

Bayesian modelling of water resource stress and drought monitoring in southeastern France

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▶ To cite this version:

H. Di Costanzo, Philippe Martin. Bayesian modelling of water resource stress and drought monitoring in southeastern France. First Ozcar - Tereno International Conference, Oct 2021, Strasbourg, France. hal-03426959

HAL Id: hal-03426959 https://hal.science/hal-03426959

Submitted on 12 Nov 2021

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1ère conférence internationale OZCAR-TERENO : Advancing Critical Zone Science (5-7 octobre 2021, Strasbourg)

An Expert Desision Support System for drougth monitoring in Cevennes (French South-East): a use case of Bayesian Networks

Scientific and operational problems

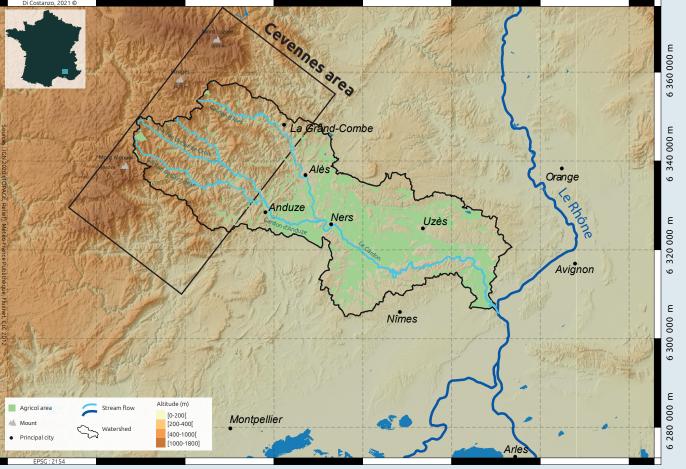
In the Mediterranean region, a strong increase in temperatures and a decrease in precipitation in certain areas was observed during the 20th century (Norrant and Douguedroit, 2006; Stagge and al., 2017). These trends should be confirmed at the lead to conflicts between the various water users in the basin. end of the 21th century (Milano and al., 2013). In theory, a decrease in the quantity of water available in the Mediterranean watersheds is expected. In addition, the population is growing. A gradual increase in the pressure on water resources during the 21th century is to be feared.

The **Cevennes** (figure 1) is a pilot area for studying drought in small and medium-sized Mediterranean watersheds (between 50 and 300 km²). It is a territory subject to hydrological extremes (Herring and al., 2015). The literature on Cevennes floods is abundant, but not for droughts. However, low water in this area can be particularly **severe** (Martin and al., 2015, 2016, 2017, 2018, 2019) due to the small size of the aquifer reserves (mineral geological formation with low permeability).

and the supply of drinking water. **Tourism** implies an increase **babilistic approach** is proposed as an alternative to the calin the local population that can **double** during the **summer**. In culation of the water balance ($Q + ETR = P \pm R$) which is difficult fact, The Cevennes are exposed to water stress problems that to estimate for intermediate size basins.

dological approach for monitoring drought in a Medi- compare the **effectiveness** of environmental management terranean watershed. It implies to consider both the avai- policies, evaluate the effects of planning on a territory, lable water resource and the anthropogenic demand explore alternative policies, or determine the weight of (Charre, 1977; Martin and al., 2020) *i.e.* to reason on **water uncertainties on estimates**. The technical approaches differ stress (environmental supply versus social demand). In a according to the objectives (inference, classification, regrescontext of **uncertainty** on the measurement (quality, gaps, sion). In the case of drought, we use an influence network for spatial representativity...) and lack of knowledge of the stu-the decision making approach. A Bayesian Decision died system (structuring element and causal relationship), **Network (BDN)** is an efficient tool for incorporating different Bayesian networks are an adapted tool for the management of aspects related to **decision making**, *i.e.* analyzing the expecwater resources (Phan and al., 2016) and environmental risk in a ted effects of a management policy while taking into account more general way (Sperotto and al., 2017). They allow the inte- the uncertainties of each variable. gration of different types of knowledge (variables and causal

The use of Bayesian networks is recent in environmental In this PHD project, we propose **an operational metho-** studies (Kaikkonen et al., 2021). They have mainly been used to



8 00 000 m 8 20 000 m 8 40 000 m 8 60 000 m Figure 1 : Gardon Waterhed localisation

Data and methods

Different datasets (figure 2), centralized in a Spatial Relational Database (SRDB), provide representative information on the in the model building process. The objective of the proposed different states of **hydric deficit** (atmospheric, edaphic, hydrological drought) and on the **social demand** in the basin. Data is aggregated at bassin scale.

A Bayesian network (Pearl, 2008) is defined as a multi**variate statistical model** composed of a set of variables X = $\{X_1, \dots, Xn\}$. It consists of two components :

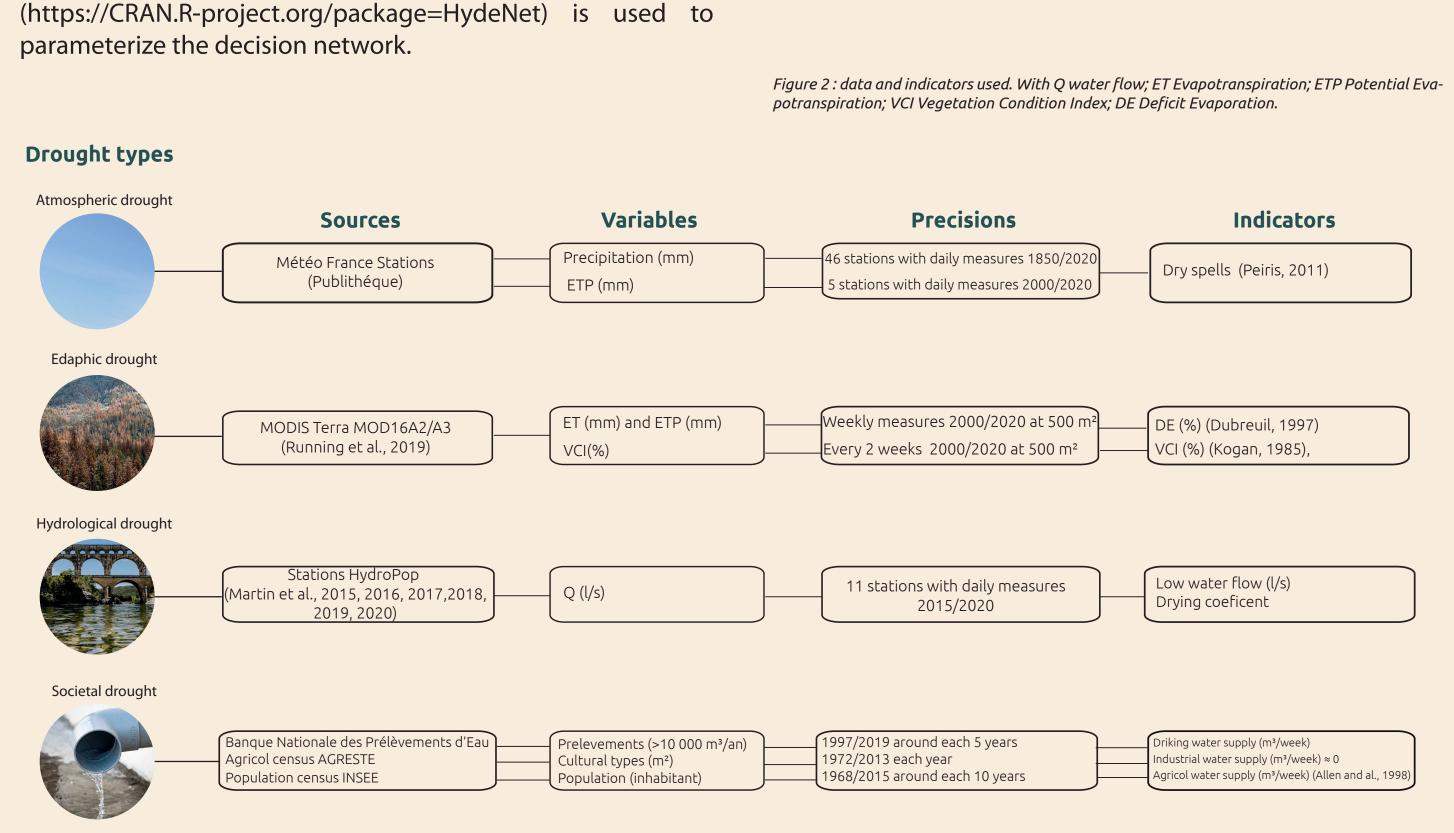
-A qualitative which correspond to a directed acyclic graph where each vertex corresponds to a variable of the model and each link materializes a **dependence** between the vertices. -A quantitative one which defines the **conditional distributions** p(xi|pa(xi)) for each variable Xi, given its parents in the graph, noted pa(xi). Taking into account the independence encoded by the acyclic graph, the joint distribution on all variables is equal to the product of the conditional distributions attached to each node. This calculation is based on Bayes' theorem:

P(A|B) = [P(B|A)P(A)]/P(B).

Where P(A) and P(B) are the observed probabilities of the independent nodes A and B; P(B|A) is the conditional probability of B knowing A; and P(B|A)/P(B) the Bayes or likelihood factor.

Chen and Pollino (2012) details the different steps required model is to allow an **estimation of the water stress** from disponibilities data on the watershed. Among the great variety of drought indicators already existing (Zargar and al., 2011), we have selected one or more indicators of atmospheric, edaphic, hydrological drought adapted to our sector to estimate its water status (figure 2). The data that can approximate the social demand for water is scarce, it is for the most part determined by expert opinion. We have chosen to use a hybrid BDN. This technical choice allows to take into account the diversity of the distribution families of the variables used and to model the statistical relations between these different distribution families. The structure of the model was built **in an expert way**. The relationships between measured dependent variables are statistically determined by generalized linear models. 2015-2020 is the period when all the measured data on the basin are available. The cross-validation method is used on this period to calibrate and validate the robustness of the model over time.

The computation of conditional distributions is done with the Rjags package (https://CRAN.R-project.org/package=rjags). Jags is a program allowing to approximate conditional distributions (Markov Chain Monte Carlo algorithm) in the case of presence of discrete and continuous variables in the network. The Hydenet package



First résults

Two branches of the model (figure 4) are to be distinguished : natural resources (utility node WR) and anthropogenic needs (utility node AC) for the calculation of water trajectories of water stress in the Cevennes socio-environmenstress. **Utility node** correpond to a variable who want to minimise or maximise the value in the network.

Caliano et al (2017) distinguish three types of water **use:** industrial, agricultural and water supply. As the area is no industrialized, we make the assumption that water consumption for industrial activities are equal to zero. The FAO crop coefficients method (Allen and al., 1998) is used to estimate the amount of water needed (the agricultural demand) in the case of an optimal crop yield (AGRESTE 2010 census). We simplify the drinking water demand by the population variable. Anthropogenic consumption is approximated by the joint distribution of the three types of estimated consumption.

The water resource is approximated by the joint distribution of indicators describing the water status of each component of the water cycle. A water deficit state is identified when all the indicators estimate a water deficit situation (extreme values of the distributions).

The decision node "Arrete" allows to simulate the effect of the implementation of the abstraction restrictions in the basin (French arrété sécheresse). The network allows to propose which level of restriction (0 to 3) should be implemented to minimize the tension on the water resource according to the situation. The weekly decision node allows to integrate the temporal dimension in the monitoring of the tension. It allows the seasonal monitoring of the stress on the water resource.

The Fresh Water System Performence and Agricol Water System Performence nodes were determined by expert opinion (Plan Gestion de la ressource en eau of EPTB Gardon). The credibility of these values is modeled by a probability distribution.

The drought matrix (Figure 3) is a way of representing the tal system over the year. It allows a quick reading of the evolution of the water stress situation for basin managers.

Figure 3 : Drougth matrix in hypothetical case of water ressource join distribution and anthropogenic consumption join distribution are normal.

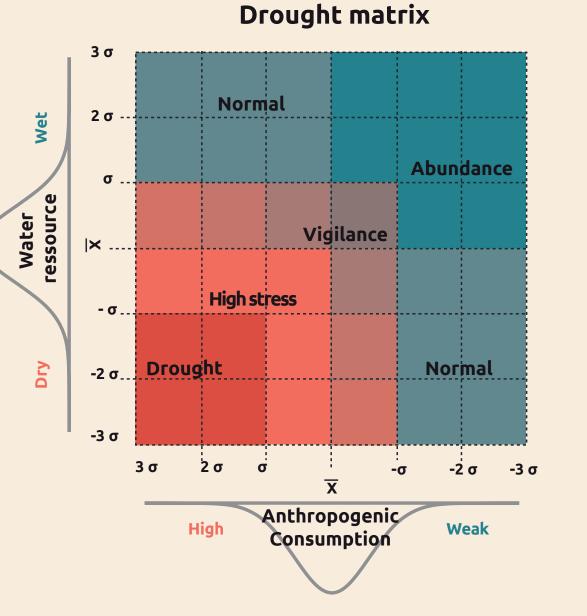
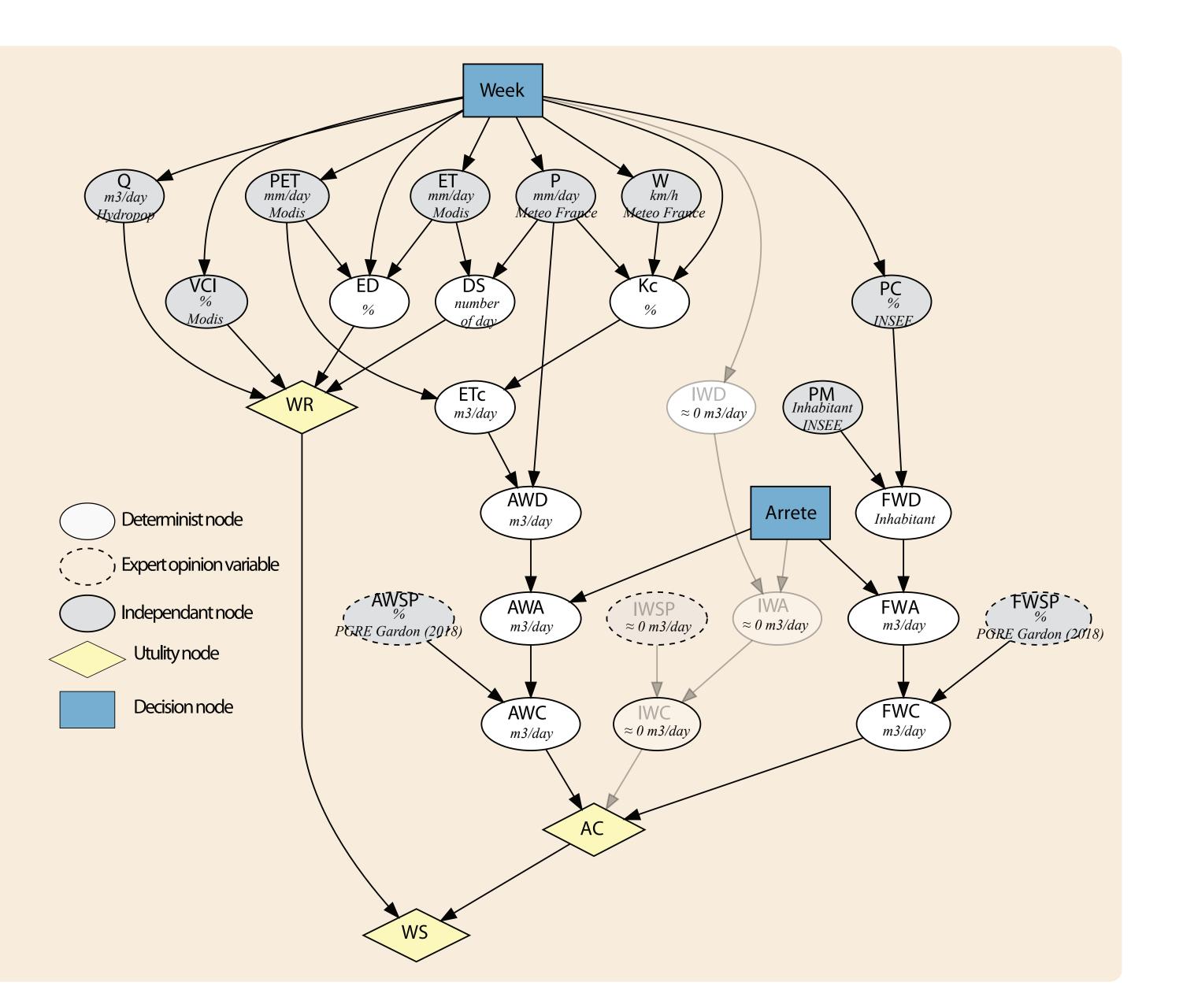


Figure 4 : First DBN conceptual proposition of water stress in up-stream Gardon Watershed. In order for each node : variable code, unit and source. With Q is water flow, PET is potential evapotranspiration, ET is evapotranspiration, P is cummul precipitation, W is the median wind speed, VCI is Vegetation Condition Index, ED is evaporation deficit, DS is dry spell, Kc is cultural coefficient, WR is water ressource, ETc agricol plant transpiration, PC week variation coefficient of population, PM population of municipalities, AWD is agricultural water demand, IWD is industrial water demand, FWD is fresh water demand, AWSP is agricultural water system performence, IWSP is industrial water system performence, FWSP is fresh water system performence, AWA is agricultural water abstraction, IWA industrial water abstraction, FWSP is fresh water abstraction, AWC is agricultural water consumption, FWC is fresh water consumption, IWC is industrial water consumption, AC is Anthopogenic consumption and WS is water stress.



First conclusions, some limitation and perspectives

The proposed DBN allows a conceptual formalization of the water deficit monitoring need to be further explored to improve complex calculation of water stress. This estimation method is the inference of the environmental branch of the DBN. The tempoexploratory and network form could be upgrade. It presents ral hindsight on hydrometric data limits the quaity of water deficit the variables necessary for its calculation, including those for estimation for surface rivers at the moment. An estimate of which no measurements are available (expert opinion). Each groundwater hydrologic drought is absent. No piezometers reprevariable is associated with a **credence interval**. This leads to rea- sentative of the area and measuring over the long term are avaisoning with **probabilist reasonment**. The **quality and preci-** lable. In Cenvenne context ("natural rivers"), we have exclu in the **sion** of DBN estimates should tend to **improve** with the increase model big hydraulic amenagment impact, industrial impact and in the temporal length of the data and the addition of new data water quality. Agricol water need estimated by FAO method ovesets that will eventually replace the distributions determined by restimate probably the demand and calcul repose on larges simpliexpert opinion. When the calibration is good, this type of model ficatrice hypotheses of plant developpement and on a approxihas the advantage of estimating the **missing elements** in the cal- mate surface of cultures types. In case the robustness of the model culation knowing the elements available in the network is validated, **environmental scenarios** (effect of climate change (inference). It allows, according to the values taken by the decisio- on the mode and dispersion of the distribution laws of the indicanal nodes, to give suggestions on the water resource manage- tors) and social evolution (increase in population, tourist attracment policies of the watershed. In the case of the drought in tiveness...) will be engaged. France, the "arrété sécheresse" is a policy of control of the abstraction water. Some statistical relationships between indicators of

References

- . Allen, R.G., Pereira, L.S., Raes, D., Smith, M. (1998) Crop evapotranspiration —guidelines for computing crop water requirements. FAO Irrigation and drainage paper 56. Food and Agricultu re Organization, Rome.
- . Charre, J. A propos de sécheresse. geocar 52, 215–226 (1977).
- Chen, S. H. & Pollino, C. A. Good practice in Bayesian network modelling. Environmental Modelling & Software 37, 134–145 (2012).
- . Dubreuil, V. La sécheresse dans la France de l'Ouest : une contrainte climatique trop souvent oubliée. Secheresse 8, 47–55 (1997).
- Herring, S. C., Hoerling, M. P., Kossin, J. P., Peterson, T. C. & Stott, P. A. Extreme fall 2014 precipitation in cevennes mountains. 12.
- Martin, P. et al. L'étiage 2015 dans le Gardon amont (Cevennes). 55 (2015).
- Martin, P., Didon-Lescot, J.-F., Ayral, P.-A., Domergue, J.-M. & Grard, N. L'étiage 2016 dans le Gardon amont (Cévennes). 63 (2016).
- Martin, P., Didon-Lescot, J.-F., Ayral, P.-A., Domergue, J.-M. & Grard, N. L'étiage 2017 dans les Gardons amont (Cévennes). Projet pilote de suivi des débits d'étiages. 3eme rapport sur huit stations temporaires d'étiage et deux stations pérennes. 59 (2017).
- . Martin, P. et al. L'étiage 2018 dans les Gardons amont (Cévènnes). Projet pilote de suivi des débits d'étiage. Premier rapport sur huit stations temporaires d'étiage et deux stations pérennes. 71 (2018).
- Martin, P. et al. L'étiage 2019 dans les Gardons amont (Cévennes). Projet pilote de suivi des débits d'étiage. Rapport sur huit stations temporaires d'étiage et deux stations pérennes. 52 (2019).
- Milano, M. et al. Current state of Mediterranean water resources and future trends under climatic and anthropogenic changes. Hydrological Sciences Journal 58, 498–518 (2013). Norrant, C. & Douguédroit, A. Monthly and daily precipitation trends in the Mediterranean (1950–2000). Theor. Appl. Climatol. 83, 89–106 (2006).
- Kaikkonen, L., Parviainen, T., Rahikainen, M., Uusitalo, L. & Lehikoinen, A. Bayesian Networks in Environmental Risk Assessment: A Review. Integr Environ Assess Manag 17, 62–78 (2021). Kogan, F. N. Droughts of the Late 1980s in the United States as Derived from NOAA Polar-Orbiting Satellite Data. Bulletin of the American Meteorological Society 76, 14 (1995). Pearl, J. Probabilistic reasoning in intelligent systems: networks of plausible inference. (Kaufmann, 2008).
- Peiris, T. Critical Evaluation of Dry Spell Research. 11, 8 (2011).
- Phan, T. D., Smart, J. C. R., Capon, S. J., Hadwen, W. L. & Sahin, O. Applications of Bayesian belief networks in water resource management: A systematic review. Environmental Modelling & Software 85, 98–111 (2016).
- Running, S. W., Mu, Q., Zhao, M. & Moreno, A. User's Guide MODIS Global Terrestrial Evapotranspiration (ET) Product (MOD16A2/A3 and Year-end Gap-filled MOD16A2GF/A3GF). (2019). Sperotto, A., Molina, J.-L., Torresan, S., Critto, A. & Marcomini, A. Reviewing Bayesian Networks potentials for climate change impacts assessment and management: A multi-risk perspective Journal of Environmental Management 202, 320–331 (2017).
- Stagge, J. H., Kingston, D. G., Tallaksen, L. M. & Hannah, D. M. Observed drought indices show increasing divergence across Europe. Scientific Reports 7, (2017).



The authors thank the OHMCV, the RMC Water Agency the EPTB Gardons and AB-Cèze for their help on the hydrometric hydrometric measurement campaigns.

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