Impacts of large-scale extreme hydroclimatic variations on ecosystem function in Southeastern Australia

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Abstract

Amplification of the hydrologic cycle as a consequence of global warming is predicted to increase climate variability and the frequency and severity of droughts. Recent large-scale drought and flooding over numerous continents provide unique opportunities to understand ecosystem responses to climatic extremes. In this study, we investigated the impacts of the early 21st-century extreme hydroclimatic variations in southeastern Australia on phenology and vegetation productivity using Moderate Resolution Imaging Spectroradiometer Enhanced Vegetation Index and Standardized Precipitation-Evapotranspiration Index. Results revealed dramatic impacts of drought and wet extremes on vegetation dynamics, with abrupt between year changes in phenology. Drought resulted in widespread reductions or collapse in the normal patterns of seasonality such that in many cases there was no detectable phenological cycle during drought years. Across the full-range of biomes examined, we found semi-arid ecosystems to exhibit the largest sensitivity to hydroclimatic variations, exceeding that of arid and humid ecosystems. This result demonstrated the vulnerability of semi-arid ecosystems to climatic extremes and potential loss of ecosystem resilience with future mega-drought events. A skewed distribution of hydroclimatic sensitivity with aridity is of global biogeochemical significance because it suggests current drying trends in semi-arid regions will reduce hydroclimatic sensitivity and suppress the large carbon sink that has been reported during recent wet periods (e.g., 2011 La Niña).

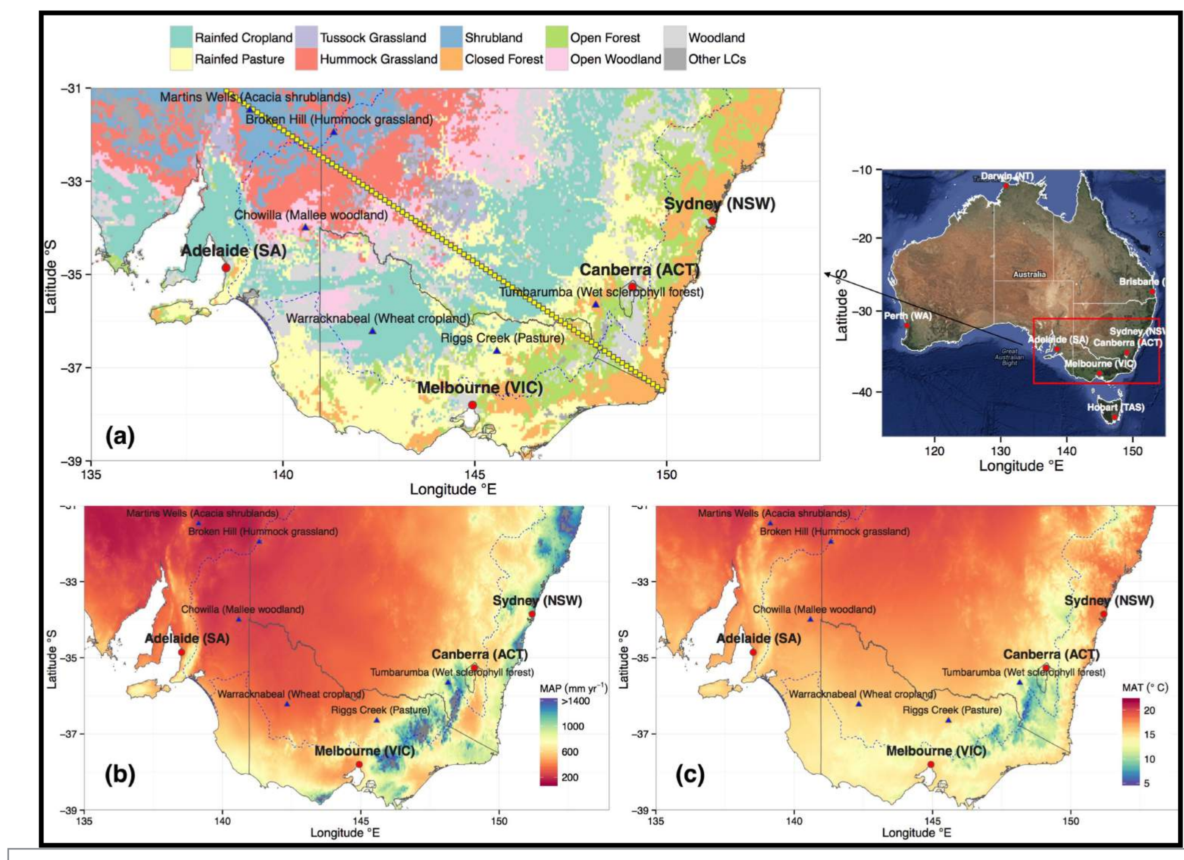

Figure 1. Land cover type and mean climatology of Southeastern Australia. (a) Land cover map, (b) mean annual precipitation, and (c) mean annual temperature. Solid blue triangles are six local sites that represent different land covers.

Research Objectives

The objectives of this study were to (1) investigate shifts in phenology and vegetation productivity across extreme drought and wet years; (2) determine the consequences of contemporary, the early 21st century climate extremes on ecosystem functioning in southeastern Australia; (3) assess the interactions and relative importance of climatic conditions and vegetation types in determining ecosystem sensitivity and resilience to the impacts of drought. We focused on Australia because it has one of the most variable climates around the globe, and thus, it is of interest and importance to know how ecosystems behave under such extreme climate variability.

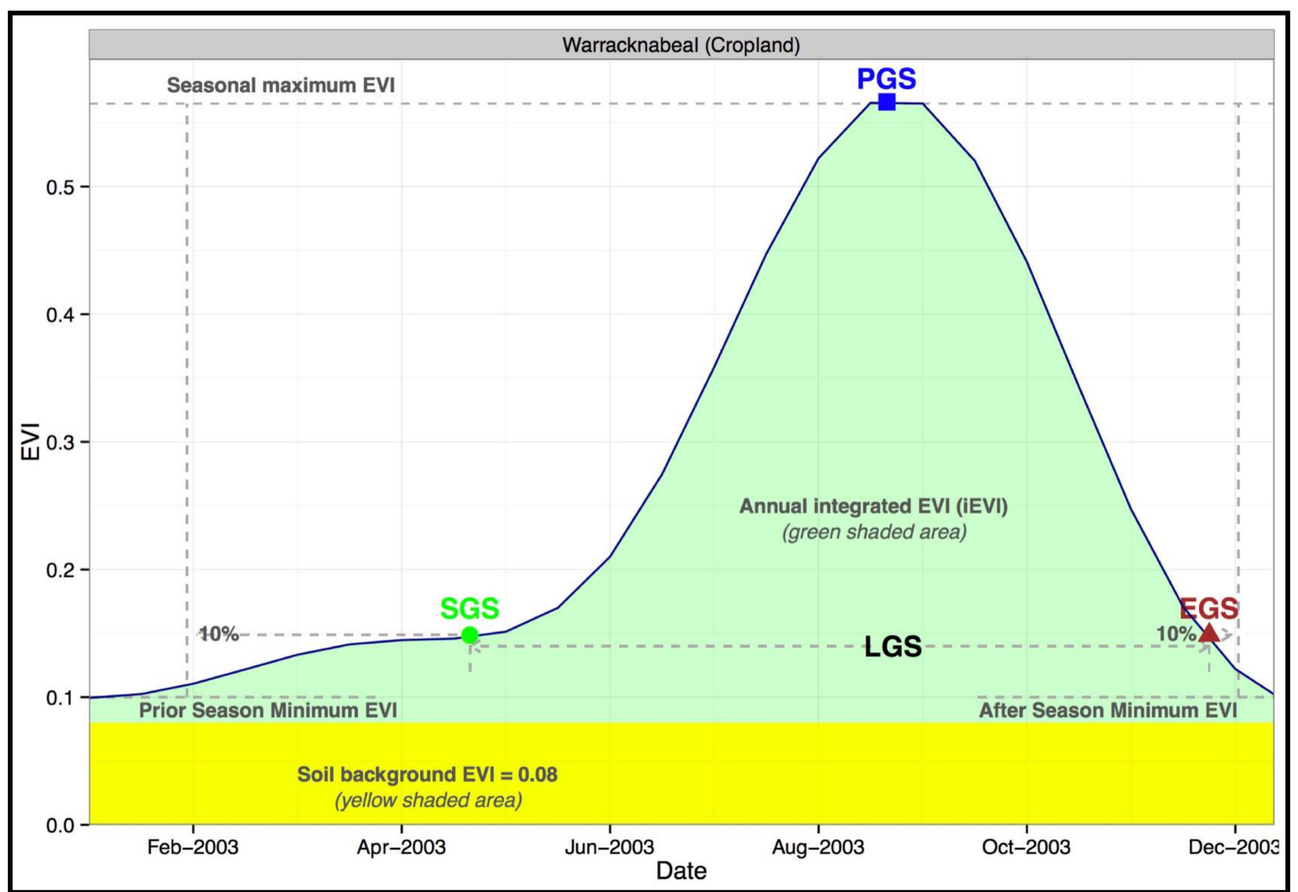

Figure 2. Diagram of algorithm for deriving phenological metrics and annual integrated EVI (iEVI).

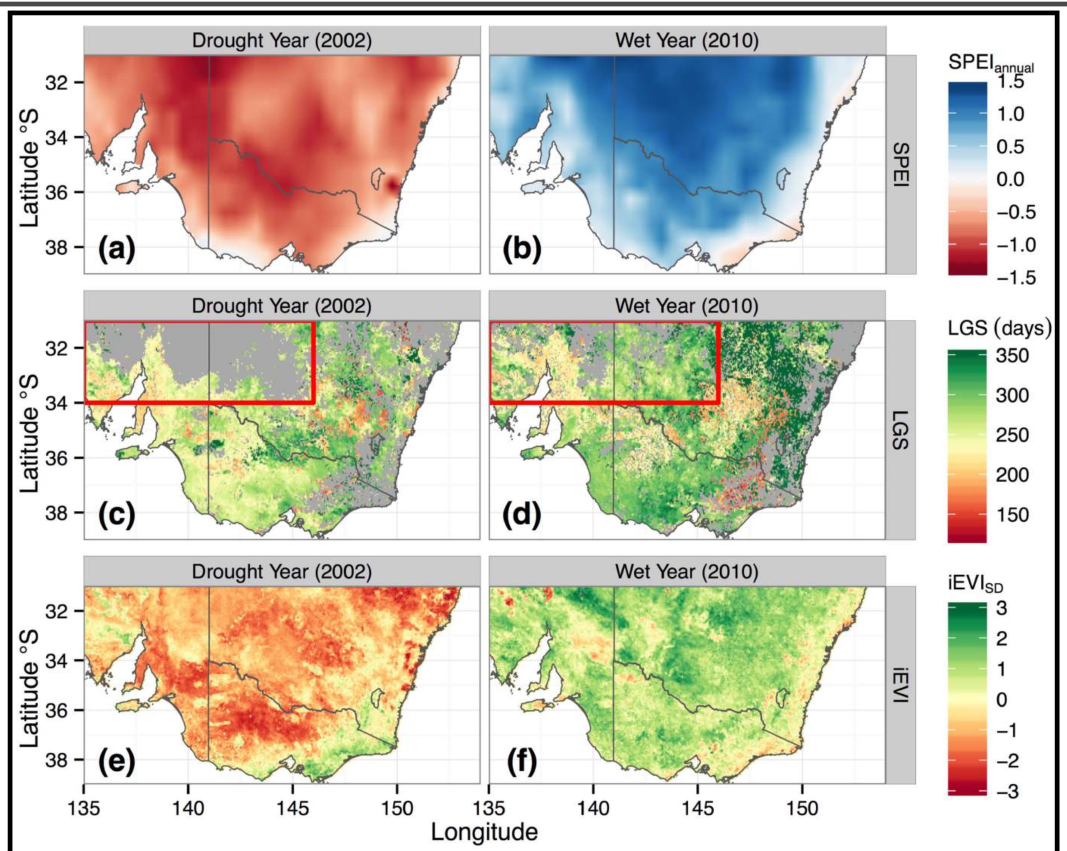

Figure 4. Biogeographical patterns of vegetation phenology and productivity over the SE Australia study area along with SPEI drought index in the driest year (2002) and the wettest year (2010) during the 2000–2013 time period respectively. (a and b) Annual mean SPEI, (c and d) length of growing season (LGS), (e and f) standardized anomaly of iEVI (iEVIsd). Grey shaded area indicates the pixels either water body or without detectable phenology due to weak seasonality (seasonal EVI amplitude < 0.02). The red rectangle in Figures 5c and 5d highlights the regions where phenology over majority of pixels was not detectable during 2002 drought year.

Data and Method

MODIS EVI

Approximately 14 years (February 2000 - December 2013) of 16-day 0.05° resolution MODIS Enhanced Vegetation Index (EVI) data (MOD13C1, Collection 5) were obtained from the NASA/USGS data archive centre (https://lpdaac.usgs.gov/). Quality control was applied to retain high-quality observations while minimising aerosol and cloud contamination. EVI is a proxy for canopy "greenness", which is an integrative composite property of green foliage, leaf chlorophyll content, and canopy architecture. Annual integrated EVI (termed iEVI) has been widely used as a remote sensing surrogate of annual vegetation productivity from arid grassland to forests. In Australia, MODIS EVI has been found to be strongly correlated with eddy-covariance flux tower derived gross primary productivity (GPP).

Standardised Precipitation-Evapotranspiration Index (SPEI)

SPEI is a multiscalar drought index, which takes into account both precipitation and temperature to determine drought severity. SPEI reflects the cumulative effect of the imbalance between atmospheric supply (precipitation) and demand (potential evapotranspiration). We used SPEI that was computed at 3 month time scale considering that the water balance at this short time scale is primarily related to soil water dynamics that is important for plant growth.

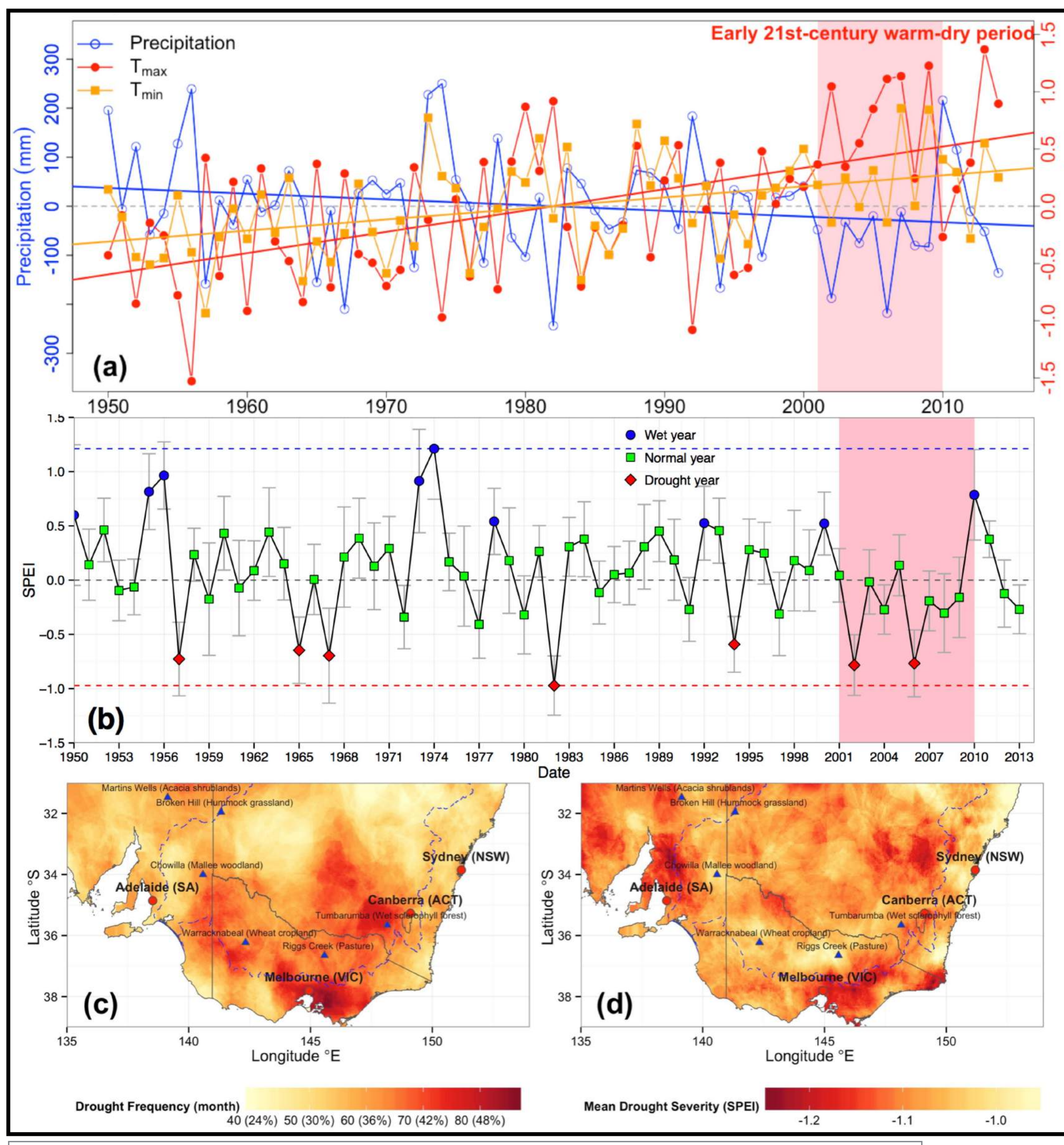

Figure 3. Characteristics of climatology and drought in Southeastern Australia from 1950 to 2014. (a) Region-wide average of annual precipitation anomaly, daily maximum temperature (Tmax) anomaly, and daily minimum temperature (Tmin) anomaly from 1950 to 2014. Solid straight lines indicate the trend lines for each variable. (b) region-wide average annual SPEI over SE Australia from 1950 to 2014. (c) Drought frequency, represented as number of drought months (SPEI < −0.5) during the 2000–2013 time period. Number in bracket is the percentage of drought months regarding 14 years (i.e., number of drought months/168 months). (d) Mean drought severity, defined as the mean SPEI of drought period (SPEI < −0.5) during 2000–2013. A drought month, or year, is defined as when SPEI was less than −0.5, and a wet month, or year, is defined as when SPEI was greater than 0.5. The normal period was defined as when −0.5 < SPEI < 0.5. The grey horizontal dashed line in Figure 3a indicates the position of precipitation and temperature anomaly equal to zero, while the grey, blue, and red horizontal dashed lines in Figure 3b indicate that the position of SPEI is equal to zero, maximum and minimum SPEI during the 1950–2013.

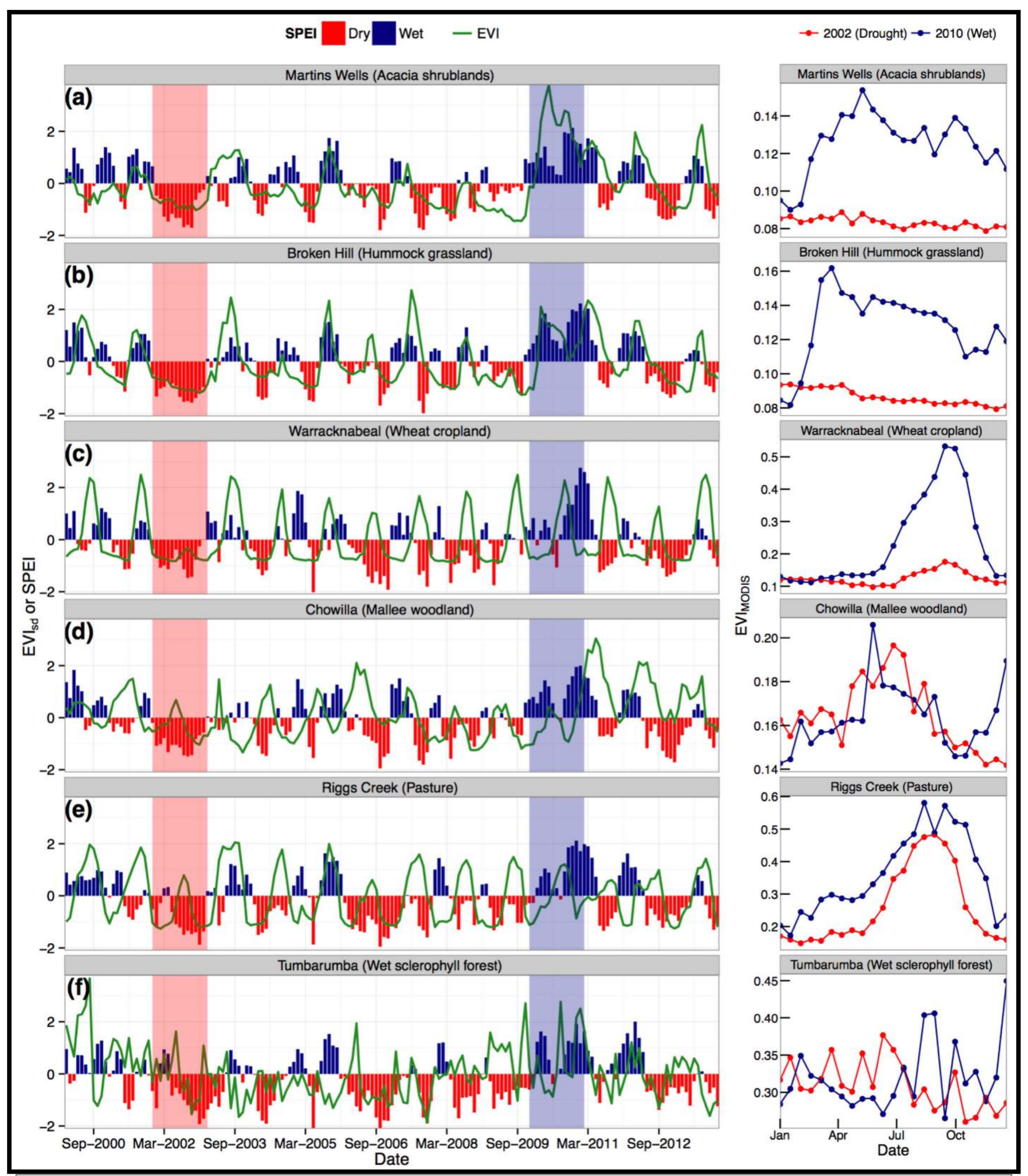

Figure 6. Seasonal and interannual variations in EVI and SPEI at six local sites within southeastern Australia. The solid green line is standardized anomaly of monthly MODIS EVI (EVIsd). Vertical bars are monthly SPEI, with positive SPEI (blue) that indicates wet condition and negative SPEI (red) that indicates dry condition. Right column shows the seasonal EVI profile during 2002 (drought year) and 2010 (wet year) for each site.

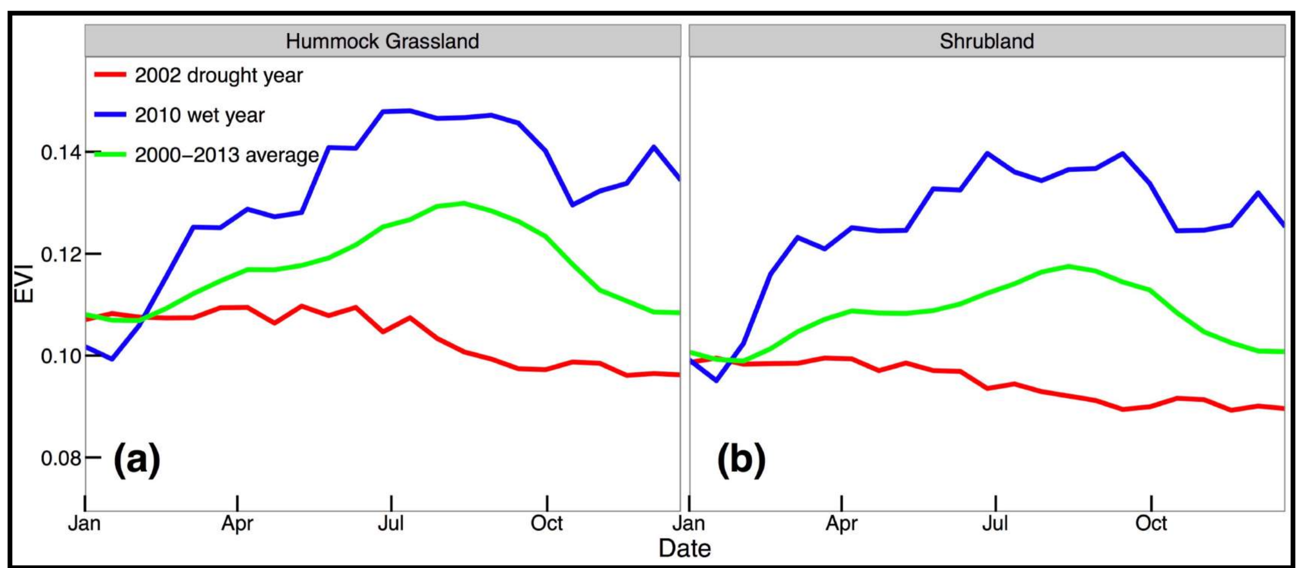

Figure 5. Comparison of hydroclimatic variation-induced shifts in seasonality for hummock grassland and shrubland, respectively. The solid red and blue lines show the EVI profiles for these two vegetation types in 2002 drought and 2010 wet years, respectively, while the solid green line shows the climatology average EVI profiles for entire 2000–2014. EVI profiles were averaged using pixels seriously affected by 2002 drought; thus, no phenology was detected during that year (grey shaded area within the region highlighted by red rectangles on Figures 4c and 4d).

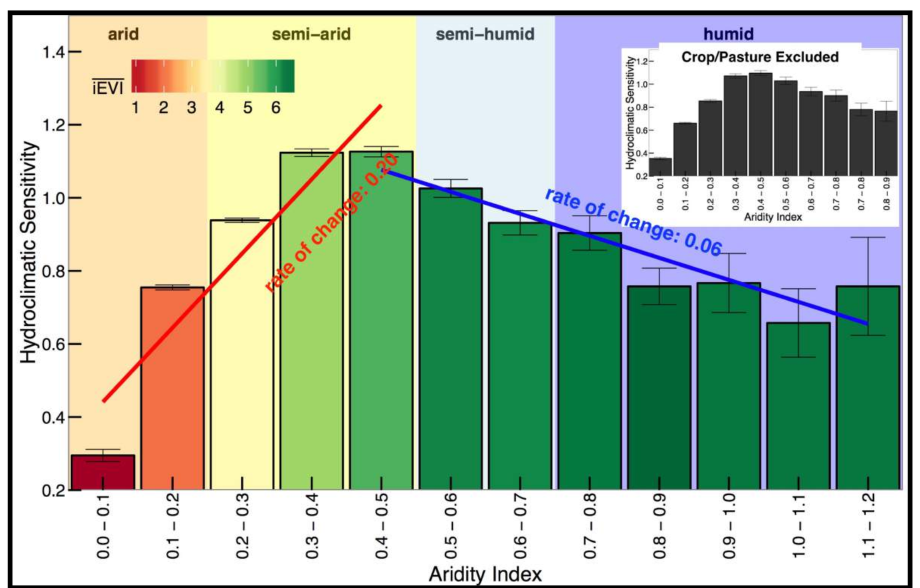

Figure 7. Sensitivity of vegetation productivity to hydroclimatic variations across arid to humid climate regimes. Pixel values over the entire SE Australia study area were averaged by bin (every 0.1 increment) of aridity index. Filled color bars indicate mean annual vegetation productivity (iEVI) for each aridity index group. Vertical bars indicate 95% confidential interval of the mean value of hydroclimatic sensitivity.

Ma, X., A. Huete, S. Moran, G. Ponce-Campos, and D. Eamus (2015), Abrupt shifts in phenology and vegetation productivity under climate extremes, *J. Geophys. Res. Biogeosci.*, 120, 2036–2052.

Summary

- Climate extremes resulted in abrupt change in phenology and productivity;
- Ecosystem sensitivity to hydroclimatic variations peaked in semiarid regions;
- Drying trend in semiarid ecosystems will result in loss of carbon sink in future.

Acknowledgement

This work was funded by an Australian Research Council - Discovery Project: Impacts of extreme hydro-meteorological conditions on ecosystem functioning and productivity patterns across Australia (ARC-DP140102698, Huete lead) and NASA SMAP Science Definition Team under agreement 08-SMAPSDT08-0042, and the NASA SMAP Science Team under agreement NNH14AX72I.

AGU PUBLICATIONS JGR

Journal of Geophysical Research: Biogeosciences

RESEARCH ARTICLE

10.1002/2015JG003144

Key Points:
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- Ecosystem sensitivity to hydroclimatic variations peaked in semiarid regions
- Drying trend in semiarid ecosystems will result in loss of carbon sink in future

Abrupt shifts in phenology and vegetation productivity under climate extremes

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ECOLOGY *Nature*, 19 November 2015

Ecosystem responses to climate extremes

Extreme drought or wet conditions have now been found to strongly influence the vegetative development of ecosystems. Semi-arid regions are most affected — raising concerns about their vulnerability to long-term drought in the future.

ANJA RAMMIG & MIGUEL D. MAHECHA

Extreme climatic conditions such as drought or heatwaves are likely to intensify in the next few decades[1]. Long-term observations[2] of past decades suggest that periodicities in an organism's life, such as the annual cycles of plant leaf development. Writing in the *Journal of Geophysical Research*, Ma *et al.*[5] describe how climate extremes modify the seasonal vegetation development of different ecosystems.