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VALIDATION OF THE MARINE MULTI-HAZARD SYSTEM OF NIMH-BAS THROUGH THE SATELLITE EARTH OBSERVATION DATA

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Key words: *Satellite altimetry, scatterometer, wave modeling, Black Sea, coastal hazards, IncREO.*

Abstract: *Strong winds, high waves and storm surges are the greatest environmental danger for the coastal areas. Therefore accurate prediction of the sea-state is absolutely necessary to minimize the risk at the sea and along the coastal zones. Wind waves and storm surge forecasting is the main part of the marine multi-hazard warning system for the western part of the Black sea. The National Institute of Meteorology and Hydrology, Bulgarian Academy of Sciences (NIMH-BAS) is responsible for this forecast services in Bulgaria and has combined its wave prediction system with a verification system in order to issue more accurate operational forecast products. The wind and wave model evaluation for the Black Sea is a difficult task because of the lack of conventional (in situ) wave data from buoys and weather ships. The advancement in satellite technology has created a possibility to use remotely sensed wave data for the validation of the atmospheric and wave models. Altimeter and scatterometer data from the satellite missions ERS-1/2, TOPEX-POSEIDON, ENVISAT, JASON1/2 and Metop-A has played a key role in the development of the operational numerical wind and wave forecast at NIMH-BAS during the last two decades. Wind speed and wave height measured by satellite scatterometer and altimeter over the Black Sea area represent a reliable data source to the study of regional wind and wave conditions. Simulation of historical storm situations is a key tool in examining potential natural hazards along the Bulgarian coast of the Black Sea. The wind and wave model data from the simulation of historical storm situations in the Black sea are compared with altimeter wind and wave data from ENVISAT, JASON1/2 satellites and the scaterometer wind data from the Advanced Scatterometer (ASCAT) on board the Metop-A satellite. This study has been done in the frame of FP7 EU Project "Increasing Resilience through Earth Observation" (IncREO). The results from the statistical model validation show that the model simulations are in good agreement with altimeter measurements in terms of the mean and standard deviation of the variables (significant wave height and wind speed).*

ВАЛИДИРАНЕ ЧРЕЗ СПЪТНИКОВИ ДАННИ НА МОРСКАТА СИСТЕМА НА НИМХ-БАН ЗА ПРОГНОЗА НА ОПАСНИ ПРИРОДНИ ЯВЛЕНИЯ

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Ключови думи: *Спътникова алтиметрия, скатерометър,моделиране на вълнение,Черно море, крайбрежие, природни бедствия*, IncREO.

Резюме: *Силният вятър, щормовото вълнение и покачването на морското ниво представляват най-голямата опасност за крайбрежните райони. Затова точното предсказване на състоянието на морето е абсолютно необходимо за да се минимизира рискът за тези. Прогнозирането на морското вълнение и морското ниво е основна част на морската мулти-рискова система за предупреждения за западната част на Черно море. Националният институт по метеорология и хидрология към Българска академия на науките (НИМХ-БАН) е отговорен за този вид дейност в България и е съчетал своята система със система за проверка, за да се изготвят по-точни прогнозни продукти. Оценката на вятъра и вълнението от числения модел за Черно море е трудна задача, поради липсата на морски данни от буйове и метеорологични кораби. Напредъкът в сателитните технологии дава възможност да се използват дистанционно получените за вятър и вълнение данни за валидиране на атмосферните модели и вълновите модели. Алтиметричните данни от спътниците ERS -1 /2, Topex - POSEIDON , Envisat , JASON1 / 2 и данните от скатерометъра*

ASCAT Metop -A играят ключова роля в развитието на оперативните числени прогнози на НИМХ -БАН през последните две десетилетия. Данните за скоростта на вятъра и височината на вълните, измерени от спътниците над района на Черно море представляват надежден източник на данни за изследването на регионалния вятър и състоянието на морето. Симулацията на исторически щормови ситуации е ключов инструмент при разглеждането на потенциалните природни бедствия по българското черноморско крайбрежие. Резултатите от модела като вятър и височина на вълната от симулацията на исторически щормови ситуации в Черно море се сравняват с алтиметричните данни за вятър и височина на вълната от сателитите Envisat , JASON1 / 2 и данните за вятър от скатерометъра- Advanced Scatterometer (ASCAT) на борда на сателита Метор -А. Изследванията са направени в рамките на проекта по 7РП на ЕС "Увеличаване на устойчивостта чрез наблюдение на Земята " (IncREO) . Статистическите резултатите от валидицията показват, че симулациите на моделите са в добро сходство с алтиметричните измервания по отношение на средната стойност и стандартното отклонение на променливите (значима височина на вълните и скорост на вятъра) .

Introduction

Wind waves affect human activities and have great geophysical significance. The description of the sea-state now is mandatory in the international safety bulletins. Accurate forecasting of sea conditions and adequate forewarning is essential for the safety of people, equipment and the environment. Wind waves, together with the strong winds and storm surge events, are major hazards in the coastal areas. The accurate forecast of such events is of a great importance for the national meteorological services in order to be able to issue reliable early warnings to the authorities, general public and users of specialized forecasts, ships, offshore platforms etc. In Bulgaria the organization, which is responsible to issue such warnings on operational basis is the National Institute of Meteorology and Hydrology (NIMH). The wind and wave model evaluation for the Black Sea is a difficult task because of lack of conventional (in situ) wave data from buoys and weather ships. The advances in satellite technology have created a possibility to use remotely sensed wave data for the validation of the atmospheric and wave models [6].

Satellite Altimetry and Scatterometer Data

Satellite Earth Observation (EO) altimetry data plays an important role in the wave modeling and forecasting. Recent advances in satellite technology have created a possibility to use remotely sensed wave data for wave model validation. Satellite Earth Observation techniques have over the last two decades matured to such a stage, that quality products of ocean wind, waves, can be produced routinely. The most frequent variables retrieved from satellite sensors used in the national and international pre-operational and operational systems are wind and waves altimeter data. Significant wave height can be determined using satellite altimeter measure and such measurements have been used to validate numerical wave forecasting models.

Intercomparison studies of satellite data and model results have been previously carried out for the validation of wave models. The use of ERS1/2 and TOPEX-Poseidon altimeter data for ~~the~~ wave model verification for the Black Sea has been demonstrated in [7,8] and use of ENVISAT and Jason-1 altimetry in [15].

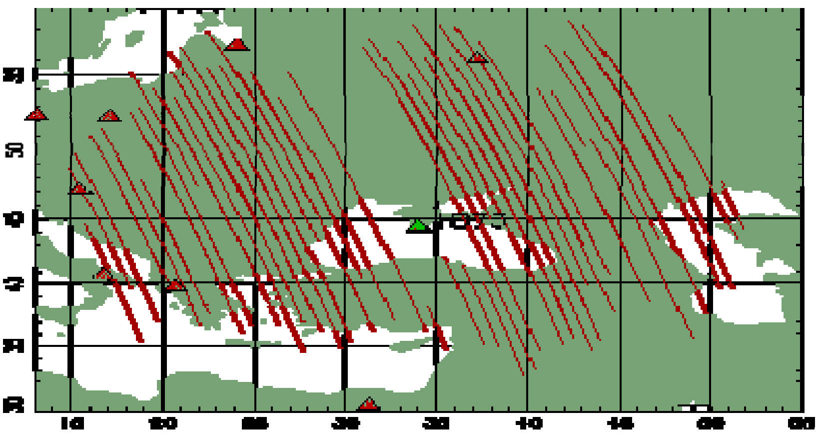

Fig. 1. Spatial coverage of the ERS-2 tracks

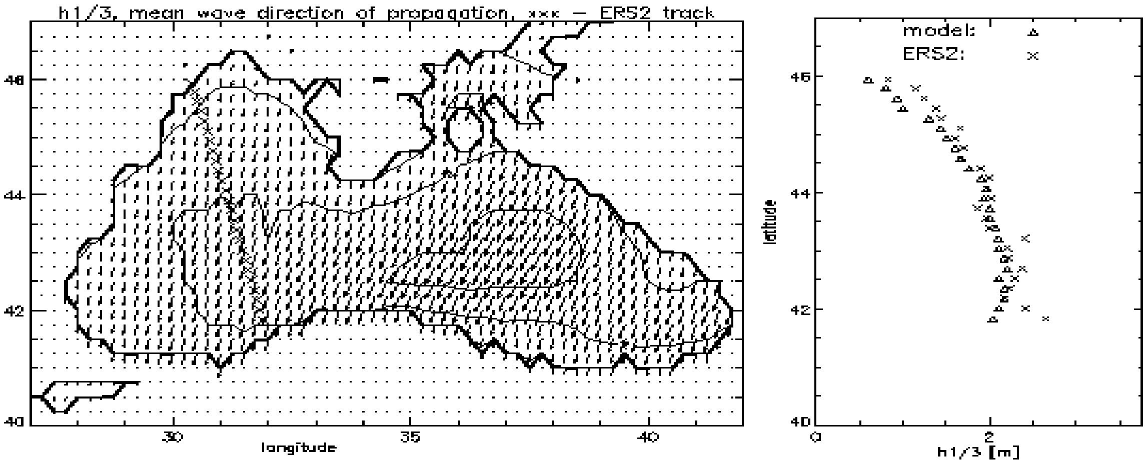

Figure 1

Fig. 2. Comparison of modeled by VAGBUL SWH and ERS-2 altimeter data during the storm in the Black Sea on 23.12.1996 at 12.00 UTC (A. Kortcheva, J-M Lefevre, 1998)

Satellites Jason 1 and Jason2 are continuation to TOPEX/Poseidon. Jason-2 was launched on June 20, 2008, as a collaboration effort between CNES, NASA, NOAA and EUMETSAT and flies in a low-Earth orbit at latitude of 1336 km, with global coverage between 66°N and 66°S latitude and a 10-day repeat of the ground track. Space-borne altimeter-derived wave heights Jason-2 are available along the satellite ground track (Fig.3). Fig.4 shows a repetitive pattern for the Jason-2 satellite path over the Black Sea. Jason-2 operates using two different radar frequencies: one in the Ku-band (13.6 GHz) and the other in the C-band (5.3 GHz). Ku band is the most commonly-used frequency (used for ERS, Topex/Poseidon, Jason-1, Envisat). This study use a Ku-band significant wave height (SWH) only.

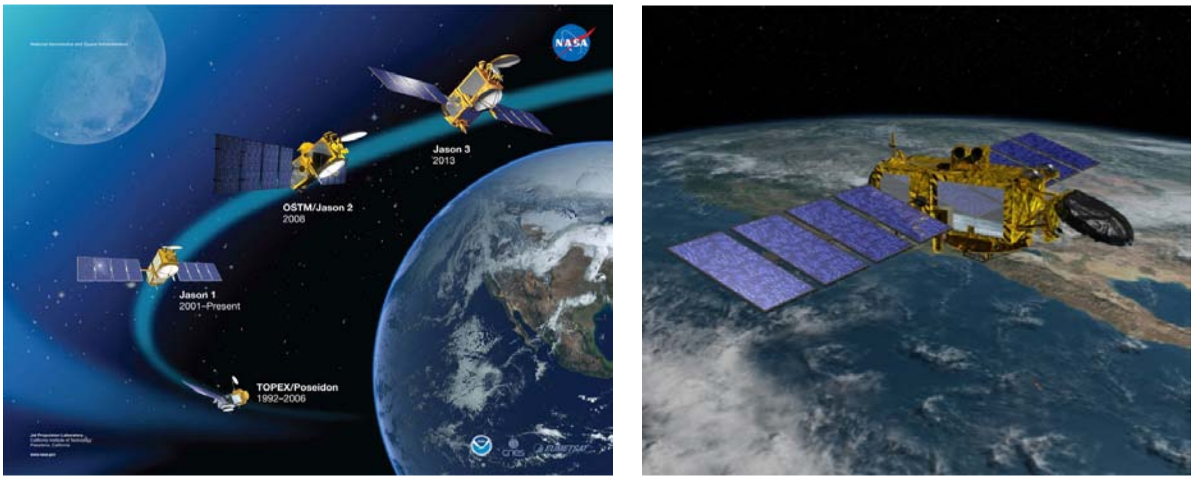

Fig. 3. Jason-2 along track measurements

The main data set used is in the Binary Universal Form for the Representation of meteorological data (BUFR) version (WMO Codes) of the Operational Geophysical Data Record (OGDR) of Jason-2 radar altimeter. Jason-2 BUFR products are designed primarily for dissemination via the Global Telecommunication System (GTS) and they consequently follow the format conventions defined by the World Meteorological Organization (WMO) for all data disseminated on the GTS. The WMO FM-94 BUFR is a binary code designed to represent, employing a continuous binary stream, any meteorological data. It has been designed to achieve efficient exchange and storage of meteorological and oceanographic data. This data is produced and disseminated by EUMETSAT and NOAA in the Near Real Time (NRT) within a few hours, which makes it suitable for operational use in atmospheric and ocean wave forecasting systems. The satellite altimeter data represent a high quality, independent and globally covering wave and wind data set which can be used for direct validation of the wave model data, even though this is limited to significant wave height and wind speed. Jason-2 OGDR-BUFR product has been routinely streamed via GTS to NIMH-BAS since July 2012[9].

The near real time satellite significant wave height from Radar Altimeter instruments on the Jason-2 satellite are received, processed and used for the wave model validation for the Black sea.

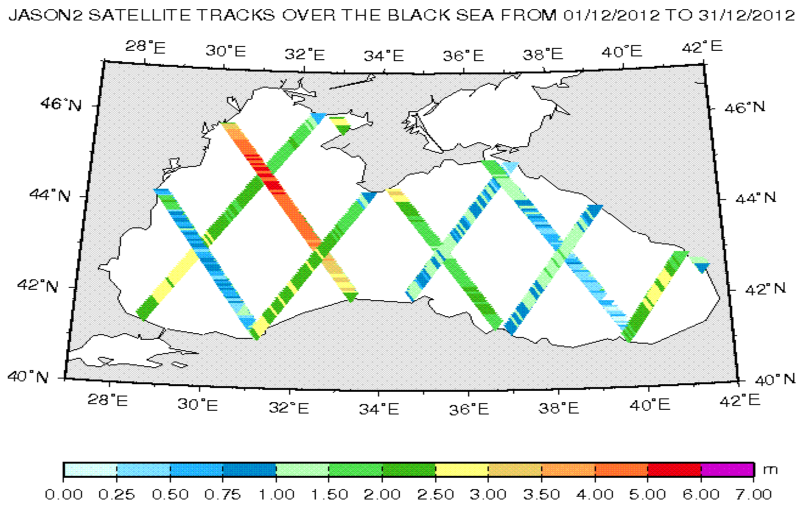

Fig. 4. Jason-2 Satellite tracks over the Black sea for December 2012

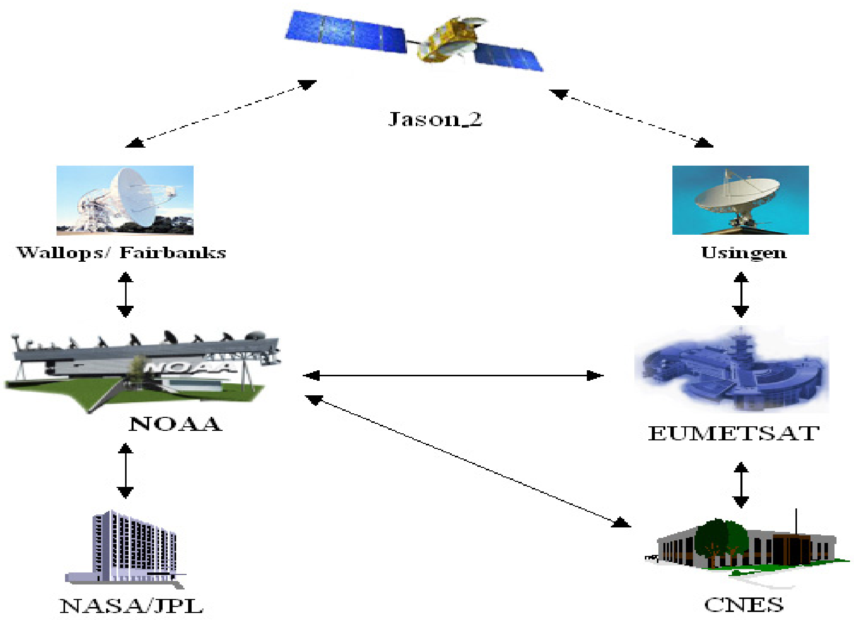

Fig. 5. The way of receiving of altimeter data

Trough the bilateral agreement between NIMH and ROSHYDROMET (Russian Federal Service for Hydrometeorology and Environmental Monitoring), ROSHYDROMET is providing us wind data from the Advanced Scatterometer (ASCAT) on board the Metop-A satellite (Fig.6).

The prime objective of ASCAT is to measure wind speed and direction over the oceans. With the rapid global coverage, day or night and all-weather operation, ASCAT offers a unique tool for long-term climate studies. ASCAT is a real aperture radar, operating at 5.255 GHz (C-band) and using vertically polarised antennas. It transmits a long pulse with Linear Frequency Modulation ('chirp').Ground echoes are received by the instrument and, after de-chirping, the backscattered signal is spectrally analysed and detected. In the power spectrum, frequency can be mapped into slant range, provided the chirp rate and the Doppler frequency are known. The processing is, in effect, a pulse compression, which provides range resolution.From around 837 km altitude, the instrument transmits well characterised pulses of microwave energy towards the sea surface. Winds over the sea cause small scale (centimetric) disturbances of the sea surface which modify its radar backscattering characteristics in a particular way. These backscattering properties are well known and are dependent on both the wind speed over the sea and the direction of the wind, with respect to the point from which the sea surface is observed.

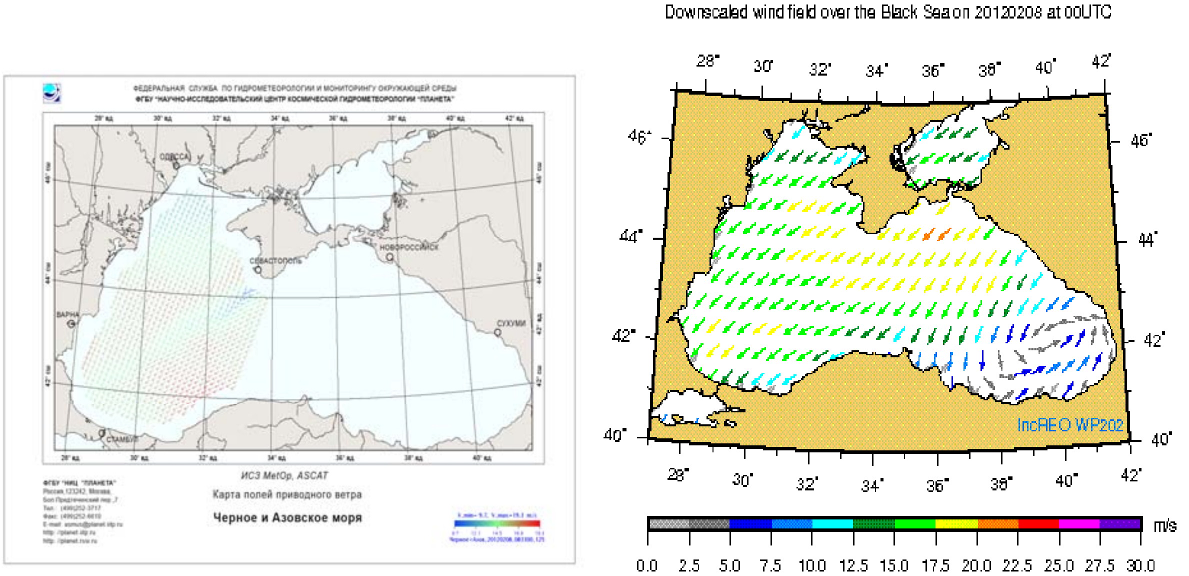

Fig. 6. Examples of ASCAT, Metop-A scatterometer wind data and obtained by simulations of the atmospheric model for 07.02.2012 and 08.02.2012

WAVEWATCH III Model

WAVEWATCH III (WW3) is an operational numerical wave model implemented at NIMH-BAS for wind waves forecasting in the Black Sea. WW3 is a 3rd generation wave model developed by NOAA/NCEP [13] and based on finite difference solving of the balance equation of the spectral wave action in the approximation of phase averaging. The numerical wave model was implemented on a spherical grid cover the area of the Black Sea from 40°N to 47°N and from 27°E to 42°E on a regular latitude-longitude grid. The grid resolution is 0.125°x0.125° mesh size and it's driven by the 10 m surface wind fields from the limited area NWP model ALADIN. Initial conditions for each forecast, consisting of spectral density distribution of sea surface variance at the start time, generated during the previous forecast cycle. Wave energy two-dimensional spectra is post-processed from the numerical model to provide the output fields of the following variables: significant wave height (SWH), peak wave period, mean wave period, peak wave direction and mean wave direction (Fig.7).

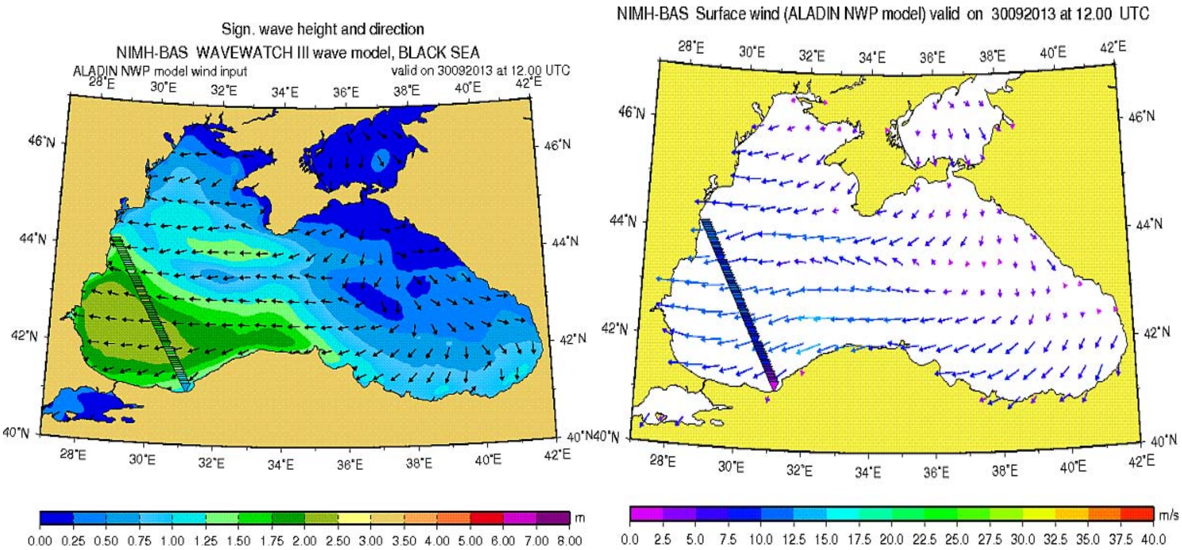

Fig. 7. Left- Map of SWH (WW3 model) in the Black Sea (the arrows indicate the mean wave directions), the black line denotes the ground track of Jason-2 above the Black Sea on 30.09.2013 at 11h26min. Right- Surface wind field (ALADIN model) and the ground track of Jason-2 on 30.09.2013 at 11h26min

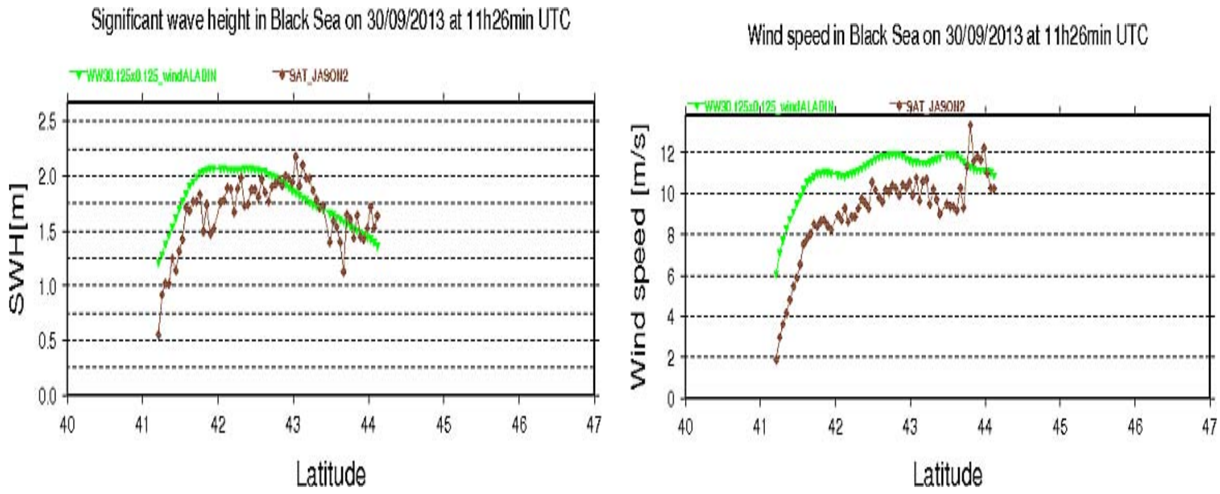

Fig. 8. SWH (WW3 wave model) and altimeter SWH along the Jason-2 track on 30.09.2013 at 11h26min-left. Wind speed (Aladin atmospheric model) and altimeter Jason-2 track wind speed on 30.09.2013 at 11h26min-right

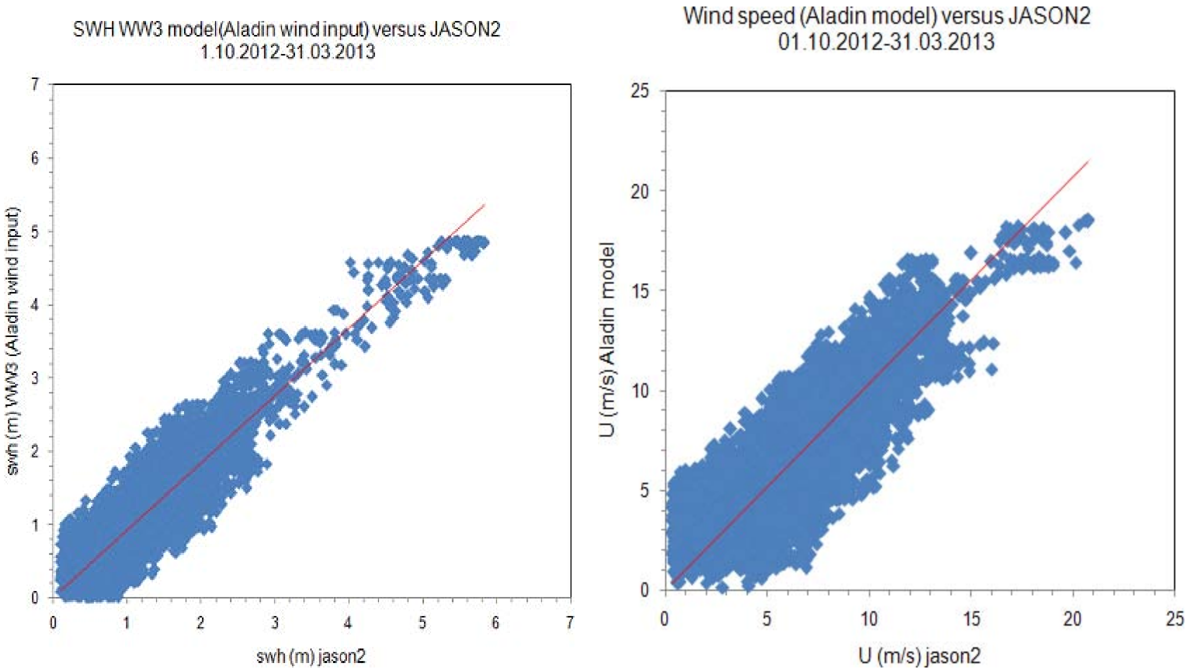

Fig. 9. Scatter diagram WW3 SWH versus the corresponding Jason-2 altimeter data during the period 01.10.2012-31.03-2013- left. Scatter diagram ALADIN wind speed versus the corresponding Jason-2 altimeter data during the period 01.10.2012-31.03.2013-right

Tab. 1 SWH (WW3 model) versus JASON2 altimetry for the period of 01.10.2012-31.03.2013

	Nb.	SWH WW3 (m)	SWH JASON2 (m)	Bias (m)	RMS error (m)	Scatter index
all	8964	1.11	1.19	-0.08	0.33	0.28
0.5-1 m	3193	0.72	0.76	-0.04	0.27	0.36
1-2 m	3834	1.29	1.40	-0.11	0.33	0.25
2-3 m	772	2.12	2.34	-0.22	0.44	0.19
>3 m	164	3.88	4.29	-0.40	0.54	0.13

Statistical results from the comparison of the altimeter-derived SWH and those from the wave model WW3 (Tabl.1) show that the absolute values of mean errors were relatively small during the period. The scatter plot (Fig.9) also shows a good agreement between the observed and the modeled SWH for WW3 wave model. In general WW3 wave model can provide accurate numerical simulation of the wave conditions over the Black Sea.

SWAN Model

SWAN (Simulating Waves Near Shore) is a third generation spectral wave model, developed in the technical university of Delft, Netherlands (TU- Delft) [14], with the purpose to be a coastal wave transformation model, which solves the action density balance equation. This high resolution wave model was implemented at NIMH in 2011[15]. The coastal wave prediction system was tested during the winter of 2011/2012. Fig.11 presents SWH during the most significant storm in the Black Sea in the last two decades (06-09 February 2012) which caused significant damage around the Bulgarian coast. The model is runing with grid resolution 0.0333°x0.0333° mesh size and it's driven by the 10 m surface wind fields from the output of ARPEGE/ ALADIN regional atmospheric model (the operational atmospheric model of NIMH-BAS), producing a forecast for the next 72 hours. Output from the SWAN model for near shore locations with depth below 20m was verified by comparing a satellite altimetry data from JASON1 and ENVISAT satellites (Fig.10 and Tab.2). In general the model can provide reliable wave forecasts for the Black Sea and coastal waters. For the entire Black Sea basin the corresponding statistics for several consecutive storms (observed significant wave height mean is 4.7m) is: bias -0.28m, root mean square error 0.61m and scatter index 0.13. Taking into account that we are investigating the behavior of the model under stormy (and not ordinary) conditions, such bias is 6% of the measured average value and taking into account that the scattering is below 0.15 we may conclude that SWAN when properly calibrated (replacement of the default choice of parameterizations) may work very satisfactory for extreme conditions (with the prerequisite that the atmospheric input is adequate enough)

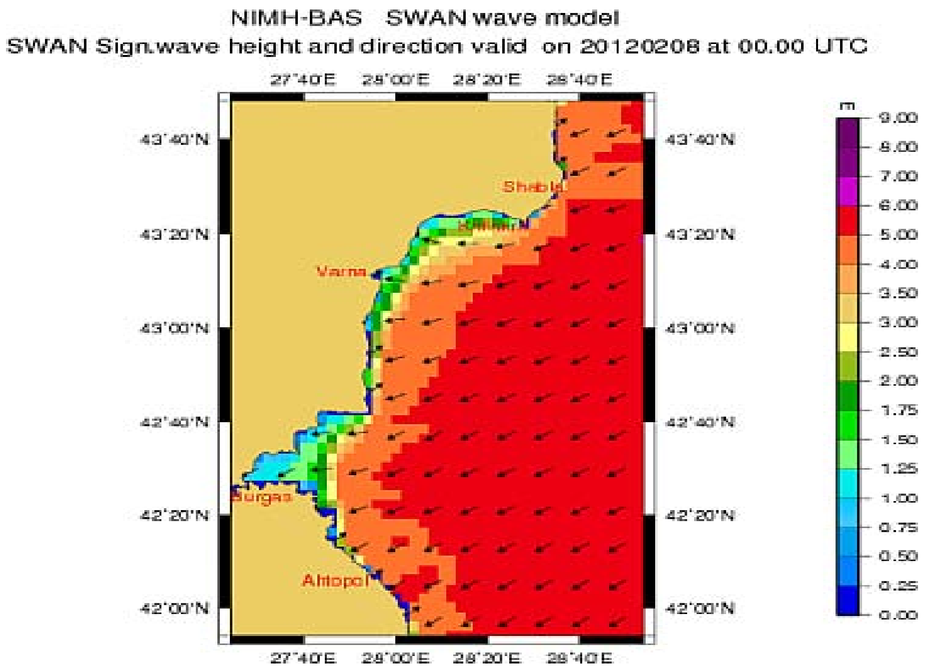

Fig. 10. Map of SWH (SWAN model) along the coastal area of the Black Sea on 08.02.2012 at 00:00UTC

Tab. 2. Comparison of SWH (SWAN wave model) with altimeter data from ENVISAT and JASON 1 only for locations with depth 10-20m but at least 10km from the coast during storms (the average measured wave height at these locations is 3m)

Significant Wave Height [m]- SWAN – shallow waters	Bias [m]	Root Mean Square Error (RMSE) [m]	Scatter Index
Entire period of the Forecast (+6- +72h)	-0.24	0.42	0.14

Fig. 11. Right track-SWH (m), measured by ENVISAT satellite on 07/02/2012, 21UTC and left track-SWH from JASON1 on 08/02/2012

Conclusion

The Earth Observation Satellite data helps to verify and improve the marine forecast and early warning system in order to increase the resilience of the coastal communities to the weather-related hazards. The overall conclusion is that operational wave models was found to produce a reliable wave forecasts for the Black Sea not only at deep, but also at coastal area. There is a good agreement in terms of statistical characteristics between the models output and the satellite data.

Acknowledgments

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References:

1. B o g a t h e v, A., (2008) Changes in operational suite of ALADIN-BG, ALADIN Newsletter No 34.
2. B o o i j, N., R. R i s, & L. H o l t h u i j s e n,(1999) A third-generation wave model for coastal regions 1. Model description and validation, Journal of geophysical research 104(C4), 7649- 7666.
3. C h e l t o n, D. B., J. C. R i e s, B. J. H a i n e s, L. L. F u, and P. S. C a l l a h a n, (2001) "Satellite Altimetry", Satellite Altimetry and Earth Sciences, ed. L.L. Fu and A. Cazenave, pp. 1-131.
4. J a n s s e n, P.A.E.M., (2007) Progress in ocean wave forecasting, J. Comput. Phys**.** 227, pp. 3572–3594.
5. J a n s s e n, P., B. H a n s e n, & J.-R. B i d l o t, Verification of the ECMWF forecasting system against buoy and altimeter data, (1997) Wea. Forecasting, 12, 763-784
6. J e a n – M i c h e l L e f e v r e, L o t f i A o u f, C h a f i h S k a n d r a n i, P i e r r e Queffeulou, Contribution of Satellite Altimetry to Wave Analysis and Forecasting, 15 years of progress in radar altimetry Symposium, Venice, Italy, 2006, http://earth.esa.int:80/workshops/venice06/participants/1268/index.html
7. K o r t c h e v a, A, (1998) Use of the ERS-2 satellite date for validation of wave model VAGBULH1 for the Black Sea. Bulgarian Journal of Meteorology & Hydrology, 6, 1-10.
8. K o r t c h e v a, A, K o r t c h e v, G, J-M. L e f e v r e. (2000) Operational numerical wind wave model for the Black Sea. Medit. Mar. Sci., 1/1, 2000, 65-69.
9. D i m i t r o v a, M., A. K o r t c h e v a, V. G a l a b o v, Validation of the operational wave model WAVEWATCH III against altimetry data from JASON-2 satellite , Bul. J. Meteo & Hydro 18/1-2(2013) 4-17
10. M a z a r a k i s, N., V. K o t r o n i, K. L a g o u v a r d o s, and L. B e r t o t t i,(2012) High-resolution wave model validation over the Greek maritime areas, Nat. Hazards Earth Syst. Sci., 12, 3433–3440.
11. OSTM/Jason-2 Products Handbook, (2011) EUM/OPS-JAS/MAN/08/0041, http://www.aviso.oceanobs.com/fileadmin/documents/data/tools/hdbk_j2.pdf
12. S a l e h A b d a l l a, P e t e r A. E. M. J a n s s e n, and J e a n-R a y m o n f B i d l o t, (2010) Jason-2 OGDRWind andWave Products: Monitoring, Validation and Assimilation, Marine Geodesy, 33(S1): 239–255.
13. T o l m a n, H. L, (2009) User Manual and System Documentation of WAVEWATCH III TM Version 3.14. *NCEP Technical Note*, 220 pp.
14. The SWAN Team (2011) Implementation Manual SWAN Cycle III version 40.85. Delft University of Technology
15. G a l a b o v, V., A. K o r t c h e v a, M. D i m i t r o v a, (2012) Towards a system for sea state forecasts in the Bulgarian Black Sea coastal zone: the case of the storm of 07-08 February, 2012SGEM2012 Conference Proceedings/ ISSN 1314-2704, Vol. 3, 1017 - 1024 pp, DOI: 10.5593/SGEM2012/S14.V3012.
16. WMO Codes, http://www.wmo.int/pages/prog/www/WMOCodes/OperationalCodes.html
17. W o o d, A new dynamical core for the Met Offices global and regional modelling of the atmosphere, (2005) Q. J. R. Meteorol. Soc. 131. 1759-1782.