CHARLES UNIVERSITY IN PRAGUE
FACULTY OF SCIENCE
Department of Physical Geography and Geoecology

The influence of long-term changes of atmospheric circulation on observed trends of surface climatic elements in the Czech Republic and Europe

(Vliv dlouhodobých změn atmosférické cirkulace na pozorované trendy přízemních klimatických prvků v ČR a Evropě)

doctoral dissertation
RNDr. Monika Cahynová

Supervisor: RNDr. Radan Huth, DrSc.

Praha 2010

Prohlašuji, že jsem předloženou disertační práci zpracovala samostatně a všechny použité zdroje jsem řádně ocitovala. Tato práce ani její podstatná část nebyla předložena k získání jiného nebo stejného akademického titulu.

This dissertation describes my original work except where acknowledgement is made in the text. It is not substantially the same as any work that has been, or is being submitted to any other university for any degree, diploma, or any other qualification.

RNDr. Monika Cahynová

Poděkování

Děkuji školiteli RNDr. Radanu Huthovi, DrSc. za vědecké směrování mé práce.

Dále bych chtěla poděkovat své rodině za podporu během doktorského studia, a kolegům z projektu COST733 za poskytování mnohých rad i nepostradatelných datových souborů.

Práce vznikla jako součást evropského projektu COST733 “Harmonisation and Applications of Weather Type Classifications for European Regions”. Česká účast na tomto projektu je podporována Ministerstvem školství, mládeže a tělovýchovy České republiky v rámci projektu OC115. Práce byla dále podpořena Grantovou agenturou ČR, projekt IAA300420506.

Acknowledgements

I would like to thank my supervisor RNDr. Radan Huth, DrSc., for the scientific guidance of my work.

I am grateful to my family for their help and support during my studies, and to my colleagues from the COST733 Action for their counselling and provision of invaluable input data.

This dissertation is part of the COST733 Action “Harmonisation and Applications of Weather Type Classifications for European Regions”. Czech participation in COST733 is supported by the Ministry of Education, Youth, and Sports of the Czech Republic, project OC115. The work was further supported by the Grant Agency of the Czech Republic, contract IAA300420506.

Abstract (English)

The influence of long-term changes of atmospheric circulation on observed trends of surface climatic elements in the Czech Republic and Europe

The aim of this thesis is to quantify the links between recent atmospheric circulation changes over Europe and local surface climatic trends. We employ several parallel classifications of circulation types that were collected and developed within the COST733 Action "Harmonisation and Applications of Weather Types Classifications for European Regions". To our knowledge, such a comparative approach has not been used so far.

Atmospheric circulation changes over Europe were studied in terms of changing seasonal frequency and persistence of daily circulation types in the second half of the 20th century. The extensive collection of both subjective and objective catalogues of circulation types in European regions from the COST733 Action served as a platform for comparison of different classification methods, varying numbers of circulation types, and spatial scale of circulation processes. The most prominent trend – winter increase in the number of days with westerly flow – clearly stems from the strengthening of the North Atlantic Oscillation. The objective classifications did not show any systematic change of persistence of synoptic situations in the study period, whereas in the subjective catalogues (Brádka's Czech–Czechoslovak, German Hess–Brezowsky, and Hungarian Péczely) we have detected inhomogeneities – sudden shifts in the persistence.

We have studied the influence of changes in the frequency of circulation types on seasonal climatic trends of eleven surface climatic variables on the territory of the Czech Republic in the period 1961–1998. The selected circulation classifications were created using eight methods, each applied on sea level pressure fields in three variants with fixed numbers of types (9, 18, and 27). Additionally, three subjective catalogues of circulation types were used. There is large variability within the results obtained with different circulation classifications and also within the 21 individual stations (despite the relatively small spatial scale of the Czech territory). We only found substantial influence of circulation changes on winter temperature trends, which suggests that it is rather the change of climatic properties of individual circulation types (within-type change) that drives most of the observed climatic trends.

At the scale of Europe, the influence of circulation changes on seasonal climatic trends in the period 1961–2000 was studied using daily maximum and minimum temperature and precipitation at 29 stations. To study the effect of spatial scale of atmospheric processes on local climatic trends, we have used the 24 selected circulation classifications computed at the scale of the whole Europe and at smaller European regions. Circulation changes in the small domains are usually more tightly connected with climatic trends than those in the large domain except for Icelandic and Scandinavian stations where circulation over the whole Europe explains a larger part of the observed trends. Seasonal climatic trends in the period 1961–2000 can be only partly explained by the changing frequency of circulation types, the link being again the strongest in winter. In the other seasons, within-type climatic trends are responsible for a major part of the observed trends, which confirms the previously reported instationarities in the relations between atmospheric circulation and local climate. The attribution of European climatic trends again showed marked differences within the results obtained using 24 parallel, fully comparable objective circulation classifications. We therefore think such a comparative approach is highly desirable in synoptic-climatological studies.

Abstrakt (česky)

Vliv dlouhodobých změn atmosférické cirkulace na pozorované trendy přízemních klimatických prvků v ČR a Evropě

Cílem této práce je kvantifikovat vztahy mezi současnými změnami atmosférické cirkulace v Evropě a lokálními klimatickými trendy. K tomuto účelu používáme několik paralelních klasifikací cirkulačních typů, které byly shromážděny a vyvinuty v rámci projektu COST733 „Harmonizace a využití klasifikací typů počasí v evropských regionech“. Pokud je nám známo, nebyl dosud takový srovnávací přístup uplatněn.

Změny atmosférické cirkulace v Evropě byly studovány pomocí trendů sezónní četnosti a persistence (doby trvání) denních cirkulačních typů ve druhé polovině 20. století. Rozsáhlý soubor subjektivních a objektivních katalogů cirkulačních typů z projektu COST733 sloužil ke srovnání různých metod klasifikace, rozdílného počtu cirkulačních typů a prostorového rozsahu cirkulačních procesů. Nejvýraznější trend – zimní nárůst počtu dní se západní složkou proudění – je způsobován zesilováním Severoatlantické oscilace. V objektivních klasifikacích nebyla zjištěna žádná systematická změna v době trvání synoptických situací ve sledovaném období, zatímco v subjektivních katalozích (Brádkův český-československý, německý Hesse a Brezowského, maďarský Péczely) se projevují nehomogenity – náhlé změny doby trvání.

Zkoumali jsme souvislost mezi změnami četnosti cirkulačních typů a sezónními trendy jedenácti přízemních klimatických prvků na území České republiky v období 1961–1998. Vybrané klasifikace atmosférické cirkulace byly vytvořeny pomocí osmi metod, z nichž každá byla aplikována na pole tlaku vzduchu přepočítaného na hladinu moře ve třech variantách s předdefinovaným počtem typů (9, 18 a 27). Dále jsme použili tři subjektivní klasifikace. Výsledky získané za použití různých cirkulačních katalogů jsou značně rozdílné a velké rozdíly jsou i mezi 21 jednotlivými stanicemi, přestože Česká republika není příliš rozlehlá. Významný vliv cirkulačních změn na klimatické trendy byl nalezen pouze v zimě u teploty vzduchu, což naznačuje, že současné klimatické trendy jsou převážně způsobovány změnami klimatických vlastností jednotlivých cirkulačních typů.

V měřítku Evropy byl vliv cirkulačních změn na trendy maximální a minimální teploty vzduchu a srážek studován na 29 vybraných stanicích v období 1961–2000. S pomocí 24 objektivních klasifikací vyvinutých v měřítku celé Evropy a v jedenácti evropských regionech jsme se také věnovali otázce prostorového rozsahu atmosférických procesů a jeho vazeb na lokální proměnlivost a změny klimatu. Atmosférická cirkulace popsaná v regionálním měřítku je obvykle těsněji svázána s pozorovanými klimatickými trendy v porovnání s cirkulací v měřítku celé Evropy s výjimkou Islandu a Skandinávie, kde má větší vliv velkoprostorová cirkulace. Sezónní trendy klimatických prvků v období 1961–2000 jsou jen částečně způsobovány změnami četnosti cirkulačních typů, přičemž největší vliv byl opět pozorován v zimním období. V ostatních sezónách jsou hlavní příčinou pozorovaných klimatických trendů změny v rámci jednotlivých typů, což je důkazem již dříve zjištěných nestacionarit ve vztazích mezi atmosférickou cirkulací a místním klimatem. Při zkoumání příčin současných klimatických trendů v Evropě opět nacházíme velké rozdíly mezi výsledky získanými pomocí 24 paralelních, plně srovnatelných objektivních klasifikací atmosférické cirkulace. Proto se domníváme, že tento srovnávací přístup může být pro synopticko-klimatologické studie velmi přínosný.

List of publications used as a part of dissertation

Seznam publikací použitých jako součást práce

I. Cahynová M., Huth R. (2007a): Trendy v kalendáři povětrnostních situací HMÚ/ČHMÚ v období 1946–2002 (Trends in the HMI [Czech, formerly Czechoslovak] subjective classification of synoptic types in the period 1946–2002). Meteorologické zprávy (Meteorological Bulletin) 60: 175–182.

II. Cahynová M., Huth R. (2007b): Short note on inhomogeneities in the Hess–Brezowsky catalogue of circulation types. Meteorologický časopis (Meteorological Journal) 10: 171–174.

III. Cahynová M., Huth R. (2009a): Enhanced lifetime of atmospheric circulation types over Europe: fact or fiction? Tellus Series A–Dynamic Meteorology and Oceanography 61: 407–416. IF: 2.214

IV. Cahynová M., Huth R. (2009b): Changes of atmospheric circulation in central Europe and their influence on climatic trends in the Czech Republic. Theoretical and Applied Climatology 96: 57–68. IF: 1.776

V. Cahynová M., Huth R. (2010): Circulation vs. climatic changes over the Czech Republic: A comprehensive study based on the COST733 database of atmospheric circulation classifications. Physics and Chemistry of the Earth 35: 422–428. IF: 0.975

Table of contents

1. Introductory part

1.1 Introduction

Recent climatic change is one of the most urgent environmental challenges that already threatens our vulnerable civilization – and will do so even more in near future. Global surface air temperature has risen by 0.6±0.2 °C during the 20th century, while most of the trend occurred since the 1970s (Trenberth et al. 2007). The warming is more pronounced over the continents compared to the oceans, which results in a steeper temperature rise in the northern hemisphere. Shift of seasons, changes of regional precipitation patterns and runoff, melting of glaciers and ice sheets, and rising sea level are just a few examples of the consequences of global warming. Even though natural climatic shifts similar to or greater than this one took place many times in the geological past, this is probably the fastest global change in the last 10,000 years – and as such remains unprecedented in the history of mankind. One of the ways to describe and understand recent climatic trends is through the study of atmospheric circulation and its changes.

Atmospheric circulation is one of the key factors influencing both weather and climate. Since the dawn of meteorology, attempts were made to unlock the links between large-scale atmospheric processes and local weather, mainly for the purpose of weather forecasting. One of the ways to describe atmospheric circulation is the classification of circulation types that has been used in many forms since the 19th century. With the advent of numerical weather prediction, classifications of atmospheric circulation were gradually employed in various topics of synoptic climatology, e.g. the study of long-term changes of circulation patterns (Werner et al. 2000), the influence of atmospheric circulation on different climatological and environmental variables (Hanssen-Bauer and Førland 2000), the occurrence of severe weather phenomena (Kyselý 2008), possible links with anthropogenic climate change (Osborn and Jones 2000), and validation of climate models (Demuzere et al. 2009).

The classification methods underwent a development from manual (subjective) evaluation of daily synoptic maps (e.g. the Hess and Brezowsky "Grosswetterlagen", Hess and Brezowsky 1952, or the Lamb weather types, Lamb 1972) to computer-assisted (automated, "objective") classification of various input fields at different time- and spatial scales. A huge problem accompanying the use of different "objective" classifications in various case studies is the absence of comparable results, as there are numerous approaches to the classification of circulation and/or weather types. The urge for comparison and unification of classification methods led to the establishment of the European project COST733 Action: "Harmonisation and Applications of Weather Types Classifications for European Regions". Several tens of classification methods have been collected within the COST733 Action (Huth et al. 2008a), about twenty of them applied on fixed input data, and the resulting catalogues of daily circulation types are thoroughly studied and further applied.

Classifications of atmospheric circulation can serve as a tool for studying past and recent climatic changes, no matter if these are caused by natural processes or (more recently) by anthropogenic greenhouse gas emissions and land use changes. One of the key questions of synoptic climatology is whether a certain circulation type (further abbreviated as "CT") is directly linked to typical surface weather, and whether this relationship remains stable over long time periods. The attribution of observed climatic trends to either the changing frequency of circulation types or the changing climatic characteristics within the individual types can tell us a lot about the underlying physical processes. If – hypothetically – the observed climatic trends were caused only by changing frequency of types, then the circulation-to-environment link would remain stable, which is one of the requirements for statistical downscaling. If, however, the climatic properties of each circulation type were changing over time, this basic requirement would be violated, and the study of e.g. future circulation and climatic changes modelled by general circulation models would be strongly limited (as we can hardly assume the future climatic properties of the individual types). Previous studies have revealed major non-stationarities in the links between circulation and surface climate (e.g. Slonosky et al. 2001, Beck et al. 2007, Beranová and Huth 2008), suggesting that both the frequency-related and the within-type changes play a certain role in the observed climatic trends. It cannot, however, be viewed in a way that the frequency-related part of the observed climatic trends is attributed to "natural" processes, while the within-type changes are linked to anthropogenic global warming (as was slightly misinterpreted by Osborn and Jones 2000). The observed circulation changes might actually result from anthropogenic alteration of the global climate system; therefore it is impossible to distinguish between the cause and effect.

1.2 Goals and structure of the thesis

The main objective of this dissertation – to quantify the links between large-scale circulation changes over Europe and local surface climatic trends – will be addressed through these specific goals:

- to analyze circulation changes over European regions in the second half of the 20th century using a large sample of fully comparable objective (computer-assisted, automated) classifications of daily circulation types developed within the COST733 Action,
- to compare the available subjective circulation catalogues developed for Central Europe with the objective ones, and to detect possible inhomogeneities in the subjective catalogues,
- to evaluate and compare several circulation classifications according to their ability to stratify daily station climatic data into circulation types,
- to assess the magnitude of recent climatic trends in the Czech Republic and Europe that can be linked to changing frequency of circulation types (as opposed to changing climatic properties of individual circulation types),
- to assess the effect of spatial scale of atmospheric circulation on the links between individual circulation catalogues and local climatic variability and trends, i.e. to compare the results obtained with classifications derived from a large European domain and from smaller sub-domains representing European regions.

We will address these topics in the following sections of the thesis:

Section 1.3 comprises a theoretical basis for our research. Here we present current approaches to the classification of atmospheric circulation and a comprehensive list of methods used to study the links between large-scale atmospheric circulation and climatic variability and trends.

Sections 2–6 are papers by M. Cahynová and R. Huth that were published in Czech and international peer-reviewed journals (2007a, b, 2009a, b, 2010). Sections 7–10 represent recent unpublished research of M. Cahynová.

Section 2 (Paper I) **“Trends in the HMI (Czech, formerly Czechoslovak) subjective classification of synoptic types in the period 1946–2002”** analyses trends in the frequency and persistence of circulation types and groups of types in the so-called Brádka’s catalogue (Brádka et al. 1961), and discusses them in the context of a comparable German subjective classification (the Hess–Brezowsky catalogue, Hess and Brezowsky 1952).

Section 3 (Paper II) **“Short note on inhomogeneities in the Hess–Brezowsky catalogue of circulation types”** focuses on one possible source of inconsistencies in this subjective catalogue, i.e. the manual data evaluation that is done on a monthly basis.

In Section 4 (Paper III) **“Enhanced lifetime of atmospheric circulation types over Europe: fact or fiction?”** the long-term trends of persistence (lifetime) of circulation types are studied in several classifications – both subjective and objective – in selected European regions in the period 1957–2002. We wanted to find out if the previously reported enhancement of persistence in the subjective Hess–Brezowsky catalogue in the mid-1980s (Werner et al. 2000, Kyselý and Huth 2006, Kyselý and Domonkos 2006) is reflected in the objective classifications.

Section 5 (Paper IV) **“Changes of atmospheric circulation in central Europe and their influence on climatic trends in the Czech Republic”** deals with seasonal trends in the frequency of circulation types in two subjective classifications – Czech–Czechoslovak (Brádka’s) and German (Hess–Brezowsky) and their links with seasonal trends in eleven climatic variables in the period 1961–1998.

Section 6 (Paper V) **“Circulation vs. climatic changes over the Czech Republic: A comprehensive study based on the COST733 database of atmospheric circulation classifications”** expands the topic of attribution of climatic trends using 8 selected objective classification methods for the description of atmospheric circulation (each of which comes in 3 variants with a predefined number of 9, 18, and 27 circulation types), and furthermore two versions of the Hess–Brezowsky subjective catalogue (one with 29 types and the other with 10 types). The “skill” of classification methods to stratify station climatic data into types is also discussed. All the variants of analysis enable us to compare two spatial scales of atmospheric circulation (using objective classifications over Central Europe and over the whole Europe), as well as the dependence of results on the number of circulation types.

In Section 7 we present seasonal trends in the frequency of circulation types in the 24 previously used objective circulation classifications in 12 European regions in the period 1961–2000. The classifications are compared according to their skill to stratify daily climatic data at 29 European stations into types in Section 8. Section 9 describes the seasonal variability and long-term trends of daily maximum and minimum temperature and precipitation at European stations in 1961–2000. The influence of circulation changes in 24 objective classifications on these observed climatic trends is discussed in Section 10. Each of the stations is tested at least twice, using circulation classifications computed in the large European domain and in the small domain that best represents the station’s location (some stations are tested with two small domains, i.e. the Alpine stations with the Central European domain as well as with the smallest Alpine domain).

Section 11 provides a comprehensive summary and discussion of the most important results presented in detail in Sections 2–10, while in Section 12 a brief conclusion of the whole thesis is outlined.

References to Papers I–V are displayed at the end of each paper. Section 13 contains references to Sections 1 & 7–12. Used abbreviations are listed in Section 14.

Results of this thesis might be useful for further studies in synoptic climatology, especially those dealing with the attribution of past and modelled future climatic changes, and statistical downscaling. The discussed topic of skill of subjective and several objective circulation classification methods to represent daily climatic variability is a step towards finding the most appropriate circulation catalogue for the description of local climatic conditions in European regions.

1.3 Classification of atmospheric circulation and its use in climate research

1.3.1 Methods for the description of atmospheric circulation

General circulation of the Earth's atmosphere is driven by planetary factors (such as the Sun–Earth distance, tilt of the Earth's rotation axis, and variations of its orbit) that together control the total amount and spatial distribution of solar radiation incident on the top of the atmosphere. Large-scale geographical features, albedo of different surfaces, and atmospheric composition further modify the distribution of energy in the atmosphere (Barry and Carleton 2001). All these factors together with the rotation of the Earth make up the general circulation as we know it: with a band of low pressure around the equator, semi-permanent subtropical anticyclones, zones of mid-latitude westerlies, sub-polar low pressure systems, and polar easterlies.

Most of continental Europe lies in the temperate zone of northern mid-latitude westerlies, and therefore the North Atlantic region has to be included in every study of European atmospheric circulation. Two major centers of action are located in the North Atlantic: the Azores high and the Icelandic low, the latter being an area into which deep cyclones move with high frequency rather than a permanent area of low pressure (Pettersen 1950, in Barry and Carleton 2001). In winter, a shallow cold Siberian high covers most of Asia, sometimes blocking the westerly flow over Europe and causing harsh winters with northerly or easterly flow. In summer, a large low pressure system develops over Asia, its center stretching from the Persian Gulf to northwestern India.

The global atmospheric circulation comprises several large-scale modes of low-frequency variability, often referred to as teleconnections. According to Wallace and Gutzler (1981), teleconnections are “contemporaneous correlations between geopotential heights on a given pressure surface at widely separated points on earth”. The teleconnections can be identified according to the strongest negative correlation of a given location with another place that is several thousands of kilometers far. Walker (1924) and Walker and Bliss (1932) identified three teleconnection patterns: the North Atlantic Oscillation (NAO) between the Icelandic low and Azores high, the North Pacific Oscillation (NPO) between the Aleutian low and North Pacific High, and the Southern Oscillation (SO) between the southeastern Pacific high and the equatorial trough in the Indonesian region. Another way to detect large-scale modes of circulation variability is through principal component analysis (PCA) of geopotential height fields. Barnston and Livezey (1987) provide a comprehensive analysis of PCA-based modes in the Northern Hemisphere in winter, and they note that these modes generally correspond to the previously known teleconnections.

For a simple quantitative description of large-scale modes of variability, various circulation or teleconnection indices have been devised. Time series of such indices are used to study multidecadal variability of the given modes. The most prominent ones are the North Atlantic Oscillation Index (NAOI) describing normalized sea level pressure difference between the Azores (or Iberian peninsula) and Iceland, and Southern Oscillation Index (SOI) that combines pressure data from Tahiti and Darwin (Australia). The NAO index spans back to 1821 if Gibraltar and Reykjavík (Iceland) are taken into account (Hurrell et al. 2003). Other stations used for the computation of NAOI are Ponta Delgada (Azores), Lisbon (Portugal), and Stykkisholmur (Iceland). Wintertime NAO index is very well correlated with European temperature and precipitation, as the NAO controls the strength of the mild westerlies. During the positive phase of the NAO both the Azores high and the Icelandic low are well developed, giving rise to strengthened westerly winds over Europe. Precipitation is enhanced in Northern Europe because cyclone tracks are shifted northwards, while Central Europe and the Mediterranean experience below-average precipitation (Hurrell 1995). In the negative phase of the NAO the westerly circulation is suppressed, and temperatures over Europe are lower than average.

One of the many circulation indices is the zonal index, first introduced by Rossby (1939). It is a measure of strength of the mid-latitude westerlies, expressed as geostrophic wind speed between two parallels (usually 35°N and either 55°N or 65°N) over the whole hemisphere or in certain sectors (e.g. the North Atlantic/European sector).

Another way of describing large-scale circulation variability is that of weather regimes. These can be viewed as recurrent, preferred states of atmospheric circulation present at continental scales. Although the term "weather" is generally used, these regimes are mostly defined on various geopotential height fields, thus describing solely the atmospheric circulation. On the other hand, Casty et al. (2005) identified three "climate" regimes in the North Atlantic-European sector in winter, using both upper-air and surface climatic data. One regime resembles the positive phase of the NAO; the other two are blocking situations over Europe. Other studies had also detected a very limited number of weather regimes (from three to five) in different regions of the world, e.g. Casty et al. (2005b), Michelangeli et al. (1995), Plaut and Simonnet (2001).

For certain applications, a partition of the dataset into a relatively small number of distinct classes is desired (see a review in Huth et al. 2008a). Classifications are sometimes used for regionalization, which results in finding coherent regions of similar statistical characteristics of the classified variable (e.g. its time evolution or annual cycle). Other classification approach – the one used throughout the whole thesis – involves the grouping of time realizations (usually daily observations, or monthly, seasonal, and even annual means) into classes. Non-circulation classifications include weather classification based on observations of several surface meteorological variables at a single site or at many sites, and air mass classification that takes into account variables from multiple tropospheric layers. Atmospheric circulation can be described and classified in many ways, and the resulting circulation classifications include e.g. that of backward air trajectories, storm tracks, wind fields, and atmospheric circulation types that are described in detail in the following section.

1.3.2 Classification of atmospheric circulation types

Classification of atmospheric circulation consists in the assignment of circulation patterns to distinct classes – circulation types. A circulation pattern in this context is a spatial configuration of sea level pressure field, geopotential height field of a selected pressure level, or a field of another variable, describing atmospheric circulation at a given timescale (from hourly to monthly or even seasonal), usually based on a regular spatial grid.

The term "classification" means both the procedure of dividing the dataset into classes, and the output of this procedure – the (usually daily) catalogue of circulation types. In Czech literature, however, the term “catalogue” is reserved for the mere list of circulation types, while the output of the assignment of daily circulation patterns to these types is called “calendar”. In this thesis we do not stick to the Czech rule. By the word “catalogue” we mean the daily calendar of CTs, and the meaning of “classification” is always deducible from the context. “Circulation types” or simply “types” are sometimes called “classes”, “patterns”, “clusters”, “categories”, or – mostly in the context of subjective classifications – “synoptic types”. The terms “weather type” or “circulation weather type” are used incorrectly for true circulation classifications that do not classify weather variables (James 2006, Makra et al. 2007, and Stefanicki et al. 2008 use the former; Trigo and DaCamara 2000 and Lorenzo et al. 2008 use the latter).

Classification procedures can be grouped according to the methods used for defining the circulation types and for assigning the individual cases to these types. Manual (subjective) classification defines CTs either by expert knowledge (e.g. the German Hess–Brezowsky catalogue, Hess and Brezowsky 1952) or by setting thresholds of airflow direction and cyclonicity (e.g. the Lamb catalogue for the British Isles, Lamb 1972). Daily synoptic maps are then manually assigned to these predefined types. The Hess–Brezowsky catalogue, developed by Baur (Baur et al. 1944), is centered over Germany but covers a large part of Europe. The assignment of circulation patterns to CTs was based on sea level pressure fields at first; geopotential heights of the 500 hPa level have been used in addition to SLP since the late 1940s. The catalogue contains 29 CTs that are required to last at least 3 days, and one transitional (unclassified) type. It spans back to 1881, being regularly updated (most recently by Gerstengarbe and Werner 2005), and it is still widely used in climatological studies (e.g. Bárdossy and Caspary 1990, Werner et al. 2000). Several national derivatives of the Hess–Brezowsky catalogue have been produced; in this thesis we analyze the Czech–Czechoslovak Brádka’s catalogue (Brádka et al. 1961) and the Hungarian Péczely catalogue (Péczely 1983).

In case the types are predefined but the assignment of cases to these types is fully automated, we speak about “hybrid” or “mixed” classifications. These include “objectivized” versions of the subjective classifications: Jenkinson and Collison (1977) for the Lamb catalogue, and objectivized Hess–Brezowsky by James (2007); as well as new catalogues based on correlation of circulation field with predefined “circulation prototypes” (GWT classification of Beck et al. 2007) or division of simple flow and vorticity indices into classes (Lityński 1969). In this thesis we use two versions of the objectivized Hess–Brezowsky catalogue for a direct comparison with the original: one that follows the original rule of a minimum 3-day duration of CTs, and the other one without such a constraint. Additionally the GWT and Lityński classifications are used.

The objective classifications (also known as computer-assisted, automated) define circulation types and assign individual cases to them according to a numerical computation. However, some degree of subjectivity is always present through the selection of input data, their pre-processing, and parameters of the method used for classification. The term "objective" is thus not fully appropriate, albeit widely used. Sometimes the hybrid (mixed) classifications are also called "objective" just for simplicity, which is also the case of this thesis.

There are several methods that can be employed in objective classification of circulation types; here we describe the major ones according to a review paper of Huth et al. (2008a).

Correlation-based methods define the CTs with respect to the similarity of circulation patterns, expressed by correlation coefficient or sums of squares of differences. In the first step a keyday pattern is identified, i.e. the day with the largest number of correlations above a given threshold with all the other days. The well-correlated days are assigned to type 1 and excluded from the dataset, then the second keyday pattern is found, etc., until all days are classified or the size of classes is too small. This method tends to produce one large circulation type and many small ones, and often leaves a lot of days unclassified. Examples of correlation-based classifications used in this thesis are the LUND catalogue (Lund 1963) and PETISCO (Petisco and Martín 1995).

Cluster analysis is a multivariate method primarily designed for producing classes, and as such is widely used for classification of circulation types. Different clustering algorithms are grouped into hierarchical and non-hierarchical methods. Hierarchical clustering begins with each case forming its own cluster; the cases are then grouped according to a distance measure until they form one cluster containing all cases. Non-hierarchical algorithms, e.g. the k-means method, require a predefined number of types. The cases are then assigned to cluster centroids. The k-means procedure usually produces equally-sized clusters, which may not be a proper representation of reality. An example of k-means clustering classification used here is CKMEANS (Enke and Spekat 1997). An optimized version of k-means clustering is called simulated annealing; here it is represented by the SANDRA catalogue (Philipp et al. 2007).

Another multivariate method used for classification of CTs is principal component analysis (PCA) also known as empirical orthogonal function (EOF) analysis. This method generally removes colinearity within the data and reduces dimensionality of the dataset. The original dataset is transformed into a set of a few mutually uncorrelated principal components

(PCs). For the purpose of classification of CTs, PCA should be applied in T-mode – i.e. rows of the data matrix are grid points, while columns are time realizations. The other arrangement of the data matrix – S-mode – produces modes of variability instead of CTs. For details on the use of PCA see Huth (1993) and Compagnucci and Richman (2008). In this thesis we employ the TPCA classification (Huth 2000) as a representative.

Nonlinear methods can also be used for classification of CTs. One example are neural networks, in this context applied solely with one type of architecture of the neural net that is called self-organizing maps. For details concerning self-organizing maps and their applications in synoptic climatology see Hewitson and Crane (1994, 2002) and Michaelides et al. (2007).

Fuzzy methods represent a specific approach to circulation classification that allows for multiple membership of each case. Each (usually daily) circulation pattern can belong to several circulation types, with different intensities of membership. Although this approach might be more proper for the description of continuous development of atmospheric circulation rather than the assignment of cases to disjunct classes, the resulting catalogues are impractical to work with. An example of fuzzy rule-based classification is provided by Bárdossy et al. (1995), but this approach generally did not gain much popularity within the climatological community.

1.3.3 Climatological applications of circulation type classifications

The primary aim of circulation classifications was to find analogous synoptic situations that produce typical local weather patterns, and therefore to forecast local weather more accurately on medium- to long-term timescales. With the use of numerical weather prediction models, the main focus of circulation type classifications has shifted towards general climatological studies, as well as different environmental and socioeconomic applications. Another rapidly developing area that is benefiting from circulation classification is the validation of global and regional climate models (GCMs and RCMs) and the study of atmospheric circulation in future climates simulated by these models.

The most urgent current problem of synoptic climatology is the huge number of classification methods and resulting catalogues used by various researchers, which strongly limits the comparability of their findings. A necessary step – unification of input data, spatial domains, and predefined numbers of CTs for classification – was carried out within the COST733 Action, enabling simultaneous use of many circulation catalogues and identifying their strengths and weaknesses. However, even the most rigorous evaluation of classification methods sometimes does not answer our question of applicability of individual catalogues, as the results may depend on the used evaluation criteria. Thus the primary goal of the COST733 Action – to find the single best classification method applicable to different time- and spatial scales and different atmospheric variables – cannot be fulfilled.

In the following paragraphs we provide an outline of existing methods currently used for the analysis of atmospheric circulation and its links with local climatic variability and trends. Each of the methods is documented by specific applications reflecting recent state of knowledge about circulation and climatic changes mainly over Europe. Here we focus on climatological applications, although the scope of actual and potential users of circulation classifications is much broader.

The methods include:

- **Analysis of circulation type frequencies, persistence, and their trends** within the circulation catalogues themselves – i.e. without taking into account the environmental consequences of CTs. This basic approach is a simple and strong tool for detecting large-scale circulation changes; nevertheless, it should be viewed more as a prerequisite for further applications rather than as climatic research standing on its own. The crucial question in synoptic climatology is the link between atmospheric circulation and local climatic variables, and because this link is often found to be nonstationary in time (as will be shown further), such a simple analysis of circulation changes might not reflect all processes at stake.

Stefanicki et al. (1998) studied trends in the seasonal frequency and persistence of CTs in the Swiss subjective catalogue of Schüepp (1968) in the period 1945–1994. They note an increase of the high-pressure type and a decrease of the northerly type in winter. These trends were caused by changing duration of the respective synoptic situations (i.e. increasing and decreasing persistence, respectively), while their total number per season remained unchanged.

Regular updates and time series analyses of the Hess–Brezowsky ”Katalog der Grosswetterlagen Europas” are provided in German by the Potsdam Institute for Climate Impact Research (PIK) (Gerstengarbe and Werner 1993, 2005, Gerstengarbe et al. 1999). Apart from that, the Hess–Brezowsky catalogue has been used many times to study circulation and climatic changes in Europe since 1881, e.g. by Bárdossy and Caspary (1990), Werner et al. (2000), Kyselý and Domonkos (2006), Kyselý and Huth (2006). All these studies note an enhancement in the occurrence of the westerly CTs in winter from the 1960 to the early 1990s, with a concomitant decrease of occurrence of the cold meridional types. These trends were also found in an objective circulation classification and an analysis of modes of variability in Kyselý and Huth (2006). Werner et al. (2000) detected an increase in the persistence of the group of westerly CTs in the Hess–Brezowsky in winter in the decade 1981–1990, which was also confirmed by a similar trend in one objective classification. Kyselý and Domonkos (2006) found increasing persistence of most groups of the CTs in most seasons since the 1970s with a major changepoint in the mid-1980s. None of these studies allowed for an inhomogeneity in the Hess–Brezowsky subjective catalogue, as it was claimed homogeneous by Gerstengarbe et al. (1999). First doubts about the credibility of persistence trends in the Hess–Brezowsky were raised by Kyselý and Huth (2006) who compared it with one objective classification. They ascribed the observed discrepancy – unrealistically high trends of persistence – to the different methodology used in the Hess–Brezowsky catalogue where all synoptic situations (i.e. sequences of days classified with the same CT) are at least three days long.

An analysis of one objective (SANDRA) classification of daily reconstructed SLP patterns in the period 1850–2003 was performed by Philipp et al. (2007). They observed a pronounced decadal to multi-decadal variability and several long-term trends in the seasonal frequency of the individual CTs. In winter, a type resembling the positive phase of the NAO was abundant between 1850 and 1870 and again since 1985, but no overall trend was detected. Another westerly type connected with cyclonic activity north of the British Isles shows a significant increase in winter frequency. In spring, there is an increase of blocking highs over Europe and a decrease of type with cyclones in the eastern Scandinavia. In summer, the warm type with anticyclone centered over Europe underwent major long-term fluctuations, with maxima until 1875, during the 1930s, and since about 1980. Autumn shows the least pronounced interdecadal variability, but there are some long-term trends: a decline of strengthened and/or westward extended Russian high, and an increase of southerly shifted Russian highs.

In this thesis we present an analysis of long-term trends in the seasonal frequency of CTs in the second half of the 20th century in various subjective and objective classifications in Sections 2, 5, 6, and 7. The persistence of CTs and its trends are discussed in Sections 2 and 4.

- **Identifying typical (average) weather conditions of CTs** in seasons or months. This is only a “first look” at the circulation-to-environment relationship, as it does not take into account the within-type variability and trends. Nevertheless, it is a necessary step to understand the physical causes of observed weather patterns on a local to regional scale (as used e.g. by Brádka et al. 1961, Fragoso and Tildes Gomes 2008, Goodess and Jones 2002, Kostopoulou and Jones 2007, Twardosz and Niedźwiedź 2001). This kind of analysis had been done within the COST733 by producing composite maps of SLP, air temperature, and precipitation under each CT for each season. This "visual" evaluation is, however, very lengthy or even impossible when using a large collection of different classifications. From our experience, we think that classifications with predefined CTs that are based on simple flow and vorticity characteristics are generally more user-friendly for this purpose, as the user is able to visualize the given circulation pattern without studying the map of the classified variable(s) for each CT.

- **"Skill" of circulation classifications to stratify (separate) daily climatic data into CTs**. The process of classification of circulation types naturally aims at reducing within-type variability, while maximizing inter-type separability. There are several indices that compare the within-type variability with the overall variability of a studied variable, e.g. within-type standard deviation (WSD) and explained variance (EV) index. Other tests compare the probability density functions (PDFs) of the studied variable under every CT with the overall PDF of the variable – e.g. the Kolmogorov–Smirnov test used by Huth (2010). For a detailed list of skill indices and methods see Beck and Philipp (2010). The skill indices can be applied to the variable used for classification, as well as to station or gridded climatic data, teleconnection indices, or other environmental indicators for which data are available in the same time resolution as the circulation classification (which is usually daily). We have to bear in mind that most of the skill indices are sensitive to the number of classes (CTs) by definition, so it only makes sense to compare classifications with similar numbers of CTs. The skill indices serve as a tool for the ranking of classifications (and possibly for disqualifying the worst ones from further use); however, we might get different rankings for different studied variables (e.g. air temperature, precipitation, wind speed, concentration of air pollutants), regions, and seasons.

In this thesis we test the performance of circulation classifications using the EV index in Sections 6 and 8 for the Czech Republic and Europe, respectively; additionally the WSD is applied at Czech stations in Section 6.

- **Simple or multiple regression of CTs frequencies with monthly (seasonal) means of climatic variable (or teleconnection pattern)**, e.g. Goodess and Jones (2002), Lorenzo et al.

(2008), Sepp (2005), Trigo and DaCamara (2000). Again, this approach does not take into account the within-type trends, assuming that the climatic properties of individual CTs do not change during the study period. The correlation between the observed monthly or seasonal time series of a climatic variable and the series modelled by the regression equation can also be used as a skill score to compare different classifications. Even though the regression model uses circulation and climatic data with daily time resolution, part of the daily information is lost because the frequencies of CTs are correlated with monthly or even seasonal mean of the climatic variable. The individual CTs are thus not directly compared with local conditions present during their occurrence.

- **Circulation type as a "predictor"**: construction of a new daily time series of a specific climatic element, whose value on each day is equal to the long-term average of the given element (monthly or seasonal) under the CT present on that day. A new, "circulation-induced" or "reconstructed" daily time series of the given climatic element is produced and can be handled in several ways:

Correlation of the reconstructed and observed daily time series of the given variable may serve as one of the scores that measure the skill of circulation classifications to separate daily climatic data into CTs. This approach is used in Section 6 together with two previously mentioned indices to study the skill of several classifications to stratify daily climatic data into CTs at Czech stations. Buishand and Brandsma (1997) compared three classification catalogues according to their relation with local temperature and both local and regional precipitation data in the Netherlands, and found marked differences between the classifications for temperature. They also note that the classifications better "predict" daily temperature than local precipitation, because certain part of precipitation is connected with convective storms unrelated to CTs (these occur mainly in summer). A better stratification by CTs was obtained for the area-average precipitation. Monthly mean values of the observed and reconstructed time series were better correlated than the daily series; this effect was the most pronounced for precipitation. Bárdossy and Caspary (1990) found correlations between 0.7 and 0.9 for monthly mean precipitation in Germany under the Hess–Brezowsky classification, which is comparable to the results of Buishand and Brandsma (1997) obtained for the Netherlands.

The "circulation-induced" daily time series may serve for the assessment of "hypothetical" (circulation-conditioned) trends. These trends are "hypothetical" because we assume that the climatic properties of individual CTs are not changing over time, as we replace the daily values of the studied variable by its long-term mean under the given CT in the given month or season. When dividing the “hypothetical” trend magnitude by the observed trend, we get a proportion of the observed trend that is directly linked to changing frequency of CTs. This method was used for the attribution of climatic trends at two Czech stations in 1949–1980 by Huth (2001) who noted that circulation changes are unrelated with observed trends in summer and only partly related in winter. An attribution of seasonal trends using this method is presented in Sections 5 and 6 for eleven climatic variables in the Czech Republic in the period 1961–1998, and for maximum and minimum temperature and precipitation over Europe in 1961–2000, respectively.

- **Assessment of within-type climatic trends**, that is, changes in the climatic properties of individual CTs on a seasonal or monthly basis. These within-type climatic changes may affect all the circulation types (that would point to a large-scale driver of changes, i.e. global warming), or may be restricted only to certain synoptic conditions. A detailed methodological overview of within-type climatic trends was presented by Huth (1999) who suggested several ways to compute these trends. The problem is that individual CTs are unevenly distributed over time – each year (month, season) we observe different frequency of occurrence of the CTs. Furthermore, each CT has a different overall frequency, and thus we do not gain a “general” within-type trend by simply averaging the within-type trends of the individual CTs.

Within-type climatic trends should be studied together with the observed overall trends. For example, a simple ratio of the within-type trend and the overall trend tells us if the within-type changes follow the observed climatic changes, or are larger, smaller, or even of opposite sign. If the ratio is one, the climatic properties of individual CTs are changing at the same rate as the overall climate and the observed climatic trend is caused only by within-type changes. If the ratio is zero, then the climatic properties of CTs are stable over time and the observed climatic changes result only from trends in the frequency of CTs.

The observed within-type trends might be caused by changing dynamical properties (intensity of flow, vorticity) of the individual CTs, but Beck et al. (2007) noted that other causes including subgrid-scale processes, synoptic-scale variations, and modifications of the climatic boundary conditions contribute to the within-type trends.

Seasonal within-type trends of maximum and minimum temperature and precipitation in Europe are briefly discussed and compared with overall trends in Section 10.

- **Decomposition of climatic change** that occurred between two time periods into frequency-related part and within-type related part. A simple equation presented in Sections 5, 6, and 10 (originally proposed by Barry and Perry 1973) enables us to detect the ratio of the two causes of the observed change: (i) changes in the frequency of CTs, and (ii) within-type climatic changes. The time periods need not be subsequent: Beck et al. (2007) used 31-year time slices from the period 1780–1995 and compared each one with a 31-year period shifted by one year. This was done for each month separately, using reconstructed circulation and climatic data for Central Europe with a monthly time resolution. The resulting long time series of "moving results" suggest that the links between circulation and regional climate are unstable in time, showing large decadal to multidecadal variations. Küttel et al. (in press) performed a similar analysis on mean winter sea level pressure fields over Europe and North Atlantic, and gridded mean winter temperature and precipitation in Europe, reconstructed back to 1750. A decomposition of climatic differences between the period 1950–1999 and all preceding 50-year periods revealed that within-type climatic variations are responsible for a major part of the observed changes.

We use this decomposition in Sections 5, 6, and 10 as a supplementary method for the attribution of climatic changes that took place between the 1st and the 2nd half of our study period (which is 1961–1998 in the Czech Republic and 1961–2000 in Europe).

- **"Conditional downscaling"** separately for every circulation type (Enke and Spekat 1997, Huth et al. 2008b). Downscaling generally aims at finding links between large and small-scale atmospheric conditions in order to obtain high-resolution results from the coarse output of global climate models. Conditional downscaling assumes that the relationship between large-scale predictor and local predictand can be different under every circulation type. However, Huth et al. (2008b) did not find its results superior to the standard downscaling methods.

Section 2 – Paper I: Cahynová M., Huth R. (2007a): Trendy v kalendáři povětrnostních situací HMÚ/ČHMÚ v období 1946–2002 (Trends in the HMI [Czech, formerly Czechoslovak] subjective classification of synoptic types in the period 1946–2002). Meteorologické zprávy (Meteorological Bulletin) 60: 175–182.

2. Paper I: Trends in the HMI (Czech, formerly Czechoslovak) subjective classification of synoptic types in the period 1946–2002

Monika Cahynová, Institute of Atmospheric Physics ASCR, Boční II 1401, 141 31 Praha 4-Spořilov; Charles University in Prague, Faculty of Science, Department of Physical Geography and Geoecology
Radan Huth, Institute of Atmospheric Physics ASCR, Boční II 1401, 141 31 Praha 4-Spořilov, e-mail: huth@ufa.cas.cz

(English translation of the Czech paper)

Keywords: synoptic situations – typing – trends – Czechoslovakia

Abstract

The aim of this study is to present trends and inhomogeneities in the occurrence and persistence (lifetime) of synoptic situations over the Czech Republic as they are classified based on a subjective catalogue created at the former Czechoslovak Hydrometeorological Institute. The most notable trend is the increasing number of cyclonic types in winter and spring but especially in autumn. The occurrence of west and northwest types increases in winter, summer, and autumn from the 1960s until the mid-1990s, following the positive trend of the North Atlantic Oscillation. Annual persistence of synoptic situations has decreased by 2.3 days in the period 1946–2002 mainly due to personal changes in the research team in early 1970s. The series is inhomogeneous because of a changing approach to circulation classification over time.

2.1 Introduction

For the area of Czechoslovakia, the catalogue of synoptic situations had been developed in the former Hydrometeorological Institute (HMI) by Brádka et al. since 1946 [4]. The primary aim for the creation of an independent classification for this domain was the improvement of medium-range weather forecasts, the types were defined so that they represented typical local weather. The methodology reflects the German subjective classification of synoptic types by

Hess and Brezowsky (1st edition in 1952 [2], the catalogue is being updated and analysed regularly). Atmospheric circulation of each day is classified with one of 28 synoptic types, whereas in the German catalogue there are 29 types and one transitional (undefined) type. The HMI catalogue is published separately for the Czech and Slovak Republics since 1991 (but in close cooperation of the Czech and Slovak Hydrometeorological Institutes). Here we analyze the Czechoslovak catalogue and since 1991 its Czech version. The whole catalogue is available for download at the CHMI web pages [8], where we can also find the description of types. Yearly catalogues of synoptic situations are published in print since 1972 in the Meteorological Bulletin (Meteorologické Zprávy). At the web pages, due to technical reasons, there are no "dividing lines" in sequences of the same synoptic types that have been naturally interrupted but continue the next day as the same type. We can find the description and climatological features of individual types in Křivancová and Vavruška [5] for the period 1961–1990. In Table 2.1 we present the list of synoptic types and their grouping according to their cyclonicity and prevailing flow direction.

The aim of this work is the assessment of trends in the frequency and lifetime of individual types with regard to possible inhomogeneities in the catalogue that might be caused e.g. by changes in the research team or methodology (even though these could be minor or subjective). Despite the fact that the HMI classification is being widely used in meteorology as well as in climatological and hydrological applications, the only thorough analysis was published in 1989 in the Proceedings of the CHMI for the period 1946–1985 [9].

Section 2 – Paper I: Cahynová M., Huth R. (2007a): Trendy v kalendáři povětrnostních situací HMÚ/ČHMÚ v období 1946–2002 (Trends in the HMI [Czech, formerly Czechoslovak] subjective classification of synoptic types in the period 1946–2002). Meteorologické zprávy (Meteorological Bulletin) 60: 175–182.

Table 2.1. Division of synoptic types into groups according to their cyclonicity and prevailing wind direction. Source [1].

Abbrev.	Description	Cyclonicity	Direction
Wc	west cyclonic	C	W+NW
Wcs	west cyclonic with southern track of cyclones	C	W+NW
Wa	west anticyclonic	A	W+NW
Wal	west anticyclonic of a summer type	A	W+NW
NWc	northwest cyclonic	C	W+NW
NWa	northwest anticyclonic	A	W+NW
Nc	north cyclonic	C	N+NE
NEc	northeast cyclonic	C	N+NE
NEa	northeast anticyclonic	A	N+NE
Ec	east cyclonic	C	E+SE
Ea	east anticyclonic	A	E+SE
SEc	southeast cyclonic	C	E+SE
SEa	southeast anticyclonic	A	E+SE
Sa	south anticyclonic	A	S+SW
SWc$_1$	southwest cyclonic with fronts moving north to northeastwards	C	S+SW
SWc$_2$	southwest cyclonic with fronts moving northeast to eastwards	C	S+SW
SWc$_3$	southwest cyclonic with frontal zone shifted southwards	C	S+SW
SWa	southwest anticyclonic	A	S+SW
A	stationary anticyclone over central Europe	A	–
C	cyclone over central Europe	C	–
Cv	upper-air cyclone	–	–
B	stationary trough over central Europe	C	–
Bp	eastward traveling trough	C	–
Vfz	frontal zone entrance	–	–
Ap$_1$	anticyclone traveling northeastwards	A	–
Ap$_2$	anticyclone traveling eastwards	A	–
Ap$_3$	anticyclone traveling southeastwards	A	–
Ap$_4$	anticyclone traveling southwards	A	–

2.2 Trends in the frequency of synoptic types

Trends in the frequency of synoptic types were analysed by linear regression using the least squares method. The frequency of types was set as the total annual number of days with a given type, and similarly for the four seasons (MAM, JJA, SON, and DJF) in the period 1946–2002. Long-term average annual frequencies and lifetime of synoptic types and groups of types are displayed in Tables 2.2 and 2.3. Years when a significant shift in the mean occurred are highlighted.

In the annual frequency of synoptic types we observe these statistically significant trends (at the 95% level): increase in the number of Ap_1, Ap_2, and Ap_3 (traveling anticyclones, increasing trend since the end of the 1960s), Bp (traveling trough), Cv (upper-air cyclone), SEc (southeast cyclonic), and Wc – west cyclonic type (see Fig. 2.1). The largest positive trend is present in Bp – the annual count has risen by 31.8 days in 57 years. There is a decrease of frequency of B (trough), Ea (east anticyclonic), NWa, SWa, and Wa (northwest, southwest and west anticyclonic types). The decrease of Ea and the increase of Bp are the only trends significant in all seasons.

In winter there is a significant increase in Ap_1, Ap_2, Bp, and Wc; decreasing trend affects only two types – B and Ea (Fig. 2.2). In spring there is an increase of Ap_2, Bp, Wc, and SEc, significant decrease is observed in types Ea and NWa. In summer and autumn there is a high proportion of significant trends – 8 increasing in each of the two seasons, one (five) decreasing in summer (autumn), respectively. In summer the only type with a downward trend is Ea, the other significant trends are positive (Ap_1, Ap_2, Ap_3, Bp, Cv, Sa, SEa, and SEc). In autumn there is a decrease of A (anticyclone), Ap_4, B, Ea, and Wa; the number of Ap_1, Ap_3, Bp, NEc, SEc, SWc_3 (southwest cyclonic no. 3), Vfz (frontal zone entrance), and Wc is increasing.

We can see the following annual trends in the groups of synoptic types grouped by their direction of advection: increase in the number of days with W and NW types from the mid-1970s to the beginning of 1990s (Fig. 2.3), followed by a sharp decrease together with an increase of types with undefined direction (A, $Ap_{1\text{-}4}$, B, Bp, C, Cv, Vfz). The number of days with E and SE types decreases between 1953 and 1990, in the 1990s there is an increase followed by a decrease. Until the beginning of the 1970s the occurrence of S and SW types decreases, and then increases since 1980. There is no pronounced trend in the frequency of N and NE types in the study period. The same trends as in the whole year are present in all seasons but spring for W and NW types, their increase starting already in the 1960s. Summer contributes the most to the annual increase of days with undefined direction of advection.

Table 2.2. Average annual frequency (days, 2nd column) and persistence (lifetime, 5th column) of individual synoptic types, inhomogeneity in a series of annual averages (SNHT test – shift in mean value, 95% significance level). Year of change – the first year following the change. The asterisk means that in a given series a statistically significant inhomogeneity does not occur. The change in days (the 4th and 7th columns) is defined as a difference of averages of 10 years before change and 10 years after it.

type	average frequency	year of change	change (days)	average persistence	year of change	change (days)
Wc	32.6	1973	15.6	3.9	*	*
Wcs	12.4	*	*	4.1	1974	-1.5
Wa	12.5	1977	-6.2	3.6	1976	-1.1
Wal	12.6	*	*	6.7	*	*
NWc	18.2	*	*	3.4	1969	-1.0
NWa	6.2	*	*	3.3	1975	-0.9
Nc	13.3	*	*	3.5	1975	-2.4
NEc	18.5	*	*	3.6	1984	-1.1
NEa	12.1	*	*	3.5	1972	-0.8
Ec	16.3	*	*	3.7	1977	-1.7
Ea	15.8	1970	-11.6	3.6	1973	-1.1
SEc	10.4	1971	8.2	3.3	1975	-1.4
SEa	7.5	*	*	3.5	1977	-1.7
Sa	8.0	*	*	3.3	1974	-1.1
SWc$_1$	11.1	1990	9.8	3.6	1976	-1.7
SWc$_2$	19.3	*	*	3.6	1974	-1.5
SWc$_3$	13.2	*	*	3.6	1978	-1.0
SWa	8.9	*	*	3.3	1969	-1.0
A	21.2	1990	-10.3	4.2	1973	-1.3
C	12.5	*	*	4.3	1973	2.5
Cv	3.4	1972	3.3	2.6	*	*
B	32.6	1982	-16.3	4.4	1976	-1.3
Bp	17.3	1997	22.0	2.7	1949	-1.5
Vfz	10.3	*	*	3.6	1973	-1.9
Ap$_1$	3.4	1967	2.6	1.4	1987	-0.4
Ap$_2$	8.6	1976	6.9	1.6	1950	-0.9
Ap$_3$	4.9	1986	5.4	1.9	1947	-2.7
Ap$_4$	2.1	*	*	2.0	1982	-1.0

Table 2.3. Average annual frequency and persistence of groups of synoptic types, inhomogeneity in a series of annual averages (SNHT test – change in an average, 95% significance level). Explanations as in Table 2.2.

direction of advection	average frequency	year of change	change (days)	average persistence	year of change	change (days)
N+NE	43.9	*	*	3.5	1973	-1.2
E+SE	49.9	*	*	3.6	1976	-1.4
S+SW	60.6	*	*	3.5	1974	-1.0
W+NW	94.5	*	*	3.9	1973	-1.1
undefined	116.3	1962	23.2	3.1	1976	-1.4
cyclonicity						
C	227.8	1974	24.2	3.7	1973	-1.2
A	123.8	1974	-22.1	3.2	1974	-1.3
undefined	13.6	1997	11.0	3.3	1970	-1.1

If we group the synoptic types according to their cyclonicity (cyclonic, anticyclonic, and undefined), it is obvious that the frequency of the cyclonic types increases in all seasons except for summer when trends are negligible (Fig. 2.4). In autumn this increase is as high as 21.7 days in 57 years – nearly a month in a three-month season (!). In winter the frequency of days with anticyclonic circulation has increased by 9 days. In spring there is an increase of 14.5 cyclonic days until the beginning of 1970, followed by stationary state and a slight decrease in the 1990s. The major contribution to these trends is the increase in the number of traveling troughs (Bp), which bears a positive trend of seven to ten days in summer and winter, respectively.

Section 2 – Paper I: Cahynová M., Huth R. (2007a): Trendy v kalendáři povětrnostních situací HMÚ/ČHMÚ v období 1946–2002 (Trends in the HMI [Czech, formerly Czechoslovak] subjective classification of synoptic types in the period 1946–2002). Meteorologické zprávy (Meteorological Bulletin) 60: 175–182.

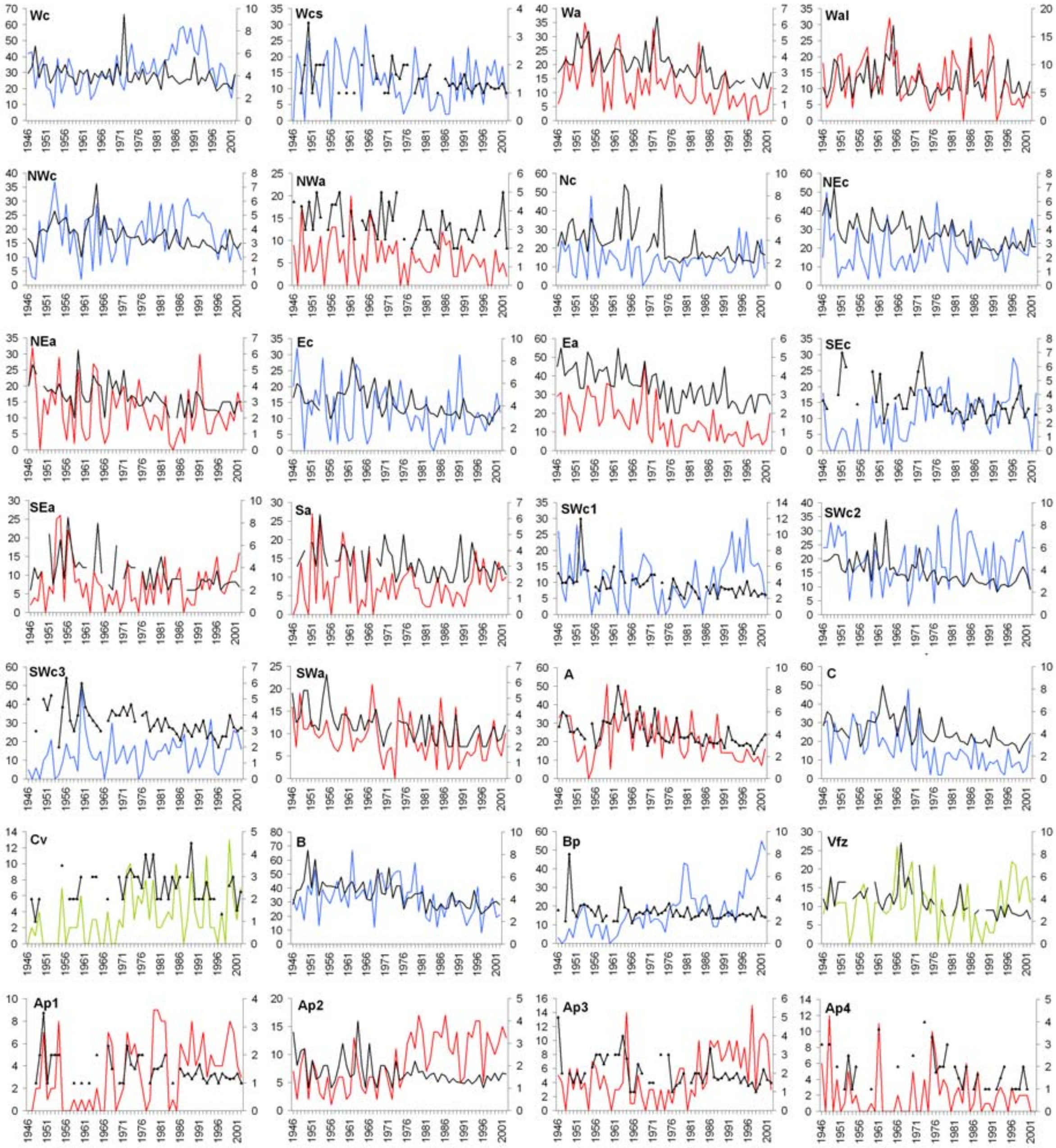


Fig. 2.1. Number of days with specific synoptic type per year – left axis and coloured lines (red–anticyclonic, blue–cyclonic, green–other); and average annual persistence of synoptic situations – black line and right axis.

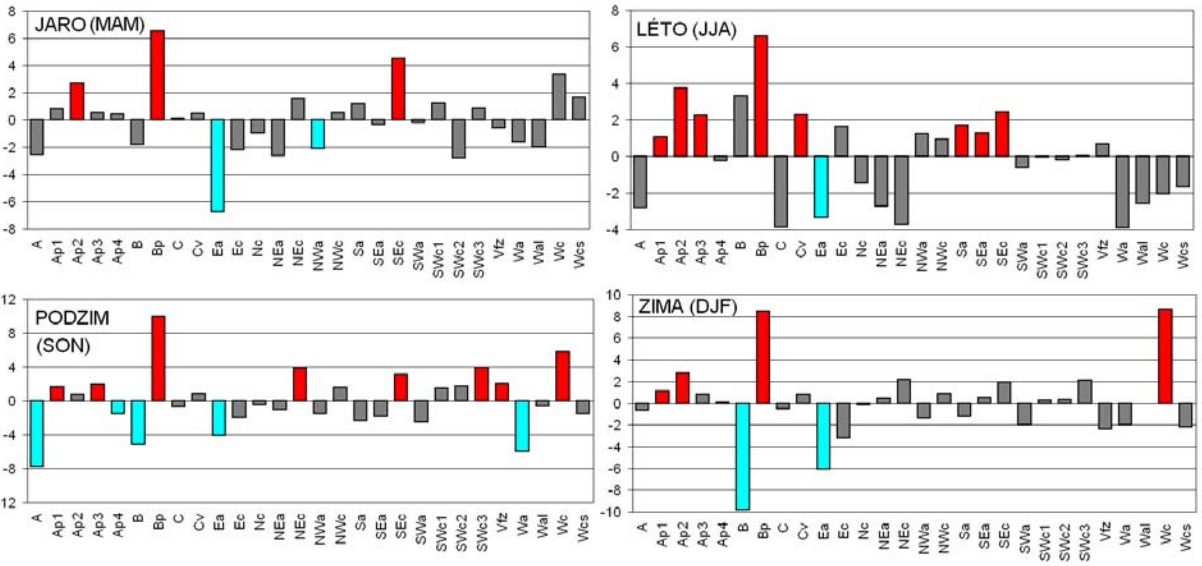


Fig. 2.2. Linear trends of seasonal occurrence of circulation types, change in days per 57-year period 1946–2002. Trends significant at 95% level are shown in color.

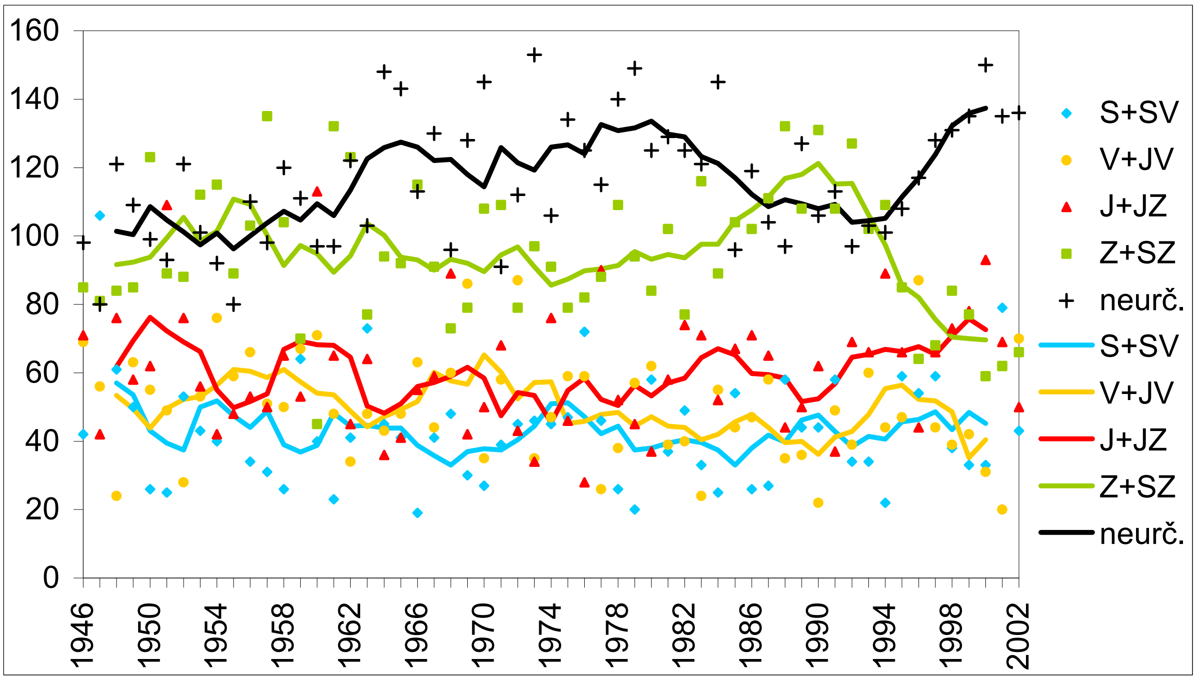


Fig. 2.3. Annual number and five-year moving averages of days with synoptic types grouped according to the direction of flow (S+SV=N+NW, V+JV=E+SE, J+JZ=S+SW, Z+SZ=W+NW, neurč.=undefined).

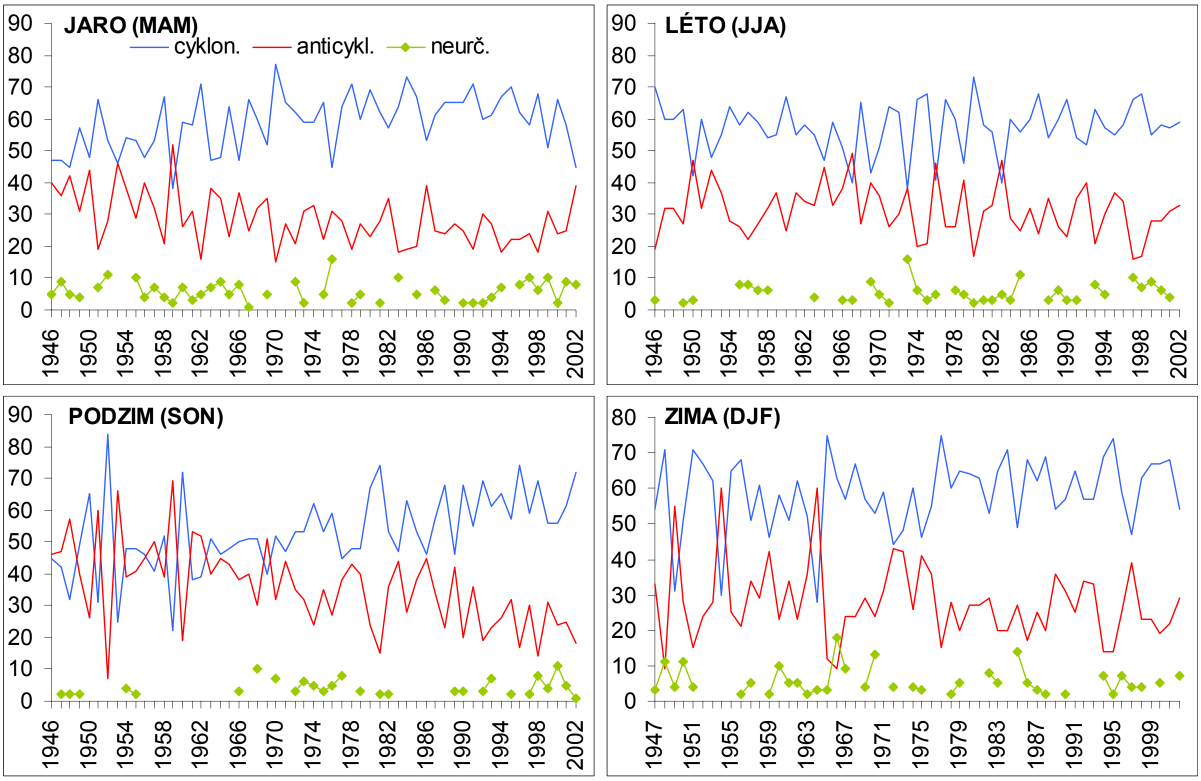


Fig. 2.4. Seasonal frequency of days according to their cyclonicity.

2.3 Changes in the lifetime (persistence) of synoptic situations

The persistence of synoptic situations, i.e. the number of consecutive days classified with the same type, is an important variable that can reflect long-term changes of circulation regime in a certain region. However, subjective classifications can be influenced by systematical errors, such as a slight change in the methodology of classification, or a personnel change. In the following analysis we will focus on the persistence of synoptic situations without taking into account the "dividing lines" in sequences of the same synoptic types that have been naturally interrupted but continue the next day as the same type. The annual number of such "dividing lines" is around 5, and their number was relatively low from the mid-1960s to the mid-1990s.

The HMI classification of synoptic types is quite interesting in terms of persistence of types. There is an overall decreasing trend (i.e. shortening of synoptic situations) in the whole period 1946–2002 (Fig. 2.5, see also Fig. 2.1). Long-term average persistence is 3.6 days and the magnitude of trend per 57 years is –2.33 days. The series of annual means of persistence is inhomogeneous with a shift between 1972 and 1973 (tested in the AnClim software [10] by

Standard Normal Homogeneity Test – SNHT), when a sudden drop in the length of synoptic situations occurred. Until the "turning point" in 1972 the trend of persistence was negative but insignificant at the 80% level. Since 1973 we observe a decreasing trend significant at the 99% level.

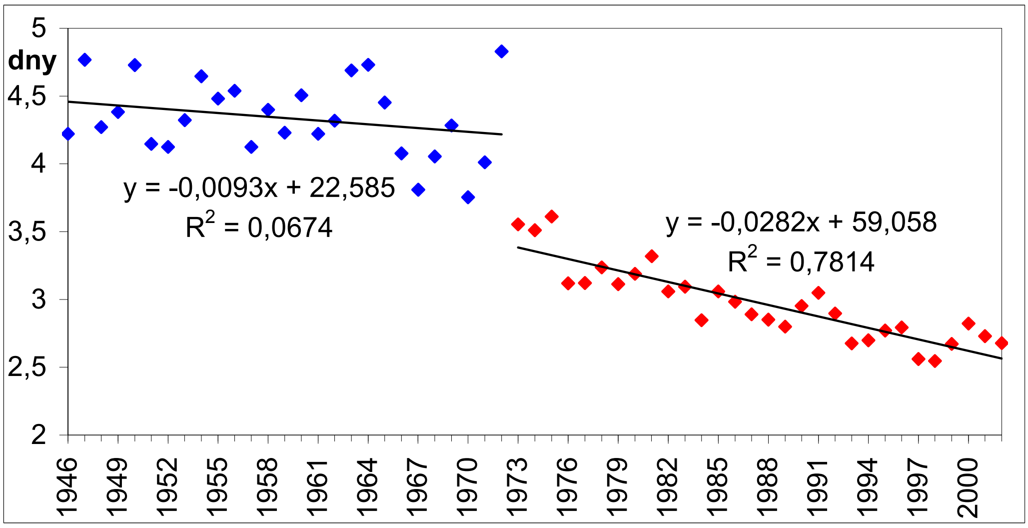


Fig. 2.5. Average annual persistence (lifetime) of synoptic situations.

Until the beginning of the 1970s, one-day and two-day synoptic situations were very rare (Fig. 2.6) – their combined annual count was around ten. After 1972 a sharp increase of two-day situations begins, and culminates at about 60 per year in the 1990s.

The decrease in persistence affects all synoptic types with the exception of Cv (small positive trend). Type Wal (west anticyclonic summer type) bears a negative but insignificant trend (Fig. 2.7). The most pronounced decrease – 3.5 days – is present in type C (cyclone over Central Europe). Other types with a strong decrease in their persistence (between 2.5 and 3 days) are B, Ec, Nc, SWc$_1$, SWc$_2$, Vfz, and Wcs.

According to the SNHT (Single shift in mean level) 25 out of 28 annual series of persistence are inhomogeneous (Table 2.2). The shifts occur from 1947 to 1987; at the majority of series (18) the shift has taken place between 1969 and 1972. The time series of persistence of groups of types with respect to the direction of advection are all inhomogeneous with a shift twice in 1973, twice in 1976 and once in 1974 (Table 2.3).

In certain synoptic types there is a good accord of the annual count of days and the average annual persistence, thus the annual frequency of such situations (i.e. sequences of days with the same type) does not change with time. This feature is present in A, Ap$_4$, B, C, Ea, Ec, NEa, SWa, Wa, and Wal. In other types the shortening of situations is connected with a higher annual number of days with a given type. These situations (Ap$_1$, Ap$_2$, Ap$_3$, Bp, NEc, NWc, SEc, SWc$_1$, SWc$_2$, SWc$_3$, Vfz, Wc) thus become shorter, but occur more frequently during the year.

When we study the persistence of groups of types, we can see that the west and northwest types have the longest average persistence (3.9 days) and the difference from the other groups of types is most pronounced in the 1980s and 1990s.

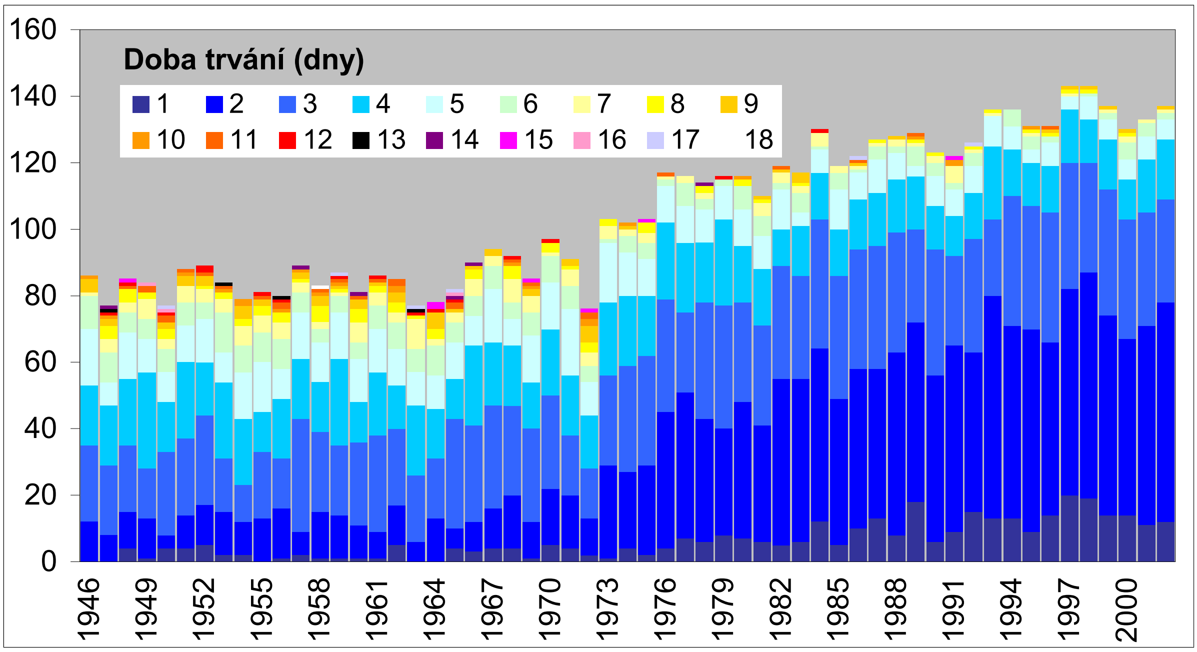


Fig. 2.6. Annual number of synoptic situations with respect to their persistence.

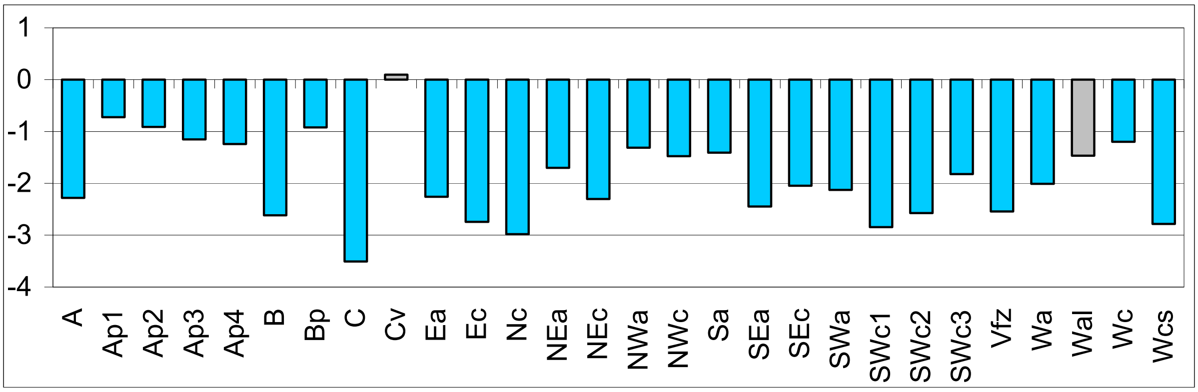


Fig. 2.7. Linear trend in persistence of synoptic situations (change in days per 57 years, 1946–2002).

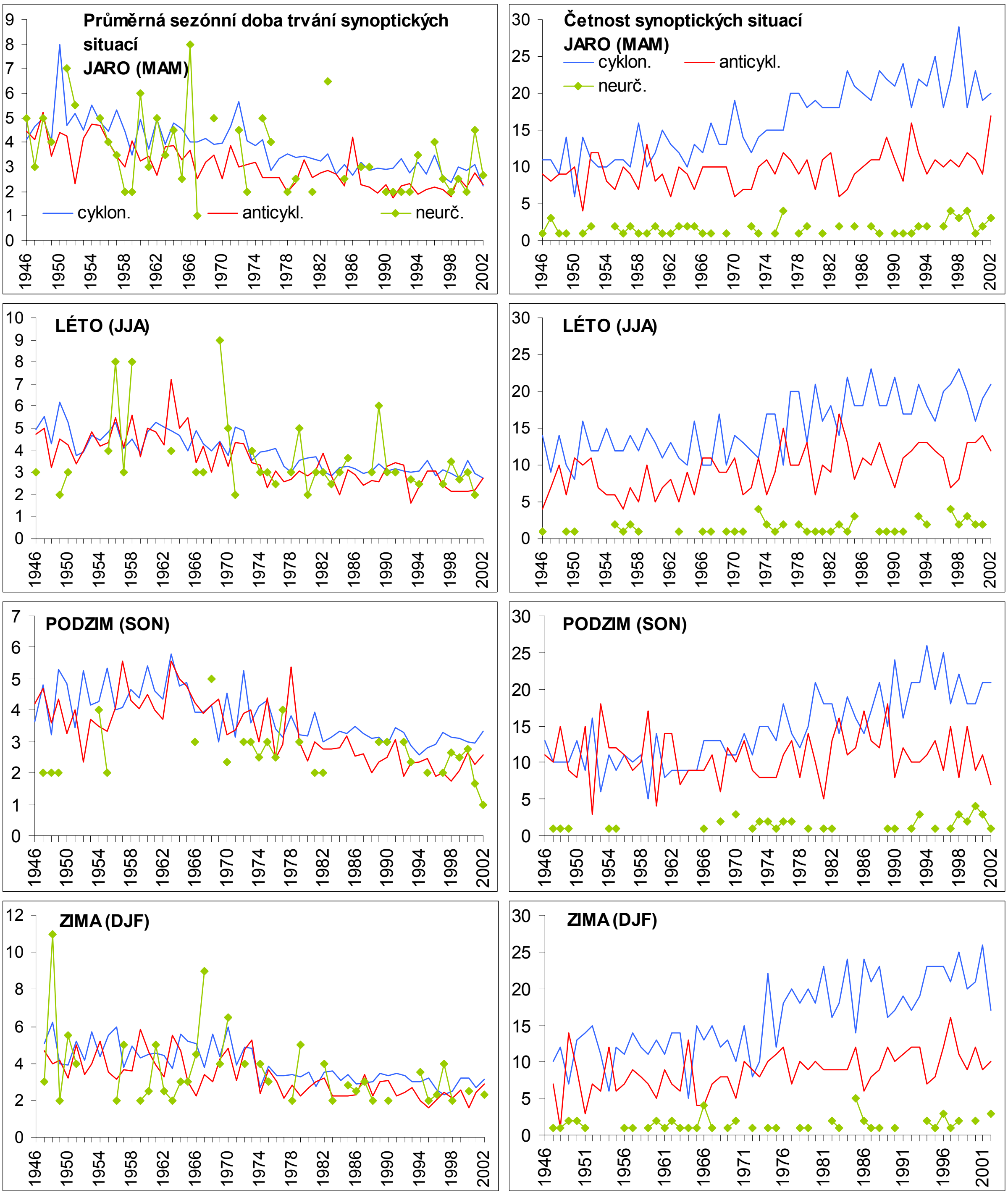


Fig. 2.8. Seasonal trends in mean lifetime (left) and occurrence (right) of cyclonic and anticyclonic situations (compare with Fig. 2.4).

Cyclonic types last on average 0.5 days longer than the anticyclonic ones (see Table 2.3), but both groups reflect the overall decreasing trend in persistence (Fig. 2.8). Even though the number of anticyclonic days decreases notably, the number of anticyclonic situations slightly increases (in autumn only between the beginning of the 1960s to the end of the 1980s). The increasing trend in the number of cyclonic situations is several times higher than that of anticyclonic situations; the increase in the number of cyclonic days is thus caused by more frequent recurrence of these situations (no matter that the individual situations are shorter on average). In autumn the anticyclonic situations undergo a more massive shortening than the cyclonic ones.

The observed shortening of synoptic situations is for sure caused by different approach to classification performed by different meteorologists over the course of the years in CHMI and SHMI. The evident shift between 1972 and 1973 that was detected as a statistical inhomogeneity coincides with the death of dr. Brádka in 1974 (and thus with a probable methodology change).

2.4 Discussion

In the region of Central Europe we can compare the HMI catalogue with the German Hess and Brezowsky "Grosswetterlagen" [2] that is also based on a subjective assignment of predefined circulation types to individual days. Here the trend in the persistence is quite opposite – since the mid-1980s we can see a prolongation of circulation types (mainly zonal – west types in winter). The enhancement of persistence of mainly the west types has also been found with the use of an objective method of classification of atmospheric circulation in Central Europe [7, 11]. The authors of [6] explain these trends by the northward shift of cyclonic paths due to global warming and strengthening of the North Atlantic Oscillation. The observed discrepancy between the Czech (formerly Czechoslovak) and German catalogue probably stems from the fact that there is a constraint of a minimum 3-day duration of sznoptic situations in the Hess–Brezowsky catalogue (except for the transitionary type). Whereas in the German catalogue the frequency of the transitionary (the shortest) type has decreased in the last decades, in the HMI catalogue the number of (very short) traveling anticyclones (Ap_1, Ap_2, Ap_3) and troughs (Bp) has increased notably. (Until the mid-1990s there had been a constraint of a minimum 2-day duration of synoptic situations in the HMI catalogue, however it never referred to the traveling anticyclones.) Due to the higher recurrence of these traveling types the other types are being "fragmented" and become shorter. Thus the pronounced shift in the persistence of synoptic situations in 1972/1973 seems to be caused by methodology change, in the following period the persistence shortened considerably and its interannual variability decreased. Our assumption was confirmed by Stanislav Racko (CHMI) who also points to the fact that meteorologists today consider the synoptic situation on a smaller scale (which also reflects the division of the HMI catalogue into Czech and Slovak parts). Previously the meteorologists tried to classify the situation more "generously", keeping in mind that the "natural synoptic situation" should last as long as possible. The group of meteorologists working on the HMI catalogue has changed its personnel in 1969, 1973, 1979, 1989, 1994, and 1998. Another problem stems from the fact that the catalogue does not include north anticyclonic type, south cyclonic type, and flat low. These types have only been included and used in an unofficial, parallel classification used for internal purposes of CHMI since 2001. Contrary to the Hess–Brezowsky catalogue, the HMI classification does not suffer from a more frequent change of types at the ends of months and years that is caused by monthly manual data evaluation.

In the HMI catalogue as well as in the Hess–Brezowsky and one objective classification (analyzed by Kyselý and Huth [7]) we can see an increase of frequency of zonal (westerly) types in winter between the 1960s and the beginning of the 1990s, with a decrease hereafter. This trend is also pronounced in autumn and summer in the HMI catalogue, on the other hand in the German catalogue the number of zonal situations in summer decreases between the 1960s and the 1990s. We can explain the winter coincidence by the behaviour of the North Atlantic Oscillation, whose strengthening is connected with enhanced westerly flow in the whole Central European region.

The differences between the HMI and the German subjective catalogues also affect trends in the occurrence of cyclonic and anticyclonic types – whereas in the HMI catalogue we see an increase of cyclonic types over the whole period in all seasons but summer, in the German catalogue the number of cyclonic days decreases over the whole year from the end of the 1960s until the beginning of the 1990s. Trends in the objectively defined types in paper [3] follow the German catalogue: in 1949–1980 there is an increase in the occurrence of anticyclonic types in winter and summer (other seasons were not studied). These discrepancies are probably caused by a different spatial extent of regions used for classification – the synoptic situation over Central Europe is, naturally, classified different from the view of the Czech Republic (Czechoslovakia) and Germany. If we compare the day-to-day assignment of cyclonicity in the Czech and German catalogues (in 1946–2002, the German catalogue consists of 12 anticyclonic and 13 cyclonic types according to [7]), we can see that in most of the days the cyclonicity is the same (in 63.5% days, see Fig. 2.9). The best accord (66.4%) occurs naturally in winter, the worst (59.4%) in summer. There are generally more cyclonic days in the HMI catalogue than in the German one (62.3% and 47.3%, respectively). That means that a certain proportion of "Czech cyclonic" days are classified as anticyclonic in the German catalogue (in Fig. 2.9 these days are displayed in blue). The average occurrence of such days is 15.1% annually; they are mostly present in summer when they occupy 19.1% of days, whereas in winter and autumn they account only for 13% of days. The most interesting fact is that since the 1960s the number of such "disputable" days increases, as does the occurrence of cyclonic types in the HMI catalogue.

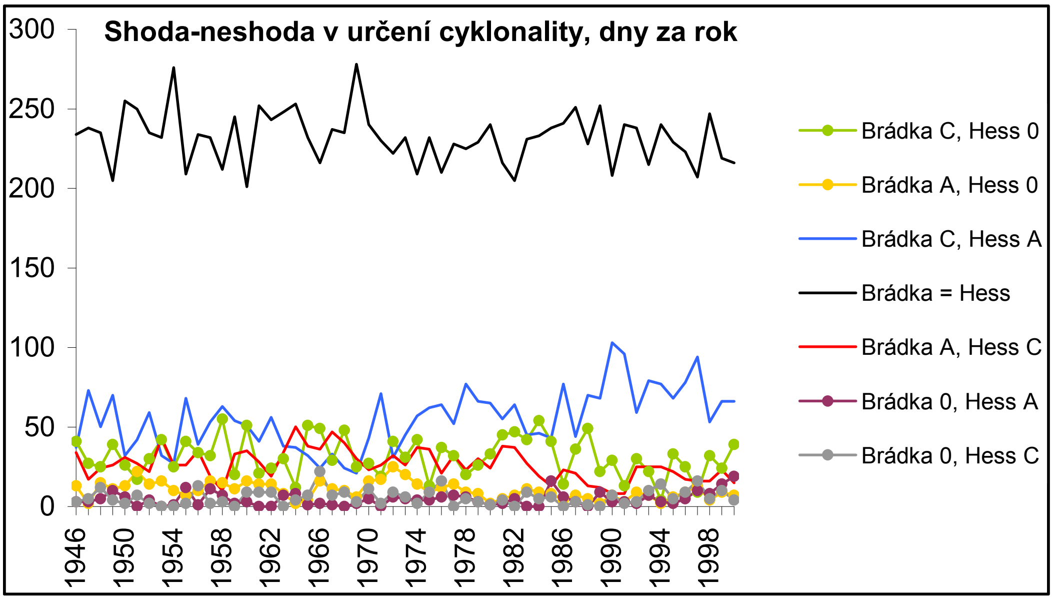


Fig. 2.9. Comparison of cyclonicity of synoptic types in the Brádka's Czech (Czechoslovak) and German (Hess–Brezowsky) catalogues (number of days per year).

2.5 Conclusion

In this study we present an analysis of trends in the occurrence and persistence of synoptic types in the Czech–Czechoslovak HMI catalogue (produced according to the methodology of Brádka et al.) in the period 1946–2002. The synoptic types were grouped according to their cyclonicity (anticyclonic and cyclonic) and prevailing direction of advection (W+NW, N+NE, E+SE, S+SW).

The frequency of the cyclonic types increases and that of the anticyclonic types decreases in all seasons but summer when trends are negligible. The most notable positive trend of the cyclonic days is present in autumn. In spring the number of the cyclonic days increases until the beginning of the 1970s, and decreases in the 1990s after a period of stagnation. These trends are caused mainly by more frequent traveling troughs (Bp). Both the cyclonic and the anticyclonic situations shorten in the study period, thus the increase of the cyclonic days is caused by a more frequent recurrence of these situations and not by their longer duration.

The occurrence of the westerly and northwesterly types generally rises from the mid-1970s to the beginning of the 1990s; seasonal trends are similar (except for spring) from 1960s until the 1990s. Afterwards the westerly types rapidly decline and are replaced by situations with undefined direction of advection (A, $Ap_{1\text{-}4}$, B, Bp, C, Cv, Vfz). Between 1953 and 1990 the number of the easterly and southeasterly types decreases. In the southerly and southwesterly types there is a decrease until the beginning of the 1970s and an increase since 1980, in the northerly and northeasterly types there is no pronounced trend.

The average persistence of synoptic situations (averaged over all types) has shortened by 2.33 days in the study period. In 1972/1973 there was a sudden decline, with a significant slow decrease afterwards. This inhomogeneity was probably caused by personnel changes in the research team and the decline from the former concept of a long “natural synoptic situation”. The negative trends in persistence affect all types except the upper-level cyclone (Cv) and westerly anticyclonic summer type (Wal). We did not find any inhomogeneity at the beginning of the 1990s when the Czechoslovak catalogue was split into two versions – Czech and Slovak.

Acknowledgements

The authors thank to Stanislav Racko (CHMI, Prague) for the provision of data and invaluable information on the history of the Catalogue. This work was supported by the Grant Agency of the Czech Republic, contract IAA300420506. It is part of the COST733 Action “Harmonisation and Applications of Weather Type Classifications for European Regions”. Czech participation in COST733 is supported by the Ministry of Education, Youth, and Sports of the Czech Republic, project OC115.

2.6 References

[1] BERANOVÁ, R. – HUTH, R., 2005. Long-term changes in the heat island of Prague under different synoptic conditions. *Theoretical and Applied Climatology*, **82**, 113-118. ISSN 0177-798X.

[2] HESS, P. – BREZOWSKY, H., 1952. Katalog der Grosswetterlagen Europas. Berichte des Deutschen Wetterdienstes in der US-Zone, Nr. 33. Bad Kissingen.

[3] HUTH, R., 2001. Disaggregating climatic trends by classification of circulation patterns. *International Journal of Climatology,* **21**, 135-153. ISSN 0899-8418.

[4] KOLEKTIV AUTORŮ (COLLECTIVE TEAM), 1972. Katalog povětrnostních situací pro území ČSSR (Catalogue of synoptic types for the territory of Czechoslovakia). Praha: HMÚ, 40 p.

[5] KŘIVANCOVÁ, S. – VAVRUŠKA, F., 1997. Základní meteorologické prvky v jednotlivých povětrnostních situacích na území České republiky v období 1961–1990 (Basic meteorological elements in individual synoptic situations on the territory of the Czech Republic in the period 1961–1990). Národní klimatický program ČR, Praha: ČHMÚ, **27**, 114 p. ISSN 1210-7565.

[6] KYSELÝ, J. – DOMONKOS, P., 2006. Recent increase in persistence of atmospheric circulation over Europe: comparison with long-term variations since 1881. *International Journal of Climatology*, **26**, 461-483. ISSN 0899-8418.

[7] KYSELÝ, J. – HUTH, R., 2006. Changes in atmospheric circulation over Europe detected by objective and subjective methods. *Theoretical and Applied Climatology*, **85**, 19-36. ISSN 0177-798X.

[8] RACKO, S. Typizace povětrnostních situací pro území České republiky (Typing of synoptic situation on the territory of the Czech Republic). (information+download) http://www.chmi.cz/meteo/om/mk/syntypiz/kalendar.html

[9] STARÝ, J., 1989: Rozbor výskytu povětrnostních situací a počasí s nimi spojeného (Analysis of occurrence of synoptic situations and connected weather). In: Sborník prací ČHMÚ (Proceedings of the CHMI) 35. Praha, ČHMÚ, 163 p. ISSN 0232-0401

[10] ŠTĚPÁNEK, P., 2005: AnClim – software for time series analysis. Geographical Institute, Faculty of Science, Masaryk University, Brno, Czech Republic. 1.47 MB. http://www.klimahom.com/software/AnClim.html

[11] WERNER, P. C. – GERSTENGARBE, F.-W. – FRAEDRICH, K. – OESTERLE, H., 2000. Recent climate change in the North Atlantic/European sector. *International Journal of Climatology*, **20**, 463-471. ISSN 0899-8418.

3. Paper II: Short note on inhomogeneities in the Hess–Brezowsky catalogue of circulation types

Monika Cahynová (1, 2)

Radan Huth (1)

1) Institute of Atmospheric Physics, Academy of Sciences of the Czech Republic, Boční II 1401, 141 31 Prague 4

2) Charles University in Prague, Faculty of Science, Department of Physical Geography and Geoecology, Czech Republic

Keywords: atmospheric circulation, Hess–Brezowsky classification, homogeneity

Abstract

An inhomogeneity was proved in the Hess–Brezowsky catalogue of atmospheric circulation types (Grosswetterlagen), i.e. the higher probability of change of type at the ends of months and years caused by monthly subjective data evaluation. This leads to an overall 42 % higher probability of change of type at the ends of months and 56 % at the ends of years (compared with the average frequency in all other days, 1881–2000). The period of extremely high frequency of change of types at the ends of months and years during the 1980s coincides with the observed increasing persistence (duration in days) of the Hess–Brezowsky circulation types. However, the prolongation of persistence is most probably not being caused by inhomogeneities in the series as it was detected in an objectively defined circulation catalogue as well.

3.1 Introduction

The aim of this study is to present some inhomogeneities found in the Hess–Brezowsky catalogue of circulation types, i.e. the higher probability of change of type at the end of months and years caused by manual data evaluation. The Hess–Brezowsky classification of circulation types is a well-known catalogue of subjectively assigned circulation types for Central Europe with the emphasis on Germany. It covers the time span 1881–today. It was first published by Paul Hess and Helmuth Brezowsky in 1952 as the "Katalog der Grosswetterlagen Europas", then it was revised and updated in 1969, 1977, 1993 and 1999. Each day is characterized by one of the 29 distinct circulation types (Grosswetterlagen) or it stays unclassified. There is a constraint of at least 3-day duration of every synoptic situation, however this does not apply to the unclassified type, which therefore can serve as a short transient period.

The Hess–Brezowsky catalogue has been widely used in climatological studies in Central Europe. Nevertheless, the authors do not discuss the question of homogeneity of this subjective classification. The catalogue was recently claimed homogenous (Gerstengarbe et al., 1999). Still there are obvious imperfections that rise from the manual evaluation of the time series which is being done monthly. Such approach leads to higher frequency of change of one circulation type to another at the end of months and years. Gerstengarbe and Werner (1993) show that a change of type is more probable at the end of month and notably at the end of year but only long-term averages of the probability of change for every day in an “average” year (1881–1992) were presented in this work, time evolution of this problem has not been discussed so far. These authors consider such subjectively caused errors insignificant.

3.2 Results

We have calculated the frequency of change of type at the end of month for every year from 1881 till 2000. When we divide this number by the “average” probability of change in all days of the given year except the ends of months, this ratio would stay around 1 was the time series homogenous (unbiased). As we see in Figure 3.1 and 3.2, this does not hold true in the case of the Hess–Brezowsky catalogue. The long-term average of this ratio is 1.46, therefore a change of one circulation type to another at the end of month is 46 % more probable than in all other days of the specific year. There is a distinct peak in the series of this ratio in the 1980s and early 1990s. It is well known that this is also the period of increasing persistence (duration) of circulation types, as was shown in Werner et al. (2000) and Kyselý and Domonkos (2006). When the circulation types last longer, the daily probability of change of type decreases. This fact has affected the series shown in Figure 3.1 so that the 1980s values are extremely high. To remove this bias we can simply look at the yearly number of months that ended with a change of circulation type (Fig. 3.3). The two maxima (nine and eight months) both appear in the 1980s and the curve is very well correlated (R=0.957) to the one shown in Figure 3.1 (the ratio of frequencies calculated separately for each year). The chi-square test shows that if the yearly number of months that ended with a change of circulation type lies between 0 and 5 then the annual frequency of change of type at the ends of months is not significantly different from the long-term average probability of change in all other days.

Years with 6 or more months that ended with a change of type (1883, 1887, 1892, 1943, 1950, 1982–85, 1987–88, and 1990) are outliers at the 95 % level of significance. The overall frequency of change of type at the ends of months is 1.42 times higher than the long-term average probability of change in all other days, which is significant at the 99.9 % level.

The probability of a change of type at the end of year is 0.32, whereas in all days except the ends of months ("unbiased series") it is 0.20. The ratio (1.56) is even higher than that for the ends of months (1.42). Again, there is a cluster of frequent circulation type changes at the ends of years from late 1970s until early 1990s and also in 1880s and early 1890s (see Figure 3.4).

When we calculate the daily probability of change of type during an "average" year throughout the period 1881–2000 we can see that the beginnings of months all show above-average values. Quite surprisingly, the maximum probability (0.41) does not occur on January 1st but at the beginning of May (see Fig. 3.5).

Previous analysis of this problem presented in Gerstengarbe and Werner (1993) allows us to compare the 1993 version of the catalogue with one of the recently revised versions (that one we use in this work). Unfortunately we did not have the older catalogue itself, only the table that shows total daily number of changes of type for the period 1881–1992. The authors admit that the types change more often at the beginning of months and years. The two versions of the catalogue differ significantly – the probability of change of type is much lower in the latter one on average, not only on the 1st day in a month or year (see Table 3.1, Fig. 3.6, 3.7). There are 14.5 more changes of type annually (1881–1993 average) in the older version so the persistence (duration) of a "typical" synoptic situation increased from 4 days in the older version to 4.76 days in the revised version of the catalogue.

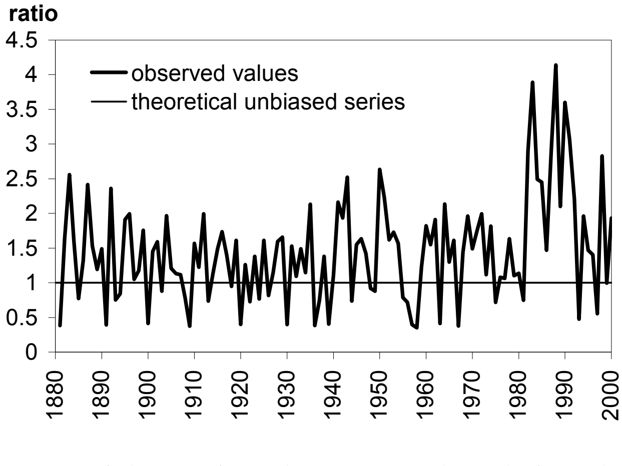


Figure 3.1. Ratio of the frequency of change of circulation type at the end of month and the frequency of change in all other days of the given year (1881–2000), long-term average is 1.46.

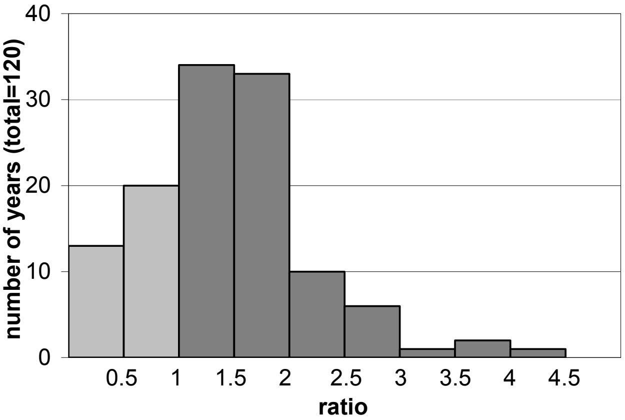


Figure 3.2. Histogram: ratio of frequency of change of type at the end of month and the frequency of change in all other days of the given year. This ratio should be around 1 in an unbiased dataset.

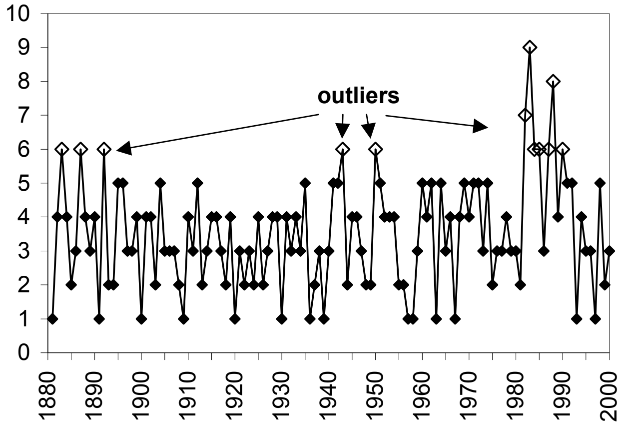


Figure 3.3. Annual number of changes of type at the end of month (max. possible=12 as the change at the end of a given year is added to this year).

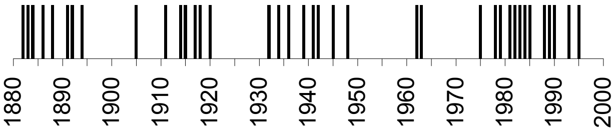


Figure 3.4. Years that begin with a different circulation type on January 1st compared to the previous day.

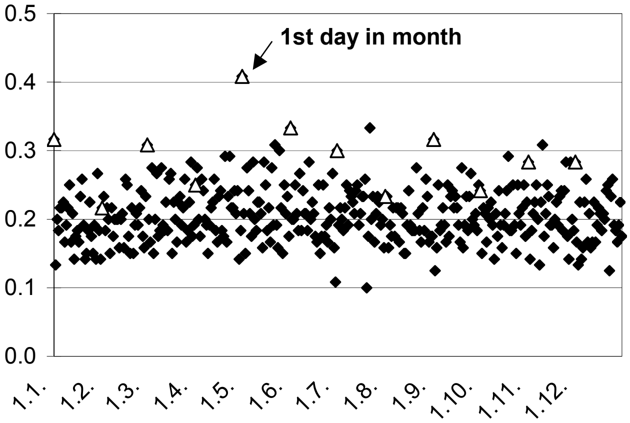


Figure 3.5. Daily probability of change of Hess–Brezowsky type during an "average" year, 1881–2000.

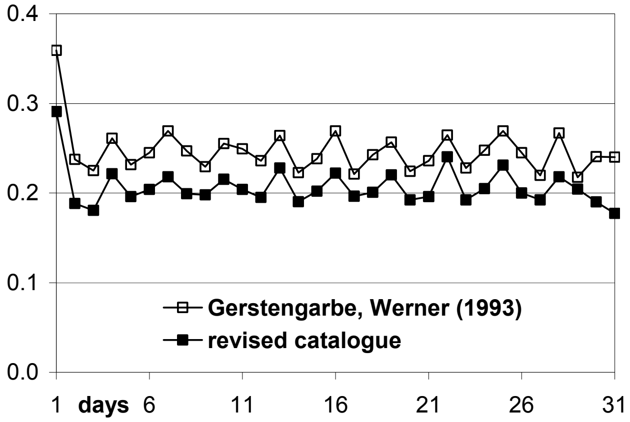


Figure 3.6. Daily probability of change of type during an "average" month, 1881–1992.

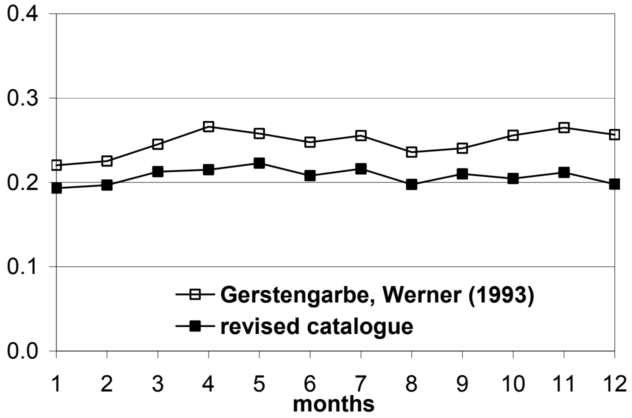


Figure 3.7. Monthly average probability of change of type, 1881–1992.

Table 3.1. Daily frequency of change of type (1881–1992): difference between original (Gerstengarbe and Werner, 1993) and revised datasets. Original data show 14.5 more changes of type annually.

day	**month 1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	Σ
1	14	8	13	14	1	1	-1	7	6	13	10	5	91
2	2	-1	1	3	11	7	16	-4	11	5	1	12	64
3	5	4	2	8	4	3	3	6	0	10	4	11	60
4	2	4	4	4	2	8	7	2	1	6	8	4	52
5	2	1	4	1	5	1	2	3	4	9	3	12	47
6	3	7	2	6	2	6	4	3	5	4	11	4	57
7	3	-2	3	12	5	4	4	5	4	6	4	13	61
8	4	4	8	4	-3	4	12	5	8	4	9	4	63
9	3	1	2	7	4	6	-5	3	5	4	3	6	39
10	1	2	1	4	6	2	11	6	1	8	3	5	50
11	3	4	6	12	2	8	6	4	6	4	7	6	68
12	2	5	5	0	4	5	4	6	1	4	8	8	52
13	3	2	0	12	3	1	4	1	1	8	5	-1	39
14	3	5	9	0	6	1	5	6	0	-1	3	10	47
15	2	2	-1	6	4	4	4	7	2	7	7	2	46
16	5	2	5	5	-1	7	3	6	5	3	13	11	64
17	-1	5	3	6	8	0	4	3	-1	7	2	-2	34
18	4	-1	3	12	4	4	1	4	6	0	9	7	53
19	1	4	1	2	3	3	5	4	4	6	6	7	46
20	1	0	1	6	1	6	2	4	1	0	4	12	38
21	1	3	9	4	7	3	5	1	4	8	5	3	53
22	4	3	-4	2	1	12	1	3	-1	4	7	6	38
23	3	2	6	3	8	1	4	2	4	9	1	5	48
24	3	7	3	5	3	6	2	5	-1	8	14	5	60
25	4	1	3	4	2	3	4	5	5	5	1	9	46
26	3	6	3	6	6	5	10	4	2	3	7	6	61
27	0	5	4	2	2	6	-1	1	2	9	7	3	40
28	6	8	4	5	5	1	10	5	6	2	2	9	63
29	1	-1	1	3	2	4	0	10	4	1	6	7	38
30	4		4	12	4	8	2	-3	5	11	6	6	59
31	0		0		7		10	14		6		8	45
Σ	91	90	105	170	118	130	138	128	100	173	176	203	**1622**

3.3 Conclusion

The homogeneity of the Hess–Brezowsky catalogue of circulation types is influenced by monthly subjective data evaluation. This leads to an overall 42 % higher probability of change of type at the ends of months and 56 % at the ends of years (compared with the average frequency in all other days, 1881–2000). The period of extremely higher frequency during the 1980s coincides with the observed increasing persistence (duration in days) of the Hess–Brezowsky circulation types. However, the prolongation of persistence is most probably not being caused by inhomogeneities in the time series as it was detected in objectively defined circulation catalogues as well (Werner et al., 2000; Kyselý and Huth, 2006). The previous version of the catalogue (Gerstengarbe and Werner, 1993) is even more influenced by this inhomogeneity and shows generally more changes of types (and therefore shorter circulation types persistence) than one of the revised versions we used in this study (for the period 1881–2000).

Acknowledgements

The authors thank Friedrich-Wilhelm Gerstengarbe and Peter C. Werner, Potsdam Institut für Klimafolgenforschung, Potsdam, Germany, for providing us with the Hess–Brezowsky catalogue and related reports, and for useful discussions. The work was carried out within the COST733 Action “Harmonization and Applications of Weather Types Classifications for European Regions”. The participation of the Czech Republic in this action is supported by the Ministry of Education, Youth, and Sports of the Czech Republic under contract OC115. The study was also supported by the Grant Agency of the Academy of Sciences of the Czech Republic, contract A300420506.

3.4 References

Gerstengarbe, F.-W.–Werner, P.C., 1993, Katalog der Großwetterlagen Europas nach Paul Hess und Helmuth Brezowsky: 1881–1992. Ber. Dt. Wetterd. 113, Offenbach a. M., 249 pp.

Gerstengarbe, F.-W.–Werner, P.C.–Rüge, U., 1999, Katalog der Großwetterlagen Europas (1881–1998) nach Paul Hess und Helmuth Brezowsky. Potsdam, Offenbach a. M.

Hess, P.–Brezowsky, H., 1952, Katalog der Großwetterlagen Europas. Ber. Dt. Wetterd. in der US-Zone 33, 39 pp.

Kyselý, J.–Domonkos, P., 2006, Recent increase in persistence of atmospheric circulation over Europe: comparison with long-term variations since 1881. International Journal of Climatology, Vol. 26, 461–483.

Kyselý, J.–Huth, R., 2006, Changes in atmospheric circulation over Europe detected by objective and subjective methods. Theoretical and Applied Climatology, Vol. 85, 19–36.

Werner, P.C.–Gerstengarbe, F.-W.–Fraedrich, K.–Oesterle, H., 2000, Recent climate change in the North Atlantic/European sector. International Journal of Climatology, Vol. 20, 463–471.

4. Paper III: Enhanced lifetime of atmospheric circulation types over Europe: fact or fiction?

Monika Cahynová[1, 2]*, Radan Huth[1]

[1]Institute of Atmospheric Physics, Academy of Sciences of the Czech Republic, Boční II 1401, 141 31 Prague, Czech Republic

[2]Department of Physical Geography and Geoecology, Charles University, Prague, Czech Republic

*Corresponding author

E-mail: cahynova@ufa.cas.cz

Keywords: atmospheric circulation; classification; circulation types; persistence; synoptic climatology

Abstract

We analyze the lifetimes (persistence) of circulation types using 23 classifications (of which 18 are objective and 5 subjective) in the period 1957–2002 over Europe and its sub-regions. The objective catalogues are developed on the same gridded climatic data (ECMWF ERA-40 reanalysis), but differ in the classification method used and in the number of synoptic types. Significant seasonal trends in the lifetime (both positive and negative) are fairly scarce, and are present in all seasons in the manual catalogues only. In the subjective Hess–Brezowsky catalogue, there is an abrupt shift towards higher persistence in 1986, whereas in the Hungarian manual catalogue a smaller but significant negative shift took place in the same year. These statistical inconsistencies probably result from inhomogeneities in the subjective catalogues. Our results suggest that the increase in the persistence of circulation types reported recently in several papers for the Hess–Brezowsky catalogue is an artifact rather than a real feature.

4.1 Introduction

The persistence of atmospheric circulation is an important factor influencing both weather and climate and can be viewed from many points. Climatologists study the persistence of either surface pressure fields or geopotential height fields on a daily or monthly basis, using lagged autocorrelations (e.g., Gutzler and Mo, 1983), pattern correlations between successive maps (e.g., van den Dool, 1983; Horel, 1985), or persistence of modes of variability (Barnston and Livezey, 1987). Another way to describe the persistence of atmospheric circulation – the one we choose in this paper – is to study the lifetimes of circulation types, defined by various classification methods (Werner et al., 2000; Kyselý and Domonkos, 2006; Kyselý and Huth, 2006).

The longest European subjective circulation classification available, the German Hess–Brezowsky catalogue (Hess and Brezowsky, 1952), indicates a rapid increase in the persistence of circulation types since the mid-1980s (Werner et al., 2000; Kyselý and Domonkos, 2006). However, because of its subjectivity, the question if this change is real or artificial has arisen. It has not been resolved yet; only Kyselý and Huth (2006) compared the persistence trends in the Hess–Brezowsky catalogue with one objective classification, but without a definitive conclusion. The increase in the lifetimes of circulation types, if real, would be a demonstration of a general increase in persistence of atmospheric circulation. It would be likely accompanied by changes in other circulation characteristics, such as increasing frequency and/or duration of blockings, and decreasing frequency of cyclones. Whereas the former is not the case, the trends in blocking frequency in the Atlantic sector being insignificant during the last decades (Wiedemann et al., 2002), the frequency of cyclones over Europe and eastern North Atlantic has declined significantly (e.g., Gulev et al., 2001; Trigo, 2006). The message on changing persistence from analyses of other circulation features is thus ambiguous as well.

Over 20 circulation classifications have recently been made available by networking within the COST (European Cooperation in the field of Scientific and Technical Research) Action 733 "Harmonisation and Applications of Weather Types Classifications for European Regions" (http://www.cost733.org). This brings an opportunity to disclose whether or not the increase in the lifetime of circulation types in the Hess–Brezowsky catalogue is real. The analysis of changes in lifetimes of circulation types in a relatively large number of classifications is the goal of the present study.

This paper is organized as follows: in Section 4.2, we introduce the selected methods for the classification of atmospheric circulation and the resulting catalogues of circulation types used in this study. Long-term statistics and seasonal trends in the persistence of circulation types are presented in Section 4.3, and concluding remarks are contained in Section 4.4.

4.2 Data and methods

For the analysis of recent trends in the lifetime (persistence) of atmospheric circulation over Europe, we use the catalogues of atmospheric circulation types covering the period September 1957 through August 2002 that have recently been made available within the COST733 Action. The "objective", i.e. computer-assisted, methods of classification are developed on the ECMWF ERA-40 dataset (Uppala et al., 2005) to ensure a full comparability of the catalogues. The classification procedures were applied on the scale of entire Europe (domain 00) and eleven European sub-domains, typically covering the area of a few countries, of which we chose four for our analysis. The definition of domains and the resolution used to calculate the classifications are provided in Table 4.1. The catalogues used are listed in Table 4.2, together with references to the papers and reports where they are defined or described in more detail, a brief description of the method used for classification, and the number of types classified in each of the selected spatial domains. The catalogues cover a wide range of classification methods, comprising all relevant procedures having been used for classification of circulation patterns in the recent past. The methods include (i) various kinds of cluster analysis, from k-means with different procedures to select the initial seed-points (CEC, PCACA, PCAXTRKM) to the simulated annealing both of daily patterns (SANDRA) and their 3-day sequences (SANDRAS); (ii) correlation-based methods (LUND, PETISCO); (iii) principal component analysis in a T-mode (TPCA07, TPCAV); (iv) neural networks, namely the self-organizing maps (NNW); (v) procedures assigning individual patterns to the types according to their similarity with simple flow patterns (GWT), S-mode principal component loadings (P27), or their extremes (PCAXTR); (vi) methods based on threshold values of circulation variables, i.a. large-scale flow direction (LITTC, LWT2, WLKC733).

Five subjective catalogues are also included: Hess–Brezowsky Grosswetterlagen (HBGWL), Hungarian Péczely catalogue (PECZELY), two Swiss catalogues (PERRET, SCHUEEPP), and an Austrian one (ZAMG). We further employ two "objectivized" versions of the Hess–Brezowsky catalogue, the OGWL and OGWL-3d+ classifications. They differ by the methodological constraint of a minimum 3-day duration of synoptic types imposed on the latter (James, 2007), which is identical to the original manual Hess–Brezowsky, making a direct comparison between the manual catalogue and its objectivized version possible. Please note that the manual catalogues and both of the "objectivized" versions of Hess–Brezowsky

Grosswetterlagen are defined independently of the geographical domains, but are listed as pertaining to domain 00 in Tables 4.2, 4.3, and 4.5 just for the sake of simplicity.

The persistence (lifetime) of circulation types is defined as the length of a sequence of days that are classified with one type, while preceded and succeeded by another type. Such a sequence is also referred to as an event. We calculate average annual and seasonal (DJF, MAM, JJA, SON) persistence of all circulation types combined together for each classification and estimate its linear trends by the least squares regression. The t-test was applied to detect the statistical significance of trends. The presence of abrupt shifts in the mean annual persistence was tested with Standard Normal Homogeneity Test (SNHT) (Alexandersson, 1986) in the AnClim software (Štěpánek, 2006).

Table 4.1. Definition of domains and spatial resolution used.

number	*description*	*W / E*	*S / N*	*resolution (latitude x longitude)*
00	whole Europe	37°W / 56°E	30°N / 76°N	2° x 3°
02	Norwegian Sea, W Scandinavia	6°W / 25°E	57°N / 72°N	1° x 1°
04	British Isles, Benelux, N France	18°W / 8°E	47°N / 62°N	1° x 1°
07	Central Europe	3°E / 26°E	43°N / 58°N	1° x 1°
09	Iberia, W Mediterranean	17°W / 9°E	31°N / 48°N	1° x 1°

Table 4.2. Description of atmospheric circulation classifications available from the COST733 inventory for the European region. Selected spatial domains: D00 – whole Europe, D02 – Western Scandinavia, D04 – the British Isles, D07 – Central Europe, D09 – Iberia. Abbreviations used for variables: Z500, Z925, Z1000 – 500, 925, 1000 hPa geopotential heights; SLP – sea level pressure; U700, V700 – zonal and meridional wind components at 700 hPa; PW – precipitable water. In references, we prefer open scientific literature to internal reports and conference proceedings wherever possible, thereby sometimes neglecting the original data source.

classification	*method*	*variable used for definition*	*reference*	*number of circulation types*				
				D00	*D02*	*D04*	*D07*	*D09*
HBGWL	manual – Europe (centered on Germany)		Hess and Brezowsky, 1952; Bárdossy and Caspary, 1990; Gerstengarbe et al., 1999, 2005	29 a)				
PECZELY	manual – Hungary		Péczely, 1983	13 a)				
PERRET	manual – Switzerland		Perret, 1987	31 a)				
SCHUEEPP	manual – Switzerland		Stefanicki et al., 1998	40 a)				
ZAMG	manual – Eastern Alpine ridge			43 a)				
CEC	k-means	Z500, Z1000	Enke and Spekat, 1997	10 b)	10 b)	10 b)	10 b)	10 b)
GWT	circulation prototypes	SLP	Beck et al., 2007	18	18	18	18	18
LITTC	hybrid	SLP	Lityński, 1969	27	27	27	27	27
LUND	correlation-based	SLP	Lund, 1963	10	10	10	10	10
LWT2	objectivized Lamb catalogue	SLP	James, 2006	26	26	26	26	26
NNW	artificial neural networks	Z500	Michaelides et al., 2007	20	20	16	12	12
OGWL	objectivized Hess–Brezowsky catalogue	SLP, Z500 c)	James, 2007	29 a)				
OGWL-3d+	objectiv. Hess–Brezowsky, minimum 3 days duration	SLP, Z500 c)	James, 2007	29 a)				
P27	subdivision according to S-mode PCA-scores	Z500	Buishand and Brandsma, 1997	27	27	27	27	27
PCACA	k-means	SLP	Ekström et al., 2002	11	4	5	4	4
PCAXTR	extreme S-mode PCA scores, without iterations	SLP	Esteban et al., 2006	17	12	12	12	12
PCAXTRKM	extreme S-mode PCA scores, with iterations	SLP	Esteban et al., 2006	17	12	12	12	12
PETISCO	correlation-based	SLP, Z500	Petisco and Martín, 1995	14	25	30	28	32
SANDRA	simulated annealing	SLP	Philipp et al., 2007	18	21	22	23	19
SANDRAS	simulated annealing of 3-day sequences	Z925, Z500	Philipp, 2008	30	30	30	30	30
TPCA07	T-mode PCA	Z500	Huth, 2000	7	7	7	7	7
TPCAV	T-mode PCA	Z500	Huth, 2000	12	11	9	9	9
WLKC733	hybrid	U700, V700, Z925, Z500, PW	Bissolli and Dittmann, 2001	40	40	40	40	40

a) Subjective catalogues and their objectivized versions cannot be directly attributed to any of the spatial domains; they are related to D00 just for simplicity of display.

b) Types are defined separately in each season, i.e., there are 40 types altogether.

c) NCEP/NCAR reanalysis was used in the period from 1948 to August 1957, and operational ECMWF analyses after August 2002.

4.3 Results

Average persistence of circulation types in the period 1957–2002 (see Table 4.3) ranges from 1.2 days in LWT2 to 5.3 days in Hess–Brezowsky "Grosswetterlagen" (HBGWL), which are methodologically constrained to a minimum 3-day duration of circulation types. The average persistence is higher in the 00 domain (entire Europe) than in the sub-domains for all but two catalogues, in which the lower persistence stems from a higher number of types in the large domain. The higher persistence in the large domain is a natural consequence of the variability on larger spatial scales taking place on longer temporal scales. The number of short-lived, 1-day circulation types (3-day for HBGWL and OGWL-3d+) is prominent in all the classifications. The percentage of days occupied by these shortest events in domain 00 ranges from 8.0% in SANDRAS to 53.1% in LITTC; among the manual and objectivized catalogues, which are not directly related to domain 00, the highest share of the 1-day events is 63.2% in the manual Swiss SCHUEEPP (see Fig. 4.1).

Table 4.3. Long-term average persistence of circulation types (1957–2002). See Table 4.2 for the description of individual classifications. Selected spatial domains: D00 – whole Europe, D02 – W Scandinavia, D04 – the British Isles, D07 – Central Europe, D09 – Iberia.

domain	HBGWL	PECZELY	PERRET	SCHUEEPP	ZAMG	CEC	GWT	LITTC	LUND	LWT2	NNW	OGWL	OGWL-3d+	P27	PCACA	PCAXTR	PCAXTRKM	PETISCO	SANDRA	SANDRAS	TPCA07	TPCAV	WLKC733
D00	5.3	1.7	1.7	1.3	1.6	2.8	1.7	1.4	2.5	1.5	1.7	1.7	4.8	1.8	2.2	1.9	2.0	2.2	2.4	3.2	3.0	2.2	1.5
D02						2.0	1.3	1.3	1.6	1.2	1.9			1.3	2.4	1.5	1.5	1.3	1.5	2.0	1.7	1.4	1.3
D04						2.0	1.4	1.3	1.9	1.2	1.9			1.3	2.6	1.5	1.5	1.3	1.5	2.0	1.7	1.5	1.3
D07						2.0	1.4	1.3	1.6	1.2	2.4			1.3	2.8	1.5	1.6	1.4	1.5	2.0	1.7	1.6	1.3
D09						2.1	1.5	1.4	1.9	1.2	2.4			1.4	3.4	1.6	1.7	1.4	1.7	2.3	2.0	1.7	1.3

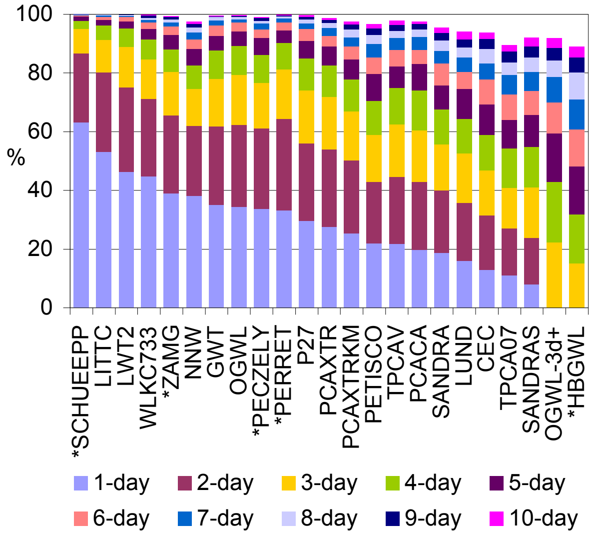


Fig. 4.1. Percentage of days occupied by circulation types grouped by event length in domain 00 – whole Europe (except for the subjective catalogues, denoted by asterisks, and their "objectivized" versions).

The interannual variability of persistence considerably differs among the catalogues: the correlations of time series of the annual mean persistence between individual catalogues are fairly low. Only 29 cases out of 253 pairs of catalogues in domain 00 yield significant positive correlation (at the 95% confidence level), the highest correlation coefficient being 0.43 (see Table 4.4). In four cases, the relation is significant but negative. The strong negative correlation between Hess–Brezowsky and PECZELY (–0.71) is caused by a simultaneous shift to longer persistence in Hess–Brezowsky and shorter persistence in PECZELY (see below). The subjective catalogues of Hess–Brezowsky, PECZELY, and ZAMG are involved in the remaining three pairs of significant negative correlations. This means that the interannual variations of lifetimes of circulation types are determined more by the classification methodologies than the persistence properties of atmospheric circulation itself.

Table 4.4. Correlation of annual averages of persistence of circulation types between individual classifications in domain 00 – whole Europe (except for the subjective catalogues and their "objectivized" versions). Boldface denotes correlations significant at the 95% level.

	HBGWL	PECZELY	PERRET	SCHUEEPP	ZAMG	CEC	GWT	LITTC	LUND	LWT2	NNW	OGWL	OGWL-3d+	P27	PCACA	PCAXTR	PCAXTRKM	PETISCO	SANDRA	SANDRAS	TPCA07	TPCAV	WLKC733
HBGWL		**-0.7**	0.1	0.2	0.0	**-0.3**	0.2	-0.2	-0.3	-0.1	0.2	0.0	0.2	0.1	-0.1	-0.1	-0.2	0.0	0.1	0.1	-0.2	0.0	-0.1
PECZELY	**-0.7**		-0.1	0.1	0.2	0.3	0.0	**0.3**	**0.3**	0.3	**-0.3**	0.1	-0.1	-0.1	0.2	0.0	0.2	0.2	0.2	-0.1	0.2	0.0	**0.3**
PERRET	0.1	-0.1		0.2	0.1	**0.4**	-0.1	0.0	0.1	-0.1	0.0	0.1	0.0	0.1	0.1	0.0	0.2	0.3	0.2	0.1	0.1	0.1	0.2
SCHUEEPP	0.2	0.1	0.2		**0.4**	0.0	**0.3**	0.2	0.2	0.2	0.2	**0.4**	0.1	0.2	-0.1	-0.1	0.0	0.3	**0.3**	0.2	**0.3**	0.0	**0.3**
ZAMG	0.0	0.2	0.1	**0.4**		-0.1	0.1	-0.1	-0.1	0.0	-0.1	0.1	**0.4**	**0.4**	**-0.4**	-0.3	0.1	0.2	0.2	0.0	0.2	-0.1	0.1
CEC	**-0.3**	0.3	**0.4**	0.0	-0.1		0.0	0.1	**0.4**	0.3	0.2	0.0	-0.2	0.1	0.1	0.0	0.0	0.2	0.1	0.1	0.1	-0.1	0.0
GWT	0.2	0.0	-0.1	**0.3**	0.1	0.0		0.1	0.1	**0.4**	**0.3**	0.2	**0.3**	0.1	-0.1	0.2	0.0	**0.3**	-0.1	0.2	0.1	0.1	**0.4**
LITTC	-0.2	**0.3**	0.0	0.2	-0.1	0.1	0.1		0.2	0.2	0.0	0.1	-0.1	-0.1	0.2	0.0	0.0	0.1	0.2	0.2	0.1	0.1	0.0
LUND	-0.3	**0.3**	0.1	0.2	-0.1	**0.4**	0.1	0.2		0.2	0.2	0.1	-0.3	-0.1	0.2	**0.4**	0.2	**0.4**	0.2	0.1	0.2	-0.1	0.2
LWT2	-0.1	0.3	-0.1	0.2	0.0	0.3	**0.4**	0.2	0.2		0.2	**0.3**	-0.1	0.1	0.3	0.2	-0.1	0.1	0.1	0.1	0.0	0.2	0.1
NNW	0.2	**-0.3**	0.0	0.2	-0.1	0.2	**0.3**	0.0	0.2	0.2		0.0	0.1	0.1	0.0	**0.3**	-0.2	0.2	0.0	**0.4**	0.0	-0.1	-0.1
OGWL	0.0	0.1	0.1	**0.4**	0.1	0.0	0.2	0.1	0.1	**0.3**	0.0		0.2	0.2	0.1	0.0	0.2	0.2	**0.4**	0.0	0.1	0.2	**0.3**
OGWL-3d+	0.2	-0.1	0.0	0.1	**0.4**	-0.2	**0.3**	-0.1	-0.3	-0.1	0.1	0.2		0.3	-0.2	-0.2	0.2	0.0	-0.1	0.2	0.0	-0.2	0.1
P27	0.1	-0.1	0.1	0.2	**0.4**	0.1	0.1	-0.1	-0.1	0.1	0.1	0.2	0.3		-0.2	0.0	0.2	0.0	0.3	**0.4**	0.1	0.1	-0.1
PCACA	-0.1	0.2	0.1	-0.1	**-0.4**	0.1	-0.1	0.2	0.2	0.3	0.0	0.1	-0.2	-0.2		0.1	0.2	-0.3	0.1	0.0	0.0	0.2	0.0
PCAXTR	-0.1	0.0	0.0	-0.1	-0.3	0.0	0.2	0.0	**0.4**	0.2	**0.3**	0.0	-0.2	0.0	0.1		0.1	0.3	-0.1	**0.3**	-0.3	0.0	0.0
PCAXTRKM	-0.2	0.2	0.2	0.0	0.1	0.0	0.0	0.0	0.2	-0.1	-0.2	0.2	0.2	0.2	0.2	0.1		0.0	**0.3**	0.1	-0.2	0.0	0.3
PETISCO	0.0	0.2	0.3	0.3	0.2	0.2	**0.3**	0.1	**0.4**	0.1	0.2	0.2	0.0	0.0	-0.3	0.3	0.0		0.1	0.1	0.1	0.1	**0.4**
SANDRA	0.1	0.2	0.2	**0.3**	0.2	0.1	-0.1	0.2	0.2	0.1	0.0	**0.4**	-0.1	0.3	0.1	-0.1	**0.3**	0.1		0.3	0.2	0.2	0.1
SANDRAS	0.1	-0.1	0.1	0.2	0.0	0.1	0.2	0.2	0.1	0.1	**0.4**	0.0	0.2	**0.4**	0.0	**0.3**	0.1	0.1	0.3		0.2	0.1	-0.2
TPCA07	-0.2	0.2	0.1	**0.3**	0.2	0.1	0.1	0.1	0.2	0.0	0.0	0.1	0.0	0.1	0.0	-0.3	-0.2	0.1	0.2	0.2		0.3	0.2
TPCAV	0.0	0.0	0.1	0.0	-0.1	-0.1	0.1	0.1	-0.1	0.2	-0.1	0.2	-0.2	0.1	0.2	0.0	0.0	0.1	0.2	0.1	0.3		0.2
WLKC733	-0.1	**0.3**	0.2	**0.3**	0.1	0.0	**0.4**	0.0	0.2	0.1	-0.1	**0.3**	0.1	-0.1	0.0	0.0	0.3	**0.4**	0.1	-0.2	0.2	0.2	

Annual and seasonal linear trends in persistence of all circulation types combined are shown in Table 4.5. In the objective classifications, trends are negligible and mostly insignificant in all the studied spatial domains. The highest positive trends, and the only ones positive in all seasons and the whole year, occur in the subjective Hess–Brezowsky catalogue. They are caused by an abrupt shift to a longer duration of events in the mid 1980s; the SNHT test localizes the shift to 1986 (see Fig. 4.2). One theoretical explanation could be that since 1986 the sequences of closely related types (e.g. westerly cyclonic and westerly anticyclonic) are classified more often as long events of one circulation type rather than sequences of events of related types. We have ruled out this explanation because a similar inconsistency was detected in the persistence of groups of the Hess–Brezowsky types that are mainly based on the flow direction (10 "Grosswettertypes"; not shown). Therefore, the longer persistence of individual types cannot be attributed to less frequent transitions between closely related types. The shift in the duration of events is mainly caused by a sudden drop of the frequency of 3-day events, which are the most common ones in the Hess–Brezowsky catalogue (Fig. 4.3). Such a shift is not present in any of the objective classifications we have analyzed, in particular not even in the objectivized Hess–Brezowsky catalogue that reproduces the minimum 3-day duration of circulation types (OGWL-3d+). The comparison of winter persistence of westerly and non-westerly circulation types in Hess–Brezowsky and OGWL-3d+ is shown in Fig. 4.4. The persistence of westerly circulation types steeply increased in the late 1980s in Hess–Brezowsky (as was already noted in Werner et al., 2000), but this behavior is again not present in the objective catalogue. To further document this discrepancy we can look at long-term trends of annual mean persistence of every circulation type rather than that of all types combined. The magnitude of such individual trends varies greatly between the classifications, but in Hess–Brezowsky the trends are mostly positive (see Fig. 4.5) and up to 1.5 times higher than the highest trend achieved in the other catalogues in domain 00. The shift to a higher persistence of circulation types and the decline of the occurrence of 3-day events in recent decades was recently reported (in German) by Gerstengarbe and Werner (2005), but no reason was offered for such an unprecedented behavior. Additionally, Gerstengarbe and Werner (2005) used moving averages in their analysis, which blurs the existence of sharp changes, so the single breakpoint remained undetected. The subjective Hess–Brezowsky catalogue was claimed homogeneous by Gerstengarbe et al. (1999); we are nevertheless convinced that the shift to longer persistence is a result of an inhomogeneity due e.g. to methodological or personnel changes. A simultaneous but negative and much smaller change was detected in the Hungarian manual catalogue (PECZELY). Two other classifications in domain 00 yield slight but significant sudden negative shifts in the annual persistence – PERRET (Swiss manual catalogue) in 1970, and CEC in 1961 and 1977.

The likely inhomogeneity of the Hess–Brezowsky catalogue is further documented by changes of the annual number of days classified with the same circulation type as in its two objectivized versions, OGWL and OGWL-3d+ (see Fig. 4.6). This “skill” of the objectivized catalogues to represent the original Hess–Brezowsky declines in the 1980s, the period 1986–2000 being an outlier in both cases.

Table 4.5. Linear trends in mean annual and seasonal persistence of synoptic types (change in days per 45 years, 1957–2002). Boldface denotes trends significant at the 95% level. Years start in December in order to encompass the whole winter season. See Table 4.2 for the description of individual classifications. Selected spatial domains: D00 – whole Europe, D02 – W Scandinavia, D04 – the British Isles, D07 – Central Europe, D09 – Iberia.

	domain	HBGWL	PECZELY	PERRET	SCHUEEPP	ZAMG	CEC	GWT	LITTC	LUND	LWT2	NNW	OGWL	OGWL-3d+	P27	PCACA	PCAXTR	PCAXTRKM	PETISCO	SANDRA	SANDRAS	TPCA07	TPCAV	WLKC733
trend year	D00	**2.0**	**-0.4**	-0.1	0.0	0.0	**-0.6**	0.1	-0.1	**-0.2**	0.0	**0.1**	0.0	0.1	0.0	-0.1	0.0	-0.1	0.0	0.0	0.0	-0.1	0.0	0.0
	D02						0.0	0.0	**-0.1**	-0.1	0.0	0.0			0.0	0.0	0.0	0.0	-0.1	0.0	-0.1	-0.1	-0.1	0.0
	D04						0.0	0.0	**-0.1**	0.1	0.0	**-0.2**			**0.0**	-0.1	**-0.1**	0.0	-0.1	0.0	-0.1	0.0	0.0	0.0
	D07						0.0	0.0	0.0	0.0	0.0	-0.1			0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0
	D09						0.0	0.0	0.0	0.0	0.0	-0.1			0.0	-0.1	0.0	0.0	0.0	0.0	0.1	-0.1	-0.1	0.0
trend DJF	D00	**2.4**	**-0.4**	0.0	**0.1**	0.0	-0.4	0.2	-0.1	-0.1	0.0	0.3	0.0	0.3	0.0	-0.1	0.2	0.1	0.1	0.2	0.3	-0.2	-0.1	0.0
	D02						0.0	0.0	-0.1	-0.1	0.0	0.1			0.0	0.0	-0.2	-0.1	**-0.1**	0.1	0.1	-0.1	0.0	0.0
	D04						0.1	0.1	0.0	**0.4**	0.0	-0.2			0.0	0.1	-0.1	0.0	-0.1	0.0	0.0	-0.1	0.0	0.0
	D07						0.5	**0.2**	0.0	0.1	0.1	**-0.4**			**-0.1**	0.5	0.1	0.1	**0.1**	0.1	0.0	-0.1	-0.1	0.0
	D09						0.0	0.0	0.0	0.0	0.1	**-0.8**			0.1	0.3	-0.1	-0.1	0.0	0.1	0.3	0.0	0.0	0.0
trend MAM	D00	**1.6**	**-0.5**	0.0	0.0	0.0	-0.8	0.1	0.0	**-0.4**	0.0	0.1	-0.1	-0.1	0.0	0.0	-0.2	-0.1	-0.1	-0.2	-0.3	0.1	0.0	0.0
	D02						0.0	0.0	-0.1	0.0	0.0	-0.1			0.0	-0.3	-0.1	0.0	0.0	0.0	-0.1	-0.1	-0.1	0.0
	D04						0.0	0.0	-0.1	-0.1	0.0	-0.1			-0.1	**-0.6**	-0.1	-0.1	-0.1	-0.1	0.0	0.1	0.0	0.0
	D07						-0.2	0.0	0.0	-0.1	0.0	-0.2			0.0	-0.2	-0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0
	D09						0.0	0.0	0.0	-0.1	0.0	0.0			0.0	-0.2	0.0	0.0	0.0	0.0	0.2	-0.1	0.0	0.0
trend JJA	D00	**2.1**	**-0.3**	-0.1	0.1	0.0	**-0.6**	0.2	0.0	0.0	0.1	0.0	0.1	-0.1	0.1	0.2	-0.1	-0.1	0.2	0.1	0.0	0.2	**0.4**	0.1
	D02						-0.1	-0.1	0.0	-0.1	0.0	0.0			0.0	-0.2	0.1	0.1	0.0	0.0	0.2	-0.1	-0.2	0.0
	D04						0.0	0.0	-0.1	-0.1	0.0	0.0			-0.1	0.3	-0.1	0.1	0.0	0.0	-0.2	-0.1	0.0	0.0
	D07						0.0	0.0	0.0	-0.1	0.0	0.6			-0.1	0.0	**-0.1**	-0.1	0.0	0.0	0.0	0.1	**0.1**	0.0
	D09						-0.1	-0.1	0.0	0.0	0.0	**1.1**			0.0	0.8	-0.1	0.0	0.0	0.1	0.4	-0.1	-0.1	0.0
trend SON	D00	**2.2**	**-0.6**	**-0.3**	-0.1	**-0.3**	-0.5	-0.1	-0.1	-0.1	-0.1	0.0	0.0	0.3	0.0	**-0.3**	0.1	0.0	-0.1	0.0	-0.2	-0.2	0.1	0.0
	D02						0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.1	0.0	0.0	-0.1	0.0	0.0	0.0
	D04						0.0	0.0	-0.1	0.0	0.0	0.0			-0.1	-0.2	-0.1	-0.1	0.0	0.0	-0.2	0.0	0.0	0.0
	D07						0.0	-0.1	0.0	0.0	0.0	-0.1			0.1	0.0	0.1	0.1	-0.1	-0.1	-0.2	-0.1	-0.1	0.0
	D09						0.0	0.0	-0.1	0.0	0.1	-0.1			-0.1	-0.7	0.0	-0.1	-0.1	-0.1	0.0	0.1	-0.1	0.0

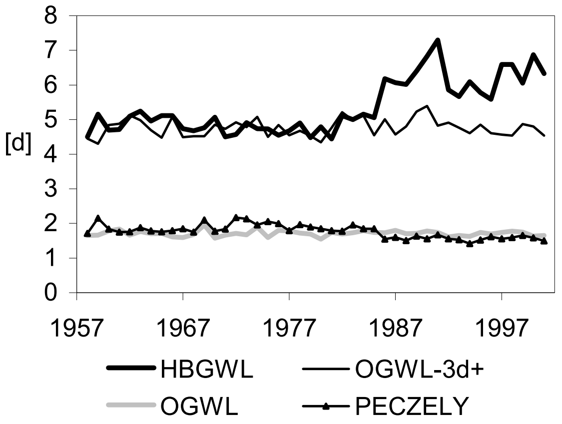


Fig. 4.2. Changes in the mean annual persistence of circulation types in selected manual (HBGWL, PECZELY) and objective (OGWL, OGWL-3d+) classifications. Years start in December in order to encompass the whole winter season.

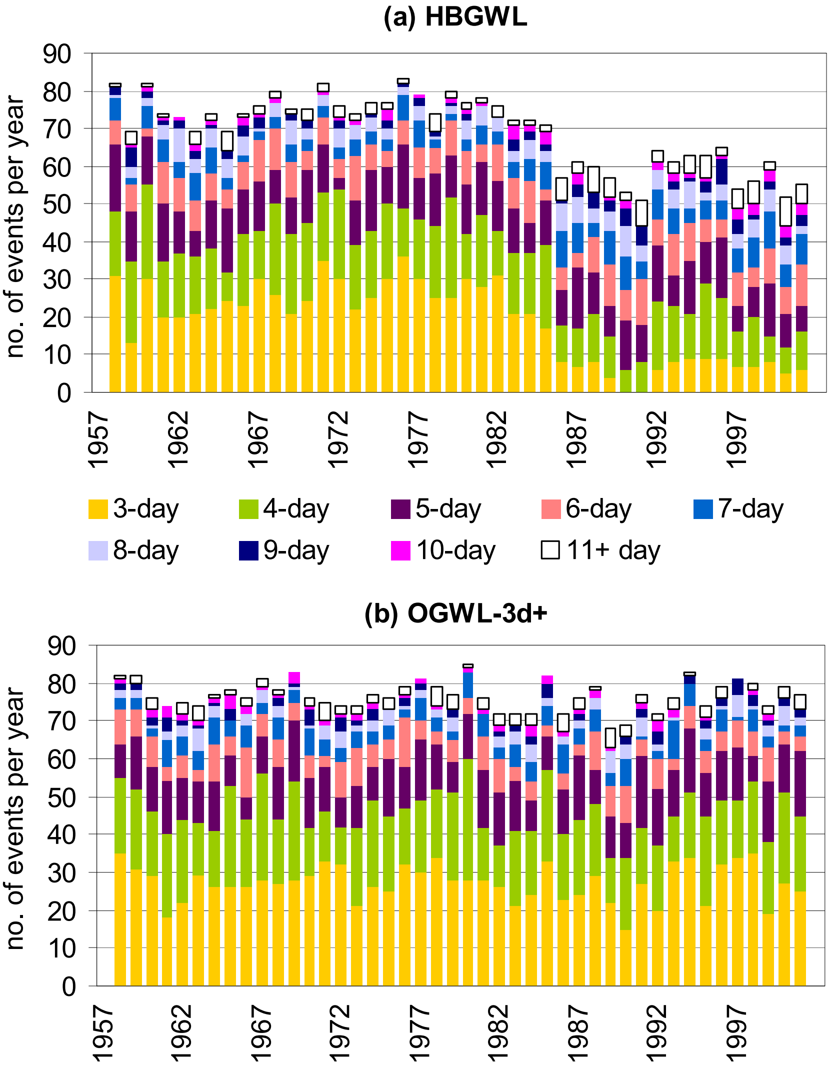


Fig. 4.3. Annual number of circulation types grouped by event length in (a) HBGWL (subjective) and (b) OGWL-3d+ (objective) catalogues.

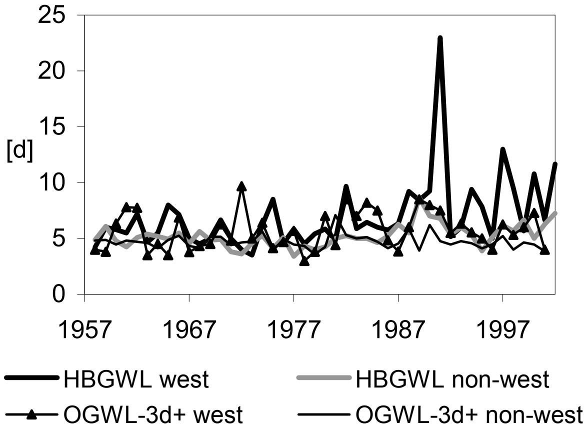


Fig. 4.4. Winter persistence of circulation types within two groups: westerly (WA, WZ, WW, WS) and non-westerly, in HBGWL (subjective) and OGWL-3d+ (objective) catalogues.

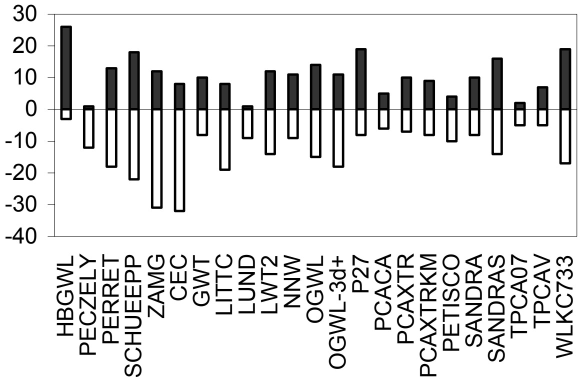


Fig. 4.5. Number of positive and negative linear trends (irrespective of their magnitude and significance) in annual persistence of individual circulation types in domain 00 – whole Europe (except for the subjective catalogues and their "objectivized" versions).

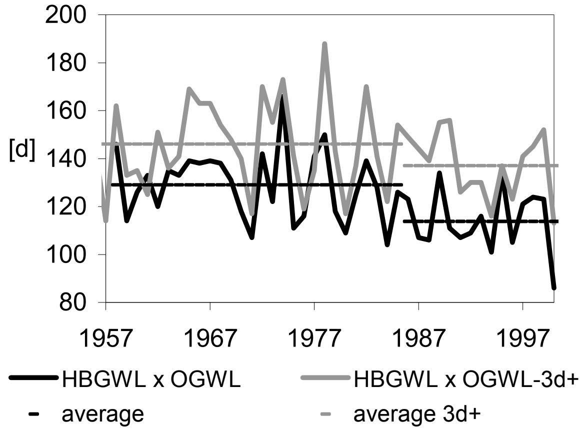


Fig. 4.6. Annual number of days classified with the same type in the Hess–Brezowsky "Grosswetterlagen" (HBGWL) and in its two objectivized versions (OGWL, black line; OGWL-3d+, grey line). Horizontal lines show the average before and after 1986, the year when the persistence of Hess–Brezowsky types suddenly increased.

4.4 Conclusion

In this paper we focus on trends in the lifetime (persistence) of atmospheric circulation types in Europe, using both objective and manual circulation classifications in the period 1957–2002. The recently reported enhancement of the persistence (i.e. a longer duration of circulation types) since the 1980s in the subjective Hess–Brezowsky catalogue (Werner et al., 2000; Kyselý and Huth, 2006; Kyselý and Domonkos, 2006) was not confirmed in any of the 18 objective catalogues, of which 16 were studied over five European domains, differing in their size and location. Significant annual and seasonal linear trends in persistence are scarce except for the Hess–Brezowsky (increase in persistence) and Hungarian (PECZELY; decrease in persistence) manual classifications. The increase in the lifetime of atmospheric circulation types in the subjective Hess–Brezowsky catalogue appears therefore to be fictitious rather than real. This casts serious doubts on the homogeneity of the Hess–Brezowsky catalogue and disqualifies it from being used in climatological analyses that involve persistence.

Our analysis suggests that a simultaneous use of more circulation classifications than a single one may be beneficial for the reliable detection of real climatic changes.

Acknowledgments

The authors are grateful to Paul M. James for providing the OGWL-3d+ catalogue and would like to thank Andreas Philipp, Friedrich-Wilhelm Gerstengarbe, Peter C. Werner, and three anonymous reviewers for their comments on the manuscript. This paper benefited from networking within the COST733 Action “Harmonisation and Applications of Weather Types Classifications for European Regions” (http://www.cost733.org). The COST program is funded by the European Union. The participation of the Institute of Atmospheric Physics in COST733 is supported by the Ministry of Education, Youth, and Sports of the Czech Republic under project OC115. The study was also supported by the Grant Agency of the Academy of Sciences of the Czech Republic, contract A300420506.

4.5 References

Alexandersson, H. 1986. A homogeneity test applied to precipitation data. *Int. J. Climatol.* **6**, 661–675.

Bárdossy, A. and Caspary, H. J. 1990. Detection of climate change in Europe by analysing European atmospheric circulation patterns from 1881 to 1989. *Theor. Appl. Climatol.* **42**, 155–167.

Barnston, A. G. and Livezey, R. E. 1987. Classification, Seasonality and Persistence of Low-Frequency Atmospheric Circulation Patterns. *Mon. Weather Rev.* **115**, 1083–1126.

Beck, C., Jacobeit, J. and Jones, P. D. 2007. Frequency and within-type variations of large scale circulation types and their effects on low-frequency climate variability in Central Europe since 1780. *Int. J. Climatol.* **27**, 473–491.

Bissolli, P. and Dittmann, E. 2001. The objective weather type classification of the German Weather Service and its possibilities of application to environmental and meteorological investigations. *Meteorol. Z.* **10**, 253–260.

Buishand, T. A. and Brandsma, T. 1997. Comparison of circulation classification schemes for predicting temperature and precipitation in the Netherlands. *Int. J. Climatol.* **17**, 875–889.

Ekström, M., Jönsson, P. and Bärring, L. 2002. Synoptic pressure patterns associated with major wind erosion events in southern Sweden (1973-1991). *Clim. Res.* **23**, 51–66.

Enke, W. and Spekat, A. 1997. Downscaling climate model outputs into local and regional weather elements by classification and regression. *Clim. Res.* **8**, 195–207.

Esteban, P., Martín-Vide, J. and Mases, M. 2006. Daily atmospheric circulation catalogue for Western Europe using multivariate techniques. *Int. J. Climatol.* **26**, 1501–1515.

Gerstengarbe, F.-W. and Werner, P. C. 2005. Katalog der Großwetterlagen Europas (1881-2004) nach Paul Hess und Helmut Brezowsky. *PIK Report 100*. Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany, 148 pp. Available at: http://www.pik-potsdam.de/research/publications/pikreports/.files/pr100.pdf

Gerstengarbe, F.-W., Werner, P. C. and Rüge, U. 1999. Katalog der Großwetterlagen Europas (1881-1998) nach Paul Hess und Helmuth Brezowsky (in German). Potsdam, Offenbach a. M., Germany, 138 pp. Available at: http://www.pik-potsdam.de/~uwerner/gwl/gwl.pdf

Gulev, S. K., Zolina, O. and Grigoriev, S. 2001. Extratropical cyclone variability in the Northern Hemisphere winter from the NCEP/NCAR reanalysis data. *Clim. Dyn.* **17**, 795–809.

Gutzler, D. S. and Mo, K. C. 1983: Autocorrelation of Northern Hemisphere geopotential heights. *Mon. Weather Rev.*, **111**, 155–164.

Hess, P. and Brezowsky, H. 1952. *Catalogue of European Large-scale Weather Situations (Katalog der Großwetterlagen Europas)* (in German). Berichte des Deutschen

Wetterdienstes in der US-Zone 33, Bad Kissingen, Germany.Horel, J. D. 1985. Persistence of the 500 mb Height Field during Northern Hemisphere Winter. *Mon. Weather Rev.* **113**, 2030–2042.

Huth, R. 2000. A circulation classification scheme applicable in GCM studies. *Theor. Appl. Climatol.* **67**, 1–18.

James, P. M. 2006. Second Generation Lamb Weather Types. A new generic classification method with evenly tempered type frequencies. Paper presented at 6th Annual Meeting of the European Meteorological Society/6th European Conference on Applied Climatology (ECAC), EMS2006A00441, Ljubljana, Slovenia.

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

Kyselý, J. and Domonkos, P. 2006. Recent increase in persistence of atmospheric circulation over Europe: comparison with long-term variations since 1881. *Int. J. Climatol.* **26**, 461–483.

Kyselý, J. and Huth, R. 2006. Changes in atmospheric circulation over Europe detected by objective and subjective methods. *Theor. Appl. Climatol.* **85**, 19–36.

Lityński, J. 1969. Numerical classification of circulation types and weather types of Poland (Liczbowa klasyfikacja typów cyrkulacji i typów pogody dla Polski) (in Polish). *Prace PIHM*, **97**, 3–14.

Lund, I. A. 1963. Map-Pattern classification by statistical methods. *J. Appl. Meteorol.* **2**, 56–65.

Michaelides, S. C., Liassidou, F. and Schizas, C. N. 2007. Synoptic classification and establishment of analogues with artificial neural network. *Pure Appl. Geophys*. **164**, 1347–1364.

Péczely, G. 1983. *Catalogue of the macrosynoptic types for Hungary (1881–1983)* (in Hungarian). Publications of the Hungarian Meteorological Service, Volume 53, Budapest, Hungary, 116 pp.

Perret, R. 1987. Classification of meteorological situations for the needs of prediction. Meteo Swiss, 46, 127 pp (in French). (Une classification des situations météorologiques à l'usage de la prévision.)

Petisco, E. and Martín, J. M. 1995. Characterization of the atmospheric general circulation in the Iberian Peninsula and Balearic Islands (Caracterización de la Circulación General Atmosférica en la Península Ibérica y Baleares) (in Spanish). *Tech. Note 5,* Service of Analysis and Research of Climate, Instituto Nacional de Meteorología, Madrid..

Philipp, A. 2009. Comparison of principal component and cluster analysis for classifying circulation pattern sequences for the European domain. *Theor. Appl. Climatol.* **96**, 31–41.

Philipp, A., Della-Marta, P. M., Jacobeit, J., Fereday, D. R., Jones, P. D., Moberg, A. and Wanner, H. 2007. Long-term variability of daily North Atlantic-European pressure patterns since 1850 classified by simulated annealing clustering. *J. Climate* **20**, 4065–4095.

Stefanicki, G., Talkner, P. and Weber, R. O. 1998. Frequency changes of weather types in the Alpine region since 1945. *Theor. Appl. Climatol*. **60**, 47–61.

Štěpánek, P. 2006. *AnClim – software for time series analysis (for Windows)*. Dept. of Geography, Faculty of Science, Masaryk University, Brno, Czech Republic, 1.47 MB. Available at: http://www.klimahom.com/software/AnClim.html

Trigo, I. F. 2006. Climatology and interannual variability of storm-tracks in the Euro-Atlantic sector: a comparison between ERA-40 and NCEP/NCAR reanalyses. *Clim. Dyn*. **26**, 127–143.

Uppala, S. M., Kållberg, P. W., Simmons, A. J., Andrae, U., Da Costa Bechtold, V. and co-authors. 2005. The ERA-40 re-analysis. *Q. J. R. Meteorol. Soc.* **131**, 2961–3211.

van den Dool, H. M. 1983. A possible explanation of the observed persistence of monthly mean circulation anomalies. *Mon. Weather Rev*. **111**, 539–544.

Werner, P. C., Gerstengarbe, F.-W., Fraedrich, K. and Oesterle, H. 2000. Recent climate change in the North Atlantic/European sector. *Int. J. Climatol*. **20**, 463–471.

Wiedemann, J. M., Lupo, A. R., Mokhov, I. I. and Tikhonova, E. A. 2002. The climatology of blocking anticyclones for the Northern and Southern Hemispheres: Block intensity as a diagnostic. *J. Climate* **15**, 3459–3473.

5. Paper IV: Changes of atmospheric circulation in central Europe and their influence on climatic trends in the Czech Republic

Monika Cahynová[1, 2], Radan Huth[1]

[1]Institute of Atmospheric Physics, Academy of Sciences of the Czech Republic, Boční II 1401, 141 31 Prague 4, Czech Republic

[2]Department of Physical Geography and Geoecology, Faculty of Science, Charles University

e-mail: cahynova@ufa.cas.cz

Keywords: atmospheric circulation – classification – Hess–Brezowsky catalogue – climatic trends – Czech Republic

Abstract

This work deals with the influence of changes of atmospheric circulation on observed trends of 11 climatic elements at 21 stations in the Czech Republic in the period 1961–1998. Atmospheric circulation in central Europe is described by the German (Hess–Brezowsky) and Czech–Slovak (Brádka's) subjective catalogues of synoptic types. In the study period there is a strong downward trend in the occurrence of anticyclonic types in Brádka's catalogue in all seasons while mostly in autumn. Westerly and northwesterly types become more frequent in autumn and winter, less frequent in spring and summer under both classifications. In the Hess–Brezowsky catalogue the occurrence of anticyclonic types increases in winter, spring, and summer. To assess the effect of circulation changes on observed climate trends we have used the method of "hypothetical" seasonal trends that are calculated from a daily series, constructed by assigning the long-term monthly average of the given climatic element under a specific circulation type to each day classified with this type. The ratio of these circulation-conditioned trends and observed seasonal trends shows that changes in atmospheric circulation are the primary cause of massive winter warming and autumn cooling, which is connected with increasing precipitation and humidity. Summer climate trends are unrelated to changes in atmospheric circulation. Simultaneous use of more circulation classifications for the detection of climatic changes is highly recommended, as the long-term circulation trends depend on the catalogue applied.

5.1 Introduction

In recent decades the climatological community, as well as the general public, became aware of the ongoing anthropogenic climate change. One of the key issues of understanding the observed changes is finding the links between changes of atmospheric circulation and local climate. Several authors have studied these relationships in the European-Atlantic region using different methods, time and spatial scales. The decadal variability of the North Atlantic Oscillation has been interpreted as a major predictor of wintertime temperatures and precipitation over much of Europe (Hurrell, 1995), although the relationship may be nonlinear (Pozo-Vázquez et al., 2001). The well-documented strengthening of zonal flow over Europe in the decades preceding the 1990s (Bárdossy and Caspary, 1990; Slonosky et al. 2000; Werner et al. 2000; Kyselý and Huth, 2006; James, 2007) is considered to be the main cause for the observed wintertime warming. Slonosky et al. (2000) note, however, that the recent (until the 1990s) shift of the NAO is not unusual in the 200-years perspective.

More and more studies are trying to attribute the climatic trends and variability to atmospheric circulation, taking into account either various characteristics of the pressure field (e.g. circulation indices) or synoptic types classifications. Chen (2000) has used a stepwise multiple regression model, considering several circulation indices as predictors and January temperature anomalies in Sweden as predictands. Regression of circulation types frequencies and winter precipitation totals over the Iberian peninsula was presented in the work of Goodess and Jones (2002). Huth (2001) has compared the observed linear trends of surface climate variables with circulation-induced climatic trends, i.e. “hypothetical” trends affected only by changing frequency of circulation types.

Generally, the links are found to be more pronounced in the winter season (e.g. Chen, 2000; Huth, 2001; Beck et al., 2007; Kostopoulou and Jones, 2007). When analyzing century-long or longer time series, the authors point out that the relationships between circulation and climate are changing on decadal time scales (Hanssen-Bauer and Førland, 1998, 2000; Beck et al., 2007; Beranová and Huth, 2008), thus strongly limiting the usefulness of statistical downscaling models. Jacobeit et al. (2001) note that running correlations between several zonal indices and four European regional temperature time series are all indicating major instationarities in these relationships. Other causes than circulation changes are blamed for at least part of the local climate variability (e.g. Huth, 2001; Goodess and Jones, 2002).

In this study, we (i) present recent changes in atmospheric circulation in central European region in terms of occurrence as well as persistence of synoptic types, and (ii) assess their possible links with observed seasonal trends of eleven climatic elements in the Czech Republic in the period 1961–1998.

5.2 Data and methods

5.2.1 Circulation data

For the description of atmospheric circulation in central Europe two subjective catalogues of synoptic types are used: the Hess–Brezowsky Grosswetterlagen, further referred to as H–B (Hess and Brezowsky 1952; Gerstengarbe and Werner, 1993; Gerstengarbe et al., 1999), which is available back to 1881, and the so-called Brádka's catalogue (later simply BR), produced by the former Hydrometeorological Institute of Czechoslovakia since 1946 (Brádka et al., 1961; Hydrometeorological Institute, 1968). Both catalogues are being updated regularly, the up-to-date Czech (formerly Czechoslovak) catalogue is available online (http://www.chmi.cz/meteo/om/mk/syntypiz/kalendar.html).

The H–B catalogue, although designed for the area of Germany, represents the atmospheric circulation over much of Europe and has been widely used in studies diagnosing decadal-scale climatic changes (e.g. Bárdossy and Caspary, 1990; Werner et al., 2000) and the influence of atmospheric circulation on surface climate elements (Buishand and Brandsma, 1997; Keevallik and Russak, 2001; Sepp and Jaagus, 2002; Domonkos, 2003; Domonkos et al., 2003; Kyselý, 2007). For the description of the 29 H–B circulation types, their grouping according to the direction of advection, as well as their connection to German weather, see Gerstengarbe et al. (1999).

BR catalogue is based on the Hess–Brezowsky methodology, modified for the region of former Czechoslovakia. There are 28 synoptic types and all days are classified. The classification is being compiled separately for the Czech and Slovak Republics since 1991. Until the mid-1990s there was a requirement of at least 2-day duration (persistence) of circulation types, which however did not apply to traveling anticyclones and troughs. Similar but 3-day minimum residence time applies to the H–B types with the exception of transient (unclassified – U) type.

In order to detect relevant and comparable trends in both catalogues, the types are grouped with respect to their (anti)cyclonicity and the direction of airflow. Four directional "supertypes" were established, with the northerly to northeasterly flow (N+NE), easterly to southeasterly flow (E+SE), southerly to southwesterly flow (S+SW), and westerly to northwesterly flow (W+NW). The assessment of cyclonicity in the H–B follows the work of

Domonkos et al. (2003) who discern 12 anticyclonic and 13 cyclonic types. For the English description of BR types and their grouping into "supertypes" see e.g. Beranová and Huth (2005).

5.2.2 Surface meteorological data

Station meteorological data used in this study are basically the same as those employed in the papers of Huth and Pokorná (2004, 2005), i.e. daily values of eleven climatic variables at 21 stations in the Czech Republic in the period 1961–1998. The variables include daily maximum (TX), minimum (TN), and mean (T) temperature, daily precipitation amount (PR), the occurrence of precipitation (PRO – either 0 or 1), relative humidity (RH), cloudiness (CL – in tenths), sunshine duration (SUN), zonal (ZW) and meridional (MW) wind components, and total wind speed (W). The wind, relative humidity, and cloudiness are recorded at 14:00 of the Central European Time (CET = UTC + 1h); the daily mean temperature is calculated according to the climatological practice in the Czech Republic from temperatures measured at 7, 14 and 21 hours as $T = 0.25\ (T7 + T14 + 2\text{x}T21)$. The zonal and meridional wind components are positive for west and south wind, respectively. The stations included in the study are listed in Table 5.1; at three of them, sunshine duration data are not available, and relative humidity data are missing at one station.

Table 5.1. List of stations, ordered by elevation.

Station name	Latitude (°N)	Longitude (°E)	Elevation (m a.s.l.)
Doksany	50°28′	14°10′	158
Holešov	49°19′	17°34′	224
Praha-Karlov	50°04′	14°26′	232
Brno-Tuřany	49°09′	16°42′	241
Ostrava-Mošnov	49°41′	18°07′	251
Hradec Králové	50°11′	15°50′	278
Kuchařovice	48°53′	16°05′	334
Praha-Ruzyně[a]	50°06′	14°17′	380
České Budějovice [a]	48°58′	14°28′	384
Liberec	50°46′	15°01′	400
Havlíčkův Brod [a]	49°37′	15°35′	455
Cheb	50°05′	12°24′	474
Přibyslav	49°35′	15°46′	530
Vyšší Brod	48°37′	14°19′	559
Kostelní Myslová	49°11′	15°28′	569
Svratouch[b]	49°44′	16°02′	737
Přimda	49°40′	12°40′	745
Červená	49°46′	17°32′	750
Milešovka	50°33′	13°56′	833
Churáňov	49°04′	13°37′	1118
Lysá hora	49°32′	18°27′	1324

[a] *Sunshine duration data are missing*

[b] *Relative humidity data are missing*

5.2.3 Methods

Most analyses are based upon commonly used 3-month seasons, where spring comprises of March, April, and May (MAM), summer of JJA, autumn of SON, and winter of DJF (while December belongs to the preceding year).

Observed seasonal circulation and climatic trends in the period 1961–1998 were estimated using linear least-squares regression applied to the occurrence of days with a specific circulation pattern, to the average residence time (persistence) of synoptic situations, and to the seasonal means of each climatic variable. The common *t*-test of the regression model was performed to evaluate the statistical significance of trends. The seasonal series of the persistence of circulation types were tested for the shift in the mean using Standard Normal Homogeneity Test (Alexandersson, 1986; Štěpánek, 2006). To compare climatic trends in different variables at individual stations, a simple standardization method was employed – linear climatic trends were divided by the standard deviation of the seasonal time series of the specific variable. Such trends therefore illustrate the amount of change relative to the interannual variability of the given element.

For the detection of relationships between changes in atmospheric circulation and trends in surface climate elements, the method of "hypothetical" linear trends was employed. This method, which had been used e.g. by Huth (2001) for two Czech stations, is based on the assumption that changes in the occurrence of circulation types are the only factor causing the observed climate trends. All days classified with the same type are expected to bear the same value of a climatic element in a specific month (averaged over the whole period, e.g. all Januaries). Conditional mean values of each climatic element under every synoptic type are calculated separately for each of the twelve months, and these time series are then used instead of the observed data to assess the long-term "hypothetical" (circulation-conditioned) seasonal trends. We can then compare these "hypothetical" trends to real changes simply by dividing them by the observed linear trends. This ratio would stay around one if climate trends were caused by circulation changes only. Bárdossy and Caspary (1990) had shown that such a "hypothetical" daily series reconstructed using the Hess–Brezowsky circulation catalogue is a fairly good approximation of the observed monthly mean temperature and precipitation at German stations, with correlation coefficients ranging from 0.7 to 0.9.

5.3 Trends in atmospheric circulation over central Europe

Many previous studies have analyzed changes of atmospheric circulation in various regions of Europe and the world. When addressing these works, we have to bear in mind that different circulation classification methods (and resulting catalogues of circulation types) that are mainly used for the detection of circulation and climate changes are a mere imperfect description of the reality. The other problem is the different spatial scale and region on which the individual classifications are based.

In the Alpine region, Stefanicki et al. (1998) found an increase of the anticyclonic weather pattern in winter and a simultaneous decrease of northerly weather types in the period 1945–1994. Bárdossy and Caspary (1990) analyzed the H–B catalogue, and reported an increase of the frequency of zonal circulations in winter (December and January) and a corresponding decrease of cold meridional circulations. Change points in the series occurred with high probability during the 1970s. Werner et al. (2000) also show an increase in the frequency of

H–B zonal types in winter since the 1970s that is linked to an unprecedented strengthening of the westerlies over Europe. Kyselý and Huth (2006) found very similar features in the H–B and an objective circulation catalogue during the last four decades. Their major results include the strengthening of the zonal flow in winter since the 1960s to the early 1990s, and the increase (decrease) in frequency of anticyclonic (cyclonic) types in winter from the late 1960s to the early 1990s, with a subsequent decline (rise).

In this study, we want to compare BR Czech (Czechoslovak) and German H–B circulation classifications in terms of trends in seasonal occurrence of days belonging to a specific major type, as well as the persistence of synoptic situations. The longest period with data available from both catalogues spans from 1946 to 2000; however, we will focus mainly on a shorter (1961–1998) period on which the further analyses using surface climate data are based. Possible explanations for the disparities between the two catalogues will be proposed.

5.3.1 Changes in the occurrence of circulation types

The seasonal occurrence of days with cyclonic and anticyclonic circulation patterns is shown in Figure 5.1 for BR and in Figure 5.2 for HB. The prevalence of cyclonic patterns is present in all seasons in BR while only in winter in H–B. The proportion of days with undistinguished cyclonicity is about three times greater in H–B so the trends of the cyclonic and anticyclonic major types are not necessarily opposite.

According to BR, there is a strong upward (downward) trend in the occurrence of cyclonic (anticyclonic) days in winter, summer and even more in autumn from 1960 to the mid-1990s. In spring, such a trend is present only until the 1980s. Table 5.2 shows the magnitude and significance of linear trends in the occurrence of major types in 1961–1998. In this period only the decline of anticyclonic types in spring, summer, and autumn, and the rise of cyclonic types in autumn are significant at the 95% level.

In the H–B catalogue the trends are quite different. In winter the number of cyclonic (anticyclonic) types decreases (increases) from the 1960s to the early 1990s, with only the anticyclonic rising trend being significant in the period 1961–1998 (see Table 5.2). In spring, the highest frequency of anticyclonic days occurred around the years 1960 and 1990 with lower values in between. The steep increase during the 1980s is the reason for the significant positive trend of anticyclonic patterns in 1961–1998. Trends in summer and autumn are minor with great interannual variability dominating, although there is a slight decrease (increase) of cyclonic (anticyclonic) patterns in summer from the late 1960s until the early 1990s.

The contradictory results obtained from two different catalogues most probably stem from the different spatial domain covered, although in most days the cyclonicity assessment is similar in both classifications. Figure 5.3 shows that about 200 to 260 days annually (64% of all days) are classified with the same type, anticyclonic or cyclonic. Seasonally, this proportion ranges from 59% in summer to 66% in winter. A substantial proportion of days (15%) is classified as cyclonic in BR but as anticyclonic in H–B. The frequency of such days gradually increases since the late 1960s. This positive trend is present in all seasons; however, it is most notable in autumn and winter since in spring and summer the numbers of cyclonic (BR) and at the same time anticyclonic (H–B) days had been relatively high prior to the mid-1960s (not shown). Its reason is unknown to us.

Seasonal changes in the occurrences of major directional types (N+NE, E+SE, S+SW, and W+NW) are shown in Figure 5.4 both for BR and H–B. In all seasons except for spring, the westerly and northwesterly flow dominates, which is the most pronounced in H–B in autumn and winter. The total percentages of days occupied with the major directional types for the BR (H–B) catalogue are shown in the last row (column) of Table 5.3. The days without a pronounced advection were divided into cyclones and anticyclones. In BR there are fewer days with W+NW flow but more with non-directional cyclones.

The temporal variability of the number of W+NW types is quite consistent between the two catalogues in all seasons but summer. A good correspondence between the catalogues is present for all groups of types in autumn and winter. The number of W+NW types has increased from the 1960s to the early 1990s in both catalogues in autumn and winter, with a subsequent decline afterwards. In autumn the rising trend was interrupted by a decline in the 1970s. A strong decrease of W+NW types occurrence in the 1990s can also be seen in summer. In spring the number of W+NW types rose until the mid-1960s, then decreased until the late 1980s and again increased afterwards. Winter frequency of N+NE types peaks around 1965 and then falls quickly and stays low. The spring peak of N+NE types in the 1950s in H–B is not reproduced in BR. In summer the seasonal number of N+NE types rises from the 1960s to the 1980s in H–B at the expense of W+NW types while little changes are seen in the frequency of N+NE types in BR. There is a peak of S+SW types in spring around 1980 and of E+SE types around 1970 in winter and summer. The other series show a rather oscillatory pattern with several stages of positive and negative trends. In the period 1961–1998 only three trends are significant (see Table 5.2): the winter increase of W+NW types in H–B, and the rise (decline) of N+NE types in BR in autumn (in H–B in winter).

The proportion of days classified with the same directional “supertype” in both catalogues is smaller (50% of all days) than for the cyclonicity assessment (64%). Seasonal variations of the number of days classified with the same direction of advection are shown in Figure 5.5. Large interannual changes occur, and there is generally a downward trend (i.e. a decrease of agreement between the catalogues) in all seasons until the 1980s. The highest agreement occurs again in winter when 54% of days are classified with the same direction of flow, while the lowest values are found in spring and summer (48%). In Table 5.3 we present the relationships of the daily assessment of directional types between the two catalogues. Not surprisingly, days with the W+NW flow are classified mostly the same. Such days classified as W+NW in both catalogues comprise 18.8% of all days, compared to the total proportion of W+NW types which is 26.2% in BR and 34.2% in H–B. Cyclones without a pronounced direction of advection (types C – stationary cyclones, B – troughs, and Bp – traveling troughs) that are 2.5 times more frequent in BR are classified mostly as W+NW types or similarly as cyclonic non-directional types in H–B, which seems sound from a synoptic point of view.

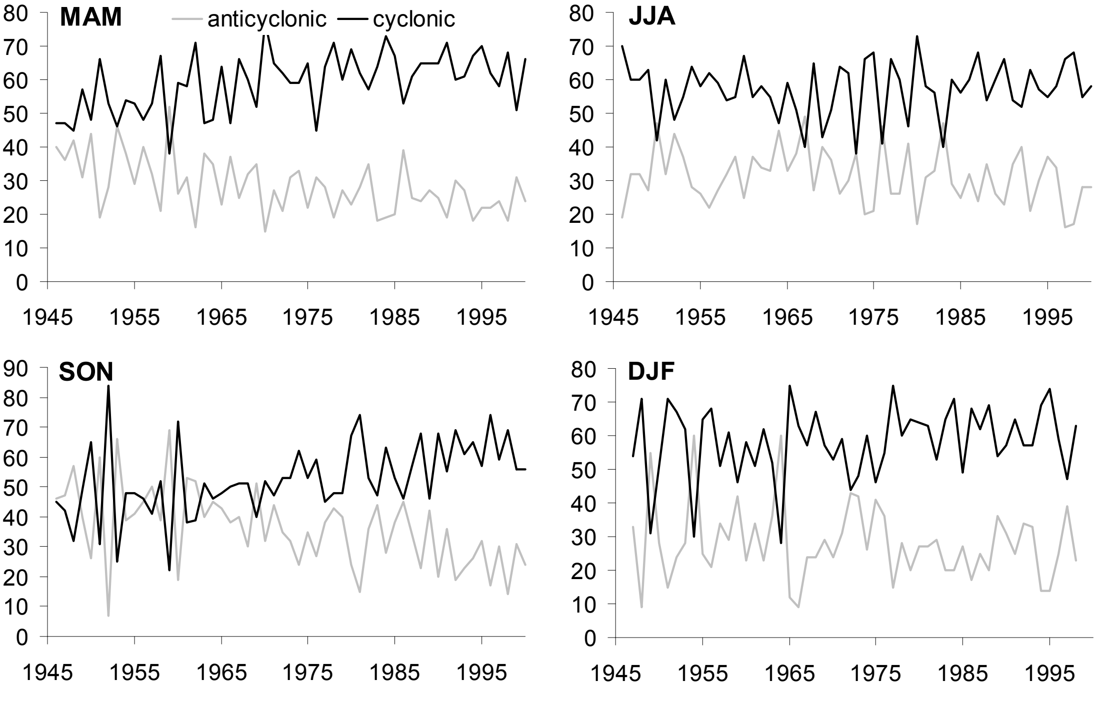


Fig. 5.1. Seasonal frequency of days with cyclonic and anticyclonic circulation according to BR catalogue.

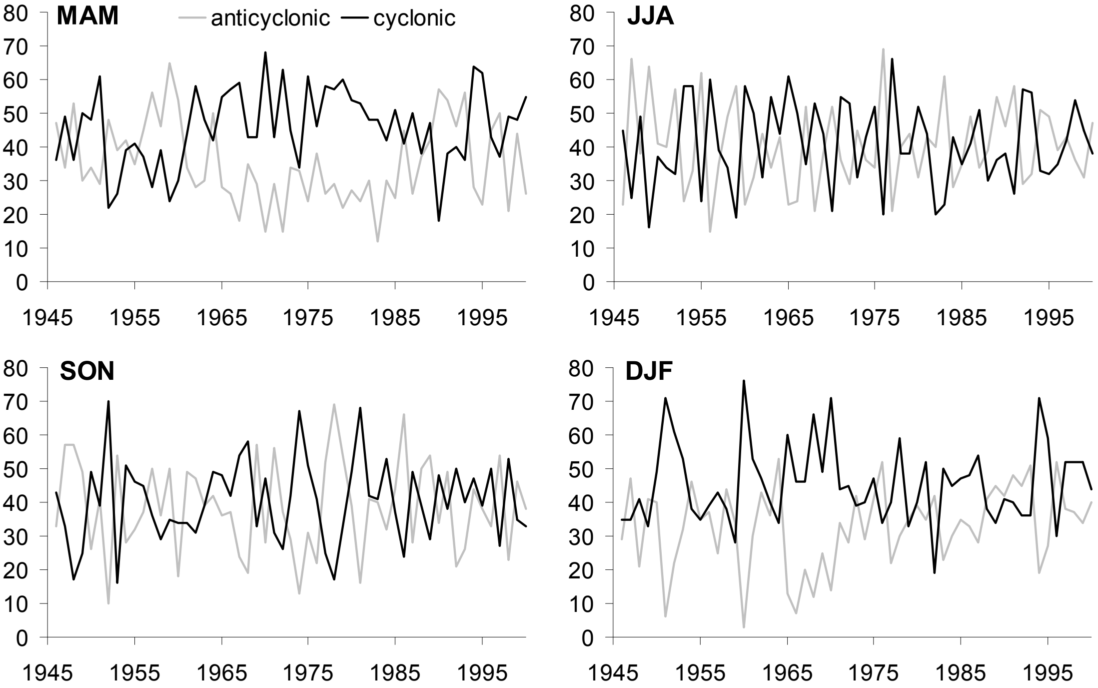


Fig. 5.2. Seasonal frequency of days with cyclonic (13 out of 29 types) and anticyclonic (12 types) circulation according to the H–B catalogue.

Table 5.2. Linear trends of seasonal occurrence of groups of circulation types in BR and H–B, presented in days per 38 years (1961–1998).

		A	C	N+NE	E+SE	S+SW	W+NW
MAM	Brádka	-7.5[a]	7.7	1.1	-1.2	2.4	-4.5
	Hess–B.	13.4[a]	-9.5	-0.9	-4.8	4.5	-6.0
JJA	Brádka	-10.7[a]	8.6	-1.2	-2.0	6.0	-6.9
	Hess–B.	9.1	-7.2	8.2	-6.8	-0.8	-7.7
SON	Brádka	-21.7[a]	21.3[a]	8.0[a]	0.3	2.3	2.2
	Hess–B.	0.1	0.6	3.9	4.7	-7.6	8.5
DJF	Brádka	-5.8	8.3	-3.3	-3.1	1.1	10.4
	Hess–B.	15.3[a]	-0.3	-10.8[a]	-2.5	-2.8	18.0[a]

[a] *Trends significant at the 95% level*

The grouping according to cyclonicity is independent of the directional grouping

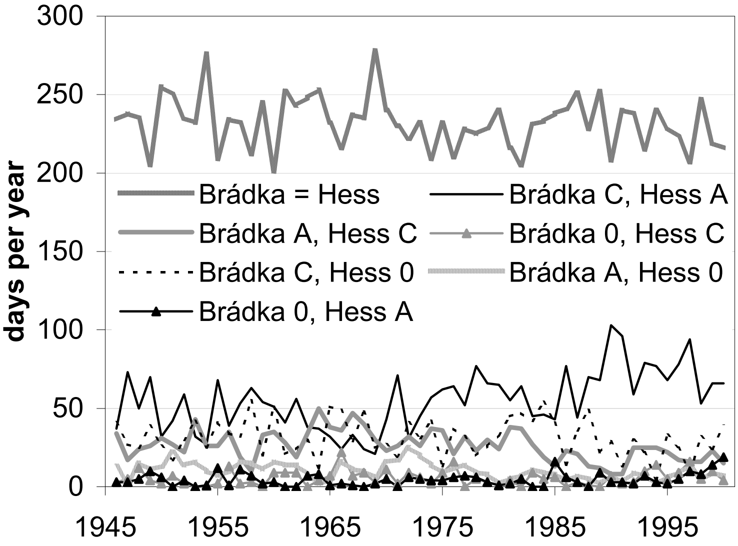


Fig. 5.3. Comparison of daily cyclonicity assessment in BR and H–B circulation classifications.

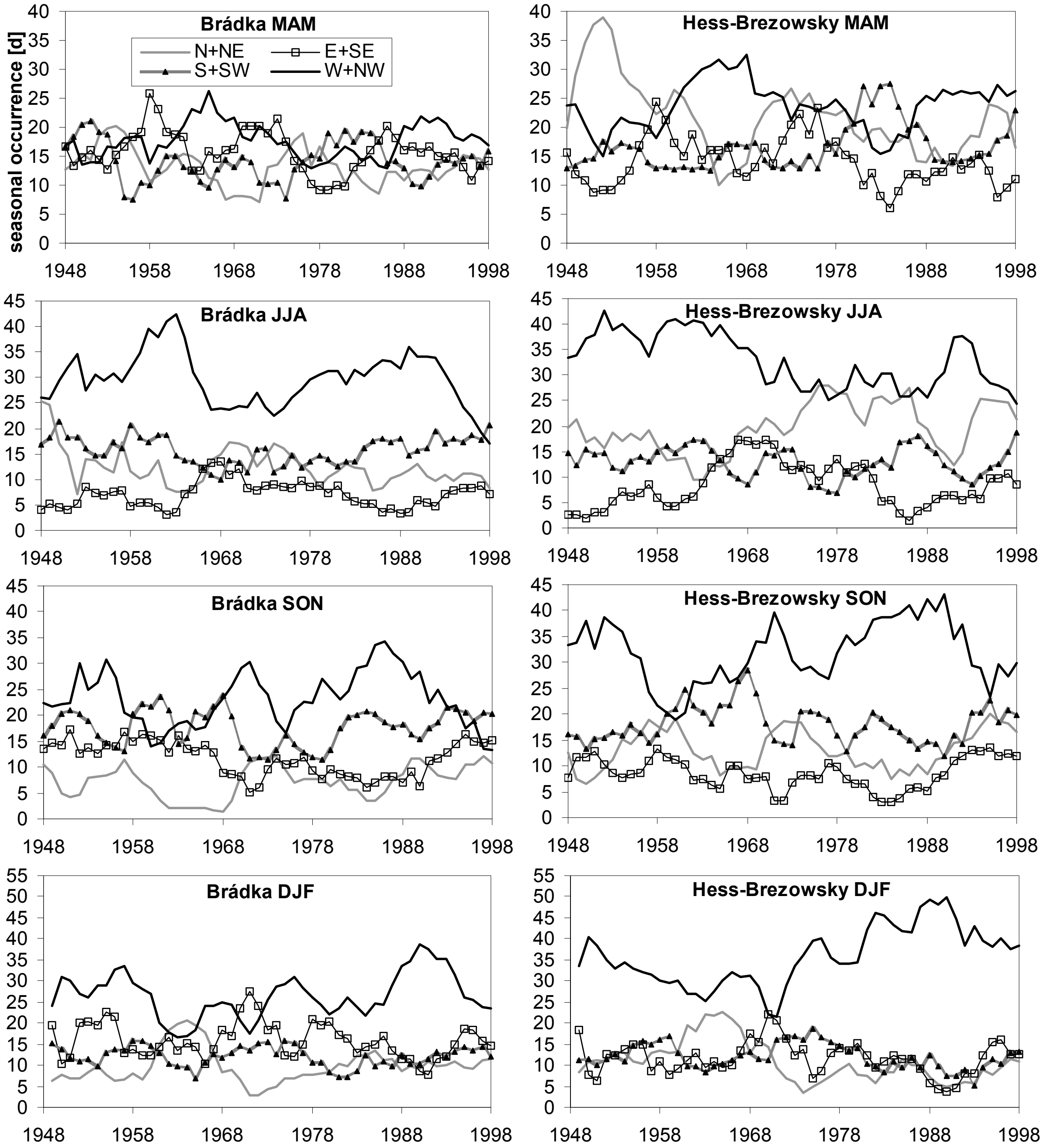


Fig. 5.4. Seasonal occurrence of days grouped according to the direction of flow (N+NE, E+SE, S+SW, and W+NW) in BR and H–B. Five-year moving averages are shown.

Table 5.3. Comparison of the daily direction of flow in BR vs. H–B catalogue. Percentage of the total number of days in the period 1946–2000 is shown; maximum of a row (column) is in bold type (underlined). Note that non-directional types are grouped with respect to their (anti)cyclonicity. The "unclassified" group comprises of only the U (transient) type in H–B, of upper-air cyclone (Cv) and frontal zone entrance (Vfz) in BR catalogue.

Hess–B.	Brádka							
	N+NE	E+SE	S+SW	W+NW	A	C	–	Σ Hess–B.
N+NE	**6.1**	1.5	0.8	1.8	0.7	2.5	0.6	13.9
E+SE	2.1	**6.3**	1.0	0.2	0.6	0.9	0.5	11.7
S+SW	0.2	1.5	**8.8**	1.3	1.8	2.3	0.5	16.5
W+NW	1.3	0.9	4.5	**18.8**	2.2	5.1	1.3	34.2
A	1.6	2.9	0.9	3.2	**5.5**	1.2	0.6	15.9
C	0.4	0.5	0.5	0.6	0.1	**4.5**	0.1	6.7
–	0.1	0.1	0.1	0.2	0.2	**0.2**	0.1	1.1
Σ Brádka	11.9	13.7	16.6	26.2	11.1	16.9	3.7	Σ diag. 50.1

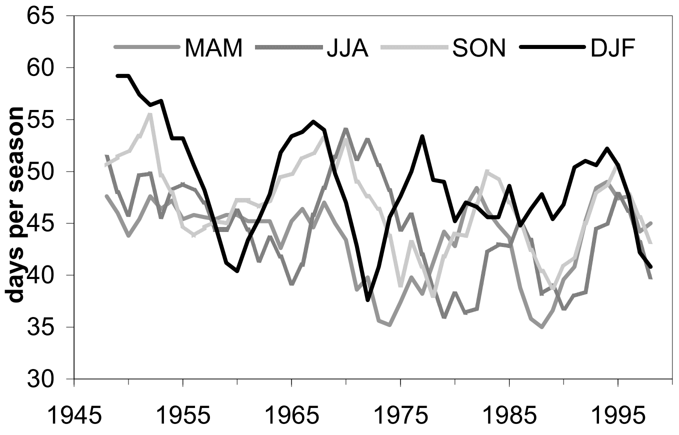


Fig. 5.5. Seasonal number of days classified with the same direction of flow in BR and H–B. Five-year moving averages are shown.

5.3.2 Trends in the persistence (mean residence time) of circulation types

Previous studies have detected a sharp increase in the persistence of the H–B Grosswetterlagen in the 1980s, most notable for the zonal types in winter (Werner et al., 2000; Kyselý and Domonkos, 2006) and similar but less pronounced changes in objective circulation classifications (Werner et al., 2000; Kyselý and Huth, 2006). Domonkos et al. (2003) and Kyselý (2007) have shown that the enhanced persistence of atmospheric circulation can affect the frequency and severity of temperature extremes.

We have tested the series of the seasonal mean persistence of all the H–B and BR circulation types using Standard Normal Homogeneity Test in the AnClim software (Štěpánek, 2006) for the detection of possible significant shifts. Its results show a shift in the H–B towards higher persistence in all seasons in the 1980s, which is significant at the 95% confidence level. In spring and summer, the change occurred between the years 1985 and 1986, in autumn between 1984 and 1985, and the strongest shift took place in winter between 1986 and 1987.

Figure 5.6 (upper panel) shows the annual number of synoptic situations according to their persistence in H–B. Prior to 1985, the most common persistence of synoptic situations was three days, which is the minimum duration possible according to the methodology. The number of 3-day situations then dropped suddenly, and in 1990 and 1991 there were none. Such an unprecedented sudden shift is rather suspicious and may indicate a change in methodology, and hence an inhomogeneity in the catalogue.

Entirely different trends are present in the persistence of circulation types in BR (Fig. 5.6, lower panel). The overall persistence is generally shorter than in H–B (long-term average is 3.6 days vs. 5.0 days). This stems mainly from the fact that in the Czechoslovak methodology, the minimum persistence was set to only two days with the exception of traveling anticyclones and troughs that can last one day only. Mean annual persistence for all BR types combined exhibits a sudden drop between the years 1972 and 1973 with a further downward trend of –0.28 days per decade, which is significant at the 95% level. The inhomogeneity is caused by a different approach of meteorologists to subjective synoptic classification after personal changes took place in the early 1970s. In Figure 5.6 we can see that the number of 2-day situations rose since 1973 at the expense of 5-day and longer situations. A decrease in the persistence of synoptic situations is present under both cyclonic and anticyclonic conditions throughout the whole year. This implies that the positive trends of seasonal number of cyclonic days in BR realize through more frequent recurrence of cyclonic situations, not through their longer residence times.

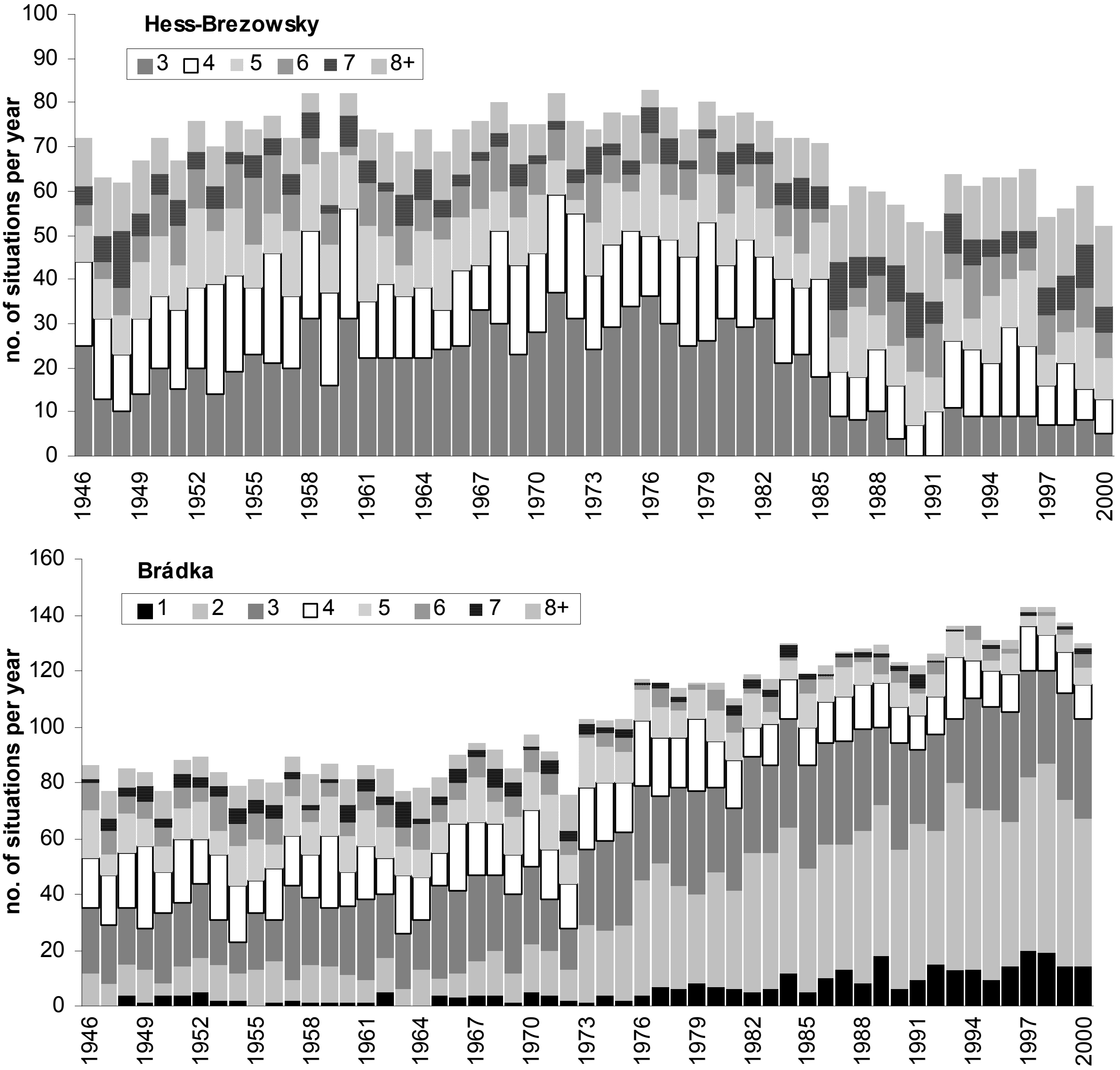


Fig. 5.6. Annual number of synoptic situations with respect to their persistence (lifetime in days) in H–B and BR.

5.4 Climatic trends and their relation to atmospheric circulation changes

5.4.1 Observed climatic trends, 1961–1998

Seasonal trends in surface climatic elements in the Czech Republic in the period 1961–1998 were presented by Huth and Pokorná (2004, 2005). However, further analysis of the data used in these studies revealed some errors in the primary data files. As a result, the seasonal trends for five climatic elements at two stations (Kuchařovice – W, Cheb – RH, CL, ZW, MW) had to be recalculated. Our results are in good accord with those presented by Brázdil and Macková (1998).

Linear climate trends at 21 stations for the 38-year period are shown as box-whisker plots in Fig. 5.7, both in observed physical units and normalized by dividing the trend by standard deviation. Relative humidity (RH) trends were divided by ten and trends in the probability of a day with precipitation (PRO) were multiplied by ten for a better graphical display within the used scale. The numbers of seasonal climatic trends significant at the 95% confidence level are shown in Table 5.4. In spring, summer, and notably in winter there is a pronounced warming trend, whereas in autumn a cooling trend was found. In all seasons at the majority of stations the trends in daily maximum temperature are greater than those of the daily minima, so that the daily temperature range increases in all seasons but autumn. The greatest trends in daily maximum temperature in winter exceed +2.5°C in the period 1961–1998, which corresponds to +0.66°C per decade. Trends in other variables are consistent with temperature changes: relative humidity and cloudiness decrease and sunshine duration increases in spring, summer, and winter; in autumn these trends are again of opposite sign. Precipitation trends in spring, summer, and winter are mostly insignificant (both positive and negative trends occur); in autumn we can see the rising probability of a rainy day, which is in agreement with increased cloudiness. Zonal and meridional wind component trends are mostly insignificant and spatially inconsistent, i.e. their sign varies among individual stations. Trends in total wind speed are of larger magnitude (ranging from –3.4 to +2.1 m/s change per 38 years) but also geographically incoherent. However, it seems that winds weaken at stations in higher elevations – approximately above 550 m a.s.l. with the exception of the Milešovka mountaintop station where wind speed increases in all seasons but summer.

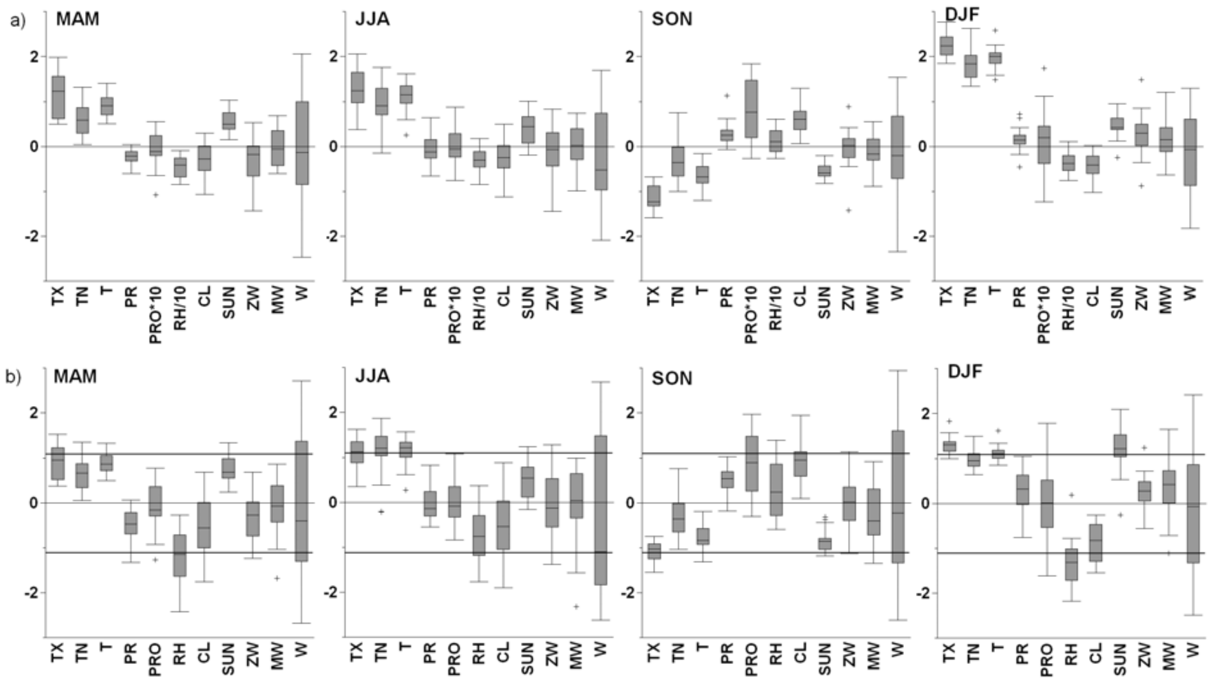


Fig. 5.7. Box-whisker plots showing seasonal trends in eleven climatic elements at 21 stations in the Czech Republic during 1961–1998, a) in physical units, b) normalized by standard deviation; trends significant at the 95% level are greater (lower) than the upper (bottom) thick horizontal line. See section 2.2 for the explanation of abbreviations.

Table 5.4. Seasonal number of linear climatic trends in 1961–1998 significant at the 95% level. Total number of stations is 21. See section 2.2 for the explanation of abbreviations.

	TX	TN	T	PR	PRO	RH	CL	SUN	ZW	MW	W
MAM	6	1	3	1	1	11	3	3	2	1	13
JJA	11	14	15	–	–	5	4	1	4	2	15
SON	7	–	3	–	9	1	6	2	2	2	12
DJF	18	4	19	–	3	14	7	11	1	2	9

5.4.2 Circulation-induced climatic changes

In Figure 5.8 the ratio of “hypothetical” (circulation-conditioned) and observed seasonal trends is shown separately for each season and for the two circulation catalogues used. Only stations with observed trends of individual surface climatic variables significant at the 95% confidence level were chosen for the comparison, their quantity is shown in Table 5.4. The reason for the omission of insignificant trends is that dividing the circulation-conditioned trends by insignificant (and therefore very small) real trends would yield unrealistic, highly variable results.

In winter, variations in the occurrence of circulation types are responsible for about half of the observed warming trends in daily maximum, minimum, and average temperature. Using the H–B classification, the circulation-conditioned trends can also partly explain positive trends of sunshine duration and the decrease of relative humidity and cloudiness. On the other hand, the "hypothetical" trends of these variables (and also of wind speed) are of opposite sign in some cases for the BR classification. Trends in the frequency of the BR and H–B circulation types fail to interpret (somewhat surprisingly) the winter trends in wind speed. A possible reason is that the observed trends in wind speed are very different among individual stations (both positive and negative in all seasons) and are caused by local factors rather than large-scale circulation changes.

Autumn is the only season, which can be characterized with cooling and rising probability of precipitation. Circulation changes account for more (less) than a half of these trends under the BR (H–B) classification. Trends in precipitation days, relative humidity, cloudiness, and sunshine duration are also well reproduced by the hypothetical trends, i.e. are to a large extent caused by changing frequency of circulation types. In the case of BR, the "hypothetical" trends at some stations are more pronounced than the observed trends; i.e. there would have been even more rainy days and cloudiness, and less sunshine if circulation changes were the only cause of climatic trends. The circulation-conditioned trends of wind speed are variable and even contradictory to the observed trends at several stations.

In spring and summer, there is virtually no link between circulation changes, described by the BR catalogue, and climatic trends. Circulation-induced trends of all climatic elements are negligible, so the ratio of these and the observed trends stays around zero. In summer, the circulation-induced changes of daily maximum, minimum, and average temperature are mostly of opposite sign than the observed (warming) trends. Changes in the frequency of BR circulation types therefore favor a cooling rather than warming trend in summer. Under the H–B classification, circulation changes partially explain the observed trends, mostly in spring, up to the half of the real trends is explained (but the rate is only 0 – 0.2 for TX, TN and T). In summer, the proportion of observed trends explained by changing frequency of H–B circulation types is less than 0.2 for temperature (the same holds for spring), and up to 0.35 for other variables.

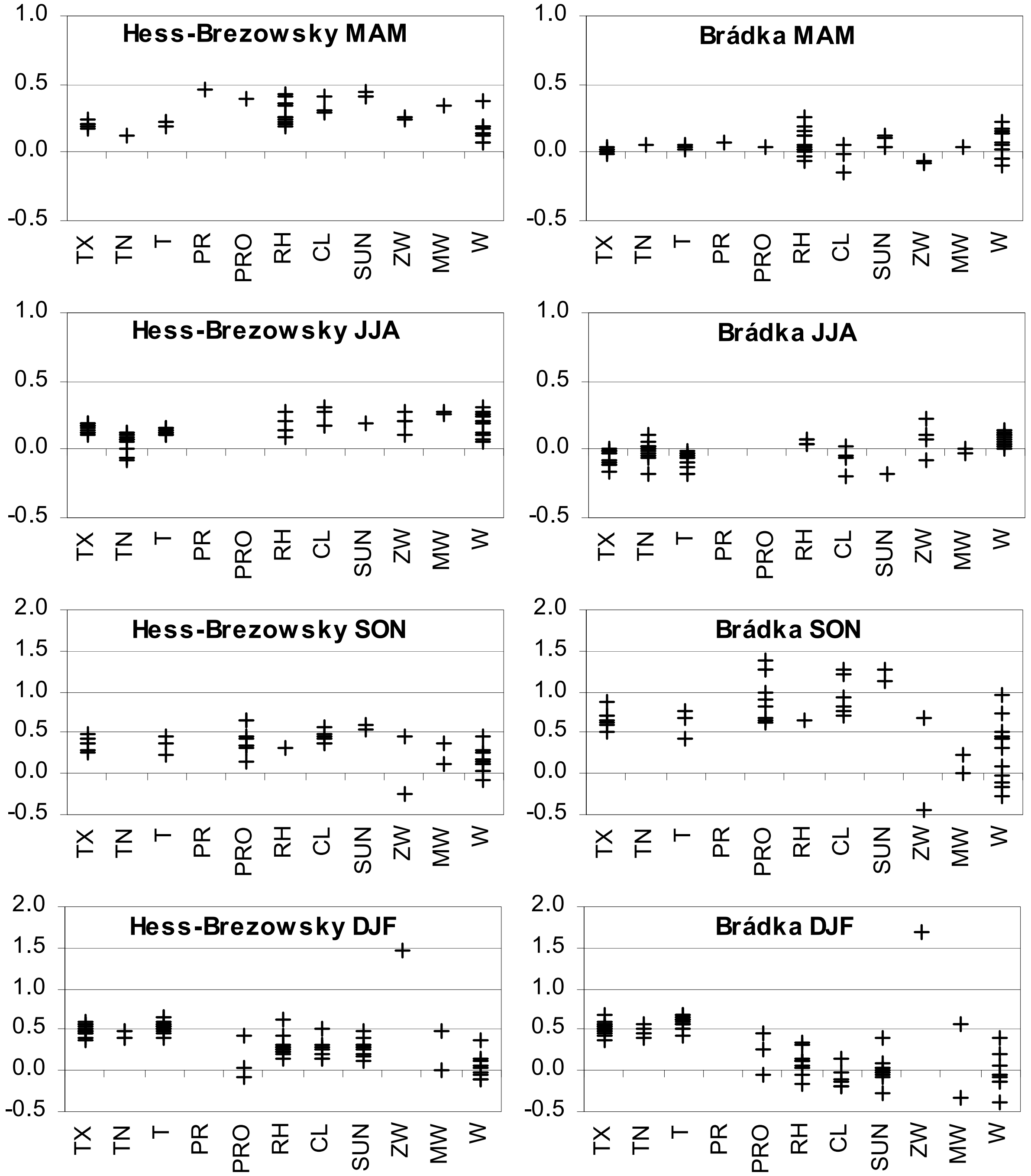


Fig. 5.8. Ratio of "hypothetical" (linked to changes in atmospheric circulation) and observed seasonal trends at Czech stations (1961–1998) – only the values from stations with significant observed trends of the given climatic element are shown.

5.5 Discussion and conclusions

In this study we have compared seasonal trends in the occurrence and persistence of major circulation types in the Hess–Brezowsky and Czech–Slovak (so-called Brádka's) catalogues. Using these two classifications, we have assessed the influence of circulation changes on observed trends of eleven surface climatic elements in the Czech Republic in the period 1961–1998.

The major findings include:

- The rising frequency of cyclonic types, and decline of anticyclonic types in the BR catalogue in all seasons (in spring until the 1980s), but a rising trend of anticyclonic patterns in H–B in winter, spring and summer. Generally, there are more days with cyclonic circulation in BR, and the rate of opposite (anticyclonic) code for these days in H–B increases.
- Enhancement of the westerly and northwesterly advection in winter (in both catalogues) and autumn (in H–B), and winter decrease of northerly and northeasterly flow in H–B.
- Ambiguous trends in the persistence of circulation types: a rise in H–B in the mid-1980s when the formerly frequent 3-day situations diminish, but a drop in BR in the early 1970s (which is probably an inhomogeneity) followed by further decline.
- Changes in atmospheric circulation are responsible for more than a half of the observed winter warming. In autumn, while H–B explains less than the half of the trend-magnitudes, using BR the temperature trends are well captured, and some trends of precipitation probability, cloudiness and sunshine should have been even more pronounced had they been caused by circulation changes only.
- In spring and summer when we see a warming trend, the links with circulation changes are negligible, except that the H–B explains certain parts of the trend magnitudes, but the explained rates are always lower than 0.5. Other causes, such as the changing internal properties of circulation types, are therefore responsible for most of the observed climatic trends.

Using a single circulation classification (catalogue) may lead to misleading results on long-term circulation trends. Parallel investigation of more catalogues is therefore highly recommended.

The inconsistency of trends within the two subjective catalogues may be caused by the different spatial domains covered (BR classification was designed for the area of Czechoslovakia, which stretched much farther east than the area covered by H–B), and by the slightly different approaches of individual meteorologists to the synoptic classification. The shortening duration of BR types in recent decades reflects rather an inhomogeneity than real climatic changes. The increasing persistence of H–B circulation types was partly confirmed by an analysis of objective synoptic catalogue in Kyselý and Huth (2006) and is hypothesized to be a consequence of global warming, connected with a northward shift of midlatitude storm tracks.

The main feature of the European-North Atlantic circulation since 1960, viz. the wintertime strengthening of the westerlies due to more prevalent positive phase of the NAO (e.g. Hurrell, 1995), is well reflected by both the circulation catalogues used, and has been confirmed as a main cause of the positive temperature trend in central Europe.

The presented results agree with the formerly published work of Huth (2001) who found a relationship between circulation changes (described by an objective classification by principal component analysis) and climate trends at two Czech stations in winter in the period 1949–1980 but no link in summer.

The subjective catalogues of circulation types, although not necessarily homogenous, can still serve as a useful tool for such analyses. A comparison of these with objective synoptic classifications can shed light on further details of the recent climatic changes, and will be a subject of our future studies.

Acknowledgments

The authors thank Friedrich-Wilhelm Gerstengarbe and Peter C. Werner, Potsdam Institut für Klimafolgenforschung, Potsdam, Germany, for providing us with the Hess–Brezowsky catalogue and related reports, and for useful discussions; and to Stanislav Racko, Czech Hydrometeorological Institute, Prague, Czech Republic, for information on the history of Brádka's catalogue. The work was carried out within the COST733 Action "Harmonization and Applications of Weather Types Classifications for European Regions". The participation of the Czech Republic in this action is supported by the Ministry of Education, Youth, and Sports of the Czech Republic under contract OC115. The study was also supported by the Grant Agency of the Czech Academy of Sciences, contract A300420506.

5.6 References

Alexandersson H (1986) A homogeneity test applied to precipitation data. Int J Climatol 6: 661–675

Bárdossy A, Caspary HJ (1990) Detection of climate change in Europe by analyzing European atmospheric circulation patterns from 1881 to 1989. Theor Appl Climatol 42: 155–167

Beck C, Jacobeit J, Jones PD (2007) Frequency and within-type variations of large-scale circulation types and their effects on low-frequency climate variability in central Europe since 1780. Int J Climatol 27: 473–491

Beranová R, Huth R (2005) Long-term changes in the heat island of Prague under different synoptic conditions. Theor Appl Climatol 82: 113–118

Beranová R, Huth R (2008) Time variations of the effects of circulation variability modes on European temperature and precipitation in winter. Int J Climatol 28: 139–158

Brádka J, Dřevikovský A, Gregor Z, Kolesár J (1961) Weather on the territory of Bohemia and Moravia in typical weather situations (in Czech). Hydrometeorological Institute, Prague, 32 pp

Brázdil R, Macková J (1998) Series of mean annual air temperatures of the Czech Republic in 1828–1995 (in Czech). Met Zpr 51: 17–21

Buishand TA, Brandsma T (1997) Comparison of circulation classification schemes for predicting temperature and precipitation in the Netherlands. Int J Climatol 17: 875–889

Chen D (2000) A monthly circulation climatology for Sweden and its application to a winter temperature case study. Int J Climatol 20: 1067–1076

Domonkos P (2003) Recent precipitation trends in Hungary in the context of larger scale climatic changes. Nat Hazards 29: 255–271

Domonkos P, Kyselý J, Piotrowitz K, Petrovic 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

Gerstengarbe F-W, Werner PC (1993) Katalog der Großwetterlagen Europas nach Paul Hess und Helmuth Brezowsky: 1881–1992. Ber Dt Wetterd, vol 113, Deutscher Wetterdienst, Offenbach a M, Germany, 249 pp

Gerstengarbe F-W, Werner PC, Rüge U (1999) Katalog der Großwetterlagen Europas (1881–1998) nach Paul Hess und Helmuth Brezowsky. Potsdam Institute for Climate Impact Research, Potsdam, Germany. http://www.pik-potsdam.de/~uwerner/gwl/welcome.htm. Accessed December 2008

Goodess CM, Jones PD (2002) Links between circulation and changes in the characteristics of Iberian rainfall. Int J Climatol 22: 1593–1615

Hanssen-Bauer I, Førland EJ (1998) Long-term trends in precipitation and temperature in the Norwegian Arctic: can they be explained by changes in atmospheric circulation patterns? Clim Res 10: 143–153

Hanssen-Bauer I, Førland EJ (2000) Temperature and precipitation variations in Norway 1900–1994 and links to atmospheric circulation. Int J Climatol 20: 1693–1708

Hess P, Brezowsky H (1952) Katalog der Grosswetterlagen Europas. Ber Dt Wetterd in der US-Zone, Nr. 33, Deutscher Wetterdienst, Offenbach a M, Germany

Hurrell JW (1995) Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation. Science 269: 676–679

Huth R (2001) Disaggregating climatic trends by classification of circulation patterns. Int J Climatol 21: 135–153

Huth R, Pokorná L (2004) Parametric versus non-parametric estimates of climatic trends. Theor Appl Climatol 77: 107–112

Huth R, Pokorná L (2005) Simultaneous analysis of climatic trends in multiple variables: an example of application of multivariate statistical methods. Int J Climatol 25: 469–484

Hydrometeorological Institute (1968) Catalogue of weather situations for the territory of Czechoslovakia (in Czech). Hydrometeorological Institute, Prague, 94 pp

Jacobeit J, Jönsson P, Bärring L, Beck C, Ekström M (2001) Zonal indices for Europe 1780–1995 and running correlations with temperature. Clim Change 48: 219–241

James PM (2007) An objective classification method for Hess and Brezowsky Grosswetterlagen over Europe. Theor Appl Climatol 88: 17–42

Keevallik S, Russak V (2001) Changes in the amount of low clouds in Estonia (1955–1995). Int J Climatol 21: 389–397

Kostopoulou E, Jones PD (2007) Comprehensive analysis of the climate variability in the eastern Mediterranean. Part II: relationships between atmospheric circulation patterns and surface climatic elements. Int J Climatol 27: 1351–1371

Kyselý J (2007) Implications of enhanced persistence of atmospheric circulation for the occurrence and severity of temperature extremes. Int J Climatol 27: 689–695

Kyselý J, Domonkos P (2006) Recent increase in persistence of atmospheric circulation over Europe: comparison with long-term variations since 1881. Int J Climatol 26: 461–483

Kyselý J, Huth R (2006) Changes in atmospheric circulation over Europe detected by objective and subjective methods. Theor Appl Climatol 85: 19–36

Pozo-Vázquez D, Esteban-Parra MJ, Rodrigo FS, Castro-Díez Y (2001) A study of NAO variability and its possible non-linear influences on European surface temperature. Clim Dyn 17: 701–715

Sepp M, Jaagus J (2002) Frequency of circulation patterns and air temperature variations in Europe. Boreal Environ Res 7: 273–279

Slonosky VC, Jones PD, Davies TD (2000) Variability of the surface atmospheric circulation over Europe, 1774-1995. Int J Climatol 20: 1875–1897

Stefanicki G, Talkner P, Weber RO (1998) Frequency changes of weather types in the Alpine region since 1945. Theor Appl Climatol 60: 47–61

Štěpánek P (2006) AnClim: software for time series analysis (for Windows). Dept. of Geography, Faculty of Science, Masaryk University, Brno, Czech Republic. http://www.klimahom.com/software/AnClim.html

Werner PC, Gerstengarbe F-W, Fraedrich K, Oesterle H (2000) Recent climate change in the North Atlantic/European sector. Int J Climatol 20: 463–471

6. Paper V: Circulation vs. climatic changes over the Czech Republic: A comprehensive study based on the COST733 database of atmospheric circulation classifications

Monika Cahynová[a,b], Radan Huth[a]

[a] Institute of Atmospheric Physics, Academy of Sciences of the Czech Republic, Boční II 1401, 141 31 Prague 4, Czech Republic

[b] Department of Physical Geography and Geoecology, Faculty of Science, Charles University, Prague, Czech Republic

Keywords: atmospheric circulation – classification – circulation type – climatic trends – Czech Republic

Abstract

We have analyzed the effect of changes in the frequency of circulation types on significant seasonal trends of eight climatic variables (maximum, minimum, and average daily temperature, precipitation amount and occurrence, relative humidity, cloudiness, and sunshine duration) at 21 Czech stations in the period 1961–1998 using 24 objective and two subjective atmospheric circulation classifications collected and developed within the COST733 Action.

Using two independent methods, we show that recent climatic trends can be only partly explained by changes in the frequency of circulation types. In winter, such changes in the objective catalogues explain around 30% of long-term linear temperature trends and around 50% of temperature changes that took place between the first and the second half of the study period. Changing internal properties of individual circulation types (i.e. within-type climatic changes) are responsible for a major part of the observed climatic trends in spring, summer, and autumn; but also in winter for variables other than temperature.

The subjective catalogues are usually more tightly connected with the observed climatic changes than the objective ones. These results are consistent with the fact that except for winter, very few circulation types in the objective catalogues yield significant long-term trends in their seasonal occurrence. On the contrary, both used versions of the subjective Hess–Brezowsky catalogue bear a substantial proportion of significant trends in the occurrence of circulation types in all seasons.

Very high variability in the results, caused both by the variability within stations and within the circulation classifications used, suggests that such a comparative approach is highly desirable in synoptic-climatological studies.

6.1 Introduction

In recent decades the awareness of anthropogenic climate change has boosted research in the field of synoptic climatology. More and more studies are trying to attribute the climatic trends and variability to atmospheric circulation, taking into account either various characteristics of the pressure field (e.g. circulation indices) or synoptic types classifications.

Generally, the links are found to be more pronounced in the winter season (e.g. Chen, 2000; Huth, 2001; Beck et al., 2007; Kostopoulou and Jones, 2007). The well-documented strengthening of zonal flow over Europe connected with a positive trend in the North Atlantic Oscillation in the decades preceding the 1990s (Hurrell, 1995; Bárdossy and Caspary, 1990; Slonosky et al., 2000; Werner et al., 2000; Kyselý and Huth, 2006; James, 2007) is considered to be the main cause for the observed wintertime warming. When analyzing century-long or longer time series, the authors point out that the relationships between circulation and climate are changing on decadal time scales (Hanssen-Bauer and Førland, 1998, 2000; Beck et al., 2007; Beranová and Huth, 2008), thus strongly limiting the usefulness of statistical downscaling models. Jacobeit et al. (2001) note that running correlations between several zonal indices and four European regional temperature time series are all indicating major instationarities in these relationships. Other causes than circulation changes – e.g. changes in the climatic properties of the individual circulation types – are blamed for at least part of the local climate trends (e.g. Huth, 2001; Goodess and Jones, 2002). These within-type climatic changes may affect all the circulation types (that would point to a large-scale driver of changes, i.e. global warming), or may be restricted only to certain synoptic conditions.

In our previous paper (Cahynová and Huth, 2009) we have studied the trends of atmospheric circulation in two subjective Central European catalogues and their effect on climatic trends at Czech stations. In this study we present a broader comparative approach to the same topic, benefiting from cooperation and collection of tens of circulation classifications within the COST733 Action "Harmonisation and Applications of Weather Types Classifications for European Regions" (http://www.cost733.org). We focus on the following issues: (i) ranking of the selected circulation classifications according to their "skill" to stratify daily climatic data into types, (ii) evaluation of long-term trends in the seasonal frequency of circulation types, and (iii) assessment of the proportion of long-term climatic changes directly linked to circulation changes.

6.2 Data and methods

6.2.1 Circulation data

For the analysis of recent trends in the frequency of atmospheric circulation types over Europe and their relation with climatic trends in the Czech Republic, we use a subset of catalogues of atmospheric circulation types that have recently been made available within the COST733 Action. For a thorough description of COST733 circulation classifications see Philipp et al. (this issue), and Huth et al. (2008). The "objective", i.e. computer-assisted, methods of classification were developed using daily sea level pressure data from the ECMWF ERA-40 dataset (Uppala et al., 2005). The classification procedures were applied on the scale of entire Europe (domain 00) and 11 European sub-domains, typically covering the area of a few countries. We have chosen the whole European domain (D00, 37°W–56°E, 30°N–76°N) and Central Europe (D07, 3°E–26°E, 43°N–58°N) for our analysis. The catalogues used are listed in Table 6.1, together with references to the papers and reports where they are defined or described in more detail, a brief description of the method used for classification, and the number of types classified. Although the catalogues cover the period September 1957 through August 2002, we will focus on a shorter period 1961–1998 for which we have obtained the daily station climatic data from the Czech Republic.

The selected catalogues cover a wide range of classification methods, which include: (i) various kinds of cluster analysis, from k-means with different procedures to select the initial seed-points (CKMEANS) to the simulated annealing of daily patterns (SANDRA); (ii) correlation-based methods (LUND, PETISCO); (iii) principal component analysis in a T-mode (TPCA); (iv) procedures assigning individual patterns to the types according to their similarity with simple flow patterns (GWT) and S-mode principal component loadings (P27); (v) methods based on threshold values of circulation variables, i.e. large-scale flow direction (LITADVE, LITC18, LITTC).

Two versions of the German subjective catalogue are also included: the Hess–Brezowsky Grosswetterlagen (HBGWL), and its variant where the original 29 circulation types are grouped into 10 "supertypes" according to the direction of air flow and the position of pressure systems (HBGWT). These catalogues, although designed for the area of Germany, represent the atmospheric circulation over much of Europe and had been widely used in studies diagnosing decadal-scale climatic changes (e.g. Bárdossy and Caspary, 1990; Werner et al., 2000) and the influence of atmospheric circulation on surface climate elements (Buishand and Brandsma, 1997; Keevallik and Russak, 2001; Sepp and Jaagus, 2002; Domonkos, 2003; Domonkos et al., 2003; Kyselý, 2007).

Table 6.1. Description of selected atmospheric circulation classifications available from the COST733 inventory for the European region. In references, we prefer open scientific literature to internal reports and conference proceedings wherever possible, thereby sometimes neglecting the original data source.

catalogue	*classification method*	*reference*	*number of circulation types*
HBGWL	manual – Europe (centered on Germany)	Hess and Brezowsky, 1952; Bárdossy and Caspary, 1990; Gerstengarbe et al., 1999, 2005	29
HBGWT			10
CKMEANS	*k*-means clustering	Enke and Spekat, 1997	9, 18, 27
GWT	circulation prototypes	Beck et al., 2007	10, 18, 26
LITADVE, LITC18, LITTC	threshold-based	Lityński, 1969	9, 18, 27
LUND	correlation-based	Lund, 1963	9, 18, 27
P27	subdivision according to S-mode PCA-scores	Buishand and Brandsma, 1997	8, 18, 27
PETISCO	correlation-based	Petisco and Martín, 1995	9, 18, 27
SANDRA	simulated annealing clustering	Philipp et al., 2007	9, 18, 27
TPCA	T-mode PCA	Huth, 2000	9, 18, 27

6.2.2 Surface meteorological data

Station meteorological data used in this study are basically the same as those employed in the papers of Huth and Pokorná (2004, 2005), i.e. daily values of eight climatic variables at 21 stations in the Czech Republic in the period 1961–1998. The variables include daily maximum (TX), minimum (TN), and mean (T) temperature, daily precipitation amount (PR), the occurrence of precipitation (PRO – either 0 or 1), relative humidity (RH), cloudiness (CL – in tenths), and sunshine duration (SUN). Relative humidity and cloudiness are recorded at 14:00 of the Central European Time (CET = UTC + 1 h); the daily mean temperature is calculated according to the climatological practice in the Czech Republic from temperatures measured at 07:00, 14:00 and 21:00 local time as T = 0.25(T7 + T14 + 2 × T21). The stations are: Doksany (158 m), Holešov (224 m), Praha-Karlov (232 m), Brno-Tuřany (241 m), Ostrava-Mošnov (251 m), Hradec Králové (278 m), Kuchařovice (334 m), Praha-Ruzyně (380 m), České Budějovice (384 m), Liberec (400 m), Havlíčkův Brod (455 m), Cheb (474 m), Přibyslav (530 m), Vyšší Brod (559 m), Kostelní Myslová (569 m), Svratouch (737 m), Přimda (745 m), Červená (750 m), Milešovka (833 m), Churáňov (1118 m), Lysá hora (1324 m). At three stations, sunshine duration data are not available, and relative humidity data are missing at one station. Homogeneity of the data was tested by Pokorná et al. (2007), and very few problems were detected. These occurred mainly at Praha-Ruzyně that had been moved in 1976, and Praha-Karlov; however, their long-term climatic trends agree very well with the spatial distribution of trends within the Czech Republic. We have used all the stations in our study since we focus on a general spatial picture rather than peculiarities of individual stations.

6.2.3 Methods

For the assessment of "skill" of circulation classifications to stratify Czech daily climatic data into types, we have applied three following methods: explained variance index, within-type standard deviation normalized by dividing by the overall long-term standard deviation (for equations see Beck and Philipp (this issue)), and Pearson correlation coefficient of observed daily series and series reconstructed by replacing the daily value of the given climatic variable by its long-term monthly mean under the circulation type that occurred that day (as employed by Demuzere et al. (2009)). These methods were applied to every climatic variable at each station under each circulation classification in domain 00 (whole Europe) and domain 07 (Central Europe), separately for January, April, July, and October. To ease the interpretation of such manifold results we have then averaged the values of all stations and all variables, thus obtaining one value for every index, classification, and month used.

All the following analyses are based upon commonly used 3 month seasons, where spring comprises March, April, and May (MAM), summer JJA, autumn SON, and winter DJF (while December belongs to the preceding year).

Observed seasonal circulation and climatic trends in the period 1961–1998 were estimated using linear least-squares regression applied to the seasonal occurrence of days with a specific circulation type, and to the seasonal means of each climatic variable. The common t-test was performed to evaluate the statistical significance of trends.

For the detection of relationships between changes in atmospheric circulation in the whole Europe and Central Europe and trends in surface climatic variables at Czech stations, two methods were used: first the method of "hypothetical" linear trends, and second the decomposition of climatic changes.

The first method of "hypothetical" trends, used e.g. by Huth (2001) for two Czech stations, is based on the assumption that changes in the occurrence of circulation types are the only factor causing the observed climate trends. All days classified with the same type are expected to bear the same value of a climatic element in a specific month (averaged over the whole period, e.g. all Januaries). Conditional mean values of each climatic element under every circulation type are calculated separately for each of the 12 months, and these time series are then used instead of the observed data to assess the long-term "hypothetical" (circulation-conditioned) seasonal trends. We can then compare these "hypothetical" trends with real changes simply by dividing them by the observed linear trends. This ratio would stay around one if climate trends were caused by circulation changes only. Bárdossy and Caspary (1990) had shown that such a "hypothetical" daily series reconstructed using the Hess–Brezowsky circulation catalogue is a fairly good approximation of the observed monthly mean temperature and precipitation at German stations, with correlation coefficients ranging from 0.7 to 0.9.

The second method, used e.g. by Beck et al. (2007), is a simple decomposition of climatic difference between the first and the second half of the study period ($\Delta\overline{C}$) into two parts – one related to changed climatic properties of individual circulation types (within-type changes), and the other caused by changed frequency of circulation types:

$$\Delta\overline{C} = \sum_{i=1}^{G} \left[\Delta F_i \left(C_i + \Delta C_i \right) / n + F_i \cdot \Delta C_i / n \right]$$

where G is the number of circulation types, Fi is the frequency of circulation type i during the first period, Fi + ΔFi is the frequency of circulation type i during the second period, n is the number of time units during the first period, Ci is the climatic mean of circulation type i during the first period, Ci + ΔCi is the climatic mean of circulation type i during the second period.

The expression [ΔFi(Ci + ΔCi)/n] describes the change in climate between the two periods due to frequency changes of circulation type i, whereas [Fi·ΔCi/n] depicts the degree of climate change assigned to a modified climate linked with circulation type i.

We have applied these two methods of detection of circulation-induced climatic change only to stations and climatic variables whose linear trends are significant at the 95% level in the study period 1961–1998. This is done in order to avoid unrealistic values of results, which might arise from dividing the "hypothetical" trends by very low values of insignificant observed trends.

6.3 Results

6.3.1 "Skill" of circulation classifications to stratify Czech climatic elements into types

In order to rank the circulation classifications according to their ability to stratify daily climatic data into types, we have compared the results of three indices (see Section 2) in January, April, July, and October, averaged over all the 21 stations and eight climatic variables. Generally, the classifications defined on domain 07 (Central Europe) performed better than those defined on the whole Europe (D00). The expected best "skill" in the winter season was only confirmed by explained variance (EV) index in D00, and for certain classifications also by the correlation of reconstructed and observed data in both spatial domains. Normalized within-type standard deviation (WSD) gives the best results mostly in July in both domains, as does the EV index in Central Europe.

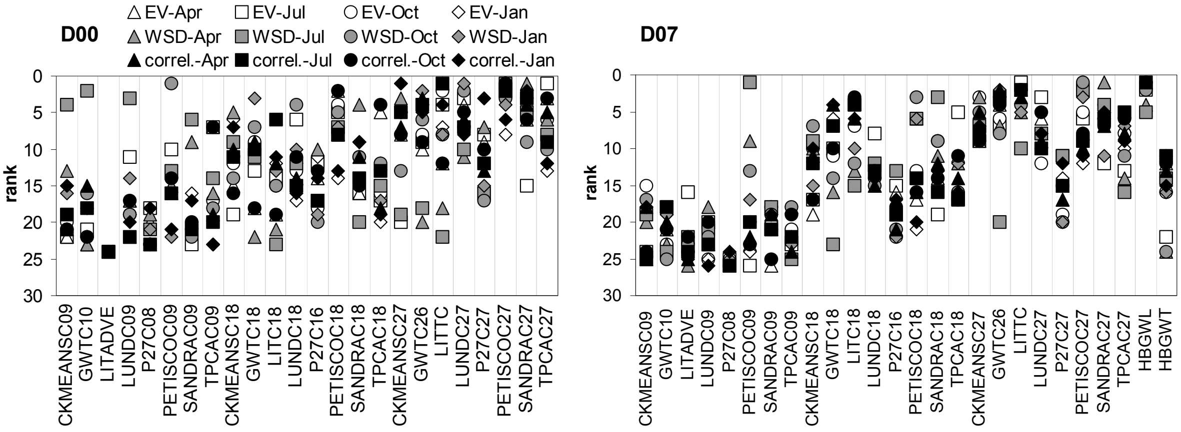


Fig. 6.1. Rank of circulation clasifications according to three studied indices of "skill" to stratify Czech climatic data into circulation types. The four months used are denoted by symbols, the three individual indices by shading. Ranking is based on results averaged over 21 stations and eight variables. Subjective HBGWL and HBGWT catalogues have a slightly different spatial extent than domain 07.

All of the indices are sensitive to the number of circulation types in the sense that more types results in a better stratification into types. The ranking of classifications based on the three indices in January, July, April, and October is shown in Fig. 6.1. Note the large differences of results obtained by the three indices. The top ranks in the whole European domain (D00) usually involved PETISCO, SANDRA, and LUND catalogues with 27 types; the lowest were occupied by LITADVE, P27C08, and GWTC10. In Central Europe the best classifications are LITTC, GWTC26, and PETISCOC27; among the worst are P27C08, LITADVE, and LUNDC09. If we include both versions of the Hess–Brezowsky subjective catalogue into the ranking in D07, then the HBGWL with 29 types usually outperforms all the objective catalogues. The HBGWT with 10 types proved very suitable, too, in certain cases performing better than some of the objective classifications with 18 and even 27 types.

6.3.2 Seasonal trends in the frequency of circulation types

We focus on seasonal trends in the frequency of circulation types in 1961–1998 that are significant at the 95% level. There are several ways to deal with the results: we can simply plot the number (or better the percentage) of these circulation types (not shown); or, knowing that each type has a different overall occurrence, we can calculate the percentage of days occupied by these circulation types (see Fig. 6.2). For classifications defined over the whole Europe this percentage lies between 0% and 27% in individual classifications and seasons. The highest percentage is usually present in winter, while the lowest – mostly zero – in summer. For classifications defined over Central Europe (domain 07) this proportion of days occupied by types with significant trends in frequency is lower in spring but markedly higher in winter compared to D00. The Hess–Brezowsky catalogues have a slightly different behaviour in this sense – the percentage of days occupied by types with significant trends in frequency is quite high in all seasons, in winter reaching 26% and 48% in HBGWL and HBGWT, respectively; in spring, summer, and autumn the values are around 15%, which is still very high compared to the objective catalogues in D07. There are several catalogues (GWT, LUND, PETISCO, and subjective HBGWL + HBGWT) in which the significant trends in frequency affect mainly the prevailing (most frequent) types in winter in Central Europe. In other seasons and in D00 there is no such a preference, neither for lower-than-average nor for higher-than-average total occurrence of the circulation type to have a significant long-term trend in seasonal frequency. The magnitude of significant trends in the frequency of circulation types (both positive and negative) is the greatest in winter in the objective catalogues as well as in the subjective ones.

The specific circulation types that bear significant trends in their seasonal occurrence can be easily identified in catalogues that deal with pre-defined types, i.e. GWT, LITADVE (together with LITC18 and LITTC), and subjective HBGWL and HBGWT. In Central Europe in winter we observe increasing frequency of westerly types at the expense of northerly and northeasterly types, which corresponds with the observed strengthening of the North Atlantic Oscillation in the study period (Hurrell, 1995). In spring and summer, we can see an increase in the occurrence of anticyclonic types and a decline in cyclonic types. In autumn, northerly types gain at the expense of southerly types.

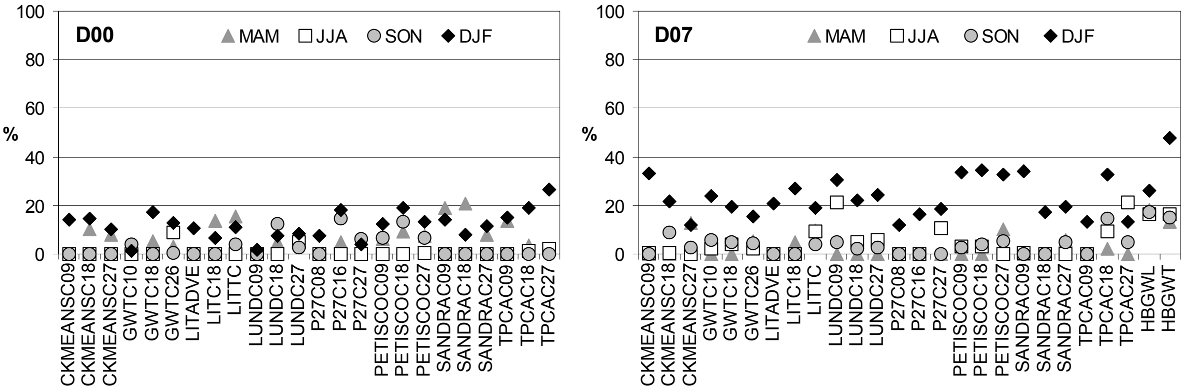


Fig. 6.2. Percentage of days occupied by circulation types with trends in the seasonal occurrence in 1961–1998 significant at the 95% level, in domains 00 – whole Europe and 07 – Central Europe. Subjective HBGWL and HBGWT catalogues have a slightly different spatial extent than domain 07.

6.3.3 Observed climatic trends, 1961–1998

Seasonal trends in surface climatic elements in the Czech Republic in the period 1961–1998 were presented by Huth and Pokorná (2004, 2005). However, further analysis of the data used in these studies revealed some errors in the primary data files. As a result, the seasonal trends for two climatic elements at one station (Cheb – RH, CL) had to be recalculated. Our results are in good accord with those presented by Brázdil and Macková (1998).

Linear climatic trends at 21 stations for the 38-year period that are significant at the 95% confidence level are shown in Fig. 6.3a in physical units corresponding to each variable (i.e. °C for TX, TN, and T; mm/day for PR; ratio for PRO; % for RH; 1/10 for CL; h/day for SUN). Relative humidity (RH) trends were divided by ten and trends in the probability of a day with precipitation (PRO) were multiplied by 10 for a better graphical display within the used scale. In spring, summer, and notably in winter there is a pronounced warming trend, whereas in autumn a cooling trend was found. In all seasons at the majority of stations the trends in daily maximum temperature are greater than those of the daily minima, so that the daily temperature range increases in all seasons but autumn. The strongest trends in daily maximum temperature in winter reach +3 °C in the period 1961–1998, which corresponds to +0.8 °C per decade. Trends in other variables are consistent with temperature changes: relative humidity and cloudiness decrease and sunshine duration increases in spring, summer, and winter; in autumn these trends are again of opposite sign. Precipitation trends in spring, summer, and winter are mostly insignificant (both positive and negative trends occur); in autumn we can see the rising probability of a rainy day, which is in agreement with increased cloudiness.

When we display the climatic changes as a simple difference between the average of the first and the second half of the period 1961–1998, we can see in Fig. 6.4a that the magnitude of changes is (not surprisingly) lower than the linear trends for the whole period. The observed warming in spring and summer is in this case fully comparable to that seen in winter.

6.3.4 Relations between circulation changes and seasonal climatic trends

First we compare the circulation-induced seasonal climatic trends (computed from a “hypothetical” daily series constructed by replacing the daily data by their long-term monthly mean under the specific circulation type) with observed seasonal trends significant at the 95% level. The resulting proportion of climatic trends caused by circulation changes is plotted in Fig. 6.3b for the 24 objective classifications in Central Europe (D07) and in Fig. 6.3c for HBGWL and HBGWT. Each data point of the box-whisker plots represents the result for one station (with a significant trend in the given variable) and one circulation classification. In winter, circulation changes in the objective catalogues in Central Europe explain around 30% of the observed temperature trends. In autumn the ratio is around 20% for temperature, and even lower for the other variables (this can also be seen in winter). The effect of circulation changes on temperature trends is negligible in spring and summer and even negative in some cases in summer. In spring the circulation changes account for about 20% of trends in precipitation, humidity, cloudiness, and sunshine, while in summer the results for these variables are close to zero. This same method applied to classifications defined on the whole Europe (D00, not shown) gives very similar results in most cases. Only in summer the link between circulation and temperature trends is stronger for the whole European classifications while in spring the circulation in Central Europe is more closely linked to changes in PRO, RH, CL, and SUN.

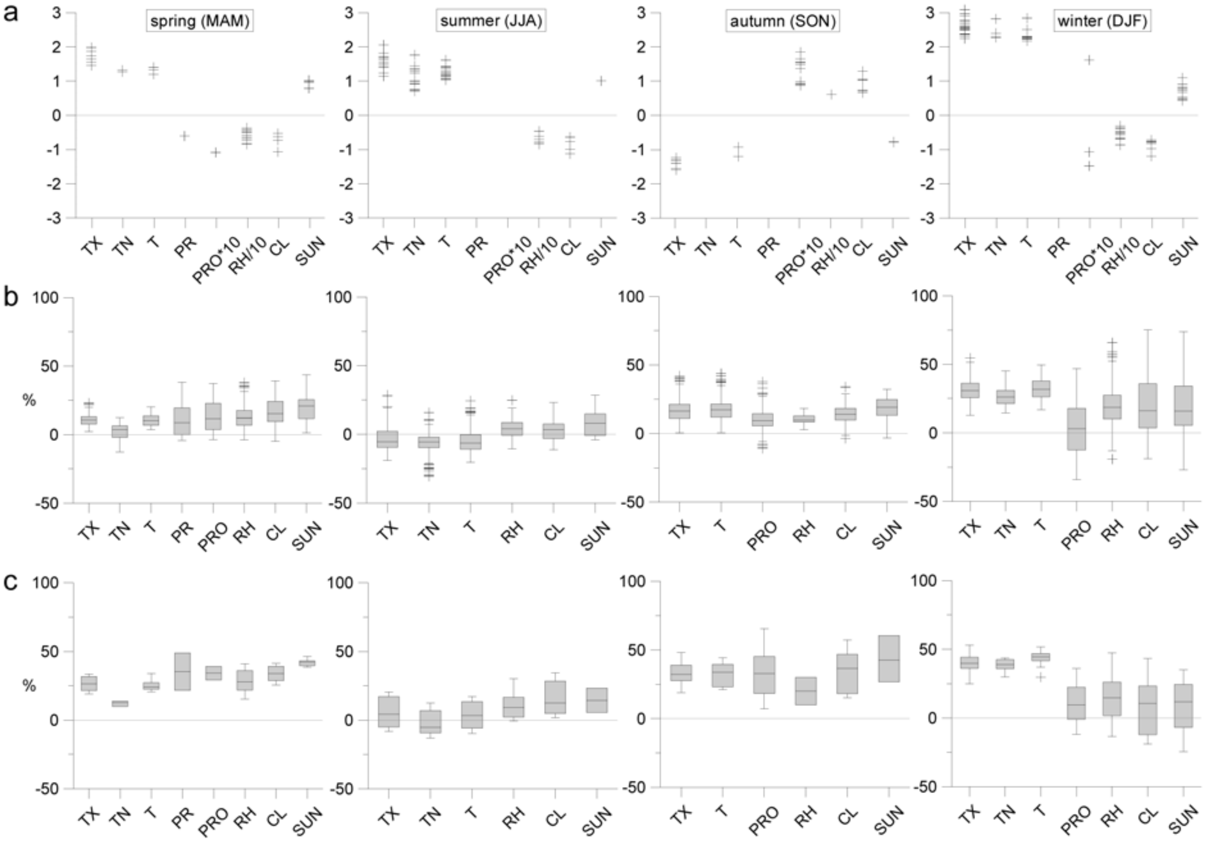


Fig. 6.3. (a) Seasonal linear climatic trends per 38 years (1961–1998) significant at the 95% level. See section 2.2 for the explanation of abbreviations. Values are displayed in units corresponding to each variable; (b) proportion of seasonal trends caused by frequency changes of circulation types. Results from 24 individual objective classifications in Central Europe (domain 07) and individual stations with significant observed trends are shown; (c) as in (b) but for subjective HBGWL and HBGWT circulation catalogues.

Using a different method – decomposition of climatic changes between the first and the second half of the study period into frequency-related part and within-type related part – we arrive at similar results (see Fig. 6.4b and c). In winter the frequency-related (circulation-induced) part of temperature changes is even more pronounced than using the first method, explaining about 50% of the observed changes. On the other hand, most of the climatic changes in spring, summer and autumn can be attributed to changing properties of individual circulation types (within-type changes). In winter and spring higher proportions of circulation-induced changes are generally obtained in Central Europe but in summer and autumn we can see a stronger influence of circulation changes of the whole European classifications compared to Central European ones.

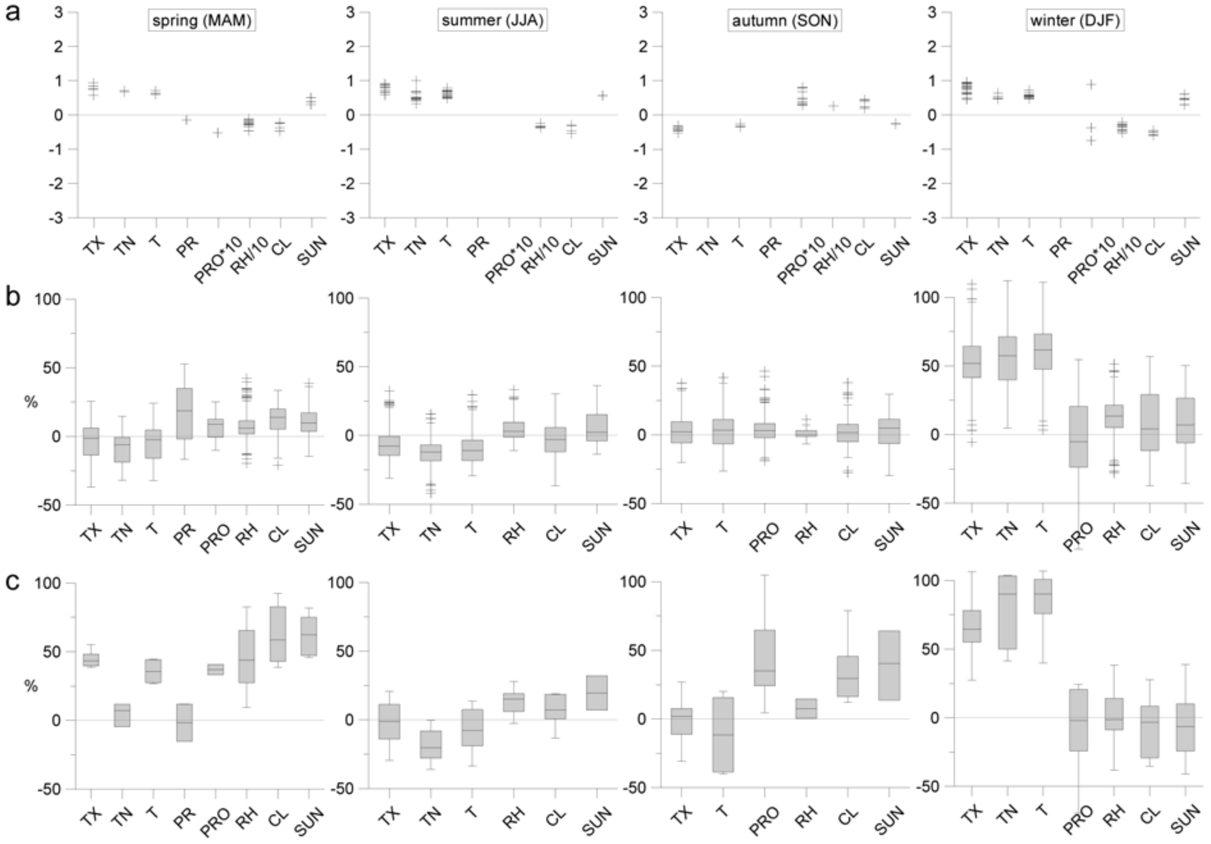


Fig. 6.4. (a) Average seasonal climatic change between the first and the second half of the period 1961–1998. Only the values from stations with significant observed trend of the given climatic element over the whole period are shown. See section 2.2 for the explanation of abbreviations. Values are displayed in units corresponding to each variable; (b) proportion of climatic change between the first and the second half of the period caused by frequency changes of circulation types in 24 objective classifications in Central Europe (domain 07). Only the values from stations with significant observed trend of the given climatic element are shown; (c) as in (b) but for subjective HBGWL and HBGWT circulation catalogues.

The link between circulation and climatic trends is not affected by the number of circulation types in general. It is also quite impossible to rank the circulation classifications according to their connection with climatic trends due to the fact that the results depend on the spatial scale of circulation, the season, the climatic variable, and the method used for the assessment of circulation-induced climatic changes. There is no clear dependence of the results on the geographical location of the stations.

The two subjective catalogues used produce substantially higher proportion of circulation-induced changes than the objective ones (for both methods of assessment) in winter for temperature, and in spring and autumn for nearly all climatic variables (see Figs. 6.3c and 6.4c). These results are consistent with the fact that except for winter, very few circulation types in the objective catalogues yield significant long-term trends in their seasonal occurrence. On the contrary, both versions of the subjective Hess–Brezowsky catalogue bear a substantial proportion of significant trends in the occurrence of circulation types in all seasons.

Another fact worth noting is the very high variability contained in the results. The proportion of circulation-induced climatic changes can range from below zero to above 100% in one season for one climatic variable, e.g. for TX in winter (see Fig. 6.4b)! This variability stems from the variations among the 24 individual classifications and from the differences among the stations. We should therefore be very cautious when interpreting any synoptic-climatological study based on a limited collection of input data (regarding both the circulation and the surface data).

6.4 Conclusion

In this study we have focused on trends in the seasonal occurrence of circulation types in 24 objective and two subjective circulation classifications from the COST733 database. Using these classifications, we have assessed the influence of circulation changes in Central Europe as well as over the whole Europe on significant observed trends of eight surface climatic elements in the Czech Republic in the period 1961–1998.

The major findings include:

- Very low number of circulation types that bear significant seasonal trends in occurrence except for Central Europe in winter, for which we see an enhancement of westerly types. On the other hand, in two versions of the subjective Hess–Brezowsky catalogue, circulation types with significant trends in occurrence are more numerous in all seasons.
- Relatively weak links between circulation changes and observed surface climatic trends, again with the exception of winter when circulation changes in the objective catalogues explain around 30% of long-term linear temperature trends and around 50% of temperature changes that took place between the first and the second half of the study period. Changing internal properties of individual circulation types (i.e. within-type

climatic changes) are responsible for a major part of the observed climatic trends in spring, summer, and autumn; and also in winter for variables other than temperature.

- The subjective catalogues are usually more tightly connected with the observed climatic changes than the objective ones. This is in good accord with a larger proportion of circulation types in the subjective catalogues that show significant trends in seasonal occurrence.
- Very high variability within the results, caused by variations both among the individual classifications and among the stations, suggests that such a comparative approach is highly advisable.

The main feature of the European–North Atlantic circulation since 1960, viz. the wintertime strengthening of the westerlies due to more prevalent positive phase of the NAO (e.g. Hurrell, 1995), is well reflected in the circulation catalogues used, and has been confirmed as a main cause of the positive temperature trend in Central Europe in winter.

The presented results agree with Huth (2001) who found a relationship between circulation changes (described by an objective classification by principal component analysis) and climate trends at two Czech stations in winter in the period 1949–1980 but no link in summer.

Acknowledgements

This paper benefited from networking within the COST733 Action “Harmonisation and Applications of Weather Types Classifications for European Regions” (http://www.cost733.org). The COST program is funded by the European Union. The participation of the Institute of Atmospheric Physics in COST733 is supported by the Ministry of Education, Youth, and Sports of the Czech Republic under project OC115.

6.5 References

Bárdossy, A., Caspary, H.J., 1990. Detection of climate change in Europe by analyzing European atmospheric circulation patterns from 1881 to 1989. Theor. Appl. Climatol. 42, 155–167.

Beck, C., Jacobeit, J., Jones, P.D., 2007. Frequency and within-type variations of large-scale circulation types and their effects on low-frequency climate variability in central Europe since 1780. Int. J. Climatol. 27, 473–491.

Beck, C., Philipp, A., this issue. Evaluation and comparison of circulation type classifications for the European domain. Phys. Chem. Earth.

Beranová, R., Huth, R., 2008. Time variations of the effects of circulation variability modes on European temperature and precipitation in winter. Int. J. Climatol. 28, 139–158.

Brázdil, R., Macková, J., 1998. Řada průměrných ročních teplot vzduchu pro Českou republiku v období 1828–1995 (Series of mean annual air temperatures of the Czech Republic in 1828–1995). Met. Zpr. 51, 17–21 (in Czech).

Buishand, T.A., Brandsma, T., 1997. Comparison of circulation classification schemes for predicting temperature and precipitation in the Netherlands. Int. J. Climatol. 17, 875–889.

Cahynová, M., Huth, R., 2009. Changes of atmospheric circulation in central Europe and their influence on climatic trends in the Czech Republic. Theor. Appl. Climatol. 96, 57–68.

Chen, D., 2000. A monthly circulation climatology for Sweden and its application to a winter temperature case study. Int. J. Climatol. 20, 1067–1076.

Demuzere, M., Trigo, R.M., Vila-Guerau de Arellano, J., van Lipzig, N.P.M., 2009. The impact of weather and atmospheric circulation on O3 and PM10 levels at a rural mid-latitude site. Atmos. Chem. Phys. 9, 2695–2714.

Domonkos, P., 2003. Recent precipitation trends in Hungary in the context of larger scale climatic changes. Nat. Hazards 29, 255–271.

Domonkos, P., Kyselý, J., Piotrowitz, K., Petrovic, 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.

Enke, W., Spekat, A., 1997. Downscaling climate model outputs into local and regional weather elements by classification and regression. Climate Res. 8, 195–207.

Gerstengarbe, F.-W., Werner, P.C., 2005. Katalog der Großwetterlagen Europas (1881–2004) nach Paul Hess und Helmut Brezowsky. PIK Report 100, Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany (in German), 148 pp. Available from: <http://www.pik-potsdam.de/research/publications/pikreports/.files/pr100.pdf>.

Gerstengarbe, F.-W., Werner, P.C., Rüge, U., 1999. Katalog der Großwetterlagen Europas (1881–1998) nach Paul Hess und Helmuth Brezowsky. Potsdam, Offenbach a. M., Germany (in German) Available from: < http://www.pik-potsdam.de/~uwerner/gwl/gwl.pdf >.

Goodess, C.M., Jones, P.D., 2002. Links between circulation and changes in the characteristics of Iberian rainfall. Int. J. Climatol. 22, 1593–1615.

Hanssen-Bauer, I., Førland, E.J., 1998. Long-term trends in precipitation and temperature in the Norwegian Arctic: can they be explained by changes in atmospheric circulation patterns? Climate Res. 10, 143–153.

Hanssen-Bauer, I., Førland, E.J., 2000. Temperature and precipitation variations in Norway 1900–1994 and links to atmospheric circulation. Int. J. Climatol. 20, 1693–1708.

Hess, P., Brezowsky, H., 1952. Katalog der Grosswetterlagen Europas. Ber. Dt. Wetterd. in der US-Zone, Nr. 33.

Hurrell, J.W., 1995. Decadal trends in the North Atlantic Oscillation: Regional temperatures and precipitation. Science 269, 676–679.

Huth, R., 2000. A circulation classification scheme applicable in GCM studies. Theor. Appl. Climatol. 67, 1–18.

Huth, R., 2001. Disaggregating climatic trends by classification of circulation patterns. Int. J. Climatol. 21, 135–153.

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. In: Gimeno, L., Garcia Herrera, R., Trigo, R.M. (Eds.). Trends and Directions in Climate Research, Ann. NY Acad. Sci. 1146, 105–152, Wiley-Blackwell.

Huth, R., Pokorná, L., 2004. Parametric versus non-parametric estimates of climatic trends. Theor. Appl. Climatol. 77, 107–112.

Huth, R., Pokorná, L., 2005. Simultaneous analysis of climatic trends in multiple variables: an example of application of multivariate statistical methods. Int. J. Climatol. 25, 469–484.

Jacobeit, J., Jönsson, P., Bärring, L., Beck, C., Ekström, M., 2001. Zonal indices for Europe 1780–1995 and running correlations with temperature. Climatic Change 48, 219–241.

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

Keevallik, S., Russak, V., 2001. Changes in the amount of low clouds in Estonia (1955–1995). Int. J. Climatol. 21, 389–397.

Kostopoulou, E., Jones, P.D., 2007. Comprehensive analysis of the climate variability in the eastern Mediterranean. Part II: relationships between atmospheric circulation patterns and surface climatic elements. Int. J. Climatol. 27, 1351–1371.

Kyselý, J., 2007. Implications of enhanced persistence of atmospheric circulation for the occurrence and severity of temperature extremes. Int. J. Climatol. 27, 689–695.

Kyselý, J., Huth, R., 2006. Changes in atmospheric circulation over Europe detected by bjective and subjective methods. Theor. Appl. Climatol. 85, 19–36.

Lityński, J., 1969. Liczbowa klasyfikacja typów cyrkulacji i typów pogody dla Polski (Numerical classification of circulation types and weather types of Poland). Prace PIHM 97, 3–14, Warszawa, Poland (in Polish).

Lund, I.A., 1963. Map-pattern classification by statistical methods. J. Appl. Meteorol. 2, 56–65.

Petisco, E., Martín, J.M., 1995. Caracterización de la Circulación General Atmosférica en la Península Ibérica y Baleares (Characterization of the atmospheric general circulation in the Iberian Peninsula and Balearic Islands). Tech. Note 5, Service of Analysis and Research of Climate, Instituto Nacional de Meteorología, Madrid (in Spanish).

Philipp A., Bartholy, J., Beck, C., Erpicum, M., Esteban, P., Fettweis, X., Huth, R., James, P.M., Jourdain, S., Kreienkamp, F., Krennert, T., Lykoudis, S., Michaelides, S., Pianko, K., Post, P., Rassilla Álvarez, D., Schiemann, R., Spekat, A., Tymvios, F.S., this issue. COST733CAT – a database of weather and circulation type classifications. Phys. Chem. Earth.

Philipp, A., Della-Marta, P.M., Jacobeit, J., Fereday, D.R., Jones, P.D., Moberg, A., Wanner, H., 2007. Long-term variability of daily North Atlantic-European pressure patterns since 1850 classified by simulated annealing clustering. J. Climate 20, 4065–4095.

Pokorná, L., Beranová, R., Huth, R., 2007. Vztahy mezi cirkulačními mody a klimatickými prvky v České republice a jejich časová proměnlivost (The relationships between circulation modes and climatic elements in the Czech Republic and their time variations). Met. Zpr. 60, 65–76 (in Czech).

Sepp, M., Jaagus, J., 2002. Frequency of circulation patterns and air temperature variations in Europe. Boreal Environ. Res. 7, 273–279.

Slonosky, V.C., Jones, P.D., Davies, T.D., 2000. Variability of the surface atmospheric circulation over Europe, 1774–1995. Int. J. Climatol. 20, 1875–1897.

Uppala, S.M., Kållberg, P.W., Simmons, A.J., Andrae, U., Da Costa Bechtold, V., Fiorino, M., Gibson, J.K., Haseler, J., Hernandez, A., Kelly, G.A., Li, X., Onogi, K., Saarinen, S., Sokka, N., Allan, R.P., Andersson, E., Arpe, K., Balmaseda, M.A., Beljaars, A.C.M., Van De Berg, L., Bidlot, J., Bormann, N., Caires, S., Chevallier, F., Dethof, A., Dragosavac, M., Fisher, M., Fuentes, M., Hagemann, S., Hólm, E., Hoskins, B.J., Isaksen, L., Janssen, P.A.E.M., Jenne, R., McNally, A.P., Mahfouf, J.-F., Morcrette, J.-J., Rayner, N.A., Saunders, R.W., Simon, P., Sterl, A., Trenberth, K.E., Untch, A., Vasiljevic, D., Viterbo, P., Woollen, J., 2005. The ERA-40 re-analysis. Q. J. R. Meteorol. Soc. 131, 2961–3211.

Werner, P.C., Gerstengarbe, F.-W., Fraedrich, K., Oesterle, H., 2000. Recent climate change in the North Atlantic/European sector. Int. J. Climatol. 20, 463–471.

7. Seasonal trends in the frequency of atmospheric circulation types in European regions (1961–2000)

7.1 Data and methods

For the analysis of recent trends in the frequency of atmospheric circulation types over Europe (this Section), links between circulation classifications and daily climatic variability (Section 8), and the relation of circulation changes with climatic trends at European stations (Section 10), we use a subset of catalogues of daily atmospheric circulation types that have recently been made available within the COST733 Action in version 1.2. For a thorough description of COST733 circulation classifications see Philipp et al. (2010). The "objective", i.e. computer-assisted, methods of classification were developed using the sea level pressure data from the ECMWF ERA-40 dataset (Uppala et al. 2005). The classification procedures were applied on the scale of entire Europe (domain 00) and eleven European sub-domains, typically covering the area of a few countries (see Fig. 7.1). The catalogues used are listed in Table 7.1, together with references to the papers and reports where they are defined or described in detail, a brief description of the method used for classification, and the number of types classified. Although the catalogues cover the period September 1957 through August 2002, we will focus on a shorter period 1961–2000 for which we have the daily station climatic data that we use in the following sections.

The selected catalogues cover a wide range of classification methods, which include (i) various kinds of cluster analysis, from k-means with different procedures to select the initial seed-points (CKMEANS) to the simulated annealing of daily patterns (SANDRA); (ii) correlation-based methods (LUND, PETISCO); (iii) principal component analysis in a T-mode (TPCA); (iv) procedures assigning individual patterns to the types according to their similarity with simple flow patterns (GWT) and S-mode principal component loadings (P27); (v) methods based on threshold values of circulation variables, i.e. large-scale flow direction (LITADVE, LITC18, LITTC).

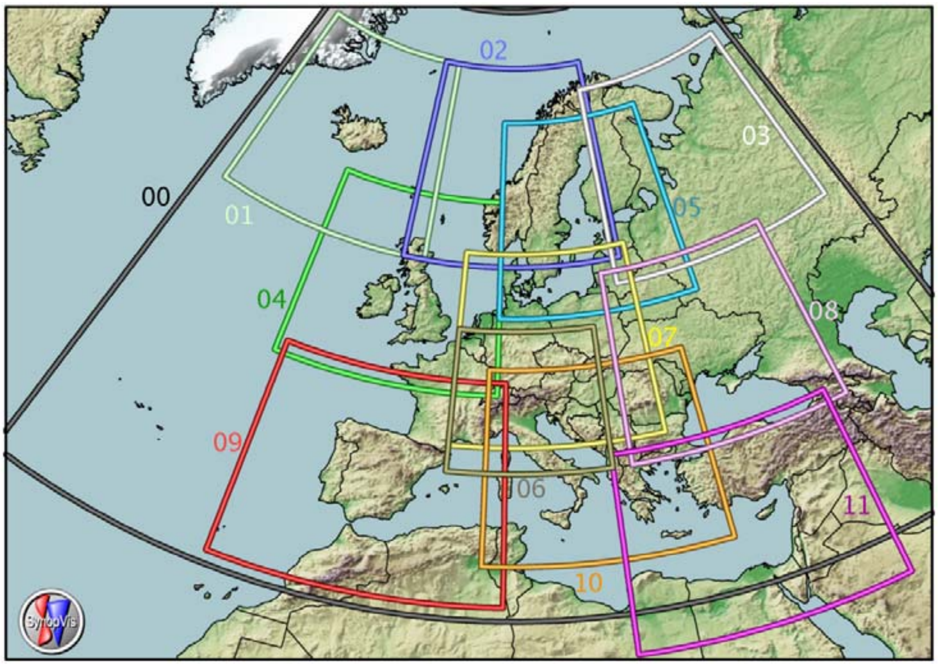


Fig. 7.1. Spatial domains used for the classification of circulation types. Source: http://www.cost733.org.

Table 7.1. Description of selected atmospheric circulation classifications from the COST733 collection for Europe and 11 European domains. In references, we prefer open scientific literature to internal reports and conference proceedings wherever possible, thereby sometimes neglecting the original data source.

Catalogue	Classification method	Reference	Number of circulation types
CKMEANS	k-means clustering	Enke and Spekat (1997)	9, 18, 27
GWT	circulation prototypes	Beck et al. (2007)	10, 18, 26
LITADVE, LITC18, LITTC	threshold-based	Lityński (1969)	9, 18, 27
LUND	correlation-based	Lund (1963)	9, 18, 27
P27	subdivision according to S-mode PCA-scores	Buishand and Brandsma (1997)	8, 18, 27
PETISCO	correlation-based	Petisco and Martín (1995)	9, 18, 27
SANDRA	simulated annealing clustering	Philipp et al. (2007)	9, 18, 27
TPCA	T-mode PCA	Huth (2000)	9, 18, 27

All the analyses are based upon commonly used 3-month seasons, where spring comprises March, April, and May (MAM), summer JJA, autumn SON, and winter DJF (while December belongs to the preceding year).

Observed seasonal circulation trends in the period 1961–2000 were estimated using linear least-squares regression applied to the seasonal occurrence of days with a specific circulation type. The common *t*-test was performed to evaluate the statistical significance of trends.

7.2 Seasonality of occurrence of circulation types

The selected circulation catalogues bear very different features, depending on the method used for classification. One of the ways to describe the differences is the annual cycle of relative frequency of individual circulation types. The 12 spatial domains exhibit certain features in the annual cycle common to almost all the classifications: there is virtually no intraseasonal variability in the occurrence of types in D01–D08, whereas in the Mediterranean (D09–D11) and in the whole Europe (D00) the seasonality is clearly pronounced – usually a small number of types occupies most of the days in summer.

An example of long-term average monthly relative frequency of circulation types is displayed in Fig. 7.2 for classifications with 9 types (or close number) in domain 00 (whole Europe), and in Fig. 7.3 for domain 07 (Central Europe). In certain catalogues (CKMEANS, SANDRA), a small subset of types occupies the summer season, while in winter the types are more or less evenly distributed. In PETISCO, several types are dominating throughout the whole year. An extreme case is the Lityński classification (LITADVE, LITC18, and LITTC), which distributes the days into circulation types almost strictly evenly in all months. It is because it distributes the daily values of three used circulation indices (zonal, meridional, and cyclonic) into equally probable classes. Furthermore, this approach is applied to each month in the year separately, thus producing separate classifications for January, February, etc. This is a very specific approach that can hardly account for the natural occurrence of types based on the direction of flow and cyclonicity. The thresholds of the circulation indices that define the types are therefore forced to shift in the direction of the most frequent type.

We propose a new measure – "weighted seasonality index" – for the quantification of average annual cycle in the frequency of circulation types. The index is constructed as follows: we compute the long-term average relative frequency of each CT separately for each month. Then for each CT we calculate the difference (range) between the maximum and the minimum monthly relative frequency, and weigh it by multiplying by the CT's overall relative frequency. The sum over all CTs then describes the overall seasonality with respect to their different relative frequencies. This weighted seasonality index can reach values from 0 to 1, higher values meaning more pronounced annual cycle in the frequency of CTs. As we can see in Fig. 7.4, the weighted seasonality index of the 24 used classifications in the 12 domain ranges from virtually zero to 0.87.

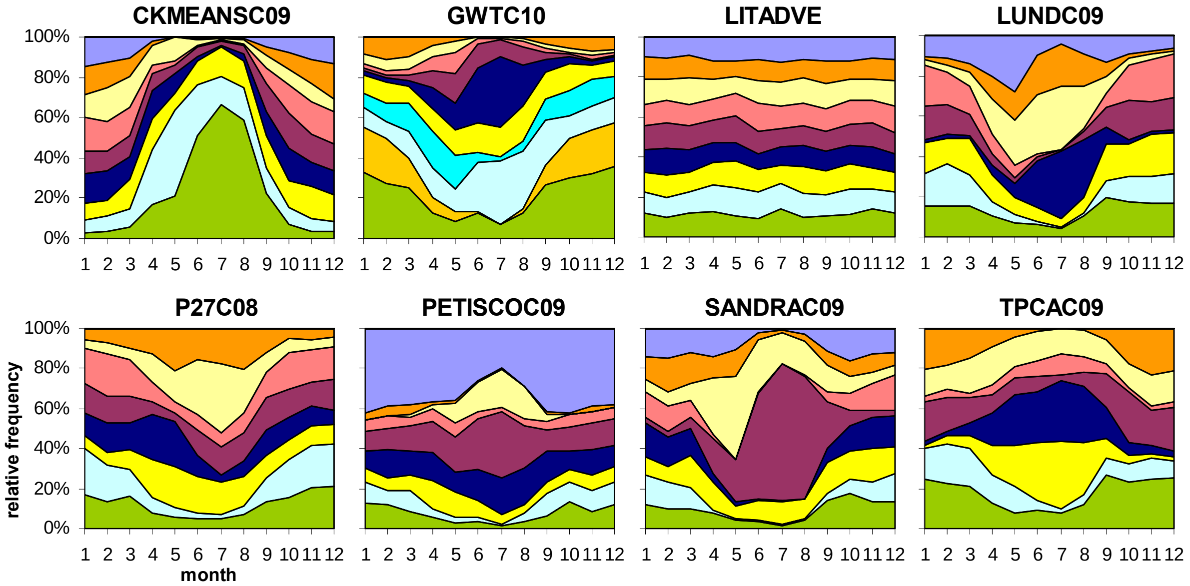


Fig. 7.2. Monthly relative frequency of circulation types in classifications with 9 types in 1961–2000 in domain 00 (whole Europe).

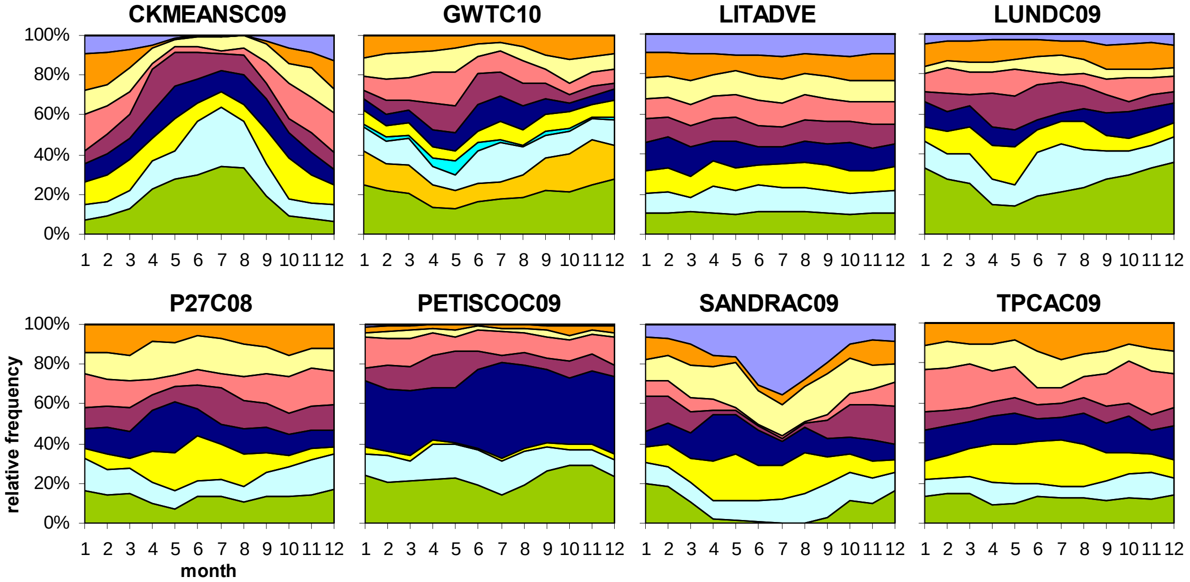


Fig. 7.3. Monthly relative frequency of circulation types in classifications with 9 types in 1961–2000 in domain 07 (Central Europe).

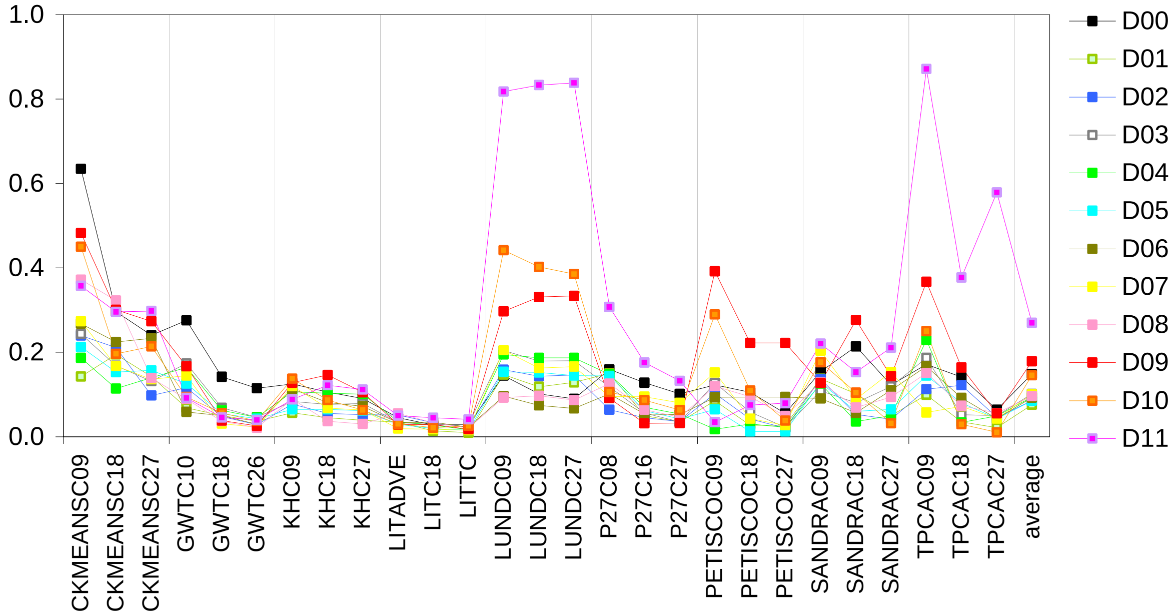


Fig. 7.4. Weighted seasonality index of circulation classifications. See text for explanation.

7.3 Seasonal trends in the frequency of circulation types

Here we assess the long-term trends in the frequency of individual circulation types. This has been done for every type in the 24 selected classifications in 12 spatial domains on a seasonal basis – more than 20,000 individual trends were analysed. We have then selected the types that bear a seasonal trend in the frequency significant at the 95% confidence level in 1961–2000. Because each type has a different overall frequency, we focus on a proportion of days classified with these types rather than on the mere number (or percentage) of such types. The percentage of days that occurred in circulation types with a significant trend in frequency is shown in Fig. 7.5 for every spatial domain, season, and classification. In all the regions, winter clearly dominates in terms of significant trends. A relatively lower number of days in types with a significant trend in winter frequency is found in Northern Europe (D01–03). In the Alpine region (D06) and in the eastern Mediterranean (D11), a substantial proportion of days occurs within types that bear notable trends in frequency also in summer. In D11 this is caused by a pronounced seasonality – a limited number of types (sometimes just 1 or 2) occupies a majority of days in summer.

We describe seasonal trends in the frequency of specific circulation types in the GWTC10 classification as an example, as it clearly defines 10 types according to the direction of flow (8 main directions) and cyclonicity (cyclonic and anticyclonic type). As mentioned earlier, the largest number of types with frequency trends significant at the 95% level occurs in winter, and these trends are also of the highest magnitude (quantified in terms of seasonal increase/decrease in days per 40 years in Table 7.2). Winter frequency of the westerly type increases in the whole Europe (D00) and in the central latitudinal belt from the British Isles all the way east to Ukraine (D04, D06–08). The highest magnitude of trend (+20 westerly days) is present in Central Europe (D07). Over the British Isles, the southwesterly type becomes more frequent at the same rate as the westerly type (+13 days). Decreasing trends are seen in the occurrence of the easterly type in Western and Central Europe (D04, D06–07), and in the southerly type over the British Isles (D04), Central and Eastern Europe (D07–08), and central and eastern Mediterranean (D10–11). Another notable trend in D11 in winter is the increase of the northeasterly type (+14 days). Cyclonic days become more common in Iceland (D01), whereas their number decreases in the whole Europe (D00), Ukraine (D08), and central Mediterranean (D10). The anticyclonic type slightly gains weight in D10 and the Alps (D06).

In spring, summer, and autumn there are virtually no "systematic" changes in the frequency of circulation types apart from the spring decrease of the easterly type in whole Europe (D00), Iceland (D01), and Northeastern Europe (D03).

An example of winter timeseries of relative frequency of circulation types is shown in Fig. 7.6 for the GWTC10 catalogue in Central Europe (D07) in the period 1961–2000. The increase in the number of days with westerly circulation is forced by more prevalent positive phase of the North Atlantic Oscillation (e.g. Hurrell 1995). At the same time the number of days with easterly flow significantly decreases.

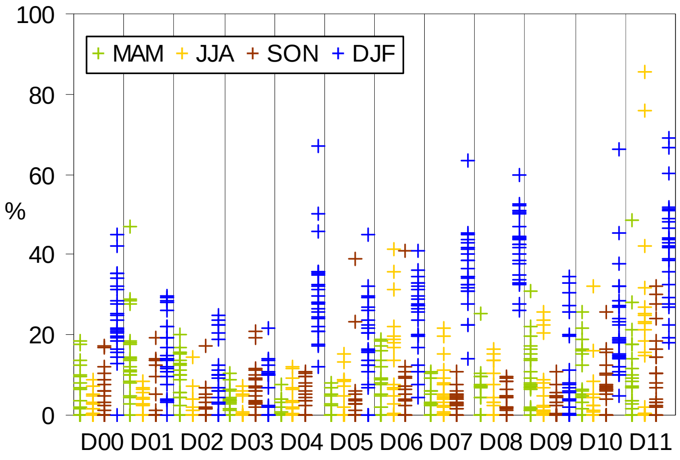


Fig. 7.5. Percentage of days classified with circulation types with trends in the seasonal frequency significant at the 95% level in 1961–2000. Each cross represents one classification.

Table 7.2. Magnitude of trends in the seasonal frequency of circulation types in classification GWTC10 (days per season over the whole period 1961–2000) for the trends significant at the 95% level. C – purely cyclonic type, A – purely anticyclonic, other abbreviations refer to directions of flow.

domain		W	SW	NW	C	A	N	NE	E	SE	S		W	SW	NW	C	A	N	NE	E	SE	S
00	spring (MAM)								-5			autumn (SON)		9								
01									-8													
02		6			-3																	
03									-5										3	4		
04																						
05																						
06																						
07																		3				
08																3						
09								-8		5	3											
10																						
11																						
00	summer (JJA)											winter (DJF)	16			-8			-3			
01							-4									6						
02														7								
03																						
04													13	13						-7		-7
05																						
06						2							9				3			-8		
07					-2								20							-6		-7
08													16			-3					-10	-8
09							-7															
10					-2										5	-4	2					-6
11																			14			-7

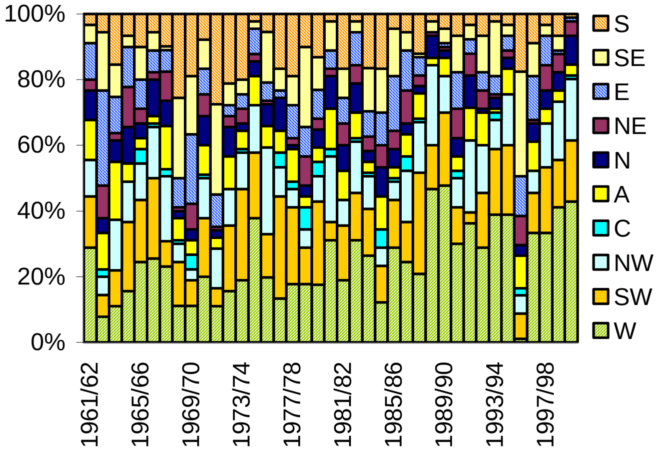


Fig. 7.6. Changes in winter relative frequency of circulation types in classification GWTC10 in Central Europe (D07). Upward (downward) stripes denote types with positive (negative) linear trend significant at the 95% level.

8. “Skill” of circulation classifications to reproduce daily climatic variability

The “skill” to stratify daily climatic data into types is an important feature that might reveal the usability of individual classifications for specific applications. Even though the “skill” does not necesarilly describe the links between long-term trends of circulation and climate, we have employed it in our study as a measure for the ranking of the used classifications. There are various indices for the description of “skill” of classifications; for a detailed list see Beck and Philipp (2010). The “skill” indices generally compare the within-type variability of the given climatic (or environmental) variable to its overall variability. The ultimate goal of circulation classifications is to minimize within-type variability, while maximazing inter-type separability.

8.1 Circulation and climatic data

The used circulation classifications are decribed in Section 7.1. We have selected eight classification methods from the COST733 database. Each of the methods was applied with 9, 18, and 27 types, resulting in a total number of 24 selected classifications. All classifications were computed over whole Europe and eleven European regions (see Fig. 7.1), but due to the lack of usable station data in domain 03 we limit the analysis to 10 regional domains.

We have used daily data of maximum air temperature at 2 metres (TX, in ºC), minimum air temperature at 2 metres (TN, in ºC), and precipitation amount (RR, in mm/day) at 29 stations from the European Climate Assessment & Dataset (ECA&D, Klein Tank et al. 2002, Klok and Klein Tank 2009) in the period 1961–2000 for the analysis of “skill” of classifications (this Section), and for the assessment of climatic trends (Section 9) and their dependence on circulation changes (Section 10). The data were retrieved in November 2008. At most of the stations, all the three variables are available. However, at several stations, RR data were missing. In such cases we have chosen a relatively close station with available complementary data. The location of stations is shown in Fig. 8.1 and Table 8.1.

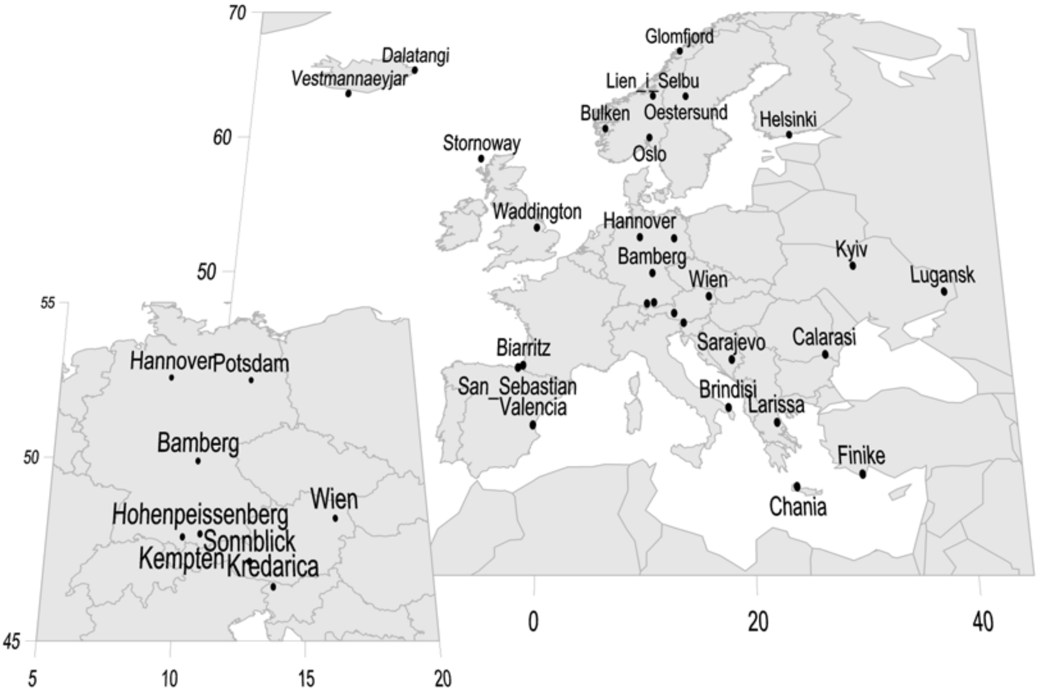


Fig. 8.1. Location of stations from the ECA&D inventory.

Table 8.1. List of stations, and spatial domains of atmospheric circulation representing them.

Station	Domain	Country	Latitude	Longitude	Altitude (m a. s. l.)	Variable
Dalatangi	01	Iceland	65°16’N	13°34’W	9	TX, TN, RR
Vestmannaeyjar	01	Iceland	63°23’N	20°16’W	118	TX, TN, RR
Bulken	02	Norway	60°38’N	6°13’E	323	RR
Glomfjord	02	Norway	66°49’N	13°58’E	39	TX, TN
Oslo	02	Norway	59°57’N	10°43’E	94	TX, TN
Lien i Selbu	02	Norway	63°12’N	11°06’E	255	RR
Oestersund	02, 05	Sweden	63°10’N	14°28’E	376	TX, TN, RR
Stornoway	04	Great Britain	58°19’N	6°19’W	9	TX, TN, RR
Waddington	04	Great Britain	53°10’N	0°31’W	68	TX, TN, RR
Helsinki	05	Finnland	60°10’N	24°57’E	4	TX, TN, RR
Hohenpeissenberg	06, 07	Germany	47°47’N	11°01’E	977	TX, TN, RR
Kempten	06, 07	Germany	47°43’N	10°19’E	705	TX, TN, RR
Kredarica	06, 07	Slovenia	46°22’N	13°51’E	2514	TX, TN, RR
Sonnblick	06, 07	Austria	47°02’N	12°57’E	3106	TX, TN, RR
Wien	06, 07	Austria	48°13’N	16°21’E	198	TX, TN, RR
Bamberg	07	Germany	49°52’N	10°52’E	282	TX, TN, RR
Hannover	07	Germany	52°28’N	9°40’E	56	TX, TN, RR
Potsdam	07	Germany	52°22’N	13°04’E	81	TX, TN, RR
Calarasi	08	Romania	44°12’N	27°19’E	19	TX, TN, RR
Kyiv	08	Ukraine	50°23’N	30°31’E	166	TX, TN, RR
Lugansk	08	Ukraine	48°34’N	39°15’E	59	TX, TN, RR
Biarritz	09	France	43°27’N	1°31’W	70	TX, TN
San Sebastian	09	Spain	43°18’N	2°00’W	259	RR
Valencia	09	Spain	39°28’N	0°21’W	11	TX, TN, RR
Brindisi	10	Italy	40°37’N	17°55’E	10	TX, TN, RR
Larissa	10	Greece	39°38’N	22°27’E	73	TX, TN, RR
Sarajevo	10	Bosnia and Herzegovina	43°51’N	18°22’E	577	TX, TN, RR
Finike	11	Turkey	36°17’N	30°08’E	2	TX, TN
Chania	11	Greece	35°30’N	24°01’E	151	TX, TN, RR

8.2 Methods

For the assessment of “skill” of circulation classifications to stratify daily climatic data into circulation types we have applied the explained variance index (EV index, see Beck and Philipp 2010):

$$EV = 1 - \frac{ss_i}{ss_t}$$

where ss_i = sum of squares within types, and ss_t = total sum of squares.

The EV index can reach values from 0 to 1, zero means no skill to stratify climatic data into types, whereas 1 means that there is no within-type variability (the data within every circulation type are uniform). The value of EV index depends on the number of classes (i.e. circulation types) – the higher the number of types, the better the division of data into these types. We have calculated the EV index for each station and climatic variable in the four seasons, separately with classifications describing atmospheric circulation in the whole European domain (D00) and in the small domains in order to study the effect of spatial scale of circulation on the “skill” of the used classifications. Several stations were tested using circulation classifications from two small domains – this regards mainly the Alpine region that lies in the Central European domain (D07) as well as in a smaller Alpine domain (D06). To ease the interpretation of such manifold results we have then averaged the results from all stations under each classification to compare the classifications by their “skill”. We have also averaged the results of all classifications at each station to gain a spatial picture of the “skill” of all the classifications combined.

8.3 Results

We have used the explained variance (EV) index to compare the “skill” of 24 individual classifications to stratify (separate) daily station temperature and precipitation data into circulation types. The EV index reaches the highest values for TX in winter for classifications computed over the small domains (up to 0.5). The link between circulation classifications and local climate variability is usually tighter for atmospheric circulation in the small domains than in whole Europe (D00). However, for TN at most of the stations in spring, and for TX in Scandinavia and Ukraine in spring and autumn, the classifications have a better “skill” when they cover D00.

We have ranked the classifications according to the EV index averaged over all the stations, separately for each season, spatial extent of circulation (i.e. D00 vs. the small domains), and climatic variable. Then we calculated an average rank for each classification and each variable from the 8 values of rank (4 seasons x 2 spatial domains of circulation). In the case of TX, this average rank does not vary much between the individual classifications (there is no clear “winner”), and the catalogues with 27 types do not always score among the best as would be expected as an inherent feature of the EV index. For TN the EV index generally has lower values than for TX, but the ranking of classifications is more pronounced – the best ones are SANDRAC27, CKMEANSC27, and PETISCOC27; the worst ones P27C08, LITADVE, and GWTC10. Precipitation is, not surprisingly, the variable that is least connected with the type of circulation because its substantial proportion may originate from local convective storms that are not represented by the circulation types. The best “predictors” of daily RR are SANDRAC27, LITTC, and GWTC26; the bottom line of the ranking is occupied by LITADVE in all the cases. Values of EV index for TX, TN, and RR are shown in Fig. 8.2. Panel (a) displays the average over all stations for each classification, while on panel (b) the average over the 24 classifications at individual stations is shown. The stations are ranked according to the overall average of EV index from the best to the worst; the classifications are not ranked. The ranking of stations is quite different for the three variables used; nevertheless the top ranks are usually occupied by the Icelandic, Norwegian, and Alpine stations. In the Alpine region, it is the smallest domain D06 that is most tightly connected to station climatic variability when compared to D07 (Central Europe) and D00. Eastern Mediterranean stations Finike and Chania are the only sites where circulation classifications do not explain the largest proportion of temperature variability in winter but in autumn (for TN this is true at both stations, while for TX only in Finike).

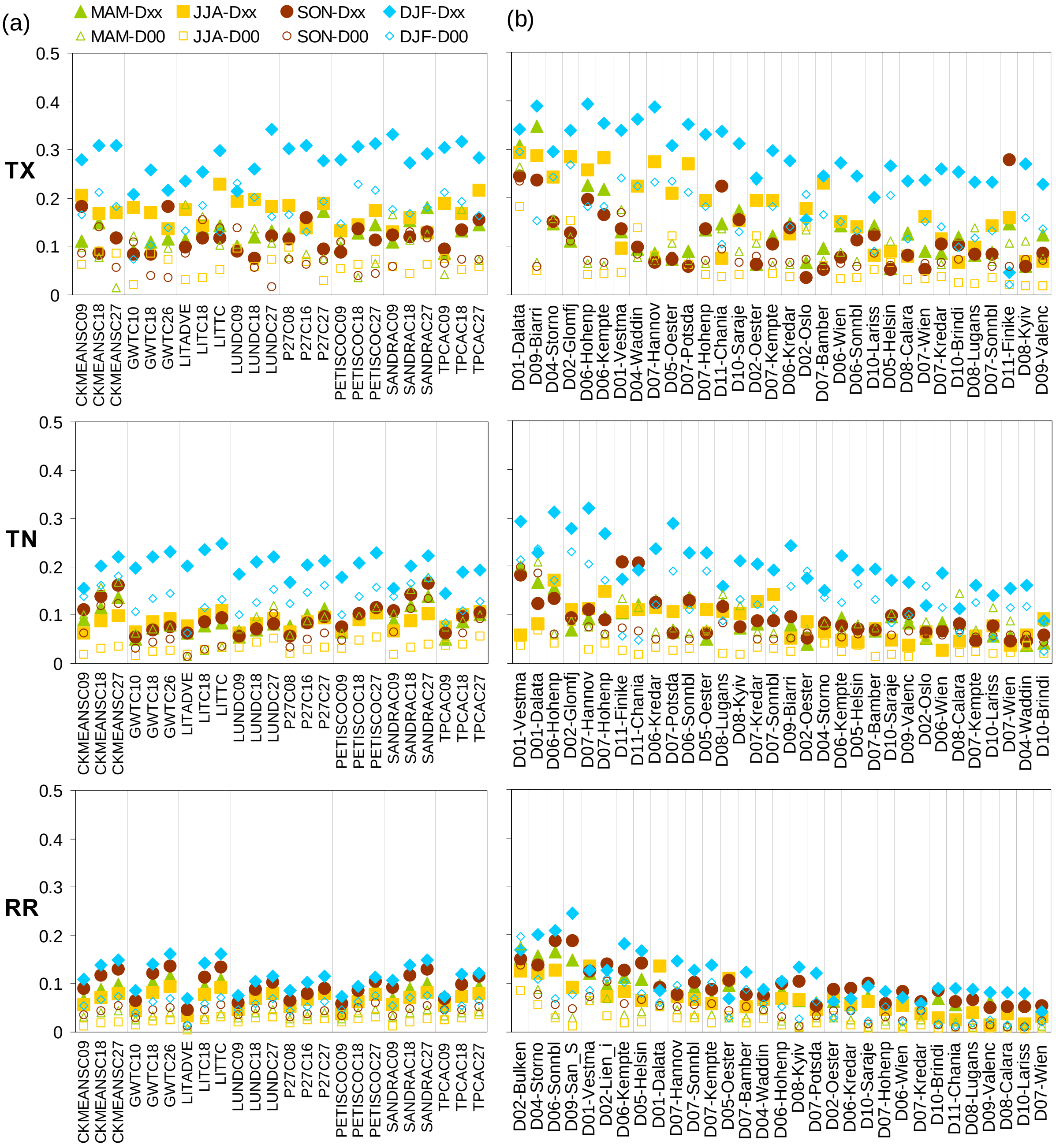


Fig. 8.2. Seasonal explained variance (EV) index of daily maximum temperature (TX), minimum temperature (TN), and precipitation (RR) in 1961–2000. Averages of individual stations (a) and classifications (b). Results obtained with classifications from the small domains (Dxx) and the entire European domain (D00) are shown. Stations are ordered from the best average result to the worst, from left to right.

9. Seasonal climatic variability and trends at European stations (1961–2000)

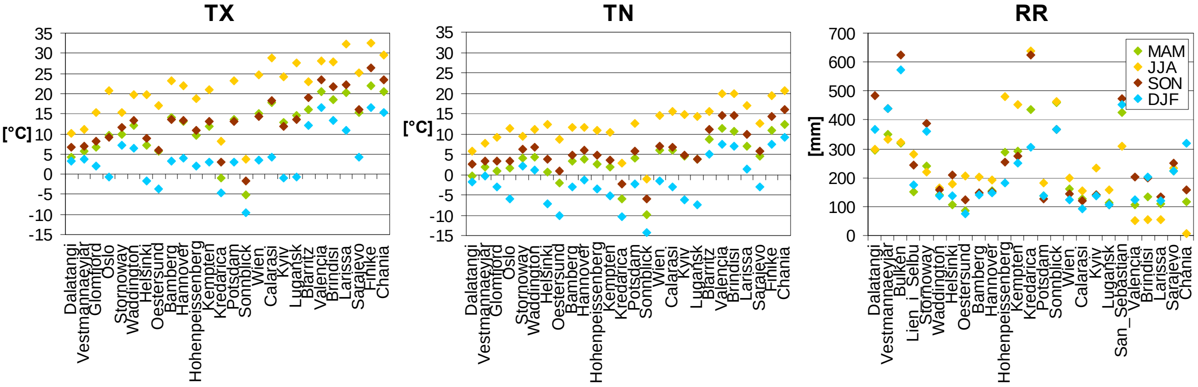
For the study of seasonal climatic trends and variability we use 29 stations from the ECA&D database (Klein Tank et al. 2002, Klok and Klein Tank 2009) that are listed in Section 8.1. Daily data of maximum and minimum air temperature (TX and TN, respectively) and precipitation amount (RR) were used. Although we have only used a limited number of stations covering more or less whole Europe, we can still notice some clear regional patterns in the trends and variability of temperature and precipitation in the period 1961–2000.

Long-term seasonal mean of TX, TN, and RR is presented in Fig. 9.1 (a). Figure 9.1 (b) shows the interannual variability of seasonal averages, described by standard deviation. The highest interannual variability of temperature is observed in winter in Scandinavia, Central, and Eastern Europe. Iceland and the Mediterranean bear little interannual temperature variability in all seasons. Precipitation variability is the greatest in Norway (most probably caused by orographic effects in Bulken), in Iceland, on the Alpine summit Kredarica, and also in San Sebastian.

Seasonal linear trends of TX, TN, and RR obtained by least-squares regression are shown in Fig. 9.2 (a) as a magnitude of trend per 40 years, and in (b) standardized by dividing the trend magnitude by standard deviation of seasonal averages. The study period was one with clearly pronounced warming trends in winter, spring, and summer at most of the stations. The greatest warming exceeded 3°C/40 years for both TX and TN in winter; however, due to high interannual variability of mean winter temperature the largest standardized trends are present in summer (around 2 sigma for TN, and slightly less for TX). At the Icelandic stations, very slight warming or even some insignificant cooling trends took place in winter. In autumn the trends of TX are insignificant at the 95% level with the exception of Kyiv (negative trend) and Valencia (positive trend). Generally, autumn maximum temperatures are slightly rising in Northern Europe but falling in Central and Eastern Europe. On the other hand, TN exhibits a slight warming in autumn in Central Europe, thus lowering the daily temperature range. Precipitation trends are only significant (positive) at a few northern stations, and Stornoway and Brindisi (with different seasons being involved), and negative in Kyiv in winter and Chania in summer.

Apart from linear climatic trends, we have used a simple seasonal climatic difference between the average of the 1st and the 2nd half of the study period (i.e. 1961–1980 vs. 1981–2000) for the attribution of climatic changes. The results (not shown) resemble those of the seasonal linear trends, but are of a smaller magnitude because the averages of two subsequent 20-year periods are compared. The most pronounced changes in TX and TN hardly reach 1.5°C in winter, whereas the largest positive change of RR is 225 mm in Bulken (also in winter).

(a) long-term seasonal mean



(b) standard deviation of seasonal means

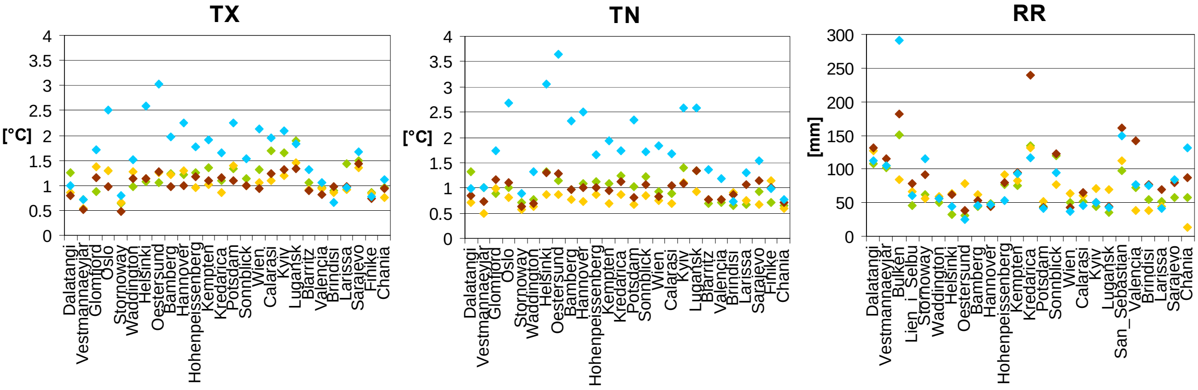
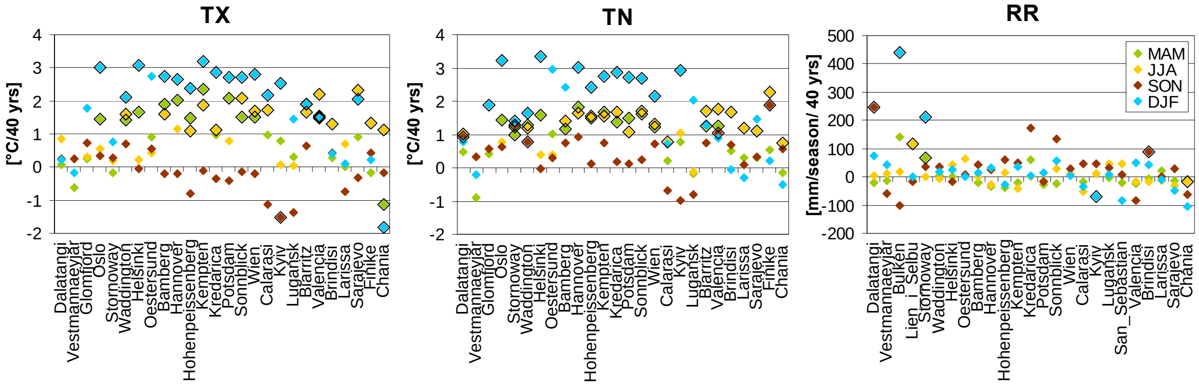


Fig. 9.1. (a) Long-term seasonal mean of TX, TN, and RR in 1961–2000, (b) interannual variability of seasonal means (described by standard deviation).

(a) trend per 40 years (1961-2000)



(b) standardized trend per 40 years (1961-2000)

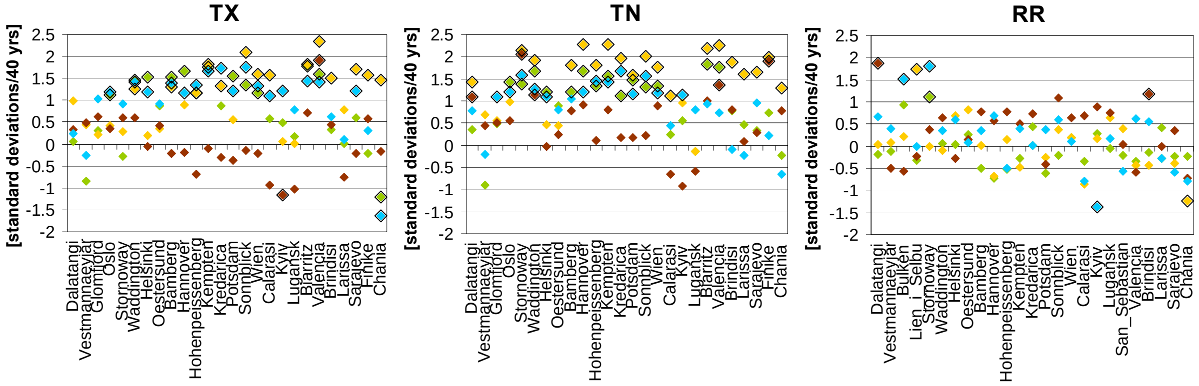


Fig. 9.2. Seasonal trends of TX, TN, and RR in 1961–2000. (a) Magnitude of trend per 40 years, (b) standardized trend (trend divided by long-term standard deviation). Trends significant at the 95% level are highlighted by black diamonds.

10. Links between circulation and climatic trends in Europe

10.1 Circulation and climatic data

To study the links between trends in the seasonal frequency of circulation types and observed local climatic trends, we have used 24 circulation classifications from the COST733 database, described in detail in Section 7.1. These were obtained by applying 8 classification methods to sea level pressure fields in Europe and 11 European regions (of which we use 10) with pre-defined numbers of 9, 18, and 27 circulation types.

Climatic data comprise daily maximum and minimum temperature (TX and TN) and daily precipitation amount (RR) in the period 1961–2000 from 29 European stations listed in Section 8.1.

10.2 Methods

For the quantification of relationships between changes in the seasonal frequency of atmospheric circulation types in the whole Europe and European regions and local climatic trends, two methods were used: first the method of "hypothetical" (circulation-induced) linear trends, and second the decomposition of climatic changes that occurred between the two halves of the study period. The methods were applied separately in the four seasons: MAM, JJA, SON, and DJF.

The first method, used e.g. by Huth (2001) for two Czech stations, is based on the notion of "hypothetical" trends which assume that changes in the occurrence of circulation types are the only factor causing the observed climate trends. All days classified with the same type are expected to bear the same value of a climatic element in a specific month (averaged over the whole period, e.g. all Januaries). Conditional mean values of each climatic element under every circulation type are calculated separately for each of the twelve months, and a time series is obtained by replacing the observed daily data by these conditional means. The new time series is then used instead of the observed data to assess the long-term "hypothetical" (circulation-conditioned) seasonal trends. These "hypothetical" trends are then compared with real changes simply by dividing them by the observed linear trends. This ratio would stay around one if climate trends were driven by circulation changes only. Bárdossy and Caspary (1990) had shown that such a "hypothetical" daily series reconstructed using the Hess–Brezowsky circulation catalogue is a fairly good approximation of the observed monthly mean temperature and precipitation at German stations, with correlation coefficients ranging from 0.7 to 0.9. Complementary to the "hypothetical" trend method is the analysis of "within-type" trends, i.e. trends in the climatic properties of individual circulation types. Within-type trends can be calculated in several ways – e.g. from daily climatic data under each circulation type, or from seasonal averages of such daily values (see Huth 1999). We have used daily data under each circulation type on a seasonal basis, regressing the daily values upon the year when that day occurred. Thus we neglect the position of the specific day within one season, on the other hand we do not lose information about the number of days with a given circulation type in that season (as would result from simply averaging the data over the season). We divide these within-type trends by the observed seasonal climatic trends to see if the within-type trends follow the observed trends or are independent of them. If this ratio is close to 1, then the within-type trends go hand in hand with the observed trends, thus the climatic properties of circulation types are changing at the same rate as the whole season. On the other hand, the ratio close to 0 indicates that the properties of circulation types are stable in time and the climatic trends are driven only by changing frequencies of circulation types. To gain one single within-type trend for each classification, we compute weighted average of the individual trends, where the weight represents the long-term relative frequency of given circulation type in a given season. Such weighing only makes sense when the individual trends in a given classification are not very variable, which was indeed our case.

The second method of attribution of climatic changes, originally proposed by Barry and Perry (1973) and used e.g. by Beck et al. (2007), is a simple decomposition of climatic difference between the averages of the 1st and the 2nd half of the study period ($\Delta\overline{C}$) into two parts – one related to changed climatic properties of individual circulation types ("within-type change"), and the other caused by changed frequency of circulation types ("frequency-related change"):

$$\Delta\overline{C} = \sum_{i=1}^{G} \left[\Delta F_i \left(C_i + \Delta C_i \right) / n + F_i \cdot \Delta C_i / n \right]$$

where

G = number of circulation types

F_i = frequency of circulation type *i* during the first period

$F_i + \Delta F_i$ = frequency of circulation type *i* during the second period

n = number of time units during the first period

C_i = climatic mean of circulation type *i* during the first period

$C_i + \Delta C_i$ = climatic mean of circulation type *i* during the second period

The expression [$\Delta F_i (C_i + \Delta C_i)/n$] describes the change in climate between the two periods due to frequency changes of circulation type *i*, whereas [$F_i \cdot \Delta C_i / n$] depicts the degree of climate change assigned to a modified climate linked with circulation type *i*.

We have applied these two methods of detection of circulation-induced climatic change only to stations and climatic variables whose seasonal linear trends are significant at the 95% confidence level in the study period 1961–2000. This is done in order to avoid unrealistic values of results, which might arise from dividing the "hypothetical trends" and "frequency-related change" by very low values of insignificant observed trends and by negligible climate change between the 1st and the 2nd half of the study period, respectively.

10.3 Results

Using the method of comparison of "hypothetical" (circulation-induced) and observed seasonal climatic trends, we can assess the contribution of changes in the frequency of circulation types on the observed trends of three used climatic variables (TX, TN, RR) that are significant at the 95% level. When comparing climatic trends with circulation changes, we have to bear in mind that there is obviously no "better" or "worse" result as opposed to the outcome of different "skill" indices (e.g. the EV index discussed earlier) that give an easy clue on the applicability of classification methods and their variants.

The ratio of "hypothetical" and significant observed trends is shown in Fig. 10.1 for TX, TN, and RR; separately for each station using 24 circulation classifications. Each station was tested twice to study the effect of spatial scale of circulation processes on local climatic trends: red color in Fig. 10.1 refers to results obtained with classifications that were calculated from sea level pressure fields in the large domain (D00), while black color stands for classifications computed in the small domains that best represent each station's location. The stations are ordered from left to right according to the domain number, i.e. from Iceland (D01) eastwards to Scandinavia (D02), then from Great Britain (D04) east to Ukraine (D08), and finally from the Iberian Peninsula (D09) to the Eastern Mediterranean (D11). We can clearly see a very high variability in results obtained by the 24 individual classifications – and this raises serious concern about the credibility of synoptic-climatological studies that take into account only a limited subset (or frequently just one) of classification catalogues. Of course, the results presented here are – as any other ones – dependent on a rather "subjective" selection of data, methods, and period of investigation; nevertheless they give us at least an insight into the striking variability within several classification catalogues.

There are marked differences between results obtained with circulation classifications computed from SLP fields coveringthe small domains and those computed over the whole Europe (D00); however, the picture is not uniform in the sense that smaller domain of atmospheric circulation would always mean higher correspondence of circulation and climatic changes. In spring and winter, the classifications in the small domains are more tightly connected with climatic trends at most of the stations except for Iceland and Scandinavia where circulation in D00 has a larger influence on climatic trends. In summer, both positive and negative differences occur between the results obtained with classifications from D00 and the small domains. Autumn shows very few significant climatic trends, so we cannot arrive at any broader conclusion, but the few resulting differences between D00 and the small domains are again both positive and negative as in summer.

In spring the circulation changes in the small domains are responsible for about one fourth of the observed trends of TX and RR, and even a bit less in the case of TN. The only station where the ratio of circulation-induced and observed trends is higher than 0.5 (under some classifications in D06) is the Alpine station Hohenpeissenberg. In summer the circulation changes have virtually no influence on the observed trends of TX, TN, and RR, the ratio being close to zero in most cases (and sometimes even negative values occur). It means that the within-type trends – i.e. changes in the internal climatic properties of individual circulation types – are the main driver of summer climatic trends. Seasonal within-type trends were analysed as well, but are not shown here because they basically account for the part of observed trends that cannot be explained by changing frequencies of circulation types. The minor deviations from this rule that we came upon might have stemmed from the specific method of calculation of within-type trends, as there are more methods and some may not always be fully comparable to the "hypothetical trends" method (for details see Section 10.2).

In autumn very few climatic trends are significant, and the influence of circulation changes on these trends is again very small for all the three variables (usually between 0 and 30%). Winter is the only season when circulation changes play a major role in the observed climatic trends, however, there are some stations in the Balkans and the Mediterranean where the within-type changes are still more important even in this season. Circulation changes have a major influence (around or more than 50%) on the massive recent warming over the British Isles and Central Europe. Precipitation trends in winter are best resolved by circulation changes at one of the easternmost stations – Kyiv – that underwent substantial desiccation in 1961–2000, and this is the only case that the ratio of circulation-induced and observed trend reaches 1 (although only by one classification).

Using five stations in the Alpine region, we can further assess the influence of the size of the domain used for classification of circulation patterns on the long-term temperature trends. The stations were tested using circulation classifications computed over domain 07 (Central Europe) and the smallest domain 06 that includes the Alpine region and its vicinity. Classifications performed on the small Alpine domain (D06) are better "predictors" for temperature trends in 84% of all cases (individual classifications and stations) for TX, and 70% for TN in spring. In summer the differences between results from D06 and D07 are both positive and negative with approximately the same number of cases above and below zero. In autumn there are no significant temperature trends in this region. In winter the Central European domain D07 dominates over D06 in 80% and 70% of cases for TX and TN, respectively; thus the temperature trends are more tightly connected to larger-scale circulation changes. The differences between results obtained with classifications from the two domains are displayed in Fig. 10.2 as an average over the five stations for each classification, and as an average over the 24 classifications at each station. These different influences of circulation changes in D07 and D06 in the four seasons might reflect not only the size of the two domains, but also the fact that D06 is centered over the Alps so that it contains a large part of the Mediterranean south of the Alpine ridge. In general, it is probably not possible to discern between the effect of dimension of circulation processes and the local geographical factors influencing them, namely in such a complex region as the Alps.

We have used another method for the attribution of climatic changes, i.e. the decomposition of change between the average of the 1st and the 2nd half of the study period 1961–2000 into circulation-related and within-type related parts, and its results seem to be comparable to those of the "hypothetical" trends method. Results of this simple decomposition are shown in Fig. 10.3 in the same format as for the first method, that is, at each station where the observed long-term trend is significant at the 95% level, using individual classifications in D00 and in the small domains. One may note that at several stations the results of this second method are missing; this is because there were gaps in the primary data files (while this method is very sensitive to missing data).

In summer and autumn the frequency-related part of climatic changes is virtually similar – that is, mostly very small – to the ratio of "hypothetical" and observed climatic trends. In spring, the frequency-related part of climatic changes is negligible for classifications in the small domains, and even of opposite sign than the "real" climatic changes for classifications in D00. This means that the within-type changes generally follow the observed overall changes, but are even more pronounced than these observed changes. In winter the percentage of change attributed to changing frequency of circulation types is very similar to the results of the first method, while at several stations (Waddington, Bamberg, Hannover, Hohenpeissenberg, Potsdam, Wien) the circulation influence is even more pronounced and accounts for 50% to 100% of climatic change that took place between the 1st and the 2nd half of the study period. The differences between results obtained with individual classifications at a single station are in this case even larger than using the first method.

Until now we have focused on the influence of circulation changes on climatic trends at the individual stations throughout Europe, here we will finally address the differences between the 8 methods of classification of atmospheric circulation, each of which comes in 3 variants with 9, 18, and 27 types. For this purpose we have averaged the results of all the stations under each classification – even though this is not quite physically meaningful, it is the easiest way of comparing the main outcome of the different classifications in different seasons and spatial domains. The results for TX and TN are shown in Figures 10.4 and 10.5 for the two methods of attribution used: Fig. 10.4 shows the ratio of “hypothetical” (circulation-induced) and observed trends in 1961–2000, while in Fig. 10.5 the frequency-related part of climatic change between the 1st and the 2nd half of this period is depicted. Precipitation was not taken into account this time because of a very small number of stations with significant seasonal trends that would make the average of stations unrepresentative. In these figures we can address several questions: the dependence of results on the method of classification and on the number of circulation types; and the differences between results obtained with classifications computed from SLP in the whole Europe vs. in the small domains. Those stations that were tested in two small domains, e.g. D06 and D07, were then counted twice in the averaging.

In the results of the first method of attribution we can see a distinct pattern of higher values for classifications with a higher number of circulation types for both TX and TN. For the second method, this only holds true for some classification methods and some seasons. There are several classifications that give a similar or higher result for D00 compared to the small domains in winter, these include CKMEANS, P27, PETISCO, and SANDRA for both TX and TN; and GWT in addition for TN.

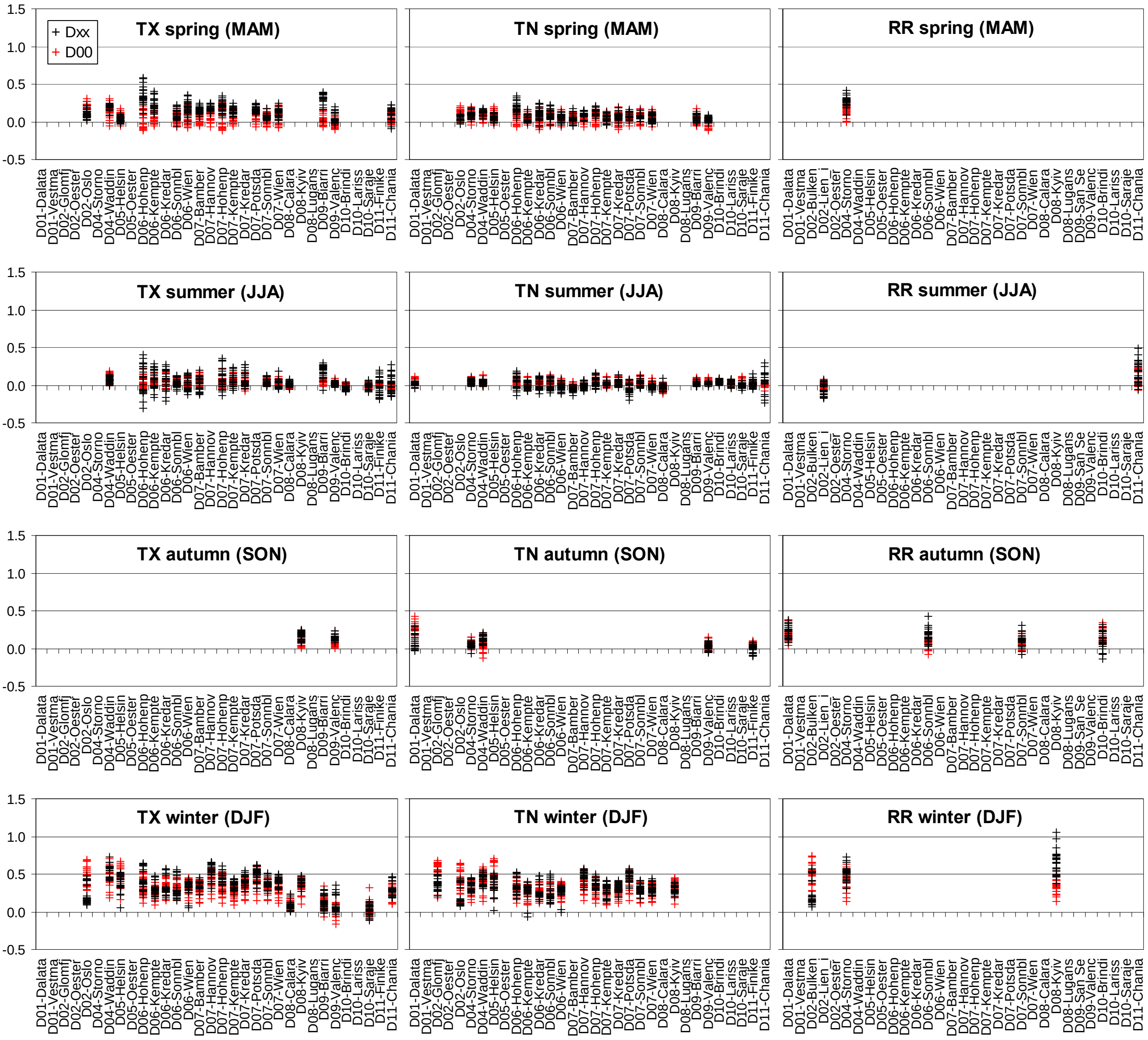


Fig. 10.1. Ratio of “hypothetical“ (circulation-induced) and observed climatic trends (significant at the 95% level) in 1961–2000. Each cross at a single station represents a result obtained with one of the 24 classifications. Colors denote the spatial scale of circulation classifications: black for small domains (Dxx), red for the entire European domain (D00).

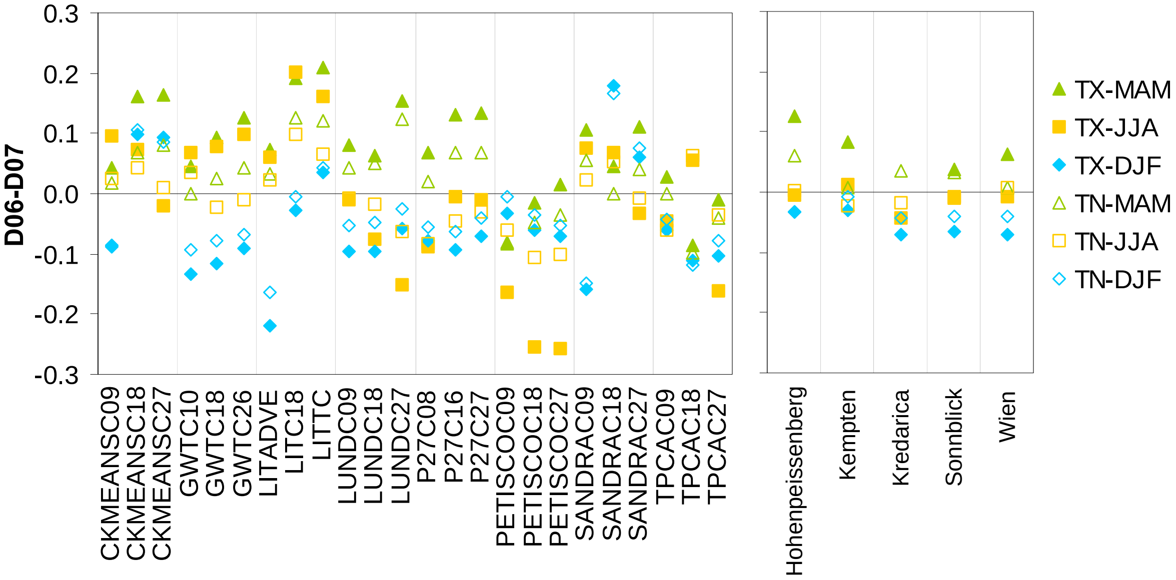


Fig. 10.2. Ratio of “hypothetical“ (circulation-induced) and observed climatic trends (significant at the 95% level) in 1961–2000: average difference between results obtained with classifications from the Alpine domain (D06) and the Central European domain (D07). Averages of 5 individual stations (left) and 24 classifications (right).

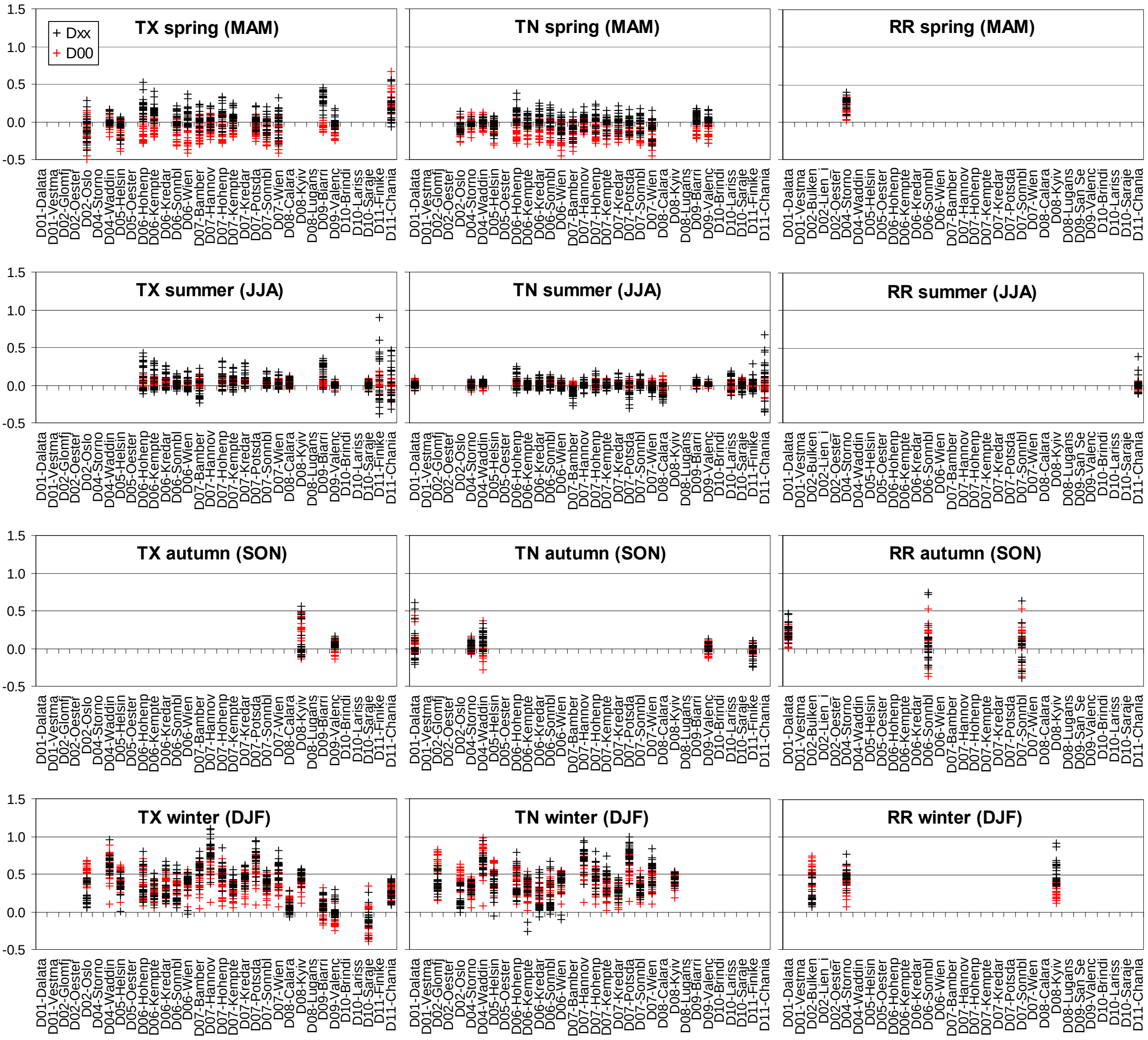


Fig. 10.3. Proportion of climatic change between the average of the 1st and the 2nd half of the period 1961–2000 that can be attributed to changing frequency of circulation types (at stations where long-term linear trends are significant at the 95% level). Each cross at a single station represents a result obtained with one of the 24 classifications. Colors denote the spatial scale of circulation classifications: black for small domains (Dxx), red for the entire European domain (D00).

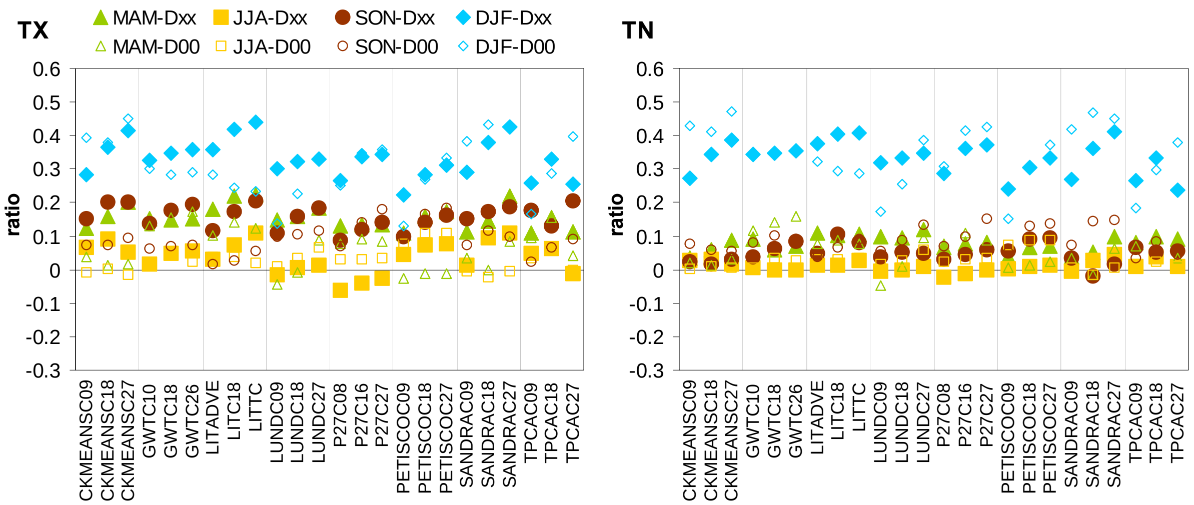


Fig. 10.4. Ratio of “hypothetical“ (circulation-induced) and observed trends of maximum and minimum temperature in 1961–2000 (averages of individual stations where observed trends are significant at the 95% level). Results obtained with classifications from the small domains (Dxx) and the entire European domain (D00) are shown.

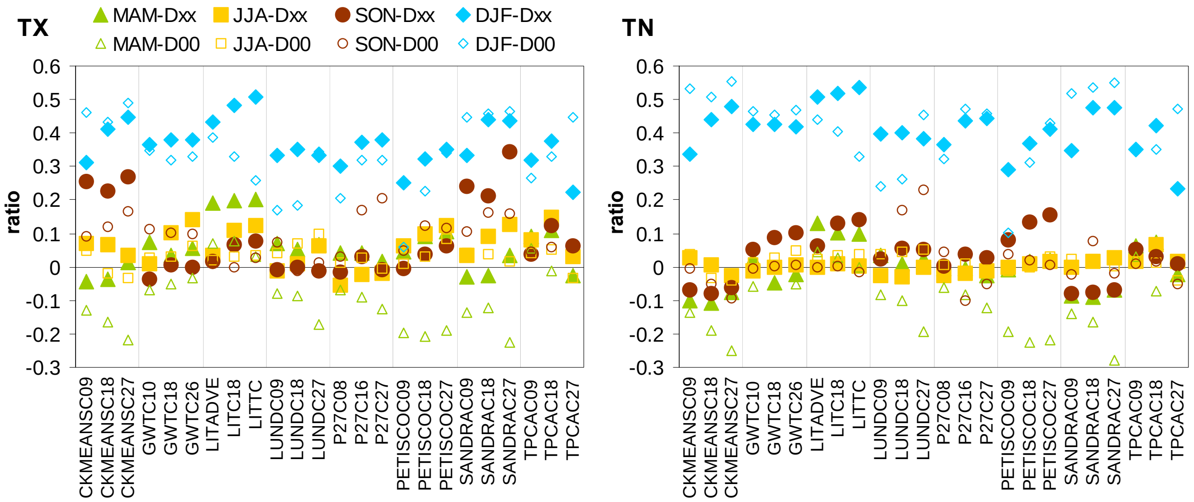


Fig. 10.5. Proportion of change of maximum and minimum temperature between the average of the 1st and the 2nd half of the period 1961–2000 that can be attributed to changing frequency of circulation types (averages of individual stations where observed trends are significant at the 95% level). Results obtained with classifications from the small domains (Dxx) and the entire European domain (D00) are shown.

11. Summary and discussion

In Sections 2–10 we have presented an extensive study on the changes of atmospheric circulation over Europe in the second half of the 20th century and their influence on observed climatic trends. Here we summarize the key findings of our topics of interest and discuss them within the context of previous studies.

11.1 Persistence (lifetime) of atmospheric circulation types and its trends

The lifetime of circulation types – i.e. duration of a sequence of days classified with the same type – is an important factor that can both reflect and affect climatic changes. From several recent papers in this field (Werner et al. 2000, Kyselý and Domonkos 2006, Kyselý and Huth 2006), we get a notion of a systematic change towards longer lifetime of circulation types in the North Atlantic/European domain in the mid-1980s. However, most of these studies based their findings on a single subjective classification of circulation types, the well-known and still widely used German Hess–Brezowsky catalogue that is available back to 1881 (Hess and Brezowsky 1952, Gerstengarbe and Werner 2005). We have studied the persistence of synoptic types and its trends in the second half of the 20th century (see Section 2 – Cahynová and Huth 2007a, and Section 4 – Cahynová and Huth 2009a) in 18 objective and 6 subjective classifications collected within the COST733 Action, including the subjective Hess–Brezowsky and two versions of its objective "counterpart" developed by James (2007). Although the objective circulation catalogues differ from one another in terms of the average persistence of synoptic situations, and despite the fact that there is little correspondence between them regarding the year-to-year variability of persistence, there is one feature common to them all: we do not see any systematic change in the persistence of circulation types in the study period, nor as a long-term trend neither as a single changepoint. This suggests that the enhancement of persistence in the Hess–Brezowsky catalogue in 1985/86 is rather an inhomogeneity than a real feature. The catalogue had been claimed homogeneous (Gerstengarbe et al. 1999); however, the authors did not substantially prove its homogeneity nor did they provide metadata about the history of the catalogue. Additionally, we have found that the changes of one type to another are more frequent at the ends of months and years compared to all other days, which is caused by manual data evaluation that is done on a monthly basis (see Section 3 – Cahynová and Huth 2007b). An inconsistency that led to a sudden shift in persistence was also found in the Czech–Czechoslovak Brádka's catalogue (a drop in 1972/73 and negative trend thereafter), and in the Hungarian Péczely catalogue (also a drop in persistence that occurred in 1985/86, coinciding with the enhancement in the Hess–Brezowsky probably by chance). We therefore recommend a rather cautious use of the subjective circulation catalogues, namely in studies that take into account the persistence of synoptic situations.

11.2 Changes in the frequency of circulation types

Changes in the frequency of circulation types were thoroughly analyzed in two subjective circulation classifications that have a direct relation to the Czech territory: the Czech–Czechoslovak (Brádka's) catalogue in the period 1946–2002 (see Section 2 – Cahynová and Huth 2007a), and the German Hess–Brezowsky in 1946–2000 (Section 5 – Cahynová and Huth 2009b). At the scale of the whole Europe and eleven European regions, we have studied seasonal linear trends in the frequency of circulation types in the period 1961–2000 in 24 selected objective circulation classifications, i.e. 8 classification methods applied with a pre-defined number of 9, 18, and 27 types (Section 6 – Cahynová and Huth 2010, and Section 7).

In the Brádka's catalogue, the most prominent feature is the increasing number of days with cyclonic circulation in winter, spring, and most notably in autumn. In spring the number of cyclonic days increases until the beginning of the 1970s, and decreases in the 1990s after a period of stagnation. These trends are caused mainly by more frequent traveling troughs (type Bp). Both the cyclonic and the anticyclonic situations shorten in the study period, thus the increase of frequency of the cyclonic days is caused by a more frequent recurrence of these situations and not by their longer duration. In the Hess–Brezowsky catalogue the trends are quite different. In winter the number of the cyclonic (anticyclonic) types decreases (increases) from the 1960s to the early 1990s. In spring, the highest frequency of anticyclonic days occurred around the years 1960 and 1990 with lower values in between. Trends in summer and autumn are minor with great interannual variability dominating, although there is a slight decrease (increase) of the cyclonic (anticyclonic) patterns in summer from the late 1960s until the early 1990s. The contradictory results obtained from the two subjective catalogues most probably stem from the different spatial domain covered, although in most days the cyclonicity assessment is similar in both classifications (from 59% of days in summer to 66% in winter). Circulation types with westerly and northwesterly flow (W+NW) dominate in both the catalogues in all seasons except for spring. In the period 1961–1998 that was further employed in the analysis of climatic trends, only three directional "supertypes" exhibited significant trends in their seasonal frequency (at the 95% level): the number of the W+NW types increased in winter in the Hess–Brezowsky, and the number of the N+NE types rose in Brádka's catalogue in autumn but declined in Hess–Brezowsky in winter.

In the 24 selected circulation catalogues based on SLP in Europe and 11 European regions, winter clearly dominates the seasons in terms of significant trends in the frequency of circulation types. A relatively lower number of days in types with a significant trend in winter frequency is found in Northern Europe (D01–03). In the Alpine region (D06) and in the eastern Mediterranean (D11), a substantial proportion of days occurs within types that bear notable trends in frequency also in summer. In D11 this is caused by a pronounced seasonality – a limited number of types (sometimes just 1 or 2) occupies a majority of days in summer. We describe seasonal trends in the frequency of specific circulation types in the GWTC10 classification as an example, as it clearly defines 10 types with regard to the direction of flow (8 main directions) and cyclonicity (cyclonic and anticyclonic type). As was mentioned earlier, the largest number of types with frequency trends significant at the 95% level occurs in winter, and these trends are also of the highest magnitude. Winter frequency of the westerly type increases in the whole Europe (D00) and in the central latitudinal belt from the British Isles all the way east to Ukraine (D04, D06–08). The highest magnitude of trend (+20 westerly days) is present in Central Europe (D07). Over the British Isles, the southwesterly type becomes more frequent in a same rate as the westerly type (+13 days). Decreasing trends are seen in the occurrence of the easterly type in Western and Central Europe (D04, D06–07), and in the southerly type over the British Isles (D04), Central and Eastern Europe (D07–08), and central and eastern Mediterranean (D10–11). Another notable trend in D11 in winter is the increase of the northeasterly type (+14 days). Cyclonic days become more common in Iceland (D01), whereas their number decreases in the whole Europe (D00), Ukraine (D08), and central Mediterranean (D10). The anticyclonic type slightly gains weight in D10 and the Alps (D06). These winter trends reflect the strengthening of the North Atlantic Oscillation (e.g. Hurrell 1995), i.e. the tendency towards a more pronounced Icelandic low and Azores high that is responsible for enhanced westerly flow from the North Atlantic towards Europe and for the northward shift of cyclonic paths. Philipp et al. (2007) also noted a positive trend of two types with westerly flow over Central Europe in an objective classification of SLP patterns in the last decades of the 20th century. In spring, summer, and autumn there are virtually no "systematic" changes in the frequency of circulation types apart from spring decrease of easterly type in the whole Europe (D00), Iceland (D01), and Northeastern Europe (D03).

11.3 “Skill” of circulation classifications to stratify daily station climatic data into types

We have used the explained variance (EV) index to compare the “skill” of 24 individual circulation catalogues to separate station climatic data (maximum temperature TX and minimum temperature TN at 26 stations, and precipitation amount RR at 25 stations) into circulation types (see Section 8). Each station has been tested at least twice, using classifications developed for the whole European domain (D00) and for the small domain(s) best representing the station. The EV index reaches the highest values for TX in winter for classifications in the small domains (up to 0.5, while the theoretical range of EV index is 0 to 1). The link between circulation classifications and local climate variability is usually tighter for atmospheric circulation in the small domains than in D00. However, for TN at most of the stations in spring, and for TX in Scandinavia and Ukraine in spring and autumn, the classifications have a better “skill” in D00.

We have ranked the 24 used circulation catalogues according to the EV index averaged over all the stations, separately for each season, spatial extent of circulation (i.e. D00 vs. the small domains), and climatic variable. Then we calculated an average rank for each classification and each variable from the 8 values of rank (4 seasons x 2 spatial domains of circulation). In the case of TX, this average rank does not vary much between the individual classifications (there is no clear “winner”), and the catalogues with 27 types do not always score among the best as would be expected as an inherent feature of the EV index. For TN the EV index generally has lower values than for TX, but the ranking of classifications is more pronounced – the best ones are SANDRAC27, CKMEANSC27, and PETISCOC27; the worst ones P27C08, LITADVE, and GWTC10. Precipitation is, not surprisingly, the variable that is least connected with the type of circulation because its substantial proportion may originate from local convective storms that cannot be described by large-scale circulation patterns. The best “predictors” of daily RR are SANDRAC27, LITTC, and GWTC26; the bottom line of the ranking is occupied by LITADVE in all the cases.

The ranking of stations according to the EV index averaged over the 24 circulation catalogues is quite variable among the three variables used; nevertheless the top ranks are usually occupied by the Icelandic, Norwegian, and Alpine stations. In the Alpine region, it is the atmospheric circulation in the smallest domain D06 that is most tightly connected to station climatic variability when compared to D07 (Central Europe) and D00. Eastern Mediterranean stations Finike and Chania are the only sites where circulation classifications do not explain the largest proportion of temperature variability in winter but in autumn (for TN this is true at both stations, while for TX only in Finike).

Our findings generally follow those presented recently by Beck and Philipp (2010) who used the EV index for an extensive testing of circulation catalogues on gridded climatic data over Europe. The authors note that the EV index is higher in more westerly and maritime domains (Iceland, W Scandinavia, British Isles, Baltic, W Mediterranean) while EV values are somewhat lower for the eastern and more continental domains (Central Europe, NE Europe, E and SE Europe, E Mediterranean) due to a stronger influence of orography and land surface characteristics. Also the EV results of classifications computed over D00 were generally lower than those obtained by classifications from the small domains, and in the Alpine region it was the smallest domain of circulation (D06) that produced the best results.

At the scale of the Czech Republic, we have compared 24 objective classifications and two versions of the subjective Hess–Brezowsky using three “skill” indices applied on eight climatic variables at 21 stations in January, April, July, and October (see Section 6 – Cahynová and Huth 2010). The final ranking of classifications varies with the season and the given index (EV index, within-type standard deviation, and correlation of daily observed time series with that reconstructed using circulation types). The Hess–Brezowsky classification with 29 types (HBGWL) scores the best when compared with the 24 objective classifications that are computed over the Central European domain. Hess–Brezowsky catalogue with 10 types (HBGWT) is the best of all the catalogues that have around 9 types, and often ouperforms even some of the catalogues with 18 and 27 types. This extraordinarily good performance of the Hess–Brezowsky catalogue was already noted by Buishand and Brandsma (1997) who compared it with two objective classification schemes, using temperature and precipitation data in the Netherlands. The authors came with a plausible explanation that the Hess–Brezowsky catalogue is produced on the basis of both surface and upper-air synoptic charts since 1949, while only sea level pressure served as input for the objective classifications (which was also the case of our analysis).

11.4 Seasonal trends of surface climatic variables in the Czech Republic and Europe

Seasonal linear trends in eleven climatic variables in the Czech Republic in the period 1961–1998 were presented by Huth and Pokorná (2004, 2005) and slightly corrected (due to some errors in two primary data files) in Cahynová and Huth (2009b, 2010, i.e. Sections 5 and 6). Our results are in good accord with those presented by Brázdil and Macková (1998) and Brázdil et al. (2009). In spring, summer, and most notably in winter there is a pronounced warming trend significant at the 95% level at most of the 21 used stations, whereas in autumn a significant negative trend of maximum temperature was found. In all seasons at the majority of stations the trends in daily maximum temperature are greater than those of the daily minima, so that the daily temperature range increases in all seasons but autumn. Trends in daily maximum temperature in winter mostly exceed +2.5°C and reach up to 3°C at Lysá hora (1324 m a. s. l.) in the period 1961–1998, which corresponds to +0.83°C per decade. Trends in other variables are consistent with temperature changes: relative humidity and cloudiness decrease and sunshine duration increases in spring, summer, and winter; in autumn these trends are again of opposite sign. Precipitation trends in spring, summer, and winter are mostly insignificant (both positive and negative trends occur); in autumn we can see the rising probability of a rainy day, which is in agreement with increased cloudiness. Zonal and meridional wind component trends are mostly insignificant and spatially inconsistent, i.e. their sign varies among individual stations. Trends in total wind speed are of larger magnitude (ranging from –3.4 to +2.1 m/s change per 38 years) but also geographically incoherent. Wind speed trends are most likely influenced by several factors other than climatic change, such as changes of the instrumentation or in tree and building height in the vicinity of the anemometer.

Climatic changes in European regions were studied in the period 1961–2000, using daily maximum (TX) and minimum (TN) temperature data from 26 stations, and daily precipitation amount (RR) at 25 stations (see Section 9). Although we have used a limited number of stations covering more or less the whole Europe, we can still address some clear regional patterns in the trends and variability of temperature and precipitation. The highest interannual variability of temperature is observed in winter in Scandinavia, Central, and Eastern Europe. Iceland and the Mediterranean bear little interannual temperature variability in all seasons. Precipitation variability is the greatest in Norway (most probably caused by orographic effects in Bulken), in Iceland, on the Alpine summit Kredarica, and also in San Sebastian. The study period was one with clearly pronounced warming trends in winter, spring, and summer at most of the stations. The greatest warming exceeded 3°C/40 years for both TX and TN in winter (that is up to 0.86°C per decade); however, due to high interannual variability of mean winter temperature the largest standardized trends are present in summer – around 2 sigma for TN, and slightly less for TX. At the Icelandic stations, very slight warming or even some insignificant cooling trends took place in winter. In autumn the trends of TX are insignificant at the 95% level with the exception of Kyiv (negative trend) and Valencia (positive trend). Generally, autumn maximum temperatures are slightly rising in Northern Europe but falling in Central and Eastern Europe. On the other hand, TN exhibits a slight warming in autumn in Central Europe, thus lowering the daily temperature range. Precipitation trends are only significant (positive) at a few northern stations, and Stornoway and Brindisi (with different seasons being involved), and negative in Kyiv in winter and Chania in summer.

11.5 The influence of circulation changes on observed climatic trends

Using the method of comparison of "hypothetical" (circulation-induced) and observed seasonal climatic trends, we can assess the contribution of changes in the frequency of circulation types on the observed trends of eleven climatic variables at Czech stations in the period 1961–1998 (Sections 5 and 6 – Cahynová and Huth 2009b, 2010), and three variables (TX, TN, RR) at more than 20 European stations in the period 1961–2000 (Section 10). When comparing climatic trends with circulation changes, we have to bear in mind that there is obviously no "better" or "worse" result as opposed to the outcome of different "skill" indices (e.g. the EV index discussed earlier) that give an easy clue on the applicability of classification methods and their variants.

In winter, circulation changes in the 24 objective catalogues that are based on sea level pressure in Central Europe explain around 30% of the observed temperature trends in the Czech Republic. In autumn the ratio is around 20% for temperature, and even lower for the other variables (this can also be seen in winter). The effect of circulation changes on temperature trends is negligible in spring and summer and even negative in some cases in summer. In spring the circulation changes account for about 20% of trends in precipitation, relative humidity (RH), cloudiness (CL), and sunshine (SUN), while in summer the results for these variables are close to zero. This same method applied on circulation classifications defined over whole Europe (D00) gives very similar results in most cases. Only in summer the link between circulation and temperature trends is stronger for the European classifications while in spring the circulation in Central Europe is more closely linked to changes in the occurrence of precipitation (PRO), RH, CL, and SUN.

Using a different method – decomposition of climatic changes that took place between the first and the second half of the study period into frequency-related part and within-type related part – we arrive at similar results for the Czech Republic. In winter the frequency-related (circulation-induced) part of temperature changes is even more pronounced than using the first method, explaining about 50% of the observed changes. On the other hand, most of the climatic changes in spring, summer and autumn can be attributed to changing properties of individual circulation types (within-type changes). In winter and spring higher proportions of circulation-induced changes are generally obtained for classifications defined over Central Europe but in summer and autumn we can see a stronger influence of circulation changes of the whole European classifications compared to the Central European ones.

The link between circulation and climatic trends in the Czech Republic is not affected by the number of circulation types in general. It is also quite impossible to rank the 24 circulation classifications according to their connection with climatic trends due to the fact that the ranking depends on the spatial scale of circulation, the season, the climatic variable, and the method used for the assessment of circulation-induced climatic changes. There is no clear dependence of the results on the geographical location of the stations.

The three subjective catalogues used (the German Hess–Brezowsky catalogue with 29 types and 10 types, and the Czech–Czechoslovak “Brádka’s”) produce substantially higher proportion of circulation-induced climatic changes in the Czech Republic than the objective ones for both methods of assessment in winter for temperature, and in autumn and spring for nearly all climatic variables (in spring this is true for Hess–Brezowsky but Brádka gives very low results). These results are consistent with the fact that except for winter, very few circulation types in the objective catalogues yield significant long-term trends in their seasonal occurrence. On the contrary, the subjective catalogues bear a substantial proportion of significant trends in the occurrence of circulation types in all seasons (except for Brádka in spring).

The links between circulation and climatic changes were further studied at the above-mentioned European stations in the period 1961–2000, again using 24 selected circulation classifications applied on the large domain (D00) and on the small domains. Each station was tested twice, using large-scale circulation classifications (computed over D00) and regional classifications from the specific spatial domain best representing the station’s location. We have found very high variability in results obtained using the individual classifications – and this raises serious concern about the credibility of synoptic-climatological studies that take into account only a limited subset (or frequently just one) of classification catalogues. Of course, the results presented here are – as any other ones – dependent on a rather “subjective” selection of data, methods, and period of investigation; nevertheless they give us at least an insight into the striking variability within several classification methods.

For both methods of attribution of climatic changes, we have found marked differences between results obtained with circulation classifications computed from SLP fields covering the small domains and those computed over the whole Europe (D00); however, the picture is not uniform in the sense that smaller scale of atmospheric processes would always mean higher correspondence of circulation and climatic changes. In spring and winter, the classifications computed over the small domains are more tightly connected with climatic trends at most of the stations except for Iceland and Scandinavia where circulation in D00 has a larger influence on climatic trends. In summer, both positive and negative differences occur between the results obtained with classifications computed over D00 and over the small domains. Autumn shows very few significant climatic trends, so we cannot arrive at any broader conclusion, but the few resulting differences between D00 and the small domains are again both positive and negative as in summer.

Results of the first method of attribution – the ratio of "hypothetical" and observed climatic trends – show that in spring the circulation changes in the small domains are responsible for about one fourth of the observed linear trends of TX and RR, and even a bit less in the case of TN. The only station where the ratio of circulation-induced and observed trends is higher than 0.5 (under some classifications in D06) is the Alpine station Hohenpeissenberg. In summer the circulation changes have virtually no influence on the observed trends of TX, TN, and RR, the ratio being close to zero in most cases (and sometimes even negative values occur). In autumn very few climatic trends are significant, and the influence of circulation changes on these trends is again very small for all the three variables (usually between 0 and 30%). It means that the within-type trends – i.e. changes in the internal climatic properties of individual circulation types – are the main driver of observed climatic trends in spring, summer, and autumn.

Winter is the only season when circulation changes play a major role in the observed climatic trends, however, there are some stations in the Balkans and the Mediterranean where the within-type changes are still more important even in this season. Circulation changes have a major influence (around or more than 50%) on the massive recent warming over the British Isles and Central Europe. Precipitation trends in winter are best resolved by circulation changes at one of the easternmost stations – Kyiv – that underwent substantial desiccation in 1961–2000, and this is the only case that the ratio of circulation-induced and observed trend reaches 1 (although only by one classification).

The frequency-related part of climatic change between the first and the second part of the study period is virtually similar – that is, mostly very small – as the ratio of "hypothetical" and observed climatic trends in summer and autumn. In spring, the frequency-related part of climatic changes is negligible for classifications in the small domains, and even of opposite sign than the "real" climatic changes for classifications in D00. This means that the within-type changes generally follow the observed overall changes, but are even more pronounced than these observed changes. In winter the percentage of change attributed to changing frequency of circulation types is very similar to the results of the first attribution method, while at several stations (Waddington, Bamberg, Hannover, Hohenpeissenberg, Potsdam, Wien) the circulation influence is even more pronounced and accounts for 50% to 100% of climatic change that took place between the first and the second half of the study period. The differences between results obtained with individual classifications at a single station are in this case even larger than using the first method.

The rate of influence of circulation changes on observed trends of TX and TN depends on the number of circulation types: classifications with more CTs produce higher results. This holds true for the first method of attribution, but only for some classifications in some seasons in case of the second method of attribution.

Our results of attribution of climatic trends follow those presented by Huth (2001) who concluded that summer climatic trends at two stations in the Czech Republic in the period 1949–1980 were unrelated to circulation changes in an objective classification of 500 hPa geopotential height fields, whereas in winter the circulation changes were responsible for parts of the observed warming and strengthening of southerly winds.

Most of the previously published studies on the attribution of climatic changes to changes in atmospheric circulation are based on data with monthly or seasonal time resolution, which is not directly comparable to our findings obtained with daily time series. Also, we are not aware of any previous study that would take into account more parallel circulation classifications. Nevertheless, previous studies have reported major nonstationarities in the circulation-climate relationships, which was also the main finding of our recent research. Beck et al. (2007) studied monthly spatially averaged Central European temperature and precipitation with regard to time variations of circulation types derived from a reconstructed SLP grid back to 1780. They constructed a continuous time series of within-type related and frequency-related climatic variations for January, April, July, and October. The relative contributions of both the within-type related and the frequency-related series exhibit distinct decadal changes in all months and for both variables, with values changing from nearly 0% to nearly 100% with no apparent physical reason. Another study by Küttel et al. (in press) provides a similar long-term analysis of European mean winter circulation patterns and gridded temperature and precipitation since 1750. Comparing the recent 50 years with all preceding 50-year periods, the authors conclude that the major part of multidecadal winter climatic changes is caused by within-type variations, i.e. the temperature and precipitation fields related to a particular SLP pattern change their characteristics over time.

12. Conclusion

In this thesis we have presented our recent research in the field of synoptic climatology that is part of – and largely benefited from – the European-funded COST733 Action "Harmonisation and Applications of Weather Types Classifications for European Regions".

Atmospheric circulation changes over Europe were studied in terms of changing seasonal frequency and persistence of daily circulation types in the second half of the 20th century. The extensive collection of both subjective and objective catalogues of circulation types served as a platform for comparison and detection of inhomogeneities in the subjective ones (Brádka's Czech–Czechoslovak catalogue, German Hess–Brezowsky, and Hungarian Péczely).

We have studied the influence of changes in the frequency of circulation types on seasonal climatic trends of a dozen surface climatic variables on the territory of the Czech Republic. It was shown that there is a large variability within the results obtained with different circulation classifications (3 subjective and 24 objective) and also within the 21 individual stations (despite the relatively small spatial scale of the Czech territory). We only found substantial influence of circulation changes on winter temperature trends, which suggests that it is rather the change of climatic properties of individual circulation types (within-type change) that drives most of the observed climatic trends – even the autumn cooling.

We have then extended our domain of interest to the whole Europe, again looking for the influence of circulation changes on recent trends of maximum and minimum air temperature and precipitation. Using several objective circulation classifications developed for the whole Europe and eleven European sub-domains, we have also addressed the question of spatial scale of atmospheric processes and its connection with local climatic variability and trends. It was shown that smaller scale of circulation means tighter link with local climatic variability and usually (but not always) also a larger degree of influence of circulation trends on climatic trends. The attribution of climatic changes again showed marked differences within the results obtained using many (24 objective in this case) circulation classifications. This is probably the most valuable – and unprecedented, as far as we know – outcome of this thesis. We would thus like to emphasize that the selection and use of a limited number of classifications of circulation types (usually just one or two) as an input for synoptic-climatological studies produces a certain result that is, in fact, just a random representative of a wide range of results one could have gained using a broader collection of parallel input data. More generally, in all kinds of scientific research we always have to bear in mind that our results are never "universal" but only refer to the specific data, space, time, and methods that we use.

13. References for sections 1, 7–12

Bárdossy A., Caspary H.J. (1990): Detection of climate change in Europe by analysing European atmospheric circulation patterns from 1881 to 1989. Theor. Appl. Climatol. 42: 155–167.

Bárdossy A., Duckstein L., Bogárdi I. (1995): Fuzzy rule-based classification of atmospheric circulation patterns. Int. J. Climatol. 15: 1087–1097.

Barnston A.G., Livezey R.E. (1987): Classification, seasonality and persistence of low-frequency atmospheric circulation patterns. Mon. Weather Rev. 115: 1083–1126

Barry R.G., Carleton A.M. (2001): Synoptic and dynamic climatology. Routledge, London and New York, 620 pp.

Barry R.G., Perry A.H. (1973): Synoptic climatology: methods and applications. Methuen, London, 555 pp.

Baur F., Hess P., Nagel H. (1944): Kalender der Grosswettelagen Europas 1881–1939. DWD, Bad Homburg, Germany (in German).

Beck C., Jacobeit J., Jones P.D. (2007): Frequency and within-type variations of large-scale circulation types and their effects on low-frequency climate variability in central Europe since 1780. Int. J. Climatol. 27: 473–491.

Beck C., Philipp A. (2010): Evaluation and comparison of circulation type classifications for the European domain. Phys. Chem. Earth 35: 374–387.

Beranová R., Huth R. (2008): Time variations of the effects of circulation variability modes on European temperature and precipitation in winter. Int. J. Climatol. 28: 139–158.

Brádka J., Dřevikovský A., Gregor Z., Kolesár J. (1961): Počasí na území Čech a Moravy v typických povětrnostních situacích (Weather on the territory of Bohemia and Moravia in typical weather situations). Hydrometeorological Institute, Prague, 32 pp. (in Czech)..

Brázdil R., Chromá K., Dobrovolný P., Tolasz R. (2009): Climate fluctuations in the Czech Republic during the period 1961–2005. Int. J. Climatol. 29: 223–242.

Brázdil R., Macková J. (1998): Řada průměrných ročních teplot vzduchu pro Českou republiku v období 1828–1995 (Series of mean annual air temperatures of the Czech Republic in 1828–1995). Met. Zpr. 51: 17–21 (in Czech).

Buishand T.A., Brandsma T. (1997): Comparison of circulation classification schemes for predicting temperature and precipitation in the Netherlands. Int. J. Climatol. 17: 875–889.

Cahynová M., Huth R. (2007a): Trendy v kalendáři povětrnostních situací HMÚ/ČHMÚ v období 1946–2002 (Trends in the HMI [Czech, formerly Czechoslovak] subjective classification of synoptic types in the period 1946–2002). Met. Zpr. (Met. Bulletin) 60: 175–182 (in Czech).

Cahynová M., Huth R. (2007b): Short note on inhomogeneities in the Hess–Brezowsky catalogue of circulation types. Met. časopis (Met. Journal) 10: 171–174.

Cahynová M., Huth R. (2009a): Enhanced lifetime of atmospheric circulation types over Europe: fact or fiction? Tellus 61A: 407–416.

Cahynová M., Huth R. (2009b): Changes of atmospheric circulation in central Europe and their influence on climatic trends in the Czech Republic. Theor. Appl. Climatol. 96: 57–68.

Cahynová M., Huth R. (2010): Circulation vs. climatic changes over the Czech Republic: A comprehensive study based on the COST733 database of atmospheric circulation classifications. Phys. Chem. Earth 35: 422–428.

Casty C., Handorf D., Sempf M. (2005): Combined winter climate regimes over the North Atlantic/European sector 1766–2000. Geoph. Res. Lett. 32, doi:10.1029/2005GL022431.

Casty C., Handorf D., Raible C.C., González-Rouco J.F., Weisheimer A., Xoplaki E., Luterbacher J., Dethloff K., Wanner H. (2005b): Recurrent climate winter regimes in reconstructed and modelled 500 hPa geopotential height fields over the North Atlantic/European sector 1659–1990. Clim. Dyn. 24: 809–822.

Compagnucci R.H., Richman M.B. (2008): Can principal component analysis provide atmospheric circulation or teleconnection patterns? Int. J. Climatol. 28: 703–726.

Demuzere M., Werner M., van Lipzig N.P.M., Roeckner E. (2009): An analysis of present and future ECHAM5 pressure fields using a classification of circulation pattern. Int. J. Climatol. 29: 1796–1810.

Enke W., Spekat A. (1997): Downscaling climate model outputs into local and regional weather elements by classification and regression. Climate Res. 8: 195–207.

Fragoso M., Tildes Gomes P. (2008): Classification of daily abundant rainfall patterns and associated large-scale atmospheric circulation types in Southern Portugal. Int. J. Climatol. 28: 537–544.

Gerstengarbe F.-W., Werner P.C. (1993): Katalog der Großwetterlagen Europas nach Paul Hess und Helmuth Brezowsky: 1881–1992. Ber. Dt. Wetterd. 113, Offenbach a. M., 249 pp. (in German).

Gerstengarbe F.-W., Werner P.C. (2005): Katalog der Großwetterlagen Europas (1881–2004) nach Paul Hess und Helmut Brezowsky. PIK Report 100, Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany, 148 pp (in German). Available from: <http://www.pik-potsdam.de/research/publications/pikreports/.files/pr100.pdf>.

Gerstengarbe F.-W., Werner P.C., Rüge U. (1999): Katalog der Großwetterlagen Europas (1881–1998) nach Paul Hess und Helmuth Brezowsky. Potsdam, Offenbach a. M., Germany (in German).

Goodess C.M., Jones P.D. (2002): Links between circulation and changes in the characteristics of Iberian rainfall. Int. J. Climatol 22: 1593–1615.

Hanssen-Bauer I., Førland E.J. (2000): Temperature and precipitation variations in Norway 1900–1994 and links to atmospheric circulation. Int. J. Climatol. 20: 1693–1708.

Hess P., Brezowsky H. (1952): Katalog der Grosswetterlagen Europas. Ber. Dt. Wetterd. in der US-Zone, Nr. 33, DWD, Offenbach a. M., Germany (in German).

Hewitson B.C., Crane R.G. (1994): Neural Nets: Applications in Geography. Springer, New York, Berlin, Heidelberg, 208 pp.

Hewitson B.C., Crane R.G. (2002): Self-organizing maps: applications to synoptic climatology. Clim. Res. 22: 13–26.

http://www.cost733.org/ – official website of the COST733 Action: Harmonisation and Applications of Weather Type Classifications for European Regions

Hurrell J.W. (1995): Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation. Science 269: 676–679.

Hurrell J.W., Kushnir Y., Ottersen G., Visbeck M. (2003): An overview of the North Atlantic Oscillation. In: The North Atlantic Oscillation: Climatic Significance and Environmental Impact. Hurrell J.W., Kushnir Y., Ottersen G., Visbeck M. (eds.). Geophysical Monograph Series 134, American Geophysical Union, Washington, DC, pp. 1–35.

Huth R. (1993): An example of using obliquely rotated principal components to detect circulation types over Europe. Meteorol. Z. 2: 285–293.

Huth R. (1999): Testing for trends in data unevenly distributed in time. Theor. Appl. Climatol. 64: 151–162.

Huth R. (2000): A circulation classification scheme applicable in GCM studies. Theor. Appl. Climatol. 67: 1–18.

Huth R. (2001): Disaggregating climatic trends by classification of circulation patterns. Int. J. Climatol. 21: 135–153.

Huth R. (2010): Synoptic-climatological applicability of circulation classifications from the COST733 collection: First results. Phys. Chem. Earth 35: 388–394.

Huth R., Beck C., Philipp A., Demuzere M., Ustrnul Z., Cahynová M., Kyselý J., Tveito O. E. (2008a): Classification of atmospheric circulation patterns – Recent advances and applications. Ann. N. Y. Acad. Sci. 1146: 105–152.

Huth R., Kliegrová S., Metelka L. (2008b): Non-linearity in statistical downscaling: does it bring an improvement for daily temperature in Europe? Int. J. Climatol. 28: 465–477.

James P.M. (2006): Second Generation Lamb Weather Types. A new generic classification method with evenly tempered type frequencies. Paper presented at 6th Annual Meeting of the EMS/6th ECAC, EMS2006A00441. Ljubljana, Slovenia.

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

Jenkinson A.F., Collison B.P. (1977): An initial climatology of gales over the North Sea. Synop. Climatol. Branch Memo 62, Meteorological Office, London, UK, 18 pp.

Klein Tank A.M.G., Wijngaard J.B., Können G.P., Böhm R., Demarée G., Gocheva A., Mileta M., Pashiardis S., Hejkrlik L., Kern-Hansen C., Heino R., Bessemoulin P., Müller-Westermeier G., Tzanakou M., Szalai S., Pálsdóttir T., Fitzgerald D., Rubin S., Capaldo M., Maugeri M., Leitass A., Bukantis A., Aberfeld R., Van Engelen A.F.V., Førland E., Mietus M., Coelho F., Mares C., Razuvaev V., Nieplova E., Cegnar T., Antonio López J., Dahlström B., Moberg A., Kirchhofer W., Ceylan A., Pachaliuk O., Alexander L.V., Petrovic P. (2002): Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. Int. J. Climatol. 22: 1441–1453.

Klok E.J., Klein Tank A.M.G. (2009): Updated and extended European dataset of daily climate observations. Int. J. Climatol. 29: 1182–1191.

Kostopoulou E., Jones P.D. (2007): Comprehensive analysis of the climate variability in the eastern Mediterranean. Part II: relationships between atmospheric circulation patterns and surface climatic elements. Int. J. Climatol. 27: 1351–1371.

Küttel M., Luterbacher J., Wanner H. (in press): Multidecadal changes in winter circulation-climate relationship in Europe: frequency variations, within-type modifications, and long-term trends. Clim. Dyn., DOI 10.1007/s00382-009-0737-y.

Kyselý J. (2008): Influence of the persistence of circulation patterns on warm and cold temperature anomalies in Europe: analysis over the 20th century. Glob. Planet. Change 62: 147–163.

Kyselý J., Domonkos P. (2006): Recent increase in persistence of atmospheric circulation over Europe: comparison with long-term variations since 1881. Int. J. Climatol. 26: 461–483.

Kyselý J., Huth R. (2006): Changes in atmospheric circulation over Europe detected by objective and subjective methods. Theor. Appl. Climatol. 85: 19–36.

Lamb H.H. (1972): British Isles Weather Types and a Register of Daily Sequence of Circulation Patterns, 1861–1971. Geophysical Memoir 116, HMSO, London, UK, 85 pp.

Lityński J. (1969): Liczbowa klasyfikacja typów cyrkulacji i typów pogody dla Polski (Numerical classification of circulation types and weather types of Poland). Prace PIHM 97, 3–14, Warszawa, Poland (in Polish).

Lorenzo M.N., Taboada J.J., Gimeno L. (2008): Links between circulation weather types and teleconnection patterns and their influence on precipitation patterns in Galicia (NW Spain). Int. J. Climatol. 28: 1493–1505.

Lund I.A. (1963): Map-pattern classification by statistical methods. J. Appl. Meteorol. 2: 56–65.

Makra L., Mika J., Bartzokas A., Sümeghy Z. (2007): Relationship between the Péczely's large-scale weather types and air pollution levels in Szeged, southern Hungary. Fresenius Environmental Bulletin 16: 660–673.

Michaelides S.C., Liassidou F., Schizas C.N. (2007): Synoptic classification and establishment of analogues with artificial neural networks. Pure Appl. Geophys. 164: 1347–1364.

Michelangeli P.-A., Vautard R., Legras B. (1995): Weather regimes: recurrence and quasi stationarity. J. Atmos. Sci. 52: 1237–1256.

Osborn T.J., Jones P.D. (2000): Air flow influences on local climate: observed United Kingdom climate variations. Atmos. Sci. Let. 1: 62–74.

Péczely G. (1983): Catalogue of the macrosynoptic types for Hungary (1881–1983). Publications of the Hungarian Meteorological Service, Volume 53, Budapest, Hungary, 116 pp. (in Hungarian).

Petisco E., Martín J.M. (1995): Caracterización de la Circulación General Atmosférica en la Península Ibérica y Baleares (Characterization of the atmospheric general circulation in the Iberian Peninsula and Balearic Islands). Tech. Note 5, Service of Analysis and Research of Climate, Instituto Nacional de Meteorología, Madrid, Spain (in Spanish).

Pettersen S. (1950): Some aspects of the general circulation of the atmosphere. Centennial Proc. Roy. Meteor. Soc. London, 120–155.

Philipp A., Bartholy J., Beck C., Erpicum M., Esteban P., Fettweis X., Huth R., James P., Jourdain S., Kreienkamp F., Krennert T., Lykoudis S., Michalides S.C., Pianko-Kluczynska K., Post P., Álvarez D.R., Schiemann R., Spekat A., Tymvios F.S. (2010): COST733CAT – a database of weather and circulation type classifications. Phys. Chem. Earth 35: 360–373.

Philipp A., Della-Marta P. M., Jacobeit J., Fereday D. R., Jones P. D., Moberg A., Wanner H. (2007): Long-term variability of daily North Atlantic-European pressure patterns since 1850 classified by simulated annealing clustering. J. Climate 20, 4065–4095.

Plaut G., Simonnet E. (2001): Large-scale circulation classification, weather regimes, and local climate over France, the Alps and Western Europe. Clim. Res. 17: 303–324.

Rossby C.-G. (1939): Relations between variations in the intensity of the zonal circulation of the atmosphere and the displacements of the semipermanent centers of action. J. Mar. Res. 2: 38–55.

Sepp M. (2005): Influence of atmospheric circulation on environmental variables in Estonia. Dissertationes geographicae universitatis Tartuensis 25, Tartu, Estonia.

Schüepp M. (1968): Kalender der Wetter- und Witterungslagen von 1955 bis 1967. MeteoSchweiz Veröffentlichungen, 11, 44 pp. (in German).

Slonosky V.C., Jones P.D., Davies T.D. (2001): Atmospheric circulation and surface temperature in Europe from the 18th century to 1995. Int. J. Climatol. 21: 63–75.

Stefanicki G., Talkner P., Weber R.O. (1998): Frequency changes of weather types in the Alpine region since 1945. Theor. Appl. Climatol. 60: 47–61.

Trenberth K.E., Jones P.D., Ambenje P., Bojariu R., Easterling D., Klein Tank A., Parker D., Rahimzadeh F., Renwick J.A., Rusticucci M., Soden B., Zhai P. (2007): Observations: Surface and Atmospheric Climate Change. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon S., Qin D., Manning M., Chen Z., Marquis M., Averyt K.B., Tignor M. and Miller H.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Trigo R.M., DaCamara C.C. (2000): Circulation weather types and their influence on the precipitation regime in Portugal. Int. J. Climatol. 20: 1559–1581.

Twardosz R., Niedźwiedź T. (2001): Influence of synoptic situations on the precipitation in Kraków (Poland). Int. J. Climatol. 21: 467–481.

Uppala S.M., Kållberg P.W., Simmons A.J., Andrae U., Da Costa Bechtold V., Fiorino M., Gibson J.K., Haseler J., Hernandez A., Kelly G.A., Li X., Onogi K., Saarinen S., Sokka N., Allan R.P., Andersson E., Arpe K., Balmaseda M.A., Beljaars A.C.M., Van De Berg L., Bidlot J., Bormann N., Caires S., Chevallier F., Dethof A., Dragosavac M., Fisher M., Fuentes M., Hagemann S., Hólm E., Hoskins B.J., Isaksen L., Janssen P.A.E.M., Jenne R., McNally A.P., Mahfouf J.-F., Morcrette J.-J., Rayner N.A., Saunders R.W., Simon P., Sterl A., Trenberth K.E., Untch A., Vasiljevic D., Viterbo P., Woollen J. (2005): The ERA-40 re-analysis. Q. J. R. Meteorol. Soc. 131: 2961–3211.

Walker G.T. (1924): Correlation in seasonal variation of weather, IX, A further study of world weather. Mem. Ind. Met. Dept 24: 275–332.

Walker G.T., Bliss E.W. (1932): World weather V. Mem. Roy. Meteor. Soc. 4: 53–84.

Wallace J.M., Gutzler D.S. (1981): Teleconnections in the geopotential height field during the Northern Hemisphere winter. Mon. Weather Rev. 109: 784–812.

Werner P.C., Gerstengarbe F.-W., Fraedrich K., Oesterle H. (2000): Recent climate change in the North Atlantic/European sector. Int. J. Climatol. 20: 463–471.

14. List of abbreviations

A	anticyclonic
BR	subjective circulation type classification of HMI/CHMI according to the methodology of Brádka et al. (1961)
C	cyclonic
CEC	objective circulation type classification based on k-means clustering
CHMI	Czech Hydrometeorological Institute
CKMEANS	objective circulation type classification based on k-means clustering
CL	cloudiness (in tenths)
COST	European Cooperation in Science and Technology – intergovernmental framework funded by the European Comission
COST733	project within the COST program, 2005–2010, title: Harmonisation and Applications of Weather Type Classifications for European Regions
CT	circulation type
DJF	winter (December, January, February)
DWD	Deutscher Wetterdienst (German Weather Service)
E	east; easterly
ECA&D	European Climate Assessment & Dataset
ECMWF	European Centre for Medium-Range Weather Forecasts (Reading, Great Britain)
EOF	empirical orthogonal function
ERA-40	reanalysis of surface and upper-level climate for the period 9/1957–8/2002, produced by the ECMWF
EV	explained variance
GCM	global climate model
GWT	objective circulation type classification based on similarity with circulation prototypes
H–B	subjective circulation type classification of DWD according to the methodology of Hess and Brezowsky (1952)
HBGWL	same as H-B (original Hess–Brezowsky catalogue with 29 types)
HBGWT	HBGWL with the 29 circulation types grouped into 10 major types
HMI	Hydrometeorological Institute of the former Czechoslovakia
JJA	summer (June, July, August)
LITADVE	objective circulation type classification based on flow and vorticity indices (9 types)
LITC18	objective circulation type classification based on flow and vorticity indices (18 types)

LITTC	objective circulation type classification based on flow and vorticity indices (27 types)
LUND	objective circulation type classification based on correlation between circulation patterns
LWT2	objective circulation type classification based on flow and vorticity indices
MAM	spring (March, April, May)
N	north; northerly
NAO	North Atlantic Oscillation
NAOI	North Atlantic Oscillation Index
NCAR	National Center for Atmospheric Research (Boulder, Colorado, USA)
NCEP	United States National Centers for Environmental Prediction
NCEP/NCAR	reanalysis of surface and upper-level climate since 1948, updated regularly
NE	northeast; northeasterly
NNW	objective circulation type classification based on artificial neural networks
NPO	North Pacific Oscillation
NW	northwest; northwesterly
OGWL	objectivized Hess–Brezowsky classification
OGWL-3d+	objectivized Hess–Brezowsky classification with a minimum 3-day duration of CTs
P27	objective circulation type classification based on S-mode PCA scores
PCA	principal component analysis
PCACA	objective circulation type classification based on k-means clustering
PCAXTR	objective circulation type classification based on extreme S-mode PCA scores, without iterations
PCAXTRKM	objective circulation type classification based on extreme S-mode PCA scores, with iterations
PDF	probability density function
PECZELY	Hungarian subjective circulation type classification
PERRET	Swiss subjective circulation type classification
PETISCO	objective circulation type classification based on correlation between circulation patterns
PIK	Potsdam Institute for Climate Impact Research (Potsdam-Institut für Klimafolgenforschung)
PR	daily precipitation amount at Czech stations (in mm)
PRO	occurrence of precipitation equal to or higher than 0.1 mm/day (values either 0 or 1)
PW	precipitable water
RCM	regional climate model

RH	relative humidity (in %)
RR	daily precipitation amount at the ECA&D stations (in mm)
S	south; southerly
SANDRA	objective circulation type classification based on optimized clustering (Simmulated ANnealing and Diversified RAndomization)
SANDRAS	objective circulation type classification of 3-day sequences based on optimized clustering (Simmulated ANnealing and Diversified RAndomization)
SCHUEEPP	Swiss subjective circulation type classification
SE	southeast; southeasterly
SHMI	Slovak Hydrometeorological Institute
SLP	sea level pressure (in hPa)
SO	Southern Oscillation
SON	autumn (September, October, November)
SUN	sunshine duration (in h/day)
SW	southwest; southwesterly
T	mean daily surface air temperature (in °C)
TN	minimum daily surface air temperature (in °C)
TPCA	circulation type classification based on T-mode PCA
TPCAV	circulation type classification based on T-mode PCA, with variable number of types
TX	maximum daily surface air temperature (in °C)
U700	zonal component of wind at the 700 hPa level
V700	meridional component of wind at the 700 hPa level
W	west; westerly
WLKC733	objective circulation type classification based on predefined thresholds of flow indices and PW
WSD	within-type standard deviation
Z500	geopotential height of the 500 hPa level (in gpm)
ZAMG	Zentralanstalt für Meteorologie und Geodynamik (Austrian Weather Service), and a subjective circulation type classification produced therein