DISSERTATIONES GEOGRAPHICAE UNIVERSITATIS TARTUENSIS

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INFLUENCE OF ATMOSPHERIC CIRCULATION ON ENVIRONMENTAL VARIABLES IN ESTONIA

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LIST OF PAPERS

This dissertation is based on following papers I–IV, which are referred to in the text by their Roman numerals:

I **Sepp, M**., & Jaagus, J. (2002) Frequency of circulation patterns and air temperature variations in Europe. Boreal Environment Research, 7(3), 273–279.

II Aasa, A., Jaagus, J., Ahas, R., & **Sepp, M**. (2004) The influence of atmospheric circulation on plant phenological phases in central and eastern Europe. International Journal of Climatology, 24(12), 1551–1564.

III **Sepp, M**., Post, P. & Jaagus, J., (2005). Long-term changes in the frequency of cyclones and their trajectories in Central and Northern Europe. Nordic Hydrology, 36, 297–309.

IV Pensa, M., **Sepp, M**. & Jalkanen, R., Connections between climatic variables and the growth and needle dynamics of Scots pine (*Pinus sylvestris* L.) in Estonia and Lapland. International Journal of Biometeorology (in press)

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I The author is responsible for the theoretical part, data collecting and processing, analysis and discussion of results, and the preparation of the manuscript.

II The author participated in the data preparation, description of the circulation characteristics, analysis and interpretation of results.

III The author is responsible for the initiation of the study, for the theoretical part, data processing, analysis and discussion of results, and the preparation of the manuscript.

IV The author is the initiator of the study, partly responsible for data processing and theoretical part of article, analysis and interpretation of results.

ABSTRACT

Climatology, including synoptic climatology, has very rapidly developed since the 1990s. After the Brent Yarnal's summarising monograph (Yarnal, 1993), the study area of synoptic climatology has broadened significantly. Research methods, which were earlier used only in atmospheric sciences, are now used to analyse all environmental characteristics depending on climate.

This research proceeds from the definition of synoptic climatology presented by Yarnal. Accordingly, it is a branch of climatology that studies relationships between the processes of atmospheric circulation and environmental variables.

In the theoretical part of the thesis, an overview of the history, method and perspectives of synoptical climatology are presented. The development of the Vangengeim-Girs classification of atmospheric circulation is discussed in detail, since the classification is one of the main topics of the thesis.

In the empirical part, relationships between circulation and environmental parameters are analysed. Relationships between the frequency of the circulation forms W, E and C according to the Vangengeim-Girs classification and air temperature in Europe and specifically in Estonia are studied using the correlation analysis. The results testify that this classification has a high correlation with air temperature in northern and eastern Europe including Estonia. The closest relationships proved to occur in winter and summer. The zonal circulation form W reflects the prevalence of westerlies. Its frequency is positively correlated with air temperature in winter and negatively in summer, especially in the Baltic Sea region and northwestern Russia. The meridional circulation form E reflects easterly, southeasterly and southerly airflow in Estonia. Its frequency has opposite relationships with temperature in comparison with the form W. Accordingly, positive correlation exists in summer, especially in northern Europe, and negative correlation in winter, covering a huge territory. The frequency of the circulation form C reflecting northerly airflow has a negative correlation with air temperature throughout a year with maximums in spring and autumn. Similar relationships between circulation and temperature were obtained also for Estonia.

Substantial fluctuations have occurred in the frequencies of the circulation forms during the study period (1891–2001). Results of linear regression analysis detected an increasing tendency in the frequency of the form E and decreasing trends in the other circulation forms. However, these trends are not present when we look at smaller time intervals of the long series. Large variations have been observed in circulation. Also, the correlation varies significantly during more than 100 years. It refers to the possibility that substantial variations exist in the frequencies of single circulation types, which are grouped into the three main circulation forms.

Due to the fact that the Vangengeim-Girs classification data do not allow, at the moment, a more detailed analysis on the level of circulation types, an

analysis based on a cyclone database was carried out. Weather conditions in Estonia and over the whole Baltic Sea region depend very much on the frequency and trajectories of cyclones coming from the Atlantic. They conduct the movement of air masses. Depending on cyclone trajectories, mild and moist maritime air from the Atlantic, dry and cold (in winter) or warm (in summer) continental air from the East European Plain or cold and dry Arctic air may dominate in Estonia. During the period 1948–2000, the number of cyclones passing Estonia from the northern side is increased in winter. These cyclones induce advections of mild and moist maritime air to the territory of Estonia.

In the third part of the results, the influence of large-scale atmospheric circulation on phenological phases, and on Scots pine growth indicators and needle dynamics are discussed. While the spring phenophases depend very much on air temperature during the winter and early spring, correlations between circulation variables and phenophases dates are close.

The Scots pine growth indicators do not have clear relationships with circulation at least in Estonia. The growth of trees is much more specifically determine by other, mostly local factors.

1. INTRODUCTION

Climatology is a rapidly developing science. An enormous quantitative and qualitative advance has been made during the last 15 years, supported by a number of important developments. Contemporary computers allow almost limitless data processing; huge climatological datasets have been composed and made freely available on the Internet.

A wide public interest in the problems of climate change has been the second "driving engine" accelerating climatological studies. The media is reflecting every weather related catastrophe all over the world. Theories of the greenhouse effect and climate warming are also widely discussed in the scientific community. Governments are worried about fast climate changes that can cause security risks and threaten public wealth. All these circumstances have prepared a fertile ground for the development of synoptic climatology.

The knowledge on how climate affects environmental variables and society has significantly extended, having led to the widening of the scope of synoptic climatology. This study proceeds from the definition of synoptic climatology presented by Brent Yarnal (1993), stating that its research field would not be only meteorological phenomena but also all characteristics of the environment, which are affected by atmospheric circulation and weather fluctuations.

Meteorological conditions in Estonia are very variable, always changing, being affected by atmospheric circulation — the permanent moving of air masses. Depending on the peculiarities of circulation, the area is frequently governed by maritime polar air bringing mild weather in winter and cool moist weather in summer, as well as by continental polar air followed by frost in winter and warmth in summer. In addition, advections of the Arctic air are often observed in winter and spring, and of tropic air — sometimes in summer. Relating synoptic processes with climate changes gives an opportunity to compose long-term weather forecasts.

The main objective of this dissertation is to get better acquainted with mechanisms of atmospheric circulation influencing climate in Estonia, and with their impacts on natural environment. To reach this objective, a number of tasks should be solved:

- to present a theoretical overview on synoptic climatology and its research area;
- to describe the Vangengeim-Girs classification of atmospheric circulation, which is rarely used nowadays, and to analyse long-term fluctuations and trends in the frequency of the main circulation forms;
- to analyse relationships between the frequency of the circulation forms and temperature in Estonia and in the whole Europe;
- to analyse dynamics of the frequency of different cyclone trajectories over northern Europe;

- to analyse the influence of atmospheric circulation on some vegetation parameters in Estonia.

This thesis consists of two major parts. The first part is theoretical, offering an overview of the history, developments and methods of synoptic climatology. Its aim is to summarise the achievements, current situation and perspectives in this field of science in the world and also in Estonia. The empirical second part is based on the four articles included into the thesis. Chapter 4 deals with frequencies in the circulation forms and their relations to air temperature, Chapter 5 discusses problems of cyclones frequencies and trajectories and Chapter 6 observes the influence of atmospheric circulation on vegetation.

2. SYNOPTIC CLIMATOLOGY: OVERVIEW OF ITS HISTORY, DEVELOPMENT AND METHODS

2.1. Definition of synoptic climatology

The developments of the few last decades in the science methodology and an increase in computer capacity have brought along changes in many concepts of climatology (Byrson, 1997). Important changes can also be viewed in the ways synoptic climatology is defined.

Presumably, the term ‘synoptic climatology’ first appeared in climate research that was conducted under the jurisdiction of the US Air Force Headquarters (Jacobs, 1947; Barry, Perry, 1973; Harman, Winkler, 1991). In the process, synoptic data that had been collected during the previous decades was processed with the aim to find statistical regularities in the sequence of weather phenomena, and present long-term forecasts accordingly. At about the same time and in similar context, the same term was also taken to use by the British scientists (Barry, Perry, 1973).

Since that time, several definitions for synoptic climatology have been offered at different climate research centres around the world. In a book published in 1973, R. G. Barry and A. H. Perry summarised and analysed everything that had been achieved in the field of synoptic climatology by that time. By the authors’ definition, the aim of synoptic climatology is to study correlations between atmospheric circulation and local or regional climate. They think that there are two main stages that characterise the studies falling under synoptic climatology: 1) classification of the atmospheric circulation and 2) finding the correlations between the assigned circulation types and weather elements (Barry, Perry, 1973).

The base of synoptic climatology is therefore the classification of atmospheric circulation processes (e.g. circulation types, forms, patterns, etc). In turn, the basis of classification has been the observation that there are some spatial and temporal similarities occurring in the circulation processes. That means that from time to time, there occur analogues with previous situations in terms of pressure area locations and cyclone trajectories, as well as other variables that describe weather. Such processes that evolve by one scenario follow the same direction for approximately 3–4 days, after which there is a rapid, steep change in circulation conditions (Baur, 1963; Girs, 1960, 1971, 1974; Barry, Perry, 1973, Dzerdzeevski, 1975; Girs, Kondratovich, 1978; Bárdossy, Caspary, 1990).

Another feature that is characteristic to synoptic climatology is spatial dimension or more specifically: regionality. More simply, it could be said that synoptic climatology is engaged in the classification of circulation processes and studying their influences on a smaller area than a hemisphere. In scales, the synoptic climatology differs from its “elder brother”, dynamic climatology that studies the processes on the level of hemispheres and bigger (Barry, Perry, 1973).

But if we wish to define as precisely as possible the spatial dimension of synoptic climatology, we could base on the definition of F. K. Hare (1955; Barry, Perry, 1973), by which the synoptic climatology "deals specifically with regions small enough for the recognized circulation types to be interpreted in the ordinary weather elements". In practice, neither the general, nor the specific definition of spatial dimension, are the one and only true definitions. Generally, the scales of dynamic climatology are determined by the dimension of total circulation processes. The observed area is so big that it is possible to describe the emergence and intensity of the (circulation) systems that are clearly distinguishable and more or less closed in a thermodynamic sense (Bergeron, 1930; Barry, Perry, 1973). This area may be, for example, the so-called Atlantic-Eurasian sector. The synoptic climatologists very often proceed from the applicable aims (or pragmatic considerations) when choosing spatial dimensions — "local" or "regional" conditions are under observation. 'Regionality' can by the example of USA denote the whole country, state, a group of states (e.g. the North East, New York region) or a drainage area of a river (e.g. Missouri) (Barry, Perry, 1973; Yarnal, 1993; Yarnal *et al,* 2001).

However, the classifications that focus only on regionality, have been severely criticized (Dzerdzeevski, 1975; Girs, 1971; 1974; Girs, Kondratovich, 1978). The main argument of the critics is the fact that several of these classifications tackle weather processes above a region, as if they stood apart from the general atmospheric circulation processes. But in case of especially small regions, it can create a situation where formally similar, but genetically different circulation conditions are grouped in one class.

At the same time, the classifications that encompass the circulation of the whole hemisphere are not particularly good for solving regional functions — their generalization is too wide. For example, a two-hundred-kilometre shift of a thermo-baric wave does not necessarily mean its belonging in another circulation type. However, this kind of a 'nudge' in the context of Estonia would bring along absolutely different weather conditions. Therefore, the classifications with a big generalisation are also usually divided into smaller subtypes, or the circulation processes are viewed by hemispheric sectors (Girs, 1971; 1974; Dzerdzeevski, 1975; Girs, Kondratovich, 1978).

After the fundamental work of Barry and Perry, synoptic climatology has substantially evolved. There have emerged new generalizing works (e.g. Yarnal, 1993, Barry, Carleton, 2001). The idea of what is the study object of the discipline has greatly changed due to Brent Yarnal's works. The new developments mentioned have been more thoroughly treated in the following subchapter.

2.2. History and developments in synoptic climatology

The attempts to classify circulation processes were already made in the 19th century. W. Köppen and W. J. van Bebber are most often mentioned among the first researchers. Köppen studied how the weather in St. Petersburg depended of the positions of air pressure areas. He distinguished six typical situations (classes): the centre of a cyclone or an anti-cyclone is above St. Petersburg; the prevailing air currents originate either from the cyclone or the anti-cyclone; two intermediate (transition) situations. As a relatively simple classification principle, Köppen's approach is also quite usual nowadays, especially in describing the circulation conditions of the smaller areas (Barry, Perry, 1973).

W. J. van Bebber based his research on anti-cyclone locations, and depression trajectories. He determined five basic cyclone trajectories. But the analysed time-series was very short (5 years), and the mentioned trajectories do not characterize all the main movements of cyclones, on account of which van Bebber's works have merely the historical value (Barry, Perry, 1973; Girs, Kondratovich, 1978; Heyer, 1988).

The interest to study and classify atmospheric circulation processes increased in 1930s. Most relevant parts of the weather system that direct circulation, were largely by then thoroughly studied and described. All preconditions developed for the birth of synoptic climatology. Due to the 'Bergen school', headed by V. Bjerknes (1862–1951), the synoptic meteorology had already developed in the second decade of the 20th century (Bjerknes *et al,* 1933). In 1920s, the synoptic meteorology also developed outstandingly fast in the Soviet Russia, under the leadership of B.P. Multanovski (1876–1938) (Girs, 1971; 1974; Girs, Kondratovich, 1978).

Another presumption of the synoptic climatology was the sufficiently long (in some places up to 50-year-long) time-series of meteorological data that enabled to do statistically reliable generalizations.

The first works that can be placed under synoptic climatology in their contents, started practically in parallel in Germany and the Soviet Union. In Germany, 1929, the Ministry of Agriculture initiated the founding of a research institute, with a purpose to compile long-term weather forecasts for the Central Europe (Germany). After experimenting with different methods the classification of weather types was started. Under the direction of Franz Baur (1887–1977), a treatise was published in 1944 (Baur, 1963; Bardossy, Caspary, 1990), where were presented the developed classification principles.

The basis of the classification that concentrated on the Central European weather conditions is the so-called *Grosswetterlagen* (GWL). In total, 29 circulation types were distinguished that further aggregate into three circulation groups — zonal, meridional and half-meridional (Bardossy, Caspary, 1990; Gerstengarbe *et al*, 1993).

Unfortunately, the science institute where classifications were done, was financed by *Luftwaffe* during the Second World War, and was abolished after the victory of the coalition (Baur, 1963; Barry, Perry, 1973). His connections with the army is probably the reason why F. Baur's name does not have a place in the science circles for a still successfully persisting classification name. In these days, it is known by the names of Paul Hess and Helmuth Brezowsky (1969) that developed the work on (Bardossy, Caspary, 1990).

In the Soviet Union, a branch separated from the renowned Multanovski School in 1930s, seeing the solution of synoptic problems in the classification of general atmospheric processes. B. Multanovski's student, Georgi Vangengeim (1896–1961), whose classification is more precisely treated in the next chapter, became the leader of the new school.

The scientific branch that had primarily originated from a militaristic need made fast development after the war. New classifications or approaches for describing weather processes were made practically at every part of the world (Barry, Perry, 1973). Of the post-war works the one by Boris Dzerdzeevski (1898–1971) who created a classification of the whole northern hemisphere, in the Institute of Geography of the Soviet Academy of Sciences, should especially be brought forth (Dzerdzeevski, 1975); as well as Humbert H. Lamb's classification of a circulation above the British Isles (Lamb, 1972) and Muller's classification in USA (Muller, 1977). Studying the circulation, and weather as a whole with the means of classification, lasted almost until the end of the sixties (eighties in the Soviet region). It was also quite common to modify a pre-made classification and apply it in the local region (Yarnal, 1993; Buishand, Brandsma, 1997). The modifications of *Grosswetterlagen* spread in Europe. For example, in Hungary (Peczely, 1957) and Czechoslovakia (Bradka *et al,* 1961) a local GWL classification was created. The Austrians worked out a classification that describes the circulation conditions of the Alpine region deriving from the principles of GWL (Schüepp, Fliri, 1967). The treatment on the British Isles by H.H. Lamb, which is also widely renowned in Europe, has similarities with Hess-Brezowsky's classification (Lamb, 1972). Lamb's classification is much simpler than its predecessor and is in turn a basis for several regional classifications — for example in Poland, to describe the circulations above the pool of the upper course of river Visla (Niedźwiedź, 1983; 1992). B. Osuchowska-Klein (1978) developed rather simple classification with 13 circulation types covering whole Poland.

Until the end of 1960s the classification of circulation processes meant only the reasoning of only one scientist or a group of practitioners. All mentioned classifications, were compiled namely by this method. Usually, the classifiers were forecasters with long-term experience.

This kind of a classification 'by eye' however, suffers from subjectivities. By the same initial sources and methods of classification, the different researchers form a different time-series. That means that different people 'see' (cognise) circulation processes absolutely differently and therefore divide them into different classes. Brent Yarnal did an experiment, where two similarly instructed groups of classifiers appointed into classes the circulation data for every day during exactly the same period. The concurrencies of the two time-series were only 75% in average (Yarnal, 1993; Frakes, Yarnal, 1997).

After the works of Lund (1963), Kirchhofer (1973) and many others (e.g. Stidd, 1967; Bryson, 1966; Cristensen, Bryson, 1966; Kutzbach, 1967) in which the most current, computer-operated classification methods were presented — the so-called subjective classifications, were struck by serve criticism. The works done by computers were declared "objective". This way, Barry and Perry (1973) divide the classifications into two clear groups by the principles of used methodology: subjective (humans appoint) and objective. The objective classification is done by certain mathematical algorithms, which are resolved by the computer. With the same initial data, the time-series is identically repeatable by anyone.

The so-called computer boom brought along the transformation of synoptic climatology and a relative low of it (Yarnal, 1993). For example, according to the referring magazine *Meteorological and Geoastrophysical Abstracts,* the number of articles related to the synoptic climatology, published from 1970s to the mid-1980s, was almost only half of what was published in 1960s (Smithson, 1988). The reason for the low period might also be the changing of the generation or then paradigm — the classifications by the 'old school' climatologists-forecasters were not taken seriously anymore. The modelling of climate processes, which seemed to be more progressive with the relatively limited computer resources, captured the young weather scientists, who knew computer techniques.

However, we cannot say that there was no activity in the field of classification of the circulation processes. The more relevant issues of the so-called subjective classifications were published namely in 1970s. Still, we should mention that they are summaries that give an overview of the research done in the previous thirty to forty years.

Of course, some totally new approaches were also published, like the attempt of Jenkinson and Collison (1977) to make Lamb's classification automatic. But as a general tendency, the leading role in synoptic climatology went over from the forecasters to people educated in geography. As a result of this tendency, the application of the scientific branch developed immensely, although not in the area of weather forecast.

Soon, there was a situation, where the definition of synoptic climatology by Barry and Perry (1973) did not cover all the areas, where the principles and methods of the given branch of science were used. So, many of the scientists who were engaged in the classification of circulation processes, did not define themselves as synoptic climatologists, and in the "key words" of articles, the connection with this branch of climatology was not mentioned. Often, the corresponding articles were published in issues that were not dealing with weather science or even geography (Yarnal, 1993).

The book that was published in 1993 by Brent Yarnal, a geographer at the University of Pennsylvania, USA, became a sign of an entirely new era. He treats the field of research of synoptic climatology much wider than it would be allowed by the definition of Barry and Perry. While their definition speaks about finding correlations between 'circulation types and weather elements', then instead of weather elements, Yarnal used 'environmental conditions'.

Yarnal (1993) divides the researches that fall under synoptic climatology into two by aims and methodology of the research: either the correlation between environment indicators and circulation is studied, or the influence of circulation to the environment. In the first case, the specific environmental conditions close to ground are being observed, and the study object is the correlation with circulation processes. On most cases, the environmental condition are still seen to consist of weather indicators (temperature, precipitation, etc), but in the newest approaches, for example acid rains or division process of ozone, human health problems, and also how the distribution of plant pests depends on circulation types, is seen as environmental conditions.

The other possibility is that firstly, classification time-series are being observed, and compared to the environmental indicators. It might seem that it is only a word-play (circulation-environment, environment-circulation), but in its contents it signifies the difference of the scientists' worldviews.

This kind of a broadening of the study area (or the world view) brought along a boom of articles in 1990s in especially the science circles of the US (Yarnal *et al,* 2001). The geographers of the younger generation, who study changes in the environment and their possible dependence on atmospheric circulation, have started to identify themselves as synoptic climatologists.

On the other hand, there is a certain conflict between the meteorologists and geographers. In addition to the branch of science that had originally come about to perform long-term weather forecasts, the geographers have created new study areas, that can barely associate with weather forecasts.

It must be said that the forecasters themselves have abandoned synoptic climatology, preferring first and foremost the numerical modelling, dynamic climatology and other science methods or their combinations in compiling the long-term forecasts (Harman, Winkler, 1991; Yarnal, 1993; Yarnal *et al,* 2001).

The merging or different study methods have brought along a situation, where the placing of some study under one or another branch of science, is quite complicated. In articles (Oliver *et al,* 1989, Rogers *et al,* 2000), an idea was offered to avoid misunderstandings that all the different sciences that study climate changes should be united under a singe term, for example *climate dynamics*. Until this day, this proposal has not taken root.

When talking about the future perspectives of synoptic climatology, then two things are kept in mind: application of classifications and developments of the methodology (Harman, Winkler, 1991; Yarnal, 1993; Yarnal *et al*, 2001). Developments in methodology are discussed in next sub-chapter.

As we can conclude from the above, the modern synoptic climatology has not very much in common with the aims for which it was initially established — to compile long-term weather forecasts.

While the long-term weather forecasts are on an important place in the book by Barry and Perry (1973), then Yarnal (1993) barely touches upon the questions of weather forecasting. The forecast of circulation conditions is also not treated in the book by Barry and Carleton (2001). Such a drastic change is logical, regarding the development of synoptic methods in the last four decades — in that department, the numerical methods and modelling, have become predominant. The classifications of atmospheric processes have been set-aside in the context of weather forecasting. The author has met actual long-term prognosis very rarely. One of them is the application of Klein's (1983) method to forecast the air temperature above USA. The other is the prognosis of the ice conditions on the Northern Ice road by Vangngeim-Girs classification (Girs, 1971, 1974; Girs, Kondratovich, 1978). But in connection with the degradation of economy in the northern area of Russia, the prognosis of the navigation conditions in the polar seas have lost their clients, and have fallen on the verge of extinction (Dmitriev, 2002).

One of the outstanding attempts to forecast the background of the circulation conditions of the following decade via the changes of solar activity is presented by M. Bolotinskaja (1965; Bolotinskaja, Beljazo, 1969). The correlations brought out in the works (Bolotinskja, 1965; Bolotinskaja, Beljazo, 1969) between the solar activity and the frequency of circulation types, are encouraging in a synoptic sense: the so-called subsequent coincidence of the prognosis with the actual conditions in the analysed period of 1901–1962 was 68% in average. Unfortunately, the prognosis for 1965–2000, given by Bolotinskaja and Beljazo (1969), failed entirely. M. Bolotinskaja admitted in an article published in 1986 that the given forecast did not fulfils, but she brought as the objective reason for the failure the total falseness of the forecast for solar activity that was the basis for the prognosis (Bolotinskaja, 1986).

When reading the works on synoptic climatology from the past twenty years, one gets an impression that there is a mutual agreement due to which people are waiting when the mathematical statistics or non-linear mathematics will find a method for compiling sufficiently reliable prognosis (or until the helio-physicists have solved the mysteries of the cyclicity of solar activity). But until that the scientists are engaged in finding all kinds of correlations between classifications and different natural or also social processes.

Thus, one can presume that the grip of geographers in synoptic climatology will become even stronger. Certainly, this kind of development will only contribute to geography as a science. Very many natural processes are largely dependant on the climatic, including circulation processes, and the study methods of synoptic climatology are quite comfortable for finding and evaluating different correlations. But on the other hand still, is it all right to use the term ’synoptic climatology’, if the activity has nothing to do with forecasting anymore?

One can presume that also the other sciences the study objects that are dependant on weather changes (like botany, zoology, etc) apply the principles of synoptic climatology in their work, and offer their own solutions for the work under discussion. For example a hybrid of dendrology and synoptic climatology would be the synoptic dendro-climatology.

The applying of new methods (Monte Carlo test, etc) for evaluating the connections between circulation types and environmental conditions is very important (Yarnal *et al*, 2001). The hope expressed in a book by Yarnal (1993) to apply the principles of geographical information system (GIS) in synoptic climatology, has initially not come true in great extent (Yarnal *et al,* 2001). True, during the last decade, great work has been done to build up electronic databases for meteorology, and to integrate them and make them accessible via the Internet. Even with the simplest and generally used programs (e.g. MS Excel, not to mention StatSoft Statistica or SAS), it is possible to perform the analysis of such data that would not have been possible 25 years ago, or would have taken very much time. Also, compiling figures, graphs and other illustrative parts of research papers have become very simple using computers (Maracchi *et al,* 2001, Yarnal *et al*, 2001). Unfortunately, the most important side of GIS — analysis — remains too weak for the climatologic appliances (Yarnal *et al,* 2001). Although all the conditions and the means are there (Maracchi *et al*, 2001) the thoroughgoing analysis will probably take time. Primarily, there is much to do in finding correlations between environmental indicators and atmospheric processes.

2.3. Methods of classification

Another remarkable feature of Yarnal’s book (1993) is the profound overview of the positive sides and weaknesses of different classification methods. The main distinctive feature of his previous summarizing works is that he rehabilitated the so-called subjective classifications of the atmospheric circulation. While in the article by A. Perry (1983) and also in the article by A.K.A El-Kadi and P.A. Smithson, published in 1992, all the classifications are traditionally divided in two groups: subjective and objective, then B. Yarnal denies such division. In the more recent articles (Yarnal, White, 1987; Yarnal *et al*, 1988) it has been shown that actually, the classifications that are compiled by the use of computers are not principally more 'objective' than the subjective classifications. Although the computer-operated works are free of homogeneity problems, the works still remain subjective from the start. It remains to be decided by the researcher, what will be the structure of the classification, how and which initial data, algorithms, etc to use. This way, Yarnal recommends giving up the emotional division of classifications into subjective and objective, but either manual or automatized (Yarnal, 1993).

In addition, Yarnal finds that there is a certain unsurpassed virtue to the hand-made approaches that gets lost in automatizing the classifications. That could provisionally be called an empirical generalization. While the computer ’sees’ and ’slices’ the circulation processes only according to the given limit values, then a person can fathom the processes on synoptic maps as an undivided temporal and spatial whole. He can capture also those nuances of dynamics that have been impossible so far to explain to the computer (Yarnal, 1993).

This is why B. Yarnal places the hand-made classification method next to others as an equal. By him (Yarnal, 1993; Yarnal *et al,* 2001), eight most used classification methods can now be distinguished in synoptic climatology:

1. *Manual classifications* or the so-called subjective classifications of the general atmospheric circulation. During the work, every classifier looks at the synoptic maps of each day of the processed period, and divides them into circulation types according to the direction of atmospheric circulation processes, fronts, positions of pressure areas, etc, and basing on one’s own experience (Barry, Perry, 1973; Yarnal, 1993).
2. Correlation-based map patterns or the Lund’s (1963) and Kirchhofer’s (1973) method. The automatized method that spread in 1970s–1980s. The computer calculates according to the specific instructions the correlations between the real synoptic maps and an example map that are given as a standard.
3. Compositing. The researcher will choose criteria (e.g. the amount of precipitation) by his/her own will, determines the limit values, and groups all the circulation situations that meet the given conditions, into one group. For example, if at the given situation, the amount of precipitation in some spot was between 50–60mm, it belongs to the corresponding group.
4. Circulation indices. For example NAO (North Atlantic Oscillation), PNA (index of the Pacific and North-America), Kats's index, etc. It is usually an index that is calculated from the difference of atmospheric pressure in pressure areas, which characterizes the zonality or meridionality of a circulation.
5. Specification or Klein’s (1983) method. On the basis of the multiple regressions of the anomalies’ network of 700mb geo-potential are made the long-term prognostic conclusions on the air temperature changes.
6. *Eigenvector*-based synoptic types.
7. *Eigenvector*-based maps pattern.
8. *Eigenvector*-based regionalizations.

The three last methods have become especially popular during the last decade. This is because before there was not enough computer power to apply these methods, and in comparison with the other possibilities mentioned, the eigenvector methods seem especially 'objective', meaning that the role of computers in classification is remarkably great. According to the researcher’s aims, the main components of the initial data are analysed by the method of factor analysis, analysis of the main components or the orthogonal function. However, the classification is done regarding the weight of the main component, etc (Yarnal, 1993).

In the few last years, two new classification methods have widely been taken into use:

- Spatial Synoptic Classification (SSC) (Kalkstein *et al*, 1996; Sheridan, 2002)
- Self-organizing maps (SOM) (Hewitson, Crane, 2002).

In addition to the mentioned methods, there are some more rarely used classification techniques, and several hybrids or combinations of different methods. Experience has shown that the totally ideal method has not yet been worked out in the synoptic climatology.

All the classification methods have their weaknesses (Yarnal, 1993). For example, the correlation-based map pattern (the Kirchhofer's method that is based on the sum of squares) has got especially strong setbacks. When talking about the preciseness of the given method, the main determiner is the correlation index between the map pattern, which is the standard, and the database of the comparable synoptic map. The main thing is to set a limit value that the correlation of two maps under comparison must respond to, to belong to the class that is describable by the map pattern. The closer the correlation quotient is to value 1, the more precise the classification is, but the more days are left out of classes. The lower the limit value is, the more maps are divided into classes, but the bigger is the danger that practically different circulation conditions are taken into one group (Perry, 1983; Yarnal, White, 1987; El-Kadi, Smithson, 1992; Frakes, Yarnal, 1997). To compensate for the weaknesses of correlating with the 'pattern maps', it has been combined with the principles of the 'hand-made' classifications. The made hybrid has the best qualities of both methods — it is more 'objective' than the 'hand-made' methods usually are. At the same time, the researcher has a bigger overview and control over the classification process, than usually possible in case of the automatic classification; and the method gives noticeably more reliable results (Frakes, Yarnal, 1997).

2.4. Synoptic climatology in Estonia

The correlations between atmospheric circulation and local weather have been discussed in Estonia during the previous century several times (Jaagus *et al*, 2001, Jaagus, Post, 2004). For example, Ille Palm compared in her dissertation the dependence of human bioclimatic characteristics (e.g. the sensation of warmth) of atmospheric circulation (Palm, 1973). The indicators in the work were the origin and attributes of the air masses prevailing in the Estonian weather. In the article by Ago Jaani (1973), the ice conditions on Lake Peipsi were associated with the alternating of the circulation classes of Vangengeim-

Girs classification. A detailed overview of circulation conditions in Estonia and cyclone trajectories over northern Europe in period 1965–1974 was published in (Klimat Tallina, 1982).

Still, we can talk of synoptic climatology in Estonia more seriously from the end of 1990s. A big part of articles that were published in 1999 in the collection of geographical works of the University of Tartu (Keevallik, Loitjärv, 1999; Post, Tuulik, 1999a; Russak, 1999; Sepp, 1999, Tomingas, Jaagus, 1999; Tuulik, Post, 1999) can be placed under the name of synoptic climatology due to their contents and used methodology. At the same time, two articles on the same subject were published in international science magazines (Keevallik *et al*, 1999; Post, Tuulik, 1999b).

In most of the works mentioned (Keevallik *et al*, 1999; Keevallik, Loitjärv, 1999; Post, Tuulik, 1999a; Post, Tuulik, 1999b; Russak, 1999; Sepp, 1999; Tuulik, Post, 1999), the Hess-Brezowsky's classification was used to compare circulation conditions with Estonian weather data.

In practically all mentioned works (Keevallik *et al*, 1999; Post, Tuulik, 1999a; Post, Tuulik, 1999b; Sepp, 1999; Tuulik, Post, 1999) the researchers have found that the correlations between circulation groups of Hess-Brezowsky's classification and Estonian weather are not satisfactory. The disturbing factor is the fact how the classification is focused on Central Europe, as well as the relatively large distance between Estonia and Germany. A cyclone can fit between two countries so that we are affected by one and Central Europe by another edge of the vortex. But that means totally different circulation, especially weather conditions. Also came out that several circulation types that are generally anti-cyclonic for Central Europe are cyclonic for Estonia, and vice versa.

After the introductory articles, the study of circulation processes in Estonia has started to develop mainly in three directions: the automatic classifications and indexes are adjusted for Estonian needs (Tomingas, 2002; Post *et al*, 2002), the correlations of the alternation of circulation types and Estonian weather indicators are studied (Keevallik, Russak, 2001; Keevallik, Rajasalu, 2001), and the correlations of atmospheric circulation classifications time series more widely with European weather (Jaagus *et al*, 2002, PAPER I) and vegetation indicators (PAPER II, PAPER IV).

Another collection of geographical works of the University of Tartu was published in 2003. The volume was dedicated to climate research in Estonia and number of articles was about synoptic climatology. Mostly they were articles in Estonian of those three directions.

In last few years, also investigation of frequency and trajectories of cyclones (PAPER III) has become a new branch of investigations in Estonia. As a sensitive tool, time series of cyclones allow more detailed approaching to relationship between atmospheric circulation and local environment.

In Estonian science, there is much to be done in synoptic climatology, that both in the 'traditional' weather data, as well as studying the other environmental indicators (e.g. in characterizing the spreading of air pollution).

3. DATA AND METHODS

Through the present thesis, data of the Vangengeim-Girs classification are used to describe atmospheric circulation. Monthly, seasonal and annual frequencies of circulation forms by the Vangengeim-Girs classification, one zonal — W, and two meridional — E and C are used in the analyses. Seasons are defined and used through the thesis as follows: spring (MAM), summer (JJA), autumn (SON) and winter (DJF). The data of the Vangengeim-Girs classification were obtained from Bolotinskaja and Ryzhakov (1964) and updated using personal contacts in the Arctic and Antarctic Research Institute, St. Petersburg (AARI). The time series covers the period 1891–2001. For some analyses in Chapters 4 and 5, shorter periods are used, mostly the period 1948–2000.

In general, the zonal circulation form W represents the prevailing of westerlies, while the form E expresses a trough and form C a ridge over Central Europe. Correspondingly, meridional flow from the south, southeast or east (E) and from the northern directions (in case of C form) are observed. The essence and meaning of the above-mentioned classification and its circulation forms are described in detail in the subchapter 4.1.

In PAPER I and Chapter 4, the climate variability in Europe is expressed using 5x5 degree gridded values of monthly sea-level pressure (SLP) and surface air temperature in sector between 35ºN and 75ºN, and 30ºW and 60ºE covering the territory of Europe. The gridded data were obtained from the Global Climatological Dataset created by the Climate Research Unit, University of East Anglia, UK (http://www.cru.uea.ac.uk/cru/data).

For illustration, correlation maps for Europe were drawn indicating the spatial distribution of correlation coefficient between SLP and the frequency of the circulation forms. Correlation coefficients were calculated for every grid cell. The kriging method (Legendre and Legendre, 1998) was used for spatial interpolation. The maps reflect a long-period mean synoptic situation, i.e. the location of high- and low-pressure regions in case of the circulation forms at different seasons. The main airflows can easily be deducted from the correlation maps.

The same mapping technique was applied to analyse the spatial distribution of correlation between circulation and air temperature in Europe. Correlation fields were drawn and a great number of maps were analysed. The statistically significance level $P<0.05$ was used. Areas of significant correlation are dashed on the maps. Based on the correlation maps, the general regularities concerning the influence of atmospheric circulation on the formation of temperature in Europe were formulated.

Trends in time series of the frequency of the circulation forms are analysed in Chapter 4 using linear regression analysis. Trends on the level $P<0.05$ were considered statistically significant. Trend analyses were made separately for two periods — the long (1891–2001) and the short (1948–2000) one. Trends are characterised by changes in days by trend line. For that, the slope was calculated for every trend line. The slope indicates a mean change per year. The change by trend line is calculated by multiplying the slope with the number of years — in the present case with 111 or 53.

The air temperature variation characteristics in Estonia used in Chapters 4 and 5 constitutes the observation data from the Tartu meteorological station. The station is located close to the centre of the continental part of Estonia. The time series can be considered nearly homogeneous and representative for that area.

The canonical correlation analysis method was used to analyse relationship between air temperature in Estonia and the frequency of circulation forms. Pearson's correlation coefficients were calculated and the statistical significance was controlled using the Student's t-test. Coefficients on the $P<0.05$ level were considered statistically significant. Changes in the strength of relationship between the frequency of circulation forms and air temperature in Estonia were analysed using 30-year moving correlation coefficients. The first correlation coefficient was calculated for the first 30 years (1891–1920) and later, the period is moved forward by one year. All together, there is an 82-year time series of correlation coefficients.

In PAPER III and Chapter 5, changes in the frequency and trajectories of cyclones are analysed on the basis of the database of cyclones, described in detail by Gulev et al. (2001). The database consists of cyclone tracking output of the 6-hourly NCEP/NCAR reanalysis (Kalnay *et al*, 1996) SLP fields using the software worked out by Grigoriev et al. (2000). Cyclones are presented by the geographical coordinates of their centres and minimum SLP.

Changes in the frequency and tracks of cyclones in northern and central Europe are analysed during the period 1948–2000. In PAPER III, the annual number of cyclones over the whole Atlantic-European sector (30ºW-45ºE, 35ºN-75ºN) was counted. Cyclones were also counted in circles with the radius of 500, 1000, 1500 and 2000 km. The centre of these circles was located on the coordinates of 60ºN, 22.5ºE. In present thesis, as well as in PAPER III, cyclones crossing the 5ºE and 20ºE meridians from the west to the east between 45ºN and 75ºN were counted. The frequency was analysed using three main zones and six sub-zones (Fig. 3.1). In the present thesis, cyclones crossing 50°E within the same meridian interval and sub-zones are also counted and analysed.

Many cyclones influencing the weather in Estonia move to the Baltic Sea region from the south or the north. The southern cyclones usually form over the southern seas (the Mediterranean, Black Sea, Caspian Sea), and the northern cyclones — over the North Atlantic or Barents Sea. A southern cyclone is defined as a cyclone that has crossed 52°N from the south to the north within 5–50°E.

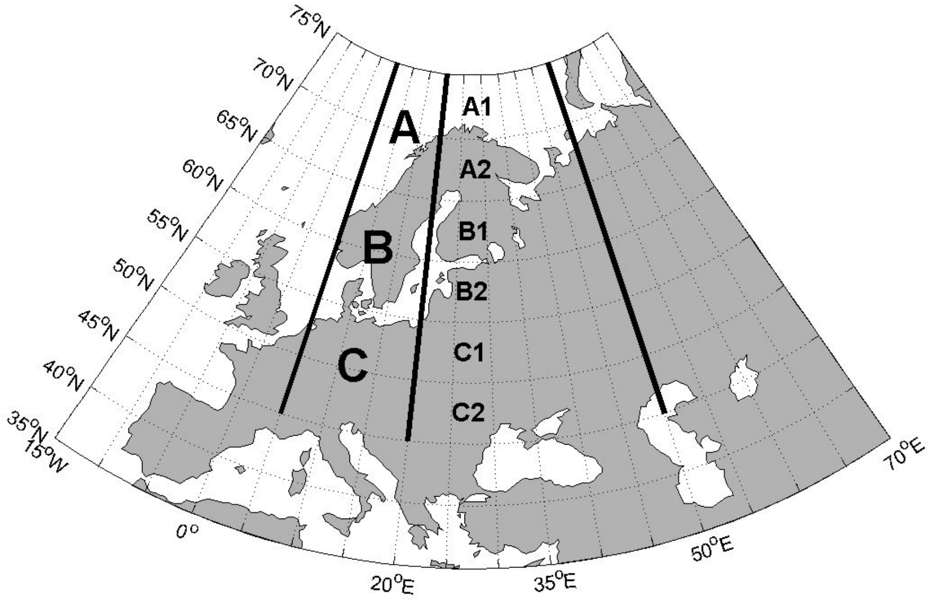

Fig. 3.1. Location map of the area around meridians 5ºE, 20ºE and 50ºE with the zones A, B and C and their sub-zones.

This interval is divided into three sectors (I — 5–20°E, II — 20–35°E and III — 35–50°E) (Fig. 3.2). The southern cyclones passing the territory of Estonia from the western side (sector I) cause an advection of a warm southern air mass. The other southern cyclones passing Estonia from the eastern side (sectors II and III) are related to an advection of a cold northern air mass. The cyclones crossing 67°N from the north to the south within 5–50°E are counted and analysed separately. The parallel is also divided into three sectors as in the case of southern cyclones (Fig. 3.2).

In PAPER III, all low-pressure systems were counted despite the air pressure values in their centres. In the analyses presented in this thesis, deep cyclones are processed separately. A cyclone is defined as deep when the sea-level pressure in the centre of the cyclone has dropped below 1000 hPa during at least one observation time.

Changes in the frequency of cyclones by different sub-zones are analysed in subchapters 5.1–5.3. Similarly to the analyses of changes in time-series of circulation forms, also here the linear regression analysis was used for determining trends in the time series of a number of cyclones. Trends on the level $P<0.05$ were considered statistically significant.

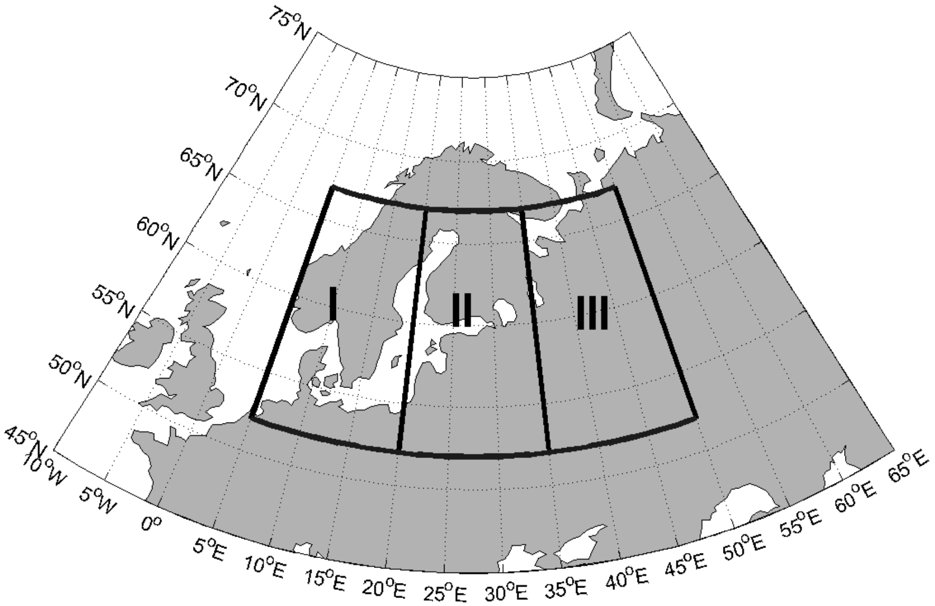

Fig. 3.2. Location map of the area around parallels 52ºN and 67ºN with the sectors I, II and III.

In sub-chapter 5.4 and 5.5, the canonical correlation analysis method is used to analyse relationships between time series of cyclones in different zones and of the air temperature in Tartu and the frequency of circulation forms by the Vangengeim-Girs classification. Correlation coefficients on the level $P<0.05$ were considered statistically significant.

The influence of atmospheric circulation on the phenological development of nature in Europe is assessed in PAPER II and Chapter 6.1 of the present thesis. Phytophenological data from the European plant phenology database, compiled under the European Union 5th framework programme project *POSITIVE* (Phenological Observations and Satellite Data (NDVI): Trends in the Vegetation Cycle in Europe) in 2001 (Ahas *et al*, 2002), are used. The period under observation is 1951–1998. Relationship between the beginning dates of three spring phases — the flowering of Colts foot (*Tussilago farfara* L.), birch (*Betula pendula* Roth.) leaf unfolding and the flowering of lilac (*Syringa vulgaris* L.) — and atmospheric circulation is analysed using linear correlation coefficients. The selected species are good phenological indicators and they have a broad geographical distribution in the study area, presented in Fig. 1 of PAPER II. Linear correlation coefficients were calculated separately for each phase for each point of observations. Similarly to the analysis presented in PAPER I, the results were mapped using the kriging method for spatial interpolation. The statistical significance of correlation coefficients was checked for randomness and, as a result, relationships stronger than ±0.3 proved to be statistically significant.

In subchapter 6.2 and PAPER IV, relationships between atmospheric circulation and Scots pine (*Pinus sylvestris* L.) growth indicators and needle dynamics were analysed in three stands in Estonia and in four stands located near the timberline in Lapland. Scots pine growth attributes are the radial and height increments; the needle dynamics are characterised by needle production, density, loss and the number of needles in shoot. The exact methodology of detecting of growth indicators and needle dynamics is presented in PAPER IV and (Aalto, Jalkanen 1998). M. Pensa, R. Jalkanen and their colleagues made all field and laboratory measurements. Time series of the analysed data cover period 1930–2000.

In data analysis the attributes of pine growth were standardised by removing the age trend from the time series. Smoothing mathematical functions were fitted to the mean age curve of each attribute (e.g., polynomial functions of different order, negative exponential function) by using the non-linear regression method.

Then the mean correlation technique (Cook *et al*, 1990) was used to express the signal strength in the standardised time series of the attributes of Scots pine growth indicators and needle dynamics within and between the stands. Data on both the previous and current year's climatic variables were correlated against the tree data. Each single time series was correlated with all circulation variables, and the mean coefficients and 95% confidence intervals for each pair of the tree attribute and climatic variable were determined for Estonia and Lapland.

4. RELATIONSHIPS BETWEEN AIR TEMPERATURE AND FREQUENCY OF CIRCULATION FORMS BY VANGENGEIM AND GIRS

4.1. Classification of atmospheric circulation by Vangengeim and Girs

B. P. Multanovski (1876–1938) was one of the most outstanding developers of synoptic climatology in Russia during the first quarter of the 20th century. His own research and that of his school was based on the analysis of moving anti-cyclones and their activities. Here, activity means the number and intensity of airflows originating from these centres of action, mostly the Azores and the polar highs. Investigations revealed that during certain time intervals the centres of cyclones were observed in one part of the study area and anti-cyclones — in the other part. Such the synoptic situations lasted for 5–7 days after which a rapid change occurred. Multanovski defined the time interval with the stable pattern of air pressure formations as a natural synoptic period (NSP).

The theory of the NSPs became a fundamental of the weather prediction method presented by Multanosvki. In Russia, weather forecasts have been prepared according to these principles since 1922. The forecasts were made for 8–10 days as well as for the whole season (Barry, Perry, 1973; Girs, 1960; 1971, Girs, Kondratovitch, 1978; Heyer, 1988).

In the 1930s, a branch directed by Georgi Vangengeim (1896–1961) emerged from the Multanovski's school. The new school saw a solution for synoptic problems in the classification of the general circulation processes of the atmosphere. The scientific credo of Vangengeim was to "study atmospheric processes in their unstoppable development, dividing the processes in types that actually exist; find out the patterns of type alternations; study both the smaller processes, as well as the large stages; and study the atmospheric processes in a smaller area on the background of macro processes" (Girs, 1960, 1971; Girs, Kondratovich, 1978).

These principles became a basis for research aimed at working out a method for long-term weather forecasts. The basics and principles of the so-called macro-circulation prognosis method were developed under the leadership of Vangengeim in 1932–1939.

One of the first presentations of the new classification was published in 1935 (Vangengeim, 1935), analysing the circulation conditions of four years (1932–1935). Vangengeim coined the term 'elementary synoptic process' (ESP), which became the basis of his classification. The atmospheric processes belonged into one of the ESP types, if the following criteria were met:

1) similar development and geographical distribution of the leading (directing) pressure areas;

2) similar direction of prevailing winds;
3) similar attributes of the main invasions of air masses.

26 elementary synoptic processes were distinguished. A letter code was given to every sub-type, marking the areas were the anti-cyclones invaded or stayed.

Some sub-types can be described by two stages of development. On the first stage, which was usually marked by ‘a’, cold anti-cyclones form in the northern part of Europe and Western Siberia. In the second stage (‘b’) the anti-cyclones move to the south, southeast or southwest, and they settle down on more southern latitudes. In some cases the both stages develop very quickly, e.g. during one ESP. In these cases, the sub-types were marked with ’ab’ (Vangengeim, 1935).

In the early 1940s, G. Vangengeim (1940) generalised all the sub-types into three so-called circulation forms — one zonal (W) and two meridional circulation forms (E and C). This generalisation was based on certain similarities inside 26 sub-types.

The main principles of such a grouping of the ESPs were the following:
1) similarity in the sea-level baric formations and the direction of isallobaric centres;
2) similar direction of thermal and baric gradients in the troposphere;
3) similar direction of the main air flow in the troposphere.

The circulation forms W, E and C describe the processes on much greater spatial scales than the ESPs, reaching up to the hemispheric measures.

According to Vangengeim (1946, 1952), the form W (Fig. 4.1) marks a situation where a transmission of air masses from the west to the east develops above the Atlantic and Europe. The baric gradient is directed from the south to the north (e.g. there air pressure is lower in the north).

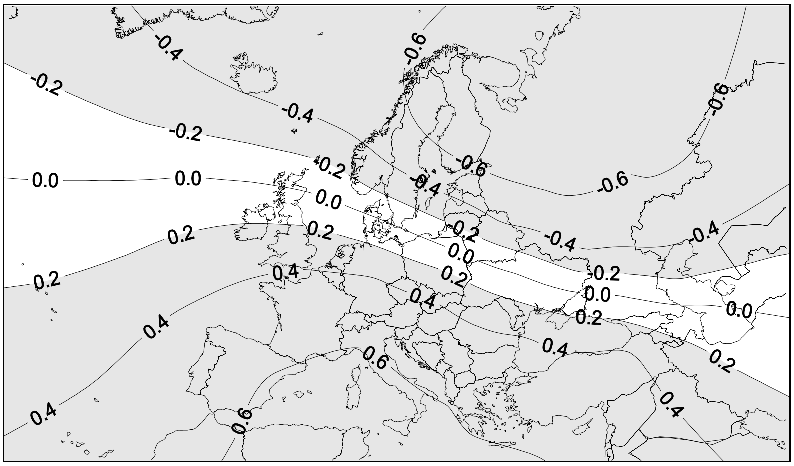

Fig. 4.1. Correlation between the frequency of the circulation form W and mean air pressure in winter.

The form (E) is characterised by disturbances in the west-east transmission of air masses, or even the developing of an east-west airflow in the central latitudes of the hemisphere. This situation develops when a large and stable anti-cyclone exists in eastern Europe (in the European part of the former Soviet Union), or if the anti-cyclones move from the east or northeast in the eastern part of Europe (Fig. 4.2). In case of such a position of anti-cyclones, there is an advection of a continental polar air mass, which means a considerably lower air temperature than average in eastern Europe in winter.

The form C represents a northerly meridional circulation in eastern Europe. It develops in correlation with the forming of an anti-cyclone over Central Europe and the British Isles, and due to the positioning of meridionally stretched cyclones in Atlantic, Central Asia and Western Siberia (Fig. 4.3). In case of a similar distribution of the main pressure areas, there occurs a spreading of warmer air masses from the south to the north in the western side of the anti-cyclone and the advection of a cold airflow from the north to far south. Generally, the C type can be seen as a special form of meridional circulation, or the transition form of types W and E (Vangengeim, 1946, 1952).

The 26 sub-types were divided among three circulation forms; 9, 10 and 7 ESPs, respectively, belonged in the types W, E and C (Girs, 1960).

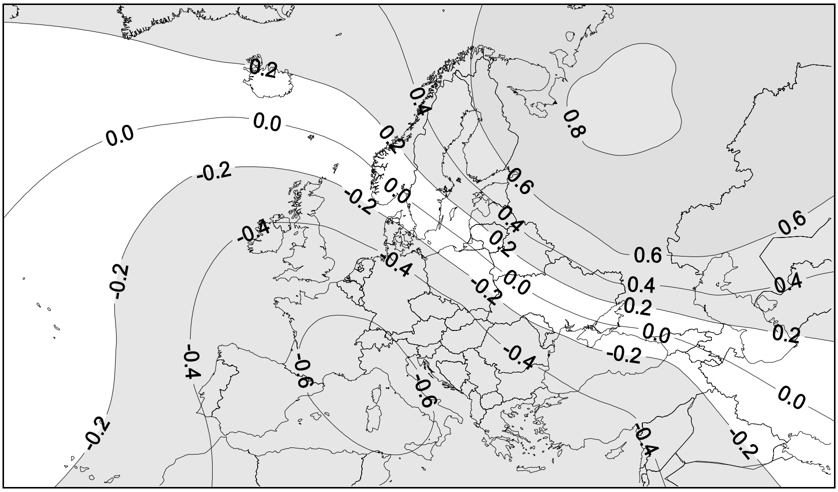

Fig. 4.2. Correlation between the frequency of the circulation form E and mean air pressure in winter.

G. Vangengeim's work was continued and complemented by his student at the Arctic and Antarctic Research Institute in Leningrad, A. A. Girs (1913–1983). During his life, Girs wrote several books and many articles, where he analysed the correlations between classification and weather processes. In addition, he tried to enhance the methods of forecasting. One initial idea of the classification was namely the Northern Ice Way, and the developing of the method of forecasting the ice conditions of the rivers in Siberia. A certain success was achieved in this field — the method enabled to forecast successfully the ice conditions half a year in advance. Later, in the 1970s, attempts were made to apply the principles of classification to the conditions in Antarctica (Girs, 1971; 1974; Girs, Kondratovich, 1978). Unfortunately, it was difficult to evaluate objectively the operational ability of the given method of forecasting, because of shortness of objective data (the same institution compiled and controlled the forecasts). On the other hand, the author of the current work has also not found constructive criticism against the given forecasting method.

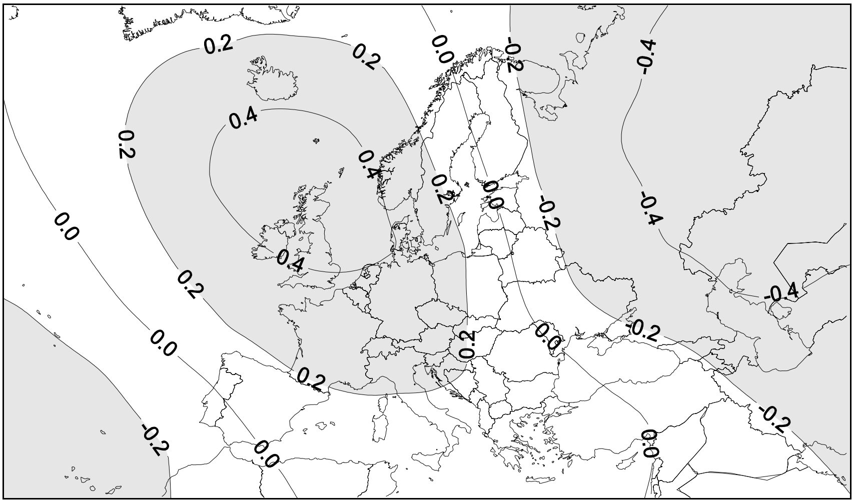

Fig. 4.3. Correlation between the frequency of the circulation form C and mean air pressure in winter.

A. A. Girs studied the vertical structure of circulation forms, and in 1948, proved the relationships of forms W, E and C with the long thermo-baric, so-called Rossby waves. In case of type W, there are little-amplitude thermo-baric waves in the troposphere that move quickly from the west to the east. E and C are two separate meridional forms characterised by high amplitudes of Rossby waves. In case of the form E, a trough is situated over central Europe while the form C is related to a ridge over the same region (Fig 4.4). In troposphere, the less movable waves with great amplitude correspond to them (Girs, 1971, 1974).

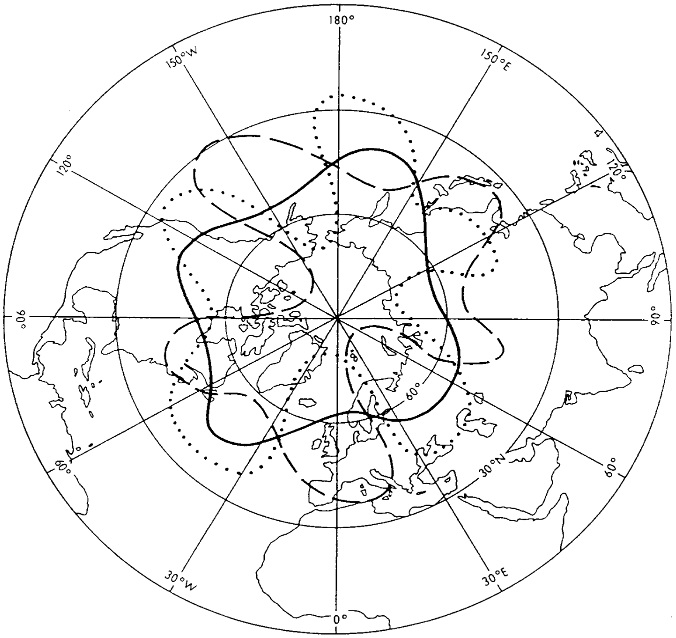

Fig. 4.4. Idealised contour of 500 mb height defining the circulation forms W, C and E according to the Vangengeim-Girs classification over the northern hemisphere (Lamb, 1972). ______ W, _ _ _ _ _ E, ... C.

Vangengeim's attention centred, due to lack of data, on compiling the classification for the so-called European-Atlantic sector. Girs widened the classification on the sector of North America and the Pacific Ocean. It occurred that in the given sector, one zonal (Z) and two meridian circulation forms (M1 and M2) differentiated. Similarly to the types in the first sector, the thermobaric waves with small amplitudes corresponded in the troposphere to the zonal circulation type, because in case of meridional forms, there are waves of great amplitudes.

If we were to describe the circulation of the northern hemisphere, then the types of two sectors will be united. Nine circulation types combine: EZ, EM1, EM2, WZ, WM1, etc. But it has been statistically proved (Gruza, Rankova, 1996) that the frequencies of circulation types in the Atlantic-European, and the American and Pacific Ocean sector are not dependent on each other, i.e. both sectors are relatively isolated from each other circulation-wise. Therefore, the separate parts of the hemisphere depend on practical assignments viewed separately.

After the spatial widening of the classification, Girs (1971, 1974; Girs, Kondratovitch, 1978) divided the circulation processes in the four circulation development stages on the basis of temporal duration:

1) elementary circulation processes (ESP) — duration 3–4 days;
2) similar circulation processes — 8–12 days;
3) stages inside a year — 2–4 months;
4) epochs — 10–13 years and stages of epochs (2–6 years).

The four named stages mark four separate study directions. Girs and his colleagues paid somewhat greater attention to the analysis of the inside-a-year and epoch stages. The nature of circulation and its forecasting were discussed. The synoptic scale (2–3-day period) was touched upon fairly rarely.

A. Girs does usually not mention the 26 sub-types, and after G. Vangengeim deceased, the level of sub-types was almost not touched upon. If there should be an ESP level, then the topic is discussed by W, E and C forms, not by the Vangengeim's sub-types.

The methodology of G. Vangengeim and A. Girs of the division of circulation processes between three forms can be seen as quite successful with respect to the Atlantic-European sector. Many studies (e.g. Kozuchowski, Marciniak, 1988; Gruza, Rankova, 1996; PAPER I) have shown good correlations between the frequency of circulation forms and weather indicators in the scale of Europe. The especially strong correlations appear above northern and eastern Europe, especially in winter.

But it is clear that for solving the regional assignments, such division of the circulation processes remains too limited. Thus the weather in a particular area depends on the movement trajectories of the pressure areas that presently significantly influence the whole circulation system. Depending on the position, the moist and maritime air or dry tropic air can transmit to the given area, etc. At the same time, due to their similar genesis and development, both situations belong into one and a same circulation form. This is one of the reasons why the correlations with the local (one meteorological station or small area) weather data may be relatively weak. Practically all the atmospheric circulation classifications that concentrate on the treatment of large-scale processes (e.g. Dzerdzeevski's classification) (Yarnal, 1993) suffer from the weak correlations with the local weather conditions. There is quite a sharp conflict between the generalisations and applications.

In answer to the critical article by N.A. Bagrov (1978), A.A. Girs recommended that the approach to the regional questions were still based on the macro-circular background of hemisphere (the alternation of circulation forms), bearing in mind what kind of weather the given processes bring to the area under examination. According to this, a local classification was developed, considering both the general background (e.g. the main form W) and the local peculiarities (W1, W2, W3…) (Girs, 1981).

Using this principle, several regional approaches have been developed from the Vangengeim-Girs classification (Dydina, 1982; Baidal, Hanzhina, 1986;

Dmitriev *et al*, 1989; Dmitriev, 2000). At the same time, a question is still asked — why create a separate classification if Vangengeim's sub-types can be used?

One possible reason why the sub-types were left aside was that the final number of the sub-types is actually open. As mentioned before, the 26 ESPs determined by Vangengeim get referred to (Girs, 1960, 1974). But in the research (Bolotinskaja, 1963) analysing the circulation conditions of years 1949–1959, the 31 sub-types and with the indexes ‘a’ and ‘b’, the whole of 45 varieties of synoptic processes are distinguished.

In 1964, a directory of macro-synoptic processes of the Vangengeim's classification was published, giving the ESPs from 30 December 1890 to 31 December 1962. The introduction to the catalogue offers a brief overview of the structure of the classification (Bolotinskaja, Ryzhakov, 1964), indicating that Vangengeim had restructured his classification during the last years of his life. In the latest version, 4 types belonged to the form W, 7 types to E and 3 sub-types belonged to C. If we consider the stages of sub-types ‘a’ and ‘b’ as different types too, then there are additional 8 types for the form E, and 4 sub-types for the form C. And since some types can comprise both stages (’ab’), there are 4 additional types in E, and 2 possible sub-types in the form C.

The fact that some types can be classified into two circulation forms depending on the background, intensiveness and process speed, could be seen as an important change. Depending on the position of pressure areas, these two types are either W or E.

There are 7 variants or types that can belong in both the E and W forms. 6 stage types are added (either ‘a’, ‘b’ or ’ab’ stages). 7 sub-types and 6 possible stage types belong to the C and W types. Two sub-types and 3 stage types can be divided between E and C.

In addition to that, there are four subtypes marked in the introduction of the catalogue as ‘have gone out of use during the last years’ (Bolotinskaja, Ryzhakov, 1964). One of the sub-types belongs to W, one to C and two both to the W and E circulation forms.

So, if we divide all the possible variants (both the sub-types that divide among the two forms, as well as the types that describe different stages) between circulation types, then we conclude that 33 belong to the type W, 39 to the type E and 28 to the type C, or 100 possible variables all together.

But when entering them into a computer, the author of the present work coded separately all possible variants that actually figured in the catalogue and manuscript, getting as a result 60 in W, 69 in E, and 57 in the C sub-types of the circulation form.

As mentioned above, the singular circulation sub-types disappeared from the AARI treatment of public scientific works. In many cases (e.g. Girs, 1974; Dydina, 1982) the calendars of circulation forms were published, but the publishing of a detailed catalogue (similarly Bolotinskaja, Ryzhakov, 1964) has ceased. The data on the circulation sub-types have been gathered by personal contacts from the AARI department of long-term weather forecasts (Dmitriev, 2002). Only manuscript material exists on the period starting 1 January 1963.

Generally, it has to be said that in the manuscript catalogue there are much less ‘extraordinary’ types in the circulation classification, since the compilers tried deal only with those, which were defined in the introduction to the catalogue of 1964. Possibly, the continuers of Vangengeim’s legacy tried to be more precise than their teacher had been.

In general, the frequency of sub-types in both the manuscript and the catalogue have significantly changed. Many types have become ‘rare’ since the 1940s.

These changes refer to two possible reasons:

1) Climate changes. It is possible that the first part of the 20th century was more varied in terms of circulation processes.
2) Homogeneity problems. Different people ‘see’ circulation processes on the synoptic maps differently (Yarnal, 1993).

Probably, it is a combination of both reasons in this case.

Although the dividing of circulation processes into one or another sub-type is performed collectively in the AARI department of long-term weather forecasts (Dmitiev, 2002), it does not make non-existent the change in the generation of decision-makers that occurred after the death of G. Vangengeim in 1961. To prevent the accusations of homogeneity that are very typical in manual classifications, the determining process of the Vangengeim-Girs sub-types should be performed in a single group of same indicators. Similar work has been done by Gerstengarbe and his colleagues regarding the Hess-Brezowsky’s classification (Gerstengarbe *et al*, 1999).

Despite the above-mentioned problems with subtypes, we can state that the Vangengeim-Girs classification is quite reliable with respect to the circulation forms. They express more generalised characteristics of circulation processes in the atmosphere and in this case it can be assumed that mistakes in classification are less probable. In the following, all analyses were computed using only the data of the circulation forms. An exception was made only in Chapter 4.5, where daily subtypes were also used.

4.2. Changes in time series of the frequency of the circulation forms

Clarification of long-term changes in the frequency of circulation forms is one of the main objectives of the studies using the Vangengeim-Girs classification. Changes in circulation and variations in the circulation epochs were thoroughly studied by A.A. Girs and other researchers from the AARI (Girs, 1974, Dmitriev *et al,* 1989). Besides, alternation of the epochs explains long-term changes in air temperature, precipitation etc. in different regions. In the following, long-term changes in the frequency of the circulation forms are analysed for two periods — 1891–2001 and 1948–2000.

At the beginning, some general statistical characteristics describing the time series are presented. During 1891–2001, the circulation form W was observed on 13383 days (33%), the form E — 16829 days (41.5%) and the form C — 10333 days (25.5%). The mean numbers of the circulation forms per year are 120.6, 151.6 and 93.1 days, respectively. Monthly distribution of the circulation forms is depicted in Fig. 4.5.

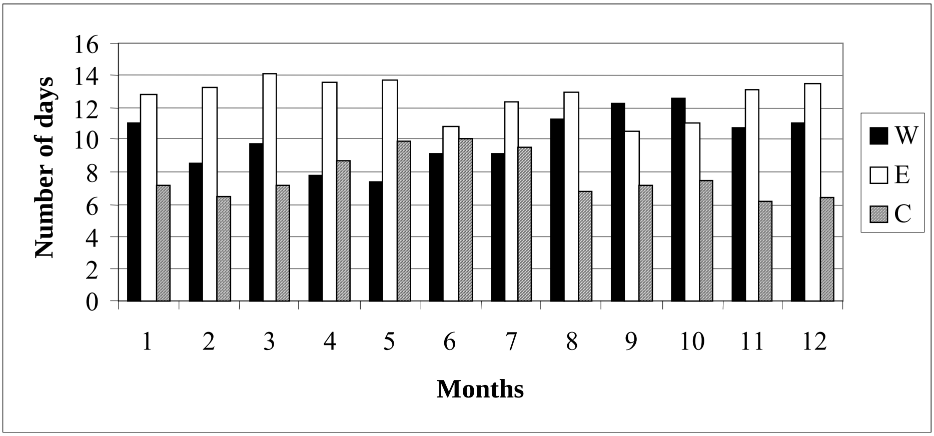

Fig. 4.5. Mean monthly frequencies of the circulation forms W, E and C according to the Vangengeim-Girs classification during 1891–2001.

Comparing these data with the mean values for 1948–2000, significant changes can be noticed. The mean annual frequencies of the circulation forms during the shorter period are as follows: W — 100 days, E — 175.7 days and C — 89.6 days. It is obvious that during the second half of the 20th century the part of the form E is much higher and that of the form W — lower than the mean values for the century.

These differences by months are presented in Fig. 4.6 where the mean frequency for the long period (1891–2001) is deleted from the mean frequency for the short period (1948–2000). The most important changes have occurred during the warm half-year when the part of E remarkably increased and the part of W and C — decreased.

Such a dramatic change becomes evident also in Fig. 4.7. The frequency of the form E has increased by 88 days during the 111-year time series according to the linear trend. At the same time, the number of days with the circulation form W has decreased by 71 days and that of the form C — by 17 days. All three trends are statistically significant (Table 4.1).

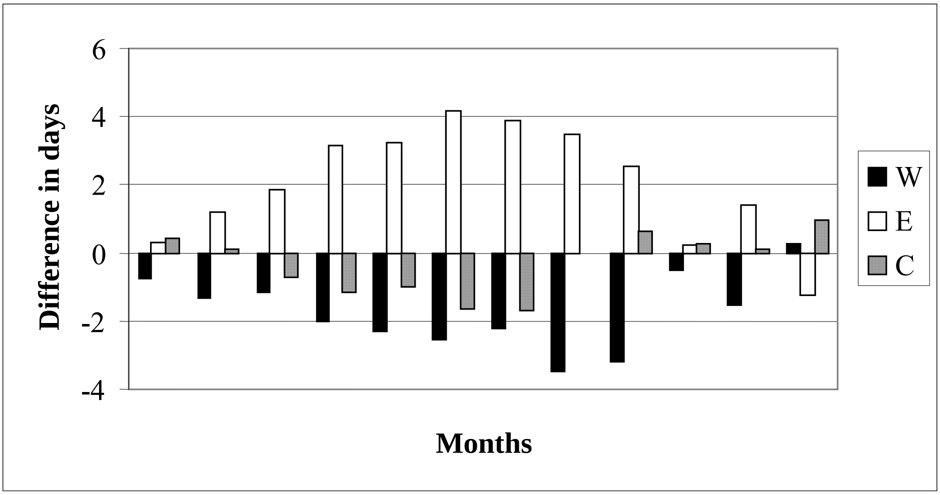

Fig. 4.6. Differences in the monthly mean frequencies of the circulation forms W, E and C according to the Vangengeim-Girs classification during 1891–2001 and 1948–2000.

Table 4.1. Changes by trend (in days) in the frequency of the circulation forms W, E and C according to the Vangengeim-Girs classification during the long and the short period. Statistically significant trends are marked in bold.

	1891–2001			1948–2000		
	W	E	C	W	E	C
January	–2.7	2.0	0.7	3.1	–3.5	0.4
February	–2.2	2.4	–0.1	**9.2**	**–9.5**	0.2
March	–2.2	4.4	–2.2	3.2	3.1	**–6.2**
April	–3.7	**7.9**	**–4.2**	4.2	–2.6	–1.6
May	**–7.2**	**9.9**	–2.8	2.4	1.2	–3.6
June	**–8.6**	**14.3**	**–5.7**	–3.0	4.5	–1.5
July	**–9.8**	**17.1**	**–7.2**	–1.5	**7.7**	**–6.3**
August	**–13.1**	**14.6**	–1.6	0.0	0.1	–0.1
September	**–12.4**	**10.1**	2.3	–3.9	4.0	–0.1
October	–1.6	1.3	0.3	2.7	0.9	–3.6
November	**–6.3**	**6.4**	–0.1	0.6	0.1	–0.7
December	–1.6	–2.3	**3.9**	3.8	–6.2	2.4
Annual	**–71.3**	**88.1**	**–16.8**	20.8	–0.2	**–20.6**
Spring	**–13.0**	**22.2**	**–9.2**	**9.8**	1.6	**–11.4**
Summer	**–31.4**	**46.0**	**–14.6**	–4.5	**12.4**	–7.9
Autumn	**–20.3**	**17.8**	2.5	–0.6	5.0	–4.4
Winter	–6.3	1.9	4.4	**15.8**	**–19.5**	3.8

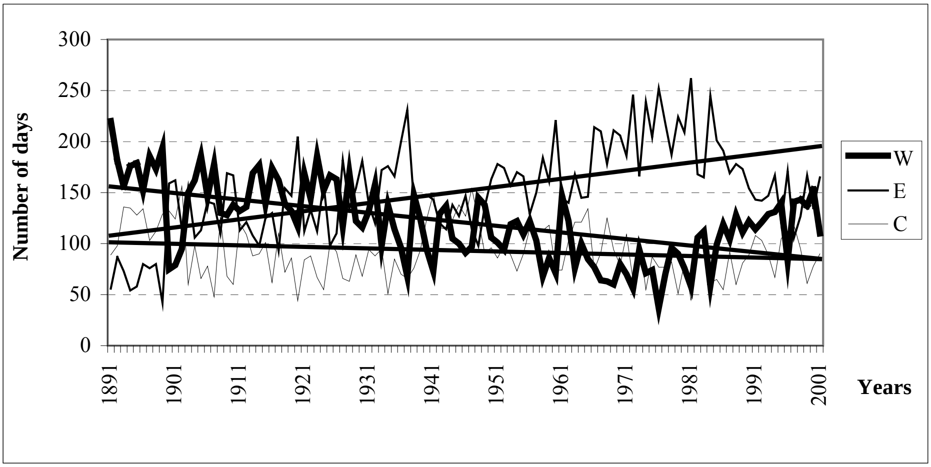

Fig. 4.7. Time series of the annual frequencies of the circulation forms W, E and C according to the Vangengeim-Girs classification and their linear trends.

Statistically significant trends in frequency of the circulation forms W and E are found in spring, summer and autumn. The most drastic changes in monthly values have occurred in summer. The frequency of the form W has decreased in August by 13.1 days and in September by 12.4 days. The number of days with the circulation form E has increased in June by 14.3, in July by 17.1 and in August by 14.6 days. Frequency of the circulation form C has significant decreasing trends in spring and summer. Its monthly values have significantly decreased in April, June and July. The highest decrease was observed in July — by 7.2 days. Unlike the forms W and E, the form C has a significant positive trend in December. Its frequency has risen by 3.9 days (Table 4.1).

Looking at Table 4.1, statistically less significant trends can be noticed during the short period (1948–2000). The only statistically significant change reveals that the frequency of the form C has decreased by 20.6 days by 53 years. In comparison with the trends during the long 111-year period, also other changes appear. Although the form W has increasing trends in annual values, it is not a statistically significant trend. Seasonal values for spring and winter have increased significantly. The most remarkable increase (by 9.2 days) has taken place in February.

The frequency of the form E has significantly increased only in July and summer (by 12.4 days). Its time series in February and in the whole winter have negative trends. The number of days with the form E in winter has decreased by 19.5 days.

The part of the form C has significantly decreased in March, July, spring and in the whole year. A decrease of 11.4 days has occurred in the form C in spring.

Fig. 4.7 demonstrates that linear trends are not suitable for the description of long-term dynamics of the circulation forms neither during the 111-year period nor the shorter one. Remarkable decadal fluctuations are smoothed or even lost. For example, there are no statistically significant trends in the annual frequency of the circulation forms W and E during the second half of the 20th century (Fig. 4.7). At the same time, the substantial increase up to the 1980s and the later decrease are clearly visible in the form E. In such a way, it is possible to distinguish the periods during which the direction of change is opposite to the general centennial trend. For example, the frequency of the meridional circulation form E significantly dropped in 1910–1917, 1920–1926, 1937–1938 and 1960–1966. An especially dramatic decrease occurred in the last part of the time series (1981–2001). Similar fluctuations are persistent also in time series of the frequency of the circulation forms W and C.

As it was mentioned above, the circulation epochs are distinguished on the basis of the Vangengeim-Girs classification. These periods have a length of about ten years. They are defined when the frequency of one (or two) circulation form(s) exceed(s) the long-term mean value. Although another form may prevail during short periods, the general circulation background during an epoch is determined by on (or two) prevailing form(s). If we know, whether the increasing or decreasing stage of the epoch is coming on, it is possible to predict the governing circulation processes for some years in advance (Girs, 1960, 1971; 1974; Girs, Kondratovich, 1978).

In conclusion, it is possible to state that the frequencies of the circulation forms according to the Vangengeim-Girs classification demonstrate that dramatic fluctuations and changes in the atmospheric circulation have occurred over Europe during the 20th century. Prevalence of the form W (westerlies) during the first decades of the century was replaced by the form E (blocking of westerlies) in the second half of the century. During the last 20 years its part has diminished but it has remained the leading circulation form.

4.3. Relationships between the frequency of circulation forms and air temperature in Europe

The annual mean air temperature in northern Europe (incl. Estonia) is much higher than on the same latitudes in Siberia and North America. It is significantly influenced by westerly airflow, which brings moist and comparatively warm air from the Atlantic up to the Ural Mountains. The heating influence of the ocean is the most intense in winter.

This kind of relationship leads to the conclusion that changes in time series of atmospheric circulation should be expressed in air temperature time series in Europe. It can be assumed that the remarkable climate warming, which has been the most impressive in northern Europe, was originated by changes in atmospheric circulation.

Climate variability in northern Europe in relation to the large-scale atmospheric circulation has been studied by a number of authors (e.g. Chen, Hellström, 1999; Keevallik *et al*, 1999; Thompson, Wallace, 1998). Thereby, different ways have been applied to describe circulation conditions; the use of NAO indices is most widely used nowadays. The Vangengeim-Girs classification is also used for the analysis of relationships between circulation and air temperature; the most thorough analyses have been carried out by A.A. Girs (1960; 1971; 1974; Girs, Kondratovich, 1978), who mostly concentrated his research on air temperature anomalies during different circulation epochs and their stages. Relationships between circulation and temperature were considered as self-evident.

Although the Vangengeim-Girs classification has been referred to by some researchers outside the former Soviet Union (i.e. Lamb 1972, Barry and Perry 1973), it has been very rarely used and discussed in scientific literature in English. Only one article (Kozuchowski, Marciniak, 1988) analysing relationships between the frequencies of the circulation forms according to the Vangengeim-Girs classification and air temperature and precipitation in Europe could be pointed out. Correlations between the frequency of the circulation forms W, E and C, and monthly mean air temperature and precipitation were calculated. Data from 30 weather stations all over the Europe during 1901–1978 were used. Correlation coefficients were mapped and areas of statistically significant correlation were dashed.

The results indicated that in Europe, air temperature and partly, precipitation, are significantly dependent on atmospheric circulation, especially in winter.

The frequency of the circulation form W has a highly positive correlation with air temperature in January on the territory north of 45°N. The highest correlation coefficient was obtained for Warsaw ($r = 0.66$). The correlation with the frequency of the form W in summer was negative. The area of significant correlation in July covers the Baltic Sea regions and eastward. The form C has negative relationships in January as well as in July but mostly in northern and eastern Europe.

The frequency of the circulation form E is highly negatively correlated with air temperature in January in central and eastern Europe. The highest correlation was calculated for Moscow ($r = -0{,}72$). The authors conclude that, in case of such a close correlation and having a reliable method of weather forecast, it would be possible to make rather good predictions of seasonal air temperature over large areas in Europe (Kozuchowski, Marciniak, 1988).

A large part of PAPER I has been inspired by the methods used in the above-described paper. The objective of the study was to analyse the spatial distribution of correlation between circulation characteristics and air temperature in Europe.

In comparison with the previous study (Kozuchowski, Marciniak, 1988), the dataset used in PAPER I is much denser and covers evenly the territory of Europe. Analysis was made for all months and seasons. Therefore, it is assumed that the results of this study are more representative.

In general, results of PAPER I and those presented by K. Kozuchowski and K. Marciniak (1988) are similar. The Vangengeim-Girs classification describes better air temperature fluctuations in northern and eastern Europe. The area of closer correlation is located near the Baltic Sea and in the northwestern part of Russia.

The frequency of the zonal circulation form W has a significant positive correlation with winter temperature over a large territory (Fig. 4.8). The highest correlation is located not in western Europe but just in the central and eastern parts of the continent where the mild air from the ocean causes a substantial positive anomaly of air temperature. In summer this correlation is negative (Fig. 4.9). It is the closest in the Baltic and North Sea regions — stronger than [–0.4]. Airflow from the ocean produces moist, cool and cloudy weather.

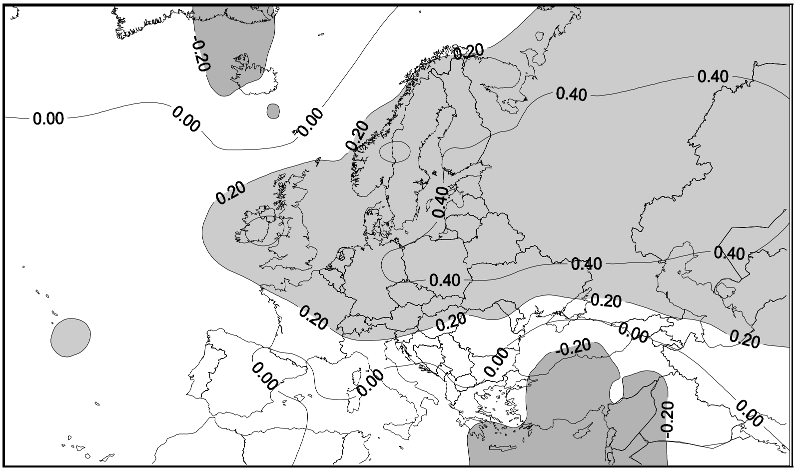

Fig. 4.8. Correlation between the frequency of the circulation form W and mean air temperature in winter.

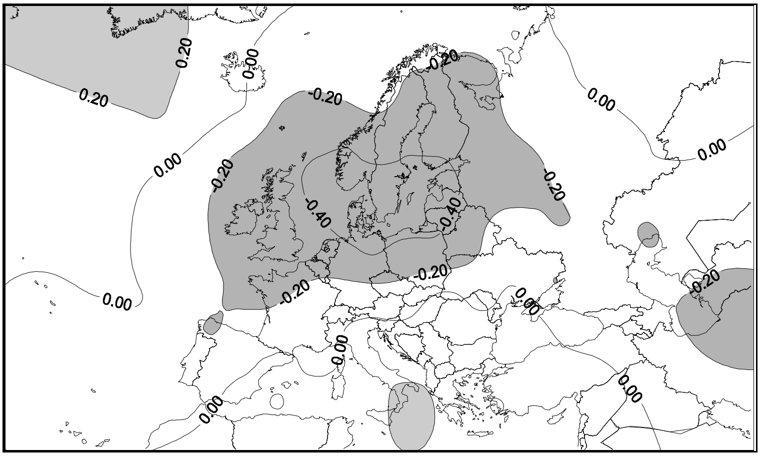

Fig. 4.9. Correlation between the frequency of the circulation form W and mean air temperature in summer.

In case of the circulation form E, the correlation is of the opposite sign — highly negative in winter and positive in summer. The highest negative correlation in winter is located in the East European Plain and in the Baltic Sea region (Fig. 4.10). This is caused by the influence of the high-pressure area and of the cold airflow from the eastern directions. The highest positive correlation between the frequency of the circulation form E and air temperature in summer is typical for the northern Europe (Fig. 4.11). In the synoptic situation when a high has expanded over northern Russia, warm continental air is moving along the southern and western periphery of the high from the east, southeast and south to far north up to the coast of the Barents Sea.

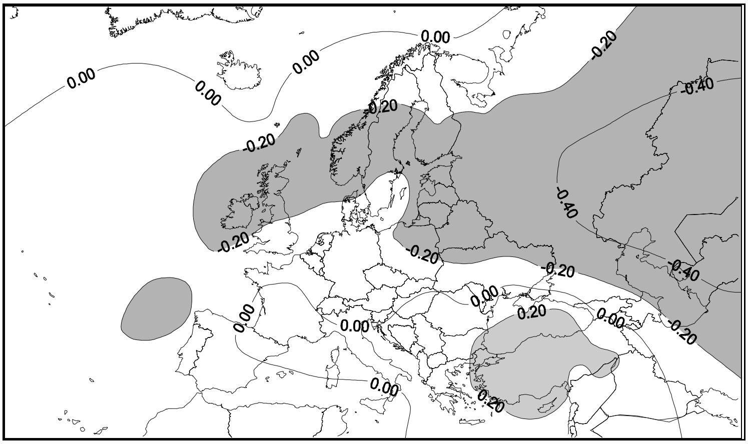

Fig. 4.10. Correlation between the frequency of the circulation form E and mean air temperature in winter.

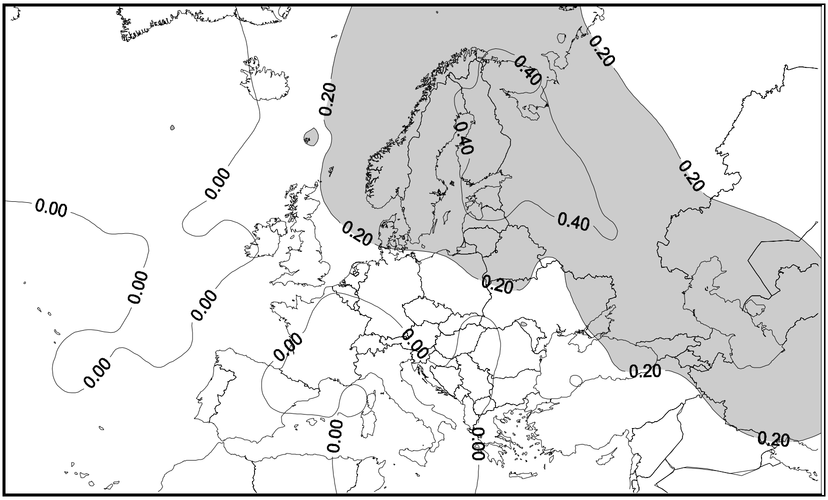

Fig. 4.11. Correlation between the frequency of the circulation form E and mean air temperature in summer.

Correlations between the frequencies of the circulation types W and E and air temperature in spring and autumn are generally negligible. As it will be shown in the next subchapter, circulation types grouped into the same circulation form may cause very different weather conditions during these intermediate seasons. The frequency of the form C is negatively correlated with air temperature throughout a year but especially in spring and autumn (Fig. 4.12). In a synoptic situation when a high-pressure area has extended over western Europe and a low-pressure area covers the easternmost part of Europe, there are favourable conditions for an intense airflow from the north to the south. The form C is related to advection of the Arctic air to eastern Europe up to Turkey. A positive correlation between the form C and air temperature is evident in the westernmost and north-westernmost regions of Europe, first of all on Iceland, which are located in the western periphery of the high.

Comparing the two subjective classifications of atmospheric circulation — Vangengeim-Girs and Hess-Brezowsky, it is not possible to judge, which of them describes circulation better (PAPER I). It is evident that they are elaborated for different regions and they have higher correlations with air temperature at different parts of Europe. As stated in PAPER I, the Vangengeim-Girs classification better describes the large-scale atmospheric circulation over the northern and eastern Europe while the Hess-Brezowsky classification is better applied to central, western and southern Europe.

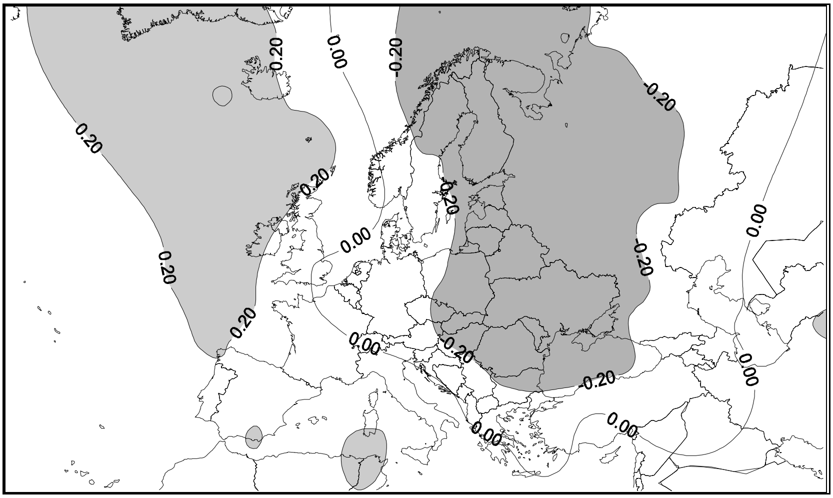

Fig. 4.12. Correlation between the frequency of the circulation form C and mean air temperature in spring.

The circulation forms W, E and C of the Vangengeim-Girs classification better reflect circulation conditions over the territory of Estonia. As mentioned before, many Estonian authors (e.g. Keevallik *et al,* 1999) have concluded that weather types (*Grosswetterlagen*) collected into one circulation group may be related to very different circulation and weather conditions found in Estonia.

4.4. Relationships between the frequency of circulation forms and air temperature in Estonia

PAPER I analyses air temperature interpolated into grid cells. It reflects the influence of large-scale circulation on the continental scale temperature field very well. At the same time, this approach is not sufficient for the analysis of relationships of a local scale. The influence of frequencies of the circulation forms according to the Vangengeim-Girs classification on air temperature in Estonia is analysed in this subchapter. Air temperature variability in Estonia is characterised by the observation data gathered at the Tartu station. It is representative for the whole continental part of Estonia while air temperature on the coast and on the islands is very much influenced by the sea surface temperature, ice cover and other local peculiarities.

Correlation coefficients between the frequency of the circulation forms W, E and C, and mean air temperature in Tartu are presented in Table 4.2. The values for the long (1891–2001) and the short (1948–2000) periods are shown separately. The correlations are rather high and easily explainable. The frequency of the circulation form W has a negative correlation with air temperature in summer and a highly positive correlation in winter. The form E is related to higher than normal air temperature in summer and to substantially lower than normal temperature in winter. The form C brings cold weather in spring and autumn. It has a significant negative correlation also with annual mean air temperature. The forms W and E have no correlation with temperature in annual values due to opposite correlations in summer and winter.

Table 4.2. Correlation coefficients between mean air temperature in Tartu and the frequency of the circulation forms W, E and C. Statistically significant correlations on $p<0.05$ level are typed in bold.

	1891–2001			1948–2000		
	W	E	C	W	E	C
January	**0.58**	**–0.35**	–0.23	**0.62**	**–0.35**	–0.28
February	**0.63**	**–0.40**	–0.22	**0.72**	**–0.52**	–0.21
March	**0.36**	–0.04	**–0.35**	**0.48**	–0.24	–0.24
April	0.00	**0.26**	**–0.33**	0.16	0.05	–0.23
May	–0.22	**0.50**	**–0.38**	–0.32	**0.59**	**–0.45**
June	**–0.42**	**0.53**	–0.22	–0.34	**0.59**	**–0.45**
July	**–0.37**	**0.40**	–0.15	–0.33	**0.39**	–0.25
August	**–0.43**	**0.48**	–0.10	**–0.49**	**0.54**	–0.06
September	–0.07	**0.44**	**–0.43**	–0.09	**0.47**	**–0.47**
October	0.13	0.19	**–0.39**	0.21	0.04	**–0.36**
November	0.22	0.03	**–0.33**	0.19	0.05	–0.29
December	**0.33**	–0.12	**–0.26**	**0.42**	–0.15	–0.27
Annual	0.15	0.05	**–0.31**	**0.47**	–0.30	–0.11
Spring	0.16	0.13	**–0.35**	**0.39**	–0.17	–0.20
Summer	**–0.35**	**0.39**	–0.15	–0.23	0.35	–0.21
Autumn	0.09	0.22	**–0.40**	0.14	0.10	–0.30
Winter	**0.54**	**–0.36**	–0.13	**0.72**	**–0.51**	–0.16

Comparing the correlation coefficients calculated for the long and the short period in Table 4.2 some differences appear. As a rule, the correlation coefficients for the shorter period are higher. During 1948–2000, the frequency of the form W has statistically significant correlations with annual, winter and spring mean temperature but in summer only with air temperature in August.

Correlation between the frequency of the circulation form E and air temperature in the short period has been very high in winter. Significant correlations in monthly values revealed from May until September.

All correlation coefficients between the frequency of the form C and air temperature in Tartu are of negative sign. At the same time, the number of statistically significant correlations is obviously lower than in case of other circulation forms. Mostly, higher correlation is typical for spring and autumn months.

Accordingly, correlation between the frequency of the circulation forms and air temperature in Estonia is a variable depending on the period. During some periods, the correlation is much higher or lower.

Moving correlation coefficients are used to analyse temporal variations in the strength of the relationships. The first correlation coefficient is calculated for the first 30 years (1891–1920) and later, the period is advanced by one year. The last interval for which the correlation coefficient was calculated was 1972–2001. All together, there is an 82-year time series of correlation coefficients.

Figures 4.13–15 demonstrate that correlation between the frequencies of the circulation forms and air temperature in Tartu is significant but highly variable. The correlation coefficients calculated for the 30-year time series are statistically significant on the p<0.05 level in case when their value r>±0,4.

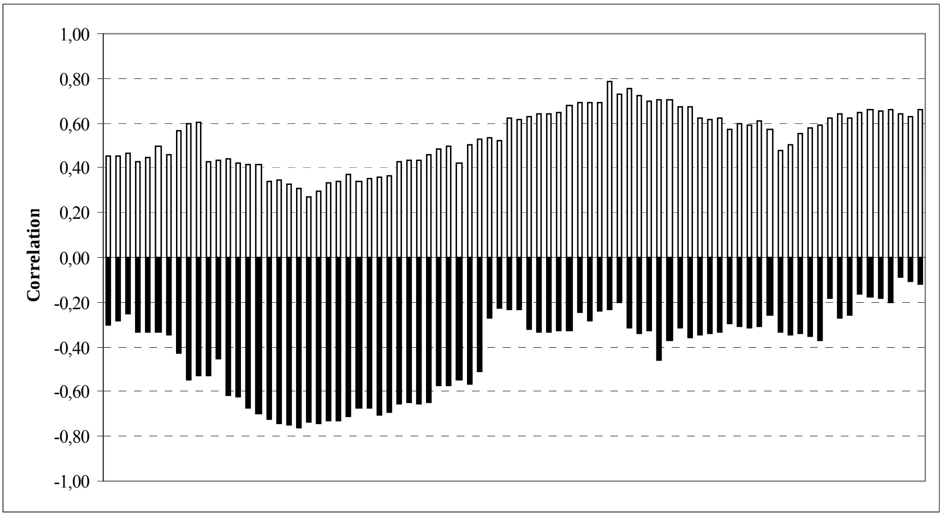

Fig. 4.13. 30-year moving correlation coefficient between seasonal mean air temperature and the frequency of the circulation form W in winter (positive values) and in summer (negative values) during the time interval from 1891–1920 to 1972–2001.

The graphs of the time series of moving correlation coefficients distinguish the periods with higher correlation. For example, the form W has had a maximum (negative) correlation with summer air temperature during the first half of the 20th century and a maximum positive correlation with winter temperature during the second half of the century (Fig. 4.13). In case of the form E, the highest positive correlation with summer temperature has been observed during the first half of the 20th century, while the higher negative correlation with winter temperature is revealed at the end of the time series (Fig. 4.14). Thus, it can be concluded that correlation between atmospheric circulation and air temperature in Estonia in the summer season was the highest during the first half of the 20th century and in winter — during the second half. Correlation between the frequency of the circulation form C and air temperature in spring and autumn is higher during the first half of the time series (Fig. 4.15).

A clear regularity appears in Figures 4.13–14. When summer correlations are higher then winter correlations are lower, and vice versa.

In conclusion, during the 111-year period there have been shorter time intervals when the frequency of the circulation forms according to the Vangengeim-Girs classification describes the majority of air temperature variability in Estonia. At the same time, there have been periods when the relationships remained weak. The cause of this kind of variability can, probably, be the fact that there may be a significant temporal variability in single circulation types, which are grouped into the three main circulation forms in the Vangengeim-Girs classification. On the regional scale, different circulation types gathered into one circulation form may cause different weather conditions. Therefore, it is reasonable to include more detailed information into studies of relationships between circulation and climate variability in smaller regions. One example of such research is presented in the next subchapter.

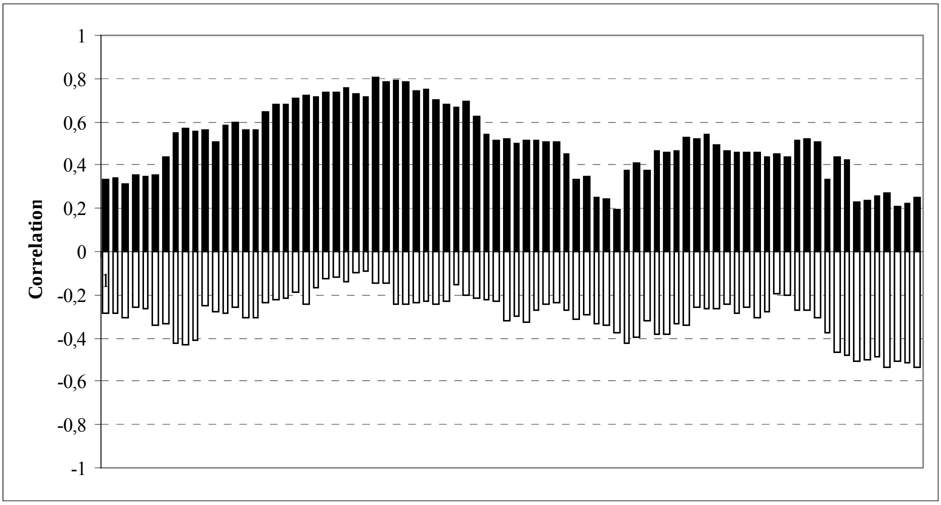

Fig. 4.14. 30-year moving correlation coefficient between seasonal mean air temperature and the frequency of the circulation form E in summer (positive values) and in winter (negative values) during the time interval from 1891/1920 to 1972/2001.

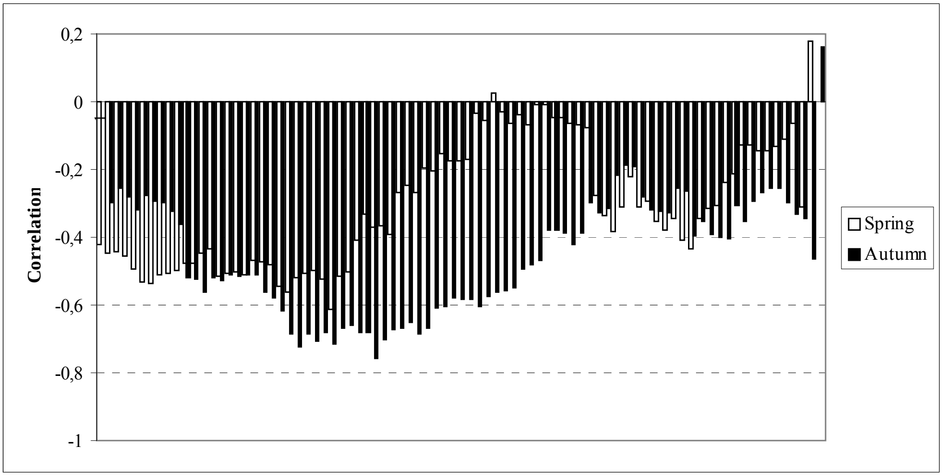

Fig. 4.15. 30-year moving correlation coefficient between seasonal mean air temperature and the frequency of the circulation form C in spring and in autumn during the time interval from 1891/1920 to 1972/2001.

4.5. Relationship between atmospheric circulation and air temperature in Estonia in March

Climate warming in Estonia during the second half of the 20th century is expressed in the most significant and obvious way in spring, especially in March (Keevallik, 2003). The increase in monthly mean air temperature has also been the highest just in March (Jaagus, 2006). At the same time, significant correlations between air temperature and the frequency of the circulation forms W and C exist only during some periods.

Data in Table 4.1 indicate that the frequency of the circulation form C has decreased by 6.2 days during the period 1948–2000. It is a substantial decrease if taking into account that the mean number of days with the form C in March during the same period was 6.5. Thus, it can be assumed that the warming trend in March is related to the minimal frequency in the end of the study period of the circulation form C favouring the advection of Arctic air.

Air temperature is extremely dependent on the state of land surface in March, first of all on snow cover, which, in its turn, depends on the weather conditions during some previous months in the same winter. As it is indicated in Table 4.1, the frequency of the circulation form W in winter has significantly increased during the last half of the 20th century. Therefore, winters and the following springs have become warmer.

It is supposed that the March mean air temperature in Estonia is very sensitive to advections of different air masses. Synoptic processes, the locations of lows and highs, in their turn determine the advections. Relationships between circulation and temperature have to be analysed in more detail, on the level of single circulation types, not of circulation forms.

Hereby, an assumption is made that the data of circulation sub-types in the Vangengeim-Girs classification are homogeneous on some level of generalization.

By average air temperature ESP-s are divided into eight classes, which are generalised into two groups — warmer or colder than the long-term average midnight air temperature in Tartu in March (-4˚C).

As a result, six groups of circulation types were formed: Wcold, Wwarm, Ecold Ewarm, Ccold, Cwarm (Table 4.3). Time series of frequencies of these six circulation groups were composed.

Table 4.3 Number of days of ESP-s belonging to different temperature classes (period 1949–1996)

Total of days with **warm** ESP-s of form		Total of days with **cold** ESP-s	
W	361	41	W
E	441	361	E
C	53	231	C
Sum of warm days	855	633	Sum of cold days

The analysis shows that the frequency of the ESP-s, which causes higher air temperatures in March, increased during the period 1949–1996. Frequency of “cold” ESP-s decreased substantially. (Fig. 4.16).

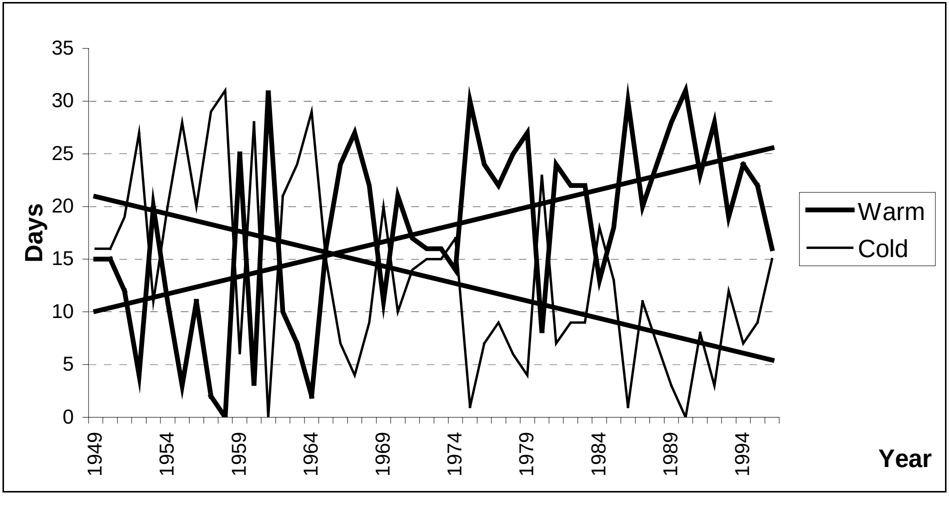

Fig. 4.16. Frequency and trend lines of “warm” and “cold” ESP-s in period 1949–1996

The most dramatic changes can be observed in the frequency of ESP-s belonging to the meridional circulation form E. Generally, the frequency of the form E increased since the beginning of the period until it achieved maximum in 1970–1980. At the same time, the frequency of "cold" ESP-s of the form E decreased and the frequency of "warm" ones increased (Fig. 4.17). Significant increase can be observed also in case of the frequency of "warm" ESP of the form W (Figure 4.18).

All trend lines, showed in fig. 4.16–4.18 are statistically significant. Also all time series (except W cold in fig. 4.18) presented in mentioned figures are strongly correlated with air temperature in Estonia in March.

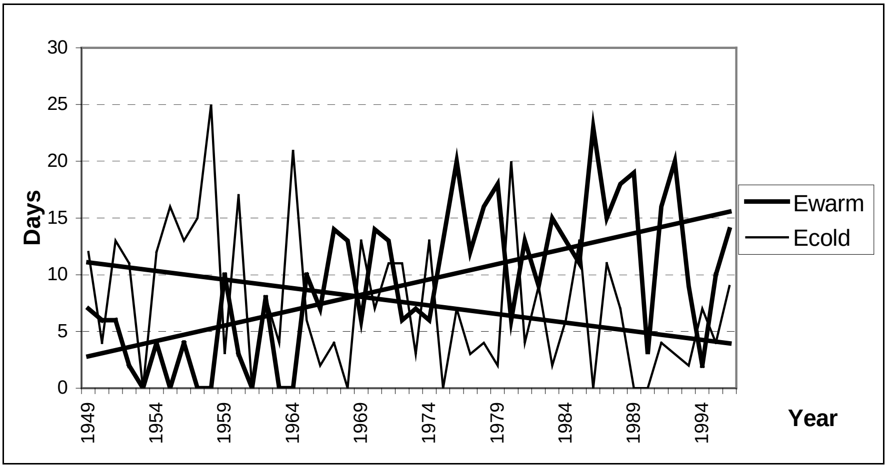

Fig. 4.17. Frequency and trend lines of "warm" and "cold" ESP-s of the circulation form E in period 1949–1996

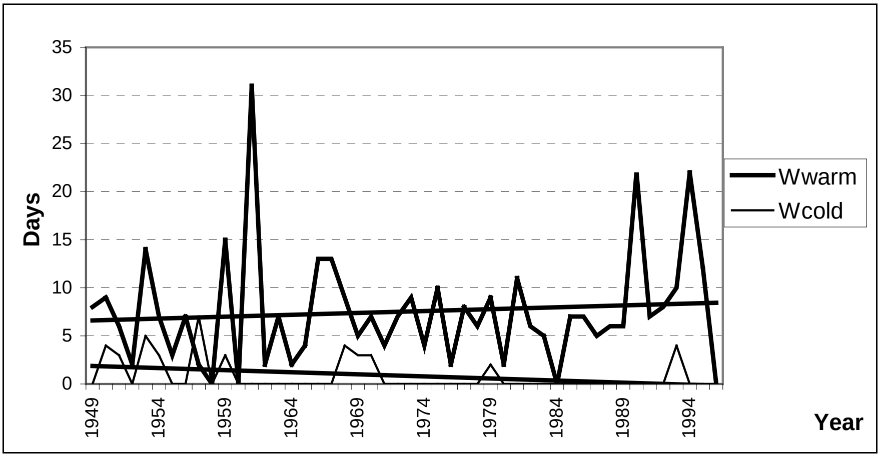

Fig. 4.18. Frequency and trend lines of "warm" and "cold" ESP-s of the circulation form W in period 1949–1996

5. CHANGES IN FREQUENCY AND TRAJECTORIES OF CYCLONES

Weather conditions at a concrete location are determined not only by large-scale atmospheric circulation but also by the locations of highs and lows, and by the trajectories of their movement. For example, when a cyclone passes Estonia in winter from the northern side, it causes an advection of mild and moist air coming from the Atlantic. At the same time, when a cyclone passes Estonia from the southern side, it leads to the advection of cold and dry continental air from the east and northeast. Weather conditions in winter are dramatically different in these two cases. As we saw in Chapter 4, drastic changes in circulation occurred not only in the frequency of circulation forms but also inside of those forms. For more detailed analysis of climate changes, which have occurred in Europe and especially in Estonia, we have to look at the time series of cyclones.

In PAPER III, the frequency and trajectories of cyclones in northern Europe are analysed during the period 1948–2000 using database of cyclones (Gulev *et al*, 2001). The PAPER III is based on two hypotheses:

1) Due to the increase in deep and long-living cyclones in the Northern Atlantic, reported by numerous authors (e.g. Gulev *et al.* 2001, Zhang *et al.* 2004), more cyclones reach northern Europe and that is the main reason, why climate conditions have become more maritime.
2) If the number of cyclones has significantly increased in the European Arctic, as noticed in Gulev et al. (2001), then probably the cyclones in northern Europe also “prefer” to use more of the northern tracks and less of the southern ones.

The main result of PAPER III is that long-term changes in cyclones are clearly zonal (latitudinal) — the number of cyclones has increased in the Baltic Sea region, especially in winter, and decreased in central Europe, especially in summer. These changes allow assuming that the air temperature increase in northern Europe and precipitation decrease in many regions in central Europe can be related to changes in the frequency of cyclones.

All the cyclones are analysed in PAPER III despite their physical parameters (air pressure). A cyclone is defined as an area with lower sea-level pressure than in its surroundings (Gulev *et al*, 2001). Its isobars form a closed contour. It means that the database contains a number of centres of shallow lows.

It is natural that deep and long-lasting cyclones have much stronger influence on regional climate variability than shallow cyclones. In the following, only deep cyclones are analysed. They are selected from the same database of cyclones (Gulev *et al*, 2001) which has been used in PAPER III. A cyclone is defined as deep when sea-level pressure in the centre of the cyclone has dropped below 1000 hPa during at least one observation time. The same criterion has been applied in some other studies (Gulev *et al*, 2001, Zhang *et al*, 2004). These studies conclude that the number of cyclones in the Northern Hemisphere has decreased during the second half of the 20th century, but the number of deep cyclones has significantly increased. This result allowed assuming that the number of deep cyclones over northern Europe has increased due to the increase in the whole Atlantic-European sector. Generally, the results of the analysis presented in PAPER III confirm this assumption.

Hereby, long-term changes in time series of a number of deep cyclones are studied and compared with time series of all cyclones.

5.1. Changes in the frequency of deep cyclones crossing meridians 5ºE, 20ºE and 50ºE

The number of all cyclones, as well as deep cyclones, decreases from the north to the south (Fig. 5.1, 5.2). The total number of cyclones crossing the meridian 20°E in the sub-zone C2 (45–50°N) is a remarkable exception. The highest number of cyclones during the period 1948–2000 (4284) was observed at the meridian 20°E. At 5°E, it was less by 851 and at 50°E — by 466 cyclones.

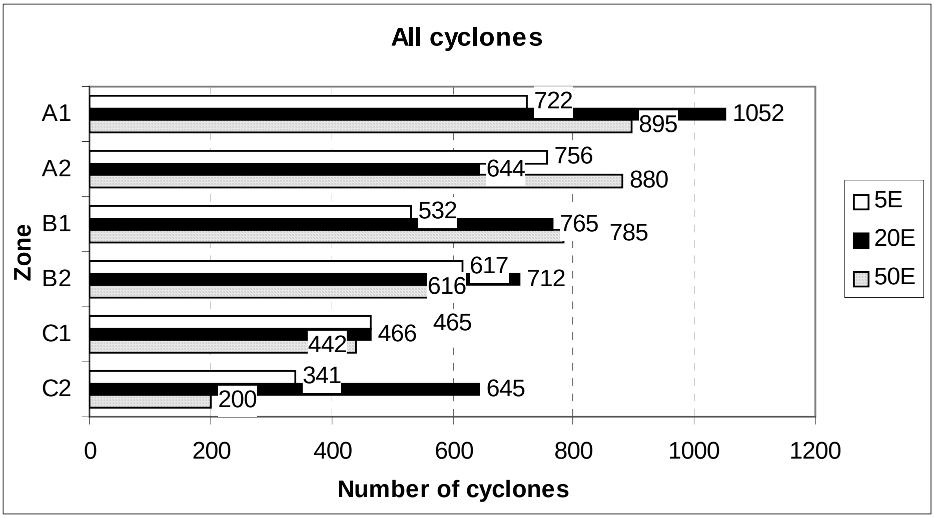

Fig. 5.1. The number of all cyclones that crossed the meridians 5ºE, 20ºE and 50ºE during the period 1948–2000.

Generally, the percentage of deep cyclones crossing all three meridian intervals in zones A (65–75°N) and B (55–65°N) lies between 75.5 and 92.1. It can be assumed that the changes in the number of all cyclones moving from the west to the east presented in PAPER III are valid also for deep cyclones.

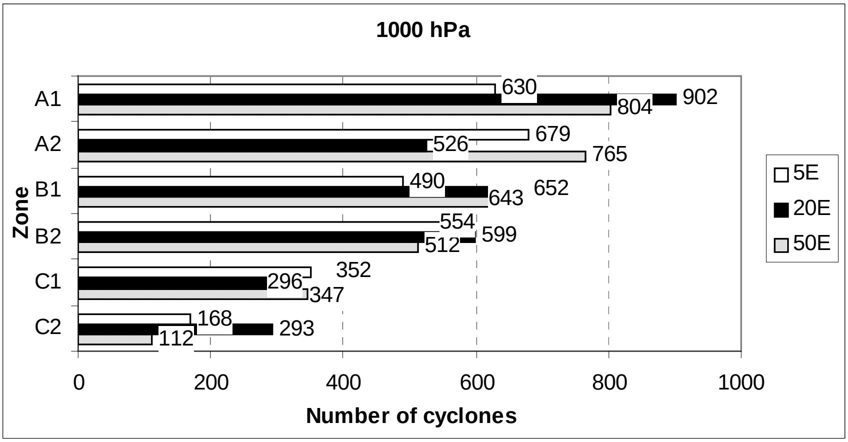

Fig. 5.2. The number of deep cyclones that crossed the meridians 5ºE, 20ºE and 50ºE during the period 1948–2000.

The part of deep cyclones using the southern trajectory (zone C, 45–55°N) is obviously less than in the zones A and B. It is the most expressive at 20°E where the number of deep cyclones is only 53% of the total number of cyclones crossed zone C.

The frequency of cyclones has a well-determined annual cycle. The maximum is usually observed in autumn and winter, and the minimum — in June and July (Fig. 5.3). This curve is similar for zones A and B in case of all cyclones as well as of deep cyclones only. The percentage of deep cyclones varies from 69 (5°E zone A in May) to 98 (5°E zone B in December).

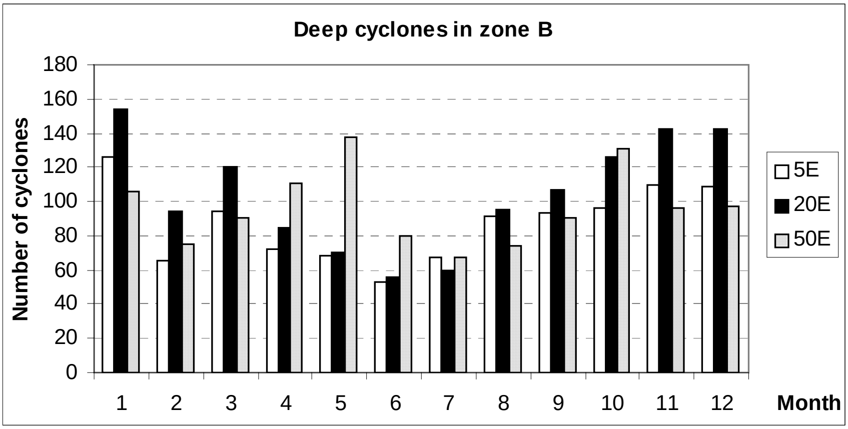

Fig. 5.3. Monthly distribution of deep cyclones that crossed the meridians 5ºE, 20ºE and 50ºE in zone B.

Different features are present in the zone C. The part of deep cyclones is comparatively small throughout a year rarely increasing above 50%. A peculiar seasonal distribution of cyclones revealed at 20°E. While the total number of cyclones crossing that meridian is the highest in summer (Fig. 5.4), the number of deep cyclones reaches its annual minimum at the same season (Fig. 5.5). The part of deep cyclones crossing 20°E in the zone C in May, June and July is less than 35%.

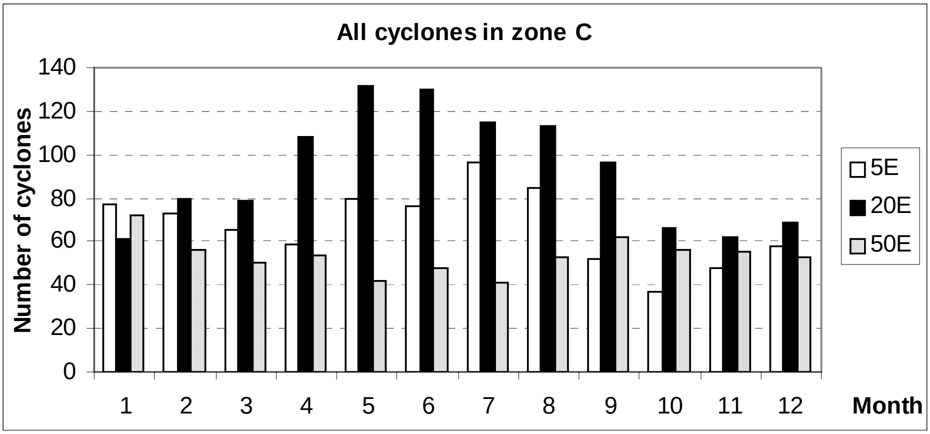

Fig. 5.4. Monthly distribution of all cyclones that crossed meridians 5ºE, 20ºE and 50ºE in zone C.

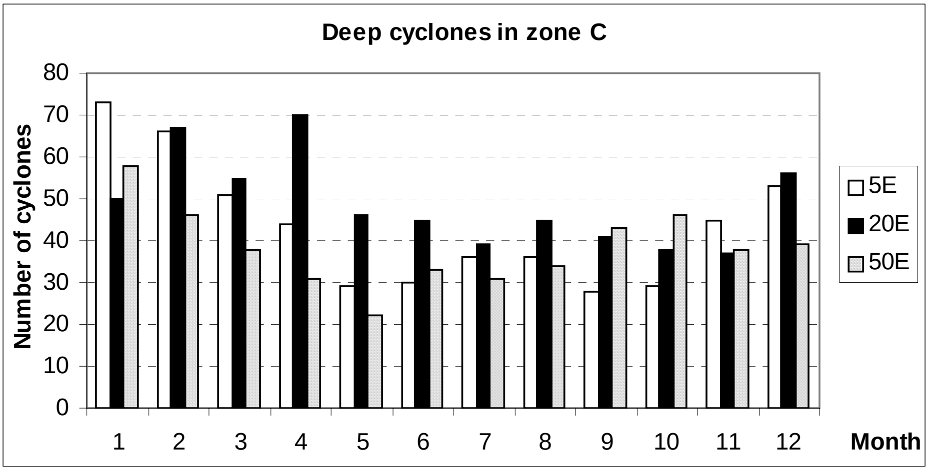

Fig. 5.5. Monthly distribution of deep cyclones that crossed meridians 5ºE, 20ºE and 50ºE in zone C.

Using linear regression analysis trends in time series of number of cyclones crossing different meridians at several latitudes are analysed. The summary results for deep cyclones are presented in Table 5.1. Generally, trends in total number of cyclones and in number of deep cyclones in zones A and B are very similar. Thus, trends in deep cyclones determine trends in the total number of cyclones.

In the northernmost sub-zone (A1, 70–75°N), a significant increase in the frequency of cyclones is observed in summer season and in August and September only at 5°E (Fig. 5.6). Due to the fact that there is no trend in number of cyclones crossing 20°E during the same periods, it could be assumed that the increase is caused by cyclones moving to the northern direction towards Spitsbergen. A change in this kind of cyclones has been detected also by Zhang et al. (2004) analysing Arctic cyclones.

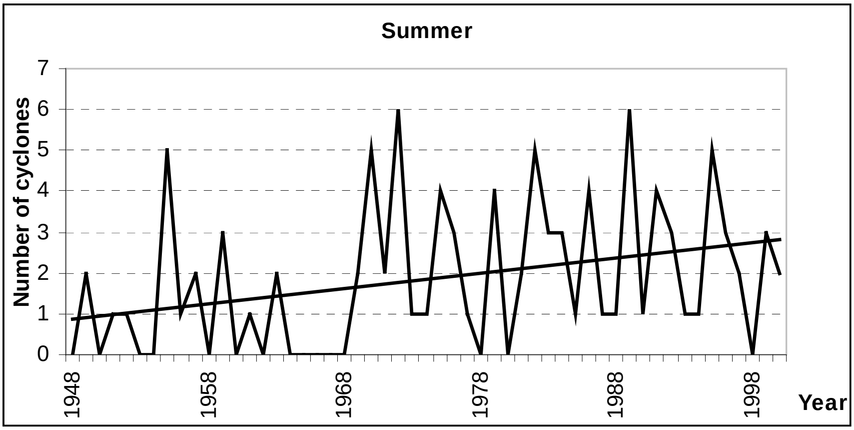

Fig. 5.6. Time series and the trend line of the frequency of summer cyclones crossing 5ºE in sub-zone A1.

Another remarkable increasing tendency revealed in winter mostly for the sub-zone B1, 20ºE. This trend is analysed in more details in PAPER III. The number of deep cyclones has indeed increased over the Norwegian, Bothnian and the Baltic Seas (Baltic Proper) in winter (Fig. 5.7). Among the winter months, the highest increase occurred in February. This change could easily be related to winter warming in Estonia.

A significant decrease in the annual and spring number of cyclones crossing 20°E in the sub-zone A2 (65–70°N) was detected. It is located in northern Scandinavia and it is describing cyclones moving over the Scandinavian Mountains. Probably, more cyclones have started to use other trajectories. A positive trend was detected over the central part of the Baltic Sea (20°E sub-zone B2) in August and during the whole summer.

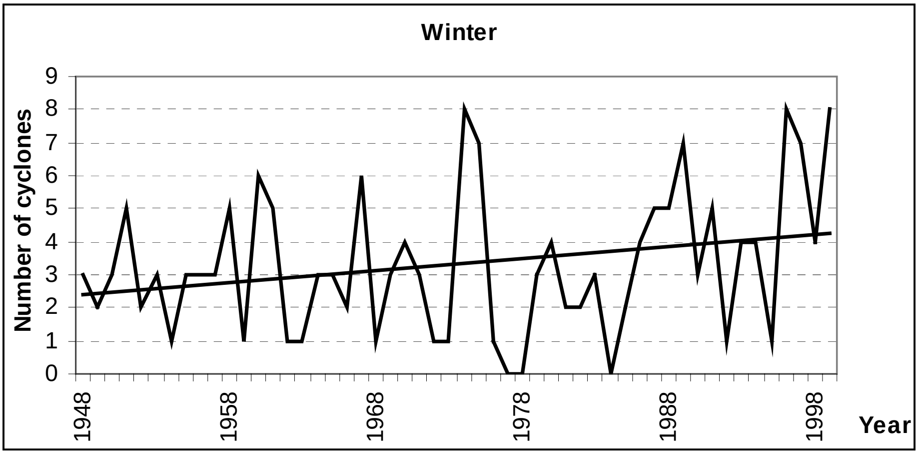

Fig. 5.7. Time series and the trend line of the frequency of winter cyclones crossing 20ºE in sub-zone B1.

Mostly decreasing trends have been observed in the frequency of deep cyclones in the southern zone C (Fig. 5.8). But they are much weaker than the trends for the total number of cyclones analysed in PAPER III, whose annual value has decreased by 12.8 during the same period. Consequently, mostly the number of weak cyclones has decreased.

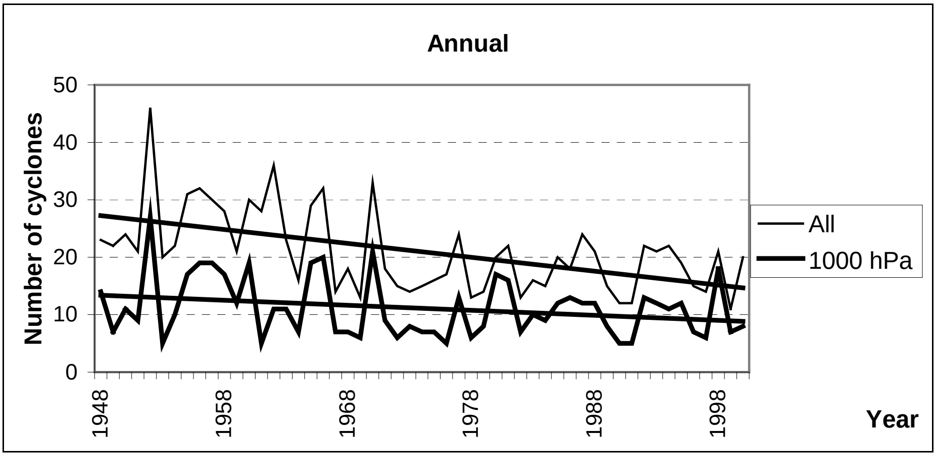

Fig. 5.8. Time series and trend lines of the annual frequency of all and deep cyclones crossing 20ºE in zone C.

Table 5.1 indicates that the number of deep cyclones crossing 5°E between 45–75°N has increased by 6.7 cyclones while the highest growth has taken place in winter. The number of cyclones crossing 20°E has increased in winter and autumn,

Table 5.1. Changes by trend in the number of deep cyclones during 1948–2000 crossing the meridians 5°E, 20°E and 50°E at different sub-zones. Statistically significant trend on the P<0.05 level are marked in bold.

Sub-zone	A1			A2			B1			B2			C1			C2			Total		
Meridian	5°E	20°E	50°E	5°E	20°E	50°E	5°E	20°E	50°E	5°E	20°E	50°E	5°E	20°E	50°E	5°E	20°E	50°E	5°E	20°E	50°E
Jan	0.6	–0.1	–0.3	0.3	–0.1	–0.9	0.5	0.3	0.6	–0.1	0.6	1.0	–0.1	0.0	0.0	–0.3	**–0.8**	–0.4	0.8	0.0	–0.1
Feb	–0.2	–0.1	0.4	**1.2**	0.5	0.1	**0.9**	**1.0**	0.1	–0.2	0.1	0.6	–0.1	**–1.0**	–0.2	–0.1	–0.6	0.0	1.5	–0.1	1.1
Mar	–1.1	–0.6	–0.3	0.5	–0.7	–0.2	0.2	0.7	–0.7	0.0	–0.4	–0.2	0.2	0.3	**–0.7**	–0.2	–0.7	–0.1	–0.4	–1.5	–2.1
Apr	0.2	–0.4	–0.2	–0.8	–0.8	–0.7	–0.3	0.8	1.0	0.3	0.0	0.2	0.3	–0.7	0.1	0.4	0.2	0.2	0.2	–0.9	0.5
May	0.3	0.4	0.5	–0.2	–0.3	–0.9	–0.3	0.3	–1.0	0.3	0.0	0.2	0.3	0.3	0.2	–0.2	0.0	**0.3**	0.1	0.7	–0.8
Jun	0.6	0.7	0.7	0.0	–1.1	–0.1	–0.1	0.0	0.1	0.5	0.5	0.0	–0.1	–0.7	–0.3	–0.3	–0.2	–0.1	0.6	–0.8	0.4
Jul	0.4	–0.3	0.8	0.1	–0.7	0.0	–0.1	–0.2	**–0.5**	–0.3	–0.1	–0.7	–0.2	–0.1	**–0.8**	–0.1	–0.4	–0.2	–0.2	**–1.9**	–1.3
Aug	**0.9**	0.0	0.0	0.2	0.4	–0.1	0.2	–1.1	0.3	–0.2	**0.8**	0.3	0.3	0.0	–0.1	–0.4	–0.1	0.0	1.1	–0.1	0.3
Sep	**1.1**	0.6	–0.4	0.4	–0.3	–0.3	–0.3	0.3	**–1.2**	–0.3	–0.6	0.3	0.4	0.0	**1.1**	0.0	0.3	0.0	1.4	0.3	–0.3
Oct	–0.2	1.1	0.9	–0.1	–0.7	0.6	–0.2	0.4	0.2	0.3	0.4	0.4	0.5	0.4	–0.1	–0.1	–0.3	0.0	0.2	1.2	2.1
Nov	–0.5	0.3	0.1	–0.4	0.1	0.3	0.1	0.1	0.5	0.6	0.4	–0.1	0.2	–0.3	0.2	–0.2	–0.4	–0.3	–0.3	0.3	0.7
Dec	–0.3	1.2	0.9	0.2	–0.5	–0.3	0.3	0.5	0.5	0.9	0.9	0.3	0.1	0.4	**0.9**	0.3	–0.2	0.1	1.7	2.4	**2.4**
Year	1.8	2.7	3.1	1.4	**–4.2**	–2.5	0.8	3.2	–0.1	1.9	2.7	2.4	1.9	–1.4	0.4	–1.2	–3.2	–0.4	6.7	–0.3	2.9
Winter	–0.1	1.0	1.2	1.6	–0.1	–1.4	**1.9**	1.9	1.4	0.8	1.9	**2.0**	0.3	–0.3	0.7	–0.3	**–1.6**	–0.4	**4.2**	2.8	3.6
Spring	–0.6	–0.6	0.0	–0.5	**–1.8**	–1.8	–0.4	**1.9**	–0.7	0.7	–0.4	0.2	0.8	–0.1	–0.4	–0.1	–0.5	0.4	–0.1	–1.6	–2.4
Summer	**2.0**	0.3	1.5	0.2	–1.4	–0.1	0.0	**–1.4**	–0.1	0.0	**1.2**	–0.4	0.0	–0.8	**–1.2**	–0.7	–0.7	–0.3	1.5	**–2.7**	–0.6
Autumn	0.4	2.0	0.6	–0.1	–0.9	0.6	–0.5	0.8	–0.4	0.7	0.2	0.7	1.2	0.1	1.2	–0.3	–0.4	–0.2	1.3	1.8	2.5

and decreased in spring and summer, especially in July when a negative trend was persistent in all sub-zones and meridian intervals. The same changes have occurred also in the number of cyclones crossing 50°E while the increase was the highest in winter and decrease in spring. Generally, the results demonstrate the intensification of cyclonic activity over northern Europe and it's weakening in the central Europe. Consequently, the storm track has shifted to higher latitudes.

5.2. Changes in the frequency of deep cyclones crossing the parallel 67°N

The parallel 67°N located near the Polar Belt was crossed between 5–50°E by 982 so-called "diving" cyclones moving from the north to the south. 771 of them were deep. Their part varied between 73–81% between the three sectors (Fig. 5.9).

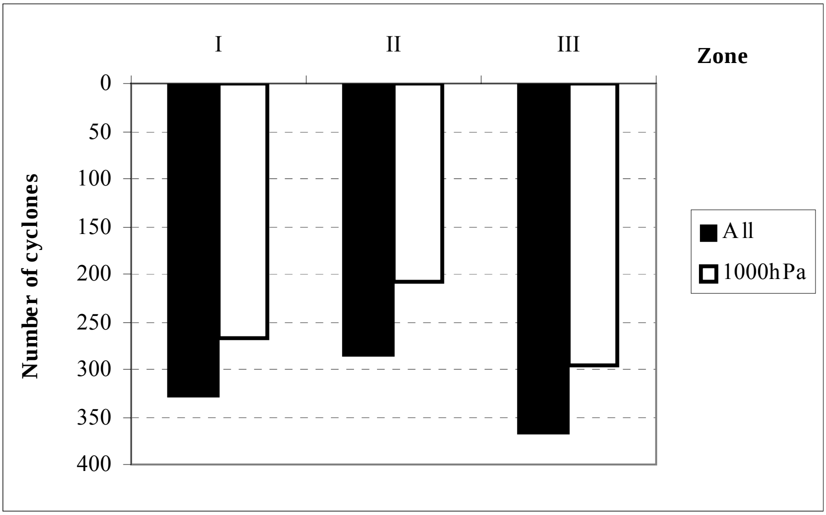

Fig. 5.9. Total number and the number of deep cyclones that crossed the parallel 67°N by sub-zones during the period 1948–2000.

The total number of cyclones moving from the north to the south is many times less than the number of cyclones moving along the usual trajectories from the west to the east. Diving cyclones are observed in certain synoptic conditions when the westerlies are broken by a huge anti-cyclone over the British Isles. It is not a usual situation.

It can be assumed that the Scandinavian Mountains serve as an important obstacle on the way of "diving" cyclones. Probably, the low number of cyclones crossing the sector II can be explained by this fact. The 45 degrees on the parallel 67°N is only 1935 km, which is only a little more than a half of the 30-degree intervals on meridians.

Nevertheless, it can be presumed that the cyclones moving from the north to the south favour an advection of cold air from northern directions.

Monthly distribution of these cyclones between the sectors is different. The maximum frequency of the cyclones in the sectors I (Norwegian coast) and III (coasts of the Barents and White Seas) were observed in winter and the minimum in summer, while the opposite situation was typical to the sector II (Lapland, Kola Peninsula). Different types of surfaces can explain this. The sector II covers a continental land area while the sectors I and III mostly lie over the sea surface and coastal area. Cyclones prefer warmer surface, which is the sea in winter and land area in summer.

Some significant trends were detected in the analysis of the frequency of "diving" cyclones (Table 5.2). A decreasing trend at the sector II and an increase at the sector III in spring are the most obvious changes. Due to a small number of cyclones, the results are not so reliable.

Table 5.2. Changes by trend in the number of deep cyclones during 1948–2000 crossing the parallel 67°N from the north to the south and crossing the parallel 52°N from the south to the north at different sectors. Statistically significant trend on the P<0.05 level is marked in bold.

Parallel	67°N				52°N			
Sector	I	II	III	Total	I	II	III	Total
Jan	0.2	0.1	0.0	0.3	0.0	–0.6	0.0	–0.6
Feb	0.3	0.1	–0.1	0.2	–0.1	–0.6	–0.4	–1.1
Mar	0.1	**–0.6**	0.1	–0.4	0.3	–0.4	–0.2	–0.3
Apr	0.2	0.2	0.4	0.8	0.3	0.1	0.4	0.7
May	–0.2	–0.4	**0.6**	0.1	0.7	**–1.1**	–0.6	–1.1
Jun	**–0.4**	–0.3	–0.4	**–1.2**	–0.2	–0.4	0.3	–0.3
Jul	–0.1	0.4	–0.2	0.0	0.2	0.4	–0.6	0.0
Aug	0.1	0.1	0.5	0.7	–0.4	–0.6	–0.5	**–1.6**
Sep	0.2	0.0	–0.4	–0.1	0.0	0.3	**0.9**	1.2
Oct	0.4	–0.1	0.4	0.8	–0.5	0.0	0.4	0.0
Nov	–0.4	0.0	0.4	0.1	–0.2	–0.2	0.4	0.1
Dec	0.3	0.2	0.4	0.9	–0.3	–0.8	0.6	–0.5
Year	0.7	–0.3	1.8	2.1	–0.2	**–3.9**	0.7	–3.5
Winter	0.6	0.3	0.2	1.1	–0.5	**–2.1**	0.3	–2.4
Spring	0.1	–0.8	**1.1**	0.5	1.3	–1.5	–0.4	–0.6
Summer	–0.5	0.1	–0.1	–0.5	–0.5	–0.6	–0.8	–1.9
Autumn	0.3	0.0	0.5	0.7	–0.6	0.1	**1.7**	1.2

5.3. Changes in the frequency of deep cyclones crossing the parallel 52ºN

During the 53-year period, the total number of 2101 the so-called southern cyclones was counted. Only 1336 of them or 63.6% were deep. They crossed the parallel 52°N between 5–50°E.

The number of the southern cyclones is more than two times higher than that of the "diving" cyclones. It is related to the fact that the 45 degrees on 52°N is more than 800 km longer than on 67°N. The warm sea surfaces of the Mediterranean, Black and Caspian Sea offer favourable conditions for the formation of cyclones.

The cyclones are unevenly distributed between the three 15-degree sectors (Fig. 5.10). Significantly higher amount of cyclones cross 52°N in the II sector (mostly the territory of Ukraine). It is partly explainable by orographic factors. The sector I is shaded from the southern directions by the Alps. The sector II is mostly lowland where cyclones from the Black Sea or the Mediterranean are moving to the north. Probably, some cyclones move along the northern edge of the mountains from the west to the east and turn to the north in the sector II. Cyclones of the sector III are mostly originated from the Caspian and Black Sea basins.

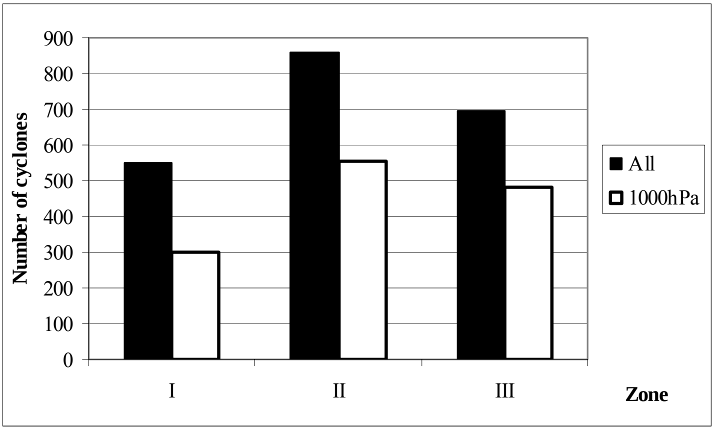

Fig. 5.10. Total number and the number of deep cyclones that crossed the parallel 52°N by sub-zones during the period 1948–2000.

Monthly distribution of the southern cyclones is nearly similar, especially for the sectors I and II. The maximum was observed in spring and in early summer and the minimum — in winter (Fig. 5.11). At the same time, the part of deep cyclones decreases in summer up to 35%. The monthly contrasts in the frequency of cyclones are not so big in the sector III.

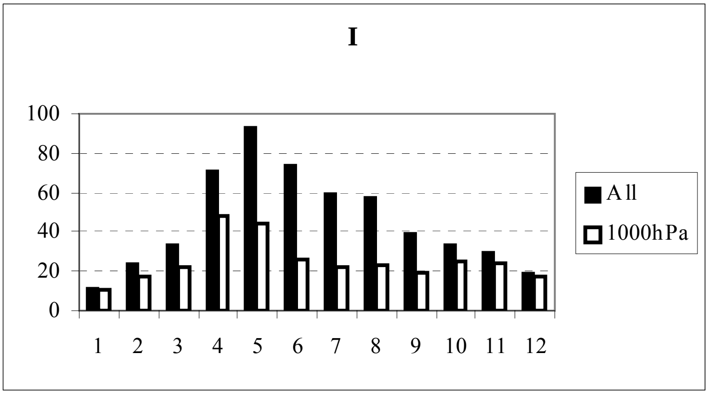

Fig. 5.11. Monthly distribution of the cyclones that crossed 52°N in the sector I during the period 1948–2000.

Changes in the frequency of cyclones crossing 52°N are much stronger than that of crossing 67°N (Table 5.2). The majority of the changes are related to changes in deep cyclones. The highest changes have taken place in the sector II (Ukraine and south-eastern Poland). The number of cyclones has significantly decreased there during winter, as well as in whole year (Fig 5.12). This change lies in a good concordance with the decreasing trend in cyclones crossing the meridian 20°E in the zone C. Probably, both these trends express the same process. Correlation coefficients between the numbers of deep cyclones crossing 20°E in the zone C and 52°N in the sector II are close and statistically significant for annual values (r=0.59), as well as for winter (r=0.60). The time series of corresponding values are rather coherent (Fig. 5.13).

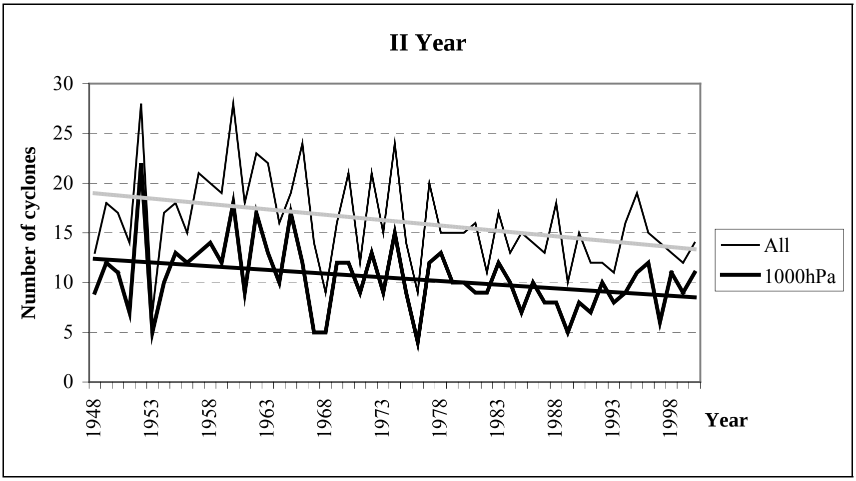

Fig. 5.12. Time series and trend lines of the annual frequency of all and deep cyclones crossing 52°N in the sector II.

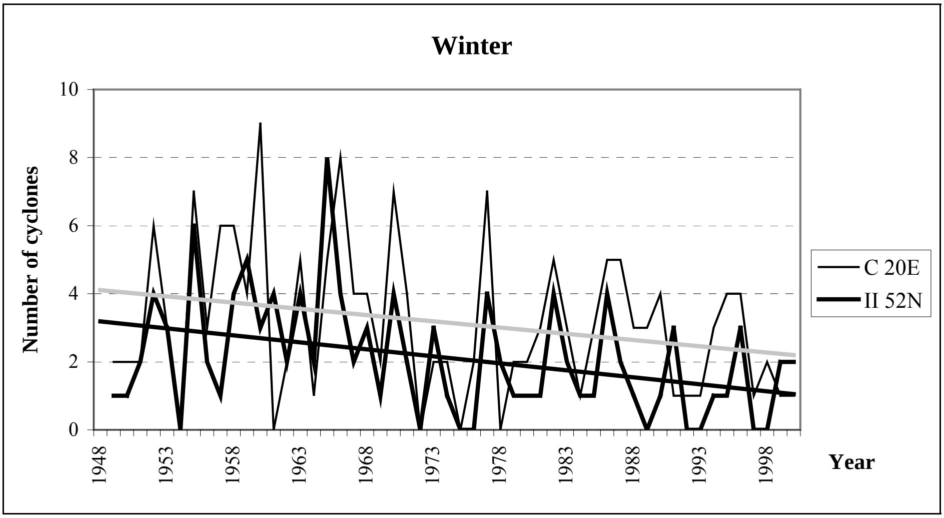

Fig. 5.13 Time series and trend lines of the frequency of winter deep cyclones crossing 20°E in the sub-zone C and the deep cyclones crossing 52°N in the sector II.

A significant increase in the frequency of cyclones crossing the sector III was detected in September and the whole autumn season. Unlike the trends in the monthly number of cyclones crossing 67°N, trends in monthly frequencies of cyclones crossing 52°N are reliable due to the greater numbers of cyclones.

5.4. Relationship between time series of deep cyclones and air temperature in Estonia

Results of the previous subchapters demonstrated that changes in the frequency of cyclone trajectories lie in correspondence with air temperature in Estonia during the second half of the 20th century. Warming in winter may be related to an increase in the number of cyclones passing Estonia from the northern side between 60–65°N. Thus, warming in the Baltic Sea area can be at least partly explained by the change in cyclonic activity. But, as mentioned in Paciorek et al. (2002), correlation between the frequency of cyclones and local climatic variables should not be high. Differences between cyclones are quite large. A number of cyclones during a month convey little information about their properties (extent, moisture content, stage of evolution etc.), which determine the influence of the cyclone on local weather conditions. It is not clear how much the passing of cyclones influences the monthly of seasonal mean air temperature.

In the following, correlation between the frequency of deep cyclones and air temperature in Tartu is analysed. The relationship is rather close and its zonal distribution can easily be explained (Table 5.3). The cyclones moving from west to east using the northern trajectories (zone A, sub-zone B1) have a positive correlation with air temperature in Estonia while cyclones using the southern trajectories (zone C) cause lower temperature. It confirms the assumption that changes in air temperature in the Baltic Sea region are dependent on the frequency of cyclones coming from the Atlantic. Cyclones crossing the sub-zone B2 are moving directly over Estonia and have a lower correlation with temperature. Similar relationship can be noticed between air temperature in Estonia and the frequency of cyclones crossed 50º E.

Southern cyclones also have a significant relationship with air temperature. If a southern cyclone passes Estonia from the eastern side (sector III), then it causes northerly circulation and negative correlation with air temperature throughout a year (Fig. 5.14).

If a cyclone passes Estonia from the western side (sector I), it is related to the southerly airflow and mostly positive correlation with temperature in Estonia, especially in spring.

The diving cyclones moving from the north to the south do not have such a strong influence on air temperature. It is understandable because the total number of diving cyclones is too low. Generally, correlations between air temperature and the number of diving cyclones have an opposite sign to that of southern cyclones. Cyclones passing Estonia from the western side (sector I) have a cooling effect, and from the eastern side (sector III) — a warming effect.

Another question is to how large an extent are the processes on different intervals of meridians and parallels connected. As demonstrated in PAPER III, a large part of the cyclones that have crossed 20°E have earlier crossed also 5°E. More exact answer to the question will be obtained when the trajectories of cyclones of different origin will be studied during their entire life cycle. As it was clarified in the previous subchapter, a great part of the variability of the frequency of cyclones crossing 20°E in zone C is determined by southern cyclones.

Table 5.3. Correlation coefficients between mean air temperature in Tartu and the frequency of cyclones crossing 5°E and 20°E at different sub-zones. Statistically significant correlation on the P<0.05 level is typed in bold.

Subzone	A1		A2		B1		B2		C1		C2	
Meridian	5°E	20°E	5°E	20°E	5°E	20°E	5°E	20°E	5°E	20°E	5°E	20°E
Jan	0.26	0.26	0.21	0.25	**0.27**	**0.44**	0.13	–0.11	–0.07	–0.24	**–0.37**	–0.08
Feb	–0.02	0.20	**0.47**	0.25	**0.46**	**0.46**	**0.31**	0.11	0.01	–0.03	–0.23	–0.22
Mar	0.21	**0.35**	**0.41**	0.18	**0.32**	0.08	–0.05	–0.04	**–0.29**	0.01	–0.10	**–0.52**
Apr	–0.24	–0.17	**–0.31**	0.25	0.10	0.11	–0.13	–0.23	0.05	–0.18	0.13	–0.06
May	–0.08	**0.31**	0.12	–0.06	0.12	–0.12	–0.20	–0.03	–0.12	**–0.31**	0.06	0.00
Jun	0.07	0.23	–0.04	0.15	0.05	–0.21	–0.09	–0.17	–0.18	–0.11	–0.08	–0.01
Jul	**0.30**	**0.27**	0.04	0.12	0.06	–0.14	**–0.31**	–0.22	–0.08	**–0.30**	**–0.31**	–0.22
Aug	**0.39**	0.24	0.12	0.11	–0.14	**–0.32**	–0.08	–0.13	–0.10	**–0.36**	–0.11	–0.18
Sep	–0.01	0.11	0.21	0.22	–0.11	–0.14	0.23	–0.13	–0.13	**–0.28**	0.09	–0.05
Oct	–0.07	0.13	0.27	0.17	0.04	0.10	0.11	–0.19	–0.14	**–0.35**	–0.18	–0.21
Nov	0.17	**0.30**	0.22	0.11	0.19	**0.37**	–0.16	–0.14	–0.12	–0.16	0.02	–0.03
Dec	0.08	0.18	0.24	0.22	0.20	0.21	–0.08	–0.04	**–0.29**	**–0.28**	–0.15	–0.06
Year	0.26	**0.39**	**0.44**	0.12	0.20	**0.32**	–0.01	–0.05	–0.16	**–0.31**	**–0.38**	**–0.31**
Winter	0.24	**0.38**	**0.47**	**0.28**	**0.37**	**0.49**	0.00	–0.03	**–0.32**	**–0.30**	**–0.53**	–0.18
Spring	0.13	**0.35**	0.14	0.04	0.25	0.25	–0.02	–0.01	–0.08	0.04	0.07	–0.25
Summer	**0.37**	0.25	0.04	0.04	0.20	–0.20	–0.25	–0.01	–0.23	–0.14	–0.19	–0.20
Autumn	0.17	0.17	**0.45**	0.16	–0.02	0.07	0.09	–0.19	**–0.30**	**–0.51**	–0.10	–0.20

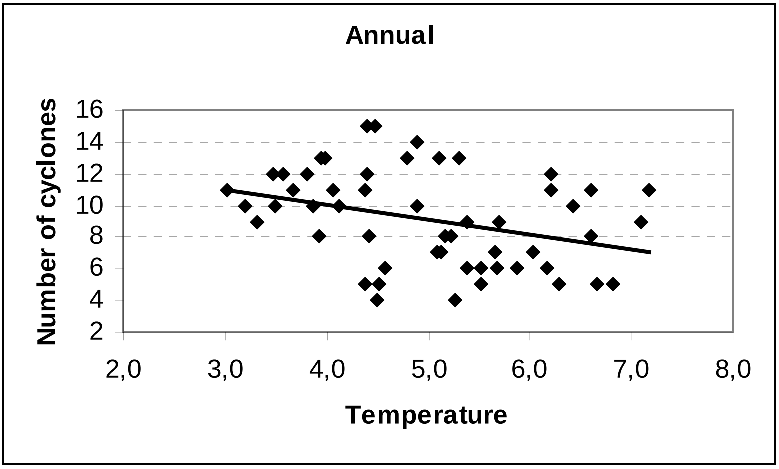

Fig. 5.14. Correlation between annual air temperature in Estonia and the frequency of deep cyclones that crossed the parallel 52ºN in sector III; r= –0.32.

5.5. Relationship between time series of deep cyclones and the circulation forms according to the Vangengeim-Girs classification

This study is largely focussed on the classification of atmospheric circulation elaborated by Vangengeim and Girs. It was also clarified that only the data on the three main circulation forms is not sufficient for more detailed studies of smaller territories. The same circulation forms may cause rather different weather conditions. Therefore, an analysis of the frequency and trajectories of cyclones are emphasised in this study.

A counting of cyclones crossing different meridian intervals can be treated as a classification of circulation processes. Thereby, for example, the westerly airflow can be described at different latitudes. A question arises, to what extent are the time series of the frequency of the circulation forms W, E and C, in accordance with the number of cyclones crossing different zones and sub-zones. To answer this question, the corresponding correlation coefficients were calculated, using time series of the period 1948–2000.

The results of the correlation analysis indicate a close relationship between the frequency of the circulation forms and deep cyclones of different trajectories. The frequency of the zonal circulation form W (Table 5.4) has a clear positive correlation with a number of cyclones crossing 5°E, 20°E and 50°E, especially in the zone B (55–65°N) (Fig. 5.15). A significant negative correlation was detected for cyclones crossing the zone C on the meridian 5°E (France). It marks the regions where high pressure is prevailing in case of these circulation forms. The circulation form W describes quite well the situation when cyclones are crossing the Baltic Sea region, especially the Gulf of Finland, and the territory of Finland and Lapland.

The frequency of the form E is negatively correlated with the number of cyclones moving from the west to the east (Table 5.4). The higher correlation is observed in the zones A and B (Fig. 5.16). The number of cyclones in southern France is positively correlated with the form E. This fact gives evidence of the existence of opposite air pressure and circulation conditions between the Baltic Sea and the Mediterranean regions. If the number of cyclones in the Baltic (form W) is large, there is a high in the Mediterranean, and vice versa (form E). The highest correlation with the frequency of the form E is located in the zone B of the meridian 50°E dominated by a wide and strong high-pressure system.

Table 5.4. Correlation coefficients between the frequencies of the circulation forms according to the Vangengeim-Girs classification and of the number of cyclones crossing the meridian 20°E at different latitudinal zones. Statistically significant correlation on the P<0.05 level is typed in bold.

Form	W			E			C		
Zone	A	B	C	A	B	C	A	B	C
Jan	**0.31**	**0.36**	0.05	**–0.27**	**–0.29**	0.13	–0.02	–0.06	–0.23
Feb	**0.31**	**0.40**	–0.01	**–0.43**	**–0.31**	0.11	0.24	–0.10	–0.14
Mar	**0.38**	0.07	–0.13	**–0.47**	0.01	0.03	0.16	–0.09	0.11
Apr	**0.41**	**0.46**	0.02	–0.19	–0.23	0.18	–0.20	–0.21	–0.25
May	0.03	**0.45**	0.00	0.05	**–0.34**	–0.10	–0.08	0.06	0.12
Jun	0.11	0.03	–0.01	0.14	–0.16	0.00	**–0.30**	0.19	0.02
Jul	–0.19	0.16	0.15	–0.05	–0.05	**–0.33**	0.21	–0.05	**0.30**
Aug	–0.15	**0.60**	**0.36**	0.15	**–0.42**	–0.21	0.00	–0.22	–0.18
Sep	0.02	**0.47**	0.04	0.00	–0.21	0.08	–0.03	**–0.30**	–0.15
Oct	0.19	**0.47**	–0.02	–0.21	**–0.39**	0.08	0.02	–0.15	–0.09
Nov	**0.33**	**0.34**	0.13	**–0.34**	–0.21	–0.03	0.16	–0.05	–0.09
Dec	0.10	**0.49**	0.06	–0.25	**–0.40**	0.07	0.24	0.00	–0.17
Winter	**0.41**	**0.48**	–0.20	**–0.49**	**–0.36**	0.26	0.24	–0.06	–0.17
Spring	**0.34**	**0.36**	0.03	**–0.36**	–0.12	0.07	0.10	–0.23	–0.12
Summer	–0.10	0.19	**0.35**	0.02	–0.12	**–0.31**	0.09	–0.05	0.04
Autumn	0.15	**0.40**	–0.09	–0.20	–0.26	0.18	0.10	–0.11	–0.13

The frequency of the circulation form C has much less correlations with the number of cyclones. An exception is the meridian 50°E where it is highly correlated with the number of cyclones crossing the zones B and C. The form C is related to a high over Scandinavia and low over the East European Plain and Siberia, and prevailing of northerly airflow in Estonia.

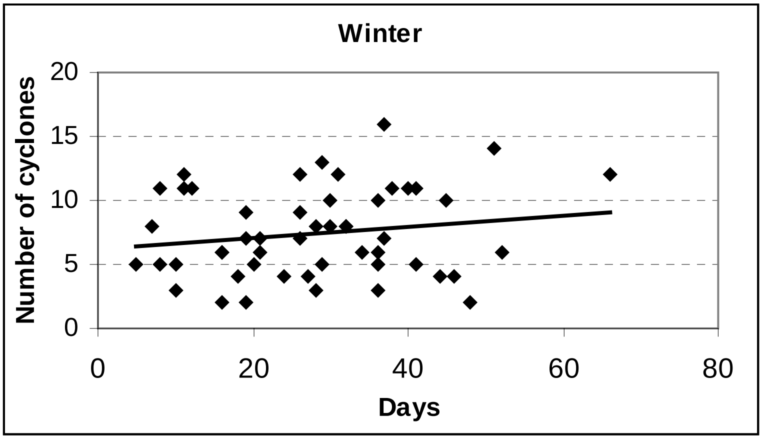

Fig.5.15. Correlation between the circulation form W and the frequency of deep cyclones that crossed the meridian 20ºE in zone B in winter; r= 0.48.

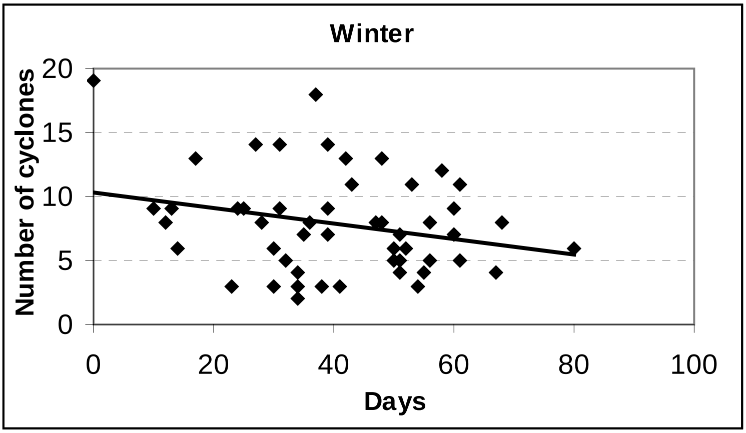

Fig.5.16. Correlation between the circulation form E and the frequency of deep cyclones that crossed the meridian 20ºE in zone A in winter; r= -0.49.

The "diving" cyclones moving from north to south have a close correlation with the frequency of the meridional circulation forms E and C. The form W has only a positive correlation with the cyclones in the sector III. The form E has mostly negative correlation. The more frequent the form E, the less cyclones are moving from north to south crossing 67°N. The highest negative correlation revealed in the sector III. The form C has an opposite correlation with the number of diving cyclones.

The frequency of the southern cyclones also has a closer correlation with the frequency of the meridional circulation forms E and C. In case of the form W, some seasonal differences appear. Correlation in winter is negative and in summer — positive. In case of the forms E and C, differences were revealed between the sectors. In sectors I and II, correlation between the number of cyclones and the frequency of the form E is positive, and with the form C — negative. In the sector III on the parallel 52°N the correlation is of opposite sign — positive with C and negative with E.

In conclusion, it can be stated that the Vangengeim-Girs classification describes rather well weather processes including the frequency of cyclones, especially in the Baltic Sea region.

6. RELATIONSHIP BETWEEN ATMOSPHERIC CIRCULATION AND VEGETATION

Since the extension of the definition of synoptic climatology, presented by B. Yarnal (1993), new branches of science have found methods of synoptic climatology as a useful investigation tool. Mostly, those branches are dealing with processes in animate nature. A number of vegetation characteristics depend on climatic factors. Variations in weather conditions are the main cause of annual differences in the seasonal or even long-term development of nature.

In general, two types of the influence of atmospheric circulation on vegetation can be distinguished, first of which is the proxy influence. As a main determiner of local climate in temperate zones, atmospheric circulation conditions the past and the present season, shaping the meteorological background to the beginning and developing of the vegetation period. On some scale, the influence may be direct. For example, circulation types may express not only the general airflow directions but also the weather conditions, i.e. they express a confluence of meteorological values.

In the following, based on PAPER II and PAPER IV, two examples of the use of the methods of synoptic climatology in environmental studies are presented. At first, relationship between atmospheric circulation and phenological phases and later, relationship between atmospheric circulation and Scots pine (*Pinus sylvestris* L.) growth indicators are discussed.

6.1. Atmospheric circulation and phenological phases

The timing of phenological phases in temperate zones is driven by air temperature, which is generally determined by atmospheric circulation. In Paper II, relationship between the beginning dates of flowering of Colts foot (*Tussilago farfara* L.), of birch (*Betula pendula* Roth.) leaf unfolding and of flowering of lilac (*Syringa vulgaris* L.) in central and eastern Europe, and the North Atlantic oscillation (NAO) and the Arctic oscillation (AO) indices, frequencies of the circulation forms by Vangengeim-Girs, and of the groups of *Grosswetterlagen* presented by Hess and Brezowsky were analysed using linear correlation coefficients. Results of the correlation analysis were mapped similarly to works (Kozuchowski, Marciniak, 1988; PAPER I).

Proceeding from the main goal of the present thesis, only the results obtained with Vangengeim-Girs classification are presented in this text.

The results of analyses in PAPER II demonstrate significant relationships between the parameters of large-scale atmospheric circulation and the beginning dates of the above-mentioned three phenological phases. The table of correlation coefficients is presented in the attached PAPER II (Table II). The circulation form W, reflecting the intensity of westerlies, has a significant negative correlation with all the studied phenophases. This means that the higher frequency of the form W in winter, the earlier begin the phenophases in spring (PAPER II, Fig. 7–3). The highest negative correlation is present in Ukraine and in the Baltic Sea region.

The circulation form E influences the phenophases with opposite sign. Prevailing of the form E in winter is related to late spring. Cold winters cause a long-time persistence of snow and ice cover in early spring, which in its turn causes late beginning of the spring season. The influence of the form C is significant only in spring at some locations (PAPER II, Fig. 8–3). It is natural that the frequency of the form C, related to northerlies in eastern Europe, is positively correlated with phenophases, i.e. causing a delay in the phenological development of nature.

As expected, maps of correlation between circulation forms and phenophases are rather similar to the correlation maps of air temperature presented in PAPER I. The onset of flowering of Colts foot and the leafing of birch are most closely correlated with the circulation form W that describes the strength of the westerly airflow in winter, for which $r>|-0.6|$. Of this classification, the frequency of the form W in March most accurately describes the onset of the flowering of lilac ($r>|-0.6|$). If the influence of the westerly air flow (form W) is more pronounced in the winter half-year and it weakens and disappears as spring advances, then forms C and E have a greater influence in springtime, particularly in the northernmost and southernmost regions of the area under observation. Compared to correlation between air temperature and circulation (PAPER I), the correlations between the onset of different phenological phases and atmospheric circulation patterns have considerably larger spatial variances. This is partially due, to the fact that, in the case of air temperature, gridded data was used, while this study uses the raw observation data of selected stations. Phenological data are much more site-specific, i.e. dependent on local climatic and landscape conditions. Phenological data are also more biased, as the observation methodology is not uniform in all countries and networks as it is in meteorological stations.

Correlations between circulation types and phenophases weaken in March and April because the observed scale changes from a climatological one to a synoptical one. This means that when the values averaged over several months are used, the geographic effects of individual baric formations are smoothed out. In monthly averages, however, the effects of individual cyclones or anticyclones predominate. In the case of zonal circulation, for instance, particularly in the spring months, air temperature and, as a result, the beginning date of phenophases at every individual location depends on the trajectory of the cyclone in respect to that location. As discussed earlier in Chapter 5, the trajectory of a low determines whether zonal circulation in spring brings warm weather or, conversely, assists in cold air advection.

None of the circulation parameters used in PAPER II universally describes the onset of phenological phases in central and eastern Europe. Each circulation characteristic has certain specific regions in which it most closely describes the variation in plant phenological phases individually. As expected in the case of Vangengeim-Girs classification, best results are in Eastern Europe.

Relationship between phenophases and climate variables in Estonia is discussed in detail in Ahas et al. (2000). In this article, strong correlation with air temperature is found in winter and early spring. Mostly, correlations between phenophases and air temperature are stronger, than with circulation variables. As mentioned, the circulation indexes or the frequency of circulation forms are still proxy data and the beginning of phenophases strongly depends on microclimatic conditions of the observation area. Circulation forms are still a useful tool for explaining large-scale changes in phenophases and it also helps to investigate relationship between animate nature and climate change in areas, where meteorological measurements are not available.

6.2. Relationship between atmospheric circulation and Scots pine (*Pinus sylvestris* L.) growth indicators

One of the interdisciplinary branches of science focusing on relationships between atmospheric circulation and biotic environment is dendroclimatology. Dendroclimatology was originally defined as “a sub-field of dendrochronology that uses dated tree rings to reconstruct and study past and present climate” (Fritts 1976). The term has been expanded to encompass an entire suite of approaches that links climate and tree rings (Hirschboeck *et al*, 1996). Besides tree rings, other indices of tree growth can be used in dendroclimatology. The expansion of focus from tree rings to other characteristics of tree growth can be explained by the fact that under certain circumstances other characteristics may respond more strongly to climate than does the width of tree rings (Jalkanen, Tuovinen, 2001). The multi-proxy approach combines different chronologies of tree growth to reconstruct past climate. Therefore this approach is becoming more and more important because it may give more precise estimates of past climate than tree-ring based estimates do (McCarroll *et al*, 2003).

In PAPER IV, spatial variation in the impact of weather conditions on the growth and foliage dynamics of Scots pine in northern timberline conditions and in optimal conditions was analysed. Height and radial growth, and needle dynamics (needle production, density, loss, overall number of needles) were correlated with air temperature, precipitation, the Ponta Delgada index of NAO (PD-NAO) and AOI, and also with the circulation forms of the Vangengeim–Girs classification.

Comparison with the climatic records suggests that the annual variability in the studied variables is more strongly controlled by climate in Lapland than in Estonia. High air temperatures during the summer months of the previous growing season were favourable to leader-shoot elongation and to needle production in Lapland (correlation coefficients 0.64). This is a conformation to earlier results indicating that the air temperature of the previous July had a determining role in the development of leader-shoots of Scots pine at the northern range limit (Jalkanen, Tuovinen, 2001; McCarroll *et al.* 2003). This indicates that the temperature regime of the summer bud formation determines the number of nodes in the terminal bud of Scots pine at high latitudes, and it concurs with the observations that temperature is a growth-limiting factor in northern populations of Scots pine (Hustich 1978; Junttila, Heide 1981).

All other studied variables showed weak correlations, which were more variable than those of height increment and needle production. For example, radial increment, which is widely used in dendroclimatology, correlated most strongly with the July temperature of the current year (r = 0.29±0.10; mean ±95% confidence intervals); also, the annual average temperature influenced radial growth in Lapland.

In accordance with the low values of signal strengths observed in the chronologies of growth and needle dynamics, none of the measured attributes correlated with climatic variables stronger than 0.2 in Estonia. Although some trees may exhibit fairly strong correlations with weather conditions, the averaging of the correlation coefficients shows that weather conditions do not have a controlling effect on the growth and needle dynamics of Estonian trees. Overall, in the middle of a species distribution area, the correlations between growth attributes and climatic variables tend to be weak and their value seldom exceeds 0.5 (Cedro 2001).

The assumption that the growth of Scots pine might be related to indices of atmospheric circulation was not supported by the results of PAPER IV. The correlations of the studied variables with the indices of atmospheric circulation and with the frequency of the circulation forms were very weak. The average correlations with circulation types and indices were significantly lower than with air temperatures. In present case, height increment and needle production of the trees in Lapland again showed the strongest correlations. The PD-NAO of the previous summer was most strongly associated with these two studied variables (r = 0.29±0.09 and 0.31±0.08, respectively). Also, the PD-NAO of the current winter correlated with the same strength with height increment and needle production in Lapland (r = 0.30±0.07 and 0.35±0.09, respectively). There were a few other correlations with absolute values higher than 0.20 in Lapland. If we consider the correlation coefficients with values greater then ±0.30 as statistically significant, then we can deduct that growth indicators of only some single trees are led by climate variables.

The height increment and needle production of trees growing in Lapland gave the strongest correlation coefficients with the PD-NAO. The higher the NAO index, the more intensive is the cyclone activity and western air inflow to eastern, and especially to northern Europe. Thus, higher values of the PD-NAO should mean that winters are mild and have a lot of snow, but summers are cooler and rainy (Greatbach 2000; Wanner *et al*, 2001). However, since the correlation between height increment and the PD-NAO was weak but positive, summers should be warmer in Lapland when the PD-NAO has higher values, because height increment is controlled by the summer air temperature. It is also interesting to note that the PD-NAO of the current winter has a relatively high correlation with height increment and needle production. The mean air temperature and precipitation of the current winter, however, did not correlate with height increment and needle production. This hints that similar conditions of atmospheric circulations may prevail for a longed period, so that high values of PD-NAO in summer are followed by higher PD-NAO values next winter.

There were no significant correlations between growth indicators and the frequency of circulation forms by Vangengeim-Girs classification. It is quite surprising in the case of Lapland where the growth indicators are led by air temperature regime. As we saw in PAPER I and in Chapter 4 of the present thesis — air temperature in northern Europe, (i.e. Lapland) is well correlated with the frequency of circulation forms. But if we look closer, for example Fig. 4.8 or 4.9, it is easy to notice that Lapland is located very close to the border of area with significant correlations. We also have to take into consideration the fluctuations of correlation coefficients presented in sub-chapter 4.4. From previous, we can conclude that the Vangengeim-Girs classification does not express well circulation processes, which form air temperature regime in Polar Regions of northern Europe.

7. CONCLUSIONS

The study of relationships between atmospheric circulation and environmental variables resulted in a number of main conclusions.

1. The circulation forms according to the Vangengeim-Girs classification describe the circulation processes over northern and eastern Europe rather well. Correlation between the frequency of the circulation forms W, E and C and mean air temperature is statistically significant in many cases. The highest correlation revealed in winter. The prevailing of the zonal circulation form W has high positive values while the form E is negatively correlated with winter temperature. The first form reflects westerly airflow and the second one — the eastern, southeastern and southern circulation. Correlation between the frequency of these two circulation forms and temperature is of the opposite sign. The area of maximum correlation embraces the Baltic Sea region and northwestern Russia. The frequency of the circulation form C (northerly airflow) has a negative correlation with air temperature throughout a year with clear maximums in spring and autumn. The area with the highest correlation is located in the East European Plain.
2. Remarkable fluctuations have occurred in the frequencies of the circulation forms according to the Vangengeim-Girs classification during many decades. The second half of the 20th century has been dominated by the form E while the first half — by the form W. During the last two decades of the century, the frequency of the zonal circulation form W has rapidly increased. Probably, this change is related to the warming in winter and in spring in Estonia. The percentage of the meridional circulation forms E and C has decreased.
3. Correlation coefficients between the frequency of the circulation forms W, E and C, and air temperature in Estonia are significant and similar to those observed in the whole northern and eastern Europe. During the period 1891–2001, the correlation has not been constant but quite variable. Periods with higher correlation have alternated with periods of lower correlation. It refers to significant fluctuations in circulation types and sub-types, which are grouped into the three main circulation forms.
4. The frequency and trajectories of cyclones in the Baltic Sea region have significantly changed during 1948–2000. The number of cyclones moving from the west to the east between 60–65°N (i.e. over Finland) has significantly increased in winter. This trajectory of cyclones is favourable to the advection of mild and moist air from the Atlantic to the territory of Estonia. A remarkable decrease in the frequency of cyclones in summer has occurred in central Europe between 45–50°N (southern Poland, Slovakia). It may be related to the decreasing tendency in precipitation at some locations of that region.

5. Most of the changes in the Baltic Sea region were caused by changes in the frequency of deep cyclones. Drastic changes in the frequency of cyclones over central Europe were caused by rapid decrease in the number of shallow cyclones.
6. Correlations between the time series of cyclones and circulation forms according to the Vangengeim-Girs classification show that they both describe rather similar atmospheric circulation processes over the Baltic Sea region.
7. Methods of synoptic climatology could be successfully applied in other branches of natural sciences whose research objects depend on climatic and meteorological conditions. Although correlations with circulation parameters are not closer than with usual climatic variables, knowledge about the relationships with circulation could became valuable in regions of sparse meteorological network.
8. Statistically significant correlation between the frequency of the circulation forms according to the Vangengeim-Girs classification and some phenological phases were detected at some locations in central and eastern Europe. They were of similar origin with relationships between circulation and air temperature. Generally, the circulation conditions and air temperature during a winter determine the character of phenological development of nature in the following spring. The highest correlations between circulation and phenophases were observed in the Baltic Sea region.
9. There are no significant correlations between the frequency of the circulation forms according to the Vangengeim-Girs classification and Scots pine growth indicators in Estonia, nor in Lapland. The weather indicators are not common growth controllers for pines situated far from the timberline — e.g. pines growing in Estonia. On the other hand, in Lapland, where air temperature regime has a limiting role in the growth of pines, there is quite weak correlation between circulation processes, described by the Vangengeim-Girs classification and local air temperature.

8. SUMMARY IN ESTONIAN

Atmosfääri tsirkulatsiooni mõju keskkonna muutujatele Eestis

Alates 1990-ndatest on klimatoloogia, sealhulgas ka sünoptiline klimatoloogia väga kiiresti arenenud. Peale Brent Yarnali kokkuvõtvat tööd, mis ilmus 1993 aastal, on sünoptilise klimatoloogia uurimisvaldkond oluliselt suurenenud. Algselt ilmastiku pikaajaliste prognoosidega tegelenud teadusharu uurimismeetodeid rakendatakse kõikide ilmastikust sõltuvate keskkonnanäitajate analüüsimiseks.

Käesolev töö lähtubki Yarnali esitatud sünoptilise klimatoloogia definitsioonist, mille järgi see uurib seoseid atmosfääri tsirkulatsiooniprotsesside ja keskkonnanäitajate vahel.

Töö teoreetilises osas antakse põhjalik ülevaade sünoptilise klimatoloogia ajaloost, metoodikast ja arenguperspektiividest. Detailselt käsitletakse atmosfääri üldise tsirkulatsiooni Vangengeim-Girsi klassifikatsiooni arengulugu. Mainitud klassifikatsioon on läbivaks teemaks kogu käesolevate teeside.

Empiirilises osas uuritakse tsirkulatsiooninäitajate ja keskkonnanäitajate omavahelisi seoseid. Esiteks analüüsitakse Vangengeim-Girsi klassifikatsiooni tsirkulatsiooni-vormide esinemissageduse korrelatsioone Euroopa ja Eesti õhutemperatuuriga. Analüüsist selgub, et mainitud klassifikatsioon annab küllaltki tugevaid seoseid õhutemperatuuriga Ida- ja Põhja-Euroopas. Eriti tugevad on seosed talvel aga ka suvel. W tüübi korral on korrelatsioonid suvel negatiivsed ja talvel positiivsed, E tüübi puhul suvel positiivsed ja talvel negatiivsed. C tüübi puhul on seosed aasta läbi negatiivsed, kuid tugevamad kevadel ja sügisel. Seosed tsirkulatsioonivormide ja Eesti õhutemperatuuri vahel on täpselt sama sugused.

Töös vaadeldava 111 aastase (1891–2001) perioodi jooksul on tsirkulatsioonivormide esinemissageduses toimunud olulisi muutusi — trendijoone järgi on W tüübi esinemissagedus oluliselt ja C mõnevõrra vähenenud, E tüübi oma tõusnud. Ent vaadeldava perioodi erinevatel ajalõikudel ei ole mainitud trendi suunad ainuvaldavad. Ka tuleb käesoleva töö analüüsist välja, et tsirkulatsioonivormide korrelatsioonid Eesti õhutemperatuuriga ei ole läbi kogu aegrea ühtlase tugevusega — perioodiliselt seosed tugevnevad, siis jälle nõrgenevad. See viitab võimalusele, et perioodiliselt muutuvad tsirkulatsioonivormide sisesed näitajad ehk alltüüpide esinemissagedused.

Kuna Vangengeim-Girsi klassifikatsioon ei võimalda hetkel usaldusväärset analüüsi alltüüpide tasemel, siis detailsemaks analüüsiks on kasutatud tsüklonite keskmete andmebaasi. Teatavasti sõltub Eesti ilmastik suuresti Atlandilt siia kanduvate tsüklonite esinemissagedusest ja nende trajektooridest. Olenevalt viimasest kandub siia kas niiskemaid ja talve jaoks oluliselt soojemaid õhumasse Atlandilt või hoopis külmasid arktilisi õhumasse. Käesolevas töös on leitud, et perioodil 1948–2000 on eriti just talvel suurenenud nende tsüklonite osakaal, mis mööduvad Eestist põhja poolt (Lõuna-Soome kohalt), ehk siis nende madalrõhkkondade arv, millega siin kaasnevad soojade õhumasside sissetungid. Vaadeldava 53 aasta jooksul on drastiliselt vähenenud tsüklonite arv Kesk-Euroopa (Lõuna-Poola, Tšehhi Vabariik, Slovakkia) kohal. Antud juhul on vähenemistendentsi põhjuseks nõrkade tsüklonite (tsüklonid mille eluea jooksul ei lange õhurõhk keskmes alla 1000 hPa) esinemissageduse kiire vähenemine.

Korrelatsioonianalüüsi alusel saab väita, et 20. sajandi II poolel ilmnenud talvede soojenemine on vähemalt osaliselt seletatav nii meist põhjast mööduvate tsüklonite arvu suurenemise, kui ka lõunast mööduvate madalrõhkkondade arvu vähenemisega.

Korrelatsioonianalüüsi tulemused näitavad, et Vangengeim-Girsi klassifikatsioon kirjeldab samuti suurel määral tsüklonite esinemissageduse muutusi, seda eriti just Läänemere piirkonnas.

Kolmanda osana on uuritud tsirkulatsiooni mõju fenofaaside ilmnemisele Euroopas ja mändide juurdekasvunäitajatele Eestis ja Lapimaal. Kuna kevadiste fenofaaside alguskuupäev on tugevalt seotud õhutemperatuuri käiguga eelnenud talvel ja varakevadel, siis korreleeruvad need küllaltki tugevalt ka talviste tsirkulatsiooninäitajatega, mis Kesk- ja Ida-Euroopas on üheks peamiseks temperatuurirežiimi kujundajaks.

Mändide juurdekasvunäitajate ja tsirkulatsiooninäitajate vahelisi lineaarseid seosed statistiliselt usaldusväärsel tasemel ei ilmnenud. Eriti nõrgad olid seosed Eestis, mis on mändide kasvu optimumi piirkond. Osutus, et tsirkulatsiooninäitajad ei ole ühtseks juurdekasvu suunavaks teguriks ning puud käituvad siin olenevalt oma kasvukoha teistest mõjuritest, üsna individualistlikult.

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