow is only significant for more significant values of slope flow. For small values of slope flow, relative humidity most likely behaves based on completely different phenomenon. However, as the rate of upslope flow increases, the lower cutoff for relative humidity also increases. Although it is quite possible for relative humidity to be high without significant upslope, it is highly unlikely for relative humidity to be low with significant upslope.