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Drought in Europe March 2023

GDO Analytical Report

Copernicus
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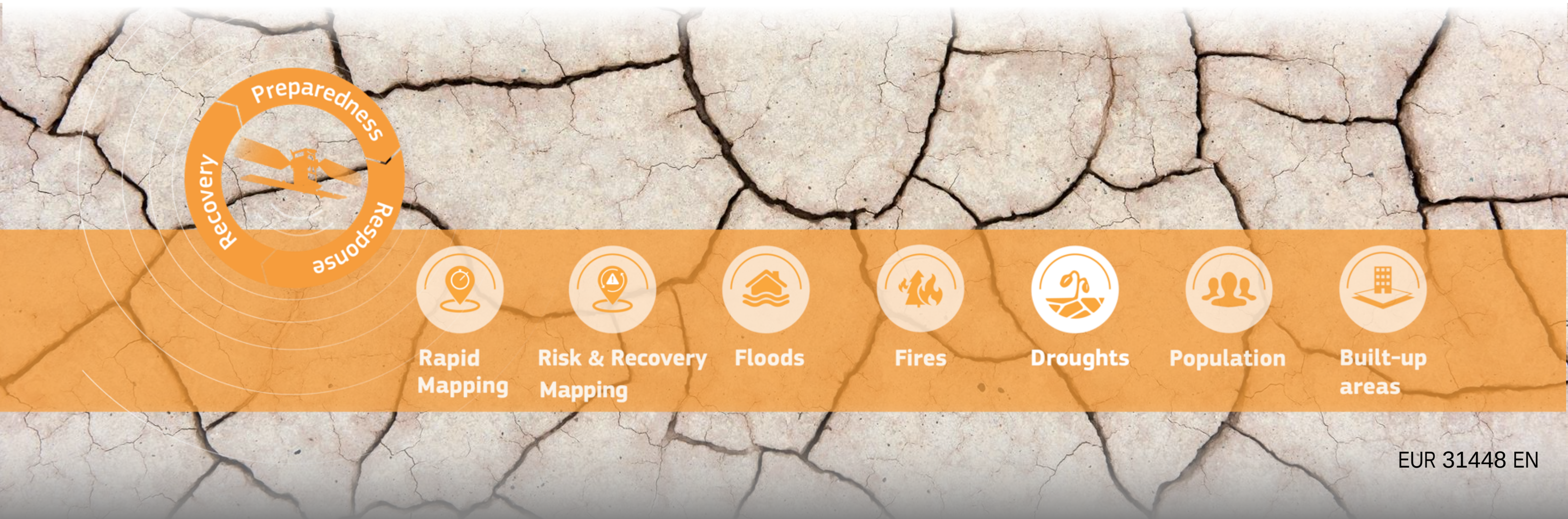
Emergency Management Service

2023



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GDO Analytical Report

Drought in Europe - March 2023

JRC Global Drought Observatory (GDO) of the Copernicus Emergency Management Service (CEMS) - 10/03/2023

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Executive summary

- Most of southern and western Europe is affected by substantial anomalies of soil moisture and river flow due to an exceptionally dry and warm winter.
- The snow water equivalent in the Alps is far below the historical average, and is even lower than that for the 2021-2022 winter. This will lead to severe reduction of snowmelt contribution to river flows in the perialpine region during spring and the early summer 2023.
- Impacts of the emerging drought are already visible in France, Spain, and northern Italy and raise concerns on water supply, agriculture and energy production.
- Seasonal forecasts show a warmer than average spring over Europe, while precipitation forecasts are characterized by higher spatial variability and uncertainty. Close monitoring and proper water use plans are required to deal with a season that currently has a high risk of being critical for water resources.

Combined Drought Indicator (CDI)

Dry conditions associated with potential impacts on water resources availability are emerging in wide areas of western and north-western Europe and several smaller areas in southern Europe. These late winter conditions are similar to the ones of 2022 which led to the severe-to-extreme drought and impacts later in that year[1].

The Combined Drought Indicator (CDI) at the end of February 2023 shows widespread warning conditions for drought in southern Spain, France, Ireland, the United Kingdom, northern Italy, Switzerland, most Mediterranean islands, the Black Sea regions of Romania and Bulgaria, and Greece (Fig. 1).[2]

The persistent lack of precipitation and a weeks-long sequence of warmer-than-average temperatures have led to negative soil moisture and river flow anomalies, particularly in southern Europe. Vegetation and crops at the beginning of the growing season have not been significantly affected yet, but the current situation may become critical in the coming months if temperature and precipitation anomalies will persist in spring 2023.

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[1] GDO Analytical Reports: https://edo.jrc.ec.europa.eu/documents/news/GDO-EDODroughtNews202203_Northern_Italy.pdf; https://edo.jrc.ec.europa.eu/documents/news/GDO-EDODroughtNews202204_Europe.pdf

[2] For more details on the CDI, and the other GDO and EDO indicators of drought-related information used in the report, see the Appendix at the end of the document.

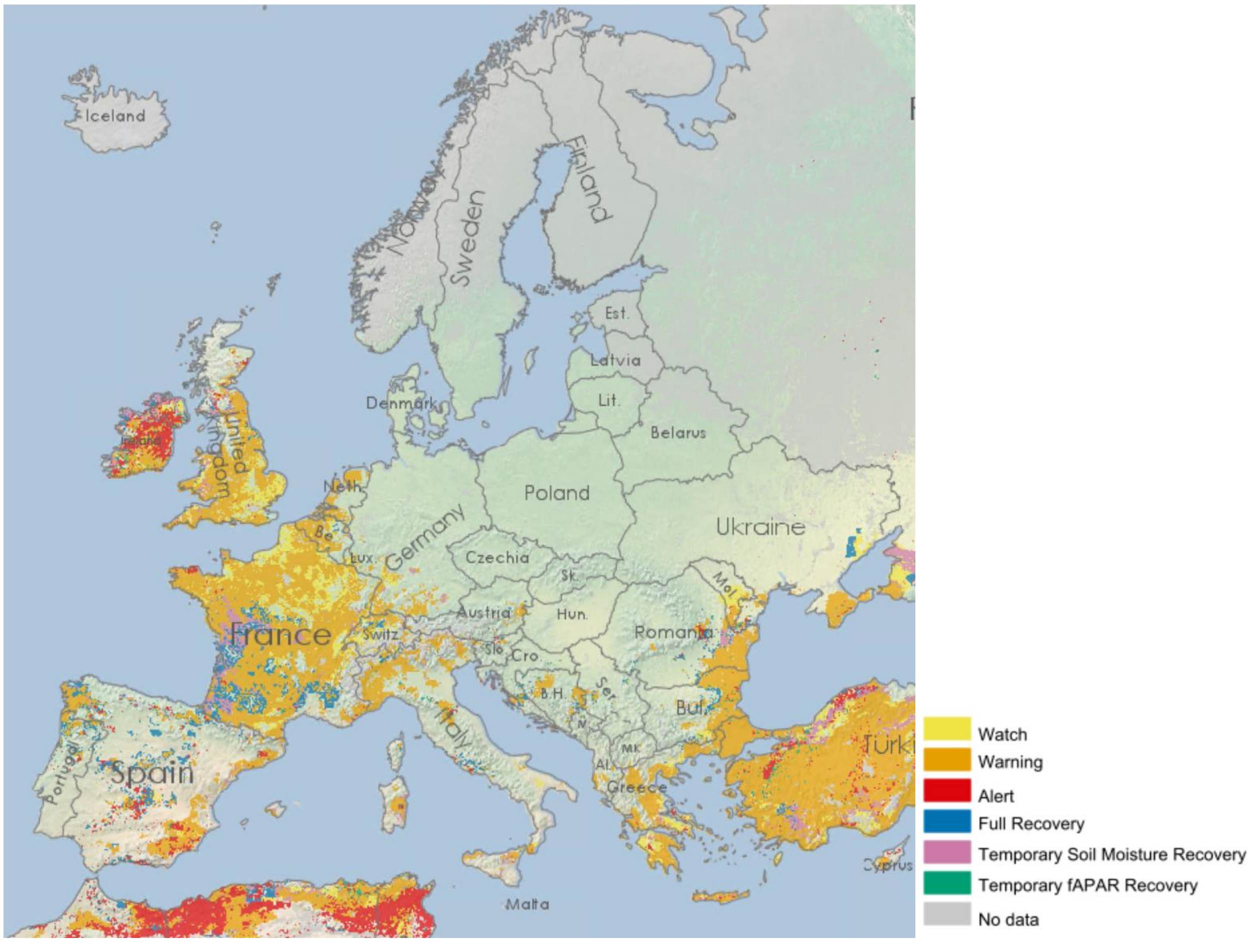

Figure 1: *The Combined Drought Indicator (CDI), based on a combination of indicators of precipitation, soil moisture, and vegetation conditions, end of February 2023.*[2]

The comparison of CDI at the end of February 2021, 2022 and 2023 gives a clear picture of the severity of the drought (Fig. 2). In 2021 CDI showed close to normal conditions. In 2022 many regions of southern Europe were under warning condition. In 2023 drought is affecting especially central-western Europe so far.

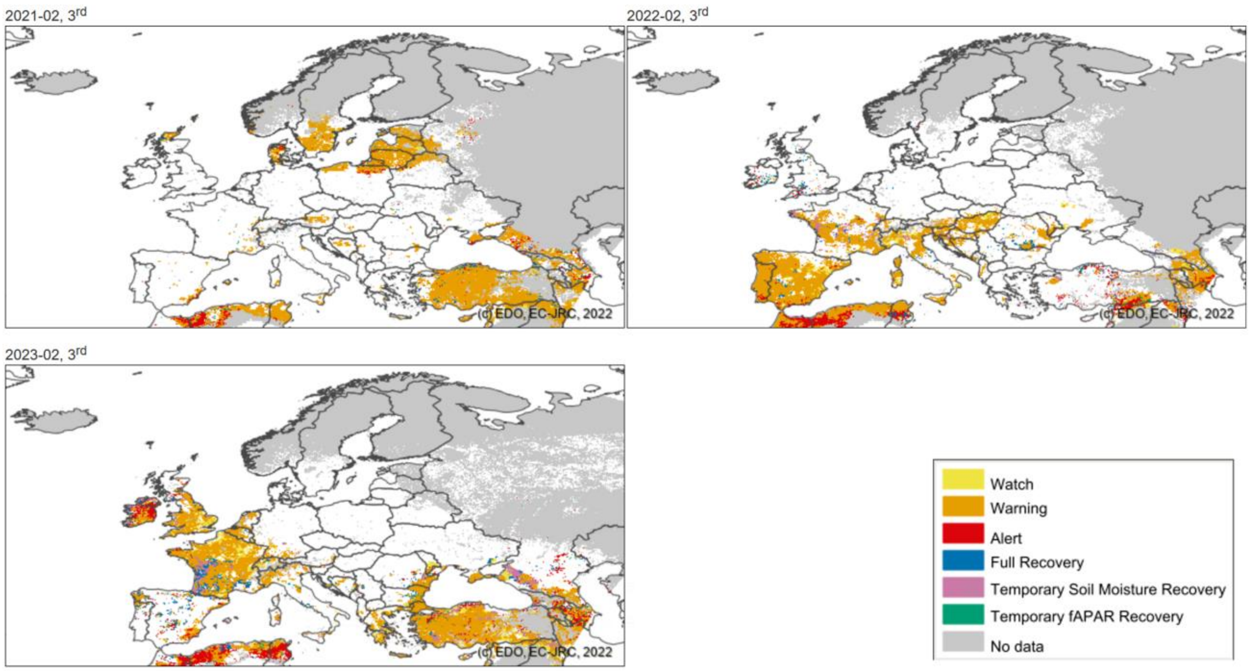

Figure 2: *The Combined Drought Indicator (CDI), based on a combination of indicators of precipitation, soil moisture, and vegetation conditions, end of February 2021 (top-left), 2022 (top-right), and 2023 (bottom-left).*[2]

Standardized Precipitation Index (SPI)

Persistent negative anomalies of precipitation have been affecting many parts of Europe for more than a year. The SPI-12 (i.e. SPI computed for an accumulation period of 12 months) shows dry anomalies in most of France, Germany, northern Italy, northern Poland, and Black Sea coast (Fig. 3a). The SPI-3 (i.e. SPI computed for an accumulation period of 3 months) shows that winter has been severely dry in central Europe, in particular in eastern France, southern Germany, and over the Alps (Fig. 3b). Snow is almost completely absent below 2000 metres, and at higher altitudes the thickness of the snowpack is extremely low. The SPI-1 (i.e. SPI computed for an accumulation period of 1 month) shows that the last 30 days assessed have been extremely dry in western and south-eastern Europe (Fig. 3c).[3]

[3] For more details on the SPI, and the other GDO and EDO indicators of drought-related information used in the report, see the Appendix at the end of the document.

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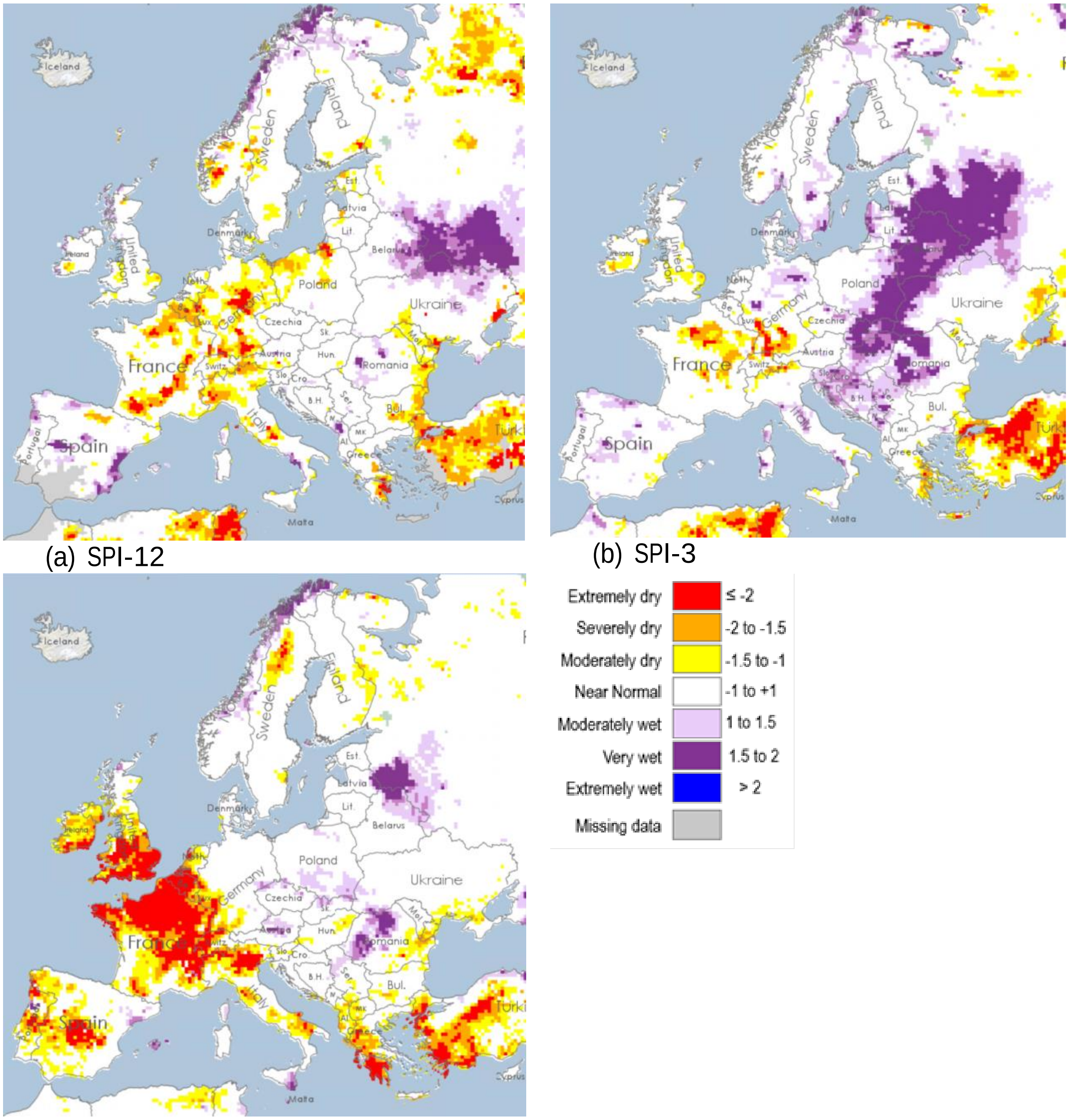

Figure 3: Standardized Precipitation Index SPI-12 (a), SPI-3 (b), and SPI-1 (c), for the 12-, 3-, and 1-month accumulation periods ending on February 28th 2023.[3]

Temperature

Most of Europe experienced prolonged above-average temperatures in mid-winter. The 30-day average temperature anomaly on December 20th 2022 ranged between 3 °C and 6 °C for central Europe and eastern Scandinavia, with a small area above 6° C at the border Romania-Ukraine. Elsewhere the anomaly generally ranged between 1 °C and 3 °C. Only over Scotland, Ireland and some regions of central Scandinavia temperatures were close to the average (reference period 1989-2021) while Iceland showed significantly lower-than-average temperatures (Fig. 4 - left).

Subsequent less severe warm-spells affected particularly central-eastern and northern Europe as shown by the 30-day average temperature anomaly on February 28th 2023 with the highest anomalies (between 3 °C and 6 °C) in northern Scandinavia (Fig. 4 - right).

These long-lasting and intense warm spells worsened the effect of the precipitation deficit on the soil moisture content.

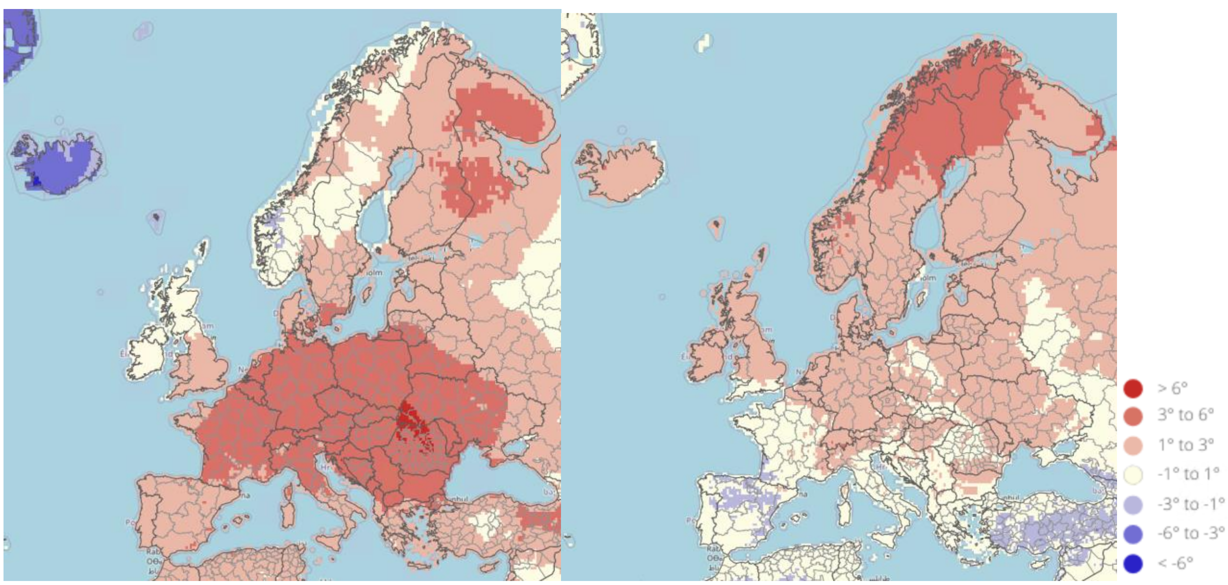

Figure 4: *30-day moving average temperature anomaly (ERA5) for 20th December 2022 (left) and for 28th February 2023 (right). Source: The JRC's ASAP (Anomaly Hotspots of Agricultural Production) global early warning system.*[4]

[4] The JRC's Anomaly Hotspots of Agricultural Production (ASAP) online decision support system for early warning about hotspots of agricultural production anomaly (crop and rangeland): https://mars.jrc.ec.europa.eu/asap/

Snow Water Equivalent (SWE)

At the end of February 2023, snow distribution over the Alps was scarce, with a higher than usual snow line and a thinner than usual snowpack, because of scarce precipitation and warmer than average winter temperature. The most used quantity for the assessment of snow water resources is the Snow Water Equivalent (SWE), which represents the amount of water stored within the snowpack.

The SWE anomaly for the Italian Alps during 2022-23 is shown in Figure 5. It can be seen that the snow season 2022-2023 started several weeks later than for the historical period 2011-2021 (Fig. 5b). Late winter 2022-2023 conditions were lower than usual, due to scarce snowfall. The only two periods with significant snowfall in the 2022-2023 snow season (first half of December and second half of January) were both followed by warm spells that partially depleted the snowpack.[5]

As a result, SWE in the Italian Alps at the end of February 2023 was below the first quartile, similar to 2022 values in late winter (Fig. 5b) when the deficit was -67%. This means that, in the Italian Alps, only about one third of the usual SWE was available. This deficit is now even larger (-30% anomaly compared to the end of February 2022).

This difference between 2022 and 2023 is due to the spatial distribution of the SWE anomaly. At the end of February 2022, the deficit mainly affected the north-western side of the Italian Alps[6]. At the same time in 2023, also the eastern side of the Italian Alps has been affected, so that the whole Italian Alps has been lacking snow (Fig. 5a).

The Italian Alps have stored nearly 2.9 cubic gigametres (Gm^3) of SWE (end of February 2023), compared to 8.7 Gm^3 (median 2011-2021) and 4.0 Gm^3 (end of February 2022). Thus, nearly 6 Gm^3 SWE are estimated to be missing at the end of February compared to the long-term average. The average timing of peak accumulation in Italy is early March (March 4 ± 10 d, reference period 2010-2021).

[5] The analysis over the Italian Alps is based on data and information provided by the operational snow monitoring system for Italy (S3M -Italy) developed and maintained by CIMA (Centro Internazionale in Monitoraggio Ambientale, International Center for Environmental Monitoring) Research Foundation on behalf of the Italian Civil Protection Department (DPC). This system provides hourly snapshots of snow depth and mass content (Snow Water Equivalent, SWE) at 200 metres resolution (Avanzi et al., 2023, https://essd.copernicus.org/articles/15/639/2023/essd-15-639-2023.html).

[6] Toreti et al., 2022. Drought in northern Italy - March 2022: GDO analytical report. https://publications.jrc.ec.europa.eu/repository/handle/JRC128974

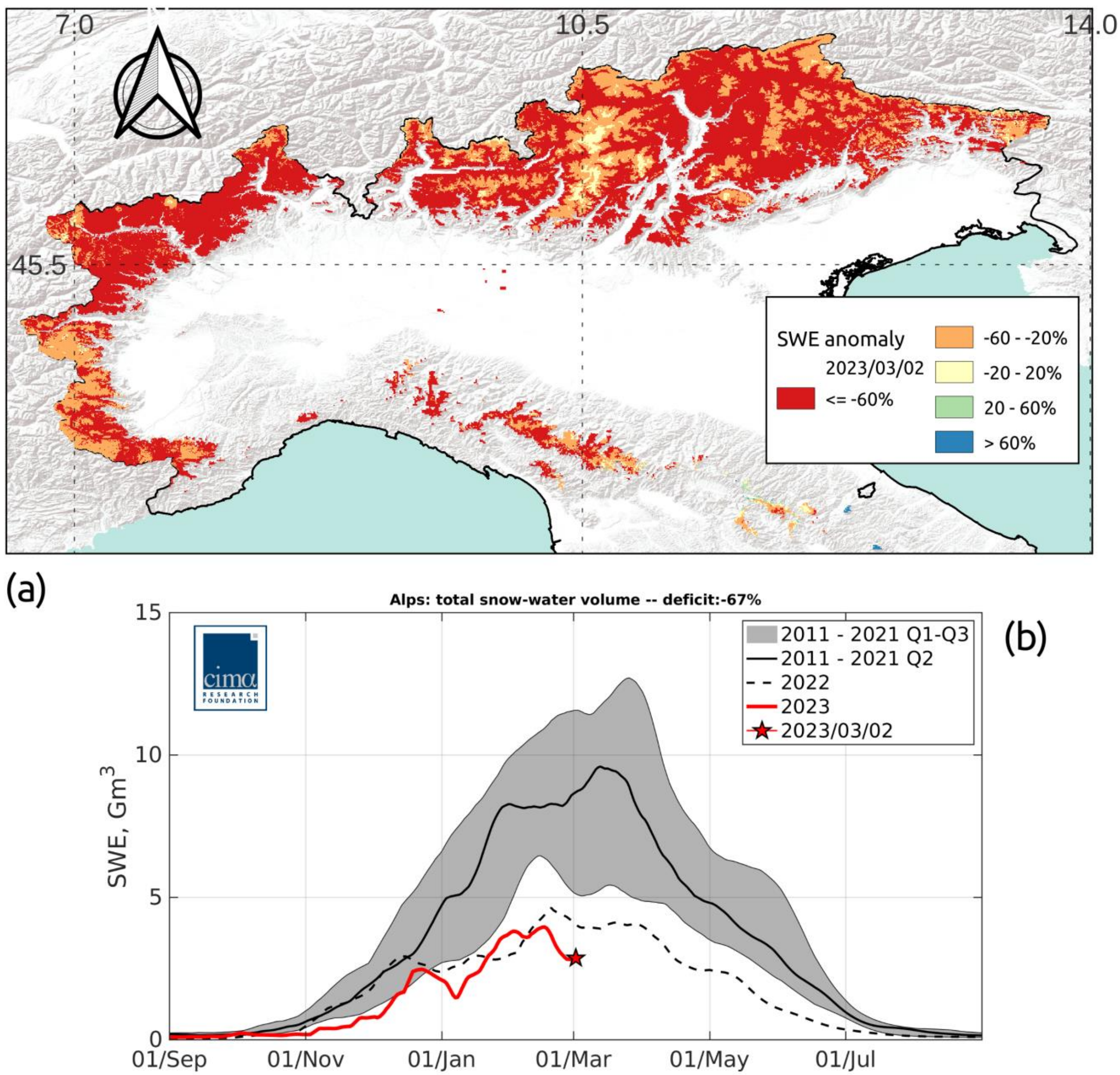

Figure 5: Snow Water Equivalent (SWE) anomaly for the Italian Alps, for the snow season 2022-2023. (a): Spatial distribution of the percentage SWE anomaly on 2nd March 2023 compared with 2011-2021. (b) The total SWE for the 2022-2023 snow season (red line) and 2021-2022 (black dashed line) compared to the 2011-2021 climatology for all the Italian Alps. The black line represents the median (Q2), while the light grey area encloses the range between the first (Q1) and third (Q3) historical quartiles. Source: CIMA Research Foundation.

Over the Swiss Alps, the snow season 2022-2023 started close to the historical first quartile during the period 1998-2022 (Fig. 6). After mid-December 2022 scarce snow accumulation and above-average temperatures led to the minimum SWE value for the beginning of March since 1998. Compared with 2021-2022, SWE is currently considerably lower and, at the beginning of March 2023, about 50% of the previous year's value. According to the historical data, peak accumulation occurs around the end of March with a tendency towards earlier dates in the case of low-snow winters (Fig. 6).[7]

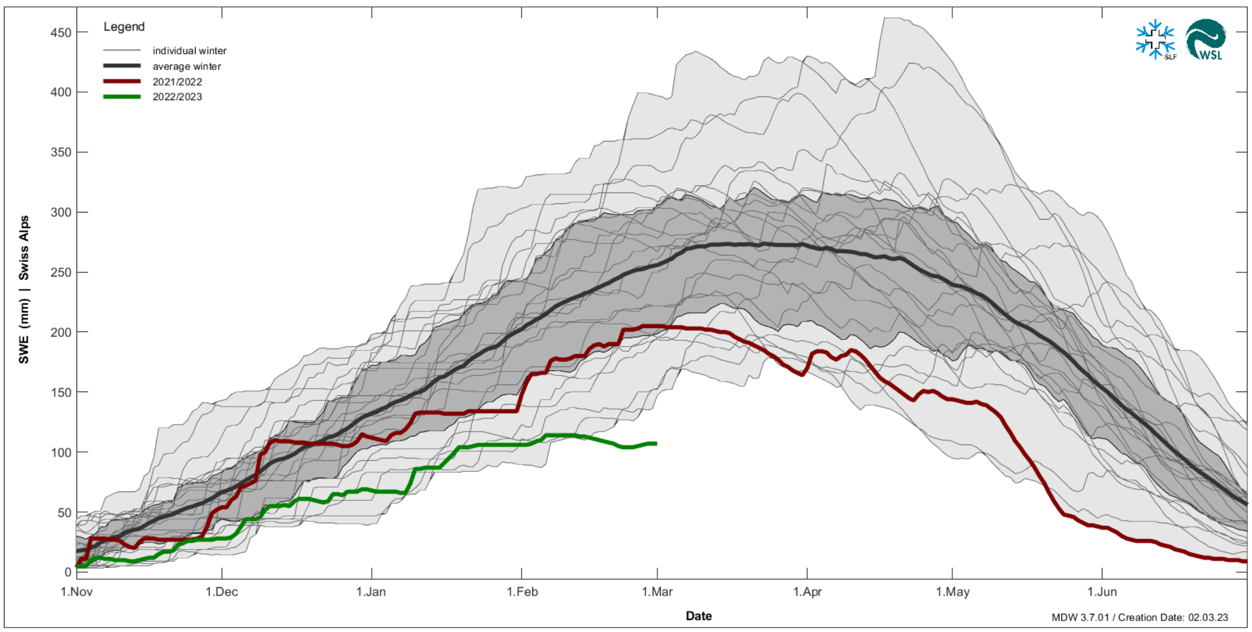

Figure 6: Average SWE for the 2022-2023 snow season (green line) and 2021-2022 (red line) compared with the 1998-2022 climatology, for the Swiss Alps. The black line is the mean, the medium grey area is the 25-75 percentile, and the light grey area is the 0-100 percentile. Light grey lines indicate data from individual years. Source: Institute for Snow and Avalanche Research (SLF) of the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL).

A spatial map of the SWE deficit at the beginning of March 2023, relative to the long-term mean, demonstrates that below-average SWE values are widespread across the entire Swiss Alps. All regions show a SWE deficit with values up to 200-300 mm, where central and eastern Switzerland are slightly more affected than other regions (Fig. 7).

[7] The analysis over the Swiss Alps is based on data and information provided by the Institute for Snow and Avalanche Research (SLF) of the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL).

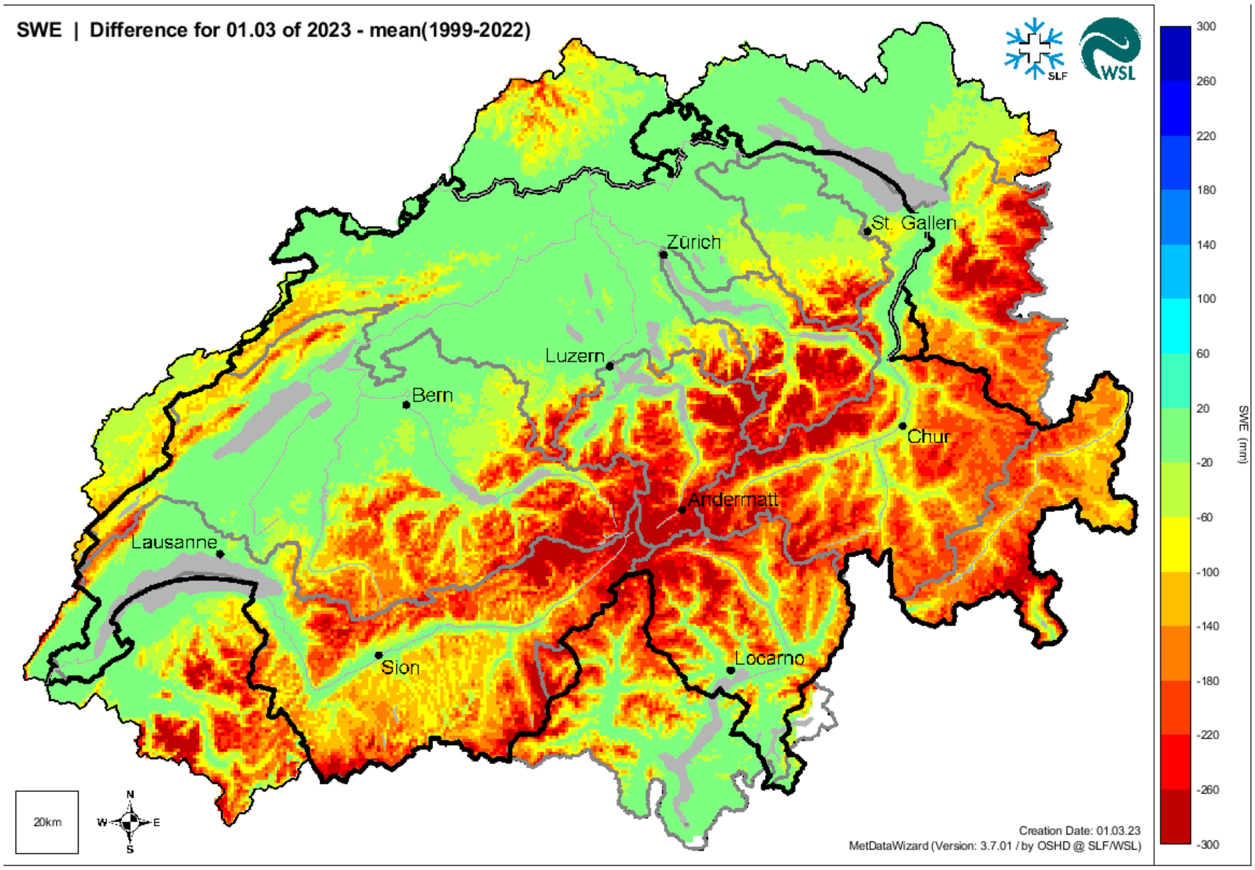

Figure 7: Snow Water Equivalent (SWE) absolute anomaly for the Swiss Alps on 1st March 2023, compared with 1998-2022. Source: Institute for Snow and Avalanche Research (SLF) of the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL).

The widespread lack of SWE over the entire Alpine Range will limit the availability of snowmelt water contribution during the melting season.

Soil moisture

At the end of February 2023, the Soil Moisture Index (SMI) Anomaly is remarkably negative in western Europe, due to a combination of low precipitation and warm-spells in the previous months (Fig. 8). The most affected regions are in Ireland, the United Kingdom, France, the Benelux countries, Spain, the Black Sea regions of Romania and Bulgaria, and northern Italy. The negative anomaly pattern is consistent with the winter precipitation pattern (highlighted by SPI-1 and SPI-3). The regions with the strongest precipitation anomalies were also affected by the warm spell, which contributed to increase the drying of the soil. Large areas show a Soil Moisture Index Anomaly below -2 (corresponding to the driest class of the EDO indicator, Fig. 8).[8]

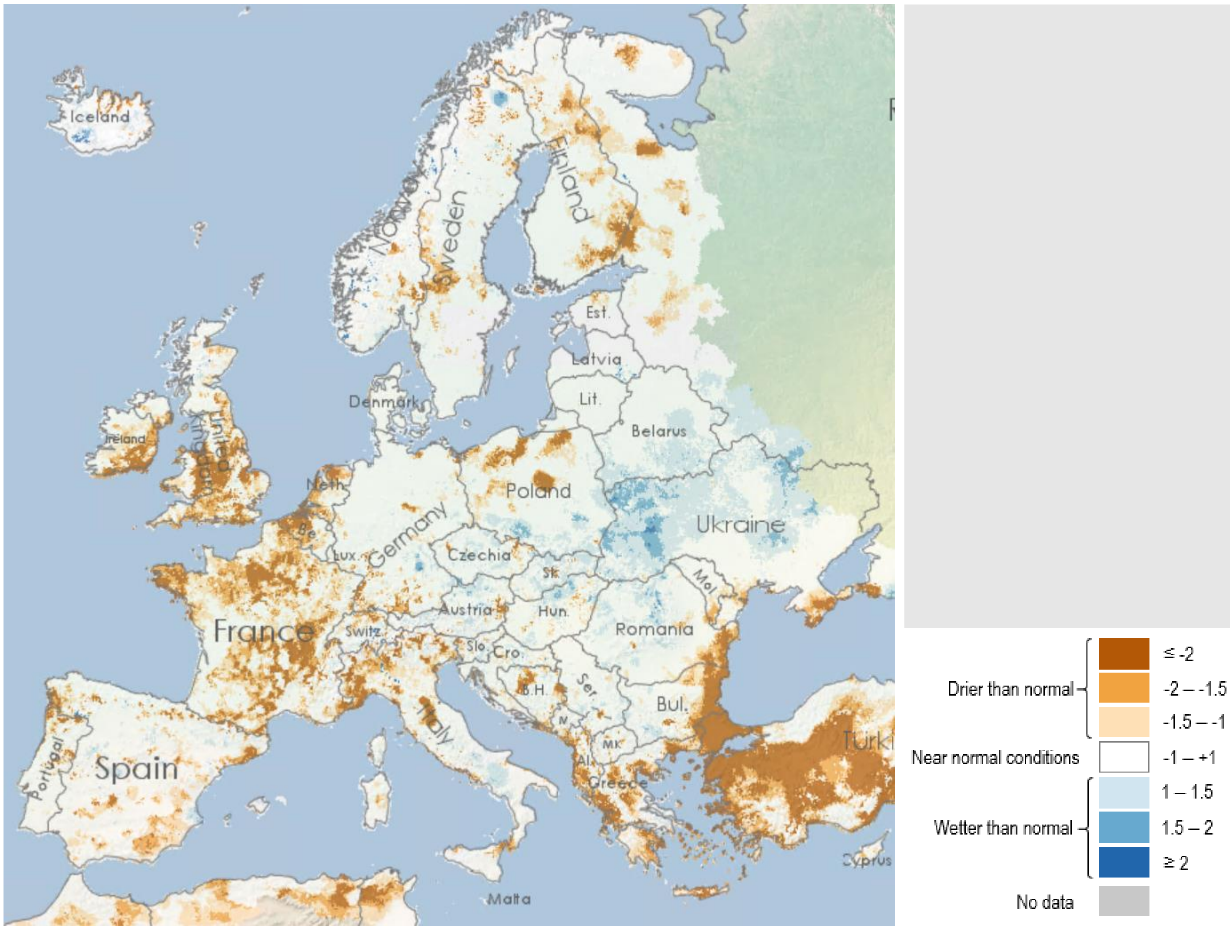

Figure 8: *Soil Moisture Index (SMI) Anomaly, end of February 2023.* [8]

The evolution of the soil moisture anomaly during the year from March 2022 to February 2023 clearly highlights the severity, the extent, and the persistence of the dry conditions over Europe (Fig. 9).

[8] For more details on the SMI Anomaly, and the other GDO and EDO indicators of drought-related information used in the report, see the Appendix at the end of the document.

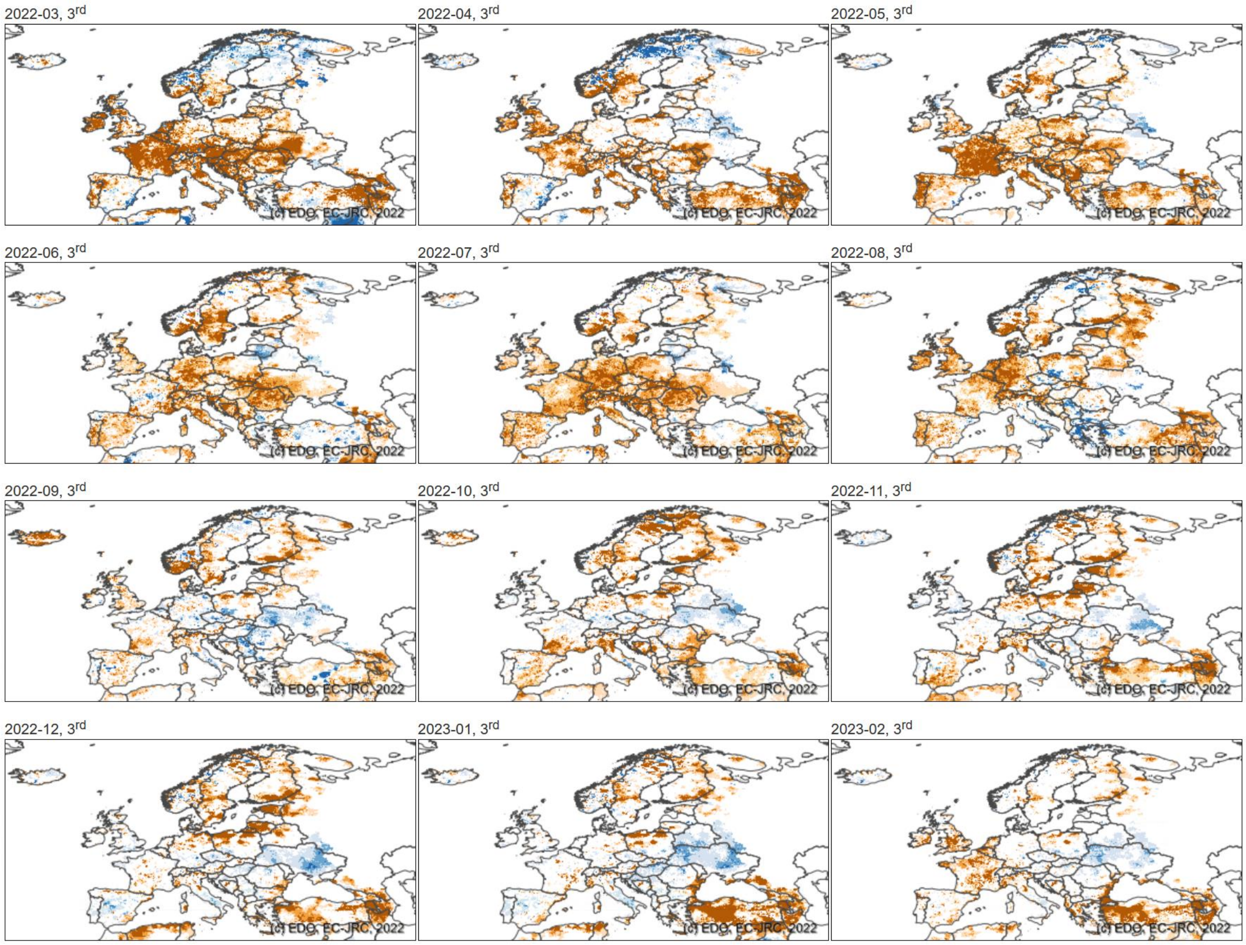

Figure 9: *Soil Moisture Index (SMI) Anomaly for Europe, from March 2022 to February 2023.*[8]

The Total Water Storage (TWS) Anomaly indicator is used for determining the occurrence of long-term hydrological drought conditions, and is often used as a proxy of groundwater drought. It is computed as anomalies of TWS data derived from the GRACE (Gravity Recovery and Climate Experiment) twin satellites.[9] TWS has good correlation with long-term SPI (12, 24, 48 months).[10]

[9] Landerer, F.W.; Swenson, S.C. Accuracy of scaled GRACE terrestrial water storage estimates. Water Resour.Res. 2012, 48, W04531

[10] Cammalleri, C., Barbosa, P., Vogt, J.V. 2019. Analysing the Relationship between Multiple-Timescale SPI and GRACE Terrestrial Water Storage in the Framework of Drought Monitoring. Water 11(8), 1672. https://doi.org/10.3390/w11081672.

The TWS anomaly represents a reliable indicator of groundwater availability anomaly and hence is a proxy for detecting anomalies in river flow levels. In December 2022 the majority of continental Europe, the United Kingdom, Ireland and eastern Scandinavia were suffering from severe negative anomalies (Fig. 10).[11]

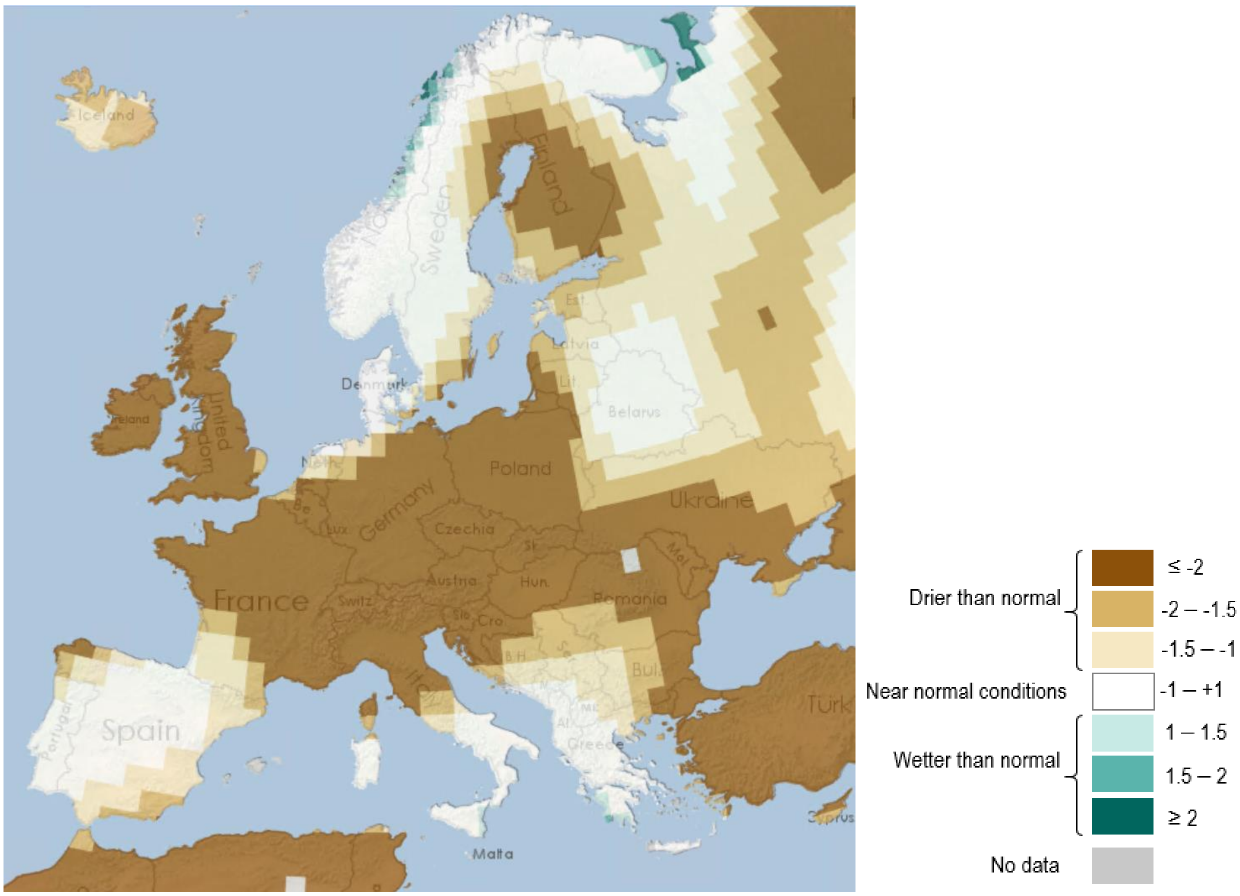

Figure 10: *GRACE-derived Total Water Storage (TWS) Anomaly, for December 2022.*[11]

Vegetation biomass

At the end of February 2023, the satellite-derived fAPAR anomaly indicator (Fig. 11) shows vegetation stress only in Ireland, southern Spain, and (slightly) central Poland, due to the warm-spell and lack of precipitation. In the rest of Europe, higher than usual photosynthetic activity is detected due to milder winter temperatures, triggering an early development of vegetation.

[11] For more details on the GRACE-derived Total Water Storage (TWS) Anomaly indicator, and the other GDO and EDO indicators of drought-related information used in the report, see the Appendix at the end of the document.

Drought impacts are expected in case the current hydro-meteorological conditions will persist in spring 2023.[12]

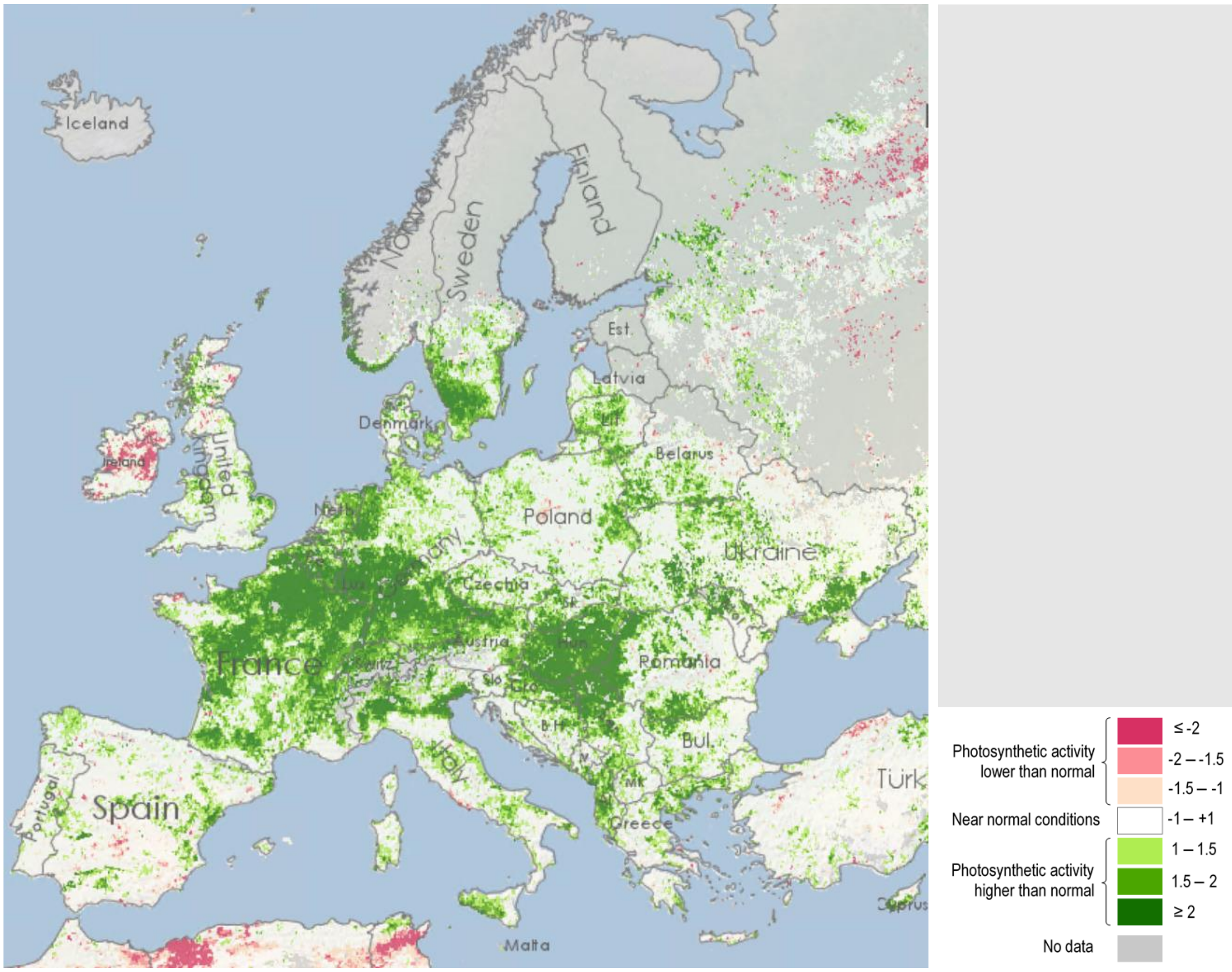

Figure 11: *Satellite-derived fAPAR anomaly indicator, measuring photosynthetic activity of vegetation in Europe, at the end of February 2023.*[12]

Dedicated information concerning agricultural production for Europe can be found in the JRC MARS Bulletin[13].

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[12] For more details on the satellite-derived fAPAR anomaly indicator, and the other GDO and EDO indicators of drought-related information used in the report, see the Appendix at the end of the document.

[13] https://joint-research-centre.ec.europa.eu/monitoring-agricultural-resources-mars/jrc-mars-bulletin_en

River flow

As of February 2023, the Low-Flow Index (LFI) shows critical values mainly over France, the United Kingdom, southern Germany, Switzerland, and northern Italy (Fig. 12). The flow reduction clearly correlates with the severe lack of precipitation of the last months, as the SPI-1 and SPI-3 both show (Fig. 3). River flows in the Rhone and the Po basins are very low with a downward trend during February 2023.[14]

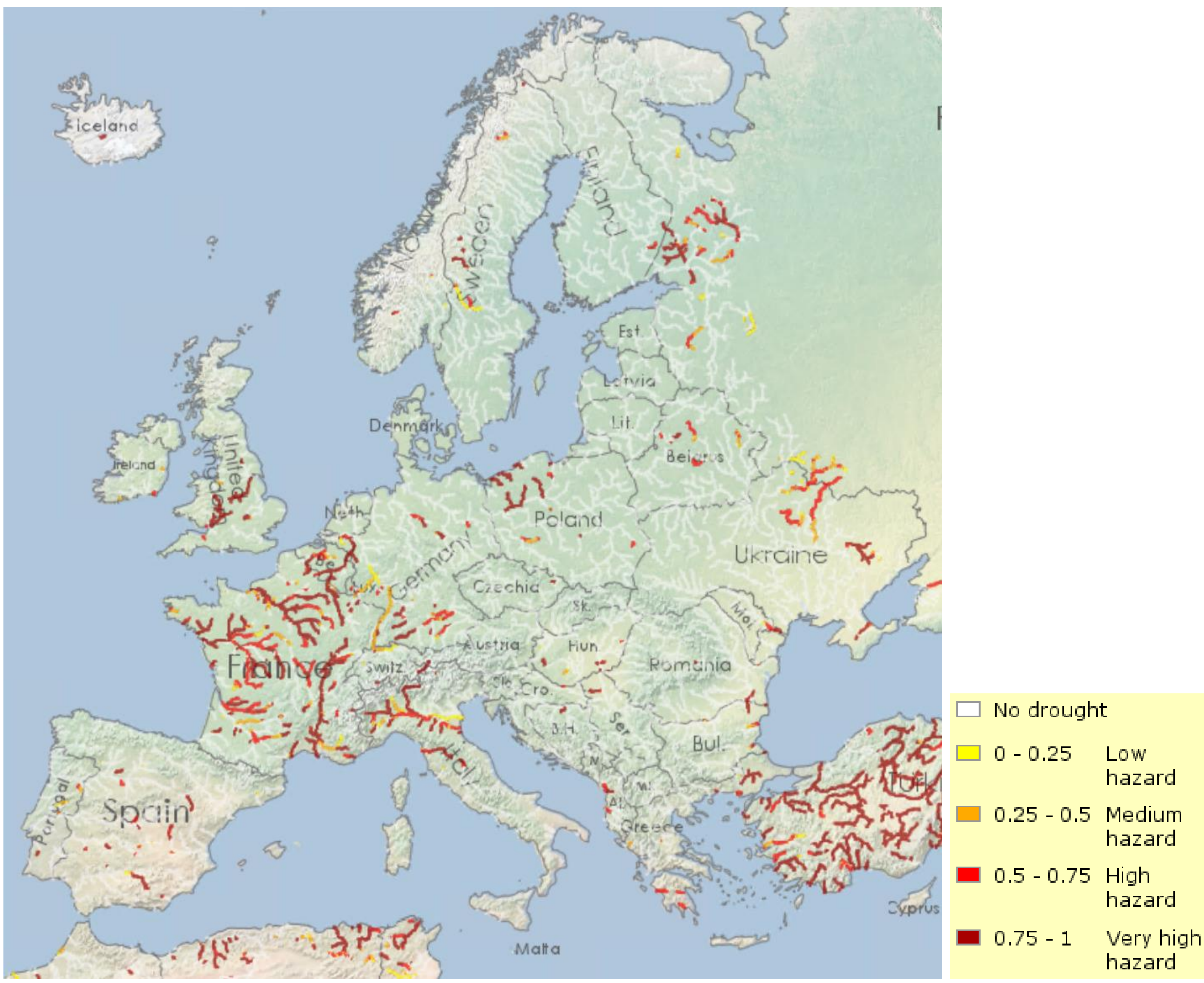

Figure 12: *Low-Flow Index (LFI) at the end of February 2023. Low-Flow Index ranges from 0 (no drought) to 1 (very high drought hazard).*[14]

[14] For more details on the Low-Flow Index (LFI), and the other GDO and EDO indicators of drought-related information used in the report, see the Appendix at the end of the document.

Large-scale atmospheric conditions

December 2022 was characterized by strong gradients of geopotential height anomalies in the lower troposphere over Europe. There were negative anomalies centred over the East Atlantic and covering western Europe, and positive anomalies in eastern Europe and the eastern half of the Mediterranean (Fig. 13). This atmospheric configuration led to an anomalous southerly wind flow from the African continent into Europe across the Mediterranean likely causing the warm and dry conditions present over large parts of Europe during the end of 2022 (Figs. 3 and 4). It is worth noting that the first half of December 2022 was characterized by a negative phase of the North Atlantic Oscillation (NAO) which explains the strong North Atlantic meridional dipole in geopotential height anomalies[15].

February 2023 was dominated by positive anomalous geopotential heights in the lower troposphere centred over Central Europe (Fig. 13). This led to anomalous southerly flow from the African continent into western Europe (e.g., the Iberian Peninsula, France, the United Kingdom, Ireland) explaining the observed low precipitation (Fig. 3) and the positive temperature anomalies in that part of the continent (Fig. 4).

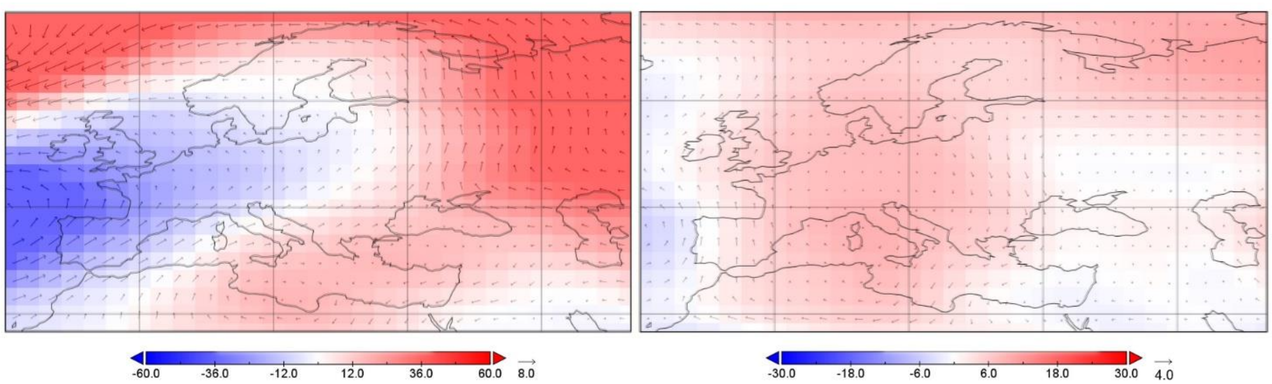

Figure 13: Geopotential height (metres; colour shading) and wind (metres / second; arrows) anomalies at 850 hPa for December 2022 (left), and for 27th January - 26th February 2023 (right). Source: NCEP/NCAR reanalysis.

Seasonal forecast

Close-to-average conditions are forecasted for most of Europe from February to April 2023. Slightly drier than average conditions (baseline 1981-2016) are predicted for western Europe (Fig. 14). A close monitoring is required for the beginning of the growing season.

[15] https://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/nao.shtml

Seasonal forecasts up to May 2023 point to likely warmer-than usual conditions in Europe, with larger positive anomalies in central-southern regions.[16] Precipitation forecasts show some variability between models, ranging from mid-drier to mid-wetter conditions. Close monitoring is required to better understand the impacts expected for the coming growing season.

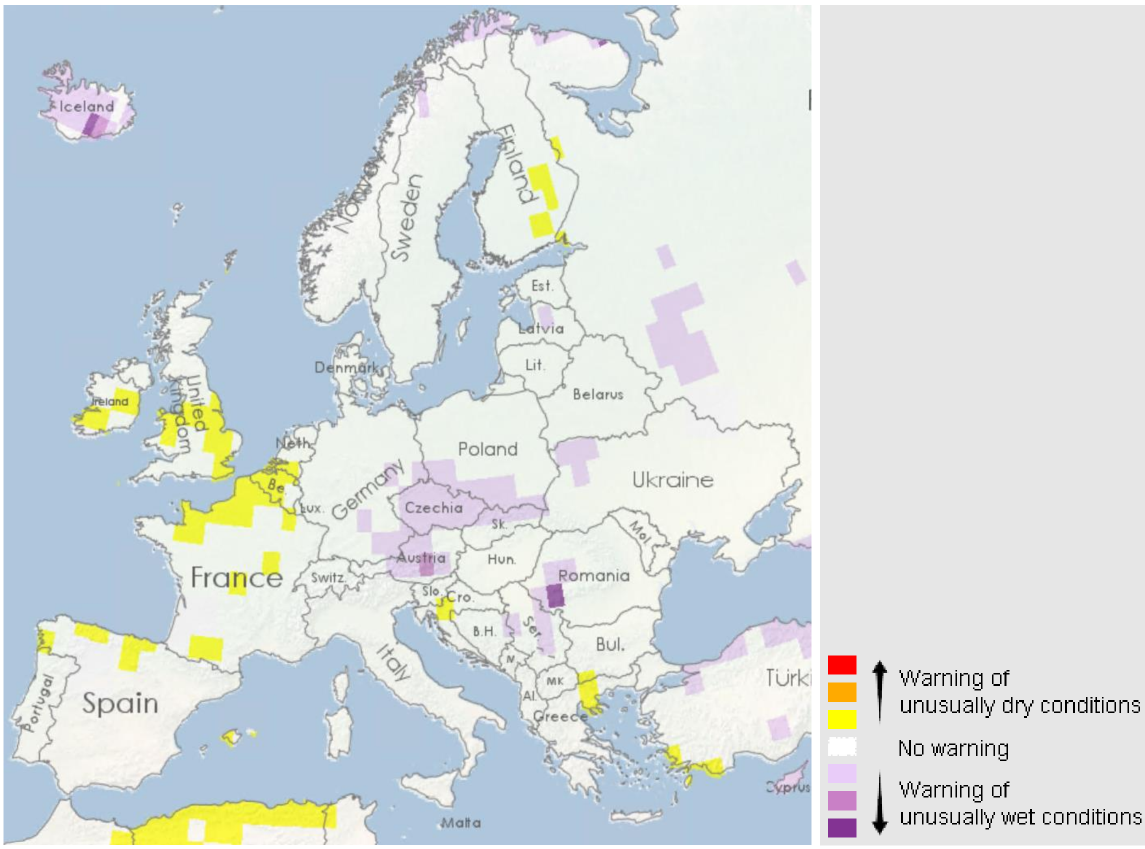

Figure 14: *Indicator for Forecasting Unusually Wet and Dry Conditions from February to April 2023 (based on ECMWF SEAS5).*[17]

[16] https://climate.copernicus.eu/seasonal-forecasts

[17] For more details on the Indicator for Forecasting Unusually Wet and Dry Conditions, and the other GDO and EDO indicators of drought-related information used in the report, see the Appendix at the end of the document.

The probability of occurrence of low flows for rivers from the end of February to beginning of April 2023 ranges from medium to high for most of Scandinavia and north-eastern Europe, and it is high for eastern France, western Germany, Switzerland, and northern Italy (Fig. 15)[18, 19].

The prolonged lack of precipitation and the forecast of a warmer-than-average spring is likely to cause a further reduction of river flows, with direct impacts on agriculture, ecosystems and energy production. Water resource management should be cautiously planned in order to limit impacts and identify adaptation strategies.

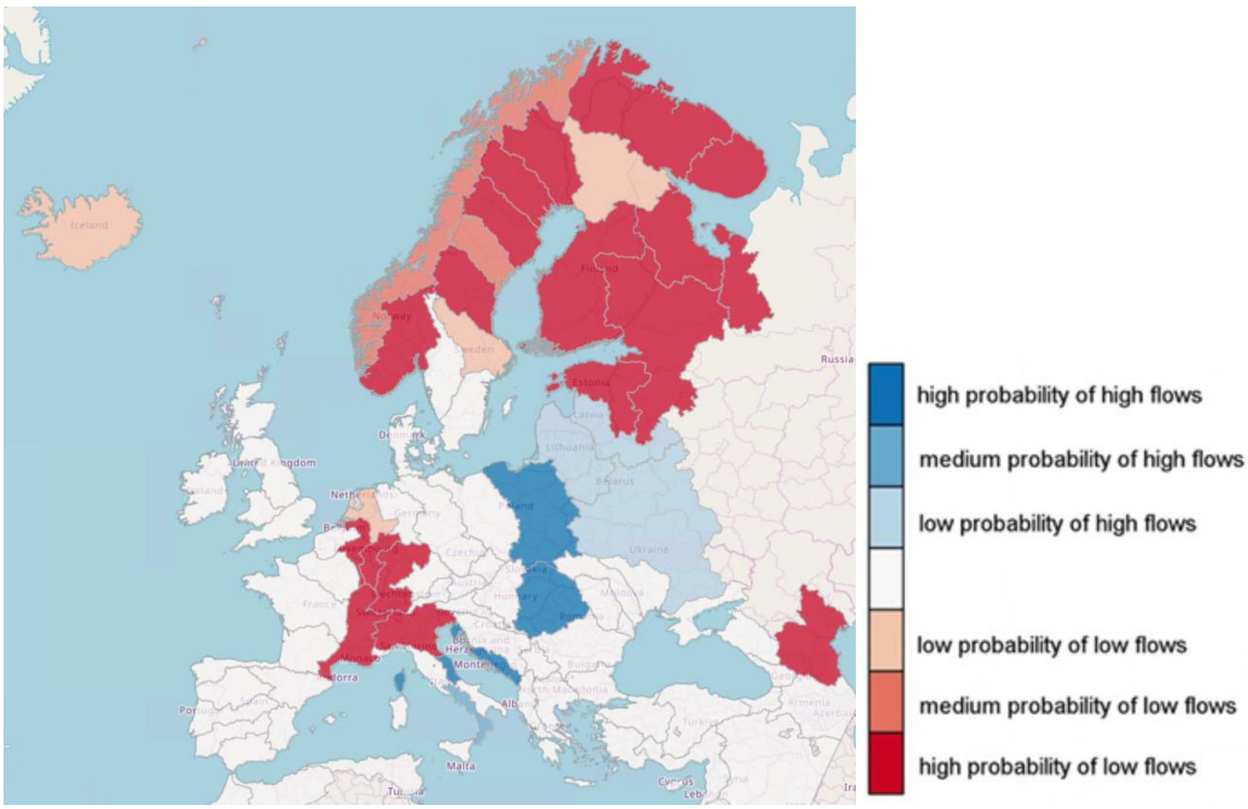

Figure 15: *Probability of occurrence of river flow anomaly for the next six weeks (end of February to beginning of April 2023), issued on 27th February 2023. The thresholds for high and low probability refer to the 90th and 10th percentiles of the simulated discharge from a 29-year model climatology run (1991 - 2019) Source: The European Flood Awareness System (EFAS) of the Copernicus Emergency Management Service:* https://www.efas.eu

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[18] The analysis is based on the LISFLOOD hydrological model outputs driven by 51 ensemble members of the ECMWF extended-range ensemble forecast. For more information on LISFLOOD: De Roo et al., 2000. Physically based river basin modelling within a GIS: the LISFLOOD model. Hydrological Processes, 14, 1981–1992.

[19] The regions displayed in Fig. 15 were created by merging several basins together, while respecting hydro-climatic boundaries: they allow to capture large-scale variability in the weather and to summarise the information contained in the forecast. The map shows the river flow anomaly for each region over the forecast horizon (46 days): red [blue] colours indicate the probability of a low [high] flow anomaly. The intensity of the colour represents the highest forecasted probability of falling below [exceeding] the low [high] threshold within the forecast horizon.

Reported impacts

The dry and warm European winter of 2023 has been affecting mainly France, Italy, and Spain. Effects of the 2022 drought event are still perceptible in early 2023 in some areas; a winter drought following a dry year implies that water buffers in the snow pack, groundwater and reservoirs are still or already low and any further precipitation and temperature anomaly may affect water availability and supply, with impacts on sectors such as agriculture, hydropower energy production.[20]

France is already reporting and acting on the exceptional winter drought. On 23rd February 2023, one month earlier than in 2022, the first hydrological planning and monitoring committee convened by the Ministry of the Environment. The committee started to define and plan for possible spring and summer water shortages.[21]

February 2023 has been the driest since 1959 in France. The complete replenishment of the Canal du Midi has been postponed until 15th March. The priority is now to ensure drinking water supply. Reservoirs are filled up to only 55% against 85% at the same time in 2022. A water sobriety plan is being developed by the Minister of Ecological Transition and is to be included in a wider “Water Plan”.[22]

The Minister of the Ecological Transition said that “soft” restrictions could be imposed, to take effect in March and avoid “catastrophic conditions” during summer.[23] He also said that “the situation is more serious than the same time last year, and we are two months behind on groundwater recharge” and up to 40% less water would be available in the coming years. By 28th February 2023, five departments have been already placed on reinforced alert on at least part of their territory[24] and water restrictions have been already imposed, with residents told to avoid watering their gardens at certain times, filling their swimming pools, or washing their cars. Moreover, farmers have been asked to cut down their water consumption by up to half.[25]

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[20] https://www.euronews.com/green/2023/02/21/in-pictures-parts-of-europe-face-risk-of-drought-after-historically-low-winter-rainfall
[21] https://www.lemonde.fr/en/environment/article/2023/02/23/exceptional-winter-drought-puts-french-authorities-on-alert_6017027_114.html
[22] https://france3-regions.francetvinfo.fr/occitanie/haute-garonne/toulouse/secheresse-la-remise-en-eau-complete-du-canal-du-midi-differee-au-15-mars-pour-economiser-la-ressource-2721874.html
[23] https://www.bbc.com/news/world-europe-64730653
[24] https://www.ecologie.gouv.fr/secheresse-economiser-leau
[25] https://www.rfi.fr/en/france/20230228-france-headed-for-water-curbs-as-dry-winter-intensifies-drought

According to BRGM (Bureau of Geological and Mining Research), the groundwater recharge is low and more than 75% of the water tables remain below the monthly average. Moreover, such levels significantly lowered since December 2021.[26]

In Italy, the observatory on water resources of the National Association of Land Reclamation, Irrigation, and Land Improvements (ANBI) reports severe drought risk for public water supply for more than 3 million people. This adds up with the risk of impacts on agriculture. The lack of precipitation is reducing river flows (ranging about from 30% to 70% less than average) and storage in the major lakes (40% to 15% of filling) in northern Italy. The water level in the Po river is lower than the historical minimum. Measured discharge in Turin is 15.7 m^3/s against an average value for the same period of more than 60 m^3/s. Near the mouth of the Po, at Pontelagoscuro (Ferrara), the discharge is close to the lower limit to counteract the advancement of the salt wedge.[27]

The latest bulletin of the Permanent Observatory on Water Use in the Hydrographic District of the Po River assesses a mid-level drought severity, registering a continuous lowering of river flow and a stable filling level for the major lakes.[28]

Because of this critical scenario, a working-meeting on water resources and related crisis is planned, involving the Ministries of Environment and Energy Security, of Transports, and of Agriculture.[29]

Rice is one of the earlier affected crops in northern Italy. First assessments of the area to be sown point to be a value that may be the lowest since 2000. In 2022, northern Italy lost about 26.000 ha of rice paddies.[30]

On 2nd March 2023 Enterisi updated its annual assessment on rice sowing. On the base of 840 rice producers representing 23% the rice cultivated area in Italy, they estimated a decrease in the 2023 rice sown area of -7421 ha, corresponding to a decrease of -3.4% compared to the previous season (which was already low, if compared to historical values).[31]

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26 https://www.brgm.fr/fr/etat-nappes-eau-souterraine-suivi-assure-brgm
27 https://www.anbi.it/art/news/7169-osservatorio-anbi-risorse-idriche-oltre-tre-milioni-di-itali
28 https://www.adbpo.it/wp-content/uploads/2023/02/01_Bollettino-Osservatorio_09feb23.pdf
29 https://www.ilsole24ore.com/art/l-anbi-35-milioni-italiani-rischiano-non-avere-l-acqua-rubinetto-AEIrUMsC
30 https://www.ansa.it/canale_terraegusto/notizie/mondo_agricolo/2023/02/24/ente-risi-con-siccita-minore-superficie-coltivata-dal-2000_34f9e7ca-8a07-429f-ae8f-ec3079189d3f.html
31 https://www.enterisi.it/servizi/notizie/notizie_fase02.aspx?ID=34455&categoriaVisualizzata=19

One of the possible solutions to adapt and mitigate the impact of drought on rice yields could be the alternating wetting and drying of the soil, supported by measuring and monitoring soil moisture, to reduce the effective water consumption of the crops.[32]

According to the water resource bulletin issued on 24th February by ARPA Lombardia, the total amount of the water resources available in February 2023 is 55.9% smaller than the 2006-2020 average with a severe reduction of the snow water equivalent (-63.4%) which represents about 2/3 of the total water storage) [33].

In terms of energy the Italian hydropower generation has been affected by the drought, especially in the northern part of the country, where most of the installed capacity is located. The stored energy in the northern Italy bidding zone at the end of February 2023 is below 900 GWh (Source: ENTSO-E Transparency Platform) corresponding to the minimum value for 2016-2023 at the same date (Fig. 16).

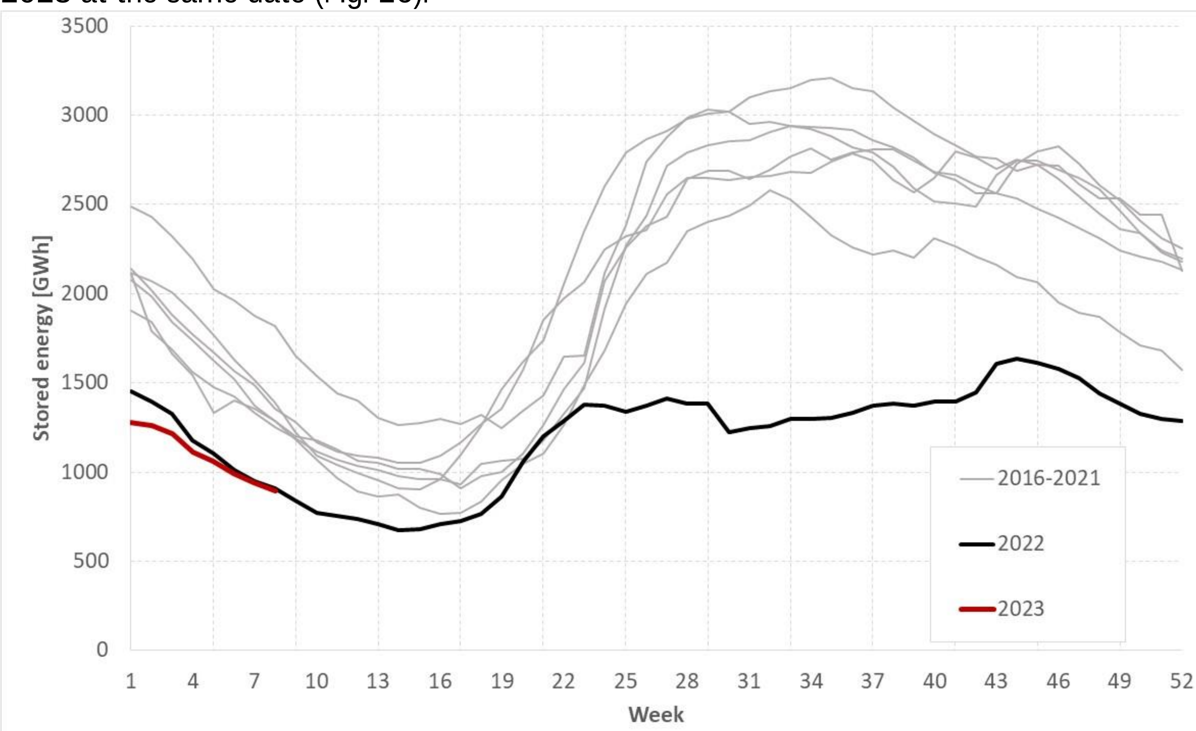

Figure 16: Hydropower storage levels in northern Italy for the period 2016-2023. Each grey line represents a specific year (2016-2021), the black line represents 2022, and the red one represents 2023. Source: ENTSO-E Transparency Platform.

[32] https://www.risoitaliano.eu/la-ricetta-dellente-risi-per-la-siccita/
[33] https://www.arpalombardia.it/Pages/Meteorologia/Osservazioni-e-Dati/Il-tempo-di-ieri/Download-Bollettini.aspx?use=storico&isel=68527

In southern and north-eastern Spain, water resource storage of reservoirs is severely reduced, ranging from 40% to below 25%. The national average is about 50% (General Directorate of Water - Ministry for the Ecological Transition and the Demographic Challenge[34]). This directly translates into a reduction of the available energy in the hydropower plants. Southern and north-eastern Spain are the most affected regions in terms of persistent drought and water scarcity according to the Ministry for the Ecological Transition and the Demographic Challenge[35]

In Barcelona and in the north-eastern region of Catalonia, water restrictions due to the lack of rain are now in place. The measures include banning the use of drinking water to wash the exterior of houses or cars, or to fill swimming pools and reducing the amount of water used for irrigation.[36]

According to data from the Guadalquivir Hydrographic Confederation, the province's reservoirs are at 19.36 % of their capacity, with a total of 642 973 cubic hectometres, while the total for the basin rises to 25.73 %.[37]

[34] https://miteco.maps.arcgis.com/apps/dashboards/912dfee767264e3884f7aea8eb1e0673
[35] https://www.miteco.gob.es/es/agua/temas/observatorio-nacional-de-la-sequia/informes-mapas-seguimiento/
[36] https://www.france24.com/en/france/20230221-france-goes-31-days-without-rainfall-unprecedented-in-winter
[37] https://www.diariocordoba.com/agricultura-medio-ambiente/2023/03/06/sequia-nivel-embalses-pantanos-cordoba-hoy-64091994.html

Appendix: GDO and EDO indicators of drought-related information

The Combined Drought Indicator (CDI) of the European Drought Observatory (EDO) is used to identify areas that may be affected by agricultural drought. The CDI is derived by combining the Standardized Precipitation Index (SPI), the Soil Moisture Index Anomaly (SMA), and the FAPAR anomaly. Areas are classified according to three primary drought classes: (1) "Watch", indicating less than normal precipitation; (2) "Warning", indicating that also soil moisture is in deficit; (3) "Alert", indicating that also vegetation shows signs of stress. Three additional classes – i.e. "Full Recovery", "Temporary Soil Moisture Recovery" and "Temporary FAPAR Recovery" – identify the stages of drought recovery processes in terms of impacts on soil moisture and vegetation.

The Standardized Precipitation Index (SPI) provides information on the intensity and duration of the precipitation deficit (or surplus). SPI is used to monitor the occurrence of drought. The lower (i.e., more negative) the SPI, the more intense is the drought. SPI can be computed for different accumulation periods: the 3-month period is often used to evaluate agricultural drought and the 12-month (or even 24-month) period for hydrological drought, when rivers fall dry and groundwater tables lower.

The Heat and Cold Wave Index (HCWI) is used to detect and monitor periods of extreme-temperature anomalies (i.e., heat and cold waves) that can have strong impacts on human activities, health and ecosystem services such as sprouting of crops. It is based on the persistence for at least three consecutive days of events with both daily minimum and maximum temperatures (T_{min} and T_{max}) above the 90th percentile daily threshold (for heat waves) or below the 10th percentile daily threshold (for cold waves). For each location, the daily threshold values for T_{min} and T_{max} are derived from a 30-year climatological baseline period (1991-2020), using the GloFAS/ERA5 derived temperature data.

Lack of precipitation induces a reduction of soil water content. The Soil Moisture Index Anomaly provides an assessment of the deviations from normal conditions of root zone water content. It is a direct measure of drought associated with the difficulty of plants in extracting water from the soil.

The satellite-based fraction of Absorbed Photosynthetically Active Radiation (fAPAR) monitors the fraction of solar energy absorbed by leaves. It is a measure of vegetation health and growth. FAPAR anomalies, and specifically negative deviations from the long-term average, are associated with negative impacts on vegetation.

The Low-Flow Index (LFI) is based on daily river water discharge simulated by the LISFLOOD hydrological model. It captures consecutive periods of unusually low streamflow. It compares the consequent water deficit during those periods with historical climatological conditions.

The Indicator for Forecasting Unusually Wet and Dry Conditions provides early risk information for Europe. The indicator is computed from forecasted SPI-1, SPI-3, and SPI-6 derived from the ECMWF seasonal forecast system SEAS5.

Check https://edo.jrc.ec.europa.eu/factsheets for more details on indicators.

Glossary of terms and acronyms

ANBI	National Association of Land Reclamation, Irrigation and Land Improvements
ASAP	Anomaly Hotspots of Agricultural Production
CDI	Combined Drought Indicator
CEMS	Copernicus Emergency Management Service
EDO	European Drought Observatory
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
ERA5	ECMWF Reanalysis v5
ERCC	European Emergency Response Coordination Centre
fAPAR	Fraction of Absorbed Photosynthetically Active Radiation
GDO	Global Drought Observatory
GloFAS	Global Flood Awareness System
GRACE	Gravity Recovery and Climate Experiment
HCWI	Heat and Cold Wave Index
JRC	Joint Research Centre
LFI	Low-Flow Index
MARS	Monitoring Agricultural Resources
SMI	Soil Moisture Index
SMA	Soil Moisture Index Anomaly
SPI	Standardized Precipitation Index
SWE	Snow Water Equivalent
TWS	Total Water Storage
VIIRS	Visible Infrared Imaging Radiometer Suite

GDO and EDO indicators versioning

The GDO and EDO indicators appear in this report with the following versions:

GDO, EDO indicator	Version
▪ **Combined Drought Indicator (CDI)**	*v.2.2.1*
▪ **fAPAR (fraction of Absorbed Photosynthetically Active Radiation) Anomaly**	*v.1.0.0*
▪ **Low-Flow Index (LFI)**	*v.2.1.0*
▪ **Soil Moisture Index Anomaly (SMA)**	*v.2.1.2*
▪ **Indicator for Forecasting Unusually Wet and Dry Conditions**	*v .1.1.0*
▪ **Standardized Precipitation Index (SPI)**	*v.1.0.0*
▪ **GRACE Total Water Storage (TWS) Anomaly**	*v.1.1.0*

Check https://edo.jrc.ec.europa.eu/download for more details on indicator versions.

Distribution

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List of Figures

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JRC Global Drought Observatory (GDO) of the Copernicus Emergency Management Service (CEMS) - 10/03/2023

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