Hidden Markov Models for Relating Atmospheric Circulation Patterns to Bulgaria Daily Precipitation Occurrence and Amounts

Neykov[1], N. M., Zucchini[2],W., Neytchev[1], P., and Hristov[1], H. P.
[1]*Nat. Inst. of Meteorology and Hydrology, Bulgarian Academy of Sciences, 66 Tsarigradsko chaussee Blvd., Sofia 1784, Bulgaria, neyko.neykov@meteo.bg and*
[2]*Institute of Statistics and Econometrics, University of Göttingen, Platz der Göttinger Sieben 5, D-37073 Göttingen, Germany, wzucchi@uni-goettingen.de*
(Dated: July 14, 2007)

I. INTRODUCTION

Precipitation is important because of it strong impact on human society. Stochastic models for precipitation can aid in understanding the probabilistic structure of precipitation. These models are important for generating simulations that can be used as input into models of flooding, runoff, stream flow and climate models, to name a few. Relating rainfall characteristics to large-scale atmospheric circulation guarantees that the precipitation simulations are consistent with the observable atmospheric information. These artificial daily precipitation sequences can be used to estimate statistics relating to precipitation events in exactly the way one would do so if a long sequence of real precipitation data were available. The precipitation modeling is required to generate artificial time series as for most locations rainfall data is not available at the required level of detail. In this way precipitation event scenarios can be considered and various risk assessment can be made. Therefore development of models that account the relationship between large scale circulation patterns and daily rainfall precipitation is of crucial interest in predicting floods, droughts or simply the management of water supply, having as input atmospheric quantities forecast.

In this study various non-homogenous hidden Markov models (NHMMs) are used to relate daily precipitation totals at a network of rain gauge stations broadly covering the territory of Bulgaria to synoptic atmospheric data. A validation is carried out on various aspects of the models.

II. METHODS AND DATA

The NHMMs link large-scale atmospheric patterns to daily precipitation data at a network of rain gauge stations, via several hidden (unobserved) states called the "weather states". The evolution of these states is modeled as a first-order Markov process with state-to-state transition probabilities conditioned on some indices of the atmospheric variables. Due to these weather states the spatial precipitation dependence can be partially or completely captured. Details can be found in Zucchini and Guttorp, 1991; Hughes and Guttorp, 1994; Charles et al., 2003; Hughes et al., 1999.

In this study the focus is on the validity and applicability of the model rather than on its novelty from a statistical point of view. We intend to demonstrate how one can go about modeling the daily precipitation process over Bulgaria as the NHMMs have not been yet employed for this purpose across the Europe. At each site a 40-year record (1960-2000) of daily precipitation amounts is included. The atmospheric data consists of daily sea-level pressure, geopotential height at 850 hPa, air temperature at 850 hPa, the relative humidity at 700 hPa and 850 hPa on a 2.5 x 2.5 grid based on NCEP-NCAR reanalysis dataset covering the Europe-Atlantic sector 30W-60E, 20N-70N for the same period. The first 30 years data are used for model fitting purposes while the remaining 10 years are used for model evaluation. Fitting the NHMMs follows closely the steps outlined in Bellone et. al. 2000; and MacDonald and Zucchini, 1997. At first an expected number of weather states were determined by fitting models without atmospheric variables by the standard HMM discussed in Zucchini and Guttorp, 1991. Selecting an optimal NHMMs is based on the Bayesian information criterion, in terms of physical realism, distinctness of the weather state patterns and model interpretability.

III. RESULTS AND CONCLUSIONS

The contour plots for the precipitation occurrence probabilities, two sea level pressure plots, two relative humidity at 700 hPa and 850 hPa plots and two geopotential height at 850 hPa plot, for a model based on eight-state NHMM are shown in Fig. 1 and 2, respectively. Each weather state is associated with a distinct spatial pattern of precipitation occurrence. As regards the presented patterns associated with the plots we note that each day is first classified into its most likely state using the Viterbi algorithm, and second, all days in a particular state are then averaged at each grid node for the atmospheric variables to obtain the composite fields. Weather states 1 and 8 are characterized by a low and high probability of rainfall at all sites. They occur on 46% and 12% of days, respectively. The synoptic pattern associated with state 1 shows a typical dominant high pressure system centered at Balkan Peninsula. The weather states from 2 till 8 are characterized by various spatial distributions of the precipitation probabilities. For instance, the weather states from 5 till 8 are associated with a de-

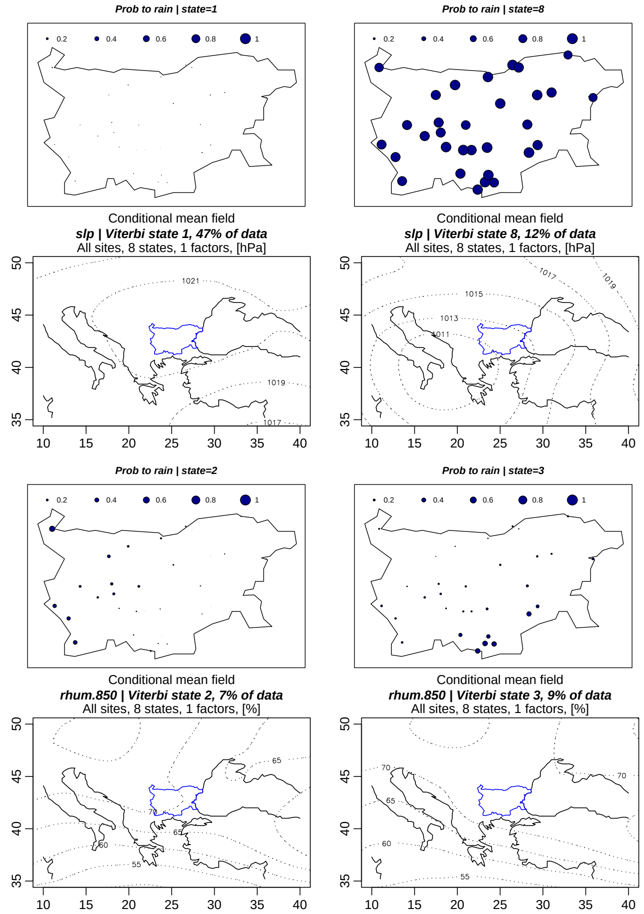

FIG. 1: Diameters of circles proportional to probability of a wet-day; Various composite fields averaged over all days classified under each weather state for the fitted model.

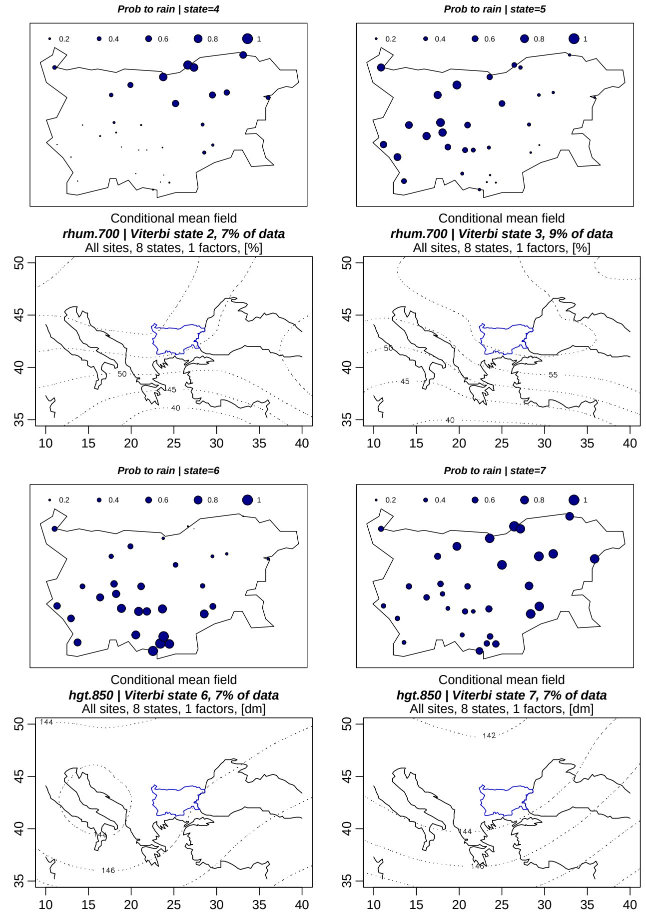

FIG. 2: Diameters of circles proportional to probability of a wet-day; Some composite fields averaged over all days classified under each weather state for the fitted model.

pression centered over the central Mediterranean and the Southern Italy in the mean sea-level pressure field and an upper-level trough with different amplitude and tilt in the geopotential height at 850 hPa. The model adequately accounts what the general sense suggests that the most likely precipitation events occur below the most humid middle troposphere as well as within the polar frontal zone (there is a strong thermal North-South gradient, not presented here due to space limitation) which follows from the patterns associated with the relative humidity at 700 and 850 hPa. The identified 8 weather states are found to be physically interpretable in terms of regional hydroclimatology.

IV. AKNOWLEDGMENTS:

The research of P. Neytchev and N. Neykov is supported by the grant 436 BUL 113/136/0-1 of the Deutsche Forschungsgemeinshchaft within the framework of cooperation between the Deutsche Forschungsgemeinshchaft and the Bulgarian Academy of Sciences.

V. REFERENCES

Bellone E., Hughes J.P., Guttorp P. 2000: A hidden Markov model for relating synoptic scale patterns to precipitation amounts. *Climate Research*, 15, 1-12.

Charles S., Bates B., Vilney N., 2003: Linking atmospheric circulation to daily rainfall patterns across the Murrumbidgee River Basin, *Water Science and Technology*, 48, 223-240.

Hughes J.P., Guttorp P., Charles S., 1999: A nonhomogeneous hidden Markov model for precipitation occurrence. *J R. Stat. Soc.* Ser C, 48, 15-30.

MacDonald I., Zucchini W., 1997: *Hidden Markov and other models for discrete-valued time series models.* Chapman&Hall, London.

Zucchini W., Guttorp P., 1991: A hidden Markov model for space-time precipitation. *Water Resour. Res.,* 27, 1917-1923.