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MARINE PHYSICS

Global Historical Archive of Wind Waves Based on Voluntary Observing Ship Data

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Abstract—A new global archive of wind wave characteristics has been developed based on Voluntary Observing Ship (VOS) data for the period of 1888–2015. In addition to the basic meteorological variables, we have derived the records of visually observed heights, periods, and wind sea and swell directions. The main parameters have been supplemented by significant wave height and dominant period estimates, as well as wave geometry characteristics: steepness, wave age, and wavelength. Multistage quality control has been applied to correct or eliminate spurious values. Data are presented as individual records for every month and as original monthly means fields for every parameter. Easy access and use, along with representative data, make the new archive particularly special and applicable in different ways without any additional preprocessing. Visual wave observations assimilated in the new archive can be used to develop global and regional climatologies, estimate extreme wave characteristics and long-term trends in wave climate, verify and compare them with satellite measurements and model analysis, and test the theoretical laws of ocean wave development and propagation.

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INTRODUCTION

Modern wave research uses various information sources for the purposes of developing and testing theoretical laws and practical analysis of the wave climate. Data are derived from up-to-date computational models [5]; buoy measurements [6, 11]; satellite altimetry [1, 3, 13]; and field experiments. However, it is Voluntary Observing Ship (VOS) data that have the longest continuity dating back to 1870 and provide separate estimates of wind sea and swell covering the World Ocean.

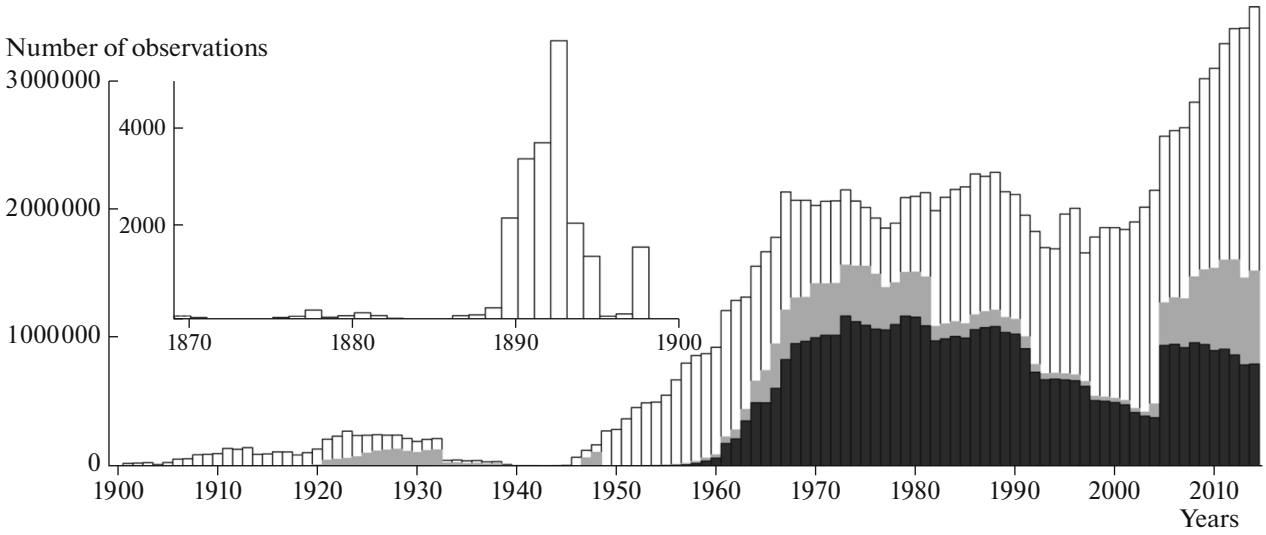
World Ocean collection of visual observations is assimilated in ICOADS archive (http://icoads.noaa.gov/) [1]. It contains all Voluntary Observing Ship data (VOS) from 1662 till nowadays and is updated permanently by means of new modern observations as well as historical logbook records [12]. Apart from wind wave parameters ICOADS archive contains information on more than a hundred characteristics of ocean state and near-surface atmosphere. But the records in the archive only undergo initial data control based on quality flags. Therefore, it is common for ICOADS data to have artificial errors in dates and coordinates, improbable wave heights (e.g., 33.5 m or higher), negative wave periods, and spurious values of accompanying meteorological parameters (e.g., a wind speed of 20 m/s for a zero wave height).

The main goal of this study was to develop an advanced wave climatology with a corresponding data archive based on visual wave observations. Easy access, thorough quality control and continuous data stream of all wave parameters make the new archive applicable in a number of ways for scientific and practical purposes.

VOS STATISTICS OF WIND WAVE DATA

The key feature of VOS wave data is that the observation practice hasn't been changed since 1853, unlike the coding system. The most important changes occurred in the mid-20th century. Until 1950, only the maximum of two components (wind sea and swell) was reported; and the upper limit of wave height was 16 m. After 1950, wind sea and swell parameters have been estimated separately and the possible maximum of height was established to be 25 m. This effect was partially taken into account when estimating long-term trends in wind waves [7]. Since 2006 all wave height restrictions in the VOS collection were removed. The coding precisions for visual observations are 0.5 m for wave heights, 1 s for periods, and 10 deg for directions.

Wave information was reported from 1870 but was inhomogeneous; therefore, continuous observational time series could only be formed since 1888 in local



Temporal distribution of the number of VOS reports containing visually observed wave parameters for 1870–2015. White color corresponds the number of wind sea heights, grey color – wind sea heights and swell heights, black color corresponds reports which contain all wave parameters.

regions, primarily along the major ship routes. The significant increase in the number of visual observations began from the mid-twentieth century when the sampling density allowed for the reproduction of global fields of wave parameters. It was this period that was used to construct regional [9] and global [8] wind wave climatologies. Temporal distribution of the number of wave reports is presented on figure 1 for the period 1870-2015. Note that wind sea height is the most frequently reported parameter (from 30 to 80% of the total number of records). The rarest observational parameter is the swell period (from 10 to 40%) which ultimately limits the number of records containing all wave characteristics (figure, black). A negative trend in the number of observations is marked from 1990 up to the middle-2000th which is typical for many others parameters and connected with increasing the role of satellite measurements.

Taking into account the features of VOS observations before and after 1950, as well as a different number of records for each parameter, a new archive of wind wave characteristics is presented in three streams:

Centennial (1888+): contains only significant wave height defined as the maximum of two observed components (wind sea and swell) [8, 9], dominant period, direction of wave propagation, wavelength, steepness, and wave age.

Interdecadal-1 (1950+): contains only wind wave parameters, such as wind sea height, period, direction, wavelength, steepness, and wave age.

Interdecadal-2 (1970+): includes all available wind wave parameters—wind sea and swell characteristics separately (heights, periods, directions, steepness, wavelength, and wave age), significant wave heights calculated by three methods [2, 8], dominant periods, steepness, and wavelength.

Every individual record also contains the time and coordinates of observation, wind direction and speed, SLP (sea level pressure), platform type, ship speed and ship course, SST (sea surface temperature), and SAT (surface air temperature).

DATA CONTROL AND PREPROCESSING FOR THE ARCHIVE

It is inevitable for such a huge amount of VOS data to suffer from different uncertainties caused by a variety of reasons, from incorrectly recorded and unprofessionally observed wave parameters to errors when digitizing old logbooks. Some of these mistakes can be corrected, other records have to be excluded.

The work began with the construction of the real distributions of the studied parameters in discrete measurement units: in seconds for periods, in half-meters for wave heights. This way any anomalies are easy to notice as the whole picture can be seen. Combined quality control criteria also proved to be effective for data monitoring. They include several variables essential for the phenomenon in question instead of checking parameters individually (one by one).

The first stage of quality control corrected errors related to artificial date and coordinates and deleted telegrams with inconsistencies in wave parameters (e.g., zero heights for nonzero periods and vice versa). Then we excluded all records with wave heights exceeding 25 m, corrected small seas, checked the accuracy of wind sea and swell separation, and carefully researched cases of zero wave heights, analyzing whether the given situation was indeed calm or is miss-

ing values. Lastly, steepness and wave age control have been applied (combined criteria). After all of the procedures, we were left with no more that 30% of records initially available in the ICOADS archive. All data control stages are described in detail in [2, 4, 8].

WIND WAVE CHARACTERISTICS ARCHIVE

New historical archive covers the globe from 80° N to 80° S and is free to download at http://www.sail.msk.ru/wow. The dataset is presented in three data streams. Every stream contains serial files with records which were left after preprocessing procedures. Additionally blocks of individual monthly means matrixes (80 × 180, 2° boxes) for every parameter are calculated. First coordinates are 79° N and 1° E. The choice of 2° spatial resolution is optimal to compensate the space-time inhomogeneity of VOS data, especially in the Southern Ocean [10]. Individual records are grouped by month to make it easier to get the desired information without having to download the whole archive.

The archive contains only reliable wind wave characteristics that have passed multistage quality control. It accumulates all visual wave observations for more than one hundred years and can be used without additional quality control, which makes it unique among similar collections. The archive can effectively serve as a basis for solving a variety of problems in oceanology, marine physics, and the safety of maritime activity. It was successfully used for constructing global and regional wind wave climatologies, extreme wave estimations and long-term trends assessments. The relatively stable spatiotemporal density of observations in recent decades makes them useful for verification and comparison with satellite measurements and ocean models, as well as for testing theoretical laws of wave development in the ocean. The archive will be updated as and when new data becomes available.

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