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INLET DYNAMICS INITIATIVE ALGARVE (INDIA)

REPORT OF THE CONTRIBUTION OF THE INSTITUTE FOR BIODIVERSITY AND ECOSYSTEM DYNAMICS, UNIVERSITY OF AMSTERDAM

5 MODELLING OF DUNE DYNAMICS IN THE ALGARVE

Introduction

Aeolian dune development can be simulated with the models HILL and SAFE (van Boxel *et al.*, 1999 and van Dijk *et al.*, 1999). One of the most important parameters for the prediction of aeolian transport is the friction velocity U_*. On a flat and homogeneous surface, the wind speed linearly increases with log-height, and the friction velocity can be derived from the logarithmic wind profile. In a dune terrain, the surface is never homogeneous. Due to roughness (vegetation) changes and topography the wind profile strongly deviates from the log-profile. Theoretically, friction velocities can be derived from wind speed measurements very close to the bed, which in reality is impossible. Modelling of the airflow provides a solution. The modelled airflow can then be used for the calculation of sand transport over the dune profile, and the resultant changes in height.

The airflow model HILL is based on the theory of Zeman and Jensen (1987). Besides the mean wind, also the turbulent components are modelled. The model uses the scaling concept, which states that the ratio of wind speeds at any location, relative to a reference wind speed, is independent of the wind speed itself (Arens *et al.*, 1995). The friction velocity at any point in the profile is calculated. If vegetation is present, the friction velocity under the vegetation canopy is calculated using an equation proposed by Raupach *et al.* (1993).

The transport model SAFE uses the results of HILL to calculate sand transport and the resulting change in topography. Since changes in topography result in changes in airflow, the modules are linked. When the change exceeds a certain threshold, the airflow is recalculated. Sediment transport is calculated using published deterministic and empirical relationships, describing the influence of meteorological conditions, topography, sediment characteristics and vegetation. Changes in topography are derived from the predicted transport, using the continuity equation.

In the INDIA project, the models SAFE and HILL are used to compute the effects of different events, and to estimate the effects of a large storm that occurred prior to the fieldwork. In future, the models can be used for estimating long term dune development over a period of years, if wind data for the long term will be available. Presently, only wind data for the period July 1997 to March 2000 are available.

Methods

For application of the models SAFE and HILL, the following data are required:

- mean grain size

- friction velocity and wind direction over time
- dune profile
- vegetation height and cover over the dune profile

grain size
A mean grain size of 350 µm is used in the model. This value is only used for the calculation of the standard threshold friction velocity. The model cannot cope with different grain size populations in the profile. This is one of the reasons of the deviation between measured and predicted transport rates.

friction velocity and wind direction
Friction velocities and wind directions are derived from hourly wind recordings at Faro Airport.

By means of regression analysis we have established regression equations for the relation between wind speed measured at Ancão and at Faro Airport. For different wind directions, these equations are:

wind direction:	**wind speed calculated with:**
150-180	$U_{FA}=0.7297U_{Ancão}+0.8566$
180-210	$U_{FA}=0.6479\ U_{Ancão}+0.9692$
210-240	$U_{FA}=0.7307\ U_{Ancão}+0.7142$
240-270	$U_{FA}=0.8712\ U_{Ancão}+0.2946$
270-300	$U_{FA}=0.7252\ U_{Ancão}+0.2257$

In order to convert wind speeds to friction velocities, a number of wind profiles measured on the beach were compared to wind speeds measured at the dune crest. A simple linear regression equation was derived to compute friction velocities from wind speeds. The computed (hourly) friction velocities were then used as input in SAFE. For onshore and oblique onshore winds the friction velocity is calculated by:

wind direction:	**friction velocity calculated with:**
135-180	$U_*=0.0631U_{4.2}$
180-270	$U_*=0.0518U_{4.2}$
270-315	$U_*=0.0631U_{4.2}$

The calculated friction velocities for 31-12-1998, that are used as input for the model are displayed in Figure 1.

Wind directions recorded at Ancão and at Faro Airport appeared to be well correlated. There was only a slight deviation between the wind directions. Therefore, no adaptations of the wind direction measured at Faro Airport were necessary.

dune profile
All model runs use the same profile, recorded at 6-2-1999 with a laser-theodolite.

vegetation height and cover over the dune profile
Vegetation parameters are needed as input in the models to calculate the friction velocity near the surface under a vegetation cover. SAFE was run with an adapted vegetation module, as proposed by Arens *et al*. (2001). Vegetation parameters were recorded at several transects

over the dune. From these recordings, an average vegetation profile was derived, which was used as input in SAFE and HILL.

application of the models

The models are run in the simplest version:

- all wind directions between 150 and 300º are accounted for as onshore winds;
- frozen tidal state: there is no influence of tide;
- no connection to beach building processes: there is no recovery of the beach after wind erosion, therefore the beach is eroded to a specified minimum level (mostly 4 m);
- no vegetation growth: once buried, the vegetation stays buried.

In the results the influence of these limitations on the model results will be discussed.

SAFE is run with different sets of parameters. In Table 1 the values for the parameters are indicated for each run. The parameter that is changed in a run is indicated with shaded grey.

Table 1. Parameter sets for different runs of SAFE.

	standard	run 2	run 3	run 4	run 5	run 6
Tend	1	1	1	1	1	1
deltaT	0.005	0.005	0.005	0.005	0.005	0.005
dtOut	0.1	0.1	0.1	0.1	0.1	0.1
Xstep (m)	1	1	1		1	
Q0	0	0	0	0	0	0
χ_1	20	20	20	30	20	20
χ_2	3	20	3	30	10	3
GrainDiam	350 µ	350 µ	350 µ	350 µ	350 µ	350 µ
Deflation limit (m)	4	4	4	4	4	2
Tide	-	-	-	-	-	-
Z0ref (m)	0.001	0.001	0.001	0.001	0.001	0.001
Rain	-	-	-	-	-	-
Critdz (m)	0.025	0.025	0.1	0.025	0.025	0.025
Dynamic link to HILL	yes	yes	yes	yes	yes	yes

Results

Table 2 repeats the calculated and measured transports, with a column added of the results of SAFE / HILL.

Table 2. Results of transport calculations.

date	*Kawamura*	*SAFE*	*"measured"*	
31-12-98	9.98	8.90	8.25	$m^3m^{-1}.day^{-1}$
9-2-99	0.78	1.34	0.16	$m^3m^{-1}.day^{-1}$
24-2-99	0.32	0.63	0.02	$m^3m^{-1}.day^{-1}$
3-3-99	0.68	0.85	0.12	$m^3m^{-1}.day^{-1}$
4-3-99	0.28	0.29	0.01	$m^3m^{-1}.day^{-1}$
10-3-99	0.51	0.69	0.00	$m^3m^{-1}.day^{-1}$
11-3-99	0.61	0.65	0.05	$m^3m^{-1}.day^{-1}$
12-3-99	1.15	3.44	0.04	$m^3m^{-1}.day^{-1}$
13-3-99	0.13	1.09	0.00	$m^3m^{-1}.day^{-1}$
23-3-99	0.00	0.05	0.00	$m^3m^{-1}.day^{-1}$
24-3-99	0.19	0.16	0.00	$m^3m^{-1}.day^{-1}$
25-3-99	0.57	0.56	0.09	$m^3m^{-1}.day^{-1}$
26-3-99	0.29	0.47	0.01	$m^3m^{-1}.day^{-1}$

Total	15.52	19.11	8.75	$m^3.m^{-1}$
Total 1999	5.53	10.21	0.50	$m^3.m^{-1}$

In this version of SAFE different wind directions are not taken into account: all onshore winds, between 150 and 300 º are treated in the same way. Therefore, the prediction by SAFE is an overestimation. However, Table 2 indicates that the predicted amounts are comparable to the amounts predicted by the simple application of the Kawamura equation. In this case, the merits of SAFE are in the prediction of the profile development, and in the estimation of transfer of sediment over the barrier and dune ridge, into the lagoon.

Differences between the runs are discussed here. The standard run uses the default values for the important parameters in SAFE (dynamic link with HILL, a value of 20 for χ_1 and 3 for χ_2, a critical dz of 0.025 m after which the air flow is recalculated). With these values the model is tested (see van Dijk et al., 1999). However, Arens et al. (2001) discuss the value of χ_2 and its probable dependence on several other factors. For this reason the model is run with several other values for χ_2.

The standard run for 31-12-1998 indicates erosion on the beach, and deposition at the point where the vegetation starts (dunefoot, approximately at 0 m, Figure 1, z at T=0 and T=1). In Figure 2 the calculated effective friction velocities at time intervals of 0.1 days are displayed, in Figure 3 the calculated transport rates and in Figure 4 the resultant changes in Frontal Area Index FAI, due to vegetation burial. During part of the day the friction velocity is extremely high, resulting in an also extremely high transport. However, Figure 3 clearly indicates that the transport is limited to the dune area, and declines to very low values at the back of the dune, due to the presence of the vegetation. At two time intervals (T=0.4 and T=0.5) some transport on the back of the dune occurs, but this is only limited, and does not result in significant changes in height. Figure 3 illustrates the steep gradients in transport, which causes a very rapid deposition in the vegetation. As is shown in Figure 4 deposition occurs over a short distance and vegetation changes from totally buried to not affected over a distance of 10 m.

As was mentioned before, Arens et al. (2001) discuss the value of χ_2 and its effect on dune building. Their conclusion was that χ_2 depends on vegetation properties. It is very likely, that this parameter also depends on transport mechanisms. From field measurements, we know that transport gradients are less sharp than suggested by the model (see paper on dune dynamics). During strong onshore winds sand is moved over the dune in a suspension cloud. In fact, this process is not described well by the model, since the model assumes that all transport occurs in saltation. In saltation, sand grains are in contact with the bed and transport declines sharply when the vegetation cover on the bed increases, whereas in suspension, there is no interaction between sand grains and the bed, and grains can move over vegetated surfaces (Arens, 1996). Although this process is not treated well by the model, it can be simulated roughly by accepting a large value for χ_2 in case of suspension.

When we use χ_2=20 (run 2) the decrease in transport is much more gentle and the burial of vegetation is more gradual (Figure 5). Using a value of χ_2=30 (run 4) gives smoother transitions, but basically not different, while a value of 10 (run 5) gives intermediate results. Unfortunately we do not have exact data on the vegetation burial resulting from the event on 31-12-1998, but only photographic evidence. However, based on field inspection, it seems that the results with χ_2 appear to be more realistic than those with χ_2=3. Although we cannot conclude on the exact value of χ_2, we can suggest that a higher value for χ_2 seems legitimate in case of transport over the back of a dune in some kind of suspension mode.

For run 3 we use a higher value of Critdz, which means that the airflow is recalculated after larger changes in height somewhere on the profile. Default we use a value of 0.025 m, but in run 3 a value of 0.01 m is used. The advantage of a higher Critdz is a decrease in computing time. However, in this way the model is less stable, resulting in unrealistic features on the seaward slope of the dune. Therefore the results of run 3 are not discussed further.

Run 6 uses a lower value of the deflation limit (2 m). The results in effectively in a wider beach and therefore a larger source, and a higher possible input of sediment. The net input into the dune zone is higher, 11.7 $m^3m^{-1}day^{-1}$ opposed to 8.9 $m^3m^{-1}day^{-1}$ for the standard run. However, the development of the dune is the same, but the extend of sand burial is further than in case of the standard run.

All runs for 31-12-1998 indicate that during the day transport is limited to the dune zone. All sand is deposited within the vegetation on the dune, and there is no transfer into the lagoon. The beach is severely eroded by the wind. There is no evidence at all of the change in beach shape during the event. However, since the accretion on the dune as measured from the vegetation burial is in the same order of magnitude as the predicted (potential) sediment input, we believe that the amount of wind erosion on the beach is also comparable to what is predicted by the model.

Figures 6 and 7 display the modelling results for all aeolian events during the fieldwork period. Basically the results are comparable to those of the big event. Dune building occurs in the highest part of the profile, and there is no transfer into the lagoon. Predictions of transport are highly overestimated, as was already concluded in the paper on dune building. During the fieldwork, maximum changes in height of 4 cm were recorded, which are much lower than the changes predicted by the model. For some days the predictions are totally wrong, due to the combined occurrence of rain and strong winds.

Conclusions

For the storm event of 13-12-1998, modelling results are in agreement with the (limited) field observations. Irrespective of the exact model configuration, the model predicts total burial of the vegetation on top of the dune but no transfer of sand into the lagoon.

For other storms during the measuring period transport is overestimated. The amount of overestimation is not constant, and depends on many factors. Besides rain, the source and grain size distribution of sand in the Ancão system is a limitation for transport. This is an important issue for further research.

Despite all overestimations of transport, the model predicts no transfer of sand into the lagoon.

Discussion

The model shows that during strong onshore winds the sediment is stored in the vegetation. There is no transfer into the lagoon. Possibly there is a substantial transfer in built-up areas, where no storage in the profile is possible because of the absence of vegetation.

One of the major problems with the long term modelling is the supply of sediment to the beach by waves. There is no solution for this yet, other than manually adapting the beach profile every now and then. From the field experiment we know that the processes on the beach act much more dynamically then those in the dunes. It is sure that on the long term the changes on the beach affect the sand supply to the dunes. On the short term, disturbance of the surface by waves is important for the removal of coarse grains, the supply of finer grains, or the mixing of sediment at the surface. The effects of these processes are not incorporated in the model, but are important with respect to the final supply of sediment to the dunes.

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Figures

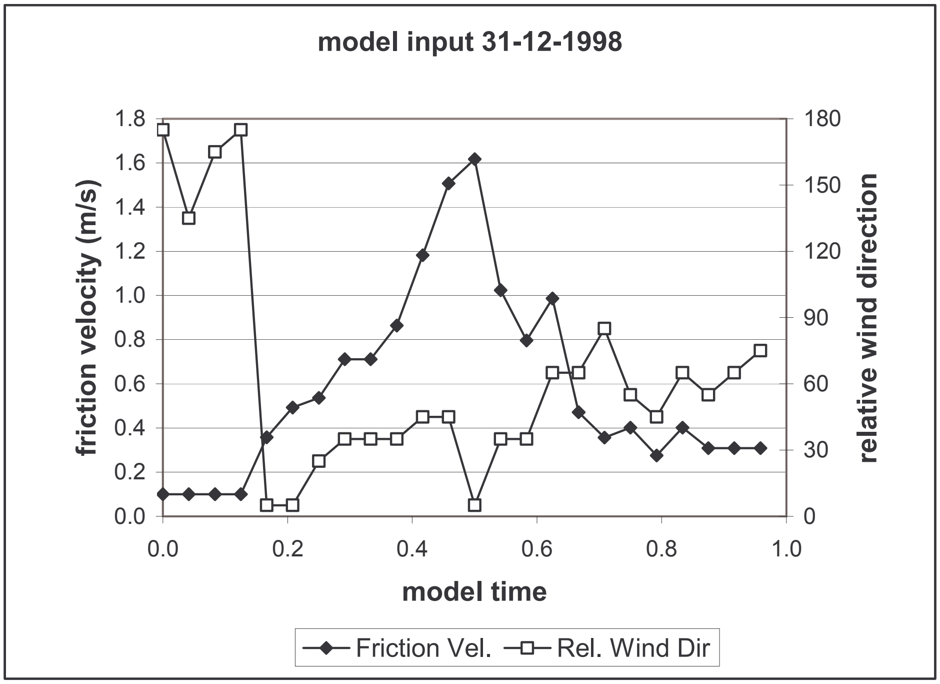

Figure 1. Friction velocity on the beach, which is used as input for SAFE / HILL.

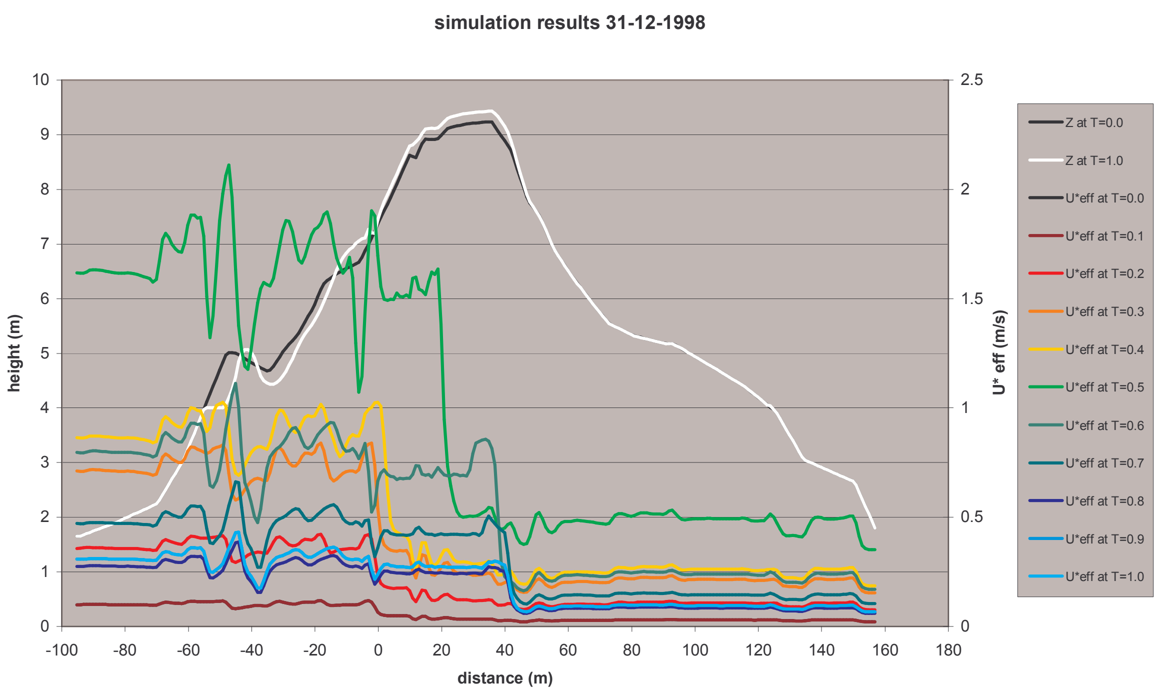

Figure 2. Calculated friction velocities over the dune profile, standard run, 31-12-1998.

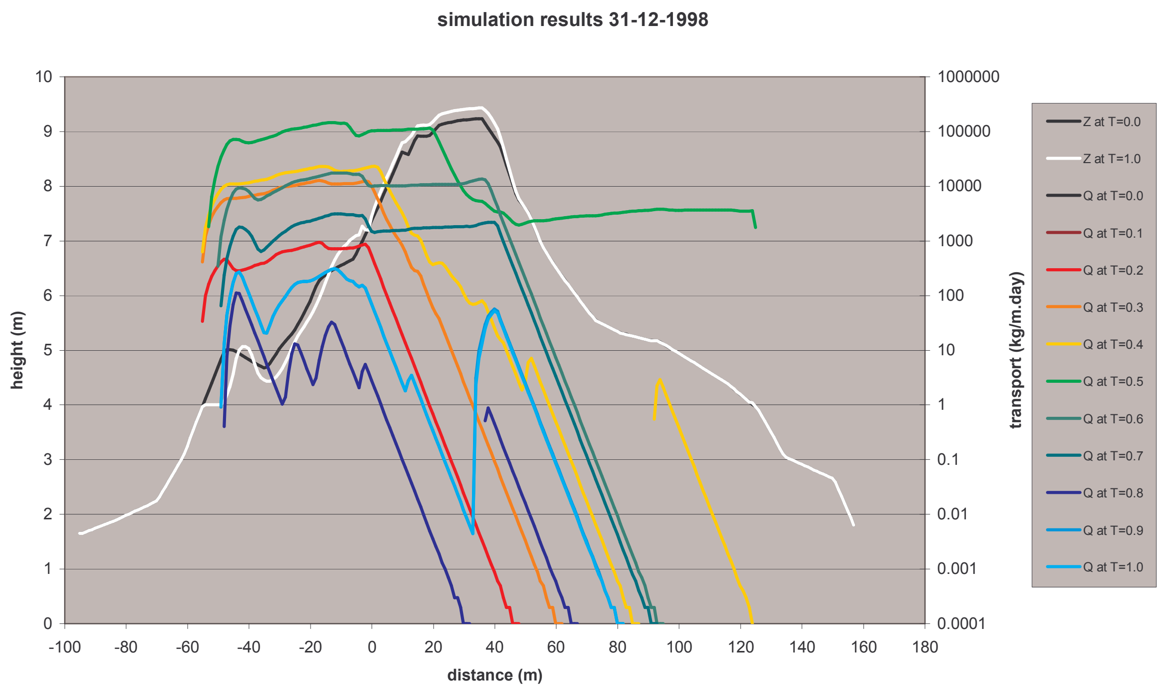

Figure 3. Calculated transport rates over the dune profile, standard run, 31-12-1998.

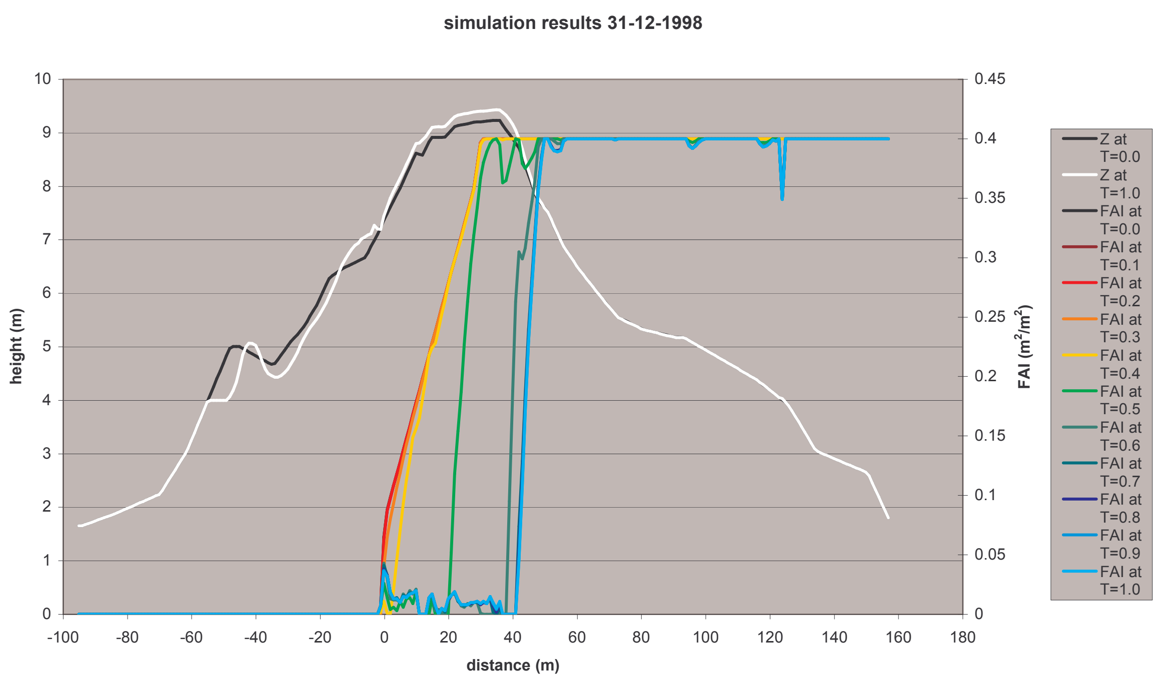

Figure 4. Calculated changes in FAI (vegetation), standard run, 31-12-1998.

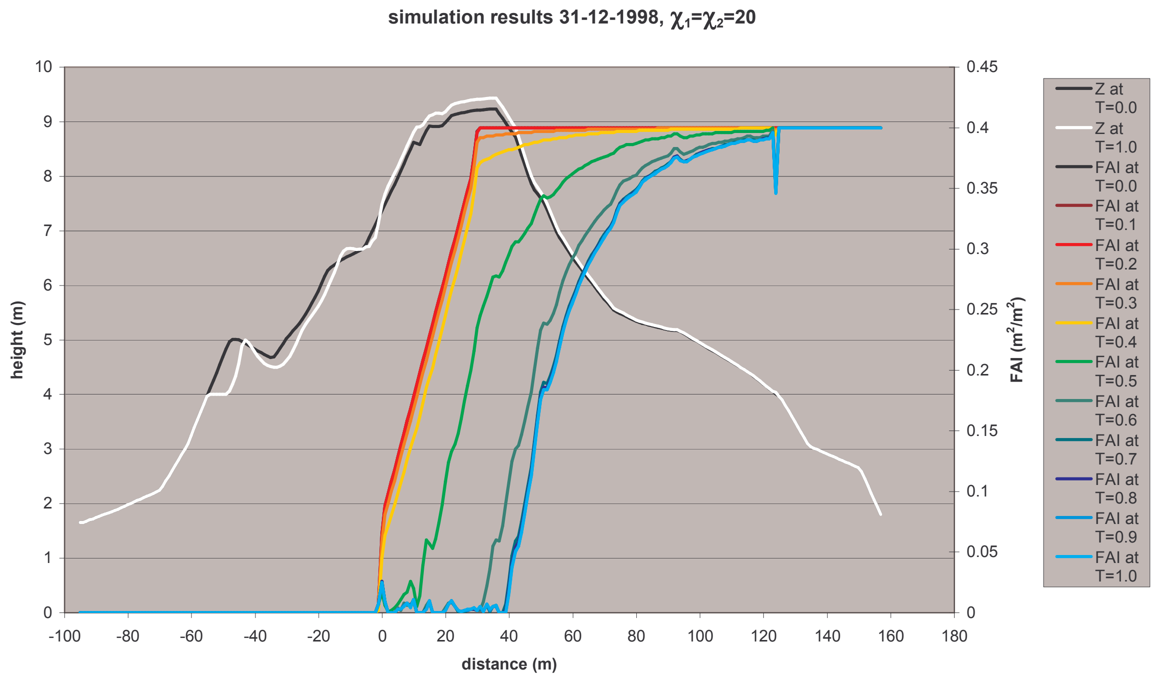

Figure 5. Calculated changes in FAI (vegetation), run 2, 31-12-1998.

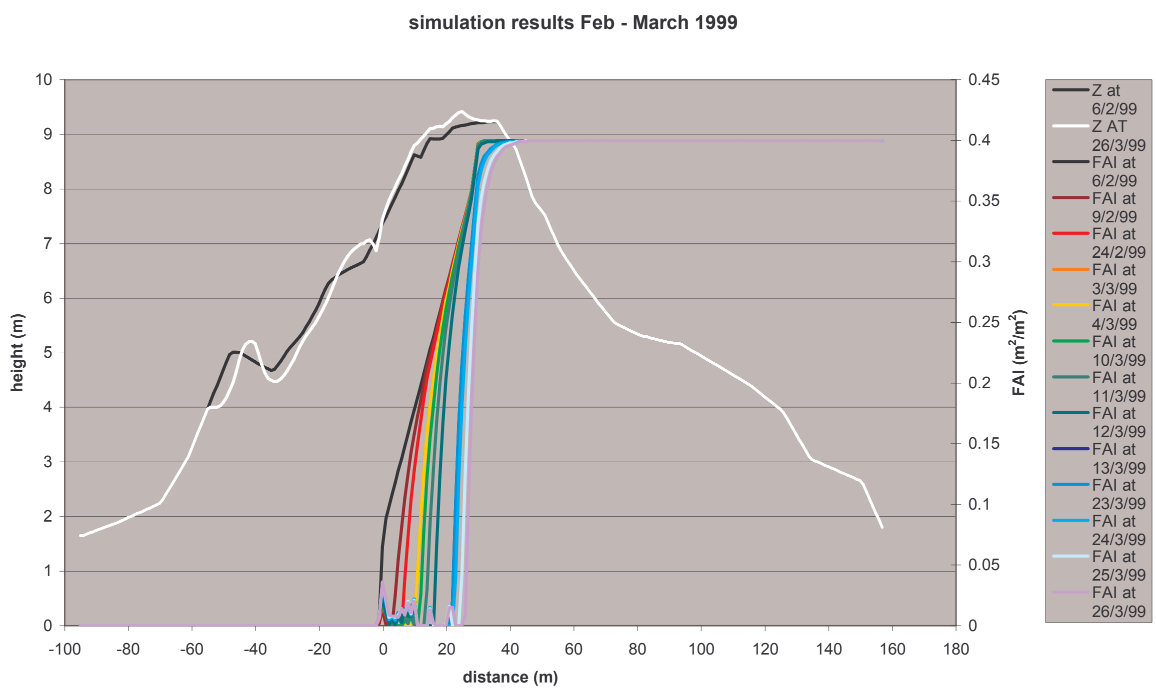

Figure 6. Calculated changes in FAI (vegetation), standard run February-March 1999.

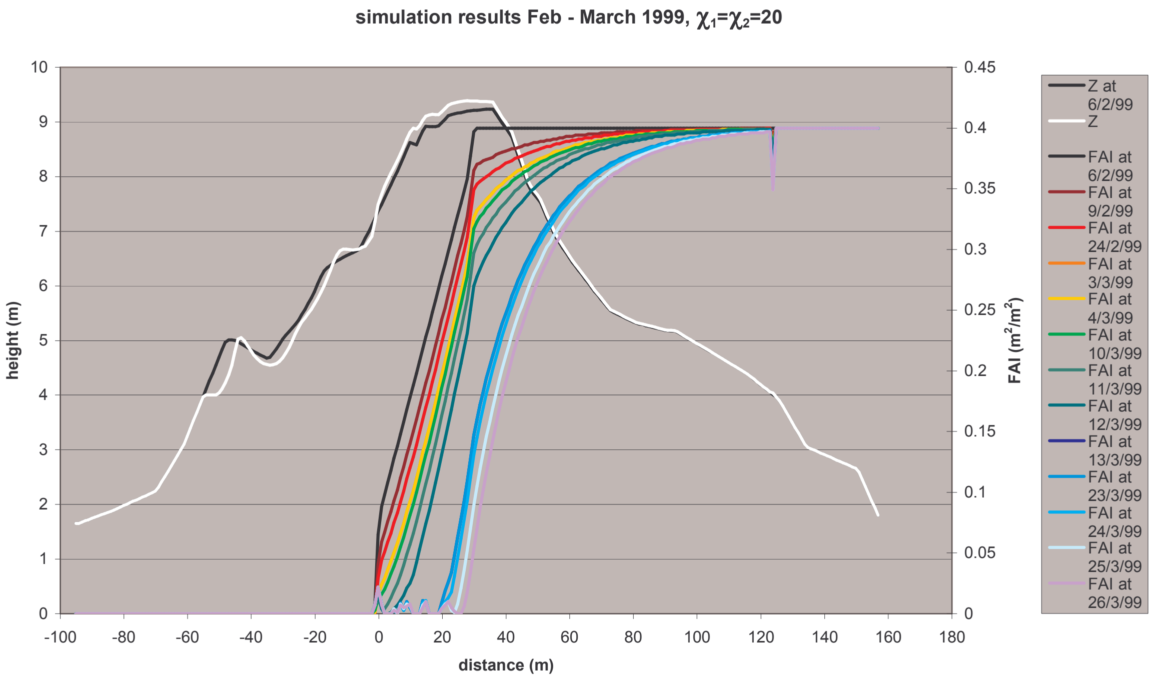

Figure 7. Calculated changes in FAI (vegetation), run 2 February-March 1999.