# Authors initial response to reviewers

The authors would like to thank all three reviewers for their comments on the manuscript. I have responded to each of the comments in turn.

## 1.0 Reviewer 1

## 1.1 Response to general comments from reviewer 1

In response to the general comments from reviewer 1, I will separate out the results section into three sections: results, discussion and conclusions. I will also clarify the reasons for what is being discussed. I did not include the regional simulations in this paper as they have not been fully evaluated yet. However, I will include a clear explanation of how these point simulations have informed the regional simulations and include some prototype regional simulations to show how the method is extended from point to regional runs. I will also include reference to an earlier paper that includes a method to derive sowing and harvest dates for this region from the Asian Summer Monsoon. This is a simple method that does not require a lot of observed data. I will also refer to the ICRISAT crop area data set which will facilitate the calculation of where the crops are grown.

## 1.2 Response to individual comments

1. P 4, L 22-24: I believe there is a lot of discussion in section 6. Either the discussion should go in section 7 or relabel the sections to reflect that. Also, section 5 is not listed here and should be for consistency.

This is addressed in the Section 1.1 above. We will amend the manuscript to have results, discussion and conclusion sections and thank you for pointing out that section 5 is missing from this list, this will also be corrected.

2. P 5, L 6: Can this be clarified to indicate air or leaf temperature?

We will clarify this in the text, in JULES this is air temperature.

3. P 5, L 23: Please include the reference for the dataset(s) that were used for the sowing and harvest dates when observations weren't available?

We will include this in the text. We refer to a method from a previous paper that estimates the sowing and harvest dates based on the Asian Summer Monsoon published in ESD (Mathison et al 2018).

4. P 6, L 8-9: Is forcing a harvest before maturity is reached realistic? Did any of the model simulations need to use this constraint any year?

This is a safeguard built into the model in order that the model can move onto the next crop in a clear and clean way. This latest harvest date is usually set to a date well after the expected harvest date and therefore the crop is expected to be harvested by this time. If the model is working correctly this should not be needed, however if it is used then the user knows that the harvest has been triggered because the crop has not matured. This means the user knows when the model is not

working correctly and can investigate this further. The latestharvestdate was not needed in either the point or the regional simulations that will be presented in the new manuscript. However, this safeguard, is preferable to the simulation of a crop growing for an unrealistically long time and overlapping into next growing season, thereby disrupting the simulation of the second crop. The latestharvestdate is particularly useful for checking if the sequential cropping is being implemented correctly on a regional or global scale. JULES is run for a wide variety of environments and conditions, with some quite different to where the model has been developed and tuned. This variety of the uses of JULES mean that it important to make sure that the crops are running properly and being harvested as expected. I will include explanation of this in the manuscript and explain that this is ideally not used. When it is needed it allows any problems to be properly investigated.

5. P 6-7, Section 3: The DVI discussion might be better in section 2 where the model description is provided

The paragraph on DVI in this section will be incorporated into the previous model description section.

6. P 7, L 6-7: What do you mean when you state the effective temperature differs "between models"?

The effective temperature is the function that the model uses to relate temperature to the cardinal temperatures that define when a plant develops. Different models define their effective temperature function in different ways. This is described in Wang et al 2017. I will explain this more clearly in the text and include this reference.

7. P 7-8, Section 4: The authors should expand on how these specific variables are important for the crop model and how they influence the variables that are being compared with observations (e.g., GPP, latent heat flux, sensible heat flux).

Explanation will be added to the text.

8. P 8, Section 4.1: The authors mention that the Avignon site is in France in the introduction. Location information (including approximate latitude and longitude) would be good in this section.

This will be added to the text.

9. P 10, Section 5: It would be useful to have some climate information for all the sites. While some information is provided for the India sites in Figure 2, Section 6.2 and Figure 6, similar information should be included for the Avignon site.

I will add some climate information for Avignon to this section.

10. P 11, Section 6: There is a lot of discussion in this section, which should just be results.

See section 1.1 and reply to comment 1 in this section.

11. P 11, L 5: I do not see AviJUL-grass results in Figure 3.

AviJUL-grass results are not shown in this Figure, primarily because LAI and canopy height are prescribed in these simulations and would therefore follow the observations exactly. I will explain this more clearly in the text.

12. P 11, L 10-27: I do not think it is very surprising that the simulations do not capture the observed biomass and LAI. The crops in JULES are corn and spring wheat whereas the crops at the Avignon site are sorghum and winter wheat. The fact that the model did well for the 2009 sorghum season, which was an anomaly for that crop at the observed site, indicates the crop parameters need to be tuned for a true comparison. I'm not suggesting the authors need tune the model for this manuscript, however, the different crops could play a large role in the model performance, which should have a place in the discussion.

This will be included in the redrafted discussion section

13. P 11 L 28- P12: The discussion for p0 comes completely by surprise. The authors don't explain how p0 affects GPP and what the different values represent. This part feels like a discussion and doesn't belong in the results section, considering these additional water sensitivity simulations weren't discussed previously. The additional simulations with modified p0 do not add value to the results and I suggest they be removed (along with Figure A5). Then suddenly, the paragraph changes gears, jumping to GPP. The GPP results includes a grass simulation comparison, which I find unnecessary. The focus should be comparing the crops simulations and observations to be consistent with the rest of the section 6.1. The paragraph needs some editing and is written sloppily. For example, in L 15, "...early the decline is very close to the observations" does not make sense. Finally, delete the last paragraph on page 12.

This is noted and will be addressed in the redrafted results and discussion sections

14. P 14 L4-5 – P 15: This paragraph is confusing. It is not clear how soil moisture avail-ability factor (beta) is calculated for the model or observations, nor is it clear what the impact has on simulations, other than an early decline in GPP. What is not discussed is that part of the problem could be related to how irrigation is handled in the model. It was stated in the beginning of the manuscript that the irrigation for sorghum was included in the rainfall data, but it was not specified how. If the timing of irrigation is off,that could explain some of the water stress for sorghum that is seen in the model but not in the observations (figure 5). Regardless, I think this is taking away from the main point of the results and I do not feel it is necessary. If it is kept, it should be moved to section 7.

This is noted and will be addressed in the redrafted results and discussion sections

15. P 15, L6: Do the "four levels" refer to four soil layers in JULES?

Yes, in these simulations there are four soil layers in JULES at 0.1, 0.25, 0.65 and 2.0 m so that the bottom layer is at 3.0 m. I will clarify this in the text.

16. P 16-17: "the aim of this simulation is to demonstrate the method rather than provide a perfect representation of either of these crops." Yes – I agree with this statement. This should be the focus of section 6.1 – how this method improves the crop simulations. All the discussion about soil moisture and water stress muddle this point. Highlight positives of the approach and mention the tuning discussion for future work.

This is noted and will be addressed in the redrafted results and discussion sections.

17. P 19, L 17: the decline in NPP for wheat is hard to see in the figure.

The NPP shown here is gridbox NPP which declines during the wheat season shown by the yellow blocks on Figure 10 (c), this happens about two thirds of the way through the season. I will clarify this in the text. If this does not help, plots per tile are also available (similar to Figure B1) which show NPP and GPP for each tile (rice and wheat) in two colours (red and black)) for each location on a separate plot. I will establish which of these options is clearer and amend the manuscript accordingly.

18. P 20, L 20-33: The VPD discussion here belongs in section 7, it is not results, but discussion. Furthermore, it is not known what the effect of VPD on is on the model yields. The discussion on the plant response to VPD is difficult to follow and clearly does not belong here.

This is noted and will be addressed in the redrafted results and discussion sections

19. P 21: It is unclear in this discussion how much of this is related to poor wheat parameterization in JULES or how much is related to the sequential cropping component.

This will be clarified in the manuscript. This discussion is suggesting that the way that carbon is allocated between carbon pools for wheat is worthy of investigation into the lower yields for wheat.

## 1.3 Technical Comments:

1. Define all acronyms (for example, GPP is never defined; DVI is not defined until Appendix B)

This will be corrected in the manuscript

2. P 7, L 4: switch the ";" to a ":"

This will be corrected in the manuscript

3. P 19, L35: the sentence beginning "Therefore suggesting it is not water stress..." is a fragment.

This will be corrected in the manuscript

4. P 20, L 11-12: "in the simulations" is used twice.

This will be corrected in the manuscript

5. P 20, L 12 and L14: Use first and second rather than "firstly" and "secondly"

Noted. This will be corrected.

6. P 27, L2-3: The sentence beginning "In general the model produces..." is unclear.

This will be addressed in the redrafted results and discussion sections

7. Figures need consistent labeling. Put units on the y-axis. Some figures have the y-axis units in the title, others don't have any at all. Also, in Figures 3,4,5,A1,A2,A3,A4,A5 the label "modelled soil moisture and LAI" is confusing. Shouldn't it be AviJUL_sqcrop?

All figures will be checked for consistent labelling and units. The labels will be changed to AviJUL-sqcrop etc for clarity and consistency with the text

8. Figure A1: What four simulations are you referring to in the caption?

This is a missed deletion. This is an older caption and will be updated in the manuscript.

# 2.0 Reviewer 2

## 2.1 Response to general comments from reviewer 2

I have summarized the comments from reviewer 2 to respond to them.

1. The manuscript lacks key significant objectives and the rest of the manuscript strongly suffers of this absence.
2. The manuscript really needs more challenging scientific objectives.
3. What's the added value of representing the sequential cropping on a given variable or process?

The manuscript does have significant objectives, and these are now better articulated in the introduction. Sequential cropping provides clear added value for two reasons:

i. to improve simulations of water resources where this type of cropping system is in use. This cannot be done if the model only simulates one crop per year because this does not happen in the real world.
ii. including sequential cropping in models is also a more realistic representation of the land surface in terms of land cover and therefore fluxes. The climate affects both the water and crops in this standalone setup, while simultaneously allowing the interactions between water and crops across the year.

These interactions are important for understanding water resources. I will clarify these points in the text.

4. I would strongly encourage the authors to include these regional simulations in the present study. Performing such regional simulations for present-day conditions, with and without the sequential cropping (ie with only one of the two crops grown within a year) would enable to investigate the impact of the sequential cropping on the vegetation intensity and the soil moisture at regional scale and to directly compare these modelled variables with observation-based data provided by remote-sensed products (LAI (or fPAR) and soil moisture from satellite sensors such as MODIS or GRACE for instance). This could be performed on the studied region of North India.

As suggested by the reviewer in future work, I intend to use the GRACE, MODIS and SMOS satellite data for evaluation of regional simulations but this is probably beyond the scope of this paper which is primarily to present the method and model developments. However, I will include some prototype results for the regional simulations that cover the same Uttar Pradesh and Bihar region as the point simulations. This should help demonstrate the application of the method for a region.
I also considered using MODIS LAI in this paper for checking the crop seasons, however MODIS doesn't include crop specific information, so the LAI observed might be for a different crop to the one being modelled in JULES.

## 2.2 Response to specific comments from reviewer 2

1. The manuscript presents the development of a sequential cropping capability in the JULES model. The authors define the sequential cropping as the cultivation of two or more crops on the same field in a given year (page 2 line 20). Later, the results of this new version are shown on a site in France (Avignon) where sorghum and wheat are grown. Page 7 line 1, it is written that sorghum is grown in summer and winter wheat in winter. I don't think this is correct. Winter wheat is sown in winter but grows over the spring up to early summer, while sorghum is sown in spring and grows up to late summer (see figure 3). In this respect, Avignon is not a site where sequential cropping is applied but rather a site with the rotation of two crops (sorghum and wheat) over two consecutive years. This should be clarified in the manuscript. Although I have no doubt that Avignon is a super site where a huge set of measurements are performed, I don't clearly see the gain of applying JULES on this site when evaluating the sequential cropping functionality as it is not strictly speaking a site where sequential cropping is practiced. The motivations for using that site mentioned by the authors are "to illustrate that the new sequential cropping functionality in JULES can simulate more than one crop within a year and reproduce the correct growing seasons for each crop" (Page8 line 9).

I will clarify this detail regarding Avignon in the manuscript. The flexibility of our method allows it to be applied to both a strict sequential cropping system and one that is more irregular. However, this method is still operating in a similar way to a pure sequential cropping system at this site because in some years Sorghum is planted first and is immediately followed by wheat within a month or two. On this basis it is still an appropriate site for demonstrating this method, valid for both crop rotations and sequential cropping.

2. In the results section it is also mentioned that "the aim of presenting this simulation is to demonstrate the method rather than provide a perfect representation of either of these crops" (Page 16 line 9). These objectives could be achieved by performing model simulations elsewhere than in Avignon, in regions where sequential cropping is commonly applied (like the region of India you focus on in the manuscript for instance). Also, about the model simulations performed for the Avignon site, I don't clearly understand the need/interest of the AviJUL-grass simulation which is driven by observations for LAI and the canopy height.

The purpose of including Avignon is because it provides a wealth of observations for evaluating Land surface models. Without observations of these fluxes there is no way of knowing if the model is correctly representing the fluxes and the coverage of the land surface. The purpose of including a simulation that does not use the crop model but approximates crops using grasses is to show how the model performs with the correct LAI and height i.e. it is a clean test of the representation of leaf photosynthesis, stomatal conductance, water stress and leaf-to-canopy scaling within the model (these parts of the code are shared by both natural vegetation and crops). There is also no equivalent site for South Asia.

3. Some figures would need some improvements. Especially, avoid the repetition of a same information in any sub-panel of a same figure. This is the case on Figure 3, Figure 4, Figure5 about the location (Avignon). You can simply mention once at the top of the figure that it is for Avignon (or only in the Figure legend). The same with "India Points" for Figures 6, 10, 11, B2, B3, ... There are also redundancies between the information on the top of some subpanels and the information on the y-axis legend: on Figure 3 (total above ground biomass, LAI, canopy height), on Figure 4, Figure 5, Figure 6, Please specify one information at only a single location in one panel. On the other hand, there is information missing about variable units on Figure 4. Units of GPP, Latent heat flux and sensible heat flux are not specified at any place in the figure and not in the figure legend. The same on Figure 5 for "available moisture"

These comments have been noted and as outlined in the responses to reviewer 1, all figures will be reviewed and checked for consistency, units and titles.

## 2.3 Technical comments

1. Page 3 line 11: Maybe explain what are the kharif and rabi seasons as they are quite specific terms.

The kharif season is the monsoon season and the rabi season is the dry season in South Asia. This will be clarified in the text

2. Page 5 line 20: Define DVI before to use it.

This means Development Index which is first referred to in Equation 3 of Section 2although it is not explicitly defined here, so we will add this to the text.

3. Page 7 line 7: “between models”. Which models do you refer to ?

Different models define the effective temperature function in different ways. In Wang et al (2017) various temperature response functions are shown in Figure 1, In this paper JULES is most similar to type 4. Each have a different effect on the development of crops. In JULES the temperature response function defined by the effective temperature increases gradually to the optimum with a steeper decline toward the maximum. Other models have a flatter top to this function and others have no decline above the optimum. This will be clarified in the text.

4. Page 7 line 19: “The simulations are divided ...”. Please, rephrase: The description of the simulations is divided ....

This will be rephrased

5. Page 7 line 19: “Section 4.1 applies the method...”. Please, rephrase: Section 4.1 presents how the method is applied...”

This will re-phrased in the text

6. Page 7 line 23: Please define PFT before to use it.

PFT means Plant functional type which is defined in the caption of Table 2, which was subsequently moved to the end of the manuscript during editing before submission. This definition will be added to the text of the manuscript as well.

7. Page 7 lines 26 to 30: Provide units to the variables and parameters used (vcmax, neff,nl, mu_rl, mu_sl) and a more physiological meaning to them.

$V_{cmax}$ : Maximum rate of carboxylation of Rubisco (mol $CO_2\, m^{-2} s^{-1}$)
$n_{eff}$ : Scale factor in the $V_{cmax}$ calculation (mol $CO_2$ m $^{-2}$ s $^{-1}$ kg C (kg N) $^{-1}$ )
$n_l(0)$: Mass of Nitrogen per mass of Carbon at the top of the canopy kg N (kg C) $^{-1}$

These two parameters affect the respiration of the plant.

$\mu_{sl}$ : Ratio of stem nitrogen concentration to leaf nitrogen concentration, i.e the mass ratio of nitrogen to carbon in the stem divided by the ratio of nitrogen to carbon in the leaves
$\mu_{rl}$ : Ratio of root nitrogen concentration to leaf nitrogen concentration, i.e. the mass ratio of nitrogen to carbon in the roots divided by the ratio of nitrogen to carbon in the leaves

This will be added to the text

8. Table 2: Could you clarify the value of 1 for Q10. Does it mean that Vcmax is insensitive to temperature?

$Q_{10\_leaf}$ : $Q_{10}$ value for carboxylation of Rubisco used in the $V_{cmax}$ calculation.
No, there is still a dependence on temperature ($T_{low}$ and $T_{upp}$). These relationships will be clearer by showing the equations in the manuscript. In response to the reviewer's points 7 and 8, I will include the equations and explanations for these parameters in the text in section 2. These were omitted from the initial submission to avoid further repetition of previous publications but including them will help explain the parameter choices.

9. Page 8 line 16: Could you clarify the use of a spring wheat parametrization to represent the C3 winter wheat crop at Avignon. Especially regarding what is mentioned later for India Simulations Page 8 line 33 (the wheat varieties grown in this region are spring wheat, this is an important distinction as spring wheat does not require a vernalization period which is important for winter wheat varieties. Does the wheat variety sown in Avignon in winter need a vernalization period or not?

In the real world the fact that winter wheat requires a vernalization period and spring wheat does not is an important distinction between the two varieties. However, in JULES temperatures cannot damage any of the crops being modelled, either by being too high, too low or not low enough. When temperatures are outside the optimum range for development in JULES, development is slowed down but as soon as the temperatures return to within the optimum range the crop continues its development from where it left off. The lack of vernalization does not therefore cause the yields to completely fail in JULES as they do in reality. While this process is missing from JULES, it is acceptable to approximate winter wheat using spring wheat. I will clarify this in the text and describe the implications for the results.

10. Page 9 line 7: Map (b) in Figure 2

Fig will be added prior to the number of the figure in this sentence.

11. Page 10 line 23: include measurements of soil moisture

This sentence will be corrected.

12. Page 10 line 31: Citations need parenthesis.

These citations are part of the text and therefore do not need parentheses. However, I will add punctuation as this should clarify that these references are part of the text.

13. Page 11 line 24: The sentence "For 2008 and 2012..." has the same meaning than the previous sentence.

The clearer sentence will be retained and the other deleted.

14. From Page 11 line 28 to Page 12 line 1: Should be put in the Methods section

As mentioned in response to reviewer 1, Section 6 and Section 7 will be redrafted into separate results, discussion and conclusions sections. This paragraph will be moved to the methods section or most appropriate section as part of this redrafting.

15. Page 13 line 4 (and table 6): Provide units to the values of RMSE and Bias

The manuscript will be updated to include this information.

16. From Page 16 line 1 to Page 17 line 6: This paragraph should be moved to the Discussion or Conclusion sections.

As mentioned in response to reviewer 1, Section 6 and Section 7 will be redrafted into separate results, discussion and conclusions sections.

17. Figure 7: When comparing harvested biomass from JULES to the two observation-based estimates, I think that it would be more suitable to present the model/data comparisons with scatter plots. It will better highlight the model capacity at simulating observed interannual variability than using time-series.

I am not sure there are enough observations of biomass for the scatter plot to work. However, I will investigate alternative ways of displaying this information for the updated manuscript

# 3.0 Reviewer 3

## 3.1 Response to general comments from reviewer 3

1. The section described the model development only took about half page with a simple flowchart, which is also not very informative. Even the settings of the simulations are described in more detail. In addition, all the equations presented are developments made by previous studies. All these make the reviewer think the manuscript is more like a model application rather than a model development.

JULES needed substantial code changes for the implementation of the new double cropping scheme. The inclusion of double cropping within JULES is a necessary development for applications which require simulation of the annual cycles of water and carbon fluxes in many regions of the world, including India. The addition of this functionality can therefore can be placed in the category of model development. The relevant equations from existing parts of JULES were reproduced here for completeness with the flowchart clearly showing the way that the crop rotation is done within JULES. There was no need for anymore text regarding model development.

2. Although the authors presented a lot of figures, many of them are not central to questions in which readers may be interested. The authors show the model performance accounting sequential cropping, but how does it compare with the one not accounting sequential cropping? What will be the difference if simulating two seasons of crops as two tiles? Will the LAI be different? Will the yield? At least to this reviewer, the authors fail to prove the improvements brought to the land surface model.

One of the main reasons for including sequential cropping is to improve simulations of water resources across a single monsoon season. The very fact that the land surface is more representative of reality with two crops growing in sequence representing the real coverage of the land will produce more realistic fluxes and interactions with the atmosphere. This is important for the simulation of water resources and the interactions between water and agriculture. ISIMIP adopt the approach that assumes a small amount of each crop in each of the gridboxes and scale up. Even using this approach, it is difficult to see the whole effect this would have on the fluxes. Including the double cropping is to look in a wholistic way at the land-surface coverage and the effects this has on the fluxes for a region.

3. The authors set a "deadline" to harvest a crop even if it is not mature, in order to facilitate the next season of crop. However, it is hard to imagine this is a reasonable manner to simulate farmers' behaviour. Will farmers cut down their crop grown for several months just for growing a new season of crop?

This is a model safeguard and ideally would not be used, please see response to reviewer 1 in section 1.2 point 4.

4. Large scale applications of sequential cropping may face a lot more challenges than the few tested sites here. It is not yet convincing that the model is ready for larger-scale application at its present form.

Regional simulations have been completed so the model, is to some extent, ready for large-scale application. In the previous response to reviewer 2 (section 2.1, point 4), I will be including recently completed prototype regional simulations as a demonstration of applying this method to a region. However, the reviewer raises an important point regarding the many possible choices for the regional crop simulations, regarding for example, the rotations, timings and crops. I will make the assumptions clear in the text and explain any limitations.