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Climate Change in the 21st Century and the Impact on Dunefield Mobility in the Kalahari

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Introduction

The Mega Kalahari is over 2,500,000km², fringing Angola and Zambia in the north and Botswana and southern Africa in the south (Grove, 1969). Sand dunes are considered vegetated and degraded in the northeastern reaches (Thomas *et al*, 2000) whilst episodic activity has been witnessed in the drier southwest. Here the climate and therefore dune activity has been dynamic over the past few decades, resulting in increased dune mobility throughout the droughts of the 1980s and 1990s (Bullard *et al*, 1997).

If this warming trend continues over the next one hundred years it may lead to some change in the geomorphology of southern Africa. Bridgman (1998) warns that the predicted northward shift in the Inter-Tropical Convergence Zone (ITCZ) and the strengthened El Nino Southern Oscillation (ENSO) phenomenon could lead to such a scenario, with the associated drying effect being a result of a 10 to 20% reduction in precipitation. Even wind speeds may reflect fluctuating ITCZ boundaries making it possible for increased aridity and enhanced windiness in areas where dunes are presently bordering the critical threshold for sand movement. However Joubert *et al* (1996) describe a wetter southern Africa where vegetation could flourish, which would provide the potential to stabilise all dunes in the Kalahari region.

In addition to the work completed in north America by Muhs and Maat (1993) and Wolfe (1997), it will be important to see what effect climate change may have on dune activity in a southern hemisphere dunefield, the spatial extent of such changes, its magnitude and any seasonal alterations in the timing of peak activity. It is also important to investigate the methods used to predict the extent of dunefield activity by highlighting the problems and uncertainties of using Global Climate Models (GCMs).

Methods

Dune mobility for each calendar month is modelled using the simple indices of Lancaster (1988) and Talbot (1984), which consider both erosivity (wind power) and erodibility (soil moisture). These are given in equations 1 and 2 respectively:

$$\text{Lancaster} = W / (P:PE) \quad \text{(Eq. 1)}$$

$$\text{Talbot} = V^3 / Mo^2 \quad \text{(Eq. 2)}$$

Where W is the percentage of time the wind is above the threshold for sediment movement, P is precipitation, PE is potential evaporation, V is wind speed and Mo is the Thornthwaite moisture index.

Future predictions for climate are gained from the results of four GCMs that consider a doubling of atmospheric carbon dioxide and an increase of carbon dioxide that is combined with an increase in cooling sulphates.

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Challenges

Three main areas of uncertainty have been identified; what GCM results provide for those assessing climate change impacts on the environment; what data are available for dune mobility index calibration; and how equations one and two represent monthly dune activity when the original intention was to produce an annual potential (Table 1). Two subsets of these problems are particularly relevant to aeolian studies: one questions the integration of GCM output with Lancaster's and Talbot's mobility indices and the other concerns the calculation of dune mobility for each calendar month.

Table 1. Challenges of predicting future dune mobility using climate predictions made by GCMs and simple mobility indices.

Challenges
GCM climate output
Coarse spatial resolution of output (finest is 2.5° lat. x 3.5° long.)
Data integration problems with impact assessment models (mobility indices)
Lack of natural inter-annual variability in climate predictions made for the next 100 years
Uncertainty surrounding GCM performance and accuracy
Calibration of monthly mobility values
Lack of ground truth data or measurements of dune mobility for each calendar month
Problems of different grid resolutions when validating GCM output
Dune mobility indices
Often very simple
Zero precipitation yields high mobility values and there are no lag times considered
High values do not fit into the original mobility categories
Output describes only one of four activity states

Data integration

There are problems with the temporal and spatial resolution of available climate data, the number of variables simulated and the format in which they are provided. For example some GCMs do not provide predictions for wind power. When they do, data are not ideal for input into the mobility indices as one mean monthly value is given whereas the extreme speeds or range would be much more useful. In addition, for the Talbot index, Thornthwaite moisture values are not modelled and some metric to imperial data conversion has to take place. Predictions are made for each grid cell but these cells can cover large areas incorporating places with differing levels of dune activity (Fig. 1). To solve some of these problems several alternatives have been investigated such as using climate generators to simulate a future wind environment, using Weibull distributions to calculate the probabilities of sand transporting events, or modification of the existing mobility indices to better incorporate what is available from the GCMs. Each have their own set of advantages and limitations but rarely do they overcome all the problems revealed.

Calibration of dune mobility values calculated for each month

Mobility values calculated per month do not fall into the original categories of dune activity created by Lancaster and Talbot that define crest activity, interdune movement and inactivity (fig. 2). Therefore values are produced which have not been related to what is observed in the field as there are very few records that can be used to compare what has been postdicted by the GCMs to that which has been measured on a monthly basis. Zero precipitation yields infinite mobility values and the lack of lag times means that mobility output responds instantaneously to reduced rainfall. Smoothing procedures can incorporate artificial lag responses but these can average the temporal trend too severely. Remote sensing products may help to identify lag relationships between rainfall and vegetation dieback , which can then be incorporated into a more realistic model of intra-annual dune mobility.

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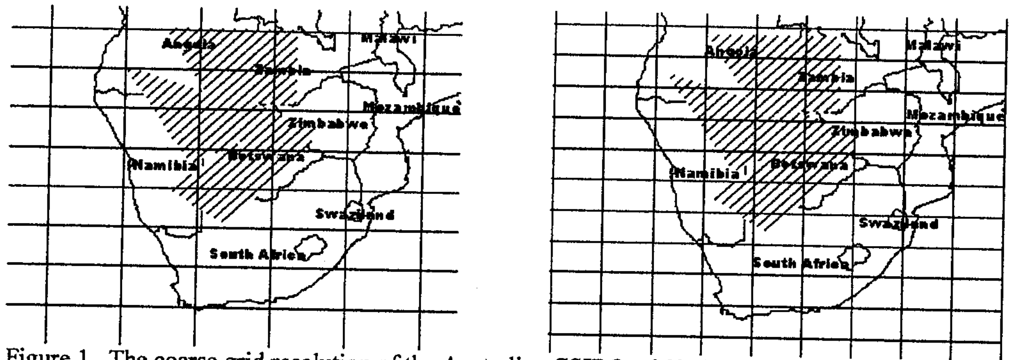

Figure 1. The coarse grid resolution of the Australian CSIRO mk2b GCM compared to the finer spatial resolution of the British HadCM2 GCM. Each Hadcm2 grid cell covers an area approximately 82,000 Km²

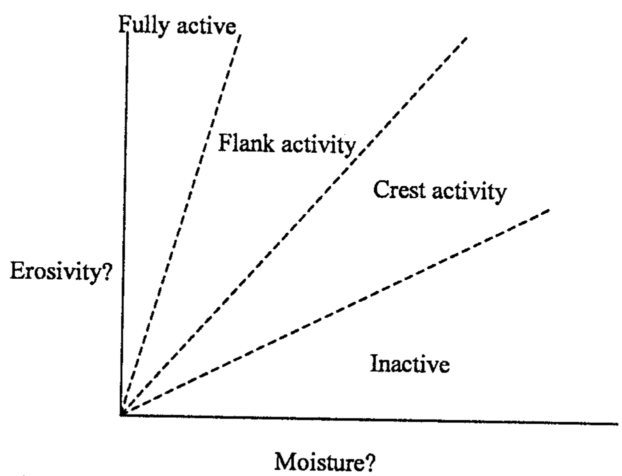

Figure 2. The need for assigning new category values for dune mobility calculated on a monthly basis (adapted from Lancaster, 1988).

Overview

Several areas of uncertainty have been revealed when attempting to predict future states of sand dune activity, which include the use of GCM results, the use of simple indices to calculate monthly mobility and the calibration of what is predicted to what has been observed. Despite these uncertainties dune mobility indices may still be extremely useful when coupled with GCM output as their simplicity allows predictions to be made with very little input data. They are easy to use, they provide some indication as to the magnitude of dune mobility and they have been calibrated in several different dunefields across the world. However there is great potential for discussion on the issues identified.

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