Monitoring droughts and impacts on the agricultural production: Examples from Spain

Rossi S., Niemeyer S.

in

López-Francos A. (comp.), López-Francos A. (collab.).
Economics of drought and drought preparedness in a climate change context

Zaragoza : CIHEAM / FAO / ICARDA / GDAR / CEIGRAM / MARM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 95

2010
pages 35-40

Monitoring droughts and impacts on the agricultural production: Examples from Spain

S. Rossi and S. Niemeyer

Institute for Environment and Sustainability, European Commission Joint Research Centre,
Via E. Fermi 2749, I-21027 Ispra (Italy)

Abstract. Droughts can have a substantial impact on the agriculture sector limiting the productivity of crops and leading to reduced yields. Recent droughts caused important economic losses in several areas of the world. In order to detect, monitor and forecast droughts at the continental scale the European Commission Joint Research Centre (JRC) is developing the prototype of the European Drought Observatory (EDO). A multidisciplinary set of indicators is used within EDO to constantly monitor the various environmental components potentially affected by this hazard (soil, vegetation, etc.) to obtain a comprehensive and updated picture of the situation. In this paper, two indicators produced within EDO are compared with statistics about crop yields to evaluate the effects of drought events on the agricultural production. The test area is Spain, which has recently suffered from prolonged drought events. Results show that crop yields are significantly reduced in coincidence with drought events detected by the indicators.

Keywords. Droughts – European Drought Observatory – Yields – Spain.

Surveillance des sécheresses et des impacts sur la production agricole : Exemples sur l'Espagne

Résumé. *Les sécheresses peuvent avoir un impact substantiel sur le secteur agricole, limiter la productivité des cultures et conduire à des rendements réduits. Les récentes sécheresses ont causé d'importantes pertes économiques dans plusieurs régions du monde. Afin de détecter, suivre et prévoir les sécheresses à l'échelle continentale le Centre Commun de Recherche (Joint Research Centre-JRC) de la Commission européenne est en train de développer le prototype de l'Observatoire Européen sur les Sécheresses (European Drought Observatory-EDO). Un ensemble multidisciplinaire d'indicateurs est utilisé dans EDO pour surveiller en permanence les différentes composantes de l'environnement qui risquent d'être touchées par ce danger (sol, végétation, etc.) afin d'obtenir un tableau complet et actualisé de la situation. Dans cet article, deux indicateurs produits au sein de EDO sont comparés avec des statistiques sur le rendement des cultures afin d'évaluer les effets de la sécheresse sur la production agricole. La zone d'essai est l'Espagne, qui a récemment souffert d'épisodes de sécheresse prolongée. Les résultats montrent que les rendements des cultures sont considérablement réduits en coïncidence avec les événements de sécheresse détectés par les indicateurs.*

Mots-clés. *Sécheresse – Observatoire Européen sur les Sécheresses – Rendements agricoles – Espagne.*

I – Introduction: The European Drought Observatory

Recent events of drought in Europe caused considerable damages to economic activities. The summer of 2003 was anomalously warm in Europe and the drought that took place showed dramatically the potential impact of a changing climate on water availability and consequently on human society. The heat wave claimed more than 20,000 lives in Europe (e.g. a large number of elderly people died in France) with huge economic losses all across Europe (the overall economic damage in Germany was around 20 billions). Inland water transport on Danube, Elbe and Rhine was interrupted with a reduction of 5.1% in 2003 in Germany and energy production was reduced for the lack of cooling water. Vegetation growth across the continent was reduced during the dry and hot summer in an unprecedented way, by about 30% (Ciais *et al.*, 2005), causing also a severe alteration of the carbon cycle, with less carbon absorption by ecosystems from atmosphere while massive fires were releasing huge quantities of carbon dioxide. Agriculture is particularly affected by drought events, since this sector consumes for irrigation purposes the greatest water share among the other uses. This share amounts to the 50% of the overall water human consumption in Italy, while in other European countries this percentage is even greater (88% in Greece, 72% in Spain, 59% in Portugal). In the USA, agriculture is responsible for the 85% of the consumptive water use (Goklany, 2002). In 2003 agricultural food production was severely damaged: according to the Italian farmers' association CIA, the drought in Italy caused a decrease in the production of the whole sector with peaks up to minus 60%, depending on the crop, and with a total economic damage up to 5 billions of Euro.

This situation calls for new tools to support the decision making process of policy-makers and authorities in charge of water management. The European Commission Communication on water scarcity and drought in Europe (European Commission, 2007) underlined the increased need for consistent and timely information on droughts at the European scale to support policy makers in the definition of adequate strategies for a sustainable use of water resources.

In this context, the DESERT Action of the European Commission Joint Research Centre (JRC) is developing the prototype of the European Drought Observatory (EDO). EDO is envisaged as a web-based platform (http://edo.jrc.ec.europa.eu) for drought detection and monitoring, forecasting, and information exchange, integrating data at different levels, from the European Continental level to the Member State level.

Droughts can be operationally defined in various ways according to local conditions and water needs, and also with reference to the disciplinary perspective from which they are considered. Since there is no single definition for drought, it is not possible to identify a unique indicator to define the onset and termination of drought events. A multidisciplinary set of indicators has therefore been developed within the EDO prototype to constantly monitor the various environmental components potentially affected by this hazard (soil, vegetation, etc.) in order to obtain a comprehensive and updated picture of the situation. These indicators are produced from data from different sources, such as meteorology, hydrological modelling, and remote sensing, and displayed as maps on the EDO Mapserver (Fig. 1).

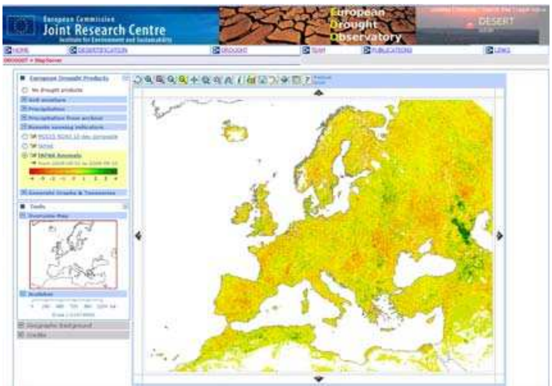

Fig. 1. The EDO prototype Mapserver (http://edo.jrc.ec.europa.eu).

The goal of this paper is to compare two drought indicators produced within EDO with statistics on agricultural production to verify if and how agricultural drought events detected by EDO influenced crop yields. Agricultural drought is due to short-term precipitation shortages and temperature anomalies that cause increased evapotranspiration and soil water. These can adversely influence crop production leading to reduction of yields in the affected regions. Crops are particularly sensitive to the amount of available soil moisture at the root zone during the various stages of crop growth, which is even more critical than the actual precipitation deficit or excess. Hane and Pumphrey (1984) found that a 10% water deficit during the tasseling and pollination stage of corn could reduce the yield by as much as 25%.

Obviously droughts are not the only influencing factor on crop yields, and appropriate countermeasures adopted by farmers and water management authorities (and difficult to be taken into account in an analysis like the one presented here) can reduce their negative effects. However, it is interesting to verify if in periods which our indicators highlight as characterized by anomalously low precipitation (meteorological drought), whose effects can be verified as an anomalously reduced vegetation development (agricultural drought), we can observe also anomalies in crop yields statistics.

II – Materials and methods

In this paper we compared two drought indicators regularly produced within EDO and available on the EDO Mapserver with statistics referring to corn yields in the years 1997-2006. Our study area is Spain, a region where water availability is a major limiting factor for vegetation development.

1. Drought indicators

A. The Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) is one of the most widely used drought indices, based on the probability of precipitation for any temporal scale (McKee *et al.*, 1993). The SPI can provide early warning of drought and help assess drought severity and has already been proposed to be used within drought monitoring systems (Tsakiris and Vangelis, 2004). Since different water resources (e.g. soil moisture, streamflow, and groundwater) respond to precipitation deficits at different temporal scales, the SPI can be calculated for different temporal scales. Within EDO, SPI is calculated at 1, 3, 6, 9 and 12 months scales. SPI calculation is based on the long-term precipitation record for the desired period, fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero. SPI at 3 months time scale (SPI3) represents the seasonal precipitation anomaly and has been recognized as the most sensitive to describe the impact of water shortages on vegetation (Ji and Peters, 2003).

B. The Fraction of Absorbed Photosynthetically Active Radiation (fAPAR)

The Fraction of Absorbed Photosynthetically Active Radiation (fAPAR) is a biophysical parameter referring to the state and photosynthetic activity of the plant canopy. It is directly correlated with the primary productivity of the vegetation. fAPAR is one of the Essential Climate Variables recognized by the UN Global Climate Observing System (GCOS) as of great potential to characterize the climate of the Earth (GCOS, 2007). Due to its sensitivity to vegetation stress, fAPAR has a potential as a drought indicator (Gobron *et al.*, 2005; Rossi *et al.*, 2008). The fAPAR estimates used within EDO are operationally produced by the European Space Agency (ESA) from Moderate Resolution Imaging Spectroradiometer (MERIS) data by means of the MERIS Global Vegetation Index (MGVI) algorithm, developed at the JRC (Gobron *et al.*, 2004). MGVI is a physically based approach which transforms the calibrated spectral directional reflectances into a single numerical value describing some information of interest while minimizing possible disturbing factors (Verstraete and Pinty, 1996). MGVI is constrained by means of an optimization procedure to provide an estimate of the fAPAR of a plant canopy. The objective of the algorithm is to reach the maximum sensitivity to the presence and changes in healthy live green vegetation while at the same time minimizing the sensitivity to atmospheric scattering and absorption effects, to soil colour and brightness effects, and to temporal and spatial variations in the geometry. These fAPAR estimates are regularly produced as the MERIS Level 2 Land Product at the reduced spatial resolution of about 1.2 km. From these products, ESA produces MERIS fAPAR Level-3 Aggregated Products 10-day time composites by means of the grid computing facility G-POD, following the approach by Pinty *et al.* (2002) and Aussedat *et al.* (2007). Data cover all Europe and the Mediterranean basin. In order to produce fAPAR anomalies we extended the MERIS fAPAR time series (ranging from end 2002 to the current day) with fAPAR estimations obtained from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) from mid 1997 with an algorithm completely compatible with the MGVI (Gobron *et al.*, 2002). The anomaly at time step t with respect to the average conditions in that time step was obtained as follows:

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

where X is the fAPAR and δ is the standard deviation.

fAPAR anomalies are well correlated with SPI3, proving its capability to detect vegetation response to drought. Rossi *et al.* (2008) found that fAPAR is better correlated with precipitation anomalies than the Normalized Difference Vegetation Index (NDVI), a widely used empirical spectral index employed in drought monitoring multisource indexes such as the VegDRI (Brown *et al.*, 2008).

2. Crop yield statistics

Statistics about crop yields averaged at the NUTS2 territorial subdivision level (*Comunidades Autónomas* in Spain) and covering the period 1975-2006 were provided by EUROSTAT CRONOS. Anomalies were calculated from this dataset for the period 1997-2006, the same used for fAPAR anomalies, following the same formula.

III – Results

Non irrigated cropland areas in Spain were identified with the GlobCover Version 2 land cover map (ESA GlobCover Project, 2008), released in late 2008 and produced at 300 m. resolution from MERIS data. Corn fields were identified using the Agricultural Land Use Maps 2000 estimated in the frame of the CAPRI-DynaSpat project (Kempen *et al.*, 2007).

Figure 2 shows a selection of the results. In these figures fAPAR anomalies are decadal data, SPI3 are monthly data, while crop yield anomalies are yearly data, and have been plotted as asterisks in the centre of each year. This is an arbitrary choice to make the visual interpretation of the plots easier, and it is based on the fact that corn is a summer crop. However, it must be stressed that each asterisk refers to the statistics about the whole annual production of corn for the considered region.

IV – Conclusions

The exam of the time series of the SPI at three months time scale (SPI3) and of the fAPAR anomalies highlights how these two drought indicators in Spain are particularly correlated, and how vegetation development reacts to seasonal water shortages. In our results this is eventually reflected also in the agricultural production statistics, as in most cases it is possible to observe negative anomalies in the corn yields during drought events. An interesting exception is the case of Castilla-La Mancha, where a drought took place in the years 2004-2006 but regional statistics show positive anomalies in corn yields for 2005 (see example in Fig. 2).

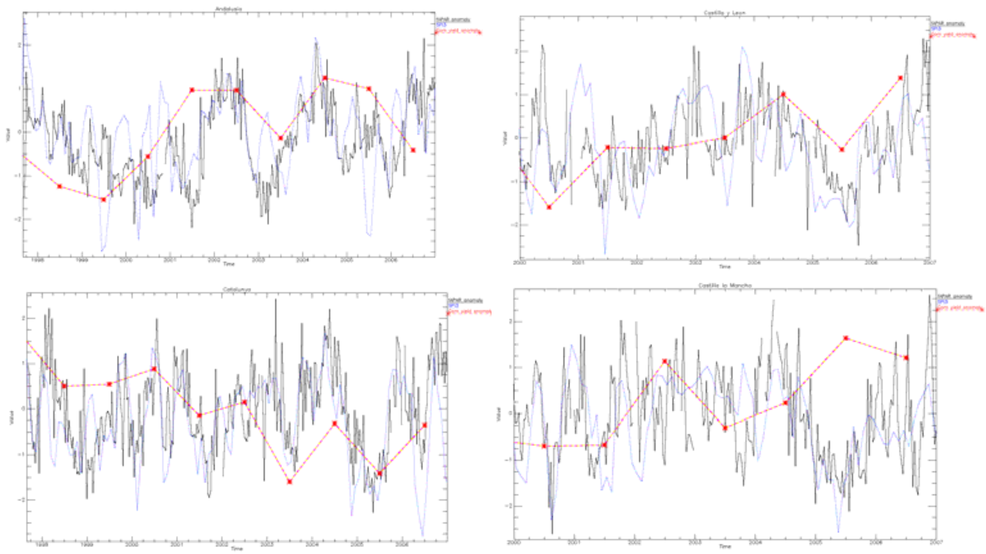

Fig. 2. Time series of fAPAR anomalies (solid black), SPI3 (dotted grey), and corn yield anomalies (dashed grey) for selected corn fields in four Spanish regions (clockwise from top left: Andalucía, Castilla-León, Castilla-La Mancha and Cataluña). Corn yield anomalies are yearly data and have been plotted in the centre of each year.

The use of indicators for drought monitoring permitted the identification of periods when droughts had a substantial impact on the agricultural production, leading to reduced yields.

Acknowledgments

We would like to thank Nadine Gobron, Monica Robustelli and Christof Weissteiner (JRC-IES). We thank also the ESA and the ESA GLOBCOVER Project led by MEDIAS France for the GLOBCOVER dataset.

References

Aussedat O., Taberner M., Gobron N. and Pinty B., 2007. MERIS Level 3 Land Surface Aggregated Products Description. Institute for Environment and Sustainability, EUR Report No. 22643 EN, 16 p.

Brown J.F., Wardlow B.D., Tadesse T., Hayes M.J. and Reed B.C., 2008. The Vegetation Drought Response Index (VegDRI): A new integrated approach for monitoring drought stress in vegetation. In: *GIScience & Remote Sensing*, 45, p. 16-46.

Ciais P., Reichstein M., Viovy N., Granier A., Ogeé J., Allard V., Aubinet M., Buchmann N., Bernhofer C., Carrara A., Chevallier F., De Noblet N., Friend A., Friedlingstein P., Grünwald T., Heinesch B., Keronen P., Knohl A., Krinner G., Loustau D., Manca G., Matteucci G., Miglietta F., Ourcival J.M., Papale D., Pilegaard K., Rambal S., Seufert G., Soussana J.F., Sanz M.J., Schulze E.D., Vesala T. and Valentini R., 2005. Europe-wide reduction in primary productivity caused by the heat and drought in 2003. In: *Nature*, 437, p. 529-533.

ESA GLOBCOVER Project, 2008. GLOBCOVER Products Description Manual. © ESA/ESA GLOBCOVER Project, led by MEDIAS-France.

European Commission, 2007. Communication on Water Scarcity and Drought in Europe, COM(2007) 414 final. Luxembourg: Office for Official Publications of the European Communities.

GCOS, 2007. Summary report of the ninth session of the GCOS/GTOS terrestrial observation panel for Climate. WMO/TD No.1371, Ispra (Italy), 28-29 March 2007.

Gobron N., Aussedat O., Pinty B., Taberner M. and Verstraete M.M., 2004. Medium Resolution Imaging Spectrometer (MERIS) – An optimized FAPAR Algorithm – Theoretical Basis Document. Revision 3.0. Institute for Environment and Sustainability, EUR Report No. 21386 EN, 20 p.

Gobron N., Pinty B., Mélin F., Taberner M. and Verstraete M.M., 2002. Sea Wide Field-of-View Sensor (SeaWiFS) – Level 2 Land Surface Products – Algorithm Theoretical Basis Document. Institute for Environment and Sustainability, EUR Report No. 20144 EN, 23 p.

Gobron N., Pinty B., Mélin F., Taberner M., Verstraete M.M., Belward A., Lavergne T. and Widlowski J.L., 2005. The state vegetation in Europe following the 2003 drought. In: *International Journal Remote Sensing Letters*, 26, p. 2013-2020.

Goklany I.M., 2002. Comparing 20th century trends in US and global agricultural water and land use. In: *International Water Resources Association*, 27, p. 321-329.

Hane D.C. and Pumphrey F.V., 1984. *Crop Water Use Curves for Irrigation Scheduling*. Corvallis (OR): Agricultural Experiment Station, Oregon State University.

Ji L. and Peters A.J., 2003. Assessing vegetation response to drought in the northern Great Plains using vegetation and drought indices. In: *Remote Sensing of Environment*, 87, p. 85-98.

Kempen M., Heckelei T., Britz W., Leip A., Koeble R. and Marchi G., 2007. Computation of a European Agricultural Land Use Map – Statistical Approach and Validation. Technical Paper. Bonn: Institute for Food and Resource Economics, University of Bonn, 17 p.

McKee T.B., Doeskin N.J. and Kieist J., 1993. The relationship of drought frequency and duration to time scales. In: *Proc. 8th Conf. on Applied Climatology*, 17-22 January 1993. Boston: American Meteorological Society, p. 179-184.

Pinty B., Gobron N., Mélin F. and Verstraete M.M., 2002. Time Composite Algorithm Theoretical Basis Document. Institute for Environment and Sustainability, EUR Report No. 20150 EN, 8 p.

Rossi S., Weissteiner C., Laguardia G., Kurnik B., Robustelli M., Niemeyer S. and Gobron N., 2008. Potential of MERIS fAPAR for drought detection. In: Lacoste H. and Ouwehand L. (eds). *Proceedings of the 2nd MERIS/(A)ATSR User Workshop*, Frascati (Italy), 22-26 September 2008. ESA SP-666, ESA Communication Production Office.

Tsakiris G. and Vangelis H., 2004. Towards a Drought Watch System based on Spatial SPI. In: *Water Resources Management*, 18, p. 1-12.

Verstraete M.M. and Pinty B., 1996. Designing optimal spectral indices for remote sensing applications. In: *IEEE Transactions on Geoscience and Remote Sensing*, 34, p. 1254-1265.