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Effects of macro-circulation on local climatic conditions of plant development

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Abstract

Agricultural or ecological impact studies, related to future climate changes, require highly resolved meteorological input data both in space and time. Since present climate models can not fulfill this requirement, gaps between the necessary and available resolution, are filled by downscaling. A possible way to downscale GCM-output fields into regional climate scenarios can be to consider the changes in the frequency distribution of model-generated macro-circulation types and to combine them with conditional climatology of each macro-type. This approach can be successful, if a great part of local climate anomalies is connected to frequency anomalies of the macro-types.

To test this assumption, a diagnostic method for separation of the local climate anomalies into circulation and non-circulation (physical) factors, allowing a mixed term, is developed, applying the subjective classification of pressure patterns by Péczely (1957). Results for monthly and seasonal anomalies of precipitation and temperature are presented for Debrecen, Hungary (47°N, 21°E). The investigated period is 30 years from 1966 to 1995.

The main feature of the results is the secondary role of the macro-circulation factor. This conclusion is formulated from the comparison of contributions by these terms to moderate and extreme anomalies; to the standard deviation and to long-term variations; and also from the correlation between the three terms and their sum, i.e. the monthly anomaly. It is impossible, however, to consider this circulation term as the maximum information contained by a series of macro-types, because the succession of macro-types and conditional relation of the local weather on different days of a given type is not taken into account by the given separation. On the other hand, the circulation term exhibits fair statistical relation to the physical term and also to the whole anomaly in many cases, which is promising considering further improvement of this approach to downscaling based on frequency of macro-synoptic types.

Keywords: Climate change; Statistical downscaling; Circulation types; Weather generator; Impact

1. Introduction

Sophisticated efforts to use GCM-outputs for regional climate scenario construction can be sorted into two groups. In both approaches, however, accuracy of the large-scale flow generated in the GCM is crucial. The first possibility is a one-way coupling of a limited-area model into the original sequence of GCM-fields. At present this approach is beyond the possibility of many research institutions due to its high demand in computer capacity and initialisation efforts.

The second way is to combine larger scale averages, or pattern components of the model-generated fields with empirical relationships, learned on measured data sets, between the large-scale characteristics and regional

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anomalies. In terminology of forecasters, this combination of model generated fields with empirical connections is a "perfect prognosis" approach. That is, a statistical model is developed between dynamic and prognostic quantities in the presently observed atmosphere, and it is applied to the simulated (future) atmosphere with no respect to the possible systematic deviation of the projected circulation patterns from the really occurring ones.

To test this approach, a method is introduced to calculate the relative contribution of macro-circulation anomalies, expressed by frequency distribution among finite number of classes, to the climate anomalies. After describing the method (Section 2.1), the applied objective macro-synoptic classification (Section 2.2) is introduced. Results are presented for monthly anomalies of five weather characteristics: precipitation, mean, maximum and minimum temperatures; and inter-diurnal change of mean temperature. The results are structured according to the presented statistical characteristics. Section 3.1 demonstrates behaviour of moderate and extreme anomalies. Section 3.2 presents the standard deviations and Section 3.3 displays contribution of the terms to the long-term tendencies. Finally, Section 3.4 analyses the correlation between the components and their sum (i.e. the anomaly). Section 4 contributes to discussion on applicability of the macro-circulation types in statistical downscaling.

2. Methods and data

2.1. The method of separation

The aim of this method is to quantify, what part of climate anomalies can be directly attributed to the anomalous frequency distribution of macro-synoptic types in the period for which the anomaly is formed. The following elementary operations will conclude at a separation of the anomalies, where this term is one of their three, non-zero components (Mika, 1993).

Let us have a macro-synoptic classification, containing **M** macro-types. Assuming that the ith day of the record is characterised by the Ith macro-type, value of an appropriate weather element can be characterised as $A_I(i)$. The difference between this actual value and its climatic mean is $\Delta A_I(i)$, where

$$\Delta A_I(i) = A_I(i) - \{A\}. \tag{1}$$

Let us further introduce the conditional climatic average $\{A_I\}$ in the same period as for the unconditional $\{A\}$. Let us add to, and subtract from Eq. (1) $\{A_I\}$. Then $\Delta A_I(i)$ can be divided into two parts

$$\Delta A_I(i) = [A_I(i) - \{A_I\}] + [\{A_I\} - \{A\}] = A'_I(i) + \{\Delta A_I\}, \tag{2}$$

where $A'_I(i)$ is the actual anomaly relative to the conditional climate average; $\{\Delta A_I\}$ is the difference between conditional and unconditional climate averages. So, the second term is the part of daily weather anomalies which is fully determined by the macro-type, itself. The first term, however, is the part of anomalies which can not be estimated at all, if knowing just the actual macro-type. Let us further have a period which is much shorter than that used for climate averages. For this period, the mean anomaly related to macro-type I is designated by $\langle \Delta A_I \rangle$. Omitting ($i$) indices from Eq. (2), this term is averaged, as

$$\langle \Delta A_I \rangle = \langle A'I \rangle + \{\Delta A_I\}. \tag{3}$$

Within the shorter period for which components of the anomalies are being investigated, the actual relative frequency of the Ith macro-type, $\langle q_I \rangle$ can also be divided into its climatological relative frequency $\{q_I\}$ and anomaly $\langle q'_I \rangle$, similarly to the way followed in Eqs. (2) and (3):

$$\langle q_I \rangle = \{q_I\} + \langle q'_I \rangle. \tag{4}$$

Approaching to our goal, the anomaly of the whole period, $\langle \Delta A \rangle$ is equal to the sum of average conditional anomalies, weighted by relative frequencies of the specific macro-types

$$\langle \Delta A \rangle = \sum_{I=1}^{M} \langle q_I \rangle \langle \Delta A_I \rangle. \tag{5}$$

Putting Eqs. (3) and (4) into Eq. (5), after elementary operations this expression can be written as

$$\langle \Delta A \rangle = \sum_{I=1}^{M} \{q_I\}\{\Delta A_I\} + \sum_{I=1}^{M} \langle q'_I \rangle \{\Delta A_I\} + \sum_{I=1}^{M} \{q_I\} \langle A'_I \rangle + \sum_{I=1}^{M} \langle q'_I \rangle \langle A'_I \rangle, \tag{6}$$

where the first term is equal to zero, if only $\{q_I\}$ and $\{\Delta A_I\}$ are calculated from the same reference period. The remaining three terms can be interpreted as follows:

$\sum \langle q'_I \rangle \{\Delta A_I\}$ is the part of the $\langle \Delta A \rangle$ anomaly due to anomalous frequency distribution of macro-types. This term of *circulation* origin is further referred as **C**.
$\sum \{q_I\} \langle A'_I \rangle$ is the part of anomaly, directly not influenced by frequencies of macro-types. This *physical* or *non-circulation* term, **P**, will be discussed in detail below.
$\sum \langle q'_I \rangle \langle A'_I \rangle$ is the term, **M**, due to *mixed* influence of both circulation and non-circulation (physical) origin.

Let us mark $\langle \Delta A \rangle$ in the following as DY. Anomaly of a given period is equal to the sum of three terms

$$DY = \mathbf{C} + \mathbf{P} + \mathbf{M}. \tag{7}$$

Information contained by frequency of macro-synoptic types, related to expected use of GCM-outputs, is included in term **C** and partly in term **M**. The physical term is determined by three processes:

The *first* one is the initial large-scale anomaly, compared to the climatic mean pattern of the given macrotype, which is not great enough to select this pattern into a different class. This large-scale source of term **P** can appear parallel to climate variations and changes. The *second* source of term **P** can be originated in the local anomalies of the underlying surface (heat and moisture content) that, of course, might indirectly be influenced by the sequence of macro-types within their fixed frequency distribution. *Third*, term **P** may also contain the effects of scales not resolved by the horizontal grid-structure of the classification, or those connected to peculiarities of the actual vertical profiles, which are not represented by the sea-level pressure distribution, used by the classification.

2.2. The macro-synoptic classification

Macro-synoptic classification is a description of spatial distribution of the sea level pressure or mid-tropospheric geopotential height by subjective or objective methods. Considering weather events in Hungary, Péczely (1957) defined a subjective macro-synoptic classification, based on the position of cyclones and anticyclones on the sea-level pressure maps. Thirteen types are separated and also grouped according to the direction of the prevailing current (Table 1). Péczely (1961) also published conditional average values of several meteorological elements, the transition-matrices between different types and other statistical characteristics for 1881–1983 (Péczely, 1983). Since his death, Károssy (1987 and updated) continues the tradition, determining the actual codes, with the intention to follow the subjective, non-documented elements of the macro-type identification. Monthly mean relative frequencies of all individual types are documented in Table 2 demonstrating that each macro-type exhibit considerable frequency at least in several months. For conditional climatology, see Mika and Domonkos (1994). A possible amalgamation of the 13 types into 5–7 ones is presented by Rimóczi-Paál et al. (1997).

In relation to this macro-synoptic classification, local anomalies of monthly precipitation and mean temperature are investigated. The computations were performed

Table 1
Five groups and 13 individual types of the Péczely (1957) macro-synoptic classification

Meridional types	Zonal and central types
Types connected with northern current	*Types connected with westerly current*
mCc—H is in the rear of a West-European cyclone	zC—zonal flow, slightly cyclonic influence
AB—anticyclone over the British Isles	Aw—anticyclone extending from the west
CMc—H is in the rear of a Mediterranean cyclone	As—anticyclone to the south from Hungary
Types connected with southerly current	*Types connected with easterly current*
mCw—H is in the fore of a West-European cyclone	An—anticyclone to the north from Hungary
Ae—anticyclone to the east from Hungary	AF—anticyclone over the Fenno-Scandinavia
CMw—H is in the fore of a Mediterranean cyclone	
	Types of pressure centres
	A—anticyclone centre over Hungary
	C—cyclone centre over Hungary

Table 2
Frequency (per mille) of the 13 peczély macrotypes, 1961–1990 (Mika and Domonkos, 1994)

	mCc	AB	CMc	mCw	Ae	CMw	zC	Aw	As	An	AF	A	C
Jan	61	31	29	89	188	69	40	153	69	132	26	101	12
Feb	64	64	44	93	143	112	45	100	55	162	27	79	12
Mar	59	38	27	108	167	110	55	140	48	120	41	69	19
Apr	97	78	70	114	99	111	36	106	41	113	29	59	48
May	98	63	39	128	78	74	42	119	34	144	73	59	47
Jun	116	88	32	89	66	60	32	201	24	117	32	103	40
Jul	97	100	22	58	60	28	42	267	31	119	43	122	12
Aug	76	67	17	76	101	43	28	197	26	147	65	139	18
Sep	42	82	23	69	143	69	28	177	57	118	26	158	9
Oct	33	49	19	87	212	68	16	154	54	131	19	151	6
Nov	46	52	29	96	157	127	56	122	78	72	20	123	23
Dec	46	48	33	111	129	76	67	161	71	99	26	123	10

for Debrecen, Hungary (47°N 21°E), located in a representative agricultural area, in each month between 1966 and 1995. Some seasonal or semi-annual results are also computed by averaging the monthly values, to exclude majority of the obvious seasonal effects. Termination of our computations with the year 1995 was forced by a change of instrumentation (automation of observations), that could lead to inhomogeneities of the local variables.

3. Results of separation

3.1. Extreme and moderate anomalies

Results of separation for the extreme anomalies (++ and −−) are presented in Fig. 1. Note the equal direction of all components in case of monthly precipitation and mean temperature. Dominance of the **P** component is unequivocal mainly in case of the mean temperature. The largest part of the anomaly is "explained" by the physical (**P**) term, whereas the circulation term (**C**) plays a secondary role. Relative weights of circulation, physical and mixed components have no clear annual cycles.

To compare the extreme anomalies with the moderate ones, seasonal mean weights of the three components, averaged from the monthly values, are presented in Table 3. These numbers demonstrate that primary role of non-circulation (physical) terms is characteristic not only for the extreme anomaly.

3.2. Standard deviation

Standard deviation, computed for each component and for their sum, represents overall relation along the whole 30 years sample, as it is presented in Fig. 2. Standard deviation of the sum is always much larger than that of the individual components. Dominating role of the physical term is also seen in these statistics, whereas circulation and mixed terms represent nearly identical contribution. Annual cycle of standard deviation for the sum (i.e. the total anomaly) is clearly reflected in the physical term and to much less extent in the other two terms.

3.3. Long-term variations

Statistical downscaling of climate changes would mean application of relations, which are valid not only at the time scales of inter-annual variations, but also for the long-term changes. For this reason we computed five-year's averages of the monthly anomalies and also averaged them for the winter and summer half-years. Results of these operations are presented in Fig. 3.

Precipitation exhibit considerable differences in the two half-years considering the trends of the sum and the relative proportion of the terms. In the winter half-year fluctuations of the sum are not well reflected by any of the terms contributing to precipitation. In the summer half-year, the physical term largely contributes to long-term variations of the sum.

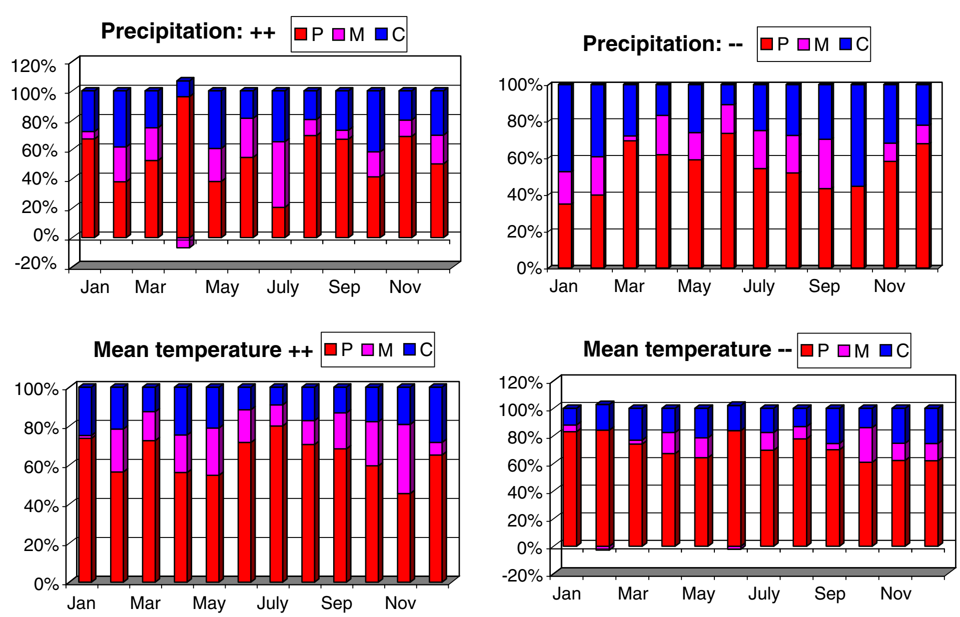

Fig. 1. Results of separation for the extreme positive and negative 20% and −20% (6–6 cases in each month) of the anomalies. Note the equal direction of all components in case of monthly precipitation and mean temperature. The largest part of the anomaly is "explained" by the physical (**P**) term, whereas the circulation term (**C**) plays a secondary role.

Table 3
Proportion of physical (**P**) and circulation (**C**) terms in the precipitation and temperature anomalies, expressed in %, for the four seasons and anomaly groups (Debrecen, Hungary): ++ extremely (wet) warm, + moderately (wet) warm, moderately (dry) cold, etc. groups

	DJF **C**	DJF **P**	MAM **C**	MAM **P**	JJA **C**	JJA **P**	SON **C**	SON **P**
Precipitation								
++	32	53	27	60	24	48	30	58
+	33	52	26	112	31	64	29	83
–	23	37	18	62	34	46	33	62
=	36	49	24	62	20	61	38	49
Temperature								
++	24	65	19	62	13	75	17	58
+	16	71	17	69	25	46	28	53
–	22	82	20	67	11	74	13	71
=	18	78	21	69	16	77	22	64

The central group is omitted.

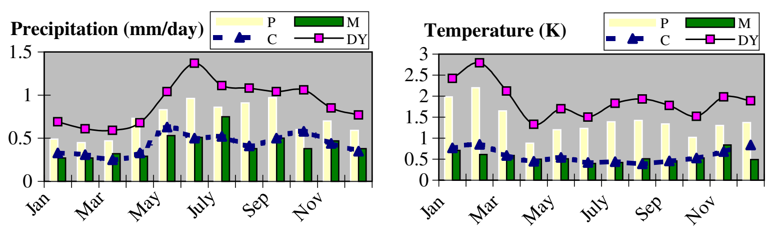

Fig. 2. Standard deviation of non-circulation physical (**P**), mixed (**M**) and circulation (**C**) terms and also of their sum (**DY**, the monthly anomaly) for precipitation and temperature in each month of the year.

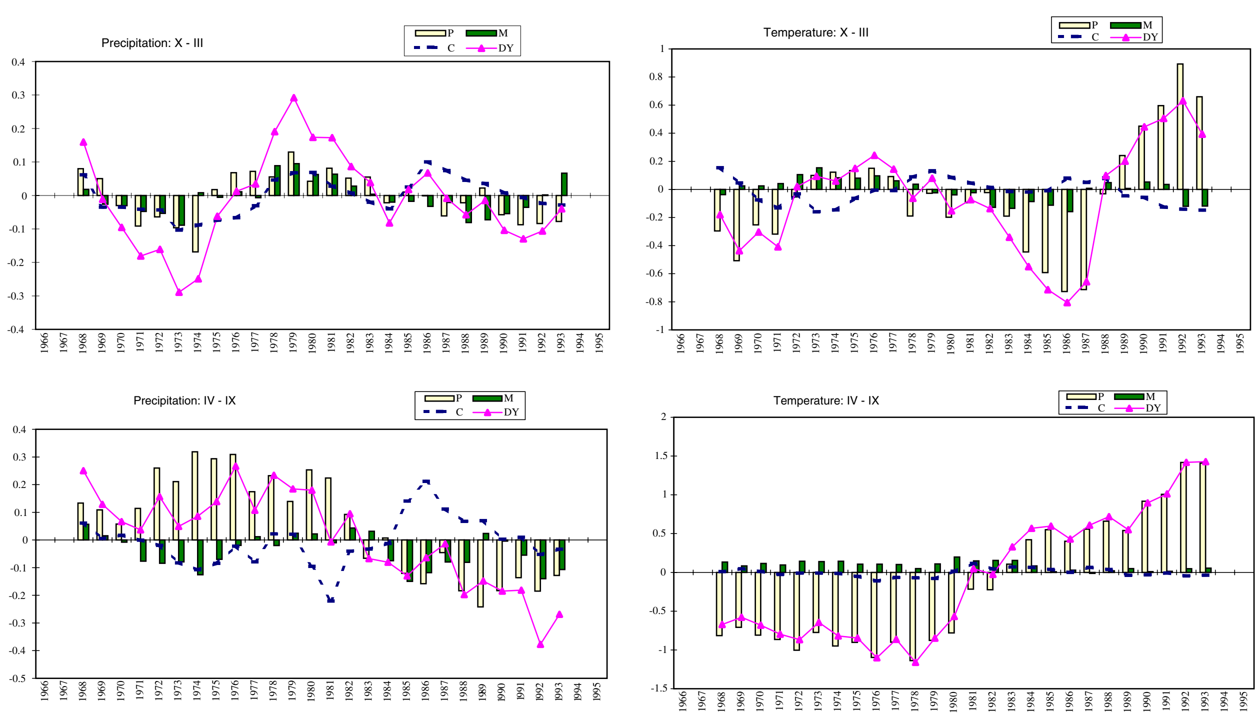

Fig. 3. Contribution of the **P**, **M** and **C** terms to long-term variations of precipitation and temperature (five-years' moving averages). Note the big differences between the half-years in case of precipitation and the parallel run of the sum and the physical term in case of temperature. In the latter case, contribution of circulation and mixed terms are negligible.

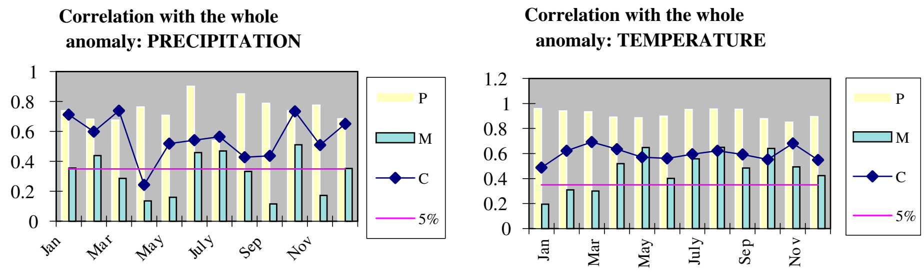

Fig. 4. Correlation of the physical (**P**), mixed (**M**) and circulation (**C**) terms to their sum (**DY**, i.e. the monthly anomaly) in each month of the year. The 95% significance level ($r = 0.35$) is also indicated.

In case of temperature, **C** and **M** terms are not able to reflect a considerable part of the long-term behaviour of the sum, since the **P** term dominates the whole anomaly along the year. Moreover, this term exhibits almost identical run with the whole anomaly.

These results are not at all promising from the viewpoint of statistical downscaling based on frequency projections of diurnal circulation types.

3.4. Correlation between the circulation term and the whole anomaly

Besides relative contributions to the average or standard deviation, it is worth analysing how the individual components correlate with their sum (i.e. with the monthly anomaly). Results of these computations are presented in Fig. 4, from which one can realise the leading role of the physical term, again. Correlation of this term with the sum is always above the 95% significance limit (0.35), except the inter-diurnal change in the majority of months. Correlation of the circulation term to the sum is also significant for both climate elements with the only exception of April in case of precipitation.

This result is promising, considering feasibility of downscaling through frequency of circulation types: even if low percentage of the anomaly is only captured by the circulation, high correlation of this component to the anomaly may lead to statistical additions that helps to better estimate the anomaly.

4. Discussion

In the presented calculations, the most important conclusion is the relatively minor role of the circulation term, except for the low precipitation anomalies. It is impossible, however, to consider this circulation term as the maximum information contained by a series of macro-types, because the succession of macro-types is not taken into account by the separation. E.g. cool and wet westerlies at the beginning of the period, followed by warm and dry anticyclones could cause a much different monthly anomaly than the opposite case, although the frequency distribution would be the same.

Significant positive correlation of the circulation term with the whole anomaly is also promising in connection with the possibility of downscaling from the frequency of macro-types, possibly in a more complex way. Such a way is demonstrated e.g. by Bartholy et al. (1995), who considered conditional autocorrelation under the given macro-type, as well. Another way to improve estimation capacity of diurnal circulation types is an inverse approach, where the classification is focused at a target element, not the large-scale patterns, themselves (see IPCC, 2001 Chapter 10 and 13 for further citations).

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