VEÐURSTOFA ÍSLANDS

Report

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Wind erosion rates in Big Springs, Texas

VÍ-G00006-ÚR02
Reykjavík
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Formáli

Hér segir frá tilraunum undirritaðs með jarðvegsroflíkanið WEAM (Wind Erosion Assessment Model), sem gerðar voru við dvöl hans við Háskólann í New South Wales í Sydney í Ástralíu, í mars árið 2000. Líkanið var reynt á gögnum frá Bandaríkjunum og er ætlunin að bera niðurstöður saman við árangur annarra líkana sem vísindamenn hafa þróað.

Líkanið tekur inn upplýsingar um vindhraða, rakastig jarðvegs, kornastærðardreifingu hans, og loks tvenns konar upplýsingar um hrjúfleika yfirborðs, þ.e. það sem kallað er aerodynamic roughness length, og frontal area index. Það skilar svo út láréttu flæði sands sem skríður og skoppar eftir yfirborðinu, og lóðréttu flæði ryks sem þyrlast upp og getur fokið langar leiðir.

Líknanið hefur nú verið sett upp á Veðurstofunni og verður væntanlega beitt á jarðvegsrof á Íslandi á næstunni.

1 Introduction

The author of these notes stayed as a visitor at Center for Environmental Modeling And Prediction (CEMAP) in Sydney in Australia from the 2nd March to 25 March 2000. The purpose of the visit was studying wind erosion modeling, as a part of his M.Sc. study at the University of Iceland.

It was decided that the author would perform calculations on erosion, based on weather and soil type data provided by USDA, for comparison with performance of other erosion models. These data were collected at different locations in N-America.

This paper reports the work on these calculations. A brief description of the dataset will be given. Values of input parameters, such as roughness lenght and frontal area index will be derived and finally the results of model calculations will be presented and compared with measured values.

2 Description of data

The data USDA provided comes from seven locations in N-America. These are Big Springs, Eads, Elkhart, Kennet,Mobton, Prosser and Sidney. The data consists of meteorological records for periods of several weeks at each site, and measured erosion in occational dust storms.

2.1 Weather data

Weather data includes two types of records.

- One minute averages. Time of the record, wind speeds and wind direction, SENSIT particle count and SENSIT kinetik energy. Wind speed is measured at 0.2, 0.6 1.0 and 2.0 m heights.
- Ten minutes averages. Time of the record, temperatue at different heights above ground and, soil temperature, relative humidity, solar radiation, rain, and in a few instances soil moisture.

2.2 Erosion data

The flux of eroding material was measured with BSNE samplers mounted at five different heights above ground. Regression lines were fitted to the data and integrated to obtain total flux per meter. For three of the lower samplers, a line of the type

$$q_{salt} = a \exp(-bz)$$

was used and the integral interpreted as total flux by saltation. For the third, fourth and fifth samplers a line of the type

$$q_{susp} = a\, z^b$$

was fitted and the itegrated flux interpreted as total horizontal flux by suspension.

3 Derived meteorological varibles

Friction velocity must be determined from the measured wind profile. Soil moisture had to be determined from uncalibrated measurements.

3.1 Friction velocity

It seems straightforward to calculate friction velocity by linear regression of the logarithmic wind profile equation,

$$u(z) = \frac{u_*}{\kappa} \ln \frac{z}{z_0} \tag{1}$$

in the case no saltation is present. A function for doing this was written. If the friction velocity obtained in this way is greater than a predefined threshold value, a new value is calculated by fitting a new equation that takes into account the effect of saltation on the wind profile. First "Raupachs equation"[2]

$$u(z) = \frac{u_*}{\kappa} \ln \frac{z}{z_{salt}} \tag{2}$$

where

$$z_{salt} = (A\frac{u_*^2}{2g})^{1-\sqrt{r}} z_0^{\sqrt{r}}$$
$$r = \frac{{u_{*t}}^2}{{u_*}^2}$$

was tried. Here, A is constant of the order one. Equation 2 was found not to be able to describe high wind speed, since it takes maximum value of wind speed for friction velocity of about 1.5 m/s. Shao et. al., see [3] modified this formula, it has the same basic form as Equation 2 but A is not constant, but

$$A = \beta\alpha^2 \exp(-r/n)$$
$$n = 2.02 - 2.47\, u_* - 0.34\, u_*^2$$

Here, $\beta = 1.0$ and $\alpha = 0.55$. This formula was found not to have this drawback, and it predicts lower friction velocities than Raupach's formula.

In either case (saltating and none-saltating) the roughness length for non-saltating condition is assumed to be known beforehand.

3.2 Soil moisture

Only datafiles from Big Springs in 1997 provide measure on soil moisture, that is voltage output of some measurement device. Actually measurements are taken at 1, 2, and 4 cm depths, but only the measurement for 1 cm depth was used. The measurements were calibrated by assuming the lowest device output recorded (0.361V) to represent the lowest possible soil moisture θ_r (wind dry moisure content) noting that it was recorded in a long period of no precipitation, and the highest recorded value (0.985V) represent the saturation value θ_s, noting that it was recorded when raining. A linear interpolation was made between these two extreme values.

The soil class at Big Springs is sandy loam, for that class $\theta_r = 0.041$ and $\theta_s = 0.453$, according to Shao and Irannejad. In this case the actual soil moisture is

$$\theta = 0.660\, r - 0.197$$

where r is the voltage output. Shao suggested that the wind dry moistue should be subtracted from the right hand side of the equation to give moisture content used by the model, then the calibration equation will be

$$\theta = 0.660\, r - 0.238$$

Model runs were made using both equations, and results will be presented in section 5.

4 Surface parameters

4.1 Roughness length

The aerodynamic roughness of each surface was determined in the following way: Ten minutes averages of wind speed at each height were calculated. The roughness length for each ten minutes interval was calculated by least squares fitting the logarithmic wind profile equation to the measured wind. Thus a wide range of different roughness lengths was obtained. Then a histogram for the frequency of different values was formed and the most frequent one taken as the roughness length representative of that surface. The results are listed in the table 1.

Site	z_0 (m)	Quality
Big Springs	0.0007	Poor
Eads	0.0020	Good
Elkhart	0.0011	Good
Kennet	0.005	Good
Mabton	0.0015	Good
Prosser	0.00006	Poor
Sidney	0.0007	Good

Table 1: Roghness lengths

The histograms of five of the sites showed a definite peak in frequency of roughness lengths, thus the roughness length can be considered well defined, and those sites are classified as "good" in the table. The two remaining sites Big Springs and Prosser did not show a well defined peak. Thus it's difficult to determine their roghness length from the data given here. The value for Big Springs is assumed to be 0.0007 m.

4.2 Frontal area index

Frontal area index of the surfaces is not explicitly given in the data. In some cases chain roughness is given. Chain roughness can be converted to frontal area index, the relation is

$$\lambda = \frac{CH}{2(100 - CH)} \tag{3}$$

where CH is chain roughness. In other cases no roughness is given at all. Measured chain roughness for a few periods of time in 1997 at Big Springs is given in Table 2, and frontal area index calculted by equation 3.

Time	CH	λ
97-01-22	4.8	0.025
97-02-28	1.4	0.007
97-04-02	1.2	0.006
97-05-20	1.1	0.006

Table 2: Chain roughness and frontal area index at Big Springs 1997

5 Model run results

Figures 1 through 7 show the weather records and predicted erosion at Big Springs in 1997. Also it shows the observed saltation flux Q_{obs} according to scaling given later in this section. The title of the figures is the name of the output file containing the data presented in the figure. Note that the the date included in the title refers to the last day of the period shown in the figure.

Measured values of saltation flux are given for two stormy days in 1997, julian day 119, that is 29th April and julian day 122, 2nd May. The total horizontal flux these days was as follows.

Day	$Q_{salt}(kgm^{-1})$	$Q_{susp}(kgm^{-1})$
119	55.1	2.7
122	52.0	6.2

The model predicts no erosion on the 119th. That event can be seen as the first sensit response peak on Figure 5, second graph from above. By that time, measured soil moisture is too high for erosion to be predicted, even though wind speed is quite high. The soil moisture is measured at 1 cm depth. Soil moisture is obviously dropping fast by this time, but moisture at 1 cm depth could lag behind the moisture at the surface, where it could actually be low enough to allow particles to move in the wind. Exactly the same pattern can be seen on day 95, when $Q_{obs} = 19\ kgm^{-1}$ but the predicted value is $7\ kgm^{-1}$

Table 3 lists the total saltation flux and dislodgement of dust going into suspension, for each day erosion is predicted by the model.

According to some authors, (see for example [1]) sensit kinetic energy response is proportional to mass flux. Assuming this, the measurements can be scaled to estimate the mass flux throughout the recorded period, using the directly measured mass flux on days 119 and 122 for calibration. A calibration coefficient was found by dividing the total measured flux to the sensit response. First background signal S_b was subtracted from the total signal S and summing up for the whole day. Then the calibration constant c is

$$c = \frac{\sum q_i}{\sum (S_i - S_b)} \tag{4}$$

where q is the measured flux. For day 119 $c = 8.88 \cdot 10^{-4}$ and for day 122 $c = 9.29 \cdot 10^{-4}$. For calibrating the rest of the measurements, the average, $c = 9.09 \cdot 10^{-4}$ was used. In Table 3 also includes the saltation flux estimated by this method, for the days erosion is predicted.

Julian Day	Week	Q (kg/m)	F (kgm^{-2})	Q_{obs} (kg/m)
88	First	29	0.18	32
89	First	1	0.00	1
92	First	1	0.00	1
95	Second	7	0.02	19
98	Second	46	0.22	18
100	Second	24	0.08	24
105	Third	1	0.00	6
112	Fourth	3	0.00	26
114	Fourth	74	0.68	126
121	Fifth	27	0.06	26
122	Fifth	66	0.82	50
123	Fifth	3	0.05	0
124	Fifth	48	1.01	8
125	Fifth	15	0.31	1
126	Sixth	9	0.13	3
127	Sixth	23	0.29	6
128	Sixth	1	0.01	14
138	Seventh	11	0.10	4
139	Seventh	26	0.42	12

Table 3: Total daily fluxes.

Figure 8 shows time series for the predicted daily flux by saltation and the measured flux according to the sensit instrument. In Figure 9 the predicted saltation flux is plotted versus the observed saltation flux.

A time series for daily integrated modelled saltation flux and the saltation flux according to sensit measurements are shown in Figure 8. Figure 9 shows calculated saltation flux is plotted against the measured flux. A least squares fit through the points gives $Q_{obs} = 0.985\,Q$ where Q_{obs} is the observed saltation flux and Q is the calculated flux. The corresponding correlation coefficient is $R^2 = 0.48$.

In most cases the predicted erosion is within a factor of five within the observed erosion. Exceptions from this is are days 105, 112, 119, (where the failure has been explaned), 123, 124, 125, and 128.

On day 105 no peak is seen on the Q_{obs} time series, see Figure 3, therefor the daily integrated erosion observed is most likely due to background signal somewhat higher than average.

On day 112 soil moisture is relatively high for erosion periods. Either the relation for thereshold friction velocity as a function of soil moisture is not correct for that high values, or the soil moisture is overestimated.

The lowest soil moisture values occur in days 123 through 125. The erosion is overestimated on these days, by one order of magnitude or more. In these cases the threshold friction velocity seems underestimated.

On day 128 the peak in Q_{obs} is almost certainly associated with precipitation and high wind speed (see Figure 6), not erosion.

6 Conclusions

From this it can be concluded that in most cases the performance is satisfactory.

The greatest errors seen here probably rise from two main sources:

- Incorrect information on soil moisture content at the surface when the soil is drying quickly, that and has nothing to do with the model itself.
- Threshold friction velocity seems underestimated when soil moisture is very low, which must be considered as the main drawback of this model.

References

[1] Dale A. Gillette, D. W. Fryrear, Jing Bing Xiao, Paul Stockton, Duane Ono, Paula J. Helm, Thomas E. Gill, and Trevor Davis. Large-scale

variability of wind erosion mass flux rates at owens lake. *Journal of Geophysical Research*, 102:25977–25987, 1997.

[2] Michael Raupach. Saltation layers, vegetation canopies and roughness lengths. *Acta Mechanica*, 1:83–96, 1991.

[3] Yaping Shao and An Li. Numerical modelling of saltation in the atmospheric boundary layer. *Boundary-Layer Meteorology*, 91:199–225, 1999.

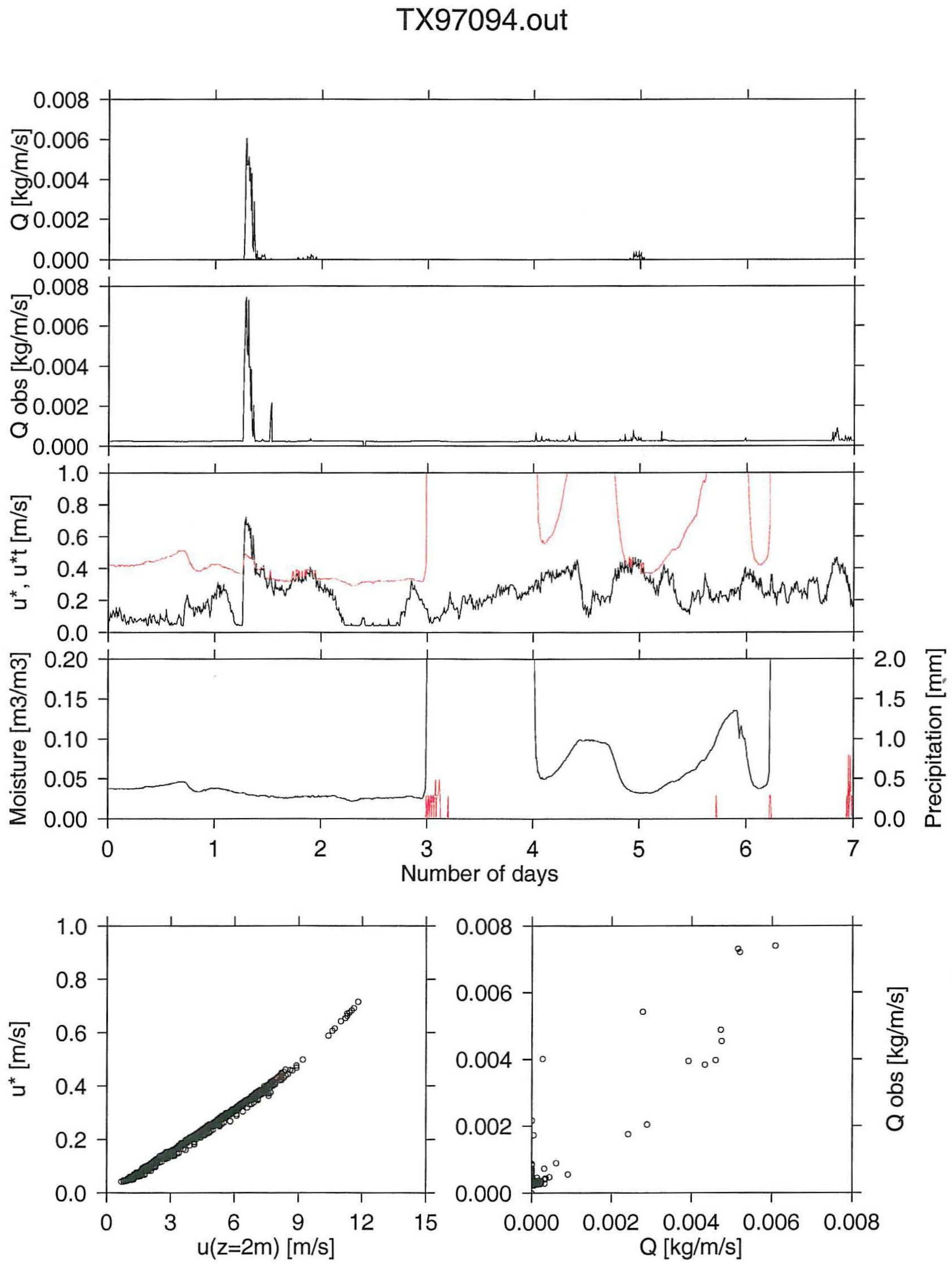

Figure 1: First week

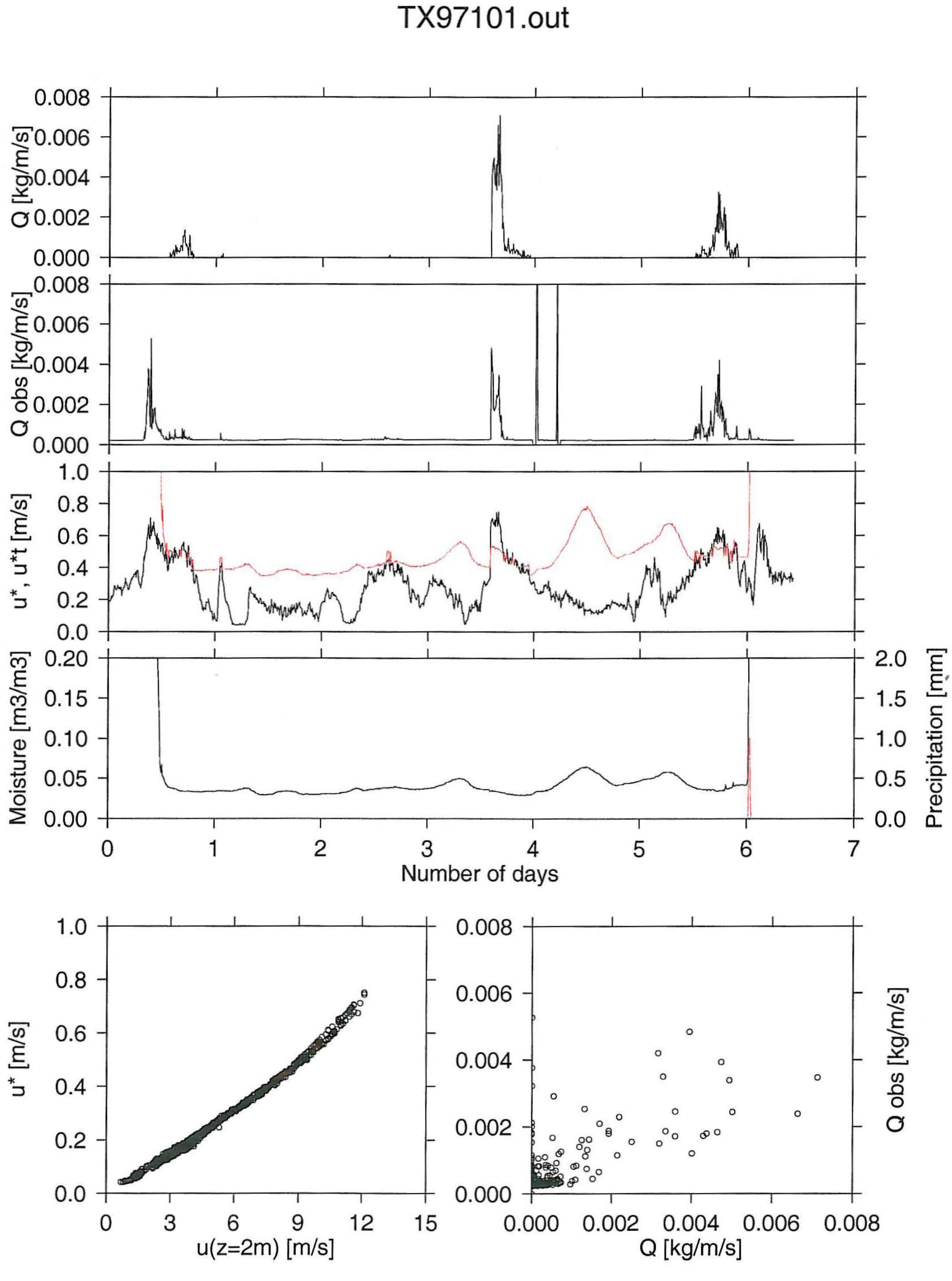

Figure 2: Second week

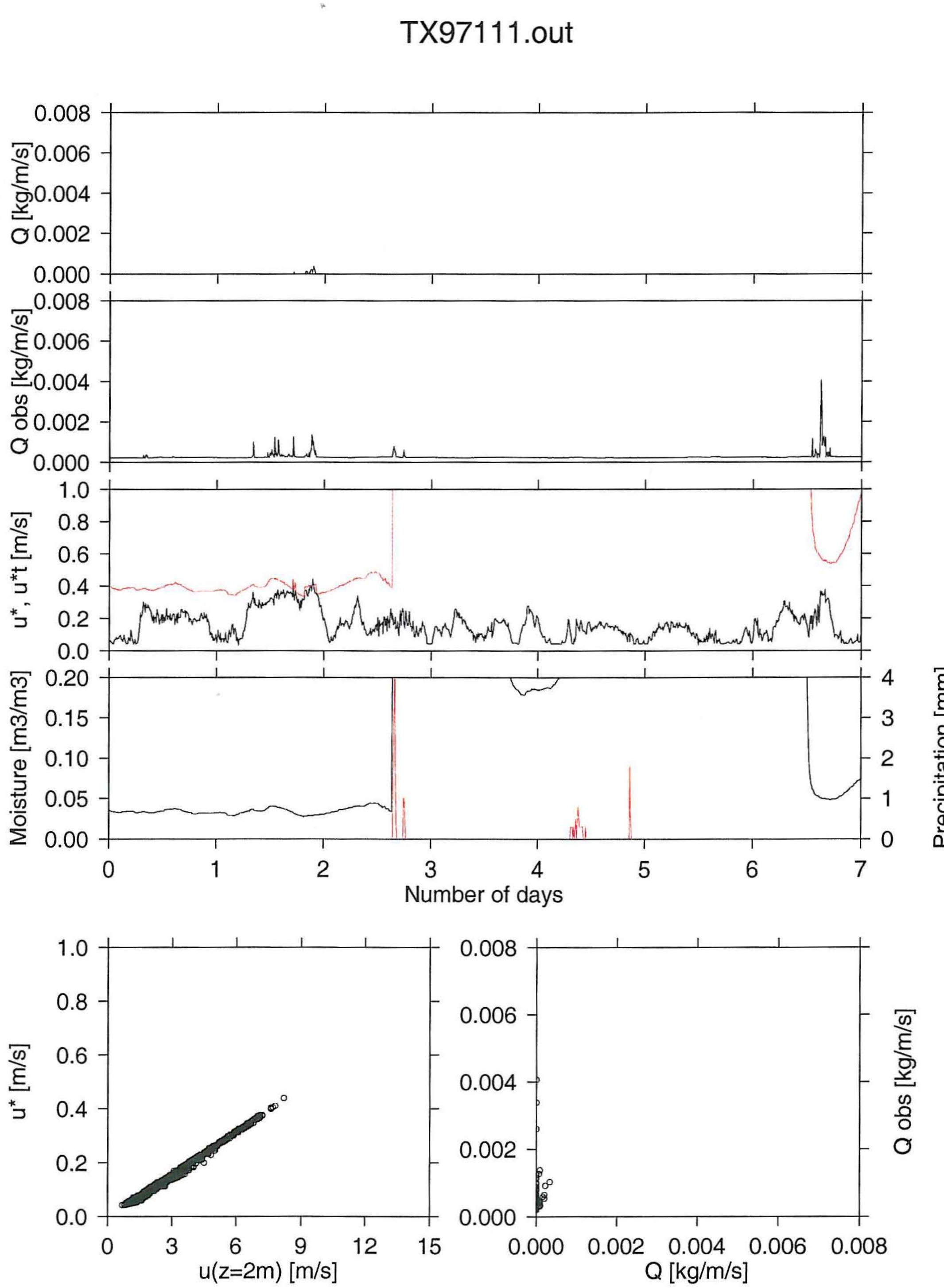

Figure 3: Third week

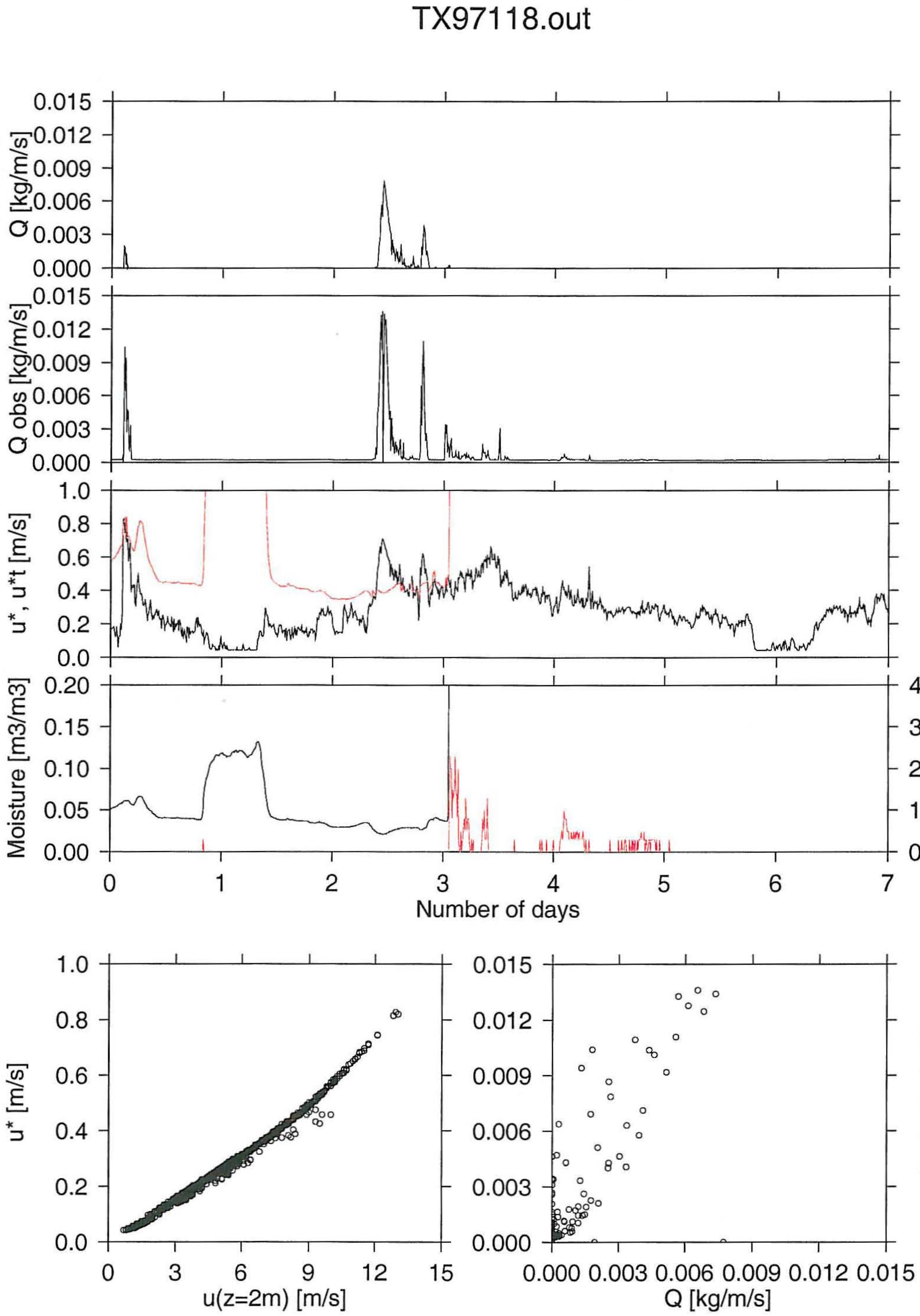

Figure 4: Fourth week

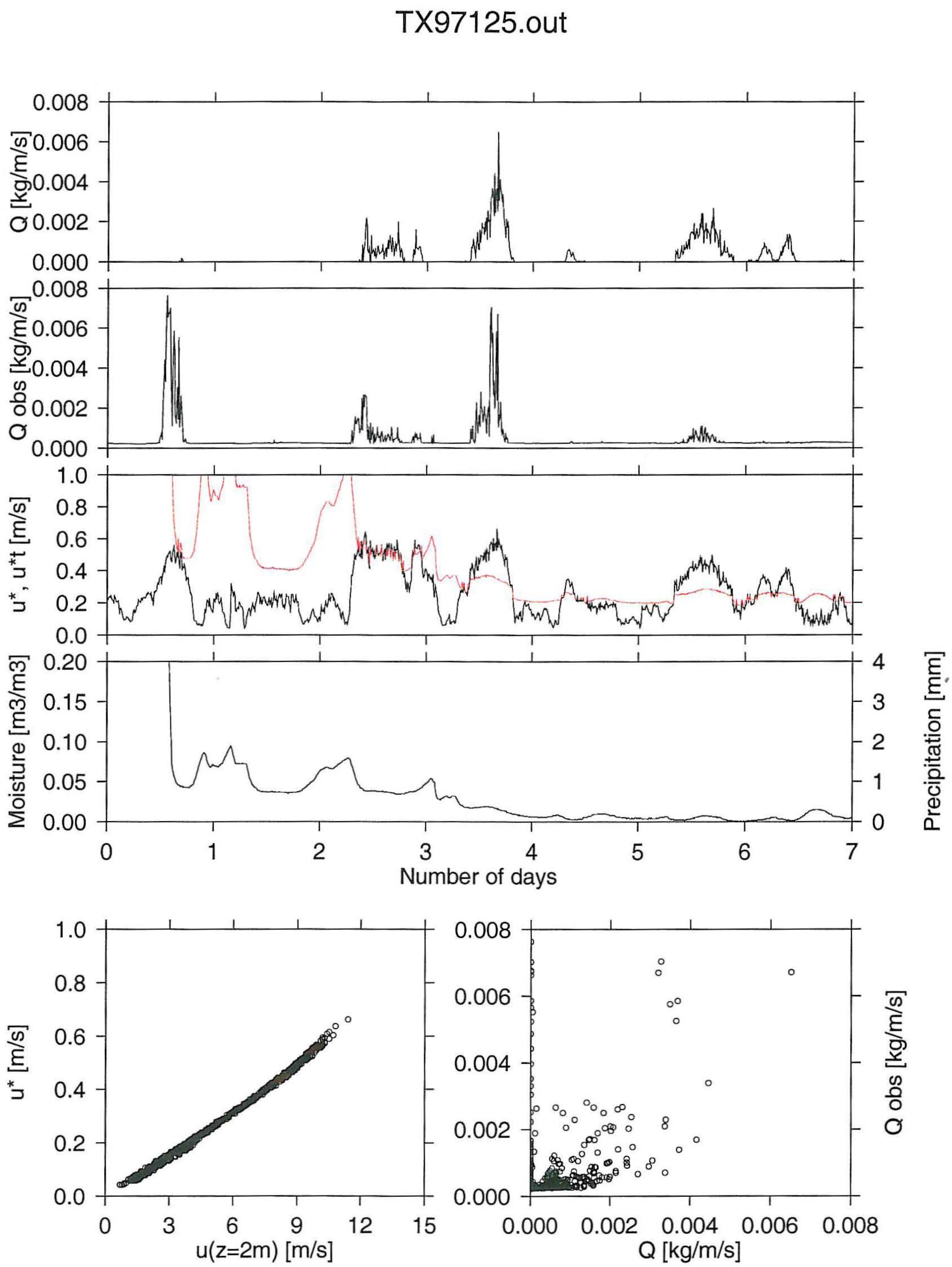

Figure 5: Fifth week

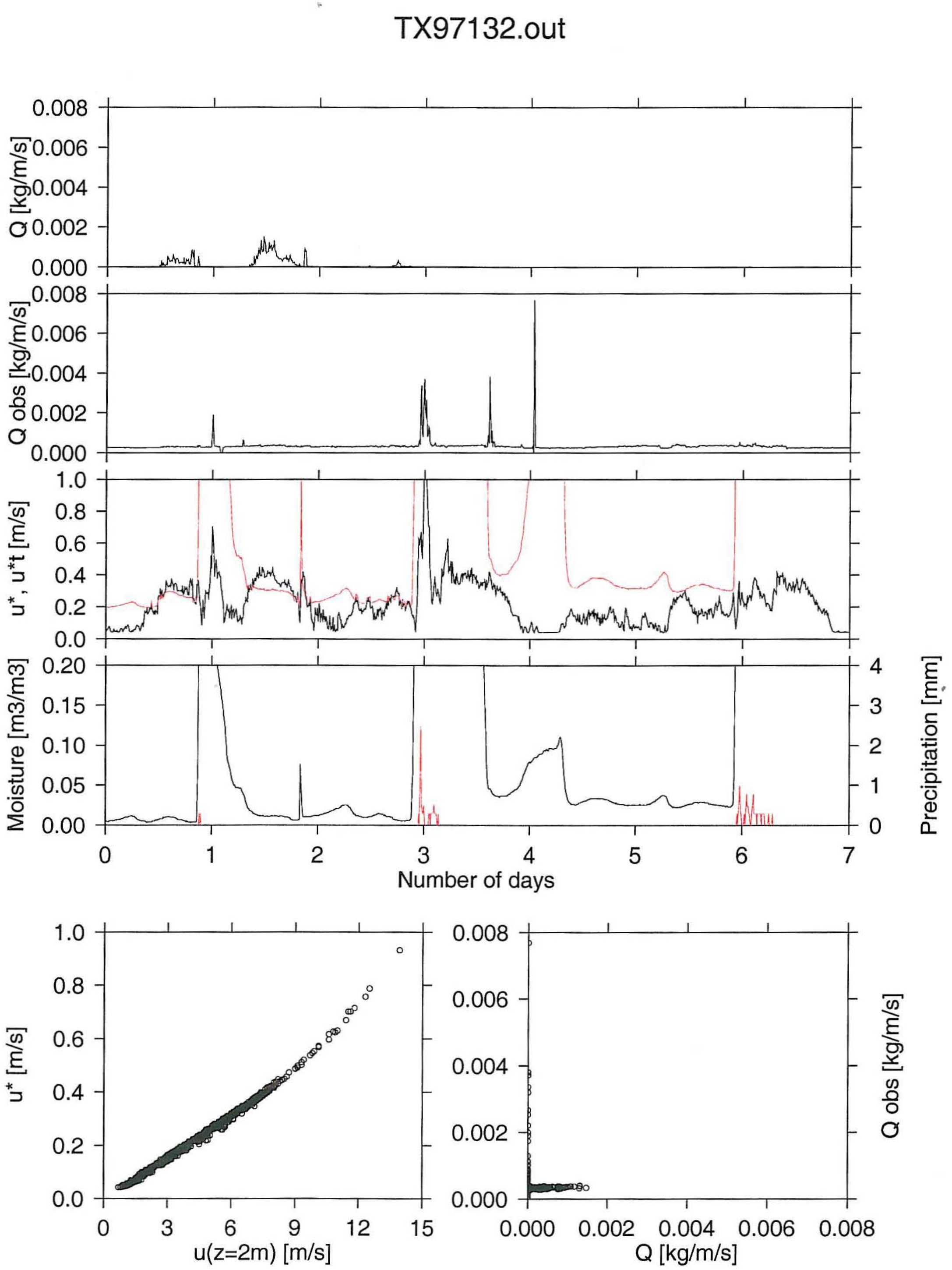

Figure 6: Sixth week

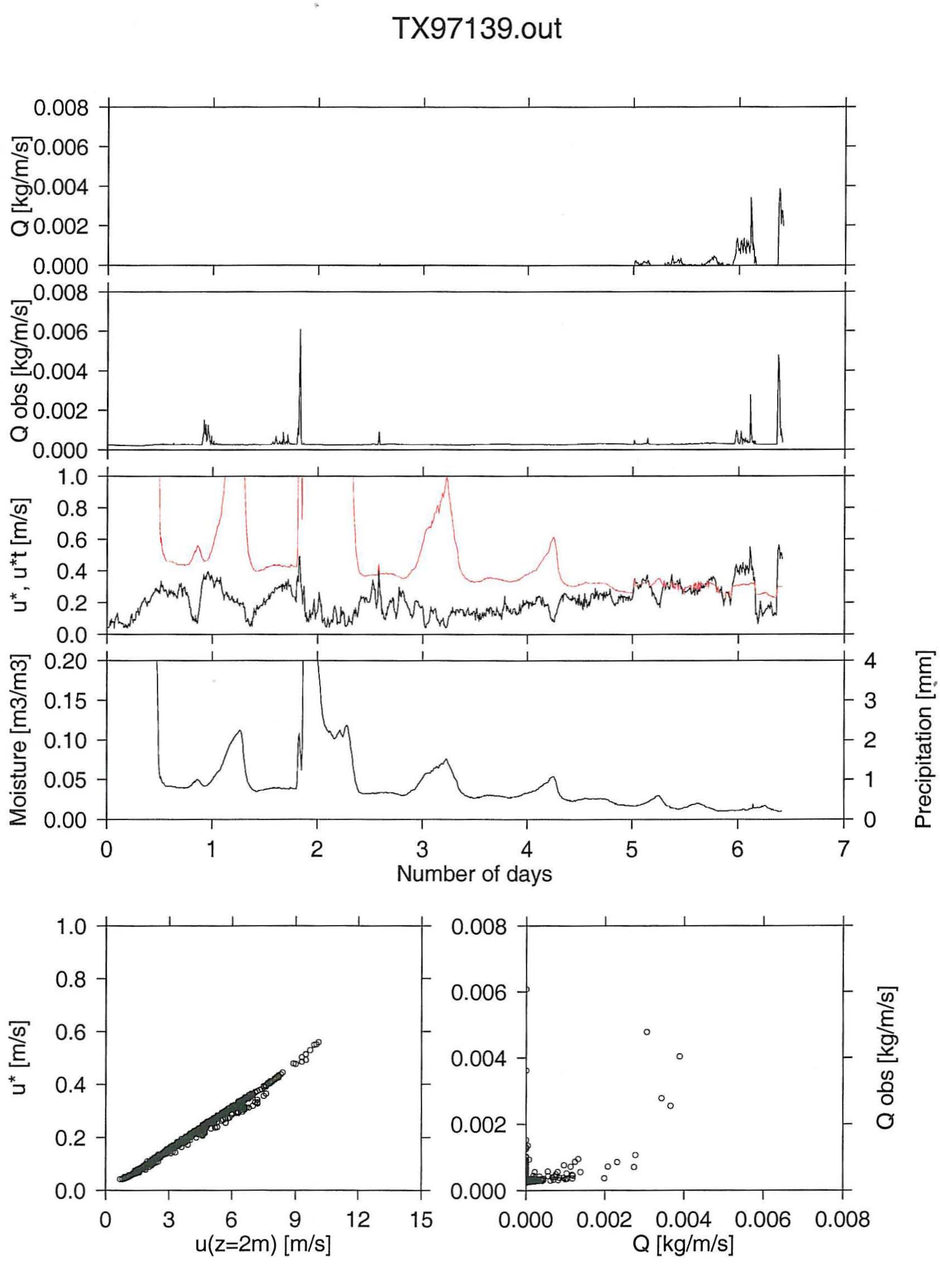

Figure 7: Seventh week

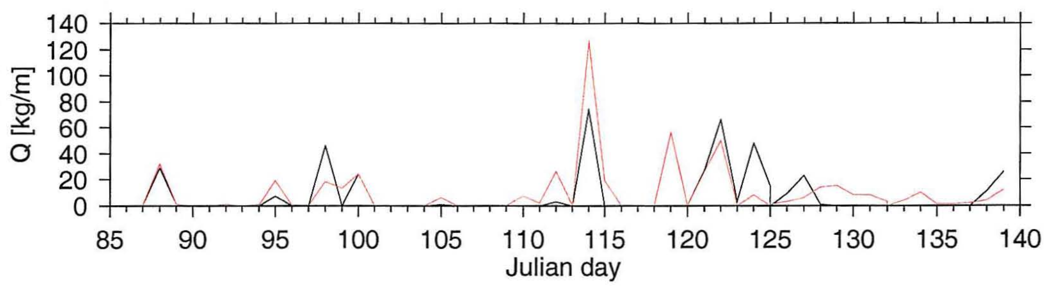

Figure 8: Daily integrated saltation flux, observed (red line) and predicted (black line).

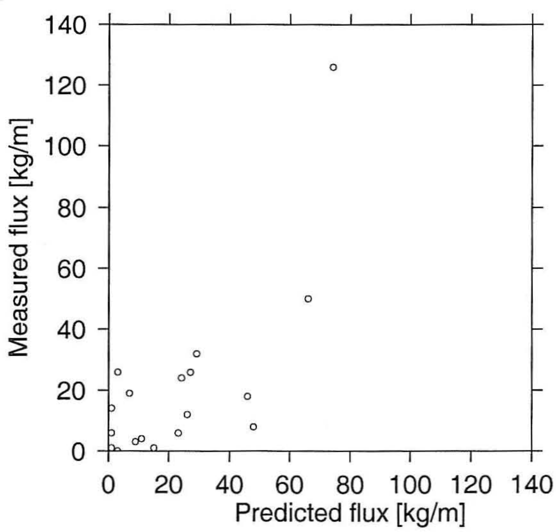

Figure 9: Observed daily integrated flux Q_{obs} versus predicted flux Q. $Q_{obs} = 0.985\,Q$ and $R^2 = 0.48$.