Combined Drought Indicator (CDI) v2

This Factsheet provides a brief technical description of the Combined Drought Indicator (CDI) version 2 (v2) as implemented in the Copernicus European Drought Observatory (EDO). It is used for detecting and monitoring areas that either are affected by or are at risk of imminent agricultural drought. The meteorological, hydrological and satellite-derived biophysical variables upon which the CDI indicator is based, as well as its temporal and spatial scales and geographic coverage, are summarized below. An example of the CDI v2 indicator is shown in Figure 1.

Variables	Temporal scale	Spatial scale	Coverage
Precipitation, soil moisture, and vegetation response.	10 days (= 1 dekad)	5 km	Europe

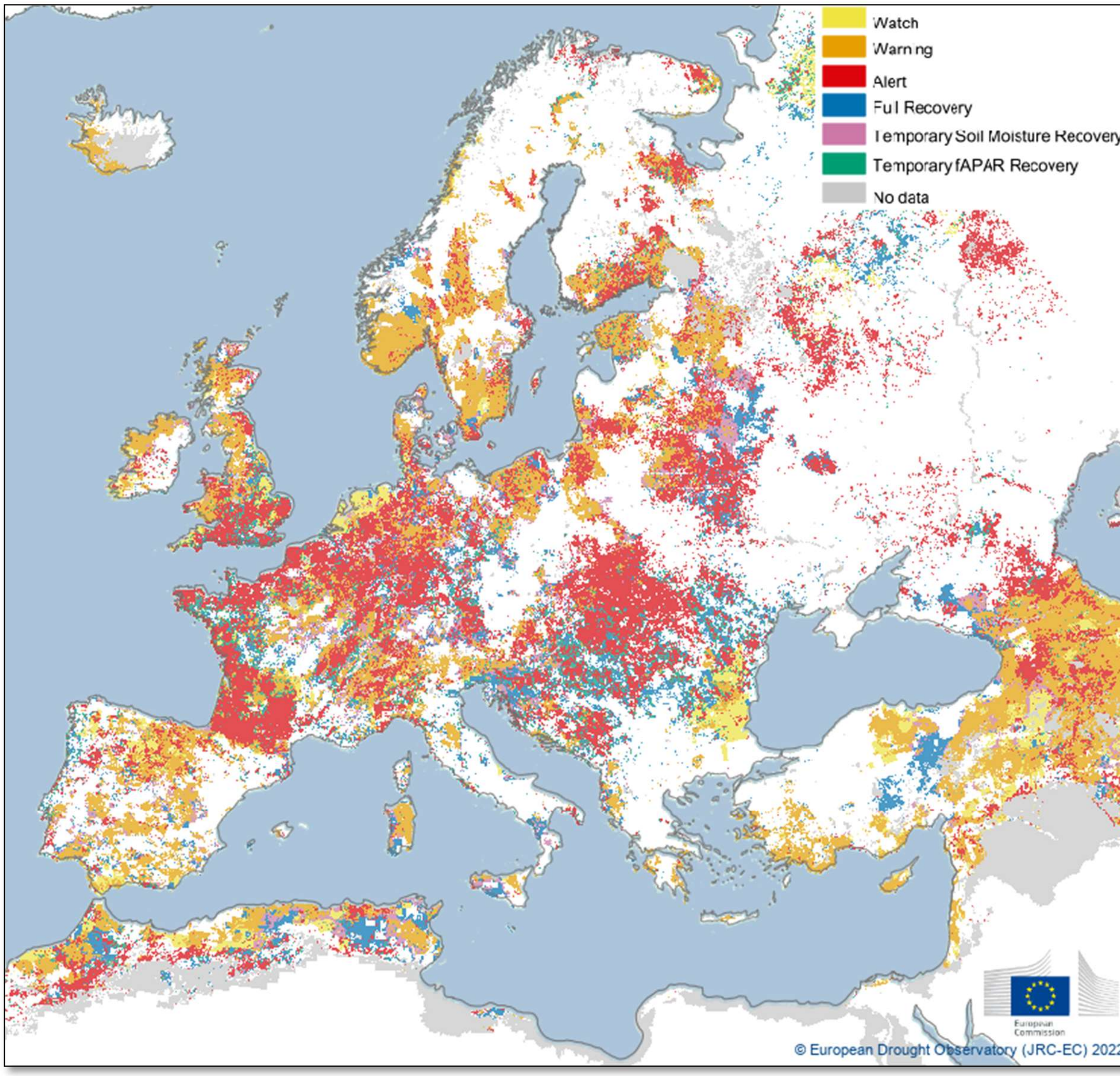

***Figure 1**: Example of the continuously updated Combined Drought Indicator (CDI) v2 in EDO, computed for the third 10-day period of September, after the 2022 severe spring / summer drought in Europe.*

1. Brief overview of the indicator

The Combined Drought Indicator (CDI) v2 is available on the European Drought Observatory (EDO) since July 2022. It is described in Cammalleri et al. (2021) as a revision of the CDI v1, which was based on the previous findings of Sepulcre-Canto et al. (2012). The Combined Drought Indicator is used to identify and monitor areas that either are affected by or are at risk of imminent agricultural drought.
The indicator is derived by combining three drought indices produced operationally in the EDO framework, namely: the Standardized Precipitation Index (SPI), the Soil Moisture Anomaly (SMA), the FAPAR Anomaly. The Combined Drought Indicator uses three primary drought classes: "Watch", "Warning" and "Alert". Three additional recovery classes ("Temporary Soil Moisture recovery", "Temporary fAPAR recovery" and "Full Recovery") identify the stages of the drought recovery process.

2. What the indicator shows

The CDI mainly addresses agricultural drought, which is one type of drought among those defined e.g. in Mishra and Singh (2010). This drought is characterized by a reduced crop productivity due to meteorological and soil critical conditions.

The CDI identifies areas at risk of imminent agricultural drought, areas where the vegetation is already affected by drought conditions and areas in the process of recovery to normal conditions after a drought episode. The CDI is based on a cause-effect relationship for agricultural drought, whereby a shortage of precipitation leads to a soil moisture deficit, which in turn results in a reduction of vegetation productivity. The indicator combines anomalies of precipitation, soil moisture and satellite-measured vegetation photosynthetic activity as measured by, respectively, the Standardized Precipitation Index, Soil Moisture Anomaly, and FAPAR Anomaly. It uses a classification scheme consisting of six drought levels corresponding to the different stages of the cause-effect relationship for agricultural drought, as shown in Table 1.

Table 1*: The six drought impact levels used in the CDI v2, with colours[1] as in EDO.*

#	*LEVEL*	*INTERPRETATION*
0	***No drought***	Normal conditions.
1	***Watch***	Observed precipitation deficit.
2	***Warning***	Precipitation deficit accompanied by negative soil moisture anomaly.
3	***Alert***	Precipitation deficit, negative soil moisture anomaly and negative anomaly of vegetation growth.
4	***Full recovery***	After a drought episode, both meteorological conditions and vegetation growth return to normal.
5	***Temporary Soil Moisture recovery***	After a drought episode, soil moisture conditions are above the drought threshold but not enough to consider the episode closed
6	***Temporary FAPAR recovery***	After a drought episode, vegetation conditions are above the drought threshold but not enough to consider the episode closed
8	***Not assessed***	Either bad data, no data or masked data

[1] The colour palette for CDI v2 is the scientific one elaborated by Okabe and Ito (2008) where the red colour is slightly brighter in order to highlight the Alert class and improve CDI visual inspection through the EDO website.

3. How the indicator is calculated

The CDI v2 is derived by combining the following three main drought indicators, which are implemented operationally within EDO, as explained below:

- **Standardized Precipitation Index** (SPI): The SPI indicator measures precipitation anomalies at a given location, based on a comparison of observed total precipitation amounts for an accumulation period of interest (e.g. 1, 3, 6, 9, 12, 48 months), with the long-term historic precipitation record for that period (McKee et al., 1993; Edwards and McKee, 1997).
  For the CDI computation, the one-month and three-month Standardized Precipitation Index (SPI-1 and SPI-3) are considered. Several studies (e.g. Ji and Peter, 2003; Rossi and Niemeyer, 2012) have shown that SPI-3 has the strongest correlation with the vegetation response, and is therefore the most suitable for identifying agricultural drought. SPI-1 can detect extreme short-term dryness that can dramatically affect the vegetation condition depending on its stage of development.

- **Soil Moisture Anomaly** (SMA): The SMA indicator is derived from anomalies of estimated daily soil moisture (or soil water) content - represented as standardized soil moisture index (SMI) - which is produced by the JRC LISFLOOD hydrological model (de Roo et al. 2000), and which has been shown to be effective for drought detection purposes (Laguardia and Niemeyer, 2008).

- **FAPAR Anomaly**: The FAPAR Anomaly indicator is computed as deviations of the biophysical variable Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), composited for 10-day intervals, from long-term mean values. Satellite-measured FAPAR represents the fraction of incident solar radiation that is absorbed by land vegetation for photosynthesis, and is effective for detecting and assessing drought impacts on vegetation canopies (Gobron et al., 2005).

- Additionally, values of the **CDI** of the previous 10-day period are considered, as described in Cammalleri et al. (2021), in order to enhance temporal consistency of the indicator.

For SPI-3, FAPAR Anomaly and SMA indicators, a threshold of minus one (-1) standard deviation is used, which roughly equates to a return period of 6.3 years, and corresponds to "moderate drought", according to the SPI classification of McKee et al. (1993).
In the case of SPI-1, a threshold of minus two (-2) standard deviations is used, corresponding to extreme drought conditions.
Additional thresholds have been implemented in the operational code upgrading the version of the indicator from the original v2.0 described in Cammalleri et al. (2021) to the current v2.2.
A temporal constraint is set for the two "Temporary recovery" classes in order to avoid that the indicator remains locked in these classes for long periods. For this reason, the maximum duration of the Temporary recovery stages is fixed at four 10-day periods.

4. How to use the indicator

An assessment of the behavior of the CDI for the main European droughts between 2000 and 2011 demonstrated its capability to discriminate areas where the drought impacts were the most severe, and highlighted its optimal use in an early warning system (Sepulcre-Canto et al., 2012). Cammalleri et al. (2021) improved the indicator's performance without altering either the modelling conceptual framework or the required input datasets, especially for long-lasting events, and reducing the overall temporal inconsistencies in stage sequencing.

The CDI shows its potential use in an early warning system by identifying areas prone to suffer drought effects, or as a monitoring system like in Figure 2, where the temporal evolution of the 2018 northern European drought is described comparing the CDI v1 and v2.

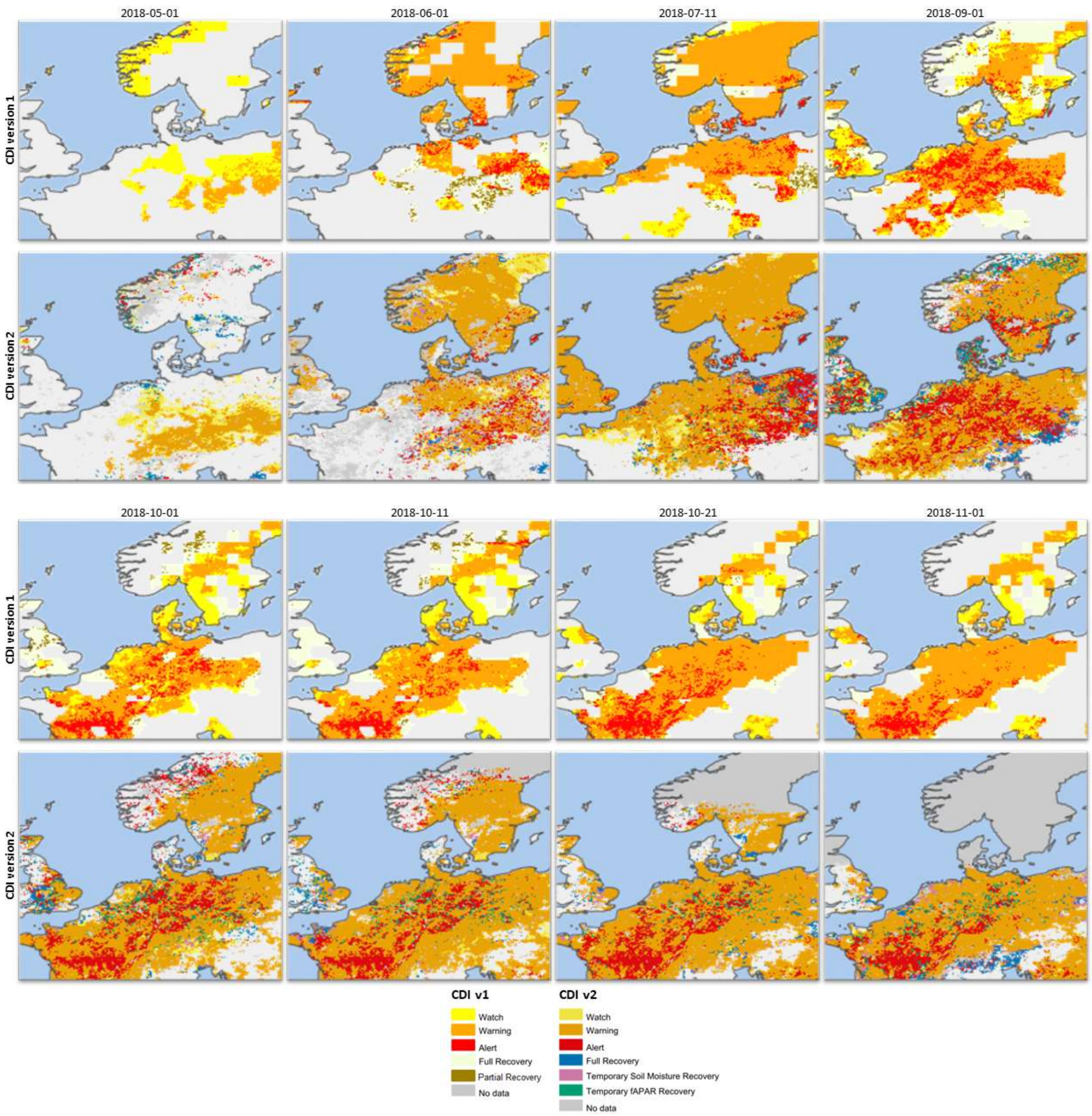

Figure 2: *Temporal evolution of the 2018 northern European drought according to the CDI v1 and v2. Images depict the spatial distribution of CDI v1 (first and third rows) and CDI v2 (second and fourth rows) for the indicated 10-day periods.*

The map in Figure 2 shows that the percentage of the area that is considered under drought has a similar temporal behaviour for the two versions of the indicator, with the latter having a larger spatial coverage in the event. An examination of the maps, however, highlights that even if the total area affected is similar, the partitioning among the different stages may differ. The maps for CDI v1 and CDI v2 look quite similar at the beginning of the event, but subsequently CDI v2 becomes much more uniform, with a higher number of cells under the Alert stage. The CDI v2 describes better the evolution of the drought where conditions point to recover but only temporarily. Consider for example Pomerania (the region on the Baltic shore between Germany and Poland): CDI v1 reports warning conditions in July, then no drought conditions from September to the second 10-day period of October and then warning conditions again from the last 10-day period of October. Instead, CDI v2 keeps the warning conditions open for the entire period, hence defining the event as unique and continuous.

5. Strengths and weaknesses of the indicator

Strengths:

- The development of a combined indicator that integrates meteorological, hydrological and remote sensing data, can help to reduce false alarms, which may arise for example in the case of vegetation-based indicators (e.g. FAPAR Anomaly) where a biomass reduction can be caused by factors other than a drought-induced water stress.

- An integrated approach that provides a convergence of indicators and therefore evidence of drought, can also support policy-makers in effective risk management and decision-making.

With respect to the previous version, the CDI v2 brings two major improvements:
- Avoid unrealistic early interruptions in drought events evolution;
- Ensure temporal continuity in case of small gaps within an event.

Weaknesses:

- The Alert impact levels should only be considered during the growing season, which in Europe may be defined to be, on average, from March to October. However, southern countries in Europe have longer growing seasons, and advanced with respect to the mean. Next versions of the indicator will include the use of spatial indicators of phenology. In the current v2 implementation, no CDI computation is done where FAPAR is not detected.

- The satellite-derived FAPAR Anomaly indicator is based on reflected solar radiation, with wavelengths in the optical (i.e. visible and infrared wavelength) region of the electromagnetic spectrum, and is therefore not effective in the presence of clouds. Clouds are generally masked out before the indicator is computed. However, low clouds are not always detected, resulting in erroneous indicator values. This is a particular problem in northern European countries. One way to address this issue would be to use more than one indicator related to vegetation growth.

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