NordFoU: External Influences on Spray Patterns (EPAS)

Report 15: Local wind profile for the test road at Bygholm

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ABSTRACT

The purpose of the present study was to convert wind data collected at the local weather station at a reference height of 4 m to lower heights in the range 0.05-0.5 meters with focus on salt spreader disks that usually operates in a height of 0.4 meters.

To measure the wind velocity two TSI hotwire anemometers were used. The anemometers were attached to a tripod that was placed on the middle of the test road at Engineering Centre Bygholm. One anemometer was placed at a local reference height of 0.5 m above the road. The other anemometer was positioned at different heights between 0.05 and 4.0 m. The ratio between the wind velocity at any such height and the wind velocity at the reference height was used as a relative measure to express the mean velocity variation with height.

During the measurements the wind velocity varied between 2 and 6 m/s. The direction was fairly constant from west with short bursts from west-southwest or west-northwest. In these directions the upwind terrain is flat due to the asphalt surface.

In the boundary layer from 5cm up to 50cm the data indicates that the wind profile is linear with a velocity variation from 57% - 69% of the reference velocity at 4 meters height. In the layer above 50cm an exponential wind profile was fitted.

INTRODUCTION

The spreading pattern of a salt spreader is traditionally tested under laboratory conditions in the spreading hall at Bygholm. The tests are carried out at low driving speeds so repeatability is not impaired by wind and vortices created by the salt truck.

To get more realistic data, tests at normal driving speeds on an outdoor test road are under consideration. This may reduce repeatability as air movements created by wind is expected to interfere with the salt spreading pattern. More knowledge of the wind encountered on the test road was needed to determine the duration of wind velocity acceptable for outside testing at normal driving speeds up to 80km/h.

A photo looking westwards from the middle of the road, where the wind measurements were performed, is shown in figure 1. The test road is 10m wide and approximately 800m long with asphalted surface. It is running east-west and has turning roundabouts at both ends.

Figure 1. Photo of the test road at Bygholm looking westwards.

Data from a local weather station at the test road is made available from the Danish Road Directorate. The local wind data are collected at a height of 4 m.

The experiment was divided into two parts:

1. The general wind profile from 0,5m - 4,0m.
2. The wind profile close to the road surface up to 0,5m

Two hot wire anemometer type Air Velocity Meter model 9555 Series from TSI was used. They are referred to as TSI 1 and TSI 2. The ratio between the velocity at any height and the velocity at the local reference height of 0.5 m was used as an expression of the general variation with height. The wind velocity was time averaged over 180 seconds for each run.

EXPERIMENT 1: GENERAL WIND PROFILE

Experimental set-up

The first part of the experiment was to determine the general wind profile from 0.5m to 4.0m above the road surface. A tripod made of wooden boards was made, and the anemometers were attached to the vertical board. Anemometer TSI 1 was placed 0.5m above the road surface and used as local reference. The other anemometer was placed at 2 m and 4 m above the road. The tripod was placed near the center line of the road as shown in figure 2.

The hot wire sensors were extended 80 cm horizontally from the vertical board and oriented to be out of the wake created by the boards. During data collection the sensors were oriented perpendicular to the wind direction as observed by a banner placed on top of the vertical board.

Velocities were collected for 3 minutes and the average wind velocity was saved. Repetitions were ensured by collecting data for 5 successive 3 minute periods for each height combination.

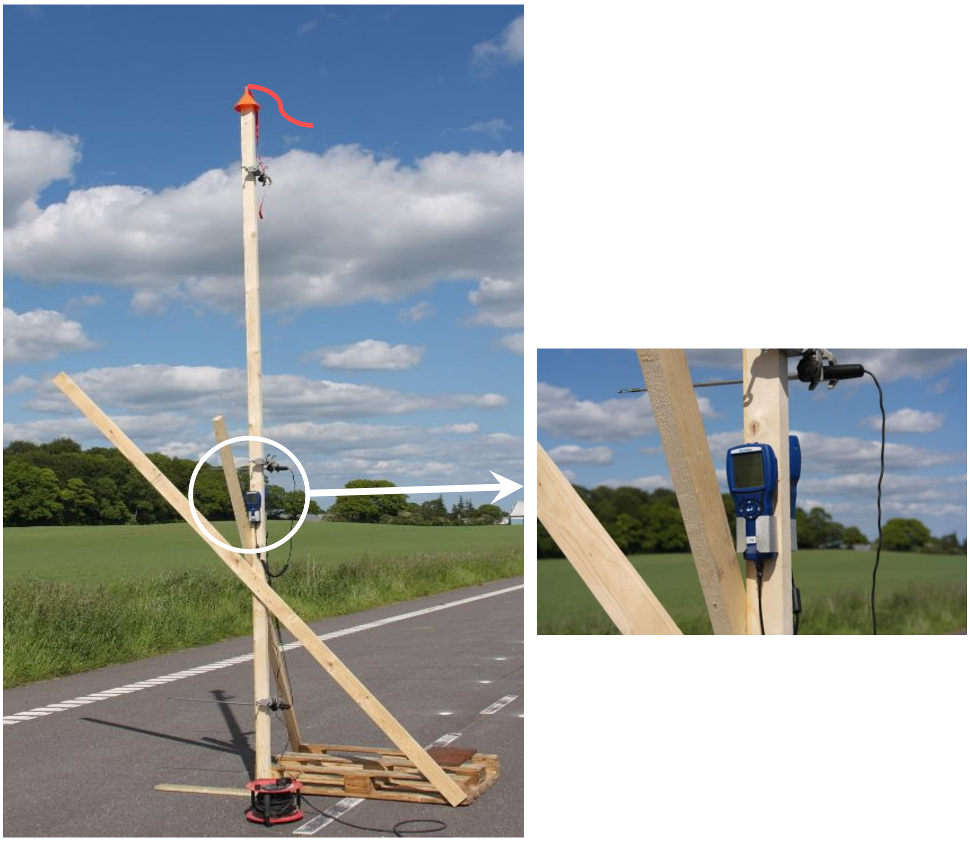

Figure 2. Anemometers and banner on the test road.

Results

As shown in figure 3 the wind velocity declined rapidly during the 45 minutes measurement period. At the local reference height it varied from 4.05 to 4.65 m/s during the first period with the TSI 2 sensor 2m above road and between 1.84 and 3.00 m/s in the second period with the sensor moved up to 4m.

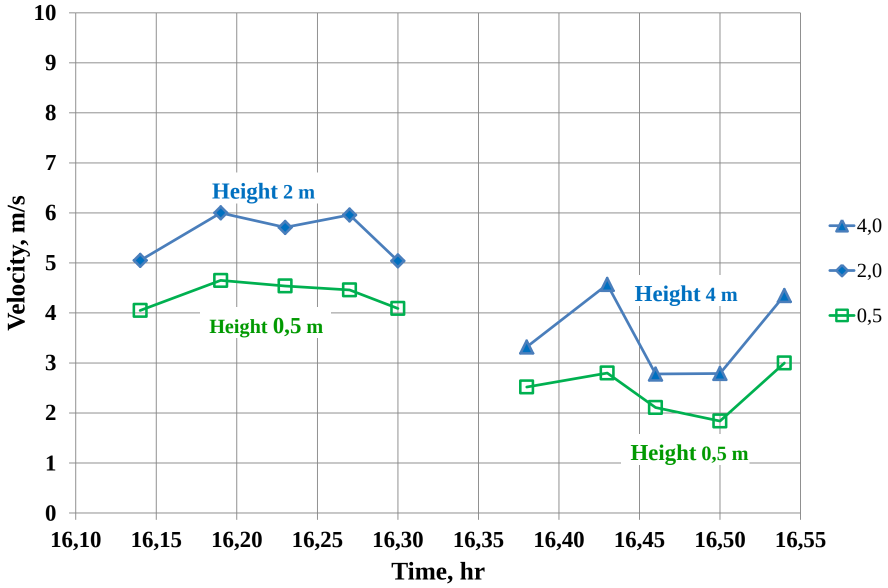

Figure 3. Wind velocity at 2m and 4m together with the local reference velocity at 0.5m.

An alternative way to present the measured wind velocity variation with height is to use the wind velocity at one height relative to the local 0.5m reference height. In average the ratio increased from 1.27 at 2m to 1.45 at 4m, figure 4.

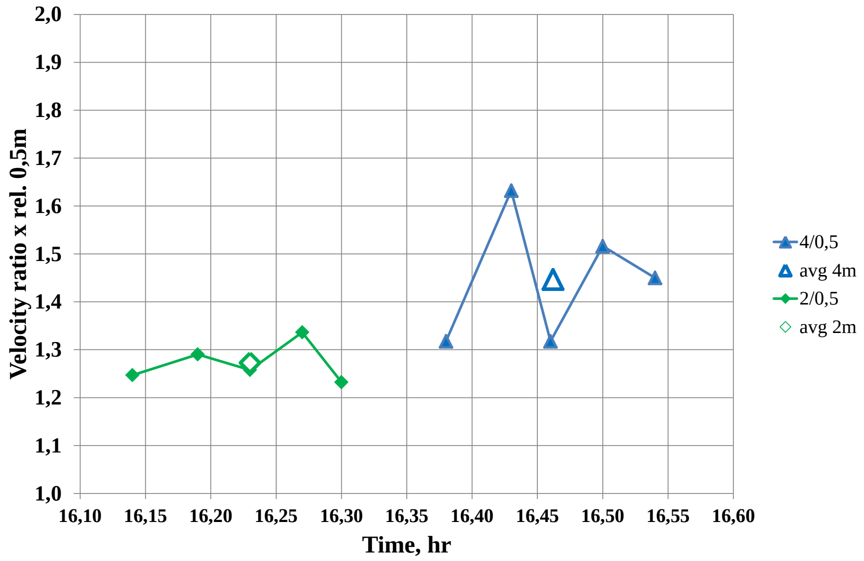

Figure 4. Wind velocity ratio relative to 0.5m at height 2m and 4m.

A simplified average wind velocity ratio profile that disregard boundary effects near the asphalt is shown in figure 5. The wind velocity ratio at height 0.01m is set to 0.01 to allow an exponential tendency line to handle the 0/0 condition. The R^2-value is seen to be high, but the spread of the individual measurements at particularly 4m are considerable. The expression for the wind ratio profile makes it possible to convert the wind velocity measured at one height to another height, however.

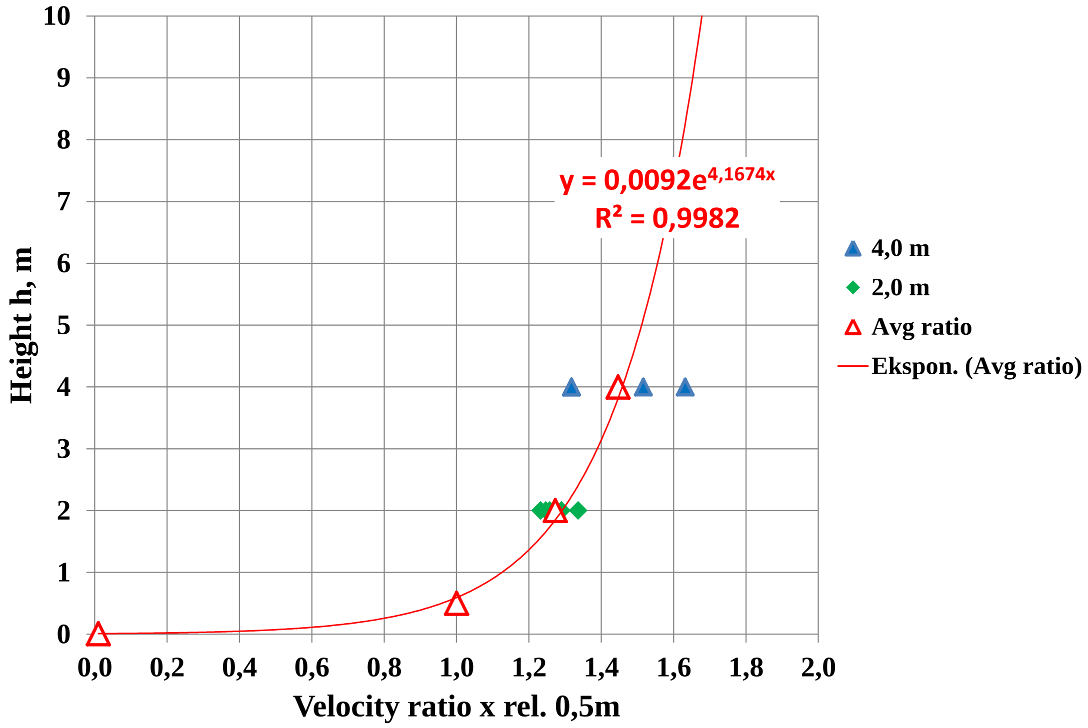

Figure 6. A simplified velocity ratio profile relative to 0.5m height.

EXPERIMENT 2: WIND PROFILE CLOSE TO THE ROAD SURFACE

For salt spreading purposes the wind velocity around and below the actual height of the spreader disk is of prime importance for the salt spreading pattern. Close to the road surface a non-exponential variation may be present, however. Supplementary measurements were therefore carried out with the TSI 1 anemometer at heights between 0.05 and 1.0m. The TSI 2 anemometer was placed at height 0.5m and used as local reference.

The two anemometers were attached to a small test rig where they could slide on a vertical aluminum pipe and secured at the prescribed height. The pipe was supported by a tripod made of 2 mm aluminum angles with one flange 20 and the other 40 mm. The shortest flange was placed so it faced the wind in order to produce minimum turbulence, figure 6.

Figure 6. The small test rig carried the two anemometers close to the test road.

The test rig was placed at the center of the test road with the hot wire sensors extended 0.80m to the right (north) of the center line. A small pole with three threads attached was used to evaluate the wind direction. During data collection the sensors were oriented perpendicular to the wind direction as observed by the threads

Close to the road the near terrain roughness are important for the resulting wind velocity. The view westwards from the measuring point was shown in Figure 1. The landscape is flat with long, uncut grass on the northern bank and short, cut grass on the southern. In the westward direction the asphalted test road is only disrupted by a low heap of wood shavings at a distance of a few hundred meters.

RESULTS

Data collection was carried out following the same procedure as described for experiment 1. Velocities were collected for 3 minutes and the average wind velocity, the standard deviation and the turbulence intensity were stored. Data were collected for 5 successive 3 minute periods for each height combination.

The average wind velocity at the local reference height was 4 m/s during the 2 ½ hours measurement period. Considerable variations were experienced, though, with a maximum of 5.4 m/s early in the period to a low 2.5 m/s at the end.

The wind velocity ratio based on the local reference height 0.5 m is shown in figure 7. In the diagram the differences are exaggerated by the selected scale on the y-axis to make the tendency of increasing wind velocity with height clearly visible.

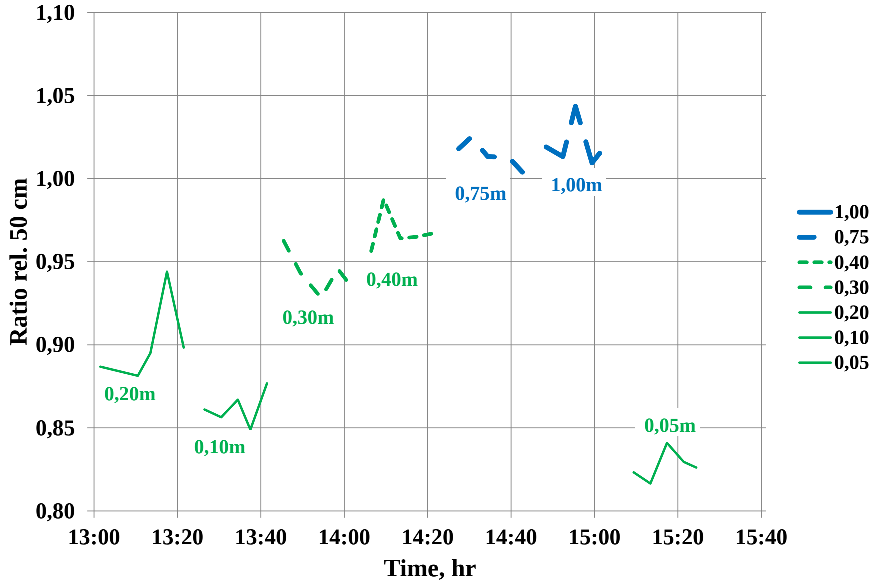

Figure 7. Wind velocity ratios at heights close to test road relative to 0.5m.

The average wind velocity ratio profile close to the test road is shown in figure 8. The R^2-value for the mean values is again seen to be high, but the spread of the individual measurements are considerable.

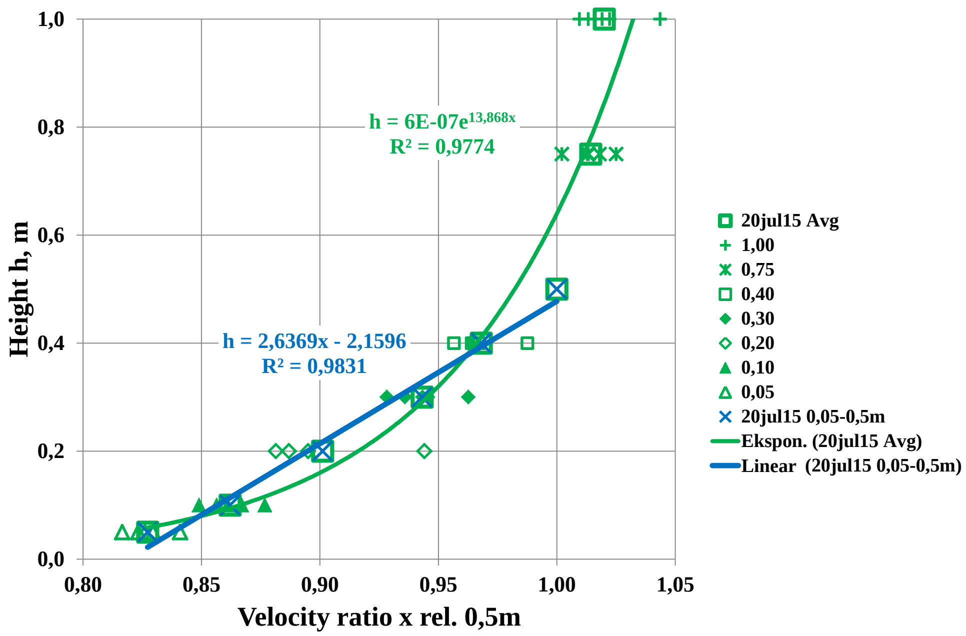

Figure 8. Variation of wind velocity ratio close to road surface relative to 0.5m.

Surprisingly a linear tendency line is well suited for heights up to 0.5m with a higher R^2 value than the exponential tendency line covering heights up to 1m. The linear tendency line also results in a wind velocity ratio closer to 1.00 at the reference height.

RESULTS

The results from the two parts of the experiment are combined in figure 9 where average values of the measured wind velocities are presented for each height. The general wind ratio profile from the road to the 4m reference height is shown in black for the exponential tendency curve assuming a velocity ratio of 0.01 at height 0.01m. The red curve is based on the average of measured values from 0.5 m and up and not assuming a wind velocity ratio at height 0.01m. The difference between the black and the red curve is small. The advantage of selecting the red curve is that it intersects a wind velocity ratio of 1.0 at height 0.5 m.

The exponential wind profile close to the road is presented in green with all measurement values from 0.05 to 1.00 m. The blue wind ratio profile is the linear tendency line based on the average values from 0.05 to 0.5 m.

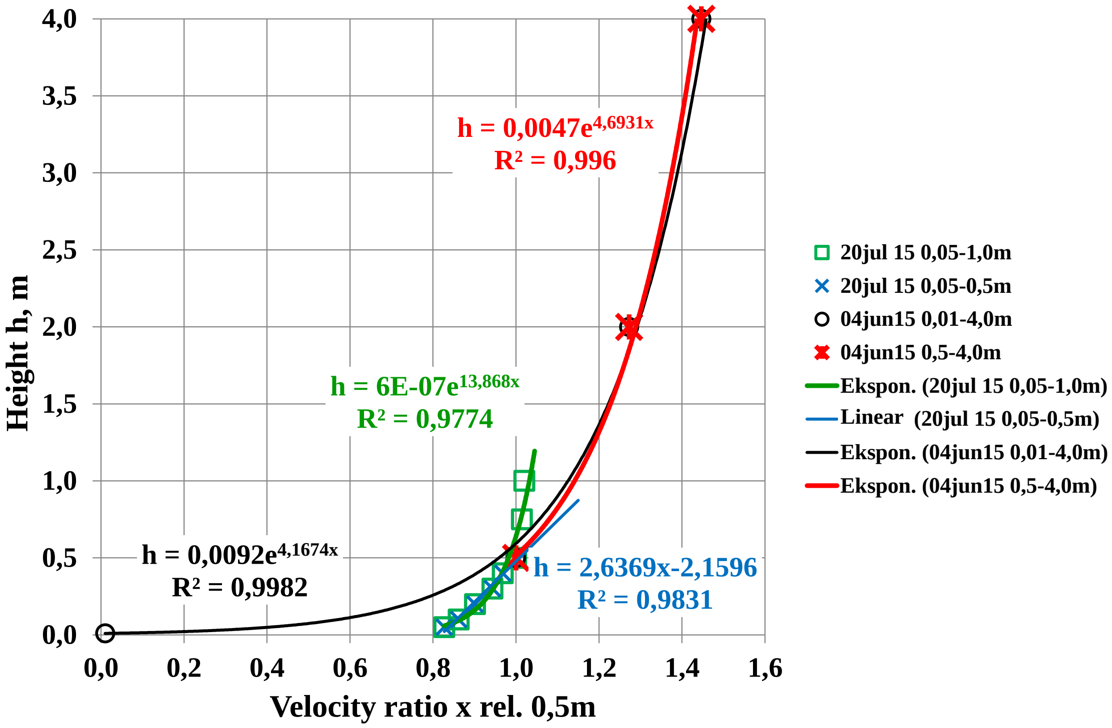

Figure 9. Results from the two experiments combined.

The blue and the red wind ratio profiles are both closely intercepting at height 0.5m, and the corresponding combined wind ratio profile is shown in figure 10.

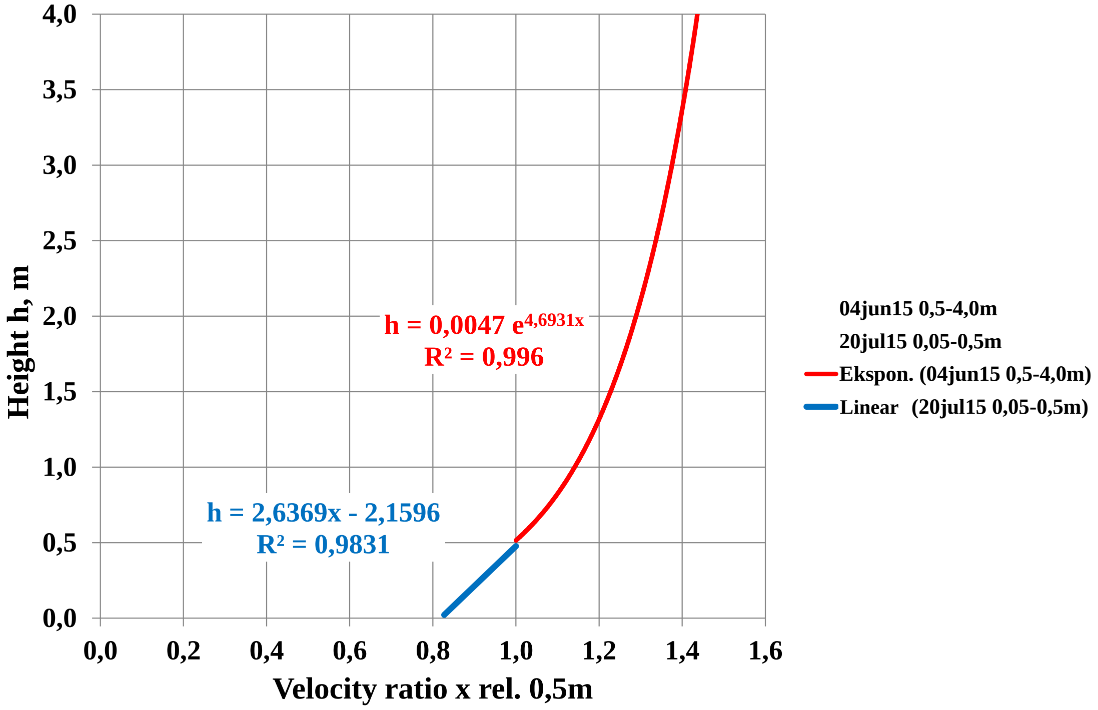

Figure 10. Combined wind profile being linear close to road and exponential higher up

The equations for the combined wind profile with local reference height 0.5 m may be used to determine the wind velocity profile for other reference heights. The regression curve for heights 0.05 to 0.5 m and the regression curve for heights 0.5 to 4.0 m above the road are shown in table 1. For the velocity ratios with Href = 0.5 m the constants *b* and *d* are used as specified in the regression while the constants *a* and *c* fine-tuned to provide an intersection value of x = 1.000 at the local reference height 0.5m. The wind velocity ratios for Href = 4.0 m are found by maintaining the *a* and *c* constants and tuning constants *b* and *d* to give x = 1.000 at the reference height 4.0 m and make sure that there is intersection at 0.5 m.

Table 1. Determination of the wind ratio profile for reference height 4.0 m

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Experiment	Regression	Conversion	Height, h	Velocity ratio x Href=0,5m	Velocity ratio x Href=4m
		Fixed	c =	0,00457	0,00457
		Adjusted	d =	4,6931	6,775
			m		
20jul15 0,05-0,5m	h = 2,6369x - 2,1596	x = (h+2,1596)/2,6369			
		X = (h + a) / b	0,05	0,829	0,575
		a = 2,160	0,5	1,000	0,693
		b = 2,6369			
04jun15 0,5-4,0m	h = 0,0047e4,6931x	x = (ln(h/0,0047))/4,6931			
		x = (ln (h/c)) / d	0,5	1,000	0,693
		c = 0,00470	4	1,444	1,000
		d = 4,6931	10	1,639	1,135
	h = height, m				
	x = velocity ratio				

The resulting wind profile with reference height 4.0 m is shown in figure 11 together with the wind profile with local reference height 0.5 m.

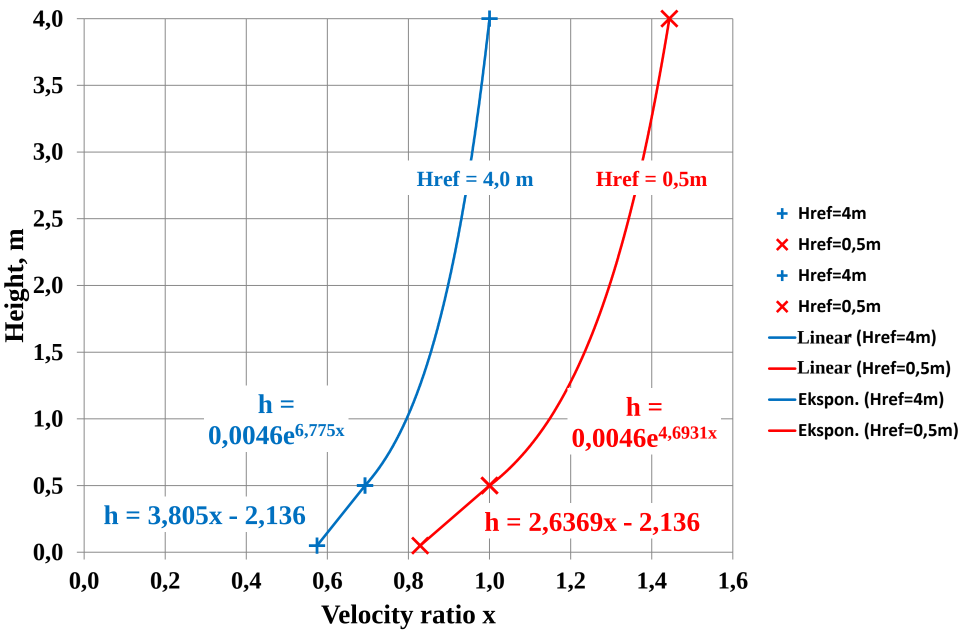

Figure 11. Combined wind profiles for reference heights 0.5 and 4.0m

The purpose of the two experiments was to provide information on how to convert wind data collected at a height of 4m to lower heights relevant for testing of salt spreaders. This may be achieved by converting the blue curve using the height as the x axis and the wind velocity ratio as the y-axis. The result is shown in figure 12. When the wind velocity at the reference height 4.0 m is known the wind velocity at another height is achieved by multiplying with the conversion factor. As an example it is seen that with a wind velocity of 1 m/s at height 4.0 m the wind velocity at height 0.5 m may be estimated at 0.69 m/s. At a height of 0.05 m above the road the equivalent wind velocity may be estimated to 0.57 m/s.

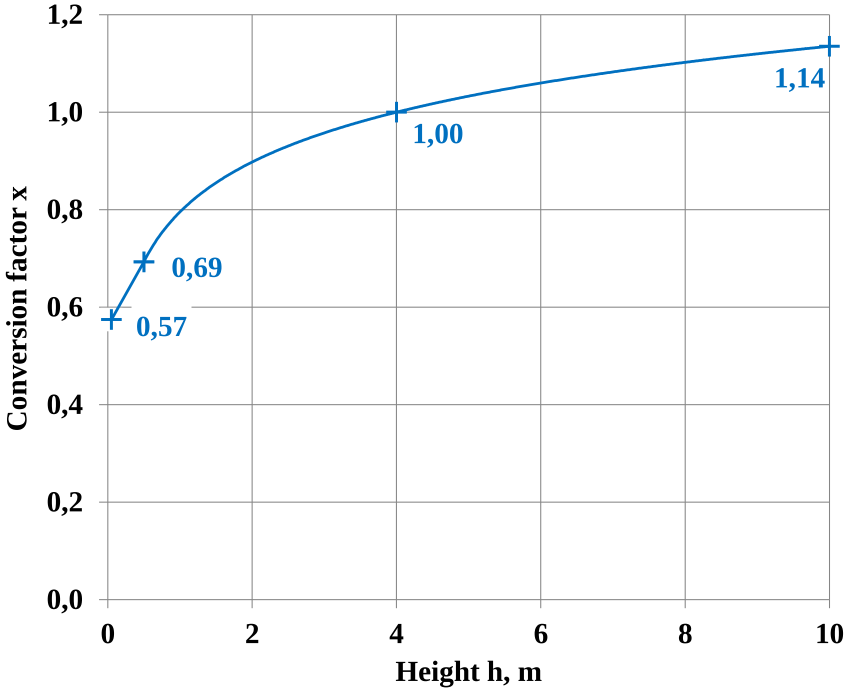

Figure 12. Factors for conversion of wind velocity at height 4m to other heights

In figure 13 the focus is on heights up to 0.5 m. As an example it is seen that with a wind velocity of 1 m/s at height 4.0 m the wind velocity at the height 0.4 m of a spreader disk 1.0 m may be estimated at 0.67 m/s. At a height of 0.05 m above the road the equivalent wind velocity may be estimated to 0.57 m/s.

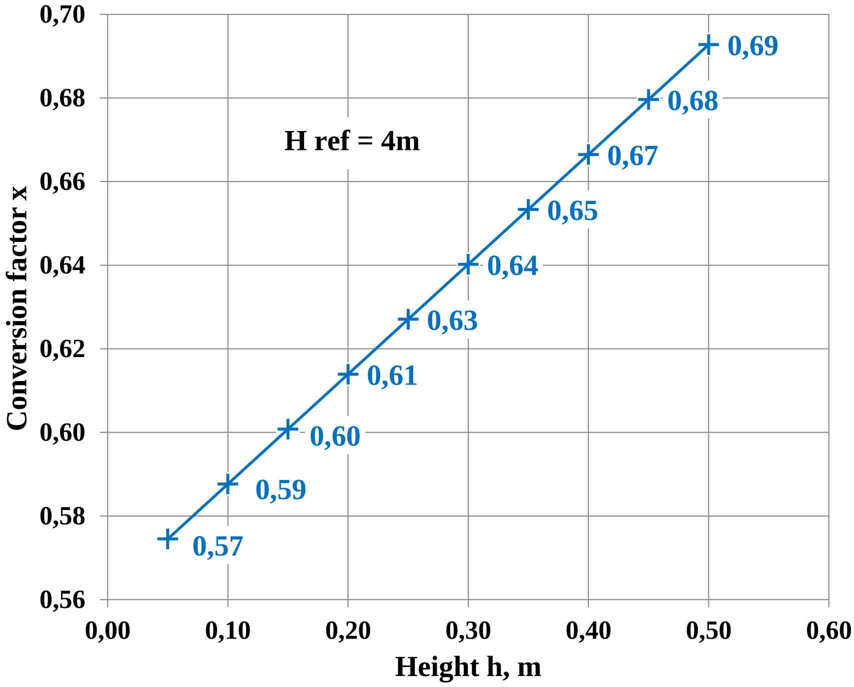

Figure 13. Conversion of wind velocity measured at the height 4m to wind velocities near the road.

DISCUSSION

During the measurement periods the wind direction was fairly constant from west with short bursts from west-southwest or west-northwest. In these directions the roughness is small due to a flat terrain that is mainly covered with asphalt. In easterly directions the terrain is also asphalted and therefore a similar wind profile is expected. The test road is more sheltered by vegetation in other directions probably resulting in another wind profiles. Additional measurements are needed to cover wind from the other directions than westerly.

At westerly winds the acquired data fit a linear wind profile in the boundary layer close to the road and a general exponential wind profile above. According to this study the velocity is changing linearly with height up to 0.5m. Between 0.5 and 1.0 m the two sets of data are diverging for the selected exponential fit.

In this study the variations in wind velocity across the 10 meter wide road was not a subject. With the different vegetation on the two banks the wind profile close to the road is expected to be sensitive to wind direction. More knowledge is needed on the crosswise variations in the wind profile and its effect on the spreading pattern.

Only a limited amount of data was collected during the experiments. Supplemental data are therefore needed to verify the results.

CONCLUSION

The purpose of the study was to provide information on how to convert wind data collected by a local weather station sensor at 4meters height to lower heights relevant for testing of salt spreaders. It was found that the wind velocity increased linearly from 57% at height 0.05 m to 69% at height 0.5 m compared with the wind velocity measured by the weather station.

During the measurement periods the wind direction was constant from west with short bursts from west-southwest or west-northwest. The wind profiles in other directions are presumably different, and additional measurements are needed to cover wind from other directions than westerly.