Universiteit Utrecht

Faculteit Bètawetenschappen

Relation between Cloud Cover and Relative Humidity

Bachelor Thesis

Nahom Giorgio

Study: Natuur- en Sterrenkunde

Supervisor:

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Abstract

A empirical relation exists between the total cloud cover fraction and the relative humidity at the surface. In this research project I test this using a certain model on data from the Netherlands. The required data, which are the temperature, dew point and cloud cover will all be measured at Cabauw, with a time resolution of 10 minutes. The cloud cover is measured with a scanning pyrometer called the nubiscope. From the temperature and dew point the relative humidity will be approximated. This project has also been done by my supervisor for two different locations outside of the Netherlands with two different climates. The results showed that the model works, and that makes it interesting to also test it for the Netherlands. I will test it for every month of the year using data collected over 7 years. This way we can compare the month to month results and differences due to the seasons. Furthermore different cloud types occur more often based on the seasons. By comparing the seasonal results we will find out of there is a dependence on the cloud type.

Contents

1 Introduction

One can imagine that a relationship exists between the relative humidity and the cloud cover. Because both have something to do with the amount of water vapour in the air. We can further examine this relationship by taking a look at the water cycle [1]. The annual mean and global mean energy balance tell us that the incoming solar radiation is 341 W m^{-2}, of which: 79 W m^{-2} gets reflected by clouds and the atmosphere, 78 W m^{-2} gets absorbed by the atmosphere, 161 W m^{-2} gets absorbed by the surface and 23 W m^{-2} gets reflected by it. On top of that the surface sends out 356 W m^{-2} longwave radiation, of which 333 Wm^{-2} is reflected back by the atmosphere. The conclusion of all these numbers is: an amount of energy, almost equal to a third of the incoming solar radiation, is absorbed by the surface. This is used partly to heat the surface and evaporate water from the surface.

The heat conducts to the air above the surface, which causes a hydrostatic instability [1]. The air will then rise due to a vertical pressure gradient, and as the air cools down with altitude, the relative humidity will increase, given that all the other factors on humidity are constant. When the relative humidty reaches 100% the air becomes saturated and clouds will form. This is how the beautiful cumulus clouds that we so often see in the Netherlands are formed.

Based on the previous work of my supervisor a relationship between the cloud cover and the relative humidity is clearly present [1]. This was concluded from data collected on Badajoz and Helgoland over several decades. These two cites have different climates and thus a different relative humidity distribution. Badajoz is known for wet winters and dry summers. Helgoland has a purely maritime climate all year round. With this difference in the climates, the same assumed model still holds in both instances. A question that one could ask then is: will the same model also hold on a smaller timescale of several years, instead of decades? It would be interesting if it would be so with the wet climate in my country, the Netherlands.

The idea of this thesis is to examine the relative humidty at ground level, and find out if the assumed relationship with the cloudcover will test positive. This will be done using data measured in Cabauw, the Netherlands. If it is true, we have acces to a relatively easy but useful method of doing weather calculations and predictions with respect to those two parameters. The relative humidity at 200m altitude will also be examined to test if the found relation will hold at that altitude. The results will be examined per month, and for every month the data is composed by measurments done over a period of 7 years. The weather ofcourse is different every month/season, so it is also interesting to compare the differences, which will be visible through the different model parameters.

2 Theory and hypothesis

The relative humidity is defined as the ratio between the specific humidity and the saturation specific humidity [2]. The saturation specifc humidity represents the partial pressure of water vapor at the dew point temperature. While the specific humidity equals the partial pressure of water vapour for a given temperature. The dew point is defined as the temperature at which an air parcel is saturated with water vapour. The dew point is always $\leq$ the temperature. To put it simply warmer air can hold more water. Thus the relative humidity decreases with increasing temperature, and increases with decreasing temperature, for a constant amount of water vapour.

The following model will be tested:

$$CC = \begin{cases} C(RH - RH_0), \text{if RH} > RH_0 \\ 0, \text{for RH} \leq 0 \end{cases} \tag{1}$$

This is the same model used by my supervisor, which gave the results described in the introduction [1]. That is why I will also use it in this case. 'C' is a constant number and 'RH_0' is the relative humidity below which the sky is cloudless. We will also refer to it as 'the critical relative humidity'.'RH' is the relative humidity and 'CC' stands for the cloud cover.

As was briefly mentioned in the introduction; the model will expect to hold best for cumulus clouds, because of the way they are formed. These type of clouds are more common during the summer season, because of the higher exposure to solar radiation. Other cloud types are layered clouds such as stratus [1]. They are formed by slow slanted and weak ascent of relatively warm air over large regions. This process involves adjustments to the thermal wind balance to result in the formation of these clouds. Such clouds are more common during the winter season. However, this does not indicate that the model won't give desired results during the winter season, only that we have some kind of certainty that it will during the summer. If the results are still similar, it would make the relationship between surface and relative humidity even stronger. Because there would be no dependence on the cloud type.

3 Measuring Techniques

Our two relevant variables are the relative humidity and the cloudcover. The measurements of the cloudcover are done by the nubiscope stationed in Cabauw, the Netherlands [3]. The cloudcover is measured with a time resolution of 10 minutes. Only measurements 20 degrees above horizon are used to create a hemispherical cloud mask.

The nubiscope is a scanning pyrometer mounted on a pan and tilt unit. It performs a scan of the entire hemisphere every 10 minutes, including 2 surface temperature measurements. The surface measuremens are done at a height of 2m to be exact. So whenever the term surface is used, it means at that altittude. The accuracy of the nuciscope was tested against that of a ceilometer by the KNMI, during a period of a year. 44% of the time the nubiscope and the ceilometer gave identical result. 80% and 87% of the time the differences were within 1 and 2 okta respectively. This is similar to the difference between an observer and a ceilometer. A big advantage of the nubiscope over the ceilometer is that it can detect clouds in clear sky situations, or gaps in overcast situations. Due to this there are less measurements of 0 okta (= a completely clear sky) and 8 okta (=a completely clouded sky). This is in better agreement with human observed distributions.

The KNMI concluded that the nubiscope gives better results of the total cloud cover than the ceilometer [3]. However it is not trustworthy for applications involving the cloud heighth. So calculations involving cloud altitude, such as the relative humidity versus the cloudcover for clouds with cloudbases at different heights, cannot be done. It would be interesting if it were possible, to test the model for clouds that have higher bases than stratus and cumulus. Overall it was still found to be a very usefull device and is now stationed permenantly at Cabauw.

4 Method

The relative humidity cannot be directly measured, however it can be calculated from the temperature (T) and the dewpoint temperature (T_d). The temperature is also measured in Cabauw with the same time resolution. $T_d \leq$ T. The relative humidity (RH) can then be calculated by looking at the saturation vapor pressure ratio at (T) and (T_d). For this step Bolton's empircal water vapor pressure formula will be used [4]:

$$RH = \frac{e^{\frac{17.625T}{243.04+T}}}{e^{\frac{17.625T_d}{243.04+T_d}}} * 100\% \tag{2}$$

The next step is to divide the relative humidity up in fifty bins of 2%. For each bin of 2% in relative humidity the sum of all values of cloud cover is computed and this number is divided by the total number of measurements in the particular bin. This will be done for all the months in a year, over a period of 7 years. A comparison will also be made by examining only the data observed during daytime (09:00 - 16:00), and by taking the daily averages of the cloud cover and relative humidity. Both adjustments could have a noticable influence on the results because: after sunset the temperature drops, which gives rise to higher relative humidities. When it drops to the dewpoint, as the name indicates dew will start to form. This might interfer with the measurements done by the nubiscope. It could cause some extreme values, where relatively low cloud covers might be observed for high relative humidity.

I choose 09:00 and 16:00 because over a whole year 09:00 is the latest time, rounded up, that the sun has risen. And 16:00 is the earliest time the sun has set, rounded down[7].

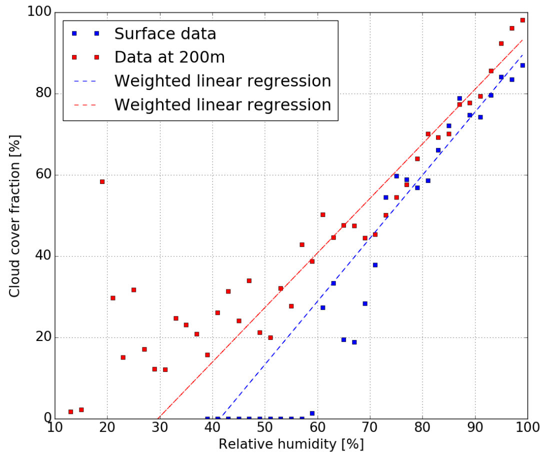
Furthermore measurements made every ten minutes might be too small of a timescale to produce a clear relationship between the variables. A change in the relative humidity at the surface might have it's effect on the cloud cover at a time significantly later than 10 minutes. Thats why comparing the average daily values might give rise to a more clear relationship than in the normal case. It is worth it to take a look at.

We will also look at the weighted correlation coefficients for each different case and compare them for the different months. If there is a direct relationship between the cloud cover and the relative humidity it should be about the same every month. Which month gives the best correlation coefficient and why is this the case? During which season will this occur? Those are all interesting subquestions to take a look at.

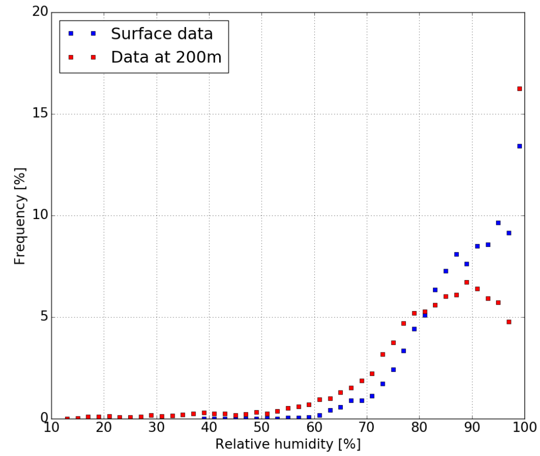
Lastly the relative humidity distribution at the surface will be examined and compared for the months. This is expected to differ strongly for winter and summer months, because of the difference in weather. The winters are relatively more humid, and the summer is dryer, so the average relative humidity is expected to be higher during the winter months [6]. Also the relative humidity distribution at 200m will be plotted. Due to different temperatures and dew points at that altitude, the relative humidity distribution will differ from the surface. But the month to month difference is hard to say something about beforehand.

5 Results

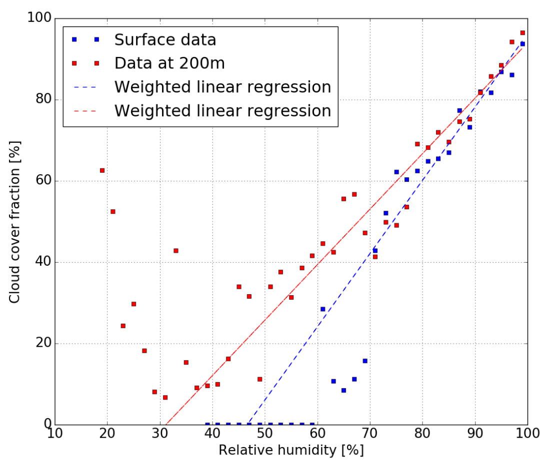
5.1 January



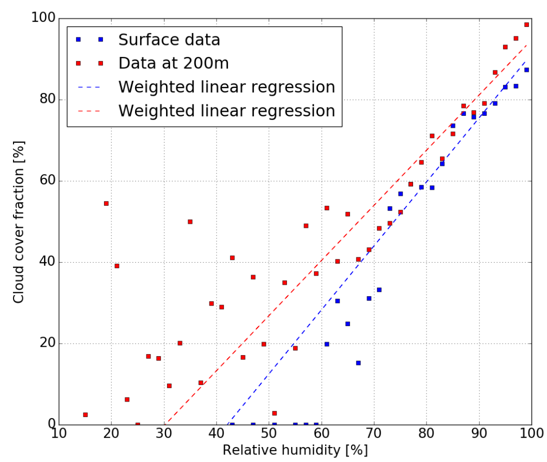
(a) Cloud cover versus relative humidity.



(b) The relative humidity distribution



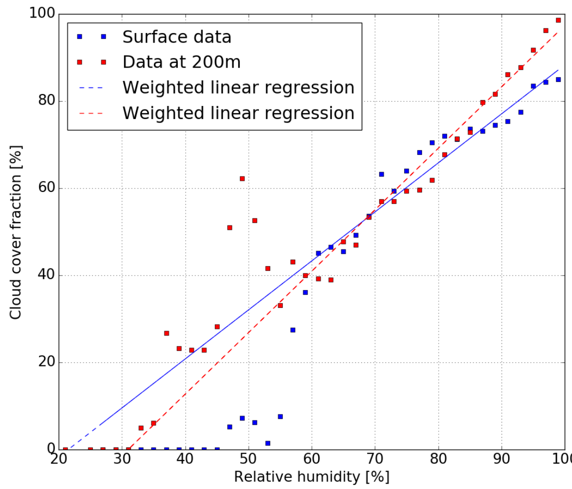
(c) Cloud cover versus relative humidity, but only including measurements during daytime (09:00-16:00)



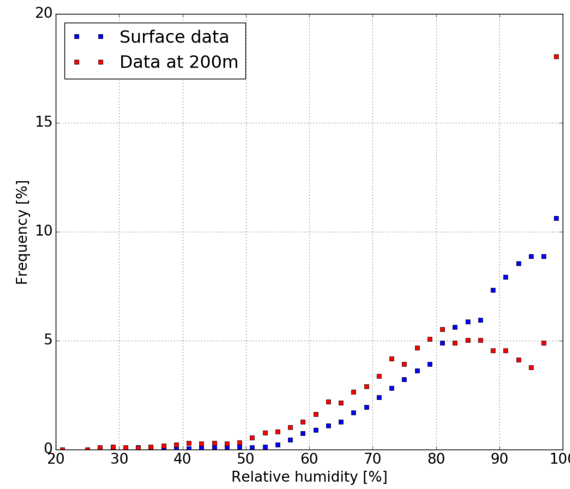
(d) Cloud cover versus relative humidity, but now taking daily averaged values

Figure 1: The results are based on the years 2009 - 2016, with exception of 2013. The relative humidity is divided in bins of 2%. The amount of cloud cover measurements in each bin during this 7 year period is then counted, and divided by the amount of events in the particular bin.

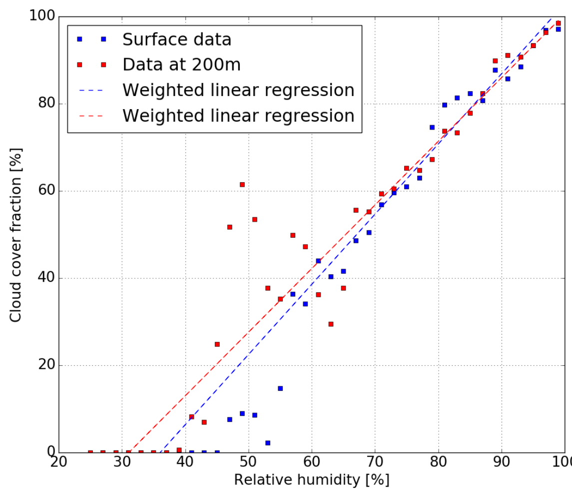
5.2 February



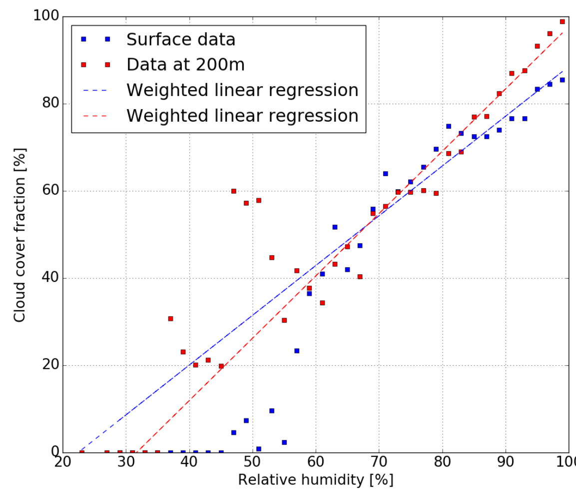
(a) Cloud cover versus relative humidity.



(b) The relative humidity distribution



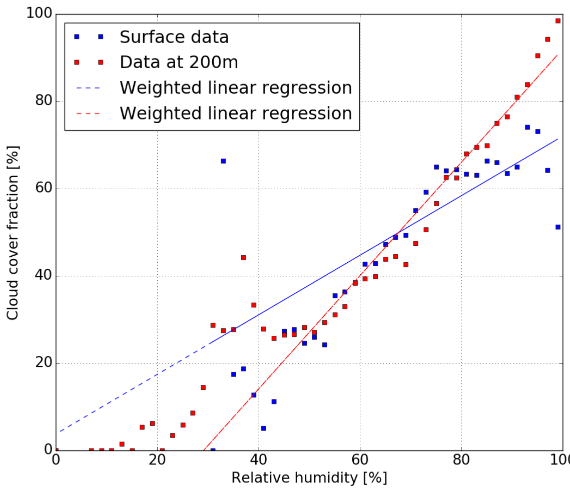
(c) Cloud cover versus relative humidity, but only including measurements during daytime (09:00-16:00)



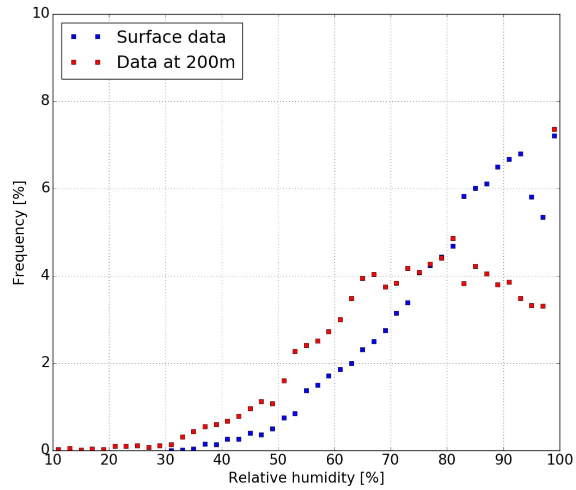
(d) Cloud cover versus relative humidity, but now taking daily averaged values

Figure 2: The results are based on the years 2009 - 2016, with exception of 2013. The same method as described under January is used.

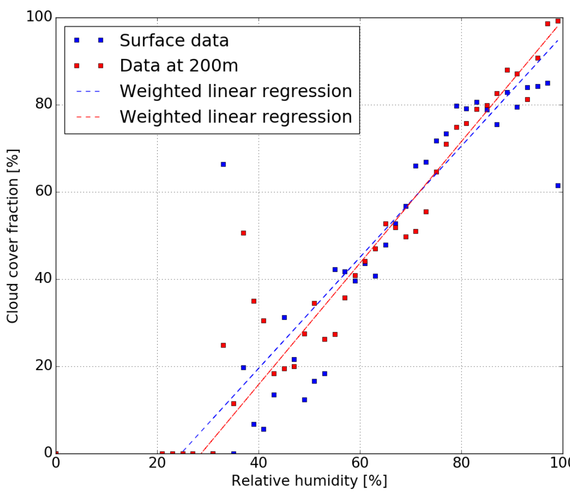
5.3 March



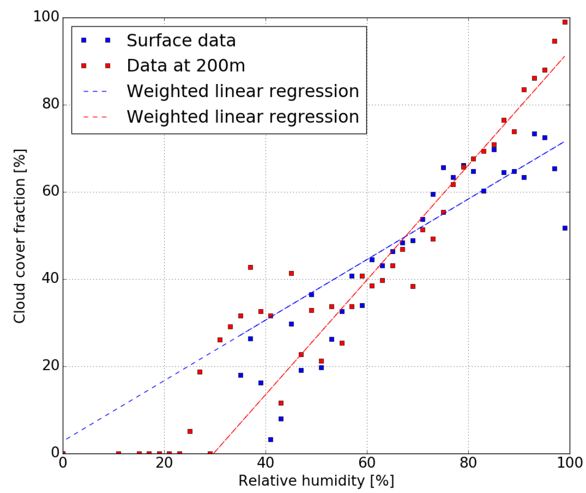
(a) Cloud cover versus relative humidity.



(b) The relative humidity distribution



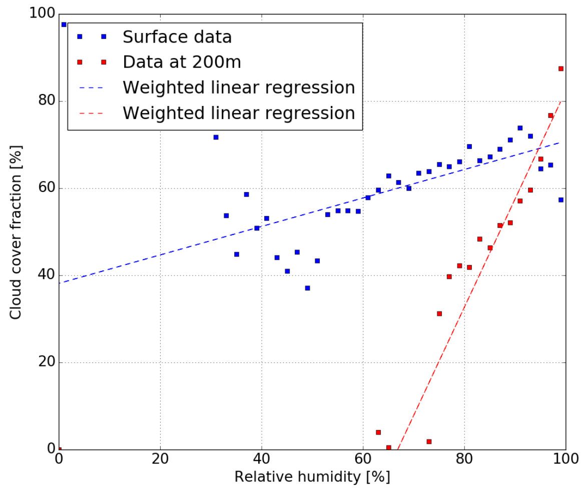
(c) Cloud cover versus relative humidity, but only including measurements during daytime (09:00-16:00)



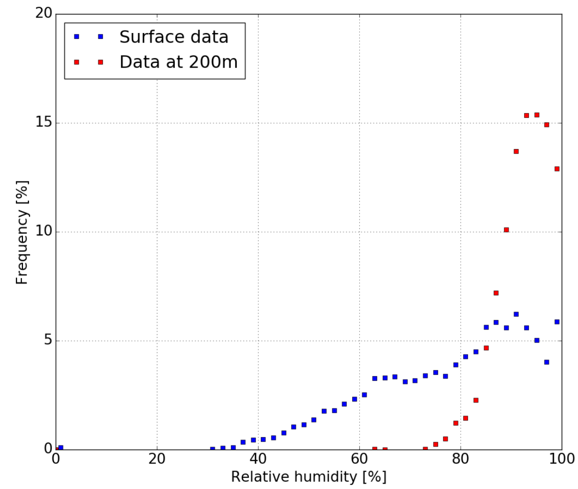
(d) Cloud cover versus relative humidity, but now taking daily averaged values

Figure 3: The results are based on the years 2009 - 2016, with exception of 2013. The same method as described under January is used.

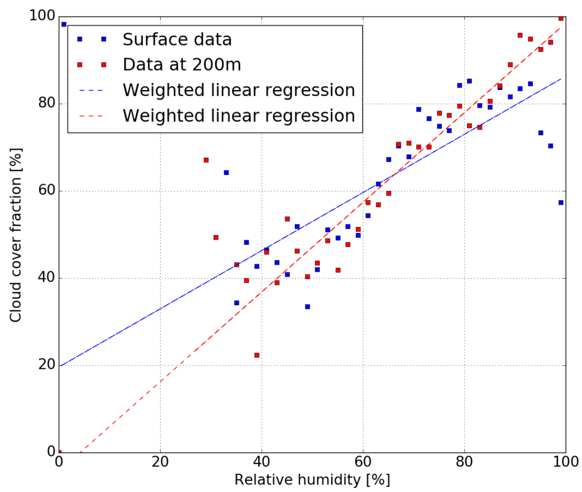
5.4 April



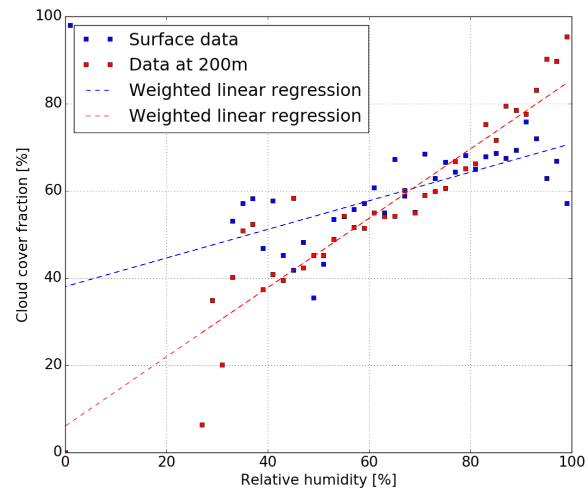
(a) Cloud cover versus relative humidity.



(b) The relative humidity distribution



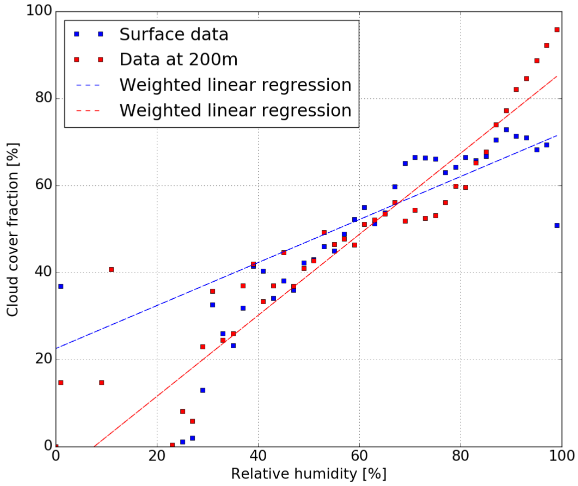
(c) Cloud cover versus relative humidity, but only including measurements during daytime (09:00-16:00)



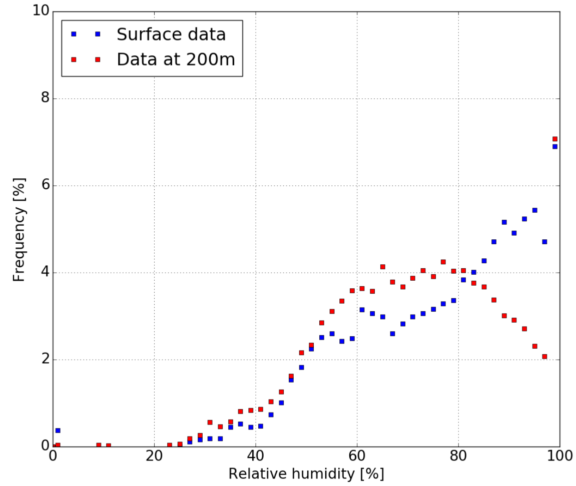
(d) Cloud cover versus relative humidity, but now taking daily averaged values

Figure 4: The results are based on the years 2010 - 2016, with exception of 2011 and 2015. Due to these years containing NaN data we only have 5 instead of 7 years available for August. The same method as described under January is used.

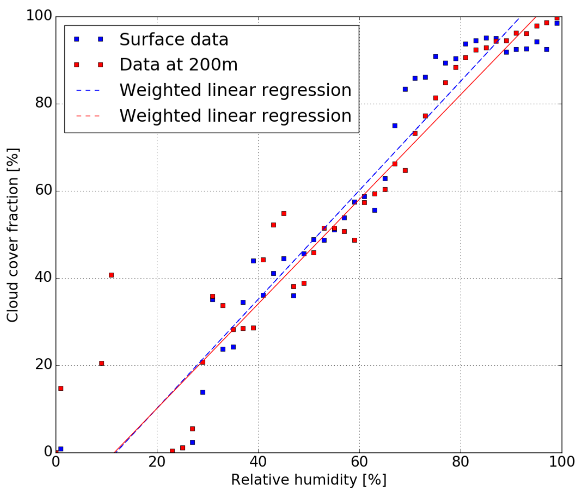
5.5 May



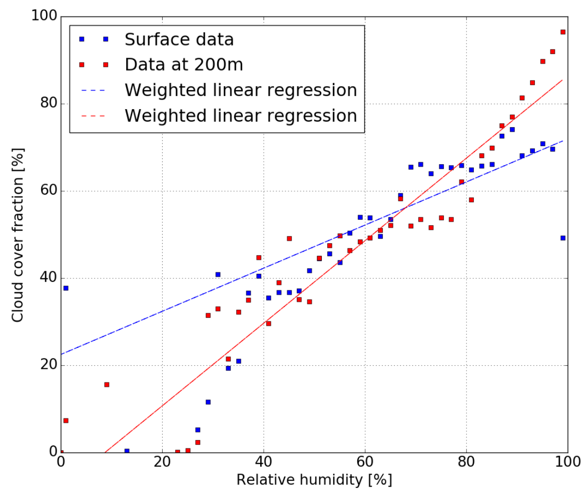
(a) Cloud cover versus relative humidity.



(b) The relative humidity distribution



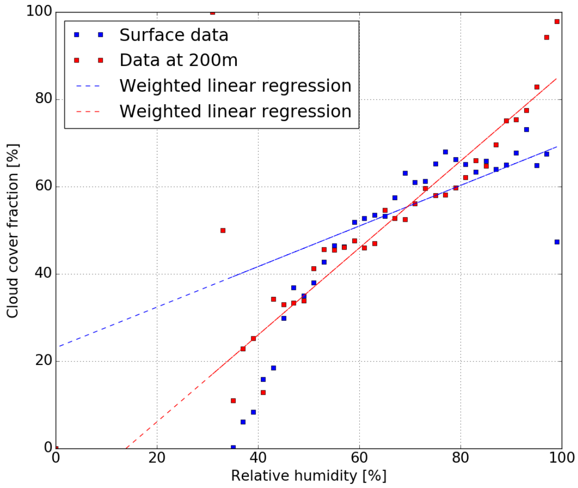
(c) Cloud cover versus relative humidity, but only including measurements during daytime (09:00-16:00)



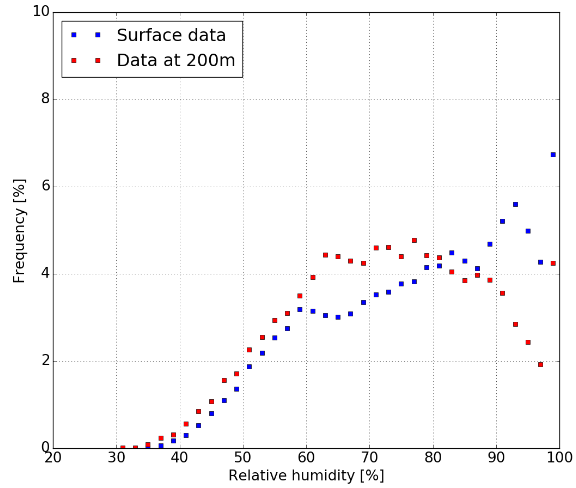
(d) Cloud cover versus relative humidity, but now taking daily averaged values

Figure 5: The results are based on the years 2009 - 2015. The same method as described under January is used.

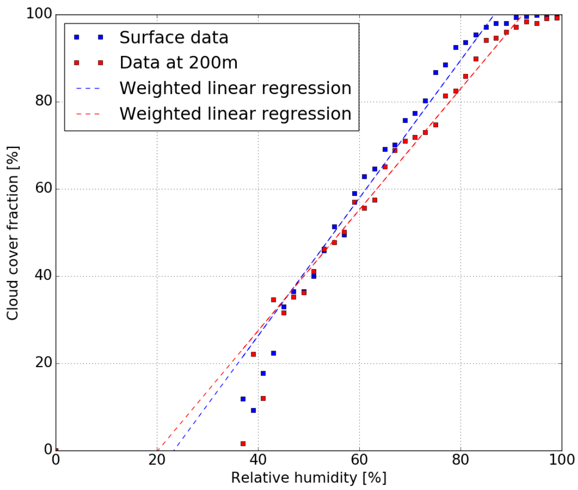
5.6 June



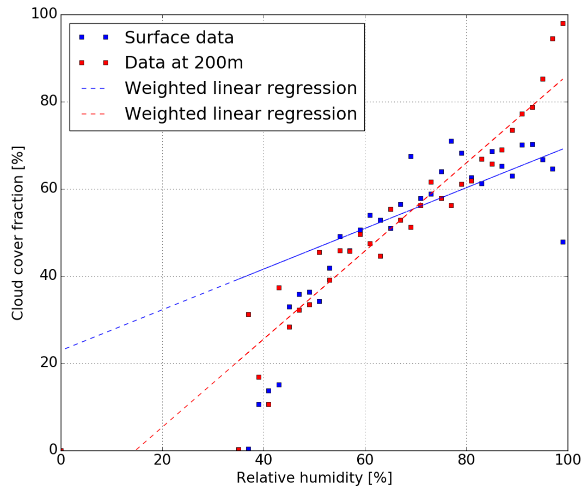
(a) Cloud cover versus relative humidity.



(b) The relative humidity distribution



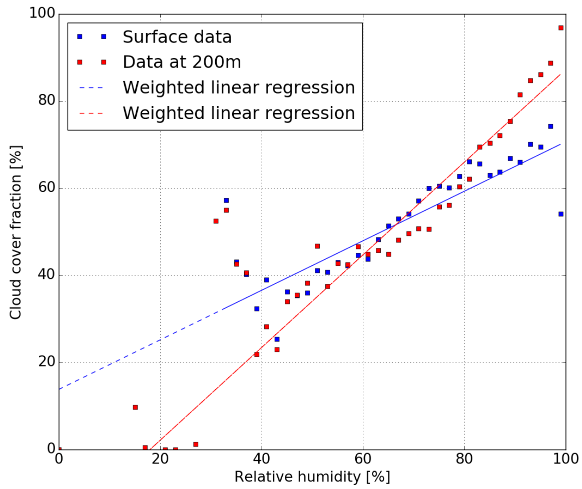
(c) Cloud cover versus relative humidity, but only including measurements during daytime (09:00-16:00)



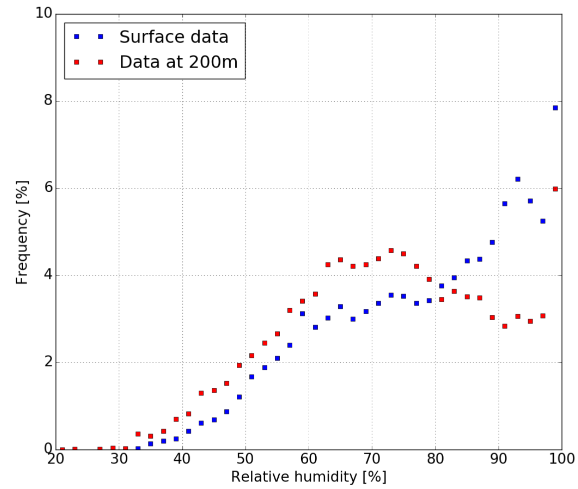
(d) Cloud cover versus relative humidity, but now taking daily averaged values

Figure 6: The results are based on the years 2009 - 2015. The same method as described under January is used.

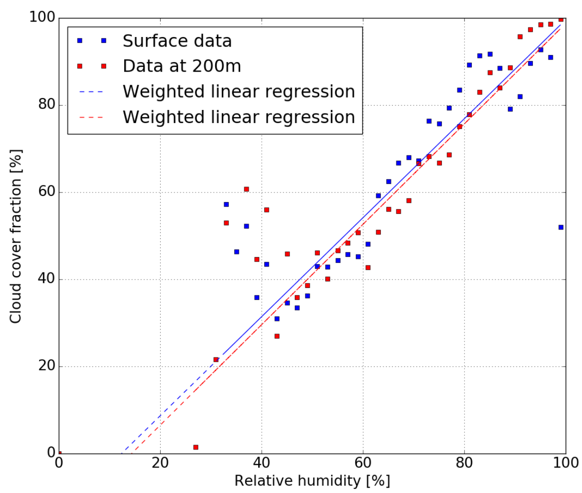
5.7 July



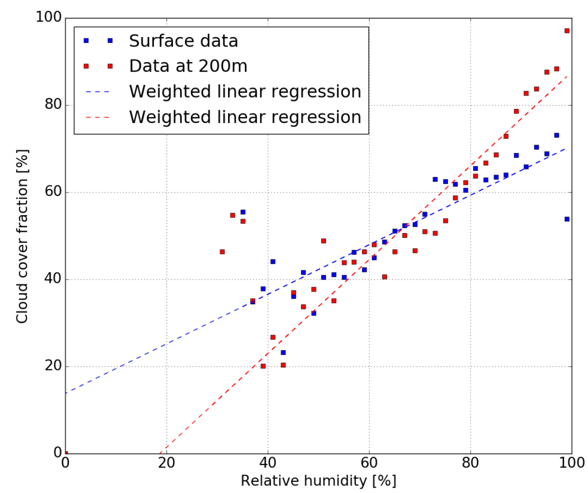
(a) Cloud cover versus relative humidity.



(b) The relative humidity distribution



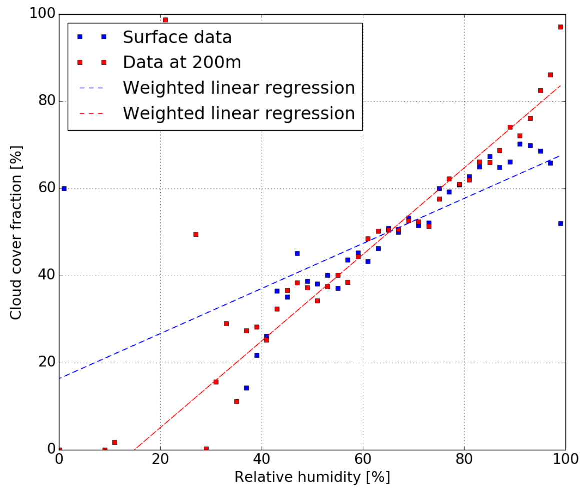
(c) Cloud cover versus relative humidity, but only including measurements during daytime (09:00-16:00)



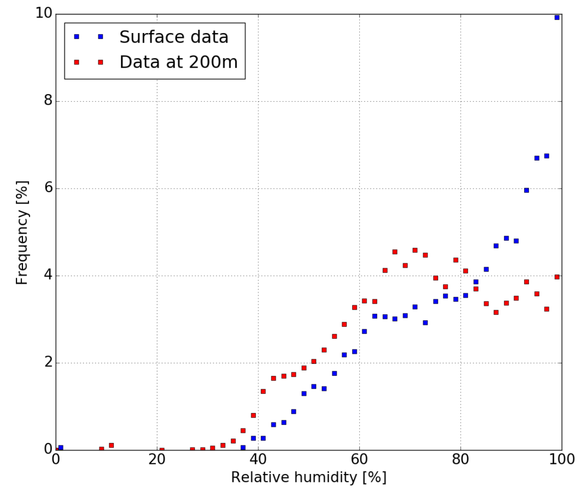
(d) Cloud cover versus relative humidity, but now taking daily averaged values

Figure 7: The results are based on the years 2009 - 2015. The same method as described under January is used.

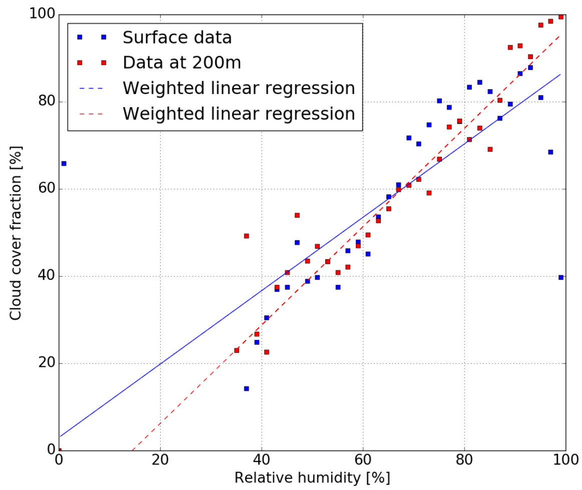
5.8 August



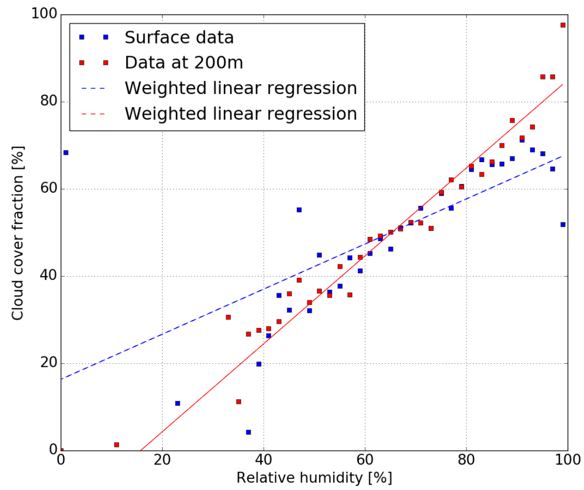
(a) Cloud cover versus relative humidity.



(b) The relative humidity distribution



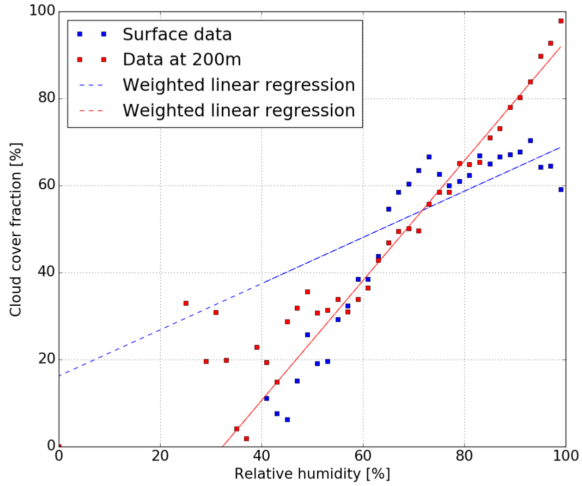
(c) Cloud cover versus relative humidity, but only including measurements during daytime (09:00-16:00)



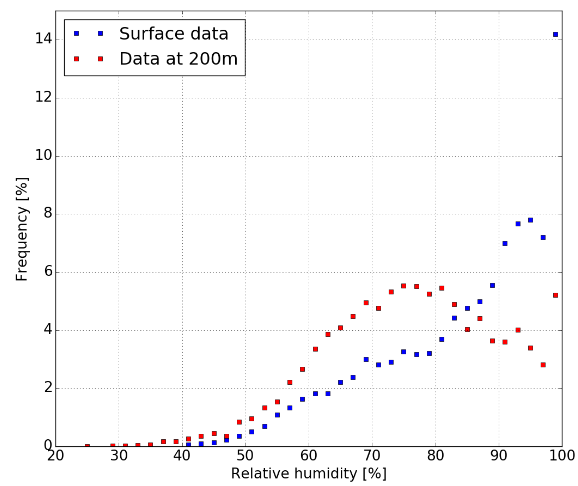
(d) Cloud cover versus relative humidity, but now taking daily averaged values

Figure 8: The results are based on the years 2008 - 2015, with exception of 2011 and 2014. Due to these years containing NaN data we only have 6 instead of 7 years available for August. The same method as described under January is used.

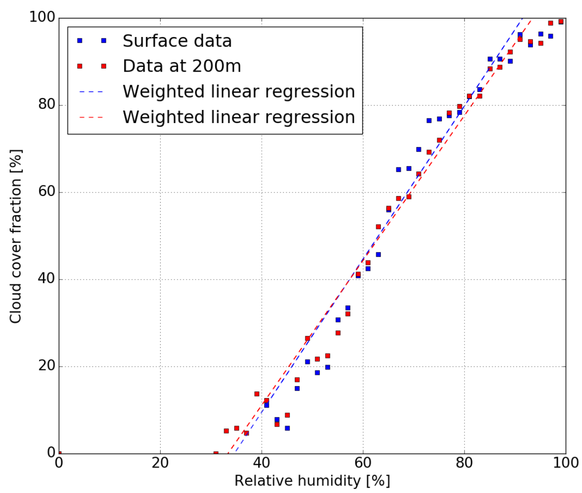
5.9 September



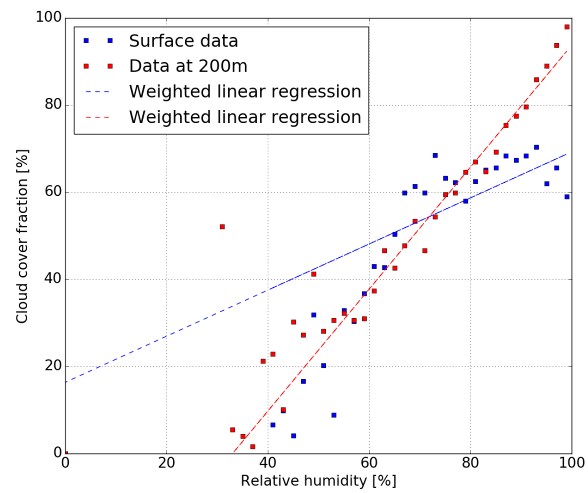
(a) Cloud cover versus relative humidity.



(b) The relative humidity distribution



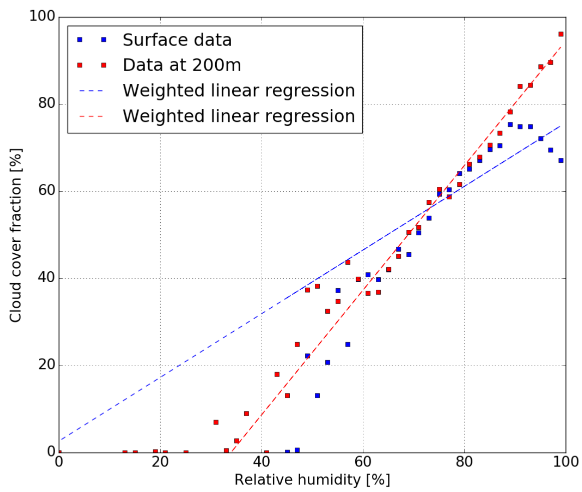
(c) Cloud cover versus relative humidity, but only including measurements during daytime (09:00-16:00)



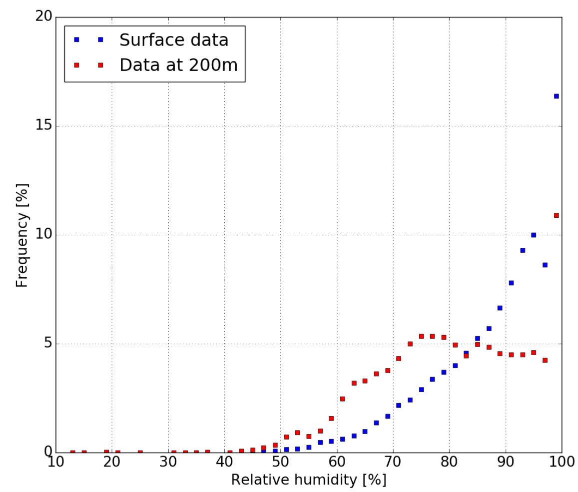
(d) Cloud cover versus relative humidity, but now taking daily averaged values

Figure 9: The results are based on the years 2008 - 2015, with exception of 2011 and 2014. Due to these years containing NaN data we only have 6 instead of 7 years available for September. The same method as described under January is used.

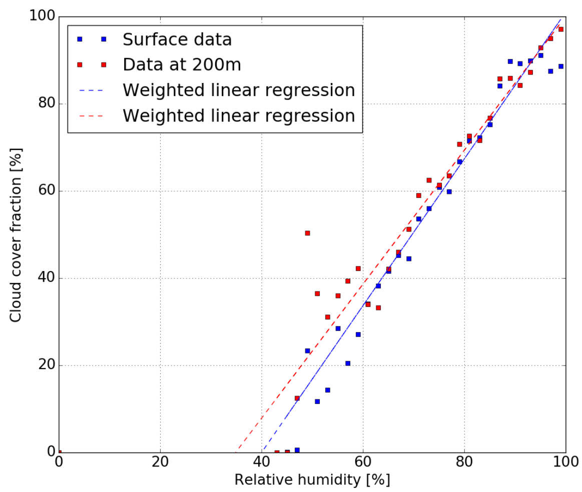
5.10 October



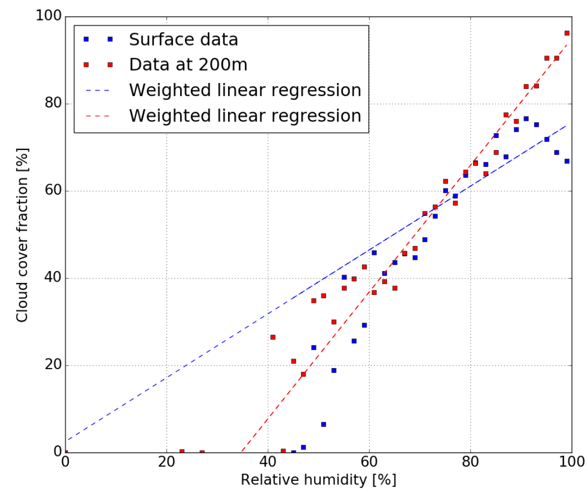
(a) Cloud cover versus relative humidity.



(b) The relative humidity distribution



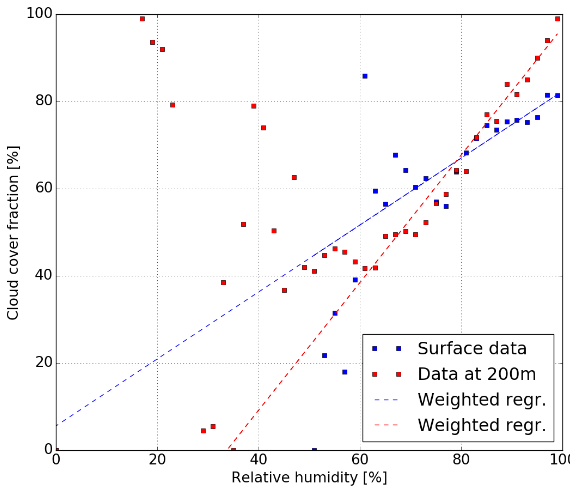
(c) Cloud cover versus relative humidity, but only including measurements during daytime (09:00-16:00)



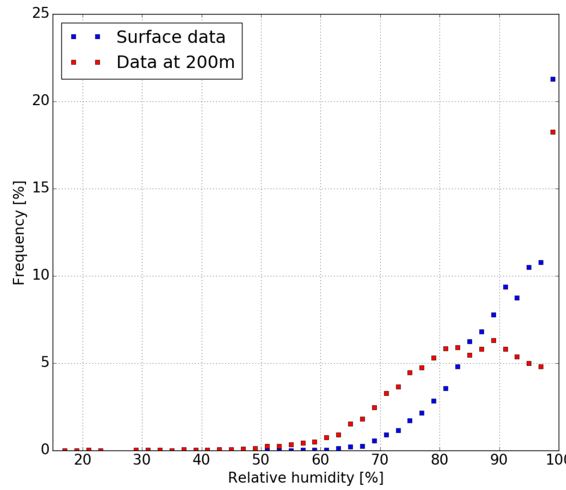
(d) Cloud cover versus relative humidity, but now taking daily averaged values

Figure 10: The results are based on the years 2008 - 2015, with exception of 2009. The same method as described under January is used.

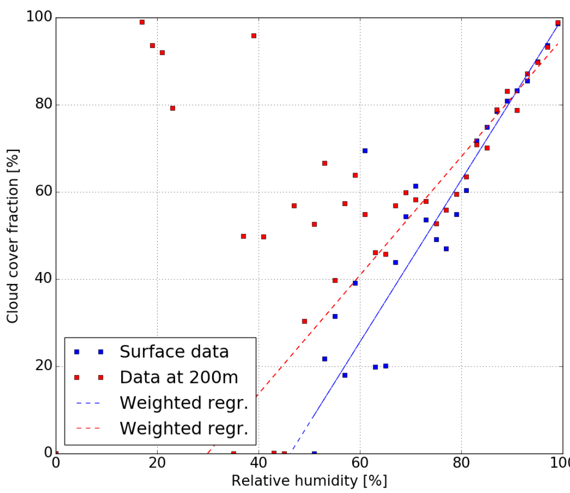
5.11 November



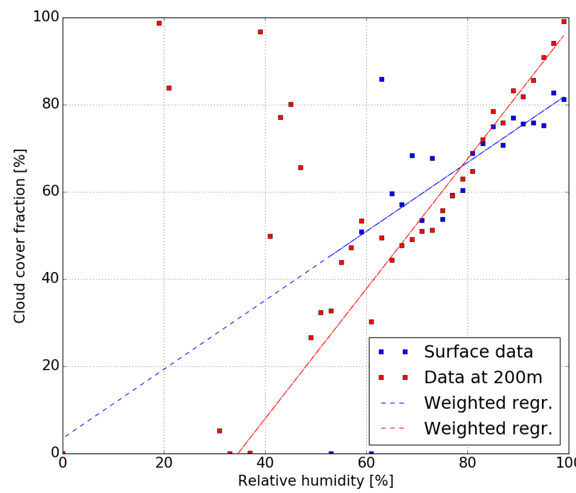
(a) Cloud cover versus relative humidity.



(b) The relative humidity distribution



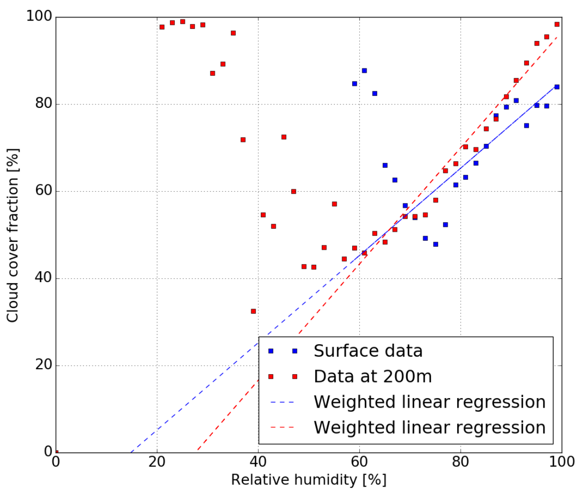
(c) Cloud cover versus relative humidity, but only including measurements during daytime (09:00-16:00)



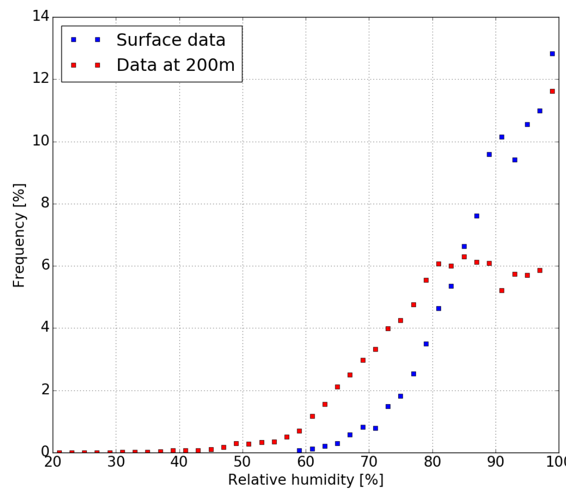
(d) Cloud cover versus relative humidity, but now taking daily averaged values

Figure 11: The results are based on the years 2008 - 2015, with exception of 2009. The same method as described under January is used.

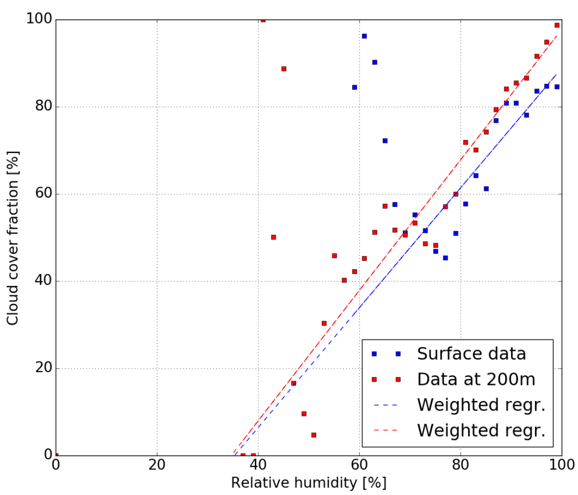
5.12 December



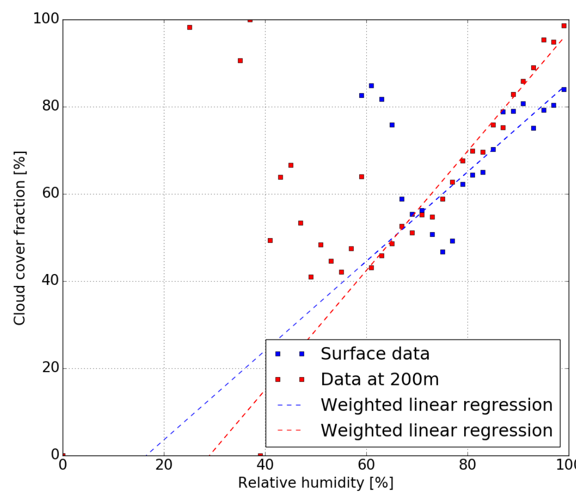
(a) Cloud cover versus relative humidity.



(b) The relative humidity distribution



(c) Cloud cover versus relative humidity, but only including measurements during daytime (09:00-16:00)



(d) Cloud cover versus relative humidity, but now taking daily averaged values

Figure 12: The results are based on the years 2008 - 2015, with exception of 2009. The same method as described under January is used.

5.13 Surface weighted correlation coefficients

Month	**case (a)**	**case (c)**	**case (d)**
January	0.943	0.942	0.950
February	0.949	0.980	0.943
March	0.764	0.897	0.761
April	0.675	0.732	0.638
May	0.764	0.954	0.752
June	0.670	0.978	0.660
July	0.846	0.907	0.839
August	0.781	0.778	0.763
September	0.685	0.963	0.669
October	0.802	0.977	0.782
November	0.920	0.959	0.876
December	0.850	0.844	0.841

5.14 Weighted correlation coefficients at 200m

Month	**case (a)**	**case (c)**	**case (d)**
January	0.945	0.951	0.932
February	0.975	0.970	0.967
March	0.965	0.964	0.957
April	0.935	0.933	0.934
May	0.933	0.966	0.925
June	0.953	0.986	0.948
July	0.940	0.932	0.935
August	0.969	0.955	0.967
September	0.985	0.979	0.980
October	0.987	0.982	0.983
November	0.957	0.908	0.949
December	0.952	0.949	0.951

6 Discussion

6.1 January

January is a relatively humid month according to the distribution (b). The two distributions have a similar shape, but with a higher average value for the surface. The tested model seems to give similar results for every case at 200m, with a critical relative humidity of 30%. For the surface we get similar results in case (a) and (d), but the critical relative humidity becomes slightly higher (about 5%), when you only look at the daytime data (c). This indicates that during the night, high relative humidities with relatively low cloud cover are observed.

6.2 February

The average relative humidity again seemed to be higher for the distribution at the surface, also this time we observe that the mode at 200m is the highest bin. Since we see the same mode at the surface, it has to be due to fog. The model again gives similar results for case (a) and (d) at the surface, and a 15% higher critical relative humidity for case (c). This is due to the same reason given for January... At 200m we get similar results again for every case, with a critical relative humidity of again 30%.

6.3 March

For the surface the best regression seems to be case (c). In fact it is the only one that gives a meaningful value for the critical relative humidity. Case (a) and (d) have a weighted correlation coefficient of 0.764 and 0.761, while case (c)'s is 0.897. This is again due to high relative humidity measurements, and low cloud cover at night.

6.4 April

April is an odd month. Every critical relative humidity value is negative and there is a measurement error of close to 0% relative humidity. This has to be a measurement error because such dry conditions don't accur. So the model fails at the surface and this time even at 200m for case (d). The other two cases have critical relative humidity values that differ with 60% from each other. This seems very unlikely. There is also a very high average value for the relative humidity at 200m. Higher than for the previous months, and even higher than for it's surface. The data for this month seems untrustworthy, or more random than the rest. I will come back on this at the at the conclusion.

6.5 May

The best regression for the surface is again (c). It's interesting that at the surface and at 200m the results are almost identical for case (c). During daytime the vertical relative humidity gradient has to be almost 0. The weighted correlation coefficients are 0.764, 0.954 and 0.752 for case (a), (c) and (d). The effect of the night is the cause for this result. At 200m the results are similar again for every case.

6.6 June

Like in the previous month for case (c) the results at the surface and at 200m are very similar. In the other two cases the surface results are useless due to the returning effect of the night. The results at 200m are also similar for every case. The distribution show a lower relative humidity average than during the winter months.

6.7 July

It seems during the summer months that (c) gives the best regression for the surface. The mode for the surface and at 200m is again the highest bin. This is due to the temperature dropping at night and the relative humidity increasing. This effect is visible in the winter aswell as in the summer. The cooling happens due to the surface losing energy through radiation, and the effect is stronger when there is a clear sky.

6.8 August

The model fails for the second time at the surface, just like in April. Furthermore there is also an outlier with an extremely low relative humidity value, close to 0%. This has to be a measurement error because such dry conditions don't accur. There is also a measurement of relative humidity close to 100%, and a cloud cover average having about half that percentage. It seems like an error, but this relative humidity bin is the mode for the distribution. Since this makes the likelihood of it being a measurement error is smaller, the explanation can also be a weather phenomenon specific to August.

6.9 September

(c) gives the only usable regression for the surface. This can again be attributed to the effect described earlier. Since this is a reoccuring issue, case (c) seems to be preferrable over the others by default everytime. The surface and 200m regression results are very close to each other too for (c). This indicates that during daytime the relative humidity was almost uniformly distribution in the vertical direction.

6.10 October

And again case (c) gives the only usable results for the surface. The effect of the night is visible again.

At 200m we have similar results for each case. Both distributions have their highest bin as the mode. This is because of the relative humidity increasing at night. The surface distribution average is getting higher compared to the previous months.

6.11 November

Case (a) and (d) for the surface are not usable again. We see that the high relative humidity with low cloud cover measurements that cause this, go away for case (c).
At 200m the results are similar for all cases. There are some extreme measurements of high cloud cover and low relative humidity. They appear with low frequency and are not bounded to the night. Furthermore this appears at 200m but not at the surface. This means that the air was relatively hot at 200m for some short instances. This seems more like a local random cause than a weather phenomenon.

6.12 December

December gives usable results in every case, but there are outliers of low relative humidity and high cloud cover in every plot at 200m. They all have a very low frequency though, so the effects on the regression are minimal. Most of them dissapear for the daytime only case (c) and the daily average case (d). So this means that a few extreme measurements were made during the night. This is probably caused by a weather phenomenon like snow.
The surface also shows the same phenomenon for it's lowest relative humidity measurements. The difference is now that they don't disappear during daytime and/or when taking daily averaged values. Yet again their frequency is low.

7 Conclusions

Overall case(c), which only uses the data from 09:00-16:00, gives the best results. Eliminating the data measured after sunset until sunrise seems to fix the problem of extreme values caused by cooling at night time. So it makes sense that the regression where this issue is eliminated gives the best results. Only twice, in August and April, do we get a negative critical relative humidity value. This also shows in table 5.13, where those 2 months have the lowest weighted correlation coefficient in their column. Both are under 0.8. So the model worked for 10 out of the 12 months in this case, and for some reason didn't for those two. This has to be due to some weather phenomenon specific to these two months or measurement errors.

April is the month with the lowest average relative humidity in the Netherlands [6]. It also has an equal amount of days where it: snows, hails and and when there is a thunderstorm [6]. It seems like a month where everything can happen. There even is a dutch saying that goes as follows: 'April doet wat hij wil', which translates as: April does what it wants. It refers to the unpredictability of the weather for this month. I suppose that there are many factors that influence April's weather, and that is why the model, which doesn't include these factors, fails here.

There is no sign of a season giving better results than the others for case (c). However the winter season shows the smallest difference between the 3 cases. This has to be because during the winter we receive the least amount of sunlight, and thus have the least amount of evaporation[6]. This makes the relative humidity more constant than in the summer and that is why the effect of the night is smaller.

August contains extreme observations on both ends in every case. It has low relative humidity with high cloud cover, and high relative humidity with low cloud cover. The latter being observerd 10% of the time. Since there are no wheather phenomena that can explain this, and the fact that I had to use data from 2008 due to NaN data in later years, which I didn't have to do for the months before this one, the data will be assumed to be untrustworthy.

Using daily averaged values for the surface didn't do much for most of the months. Sometimes it made an outlier go away like in March. So it helps for evening out odd measurements that occur with low frequency, but the overall results don't seem to be any better. The weighted correltation coefficients are even slightly worse than in case (a). Instead of daily averaged values, using the day- and night average values maybe would've given better results.

At 200m the model seems to work in every case, and also give similar weighted correlation coefficients. April is an exception here. Unlike at the surface, case (c) doesn't seem to be significantly better than (a) and (d). From this we can conclude that the day and night temperature differences at 200m don't differ as great as at the surface. And the daily averaged data follows a similar distribution as the normal data. The average relative humidity at 200m is also lower than it is at the surface. So the conclusion is that there is a relationship between the relative humidity at 200m and the cloudcover.

Considering all the reasons why the model didn't work for April and August, I conclude that there is a relationship between the relative humidity at the surface and the cloud cover. And because it's there throughout every season, I also conclude that it does not matter what the cloud type is.

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