Chapter 14
Russian Drifting Stations on Arctic Ice Islands

Igor M. Belkin and Sergey A. Kessel

Abstract A summary of Russian discoveries of Arctic ice islands – peculiar tabular icebergs – is presented, complete with a chronological account of drifting stations installed on ice islands. Of 40 'North Pole' drifting stations established from 1937 through 2013, six were set up on five ice islands: North Pole-6, 18/19 (same ice island), 22, 23, and 24. These ice islands served as reliable long-term research platforms as evidenced by the extensive bibliography of scientific publications based on observations made from manned ice island stations. Studies were conducted of structure and morphology of ice islands; under-ice biota; deep Arctic Ocean benthos; meteorology and climate; and oceanography. Biological collections from these ice islands are still being analyzed.

Keywords Ice island • Arctic Ocean • Ice shelf • Canada Basin • North Pole drifting stations • NP-22

14.1 Introduction

The first observations of ice islands by Russians might have been made centuries ago. In the sixteenth to seventeenth centuries, Russian fishermen, hunters, traders, and surveyors began to explore Russia's northern seas. In the early sixteenth century, the first ethnic Russian group to colonize the coasts of the White and Barents seas, the so-called *pomors* began hunting walrus and seals off Novaya Zemlya, and, probably, Svalbard (Yurchenko 2005). Gradually, Russians advanced eastward from the Barents Sea, exploring the Kara Sea, Laptev Sea, East Siberian Sea, and the Chukchi Sea, up to Bering Strait.

While exploring the newly discovered coasts and coastal seas, they sighted what appeared to be distant offshore lands whose reality seemed unquestionable at the time. Over the next centuries, many expeditions tried in vain to reach these lands,

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hence dubbed "phantom lands". These "phantom lands" are now believed to have been made largely of ground ice which were subsequently destroyed by thermal erosion (Gavrilov et al. 2003; Günther et al. 2015).

The number of such sightings grew with time until 1946 when, independently, the U.S./Canadian and Soviet polar aviators on ice reconnaissance flights into the Arctic Ocean discovered unusual tabular icebergs with a characteristically corrugated (undulating) upper surface that have become known as ice islands (Koenig et al. 1952; Burkhanov 1954). The first-ever manned drifting station on an ice island was established by the U.S. in 1952. By that time, the Russians already had extensive experience with a series of long-term drifting stations known as 'North Pole' (NP), which were set-up on ice floes. The first-ever drifting station NP-1 operated for 9 months in 1937, followed after World War II by NP-2, 3, 4, and 5 (1950–1956). It was a matter of time for Soviet sea ice reconnaissance to find an ice island suitable for a manned drifting station, which happened to be NP-6. Since then, the Soviets set up five more stations on four ice islands: NP-18/19 (same island), 22, 23, and 24.

This chapter is a brief account of Russian discoveries of Arctic ice islands and a summary of scientific studies conducted from the North Pole drifting stations NP-6, 18, 19, 22, 23, and 24. The references include mostly English-language publications that could serve as entry-points to the relevant Russian-language literature. Two Russian-language books by Kessel (2005) and Dremlyug and Kessel (2007) are dedicated exclusively to ice islands and their history, while the English-language monograph by Frolov et al. (2005) and the Russian-language compendium by Kornilov et al. (2010) sum up multi-disciplinary studies conducted from all manned drifting polar stations established by the USSR/Russian Federation in the Arctic Ocean.

14.2 Early Discoveries of Arctic Ice Islands

14.2.1 Ferdinand Wrangell: Possible Discovery of Ice Islands in 1821

In 1820–1824, Lieutenant Ferdinand Petrovich Wrangell led a Russian expedition along the Arctic coast of Northeastern Siberia, conducting offshore surveys east of the Kolyma River mouth. Wrangell's observations were first published by Professor Friedrich Parrot, to whom Wrangell gave his materials (Parrot 1826; Wrangel 1826). Later, slightly different versions of Wrangell's full account were published in French, German, English, and Russian in 1839–1841 (e.g., Wrangell 1841) so that this account became well-known among scientists and polar explorers as evidenced by Charles Darwin's citation of Wrangell's book (Darwin 1873).

The most complete version of Wrangell's account contains tantalizing descriptions of peculiar ice formations; some of them might have been ice islands or their fragments. On April 4, 1821, traveling along the coast of the East Siberian Sea, the expedition traversed huge conical ice hills (up to 27 m high), with long valleys in-between; these hills were utterly different from the previously encountered immense "winter hummocks" (up to 24 m in height). The conical hills consisted of dark ice, described as "smooth and even, its colour varying from whitish grey to black: it had a perfectly fresh taste, and was large-grained and opaque" (Wrangell 1841, p. 142). These ice formations might have been remnants of grounded ice islands. Based on the above description, Wrangell might reasonably be credited as a possible discoverer of the Arctic ice islands even though in the original English-language account (Wrangell 1841) the term ice-island is only used once to describe a common ice floe, upon which Wrangell and his people drifted across a coastal polynya, and not a true ice island defined in this chapter as a tabular iceberg with a corrugated (undulating) surface.

14.2.2 The Modern Era: Arctic Aviation and Ice Islands

The most credible observation of an ice island before the advent of polar aviation was made by the Russian schooner *Krestianka* in summer 1934 in the Chukchi Sea. There the crew saw an island-like feature, described it, determined its coordinates, and reported their findings by radio (Dremlyug and Kessel 2007, p. 9). Based on the radio report, Soviet hydrographers put Krestianka Island on a map. Tragically, on return passage *Krestianka* and all aboard perished in October 1934 during a storm in the Okhotsk Sea (Bollinger 2003, p. 58). Yet, Soviet hydrographers were confident enough to send the expedition vessel *Smol'nyi* to the Chukchi Sea in 1943 to search for Krestianka Island. Even though search conditions were good, with almost no sea ice and good visibility, the island was not found and was removed from nautical charts. If Krestianka Island indeed was a drifting ice island, then its disappearance from the original location can be easily explained by its drift.

From mid-September until October 12, 1937, the personnel of the Soviet polar station on Henrietta Island (77°06′N, 156°30′E; the northernmost island of De Long Islands), repeatedly observed what seemed to be an ice island to the northeast of Henrietta Island. Drawings were made of the ice island (Burkhanov 1954, his Fig. 3), with two characteristic hills. Later, a large tabular iceberg with two hills was observed in the same area by pilot I.I. Cherevichny and navigator V.I. Akkuratov; the iceberg was slowly moving to the north, then northwest. This "phantom land" was alternatively named "Mukhanov Land" (after the station leader) or "Polyarniks Land" (Burkhanov 1954, his Figs. 1 and 3).

In the late 1930s before World War II, numerous sightings of drifting ice islands were reported by Soviet ice reconnaissance north of Kotelny Island (part of the New Siberian Islands or Novosibirskie ostrova) and east of Severnaya Zemlya (Burkhanov 1954). In March 1941, a large ice island was observed at 74°N north of Bear Islands (Medvezhyi Islands) in the East Siberian Sea. This ice island was quite different from the aforementioned ice islands observed north of Henrietta Island and northwest of Kotelny Island. It had undulating surface, with several frozen streams and lakes clearly visible; even the most experienced Russian ice observers could hardly tell it from Arctic tundra. Later this ice island was observed drifting to the north and was named Andreev Land after the Russian explorer Stepan Andreev who reported seeing a land north of Bear Islands in 1764 (Burkhanov 1954).

One of the most experienced Russian ice specialists, oceanographer P.A. Gordienko reported close encounters with – and even visiting – tabular icebergs (possibly, ice islands) during ice reconnaissance on icebreaker *Anastas Mikoyan* in the late 1930s and through the 1940s in the East Siberian and Chukchi seas (Burkhanov 1954). One of these ice islands spotted north of Wrangell Island was surveyed on August 23, 1947 by a boat team from *Mikoyan* led by P.A. Gordienko. After approaching the ice island, oceanographer A.L. Sokolov made close-up drawings of the ice island's walls with well-defined horizontal layers, 2–20 cm thick (published by Kessel 2005, his Fig. 6). A brief account of this survey appeared in *Polar Record* in May 1955 (Anonymous 1955), apparently based on Admiral Vasily Burkhanov's first public presentation of Soviet discoveries of ice islands (delivered on February 18, 1954) and his subsequent article (Burkhanov 1954) described below.

Another ice island encountered by icebreaker *Mikoyan* on September 21, 1948 in the central East Siberian Sea was examined by P.A. Gordienko and the ship's captain who boarded the ice island. According to Gordienko's account, the ice island's upper surface featured gentle hills up to 6 m high, with frozen streams in-between; the ice island's walls had bluish color and consisted of exceptionally strong ice that the icebreaker could not crush (Burkhanov 1954).

During ice reconnaissance in De Long Strait in 1939–1942 P.A. Gordienko repeatedly observed strange cube-shaped ice blocks, up to 20 m across, and up to 7 m higher than the surrounding ice floes. These blocks consisted of monolith ice of peculiar light-to-deep-blue colour. As determined by subsequent chemical analysis, the ice was absolutely fresh. Similar ice blocks were also observed by N.A. Volkov in 1935–1937 in the Bering Strait (Burkhanov 1954).

The advent of polar aviation accelerated the Arctic Ocean exploration. In 1946–1950, extensive airborne ice reconnaissance by the U.S./Canada and USSR led to independent, practically simultaneous discoveries of three large ice islands. These discoveries remained classified for several years in all three countries involved. In November 1950, the U.S./Canadian discoveries and observations of these ice islands (named T-1, T-2, and T-3) were made public at the First Alaskan Science Conference in Washington, D.C. (Fletcher 1950; Koenig et al. 1952). On February 18, 1954 Admiral Vasily Burkhanov made presentation at Moscow Branch of Geographical Society of the USSR, in which he revealed the hitherto classified Soviet observations of the same ice islands (T-1, T-2, and T-3) that have been independently discovered and reported by Soviet sea ice reconnaissance pilots; therefore, Burkhanov referred to these ice islands using the respective Soviet pilot's last name as "Kotov Island" (T-1), "Mazuruk Island" (T-2), and "Perov Island" (T-3) (Fig. 14.1, reproduced from Burkhanov 1954, Fig. 6). This presentation was publicized by Russian newspapers, whose detailed accounts were summed up by *Polar Record* (Anonymous 1955). Numerous Russian publications on ice islands and their putative associations

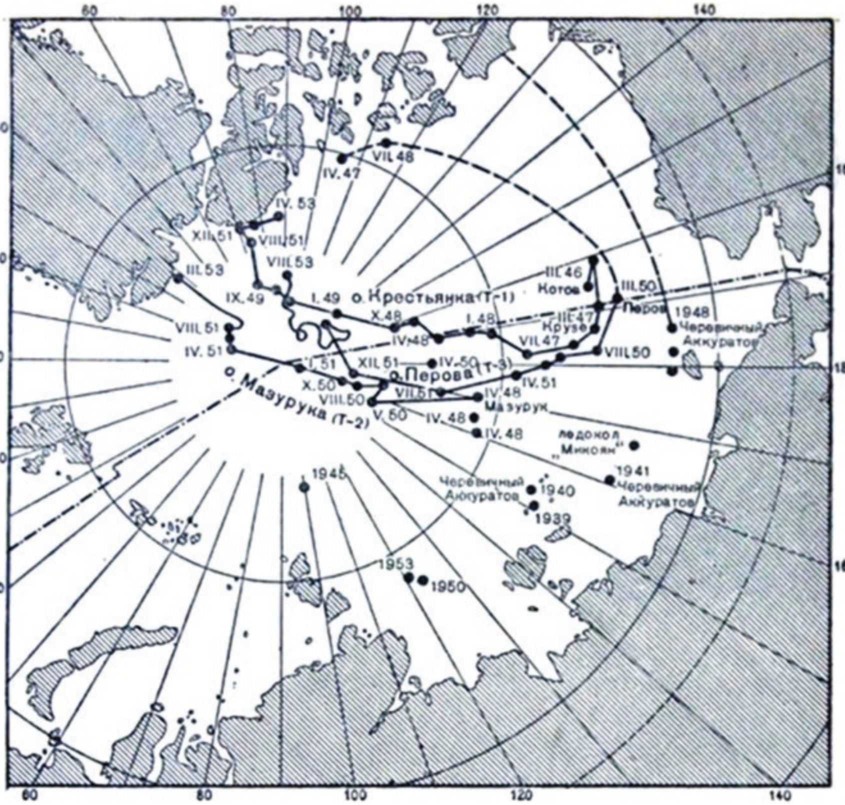

Fig. 14.1 Sightings and drift of ice islands reported by Russians in 1939–1953. Transliterations and translations of Russian names, with comments: "о. Крестьянка (Т-1)" ("ostrov Krestianka/ Krestyanka"), Krestianka Island (also known as Kotov Island) identified with T-1; "о. Мазурука (Т-2)" ("ostrov Mazuruka"), Mazuruk Island identified with T-2; "о. Перова (Т-3)" ("ostrov Perova"), Perov Island identified with T-3; "Черевичный Аккуратов", sightings of ice islands made by pilot Cherevichny and navigator Akkuratov in 1939, 1940, 1941, and 1948; "Крузе" (Kruze), sighting of Krestianka Island by pilot L.K. Kruze; "ледокол Микоян" ("ledokol Mikoyan"), sighting of an ice island from icebreaker Mikoyan; also shown are three Russian sightings of ice islands between 100°E and 123°E made in 1945, 1950, and 1953 (observers unknown). I.I. Cherevichny, I.S. Kotov, L.K. Kruze, I.P. Mazuruk, and V.M. Perov were among the most experienced pilots in the Soviet sea ice reconnaissance, while V.I. Akkuratov was a famed navigator (Reproduced from Burkhanov (1954, Fig. 6) with permission)

with "phantom lands" followed; some articles were promptly translated into English (e.g., Zubov 1955).

Beginning in spring 1946, Soviet sea ice observers on reconnaissance flights across the Chukchi Sea northeast of Wrangell Island, at 75°N–76°N, reported numerous sightings of ice islands, whose height and appearance were markedly different from the surrounding ice floes. In March 1946, pilot I.S. Kotov spotted what he believed was Krestianka Island northeast of Wrangell Island at 76°N, 165°W. It

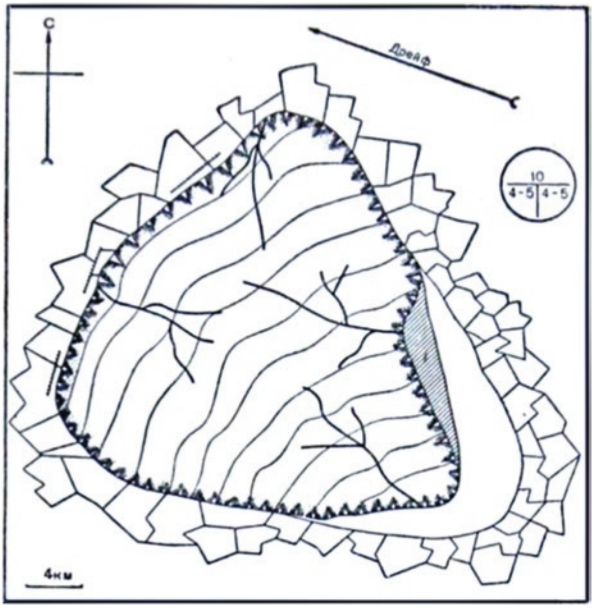

Fig. 14.2 Drawing of Kotov Ice Island made by navigator V.I. Akkuratov on March 19, 1947. The 4-km scale bar in the *bottom left corner* is for the island size only, not for the wave pattern, which is shown highly schematically, with the wave length (crest-to-crest distance) exaggerated many times (see text; also cf. Koenig et al. 1952, Fig. 6). North is at the *top*. Dendritic patterns are frozen streams that drain meltwater in summer. The hatched area east of the ice island is fast ice. The ice island was surrounded by ice floes except for open water (*white*) in its wake as the ice island was drifting WNW. The drift direction is shown with *arrow* at the top, where "Дрейф" means "Drift" (Reproduced from Burkhanov (1954, Fig. 7) with permission)

measured 25 km × 30 km, with an area of 520 km^2. In retrospect, this identification of Kotov Island with Krestianka Island seems highly dubious given the time span of 12 years between these sightings of drifting ice islands in 1934 and 1946. On March 19, 1947 pilot L.K. Kruze spotted the same ice island that pilot I.S. Kotov saw in March 1946 but it was now at 76°N, 173.5°W – 200 km west of the original sighting. Evidently, this was a drifting ice island. A drawing made during that flight by navigator V.I. Akkuratov and first published by Burkhanov (1954, his Fig. 7) shows a heart-shaped feature with a characteristic undulating surface pattern (Fig. 14.2). U.S. Air Force pilots independently discovered this same ice island, later termed T-1, measuring 28 km × 33 km and in a shape resembling an arrowhead or a chicken's heart, on August 14, 1946 at 76°15′N, 160°15′W (Koenig et al. 1952). Burkhanov (1954) identified T-1 with Kotov Island (Fig. 14.1). It must be noted here that Akkuratov's sketch has grossly exaggerated the wavelength of the corrugated surface of this ice island. Indeed, his sketch shows 11 waves (hence, an average crest-to-crest distance of 3 km), while a low-altitude photo of the same island (T-1) taken on August 1, 1951 (Koenig et al. 1952, their Fig. 6) shows >40 parallel

Table 14.1 Russian ice island sighting dates, dimensions and other characteristics

Ice island	First and last sighting (month/year)	Dimensions (km)	Thickness (m)	Mean distance (m) between waves (ridges) on the upper surface
NP-6	04/1956 – 09/1959	13.8 × 8.3	6–12	No waves
NP-18/19	04/1968 – 04/1973	12.6 × 6.7	32–36	210
NP-22	04/1973 – 04/1982	4.8 × 2.0	22–30	220
NP-23	08/1975 – 11/1978	7.5 × 3.0	6–18	170
NP-24	03/1978 – 11/1980	16.0 × 6.5	15–40	280

Data from Grishchenko and Simonov (1985, their Table 1), Dremlyug and Kessel (2007, foldout table pp. 100–101), with corrections, and from Sychev (1961, 1962) for NP-6

troughs filled with meltwater. As we know today, the wave-like pattern of most ice islands and ice shelves of the Arctic Ocean has a length scale of a few hundred metres, between 170 and 280 m according to Grishchenko and Simonov (1985, their Table 1; Table 14.1).

In April 1948, at 82°N, 170°E, pilot I.P. Mazuruk observed an ice island with a characteristic undulating surface measuring 28 km × 32 km. In May 1950, Soviet pilots reported to have seen the same island at 87°N, 155°E (Dremlyug and Kessel 2007, pp. 28–29; Burkhanov 1954, his Fig. 6; Fig. 14.1). On July 21 1950, U.S. pilots independently discovered and reported this same ice island measuring 31 km × 33 km at 86°40′N, 167°00′E, and termed it T-2 (Koenig et al. 1952). Burkhanov (1954) identified T-2 with Mazuruk Island (Fig. 14.1).

In March 1950, pilot V.M. Perov discovered an ice island with an area of 100 km^2 northeast of Herald Island at 74.5°N, 169°W (Burkhanov 1954; Fig. 14.1). The U.S. Air Force pilots independently discovered this same ice island on July 29, 1950 at 75.4°N, 173°W (Koenig et al. 1952). It measured 16.6 km × 8.3 km, had a kidney shape, and was termed T-3. Later, it was realized that U.S. pilots had observed T-3 much earlier, on April 24 and 27, 1947 north of Ellef Ringnes Island and on July 9, 1948 off the west coast of Prince Patrick Island (Koenig et al. 1952). Burkhavov (1954) identified T-3 with Perov Island (Fig. 14.1).

Burkhanov's identification of Russian vs. U.S./Canadian ice islands remains uncontested to date, even though no comparative study of Russian and U.S./Canadian discoveries of these islands has ever been published in the scientific literature.

Numerous Russian publications on ice islands were summed up by Kessel (2005) and Dremlyug and Kessel (2007), who also compiled sightings of small ice islands in the East Siberian and Chukchi seas reported by Soviet airborne ice reconnaissance and observers from naval icebreakers in the 1930s–1940s. No Soviet reports of ice islands observations exist between 1950 and April 1956, when an ice island was discovered on which NP-6, the first Soviet ice island station, was established, thereby opening an era of Soviet/Russian scientific exploration and exploitation of ice islands, described in the next section.

14.3 North Pole Manned Drift Stations on Ice Islands

In 1956–1980, six Russian manned stations were set up on five ice islands that drifted in the Beaufort Gyre and Transpolar Drift (Fig. 14.3).

NP-6 In April 1956, at 74°24′N, 177°10′W, pilot V.I. Maslennikov discovered an ice island measuring 13.8 km × 8.3 km. The first Soviet station on an ice island, North Pole-6 (NP-6), was soon established and was occupied for 3 years (Sychev 1961, 1962) (Fig. 14.4).

Relative to other ice islands, this ice island was rather thin, with its thickness ranging from 6–12 m (Sychev 1961, 1962). Despite being relatively thin, this ice

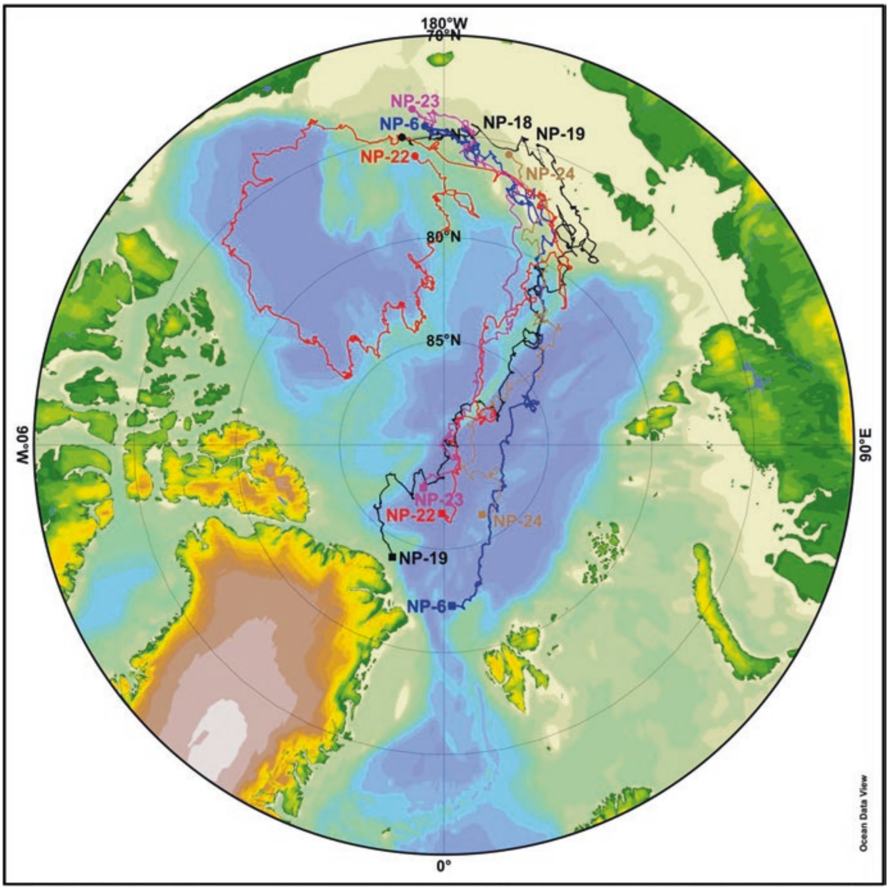

Fig. 14.3 Drift tracks of Russian North Pole stations established on ice islands. Drift data from the Arctic Climatology Project (Environmental Working Group 2000a) are mapped with the Ocean Data View software (Schlitzer 2016). The beginning and end of each track are marked with *circles* and *squares*, respectively. NP-19 was set up on the same ice island as NP-18 (both shown in *black*), with a 6-month break in-between (*black dashed line*)

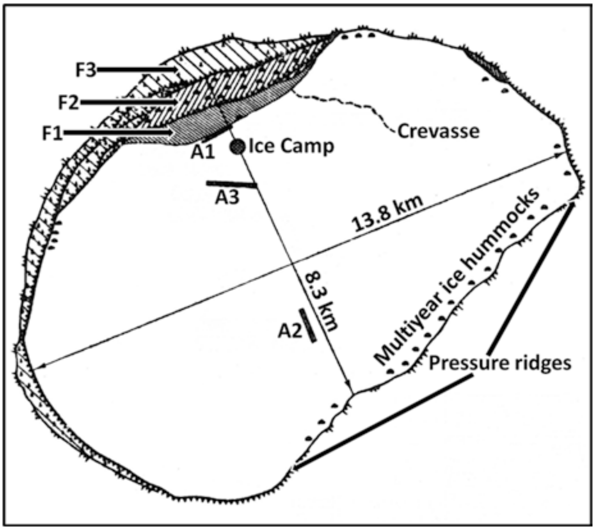

Fig. 14.4 Ice island NP-6. Acronyms: *A1* airstrip in April–May 1957, *A2*, airstrip in June–August 1957, *A3* airstrip since September 1957, *F1* multiyear fast ice with hummocky surface, *F2* multiyear fast year with ice hummocks smoothed, *F3* 2-to-3-year-old fast ice with old and young ice hummocks (Adapted from Kessel (2005, Fig. 20, after Sychev 1962))

island survived intact for the entire duration of the manned station NP-6, from April 1956 up to September 1959. Ice studies by Cherepanov (1964) revealed a very peculiar structure and properties of this ice island that set it apart from other ice islands. In particular, the crystalline structure of NP-6 markedly differed from that of other ice islands studied before and also of the ice shelf of northern Ellesmere Island. Therefore, Cherepanov (1964) stressed that NP-6 is not a typical ice island.

NP-18 On April 19, 1968 a roughly rectangular ice island was found at 71°36′N, 163°00′W, measuring 13.6 km × 7.4 km (Dremlyug and Kessel 2007, foldout table between pp. 100 and 101; yet 12.6 km × 6.7 km according to Grishchenko and Simonov 1985, their Table 1), with an area of 82 km^2 and an estimated thickness of 35 m. The drifting station NP-18 set up on this ice island became operational on October 9, 1968. On May 9, 1969 the NP-18 station was relocated to an ice floe 230 km northeast of the ice island (Kornilov et al. 2010, p. 245), but the ice island was later used as a platform for the next station, NP-19; therefore, we refer to this ice island as NP-18/19 (Fig. 14.5).

NP-19 This station was set up on the same ice island as NP-18 and began regular observations on November 7, 1969. In January 1970, the ice island grounded on shoals off De Long Islands and lost 19 km^2 or ~20% of its area. The station survived the break-up. NP-19 closed on April 14, 1973. The drift of NP-19 is described by Chilingarov et al. (1972, 1986, 2014).

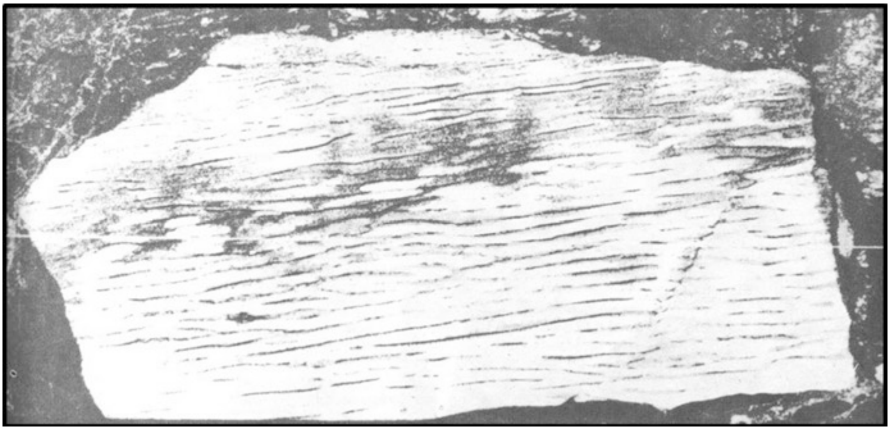

Fig. 14.5 Ice island NP-18/19. Aerial photo from an altitude of 10,000 m on April 19, 1968, when this ice island was discovered by the Russian sea ice reconnaissance (Adapted from Kessel (2005, Fig. 23, after Chilingarov et al. 1972, photo on p. 5))

NP-22 This ice island was discovered on April 6, 1973 (Kessel 2005, his Table 1 on pp. 29–32). The drifting station NP-22 (Figs. 14.6 and 14.7) was manned without interruptions for 8½ years, from September 13, 1973 until April 8, 1982 (Romanov et al. 1997) – the longest continuously occupied drifting station ever. After completing a full circle around the Beaufort Gyre, NP-22 escaped from the gyre into the Transpolar Drift. Owing to the island's longevity, successive NP-22 crews expanded and upgraded NP-22 facilities and conducted diverse studies of the ice island and its environment.

NP-23 In August 1975, an ice island measuring 7.5 km × 3.0 km was found northeast of Wrangell Island, at 72°45′N, 176°05′W (Kessel 2005, his Table 1 on pp. 29–32). It was chosen as a platform for NP-23 (Fig. 14.8) that remained in operation from December 5, 1975 until November 1, 1978. The ice island's thickness varied spatially from 6–18 m and averaged 15 m. In summer 1977, the island lost 1.5–2.0 m of ice from its upper surface because of intense ablation (Kessel 2005, pp. 62–63).

NP-24 This station was set up from icebreaker *Sibir* on June 23, 1978 at 76°45′N, 163°00′E on an ice island found on March 9, 1978 at 75°12′N, 172°00′E (Kessel 2005, p. 63; Fig. 14.9). This ice island was first observed in the northern Chukchi Sea in 1977: visually in August, then with airborne side-looking radar in December (Kornilov et al. 2010, p. 391). The ice island dimensions were 17 km × 6 km (Kessel 2005; 16.0 km × 6.5 km according to Grishchenko and Simonov 1985, their Table 1). Its thickness varied spatially from 15–40 m (Kessel 2005). NP-24 was occupied until November 19, 1980 (Romanov et al. 1997).

NP-24 was the last Russian station thus far established on an ice island. A pause in the disintegration of the Ward Hunt Ice Shelf – the main supplier of ice islands in

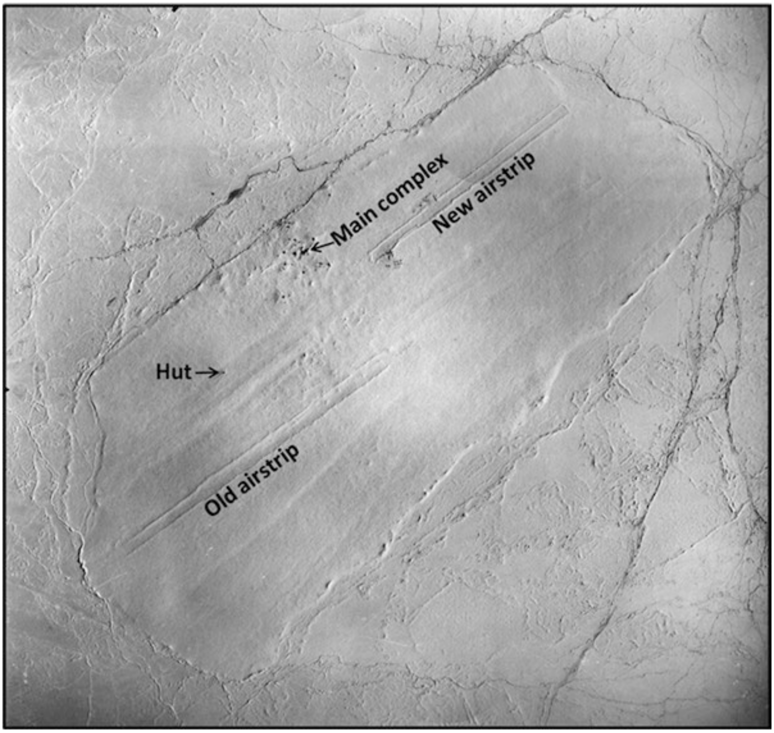

Fig. 14.6 Aerial photo (nadir view) of ice island NP-22 in 1979 (Adapted from Kessel (2005, Fig. 28, from V.K. Yakimyuk's personal archive)) The ice island dimensions are 4.8 km × 2.0 km (Grishchenko and Simonov 1985; Table 14.1). The main complex of several interconnected prefabricated huts is in the *centre* of the ice camp (for its close-up photo see Fig. 14.7) surrounded by individual huts. Photos of the stand-alone hut on the *left* taken before and after the 1977 melt season are shown in Figs. 14.10 and 14.11 respectively. Air strips were prepared each season anew as previous air strips were destroyed by summer melt. Faint surface manifestations of older air strips are still visible in this photo

the Arctic (Jeffries 1992) – was the main reason for the absence of ice-island-based stations.

A summary of key parameters of the Russian ice islands (Table 14.1) is based mostly on Grishchenko and Simonov (1985, their Table 1) and Dremlyug and Kessel (2007, foldout table between pp. 100 and 101), with corrections, while data for NP-6 are from Sychev (1961, 1962); included are only those ice islands on which North Pole manned drifting stations were set up. Dimensions and thickness were usually measured early during the occupation of each ice island. In case of NP-22, its attrition was studied over several years (Grishchenko 1980; Grishchenko and Simonov 1985). Thickness is observed to decrease with time due to the upper surface ablation and the bottom surface scouring by currents. For example, NP-22 thinned by ~1 m year^{-1} while occupied.

Fig. 14.7 Main complex of several interconnected prefabricated huts on drifting station NP-22 in May 1977. Developed by Russian designers Kanaki and Ovchinnikov, these comfortable mobile huts were officially termed PDKO after them, with *PD* standing for *polyarny dom* (in Russian) or polar house. The complex included mess room, kitchen, food storage, recreation room, and sauna. The sign reads: “NP-22 Vladivostok Square” after icebreaker *Vladivostok*, which together with M/V *Captain Kondratiev* delivered supplies, including the huts, for the first party of 10 in September 1973. The huts were assembled onboard before the ice camp was set up on the ice island (Photo by Igor Belkin)

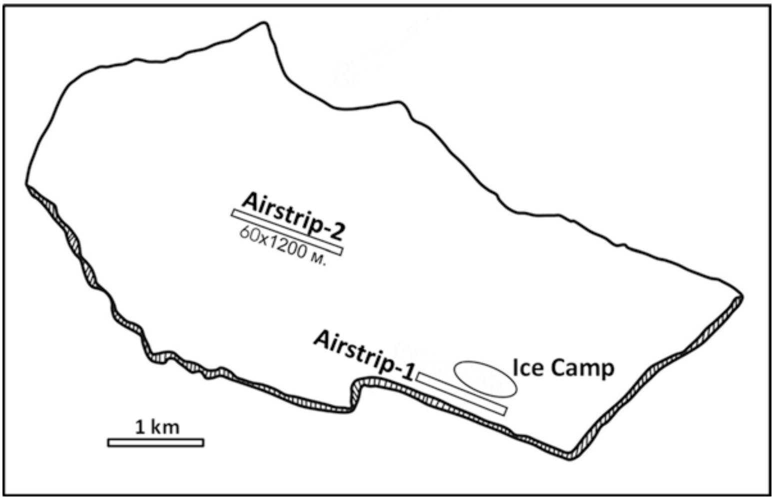

Fig. 14.8 A sketch of Ice Island NP-23 (Adapted from Kessel (2005, Fig. 34))

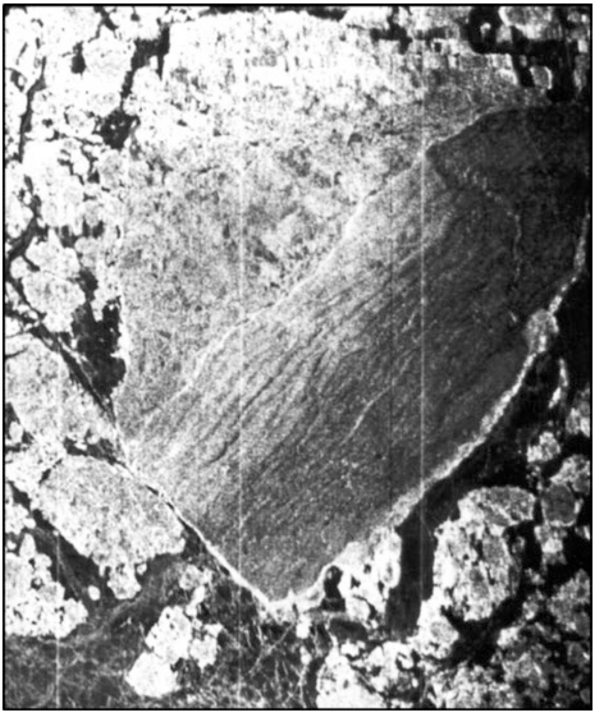

Fig. 14.9 Ice Island NP-24 (nadir view with airborne side-looking radar). The ice island dimensions are 16.0 km × 6.5 km (Grishchenko and Simonov 1985; Table 14.1) (Adapted from Kessel (2005, Fig. 35))

A comparison between ice island stations and other stations set up on ice floes (Romanov et al. 1997; Frolov et al. 2005, pp. 29–33, their Tables 1.1 and 1.2; Kornilov et al. 2010) illustrates the substantial benefits conferred by ice islands. First, the longevity of ice islands far exceeds that of ice floes. Therefore, as observational platforms, ice islands are more useful than ice floes. Second, ice islands are solid enough to withstand landings of relatively large aircraft, thus allowing heavy and bulky scientific equipment to be delivered. On the balance, the ice islands turned out to be superior platforms as evidenced by the number and duration of studies conducted from these islands and briefly described in the next section.

14.4 Scientific Observations from the Russian Ice Islands

Scientific investigations conducted from the Russian drifting stations are described by Frolov et al. (2005) and Kornilov et al. (2010), including all six stations established on five ice islands: NP-6, NP-18/19, NP-22, NP-23, and NP-24. Many investigations conducted from ice islands were similar to the studies conducted from drifting stations on ice floes, especially if the emphasis was on standard meteorological and oceanographic observations. There were, however, studies for which ice islands played a key role, e.g., the biology of the under-ice and benthic realms, Beaufort Gyre oceanography, and others. Finally, glaciological studies of the ice islands were quite specific – if not unique – since the ice islands' structure and morphology differ from that of ice floes. Below we review a few fields, where the ice islands played the most important role.

14.4.1 Ice Island Structure and Morphology

Stratigraphic studies are especially important in helping to determine ice island source, thereby providing clues to its drift pattern after calving. Three ice islands – NP-6, NP-18/19, and NP-22 – were studied by ice specialists, using various means, including ice coring and scuba diving (Cherepanov 1964; Legen'kov 1973; Legen'kov and Chugui 1973; Legen'kov et al. 1974; Grishchenko 1980; Grishchenko and Simonov 1985). The most extensive observations of ice island structure and morphology were conducted from NP-22, owing largely to its longevity.

NP-6 The first Russian studies of ice island stratigraphy and crystallography were conducted by N.V. Cherepanov using data collected on NP-6, where six pits were dug in the 10–12 m thick ice island (Cherepanov 1964). This study yielded the first-ever data on the structure of very thick sea ice growing up to 12 m thick under natural conditions. The ice island's structure was quite peculiar and different from that of previously studied ice islands and ice shelves. Therefore, Cherepanov (1964) stressed that this ice island is a rare ice formation in the Arctic. At the same time, he noted that such ice formations are encountered in the Arctic quite often, featuring a flat even upper surface, a rather low freeboard of 0.5–1.0 m, a moderate size of less than 0.5–1.0 km, and lack of terrestrial debris. The crystalline structure of NP-6 was unusual for multi-year sea ice in that ice crystals were uniformly shaped and their optical axes were uniformly oriented (aligned). Below the top surface 30–50 cm layer with numerous inclusions (sediment debris), the ice was completely uniform down to 8.5 m depth, with a distinct fibrous (sponge-like) structure of drainage channels traceable all the way to the bottom surface. The ice salinity increased from 0 at the upper surface to 3 ppt at 2 m depth and remained constant between 2 and 6 m, then decreased to 2.5 ppt at 8.5 m depth. The vertically-averaged salinity was 2.26 ppt, similar to that of multi-year ice, e.g., the NP-4 ice floe (2.2 ppt). Based on ice texture, crystalline structure, salinity and density, Cherepanov (1964) concluded that the NP-6 ice island was of marine origin.

NP-18/19 The morphology, stratigraphy, temperature regime, and thermally induced stresses and deformations of this ice island were documented by Legen'kov (1973), Legen'kov and Chugui (1973), and Legen'kov et al. (1974). The ice island was composed of two very different strata (Legen'kov et al. 1974): the upper 0–16 m stratum consisted of fresh ice while the stratum between 16 and 32.5 m (bottom surface) consisted of saline ice whose salinity was approximately 8 ppt. According to Kessel (2005, p. 53), stratigraphic studies conducted by another group of researchers revealed three strata: 0–17 m, glacier ice (which could be 'iced firn' - a meteoric ice type that forms from snow and rainfall (in situ accumulation) discussed in the early Ellesmere ice shelf literature; for a review see Jeffries(1992)); 17–25 m, infiltration-congelation ice (from sea water and wet snow); and 25–36 m, congelation ice (from sea water). The close-up fixed-location stratigraphic inspection of a 1-m thick stratum between 5.25 and 6.25 m depth from the upper surface of the ice island revealed a series of fine layers, 10–14 cm thick (average, 12 cm), apparently formed by annual accumulation; thus, the maximum thickness of 36 m corresponds to 300 years of accumulation (Legen'kov and Chugui 1973).

The upper surface of the ice island featured parallel undulations, with a crest-to-crest distance of 200–300 m (Legen'kov and Chugui 1973), with an average distance of 210 m (Grishchenko and Simonov 1985, their Table 1). The summer ablation was most pronounced (up to 50 cm) on the island's topographic highs, thereby gradually smoothing its undulating relief (Kessel 2005, p. 53).

Annual variations of ice temperature decreased with depth: While at the upper surface the ice temperature ranged from −29°C in February to 0°C in August, at 13 m depth the magnitude of seasonal variations was just 0.8°C, decreasing to 0°C at 32.5 m depth (near the bottom surface). Below 20 m, ice temperature was nearly constant throughout the year, increasing with depth from −7°C at 20 m to −1.8°C at 32.5 m (bottom surface) (Legen'kov et al. 1974).

NP-22 Morphological and structural characteristics of this ice island and its attrition were studied by Grishchenko and Simonov (1985). In 1974, the ice island's parameters were: maximum length 4.8 km; maximum width 2.0 km; mean freeboard 3.4 m; mean draft 25 m; mean thickness 29 m; mean distance between ridges 220 m. During the summer of 1974 (June 18–September 10), the surface ablation/melt averaged 40–45 cm across the ice island, whereas the surrounding ice floes lost 26–30 cm to surface melting. The bottom ablation/melting continued even after September 10.

During the anomalously warm melting season of 1977 Igor Belkin and Igor Afanasyev surveyed the entire freeboard (approximately 12 km in length) of NP-22 and counted 16 streams draining meltwater into the ocean. As a result of the exceptionally sunny and warm late spring and early summer of 1977, NP-22 has lost to ablation about 1 m of ice from the ice island's upper surface because of intense surface melt (Figs. 14.10 and 14.11). This is comparable to the loss of 1.5–2 m of ice observed during that same season from another Russian ice island, NP-23 (see below).

Scuba divers surveyed NP-22 from September 1974 until April 1975 (Grishchenko 1980; Grishchenko and Simonov 1985). They found that ice accretion on the ice island's sidewalls was only observed near the surface; the accretion rapidly decreased with depth and vanished at 5 m depth. Below 5 m, both along the island's sidewalls and on its bottom surface, ice erosion by currents dominated in the ice island's ablation. Ice loss due to bottom ablation (scouring by currents) was 47 cm year^{-1}. Thus, the total decrease of the ice island thickness due to the combined effects of surface melt and bottom erosion was ~1 m year^{-1}. The ablation rate at the bottom and sidewalls correlated strongly with mean monthly water temperature in

Fig. 14.10 Triple-hut complex housing a laboratory and living quarters for three people on drifting station NP-22. This photo was taken before the 1977 melt season (compare with Fig. 14.11 taken after the melt season). Geophysicist Alexander Baranov is standing in front of the entrance, accompanied by Toros (the dog) (Photo by Igor Belkin)

Fig. 14.11 The same triple-hut complex as in Fig. 14.10 but after the 1977 melt season (Photo by Igor Belkin)

the upper 0–25 m layer and with mean monthly drift speed of the ice island (Grishchenko and Simonov 1985, their Fig. 3).

Throughout its thickness, this ice island consisted of fresh glacier ice. The ice island's stratigraphic structure included two layers of fine-grained mineral inclusions of aeolian origin at depths of 10 and 23 m below the ice island's upper surface. Annual layers were pronounced throughout the entire thickness of NP-22. In the upper 10-m stratum, the annual layers consisted of blue ice (10–12 cm) separated by whitish ice (1–3 cm; its colour ascribed to numerous air bubbles); hence, the annual accumulation was approximately 13 cm, similar to 12 cm on NP-19 (Legen'kov and Chugui 1973). Below the top 10-m stratum, the annual layers were thicker, composed of 20–30 cm of blue ice and 5 cm of whitish ice.

14.4.2 Marine Biology

Biological studies conducted from ice islands included phytoplankton, zooplankton, benthos, nekton, and cryobiota (Frolov et al. 2005; Kornilov et al. 2010). Historically, first investigations based on observations and collections from drifting ice stations, including ice islands, focused on zooplankton (Brodsky and Pavshtiks 1976) and fishes, particularly gadoids (Andriashev et al. 1980). Multidisciplinary studies based on collections from Russian manned drifting stations, including those set up on ice islands, comprised the first-ever monograph on the biology of the central Arctic Basin (Vinogradov and Melnikov 1980a, b). Extensive observations on the Arctic sea ice ecosystem, including the NP-22 and NP-23 ice islands, were made by Melnikov (1989).

During the drift of NP-22 in 1976–1977 across the hitherto unexplored northern and eastern parts of the Canada Basin, Afanasyev (1978) made 50 hydrobiological benthic stations over the Canadian Abyssal Plain, in a water depth between 2600 and 3550 m. According to Afanasyev (1978), only 13 deep stations (>3000 m) were made in the Arctic Basin prior to 1977. Thus, the biological collections from NP-22 in 1976–1977 resulted in a step-like four-fold increase of the Arctic Ocean deep water data base. The Afanasyev dataset is still the only one yet collected in the eastern Canada Basin, available from the Census of Marine Life's Arctic Ocean Diversity Project database, http://www.arcodiv.org/Database/Plankton_datasets.html.

Bluhm et al. (2011) pointed out that the largest data gaps in sampling Arctic deep-sea (>3000 m) invertebrate benthos exist in the eastern Canada Basin. It is precisely the eastern side of the Canada Basin that NP-22 drifted across, enabling sampling of the hitherto unexplored region (Afanasyev 1978) and allowing the biology of the Canada Basin to be comprehensively studied for the first time (Vinogradov and Melnikov 1980a, b). Biological collections made in the 1970s from NP-22 and NP-23 were promptly described in a series of papers (Afanasyev and Filatova 1980 (benthic fauna); Averincev 1980 (polychaetes); Belyaeva 1980 (phytoplankton); Geinrikh et al. 1980 (copepods); Jirkov 1980 (polychaetes);

Kamenskaya 1980 (amphipods); Kondakov et al. 1980 (octopodes); Kosobokova 1980 (copepods); Moskalev 1980 (benthic fauna); Pasternak 1980 (sea pens); Pavshtiks 1980 (zooplankton); Tsynovsky 1980a, b (fishes); Tsynovsky and Melnikov 1980 (snailfish); Vinogradov and Melnikov 1980b (pelagic ecosystems); Zezina 1980 (brachiopods); Levenstein 1981 (polychaetes), and Kosobokova 1982 (zooplankton)). Most of these papers comprised the Russian-language monograph "Biology of the Central Arctic Ocean" (Vinogradov and Melnikov 1980a, b); some of these papers have been translated into English (see References).

Collections made from NP-22 and other ice islands were later used in numerous studies; a partial chronological list of selected papers (with just a few representative papers by the same author) includes Margulis 1982 (siphonophores); Kussakin 1983 (isopods); Markhaseva 1984 (calanoid copepods); Vasilenko 1988 (cumaceans); Kruglikova 1989 (radiolarians); Petryashov 1989 (mysids); Stepanjants 1989 (hydrozoans); Vassilenko 1989 (cumaceans); Petryashov 1993 (mysids); Malyutina and Kussakin 1995a, b, 1996 (isopods); Markhaseva 1996 (calanoid copepods); Kosobokova and Hirche 2000 (zooplankton); Jirkov 2001 (polychaetes); Sirenko 2001 (invertebrates); Bjørklund and Kruglikova 2003 (radiolarians); Buzhinskaja 2004 (polychaetes); Petryashov 2004 (mysids); Sirenko et al. 2004 (deep-water communities); Rogacheva 2007 (holothurians); Salazar-Vallejo et al. 2007 (polychaetes); Kruglikova et al. 2009 (radiolarians); Sanamyan et al. 2009, 2016 (sea anemones); Kosobokova et al. 2011 (zooplankton); Jirkov and Leontovich 2012 (polychaetes); Zasko and Kosobokova 2014 (plankton radiolarians) and a special volume on invertebrates (Gebruk et al. 2014). Massive sampling of bottom fauna from the previously unexplored abyssal depths of the Canada Basin contributed greatly to zoogeographical studies of the Arctic Basin (Vinogradova 1997). A comprehensive up-to-date bibliography of biological studies based on collections from ice islands is yet to be compiled.

14.4.3 Oceanography and Meteorology

The drift of NP-22 supported sustained oceanographic and meteorological observations in the Canada Basin and northern Beaufort Gyre. Other ice islands (NP-6, 18/19, 23, and 24) drifted mostly in the southern Beaufort Gyre or in the Transpolar Drift. The data collected from these stations, *inter alia*, shed a new light on the distribution of the Atlantic and Pacific waters in the central Arctic Basin (Rusanov et al. 1979; Frolov et al. 2005). Meteorological, climatological, and radiosonde observations from these ice islands filled data gaps in the most remote parts of the Arctic, thereby enhancing climatological summaries of various observables (e.g., Kahl et al. 1999; Warren et al. 1999). Oceanographic and meteorological observations from the Russian stations on ice islands have comprised an important part of the database used in the atlases published under the aegis of the Arctic Climatology Project (Environmental Working Group 1997, 2000a, b). At the same time, the original oceanographic data collected from these ice islands have not made it yet to the

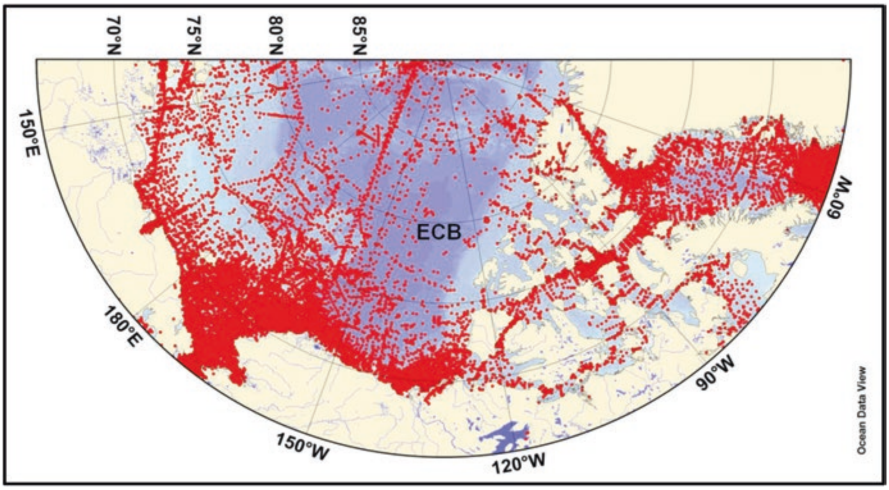

Fig. 14.12 Oceanographic data distribution map illustrating data paucity in the eastern Canada Basin (*ECB*) and over the nearby continental shelves of the Canadian Arctic Archipelago. Shown are all oceanographic stations with temperature and salinity measurements (both Nansen bottle data and CTD) available at the National Oceanographic Data Center (NODC; presently National Centers for Environmental Information, NCEI/NOAA) as part of the World Ocean Database 2013 (Boyer et al. 2013) and mapped with the Ocean Data View software (Schlitzer 2016)

publicly available World Ocean Database (WOD), which for the last half-century has been maintained by the National Oceanographic Data Center of the National Oceanic and Atmospheric Administration (now – since 2015 – part of the National Centers for Environmental Information, NCEI). As a result, the northern and eastern parts of the Canada Basin feature the sparsest data coverage in the entire Arctic Ocean (Fig. 14.12).

The legacy collections and data sets from ice islands also serve as valuable benchmarks, against which future changes in the Arctic could be evaluated. Comparisons with observations from NP-22 made in the 1970s and early 1980s revealed drastic changes of Arctic ecosystems, including those of sea ice; some of the ecosystem changes are deemed to have resulted from the long-term decrease of multi-year fraction of sea ice cover and its replacement with seasonal ice (Melnikov 2005; Melnikov and Semenova 2013). Future changes in the warming Arctic Ocean (Wassmann et al. 2011; Arrigo 2014) are expected to include range expansion of various species, including benthos (Renaud et al. 2015).

14.5 Conclusions

With the world's longest coastline facing the Arctic Ocean between 30°E and 170°E, Russia was traditionally at the forefront of Arctic exploration, including the search for "phantom lands" that have been sighted numerous times over centuries. There is little doubt that most sightings were of real objects (islands or "lands") yet all attempts to reach these lands turned out to be fruitless, thus giving rise to the term "phantom lands." Some of these "phantom lands" were likely islands partly composed of ground ice, which explains their eventual disappearance as a result of thermal erosion due to climate amelioration and mechanical erosion due to actions of waves and sea ice (Gavrilov et al. 2003; Günther et al. 2015). Other "phantom lands" were probably drifting (or temporary grounded) icebergs, including ice islands.

One of the first explorers of the Siberian coast, Ferdinand Petrovich Wrangell led an expedition in 1820–1824 (Wrangell 1826, 1841; Parrot 1826) that made observations of strange ice formations that were drastically different from regular ice floes, hummocks, or pressure ridges. In retrospect, these ice formations could have been remnants of what we now call ice islands.

With the advent of polar aviation in the twentieth century and ever-increasing shipping activity along the Northern Sea Route, pilots and navigators of the Soviet Ice Reconnaissance Service reported numerous sightings of ice islands in the Soviet sector of the Arctic Ocean and beyond, although those reports have not been made publicly available. The growing importance of the Arctic has justified the establishment of manned drifting stations on ice floes (Frolov et al. 2005; Kornilov et al. 2010). Five large ice islands discovered by Russians since 1946 were chosen as platforms for drifting stations North Pole-6, 18/19, 22, 23, and 24 that operated much longer than other stations thanks to the superior thickness (between 10 and 40 m) of these ice islands and their near indestructibility. Indeed, these stations combined served 23 years as reliable platforms and were the objects of various studies. Of particular importance was the 8½-year trajectory of NP-22 – the longest continuously occupied drifting station ever – that facilitated studies of physical and biological oceanography of the Beaufort Gyre and Canada Basin.

Until this day the Canada Basin remains poorly explored, especially its northern and eastern parts. Notwithstanding the ongoing warming in the Arctic and the attendant long-term attrition (shrinking and thinning) of the Arctic ice cover, the multiyear pack ice in the eastern part of the Canada Basin still presents a formidable problem even for modern icebreakers. Similarly, research submarines would typically circumvent this area since the thick ice pack would prevent emergency surfacing while deep keels of ice hummocks would present a constant hazard. The Submarine Arctic Science Program (SCICEX) scientific cruises of U.S. Navy's nuclear submarines in 1993–2003 carefully avoided the eastern Canada Basin (SCICEX Science Advisory Committee 2010).

The data paucity in the Canada Basin is particularly notable with regard to biological collections and sediment sampling (e.g., Bjørklund and Kruglikova 2003; Jirkov and Leontovich 2012; Hunt et al. 2014; Xiao et al. 2014; Zasko and Kosobokova 2014; Bluhm et al. 2015; Wassmann et al. 2015). Therefore, the legacy collections from Russian ice islands, especially NP-22, remain indispensable. Numerous new species of pelagic and benthic fauna were discovered in the Canada Basin thanks to the collections from NP-22 and other ice islands. More species likely await discovery in these collections.

Acknowledgments The splendid record of the Russian manned drifting stations on Arctic ice islands owes everything to the courage, determination, skill, and vision of Russian *polyarniks* – specialists in all things polar – seafarers, airmen, ice observers, and scientists – who devoted their lives to Arctic exploration and research. We are deeply indebted to all of them and particularly to the crew members of the North Pole drifting stations who worked under the most trying environmental conditions to collect unique scientific data. Logistical support provided by the Arctic and Antarctic Research Institute (AARI), St. Petersburg, during our work in the Arctic is greatly appreciated. We are especially thankful to Martin Jeffries for suggesting this chapter and to Derek Mueller and Luke Copland, editors, for encouraging us. The manuscript has been substantially improved thanks to numerous edits and comments by William Althoff, Derek Mueller, Daphne Johnson, Nikolai Kornilov, Zalman Gudkovich, Eduard Sarukhanian, Yuri Gorbunov, Vladimir Radionov, Vasily Smolyanitsky, Andrey Glazovsky, Igor Melnikov, Ksenia Kosobokova, and Yuri Yakovlev, while Alexander Merkulov, Igor Jirkov, Elena Markhaseva, and Yuri Rudyakov provided hard-to-get Russian papers. Maps in Figs. 14.3 and 14.12 were created by Daphne Johnson using the Ocean Data View software (Schlitzer 2016). Permission to reproduce figures from the "Problems of Geography" series was kindly granted by its Editor-in-Chief, Vladimir Kotlyakov. The series is freely available online courtesy of the Russian Geographical Society. For 6 months in 1977, Igor Belkin worked together with Igor Afanasyev on the best drifting station of all time – North Pole-22 – under the cheerful leadership of Igor Simonov. This chapter is dedicated to his memory, as well as the memory of Valentin Dremlyug, who inspired Sergey Kessel's interest in ice islands.

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