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Development and assessment of non-linear and non-stationary seasonal rainfall forecast models for the Sirba watershed, West Africa

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ABSTRACT

Study region: The Sirba watershed, Niger and Burkina Faso countries, West Africa.

Study focus: Water resources management in the Sahel region, West Africa, is extremely difficult because of high inter-annual rainfall variability. Unexpected floods and droughts often lead to severe humanitarian crises. Seasonal rainfall forecasting is one possible way to increase resilience to climate variability by providing information in advance about the amount of rainfall expected in each upcoming rainy season. Rainfall forecasting models often arbitrarily assume that rainfall is linked to predictors by a multiple linear regression with parameters that are independent of time and of predictor magnitude. Two probabilistic methods based on change point detection that allow the relationship to change according to time or rainfall magnitude were developed in this paper using normalized Bayes factors. Each method uses one of the following predictors: sea level pressure, air temperature and relative humidity. Method M1 allows for change in model parameters according to annual rainfall magnitude, while M2 allows for changes in model parameters with time. M1 and M2 were compared to the classical linear model with constant parameters (M3) and to the climatology (M4).

New hydrological insights for the region: The model that allows a change in the predictor–predictand relationship according to rainfall amplitude (M1) and uses air temperature as predictor is the best model for seasonal rainfall forecasting in the study area.

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1. Introduction

Several studies show the degree to which West Africa is vulnerable to climate variability, including those by Giannini et al. (2008) and Christensen et al. (2007). The Sahelian rainfall pattern is season dependent and is directly related to the West African Monsoon (WAM) which dynamic is yet to be fully understood by climatologists (Mohino et al., 2011; Caminade and Terray, 2010; Biasutti et al., 2008; Camberlin et al., 2001; Rowell, 2001, 2003; Janicot et al., 2001; Palmer, 1986). This lack of knowledge about the WAM dynamic is part of the reason for which forecasts in the Sahel at all scales are problematic. The uncertainty in the forecasts directly affects local populations (Hayes et al., 2005). Indeed, the lack of awareness of the short and medium term evolution of rainfall and streamflows often results in populations being poorly prepare to cope with increasingly frequent climate extremes, including lack of precipitation, and floods and their direct corollaries such as lower crop yields, total loss of agricultural production or the destruction of economically valuable infrastructure, such as roads and dams (Tarhule, 2005; Samimi et al., 2012). Recurrent droughts also regularly affect agricultural production, streamflows often take authorities and largely rural local populations by surprise, despite over a decade of publication of seasonal forecasts in West Africa (*PRESAO: Prévision Saisonnière en Afrique de l'Ouest*. Hamatan, 2002; Ogallo et al., 2000). In such an unstable situation, any scientific information regarding the short (24 h) and medium (6 months) terms of rainfall and streamflow trends becomes a crucial tool for decision-making and water resources management. Agriculture, the primary socio-economic activity in the Sahelian zone, could be more efficient if, local and reliable seasonal information was available to help farmers make critical agricultural decisions (Hansen, 2002). Thus, the development of seasonal rainfall and streamflow forecast models is highly anticipated by all concerned, particularly the rural population, as it would enable effective use of climatic information that would help ensure food security. The models would increase resilience to climate variability by providing advance information about the expected amount of rain or runoff in the next rainy season (Hansen et al., 2011).

Relevant efforts of the scientific community are based on three different but complementary approaches (Hastenrath, 1995): dynamical (based purely on numerical models), statistical (based purely on statistics) and hybrid statistical-dynamical (a combination of statistics and numerical models).

The dynamical approach is based on numerical models of physics and dynamics equations that describe the climate system (Kumar et al., 1996; Brankovic and Palmer, 1997; Palmer et al., 2000, 2004). The statistical approach consists of establishing a direct relationship between the state of the atmosphere or ocean at the moment of the forecast and during event occurrences (e.g. precipitation) within the period of a few months or weeks (Schepen et al., 2012; Lopez-Bustins et al., 2008). The existence of sufficiently strong and robust physical links between certain variables is regarded as foreseeable, and is the basis of the statistical forecast. The hybrid statistical-numerical approach also known as model output statistics (MOS), is a combination method based on the principle of applying statistical methods to the output obtained from numerical models, in order to perform further analysis.

Statistical models are quite popular, given their ease of development and the limitations of dynamical models (Sittichok et al., 2014; Ibrahim et al., 2014; Mara, 2010; Bouali, 2009; Biasutti et al., 2008; Hayes et al., 2005; Philippon and Fontaine, 2002; Janicot et al., 2001; Hunt, 2000; Thiaw et al., 1999). However, it is notable that all models developed from these studies arbitrarily consider the relationship between the predictors and the predictand (rainfall in the Sahel) to be independent of time and rainfall magnitude.

The objective of this paper is to depart from that hypothesis to develop statistical seasonal rainfall forecasting models with changing parameters, and to instead compare the new models to the classical linear model with constant parameters and to the climatology.

First, a linear rainfall forecasting model is developed for each of the predictors under consideration, as in Sittichok et al. (2014). At the end of the process, an optimal lag time and optimal season are obtained to average the predictor. Using the latter lag time and the predictor time series, new models are developed that allow the linear regression parameter to change according to time or rainfall amplitude. The performance of the new models is then compared to that