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SELECTED ASPECTS OF THE VARIABILITY OF ATMOSPHERIC CIRCULATION REGIMES IN THE EURO-ATLANTIC REGION DURING XXI CENTURY

Wybrane aspekty zmienności reżimów cyrkulacyjnych w obszarze atlantycko-europejskim w XXI wieku

Streszczenie. Wiek XX charakteryzował się występowaniem odrębnych reżimów cyrkulacyjnych w przebiegu charakterystyk strefowego przepływu powietrza zarówno w skali hemisferycznej, jak i regionalnej. Podstawowym celem badań była próba identyfikacji reżimów cyrkulacyjnych w XXI wieku z wykorzystaniem projekcji/modeli zmian klimatu, dostępnych dla scenariuszy emisyjnych SRES opracowanych przez IPCC (Intergovenmental Panel on Climate Change). W toku badań zweryfikowano hipotezę o możliwości wystąpienia istotnych zmian (*regime shifts*) w systemie przepływu powietrza nad obszarem atlantycko-europejskim w XXI wieku dla wybranych scenariuszy emisyjnych SRES z modelu ECHAM5.

Słowa kluczowe: cyrkulacja atmosferyczna w XXI wieku, zmiany reżimów cyrkulacyjnych, ECHAM5
Key words: XXI century atmospheric circulation, regime shifts, ECHAM5

INTRODUCTION

The characteristics of atmospheric circulation are among most important factors governing the variability of climate. XX century faced at least couple of significant reorganizations of air flow in mid-latitudes (Degirmendžić 2000) that brought about major changes in the ecosystems (Mantua 1997). Thus, it seems important to investigate the possibility of occurrence of such phenomena during XXI century.

The area of research comprised so called Euro-Atlantic region which spatial domain can be described with following coordinates 40°W-40°E, 35°N-75°N. Air flow is to large extent governed by SLP (Sea Level Pressure) thus the variable used was monthly SLP values that were the output from general circulation model model ECHAM5. It was developed in Max Planck Institute for Meteorology, Germany (Roeckner 2003) and its spatial resolution is ca. 1.9 latitude/longitude degree which results in 1035 grid data points in the research area. Temporal coverage of the analysis comprised reference period spanning years 1951–2000 (XX century 20C3M scenario was utilised) and XXI century (in some analyses 2011–2100). The data used were the result of climate system modelling under different emission scenarios described in SRES (Nakicenovic 2000). Three most commonly used scenarios were selected: A1B which is assuming sustainable path of development with rapid economic growth and quick introduction of more efficient technologies, A2 – economically divergent world with fast population growth (this might be called *worst case* scenario) and the B1 which assumes moderate population growth and economically convergent world (sadly, one may consider it just a *wishful thinking* scenario).

Conducted research comprised compositing (Wilks 2008) of SLP values for arbitrary selected 30-year periods of XXI century together with SLP values trend analysis for 2011–2100 period. The idea of atmospheric circulation regimes identification resulted in application of *eigenfunction* techniques which allowed the recognition of the major modes (EOFs) of SLP variability in XXI century. The comparison with 1951–2000 period's EOFs was also carried out. The resulting PC (Principal Component) series that mirror the share of the given EOF in total SLP variability served as a basis of regime shift identification analysis.

The question of possible regime shift in the course of atmospheric variables is one of great importance in contemporary climate research as stated in the report on abrupt climate change prepared by National Research Council, USA (2002). Regime shift (RS) itself can be described as a rapid reorganisation of ecosystem from one relatively stable state to another (Rodionov, Overland 2005). The most common problems with the identification of RSs are: multiple shifts, trend in the data, deterioration of analysis near the end of time series and autocorrelation. Rodionov (2004, 2005, 2006) proposed a method (STAR – Sequential t-test Analysis of Regime Shift) which solves most of those inconvenience and is capable of detection of RSs of different time scales and magnitudes. It is fully described in his aforementioned publications thus it shall not be addressed in detail herein. The major features of the method is that the number of observation is not fixed – they come in sequence and for each new observation a new test is performed to determine the validity of the null hypothesis – the existence of RS.

During the research STAR algorithm was used to identify the RSs in the course of 1st PC of SLP for selected emission scenarios thus covering the most important mode of SLP variability. The analyses were also performed on first three PCs (not shown) covering majority of SLP variability. Resulting circulation regimes time line was subsequently a basis for compositing procedure which allowed the depiction of SLP anomalies during regimes of XXI century atmospheric circulation thus presenting possible changes in the air flow system characteristics over the area of research.

RESULTS

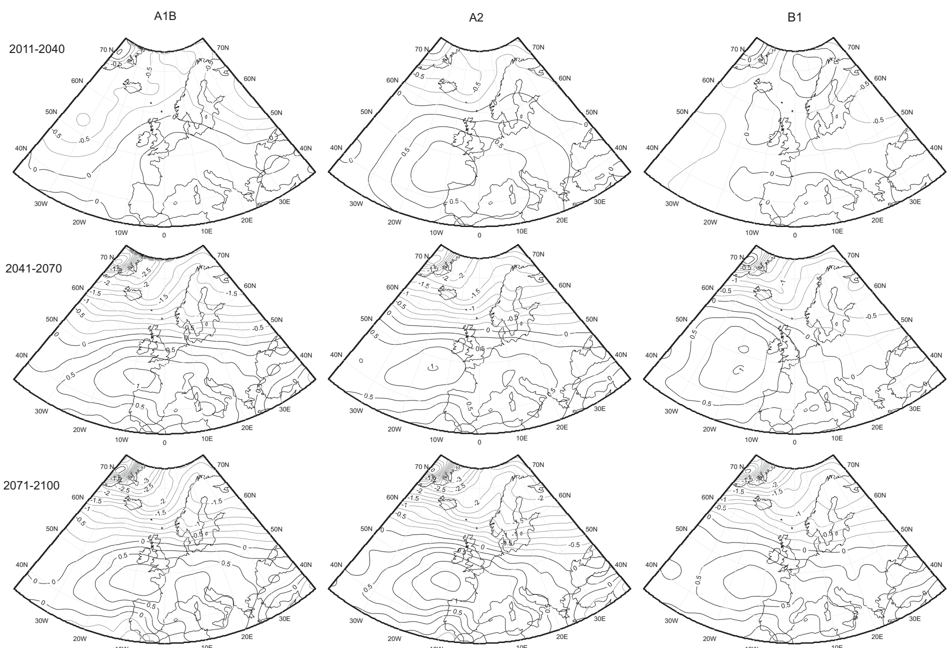


Fig. 1. SLP anomalies (hPa) during selected sub-periods of XXI century (reference period:1951–2000)
Ryc. 1. Anomalie SLP (hPa) w wybranych 30-leciach XXI wieku względem okresu 1951–2000

SLP anomalies during sub-periods of XXI century (Fig. 1) reveal relatively insignificant changes for the first period (2011–2040) with anomalies not exceeding ±1hPa. The deviations are most prominent for scenarios A1B and A2 and generally the northern part of the research area is dominated by negative anomalies whereas the southern part exhibits positive ones. A1B is the scenario with the greatest extent of negative change covering almost entire Atlantic foreground of the continent (with anomalies below –0,75hPa). Central and southern Europe exhibit slight positive SLP change. Area of negative SLP anomalies for A2 scenarios is more confined and covers the areas north of 60°N (Fig. 2). Major feature is the vast area of positive anomalies with the centre located west of Biscay Bay (>+0,75hPa). Such anomalies patterns result in the intensification of SW advection in North Atlantic and NW over Europe (A1B) while in the case of A2 scenarios in the overall intensification of zonal flow especially in the northern part of the research area. B1 scenario does not reveal any coherent pattern of SLP anomalies in this period.

During following sub-periods the SLP change seems to be more pronounced. Again, it is most prominent for A1B and A2 scenarios and the weakest for B1 (notably during 2041–2070). It seems that during the second half of the XXI century we may witness significant intensification of zonal flow as for most of the scenarios the SLP difference (amplitude of anomalies) over North Atlantic and Europe shall increase by c.a. 3hPa. The above analysis is further confirmed by the shape of the total SLP change during 2011–2100 period. Significant (negative) values are mainly present in the northern part of the research area with the greatest extent of significant values for A2 scenario. In case of all scenarios the changes are collectively significant in the research area as the number of grid points (with significant trend coefficients) exceeds the critical value (confirmed with binominal testing under multiplicity) (Wilks 2008). A2 is the only scenario with the expansion of significant values over Europe (Scandinavia). In case of other scenarios this situation is restricted to part of North Atlantic basin north of Iceland.

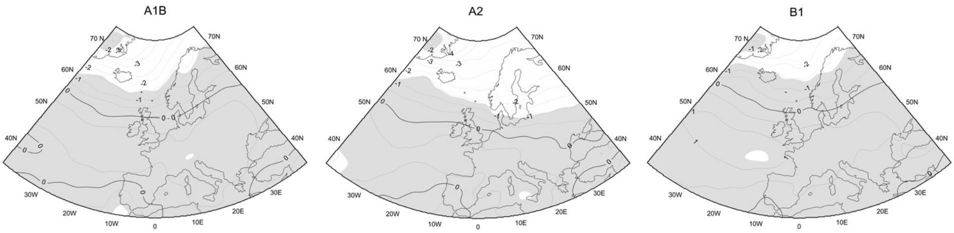


Fig. 2. Overall SLP change (hPa) in the period 2011–2100. Shaded areas indicate points with insignificant trend coefficients

Ryc. 2. Zmiana SLP (hPa) 2011–2100 (zacieniowano obszary o nieistotnych wartościach współczynników trendu)

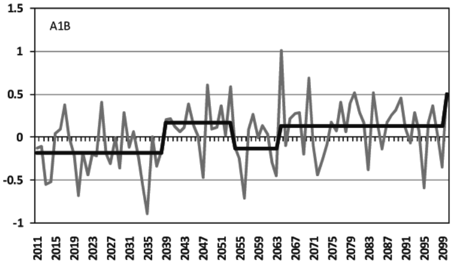
Variance explained by XXI century SLP EOFs seems to be relatively stable in comparison with 1951–2000 period (Tab. 1). What can be noted is the increase by 4 to 6% in the case of 1st EOF and drop (by 3%) in the case of the 3rd. Collectively EOFs (1st – 3rd) account for 76 to 79% and (1st – 6th) slightly above 90% of SLP variance. *Eigenfunction* tools used for SLP field show that the spatial

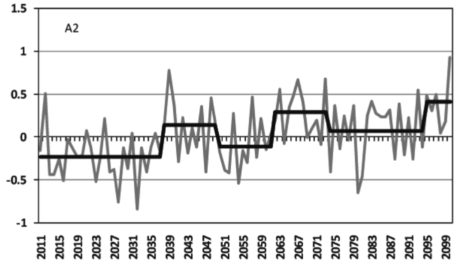
Table 1. SLP variance (%) explained by successive EOFs (XXI century along with reference period 1951–2000) for selected emission scenarios
Tabela 1. Wariancja pola SLP (%) wyjaśniana przez kolejne wektory własne (2001–2100 oraz okresu odniesienia 1951–2000) na podstawie wybranych scenariuszy emisyjnych

SRES/EOF	1st EOF	2nd EOF	3rd EOF	4th EOF	5th EOF	6th EOF	Σ (1–6)	Σ (1–3)
1951–2000	34	22	20	8	5	4	93	76
A1B (2001–2100)	40	22	17	7	4	3	93	79
A2 (2001–2100)	38	22	16	8	5	4	93	76
B1 (2001–2100)	38	22	16	8	4	4	92	76

structure of SLP field changes but a little (not shown) during the XXI century in comparison with 1951–2000 period. This is mostly true for the 1st EOF of SLP where the changes are almost negligible. Some changes, however, are noted for successive EOFs. Those reveal slight shift of identified anomalies centres not changing the overall pattern. What must be also stated is a statistically significant (for all emission scenarios) positive trend in the 1st PC thus indicating increasing importance of this mode which is associated with the increasing zonal flow depicting strong SLP dipole over the research area.

STAR algorithm applied to 1st PCs of XXI century SLP field allowed (Fig. 3) the identification of RSs for all selected emission scenarios and all of them are





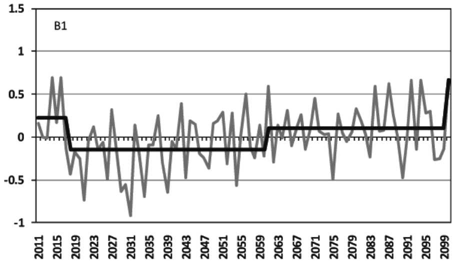


Fig. 3. SLP 1st PC (principal component) course (grey line), PC's averages for identified regimes (black line) 2011–2100
Ryc. 3. Przebieg serii stowarzyszonych (PC) z pierwszymi wektorami własnymi pola SLP (linia szara). Średnie wartości PC w wyznaczonych reżimach 2011–2100

significant at 0.05 level. The least complex situation is noted for B1 with only 3 regimes (2011–2017, 2018–2060, 2061–2100). Most variable is A2 (6 regimes – 2011–2037, 2038–2049, 2050–2061, 2062–2073, 2074–2094, 2095–2100). There is a visible seesaw between lower and higher values of PCs but in the case of A1B and B1 scenarios one sees a symmetry around the zero value where as for A2 scenario each positive/negative regime seems to attain higher values thus indicating most prominent changes with the apparent trend towards higher PC values signifying increasing importance of this mode of variability.

Identified regimes served as a time reference frame for aggregating future SLP values that are subsequently presented as anomalies from the 1951–2000 reference period (Fig. 4). There are 4 regimes for A1B scenarios. 1st (2011–2038 – with weakened input of 1st EOF pattern) with faintly indicated deviations where North Atlantic is dominated with negative anomalies (not falling below −1hPa). Values of this sign are also present in the north-eastern part of research area. 2nd regime (2039–2053 – with positive shift of PC values) reveals substantial increase of meridional SLP gradient. 3rd one, relatively short (2054–2063), shows a centre of positive SLP anomalies over Europe with values over +0,75hPa. This connected with significant drops over the North Atlantic might indicate the intensification of meridional airflow that would clearly disturb the zonal advection. The last of identified regimes is similar to the second one with the intensified zonal flow.

As it was aforementioned A2 scenario is the one with the highest complexity (6 regimes) but for the sake of simplification one can define two major types of SLP field response. 1st and 3rd regimes are characterised with the weakest deviations from the 1951–2000 period average with anomalies rarely exceeding ±1hPa. The difference is that in the case of the 1st regime SLP will experience *en masse* SLP increase over almost all the research area whereas for the latter the decrease with the centre east of Iceland. Other regimes identified for A2 scenario (2nd, 4th, 5th & 6th) exhibit substantial increase in the meridional pressure gradient over the whole research area. The increase of SLP difference between Azores High and Icelandic Low exceeds 5hPa (regimes 4th & 6th) thus meaning significant zonal flow intensification in the second half of the XXI century. The identified regimes and resulting SLP anomalies are the weakest in case of B1 scenario. 1st regime is characterised with the increased meridional SLP gradient but this feature is restricted to North Atlantic basin and the anomalies amplitude is minor (barely exceeds 2hPa). During the 2nd regime there is no significant change in comparison with 1951–2000 period. And finally, the SLP anomalies during the 3rd regime spanning over the last 40 years of XXI century are similar to the ones from the 1st regime with slightly stronger indication and northward shift of positive anomalies centre over the North Atlantic.

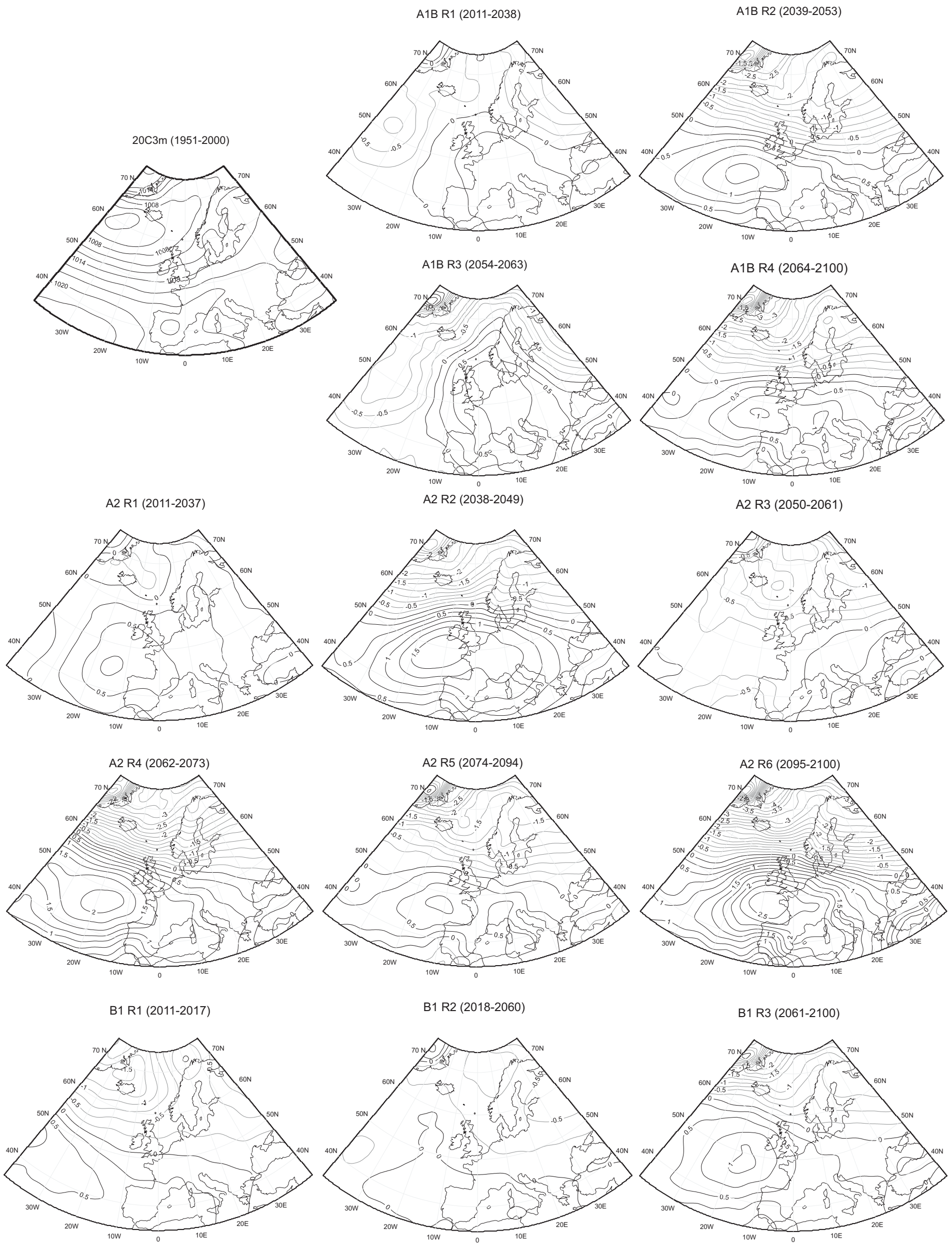


Fig. 4. SLP average (hPa) during second half of XXth century (1951–2000 20C3M scenario) together with SLP anomalies (hPa) during identified regimes (R1, R2, etc.) for selected emission scenarios (A1B, A2, B1)

Ryc. 4. Średnie wartości SLP(hPa) w II połowie XX wieku (1951–2000, scenariusz 20C3M) oraz anomalie SLP (hPa) w wyznaczonych reżimach (R1, R2, itd.) według wybranych scenariuszy emisyjnych (A1B, A2, B1)

CONCLUSIONS

SLP anomalies for selected sub-periods (30 years) of XXI century show increasing meridional pressure gradient in the second period (2041–2070) – thus possible increased zonal flow intensity. This is most prominent for A1B & A2 scenario. 2071–2100 period shows further intensification – apparent for all selected scenarios. Total change (2011–2100) of SLP shows noticeably negative trends for northern part of the research area.

STAR algorithm allowed the identification of regimes in the course of PCs of SLP

They are most pronounced in case of 1st PC (A1B, A2 & B1) – all RSs are statistically significant at 0.05 level. Compositing procedure showed pronounced differences in the SLP fields for identified regimes in distinctive emission scenarios which might indicate relatively diverse advection conditions and thus, in combination with other factors, substantial changes in climatic conditions over the area of research.

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