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Interactive comment on "Water availability limits tree productivity, carbon stocks, and carbon residence time in mature forests across the western United States" *by* Logan T. Berner et al.

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Anonymous Referee #1

General Comments: This is a very interesting paper that uses forest inventory and satellite data to evaluate the influence of mean annual moisture balance on forest productivity and biomass across the western US with a particular focus on California, Oregon, and Washington. While it is no surprise that productivity and biomass in this region are affected by water availability, this paper provides the most thorough quantification of this influence to date and represents a fantastic use of US Forest Service survey data. This thorough quantification leads to the conclusion that water balance has not just an important influence on forest carbon in the western US, but that it is instead

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THE dominant driver in this region, with a strong and reliable effect on both biomass and productivity, which translates to a strong and reliable effect on carbon residence time. This information has clear implications for future forest carbon dynamics in a warmer world with altered precipitation regimes, which is importance since dynamic vegetation models are still in need of substantial improvement before their representations of future shifts in forest demographics across regions as large and complex as the western US are taken seriously. I recommend publication after some minor points below are addressed.

RESPONSE: Thank you for your feedback on our manuscript. Your comments were very helpful in preparing a revised version of our manuscript. We made the minor revisions that you suggested, as detailed below.

Specific Comments:

L79: The Singh et al. study is a great one but the focus is not on the impact of recent warm temperatures on west coast drought, but rather on an observed increase in the frequency of east-west dipole years when the western US is anomalously warm and the eastern US is anomalously cool. There have been many papers that more compellingly evaluate the role of temperature in exacerbating recent drought conditions on the west coast, particularly CA, than either of the references provided here:

AghaKouchak, A., L. Cheng, O. Mazdiyasni, A. Farahmand (2014), Global warming and changes in risk of concurrent climate extremes: Insights from the 2014 California drought, Geophysical Research Letters, 41(24), 8847-8852, doi:10.1002/2014GL062308.

Griffin, D., K. J. Anchukaitis (2014), How unusual is the 2012–2014 California drought? Geophysical Research Letters, 41(24), 9017-9023, doi:10.1002/2014GL062433.

Mao, Y., B. Nijssen, D. P. Lettenmaier (2015), Is climate change implicated in the 2013-2014 California drought? A hydrologic perspective, Geophysical Research Letters,

42(8), 2805-2813, doi:10.1002/2015GL063456.

Mote, P. W., D. E. Rupp, S. Li, D. J. Sharp, F. Otto, P. F. Uhe, M. Xiao, D. P. Lettenmaier, H. Cullen, M. R. Allen (2016), Perspectives on the causes of exceptionally low 2015 snowpack in the western United States, Geophysical Research Letters, 10.1002/2016GL069965, In press, doi:10.1002/2016GL069965.

Shukla, S., M. Safeeq, A. AghaKouchak, K. Guan, C. Funk (2015), Temperature impacts on the water year 2014 drought in California, Geophysical Research Letters, 42(11), 4384-4393, doi:10.1002/2015GL063666.

Williams, A. P., R. Seager, J. T. Abatzoglou, B. I. Cook, J. E. Smerdon, E. R. Cook (2015), Contribution of anthropogenic warming to California drought during 2012-2014, Geophysical Research Letters, 42(16), 6819-6828, doi:10.1002/2015GL064924.

RESPONSE: Thank you for guiding us towards several more appropriate references. We removed the citation to Singh et al. (2016) found several of the suggested citations to be more appropriate (e.g., Mote et al. 2016; AghaKouchak et al. 2014).

L132-136: The allometric equations and LAI-vs-root relationship should be cited, particularly for the diverse (non-forestry) readership of this journal.

RESPONSE: We added the appropriate citations for the allometric equations (Means et al. 1994; Law et al. 2001) and equation for estimating root biomass from leaf area index (Van Tuyl et al. 2005).

L140: I don't think it's necessary to specify that stands of >100 years of age are considered here since it was already stated that only stands of this age group were considered in the analysis.

RESPONSE: Suggestion adopted.

L177-194: The circularity involved in using the MODIS NPP product, which incorporates climate data, to evaluate the relationship between NPP and climate needs to be

acknowledged.

RESPONSE: We agree that the circularity should be acknowledged and added the following sentence to the methods (section 2.1.2):

"We acknowledge a degree of circularity in relating NPPsat to CMI given that both computations incorporate temperature data, specifically, temperature-effects on VPD."

L341-344: Is this artifact due to saturation of satellite-derived NDVI/LAI in densely vegetated areas? It seems like the likely reason for the false plateauing in the satellite obs could be stated.

RESPONSE: It is possible that the apparent saturation of MODIS NPP in the wettest areas was related to MODIS becoming less sensitive to variation in FPAR in densely vegetated areas. We modified part of the text to read (starting on line 337):

"The NPP-CMIwy relationship was similar when NPP was assessed using field measurements from across WAORCA or using MODIS covering the western US. MODIS did show NPP leveling off in the wettest parts of WAORCA (CMIwy $\approx$ 100-200 cm yr-1), whereas this was less evident in the field measurements. The inventory sites and MODIS forestland occurred at similar elevations along the CMI_Âŕwy gradient in WAORCA, suggesting that this discrepancy in NPP was not due to MODIS systematically including cold, high-elevation areas not sampled by the inventory sites. One possibility is that MODIS NPP did not increase in the wettest areas because MODIS becomes less sensitive to increases in the fraction of photosynthetically-active radiation (FPAR) absorbed by plant canopies in densely vegetated areas (Yan et al., 2016)."

L459-460: The projected soil moisture trends in Dai (2013) are for just 0-10 cm. For model projections of the more important 1-2 m layer, Cook et al. (2015) is a good reference, at least for CA and the Southwest. Cook, B. I., T. R. Ault, J. E. Smerdon (2015), Unprecedented 21st century drought risk in the American Southwest and Central Plains, Science Advances, 1(1), e1400082, doi:10.1126/sciadv.1400082.

RESPONSE: Thank you for the suggestion. We incorporated this reference into our discussion.

L469-472: But isn't it under hotter/drier conditions where, all else held equal, vegetation stands to benefit the most from increased CO2. The argument that recent drought-driven declines in productivity in the Southwest is evidence for a lack of a CO2 effect is an incomplete argument, as it could be counter-argued that the recent drought period has been particularly intense and that the consequences would have been more severe without CO2 fertilization. There is still much that is unknown about CO2 fertilization, the forests that will benefit from it, and how these benefits will manifest, but just as it is unwise to argue that CO2 fertilization will definitely allow semi-arid forests to become more productive in a warmer world, it is also unwise to imply without a thorough evaluation of evidence that CO2 fertilization will not have any effect on the future relationship between CMI and NPP, BIO, or CRT.

RESPONSE: Following this comment and feedback from Reviewer 2, we chose to remove the 'Climate change implications' section and replace it with a section called 'Predicting ecosystem response to environmental change' that reads (starting on line 475):

"Water availability is projected to decline in much of the western US over the coming century, in part due to higher temperatures increasing atmospheric evaporative demand (Dai, 2013; Walsh et al., 2014; Cook et al., 2015). Predicting the timing, magnitude and extent of ecological response to regional climate change remains a challenge. Our study showed that water availability is a key determinant of forest structure and function in the western US, broadly suggesting that chronic reductions in regional water availability could reduce the NPP, BIO, and CRT of mature stands. Nevertheless, it is problematic to predict the temporal response of extant forest communities to near-term climatic change based on ecoclimatic relationships derived from spatial data. For instance, recent studies found that the slope of the NPP-precipitation relationship was much steeper when derived from spatial data than when derived from the temporal re-

sponse of NPP to interannual variation in precipitation (Jin and Goulden, 2014; Wilcox et al., 2016). Near-term effects of climate variability depend on the physiological characteristics of species in the extant plant community, yet ecoclimatic relationships derived from spatial data reflect gradual adjustment of community composition and population size to climate over long periods of time (Jin and Goulden, 2014; Wilcox et al., 2016). Furthermore, ecoclimatic models derived from spatial data cannot account for other ecophysiological impacts of environmental change, such as (1) enhanced plant water use efficiency from CO2 fertilization (Soulé and Knapp, 2015); (2) increased likelihood of tree mortality due to hotter drought (Adams et al., 2009); or (3) novel changes in disturbance regimes (Dale et al., 2001; Hicke et al., 2006). Consequently, predicting ecological response to environmental change over the coming century will require the use of mechanistic ecosystem models that account for physiologic, demographic, and disturbance processes at fine taxonomic and spatial scales (Hudiburg et al., 2013; Law, 2014). Although spatial models may not be suitable for near-term projection of ecosystems change, they do provide insight into long-term ecosystem adaptation to local climate and, furthermore, can be used to validate and refine mechanistic models if constructed from a representative sample of forestlands."

Technical Corrections:

L39 & 41: CMI should be defined on L39, therefore allowing the definition of CMIwy on L41 to make more sense.

RESPONSE: Suggestion adopted.

L94: Should “be” be “by”?

RESPONSE: Yes, thank you.

L112: The specification of the converse hypothesis is unnecessary.

RESPONSE: The converse hypothesis has been removed.

L125: Should “using” be “used”?

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RESPONSE: Yes, thank you.

L237: Should “extensive” be “extensively”?

RESPONSE: Yes, thank you.

L443: “elucidate underlying mechanism” may be missing a word or letter.

RESPONSE: We changed the sentence to read, “. . .additional efforts are needed to determine the underlying mechanism by which changes in water availability affect CRT.”

L847 (Fig 2 caption): Should “annual” be “annually”?

RESPONSE: Yes, thank you.

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