INVESTIGATION HYDROMETEOROLOGICAL REGIME OF THE WHITE SEA BASED ON SATELLITE ALTIMETRY DATA

Sergey A. Lebedev (1, 2)

(1) Geophysical Center of the Russian Academy of Sciences, 3, Molodezhnaya Str., Moscow, 119296, Russian, Email: lebedev@wdcb.ru
(2) Space Research Institute of the Russian Academy of Sciences, 84/32, Profsoyuznaya Str, Moscow, 117997, Russia, Email: sergey_a_lebedev@mail.ru

ABSTRACT

The White Sea are the seas of the Arctic Ocean. Today complicated hydrodynamic, tidal, ice, and meteorological regimes of these seas may be investigated on the basis of remote sensing data, specifically of satellite altimetry data. Results of calibration and validation of satellite altimetry measurements (sea surface height and sea surface wind speed) and comparison with regional tidal model show that this type of data may be successfully used in scientific research and in monitoring of the environment. Complex analysis of the tidal regime of the White Sea and comparison between global and regional tidal models show advantages of regional tidal model for use in tidal correction of satellite altimetry data. Examples of using the sea level data in studying long-term variability of the Barents and White Seas are presented. Interannual variability of sea ice edge position is estimated on the basis of altimetry data.

1. INTRODUCTION

The White Sea is a semi-enclosed inland sea (Fig. 1). The sea border with the Barents Sea is a line joining Cape Svyatoy Nos (northeastern coast of Kola Peninsula) with Cape Kanin Nos (northwestern extremity of Kanin Peninsula). The northern part of the sea is called the Voronka (funnel). The southern and central parts of the White Sea called the Basin are the largest and deepest parts of the sea. There are also several large and shallow bays in the area, namely the Dvinsky, Onega, Mezen, and Kandalaksha bays. The Gorlo (neck) is a narrow strait connecting the Basin and Voronka. The total water surface area is 90,873 km^2 including islands, and the total volume is 6,000 km^3 including also the Voronka area opening to the Barents Sea. Thus, the White Sea covers approximately 6% of the total open water area of both seas and comprises only 2% of the total volume of marine water, but it assumes more than half of the river runoff in the region. The White Sea watershed area is 729,000 km^2 [1]. The total river runoff is 259 km^3/year, which is about 4% of the total amount of the White Sea water volume. The main rivers are the Severnaya Dvina, Onega, and Mezen having runoff of 111, 18, and 26 km^3/year correspondingly [2–3]. In the White Sea, winds from the south, southwest, and west prevail from October to

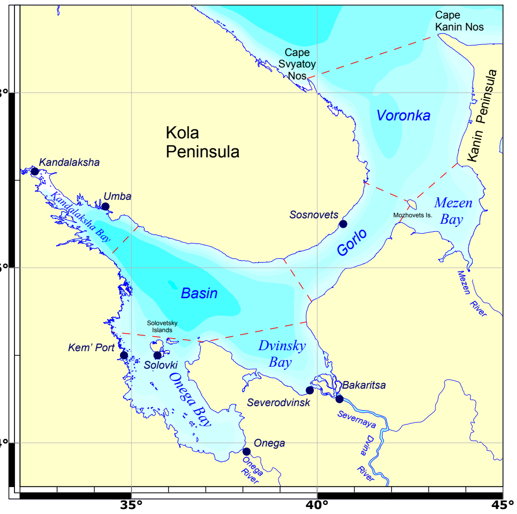

Figure 1. Maps of the White Sea. Dashed lines show boundaries of the seas and their internal parts. Circles mark tide gauges location [4].

March, whereas in May–August winds from north, northeast, and east are most frequent [2]. Southeasterly winds are frequently observed at the top of the bays (in ports Mezen, Kandalaksha, Onega). Monthly mean wind speed in the open sea and on islands is 7–10 m/s from September to April and 5–7 m/s from May to August. In the bays running deeply on land side, mean wind speed does not exceed 3–5 m/s during the whole year.

The general circulation and sea level variations in the Barents and White seas are formed under cumulative effect of wind forcing, water interaction, and exchanges among surrounding seas, strong tides, peculiarities of bottom topography, seasonal variability of river runoff, precipitation and ice cover, and other factors. Thus, sea level variations in the Barents and White seas have a complex nature and are characterized by a significant spatial and temporal variability.

The seasonal variations of the sea level in the Barents and White seas are caused by an impact of atmospheric pressure and wind, temperature and salinity, river runoff, precipitation, and ice cover [3]. A range of seasonal variations in the White Sea level are observed in the estuary zones of the Onega and Severnaya Dvina rivers and may reach 30–60 cm [3, 5].

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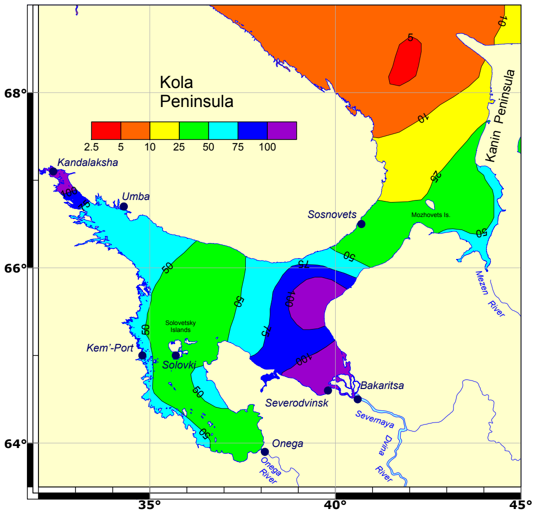

Figure 2. The ratio (%) of total nonlinear harmonic amplitudes to total main tidal component Amplitudes for the White Sea [4].

Tides play the key role in the coastal water dynamics in the White Sea, and dominate in total sea level variations. The tidal heights in the White Sea vary from 8 m in the Mezen Bay to 1 m in the Dvinsky Bay [3, 6−7].

As a result of nonlinear tidal phenomena and nonlinear interaction of the main tidal components (M_2, S_2, N_2, K_2, K_1, O_1, P_1, Q_1), there is a set of additional tidal harmonics [8]. According to the results of numerical simulation [9], in the White Sea, the maximum value is about 100% for the Severnaya Dvina and Kandalaksha bays (Fig. 2).

Ice cover is also a cause of seasonal variability of the White Sea level and when most of the marine areas are frozen in winter [3].

Historically, sea level variability in the White Sea (tidal, storm surge, seasonal and interannual variations) has been investigated on the basis of the tide gauge data and so, such studies were limited within a coastal zone. Analysis of sea level variations offshore has become possible with a development of mathematical and numerical hydrodynamic simulation. Since 1992, a new reliable source of information about variability of the sea level and ice cover extent, as well as of wind speed and wave height – satellite altimetry data has become available.

2. VALIDATION OF SATELLITE ALTIMETRY MEASUREMENTS

In the framework of the ALTICORE Project (ALTImetry for COastal REgions, http://www.alticore.eu), we have analyzed altimetric measurements (1 Hz data) from the satellites TOPEX/Poseidon (T/P), ERS-1/2, Envisat Geosat Follow-On (GFO), and Jason (J1) from September 1992 to December 2008 in order to compare satellite-derived data on sea level and wind speed in the coastal zone with in situ measurements at coastal meteorological station (MSs) of the White Sea [10]. Satellite altimetry data were received from the following data bases:

- T/P, ERS-1, ERS-2, Envisat, GFO, and J1 were obtained from the Ocean Altimeter Pathfinder Project at the Goddard Space Flight Center (GSFC) NASA [11−12].
- Besides, T/P Merged Geophysical Data Records generation B (MGDR-B) were obtained from the NASA Physical Oceanography Distributed Active Archive Center (PODAAC) at the Jet Propulsion Laboratory (JPL) of California Institute of Technology [13].
- The J1 Interim Geophysical Data Records (IGDR) and Geophysical Data Records (GDR), generation A, B, C, were obtained from Archiving, Validation, and Interpretation of Satellite Oceanographic data (AVISO) and PODAAC [14].
- T/P, ERS-1, ERS-2, Envisat, GFO, and J1 data were obtained also from Radar Altimeter Database System (RADS) [15].
- GFO GDR data were received from Laboratory for Satellite Altimetry (LSA) at NOAA's National Environmental Satellite, Data and Information Service (NESDIS) [16].

Information and software of the Integrated Satellite Altimetry Data Base (ISADB) developed in the Geophysical Center of Russian Academy of Sciences (GC RAS) [17−18] have been used for data processing and analysis.

ISADB has three levels of information: input altimeter data, the supplementary geophysical and geodetic information, and the results of the problem-oriented preliminary processing. The database management system (DBMS) has the problem-oriented modes of a complex analysis of data and provides the space-time graphic presentation of results of processing in addition to the routine DBMS functions. It also allows recalculating the corresponding corrections, when new or updated geophysical models are linked to the ISADB.

In situ tide gauge (TG) data were obtained from Hydrometeorological Research Center (HMRC) of Russian Federation.

In situ meteorological data on 6-hourly (0, 6, 12, 18 GMT) wind speed at coastal meteostations (World Meteorological Organization [WMO] weather stations) were obtained from Russian Weather Server (http://meteo.infospace.ru/main.htm).

3. WIND SPEED

In the framework of the ALTICORE project, the consistency between altimeter-derived wind speed and measurements on coastal meteorological stations (MS) was checked. Satellite derived wind data used were obtained from the RADS data base. Methods of choosing satellites and their tracks, spatial coordinates,

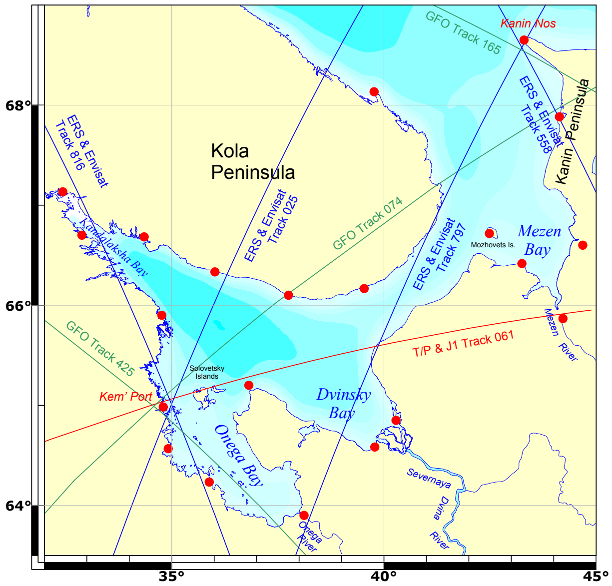

Figure 3. ERS & Envisat GFO, and T/P & J1 satellites tracks in the White Sea which were used for the comparative analysis between altimetric and MS in situ data. Red circles mark locations of MSs [4].

and time of satellite measurements of wind speed for every coastal place under consideration as well as peculiarities of computer processing of the formed data files are described in [19].

For the comparison, 21 MSs on the White Sea coast were selected. As an example, we show results of the comparison for two MSs – Kem' Port (White Sea) and Kanin Nos (Barents Sea). Satellites and their tracks chosen for these coastal places were as follows:

- For Kem' Port, ERS & Envisat (tracks 025, 816), T/P & J1 (track 061), and GFO (tracks 074, 425).
- For Kanin Nos, ERS & Envisat (tracks 558, 797) and GFO (track 165).

The ERS & Envisat, GFO, and T/P & J1 satellite tracks, which were used when obtaining satellite-derived wind speed data for Kem' Port and Kanin Nos are shown in Fig. 3. Examples of altimeter and observed (in situ) data on wind speed and corresponding scatter plots for these MSs are given in Fig. 4 and 5, respectively.

In the cases of both Kem' Port and Kanin Nos (Fig. 3), MS databases for 2000–2007 were used (Fig. 4a and 5a, respectively). Altimeter wind speed values for Kem' Port were in most cases noticeably less than meteo ones (Fig. 4a and 4b) and correlation between them was practically absent (r = 0.16). Influence of land may be supposed as a possible reason of such poor correlation. Better correlation (r = 0.45) was observed in the Kem' Port.

Such a "wind decomposition procedure", which was successfully tested in the Black and Caspian seas also [19–20], seems to be very promising in the calibration and validation of altimeterderived data in coastal regions of the World Ocean.

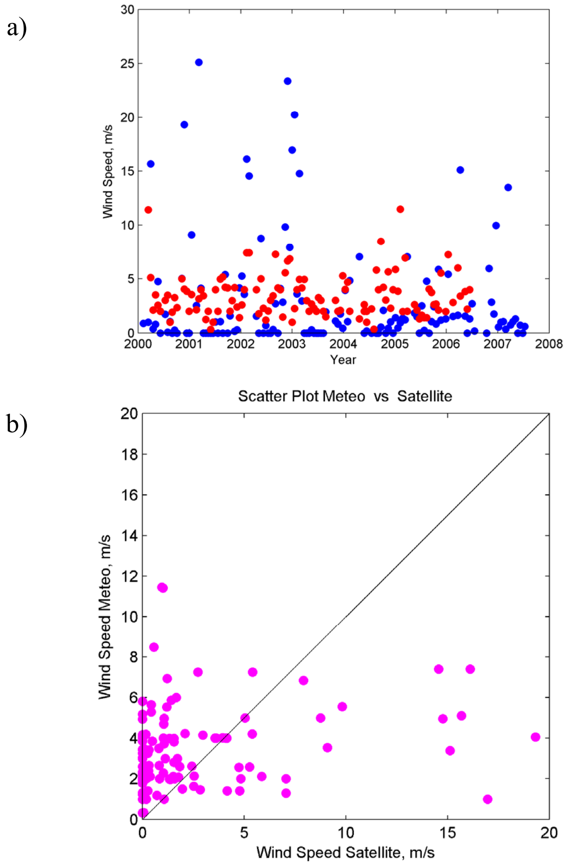

Figure 4. Temporal variability of in situ MS (red circles) and altimetry (blue circles) wind speed (a) and scatter plot of observed versus GFO altimeter data (track 425) (b) for Kem' Port [4].

4. SEA SURFACE HEIGHT

Also in the framework of the ALTICORE project, the consistency between altimeter sea surface height (SSH) data acquired by the satellites T/P, ERS-1/2, Envisat GFO, and J1, and measurements of 8 TGs in the White Sea was investigated (Fig. 1). Processing of satellite altimetry data included calculation of sea surface height anomaly (SSHA) by using all corrections without tidal and inverse barometer correction. Then, for every cycle of the selected satellite passes, spatial coordinates of the point nearest to the concrete TG location (within 15 miles) were determined.

For the White Sea, a comparison between satellite and TG SSHA data also shows significant correlations (>0.6) for all the satellites except GFO. Greater values of correlation for TG Onega (0.76 for T/P and J1 data; 0.96 for ERS-1/2 and Envisat data) and TG Severodvinsk (0.97 and 0.98, respectively) are conditioned by their location. Both TGs are situated in river estuaries; therefore, river runoff has a strong influence on the hydrological regime in these parts of the White Sea. Correlation minimum (0.66 and 0.61, respectively) is observed at TG Kem' Port where

nonlinear and residual tidal phenomena are important on shallow water. Some details of sea level comparison are shown in [4]. This result is also in accordance with our previous investigations [21−22].
According to the results obtained, satellite altimetry SSHA data are in good consistency with TG SSHA.

5. LONG-TERM VARIABILITY OF SEA LEVEL

Sea level reflects changes in practically all dynamic and thermodynamic processes of terrestrial, oceanic, atmospheric, and cryospheric origin. During the period 1954–1989 the observed sea level at TGs over the Russian sector of the Arctic Ocean rose at a rate of approximately 0.12±0.06 cm/year; taking into consideration corrections for the process of Earth's crust uplift and glacial isostatic adjustment, this rate was approximately +0.18±0.08 cm/year [23]. According to other investigations, this value was +0.12±0.08 cm/year [4].
However, the coast of Kola Peninsula on the White Sea rises with a rate of 4–8 mm/year [24].
At the end of investigation of long-term variability of sea level anomaly (SLA) of the White Sea level was calculated by satellite altimetry data and it showed that SLA had rate of increase 0.32±0.07 cm/year (Fig. 5).

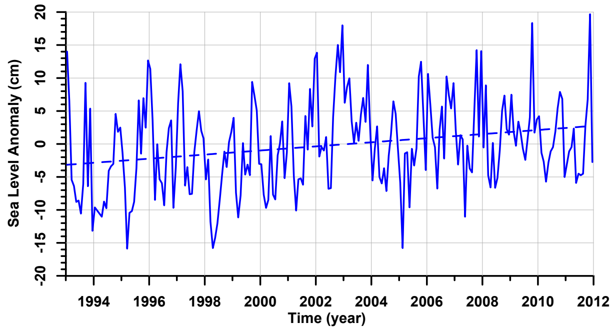

Figure 5. Temporal variability of in situ MS (red circles) and altimetry (blue circles) wind speed (a) and scatter plot of observed versus GFO altimeter data (track 425) (b) for Kem' Port [4].

6. ACKNOWLEDGEMENTS

Spatial and temporal coverage of the White Sea by satellite altimetry missions offers the possibility of continuous high-precision monitoring of sea level and sea surface wind speed. Influence of tides must be successfully estimated using numerical simulation based on the regional tidal models rather than global ones. The results obtained seem to be promising in application of satellite altimetry data on SLA and wind speed for monitoring a number of environmental parameters of the and White Sea.

7. ACKNOWLEDGEMENTS

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