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The Wind Regime of Romania – Characteristics, Trends and North Atlantic Oscillation Influences

Alfred VESPREMEANU-STROE[1,*], Sorin CHEVAL[2], Florin TĂTUI[1]

[1] Faculty of Geography, University of Bucharest, N. Bălcesu Blvd, no 1, Bucharest, Romania
[2] National Administration of Meteorology, Bucharest-Ploiesti Road, no 97, 71552 Bucharest, Romania
* *Corresponding author*, fredi@geo.unibuc.ro

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Abstract

The present study attempts to develop a comprehensive perspective of the wind regime on the Romanian territory, focusing on the characteristics and tendencies encountered over the past 50 years, as well as on the NAO projection on it, using several data categories gathered from 167 meteorological stations. Based on the recorded multiannual averages and on the strong correlation (r = 0.87) established between altitude and wind speed in wind exposed areas, we created the map of mean (multi)annual wind speed. The highest aeolian potential corresponds to the Carpathians (7-10 m/s on the ridges and 3-7 m/s on the slopes and within valleys) and the Black Sea Shore (5-7 m/s); nevertheless, the two areas develop extreme values of the wind turbulence – maximum in the Carpathians and minimum in the coastal units. Tablelands in Moldova and Dobrogea, as well as the northern part of Bărăgan show ideal conditions for the development of aeolian parks (moderate and strong winds, low turbulences). On a country-size scale, the month with the highest mean wid speed is March, whereas August is the calmest one. For the first time, the map of resultant wind direction (DRV) was designed, expressing both the resultant wind orrientation and its intensity (high intensity = low directional variability). Concerning NAO, a negative correlation is observed between its indices and the wind speed (mean speed, frequency and intensity of the stromic events) at a multiannual and multidecadal scale. The correlation coefficients present high values in the extra-carpathian areas and small or moderate values in the intra-carpathian areas. The positive (negative) NAO associated with low (high) cyclogenesis over the Mediterranean area induce low (high) winds over the Romanian territory due to diminished (enhanced) frequency of cyclones reaching Romanian regions.

Keywords: *wind regime, North Atlantic influences, wind direction*

Rezumat. Regimul vânturilor din România – Caracteristici, tendinţe şi influenţele oscilaţiilor nord-atlantice

Prezentul studiu încearcă să compună o perspectivă comprehensivă asupra regimului eolian de pe teritoriul României, insistând asupra caracteristicilor şi tendinţelor manifestate în ultimii 50 ani, precum şi a influenţei Oscilaţiei Nord-Atlantice, utilizând în acest scop diverse categorii de date adunate de la 167 staţii meteorologice. Pe baza mediilor multianuale înregistrate şi a corelaţiei puternice (r = 0.87) stabilite între altitudine şi viteza vântului din spaţiile interfluviale a fost compusă harta vitezelor medii anuale. Regiunile cu cel mai ridicat potenţial eolian sunt Carpaţii (7-10 m/s pe creste şi 3-7 m/s pe versanţi şi văi) şi Litoralul Mării Negre (5-7 m/s); de altfel, cele două regiuni dezvoltă valori extreme ale turbulenţei eoliene – maxime în Carpaţi şi minime în unităţile litorale. Interfluviile din Podişul Moldovei şi Podişul Dobrogei precum şi Bărăganul Nordic prezintă condiţii ideale (vânturi medii şi puternice şi turbulenţe scăzute) pentru dezvoltarea parcurilor eoliene. La nivel naţional, luna cu cea mai mare viteză medie este martie, iar august luna cea mai calmă. În premieră, a fost concepută la scară naţională harta direcţiei rezultante a vântului (DRV), care exprimă atât orientarea rezultantă a vântului cât şi intensitatea acesteia (intensitate mare = variabilitate direcţională mică). În ceea ce priveşte influenţa NAO se remarcă o corelaţie negativă între indicii acesteia şi viteza vântului (viteza medie, frecvenţa şi intensitatea furtunilor) la nivel multianual şi multidecadal. Coeficienţii de corelaţie prezintă valori ridicate în regiunile extracarpatice şi valori mici sau medii în cele intracarpatice. Fazele pozitive/negative ale NAO, asociate cu intensitatea scăzută/ridicată a ciclogenezelor din zona mediteraneeană, induc viteze mari/reduse ale vântului în acord cu frecvenţa scăzută/ridicată a ciclonilor care traversează România.

Cuvinte-cheie: *regimul vântului, influenţa nord-atlantică, direcţia vântului*

Introduction

North Atlantic Oscillation (NAO) is one of the most important modes of large scale variability in the Northern Hemisphere. It occurs especially during boreal winter (when the atmosphere is dynamically the most active), while the NAO summer signal is quite null. The phenomenon has been defined as an anomaly in the sea level air pressure (SLP) distribution with centers of action near the Icelandic low and the Azores (Van Loon and Rogers, 1978). Conventionally, the index of the NAO is based on the difference of the standardized sea level pressure (SLP) anomaly measured at Lisbon, Portugal and at Stykkisholmur, Iceland (Hurrell, 1995).

Research studies revealed that changes in the mean air flow and storminess associated with swings in the NAO are reflected in large-amplitude patterns in the anomalies of temperatures, precipitation, heat fluxes and wind speed in the Atlantic-European region (Kushnir, 1994; Hurell, 1995; Thompson and Wallace, 1998, 2000; Bojariu and Giorgi, 2005).

When the NAO index is positive, enhanced westerly flow across the North Atlantic during winter moves relatively warm (and moist) maritime air over much of Europe, enhanced precipitation over northern Europe associated with less precipitation over central and southern Europe occurs (Hurrell, 1995; Hurrell and van Loon, 1997; Râmbu et al., 2002; Bojariu and Gimeno, 2003). A reverse situation occurs during the negative phase of the NAO.

In Romania, positive thermal anomalies are associated with positive NAO phases due to the prevalence of zonal circulation over the Northern and Central Europe and negative thermal anomalies over Romania are associated with negative NAO phases. The winter precipitation pattern over Romania is indirectly related to the NAO (Bojariu and Paliu, 2001; Zaharia et al., 2002).

The study of NAO projection on temperature and precipitation regime in Romania show that the winter NAO related signal is stronger in the extra-Carpathian regions, due to the orographic effects imposed by the Carpathian Mountains on the atmospheric flow (Bojariu and Paliu, 2001). Previous works of the authors highlight the NAO control upon the climate and the morphodynamics of the Romanian Coast (Vespremeanu-Stroe et al., 2007; Vespremeanu-Stroe and Tătui, 2011).

All the papers which refer to the NAO show that this phenomenon influences all climatic parameters, but there are no references regarding a clear mark of the NAO signal upon the wind regime. The goal of this paper is to reveal the main characteristics and trends of the Romanian wind regime (especially wind speed) and to investigate the NAO projection on it.

Data and Methods

Data

The primary data used in this study consist in monthly and annual means (115 meteorological stations) of wind speed, sums of winter storms (69 stations) and annual means of wind direction (167 stations). In addition, we used the Hurrell's NAO index (Hurrell, 1995). All wind and NAO data covered January 1961 – December 2003 interval.

Methodology

Data used for graphics were normalized extracting from each value the long-term mean and dividing it to standard deviation. The wind speed normalized anomalies were smoothed with a three-year running mean filter to obtain a multi-annual component of the series.

The linkage between NAO variability and Romanian wind regime is identified computing the correlation coefficients between NAO index and wind data and by mapping them. The spatial distribution of wind data and of the correlation coefficients was computed using ArcGIS 3.2, cokriging interpolation method and the wind speed – altitude linear regression (Fig. 1). For storm analysis, we selected wind speed values higher than 10 m/s and 15 m/s, for minimum 6 hour interval. Concerning the wind direction analysis, our interest limited to western circulation frequency expressed by West/East (W/E) ratio which was obtained by dividing the sum frequencies of western winds (from NNW to SSW) to eastern winds (NNE-SSE).

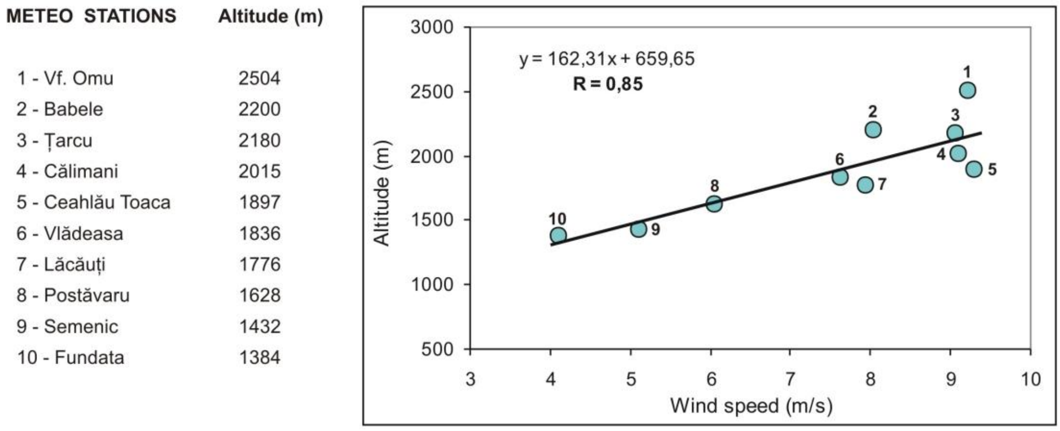

Fig. 1 The influence of altitude on the mean wind speed (wind-exposed areas)

Results

Mean wind speed and storm frequency

The distribution of the mean wind speed over the Romanian territory revealed the influence of the Carpathian chain on the regional response to the large scale atmospheric circulation. The South-Eastern Carpathians represent a roughness element for the atmospheric flow, acting as a complex barrier (Ion-Bordei, 1988).

In order to quantify the effects of altitude upon wind speed, a correlation between altitude and mean wind speed was computed for 10 mountain meteorological stations placed in wind-exposed areas at altitudes higher than 1200 m (Fig. 1). The resulting correlation coefficient (0.85) indicates a strong linkage; the regression formula was further applied for all mean wind speed data used on the Romanian territory (Fig. 2).

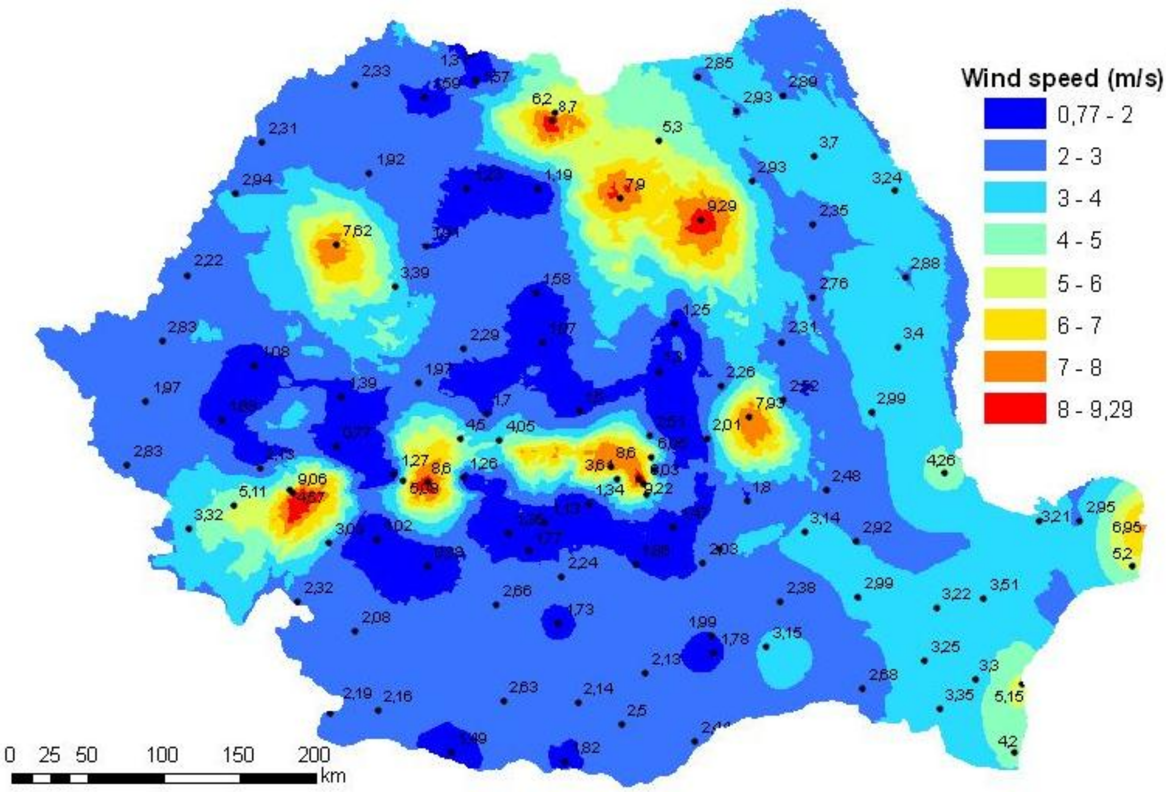

Fig. 2 The mean wind speed distribution over the Romanian territory

As a consequence, the regions between the Carpathians branches (Ardeal) and the intra-mountain and sub-mountain depressions present small annual wind speed values (1-2 m/s), moderate values (2-4 m/s) for the extra-Carpathians regions (Moldova, Muntenia, Oltenia, Dobrogea, Banat, Crişana) while the mountain wind-exposed areas have the highest values (5-9.3 m/s). Another region with relative high wind speed values (4.2-6.95 m/s) is the Romanian Black Sea coast due to the complex connections between the Atlantic storm track, the cyclogenesis activity over the Mediterranean area and the atmospheric circulation over Black Sea (Fig. 2). For the eolian energy, the most suitable locations have to record high speeds and low turbulences which are rare in Carpathians (especially restricted to wide plateaus: Mt. Mic, Godeanu, Semenic) but frequent in the coastal zone and on the exposed areas of the Moldavian and Dobrogea tablelands or in Bărăgan.

In order to quantify the NAO projection on wind speed pattern over the Romanian territory, we computed the correlation coefficients between Hurrell's NAO index and mean wind speed. For the Romanian territory, the positive wind speed anomalies are associated with negative NAO phases (Fig. 3A). The correlation coefficient (-0.52) is characteristic for the entire Romanian area in the context of a general decreasing trend from large territories to small regions (Fig. 3B, Fig. 4A).

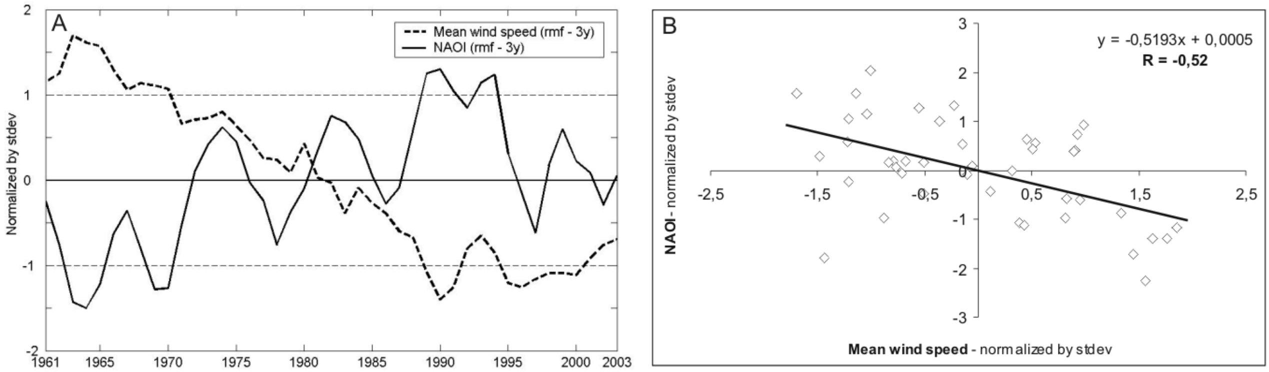

Fig. 3 Time evolution of mean wind speed and Hurrel's NAO index (A) and correlation coefficients between NAOI and wind speed (B) over the Romanian territory

The correlation pattern for wind speed anomalies (Fig. 4A) reveals a strong NAO related signal in extra-Carpathian areas due to an enhanced (diminished) frequency of Mediterranean and arctic cyclones and westerly air flows reaching these regions during negative (positive) NAO phases. The barrier role of the Carpathians against these complex influences determines small correlation coefficients between NAO index and wind speed anomalies in intra-mountain areas and even inverse values in some depressions. A strong NAO signal is found on the Romanian Black Sea coast due to the cyclogenesis activity over the Mediterranean Sea with complex influences upon Black Sea basin. Generally, the same pattern of correlation coefficients spatial distribution occurs for storm frequency and NAO index (Fig. 4B), with a better and more homogeneous distribution in the south-eastern part of Romania, which is an open territory for the Siberian Anticyclone activity (strong winter winds).

Storm distribution during the last four decades of the 20th century show an important shifting at the end of the 70's and the beginning of the 80's, which is synchronous with NAO signal (Fig. 5). A prominent contrast between a very active interval (1961-1978) and a relatively quiet period with low variability (1979–2003) is noticeable. Temporal evolution of storm activity is in good agreement, but negatively correlated with Hurrell's NAO index.

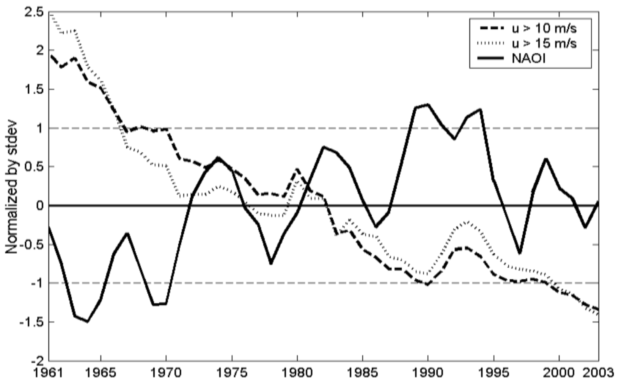

Fig. 4 Time evolution of storm incidence and Hurrel's NAO index

Another issue of our study was to find the spatial distribution of the windiest interval (monthly) over the Romanian territory, for a multidecadal scale (Fig.

6). It is obvious that there exists a compact grouping of the areas with the same windy intervals controlled by the position of the Carpathians and the west-east distribution. In the Carpathians and along the Black Sea coast, the regular winter (December-February) is the windiest period, while in the mountainous and sub-mountainous depressions and in the limitrophe regions of the Carpathians (e.g. the Subcarpathians), the windiest interval corresponds to the medium and late spring (April-May). The eastern part of Romania (Dobrogea, Moldavian Plateau, Bărăgan) is affected by strong winds at the end of winter (February-March). The central and the western parts record the highest wind speed at the beginning of the spring: March-April.

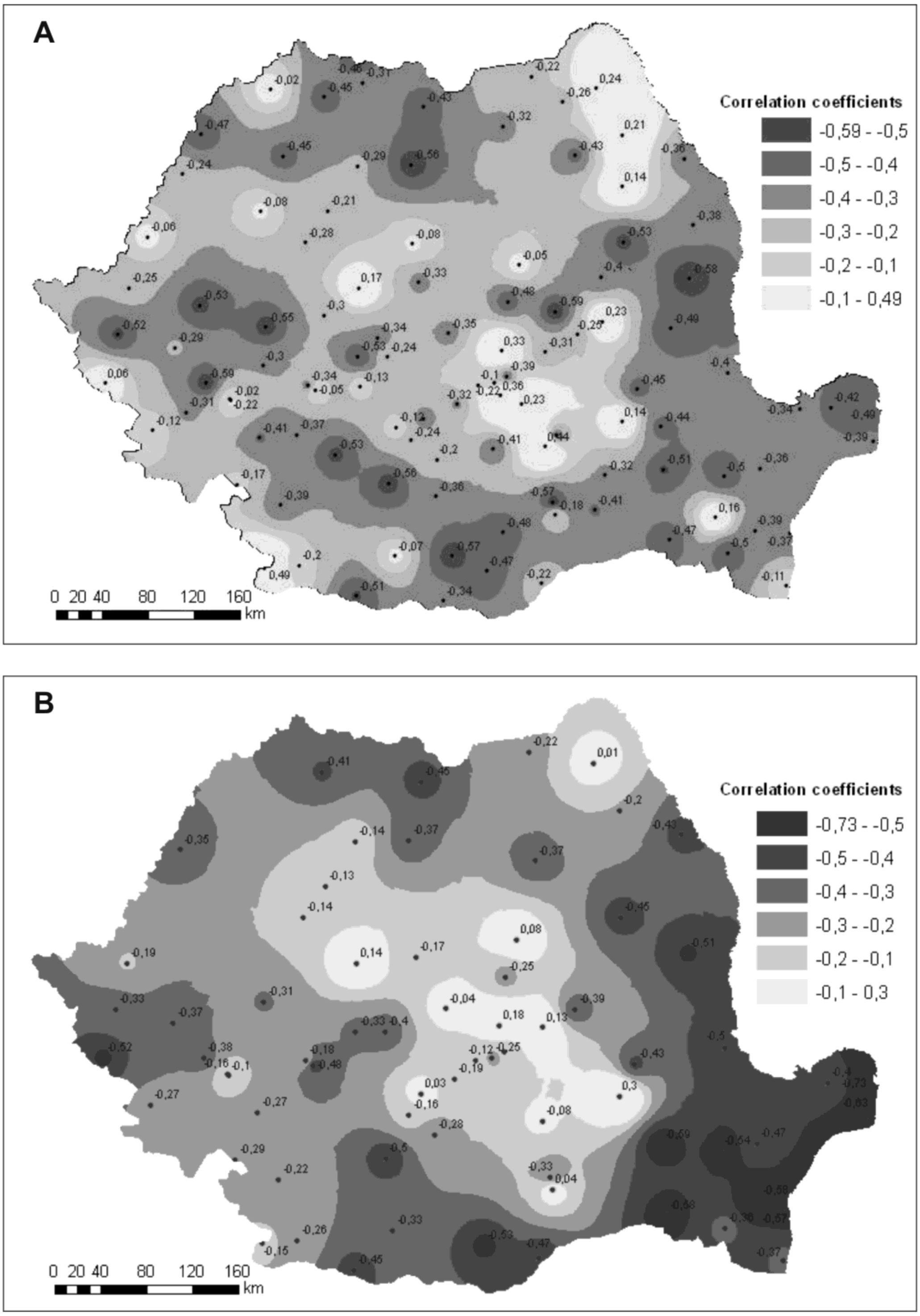

Fig. 5 The NAO patterns of correlation coefficients for mean wind speed (A) and storm frequency (B) over the Romanian territory

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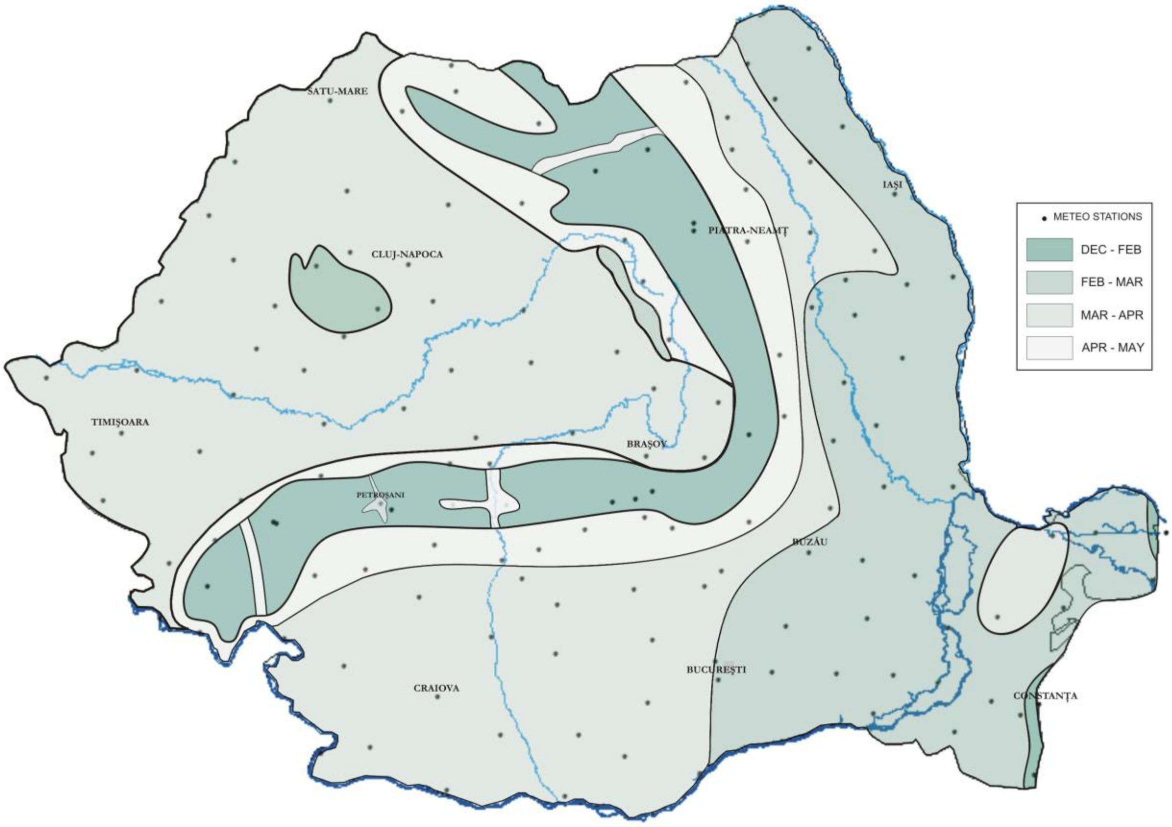

Fig. 6 The windiest interval distribution over the Romanian territory

Regarding the mean monthly wind speed, January – April is the most active period over the entire Romanian territory, with the highest values of wind speed (3 – 3,3 m/s) and the maximum means in March, while August is the most calm month of the year. The greatest variability of wind regime is registered in November – March interval, with maximum in January and February (winter conditions) and minimum in May – September under summer conditions (Fig. 7).

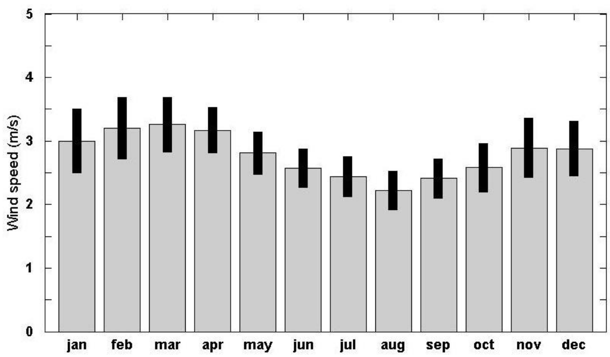

Fig. 7 The mean monthly wind speed in Romania (115 meteo stations). Gray columns represent the mean wind speed and the black overimposed small columns the standard deviation

Resultant wind direction

Based on the directional wind speed and frequency, we computed the direction and magnitude of the vectors representing the Resultant Wind Direction (RWD) for 167 meteorological stations spread over the Romanian territory (Fig. 8). The highest magnitudes of RWD (expressed in vector-units: vu) exceed the value of 200 vu and are representative for the meteorological stations placed on the alpine plateaus of the Romanian Carpathians. The general directional trend for these vectors is eastward, sometimes with a south-eastern component (especially for the Southern Carpathians). As expected, the meteo stations situated in the intra-mountainous areas (valleys, corridors, depressions) show a directional distribution of the RWD vectors in accordance with their general orientation.

The directional distribution of the vectors shows some discrepancies between W/E and N/S ratios. Thus, 75% of the total vectors are oriented to the East (from 0 to 180 degrees) and only 25% to the West (from 180 to 360 degrees), while 69% are oriented to the South (from 90 to 270 degrees) and only 31% to the North (from 270 to 90 degrees).

Moreover, the strongest resultant directions (> 50 vu) are recorded in the most cases (95%) on eastward and southward directions. Also, the average direction of the vectors is 141 degrees (SE). These results give a very good picture of the general airflows which pass over the Romanian territory and which are oriented to the east and south. A marked pattern is the directional grouping of the vectors for the meteo stations placed in the same region of the country. Thus, we separated the following situations: i) the vectors for the Eastern part of Romania which are oriented mainly to the SE (for Moldova) and S (for Dobrogea), according to the orographic effect of the Eastern Carpathians and the influence of the Black Sea; ii) the southern part of the country (Muntenia and Oltenia) is dominated by southward air flows over the Subcarpathians and Getic Plateau, due to the influence of the Southern Carpathians. The most part of the low areas (plain level) are affected by northeasterly winds, while the imprint of the Danube corridor gives a south-eastward component, especially for the meteo stations situated on the Danube River; iii) the vectors from the central part of Romania (Transilvania) are south-eastern oriented as a result of the air flows from West which dominate this region; iv) the vectors from the western part of the country do not present a general direction trend, possible due to the complex air flows which pass this area from North, South and West.

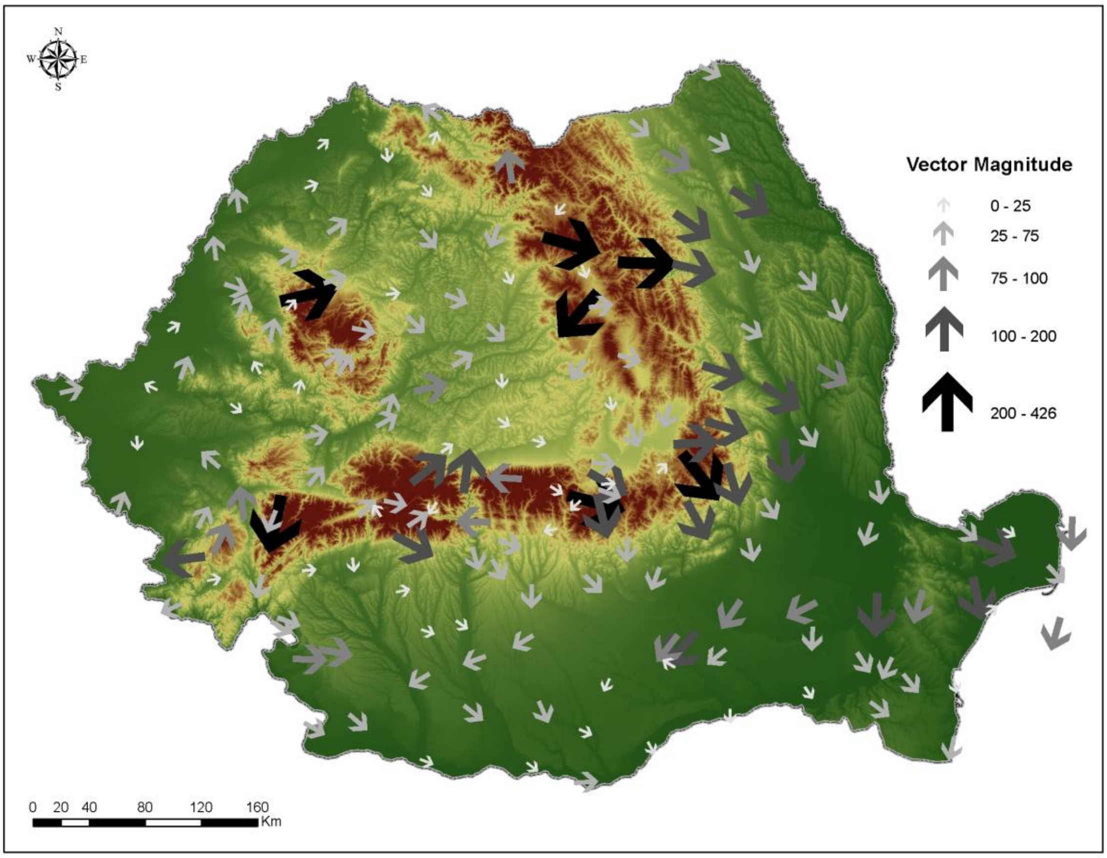

Fig. 8 The resultant wind direction over the Romanian territory

The NAO and wind direction

As NAO controls the mass circulation pattern over the Europe, we assessed the NAO role in western circulation strengthening or weakening over the Romanian territory. The temporal pattern of W/E wind frequency ratio during the last four decades indicates an intensification of western circulation in the last two decades (Fig. 9A). In this case a direct proportionality relation is established between the western circulation frequency and NAO. Positive/negative anomalies of western circulation frequency over the Romanian territory are associated with positive/negative NAO phases (positive statistical dependency) with a good correlation coefficient (0.69) based on wind data from 122 meteorological stations (Fig. 9B).

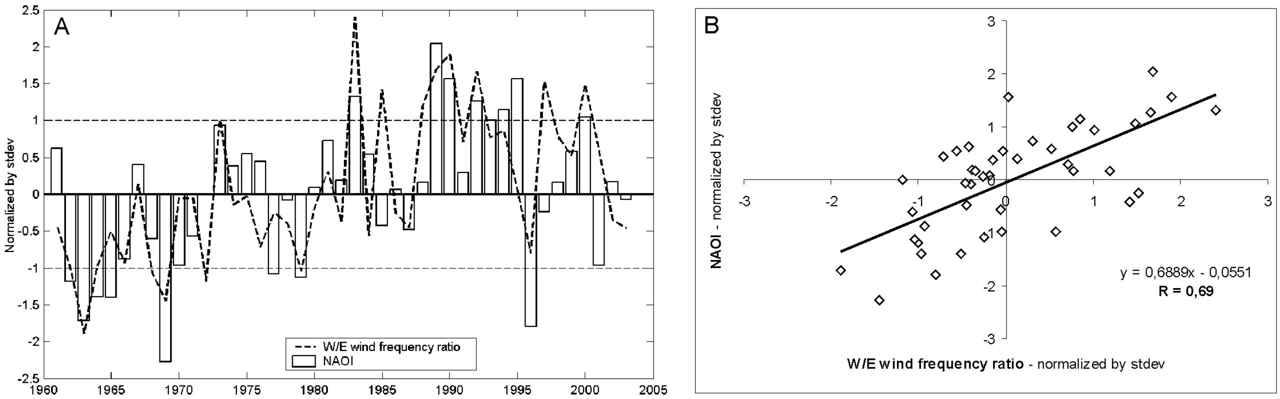

Fig. 9 Time evolution of W/E wind frequency ratio and NAOI (A) and correlation coefficients between NAOI and western circulation (B) over the Romanian territory

The correlation pattern for W/E wind frequency indicates a strong positive dependent NAO signal in extra-Carpathian areas (especially in south and south-east). The arch configuration of the Carpathians standing against large scale circulation determines small correlation coefficients in the center and eastern part of Romania and very small correlation values in intra–mountain and sub-mountain areas.

Conclusion

It is widely accepted that NAO controls the overall distribution of temperatures and precipitations in Europe (van Loon and Rogers, 1978; Hurell and van Loon, 1997; Bojariu and Paliu, 2001; Râmbu et al., 2002; Zaharia et al., 2002); our results indicate that the wind regime over the Romanian territory is also strongly related to NAO phases (Fig.4, Fig.5).

Over the Romanian territory, the position of the Carpathians mountains induces a high variability for the spatial distribution of the eolian parameters characteristics and influences the local response to the NAO variability. Thus, the extra (intra-) Carpathian regions are characterized by high (medium to low) correlation coefficients between the NAO index and wind anomalies.

The correlation coefficients point out that positive wind speed and storm occurrence anomalies are associated with negative NAO phases (negative statistical correlation), while positive W/E wind frequency variability is correlated with positive NAO phases (positive statistical dependency).

The positive (negative) NAO associated with low (high) cyclogenesis over the Mediterranean area induce low (high) winds over the Romanian territory due to diminished (enhanced) frequency of cyclones reaching Romanian regions.

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