Standardized Precipitation Index (SPI)

This factsheet provides the technical description of the Standardized Precipitation Index (SPI), produced by the Copernicus European (EDO) and Global (GDO) Drought Observatories. SPI indicates how precipitation deviates from the climatological average over a given accumulation period. The indicator is suitable and is commonly used for detecting and characterizing meteorological drought. The longer accumulation periods are related to persistent droughts and may give information also in terms of agricultural and or hydrological drought. An example of the SPI indicator computed for a three-month accumulation period (i.e. SPI-3), is shown in Figure 1.

Variable	Temporal scale	Spatial scale	Coverage
Precipitation	10-daily or monthly (for a range of accumulation periods)	Data dependent	Europe and global

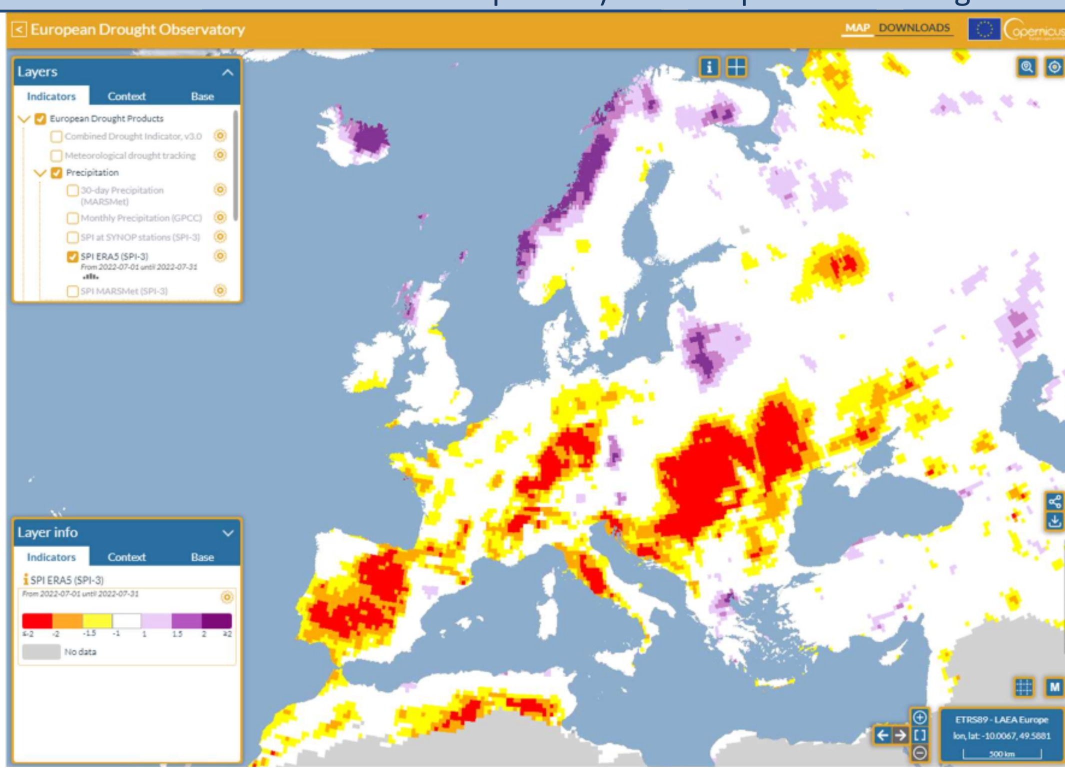

Figure 1*: Example of the SPI-03 indicator for July of 2022, produced by the Copernicus European Drought Observatory (EDO) and as seen at the map viewer of EDO. The classification scheme used for SPI is described in Section 4 below.*

1. Brief overview of the indicator

The Standardized Precipitation Index (SPI) is the most commonly used indicator worldwide for detecting and characterizing meteorological droughts. The World Meteorological Organization (WMO) has recommended SPI to be used by all National Meteorological and Hydrological Services around the world to characterize meteorological droughts (World Meteorological Organization, 2012). The indicator, which was developed by McKee et al. (1993) and described in detail by Edwards and McKee (1997), measures precipitation anomalies at any given location based on a comparison of total precipitation amounts for an accumulation period of interest (e.g. 1, 3, 12, 48 months) with respect to a baseline period derived from a long-term precipitation record for that same accumulation period of interest. The precipitation values from the baseline period are commonly fitted to a "gamma" probability distribution, which is then transformed into a normal distribution such that the mean SPI value for that location and period is zero, and the standard deviation equals one. For any given region, increasingly severe precipitation deficits (i.e., meteorological droughts) are indicated as SPI decreases below −1.0, while increasingly severe excess precipitation are indicated as SPI increases above 1.0. Because SPI is unitless and represents the deviation from the long-term mean, the indicator can be used to compare precipitation anomalies for any geographic location and for any number of time-scales. Note that the name of the indicator is usually modified to include the accumulation period, usually expressed in months. Thus, SPI-3 and SPI-12, for example, refer to accumulation periods of three and twelve months, respectively.

2. What the indicator shows

A meteorological drought is defined as a period with an abnormal precipitation deficit with respect to the long-term average conditions for a certain location in space. The SPI indicator shows the anomalies (deviations from the long-term mean) of the observed total precipitation, for any given location and accumulation period of interest. The magnitude of the anomaly is a measure of the severity of a wet (positive anomaly) or dry (negative anomaly) event. Since SPI can be calculated over different precipitation accumulation periods (typically ranging from 1 to 48 months), the resulting values allow for estimating different potential impacts of a meteorological drought:

- **SPI-1 to SPI-3**: When SPI is computed for shorter accumulation periods (e.g. 1 to 3 months), it can be used as an indicator for supporting the assessment of reduced soil moisture, snowpack, and flow in smaller creeks.

- **SPI-3 to SPI-12**: When SPI is computed for medium accumulation periods (e.g. 3 to 12 months), it can be used as an indicator for reduced stream flow and reservoir storage.

- **SPI-12 to SPI-48**: When SPI is computed for longer accumulation periods (e.g. 12 to 48 months), it can be used as an indicator for reduced reservoir and groundwater recharge.

While SPI can give an indication on the potential implications due to droughts, the exact relationship between the accumulation period and drought depends on the natural environment (e.g., geology, soils) and human interference (e.g., existence of irrigation schemes). To get a full picture of the potential impacts of a drought, the SPI should be calculated and compared for different accumulation periods, as well as compared with other drought indicators that can be more suitable for assessing the actual impacts of droughts on the vegetation cover and different economic sectors.

3. How the indicator is calculated

The Standardized Precipitation Index (SPI) is computed by first fitting the long-term baseline precipitation values to a probability distribution (commonly the “gamma” distribution) and then by transforming this fitted probability to the normal distribution with a mean of zero and standard deviation of one (i.e. standardization), as schematically shown in Figure 2.

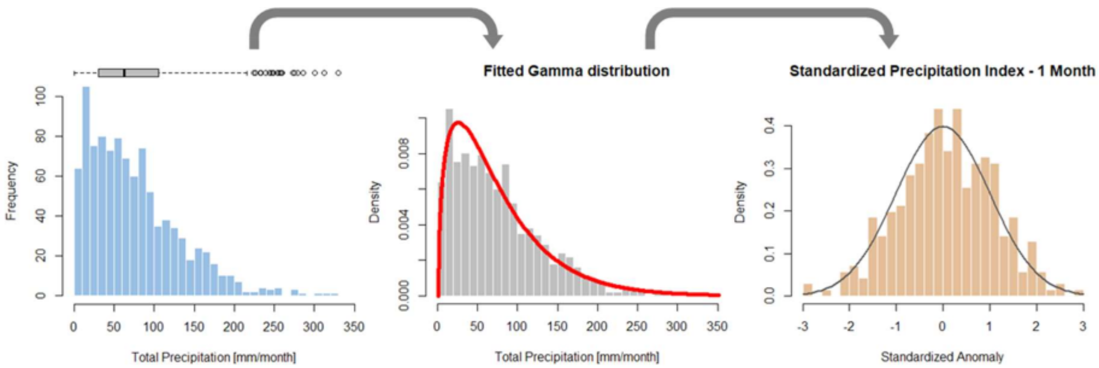

***Figure 2**: Schematic representation of the main steps involved for computing the SPI.*

For computing the SPI in EDO and GDO, the empirical distribution of precipitation accumulations (e.g. 1, 3, or 6 months) for pre-defined intervals (e.g. daily; 10-daily, or monthly) over a long-enough baseline period (e.g. historical observations over 30 years) is fitted to a two-parameter continuous “gamma” probability distribution using the L-moments method. The two parameters that describe the “gamma” distribution are the shape parameter (α) and the rate parameter (λ, or the inverse scale parameter 1/θ), both being positive real numbers. In order to compute the SPI for a certain precipitation accumulation period of interest (e.g. 1, 3, 12 or 48 months), the two-parameter “gamma” distribution is fitted to all non-zero empirical precipitation accumulation data from the reference baseline period. In EDO, the reference baseline is assumed to be the period from January 1991 to December 2020. For the computation of SPI in EDO and GDO, zero precipitation is assumed to be any precipitation accumulation value lower than 0.01 mm. The removal of zero precipitation accumulation values is important when performing the fitting procedure to a “gamma” distribution as the “gamma” function is defined only for positive real numbers. In EDO and GDO, the fitting procedure is performed only if at least 10 non-zero data points are available from a 30-year reference baseline period, otherwise a missing value is reported. Once the fitting of non-zero empirical precipitation accumulation values to the “gamma” function is performed and the shape (α) and scale (θ) parameters of the “gamma” function are derived, the cumulative probability values of the empirical precipitation accumulation data are computed following the cumulative distribution function shown in Eq. 1.

$$F(x,\alpha,\lambda) = \int_0^x f(u,\alpha,\lambda)du \qquad [1]$$

To account for the probability of zero precipitation (p_0) in the cumulative probability results derived from Eq. 1, the probability values are adjusted following the function shown in Eq. 2:

$$F_{p_0}(x,\alpha,\lambda) = p_0 + ((1-p_0)\cdot F(x,\alpha,\lambda)) \qquad [2]$$

Finally, the p_0-adjusted cumulative probability values are then transformed (converted) to the standard normal random variable with mean zero and standard deviation of one by applying the percent point function of the normal distribution to the adjusted cumulative probability values (i.e. inverse of the normal cumulative distribution function). This final transformed value is the SPI.

The different input datasets used to compute SPI in EDO and GDO are summarized in Table 1 below. The baseline is 1991-2020 for all the products, except for SPI SYNOP Stations and SPI GPCC (1981-2010).

Table 1: Summary of meteorological datasets used in the computation of SPI indicator in EDO and GDO.

Data source	*Description*	*Geographical coverage*	*Spatial resolution*	*Temporal scale*
SYNOP	Daily precipitation totals collected from SYNOP stations.	Europe (17.88°W, 22.78°N, 86.22°E, 78.07°N)	Station data interpolated to 0.25 x 0.25°	Daily, accumulated into monthly totals at end of each month
GPCC	Monthly gridded precipitation from DWD.	Global	1.0 x 1.0°	Monthly
MARSMet	Monthly cumulated precipitation, based on interpolated SYNOP station precipitation data from the JRC MARS Crop and Weather Monitoring project.	Europe (36°W, 23°N, 74°E, 73°N)	25 x 25 km	Monthly window updated every ten days
ERA5	Cumulated precipitation data from hourly reanalysis v5 (ERA5) data provided by ECMWF.	Global	0.25 x 0.25°	SPI-01 and SPI-03: Monthly window updated every ten days SPI-06, SPI-09, SPI-12, SPI-24, SPI-48: monthly
CHIRPS	InfraRed precipitation gridded dataset with Station data (CHIRPS), Rainfall Estimates from Rain Gauge and Satellite Observations Climate Hazards Group.	Quasi-global (all Longitudes, 50°S to 50°N Latitude)	0.05 x 0.05°	SPI-01 and SPI-03: Monthly window updated every ten days SPI-06, SPI-09, SPI-12, SPI-24, SPI-48: monthly
CPC	Precipitation gridded dataset provided by NOAA CPC.	Global	0.5 x 0.5° (to be confirmed)	SPI-01 and SPI-03: Monthly window updated every ten days SPI-06, SPI-09, SPI-12, SPI-24, SPI-48: monthly
E-OBS	Precipitation gridded dataset based on the station time series from ECA&D.	Europe (25°W, 25°N, 45.5°E, 71.5°N)	0.1 x 0.1° (to be confirmed)	SPI-01 and SPI-03: Monthly window updated every ten days SPI-06, SPI-09, SPI-12, SPI-24, SPI-48: monthly

4. How to use the indicator

In EDO and GDO, the SPI values for any given location and accumulation period are classified into seven different precipitation classes ranging from dry to wet, as shown in Table 2. Increasingly severe precipitation deficits (i.e. meteorological droughts) are indicated for SPI values lower than –1.0, while increasingly severe precipitation surplus is indicated for SPI values above 1.0. In EDO, the SPI indicator can be displayed either in the form of maps, or as time series graphs for single locations.

Table 2: SPI classification scheme used in EDO and GDO.

ANOMALY	*RANGE OF SPI VALUES*	*PRECIPITATION REGIME*	*CUMULATIVE PROBABILITY*	*PROBABILITY OF EVENT (%)*	*COLOUR*
Positive	2.0 < SPI 1.5 < SPI ≤ 2.0 1.0 < SPI ≤ 1.5	Extremely wet Very wet Moderately wet	0.977 - 1.000 0.933 - 0.977 0.841 - 0.933	2.3 4.4 9.2	**Purple** **Plum** **Lilac**
Near Normal	-1.0 < SPI ≤ 1.0	Normal precipitation	0.159 - 0.841	68.2	**White**
Negative	-1.5 < SPI ≤ -1.0 -2.0 < SPI ≤ -1.5 SPI ≤ -2.0	Moderately dry Very dry Extremely dry	0.067 - 0.159 0.023 - 0.067 0.000 - 0.023	9.2 4.4 2.3	**Yellow** **Orange** **Red**

5. Strengths and weaknesses of the indicator

Strengths:

- The fact that SPI values are in units of standard deviation from the long-term mean allows SPI to be computed and compared for any geographic location and for any number of time scales.
- In addition, because the SPI is normalized and its results are presented as anomalies with respect to the long-term mean, it is effective for supporting analysis of both wet and dry periods and cycles.
- The SPI indicator is based on only one input information (precipitation accumulation), and thus requires less data to compute than other drought indicators, such as the Palmer Drought Severity Index.

Weaknesses:

- The parameters of the "gamma" distribution are fitted using only **non-zero precipitation** accumulation data. For locations where many zero precipitation accumulation data exist, the estimated gamma distribution may not adequately fit to the empirical distribution of the baseline precipitation. Therefore, in regions with a high probability of zero precipitation (e.g. arid climates), the SPI indicator should be interpreted with care.
- Because SPI is based only on precipitation, it does not address the effects of high temperatures on drought conditions, such as by damaging cultivated and natural ecosystems, and increasing evapotranspiration and water stress. Alternative drought indicators such as the Standardized Precipitation and Evapotranspiration Index (SPEI; Vicente-Serrano et al., 2010) might be considered when the interaction between precipitation and temperature is relevant.

References

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- McKee, T.B., N.J. Doesken and J. Kleist. 1993. The relationship of drought frequency and duration to time scale. In: Proceedings of the Eighth Conference on Applied Climatology, Anaheim, California, 17–22 January 1993. Boston, American Meteorological Society, 179–184.

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Acronyms

CHIRPS	Climate Hazards Group InfraRed Precipitation with Station
CPC	Climate Prediction Center
DWD	Deutscher Wetterdienst
E-OBS	ECA&D observational dataset
ECA&D	European Climate Assessment & Dataset
ECMWF	European Centre for Medium-Range Weather Forecasts
EDO	European Drought Observatory
ERA5	ECMWF Reanalysis v5
GDO	Global Drought Observatory
GPCC	Global Precipitation Climatology Centre
NOAA	(USA) National Oceanic and Atmospheric Administration
SPI	Standardized Precipitation Index
SYNOP	Surface Synoptic Observations