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THE CLASSIFICATIONS OF ATMOSPHERIC CIRCULATION

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Abstract: The classifications of atmospheric circulation patterns are a specific research area within synoptic climatology. In general, there are three main groups of classifications: subjective, mixed and objective. In methodological aspect, the recent tendencies are presented in full objectification of classification procedure by mathematical-statistical methods. The classifications of atmospheric circulation are very useful tools in climate change research; for reconstruction of the past climate, analysis of variability of the present climate and in the estimates of future climate. The practical application is to produce weather forecasts in meteorology and for more specific purpose e.g. analysis of air quality, wind atlas, the studies of human health. There are many scientific and operational applications of classifications circulation types, but there is a lack of researches who deal with this issue in scientific literature in Serbia. Only in recent years, there are a few papers that explore the correlation between the climate variability in Serbia and the features of circulation types.

Key words: synoptic climatology, atmospheric circulation, classification method

Introduction

The classification is one of the most used statistical methods in atmospheric sciences. The classifications of atmospheric circulation patterns are a specific research area within synoptic climatology. Only conditionally the atmospheric circulation can be regarded as a system with clearly defined subsystems, and each of its classifications is conditional (Huth *et al*., 2008). However, the application of this method does not lose the importance in researches. This is in accordance with growth of interest in study of weather and climate conditions, especially regarding to their impact on social activities and environment. Depending on time series for which data are available it is possible to reconstruct the climate in past, to determine recent climate change and simulate the climate conditions in the future using various mathematical models (Global Climate Models, General Circulation Models).

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There are numerous classifications that are distinguished by their temporal and spatial resolution, methodological approaches, the number of types and applications. All of them can be divided into three groups: subjective, mixed and objective classification of atmospheric circulation. Contemporary methodological tendencies consist in establishing an objective mathematical and statistical approach with spatial-temporal resolution that enables the identification macro circulation features and where the results can be reconcile on a local scale. A working group COST733[2] Action within organization European Cooperation in Science and Technology (COST) determined the aims in field harmonization and applications of weather type classifications for European Regions. The main objective of this Action is to: "achieve a general numerical method for assessing, comparing and classifying weather situations in Europe, scalable to any European (sub)region with time scales between 12 h and 3 days and spatial scales of ca. 200 to 2000 km, applicable for a number of applications" (www.cost733.org/about_cost733.htm).

There is a lack of researches that deal with this issue in scientific literature in Serbia. This papers presents a general overview of the methods, approaches, innovations, and applications (in science and practice) of classifications of atmospheric circulation. Also presents the possibilities of certain classification procedures for investigation climate caracteristics of Serbia.

The concept of circulation types

Classification is the process of grouping of entities i.e. objects, phenomena and processes in a certain number groups (classes, types, sets) on the basis of their properties, and entities of one group show some similar characteristics, while there are the differences between groups. The classification method is developed over time, so today we talk about it in terms of different methodological and application approaches. The measure of similarity/dissimilarity between the elements of one set or subset represents the qualitative and quantitative relationships between them. This means that the classification is not only a

[2] COST733 Action Harmonization and applications of weather type Classifications for European Regions is a working group within organization COST. A group was formed in 2005. The Last Event of this Action will be held in November 2010 with present results about recent advances in circulation and weather type classification methods, evaluation and verification of circulation and weather type classifications and future directions of classifications within atmospheric and environmental science.

mechanical process. Relations between members of one class are systematically arranged and from them we can get new knowledge and causal links.

The first application of classification of atmospheric circulation was in meteorology for the weather forecasting. The development of computers allows to working with large databases and improving the classification methods. Also the weather forecast techniques have changed. Thus, the classifications have become a significant part of statistical and synoptic climatology (Huth *et al*., 2008).

The atmospheric circulation can be defined in different ways. This means that there are various ways for its classification. However, the atmospheric circulation is in the essence a whole before the parts, a continuum. Only under the certain conditions we can observe the atmosphere as a system with clearly separated and defined subsystems, and each of its classification is conditional. Huth *et al.* (2008) pointed out that the function the classification of atmospheric circulation is simplification of physical reality. Also, these authors say "that no absolutely correct classification than more or less suited for particular purpose".

The circulation types are the products of classification of atmospheric circulation. Their number is different for the different classification. In a period before application of computers the name for classified circulation types was the catalogue of synoptic types (Huth *et al.*, 2008). COST733 Action has done a questionnaire in order to make an inventory of existing classifications in Europe. The results are presented in a few papers (Huth *et al*., 2006, Huth *et al*., 2008). This questionnaire has shown that the number types varies in most cases between 4 to 40, while the number of different subtypes up to 209.

The circulation types are determined by spatial and temporal resolution, also by variables that are used for their definition. According to the aforementioned questionnaire, 84% of classification is based on the values of sea level pressure, geopotential heights or wind fields. In most of cases, one of the levels that is frequently used as input is geopotential height 500 hPa. Using multiple level inputs gets a little more information because of the high degree of dependence between individual levels (Huth *et al*., 2008). Also it should be noted that there is a difference between the circulation types, weather types and types of air masses. Each of them is bases on different data used in classification procedures.

Various variables as hourly, daily or monthly values are used for the definition of circulation types. The spatial resolution is typically ranges from local to continental scale. The data are organized like grids or network of stations. The

questionnaire has shown that of existing classification methods in Europe on daily data is based 84%, and 9% on short time scale of 12 to 6 hours. Only 5% of the classifications use the monthly values. However, this difference was not due to a methodological approach but the available data (Huth *et al*., 2006). According to spatial coverage, 50% of classifications are continental, 22% subcontinental, 20% country, 3% regional and 5% local scale.

Methods of classification

There are the different ways and approaches for classification the patterns of atmospheric circulation. Two successive steps in the classification procedure are: the definition of types and the assignment of cases to the types. Those processes can be guided by expert knowledge or mathematical and statistical modeling, and there are three main groups classification: subjective, mixed and objective classification of atmospheric circulation. The circulation types are defined prior to the assignment stage or the types are derived and evolve during the process of classification itself (Huth *et al*., 2008).

Subjective classifications

Knowledge of experts is main criteria for the subjective (manual) classifications. The types are subjectively defined a priori, and the assignment of individual cases to the types is also subjective. The manul classifications are the first steps of meteorologist for detect, define and publish behavior of atmospheric circulation. The most famous from this group are Hess-Brezowsky, Lamb, Vangengeim-Girs and Schüepp classification. Although subjective, they are frequently used in various investigations. One of reasons for that is lenght of their time series. Their main features are shown in Table 1.

The Hess-Brezowsky classification is the most famous and commonly used from this group. This classification has used frequently in many studies of analysis of recent climate change for the Europe. The Hess-Brezowsky (HB) catalogue covers the time period of 1881 to 2004, also it has improved and has homogenized for a several times. HB classification was originally developed by F. Baur with the first edition in 1944, followed by editions in 1952 and 1957 by P. Hess and H. Brezowsky. The last edition (2005) is edited by F.W. Gerstengabe и P.C. Werner. The main criteria for definition of 29 types (Grosswetterlagen-GWL) and one group unclassified situations are the direction of air masses and the positions of action centers in regard to Central Europe. The duration of each GWL is kept at three days at minimum (except for the unclassified group). The GWL are grouped in 10 super types (Grosswettertypen-

GWT). The frequency and persistence of HB types are often used in studies of climate change. One of the main critiques of this classification is its strong focus on the area of Central Europe (the method was made in Germany). James (2007) pointed out that "the GWL catalogue is also rather inconsistent in the level of focus on the circulation directly over Central Europe. When this becomes too strong, the larger scale pattern may be incorrectly determined".

One of the most widely used daily synoptic classifications for the British Isles is Lamb catalogue. The first edition of this catalogue was published in 1972, and the full original Lamb Catalogue[3] runs from 1 January 1861 to 3 February 1997. The main criteria for the classification of synoptic types are based on physical and geometrical characteristic of air masses over the British Isles, such as direction of air flow, the strength and the degree to which the air masses has a cyclonic/anticyclonic features (Barry, Carleton, 2001). According to direction of movement of air masses, this classification distinguishes 8 super types which are futher classified (28 types) in relation to the dominance of cyclonic/anticyclonic features. As in HB catalogue, there is also one group unclassified situation, while no limit to the time duration of types.

Table 1. The main features of the most famous subjective classifications

Subjective method	Definition of types	Assignment to types	Spatial resolution	No. types	No. super types	Time period covered by catalogue
Hess-Brezowsky	Expert knowledge	According to visual attribution of individual patterns	Europe	29	10	1881-2004
Lamb	Physical-geometrical		British Isles	28	8	1861-1997
Vangengeim-Girs	Expert knowledge		North hemisphere	26	3	From 1891
Schüepp	Physical-geometrical		Switzerland	40	10	From 1945

The other two classifications (from the subjective group) which have also international recognition are Vangengeim-Girs and Schüepp classification. Vangengeim-Girs is classification of hemispheric circulation (35°N to 80°N) and basically distinguishes three main groups of circulation: westerly, easterly and meriodional (Barry, Carleton, 2001). This method is the most used for research in Russia and the former Soviet Union. In study based on correlation

[3] The catalogue is available online http://www.cru.uea.ac.uk/cru/data/hulme/uk/lamb_all.dat

analisys between the frequency circulation types and SLP for the period of the 20th century, Stepp and Jaagus (2002) concluded that Vangengeim-Girs better describes the atmospheric circulation in Eastern and Northern Europe, while Hess-Brezowsky better shows the circulation in Central, Western and Southern Europe.

Schüepp classification focuses on the territory of Switzerland with time series since 1945. The main criterion for the classification is the air movement in the horizontal and vertical direction. The classification is done using the weather parameters as the surface pressure distribution, wind distribution and strength and the position of the 500 hPa level. The number of types is 40 and they can be grouped in ten super types (Liniger, Frei, 2006). This method is still used for the analysis of weather and circulation conditions that show some specifics (Alpine mountain system).

Mixed classifications

In case of mixed (hybrid) classification the types are defined subjectively a priori, while the cases are assigned by objective criteria. According to Huth *et al*. (2008) the objective procedures include setting threshold criteria, using a distance measure and means of artificial intelligence (self-organizing maps-SOM).

So far only Hess-Brezowsky and Lamb catalogue are objectified (Table 2). The Objective GWL catalogue[4] represents an objective computational version of the 29 HB types with the same meaning and nomenclature as the original types. The Objective GWL has the same duration as original HB types (James, 2007). Daily Objective GWL Catalogue is available since 1850. This catalogue has a greater spatial coherence outside of Central Europe in compared to original HB GWL.

Table 2. The main features of two mixed classifications

Mixed method	Definition of types	Assignment to types	Spatial resolution	Time period covered by catalogue
Objective GWL system	Expert knowledge	Method distance	Europe and North East Atlantic	From 1850
Objective Jenkinson 'Lamb' Catalogue	Physical-geometrical	Method threshold criteria	British Isles	From 1880

[4] The catalogue is available online http://www.cost733.org/GWL/ObjGWL.html

The objective Jenkinson 'Lamb' Catalogue[5] is available since 1880. The attempts for objectification of Lamb catalogue proved to be very successful (for the territory of Iberian Peninsula and Norway). In this sense, as an optimal solution, there is imposed the transfer of the spatial network as in original version (The British Isles) to the certain parts of Europe, thus making a mosaic image. However, it is very difficult to integrate all the information into a continent-wide whole picture and the quality of these results is still uncertain (James, 2007).

Objective classifications

In case of objective (computer based, automated) classification both type are defined and the cases assigned by a numerical procedure. However, it should be noted that these methods are not objective in whole; there are some subjective decisions (the number of types, the measure of dis/similarity) (Huth *et al*., 2008).

According to Huth *et al*. (2008) the methods used in the objective classification can be divided into several groups: methods based on the correlation (correlation, sums of squares of difference), cluster analysis (average linkage, Ward method, k-mean method), principal components analysis-PCA (T-mode and S-mode), nonlinear methods (self-organizing maps, classification and regression tree), fuzzy method and other mixture methods.

The results of questionnaire organized by COST733 have shown that of the all classifications in Europe 45% are objective, 30% - subjective and 25% - mixed. From the group of objective classifications the cluster analysis is the most common statistical procedure with k-mean non-hierarchical technique. However, it seems that has not been established objective classification procedures that could answer on the greatest claims; finding an optimum number of types, reducing within type variability and making the universal objective classification method (as defined in introduction of this paper). One of the statistical procedures that are very promising in this field is the specifically designed neural networks. Also, expanding research on the stratospheric circulation brings new knowledge about the atmospheric dynamic and the mechanism of transfer agents (Huth, Canziani, 2003), and overall better understanding of the climate system.

[5] The catalogue is available online http://www.cru.uea.ac.uk/cru/data/hulme/uk/lambjenks_all.dat

The scientific and practical applications of classifications

The classifications of atmospheric circulation are very useful tools in climate change research. Depending on data available the classification can be used for reconstruction of the past climate, analysis of variability of the present climate and estimation of future climate.

In the reconstruction of past climate the limited factor is availability of time series with records to less than a century in the most cases. In recent years, a few projects have done with aim to create a database of air pressure for Europe and North Atlantic. The aim of project EMULATE[6] (EU-Project European and North Atlantic daily to multidecadal climate variability) was to create daily fields of mean sea level pressure over North Atlantic and Europe, on a 5°x5° grid spacing, since 1850 to present. This provides the analyses of European circulation patterns and their influences on surface climate variations. The project ADVICE[7] (Annual to Decadal Variability in Climate in Europe) has two main goals: the first is to characterize as fully as possible the variability of climate over Europe and North Atlantic for period 1780-1997 using the historical instrumental data from greater Europe, and the second is to reconstruct climate during the Late Maunder Minimum (LMM), from 1675 to 1715, using documentary sources. This database may be use in different research in a field of atmospheric circulation, especially in studies of natural climate variability and of anthropogenic forcing climate change.

In studies of recent climate variability the emphasis is on the determining the correlation between the atmospheric circulation and extreme climate events. The Hess-Brezowsky catalogue is one of the most used in this analysis. The changes of frequency and persistence of circulation types are related to intesity and frequency of extreme cold and warm waves (Domonkos *et al*., 2003, Cony *at al*., 2008, Kyselỳ, 2007, Kyselỳ and Huth, 2008).

Only in recent years, there are a few papers that explore the correlation between the climate variability in Serbia and the features of types of atmospheric circulation for the second half of the 20th century (Radovanović, Ducić, 2004, Ducić *et al*., 2010a, Ducić *et al*., 2010b). The temperature and precipitation variables and the subjective classifications (Hess-Brezowsky circulation types and Dzerdzeevski's circulation mechanisms) are used in those papers. This opens the possibility for new research, especially in analyzing the correlation

[6] http://www.cru.uea.ac.uk/cru/research

[7] http://www.uea.ac.uk/~f094/advice.html

between extreme climate events in Serbia and atmospheric circulation. However, a significant problem is that the region of Southeast Europe into outer spatial domain of existing classifications. In this sense, we must to do one comparative study for determine dis/advantages of existing classifications which can be use in climate research in these areas.

The classifications of atmospheric circulation were used mainly in weather forecasting. With development of computers, the classifications have become a part of synoptic climate analysis. However, classifications as a tool for weather forecasting are again current. The new approaches and improved methodologies open up the new possibilities in this field. One of them is ensemble forecasting that means creating the multiple forecasts from one time point and each of them with slightly modified initial conditions.

The practical application of classification is to produce weather forecasts in meteorology and for more specific purpose e.g. analysis of air quality, wind atlas, forest fires, the studies of human health (Huth *et al*., 2006). Kassomenos *et al.* (2001) were obtained the statistical significant correlation between the daily mortality and circulation types in Athens. The classifications of atmospheric circulation have a great importance both in scientific research and in practice. The appropriate methodological approach and data sets are still topical issue for the application the classification methods in analyzing the dynamics of atmospheric circulation.

Conclusion

The classification of atmospheric circulation patterns is a specific research area within synoptic climatology. There are many different classifications. According to methodological approach they are divided into three groups: subjective, mixed and objective classification of atmospheric circulation. Recent methodological tendencies consist in establishing a fully objective mathematical and statistical method. Also, longer data sets allow detecting the characteristic features of atmospheric circulation and the relation between it and surface climate variable is more reliable.

The practical application of classification is in its re-activation for weather forecasting in meteorology, but also in various studies like analysis of air quality, wind atlas, forest fires, the studies of human health.

Only in recent years, there are a few papers that explore the correlation between the climate variability in Serbia and the features of circulation types for the

second half of the 20th century. This opens the possibilities for new researches and specially in analyzing the correlation between extreme climate events and atmospheric circulation. In this sense, we must to do one comparative study for determine dis/advantages of existing classifications which can be use in climate research in these areas.

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References

Barry, R. G. & Carleton, A. M. (2001). *Synoptic and dynamic climatology*. London: Taylor and Francis Group.

Cony, M., Hernández, E. & Del Teso, T. (2008). Influence of synoptic scale in the generation of extremely cold days in Europe. *Atmósfera, 21* (4), 389-401.

Domonkos, P., Kyselỳ, J., Piotrowicz, K., Petrović, P. & Likso, T. (2003). Variability of extreme temperature events in South-Central Europe during the 20th century and its relationship with large-scale circulation*. Int. J.Climatol., 23*, 987-1010.

Ducić, V., Luković, J. & Stanojević, G. (2010). The atmospheric circulation and fluctuation of precipitation in Serbia in 1949-2004 period. *Bulletin of serbian geographical society, 90 (2),* 85-96. (Дуцић, В., Луковић, Ј., & Станојевић, Г., 2010. Циркулација атмосфере и колебање падавина у Србији у периоду 1949-2004. *Гласник српског географског друштва, 90* (2), 85-96.)

Ducić, V., Stanojević, G. & Ikonović, V. (in press). The atmospheric circulation and fluctuation of air temperature in Serbia in 1949-2004 period. *Collection of papers of Geographical faculty*. (Дуцић, В., Станојевић, Г. & Иконовић В. (у штампи). Циркулација атмосфере и колебање температуре ваздуха у Србији у периоду 1949-2004. *Зборник радова Географског факултета*.)

Gerstengarge, F. W. & Werner, P.C. (2005). *Katalog der Grosswetterlagen Europas Nach Paul Hess und Helmuth Brewowsky 1881-2004*. Potsdam: Potsdam-Inst. F. Klimafolgen-forschung.

Hess, P. & Brezowsky, H. (1952). *Katalog der Grosswetterlagen Europas*. Bad Kissingen: Berichte des Deutschen Wetterdienstes in der US-Zone 33.

Hess, P. & Brezowsky, H. (1977). *Katalog der Grosswetterlagen Europas 1881–1976, 3. verbesserte und ergänzte Aufl*. Offenbach am Main: Berichte des Deutschen Wetterdienstes 113.

Huth, R. & Canziani, P. O. (2003). Classifcation of hemispheric monthly mean stratospheric potential vorticity fields. *Annales Geophysicae*, *21*, 805–817.

Huth, R., Beck, C., Philipp, A., Demuzere, M., Ustrnul, Z., Cahynová, M., Kyselý, J. & Tveito, O. E. (2008). Classifications of Atmospheric Circulation Patterns. Recent Advances and Applications**.** *Trends and Direction in Climate Research*: *Ann. N.Y. Acad. Sci*., *1146*, 105-152.

Huth, R., Ustrnul, Z., Dittmann, E., Bissolli, P., Pasqui, M. & James, P. (2006). Inventory of Circulation Classification Methods and Their Applications in Europe within the COST 733 Action. U O. E. Tveito & M. Pasqui (ed.), *Proceedings form the 5 annual meeting of the European Meteorological Society*, *Session AW8 – Weather types classifications*, (9-17). Utrecht: COST733.

James, P. M. (2007). An objective classification method for Hess and Brezowsky Grosswetterlagen over Europe. *Theor. Appl. Climatol.*, *88*, 17-42.

Kassomenos, P., Gryparis, A., Samoli, E., Katsouyanni, K., Lykoudis, S. & Flocas, H. A. (2001). Atmospheric Circulation Types and Daily Mortality in Athens, Greece. *Environmental Health Perspectives*, *9* (6), 591-596.

Kyselỳ, J. (2007). Implications of enhanced persistence of atmospheric circulation for the occurrence and severity of temperature. *Int. J. Climatol.*, *27*, 689-695.

Kyselỳ, J. & Huth, R. (2008). Relationships of surface air temperature anomalies over Europe to persistence of atmospheric circulation patterns conductive to heat waves. *Advances in Geosiences*, *14*, 243-249.

Liniger, M.A. & Frei, C. (2006). Weather type classification: Approaches in Switzerland. U O. E. Tveito & M. Pasqui (ed.), *Proceedings form the 5 annual meeting of the European Meteorological Society*, *Session AW8 – Weather types classifications*, (55-61). Utrecht: COST733.

Radovanović, M. & Ducić, V. (2004). Fluctuation of air temperature in Serbia in second half of XX century. *Bulletin of serbian geographical society, 84 (1),* 19-29. (Радовановић, М., & Дуцић, В., 2004. Колебање температуре ваздуха у Србији у другој половини XX века. *Гласник српског географског друштва, 84* (1), 19-29.)

Sepp, M. & Jaagus, J. (2002). Frequency of circulation patterns and air temperature variations in Europe. *Boreal Environment Research*, *7*, 273-279.