,

Horizon 2020 Societal challenge 5: Climate action, environment, resource efficiency and raw materials

VERIFY

Observation-based system for monitoring and verification of greenhouse gases

GA number 776810, RIA

Deliverable number (relative in WP)	D5.13
Deliverable name:	Analysis of recent extreme events' impacts on GHG budgets anomalies
WP / WP number:	5
Delivery due date:	Month 34 (31/01/2021)
Actual date of submission:	Month 49 (18/02/2022)
Dissemination level:	Public
Lead beneficiary:	CEA
Responsible	Philippe Ciais
Contributor(s):	Ana Bastos (LMU, MPG)
Internal reviewer:	Aurélie Paquirissamy and Philippe Peylin (CEA)

Changes with respect to the DoA
delay to finalize the writing, the analysis and the overall internal review
Dissemination and uptake
Public
Short Summary of results (<250 words)
The carbon balance of European ecosystems was studied for the 2018 mega drought event from a large ensemble of models and satellite observations to quantify spatial and temporal patterns on the net European land carbon sink and carry over effects from spring to summer. We found that the carbon sink in Europe was mostly enhanced in spring because of high radiation and temperature without soil moisture limitations, whereas a strong negative anomaly (smaller sink) was found later in temperate regions and a positive anomaly in northern Europe. The net carbon balance anomaly is composed of direct adverse summer climate effects on carbon uptake and of indirect adverse effects carried over from spring to summer in central Europe, but positive legacy effects in northern Europe.
Evidence of accomplishment
Article published. (Bastos et al., 2020) in Science Advances

Version	Date	Description	Author (Organisation)
V0.1	7/06/2021	Creation/Writing	Philippe Ciais (LSCE) and Ana Bastos (LMU, MPG)
V1	25/06/2021	Formatting/Delivery on the Participant Portal	Aurélie Paquirissamy and Philippe Peylin (CEA) and Geraud Moulas (ARTTIC)

Table of content

1. Glossary

Abbreviation / Acronym	Description/meaning
DGVM	Dynamic Global Vegetation Models
ERA5	ECMWF climate reanalysis
GOME	Global Ozone Monitoring Experiment-
GPP	Gross photosynthesis uptake
JJA	June-August
L-VOD	L-band vegetation optical depth
MAM	March-May
NEE/NBP	Difference between GPP and TER (NEE at site scale, NBP at regional scale
NBP	Net C balance of ecosystems (>0 if ecosystems gain carbon)
SIF	Solar-induced chlorophyll fluorescence
SMOS	Soil Moisture and Ocean Salinity (ESA mission)
SPEI	Standardized Palmer drought Index
SWR	Solar shortwave radiation
TER	Total ecosystem respiration
TROPOMI	TROPOspheric Monitoring Instrument

2. Executive Summary

In the past two decades, Europe has been subject to severe droughts, which are believed to be most severe on record compared to tree rings reconstructions over central Europe. The drought of 2018 is characterized by high temperature in spring and extreme summer water deficits also accompanied by higher than normal temperature. This event was studied in light of its abnormal character and because satellite observations and model simulations from a large ensemble of models were available and coordinated, to appreciate spatial and temporal differences on the net European land carbon sink and carry over effects (positive or negative) from spring to summer. We found that spring NBP (sink) was mostly enhanced because of high radiation and temperature without soil moisture limitations, whereas in summer a strong negative NBP anomaly (smaller sink) was found in temperate regions of central Europe and southern Scandinavia, and a positive anomaly in northern Europe. The NBP anomaly is composed of direct adverse summer climate effects on carbon uptake and of indirect adverse effects carried over from spring to summer in central Europe, but positive effects carried over from spring to summer in northern Europe.

3. Introduction

In the past two decades, Europe has been stricken by major summer heat waves and drought, with heavy impacts on food production, public health, air pollution, and ecosystem carbon productivity. For instance, the drought-heat extreme (E) events of 2003 and 2010 in central Europe and western Russia, respectively (referred to here as 2003 and 2010), broke, at the time, the >500-year-long summer temperature record over the continent. In the northern hemisphere, 2018 was the hottest summer ever. In 2019, record heat was observed in parts of Western Europe. While these events were exceptional at the time, their likelihood will increase in the coming century due to anthropogenic global warming. In 2018, the European summer land temperature anomaly broke the record yet again, with specific spatiotemporal patterns. The 2018 summer was characterized by extreme drought in central and northern Europe (Fig. 1), with several countries suffering major economic costs from crop failure. Compensations to farmers from crop losses due to drought in 2018 reached €340 million in Germany and €116 million in Sweden.

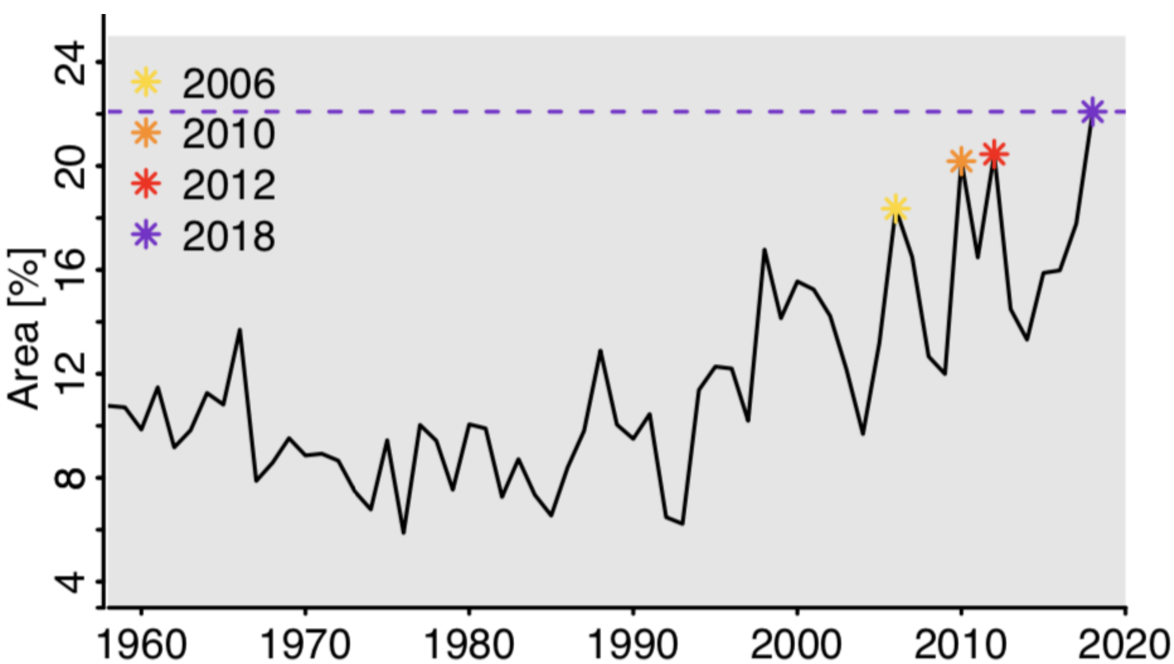

Figure 1: Area with hot temperature records being recorded in the northern hemisphere since 1959 (Vogel et al., 2019)

In this deliverable we show how interannual and seasonal anomalies of temperature and precipitation are statistically associated with observed anomalies of gross photosynthesis uptake (GPP), total ecosystem respiration (TER) and their difference (NEE at site scale, NBP at regional scale). Analysis is performed for site level data of the ICOS network, using 11 land surface models integrated across Europe using the ERA5 forcing and factorial experiments to study the carry-over impact of climate from the spring -> summer and autumn, and of summer -> autumn, using satellite observed vegetation optical depth (a proxy of biomass change and water content), satellite observed soil moisture from the SMOS ESA mission, and satellite observed sun induced fluorescence from S5P Tropomi (SIF as a proxy of photosynthesis). The expectation is that the northernmost European ecosystems are positively sensitive to temperature, i.e. that warmer growing season temperatures will increase GPP and NBP during an abnormally hot and dry season like 2018, whereas temperate and southern ecosystems are negatively sensitive to hot anomalies from co-occurring rainfall deficit less, limiting soil moisture available for plants. The results have been published in Bastos et al. 2020.

4. Main Results

Figure 2 presents the patterns of the SPEI drought index, composed of precipitation and temperature across Europe from left to right in the summers of 2003, 2010, 2015 and 2018. 2015 was not associated with extreme high temperatures, but had a prevailing extreme water deficit. We observe that extreme drought occurred in Western Europe in 2003, in western Russia in 2010 and in central Europe covering Germany, Netherlands, Poland, Baltic countries and Scandinavia in 2018 (Bastos et al., 2020; Smith et al., 2020; Vogel et al., 2019). The drought was less extreme in 2015 but covers a large area going from the Iberian Peninsula to Eastern Europe (from Baltic Sea to Black Sea) with most negative SPEI anomalies found north of the Black Sea.

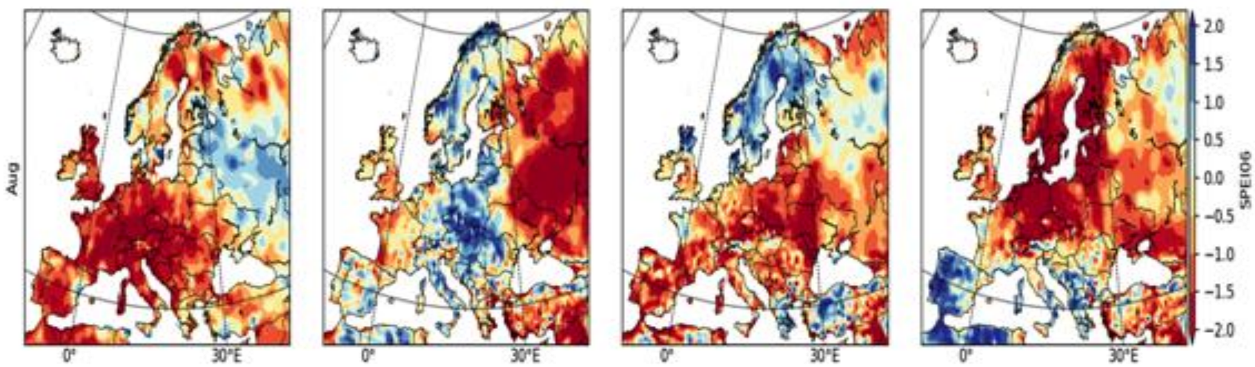

Figure 2: SPEI (Palmer drought index) anomalies for 2003, 2010, 2015 and 2018 growing seasons

Several studies analyzed the impacts of extreme drought events resulting from concurrent SM deficits, heat stress, and fire activity (direct impacts) on ecosystems' carbon balance. The influence of preceding climate conditions in the ecosystems' response to the summer extremes (legacy effects) has been less studied. All three drought & heat events (2003, 2010, 2018) in Europe were composed of warm springs, with reduced rainfall and sunnier conditions. Followed by dry summers, these spring climate anomalies can affect the carbon balance by (i) directly affecting ecosystem productivity, (ii) altering the water and energy balance in the following seasons due to land-atmosphere feedbacks, and (iii) affecting the response of ecosystems to climate anomalies in subsequent seasons by altering their baseline state. Warm and sunny conditions in spring directly result in earlier vegetation green-up and growth, which might partly compensate for the summer productivity losses from drought and extreme heat. However, spring climate conditions can have different legacy effects to the summer and annual carbon balance. Previous studies have highlighted the role of spring precipitation deficits, increased solar radiation and warming in amplifying the high temperature anomalies in summer.

In Figure 3, we compare the temporal evolution of the anomalies of the standardized Palmer drought index between the 4 droughts shown in Figure 2. The drought of 2018 is mostly characterized by an abrupt inception of drought with a cross over from positive to negative values in May (later than in 2003) and a more severe drought peak intensity than in 2010 and 2015. In terms of area affected severely by drought, we found a large extent over the continent during which drought index anomalies reached values surpassing 2.5 standard deviations. In this respect, the drought of 2018 is a ‘megadrought’ of similar extent than 2010, 2015 and more than four times larger than 2003.

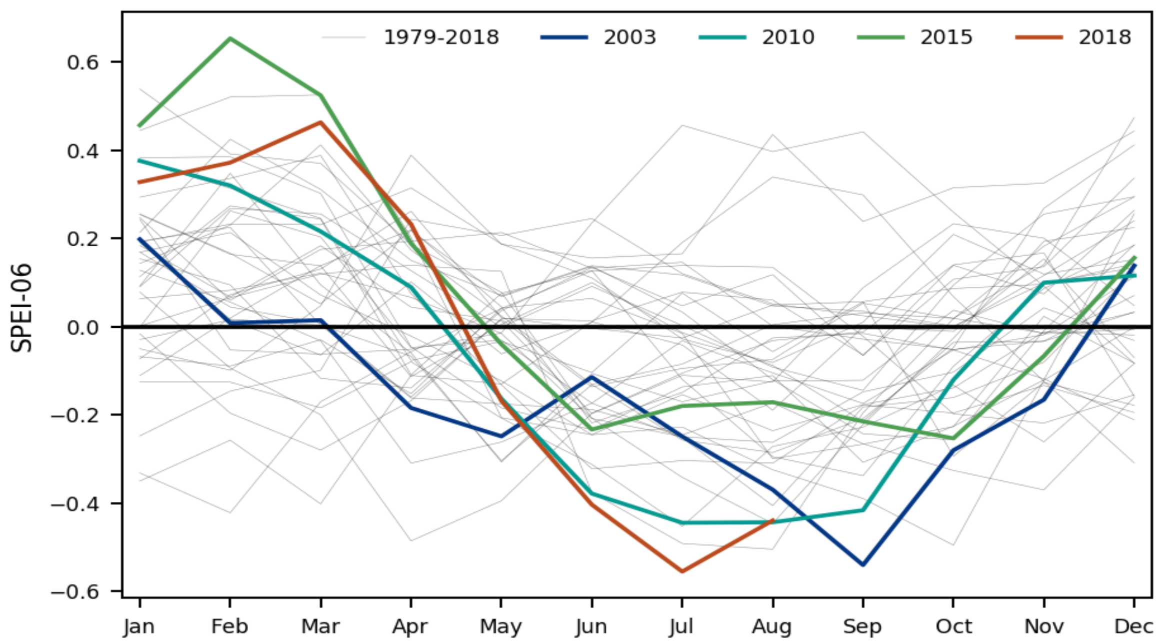

Figure 3: Normalized SPEI (Palmer) drought index over Europe for the 4 megadroughts and other normal years.

Satellite observations of sun induced fluorescence from the S5P TROPOMI spaceborne instrument show an increase in spring 2018 within the range of previous years (combined TROPOMI and GOME data) but an early reversal indicative of water stress on plant photosynthesis, starting in

May and continuing until October. The maximum deficit of SIF occurred in August 2018 compared to the climatology during the period 2003-2017

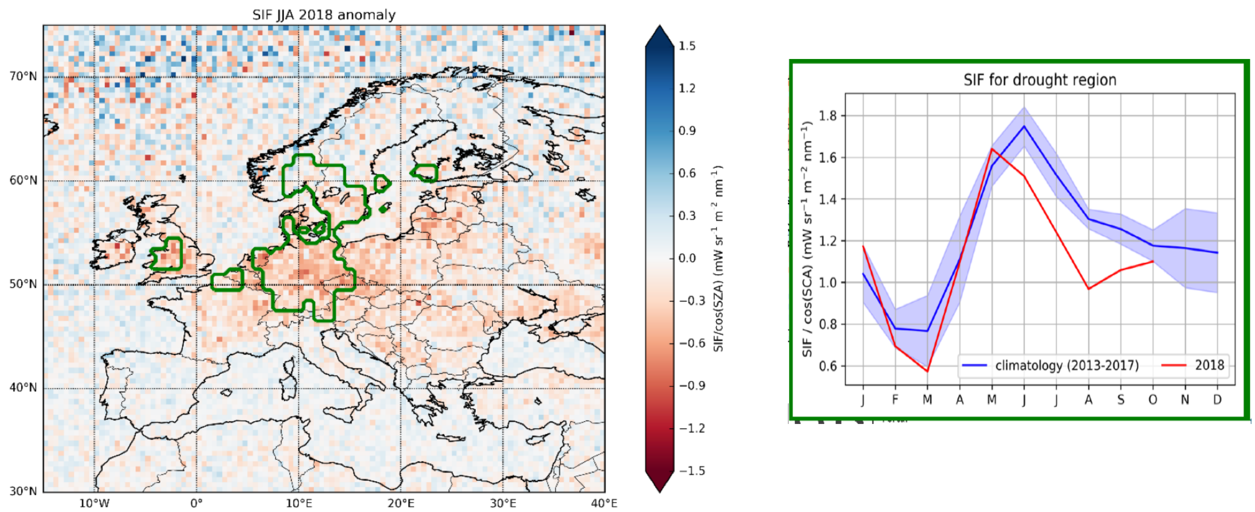

Figure 4: SIF anomaly patterns and SIF temporal anomaly in 2018 compared to other years. After (Smith et al., 2020))

Spring anomalies

According to the DGVM, spring 2018 was associated with positive net biome production (NBP) anomalies (defined positive for above-average CO_2 uptake) of 5 to 10 gC m^{-2} $month^{-1}$ (Fig. 2A). Higher CO_2 uptake occurred in southern (Balkans, Turkey) and northern regions (western Russia, Scandinavia, and Baltic countries) of Europe. In summer, NBP anomalies negative over western and central Europe and western Russia with below average CO_2 uptake (Fig. 2B), but positive NBP anomalies were modeled in Scandinavia and southern Europe (which was wetter than usual). Central Europe and southern Sweden are modeled to have record-low sinks, with CO_2 uptake dropping by more than 50% but these regions remained CO_2 sinks and did not turn to CO_2 sources. The DGVM model results show consistent patterns with SIF and vegetation optical depth (L-VOD) from the SMOS instrument. L-VOD reflect changes in aboveground biomass carbon and vegetation water content. Negative L-VOD anomalies are observed from northwestern France to eastern Poland, Baltic countries, and southern Scandinavia. L-VOD increased however in central and northern Scandinavia, northwestern Russia, and most of southern Europe. L-VOD changes showed good agreement with DGVM NBP. The positive DGVM NBP anomalies in spring and summer match positive GPP anomalies in observation-based products. In spring, models estimate widespread GPP increase and record-high values in Scandinavia and southern Europe. These patterns are consistent with GPP estimates from SIF and from the eddy covariance data-driven product FLUXCOM.

Summer anomalies

In summer, regions with negative NBP anomalies are associated with below average GPP, and vice versa, and regions with extremely high or extremely low NBP match regions with record GPP anomalies. Only in Eastern Europe, we found a strong contribution of total ecosystem respiration (TER) and, to a lesser extent, of fires to NBP anomalies. The results indicate an asymmetry in the summer carbon flux anomalies, with the northern sector of the drought-affected region showing increased NBP and GPP during summer, while the southern sector registered strong decreases in both variables. This asymmetry may be due to distinct responses of ecosystems to summer warming and drying but also to different carry over effects from spring climate to summer NBP. The region affected by drought in 2018 is split in two sectors for further analysis: R1 (southern sector, reduced summer CO_2 uptake) and R2 (northern sector, increased summer CO_2 uptake).

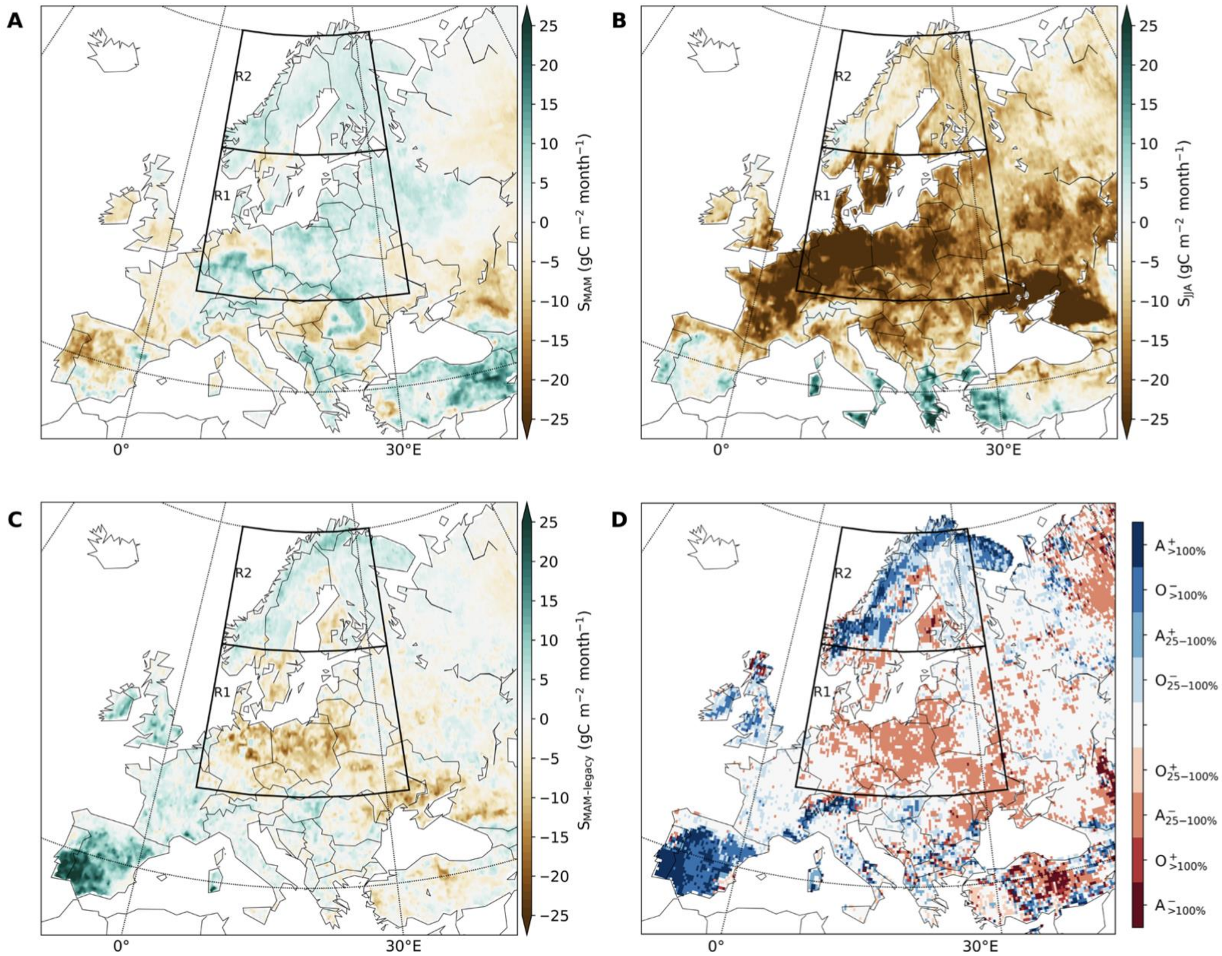

Figure 5: Direct and legacy effects of spring and summer climate to the drought-2018 carbon balance. Spatial distribution of the average net effect of (A) spring climate anomalies direct impact on spring NBP (MAM), (B) summer climate anomalies direct impact on summer NBP (JJA), (C) spring-> summer climate legacy effects from MAM -> JJA, and (D) relative carry-over impact of spring climate to summer NBP anomalies compared to the direct impact of summer climate to summer NBP anomalies (on a relative scale, red means a negative spring -> summer NBP carry over and blue means a positive one). The regions analyzed separately in Fig 6 are R1 where spring -> summer carry over effect on NBP is mainly positive and R2 where it is mainly positive. From Bastos et al. 2020

Carry over effects of spring climate on summer carbon fluxes

Based on factorial DGVM simulations (where climate of each season is prescribed as observed, or follows a climatology) we find differences between the impacts of each season on carbon fluxes and the seasonal anomalies of C fluxes. The spring-related NBP anomalies largely reflect a positive correlation with temperature and radiation anomalies. DGVMs estimate a direct negative effect of spring climate to NBP in spite of positive spring NBP anomalies in some regions (western Europe). By contrast, models estimate a strong direct summer climate induced decrease in NBP over most of Europe, including the northern region where models still keep a positive summer NBP anomaly. Spring conditions attenuated the direct negative effect of summer conditions on the loss of summer NBP, a positive carry over spring -> summer impact, only in regions where summer was wetter than average, mostly in northern and southern Europe.

Spring legacy effects to summer NBP show regionally distinct patterns with regions with positive effect of spring climate on spring NBP and positive spring -> summer NBP effects (Scandinavia, South Europe), regions with spring increase in NBP being offset by negative NBP spring-> summer legacy effects (central and eastern Europe), and regions with negative spring effects on spring NBP (weaker sink) offset by positive spring->summer effects (western Europe). While the generalized enhancement in spring CO_2 uptake might have contributed to partly offset summer carbon losses in central and western Europe, the mismatch between NBP anomalies simulated by DGVMs for each season and those resulting from the direct impact of each individual season hints that legacy.

We evaluated how much spring climate legacy effects contributed to amplify or offset the individual impact of the drought and heat in summer. In about 75% of the area, legacy effects from spring climate contributed by 25% or more to offset or amplify the impact on summer NBP. In most of eastern Europe, southern Sweden, and southern Finland marked by strong spring warming and higher radiation, spring climate anomalies contributed to amplify the negative summer impacts of summer conditions. On the contrary, more northern regions are dominated by positive legacy contribution of spring warming to summer NBP anomaly. In the Scandinavian mountains and parts of the Kola Peninsula, spring legacy effects were positive and thus offset a negative summer impact on NBP by more than 100%. In the Iberian Peninsula, spring legacy effects amplified positive NBP anomalies in response to summer climate by more than 100% (i.e., doubling the sink response) because this Iberian region was not under drought in 2018.

VERIFY is a research project funded by the European Commission under the H2020 program. Grant Agreement number 776810.

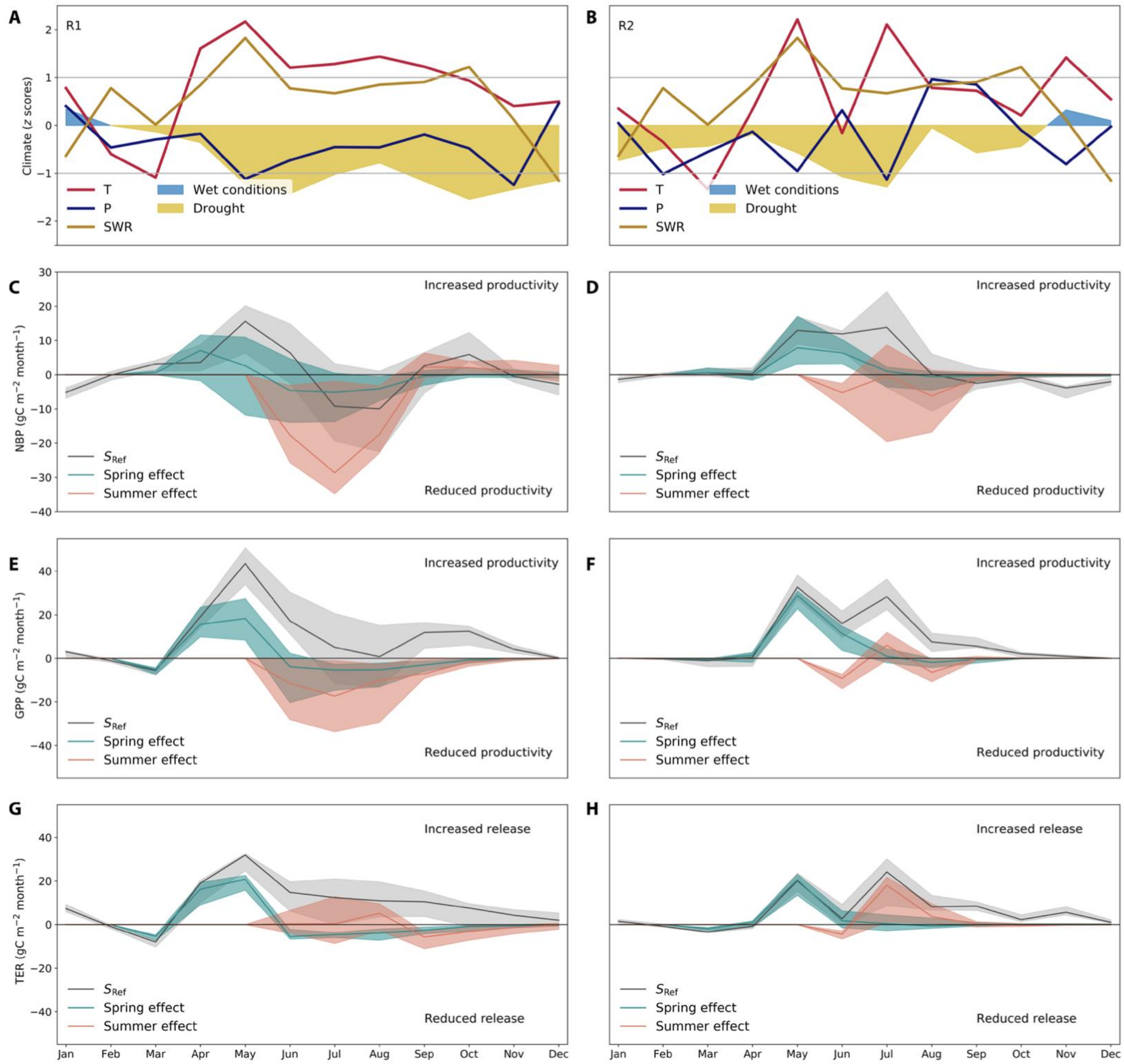

Figure 6: Seasonal evolution of climate and NBP uptake during 2018 in the R1 (first column) and R2 regions (second column). Spatially averaged standardized anomalies of temperature (T, red lines), precipitation (P, blue lines), solar shortwave radiation (SWR, yellow lines), and Palmer drought index (shaded areas, blue for wetter than-average conditions, yellow for drier-than-average ones). In (C) and (D), the corresponding regional anomalies in NBP (back line and gray shades for DGVM mean and interquartile range). Note the different y-axis range in (C) and (D). The blue (red) line indicates the individual effect of spring (summer) climate, and the interquartile range is shown by the shaded area. These effects are estimated by the factorial simulations with climatological spring (summer) vs. Real – observed spring (summer). Below are GPP anomalies TER anomalies for both regions.

5. Conclusions

We have analyzed the impact on the European carbon balance of extreme spring and summer temperatures and drought conditions in 2018. A positive or normal GPP anomaly was found in spring and generally a higher net uptake, whereas in summer, a lower-than-normal uptake was detected in central Europe, from a deficit of GPP partly explained by spring -> summer legacy effects. In northern Europe, despite fires CO2 emissions in Sweden, the net carbon balance anomaly was positive or close to zero, according to DGVM models. Further work is being performed for analyzing recovery (or lack of) in 2019 in the central European temperate regions that were affected by drought stress during 2018.

6. References

Bastos, A., Ciais, P., Friedlingstein, P., Sitch, S., Pongratz, J., Fan, L., et al. (2020). Direct and seasonal legacy effects of the 2018 heat wave and drought on European ecosystem productivity. *Science Advances*, *6*(24). https://doi.org/10.1126/sciadv.aba2724

Smith, N. E., Kooijmans, L. M. J., Koren, G., van Schaik, E., van der Woude, A. M., Wanders, N., et al. (2020). Spring enhancement and summer reduction in carbon uptake during the 2018 drought in northwestern Europe. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *375*(1810), 20190509. https://doi.org/10.1098/rstb.2019.0509

Vogel, M. M., Zscheischler, J., Wartenburger, R., Dee, D., & Seneviratne, S. I. (2019). Concurrent 2018 Hot Extremes Across Northern Hemisphere Due to Human-Induced Climate Change. *Earth's Future*, *7*(7), 692–703. https://doi.org/https://doi.org/10.1029/2019EF001189