Extreme hydroclimatic events compromise adaptation planning in agriculture based on long-term trends

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- agriculture response
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- European climate

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Abstract

Climate projections suggest an increase in drought frequency and intensity in various places over the globe, one of them being Southern Europe, expected to become a hotspot. However, 2018 presented an anomaly with the emergence of a rare "water seesaw" phenomenon, leading to severe drought in Central and Northern Europe while Southern Europe experienced high humidity. This unexpected event resulted in significant agricultural disparities, emphasizing the influence of interannual variability. The commentary underscores the danger of overlooking short-term climate variability, vital for accurate adaptation planning, especially for vulnerable regions, when focusing solely on long-term trends. This case serves as a motivation for exploration of global atmospheric circulation changes, emphasizing the need for nuanced modeling approaches to grasp subtle complexities in climate predictions and considering short-term climate variability alongside long-term trends.

Plain Language Summary

In 2018, Europe experienced an unusual weather pattern known as the "water seesaw." While Southern Europe was humid, Central and Northern Europe faced severe drought. This unexpected event had significant consequences, especially on agriculture. The study highlights that short-term climate variations, like this seesaw effect, can profoundly impact regions differently, challenging long-term climate predictions. The commentary shows the rarity of such event as well as its effect on European agriculture and urges for a closer look at global weather patterns and improved interpretations of modeling outcomes. Recognizing these complexities is crucial for adapting to climate change, especially in vulnerable areas, and ensuring food security in the face of unpredictable weather events.

1 Introduction

The assessment of climate change concludes that during recent decades mean precipitation has increased over Northern, Western and Central Europe, while the magnitude and sign of observed precipitation trends depend substantially on the time period and study region in the Mediterranean (Arias et al., 2021; Douville et al., 2022; Gutiérrez et al., 2021; Ranasinghe et al., 2021) and agricultural production in Southern Europe experiences increasing heat stress (Fontana et al., 2015; Ceglar et al., 2019). Moreover, climate projections also show that reductions in agricultural yields will be higher in the south, with lower losses or gains in the north (Trnka et al., 2014; Webber et al., 2016; Szewczyk et al., 2020). The Mediterranean is at the same time identified as one of the hotspots of future drought risk, while the majority of climate projections suggest a wetting trend over Central to Northern Europe (Arias et al., 2021; Gutiérrez & Yoon, 2021).

While some of the exceptional agricultural production losses in recent years (2012, 2016, 2018; (Ben-Ari et al., 2018; Van der Velde et al., 2018; Zscheischler et al., 2018)) followed this north-south pattern, the year 2018 revealed a very different picture. The agricultural productivity in Central and Northern Europe was harmed while it was enhanced over the south, showing that natural variability can manifest in unusual spatial patterns that can be neglected when focusing solely on long-term trends. In the present commentary, we report this strong deviation from the expected future conditions as a warning against disregarding the impacts of interannual variability and its effect on crops (X. Zhao et al., 2021) leaving agriculture vulnerable to hydroclimatic fluctuations. Since both yield stability and yield increasing rate are important to ensure global food security (Ray et al., 2013; Tigchelaar et al., 2018), the unexpected socioeconomic disruption observed in 2018 is yet again worth highlighting.

2 What happened in Europe 2018: Climate

During the year 2018, a particular atmospheric mode dominated Europe: the "water seesaw" phenomenon (Toreti et al., 2019). Its main driver was atmospheric blocking (known for modulating the precipitation regime in different parts of the world (Hoerling et al., 2014)) over Central Europe (Figure 1a), which impeded the movement of frontal systems coming from the Atlantic Ocean or the Mediterranean Sea to Central and Northern Europe. Central and Northern Europe experienced an exceptionally hot and dry summer, while rather humid conditions prevailed in Southern Europe / Mediterranean (Figure 1b). A very similar spatial pattern could be seen on accumulated Evaporative Stress Index (ESI) map (Figure 1c). The ESI can capture early signals of "flash drought," a condition brought on by extended periods of hot, dry, and windy conditions leading to rapid soil moisture depletion (Otkin et al., 2018). As 2018 was globally the fourth warmest year in the instrumental records (Blunden & Arndt, 2019), we cannot dismiss the possibility that this behaviour could be a characteristic event of a warmer climate.

3 What happened in Europe 2018: Agriculture

The extreme hydroclimatic conditions substantially affected ecosystem functioning over various locations in Europe, whereas the impacts on agriculture presented remarkable spatial heterogeneity and contributed to crop yields differently based on given region (Beillouin et al., 2020). As expected, the consequences in the agricultural sector were similarly severe, since extremes in temperature and precipitation (either deficit or very heavy rainfall) are both associated with negative yield anomalies. Our investigation shows that the spatial pattern of crop yield follows the "water seesaw" pattern (Figure 1d and 2). On one hand, in the Mediterranean and the Balkans, the combination of wetter-than-usual and warm conditions attributed to a positive crop yield anomaly. On the other hand, the arid and very warm conditions resulted to a negative crop yield anomaly in Central and Northern Europe. This is to be expected especially when drought is combined with unseasonably high temperatures. The relative timing of the drought / heat stress in relation to the sensitive stage of the crops contributed to different crop response over the Europe (e.g., crops in Norther Europe were more likely to be caught in their sensitive period compared to the Central Europe). Thus, it is important to consider the crop's susceptibility to dry or wet conditions based on its region of origin (Shavrukov et al., 2017).

4 European water seesaw in 2018 from long term perspective

While the 2018 drought extremity falls amongst the most severe ones, especially in Central Europe, it does not reach the levels observed in the past, for example, in the first half of the 20th century. When 2018 is considered as part of the multi-year period 2018–2019 (Hari et al., 2020) or 2014–2018 (Moravec et al., 2021), the extremity is unprecedented and presents possible future European climate (Rakovec et al., 2022).

In addition, Toreti et al. (2019) pointed out that very few years in the past 500 years have shown a similarity in the spatial distribution of precipitation or temperature, implying that the water seesaw in 2018 was a rare occurrence. Interestingly, a few of them happened already during the Medieval Climate Anomaly between 1302 and 1307 (Bauch et al., 2020). Looking at the 500-year temperature (Luterbacher et al., 2004) and precipitation (Pauling et al., 2006) reconstruction data, we found 10 years with water seesaw spatial pattern similar to 2018 (see Figure 3) assigning the empirical return period of about 50 years. Although all these years show a significant difference between average precipitation over the Mediterranean and Central+Northern Europe (see Figure 4 (a)), there are other years with similar average differences, however, without consistent negative (positive) anomalies over the whole regions.

5 Why the 2018 was unexpected?

What is surprising is that the current hydroclimatic trends, as well as model projections, are characterized by the opposite spatial pattern of climate conditions than those in 2018. High latitudes are getting wetter (Bhend & Von Storch, 2008), while the Mediterranean is facing aridification (Hoerling et al., 2012). These conditions are expected to be intensified in the next decades (Spinoni et al., 2018), making Mediterranean region one of the hotspots for future climatic-induced hazards (Tuel & Eltahir, 2020). The anticipated changes in the Mediterranean include a substantial increase in summer temperatures and a decline in winter precipitation (Lionello & Scarascia, 2018). However, in 2018 the reality was strikingly different confirming that short-term climate variability and long-term climate change need to be considered separately (Porter & Semenov, 2005). This is related to a strong role of natural variability of precipitation dominating the trends even over multi-decadal time scales (Shepherd, 2014). This also implies much more considerable uncertainty when compared to temperature projections.

This is also illustrated in Figure 4 (b) showing the differences in a number of seesaw events between historical and scenario runs of the Max Planck Institute Earth System Model (MPI-ESM; (Maher et al., 2019)) from the single-model initial-condition large ensemble (SMILEs) consisting of 100 members for each of three Representative Concentration Pathways RCP2.6, RCP4.5 and RCP8.5. Obviously, there is a strong uncertainty related to the differences in the number of seesaw events spanning the range of ± 1 event per 30 years with only RCP8.5 showing more confidence in the projections, likely due to a strong intensification of the water cycle under RCP8.5. This shows that not only the year-to-year variability may demonstrate in unusual patterns but also the individual ensemble members may show different sign of change in rare events such as seesaw pattern.

6 Implications for water resource management

This study shows an example of European climate conditions over the year 2018 which completely contradict the climate projections for Europe showing a robust increase in annual mean precipitation in Northern and Central Europe, while leaving the Mediterean without any significant trend (Arias et al., 2021; Gutiérrez & Yoon, 2021). The study highlights that individual years can have contrasting precipitation patterns which can consequently translate into agriculture failure. Modelling unique events like this with satisfactory confidence is a difficult task which was previously discussed in, for example, (Sutton, 2018) and summarized in (Arias et al., 2021). Here we show the probability of water seesaw events as well as the uncertainty in the estimation of future occurrences (see Figure 4). With that being said, we highlight that ensembles of climate projections cannot be interpreted without considering the uncertainty (Kirtman et al., 2014; Madsen et al., 2017; Hall et al., 2019), in particular in the context of adaptation planning. The analysis is based on a 10-year data set of European crop yields because that is where the most robust and reliable data were found, but very similar trends were also found in the 20-year data set including also years 2019–2021 (see Supplementary Information).

The large uncertainty related to dynamical changes in precipitation results in the inability of the models to provide confident projections of specific outcomes. Therefore, the use of the median or mean projected changes for future adaptation decisions could substantially underestimate the risk of large changes in precipitation and it could mean that the risk of the opposite sign of changes is not accounted for (IPCC AR6 WG2; Water (Caretta et al., 2022)). Consequently, information on the range of possible outcomes can be valued by users for effectively informing risk assessments (Löwe et al., 2018) and story-line approaches examining unlikely events with severe consequences are required (Shepherd et al., 2018).

The European case that we highlight in this commentary, is a prominent example of how food security can be compromised if we underestimate the role of interannual variability. In other, less economically resilient, regions of the world, similar events can have vastly greater impacts, causing severe socioeconomic disruption. Therefore, this commentary serves as a motivation for the atmospheric science community to provide more insight into the changes in global atmospheric circulation patterns. More attention should also be paid to describing the outputs of all model projections using, for example, plausible storyline approaches (Zappa & Shepherd, 2017), or probabilistic risk-based methodologies (Shepherd, 2014) to encompass rather subtle information which is present in the models, but we are unable to grasp it using conventional approaches (i.e., mean and spread of projections). From the agricultural perspective, there is an increasing need for a better understanding of the plant response to changing water availability, especially when their productivity is expected to decrease substantially during the 21st century (C. Zhao et al., 2017). Bridging these gaps can help us mitigate the impacts of future hydroclimatic extremes across the world.

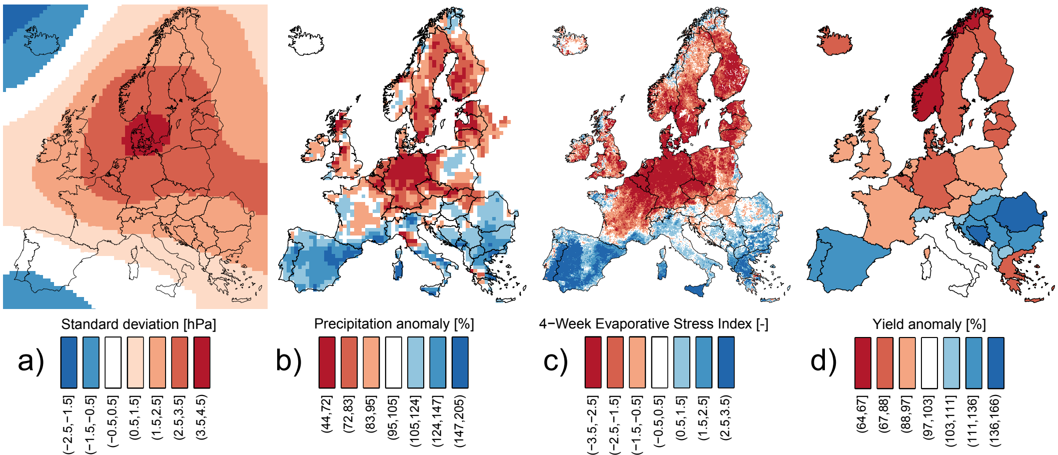

Figure 1. a) Standardized pressure anomalies in 500hPa layer over the period April–September 2018. The anomalies are calculated with respect to 1979–2018 period. **b) Relative precipitation anomaly across Europe for the year 2018 with respect to 1981–2010. c) 4-week accumulated Evaporative Stress Index (ESI) between July 17 and August 13 of 2018 d) Percentage difference of 2018 cereals yield with respect to 2008–2017 cereals yield.** Cereals class includes wheat, rye, maslin, barley, oats, mixed grain other than maslin, grain maize, sorghum, triticale, and other cereal crops such as buckwheat, millet, canary seed and rice.

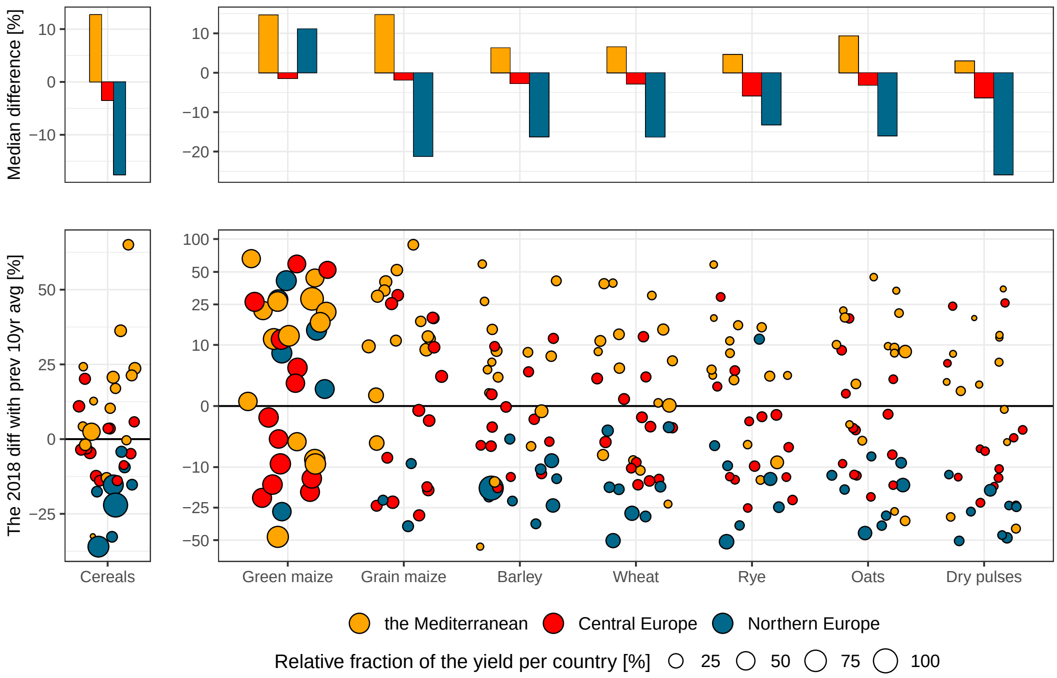

Figure 2. Comparison of crop yield in 2018 and the average of 2008–2017. The panels show the ratio between yield from 2018 and the average yield from 2008 to 2017 for various crops (upper panels; median per region) and countries (lower panels), according to European Commission Statistics (2020). The left panels show the ratio for all cereals together (wheat, rye, maslin, barley, oats, mixed grain other than maslin, grain maize, sorghum, triticale, and other cereal crops such as buckwheat, millet, canary seed and rice) and the right panels present the individual crops. The circles and their size represent the relative yield fraction of the given crop among the other reported crops within each country. The bigger the circle the higher the yield of given crop.

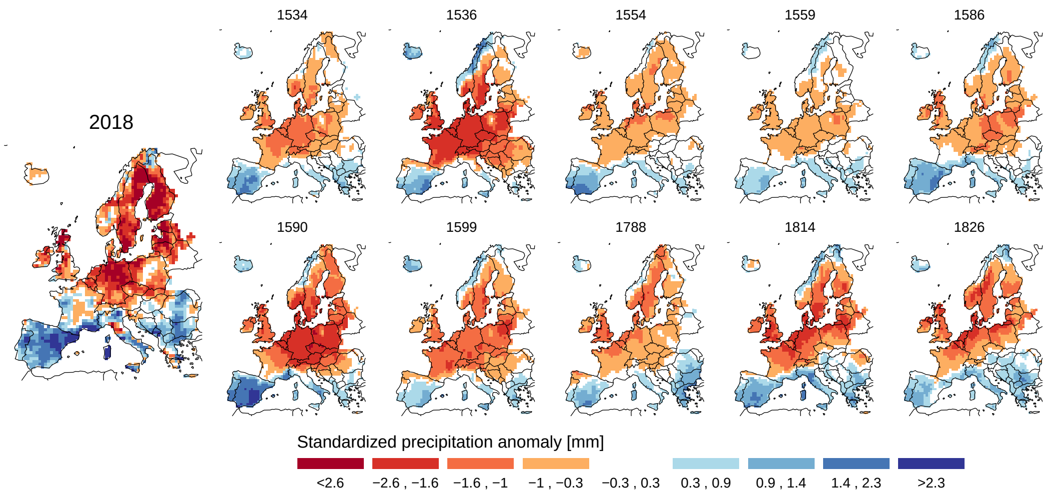

Figure 3. Water Seesaw years since 1500 CE. Shown via standardized precipitation anomaly. The categories are classified using Jenks natural breaks classification method.

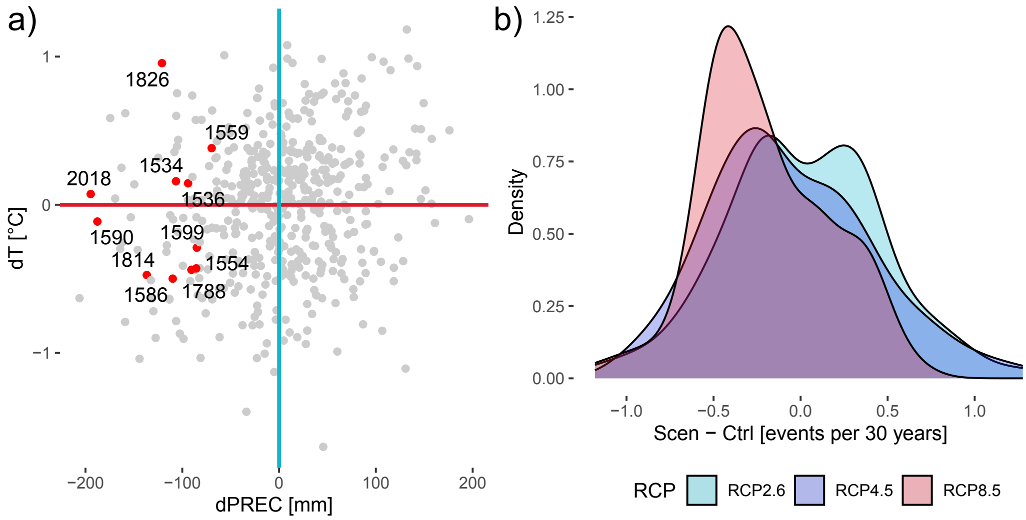

Figure 4. a) Differences in precipitation and temperature anomalies between the Mediterranean and Central+Northern Europe. The annual anomalies are calculated with respect to the previous 30-year average. Negative $dPREC$ corresponds to wetter conditions in the Mediterranean compared to Central+Northern Europe (water seesaw), and positive dT suggests relatively warmer Central and Northern Europe. Position close to the x-axis (red line) suggests equal temperature anomaly for both regions. **b) The distribution of differences in a number of seesaw events** between historical and scenario runs of the Max Planck Institute Earth System Model (MPI-ESM; (Maher et al., 2019)) from the single-model initial-condition large ensemble (SMILEs) consisting of 100 members for each of three Representative Concentration Pathways (RCP2.6, RCP4.5 and RCP8.5.)

7 Open Research

All data used for this commentary are freely available on Eurostat database (European Commission Statistics, 2020), in particular datasets:

- Cereals for the production of grain (including seed) by area, production and humidity, `https://ec.europa.eu/eurostat/databrowser/view/tag00027/default/table?lang=en`;
- Green maize by area, production and humidity, `https://ec.europa.eu/eurostat/databrowser/view/tag00101/default/table?lang=en`;
- Grain maize and corn-cob-mix by area, production and humidity, `https://ec.europa.eu/eurostat/databrowser/view/tag00093/default/table?lang=en`;
- Barley by area, production and humidity, `https://ec.europa.eu/eurostat/databrowser/view/tag00051/default/table?lang=en`;
- Wheat and spelt by area, production and humidity, `https://ec.europa.eu/eurostat/databrowser/view/tag00047/default/table?lang=en`;
- Rye and winter cereal mixtures by area, production and humidity, `https://ec.europa.eu/eurostat/databrowser/view/tag00049/default/table?lang=en`;
- Oats and spring cereal mixtures by area, production and humidity, `https://ec.europa.eu/eurostat/databrowser/view/tag00053/default/table?lang=en`;
- Dry pulses and protein crops for the production of grain (including seed and mixtures of cereals and pulses) by area, production and humidity, `https://ec.europa.eu/eurostat/databrowser/view/tag00094/default/table?lang=en`

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