BOREAL ENVIRONMENT RESEARCH 7: 281–289 ISSN 1239-6095
Helsinki 2 October 2002

Circulation weather types and their influence on temperature and precipitation in Estonia

Piia Post, Valdur Truija and Janno Tuulik

Department of Environmental Physics, University of Tartu, Ülikooli 18, 51014 Tartu, Estonia

Post, P., Truija, V. & Tuulik, J. 2002: Circulation weather types and their influence on temperature and precipitation in Estonia. — *Boreal Env. Res.* 7: 281–289. ISSN 1239-6095

An existing objective classification scheme of the atmospheric circulation, where daily circulation is determined through the strength, direction and vorticity of the geostrophic flow has been applied over the Baltic Sea region for the time period of 1968–1997. The results at sea level and the higher isobaric levels of 500 hPa, 700 hPa and 850 hPa are presented here. The analysis revealed that the most common circulation types are anticyclonic and cyclonic. The mean-square-error skill scores are used to investigate classification's suitability for describing the variability of the local (Pärnu) daily weather elements. The skill scores of the objective classification are essentially higher than those for the German Weather Service's "Grosswetterlagen" scheme, but the scores are still low due to the high variability of daily temperature and precipitation within the weather types. Temperature is best described by the classifications at higher levels of pressure (500 hPa and 700 hPa), but precipitation is best described by those at the lower levels (sea level and 850 hPa). Developing one good classification for both variables is non-trivial.

Introduction

The large-scale atmospheric circulation is an important surface climate factor. It determines the dispositions of baric systems and the dominating airflows. Therefore, several attempts have been made to relate the large-scale atmospheric circulation to local weather conditions. Inside general circulation models this is achieved by proceeding from physical laws and deriving parameterisations for unresolved processes. Traditionally there are two basic methods for describing large-scale atmospheric circulation: the use of circulation indices (NAO index etc) or weather patterns, the latter is based on similarly situated baric systems on synoptic maps. Nowadays, these simplified circulation classifications are developed mostly for two purposes: investigation of the temporal variability of atmospheric circulation with the further aim of forecasting trends in it, or downscaling of weather elements from climate models output.

Several atmospheric circulation classifications have been developed for the area of Europe. Two manual ones, applying a daily resolution, have very long time series: the German Weather Service's Grosswetterlagen (Gerstengarbe *et al.* 1993), and Lamb's classification for the British

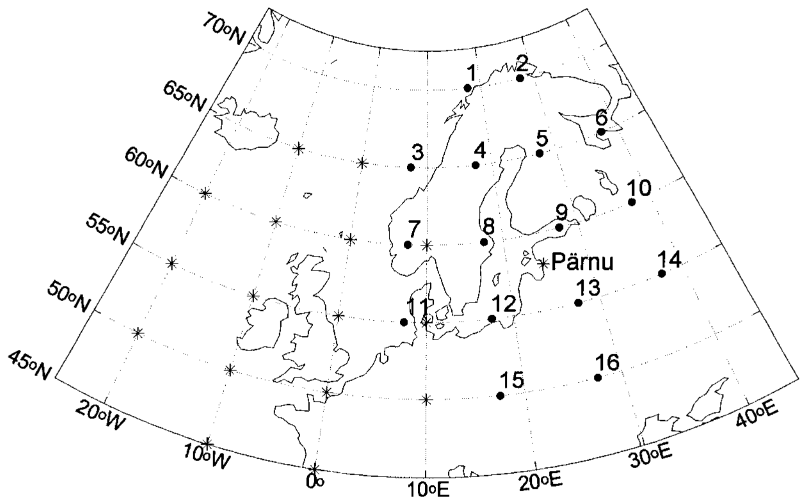

Fig. 1. Locations of classifications. Numbers mark the 16 points, applying Jenkinson and Collison (1977) scheme for the Baltic Sea area; stars mark the original location.

Isles (Lamb 1972). The other group of classifications, called "automatic" or "objective" classifications, have increased in popularity with the development of computer technology (Yarnal 1993).

Grosswetterlagen (GWL) is a planetary scale classification that is especially applicable for Central Europe (Bissoli and Dittmann 2001). Post and Tuulik (1999), and Keevallik *et al.* (1999) investigated the suitability of the GWL to describe the weather elements variability in Estonia. Their results show that the dispersion of meteorological elements within the weather types is very large, and several weather patterns could be interpreted for Estonia independently from the interpretations for Central Europe (Post and Tuulik 1999). The horizontal scale of the classification is much larger than the scale of cyclones and anticyclones, (which actually determine the circulation at higher midlatitudes), and since the process of classifying begins in the middle of the area, it does not work for peripheries (the Baltic Sea area already belongs to periphery).

Therefore, our goal was to introduce a synoptic scale, automatic classification for the Baltic Sea region atmospheric circulation, and to prove that the connections with meteorological parameters are stronger compared to GWL.

The chosen scheme for atmospheric circulation was developed by Jenkinson and Collison (1977) (JC) and was initially used for the British Isles region. It was designed as an automatic version of Lamb's classification. The circulation pattern for a given day is described using the locations of the centers of high and low pressure that determine the direction of the geostrophic airflow. It uses coarsely gridded pressure data and is therefore easily applicable in any area with available data. Besides the British Isles this method has already been exploited in several other European regions: the Netherlands (Buishand and Brandsma 1997), Sweden (Linderson 2001) and Portugal (Trigo 2000).

The classification of weather types

We applied the JC classification for the Baltic Sea area, centered at 60°N, 22.5°E. The scheme was used independently for the data at sea level and at 850 hPa, 700 hPa and 500 hPa isobar levels. The daily air pressure and geopotentional height data used in this study originated from NCEP/NCAR reanalysis (Kalnay *et al.* 1996).

The data values from 16 points (shown in Fig. 1) were used to calculate the following geostrophic airflow indices: the zonal or westerly flow, and the meridional or southerly flow. Combining of these two gives the resultant flow (*F*) and the direction of the flow. The westerly shear vorticity and the southerly shear vorticity were calculated analogically, the sum of these gives the total vorticity (*Z*). The latter describes the rotation of the atmosphere, positive values correspond to cyclonic circulation and negative to anticyclonic. The equations for these indices can be found in Jenkinson and Collison (1977). We have adjusted the constants that account for relative differences between the grid point spacing in the east–west and north–south direction to account for the more northerly location of our classification compared to the original application. The geostrophic resultant flow F units are expressed as hPa per 10° latitude at 60°N (each unit is equivalent to 0.56 m s^{-1}). The (geostrophic) vorticity Z units are expressed as hPa per 10° latitude at 60°N, per 10° latitude. 100 units are equivalent to 0.40 times the Coriolis parameter at 60°N.

The weather types are defined by comparing the numeric values of F and $|Z|$:

— if $\frac{|Z|}{F} < 1$, the airflow is straight and the atmospheric circulation is classified into eight directional weather types according to the direction of the airflow (N, NO, O, SO, S, SW, W, NW).
— If $\frac{|Z|}{F} > 2$, the airflow is strongly cyclonic ($Z > 0$) or anticyclonic ($Z < 0$), and the atmospheric circulation is classified into synoptic C (cyclonic) or A (anticyclonic) type, respectively.
— If $1 \leq \frac{|Z|}{F} \leq 2$, the airflow is partly cyclonic or anticyclonic, and the atmospheric circulation is classified into 16 hybrid types according to the direction of atmospheric rotation and the direction of the airflow (CN, CNO, CO, CSO, CS, CSW, CW, CNW, AN, ANO, AO, ASO, AS, ASW, AW, ANW).
— If the airflow is weak, an unclassified weather type (U) occurs: $|Z| < \frac{1}{5}\sigma_Z$ and $F < \frac{1}{5}\sqrt{\sigma_{WF}^2 + \sigma_{SF}^2}$, where σ_Z, σ_{WF} and σ_{SF} are the standard deviations of total vorticity, westerly and southerly flow, respectively.

In the original scheme one numeric threshold was set to distinguish the unclassified type from the others. We adapted the scheme also for higher levels, where the strenght of the flow is greater than at the sea level. Therefore, the threshold values were related to the standard deviation of airflow indices.

The Baltic Sea region atmospheric circulation description using weather types

The Baltic Sea and its adjacent coasts form a region where the influences of the climatic zones of Northwestern, Central and Northeastern Europe meet and mingle (Mietus 1998). The climate of this region is controlled, perhaps more than that in other parts of Europe, by the main great pressure systems that govern the air flow over the continent: the Islandic low, and the Azores high. Additionally, in winter, the branch of the Asian maximum that extends to the Southern Europe and the polar high pressure region are important. In winter both the Islandic low and the Azores maximum strengthen, and this results in westerly and southwesterly flow over the Baltic and a relatively mild climate over the region. But when the Islandic minimum is weakened and shifted westwards towards the American coast, the influence of Arctic is prevailing. In this case northerly and northeasterly winds blow and this causes cold and severe conditions. The mean flow is especially intensive in January. In February and March the intensity of the mean flow over the Baltic region decreases, becoming at its weakest in April. Also in May the pressure gradient is very weak.

In summer, the atmospheric pressure distribution is different. As the northern hemisphere heats more than the southern one, subequatorial zones of low pressure shift to north and with this the subtropic zone of high pressure shifts to north. High pressure regions form over the oceans, the ocean low pressure centers weaken and the Azores maximum strengthens. Over the Asian continent pressure is much lower in comparison to winter. In June and July, the mean flow could be specified as northwesterly to westerly. In August, the mean pressure gradient starts to increase again.

All these features of the Baltic Sea region atmospheric circulation are present in our data and can be seen in the compounded results presented in Table 1 and Fig. 2. In Fig. 2 the fields of normalized sea level air pressure for all SLP classified types are presented. To reduce the influence of very high and low pressures, the fields were normalized: for the highest pressure of the region it was assigned a value of 1, and for the lowest region a value of –1, therefore the units are relative. The highest and the lowest pressure areas are marked with a "+" and "–" respectively and the isolines are drawn after every 0.15. The pressure patterns are easily interpreted. In case of synoptic types, the anticyclone (A) or cyclone (C) sits in the middle of the area. In case of directional types, the pair consisting of cyclone and anticyclone determines the airflow. At the time of hybrid types the air pressure distribution is similar to the respective directional one, only the centre of the region is more influenced by the anticyclone or cyclone.

Seasonal pressure distributions are also presented. During the cold half of the year stronger pressure gradients were observed, but mostly the pressure pattern of different weather types appeared similar in all seasons. There were some exceptions. The N type in winter: because of the well pronounced low, the air flow to the Baltic proper was from the Atlantic, in summer vice versa from the Arctic. The O type in winter: the strong Siberian high caused the airflow from southeast. In summer during this type the main flow is from northeast, from the Arctic.

The dominating weather types for all seasons were anticyclonic (A) and cyclonic (C). This contradicts the well-known fact that the annual mean number of cyclones (132) passing over Estonia (and the whole Baltic region) is much larger than the number of anticyclones (65) (Prilipko 1982). The contradiction could be explained by the fact that the cyclones move faster and have smaller dimensions. Linderson (2001), who introduced

Table 1. Occurrences of weather types (%) for the 500 hPa isobar level (500GPH) and the sea level (SLP) classification for the Baltic Sea region (1968–1997) and for Southern Scandinavia (1881–1995) for comparison from Linderson (2001) = LL.

Weather type	500GPH Year	SLP Dec Jan Feb	SLP Jun Jul Aug	SLP Year	LL Year
A	17.5	18.7	19.0	19.3	17.0
C	15.1	11.7	18.7	14.6	10.7
N	4.4	3.0	6.5	4.5	3.3
NO	1.1	1.7	3.6	2.7	1.9
O	0.6	2.1	2.0	2.3	2.5
SO	0.9	3.3	1.4	2.4	3.8
S	3.6	7.1	3.4	5.5	4.4
SW	9.5	9.6	7.7	8.7	7.7
W	11.3	10.0	5.4	7.9	11.3
NW	9.5	6.9	4.4	5.6	7.7
AN	1.4	0.9	2.2	1.6	1.1
ANO	0.4	0.7	1.6	1.3	0.8
AO	0.3	0.6	1.3	1.1	1.1
ASO	0.3	1.1	1.0	1.3	1.4
AS	1.3	2.4	1.3	1.9	1.4
ASW	2.7	3.4	1.9	2.7	2.2
AW	3.8	3.4	1.8	2.8	3.3
ANW	3.6	2.6	1.6	1.9	2.5
CN	1.3	1.0	2.3	1.5	1.1
CNO	0.4	1.0	1.3	1.0	0.5
CO	0.3	0.7	0.6	0.8	0.8
CSO	0.3	0.7	0.5	0.6	0.8
CS	1.3	0.9	1.3	1.4	1.1
CSW	2.8	1.8	3.0	2.4	2.2
CW	3.3	2.5	2.9	2.5	2.5
CNW	2.9	1.8	1.5	1.4	1.9
U	0.4	0.3	1.8	0.7	4.9

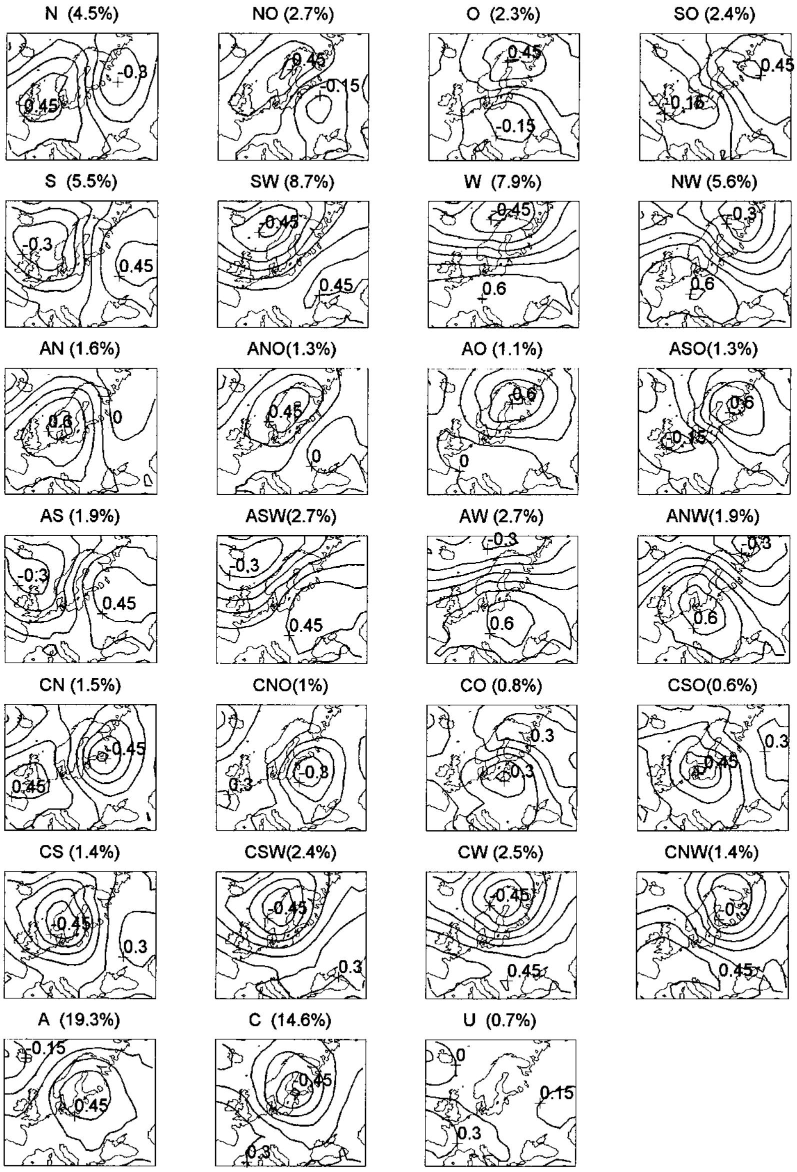

Fig. 2. Normalized annual mean sea level pressures (in relative units) of SLP weather types for the period 1968–1997. In parenthesis are shown the relative occurrences of weather types. N, NO, O, SO, S, SW, W, NW = directional types for different directions; AN, ANO, etc = anticyclonic hybrid types; CN, CNO, etc. = cyclonic hybrid types; A= anticyclonic; C = cyclonic and U = unclassified type.

the JC classification for the area, with the centre at 55°N, 15°E, also supports the dominance of anticyclonic weather. Her results are presented in the last column of Table 1. Summer was the season of the largest contribution of the cyclonic vorticity (if to take the C type and cyclonic hybrids together then 32.2% of days).

The Baltic region lies in a zone of highly variable westerlies. The main flow directions came out from the occurence distribution of the weather types in different seasons (Table 1): in winter the W, SW and S types were the prevailing directional types, and out of four seasons the directional types had the largest contribution (48.3%) (because of the large pressure gradient). The low values of pressure gradients in spring and summer were observed also from the lower load of directional types in these seasons: 38.8% and 34.5% respectively. The classification agrees with the fact that at the 500 hPa level the westerly flow is stronger than at sea level, and the easterly weather types vanish.

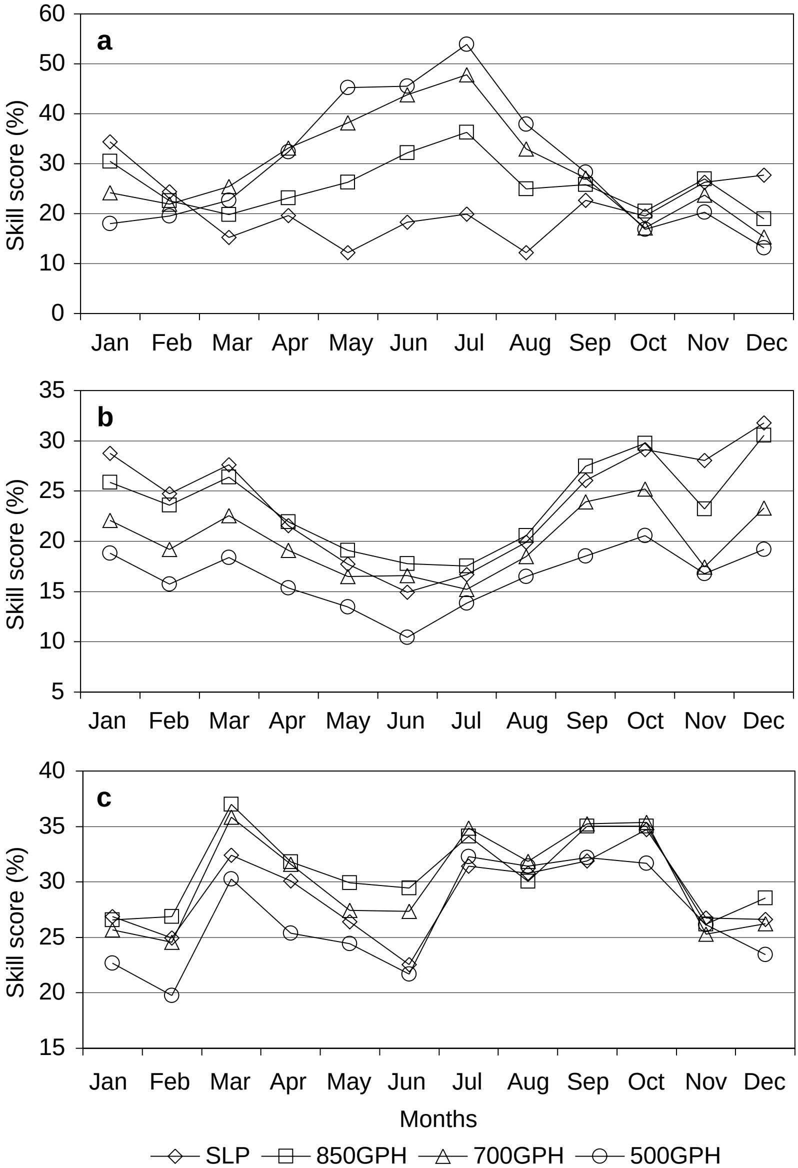

Fig. 3. Mean squared error skill scores (%) for the predicted daily values of (a) temperature, (b) precipitation sums and (c) precipitation occurrence at Pärnu in the period 1968–1997. The abbreviations are the same as in Table 2.

Classification deficiencies

The JC scheme is a simple synoptic scale atmospheric circulation classification. We have taken the scheme as it is without making any substantial modifications, but there are some approximations and deficiencies what should be considered when interpreting the results.

The scheme uses geostrophic approximation that is physically justified only for the free atmosphere. The geostrophic wind speed overestimates the real wind speed in cyclonic motion and underestimates it in anticyclonic motion. For large-scale motions in midlatitudes the discrepancy is about 10%–20%, and inside intense cyclones even larger discrepancies can occure. In the JC classification scheme for calculating the flow *F*, the means of pressures in two or three points are used. In case of a high curvature of isobars, this averaging causes a pressure gradient and consequently an underestimation of the flow strength. This averaging amplifies the difference of the geostrophic wind from the gradient wind in case of anticyclones, and decreases the difference in case of cyclonic motion.

The weather types were defined using numerical thresholds for circulation indicies. The only ground for concrete numerical values of thresholds is that the resulting mean pressure fields show different circulation patterns. But, the procedure of comparing *Z* to *F* (or dividing *Z* to *F*) kicks out many combined cases of high cyclonic vorticity, high wind speeds and powerful weather events from cases of cyclonic weather type. And from the mean pressure fields (Fig. 2) it is clearly seen that the classes NO, O, S and SW show a clear cyclonic cuvature. This also explains in part the anticyclonic prevailing: some cases of cyclonity are included into directional types.

The influence of weather types on the daily temperature and precipitation

One of our purposes was to investigate the influence of atmospheric circulation on the meteorological regime of the Baltic region. Under research were data from several meteorological stations in Estonia, but the results coincided to such extent that only results from Pärnu meteorological station (58.37°N, 24.50°E) are presented here. The location of Pärnu on the eastern coast of the Baltic Sea is shown in Fig. 1. Daily deviations from the long-term monthly mean temperature, daily precipitation sums and the proportion of rainy days (precipitation occurrence) for the distinct weather types over the period of 1968–1997 were calculated.

To evaluate the capability of the classification to describe the variability of the local (Pärnu) temperature and precipitation, the dispersion analysis was used. We calculated the mean-squared-error skill scores as done by Buishand and Brandsma (1997) for the predicted daily values that show to how large extent the variability of the temperature and precipitation is determined by the changing of weather types. The skill score gives the proportion of the explained variance and is the square of the multiple correlation coefficient. The magnitude of the skill score is determined by the squared deviations of the individual values from monthly averages.

The skill scores reveal which pressure levels were the most suitable for explaining the temporal variability of surface weather elements (Fig. 3). The skill scores had a strong annual cycle for temperature. In summer the skill scores were the largest for the 500 hPa classification and in winter for the sea level pressure classification. This shows that in summer the daily temperature of the local area was more connected with movements in the free atmosphere, but in winter the processes in the boundary layer were more important. From here it follows that the classification describes temperature variations better if several levels in the atmosphere are taken into account. Precipitation processes were more related to surface conditions: the largest skill scores were for the sea level and 850 hPa classifications.

For the objective classification at sea level, the precipitation skill scores were higher in Pärnu than in De Bilt (in the Netherlands), but skill scores for temperatures showed the opposite (Table 2). We also included the results of Grosswetterlagen to obtain comparison with the previous works (Keevallik *et al.* 1999, Post and Tuulik 1999). For GWL the skill scores in Pärnu were lower than in De Bilt for all weather

Table 2. Annually averaged mean squared error skill scores (%) for the predicted daily values of weather elements at Pärnu (1968–1997) and in parenthesis at De Bilt (1949–1993) (Buishand and Brandsma 1997). SLP-classification for the sea level, 850GPH for the 850 hPa level, 700GPH for the 700 hPa level, 500GPH for the 500 hPa level and GWL = German Weather Service's Grosswetterlagen.

	SLP	850GPH	700GPH	500GPH	GWL
T	21.0 (28.7)	25.7	29.2	29.5	22.8 (39.6)
P_{sums}	23.9 (19.3)	23.7	20.0	16.5	10.8 (16.1)
P_{occ}	28.8 (24.8)	30.9	30.1	26.8	14.5 (25.8)

elements. That proves that the Grosswetterlagen classification is less suitable for Estonia than for the Netherlands. Concerning temperature, the Baltic Sea area is a problem also for the objective scheme (skill scores are lower than for the Netherlands). It could be related to the fact that for this spatial scale of classification, the Atlantic Ocean as a homogeneous boundary surface is too far from the Baltic area, but close enough to the Netherlands. As our results for the precipitation were better than those for Netherlands, the determining scale maybe more local in this case and the vicinity of Atlantic may not play a role. Nevertheless, the skill scores for the objective weather types at Pärnu were higher than for Grosswetterlagen. It should therefore be possible to develop a classification that better describes the variability of weather elements. The investigation shows that classifications cannot describe the variability of temperature and precipitation equally well. The solution would be to find relations between the circulation parameters (direction and strenght of the dominant airflow, and vorticity) and any weather element separately, as it has been done in many downscaling studies, and based on the results, to establish respective classifications. This would eliminate also the subjectivity of thresholds.

Discussion and conclusion

From the present work, it follows that for investigating the temporal variability of the atmospheric circulation in the Baltic Sea region the Jenkinson and Collison (1977) scheme is certainly good enough. It distinguishes certain different weather patterns; it is physically easily interpretable and uses only sea level pressures (that have the longest available time series). Its simple applicability to the Baltic Sea area pressure fields on different levels has also given better relations with weather elements than GWL. Temperature is best described by the classifications at higher levels of pressure (500 hPa and 700 hPa) and precipitation at the lower ones (sea level and 850 hPa). But the skill scores stay still low, which means that the scheme should be improved for downscaling purposes.

The results suggest that if we want the classification to describe well the variability of regional weather elements, then several circulation indices on different height levels should be taken into account. The use of simple physical models, like geostrophic wind approximation, gives a direct physical interpretation of the classification and a reasonable number of classes. The approximation of geostrophic wind is physically justified only for the free atmosphere. If we have only sea level pressure fields, some statistical classification could be used. If the task is to conserve also the physical meaning, the sea level winds in combination with empirical relations from the boundary layer dynamics could be used to get upper air motions.

Acknowledgements: This work was financially supported by the Estonian Science Foundation (grant No 4347). Two anonymous reviewers gave many useful comments to the first version of the paper. All this is gratefully acknowledged.

References

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

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

Gerstengarbe F.W., Werner P.C., Busold W., Rüge U. & Wegener K.-O. 1993. Katalog der Grosswetterlagen Europas nach Paul Hess und Helmuth Brezowsky. *Ber. Dtsch. Wetterdienstes,* 113, 4th ed., Selbstverlag des Deutschen Wetterdienstes, Offenbach am Main, Germany, 249 pp.

Jenkinson A.F. & Collison F.P. 1977. An initial climatology of gales over the North Sea *Synoptic Climatology Branch Memorandum* No. 62, Meteorological Office, Bracknell, 18 pp.

Kalnay E., Kanamitsu M., Kistler R., Collins W., Deaven D., Gandin L., Iredell M., Saha S., White G., Woollen J., Zhu Y., Leetmaa A., Reynolds R., Chelliah M., Ebisuzaki W., Higgins W., Janowiak J., Mo K.C., Ropelewski C., Wang J., Jenne R. & Joseph D. 1996. The NCEP/NCAR 40-year reanalysis project. *Bull. Am. Meteorol. Soc.* 77: 437–472.

Keevallik S., Post P. & Tuulik J. 1999. European circulation patterns and meteorological situation in Estonia. *Theor. Appl. Climatol.* 63: 107–116.

Lamb H.H. 1972. British Isles weather types and a register of daily sequence of circulation patterns, 1861–1971. *Geophys. Mem.* 110, Meteorol. Office, London, 85 pp.

Linderson M.L. 2001. Objective classification of atmospheric circulation over Southern Scandinavia. *Int. J. Climatol.* 21: 155–169.

Mietus M. 1998. The climate of the Baltic Sea Basin. *Marine Meteorology and Related Oceanographic Activities*, Report No. 41, WMO/TD-No. 933, 180 pp.

Post P. & Tuulik J. 1999. About the relationships between Estonian weather elements and European circulation patterns. *Phys. Chem. Earth (B)* 24: 97–102.

Prilipko G.I. [Прилипко Г.И.] (ed.) 1982. [*The climate of Tallinn*], Gidrometeoizdat, Leningrad, 267 pp. [In Russian].

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

Yarnal B. 1993. *Synoptic Climatology in Environmental Analysis,* Belhaven Press, London, and Florida, 195 pp.

Received 23 January 2002, accepted 25 June 2002