EDO - European Drought Observatory

Emergency Management Service

EDO INDICATOR FACTSHEET

Soil Moisture Anomaly (SMA)

This Factsheet provides a detailed technical description of the indicator Soil Moisture Anomaly (SMA) which is implemented in the Copernicus European Drought Observatory (EDO), and used for detecting and monitoring agricultural drought conditions. The variable of the hydrological cycle upon which the SMA indicator in EDO is based, as well as the indicator's temporal and spatial scales and geographic coverage, are summarized below. Examples of the SMA indicator are shown in Figure 1.

Variable	Temporal scale	Spatial scale	Coverage
Soil moisture	Daily	5 km	Europe

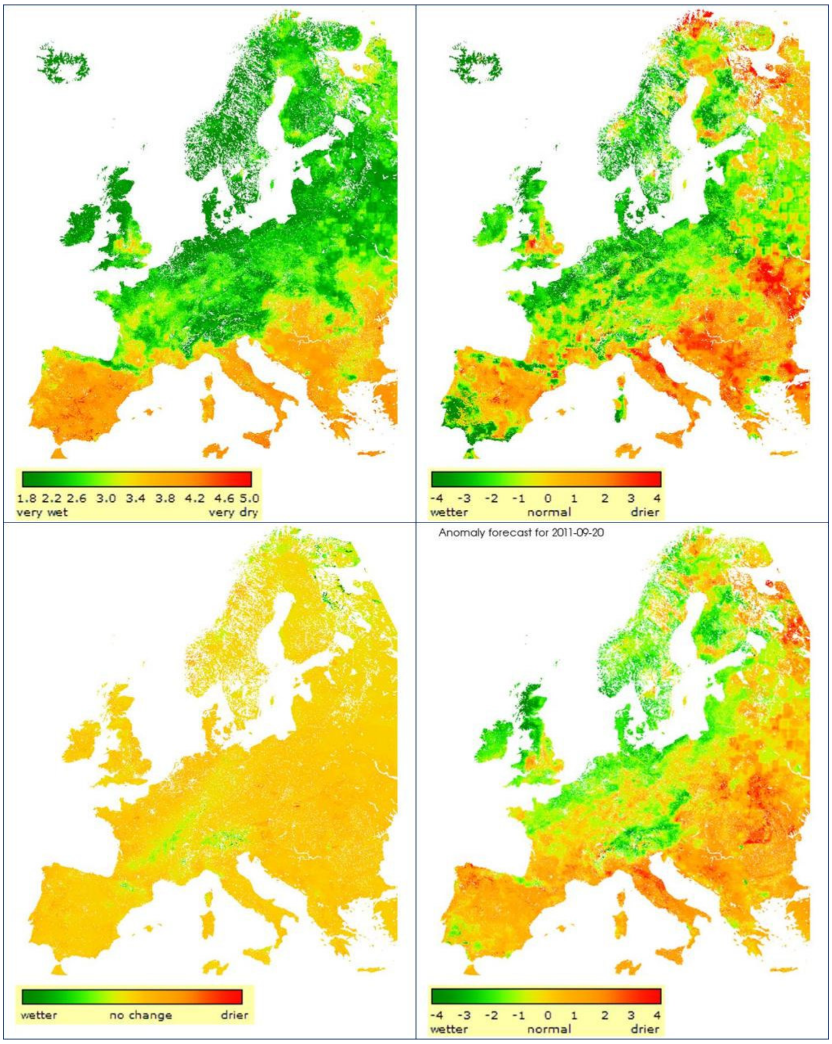

***Figure 1**: Examples of the continuously updated Soil Moisture Anomaly (SMA) indicator in EDO. Top left: Daily soil moisture content (pF). Top right: Daily SMA (normalized). Bottom left: Soil moisture content (pF), forecasted for 7 days. Bottom right: SMA (normalized), forecasted for 7 days.*

1. Brief overview of the indicator

The Soil Moisture Anomaly (SMA) indicator that is implemented in the Copernicus European Drought Observatory (EDO) is used for determining the start and duration of agricultural drought conditions, which arise when soil moisture availability to plants drops to such a level that it adversely affects crop yield, and hence, agricultural production. The SMA indicator in EDO is derived from anomalies of estimated daily soil moisture (or soil water) content - represented as soil suction, or “pF” - which is produced by the JRC’s in-house LISFLOOD hydrological model (de Roo et al. 2000), and which has been shown to be effective for drought detection purposes (Laguardia and Niemeyer, 2008).

2. What the indicator shows

Soil moisture (or soil water) content is an important variable for plant growth, and - together with precipitation and evapotranspiration - is a basic component of the hydrological cycle. The SMA indicator in EDO, which is computed based on daily estimates of soil moisture produced by the JRC’s LISFLOOD hydrological model, and their anomalies relative to a climatological reference period (1995-2017), shows both the daily soil moisture content and anomalies for a given day, as well as the forecasted trend for seven days (see Figure 1). The SMA indicator is used to detect and monitor agricultural drought, which is one of three main types of drought that are defined according to the variables of the hydrological cycle (i.e. precipitation; soil moisture; groundwater; streamflow) that are most affected. **Meteorological drought** is a prolonged period of less than average rainfall in a given region, which generally precedes **agricultural drought**, when there is reduced crop production due to insufficient soil moisture, and **hydrological drought**, when there is below-normal water availability in rivers, streams, reservoirs, lakes, or the groundwater table.

3. How the indicator is calculated

The SMA indicator which is implemented in EDO is computed based on estimates of daily soil water potential (or soil water suction) which is one of the output parameters of the JRC’s LISFLOOD hydrological model. Soil water potential, which is defined as the energy required for extracting a unit volume of water from soil, provides an assessment of the difficulty for plants to extract water from the soil matrix, and is measured in units of “pF”, ranging from 0 (saturated soil) to 7 (oven-dry soil). The SMA indicator is computed in three main steps, as described below.

1. Calculation of daily soil moisture content:

LISFLOOD is a hydrological rainfall-runoff model which has been developed by the Joint Research Centre (JRC) of the European Commission in order to reproduce the hydrology of large and trans-national European river catchments (de Roo et al., 2000; van der Knijff et al., 2008), and which currently runs operationally within the Copernicus European Flood Awareness System (EFAS, http://www.efas.eu/). Input data for the LISFLOOD model include daily meteorological observations for the European continent, updated with a two-day delay, which are obtained from the JRC’s MARS-AGRI4CAST database[1], and which are extended for seven days using numerical weather forecasts produced by the European Centre for Medium-Range Weather Forecasts (ECMWF).

---

[1] http://agri4cast.jrc.ec.europa.eu/DataPortal/

The LISFLOOD model, which is illustrated in Figure 2 below, is made up of the following components:

- A 2-layer soil water balance sub-model.
- Sub-models for the simulation of groundwater and subsurface flow (using 2 parallel interconnected linear reservoirs).
- A sub-model for the routing of surface runoff to the nearest river channel.
- A sub-model for the routing of channel flow (not shown in Figure 2).

The processes that are simulated by the model include snowmelt (not shown in Figure 2), infiltration, interception of rainfall, leaf drainage, evaporation and water uptake by vegetation, surface runoff, preferential flow (bypass of soil layer), exchange of soil moisture between the two soil layers and drainage to the groundwater, sub-surface and groundwater flow, and flow through river channels. Groundwater storage and transport are modelled using two parallel linear reservoirs. The upper zone represents a quick runoff component, which includes fast groundwater and subsurface flow through macro-pores in the soil. The lower zone represents the slow groundwater component that generates the base flow. Concerning land use and calculation of the "effective rainfall" as well as the "actual evapotranspiration", Leaf Area Index (LAI) is calculated from satellite-measured Normalized Difference Vegetation Index (NDVI), averaged over several years. A fixed look-up table of LAI for each 5 km pixel is produced on a daily time step. Rooting depth is linked with LAI and changes according to phenological phase.

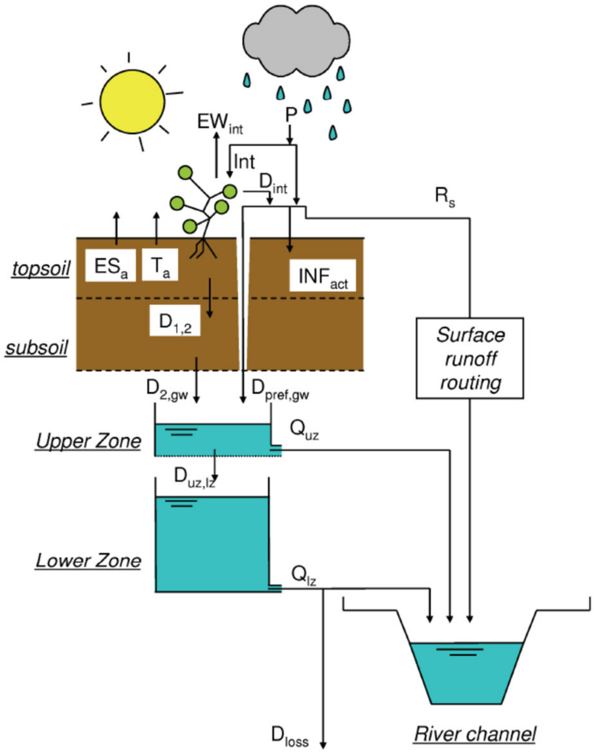

*Figure 2. Overview of the LISFLOOD model. **P** = precipitation; **Int** = interception; **EWint** = evaporation of intercepted water; **Dint** = leaf drainage; **Esa** = evaporation from soil surface; **Ta** = transpiration (water uptake by plant roots); **INFact** = infiltration; **Rs** = surface runoff; **D1,2** = drainage from top- to subsoil; **D2,gw** = drainage from subsoil to upper groundwater zone; **Dpref,gw** = preferential flow to upper groundwater zone; **Duz,lz** = drainage from upper to lower groundwater zone; **Quz** = outflow from upper groundwater zone; **Ql** = outflow from lower groundwater zone; **Dloss** = loss from lower groundwater zone. Note that snowmelt is not included in the figure (even though it is simulated by the model). From: van der Knijff et al. (2008).*

2. Calculation of daily soil moisture anomalies:

For each location (grid-cell), the daily soil moisture anomaly is calculated as follows:

$$Anomaly_t = \frac{X_t - \bar{X}}{\delta}$$

where X_t is the soil moisture of calendar-day t of the current year, $\bar{X}$ is the long-term average and δ is the standard deviation, which are both calculated for the same period t over the available time series (1995-2017). According to this definition, the anomaly values are expressed as units of standard deviation.

3. Calculation of the forecasted trend:

The forecasted values of daily soil moisture and anomalies are calculated over the ECMWF numerical weather forecast. In practice, the LISFLOOD model calculates soil moisture from the most recent observation for the following seven days. The forecasted values provide an estimate of the tendency during the coming days in terms of the variation of soil water potential (pF) between the last day of simulation for the observed data (t_0), and day t_0+7.

4. How to use the indicator

The EDO MapViewer automatically updates, on a daily basis, the maps of soil moisture content and soil moisture anomalies (see Figure 1), based on the most recent ground observations available, and the weather forecast. These maps provide information on the spatial distribution of soil water, and its evolution over time.

Soil moisture content can be used as a direct indicator for determining the start and duration of agricultural drought conditions. In fact, soil moisture content, expressed as “water potential” (pF), provides an assessment of the difficulty for plants to extract water from soil (with pF values varying between 0, when saturated, and 7, when extremely dry), or more generally, of soil water availability for plants’ needs. Soil moisture content is also obviously related to plant biomass accumulation (i.e. gross primary production) in many environments (e.g. dry; semi-arid; arid) where water availability is the main limiting factor.

The maps of soil moisture content and soil moisture anomalies, shown in Figure 1, can be used as a “proxy” for the presence of potential drought conditions, as indicated by a soil moisture content above 4.2 - 4.4 pF, and / or by large deviations (anomalies) from the long-term average conditions. Of course, the presence of actual water stress conditions will also depend on the specific plants’ resistance and capacity for water extraction from the soil matrix. In addition, a soil moisture content below 2 pF could be considered as an indicator of soil water excess (saturation).

5. Strengths and weaknesses of the indicator

Strengths:

- The daily update of the SMA indicator in EDO, together with the use of weather forecast data, provides continuous information on the modelled soil moisture content, and of the spatial extension of the area affected by or at risk of drought conditions. Moreover, analysis of a time-series of SMA indicators can be used to estimate the duration and the severity of drought.

Weaknesses:

- The various conceptual generalizations and scientific assumptions that are intrinsic in the LISFLOOD soil water balance model – for example regarding soil physics, land use, canopy cover, meteorological data interpolation, etc. – and also the calibration of the model, may produce in some case large approximations of the actual soil moisture content, and a progressive divergence with the real conditions.

References

- de Roo, A., C. Wesseling, and W. van Deursen. 2000. Physically based river basin modelling within a GIS: the LISFLOOD model, Hydrological Processes, 14, 1981–1992. https://doi.org/10.1002/1099-1085(20000815/30)14:11/12<1981::AID-HYP49>3.0.CO;2-F

- Laguardia, G. and S. Niemeyer. 2008. On the comparison between the LISFLOOD modelled and the ERS/SCAT derived soil moisture estimates. Hydrology and Earth System Sciences, 12, 1339-1351. https://www.hydrol-earth-syst-sci.net/12/1339/2008/

- van der Knijff, J., J. Younis, and A. de Roo. 2008. LISFLOOD: A GIS-based distributed model for river basin scale water balance and flood simulation. International Journal of Geographical Information Science, Vol. 24, No. 2, p. 189-212. Doi: 10.1080/13658810802549154