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A review of the use of large-scale atmospheric circulation classification in spatial climatology

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A review of the use of large-scale atmospheric circulation classification in spatial climatology

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SUMMARY:

The spatial distribution of weather and climate elements is strongly related to the atmospheric circulation.

Different approaches to circulation indices and circulation types are presented and discussed with emphasis on how such information could be applied in methods for spatialisation of weather and climate elements.

Such information should have a large potential in describing spatial patterns of weather and climate elements, but this capability has not yet been utilized properly.

KEYWORDS:

weather type classification, circulation indices, spatialisation, Geographical information systems,

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Introduction.

The atmospheric circulation is an important driving force determining the regional and local climate. It is well known that the climate depends upon the prevailing winds, e.g. will climatic elements respond differently on advection from a maritime environment than airflow from a continental area.

The influence of atmospheric circulation can be found on several scales, both temporal and spatial. The variations are most obvious when considering a synoptic scale. E.g. will westerly air-flows most likely give precipitation along the western coasts of Scotland and Scandinavia (Prudhomme and Reed 1999, Tveito et al. 2000). In a similar way north-easterly advection produces precipitation in Central Europe (Ustrnul and Czekierda, 2001). Such variations are also found on local scales, where certain wind directions emphasize particular responses on climatological elements. Also seasonal variations in the circulation have a major impact on the climate. Typical monsoon climates are examples where the circulation shows strong seasonal variations. Such variability usually impacts a wide region. The low-frequenciest signals in atmospheric circulation have variations with amplitudes of several years. The well-known ENSO effect is such a signal, where the amplitude of the signal can be several years. Another signal of this type might be the decadal variations in the NAO. This is however a signal which not shows as strong signals as the ENSO. These low-frequency signals do however have an impact on a large region, the ENSO probably on most of the mid-latitudes of the globe.

There exist a wide variety of atmospheric circulation indices, which basically are developed to establish relations between atmospheric circulation features and responses in climate elements. Which type of index, and what kind of response varies with the purpose of the relationship. They cover however all scales from local indices to large scale teleconnection patterns.

During the recent years, climate change issues have demanded easy links between GCM-scale fields and regional and local climate. Linking the atmospheric circulation to local climatological response is therefore an important issue in downscaling GCM-results. Many authors have tried to develop relationships between the macro- and meso- or microscale variations applying atmospheric circulation as a link in order to estimate local effects of a climate change. This type of information may also be used to improve models for describing local climatological variations.

The objective of this paper is to discuss how information about atmospheric circulation might be used to improve the methods for describing continuous climatology. By combining such methods and geographical datasets in a geographical information systems (GIS), estimates of climate elements in arbitrary points or as continuous maps could be derived. This work is based on a review of selected papers discussing the use of circulation patterns, circulation types and circulation indices in climate analysis. The review study is based on papers available by the authors, and is therefore by no means a complete survey of the literature on this topic. Yarnal et al. (2001) just recently gave an extensive review on the latest developments on this subject.

The paper is organized as follows; first the principles for describing atmospheric circulation are presented. Thereafter some examples of using such information are given, and finally some thoughts how such methods can be utilized for climate mapping in a GIS-environment are discussed.

This work is carried out within the frame of COST Action 719: "The use of geographical information systems in climatology and meteorology", and is a contribution to working group 2 on spatialisation.

Methods

There are different methods approaching a classification of the large-scale atmospheric circulation. Yarnal (1993) gives a thoroughly overview of these methods, so just the basic concepts of the methods will be presented here. Recently Yarnal et al. (2001) presented the latest developments of these issues.

When discussing different approaches to classification of atmospheric circulation, it is important to know the terms or concepts that are used. There are three common expressions that are frequently used;

- Weather types
- Circulation patterns
- Circulation indices

If the result of a classification is a distinct grouping of the cases into classes, these classes often are referred to as circulation classes, circulation types or weather types. In synoptic climatology the difference between weather types and circulation types is quite distinct. Circulation type refers to the atmospheric circulation (advection, type of the baric system etc), while the weather type concerns the real weather conditions (mainly: cloudiness, humidity, precipitation etc) usually without discussion about the synoptic situation and circulation type background (in the first step of considerations). Though circulation and weather types are closely related to each other, they should absolutely be treated separately. Maheras (Maheras 1988, Maheras 1989, Maheras and Kolyva-Machera 1990) used weather types instead of circulation ones, and confirmed (Maheras (1988, 1989)) that weather types more precisely define distributions of the particular elements than circulation types.

Circulation patterns is a general term that can be used when e.g. the classification results in a new fields, e.g. when using EOF-analysis etc. However, all these terms, including some others like e.g. weather types and synoptic types, are not officially defined and in many studies are being used in the same or similar meaning (Yarnal, 1993). The circulation indices are physical properties related to the pressure field(s) used for classification. This may be the zonal and meridional components, vorticity, geostrophic winds etc.

An important issue is the division between subjective and objective methods. Historically subjective (manual) methods have been dominating, with the drawback that personal interpretation might influence the results. These methods are not objective, and thereby probably not consistent. However a few long fairly homogeneous records of such classification schemes exist and these will be presented below. By the development of computer techniques and thereby the possibilities to handle large data sets, automatic and usually objective methods have been developed. These are consistent and reproducible, and the most common approaches will be presented below.

Manual methods

Weather types

Manual methods for classification of atmospheric circulation are also often called subjective methods, but since also computer assisted methods in many respects also can be considered as subjective methods, the traditional pre-computer based methods will referred to as manual methods. These methods have usually a long history, and were developed for specific regions usually reflecting the dominating features of the atmospheric circulation influencing the climate in the targeting region.

These methods can be divided in different ways depending on the area of interest, historical background, type of the synoptic elements used etc. The key problem is the spatial scale. As discussed in the introduction, the scale of the atmospheric circulation signals has a clear link to the area of influence. So the choice of atmospheric circulation index to use should be related to the problem to be discussed.

Manual classification schemes exist for all scales, however with predomination of macro- and meso-scale approaches. If the area of interest is a hemisphere or a continent, the methods are usually defined as macro-scale. If the region is small (like e.g. the British Isles or Poland) the methods are considered as mesoscale. The transition between macro- and mesoscale is however not distinct.

There are a number of macroscale classifications well known in the synoptic-climatological literature. Wangenheim (1938) established a classification for the European-Atlantic region. It describes the elementary synoptic process He listed 26 types of elementary synoptic processes. These weather types are however regarded as variants belonging to one of three typical circulation forms. Circulation form W describes westerly air-flow from Atlantic and Europe (Zonal flow towards Russia). The forms E and C are connected to meridional circulation over Europe. The differences between C and E consist on different location of anticyclones ridges and cyclonic troughs. Following the same principles, Girs (1948) made adequate forms for the Pacific-American territory. He called them Z, M1 and M2 (analogue to the classes W, C and E by Wangeneim).

The combination of these two classifications gives the nine different Wangenheim-Girs circulation forms for the northern hemisphere. Based on Wangenheim-Girs principles, Dydina(1982) established a circulation classification for the Arctic.

Dzerdzeevskij (1970) used the concept of thirteen macro-processes (different sectors), covering the Northern Hemisphere. The circulation types were defined based on the location of pressure centres, and the zonal airflow and anti-cyclonic disturbances. Four groups are defined, based on strict zonal circulation, zonal disturbances, northerly or southerly meridional flow.

In Europe the concept of Grosswetterlagen for central Europe (Hess and Brezowsky 1952, Gerstengarbe and Werner 1993) is probably the best known. It is based on surface pressure and 500hPa height. It gives 30 circulation types based on the circulation direction and the location of the main pressure centres.

Some other classifications are well known in other areas e.g. Muller (1977) for the Southern United States and Alt (1978) for the Canadian Arctic. The Muller classification consists of eight typical surface weather patterns, established on the base of location of pressure centres, ridges and troughs over the United States, and the climate response on the US Gulf Coast. Alt's classification consists of three synoptic types used to relate the mass balance of glaciers on Queen Elizabeth Island in Canada to the atmospheric circulation.

Another circulation classification well-known in Europe is the classification given by Lamb (1950, 1972) for the British Isles. It can be discussed whether this is a macro- or mesoscale classification since the area of interest is smaller than for the classifications described above, but still covers a considerable large region. The classification principle is quite simple, taking two elements into account, direction of the airflow and type of the baric system. There are eight directional classes, each divided into cyclonic, anticyclonic and unspecified categories, and three non-directional types. This gives 26 circulation types: eight directional anticyclonic, eight direct cyclonic, pure cyclonic and anticyclonic (without direction), and eight direct types without cyclonity. In addition a 27th class is mentioned. This class consists of days which are unclassifiable, which means days with chaotic weak flow, rapid changes during the day or days when incompatible hybrids are formed. Lamb divided his types into seven basic and nineteen hybrid types, in a notation that differs from the later developed objective scheme following the same principle (Jenkinson and Collison, 1977).

On the other hand there are numerous circulation-type classifications for local scale (mesoscale) established to be applied for different regions. Most of them are based on the Lamb principle. A few examples are: Konček and Rein (1971) and Hydrometeorologicki Ustav (1967) both done for the former Czechoslovakia, Lauscher (1976), Schüpp (1979) and Steinacker (1991) for the Alps, Peczely (1983) for Hungary, Oschuchowska-Klein (1975) for Poland and Niedzwiedz (1981) for Southern Poland.

All these methods are based on synoptic like analysis defining circulation types according to the general atmospheric circulation, location of high and low pressure centres, ridges and fronts. The advantage of such methods is that they have a physical basis. They are dedicated to the region for which they are adapted, which however also make them less transferable. If the same person or same group of persons does the classification, it will probably be homogenous and consistent. But as it is not objective, it is not reproducible since in some cases the subjective choices necessarily will be different. One large disadvantage with these methods is that they are time consuming in means of human resources, and they are therefore not ideal when doing analysis for long time periods/time series. Many of these methods, like the Grosswetterlagen and Lamb have long records that make them interesting for climate variability studies. The Grosswetterlagen are monthly updated by the German Weather Service (DWD) in the bulletin "Die Grosswetterlagen Europas". The Lamb types were updated by CRU at East Anglia University (http://www.cru.uea.edu.uk/) until 1997. Another important point is that these methods usually give a circulation type, not indices. So they can be used as conditioning methods (re-sampling), but not as co-variables in further analysis due to their discrete nature.

Circulation indices methods

Circulation indices can be used to categorize the circulation. Circulation indices are quantitative measures describing the type and/or intensity of the atmospheric circulation. Basically they can be divided into two groups, direct and in-direct indices.

Direct indices are usually derived from air pressure fields or observations. For long historic timeseries sea level pressure (SLP) values are usually applied, while for analysing recent circulation, 700 or 500 hPa geopotential heights data are often used.

The simplest method is to study pressure gradients by the means of simple or standardized differences of pressure at two locations/regions/gridpoints etc. For example they consider the parallels 35°-65°N, 40°-70°N or their specific parts (Rossby 1939, Namias 1950, Lorenz 1951, Emmrich 1991). They are named according to the area of interest, purpose and the type of circulation investigated. (e.g. zonal, circumpolar). More or less they show the predominance of the zonal (westerly, progression) or meridional (southerly) circulation over the area of interest and during the specified period. The most known circulation index in this respect over Europe is the North Atlantic Oscillation (NAO), which is defined as the pressure gradient between Ponta Delgada on the Azores and Akureyri on Iceland (Rogers 1984). Due to availability and homogeneity also other stations have been used, like Stykkisholmur and Reykjavik on Iceland, and Lisbon and Gibraltar as the southern location (Hurrel, 1995, Jones et al.1997). However, the concept of NAO was already used first time by Walker and Bliss in 1932, and permanently introduced into the literature by Wallace and Gutzler (1981) and Barnston and Livezey (1987). NAO is maybe the most important index for Europe but not only one. There are some other pressure anomalies like East Atlantic/Western Russia (EATL/WRUS) also called Eurasia-2 (Barnston and Livezey, 1987) or Scandinavia (SCAN, so-called Eurasia-1, Barnston and Livezey, 1987). Those indices are often being distinguished on the basis of the objective methods based on the Principal Component Analysis (PCA) quite often with rotation (RPCA) (see: Eigenvector based methods). These indices are often used to describe so-called teleconnection patterns of pressure fields.

An often-used approach is to calculate circulation indices or just circulation types on the basis of the geostrophic wind. It reveals as the objective method where direction and/or wind speed describe the circulation conditions. It can be simply calculated for specified grid points (Ustrnul, 1997) or with the help of triangles (Alexandersson et.al, 1998).

Recently an objective classification scheme for Germany has been developed (Dittman et al, 1995, Bissolli & Dittmann 2001). This classification uses meteorological elements from the operational DWD analysis and forecast scheme. It produces 40 weather types, where the advection of air masses, cyclonality at the surface and in thee upper air and the humidity of the troposphere is used as classification criterions. The analysis is a nested approach, giving higher weight to the central area of the targeting domain, and less to the outer parts.

Jenkinson and Collison (1977) have developed an objective scheme comparable to the Lamb catalogue is based upon mean sea level pressure in 16 grid-nodes. This approach reproduces circulation types not significantly different from the Lamb catalogue (Jones et al., 1992). The Jenkinson-Collison (JC) scheme produces 27 weather types, like the original Lamb scheme. One advantage of the objective scheme is that it can be applied anywhere, adjusting the parameters according to the latitude. This classification has e.g. been transferred and used for southern Scandinavia (Chen, 1999, Tveito et al. 2000, Tveito 2002, Linderson, 2001) with reasonably great success.

Hovmöller (1979) have developed an objective circulation classification scheme for Iceland, based on 500 and 1000 hPa height values in 9 gridpoints covering Iceland. This scheme provides circulation indices which are used for weather type classification. It is also used to estimate temperature and precipitation in Iceland, where the thickness is a significant predictor (Jónsson, pers.comm).

Indirect circulation indices might be indices constructed based on previously described circulation type categories. Circulation index series might be derived from events belonging to specific circulation classes, and such measures could be used in statistical analysis. Good examples of such are given by Murray and Lewis (1966), Murray and Benwell (1972) and Niedzwiedz (1993).

Circulation patterns

Correlation based methods.

Correlation based methods are based on measures of similarity between observed pressure fields. Lund (1963) described this approach, and since then very few changes has been done with this technique. Basically the methods are based on a selection of typical grids, representing typical synoptic weather situations. The method is straightforward when deciding the typical grids. The key issue is to define the typical grids. Lund (1963) suggests selecting the synoptic situation having most occurrences with correlation above 0.7 with all the other situations as weather type A. All situations having a correlation with this pattern higher than 0.7, are assigned to this weather type (type A). All these episodes are removed from the dataset, and the procedure is repeated for all remaining situations until all are classified. Lund (1963) chose the threshold r=0.7 to prevent too many unclassified days, but this threshold should be selected individually in order to establish a suitable number of circulation patterns. Kirchofer (1973) has presented a similar approach, but used a sum of squares instead of the correlation coefficient to find the similarity between the situations.

Cluster analysis is one classification methods that belongs to such methods. The distance function used for clustering might though also not based on correlation or co-variance, but e.g. Euclidian distance between variables.

Eigenvector based methods.

During the last decades principal component analysis (PCA) and the method of empirical orthogonal functions (EOF) have been used frequently in analysis of atmospheric fields. Basically the methods are used to decompose observed fields into fewer sets of orthogonal, and thereby statistical uncorrelated fields. One result is that redundant information is removed. These are pure statistical methods, and have therefore no direct physical explanation. Their advantage is their capability to, in an easy way, handle large datasets, and thereby the size of the areas studied may be increased, an advantage that has been used by many scientist. PCA/EOF analysis is one of the most used methods in downscaling GCM to local response. Preissendorfer (1988) gives an excellent introduction to the use of EOF-analysis in meteorology and oceanography.

Eigenvector based methods can be used both for defining circulation patterns and for regionalisation. Regionalisation can be done by studying scatterclouds of the eigenvectors (e.g. Hisdal and Tveito, 1993). These methods are objective and consistent, and can be applied on any type of data.

Fuzzy rules

A combination between discrete and continuous classifications is the fuzzy logic approach. Fuzzy logic replaces binary logics (in the meaning categorization or discretization) with a probabilistic approach. A set of fuzzy rules and according membership functions are defined in order to decide to which degree of fulfilment a realization belongs to a certain class. The rules are subjectively decided, and consist usually of Boolean criterions. Bardossy et al. (1995) made an objective classification applying fuzzy rules on normalized 700 hPa geopotential heights. The rules were defined based on pressure characteristics of the Grosswetterlagen circulation types. The automatic fuzzy rule algorithm was able to satisfactorily reproduce the same circulation types as the Hess-Brezowsky catalogue.

The use of classification methods in spatialisation

Information about the atmospheric circulation is often used to explain variability in climate elements. The focus of this paper is on spatialisation of climatological and meteorological variables. Most of the literature concerns on temporal variability and the spatial dimension is not that emphasized. However, in order to relate atmospheric circulation to local climate, the spatial dimension is included, even if this relation seems to be "hidden" in some cases.

Temperature

Temperature is strongly related to the atmospheric circulation, and the most often analysed element. In Europe e.g. the occurrence of a blocking high in eastern central Europe has a significant influence of the spatial temperature distribution. E.g. Chen (1999) has related winter temperature anomalies in southern Sweden to JC weather types (Jenkinson and Collison, 1977), showing significant differences between different weather types. A model using circulation indices is able to explain 84% of the variance of the January anomalies. Linderson (2001) have also studied the temperature anomalies in southern Sweden using the JC classification. As Chen (1999), she discusses the problem of within type variability using distinct weather types, a problem Chen overcame by using the indices in his model.

Corault and Monestiez (1999) suggest a method for interpolation of regional maximum and minimum temperatures for a region in France utilizing circulation patterns. The CPs were provided by an automatic classification at MeteoFrance using fifteen variables as input, including geopotential heights. A detrended kriging spatial interpolation was used, using altitude as trend-variable. The trend coefficients were analysed for each CP, giving a variation of the lapse rate between 0.31 and 0.85 °C/100m. The study showed an improvement of 0.5°C in the accuracy of maximum temperature estimates. Most of this improvement was due to the detrending, including the CPs just slightly improved the results. It shows the potential using CPs in temperature interpolation. Tveito (2002b) found similar results for winter temperatures in Norway in a similar approach based on JC weather types. He also includes terrain shapes in means of EOFs of local terrain (based on the AURELHY principle, Benichou (1986)).

Huth (2001) have studied the trends in frequency of atmospheric circulation patterns and the variability in climatic elements at two stations in the Czech Republic, showing significant differences between mountain and lowland.

Buishand and Brandsma (1997) discussed the use of different classification schemes to predict temperature and precipitation at DeBilt observatory in the Netherlands. The GWL, JC and the objective Dutch P27 scheme were compared. They found that for most seasons, the circulation could explain 30-40% of the daily temperature variance. The JC scheme did not perform well for temperature, probably because this method, opposite to the others, does not include upper-air data.

Precipitation

Kilsby et al. (1998) uses the JC scheme for defining the indices included in a regression model for predicting rainfall statistics in England and Wales. They implemented the regression model in a GIS, deriving grid-maps of mean monthly rainfall and proportion of dry days with a 10x10 km^2 resolution. This is one of the very few examples where circulation type classification and GIS are used in combination.

Wilby et al. (1995) discusses the rainfall variability using the Lamb weather types and a subjective classification of fronts, showing that such information is significant. The analysis was carried out for single locations only.

Hay et al. (1991, 1992) uses the classification of McCabe (1989), which is based on wind direction and cloud cover. This simple approach results in 6 weather types, and Hay and co-authors are using Markov chains in a weather type precipitation model. Bardossy and Plate (1991) used a similar approach, but applied the much more numerous Grosswetterlagen.

Ustrnul and Czekierda (2001) shows that the regional distribution of precipitation in Poland has a distinct relation to atmospheric circulation, and that the highest rainfall occurs when having northerly to easterly cyclonic flow. Using long (1951-1999) time series of 53 precipitation series and the Grosswetterlagen probability statistics for precipitation events was derived both for single stations as well as area means. The study also showed that there are seasonal variations in the relation between atmospheric circulation and local and regional precipitation response.

Biau et al. (1999) discusses the application of non-linear methods to describe the relation between large scale atmospheric circulation and precipitation. They say that non-linear methods are necessary when the large-scale and small-scale phenomena follow different probability laws. They applied kriging, which behaves nonlinear with respect to the spatial coordinates in the EOF space of mean sea level pressure. This approach is another downscaling approach, and is done station wise.

Wibig (1999) analyses the relation between atmospheric circulation and monthly precipitation during the winter season in Europe. Five circulation types were defined by a principal component analysis of the 500 hPa geopotential height fields. She presented maps showing the correlation between the monthly precipitation and circulation patterns varies in Europe. NAO showed to be the most significant signal for North-western Europe (British Isles, Ireland and Scandinavia) where positive NAO result in positive precipitation anomalies. Such NAO signal gives however drier conditions in Iberia than in average. The Scandinavian pattern was the second most important signal, influencing mainly the precipitation in Eastern Europe. The three remaining patterns showed more local behaviour. She also analysed how the signals varied between different months in the winter season.

In another study, Stahl and Demuth (2001) studied the regional variation on droughts related to the atmospheric circulation in Europe. They did also use the Grosswetterlagen as indicators for the circulation. Droughts is an issue that are concerned with persistence of weather types giving dry conditions for an area, and such type of analysis is in that respect interesting in the light of climate change.The discussion about a changing climate has induced numerous studies of the future variability in local climate based on downscaling of GCM or RCM scenarios. One approach to such downscaling is empirical downscaling. Such an approach is based on relations between observed climate variability and fields that are predicted by the climate model control runs. Pressure fields are frequently used and one of the most used approaches is to apply PCA of EOF-analysis of such fields, and establish a linear model between the eigenvectors and the local precipitation and temperature.

Utilizing circulation types in spatial interpolation

Descriptions of the atmospheric circulation have been used in many applications within climatology, especially within climate variability studies. Yarnal et al. (2001) give an overview of the recent developments of this topic. Most of the applications are related to studying temporal variability of climatological elements, studying connections between atmospheric circulation and climatological response (downscaling). However, the use of such information has been limited in spatial structure analysis. Tveito (2002a) has shown that the spatial distribution of precipitation in Southern Norway is strongly related to the circulation patterns. Therefore such information could be used in spatial analysis like universal kriging or co-kriging in order to achieve the assumptions of weak second order stationarity (see e.g. Cressie, 1993). Descriptions of circulation type could also be used to define zones and directions of influence in order to adjust for anisotropy.

Yarnal (1993) pointed out utilizing of GIS as one of the areas where he expected development of synoptic climatology in the years to come. In the recent review (Yarnal et al., 2001) it is stated that this expectation failed. It is however a large potential in combining circulation type classification, spatial interpolation methods and also the possibilities given by GIS in developing methods and application for describing the spatial distribution of climatological elements.

In many cases a dynamical meteorological model is not applicable. They have limitations concerning spatial and temporal resolution. Traditional climatological analysis demands a spatial resolution of typical 1 x 1 km2, which also imply short timesteps in a dynamical model.. The models are not yet parameterized for such scales. Also high computation costs and long computation time are limiting factors. An often used approach within climatology is therefore to use statistical or geostatistical methods. In order to apply such methods some basic assumptions should be fulfilled. The central assumption in geostatistics is the intrinsic hypotesis (Cressie, 1993). As pointed out by many authors this criterion is seldom obtained looking at natural climatological fields. Bacchi and Kottegoda (1995) discussed these fundamental issues when analysing spatial correlation patterns of rainfall. They identified the anisotropy and chaotic behaviour of rainfall, and were especially concerned on the scale issue. They discussed the effects of spatial and temporal scales. However the possibilities using co-variables or conditioning parameters in order to fulfil the intrinsic hypothesis was not included/discussed.

Other statistical methods can also be applied in spatialisation. E.g. are linear models (like regression) widely applied, often in a combination with geostatistics. Also such methods are concerned with basic assumptions not obtained in most observed climatological fields. To obtain fields that fulfils the assumptions for applying (geo-)statistical methods, a model including additional variables or parameters explaining the non-stationary features of the climatological field should be applied in order to remove, or at least reduce the non-stationarity. Terrain characteristics, landuse and other geographical parameters have been widely applied for this purpose, mostly with success. However, structural analysis of the spatial correlation patterns, in terms of anisotropical semivariogram parameters are not widely dicussed. However many authors (Wibig 1999, Tveito et al. 2000) show that there are evidence that the spatial correlation patterns are dependent upon the circulation type, and that this spatial structures not can be resolved by land surface characteristics alone.

Circulation type classification gives distinct classes, which can be used at categorizing criteria in a spatialisation algorithm. The problem applying such conditional approaches is to ensure continuity between different categories. If the classification also provides circulation indices, these can be applied as (co)variables in spatialisation. An interesting feature is to describe the probability fields of precipitation above certain thresholds, as presented by Tveito et al. (2000) and Ustrnul and Czerkierda (2001). A spatial analysis of such probability fields related to circulation types or, even better continuous circulation indices, might be used to detect and describe non-stationary features of climatological elements. This type of analysis is especially important concerning climatological elements showing non-continuous characteristics, e.g. precipitation.

Summary and conclusions

Circulation has a significant influence on the spatial variability of the local climatological elements, and there are many approaches to classify atmospheric circulation in order to relate it to local climatological response. Some are based on manual/subjective methods, like the original Lamb weather types and Grosswetterlagen. Some are using objective automatic procedures to derive circulation indices like wind direction, geostrophic wind speed and vorticity (e.g. the Jenkinson-Collison scheme). Eigenvector methods are also frequently used, despite that they lack a direct coupling to the airflow physics, and therefore should be interpreted physically with care.

What is rather surprising is the traditional way methods for categorizing atmospheric circulation are implemented. They are based on tuning of models explaining the temporal variations in means of atmospheric circulation. Only a few, but promising works are presented combining atmospheric circulation and spatial variability analysis. The papers by Kilsby et al (1998) and Biau (1999) are examples were such thought are presented. Tveito (2002a) showed that circulation types can be used as a prognostic model describing the spatial distribution of rainfall probability occurrence and probable rainfall amounts. He also found indications that these spatial patterns can be related to the magnitude of the circulation indices, and that the precipitation variations also seems to be linked to geographical features. Utilization of GIS techniques in coupling circulation indices and geographical datasets describing the spatial variations in climatological elements has a high potential. The challenge is to find the best possible combination of different explanatory variables. GIS provides easy tools for combination of different geographic datasets. However are the in-built spatialisation capabilities still limited in most software packages (Tveito and Schöner, 2002), but “add-on” modules or self standing software can easy be applied in combination with most GIS-software.

One limitation in GIS has been that it has basically been a mapping tool, lacking capacity in handling the temporal dimension of data. This has now become an issue in GIS-development, and the disappointment of Yarnal et al. (2001) concerning the lack of use of GIS in synoptical climatology should not be long-lasting.

If GIS and geographical datasets can be used in combination with descriptions of the atmospheric circulation to obtain good descriptions of the spatial variability of climate elements, it will certainly give maps with an increased accuracy. At the same time application of geostatistical models also give a unique opportunity to access uncertainty measures, which is crucial when applying such information in practical climatological applications, like dimensioning analysis. Another application of such methods could be to serve as a quite simple base for prognostic modelling of surface meteorological fields.

Synoptic climatology has been given a lot of attention in climate change analysis, especially in different downscaling of scenarios of the future climate from GCM runs. In order to be able to give reliable estimates of the local future climate, increased understanding of the relation between large scale atmospheric circulation and local climate variability is needed. Using circulation type information in combination with spatial models might help us achieve this understanding. Such models would be able to establish fine scale continuous fields as input to e.g. distributed hydrological models able us to investigate impacts of future climate change on ecological and social systems.

There is therefore a challenge to incorporate information about atmospheric circulation, terrain, landuse etc. in spatial interpolation models for meteorological and climatological elements. It should be investigated how different atmospheric circulations influence the parameters of the spatial structure functions used in such models. This issue will be considered within the frames of COST 719 activities on spatialisation methods. A benchmark on different spatialisation methods for different climatological and meteorological elements is in progress, and the effect of this type of information will be validated against traditional approaches.

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