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MEAN MONTHLY SERIES OF SEA LEVEL OBSERVATIONS (1777-1993) AT THE KRONSTADT GAUGE

by

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Preface

The work of the Special Study Group 5.147 of the International Association of Geodesy began already back in 1989, when an ad hoc study group was created at the IAG General Meeting in Edinburgh. At the IAG General Assembly in Vienna in 1991, the ad hoc group was turned into a study group.

The goals of the study group, called the Baltic Sea Level Project (BSL), were (Kakkuri, ed. 1995):

- To unify vertical datums and their time variability for countries around the Baltic Sea;
- To contribute to the determination of the gravity field and geoid in the Baltic Sea region;
- To determine the sea level and sea surface topography of the Baltic Sea;
- To study the effect of sea floor topography;
- To monitor postglacial rebound, especially in the sea area; and
- To remeasure the Baltic Ring for horizontal crustal deformation study.

In the course of its successful work, among many other things, three major GPS campaigns were organized in the Baltic Sea area, in 1990, 1993 and 1997. The last campaign was co-ordinated with the EUREF Subcommission's EUVN (European Unified Vertical GPS Network) GPS campaign, and included a number of North-West Russian sites - amongst which are several of the mareograph sites referred to also in the current Report (Abalakin et al. 1998a).

There are only a handful of mareograph sites in the world which offer a sea level time series extending over centuries. Such time series are of great importance for studying the problem of the mean sea level and its possible changes over time. Kronstadt is one of these sites. Therefore the current study, aimed at critically documenting and analysing the historical record, is a vital contribution to the ongoing work that was initiated by the Baltic Sea Level project. Already earlier, related studies (Bogdanov 1995a; Bogdanov and Taybatorov, 1995) appeared in the Reports series of our Institute, and, as part of our co-ordinating role, the Finnish Geodetic Institute is happy to offer this opportunity to our Russian colleagues to publish this essential reference data.

Masala, January 28, 2000

Risto Kuittinen

Director-General, Finnish Geodetic Institute

Contents

List of some local topographical names

Name in text	English translation and/or locality
Baltic Sea	
Svetlogorsk	City in the Kaliningrad region
Rybnyy, Settlement	[Fish] port in the Svetlogorsk area
Gulf of Finland (GF) and surrounding territories	
Gogland, Ostrov	Gogland Island, in W part of GF
Kotlin, Ostrov	Kotlin Island, in E part of GF
Kronstadt	City, on the Kotlin Island
Lomonosov	City, 5 km S of Kronstadt
Nevskaya Guba	[Neva] Bay, in E part of GF, from Neva delta to Kotlin Island
Pulkovo, Settlement	Within the St.Petersburg limit
Shepelevo, Settlement	40 km W of Lomonosov
St.Petersburg	Port and City in Neva River delta
Svetloe, Settlement	In the Karelian Isthmus
Vyborg	Port and City, in NE part of GF
Kronstadt area	
Admiralteyskiy (Obvodnyy) Kanal	[Admiralty] ([Bypass]) Channel
Ital'yanskiy Prud	[Italian] Pond, between [Blue] Bridge and [Merchant] Harbour
Kanal Petra Velikogo	[The Peter the Great's] Channel, between [Merchant] and [Middle] Harbours
Kronshlott	First crib fort near Kotlin Island
Kupecheskaya Gavan'	[Merchant] Harbour
Obvodnyy Kanal	[Bypass] ([Admiralty]) Channel
Siniy Most	[Blue] Bridge over [Bypass] Channel
Srednyaya Gavan'	[Middle] Harbour
Voyennaya Gavan'	[Naval] Harbour
Lomonosov area	
Oraniyenbaum	Railway station, Lomonosov
Shepelevo area	
Kamennyy, Mys	[Stone] Cape in [Battery] Bay
Batareynaya, Bukhta	[Battery] Bay
St. Petersburg area	
Moika, Reka	"Moika" [Wash] River
Nyensckans	Fortified port before St.Petersburg
Siniy Most	[Blue] Bridge over "Moika" River
Vasil'yevskiy Ostrov	Island in delta of the Neva River

Abstract

The versions of mean monthly (MMSL) and mean annual (MYSL) sea level observation series for 1777-1993 at the Kronstadt gauge and for 1989-1993 at its Shepelevo duplicate (Baltic Sea, Gulf of Finland, Isle of Kotlin, Russia) are submitted for the first time. The archival, fund and published materials of the State Hydrographical Service of the Navy, State Hydrometeorological Service, State Geodetic Service, Russian Academy of Sciences are used. The Kronstadt gauge is the oldest sea level station of Russia, which zero point is accepted as the Initial Point of the State Levelling Network and the Origin of National ("Baltic") System of Heights. The basic information about the tide gauges, sea level observations, datum level, geodetic control and methods of restoration of long-term series is given. Some results and prospects of the further works are discussed.

1 Introduction

The fundamental scientific and large practical importance of the secular series of instrumental observations on the fluctuations of levels of underground waters, lakes, seas and oceans for decision of various tasks of geodesy, geophysics, climatology, navigation, and oceanology is well-known. One such series has been accumulated at the Kronstadt gauge, the oldest in Russia, which is among the first three in the world list of observatories with the most long-term available observation series besides Amsterdam (since 1700) and Stockholm (since 1774), (Ekman, 1988; Woodworth, 1990; Bogdanov, 1993b). By special resolution of the USSR Council of Ministers in 1946 its zero point was accepted as the initial point of the State Levelling Network and the Origin of the National ("Baltic") System of Height (Baltic Height Datum).

However, despite the all-round attention of experts to the Kronstadt gauge for more than two centuries, its history has not been investigated with sufficient completeness for scientific and practical purposes. Such a situation is characteristic for many observatories of the world. Political and social-economical cataclysms, wars and revolutions, natural and anthropogeneous changes, change of scientific paradigms, ideologization of science and departmental isolation of researches effected and continue to effect negatively the quality and safety of materials of the unique long-term measurements.

The Kronstadt gauge repeatedly was moved from place to place, its zero points and operational bench marks of levelling reference of observations underwent changes, purposes and tasks of the observations evolved. At the same time, the richest archival material on the gauge and the changes in this area influencing the long-term representativeness of measurements, gives unique opportunity to specify the history of the Kronstadt station and the observations carried out at it, as well as to develop a methodology of restoration of the Kronstadt series and sea level series analogous to it.

The analysis of available materials testifies not only to the advantages and the lacks of such observations of the past, but also gives principal opportunity to create on a modern technical and methodological basis a uniform global observatory network of a new generation and to form a series of completely homogeneous precision on intervals for not less than first hundred years. From these positions, restoration of the Kronstadt sea level series is considered as the initial stage of such works which are also necessary for fundamental observatory research of secular changes in the St. Petersburg region in the third millennium (Bogdanov, 1996c).

The following materials were used in the course of work: fund, archival and published materials of the State Hydrographical Service of the Russian Navy Department (till 1952), Federal Service of Hydrometeorology and Environmental Monitoring, Federal Service of Geodesy and Cartography, Russian Academy of Sciences (National Working Group "Baltica" of the St. Petersburg Scientific Centre, Central Astronomical Observatory at Pulkovo, Joint Institute of Physics of the Earth, Institute of Limnology), as well as the report "Sea Level at Kronstadt" prepared in 1992 by St. Petersburg Branch of the State Oceanographic Institute of the Federal Service of Hydrometeorology and Environmental Monitoring under Contract No. 0020-92 with the Joint Institute of Physics of the Earth of the Russian Academy of Sciences.

This work was executed within the framework of the National Working Group "Baltica" of the Russian Academy of Sciences and the Subcommission 1 of the Special Commission 8 (formerly Special Study Group 5.147) "Studies of the Baltic Sea" of the International Association of Geodesy.

2 Brief historical information on the sea level observations in the region

As far back as in the VIII-XI centuries the Volkhov-Ladoga-Neva waterway was the most important part of the transcontinental trade way from the Arabian East and Byzantium to the North Europe and in the opposite direction (Sorokin, 1997). It is doubtless that the navigation along this way required some form of observations on the changes of its water regime. However, the saved data on observations are not numerous and refer to later time. In particular, A. I. Hipping quotes the note on the Swedish map "Geometrisk Delineation uthaf Newa-Strömmen ifrån Ladoga-Sjön och Nötheborg intill Nyen-Skantz, men den öfriga delen intill Öster-Sjön är obiter och ungefehr tecknat... " about the rise of the Neva level near Nyensckans during the storms of western bearings by 2.3-2.4 m "above the ordinary" (Hipping, 1909, II, p. 183). The map is dated October 1681 and is signed "E. F. P. Bgh".

Since the end of the XVIII century the method of water levels fixation by cuts on rocks or erratic boulders has been widely practised. One of the early messages of such kind refers to 1697, when Simon Mattsson marked by cut the Gulf of Bothnia level near Vargö, which by 1853 had increased by 181 cm above the ordinary (mean) sea level (Bogdanov, Kakkuri, 1998). However, observations of the sea level gradually concentrated in large commercial or military ports and were carried out on the vertically installed rods (gauges). At such stations some of the most long-term series of sea level observations in Amsterdam (1700-1925), Stockholm (1774-), Kronstadt (1777-), Brest (1807-), Swinoujscie (1811-), etc. have been accumulated (Lazarenko, 1951; Ekman, 1988; Woodworth, 1990; and others).

The start of the sea level observations in the area of present Kronstadt (Kronshtat, Cronstadt) is usually associated with the name of Peter I and the year 1703, though direct confirmations of this have not been found yet. Anyway, Peter I displayed great interest in depth sounding and search of favourable waterways in this area, and on the project drawing of the first crib fort Kronshlott (Crohn-Schlott, Cron Schloss), located near Kotlin Isle, all its height marks had been already reduced to the "ordinary" (mean) sea level (Bogdanov, 1996b).

According to (Reference 1972) observations in Kronshlott have been known since 1707. The analogous observations at Peter and Paul's Fortress in St. Petersburg started at least before 1715 (Georgi, 1794). For the period 1721-1729 the maximum levels of the Neva were published, and for the first time the reasons for the necessity of creation of the observatory network for studying the Neva floods phenomenon (Leutmann, Euler, 1729) were stated. Extracts from meteorological magazines about water levels (1726-1744) were regularly published in the Academy of Sciences publications (Krafft, 1780).

There is information on observations carried out by the gauge located on the quay of Vasil'yevskiy Ostrov (Gellert, 1741) in St. Petersburg in 1740-1741 and in 1749-1777 by the "scale" established on Reka Moika 840 feet (~256 m) E from Siniy Most (Krafft, 1780). By the comparison in the Kronstadt area of the repeated depth soundings of 1739 and 1744 their great difference was found out. In this connection, in 1752 A. I. Nagayev offered to reduce all soundings to the same ordinary sea level determined by hourly observations at the Kronstadt gauge.

After the catastrophic flood of 1777 the Navy Department organized a special service, the basic task of which was to notify the inhabitants of St. Petersburg and Kronstadt about the menace of floods. However, regular sea level observations at the Kronstadt gauge are known now only since 1806, and their mean values have been published since 1815 (Notes 1807-1827; Bogdanov, 1993b). The materials of the sea level observations in the XVIII century are available at present only for 1777 (Krafft, 1780, Bogdanov *et al*., 1993).

3 Basic knowledge of the Kronstadt and Shepelevo gauges and peculiarities of secular series restoration methods

The Kronstadt gauge is located in the east part of the Gulf of Finland in the Baltic Sea (in Nevskaya Guba named also "Marquess Pool") on Ostrov Kotlin within the Kronstadt city limits. Its present zero point is fixed on the pier of Siniy Most over Obvodnyy (Provodnoy, Admiralteyskiy, Sovetskiy) Kanal. A metal rod (3.6 m) is established at the same place and 12 m from it, in the pavilion specially constructed in the 1950s, a mareograph is placed (φ = 59°59', λ = 29° 46'). Earlier, since 1896, a mareograph was placed in a hut located in the same channel, approximately 230 m from Siniy Most (φ = 59°59', λ = 29°47').

Obvodnyy Kanal in the area of Siniy Most is connected with the open sea through Ital'yanskiy Prud and Kupecheskaya Gavan'. Due to the channel orientation in SW direction in this site, the level in it is rather sensitive to the winds of the same (prevailing) direction.

Since 1886 the constant operational bench mark was that on the P. K. Pakhtusov monument, which was recently replaced by the wall mark of the Navy Hydrographical Service. "Ordinary" (mean) sea level; marks of M. F. Reinecke, F. F. Vitram, Chr. -F. Tonberg; the present zero point; the above mentioned wall mark - the present operational bench mark of the station, were used as the zero point for sea level observations at different times.

There are many "white spots" in the history of the Kronstadt gauge, its zero point and Siniy Most. Contradictory information is available on the functioning of several gauges till 1840, transfers and positions of levelling devices, processing and representation of the data, terms of observations, calendar systems used, repairs on Siniy Most, etc. This information is given in brief below and described in more detail in the publications listed in the reference.

According to the USSR Council of Ministers Decree No. 760 of April 7, 1946 and the Decree of the Collegium of the Head Department of Geodesy and Cartography under the USSR Council of Ministers of August 12, 1946 the Kronstadt gauge zero point was accepted as the initial point of State Levelling Network and the Origin of the National ("Baltic") Height Datum (Meshcherskiy, 1975; Sorokin, 1990; Borisov, 1973). Up to the middle of the XX century the sea level and associated observations were carried out by the Naval Department under the scientific supervision of the Academy of Sciences and since the 1950s the observations were carried out by the State Hydrometeorological Service.

A new stage in the history of the Kronstadt gauge is connected to the beginning of the Leningrad Dam construction – a complex of flood defence facilities, as a result of which the Kronstadt gauge appeared to be located in the part of the Gulf of Finland water area separated by the dam where the hydrological regime had changed.

In this connection in 1982-1988 according to the Leningrad Administration Order No. 931-r of July 16, 1984 and Leningrad Administration Resolutions No. 286 of May 27, 1985; No. 563 of September 30, 1985; No. 718 of August 30, 1988 measures of the national importance, taking into account concrete conditions, natural and technogeneous processes in the region, anthropogeneous expansion of the St. Petersburg Megalopolis, were developed and realized. As a result, the Shepelevo Duplicate of the Kronstadt gauge (modern sea level and geodynamic observatory) was constructed 40 kms W of Kronstadt, outside the zone of essential influence of the Leningrad flood defence facilities complex and significant anthropogeneous influence of the St. Petersburg Megalopolis; it was put into operation in 1988.

In Kronstadt, Lomonosov and Shepelevo three deep well bench mark stations were built for fundamental secular control of zero points stability of gauges, mareographs, geodetic bench marks. At the same time group of hydrogeological wells for all aquifers in Shepelevo, network of secular gravimetric stations and microlevelling ranges and the Leningrad permanent geodynamic range were created. This allowed to begin fundamental geodetic, hydrogeological, sea level, gravimetric and other researches to study the secular fluctuations of the sea level and present crustal movements (Boulanger *et al*., 1986, 1990a,b, 1992; Bogdanov, 1991, 1993a,b, 1996b, 1997; Bogdanov, Boulanger, 1997; Abalakin *et al*., 1998a,b).

The Shepelevo gauge (φ = 59°58', λ = 29°06') was constructed on the southern coast of the Gulf of Finland S of Shepelevskiy Lighthouse and Mys Kamennyy in Bukhta Batareynaya. Sea level observations have been carried out synchronously with observations in Kronstadt and Lomonosov under the uniform program since November 1, 1987. The wall bench mark No. 7271 is used as the operational bench mark of the station. The control of bench marks height position is carried out by the Russian Academy of Sciences. The Shepelevo sea level and geodynamic complex (Boulanger *et al*., 1990a,b, 1992; Bogdanov, 1994, 1997) includes the following:

1) observatory building with service premises and living accomodations;
2) maritime part (mareograph tower, inlet pipes, suction wells),
3) approach dam connecting mareograph well to the coast;
4) hydrometeorological station of the second category;
5) deep well (hole) bench mark station (system);
6) group of hydrogeological observation wells for all aquifers;
7) micropolygon (test area) of precision repeated levelling,
8) secular gravimetrical station.

Sea level observations at the Kronstadt gauge and its Shepelevo duplicate are described in the following sections and in the form of mean monthly (MMSL) and mean yearly (MYSL) series are given in Appendixes. All MMSL and

MYSL values are reduced to the Kronstadt gauge zero point (to the same Origin of the Baltic Height Datum) for all the time of the stations functioning. These values were obtained as a result of averaging real fixed-date observations by gauge or hourly levels read from mareograph tape. The information on the sea level observations at the Kronstadt gauge is given in Tables 1-3. All observations in the XIX-XX centuries were carried out in compliance with special instructions (Notes, 1807-1827, 1842-1852; Manual, 1897, 1902; The Directions, 1975; etc.).

The local datum level and levelling control of the sea level observations at the Kronstadt gauge is shown in Tables 1,4-5. As it follows from Table 1, the system of the "ordinary" (mean) level, determined for different time intervals and fixed either with labels on the walls of channels and lock gates (till 1841), or with cuts and copper plates on the granite facing of Obvodnyy Kanal walls (since 1841) had been used for a long time.

Since 1886 the control of stability of the zero point, established on the engineering construction of Siniy Most pier, was carried out by precision repeated levellings of the zero point with the operational bench mark of the station on the P. K. Pakhtusov monument (Table 4). Finally, since 1872 analogous control was carried out by repeated levelling connections between the zero point of the Kronstadt gauge and the continental marks on the Oraniyenbaum coast (Table 5). From modern positions, the materials presented in these Tables demonstrate defects of traditional long-term control of the zero points and geodetic bench marks stability.

The Shepelevo station and the Kronstadt gauge have been included into precision GPS network of the International Geodetic and Geodynamic Project "Baltic Sea Level" since 1993 and 1997, respectively. All works under this project are coordinated by the International Association of Geodesy (Kakkuri *et al*., 1990; Kakkuri, 1994, 1995; Abalakin *et al*., 1995, 1998a).

The following sea level stations were included into GPS campaign in 1993: in Vyborg, in Shepelevo, on Ostrov Gogland and in Svetlogorsk (Kaliningrad region, Rybnyy Settlement), as well as in Pulkovo (the territory of the Central Astronomical Observatory of the Russian Academy of Sciences) and in Svetloye Settlement (the territory of the Institute of Applied Astronomy of the Russian Academy of Sciences). The same stations (except Svetlogorsk) and the Kronstadt gauge were included into the GPS campaign in 1997. GPS points in Vyborg, Kronstadt, Pulkovo, Shepelevo and on Gogland are included in the Leningrad (St. Petersburg) geodynamic polygon (test area) (Boulanger *et al*., 1990b; Bogdanov, 1997).

Thus, there is a real opportunity to control the changes of the zero point elevations of all sea level stations and normal zeros (Normal-Null) of the Baltic Countries in a uniform precision system related to the modern World Geodetic System of coordinates. In this connection the check of known estimations of elevation of a number of European points obtained by E. Blomqvist and H. Renqvist (Blomqvist, Renqvist, 1914) by classical methods at the beginning of XX century is of interest (Table 6).

On the other hand, the modern metrological approach to providing precision sea level and geodynamic researches in the area of St. Petersburg Megalopolis and tectonically active southern slope of Fennoscandia requires the creation of a fundamental secular regional observatory network of the highest class of accuracy and representativeness and organization on its basis of complex observations on deformational natural and anthropogeneous processes for not less than the first hundreds of years (Bogdanov, 1996c, 1997; Bogdanov, Boulanger, 1997). In this respect the acquaintance with the unique experience of organization and long-term maintenance of observations at the Kronstadt gauge is of doubtless practical and scientific interest.

Methods of restoration of sea level secular observations are not developed at present (Bogdanov, 1991, 1996c, 1997; Bogdanov *et al*., 1994). The version of mean monthly sea level observations at the Kronstadt gauge was prepared by V. I. Bogdanov in the development of a work on the restoration of mean yearly series (Bogdanov *et al*., 1994). Its basic features are:

1) complex methodological approach to the restoration of series;
2) priority of primary publications and sources;
3) refusal of "regulation" and "corrections" to the series post factum;
4) cataloguing divergences of the versions and all perturbations at the observation station for all the time of the gauge functioning;
5) preparation for publication of all preserved till now versions and materials without exceptions.

The complete realization of such program, however, is impossible without a detailed acquaintance with some original archival materials of various departments, inaccessible, unfortunately, for different reasons up to the present time. Hence it is necessary to initiate the creation of a uniform State archival storage of all materials of the historical observations. In this connection we consider the present work as the first scientific experience in the problem of restoration of the secular observatory series requiring wide discussion and further improvement, with enlisting new archival materials and methods of historical and special analysis of sources.

Table 1. Sea Level Observations Characteristic

Interval, years	Type of series	Calendar System	Time System	Time of observations, hours	Local datum level
			Kronstadt gauge		
< 1777	–	–	–	–	–
1777	MMSL	Julian	MST	3 times per day	Ordinary
1778-1805	–	–	–	–	–
1806-1814	MMSL	Julian	MST	7,14,21	Ordinary
1815-1817	MMSL	Julian	MST	7,14,21	Ordinary
1818-1823	MYSL	Julian	MST	7,14,21	Ordinary
1824	MMSL	Julian	MST	7,14,21	Ordinary
1825-1826	MYSL	Julian	MST	7,14,21	MSL
1827-1834	–	Julian	MST	6-20, every 2 hours	MSL
1835-1840	MMSL	Gregorian (?)	MST	6-20, every 2 hours	MSL
1841-1843	MMSL	Julian	MST	8,12,16,20	Reinecke
1844	MMSL	Julian	MST	–	Reinecke
1845-1846	MMSL	Julian	MST	6-22, every 2 hours	Reinecke
1847	MMSL	Gregorian	MST	6-22, every 2 hours	Reinecke
1848-1850	MMSL	Julian	MST	6-22, every 2 hours	Reinecke
1851-1872	MMSL	Gregorian	MST	6-22, every 2 hours	Reinecke
1873	MMSL	Gregorian	MST	7-21, every 2 hours	Reinecke
1874-1886	MMSL	Gregorian	MST	7-21, every 2 hours	MSL
1887-1895	MMSL	Gregorian	MST	7-21, every 2 hours	Vitram
1896-1913	MMSL	Gregorian	MST	mareograph	Vitram
1914	MMSL	Gregorian	MST	mareograph	Tonberg
1915-1935	MMSL	Gregorian	MST	mareograph	Tonberg
1936-1950	MMSL	Gregorian	MST	mareograph	Tonberg
1951-1960	MMSL	Gregorian	MST	mareograph	ZKG
1961-1990	MMSL	Gregorian	MT	mareograph	ZKG
1991-1993	MMSL	Gregorian	MT	mareograph	HS, BS
			Shepelevo duplicate		
1989-1993	MMSL	Gregorian	MT	mareograph	7271, BS

Notes:
1) MMSL – Mean Monthly Sea Level;
2) MYSL – Mean Yearly Sea Level;
3) MST – Mean Solar Time;
4) MT – Moscow Time (the so-called "winter" decree time = zone time + 1 hour, which differs from UT by 3 hours);
5) Ordinary – ordinary (mean) sea level fixed on the walls of the canal and lock gates (21 feet above the bottom of Kanal Petra Velikogo in Kronstadt in 1777);
6) MSL – unknown ordinary (mean) sea level after disastrous flood in 1824 and during the periods of gauge zero points removals or losses;
7) ZKG – present zero point of the Kronstadt gauge;
8) BS – heights of marks HS (Navy Hydrographical Service) and 7271 in the Baltic System of Height (Baltic Height Datum).

Table 2. Information on observation sites in Kronstadt.

Interval, years	Site	Main References
1707-1730	Kronshlott	(Reference 1972)
1731-1776	Srednyaya Gavan'	(Reference 1972)
1777	Kanal Petra Velikogo	(Krafft, 1780)
1777-1799	Kupecheskaya Gavan'	(Reference 1972)
1800-1972	Obvodnyy Kanal, Siniy Most	(Reference 1972)
1806-1809	Voyennaya Gavan'	(Notes 1807-1827)
1810	Harbour	(Notes 1807-1827)
1811-1812	Channel	(Notes 1807-1827)
1841-1873	Western wall of Obvodnyy Kanal near Siniy Most	(Tillo, 1876; Cinger, 1878; Bogdanov, 1993a)
1874	Ital'yanskiy Prud	(The Russian Navy State Archives, file 275)
1875-1929	Obvodnyy Kanal, Siniy Most pier	(Reference 1972)
1930-1940	Kupecheskaya Gavan'	(The Archives 1951)
1941-1993	Obvodnyy Kanal, Siniy Most pier	(Sundukova, 1951)

Table 3. List of doubtful or lost materials on the sea level observations at the Kronstadt gauge as of 1947, according to the Navy Hydrographical Service, (The Archives 1951).

Years	Gaps in the series	Reasons
1806	1-13/I	1
1807	13/VIII - 13/IX	1
1808	13/I - 13/XI	1
1811	13/V - 13/VI	1
1818-1823	Completely lost	2
1824	1-13/I; 11,12/IX	1
1825-1834	Completely lost	2
1835	1-13/I	1
1872	Completely lost	2
1898	1/I - 2/III; XII	3
1899	1-5/I; 1/VIII; 1,2,24,25/XI; 12-31/XII	3
1900	1,2,9,10/I; 9,10,13-16,20,23,24/II; 2,3/III; 9-14/IV; 9,10/VIII; IX-XII	3
1901	Completely lost	3
1902	I-V; 19,20/IX	3
1906	18-31/XII	3
1907	1/I; IV-V	3
1908	28-31/I; 4,22-24/V; 7-9,23-25/VI; VIII-X; 1/XI	3

Table 3 (Continued)

Years	Gaps in the series	Reasons
1909	17-19/II; 10-29/III; 19-22/VII; 20-22,29,30/VIII; 6,7/IX; 7-11,21,23,24/XII;	3
1910	9-12/II	3
1914	4,5/II; 27,29,30/VI; VII-XI	3
1915	13-15/I	3
1916	12-25/V; 13-14/IX	3
1919	Completely lost	2
1920	9-16,19,20/II	3
1921	Completely lost	2
1922	10-12/II	3
	IX-XII	2
1923	III-X	2
1924-1929	Completely lost	2
1930	1-5/II; 21-23/III; 1,25-28/VI; 6-8,20,21/VII; 10-12,17,18,20-22/IX; 3,4,17,18, 25,28,29/IX; 1,2,9/XII	3
1931	20,21,31/III; 24,26/V; 6,14,29,30/VI;	3
	1,3,4/VII;	4
	VIII; IX; XII	2
1932	14,15/III; 20/VI; 1/VII	4
1933	31/I; 24-27/III; 8,9,16-19,25-30/XI	3
1934	20,21/VI; 1-7/X	4
1935	23,24/VI; 9,10/IX; 31/X; XI; XII	3
1936	IV; V; 27,28/VIII; 8,13,18,19,23/IX; 4,7,12,13,18,19/X; 2-4,17,18,29,30/XI	3
	1-13,17,18/XII	4
1937	12/VIII	4
1938	24-26/VIII; 12/IX	4
1939	4/I; 3/II; 11/III; 26/IV	4
1940	18,19,22,27/I; 23,25,26/II; III; 30/V; 17/VI; 9,20,21/VII; XI; XII	4
1941	21-25/I; II; 3/IV; 1,8,14-16/VI; VIII; X; 1-13/XI; 12-17,27,28/XII	4
1942	17,28/IV	4
1943	VI; VII; 9,10/XI; 6,7/XII	4
1944	25/I; 13-16/II; 1,6,7, 26,27/IX; 1/X; 2-5,8-11,23-25,31/XII	4
1945	1,23-26/III; 17-27/IV; 9,24,25/XI; 8,9,26-31/XII	3
1946	1/I; 9,10/V	4
1947	4-8/IV	4

Note: The items of information for the period 1890-1914 are verified and corrected by the data (Proceedings 1898-1923).
Reasons: 1 – unknown;
2 – materials are lost;
3 – mareograph was not in function or was in malfunction;
4 – doubtful materials.

Table 4. Change of the levelling elevations of the operational bench mark of sea level station (P. K. Pakhtusov monument) above the Kronstadt gauge zero point; L ~ 100 m.

Years	Observers, Organizations or References	Δh_1, m	Δh_2, mm	Δh_3, mm
1886	F. F. Vitram, Observatory at Pulkovo	5.2251	+1.0	+1.0
1892	F. F. Vitram, N. O. Shchyotkin (Vitram, 1894)	5.2251	+1.0	+1.0
1903	Chr. -F. Tonberg (Tonberg, 1913)	5.2266	+2.5	+2.5
1905	Chr. -F. Tonberg (Tonberg, 1913)	5.2239	–0.2	–0.2
1907	Chr. -F. Tonberg (Tonberg, 1913)	5.2246	+0.5	+0.5
1911	Chr. -F. Tonberg (Tonberg, 1913)	5.2254	+1.3	+1.3
1912	Chr. -F. Tonberg (Tonberg, 1913)	5.2230	–1.1	–1.1
1913	Chr. -F. Tonberg (Tonberg, 1913)	5.2241	0.0	0.0
1931	V. Shavrov, V. Koposov (Pavlov, 1937)	5.2250	+0.9	+0.9
1934	Morokov, Navy Hydrographic Survey, Leningrad	5.226	+2	+2
1945	Butenko, Navy Hydrographic Survey, Leningrad	5.228	+4	+4
1947	V. Klimakhin, A. Kamenskiy (Sherman, Bulanov, 1949)	5.2266	+2.5	+2.5
1951	S. I. Sundukova (Sundukova, 1951)	5.2252	+1.1	+1.1
1968	A. Ya. Durnov, State Geodetic Survey, Leningrad	5.2376	+13.5	+3.5
1976	M. P. Pavlov, State Geodetic Survey, Leningrad	5.2395	+15.4	+5.4
1977	M. P. Pavlov, State Geodetic Survey, Leningrad	5.2423	+18.2	+8.5
1978	V. A. Volkov, State Geodetic Survey, Leningrad	5.2388	+14.7	+4.7
1981	V. N. Petrov, State Geodetic Survey, Leningrad	5.2446	+20.5	+10.5
1982	V. A. Sechkov, State Geodetic Survey, Leningrad	5.2445	+20.4	+10.4
1987	L. M. Gorbatov, State Geodetic Survey, Leningrad	5.2417	+17.6	+7.6
1994	L. M. Gorbatov, State Geodetic Survey, St. Petersburg	5.2415	+17.4	+7.4

Notes:

1) Δh_1 – measured elevations;
2) Δh_2 – the same referring to the epoch of 1913;
3) Δh_3 – the same with the account of the levelling bench mark observable side replacement on the Pakhtusov monument in 1968;
4) the items of information about levelling of 1886 are given in Technical Notes of the Kronstadt gauge;
5) While carrying out regular State levellings in 1931 and 1947 the middle horizontal part of the letter "П" cut in the Russian word "*profit*" was observed (Pavlov, 1937; Sherman, Bulanov, 1949); the information on which of the three sides of this cut had been levelled before 1931 is not available now; since 1968 its top edge has been levelled.

Table 5. The results of levelling connections between the zero point of the Kronstadt gauge and the continental bench marks

Years	Elevations of bench marks on the Oraniyenbaum coast above zero point of the Kronstadt gauge, metres		Δh_1 metres	Δh_2 mm	Observers, Method of levellings, References
	173 MTD HQ	MRC			
1872	5.571 ± 0.017	–	5.753	+110	Ignat'yev, Fedotov; Simultaneous determination of heights by level theodolite (Cinger, 1878)
1875	5.512 ± 0.015	–	5.694	+51	A. A. Tillo, V. E. Fuss; Geometrical levelling on ice (Tillo, 1876)
1886	5.493 ± 0.022	–	5.675	+32	V. E. Fuss, V. A. Astaf'yev; Geometrical levelling on ice (Vitram, 1894)
1886	5.462 ± 0.013	–	5.644	+1	V. E. Fuss, V. A. Astaf'yev; Water levelling in calm weather (Vitram, 1894)
1888	5.494 ± 0.014	–	5.676	+33	V. E. Fuss, V. A. Astaf'yev; Geometrical levelling through forts (Vitram, 1894)
1890	5.465 ± 0.010	–	5.647	+4	F. F. Vitram, N. A. Novgorodtsev *et al*; Measuring of heights by Repsold vertical circles (Vitram, 1894)
1892	5.4663±0.0029	5.6420±0.0029	5.642	–1	F. F. Vitram, N. O. Shchyotkin; Geometrical levelling from scow (Vitram, 1894)
1931	5.4608±0.0041	5.6427±0.0041	5.643	0	V. Shavrov, V. Koposov, V. Stepanov; Geometrical levelling on ice and with piles (Pavlov, 1937)
1947	–	5.6352±0.0016	5.635	–8	V. S. Klimakhin, A. P. Kamenskiy; Geometrical levelling on ice and with piles (Sherman, Bulanov, 1949)
1969	–	5.6480±0.0016	5.649	+6	L. Ya. Tamme *et al*; Hydrostatic levelling through aquatory (Tamme, 1971)
1988-89	–	5.6677±0.0065	5.668	+25	V. L. Averin, L. M. Gorbatov, V. N. Telepayev; Geometrical Levelling through Leningrad Dam and the Gorskaya Railway Station, 172.7 km
1994	–	5.6456±0.0011	5.646	+3	L. M. Gorbatov, E. A. Bykova; Geometrical levelling through Leningrad Dam and the 900-metres shipping channel of the dam, Archives of the State Geodetic Survey

Notes:

1) Δh_1 – conventional elevation of the mark MRC (Ministry of Railway Communications), calculated assuming that the difference of this mark, measured in 1931, and the mark 173 MTD HQ (Military Topographic Division of the Headquarters) applies to all previous period;

2) Δh_2 – the same referring to epoch of 1931;

3) It was accepted to characterize the levellings of the last century by mean probable error;

4) For the levelling elevation of 1872: the elevation is given according to (Cinger, 1878); in a private letter to A. A. Tillo, however, N. J. Cinger reported the other value of this elevation, namely: 5.550±0.020 metres (Tillo, 1876); and finally, F. F. Vitram (Vitram, 1894), N. A. Pavlov (Pavlov, 1937), and later many other geodesists reported the third value 5.541±0.017 metres;

5) For the levelling elevation of 1875: in the paper (Tillo, 1876) there was a misprint, the value 5.412 metres was given;

6) For the levelling elevation of 1969: in the paper (Tamme, 1971) preliminary value of the total elevation 5.6487 metres is given; in Table 5 the value of this elevation is given according to the data of the State Geodetic Survey.

Table 6. Elevations of the main bench marks in Denmark, Finland, Germany, Russia and Sweden according to Blomqvist, Renqvist, 1914)

Bench marks	Elevations, mm	Elevations, mm
Berlin, NN (Normal-Null)	+346	+240
Sweden, NP (Nullpunkt)	+196	+90
Kronstadt, NP (Nullpunkt)	+106	0
Denmark, NN (Normal-Null)	+101	−5
Helsinki, NN (Normal-Null)	0	−106

4 Description of mean monthly series (1777-1993) at the Kronstadt gauge

MMSL at the Kronstadt gauge is described below by the time intervals singled out in conformity either with existing versions of series or with some particularities of observations. Thus, we were compelled to reject the wide known K. F. Rudovitz version of 1841-1913 (Rudovitz, 1917) for the reason of its insufficient clearness of the compilation structure, reproduction of errors, mistakes and misprints of the former versions, and indefinite indications to use only three excerpts from daily observations. In the course of series restoration various MMSL versions (Notes 1842-1852; Fuss, 1876, 1896, 1911; Saltykov, 1886, 1888; Proceedings 1898-1923; Reference 1972; Mikhaylov, 1992; etc.), as well as MYSL versions (Notes 1807-1827; Bonsdorff, 1891; Ryl'ke, 1896; Blomqvist and Renqvist, 1914; Lazarenko, 1951, 1961; Bogdanov *et al*., 1994; etc.) were analysed.

(<1777). According to (Reference, 1972), the items of information on observations of sea level in Kronstadt have been available since 1707. Originally they were carried out in Kronshlott (1707-1730), and then in Srednyaya Gavan' (1731-1776). The materials of this period were apparently not saved.

1777. The version of the series (Krafft, 1780) was used. The Julian calendar system. The local mean solar time. The gauge was located in Kanal Petra Velikogo, which ordinary depth was 21 feet, i.e.~6.4 m from the bottom of the channel (Kozakevich, 1848). The diagram of daily observations of L. W. Krafft (3 times per day) was averaged "in two hands" (twice), and the averaged values were transferred into metric measure (Bogdanov *et al*., 1993). In the same work of L. W. Krafft the results of wind observations of Mr. Bogemel (Pastor of the Lutheran Church) and the diagram of changes of atmospheric pressure by daily observations of Professor I. A. Euler in St. Petersburg matched with the sea level diagram were given.

(1778-1805). The materials of this period have not been found yet.

1806-1814. The version of series (Reference 1972), local mean solar time was used; time of observations: 7, 14, 21 hours; with the following changes resulting from comparison with the publications (Notes 1807-1827). First, the version of series (Reference 1972) for this period is determined in the Julian calendar system (Bogdanov, 1993b). Secondly, from comparison of yearly extreme levels of series of this version and the version (NOTES 1807-1827) of 1806-1824 it follows that the correction of 6.8 inches (~17 cm), determined by M. F. Reinecke in 1841 (The Russian Navy State Archives, file 1028) was entered into the first of them as "correction of gauge" probably shifted during the catastrophic flood of 1824 (Kozakevich, 1848). In this connection it is incorrect to apply such correction to the period preceding the flood of 1824. Therefore, all values of the version (Reference 1972) for the period considered were reduced by 17 cm (Bogdanov, 1993b; Bogdanov *et al*., 1994).

By comparison of extreme values of both versions of series for the period 1806-1812 the abnormal divergences in the minimum level by 58 cm in 1810 and in maximum level by 10 cm in 1812 (Bogdanov, 1994) were also revealed. Finally, we should admit that according to (Reference 1972) the geodetic levelling observations in 1806-1814 were carried out in Obvodnyy Kanal in Kronstadt. But according to (Notes 1807-1827) the observations in 1806-1809 were carried out by the Astronomer of the 8th grade Abrosimov in Voyennaya Gavan' of Kronstadt; in 1810 by the Assistant Astronomer of the 12th grade Spolokhov in the "Harbour"; and in 1811-1812 by the same person in the "Channel" (without names of the Harbour and the Channel), (Bogdanov, 1993b, 1994).

1815-1817. The version of the series (Reference 1972), with the same correction of 17 cm as for the period 1806-1814, was used. The Julian calendar system. The local mean solar time. Time of observations: 7, 14, 21 hours. The interval was singled out for the reason of essential divergence in the mean yearly values of versions (Notes 1807-1827) and (Reference 1972), reaching +14 and −20 cm for 1815 and 1817, respectively. The mean yearly values of the version of series (Notes 1807-1827) in 1815-1817 are equal to −6, −9 and −24 cm. The only divergence in extreme values equal to −3 cm, was established for the maximum level of 1815 (Bogdanov, 1991, 1993b, 1994). The observations were carried out by the Assistant Astronomer of the 8th grade Ivanov; the location of the gauge was not stated (Notes 1807-1827).

(1818-1823). Only the mean yearly values of the level equal to −13, −23, −20 (misprint in the original: the value 7 feet and 9 inches was given, it was accepted to be 7.9 inches = 20 cm), −6, −1 and −18 cm, respectively, were saved (Notes 1807-1827; Bogdanov, 1993b). The Julian calendar system. The local mean solar time, time of observations: 7, 14, 21 hours (Reference 1972). The observations of this period were carried out by the Assistant Astronomer Checherin in 1818; by the Assistant Navigator of the 14th grade Verkhovskiy in 1819-1820; by the Astronomer Tobisen in 1821-1823. The location of the gauge was not marked.

1824. The version of the series (Reference 1972) with the same corrections as for the periods 1806-1814 and 1815-1817 was used. The Julian calendar system. The local mean solar time, time of observations: 7, 14, 21 hours. The mean yearly value calculated for the incomplete year differs from the mean yearly value of the version of series (Notes 1807-1827) by −2.3 cm (i.e. approximately by −1 inch), (Bogdanov, 1993b). The observations were carried out by the Astronomer Tobisen; the location of the gauge was not stated (Notes 1807-1827).

(1825-1826). Only the mean yearly values of the level (Notes 1807-1827) equal to +7 and -1 cm, respectively (after correction by the value of M. F. Reinecke correction), were saved. The Julian calendar system. The local mean solar time, time of observations: 7, 14, 21 hours (Reference 1972). The observers of this period and location of the gauge was not stated.

(1827-1834). The Julian calendar system. The local mean solar time. Time of observations according to (Reference 1972) - from 6 o'clock till 20 o'clock, every 2 hours. The materials of this period, apparently , were not saved.

1835-1840. The version of the series (Reference 1972) was completely used. The Gregorian calendar system (?). The doubts as for the use of the Gregorian calendar system result from the comparison of two versions of the series (Reference 1972) and (Notes 1807-1827) before 1835 and after 1840. The local mean solar time. Time of observations: from 6 o'clock till 20 o'clock, every 2 hours.

1841-1846. The version of the series (NOTES 1842-1852) was used. The Julian calendar system. Civil (local mean solar) time. Time of observations: 8, 12, 16 and 20 hours in the period 1841-1843; not specified for 1844; and every 2 hours from 6 o'clock till 22 o'clock in the period 1845-1846. According to (Reference 1972), time of observations in the period till 1844 - every 2 hours from 6 o'clock till 20 o'clock, and since 1844 - every 2 hours from 6 o'clock till 22 o'clock.

The height of the water horizon was observed by the rod, established at the granite wall of Admiralteyskiy Kanal near the Navigation School. The gauge zero point (ordinary level) was marked in June, 1840 from the average conclusion of observations for the previous 10 or 15 years obtained by M. F. Reinecke (Reinecke, 1841; The Russian Navy State Archives, file 1028; Bogdanov, 1993a). The observations were carried out in the First Navigation Half-Crew at Port Telegraph under the supervision of Vyakhirev, the Captain of the Fleet Navigators Corps.

By comparison of this series version with the versions (Saltykov, 1886, 1888; Fuss, 1896; Rudovitz, 1917; Reference 1972; etc.) it was established, that the latter used the average values of version (Notes 1842-1852), but referred them to the Gregorian calendar system (Bogdanov, 1993b, 1994). Besides, the mean yearly values of two versions of the series (Reference 1972) and (Notes 1842-1852) differ from each other by −5.5; −9.2; −2.5; +1.7; +7.7 and +7.3 cm, respectively. The reason for such divergences is the errors in translating the values expressed in feet and inches of the English measure system into Metric system (Bogdanov, 1991, 1993b, 1994).

1847. The version of the series (Notes 1842-1852) was used. The Gregorian calendar system. Civil time. The observations were carried out at the same gauge and by the same program, under the supervision of Vyakhirev, the Captain of the Fleet Navigators Corps, every 2 hours from 6 o'clock till 22 o'clock. The mean yearly values of two versions of the series (Reference 1972) and (Notes 1842-1852) differ from each other by +1.3 cm (Bogdanov, 1994).

1848-1850. The version of the series (Notes 1842-1852) was used. MMSL value for August, 1849 (+43 inches) and the mean value for the year (+1,0 inches) were replaced by the values +4 inches (+10.2 cm) and −1.2 inches (−2.9 cm), respectively, in accordance with (Saltykov, 1886). The Julian calendar system. Civil time. The observations were carried out at the same gauge and by the same program, under the supervision of Vyakhirev, the Captain of the Fleet Navigators Corps, every 2 hours from 6 o'clock till 22 o'clock. Mean monthly values of the versions (Notes 1842-1852) and (Saltykov, 1886) for October, 1850 are equal to +1 inch, while in the version (Rudovitz, 1917) the value −1 inch is given. The mean yearly values of two versions of the series (Reference 1972) and (Notes 1842-1852) differ from each other by −3.6; +2.8 and +1.8 cm, respectively (Bogdanov, 1994).

1851-1873. The version of the series (Saltykov, 1888) was used. The Gregorian calendar system. Local mean solar time. Time of observations: 1) according to (Saltykov, 1886, p. 47) - every 2 hours from 6 o'clock till 22 o'clock in the period till 1873 and every 2 hours from 7 o'clock till 21 o'clock since 1873; 2) according to (Fuss, 1896, p. 96) - every 2 hours from 6 o'clock till 22 o'clock in the period of 1841-1873. ; 3) according to (Reference 1972, p. 10) - every 2 hours from 6 o'clock till 22 o'clock in the period till 1872 and every 2 hours from 7 o'clock till 21 o'clock since 1872. The observations were carried out by the rods established in Obvodnyy Kanal. In the mean yearly version of the series (Reference 1972) for 1866 a misprint was found: the value −6 cm was given, the correct value is +6.1 cm. In 1872 the first levelling connection of the Kronstadt gauge zero point (M. F. Reinecke mark) with the mark 173 MTD HQ (Military Topographic Division of the Headquarters), established on the continent in the Oraniyenbaum area, was executed (Cinger, 1878).

1874-1886. The version of the series (Saltykov, 1888) was used. The Gregorian calendar system. Local mean solar time. Time of observations - every 2 hours from 7 o'clock till 21 o'clock. In 1874, in connection with construction of a new iron rotating bridge instead of the shabby wooden Siniy Most, the observations were temporarily carried out in the

Ital'yanskiy Prud in Kronstadt (The Russian Navy State Archives, files 275, 2040; Bogdanov, 1993a,b, 1994).

During construction works the M. F. Reinecke zero point was destroyed, and the new zero point which was cut on the pier of the same bridge differed from the former by about a decimetre in the course of some years that followed (Shpindler, 1913). The detailed analysis of the first levelling connections of the Kronstadt gauge zero point with the continent in the Oraniyenbaum area, which were executed in 1872 and in 1875 (Table 5), did not contradict this conclusion (Bogdanov, 1993a, 1994).

In 1886 V. E. Fuss and V. A. Astaf'yev executed two connections of the Kronstadt gauge zero point with the continental bench mark 173 MTD HQ. In the same year (1886) for more precise fixation of the Kronstadt gauge zero point, the existing cut on the Siniy Most pier of 1875 (Bogdanov, 1993a,b, 1994), was closed by a copper plate (Vitram, 1894). It was then that F. F. Vitram executed the first levelling connection of this zero point with the basic bench mark of the Kronstadt station on the P. K. Pakhtusov monument (Table 4). The levelling elevation of the mark above the zero point was +2.4490 sazhens (+5.2252 m), (Vitram, 1894).

1887-1895. The version of the series (Fuss, 1896), with corrections of the values for February, 1888 and July, 1889 by (Ryl'ke, 1896), and completely for 1895 (Fuss, 1911) was used. The Gregorian calendar system. Local mean solar time. Time of observations: 1) according to (Saltykov, 1886; Fuss, 1896) - every 2 hours from 7 o'clock till 21 o'clock; 2) according to (Reference 1972) - every 2 hours from 7 o'clock till 21 o'clock in 1887-1888 and 1890; at 7, 13 and 21 hours in 1889, 1891 and 1893. ; at 7, 9, 13, 17 and 21 hours in 1892, 1894 and 1895.

The observations were carried out by the rod established at the pier of Siniy Most over Obvodnyy Kanal, by F. F. Vitram zero point. In 1890 I. B. Shpindler published the article (Shpindler, 1890) about the organization of water level observations, the basic provisions of which were later used practically in all instructions on works execution (Manual, 1897, 1902; The Directions 1975; etc.). In 1888, 1890 and 1892 three more levelling connections of the Kronstadt gauge zero point with the mark 173 MTD HQ on the continent in the Oraniyenbaum area were executed by V. E. Fuss and V. A. Astaf'yev; F. F. Vitram, N. A. Novgorodtsev and others; F. F. Vitram and N. O. Shchyotkin (Vitram, 1894), (Table 5).

1896-1914. Mareograph version of the series (Proceedings 1898-1923) was used as the basic one. Gaps in this version were filled in by the values, according to (Proceedings 1898-1923), obtained from the observations by the gauge established on the pier of Siniy Most over Obvodnyy Kanal by F. F. Vitram zero point (till 1913). The values for January, February and December, 1898, and December, 1899 are given according to the gauge version (Mikhaylov, 1992). Misprint in the value −51.4 cm for April, 1914 was corrected to −5.1 cm. The Gregorian calendar system. Local mean solar time. The principal time of observations: 7, 13, 21 hours till 1900 and since 1904; 7, 13, 17, 21 hours in 1900-1903. On May 15(28), 1909 the sea level rod was lifted by 1.75 inches to put its zero in conformity with the F. F. Vitram zero point.

On October 1, 1909, March 17, 1911 and February 13, 1912 the sea level rods were replaced by new ones. Mareograph was established in 1896 in the same channel approximately 230 m from the historical gauge ($\varphi = 59°59'$, $\lambda = 29°47'$). They started to get normal records on it since 1898. The observers were Lieutenant-colonel K. M. Larionov (1908-1909), Captain 1st rank P. V. Shchelkunov (1909-1914) and Chr.-F. Tonberg (1914), Manager of the Tool Chamber Depot of Charts in Kronstadt. As the mareograph zero point the local ordinary level was used, by which the auxiliary rod was established later on. The readings of this rod were taken daily at 1 o'clock p.m. The materials on the dependence of the local water levels in the sites of the historical gauge and mareograph from the wind regime have not been found.

In spring 1913 the copper plate of the F. F. Vitram zero point dropped out and got lost. In June of the same year Chr.-F. Tonberg established a new zero point nearby (green copper plate with indication of horizontal line and the centre of the mark). By numerous levelling connections with the basic bench mark of the Kronstadt station on the Pakhtushov monument he showed that the centre of the new zero point coincided with the centre of the F. F. Vitram lost point within the limits of probable error of one measurement.

The new elevation of the operational bench mark above the Kronstadt gauge zero point measured in 1913 was equal to +2.4485 sazhens (+5.2241 m), (Tonberg, 1913). The assumptions of gauge incorrect installation and shortcoming of reduction technique of mareograph observations in the period 1898-1909, which generated errors up to 6 cm (1905), were stated in papers (Fuss, 1911; Yakubovskiy, 1986). In 1902-1917 under the initiative of N. M. Maksimovich the question of the construction of the basic bench mark of the Russian uniform levelling network on the continent near the Kronstadt gauge was discussed (The Russian Navy State Archives, file 1816; Bogdanov, 1994, 1995b).

1915-1935. Mareograph version of the series (Mikhaylov, 1992) was used. Gaps or doubtful values in this version were filled in or replaced by the mean monthly values obtained on the basis of excerpts from daily observations of the historical gauge at 7, 13 and 21 hours given there. The gauge was located on the pier of Siniy Most over Obvodnyy Kanal and was established by Chr.-F. Tonberg zero point of 1913. The Gregorian calendar system. Local mean solar time (Reference 1972).

Essential divergences between the mean values calculated from observations by the gauge (3 time terms: 7, 13, 21 hours) and by mareograph data (24 hour values) have no explanations (Mikhaylov, 1992). Such divergences equal to or exceeding $|\pm 2|$ cm were detected for the following years and months - **1919:** I (+35.7 cm), II (+28.1 cm), III (+8.3 cm), IV (−29.2 cm), V (−6.3 cm), VI (+6.6 cm), VII (+4.7

cm), VIII (−27.0 cm), XI (+26.0 cm), XII (−5.5 cm) and in the mean yearly value (+3.2 cm); **1920:** X (−2.0 cm); **1921:** XII (−3.2 cm); **1922:** X (−6.8 cm); **1926:** III (−4.9 cm); **1930:** IV (−3.8 cm); **1931:** III (−2.1 cm); **1932:** IV (+2.0 cm); **1933:** VII (+2.7 cm) and XII (+2.7 cm), (Bogdanov, 1994).

Besides, not any of the considered versions of the series for 1919 (Mikhaylov, 1992) conform with the similar version of the series (Reference 1972). Verification of the specified versions is impossible without studying the original and archival data. There is scanty information that Kronstadt gauge from 1930 to 1941 was located in the Kupecheskaya Gavan' (Bogdanov, 1983, 1994; Yakubovskiy, 1986; Mikhaylov, 1992).

In 1926-1927 at the 1st and 2nd Geodetic Meetings held by the Gosplan (Ministry of Planning) of the USSR, among other, measures were planned to give the Kronstadt gauge the status of the initial point of the State levelling network (Shokal'skiy, 1927, 1930). In 1930 to implement these recommendations a group of secular bench marks was established on the continent in Chudovo for fundamental fixation of the Kronstadt gauge zero point (Safonov, 1934; Pavlov, Bulanov, 1935). In 1931 V. Shavrov, V. Koposov and V. Stepanov executed the first levelling connection of the gauge zero point with this group of secular bench marks (Pavlov, 1937). However, the remoteness of Chudovo secular bench marks group from the Kronstadt gauge did not promote often and exact performance of levelling connections between them. Therefore, after the war a group of standard fundamental bench marks was established in Lomonosov (Bogdanov, 1994, 1995b, 1997).

1936-1950. Mareograph version of the series (Mikhaylov, 1992) was used. Gregorian calendar system. Local mean solar time (Reference 1972). Time of observations by the gauge in this period had undergone changes. Since 1941 the gauge was located at the pier of Siniy Most over Obvodnyy Kanal. During the World War 1941-1945 it suffered a lot: the rod was bent, the zero point mark was damaged, the connecting well got clogged (The Central Naval Archives, file 617; The Archives 1951). In the war time the continental mark 173 MTD HQ in the Oraniyenbaum area was destroyed (Sherman, Bulanov, 1949; see also Zhemerov, 1933, p. 28).

Within the framework of the USSR Council of Ministers Decree No. 760 of April 7, 1946 and the Decree of the Collegium of the Head Department of Geodesy and Cartography under the USSR Council of Ministers of August 12, 1946 on assigning to the Kronstadt gauge the status of the initial point of the State Levelling Network and the Origin of the National ("Baltic") Height Datum, measures on regulating of Kronstadt gauge were developed and implemented later on (Resolution 1948).

These measures included the following: construction of a new mareograph pavilion 12 m from the gauge, repairs of the gauge zero point and its protection by special bronze framework, performance of precision levelling works, development of a sea level network in the region (Sherman, Bulanov, 1949; Sundukova, 1951; Lazarenko, 1951; Bogdanov, Taybatorov, 1995).

1951-1990. Mareograph version of the series (Mikhaylov, 1992) was used. The Gregorian calendar system. Local mean solar time till 1961, Moscow Time since 1961 (the so-called "winter" decree time = zone time + 1 hour, which differs from UT by 3 hours), (Reference 1972). Time of observations by the gauge in this period had undergone changes. The observations were carried out by mareograph, which was established in the new pavilion, 12 m from the gauge on the pier of Siniy Most (φ = 59°59'24'', λ = 29°45'54'').

In the middle of the 1950s the Kronstadt gauge for the first time of its existence was transferred from the Navy Department to the USSR Hydrometeorological Service. At present it has been found out that after these decisions the observation regulations were changed, the zero point mark and operational bench mark of the sea level station were apparently replaced (Bogdanov, 1995b, 1996a). By the diagrams of differences between MYSL series for the Kronstadt, Vyborg, Gogland and Helsinki stations, Yu. A. Trapeznikov found a sudden change of 4.5 cm in 1995 at the Kronstadt gauge (Trapeznikov, 1994).

In 1969 the next levelling connection of the Kronstadt gauge zero point with the continent was executed (Tamme, 1971). In 1982, in connection with the beginning of the Leningrad flood defence facilities complex construction, there were doubts concerning the gauge hydrological regime invariability and elevation stability of fundamental geodetic bench marks (Bogdanov, 1983, 1991; Boulanger *et al*., 1986, 1990a). With this view national measures on the Kronstadt gauge problem solution were developed and subsequently implemented (Boulanger *et al*., 1986, 1990a,b, 1992; Bogdanov *et al*., 1987; Bogdanov, 1991, 1993a,b, 1996b, 1997; Bogdanov, Boulanger, 1997; Abalakin *et al*., 1998b).

1991-1993. The results of mareograph observations of the North-West Department of the Hydrometeorological Service were used. The Gregorian calendar system. Moscow Time (zone time + 1 hour). The control readings were taken every 3 hours by the rod established by the present zero point (ZKG) on the pier of Siniy Most over Obvodnyy Kanal (Bogdanov, 1996a). The materials of sea level and levelling observations were given to the participants of joint works in the framework of GPS campaign 1993 under the International Project "Baltic Sea Level", coordinated by the International Association of Geodesy (Kakkuri *et al*., 1990; Kakkuri, 1994, 1995; Bogdanov, 1995a; Abalakin *et al*., 1995). The Kronstadt gauge was included into the International network during the next measuring GPS campaign of this project which was carried out in 1997 (Abalakin *et al*., 1998a).

5 Description of mean monthly series (1988-1993) at the Shepelevo duplicate of the Kronstadt gauge

1987-1988. The results of observations of the North-West Department of the Hydrometeorological Service were used. The Gregorian calendar system. Moscow Time (the so-called "winter" decree time = zone time + 1 hour, which differs from UT by 3 hours). The mareograph and sea level rod were established on the approach dam. The observations over the sea level were started on November 1, 1987 synchronously with observations on sea level stations in Kronstadt and Lomonosov (Oraniyenbaum coast) analogous to the Kronstadt gauge standard program. The wall bench mark 7271, established in the wall of the chamber of the deep hole bench mark system was used as the operational bench mark. The sea level observation materials for this period cannot be recognized as standard due to appreciable deformations of the approach dam and operational bench mark subsiding. The Shepelevo Duplicate of the Kronstadt gauge was officially put into operation by the Leningrad Administration Decree No. 718 of August 30, 1988.

1989-1993. The results of observations of the North-West Department of the Hydrometeorological Service were used. Deformations of the approach dam and operational bench mark 7271 of the station were stabilized. The programs of observations and materials processing are standard, analogous to those of Kronstadt gauge. Gregorian calendar system. Moscow Time (zone time + 1 hour). The sea level rod was fixed on the approach dam in the former place. The instability of the bench mark 7271 was controlled by the precision levelling connections with the bench marks of the deep hole bench mark system (Bogdanov, Boulanger, 1997). In this period levelling connection of the 1st class of the Kronstadt and Shepelevo gauges zero points accuracy was executed.

The complex researches of deformation processes were carried out by different organizations and included repeated precision levellings on the basis of deep hole bench mark group; regular observations over fluctuations of underground waters levels; gravimetrical and geophysical measurements; experimental pumping of artesian waters to determine filtration and deformation properties of the Gdov aquifer (Bogdanov, 1994, 1997). Since 1993 three GPS stations were founded in the Shepelevo complex area, one of which (GPS-4) was included into measuring campaign of the International Geodetic and Geodynamic Project "The Baltic Sea Level" in 1993 (Kakkuri, 1995). In 1997 measurements were carried out at stations GPS-4 and GPS-5 (Abalakin *et al.*, 1998a).

6 Brief characteristic of sea level series

The versions of mean monthly series of observations at the Kronstadt and Shepelevo gauges described above are given in full in Appendix 1 and Appendix 2. The diagrams of mean yearly and monthly series of observations at the Kronstadt gauge are reproduced in Fig. 1, 2, an mean monthly series of observations at Kronstadt and Shepelevo are given in Fig. 3.

The Kronstadt sea level series may be subdivided conditionally into three periods. For the first of them (1777-1840), besides some negative facts, which were given in the description, the use of "ordinary" level, i.e. the mean level for uncertain interval of time, which is essentially dependable on the observations site and interval of averaging, as the reference one is typical. Judging by the value of the assumed shift of the gauge during catastrophic flood of 1824 estimated by M. F. Reinecke in 6.8 inches (~17 cm), long-term trends of this period could be complicated by errors of systematic character, approximately 0.25-0.5 feet (8-15 cm).

The aspiration for reliable fixation of permanent (constant) zero point of the station is characteristic for the second period (1841-1897). By the end of this period the precise geodetic methods of long-term control over its stability had been already tested. However, as the experience of observations at the Kronstadt gauge testifies, the losses and replacements of zero point mentioned above could generate systematic distortions of the series, approximately 10 cm.

The prevalence of mareograph observations is characteristic for the third period (1898-1993). The experience of observations at the Kronstadt gauge testifies, however, that the long-term accuracy of mareograph observations essentially depends on the various hydrological, technical and methodical factors requiring constant qualified observatory and metrological control of the measurements. To ensure completely such control while carrying out precision measurements in intervals of about first hundreds of years, is not possible for departmental non-scientific organisations which are now carrying out works at unique observatory objects (Bogdanov, 1994, 1996c, 1997).

The diagram of differences of the sea level mean monthly values on the basis of observations carried out in 1989-1993 at the Kronstadt gauge and its Shepelevo duplicate is given in Fig. 4. It is obvious from the figure that the diagram reflects the difference of hydrological regimes at these stations caused, in particular, by adverse influence of the Leningrad flood defence facilities complex as well.

By the example of the Kronstadt sea level series it is of particular interest to check the hypothesis about the stability of multi-year mean sea level used in geodesy and in sea level observations since XVII century as the reference surface and the origin of height datum from "ordinary water level" (Bouguer, 1748; Bogdanov, 1997).

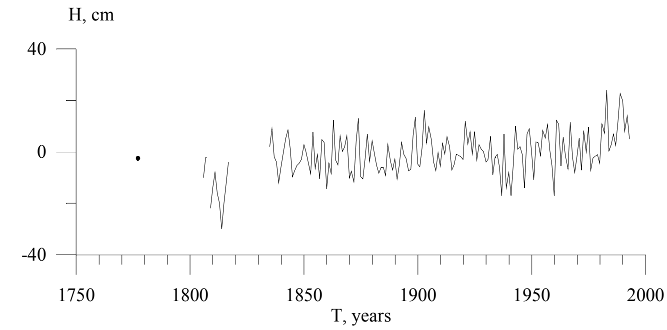

Fig. 1 Mean yearly series of sea level observations (1777-1993) at the Kronstadt gauge.

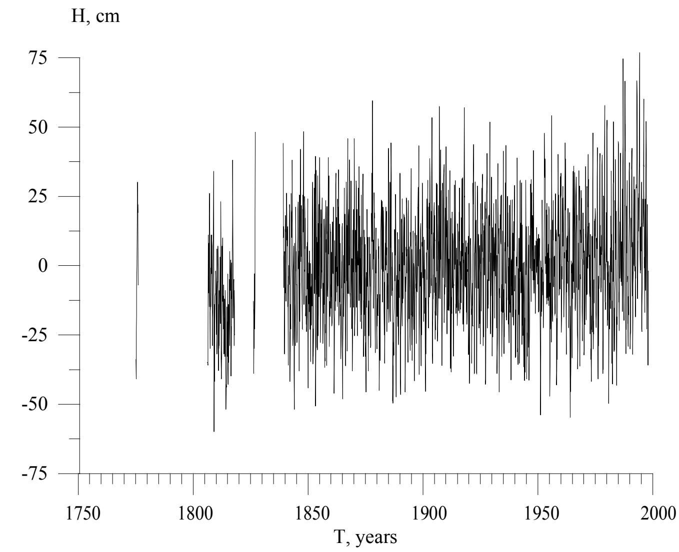

Fig. 2 Mean monthly series of the sea level observations (1777-1993) at the Kronstadt gauge.

The diagram of the current multi-year mean sea level calculated for each next year as the average for the period, beginning from 1841, is given in Fig. 5. The conclusion about temporary heterogeneity of the used height datum based on the mean (ordinary) sea level, follows from the figure. Fluctuations of the multi-year average at the Kronstadt gauge are comparable with postulated accuracy of observations (±1 cm). As a result of the analysis carried out signs of temporary series persistency (Bogdanov *et al.*, 1994) were revealed, which together with the information on multi-year average instability testifies the necessity of special study of the nature of the Baltic Sea level changes of different dimensions.

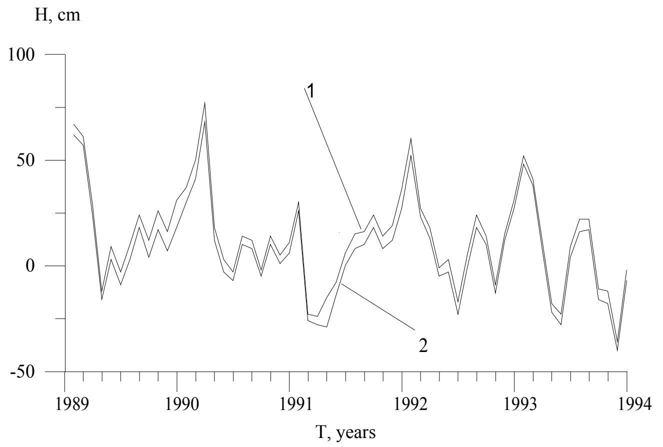

Fig. 3 Mean monthly series of sea level observations (1989-1993) at the Kronstadt (1) and Shepelevo (2) gauges .

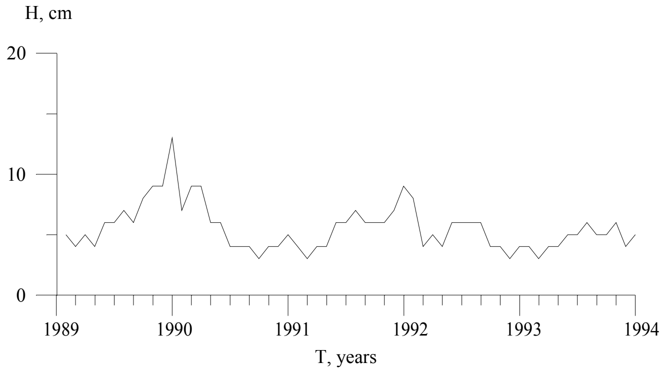

Fig. 4 The difference of mean monthly values of sea level observations (1989-1993) at the Kronstadt gauge and its Shepelevo duplicate.

The estimation of the series linear trend inclination by observations in Kronstadt for various periods, except for the results by A. R. Bonsdorff, for the periods of 1841-1858 and 1841-1885, and by E. Kääriäinen, for 1898-1927, do not surpass 0.5 mm/year in absolute value. For comparison: the average rate of level changes for the period of 1885-1984 by similar series in Stockholm, on the basis of the data by M. Ekman, was −3.9±0.1 mm/year (Ekman, 1993; Bogdanov, 1994; Bogdanov *et al*., 1994; Abalakin *et al*., 1998b).

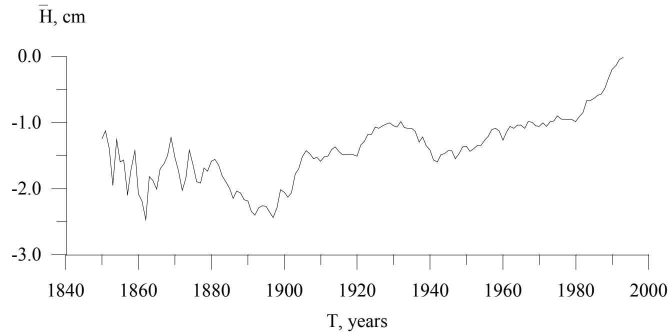

Fig. 5 The current multi-year mean series of sea level observations since 1841 of the Kronstadt gauge.

By interpretation of the Kronstadt gauge materials it is necessary to take into account peculiarities of observations in different epochs, methods of the series restoration, instability of its various zero points, geodynamic and anthropogeneous (technogeneous) changes in the region. For example, the insignificant increase of the level recorded since the 1950s, which is associated by some researchers with the World ocean level increase as a result of the so-called “Greenhouse” effect and thawing of the Antarctic Continent and Greenland continental glaciers, can be explained by other reasons. Thus, it is in this period that:

1. change of the departments responsible for observations at the Kronstadt gauge has occurred and observation regulations have been changed;
2. the amount of technogenous load of Siniy Most, on the pier of which the gauge zero point is fixed, has increased considerably;
3. the amount of piezometric depression has increased sharply up to regional scales (radius about 50-100 km, amplitude ~60 m), with the centre in St. Petersburg, this depression was formed in the course of intensive exploitation of the Gdov aquifer underground waters;
4. the level regime has changed as a result of the construction of the Leningrad dam (the complex of flood defence facilities); etc.(Bogdanov, 1993b, 1995b, 1997; Abalakin *et al.*, 1998).

7 Conclusion

The investigations carried out testify to some shortcomings of proposed MYSL and MMSL versions of the Kronstadt sea level series. Partial elimination of these shortcomings is possible after the detailed analysis of the saved original materials and continuation of purposeful complex archival and library search for new information. However, we consider that the most effective strategy is simultaneous preparation of the following versions: MYSL, MMSL, mean daily sea level, mean fixed-time sea level and mean hourly sea level. Only by combined analysis of all these versions prepared in different time and by different researchers, it is possible to verify the source materials. On this basis the development and further improvement of the unified methods of analogous series restoration is possible. It is necessary to involve in such work a wide circle of all interested organizations, experts and scientists.

The materials of representative secular sea level observations at the oldest preserverd tide gauges are of great interest for many branches of the Earth science, in particular, for investigation of global changes. It is reasonable to develop the International Program of secular changes providing, in particular:

1) saving (archiving, publication, etc.) of all materials on the oldest tide gauges in the world;
2) scientific and technical support of continuation of their functioning;
3) investigations of instability of the zero points of these tide gauges by the method of regular precision redefinition of their position in the uniform World Geodetic System.

With this view the oldest tide gauge stations require the status of observatory objects of National and International significance.

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Appendices

Appendix 1 The mean monthly series of sea level observations (1777-1993) at the Kronstadt gauge (Baltic Sea, Gulf of Finland, $\varphi = 59°59'$, $\lambda = 29°46'$)

Years	MONTHS centimetres												Mean
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1777	-34	-41	-24	-18	-7	0	15	15	30	19	22	-7	-2.2
1806	–	-35	-35	-36	-27	11	10	-10	8	1	-15	18	-10
1807	26	7	-9	-30	-17	-15	-1	-15	10	11	-3	11	-2
1808	9	7	5	-29	-19	-16	-16	–	–	–	–	34	–
1809	-60	-29	-14	-42	-24	-11	–	–	-10	-2	-7	-25	-22
1810	-25	-9	6	-32	-26	-10	-6	-6	7	-2	-25	-38	-14
1811	-14	-30	-9	-29	–	–	-8	1	3	-21	3	23	-8
1812	0	-34	-41	-31	-34	-15	7	-13	10	-12	-13	-11	-16
1813	-23	-7	-7	-17	-32	-19	-31	-12	-32	-33	-9	-20	-20
1814	-33	-41	-52	-43	-44	-35	-15	-20	-21	-33	-24	-3	-30
1815	-37	-43	-25	-14	-35	-30	-20	-5	-5	-29	5	-4	-20
1816	-2	-9	2	-5	-40	-22	-30	1	-12	-3	-19	2	-11
1817	17	38	9	0	-19	-6	-9	-5	-29	-9	-15	-25	-4
1824	–	-13	-18	-39	-16	-30	-3	-3	-23	-12	18	48	-8
1835	–	44	10	14	-8	-7	3	5	-32	-8	-10	13	2
1836	12	18	6	-13	-6	3	26	26	9	13	7	10	9
1837	14	-15	-7	-36	-17	-4	-4	0	-7	12	22	19	-2
1838	-42	-24	-31	-14	-23	-6	0	26	10	16	19	20	-4
1839	38	12	-27	-29	-26	-2	1	7	-4	-23	-39	-52	-12
1840	8	-12	-19	-19	-29	3	21	-2	5	-7	-7	-8	-6
1841	-22.9	-27.9	-20.3	-3.8	5.1	10.2	20.3	22.9	-1.3	2.5	5.1	1.3	-0.7
1842	-38.1	25.4	-14.6	-6.4	-20.3	15.9	27.9	41.9	1.3	3.8	3.2	20.3	5.2
1843	21.6	-3.5	-4.7	-12.7	-22.9	-7.6	13.5	20.3	11.9	25.4	12.7	48.3	8.5
1844	16.0	-5.6	-14.2	-1.8	-2.0	24.9	19.6	6.1	17.0	-10.9	-18.3	-16.0	1.3
1845	-11.2	-21.3	-10.9	-23.9	-18.5	6.9	-8.6	8.4	1.3	24.1	-18.3	-44.2	-9.7
1846	-2.8	-13.5	1.0	-14.0	-1.5	-16.8	5.3	-9.9	-9.9	-23.1	-2.8	0.8	-7.3
1847	-34.8	-8.4	-7.9	-10.7	-21.6	-3.6	-3.0	-14.7	4.8	9.6	30.0	-3.3	-5.3
1848	-35.6	-22.9	-33.0	-25.4	-7.1	1.8	25.4	27.9	-10.2	-1.3	33.0	-5.1	-4.4
1849	19.0	39.4	-50.8	-33.5	-20.8	34.3	7.1	10.2	-10.4	8.4	-29.7	-8.1	-2.9
1850	-30.5	32.3	-11.4	-25.4	-17.3	15.2	-3.6	22.1	-11.4	2.5	22.1	38.9	2.8
1851	11.7	0.5	-20.3	-27.9	-11.4	20.1	10.2	15.0	-8.4	-1.8	-2.5	15.7	0.1
1852	24.4	0.0	-10.7	-19.6	-28.2	-19.3	-6.4	-17.3	4.6	16.5	-14.2	16.8	-4.4
1853	12.4	-36.8	-33.3	-34.5	-21.3	-24.4	13.5	23.4	4.6	9.4	-4.3	-10.4	-8.5
1854	-36.1	21.3	11.4	12.2	-8.6	-11.2	-5.3	-4.1	38.9	37.6	4.1	32.3	7.7
1855	25.7	-23.9	-29.2	-13.0	-17.5	-18.5	-17.0	15.0	11.9	11.9	-15.5	-6.9	-6.4
1856	-11.2	4.8	-13.2	-21.8	-20.6	4.8	15.7	8.6	-2.0	-3.0	3.0	21.1	-1.1
1857	-7.9	-17.0	-19.6	-46.2	-33.5	-11.7	8.9	-1.3	-16.3	3.3	-13.0	29.2	-10.4
1858	33.3	1.3	-2.3	17.3	-5.6	-9.7	-0.5	-15.0	6.1	23.9	16.8	-7.4	4.8
1859	21.1	16.0	34.5	12.7	-21.6	-17.3	11.9	15.0	-8.9	-13.2	7.9	-14.7	3.6
1860	-18.3	-14.0	-33.8	-28.7	-18.5	-10.7	1.3	-8.1	13.7	15.2	-23.1	-48.3	-14.4
1861	-31.8	-23.6	-10.2	-16.8	3.6	-18.5	-10.7	27.9	18.8	-6.4	-3.0	18.5	-4.4
1862	-13.2	-19.8	-36.3	-20.3	-17.0	1.5	30.0	14.5	-5.6	14.5	-18.0	-31.0	-8.4
1863	17.8	45.7	-10.2	-10.2	0.0	-10.2	17.8	20.3	7.6	0.0	33.0	38.1	12.4
1864	12.7	-10.2	-10.2	-12.7	-15.2	-2.5	7.6	30.5	2.5	-5.1	-12.7	-22.9	-3.2
1865	2.5	-25.4	-38.1	-25.4	-10.2	12.7	2.5	-2.5	20.3	-15.2	5.1	12.7	-5.1
1866	45.7	22.9	-25.4	-20.3	-12.7	-10.2	12.7	2.5	2.5	-2.5	30.5	27.9	6.1
1867	-15.2	12.7	20.3	-5.1	-25.4	-2.5	5.1	0.0	2.5	10.2	27.9	12.7	0.2
1868	-12.7	35.6	7.6	-10.2	5.1	17.8	0.0	-20.3	2.5	-10.2	10.2	-2.5	1.9
1869	-17.8	25.4	-20.3	-22.9	-12.7	10.2	7.6	12.7	27.9	33.0	33.0	0.0	6.3
1870	-7.6	-33.0	-12.7	-17.8	12.7	2.5	10.2	-25.4	7.6	-10.2	-15.2	-33.0	-10.2

Appendix 1 (Continued)

Years	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Mean
	MONTHS centimetres												
1871	-27.9	-45.7	-5.1	-2.5	-10.2	-15.2	0.0	20.3	0.0	-7.6	-7.6	10.2	-7.6
1872	-5.1	-38.1	-30.5	-15.2	-12.7	-25.4	-5.1	-5.1	10.2	-2.5	-2.5	-7.6	-11.6
1873	4.1	-11.7	-29.7	-29.0	-11.9	-4.8	2.5	18.8	8.9	33.3	8.6	59.4	4.0
1874	53.8	29.2	-1.5	3.8	-15.5	9.1	2.3	15.0	26.2	17.0	19.0	-3.8	12.9
1875	-13.2	-17.5	-31.5	-3.6	4.6	13.5	-2.8	0.5	5.6	-21.8	-30.2	-19.0	-9.6
1876	-11.9	-21.8	-10.4	-15.2	-18.0	-11.4	9.7	2.5	6.9	2.3	-14.7	-45.2	-10.6
1877	-31.5	-10.4	-11.2	-34.3	-23.6	0.8	7.4	12.4	18.0	18.0	23.6	-1.5	-2.7
1878	5.3	17.8	23.1	-13.2	-13.2	14.7	21.1	-2.3	19.8	14.0	0.5	-3.6	7.0
1879	-16.0	-25.1	-6.1	-35.3	-19.8	2.0	8.1	-1.8	13.7	21.1	3.6	10.9	-3.7
1880	19.6	0.0	6.4	-23.9	-7.4	-4.1	-2.8	-7.6	-15.7	7.1	37.8	42.2	4.3
1881	17.5	-20.6	-17.5	-9.9	-9.4	-2.0	11.7	30.0	-8.1	-20.3	15.2	6.4	-0.6
1882	44.2	33.0	32.5	-10.9	-10.9	-0.5	-9.1	4.6	-11.7	-49.0	-36.1	-49.8	-5.3
1883	-27.7	-33.0	-20.6	-32.5	-18.5	-15.2	0.0	13.0	-5.6	12.4	3.6	24.6	-8.3
1884	25.7	15.2	-32.0	-47.5	-10.7	-7.4	-3.6	-11.4	-18.5	11.9	9.4	-2.8	-6.0
1885	-18.5	-22.1	-5.3	-28.7	-21.6	9.4	-5.3	-11.7	0.3	-2.0	-1.0	33.3	-6.1
1886	5.6	-40.6	-46.7	-25.4	-21.1	-15.0	15.2	16.8	13.5	-14.0	-21.8	24.1	-9.1
1887	-13.7	4.6	-4.6	-10.2	-11.9	2.5	9.9	18.5	0.0	18.0	4.6	17.3	2.9
1888	2.3	-20.3	-45.7	-33.0	-4.1	-9.4	-3.8	6.6	3.3	24.4	22.6	15.7	-3.4
1889	-2.8	5.8	-18.3	-20.8	-35.0	-21.8	-3.3	23.4	4.8	-19.3	-2.5	4.1	-7.1
1890	6.8	-4.3	-8.9	-25.4	-30.7	1.3	11.9	9.1	6.9	35.0	-17.8	-17.8	-2.8
1891	-28.7	5.8	-1.3	-34.3	-16.8	-18.5	-15.2	-2.8	12.4	-4.6	-23.1	0.8	-10.5
1892	-0.8	-6.4	-41.7	-19.0	-9.1	-2.3	11.7	7.1	17.8	-2.5	-8.1	-6.6	-5.0
1893	-28.2	-13.5	10.9	5.6	-9.4	-0.8	-9.6	0.0	20.8	20.6	28.2	18.5	3.6
1894	-0.3	43.2	2.8	-39.4	-30.5	-18.3	-1.0	5.8	5.1	-7.6	13.0	15.2	-1.0
1895	-12.2	-36.3	-14.0	-2.5	-25.1	-11.2	8.4	6.9	29.7	16.3	13.2	-4.6	-2.6
1896	5.6	10.2	-20.1	-20.3	-5.3	-3.3	9.1	-4.3	-17.3	-8.4	-1.5	-33.8	-7.5
1897	-45.5	-11.7	-32.0	-29.5	-19.3	-6.1	4.6	-5.1	24.1	13.4	21.1	5.6	-6.7
1898	30.7	19.6	-12.0	-22.2	-22.7	-10.7	21.1	13.2	22.5	-11.5	9.6	38.6	6.4
1899	29.7	12.3	7.6	5.6	-10.0	-4.7	-7.3	19.6	11.3	33.6	53.4	9.6	13.4
1900	-31.4	-35.5	-22.5	-16.0	-3.4	-12.1	11.8	2.4	19.3	22.6	-9.9	18.0	-4.7
1901	12.4	9.1	-26.7	-16.5	-23.4	-4.3	-10.9	-6.4	-18.0	-13.2	29.7	-2.0	-5.8
1902	29.2	4.8	-3.6	-27.4	-21.8	-13.8	11.4	19.1	21.6	2.0	8.6	-11.9	1.5
1903	12.5	57.4	19.0	10.8	-6.5	-12.1	10.5	41.7	29.9	2.1	27.0	-0.2	16.0
1904	-2.3	-15.5	-36.2	-21.1	1.7	6.5	29.7	23.2	-4.5	0.8	27.9	31.8	3.5
1905	33.8	36.4	-20.7	-13.9	-7.0	-10.4	15.0	16.6	20.7	10.6	-7.9	42.9	9.7
1906	22.6	10.2	24.8	-3.3	-24.7	-0.7	13.8	16.2	0.6	-13.9	-16.2	27.2	4.7
1907	2.7	-9.4	2.4	-16.3	1.3	-14.7	5.0	34.2	29.9	-16.3	-29.4	-37.2	-4.0
1908	-16.4	17.0	-38.5	-34.1	-11.5	-17.4	-13.2	2.3	19.3	-8.1	1.0	11.5	-7.3
1909	8.5	-1.0	-32.8	-16.3	-6.9	-4.6	7.7	29.0	-1.5	2.4	11.9	0.3	-0.3
1910	30.6	3.0	-3.0	-17.4	-14.2	-13.9	6.3	-15.2	-9.9	2.1	-21.7	-14.1	-5.6
1911	15.1	11.5	1.3	-11.0	-16.4	-11.7	12.2	-0.1	19.2	8.8	28.0	-17.2	3.3
1912	-13.6	-15.1	-15.9	1.4	-4.9	5.2	-13.5	-6.6	17.2	-5.1	10.1	31.3	-0.8
1913	6.4	3.3	31.6	-9.0	-21.3	8.0	0.9	2.0	-23.8	-9.0	23.2	56.9	5.8
1914	24.6	25.1	-7.4	-5.1	4.6	-7.9	-7.9	8.9	4.6	-4.6	-17.0	6.7	2.0
1915	-19.0	-21.3	-15.4	-1.5	-2.2	8.1	4.0	7.1	10.6	-32.2	-19.6	-6.7	-7
1916	22.4	6.4	-42.6	-23.0	-16.0	-7.4	-2.4	9.8	7.3	9.8	-7.5	-15.5	-5
1917	-17.8	-15.8	-35.3	-11.8	-6.4	-14.5	-10.4	-21.8	29.7	22.1	28.8	43.7	-1
1918	16.2	6.1	-17.4	-39.0	-38.9	4.2	4.6	9.4	30.2	15.5	0.9	-8.1	-1.4
1919	16.3	5.3	-18.7	-38.7	-39.3	5.0	5.0	9.3	28.7	14.7	-1.0	-8.3	-2
1920	9.2	11.3	8.3	-22.7	-2.6	1.6	5.9	7.2	-2.5	-21.0	-2.2	-28.4	-3
1921	22.3	0.7	11.3	0.0	-16.6	5.6	27.8	16.6	28.8	32.9	4.9	15.2	12
1922	10.1	-29.0	2.7	-25.9	0.7	12.5	8.7	14.4	0.4	-3.5	20.0	22.9	3
1923	18.1	-6.6	-43.0	-40.9	-8.8	20.5	16.9	25.4	26.8	33.2	40.4	10.2	7.7

Appendix 1 (Continued)

Years	MONTHS centimetres												Mean
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1924	-22.7	-5.1	-15.5	-10.2	-14.1	-4.0	17.7	-5.6	18.1	1.4	14.6	14.5	-0.9
1925	51.7	25.8	-10.3	-15.4	-24.8	4.4	-11.0	0.5	18.8	31.9	12.5	10.6	7.9
1926	-11.3	-32.7	13.6	-15.1	-25.9	-14.6	-6.7	12.3	22.3	12.0	-2.1	10.1	-3.2
1927	7.4	-7.2	-19.1	6.6	7.4	15.1	-3.9	2.6	11.8	23.8	11.3	-22.6	2.8
1928	-5.6	3.6	-39.1	-31.2	-25.6	8.6	36.7	24.5	13.6	8.6	4.2	13.3	1.0
1929	-12.3	-45.7	-14.3	-8.2	-11.7	6.6	18.3	16.8	13.1	25.0	9.0	7.7	0
1930	25.4	-16.7	-6.9	-32.9	-23.2	-13.0	-4.3	12.4	-17.0	-3.0	41.2	-11.5	-4
1931	-8.7	-31.9	-17.2	-22.0	-25.9	5.7	8.2	5.1	13.1	29.8	-6.5	12.3	-3
1932	43.3	13.7	-18.7	-11.7	-19.8	-4.5	-3.3	5.7	25.0	15.7	6.7	19.0	6
1933	-12.5	-0.4	-21.3	2.7	-21.0	-28.0	4.3	21.7	-13.9	-11.4	-17.0	-14.4	-9
1934	-0.4	23.4	-11.0	-41.4	-8.1	1.8	-7.6	2.3	-10.8	23.7	16.7	-15.2	-2.2
1935	-18.7	11.7	-6.4	-8.7	-21.6	-7.3	15.9	5.3	8.3	28.9	-9.3	-7.7	-1
1936	-3.6	-19.8	-33.3	-16.*	-33.*	-13.2	-1.5	3.1	2.6	-0.3	8.1	38.8	-6
1937	-6.6	-31.2	-30.6	-35.8	-22.3	-14.4	-1.1	-17.8	9.9	-8.6	-4.8	-35.3	-17
1938	-9.8	19.8	30.4	30.6	-2.2	15.3	5.5	-10.0	1.1	7.5	29.8	-28.6	7
1939	-23.0	14.6	-21.6	-12.8	-25.3	-5.6	0.9	-14.7	-24.8	-36.6	-17.8	1.2	-14
1940	-13.0	-41.6	-19.*	-23.0	-38.6	-13.6	-6.4	16.7	30.7	-3.4	0.*	14.*	-8
1941	-26.2	-41.*	-24.4	-32.8	-28.4	-14.2	-12.6	3.*	14.1	–	-29.6	7.4	-17
1942	-19.9	-41.5	-29.0	-29.7	-24.0	-0.8	10.8	-1.1	7.6	29.4	18.3	22.6	-5
1943	-13.1	31.0	13.4	26.2	12.1	-2.0	7.4	18.0	5.6	17.1	-5.4	13.0	10
1944	41.4	17.5	-2.7	-10.1	2.2	-1.2	-4.9	-5.3	7.2	-5.6	-17.4	-4.5	1
1945	-4.*	-3.1	8.7	8.5	-2.6	13.6	2.0	-0.4	1.0	9.7	-6.8	-6.8	2
1946	8.8	9.3	-16.9	11.3	-16.6	1.0	4.4	9.8	8.7	-4.4	-10.0	-22.8	-1
1947	-41.6	-54.0	-32.4	1.7	-18.4	-13.2	-0.8	-16.7	-8.9	23.6	0.6	-2.4	-14
1948	-1.6	-10.8	-6.0	-11.1	-22.5	-2.2	2.3	8.3	20.3	47.7	32.6	31.7	7
1949	38.5	34.5	0.7	3.3	-3.0	2.1	-2.8	20.0	-11.8	22.4	-14.0	18.1	9.0
1950	-6.4	-11.6	4.5	-4.3	-12.7	6.1	7.7	-14.6	21.2	20.1	-11.2	2.6	0.1
1951	-15.5	-47.2	-36.1	-6.3	-23.0	-17.4	12.8	-9.0	2.5	-16.2	-27.8	54.0	-10.8
1952	35.4	9.7	-14.9	-16.3	-20.2	15.8	16.4	9.0	23.5	-7.8	-7.3	3.0	3.9
1953	-2.8	-4.0	3.4	-7.3	-17.6	-17.0	6.5	25.9	21.0	8.7	11.7	12.9	3.5
1954	11.2	-43.2	-38.2	-19.1	-34.0	-15.2	8.7	13.0	29.7	40.1	18.9	10.4	-1.5
1955	25.4	-1.1	-10.7	-10.4	11.3	0.9	-0.4	-8.6	10.4	32.1	24.9	25.2	8.3
1956	33.3	-24.2	-19.4	-19.1	-0.4	-5.0	3.4	24.3	12.0	28.6	6.9	24.4	5.4
1957	15.3	15.2	-18.7	-16.7	-9.5	4.7	2.6	10.8	20.6	44.2	19.9	38.5	10.6
1958	15.1	12.2	-15.4	-32.1	5.5	-9.6	9.7	9.2	-6.5	10.7	9.0	1.4	0.8
1959	20.6	11.9	-6.5	-15.5	-22.5	1.5	1.7	4.3	19.1	0.1	-24.4	-54.9	-5.4
1960	-14.7	-22.9	-45.6	-38.3	-20.6	1.7	-1.8	-2.7	0.3	-33.4	-31.1	1.0	-17.3
1961	-12.1	6.9	34.0	9.3	-5.8	11.4	25.8	35.8	17.1	-9.9	11.4	22.6	12.2
1962	33.5	25.0	-15.6	-16.3	-12.7	10.8	14.7	24.6	31.9	21.9	-8.0	18.1	10.7
1963	-8.9	-23.8	-26.9	-37.4	-27.3	-13.8	8.0	-8.8	2.8	34.2	16.2	19.0	-5.6
1964	28.7	11.1	-36.4	-31.4	-3.3	-4.9	12.8	10.0	27.0	8.1	22.2	24.3	5.7
1965	2.4	2.1	-15.1	-27.3	-21.7	-12.3	19.0	13.7	4.7	13.2	0.3	1.8	-1.6
1966	-32.4	-30.6	5.3	-20.1	-21.4	-9.2	11.2	10.0	35.7	3.9	-12.1	-19.7	-6.6
1967	3.1	-10.7	28.4	9.7	-10.4	2.5	10.3	14.0	-1.1	40.1	21.1	31.1	11.5
1968	3.2	8.2	15.3	7.6	-9.6	-11.3	3.7	-10.0	-24.8	11.2	-12.3	-5.5	-2.0
1969	-34.0	-30.0	-42.0	-18.2	-23.1	-15.1	10.6	-24.1	7.0	29.6	47.8	-5.2	-8.1
1970	-30.2	-20.3	-24.8	-5.1	-13.7	-11.6	16.1	2.7	16.8	10.4	20.6	17.5	-1.8
1971	10.6	-0.8	-17.0	-22.4	-21.1	-16.2	9.9	7.5	5.9	31.2	42.5	34.1	5.4
1972	-27.4	-41.0	-38.0	-3.8	-29.1	-8.4	-8.3	-8.0	-4.8	5.4	36.5	40.4	-7.2
1973	0.0	14.5	3.8	6.8	-9.7	-4.6	-8.0	10.9	3.8	5.6	36.0	39.8	8.2
1974	4.4	2.3	-39.0	-27.5	-37.6	-2.4	25.1	24.4	6.3	-5.3	5.1	42.9	-0.1
1975	57.7	18.9	-13.1	-13.4	-16.0	0.4	-1.1	1.6	19.1	11.1	1.2	48.3	9.6
1976	52.4	-7.9	-21.7	-2.5	-19.7	1.5	-4.0	-2.1	-11.0	-49.9	-21.1	-0.1	-7.2
1977	-15.9	-23.0	-11.7	-6.3	-12.5	-11.3	6.4	-15.6	17.8	10.4	34.1	-2.4	-2.5
1978	11.2	-35.3	-12.9	-24.3	-42.9	-11.1	5.4	-5.8	29.4	30.1	51.9	-15.6	-1.7
1979	-31.1	-15.4	-19.6	-30.6	-10.4	-6.8	23.5	8.0	38.3	8.9	2.0	19.6	-1.1

Appendix 1 (Continued)

Years	MONTHS centimetres												Mean
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1980	-11.6	-24.2	-43.3	-18.6	-21.4	-12.3	-6.3	-4.1	6.8	12.3	24.1	44.7	-4.5
1981	43.7	23.5	-13.2	-9.8	-23.6	3.8	9.1	15.7	-4.7	17.6	40.5	28.1	10.9
1982	-1.2	-5.1	-5.9	8.6	7.1	-7.3	-5.6	6.2	27.6	-16.7	35.6	44.1	7.3
1983	74.6	26.0	4.2	-10.7	-19.9	0.6	10.3	14.3	21.6	66.5	59.4	41.2	24.0
1984	50.9	-13.2	-31.9	-21.6	-23.2	-10.9	21.4	4.4	8.7	30.6	-6.0	-3.8	0.4
1985	-21.1	-15.6	-29.3	-11.3	-17.9	-5.3	7.2	15.4	33.7	37.1	19.0	19.9	2.7
1986	7.6	-30.2	-25.1	-24.0	-11.5	-5.0	17.1	6.6	41.4	34.8	42.2	28.3	6.9
1987	-11.1	8.4	-32.1	-18.8	-6.9	-2.3	14.3	19.1	32.0	0.4	-0.3	27.4	2.5
1988	21.5	-2.1	-0.4	-1.4	-18.6	-4.7	-4.6	26.1	29.1	27.8	28.0	38.0	11.6
1989	66.6	61.1	28.8	-12.0	8.7	-2.7	10.2	24.4	12.3	25.9	16.4	31.4	22.6
1990	37.2	50.0	76.8	18.3	3.3	-2.8	13.7	12.4	-1.7	14.0	5.2	10.6	19.8
1991	30	-23	-24	-15	-8	6	15	16	24	14	19	36	8
1992	60	27	18	-1	3	-17	5	24	14	-9	15	31	14
1993	52	41	12	-18	-23	9	22	22	-11	-12	-36	-2	5

Notes:
1) 1777 - according to (Krafft, 1780; Bogdanov *et al.*, 1993); Julian calendar system.
2) 1806-1824 - according to (Reference, 1972), but without M. F. Reinecke correction (-17 cm); the values obtained on the basis of incomplete year data are shaded; intervals of 1815-1817 and 1824 are singled out because of large difference between two mean yearly versions: (Reference, 1972) and (Notes, 1807-1827); Julian calendar system.
3) 1835-1840 - according to (Reference, 1972); Gregorian calendar system (?); the value obtained on the basis of incomplete year data is shaded.
4) 1841-1846 - according to (Notes, 1842-1852); Julian calendar system.
5) 1847 - according to (Notes, 1842-1852); Gregorian calendar system.
6) 1848-1850 - according to (Notes, 1842-1852); Julian calendar system; the misprint in the original is shaded.
7) 1851-1886 - according to (Saltykov, 1886,1888); here and further - Gregorian calendar system.
8) 1887-1895 - according to (Fuss, 1896);values according to (Ryl'ke, 1896; Fuss, 1911) are shaded.
9) 1896-1914 - mareograph data, according to (Proceedings 1898-1923); gauge values or those calculated on their basis are shaded.
10) 1915-1935 - mareograph data, according to (Mikhaylov, 1992); the values obtained by gauge measurements (3 times per day) or on their basis are shaded.
11) 1936-1950 - mareograph data, according to (Mikhaylov, 1992), the values obtained on the basis of incomplete month, year data are shaded; the values marked by (*) are given according to (Reference, 1972).
12) 1951-1990 - mareograph data, according to (Mikhaylov, 1992).
13) 1991-1993 - mareograph data, according to the North-West Department of the Hydrometeorological Service of Russia.

Appendix 2 The mean monthly series of sea level observations (1989-1993) at the Shepelevo duplicate of the Kronstadt gauge (Baltic Sea, Gulf of Finland, $\varphi = 59°58'$, $\lambda = 29°06'$)

Years	MONTHS centimetres												Mean
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1989	62	57	24	-16	3	-9	3	18	4	17	7	18	16
1990	30	41	68	12	-3	-7	10	8	-5	10	1	6	14
1991	26	-26	-28	-19	-14	0	8	10	18	8	12	27	2
1992	52	23	13	-5	-3	-23	-1	18	10	-13	12	27	9
1993	48	38	8	-22	-28	4	16	17	-16	-18	-40	-7	0

NOTE: All values are given referring to the Baltic Height Datum, which differs from the "zero point" accepted by the Hydrometeorological Service of Russia by −5.00 metres (Bogdanov, 1995a).