Instantaneous and Mean Aeolian Sediment Transport Rate on Beaches: an Intercomparison of Measurements from Two Sensor Types.


ABSTRACT


Recently several new instruments, such as the Saltiphone, Sensit, Safire and laser sensors, have made it possible to measure aeolian transport in the field at a frequency of 1 Hz, allowing us to evaluate the relationship between varying wind speed and instantaneous transport. The correlation between the two variables at this frequency is often very low and the exponent can range from <2 to >5. Since several of the instruments can be used for long-term monitoring of coastal dunes, it is important that we understand the causes of this poor correlation and the relationship to averages derived from trap measurements. In this paper we compare measurements from Safire piezo-electric sensors and Wenglor laser sensors under conditions of intermittent and continuous transport. The laser sensor generally measures a higher rate of transport than does the Safire and has fewer periods of zero transport (lower intermittency). This may reflect detection of relatively slow moving grains which may not have sufficient momentum for the impact to register on the Safire. Nevertheless, calibration of Safire output averaged over a period of 15-20 minutes against trap data results in high R^2 values. The fit of a power curve to saltation intensity regressed against instantaneous wind speed is usually stronger for the laser sensor compared to a Safire but both show a wide range in the exponent of the power function.

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ideally the total transport must be obtained by deploying several instruments in a vertical array. The third group may sample a greater proportion of the total transport, for example the horizontal trap designed by JACKSON (1996) or they may make use of a vertical trap that samples all or most of the effective vertical profile (DAVIDSON-ARNOTT et al., 2005).

In this preliminary paper we compare instantaneous sediment transport measured by Safire piezo-electric sensors to measurements of wind speed at the same frequency as well as comparing mean values of transport intensity over periods of 15-20 minutes with mass transport rates over the same period collected by integrating vertical traps. Finally, we compare the output from a Safire sensor to a co-located Wenglor laser sensor to explore the differences between the two instruments.

**INSTRUMENTATION AND EXPERIMENTAL DESIGN**

Data discussed here are taken from two field experiments carried out at Greenwich Dunes, Prince Edward Island, Canada in October 2004 and October 2007. The October 2004 experiment is described in detail in DAVIDSON-ARNOTT and BAUER (2009), BAUER et al. (2009), and WALKER et al. (2009). Winds were obliquely onshore for a period of ten hours or more blowing over a flat, gently sloping beach with a surface moisture content on the upper beach of 2-4 %. Data presented here are from two Safires deployed on the upper beach with the sensor ring at 2-4 cm above the bed. They were colocated with R.M. Young cup anemometers deployed at a height of 0.25 m. The Safires were oriented with their ‘sweet spot’ – BAAS, 2004) facing the wind. Transport was generally fully developed in this zone and there was a slight decrease in wind speed towards the top of the beach due to internal boundary layer development (DAVIDSON-ARNOTT and BAUER, 2009), BAUER et al. (2009). In the second experiment winds were again obliquely onshore but there was a well-developed flat berm with steep foreshore slope. Windflow was measured using 2-D and 3-D sonic anemometers mounted on 4 H frames spaced 10 m apart landward of the berm crest and aligned along the wind direction (Figure 1). Wind speed measurements are taken from the lowermost 3-D sonic anemometer centred at a height of 0.25 m. The Safire was again mounted at a height of 2 cm with its sweet spot oriented in to the wind. The laser sensor was deployed immediately adjacent to the Safire.

The laser sensor is a commercial unit made by Wenglor Co. Ltd., and used primarily for sensing objects on conveyor belts. The instrument consists of a laser and photo sensor mounted within a U shaped frame with a spacing (path length) of 3 cm and a beam diameter of 1 mm. The instruments detect the drop in voltage at the photo sensor resulting from the passage of individual grains through the beam. The counting circuitry is contained within the instrument and is capable of detecting 700-800 grains per second. Data were recorded using an Onset counting circuit and Onset Hobbo data logger. The Safire is made by Sabajo in the Netherlands and records the impact of saltating grains on a 2 cm high ring. The electronics are housed within the 2 cm diameter tube on which the ring is mounted and in this deployment the voltage output was recorded with a nominal 200 impact per second corresponding to the maximum 5 volts output. The instrument has been described in detail by BAAS (2004). The instruments deployed here were later versions with somewhat better sensitivity and reduced variation in output around the ring than those described by BAAS (2004). In both experiments cross calibration at the site of all sensors was carried out at the end of the day.

**RESPONSE OF SAFIRE PROBES**

A major concern with the deployment of probes such as the Safire piezo-electric sensors is the similarity of response between instruments, especially given earlier tests which have shown considerable variation in sensitivity around the circumference of the probe (BAAS, 2004). In short-term experiments these can be deployed so that they are always oriented with the same spot into the wind which should reduce this effect, but there is still concern that the sensitivity varies considerably from one instrument to another, making it difficult to compare the response of instruments deployed at different locations. Figure 2 shows results from a cross calibration of three saltation probes carried out at the end of the day of the field experiment described in DAVIDSON-ARNOTT and BAUER (2009) and BAUER et al. (2009). The probes were deployed 0.1 m apart at the back of the beach and allowed to record for one hour. There was a close correspondence in the response of all three probes to fluctuations in wind speed over this period (Figure 2a) and the mean saltation intensity for ten minute intervals during the cross calibration period were very similar (Figure 2b). Some deviation is expected between instruments even with this close spacing (BAAS and SHERMAN, 2006). The differences between means is greater for higher mean transport intensity at the beginning and end of the calibration period, but it is notable that probe 8 had the highest mean value at the beginning of the period and the lowest at the end of the period so that there is no consistent difference in the response of the probes. The results of the cross calibration showed that, for the conditions under which the field experiment was carried out, the response of the three probes is indistinguishable.
A key reason for the deployment of Safires is to examine the relationship between instantaneous sand transport and wind speed or bed shear velocity. Wind tunnel studies, as well as some field experiments where transport is fully developed, show that transport varies as a function of \( U^3 \) or \( U^3 \). A number of studies have shown a general relationship between wind speed fluctuations and the saltation intensity recorded by piezo-electric sensors such as the Sensit and Safire (WIGGS et al., 2004; DAVIDSON-ARNOTT et al., 2008; DAVIDSON-ARNOTT and BAUER, 2009) but much work still remains to be done to determine the correspondence between mean values determined from measurements over ten or fifteen minutes and measurements made at a frequency of 1 Hz.

Figure 3 illustrates the general relationship between mean saltation intensity and the cube of mean wind speed measured at two locations on the upper beach for ten minute intervals in October 2004 (DAVIDSON-ARNOTT and BAUER, 2009). The relationship for both probes is significant at the 0.05 level and the relationship appears to hold for conditions where transport is fully developed over a substantial fetch distance. With a shorter fetch transport is much more intermittent and the strength of the relationship decreases rapidly.

Figure 3. Comparison of mean saltation intensity measured by saltation probes and the cube of mean wind speed measured by a co-located cup anemometer for ten minute intervals taken from continuous measurements over a period of 280 minutes: a) probe salt 7 located at the back of the beach; b) probe 10, located about 6 m seaward of probe 7. The greater scatter for probe 10 may reflect a much reduced fetch near the end of the recording period and consequently full transport conditions may not have been achieved.

**RELATIONSHIP BETWEEN SALTATION INTENSITY AND SAND TRANSPORT RATE**

Rates of sand transport were measured on 5 occasions during the field experiment using integrating vertical traps co-located with the saltation probes, thus permitting a comparison of the mean transport intensity measured by the saltation probes with the mean transport rate measured by the traps (Figure 4). There is a strong and significant relationship between the two measures of sand transport which again serves to indicate that the mean transport intensity measured by the probes is an adequate representation of mean transport rates on the beach. The calibration however is only valid for the particular bed conditions under which the measurements were made.
While the relationship between saltation intensity and wind speed appears to be quite robust for averages taken over ten minutes or more, the instantaneous values show considerable scatter and are often not statistically significant, with $R^2$ values generally below 0.2. Where sand transport is fully developed, the exponent for a power relationship ranges from $<2$ to $>4$ (Figure 5). The relationship may be improved somewhat with a lag of one second between saltation intensity compared to wind speed but decreases rapidly with a further increase in the lag.

COMPARISON OF SALTATION PROBE WITH CO-LOCATED LASER SENSOR

In the field experiment carried out on October 21, 2007 Wenglor laser sensors were deployed adjacent to Safires with wind speed at 0.25 m measured by 3-D sonic anemometers (Figure 1). Sand transport was measured over a period of about 4 hours at a sampling frequency of 1 Hz. A two-minute portion of the record from Station 3 located about 10 m landward of the berm crest is shown in Figure 6a. In general the saltation intensity (grain counts per second) registered by the laser probe was about 3 times higher than that for the Safire even though the nominal sensing area is smaller, and this was consistent throughout the record. One result of this was that as the transport rate dropped the Safire registered many periods with zero transport (high intermittency) while the laser sensor registered continuous transport.

There was also a much weaker relationship between wind speed and instantaneous transport for the Safire as compared to the laser sensor. This is illustrated in Figure 6 b, c for the 2 minute record shown in Figure 6a.
DISCUSSION

Our experience in the deployment of Safire piezo-electric probes is that they can provide a useful indication of the presence of sand transport and a qualitative indication of the relative strength of sand transport intensity. With careful laboratory testing to determine the location of the sector with the most inconsistent response on the circumference of the probe, they can be deployed for short-term experiments with that sector aligned into the wind. Cross calibration in the field is essential if comparisons are to be made between probes deployed at different locations. The strong relationships found between mean saltation intensity measured by the Safires and mean wind speed measured over ten minutes indicates that they provide a robust measure of relative sand transport. Likewise, the strong relationship between transport intensity and total sand transport rate measured by integrating vertical traps suggests that with this form of field calibration the Safires could be used to provide a measure of the actual transport rate rather than simple transport intensity. However, since the shape of the vertical concentration profile is likely to vary with different surfaces and different grain size distributions, field calibration is always necessary.

The lower counts registered by the Safire probe during the experiment in October 2007 may reflect in part the presence of a loose dry surface at this location and thus likely a greater proportion of low velocity (reptating) grains compared to the relatively dam, hard surface associated with the 2004 experiment. It is likely that many of these grains did not have sufficient momentum to be registered on the piezo-electric sensor but they would be detected by the laser sensor. The poor correspondence between instantaneous transport and wind speed for the Safire probes suggests that their sampling volume is too small to adequately represent total transport at a frequency of 1 Hz though they provide a good measure of transport at a lower frequency. It also calls into question their use for calculating a transport threshold using the time fraction equivalence method proposed by BUTTERFIELD (1991). But it is likely that many of these grains did not have sufficient momentum to be registered on the piezo-electric sensor but they would be detected by the laser sensor. The poor correspondence between instantaneous transport and wind speed for the Safire probes suggests that their sampling volume is too small to adequately represent total transport at a frequency of 1 Hz though they provide a good measure of transport at a lower frequency. It also calls into question their use for calculating a transport threshold using the time fraction equivalence method proposed by BUTTERFIELD (1991).

LITERATURE CITED


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