ISSN 0001-4370, Oceanology, 2016, Vol. 56, No. 2, pp. 301–306. © Pleiades Publishing, Inc., 2016.
Original Russian Text © A.V. Gavrikov, M.A. Krinitsky, V.G. Grigorieva, 2016, published in Okeanologiya, 2016, Vol. 56, No. 2, pp. 322–327.

RESEARCH METHODS AND INSTRUMENTS

Modification of GlobWave Satellite Altimetry Database for Sea Wave Field Diagnostics

A. V. Gavrikov, M. A. Krinitsky, and V. G. Grigorieva

Shirshov Institute of Oceanology, Russian Academy of Sciences, Moscow, Russia

e-mail: gavr@saik.msk.ru, krinitsky@sail.msk.ru, vika@sail.msk.ru

Received June 11, 2015; in final form, August 4, 2015

Abstract—A new database of ocean wave parameters has been created based on satellite altimetry observations. The basis was data from the European Space Agency project GlobWave (www.globwave.org), which was transformed to suit upcoming requirements for global wave analysis. The new database contains additional wave characteristics (altimetry wind speed estimated using different parametric models, steepness, period, and some quality control parameters). It provides up-to-date tools for mass data preprocessing. The new database makes it possible to optimize wave field diagnostics on regional and global scales. Using the Envisat and Jason-1 satellite missions as an the example, we demonstrate the specific features of using the initial GlobalWave data set and the modified database.

DOI: 10.1134/S0001437016020065

INTRODUCTION

As of today, satellite altimetry data exhibit high accuracy in measuring significant wind wave heights (a less than 5% error in the range from 0.5 to 20 m) and result in uniform global coverage of the World Ocean except for higher latitudes. The standard averaging of the onboard altimeters matches the problems and methods of the monitoring the ocean state and evaluation and forecasting of wind waves and swells [1, 2]. The international project GlobWave (www.globwave.org) was initiated by the European Space Agency in 2009. A special-purpose database was created in the framework of the project. The base involves nine satellite altimeter missions (GEOSAT, ERS-1/2, TOPEX/Poseidon, GFO, Envisat, Jason-1/2, and CryoSAT) and covers the entire period of 1985 to the present. The GlobWave data have the advantage of a single data storage format and free access, which facilitates the use of data for dealing with a wide range of oceanographic problems related to sea wave patterns.

The GlobWave database stores NetCDF files (https://earthdata.nasa.gov/files/ESDS-RFC-022v1.pdf) with satellite altimetry Level 2 data averaged over a period of 1 s (about 7 km along the length of the satellite track) [8]. Normally, every file corresponds to 50 min (half an orbit pass) of measurements by a single satellite mission and involves more than 40 parameters of sea surface waves as well as quality flags and error estimates.

Use of altimetry data in the World Ocean study at climatic scales leads to a number of difficulties related to dealing with the large amount of data, filtering of the latter according to a number of criteria, elimination of gaps in data series, etc. For instance, about 0.7 million files should be processed in order to estimate of the global wave climate parameters using all nine missions. This structural feature of the GlobWave data array determines the unacceptably low information processing rate and requires a complex set of software.

We created a new database to accelerate data processing and simplify access to data primarily as applied to problems of wind wave analysis at global and regional scales.

Two quantities can be referred to direct altimetry measurements of sea waves, namely, the significant wave height (*swh*) and backscattering cross-section coefficient σ_0. They are computable from the shape of a signal pulse reflected from the water surface.

The GlobWave array involves both the uncalibrated significant wave height, taken from the initial AVISO data array, and the calibrated one, together with corrections provided by the GlobWave support team based on additional data verification (usually, from a network of NDBC buoys) [1, 5, 12]. As a rule, these corrections are introduced as functions of the *swh* itself and are lower than 10 cm. The surface wind velocity, sea surface temperature, pressure, humidity, and temperature of surface air are usually taken from model calculations [3, 6, 7, 9, 13]. However, every wind wave characteristic is required to solve problems of analyzing and forecasting the wave climate of the ocean (wavelengths and periods of waves, their steepness, age, etc.). Therefore, we have specified the goal of extending every record in the new database owing to additional diagnostic parameters that describe the state of the ocean.

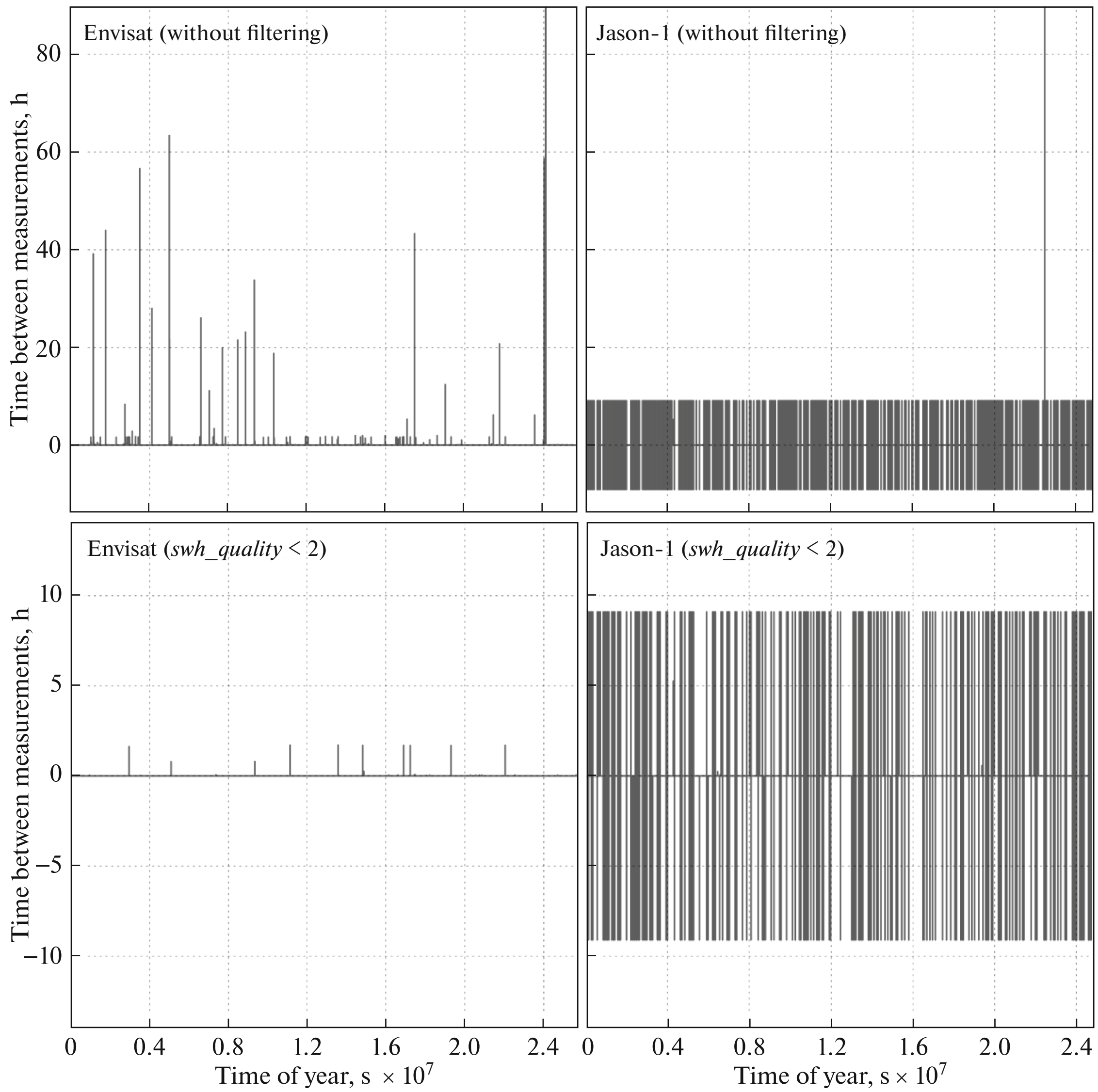

Fig. 1. Time difference between consecutive measurements (parameter *dtime*) in data of Envisat (left) and Jason-1 (right) without filtering (upper panel) and with minimal filtering *swh_quality* < 2 (lower panel), 2003.

SPECIAL ASPECTS OF INITIAL DATA PROCESSING

Initial satellite information is not protected from a variety of technical glitches and features of the recording equipment. Some errors are well documented and reflected in the data quality flags, while information on other errors is completely lacking. Figure 1 shows the magnitude of parameter *dtime* (the time difference between sampling in seconds) for cases of different degrees of filtering. A straight line should pass the points where the time gap between the measurements is 1 s, because the data are averaged to frequencies of 1.01–1.1 Hz (depending on the mission). However, two satellite missions Envisat and Jason-1, chosen as examples of unfiltered data, exhibit lags between the measurements as long as several days (Fig. 1, upper panel). The lags in the Jason-1 data are mostly systematic in nature and relate to the fact that a glitch occurs in the time recording almost every day at the same instant. This peculiar event has no effect on the quality of other parameters treated independently (pointwise), but it may be of fundamental importance when estimating the spatial gradients of given quantities.

The initial GlobWave array involves many capabilities for data filtering. For example, the integer parameter of quality assessment of the significant wave height *swh_quality*, which varies from zero (the most reliable measurement) to two (probably bad measurement), is useful for primary data monitoring. If one retains just the recordings with the highest quality flag *swh_quality*=0, then the pattern for the

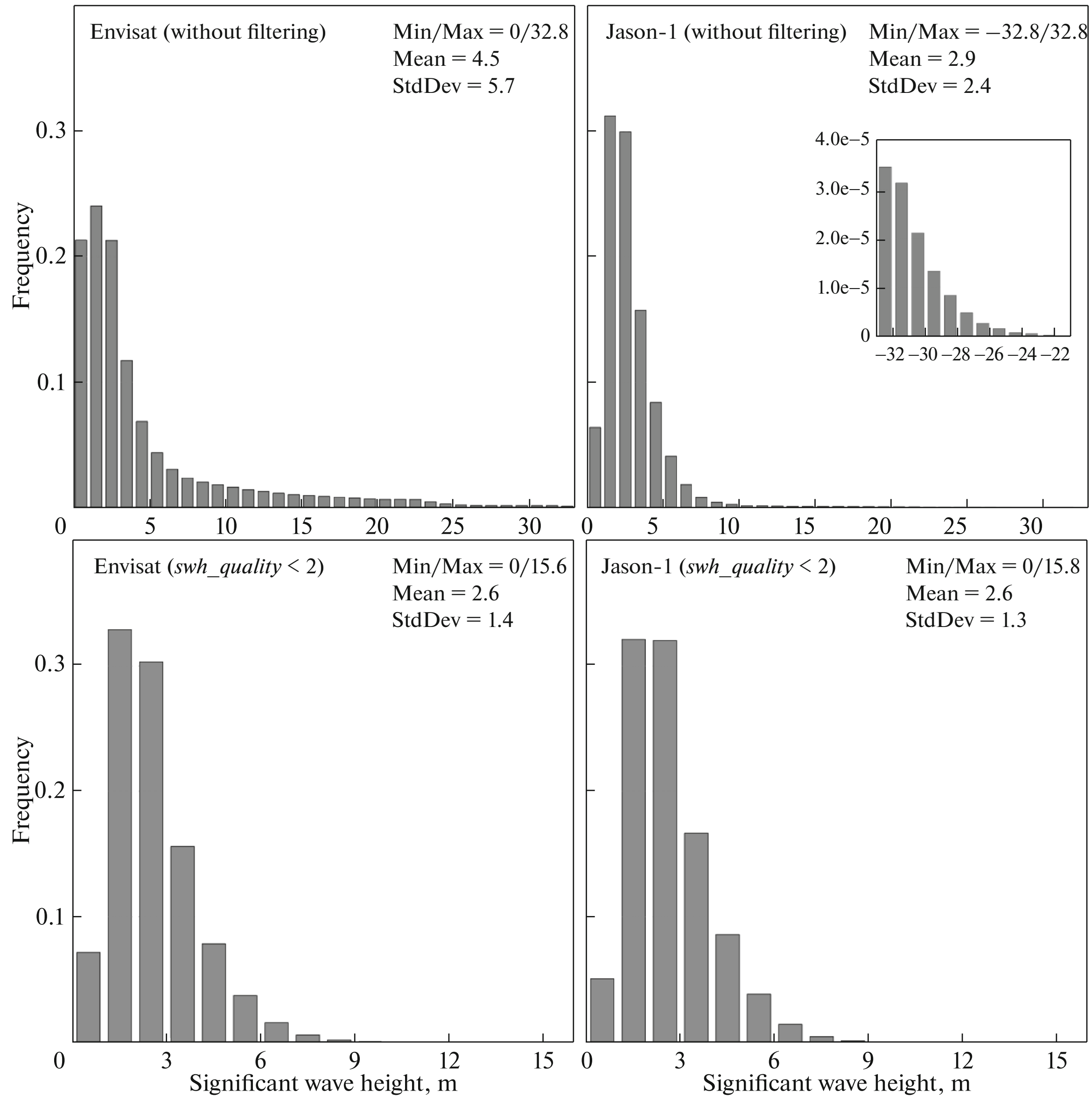

Fig. 2. Histograms of significant wave heights according to data of Envisat (left) and Jason-1 (right) without filtering (upper panel) and with minimal filtering *swh_quality* < 2 (lower panel). Main statistical characteristics for 2003 are given in the upper right corner.

dtime parameters substantially improves too (Fig. 1, lower panel). It is easy to see that filtering based on the quality flags of concomitant parameters does not completely solve the problem of time lags: the systematic errors in time recordings of the Jason-1 mission and certain lags in the Envisat mission remain.

Let us assess the quality of the GlobWave initial data using the significant wave height as the most important and directly measurable characteristic. The upper panel in Fig. 2 displays the filtration-free histograms of *swh* from Envisat (left) and Jason-1 (right), while the lower panel shows the same histograms after minimal filtering by the quality flag *swh_quality*. It is evident that the raw data are useless, because they involve negative values (Jason-1, insert I Fig. 2) and extremal wave heights exceeding 30 m (particularly in the case of the Envisat mission). The *swh* distribution assumes a more plausible appearance after minimal filtering at *swh_quality* ≤ 1. The degree of filtration required is determined by the specific problem. For instance, the highest quality flag (*swh_quality* = 0) is convenient for validation based on the wave buoys. When studying large waves in the open ocean, the quality degree may be reduced to one or two. In the last case, thorough control of the result is necessary (see Figs. 1 and 2, lower panels). Thus, the quality flag *swh_quality* satisfactorily filters the measurements of significant wave heights but it is unable to solve the problem of time lags and, consequently,

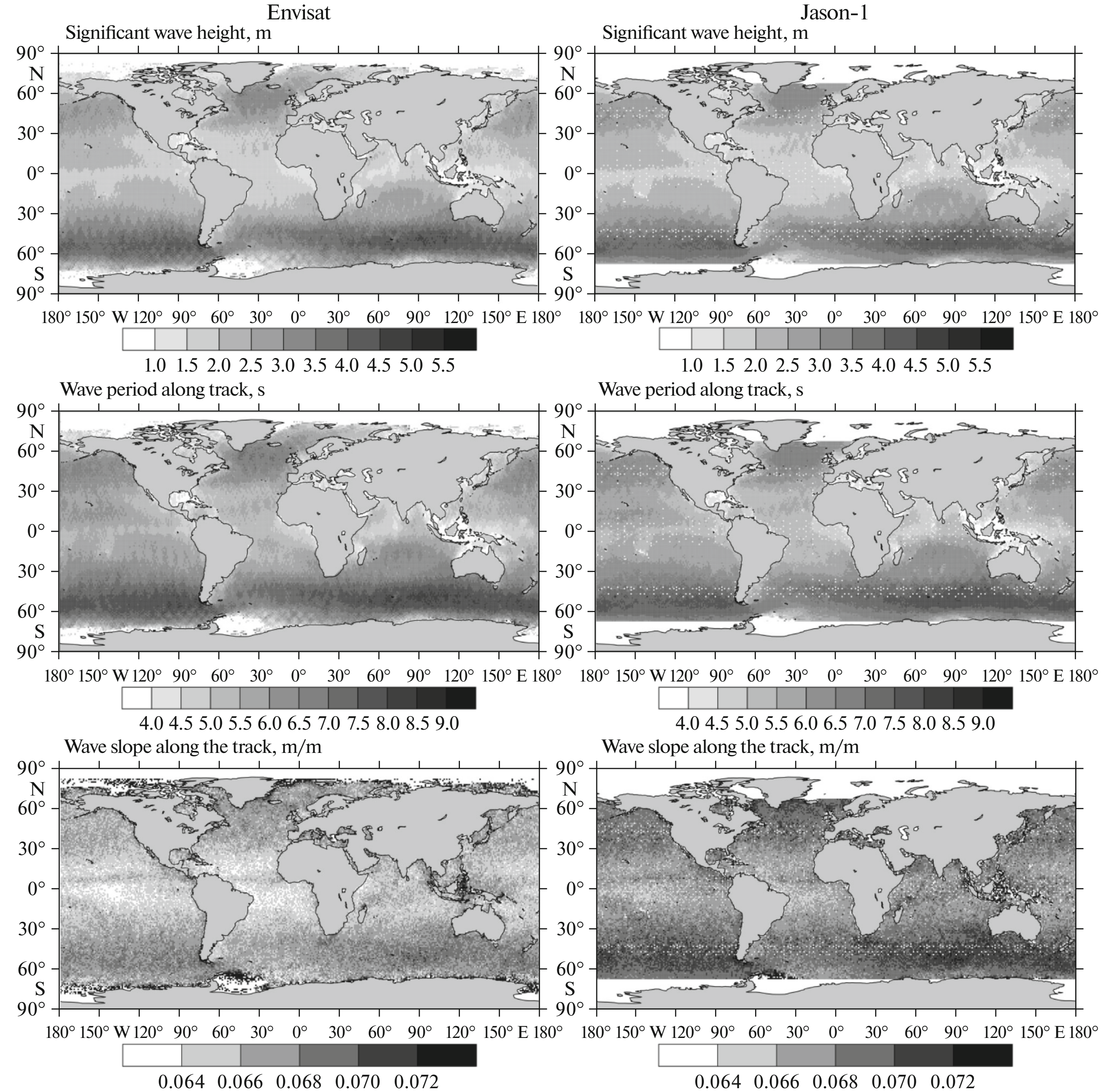

Fig. 3. Average annual significant wave heights, periods, and wave slopes for Envisat (left panel) and Jason-1 (right panel) missions after filtering by *swh_quality* < 2 and 5 km < *distance* < 8 km. This example is based on 2003 data.

intermeasurement distances, which results in lack of precision in estimating spatial gradients.

STRUCTURE OF NEW DATABASE

First, we ruled out the high frequency digitization of files when designing the modified database. The satellite cycles have been integrated into yearly packages. This substantially reduced the number of files, improved the access rate, facilitated file processing, and reduced the number of gaps when switching between files. The NetCDF format of recordings remained unchanged for the sake of inverse compatibility and better availability of information for potential users. Despite the insensitivity of NetCDF to the amount of data (this format supports direct access to files), we decided to exclude the redundant diagnostic information from GlobWave. As a result, the following unchanged data have been transferred to the new array: the time (*time*) and measurement coordinates (*lat*, *lon*); significant wave height (*swh*) with the quality flag (*swh_quality*) of both the uncalibrated and calibrated *swh* with the help of buoys; the backscattering cross-section coefficient (σ_0); the wind speed calculated from the empirical model [3] (*wind_speed_alt*); the distance to the nearest coast (*distance_to_coast*).

We decided to add extra parameters for monitoring the quality of information (*dtime* and *distance*) instead of filtering the initial *swh* because only a fraction of the information flagged as data of minimal quality (*swh_quality* = 2) are a fortiori inapplicable, and only a fraction of information flagged as data of maximum quality (*swh_quality* = 0) are saved from possible technical glitches.

Thus, the available files were integrated into annual series without losses of basic characteristics but after removal redundant information at the first modification stage of the GlobWave database. This considerably increased the rate of data reading and simplified the structure and storage of the array.

A new block of wave parameters represents the specific features of created database. Every recording is added to the estimates of the surface wind speed [6, 7, 9] and wave period [10, 14, 15] based on current empirical models. The wave slope, calculated from the physical model [4], has been added to the database as an additional parameter of high significance for diagnostics of surface wave dynamics. It should be emphasized that at present there are no alternative methods for measuring this important physical feature; hence, the issue of applicability of model [4] is extremely urgent. Calculation of wave slopes requires correct evaluation of the derivative of wave height along the length of the track. Therefore, it is necessary to solve the above problem of quality monitoring based on the *dtime* parameter. Problems of applying the model itself will be considered separately in the nearest future.

A software package for efficient use of the database has been developed. The package makes it possible to select the parameters of wind waves for any region and time period, to set different criteria for data selection and visualize the fields of wave characteristics obtained.

PRELIMINARY RESULTS OF NEW DATABASE

We assessed the efficiency of the new database for wind wave data for every parameter involved at global and regional scales. Figure 3 shows the fields of significant wave heights and diagnostic characteristics (slopes and periods of waves) calculated from model [4] for Envisat (left panel) and Jason-1 (right panel) in 2003. When calculating the diagnostic parameters, we used only the wave height data, flagged as *swh_quality* ≤ 1, when the distance between measurements (*distance*) ranged from 5 to 8 km. In this approximation, the resulting global distributions exhibit the expected climatic patterns and agree well with visual wave observations [11]. Relatively small systematic discrepancies between missions (within 2% of the measured value) can be minimized by data intercalibration with regard to the peculiarities of a specific scientific or practical problem.

The modified array incorporates the function of incrementing the database due to new satellite information and by adding new diagnostic parameters of wind waves. The software shell is being developed for interactive access of potential users. The shell involves options for choosing the desired information such as initial data sets or visualized and analyzed fields of wind wave characteristics (www.sail.msk.ru/climalt).

ACKNOWLEDGMENTS

The experimental data were prepared and processed in the framework of Russian Foundation for Basis Research project no. 14-05-00479. Calculations and analytical processing of data were supported by project no. 14-50-00095 of the Russian Science Foundation.

REFERENCES

1. O. Yu. Lavrova, A. G. Kostyanoi, S. A. Lebedev, et al., *Complex Satellite monitoring of Russian Seas* (Institute of Space Research, Russian Academy of Sciences, Moscow, 2011) [in Russian]. ISBN 978-5-9903101-1-7
2. *20 Years of Progress in Radar Altimetry Symposium September 24–29, 2012, Abstract Book* (Venice, Italy, 2012).
3. S. Abdalla, "Ku-band radar altimeter surface wind speed algorithm," in *Proceedings of the Envisat Symposium, April 23–27, 2007* (Montreux, Switzerland, 2007).
4. S. I. Badulin, "A physical model of sea wave period from altimeter data," J. Geophys. Res. **119**, 856–869 (2014). doi 10.1002/2013JC009336
5. G. Brown, "The average impulse response of a rough surface and its applications," IEEE Trans. Antennas Propag. **25** (1), 67–74 (1977). doi 10.1109/TAP.1977.1141536
6. D. J. T. Carter, P. G. Challenor, and M. A. Srokosz, "An assessment of Geosat wave height and wind speed measurements," J. Geophys. Res., C: Oceans Atmos. **97** (7), 11383–11392 (1992). doi 10.1029/92JC00465
7. D. B. Chelton and P. J. McCabe, "A review of satellite altimeter measurement of sea surface wind speed: with a proposed new algorithm," J. Geophys. Res. **90** (3), 4707–4720 (1985). doi 10.1029/JC090iC03p04707
8. *GlobWave/DD/PUG Issue 1.4, 16 December 2010* (Logica, London, 2010).
9. J. Goldhirsh and E. Dobson, "A recommended algorithm for the determination of ocean surface wind speed using a satellite-borne radar altimeter," in *Report JHU/APL SIR-85-U005* (Johns Hopkins University, Laurel, MD, 1985).
10. C. P. Gommenginger, M. A. Srokosz, P. G. Challenor, and P. D. Cotton, "Measuring ocean wave period with

satellite altimeters: a simple empirical model," Geophys. Res. Lett. **30** (22), 2150–2155 (2003). doi 10.1029/2003GL017743

11. S. K. Gulev, V. Grigorieva, A. Sterl, and D. Woolf, "Assessment of the reliability of wave observations from voluntary observing ships: Insights from the validation of a global wind wave climatology based on voluntary observing ship data," J. Geophys. Res., C: Oceans Atmos. **108** (7), 3236–3257 (2003). doi 10.1029/2002JC001437

12. P. A. Hwang, W. J. Teague, G. A. Jacobs, and D. W. Wang, "A statistical comparison of wind speed, wave height and wave period derived from satellite altimeters and ocean buoys in the Gulf of Mexico region," J. Geophys. Res., C: Oceans Atmos. **103** (5), 10 451–10 468 (1998).

13. J. Lillibridge, R. Scharroo, S. Abdalla, and D. Vandemark, "One- and two-dimensional wind speed models for Ka-band altimetry," J. Atmos. Ocean. Technol. **31**, 630–638 (2014). doi: http://dx.doi.org/10.1175/JTECH-D-13-00167.1

14. E. B. L. Mackay, C. H. Retzler, P. G. Challenor, and C. P. Gommenginger, "A parametric model for ocean wave period from Ku-band altimeter data," J. Geophys. Res., C: Oceans Atmos. **113** (03029), 16 (2008). doi 10.1029/2007JC004438

15. Y. Quilfen, B. Chapron, and M. Serre, "Calibration/validation of an altimeter wave period model and application to TOPEX/Poseidon and Jason-1 altimeters," Mar. Geodes. **27**, 535–549 (2004).

Translated by G. Karabashev