Geophysical Research Abstracts
Vol. 19, EGU2017-16217-4, 2017
EGU General Assembly 2017

A Mulitivariate Statistical Model Describing the Compound Nature of Soil Moisture Drought

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Soil moisture in Europe acts to partition incoming energy into sensible and latent heat fluxes, thereby exerting a large influence on temperature variability. Soil moisture is predominantly controlled by precipitation and evapotranspiration. When these meteorological variables are accumulated over different timescales, their joint multivariate distribution and dependence structure can be used to provide information of soil moisture. We therefore consider soil moisture drought as a compound event of meteorological drought (deficits of precipitation) and heat waves, or more specifically, periods of high Potential Evapotraspiration (PET). We present here a statistical model of soil moisture based on Pair Copula Constructions (PCC) that can describe the dependence amongst soil moisture and its contributing meteorological variables.

The model is designed in such a way that it can account for concurrences of meteorological drought and heat waves and describe the dependence between these conditions at a local level. The model is composed of four variables; daily soil moisture (h); a short term and a long term accumulated precipitation variable (Y_1 and Y_2) that account for the propagation of meteorological drought to soil moisture drought; and accumulated PET (Y_3), calculated using the Penman Monteith equation, which can represent the effect of a heat wave on soil conditions.

Copula are multivariate distribution functions that allow one to model the dependence structure of given variables separately from their marginal behaviour. PCCs then allow in theory for the formulation of a multivariate distribution of any dimension where the multivariate distribution is decomposed into a product of marginal probability density functions and two-dimensional copula, of which some are conditional. We apply PCC here in such a way that allows us to provide estimates of h and their uncertainty through conditioning on the Y in the form

$$h = h|y_1, y_2, y_3 \tag{1}$$

Applying the model to various Fluxnet sites across Europe, we find the model has good skill and can particularly capture periods of low soil moisture well. We illustrate the relevance of the dependence structure of these Y variables to soil moisture and show how it may be generalised to offer information of soil moisture on a widespread scale where few observations of soil moisture exist. We then present results from a validation study of a selection of EURO CORDEX climate models where we demonstrate the skill of these models in representing these dependencies and so offer insight into the skill seen in the representation of soil moisture in these models.