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ANALYSIS OF FREQUENCY TRENDS IN AMALGAMATED PECZELY MACRO-SYNOPTIC TYPES (1971-2020) CHARACTERISING CONTINENTAL-SCALE CIRCULATION PARALLEL TO THE GLOBAL WARMING

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ABSTRACT. Macro-synoptic classification, based on spatial fields of sea-level pressure often meet application in applied climatology, weather forecasting and in air-pollution meteorology. One of these classifications was defined by Peczely (1957), establishing 13 original classes influencing actual weather in Hungary. These types, however, are of local concern and not appropriate for diagnostic analysis of continent-scale modification of circulation, related to the on-going global climate change. In the present study, new continent-scale circulation types are defined, based on frequent transition between the original circulation types, two cyclonic (Atlantic and Mediterranean) and two anticyclonic (Northward and Central-Southward) groups are defined, joining 3x3 and 1x4 original circulation types. Frequency trends of these amalgamated circulation types are established in the recent 50 years during which period a monotonical warming trend could be established in the mean near-surface temperature of the Northern Hemisphere. An important feature of these circulation trends is that the significant trends of the amalgamated types are of the same sign in all cases, although the signs of the trends are different for the different amalgamated types. Comparison of these significant 50-year trends with those derived from two 30 years periods, however, this comparison suggests that there is no simple universal relationship between the continent-scale circulation and the hemispherical mean temperature.

Keywords: circulation types, Peczely, Europe, climate change, linear trends

1. INTRODUCTION

Macro-synoptic (or macro-circulation) classification, based on spatial fields of sea-level pressure or mid-tropospheric geopotencial. Since its first appearance in the literature, probably connected with the names of van Bebber and Köppen (1895),

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macro-synoptic types often meet application in diagnostic and sometimes in prognostic tasks of applied climatology.

The description and catalogue of Hungary's macro-synoptic fields appeared in the work of Peczely (1957). This catalogue contains daily classification of the sea-level pressure fields from 1877 until 1956. The next publication of the updated code series was issued 26 years later Peczely (1983). Peczely's classification has been widely used for diagnostic purposes to understand connections between the circulation and local weather, sometimes including air-pollution meteorology, as well. Since the 1990's years, further applications of the Peczely-types have been published. E.g. Maheras et al. (2019) compared efficiency of the original and an automated classification in delimiting local weather variables. For further references, see Mika et al (2021).

The aim of the present paper is another application of the regional-scale classification, i.e. description of the continent-scale circulation by merging the original classes. According to our view, this is a new approach of such classifications, especially considering that this merging is based on objective calculation of transition matrices, characterizing the frequency of changing the type of the actual day to the next different type.

Structure of the paper is simple: Section 2 presents the applied data and methods, i.e. the original regional-scale types and the merged continent-scale classification and the mean temperature time series used for our trial to establish linear regression relations between the hemispherical mean temperature and the merged circulation types. Section 3 follows the same structure presenting the relative frequency characteristics of the continent scale classes and their linear regression to the NH mean temperature in one 50 years period (1971-2020) and two 30 years period with contrasting hemispherical mean temperature. Conclusions are edited at the end of the paper followed by the immediately used references.

2. DATA AND METHODS

2.1. Original circulation types and their merging

The 13 macro-circulation types defined by Peczely are listed in Table 1 in the original grouping, based on the typical large-scale wind direction. The coding takes place subjectively, but the 140 years archive of diurnal types (1881-2020) is the product by two experts, only. Until 1983 the author of the classification, G. Peczely performed the coding, continued by his colleague, co-author of the present paper, C. Karossy.

Fig 1 presents examples of each circulation type, grouped according to the transition matrices presented further below in Tab. 2.

Some pairs of the original 13 circulation types differ in regional details, only. Hence, they characterize small spatial scales. Larger, e.g. Central European scales can be described by merging some of the original types. In order to find appropriate pairs to join, the transition frequencies have been calculated for each season of the whole 1881-2020 period. A given number of this transition matrix presents the proportion of transition from one circulation type to the other. Note that for the purpose to establish the frequent transitions, only those transitions are considered, where the second day circulation type differed from the first one. Repeated types from one day to the other are not considered in calculations of transition, but they will be included into the frequency distribution calculations.

Table 1. The 13 circulation types of the Péczely (1957) macro-synoptic classification, originally defined for Hungary. This original table by Peczely was edited in German, to characterize the 13 circulation types. The brief descriptions of each type are translated to English by one of the authors (JM).

MERIDIONAL TYPES	ZONAL AND CENTRAL TYPES
	Types connected with western current*:*
Types connected with northern current*:*	***zC*** - zonal flow, slightly cyclonic influence
mCc - Hu is in the rear of a West-European cyclone	***Aw*** - anticyclone extending from the west
AB - anticyclone over the British Isles	***As*** - anticyclone to the south from Hungary
CMc - Hu is in the rear of a Mediterranean cyclone	**Types connected with eastern current**:
	An - anticyclone to the north from Hungary
Types connected with southern current:	***AF*** - anticyclone over Fenno-Scandinavia
mCw - Hu is in the fore of a West-European cyclone	**Types of pressure centres*:***
Ae - anticyclone to the east from Hungary	***A*** - anticyclone centre over Hungary
CMw - Hu is in the fore of a Mediterranean cyclone	***C*** - cyclone centre over Hungary

Therefore, next investigation is the merging of the original circulation types into less groups is based on the transition matrices. Those frequencies are considered as frequent, for which its relative frequency on Day 2 was at least twice as high, as the mean frequency of occurrence from any tape occurred in Day 1. Further, it was also checked, how many times from the four seasons one can find the given cell of the matrix to be significantly higher than its average occurrence.

Tab. 2 presents those pairs of circulation types for which the transitions are significant in at least three seasons. The Table is arranged according to the grouping based on frequent transitions. Altogether, 21 significantly frequent transitions are established. Applying the grouping of the original types into two cyclonic (C1 and C2) and two anticyclonic (A1 and A2) groups, 14 significantly frequent transitions remain within the merged group, and only 7 significantly frequent transitions point out from given grouped type, and point into one of the other groups. This 14/21 =67% proportion of within-group transitions is much larger than the random proportion of 30 within-group transitions compared to the all possible 13x12= 156 transitions, i.e. 19%! As one can establish from Fig. 1 and Tab. 2 the objectively established merging of the 13 classes has led to amalgamated classes which easy to interpret from synoptic meteorology view, as well.

The four groups derived in the above described way, can be interpreted as follows.

- Group C1 (including mCc, mCw and zC types): Atlantic Cyclones,
- Group C2 (CMc, CMw, C): Mediterranean Cyclones
- Group A1 (AB, An, AF): Northward Anticyclones
- Group A2 (Aw, As, A, Ae): Central and Southward Anticyclones

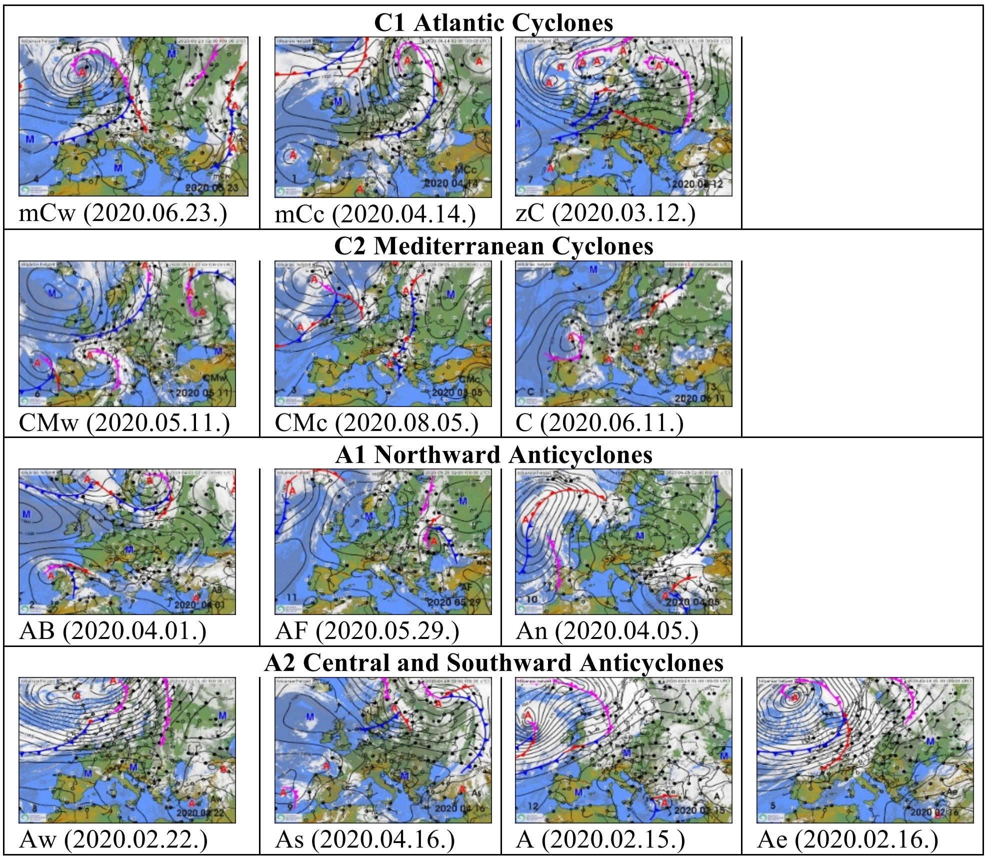


Fig. 1. ***The original macro-circulation types merged into four grouped classes based on transition frequencies, presented later in Table 2. All examples are taken from 2020, on days of circulation types indicated below each map.***

Note, that similarly to the North Atlantic Oscillation (e.g. Barnston and Livezey, 1987) we can also define Central European Oscillation by further amalgamation of the merged Peczely types. Positive anomalies of CEO i.e. strong zonality may be characterized by presence of C1 and A2, whereas negative i.e. weak zonality is caused by A1 and C2. Hence, frequencies of C1+A2 and A1+C2 will further be investigated. Furthermore, differences A2-C1 and A1-C2 will also be studied in comparison with the hemispherical mean temperature.

Table 2. Frequent transitions between the Peczely types in at least 3 seasons. A transition between two types is considered to be frequent, if its probability is at least two times higher than the probability of the second type irrespectively to the previous type. Note: cases when the type of the first day remains the same in the second day are not considered in the transition calculations.

change to		C1			C2			A1			A2			
from		mCc	mCw	zC	CMc	CMw	C	AB	An	AF	Aw	As	A	Ae
C1	mCc										**4**			
	mCw	**4**				**3**	**3**							
	zC	**3**	**4**											
C2	CMc													
	CMw				**4**		**4**							
	C	**4**			**4**									
A1	AB								**4**	**4**				
	An									**3**				**4**
	AF								**4**					
A2	Aw											**3**	**4**	
	As			**4**										
	A											**4**		**4**
	Ae		**4**											

2.2 Selection of long periods with monotonic global trends

The second part of our investigations is the linear trend analysis of the merged circulation types in preliminarily selected 50 years (1971-2020) of monotonic increase of annual mean hemispherical averages of near-surface air temperature, together with two 30 years periods, characterized by a warming (1911-1940) and a cooling (1941-1970) periods, presented in Fig. 2. The most important Northern Hemispherical statistics, characterizing the above 30- and 50-years periods, are included in Tab. 3.

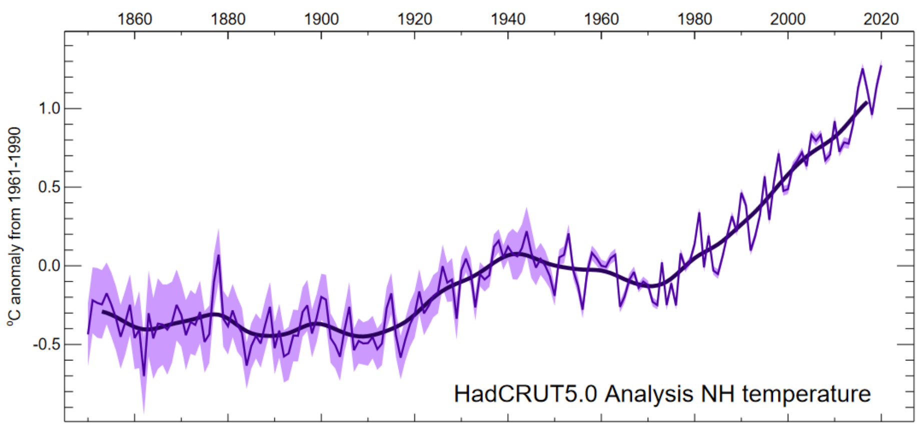


Fig. 2. *Anomalies of Northern Hemisphere annual surface air temperature since 1850 according to Hadley CRUT, a cooperative effort between the Hadley Centre for Climate Prediction and Research and the University of East Anglia's Climatic Research Unit (CRU), UK https://crudata.uea.ac.uk/cru/data/temperature/HadCRUT5.0Analysis.pdf.*

Note that though the regression coefficients of this Table are expressed in K/10 years, whereas all circulation trends included in Figures and Tables of Section 3.4 are related to single years, no mismatch has been caused, because all those results are related to the local frequency of the circulation types. I.e. the dimension of those coefficients are yr^{-1}.

Table 3. Correlation and regression coefficients of the annual mean hemispherical temperature in one 50 and two 30 years periods.

Periods	Duration	Correlation	Regression (˚C/10 years)	NH trend
1911-1940	30 years	0.843	0.20	warming
1941-1970	30 years	-0.503	-0.07	cooling
1971-2020	50 years	0.954	0.28	warming

As concerns the longest monotonous period of 50 years, its warming tendency is "very likely" influenced by the increasing concentration of the greenhouse gases (IPCC 2013). Hence, this 50 years period can be treated as a natural experiment, simulating regional features of the global warming. The external forcing factors of the shorter warming, cooling and neutral periods are most likely influenced by different complex reasons. The most recent IPCC Report (IPCC 2021) considers that the human effect is unequivocal, although proportion of the human influence is not stated.

Significance of the linear trends for the circulation frequency were established if both the correlation coefficients and the linear regression coefficient were significant according to the Z-test (Peczely (1974): Table A9) and t-test (Student (no year indicated)) applied by the SPSS software, respectively. The 95% significance threshold for the correlation coefficients is 0.27 for the 50 years samples and 0.35 for the 30 years samples.

3. RESULTS

3.1. Frequency of the types

Monthly relative frequency distribution is presented in Table 4 for the merged groups, as well, as for the string and weak Central European Oscillation (CEO) stages i.e. sums of A2+C1 and A1+C2.

From the four merged groups, the strongest annual amplitudes belong to the A2 group (48% in November and 30 % in April and May and also to the A1 group (30% in May and 12% in November). The former group (A2) group exhibits the highest frequency values, as well.

The smallest frequencies are seen in the C2 group with the smallest value of 7% in August, and relatively highest value of 18% in April. In annual mean, the C2 group occurs only in 12 % of the days. The C1 group is characterized with the smallest intra-annual fluctuation (26 % in April and May and 16 % in August.

Besides the monthly frequencies, the annual mean values are also presented. From this column, we can see that the annual mean frequency of the strong (C1+A2) and weak (C2+A1) CEO occurrences anticyclonic and cyclonic types is equal to

65:35 percent. This proportion is the highest (72:28 percent) in November and lowest (56:44 percent) in April and May.

Table 4. Relative frequency (%) of the merged circulation types in 1991-2020.

Type	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
C1	25	25	25	26	26	21	21	16	22	22	23	22	23
A2	45	44	39	30	30	41	47	46	41	45	48	47	42
C1+A2	69	69	64	56	56	62	68	62	63	67	72	69	65
A2-C1	20	19	14	4	4	20	26	30	19	23	25	25	19
C2	11	13	12	18	13	12	8	7	10	11	16	15	12
A1	20	18	24	26	30	26	24	31	27	22	12	16	23
C2+A1	31	31	36	44	44	38	32	38	37	33	28	31	35
A1-C2	9	5	12	8	17	14	16	24	17	11	-4	1	

Besides the strong and weak phases of CEO, the Table also contains the differences between the more frequent anticyclonic types and the less frequent cyclonic ones, belonging to the same stage of CEO, representing the more southward or the more northward components of the dipole of the given CEO stage.

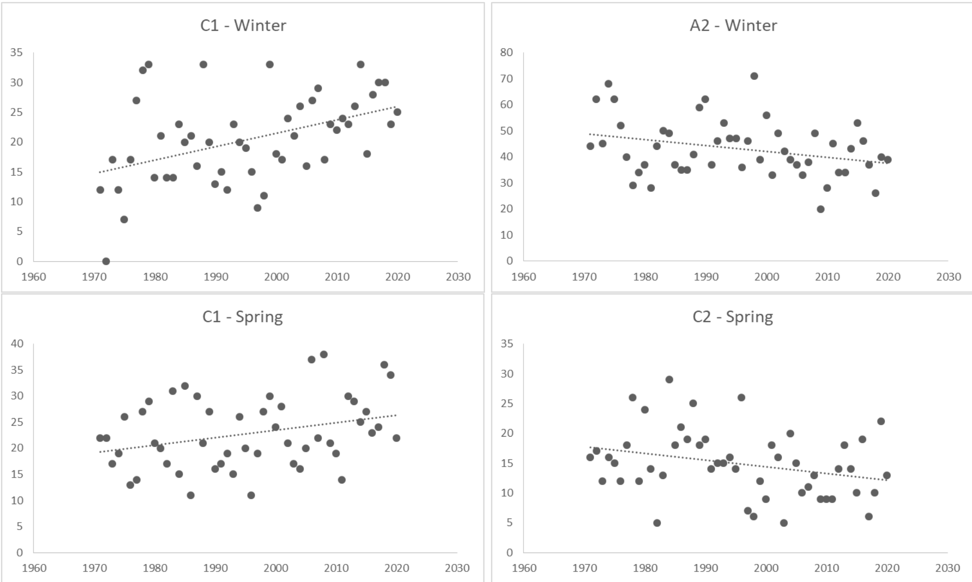
3.2 Trends in comparison with NH mean temperature

From the longest period (1971-2020) only those circulation types are involved in Fig. 3 which are significant according to both the correlation and the regression coefficients. These two criteria coincide for all significant trends. Concerning the statistically established increasing and decreasing trends in the recent 50 years, it would be ideal if one could establish whether, or not they were direct consequences of the hemispherical warming.

Therefore, in the last Table of this study the circulation frequency trends are also established for the other two 30 years periods specified in Tab. 3 of Section 2. The two other periods, taken from this latter Table, are the warming 1911-1940 and the cooling 1941-1970 years, based on hemispherical mean temperature, in the hope that the warming 30 years produce like the 50 years of warming and the cooling 30 years yields opposite results.

We can see in Fig. 3 that type C1 exhibits significantly increasing trend in the 1971-2020 globally warming period in winter and in autumn. Type C2 shows significantly decreasing trend in spring of the same 50 years period. No significant linear trend can be found in the summer season of this 50 years period.

Tab. 5 indicates that from among the altogether eight significant regression coefficients there are only two, which are significant in the previous warming and cooling 30 years periods. Furthermore, only one of them corresponds to the sign corresponding to the expectations based on the sign experienced in the 50 years period. As explained above in Section 2.2 this corresponding means identical sign in the warming 1911-1940 period but the opposite sign in the cooling 1941-1970 period.



NO SIGNIFICANT TREND IN SUMMER

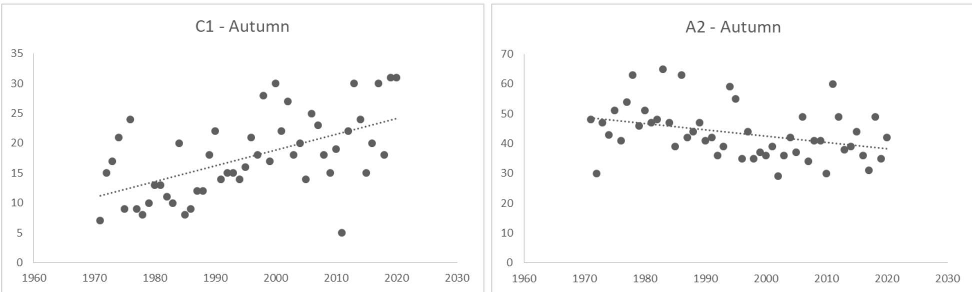


Fig. 3. ***Significant linear trends in frequency of the indicated original and merged macro-circulation types in the 1971-2020 monotonically warming period.***

Table 5. Significant trend coefficients of those merged circulation types and seasons which are significant in the 1971-2020 period. The significant values which are of appropriate sign (i.e. identical in the warming 1911-1940 and opposing in the cooling 1941-1970 period) are set in italics.

Season	Circulation types found significant in 1971-2020	Frequency trend (yr^{-1}) 1911-1940 $R(T_{NH})$=0,843	Frequency trend (yr^{-1}) 1941-1970 $R(T_{NH})$=-0,503	Frequency trend (yr^{-1}) 1971-2020 $R(T_{NH})$=0,954
Winter	C1	-0.312		+0.224
	A2			-0.225
	A2-C1			-0.407
Spring	C1			+0.142
	C2		*+0.335*	-0.113
Autumn	C1			+0.265
	A2			-0.212
	A2-C1			-0.497

4. CONCLUSIONS

Our paper presented a simple way of merging regional-scale macro-circulation types to characterize continent-scale circulation. The method is based in significantly frequent transitions, which merged the 13 original types determined by Peczely (1957) into four merged classes: C1, C2 A1 and A2. Since this semi-objective method has led to classes which are easy to interpret, names of Atlantic Cyclones, Mediterranean Cyclones, Northward Anticyclones and Central and Southward Anticyclones could also be given, respectively.

Furthermore, sum of C1 and A2, as well, as C2 and A1 could have been identified as strong (zonal) and weak (meridional) phases of Central European Oscillation. Finally, differences in frequency of the A2 vs C1 as well, as of the A1 vs. C2 types could characterize the more southward of more northward positions of the components within the given (strong or weak) phase of the CEO.

The first set of the results refer to the annual cycle of the frequencies corresponding to the merged types and to their combinations related to the Central European Oscillation.

The second set of the results i.e. establishing linear trends in two monotonically warming (1911-1940 and 1971-2020) and one monotonically cooling (1941-1970) periods, however, did not provide simple and universal relationships between the Northern Hemisphere temperature trends. This means that even the majority of the regression coefficients, significant in the longest, hemispherical warming period (1971-2020) with much higher frequency than the random 5%, are not found significant in the other 30 years periods. Furthermore, from the two coefficients repeated in one or the other 30 years periods, only one exhibited the sign expected on the basis of its sign derived from the 50 years period.

Most likely, the different reasons, causing monotonic global (hemispherical) trends, modify the continent-scale circulation differently. This question can finally be adequately treated by climate modelling, which was not available for the authors of the present paper.

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