

NORTH-ATLANTIC OSCILLATION SIGNATURE ON COASTAL DYNAMICS AND CLIMATE VARIABILITY OF THE ROMANIAN BLACK SEA COAST

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Abstract: A comprehensive analysis of data collected over the last five decades on the Romanian Black Sea coast (meteo & hydrological data, sea level, topographic maps, satellite imagery, GPS surveys and beach profiles) demonstrate that the North-Atlantic Oscillation (NAO) exerts a multi-decadal influence on the Romanian Black Sea coastal environment components. Accordingly, temperature positive anomalies are directly correlated to NAO positive phases, while precipitation, Danube discharge (including floods occurrence) and wind regime variability is inversely controlled by NAO fluctuations (out-of-phase report). Moreover, the present study reveals that coastal morphodynamics appears to be influenced by NAO via coastal storm regime. The analysis of Danube delta coast evolution revealed two time intervals with different coastal dynamics patterns: i) high shoreline mobility during 1961-1979 interval with high retreating and advancing rates, and ii) low shoreline mobility afterwards (1979-2006). The most aggressive erosion affects the sedimentary divergence zones which experienced the highest rates of coastal retreat for all 45-years study period (~20 m/yr / ~10 m/yr during 1961-1979 / 1979-2006 time interval), whereas the shoreline advanced fastest along the coast of active lobes (i.e., Chilia and Sf. Gheorghe lobes). During the second interval (1979-2006), the decrease of shoreline changes rates, reported to first period (1961-1979), was similar for the erosive beaches (with 55-66%) but non-uniform for the accretionary coasts (20-61% for open beaches and 80% for the sheltered secondary deltas). Wind data analysis reveals a good connection between multi-decadal winter storm frequency along the Danube delta coast and negative NAO phases ($r = -0.76$). The results of the present study clearly show that shoreline changes at decadal time scales are also ultimately driven by the NAO which controls the storminess on the Danube delta coast.

Key-words: NAO index, shoreline change, storminess, longshore sediment transport, climate variability, wind regime, sea level

1. INTRODUCTION

The North-Atlantic Oscillation (NAO) is one of the phenomena with significant influences on climatic fluctuations in the northern hemisphere, from the eastern coast of the United States to Siberia and from the arctic to the subtropical zone of the Atlantic. This phenomenon is intense during boreal winter (when the atmosphere reaches its maximum dynamics), while in summer NAO signal is almost absent. Considering its high impact on the northern hemisphere climate, NAO becomes a very important factor for environmental changes and human societies (Hurrell et al., 2001).

The phenomenon defines as an anomaly in sea-level atmospheric pressure distribution, with respect to the two baro-centres: the Icelandic Depression and the Azores Anticyclone (Van Loon & Rogers, 1978). The North-Atlantic Oscillation Index (NAOI) is conventionally computed basing on the difference between the standardized anomalies of sea level atmospheric pressure measured in Lisbon, Portugal and Stykkisholmur, Iceland (Hurrell, 1995).

The bipolar (anticyclone/cyclone) repartition of the atmospheric pressure above the North Atlantic leads to the formation of stratospheric high-speed east-west oriented air currents (jet streams). This currents cross over a major part of the European continent exerting their influence on the westerly winds that

carry the warm and wet air from above the Atlantic to the continent, and form a "barrier" between the warm (southern) and the polar (northern) air (Bojariu, 2002). When the course of the jet streams is northward deviated (in accordance with the positive phase of the North-Atlantic Oscillation, respectively with positive NAOI), the westerly winds intensify, transporting the oceanic warm and wet air to the continent. This induces mild and dry winters in the Central and Southern Europe while precipitations are restricted to the northern side of the continent (Hurrell, 1995; Hurrell & van Loon, 1997; Râmbu et al., 2002). During the negative phase of the North-Atlantic Oscillation, the jet streams are redirected to the south of the continent diminishing the strength of the westerly winds. This results in severe winters, with low temperatures and heavy precipitation in the south of the continent, especially in the Mediterranean Basin and the Iberian Peninsula (Bojariu, 2002).

The existing researches showed that the general air circulation changes associated with NAO variations (positive and negative phases) reflect in high amplitude modifications in temperatures, precipitation, heat fluxes and wind speed distribution within the North-Atlantic region (Kushnir, 1994; Hurrell, 1995).

In Romania, temperatures are directly correlated with the NAO index (positive temperature anomalies are associated with the positive NAO phases), whereas precipitation show a reverse correlation with the negative NAO phases (Bojariu & Paliu, 2001; Zaharia et al., 2002). The study of NAO influence on the temperature and precipitation regimes in Romania revealed that the winter NAO signal is stronger in the extra-carpathian areas, cause of the "orographic barrier" function of the Carpathian Mountains (Ion-Bordei, 1988; Bojariu & Paliu, 2001).

Due to the geographical setting, the relief and complex sea-land-atmosphere interactions, the coastal area shows a range of climatic particularities: high temperatures (11-11.3 °C), the lowest amounts of precipitation (360-400 mm/yr), elevated humidity values (>80%) and strong winds (mean multiannual speeds of 4.1 m/s at Mangalia and 6.8 m/s at Sulina) (Stoenescu, 1965; Bogdan, 1983; Mihăilescu et al., 1995). The Romanian Black Sea coast is affected by intense geomorphologic processes with a clear dominance of erosion that affects 55% of the deltaic coastline and 80% of the high shore, respectively (Vespremeanu-Stroe et al., 2007). The coastal processes occur with the highest intensity during winter, as a result of an increased coastal storm frequency and intensity, directly influenced by NAO (Vespremeanu-Stroe & Tătu, 2005). Consequent to

the longshore-induced currents, coastal storms are responsible for 61% of the longshore sediment transport (LST) and for 78.5% of the southwards directed LST (Vespremeanu-Stroe, 2004). Moreover, the fact that 85% of the storms originates in the north sector (from WNW to ENE) imposes an unidirectional development of many coastal processes with a clear southward orientation, such as LST, the aeolian sediment transport and sand wave migration (Giosan et al., 1999, 2004; Preoteasa & Vespremeanu-Stroe, 2004).

This work aims to investigate the correlations existing between NAO variations and the regime of the main components defining the geographical environment of the Romanian coastal area: temperature, precipitation, wind and storm distribution, Danube discharge and shoreline evolution. Our study focuses on the 1961-2006 interval, when NAO index had the most pronounced negative (1961-1972) and positive (1980-2002) phases registered in the existing 140-years data series of direct measurements (1865-2006). One of the main objectives is to prove and evaluate the impact of climatic variability (expressed by NAO) on the recent coastal dynamics at a multidecadal scale. As a supplementary argument, we consider the Danube delta coastline (Fig. 1) a very well suited/favourable location for studying this type of interrelations (climatic variability vs. relief dynamics), considering that it shows a stronger correlation between storm frequency and NAO index than the atlantic European coast (Lozano et al., 2004; Vespremeanu-Stroe & Tătu, 2005) and it presents a dry-temperate climate that restricts high coastal dune development and, thus, increases shoreline mobility.

2. METHODOLOGY

Basic datasets used in this study were monthly and annual means of air temperature, precipitation and wind speed and orientation frequency from the meteorological stations set on the Romanian Black Sea coast: Sulina, Sfântu Gheorghe, Constanța and Mangalia. For the analysis of coastal storms parameters, the events with wind speeds higher than 10 m/s and 16 m/s were selected using hourly wind data.

Considering that NAO signal is stronger during maritime winter which identifies with the December-March interval (Stoenescu, 1965; Vespremeanu-Stroe, 2004), the correlations were established based on the values of the December-March meteorological parameters. The entire climatic dataset covers the January 1961 - December 2006 period; for the NAO index, the values from NCEP database were used

(Hurrell, 1995). The analysis of Danube flow regime was based on the annual discharge values measured from 1921 to 2000 at Ceatal Izmail (representative for the lower Danube basin, cf. Râmbu et al., 2002). The same procedure was used in order to compute both the climatic and hydrologic data. First, the average values correspondent to the December-March interval were calculated and normalized by reducing each value with the mean of the analyzed interval and dividing it by the standard deviation. Second, the moving averages method with a three years period was applied to the annual normalized anomalies, to obtain a multiannual component of the data series. In the present study, we assumed that a storm was present when wind speed maintained at 10 m/s or more for at least 24 hours (cf. Vespremeanu, 1987).

The correlated analysis of NAO and the coastal relief dynamics was only performed for the deltaic and lagoon coast, due to the high mobility of low-lying coasts which allowed to identify the time intervals dominated by different coastal processes.

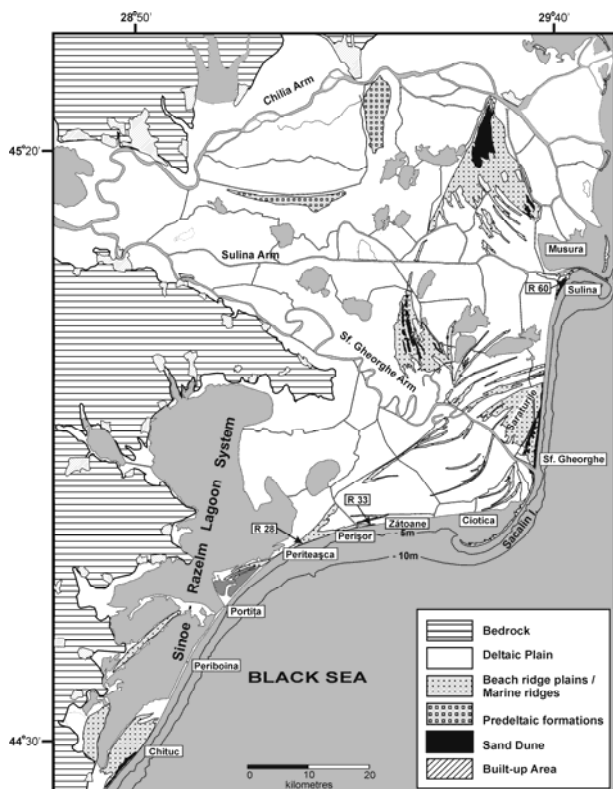


Figure 1. Position of coastal landmarks within the northern study area

Shoreline evolution for the last five decades was determined using topographic measurements set on the benchmark network from the deltaic shore (1962 – present), GPS shoreline measurements (2003-2006), topographic maps scaled 1:25000 (1961, 1979), Landsat (1989) and Aster (2006) satellite images. The 123 cross-shore profiles were executed at distances

between 0.5 and 2 km; on each profile, the shoreline evolution rates were calculated for the considered time intervals. The connection between NAO variations and the coastal environmental components is set by the correlation coefficients between NAO and the data series of the respective components.

3. RESULTS

3.1. NAO influence on the thermal and precipitation regime

On the Romanian territory a moderately positive correlation ($r = 0.25-0.55$) between winter thermal anomalies and the NAO index is detected (Bojariu and Paliu, 2001). The analysis made for the seaside meteorological stations also indicates a positive correlation, though expressed by lower correlation coefficients, ranging from 0.33 at Sulina and 0.28 at Mangalia.

Coastal precipitation distribution is indirectly connected to the NAO phenomenon. Thus, the negative NAO phases determine the increase of cyclone-genetic processes in the Mediterranean Sea Basin, and, consequently, of the frequency of Mediterranean cyclones with trans-Balkan trajectories crossing the western Black Sea basin which leads to precipitation sum superior to the local multiannual average. The correlation coefficients established between precipitation and NAO index suggest a poor correlation in the south sector of the Romanian coast (Mangalia: -0.28) and a moderate correlation in the central and north areas (Constanța -0.47; Sulina: -0.56).

3.2. NAO influence on Danube discharge regime and Black Sea level oscillations

Considering that fluvial discharge is dependent on the received precipitation quantity, there is an obvious connection between precipitation anomalies associated with the extreme NAO phases and the river discharge regimes in the Central and South-Eastern Europe (Râmbu et al., 2002). The correlated analysis of mean annual discharges at Ceatal Izmail and the NAO index during the 1921-2000 interval (Fig. 2) presents alternative periods of high – 6500-7000 m³/s (1921-1944, 1960-1980) and low – 5800-6000 m³/s (1945-1959, 1980-2000) discharges on the Danube. This evolution corresponds to the NAO index variations, supported by the correlation coefficient established between the two variables ($r = -0.41$). Thus, the absolute minimum NAO index value reached in 1969 (-4.89) is reflected by the 1970 extraordinary Danube

discharge values and the major floods on the medium and inferior course tributaries. The strongest positive NAO anomaly registered in the 1979-1995 period, corresponding to the lowest multiannual Danube discharge values from the specified time interval (Fig. 2). This negative correlation demonstrates that the variability of Danube discharge is in offset to the NAO phenomenon.

The analysis of the monthly Black Sea level at Constanța station (Fig. 3) between 1933 and 2000, highlights the unimodal sea level oscillations regime with the maximum values in May-June and the minimum in October-November. The monthly and seasonal sea level oscillations directly correlate with the hydrological regime of the main tributaries as well as with the climatic regime of maritime provinces (Malciu & Diaconu, 2000). For the Romanian and the western Black Sea coast, Danube's hydrological regime is the most important sea level control factor at medium-term scale (Vespremeanu et al., 2004), as the Danube brings 60 % of the entire fluvial discharge into the Black Sea.

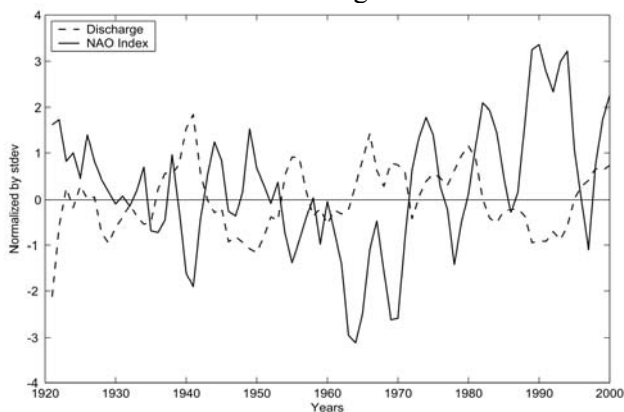


Figure 2. Danube discharge (Ceatal Izmail) and NAO index co-evolution

Regarding the inter-annual variability of the monthly Black Sea level, expressed through standard deviations, its high values are typical in the December-April interval which mostly overlays the winter season (December-March) and also corresponds to the interval with strong NAO signal (December-March). Nevertheless, the analysis of the Danube discharge variability reveals significant fluctuations in April-June, reflecting a weak direct correlation between the inter-annual ex-winter variability of the Black Sea level and Danube's discharge; this finding stands against the main role of the Danube in controlling all-year Black Sea's level evolution. Therefore, the other climatic factors (the offshore precipitation, the aeolian regime and the atmospheric pressure) existing in the north-west Black Sea province should be responsible for the sea

level inter-annual monthly variability regime.

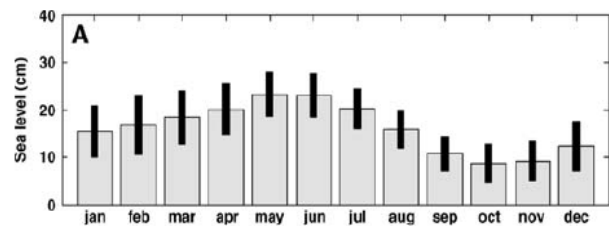


Figure 3. Monthly multiannual Black Sea level oscillations at Constanța (1933-2000). The grey columns represent the mean monthly level, while the black columns show the standard deviation.

Taking into consideration the strong correlation set between the December-March NAO index and the aeolian and precipitation regime on the Romanian Black Sea coast (Bojariu and Paliu, 2001; Vespremeanu-Stroe & Tătui, 2005), we assume that the high sea level variability during the December-April interval is indirectly influenced by NAO.

3.3. NAO control on the aeolian regime

Concerning the influence of NAO on the Romanian Black Sea coast wind regime, the positive wind speed anomalies connect to the NAO negative phases at all the coastal meteorological stations. The highest correlation coefficients are reported on the deltaic shore (Sulina: -0.61, Sfântu Gheorghe: -0.51), with a general decreasing trend towards south (Constanța: -0.42, Mangalia: -0.31).

The distribution of coastal storms during the last four decades of the XXth century highlights the discrepancy between a highly active interval with frequent storm events (1961-1971), correspondent with NAO negative phases (the average NAO index value was -0.83 and the absolute minimum reached -4.89 in 1969), and a relatively calm period of low variability (1979-1995), overlaying some intense NAO positive phases (mean NAO index of 1.32; see Fig. 4) (Vespremeanu-Stroe & Tătui, 2005). Consequently, a progressive decrease of storm intensity observed during the '70s and '80s; in the last years (2000-2006) of the analyzed time interval, when NAO oscillated around zero, the frequency of major storms remained low, but it significantly increased for the low and medium intensity storms.

The co-evolution of the NAO index and the number of strong wind situations (wind speed > 16 m/s for more than 6 hours) correlation coefficients brings forward the deltaic area as being characterized by a strong correlation (Sulina: -0.76, Sfântu Gheorghe: -0.77) oppositely of the southern coastal sector, with less-intense storms (Mangalia: 0.39).

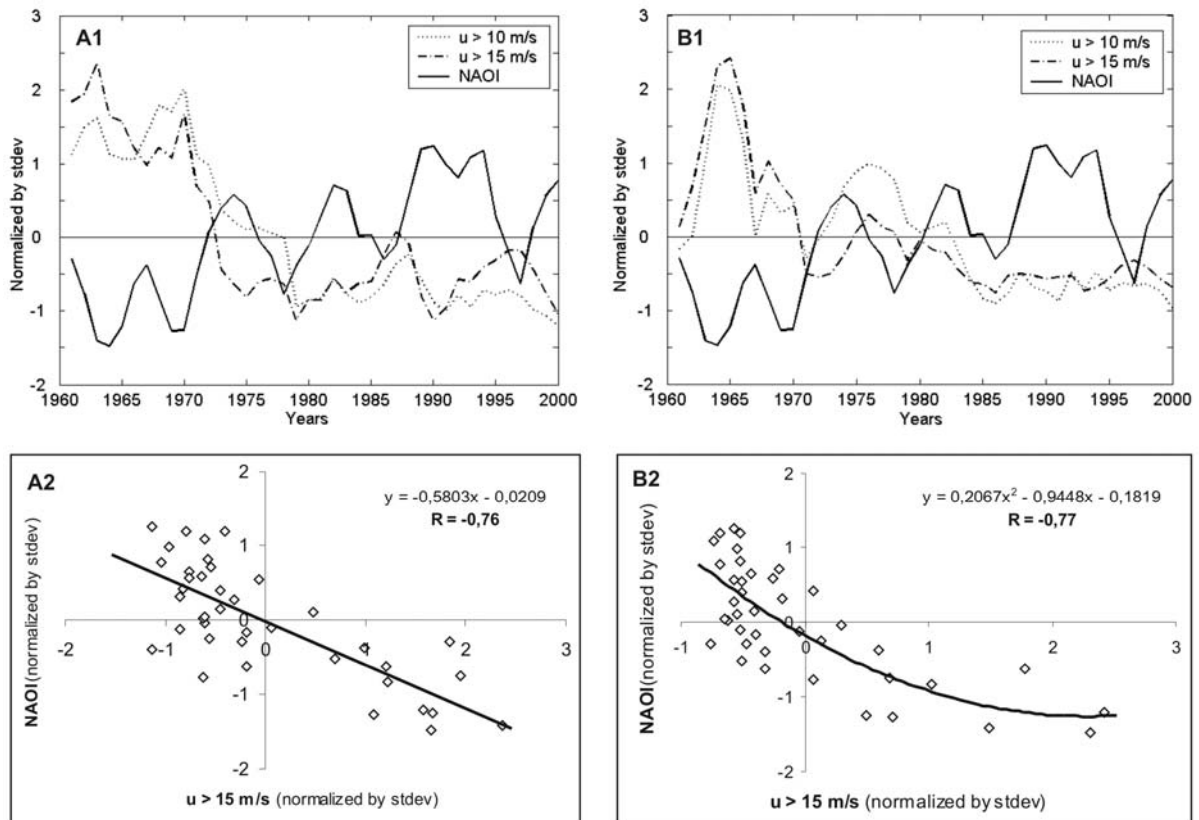


Figure 4. Storm frequency and NAO index co-evolution (1961-2000)

3.4. Danube Delta shoreline evolution and NAO index

Coastal storm frequency and intensity are directly connected with shoreline evolution. Thus, the '60s-'70s strong storm activity, overlapped on the prevailing negative NAO index values, explains the increased intensity of both erosional and accumulative coastal processes, expressed by high values of sedimentary transport that affected coastline configuration (Vespremeanu-Stroe, 2007).

In this purpose, topographic data from three benchmarks, within specific dynamics sectors representative for shoreline evolution, were compared: R 60 and R 28 benchmarks for accretional Sulina and Periteașca coastal sectors, and R 33 for Zătoane erosional sector, respectively.

The comparative analysis of shoreline evolution at the three benchmarks reflects a strong dynamic in the '60s-'70s (progradation at R 60 and R 28 and retreat at R 33 benchmarks) followed by a sudden change to a less dynamic behaviour of the three coastal sectors in the 1978-1985 interval (Fig. 5).

The modification of coastal relief dynamics occurs on the basis of the NAO signal change from mostly negative values during the '60-'70 to prevailing positive values in the '80s. Therefore,

shoreline evolution of both accretional and erosional sectors shows a negative correlation with NAO index.

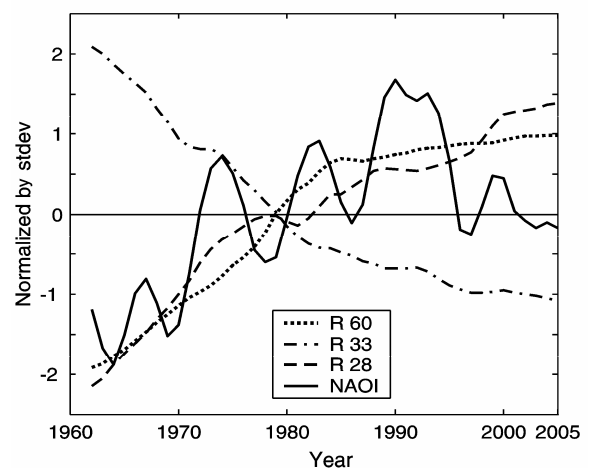


Figure 5. NAO index and shoreline dynamics at R 60, R 33 and R 28

On the interdistributary Sulina-Sfântu Gheorghe coast, erosion was highly active during the 1961-1979 period in the central-north area reaching a maximum value of -24 m/yr near km 11 (Fig. 6). Subsequently (1979-2006), the maximum erosion migrated southward along with the dominant longshore drift, registering a considerable decrease in intensity (greatest retreat rate: -10.1 m/yr at km 13; Fig. 6).

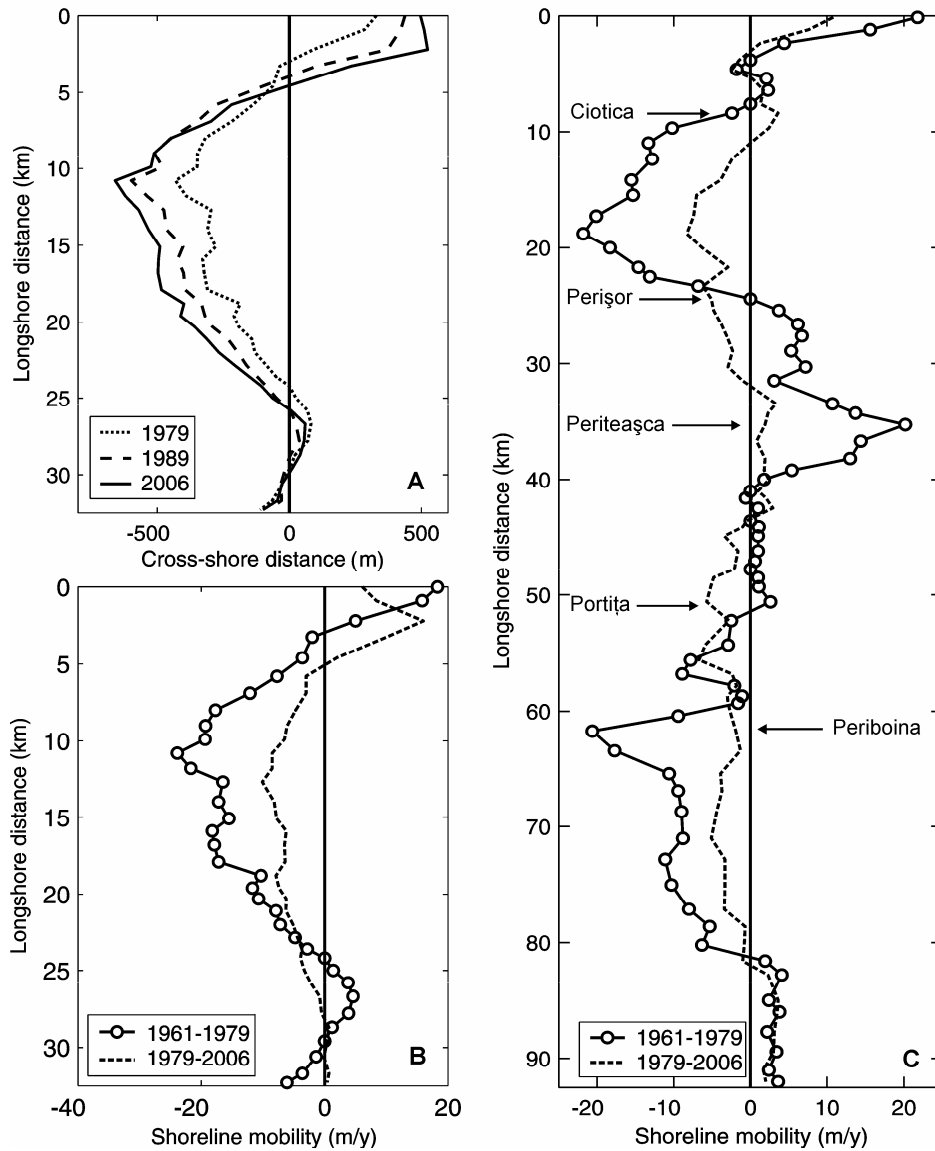


Figure 6. Shoreline evolution during the 1961-2006 interval (A, B: the interdistributary Sulina [0 km] – Sfântu Gheorghe [32 km] shore; C: Ciotica-Chituc shore, where the zero value indicates the southern arm mouth of Sfântu Gheorghe secondary delta (after Vespremeanu-Stroe et al., 2007)

Table 1. Average and maximum shoreline displacement rates for the erosional and accretional sectors of Danube delta coast (1961-2006)

Coastal sectors		Time interval	1961 – 1979		1979 - 2006	
		Mean value (m/y)	Max. value (m/y)	Mean value (m/y)	Max. value (m/y)	
Erosional sectors	E1 (Impușita – North Saraturile)	-14.0	-24.0	-6.3	-10.1	
	E2 (Sacalin I.)	-23	-37.2	-17.7	-26.9	
	E3 (Zatoane)	-14.7	-21.8	-4.9	-8.2	
	E4 (Portița – North Chituc)	-8.3	-20.5	-3.0	-6.7	
Accretional sectors	A1 (Musura – secondary delta)	52.8	91.6	10.4	15.6	
	A2 (Sulina)	12.4	15.8	8.1	10.8	
	A3 (Sf. Gheorghe –secondary delta)	16.9	21.8	3.7	6.6	
	A4 (Periteasca)	6.0	20.2	2.3	4.8	
	A5 (South Chituc)	2.8	4.1	2.3	3.5	

The average retreat rates of the Sulina-Sfântu Gheorghe coastline erosional sector show a significant decrease, with 55%, from -14 m/yr to -6.3 m/yr between the two time intervals (Table 1). On the Ciotica-Cape Midia shore, the average retreat rates decreased from -14.7 m/yr (1961-1979) to -4.9 m/yr (1979-2006) on Zătoane shoreline (66%) and from -8.3 m/yr to -3 m/yr on Portița shoreline (north of Chituc) - 64%. The accretional sectors progradation rates show several differences comparing to the relatively homogeneous behavior of the erosional sectors. On the marshy shores of Musura and Sfântu Gheorghe secondary deltas, protected by barrier-islands and/or extended near-horizontal submerges surfaces, the progradation rates reduced with about 80% between the two time-intervals (1961-1979 and after 1979). In contrast, on the open-coast accretional sectors the progradation rates lowered with 20% on the south Chituc, to 35% on Sulina beach and 61% on Periteașca beach.

Despite the magnitude difference of the coastal processes within the two time intervals, the extensive 1961-1979 erosion was clearly not characterized by an expansion of the erosional sectors along the shoreline. In opposite, a spatial development of these sectors, associated with lower retreat rates, occurred during 1979-2000 period.

3. DISCUSSIONS AND CONCLUSIONS

The results of this study demonstrate that the NAO phenomenon exerts a multi-decadal influence on the Romanian Black Sea coastal geographical environment components. Accordingly, temperature positive anomalies correlate to NAO positive phases, while precipitation, Danube discharge and eolian regime variability are inverse controlled by NAO fluctuations (offset report). Temperature positive/negative anomalies on the Romanian Black Sea coast associate with positive/negative NAO phases due to the local atmospheric circulation prevalence/restriction above Central and Northern Europe with effects upon the Mediterranean and Black Sea basins air masses circulation.

Precipitation variability, closely related to the high/low frequency of trans-Balkan directed cyclones crossing above the study area and to the strong/weak cyclone-genetic processes evolving above the Mediterranean Sea, show a reverse correlation with NAO. Reported to the country-scale values of NAO index and pluviometric anomalies correlation coefficients ($r = -0.15 \dots -0.55$, cf. Bojariu and Paliu, 2001), the highest values were obtained for the Romanian Black Sea coast and for the south-west of the country (Oltenia region).

NAO variability and hydrological data correlation analysis states the fact that river discharges record higher values than the multiannual average in Northern Europe and below average values in the Southern Europe, when NAO index is positive (Shorthouse & Arnell, 1997; Dettinger & Diaz, 2000). The negative correlation of the Danube discharge regime registered at river mouths and NAO variability determined in this study sustains these statements.

Storm frequency and intensity on the Romanian Black Sea coast are widely controlled by NAO variability. Storm activity is dependent on local climatic variability and decisively influences the dynamics and evolution of coastal landscapes. The present study clearly indicates the multidecadal NAO control on the coastal processes intensity via coastal storms: NAO phases dictate the frequency and intensity of the coastal storms that further influence the magnitude and rhythm of erosional and accretional coastal processes.

The erosional coastal sectors had a relatively homogeneous behaviour regarding the decrease of shoreline retreat rates (50-70%) when comparing the two main periods of different NAO phases (the active interval: 1961-1979 and the moderate interval: 1979-2000). The accumulative coastal sectors displayed the same decrease of accretion rates (20-80%) between the two time intervals (Vespremeanu-Stroe et al., 2007). The intensification of erosion processes connected to stormy active periods must be analyzed in close connection to the increase of the accretional processes intensity, as these processes develop simultaneously and compensate each other within the same littoral cells. Thus, the coastal sectors with intense erosion do not necessarily extend their surface during stormy periods due to the sediment volume conservation within the coastal system, which only affects the speed of shoreline retreat.

For all the investigated physical components of the geographical environment (coastal relief, Danube discharge, temperatures and precipitation, aeolian climate) it was noticed a clear northward increase of the correlation between them and NAO variability, from moderate on the southern Romanian coast to strong on the deltaic coast.

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REFERENCES

- Bogdan, O.**, 1983. *Climatic and topoclimatic regions*, in Geografia României: Geografie fizică, I, Ed. Academiei Române, 277-284 (in Romanian).
- Bojariu, R. & Paliu, D.M.**, 2001. *North Atlantic Oscillation projection on Romanian climate fluctuations in the cold season.*, in Brunet and Lopez (Eds.), *Detecting and Modelling Regional Climate Change and Associated Impacts*, Springer, 345-356.
- Bojariu, R.**, 2002. *North Atlantic Oscillation*. AdAstra, 1(2), 1-4.
- Dettinger, M. D. & Diaz, H. F.**, 2000. *Global characteristics of stream flow seasonality and variability*. Journal of Hydrometeorology, 1, 289–310.
- Giosan, L., Bokuniewicz, H., Panin, N. & Postolache, I.**, 1999. *Longshore sediment transport pattern along the Romanian Danube Delta coast*. Journal of Coastal Research, 15(4), 859-871.
- Giosan, L., Donnelly, J.P., Vespremeanu, E., Bhattacharya, J. & Buonaiuto, F.S.**, 2005. *River delta morphodynamics: Examples from the Danube delta.*, in Giosan L. and Bhattacharya J.P. (Eds.), *River Deltas: Concepts, Models and Examples*, SEPM Special Publication, 83, 87-132.
- Hurrell, J.W.**, 1995. *Decadal trends in the North Atlantic Oscillation: regional temperature and precipitation*. Science, 269, 676-679.
- Hurrell, J.W. & van Loon, H.**, 1997. *Decadal variations in climate associated with the North Atlantic oscillation*. Climatic change, 36, 301-306.
- Hurrell, J. W., Kushnir, Y. & Visbeck, M.**, 2001. *The North Atlantic Oscillation*. Science, 291, 5504, 603-605.
- Ion-Bordei, N.**, 1988. *Meteoclimatic phenomena induced by the Carpathian configuration in the Romanian Plain*. Ed. Academiei, 174 p (in Romanian).
- Kushnir, Y.**, 1994. *Interdecadal variations in the North Atlantic sea surface temperature and associated atmospheric conditions*. Journal of Climate, 7, 141-157.
- Lozano, J., Devoy D. J. N., May, W. & Andersen, U.**, 2004. *Storminess and vulnerability along the Atlantic coastline of Europe: analysis of storm records and of a greenhouse gases induced climate scenario*. Marine Geology, 210, 205-225.
- Malciu V. & Diaconu V.**, 2000, *Long-term trend of sea level at the Romanian littoral*. IOC Workshop Report, 171(III), 21–27.
- Mihăilescu, I. F., Bucșă, I. & Costea, D.**, 1995. *Contributions to the knowledge of the Black Sea influence on the temperature regime from Dobrogea*, (in Romanian). Analele Universității Al. Ioan Cuza din Iași, 4, 15-21.
- Preoteasa, L. & Vespremeanu-Stroe, A.**, 2004. *The analysis of aeolian transport potential in Danube delta*. Studii și cercetări de oceanografie costieră, 1, 47-67 (in Romanian).
- Râmbu, N., Boroneanț, C., Buță, C. & Dima, M.**, 2002. *Decadal variability of the Danube river flow in the lower basin and its relations with the North Atlantic oscillation*. International Journal of Climatology, 22, 1169-1179.
- Shorthouse C. & Arnell N.W.**, 1999. *The effects of climatic variability on spatial characteristics of European river flows*. Physics and Chemistry of the Earth Part B — Hydrology Oceans and Atmosphere, 24(1–2), 7–13.
- Stoenescu S. M.**, 1965. *Wind regime on the Romanian Black Sea shore*. Studii de hidraulică, IX, 1, 17-40 (in Romanian).
- van Loon, H. & Rogers, J.C.**, 1978. *The seesaw in winter temperatures between Greenland and northern Europe: Part I. General description*. Mon. Weather Rev., 106, 296 – 310.
- Vespremeanu, E.**, 1987. *Problems of marine geomorphology*. Editura Universității din București, 117p (in Romanian).
- Vespremeanu, E., Vespremeanu-Stroe, A. & Constantinescu, Ș.**, 2004. *The Black Sea level oscillations in the last 150 years*. Analele Universitatii Bucuresti - seria Geografie, LIII, 69-76.
- Vespremeanu-Stroe, A.**, 2004. *Longshore sediment transport and wave regime on Danube delta coast*. Studii și cercetări de oceanografie costieră, 1, 67-83 (in Romanian).
- Vespremeanu-Stroe, A. & Tătui, F.**, 2005, *The influence of North Atlantic Oscillation on Romanian Black Sea coast wind regime*. Analele Universității Bucuresti – seria Geografie, LIV, 17-26.
- Vespremeanu-Stroe, A., Constantinescu, Ș., Tătui, F. & Giosan, L.**, 2007. *Multi-decadal evolution and North Atlantic Oscillation influences on the dynamics of the Danube delta shoreline*. Journal of Coastal Research, ICS2007 (Proceedings), Australia, SI 50, 157-162.
- Vespremeanu-Stroe, A.**, 2007. *Danube delta shore – geomorphological study*. Editura Universitară, 226p (in Romanian).
- Zaharia, L., Beltrando, G., Bigot, S., Oszwald, J. & Petrache, R.**, 2002. *Pluviometrie extreme en periode chaude dans le bassin-versant de la Putna (Roumanie) et circulation atmosferique sur l'Europe Centrale*. Publications de l'Association Internationale de Climatologie, 14, 236-242.

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