

Interactive comment on “Land surface phenological response to decadal climate variability across Australia using satellite remote sensing” by M. Broich et al.

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Final Responses to Anonymous Referee #2 (marked by “»”)

»General Comments The manuscript presents a geographically comprehensive analysis of vegetation land surface phenology variability over Australia using MODIS EVI data, with TRMM precipitation and the Southern Oscillation Index as climatic drivers. The manuscript is well written, advances the current understanding of vegetation phenology over this continent, and provides clear figures illustrating the results. Clarification regarding the methods and a few minor changes are needed however. The implementation of the 7-parameter double logistic model needs to be clarified. The

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authors show in Figure 1 the 36 sites used for “algorithm development and calibration” but it is not clear how these sites were used in this regard. Stating they were calibration sites implies that they were used to either provide initial estimates of the parameters, to constrain the parameters prior to applying the model across all pixels, or perhaps to help identify the width of the smoothing filter and moving window for defining seasonal minimums. And if so, were these estimations or constraints specific to land cover types and therefore applied based on each pixels land cover? or perhaps regionally to determine areas that may exhibit dual seasonality? I suspect the sites were used simply as test cases to ensure the model produced expected results, correct? If this is the case then I don’t believe using the term calibration is correct.

>We appreciate the positive feedback from Referee #2. Our responses to general and specific comments follow (marked by “>”; new and modified figures below).

Thank for your comment re the term ‘calibration’. We agree that the term was not suitable to describe our use of the 36 sites. We changed the phrasing and now explain in more detail how we used the sites as well as the implementation of the 7-parameter double logistic model as per your suggestion.

We used the sites to determine optimized algorithm parameters such as the width of the smoothing filter and the moving window for local min and max point detection as well as the minimum cycle amplitude. The sites also served as test cases to ensure that the model algorithm, which was generic across the study area, produced expected results. We now clarify this in the text, removed the term calibration and rephrased relevant passages: e.g. in the Methods section 2.1: “For algorithm development and testing, we used a set of EVI time series at 36 sites distributed across Australia. These 36 sites represented a range of land cover and climatic zones (Table 1; (Lymburner et al., 2011; Australian Bureau of Meteorology, 2014c)) to ensure that the algorithm captures the variability in phenology across the country and we used them to determine optimized algorithm smoothing and threshold parameters.”

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Regarding the implementation of the 7-parameter double logistic model: In a first step it was necessary to identify the locations of regularly or irregularly distributed growing cycles across the time series (e.g. annually or non-annually reoccurring growing cycles). We used a Savitsky-Golay filter to smooth the data in preparation for the min and max point delimitation. The local min max point delineation is susceptible to noise not screened by the QA filter setting thus requiring prior smoothing. The local min and max point detection was used to define the boundaries of cycles and define the bounding areas for fitting of a 7 parameter double logistic curve to every cycle thus characterizing the cycles in a consistent way.

»My second concern In regard to these sites, is that only a single site is presented as an example of how well the model works (and I agree it works fairly well in this location, aside from missing a second season in 2010; see below). I would highly suggest including more plots (like those found in Figure 2) that encompass the range of land cover types and/or climate zones. They need not be as detailed as Figure 2, simply displaying the raw EVI and fitted curves would suffice. This would highlight the robustness of the model and/or the areas where the model had trouble, allowing researchers to determine whether applying this model would benefit future specific analyses.

>Thank you. To highlight the robustness of the model and to facilitate future applications of the model by readers, we added a figure (new Figure 3) showing the raw EVI, smoothed EVI and fitted curves as well as the start and end of cycle points for three additional sites representing different land cover types and rainfall.

»The second point regarding the model fits is that of dual seasonality within a year. The authors state a moving window was used to identify minimum points and hence the extent of the phenological cycle, and that the model was then fit to each of these phenological cycles. First, if this method identifies seasonal cycles without regard to fixed yearly intervals then why is it necessary to fit “a second 7-parameter double logistic curve” when a second phenological cycle was identified within a given year?

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>Thank you. We changed the phrasing in section 2.2.3 clarifying that: “We used the identified minimum points to define the temporal extent of phenological cycles in the entire time series. We then fitted the 7-parameters double logistic model for each identified interval. We did not expect one or multiple phenological cycles in fixed intervals of the year. We thus allowed cycles to be characterized at any time to better represent the highly variable rainfall-driven phenological patterns across Australia’s vast drylands and dual cycles in cropping and pasture zones.” Our algorithm first identified and characterized the cycles for each per pixel time series and then binned the identified results by calendar year.

»Second, how large was the moving window and how wide was the smoothing Savitsky-Golay moving filter? The width of each of these would greatly effect whether a “second” season was detected or not. This is very apparent in Figure 2. The EVI data points display what appears to be two seasons in 2010, but the smoothing filter dampens the second season, minimums are not identified, and the second season is not detected in the curve fit.

>We now state the width of the Savitsky-Golay filter (15 time steps) in the text in section 2.2.2. In general, the detectability of both single cycles and cycles close together is a function of the signal amplitude, the noise level and the smoothing parameters. It is arguable if there are two cycles in 2010 in Fig 2. At this stage we focused on investigating continent-scale biogeographic patterns of land surface phenology and response of phenology to rainfall and ENSO variability. However, we acknowledge that future studies are needed to refine the algorithm for better characterizing the rainfall pulse-driven patterns of vegetation growth.

»The dual seasonality problem could also be clarified by including a map showing which pixels displayed two cycles within a year and how often this occurred. This would also help to clarify the peak dates shown in Figure 4. Do these dates signify the timing of the first or second peak? Do many of the areas without a peak in a given year contain two peaks the following year (i.e. the season started late in year 1 and

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peaked in year 2, yet the pixel also displayed a second season in year 2). I realize that it may seem I am belaboring the dual season problem, but this can be a very common characteristic of highly variable rainfall-driven vegetation phenology and should not be overlooked. If a very low percentage of the land area does not display dual seasonality, then I would concede this point, but at this point it is unclear to what extent this occurs throughout the continent. Dual peaks within a year also can affect the results displayed in Figure 6B; lead time of SOI month relative to phenological peak.

>Thank you. We appreciate the comment. Two peaks during a calendar year occurred over only 25% of the Australian land surface. Within the 14 years of study, two peaks per year occurred no more than 3 times across 96% of Australia. Areas with two peaks per year occurred mostly on cropping or pasture land uses.

»In regards to the results presented in Section 3.4, I understand the authors choice to only present the most significant results (SOI in relation to peak magnitude), but I think it would be worthwhile to also present the best rainfall correlation results as well. The authors clearly state that Australia is the driest inhabited continent with one of the most variable rainfall climates in the world and vast areas of dryland systems. This warrants at least the presentation of precipitation related results, even if they were non-significant. Understanding where, and perhaps why, the EVI phenology metrics do not coincide with rainfall is an important result. A second row of maps in Figure 6 would suffice in displaying these results.

>Thank you. We added a second row of maps as per the reviewer's suggestion (new Figure 8). We added passages to the manuscript related to the expanded figure in the Results and Discussion sections. For example in the discussion section the relevant passage now reads: "We observed similar yet less concentrated pattern for the rainfall – peak magnitude correlation. We interpret this latter pattern as primarily as the effect of the large-scale atmospheric circulation patterns indicated by SOI. The lag times of correlations over North Eastern Australia varied between 1 and 6 months following SOI or rainfall. Shorter lag time (1 to 3 months) correlation patterns with SOI were observed

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near the West coast of Australia yet lag times following rainfall were longer (5-8 month). These patterns are spatially remote from the variability in convection over the Western Pacific (North East of Australia) indicated by SOI."

»Specific Comments Line 55. I believe the correct term is recurring. The term reoccur more specifically refers to a single event that happens a second time, while recurring defines periodicity.

>Thank you. We made the change as suggested throughout the manuscript.

»Lines 71-80. I would suggest moving these lines to the beginning of the introduction. They provide a good general overview of land surface phenology and would give readers unfamiliar with the topic a good initial understanding of its importance in relation to other disciplines and applications.

>Thank you. We rearranged the text as suggested now starting with: "Vegetation phenology refers to the response of vegetation to inter- and intra-annual variation of climate, specifically irradiance, temperature and water (Myneni et al., 1997; White et al., 1997; Zhang et al., 2003). Vegetation phenology is a useful indicator in the study of the response of ecosystems to climate variability (Zhang et al., 2012; Richardson et al., 2013), and an important parameter for land surface, climate and biogeochemical models that quantify the exchange of water, energy and gases between vegetation and the atmosphere (Pitman, 2003; Eklundh and Jönsson, 2010). A variety of applications that require the characterization of vegetation phenology include crop yield quantification, wildfire fuel accumulation, vegetation condition, ecosystem response to climate variability and climate change and ecosystem resilience (Schwartz, 2003; Liang and Schwartz, 2009; Peñuelas et al., 2009). Phenology of the vegetated land surface (land surface phenology, hereafter phenology) is "the seasonal pattern of variation in vegetated land surfaces observed from remote sensing" (Friedl et al., 2006)."

»Line 118-199. This sentence is a bit hard to understand; referring to 80% and then 50% of the land area does not allow for quick comprehension. Perhaps: : : rainfall

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exceeds 600mm over 20% of the land area and is less than 300mm over 50% of the land area.

>Thank you. We rearranged the sentence as per the reviewer's suggestion

»Line 128. "a set of 36 trajectories" is unclear. Please be more specific. "EVI time series over 36 sites: : ." Also, it may be more reader-friendly to use "time series" rather than "trajectories" when describing the EVI.

>We modified the phrasing as suggested and changed trajectories to time series throughout.

»Line 180. Parameters of the Savitsky-Golay filter should be identified as this can have a large effect on the resulting smoothed time-series (see general comments).

>Thank you. We now state the parameters in the text (Section 2.2.2).

»Line 186. Width of moving window needs to be identified (see general comments)

>We now state the moving window width of 9 time steps in the text (Section 2.2.3).

»Line 237. "two" should be "to"

>Thank you. We made the change.

»Figure 4. An additional map displaying the standard deviation or range in peak timing would be an ideal addition to the figure as it is difficult to trace a given pixel or area across each year to determine the extent of variability. The color bar of the legend could be larger and vertical lines denoting temporal increments would greatly help interpretation (e.g. lines at monthly intervals). >Thank you. We added the mean and standard deviation in peak timing to the figure and caption (new Figure 6). We also added the bars to the legend to identify monthly interval as per the reviewer's suggestion (new Figure 5 and 6).

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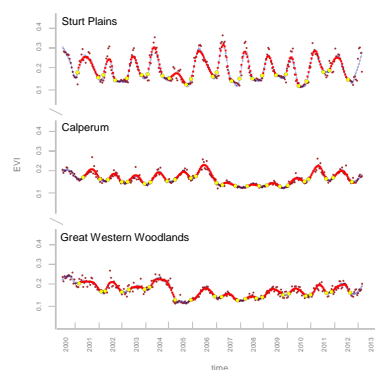


Fig. 3. Examples of temporal variability of the characterized phenological cycles for the Sturt Plains, Calperum, and Great Western Woodlands sites (refer to Fig. 1 and Table 1 for the sites' location and description, respectively). Based on 14-years of MODIS EVI data after screening out low quality observations (brown circles), EVI time series after gap filling and smoothing (blue circles), fitting 7-parameter double logistic functions (red squares) and identifying start and end of cycles points (yellow circles) delineating the characterized phenological cycles.

Fig. 1.

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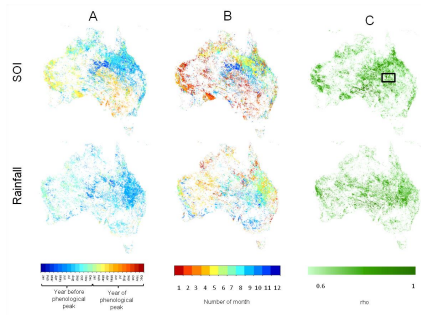


Fig. 8. Statistically significant relationships between monthly SOI and phenological cycle peak magnitude (top row) and monthly rainfall and phenological cycle peak magnitude (bottom row). (A) SOI and rainfall month most significantly correlated with peak magnitude. (B) Lead time of SOI and rainfall month relative to phenological peak and (C) Spearman's rho. Areas with $p > 0.05$ area shown in white. The black box in the top right panel marks the extent of the area shown in Fig. 7 centered on the Cooper Creek floodplain in interior Eastern Australia.

Fig. 2.

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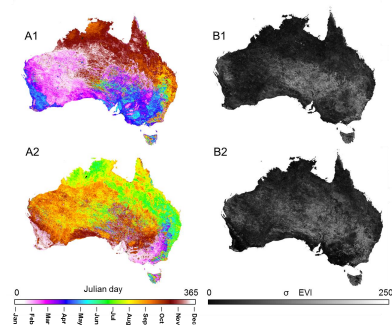


Fig. 5. Mean Julian day of the start of the phenological cycles (A1) and standard deviation of the start of the phenological cycles in number of days (B1) and mean Julian day of the end of the phenological cycles (A2) and standard deviation of the end of the phenological cycles in number of days (B2) across the 14-year time series. Fig. 5. Mean Julian day of the start of the phenological cycles (A1) and standard deviation of the start of the phenological cycles in number of days (B1) and mean Julian day of the end of the phenological cycles (A2) and standard deviation of the end of the phenological cycles in number of days (B2) across the 14-year time series.

Fig. 3.

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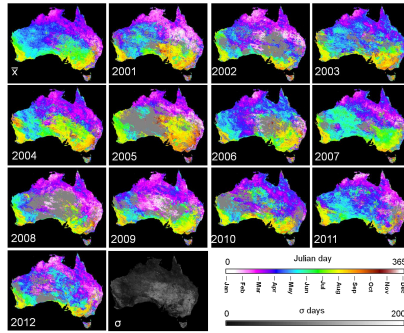


Fig. 6. Inter-annual variation in the peak timing. The Julian day of the phenological cycles' peak is displayed in the calendar year when the peak occurred. The mean (\bar{x}) and standard deviation (σ) of the cycle peak timing is provided for reference. The scale is cyclic. Areas where no peak was observed during a given calendar year are shown in gray.

Fig. 4.

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