COMPARING DIFFERENT METHODS OF SHEAR VELOCITY ESTIMATES UNDER FIELD CONDITIONS

1st year of Master internship report

Adeline Pons
supervised by Robin G. Davidson-Arnott

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Abstract

In published papers, shear velocity ($u_*$) is the fundamental variable used to predict aeolian sediment transport. Recently, in that field, 3D ultrasonic anemometers have become available which permit a precise and high-frequency measure of velocity and turbulence properties. From these measure it is possible to estimate a value of $u_*$ which in the past has usually been estimated from the wind vertical profile. Here, we compare the estimation of $u_*$ from that two methods. It seems that if we want to use the 3D ultrasonic anemometers in aeolian sediment transport prediction, the estimation of $u_*$ is not the point and we have to explore thank to these instruments another explanation than $u_*$ for transport.

Résumé

Dans la littérature, la variable fondamentale utilisée pour prédire le transport éolien sédimentaire est la vitesse de cisaillement ($u_*$). Depuis seulement récemment des anémomètres ultrasoniques et tridimensionnels existent dans ce domaine. Ceux-ci permettent une mesure précise et haute-fréquence de la vitesse du vent et des propriétés turbulente des écoulements. À partir de cette mesure du vent, il est possible de faire une estimation de $u_*$ qui jusqu’ici était usuellement estimée à partir du profil vertical des vitesses. Ici, nous comparons ces différentes estimations de $u_*$. Il semble que l’utilisation d’un anémomètre ultrasonique et tridimensionnel pour la prédiction du transport sédimentaire éolien, essayer d’estimer $u_*$ n’est pas vraiment la chose à faire mais qu’il est plus important d’explorer d’autre explications ou causes du transport, ce que cet instrument permet.
Acknowledgements

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I thank Quentin so much for saving my life when I lost my wallet in the middle of the Rockies !

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1 Introduction

Aeolian transport is an important cause of coastal and desert geomorphology generation and evolution. So studying aeolian transport is one of the key to be able to model, predict and manage such phenomena like beach evolution, littoral erosion... One of the main variables for modelling sediment transport is the force exerted on the soil by the wind. Indeed, aeolian transport is driven by momentum extraction from the wind. Actually, the parameter on which researches are focused and which is used in sediment transport modelling is the shear velocity $u_*$ ($u_* = \sqrt{\frac{\tau}{\rho}}$ where $\tau$ is the surface shear stress).

Since Bagnold [1] who proposed one of the first modelisation of the rate of aeolian sediment transport as a cubic function of $u_*$ a lot of similar models have been proposed [11]. All that models have been found from wind tunnel experiment or theoretical studies and do not model really well the field reality [11]. However, usually the measure of $u_*$ give us a average value of that variable over periods of several minutes, but it is clear that the cube of the mean shear velocity for a given period is generally not equal to the mean of the cube of the instantaneous shear velocities ($\bar{u}_*^3 \neq \bar{u}_*^3$). Then, any error in the value of $u_*$ is increased in calculation of transport rate [9].

Until recently and still now, the most common way for measuring $u_*$ is to derive it from the logarithmic wind speed vertical profile. But, now there exists high-frequency and three-dimensional anemometers which permit calculation of Reynolds stress ($RS$). $RS$ traduces the flow internal stress due to the flow turbulence, and from its measure we can obtain an estimation of $u_*$. In ideal conditions the two estimations must give the same result. Here we want to compare the well accept estimation of $u_*$ from vertical profile with the one derivated from the $RS$. The motivation of this comparison is to explore the possibility to do in aeolian domain like in the fluvial domain, and use indifferently the value of $u_*$ from one or the other method.
2 Methods of shear velocity estimates

2.1 Estimation from vertical wind speed profile

Under steady and uniform flow over a flat surface, the wind speed vertical profile is (the law of the wall) [1][4][10]:

\[ u_z = \frac{u_*}{\kappa} \ln \left( \frac{z}{z_0} \right) \] (1)

where \( u_z \) is the wind speed at the elevation \( z \), \( \kappa \) is the von Karman constant (equal to 0.4), and \( z_0 \) is the roughness length of the surface and depends only on the surface properties.

In many earth science applications, it is assumed that the profile is indeed logarithmic. So, \( u_{slog} \) is estimated from equation 1. \( u_{slog} \) is nothing else than \( \frac{u_*}{m} \) where \( m \) is the slope of the function \( \ln(z) = f(u_z) \) which is linear.

Even if there are much uncertainty in fitting a logarithmic profile to velocity data [17], this method is the most used in sediment transport research.

2.2 Estimation from Reynolds stress

Complex turbulent flow is inherent to natural aeolian environments and causes flow streamlines near the surface to diverge from the uniform, surface-parallel direction. Reynolds stress is the part of the stress due to the turbulent events. It is a tensor defined from the covariance of the fluctuation of the different wind speed components. The wind vector above the surface can be described by three orthogonal components (\( u, v \) and \( w \)). The \( x \)-axis (\( u \)-component) is oriented in the mean local wind direction, the plan formed by the \( x \) and \( y \)-axis (\( u \) and \( v \) components) is parallel to the ground surface, and \( z \)-axis is oriented upward. Each component of this wind can be split into a mean part (denoted by an overline) and a fluctuating part (denoted by a prime):

\[
\begin{align*}
    u &= \bar{u} + u', \\
    v &= \bar{v} + v', \\
    w &= \bar{w} + w'.
\end{align*}
\] (2)

With that notation, the Reynolds stress tensor is:

\[
\overline{RS} = -\rho \begin{pmatrix}
    u'^2 & u'v' & u'w' \\
    u'v' & v'^2 & v'w' \\
    u'w' & v'w' & w'^2
\end{pmatrix}
\] (3)

where \( \rho \) is the density of the air.

The shear stress at the surface boundary is equal to the vertical flux of horizontal momentum measured near the surface in other word the horizontal components of \( RS \):

\[
\overline{\tau_{xz}} = -\rho u'w' \quad \text{and} \quad \overline{\tau_{yz}} = -\rho v'w'
\] (4)
where the overbar means that the value is a mean value. While it is possible to estimate instantaneous shear stress by this method, there have been only a few studies that have done this [12][14]. In our case, we will concentrate on the mean value because \( u_{s log} \) is a mean value and it is not rational to compare a mean value to any instantaneous values.

In the literature, several definitions of shear velocity calculated from \( RS \) exist [16]:

- following an ideal picture of steady uniform flow where the Reynolds stress vector is parallel to the mean wind direction, \( u_s \) can be defined by
  \[
  \bar{\tau}_{xz} = -\rho \bar{u}' \bar{w}' \quad \text{and} \quad u_{s u} = \sqrt{\frac{\bar{\tau}_{xy}}{\rho}} = \sqrt{u'w'}
  \]  
  (5)

  So, \( u_{s u} \) can be identified to the shear stress in the \( x \) direction.

- but, usually the Reynolds stress vector and the mean wind direction are not parallel. So using the horizontal Reynolds stress vector, \( u_s \) is defined in the literature by
  \[
  \bar{\tau}_{\text{hor}} = -\rho \sqrt{u'w'^2 + v'w'^2} \quad \text{and} \quad u_{s \text{hor}} = \sqrt{\frac{\bar{\tau}_{\text{hor}}}{\rho}} = (u'w'^2 + v'w'^2)^{1/4}
  \]  
  (6)

  This definition which is used in the literature is based on the length of the mean horizontal Reynolds stress vector, but although \(-\rho u'w'\) and \(-\rho v'w'\) can be related to the mean shear stress over the period of averaging in the directions \( x \) and \( y \), the value of \( \bar{\tau}_{\text{hor}} \) not given with an associated direction does not have a real physics explanation.

- so, in this study we will use the two definitions above and a other one obtained by averaging the all the horizontal instantaneous Reynolds stress vector
  \[
  \bar{\tau}_{\text{hor}} = -\rho \sqrt{u'w'^2 + v'w'^2} \quad \text{and} \quad u_{s \text{hor}} = \sqrt{\frac{\bar{\tau}_{\text{hor}}}{\rho}} = u_{s \text{hor}} = \sqrt{(u'w'^2 + v'w'^2)}
  \]  
  (7)

  A physical explanation to focus on \( u_{s \text{hor}} \) is that it can define sort of the maximal possible value for \( u_s \) because its calculation is done from all the horizontal wind speed whereas \( u_{s u} \) must be the minimal possible value because we use only one of the wind speed components to obtain it. From this we can obtain a range of possible values (and it is clear that \( u_{s u} < u_{s \text{hor}} < u_{s \text{hor}} \)).

If the wind blows over a complex terrain, the mean wind is parallel to the topography and generally not horizontal [16] and the effect of the topography is not negligible [14]. This is can be taken in account by some rotating operations [15], but, here, because of the experimental conditions, these rotations are not needed.

However, we can expect that \( \bar{u}_{\text{hor}} \) will be the more related to \( u_{s log} \) because both are based on the mean of the total horizontal wind speed without really taking into account the wind direction.
3 Field site and data collection

3.1 Field site

The field experiment was conducted during May-June 2007 at Greenwich Dunes, Prince Edward Island National Park, Canada (fig. 1). The site is a relatively flat beach, about $30 - 40m$ wide (fig. 2). The beach sediments are dominantly quartz sand with a mean diameter of $0.26mm$. During the experiment time, prevailing winds were onshore from the north-east.

Figure 1: Study site.

Figure 2: General view of the beach.
3.2 Experiment set up

Experiment design consists of vertical array of RM Young cup anemometers with continuous DC output, collocated with a Gill 3D-windsonic sonic anemometer which provides a direct measure of the 3 components of the wind velocity (fig. 3). They are located in the mid-beach area which is relatively flat and smooth (no vegetation).

![Figure 3: Experiment set up.](image)

Because of technical problems, the number of instruments per vertical profile varied from three to four between days. The elevations of the cup anemometers were: 30, 80cm, 150cm and 210cm.

The 3D-windsonic is always mounted at the same height because $R_S$ vary a lot with the high [3][14]. We choose the height of 30cm (the lower part of the 3D-sonic is at 30cm above the surface, that means that the sampling volume is upper) because the closer to the surface it is, the better it is to have surface stress which is the surface value of $R_S$ but the instrument have to be high enough to be above the saltation cloud (cloud of saltating sand grains) which could damage it. The 3D-sonic was mounted in order to have the measuring frame well oriented to calculate $R_S$, e.g. as explain in part 2.2. Then, in order to get rid of the rotating problem, we place the vertical direction of the 3D-sonic perpendicular to the surface plan. The 3D-sonic need a power supply which was provided by a simple 12 V battery.

The data from the cup anemometers and the 3D-sonic are logged with a frequency of $1\, Hz$. The data from the four cup anemometers are logged simultaneously by the same independent logger (Hobo) and the ones from the 3D-sonic are directly recorded with the computer thanks to the softward DasyLab. The synchronisation of the two loggers was possible because the two were synchronised with the computer clock.
3.3 Different recording conditions

The table below (Table 1) summarizes all the recording conditions (number of cup anemometers, wind direction ...) for each day of experiment.

<table>
<thead>
<tr>
<th>Date</th>
<th>Number of anemometers</th>
<th>Wind direction</th>
<th>Mean wind speed (m.s^{-1})</th>
<th>Run duration (hh:mm)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>22 may</td>
<td>4</td>
<td>onshore ((\sim 45^\circ))</td>
<td>6.20 ((\sigma = 0.93))</td>
<td>00:57</td>
<td></td>
</tr>
<tr>
<td>23 may</td>
<td>3</td>
<td>onshore ((\sim 50^\circ))</td>
<td>3.50 ((\sigma = 0.49))</td>
<td>02:11</td>
<td></td>
</tr>
<tr>
<td>25 may</td>
<td>4</td>
<td>alongshore</td>
<td>2.08 ((\sigma = 1.02))</td>
<td>03:00</td>
<td>really low wind a lot a variation in the direction</td>
</tr>
<tr>
<td>26 may</td>
<td>4</td>
<td>onshore ((\sim 80^\circ))</td>
<td>2.07 ((\sigma = 0.89))</td>
<td>02:19</td>
<td>at the end of the run too low wind to have steady conditions</td>
</tr>
<tr>
<td>27 may</td>
<td>3</td>
<td>onshore ((\sim 10^\circ))</td>
<td>4.85 ((\sigma = 0.69))</td>
<td>03:00</td>
<td></td>
</tr>
<tr>
<td>30 may</td>
<td>3</td>
<td>onshore ((\sim 10^\circ))</td>
<td>2.88 ((\sigma = 0.36))</td>
<td>02:51</td>
<td></td>
</tr>
<tr>
<td>31 may</td>
<td>4</td>
<td>onshore ((\sim 10^\circ))</td>
<td>3.81 ((\sigma = 0.54))</td>
<td>02:50</td>
<td></td>
</tr>
<tr>
<td>02 june</td>
<td>3</td>
<td>onshore/alongshore ((\sim 65^\circ))</td>
<td>3.97 ((\sigma = 0.57))</td>
<td>03:00</td>
<td></td>
</tr>
<tr>
<td>05 june</td>
<td>3</td>
<td>alongshore/offshore ((\sim 10^\circ))</td>
<td>5.33 ((\sigma = 1.59))</td>
<td>02:49</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: General characteristics of the different runs.

3.4 Data selection

For all the different runs, we calculate the speed and direction of the wind from the 3D-sonic data (fig. 4).

Then, from this new set of data, we select as many as possible of separate events of 10 min (fig. 5) which satisfy "steady and uniform conditions". We defined these conditions by:

- The angle between the wind direction and the x-axis must be inferior to 60° because of the design of the 3D-sonic. That condition is explained by the desire of minimize the turbulent effects that can make the 3D-sonic itself.
- The standard deviation of the direction to the mean direction must not exceed 20°.
- The variation of the wind speed running mean over the period of 10 min must not exceed 10% of the global mean over the 10 min period. Here, the length of the moving average
interval for the running mean is 5 min; this length must be inferior to the length of the period we select but cannot be too small to be a mean and not just the data but a little bit smoother.

- The running mean of the angle (which have the same characteristic than the wind speed running mean) must not vary more than 10° aver the 10 min period.

With this method, we selected from 1 to 5 periods of 10 min per day.

It is evident that with this technique we have selected only the more "ideal" period of the different set of data, but we do not forget that natural conditions are usually far from being ideal and that in view of sediment transport applications this study has a lot of limitation.
Figure 4: Example of wind speed (blue) and direction (green) for the 27th of May. The red curves correspond to the respective running mean over a period of 5 min.

Figure 5: The three selected events (blue areas) for the 27th of May.
4 Data analysis

For each selected periods, we will calculate by the different methods \( u_\ast \), and then compare them. To permit a comparison even if we have different range of wind speed for each day, we normalize all the calculated \( u_\ast \) by \( u_{1m} \) the wind speed at 1m.

4.1 \( u_\ast \) estimation from vertical profile

The wind speed as a function of the height is of that form : 

\[
\mathbf{u}_z = \frac{u_\ast}{\kappa} \ln\left(\frac{z}{z_0}\right),
\]

so \( u_\ast \) as a function of \( \ln(z) \) is a linear function. For each set of data we do a linear fit to obtain an estimation of \( u_{slog} \), and from this fit we calculate \( u_{1m} \).

<table>
<thead>
<tr>
<th>Date</th>
<th>Run</th>
<th>( u_{slog} ) ( (m.s^{-1}) )</th>
<th>( r^2 )</th>
<th>( u_{1m} ) ( (m.s^{-1}) )</th>
<th>( \frac{u_{slog}}{u_{1m}} )</th>
<th>Number of anemometers</th>
</tr>
</thead>
<tbody>
<tr>
<td>22 May</td>
<td>1</td>
<td>0.365</td>
<td>0.987</td>
<td>6.75</td>
<td>0.054</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.346</td>
<td>0.987</td>
<td>6.37</td>
<td>0.0543</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.351</td>
<td>0.983</td>
<td>6.56</td>
<td>0.0535</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.353</td>
<td>0.964</td>
<td>6.29</td>
<td>0.0561</td>
<td>4</td>
</tr>
<tr>
<td>23 May</td>
<td>1</td>
<td>0.162</td>
<td>0.952</td>
<td>3.68</td>
<td>0.0440</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.158</td>
<td>0.965</td>
<td>3.40</td>
<td>0.0464</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.149</td>
<td>0.970</td>
<td>3.65</td>
<td>0.0409</td>
<td>3</td>
</tr>
<tr>
<td>25 May</td>
<td>1</td>
<td>0.133</td>
<td>0.987</td>
<td>2.15</td>
<td>0.0617</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.166</td>
<td>0.998</td>
<td>2.30</td>
<td>0.0722</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.117</td>
<td>0.993</td>
<td>2.25</td>
<td>0.0519</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.131</td>
<td>0.990</td>
<td>2.36</td>
<td>0.0555</td>
<td>4</td>
</tr>
<tr>
<td>26 May</td>
<td>1</td>
<td>0.102</td>
<td>0.998</td>
<td>3.12</td>
<td>0.0326</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.093</td>
<td>0.996</td>
<td>3.07</td>
<td>0.0305</td>
<td>4</td>
</tr>
<tr>
<td>27 May</td>
<td>1</td>
<td>0.259</td>
<td>0.989</td>
<td>4.52</td>
<td>0.0573</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.331</td>
<td>0.988</td>
<td>5.77</td>
<td>0.0574</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.289</td>
<td>0.978</td>
<td>4.81</td>
<td>0.0601</td>
<td>3</td>
</tr>
<tr>
<td>30 May</td>
<td>1</td>
<td>0.108</td>
<td>0.976</td>
<td>2.77</td>
<td>0.0392</td>
<td>3</td>
</tr>
<tr>
<td>31 May</td>
<td>1</td>
<td>0.152</td>
<td>0.987</td>
<td>3.82</td>
<td>0.0398</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.156</td>
<td>0.973</td>
<td>3.75</td>
<td>0.0416</td>
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</tr>
<tr>
<td></td>
<td>3</td>
<td>0.181</td>
<td>0.988</td>
<td>3.98</td>
<td>0.0455</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.175</td>
<td>0.979</td>
<td>4.055</td>
<td>0.0432</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.175</td>
<td>0.985</td>
<td>4.105</td>
<td>0.0426</td>
<td>4</td>
</tr>
<tr>
<td>02 June</td>
<td>1</td>
<td>0.200</td>
<td>0.966</td>
<td>4.39</td>
<td>0.0455</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.171</td>
<td>0.947</td>
<td>3.645</td>
<td>0.0469</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.145</td>
<td>0.929</td>
<td>4.029</td>
<td>0.0361</td>
<td>3</td>
</tr>
<tr>
<td>05 June</td>
<td>1</td>
<td>0.154</td>
<td>0.960</td>
<td>5.67</td>
<td>0.0272</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.165</td>
<td>0.984</td>
<td>5.18</td>
<td>0.0318</td>
<td>3</td>
</tr>
<tr>
<td></td>
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<td>0.171</td>
<td>0.961</td>
<td>6.02</td>
<td>0.0285</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 2: Result of all the vertical profiles fits.
Figure 6: Example for the first run of the 22<sup>th</sup> of May: a) vertical profile of the mean wind speed, b) linear fit of log(h) as a function of the wind speed.

**Accuracy of the fits.**

As we remark that the coefficient of correlation is better for the profiles with 4 anemometers than the ones with 3 anemometers ($r^2_{4a} = 0.986$ and $r^2_{3a} = 0.966$), and that when we have only 3 anemometers the one missing is one of the middle ones, we wonder if the top anemometer is really in the boundary layer. In order to test that, we calculate $u^*$ and $r^2$ for the day we have 4 anemometers by a fit of the complete profile and by a fit of only the 3 lower ones (fig. 7).

Figure 7: Fit of log(h) as a function of the wind speed a) in the case of 4 anemometers and b) in the case of the 3 lowermost anemometers. This example is for the first run of the 22<sup>th</sup> of May.
This comparison (Table 3) shows that, a linear function fits better for the 3 lower anemometers than for the all vertical profile. Then, the fact the $u_{\text{log}4} < u_{\text{log}3}$ confirm that the top anemometer is not in the boundary layer. Indeed, when more than the boundary layer part of the vertical profile is use, that generates an underestimation of $u_{*}$ [2].

As the top anemometer is not in the boundary layer, we’ll use only the day we have the 3 lower anemometers and the run with $r^2 > 0.98$.

Normalisation.

As we said before, we want to normalize the results to be able to compare than even if we have a large range of wind speed. A normalization by the wind speed at 1m ($u_{1m}$) must be good to get rid of the specific wind speed of each runs. Indeed, the equation says : $\frac{u_{*}}{u_{1m}} = -\frac{\kappa}{\ln(z_0)}$. So, $\frac{u_{*}}{u_{1m}}$ must depend only on $z_0$ which is a surface characteristic, that makes us think that over a same surface (which is our case) this normalization must is good.

In order to see the availability of that normalization, we plot $u_{*}$ as a function of $u_{1m}$.

These graphs show that $z_0$ does not depend only the surface characteristics where we calculated it, but also on the surface over which the wind blew before. So a along shore wind goes only over sand and a onshore wind goes over the sea for a long time before. And then, for a onshore wind, $z_0$ is smaller and the wind is more ”uniform” (we can see that with the variation of the wind direction).

So, as the normalization is not as ”universal” as expected, so we can only compare runs with same wind condition (at least with that normalization).
Figure 8: $u_*$ as a function of $u_{1m}$ for all the runs.

Figure 9: $u_*$ as a function of $u_{1m}$ for only the runs where the 3 lowermost anemometers were working.
4.2 \( u_s \) estimation from the Reynolds stress

After the rotation of the frame in order to have the \( x \)-axis in the mean speed direction and \( z \)-axis upward, we calculate the three different \( u_s \) estimated from the different \( RS \) for each run we decide to work with (and also the alongshore day (the 25\(^{th}\) of May)). The table (Table 4) below presents the results:

<table>
<thead>
<tr>
<th>Date</th>
<th>Run</th>
<th>( u_{sx} ) m.s(^{-1})</th>
<th>( u_{shor} ) m.s(^{-1})</th>
<th>( u_{shor} ) m.s(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>22 May</td>
<td>1</td>
<td>0.277</td>
<td>0.278</td>
<td>0.343</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.270</td>
<td>0.272</td>
<td>0.340</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.285</td>
<td>0.285</td>
<td>0.360</td>
</tr>
<tr>
<td>25 May</td>
<td>1</td>
<td>0.228</td>
<td>0.266</td>
<td>0.435</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.245</td>
<td>0.267</td>
<td>0.461</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.226</td>
<td>0.243</td>
<td>0.417</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.272</td>
<td>0.301</td>
<td>0.497</td>
</tr>
<tr>
<td>26 May</td>
<td>1</td>
<td>0.115</td>
<td>0.116</td>
<td>0.151</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.116</td>
<td>0.117</td>
<td>0.148</td>
</tr>
<tr>
<td>31 May</td>
<td>1</td>
<td>0.138</td>
<td>0.142</td>
<td>0.197</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.121</td>
<td>0.123</td>
<td>0.179</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.140</td>
<td>0.144</td>
<td>0.195</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.129</td>
<td>0.136</td>
<td>0.193</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.143</td>
<td>0.146</td>
<td>0.202</td>
</tr>
</tbody>
</table>

Table 4: The different \( u_s \) estimated from \( RS \).

4.3 Comparison of the different \( u_s \)

The table 5 presents all the normalized shear velocities obtained for the selected runs.

What we can immediately remark is that there is not a large variability in the results if we consider each day separately (fig. 10). Then, \( u_{sx} \) and \( u_{shor} \) are really close which confirms the results of Weber [16]. As we expected, \( u_{slog} \) and \( u_{shor} \) seems to be close, except for the 25\(^{th}\) of May which is the alongshore day with a really variable wind . . . The histograms below (fig. 11) confirm that.

Maybe the big difference with the 25\(^{th}\) of May is that if the wind is to variable, the perturbations we use to calculate \( RS \) are not any more perturbations because it is not worth to define a mean speed. But the problem is that natural conditions are most of the time not steady and uniform and that it is in that kind of cases that actual models work the worst way. The problem with the logarithmic approach is that it does not take in account the wind direction variability: people calculate \( u_s \) from the total horizontal speed which is two-dimensional but assume that the transport is actually in only one direction. This is one of the reasons that motivate the exploration of different methods for the calculation of \( u_s \).

Finally, it seems the two methods to calculate \( u_s \) from \( RS \) used in the literature do not fit to the one using the vertical profile. But, \( u_{slog} \) and \( u_{shor} \) are pretty close except if the
<table>
<thead>
<tr>
<th>Date</th>
<th>Run</th>
<th>$u_*$ / $u_{1,m}$</th>
<th>$u_{2,m}$</th>
<th>$u_{3,m}$</th>
<th>$u_{4,m}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>22 May</td>
<td>1</td>
<td>0.058</td>
<td>0.041</td>
<td>0.041</td>
<td>0.051</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.059</td>
<td>0.042</td>
<td>0.042</td>
<td>0.053</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.057</td>
<td>0.043</td>
<td>0.043</td>
<td>0.055</td>
</tr>
<tr>
<td>25 May</td>
<td>1</td>
<td>0.066</td>
<td>0.105</td>
<td>0.123</td>
<td>0.200</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.074</td>
<td>0.106</td>
<td>0.115</td>
<td>0.200</td>
</tr>
<tr>
<td></td>
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<td>0.055</td>
<td>0.100</td>
<td>0.107</td>
<td>0.184</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.058</td>
<td>0.115</td>
<td>0.127</td>
<td>0.209</td>
</tr>
<tr>
<td>26 May</td>
<td>1</td>
<td>0.032</td>
<td>0.037</td>
<td>0.037</td>
<td>0.049</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.032</td>
<td>0.038</td>
<td>0.038</td>
<td>0.048</td>
</tr>
<tr>
<td>31 May</td>
<td>1</td>
<td>0.043</td>
<td>0.036</td>
<td>0.037</td>
<td>0.051</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.045</td>
<td>0.032</td>
<td>0.032</td>
<td>0.047</td>
</tr>
<tr>
<td></td>
<td>3</td>
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<td>0.035</td>
<td>0.036</td>
<td>0.049</td>
</tr>
<tr>
<td></td>
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<td>0.032</td>
<td>0.033</td>
<td>0.047</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.046</td>
<td>0.035</td>
<td>0.035</td>
<td>0.049</td>
</tr>
</tbody>
</table>

Table 5: Normalized $u_*$ estimated with all the different methods.

Figure 10: All the different normalized $u_*$ plot by run.
wind direction is to variable. Then, as in the literature [3][16], we find that $u_{su}$ and $u_{shor}$ are really close (and we have always $u_{su} \leq u_{shor}$) except when the wind vector is not in parallel to the mean wind direction.

4.4 Further analysis to see if the tendencies are confirmed

In order to see if the tendencies are confirmed also for more general conditions, we divided the all run record of the selected days in 10-min periods and for each of these periods we calculated the four different $u_{*}$. The four graphs below (Fig. 12, 13, 14 and 15) show the different results.

The graphs confirm that $u_{su}$ and $u_{shor}$ are really close as long as the standard deviation of the wind direction is not too big, and they also confirm that $u_{shor}$ is the closest $u_{*}$ calculated from $RS$ to the $u_{slog}$ calculated from the wind vertical profile.

In the case of $u_{slog}$ and $u_{shor}$, even if they are close and they seems to evolve in the same way, the correlation is not obvious at all. Indeed, whereas $u_{su}$ and $u_{shor}$ increase and decrease at the same time, the evolution of $u_{slog}$ and $u_{shor}$ shows no logic. Then, the difference between the two values seems to depends on the variation of the wind direction, but here again it is not "universal".

So, we can conclude that we have two group of $u_{*}$: $u_{su}$ and $u_{shor}$ on one hand and $u_{slog}$ and $u_{shor}$ on the other. $u_{su}$ and $u_{shor}$ are strongly correlated, but $u_{slog}$ and $u_{shor}$ are close but only in good condition.
Figure 12: All the $u_*$ for the 22\textsuperscript{th} of May (the gray areas represent the period whose $r^2 \leq 0.98$).

Figure 13: All the $u_*$ for the 25\textsuperscript{th} of May (the gray areas represent the period whose $r^2 \leq 0.98$).
Figure 14: All the $u_*$ for the 26th of May (the gray areas represent the period whose $r^2 \leq 0.98$).

Figure 15: All the $u_*$ for the 31st of May (the gray areas represent the period whose $r^2 \leq 0.98$).
5 Conclusion

Different ways to estimate $u_*$ were compared in view to test the availability to use 3D ultrasonic anemometers and measure of $RS$ in aeolian sediment transport prediction.

Even if this study presents some limitations (in particular we did not explore the vertical variability of $RS$ [3][8]), we can say:

- $u_{*u}$ and $u_{*hor}$ which are the ones used in the the literature to calculate $u_*$ from $RS$ are really close as long the wind direction is not too variable.

- $u_{*log}$ and $u_{*hor}$ are not too different and the difference between them seems to increase as the standard deviation of the wind direction increases but it’s not really clear.

To conclude, even if in "perfect" conditions the different methods do not differ so much, in field conditions, it seems that the calculation of $u_*$ from $RS$ do not work in the same way that the one using the wind speed vertical profile. Then, the thing which must not be forget is that $u_*$ is used in sediment transport prediction as a surrogate for bed shear stress and that ideally it would be best to test all our measure of $u_*$ against a measure of this. However, this can only be done if we measure stress directly using a drag plate.

That make us think that the thing to do and we could not do because there was not transport during our tests, is to explore the correlation between saltation and the different $u_*$. And maybe also explore, thanks to $RS$ (and 3D anemometer which permit us to focus on higher frequency), other possible explanations (in particular try to take in account the temporal variability of the phenomenon) for the saltation rate which is not really well explained by actual models.
6 Bibliography


A Ultrasonic anemometry

This section explains the principle of the ultrasonic anemometry.

Ultrasonic anemometry calculate velocity by determining the times ($T_1$ and $T_2$) taken for an ultrasonic pulse of sound to travel over a set path length ($L$) between two sensors (Fig. 16).

\begin{align*}
T_2 &= \frac{L}{C-V} \\
T_1 &= \frac{L}{C+V} \\
V &= \frac{L}{2 \left( \frac{1}{T_1} - \frac{1}{T_2} \right)} \\
C &= \frac{L}{2 \left( \frac{1}{T_1} + \frac{1}{T_2} \right)}
\end{align*}

Figure 16: Principle of ultrasonic anemometry and parameters definition [6].

If $V$ is null, $T_1$ and $T_2$ are the same. But if there is any wind, the travel of the sound wave will be increased or decreased if the travel is with or against the wind.

With one pair of sensor (transducer) you can obtain one component of the wind speed. So to have the three components of the wind, a 3D sonic need three pairs of sensors.