Caring for our Country

Wind erosion extent and severity maps for Australia

Final report

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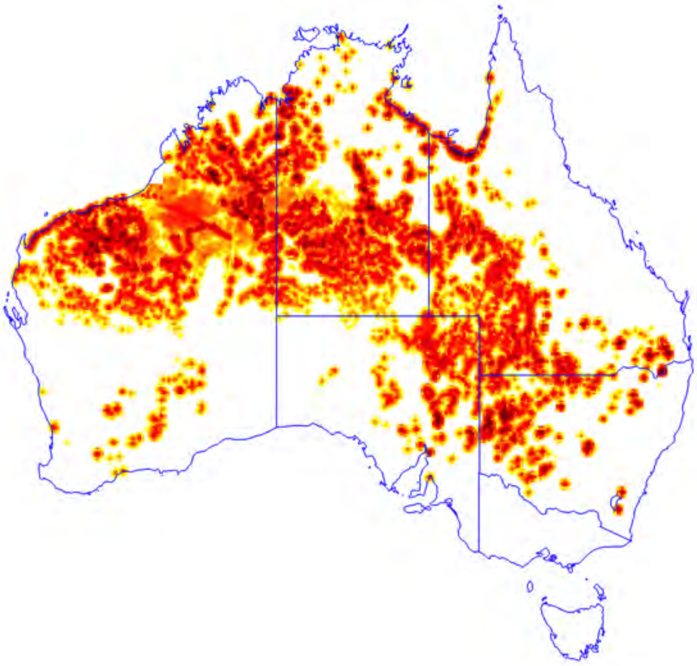

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Executive Summary

The Wind Erosion Extent and Severity Maps (WEESMAP) project for Australia has been completed. As a result of the project significant improvements were made to both the soil and vegetation input data. These improvements include:

- A new dynamic erodibility mask was created for the model, based on Fractional Cover Index (FCI) of Guerschman et al. (2009).
- Increasing the soil descriptions available from 12 to 29 soils.
- Replacing LAI GIS layer with the MODIS LAI layer, which no longer uses emperical relationships developed for AVHRR NDVI product.
- The model was extend to a 10 km resolution for the whole of the continent.

Statistical comparison of the CEMSYS model before (Version 5) and after the soil/vegatation improvements (Version 6) shows that the model over estimated daily dust concentrations at 26 of the DustWatch nodes in 2009 by approximately 3 fold for V5 and underestimated it by 0.6 for V6. The mean error between modelled and observed dust levels was reduced for V6 (0.0227 to 0.0084). Finally V6 explained twice the level of variability in the observed data compared to V5 (0.2292 to 0.3956). Given the result was comparing 26 stations over 365 days, V6 appears extremely robust over the yearly period.

In addition, the time series of available data was extended significantly. At the end of the project data the following data is available:

- Version 5 50 km data is available for February 2000–June 2012 [1]
- Version 6 50 km data is available from March 2000–June 2012 [1] .
- Version 5 10 km data is available for NSW/Victoria from February 2000–June 2012 [1] .
- Version 6 10 km data is available nationally for 2002, 2008, and 2009 [1] .

Finally several other coding improvements were made to the model to increase performance. Consequently, it is now possible to produce 50 km and 10 km maps within 10 days of the external MODIS and Atmospheric data becoming available. This means it is now possible to use the CEMSYS in monthly reporting products.

[1] July–December 2012 will be available by the end of June.

1 Introduction

The Wind Erosion Extent and Severity Maps for Australia (WEESMAP) project increased the certainty and utility of modelled wind erosion maps by improving: a) the model input data; and b) increasing the model resolution. Numerical modelling of wind erosion at the national scale offers the capacity to monitor the extent, severity and determine trends in wind erosion. The CEMSYS wind erosion and dust transport model was used to produce national maps, which identified where Caring for Our Country (CfoC) investment in land management practices would reduce wind erosion and provide the largest environmental benefits.

The project enabled the CEMSYS model to be run nationally at 10 km resolution compared to the current 50 km resolution, improve the reliability of the wind erosion estimates by using the MODIS fractional cover product and improving the representativeness of the soils data used in the CEMSYS model.

Prior to this project, CEMSYS used:

1. only five fully dispersed soil distributions[2] were available to characterise soil textures across the Australian continent;
2. where an appropriate soil distribution was not available for Australia, the closest available published soil distribution available world wide was used;
3. CEMSYS national modelled data (50 km resolution) was only available for two years;
4. CEMSYS modelled data was only available for NSW and Victoria at 10 km resolution for two years; and
5. data from the modelling was not available to the public or National Resource Management (NRMs). It was only available via contracted services.

The WEESMAP project looked at improving the reliability and representativeness of the CEMSYS modelled wind erosion products. This improvement was accomplished by:

1. improving the number of particle-size distributions of the soil textures available for use in the model;
2. updating the vegetation data used in the model;
3. developing a new dynamic erodibility mask;

[2] 12 soil distributions were available, but only five had fully dispersed profiles

4. extending the time-series of modelled data available for Australia and NSW/Victoria from two years to 12+ years; and

5. extending the 10 km resolution from New South Wales/Victoria to cover all of Australia.

Consequently, CEMSYS now uses:

1. 29 full, intermediate and minimally dispersed soil distributions to describe the variation in soil textures across Australia. This enabled CEMSYS to use the soil distribution which described the Australian soils in their most naturally dispersed state. Finally, as part of the inclusion of these soils in the CEMSYS some 29 soils were parametrised for use in the model.

2. Leaf Area Index (LAI) layer used in version 5 was derived from AVHRR NDVI using empirical relationships, this is replaced in version 6 by MODIS derived LAI products which no longer use these empirical relationships.

3. In version 5 of CEMSYS outlined by Butler et al. (2007) and Leys et al. (2009) a static erodible surface mask was used to mask out the non-erodible areas. The current version 6 of CEMSYS uses a dynamic non-erodible mask based on Guerschman et al. (2009) Fractional Cover Index (FCI) to better represent monthly changes in the erodible landscape.

4. The time-series of data available for the extent and severity of wind erosion was increased from 2 to 12+ years national at 50 km (i.e. 2000–present) and three years (2002, 2008 and 2009) is now available national at 10 km resolution. While NSW/Victoria is available at 10 km resolution from 2000–present).

5. In Version 5 the only 10 km extent and severity data available was for New South Wales and Victoria, the work in this project extends this resolution of data to the continent. Consequently, this resolution of data can be produced for each NRM region and State.

2 Summary of improvements in modelling wind erosion using CEMSYS

The following sections of the report outline the technical detail of the changes made to:

1. soil inputs required for the CEMSYS model;

2. how the vegetation/erodibility inputs have been updated;

3. improvements at 50 km resolution; and

4. how the 10 km resolution national maps are constructed.

Each of these improvement were separately applied and tested during the project. Details of each individual performance improves have been reported on in previous milestone reports for WEESMAP project, hence this report will only summarise the final improvement achieved by combining all improvements.

2.1 Soil improvements

A new GIS soil layer and Australian texture classification was developed to improve on the currently used geographical information system (GIS) soil layer in CEMSYS (v5) that is based on the AUSLIG (1980) soils map and derived textures based on the USDA soil textures. The new GIS soil map was based on the digital version of the Atlas of Australian Soils (Northcote et al., 1960-1968) from the Australian Soils Resource Information System (ASRIS) site. The resultant texture map is shown in Figure 1.

The map was created by using the estimated soil texture for the A horizon of each Principal Profile Form (PPF) from the work of McKenzie et al. (2000). There are 726 PPF descriptions for the digital Atlas of Australian Soils, these descriptions include the designation "NS" for those units without soil, e.g. lakes. There are also polygons in the map that do not have a PPF assigned to them and most commonly are associated with lakes. Many of the lakes that were mapped as having missing data are dry lakes and are known dust sources. Consequently, the missing data was sub-divided into two categories, namely missing/water or lake sediments. Only the major lakes in the Lake Eyre Basin (LEB) that do not have a continuous salt pan were classified "lake sediments". For these lakes a sample from Lake Callabonna in the LEB with loam texture was used to represent the texture of these non-salt encrusted lakes.

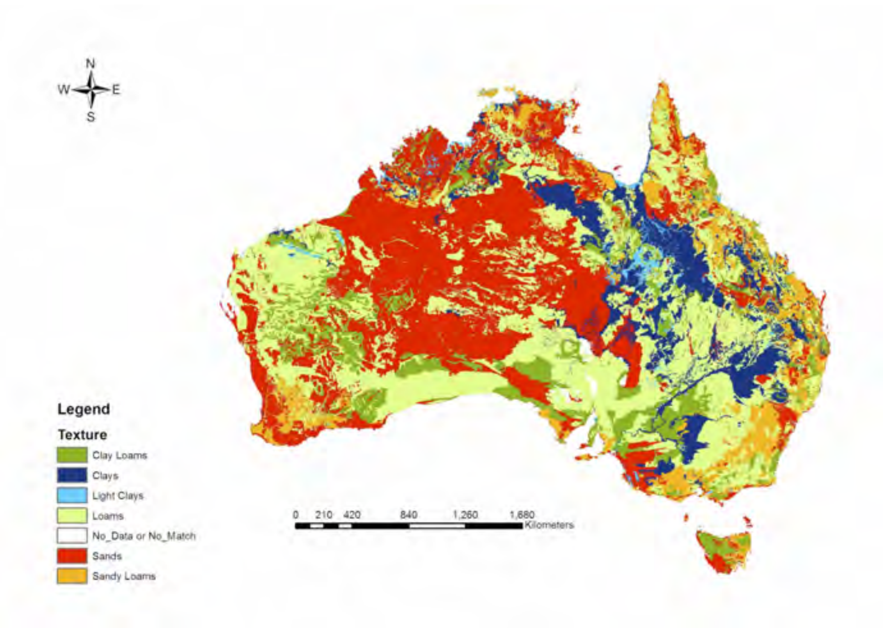


FIGURE 1: *Soil texture map of Australia. Source: AUSLIG (1980).*

For each soil texture a matching Particle-Size Distribution (PSD) is required. The PSDs to expand CEMSYS were derived from 29 sample soils denoted as the EASI soils. Each of the EASI soils was then assigned a soil texture based on a) the Australian soil texture triangle and b) the soil texture clay relationships developed by McDonald et al. (1990) as shown in Table 1. The EASI soils were originally chosen because they represented the most erodible soils in known wind erosion source areas. While they offer a good foundation, there is room for improvement as they have limited spatial representativeness (Figure 2). Each EASI soil has been classified according to its texture, using the soil properties shown in Table 1 and Australian soil texture triangle.

Table 1: *Soil texture classifications based on estimated clay content. Adapted from McDonald et al. (1990).*

Texture group	Texture	Clay Content %			Texture grade
Id.		Min.	Mean	Max	
1	Sands	0	5	8	Sand
					Clayey Sand
					Loamy Sand
2	Sandy Loams	8	15	20	Sandy Loam
					Fine Sandy Loam
					Light Sandy Loam
3	Loams	10	20	30	Loam
					Fine Sandy Loam
					Sandy Clay Loam
					Silt Loam
4	Clay Loams	20	30	40	Clay Loam
					Silty Clay Loam
					Fine Sandy Clay Loam
5	Light Clays	35	40	50	Sandy Clay
					Silty Clay
					Light Clay
					Light Medium Clay
6	Clays	45	55	100	Medium Clay
					Heavy Clay
7	Missing/Water				
8	Lake Sediments				

After discussion with ASRIS staff, to allow for the further characterisation of soil texture classes of different regions in Australia the physiographic regions of Australia (Jennings & Mabbutt, 1986) was used to further divide the country up into 21 provinces. The logic being that a sand in Western Australia wheat belt may have a different PSD than a sand in the Mallee due to the different geomorphic and pedogenic conditions that originally formed the soil. The original digital data (supplied by ASRIS) has 28 provinces, but provinces known to have little wind erosion, such as the east coast of Australia and the Top End, were amalgamated to form 21 wind erosion provinces, thus reducing the number of soils to be analysed.

Soil samples from each province are required to represent the texture classes in that province. ASRIS and NatSoil have an archive of soils with their locations shown in Figure 3. There are a total of 104 texture polygons in the 21 provinces. Of these polygons, 56 have samples in the NatSoil archive that could be analysed to increase the soil PSD data and hence improve the spatial representative-

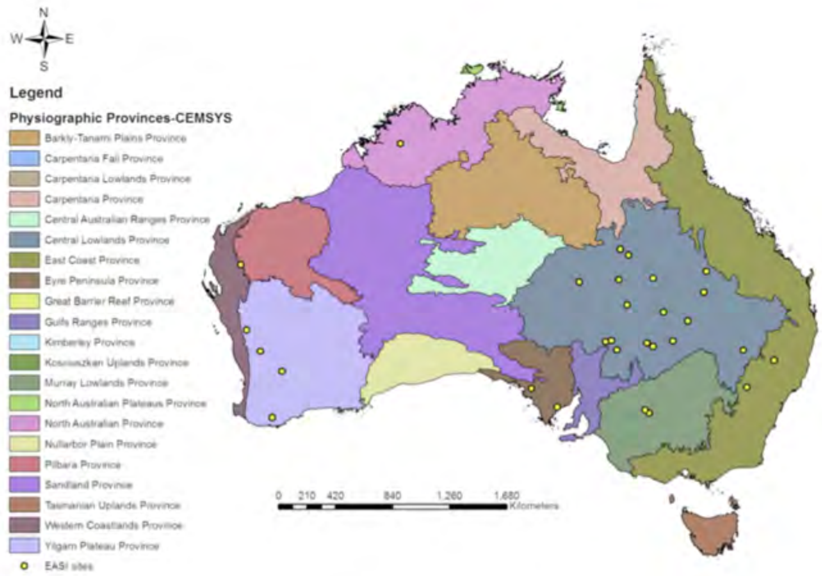


FIGURE 2: *Physiographic regions relative to EASI soil sample locations.*

ness of the soils in the CEMSYS model. While this is beyond the scope of the current project it is thought to be a critical component in improving the accuracy of the model. Consequently, samples have been obtained from the National Soil Archive and have been analysed. All that is need is for these 56 soils to be parametrised for inclusion in the model. This was not able to be accomplished within the current project. However, the available of the required analysis allows for the data to be incorporated into the model in the next major iteration of the model.

In addition to this during the reanalysis of the soils, additional information was obtained on the 1 to 10 μm soil fraction for each soil (i.e. clay fraction). This data is now available for incorporation into the model during a future iteration. However, as the clay based soils are subject to crusting and have significant binding energies, further research needs to undertaken on how to model these physical and biological processes in clay soils. With out incorporating these fundamental processes into the model, the inclusion of this information in the model is likely to significantly affect the reliability of the model. While this is clearly beyond the scope of the current project, having this data is crucial in further being able to base further model improvements around physical data.

For use in CEMSYS the particle-size distribution (full, intermediate and minimal dispersed PSDs) for a particular soil ($p(d)$) has to be expressed as a summation of several log-normal distributions (Gomes et al., 1990; Chatenet et al., 1996):

$$p(d) = \frac{1}{d} \sum_{j=1}^{n} \frac{w_j}{\sqrt{2\pi}\sigma_j} \exp\left(-\frac{(\ln d - \ln D_j)^2}{2\sigma_j^2}\right) \; ; \tag{1}$$

where n is number of modes, w_j is the weight for the j'th mode of the particle-size distribution, D_j and σ_j are parameters for the log-normal distribution of the j'th mode. The advantages of this

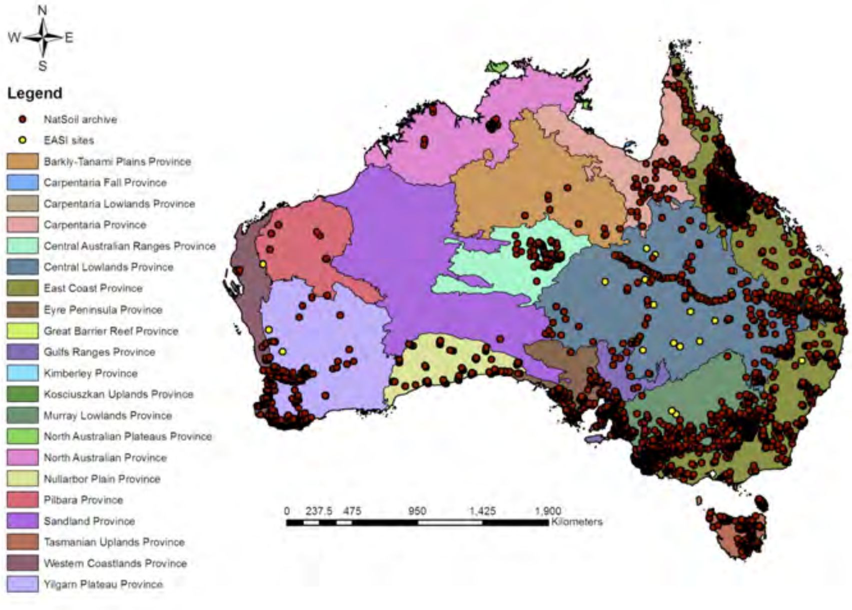


FIGURE 3: *NatSoil and EASI sites for each physiographic province.*

parametrised form is that the PSD can be specified using few parameters (12 max), and that the information for a particular soil type can be applied to similar soil types.

A non-linear least square fitting technique is employed to determine the parameters w_j, $\ln(D_j)$, and σ_j from measured particle-size distributions. Numerical tests show that it is generally sufficient to use $1 \leq n \leq 4$. To capture the typical physical modes of each soil, the lower bound and upper bounds of σ are set equal to 0.05 and 1.5, respectively, for all samples. This filters out the false, non-physical modes, which have very small or very large variance. The optimisation problem has many localised minimums and the global minimum (absolute minimum of squared error between fitted and observed particle-size distributions) is difficult to find. Hence, the several million initial values of the parameters are tried (i.e. a Monte Carlo search is used) until the smallest "acceptable" value of optimisation function (Eqn. 2) is found.

$$f_{\text{opt}} = \frac{1}{m} \sum_{k=1}^{m} \left[d_k \left(p_{\text{fit}}(d_k) - p_{\text{obs}}(d_k) \right) \right]^2 \tag{2}$$

The parametrised fit is "accepted" if the value of the optimisation function (f_{opt}) is below a critical value (current 0.01 for the EASI soils). In addition, the fitting techniques uses half the measured PSD points to create the initial fit, while the remaining points are used to test the fit (Figure 4). The PSDs parametrised in this project were derived from 29 soils denoted as the East Australian Soil Inventory (EASI) soils. The EASI soils were originally chosen because they represented the most erodible soils in known wind erosion source areas. For each EASI soil the minimally, intermediate and fully dispersed soil PSDs were parametrised using the process outlined above. The results of the parametrisation process is shown in Tables 2, 3, and 4.

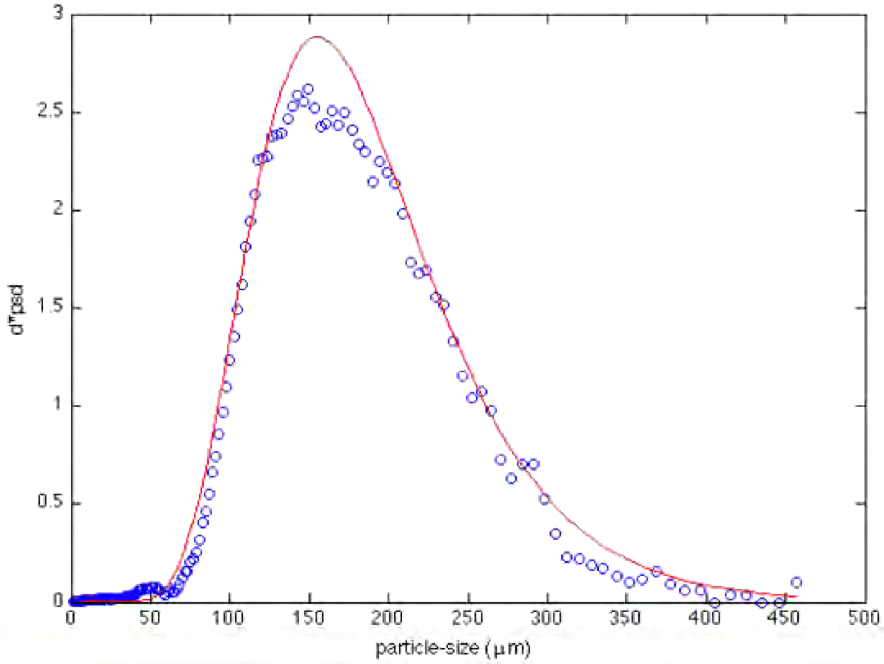


FIGURE 4: *Particle-size analysis (blue dots) and particle-size density function (red line) of the sand sample from the Simpson Desert using the fitting methodology outlined.*

2.2 Vegetation improvements

CEMSYS v5 uses a non-erodibility mask (Figure 5) to identify areas not subject to wind erosion, based on vegetation, soil and aridity. Conversely, this layer identifies areas of Australia subject to wind erosion. The current mask is static and does not account for factors such as vegetation response to rainfall and downstream flooding etc. The need to account for these factors is illustrated by considering the affect that the January 2009 northern wet season had on vegetation cover in the lower Channel Country of western Queensland (CCWQ) and the northern Lake Eyre Basin (LEB). Figure 6a illustrates that based on fractional cover measurements of bare soil during January 2009 much of the CCWQ had significant vegetation cover (i.e. small % of bare soil), as a result of flooding along the Diamantina, Georgina Rivers and Cooper Creek. This flooding was the result of rainfall in northern part of the catchment e.g. Mt. Isa January 2009 total rainfall was 535.2 mm (Australian Bureau of Meteorology , 2012*b*), compared to Birdsville January 2009 monthly total of 67.2 mm (Australian Bureau of Meteorology , 2012*a*). These floods effectively shut-down the majority of the Channel Country as a dust source during January 2009. However, the current version of CEMSYS predicted moderate erosion throughout the CCWQ during January 2009 (Figure 7) due to the static nature of the non-erodibility mask used in CEMSYS v5. Fractional cover measurements for 2009 show that there was a significant change in bare soil in northern Australia from January–December

Table 2: *Estimated PSD fitting parameters for the EASI soils under minimal dispersion.*

Soil	Parameters												f_{opt}
	w_j	$\sigma_{\ln,j}$	$\ln D_j$	w_j	$\sigma_{\ln,j}$	$\ln D_j$	w_j	$\sigma_{\ln,j}$	$\ln D_j$	w_j	$\sigma_{\ln,j}$	$\ln D_j$	
Charleville	0.4998	0.2722	5.3035	0.3247	0.4655	4.0426	1.8939	0.9756	5.5418	0.0548	0.1423	5.5536	0.0045
Betoota	0.3619	0.2157	4.2162	1.6073	0.5981	4.594	0.3584	1.0122	3.8655				0.0007
Wanaaring	0.1573	1.2169	3.6457	0.4493	0.356	5.4142	0.5307	0.3831	4.4477	1.5771	0.3319	6.0859	0.0018
Tibooburra	0.1237	0.8005	3.5479	0.7024	1.0847	6.1872	0.9069	0.4442	4.4622	0.9127	0.3588	5.1432	0.0017
Walgett	0.4683	0.2505	5.6977	0.4519	0.5382	4.2432	1.124	0.3286	5.0988	0.3029	0.1616	5.3717	0.0019
Arrabury	0.1938	0.2705	4.3368	0.0505	0.8977	3.313	1.4437	0.6681	6.0208	1.1182	0.3338	6.158	0.0027
Kimberley	0.1305	0.2384	4.462	0.9224	0.2387	5.756	0.4952	0.4829	5.2402	0.9314	0.7307	4.5026	0.0039
Manilla	1.4806	0.3242	6.2562	0.1432	0.1057	6.5528	0.0022	2.1256	1.4268	1.1176	0.6036	5.6255	0.0027
Simpson Desert	2.3545	0.3521	5.0452	0.0057	0.5598	0.4451	0.0216	0.1387	3.7912				0.0038
Wellington	0.8783	0.3738	6.4454	1.6734	0.8126	5.7598	0.2016	0.1416	6.8257				0.0025
Tapio	1.3628	0.4297	5.904	0.7442	0.5412	5.3045	0.5479	0.9693	5.2753				0.0014
Mallee Cliffs	0.3409	0.9685	5.2696	1.0525	0.5324	5.9036	1.3427	0.3663	6.4135				0.0049
Tambo	0.5752	0.2985	6.4388	0.3393	0.3856	4.6796	1.514	0.4195	5.8336	0.232	0.12	6.0533	0.0027
Windorah	0.2314	2.057	4.8852	0.3949	0.5194	3.9947	1.0435	0.396	4.61	0.6338	0.224	4.8997	0.0011
Eulo	0.5817	0.3546	6.3459	1.7423	0.6486	5.6691	0.3593	0.3284	4.2323				0.0028
Strez reserve dune	1.102	0.3682	4.748	0.9617	0.2576	5.1852	0.5171	3.1604	5.6268				0.0007
Yandama	1.2567	0.3751	4.7986	0.8107	0.3047	5.2549	0.4482	1.255	5.1246				0.0006
Mt Priscilla	0.8263	0.4643	5.5739	0.0829	1.2633	5.0867	1.7118	0.3495	6.1967	0.1031	0.0824	6.6159	0.0024
Streaky Bay	1.7926	0.5372	5.4776	0.5888	0.32	6.3241	0.3741	1.6685	5.4007				0.0032
Springvale	1.1239	0.47	5.0261	0.1061	0.8475	1.507	0.399	0.3175	4.1781	0.777	0.9337	3.9243	0.0012
Bullo Overflow	2.2692	0.7248	5.1591	0.1736	0.1872	4.2633							0.0018
Thargomindah	0.3124	0.1717	4.1426	0.9564	1.1775	3.9501	1.034	0.434	4.3088				0.0012
Lake Callabona	0.1565	0.2255	4.7421	1.4882	0.7039	4.7643	0.7647	0.2724	5.2632				0.0012
Gascoyne	1.1077	0.5587	5.7157	1.0001	0.4203	6.6796	1.0631	1.4419	5.9894				0.0063
Merridin	0.816	0.7524	6.1037	1.1117	0.2142	6.8143	1.003	0.3082	6.4213				0.0028
Lake Moore	0.6807	0.2245	6.5881	2.3205	0.7363	6.5468	0.2394	0.0957	6.8389				0.0017
Mullewa	1.9189	0.3666	6.2426	0.3598	0.1219	6.6773	0.5493	0.9373	5.5256				0.0084
Tenderden	0.0005	0.0725	1.3792	0.7031	0.2623	6.3759	0.1836	0.2668	4.5733	1.823	0.5235	5.6823	0.0031
Diamantina Lakes East Downs	0.2361	0.1803	6.2131	0.0354	0.6788	2.6919	0.8169	0.5767	4.3023	1.3845	0.3788	5.4061	0.0042

TABLE 3: *Estimated PSD fitting parameters for the EASI soils under intermediate dispersion.*

Soil	Parameters												f_{opt}
	w_j	$\sigma_{\ln,j}$	$\ln D_j$	w_j	$\sigma_{\ln,j}$	$\ln D_j$	w_j	$\sigma_{\ln,j}$	$\ln D_j$	w_j	$\sigma_{\ln,j}$	$\ln D_j$	
Charleville	0.1112	0.1994	5.3521	0.5299	1.3354	4.1136	0.3973	0.3232	3.8939	1.4185	0.6575	5.3073	0.0012
Betoota	0.3619	0.2157	4.2162	1.6073	0.5981	4.594	0.3584	1.0122	3.8655				0.0007
Wanaaring	0.4908	0.2949	4.3625	2.0152	1.4599	5.5891	0.3902	0.2865	5.8661				0.0055
Tibooburra	0.131	0.7383	3.5406	0.7129	1.1236	6.4835	0.8048	0.4169	4.4096	1.074	0.3749	5.1238	0.0017
Walgett	1.4112	0.3554	5.1778	0.0785	0.0804	5.1997	0.9338	0.977	4.8459				0.0020
Arrabury	2.1113	0.4879	6.0279	0.0005	0.4903	1.0432	0.488	0.3638	4.4428	0.0587	2.3379	1.4951	0.0074
Kimberley	0.3564	0.2153	6.0441	1.142	0.2986	5.6358	0.9474	0.6248	4.679				0.0025
Manilla	0.0688	0.0364	6.5167	2.4915	0.9928	5.8974	0.5167	0.2141	6.1365				0.0077
Simpson Desert	0.1337	0.1626	3.9185	1.3682	0.2919	4.8156	0.2816	0.186	4.6696	0.1331	1.2909	4.4563	0.0005
Wellington	0.0177	0.01	6.4196	2.5177	1.0692	5.1619	0.1439	0.0155	6.4997				0.0089
Tapio	0.2136	0.3361	4.5378	0.5949	0.3141	5.2192	0.6826	0.5141	6.022	1.1536	1.065	4.8809	0.0077
Mallee Cliffs	1.2261	0.8586	5.5394	1.4333	0.3558	6.2506	0.0033	4.0746	0.4751	0.1261	0.2014	5.4315	0.0030
Tambo	0.0657	0.4016	4.105	0.0562	2.0018	8.0666	0.7857	0.2357	5.8311	1.779	0.6078	5.8923	
Windorah	0.4802	0.2121	4.5616	0.6283	0.7611	3.7659	0.7474	0.3432	4.2261				0.0003
Eulo	0.2707	0.2017	4.1455	1.5833	1.0021	4.8004	0.7077	0.4332	5.9697				0.0067
Strez reserve dune	0.311	0.1954	5.2718	1.0411	0.5129	4.628	0.723	0.2833	4.9806				0.0040
Yandama	0.2004	0.9164	3.9073	0.4805	0.6229	5.9602	0.0667	0.5933	4.6093	1.7968	0.401	4.8007	0.0022
Mt Priscilla	0.6986	0.2366	6.5203	1.0888	0.2819	6.0534	0.7763	0.3143	5.4394				0.0024
Streaky Bay	1.3954	1.2609	5.9134	0.8953	0.4217	5.4023	0.5854	0.2837	6.3305				0.0032
Springvale	0.1876	0.9433	6.8256	0.4747	0.905	3.4099	0.7589	0.4194	4.1471	1.0631	0.4211	5.0588	0.0019
Bullo Overflow	0.1346	0.231	5.131	1.8142	0.7487	5.1759	0.4157	0.3057	4.2979				0.0069
Thargomindah	0.646	0.2062	4.1651	0.4419	1.5247	2.1507	1.2982	0.7576	4.3769				0.0022
Lake Callabona	0.1766	2.0553	4.5389	0.6511	0.3753	4.7983	0.2473	0.184	5.2523	1.4343	0.8728	4.7611	0.0019
Gascoyne	NA												
Merridin	0.6703	0.6095	5.6953	0.2803	3.2385	5.9537	1.1288	0.2871	6.3076	0.8139	0.2093	6.6395	0.0082
Lake Moore	1.1624	0.2655	6.3904	1.1116	0.5858	5.7829	0.2227	1.0251	4.6987	0.0835	0.0218	6.6399	0.0068
Mullewa	0.3759	0.1505	6.6848	0.4643	0.2517	6.2724	1.7656	0.5184	5.921				0.0030
Tenderden	0.081	0.031	6.5563	0.2354	0.1305	6.3592	0.5898	0.654	5.1131	1.7468	0.5292	6.1318	0.0063
Diamantina Lakes East Downs	NA												

TABLE 4: *Estimated PSD fitting parameters for the EASI soils for fully dispersed samples.*

Soil	Parameters												f_{opt}
	w_j	$\sigma_{\ln,j}$	$\ln D_j$	w_j	$\sigma_{\ln,j}$	$\ln D_j$	w_j	$\sigma_{\ln,j}$	$\ln D_j$	w_j	$\sigma_{\ln,j}$	$\ln D_j$	
Charleville	0.2221	0.0954	6.2787	1.4617	0.5157	5.2369	0.4629	0.4898	4.0449	0.4556	0.2454	5.6095	0.0079
Betoota	0.4013	0.2073	4.1305	0.6098	0.7899	2.6714	1.3607	0.7899	4.4492				0.0025
Wanaaring	0.5459	0.2337	5.8428	0.4633	0.2988	4.2632	0.1306	0.3299	2.9827	1.3113	0.7287	5.4227	0.0070
Tibooburra	0.2117	1.1932	1.7234	0.3443	1.274	8.0848	2.0313	0.5797	4.6291	0.1452	0.1711	4.8096	0.0024
Walgett	0.817	0.9709	1.901	0.2096	0.3213	2.9914	0.2742	0.3826	3.72	1.1324	1.2655	1.6994	0.0007
Arrabury	0.0033	0.6982	2.2503	0.7804	0.3726	4.609	1.6438	0.3569	5.6295				0.0062
Kimberley	0.9294	0.8053	4.7368	0.3033	0.3655	4.5538	0.6136	0.2358	5.4598	0.5894	0.1821	5.7653	0.0024
Manilla	0.2732	0.4444	3.5449	1.9923	1.4272	3.0677	0.0205	0.042	4.4664				0.0012
Simpson Desert	0.0302	2.0135	0.751	0.6779	0.3021	4.9407	1.112	0.244	4.7287	0.1012	0.172	3.914	0.0006
Wellington	0.4774	0.4199	3.0083	1.7785	1.0989	2.2264	0.0065	0.3256	1.7957	0.0188	0.256	0.4946	0.0028
Tapio	0.2566	1.449	2.2046	0.72	0.8731	4.3412	0.7041	0.3351	4.9161	0.6956	0.2646	5.4545	0.0018
Mallee Cliffs	0.5181	0.6924	5.5505	1.1743	0.3393	6.1641	1.0036	0.2591	6.5216				0.0030
Tambo	0.1988	0.1199	6.6302	0.1242	1.2121	3.5777	0.678	0.8709	4.7522	1.7264	0.3346	6.0547	0.0020
Windorah	0.2303	0.3839	2.6613	0.7534	0.5447	3.5712	1.051	0.9647	1.4199	0.4262	4.0893	1.6501	0.0011
Eulo	1.9867	1.2296	4.4263	0.5401	0.238	4.0552							0.0042
Strez reserve dune	0.3966	7.5643	1.6232	1.5861	0.3564	4.8395	0.126	0.2805	4.1168	0.5522	0.2125	5.167	0.0005
Yandama	0.125	0.176	4.385	1.4788	0.4592	4.8782	1.168	1.9672	5.5274				0.0015
Mt Priscilla	1.063	0.3283	6.2834	1.5225	0.4569	5.5562	0.0021	1.9866	1.5358	0.1074	0.876	4.2946	0.0040
Streaky Bay	1.0617	0.4925	5.9858	0.6505	0.3327	5.1906	1.0727	1.6261	5.023				0.0067
Springvale	0.0803	1.1159	0.8957	0.7712	1.3369	3.0003	0.3481	0.257	4.1298	1.2105	0.4382	4.9671	0.0009
Bullo Overflow	0.1654	1.1137	6.9542	0.347	0.2874	4.1829	0.2353	0.9927	2.1019	1.8008	0.6024	5.221	0.0035
Thargomindah	1.1285	0.4296	4.2288	0.7275	1.2898	3.8558	0.2438	0.1379	4.1222				0.0017
Lake Callabona	0.3641	0.5333	4.1234	1.7358	1.0279	2.1944	0.0893	0.3508	1.5834	0.1367	0.3755	1.0301	0.0018
Gascoyne	0.3032	0.4349	3.1655	1.6418	1.0182	2.6763	0.2404	0.2701	3.7557				0.0012
Merridin	1.7758	0.2992	6.6283	0.745	0.4934	5.8865	0.0044	0.6652	1.129	0.2644	0.6705	4.7102	0.0071
Lake Moore	0.7349	0.393	4.8172	1.3578	2.0502	3.8644	0.5476	0.4184	3.9999				0.0039
Mullewa	0.3163	0.4517	5.3287	0.4021	0.2242	5.6464	0.4519	0.1369	6.6131	1.526	0.3029	6.2201	0.0025
Tenderden	1.7694	0.5673	6.0279	0.1212	0.6402	4.7695	0.3519	0.2185	6.2716	0.5223	0.1651	6.5798	0.0030
Diamantina Lakes East Downs	0.3764	0.1795	5.2839	0.3364	0.1277	6.2974	0.5177	0.1732	5.6904	1.355	0.6832	4.778	0.0076

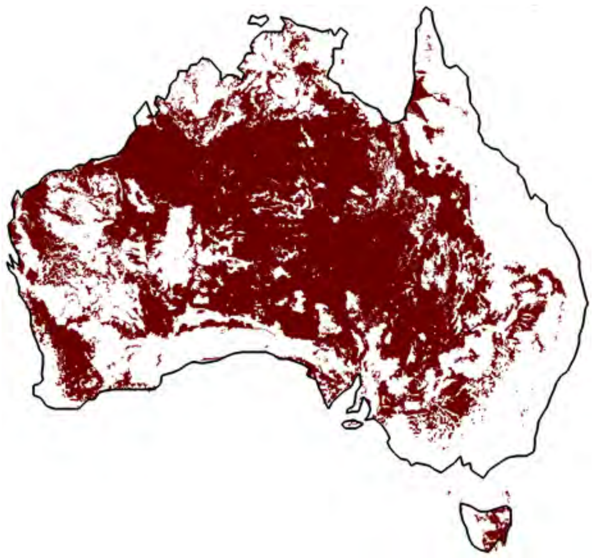


FIGURE 5: *Current static erodibility mask used in CEMSYS. Brown shading indicates the erodible area.*

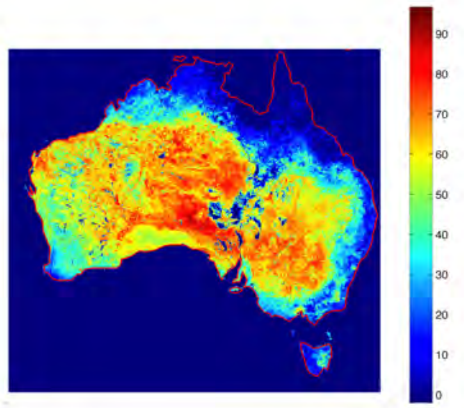
(Figure 6). Issues relating to CEMSYS v5 apparent over estimation of erodibility in Channel Country and Western NSW had been previously reported by Leys et al. (2009) and could be linked to issues relating to vegetation response to Northern wet season not being accurately accounted for in the current LAI/NDVI measurements that are used to predict soil cover.

To address this issue and produce a better estimate of wind erodible areas the Fractional Cover Index v2.1[3] (FCI) developed by Guerschman et al. (2009), was used to develop a dynamic non-erodibility mask for use in the CEMSYS model. Based on field work undertaken by Leys (1991), it was decided to mask as non-erodible areas which had less than 50% bare soil when averaged over the month. This represents the first step in replacing vegetation cover estimates in CEMSYS with the new fractional ground cover data now available from CSIRO. The next step will be to modify the emission algorithms in CEMSYS to replace LAI with fractional ground cover estimates.

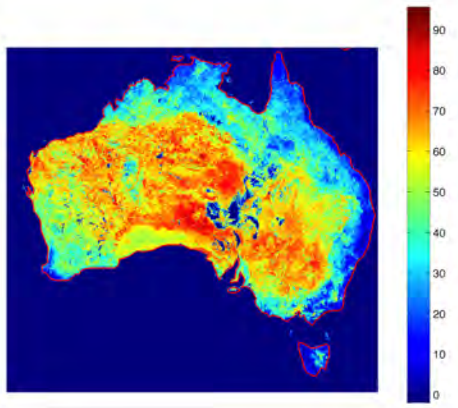
While it is possible to describe changes in the fractional cover levels at sub-monthly scale (i.e. 16 days), it was decided to continue use the monthly values of fractional cover as most studies of vegetation response to rainfall in arid/semi-arid regions indicate that it takes 1–4 months of accumulated rainfall to produce a significant increases in remote-sensed vegetation cover indices (Nightingale & Phinn, 2003; Schmidt & Karnieli, 2000). The other advantage of using monthly values of fractional cover is that it eliminates a significant amount of missing data due to cloud cover etc.

Figure 8 shows the affect of setting the erodibility mask using this new methodology. Comparing Figures 5 and 8a shows that a significant amount of Northern Australia is masked as non-erodible in January 2009 using FCI to remove non-erodible areas. The FCI mask also showed a significant increase in erodible areas in Northern Australian in September 2009 (Figure 8b), while the amount

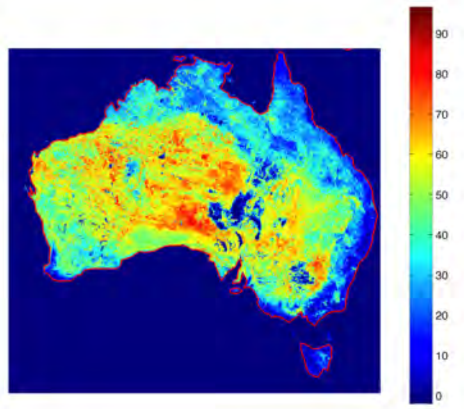
[3]Version 2.2 is used in the final production version 6 data



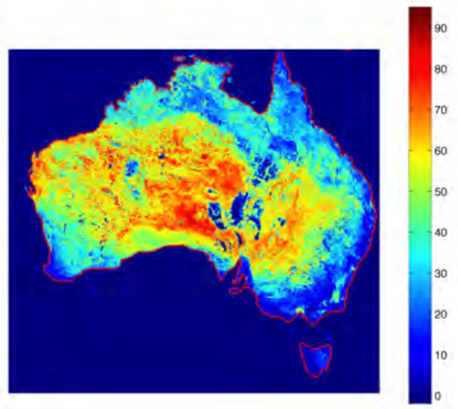
(a) January



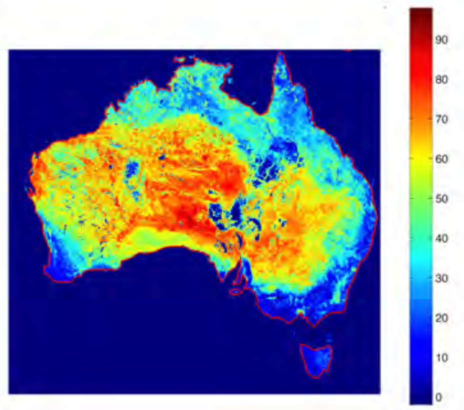
(b) March



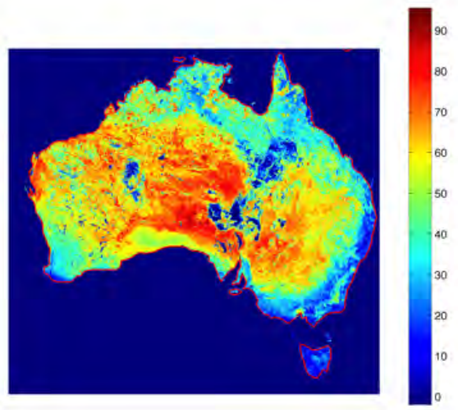
(c) May



(d) July



(e) September



(f) November

FIGURE 6: *Fractional cover variation in bare soil percentage during January, March, May, July, September and November 2009.*

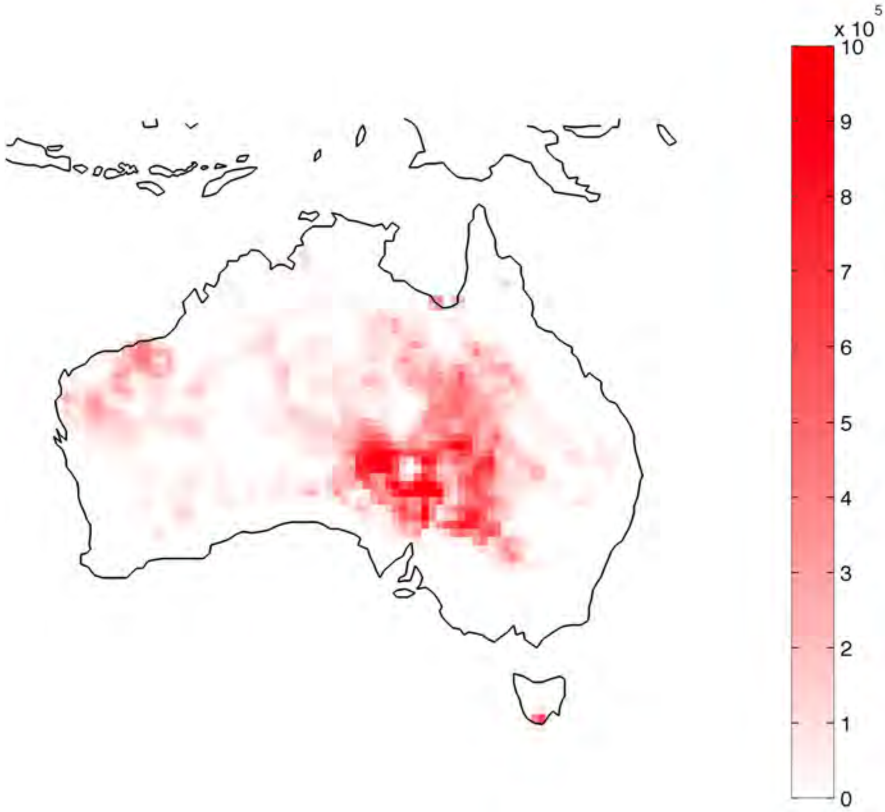
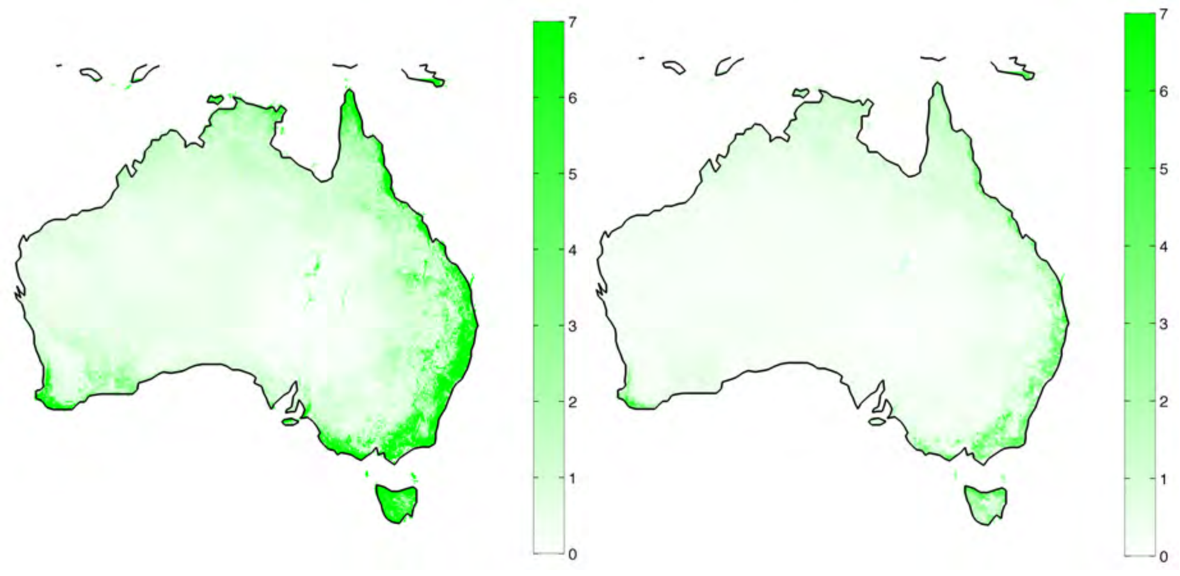


FIGURE 7: *CEMSYS v5 predicted average erosion (sand drift μg/m/s) January 2009*

(a) January non-erodible mask

(b) September non-erodible mask

FIGURE 8: *New dynamic non-erodible spatial masks. Red shading indicates erodible area based on* $\geq 50\,\%$ *bare soil.*



(a) Version 5 LAI May 2009 (b) MODIS LAI May 2009

FIGURE 9: *Comparison of a) Original LAI maps used in CEMSYS v5 and b) the current MODIS LAI product provided by CSIRO.*

erodible areas decreased in South western WA during the same period. This change is in line with the seasonality of rainfall in Australia. Modifying the non-erodibility mask in CEMSYS in a dynamic fashion allows for the erodible area to increase and decrease with climatic conditions.

As noted in the introduction, the LAI used in CEMSYS v5 is constructed from AVHRR and MODIS NDVI, and GIS vegetation data using empirical relationships outlined in Lu et al. (2001). However, the empirical relationships for doing this are dated, and needed to be reviewed. MODIS LAI data is now directly available from CSIRO. Replacing our current NDVI derived LAI layer directly with the MODIS LAI layer which is no longer based on the empirical relationships (Chappell, 2012, pers. comm.) the model. A subjective comparison of the two layers (Figure 9) shows that the v5 LAI method predicts higher LAI in semi-arid/arid regions compared to the MODIS LAI product. Hence, using the MODIS LAI layer will produce a higher sand flux (Q) and dust emissions over much of Australia. As discussed by Hill et al. (2006) the LAI quality is still not great in semi-arid/arid central Australia, hence further work still needs to be undertaken to improve the underlying algorithms in these regions. While it is possible to replace the LAI index with fractional cover completely, the advantage in remaining with LAI is that the time-series for LAI data is available back to 1981 via AVHRR and SPOT satellites. Given that the current project is looking at analysing variability in severity and intensity over time (i.e. long-term trends) therefore the availability of this long time series is an advantage. Therefore, it is possible with some addition calibration work to calibrate the MODIS, AVHRR and SPOT products to extend the current severity and extent mapping back to middle to late 1980s.

2.3 50 km CEMSYS Improvements

As documented by Butler et al. (2007); Leys et al. (2009) the 50 km model generated surface (i.e. vegetation and cover data) and atmospheric conditions is use to seed the CEMSYS model at 10 km resolution. Consequently, the 50 km data is essentially a free by–product of generating 10 km resolution data. The advantage of this approach is the 50 km becomes available faster than 10 km data. It also means that in terms of production that the initial 50 km can analysed to determine the priority periods or areas for producing the 10 km data.

Also as part of the WEESMAP project substantial progress has been made in shortening the production time (from ∼10 to 3 days) of 50 km quality controlled data set. This has been archived by the parrallisation of the current code and availability of a 204 core cluster at the University of Southern Queensland. Currently, the slowest part of the process is the availability of staff to do the quality control. This shorten of the production time, means that for the first time it is possible to use CEMSYS products for tactical reporting in the DustWatch monthly reports.

2.4 10 km CEMSYS improvements

Prior to this project limited 10 km resolution data (i.e. two years) was available for NSW and Victoria. No national 10 km (long-term data) modelled data was available. WEESMAP extended this coverage to the full Australia mainland for 2002, 2008 and 2009 and also extended the 10 km available for NSW and Vic. to 12 years (Feb 2000 – June 2012). The discussion below details the methodology used to extend the 10 km data nationally and how this has been used to produce national 10 km maps of wind erosion activity.

Australia is divided up into six approximately equal size regions, as show in Figure 10. Due to size Tasmania is run as a separate sub-region. (Note to enable joining of each distinct region each region is overlapped by approximately 10–15 pixels.) Each region is than overlaid with a 10 km grid, on which wind erosion rates are calculated (see Figure 11 as an example).

The advantages of this division is that:

1. is that each region can run separately across individual cores and in parallel, hence can be easily up scaled to larger computers available in Brisbane or Canberra;
2. if an error occurs in one of the regions, only that region needs to be rerun; and
3. if just the east coast is required only three regions need to be run.

Once completed each variable is mapped to a new national 10 km grid defined across Australia using

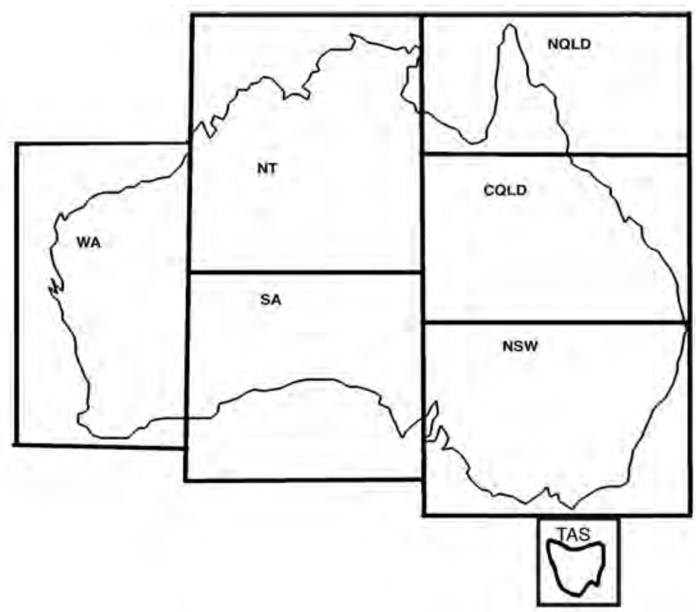


FIGURE 10: *Seven regions used to produce 10 km national wind erosion map.*

bilinear interpolation. An example of the resulting map is shown in Figure 12.

3 Comparison of the performance of CEMSYS v5 and v6

Before proceeding to outline the model evaluation methodology, it is worth noting that differences between the observed and model results (Steyn, 1988) maybe due to:

1. model formulation and inaccuracies inherent in the numerical implementation of the model;
2. sub-grid effects (e.g. related to temporal and spatial resolution especially unresolved variations in topographic features etc.); and
3. inaccuracies in the observed data.

All the above sources of disagreement exist in the current project. To increase the confidence in the model, it is necessary to qualify and quantify the relative performance of the model under the these limitations. Hence, the methodology developed and outlined below has been designed to control these possible sources of error and quantify the relative improvement of the model as changes are made to vegetation and soil data.

Measuring wind erosion emission at source is very difficult and cannot be remotely measured at present; as a result ? proposed the use of the product of wind erosion, airborne dust, as the primary indicator of degrading soil condition. The logic was simple; if dust is being produced it means that

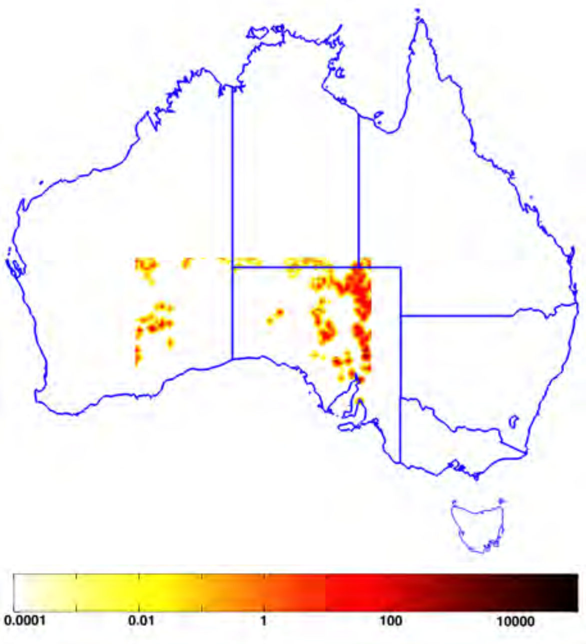


FIGURE 11: *Example showing sand drift (mg/m/s) for SA region at 10 km on 23rd September 2009*

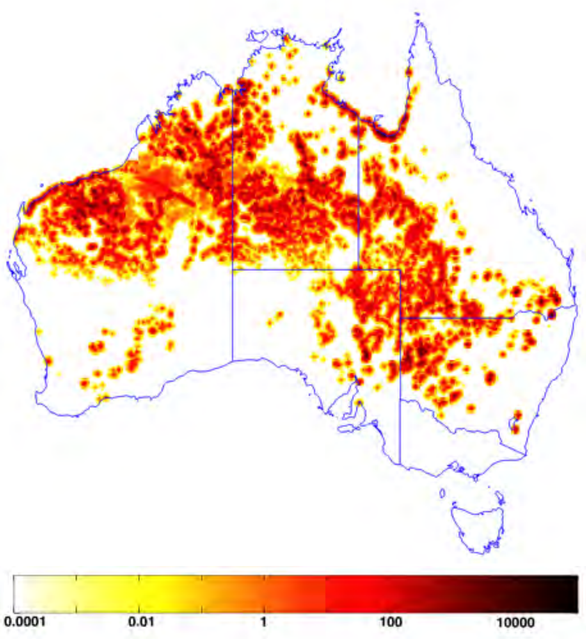


FIGURE 12: *Example showing the sand drift (mg/m/s) for Australia at 10 km on 23rd September 2009 after blending the seven regions in Figure 10.*

soil is being lost and associated losses of fertility, water storage capacity and productivity are occurring. Dust is a good surrogate because it can be measured remotely by stand-alone PM_{10} sensors such as the instruments used in the Community DustWatch program or by meteorological observers from the Australian Bureau of Meteorology (ABoM) in near real time. Hence, in this project dust is used a surrogate to quantify the performance of the model. The logic being if the model is correctly predicting a) where dust is being observed in the landscape and b) the quantity of dust being measured; the model is performing well.

3.1 Methodology

To qualify the modelling results and improvements in terms of extent the CEMSYS model results are compared to all of the following data sets.

1. Community DustWatch data for nodes (DWN) which is available from NSW Department of Environment and Climate Change;
2. Dust Event Days and visibility records (DEDV) held at Griffith University (GU);
3. MODIS TERRA/AQUA Satellite (MODISTA) data which is available from NASA; and
4. Road Side Surveys (RSS) available from ASRIS.

DWN provide hourly PM_{10} concentration data from 41 sites across Australia. This data provides the most accurate data available for the dust concentration and is therefore used statistically quantify the changes/improvements in the model results. The DED and visibility records are extracted from Australian Bureau of Meteorology (ABoM) data and summaries observed dust events on a particular day. Visibilities associated with DEDD records of the these dust events also give an estimate of the strength and duration of the event. MODISTA images give visual verification of dust activity and extent. However, cloud and small events (e.g. localised and short duration events) may not be identifiable in these images. Finally, the RSS provides ground information which can be used to ground truth the model across a wide area.

To statistically test the performance of spatial and temporal models the statistics outlined by Steyn (1988); Yin et al. (2007); and shown below have been used.

$$\text{Mean of the observed PM}_{10}\text{ dustwatch values} \quad \overline{O} = \frac{1}{N}\sum_{i=1}^{N} O_i \; ; \tag{3}$$

$$\text{Mean of the modelled PM}_{10}\text{ values} \quad \overline{M} = \frac{1}{N}\sum_{i=1}^{N} M_i \; ; \tag{4}$$

$$\text{Mean bias} \quad MB = \frac{1}{N}\sum_{i=1}^{N}(M_i - O_i) \ ; \tag{5}$$

$$\text{Mean Error} \quad ME = \frac{1}{N}\sum_{i=1}^{N}|M_i - O_i| \ ; \ \text{and} \tag{6}$$

$$\text{Agreement index} \quad d = 1 - \frac{\sum_{i=1}^{N}(M_i - O_i)^2}{\sum_{i=1}^{N}\left(|M_i - \overline{O}| + |O_i - \overline{O}|\right)^2} \ ; \tag{7}$$

where N is the total number of observations. MB gives a measure as to whether the model is over predicting (> 0) or under predicting (< 0), while ME gives a measure of the deviation of the model from the observed values (lower the better) and d gives a measure of the observed variability that the model is explaining (0 little of the observed variability is being explained, 1 all the observed variability is being explained).

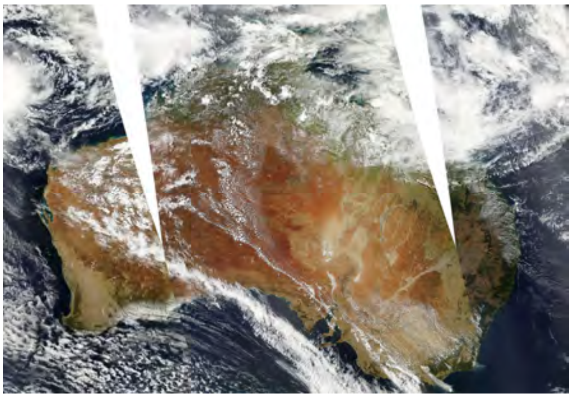
Most current temporal and spatial modelling projects only consider the agreement of the model agreement for short periods (i.e. 1 to 5 days events). In this project, these statistics summaries the daily performance of CEMSYS modelled PM_{10} against daily measure PM_{10} evaluated at 26 DWN over a whole year. Consequently, it is expected that our overall performance will be slightly lower than current literature due to the likelihood of more extremely outliers.

While these statistics provide an indication of that CEMSYS is correctly predicting the intensity of wind erosion, to quantify the spatial performance of CEMSYS in predicting the extent of wind erosion activity across Australia CEMSYS output was compared to spatial maps of reported dust activity from each of the data sets described above on a daily basis.

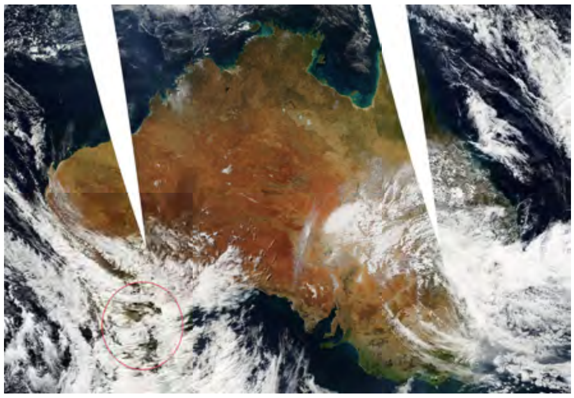
3.2 Improvements in the performance

To illustrate the performance of the improved CEMSYS model (v6) over version 5, we will use data from 2009, which had two of biggest dusts storm to be recorded on the east coast since the 1940's (Leys et al., 2011). Hence, the performance of the model will be illustrate here by a) statistical comparison of the model at 26 DWN for all of 2009; and b) comparing CEMSYS to four days which the DED/visibility data reported dust in different areas of the continent. These four events only represent a small summary of days analysed in detail during 2009 (over 20 days), and were chosen as they clearly reflected the performance differences between the two versions of the model.

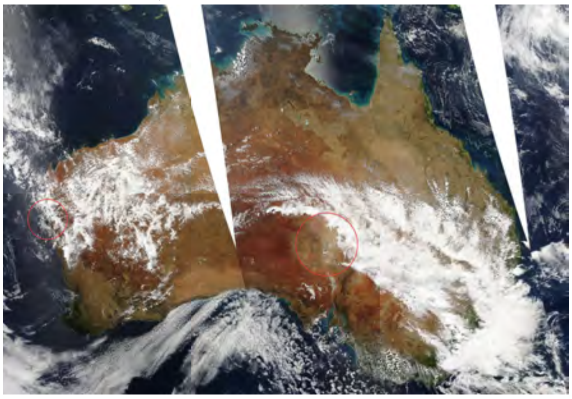
Figure 13 illustrates the dust activity observed by the MODIS satellite on the four days considered in this report (7th February 2009, 21st May 2009, 25th October 2009 and 10th December 2009). On the 7th February MODIS imagery suggests light dust activity in South Eastern Australia (along the



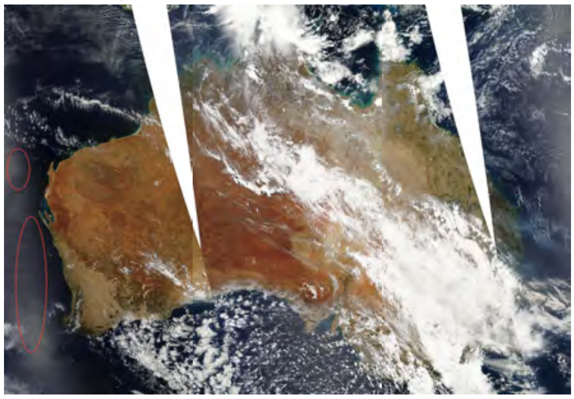
(a) 7th February



(b) 21st May



(c) 25th October



(d) 10th December

FIGURE 13: *Satellite images for the four days during 2009.*

Victorian border). MODIS imagery show that on the 21st May indicate that there was dust activity in south-western Western Australia. 25th October show dust extensively in South Australia and Western Australia, however cloud western Queensland/New South Wales border does not provide a clear indication of activity along the New South Wales border. Dust activity is indicated off the Western Australian coast on the 10th December in the MODIS imagery, while cloud again obscures much of the east coast.

To quantify the difference between the two versions of the model statistical comparison was undertaken using all the data available from the 26 DustWatch nodes in operation during 2009. These statistics are reported in Table 5 for the 50 km resolution simulations and show version 5 overestimates the amount of dust at these 26 stations over 2009, by a factor of approximately 3 (cp. 0.0076 to 0.0210). The mean bias for 2009 indicates that version 5 over estimates the amount of PM_{10} at these 26 stations during 2009. In contrast, version 6 under predicts the mean dust by 0.6. However, given that DWN incorporate some smoke, and natural background dust (i.e. dust as a result of human activity) this result may not be unreasonable. The mean bias for version 6 indicates that it slightly underestimates the concentration at these 26 stations. Comparing the mean error between the two versions indicates that version 6 has significantly reduced the error between model and observation (i.e. mean error decreased from 0.0227 to 0.0084). Finally, the increase in the *d* value from 0.2292 under version 5 to 0.3956 version 6 indicates that version 6 is explaining almost twice the variability observed in the data. Given that the version 6 value was the result of comparing daily observations for 26 stations over 365 days, further suggests that version 6 is extremely robust over most conditions. It also compares well to the value of 0.5 obtained by Yin et al. (2007) for a single event in US.

Table 6 shows the comparison of the 10 km observed concentration and modelled across the 26 DustWatch node stations for 2009. These results indicate that the 10 km is similar to the 50 km across all 26 stations. All show a significant improve over the comparable v5 data values. However, the 10 km version predicts a mean dust concentration across all 26 stations of 0.0129 compared to the 0.0076 measured. This over estimate compared to 50 km runs probably represents a compounding in the modelling/computational error at the end of each modelling period which drags the estimate above the true mean. As noted by Willmott et al. (2011), the statistics calculated above are easily affected by one or two extreme outliers. Also note that the 10 km comparison is going to be more affected by any errors in GIS maps, how representative the sensor location is of the underlying 10 km pixel, and localised affects. In the contrast, in the 50 km data these errors are averaged over wider area and hence contribute differently to the final error analysis. Due to this and other possible sources of error at the different scales (Steyn, 1988), it is hard to compare the statistics at the two modelling scales, in fact this should not be done. The important message from these statistics is that at both scales the model version 6 shows the same level of improvement over version 5.

TABLE 5: *Statistical comparison of the 50 km CEMSYS version 5 and version 6 across all 26 DustWatch nodes for 2009.*

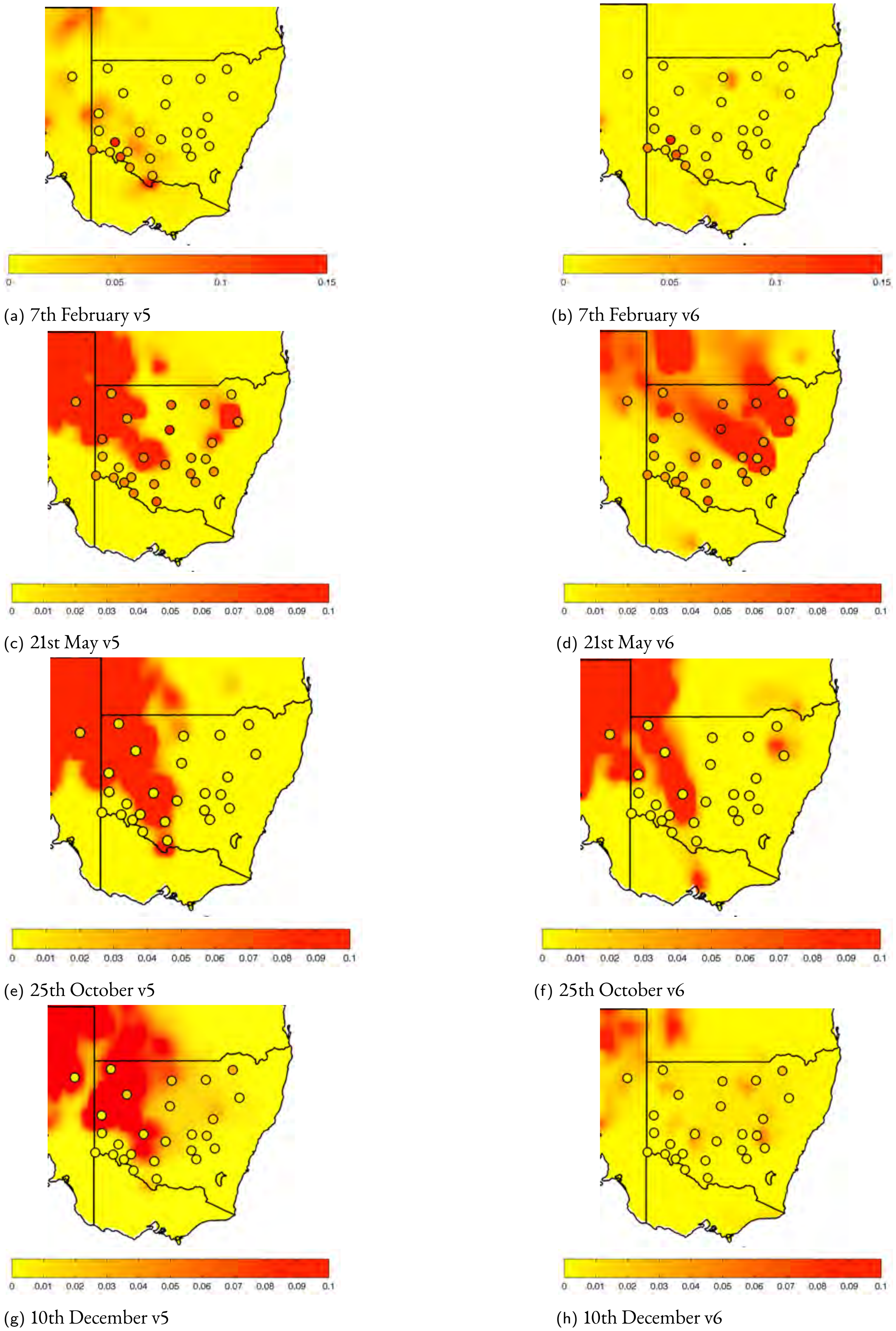
Version	$\overline{O}$	$\overline{M}$	MB	ME	d	No. of observations
5	0.0076	0.0210	0.0133	0.0227	0.2292	9388
6	0.0076	0.0043	-0.0033	0.0084	0.3956	9388

TABLE 6: *Statistical comparison of the 10 km CEMSYS version 5 across all 26 DustWatch nodes for 2009.*

Version	$\overline{O}$	$\overline{M}$	MB	ME	d	No. of observations
5	0.0076	0.0260	0.0184	0.0269	0.1726	9388
6	0.0076	0.0129	0.0057	0.0147	0.3357	9388

To illustrate the spatial performance between the two versions, the model output was compared to both DWN and DEDV data. The results of this analysis are presented for the 4th February 2009, 16th September 2009, 25th October 2009 and 10th December 2009. Figure ?? shows the comparison of CEMSYS predicted PM_{10} concentration, against PM_{10} concentration measured at each of the DWN for the four days. On the 7th February both version 5 and 6 (Figure ??a,b) show limited dust activity across the 26 sites, which is in agreement with the DWNs. On the 21st May the DWN network indicated that the higher activity was in the central-north of NSW (Figure ??c,d). Version 5 (Figure ??c) of the model did not pick this activity up, in fact it suggested that most of the activity was in north-west. In contrast, version 6 (Figure ??d) picks up this dust activity and that this activity was lower towards the western region. On the 25th October the DWN network did not show significant activity (Figure ??e,f). However version 5 (Figure ??c) suggest that there should be wide spread activity in western part of the state (i.e. it over predicts at 8 sites). In contrast, version 6 (Figure ??d) suggests that the dust activity is more patchy and it only over predicts at 5 sites. The 10th December (Figure ??g,h) illustrates that version 5 (Figure ??g) can substantially over predict in the western region of NSW, in contrast version 6 (Figure ??h) provides better agreement with the DWN network. This pattern of version 6 producing better spatial agreement with DWN network, was repeated for the other days analysed.

The analysis above suggests that version 6 is performing better is South-East Australia. However, as no data was available for 2009 outside of NSW for DWN network for 2009, it is necessary to use DEDV data to analysis the spatial performance of CEMSYS on a continental scale. Figure 14 show a comparison of DEDV observations against the CEMSYS predicted dust load for the four days. The DEDV data show activity in SA and along the NSW/Victorian border (Figure 14a,b). Version 5 (Figure 14a) suggests that the dust activity extends right across Australia. In contrast, version 6 indicates that the activity was more isolated, with an increase in the activity along the NSW/Victoria border. Figure 14c,d shows that there was activity in North Qld, WA, and central NSW on the 21st May. Version 5 (Figure 14c) picks up the activity in WA, but over predicts the activity of the east coast. In contrast, version 6 (Figure 14d) while identifying the activity in WA, suggests a spatial dust which agrees better with DEDV observations. On the 25th October the DEDV (Figure 14e,f) show that their was activity in WA, and LEB. Version 5 (Figure 14e) suggests the dust activity extend well into Qld, SA and NSW. In contrast, version 6 (Figure 14f) suggests that the activity was more constrained in the LEB around the stations observing dust, but suggests that this activity extended into WA. On the 10th December (Figure 14g,h) suggests that the LEB and NT were active dust areas. Version 5 (Figure 14g) suggests that most of the activity was confined to SA and WA. In contrast version 6 (Figure 14h) correctly identifies that activity extend up into NT, it also picks up the single dust observation in NSW. In general, the results observed throughout the days analysed suggest that version is performing better than version 5. However, both models seem to perform badly in WA. The absence of WA data could reflect that the dust events are not being captured in DEDV data. However, it is hoped that 3 DWN which are now online in WA will provide an answer to this problem.



(a) 7th February v5

(b) 7th February v6

(c) 21st May v5

(d) 21st May v6

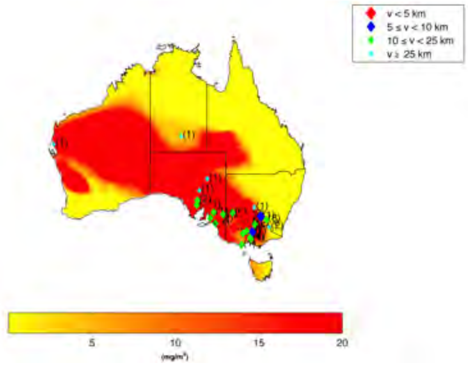
(e) 25th October v5

(f) 25th October v6

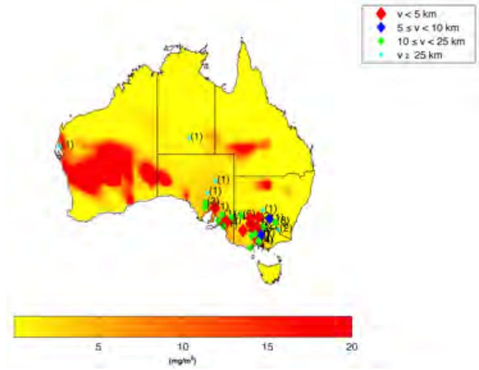
(g) 10th December v5

(h) 10th December v6

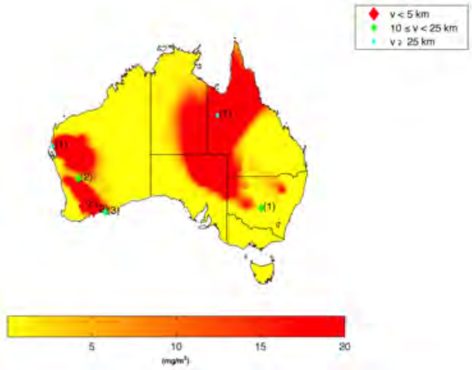
FIGURE 14: *CEMSYS v5–6 and DustWatch Node (DWN) PM_{10} (mg/m^3) comparison for specific days during 2009.*



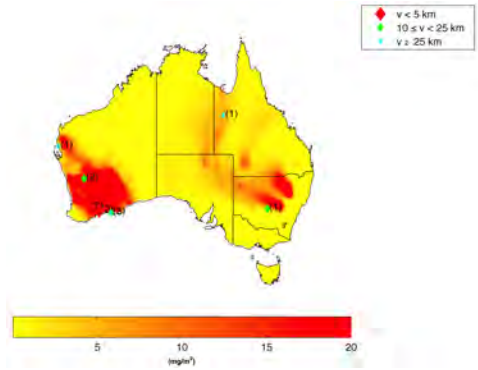
(a) 7th February v5



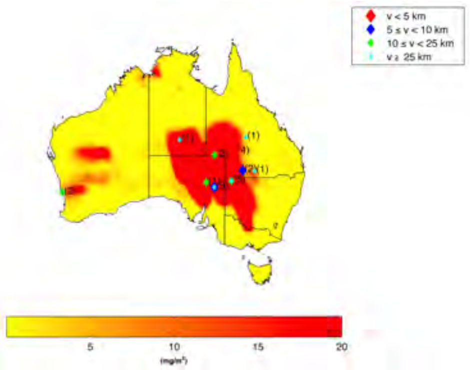
(b) 7th February v6



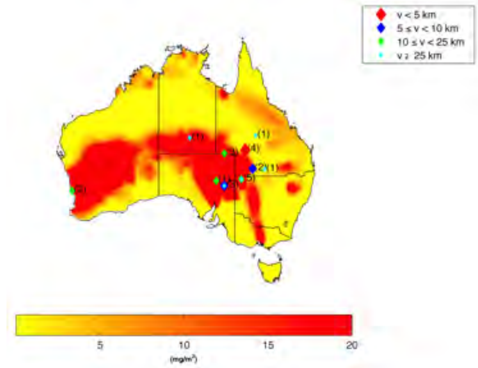
(c) 21st May v5



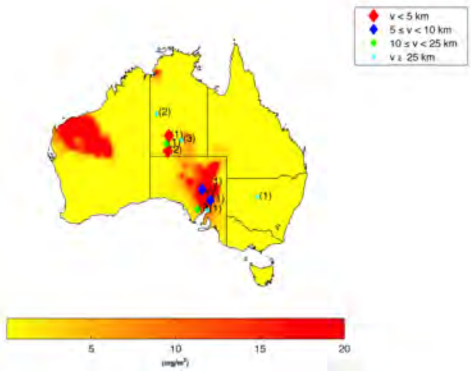
(d) 21st May v6



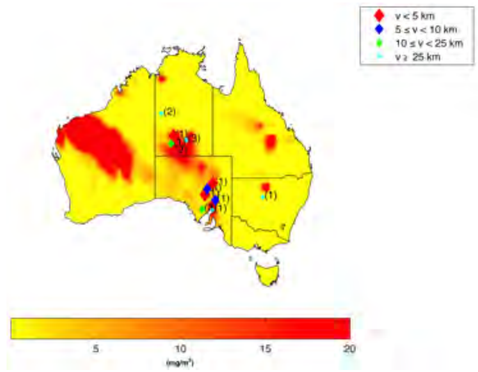
(e) 25th October v5



(f) 25th October v6



(g) 10th December v5



(h) 10th December v6

FIGURE 15: *CEMSYS v5–6 dust load and Dust Event Database (DEDB) comparison for specific days during 2009 (Cont.).*

4 Products from the CEMSYS modelling

At present 50 km national data is available from February 2000 to June 2012 for v5 (see Appendix ??) and v6 (see Tables 7 and 8) [4]. In additional, 10 km data v5 data (Table 7) is available from February 2000 until June 2012[5] for NSW and Victoria. 10 km Version 6 data (Table 8) is available nationally for 2002, 2008 and 2009. At present, all v5 50 km data is on the DustWatch web site (`http://www.dustwatch.edu.au/index.php/modelled-wind-erosion`) this will be replaced with v6 as soon as the full quality checks have been made[6]. The 10 km 2002, 2008 and 2009 is available as monthly national maps, however these still need to broken done to state and nrm regions before going on the website as maps. It is also envisaged that ASCII data files of the two data sets at 50 km will be available on the web site in the next couple of months. Note: As part of the gradual introduction of 10 km data on the website additional education material is required. This is educational material is being produced now. It also envisaged that the DustWatch monthly reports which will in the future contain CEMSYS products will also be a critical part of this educational program.

The 50 km version 5 data has been used in several projects including the CSIRO Soil Carbon in Eroded Sediments project (Chappell et al., 2012; Webb et al., 2012) and GU Southern Ocean projects (Gabric et al., 2010). As part of the soil carbon project the mean eroding and total dust emission was estimated using version 5 CEMSYS output for 2001–2011 (see Table 9). As reported in this table, the mean erodible area is 1.87×10^{12} which is approximately 24% of Australia. The maximum area eroding occurred in 2008 and represented approximately 34.5% of the Australia that was subject to some form of wind erosion. Graphically, the variation in eroding area is illustrated in Figure 17. During the decade the average amount of material emitted was estimated to be approximate 52.4 Tg, with a maximum of 152.3 Tg in 2008. However, as data in Table 9 indicates that 2008/09 were extreme years, and significantly dragged this average up. These estimates are similar to the estimates reported by Shao et al. (2011) in literature. The long term DSI analysis from 1960 onwards suggests that 2004/2005 were average erosion years (McTainsh, 2012). Ignoring, the two large years (2008/2009) indicates that the average for the remaining years is approximately 25.9 Tg, which agrees with McTainsh (2012) conclusion that 2004 and 2005 were average years.

[4] July–December 2012 will be available by the end of May
[5] July–December 2012 will be available by the end of May
[6] end of May should see version 6 on the web

Table 7: *Table of available v5 CEMSYS data*

Year	10 km NSW	10 km Vic	10 km National	50 km
2000[a]	✔	✔	✗	✔
2001	✔	✔	✗	✔
2002	✔	✔	✗	✔
2003	✔	✔	✗	✔
2004	✔	✔	✗	✔
2005	✔	✔	✗	✔
2006	✔	✔	✗	✔
2007	✔	✔	✗	✔
2008	✔	✔	✗	✔
2009	✔	✔	✔	✔
2010	✔	✔	✗	✔
2011	✔	✔	✗	✔
2012	✔	✔	✗	✔

[a]Available from February 2000

Table 8: *Table of available v6 CEMSYS data*

Year	10 km NSW	10 km Vic	10 km National	50 km
2000[a]	✔	✔	✗	✔
2001	✗	✗	✗	✔
2002	✔	✔	✔	✔
2003	✗	✗	✗	✔
2004	✗	✗	✗	✔
2005	✗	✗	✗	✔
2006	✗	✗	✗	✔
2007	✗	✗	✗	✔
2008	✔	✔	✔	✔
2009	✔	✔	✔	✔
2010	✗	✗	✗	✔
2011	✗	✗	✗	✔
2012	✗	✗	✗	✔

[a]Only available from March 2000

Table 9: *CEMSYSv5 estimated erodible area and total emission*

Year	Mean eroding area (m^2)	Mean dust flux ($g/m^2/s$)	Emission total (Tg)
2001	1.38×10^{12}	2.78×10^{-7}	15.9
2002	1.81×10^{12}	4.63×10^{-7}	35.1
2003	1.78×10^{12}	3.89×10^{-7}	30.2
2004	1.57×10^{12}	3.79×10^{-7}	26.3
2005	1.72×10^{12}	3.65×10^{-7}	26.9
2006	1.69×10^{12}	4.42×10^{-7}	31.5
2007	1.67×10^{12}	3.76×10^{-7}	26.7
2008	2.73×10^{12}	1.28×10^{-6}	152.3
2009	2.63×10^{12}	1.23×10^{-6}	138.3
2010	1.69×10^{12}	5.39×10^{-7}	40.9
2011	1.17×10^{12}	3.76×10^{-7}	14.8
Mean	1.80×10^{12}	5.56×10^{-7}	48.98

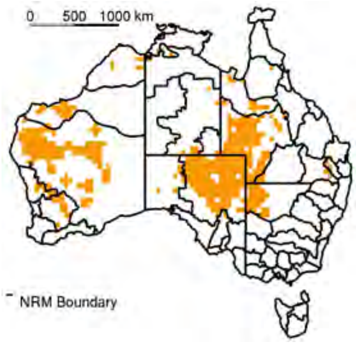
Currently, monthly national summaries of wind erosion severity and extent based on 50 km data are available for periods outlined in Tables 7 and 8 for both v5 and v6 CEMSYS data. Figure 18 show an example of these maps for 6 months during 2009. Figure 19 and 20 illustrate the 10 km maps of wind erosion extent and severity currently available at both a state and NRM scales. Currently v5 10 km extent and severity maps are available for NSW/Victoria from February 2000–June 2012 at this scale, with v6 national 10 km extent and severity maps being available for 2002, 2008 and 2009. The examples presented here, can also be presented as a time-series for each region. An example of this is shown in Figure 21. Time-series based on the 50 km data for each NRM are also available on the DustWatch web site (`http://www.dustwatch.edu.au/index.php/modelled-wind-erosion`). In addition it is also possible to produced estimate net loss maps a given period, as illustrated in Figure 22.

5 Future investments and products

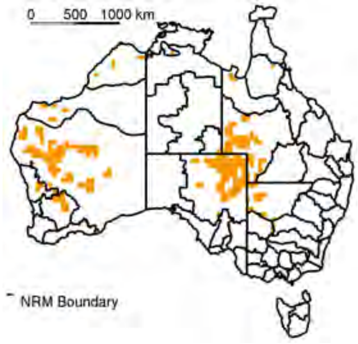
These products will be extended next year to produce:

1. a map of monthly extent and severity wind erosion map (Figure 23a);
2. a decile map for the current month (which deciles that pixel is in for the current month – Figure 23d).

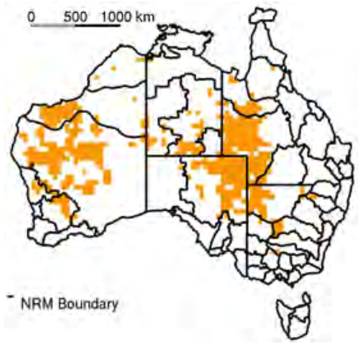
It will also be possible to produce:



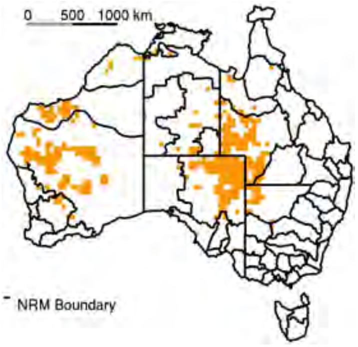
(a) 2000/2001



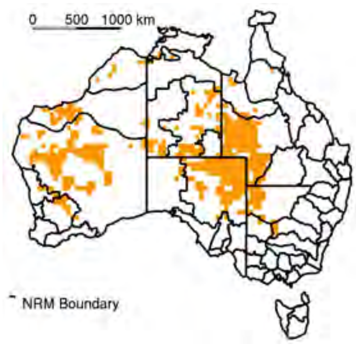
(b) 2001/2002



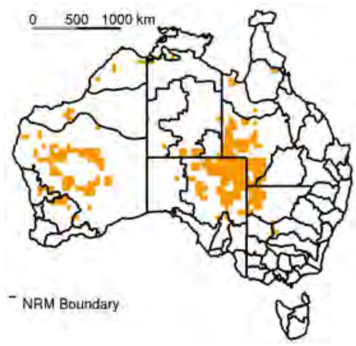
(c) 2002/2003



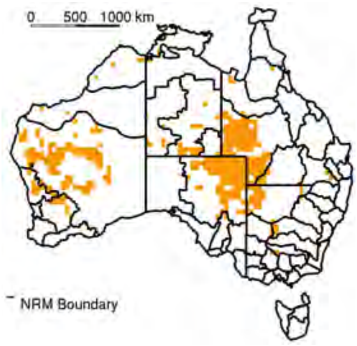
(d) 2003/2004



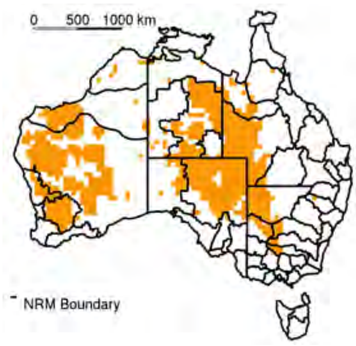
(e) 2004/2005



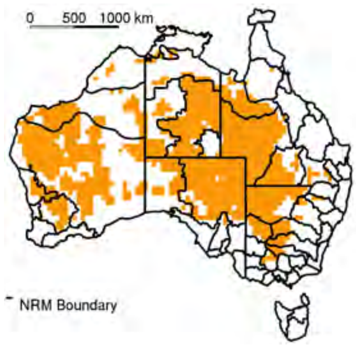
(f) 2005/2006



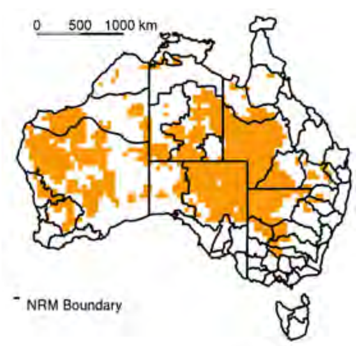
(g) 2006/2007



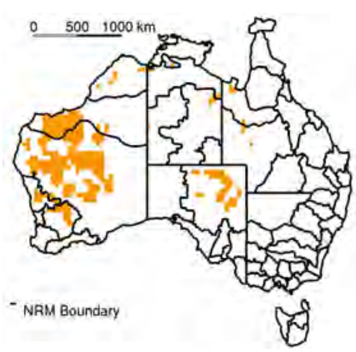
(h) 2007/2008



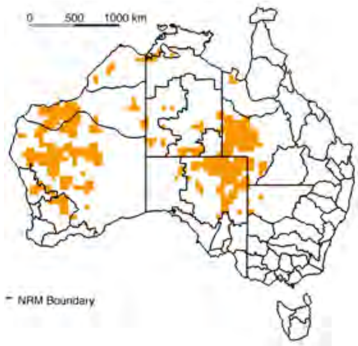
(i) 2008/2009



(j) 2009/2010

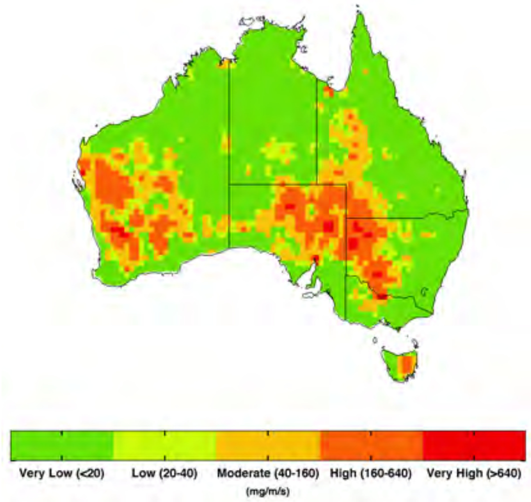


(k) 2010/2011

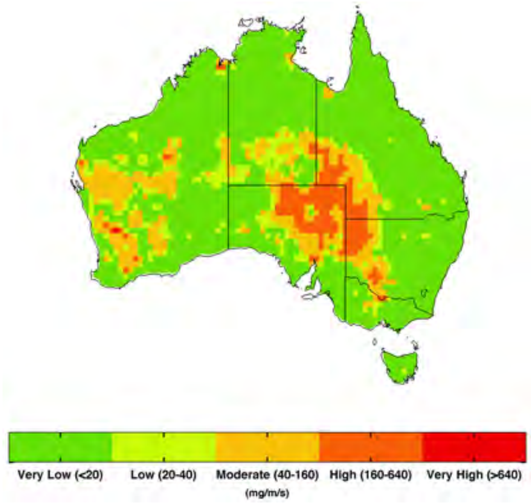


(l) 2011/2012

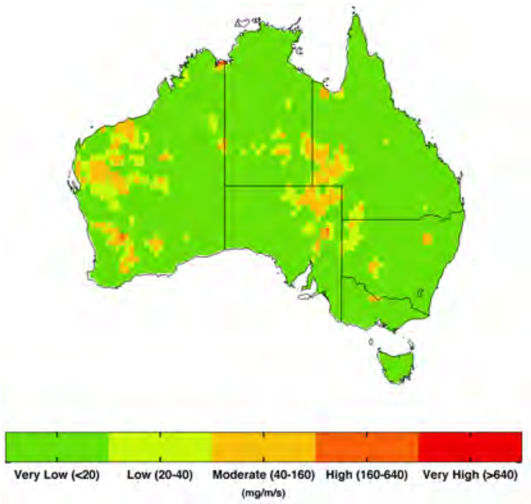
FIGURE 16: *Areas of Australia with moderate or higher levels of wind erosion.*



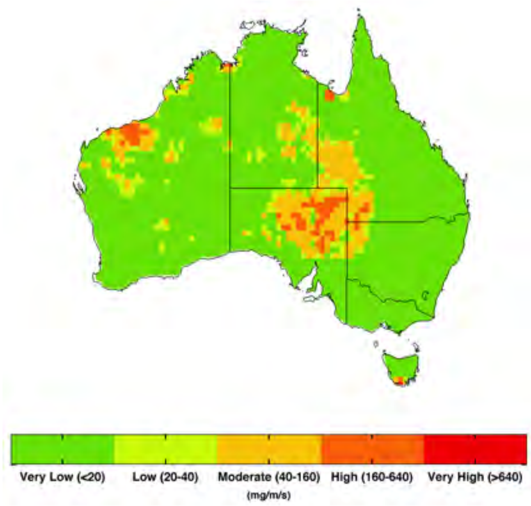
(a) January



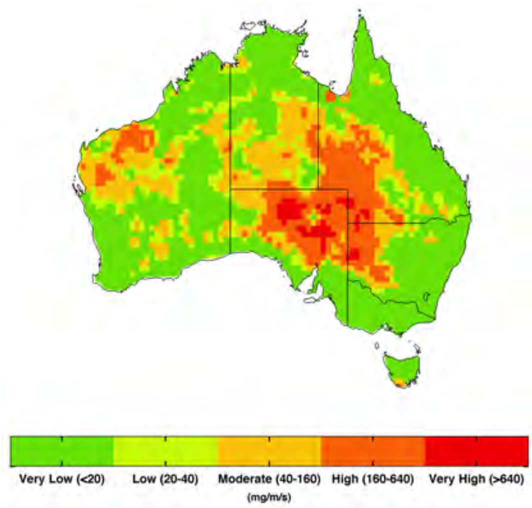
(b) March



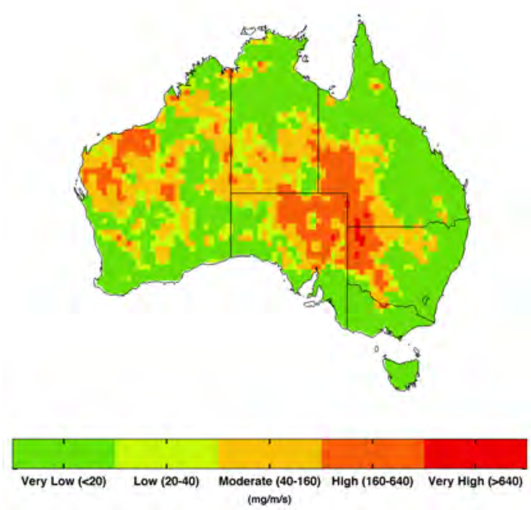
(c) May



(d) July

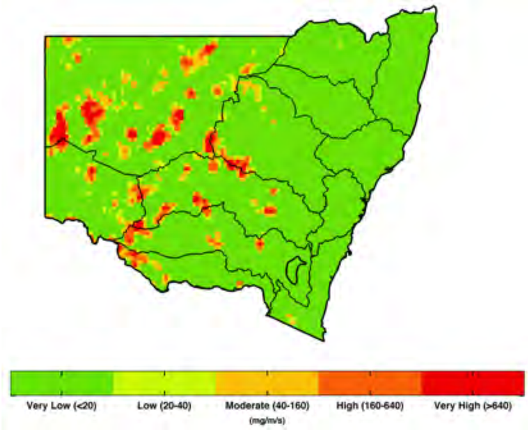


(e) September

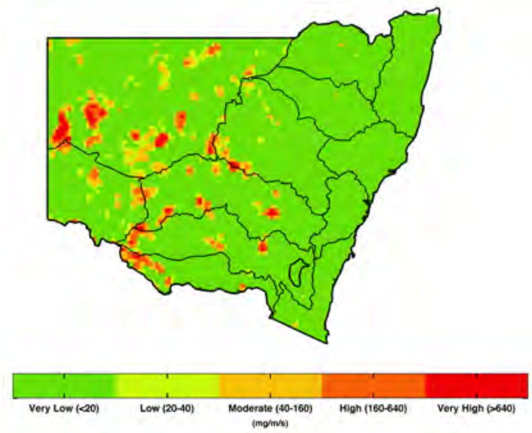


(f) November

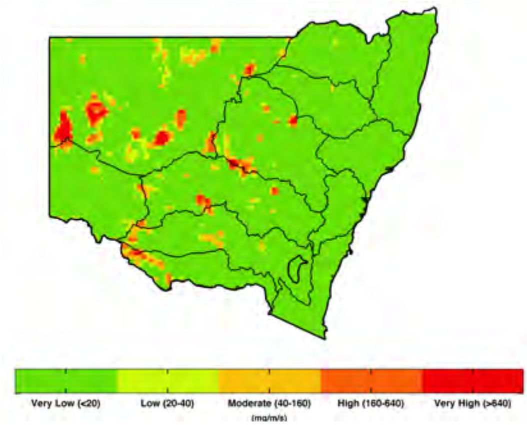
FIGURE 17: *Modelled national wind erosion activity for six months during 2009 using CEMSYS v5.*



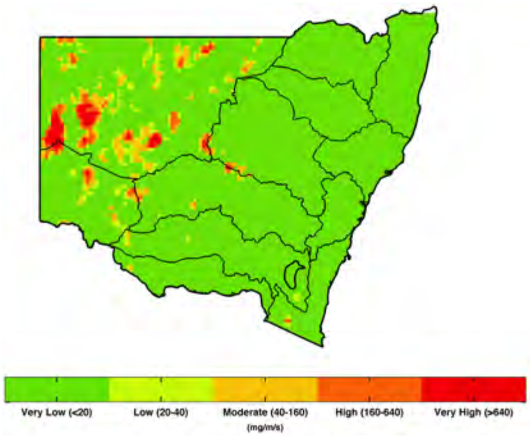
(a) January



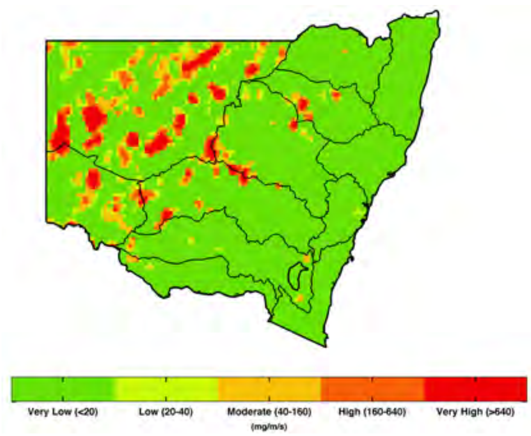
(b) March



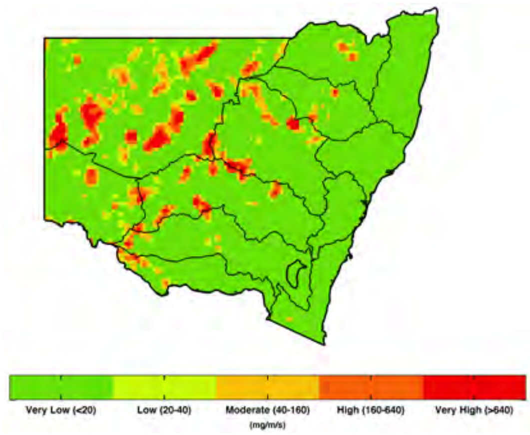
(c) May



(d) July

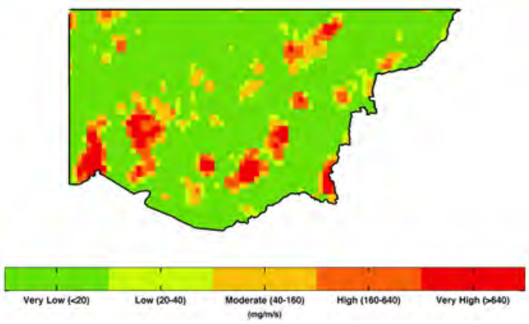


(e) September

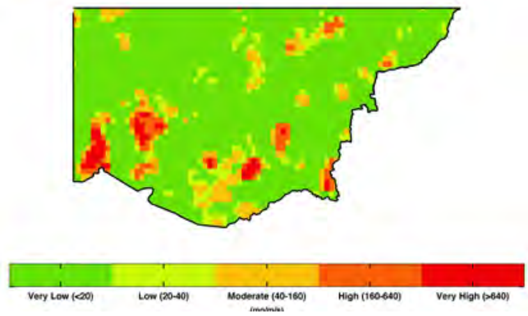


(f) November

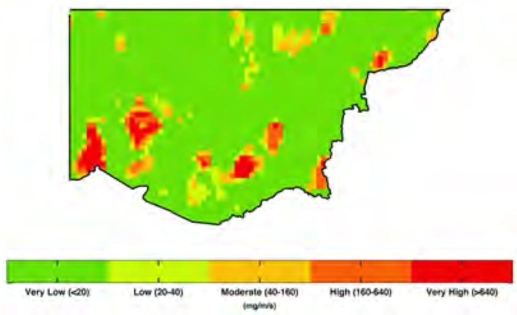
FIGURE 18: *Modelled NSW wind erosion activity maps for six months during 2009.*



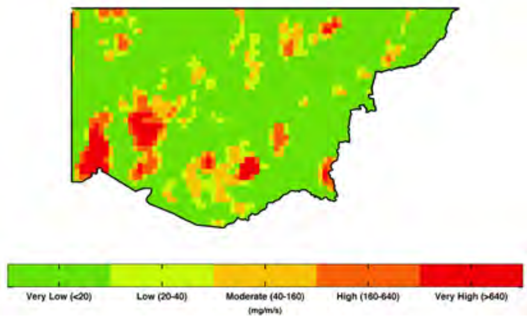
(a) January



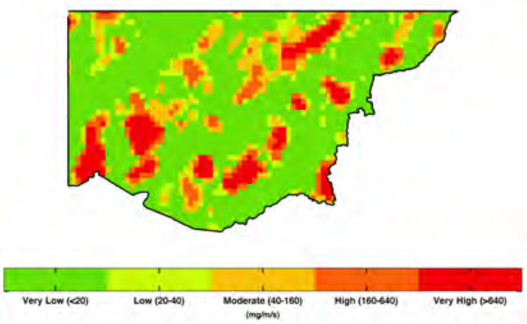
(b) March



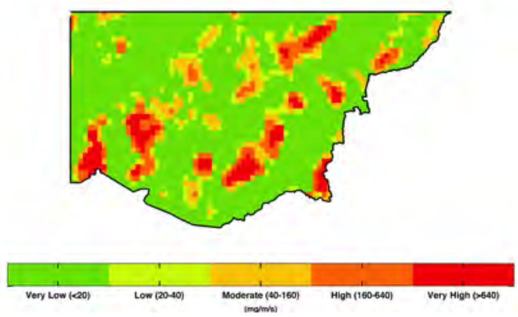
(c) May



(d) July



(e) September



(f) November

Figure 19: *Modelled Western NRM wind activity erosion maps for six months during 2009.*

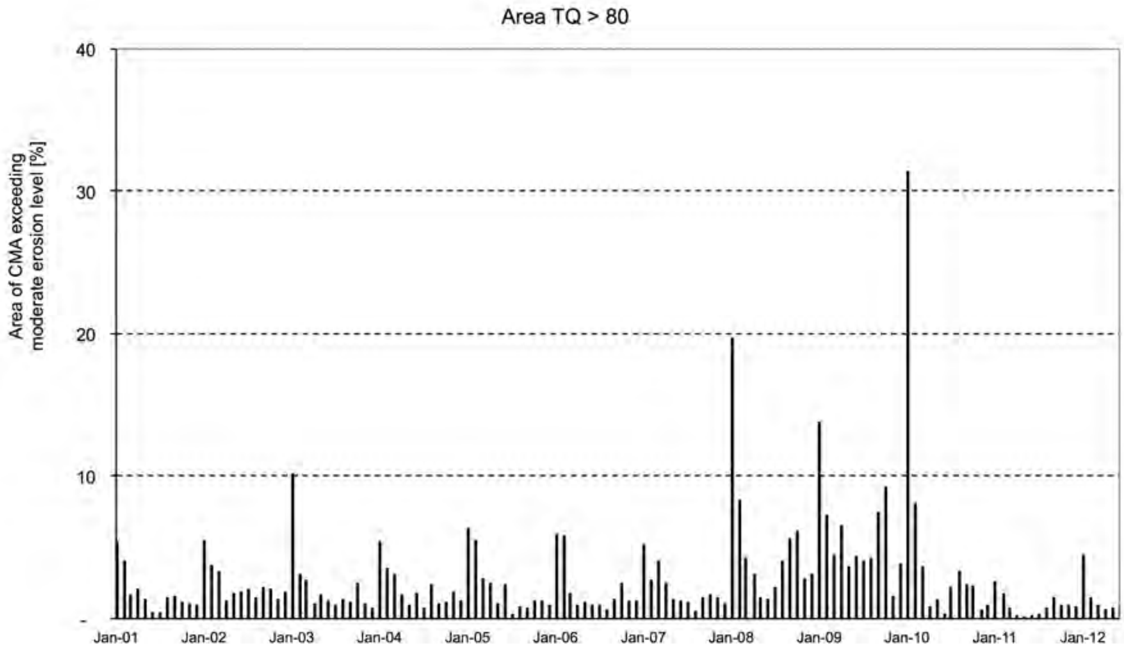


Figure 20: *Time series of showing the variation in percentage area of the western NRM above moderator erosion levels based on the CEMSYS v5 10 km NSW/Victorian data*

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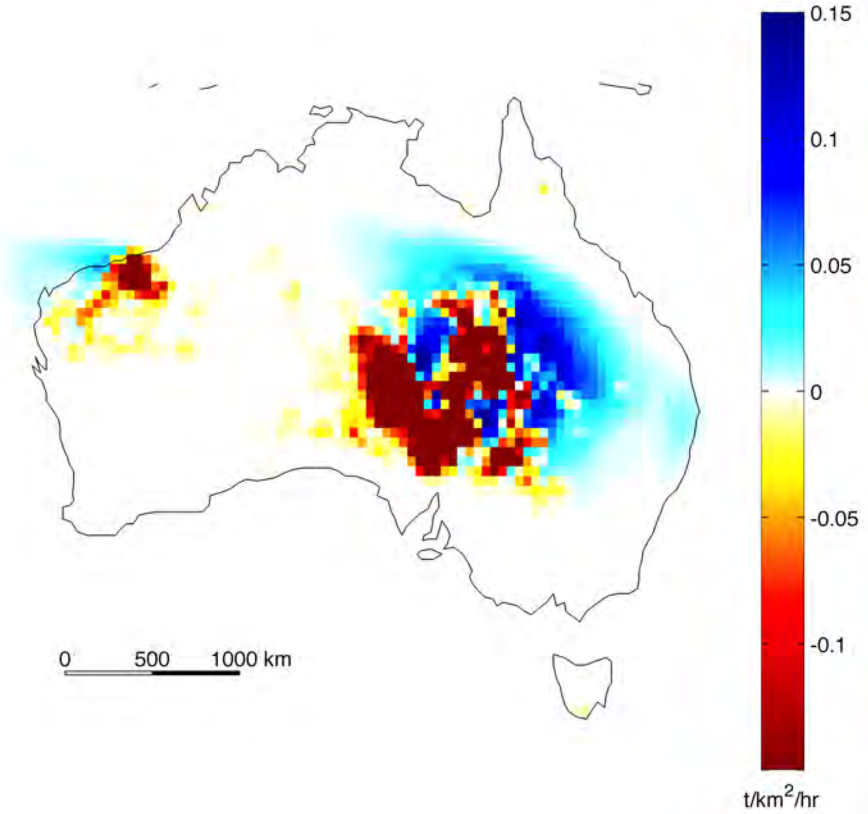


Figure 21: *Estimated net soil loss due to wind erosion for the 22nd–23rd September 2009.*

1. a anomaly map (i.e. difference of current month from long term mean for the pixels);
2. a percentage of mean map (i.e. how difference is that month from the underlying mean for each pixel).

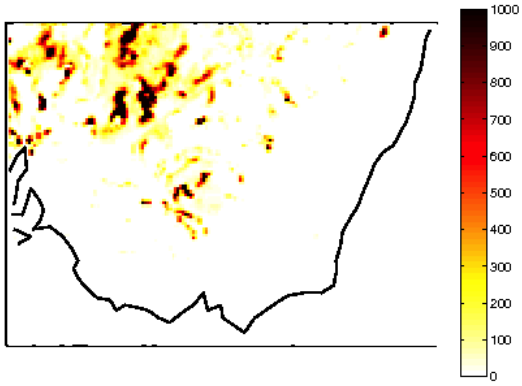
These maps will bring the CEMSYS data in line with the current ABM rainfall summaries (examples shown in Figure 24). An example of the type of information this will provide is shown in Figure 25. These maps illustrate the utility of the decile maps, in that they show that erosion in SE Australia was around normal levels in 2005, but that in 2008 a large part of the SE Australia was experiencing wind erosion the highest levels of wind erosion seen during the 2000–2012 period. As the model time-series extends the utility of these maps will increase.

It would be possible to extend the WEESMAP data back to the mid 1980s, as NDVI/LAI data is available from AVHRR. As this is a different LAI data set from the MODIS LAI, work would need to be done to calibrate the two products during 2000–2001 periods where the two products over lapped. The completion of this extra data set would increase the time-series from 10 years to 25 years. Hence, providing more historical data to evaluate the impacts of climate and management on wind erosion.

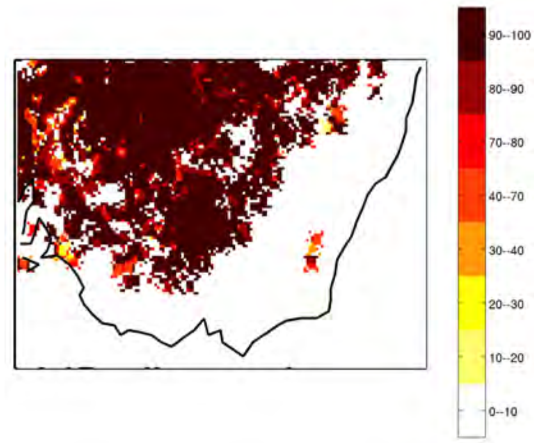
Initial work has begun on standardising the data formats of four major data sets (DEDB, Roadside survey, DWN and CEMSYS) so that the data access format is consistent between the databases. In stage one, the DEDB and CEMSYS data is currently being migrated to MySQL, along with data from the DWN network. The road side survey database will be integrated along side this data once the final version becomes available[7]. Stage 2 will involve coding web tools which are required to a) visualise and b) interpreting the dataset (i.e. writing the software interface which directly query the database). Once completed these Wind Erosion Visualisation Tools (WEVT) will form the basis functions, which will be used to query and interpret the other databases (e.g. DustWatch Node and Road Side Survey databases) and provide access to summary data for the scientific and NRM managers. The developments during this in the DWN and WEIRM (which are also part of this database) will enhance the possibility of further statistically testing the CEMSYS output nationwide. This intensive analysis at some 418 sites over several years, would also indicate possible statistical means of correcting the CEMSYS output, hence further improving the reliably of the data. Once completed this may lead us to an intelligent system which uses the best information available to predict the extent and severity of wind erosion across Australia.

It also possible at this stage to further increase the soil types available for use in CEMSYS. During the project and additional 50 soils were analysed from the Australian Soil Resource Information System (ASRIS). These can now be parametrised and included in the next iteration of the model. This will increase the model resolution at the NRM scale, and better reflect regions within NRMS

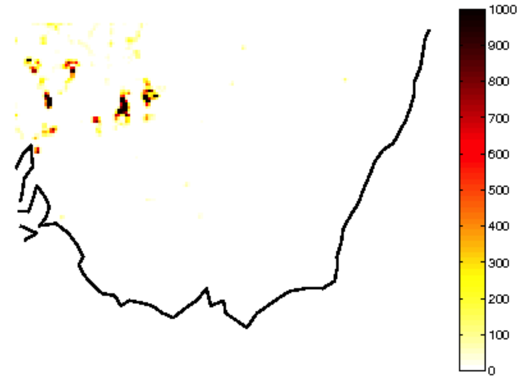
[7]initial development of some ideas for integrating this has been done on a subset of the road side survey data.



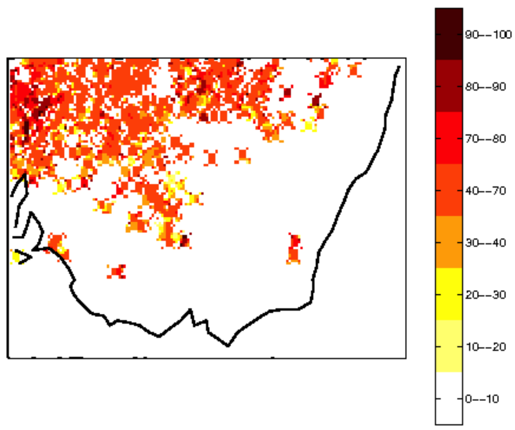
(a) CEMSYS v6 October 2008 extent and severity map (mg/m/s)



(b) CEMSYS v6 October 2008 decile anomaly map

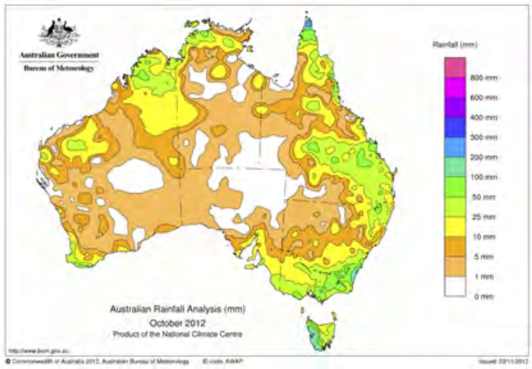


(c) CEMSYS v6 October 2005 extent and severity map

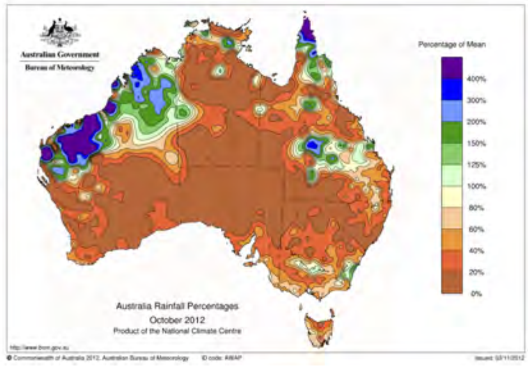


(d) CEMSYS v6 October 2005 decile anomaly map

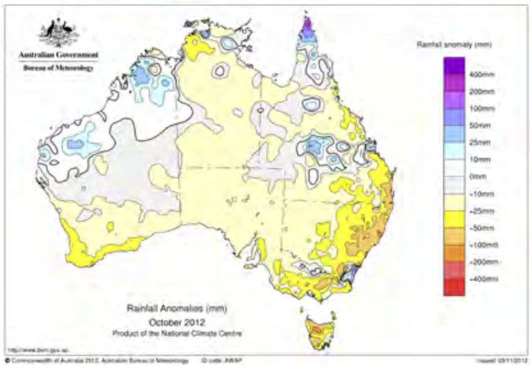
FIGURE 22: *Example of CEMSYS standardised NSW anomaly maps for October 2005 and 2008.*



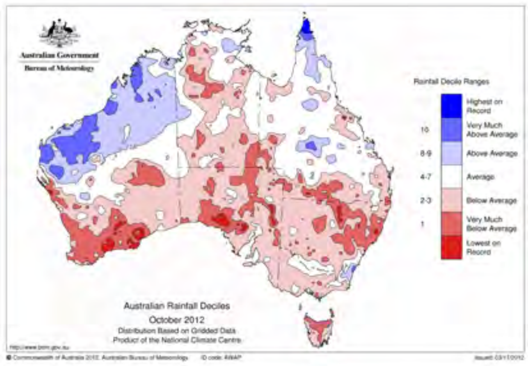
(a) BoM monthly rain



(b) BoM monthly percentage of mean



(c) BoM anomaly map



(d) BoM decile map

FIGURE 23: *Examples of BoM rainfall maps from October 2002.*

that require specific investment.

6 Summary

The improvements in the data sets outlined in §?? improved the accuracy of the CEMSYS products. Statistical analysis of Version 5 (before the improvements) and Version 6 (after the improvements) shows that the model over estimated daily dust concentrations at 26 of the DustWatch nodes in 2009 by approximately 3 fold for v5 and underestimated it by 0.6 for v6. The mean error between modelled and observed dust levels was reduced for v6 (0.0227 to 0.0084). Finally v6 explained twice the level of variability in the observed data compared to v5 (0.2292 to 0.3956). This improvement was supported by qualitative analysis of the CEMSYS data set against DEDV data. Given the result was comparing 26 stations over 365 days, v6 appears extremely robust over the yearly period.

The time-series for 50 km data has been extended to 12+ years for both v5 and v6. While the time-series available for NSW/Victoria 10 km data has also been extended to 12+ years for v5. Finally, the 10 km data v6 set has been extended national for 2002, 2008 and 2009. It is planned to complete the remaining years for the 10 km data set over the next six months. This data will be made publicly available on http://www.dustwatch.edu.au as it becomes available after completing our quality control procedures.

Acknowledgements

Queensland PM_{10} data used in the early development of version 6 was provided and collected by the Queensland Department of Environment and Resource Management (DERM), with the assistance of Andrew Chan at Griffith University in Brisbane.

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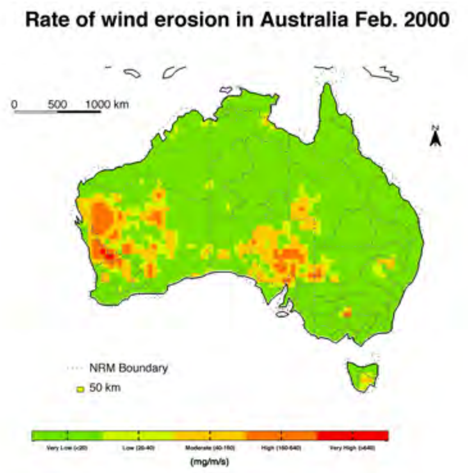
A Monthly Maps v5 February 2000 – June 2012



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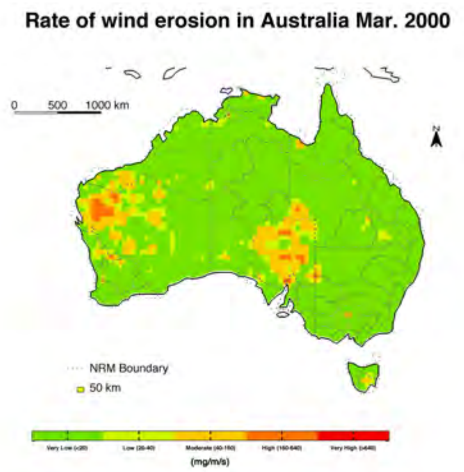

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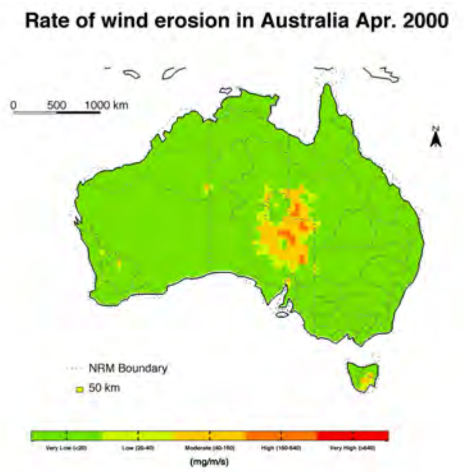

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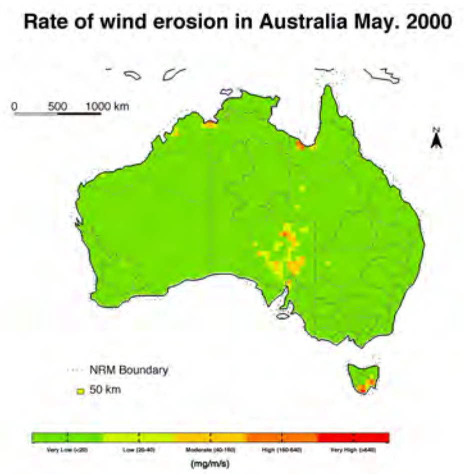

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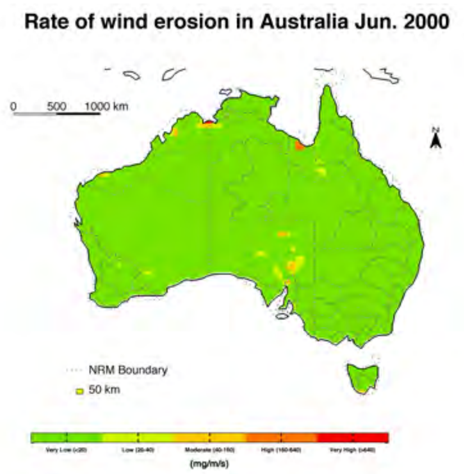
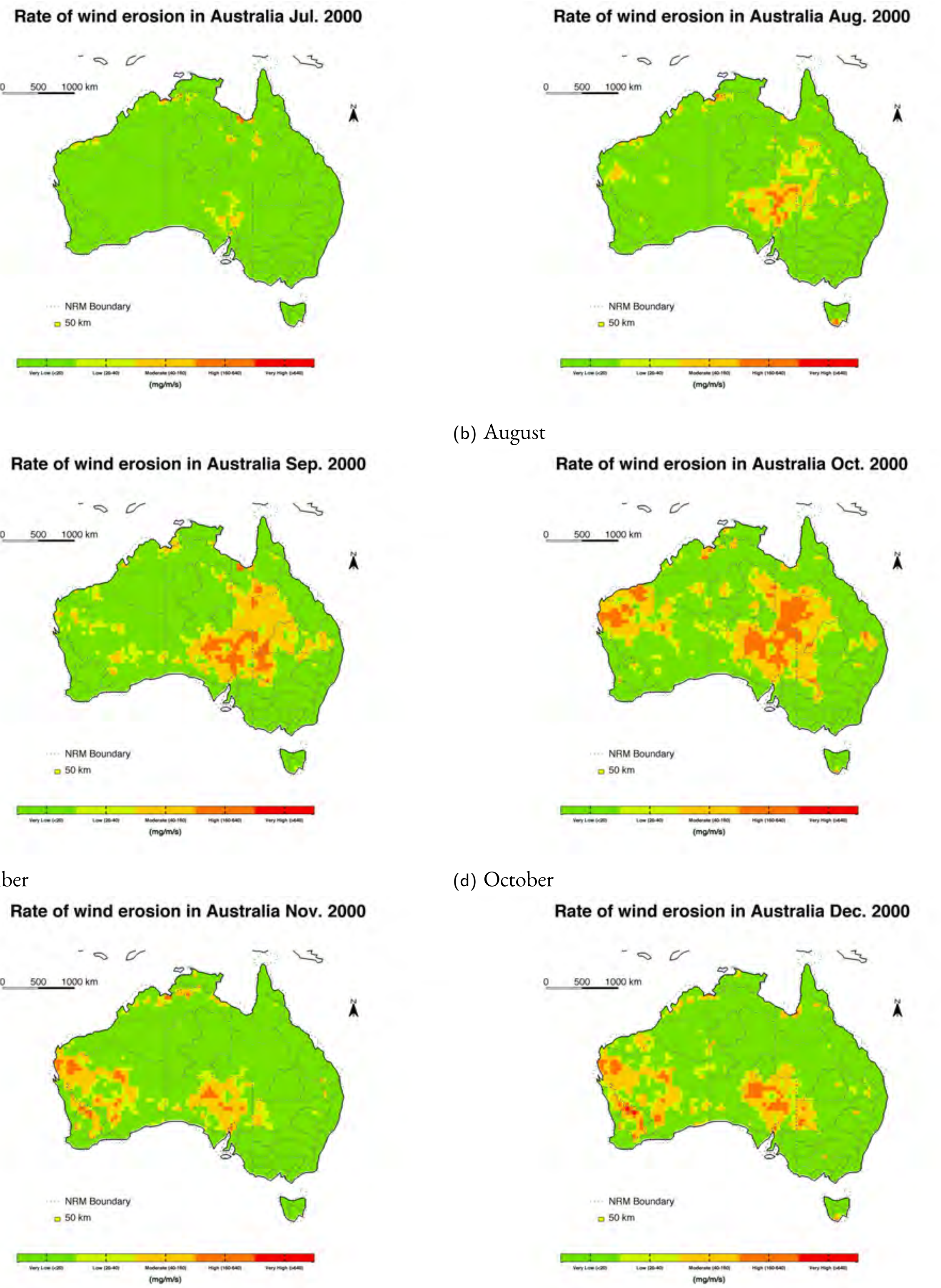


(e) June

FIGURE 24: *February – June 2000 Monthly sand drift maps*



(a) July

(b) August

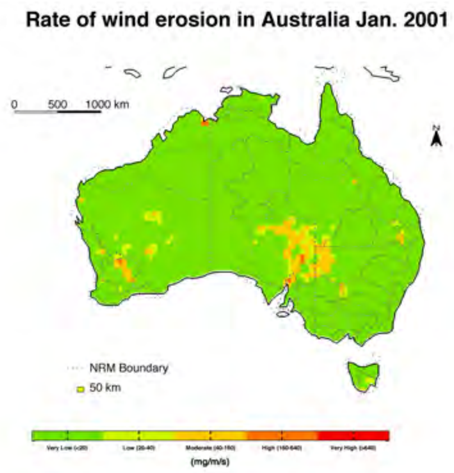
(c) September

(d) October

(e) November

(f) December

FIGURE 25: *July – December 2000 Monthly sand drift maps*



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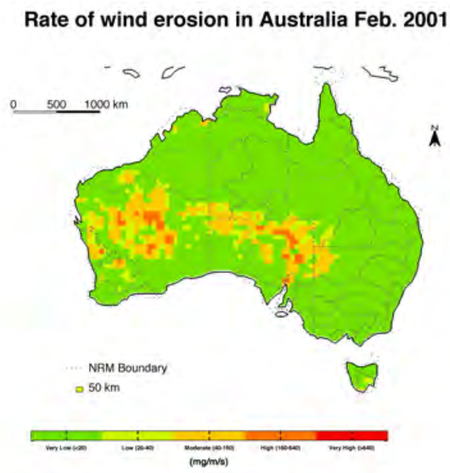

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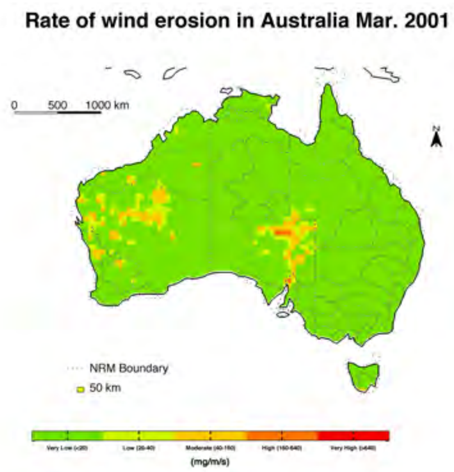

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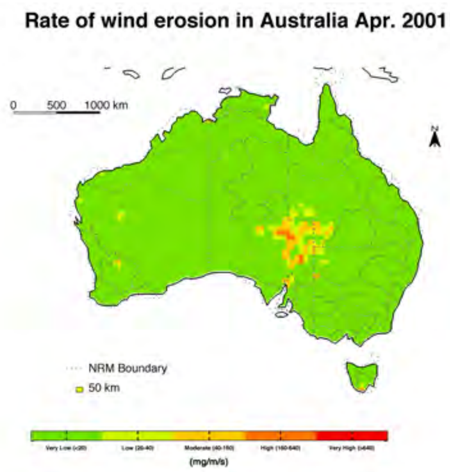

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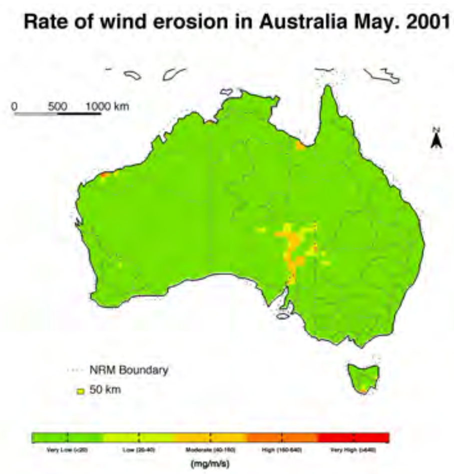

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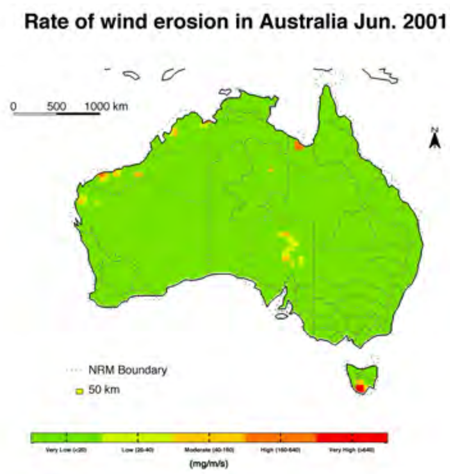
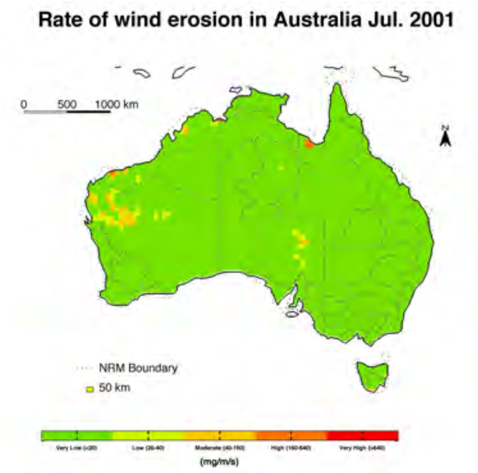
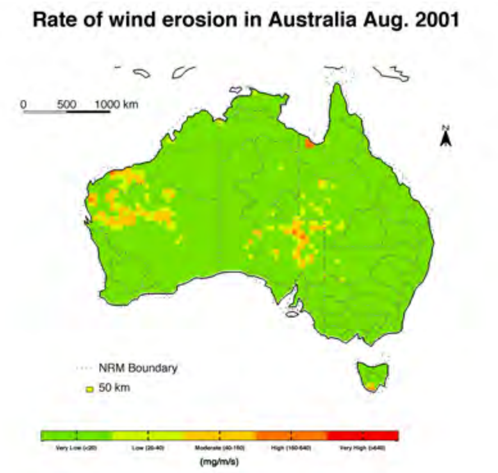


(f) June

FIGURE 26: *February – June 2001 Monthly sand drift maps*



(a) July



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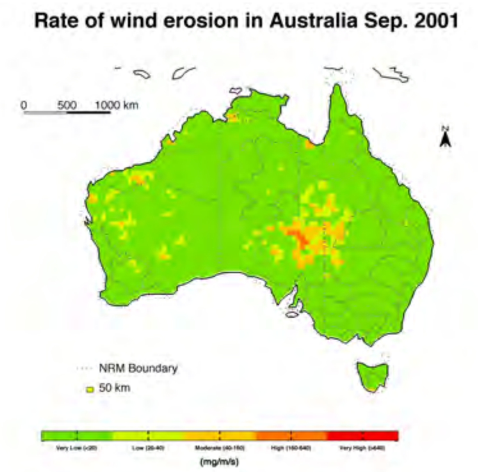

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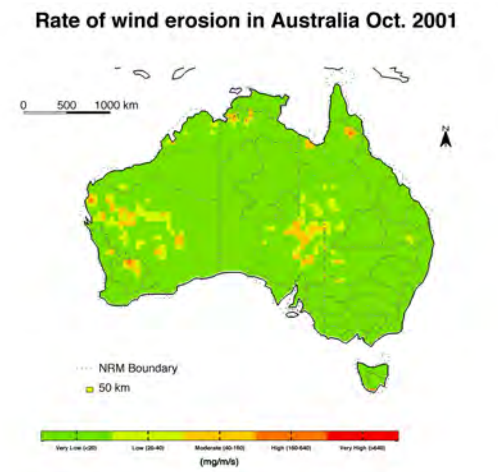

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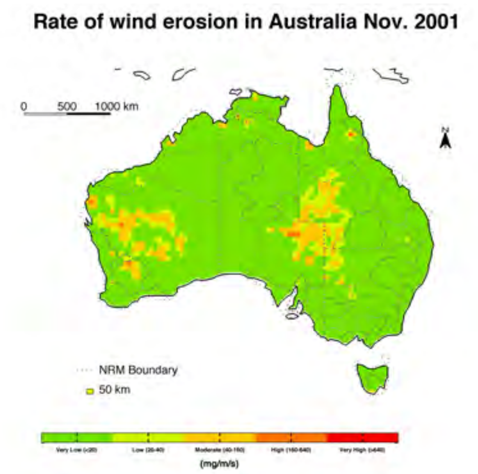

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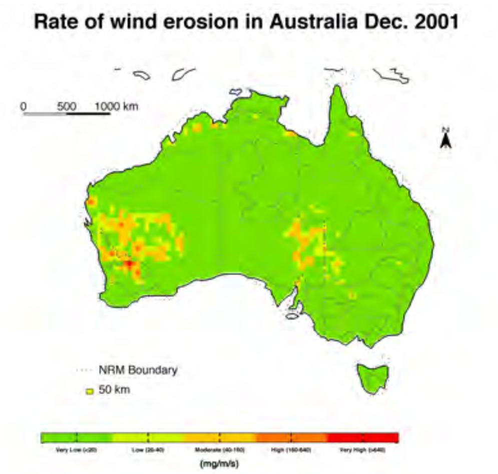
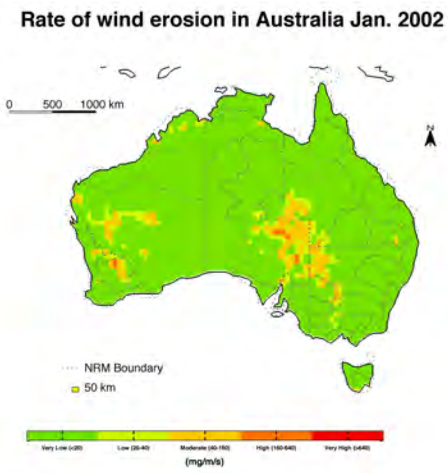


(f) December

FIGURE 27: *July – December 2001 Monthly sand drift maps*



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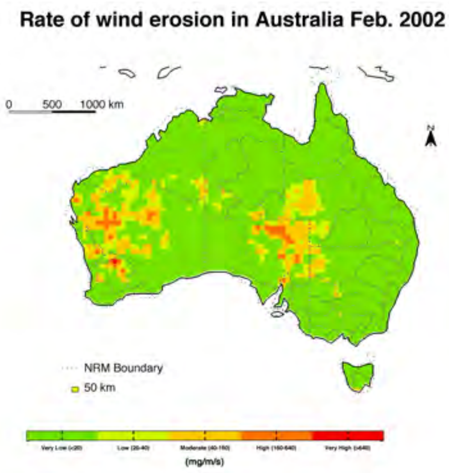

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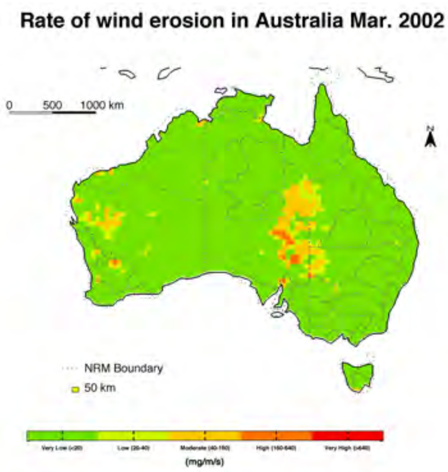

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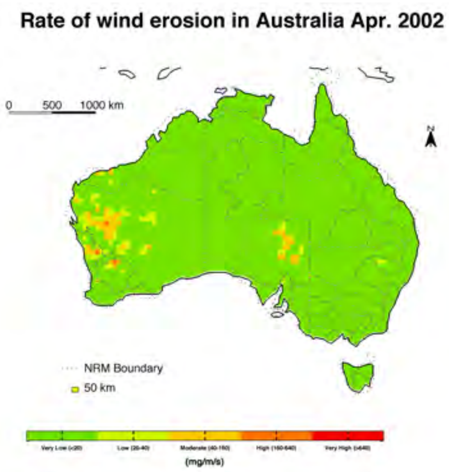

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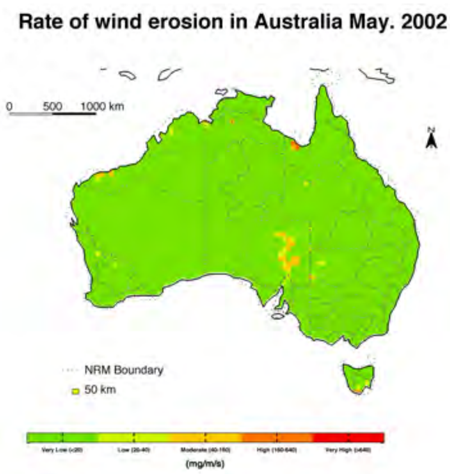

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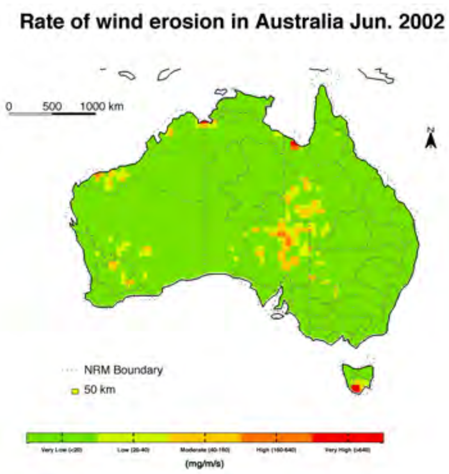
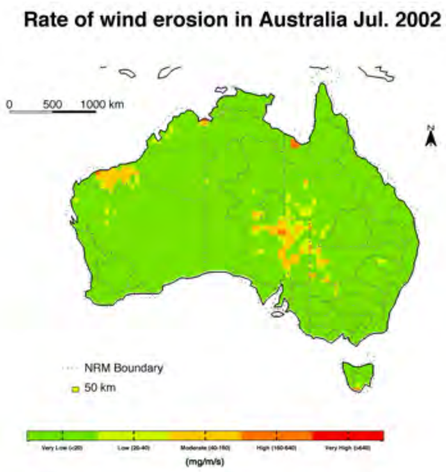


(f) June

FIGURE 28: *February – June 2002 Monthly sand drift maps*



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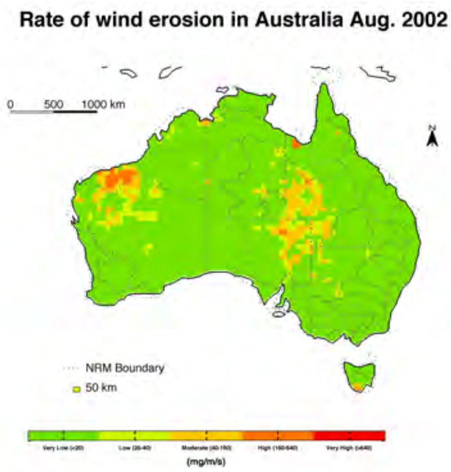

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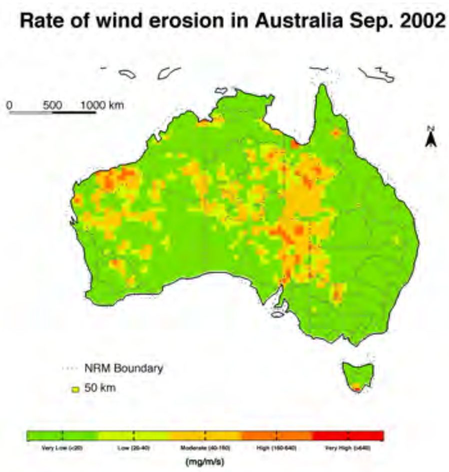

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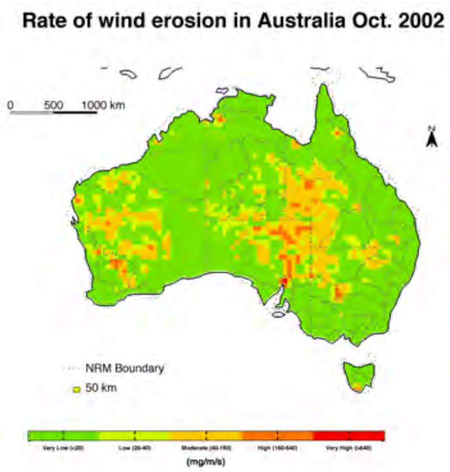

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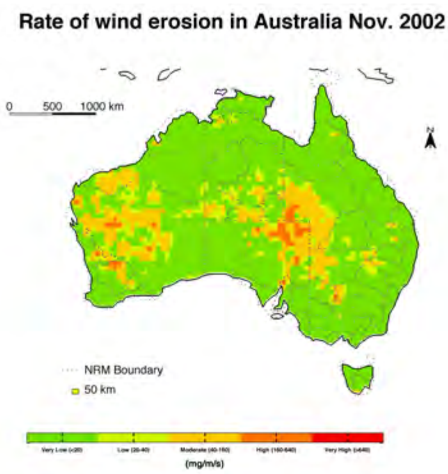

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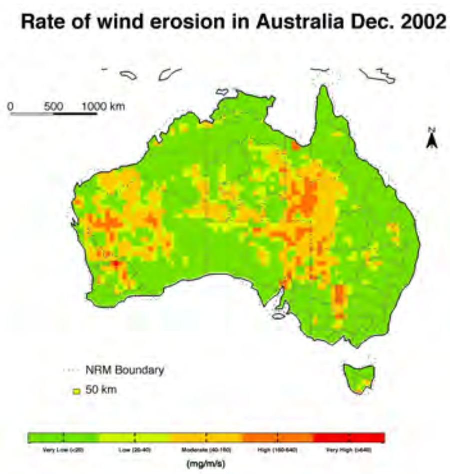
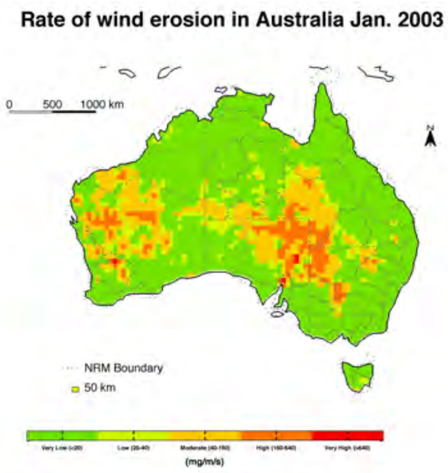


(f) December

FIGURE 29: *July – December 2002 Monthly sand drift maps*



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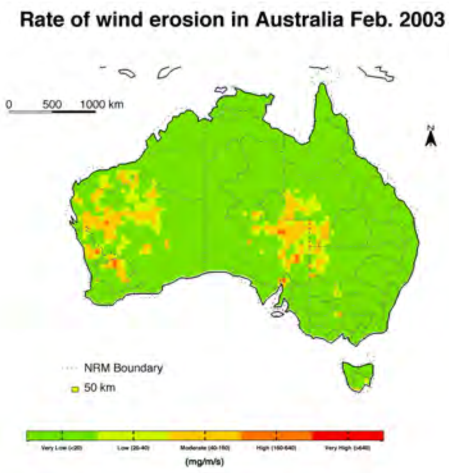

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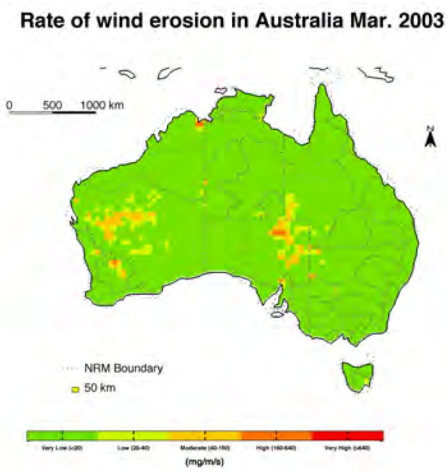

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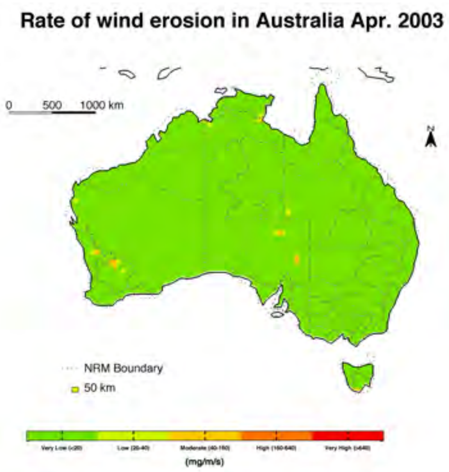

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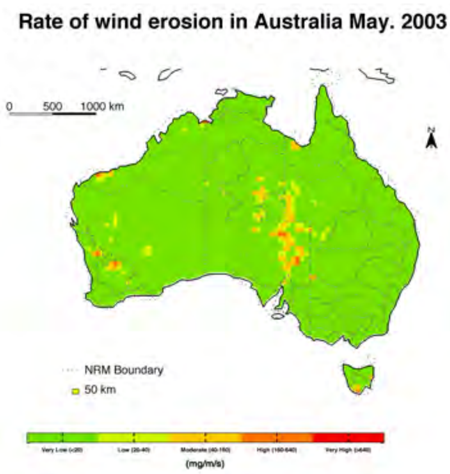

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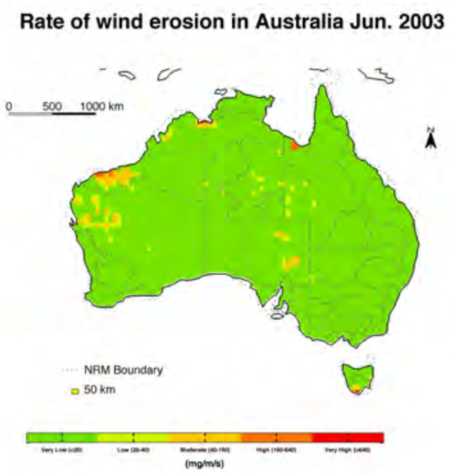
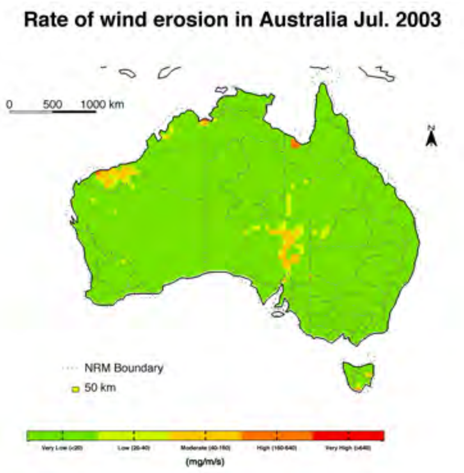
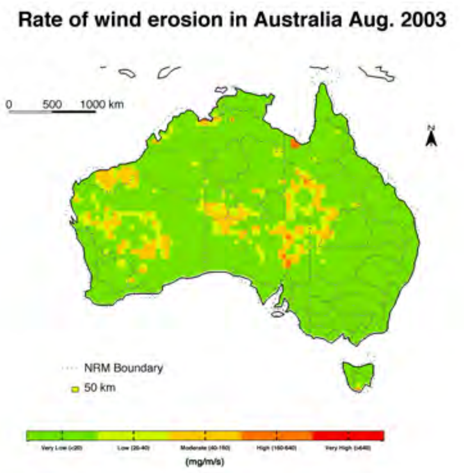


(f) June

FIGURE 30: *February – June 2003 Monthly sand drift maps*



(a) July



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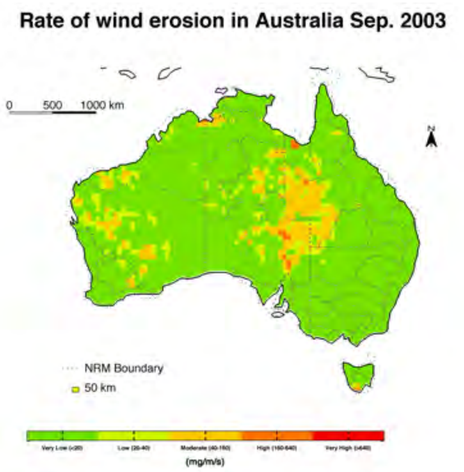

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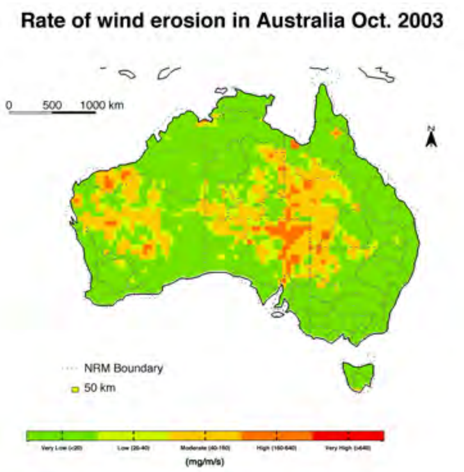
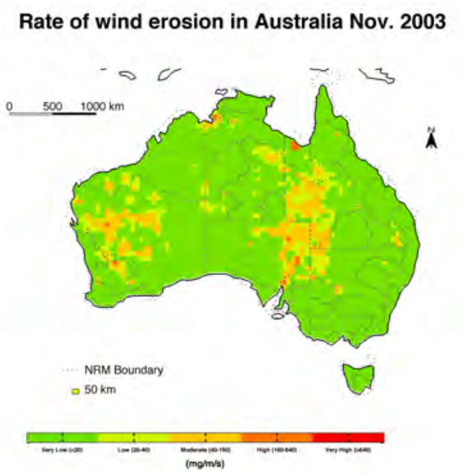
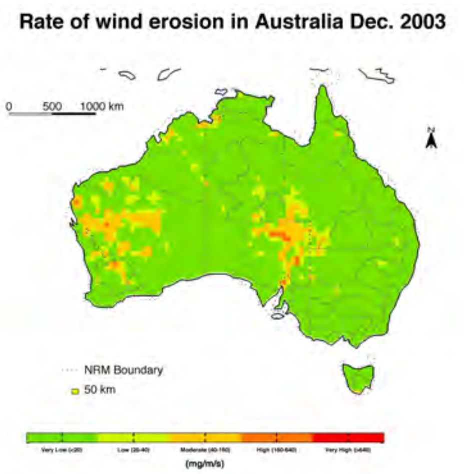


(d) October

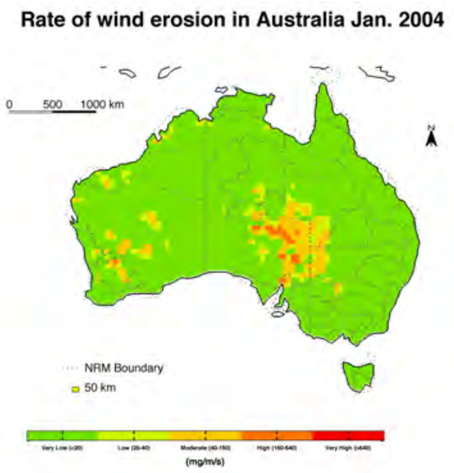


(e) November

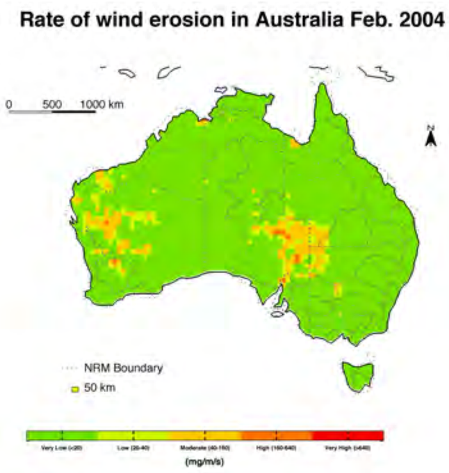


(f) December

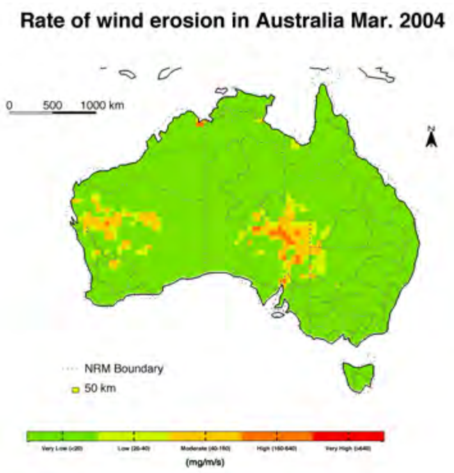
FIGURE 31: *July – December 2003 Monthly sand drift maps*



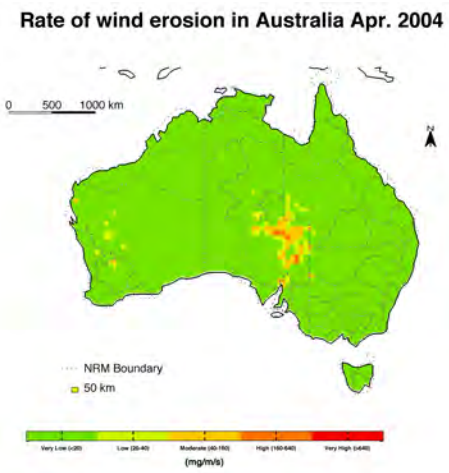
(a) January



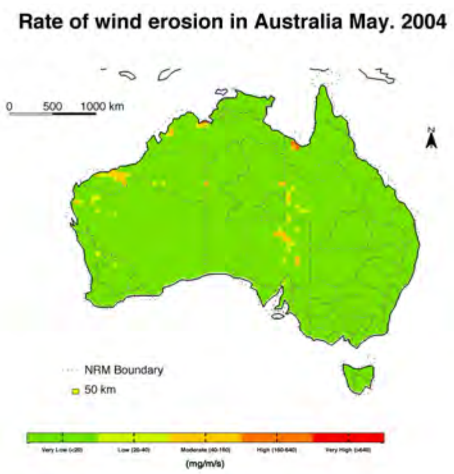
(b) February



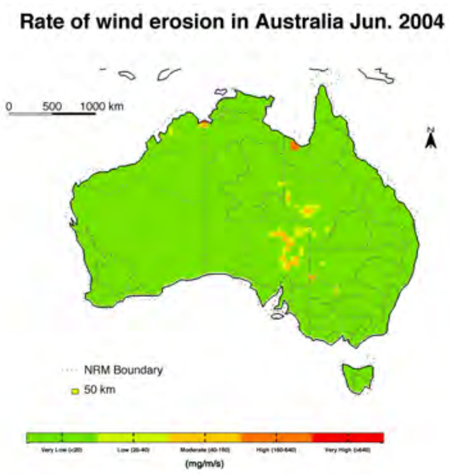
(c) March



(d) April

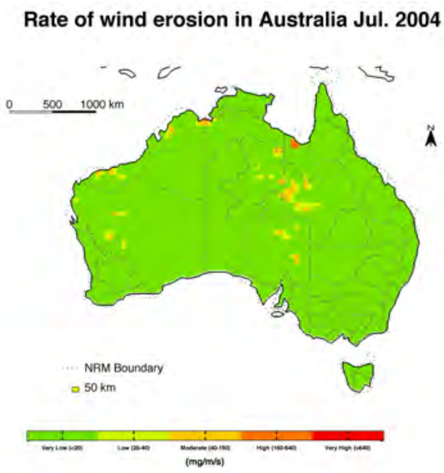


(e) May

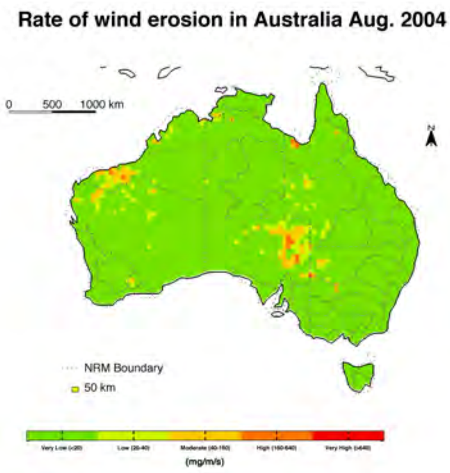


(f) June

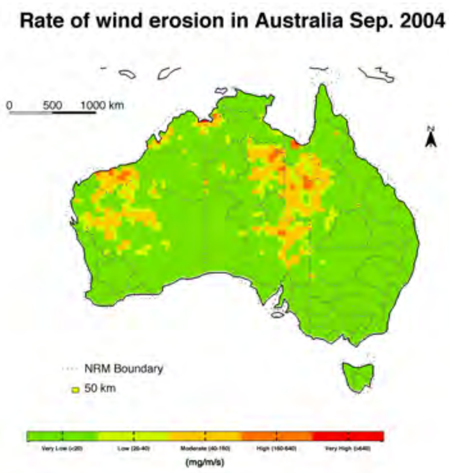
FIGURE 32: *February – June 2004 Monthly sand drift maps*



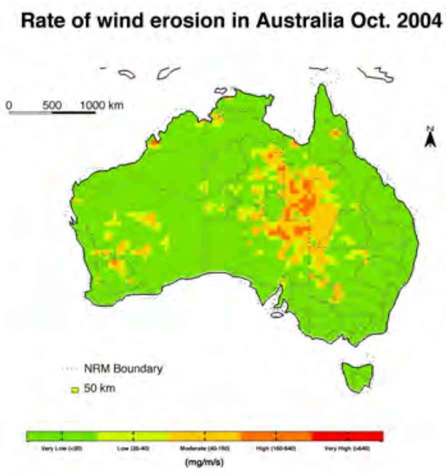
(a) July



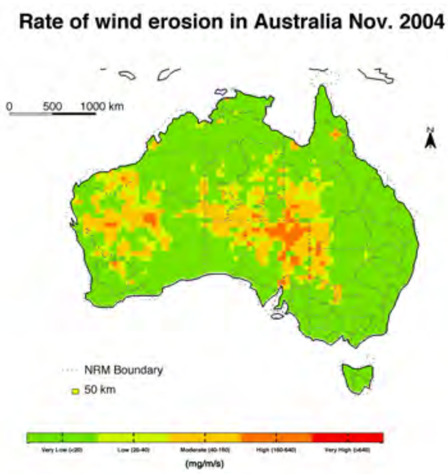
(b) August



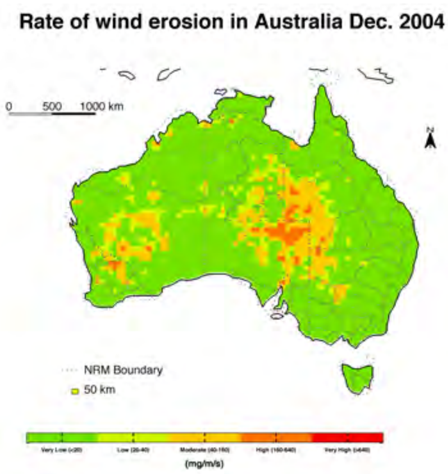
(c) September



(d) October

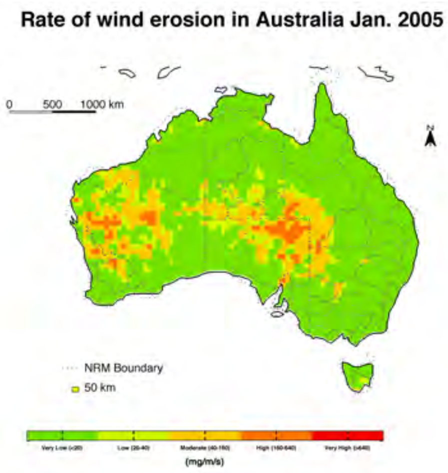


(e) November

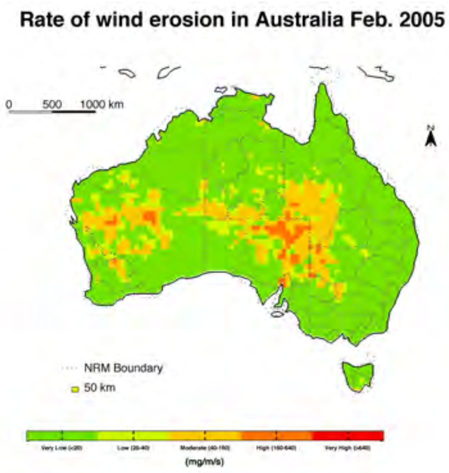


(f) December

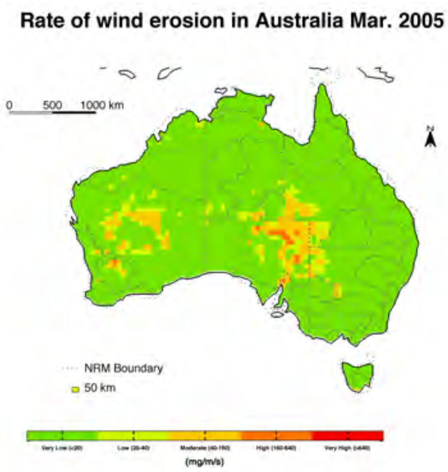
FIGURE 33: *July – December 2004 Monthly sand drift maps*



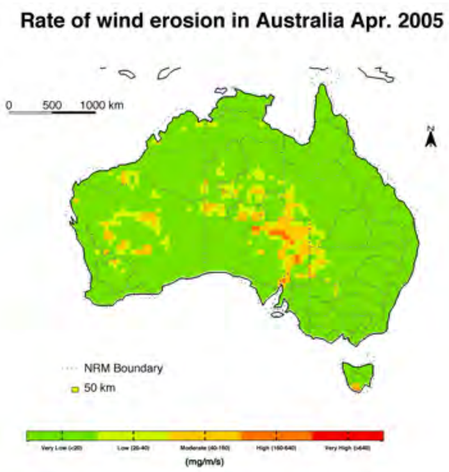
(a) January



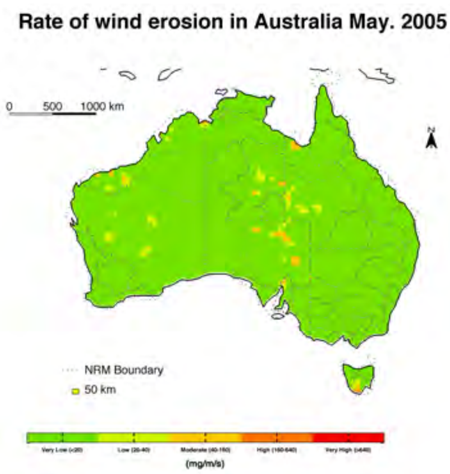
(b) February



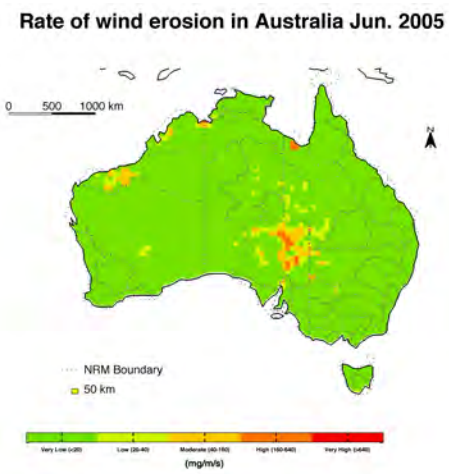
(c) March



(d) April

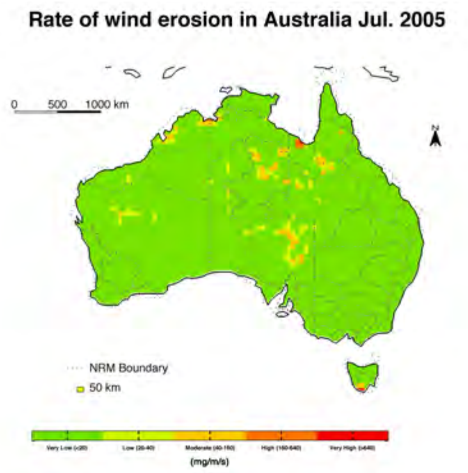


(e) May

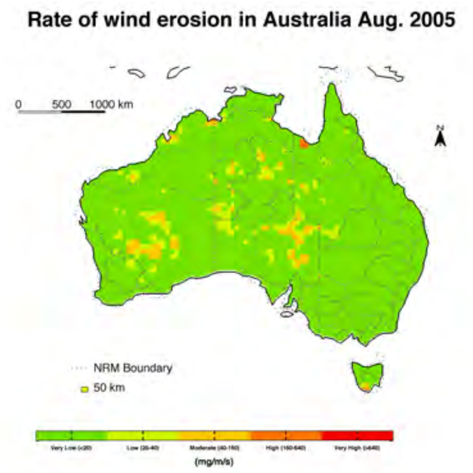


(f) June

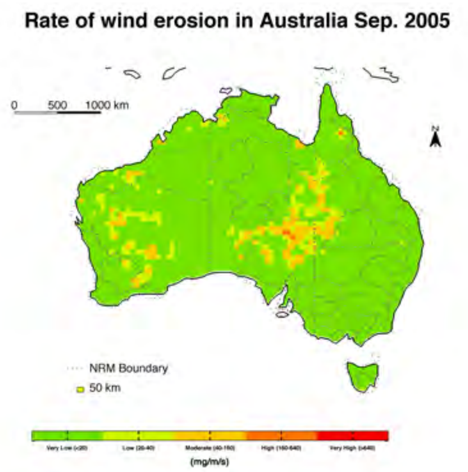
FIGURE 34: *February – June 2005 Monthly sand drift maps*



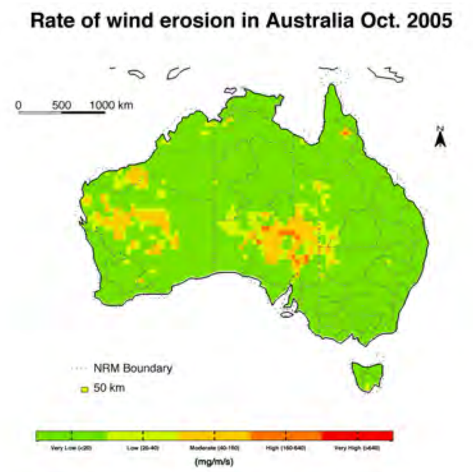
(a) July



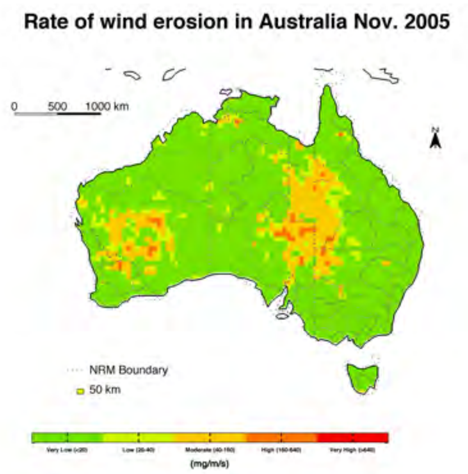
(b) August



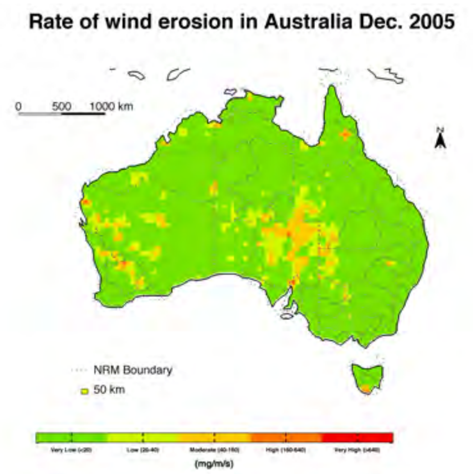
(c) September



(d) October

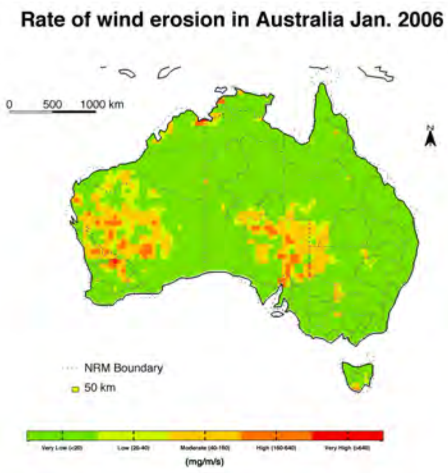


(e) November

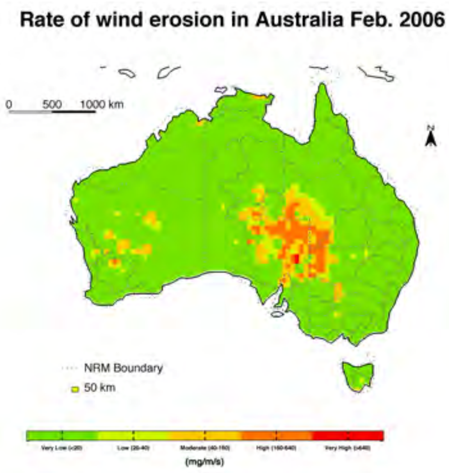


(f) December

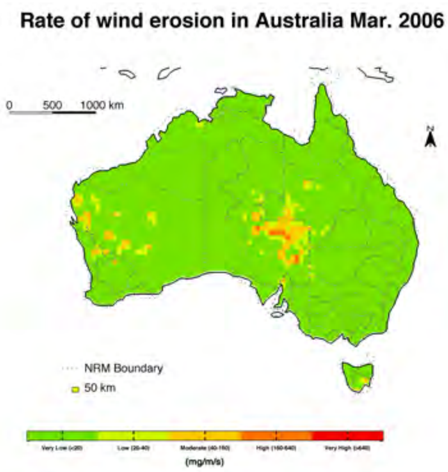
FIGURE 35: *July – December 2005 Monthly sand drift maps*



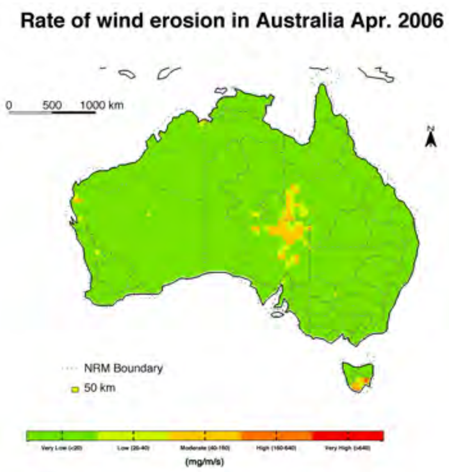
(a) January



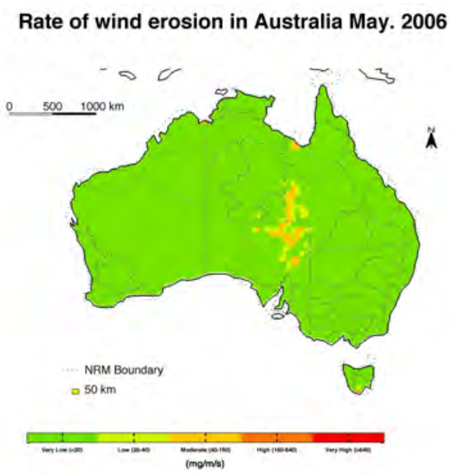
(b) February



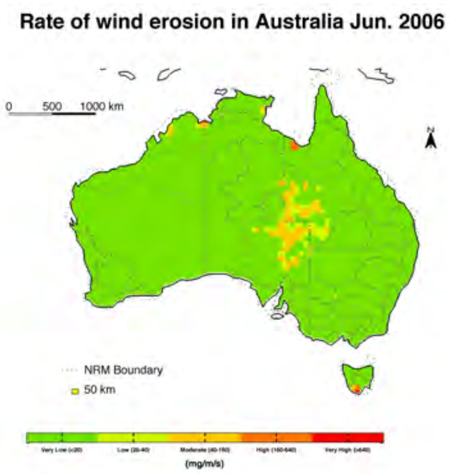
(c) March



(d) April

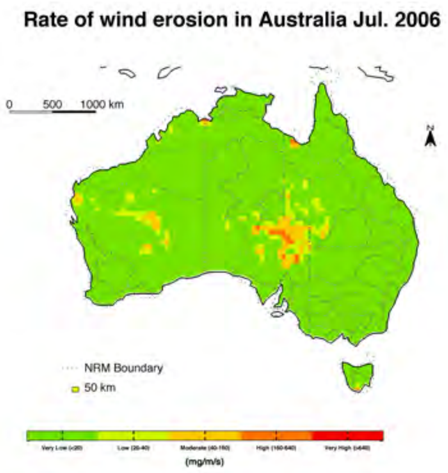


(e) May

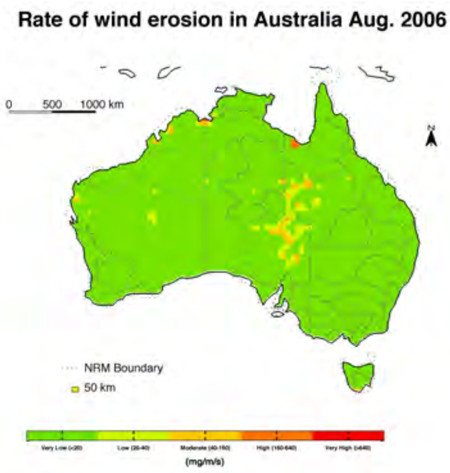


(f) June

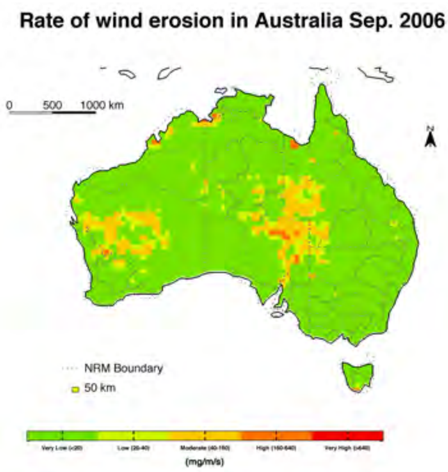
FIGURE 36: *February – June 2006 Monthly sand drift maps*



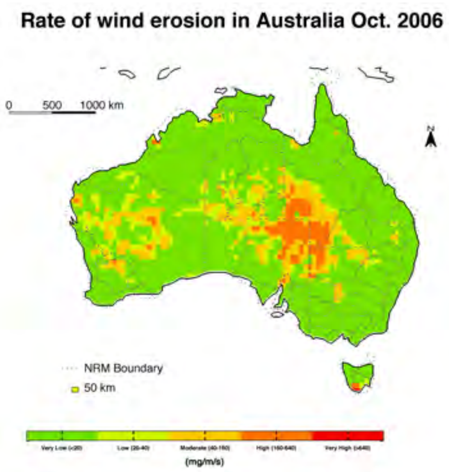
(a) July



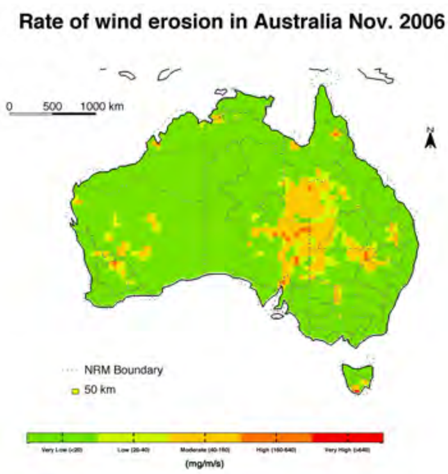
(b) August



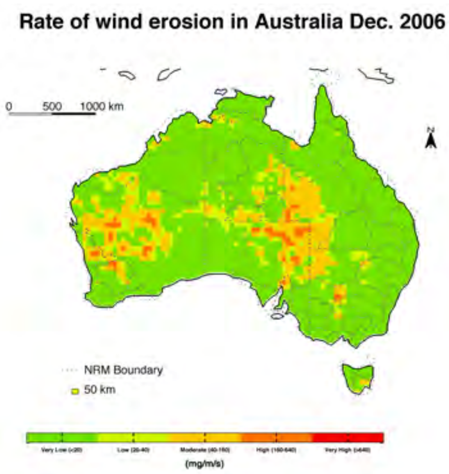
(c) September



(d) October

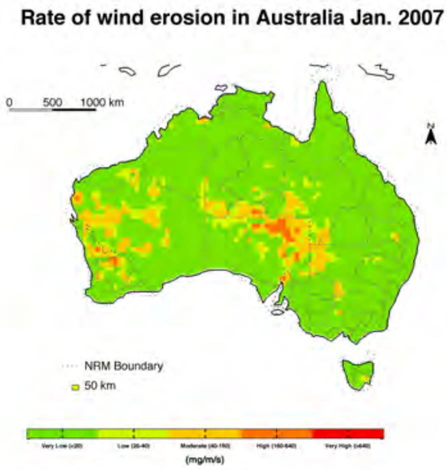


(e) November

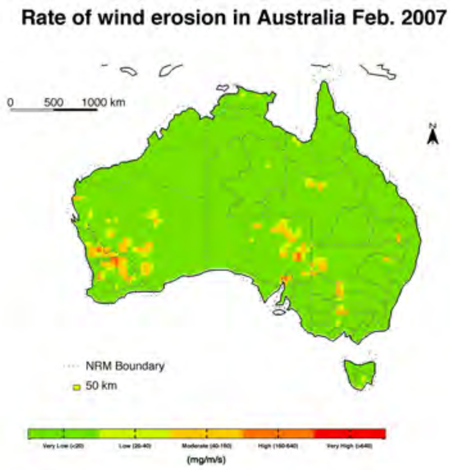


(f) December

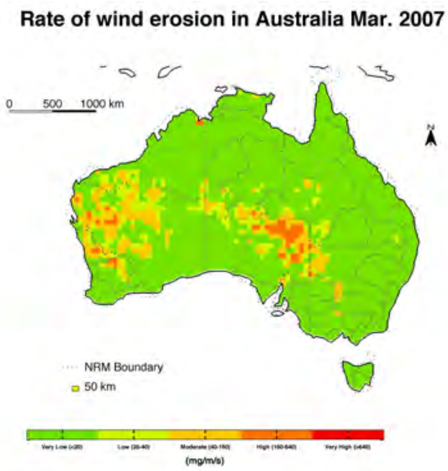
FIGURE 37: *July – December 2006 Monthly sand drift maps*



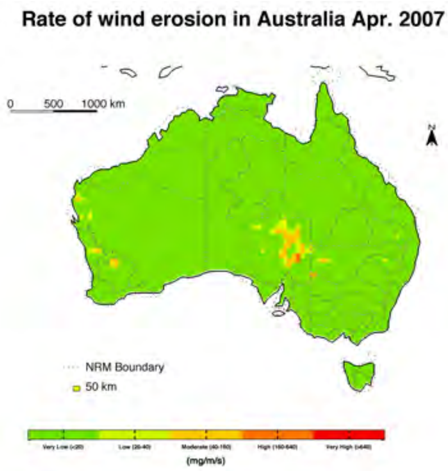
(a) January



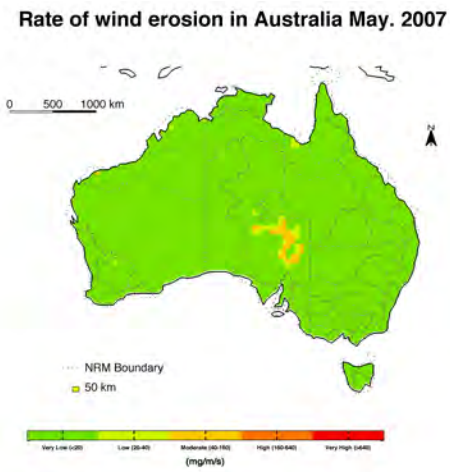
(b) February



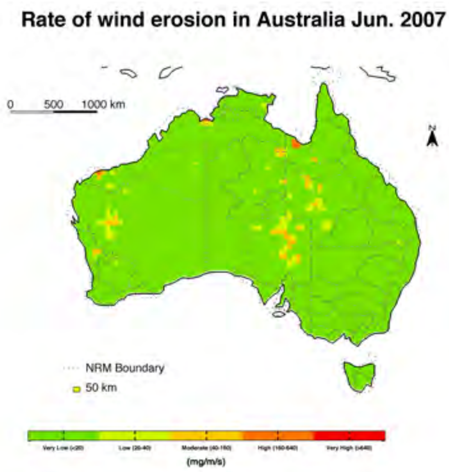
(c) March



(d) April

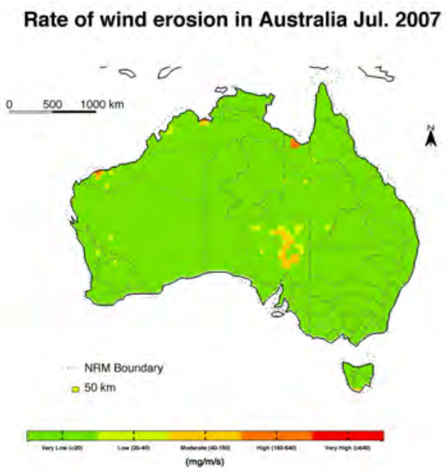


(e) May

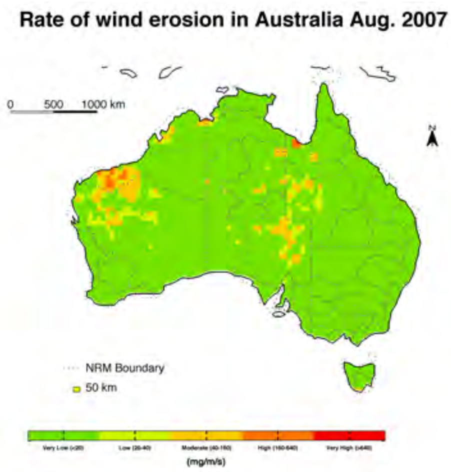


(f) June

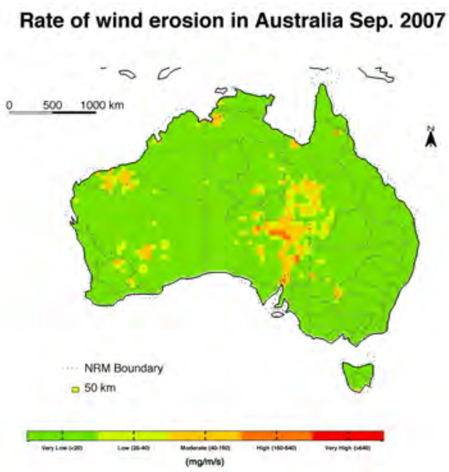
FIGURE 38: *February – June 2007 Monthly sand drift maps*



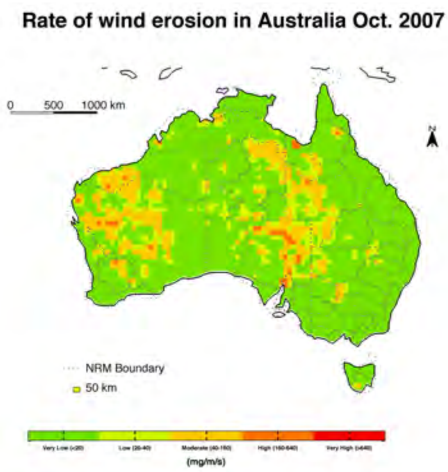
(a) July



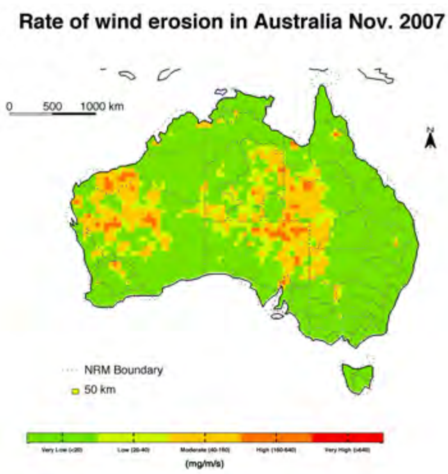
(b) August



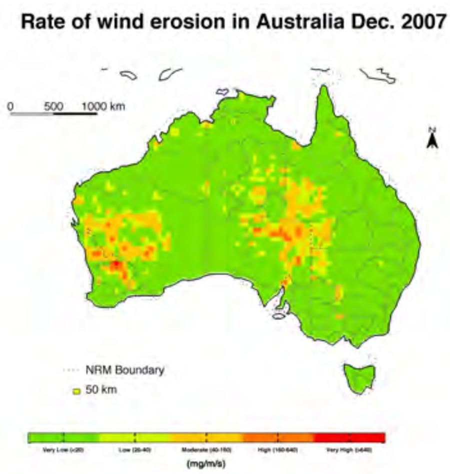
(c) September



(d) October

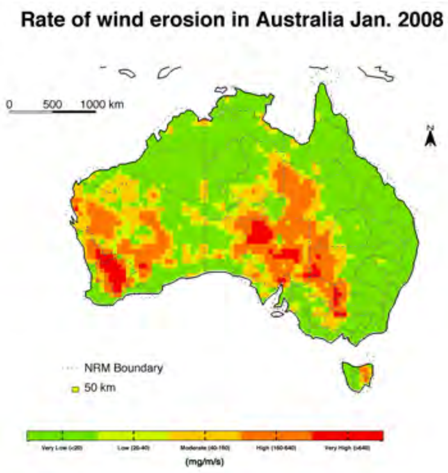


(e) November

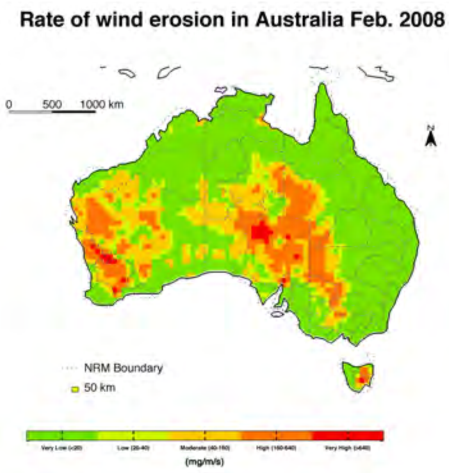


(f) December

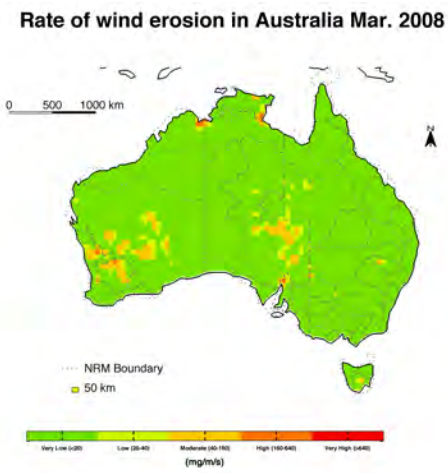
FIGURE 39: *July – December 2007 Monthly sand drift maps*



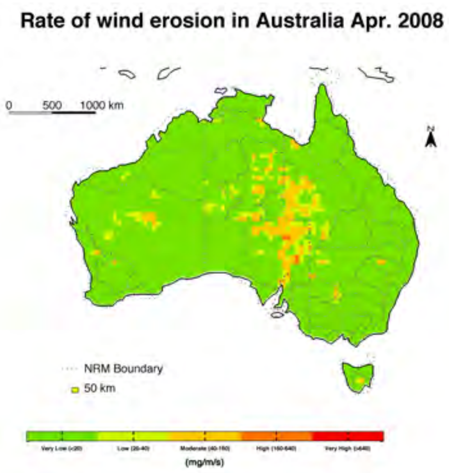
(a) January



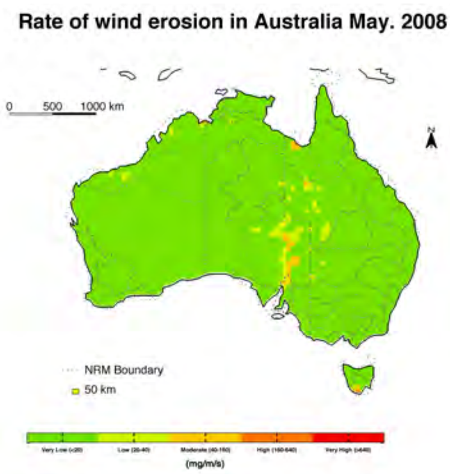
(b) February



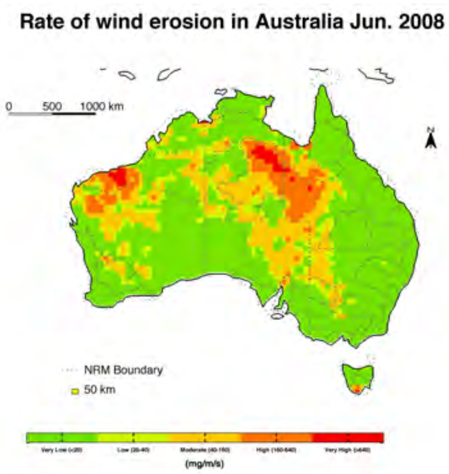
(c) March



(d) April

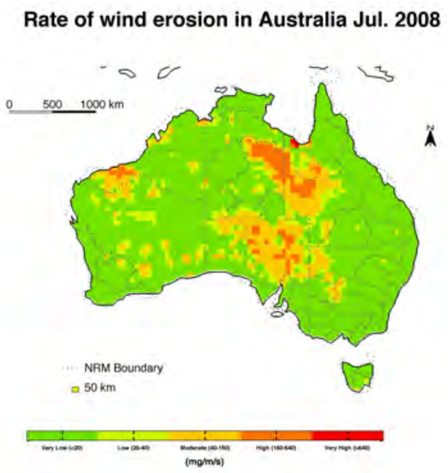


(e) May

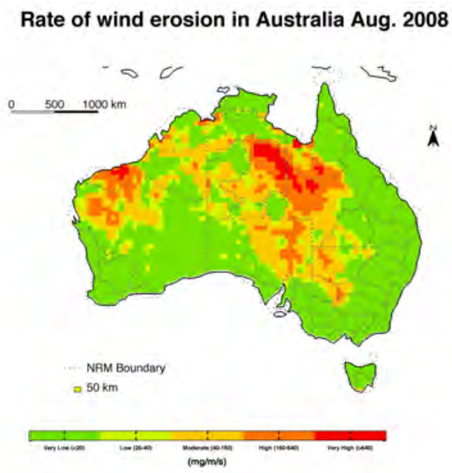


(f) June

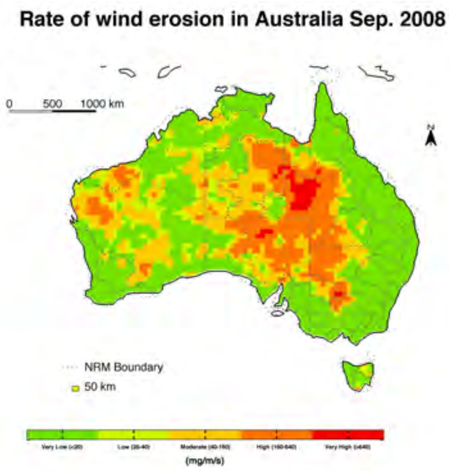
FIGURE 40: *February – June 2008 Monthly sand drift maps*



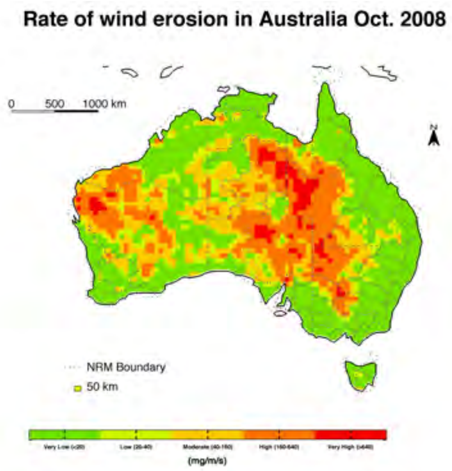
(a) July



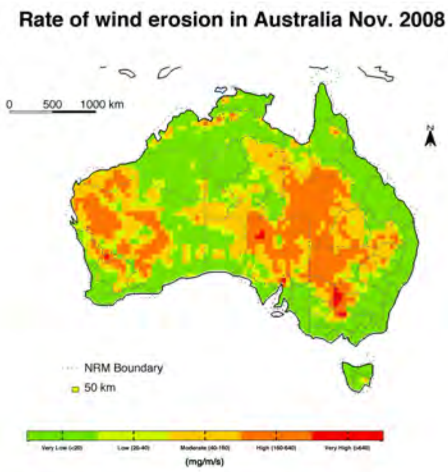
(b) August



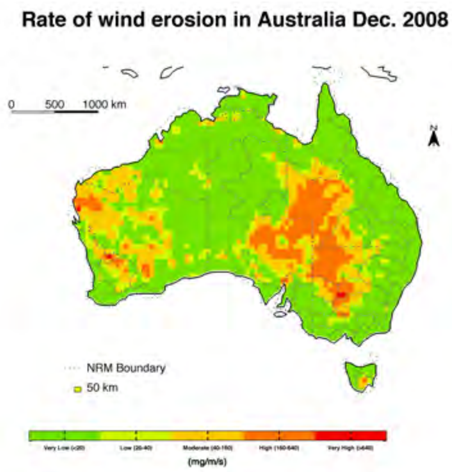
(c) September



(d) October

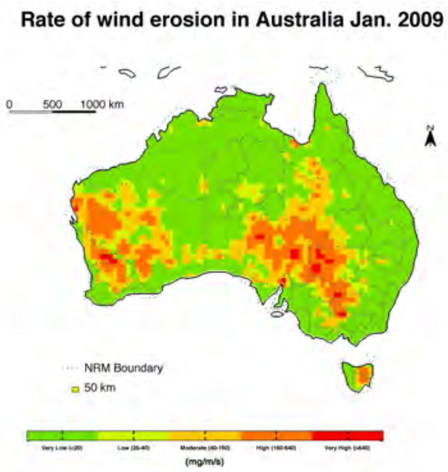


(e) November

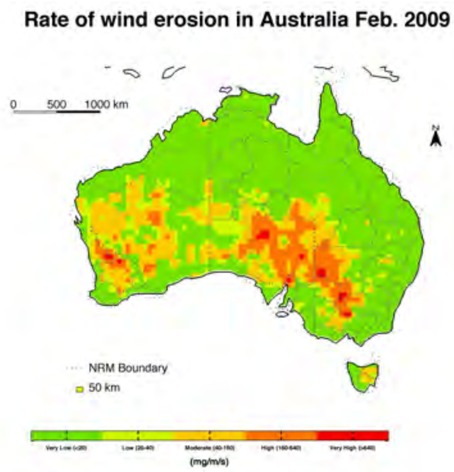


(f) December

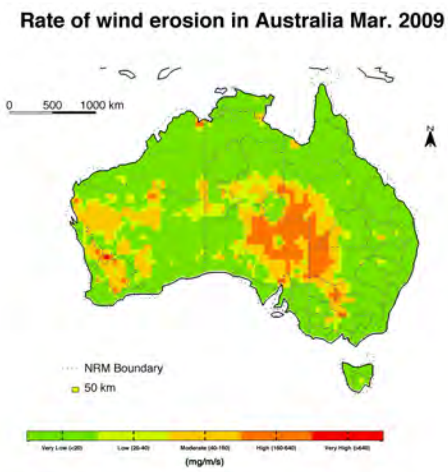
FIGURE 41: *July – December 2008 Monthly sand drift maps*



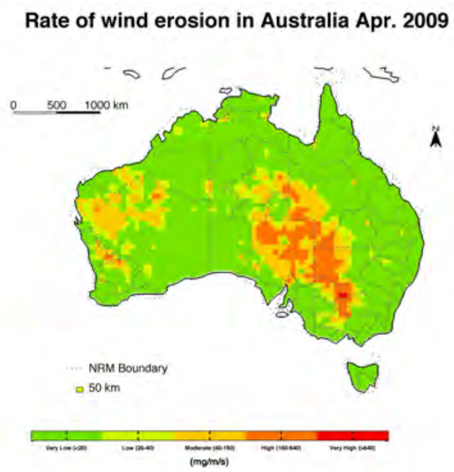
(a) January



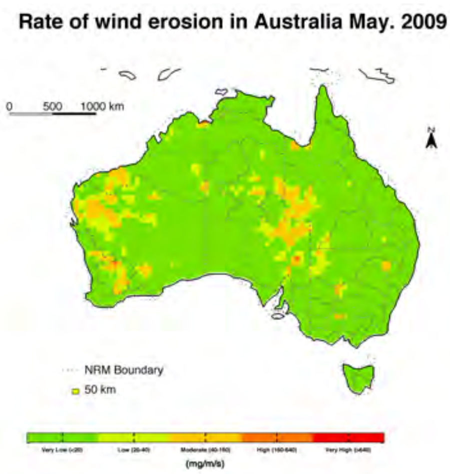
(b) February



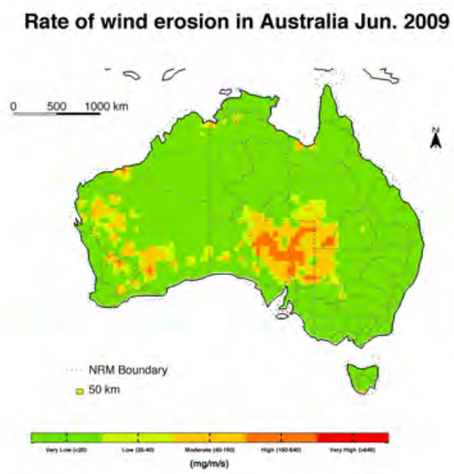
(c) March



(d) April

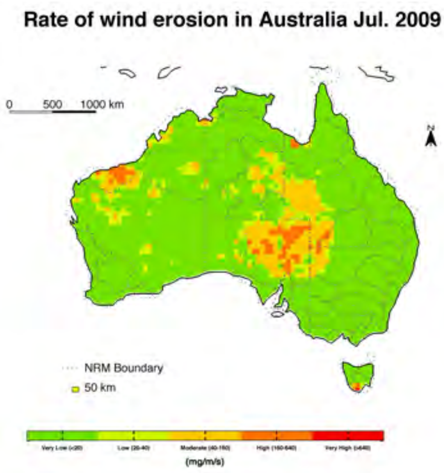


(e) May

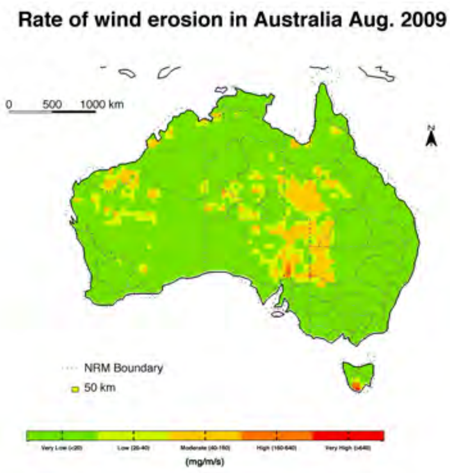


(f) June

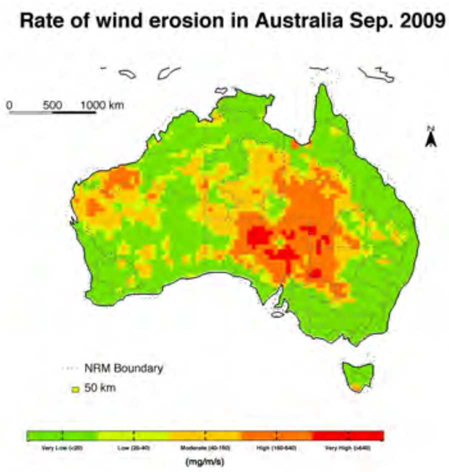
FIGURE 42: *February – June 2009 Monthly sand drift maps*



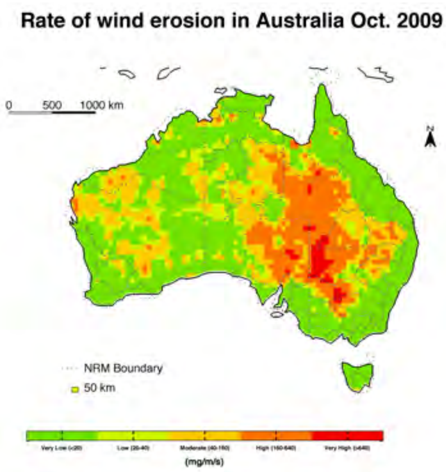
(a) July



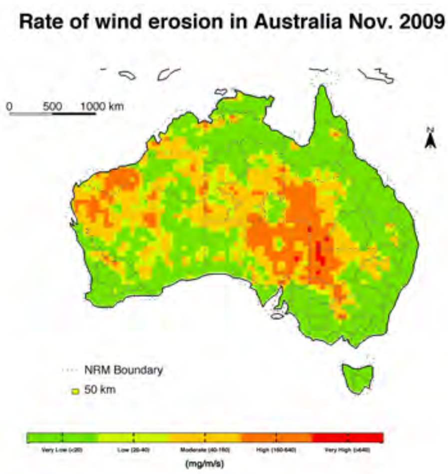
(b) August



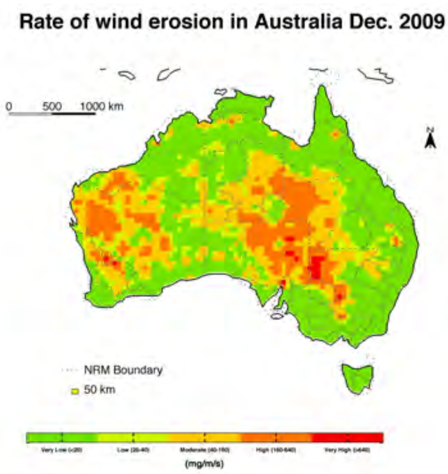
(c) September



(d) October

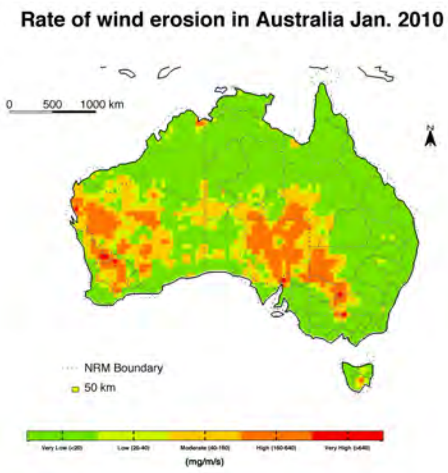


(e) November

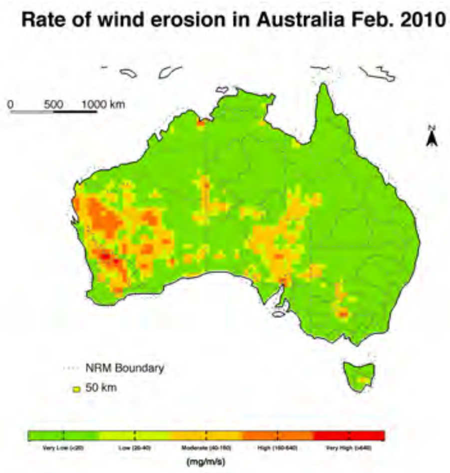


(f) December

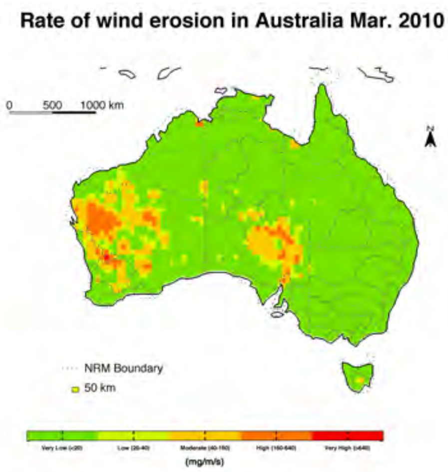
FIGURE 43: *July – December 2009 Monthly sand drift maps*



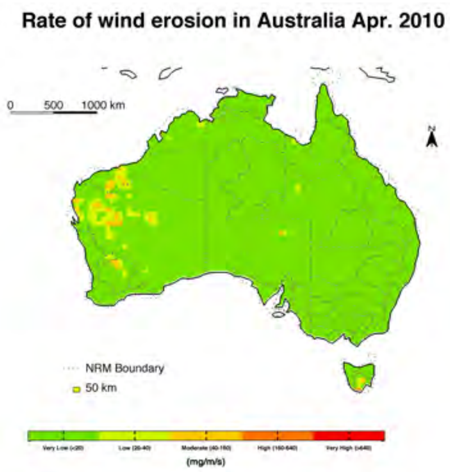
(a) January



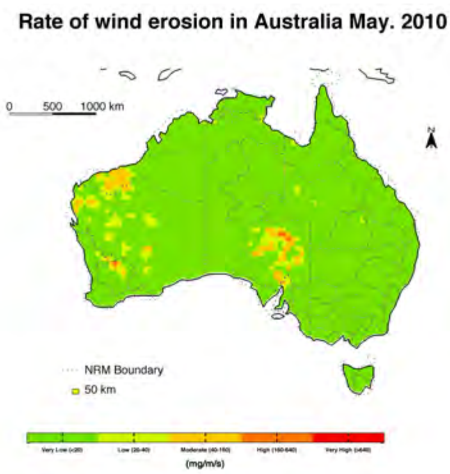
(b) February



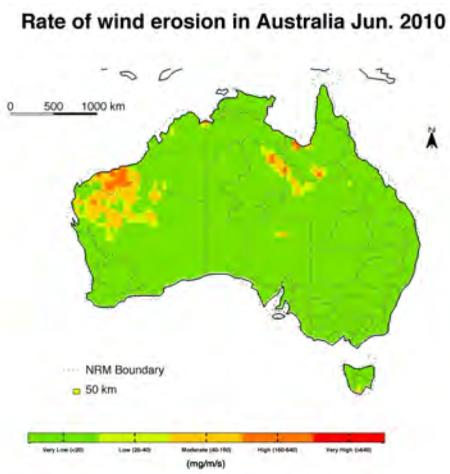
(c) March



(d) April

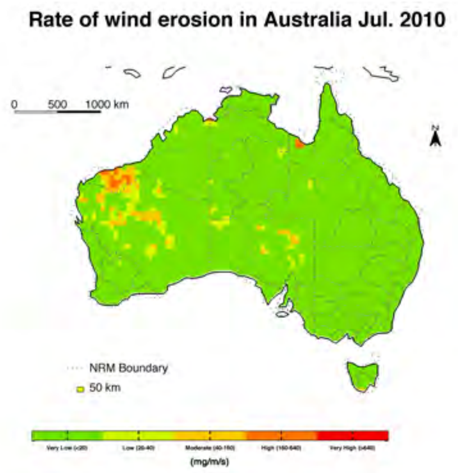


(e) May

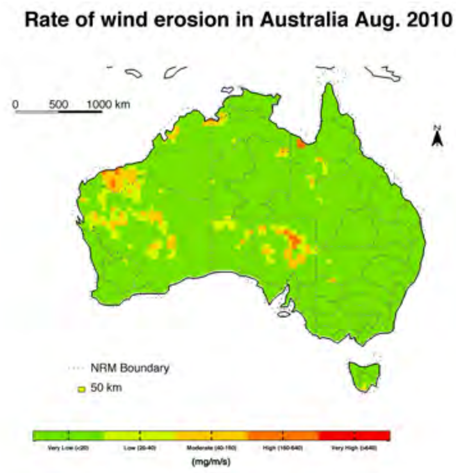


(f) June

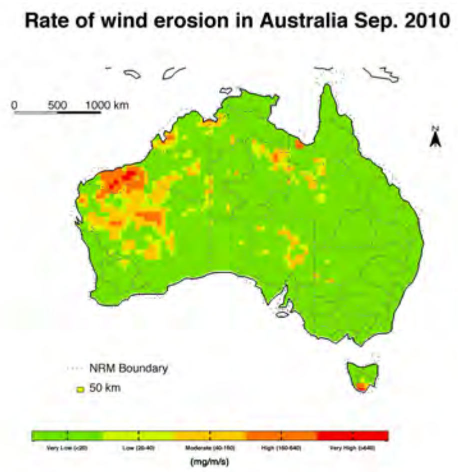
FIGURE 44: *February – June 2010 Monthly sand drift maps*



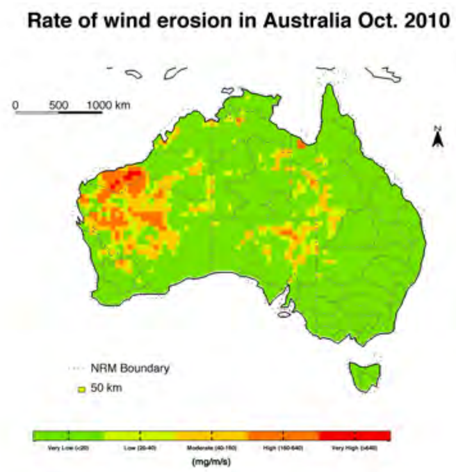
(a) July



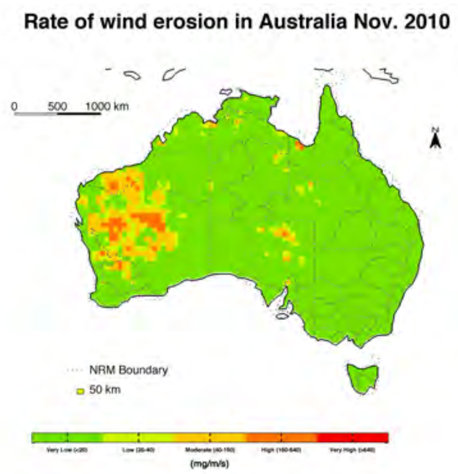
(b) August



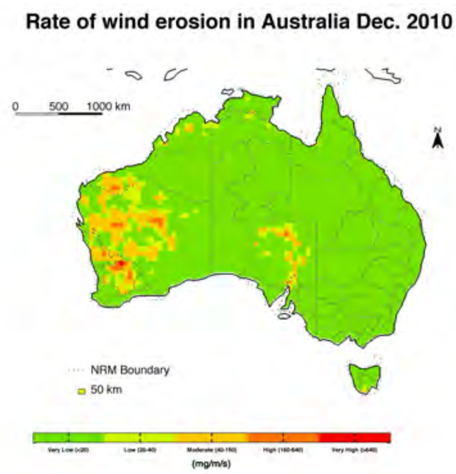
(c) September



(d) October

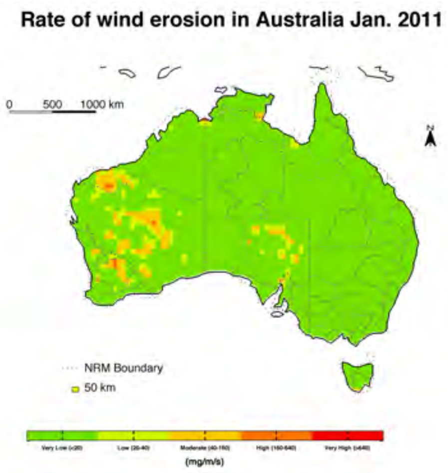


(e) November

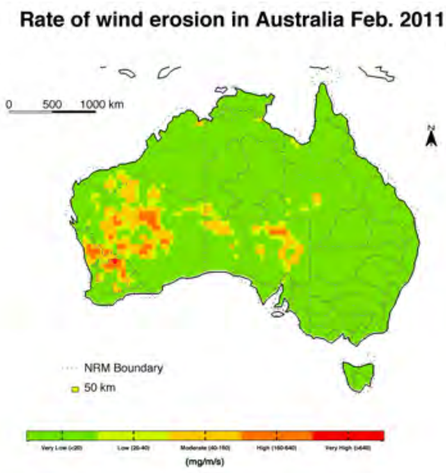


(f) December

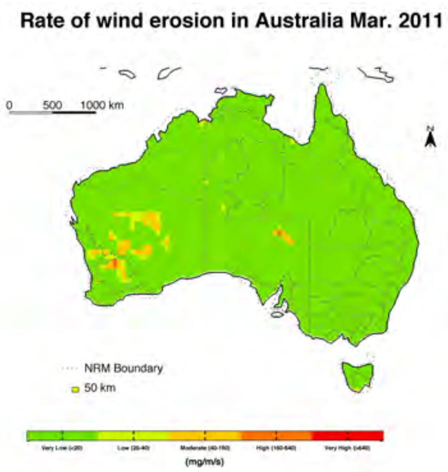
FIGURE 45: *July – December 2010 Monthly sand drift maps*



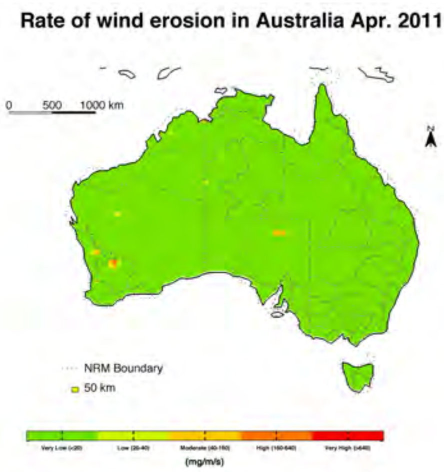
(a) January



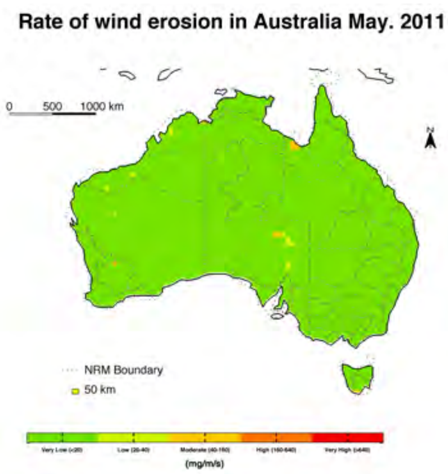
(b) February



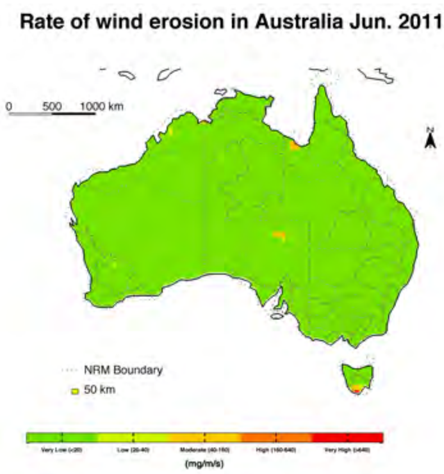
(c) March



(d) April

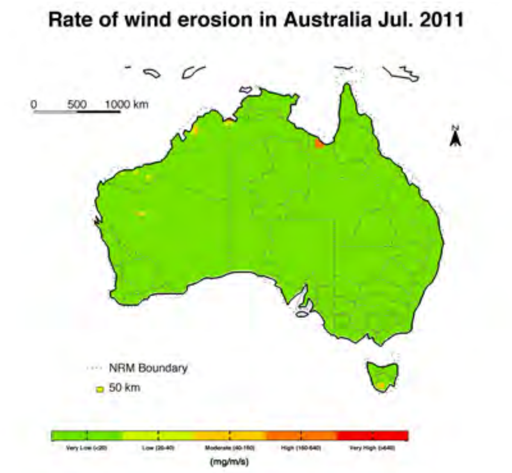


(e) May

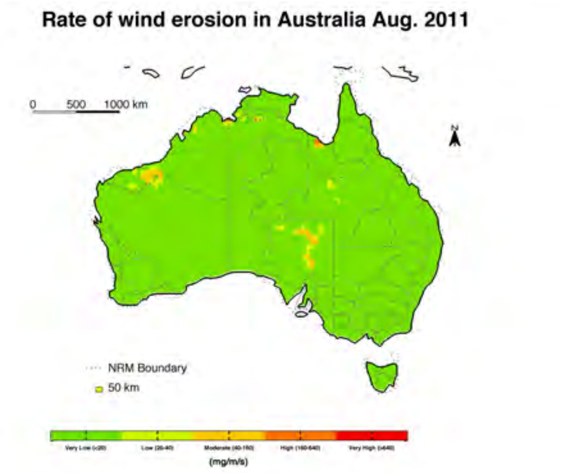


(f) June

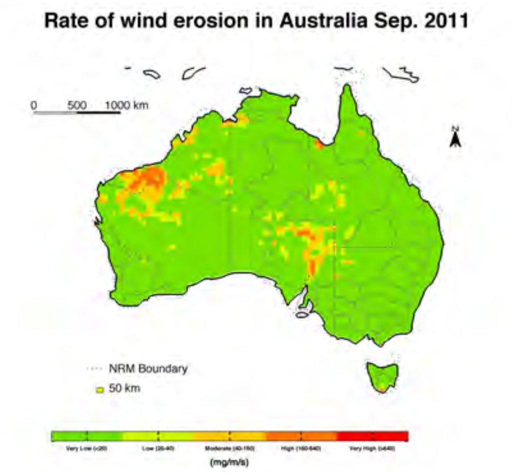
Figure 46: *February – June 2011 Monthly sand drift maps*



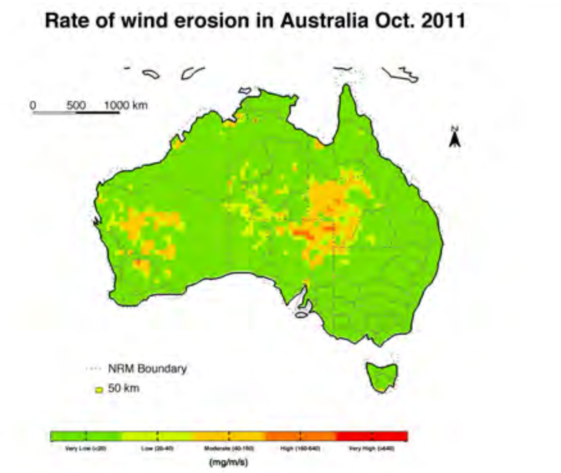
(a) July



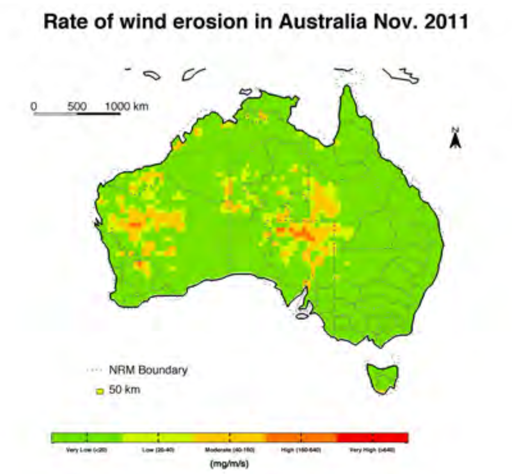
(b) August



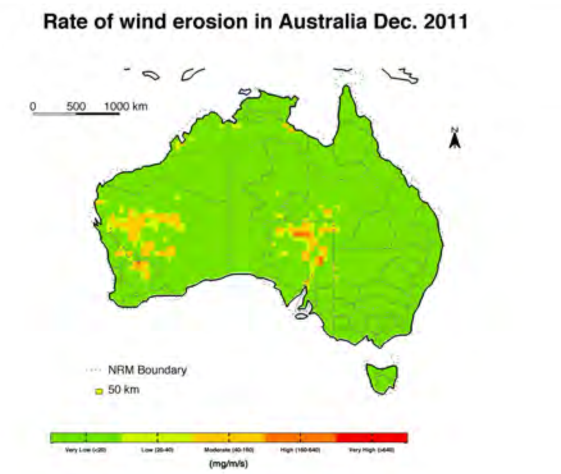
(c) September



(d) October

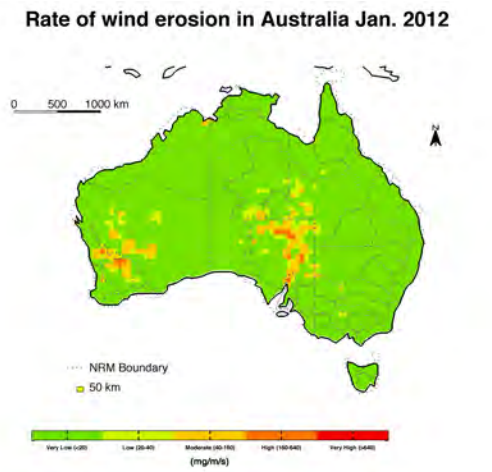


(e) November

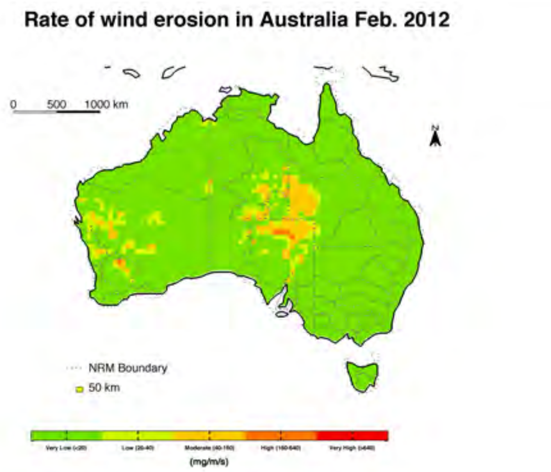


(f) December

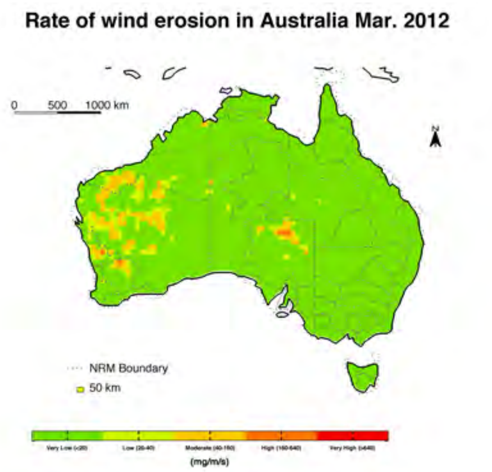
FIGURE 47: *July – December 2011 Monthly sand drift maps*



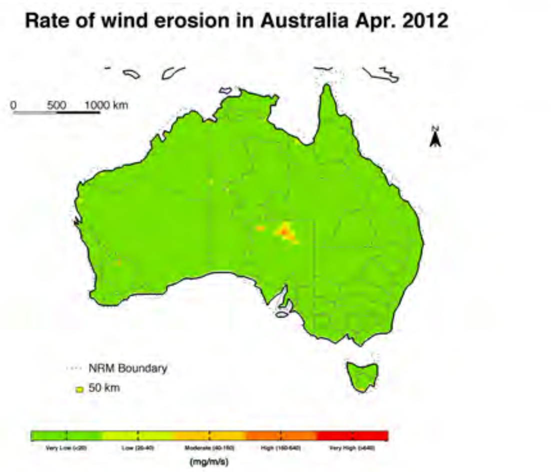
(a) January



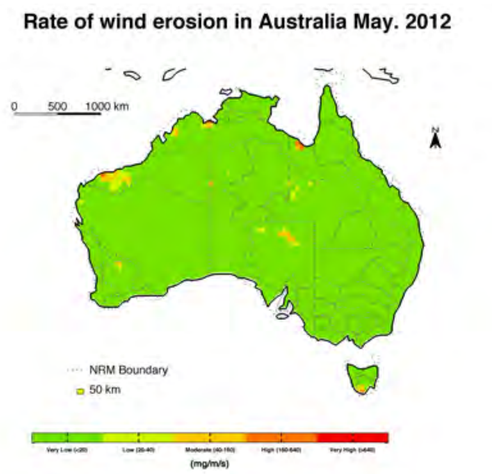
(b) February



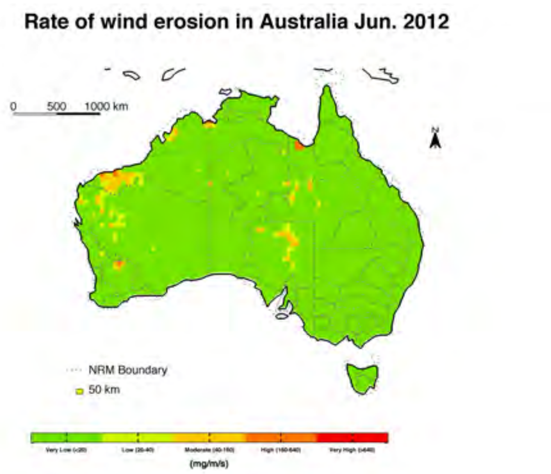
(c) March



(d) April

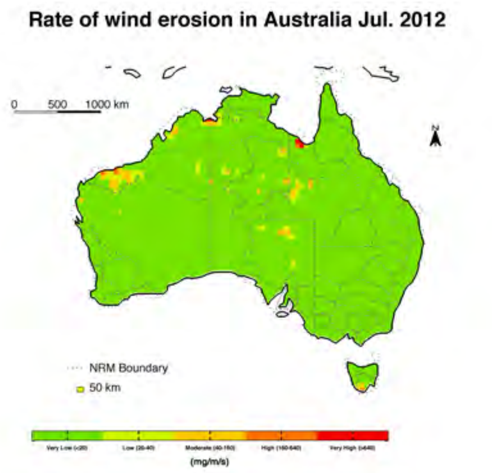


(e) May

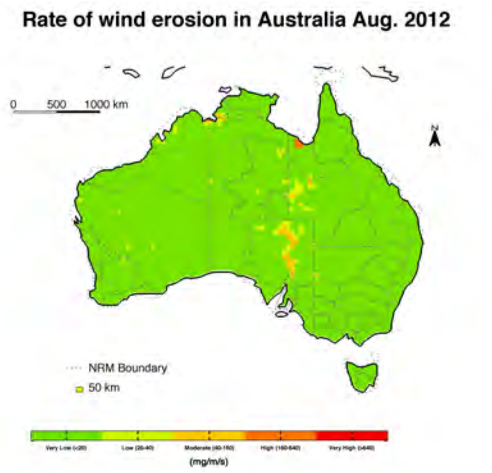


(f) June

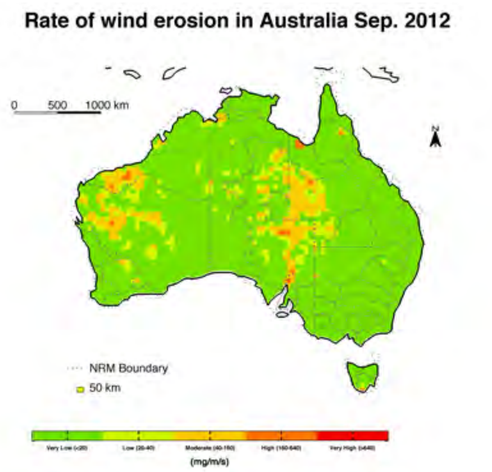
FIGURE 48: *February – June 2012 Monthly sand drift maps*



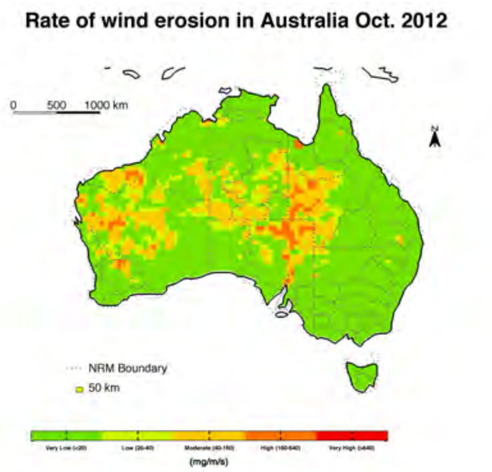
(a) July



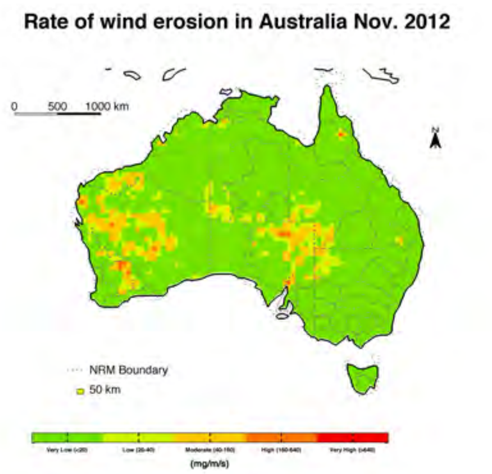
(b) August



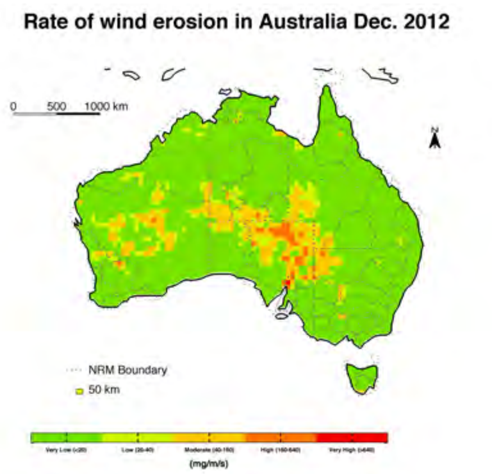
(c) September



(d) October



(e) November



(f) December

FIGURE 49: *July – December 2012 Monthly sand drift maps*