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Droughts in Europe and Worldwide 2019-2020

Barbosa P., Masante D., Arias Muñoz C., Cammalleri C., De Jager, A., Magni D., Mazzeschi M., McCormick N., Naumann G., Spinoni, J., Vogt, J

Joint Research Centre

EUR 30719 EN

Contact information
Name: Paulo Barbosa
Address: Via Fermi 2749, 21027, Ispra (VA) Italy
Email: paulo.barbosa@ec.europa.eu

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Abstract

This report summarizes a year of drought events through the monitoring and forecasting activity of European (EDO) and Global (GDO) Drought Observatories, as part of the Copernicus Emergency Management Service (CEMS). The period of interest spans from October 2019 to September 2020, during which several drought events of relevance and other minor events or intense dry spells were observed.

Executive summary

This report summarizes a year of drought events through the monitoring and forecasting activity of European (EDO) and Global (GDO) Drought Observatories, as part of the Copernicus Emergency Management Service (CEMS). The period of interest spans from October 2019 to September 2020, during which several drought events of relevance and other minor events or intense dry spells were observed.

For the third consecutive year, unexpectedly dry conditions affected most of Europe. Central and north-western European countries faced a robust dry spell during April and May (Germany, Belgium, the Netherlands, Ireland and most of the UK, the latter two recovered by August). Earlier in the spring, drier than usual conditions were observed across central and eastern Europe as well (Austria, Croatia, Slovenia, Hungary, Serbia, Bosnia), but mostly recovered by mid-July. However, increasing soil moisture deficits appeared around the western Black Sea coast since. July was much drier than usual in France, Belgium and southern Germany. Since August, central Scandinavia and Iceland showed dry conditions too. Impacts were mild overall, with slightly reduced crop yields in central and eastern Europe, while several local authorities ordered preventive measures. River flows were lower than normal at different times in several water basins (e.g., lower Danube, Warta and tributaries of Elbe, Seine and Meuse). Water supply issues were reported for both consumption and industrial cooling In France. Groundwater levels remained lower than normal across most of the continent for the whole summer 2020.

On the southern Mediterranean coast, Algeria and Morocco experienced drought during late 2019 and early 2020. Across southern Africa, coming from long-lasting dry conditions, a suboptimal start of the rainy season 2019/20 made the situation critical over wide areas of Namibia, Angola, Zimbabwe, Zambia, South Africa, Lesotho, and southern Mozambique. Food insecurity spread mainly when drought was combined with other events, such as floods and economic downturns (Zimbabwe, Mozambique). Northern Mozambique, surroundings of Lake Malawi and western Madagascar were also affected later, in mid-2020, with half a million people facing food insecurity in Madagascar as of July 2020.

On the other side of the Atlantic, the United States of America experienced intense drought over most of its western half during 2020. Widespread drought conditions were also present in the northwest of Mexico since at least July 2020. Crops were affected to the point that government intervention was deemed necessary. During 2018 and 2019 a long-lasting drought unfolded across the “Dry corridor” of Central America, with some improvement being observed from October 2019. Still, Honduras, El Salvador, Nicaragua, and Guatemala experienced food insecurity and water supply issues. Further south, Chile faced one of its worst drought crises in history. The very wide regions of Great Chaco, Pantanal and Paraná basin (northern Argentina, Bolivia, Paraguay, Mato Grosso and Mato Grosso do Sul in Brazil) had intense dryness, with wide ranging impacts on natural ecosystems (wildfires), agriculture, transportation and power generation. As of autumn 2020 the drought persisted.

In September 2020, increasing drought conditions were present north of the Black Sea and Caucasus range (Ukraine and southern Russia). The whole Caucasus area suffered strong precipitation and soil moisture deficits since March 2020. Kazakhstan faced a few dry spells at different times and locations. In southern Asia, Sri Lanka suffered of anomalous dryness from March to May. The drought over mainland Southeast Asia continued through 2020, with multifold impacts and substantial support needed from governments. Java and southern Sumatra (Indonesia) were affected in mid 2019 and a potential of 50 million people were exposed towards the end of the year, including Jakarta, but due to abundant rainfall during 2020, severe impacts were avoided. Eastern China and parts of the Korean peninsula went through drought between May 2019 and the end of the year, long enough to cause crop losses and water supply issues.

Distribution of cumulative precipitation in the midterm highlights the regions with the most enduring rainfall deficits: central Chile and neighbouring regions of Argentina, inner and southern states of Brazil, Paraguay, spots of central America, central USA, Caucasus and southern Russia, continental south-east Asia, western Australia, north of New Zealand. Groundwater deficits worsened in south-west USA, northern Mexico, Colombia and most of Europe. Middle East, central Asia, mainland Southeast Asia and Australia retained stable dry conditions as of August 2020.

The ENSO (El Niño), closely related to intense droughts in some regions of the world, was neutral from the end of 2019 until mid-2020 and can’t be linked directly to any of the droughts of the period. Moreover, La Niña conditions developed from July 2020. Concerning temperatures, the heat exacerbates or even drives drought: above average temperatures were recorded almost everywhere in the world. Among others, western Australia suffered temperature extremes under drought conditions.

1 Main drought events worldwide October 2019 – September 2020

In this chapter, a brief description of the main drought events between late 2019 and late 2020 is provided. Information is derived from the periodical reports published on the Copernicus Emergency Management Service (CEMS) European and Global Drought Observatories (EDO, GDO[1]), focusing each on a specific drought, as well as from the monitoring activity performed for the Global Disaster Alert Coordination System (GDACS[2]). We divide the chapter into broad geographical domains: North and Central America and Caribbean, South America, Sub-Saharan Africa, Europe and Mediterranean, central Asia (including Middle East) and eastern Asia, southern and Southeast Asia, Oceania. Within each domain, the significant drought events are mentioned individually, with hints on drivers, severity and reported impacts.

Despite impacts represent perhaps the most important piece of information when reporting on natural disasters, there are no near real-time sources of information for drought impacts at global scale. Nevertheless, information is collected by GDO from governmental or other institutional sources when available, or from media news otherwise, sourced from the European Media Monitor (EMM[3]).

Since the drought events presented were reported during the year as they unfolded through more specific drought reports, this summary provides additional insight into their outcome as of September 2020. Several droughts are ongoing at the time of writing, therefore the meteorological outlook into the following three months is provided (October to December 2020), as elaborated by GDO based on ECMWF S5 ensemble forecasts (Johnson et al., 2019) and displayed in . Events of 2019 or earlier are mentioned when they were still relevant as of October 2019.

It is important to specify the operational definitions of drought that will be used through this report. Drought is a recurrent feature of the climate that results from a shortfall in precipitation over an extended period, its inadequate timing compared to the needs of the vegetation cover, or a negative water balance due to an increased potential evapo-transpiration caused by high temperatures. These conditions may be exacerbated by strong winds, atmospheric blocking patterns and antecedent conditions in soil moisture, reservoirs and aquifers, for example. If this situation leads to an unusual and temporary deficit in water availability, it is termed a drought. Droughts are to be distinguished from aridity, a permanent climatic feature, and from water scarcity, a situation where the climatologically available water resources are insufficient to satisfy long-term average water requirements.

The exact definition of a drought depends on several factors, such as the prevailing effects on the hydrological system, the economic, environmental, or social sector analysed, and the related processes and impacts. Droughts are commonly grouped into three basic types. A meteorological drought is generally defined as a period with an abnormal precipitation deficit, in relation to the long-term average conditions for a region. When a meteorological drought leads to a soil moisture deficit that limits water availability for natural vegetation and crops, the result is a soil moisture or agricultural drought. A hydrological drought is associated with the effects of periods of shortfalls of precipitation (including snowfall), on surface or sub-surface water supply (i.e., streamflow, reservoir and lake levels, and groundwater). A fourth type of drought – socioeconomic drought – is sometimes defined, when the demand for some economic goods and services (e.g., water, animal fodder, food grains, fish, hydro-electric power) exceeds supply as a result of a weather-related shortfall in water availability. Environmental drought (also known as ecological drought) is an episodic deficit in water availability that drives ecosystems beyond thresholds of vulnerability, impacts ecosystem services, and triggers feedbacks in natural and/or human systems (Crausbay et al. 2017). Drought has noticeable effects on vegetation, air, soil, fauna; it increases forest fires danger and land degradation processes, and may cause forest mortality, reduce primary production and alter biodiversity (Vicente-Serrano et al. 2020).

Due to the different types of drought, its monitoring is based on the analysis of a series of drought indicators, representing different components of the hydrological cycle (e.g., precipitation, soil moisture, reservoir levels, river flow, groundwater levels) or impacts (e.g., vegetation water stress). Usually, indicators represent statistical anomalies of the current situation with respect to the long-term climatology at a given location and time interval. As such they are a measure of the probabilistic severity of a given event.

[1] https://edo.jrc.ec.europa.eu/europe/ and https://edo.jrc.ec.europa.eu/world

[2] https://www.gdacs.org/

[3] https://emm.newsbrief.eu/

1.1 The CEMS Drought Observatories

1.1.1 Europe and Mediterranean

For the third consecutive year, unusual dry conditions affected central Europe (Figure 1). Some of the central and north-western European regions faced a robust dry spell after poor rainfall during April and May 2020 (**Germany**, **Belgium**, the **Netherlands**, **Ireland** and most of the **UK**)[4]. Earlier in the spring, drier than usual conditions were already observed across central and eastern Europe (**Austria**, **Croatia**, **Slovenia**, **Hungary**, **Serbia**, **Bosnia**) and in **Italy.** July was again much drier than usual in **France**, **Belgium** and southern **Germany** and soil moisture deficits persisted[5]. Since August, central **Scandinavia** and **Iceland** showed dry conditions too. The levels of some of the major rivers were lower than normal, particularly the lower Danube, Warta and tributaries of Elbe, which recovered later, and north-east **France** and surroundings (rivers Seine and Meuse)[6].

Ireland and the UK recovered from the dry spell by August, as well as southern Europe and the western Balkans by mid-July. Significant improvements started in France at the end of September. In mid-summer, increasing soil moisture deficits appeared and intensified around the western Black Sea coast and later extended north of the Black Sea and Caucasus range (**Ukraine** and southern **Russia**). The whole Caucasus area suffered strong precipitation and soil moisture deficits since March 2020, but there is severe lack of information on impacts.

For the rest of Europe, at the end of June 2020 impacts were mild overall, with slightly reduced crop yields in central and eastern Europe[7], while several local authorities ordered preventive measures[8] [9]. Indeed, exceptional precipitation during February in north-western Europe allowed reservoirs to fill at full capacity, and more generally mitigated against the evolution towards a full-scale agricultural or hydrological drought at the end of the spring. The recurring dryness in central Europe determined a reduction of crop yield prospects[10]. Water supply issues were reported for both consumption and industrial cooling in France[11], and forests were reported as under marked water stress[12] [13].

On the southern Mediterranean coast, **Algeria** and **Morocco** (including the Atlantic coast) experienced drought during late 2019 and early 2020. The drought impacted small farmers, herders and cereal crops in general[14] [15]. Precipitation deficit mostly recovered before the summer of 2020, but groundwaters remained strained and long-term issues of water supply loom over these regions.

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4 JRC EDO Report - Drought in Europe, June 2020. https://edo.jrc.ec.europa.eu/documents/news/EDODroughtNews202006_Europe.pdf

5 JRC EDO Report - Drought in Europe, September 2020. https://edo.jrc.ec.europa.eu/documents/news/EDODroughtNews202009_Europe.pdf

6 See section 4.4 for insights on the hydrological conditions in France.

7 JRC MARS Bulletin – Crop monitoring in Europe, Vol. 28 No. 6, 15 Jun. 2020, https://ec.europa.eu/jrc/sites/jrcsh/files/jrc-mars-bulletin-vol28-no6.pdf

8 "Sécheresse : 78 départements concernés par les mesures de restriction d'eau", Ouest-France, 18 Aug. 2020, https://www.ouest-france.fr/meteo/secheresse/secheresse-78-departements-concernes-par-les-mesures-de-restriction-d-eau-6941136

9 Power J., "Six-week hosepipe ban to come into force from Tuesday", The Irish Times, 8 Jun. 2020, https://www.irishtimes.com/news/environment/six-week-hosepipe-ban-to-come-into-force-from-tuesday-1.4273066

10 https://ec.europa.eu/jrc/sites/jrcsh/files/jrc-mars-bulletin-vol28-no8.pdf

11 Woods M., "Drought provokes shutdown of nuclear reactors in northeast France", RFI, 25 Aug. 2020, https://www.rfi.fr/en/france/20200825-drought-provokes-shutdown-nuclear-reactors-northeast-france-belgium-ardennes-chooz-meuse

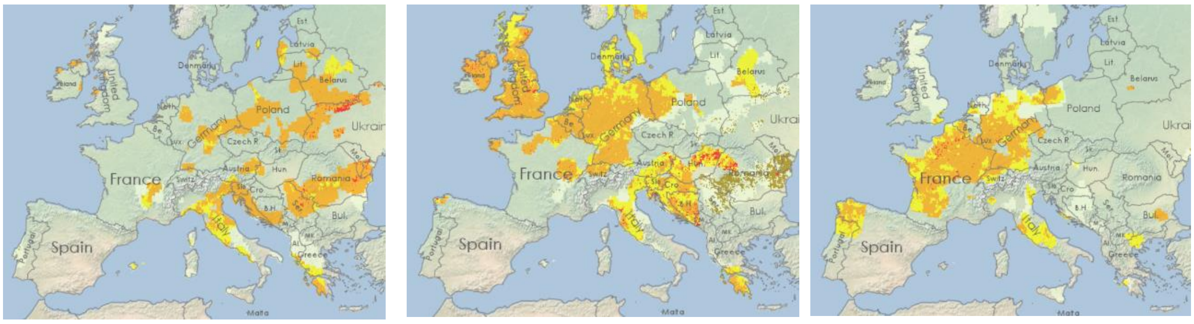
12 Kramer H., "Das Potsdamer Katharinenholz leidet unter der Trockenheit", Potsdamer Neueste Nachrichten, 15 Sep. 2020, https://www.pnn.de/potsdam/folgen-des-klimawandels-das-potsdamer-katharinenholz-leidet-unter-der-trockenheit/26181892.html

13 "Sécheresse : "Des forêts commencent à mourir" en France, alerte une hydroclimatologue", Franceinfo, 5 Sep. 2020, https://www.francetvinfo.fr/meteo/secheresse/secheresse-des-forets-commencent-a-mourir-en-france-alerte-une-hydroclimatologue_4095725.html

14 "Mauvaise campagne agricole à cause de la sécheresse au Maroc?", AgriMaroc.ma, 10 Mar. 2020, https://www.agrimaroc.ma/mauvaise-campagne-agricole-secheresse/

15 JRC MARS Bulletin – Crop monitoring in European Neighbourhood, 27 Apr. 2020 https://ec.europa.eu/jrc/sites/jrcsh/files/jrc-mars-bulletin_north_africa-april_2020.pdf

Figure 1. Combined Drought Indicator for three selected ten-days intervals through 2020. From left to right: early May, mid of June, early August.



Watch: rainfall deficit | Warning: soil moisture deficit | Alert: vegetation stress following rainfall / soil moisture deficit | Partial recovery of vegetation | Full recovery of vegetation to normal conditions

Source: European Drought Observatory.

1.1.2 Sub-Saharan Africa

Nor **Sahel** neither the **Horn of Africa** suffered from droughts between the end of 2019 and 2020, despite being very vulnerable to drought and constantly under food insecurity. Equatorial Africa had no drought events of relevance either.

Conversely, large areas of southern Africa faced drought conditions at different stages (Figure 2). Dry conditions were already present in 2018 and the rainy season of 2018/19 was poor, providing insufficient water to buffer the long dry season ahead. Consequently, drought persisted or worsened almost everywhere in the western half of southern Africa throughout 2019, as well as in Zimbabwe[16]. Moreover, a suboptimal start of the rainy season 2019/20 made the situation further difficult over wide areas of **South Africa**, **Lesotho**, **Namibia**, **Angola**, **Zimbabwe**, **Zambia** and southern **Mozambique**. Indeed, as of January 2020, some areas received only 20% of the total precipitation expected in the year, with many more at a mere 50%. Food security concerns were widespread to most of countries involved, with some open crisis where drought combined with other issues, such as floods and economic downturns (e.g., Zimbabwe, Mozambique). Crops were affected and the 2020 harvest was under expectations in both Zimbabwe and Zambia, with consequent price increase for staple food. Zimbabwe started consuming its limited grain reserve, while Zambia diverted funds to mitigate impacts. Water supply was intermittent and unsafe. Major damages to the economy of the involved countries were reported, also in relation to the low water level at the Kariba dam, threatening power supply to both Zambia and Zimbabwe[17]. As of September 2020, neither of the meteorological and humanitarian situations improved significantly, with the additional burden of COVID-19 pandemic.

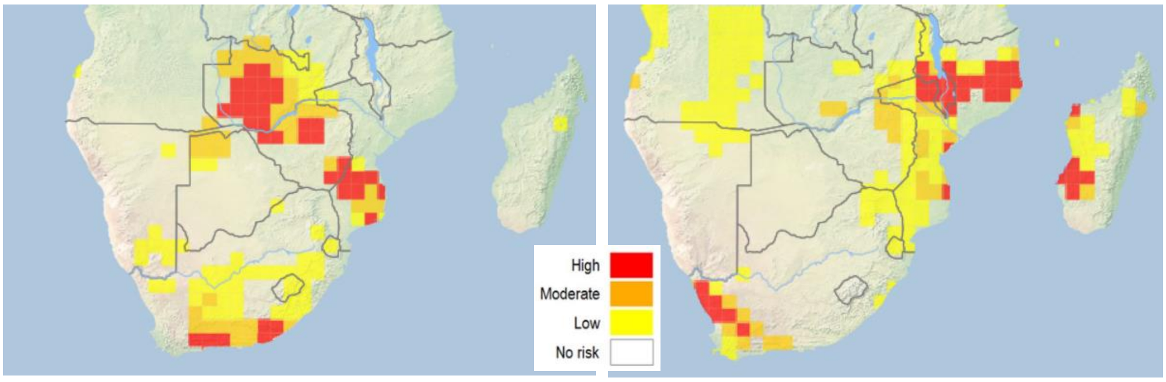
The second half of the wet season (February-April 2020) brought less rainfall than average in northern **Mozambique**, surroundings of Lake **Malawi** and western **Madagascar**. No major impacts were reported in relation to this specific event up until May 2020, mostly thanks to the late onset of the drought in crops cycle. However, mild to severe food insecurity affects endemically the countries involved, and severe natural disasters are frequent in that part of Africa. Indeed, 2019 brought one historical cyclone (Idai) and a dry spell, so even minor events may cause distress during a difficult recovery phase. Concerning southern Madagascar, 554,500 people were estimated to be severely food insecure in July 2020, with food assistance schemes fully deployed[18].

[16] JRC GDO Report - Drought in southern Africa, December 2019. https://edo.jrc.ec.europa.eu/documents/news/GDODroughtNews201912_Southern_Africa.pdf

[17] JRC GDO Report - Drought in Zimbabwe, Zambia and south Mozambique, February 2020. https://edo.jrc.ec.europa.eu/documents/news/GDODroughtNews202002_Zimbabwe_Zambia_Mozambique.pdf

[18] "Madagascar humanitarian snapshot", OCHA, BNGRC, Humanitarian partners, Ministry of Health, WHO, CCO, CHS, GEGIS, IP, 30 Jun. 2020 https://reliefweb.int/report/madagascar/madagascar-humanitarian-snapshot-june-2020

Figure 2. Risk of Drought Index for Agriculture for mid-January 2020 (left) and early June (right).



Source: Global Drought Observatory.

1.1.3 South America

During the interval October 2019 to September 2020, widespread precipitation deficits were recorded across the continent (Figure 3).

The north of **Colombia** and **Venezuela** experienced drought conditions in early 2020. Severe water supply issues were reported locally, as well as high fire hazard. Affected regions of **Colombia** mostly recovered during the wet season of mid-2020, while conditions in **Venezuela** were uncertain. Northern coasts of **Peru** suffered a dry spell between February and April 2020, which entailed low river flows and shrinking reservoirs, but no widespread and severe consequences on crops[19]. Drought affected a wide cross boundary region corresponding to central and northern Great Chaco (**Paraguay**, **Bolivia**, **Argentina**) and fringes of Pantanal (**Brazil**, **Bolivia**), between the end of 2019 and mid-2020. Both 2019 and 2020 wettest seasons were well below average. Dry conditions were recorded further east as well, between Paraguay and Paraná rivers, whose levels decreased markedly. Hydrological drought extended downstream in the lower basin. In **Brazil**, drought conditions spread further during 2020 across States of Mato Grosso, Mato Grosso do Sul and, during the third quarter of 2020, the south-east of the Country (e.g. Paraná, São Paulo). Paraguay was drier than usual all year around, despite the different rainfall pattern from east to west. Combined with high temperatures and low rainfall in the upstream river basins (e.g. Pantanal), the Country faced a drought of rare severity, which lasted for the whole of 2020. Like Paraguay, **Argentina** faced low river levels, in the north east. In general, the northern half of the country underwent a deficit of precipitation since March 2020, and temperatures were above average over the twelve-month period up to September 2020. Both conditions favoured the widespread decrease of soil moisture, a key element of hazard for agriculture. Central **Chile** was affected by one of its worst droughts on record between the end of 2019 and early 2020, following very little precipitation during 2019. Dry conditions continued well into 2020 and extended southwards, with some relief limited to June and July. More details on the drought patterns across western South America are provided in section 4.6 of this report.

Impacts were different depending on location. Mainly livestock losses in the Great Chaco; transportations and power supply issues concentrated east of Paraguay river and downstream; crops were hit in southern **Brazil**[20]. Wider than usual fires affected both Great Chaco and Pantanal since the end of 2019, with great damage to environment and ecosystems[21] [22]. High fire hazard endured into the last quarter of 2020 for all of the regions

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19 "Condiciones secas en costa y sierra norte del Perú (enero-agosto 2020)y perspectivas hasta el verano 2021", Servicio Nacional de Meteorología e Hidrología del Perú -SENAMHI, 8 Sep. 2020, https://www.senamhi.gob.pe/load/file/02662SENA-6.pdf

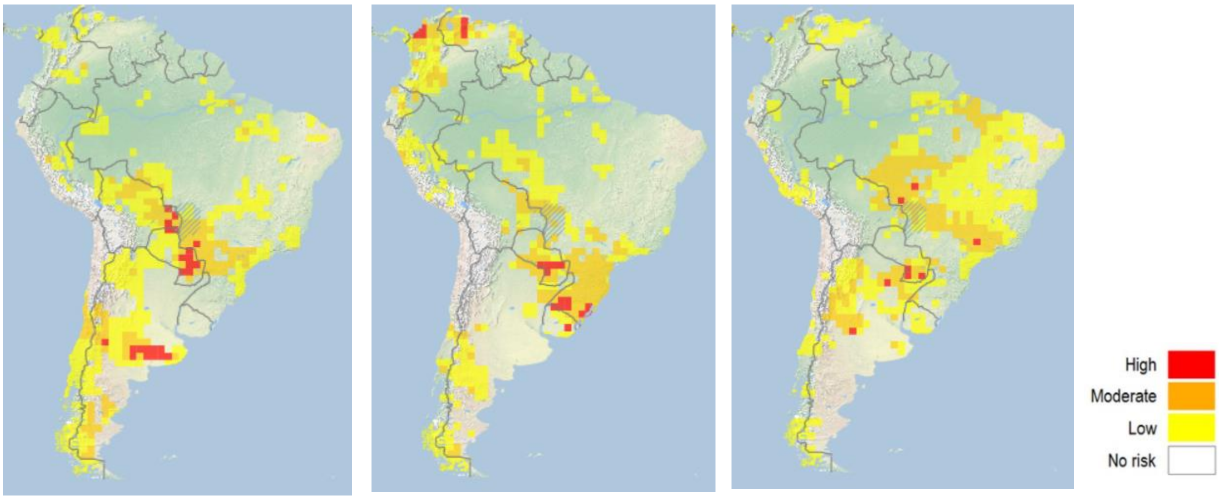
20 "Monitoramento de Secas e Impactos no Brasil - Outubro 2020", Centro Nacional de Monitoramento e Alertas de Desastres Naturais ligado (CEMADEN), 12 Nov. 2020, http://www.cemaden.gov.br/monitoramento-de-secas-e-impactos-no-brasil-outubro2020/

21 André Shalders, "Queimadas no Pantanal: multas do Ibama despencam apesar de recorde de incêndios", BBC News, 15 Sep. 2020, https://www.bbc.com/portuguese/brasil-54159499

22 Agência Brasil, "Queimadas no Pantanal e estiagem causam preocupação no MT e MS", Diario de Pernambuco, 12 Sep. 2020, https://www.diariodepernambuco.com.br/noticia/brasil/2020/09/queimadas-no-pantanal-e-estiagem-causam-preocupacao-no-mt-e-ms.html

and countries already affected. As of September 2020, the hydrological drought continued for both Paraguay and Paraná rivers, hampering supply of goods into **Paraguay**, which is highly reliant on river transportation for imports[23]. The Rosario Board of Trade (**Argentina**) estimated the aggregate value of all impacts related to low flows and depths of the Paraguay-Paraná Waterway at about 244 million USD for the first four months of 2020[24]. Chilean agriculture and water supply were hit[25], including costs for mitigation and high fire hazard, which persisted towards the end of 2020. The Country suffered already a multi-annual drought between 2010 and 2018 and hypothesis of a shift towards drier climate are brought forward (Garreaud et al., 2019). Reservoir storage remained below average as of September[26].

Figure 3. Risk of Drought Index for agriculture, for three selected ten-days intervals. From left to right: mid November 2019, late May 2020, end of September 2020.



Source: Global Drought Observatory.

1.1.4 North and Central America and Caribbean

USA experienced intense drought over most of its western half during 2020 (especially Colorado, Wyoming, Utah), with impacts to agriculture and rangelands, and high fire hazard. Poor precipitation affected North Dakota (USA), southern Saskatchewan and eastern Quebec (**Canada**) as well. In both domains, wide deficits were still present as of September 2020. Above-normal temperatures and limited moisture caused drought to expand to the foothills of Canadian Alberta.

Widespread drought conditions were observed in the northwest of **Mexico** since at least July 2020 (Figure 4). Crops were affected at a key stage of growth and feed for livestock were in jeopardy[27]. The government established mitigation measures accordingly. Earlier, the south-east of the country was hit by drought too (e.g. Veracruz), as well as the rest of Central America. The poor precipitation during summer 2019, following an already suboptimal beginning of the year, following the strong dry spell of mid-2018, determined unfavourable conditions for agriculture and local water supply issues. Compared with the beginning of 2019, later in October the drought eased or halted in the southernmost part of **Central America** (Costa Rica and Panama), while intensified northwards, as far as central Mexico. There, it lasted for some more months before regressing, past the drier months. Still, at the time food security was deemed at risk in the most vulnerable

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[23] Castedo A., "La histórica sequía del río Paraguay que tiene barcos sin poder navegar y amenaza a la economía del país", BBC News, 19 Oct. 2020, https://www.bbc.com/mundo/noticias-america-latina-54558777

[24] see section 4.5 of this Technical Report for details.

[25] Paúl F., "Megasequía en Chile: las catastróficas consecuencias de la mayor crisis del agua de los últimos 50 años", BBC News, 11 Oct. 2019, https://www.bbc.com/mundo/noticias-america-latina-49825857

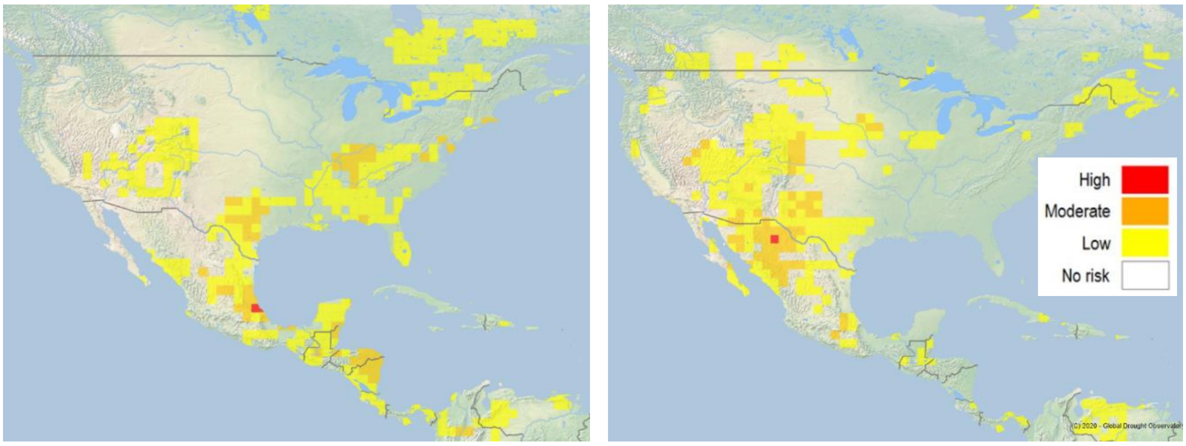
[26] Chilean Water Authority (DGA), https://www.climatedatalibrary.cl/maproom/Monitoring/Hydrological/EmbalsesDGA.html

[27] Esparza S. G., "En sequía el 79 % de los municipios de Chihuahua; piden declarar emergencia", Norte Digital, 29 Sep. 2020, https://nortedigital.mx/en-sequia-el-79-de-los-municipios-de-chihuahua-piden-declarar-emergencia/

countries of Central America[28]. **Honduras**, **El Salvador**, **Nicaragua** and **Guatemala** recovered slowly during the rainy months of mid-2020.

Most **Caribbean** islands faced some dry spells during the first half of the year, partly in relation to longer-term deficits (e.g. Dominican Republic, Haiti, eastern Cuba, Jamaica, Puerto Rico, eastern Antilles), but only local or mild impacts were reported, primarily due to the short duration of spells. As of September, none of the Caribbean islands were under drought conditions, following good rainfall in the third quarter of the 2020.

Figure 4. Risk of Drought Index for agriculture, mid October 2019 (left) and mid September 2020 (right).



Source: Global Drought Observatory.

1.1.5 Central and Eastern Asia

From the end of 2019 until September 2020 there were no major drought across Central Asia, and no relevant impacts were recorded, due in part to the sparse population. **Kazakhstan** faced dry spells at different times and locations, combined with high temperatures, mostly in the north and west. The intermittent pattern of dryness did not allow for widespread impacts to unfold, apart from reduced yield prospects for spring cereals[29] and increased risk of wildfires. The lack of precipitation and anomalous heat in parts of Siberia (**Russia**) did not yield relevant impacts on population either, but exposed forests to widespread wildfires[30].

The Middle East and eastwards countries (Iran, Afghanistan, Turkmenistan) did not experience drought during the year, whereas the arid or semiarid climates may suggest otherwise.

Most of eastern Asia received above normal precipitation in the wettest period of the year and did not carry significant deficit from the previous year. Eastern **China** and parts of the Korean Peninsula suffered drought, starting from May 2019 and until the end of the year. The drought faded away in early 2020, but lasted long enough to cause crop losses, water supply issues and low river flows[31].

1.1.6 Southern and Southeast Asia

In 2020 the Indian monsoon was at or above average and **India** did not experience any significant droughts, unlike the two previous years. **Sri Lanka** did suffer from a dry spell: starting from March 2020 about three to five hundred thousand of people faced a water supply crisis, due to lack of precipitation and sea water

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[28] "IPC Acute Food Insecurity Analysis - Honduras, November 2019 – June 2020", IPC and Technical Unit for Food and Nutritional Security Honduras (UTSAN), 1 Dec. 2020, https://reliefweb.int/sites/reliefweb.int/files/resources/IPC_Honduras_AcuteFoodSec_2019Nov2020June_English.pdf

[29] JRC MARS Bulletin – Crop monitoring European neighbourhood: Kazakhstan. Oct. 2020 https://ec.europa.eu/jrc/sites/jrcsh/files/jrc-mars-bulletin_kazakhstan-october_2020.pdf

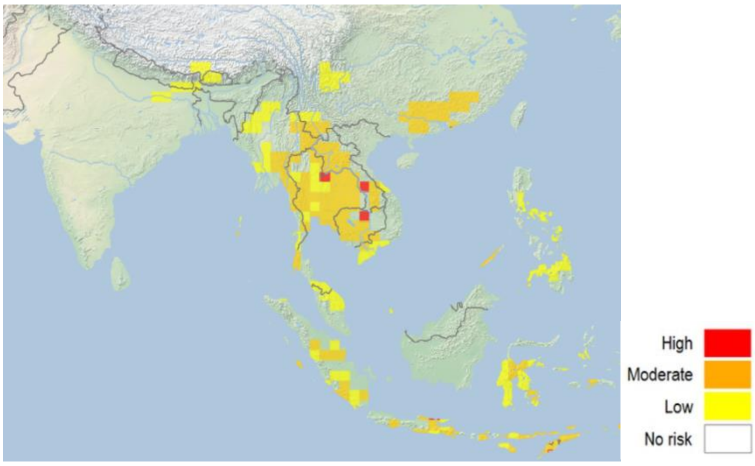
[30] Patel K., "Another Intense Summer of Fires in Siberia". Earth Observatory NASA, 6 Aug. 2020. https://earthobservatory.nasa.gov/images/147083/another-intense-summer-of-fires-in-siberia

[31] "Drought affects crops, drinking water in east China ". Xinhua, 01 Nov. 2019. http://www.xinhuanet.com/english/2019-11/01/c_138521132.htm

intrusion[32]. Despite the prolonged consequences of drought, the precipitation gap was filled from May onwards.

Continental Southeast Asia suffered drought during 2020, up until October (Figure 5). Despite a wet climate, underperforming precipitation since at least mid-2019 hampered the yearly water balance, both in terms of precipitation *per se* and downstream river flows. In March 2020, most of the Mekong river basin and neighbouring regions of the peninsula were experiencing relatively dry conditions, involving most of mainland **Thailand** and parts of **Cambodia**, **Laos** and **Vietnam**. Impacts on crops and water supply were reported, mostly in the lower Mekong basin and in relation to saline intrusion from the river delta. Tensions with upper-Mekong countries increased on allegations of water mismanagement[33]. At the time, reservoirs were lower than average for the period, but generally not critically low. Substantial support was provided by local governments. Later in the year, the drought extended north-west to **Myanmar**, after a poor start of the monsoon 2020, and strong soil moisture deficit persisted, albeit with regional variations. The rivers within the Mekong basin, and beyond, kept recording low levels for the period, and so did reservoirs. The main staple crop under stress was rice. Fisheries, power production and water supply in general were at stake too[34], so the Mekong River Commission advised all member countries to implement their drought plans in July[35].

Figure 5. Risk of Drought Index for agriculture, mid-January 2020.



Source: Global Drought Observatory.

Java and southern Sumatra (**Indonesia**) suffered from drought in mid-2019, lasting throughout the year. Periodical fires were stronger than usual and water supply issues were reported[36] [37]. Potentially, 50 million people were exposed to drought impacts, including Jakarta. Thanks to the abundant and unrelenting rainfall that was recorded since January, the deficit was filled entirely during 2020.

After a having drought in 2019, the islands of **Philippines** experienced recurring dry spells at different locations and time, with the most notable in Mindanao during early 2020, later faded. The seasonal rains of 2020 brought much less rain than expected in the northernmost areas of the Country, figuring under drought threat in September 2020. Several locations across Philippines, like many other insular countries in the world, suffer from recurrent water scarcity issues, even before accounting for drought, which may easily escalate the existing water supply problems.

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32 https://reliefweb.int/sites/reliefweb.int/files/resources/Drought_Situation_Report_on_2020__1588426512.pdf

33 Beech H., "China Limited the Mekong's Flow. Other Countries Suffered a Drought.". The New York Times, 13 Apr. 2020, https://www.nytimes.com/2020/04/13/world/asia/china-mekong-drought.html

34 Osborne Z., "The great salt drought desiccating Vietnam's Mekong Delta", Al Jazeera, 22 Apr. 2020, https://www.aljazeera.com/features/2020/4/22/the-great-salt-drought-desiccating-vietnams-mekong-delta

35 "Mekong countries urged to address low water flows", Mekong River Commission, 7 Aug 2020, http://www.mrcmekong.org/news-and-events/news/mekong-low-water-flows/

36 "Information bulletin – Indonesia: drought", International Federation of Red Cross/Crescent (IFRC) and Palang Merah Indonesia, 17 Oct. 2019, https://www.ifrc.org/docs/Appeals/19/IBIDdr171019.pdf

37 "Indonesia emerges from devastating drought", Climate Centre of IFRC, 24 Oct. 2019, https://www.climatecentre.org/news/1211/indonesia-emerges-from-devastating-drought

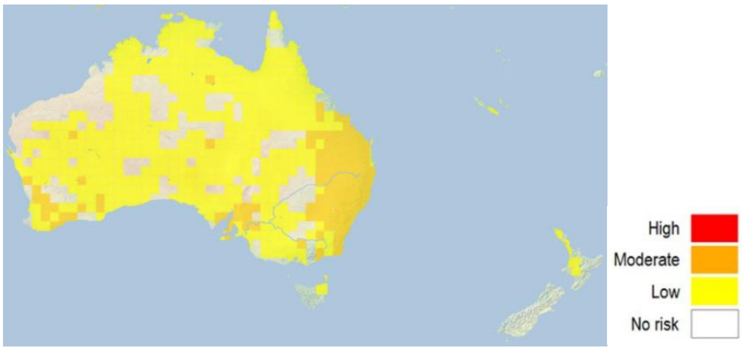
1.1.7 Oceania

The main droughts from October 2019 were observed in south-east and south-west of Australia and in the northern half of New Zealand (Figure 6). Tasmania suffered a dry spell too, towards the end of 2019.

The southern half of **Australia** faces a negative trend in precipitation, observed since around 1970, leading to more frequent and long-lasting droughts (CSIRO & BoM 2007). This entails increasing impacts and mitigation costs for communities and the Government. At the end of 2019, the wide, intense and long-lasting drought that affected south-eastern Australia since early 2017 (primarily New South Wales and southern Queensland) was still ongoing. The scant precipitation over the two years led to one of the worst droughts on record for the region. Conditions did not improve throughout 2019 and rural communities struggled to keep farming businesses viable. Government provided essential support through several assistance pathways, but the economic impact on the primary sector alone was estimated in billions of dollars and triggered big investments for mitigation[38]. Reservoir water volumes shrank to critical levels towards the end of 2019[39]. River ecosystems of the Murray-Darling basin were impacted[40], while dryness fed wide and severe bushfires. The meteorological drought across New South Wales faded away during early 2020 when short and mid-term rainfall deficits fully recovered to normal conditions. However, the longer-term deficit resulting from multi-annual drought persists.

The south-west (Western Australia) developed severe drought conditions progressively through 2020 and until September. In 2019, only the coasts were affected (e.g. Perth), much like the east of the Country, but later, as conditions on the coast improved, they worsened inland. At the beginning of 2020, reservoirs were strained, and water supply had to be delivered by trucks in several coastal towns[41]. Impacts were still unfolding on inland agriculture as the drought progressed towards the end of 2020.

Figure 6. Risk of Drought Impact for agriculture, mid of January 2020



Source: Global Drought Observatory.

New Zealand experienced a relatively short but intense drought in its northern half since February 2020, peaking in May and ranking as one of the most extreme droughts in modern times[42]. Auckland and the wider region were subject to water restrictions[43] while dam levels remained below average for the period. During the austral winter the drought eased, and soil moisture fully recovered, but in September a regression to drought was observed again.

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38 https://www.agriculture.gov.au/ag-farm-food/drought/future-drought-fund

39 Regional Monthly Drought Report, WaterNSW (Australia), 13 Dec. 2019, https://www.waternsw.com.au/__data/assets/pdf_file/0008/151892/Regional-Drought-Monthly-Report-December-2019.pdf

40 "Impact of drought on NSW river system to worsen this summer", 7news, 10 Sep. 2019, https://7news.com.au/news/nsw/impact-of-drought-on-nsw-river-system-to-worsen-this-summer-c-445804

41 Daly J., Logan T., Loney G., "Drinking water to be trucked into more than a dozen West Australian towns due to 'unprecedented' dry", ABC News, 5 Feb. 2020, https://www.abc.net.au/news/2020-02-06/wa-water-minister-warns-of-unprecedented-shortages/11934262

42 Noll B., "Auckland's drought most extreme in modern times", National Institute of Water and Atmospheric Research (NIWA), 22 May 2020, https://www.niwa.co.nz/news/aucklands-drought-most-extreme-in-modern-times

43 https://www.watercare.co.nz/Water-and-wastewater/Drought-response

1.2 Droughts on the Global Disaster Alerting Coordination System (GDACS)

GDACS is a cooperation framework between the United Nations, the European Commission and disaster managers worldwide, to improve alerts, information exchange and coordination in the first phase after major disasters.

Concerning droughts, the data supporting GDACS and its score attribution is extracted from the Global Drought Observatory (GDO) and integrated with additional information from authoritative institutions, media and scientific organizations. The purpose is to provide every ten days an overview of the droughts that are having an impact on the ground. The map of Figure 7 highlights the areas withstanding a confirmed drought for at least one month during the period from October 2019 to September 2020, including those that started earlier. Since duration is not a measure of drought severity *per se* and given the differences in coping capacity among countries, the magnitude of impacts are further specified with colors (Table 1). In most instances, a drought has only mild impacts before fading away, either due to its relatively low intensity or the sufficient coping capacity of people and assets affected.

Table 1. Description of the three main classes of drought events by impacts, from GDACS.

GDACS class ([1])	**Description**
Green	A confirmed drought, but no evidence of impacts ([2]) or mild/intermediate impacts associated to a high coping capacity. No specific action would be envisaged by international aid providers.
Orange	A drought with relevant impacts to the economy, assets or people, but not life threatening. National government provides aid in some form and official declarations of a drought/disaster are released. The drought reaches international media outlets. International humanitarian aid providers may be alerted, or international cooperation triggered.
Red	Like orange, plus very severe or life-threatening impacts to people: migrations and internal displacements, famine or starvation, violence explicitly related to water resources conflicts. International humanitarian aid is needed or has been requested/dispatched.

([1]) Sub-categories are detailed further at https://www.gdacs.org/Knowledge/models_dr.aspx

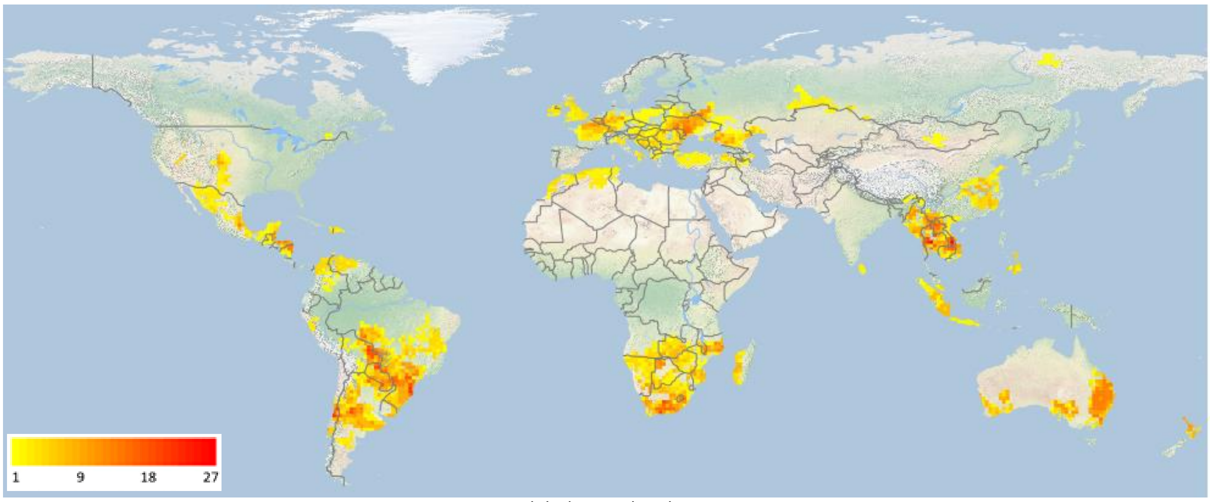
([2]) The green class is sometimes attributed also to droughts of such magnitude by duration and extension that are assumed to have at least some impacts, but there is lack of evidence.

Source: GDACS.

In total, GDO identified and monitored **40 droughts** between October 2019 and September 2020 (Figure 8), of which **1 in the red class** of utmost urgency (southern Africa), **12 in the orange class**, showing severe impacts, and **27 as green**, for those of mild or no impact (or lack of information).

The countries affected by these droughts at least to some extent were: Angola, Argentina, Australia, Belgium, Belize, Bhutan, Bolivia, Botswana, Brazil, Bulgaria, Cambodia, Canada, China, Colombia, Czech Republic, Dominican Republic, France, Germany, Guatemala, Haiti, Honduras, India, Indonesia, Iran, Iraq, Ireland, Italy, Kazakhstan, Laos, Lesotho, Luxembourg, Madagascar, Malawi, Malaysia, Mexico, Moldova, Mongolia, Morocco, Mozambique, Myanmar, Namibia, Netherlands, New Zealand, Nicaragua, Paraguay, Peru, Philippines, Poland, Romania, Russia, South Africa, Sri Lanka, Switzerland, Thailand, Turkey, Ukraine, United States, Venezuela, Vietnam, Zambia, Zimbabwe.

Figure 7. Heatmap of active droughts in GDACS during the interval October 2019 to September 2020. Unit is a ten-day interval (dekad); the colour gradient indicates the number of dekads recorded as under drought.



Source: Global Drought Observatory.

Figure 8. Map of drought events monitored by GDO for GDACS between October 2019 and September 2020.

Source: Global Disaster Alert Coordination System.

During the period considered, the longest lasting drought on GDACS affected peninsular Southeast Asia and lasted about 270 days. Still active as of September 2020, it started about two years earlier. Other long-lasting droughts were recorded, as showed by Figure 7: southern Africa, eastern Australia, southern Brazil and Paraguay, central Argentina and Chile, Ukraine and central-west Europe. A few of them were over by September 2020. The median duration of events appearing on GDACS stands at around five months, although events may not show up on the map uninterruptedly over their whole duration. The shortest event to enter the GDACS map viewer lasted 62 days (note, it is required a minimum of at least 30 days for the event to be included).

The largest area under risks linked to drought at any given time during the year comprised a wide region spanning from Argentina to Brazil and through Paraguay, affecting to some degree a surface of 560000 square kilometres, more than the size of continental France. Other wide events were in central America and south-western US, China and Australia. Europe had a few separate events that collectively may reach the top of this ranking. Median extent of events reported to GDACS is 126000 square kilometres.

Impacts of drought vary from one place to another, depending on the main economic activities, coping capacity, the amount of people and assets exposed, etc. Table 2 summarizes the most frequent proxies of impacts recorded, among those under observation. The data is structured in simple basic categories, generic enough to be transposed across regions, regardless of local specificities. As more severe and diverse the impacts become, the GDACS class rises accordingly. In the period considered, only the drought in southern

Africa reached the red alert class and indeed, most of pathways of impacts occurred there. On the contrary, during minor droughts the impacts tend to be smaller and less information is available, hence they are more difficult to assess.

Table 2. Incidence of selected impact proxies by GDACS class (green, orange, red). In brackets is the number of events for which information is unknown, out of the class total. Information are sourced from authoritative institutions, media and scientific and humanitarian organizations.

Impact proxy	**Green – 25 events**	**Orange – 14 events**	**Red – 1 event**
Crop damages	5 (13)	8 (6)	1 (0)
Food prices increase	0 (19)	3 (7)	1 (0)
Food insecurity	1 (11)	4 (4)	1 (0)
Migrations	0 (10)	1 (7)	0 (0)
Water supply issues	2 (16)	7 (7)	1 (0)
Reservoirs depleted	0 (19)	3 (8)	1 (0)
Low river flows	6 (16)	6 (8)	0 (1)
Livestock lack of feed	3 (18)	7 (6)	1 (0)
Impacts on the wider economy	0 (15)	0 (9)	1 (0)
High fire hazard	9 (13)	8 (6)	1 (0)

2 Analysis of main drivers of drought events in 2019/2020

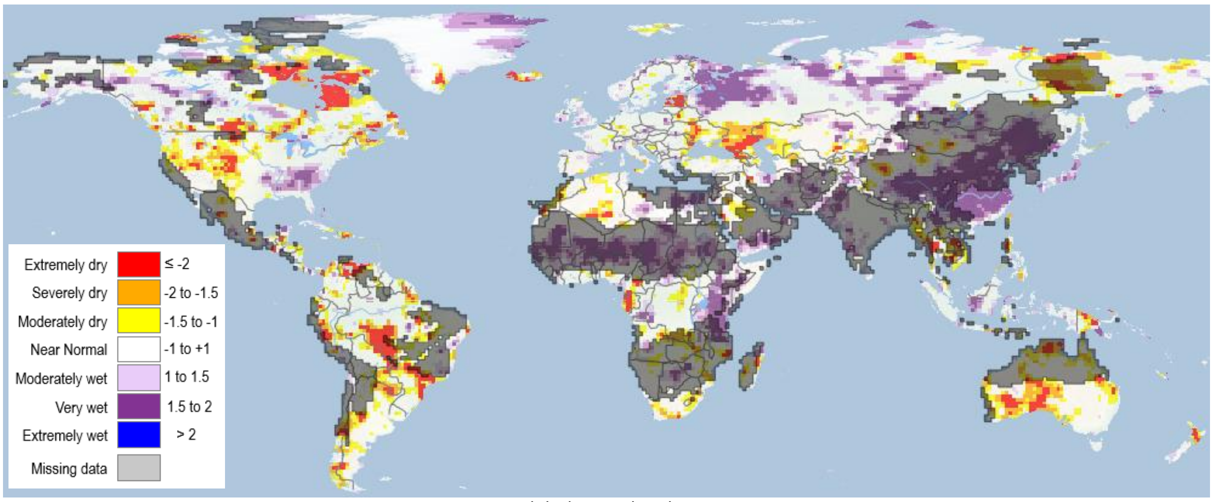
This chapter covers some of the main drivers of drought at wide scale. Beyond the lack of precipitation, factors such as climatic cycles, soil moisture and temperature play a key role in the evolution and impacts of a drought.

2.1 Anomalies of precipitation

The amount of precipitation deficit is key to determine the severity of a drought. The comparison of precipitation during a defined time interval against the long-term climatic normal provides the magnitude of deviation from normal conditions (i.e. *anomaly*). Anomalies in GDO are measured by means of the Standardised Precipitation Index (SPI), a statistical index comparing the total precipitation received at a particular location during a period of n months with the long-term precipitation distribution for the same period at that location. Precipitation data is sourced from GPCC *first guess* and *monitoring* (V6) products (Ziese et al., 2011; Schneider et al. 2018). The lower the SPI, the more intense is the drought. Each accumulation period describes a different aspect of the drought and its potential impacts. In the paragraphs below, only two SPI are considered, the first is cumulative for 12 months (SPI-12), in order to cover the full annual precipitation cycle from October 2019 to September 2020, and it is suited for climates with precipitation relatively balanced during the whole year. The second is the 6 months SPI (SPI-6), selected to focus on the core months for regions where precipitation is very unevenly distributed during the year, with a stark distinction between a wet and a dry season (e.g., monsoonal). In this chapter, the threshold to define such high seasonality is set at 50% of annual precipitation accumulated in three months or less. This threshold was selected for clarity of presentation, since it is apt to include all monsoonal regions and fits well into the six month SPI window discussed below.

Seasonality of precipitation is important in the outcome and impacts of a drought (Van Loon et al., 2014). In climates with strong rainfall imbalance during the hydrological year, like monsoonal, Mediterranean or arid climates, the failure of the rainy season entails drought conditions in the immediate aftermath and drags into deficit the whole annual precipitation balance, until the following wet season. So, regardless the vulnerability to drought, higher precipitation imbalance usually implies longer time to compensate the cumulated deficits during the wet season. Where the dry season is several months long, the meteorological drought propagates into soil moisture and hydrological drought, commonly related to impacts on agriculture and water supply.

Figure 9. Standardized precipitation index from October 2019 to September 2020 (SPI-12), as a measure of precipitation anomaly. Regions of strong rainfall seasonality (monsoonal) are greyed out and discussed separately.



Source: Global Drought Observatory.

Figure 9 shows the SPI over the twelve months from October 2019 to September 2020. North America recorded remarkable precipitation deficits in several regions. In **Canada**, southern Saskatchewan and northern Quebec had below average precipitation throughout the year, except for July and September 2020 respectively. The relatively wet summer of 2019 was barely sufficient to compensate the earlier deficits and did not benefit the following months. Bordering North Dakota, in the **USA**, shows a similar pattern. Meteorological drought conditions are present across most of the west of the Country, due to especially poor rainfall during the summer. The most affected States are Colorado (less 35% precipitation) north of Arizona, New Mexico and western Texas, Utah, Wyoming, Oregon and northern California. Wet or normal conditions persist in the eastern half of the USA.

In the Caribbean, for the third year in a row, **Haiti** and **Dominican Republic** experienced a strong deficit during the second quarter, one of the two wet trimesters of the year. Together with a poor September 2020, it brought the annual balance down to 75% of the expected long-term average.

Venezuela displays an odd precipitation pattern since May 2020, with absolute dry extremes that do not find a commensurate impact on other drought indicators. Therefore, for this specific area, the data for summer 2020 is likely underestimating actual precipitation. Strong deficits of precipitation were recorded in the very east of **Bolivia** at the Brazilian borders and across Pantanal and Mato Grosso (Brazil). The south-west of **Brazil** shows widespread negative balance of precipitation for the period considered. Rondonia, half of Mato Grosso, south of Amazonas and northern Mato Grosso do Sul, all record deficit, accumulated primarily between January and May 2020. The annual deficit continues further south, despite very different precipitation patterns: through the Chaco of western **Paraguay** and Formosa (Argentina), and through Brazilian states of Sao Paulo and Parana. In **Argentina**, mainly regions of San Luis and Mendoza accumulated rainfall deficit through the year, with no recovery as of September 2020.

Across central Africa, the overall picture is relatively positive for 2020 in terms of droughts. Indeed, only limited areas show relevant deficit. In the far south of Africa, **Eswatini** recorded 40% less rain since October 2019. **South Africa** recorded dry conditions primarily in Eastern Cape, with patchy precipitation throughout the year. Its easternmost region, north of Durban and south of Johannesburg, accumulated a marked deficit at the end of 2019, with no full recovery during 2020, despite close-to-normal conditions. Northern Cape received less than average precipitation, but the semi-arid climate and its rainfall variability prevent from classifying such dryness as an anomaly. The **Horn of Africa** (Somalia, Ethiopia) was spared by drought, as well as **Kenya** and **Tanzania**, which instead recorded much more annual precipitation than usual.

Despite widespread drought during the summer, the annual precipitation balance across Europe is neutral overall, mostly because of the compensation effect of the abundant precipitation recorded earlier in the year. A slightly negative balance is found close to the western coast of Black Sea (**Moldova**, **Romania**, **Bulgaria**) and central **Ukraine**. Further east, between the Black Sea and Caspian Sea, over **Georgia**, **Armenia**, southern **Russia** and eastern Ukraine, a strong deficit of precipitation accumulated between October 2019 and March 2020, with minor relief between May and July, and again underperforming rainfall in August and September.

In Central Asia there were no remarkable deficits over the year, apart from fringes of **Kazakhstan** and a few spots across Siberia (Russia).

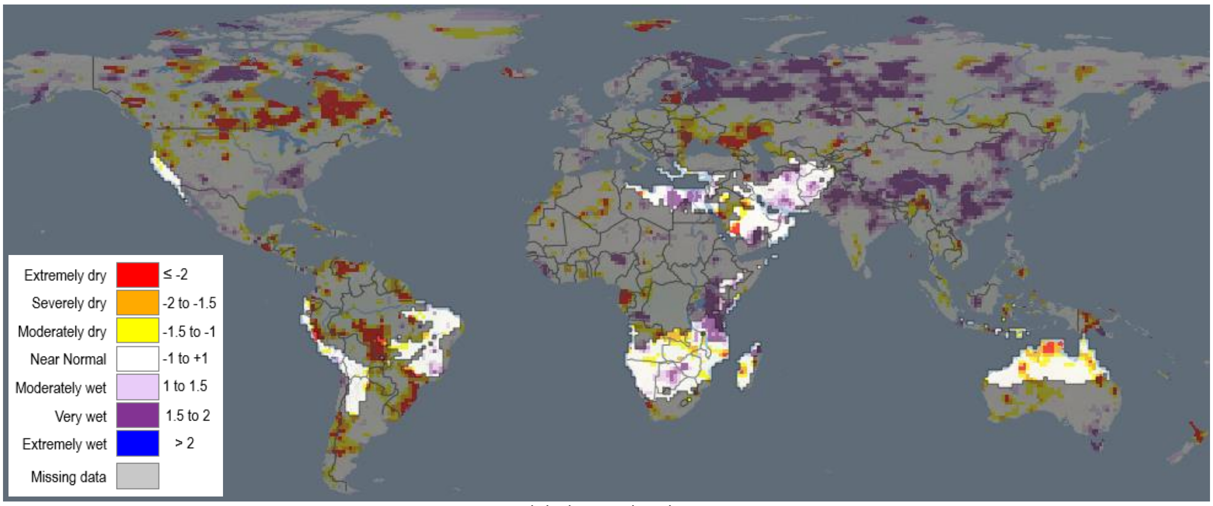
Western **Australia** suffered a marked lack of precipitation during the year. First south-eastern Australia, coming from years of drought, eventually had a normal year of precipitation, despite not sufficient to fill the gap in the longer term. Minor improvements were observed also on coasts of western Australia, whereas its inner region entered severe drought conditions that held as of September 2020. The north of **New Zealand** faced strong meteorological drought due to consistent below-average precipitation during most of 2019 and 2020.

The six months cumulative rainfall anomaly from November 2019 to April 2020 (SPI-6, Figure 10) pictures well the wettest season across southern Africa, parts of South America, Middle East, northern Australia.

In those parts of **Brazil** where rainfall seasonality is most pronounced, none were affected at the core of the rainy season, despite some intense and wide negative anomalies in neighboring regions. Only a relatively limited area of **Peru**, north of Lima, shows a severe deficit of rainfall.

In southern Africa, despite persisting deficits from previous years, the rainy season 2019/20 was within average overall, with some areas much wetter (**Botswana**, western **Zimbabwe**) and a few others drier. Specifically, a stripe running from north-east **Angola** to **Malawi** and across **Zambia** and the very south of **D.R. Congo** had a poor second half on monsoon (January to March 2020). This area extends further to the coasts of central **Mozambique**, and across the sea to western **Madagascar**. Because of the strong rainfall seasonality, all these deficits remained entirely unmitigated for the whole dry season until October 2020.

Figure 10. Standardized precipitation index from November 2019 to April 2020 (SPI-6), as a measure of precipitation anomaly. All but regions of strong rainfall seasonality in the period are greyed out.



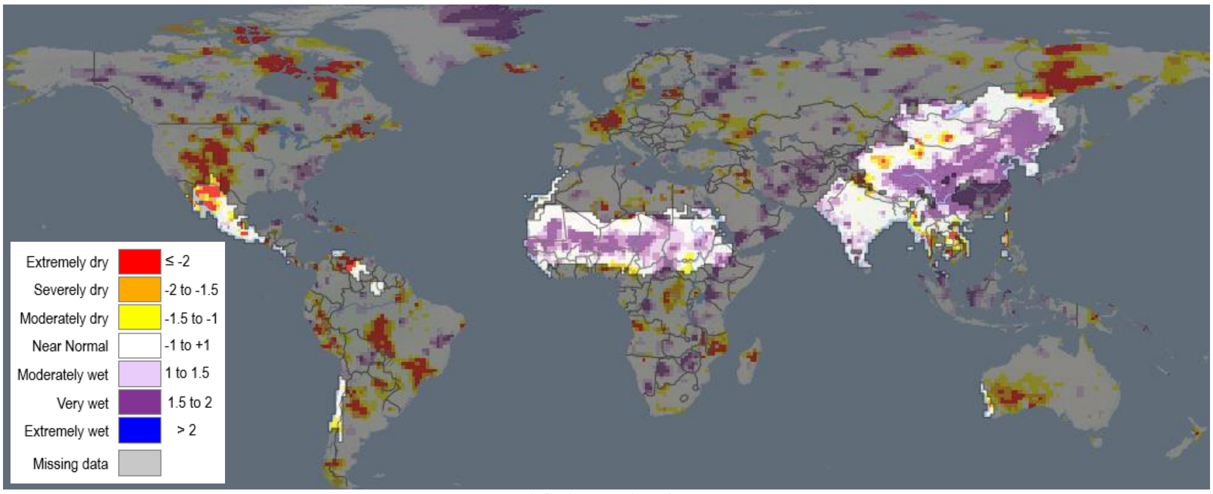
Source: Global Drought Observatory.

No special remarks concerning drought for the **eastern Mediterranean**, **Middle East** and **Iran**. In the whole region, the wettest period was normal or above average. The Arabic peninsula shows some spots of negative anomalies, but they consist of relatively small cumulative deficits over an arid region.

Between late 2019 and early 2020, northern **Australia** suffered up to 40% reduction compared to the climatic normals, with all the wettest months underperforming, and particularly November, December and following March. Considering the previous wet season, which was suboptimal too, the whole area remains under severe precipitation deficit. Northwards across the Timor Sea, between Java (**Indonesia**) and East Timor, the 2019/20 season resulted in relatively mild deficit too.

The six months cumulative rainfall anomaly from April to September 2020 (SPI-6, Figure 11) suits the wet seasons across eastern Asia, most of India, Sahel, Central America, the south-American Pacific coast, among others.

Figure 11. Standardized precipitation index from April to September 2020 (SPI-6), as a measure of precipitation anomaly. All but regions of strong rainfall seasonality in the period are greyed out.



Source: Global Drought Observatory.

In **Central America**, the north-east of **Mexico** faced marked dry conditions since August 2020, partly mitigated by the rainfall surplus cumulated previously. The rest of Mexico and the "dry corridor" southwards (El Salvador, Honduras, Nicaragua) had overall normal conditions or deficits limited to relatively small extents (e.g. parts of Oaxaca and Veracruz in Mexico, southern **Guatemala**).

Along the Pacific coast of South America, central **Chile** experienced precipitation within the lower end of the expected variability during winter (May, August, September), thus accumulating further deficit upon the extremes of winter 2019.

In Africa, countries within **Sahel** received abundant precipitation during the rainy season 2020, starting from June. Therefore, the whole region should be safe against the following long dry season.

In **India, Pakistan** and **Bangladesh**, the monsoon 2020 was within the average and brought normal to above average rainfall. On the contrary, western and southern **Myanmar** had a poor monsoon season, recording remarkable deviations from normal during three key months (May to July).

Lao, **Cambodia** and **Thailand**, where the seasonality is less marked and extends beyond September, all recorded scant precipitation, exacerbating the drought persisting since 2019. **Vietnam** wettest period is shifted towards November; nevertheless, it displays relevant deficit during the semester here under scrutiny.

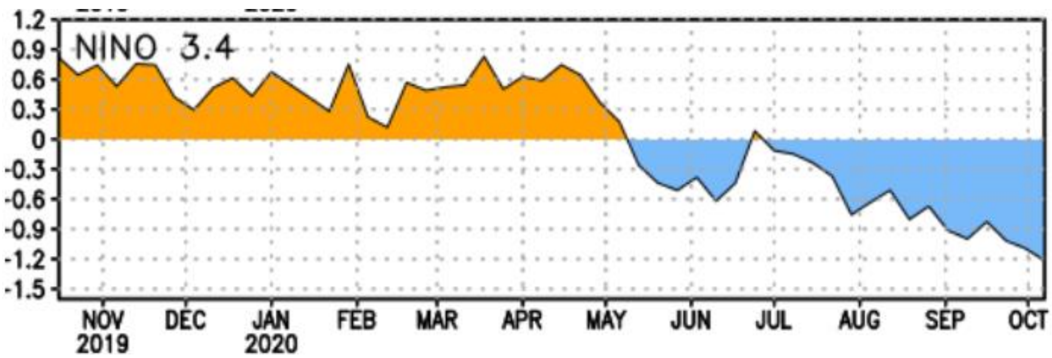
Central and eastern **China** and **North Korea** received much more precipitation than the long-term average during the wettest months of 2020 (June to September), a surplus that is likely to last into the next rainy season. Minor spots of deficit are present in **Mongolia** and north-west China.

2.2 El Niño Southern Oscillation (ENSO)

El Niño (La Niña) is a phenomenon of warm (cold) anomaly of sea surface in the equatorial Pacific Ocean. Specifically, it is defined as a five consecutive 3-month running mean of sea surface temperature (SST) anomalies in the Niño 3.4 region that is above (below) the threshold of +0.5°C (-0.5°C)44. Measured by means of the Oceanic Niño Index (ONI), the anomaly influences the atmospheric circulation and therefore the precipitation patterns in different parts of the world. El Niño is mostly known for causing or exacerbating droughts, as opposite to La Niña, despite both having the opposite effect in some regions.

After a first half of 2019 leaning towards El Niño, ENSO was already neutral in November 2019 and remained so until July/August 2020, when La Niña conditions developed (Figure 12). Such conditions are persisting through September and October and the occurrence of La Niña event is projected until February 2021 (Figure 13). Concerning droughts, none of those occurred during late 2019 and 2020 may be associated to El Niño, due to its neutrality.

Figure 12. El Niño region 3.4 sea surface temperature (SST) anomalies (C°).

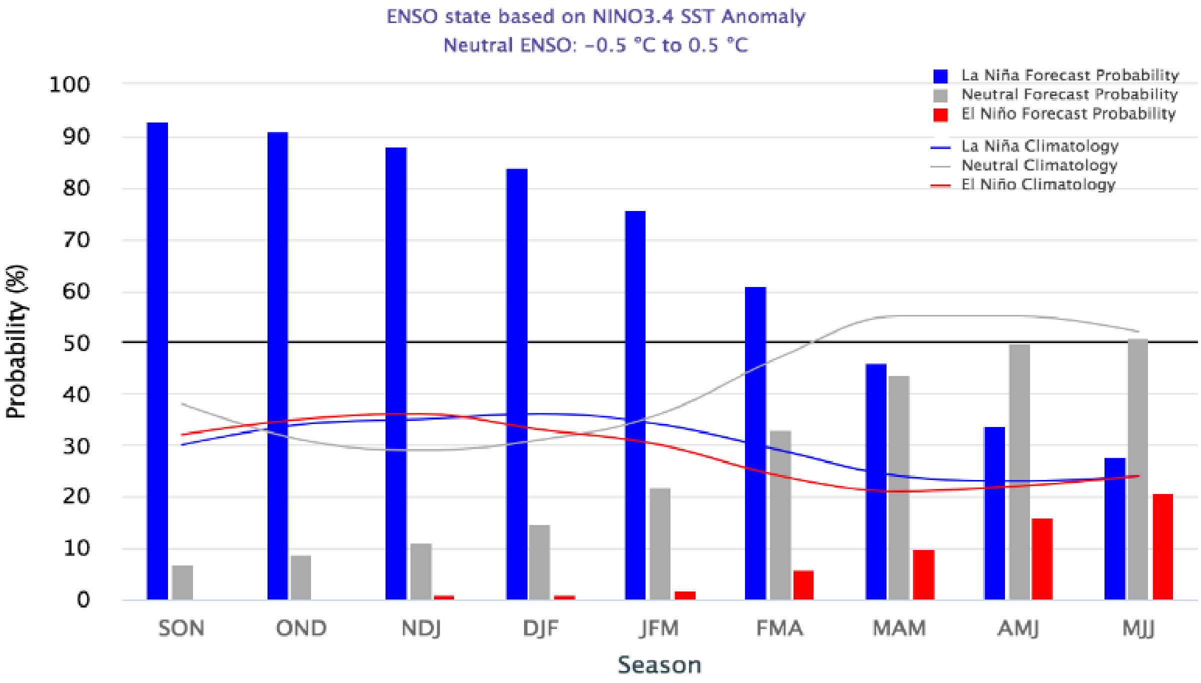


Source: NOAA

Under La Niña, more precipitation than average is expected during the summer of the southern hemisphere, over the western Pacific Ocean (Southeast Asia and Australia) and southern Africa. All these regions were affected by droughts during the last year or two. In the northern hemisphere, wetter conditions are more likely over the northern Atlantic coast of South America. Drier weather may occur in southern United States and northern Mexico, southern India and countries to the east of the Caspian Sea (Iran, Afghanistan, Turkmenistan, Uzbekistan).

44 https://www.ncdc.noaa.gov/teleconnections/enso/indicators/sst/

Figure 13. Early October 2020 CPC/IRI official probabilistic ENSO forecast.



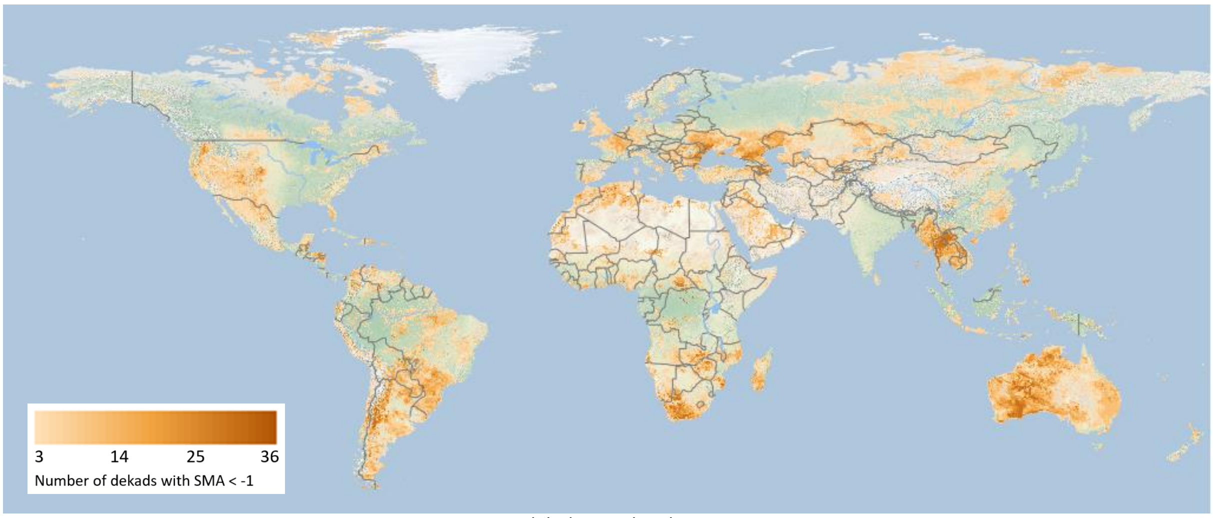
Source: NOAA

2.3 Soil moisture

Soil moisture is a major driver of drought over agricultural or other vegetated lands. In GDO, soil moisture anomaly (SMA) maps are derived from an ensemble of three products: the JRC's in-house LISFLOOD hydrological model (de Roo et al., 2000), the MODIS-derived land surface temperature (Wan and Li, 1997) and ESA combined active/passive microwave skin soil moisture (Liu et al., 2012). These products are combined to obtain a soil moisture indicator as described in Cammalleri et al. (2017a).

A summary of the SMA global dynamic in the last 12 months (October 2019 – August 2020) is obtained by mapping the number of dekads with SMA below -1, a threshold useful to isolate the most significant anomalies (Figure 14.)

Figure 14. Number of dekads with SMA < -1 in the period October 2019 – September 2020.



Source: Global Drought Observatory.

Some hot spots can be detected from the map of Figure 14. As part of an ongoing multi-annual drought, the western half of Australia experienced severely dry conditions during most of the year, with peak dryness during December 2019 and June-July 2020.

Similarly, southern Africa did not recover from the severe drought of 2018/2019, showing dry conditions at the end of 2019 and beginning of 2020, followed by stable and moderate dryness during the rest of 2020.

Extreme dry conditions were also observed during the whole period over mainland Southeast Asia, following an already dry period in the previous April-May 2019. Even if SMA remained mostly negative all along, it moved slightly towards neutrality at the end of 2020.

Several regions of Ukraine, Caucasus and western Kazakhstan show the impact on soil moisture of a sequence of dry spells since November 2019, with extreme conditions observed in March/April 2020 and at the end of July 2020 (mostly over the Caucasus range).

France, western Germany and bordering countries experienced severe SMA conditions, after a strong dry spell in the usually wet months of April and May. Even if soil moisture seemed to have partially recovered between the end of June and early July 2020, SMA were still negative overall, at the end of September.

Across Latin America, negative SMA were observed over the south of Brazil, Paraguay and northwest Argentina during October and November 2019, followed by persistent dryness throughout 2020 and no meaningful recovery. The very east of Bolivia was affected too. Andean regions and surroundings of central Chile and Argentina recorded intense and long-lasting deficits of soil moisture as well, in line with the decreasing trend of precipitation of the last few years.

Finally, in North America, most of Western US experienced severe dry conditions since June 2020, after a wet end of 2019 that provided a short relief from the previous multi-annual drought.

2.4 Groundwater

Total Water Storage (TWS), as monitored by GRACE and GRACE-FO satellites (Tapley et al., 2004), can be used to detect long-term variation in the hydrological cycle. As demonstrated in Cammalleri et al. (2019), TWS anomalies (TWSA) have good correlation with the long accumulation period of precipitation (i.e. SPI 12 months or longer), highlighting its role as proxy for groundwater drought.

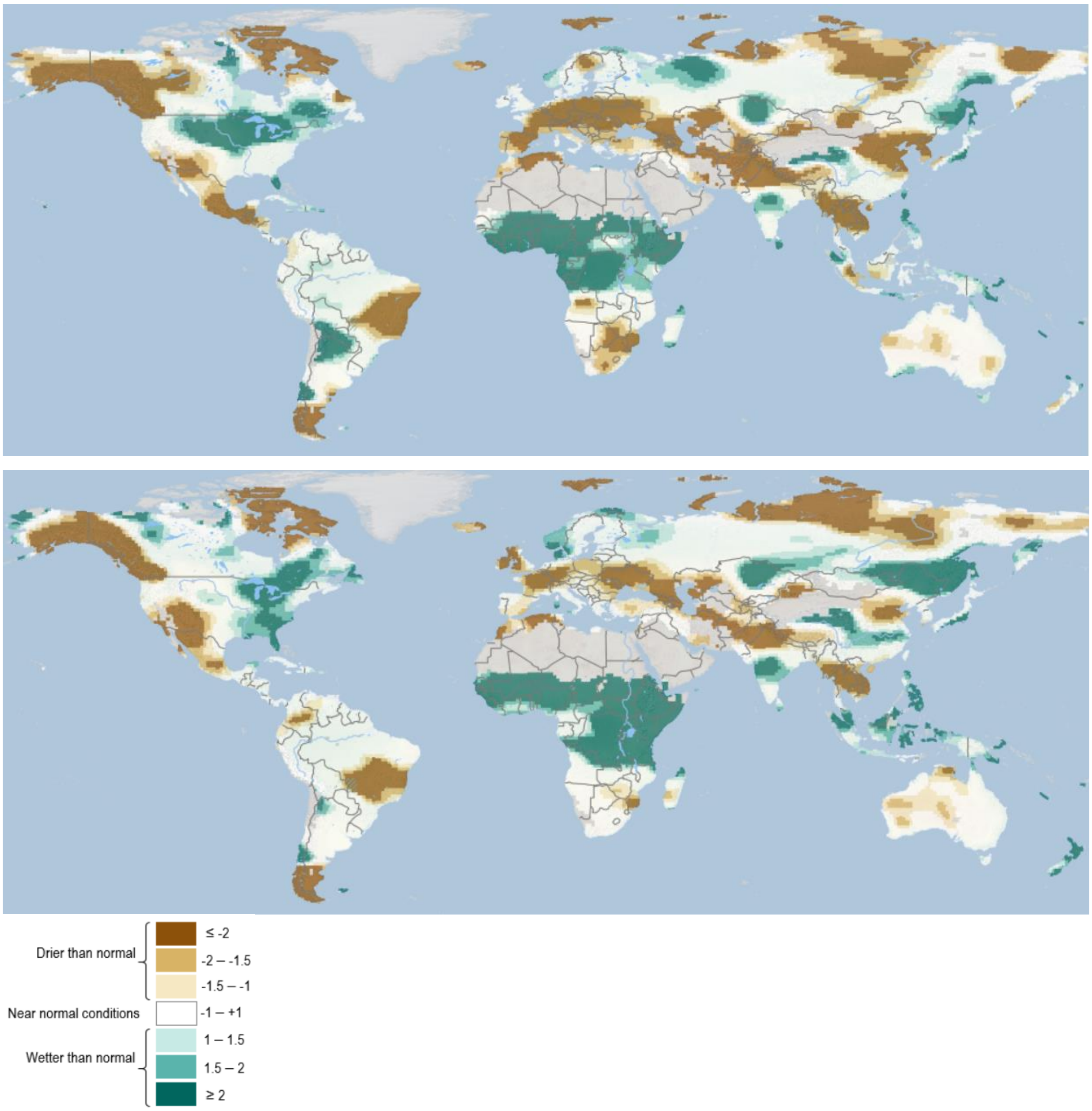
TWSA is characterized by slow temporal changes, which can be mostly detected by the differences observed between the maps at the beginning of the period (October 2019) and at the end of it (September 2020), as in the upper and lower panel respectively of Figure 15.

Among the areas under dry anomaly at the beginning of the period (TWSA < -1), the widest improvements are across southern Africa, eastern China and Korean peninsula. A recovery of soil moisture is observed in parts of western Canada, of central America, of Europe and of Central Asia. The whole archipelago of Southeast Asia moved from neutrality to wet anomaly.

Conversely, in south-western USA, northern Mexico, Colombia and Siberia, groundwater deficits worsened, despite coming from already sub-optimal conditions. Eastern Brazil, north-west of North America, mainland Southeast Asia and Australia retained stable dry conditions as of September 2020.

Some areas had significantly positive TWSA values (i.e. wetter than usual conditions) in October 2019, but moved closer to normal conditions during the year, perhaps in response to the drier conditions above ground. These include Midwest USA, north of Argentina and Paraguay, central-west Africa.

Figure 15. TWSA maps for October 2019 (upper panel) and September 2020 (lower panel). Reference: 2002-2017.



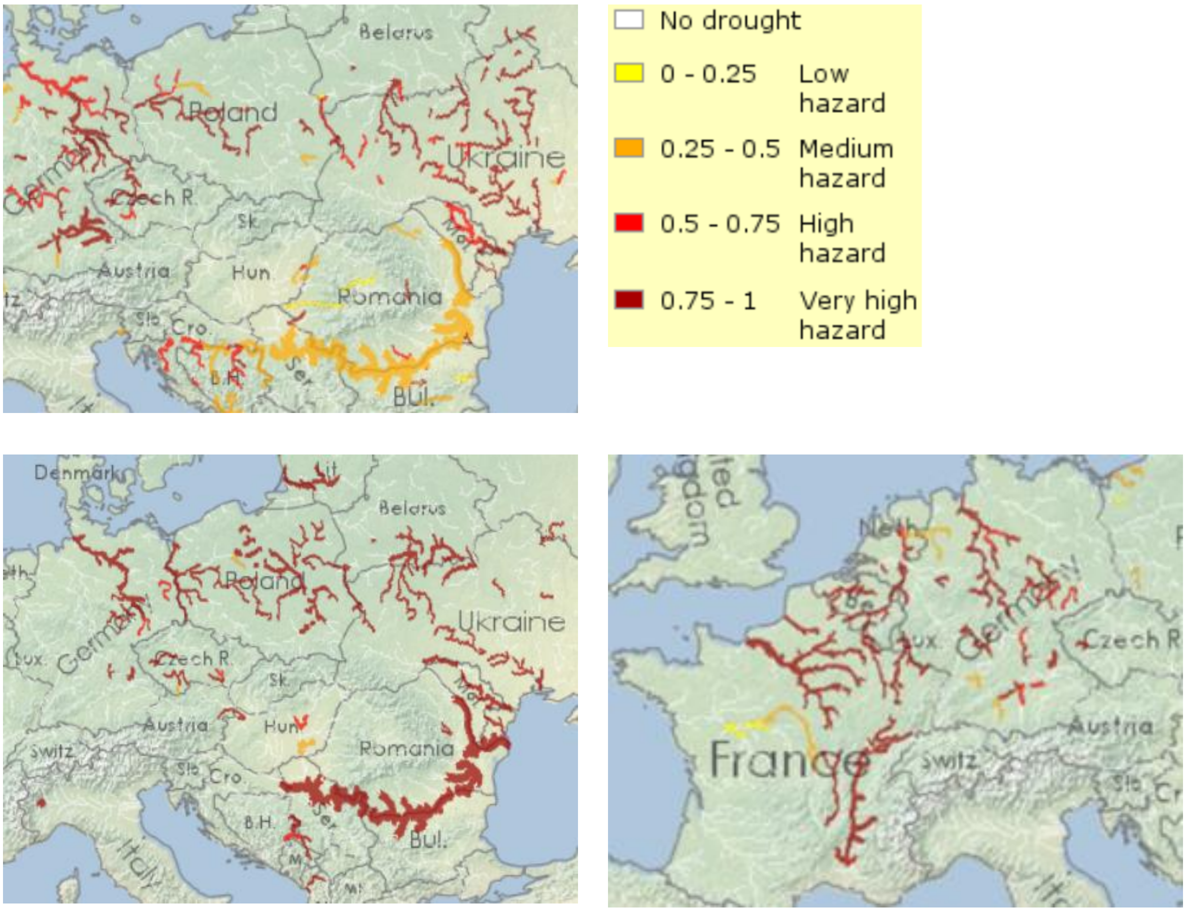
Source: Global Drought Observatory.

2.5 Hydrological highs and lows

Reduced river flow conditions are monitored over Europe as part of EDO, through the Low-Flow Index (LFI). The index is based on daily river discharge modelled by the JRC's in-house LISFLOOD hydrological model (de Roo et al., 2000) and following the threshold-based approach described in Cammalleri et al. (2017b).

The most relevant low-flow events during the 12 months considered are those observed in central and eastern Europe between November 2019 and April-May 2020. The rivers affected were, among others, the southern Bug and its major tributaries (Ukraine), Warta (Poland), Elbe (Germany), and Danube (Figure 16, upper left and lower left). The latter recovered after abundant precipitation later in the summer. At the end of July and early September, a low-flow in the main rivers of southern France was detected (Rhone and tributaries) but faded thanks to precipitation in later weeks. Mid-summer, following the expanding drought towards north-east France and across Belgium and west of Germany, the river basins of Meuse, Seine and Weser faced low flows (Figure 16, lower right). At the very east of Europe and beyond, Turkish rivers and the Caucasus were affected by persistent and strong low-flow conditions almost uninterruptedly, including the Kura river in Azerbaijan.

Figure 16.. Low-Flow Index at different times for areas interested by drought during the period October 2019 – September 2020. Top-left: late January 2020. Bottom-left: early May 2020. Bottom-right: mid-September 2020.



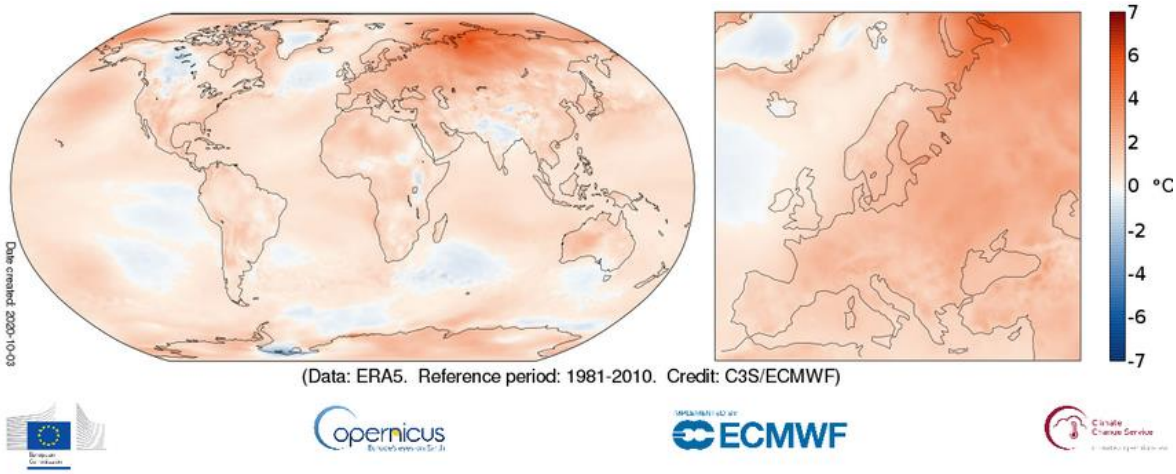
Source: European Drought Observatory, 2020.

2.6 Temperatures

In general, high temperature tends to increase the evapotranspiration rate of water from the land, while causing higher water demand for consumption. When this happens, the heat it contributes substantially to drought severity, even in the absence of relevant rainfall deficits. On the other hand, extreme cold temperatures may cause drought conditions too, due to partial freezing of water resources.

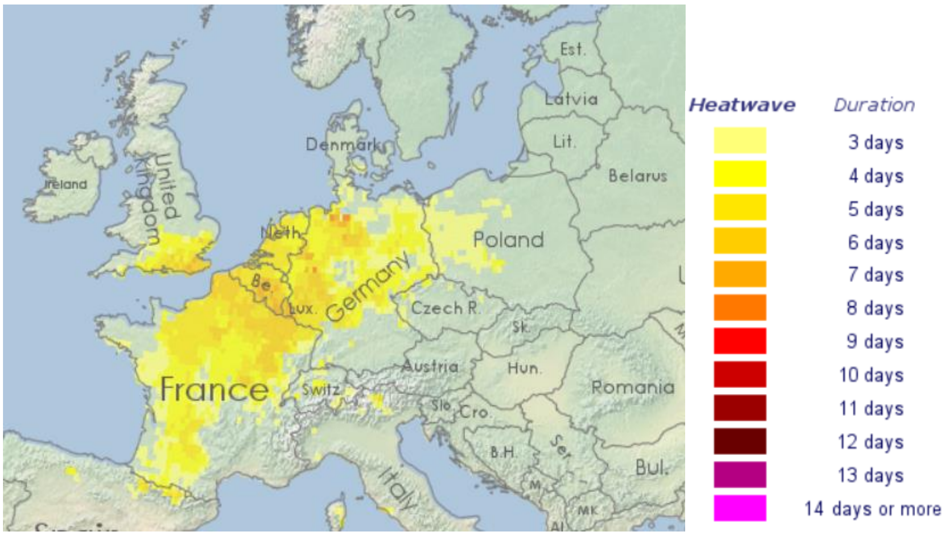
Average temperatures over the twelve-month period from October 2019 to September 2020 were above its long-term counterpart for most of the globe (Figure 17, left). The only exceptions were around inner India, western Canada and north of Lake Victoria in Africa. None of these areas experienced drought during the year. On the other hand, Siberia and the Arctic Ocean to its north recorded temperatures much above the 1981-2010 average. Western Australia was warmer than normal too, while facing drought conditions, and so did central regions of South America and south-west USA and Mexico. In Europe, temperatures were warmer than the long-term reference, particularly over France, eastern Balkans and north of the Black Sea (Figure 17, right). Nevertheless, the summer of 2020 was not marked by exceptional heat waves[45]. The ones worth mentioning occurred during mid-May in southern Balkans and central Turkey, and during the first half of August, involving Belgium, the Netherlands and most of Germany and France, as well as southern England (Figure 18). The European summer was generally above average, but not remarkably so compared with others in recent years. The heatwave played a role in exacerbating the existing rainfall deficits over central and western Europe, which indeed were facing drought in the same weeks.

Figure 17. Surface air temperature anomaly for October 2019 to September 2020 relative to the average for 1981-2010



Source: ERA5, Copernicus Climate Change Service/ECMWF.

Figure 18. Heatwave during the first half of August 2020. Yellow to red shows increasing duration in days.



Source: EDO, 2020.

[45] The Heat and Cold Wave Index (HCWI) is computed according to Lavaysse et al. (2018), based on the persistence for at least three consecutive days of events with both daily minimum and maximum temperatures (Tmin and Tmax) above the 90th percentile daily threshold (for heat waves) or below the 10th percentile daily threshold (for cold waves). The daily threshold values for Tmin and Tmax are derived from the 30-year climatological baseline period 1981-2010.

3 European and Global Drought Observatories

The European (EDO) and global (GDO) Drought Observatory became part of the Copernicus Emergency Management Service (CEMS) in January 2018. Since, they are under constant development and running in a pre-operational mode at JRC premises. Droughts are monitored through a suite of hydro-meteorological and vegetation indicators and the risk for severe drought impacts is evaluated at global level based on the dynamic natural hazard, the exposure of assets and the vulnerability of the affected societies. The map viewers are updated three times per month for a set of drought indicators, with each update valid for ten days intervals (1-10th, 11-20th, 21st-end of month). Temperature and soil moisture data in EDO are updated every day. Forecasts on precipitation and soil moisture are available as well.

During the reporting period October 2019 to September 2020, EDO and GDO systems ran without interruptions. The development of the drought observatories went ahead and new features were introduced:

- A new indicator on ground water storage: the Total Water Storage (TWS) and anomaly (standardized deviation of the GRACE satellite Liquid Water Equivalent from the baseline 2002-2017). The dataset has a monthly window and one decimal degree resolution. More detail in Cammalleri et al. (2019).
- Soil Moisture and Low Flow updated to the latest EFAS version 4.0, available on EDO website since January 2021.
- Inclusion in EDO of the Portuguese Drought Observatory SPI and PDSI layers from IPMA (Instituto Português do Mar e da Atmosfera).
- Inclusion in EDO of Rhine gauge data from ICPR (International Commission for the Protection of the Rhine).
- Neater web address to main pages of the Observatories: https://edo.jrc.ec.europa.eu/europe and https://edo.jrc.ec.europa.eu/world for EDO and GDO map viewers respectively, https://edo.jrc.ec.europa.eu/reports for reports, https://edo.jrc.ec.europa.eu/factsheets for factsheets.
- Data-download facility for selected datasets, in standard NetCDF and GeoTIFF formats.
- Improved map legends in the map viewers.
- Quicker map generation, particularly for the EDO Low-Flow Index.
- A new experimental indicator in GDO map viewer focusing on hydrological drought in protected areas under the RAMSAR wetland convention: Wetland Drought Index, plus self-generated reports on RAMSAR sites.
- Improvement of webservers' and databases' performance and security.

During the reporting period, EDO and GDO provided continuous support to the operation of the European Emergency Response Coordination Centre (ERCC), with a regular provision of maps and alerts, and detailed analytical reports on selected droughts in the world. Some of these are available on the section "Drought Reports" of the Global Drought Observatory at https://edo.jrc.ec.europa.eu/reports and a synopsis of these is also provided in this report (section 1).

Other than such activities, the Global database of meteorological drought events, previously spanning from 1951 to 2016[46], has been extended to 2019 and backwards to 1950. The new version is due for release in early 2021. During 2021, a further update to 2020 and backwards to 1921 is planned. The main improvements in the new version of such database are described in the following section, particularly the capability to evaluate the overall class of an ongoing drought compared to historical events recorded in that country or region.

[46] https://edo.jrc.ec.europa.eu/gdo/php/index.php?id=2020

3.1 Global database of meteorological drought events: updates to 2019 and 2020

The global database of meteorological drought events is part of the Global Drought Observatory since early 2018. Its data have been used by research institutions from many different countries, following the scientific paper describing the methodology behind the collection of drought events (Spinoni et al., 2019) and some derived outputs, which deal with the global drought trends of recent decades. The following table (Figure 19) lists the basic features of the current version and the two updates foreseen during 2021.

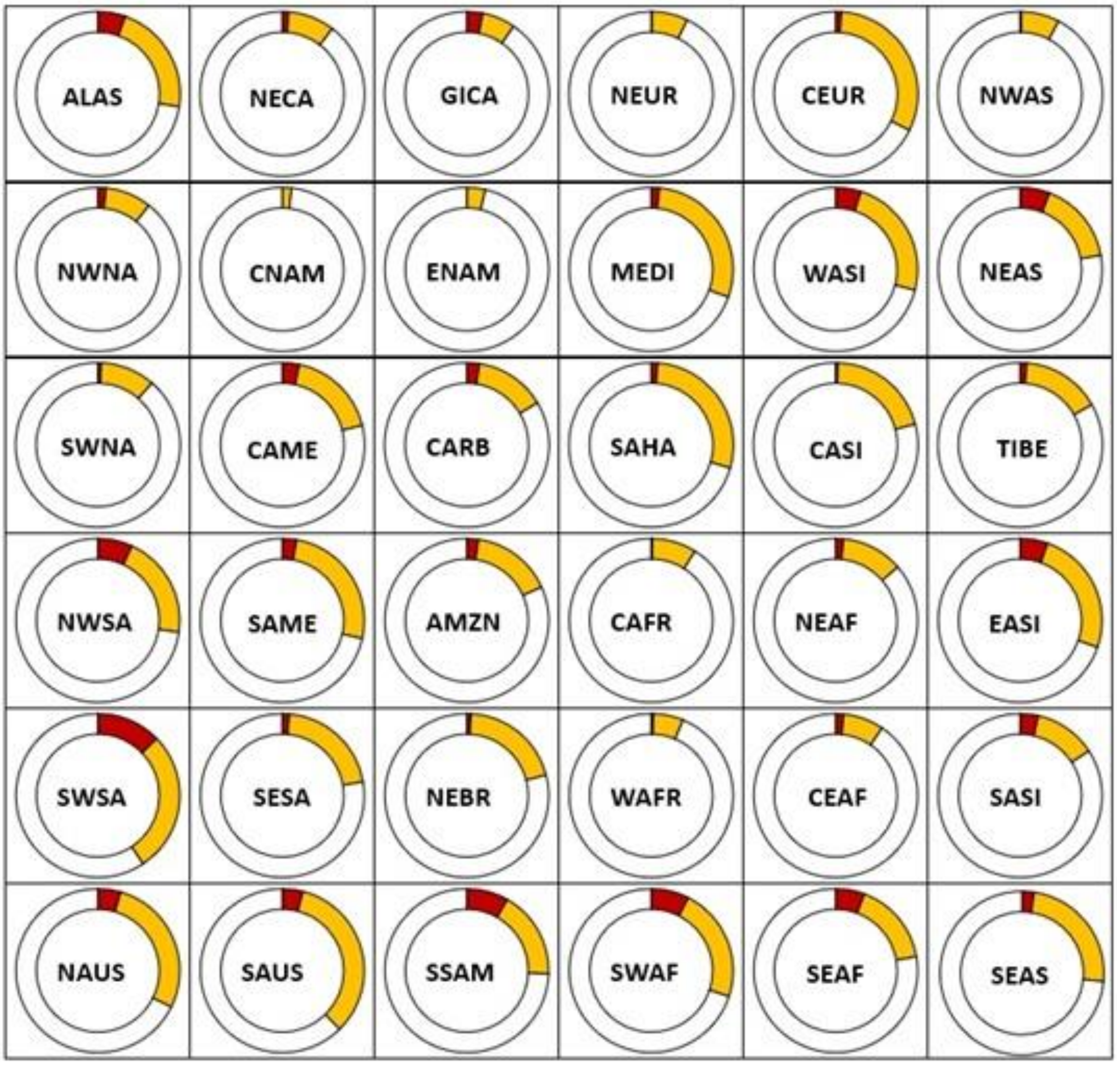
Figure 19. Main features of the three versions of the global database of meteorological droughts hosted by GDO.

	Current Version	Update (early 2021)	Further update in 2021
Time span	1951-2016	1950-2019	1921-2020
Input data	GPCC v7 (Precipitation) CRU TS v4.01 (PET)	GPCC v8 (Precipitation) CRU TS v4.04 (PET)	GPCC v8 and First Guess (Precipitation) CRU TS v4.04 (PET) ERA5 (Precipitation and PET) Berkeley Earth Climate Data (Precipitation)
Drought indicators	SPI and SPEI (3, 6, and 12)	SPI and SPEI (3 and 12)	SPI and SPEI (3 and 12)
Spatial resolution	0.5° on grid	0.5° on grid	0.25° and 0.5° on grid
Spatial aggregation	Countries and Regions	Countries, Regions (AR5), and continents	Country, Regions (AR6), and sub-regions
Number of events	4500+	7000+	?
Parameters	Duration Severity Intensity Peak Area involved	Duration Severity Intensity Peak Area involved Extremeness Area involved by extreme conditions	Duration Severity Intensity Peak Area involved Extremeness Area involved by extreme conditions Comparison with historical events during the event Progressive classification during the event
Special score	0-25 (3 classes)	0-100 (7 classes)	0-100 (7 classes)
Highlight	List of events organized per country	Biggest 250 drought events ranked	Near-real time classification of the event

As shown in Figure 19, compared to the online database of 2020, a new version of input datasets has been applied. The number of events detected is higher because more countries have been included and delineation of macro-regions was refined. For each single event, new parameters regarding the extremeness of drought have been derived. The highlight of the latest version is the new classification system (from three to seven categories), which allows to rank the biggest drought events over all countries and regions and over the entire period under investigation, thanks to rescaled parameters that allow robust comparisons between events occurring in different areas and periods. The new methodology will be thoroughly described in a scientific paper in preparation.

Using the data included in the latest version of the database, we can derive relevant statistics about the meteorological droughts of a certain year. For example, we can select an indicator (the SPEI-3 for this report) and compute the percentage of area in drought conditions (and extreme drought), at macro-regional scale (Figure 20), or the countries with the worst average drought conditions (Figure 21).

Figure 20 Fraction of area in extreme drought conditions (red), drought conditions (orange), and in normal (or wet) conditions in 2019 for thirty-six macro-regions (see Iturbide et al., 2020 for a complete list of acronyms).



Source: GDO, 2020.

For 2019, the macro-regions standing out with more than 25% of area in drought (averaged from January to December) and excluding desert areas as the Sahara, were Alaska (ALAS), the north-eastern, central, and south-western South America, Central Europe(CEUR) and the Mediterranean (MEDI), south-western Africa (SWAF), western (WASI, eastern (EASAI), and south-eastern Asia (SEAS]), and both northern (NAUS) and southern Australia (SAUS). South-western South America (SWSA) was the only macro-region with more than 10% of area in extreme drought conditions, due to very dry conditions that involved Chile during the last decade (Garreaud et al., 2018) and continued in 2019 and 2020.

According to Figure 21, Chile was ranked at the fourth place considering countries that experienced the country the most severe drought conditions over the entire year 2019. At the top of this ranking we find South Africa, that was hit by a long drought in the last few years. In 2019, according to the SPEI-3, the hotspots were central and south-western Europe in spring, southern Africa over the whole year, south-eastern pacific Asia from March onwards and pacific Oceania from September and Chile in second half of the year. As 2020 was not yet concluded at the time of writing, a short summary of meteorological drought hotspots in 2020 will be published together with the new version of the global database.

Figure 21. Countries with the lowest values of DS (i.e., highest drought severity) in 2019, the average area in drought (DA), and the average area in extreme drought (DAext) during 2019. In the last columns, the time span of meteorological drought in 2019 and its po

Continent	Country	DS	DA	DAext	WHEN	Continuing in 2020?
EUROPE	Portugal	1.0	53.7	1.4	Spring and Summer	No
	Spain	0.0	43.7	2.4	Spring and Summer	No
	Germany	0.1	41.6	0.3	Summer months	No
	Poland	0.5	32.7	2.2	Summer months	No
	Ukraine	0.3	43.6	0.8	From late Summer	Yes
	Georgia	-1.3	48.6	2.9	From late Spring	Yes
AFRICA	South Africa	-6.4	61.5	20.1	Most of the year	Yes
	Lesotho	0.8	56.9	19.4	Most of the year	Yes
	Algeria	-1.9	43.8	2.5	Second half	Yes
ASIA	Oman	0.1	39.9	14.3	Cold months	Yes
	Timor Leste	-3.4	60.4	35.4	First half	No
	Thailand	-1.7	44.1	2.5	From March	Yes
	Laos	-1.2	46.2	11.6	From March	Yes
OCEANIA	New Caledonia	-3.1	65.5	9.5	Second half	Yes
	Australia	-1.1	35.1	4.5	From September	Yes
CENTRAL AMERICA	Belize	1.0	41.7	13.5	Second half	No
SOUTH AMERICA	French Guyana	1.0	34.4	5.8	First half	No
	Colombia	0.7	27.3	5.2	Sparse months	No
	Bolivia	-0.1	33.1	4.4	Cold months	No
	Chile	-3.0	44.4	18.3	Second half	Yes

3.2 A new system to compare meteorological droughts with historical events

In the first update, we refined our special score to classify droughts at country and macro-regional scale. In the current version, a set of six parameters lead to three classes and the methodology separately applies to events derived with different drought indicators and accumulation scales. In the upcoming version, nine parameters - from a combination of two drought indicators and accumulation scales – lead to seven classes, see Figure 22 for the main differences.

Figure 22. Parameters to set the classification of drought events at country and macro-regional scales.

Parameters	Current Version	Update (early 2021)
Severity	0-5 (percentiles)	0-20 (percentiles) - Spei-12
Intensity	0-5 (percentiles)	0-10 (percentiles) - Spei-12
Area in drought	0-5 (percentage)	0-10 (percentage) - Spei-12 0-10 (percentage) - Spi-12
Top events Peak intensity	0-4 (highest in the area) 0-3 (thresholds)	
Area in drought at peak Area in extreme drought at peak	0-3 (km2)	0-5 (km2) - Spei-12 0-5 (km2) - Spei-12
Duration		0-10 (months) - Spei-3 0-10 (months) - Spi-12
Duration of extreme conditions		0-10 (months) - Spei-3 0-10 (months) - Spi-3
Classes	Moderate (0-7) Severe (8-11) Exceptonal (12-25)	Dry conditions (0-15) Mild (16-23) Moderate (24-30) Severe (31-40) Very Severe (41-53) Extraordinary (54-58) Exceptional (59-100)

According to the new classification system, at macro-regional scale (Figure 23), a few drought events taking place in 2019 continued in 2020: above all, we highlight "extraordinary" droughts in Alaska (AND, 2019), in south-western and southern South America, and "very severe" droughts in central Europe, south-western Africa, western Asia, and southern Australia.

Figure 23. List of macro-regional droughts in 2019 following the new classification system.

Macro-Region	SCORE	Continuig from 2018?	Continuing in 2020?
Alaska	Extraordinary	Yes	Yes
Caribbean	Dry	No	No
NW South America	Severe	Yes	Yes
C South America	Mild	No	Yes
SW South America	Extraordinary	Yes	Yes
S South America	Extraordinary	Yes	Yes
SE South America	Moderate	Yes	No
N Europe	Mild	Yes	No
C Europe	Very Severe	Yes	Yes
Mediterranean	Mild	No	Yes
SW Africa	Very Severe	Yes	Yes
W Asia	Very Severe	Yes	Yes
C Asia	Moderate	Yes	No
NE Asia	Moderate	No	Yes
E Asia	Mild	No	Yes
S Asia	Moderate	Yes	No
SE Asia	Moderate	No	Yes
N Australia	Severe	No	Yes
S Australia	Very Severe	Yes	Yes

With the new classification system, all closed meteorological droughts can be compared with historical events in the corresponding country or region. With the further update at the end of 2021 an algorithm will evaluate, month by month and during the event, the class of such drought versus the historical events in that area, improving the delineation of the area involved.

This new approach will derive the drought class from some of the parameters shown in Figure 22, together with others to fit a dynamic spatial evolution of the drought. Thus, a drought event will not be only assigned to a specific country or region, but to a more accurate geographical domain. This new functionality will require timely input precipitation and temperature data at medium-high spatial resolution, posing a main challenge in terms of data availability for the near real-time evaluation of natural disasters.

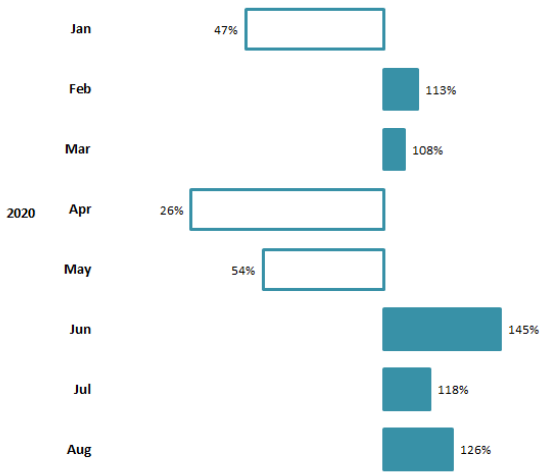
4 Drought case studies by partners in Europe and South America

4.1 The Complex Agricultural Risk Management System (Hungary)

Author: Mónika Lakatos[47]

Drought is a complex natural disaster, which regularly hits the territory of Hungary and causes losses mainly to agriculture. Precipitation decreased in Hungary since the beginning of the last century and due to climate change, especially in spring and autumn. Monthly rainfall was characterized by high variability in the recent decades. 2020 started with a very dry January, the 14th driest since 1901. The countrywide average of precipitation was 15.5 mm, less than half of the normal of 1981-2010 (Figure 24). February was very warm, the third warmest on record, with +4.8°C above the normal and slightly above normal precipitation, as in March.

Figure 24. Monthly precipitation anomalies in percentage, compared to the 1981-2020 normal period between January and August in 2020, in Hungary.

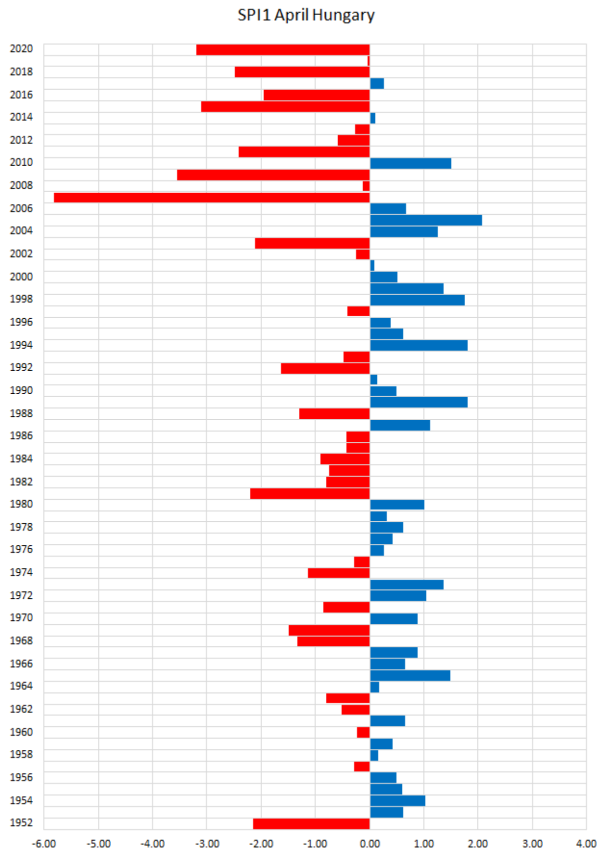


Source: Mónika Lakatos, 2020.

A drought started to develop from mid-March and got severe by the end of April. The monthly precipitation was 11.57 mm in April, that is 26% of the normal. This was the fourth driest April (1. 2007; 2. 1946; 3. 1939) since 1901. The upper 20 cm layer of the soil became extremely dry everywhere in the country, while the upper 50 cm dried up to critical level. The little precipitation of May fell unevenly in the country and evaporated rapidly, lessening the drought only in limited regions of Hungary. The country-wide average of SPI1 in April 2020 was -3.19, which is the third lowest value since 1952 (Figure 25). The SPI2 for April and May 2020 indicated extreme drought in wider regions (Figure 26).

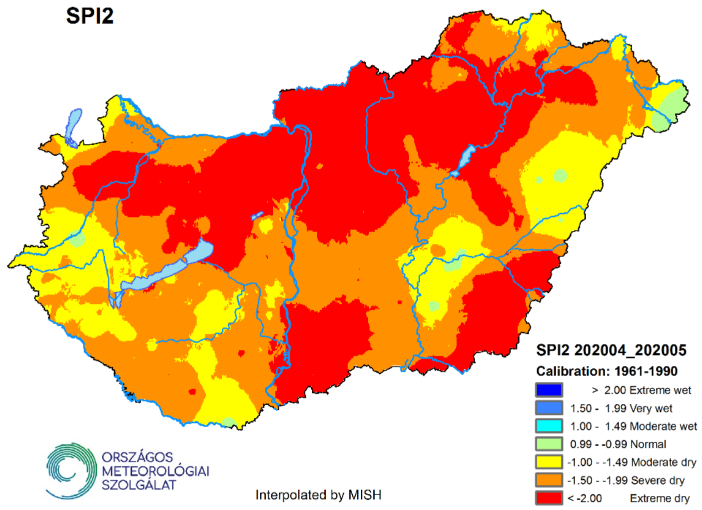
Figure 25 SPI1 series for April in the period 1952-2020 in Hungary.

[47] Éghajlati Osztály, Országos Meteorológiai Szolgálat. 1024 Budapest, Kitaibel Pál u. 1.



Source: Mónika Lakatos, 2020.

Figure 26 The spatial distribution of drought illustrated by SPI2 for May in 2020 in Hungary.



Source: ORSZAGOS, MISH. 2020.

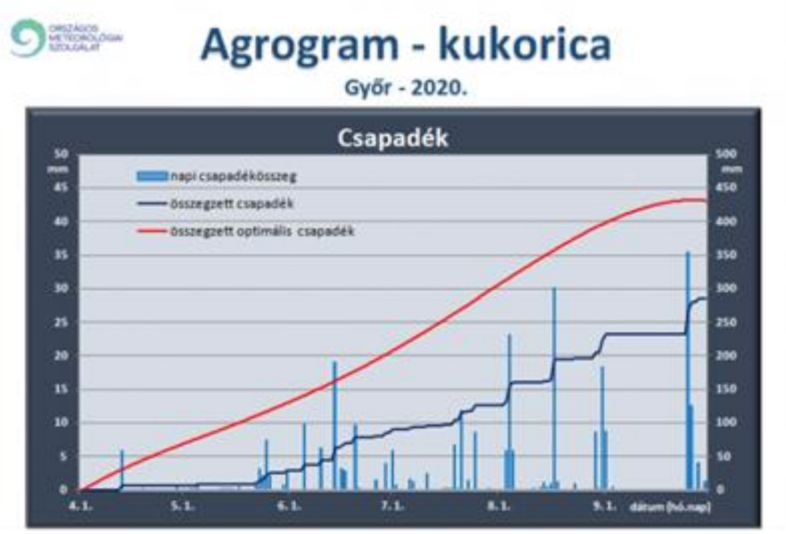
The minister of Agriculture and the Minister of Interior announced a "prolonged water scarcity period" from middle of April. Consequently, the farmers had preferential access to water for irrigation or without any payment. A total of 6307 requests were submitted into the Complex Agricultural Risk Management System as of 15th October 2020, corresponding to more than 3 million hectares. The risk management system has been operating since 2011 to reduce crop losses for farmers (see below). In 2020, the highest percentage of agricultural losses was caused by drought, as usual amongst the other weather hazards like frost or hail. In addition to drought damages, the late spring frost caused serious losses for fruit crops (82.000 hectares). Overall, approximately 4 million hectares of crops were hit by weather-related damages in Hungary between January and October 2020.

The Complex Agricultural Risk Management System in Hungary

In Hungary a complex system for mitigating agricultural damages was launched in 2011 by the agricultural administration. Risks handled by the system are agricultural damages in the production caused by winter frost, spring frost, autumn frost, drought, inland water, downpours, storms, hail and floods. Recipients are farmers whose agricultural land reaches 1 hectare in the case of plantations, 5 hectares in the case of vegetable cultivation and 10 hectares in the case of other arable land usage.

The Hungarian Meteorological Service support said System by providing information about the occurrence of frost, drought, downpours and storms in the country. Daily data measured at meteorological stations are interpolated to a 0.05° decimal degrees dense grid. In case of precipitation, radar data are also used. Each grid point is associated to human settlements. The farmers can check the meteorological hazards on their location through this free service accessible at the webpage: agro.met.hu (e.g. Figure 27).

Figure 27 Agrogram for maize for Győr (located at northwest in Hungary) from April to September 2020. The red curves represent the cumulated optimal amount of precipitation, the blue curve represents the actual accumulated precipitation and the blue shaded shows the daily precipitation sum.



Source: ORSZAGOS, 2020.

4.2 Drought in mainland Portugal during the hydrological year 2019/20

Author: Vanda Cabrinha Pires[48]

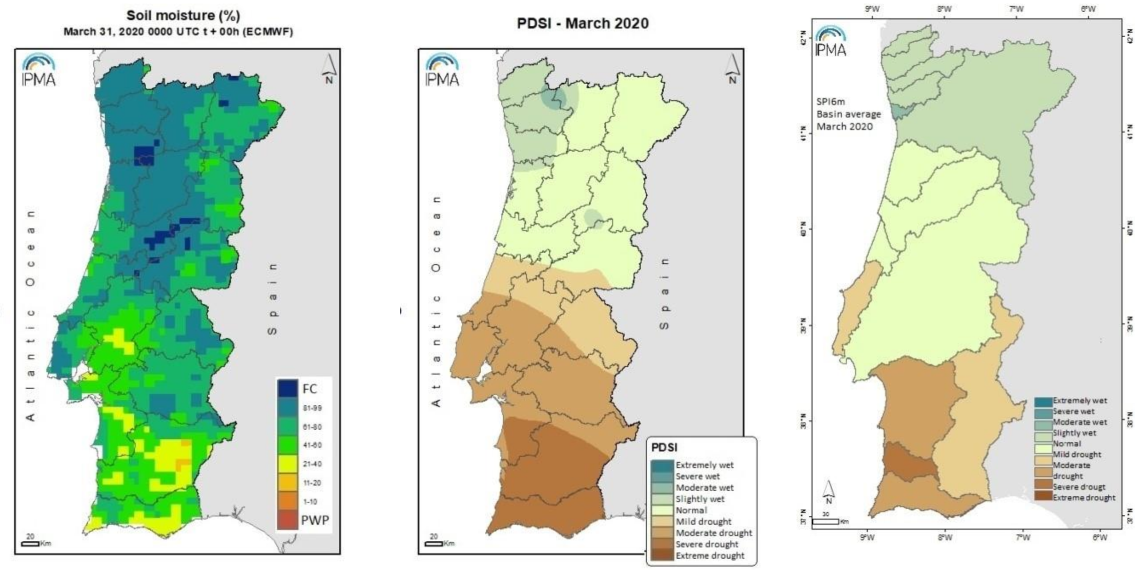
Period from October 2019 to March 2020 – Rainy period

At the beginning of the hydrological year (October 2019), the whole of mainland Portugal was under meteorological drought. In the following months, due to precipitation above the mean in November and December, drought decreased gradually in extent and intensity. By the end of the wettest period (March 2020) the northern and central regions were no longer under drought (Figure 28b) and soil moisture recovered well (Figure 28a). However, the southern regions remained under moderate to severe drought, according to PDSI index (Figure 28b). The SPI-6 shows a drought situation in the southern hydrological basins of Portugal over six months, from mild intensity in Guadiana basin to severe in Mira basin (Figure 28c).

[48] Instituto Português do Mar e da Atmosfera, I.P. (Portuguese Sea and Atmosphere Institute, I.P.) - Divisão de Clima e Alterações Climáticas (DivCA). Rua C ao Aeroporto, 1749-077 Lisboa (Portugal).

Figure 28 Soil moisture, PDSI, and SPI6 maps in March 2020

a **b** **c**



Source: PMA, 2020.

Period from April to September 2020 – Dry period

At the beginning of the dry season in April and May 2020, the abundant precipitation in the southern regions, well above normal, induced a gradual reduction of extent and intensity of the meteorological drought. However, dry conditions on the ground persisted during the months of June to September 2020, due to the high temperatures and dry summer weather. Indeed, the heat of July, August and the first 15 days of September contributed substantially to the dryness of the soil, leading to a slight increase in area and intensity of the drought.

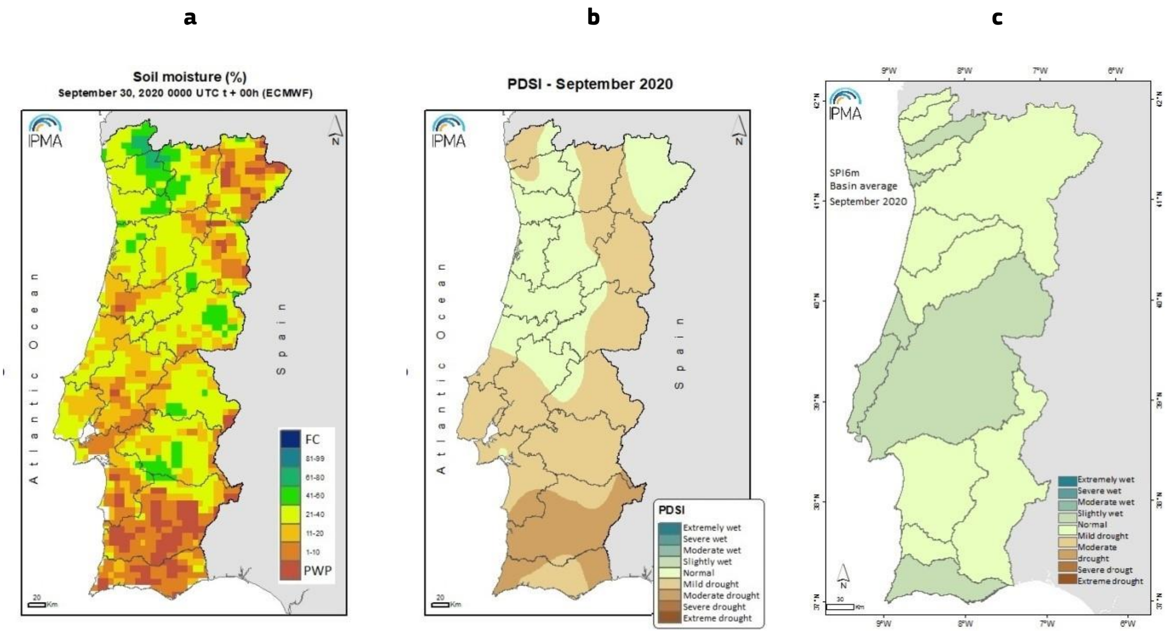
By the end of September, the soil moisture in the south was near or equal to the permanent wilting point (Figure 29a), and the regions of Alentejo and Algarve (South) were in moderate drought according to PDSI index (Figure 29b). Despite the drought over these regions, the situation was not deemed very severe meteorologically, with precipitation anomaly values close to the normal for the 6 months period up to September 2020, as it can be seen in the SPI 6m at the end of September (Figure 29c).

July and September 2020 – Very hot and very dry weather

As mentioned above, July was very warm and dry (Figure 30a and Figure 30b). This month was the warmest in 90 years and recorded three heat waves. The persistency of such hot and dry weather led to forest fires in northern and central Portugal, with more than 2 thousand fires recorded. In the central region of Oleiros, a major forest fire burnt an area of more than 6 thousand hectares. Figure 30c shows the Fire Risk Classes for July 26th, with the maximum risk across the northern half of Portugal, as well as the far south.

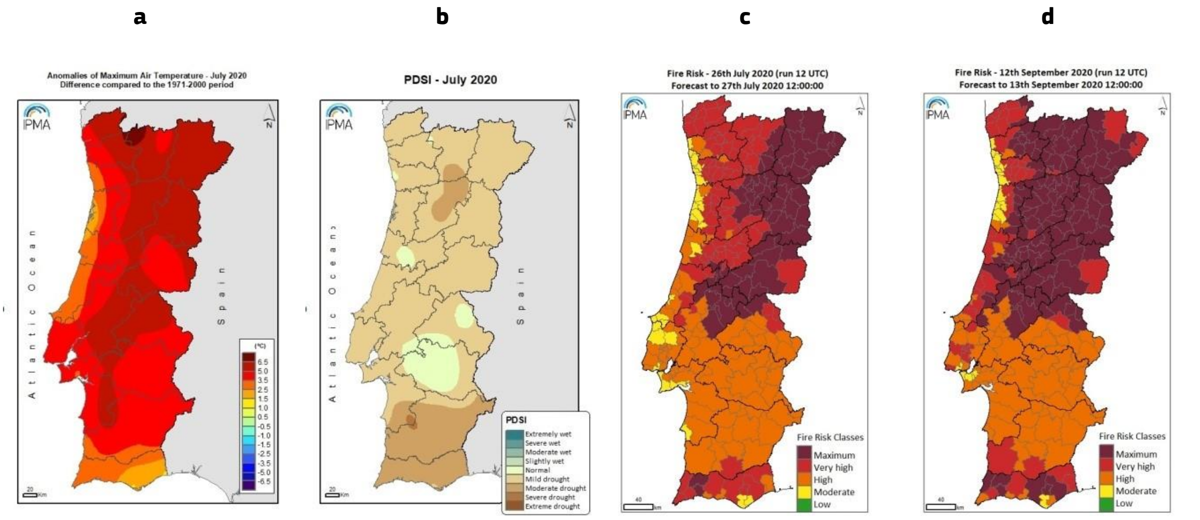
The persistent heat and the dry weather during the first half of September 2020 fuelled further forest fires. In fact, the major fire of 2020 occurred in the 5 days between 12 and 17 of September, in the region of Castelo Branco/Proença-à-Nova, across an area of more than 16 thousand hectares, roughly one third of the whole burnt area recorded in mainland Portugal during 2020. Figure 30d shows the Fire Risk Classes for mid-September, with high to extreme fire risk everywhere in the Country, but especially in the centre and north of Portugal, as well as the far south.

Figure 29 Soil moisture, PDSI, and SPI6 maps in September 2020



Source: PMA, 2020.

Figure 30 Anomalies of Max Air Temperature, PDSI, and Fire Risk maps



Source: PMA, 2020.

4.3 Meteorological drought indexes for State managed Spanish basins

Author: Jaime L. Fraile Jiménez de Muñana[49]

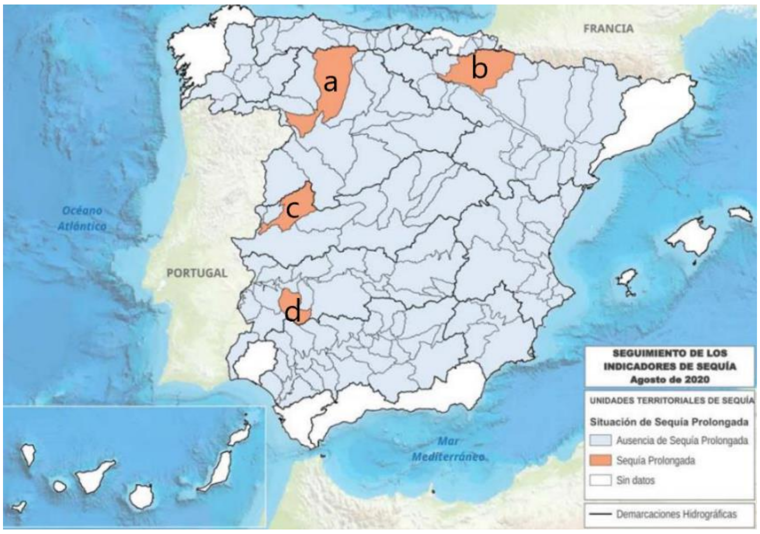
According to the Spanish Water Act (RDL1/2001), the river basins whose water runs through more than one Autonomous community must be managed by the State administration, with River Basin Authorities that will adopt the name of *Confederaciones Hidrográficas*. There are 9 such entities, each in charge of managing 10 Water Districts. They monitor drought with a focus on the impacts on several aspects of water management. The Spanish Meteorological Agency (AEMET) carries out countrywide drought monitoring activities. In 2018, all

[49] Oficina de Planificación Hidrológica, Confederación Hidrográfica del Segura, O.A. - Ministerio para la Transición Ecológica y el Reto Demográfico. Plaza de Fontes, 1, 30071 MURCIA (Spain)

the State-managed River Basin entities approved a new Drought Management Plan, following the instructions issued by the Ministry for Ecological Transition. These new plans established different indexes, designed to monitor meteorological drought in order to determine whether its occurrence caused waterbodies in a given area to miss the environmental objectives. If so, objectives could be loosed, as well as the environmental flow rate threshold, for as long as the drought took place. Every basin was divided in Territorial Drought Units (UTS, Figure 31) and an index was defined for each one of them, based on the indicator that best reflected deterioration in the ecological status and the fulfilment of the environmental flow rate. The indexes always adopt a value between 0 and 1. The threshold that indicates the existence of a prolonged drought and that justifies less stringent targets and environmental flow rates is set at a value of 0.3 in the index. UTS indexes within a single basin may be combined into a global drought index for the whole basin, with adequate ponderation.

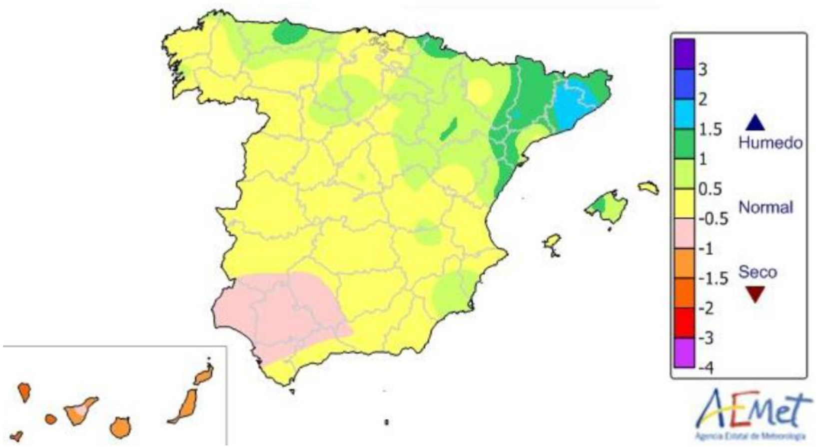
The SPI-12 map for September 2020 (Figure 32) shows that the year October 2019 to September 2020 was quite wet in the Northern and Eastern parts of Spain, average in most of the central plateau and rather dry in the South West.

Figure 31. Territorial Drought Units (UTS). In orange, the units affected by prolonged drought, as of August 2020: a) Duero; b) Ebro; c) Tajo; d) Guadiana.



Source: MiTECo, 2020.

Figure 32. Standardized precipitation index for October 2019 to September 2020



Source: AEMet, 2020.

The following is a brief summary of the evolution of such indexes in selected state-managed basin during the period from September 2019 to August 2020.

4.3.1 Duero

While the hydrological year started with a situation of prolonged drought in 11 of the 13 UTS, only 2 of them remained as such in November 2019, and none in December. Conditions remained close to normal in 2020, with only one UTS reaching prolonged drought values again. UTS4 (Esla) stayed under the threshold between June and September 2020. The global drought index for the wider basin was around average (0.46) as of September 2020.

4.3.2 Guadiana

The Guadiana River Basin was perhaps the only one suffering from a persistent drought situation in many of the 20 defined UTS. At the beginning of the hydrological year, that was the situation in 12 of them. Most of UTS came back to normal in February, with only UTS14 (Matachel) being in prolonged drought situation for 11 of the 12 months considered (only July saw a brief and slight recovery). The rest of the UTS show average index values at the end of the period. The global drought index for the basin had a similar evolution, with low values until February and average values from March onwards.

4.3.3 Tajo

At the beginning of the hydrological year, four out of ten UTS were in a situation of prolonged drought, with the others close to the threshold too. However, the rainfall during the autumn 2019 was abundant, and the values rapidly recovered. As of September 2020, only UTS 8 (Alagón) suffered from prolonged drought in the previous 2 months, with all the others having good index values. The global drought index for the basin was steady all year long, remaining around average values after the low of October 2019.

4.3.4 Ebro

The evolution of drought indexes was different, depending on UTS. Some showed consistent drought problems (UTS16, 'Cuencas del Irati, Arga y Ega'), while most had an average year, with normal or above average index values. A couple other UTS (UTS1 'Cabecera y Eje del Ebro'; UTS9 'Cuenca del Guadalope') had extreme values, with some months hitting the highest values of the index (Nov19-Jan20 in UTS1) and some other going below the prolonged drought index threshold (March and July in UTS1; Oct19 in UTS9). As of the end of the hydrological year, only one UTS (UTS16) stayed in prolonged drought situation. The global Drought index for the basin overall remainde above average all year long, which is consistent with the SPI12 map developed by AEMET (Figure 32).

4.4 Hydrogeological drought forecasting in France

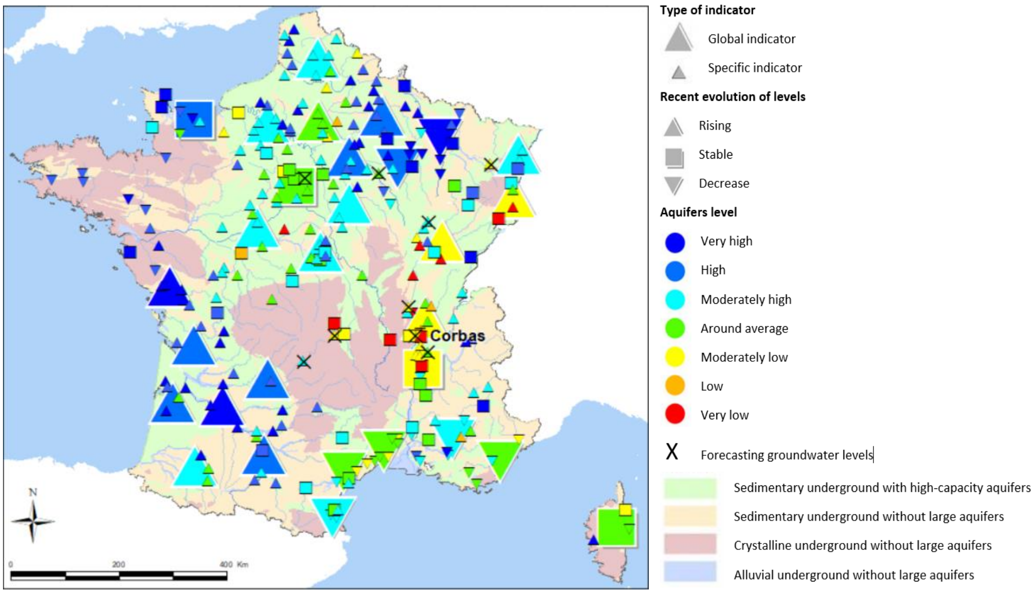
Author: Violaine Bault [50]

At the end of summer 2019, groundwater levels were particularly low. The winter aquifer recharge was therefore carefully monitored. The bulletin on the groundwater level situation, published by BRGM, reports the quantitative status of water resources at the beginning of each month (Figure 33). The specific and global indicators on the map show the filling status of major aquifers at two scales, using the Standardized Piezometric Level Indicator (SPLI) and a colour code. The trends comparing water levels to the previous month (increase, stable, decrease) are displayed with symbols. The 259 specific indicators are piezometers of the Water Framework Directive monitoring network (directive 2000/60/CE), selected to be representative of the aquifer where they are installed. The specific indicators are averaged into 31 global indicators representing the strategic aquifers.

Rainfall exceeded average values during the autumn-winter 2019-2020 and spring 2020, across most of the French territory. Precipitation led to a good recharge and groundwater levels were especially high at the beginning of spring 2020 (Figure 33). These high levels lasted during the following summer for most of the aquifers, but not all. The situation was less favourable in the East and Centre of France: Alsace, Saone and upper Rhône corridors and Central Massive. For these sectors, 2019-2020 recharge did not compensate for the precipitation deficit later in the year.

[50] Bureau de Recherches Géologiques et Minières (BRGM). 3 av. Claude-Guillemin 45060 Orléans Cedex 2 (France)

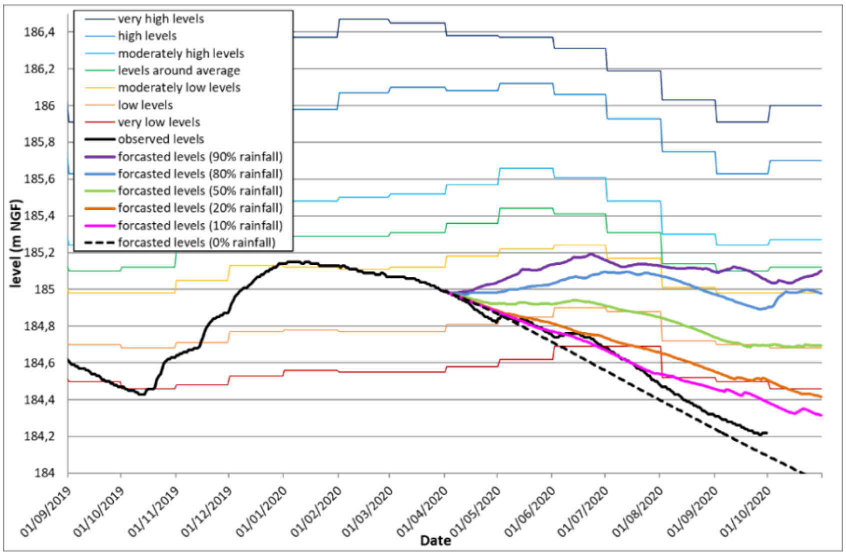
Figure 33. Quantitative status in 1st of April 2020, at the end of the 2019-2020 recharge period.



Source: BRGM, 2020.

In order to anticipate groundwater levels during low-water events, the BRGM makes forecasts using a hydrogeological model for 9 piezometers (Eros@BRGM). Water level forecasts were launched at the end of the recharge period, 1st of April 2020 (e.g. Figure 34). The models were updated at the beginning of the summer, 26th of Jun 2020. Output data, projecting a 7-months period according to various rainfall scenario, were compared to the statistical thresholds used in the bulletin (SPI).

Figure 34. Forecasting of the groundwater level at Corbas (Lyon) from 1st of April 2020



Source: BRGM, 2020.

The Environment Ministry was able to communicate effectively to local governments and stakeholders about the water resources available during the summer period. Forecasting allows a better management of extreme hydrogeological conditions and anticipates potential stress of water supply. For instance, the results at Corbas (Lyon) showed that the projected levels from April to October 2020 would be comprised between normal (50% of rainfall) and very low (10% rainfall) (Figure 34). Measures of water use restriction were then adopted in that area on the 20th April 2020 and groundwater levels followed those predicted by the scenario with under 10% difference.

4.5 Río de La Plata Basin and Waterway Transportation

Author: Guillermo P. Podestá[51]

The Río de la Plata Basin

The Río de la Plata Basin (hereafter, LPB) is the second largest river basin in South America and the fifth in the world. It drains 3.1 million km^2 (17% of South America's surface) across five countries: Brazil, Argentina, Paraguay, Bolivia and Uruguay. Three major sub-basins are within the LPB: Paraná, Uruguay, and Paraguay rivers (Figure 35). The LPB ends in the Río de La Plata estuary that drains into the Atlantic Ocean. The basin is home to about 100 million people – half the population of countries in the basin – and generates about 70% of these countries' aggregated GDP. Drought has important social, economic, and environmental impacts throughout the LPB, a region that relies mostly on rainfall to generate hydropower, sustains a large agricultural production, and transports goods along its waterways.

The LPB is one of the largest producers of hydroelectric power in the world, including the largest plant in the world in electricity generation and the second in terms of installed capacity, Itaipú. The powerplant is shared between Brazil and Paraguay, and there are two other binational plants. A system of many dams and hydroelectric plants provides over half of the energy demand of the countries in the basin. The LPB also is one of the world's major breadbaskets. Agricultural production from the LPB plays an important role in supporting global food security through the export of agricultural commodities: three countries in the basin (Brazil, Argentina and Paraguay) were among the global top five soybean producers and exporters in 2019. In that year, Brazil and Argentina also were in the top five of maize producers and exporters. The predominance of rainfed agriculture in the LPB (i.e. not irrigated) and the high reliance on hydroelectric power both make this region highly dependent on the availability of water and, therefore, very susceptible to droughts.

Figure 35. The Río de la Plata Basin. The three major sub-basins are those of the Paraguay River (light green), Paraná River (dark green) and Uruguay River (yellow). Rosario and the Greater Rosario port terminal and oilseed crushing cluster (see text) is highlighted in red.

Source: courtesy of J.C. Bertoni, 2020.

The Paraguay- Paraná Waterway

Despite the major importance of hydroelectricity generation and food production in the LPB, this section focuses on the impact of drought in 2019-20 on waterway transportation. The Paraguay-Paraná Waterway (PPW, or "Hidrovía") is a major geopolitical component of transportation systems in the LPB, as it provides

[51] Sistema de Información sobre Sequías para el sur de América del Sur (SISSA). Regional Climate Center for Southern South America (RCC-SSA)

ocean access to land-locked Paraguay and Bolivia. The 3400 km PPW joins southern Brazil to the Río de la Plata and the Atlantic. The length of the PPW is comparable to that of other major waterways such as the Mississippi (3800 km) or the Danube-Rhine systems (3500 km), although these two systems move much more freight than the PPW. Currently, perhaps as many as 4500 barges, tugs and container ships shuttle up and down the PPW carrying about 102 M tons of freight each year along the PPW.

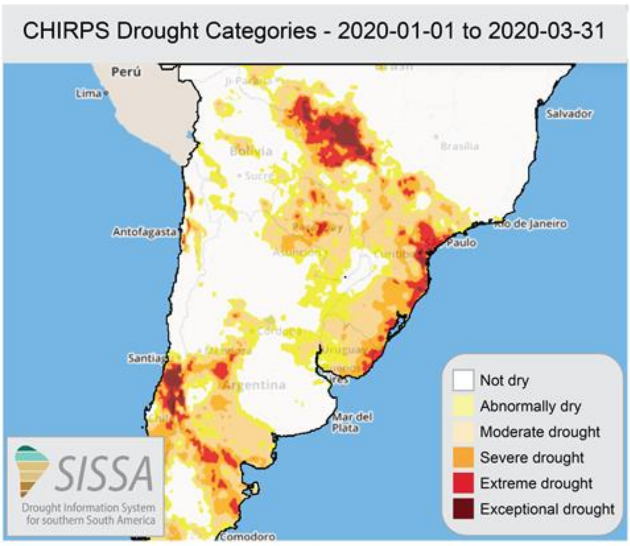
The so-called Greater Rosario area on the PPW is the main soybean processing and export hub in the world, surpassing similar clusters in New Orleans (United States) and Santos (Brazil). The Greater Rosario is a 70-km stretch on the Paraná River near the city of Rosario, Province of Santa Fe, Argentina (see red circle in Figure 35). This cluster includes about 20 port terminals through which a large proportion of agricultural commodities from the LPB are exported (in 2019, 67% of cereals and oilseeds exported by Argentina, 96% of flour and 93% of vegetal oils). The Greater Rosario cluster includes about 20 oilseed processing plants – 12 of which include a port terminal – that account for about 80% of the Argentinian crushing capacity. Soybeans from Paraguay, Brazil and Bolivia are routinely transported to the Greater Rosario crushing plants by barge using the PPW. Oilseeds can be processed there for subsequent export as soybean flour and oil, or directly transferred to ocean-going vessels to be exported as beans.

Large seafaring ships (Panamax class, 36 ft draft) can only reach the Greater Rosario area (Km 420 of the waterway). Smaller ships ("handy max", 28 ft draft) can get further north to the port of Santa Fe (Km 590). North of Santa Fe, only inland barge traffic (10 ft draft) is possible. Navigation can reach the northern end of the PPW near Puerto Cáceres, Brazil, on the upper basin of the Paraguay River. However, north of the confluence of the Paraguay and Apa rivers, navigation is challenging because of shallower depths (7-8 ft) and frequent PPW meanders. Most importantly, freight transportation along this portion of the PPW raises environmental concerns, because the waterway traverses the Pantanal, one of the world's largest wetlands.

Drought and Paraguay-Paraná Waterway Transportation

The persistent drought in the basins of upper Paraná (starting in February 2020), Paraguay and Uruguay (starting in late 2019) had multiple and diverse impacts on the LPB. Moreover, the middle LPB experienced relatively low rainfall since August 2019. To illustrate the spatial extent of the drought, Figure 36 shows drought classes calculated from CHIRPS rainfall estimates (derived from both satellite data and *in situ* observations) for January-March 2020. CHIRPS fields are produced for pentads (periods of about 5 days) and are available since 1981 on a 5 x 5 km grid. A non-parametric distribution was fitted to the time series of rainfall anomalies for each cell and pentad; the distribution was then used to estimate percentile values for each series. The percentiles were used to assign each grid cell and pentad/year combination to one of six drought categories following the U.S. Drought Monitor. The drought categories range from "not dry" (percentile values > 30) to "exceptional" (percentiles ≤ 2).

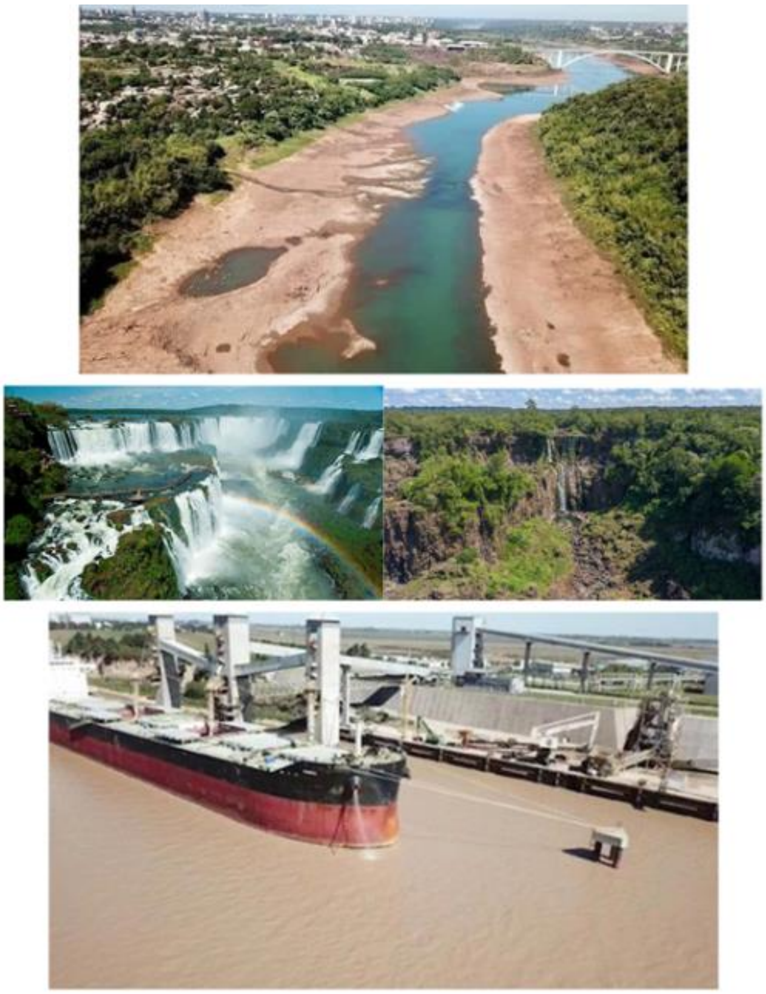
Figure 36. Drought categories for southern South America calculated from CHIRPS rainfall anomalies (see text). The anomalies correspond to the 3-month period from 1st of January to 31st of March 2020.



Source: SISSA, 2020.

Drought in the upper LPB dried up the Iguazu Falls, created water shortages for cities along the PPW, induced large fish mortality and endangered livelihoods of artisanal fishers, exposed multiple shipwrecks, and lowered electricity generation in the Yacyretá and Salto Grande power plants. Furthermore, the extremely low PPW levels created severe disruptions to the logistics of agricultural commodities in the Greater Rosario terminals (Figure 37).

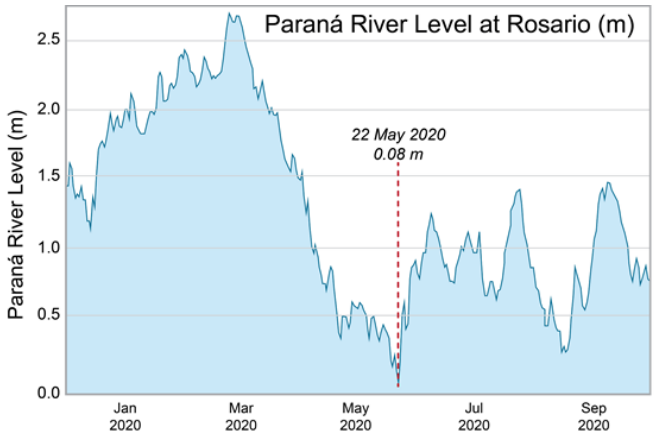
Figure 37. Some impacts of the early 2020 drought in the La Plata Basin. Top: the Parana River just downstream of the Itaipu Dam; the Friendship Bridge in the upper part of the picture joins Foz de Iguazu in Brazil with Ciudad del Este in Paraguay. Middle: the Iguazu Falls with normal flows (left) and during the 2020 drought (right). Bottom: an ocean freighter in the greater Rosario; the low Parana level is illustrated by the visible pilings in the right part of the picture.



Source: SLE Farms, InfoBAE, 2020.

The navigability of the PPW is closely tied to the depth (and streamflow) of the Paraná and Paraguay rivers. The depth of the PPW off the Greater Rosario area was significantly reduced in the first 4-5 months of 2020. Figure 38 shows the evolution of Paraná River hydrometric levels near Rosario from December 2019 to the end of September 2020. While the normal Paraná level in April is 3.76 m in Rosario, the level reached 0.4 m on April 22nd, which at the time was the lowest level recorded since 1971. The lowest level recorded since 1884 was observed on 22 May 2020: 0.08 m.

Figure 38. Level of Parana River at the Rosario hydrometer, December 2019 to September 2020. The river level decreased rapidly near the end of February 2020, reaching a minimum of 0.08 metres on May 22nd.



Source: Universidad del Litoral, Facultad de Ingenieria y Ciencias Hidricas, Santa Fe, Argentina.

The low PPW depth forced ocean freighters leaving Greater Rosario to decrease loads. Normally, a "handy max" ship carries 35,000-40,000 tons; each foot of draft lost reduces that capacity by 1500-1800 tons. The largest Panamax-sized ships (about 235 m long) that can reach Rosario ports can carry 60,000 to 75,000 tons of grains. One foot less in the draft of a Panamax freighter means that 2000-2500 tons of grain cannot be loaded. In mid-May 2020, PPW depth was about 5 feet below its normal value, thus reducing the load of a Panamax by about 11,000 tons, or the load of about 370 trucks carrying 30 tons each. The lost freight capacity thus implied higher costs per load. The low PPW levels disrupted primarily soybean and maize exports. Panamax ships loaded with maize typically leave Rosario carrying about 40,000 tons and fill up completely at deeper ocean ports (Quequén or Bahía Blanca). However, as these ports are located farther from major maize and soybean production areas in the Pampas, higher prices follow. In addition to decreased loads on ships, low PPW levels caused delays and higher costs in barge traffic upstream of Rosario. For example, waterway depths off Fuerte Olimpo in the upper Paraguay River basin were about 3.3 m in early April 2020, while normal level at that time should have been about 6 m.

Shoals and narrow passages along the Paraguay River portion of the waterway became increasingly impassable, requiring lighter loads for barges (i.e., less freight per trip), time-consuming disassembly and reassembly of barge convoys to traverse narrow channels, and slower, careful navigation to avoid groundings. As a result, Paraguayan barges took 10-15 days longer than usual to reach Rosario.

Shallow waterway depths also raise navigational hazards, often restrict operations to daylight hours and increase frequency of groundings. In August-September 2018, when the Paraná level was also low, although not as low as in early 2020, three freighters ran aground south of Rosario, delaying or cutting off navigation along the PPW for several days.

Finally, PPW low flows and depths also create problems on the land side of operations: slower navigation operations disrupt the overall flow of oilseeds and cereals. For example, maize exports reach a peak in April and May. Slower navigation and reduced loads in 2020 increased loading times. Longer loading times for ocean-going ships may cost 30-50 thousand US dollars per day, depending on ship size. At the same time, the decreased outflow implied that maize delivered to the terminals had to be stored in, and nearly saturated the capacity of port silos. In turn, this lowered the number of trucks allowed to deliver grain to the ports. Some plants had to slow down crushing in order not to saturate their soybean oil storage capacity. The crushing slowdown, in turn, delayed exports of soybean flour.

In summary, the Rosario Bolsa de Comercio (Board of Trade) estimated the aggregate value of all impacts related to low flows and depths of the PPW at about 244 million USD for the first four months of 2020. The duration of the low flows and depths in 2020 has been the longest on record since 1905. The situation was complicated further by the occurrence of La Niña event that often lowers precipitation throughout the LPB in October-December, when streamflow normally increases due to seasonal rain. As drought frequency and intensity are expected to increase due to climate change, the waterway transportation industry will have to explore options to enhance the resilience of shipping to extreme events such as the one observed in early 2020.

4.6 Drought patterns across western South America in 2020

Author: Pier Maquilón Lípari[52]

4.6.1 Chile

Since 2010, Chile has been affected by a very dry climate, with a marked change in the rainfall regime in the central regions of the country. It's the driest period in the historical records for many weather stations. The Chilean Meteorological Service (DMC) has named it "Mega-Drought". Unlike previous decades, not only the total precipitation was well below normal, but the rainy period shortened to a few weeks per year. This fact is related to the natural climate variability[53], especially with the variations of the Pacific Ocean, which has a great influence on Chilean climate. The Pacific Decadal Oscillation (PDO) has been in its negative phase, which generally means a decrease in rainfall across the country. The persistence of warm waters off New Zealand and Australia has favoured the maintenance of high pressures in south-central Chile, ensuring more stable atmospheric conditions in this region and bringing rainfall to the south. The cooling of the sea surface temperature in the equatorial zone of the Pacific during the 2020 (La Niña conditions) influenced the atmosphere, strengthening the South Pacific Anticyclone and hindering the low pressures systems that generate rainfall over central and southern Chile.

In the long term, the influence of climate change on the general circulation of the planet is causing the expansion of the Hadley Cell, contributing to the displacement of the South Pacific Anticyclone and making it difficult for the fronts to enter the central region. The air temperature coincides with the global trend towards a warmer climate. This condition is enhanced at high altitudes, where the increase in the height of the zero isotherm and the snow line, both impact the storage of fresh water and favour the retreat of the glaciers.

Year 2019 was one of the driest on record for many Chilean regions[54]. There were many heat waves, in the city of Santiago alone the frequency of these events hit an historical record, as well as the maximum temperature ever recorded (38° C). The stations reported a precipitation deficit between 50% and 80% of normal. At the beginning of 2020, rainfall remained below normal values[55] and in June rainfall was close to normal. Generally, the precipitations in Chile are concentrated between June and August (winter in the southern hemisphere), accumulating approximately 60% of the total annual precipitation. However, in the second half of July, no significant precipitation was recorded in much of the country, causing deficits to increase again. Higher than normal temperatures occurred as well. The precipitation deficits until September 2020 were about 40% of long-term average[56]. In addition, during September 2020 the beginning of a weak La Niña was declared, which increased the likelihood of dry conditions in Chile for the rest of the year.

4.6.2 Bolivia

In late 2016 and early 2017, Bolivia experienced the biggest rainfall deficit in 25 years[57]. Drought conditions have persisted since 2018, affecting the departments of La Paz, Chuquisaca, Santa Cruz, Beni, Cochabamba and Tarija.

Between July and November 2019, low rainfall and high temperatures favoured a recurring series of forest fires of wide extension and severe intensity, which caused one of the worst ecological disasters of the last decade, with 6.4 million hectares of vegetation burned in the Great Chiquitania region. At least five megafires of sixth generation were recorded[58]. These fires modified the weather regime of the surroundings and generated *pyrocumulonimbus*. In modern times, this event has only been observed twice in South America.

In 2020, despite less severe conditions than in previous years, forest fires affected 1.4 million hectares until September. The Ministry of Defense implemented the 'National Contingency Plan in the event of droughts' to serve the affected population by providing humanitarian assistance and the coordination of activities at the

[52] Centro Internacional para la Investigación del Fenómeno de El Niño - CIIFEN. Puerto Santa Ana, Ciudad del río. Edificio The Point, Of. 1904. Guayaquil - Ecuador

[53] http://blog.meteochile.gob.cl/2019/12/23/la-decada-perdida-la-sequia-sin-tregua-que-golpea-a-chile/

[54] http://blog.meteochile.gob.cl/2020/01/03/2019-el-ano-de-los-tornados-la-sequia-y-el-calor-extremo/

[55] http://blog.meteochile.gob.cl/2020/06/01/un-seco-inicio-de-2020/

[56] http://blog.meteochile.gob.cl/2020/09/17/se-cerro-la-llave-40-de-deficit-de-lluvia-a-la-fecha-y-la-nina-podria-empeorar-la-situacion/

[57] https://elpais.com/economia/2016/09/15/actualidad/1473933396_272958.html

[58] https://www.fcbc.org.bo/wp-content/uploads/2019/12/DiagnosticoIncendios.pdf

three levels of the government[59]. Among other measures: the drilling of wells, the provision of water through water tanks and the delivery of forage and feed for livestock[60]. In addition, a System for Monitoring and Warning of Droughts and a System for Seasonal Climate Forecasts was developed. In October a national disaster was declared due to the fires and drought[61].

4.6.3 Peru

Since January 2020, there was a water deficit in the Chicama river basin on the north coast of the country[62]. It caused water shortages, stress in crops and low river flows with a downward trend which are even comparable with dry years. During the rainy period from September 2019 to May 2020, there was a rainfall deficit, especially between January and March, the rainiest months. The dry season, between July and September, did not bring significant rainfall. In August 2020, a state of emergency was declared in the basin[63]. Forecasts suggested a deficit for summer 2021 on the north coast of the country due to a probable occurrence of La Niña Costera[64]. In September, a state of emergency was declared due to imminent water shortages in some provinces in the departments of Tumbes, Piura, Lambayeque, La Libertad and Cajamarca.

4.6.4 Colombia[65]

Rainfall during the first half of 2020 had values below normal, especially in the Caribbean and Andean regions[66]; these two regions were affected by rain deficits since November 2019[67]. Colombia's first rainy season is centred between April and May. The low levels of groundwaters impacted the agricultural sector (11,807 ha affected), livestock and the provision of drinking water for more than ten thousands people from 48 municipalities of 10 departments[68]. The channels of the Magdalena River reduced their flows and levels, affecting navigation. Most of these events took place between January and March 2020. 11 municipalities declared a public calamity and took measures such as rationing, delivery of drinking water through tank vehicles and the installation of water storage tanks. At the end of August, the rainfall was near the normal and above the normal in the Caribbean and Andean regions[69].

4.6.5 Ecuador

During 2019, 30% of the stations reported rainfall below the normal values. These deficits occurred in the Coastal and South inter-Andean regions.

In the first trimester of 2020, the rainy season in the Coastal region, an extraordinary current of dry air from the Pacific Ocean occurred. It increased the average temperature in almost all of continental Ecuador and the absence of rainfall for at least 20 consecutive days altered the sowing and harvesting periods for crops in the Coastal and inter-Andean regions. In February, such current weakened and allowed the return of moisture from the Amazon. To face this kind of drought events, the Ministry of Environment and Water (MAAE) is developing the National Drought Plan that seeks to articulate local contingency plans and initiatives to support farmers.

59 https://www.mindef.gob.bo/mindef/node/4105

60 https://www.mmaya.gob.bo/2020/09/gobierno-entrega-camiones-cisternas-para-mitigar-la-sequia-y-los-incendios-en-la-chiquitania/

61 https://www.mmaya.gob.bo/2020/10/gobierno-declara-desastre-nacional-por-incendios-y-sequia/

62 https://www.senamhi.gob.pe/load/file/02662SENA-5.pdf

63 RESOLUCIÓN JEFATURAL Nº 118-2020-ANA publicada el 8 de Agosto de 2020. Consultado en https://diariooficial.elperuano.pe/normas

64 http://enfen.gob.pe/download/comunicado-oficial-enfen-n-10-2020/

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68 Página de Unidad Nacional para la Gestión del Riesgo: http://gestiondelriesgo.gov.co/snigrd/emergencia.aspx?id=41

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List of abbreviations and definitions

BRGM Bureau de Recherches Géologiques et Minières

CEMS Copernicus Emergency Management Service

DG Directorate-General

ECHO European Civil Protection and Humanitarian Operations

ECMWF European Centre for Medium Range Weather Forecasts

EDO European Drought Observatory

EEA European Environment Agency

EFAS European Flood Awareness System

EMM European Media Monitor

ENSO El Niño Southern Oscillation

ERCC European Emergency Response Coordination Centre

GDACS Global Disaster Alert and Cordination System

GDO Global Drought Observatory

GeoTIFF Geographical TIFF

GPCC Global Precipitation Climatology Centre

GRACE Gravity Recovery And Climate Experiment

GRACE-FO GRACE Follow-on

LFI LowFlow Index

ICPR International Commission for the Protection of the Rhine

IPMA Instituto Português do Mar e da Atmosfera

NetCDF Network Common Data Form

PDSI Palmer Drought Severity Index

SMA Soil Moisture Anomaly

SPI Standardized Precipitation Index

SPLI Standardized piezometric level indicator

TIFF Tagged Image File Format

TWS Total Water Storage

TWSA Total Water Storage Anomaly

UN United Nations

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Annex 1. IPCC Macro regions

Names of IPCC 5th report Macro regions, Ocean regions with a * symbol are not analyzed. These Macro regions are based on climatological criteria.

Abbreviation	Name
ARC	Artic Ocean, islands and coasts
CGI	Canadian Artic Islands, Greenland, Iceland
ALA	Alaska and North West Canada
WNA	Western North America
CNA	Central North America
ENA	Eastern North America
NEU	Northern Europe
CEU	Central Europe
MED	Mediterranean
WAS	Western Asia
CAS	Central Asia
NAS	Northern Asia
TIB	Tibetan Plateau
EAS	Eastern Asia
SAH	Sahara
WAF	West Africa
EAF	East Africa
SAF	Southern Africa
CAM	Central America and Mexico
CAR	Caribbean, small islands
AMZ	Amazon
WSA	West Coast South America
SSA	Southern South America
NEB	North Eastern Brazil
SAS	South Asia

SEA	South East Asia
NAU	Northern Australia
SAU	Southern Australia and New Zealand

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