Impact of extreme weather conditions on the European crop production in 2018

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Supplementary material
Table S1. Considered climate variables included in random forests.

| Climate variable                        | Name     | Unit       | Period | Value range (1st quartile, Median, 3rd quartile) |
|-----------------------------------------|----------|------------|--------|-------------------------------------------------|
| Maximum Temperature (2 meters)          | Tmax     | °C         | JF     | 2.5, 5.3, 7.8                                    |
| Maximum Temperature (2 meters)          | Tmax     | °C         | MAM    | 12.4, 14.2, 16.3                                |
| Maximum Temperature (2 meters)          | Tmax     | °C         | JJA    | 21.3, 23.0, 26.1                                |
| Precipitation                           | P        | mm.day⁻¹   | JF     | 1.7, 2.2, 2.9                                   |
| Precipitation                           | P        | mm.day⁻¹   | MAM    | 1.7, 2.2, 2.9                                   |
| Precipitation                           | P        | mm.day⁻¹   | JJA    | 1.7, 2.5, 3.3                                   |
| Volumetric soil water Layer 1 (0-7 cm)  | VSW_1    | m³.m⁻³     | JF     | 0.31, 0.36, 0.38                                |
| Volumetric soil water Layer 1 (0-7 cm)  | VSW_1    | m³.m⁻³     | MAM    | 0.27, 0.32, 0.36                                |
| Volumetric soil water Layer 1 (0-7 cm)  | VSW_1    | m³.m⁻³     | JJA    | 0.21, 0.27, 0.32                                |
Table S2. Final parameters of the random forest used in this study. *num.trees* refers to number of trees of the random forest, *mtry* to the number candidate predictor studied at each node, and *node_size* to the number of minimum individuals at each final node. The final combination of values for the parameters were chosen among 27 combination, i.e. *mtry* \{3; 5; 7\}, *node_size* \{2; 8; 16\} and *num.trees* \{500; 1000; 5000\).

| Crop                  | Sub-region | RF with all years | RF with only 2018 |
|-----------------------|------------|-------------------|-------------------|
|                       |            | mtry  node_size   | mtry  node_size   |
| Barley (spring)       | EAST       | 7 2 5000          | 3 2 5000          |
| Maize (grain)         | EAST       | 3 2 1000          | 7 2 5000          |
| Oats                  | EAST       | 7 2 5000          | 7 2 5000          |
| Potatoes              | EAST       | 7 2 5000          | 3 16 5000         |
| Rape                  | EAST       | 7 2 1000          | 3 8 1000          |
| Rye                   | EAST       | 7 2 5000          | 3 8 1000          |
| Sugar-beet            | EAST       | 5 2 5000          | 7 2 5000          |
| Triticale             | EAST       | 7 2 5000          | 5 2 5000          |
| Wheat (winter)        | EAST       | 7 2 5000          | 5 2 5000          |
| Barley (spring)       | NORTH      | 5 16 5000         | 5 2 5000          |
| Maize (grain)         | NORTH      | 5 2 500           | 7 2 1000          |
| Oats                  | NORTH      | 7 2 5000          | 5 2 5000          |
| Potatoes              | NORTH      | 7 2 5000          | 3 2 5000          |
| Rape                  | NORTH      | 7 2 5000          | 7 2 5000          |
| Rye                   | NORTH      | 7 2 5000          | 7 2 5000          |
| Sugar-beet            | NORTH      | 5 2 500           | 3 2 500           |
| Triticale             | NORTH      | 7 2 5000          | 5 2 1000          |
| Wheat (winter)        | NORTH      | 7 2 5000          | 7 16 5000         |
| Barley (spring)       | SOUTH      | 3 2 5000          | 7 2 5000          |
| Maize (grain)         | SOUTH      | 3 8 1000          | 5 2 1000          |
| Oats                  | SOUTH      | 7 16 1000         | 5 16 1000         |
| Potatoes              | SOUTH      | 3 2 500           | 3 2 5000          |
| Rape                  | SOUTH      | 7 16 5000         | 7 16 500          |
| Rye                   | SOUTH      | 3 2 500           | 7 8 5000          |
| Sugar-beet            | SOUTH      | 5 2 5000          | 3 16 5000         |
| Triticale             | SOUTH      | 3 2 1000          | 3 2 5000          |
| Wheat (winter)        | SOUTH      | 7 2 5000          | 3 16 5000         |
| Barley (spring)       | WEST       | 7 2 5000          | 5 2 5000          |
| Maize (grain)         | WEST       | 3 2 5000          | 3 2 1000          |
| Oats                  | WEST       | 7 2 5000          | 7 2 5000          |
| Potatoes              | WEST       | 5 2 5000          | 3 8 5000          |
| Rape                  | WEST       | 7 2 5000          | 3 2 5000          |
| Rye                   | WEST       | 7 2 5000          | 5 2 5000          |
| Sugar-beet            | WEST       | 7 8 5000          | 7 2 1000          |
| Triticale             | WEST       | 7 2 5000          | 3 2 5000          |
| Wheat (winter)        | WEST       | 7 2 5000          | 3 2 5000          |
Figure S1. Duration of yield time series for the 17 European countries (Abscissa) and the nine studies crops (Ordinates) in the four European sub-regions: Northern (A), Eastern (B.), Western (C.) and Southern Europe (D.). The colors and the number represent the number of years of available data for each combination of crop and country. The length of yields time series could slightly differ within a country, only the maximum duration is mentioned in this plot.

AT: Austria, BE: Belgium, DN: Denmark, FI: Finland; FR: France, DE: Germany, HU: Hungary, IT: Italy, NL: The Netherlands, PO: Poland, PT: Portugal, RO: Romania, CZ: Czech Republic; SL: Slovakia, SP: Spain, SE: Sweden, UK: United Kingdom.
**Figure S2.** Sensitivity analysis of the estimated impacts on normalized yield anomalies of four climatic drivers: $P_{\text{JJA}}$ (A), $T_{\text{max, JJA}}$ (B), $T_{\text{max, MAM}}$ (C) and $P_{\text{MAM}}$ (D). The sensitivity analysis was run on winter wheat for Northern European sub-region. Color of the curve correspond to type of detrending method of the yield time series (blue: loess detrending; red: polynomial detrending; green: spline detrending). Line types correspond to methods for estimating impacts of climate factors on normalized yield anomalies (solid: Partial dependence plot, dotted: Accumulated local effects). We also tested two machine learning algorithms: random forest and gradient boosting (not differentiated on the plot), both with two sets of tuning parameters (RF1: $\{\text{mtry}=7; \text{node\_size}=2; \text{num\_trees}=5000\}$, RF2: $\{\text{mtry}=5; \text{node\_size}=4; \text{num\_trees}=50000\}$).
Figure S3. Explained variance of normalized yield anomalies ($R^2$) of various random forests (RF) models per crop and Sub-European regions: Northern(A), Eastern(B.), Western (C.) and Southern Europe (D.). Gray bars correspond $R^2$ (cross-validation with a validation set of 25% of the data) for all years for RF calibrated on long time-series. Orange bars correspond to $R^2$ of year 2018 for random forest calibrated on long time-series. Blue bars correspond to $R^2$ of years 2018 for RF calibrated only with year 2018.
Figure S4. Relative importance of the variables explaining yield anomalies in four regions of Europe and the nine crops, based on random forests calibrated with all years. The variable importance corresponds to the impurity measured by the Gini index calculated in the random forests. The relative importance is then calculated as the proportion of importance of each variable over the sum of importance. Higher values correspond to a stronger influence of the respective variable onto yield anomalies. The type and colors of the curve indicate the four regions of Europe. The x-axis is ranked by averaged mean importance over all nine crops.
Figure S5. Comparison of the proportion of variance of normalized yield anomalies ($R^2$) explained for year 2018 based either on a random forest calibrated with long-time series (x-axis) or only with year 2018 (y-axis). The colors correspond to the sub-regions: Northern (green), Eastern (red), Western (violet) and Southern Europe (blue).
Figure S6. Relative importance of the variables explaining yield anomalies in four regions of Europe and the nine crops, based on random forests calibrated only with 2018. The variable importance corresponds to the impurity measured by the Gini index calculated in the random forests. The relative importance is then calculated as the proportion of importance of each variable over the sum of importance. Higher values correspond to a stronger influence of the respective variable onto yield anomalies. The type and colors of the curve indicate the four regions of Europe. The x-axis is ranked by averaged mean importance over all nine crops.
Figure S7. Estimated impacts of main climate drivers on maize and sugar-beet yield anomalies in four European regions: Northern (A.), Eastern (B.), Western (C.) and Southern Europe (D.). Gray curves correspond to the effects of each the two crops estimated independently by random forests. Only the six main drivers are presented in this plot (P: Rainfall, Tmax: maximum temperature). Blue curves correspond to a loess fit over the two crops. Blue segments correspond to the experienced value of climate drivers in 2018 for each country within each region.
Figure S8. Estimated impacts of main climate drivers on barley spring (red) and rape (blue) yield anomalies in four European regions: Northern (A.), Eastern (B.), Western (C.) and Southern Europe (D.). Gray curves correspond to the effects of each of the two crops estimated independently by random forests. Only the six main drivers are presented in this plot. Blue curves correspond to a loess fit. Blue segments correspond to the experienced value of climate drivers in 2018 for each countries within each region.
Figure S9. Proportion of area with various yield anomalies since 1990 in four sub-regions of Europe: Northern (A.), Eastern (B.), Western (C.) and Southern Europe (D.). Anomalies are calculated as the mean of the nine considered crops. Colors represent the percentile of yield anomalies, with percentile 10 and 90% highlighted with a solid black curve, and percentile 50% with a solid gray curve. The last year corresponds to 2018. Dotted curves correspond to 10, 50 and 90% of areas.
Figure S10. Years with highest proportion of area with negative normalized yield anomalies per crop over Europe since 1990. 2018 is highlighted in orange.
Normalized yield anomalies estimated for the climate values observed in 2018 with random forests calibrated for wheat and either using only 2018 data or data from all years in four European sub-regions: Northern (A.), Eastern (B.), Western (C.) and Southern Europe (D.). Only the six most importance climatic drivers are presented. The colors correspond to the phase of the crop cycle: gray: January-February (JF), blue: March-April-May (MAM) and orange: June-July-August (JJA).

**Figure S11.**