www.trjfas.org
ISSN 1303-2712
Turkish Journal of Fisheries and Aquatic Sciences 14: 973-979 (2014) DOI: 10.4194/1303-2712-v14_4_17

Occurrence of Extreme Winds over the Black Sea During January Under Present and Near Future Climate

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Received 12 May 2014
Accepted 22 October 2014

Abstract

In the present study, the occurrence frequency of extreme wind speed over the Black Sea surface is analysed, aiming to assess the differences between simulated and observed characteristics under present climate (2001-2009) and to investigate the near term projected changes (2011-2040 vs. 1961-2000) of this indicator in the context of A1B scenario. We use observational data provided by measurements at meteorological stations on Romanian coast and satellite QuickScat data, as well as modelled data from numerical experiments with a high resolution regional climate model, taken from the results of the EU project ENSEMBLES. Previous climatological analysis has indicated that January is prone to extreme wind episodes, so we have focused our investigation on this month. The analysis performed for the entire Black Sea basin, as well as for two costal sites, highlights Western and Northern areas which have a significant incidence of moderate and strong wind episodes under present climate (2001-2009). In the period 2011-2040, under A1B climate change scenario, the decrease in the frequency of moderate and high wind episodes takes place over almost entire basin, except for some Southern areas of the Black Sea.

Keywords: Surface wind speed, extreme thresholds, regional climate change.

Introduction

The socio-economic role of Black Sea for the bordering countries leads to a continuously increasing interest in scientific studies over this area, with a special focus on weather-related events having high negative impact on human activities. The Black Sea basin is an area prone to the occurrence of severe weather episodes (Efimov *et al.*, 2009) due to cyclones which either develop here (Trigo *et al.*, 1999) or just cross the region. One example is the intense storm in the Strait of Kerch on 11 November 2007, when four oil tanks sank and at least 4 sailors died (http://www.cedre.fr/en/spill/kerch_strait/kerch_strait.php). The extreme weather events may have different dominant manifestations (e.g. damaging lightning strokes; heavy rain, snow accumulation etc.), but they all involve some common basic ingredients like high wind and increased atmospheric humidity shaped by the local and regional characteristics. A significant contribution to better forecast of such phenomena comes from improved knowledge on regional characteristics of key atmospheric variables synergistically analyzed from all available data sources.

In this paper we focus the analysis on one atmospheric variable closely linked with severe weather events, namely surface wind speed. Weather episodes associated with high wind speeds have a strong impact on marine and coastal environment, safety and regional economic infrastructure, as they are often associated with floods due to storm surges, infrastructure damage and even loss of human lives. Black Sea neighboring countries rely to some extent on economic activities in coastal and off-shore areas– tourism, fishery, oil extraction, maritime transport– which are all sensitive to the effects of such events. Therefore, the study focuses on identifying areas in the Black Sea basin most exposed to the incidence of high winds.

We employ data from several sources, based on both observations and numerical modelling, in order to assess the frequency of occurrence of extreme (high) values of this parameter over the Black Sea basin. The observation-based data is usually fragmented in space and time due to e.g. fixed and limited amount of locations of meteorological stations (mostly in coastal areas), sparse information on open-sea area from ships of opportunity, low spatial resolution of reanalysis, limited spatial and/or

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in cooperation with Japan International Cooperation Agency (JICA), Japan

temporal sampling (daily or coarser) of satellite-based products. Regional climate models may fill the observational gaps and project into the future the local climate, provided the inherent limitations and uncertainties are taken into account (e.g. coarse spatial resolution for capturing storms features). Finer-scale effects–like land influence on wind stress patterns along coasts (Staneva and Stanev, 1998) - may still not be properly dealt with, either by models or satellite-based data, for example due to coarse resolution or parameterization choices. However, by making use of both types of data available, a consistent description of Black Sea basin with regard to the incidence of high values of wind speed -a key parameter in severe weather episodes- may be assembled. The analysis firstly addresses the present climate, described through observation-based data for the period 2001-2009 or by outputs of long-term (1961-2000) numerical climate simulations. In the context of climate change, some expected modifications in the frequency of such situations are also investigated on near term projection (2011-2040) under A1B scenario (a moderate one from the standpoint of future emissions).

Materials and Methods

The first set of observational data of surface wind speed is provided by hourly measurements at 2 Romanian meteorological stations, for the period 2001-2009. One of the stations (Sulina-WMO #15360) is located on the coast, while the second station (Gloria-WMO #15477) is located about 80 km offshore the Romanian coast, on an oil platform. Satellite-derived product of daily surface wind speed, based on QuickScat observations, is also used as observational data for characterizing the entire Black Sea basin, for the same period. QuickSCAT (Quick Scatterometer) was launched in June 1999 and operated until November 2009. The main instrument onboard QuickScat was a radar operating at 2cm wavelength (Ku-band radar). QuickScat provided measurements of the wind speed and direction referenced to 10 meters above the sea surface at a spatial resolution of 0.25°. The overall quality of QuickSCAT retrievals depends highly on the presence of land, ice and precipitation as well as the orbital characteristics (e.g. Tang *et al*., 2004). Daily mean gridded data, with a spatial sampling of 0.25° and with high-quality as indicated by quality flags within the product, was used in the study. We additionally used daily data from reanalysis ERA-INTERIM at 0.75° x 0.75° de horizontal resolution (Dee *et al.*, 2011) from 1st of January 2001 to 31th of December 2009. Daily results from a downscaling experiment of ERA-40 using the CLM model (Bohm *et al.*, 2006) developed by DWD (Deutscher Wetterdienst), Germany were also investigated. The model was employed within ENSEMBLES project by ETHZ (Eidgenössische Technische Hochschule Zürich) center, therefore the model will be denoted as ETHZ-CLM throughout the study, following the convention from ENSEMBLES reports. The model is the climate version of non-hydrostatic limited area model LM for numerical weather prediction, which is used on operational basis in Romania for short-term weather forecast. The spatial resolution of ETHZ-CLM is 0.25° in latitude and longitude. The simulation domain of ETHZ-CLM covers the entire Black Sea basin in the control simulations–performed for period 1961-2000, with driving fields provided by ERA40 reanalysis (Uppala *et al.*, 2005).

Changes in the occurrence of moderate and high values of wind speed in the context of global climate change were investigated using high-resolution regional climate simulations performed with the ETHZ-CLM within ENSEMBLE project (Hewitt and Griggs, 2004; van der Linden and Mitchell, 2009). The ENSEMBLES climate projections were carried out under the assumptions of the Special Report on Emission Scenario (SRES) A1B scenario (IPCC 2000). For the projection of A1B SRES scenario as well as for the control run, ETHZ-CLM model was driven by a global run of HadCM3 model (Collins *et al.*, 2006), but in this case the regional domain does not include the South Eastern part of Black Sea. A similar situation with regard to (limited) simulation domain is valid for all regional models employed in ENSEMBLES project. Results of numerical simulations for the periods 1961-2000 and 2011-2040 were used in the study to assess the modelled characteristics against observational data as well as to investigate the modifications of analyzed indicator in the context of SRES A1B scenario.

Observational data and numerical simulations were analyzed with respect to the frequency of occurrence (FqO) of high values of 10m-wind speed values at seasonal scales, for the available common period (2001-2009). Near term - projected changes of this indicator under the A1B scenario for the interval 2011-2040 were assessed by comparison with model climatology for the period 1961-2000.

Results

All relevant studies so far (e.g. Bondar, 1973; Staneva and Stanev, 1998; Chronis *et al.*, 2010) have shown that Northern sub-basin is characterized by highest mean of seasonal values (7-8 m/sn in winter) while these decrease to 3-4 m/sn in the Eastern part. In particular, for the Romanian coasts, January presents the largest number of days with windy events (GLOBE project, 2011). This is why our analysis is concentrated on one month of winter season–January- and uses observational data from North Western coast as well as satellite data covering the entire basin.

Main wind characteristic used in the literature to describe stormy situations is the wind speed at 10 m high. In meteorological practice, for situations in which 10m wind speeds are larger than 10 m/sn, meteorological warnings are issued. This value also agrees with studies on Black Sea storminess (e.g. Valchev *et al.*, 2012) which has indicated it as a first threshold value for characterizing strong winds episodes. Other values for this threshold are found in literature: 12 m/sn (Chiotoriu, 1999, 2009), 15 m/sn (Belberov *et al.*, 1992), 20 m/sn (Chronis *et al.*, 2010). WMO (http://library.wmo.int/pmb_ged/wmo_558_en-v1.pdf) recommends that marine weather warnings shall be issued starting with gale conditions (wind speed over 17 m/sn), while for near-gale conditions (wind speeds larger than 13.8 m/sn) the issue of warning is optional. For this study we have used the values of 10 and 13.8 m/sn as thresholds indicating conditions for development of strong wind episodes.

Figure 1 presents the frequency of occurrence (FqO) for the two threshold values at locations of selected meteorological stations – Sulina and Gloria – for January 2001-2009. At these stations, we computed FqO from 3-hr data (values measured at every 3 hrs) and from daily mean values. The finer temporal sampling indicates higher incidence of strong winds, as expected, especially in cases when measurements correspond to situations with sustained high speed winds. However, the other observational-based datasets–QuickScat, ERA-INTERIM and ERA-40 downscaled results - provide coarser time sampling therefore the rest of the analysis uses daily mean values for computing FqO. Measured data shows for Sulina that FqO is around 15% for 10 m/sn threshold and 4.8% for 13.8 m/sn. For Gloria, the FqO values are much higher (35% and 11%, respectively); this may be due to the off-shore location of Gloria station, on a drilling platform, such that measurements at 10m above the surface (beneath the instrument) in fact translates into 42 m above the sea-surface. Even if in this case the wind speed data is not totally comparable with that from other datasets, it may still give a practical look on the incidence of strong wind cases as felt at the height of the platform. QuickScat data indicates larger FqO values at Sulina – which is on the coast, thus presence of land may affect the accuracy of satellite product. For Gloria instead, QuickScat shows a lower probability of occurrence of both thresholds; in this case, the differences are probably due to the different heights where wind speed is measured (at weather station) or estimated (from satellite product). The third dataset used here – ERA-INTERIM reanalysis – shows the lowest values of FqO for both stations and thresholds, but more pronounced for the threshold of 13.8 m/sn (e.g. no incidence of high winds for Sulina). This may suggest a limitation of the global reanalysis dataset in reproducing high wind speed values, since the stations locations are quite close (8.5 km and 18 km) to the reanalysis grid point providing data for computing FqO. The limitation of global reanalysis to deal with extreme winds over the Black Sea is tested against ERA-40 downscaled results obtained with the regional climate model (ETHZ-CLM). In this case, FqQs for both thresholds values of wind speed are larger than ERA-INTERIM FAQ at the weather stations, so ERA-INTERIM data is not further used in the basin-scale analysis.

Frequency of occurrence of daily mean wind speed values larger than 10 m/sn for January over the entire basin is shown in Figure 2. Satellite-based data (Figure 2a) indicates the largest values - between 27-35% - in the Northern sub-basin and a small off-shore area in the South Western part of the Black Sea; next region with high incidence is the Western sub-basin, where FqO has values between 21-25%, while the South Eastern part is characterized by lowest FqO values (3-9%). A similar spatial pattern is found in the ERA-40 downscaled results obtained with the simulations of ETHZ-CLM for the period 1961-2000 (Fig. 2b) even though the incidence of winds stronger than 10 m/sn is lower near the coasts and it is very low (0-3%) in the SE open-sea region, compared to QuickScat data. The historical climatology of ETHZ-

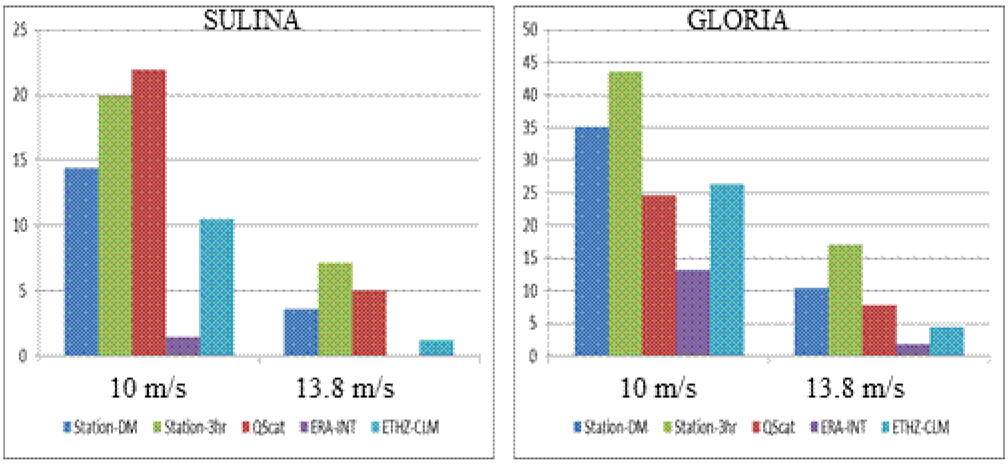

Figure 1. Frequency of occurrence of wind speed threshold values of 10m/s and 13.8 m/sn at stations Sulina and Gloria, based on several datasets for January 2001-2009.

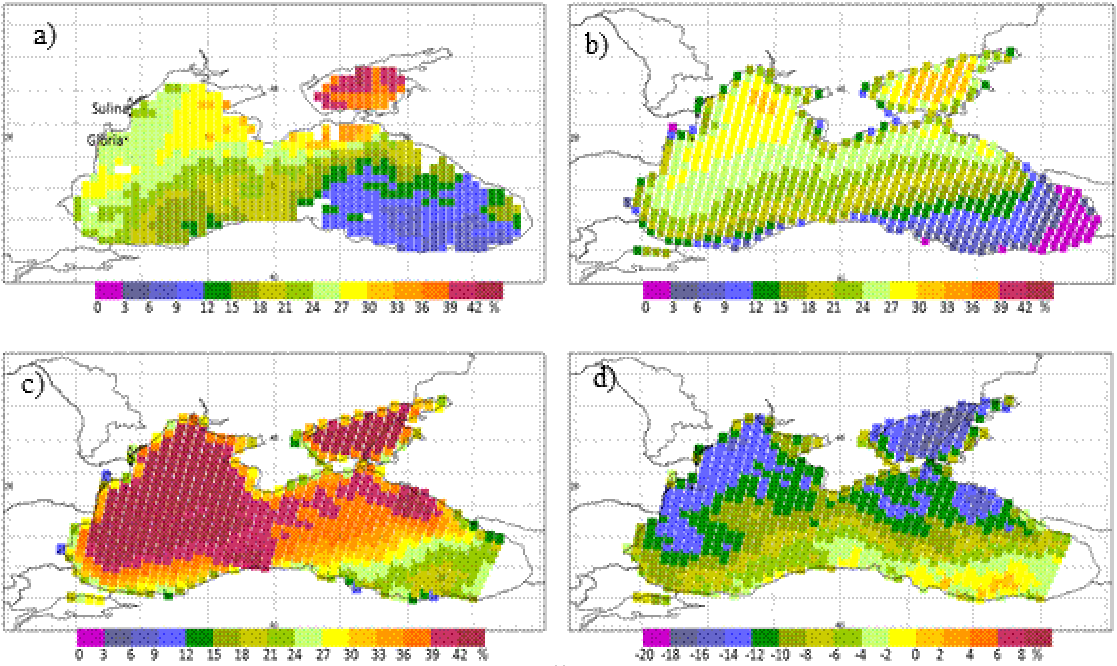

Figure 2. Frequency of occurrence of wind speed threshold value of 10m/s during January, based on a) QuickScat data (2001-2009); b) downscaled reanalysis (ETHZ-CLM driven by ERA40) (1961-2000); c) control simulation for A1B scenario (ETHZ-CLM driven by HadCM3) for period 1961-2000; d) difference between ETHZ-CLM simulated climate change scenario A1B (2011-2040) and control simulation (A1B 1961-2000).

CLM for the period 1961-2000 (Figure 2c) overestimates the frequencies of wind episodes for 10 m/sn threshold, but the basic spatial features resemble those present in the satellite-derived and ERA-40 downscaled patterns (Figure 2b). Differences between simulations of A1B scenario and model climatology (control simulation) show a significant decrease of 10 m/sn FqO over the Northern and Western regions, with a maximum reduction over the Azov Sea (up to 18%). A slight increase (0-2%) in the incidence of moderate winds is found for areas of the Southern basin.

The incidences of strong winds (wind speed values above 13.8 m/sn) based on satellite data, ERA-40 downscaling with ETHZ-CLM and ETHZ-CLM simulations are presented in Figure 3. QuickScat data shows largest FqO (8-10%) on the Western area, in agreement with other studies (e.g. Chiotoroiu and Ciuchea, 2009; Polonsky *et al.*, 2012) indicating this region as characterized by high incidence of storms over the Black Sea basin. Eastern half of the basin instead presents a very low (0-4%) probability for strong wind conditions. The spatial pattern of FqO as found in the regionally downscaled reanalysis for period 1961-2000 (Figure 3b) is in good agreement with the reference data (QuickScat), while small differences (up to 2%) in the values of this indicator are found again mainly near coastal areas. Again, the historical climatology of ETHZ-CLM for the period 1961-2000 (Figure 3c) overestimates the frequencies of wind episodes for 13.8 m/sec. threshold, but the basic spatial features resemble those present in the satellite-derived and ERA-40 downscaled patterns (Figure 3b). The projected changes of FqQs of strong winds under the A1B scenario have a similar pattern as for the threshold of 10 m/sn, suggesting a decreased incidence of strong winds (up to 10%) on a limited area in the Azov Sea and an increase (up to 4%) in the Southern Black Sea.

Even if the projected decrease in the FqOs of moderate and strong wind episodes covers a large part of the Black Sea, one can not rule out an increased probability of more intense storms over there, if other favorable atmospheric conditions–like high air moisture, instability-are met. The evolution of atmospheric moisture as simulated by the same regional model (ETHZ-CLM) under A1B scenario (Figure 4) suggests a relative increase of columnar water vapor over the entire basin in the interval 2011-2040 compared with the long-term model climatology (1961-2000). This increase is more significant in the North Western part (up to 12%) and it is in the order of 7% in the Southern area which also shows more projected episodes of moderate and strong winds in the interval 2011-2040. Such combinations could imply changes in the statistics of severe weather events over the Black Sea in the following decades.

Discussion

The study investigates the incidence of cases characterized by moderate and strong winds over the Black Sea basin in January, using measurements at two Romanian coastal stations, satellite-based

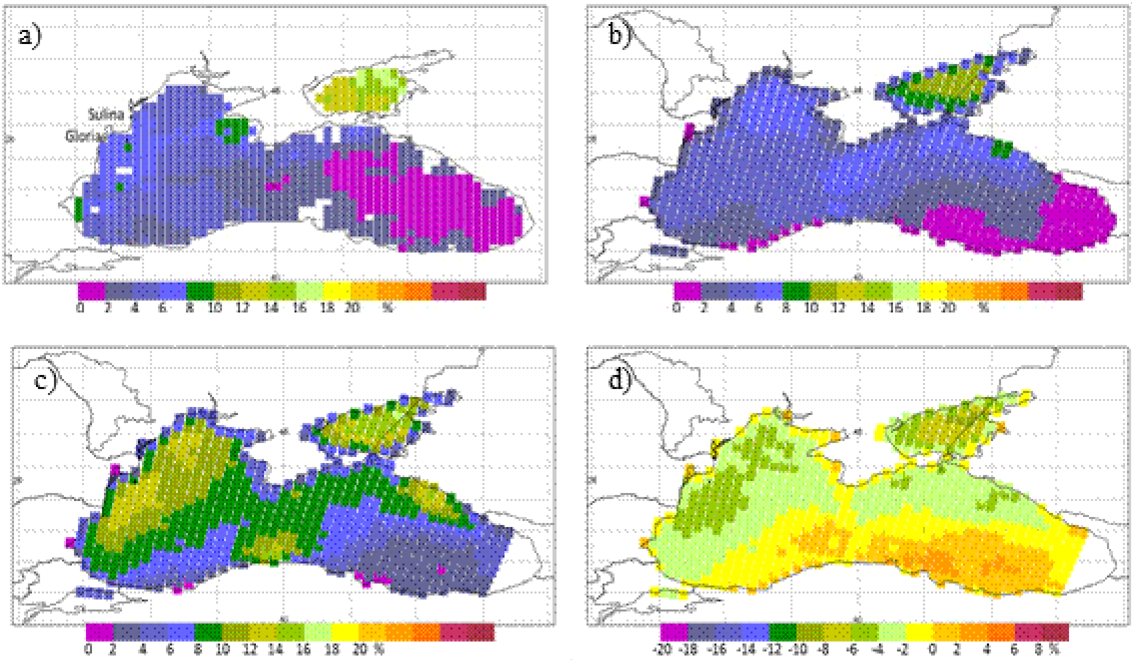

Figure 3. Frequency of occurrence of wind speed threshold value of 14m/s during January, based on a) QuickScat data (2001-2009); b) downscaled reanalysis (ETHZ-CLM driven by ERA40) (1961-2000); c) control simulation for A1B scenario (ETHZ-CLM driven by HadCM3) for period 1961-2000; d) difference between ETHZ-CLM simulated climate change scenario A1B (2011-2040) and control simulation (A1B 1961-2000).

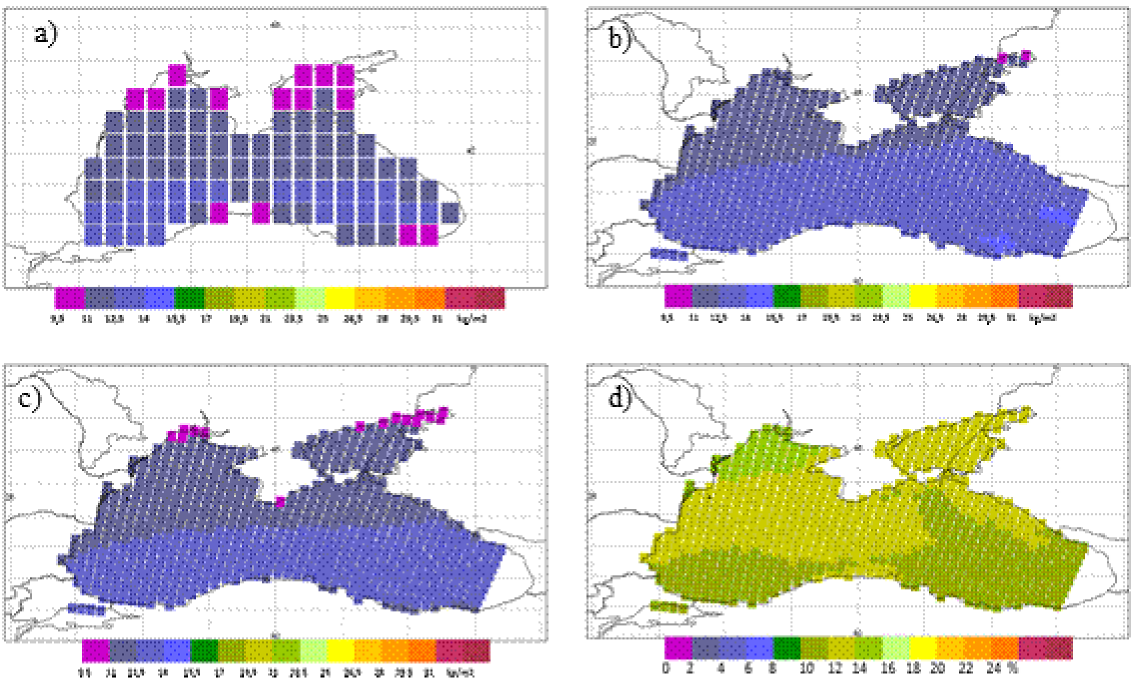

Figure 4. Seasonal (DJF) mean TPW from a) ERA-INTERIM (1979-2012); b) downscaled reanalysis (ETHZ-CLM driven by ERA40) for period 1961-2000; c) A1B control simulation (ETHZ-CLM +HadCM), 1961-2000 d) Relative change (%) between ETHZ-CLM simulated climate change scenario A1B (2011-2040) and control simulation (A1B 1961-2000).

products and model results. Each dataset presents some limitations, for example due to limited spatial or temporal resolution -in case of satellite data and ERA-INTERIM reanalysis dataset or due to parameterization choices for fine-scale processes -as is the case with climate models, or due to inherent, known limitations of the dataset/product (e.g. accuracy of QuikScat data being affected by rain). Yet, use of multiple data sources may attenuate the individual weaknesses and a well-grounded description of the parameter of interest may be assembled.

The analysis of satellite data shows that for the period 2001-2009, the Western and Northern areas present a large frequency of occurrence of wind speeds larger than 10 m/sec. (up to 21-35% of the total number of daily mean wind speed values), while the Eastern part is less affected (3-9%). A similar pattern applies for strong winds (wind speed daily mean values larger than 13.8 m/sec.), but with lower number of cases: up to 4-10% for Northern and Western regions and less than 4% for Eastern area. The present (1961-2000) climate simulations - the downscaling experiment and the control run- overestimate both moderate and high wind frequencies over the majority regions of the Black Sea. Nevertheless, the spatial patterns of frequencies of occurrence are in good agreement with the satellite-based information. Furthermore, these patterns are consistent with the coupling area between Mediterranean cyclones passing over the Western Black Sea and the Eastern European anticyclone (Cordoneanu *et al*., 1997; Trigo *et al*., 1999).

Orographic features and the magnitude of local thermal contrast between land and sea may also account for differences between the Northern and Western areas and other regions of the basin. In the case of the Black Sea the atmosphere processes are the main drivers of the climate in the area and sea-atmosphere interaction does not seem to add important features to the basin-wide patterns of extreme wind speed.

The reanalysis-driven simulations performed with the regional climate model show a good agreement with satellite-based data with regard to the spatial distribution of the frequency of both moderate and strong wind episodes, even though the sample size are different for the two types of data sets . Small differences are near coastal areas (especially for the Western half of the basin and the South Eastern region) for both wind speed thresholds: fewer cases are found in the reanalysis-driven numerical simulations compared with satellite data. Such a good agreement illustrates the added value of dynamical downscaling performed with a regional climate model having finer spatial resolution and better representation of local mechanisms. In this context, high resolution reanalysis which have been recently developed for Europe (e.g. in the framework of FP7 projects EURO4M and UERRA) are expected to deliver better results in monitoring and analyzing extreme winds. Thus, they will contribute to a better assessment of wind-related hazards and associated risks over regions poorly covered by observations such as the Black Sea basin.

The analysis of projected climate changes under A1B scenario suggests a decrease in the number of cases with moderate and strong winds on near term (2011-2040) compared to present climate (1961-2000) over almost all areas of the basin (except for Southern ones). However, the same A1B scenario simulations indicate increased atmospheric moisture over the entire basin, which is a favorable factor in the development of more intense storms over Black Sea in the following decades. Larger mean increase of columnar water vapor over North-Western part of the basin is related to stronger atmospheric warming (e.g. M&D Technical Report No.3, 2008) in this area, according to Clausius-Clapeyron relation (O'Gorman and Muller, 2010). Also, stronger warming over regions bordering the Northern Black Sea leads to reduced thermal contrast under climate change conditions and could partially explain the tendency for fewer episodes of high wind speed over Northern and Western areas. Other possible causes of change patterns in moderate and high wind speed frequency over the Black Sea could be related to the modified behavior of Eastern European anticyclone and displacements in preferred trajectories of Mediterranean cyclones passing through the analyzed area. However, a more detailed description and attribution of changes in strong wind episodes to certain local and/or regional mechanisms require further analysis of observed data, regional reanalysis and more model results, all of them backed by satellite observations with higher resolutions and longer time series.

Acknowledgements

The research leading to these results received funding from European Union, Seventh Framework Programme, under grant agreements no. 242093 and no. 293707.

QuikScat data used in the study are produced by Remote Sensing Systems and sponsored by the NASA Ocean Vector Winds Science Team. Data are available at www.remss.com.

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