OBJECTIVE LOCAL WEATHER TYPES WITH APPLICATIONS IN CLIMATE CHANGE DETECTION

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ABSTRACT. Objective local weather types with applications in climate change detection. Objective classification of daily weather is performed for 9 vs. 5 stations of Poland and Hungary based on 30 years periods (1966-1995 and 1961-1990, respectively). Eight weather elements were pre-selected, and reduced to four, by Factor Analysis. They are the mean temperature, relative humidity, cloudiness and wind speed. The redundant elements are diurnal temperature amplitude, water vapour pressure, precipitation and sunshine duration. The omitted elements will be used for independent validation of the classification. Next, hierarchical cluster analysis is performed, having tested various other approaches, leading to six classes in Hungary and southern Poland and to eight classes in the rest of Poland, as the most frequent number of classes in all months and stations. Termination of the clustering, i.e. selection of the number classes is performed in an objective process applying three numerical criteria concerning the within-classes cumulated distance measures. Finally, the types have been re-defined by the method of K-means clustering. The obtained local classifications are compared to the macro-circulation types, based on variance "explaining" capacity concerning the above four basic and four independent variables. In overwhelming majority of the 12 months and 14 stations and 8 variables the obtained local types reduce the variances more effectively than the compared Péczely (1957) types for Hungary and the amalgamated Hess-Brezowsky (1969) types (Mika et al., 1999). These types are important tools in understanding the role of weather in the environmental indicators and in detection of climate change by presenting the processes in terms of weather types. Examples of both applications will be presented in the lecture and in its written version.

Keywords: conditional climatology, cluster analysis, Poland, Hungary.

1. INTRODUCTION

Synoptic climatology i.e. classification the everyday weather states according to the pressure configuration and frontal systems has long history in meteorology. Its aim is to set a limited number of similar meteorological situations, to study any quantity of the environment. Another advantage of this, so called, macro-synoptic classification (Peczely, 1957, Puskas, 2001, Piotrowicz, 2010) is

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that having the actual class of a given day determined, the same code is applied for all stations.

The logical alternative, classification of weather according to the observed local variables is presented in our study for nine stations of Poland and five stations of Hungary. *Section 2* comprehends the initial steps of our classification, i.e. hierarchical cluster analysis to determine how many classes should be used. *Section 3* characterises the classified new types, together with *Section 4* which presents the validation of the classes against the macro-circulation types. Finally, *Section 5* provides an example for using these classes in climate change detection.

2. HIERARCHICAL CLUSTER ANALYSIS

Nine stations from Poland and five stations from Hungary in 30 years periods (1966-1995 for Poland, 1961-1990 for Hungary) were selected with 8 weather elements (see below). The stations are Łeba, Suwałki, Olsztyn, Warszawa-Okęcie, Zielona Góra, Wieluń, Rzeszów-Jasionka, Bielsko-Biała and Krakow for Poland and Szombathely, Pécs, Budapest, Szeged, Debrecen for Hungary (Fig. 1).

Fig. 1. Positions of the 9 investigated stations in Poland and five stations in Hungary. (Horizontal proportions among the countries are distorted for the aesthetics of the layout.)

The four key weather elements of classification have been selected by factor analysis from the 8 candidates. Due to skewed distribution of precipitation, its logarithm was further considered, having added 0.032 mm to each value. So, the lowest value (dry day) is -1.5. All elements have been standardised, i.e. normalised against standard deviation.

Table 1 indicates approximate results of the factor analysis for Budapest and Keakow for illustration. The main conclusion of all stations is that 4 factors are enough. The first five column of both presented tables belong always to the same two factors whereas the rest of the rest of the eigth variables vary their position along the year. The selected elements are *diurnal mean temperature* (Tm: ^{o}C), *cloudiness* (Cl: % of sky), *wind speed* (Ws: m/s) and *relative humidity* (Rh: %).

The omitted (redundant) elements are *precipitation* (Pcp: mm/d), *sunshine duration* (Sd: hour/d), *diurnal temperature amplitude* (ΔT: ^{o}C), *water vapour pressure* (Wvp: hPa). The monthly sampling has been decided after analysing the standard deviation in function of the duration from the annual (1 sample, no separation) to the daily (365 samples, full separation) amalgamation.

The hierarchical cluster analysis has been performed based on the selected four variables with 4-11 clusters in each month and station. The method of furthest neighbours has been selected for rules of joining the groups, based on Euclidean distance, after having tried several other possibilities. No Mahalanobis distance is applied since the retained four elements have no strong cross-correlations.

Since the frequency distribution of optimum numbers has a steep maximum at six classes, further we fixed this number of classes (i.e. weather types) for each station and month. Fig. 2 indicates it for the five Hungarian and three Southern Polish stations. The optimum number of the clusters was established when (i.) after using this number of clusters, the standardized average intra-group variance would be less than 70 % of the original variance of the four variables without clustering, (ii.) the difference between variances of the selected number of classes and of the by one smaller number of classes differs by more than 2 %, but (iii.) the same between the selected number and the one more clusters differ already by less than 1 %.

Since general circulation of the Northern Hemisphere exhibits major differences along the year, one may expect that the number of optimum tapes according to the above methodology could yield unequivocal seasonal differences. However, as Fig. 3 indicates, this is not the case. Hence the 6 and 8 classes is applied every month of the year.

Table 1. Results of Factor Analysis for the eight elements. Numbers indicate the factors.

Budapest	Tm	Wvp	ΔT	Cl	Sd	Rh	Ws	Pcp
J-F	**1**	**1**	*2*	*2*	*2*	**3**	**3**	*4*
M-A	**1**	**1**	*2*	*2*	*2*	**3**	*4*	*2*
M-J	**1**	**1**	*2*	*2*	*2*	**3**	*4*	**3**
J-A	**1**	**1**	*2*	*2*	*2*	**3**	*4*	**3**
SZ-O	**1**	**1**	*2*	*2*	*2*	**3**	*4*	*2*
N-D	**1**	**1**	*2*	*2*	*2*	*2*	**3**	*4*

Krakow	Tm	Wvp	ΔT	Cl	Sd	Rh	Ws	Pcp
J-F	**1**	**1**	*2*	*2*	*2*	**(3)**	**3**	*4*
M-A	**1**	**1**	*2*	*2*	*2*	**1**	**3**	*4*
M-J	**1**	**1**	*2*	*2*	*2*	**1**	**3**	*4*
J-A	**1**	**1**	*2*	*2*	*2*	**1**	**3**	*4*
SZ-O	**1**	**1**	*2*	*2*	*2*	**3**	**3**	*4*
N-D	**1**	**1**	*2*	*2*	*2*	**3**	**3**	*4*

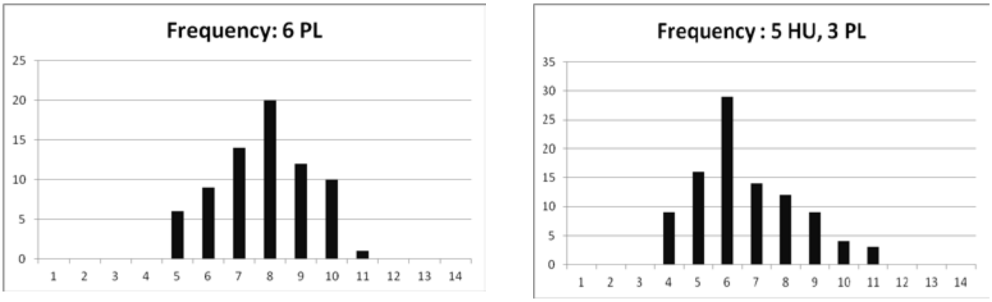

Fig. 2. Optimum number of weather types in six stations of Northern and Central Poland (left), with higher number of types according to hierarchical cluster analysis, and for five stations of Hungary and three ones of Southern Poland (right), following the same analysis. Both results are from daily analysis of temperature, relative hunmidity, wind speed and cloudiness data in 12 months of 30 years (1966-1995 for Poland, 1961-1990 for Hungary).

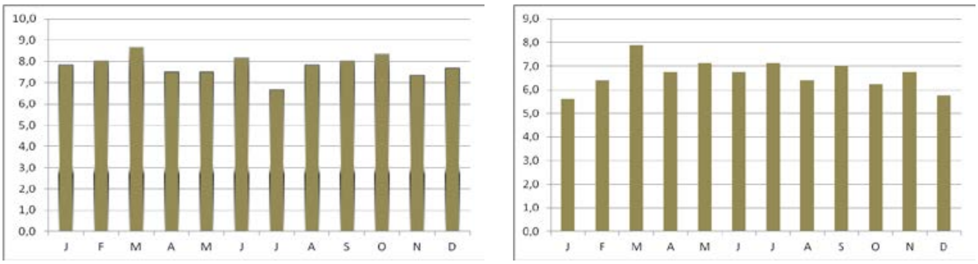

Fig. 3. Annual course of the optimum number of types according to the applied hierarchical clustering in the six stations of Poland (left) and 5 statiions in Hungary and three stations in Poland (right). No clear annual cycle is detectable.

3. K-MEANS CLUSTER ANALYSIS

Considering the steep maximum of six for the optimum number of classes this number is fixed, and limits of the types are re-defined by method of K-means for all months and stations of the two investigated countries. This method provides the best separation of the four-component vectors in the space, i.e. yields the smallest mean intra-class variance, consequently the largest inter-class variance.

Fig. 4 illustrates the six weather types for Krakow in January and July seasons. The types are characterised by their cluster means, sorted in increasing sequence of cloudiness. Some elements in a part of the seasons exhibit synoptically reasonable coincidence, but other cases they do not.

The days are distributed among the types fairly equally. The frequency extremes were 59 and 357 in January and 123 and 209 in July. The absolute minimum and the maximum frequency of any given weather type for Krakow are 53 and 377, both occurring in December (5.7% and 40.5%).

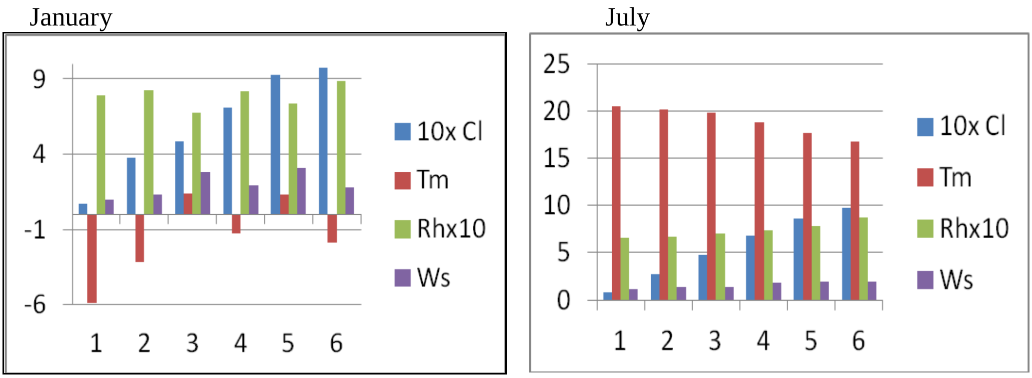

Fig. 4. Examples of objectively defined classes in Krakow in January and July. The types are in increasing order of type-mean cloudiness. The abbreviations are resolved in Section 2.

4. VALIDATION OF THE OBTAINED CLASSIFICATION

The obtained local classification is assessed in comparison with efficiency of macro-circulation types. In overwhelming majority of the months, stations and variables the local types reduce the variance more effectively than the compared Peczely (1957) types for Hungary and an amalgamated (Mika et al., 1999) version of the original Hess-Brezowsky (1969) types, based on objective classification of sea-level pressure maps, derived by Bartholy and Kaba (1990).

Table 2 and Table 3 demonstrate that the six objective types "explain" diurnal variance of the local weather elements than the 13 Peczely-types for Hungary and the 9 amalgamated Hess-Brezowsky types for Poland. Success of the new types is even more important, considering that this is achieved by 6 new classes whereas number of compared macro-synoptic classes was 13 and 9 for Hungary and for Poland, respectively. If taking 8 classes, wherever it is suggested by the left panel of Fig. 2, the results will probably further improve.

Table 2. The variance explaining capacity of the objective local weather types at the 5 Hungarian stations, as compared with that by the Peczely-types. The quotients of the two variances remained after using the centre of the groups as approaches are always smaller than 1. (The abbreviations stand for Budapest, Debrecen, Pecs, Szeged and Szombathely, respectively.) The two extra variables are the numbers of hours with over 80 % of relative humidity (r80) and over 15 m/sec wind speed (w15), respectively.

Types	Mean of the 4 basic elements (Tm, Rh, Ws, Cl)					Mean of 6 independent elements (ΔT, Pcp, Sd, Wvp, r80, w15)					All the 10 elements in average				
	Bp	De	Pe	Sze	Szo	Bp	De	Pe	Sze	Szo	Bp	De	Pe	Sze	Szo
Péczely	82%	86%	83%	84%	84%	86%	87%	86%	88%	87%	84%	88%	84%	85%	85%
6 local	47%	56%	48%	50%	48%	66%	84%	66%	67%	61%	58%	74%	58%	59%	55%
Quotient	**0,57**	**0,65**	**0,58**	**0,60**	**0,57**	**0,77**	**0,96**	**0,77**	**0,77**	**0,71**	**0,69**	**0,84**	**0,69**	**0,69**	**0,65**

Table 3. The same as Table 2 for 8 Polish stations, as compared with the capacity of the nine amalgamated Hess-Brezowsky types. (The abbreviations stand for Leba, Suwalki, Olsztyn, Warszaw, Zielona Gora, Wielun, Rzeszow, Bielsko Biala and Krakow, respectively.) Note that all validations are related to 6 classes, only.

Types	Mean of the 4 basic elements (Tm, Rh, Ws, Cl)				Mean of the 4 independent elements (ΔT, Pcp, Sd, Wvp)				All the 8 elements in average			
	Le	Su	Ol	Wa	Le	Su	Ol	Wa	Le	Su	Ol	Wa
am. HB	90%	94%	93%	90%	100%	106%	99%	106%	95%	100%	96%	98%
6 local	61%	58%	58%	56%	80%	62%	63%	85%	69%	60%	60%	70%
Quotient	**0,68**	**0,63**	**0,63**	**0,63**	**0,83**	**0,60**	**0,64**	**0,84**	**0,74**	**0,61**	**0,64**	**0,73**

Types	Mean of the 4 basic elements (Tm, Rh, Ws, Cl)					Mean of 4 independent elements (ΔT, Pcp, Sd, Wvp)					All the 8 elements in average				
	Zg	Wi	Rz	Bb	Kr	Zg	Wi	Rz	Bb	Kr	Zg	Wi	Rz	Bb	Kr
am. HB	91%	91%	93%	87%	93%	102%	105%	106%	102%	93%	97%	98%	100%	95%	93%
6 local	61%	91%	60%	95%	59%	77%	92%	61%	96%	65%	69%	91%	61%	95%	62%
Quotient	**0,67**	**1,01**	**0,65**	**1,10**	**0,64**	**0,78**	**0,91**	**0,60**	**95**	**0,70**	**0,72**	**0,95**	**0,62**	**1,01**	**0,66**

5. USING THE NEW TYPES FOR CLIMATE CHANGE DETECTION

Derivation of the local weather types opens new perspectives in various climate and weather impact applications. The new scientific tool can also be used to detect climate change in terms of local weather. Fig. 5 demonstrates frequency variations of two selected types from the January examples in Fig 4.

The diagrams do not show statistical trends, since the 30 years is too short to establish true tendencies. Nevertheless, in winter the brightes days may become (again, not in a statistically proven manner) more frequent in January but less frequent in July according to the frequency of Type 1 in the 1966-1995 basic period. For the most overcast days (Type 6) the behaviour in this short period was the opposite. Their frequency were decreasing in January but increasing in July.

Having the series extended, we may later repeat the analysis by exact trend estimations on much longer series. The K-means approach (Euclidean distance from the cluster centres) makes it feasible, since it classifies every day in order ro minimalise the average distance from the cluster centres, after statndardisation against standard deviation of each variable. Hence, the established cluster centres and the common standard deviations will be enough to extend our sereias of codes before and after the basic 30 years periods.

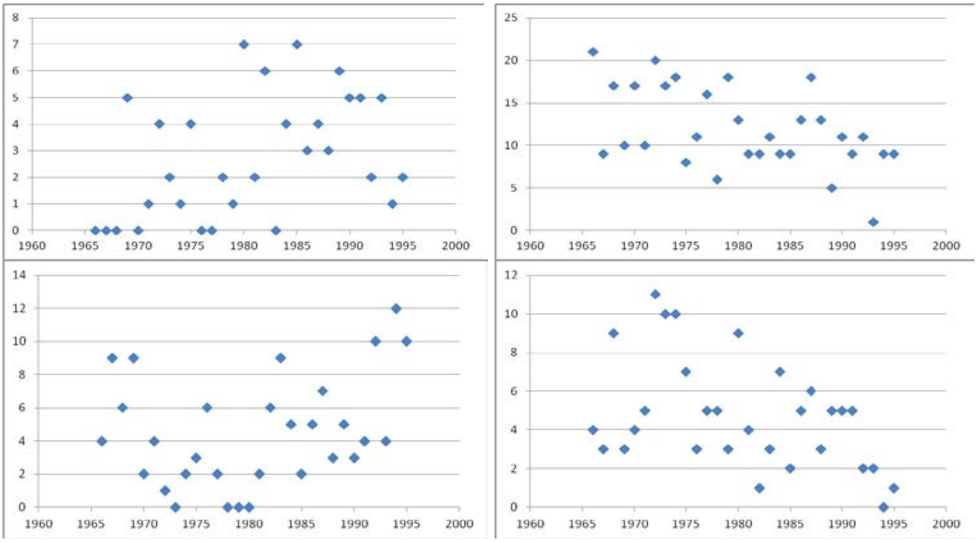

Fig. 5. Frequency variations (trends?) in extreme classes defined for Krakow in January (upper panels) and July (lover panels). The types selected for the illustration are Type 1 with the lowest average cloudiness (left panels) and Type 6 with the highest cloudiness (right panels). For the average characteristics of each type and variable, see Fig. 4.

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