To Dr Alastair Brown,

Please find, below, our responses to the reviewer comments on our recent paper submitted to *Nature Climate Change*, titled “Climate change decouples drought from early winegrape harvests in France”. Below, you will find the original review comments in *italics*, our responses in plain text, and any substantive additions to the text in the main manuscript in **bold**.

Should you have any questions, please do not hesitate to contact us.

Kind Regards,

Benjamin Cook (corresponding author)

Elizabeth Wolkovich

**Reviewer 1**

*“This paper addresses an important issue for the global wine industry namely the influence of climate change on grapevine Phenology and its central conclusion is of critical significance to the french and german wine industries that are in the main not irrigated. The work is also of significance to the majority of of the global wine industry that is irrigated because it confirms the quantitative influence of climate change on grapevine phenology central. Indeed an interesting point that the authors have not emphasised is that in this analysis of the unirrigated French industry and Webb et al's (2012)analysis of the irrigated Australian wine industry the basic temperature sensitivity of grapevine to climate change is the same - 6 days per degree C*

*The central conclusion is well supported by the data presented and I recommend that it be be published in Nature Climate change provided the authors can satisfactorily address some methodological questions that I have outlined below and also address some editorial issues in the manuscript”*

We have added text in the manuscript noting the similarity in our temperature sensitivities to Webb et al. 2012. Paragraph 5:

**Remarkably, this sensitivity is quite similar to the temperature sensitivity found for irrigated vineyards in Australia12.**

*“1. The central assumption in the use of the GHD - Core dataset from 1600 to 2007 is based on some sweeping assumptions that varieties and viticultural practise have remained relatively constant in the French and Swiss industries over this period. The following components of this assumption needs to be addressed before it can be accepted*

*“1. Was the Grape Harvest Day - CORE dataset corrected for variations in Baume'(sugar) levels on harvest day to a common Baume' level - while they are currently specified particular Appellations this is a range not a particular figure and of course influences harvest day”*

The concern regarding Baume’ (sugar) levels in our analysis relates to the fact that management changes designed to select specific sugar levels in the fruit may affect harvest dates, independent of any environmental changes (such as climate). Unfortunately, there is no information on sugar levels from the Daux et al historical dataset that we use. It is therefore impossible to adjust the data to common Baume’ level. However, there are several reasons we believe the lack of this information does not compromise our analysis and interpretations of climate change impacts on harvest date:

1) Most of our results and discussion are based on the GHD-Core composite index, which was designed specifically to minimize the influence of local management changes. Baseline sugar levels are therefore likely to vary across the regions and varieties that make up this index. And any changes in harvest practice designed to select for specific Baume’ sugar levels will unlikely be uniform across regions and grape varieties. The multi-region average of 8 sites in our GHD-Core composite will thus minimize this and other local management effects, while maximizing the signal of large-scale climate forcing.

2) Temperature is the fundamental and direct driver of harvest dates in the Daux et al dataset. Any non-climatically induced shift in harvest dates (e.g., to select for fruit with specific sugar levels) would thus be expected to decouple and weaken the temperature/harvest date relationship. However, the temperature sensitivity of GHD-Core is relatively stationary pre- and post 1980 (about -6 days per degree C of warming), indicating that the direct relationships between temperature and harvest date has not changed. This strongly suggests that any management effects that would shift the harvest date independent of climate are largely non-significant.

3) The only changing climatic relationship with harvest date is drought. There is no a piori reason, however, to believe that management changes based on Baume’ levels would specifically change this relationship, while maintaining a stationary relationship with the primary driver (temperature).

While we do not believe the lack of Baume’ information undermines our analysis, we have added additional text to the Methods section acknowledging that this information is unavailable, and making the same points above. In Methods, under “Grape Harvest Data”:

**Other analyses of climate change and historical grape harvest dates have attempted to adjust the recorded dates based on Baume’ sugar levels in the fruit12. This is because management changes designed to select specific sugar levels in the fruit may affect harvest timing, independent of any environmental changes, such as climate. Unfortunately, we could not find any information on sugar levels in the DAUX harvest date dataset. However, we believe lack of this information is unlikely to affect our results. First, for reasons described previously, our analysis is focused on the multi-site composite index GHD-Core, designed to maximize the large-scale climate sensitivity and minimize the effects of local management changes. Second, we note that the harvest date sensitivity to temperature (the primary driver) in GHD-Core has a similar magnitude pre- and post-1980. Since shifts in harvest timing to select for sugar levels would occur independent of climate, the expectation is that the temperature relationship should weaken. Since this does not occur, it is likely that any management driven shifts in harvest timing that have occurred have been relatively minor. Finally, we note that the only changing climate relationship is between harvest and drought. There is no a prori reason, however, to expect management shifts in harvest to change this relationship, while maintaining a significant relationship with the primary harvest driver (temperature).**

*“2. While the basic grape varieties within the French wine industry have remained constant over this period -significant changes have occurred through*

*1. The selection of superior clonal material with these varieties”*

[LIZZIE INFORMATION/REFERENCES ON PROBABLE DATES OF CLONAL SELECTION TO JUSTIFY THE WINDOWS THAT WE CHOSE.] We note again, however, that this was one of our primary motivations for focusing on the composite GHD-Core index, because clonal selection is unlikely to have occurred identically and at the same time for all varieties across all regions in the DAUX dataset.

To test for potential impacts of clonal selection, we have conducted a new analysis for Languedoc and GHD-Core, refitting the regression models for three intervals during which there is evidence that significant clonal selection occurred. These intervals are: 1947-1957, 1958-1969, and 1970-1980. This new analysis has been added to the Supplemental Materials, under “Clonal Analyses”:

**Selection of superior clonal material by managers may introduce changes over time that could influence vine phenology and harvest date. [LIZZIE INPUT HERE ON LANGUEDOC ETC]. To test for the potential impact of clonal selection on harvest dates, we refitted the Lan (Supplemental Figure 16) and GHD-Core (Supplemental Figure 17) regression models for three intervals across which significant clonal selection is thought to have occurred: 1947–1957, 1958–1969, and 1970–1980. Compared to the regressions using more of the available data (e.g., Lan in Supplemental Figure 8 and GHD-Core in Figure 3 from the main manuscript) the results are noisier and less significant, as expected. For both sites, however, the temperature sensitivities for both Lan and GHD-Core are similar when comparing across these 11-year intervals and previous regressions (1901– 1980 and 1981–2007). Combined with our focus on GHD-Core (which should minimize local management changes), we find it unlikely that clonal selection has had a significant impact on our results.**

*“2. Most importantly the use of American Vitus rootstocks in the French industry following its devastation by the root aphid Phylloxera in the late nineteenth century - the post 1900 datasets are derived from grafted vines whereas the pre 1900 dataset is from own roots vines.The potential significance of these major changes in viticultural practice need to be assessed and analysed in terms of their impact on the phenology of the vines”*

We have added a new analysis to investigate the potential impact of phylloxera. From Supplemental Materials, “Phylloxera”:

**In 1850s or 1860s, an exotic species of aphid (commonly known as grape phylloxera) was introduced to Europe. This resulted in a severe blight and destruction of many vineyards across France. Large-scale recovery of the vineyards and wine industry began in the late 1800s and early 1900s with the grafting of European vines onto phylloxera resistant root stock from the United States. There was thus a substantial shift in root stock composition beginning around the turn of the 20th century, a change that could conceivably affect our interpretation of climatic effects on harvest date.**

**To investigate this, we calculated regression models between GHD-Core and JJA climate (temperature, precipitation, PDSI) from the climate reconstructions (instrumental data is not available prior to 1901) (Supplemental Figure 18). Shown are three intervals: 1800–1850 (prior to the phylloxera epidemic), 1851–1900 (during the phylloxera epidemic), and 1901–1980 (after widespread grafting occurred). Results are generally consistent across all three time periods. For temperature, sensitivities, range from –4.97 to –6.56 days oC–1 with R2 values from 0.359 to 0.464, similar to results found in the instrumental regressions for this season (Supplemental Figure 13). Similar results are found for precipitation and PDSI, although precipitation is only marginally significant for 1800–1850 (PDSI is still highly significant for this period, however). Given the lack of evidence for any systematic change in sensitivities pre- and post- phylloxera, we conclude that this event is unlikely to have significantly affected our climate based analyses and interpretations.**

***“****2. The diagrams and their captions need further clarification and explanation for reader assimilation*

*“1. Diagram 1 - the normalised histograms of anomalies for 2 periods 1600-1980 (blue) and 1981-2007 (pink) - what does the mauve colour represent ? - also DAUX dataset should be referenced to reference list”*

We have rewritten the caption to be more intuitive, as well as adding the reference to the DAUX dataset. New caption for Figure 1:

**Left panel: time series of grape harvest date anomalies from GHD-Core, composited from the Alsace (Als), Bordeaux (Bor), Burgundy (Bur), Champagne 1 (Cha1), Languedoc (Lan), the Lower Loire Valley (LLV), the Southern Rhone Valley (SRv), and Switzerland at Leman Lake (SWi) regional harvest date time series in the DAUX4 dataset. All anomalies are in units of day of year anomalies, calculated relative to the average date from 1600–1900. Right panel: normalized histograms of GHD-Core harvest date anomalies from 1600–1980 (blue) and 1981–2007 (red). Dashed boxes indicate the region over which climate observations and reconstructions are averaged (2oW–8oE, 43oN–51oN) for regression analyses with GHD-Core.**

*“2. Diagram 2 - the purpose of this diagram is not clear nor explained in the caption”*

Figure 2 was meant to illustrate the changing relationship between GHD-Core and climate in a spatially explicit way, meant as a supporting analysis to the regressions in Figure 3. We have modified the text to hopefully make the purposes of Figures 2 and 3 clearer. Beginning of Paragraph 5:

**In addition to an overall trends towards earlier harvest dates, there are also substantial changes in the strength of the relationship between climate (temperature, precipitation, PDSI) and GHD- Core (Figures 2 and 3; for individual regional grape harvest date series, see Supplemental Figures 4–11). Most notably, the strength and significance of the moisture relationships (precipitation and PDSI) declines in recent years (Figure 2, bottom two rows; Figure 3, center and right columns), while the relationship with temperatures appears relatively stationary (Figure 2, top row; Figure 3, left column).**

*“3. Other minor editorial - page 2 para 1 - warmer temps..........vine phenological development from flowering to fruit maturation l and harvestvine phenology is affected by temperature throughout the full cycle - bud burst, flowering, verasion and maturity”*

We have modified the text to make this correction. The new sentence now reads:

**Specifically, warmer temperatures accelerate grape vine phenology over the full cycle of development (budburst, flowering, veraison, and maturity), while increased precipitation tends to delay winegrape phenology13.**

“*4. Final conclusions*

*1. While I agree the authors have demonstrated that climate change is not acting on phenology in the absence of drought , I do agree that this is a fundamental change physiological change in the grapevine ,in other areas we have found if drought also occurs it has an additive effort on accelerating phenology”*

Our analysis was primarily speaking to the impacts of drought on wine grape phenology, as expressed through grape harvest dates. We fully agree that drought can affect wine grapes in other ways, and we have added some text acknowledging this. From the final paragraph:

**Droughts are still likely to affect vine health and development and the wine industry independent of temperature effects, especially in wine growing regions that are significantly drier than France12,26.**

**Reviewer 2**

*“Overall a very good piece of research and the article is generally well written. Some minor issues or clarifications needed. References are sufficient to cover the background research. Only tie that would be of interest is that a long term record of spring shoots in grapevines in Hungary has shown an interesting connection to spring temperatures, but which are not always well correlated with harvest dates. Fila et al (2015) and Kiss et al (2010).”*

We were unaware of these references and thank the reviewer for pointing them out. While the inclusion of these datasets in our analysis is outside the scope of the current study, we have added them as citations where appropriate. LIZZIE WHERE TO ADD THESE DO YOU THINK?

*“I am pretty confident that the literature does not show that drought is the main driver of fruit maturation. Temperature, and even better accumulated heat, over the growing season is the main driver of fruit maturation. Rainfall in wine growing regions can be very beneficial during spring and even into MJJ as long as it is followed by relatively dry conditions into JAS. But drought is not the main driver.”*

We have modified the abstract to more clearly indicate that temperature is the primary driver:

**Across the world, winegrape phenology has advanced in recent decades1–3, in step with climate change induced trends in temperature (the main driver of fruit maturation) and drought.**

***“****Also it is worth noting that the regions you are examining have historically not used irrigation and have much wetter summer climates than other mid-latitude wine regions on west coasts of continents (Chile, Australia, western US). Seasonally dry summers in Europe are typically good for fruit quality, but much drier conditions can both stress the vines producing poor fruit and result in much lower yields. The main point is that drought is not a main driver of harvest dates, but plays a much more complicated role depending on its timing, longevity, and severity. All you have done is look at them separately and noted stronger temperature effects and lower precipitation effects.”*

We agree that drought plays an important role aside from it’s impact on grape vine phenology. To that end, we have added a modified statement and references to the final paragraph of the paper.

**Droughts are still likely to affect vine health and development and the wine industry independent of temperature effects, especially in wine growing regions that are significantly drier than France12,26.**

*“For much research that I have seen, when you run a multivariable regression the temperature signal swamps the precipitation signal and results in any measure of moisture being not included in the regression. I would like to see some attempt to quantify the entire model with your data, would temperature, precipitation, and PDSI all stay in a multivariable regression model?”*

We have added a multiple regression analysis to the Supplemental, using temperature, precipitation, and PDSI as predictors. Indeed, the addition of the precipitation and PDSI terms do not add significant skill beyond temperature in the multiple regression model. This indicates that drought variability is not acting as a direct impact on wine phenology, but is instead acting indirectly through modulation of temperature effects. The multiple regression analysis is discussed in detail in the Supplement, and we have added some text to the main manuscript noting these results. From the Supplemental, “Multiple Regression Analyses”:

**Temperature, precipitation, and PDSI are all significant predictors of grape harvest dates. However, it is unclear if moisture availability (as expressed by precipitation and PDSI) acts directly on grape phenology or indirectly through modulation of temperatures. To test this, we have conducted a multiple regression analysis to in- vestigate if significant skill is added into the model when precipitation and PDSI are included as predictors with temperature.**

**Results from the single and multiple variable regressions (1901–1980, climate data from the instrumental CRU climate grids) are shown in Table 9. Temperature is by far the single best predictor of harvest date; precipitation and PDSI are also significant predictors in their own single variable regressions. Adding precipitation and PDSI into the temperature regression model, however, does not substantially improve the explanatory power of the model (R2) and these additional moisture terms are insignificant (p > 0.05). This suggest that moisture variability does not affect grape phenology directly but, instead, acts through the modulation of temperatures (where drier equals warmer, via the mechanisms discussed previously).**

Main manuscript, paragraph 6:

**This may be due to direct drought impacts on fruit maturation by increasing abscisic acid production12 or indirectly through feedbacks between soil moisture and air temperature (the more likely explanation; see Table 9 and ‘Multiple Regression Analysis’ in the Supplemental).**

*“Why was the data set not updated to 2014? The data is available and would make your work much relevant.”*

To our knowledge, the latest data available in the publicly accessible DAUX data set ends in 2007. Our analyses are based on the version archived in the NOAA Paleoclimate Data Center, downloaded from here:

**<https://www.ncdc.noaa.gov/cdo/f?p=519:1:0::::P1_STUDY_ID:13194>**

We searched, but were unable to find an updated version of this database that includes data for more recent years. However, we note that two of our paleoclimate reconstructions (temperature and precipitation) actually end prior to the last date in the DAUX dataset (2002 for temperature; 2000 for precipitation). Some of our analyses (e.g., the anomaly compositing) are therefore limited not by the length of the DAUX data, but by the end date of the paleoclimate datasets.

*“Grapevine is one word.”*

We have modified the text to remove all uses of “grape vine” as two words.

*“Fila et al (2015) also show the effect of "the year without a summer" in spring vine shoots in Hungary.”*

Actually, Fila et al find little evidence for Tambora in their reconstructed series. From their paper:

*‘…in the reconstructed series there is little evidence of the effects of the Tambora eruption, which caused the famous “year without a summer” in 1816.’*

They attribute this to the major cooling from Tambora occurring during the summer, rather than the spring, when the shoots are recorded in the *Book of Vinesprouts.*

*“Figure 1 caption needs to define the region acronyms, as it is now it is only defined in the Supplementary Information.”*

We have added the definitions for the region acronyms into the Figure 1 caption.

*“Figure 2 needs to give the GHD-Core region box definition, not given until Figure 3.”*

We have added the GHD-Core region definition to the caption for Figure 2.