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Biogeosciences
Discussions

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 #1 (marked by "»")

»General Comments This study examined the spatial and temporal patterns of vegetation phenology in Australia. The authors also assessed the relationship between climate variability especially rainfall and vegetation phenology and productivity. The authors also developed an algorithm to extract key phenological parameters from satellite greenness index time-series. Phenological change is one of the most direct indicators of the impact of climate change to terrestrial ecosystems. Although it has been widely studied in many ecosystems, it is surprisingly rare to see landscape scale analysis of

vegetation phenology in Australia, and more importantly, how climate variability contributed to the changes. This study is thus novel and important, and will contribute to our understandings of how climate variability controls vegetation phenology. The manuscript in current form is concise and well written. It can be a better paper if the following issues are addressed:

I agree with Anonymous Referee #2 that more clarification on the fitting algorithms is needed for the readers to reproduce the method. Specifically, the moving window to identify minimum and maximum needs more clarification: are those points identified local min/max points?

>We appreciate the positive feedback from Referee #1. Our responses to general and specific comments follow (marked by ">"; new and modified figures below).

Thank you for your comments. We now provide clarification concerning the fitting algorithms as per the suggestion of both reviewers (we modified relevant passage in sections 2.1, 2.2.2 and 2.2.3. as detailed below). The identified minimum and maximum points are local min/max points, which we now also clarify in the text.

Regarding clarification 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 local min and max point delimitation (window width: 9 time steps). The local min and local max points delineation is susceptible to noises that were not screened by the QA filter setting thus requiring prior smoothing. The min and max point delineation was used to define the boundaries of cycles and define the bounding area for fitting a 7-parameters double logistic curve to every cycle thus characterizing the cycles in a consistent way.

We modified the text to clarify these points. The modified passage in section 2.1 now reads: "For algorithm development and testing, we used a set of EVI time series at 36 sites distributed across Australia (Fig. 1). 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 effectively captures the variability in phenology across the country and we used them to determine optimized algorithm parameters." The modified passage in section 2.2.2 now reads: "We used the quality assurance flags in the MOD13 products to discard observations with insufficient quality, which included any observation with either VI usefulness > code '10', snow cover, high aerosol or climatology aerosol quantity, mixed or high clouds present or water in the Land/Water Flag. For each pixel, we first used cubic spline interpolation (Dougherty et al., 1989) to temporally gap-fill the data points discarded in the previous filtering step. Next, we smoothed the time series for each pixel using Savitzky-Golay smoothing filter (Savitzky and Golay, 1964) with a window width of 15 time steps. This step effectively reduced the remaining noises in the time series that would otherwise impact the identification of minimum and maximum points and the subsequent fitting of a mathematical curve that we conducted to characterize the phenological cycles in a consistent way. " The modified passage in section 2.2.3 now reads: "We identified local minimum and maximum points of the per-pixel time series using a moving window of 9 time steps and a > 0.01 EVI amplitude threshold to identify cycles of greening and browning. 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."

»If so, how did the authors determine the window size? Did the size of the window affect the result? In addition, the authors need to explain the choice of EVI >0.01 (Page 7692) and 20% amplitude threshold for the start and end of the season.

>Large areas of Australia are sparsely vegetated and with our algorithm we aimed to characterize the low amplitude phenological cycles of this sparsely covered areas

that occupy most of Australia. The detectability of cycles is a function of the signal amplitude, the noise amplitude and frequency, and the smoothing parameters. The window size thus affects the results and we used the 36 sites to optimize the width of the smoothing filter and moving window for defining seasonal minimums and maximums 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 used the > 0.01 EVI threshold on the smoothed time series, which had lower amplitude compared to the raw, noise affected time series. The 20% amplitude threshold for the start and end of the cycle has been used in previous studies that we now cite in this context (section 2.2.3). In section 2.1 we now state that "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 effectively captures the variability in phenology across the country and we used them to determine optimized algorithm parameters."

»Some of the statements in the Discussion section need to be explicitly supported by the results from the current study. For example, the authors mentioned in P 7700 Line 17 that "however we see a fast response to rainfall pulses : : :". However, according to Fig.6B, some areas in interior Australia lag behind SOI for _12 months, which thus did not support the above claim. Another example is that in P 7700, Line 27, the authors mentioned Lake Eyre, but Lake Eyre was not annotated in the figures.

>Thank you. We changed the phrasing of the relevant passage in section 4.2 to "we interpret the high variability in start of cycle and peak timing (new Figure 4 and 5) as a fast response to rainfall pulses and the missing cycles (new Figure 5) were interpreted as dormant periods during dry years (Loik et al. 2004)."

We state in the discussion (section 4.4) that the findings regarding the lag of phenological response to SOI and rainfall "contradict the concept that rainfall pulses drive rapid phenological response (Loik et al., 2004). We interpret our findings as the dominating space-time relationship between large scale atmospheric circulation pattern variability and phenological response. Yet these patterns are unlikely to represent responses to individual storm events. However, less significant relationships with different SOI and rainfall month and lag time were also present suggesting that vegetation responds to climatic variability at multiple time scales. A more in-depth analysis of the relationship between climatic drivers and phenological response across multiple temporal scales should be investigated in future research." We now also label Lake Eyre in Fig 1 as per the reviewer's suggestion.

»Please add the spatial resolution of TRMM. As I understand the resolution is 0.25 degree by 0.25 degree, which is much larger than the spatial resolution of MODIS. Then the authors need to explain in detail how to compare the data from these two products.

>Thank you for this comment. We added the spatial resolution (0.25° x 0.25°) of TRMM_3B43.v7 to the text in section 2.1 'Study area and data used'. Prior to analysis we resample the TRMM data to the spatial resolution of our phenological variables. As for the implication of the spatial resolution of driver variables, a coarse spatial resolution driver can partially explain a fine-grained spatial response. In an extreme case, SOI is a proxy of the air pressure gradient between Darwin and Tahiti (~8500 km apart) yet we can detect a fine spatial scale correlation pattern differentiating for example the vegetation response of the Cooper Creek floodplain form its surroundings as the floodplain's topography and hydrology are different from adjacent vegetated areas at a fine spatial scale.

»It would be useful to compare the inter-annual variability of the start of season, and the end of season, and their relationship with the timing of rainfall (and SOI). As one previous study suggested that for deciduous forest in Australian tropical savannah, leaf-out (or leaf flushing) only occurs after the first rainfall event: Williams, R. J., et al. "Leaf phenology of woody species in a north Australian tropical savanna." Ecology 78.8 (1997): 2542-2558.

»Thank you for this suggestion. Analyzing the response of woody savanna vegetation to rainfall timing would be an interesting topic for future work. Remotely sensed phenology in savanna systems primarily reflects the dynamics of the grassy understory and, while attempts of signal disaggregation have been made (e.g. Donohue et al 2009), teasing out overstory dynamics in open canopy woody systems represents a research frontier. In section 4.5 "Limitations and future work" we state that: "When interpreting the phenological cycles characterized here, it should be noted that the sub pixel composition of vegetation and background as well as multi-layer vegetation structure is unknown and may change over time (Zhang et al., 2009;Walker et al., 2012;Walker et al., 2014)."

»Specific comments (P for Page, L for Line): P7686 L11: what does "internally" mean here? It would be better to avoid vague terms like this one.

>Thank you. We removed the term from the sentence.

»P7686 L15: how to define the effectiveness of the method? If the algorithm used in this study was not compared with other methods (which is the case), it will be better to refrain from using this statement.

>Done. Thank you. We rephrased the sentence to: "To fill this knowledge gap and to advance phenological research, we developed an algorithm to characterize phenological cycles and analyzed geographic and climate-driven variability in phenology across Australia."

»P7690 L06: As Referee #2 suggested that more specifics are needed here. How was the calibration done? What are the land cover types of those sites (a table will be better)?

>Thank you. We used the 36 sites to optimize the width of the smoothing filter and moving window for defining seasonal minimums and maximums as well as the minimum cycle amplitude (which we now specifically state in section 2.1). The sites also

served as test cases to ensure that the model algorithm, which was generic across the study area, produced expected results. We removed the term calibration from the text and now state that we used the sites for “algorithm development and testing” (section 2.1). As per the reviewer’s suggestion, we added Table 1, showing the land cover classes of the test sites and the average annual rainfall to differentiate phenological test sites that belong to the same land cover class.

»P7690 L13: Comparing with the 16-day EVI data used in this study, MOD09 products have higher temporal resolution (daily and 8-day), which is important for the study of phenology. The authors need to explain/discuss why the coarser temporal resolution product was selected.

>Thank you. We chose the 16-day versions of the EVI data as it attenuates the noise present in higher temporal resolution versions (Solano et al. 2013) and now state this in the text in section 2.1. The passage now reads: “We chose the 16-day versions of the products as they attenuate the noise present in higher temporal resolution versions (Solano et al., 2012).”

»P7695 L13: Please explain what is “persistent greenness”. Is it “high mean EVI, and low magnitude”?

>Persistent greenness is high mean peak EVI and high mean minimum point EVI, so EVI is always relatively high. We now state this in section 3.1. in the text. The sentence now reads: “Other areas with high levels of persistent greenness (areas with high mean peak magnitude and high mean minimum magnitude) included. . .”

»Figures: Fig.1: It will be better if the legend shows the land cover types different colors correspond to, instead of use words in the caption.

>We added a color legend to the figure as per the reviewer’s suggestion (Figure 1).

»Fig.7: This figure would be better if the location of the Cooper Creek floodplain is shown in the figure. In addition, north arrow would be good.

>Thank you. We now show the Cooper Creek floodplain in the figure and added a north arrow as per the reviewer’s suggestion (new Figure 9).

Interactive comment on Biogeosciences Discuss., 11, 7685, 2014.

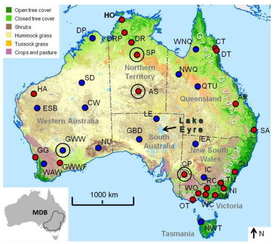

Fig. 1. Land cover map of Australia shows closed and open tree cover in dark and light green, respectively. The purple colors that occur predominantly in the South West and South East represent crops and pasture. Brown marks shrubs, orange colors mark tussock grass and light brown colors mark hummock grass cover across most of the semi-arid and arid interior (land cover classes were aggregated based on: Lymburner et al. (2011). The most prominent topographic feature is the Great Dividing Range that runs along the Eastern seaboard. Locations of the 21 OzFlux flux tower sites and 15 additional sites are shown as red and blue circles and were used for phenological trajectory evaluation. We used the EVI time series at the sites for phenological algorithm development and testing (site list provided in Table 1). The phenology for the sites marked by a large black circles is presented and discussed in Section 2.2.3. The bottom left panel shows the extent of the MDB.

Fig. 1.

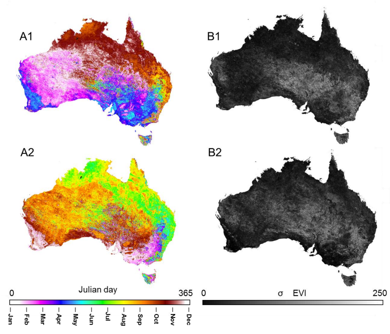

Fig. 5. Mean Julian day of the start of the phenological cycles (A1) and standard deviation of the start of the phenological cycles in number of days (B1) and mean Julian day of the end of the phenological cycles (A2) and standard deviation of the end of the phenological cycles in number of days (B2) 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. 2.

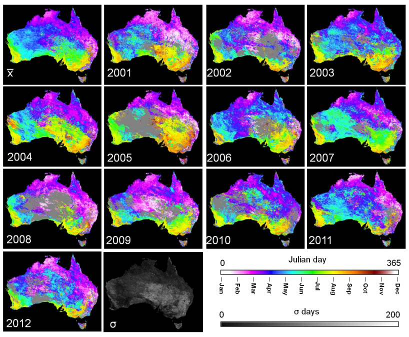

Fig. 6. Inter-annual variation in the peak timing. The Julian day of the phenological cycles' peak is displayed in the calendar year when the peak occurred. The mean (x̄) and standard deviation (σ) of the cycle peak timing is provided for reference. The scale is cyclic. Areas where no peak was observed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

Fig. 3.

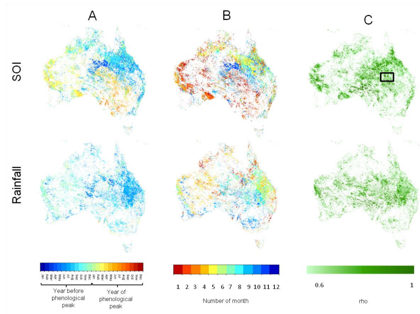

Fig. 8. Statistically significant relationships between monthly SOI and phenological cycle peak magnitude (top row) and monthly rainfall and phenological cycle peak magnitude (bottom row). (A) SOI and rainfall month most significantly correlated with peak magnitude. (B) Lead time of SOI and rainfall 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. 4.

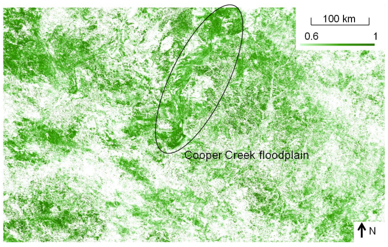

Fig. 9. Significant Spearman rho correlations (shown in green) between monthly SOI and phenological cycle peak magnitude over a region in central Australia. The Cooper Creek floodplain of the middle reach of the Cooper Creek is visible in the center. Only areas with $p < 0.05$ and rho >= 0.6 are shown.

Fig. 5.