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Correspondence to: R. L. Wilby,
Department of Geography,
Loughborough University,
Leicestershire, LE11 3TU, UK

r.l.wilby@lboro.ac.uk

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Links between native forest and climate in Australia

Ravinesh C. Deo
University of Southern Queensland, Springfield, Australia

Background

There is *very high confidence* that the global average net impact of anthropogenic activities since the 1750s has contributed to an average radiative forcing of +0.6 to +2.4 Wm^{-2} (IPCC, 2007). This effect has contributed to a rise in mean global surface temperatures of approximately 0.74 ± 0.18 degC from the onset to the end of the twentieth century. It is *very likely* that temperature extremes, heat waves and heavy precipitation events will become even more frequent in future while tropical cyclones will probably become more intense with larger peak wind speeds (IPCC, 2007). The intermittent onset of extreme climatic conditions has important consequences for our society (Hennessy *et al*., 2008).

The IPCC (2007) recognised that land-cover change (LCC) is a significant radiative component of our climate system. Recent modelling evidence (Pongratz *et al*., 2009) suggests that modifying the native vegetation can offset the natural climate. On a regional scale, this is manifested through changes in solar energy available for evaporation and transpiration processes, exchange of sensible (convective) and latent (evaporative) heat fluxes between the land surface and atmosphere, and through non-linear feedbacks on soil moisture. On a global scale, deforestation may lead to an increase or decrease in emissions and deposition of carbon, nitrogen and other chemically active species. This may downgrade the natural ecosystem through climatic feedback mechanisms (Pitman *et al.*, 2009).

We have learnt several lessons from deforestation events in the Amazon Basin, Sahel and Brazil. Studies conducted for the Amazon have shown that deforestation has contributed to reduced moisture-cycling and convective energy fluxes in the lower atmosphere and produced teleconnections in atmospheric circulation to mid and high latitudes. Los *et al*. (2006) used a statistical model of vegetation greenness to estimate vegetation-rainfall coupling strengths in the Sahel region. Their experiments demonstrated that the interaction between vegetation and rainfall can account for as much as 30% of the variability in annual rainfall in hot-spot regions. In another study, Voldoire and Royer (2004) found links between LCC and temperature extremes, where changes in land cover contributed to decreases in minimum surface temperatures, increases in maximum surface temperatures and increases in the fraction of days with no measurable rainfall. On the balance of available scientific literature, this article provides a synthesis of the impact of vegetation cover change on Australian regional climate by highlighting recent modelling outcomes and exploring the underlying physical mechanisms involved.

Current trends in the Australian climate

Over the last 100 years, the Australian continent has warmed by ~1.0 degC with the most pronounced warming in eastern Australia since the 1950s (Nicholls, 2006). Additionally, there has been an increase in the mean annual rainfall in the northwest and a decrease in central and southeastern regions (Shi *et al*., 2008) and in southwest Australia (Nicholls and Lavery, 1992). The analysis of historical rainfall by Gallant *et al*. (2007) and mean surface temperature by Alexander and Arblaster (2008) revealed increases in both extremes which were regionally confined. Since the 1950s, the frequency of hot days (daily maximum temperature ≥ 35°C) has increased by 0.10 days per year and hot nights (daily minimum temperature ≥ 20°C) by 0.18 nights per year. The number of cold days (daily maximum temperature ≤ 15°C) and cold nights (daily minimum temperature ≤ 5°C) has decreased by 0.14 days per year and 0.15 nights per year respectively (Nicholls and Collins, 2006). For eastern Australia, droughts have become hotter since 1973 (Nicholls, 2004) and their increasing persistence in the Murray-Darling Basin – Australia's 'national food basket' – is stimulating significant public debate. Climate extremes also represent an unequivocal economic cost to the Australian community. This was exemplified by the 2002/2003 El Niño drought which led to ~0.8% decrease in employment and 30% and 1.6% reduction in agricultural productivity and National Gross Domestic Product respectively (Adams *et al*., 2002).

Deforestation (LCC) in Australia

In the 200 years since European colonisation began, there is a clear footprint of widespread modification, transformation and degradation of Australia's intact native ecosystems (Figure 1; Table 1; Beeton *et al*., 2006). The regional hotspots of LCC are southeast Australia, cleared from 1800 to the mid-1900s, southwest Western Australia, cleared between 1920 and the 1980s, and more recently inland Queensland. This clearance has resulted in approximately 15% of the continent being severely modified into intensive land-use zones. Agricultural areas comprising extensive grazing zones now cover ~43% of the continent and intensive cropping and improved pastures approximately 10%. Much of this extensively grazed area has been affected by episodes of soil

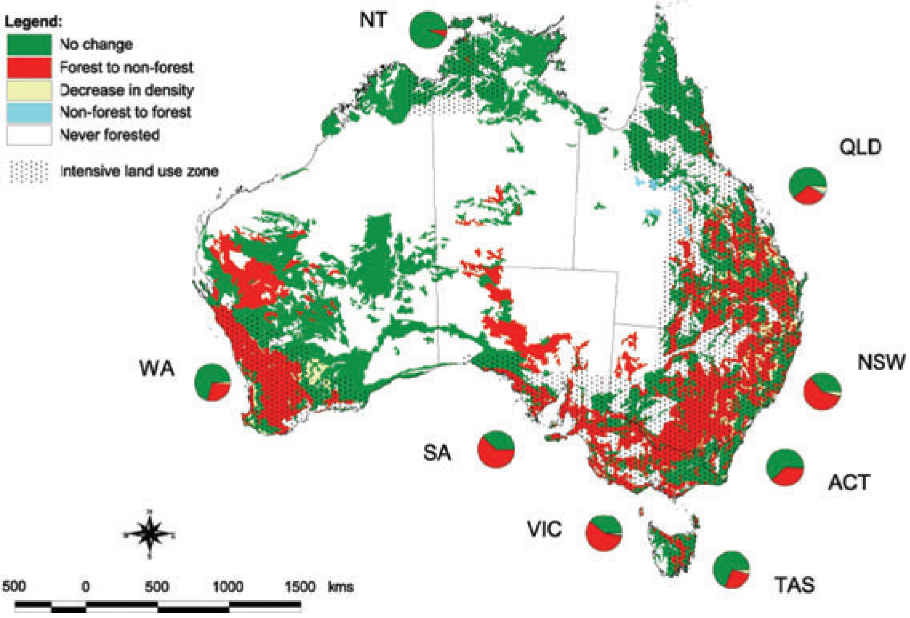

Figure 1. The land-cover map of Australia showing changes in native vegetation since European settlement. ACT, Australian Capital Territory; NSW, New South Wales; NT, Northern Territory; QLD, Queensland; SA, Southern Australia; TAS, Tasmania; VIC, Victoria; WA, Western Australia. (Data: courtesy of National Vegetation Inventory System; Barson et al., 2000.)

Table 1

The Native Vegetation Inventory Assessment (NVIS) of native vegetation by type prior to European settlement and as at 2001–2004 (Beeton et al., 2006).

Vegetation Type	*Pre-European (km^2)*	*Current (km^2)*	*Difference (km^2)*	*Percentage lost*	*Percentage left*
Rainforest	53 469	35 200	18 269	34%	66%
Eucalyptus Tall Open Forest	40 801	35 344	5 457	13%	87%
Eucalyptus Open Forest	394 280	272 121	122 159	31%	69%
Eucalyptus Low Open Forest	4 726	3 952	774	16%	84%
Eucalyptus Woodland	1 362 263	892 920	469 343	34%	66%
Acacia Forest	495 059	408 632	86 427	17%	83%
Callitris Forest	40 278	32 296	7 982	20%	80%
Casuarina Forest	166 303	149 262	17 041	10%	90%
Melaleuca Forest	106 057	99 561	6 496	6%	94%
Other Forests	80 772	72 414	8 358	10%	90%
Eucalyptus Open	498 663	458 905	39 758	8%	92%
Tropical Eucalyptus woodlands/grasslands	115 503	112 481	3 022	3%	97%
Acacia Open	320 981	314 040	6 941	2%	98%
Mallee Woodland	387 230	271 529	115 701	30%	70%
Low Closed Forest and Tall Closed Shrublands	25 819	16 278	9 541	37%	63%
Mangroves	9 664	9 325	339	3%	97%
Total Forest and Woodland	**4 101 868**	**3 184 260**	**917 608**	**22%**	**78%**
Acacia Shrubland	865 845	851 274	14 571	2%	98%
Other Shrublands	157 530	123 464	34 066	22%	78%
Chenopod Shrub, Shrub and Forbland	447 239	436 801	10 438	2%	98%
Total Shrublands	**1 470 614**	**1 411 539**	**59 075**	**4%**	**96%**
Heath	9 256	8 071	1 185	13%	87%
Tussock Grassland	559 850	525 888	33 962	6%	94%
Hummock Grassland	1 368 861	1 367 973	888	0%	100%
Other Grassland	67 977	64 810	3 167	5%	95%
Total Grassland	**1 996 688**	**1 958 671**	**38 017**	**2%**	**98%**
Total Native Vegetation	**7 578 427**	**6 562 541**	**1 015 885**	**13%**	**87%**

and pasture degradation, followed by partial recovery mainly driven by some favourable climatic conditions (McKeon *et al*., 2004).

Figure 1 shows a land-cover map of Australia with cleared regions marked in red. This information was gathered by the reconstruction of precolonisation vegetation from historical records compared with remnant native vegetation (Australian Surveying and Land Information Group, 1990). Within the intensive land-use zones of southeast and southwest Western Australia, approximately 50% of native forest and 65% of native woodland has been cleared or severely modified (Barson *et al.,* 2000). Data reported by Graetz (1995) indicates that major LCC was initiated by agricultural development, with annual rates of clearing peaking during the 1970s when extensive areas were cleared in southwest Western Australia and Queensland for grain production and grazing pasture improvement, respectively.

For southwest Western Australia, land clearing began during the 1890s to accommodate an expansion of agricultural commodities such as sheep farming and wheat production. These activities gained momentum after World War II (Allison and Hobbs, 2006). After the inception of the Federation in 1901, southwest Western Australia enjoyed a decade of rapid expansion in agriculture with the opening of farming areas such as Meckering (1889) and Yilgarn (1899). The result was an accelerated land clearing by about tenfold from ~50 000 hectares in 1890 to 490 000 hectares by 1900. This continued at a moderate rate after this period with over 13 million hectares of natural vegetation being cleared, mainly for cultivation of winter cropping (Ray *et al.,* 2003).

The direct consequences of increasing salinity due to rising groundwater table became a major challenge for environmental management in southeast and southwest Western Australia (Gordon *et al*., 2003). Despite this problem, commercial activities such as timber industry, mining and urbanisation continued to compound the nominal clearing rates. This continued until recently when active revegetation programs by the Commonwealth and State governments were implemented to address it. In Queensland, land clearing is now regulated by the Vegetation Management Act (1999) which provides a consistent framework for protecting high-value regrowth vegetation across freehold, indigenous and leasehold land. A similar practice in Western Australia is enforced by the Environmental Protection (Clearing of Native Vegetation) Regulations (2004).

How does the climate change signal correlate with loss of native vegetation?

Since the pioneering research on causal links between LCC and climate in the early 1990s (Shukla *et al.,* 1990; Meher-Homji, 1991), there is escalating evidence that the natural climate system is sensitive to perturbations in land cover. Prominent observational data for the intensive cropping regions and native vegetation areas along the 750-kilometre Bunny Fence in southwest Western Australia is a classic example (Lyons *et al.,* 1993). Experiments conducted across the Bunny Fence have demonstrated that following the clearance of intact native vegetation, the modification of surface albedo (a measure of how much solar energy is received by land surface), surface roughness (a measure of surface texture), and latent and sensible heat fluxes (measures of energy exchange) have contributed to an increase in cloud formation over natural forests (Figure 2). The impacts of land clearing on underlying climatic patterns across the Bunny Fence have been well documented by Lyons (2002) and Ray *et al.* (2003). This effect was also demonstrated by Schwerdtfeger (1993) using aerial photographs showing enhanced formation of cumulus clouds over the Bunny Fence which actually separated the woody vegetation region towards the east from agricultural farms towards the west of southwest Western Australia (Figure 2). More recently, Nair *et al.* (2007) analysed satellite data to show that the 50% replacement of native vegetation with cropping has resulted in a decrease in radiation of ~7Wm^{-2}. This effect appeared to be most pronounced during the fallow season.

Taking advantage of the rapidly growing modelling expertise, researchers are now using climate system models to predict the impact of LCC on regional climate. Narisma and Pitman (2003) used the Pennsylvania State University–National Centre for Atmospheric Research (PSU–NCAR) Mesoscale Model (MM5) to highlight anomalies in spatial patterns of climate for January and July over an eight-year period, backdating conditions in 1788 relative to those of 1988. Their study demonstrated a strong impact on surface temperatures in southwest Western Australia and a reduction in rainfall of the order of one millimetre per day over southwest regions. Pitman *et al.* (2004) used three mesoscale models to simulate five July climates for natural and current land cover. Their results concluded that LCC could explain up to 50% of the observed warming. In every simulation following LCC, they found a reduction in rainfall over southwest Western Australia and an increase in rainfall inland that matched the observations quite well. The reduction in rainfall of approximately one millimetre per day correlated well with the reduction in surface roughness due to loss of native vegetation.

Using a fully-coupled climate model with natural and anthropogenic atmospheric forcings, Timbal and Arblaster (2006) investigated the cause of rainfall decline in southwest Western Australia. Their analysis showed that land-cover modification had a direct impact on the large-scale (convective) and total rainfall, and an indirect impact on downscaled (local) rainfall. Using the coupled version of the Commonwealth Scientific and Industrial Research Organization (CSIRO) Mark 3 Global Climate Model (GCM), McAlpine *et al.* (2007) analysed data from a pair of ensembles (10 members each) for the period 1951–2003 to quantify changes in regional climate by comparing model results from pre-European and modern-day land-cover characteristics. The results demonstrated a statistically significant warming of mean annual surface temperatures of the order of ~0.1–0.6 degC in eastern Australia and southwest Western Australia. Simulations showed that mean annual rainfall decreased by 4–8% in southeast Australia, increased by 4–12% over southern and central

Figure 2. An aerial view showing the formation of cumulus clouds over the Bunny Fence in southwest Western Australia that separates the native vegetation cover region (East) from the farming areas (West). (Photograph: Schwerdtfeger, 1993.)

Australia and decreased by up to 4% in southwest Western Australia. The summer surface temperature showed a positive anomaly of 0.2–2.0 degC for eastern Australia and 0.5°C for southwest Western Australia. Mean summer rainfall showed a decrease of 4–12% in eastern Australia and 4–8% in southwest Western Australia which were both statistically significant and coincided with regions with the most extensive LCC. The results also revealed a warmer El Niño drought over the 2002/2003 period.

Narisma and Pitman (2006) conducted an interactive study using a high-resolution regional climate model to check whether any possible scenarios for LCC could moderate or amplify CO_2-induced changes in the Australian climate. The LCC scenarios included a steady-state land cover equivalent to current land cover; a low-reforestation scenario that recovered ~25% of trees replaced by grasslands within the last 200 years and a high-reforestation scenario that recovered at least 75% of the deforested regions. The results showed that reforestation had the potential to reduce the projected increase in temperatures in 2050 and 2100 by as much as 40% and 20%, respectively. This cooling effect was highly localised in regions of reforestation only, suggesting that the potential of reforestation to mitigate the impact of global warming may be limited to the spatial scale of reforestation. In order to investigate the significance of large-scale deforestation on the Australian palaeomonsoon, Pitman and Hesse (2007) produced model simulations of the atmosphere (50-kilometre resolution) for multiple Januaries using vegetation cover representative of the present day, the last interglacial (125 000 BP) and the last glacial maximum (20 000 BP). Analysis showed that there was a 5% change in rainfall primarily due to changes in the surface roughness which affected surface frictional drag, wind velocities and moisture convergence.

Using the results from CSIRO Mark 3 GCM, Syktus *et al.* (2007) analysed composite maps of austral summer's surface temperature over Australia during the five strongest El Niño and La Niña episodes over the period 1951–2003. They showed significant warming under present-day relative to pre-European land-cover conditions. However, increases in surface temperatures in eastern Australia were the highest during both episodes. On average, the strongest warming occurred during the 1982/1983 El Niño in eastern Australia and southwest Western Australia, the regions of largest land-cover change. Comparisons for the surface temperature during 1997/1998 El Niño years were similar, indicating that land-surface forcings act to amplify the effect of El Niño on the Australian climate.

While previous studies had only investigated connections between LCC and mean climate, Deo *et al.* (2009) checked the impacts on climate extremes and droughts by analysing daily rainfall and surface temperature output from the CSIRO Mark 3 GCM. This work, the first of its kind, demonstrated an increase in the number of dry days (<1mm rainfall) and hot days (maximum temperature >35°C), a decrease in daily rainfall intensity and cumulative rainfall on rain days, and an increase in duration of droughts under modified land-cover conditions. These changes were statistically significant for all years across eastern Australia, and especially pronounced during strong El Niño events. Clearly, these studies have demonstrated that LCC has exacerbated the mean climate anomaly and climate extremes in southwest and eastern Australia, thus resulting in longer-lasting and more severe droughts.

Land surface feedbacks in the climate system

The question we now ask is *what are the physical mechanisms by which deforestation can modify regional climate patterns?* The answer lies in understanding how the conversion of native forest into cropping and grazing pastures can change a range of biophysical land-surface parameters. This effect is demonstrated in Figure 3, shown as a conceptual representation of two hypothetical landscapes with two different climate patterns. The landscape comprising native vegetation has a higher leaf area index, vegetation fraction and density. This results in a larger surface roughness which determines the turbulent mixing of air near the ground surface. A land surface with native vegetation has higher surface roughness, resulting in two important effects: (1) land surface air is mixed more efficiently; (2) the rough surface can change the airflow pattern by producing lower horizontal and higher vertical wind velocities. The net effect is a more efficient turbulent mixing process and an increase in influx of water vapour into the lower atmosphere (Foley *et al*., 2003). The increase in moisture availability in the atmosphere favours the formation of rain droplets over natively-vegetated areas.

This mechanism was evidenced from the work of Pitman *et al.* (2004) who found that a reduction in surface roughness due to LCC largely explained changes in regional rainfall. Changes in turbulence intensity due

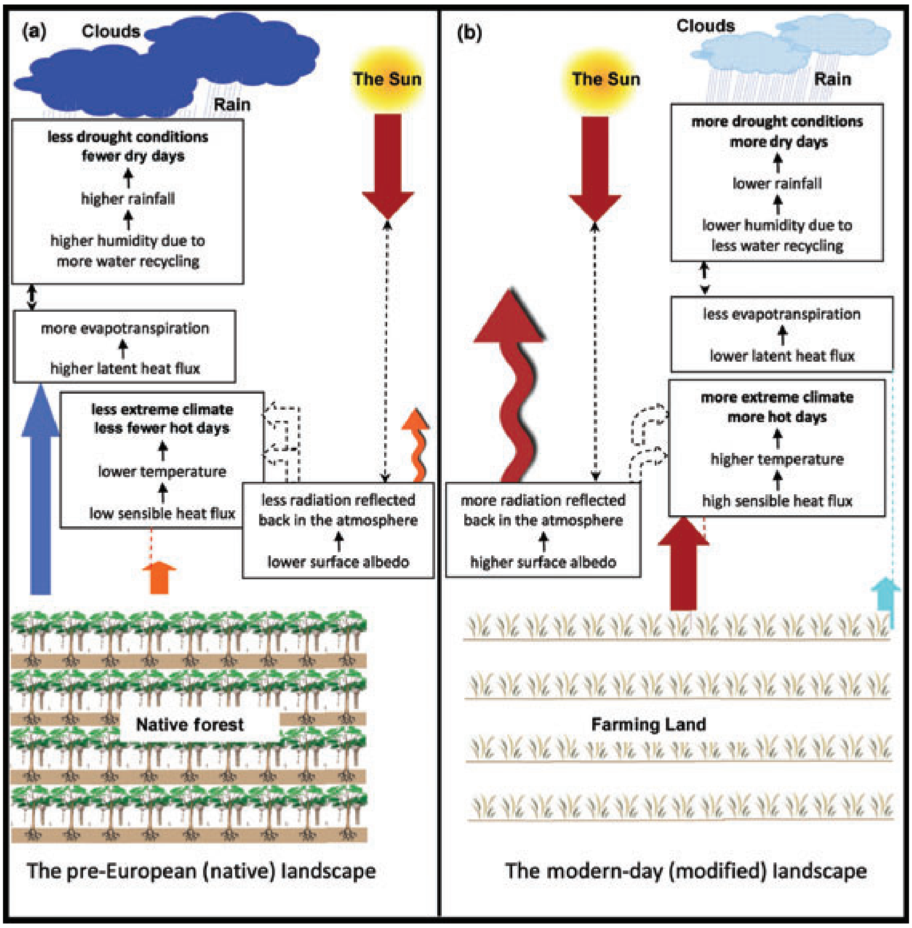

Figure 3. The impact of vegetation-cover change on surface energy balance, hydrological cycle and climate for two hypothetical landscapes: (a) pre-European (native) landscape, and (b) modern-day (modified) landscape. The coloured arrows show various energy/heat fluxes and black arrows show consequence of events or processes.

to loss of vegetation produced an increase in horizontal wind velocities and suppressed vertical velocities, thus reducing the total cumulative rainfall. The opposite effect was noted for areas with native vegetation as moisture convergence and increased vertical velocities led to an increase in rainfall. Another effect of having a higher surface roughness for a region with native vegetation is an enhanced cooling effect through an increase in rate of heat loss from the land surface to the lower atmosphere (Foley *et al.,* 2003).

The reflectance of land surface, as determined by surface albedo, has an important role too. Modified landscapes have higher surface albedo than native landscapes. A higher surface albedo should result in a cooler surface because less radiation is absorbed. However, since modified landscapes (e.g. farming areas) have lower vegetation fraction, leaf-area index and rooting depths, this dramatically reduces evapotranspiration rates relative to native forests. As a result of reduction in evaporative cooling, less heat escapes from the land surface causing an increase in mean surface temperatures (Costa and Foley, 2000). Changes in surface albedo can also contribute to changes in mean rainfall. The increase in surface albedo for modified land-cover conditions could produce a drier lower atmosphere, suppressing the formation of convective clouds and raindrops (Charney *et al.*, 1977).

The principle of energy conservation requires that the decrease in evaporative cooling (latent heat) be compensated by an increase in convective heating (sensible heat), assuming ground heat flux is negligible. As such, there is a substantial change in partitioning of available solar energy at the land surface from latent heat to sensible heat flux due to deforestation. Deo *et al*. (2009) showed that summer-averaged latent heat flux decreased by ~4.8Wm^{-2} while sensible heat increased by ~1.1Wm^{-2} as the surface was modified from a pre-European (native vegetation) to modern-day (modified) state. The large reduction in evaporative cooling is consistent with a warmer land surface for modified land-cover conditions contributing to a reduction in mean rainfall. The analysis of mean climate during strong anomalies such as the ENSO phenomenon showed further climatic impacts where the partitioning of energy for latent heat under a modified land cover was much larger during El Niño years. Such a large shift in energy flux from evaporative cooling to convective heating demonstrates that LCC can exacerbate climate anomalies, such as El Niño events.

Changes in mean climate (i.e. rainfall totals and average surface temperatures) can produce cumulative effects on daily climate extremes and droughts. This is because subtle changes in mean state of a climate variable can produce changes in the tails of probability distribution functions (Mearns *et al.,* 1984). Since the conversion of native forests into cropping and grazing pastures contribute to an increase in sensible heating, a warmer atmosphere can lead to an increase in the number of hot days. Conversely, the decrease in latent (or evaporative) heating can offset the amount of moisture available for the formation of rain through a reduction in evaporation and transpiration rates. This can produce an increase in the number of dry days. Increases in the number of dry days and more intense heating of the lower atmosphere can lead to more extreme conditions such as droughts and heatwaves. Therefore, healthy native vegetation can play a crucial role in ameliorating droughts in the tropical and subtropical regions.

Concluding comments

The combined impact of greenhouse gases on climate, coupled with land-surface feedbacks from loss of forests can pose significant risks to our natural resources, biodiversity and human health. The impact of anthropogenic climate change on comfort zones of marine and natural biodiversity could further diminish the resilience of natural ecosystems. The future risks for several sectors of our community call for collaborative action in reducing deforestation in the Tropics and Subtropics, requiring strong coordinated global and regional efforts. We believe that land clearance must be regulated and, where possible, measures put in place to actively explore reforestation options. The potential benefits would not only help tackle carbon targets in the long term, but also help achieve environmental sustainability in the short term.

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Correspondence to: Ravinesh C. Deo,
Department of Mathematics and Computing,
Faculty of Sciences,
University of Southern Queensland,
Springfield, QLD 4300, Australia

ravinesh.deo@usq.edu.au

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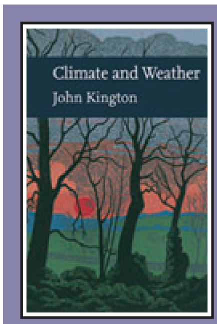
Book review



Climate and Weather

John Kington

Collins, 2010
Hardback £50, Paperback £30,
Kindle £19–99, 320 pp
ISBN 978-0-007-18501-6

This excellent book is presented in two nearly equal parts. The first explains the significant details that need to be understood in order to get the best from the 2000 years chronology of extensive and detailed meteorological and climatological data. It covers such important topics as the basis of the earth's atmospheric circulation and the basis and definition of the seasons, and briefly mentions the sources of the many and varied meteorological data that are used in collating the narrative chronology of those 2000 years – which comprises the second part of the book. The study of clouds and the renewed interest in phenology are also touched on.

The extensive chronology in the second part contains a wealth of interesting data. It covers the weather of most years from 55 BC to the early middle ages, and from about 1200 AD every significant winter and summer is mentioned, sometimes in surprising detail. Aspects of the synoptic situation associated with the more extreme years are often discussed. In addition to such directly related weather factors, there are details of the amount of volcanic dust in the atmosphere and the effect that this may have had on the runs of extreme years. This has, though, made the chronology somewhat cramped; it might have been easier for reference purposes to have put the volcanic dust index and the data on the frequency of westerly winds in appendices.

James Rothwell

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