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Comment on esd-2021-9

Anonymous Referee #1

Referee comment on "Downscaling of climate change scenarios for a high-resolution, site-specific assessment of drought stress risk for two viticultural regions with heterogeneous landscapes" by Marco Hofmann et al., Earth Syst. Dynam. Discuss., <https://doi.org/10.5194/esd-2021-9-RC1>, 2021

▪ General comments

The rationale of the paper is based on the need to improve knowledge of local climate and soil moisture in order for vineyard regions to respond appropriately to climate change. The paper emphasises the need to downscale from global climate model predictions using regional climate models in order to assess effects on the water budget of grapevines at vineyard scale, so is in line with contemporary research trends. A weather generator and a water balance model are also used, accounting for local variations in soil characteristics, the complexity of the terrain, and crop management practices, in order to provide predictions of drought risk at vineyard scale.

The overall aim of the paper is therefore in line with objectives of international research into the application of climate models to assess impacts of and develop appropriate responses to climate change by downscaling model projections of future climate to vineyard scale. Although the general approach is fine, there are several areas of weakness in the paper, as discussed in the following section. In particular, some aspects of the methodology used in the paper seem to be rather dated and not clearly described. In particular, I would have expected that more recent climate models would have been used, given the rapid climate model development that has taken place over the past decade.

▪ Specific comments

2.1 Soil moisture versus temperature

Line 31-32: I disagree with the general statement that 'Within the existing production areas, water shortage is probably the most dominant environmental constraint (Williams and Matthews, 1990)', which the authors appear to suggest applies globally. In many parts of the world, it is clear that temperature has a greater impact on grape production and wine quality, especially in 'New World' regions where irrigation is a standard practice.

2.2 Dated climate models

The climate models used in this research appear to be quite old and outdated (van der Linden and Mitchell, 2009) given the rapid developments in model design and downscaling techniques over the past decade. Even the web link for the ENSEMBLES Final Report states 'This object has been archived because its content is outdated.' (<https://climate-adapt.eea.europa.eu/metadata/publications/ensembles-final-report>). It is therefore unclear why more recent climate models from the CMIP5 and CMIP6 evaluations, or the available EURO-CORDEX model data are not used in this work. Recent publications referenced in this paper (e.g. Gutiérrez et al. 2019) appear to suggest that EURO-CORDEX is the preferred model framework for contemporary research, and there are many publications over the past decade that have been based on CORDEX climate model data.

The dated nature of the climate modelling component of this work is also evident by the reference in Section 2.2.2 to application of the 10 selected models to the old A1B emission scenario (Line 152), which was developed over 20 years ago and has since been replaced by RCP scenarios (about ten years ago) and more recently by SSP scenarios (Tebaldi et al. 2021 – see below).

Tebaldi, C., Debeire, K., Eyring, V., Fischer, E., Fyfe, J., Friedlingstein, P., Knutti, R., Lowe, J., O'Neill, B., Sanderson, B., van Vuuren, D., Riahi, K., Meinshausen, M., Nicholls, Z., Tokarska, K.B., Hurtt, G., Kriegler, E., Lamarque, J.-F., Meehl, G., Moss, R., Bauer, S.E., Boucher, O., Brovkin, V., Byun, Y.-H., Dix, M., Gualdi, S., Guo, H., John, J.G., Kharin, S., Kim, Y., Koshiro, T., Ma, L., Olivie, D., Panickal, S., Qiao, F., Rong, X., Rosenbloom, N., Schupfner, M., Séférian, R., Sellar, A., Semmler, T., Shi, X., Song, Z., Steger, C., Stouffer, R., Swart, N., Tachiiri, K., Tang, Q., Tatebe, H., Voldoire, A., Volodin, E., Wyser, K., Xin, X., Yang, S., Yu, Y., Ziehn, T., 2021: Climate model projections from the Scenario Model Intercomparison Project (ScenarioMIP) of CMIP6. *Earth System Dynamics* 12, 253–293. <https://doi.org/10.5194/esd-12-253-2021>

In addition, there is no serious critical assessment of the models selected for use in this work, particularly in relation to other potential sources of future climate model predictions mentioned above. For example, there is no serious evaluation of model bias associated with the different climate variables used to predict drought stress. How well do the selected models perform compared with more recent generations of climate model? Only generalised qualitative comments are made in this regard.

2.3 Lack of clarity regarding spatial downscaling methods

The methodological steps from the 10 climate model predictions to the daily weather generator, and subsequently to the water balance model at vineyard scale could be more clearly described. A schematic flow diagram outlining the steps involved in the methodology in Section 2.2.2 would be helpful.

Section 2.2.2 seems to suggest that the regionally downscaled climate model data are provided at a spatial resolution of 25 km, and that these data then drive the weather generator at the same resolution. Is this resolution sufficient to provide realistic spatial variability within vineyard regions in complex terrain? I found that the progression from 25 km to vineyard scale climate predictions is not well explained. In Section 2.4 it is stated that 'The study was based on the high spatial resolution of individual plots.' (Line 201), and that the digital elevation model (DEM) data appear to be at 1 m spatial resolution, while soil information is at approximately 25 m resolution (see below).

Line: 397: 'The soil data go back mainly to soil mappings conducted from 1947–1958 (Böhm et al., 2007), where at distances of 20 m x 20 m, respectively 25 m x 25 m, soil samples down to 2 m depth were taken and analyses performed.'

Much of the subsequent analysis of results in the paper is based solely on the one weather station at Geisenheim, but there is also significant discussion of future drought stress in relation to individual vineyard plots (i.e. much finer resolution). It would be good to have a clearer explanation of how the model predictions of climate data at 25 km resolution are linked to the individual vineyard plots, presumably via assessment against weather station data and using the DEM and soil data in order to downscale to vineyard scale. For example, it is not entirely clear what is meant by the following statement:

Line 424: 'In order to downscale from the spatial means of grid box data of the RCMs to the spatial scale of station data, we used a weather generator to produce point data on the same scale as the weather stations and to simulate small-scale weather patterns'.

This statement suggests that climate variables from the regional climate models represent an average over 25 x 25 km grid squares (or volumes), but the underlined section above is unclear as 'weather station scale' is not defined. Figure 1 shows weather stations located within the two vineyard regions, often separated by only 2-5 km – is this what is meant by 'the same scale as the weather stations', or is 'weather station scale' a notional area represented by a single weather station (which may vary with terrain complexity)? If so, how is the weather generator used to downscale from 25 km resolution to 2-5 km resolution? Section 2.2.2 seems to be vague on this matter. In reality, the Rheingau vineyard region could be located within only one 25 x 25 km regional model grid cell. It is therefore unclear how the 12 or so weather stations located across the region are used to provide higher spatial resolution information in order to 'simulate small-scale weather patterns'.

Also, the statement on Line 441: ‘..we downscaled the grid box means of climate models to station (point) data in order to reduce the bias...’ is vague and unhelpful, as it is obvious from the comments above that each grid box may contain several weather stations against which climate model output could be evaluated. It is therefore unclear how the model bias is assessed and/or reduced in this study.

The maps shown in Figures 11 and 12 suggest that a fine spatial resolution of drought stress was achieved, although the spatial resolution of the mapped data is not indicated in the caption.

As mentioned previously, maybe a schematic flow diagram would help to illustrate in detail the steps taken to downscale data from climate models to provide soil water information at vineyard scale.

2.4 Lack of model validation

As mentioned previously, most of the results were presented for one site (Geisenheim), and no validation against other sites was shown. Although this study is ‘....applied to individual vineyard plots of two winegrowing regions....’ (Line 508), there appears to be no real validation of the results at vineyard scale. A set of high-resolution maps is produced (Figures 11 and 12), but the lack of validation against data from a range of weather station sites would be needed to assess their true value. Figures 6, 7, 8 & 9 indicate that there is significant overlap between the climate model data (1980s to 2100) and available observations for at least some regional climate stations (1980s to 2020), which should allow a comprehensive statistical analysis of model performance.

Also, the validation results discussed in Section 3.1 are mostly subjective (e.g. ‘....no substantial bias of mean values or monthly sums between observed and synthetic values were apparent. (Lines 228-9)), and should be made more convincing through the use of rigorous statistical analysis to investigate more fully the differences between the distributions of observed and predicted variables (for a number of climate stations). Otherwise, it is not possible for the reader to properly assess the efficacy of the model downscaling and evaluate the conclusions reached in this study.

Related to the previous comment, it would have been useful to comment more fully on the results shown in Figure 2. The synthetic data in this figure show lower rainfall, higher evapotranspiration and higher solar radiation compared with observations, in addition to the smaller range of their frequency distributions. Assuming that the model predictions are correct, is it possible that this reflects a general change in weather patterns under the selected scenario from cloudy low-pressure systems to clearer high-pressure systems? If so, what other climate risks could be associated with such a trend (e.g. increased frost frequency)?

2.5 Scenarios unclear

Although both the A1B and RCP8.5 scenarios are mentioned in Section 2.2.2, there is no indication of which scenario is used in the subsequent analysis sections (until Section 4 – Discussion). A significant omission is that none of the figures in the results sections mention the scenario that has been applied to achieve the results shown in each figure (it should be included in the captions). It should also have been emphasised that the RCP8.5 scenario represents 'business as usual' and is therefore the most extreme emissions scenario. Comparative maps of different scenarios (e.g. RCP4.5 and RCP 8.5) would be an interesting addition, alongside evaluation of any differences in the seasonality of drought risk that might occur under different scenarios. Referring to other studies, it is mentioned that 'Noteworthy, the projected bandwidth for precipitation for the mitigation scenario RCP2.6 are less than half of those for RCP8.5 (Hübener et al., 2017).' (Lines 416-417), but there is no attempt to undertake such a comparison between scenarios in this study.

2.6 Statistical interpretation

There is no detailed interpretation of the p-value trends shown in Figures 6b and 7b, only the brief statements:

Lines 290-1: 'For seven simulations, the projected trends were significant after the year 2073 (Mann-Kendall trend test, $p < 0.05$, Fig. 6b).'

Lines 292-3: 'The statistical significance of the trends was comparable to the trends of precipitation (Fig. 7b).'

Presumably, the null hypothesis being tested is that predicted precipitation trends are no different from zero, but the trends in p-values for the 10 models for both annual precipitation and climate water balance are only very briefly discussed. It seems to me that until about 2030 most models show no trend in precipitation, while by about 2070 eight out of ten models appear to show a statistically significant trend (in a couple of cases a negative trend). A major shift seems to take place between about 2030 and 2050. In contrast, the results for the climate water balance shown in Figure 7 seem markedly different, with only two models showing a statistically significant trend by about 2030, and much less agreement between models as to future trends. It would be useful to have further discussion of likely mechanisms here (in Section 3.3.1).

Similarly, it would be useful to have more critical analysis of the results shown in Figure

10. The remarkable difference between the potential drought stress for the two periods (1989-2018 and 2041-2070) is not adequately explained. Presumably, the wide range of values shown for 2041-2070 for both regions could be explained by three poor-performing models, and if they were removed the differences between 1989-2018 and 2041-2070 may actually be minimal (but there is no such critical analysis here). There are some rather vague qualitative comparisons of 'bandwidth' in modelled precipitation mentioned in Section 4 (Discussion), and in relation to model evaluation, it is stated that 'This bandwidth could be reduced if the extreme models at the upper or lower edge would be excluded, but since no direct model flaws were detected, this would exclude possible future climate realisations.' (Line 411-12). However, based on the information provided in the paper there does not seem to have been any serious attempt to undertake model validation (and I am not sure what a 'direct model flaw' is). There therefore seems to have been a lack of detailed critical analysis of the rather dated climate models used in this study, as mentioned earlier, and this seems to be a major weakness of this work.

2.7 Lack of future research directions

There is no clear statement in the discussion outlining where this research might lead and what topics would be worth following up.

▪ **Technical corrections, including typing errors and English expression**

There are a lot of problems with basic English expression which in some cases make the explanations confusing. Some suggested changes are indicated below:

In several places:

Replace 'row distance' by 'row spacing'

Replace 'approx.' by 'approximately'

I would also suggest that the word 'bandwidth' is replaced with 'uncertainty' or 'variability' throughout the text as it provides a better indication of its significance in this application.

Line 11: Fix punctuation to – 'Extended periods without precipitation, observed for example in Central Europe including Germany during the seasons from 2018 to 2020, can lead to water deficit.....'

Lines 22-23: Replace 'Possible adaptation measures depend highly on local conditions and to make targeted use of the resource water,....' with 'Possible adaptation measures depend highly on local conditions and are needed to make targeted use of the resource water, while....'

Line 34: Replace 'Soil moisture decreased across Europe.....' with 'Soil moisture has decreased across Europe.....'

Line 38: Replace 'Despite of some newly emerging wine regions....' with 'Despite some newly emerging wine regions....'

Line 39: Replace '.....economically important grape cultivation of Europe.' with 'economically important grape cultivation in Europe.'

Line 50: Replace '.....cover crop or canopy management up to the implementation of irrigation systems.' with '.....cover crop or canopy management as well as the implementation of irrigation systems.'

Line 51: Replace 'Predictions on a high spatial resolution...' with 'High spatial resolution predictions...'

Line 53: Replace 'where' with 'were'

Line 57: Replace '..... the latter one also included possible changes in interannual variability.' with '..... with the latter study also including possible changes in interannual variability.'

Lines 61-64: Replace '....Moriondo et al. (2010) for expected changes for the premium wine quality area of Tuscany on a fine spatial resolution (1 km x 1 km, based on downscaling climate projections to station data and spatial interpolation). Only a few studies used data from soil maps including AWC as input data (Fraga et al., 2013; Moriondo et al., 2013), but on a spatial resolution still too coarse to represent the heterogeneity within growing regions. Recently, fine scale variability within growing regions were assessed.....' with '....Moriondo et al. (2010) for expected changes in the premium wine quality area of Tuscany at a fine spatial resolution (1 km x 1 km, based on downscaling climate projections to station scale using spatial interpolation). Only a few studies used data from soil maps that included AWC as input data (Fraga et al., 2013; Moriondo et al., 2013), but often at a spatial resolution still too coarse to represent the heterogeneity within growing regions. Recently, fine scale variability within growing regions has been assessed.....'

Lines 69-70: Replace 'Especially AWC, slope and aspect are very heterogeneous in steep slope regions and thus is the supply of and demand for water.' with 'AWC, slope and aspect are particularly heterogeneous in regions of complex terrain resulting in variability in the supply of and demand for water.'

Line 72: Replace 'like' with 'such as'

Line 73: Replace 'adapted' with 'modified'

Line 78: Replace '....the main objective of the study was to quantify the likelihood of risk for future water deficit on... ' with '....the main objective of this study is to quantify the likelihood of risk of future water deficit on....'

Line 81: Replace '... for the characterization of vineyard landscapes...' with '... in order to characterize vineyard landscapes...'

Line 90: Replace '... bounded by the Rhine river to the south and the ridge of the Taunus mountain range in the north, and the vineyards near....' with '... bounded by the Rhine river to the south and the ridge of the Taunus mountain range in the north, as well as the vineyards near....'

Line 95: Replace '...in the west...' with '.... to the west...'

Line 99: Replace 'at' with 'on'

Line 102: Replace 'predominant' with 'particularly'

Line 109: Delete 'as'

Line 110: Delete 'was'

Line 118: Replace 'We worked with four time series, two observed and two synthetic series.' With 'We worked with four time series, two observed and two synthetic.'

Line 121-123: The sense of the sentence 'All stations recorded precipitation and the station Bensheim additionally temperature and relative humidity (also used for the other stations at the Hessische Bergstraße).' is unclear.

Table 1: Some column headings need reformatting.

Lines 184 & 185: Replace '...in form of...' with '... in the form of...'

Lines 197-199: Poor English expression.

Line 215: Replace '... to assess...' with '...of ...'

Line 216: Replace '...as drought...' with '...as a drought ...'

Line 229: Replace '...on the other side...' with '...on the other hand ...'

Line 233: Replace '... for dry years...' with '... of dry years...'

[There are many more, but I don't have time to correct them all. I suggest that a native English editor is used to eliminate the remaining issues.]

Referencing errors:

Line 141: Replace 'Garofalo et al., 2018' by 'Garofalo et al., 2019'

Lines 483 and 492: Replace 'Van Leeuwen et al., 2017' by 'Van Leeuwen, C., and Destrac-Irvine, 2017'