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AN AUTOMATED CLASSIFICATION METHOD OF DAILY CIRCULATION PATTERNS FOR SURFACE CLIMATE DATA DOWNSCALING BASED ON OPTIMIZED FUZZY RULES

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ABSTRACT

A method for automated circulation patterns (CPs) definition and classification is presented, based on optimized fuzzy rules. The target of the method is to provide a basis (daily classified CPs) for downscaling of the most common climate data, i.e. precipitation and temperature.

Therefore the presented classification method is objective providing CPs that explain the dependency between the large-scale atmospheric circulation and the surface climate. Thus the downscaling can be done by means of downscaling models with parameters depending on the CPs. The CPs are defined using 700 hPa geo-potential field anomalies. Fuzzy rules are described by the position of high- and low-pressure anomalies. The fuzzy rules are obtained automatically, using an optimization for the performance of the classification. For the precipitation, the performance of the classification is measured by rainfall frequencies and rainfall amounts conditioned on the CPs. Thus, the task is to define wet or dry CPs. For the temperature, the deviation from the average long-term annual cycle is used. In this way, warm or cold CPs are identified. The presented method produces physically realistic CP definitions.

With the help of these definitions, the observed (historical) pressure fields can be classified for twelve precipitation stations and four temperature stations inside and around the Mesochora catchment in Greece.

KEYWORDS: circulation pattern, classification, downscaling, surface climate data, fuzzy rules

1. INTRODUCTION

The need to investigate future climate scenarios has arisen the issue of downscaling surface climate behaviour from large-scale atmospheric circulation. There is strong evidence that the surface climate variables depend on large-scale atmospheric circulation [5; 21; 13]. Because the influence of local factors in the atmospheric system is highly non-linear, it is rather difficult to describe the relationship between atmospheric circulation and surface climate using a deterministic approach. Instead, the complicated non-linear relationship can be quantified with the help of circulation patterns.

There are two main categories of methods for downscaling: the dynamical downscaling and empirical downscaling. In the dynamical downscaling methods, the nested regional climate models [7] are used to simulate sub-grid scale features. The main advantage of these methods is their ability to deliver meteorologically consistent variables. However, their uncertainty and their non-uniqueness of the solution are not generally considered. Empirical downscaling methods are based on local observations. These methods can generate a large number of realizations, requiring so the assessment of the prediction uncertainty. In the empirical downscaling are included the regression or the conditional-probability approaches. The regression methods define the relationship between the large-scale and local information by means of an explicit function [17; 12; 16]. The other empirical techniques use an intermediate step. The large-scale information is first classified using empirical, statistical or other methods. Downscaling is then performed using stochastic models, with parameters depending on the circulation pattern (CP) types.

The CP classification techniques include two main categories: the subjective and the objective methods [19; 20]. The advantage of the first category of methods is the full use of knowledge and experience of meteorologists. Major disadvantages are the inability for results' reproduction and the limitation of the classification application only to specific geographical methods. Many subjective classifications have been developed for various regions with different scales [3; 9; 13; 14; 15]. The second category of CP-classification methods is based on automated algorithms operating on selecting datasets allowing fast classification, which is necessary especially for climate-change scenarios. The objective-classification methods include *k*-means clustering [18], a method based on physical quantities [10]; fuzzy classification based on subjectively defined rules [1]; principal-component clustering [8], principal-component analysis coupled with *k*-means clustering [4]; and neural-network methods [6]. A detailed comparison of the Lamb subjective and objective classification schemes can be found in [11].

In the most of the aforementioned CP classification methods, the precipitation and temperature characteristics of CPs have been studied 'ex post'. The parameters of precipitation and temperature are linked to the CPs after the classification. The objective of the classification method presented here is to define CPs so that they explain the variability of local surface climate variables (precipitation, temperature) in a locally specific functional form. Therefore, the CPs can explain the dependence between the large-scale atmospheric circulation and the surface climate. The CPs determined in this study are fuzzy rule based and defined using geo-potential pressure fields (700 hPa) in a regular sector over Greece. The fuzzy rules are obtained automatically using optimization of the classification performance. The performance of the classification is measured by its conditional precipitation/temperature frequencies and precipitation amounts. The classification methodology is applied over the medium-sized mountainous catchment of Mesochora in Central Greece.

2. CLASSIFICATION METHODOLOGY

The classification method selected was the fuzzy-rules based approach [1] combined with the simulated annealing algorithm [2]. It consists of three steps: (1) data transformation; (2) definition of the fuzzy rules, and (3) classification of observed data. The classification is carried out using normalized pressure anomalies $g(i,t)$ and daily data with geo-potential (i stands for the grid-point and t for the day). The purpose of the classification is to identify unusually wet or dry, warm or cold local conditions from the large scaled pressure distribution. The pressure data used are obtained from the NMC grid-point data set for different windows over Europe with a grid resolution of $5^o x 5^o$.

Each CP is described with a fuzzy rule k represented by a vector $v(k)=(v(1)^{(k)} \ldots v(n)^{(k)})$, where n is the number of grid-points for which the air-pressure data are available. The $v(i)^{(k)}$ are the indices of the membership function describing the anomalies corresponding to the selected locations and CP. Five possible types anomalies described with their membership functions were considered. These are: very low, medium low, medium high, very high, and the case that the anomaly at the specific location has no influence on the CP. The membership functions and the calculation of the degree of fulfillment *DOF* of the rules are explicitly described in [2].

In order to find the best possible rules for local description of precipitation and temperature three types of objective functions were used to measure the classification performance. The first objective function deals with the precipitation probability on a given day and it is defined as:

$$O_1(\vartheta) = \sum_{i=1}^{S} \sqrt{\frac{1}{T} \sum_{t=1}^{T} (p(CP(t))_i - \overline{p_i})^2} \quad (1)$$

Where, S is number of stations, T is number of days, $p(CP(t)_i$ is the probability of precipitation exceeding the threshold ∂ on a day with given CP at Stn *i*, $\overline{p_i}$ is the probability of a day with precipitation exceeding ∂ for all days without classification and within the time period T.
The second objective function concerns the precipitation amount that it is defined as:

$$O_2 = \sum_{i=1}^{S} \frac{1}{T} \sum_{t-1}^{T} \left| \ln\left(\frac{z(CP(t))_i}{\overline{z_i}}\right) \right| \quad (2)$$

Where, $z(CP(t))_i$ is the mean precipitation amount on a day with a given CP at Stn *i* and $\overline{z_i}$ is the mean daily precipitation without classification at the same station. Higher values of $O_1(\partial)$ and O_2 indicate a better classification.

A separate classification with an objective function on temperature anomalies was considered to define some very cold and some very warm CPs within one classification. The objective function to be maximized is given as:

$$O_3 = \sum_{i=1}^{S} \sum_{j=1}^{N} \sum_{k=1}^{D} (T_{ijk} - T_{ik})^2 \quad (3)$$

Where, N is the number of CPs, D is the number of days in the year, T_{ijk} is the average daily CP-conditioned temperature at Stn *i*, for CP *j* and on Day *k*, and T_{ik}, is the average daily unconditioned temperature at Stn *i* and on Day *k*.

Parameters to evaluate the performance of precipitation-oriented classifications are based on the performance measures used for the classification and some additional quantities (e.g. CP occurrence frequency, precipitation probability, etc).
The quality of the classification based on temperature data is determined by using the index:

$$I_T = \frac{1}{N} \sum_{j=1}^{N} \frac{1}{D} \sum_{k=1}^{D} \left| T_{jk} - T_k \right| \quad (4)$$

Where, I_T is the average daily absolute difference in ^oC for all CPs between CP-conditioned temperature cycles and the unconditioned cycle for all CPs and 1 station, T_{jk} is the average daily CP-conditioned temperature for CP *j* and Day *k*, and T_k is the average daily unconditioned temperature on Day *k*. Higher values of I_T indicate a better classification.

3. APPLICATION

The above described classification methodology was applied in mountainous Mesochora catchment in Central Greece. The network of meteorological (precipitation and temperature) stations installed within and around the Mesochora catchment is not particularly dense. The most of the stations are cited at the lower half of the catchment over a range of elevations from 780 to 1160 m. Daily minimum and maximum temperatures were collected at the installed 4 stations for the period of 1972-1989, while daily precipitation was available at 12 stations for the time period of 1967-1992. Within each CP type the precipitation and temperature depend on the geo-potential surfaces (700 hPa, and sea-level pressure) as well as the window size from which the pressure values are taken. Even, the number of CPs should be determined so that the characteristics of the precipitation and temperature over the study area could be best described. For CP classification, which explains the precipitation and temperature variability at the same stations, it was found that the 700 hPa data in the window 20 ^{o} -65 ^{o} N, 20 ^{o} W-50 ^{o}E provided the best results. The optimal number of CPs was found to be 12 based on the described automated objective optimization procedure for precipitation and temperature.

3.1. Results for precipitation-based classification

Due to the fact that most of the precipitation stations are located in the lower half of the catchment, the Vakari station cited in the middle of this part was selected for describing the observed CPs and precipitation characteristics. It was impossible to present all the observed CPs and precipitation characteristics for the 12 stations in this paper. Thus, for the Vakari station, the conditioned on observed CPs precipitation characteristics are presented in Table 1 for summer (May-October) and winter (November-April) seasons. The occurrence frequency of CPs is slightly different in each season and presenting its higher values for the most cases in the summer. The CP09 is the most frequent CP (in a great difference to other CPs).

Figure 1 shows the distributions of the mean (1982-92) normalized 700 hPa geo-potential field anomalies for the wettest and driest CPs, i.e., CP01 and CP09 respectively. The map shows that CP09 is characterized by a pronounced high-pressure anomaly having its center directly over Greece. The map also shows that CP01 is characterized by the center of the low-pressure anomalies positioned near Greece. The maps of pressure anomalies indicate that the presented automated classification method produces physically realistic results.

Table 1. Precipitation characteristics conditioned on CP's

CP:		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Precipitation Probability (%)													
Vakari	summer	47,50	37,25	33,53	25,96	45,68	47,73	21,59	31,03	18,45	55,47	12,70	28,00
	winter	81,82	60,67	65,71	67,14	59,49	56,00	60,94	60,00	26,45	94,94	57,58	49,28
Mean wet day amount (mm)													
Vakari	summer	8,82	8,54	12,88	5,99	8,82	6,24	3,55	8,29	4,87	12,26	6,20	4,80
	winter	19,09	6,15	15,02	10,94	8,26	8,45	10,43	10,77	3,21	24,68	12,90	9,43
Standard deviation of wet day amount (mm)													
Vakari	summer	8,78	12,11	15,78	9,11	13,02	12,19	4,09	13,60	8,89	16,01	9,09	7,10
	winter	18,83	9,57	17,85	14,23	10,83	10,45	14,68	12,60	5,73	24,25	14,88	16,52
CP occurrence frequency (%)													
Vakari	summer	3,95	5,04	8,55	5,14	4,00	2,17	4,35	4,30	38,83	6,32	9,34	3,71
	winter	7,75	8,95	5,28	7,04	3,97	2,52	3,22	3,27	35,56	8,95	6,64	3,47
CP wetness index (precipitation contribution/occurrence frequency)													
Vakari	summer	1,94	1,47	2,00	0,72	1,86	1,38	0,35	1,19	0,41	3,14	0,36	0,62
	winter	2,39	0,57	1,51	1,12	0,75	0,72	0,97	0,99	0,13	3,58	1,14	0,71

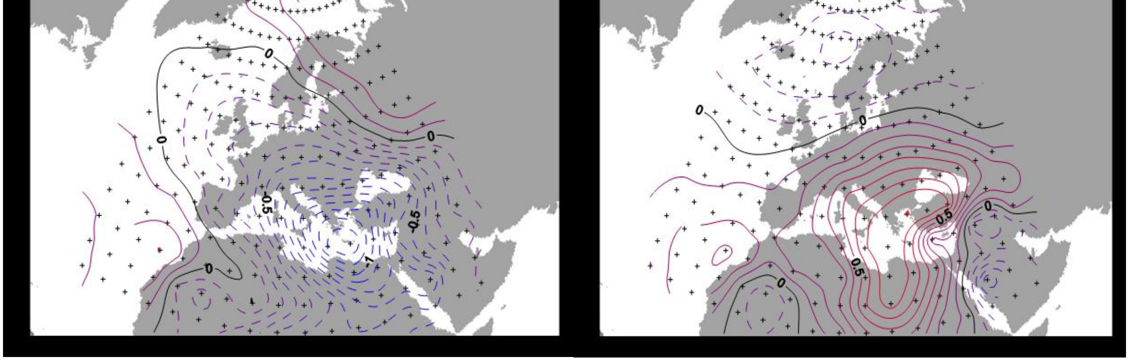

Figure 1. Mean normalized distributions of 700 hPa geopotential fields of 01 (left) and 09 (right) circulation pattern (CP) (CPs are precipitation-optimized over 1982-1992 with 700 hPa data and 12 stations of Mesochora catchment).

3.2. Results for temperature-based classification

For the temperature-based optimization, the twelve temperature-optimized CPs were classified. They were in general different from the twelve precipitation-optimized CPs. The mean normalized 700 hPa geo-potential field anomalies for the warmest and the coldest CP with the corresponding mean annual temperature cycle for the entire area of the Mesochora catchment are presented in Figs 2 & 3. CP02 is the warmest CP, producing a movement of warm air from the southwest direction over Greece. The coldest CP is CP10 (I_T=2.40 ^oC), and it is characterized by a negative pressure anomaly over the Central-East Europe.

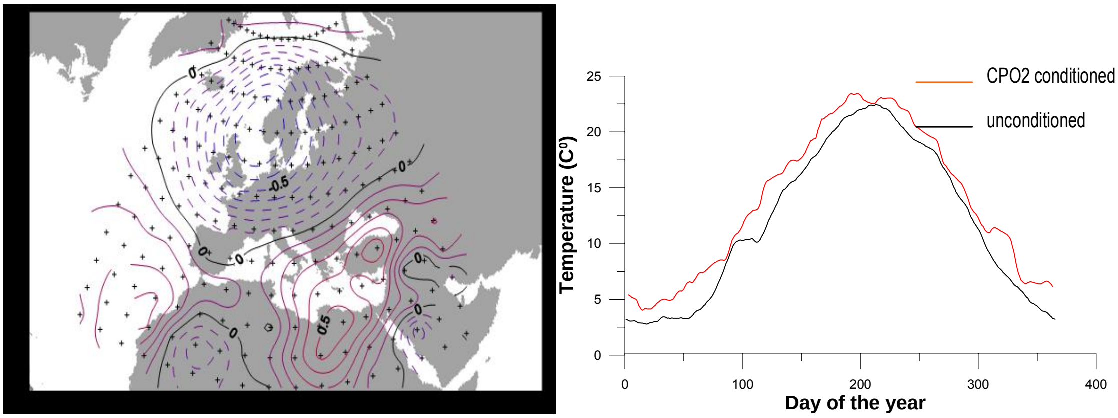

Figure 2. Mean (1980-1989) normalized distribution of 700 hPa geopotential field anomalies (left) of 1 warm CP with the corresponding mean daily temperature annual cycle for the Mesochora catchment (right)(4 stations in Mesochora).

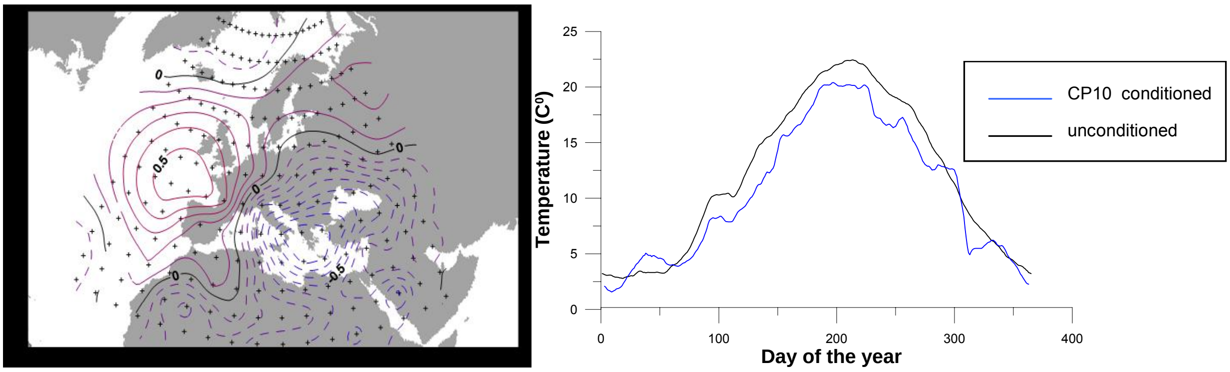

Figure 3. Mean (1980-1989) normalized distribution of 700 hPa geopotential height anomalies (left) of 1 cold CP with the corresponding mean daily temperature annual cycle for the Mesochora catchment (right)(4 stations in Mesochora).

4. DISCUSSION AND CONCLUSIONS

An automated and objective method of CP classification was presented in this study. It was based on a fuzzy rules approach describing the geopotential fields and pressure data anomalies in a mathematical way. The goal of the classification aimed at explanation of precipitation variability is to define CPs that bring wet or dry weather into the specified region. Temperature-oriented classification defined warm and cold CPs. In order to find the best set of CPs, a simulated annealing algorithm was used, which makes it possible to solve a complicated optimization problem connected with the definitions of CPs. The applied method showed the production of physically realistic CP definitions. This is clear from the presented maps of geopotential fields anomalies. The method could be used for downscaling of precipitation and temperature by means of models with parameters depending on the CPs. The advantage of the CPs' conditioning is that the CPs reflect the atmospheric circulation on large scales.

The CP definitions could also be used to classify outputs from global circulation models (GCMs). It would be valuable to compare the series of observed CPs with those from GCM control runs (1x CO_2). This is a way by which the reliability of GCM outputs could be tested. Downscaling the precipitation and temperature from GCM climate-change scenarios (2x CO_2) should be performed in order to assess the changes in local climate due to the changes in atmospheric circulation.

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