On the problem of compilation of oceanographic climatic CD atlases (using Arctic seas as an example)

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An oceanographic database compiled at the Murmansk Marine Biological Institute (MMBI) is considered. The database is intended for studying climate in the geographical region of Barents, Kara, and White Seas. It contains the information acquired by marine institutions in Russia, USA, United Kingdom, Germany, Norway, and Poland for the last century. The data have came from different sources: they were obtained by the MMBI in its research missions, taken from the literature, and received from other research institutions both in Russia and abroad. As a result of applying a specialized procedure and discarding duplicates, 206 330 oceanographic stations were selected (from more than 1 000 000) and included into the CD publication.

Seas of the Western Arctic (Barents, Kara, and White seas) occupy a particular place among polar seas because of their unique natural characteristics. Penetration of warm waters from the Atlantic and cold waters from the Arctic basin as well as significant continental discharge create here abnormal climate conditions, which manifest themselves in different forms. Sharp vertical and horizontal gradients of temperature and salinity induce intense dynamics and lead to an intense energy exchange with the atmosphere. It is just this exchange that determines the climate over vast geographical region.

At the same time, this region (especially, the Barents Sea) is one of the richest fishing regions on the globe. Hundreds of ships from different countries fish there. Sea products from the Barents Sea are consumed by people from Europe and Russia. Biological productivity of the Barents Sea strongly depends on the inflow of warm Atlantic water. Besides, in the last decade this region attracted enhanced interest of investigators because of oil and gas deposits discovered on the Arctic shelf and in connection with the problems of radiative safety. This region is also important from the viewpoint of sailing, because the ice-free Barents Sea is the only way to hard-to-reach Northern-Asian regions of Russia.

Anomalous oceanographic characteristics make this region a natural laboratory for studying a wide variety of problems associated with the ocean influence on climate and distribution of marine bioresources. Such studies require information support, especially because the situation is now uncertain: climatic trends found from limited data samples in this region contradict each other. Therefore, to conduct such studies, a great bulk of reliable and well-organized data on the atmosphere and ocean is needed.

Many countries organized research missions into the Barents Sea. As early as in 1837, the mission aboard French vessel *La Recherche* measured the temperature of the sea surface in the region of Spitsbergen reaching 79°36′ N. By 1870 oceanographic observations were conducted occasionally in Barents Sea already aboard several Russian vessels, and starting from 1880 Russian military and commercial vessels were annually used for oceanographic observations. Late in XIX the new stage associated with state organization of large marine missions began. By that time the international standards were developed and the first international scheme of oceanographic observations in Barents Sea was approved.

During the World War I oceanographic studies in Barents Sea stopped, but starting from 1917 the interest in these studies increased significantly because of organization of fishing and the necessity of developing the northern Russian regions. It was also the time of beginning of regular oceanographic missions to Kara Sea. Before the World War II practically all materials of oceanographic observations were published in the literature and can be found in libraries and archives (Ref. 13 gives the detailed bibliography of this period).

For this period more than 10 000 stations were operated in Barents, Kara, and White Seas. No more than half of these data are now involved in processing. The most part of the missed data can be found in libraries, but searching and digitizing are very time consuming and laborious.

Before the World War II different governmental departments conducted studies in this region. The Murmansk Territorial Department of the Hydrology and Meteorology Service created in 1938 monitored Barents Sea, and starting from the 1950's it collected and stored all the obtained oceanographic data on this water area (including the data obtained by other organizations). The White Sea was studied in co-operation with the Arkhangelsk Territorial Department of the Hydrology and Meteorology Service, and Kara Sea was studied by the Arctic (Amdermin and Dikson) Territorial Departments of the Hydrology and Meteorology Service, as well as by Arctic and Antarctic Scientific Research Institute (AASRI) located in St. Petersburg. Some observation data on Barents Sea are in the archive of the State Oceanographic Institute (Moscow). For a long time departments of Hydrology

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and Meteorology Service dealt with compilation of regional databases. Only Murmansk Territorial Department of the Hydrology and Meteorology Service (MTDHMS) has the joint archive of more than 350 000 oceanographic stations, 85% of which are already stored on technical carriers. Unfortunately, since 1992 the Russian State Hydrology and Meteorology Committee decreased sharply oceanographic research works in sea. However, works on digitizing the existing archives in the Murmansk Territorial Department of the Hydrology and Meteorology Service are being successfully continued. Until recently the information stored at the Hydrology and Meteorology Service could be exchanged only centrally, through the Central Research Institute of Hydrology and Meteorology Information, which simultaneously played the part of the World Center of Oceanographic Data–B (Obninsk). A significant part of the Russian data accessible after 1955 and stored in the large centers of oceanographic information [World Center of Oceanographic Data–A (USA), oceanographic centers of the US and UK Navy] were acquired through information exchange with the Central Research Institute of Hydrology and Meteorology Information.

Almost from the very beginning, oceanographic studies of Barents, Kara, and White seas were conducted for the purposes of fishing. In 1921 the Floating Marine Research Institute was founded, which then became the base for the Polar Research Institute of Marine Fishery and Oceanography (PRIMFO). For the period since 1921 until 1941 the PRIMFO conducted 100 research cruises and operated more than 3000 deep-water stations. The credit of PRIMFO in establishing the system of standard oceanographic observations in Barents Sea and conducting seasonal surveys and monthly observations on the secular section along the Kola Meridian (33°30′ E) is significant. Since April 1934 until now the Barents Sea has been studied by this system of standards, and thanks to it now we have the unique set of data.

After the World War II the Sevrybpromrazvedka under the leadership of the PRIMFO has performed a great deal of field studies. Until the late 80's the PRIMFO exchanged information with the Hydrology and Meteorology Service. For a long time the PRIMFO compiled its own database of oceanographic and fishing data and took part in data exchange with similar foreign organizations. The total volume of data available in the PRIMFO is roughly estimated as above 250 000 stations. However, only a limited fraction of the data is open for public access in the PRIMFO, and the data can be accessed mostly within the framework of international missions.

From the foundation of the Murmansk Marine Biological Institute (MMBI) in 1935, it performs complex, whenever possible, studies: hydrobiological observations in combination with geophysical (radioactivity), oceanographic, meteorological, geological, and lythodynamic ones. The institute's library has the collection of reports and monographs describing the results of observations in Barents, Kara, and White Seas and adjacent regions of the Northern Atlantic and Arctic Ocean since 1898 (Table 1). The total volume of these results can be roughly estimated as:

– no less than 30 000 oceanographic stations;

– several thousands stations on radioactive pollution of the medium;

– about 25 000 stations of hydrobiological observations;

– tens thousands of observations of sea mammals, birds, fish, bottom animals, as well as fishing and other data.

Table 1. State of database of the Murmansk Marine Biological Institute on Barents, Kara, and White seas and the North-Eastern Atlantic (the number of stations: total is shown above the bar, MMBI data are shown below the bar)

Observations	Period of observations	Total amount	Digitized
Accompanying meteorological observations	1898 until now	100000 / 10000	10000 / 5500
Physical parameters of the sea water	1898 until now	more than 1000000 / 30000	more than 1000000 / 12500
Chemical parameters of the sea water	1898 until now	55000 / 20000	25000 / 10000
Pollution	1984 until now	5500 / 3500	2000 / 1500
Radioactive pollution	1988 until now	2000–3000 / 2000–3000	200 / 200
Plankton	1954 until now	50000 / 20000	5000 / 3500
Benthos	1935 until now	500 / 300	100 / 100
Fish	1953 until now	100 / 100	100 / 100
Birds	1988 until now	10000* / 10000*	1000* / 1000*
Sea mammals	1984 until now	10000* / 10000*	1000* / 1000*

* Separate observations.

Even under severe economic conditions of the last decade, the MMBI organized no less than five to six complex marine missions a year, and the amount of information obtained by the Institute is doubled every five or six years. Besides, the Institute's archive stores about 75 000 oceanographic and hydrobiological stations received as a result of exchange between departments and more than 1 000 000 stations (on technical carriers) on the North–Eastern Atlantic regions and Barents, Kara, and White seas received through international exchange. A total of 6 500 000 oceanographic stations on the entire Global Ocean were obtained through the international exchange.

For a more detailed history of compilation of the MMBI database see Refs. 2–4.

For a long time the data were stored in the Institute's archive mostly in the form of tables and observation and ship's logs. Only a limited part of the information was stored on technical carriers, and these data were digitized, as a rule, by investigators themselves and in a random manner. Many materials are stored in private databases and archives. It was caused by the absence of the up-to-date technology for operation with data and, first of all, the technology of database formation, as well as insufficient funding.

The probability of loss is very high for paper carriers and private databases for technical reasons (obsolescence of carriers, unprotected, no copies, etc.) and because of resignation or change of research interests of their owners. Besides, these data can hardly be used in research activity and exchanged both within an Institute and between departments and different countries.

Such a situation is typical not only for the MMBI and even not only for Russia. It was just this reason that caused the appearance of the GODAR (Global Oceanographic Data Archeology and Rescue) International Project. This project was approved at the 17th Session of the International Oceanographic Commission of UNESCO in March 1993 in Paris.[11,12] The Project is supervised by the World Center of Oceanographic Data–A/ National Oceanographic Data Center (NODC) in the USA. Within the framework of this project the owners of information receive financial and technical support for compilation of oceanographic and hydrobiological databases. Materials having no branch and national restrictions come to the common archive intended for conducting climate studies, and thus they become publicly accessible. The very important element of the GODAR Project is the development and standardization of the check methods for various oceanographic and hydrobiological information, since check is the necessary part of compilation of the unified database. The MMBI takes an active part in this project for the last six years.

Initially, the information coming to the database was accepted in an arbitrary form (since it was prepared by investigators themselves) and with minimum restrictions. However, as the GODAR Project was developed and new participants were involved in it, this practice became an obstacle. It became clear that databases on technical carriers that are available in different countries as well as their formats not always correspond to even minimum requirements on databases.[3] Therefore, the MMBI and the NODC within the framework of the GODAR Project have developed the versatile information technology for formation and check of the database of observations over the state of the environment and living organisms. This technology is described in detail in Ref. 1.

The main peculiarities of this technology implemented on a personal computer are versatility and readiness of operation with data, as well as complex check of the data. Such a technology was used in the MMBI for formation of the database of shipborne observations over hydrochemical and hydrobiological parameters, plankton, and the state of chemical, oil, and radioactive pollution of Barents and Kara seas. The NODC used this technology for formation of the database of oceanographic data in the equatorial part of the Pacific Ocean from the information given by the Ecuadorian, Australian, and French participants of the El-Ninjo International Experiment in 1962–1963. In all the cases the technology showed itself sufficiently flexible in tuning to new types of information, stable, reliable, and convenient in use. The laborious and time-consuming work on conversion of the entire MMBI database into a unified format is now in progress.

One of the principal problems, which should necessarily be solved for conducting large-scale climate studies, is provision for a free access to the database for all investigators. The most efficient access method provided by modern technologies is copying the database on CDs.

The first experience in compilation of a multidisciplinary data array was gained in compilation of the laser disk "MMBI BioBase, 1999B prepared for publication in the USA. In this case the developed versatile technology of hydrobiological database formation was implemented for the first time. The technology allowed dissimilar data to be incorporated into a single array in a unified user-friendly format. The disk contains about 3000 stations for Barents, Kara, and White seas from the MMBI archives and from the literature for the period of 1919–1999. These data present the information on plankton and benthos, results of continuous recording of chlorophyll concentration, and accompanying occasional and serial oceanographic stations. Besides, it includes the software for formation of a complex database and quality check along with the reference information, namely, lists of species of phyto- and zooplankton, photoalbum of dominating species, maps of the shore line of Barents, Kara, and White seas, which were used in data check, maps of observation by species and periods, and many other information.

Such databases allow one to compare directly the climate changes and the state of biota. However, it is a hard, laborious, and very long work to convert and check a bulky multidisciplinary data arrays. Therefore, not only the complete research archive of the MMBI but also smaller thematic archives and atlases are now being prepared for publication.

The first experience of this kind was preparation and publication of the laser disk "Climatic Atlas of Barents Sea, 1898–1993. Disk 1. Version of April 1998B (Ref. 13).

This CD contains the temperature, salinity, and dissolved oxygen profiles for the period of 1898–1993. The disk includes information obtained with devices of all types which were used for oceanographic observations in this period. The data were obtained within the official borders of Barents Sea and in the northern part of the strait of the White Sea. The processing procedure and composition of the data are described in the report, which is also included in CD and attached to it in the printed form.

The disk incorporates the data of 75 000 oceanographic stations. All the stations include observations of the water temperature, and 52 000 stations have the data on salinity. Besides, more than 3 000 stations have the data on the content of dissolved oxygen in the sea water. However, different regions are nonuniformly covered by observations in some years. For investigators to be able to select the period to be studied, the Atlas includes the maps of observations for every month of the entire period.

The software package used for processing and checking the CD data corresponds, for the most part, to the procedures accepted by the International Oceanographic Commission of UNESCO.[5,14] However, because of the marked vertical variability of hydrological parameters in Barents Sea, more strict restrictions were accepted, as compared to the standard ones used in vertical interpolation.[13] The check procedure includes the check of correctness of the data formats, the check of sequential increase of observation horizons, and calculation of the vertical density stability of water.[5] The data are sorted by time order; duplicates of stations are discarded. Parameters whose values are beyond the 3σ interval are also discarded. Calculations are made for each month and horizon separately.

The Atlas presents the maps of objective analysis of temperature and salinity fields at standard horizons. The procedure of objective analysis of data, which was used in this work to draw such maps, is close to the scheme of calculating the spatial distribution of data and drawing maps.[12] The algorithm is improved significantly because of the necessity to take into account the spatial inhomogeneity of oceanographic fields in Barents Sea. The chosen parameters of data analysis allowed complete formalization of the procedure of drawing climatic fields. All the drawn maps, including the coastal zone in summer, are presented without expert corrections.

Time series and monthly maps show the periods in the database, which have the least number of observations. However, measurements were conducted in Barents Sea at that time, and their results were published in open press. Therefore, such periods should be considered as landmarks and filled in the first turn at further compilation of the database.

In spite of the gaps in data collected, some cyclicity can be seen in the interannual variability of temperature and salinity on the section along the Kola Meridian (this was mentioned by many investigators). Naturally, interannual climate changes cannot be less than the measurement error. Consequently, these plots can be used for formulation of the requirements to the measurement accuracy (for salinity, first of all). The corresponding criteria will then be used in development of the methods of data quality check and data selection for calculation of climate characteristics.

Since the CD contains all the programs for calculation and the data needed, any CD user can reproduce the obtained climate characteristics. An investigator can sample the data and analyze them for an arbitrary horizon, period, and region of observations. This is the principal difference of this work from earlier similar works, except for the fact that similar works for Barents Sea were absent at all.

In 1999 the MMBI in cooperation with the administration of the ACSYS (Arctic Climatic System) International Project developed a new BarKode–1999 CD.[10] The information technology used in this new CD is the further development of the technique which was used in preparation of the CD "Climatic Atlas of Barents Sea.B[13] The information collected at formation of the Climatic Atlas was fully included in the new version of the database. Besides, it includes the data for Barents, Kara, and White seas taken from other sources and presented by the ACSYS Project administration.

Table 2 lists the marine organizations which contributed to the CD. The NODC and MMBI data collected earlier at formation of the Climatic Atlas of Barents Sea[13] were complemented with information from the CD "World Ocean Data Base Atlas–1998.B[8]

A total of 1 000 000 oceanographic stations for the period since 1898 until 1998 (Table 3) were selected from the data on Barents, Kara, and White seas. Once the data were pooled, checked for quality, and freed from duplicates, about 200 000 stations (Fig. 1) remained. It was just this array of data that was included in the CD.

Significant improvements of the technique of database formation as compared to that used in formation of the Climatic Atlas concern the following items:

(a) for every station the information is kept, which indicates the source of data (and, in some cases, the country and the observation platform), as well as the results of data processing and correction at different stages of processing;

(b) most accurate profiles of the shore line from the CD[6] where used to check if a station falls on the shore. At this stage, 450 stations (about 1% of the total number) were rejected because they are situated on land more than 5 km from the shore line;

(c) depths of stations (and/or last horizon) were checked with the use of the grid database of the sea and ocean bottom relief with the $5' \times 5'$ grid (US NODC).[7] As an acceptable error, we took 12.5% of the maximum depth in the region of the station (for the depth more than 25 m). About 120 000 stations (19% of the total number) were rejected because of errors in the depth.

Table 2. Sources of data

No.	Code	Source of data	Period of observations
1	U	National Oceanographic Data Center – World Data Center A (NODC):	
		(a) data included in the CD "Climatic Atlas of the Barents Sea 1998.B (G. Matishov et al., 1998) (CL. Atlas)	
		(b) CD "World Ocean Data Base Atlas 1998,B Volume 1, 3 (WA–1998)	1898–1996
2	M	Archive of the Murmansk Marine Biological Institute (MMBI):	
		(a) data included in the CD "Climatic Atlas of the Barents Sea 1998.B (G. Matishov et al., 1998) (CL. Atlas)	
		(b) new data prepared by the MMBI within the GODAR Project (MMBI)	1903–1997
3*	C	Navigation Service of the US Navy (US Navy)	1901–1996
4*	K	Navigation Service of the UK Navy (UK Navy)	1900–1996
5*	D	Alfred Wegener Institute for Polar and Marine Research, Germany (AWI)	1987–1998
6*	P	Institute of Oceanology of the Polish Academy of Sciences (IOPAN)	1988–1997
7*	E	Joint Russian–American Environmental Workgroup (EWG)	1989–1995
8*	I	q D "Eastern Arctic Ice, Ocean, and Atmosphere Data,B Volume 1, 1991 (CEAREX)	1905–1989
9*	F	Navigation Service of the Norway Navy (N Navy)	1992–1998
10*	N	Norwegian Polar Institute (NPI)	1959–1995
11*	B	SALARGOS automatic drifting buoys of the Navigation Service of the US Navy (ARGOS)	1988–1992

* Data received from the ACSYS Project administration.

Table 3. Number of oceanographic stations acquired from different sources

No.	Source		Number of stations in checking			Number of stations after discarding of duplicates				
	Code	Name	Total selected	In the region	After checking for quality	MMBI	Russian	Other	Unknown	Total
1	U	CL. Atlas	458 334							
		WA–1998	192 101							
		Total NODC	650 435	404 979	3 222 001	3357	41 571	48 684	1577	95 189
2	M	CL. Atlas	101 957							
		MMBI	3599							
		Total MMBI	105 556	93 996	68 792	6384	22 130	59		22 189
3	C	US Navy	633 43	61 774	53 806	42 045				42 045
4	K	UK Navy	43 066	43 038	34 814	5431	3450	8272	53	17 206
5	D	AWI	342	327	205	205				205
6	P	IOPAN	604	585	448	406				406
7	E	EWG	863	471	287		232			232
8	I	CEAREX	3281	2245	2009	–	–	396	158	555
9	F	N Navy	536	508	309	309	–	–		309
10	N	NPI	7031	6528	3386	952	2304	19	61	3336
11	B	ARGOS	172 717	24 693	24 628	24 628		–	–	24 628
		Total	1 047 774	639 144	510 885	83 717	69 687	57 430	1849	206 300

After checking and freeing from errors, about half million stations, that is, about half of the initial data array, were accepted for further processing (see Table 3).

The existing international data acquisition and exchange system assumes multiple inclusion of the same data in arrays received from different sources. Besides, duplication is possible even in the data from the same source. Thus, when preparing the CD "Climatic Atlas of Barents Sea 1998: temperature, salinity, and oxygen,B[13] NODC archives and software were used. Then the freshly published CD "World Ocean Data Base Atlas–1998,B which is a supplemented but not fully identical version of the earlier prepared data, was included in the work.

The added complication is that in different formats and databases the same information can be stored in different format and with different loss, as well as it can have different quality. For example, some databases do not include the information on the time of a station or information of meteorological and hydrochemical observations. Others store the geographic coordinates in degrees accurate to one hundredth, rather than in degrees, minutes, and seconds of arc. This leads to additional errors due to rounding off.

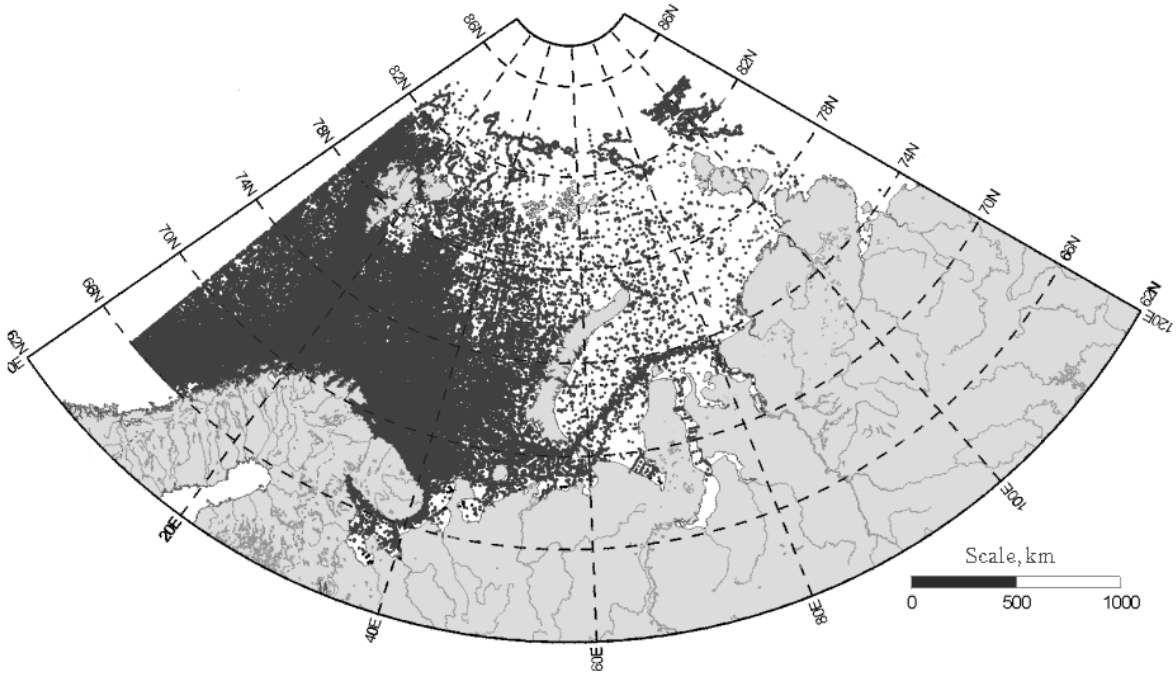

Fig. 1. Distribution of 206 300 oceanographic stations of the MMBI database.

The above reasons force us to perform an extensive search and discarding of duplicates at the final stage of the work once the main procedures of quality check are completed. This makes the work even more laborious. However, the information selected as a result of such an approach is as complete and correct as possible, what is just the main goal of this work.

From the half million oceanographic stations having passed the check, only about 200 000 stations were accepted for final processing after discarding duplicates (see Table 3). Keeping the code of the source, country, and ship in the record of an oceanographic station allows one also to make a more detailed analysis of data origin, in particular, to find Russian data.

Table 3 for each data source gives the number of stations. Besides, the number of stations obtained by Russian ships, ships of third sides, and ships with unknown identity is calculated. Some of the analyzed databases (MMBI, US Navy, Norway Navy, AWI, IOPAN, EWG, ARGOS) contain only their own data, while the others (NODC, UK Navy, NPI) mostly contain the data received from other countries.

The general structure of a database by the sources of information is shown in Fig. 2. In this diagram all the sources having the weight less than 0.5% are summed up. From the total of 95 000 oceanographic stations received from the NODC (46% of the total number of data having passed the check), 27% were found only in the NODC database and are absent in other sources. From 22 000 stations included in the database from the MMBI, only 3% stations are unique. It follows from these tables that the use of the CD "Eastern Arctic Ice, Ocean, and Atmosphere Data, 1991B[9] does not add new information to the resulting database.

The distribution of data (see Fig. 1) indicates that Barents, Kara, and White seas are the most extensively studied Arctic regions. Even taking into account multiple duplication, the available Russian data for this region from all the possible sources can be estimated as more than 500 000 oceanographic stations. The MMBI database and the BarKode–1999 CD contain only about 70 000 Russian oceanographic stations. So, the work done should be considered as only one of the first stages in compilation of the complete database on Barents, Kara, and White seas. Nevertheless, the information presented forms the basis for studying changes in climate and biota of the Western Arctic during the last century.

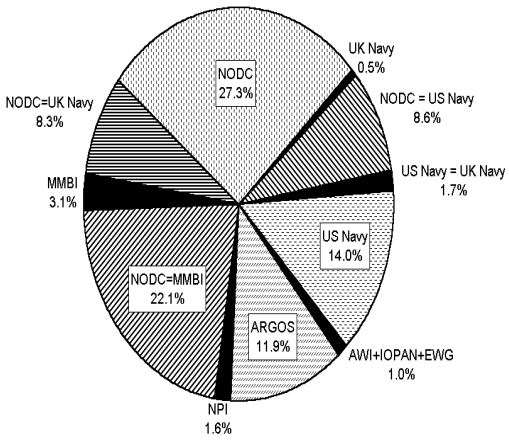

Fig. 2. Source of information used in the database, percentage of oceanographic stations from the total number (206 300): data sources for coincident stations (=); joint sources (+).

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