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Comparison of modeled wind speed fields with scatterometer wind data over the Black Sea

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Abstract. The present work is dedicated to the quality assessment of wind at 10m from atmospheric numerical weather prediction models (NWP) ALADIN and ECMWF NWP HRES for the Black Sea using the scatterometer wind data for the period January 2018 - May 2019. The accuracy of atmospheric models is of great importance for the operational marine forecasting products for the Black Sea, developed at the National Institute of Meteorology and Hydrology (NIMH). The driving forces for the wave models are the wind fields at 10 m over the sea surface provided by the atmospheric models. The output from wave models depends largely on the quality of the wind fields. Validation of the products is a difficult task because of the lack of conventional (in situ) data. For more than 50 years, satellite technology has given a possibility to use the satellite-derived wind and wave data for the validation of numerical models. The evaluation of the regional atmospheric model ALADIN and the ECMWF NWP HRES model is performed for wind at 10 m over the Black Sea through comparisons with the satellite observations from the Advanced Scatterometer (ASCAT) Ocean Surface Wind Vectors data of 12 km resolution on board the Metop-B satellite. The scatterometer wind data, which are scientifically qualified and regularly updated are provided by the Copernicus Marine Environment Monitoring Service (CMEMS), part of the Copernicus Programme. This paper presents statistical results of the verification study. The winds predicted by the limited area model ALADIN show better coincidence with the observed winds than those obtained by the ECMWF NWP HRES model.

Keywords: Copernicus,wind, scatterometer, numerical models, verification, Black Sea.

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1. INTRODUCTION

Winds over sea are essential for marine forecasting. They are used in nowcasting and numerical weather prediction to aid in off-shore activities (energy sector, transport, fisheries and recreation), particularly to secure safety of life and property. The coastal zones are highly vulnerable to natural hazards. Strong winds, wind waves and storm surge events are among the major hazards in the Black Sea. NIMH is responsible for accurate marine forecasts in the western part of Black sea, mainly in the Juliet area. The existing operational marine forecasting system of NIMH (Kortcheva et al, 2014) consists of a third-generation spectral wave models WAVEWATCH III (WW3) and SWAN, and the limited area Numerical Weather Prediction (NWP) model ALADIN. This system is aiming to produce a reliable sea state forecast at the operational level and to be able to issue adequate and timely early warnings to authorities, the general public and users of specialized forecasts. One of the main tasks is validation of the system to improve operational models for giving reliable information to high level decision makers for better risk management. Due to the lack of systematic conventional data from buoys and weather ships in the Black Sea, satellite-derived wind and wave data are the only continuous source of information to compare the atmospheric and wave models results with observations (Dimitrova et al., 2013).

The wave models compute wave field from surface winds mostly provided by atmospheric models. Transfer of energy to the wave field is achieved through the surface stress applied by wind which varies roughly as the square of the wind speed (WMO, 1998). Accurate knowledge of wind velocity is crucial for wave modeling. Wave model output is sensitive to the choice of the wind field product, such that the quality of the wind fields is reflected in the quality of the wave predictions (Holthuijsen et al., 1996, Ardhuin et al., 2007, Galabov et al., 2013, Umesh, 2017). This paper is organized as follows: Section 1 is an overview of scatterometer data from ASCAT with 12 km resolution, onboard of Metop - B satellite; Section 2 gives a brief description of the atmospheric models ALADIN and HRES; Section 3 presents comparison between models results and scatterometer data and statistical results. The paper ends with some concluding remarks in Section 4.

2. SCATTEROMETER WIND DATA

Most remotely sensed observations of winds over sea are provided by scatterometers on-board polar orbiting satellites. Basically the scatterometer is a radar but with a design and signal processing specialized for the task of measuring surface returns. This satellite-borne microwave radar instruments operate at high frequencies to penetrate clouds. Depending on the wavelength of the radiation there are scatterometers in C-band with a wavelength of about 5 cm and Ku-band with 2 cm wavelength. Spaceborne wind data are an indirect method of measurements. Scatterometers do not measure the marine surface wind directly but measure the ocean surface radar backscatter (σ_0, referred to as the normalized radar cross section), related to the magnitude of capillary waves, on different frequencies and polarizations. Calibrated backscatter can be related to wind speed through a empirical geophysical model function (GMF). GMF provides the radar cross-section as a function of several variables: the equivalent neutral wind (Liu and Tang, 1996) vector at the 10 m anemometer height, incidence angle, relative azimuth angle, radar frequency, and polarization (Hersbach, Stoffelen, and De Haan, 2007; Wentz and Smith, 1999)

$$\sigma_o^{\text{model}} = GMF(U_{10N}, \phi, \theta, p, \lambda)$$

where $U_{10\text{N}}$ - equivalent neutral wind speed (wind at 10 m height for given surface stress assuming the marine boundary layer is neutrally stratified), θ - incidence angle, ϕ - wind direction with respect to the direction of the radar beam, p - radar beam polarization, λ - microwave wavelength.

Scatterometer wind data is sensitive to surface stress, which is related to neutral, than to non-neutral 10m wind. The popular equivalent-neutral wind (simply denoted by neutral) represents the relation between stress and wind, when stability effects are neglected. The neutral wind $U_{10\text{N}}$ at height 10m is given by:

$$U_{10\text{N}} = \frac{u_* \ln(10/z_0)}{k}$$

The global average neutral wind speed is around 0.2 m s^{-1} stronger than the non-neutral wind (Brown et al., 2006). Information on wind direction can be found by determining the orientation of the backscattered energy with respect to propagation of the original pulse. Depending on scanning geometry, scatterometers measure the amount of backscattered energy from multiple directions. The backscattering is dependent on the incidence angle, which helps to derive wind speed and on the azimuth angle, which allows deriving wind direction. The wind direction is found by determining the angle that is most likely to be consistent the backscatter observed from multiple angles.

2.1. Advantages and disadvantages of scaterometer measurements

Scatterometers provide increased data availability over the Black Sea, swath fields of both wind speed and wind direction with better resolution and coverage than conventional measurements from ships and buoys. Many coastal observations are not truly representative of the marine environment because of anemometer siting and the effect of local processes. Shipbased observations of wind are notoriously unreliable and buoys often have the anemometer close to the ocean surface so they are shielded by waves in strong wind conditions (Warren et al., 2004). Scatterometers provide data with a spatial resolution of 25 or 50 km covering most of the ocean surface in two to three days while in-situ measurements are sparse and not representative for a large area like the box of a model grid. The dense coverage (Figure 1) makes the scatterometers wind useful for direct use by weather forecasters when performing the real-time interpretation of NWP model results to elaborate a forecast (Figa-Saldaña et al., 2002). Figure 1 shows almost 93% coverage of ocean surface that can be achieved with modern scatterometers. Currently, scatterometer winds from EUMETSAT's satellites MetOp-A, MetOp-B, MetOp-C and the Indian ScatSat-1 are operationally available and provide good coverage around 9:00 and 21:00 local solar time (LST).

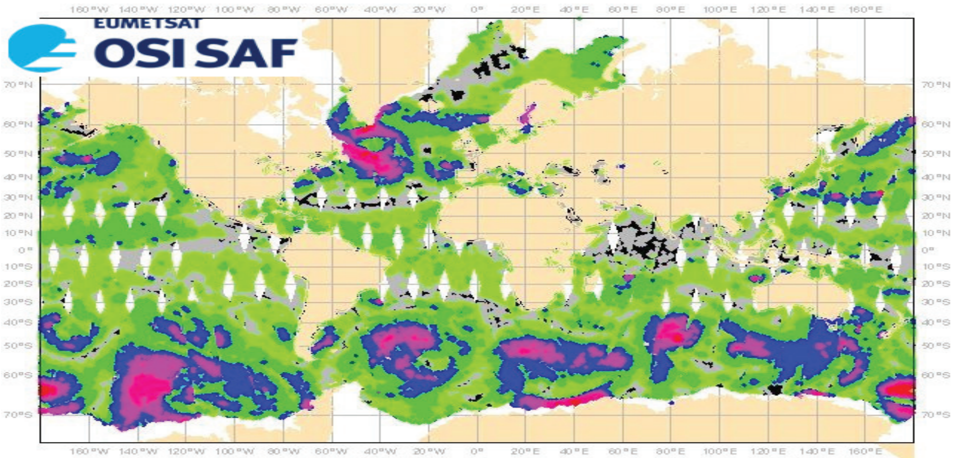

Fig. 1. Global coverage in the last 22 hours of scatterometer wind data (wind speed measurements) from ASCAT on Metop-A and Metop-B (12 km coastal wind products thinned to 25 km) and OSCAT on ScatSat-1 (25 km wind product) http://projects.knmi.nl/scatterometer

Another advantage of scatterometer observations is not only in the quantity, but also the quality of the wind observations. Many authors have discussed the quality of scatterometer products from each mission. Several studies have demonstrated high accuracy of scatterometer products, indicating that on global scale the difference from in-situ observations does not exceed 2 m/s and 20° respectively for wind speed and direction (Desbiolles et al., 2017). The impact of scatterometer data on weather analyses and forecasting is discussed in Atlas et al. (2001). One of the main applications of scatterometer missions (especially ASCAT) is assimilation of winds into NWP models. The ability of the model to provide accurate predictions is limited if there are no accurate initial conditions. Accurate initialization of NWP models can be directly related to improved forecasts (Rhome, 2003). The initialization of the models can also be evaluated by scatterometer data in situations where scatterometer data becomes available after the model initialization process. For example, wind speed from NWP models can be compared against the corresponding scatterometer data to determine if that feature is accurately positioned with the correct intensity (Rhome, 2003). Scatterometer wind data and the measurements from other scientific instruments can be combined for better understanding the mechanisms of global climate change and weather patterns.

Despite their advantages, scatterometer data can be compromised in some situations and there are several limitations and ambiguities. First, scatterometers measurements are only available at any given location approximately twice per day and not updated continuously. The forecaster has to make adjustments for cases of rapidly evolving weather systems, to compensate the data delay. There are also gaps between the sampling swaths. White regions in Figure 1 indicate unmeasured areas between the satellite swaths. These gaps are largest over the equator, smallest over the mid-latitudes, and non-existent near the poles. In such way, particular region or weather system may stay non-covered, thus providing little or no wind information for that area. The satellite swaths progress from east to west, even though the local solar time of each satellite's passage is unchanged for any latitude. This means that the satellite swath can miss a westward-moving weather system during consecutive passes, if the weather system moves at a speed similar to the satellite's progression. These difficulties are solved with the series of Metop missions (Metop A, Metop B and Metop C) with advanced scatterometer (ASCAT) instruments and provide good coverage.

The second disadvantage of scatterometer winds are their low accuracy at low wind speeds and at the inside part of the swath, the increasing root mean square error at high wind speeds due to representativeness errors. Scatterometers show varying levels of accuracy. The wind measurements are limited to wind speeds of 40 m/s, especially in C-band systems (Vogelzang et al., 2012). Several studies have demonstrated tendency to overestimate low wind speeds ($<5 \mathrm{m\ s^{-1}}$) due to low signal-to-noise ratio issues (Lindsley et al., 2016 and Ruti, P.M et al., 2018) and underestimate high wind speeds ($>13 \mathrm{\ m\ s^{-1}}$) (Carvalho et al., 2017). Most satellite wind retrievals data are performing well at moderate wind speeds ($5–13 \mathrm{\ m\ s^{-1}}$). Other limitations have been mentioned in the literature, such as inadequate temporal sampling of atmospheric variability, difficulties in areas of rapidly changing winds close to frontal disturbances (Stoffelen and Anderson, 1997), data contamination by sea ice and land, and contamination by the effect of rain. Scatterometers operating at Ku-band are more sensitive to wind variation at low speeds but they are subject to more atmospheric effects and rain (attenuation and volume scattering are strong), while these effects are less significant for C-band scatterometeres. Scatterometers on C-band are not affected by attenuation and scattering of rain, because their wavelength is greater than the diameter of raindrops (Zhou Xuan et al., 2012). Rain affects scatterometer data by reduction of the transmission of the radar pulse through the atmosphere, increased scattering by the raindrops and increased sea surface roughness caused by raindrop splashing on the ocean surface. For conditions at low wind speeds, heavy rain causes an overestimation of the wind speed, due to increased backscatter from the raindrops and increased roughness caused by splashing on the ocean surface. Conversely, rain contamination has a lesser effect on wind speed estimates for strong wind since the increased sea surface roughness caused by the wind will dominate over the rain effect. Scatterometer data includes a “rain flag” which alerts that certain wind estimates may be contaminated based on characteristics of the wind estimates that suggest presence of rain. These rain flag algorithms serve only to identify rain contamination and cannot correct it. Rain contaminated winds can be detected in the majority of cases as those wind vectors are oriented perpendicularly to the satellite track and in most of the time can increase the wind speed. These limitations may also affect the reliability of wind speed retrievals and reduce the total number of reliable observations (Desbiolles et al., 2017).

2.2. History of scatterometers

There is a long history of scatterometer observations. Figure 2 shows an overview of the current and forthcoming satellite missions carrying scatterometers.

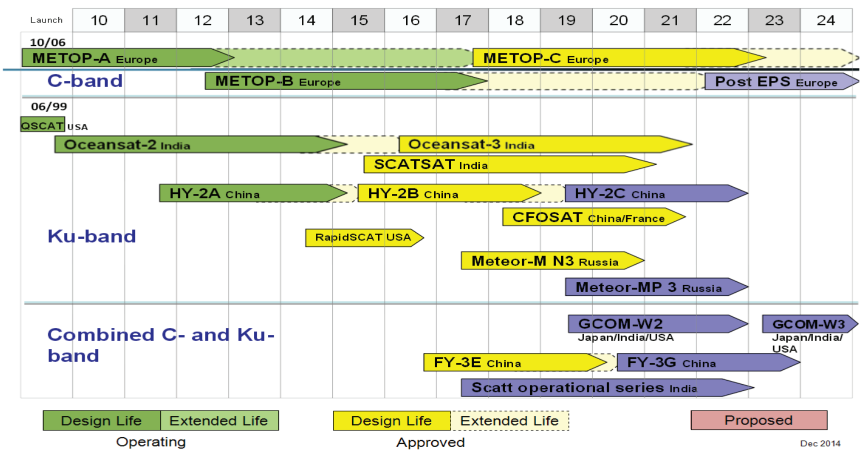

Fig. 2 Overview of finished, current and proposed satellite missions with scatterometeres onboard. (Source: http://ceos.org/ourwork/virtual-constellations/osvw/).

Scatterometry started in the 1970s with the first satellite with a scatterometer Ku band fan-beam system on the Seasat satellite that only operated for 3 months. The widespread usage of scatterometers started in the 1990s. The longest record is from the European Remote Sensing (ERS) satellites 1 and 2 beginning in 1991 and continuing to function well in the 21st century. The ERS satellites were carrying C band scatterometer instruments (25 km spatial resolution) with three antennae that generated radar beams looking 45 degrees forward, sideways, and backward with respect to the satellite’s flight direction. In 1996 NASA launched the NASA Scatterometer (NSCAT), a Ku-band fan-beam system operating with 50 km resolution and collecting data for only 9 months. A later US satellite QuikSCAT, launched in 1999, carried a new design scatterometer (known as 'SeaWinds') with a wider swath operating at Ku-band. The Indian Space Research Organisation launched a Ku-band scatterometer (OSCAT) on their Oceansat-2 platform in 2009.

The European Space Agency (ESA) and EUMETSAT form the space segment of Eumetsat's Polar System (EPS). The EPS program consists of three polar orbiting Metop satellites: Metop-A (launched on 19 October 2006), Metop-B (launched on 17 September 2012) and Metop-C (launched 7 November 2018). They are in a lower polar orbit, at an altitude of 817 kilometres and equipped with a C-band dual swath vertically-polarized fan beam radar scatterometer - ASCAT. All three Metop spacecrafts are flying simultaneously on a same orbit, half an orbit apart, to better observe rapid atmosphere evolution. The MetOp satellites have demonstrated their significant contribution to the accuracy of weather prediction and positive impact on the reduction in errors in forecasts one day in advance. They represent the most advanced polar-orbiting meteorological satellites in the world.

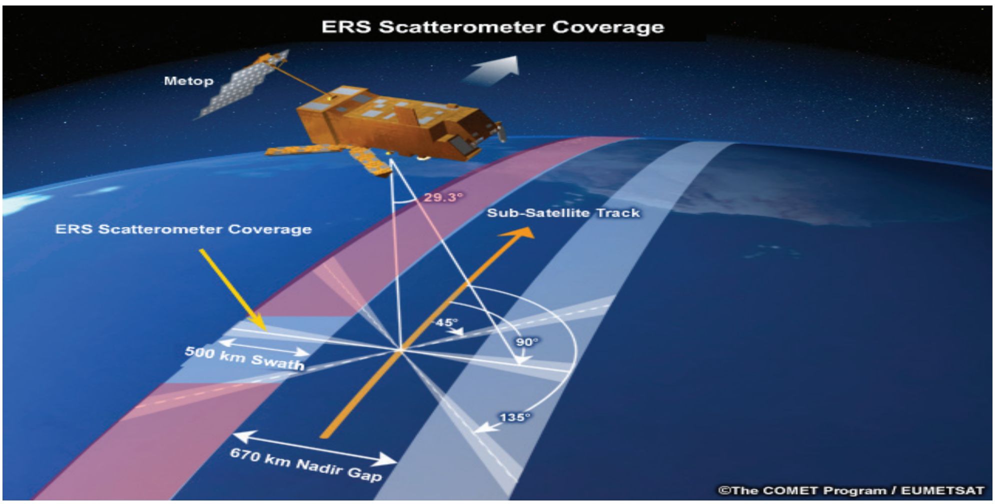

Fig. 3 The ASCAT Scatterometer Coverage.
Source: http://www.moisturemap.monash.edu.au/aaces/aaces-1/ascat.php

ASCAT actually has two sets of three antennae, which allow simultaneous observations to be made in three directions in each of its two 550 km-wide swaths (Figure 3). The design of ASCAT is based on the robust and well-understood concept of the ERS SCAT scatterometers (Figure 4). The swaths are centred at an inclination of 36° to the left and right of the satellite ground track and gridded into nodes, one triplet of averaged backscatter measurements per node. Each point on the ground is viewed sequentially three times, first by the fore-beam, then the mid-beam and finally by the aft-beam. Its fore-beam and aft-beam antennae point at 45° and 135° on each side of the satellite track. The mid-beam antenna points at 90°. The fore- and aft-beams provide backscatter coefficient measurements at incidence angles varying from 34° to 64°. The mid-beams provide σ_0 measurements at incidence angles varying from 25° to 53°. Backscatter coefficients are provided for two spatial resolutions, 25 km and 12.5 km, over the global ocean.

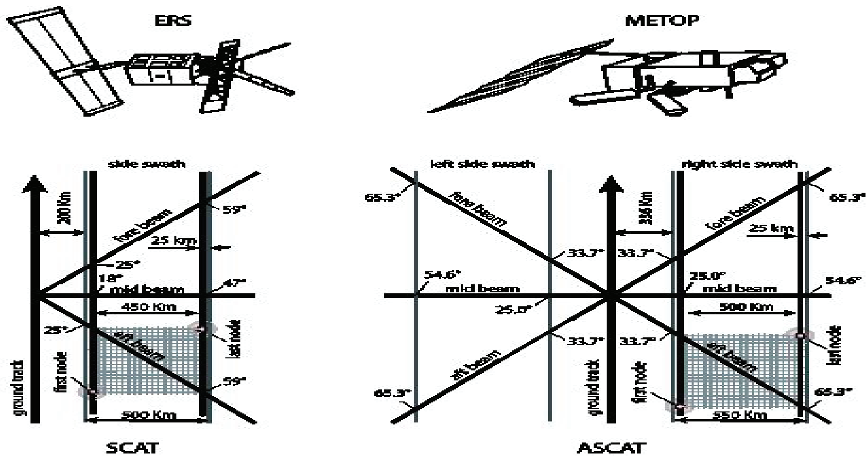

Fig. 4 Viewing geometries of the scatterometers onboard ERS and Metop satellites (V. Naeimi et al., 2010).

The ASCAT mission is designed to provide unique global ocean wind field products operationally. The main applications are in the use of the high resolution ASCAT winds in operational nowcasting (Von Ahn et al., 2006) and assimilation of those winds into NWP models (Figa-Saldaña et al., 2002). The importance for operational real-time marine applications and oceanographic research is to characterize the differences between the scatterometer and NWP products (Stoffelen et al., 2006).

2.3. Metop B ASCAT 12 km product disseminated by the Copernicus Marine Environment Monitoring Service

ASCAT, on board of Metop-B, measures over the Black Sea between 06:00 and 09:00 by descending day-time swaths, and 17:00 and 20:00 during the ascending night-time swaths. ASCAT data are available at 12 and 25 km spatial resolutions. The KNMI Global Wind Level-3 ASCAT 12 km coastal wind product was selected for this study and was downloaded from the Copernicus Marine Environment Monitoring Service (CMEMS) website. The advantages of this product include its temporal range covering, resolution of two observations daily due to ascending and descending swaths as well as being easily accessible and free. In addition, the processed Level-3 product, which consists of pre-calibrated and georeferenced data mapped on an uniform space–time grid scale allows direct use without preliminary manipulation. The WIND_

GLO_WIND_L3_NRT_OBSERVATIONS_012_002 product contains daily, Level 2 scatterometer wind vector observations which are interpolated to a regular lat-lon grid with fixed spacing. The input L2 product is operational product from the EUMETSAT OSI-SAF (Ocean and Sea Ice Satellite Application Facility) provided through the Royal Netherlands Meteorological Institute (KNMI). The L3 Wind Product is based on the extensively calibrated, validated and monitored L2 wind products. The calibration of the Global Ocean L3 Wind product consists of checking the correct functioning of the gridding. The gridding procedure is a bilinear interpolation technique within triangles spanned up by observation points and interpolated observations, using Gouraud shading technique (Driesenaar et al., 2017). The L3 grid spacing depends on the resolution of the input L2 product. The Black Sea L3 operational near-real-time coastal ocean surface wind vector retrievals from the Advanced Scatterometer (ASCAT) on MetOp-B at 12 km sampling resolution include daily wind speed, zonal and meridional wind and wind stress components, wind stress amplitude, and wind stress curl and divergence from ascending or descending passes. The resulting NetCDF product files are then made available by the CMEMS Information System at CNR. The current study compares the predicted wind speed at 10 m by the operational ALADIN model and HRES model with ASCAT B 10-m wind measurements that are scientifically qualified and regularly updated in the period from 2018-01 to 2019-05. The quality of the ASCAT winds has been assessed before, mostly over large ocean areas using comparisons with buoy measurements (Verhoef and Stoffelen, 2009). We accept these characteristics of quality and uncertainty and apply to the almost enclosed Black Sea basin to evaluate the regional NWP ALADIN.

3. ATMOSPHERIC MODELS: ALADIN AND HRES

ALADIN (Aire Limitée Adaptation dynamique Développement InterNational) is a limited area bi-spectral numerical model based on the French global model ARPEGE (Action de Recherche Petite Echelle Grande Echelle). The concept of the ALADIN project was proposed by Météo-France with the aim of building a mutually beneficial collaboration with the National Meteorological Services of Central and Eastern Europe. This collaboration is in the field of numerical weather prediction and provides the basis of modern meteorology forecasting tools. The aim of the ALADIN collaboration is to improve the value of meteorological, hydrological and environmental warning and forecast services delivered by all ALADIN members to their users. This is achieved through the operational implementation of a NWP system capable of resolving horizontal scales from the meso-beta to the meso-gamma scale thus improving the prediction of severe weather phenomena such as heavy precipitation, intensive convection and strong winds. This model is widely used in Europe. Historically, it has been developed since the beginning of the 1990s. More details can be found on the website of the ALADIN Consortium (ALADIN, 2019). The NWP ALADIN short-range model has been used as operational model in Bulgaria since June 1999 (Bogatchev, 2008). The horizontal resolution of ALADIN is approximately 12 km and it has 31 vertical levels. ALADIN provides weather forecast for 72 hours over the Balkan Peninsula and Black Sea, twice a day using as initial conditions the ARPEGE outputs from 00 and 12 UTC. ARPEGE is the operational global primitive-equation NWP system used at Météo-France and is based on the ARPEGE-IFS software developed in collaboration with ECMWF. Further details can be found in Bogatchev (2008). Since November 2017. the operational NWP version used at NIMH is with a horizontal resolution of 5 km and 105 vertical model levels, covering Balkan Peninsula and a part of the Black sea, while for the needs of the Marine group it is run additionally over the whole Black sea with the mentioned in the manuscript parameters. The wind fields from ALADIN atmospheric model over the Black Sea are available at 3-hour intervals to (T+72) on a regular latitude-longitude grid with a 0.125°x0.125° mesh size and disseminated to the end-users as charts (Figure 5-left).

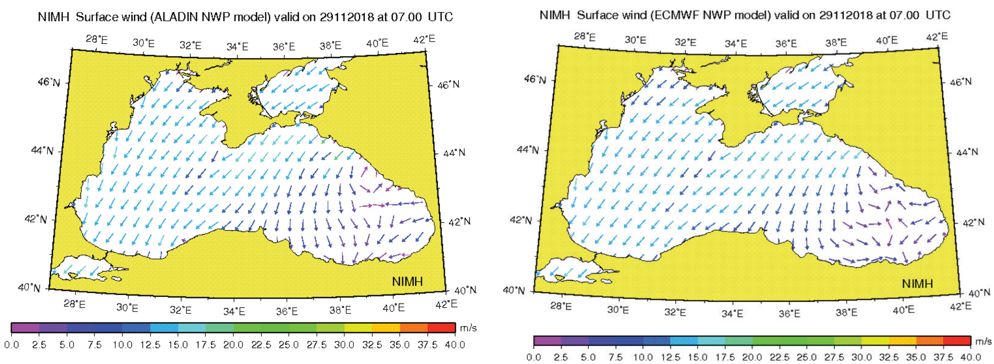

Fig. 5 ALADIN (left) and HRES (right) model wind fields at 10 m over the Black Sea for the storm situation on 29 November 2018 at 07 UTC.

HRES is an atmospheric model that provides a highly detailed description of future weather, estimated to be 10 days for large scale properties of the atmosphere. It is one of the 52 individual members of an ensemble of higher spatial resolution models for medium-range forecasts. The HRES system has a cubic reduced Gaussian grid with unchanged spectral truncation, but the grid point space resolution is increased to more accurately represent the physical processes and advection. The HRES configuration is run every twelve hours out to ten days with a horizontal resolution of 9 km using 137 vertical layers. More details can be found on the ECMWF website. As a Co-operating State of ECMWF, NIMH has access to the medium-range forecasts. Figure 5 (right) shows the wind field from HRES model during the storm from November 2019.

4. MODELS AND SCATTEROMETER DATA COMPARISONS. RESULTS

A fully automated scheme was set up at NIMH for operational use and reprocessing L3 wind data from a MetOp ASCAT B with 12 km resolution. The KNMI Global Wind Level-3 ASCAT 12 km coastal wind product is scientifically qualified, regularly updated and allowed for direct use. The first step is to extract data for the Black Sea area from the NetCDF file. The scatterometer and model data are at different time scale. The ASCAT B scatterometer wind data are chosen to be with a minimal time difference compared to the NWP models winds (less than one hour). The second step is to interpolate the atmospheric models 10-m wind components to the scatterometer observation location in time, using the bilinear interpolation method. Next step is to calculate the wind speed differences between the atmospheric models and ASCAT B observations and their visualization (Figures 8, 9, 10). At the end, calculation of the statistical variables (mean bias, root mean square error (RMSE), standard deviation of error, scatter index and R - correlation coefficient) is done (Dimitrova et al., 2013). Tables 1 and 2 show statistical results of modeled wind speed with respect to the scatterometer data for the period January 2018 - May 2019. In wind verification, only NWP wind speeds above 4 m/s are considered for wind statistics (Verspeek et al., 2008, Verhoef & Stoffelen, 2009). In this study, we use the wind speeds above 5 m/s, which can lead to a sea state of about 3 Beaufort scale.

The differences between the ALADIN and HRES real and neutral winds at 10m will be variable, but with an expected statistical mean of 0.2 m s^{-1} (Brown et al., 2006). Comparison of the results in Tables 1 and 2 shows a good correlation between atmospheric models and ASCAT B winds. The wind speed correlation coefficient for all data (≥ 5 m/s) is around 0.89 and 0.98 between 10m/s and 20m/s. The scatter index for wind speed above 20m/s from HRES model is around 0.4 (note that the number of observations is only 189), while for ALADIN model is 0.16. Overall, the atmospheric model ALADIN for the Black Sea in this study gives better statistical results, with a scatter index below 0.25. The RMS values for HRES wind speeds greater than 15m/s are largest. The statistical characteristics show that the wind speeds from HRES model are generally underestimated, ALADIN also indicates underestimation, but still shows more consistent results than HRES.

Table 1. ALADIN wind speed versus Metop-B ASCAT 12 for the period 01.01.2018-31.05.2019.

	Nb.	ALADIN wind (m/s)	ASCATB 12 wind (m/s)	Bias (m/s)	RMS error (m/s)	Correlation coefficient	Scatter index
All	635246	7.65	7.90	-0.24	1.82	0.88	0.23
5-10m/s	528366	6.94	7.08	-0.14	1.79	0.84	0.25
10-15m/s	104710	10.89	11.58	-0.68	1.92	0.90	0.17
15-20m/s	5834	14.62	16.13	-1.52	1.66	0.99	0.14
>20m/s	189	17.66	20.70	-3.04	1.42	0.99	0.16

Table 2. HRES wind speed versus Metop-B ASCAT 12 for the period 01.01.2018-31.05.2019.

	Nb.	ECMWF wind (m/s)	ASCATB 12 wind (m/s)	Bias (m/s)	RMS error (m/s)	Correlation coefficient	Scatter index
All	635246	7.35	7.90	-0.54	1.84	0.89	0.23
5-10m/s	528366	6.70	7.08	-0.37	1.66	0.86	0.23
10-15m/s	104710	10.35	11.58	-1.23	2.27	0.92	0.20
15-20m/s	6870	12.82	16.25	-3.43	4.75	0.99	0.29
>20m/s	189	13.70	20.70	-7.00	8.82	0.98	0.43

The spatial resolution and the effect of wind field smoothing lead to underestimation of the modelled wind speed above 20m/s. We need to note that with the same spatial resolution, ALADIN is more optimized and produces less smoothed fields than HRES.

Visualization of the products and tables with statistical characteristics are uploaded on the internal webpage of NIMH on a daily basis for operational use. The output of the system can be used to improve the quality of the wave forecast in the Black Sea and to give expert opinion for the benefit of state institutions and private sector.

An example of the successful operation of the system is demonstrated for the storm in the Black Sea in the period 28-30.11.2018. The storm caused by a low pressure system 1003 hPa located over the Adriatic sea moved to southeast through the Eastern Mediterranean and Asia Minor (Figures 7 and 8). There was a powerful ridge raised from north over the north Balkan Peninsula moving slowly to south-southeast. At 500 hPa geopotential height, a sharp and deep valley with a cold air mass descended from north.

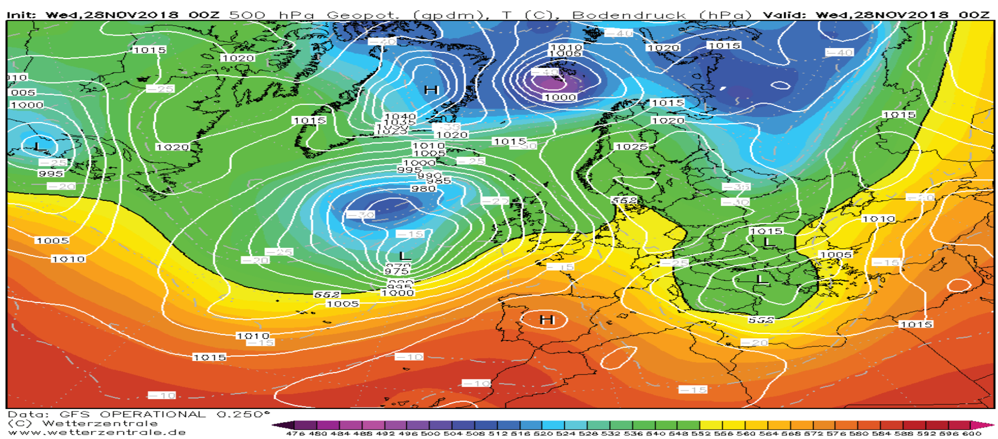

Fig. 7 GFS Analysis of storm on 28.11.2018 at 00 UTC.

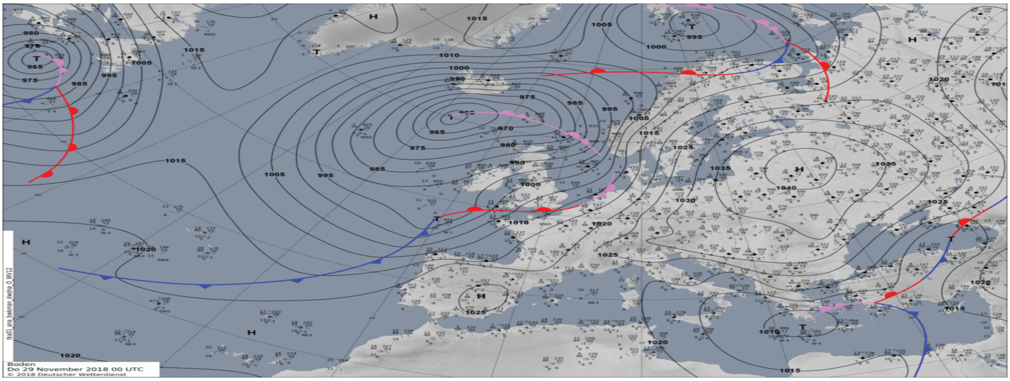

Fig. 8 DWD analysis of storm situation over Balkan Peninsula and the Eastern Mediterranean on 29.11.2018 at 00UTC.

The pressure gradient above Bulgaria quickly increased from north-northeast with very cold air and strong, temporary stormy winds over the Black Sea. In the last day of the period the gradient weakened and the field remained anticyclonic.

The maximum wind speed measured in the coastal stations reached 10-16 m/s, with gusts up to 22 m/s, from NNE. Coastal station on cape Emona measured wind speeds between 20 and 24 m/s, gust up to 30 m/s and wind direction from N. Unfortunately, buoy measurements were not available for inclusion in the study. For this storm case, maximum observed wind speed from ASCAT B in the western part of Black Sea was 17.17 m/s on 29.11.2018 at 18.31UTC (Figures 9 and 10).

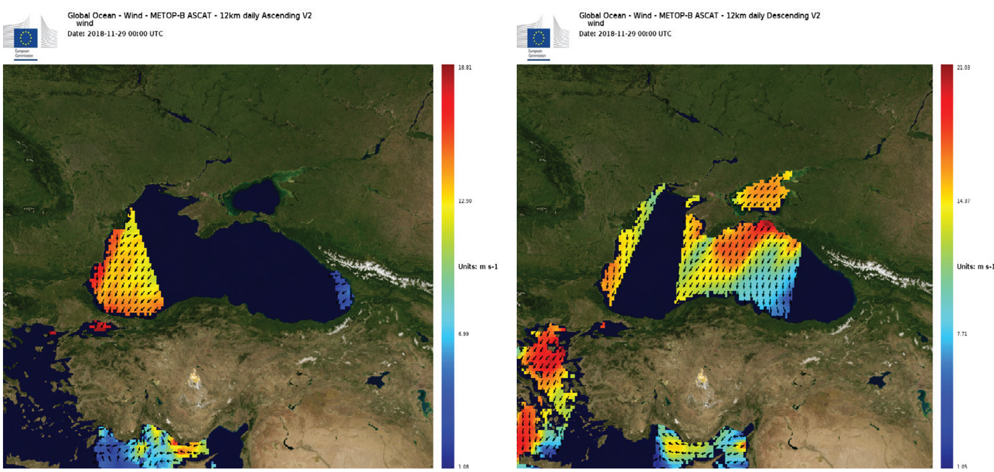

Fig. 9 Data for wind speed and direction obtained from MetOP-B ASCAT 12 km, ascending (left) and descending pass (right) on 29.11.2018.

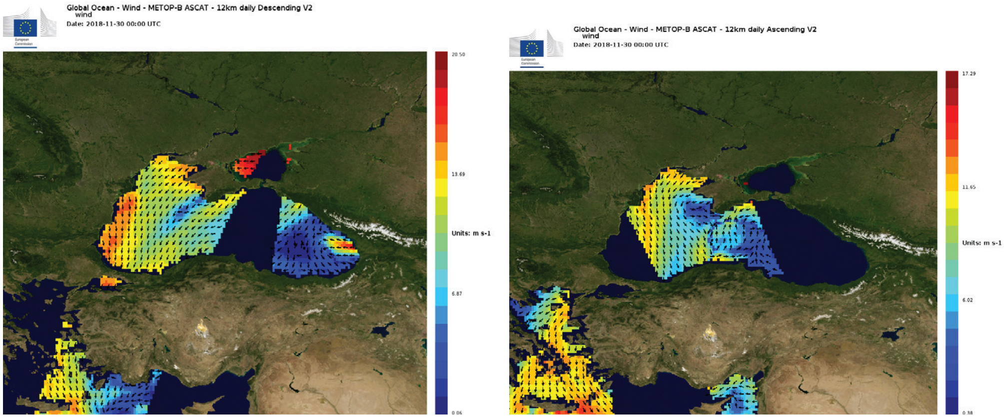

Fig. 10 Data for wind speed and direction obtained from MetOP-B ASCAT 12 km, descending pass (left) and ascending (right) on 30.11.2018.

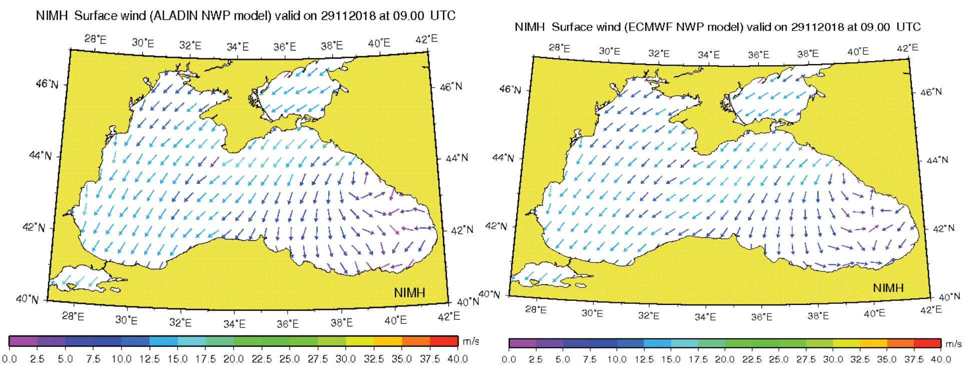

Fig. 11 Wind speed and direction from ALADIN (left) and HRES (right) models with grid mesh 12 km on 29.11.2018 at 09 UTC.

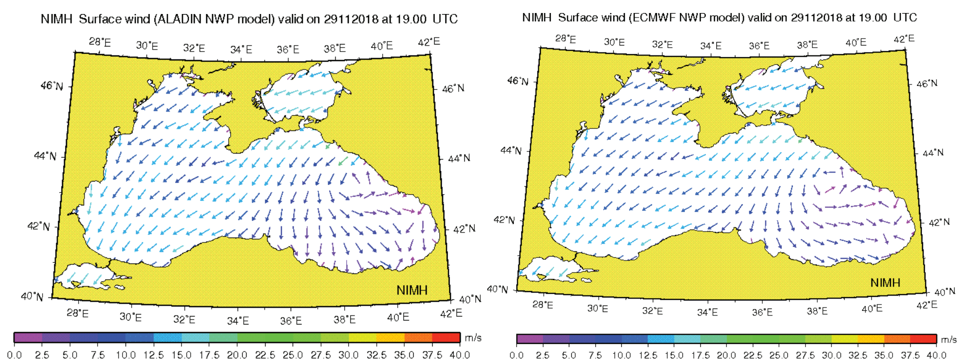

Fig. 12 Wind speed and direction from ALADIN (left) and HRES (right) models with grid mesh 12km on 29.11.2018 at 19 UTC.

The forecasted maximum wind speeds over the western part of the Black Sea by ALADIN and HRES models (Figures 11 and 12) are between 12.5 and 15 m/s with direction north-east, along the coast northern wind up to 17.5 m/s, on 29.11.2018 in the morning. ASCAT B observations indicated wind speeds between 14 and 16 m/s on 28.11.2018 and up to 16.8 m/s on 29.11.2018 at 0849 UTC. The models predict slow decreasing of wind speed on 30.11.2018 until morning. ASCAT B wind speed observation is still around 17.17 m/s at 1831 UTC on 29.11.2018 and up to 16 m/s on 30.11.2018 at 0827 UTC.

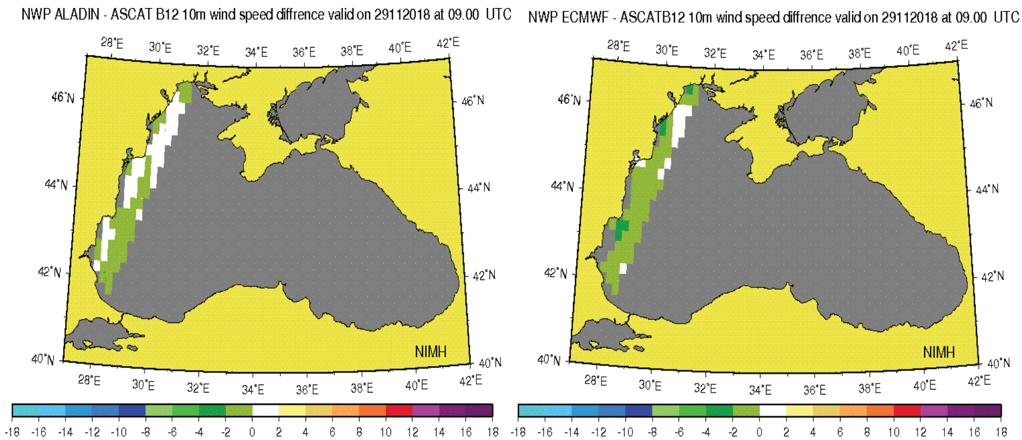

Fig. 13 Wind speed differences ALADIN-ASCAT B (left) and HRES-ASCAT B (right) models with grid mesh 12km on 29.11.2018 at 09 UTC.

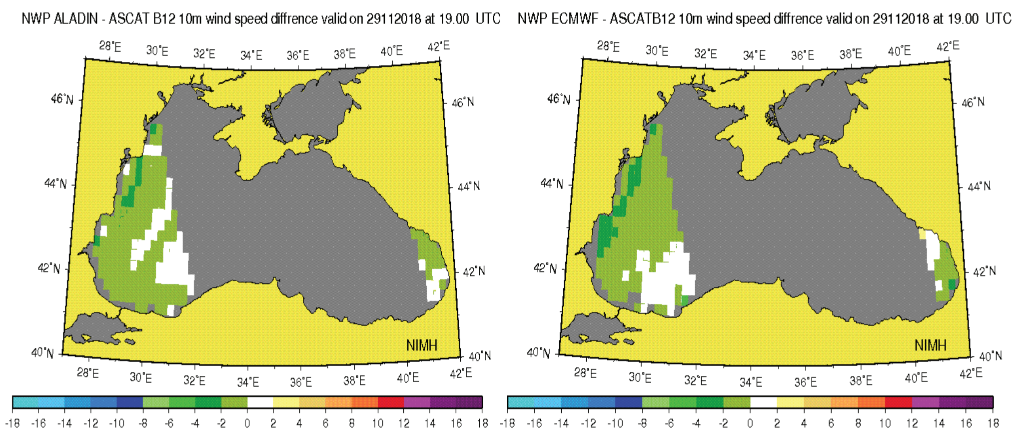

Fig. 14 Wind speed differences ALADIN-ASCAT B (left) and HRES-ASCAT B (right) models with grid mesh 12km on 29.11.2018 at 19 UTC

In general, increased spatial resolution leads to better representation of coastlines and orography with consistent gains in forecast performance for 10 m wind speed. The difference between the regional model ALADIN and ASCAT B (Figure 13) in wind speed close to the coast is smaller (around 0-2 m/s) in comparison with HRES and ASACAT B (Figure 14) around (-2 ÷ 0 m/s), and close to cap Kaliakra (-4 ÷ -2 m/s). ALADIN represents better the wind speed particularly close to the coast, because of its better land-sea mask.

For the storm situation on 28.11-30.11.2018 the model predicted winds in general showed good coincidence with the satellite observed winds. Figures 13 and 14 show the difference between predicted and observed winds over the Black Sea and are an example of good model-observations coincidence. The comparison between ALADIN and HRES shows that the areas of largest wind speeds are well predicted by both models.

The greatest benefit of ASCAT measurements is the possibility to analyze the wind fields over the sea and to understand how reliable the sea state forecast is. For the sake of brevity, the significant wave high from numerical marine forecast is not shown here, but the wave forecast was also reliable with little underestimate in the high waves in the western part of the Black Sea close to Bosporus.

It is necessary to note the current well known and documented (Verspeek et al. 2008; Verhoef and Stoffelen, 2009, Vogelzang et al., 2012, Lindsley et al., 2016; Ruti et al., 2018) weaknesses of ASCAT for marine applications and weather forecasting:

- Scatterometers limitations in representing low wind speeds (due to signal backscatter induced by rain drops and backscatter lower threshold- measured winds below 4 m s^{-1})
- Wind vectors can be unreliable at wind speeds over 25m/s (due to atmospheric attenuation of the signal and backscatter upper threshold)
- Insufficient resolution for some processes (a 25 km product with 12.5 km spacing);
- Data coverage: key weather events (e.g. storms) can be missed due to incomplete coverage. Moreover, an aliasing problem often occurs in cases with fast moving storms.

Therefore, process studies using scatterometer data will remain necessary in order to exploit scatterometer data to the full. Future developments include improved spatial and temporal resolution, near-coastal processing, user-defined grids and cloud processing (EUMETSAT, 2019).

5. CONCLUSION

The accurate prediction of atmospheric models is absolutely necessary for reliable wave forecast. It is important to assess the quality and uncertainty range of wind fields provided by the atmospheric models as their output is the driving force for the wave models in operational forecasting and hindcasting regimes in the Black Sea basin. As noted above, the observations along the Bulgarian Black Sea coast are sparse and the assessment of models performance is often not possible due to the lack of observations. Many studies have confirmed that scatterometer data are becoming important and reliable data source for marine and NWP communities. The long range of satellite observations make possible the climate study and the wind trends in the Black Sea. High resolution (12.5 km) satellite data gives the possibility to investigate small-scale features of the wind variability in the Black Sea, mainly related to the topographic effects (Kuryakov et al., 2019)

This study presents the results from evaluation of the wind speeds of the model systems by comparing the very short-range forecasts of ALADIN and HRES with the Advanced Scatterometer (ASCAT B) wind product for the period January 2018 - May 2019. This period of one year and half is insufficient to make general conclusions. Overall, the atmospheric models provide sufficient results. The coincidence of the models and ASCAT B wind speeds is reasonably good. There is a good agreement between the 10 m wind predictions over the Black Sea with satellite measurements.

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