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Wind Erosion Monitoring and Modeling Techniques in Australia

John Leys, Grant McTainsh and Yaping Shao*

ABSTRACT

Wind erosion is a part of the natural environment in Australia; however, since European settlement the extent and magnitude of wind erosion has increased. A mixture of monitoring and modeling is seen as the only way of undertaking environmental auditing as required by national and international conventions and treaties. Methods of measuring and monitoring wind erosion from plot to continental scale are discussed. Two modeling systems that are currently used in Australia for environmental audits are presented. One uses an empirical climate model and dust storm index to report the location of areas that are eroding at higher than climatic conditions would suggest. The other is an integrated climate, wind erosion, and geographical information system that uses process-based models to predict the location and intensity of wind erosion. The limitations and advantages of each model are presented.

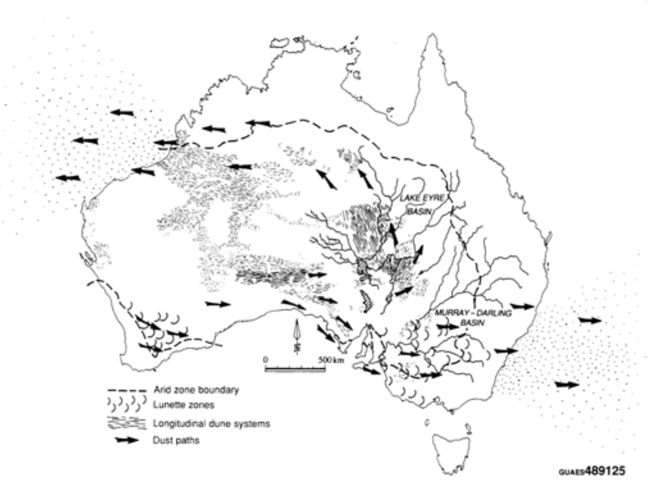

Figure 1. Dunefields, dust paths and drainage basins. (After (McTainsh and Leys, 1993)

INTRODUCTION

Wind erosion, the initiation of movement, transport and deposition of soil by wind, is part of the natural environment Australia today. Large parts of Australia have been shaped by wind erosion over the last 2 million years (Wasson, 1989) and as such a large proportion of the landscape is aeolian in origin (Fig. 1). Since the arrival of European settlement, many authors have identified that the magnitude and intensity of wind erosion has increased due to the adoption of European agricultural practices (Ratcliffe, 1938; Harrington et al., 1984; Noble and Bradstock, 1989; McTainsh and Leys, 1993). This increase in land degradation has raised concern in the government and with both landowners and land users.

To substantiate these claims of land degradation, there have been numerous attempts to quantify the level of wind erosion across the landscape. Early reports on the extent of wind erosion were generally undertaken after droughts, when the profile of wind erosion was raised within the community (Noble, 1904; MacDonald Holmes, 1946; Ratcliffe, 1938). However, these surveys and descriptions have generally been undertaken for small areas, such as, the Eyre Peninsula of South Australia (Hughes and Wetherby, 1992). There have been a limited number of nation-wide surveys (MacDonald Holmes, 1946), and unfortunately these surveys used different methodologies, which makes it difficult to compare the results (Woods, 1984). Few of the surveys were ever repeated, a notable exception being the soil erosion surveys of the Soil Conservation Service in New South Wales (Kaleski, 1945; Stewart, 1968). This lack of repeated surveys limits the use of the data as a monitoring tool.

The early surveys were undertaken to identify the extent and severity of a land degradation (Ratcliffe, 1938) or to survey the social conditions of landholders (Royal Commission to Inquire into the Condition of the Crown Tenants, 1901). These days, such surveys are undertaken to determine if land management practices are ecologically sustainable (Department of Environment Sport and Territories., 1996). The current round of surveys are largely undertaken to help the government meet its objectives associated with national environmental programs such as The National Strategy for Ecologically Sustainable Development and the various international conventions that Australia has signed. Such conventions include the Convention Concerning the Protection of World Cultural and Natural Heritage, ratified in 1974 and the Convention to Combat Desertification in 1994. The Federal Government also uses the information for reports to various international organizations such as the United Nations Environment Program (UNEP). Land degradation or natural resource surveys include many aspects of the environment: such as, air, inland waters, estuaries and the seas, oceans, terrestrial and aquatic biology, soils and cultural heritage to mention a few, this paper only includes wind erosion monitoring and

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modeling.

In the last 10 years in Australia there has been rapid progress in the understanding of wind erosion processes and modeling capabilities. This paper presents current monitoring and modeling techniques being developed and used to: (1) provide wind erosion reporting mechanisms for the above mentioned programs; (2) acquire data to help scientists unravel the processes of wind erosion; and (3) provide information on which to base better land management recommendations.

Wind Erosion Monitoring

The aim of wind erosion monitoring is to quantify changes in erosion or the factors that effect it through time; therefore, a key aspect is that the methodology has to be repeatable, and in most cases, rapid to undertake. To date monitoring has been undertaken in Australia at various scales (field to regional), at various intervals (days to years) and at various places. The following section outlines some of the current techniques.

Plot scale

To gain an understanding of wind erosion processes, there has been substantial effort at the plot scale using a portable field wind tunnel (Raupach and Leys, 1990). However for monitoring purposes, the wind tunnel is not time or cost efficient because of the large number of replications required to cope with field variability. Therefore, the wind tunnel tends to be more suited to erosion process studies (Shao et al., 1993b) or one-off comparisons of soils (Leys, 1991a) or farming systems (Leys et al., 1993).

Field scale

There are several monitoring methods that have been used to monitor the transport and deposition of eroded sediments. These methods range from simple bucket traps used for deposition studies, to highly sophisticated high volume sampling towers.

The simplest monitoring uses bucket like traps for the measurement of dust deposition (Walker and Costin, 1971; Tiller et al., 1987).

The advent of the Fryrear field dust sampler (Fryrear, 1986), and its subsequent modification with a rain hood to stop the trap overflowing with rain water (Shao et al., 1993a), made it possible to quickly and easily monitor wind erosion at field scale. These are the most widely used traps in Australia and have provided excellent saltation data over many months (Leys and McTainsh, 1996) and years (Miles and McTainsh, 1994).

Dust emission studies require high volume air samplers because the Fryrear traps are inefficient at catching particles less 40 microns in size due to the passive nature of the dust trap (Shao et al., 1993a). The preferred traps are high volume air samplers which can be used at the point of emission (Leys et al., 1998) or at the point of deposition (Boon et al., 1998). For field studies, systems used are based on the 10-m tower concept of Nickling and colleagues (Nickling and Gillies, 1993). The use of such technology has enabled monitoring if individual dust storm events with high precision, thus giving better estimates of emission rates from specific surfaces (Yu et al., 1993).

Regional scale

For monitoring at regional scale, methods tend to concentrate on the transport phase of wind erosion. The recent study by Nickling et al. (1999) used high volume sampling methods on a 10 m tower and was able to differentiate regional scale wind erosion events from local events; however, this approach is unlikely to be cost-effective at a regional scale.

It is the use of meteorological record of dust events that has been most widely used in Australia (Middleton, 1984; McTainsh and Pitblado, 1987). This approach has the advantage that the data are readily available for a large number of metrological stations and over long periods. For example, in Australia, near continuous daily data are available for 72 stations (marked as + on Fig. 2) for the past 31 years. The weakness of this approach is the low spatial resolution of meteorological stations, particularly in arid and semi-arid areas, where wind erosion is most active. The temporal record is sometimes interrupted by changes to meteorological recording protocols, such as were made at 1959 and 1974. Questions also exist as to the reliability of the observations; particularly those made by volunteer meteorological observers. Records are most reliable for dust storms and smaller scale entrainment events close to source, while dust haze records are less reliable.

The increasing use (since 1996) of automatic instrumentation in place of meteorological observations has both advantages and disadvantages for research into wind erosion at a regional scale. The advantages include an increase the quantification of meteorological observations. The disadvantages include a reduction in the number of observation sites and a change in methodology from manual observations to instrument measurements and the subsequent discontinuity of the dust record.

Dust entrainment events have recently been combined into a Dust Storm Index (DSI) (McTainsh, 1998). The DSI provides a more sensitive measure of wind erosion than dust storm frequencies, because it measures the composite effect of a range of dust event types, weighted in according to their intensity.

$$DSI = (5 \times SD) + MD + ({}^{LDE}/_{20})$$

Where:

DSI = Dust Storm Index (in dust event days)
SD = Severe dust storm (Present weather codes: 33, 34, 35 and 98; Bureau of Meteorology, 1982)
MD = Moderate dust storm (Present weather codes: 09, 30, 31 and 32)
LDE = Local dust event (Present weather codes: 07 &08)

The pattern of wind erosion for Australia during 1986-96, as measured by the Dust Storm Index (DSI) is shown in Fig. 2. A high DSI value indicates high wind erosion rates. The largest region of very high wind erosion activity covers the Lake Eyre Basin in the center of the continent. A smaller area of very high wind erosion activity is in southwest Western Australia.

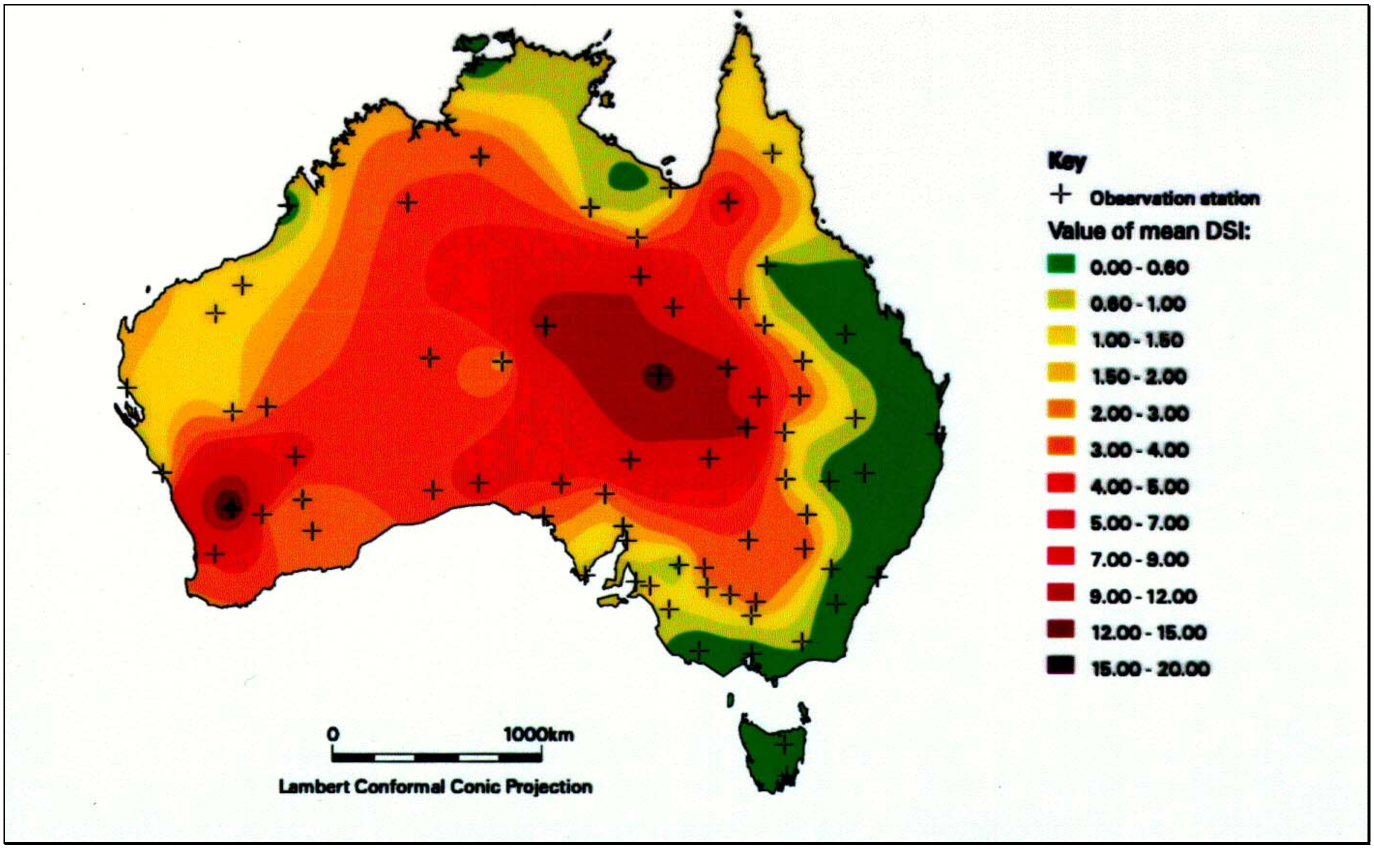

Figure 2. Interpolated values of mean Dust Storm Index (DSI) for the period 1986-1996 based on the observations of 72 meteorological stations across Australia. (After McTainsh, 1998).

Modeling

While monitoring provides site data for various points across the landscape, we can never monitor enough sites to get a full picture of the magnitude of wind erosion both spatially and temporally. With the advent of wind erosion models, geographic information systems and super computers, it is now possible to "predict" wind erosion at various scales and time intervals.

Modeling in Australia has been progressing at three levels:

1. Empirical description of the factors that influence wind erosion – such as, soil texture (Leys, 1991a) vegetation cover (Leys, 1991b), dry aggregation (Leys et al., 1996), soil moisture (Shao et al., 1996). These models were defined from plot scale experiments and have been used to provide land management guidelines to landholders (Leys, 1998).
2. Empirical climatic models which describe the influence of rainfall, evaporation, (Burgess et al., 1989) wind erosivity and soil moisture (McTainsh et al., 1990) on wind erosion.
3. Process based models that describe a number of factors, such as, soil texture, soil moisture, surface roughness, vegetation cover, wind force to the surface, saltation rate and vertical emission of dust from the surface (Shao et al., 1996) and then predict the erosion rate.

Of these approaches, it is the climatic models of McTainsh and the process-based models of Shao that offer the best methodologies for monitoring wind erosion and these will be discussed in detail below.

Empirical climatic modeling

Studies of the climatic controls upon dust storm occurrence in Australia have been developed from early models used in the USA (Chepil, 1956; Chepil et al., 1963; Fryrear, 1981). Early models, such as the *Em* model of Burgess et al. (1989), used annually averaged effective soil moisture to predict dust storm, where $em = (P - E)^{-2}$ and P – E is Thornwaite's precipitation/evaporation index. The *Em* model was later modified to include wind run in the *Ew* model of McTainsh et al. (1990). Yu et al. (1993) describe dust storm occurrence at Mildura, in relation to rainfall, using long term monthly data from eight stations in the dust source areas in southeast Australia. They describe a simple model that predicts summer dust storm activity using rainfall from the preceding autumn. More recently, McTainsh et al. (1998) developed the *Et* model which uses averaged monthly meteorological data to describe how wind speed and soil moisture interact during different seasons to influence dust storm occurrence in eastern Australia. Using the *Et* model, McTainsh and Tews (1999) were able to differentiate between accelerated and natural wind erosion for a state environmental audit. This approach has been used in an Australia-wide survey of wind erosion as part of the National Collaborative Program on Indicators of Sustainable Agriculture (NCPISA) (McTainsh, 1998) and more recently for the wind erosion section of the Queensland State of the

Environment Report (McTainsh and Tews, 1999), which covered 1,727,000 km^2, an area 2.5 times the size of Texas.

The methodology involves comparing measured wind erosion rates (DSI) with those predicted by the *Em* model of Burgess *et al.* (1989) and identifying how much land use has contributed to the unexplained variance. If, for example, the measured DSI at a station is higher than the climatic conditions predict, as shown by a regression line of the relationship between DSI and the *Em* model (R^2 0.50, P>0.0004) (Fig. 3), this is assumed to reflect the influence of factors not measured by the model. These include the two natural factors (wind conditions and soil erodibility), plus land use factors. The linear regression in Fig. 3 is strongly dependent on Birdsville, but this is to be expected because the proximity of this station to the Simpson Desert. We have no reason for excluding Birdsville as it is representative of a very large area (the Simpson Desert) that is one of the most (if not THE most) active dust storm regions in Australia; as such it is left in.

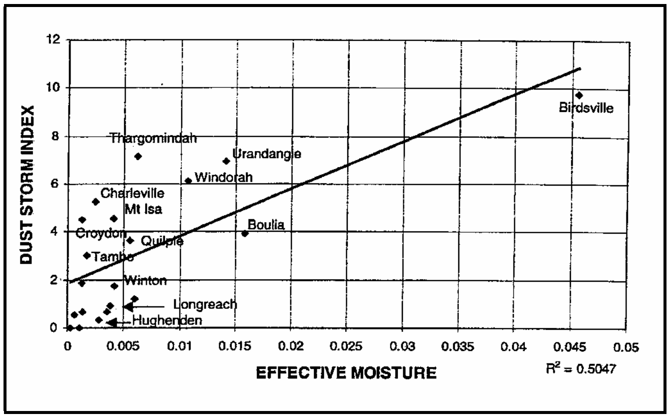

Figure 3. Relationship between measured wind erosion rates (DSI) and the *Em* model for 20 Queensland stations averaged over the period 1973-1996 (After McTainsh and Tews, 1999)

The difference between measured and predicted erosion rates (DSI) at a location is quantified as a ratio (called the Accelerated Erosion Index [AEI]). This is achieved by regressing DSI against effective moisture (Fig. 3). If a station data point is on the regression line, it will have an AEI of 1, if the value is above the line it will be >1 and if below the line it will be <1. For example, in Fig. 3, Thargomindah is a large distance above the regression line (with an AEI of 2.70), whereas Winton is below the line, (with an AEI of 0.42). Expressed in terms of erosion rates and land use effects, all other things being equal, land use activities in the Thargomindah area appear to be accelerating wind erosion to a much greater extent, than in the area around Winton.

As measured, DSI already contains a component of accelerated wind erosion; this methodology tends to understate the real levels of accelerated wind erosion. It is likely, therefore, that stations at and below the regression line still have a component of accelerated wind erosion.

The spatial pattern of wind erosion (DSI) for Queensland is shown in Fig. 4a. The overall influence of climate on wind erosion is apparent; with highest rates in the arid far south west of the State, diminishing to the east and north as rainfall increases. The map of the Accelerated Erosion Index (AEI) (Fig. 4b), indicates that the active wind erosion regions in the south west and north west of the State are eroding at higher rates than predicted by the *Em* model, whereas the central west region appears to be eroding at or below predicted rates.

Wind run data for 1960-1987 (McTainsh, 1998) show that this AEI pattern is at least partly explained by spatial patterns in wind conditions (not described by the *Em* model). For example, Urandangie (in the northwest) has the highest wind run record in Queensland and Thargomindah and Charleville (in the southwest), the second highest wind run. The main difference between the AEI pattern (Fig. 4b) and the DSI pattern (Fig. 4a) is in the central west region. Although Birdsville has the highest wind erosion rates (DSI) in the State, it has a low AEI value. In addition, the area has moderate to high wind run and erodible sandy soils, which would increase wind erosion rates above the predicted. Therefore, at this level of analysis it appears that the cattle grazing in this region is not causing measurable accelerated wind erosion.

In the Thargomindah-Charleville region, (south west) and the Urandangi-Mt Isa-Croydon region (north west), it is likely that the high AEI values also includes land use effects, as the soils are generally of only moderate erodibility. Miles and McTainsh (1994) have already raised the possibility of accelerated wind erosion in the Mulga area around Charleville. The area of apparently high accelerated erosion in the Croydon area was also identified in the NCPISA survey and has been tentatively attributed to overgrazing of erodible local sandy soils (SCARM, 1998), The low AEI values for the Mitchell grasslands around Longreach-Winton may in part reflect the low to moderate wind conditions there and the relatively low wind erodibility of these clay soils. It also suggests that grazing in this area may not be having a significant accelerating effect on wind erosion.

This modeling approach also has potential for describing temporal trends in accelerated wind erosion. The temporal trend of wind erosion rates (total DSI) for Queensland since 1973 is shown in Fig. 5. While there is a general increase in wind erosion rates through time, shorter-term fluctuations appear to reflect the overall negative relationship between wind erosion rates and rainfall. The low erosion rates in the mid-1970's are associated with higher than average rainfall and high rates in 1994 are associated with drought conditions.

Annual patterns of AEI are difficult to quantify because of the small numbers of stations involved in any year. When AEI data are blocked into time periods: 1974-1978, 1979-1985 and 1986-1996, some tentative trends emerge. It was necessary to "block" the data into groups of years, because of: (1) the small numbers of stations available for Qld (ie data points), and (2), the spasmodicity of wind erosion - which means that in some years there were few events recorded. Although the record goes back to 1960, data used here started at 1973, because in 1973 the Bureau of Meteorology introduced a new visibility criterion in the definition of a dust storm. After 1973 the max visibility limit

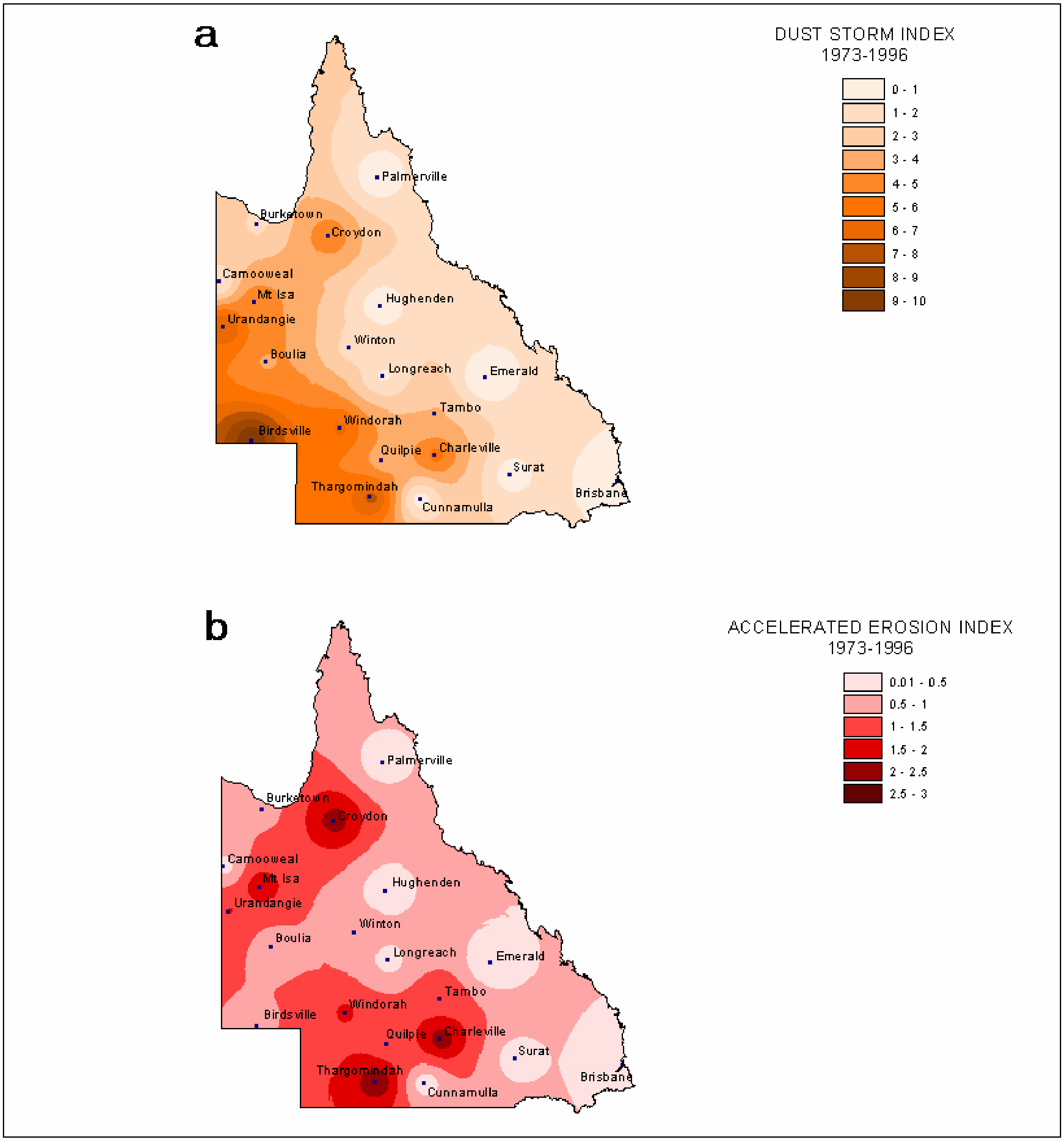

Figure 4. (a) Spatial pattern of wind erosion as represented by the Dust Storm Index (DSI) in Queensland. (b) Map of the Accelerated Erosion Index (AEI)

of a dust storm is 1,000m but prior to 1973 it was less well defined as "considerably reduced". The other time blocks were chosen as they represent periods during which dust storm activity was relatively consistent. Eg, 1974-78 low DSI, 79 - 85 moderate DSI and 86-96 high but variable DSI.

In 1974-1978 there were only five stations (in the southwest and northwest regions) with AEI values above 1, but four of these had very high values. In the latter two periods, while very high values were less common, there were larger numbers of stations in the southwest and northwest with AEI values above 1, which had the effect of extending the areas covered by these two regions. Although AEI values averaged over 1973-1996 are low, initial indications from the central western region are that, they increasing through time, which could possibly indicate an emerging accelerated erosion problem. Lack of temporal

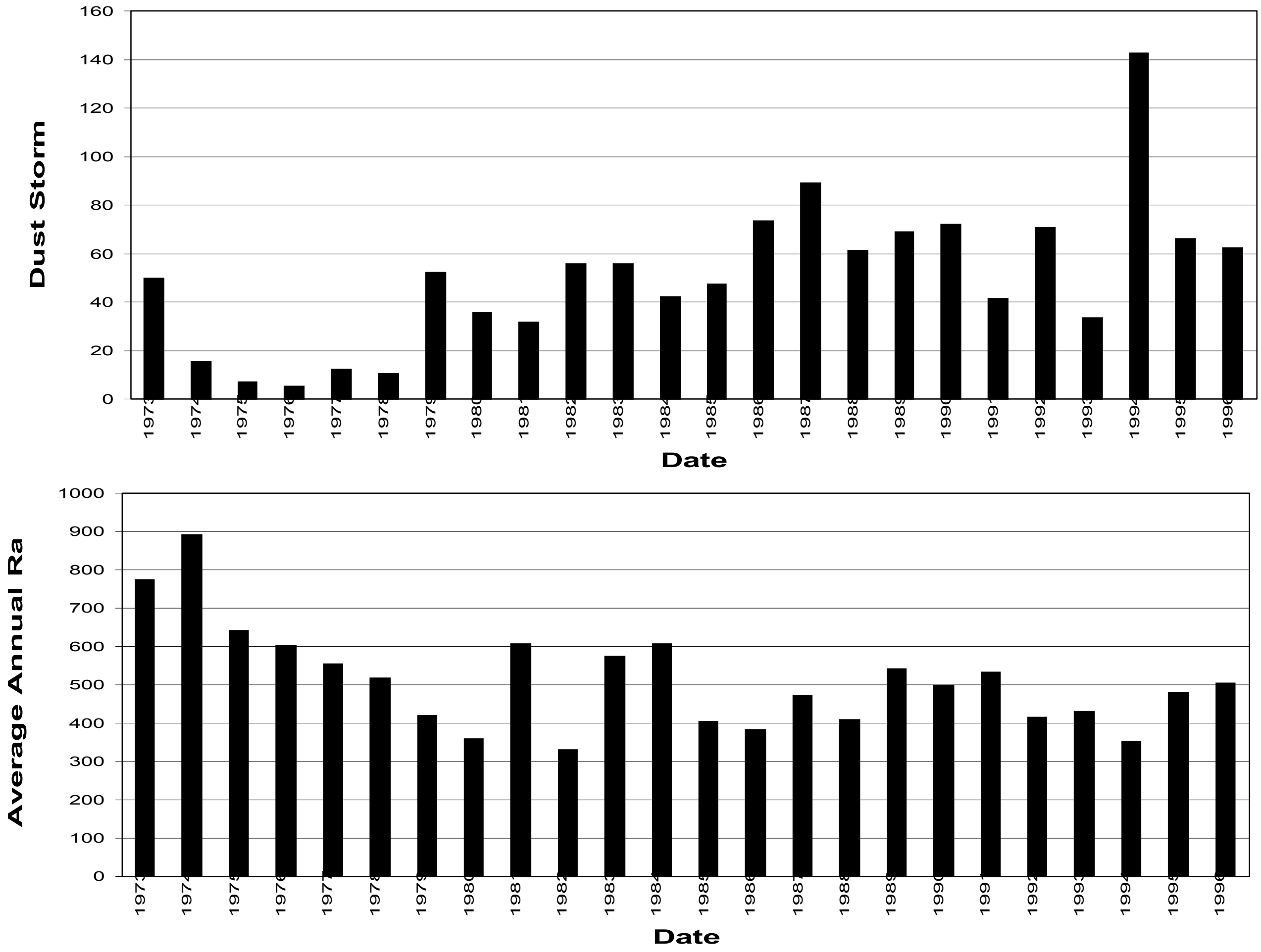

Figure 5. Temporal trends in Dust Storm Index (DSI) between 1973 and 1996 and average annual rainfall for all sites

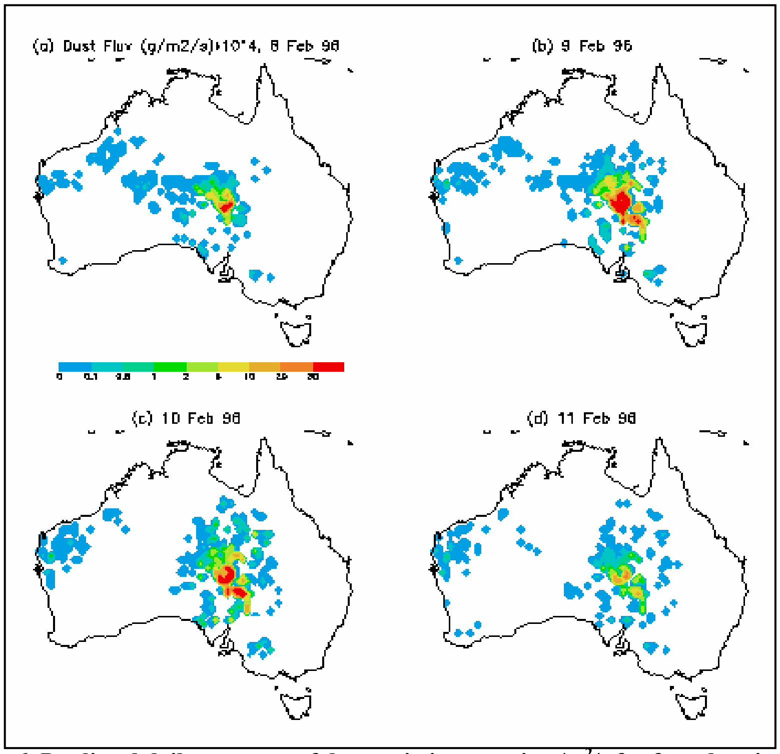

Figure 6. Predicted daily averages of dust emission rate, in g/m^2/s for four days in February 1996

data on changes in wind conditions, soil erodibility, and land use activities prevent differentiating their effects upon AEI.

In summary, this approach to differentiating natural and accelerated wind erosion has considerable potential for environmental audits; however, there remain significant measurement and modeling obstacles to be overcome. The main deficiency of the wind erosion rate measure (DSI) is the low spatial resolution of the data (20 stations for Queensland). Not only will this be a difficult obstacle to overcome; the trend towards automation of weather observations may introduce a new obstacle. The main deficiencies of the modeling are the absence of wind erosivity and soil erodibility parameters in the *Em* model. Use of the more advanced *Ew* or *Et* models of McTainsh and colleagues (McTainsh et al., 1990; McTainsh et al., 1998) will remove the wind erosivity deficiency; however, adding a soil erodibility parameter will require more model development.

Process modeling

The previous section looked at the occurrence of dust storms and partitioned them into "natural" and "accelerated". This type of modeling concentrates on the transport phase of the wind erosion process (dust storms and hazes) but lacks the ability to identify source areas and deal with horizontal and vertical sediment fluxes. To model wind erosion emissions at large spatial scales over a range of time scales (hours to weeks) requires a process-based modeling approach.

To gain quantitative estimates of wind erosion, as represented by the horizontal and vertical sediment flux, an integrated modeling system that takes into account the atmospheric conditions (wind speed, rainfall and temperature), soil conditions (soil texture and soil water) and surface vegetation has been applied in Australia. The basic underlying premise for the modeling is – that it be physically based where possible, use inputs that are readily obtainable and output the results in a graphic form.

The integrated modeling system discussed here, has been developed at University of New South Wales (Shao et al., 1996; Shao and Leslie, 1997) and couples an atmospheric prediction model, a wind erosion model, a dust transport model and dust deposition model, supported by a GIS database. This system has the capacity to model wind erosion on a continental and regional scale with a very high spatial resolution, down to 5 km, and model the processes of dust emission, transport, and deposition. The system has been implemented to the Australian continent (7.6 million km^2) with 50 km resolution (Fig. 6) and the Murray-Darling Basin (10.6 million km^2) (Fig. 7) with 5 km resolution. The location of the Murray-Darling Basin is shown in Fig. 1.

The structure of the integrated wind erosion modeling system is outlined in Shao and Leys (1997). Wind erosion events over large spatial scales can be predicted, using GIS data to infer parameters which vary primarily in space, and using atmospheric forcing data obtained from an atmospheric prediction model, which vary both in space and time. The basics of the wind erosion model have been described in Shao et al. (1997); however, the dust emission model has recently been redeveloped and is described in Lu and Shao (1999). Shao and colleagues are preparing new deposition models (both dry and wet deposition) for publication.

An example of the system application is the simulation of several wind erosion events in Australia during early February 1996. A full description of the model's performance at the continental and catchment basin scale is given in Shao and Leslie (1996) and is briefly described here. During summer 1996, frequent wind erosion activities were observed in Australia. In this paper, we present the results of the wind erosion assessment and prediction system as applied to the February 1996 period over the Australian continent at a 50 × 50 km resolution and over the Murray-Darling Basin at a 5 × 5 km resolution.

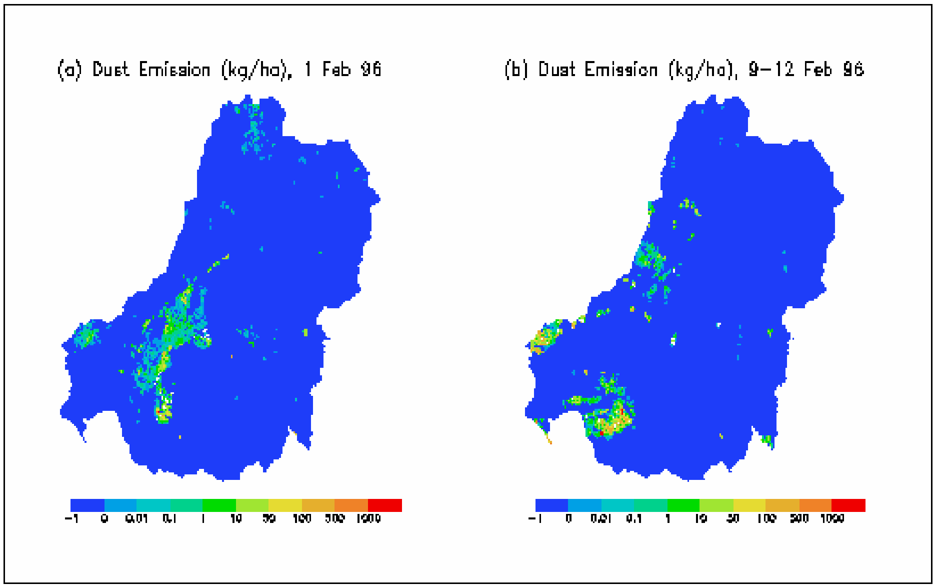

Figure 7. Total dust emission for the 1 February 1996 wind erosion event and the 8-11 February 1996 wind erosion events in the Murray Darling Basin. (After Shao and Leys 1997)

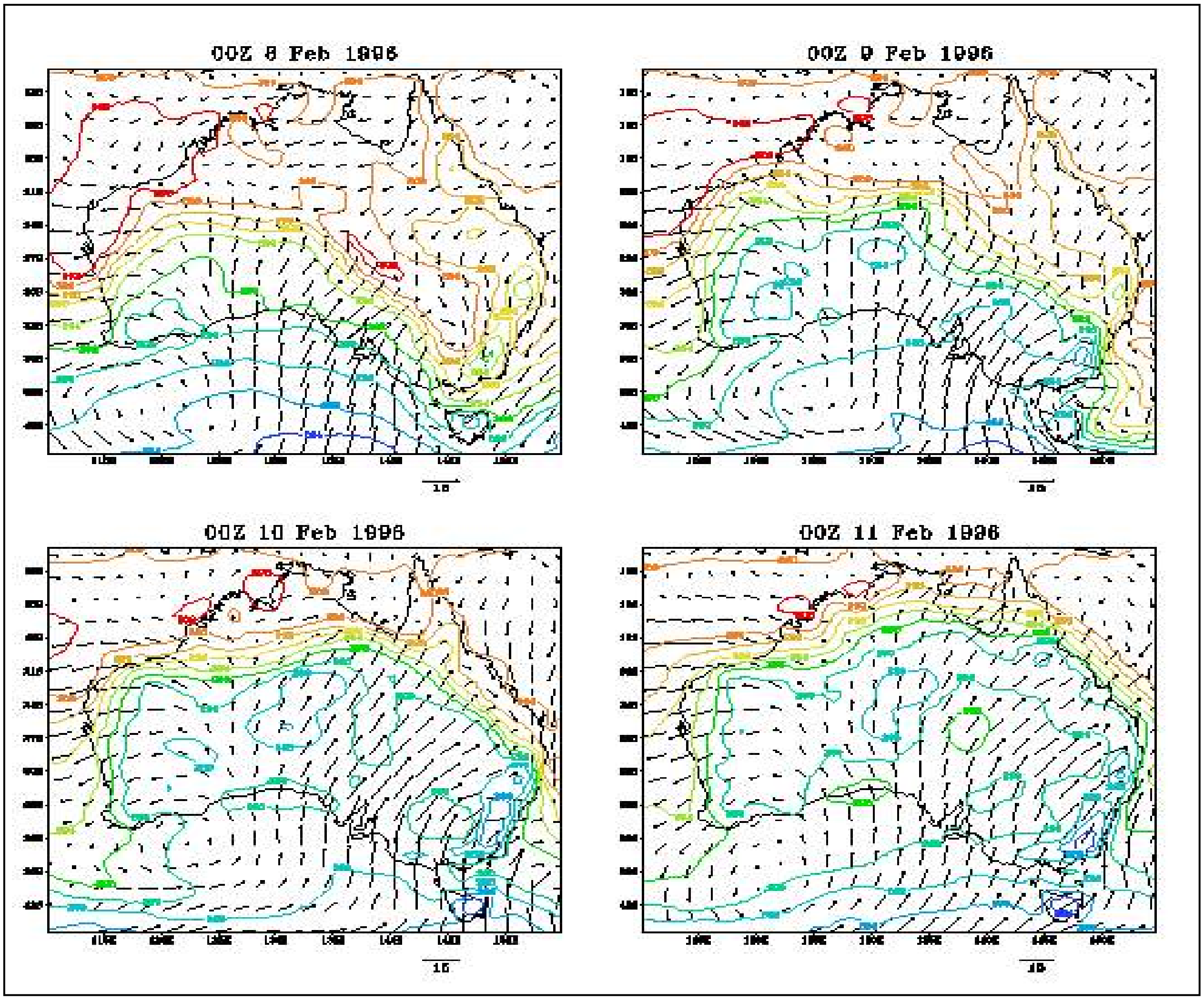

Figure 8. HIRES numerical predictions of surface winds associated with the cold front for the 8-11 February 1996 wind erosion event. The location of the frontal system can be easily identified by the spacing of the isotherms and length of the arrows which indicate wind direction and strength

Table 1. Summary of land surface information used in wind erosion prediction system.

Parameter Name	Treatment
Aerodynamic roughness length	Constant for bare soil Derived from vegetation height and LAI for vegetated surfaces (Raupach, 1994)
Zero-displacement height	Zero for bare soil Derived from vegetation height and LAI for vegetated surfaces (McVicar et al., 1996)
Leaf Area index	Derived from satellite NDVI data
Vegetation height	Adapted from the Atlas of Australian Resources
Soil particle-size distribution	Particle-size analysis from selected soils samples
Soil Moisture	Integrated soil moisture model

The particular weather pattern that produced the duststorms in February 1996, was a deep low-pressure system, which crossed the Southern Ocean to the south of Australia and the associated cold front that crossed the southeastern part of the Australian continent. The atmospheric data used in the simulation were obtained from HIRES, a HIgh RESolution limited area atmospheric prediction model developed primarily by Leslie (1998). The friction velocity u_* can be estimated from the atmospheric model predictions of surface wind speed U at a specified reference height U_z, using the Monin-Obukhov similarity theory. The numerical predictions of surface wind speed and near surface air temperature field, using HIRES, are shown in Fig. 8. The location of the frontal system can be easily identified by the spacing of the isotherms and length of the arrows, which indicate wind direction and strength.

Data Requirements

Land Surface Information: A GIS database is used in estimating the erodibility of the land surface as represented by the threshold friction velocity u_{*t}. The land surface information required for the model is summarized in Table 1. Most importantly, information for vegetation height and leaf area index (LAI) is required. For the simulation period, LAI is based on NDVI (Normalized Difference Vegetation Index) data, derived from AVHRR (Advanced Very High Radiometric Resolution) satellite records (McVicar et al., 1996).

Soil Texture: Soil texture is specified using the particle-size distribution density function. Soil types across the continent are divided into 28 soil classes. The present work uses a preliminary version of particle-size database that is being currently expanded. The particle-size distributions are considered unchanged during the erosion event in the present study.

Surface Crust: Surface crusting is subjectively estimated from a general description of soil types given in the Atlas of Australian Resources, Volume 1 (1980) and remains unchanged during the simulation period. Random roughness and changes in aggregation and soil compactness are ignored at this stage.

Soil Moisture: Soil moisture has a significant impact on wind erosion. Soil moisture changes over time scales of hours and as such is modeled accordingly (Shao et al., 1997).

Continental Scale Wind Erosion Pattern

The predicted daily averages of dust emission rate are shown in Fig. 6 for four different days. The pattern of stream-wise sand drift is similar but is not shown. For 8 February 1996, the system predicted strong wind erosion in the Simpson Desert (central Australia) and scattered weak erosion activities in the western and southern adjacent areas. The areas affected by erosion are in good coincidence with that under the influence of the cold front. By 9 Feb 1996, the intensity and extensiveness of wind erosion activities have increased over the Australian continent, especially in the Simpson Desert and surrounded areas, as near surface winds in these regions increased. By 10 February, while erosion remained severe in central Australia and extended further toward north-east and was reduced in the western parts of Australia. By 11 February, as the frontal system moved further east, the wind speed decreased over the continent and erosion levels were significantly weaker. The system predictions correlate well with GMS visible light picture and near infrared satellite images (Shao and Leslie, 1997).

The system was also applied to the Murray-Darling Basin with an increased spatial resolution from 50 × 50 km to 5 × 5 km, for the first half of February 1996 (Fig. 7). The system predicted wind erosion in two different inland areas of the Murray-Darling Basin at 1 Feb 1996 and during 9-12 February 1996. These predictions are in good agreement with the observations documented in the Monthly Weather Review published by the Australian Bureau of Meteorology.

While for some areas the total dust emission rate was small (less than 1 g/m^2), areas in the Simpson Desert were as high as 1000 g m^{-2}. The system calculated that over the week period from 6 to 12 February 1996, the total dust emission from the Australian continent was around 6 million tonnes and the total dust emission from the Murray-Darling Basin was around 1 million tonnes.

Limitations: There are fundamental challenges for wind erosion modeling. Firstly, wind erosion is sensitive to a multitude of land surface parameters. Not all these parameters are dealt with in the integrated wind erosion modeling system, such as the surface crust. In our model, leaf area index is estimated from satellite NDVI (Normalized Differential Vegetation Index). Frontal Area Index is then produced from NDVI using empirical relationships. For reasonably dense vegetated areas, the surface roughness length can be estimated from the configuration of vegetation, especially the vegetation height and the leaf area index. For areas without vegetation, there is a reasonable understanding of the roughness of bare soils. For areas with sparse vegetation, additional treatment is required by considering both the above situations. In reality, surfaces are often composed of standing roughness elements, flat surface covers, tillage ridges, and various levels of random roughness elements. For such complex surfaces, the concept of frontal area index may be too simplistic. Despite all this, the simulation results we obtained so far are very encouraging; the model reproduced wind erosion events in the right locations and right timing. It is not yet possible to validate the exact amount of dust entrainment as predicted by the model.

Advantages: The system accounts for, as much as possible, the physical processes and environmental factors that control wind erosion. It represents a major step forward toward quantitative assessment and prediction of wind erosion. The reasonable success of the system indicates that wind erosion is not unpredictable. The system also provides predictions for the transport of dust particles and their deposition. The system can be used with very high spatial resolution, down to 1 km, thus providing a detailed wind erosion pattern over a large area, such as the Murray-Darling Basin.

Future Directions: The wind erosion model can be significantly improved in at least five areas.

1. The model can be further developed to take into account the temporal changes caused by wind erosion, such as the particle-size distribution and the change of surface roughness conditions;
2. The impact of surface roughness elements, including porous vegetation and soil aggregates can be better described;
3. The effect of surface crust and soil aggregates needs to be considered;
4. Better calibration of key model parameters; and
5. The data base required for integrated wind erosion modeling must be improved in consistency, completeness and resolution.

The resolution limitation for wind erosion modeling lies in that of the GIS database because wind erosion is sporadic in both space and time; therefore, high-resolution data is very important.

CONCLUSIONS

The measurement, monitoring and modeling of wind erosion is a difficult task due to the physically complex nature of wind erosion processes, the large spatial variability in erosion and the temporal nature of the process. Significant advances have been made in all three areas of measurement, monitoring and modeling of wind erosion in Australia in the last decade. The availability of a portable wind tunnel, high volume dust sampling systems, and low cost passive dust traps have all enhanced our ability to measure wind erosion. The availability meteorological records provide a regional scale record of dust activity and this can be used to monitor the intensity of wind erosion in a region. Similarly, the development of climatic and process-based wind erosion models provide tools for predicting and understanding the conditions under which wind erosion occurs at various scales in Australia.

The climate models have the advantages of – access to long-term databases that are nation-wide, relatively few data inputs are required to run the model, separation between natural and accelerated erosion is possible and temporal trends can be identified. The disadvantages are – low spatial resolution, changes in the measurement criteria used to observe meteorological phenomena, and the lack of erodibility factor in the current models. The model's advantages have resulted in it being currently used for State of the Environment Reporting for Queensland and in a modified form for South Australia.

The process-based wind erosion prediction system has the advantage of – being physically based rather than empirical, being able to predict erosion at scales ranging from paddock to continent, including both wind erosivity and soil erodibility, using a relatively few data inputs compared to some models, being coupled to a geographic information system which allows the model to be run at short time steps, being able to use real-time and stochastic weather data. The disadvantages are – uncertainty in application of the frontal area index to all surfaces, resolution obtainable in the GIS and the non-inclusion of all the factors that are known to effect wind erosion. Despite this, the system correctly predicted the wind erosion events when used at continental scale in February 1996.

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