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Non-stationarities in the relationships of heavy precipitation events in the Mediterranean area and the large-scale circulation in the second half of the 20th century

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ABSTRACT

In the context of analyzing temporal varying relationships of heavy precipitation events in the Mediterranean area and associated anomalies of the large-scale circulation, quantile regression models were established. The models were calibrated using different circulation and thermodynamic variables at the 700 hPa and 850 hPa levels as predictors as well as daily precipitation time series at different stations in the Mediterranean area as predictand. Analyses were done for the second half of the 20th century. In the scope of assessing non-stationarities in the predictor-predictand relationships the time series were divided into calibration and validation periods. 100 randomized subsamples were used to calibrate/validate the models under stationary conditions. The highest and lowest skill score of the 100 random samples was used to determine the range of random variability. The model performance under non-stationary conditions was derived from the skill scores of cross-validated running subintervals. If the skill scores of several consecutive years are outside the range of random variability a non-stationarity was declaimed. Particularly the Iberian Peninsula and the Levant region were affected by non-stationarities, the former with significant positive deviations of the skill scores, the latter with significant negative deviations. By means of a case study for the Levant region we determined three possible reasons for non-stationary behavior in the predictor-predictand relationships. The Mediterranean Oscillation as a superordinate system affects the cyclone activity in the Mediterranean basin and the location and intensity of the Cyprus low. Overall, it is demonstrated that non-stationarities have to be taken into account within statistical downscaling model development.

1. Introduction

Since Giorgi (2006) characterized the Mediterranean area as one of the main climate change hot-spots whose climate responds more sensitive to global climate change compared to other regions, many studies had put their emphasis on the relevant processes and physical mechanisms to understand the variability of climate parameters like precipitation (e.g. Kelley et al., 2012; Lionello et al., 2014; Mariotti and Dell'Aquila, 2012), their impacts on the socio-economic structure (e.g. Iglesias et al., 2007; Latorre et al., 2001; Stefanova et al., 2015) and the terrestrial ecosystems (e.g. Batllori et al., 2013; Filipe et al., 2013; Henne et al., 2013) in this region in a changing climate. But comparisons of the modeled and the observed precipitation of the Mediterranean area offer significant contradictions especially in the seasonal cycle. For winter season Barkhordarian et al. (2013) assume that shifts of the large-scale circulation have influence on the significant underestimation of the climate change signal in this region. Since the Mediterranean area lies in a transition zone between the humid climate of Central and Western Europe and the arid climate of North Africa where different large-scale circulation modes are predominant (Dünkeloh and Jacobeit, 2003; Giorgi and Lionello, 2008), a shift of the large-scale circulation within global

Abbreviations: BS, Brier Score; BSS, Brier Skill Score; CQR, censored quantile regression; CQVS, censored quantile verification score; CQVSS, Censored Quantile Verification Skill Score; EM, Eastern Mediterranean; EMULATE, European and North Atlantic daily to MULtidecadal climATE variability; GLM, generalized linear model; GLOWA, Global Change and the Hydrological Cycle; HGT, geopotential heights; IID, independently identically distributed; LAD, least absolute deviation; MO, Mediterranean Oscillation; NCAR, National Center for Atmospheric Research; NCEP, National Centers for Environmental Prediction; PC, principal component; PCA, principal component analysis; PCS, principal component scores; POT, peak over threshold; PPP, Poisson point process; PR, precipitation region; QR, quantile regression; RHUM, relative humidity; SHUM, specific humidity; TSCQR, three-step censored quantile regression; UWND, zonal wind component; VWND, meridional wind component; WM, Western Mediterranean.

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climate change has a significant impact on total precipitation amounts and extremes all over the Mediterranean area and therefore impacts on the water availability and the terrestrial ecosystems as well.

In a complex terrain like the Mediterranean area where the topography has a great influence on the observed structure of weather systems and the regional circulation (Fernandez et al., 2003), precipitation events, especially extreme events, often occur on a small regional scale. The topography also induces fine scale features which have impacts on the precipitation change signal over the Mediterranean region (Gao et al., 2006). Hence, global climate models with their sparse horizontal resolution are unable to fully capture and assess those local weather events (Friederichs and Hense, 2008). Nevertheless, a significant fraction of the large spatio-temporal variability of winter time precipitation is related to advective processes which can be described by the large-scale circulation (Xoplaki et al., 2004). For this reason, only statistical and dynamical downscaling methods which combine the local conditions with the large scale circulation can provide reliable assessments of local weather characteristics and their variability within a changing climate (Friederichs and Hense, 2008).

Several studies based on different downscaling techniques project decreasing precipitation amounts for the southern and eastern parts of the Mediterranean area while precipitation totals of the western and northern parts are increasing (e.g. Hertig et al., 2012). In contrast to precipitation totals, projections of precipitation extremes are less conclusive because the results strongly depend on the model, the type of extreme and the region of the Mediterranean area (Hertig and Jacobeit, 2014; Toreti and Naveau, 2015). It is assumed that in many regions the total precipitation sums tend to decrease while extreme precipitation events will increase (Alpert et al., 2002). However, Hertig et al. (2012) showed that areas with mean precipitation being reduced and extreme precipitation being increased are not that common and thus might not be the dominant mode of change in the Mediterranean area. Furthermore, Toreti and Naveau (2015) showed that heavy precipitation events will increase till the end of the 21st century, but the behavior of the tails of the distribution differs, depending on the examined region or model, and is characterized by a high uncertainty. Overall, the precipitation totals of the Mediterranean area are characterized by great space-time variability where the number of precipitation events will decrease but the intensity of rainfall events will increase causing longer lasting within-season drought and changes in evapotranspiration and greater surface runoff (Maccracken et al., 2003). Because most of the precipitation is generated in winter where westward moving storms convey humidity to the Mediterranean basin, winter time precipitation is essential for the water budget in this area (Hertig and Jacobeit, 2014). For this reason only winter season is considered within this study although precipitation events of the transitional seasons, especially in the northern parts of the Mediterranean area, should clearly kept in mind in matters of the water management.

One of the major problems of estimating daily precipitation amounts is that precipitation is not Gaussian but a non-negative mixed discrete-continuous variable where no general agreement exists which distribution fits best (Friederichs and Hense, 2007). Therefore, within the range of statistical downscaling different methods like perfect prog (e.g. Klein, 1971), model output statistics (e.g. Glahn and Lowry, 1972) or a combination of both methods (Marzban et al., 2006) were applied on estimating daily precipitation sums (Friederichs and Hense, 2008). An alternative method is called quantile regression which was established by Koenker and Bassett (1978) and first applied to climate studies by Bremnes (2004). Since precipitation is a non-negative variable with a lower bound of zero it is a so-called censored variable (Friederichs and Hense, 2007). For quantile regression of censored variables two different methods are available. First, an algorithm developed by Fitzenberger (1997) called censored quantile regression (CQR) can be adapted on every quantile of interest. An alternative approach, the so-called three-step censored quantile regression (TSCQR), is presented by Chernozhukov and Hong (2002) and is divided into three steps where standard quantile regression is applied on different subsamples depending on the probability of rain and the quantile of interest. A wide range of methods is also available for estimating extremes. A comparison of three different approaches is given by Friederichs (2010). Here, the conditional precipitation quantiles were assessed for different German weather stations by means of 1) a CQR, 2) a Poisson point process model (PPP) and 3) a peak over threshold model (POT). Instead of CQR, the TSCQR can be used for estimating extreme quantiles as well like Friederichs and Hense (2007).

A further method is presented by Hertig and Jacobeit (2014), using generalized linear models based on Tweedie distribution to estimate precipitation extremes in the Mediterranean area. Here, the emphasis is put on the detection and analysis of non-stationarities in the predictor-predictand relationships in order to take them into account for future projections. Non-stationarities occur when the relationships between circulation patterns or centers of variation (predictors) and the target variable like precipitation (predictand) is more weak or intense than it can be explained by natural variability. Non-stationary behavior could either be a matter of physical variations of the circulation or a matter of so-called within-type variations (Beck et al., 2007, Hertig and Jacobeit, 2014). The importance of considering shifts of the large-scale circulation for Mediterranean precipitation projections is underlined by the study of Barkhordarian et al. (2013). The authors find that the observed winter precipitation amounts are subjected to a significant negative trend which cannot be described by the different climate models. It is assumed that shifts of the large-scale circulation are responsible for the differences between the modeled and observed precipitation which are outside the range of natural variability. However, this study is based on projections for the whole Mediterranean area and, hence, no reliable conclusions can be drawn for the influence of the large-scale circulation shifts on precipitation time series on a regional scale where topographic parameters lead to modifications of the climate change signal. For this reason, in order to obtain more confident assessments of precipitation and extremes in the Mediterranean area non-stationary behavior should be taken into account for climate change studies in the Mediterranean area (Hertig and Jacobeit, 2014).

In this study we present a detailed approach to detect and analyze non-stationary behavior within the large-scale circulation-precipitation relationships by means of one reference station of the Mediterranean area where a non-stationarity is highly distinct. For this purpose, we divide the study period into 31-year running subsamples and analyzed them separately. Thus, we not only have one regression model for the whole period, but an ensemble of regression models describing every state of the atmosphere. A comparison of composites should then determine the most suitable regression model to assess heavy precipitation events under changing climate conditions in the future. Thus, the assessment of heavy precipitation events is performed under the explicit consideration of non-stationary behavior of large-scale circulation-precipitation relationships.

Section 2 describes pre-processing and regionalization of the station data and some selection criteria for the variables of the reanalysis data set. In Section 3 a brief overview of the TSCQR and the CQVSS is given followed by a detailed description of the predictor selection and the analyzing methods. The results for the reference stations in matters of predictor selection and non-stationarities are illustrated in Section 4 followed by a more detailed description of the methods and an analysis of composites by means of an example station (Safed, Israel) where a medium negative non-stationarity (see Section 3.4) is supposed. In Section 5 we draw some conclusions of the major findings. In this study the emphasis is put on the detection of non-stationarities and the analysis of composites, assessments for future periods are not the scope of this paper.