Weather-induced crop failure events under climate change: a storyline approach

Henrique M.D. Goulart, Karin van der Wiel, Christian Folberth, Juraj Balkovic, and Bart van den Hurk

= Response to the reviewers =

Reviewer #2:

Goulart et al. analyse weather conditions leading to soybean failure in the Midwest US using crop model data, training of a random forest model, and analysing a particular historical event and possible analogous events in the present day and future. The paper is well-written and clearly describes the approaches used and the results, and I enjoyed reading it. I have some comments particularly around the justification of the data used and the storyline approach, which I have noted below.

We'd like to thank the reviewer for their positive feedback. We welcome the suggestions for the storyline section. Below we note the revisions done in response to all the suggestions.

Specific comments

- I think the reasoning behind using a crop model rather than observations is sound, however you haven't shown whether the model is reliable at modelling soybean yields in the US. Could you provide any references, or analysis (if there is observed data available), to show whether the crop model provides realistic results for soybean production in the region of interest and can reproduce some of the important impacts being considered in the paper (e.g. does the model represent the impact of hot and dry conditions on soybean plants well?)? It would then be relevant to reflect in the discussion section on how the model-based results are likely to compare to real-world crop failures.

Thank you for the very constructive comment. It is indeed necessary to contextualize the crop model performance with respect to the existing observed datasets. We added a comparison between the EPIC-IIASA simulated yields and the observed yield dataset of the USDA (United States Department of Agriculture) for the region considered. First, we detrended linearly the observed dataset, then we spatially averaged both datasets along the period of 1960 to 2016 and finally we standardized the two datasets, to focus on the interannual variability of the yield timeseries. We found that the R^2 between EPIC and the observed dataset is high, at 0.674, and that EPIC is capable of replicating the interannual variability of the observed data.

Line 115: "For validation of the crop model, we compared the EPIC-IIASA simulated yields with the observed yields from the US Department of Agriculture (USDA, www.nass.usda.gov/Quick_Stats) for the region considered. EPIC-IIASA has higher mean and standard deviations values than the observed as the simulated yields are potential (Folberth et al., 2016).To evaluate the interannual variability, we obtained a coefficient of determination, R^2, of 0.674. We also observed a good correlation between the two standardised datasets (Figure C1). We consider EPIC capable of replicating the interannual variability of the observed data."

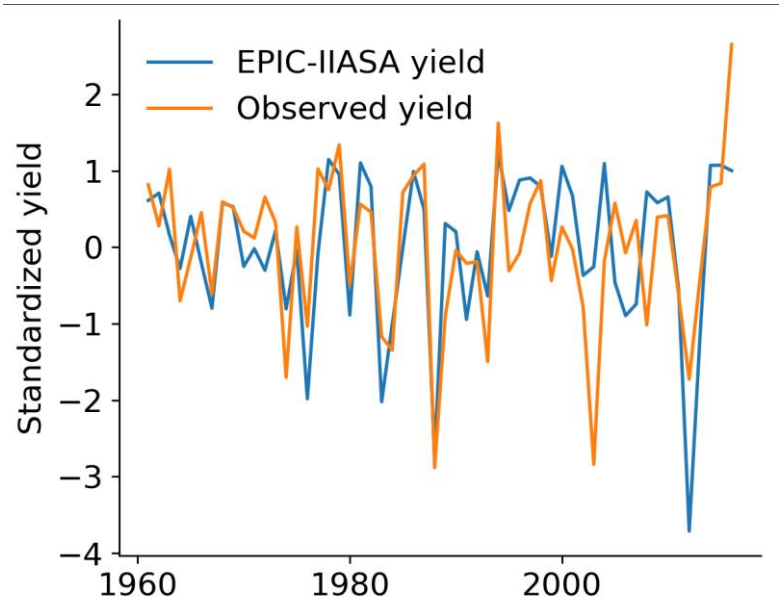


Figure C1: Standardized comparison between the EPIC-IIASA simulated yields and the observed yield dataset of the USDA (United StatesDepartment of Agriculture) for the region considered in this work.

- I assume all meteorological variables were considered at monthly scale for the analysis, but I don't think this is explicitly stated anywhere. Is there justification for using this timescale that could be provided in the text? Did you consider shorter timescale events that may also cause crops to fail but would be averaged out when looking at monthly timescales (e.g. a short very dry period), or if there are periods of less than a month in the crop lifecycle when the soybean may be more vulnerable to particular weather conditions?

Thank you for the comment. We have modified the text to make this more explicit. We decided to work using the monthly scale because other works have shown that it is possible to find strong signals between climate and crop at a monthly scale (and therefore suppress some of the noise that arises when shorter time scales are used) (Ben-Ari et al., 2018; Vogel et al., 2021; Hamed et al., 2021). Nevertheless, we acknowledge increasing the time resolution could potentially provide more information and we updated the text to mention this.

Line 122: "... covers the period from 1901 to 2019 at a monthly scale ..."

Line 385: "The meteorological variables are at a monthly scale, which has been used in past studies as well (Ben-Ari et al., 2018; Vogel et al., 2021; Hamed et al., 2021.). However, adopting shorter timescales could lead to additional information on how weather interacts with crops."

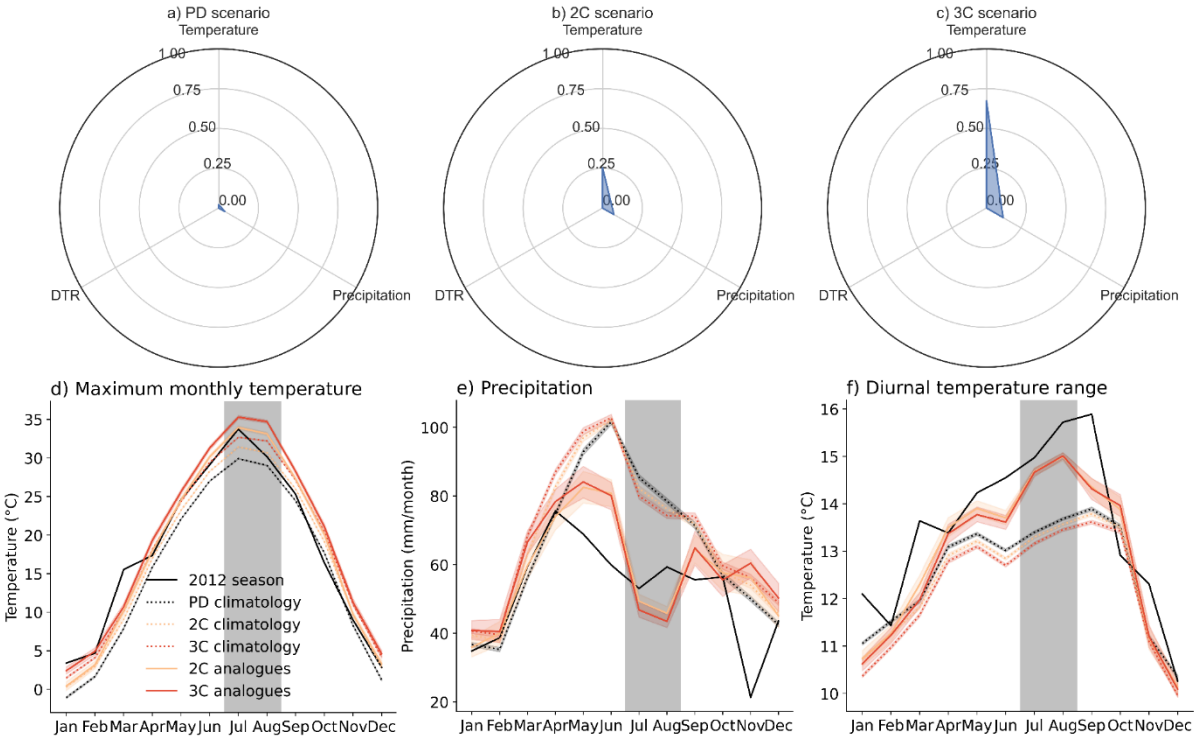
- Given that the paper is titled "a storyline approach", I think the storyline analysis is quite limited. For the 2012 season, only the meteorological variable values are presented and the probability of failure calculated. Can you include more insight into the storyline of events, e.g. how did the weather impact the crop via changes to the soil moisture? How did the high DTR affect the crop? This information would help to provide a much more complete chain of events for the 2012 season, otherwise it is unclear to me how it is a storyline approach being used to identify the drivers of the

event. I think using the impact analogues as well as the event analogues is a very interesting approach and, as you note in the discussion, the impact perspective is likely to be of more interest to society. However it would be interesting to include analysis of how the storyline chains of events differ (compared to the 2012 season and to each other) in these cases leading up to similar impacts. There is some relevant discussion already in section 4 but describing the range of plausible storylines more explicitly would help to incorporate more of a storyline approach in the paper.

Thank you for the suggestion. We agree with the reviewer that the storyline part has been rather limited. Soil moisture is very relevant for agriculture studies, but here we focus only on creating connections between basic meteorological variables and soybean yields. Adding soil moisture, while relevant, would add extra layers of complication for data and analysis. Last, soil moisture is at least partially a compound product of temperature and precipitation fluctuations, which we already address in the analysis. We discuss the role of DTR in the discussion section, but have added more information to enrich this section. There are indeed different event cascades leading to 2012 analogues. The monthly temperature values of the 2012 analogues in a warmer climate (GW) are warmer than the original 2012 event, but even the normal years are already very close to the 2012 season; there is a slight drying trend during Jul-Aug in general for GW scenarios. The 2012 analogues are drier during Jul-Aug than the 2012 season, but also slightly wetter in May-June; DTR is decreasing with GW, and therefore the analogues do not reach the original 2012 season levels.

Line 365: " In addition, by relying on the impact metric, the meteorological conditions of the analogues can be analysed for changes due to global warming (Figures 10d, e, f and C10). The impact analogues of the 2012 year show warmer temperatures during summer with respect to the original event. For precipitation, the analogues are significantly drier than the 2012 year during July and August, the months in which the RF model takes into account. Finally, the analogues present lower DTR values during most of the year"

Line 450: "Furthermore, impact-analogues of the 2012 season in the future display a change in their physical properties: they are hotter and drier, but with lower values of diurnal temperature range."



Subtitle: Radar graphs showing the number of seasons exceeding the 2012 values for each meteorological variable for Present Day (a), 2 °C global warming scenario (b) and 3 °C global warming scenario (c) scenarios. Time series of the historical years, the 2012 season, the impact analogues and their corresponding climatology for maximum monthly temperature (d), precipitation (e) and diurnal temperature range (f).

- In Figure 5a there is a pronounced jump in the observed data at return period of around 6 years. Are you able to provide any insight into why this might be?

  Thank you for the comment. The jump we see around failure likelihood 0.5 is likely due to the way random forests work. They stipulate probabilities of failures for every single year, which in the end converge to either 1 (failures > 0.5) or 0 (failures < 0.5), and the resulting "S" shape is common, with most observations falling in either side of the threshold 0.5. For cases in which the sample is small, the jumps can appear, but for cases in which there are more samples, as it is the 2000-year samples we have for the GW scenarios, the whole distribution is properly fitted.

Technical corrections

- Line 26: It seems strange to refer to Figure 2 in the text before Figure 1. Also this figure shows the mean yield rather than anything related to low yield in 2012. Combining information from Figure 9 might be relevant here to show the yield anomaly.

We agree with the reviewer and decided to remove the first mention of Figure 2:

- Figure 2: Where does this mean yield data come from (is it from the model or is it observed data)?

It comes from the crop model, we added to the text:

Figure 2: "Selected grid points for the main producer states and the mean yields (ton/ha) per grid cell as simulated by the EPIC-IIASA model"

- Line 28-30: Sentence starting "On a global level…" – I think there is a missing word or grammar check needed on this sentence

We welcome the suggestion and have rewritten the sentence:

Line 32: "On a global level, interannual climate variability is responsible for approximately 30% of the year-to-year variability in crop yields (Lobell and Field, 2007) but the influence of interannual climate variability could rise up to 60% of the yield variability in certain regions (Ray et al., 2015; Frieler et al., 2017)."

- Line 30: Change "Extremes" to "Extreme"

Thank you for the correction. It has been updated.

- Line 44-45: changing "to link" to "in linking" and "to explain" to "in explaining" would improve the readability here

Thank you for the correction. It has been updated.

- Line 166: Correct spelling of Matthews

Thank you, it has been corrected.

- Line 184: I assume RF is the abbreviation for Random Forest but this needs clarifying

Thank you. We added the abbreviation for the first time Random Forest is mentioned:

- Table C1: Need to define what the codes for the variables mean in this table or use their full names

Thank you. We updated the label of the figure to mention the full names of the variables.

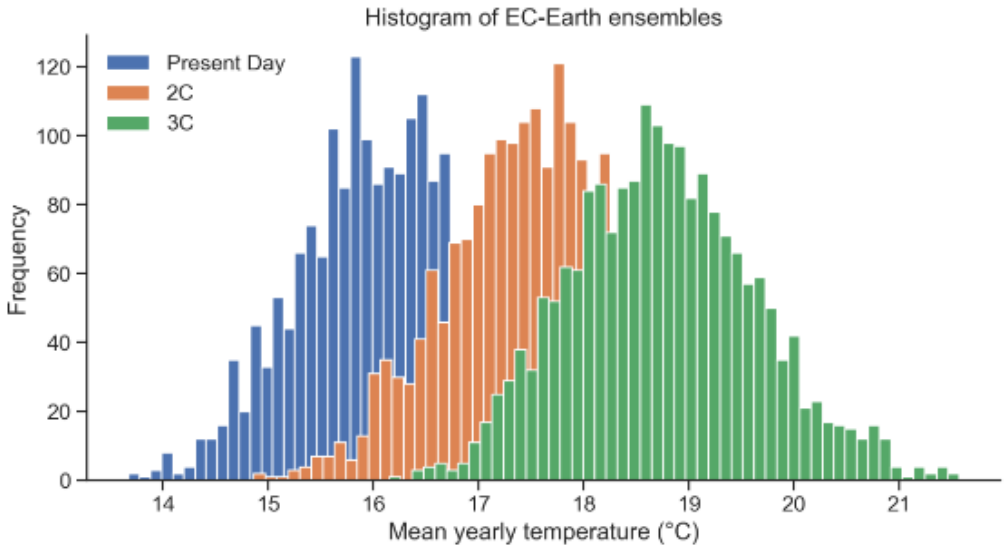


Figure C1. The distribution of mean yearly temperatures in the Midwestern US of EC-Earth ensembles for Present Day scenario (blue), 2 °C global warming scenario (2C, orange) and 3 °C global warming scenario (3C, green) scenarios.

- Line 234: Do you mean high correlations with the yield or between the variables?

We meant between the meteorological variables. We updated the text.

Line 259: "The remaining meteorological variables have high correlation levels between themselves"

- Figure 4: It would be easier for the reader to interpret the figures if you could change the axis labels to the full names of the variables. Also it is not clear what the small lines along the x axis correspond to.

Thank you for the comment. The other reviewers also questioned the purpose of the decile marks (ticks) and we decided to remove them, as they are not very informative. In addition, we added the full names of the variables as suggested.

- Line 267: Is the observed data mentioned here the yield data from EPIC-IIASA, rather than real-world observations?

The observed data has led to confusion, as it is the yield data from EPIC-IIASA. We updated the text as:

Line 291: "… is consistent with the historical data from EPIC-IIASA …"

- Figure 9a): Are these yield anomalies from the model or is other observed data used?

The yield anomalies correspond to the yield data from EPIC-IIASA. We updated the text as:

Figure 9: "… to the averaged historical yield data from EPIC-IIASA …"

- Line 374: Do you mean Figure 10d here?

Thank you for the correction, we updated the reference of the figure for the 10d.