Evidence of solar and tropical-ocean forcing of hydroclimate cycles in southeastern Australia for the past 6500 years

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Abstract
Evidence of solar and tropical-ocean forcing of climate cycles has been found in numerous palaeoclimate records. Numerical modelling studies show physical mechanisms by which direct and indirect solar forcing may affect climate, while there is mounting evidence of solar forcing of tropical ocean-atmosphere teleconnections. This study has developed a 6500 year record of dust deposition, a proxy for regional hydroclimate variability for the Snowy Mountains region of Australia. Spectral analysis of the record provides evidence of statistically significant cycles in dust deposition of 35–43 years, 62–73 years, 161 years and 2200 years. These correlate with variability in solar irradiance and the Pacific Decadal Oscillation (PDO). We present evidence to support physical links between variability in solar irradiance and change in the hydroclimate of southeast Australia and suggest that the effects of global warming and solar maxima on atmospheric circulation over extra-tropical regions may exacerbate these impacts.

Keywords
6500, past, australia, southeastern, cycles, hydroclimate, forcing, years, ocean, evidence, tropical, solar, GeoQUEST

Disciplines
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Evidence of solar and tropical-ocean forcing of hydroclimate cycles in southeastern Australia for the past 6500 years

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1. Introduction

[1] Evidence of solar and tropical-ocean forcing of climate cycles has been found in numerous palaeoclimate records. Numerical modelling studies show physical mechanisms by which direct and indirect solar forcing may affect climate, while there is mounting evidence of solar forcing of tropical ocean-atmosphere teleconnections. This study has developed a 6500 year record of dust deposition, a proxy for regional hydroclimate variability for the Snowy Mountains region of Australia. Spectral analysis of the record provides evidence of statistically significant cycles in dust deposition of 35–43 years, 62–73 years, 161 years and 2200 years. These correlate with variability in solar irradiance and the Pacific Decadal Oscillation (PDO). We present evidence to support physical links between variability in solar irradiance and change in the hydroclimate of southeastern Australia and suggest that the effects of global warming and solar maxima on atmospheric circulation over extra-tropical regions may exacerbate these impacts.


2. Method

[7] In April 2007 a 1 m peat core was collected from an ombrotrophic mire in the Snowy Mountains, Australia [lat. 37° N, 149° E] (Article Full Text).
The MHAT basis for filtration following the method of Ogurtsov et al. [2002] was then applied in order to identify epochs when the cycles found by the spectral analysis of the dust deposition time series were most dominant.

3. Results

[11] Dust deposition in the Snowy Mountains for the past 6500 years is presented in Figure 1. From ca. 6500 to ca. 5700 years BP dust deposition rates averaged approximately 4 g m$^{-2}$ yr$^{-1}$ increasing to about 16 g m$^{-2}$ yr$^{-1}$ after 5600 years BP. They decreased to approximately 4 g m$^{-2}$ yr$^{-1}$ from about 4100 years BP through until 2100 years BP when they increased again to a mean of near 14 g m$^{-2}$ yr$^{-1}$. The pronounced increase in dust deposition toward the present that peaked at 55 g m$^{-2}$ yr$^{-1}$ we believe corresponds to the introduction of European farming practices and associated land clearing throughout southeastern Australia. Dust deposition rates decreased late in the 20th century returning to pre-1800 AD levels due most likely to introduction of soil conservation practices rather than climate variability.

[12] Spectral analysis of the dust deposition record identified statistically significant cycles centered on 35, 43, 62, 73 and 161 years which all exceed the 95% confidence interval, and a 2200 year cycle which exceeded the 90% confidence interval (not shown) using the Chi$^2$ test (Figure 2). Results of the Morlet wavelet analysis are presented in Figure 3 for all cycles except the 2200 year cycle, which if shown would dominate half of the respective plot. These show that the ≈35 year cycle was most pronounced during the past 300 years with a trend toward a slightly longer period of ≈43 years around 250 years BP. This cycle also appears dominant around 550 and 850 years BP, while the ≈63–73 year cycle was dominant around 550, 1000 and 1500 years BP, and then again between 4000–4500 years BP (Figure 3a). The longer ≈161 year cycle was most pronounced during the past 1000 years (Figure 3b) and around 4200 years BP.

4. Discussion

[13] Fourier and wavelet analyses of our 6500 year record have identified highly significant cycles in dust deposition. These reflect variability in the hydroclimate of the dust source area, the MDB, with higher rates of dust deposition corresponding to periods of increased aridity which are associated with drought.

[14] The ≈35–43 years cycle in dust deposition appears to correlate with the PDO which has been shown to be a principal forcing of hydroclimate variability around the Pacific Basin including southeast Australia [Mantua and Hare, 2002; McGowan et al., 2009]. Positive phases of the PDO are associated with weather patterns, particularly during autumn, that are less conducive to rainfall over southeast Australia [Verdon-Kidd and Kiem, 2009] and likely to increase dust transport [Lamb et al., 2009]. Our record indicates that the ≈35–43 years cycle in dust deposition has been most prevalent over the past 1000 years. The reason for this is uncertain however the observation corresponds to a period when cosmogenic isotope records indicate that the Sun was in a relatively calm phase [Bard and Frank, 2006]. The associated change in insolation may have allowed the PDO to more strongly imprint on...
the hydroclimate of southeast Australia during this period although further research is clearly required to answer this issue.

[15] The ≈62–73 years cycle in the dust record may relate to the pentadecadal PDO cycle and/or the ≈88 year Gleissberg solar cycle. It is most pronounced around 550, 1000 and 1500 years BP and then again between 4000–4500 years BP. Differentiation of the exact mechanism responsible for this cycle is not possible by this study as variability in the PDO on multi-decadal and longer timescales may in-part be a response to variations in solar output [Kirov and Georgieva, 2002]. Cook et al. [2006] also identified a 62–76 years cycle in a 3600 year tree ring record from Tasmania Australia. Unlocking the cause(s) of this cycle has potential for multi-decadal forecasting of hydroclimate trends in southeast Australia and should be considered a research priority.

[16] The highly significant ≈161 year dust deposition cycle (most pronounced during the past 1000 years and around 4200 years BP) correlates closely to a ≈150 solar cycle reported by Knudsen et al. [2009] in their analyses of the 14C and 10Be data from the IntCal04 and GRIP ice core records respectively. This solar cycle was also observed by Peristykh and Damon [2003] following their analysis of the Δ13C INTCAL98 record. This cycle is much shorter than the 208–212 years Suess cycle which we find no evidence of in our dust deposition record. Our results are the first evidence of the impact of the ≈150–160 years solar cycle on the hydroclimate of mainland Australia, with the wavelet analysis confirming the greatest effect centered on 500 years BP encompassing the Maunder, Spörer and Wolf solar minima.

[17] The ≈2200 year cycle in our dust deposition record correlates with the c. 2200 year Hallstattzeit solar cycle which has been reported in many 14C and 10Be records, confirming a solar origin [Vasiliev and Dergachev, 2002; Nederbragt and Thurow, 2005]. While a longer dust deposition record would confirm the robustness of this cycle and its affects on southeast Australia, our record shows it to be a significant forcing of the mid to late Holocene climate, possibly through changes in ocean circulation and/or ice cap extent as suggested by Nederbragt and Thurow [2005]. Importantly, this cycle would appear to control the longer term millennial scale climate (wet–dry phases) in southeast Australia on which the centennial to multi-decade climate cycles are superimposed.

[18] A mechanism for the manifestation of solar cycles in wind erosion and dustiness, and by association, the hydroclimatology of southeast Australia has not been offered. The dust deposition record from the Snowy Mountains clearly shows evidence of cycles aligned with well documented solar (and tropical ocean SST) cycles. Rind et al. [2008] using the Goddard Institute for Space Studies Global Climate Middle Atmosphere Model 3 to investigate the influence of solar cycles on troposphere/stratosphere processes.
found the solar UV effect during solar maximums produced stronger westerly wind stratospheric circulation. This was able to propagate to the troposphere, particularly in the Southern Hemisphere producing a more positive SAM [Rind et al., 2008, p. 23]. The subtropical jet was also found to weaken and move southward with the Hadley Cell. Haigh et al. [2005] found a similar poleward shift of the subtropical jets and expansion of the Hadley Circulation with a more active sun which Ram et al. [2009] linked to reduced precipitation as a result of decreased cosmic ray flux and cloud contact nucleation. As a result, there is now strong evidence to support physical links between variability in solar irradiance and change in the hydroclimate of southeast Australia. The potential impact of solar variability on weather and climate in this region, and elsewhere, must therefore be accounted in prediction of future climate change. This is critical, particularly in regions such as southeast Australia where a positive trend in SAM and southward expansion of the Hadley Cell over the past two decades has been linked by some researchers to anthropogenic global warming and stratospheric ozone depletion only, and proposed as the principal cause of recent prolonged drought over southern Australia [Murphy and Timbal, 2008; Previdi and Liepert, 2007; Son et al., 2009]. This has occurred during solar minima from which it appears we are emerging to the next maxima. Haigh et al. [2005] and Ram et al. [2009] have suggested this will produce changes similar in atmospheric circulation to those postulated due to anthropogenic global warming. As a result, the effects of possible synergies occurring between global warming and solar maxima on atmospheric circulation over extratropical regions could result in severe drought becoming the typical climate state in regions such as southeast Australia.

5. Conclusion

[19] Our results imply that the hydroclimate of southeast Australia over the past 6500 years has displayed significant cyclic variability on timescales from ≈35–2200 years. Higher rates of dust accumulation between 5700 years BP to 4100 years BP and from 2100 years BP to present suggest greater variability in the climate of southeast Australia during these periods, including drought severity and dust transport. These cycles appear to be driven by multi-decadal change in Pacific Ocean SSTs through the PDO and variability in solar irradiance. Predictions of future climate...
must consider these forcings so that in water-scarce regions such as southeast Australia the effect on the hydroclimate is incorporated into the design of water allocation policy and infrastructure, and the management of environmental systems.

The adverse impact that may arise as a result of the synergies between global warming and solar maxima on atmospheric circulation over extra-tropical regions is cause for significant concern. The effect on the hydroclimate of regions could be catastrophic as a consequence of prolonged severe drought not previously experienced or planned for.

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