GENERAL CONCEPT OF COASTAL HYDROGRAPHIC MONITORING IN THE WeRA

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"In order to prepare for specific conditions in an environment, one must determine the modes of motion in that environment"
(Levis, Giuffrida 1989)

Preface

The general concept of coastal hydrographic monitoring in the WeRA is *an internal reference document* explaining the background, polar ideas, general contents and basic principles of the research work in the frameworks of the AMETHYST project. In addition to the Technical Description (Annex 1) and the Consortium Agreement (Annex 3), this shall serve for the better project management and performance. The present concept shall provide a solid base for the successful fulfilment of the project' preparatory stage concerned with the argumentation of general ideas, project set-up and data acquisition (See Annexes 4 and 5). This concept is generated on the basis of previous publications and takes into account all decisions and conclusions made at the AMETHYST kick-off meeting on October 30 – 31, 2000 in Graz.

The structure and contents of the present contribution have been strongly influenced by the international and interdisciplinary character of the scientific research based on physical-geographic, geodetic, cartographic, photogrammetric, oceanographic and remote sensing methods of studying arctic coasts. Several important, but specific questions related to geomorphology, marine geology, ecology and geophysics are not considered in this issue due to the lack of expertise within the consortium. The contribution contains twelve chapters, divided into four broad topic areas: 1) polar idea, 2) essential knowledge available, 3) acquisition of new knowledge, and 4) analysis and representation. The material in this issue is organised as follows.

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The general concept of satellite coastal hydrographic monitoring will be verified and updated in all details after all necessary data will be collected and the relevant methods for data capturing / processing will be developed and tested.

1. Terminology. Definition of terms

Joint initial discussions on the scope of the AMETHYST project revealed some terminological problems, which are typical of any multidisciplinary research work at earliest stages. The novelty of scientific discipline of coastal hydrographic monitoring and high inventive aspect of the research brought about additional difficulties in the standard formulation of the project tasks and the correct naming (definition) of main objects under observation. In order to avoid any misunderstanding and to ensure the uniformity and conformity of all internal documents and output products to international regulations, our project plan is preceded with a foregoing chapters explaining an idea and basic terminology of coastal hydrographic monitoring.

The following geographic definitions are considered to be of primary importance for the AMETHYST project:

Change detection – the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh 1989).

Coast - a land next to the sea (seashore, Webster’s New Encyclopaedic Dictionary 1996).

Coastline – seaward margin of the land, which is usually equivalent to the high tide shoreline (Byrd 1985).

Shoreline – the line where the body of water touches the shore; the water’s edge, which moves to and fro as the tides rise and fall (Byrd 1985 + Webster’s New Encyclopaedic Dictionary 1996).

Coastal geomorphology - the study of the evolution and configuration of coastal landforms (Dictionary of the English Language 1996); the scientific discipline that deals with the coastal relief features (Webster’s New Encyclopaedic Dictionary 1996).

Coastal hydrography - scientific discipline dealing with mapping of coasts and studying the properties of coastal waters with special reference to their use by man (Geographic Encyclopaedic Dictionary 1988).

Coastal hydrographic monitoring is accordingly defined as a repeated (systematic) hydrographic survey of a concrete coastline, its portion or separate coastal features aimed at the detection, measurement, analysis and documentation of actual and potential coastal changes (Sharov et al. 2000).

Hydrographic survey consists, in general, of two operations: determining the horizontal co-ordinates of points on the surface of the body of water, i.e. position fixing (including coastline) and determining the water's depth at those points (Encyclopaedia Britannica 2000). Its principal objective is “to obtain information on water areas and adjacent coasts for use as source material in the compilation or revision of nautical charts, sailing directions, and other publications of value to the mariner” (Geary 1968).

Fastice (coast ice) - sea-ice which forms and remains fast along the coast, attached to the shore, ice-wall, ice-front, shoals, or to grounded icebergs (WMO Sea-ice nomenclature 1970).

Flaw - the separation between pack-ice and fast-ice in cases of shear between the ice-types. It is narrow, usually filled with chaotic ice pieces (WMO Sea-ice nomenclature 1970).

Flaw-lead - a wider zone between the pack-ice and fast-ice. It may contain brash-ice (small ice pieces) or thin ice types. Non-linear openings are called *flaw-polynyas* (WMO Sea-ice nomenclature 1970).

Ice coast (*ice shore*) – the coast composed of glacier ice (Geographic Encyclopaedic Dictionary 1988).

Ice shelf – a large slab of ice of considerable thickness floating on the sea, but remaining attached to and partly fed by land-based ice (Geographic Encyclopaedic Dictionary 1988).

Intertidal (littoral) zone – an area adjacent to a coast that is above the low tide mark but exposed to tidal flooding (Dictionary of the English Language 1996).

Ridge is ice forced upward by pressure in shape of long hills. In case of short hill it is called *hummock*. The *ice-keels* (downward part) of the ridges or hummocks in fast-ice may often be grounded. An area with many smaller ridges or hummocks is called a *rubble-field* (WMO Sea-ice nomenclature 1970).

Stamukha - the (Russian) name of the remains of a grounded ridge or hummock after the fast ice around has melted in late spring (WMO Sea-ice nomenclature 1970).

Tide-crack is a fracture (rupture from deformation process), between an immovable *ice-foot* (narrow coastal ice fringe not moved by tides) or ice-wall, and the movable fast-ice (WMO Sea-ice nomenclature 1970).

Metainformation (from Greek *meta* – after, beyond, more, i.e. occurring after, situated behind or beyond, change, transformation) – here, information on real and potential changes of the coastline (Sharov & Gutjahr 2001).

Further harmonisation of data terminology is beyond the scope of the present concept.

2. Basic concepts of coastal hydrographic monitoring

2.1 Background. Reasons for monitoring

Socio-economic justification for the long-term monitoring of coastal areas in the Russian Arctic Sector is ensured due to the immense significance of regular and safe merchant shipping along the Northern Sea Route for the industrial development and reactivation of trade in the region and the improvement of living conditions of local human population. The Northern Sea Route (or Northeast Passage) **-** a maritime communication between the Atlantic and Pacific oceans along the northern coast of the Eurasian continent - is one of Russia’s most important waterways, which depends on icebreaking fleet and provides reliable year-round transportation of goods between marine Arctic harbours and port facilities in estuaries of Russian northern rivers. Trustworthy contemporary data on coastal changes, distribution of sea ice in coastal waters, iceberg influx, tidal effects, currents etc. are needed for a careful administration of this transport system and conducting long-term economic projects, e.g. prospecting and rational exploitation of oil and gas deposits in this inhospitable region.

In any remote region characterized by rather poor geographic knowledge, the reliable and representative results of monitoring would provide a good basis for deciding on the revision of available standard map series and for determining the required scales and intervals of hydrographic and topographic-geodetic surveys. The pattern of navigable coastal waters and the locations of potential hazards to shipping can be located and placed on the work sheets. Representative information on coastal changes is also important for taking administrative measures that may become necessary to prevent negative consequences of current changes.

The noticeable lack of reliable knowledge on environmental high-latitudinal processes and their impact on Arctic coasts requires, from the very beginning, *complex regional* monitoring, comprising both the entire unity of coastal features and wide terrestrial coverage. There are basically two functional types of complex environmental monitoring (Bayfield 1997):

- *regulatory* monitoring based on the Limits of Acceptable Change method and aimed at comparing changes against quality standards in order to trigger a management response when unacceptable change occurs;
- *non-regulatory* monitoring primarily aimed at providing information about changes in impacts of environmental pressures without a framework of defined quality standards.

In our case, the functional type of monitoring can be defined as *quasi-regulatory* mainly because the rationality and sufficiency of the information on coastal changes resulted from monitoring can be preliminarily judged using standard cartographic criterions defined in accordance with the information and accuracy requirements for Russian hydrographic charts and topographic maps at a particular scale. On the other hand, the exact user requirements could not be determined at the moment of preparing this plan. Further practical work together with real users / customers may lead to definition of standards for most of the attributes being studied in the project. The monitoring scheme could then become a regulatory status.

The dynamic environment and high rates of natural changes, the remoteness from economically developed districts and harsh environment impeding both aerial surveying and extensive field work are the principal causes for applying *satellite monitoring* in Arctic coastal areas, where natural features are predominant, complicated socio-economic objects are scarce, the relief is mostly homogeneous and vegetation cover is negligible. Techniques making use of artificial polar-orbiting satellites and digital information technologies are believed to be the most effective tools for discovering coastal changes in remote and inaccessible Arctic regions (Brandstätter, Sharov 1998). Satellite *radar* remote sensing that do not require clear sky or daylight is capable of providing reliable information on coastal processes over vast arctic territories on the periodic basis at both regional and local scale.

However, limited possibilities of modern satellite remote sensing usually do not allow for the direct investigation of submarine objects, even in shoal areas, and the main object of complex satellite monitoring is related with a particular locality, i.e. the ground / ice surface with all its external features, both natural and man-made, accessible for direct remote observations. Moreover, spaceborne surveying does not immediately allow for a comprehensive analysis of functional interdependencies in the Arctic coastal environment. One barrier to such investigations is the manifold increase in the number of thematic studies requiring additional data, specific methods and peculiar expertise that could not be provided to a sufficient degree within the frames of our project. The study of spatial relationships rather than functional interrelations between coastal features falls in the category of *coastal hydrography* (not hydrology, oceanology or geomorphology), and in order to exactly determine the subject and methodology of the present studies the term *coastal hydrographic monitoring* has been suggested (Sharov et al. 2000).

2.2 Main tasks and flow-chart of monitoring

Coastal hydrographic monitoring is defined here as a repeated (systematic) hydrographic survey of a concrete coastline, its portion or separate coastal features aimed at the detection, measurement, analysis and documentation of actual and potential coastal changes. The main tasks of coastal hydrographic monitoring are accordingly formulated as follows:

- defining key attributes of the coastland, identification of principle issues and concerns affecting Arctic coasts;
- the acquisition, assessment and collocation (coregistration) of suitable multitemporal image and non-image hydrographic data, and ancillary materials;
- revealing the most appropriate indicators of change, determining areas and modes of coastal hydrographic changes, detecting regions or separate objects undergoing extreme changes;
- identifying coastal features / objects that do not change or have remained almost unchanged throughout the period of observation and can serve as a reference point (surface) for the measurement of changes;
- change measurement and analysis (interpretation, concluding the kinds and origin of changes);
- the evaluation of relative intensity of different coastal processes and discriminating their influences on the coastline, retrospective & prospective hydrographic modeling;
- forecasting future coastal changes, verification and documentary representation of results.

Thus, coastal monitoring can be seen as a form of a long-term systematic hydrographic study of a particular coastland. A flow chart explaining the logical sequence and contents of the principal stages of satellite hydrographic monitoring is given in Figure 1. This principal flow chart is generated without taking care of specific features of *national, regional or local* monitoring schemes[1]. Different shades of grey in Fig. 1 indicate the methodological complexity of a certain stage envisaged.

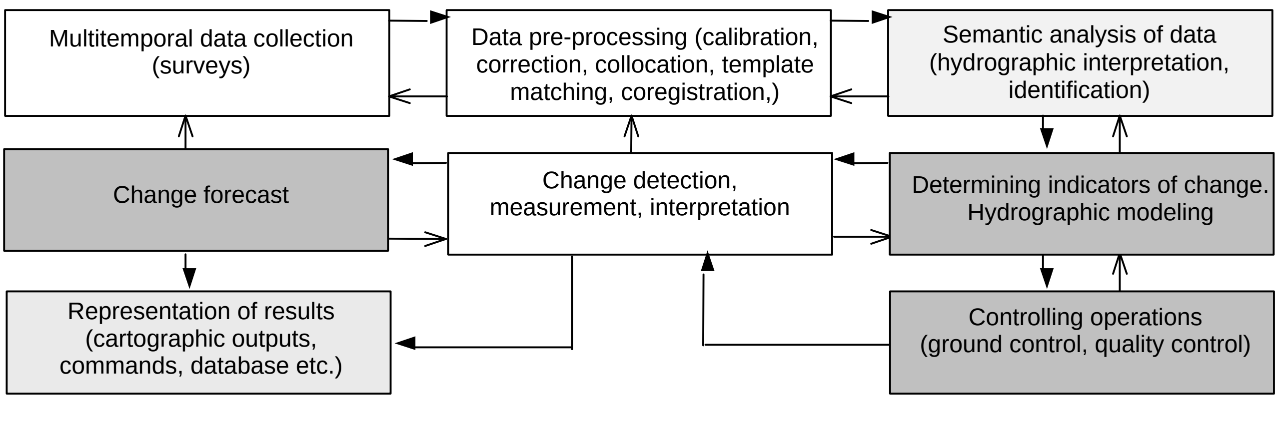


Figure 1. Principal flow chart of satellite monitoring

[1] It is worth to note that, in contrast to national scheme of monitoring dealing with first-order (continental) features (ca. 10^3 km long x 10^2 km wide x 10 km high), regional and local monitoring concerns with second-order coastal features (ca. 10^2 km long x 10 km wide x 1 km high) and coastal features of higher order.

2.3 Subject and objects of monitoring

The ultimate subject of satellite coastal hydrographic monitoring is related with the provision of new (not obligingly cartographic) reliable information on the *current* state and actual or potential changes of Arctic coasts using multitemporal data. Changes are best mapped and measured along *coastlines*, as defined in Chapter 1. The evidence for past positions of inter-tidal shorelines, which are generally submerged and difficultly surveyed, is much less reliable than the relatively easily mapped land margin, the coastline. Thus, in this research, *coastlines and their changes will be the only hydrographic features studied in detail.* Both quantitative geometric alterations and qualitative changes, e.g. changes in the category of a coastal feature or the type of natural borders, shall be investigated by coastal hydrographic monitoring. *Essential bathymetric studies are without the scope of the AMETHYST project.*

In general, the complement of coastal features under observation depends on the working scale of monitoring and can be defined by analogy with the information requirements for both hydrographic charts and topographic maps of coastlands at a particular scale. In practice, dynamic and labile (mobile) coastal features such as

- ice shores, especially ice shelves and frontal parts of outlet glaciers,
- low-lying sandy shores, marine terraces and tundra cliffs composed of permanently frozen ground,
- coastal deposits of fossil ice,
- some elements of littoral zone, sand bars, drying shoals, isolated reefs,
- inland glacial termini and hydrographic networks ashore

are of special interest for satellite coastal monitoring in the Arctic.

Some related phenomena providing ancillary information indicative of coastline changes, such as

- annual variation of glacier velocities and intensity of calving,
- distribution of fast sea ice and icebergs,
- coastal currents and wave action,
- vertical tectonic motions of the coastland,
- tides, storm surges, eustatic changes of the sea-level,
- spatial alterations in areas of pioneer vegetation

and other effects accessible for remote observations are of interest as well.

Since measurements of coastline change are usually made with reference to some terrestrial objects, which remained unchanged over the period of study, the following *reference objects* must be included in the consideration:

+ geodetic and hydrographic signals,
+ current sea level, which is well defined by the edges of the sea-ice floes,
+ steady elements of the coastline such as precipitous capes, separate rocks, crests of a cliff etc.,
+ distribution of ground control points inland, e.g. some elements of the hydrographic network, highest positions, nunataks etc.

All these objects and processes can be considered as separate functional elements of the *Arctic coastal hydrographic system* (ARCOS). A number of islands in the Russian High Arctic represent a typical example of such system (Figure 2). Principal components, i.e. primary elements of the ARCOS are the following:

- coastland,
- glacier- and sea ice,
- inland water basins and the sea.

Natural borders of these components are regarded as main structural boundaries in the ARCOS. The coastline is considered as structural boundary of the highest rank. The introduction (concept) of ARCOS provides a good basis for the use of (coast)land systems approach in studying arctic coastlines and their changes.

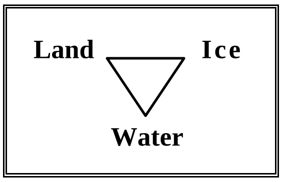
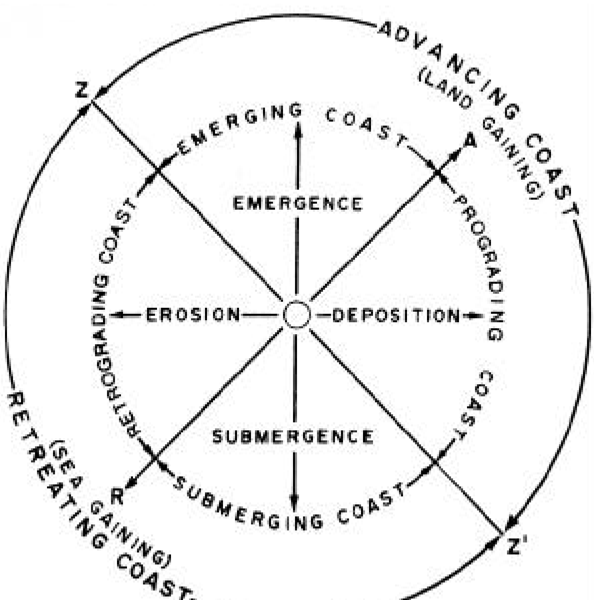


Figure 2. Arctic coastal hydrographic system (central part of FJL)

In the case of limited project resources, the study of such a system has rather methodological accent and should not be considered as a fundamental investigation of the important feedback processes that could occur due to the current environmental changes.

2.4 Main interactions in ARCOS

Some principal monitoring operations, e.g. hydrographic interpretation and modeling, identification of appropriate indicators of change and practical forecasting of coastline changes, can not be performed without reliable knowledge on main trends in ocean-land interactions within the study region. The study of spatial relationships and functional interdependencies between principal components of the ARCOS is of importance in this context. Coastline changes in the ARCOS can be expressed as an interaction of vertical movements (emergence and submergence) and horizontal movements (erosion and deposition), shown schematically in Figure 3 (after Valentine 1952).



On this diagram the point O represents an absolutely static coast and the line ZOZ' indicates stable coasts that are neither advancing nor retreating. Changes are most marked towards A, where emergence accompanied by deposition leads to rapid advance of the coast, and towards R, where erosion accompanying submergence results in rapid retreat (Bird 1985). It is possible to portray the course of evolution of a particular coast by the addition of a time-axis passing through the point O (Bloom 1965). In such three-dimensional scheme, the cycle of coastal evolution is usually represented as a wavy line.

Figure 3. Scheme for analyzing coastline changes

Several counteractive factors might and do work simultaneously in the ARCOS, namely the eustatic rise of the sea level, swaying tectonic movements, which are typical of a litospheric platform, land emergence due to the isostatic recovery following deglaciation, marine erosion, calving of ice coasts, fluvial-glacial deposition and possibly seismic impacts. Relationships between these processes vary through time. Therefore, the evaluation of the relative intensity of these processes is technically difficult and, still, there is no sole point of view on the origin and typical rates of current coastline changes in the Russian Arctic. The largest coastal changes, amounting to several kilometres across the shore, have been recorded at fronts of several large outlet glaciers and ice shelves in the Russian High Arctic (Kloster & Spring 1993, Sharov 1998). The most drastic retreat of ice coasts caused by marine abrasion and calving was detected to be 2 – 4 km in the course of several tens of years (Sharov 2000). Nevertheless, such changes are rather extraordinary and the typical rate of coastline change of ice coasts is expected to be within the range of not more than 10 to 50 meters per year.

Non-glaciated coasts composed of permanently frozen ground also subjected to sufficiently rapid changes due to thawing permafrost and melting of fossil ice. The rate of freeze-thaw disintegration and marine erosion of such shores increases due to the current climate warming in the Arctic. Many islands are known throughout the Russian Arctic, e.g. Dashka, Diomid and Mostakh, Semyonovskiy and Vasil'evskiy islands etc., which have become much smaller or even totally disappeared because of marine erosion. At present, coast recession is in progress on 30% of the Barents Sea coastline.

Summer degeneration of tundra cliffs of peaty and morainic material may result in the coastline retreat of tens of meters in a few weeks. Typical rates of coastal erosion are, however, supposed to be 5-6 m/year at lower 70-th altitudes (Bird 1984). Changes at hard rocky coasts are usually much slower. In the cold season, when the adjacent sea freezes, and wave action is weakened by the influence of sea ice cover and by the predominance of winds blowing offshore from ice caps, coastal erosion in the Arctic becomes negligible. Erosive impact by sea ice floes seems to be weak as well.

The release of morainic debris from glacier tongues and plentiful supply of sediment from disintegrated shores raises the sea bottom just offshore. This effect was proven by crew of the Dal'nie Zelentsy research vessel, which grounded on unknown bank close to Lake Cape with the real depth of 5 meters instead of 8 m given in navigational charts (Korsun, personal communication 1994). At this cape we detected photogrammetrically the retreat of sandy coastline of 80 – 100 m having occurred in the course of the past 45 years. This is the only fact known to us about present rates of coastal sediment deposition and the sand-coast recession in the High Russian Arctic.

Numerous marine terraces or so-called raised beaches spreading along the Russian Arctic coast are considered important indicators of ancient shorelines and of relative sea-level changes in the region. A number of indirect studies have been made that attempt to interpret coastline changes by comparing the heights of marine terraces with the radiocarbon ages of the organic rests (bones, timbers, molluscan fauna) sampled on the surface of those terraces (Grosswald et al. 1973, Forman et al. 1995). These studies led to the conclusion that the earth's crust in the North-western Russian Arctic had been subjected to geologically recent uplifts, although the terrace spectra, even of adjacent islands, sometimes were beyond correlation (Sharov 1997). The contemporary rate of uplift specified in different publications varies from 1-2 mm/year (Forman et al. 1996) to 3-4 mm/year (Matishov 1993). On the other hand, all scientists, who have adopted the theory of glacioisostatic uplift in the Western Russian High Arctic, do agree that the rate of uplift is decreasing at present (Grosswald et al. 1973).

The hypothesis of land emergence in the Russian High Arctic seemed to be in good correspondence with the "Walbeinhebungstheorie" originating from finds of whale bones on marine terraces of Spitsbergen, and with the theory of glacioisostatic movements in Fennoscandia. Although explorations were performed on several islands in the Western Russian Arctic, this hypothesis was later on simply extrapolated to the larger areas and even into the present time. However, many uncertainties still persist in this theory, and the new Russian map (1993) showing contemporary vertical movements of the earth's crust at 1:5,000,000 scale represents some Russian high-latitudinal archipelagoes as a "white spot" indicating the lack of appropriate data.

Meanwhile, present estimations of world-wide changes in sea level in the past century show the eustatic rise of sea level occurring at an average rate of 1.5 - 4 mm per year (Kotlyakov 1994, Psuty 1997). Regression analysis of the data recorded during 1976-1991 at tide-gauge stations in Murmansk and Polyarnoe (Annual data...1971-1994) shows that the mean annual level (MSL) of the southern Barents Sea rose for 10 cm in 16 years, i.e. 6.25 mm/year (Figure 4). In the course of the last 45 years it could amount to 20 to 25 cm and thus result in a significant deluge of coastal areas with gentle slopes. Tide gauge records are not available for many sections of the Russian Arctic coast and till present this conclusion remains somewhat speculative[2].

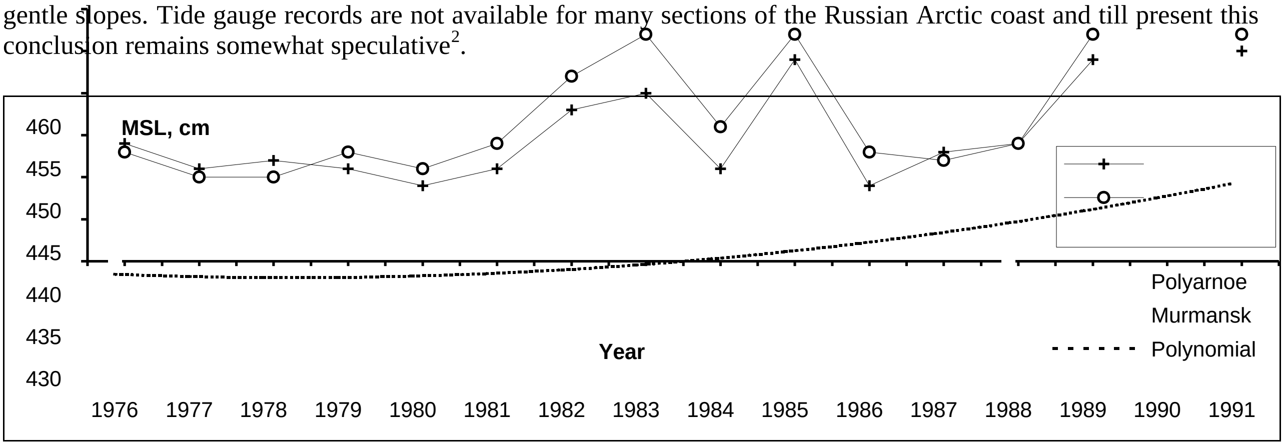


Figure 4. Annual changes of the Barents Sea level

[2] As for the tides, the Kara Sea has its own amphidromic system with mean tidal effects around the southern coasts about 0.5 m, down to 29-35 cm at the northern islands. In the Barents Sea, maximum tides are noted at the Strait Gorlo of the White Sea (up to 7 m) and in the Murman fjords; further to the north-east the range of the tides diminishes to 0.8 m around Novaya Zemlya and 20-30 cm in FJL. The Barents Sea mean level and the Kara Sea mean level connected within FJL differ by 9 cm.

2.5 Classification of Arctic coasts

Semantic ordering and detailed classification of arctic coastlines is necessary in order to provide the background required to analysing coastline changes and developing the system of cartographic symbols for detailed mapping of coastlands. Besides, the coastline classification adopted by all contractors will give necessary terminological reference on the ARCOS structure and main principles of the coastline evolution, and shall serve for the gentle incorporation of our output products into international Arctic databases such as those in ACD, GRID, etc. (See Chapter 9). The proposed classification must be broad enough to encompass internationally accepted schemes. On the other hand, it has to respect for the project specifics, i.e. be applicable to the specific objectives of the AMETHYST project.

There are different methods of coastline classification. In the geomorphological classification of coasts offered in (Shepard 1976), major coasts were classified as follows:

I. Primary coasts, with configuration resulting from non-marine processes

A. Land erosion coasts
   1. Drowned river-cut valleys
   2. Drowned glacial erosion coasts
   3. Drowned karst topography

B. Land deposition coasts
   1. Deltaic coasts
   2. Compound alluvial fan
   3. Outwash plain
   4. Mud lumps

C. Ice coasts, where glacier fronts extend into the sea

II. Secondary coasts, with configuration resulting mainly from marine agencies or marine organisms

A. Wave erosion coasts
   1. Straightened by wave erosion
   2. Made irregular by wave erosion

B. Wave deposition coasts
   1. Coastal plains built seaward by waves
   2. Barrier coast
   3. Cuspate forelands
   4. Mud flats or salt marshes

C. Glacial deposition coasts
   1. Partially submerged moraine
   2. Partially submerged drumlins

D. Wind deposition coasts
   1. Dune prograded coast
   2. Dune coast

E. Landslide coasts

F. Coasts shaped by volcanic activity

G. Coasts shaped by diastrophic movements
   1. Fault coast
   2. Fold coast
   3. Sedimentary intrusion coasts

III. Artificial or man-made coasts.

Another genetic classification devised in (Kaplin et al. 1991) considers the stage of coastal evolution and represents slight variation to the Shepard's classification. In this classification, the evolution chain looks as follows:
primary (initial) coasts - erosion coasts (intended, straight) - erosion-deposition coasts (intended, straight) - deposition coasts (intended, straight, degraded). Such classification might be useful in diagnosing the history and origin of coasts from a study of their outlines in charts and remote sensing imagery.

However, it is very doubtful whether configuration can be accepted as a reliable indication of coastal evolution. A straight coast may be produced by deposition, faulting, emergence of a featureless sea floor, or submergence of a coastal plain; an indented coast may be formed by submergence of an undulating or dissected land margin, emergence of an irregular sea floor, differential marine erosion of hard and soft outcrops at the coast, or transverse tectonic deformation (folding and faulting) of the land margin (Bird, 1985). Therefore, it is very difficult, if not impossible, to perform reliable genetic classification of coastlines without proper investigation of their geomorphological evolution. Comprehensive geomorphological studies are, however, beyond the scope of our study. Thus, other "hydrographic" approach to the coastline classification being suitable for remote sensing applications and considering rather short (several tens of years) period of observations has to be proposed.

In contrast to other coastal classifications, the coastal classification developed by Valentin (1952) is based on the observed gain or loss of land (advance or recession of coastlines) and, thus, takes into account the evidence of coastline changes in progress. *This principle of classification fits to our project tasks at best.* In accordance with Valentin's classification all coasts are divided into two large groups:

A. Coasts that have advanced
   1. emerged sea floor coasts
   2. lagoon-barrier and dune-ridge coasts resulting from marine deposition where tides are weak
   3. tideflat and barrier-island coasts resulting from marine deposition where tides are strong
   4. delta coasts resulting from fluvial deposition

B. Coasts that have retreated
   1. due to submergence of glaciated landforms
      a. fiord-skerry coasts resulting from confined glacial erosion
      b. fiard-skerry coasts resulting from unconfined glacial erosion
      c. morainic coasts resulting from glacial deposition
   2. due to submergence of fluvially-eroded landforms
      a. embayed upland coasts on young fold structures
      b. ria coasts on old fold structures
      c. embayed plateau coasts on horizontal structures
   3. due to marine erosion
      a. cliffed coasts

There are, however, some difficulties in applying this classification to our practical work mostly because typical categories of arctic coasts, e.g. the category of ice coasts, glaciated and periglaciated coastlines, coasts composed of permafrost have not been represented here in sufficient detail.

Ice coasts

To our knowledge, the detailed comprehensive classification of ice coasts has yet to be developed. Some information on different types of ice coasts and approaches to their classification can be found in (Zenkovitch 1946, Shumskiy 1963, Vinogradov & Krenke 1964). Numerous and quite different principles were applied to the categorisation of glaciated shores and the most of them can be summarised as follows:

- the manifestation and rate of glacier advancement or recession; current and potential stability / liability of the ice coast position;
- the glacier bed configuration, e.g. ice coasts with direct or inverse slope of bedrock at the grounding line;
- the buoyancy state, e.g. floating or grounded ice coasts;
- the rate of ice influx, i.e. ice coasts with relatively fast and relatively slow ice motion;
- thermal state, e.g. ice coasts with temperate ice and cold ice;
- the rate of iceberg production and calving mechanisms, e.g. collapsing of ice blocks and slabs, emergence of sub-water ice ramparts, tabular calving;
- type and rate of sedimentation at ice coasts due to the glaciofluvial deposition and debris transport;
- different internal / external mechanisms and forces (longitudinal strain, frontal bending, critical fracture strain, ice salinity, intensity of thermohaline and wave abrasion, location at an open coast or in protected bay, tidal effects, extreme weather conditions etc.).

All these principles can not be referenced within one simple classification and, in our case, geometric relationships including the configuration of the glacier surface and glacier bed, the position of ice coast with respect to the sea level and sea bottom, ice thickness, glacier motion and spatial changes onshore will be dominantly used for the ice coast classification. Graphical example of the classification scheme based on a such "mapping" approach is given in Figure 5 (Sharov & Gutjahr 2001).

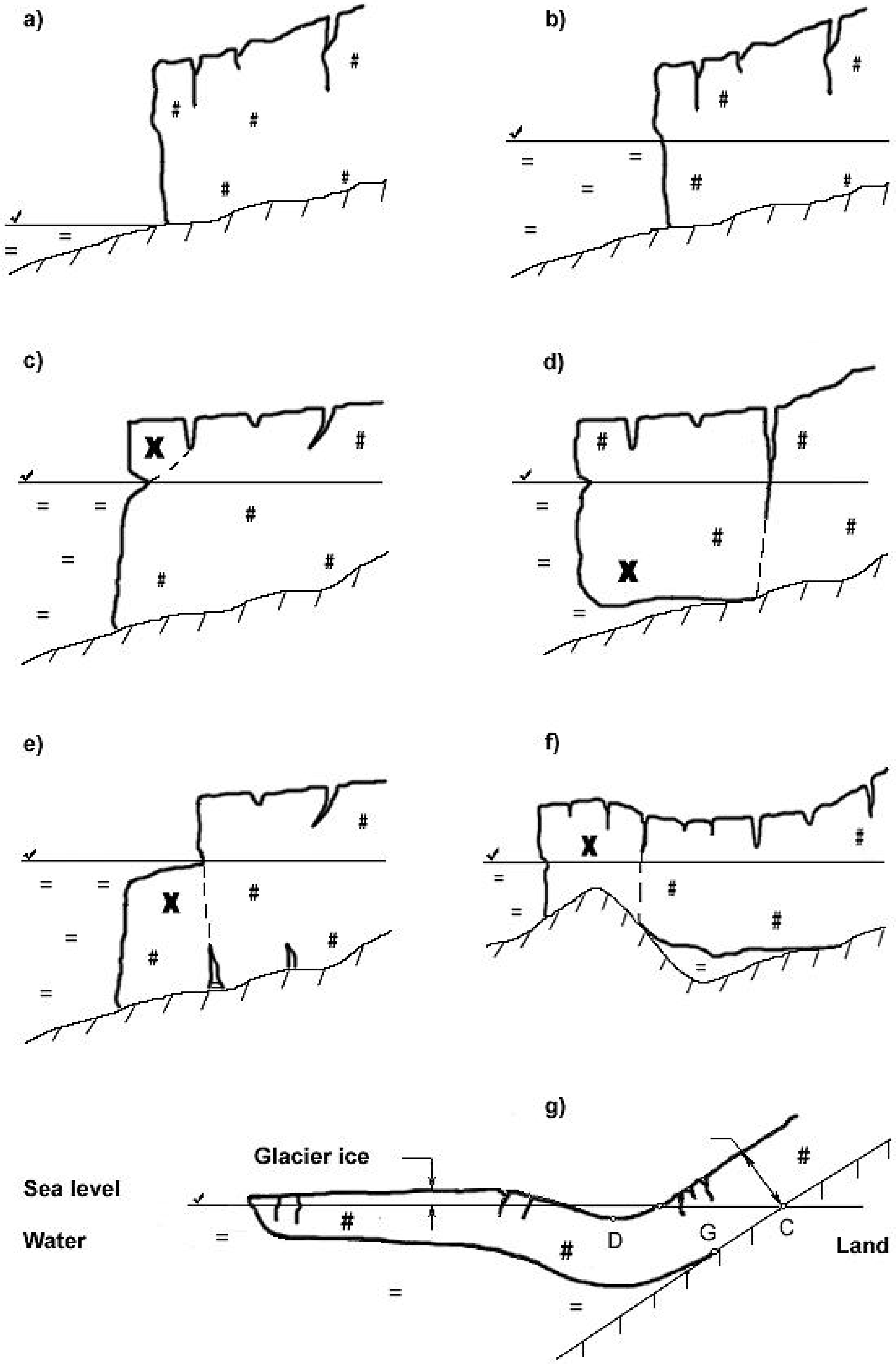


Figure 5. Different types of ice coasts (not to scale): ice shore (a), ice wall (b), collapse of ice block at sloping ice shore (c), ice front or floating glacier-margin (d), underwater ice rampart (e), ice coast with different slopes of bedrock (f), ice shelf (g).

Figure 5 represents longitudinal profiles of typical ice coasts. Profiles 5 a), b) were derived from the ice-coast classification given in (Grosswald et al. 1973) while profiles 5 c), d), e) were found in (Wilhelm 1975). Profiles 5 f), g) are also quite typical in the WeRA. There is an evidence attesting to the presence of such ice shores in the high-arctic archipelagos of FJL and SZ (Dowdeswell et al. 1994). Those interested in coastal geometry can note (Fig. 5, c, d) that, sometimes, the shoreline (in the abrasive niche) can be further ashore than the ice coastline (upper crest of the glacier slab).

The submarine part of an ice coast is subjected to an ablation process approximately 200 times higher than the part above water. Therefore, submerged and especially floating parts of ice shores (Fig. 5, d, f, g) get destroyed very fast even in cold water, and ice thickness rapidly decreases seawards. Thus, the coasts shown in Figure 5 b-g) can be classified as changeable (calving) ice shores. Figure 5, a) shows more or less stable ice coast.

Ice-free coasts

We think that, in the AMETHYST frameworks, the same mapping approach should be applied to the classification of arctic ice-free coasts as well. There are (almost) no functional relationships incorporated into the classification system and a surveyor describes what can be seen and interpreted of the coastal features in remote sensing materials. Thus, we attempt to describe the coastline in genetically neutral, geometrically defined terms. The descriptive nature of the system allows non-technical users of the information to grasp a basic picture of the coastline.

In this case, main attributes of the coastline under observation are

- ✓ morphology (steep, sloping, low) and texture,
- ✓ materials (unlithified, i.e. sandy, silty, clayey, peaty, etc., lithified, i.e. rocky, and ice),
- ✓ dominant processes and spatial changes,

and the most important types of the ice-free coastline include:

1) rock cliffs,
2) rock platforms without beaches,
3) rock platforms with beaches,
4) “tundra” cliffs of peaty and morainic material with interstitial ice contributes (permafrost),
5) periglaciated coasts with morainic remnants and irregular surface,
6) raised beaches (marine terraces),
7) gravel beaches,
8) sand beaches,
9) sand flats,
10) deltaic coasts,
11) estuaries.

Examples of possible coastal morphologies which could be described using this system are given in Figure 6. In the case of “change-mapping” approach, the proposed classification system might include some additional categories of the coastline such as steady coast, changeable (retreating or advancing) coast and the class of uncertain coastline. The possibility and methodology of including in the classification a quantitative description of the coastline complexity along the lines of a fractal dimension is not yet defined.

Figure 6. Relief forms or morphologies used in the coastline classification

Coastal taxonomy

The basic concept underlying the mapping approach to the coastline classification is that the coastline can be subdivided into smaller pieces so that the characteristics of each piece can be described and recorded. Following the subdivision hierarchy that is used by the Physical Shore-Zone Mapping System (http://www.for.gov.bc.ca/), we shall subdivide the coastline into alongshore units, part the shore units into across-shore components and categorise each of the components into zones. By subdividing into smaller pieces (blocks), the major characteristics of the coastline can be recorded in tabular or database formats that facilitate recording of large amount of information.

Definitions of these mapping building blocks are:

- *Unit* - an association of one or more across-shore components or processes that are continuous alongshore. Each shore unit is characterised by a coastline type (Page 10), which is a summary indicator of the morphology and sediment within the unit.
- *Component* - a geomorphic feature, with unique form and texture, that is uniform alongshore the coast.
- *Zone* - a vertical reference frame to categorise components in the supratidal, intertidal or subtidal elevation levels. The zones provide an indirect indication of the dominant process affecting the component. For example the transition from supratidal to intertidal implies a transition from a zone of terrestrially- dominated processes to a zone of marine-dominated processes.

Each along-shore unit is divided into four cross-shore zones which are described in terms of their shape and their material type. The cross-shore zones are identified as onshore, backshore, frontshore and offshore[3] (Figure 7). The term "frontshore" was defined to include both the foreshore and the surf zone whereas the term "backshore" was defined to refer primarily to the area landward of the active beach. The "onshore" category refers to the local to regional setting of the zone that is adjacent to those zones which are immediately affected by marine processes.

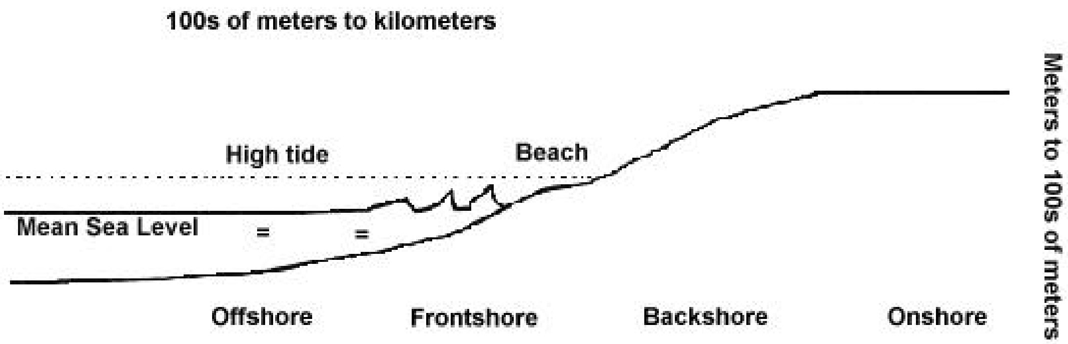


Figure 7. Schematic representation of cross-shore zones

The concept of a shore unit is fundamental to understanding and using the mapping system. Although the across-shore component is the primary building block of the mapping system, the shore unit is the primary feature portrayed on the maps. The shore unit identifies areas of morpho-dynamic homogeneity. That is, within a unit, the morphology, sediment texture and dynamic physical processes do not vary in the alongshore direction. As a general rule, a change in one or more across-shore components (i.e., a change in either form or texture) or a significant change in processes operating on the shore zone will define a new unit.

It should be noted that the units and components are dependent of the mapping scale and on the scale of the data. The same units or components might not necessarily be defined at a 1:100 000 mapping scale as at a 1:10 000 scale. Similarly, coastlines mapped during a ground survey are likely to have significantly different units than one using 1:30 000 scale air photos. An important feature of the mapping approach is that the scale of the coastal data, which is mostly recorded in an image/tabular/database format, is almost always of much greater detail than the presentation mapping scale.

Units and components are polygons that represent an area. At detailed mapping scales such as 1:2 000 or 1:5 000, it may be possible to illustrate the components as polygons. More often, components are not illustrated on maps and only the unit is indicated. At mapping scales of 1:100 000 even units are seldom illustrated as polygons because the shore zone is so narrow (a 100 m-wide shore unit would be 1mm wide); shore units are most often illustrated with a coloured or patterned line segment. It should be emphasised, however, that a coastline is seldom represented as discrete physical features but more often shows a gradation from one geomorphic feature to the next. As such, the application of the system requires professional interpretation, and a minimum level of professional experience is suggested for mapping and monitoring.

2.6 Kinds of coastline changes

Here, it is worth to note that the areal extent of coastline changes is relatively small when compared to the area covered by remote sensing image data, which brings additional difficulties in the change mapping / documentation.

[3] Note that the offshore zone is not generally accessible to direct remote observations and, thus, is beyond the scope of our research.

Only significant, steady and typical long-term changes of the coastline shall be recorded by hydrographic monitoring. Temporary alterations of the coastline resulting from catastrophic events, such as storm surges, as well as all seasonal, e.g. meteorological or tidal effects, shall be compensated and/or excluded from the consideration as being sources of errors. At present, the taxonomy of coastline changes based on the mode of motion includes

- incremental changes (marine erosion of cliffs, fluvial-glacial deposition, glacier retreat, deluge due to the eustatic rise of the sea level, vertical tectonic motions of coastland, changes in the seaward limit of backshore vegetation on beaches and deltas),
- rapid dynamic changes of mobile objects (glacier- and sea ice motion, positional changes of coastal polynyas),
- abrupt changes (glacier surges, calving, outburst of glacier-dammed lakes, landslides etc.),
- periodic fluctuations of fixed objects (tidal motions of the shoreline, vertical motions of the coast ice due to wave action).

Change categorisation may be based on the genetic, structural or methodological principle. For instance, coastline changes can be arranged in different classes according to their causes, e.g.

+	emergence,	+	deposition,	+	frontal ice growth,	+	glacier flow, surge,
-	submergence,	-	erosion,	-	thermohaline and wave abrasion, ablation,	-	calving.

One should distinguish between geometric changes (change of dimension, boundary reconfiguration and movement), topological changes such as splitting and joining, overlapping and suppressing, emergence or disappearance of features, changes in the number of elements, and thematic state changes (changes of non-spatial attributes), seasonal (or temporary) and long-term (or steady) changes, typical and anomalous changes, binary (sharp, abrupt) and continuous (gradual) changes, significant (coarse), i.e. those of large magnitude or/and serious implications, and insignificant (subtle) changes. The present classification of coastline changes has to be argued and detailed with the inclusion of natural alterations indicative of current coastline changes.

In the separate "Plan for studying fastice in the Kara and Petchora Seas" devised by the NERSC and NIERSC as an attachment to the present concept, fastice is considered as *"an important part of the WeRA coastline in the cold season"* (Sandven et al. 2001). Therefore, it has been offered to introduce quite special group of coastal changes related with spatial-temporal and physical variations of the fastice regime, such as changes in boundaries and thickness, fastice displacement in response to atmospheric forcing and tidal effects, etc.

2.7 Defining the most appropriate indicators of coastline changes

Apart from the key attributes of arctic coastlands such as morphology (slope and configuration) and materials of the coast, which can be directly used for the evaluation of potential changes, there are numerous indicators that can be useful for the indirect interpretation of the coastline changes. These indicators can be divided into three large groups depending on the area of application:

- universal indicators applicable to all types of the coastline changes such as the depth of coastal waters, tidal range, wave exposure, coastal currents, eustatic changes of the sea level, specific climatic / meteorological conditions e.g. strong winds offshore etc.,
- particular indicators for ice-coast changes,
- features attesting changes of ice-free coasts.

Some indicators from the two latter groups are given in Table 1.

Occurrence of crevasses, looped moraines, push moraines, fresh deglaciated bedrock, iced core deposits is an important indicator of glacial activity and instability of ice shore. Sea ice motion, internal waves, polynyas in the fastice (the earliest in spring or the latest in autumn) are quite reliable indicators for coastal currents and shallow waters which can be used for both, the estimation of marine abrasion of ice shores and the analysis of sedimentary deposition on the beach. Snow-covered terrain presents some additional features useful for the estimation of the coastal slope. For instance, the littoral area at the low coast is well delineated in optical imagery by the boundary of the snow cover destruction due to influence of tidal waters.

It is worth to note that Table 1 represents only some examples and should not be considered as a comprehensive list of features idicating coastline changes in the Arctic. The full specification of the most appropriate indicators for coastline changes in the WeRA shall be developed during the practical research work in the AMETHYST Project.

Table 1. Some indicators of coastline changes

No.	Indicator / Parameter	Indicated change	
		Ice coast	Ice-free coast
1	Subglacial topography / Ice thickness, bedrock elevation with respect to the sea level (positive, negative, e.g. ice caps with submersed glacier bed)	+	
2	Ice motion / Velocity, pattern of the ice motion field	+	
3	Crevasse pattern, supraglacial lakes, streams, wells	+	
4	Surficial moraines, esp. push and looped. Morainic shoals, bars, islands	+	
5	Anomalies in the glacier front position. Shape and size of icebergs	+	
6	Debris content and cover. Dirty icebergs. Diamicton deposits. Suspension overflow plumes	+	
7	Configuration of lakes and rivers in the coastland and changes in the hydrographic network onshore, ice-dammed lake outbursts	+	+
8	Sea ice conditions (polynyas, motion) and internal waves in coastal waters	+	+
9	Raised beaches. Patterned ground / cracking		+
10	Deltas, lagoons and sandbars, lakes with salty water		+
11	Destruction of the fresh snow cover		+
12	Slow changes in areas of pioneer vegetation		+

3. Technical aspects of coastal hydrographic monitoring

3.1 Technical parameters of monitoring

If typical rates V of coastline changes in the Arctic region are supposed to be known, then principal requirements for the contents of hydrographic monitoring, such as interval, detailedness (spatial resolution) and accuracy can be defined depending on the working scale M. If remote sensing imagery is used directly as a base for monitoring, the linear equation relating a monitoring scale number M to the required image ground resolution A given in meters can be presented in the following form

$$M = 5000 \cdot A \quad (1)$$

On the other hand, spatial resolution of spaceborne image data must be sufficient for the detection of typical coastal changes in the investigated region. Hence, the following relation holds

$$A \leq V \cdot \Delta T , \quad (2)$$

where $D\,T$ denotes the time interval between observations. Then, the required interval can be determined as follows:

$$\Delta T \cong c \cdot \frac{A}{V} = \frac{c \cdot M}{5000 \cdot V} , \quad (3)$$

where coefficient $c \approx 3 \div 5$ depends on the task, object type and image data, and shows that for reliable detection, measurement and visual representation the size of spatial changes must not be smaller than several elements of the image resolution. If typical rates of change $v=V/M$ are given at $1:M$ scale and expressed in mm/a, then relation (3) can be transformed into the following expression

$$\Delta T \cong 0.2 \cdot c / v . \quad (4)$$

Technical parameters of hydrographic monitoring, obtained on the supposition that $V = 10 \div 50$ m/a, are given in Table 2 (Brandstätter, Sharov 1998).

At present, the working scale of 1:100 000 is close to the methodological limit for modern spaceborne remote sensing, which means that larger scales, e.g. 1:50 000 and 1:25 000, are yet rather unrealistic for complex regional satellite monitoring in the Arctic. Nevertheless, we should distinguish here between the *full-value hydrographic* *monitoring* aimed at recording changes of all ARCOS elements and the *backup monitoring* that is focussed on separate coastal features. In the case of local backup monitoring larger scales can be permitted under favorable conditions, e.g. for restricted areas with a relatively flat topography. *In our case, the basic working scale of coastal hydrographic monitoring will be 1:100 000. Main reserve scales for regional studies are 1:200 000 and 1:500 000.*[4]

Table 2. Principal technical parameters of hydrographic monitoring in the Russian High Arctic

Working scale *1:M*	**Required accuracy, m**		**Detailedness** *A*, **m**	**Rate of change** *v* **at scale** *1:M*, **mm/a**	**Required interval between surveys** *DT*, **ys**
	Planimetric	Elevation			
1:1 000 000	200 – 500	50 – 100	200	0.01 – 0.05	15 – 25
1:500 000	100 – 250	25 – 50	100	0.02 – 0.1	10 – 15
1:200 000	40 – 100	15 – 25	40	0.05 – 0.3	7 – 10
1:100 000	**20 – 50**	**10 – 20**	**20**	**0.1 – 0.5**	**5 – 7**
1:50 000	10 – 25	5 – 10	10	0.2 – 1.0	3 – 5
1:25 000	5 – 10	2.5 – 5	5	0.4 – 2.0	1 – 2

Generally speaking, reliable extensive surveys of the Russian Arctic coastline exist only for the second half of the past century, usually the period for which air photography is available. Available topographic maps and hydrographic charts containing major spatial information about coastlines in the Russian Arctic Sector were mostly created through materials of the last aerial and geodetic surveys carried out in the 1950-s. For example, all previous extensive terrestrial surveys in Franz Josef Land including third-order triangulation and levelling, erection of geodetic and navigational signals, establishment of benchmarks and tide-gauge observations were performed in 1954-1960 by the No.10 expedition of the Hydrographic enterprise of St.- Petersburg. This means that coastline changes in the Russian Arctic could be accurately detected and measured only within the period of the past 40 – 50 years.

On the other hand, the period of study must be sufficiently long in order to compensate for the influence by global natural cycles and to ensure accurate temporal extrapolations as well as to allow the adequate conclusions on the origin of coastline changes to be drawn and subsequent hydrographic forecasts to be made. Any way, this period should not be shorter than several past decades. *Thus, the time scale of a half a century has been selected for our monitoring studies.* Still longer spans of coastline change can be determined where earlier surveys were performed, e.g. in the areas surveyed from the airship “Graf Zeppelin” in 1931.

Then, in accordance with the required interval between hydrographic surveys specified in Table 2, three- to sevenfold coverage of the study areas with multitemporal data is necessary for monitoring at 1:100 000 scale. Apart from particular cases characterised with anomalous character of coastal changes, two-fold coverage would be sufficient for regional studies at smaller scales.

All study areas must comprise some track of coastland, i.e. be situated along the coastline. The width of study areas influences both the work volume and data costs, and thus, has to be limited. Following McGill, who compiled a map of the coastal landforms of the world at 1:25 000 000 scale (1958), *the maximum width of the coastal fringe under observation is selected to be 10 - 20 km.* Therefore, the majority of islands in the Russian high-arctic archipelagos will fall entirely in the category of coastal hydrography. The exact location and size of the study region and test sites will be defined in chapter 5.

3.2 Hydrographic standards

The latest International Standards for Hydrographic Surveys were adopted by the International Hydrographic Organisation in April 1998 (IHO Standards for Hydrographic Surveys, Special Publication No. 44, 4th Edition, 23p). As a rule, national hydrographic standards e.g. the Standards for Nautical Charting and Hydrographic Surveys developed by the US Federal Geographic Data Committee, Bathymetric Subcommittee in 1998, generally follow international standards.

Geospatial Positioning Accuracy Standards provide minimum standards for the horizontal and vertical accuracy of features associated with hydrographic surveys that support nautical charting. Such features include, but are not limited to, the reference datum (horizontal and vertical), natural coastline, topographical features, water depths, objects on the seafloor, navigational aids etc. *Horizontal spatial accuracy* is the two-dimensional circular error of a data sets horizontal co-ordinates at the 95% confidence level. *Vertical spatial accuracy* is defined by the one-dimensional linear error of depths at the 95% confidence level.

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[4] Cartographic materials and image / hydrographic data at these scales are not as strictly classified as those at larger scales.

Classification of surveys

To accommodate in a systematic manner different accuracy requirements for areas to be surveyed, four orders of survey are defined. These are described below, with specific details provided in the following Table 3, which

- gives examples of areas to which an order of survey might typically be applied (row 1),
- lists positioning (horizontal) accuracies to be achieved to meet each order of survey (row 2),
- specifies parameters to be used to calculate accuracies of reduced depths to be achieved to meet each order of survey (row 3),
- specifies occasions when full bottom search should be conducted (row 4),
- specifies the detection capabilities of systems used for bottom search (row 5),

row 6 is to be interpreted as either (1) spacing of sounding lines for single beam sounders or (2) distance between the outer limits of swaths for swath sounding systems.

Table 3. Summary of minimum standards for hydrographic surveys

ORDER	**Special**	**1**	**2**	**3**
Examples of Typical Areas	Harbours, berthing areas, and associated critical channels with minimum underkeel clearances	Harbours, harbour approach channels, recommended tracks and some coastal areas with depths up to 100 m	Areas not described in Special Order and Order 1, or areas up to 200 m water depth	Offshore areas not described in Special Order, and Orders 1 and 2
Horizontal Accuracy (95% Confidence Level)	2 m	5 m + 5% of depth	20 m + 5% of depth	150 m + 5% of depth
Depth Accuracy for (1) *Reduced Depths (95% Confidence Level)* (2)	a = 0.25 m b = 0.0075	a = 0.5 m b = 0.013	a = 1.0 m b = 0.023	Same as Order 2
100% Bottom Search (3)	Compulsory	Required in selected areas	May be required in selected areas	Not applicable
System Detection Capability	Cubic features > 1 m	Cubic features > 2 m in depths up to 40 m; 10% of depth beyond 40 m	Same as Order 1	Not applicable
Maximum Line Spacing (4)	Not applicable, as 100% search compulsory	3 x average depth or 25 m, whichever is greater	3-4 x average depth or 200 m, whichever is greater	4 x average depth

(1) To calculate the error limits for depth accuracy the corresponding values of a and b listed in the Table 3 should be introduced into:

$$\pm \sqrt{[\,a^2 + (b * d\,)^2\,]}$$

where: a is a constant depth error, i.e. the sum of all constant errors, b*d is the depth dependent error, i.e. the sum of all depth dependent errors where b is a factor of depth dependent error, and d is depth.
(2) The confidence level percentage is the probability that an error will not exceed the specified maximum value.
(3) A method of exploring the seabed which attempts to provide complete coverage of an area for the purpose of detecting all features addressed in this publication.
(4) The line spacing can be expanded if procedures for ensuring an adequate sounding density are used

Special Order hydrographic surveys

Special Order hydrographic surveys approach engineering standards and their use is intended to be restricted to specific critical areas with minimum underkeel clearance and where bottom characteristics are potentially hazardous to vessels. These areas must be explicitly designated by the agency responsible for survey quality. Examples are harbours, berthing areas, and associated critical channels. All error sources must be minimised. Special Order requires the use of closely spaced lines in conjunction with side scan sonar, multi-transducer arrays or high resolution multibeam echosounders to obtain 100% bottom search. It must be ensured that cubic features greater than 1 meter can be discerned by the sounding equipment. The use of side scan sonar in conjunction with a multibeam echosounder may be necessary in areas where thin and dangerous obstacles may be encountered. Side scan sonar should not be used for depth determination but to define areas requiring more detailed and accurate investigation.

Order 1 hydrographic surveys

Order 1 hydrographic surveys are intended for harbours, harbour approach channels, recommended tracks, inland navigation channels, and coastal areas of high commercial traffic density where underkeel clearance is less critical and the geophysical properties of the seafloor are less hazardous to vessels (e.g. soft silt or sand bottom). Order 1 surveys should be limited to areas with less than 100 m water depth. Although the requirement for seafloor search is less stringent than for Special Order, full bottom search is required in selected areas where the bottom characteristics and the risk of obstructions are potentially hazardous to vessels. For these areas searched, it must be ensured that cubic features greater than 2 m up to 40 m water depth or greater than 10% of the depth in areas deeper than 40 m can be discerned by the sounding equipment. In some areas the detection of 1-meter cubic features may be specified.

Order 2 hydrographic surveys

Order 2 hydrographic surveys are intended for areas with depths less than 200 m not covered by Special Order and Order 1 and where a general description of the bathymetry is sufficient to ensure there are no obstructions on the seafloor that will endanger the type of vessel expected to transit or work the area. It is the criteria for a variety of maritime uses for which higher order hydrographic surveys cannot be justified. Full bottom search may be required in selected areas where the bottom characteristics and the risk of obstructions may be potentially hazardous to vessels.

Order 3 hydrographic surveys

Order 3 hydrographic surveys are intended for all areas not covered by Special Order, and Orders 1 and 2 in water depths in excess of 200 m.

Reference datum

In order to eliminate differences among regional and national use of datums, all investigators should refer to the Russian national (Baltic) sea level for conducting coastline studies. The horizontal reference datum should be, in our case, the Pulkovo Datum of 1942, and dimensions of the ellipsoid of Krassowskiy will be used. If other datum, e.g. WGS 84, will be used, its relationship to the Krassowskiy ellipsoid shall be documented. Vertical co-ordinate values should be referenced to the applicable chart datum and not one of the geodetic vertical datums. For instance, the mean high water line has been charted to represent the coastline in contemporary Russian topographic maps of the High Arctic. Due to the negligible effect of tidal forces, however, the sea level recorded at the time of survey is usually used as a datum plane for practical hydrographic works in the WeRA.

Positioning

The horizontal accuracy, as specified in the Table 3, is the accuracy of the position of soundings, dangers, and all other significant submerged features with respect to a geodetic reference frame. The exception to this are Order 2 and Order 3 surveys using single-beam echo sounders where it is the positional accuracy of the sounding system sensor. In such cases, the agency responsible for the survey quality should determine the accuracy of the positions of soundings on the seafloor.

If the accuracy of a position is affected by different parameters, the contributions of all parameters to the total position error should be accounted for. A statistical method, combining different error sources, for determining positioning accuracy should be adopted. The position error, at 95% confidence level, should be recorded together with the survey data. Although this should preferably be done for each individual sounding, the error estimate may also be derived for a number of soundings or even for an area, provided differences between error estimates can be safely expected to be negligible.

It is strongly recommended that whenever positions are determined by terrestrial systems, redundant lines of position should be observed. Standard calibration techniques should be completed prior to and after the acquisition of data. Satellite systems should be capable of tracking at least five satellites simultaneously; integrity monitoring for Special Order and Order 1 surveys is recommended.

Primary shore control points should be located by ground survey methods to a relative accuracy of 1 part in 100 000. When geodetic satellite positioning methods are used to establish such points, the error should not exceed 10 cm at

95% confidence level. Secondary stations for local positioning, which will not be used for extending the control, should be located such that the error does not exceed 1 part in 10 000 for ground survey techniques or 50 cm using geodetic satellite positioning.

The horizontal positions of navigation aids and other important features should be determined to the accuracy stated in the following Table 4, at 95% confidence level.

Table 4. Summary of Minimum Standards for Positioning of Navigation Aids and Important Features

Horizontal accuracy	Special Order surveys	Order 1 surveys	Order 2 and 3 surveys
Fixed aids to navigation and features significant to navigation	2 m	2 m	5 m
Natural Coastline	10 m	20 m	20 m
Mean position of floating aids to navigation	10 m	10 m	20 m
Topographical features	10 m	20 m	20 m

Depths

The navigation of commercial vessels requires increasingly accurate and reliable knowledge of the water depth in order to exploit safely the maximum cargo capabilities. It is imperative that depth accuracy standards in critical areas, particularly in areas of marginal underkeel clearance and where the possibility of obstructions exists, be more stringent than those established in the past and that the issue of adequate bottom coverage be addressed.

In determining the depth accuracy of the reduced depths, the sources of individual errors should be quantified and combined to obtain a Total Propagated Error (TPE) at the 95% confidence level. Among others these errors include:

a) measurement system and sound velocity errors

b) tidal measurement and modelling errors, and

c) data processing errors.

A statistical method for determining depth accuracy by combining all known errors should be adopted and checked. Recognising that both constant and depth dependent errors affect the accuracy of depths, the formula under Table 3 is to be used to compute the allowable depth errors at 95% confidence level by using the values from row 3 for a and b. As an additional check on data quality, an analysis of redundant depths observed at crossline intersections should be made.

For wrecks and obstructions which may have less than 40 m clearance above them and may be dangerous to normal surface navigation, the least depth over them should be determined either by high definition sonar examination or physical examination (diving). Mechanical sweeping may be used when guaranteeing a minimum safe clearance depth.

All anomalous features previously reported in the survey area and those detected during the survey should be examined in greater detail and, if confirmed, their least depth should be determined. The agency responsible for survey quality may define a depth limit beyond which a detailed seafloor investigation, and thus an examination of anomalous features, is not required. Measured depths should be reduced to chart or survey datum, by the application of tidal or water level height. Tidal reductions should not be applied to depths greater than 200 m, except when tides contribute significantly to the TPE.

Sounding density

In planning the density of soundings, both the nature of the seabed in the area and the requirements of the users have to be taken into account to ensure adequate bottom coverage. It should be noted that no method, not even 100% search, guarantees by itself the reliability of a survey nor can it disprove with certainty the existence of hazards to navigation, such as isolated natural hazards or man made objects such as wrecks, between survey lines.

Line spacing for the various orders of hydrographic surveys is proposed in Table 3. The results of a survey should be assessed using procedures developed by the agency responsible for the survey quality. Based on these procedures the adequacy of the sounding density should be determined and the line spacing reduced if warranted.

Bottom sampling

The nature of the seabed should be determined by sampling or may be inferred from other sensors (e.g. single beam echo sounders, side scan sonar, sub-bottom profiler, video, etc.) up to the depth required by local anchoring or trawling conditions. Under normal circumstances sampling is not required in depths greater than 200 meters. Samples should be spaced according to the seabed geology, but should normally be 10 times that of the main scheme line spacing. In areas intended for anchorages, density of sampling should be increased. Any inference technique should be substantiated by physical sampling.

Tidal observations

Tidal height observations should be made throughout the course of a survey for the purpose of providing tidal reductions for soundings, and providing data for tidal analysis and subsequent prediction. Observations should extend over the longest possible period, and if possible, for not less than 29 days. Tidal heights should be observed so that the total measurement error at the tide gauge, including timing error, does not exceed +/- 5 cm at 95% for Special Order surveys. For other surveys +/- 10 cm should not be exceeded.

Elimination of doubtful data

To improve the safety of navigation it is desirable to eliminate doubtful data, i.e. data which are usually denoted on charts by PA (Position Approximate), PD (Position Doubtful), ED (Existence Doubtful), SD (Sounding Doubtful) or as "reported danger". To confirm or disprove the existence of such data it is necessary to carefully define the area to be searched and subsequently survey that area according to the standards outlined in this publication.

No empirical formula for defining the search area can suit all situations. For this reason, it is recommended that the search radius should be 3 times the estimated position error of the reported hazard at the 95% confidence level as determined by a thorough investigation of the report on the doubtful data by a qualified hydrographic surveyor. If such report is incomplete or does not exist at all, the position error must be estimated by other means as, for example, a more general assessment of positioning and depth measurement errors during the era when the data in question was collected.

The methodology for conducting the search should be based on the area in which the doubtful data is reported and the estimated danger of the hazard to navigation. Once this has been established, the search procedure should be that of conducting a hydrographic survey of the extent defined in the preceding paragraph, to the standards established in this publication. If not detected, the agency responsible for the survey quality shall decide whether to retain the hazard as charted or to expunge it.

Quality control

To ensure that the required accuracies are achieved it is necessary to check and monitor performance. Establishing quality control procedures which ensure that data or products meet certain standards and specifications should be a high priority for hydrographic authorities. This section provides guidelines for the implementation of such procedures.

Quality control for positioning ideally involves observing redundant lines of position and/or monitor stations which are then analysed to obtain a position error estimate. If the positioning system offers no redundancy or other means of monitoring system performance, rigorous and frequent calibration is the only means of ensuring quality.

A standard quality control procedure should be to check the validity of soundings by conducting additional depth measurements. Differences should be statistically tested to ensure compliance of the survey with the standards given in Table 3. Anomalous differences should be further examined with a systematic analysis of contributing error sources. All discrepancies should be resolved, either by analysis or re-survey during progression of the survey task.

Crosslines intersecting the principal sounding lines should always be run to confirm the accuracy of positioning, sounding, and tidal reductions. Crosslines should be spaced so that an efficient and comprehensive control of the principal sounding lines can be effected. As a guide it may be assumed that the interval between crosslines should normally be no more than 15 times that of the selected sounding lines.

The proposed line spacing from Table 3 may be altered depending on the configuration of the seafloor and the likelihood of dangers to navigation. In addition, if side scan sonar is used in conjunction with single beam or multibeam sonar systems, the specified line spacing may be increased. Multibeam sonar systems have great potential for accurate seafloor coverage if used with proper survey and calibration procedures. An appropriate assessment of the accuracy of measurements with each beam is necessary for use in areas surveyed to Special Order and Order 1 standards. If any of the outer beams have unacceptable errors, the related data may be used for reconnaissance but the depths should be otherwise excluded from the final data set. All swaths should be intersected, at least once, by a crossline to confirm the accuracy of positioning, depth measurements and depth reductions.

It is understood that each sensor (i.e. positioning, depth, heave, pitch, roll, heading, seabed characteristic sensors, water column parameter sensors, tidal reduction sensor, data reduction models etc.) possesses unique error characteristics. Each survey system should be uniquely analysed to determine appropriate procedure(s) to obtain the required spatial statistics. These analysis procedure(s) should be documented or referenced in the survey record.

Technical Note

It may be concluded that the required positional accuracy of satellite hydrographic monitoring at 1:100 000 scale specified in Table 2 meets to the accuracy requirements by the Order 2 and/or 3 hydrographic surveys.

3.3 Methods of monitoring

There are two different methodological variants of complex regional monitoring depending on the availability of reliable up-to-date cartographic materials covering the study region:

- *Retrospective (background) monitoring* is based mostly on the comparison of available maps and published geographic data, and usually does not require additional data and substantial (extensive) hydrographic surveys. Methodologically, this is the simplest variant of monitoring, which can be performed wholly in the lab with minimum efforts and at lowest expenses. Excluding pure historical tasks, this approach requires homogeneous mutidate cartographic materials for the whole study region. In general, the technological scheme of this approach can be represented as "first mapping, then monitoring".
- *Prospective (foreground) monitoring* is applied under the lack of reliable (comparable) maps from different years and foresees the performance of new hydrographic surveys and the acquisition of modern image data. This approach is quite laborious, since it requires much field work and image data processing. The advantage of this variant is that it provides up-to-date novel results at hand and better suits for change detection, modelling and forecast in remote regions with poor cartographic knowledge. In such regions[5], this variant aids in deciding on the revision of available standard map series. The map revision begins after the monitoring is performed and the technological scheme looks like "first monitoring, then mapping".

In the Arctic, the majority of terrestrial monitoring is performed on the prospective basis because the history of explorations is typically short, available maps are usually obsolete and typical rates of changes are unknown.

Both approaches are commonly realised using four principal groups of methods:

- Methods of data acquisition/processing including terrestrial, airborne and spaceborne surveys based on
  - geodetic-topographic-hydrographic measurements,
  - photogrammetric and radargrammetric image processing, both mono and stereo,
  - photoclinometric or shape-from-shading determinations,
  - polarimetric analysis,
  - interferometric data analysis (INSAR).

- Methods of data collocation including
  - data reduction, normalisation,
  - geometric, radiometric and spectral calibration/correction,
  - georeferencing and geocoding,
  - template matching (single point and global), image co-registration,
  - synthesising colour composites,
  - ground controlling, using orbital data and imaging geometry,
  - different techniques for data fusion at pixel, feature and decision level.

- Methods of change detection / analysis, including automatic, semi-automatic and manual (visual) techniques for
  - map- or image differencing,
  - interlayer (feature – pixel) differencing,
  - gradient-based approaches and correlation techniques,
  - data coherence analysis and fringe image analysis,

[5] In the High Russian Arctic, reliable surveys of coastline exist for the past few decades, usually the period for which air photography is available.

- post-classification comparison and change vector analysis,
- deterministic and statistical comparison, regression analysis,
- proxy (indirect) methods using indicators of changes, e.g. geomorphological, biological etc.,
- parametric (numerical) and compensatory modelling, topological and prospective modelling.

• Methods of cartographic representation and change mapping including
- computer-assisted image mapping,
- data generalisation, cartographic design, map-reading and cartometry,
- hybrid GIS technologies and data integration in vertical databases,
- animation, multiscale representation and transformed visualisation,
- binary change and continuous change cartographic products, generation of a "probability of change" image,
- multistage validation.

Irrespectively of methodological variants, coastline changes are detected and measured by comparing historical maps and charts with later surveys and modern image data resulting from remote sensing. Changes can be expressed in linear terms, as advance or retreat measured at right-angles to the coastline; in areal terms, as the extent of land gained or lost from a coastal sector; or in volumetric terms, as the quantity of material added to, or lost from, the coast (Bird 1985). Volumetric studies are easy to advocate, but difficult to realise, and most reports on coastline changes in the Arctic have been based on linear or areal measurements.

Due to the unique properties of visual perception certain coastal changes can be detected and even measured without any pre-processing steps by separate visual hydrographic interpretation of multitemporal images and direct comparison with available maps. Some drastic coastline changes in the Russian Arctic revealed in this way have already been discussed in earlier publications (Dowdeswell et al. 1994; Kostka, Sharov 1996).

In operational work, more accurate technique of photogrammetric or radargrammetric comparison is usually applied in order to be able to represent and analyse smaller changes and execute precise areal measurements. Prior to comparison, images are reduced to the normal case (or to a certain cartographic projection) in order to remove distorting effects and to provide geometric identity of scenes under comparison. Basic hydrographic features including coastlines, glacial borders, hydrographic network, etc., are then vectorized, and the resultant graphic features are registered to the corresponding historical maps or images of the original survey by uniting homologous tie points taken inland. Finally, the relative differences in position of "old" and "new" natural boundaries are measured and documented (Brandstätter, Sharov 1998).

Main drawbacks to these traditional methods of survey are mostly due to difficulties in the delineation of arctic coastlines in airborne and spaceborne images, both optical and radar, which is not always obvious and requires much manual work. In some cases, e.g. when thick unbroken sea ice floes were attached to the ice coast or ice-free coasts (especially, small islands and separate rocks) were surrounded with open wavy sea, the coastline could not be reliably recognised even by joint analysis of optical and radar images under visual stereoscopic interpretation (Sharov 1997).

New promising possibilities to effectively model coastal tracts of land and to monitor rapid coastal changes in the extreme North have been recently demonstrated by using satellite radar interferometry (INSAR, Lefauconnier et al. 1993). The INSAR method is based on generation of an interferogram by combining two complex radar images, which contain the information on amplitude and phase of radio signals reflected from the Earth's surface. Each fringe in the resultant interferogram corresponds to a certain phase difference between radio signals, which in its turn depends on both, the elevation of terrain and the object motion towards or away from the sensor (Figure 8). The relative accuracy of spaceborne interferometric determinations reaches up the sub-meter range.

The interferential analysis of satellite radar images being supported with methods of numerical analysis, data fusion and GIS technologies is chosen to be the basic method of our studies because

✓ INSAR is a novel highly automatic and sensitive as well as very competitive technique.

✓ All coastlines are well detectable in INSAR products even if they are totally invisible in single radar or/and optical images due to sea waves, fast sea ice, snow cover etc.

✓ Velocities of glacier motion are well measurable in SAR interferograms.

✓ The reliable coastland surface modelling can be performed and the total areal extent of arctic archipelagos can be determined very precisely and relatively easy with this technique.

✓ Essential methodological developments resulting in significant technological simplification to main INSAR operations yet without compromising on accuracy are possible being based on our new stratagems such as phase-shifting or gradient-interferometry (GINSAR), transferential instead of differential approach, monointerference etc. (Sharov et al. 2000).

✓ Our initial tests using spaceborne repeat-pass interferometric data for topographic modelling of glaciers and shorelines in the Franz Josef Land archipelago, Russian Arctic were encouraging as a whole and attested to the feasibility of applying the INSAR method to the detailed hydrographic studies and coastal change detection in the Arctic (Sharov 1998, Raggam & Sharov 1999).

Thus, it is believed that the INSAR method will provide us with a new enhancive hydrographic knowledge and will even allow several geographic discoveries to be made within the project scope. Gaining quick and ready access to the new source of spaceborne hydrographic data, however, presents several problems in the exploitation of these data for monitoring purposes.

Spaceborne high-resolution INSAR data over the whole Russian Arctic territory are provided solely by the ERS-1/2-SAR polar-orbiting missions with orbital inclination of 98.5° and repeat pass interval of 1, 3 and more days. According to our experience only the ERS-1/2-INSAR data obtained during first two years of tandem mission in 1995-1996 with a time interval of 24 hours and effective baselines of 50 to 200 meters are applicable for reliable coastal monitoring in the Russian Arctic. There are several methodological problems in using these data including

- technological complexity of ERS-1/2-INSAR data processing,
- limited ground resolution of INSAR data due to speckle-noise,
- significant difficulties in providing homogeneous terrestrial coverage of large study regions with the tide-coordinated INSAR data obtained at close dates from appropriate baselines under favorable meteorological conditions (high atmospheric pressure) at equally high sea level (in order to delineate the high tide shoreline),

the general quality of ERS-1/2-SAR interferograms can not be ensured in advance, i.e. before the ordering data.

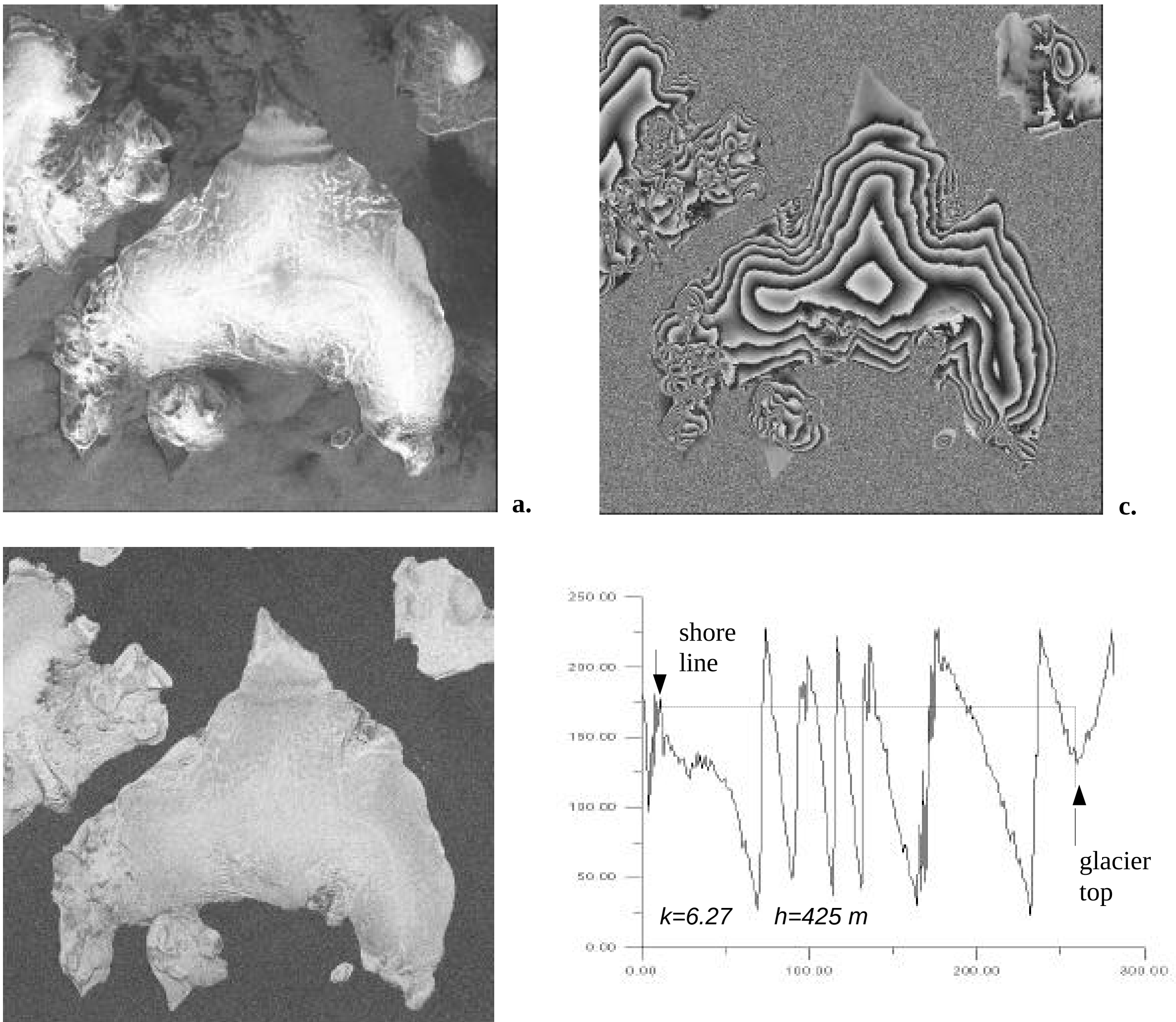

Figure 8. Results of SAR interferometric data processing: fragment of amplitude image for Hall Island, FJL (a); coherency image (b); interferogram of Moscow Ice Cap at Hall Island (c); radiometric profile taken across the interferogram (d).

The necessity of covering gaps in terrestrial and temporal coverage requires the use of additional spaceborne imagery with corresponding methods of image processing and data fusion. Optical images obtained by KATE-200 film camera from the Resource-F satellite and LANDSAT scenes are of interest in this context. These images have a ground resolution of about 30 meters, which is nearly the same as that of ERS-1/2-INSAR data and their prices are also similar to those of SAR images. The acquisition of additional optical data should not be done before the basic INSAR data processing will be performed and all gaps in the coverage will be identified.

Certainly, the long-term coastal monitoring foresees the comparison between the coastline records obtained at different times by different methods and with various accuracies. Reliable information on long-term coastline changes can be derived only if provided the limitations of topographic-hydrographic surveys performed tens of years ago are well understood. This understanding enables specific methodological measures to be taken for compensating differences in technical accuracy at the time of the original and modern surveys.

Coastline changes are measured with reference to the spatial distribution of ground control points (GCPs) inland. These GCPs will provide a benchmark for all coastline survey field work and remote-sensing analyses at the key site, and they must be easily located on the ground as well as from the air. Full documentation of the GCP location (e.g., GPS co-ordinates, photograph, recognisable site features) is essential for relocating it by different investigators over time. Of course, one must be sure that these reference points remained unchanged over the period of study. This is difficult to ensure, if the observation period extends throughout 50 years. Thus, the control or a new survey of the GCP location is also necessary. In general, reference objects are selected so that their changes are much smaller than those of the coastal features being studied. Therefore the inspection of GCPs location must be performed with higher accuracy during terrestrial surveys. Given this complications, coastal hydrographic monitoring in the Russian Arctic has to be performed on the multisensor and multistage basis, i.e. by combining and jointly analysing hydrographic data obtained by different sensors at different scales, spatial resolutions and detail. *Multistage concept* of monitoring is explained graphically in Figure 9.

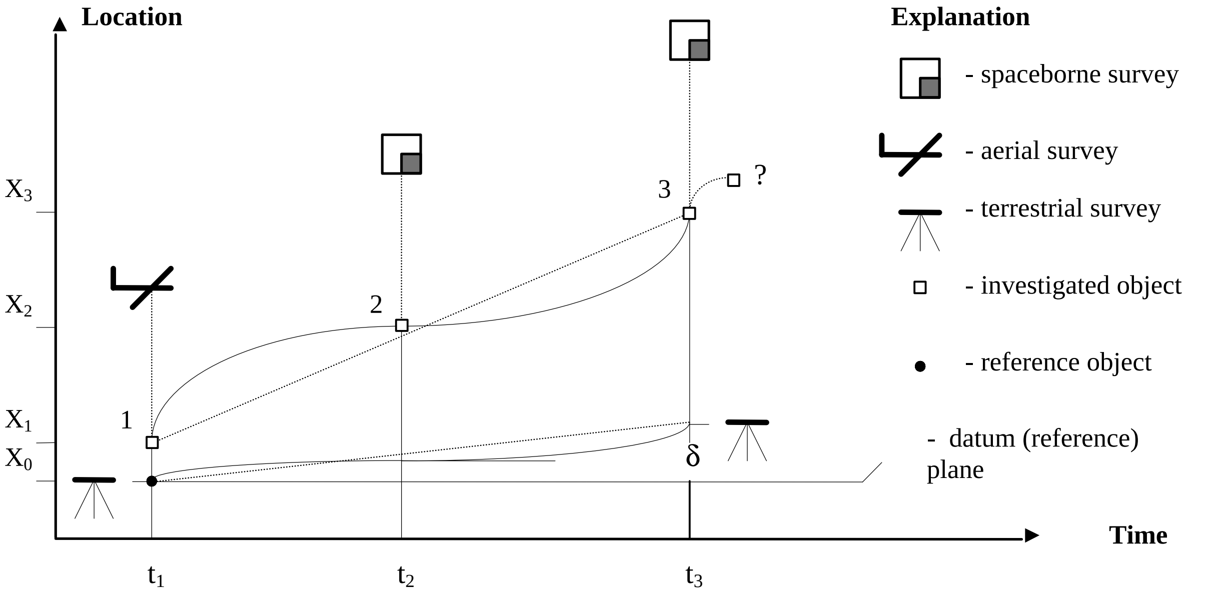

Figure 9. Concept of multistage surveys for coastal hydrographic monitoring

Site monitoring methodology

Our site monitoring methodology is based on a combined technology, which included the ground-truth data collection in key sites and assigned the major part of the routine to laboratory work. The duration of hydrographic surveys and observations *in citu* would depend primarily on site-specific objectives and methods, and range from daily field visits (distance measurement, spirit levelling etc.) to a single site measurement within 1-2 hours.

1) To provide reliable ground control and ground truth data for coastal hydrographic monitoring in the WeRA the following measurements *in citu* are planned:

- the evaluation of frontal velocities and their variations at large tidal glaciers by differential (relative) distance measurements using laser distance meter and tacheometric scheme;
- estimation of internal structure and detection of fossil ice at sandy coasts using radio-echo sounding (RES) and / or electromagnetic induction equipment;

- the detection of active outlet glaciers, calving ice shores and floating ice shelves as well as measurement of the ice thickness in test sites using RES equipment;
- estimation of vertical movements at sandy coasts in test sites by means of repeated spirit and trigonometric levelling between old geodetic signals and the current sea level;
- relative planimetric assessment of the coastline configuration in relation to benchmarks and significant changes in ice-free coastlines using standard surveying methods, including primitive GPS system, visual survey, photo points, and videography.

2) To collect additional data on the hydrographic regime and related environmental effects in the study region the following field observations will be carried out:

- the observation of daily variations in coastal currents and tidal effects,
- collecting indicators of coastal changes and evidences for the eustatic rise of the sea level,
- the evaluation the maximum extent of storm surges by studying driftwood lines and checking water salinity in several closed aquatories using batometer and salinity indicator,
- the measurement of hydrographic regime and changes in coastal networks, studying glacier-dammed lake outbursts,
- shallow drilling onshore for the definition of the saturated moisture contents and the estimation of ground ice contents,
- registering the debris content, sediment sampling, and determining material for cross-shore zones including unlithified (sand-dominated, mud-dominated, gravel-dominated), lithified (sedimentary, igneous, metamorphic) and ice (ground ice, sea ice or glacier ice),
- the measurement of - and sampling along onshore profiles and collection of geomorphological indicators such as sand bars, marine terraces, erosion features etc.;
- determining sediment sources and transport rates and interpreting site Quaternary history
- visual observation of sea ice and icebergs and estimation of their geometric parameters and distribution;
- collecting ancillary data including climatic trends and standard meteorological records, geological and seismic data, especially on recent earthquakes, icequakes, avalanches and current tectonic movements,
- the study of operational criteria considering rules and norms of safe navigation in coastal waters and identifiers of an ecological risk.

3) To catalogue typical features of hydrographic and glaciological objects in spaceborne images, both optical and radar, the interpretation of satellite imagery in the field will be performed including

- different glacier zones and structural elements of the glacier surface (dry and wet snow, firn ,bare ice, superimposed ice, percolation zone, glacier borders etc),
- different types of coastlines, especially, ice coasts, tundra cliffs and sloping coasts, beaches, and small-relief forms,
- inland basins and vegetation (if applicable).

4) To perform ground quality control and field completion of satellite image-map series and to provide favourable conditions for the RECORD database implementation we plan to carry out

- the determination of geographic co-ordinates of several new islands as well as collection of ground control points and / or control distances with allowed accuracy as well as the for cartographic purposes using distance meter and a primitive GPS system,
- the map content review and accuracy checking,
- performance tests under real natural conditions,
- demonstrations and discussions on practical implementation of the RECORD database at several national organisations.

Detailed methodology for the joint processing of image- and non-image hydrographic data (spaceborne altimetric, airborne RES, tide-gauge data and standard meteorological records) shall be described in the first scientific report. In the next chapter, the polar idea and the statement of work[6] will be given.

4. Polar idea of the research. Work statement

The polar idea of the AMETHYST project is to demonstrate the technical feasibility of SAR-interferometry to Russian operational users working / interesting in the area of arctic coastal hydrography and polar remote sensing.

Main emphasis has been put on arguing and conducting coastal hydrographic monitoring in the Western Russian Arctic (WeRA) on an economical basis by resurvey from automatic polar-orbiting satellites carrying high-resolution radar (SAR) instruments.

[6] The statement of work is not a reiteration of the technical approach and is not a list of goals of research work, but rather concise listing of statements describing what main tasks will be performed within the project scope.

Apart from the acquisition of suitable remote sensing data, *the following technical solutions are foreseen in the project scope*:

- thorough critical analysis and generalisation of existing hydrographic – cartographic knowledge, both theoretical and empirical, on coastal processes and coastline changes in the WeRA;
- developing an efficient methodology and program tools for operational assessment of the present state of coastline and coastal change detection in the Barents and Kara seas via spaceborne radar imagery;
- providing reliable basic control for coastal hydrographic monitoring in this remote region;
- determining the modes of coastal hydrographic changes and forecasting future changes;
- proving and demonstrating the necessity and economic effectiveness of satellite hydrographic monitoring in the WeRA.

For a horizontal bar graph representing the timeframe of the main tasks using time as the abscissa see in the Annex 1 (Technical Description).

5. Geographic outlines of the research region. Location of test sites

5.1 The Western Russian Arctic within the accepted boundaries

The Western Russian Arctic (WeRA) being the northernmost physiographic region of the Euroasian continent has been selected as the study region of the AMETHYST research project. WeRA comprises the continental and insular coasts of the Barents and Kara Seas. There are numerous large and small islands in Barents and Kara Seas grouped into several archipelagoes - Franz Josef Land (FJL), Novaya Zemlya (NZ), Severnaya Zemlya (SZ), Nordenskjold and others (Figure 10). Inland margin of the 20-km-wide fringe passing along the Russian Arctic continental coast can be taken as the basis for drawing the southern boundary of this region. The northern boundary of the WeRA *terra firma* passes in close vicinity to the margin of the continental shelf and approximately coincides with a seasonal border of minimal ice extent in the Arctic Ocean. Western and eastern marine boundaries of the WeRA can be drawn along the state boundary between Norway and the Russian Federation and along straight lines connecting Cape Pronchishcheva on the mainland (Taymyr Peninsula) with Sandy Cape (Bol'shevik Island) and Arctic Cape (Komsomolets Island, 81°16'N, 93°43'E), respectively.

Cape Kohlsaat, which is situated in FJL, Graham Bell Island at 81°01'N, 65°22'E, is regarded as a point where the boundaries of the Arctic Ocean, Barents and Kara Seas intersect (Atlas of the Arctic 1985). According to UN standards, Cape Zhelaniya in NZ (76°51'N, 68°38'E) is the easternmost point of Europe and Cape Fligley in FJL (Rudolph Island, 81°52'N, 59°15'E) is considered the northernmost part of the „old world" (Encyclopedia of Oceanography 1966). Arctic Cape in SZ (Komsomolets Island) is renowned as a point where the boundaries of the Arctic Ocean, Kara and Laptev Seas intersect, and Cape Pronchishcheva is the easternmost point of the WeRA.

The area of the Barents Sea is 1 424 000 km² and about 950 000 km², i.e. more than 65%, of this area belongs to the Russian Arctic Sector. The area of the Kara Sea is 883 000 km². The total land area of arctic islands within the WeRA is estimated as 150 000 km², which means that the total area of the WeRA excluding the continental part makes up $2 \cdot 10^6$ km².

5.2 Location of basic test sites

Immense dimensions of the study region require several representative *test sites* of smaller size to be selected for detailed investigation including terrestrial surveys. Basic test sites with different types of coastline and various modes of hydrographic changes were selected in those coastal areas, where significant contribution by monitoring could be expected, especially with reference to the environmental protection, natural exploration and present socio-economic activities in the study region. Thus, our test areas chosen for detailed studies, whose main characteristics are given in Table 5, include the location of possible camp sites, port facilities, drilling platforms, pipeline stations, natural reserves etc.

2 test sites (FJL and V) are situated at the Barents Sea coast. 2 test sites (SZ and BB) belongs to the Kara Sea coast. One test site (NZ) comprises both coasts of the Barents and Kara Seas. Three test sites in the arctic archipelagos of Franz Josef Land (FJL), Severnaya Zemlya (SZ) and Novaya Zemlya (NZ) exemplify insular coastlines. Two other test sites, namely Varandey (V) and Baydaratskaya Bay (BB), represent significant portions of the continental coast. FJL, NZ and V are situated in the European Arctic, and SZ and BB are in the Asiatic part of the Arctic. The land size of test areas ranges between 7 300 (BB)[7] and 23 400 km² (SZ), which means that several *key sites* (typically about 50

[7] The size is defined under the supposition that the maximum width of the coastal fringe under observation is 10 km.

– 200 km²) and observational sites of even smaller size (1 – 10 km²) must be selected for field works and aerovisual observations within each test site. As a rule, sites for which prior baseline survey data and ancillary data were already available have been selected as a key site for our field studies. According to actual hydrographic standards the minimum length of the coastline under observation within one key site should not be shorter than 300-500 meters and three-to-five onshore profiles shall be established at this length perpendicularly to the coast.

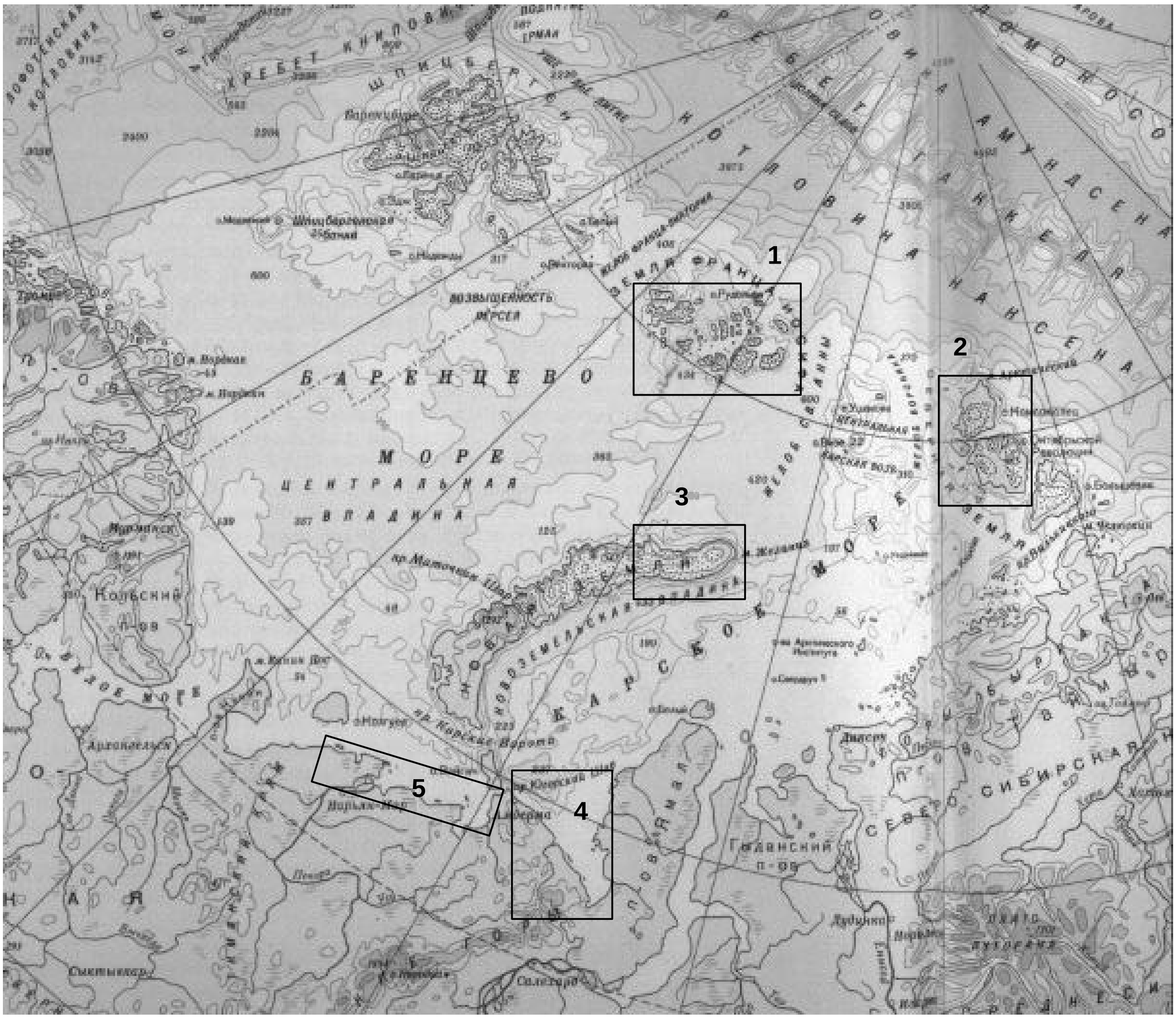

Figure 10. Location of test sites in the WeRA (1 – FJL, 2 – SZ, 3 – NZ, 4 – BB, 5 – V)

Table 5. Test sites in the WeRA

No	Name of test site	Short Description	Geographic Coordinate		Priority
			Latitude	Longitude	
1	Franz Josef Land (FJL)	Whole archipelago, especially Hall Island and Wilzeck Land (south-east)	79°46' 81°52' N	44°55' 65°25'E	High
2	Severnaya Zemlya (SZ)	Whole archipelago, especially two large northern islands with surroundings	78°40' - 81°20' N	91°00' – 100°05' E	High
3	Novaya Zemlya (NZ)	Northernmost coast including Inostranzeva Bay, Russkaya Gavan’	75°40' - 77°00' N	59°40' – 68°40' E	Mean
4	Baydaratskaya Bay (BB)	BB including the western and eastern coast with settlements Morrasale (Yamal Peninsula) and Amderma (Yugorskiy Peninsula)	68°15’ – 70°00’ N	64°55’ – 69°00’ E	Mean
5	Varandey (V)	Continental coast and islands between Pechora Mouth, Khaipudyrskaya Mouth and Yugorskiy Sound	68°30’ - 69°30’ N	50°00’ – 61°00’E	Mean

5.3 Geographic description of test areas

This chapter contains a brief summary of basic geographic details and environmental specifics that are important for the understanding of typical hydrographic-glaciological phenomena and might influence the methodology of remote sensing studies in our test areas. Those interested in detailed physical-geographical description of the study region are referred to some other comprehensive publications (Grosswald et al. 1973, Koryakin 1988, Govorukha 1989, Vasiliev 1999 et al.)

Franz Josef Land (FJL)

The FJL archipelago is situated in the north-eastern part of the Barents Sea, about 800 km from the continent of Eurasia and is regarded as the northernmost part of the European High Arctic. This archipelago consists of approximately 190 islands with total land area of 16 135 km^2. Small islands dominate, but the 135 small islands amount to only 0.4% of the total area. Prince George Land is the largest island measuring 2741.0 km^2, followed by: Wilczek Land 2054.5 km^2, Graham Bell Island 1708.4 km^2, Alexandra Land 1050.8 km^2.

The total length of the coastline is 4425 km, and the specific length, i.e. the ratio of the total coastline length to the total area of the archipelago, is 0.28 km^{-1}, which represents a little over 3.6 km^2 of *terra firma* per 1 km of the FJL coastline. This indicates the high dissection rate of the coastline and distinguishes FJL from other arctic archipelagos of Eurasia, which mainly consist of fewer and larger islands.

FJL has the highest index of glaciation of all Arctic lands: nearly 85% of the archipelago is covered with glaciers. The total glacier area and the total ice cap volume equals to 13524.8 km^2 (Sharov, 1998) and 2105.9 km^3 (Macheret et al., 1999) respectively. The average ice thickness appears to be close to 180 m. The ice shore extends over 2650 kilometers, which is 59.4% of the total FJL coastline and 75 % of the whole ice coast in Russia (Vinogradov, Krenke, 1964). The specific length of ice coast in Franz Josef Land makes up to 0.19 km^{-1}, which means that 1 km of the ice coast corresponds to ca. 5 $??^2$ of the glacier area.

According to the present notions, the glaciers of the archipelago are in the regressive stage, and thinning of outlet glaciers results in the grounding line recession, which is mostly evident at large glaciers with gentle slopes of bedrock. Therefore, large parts of glacier tongues might become afloat and, thus, produce large icebergs. Observations show that, in FJL, the time between calving events varies usually from 1 to 2-3 years. If the glacial front advances with a rate of 30-40 m/a, the length of icebergs can reach 30-120 m. However, the actual length of icebergs observed in FJL at fronts of outlet glaciers was, at least, twice more than this value. Large icebergs with the length of more than 300-m and up to several kilometers were observed by different investigators (Vize 1930, Ivanychuk 1934, Grosswald et al. 1973, Kloster & Spring 1993, Dowdeswell et al. 1994). The occurrence of so large tabular icebergs in coastal waters may also attest to the presence of floating glacier tongues (ice shelves) in FJL.

The largest iceberg observed in FJL close to the front of Renown Outlet Glacier was 2.3 km in length (Dowdeswell & Glazovskiy, unpubl.) This is one of the largest glacier-derived tabular icebergs which have been ever observed in the northern hemisphere outside the Greenland waters. Large icebergs are usually grounded on banks near the glacier front, but, after some thinning, they are carried out from the straits of archipelago, drifting mainly in the southern and south-western directions. Two stages of pronounced minimum, the first - at the end of XIX-th - beginning of XX-th cc., and the second – in the 1930-th, and two stages of drastic increase in the amount of icebergs, one in the 1870-th and other - in the first half of 1920-th, have been reported in (K. Sandford 1955). Some of those icebergs reached even the continental coast. The summary of iceberg observations in Barents Sea waters from ships and reconnaissance flights in 1933-1990, confirms the interannual variability of iceberg contents, and confirms that Franz Josef Land is the major iceberg source in this area (Abramov 1992).

The average annual glacier outflow of FJL is about 6.5-7.5 km^3, of which 2.26 km^3 is related with calving (Abramov, 1996). Studies performed at Hooker Island (Grosswald et al. 1973) indicate that the annual calving was $2x10^6$ tons of ice at fast outlet glaciers and $2x10^6$ tons at other ice coasts of this island. The extrapolation of this result to the whole archipelago gives 2.3 $x10^9$ tons of ice calving and abrasion per year. Other estimations show that 3.8 km^3 of glacier ice or about 0.3% of the total glacier volume is annualy lost due to the generally negative mass-balance. The extent of changes revealed at glacier termini clearly shows the strong tendency of relatively rapid glacial retreat in the FJL archipelago. The total glacial retreat in FJL amounts to 1.53% in the course of 1953-1993 (Sharov 1997). The most deglaciation has been observed in the south-eastern part of FJL.

Many, though far from all numerous bays, inlets and fjords in FJL are occupied with so-called apron glaciers, which are constrained and supported by shores from three sides and protected from the impact of ocean and wind. The total number of apron glaciers in FJL is reported to be 155 with a total area of to 66.6 km^2. Mean ice thickness of apron glaciers equals to 20 m, and their contribution to the total volume of ice caps is about 1.3 km^3 (Macheret et al. 1999). There is some evidence on that some parts of those glaciers are floating. The probable existence of two floating ice shelves with the size of 1-1.5 km^2 situated in Geographer's Bay at Prince George Land (Glacier No.5) and near

Bystrova Cape (Glacier No. 26) in Jackson Island has been reported as well. Large deposits of ground (fossil) ice were discovered in coastlands at Alexandra Land, La-Ronciere and Hall islands. It has been also revealed that several large ice caps in FJL have submerged bedrock below the present sea level (Dowdeswell et al. 1996).

The ice coast along such glacial fronts is subject to current rapid changes due to the impact of glacier motion, sun, wind and water. For example, big – more than 500 m long – frontier parts of outlet glaciers on Prince George Land and Hall, Jackson, Karl Alexander, McClintock and Salisbury islands were broken off and ice shores have changed significantly. Thus, a very approximate position of the coastline, especially in glacier calving areas, is represented in available topographic maps and hydrographic charts of FJL. Therefore, the present configuration of about 30% of the total coastline in FJL should be considered as uncertain (Sharov 2000).

Relatively large ice-free coastlands are situated in Alexandra, Prince George and Wilzcek lands, Graham-Bell, Hayes and Hooker islands. Ice-free coasts of the archipelago are mainly exemplified by rock cliffs and embayed plateau (basaltic) coasts usually with a sloping mass of rock debris at the base of a cliff (talus), with and without narrow beaches. The coastal lowlands are less common and presented by fluently sinking abrasion surfaces – contemporary sandy beaches. Due to insignificant slopes even negligible rise of sea level causes negative shifts of the ice-free coastline. Stationary and temporary floods in the river mouths were observed in Wilczek Land, Graham Bell and Hayes islands. Some lagoons with marine sediments dated to early Holocene are known in coastlands of Wilczek Land, Northbrook and Ziegler islands. The wide gravel and boulder beaches are less typical. Storm-deposited gravel and sea-pushed ridges can be found 2 to 3 m above the present high-tide level.

Two systems of marine terraces are known in FJL, i.e. a lower complex of terraces with elevations ranging from 3 to 35 m asl and an upper complex with maximal elevations of 150 m asl and higher. One hundred years ago F. Nansen wrote in his letter to the Russian polar explorer E. V. Toll about the possible existence of ancient marine terraces in FJL with heights reaching up to 1,000 feet (Nansen 1956). However, the genesis of those upper structures is not completely known or fully understood at present (Matishov 1993). It is supposed that the present altitude of raised beaches in FJL reflects the postglacial rise in global sea level and isostatic rebound of the lithosphere with disintegration of the last ice sheet over the Barents Sea. Thus, the analysis of the information available on coastlines in FJL is complicated because of present vertical movements in the archipelago due to the eustatic rise of the sea level, common epeirogenic tendency of the Barents-Kara shelf marginal zone and, probably, also to the glacio-isostatic factor.

For most of the year the FJL straights are covered with one-year-old fastice. Coastal waters usually begin to freeze in the middle of September, and ice spreads over the whole aquatory by the beginning of October. Sea ice attains its maximum thickness at the end of the winter season (April) and can reach 1.5 m in bays and along the shore, but remains thin (20-40 cm) in the middle of most straights. The melting and disintegration of ice is most intensive in July and August. The most straits of the archipelago are mostly released from their ice cover in the middle of August. However, some straits and bays in FJL, e.g. De Long Bay or Rhodes Channel, may remain mostly covered by unbroken sea ice during several years. Some parts of the FJL coastline are eroded by drifting ice, and the coastline retreat can reach 2-3 m/year (Govorukha, 1989).

Currents and local winds play a key role in ice destruction and are also responsible for the holes in the sea ice (polynyas) which appear in the same place each year. To our regret, we may state that extremely few data are available on coastal currents in FJL. Signs of alongshore currents didn’t meet to the authors nor in topographic maps neither in nautical charts. It is only known that surficial currents to the south-west of FJL direct to the west with velocity of 2-5 cm/s, and those to the south-east of FJL are characterised by the clockwise circulation with the velocity of less than 2 cm/s. North-western current with the velocity of less than 2 cm/s persists to the north of FJL. Southern currents with the velocity of less than 2 cm/s persist to the west and the east of archipelago. Recently, strong surficial tidal currents within FJL were registered in Italian (5 cm/s), American (14 cm/s), Booth (16-32 cm/s), Backs (36-47 cm/s), and Pohndorff (up to 80 cm/s) channels using multitemporal spaceborne imagery (Sharov 1997).

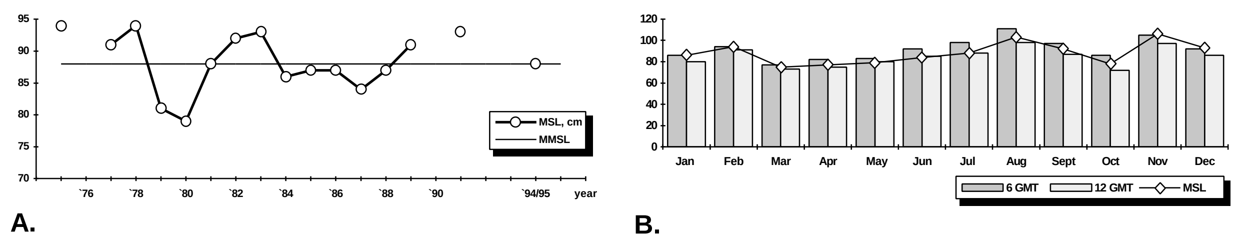

Figure 11. Barents Sea level observed at the Krenkel station, Franz Josef Land (local system of heights): multi-year (MMSL) and annual mean sea level (A); monthly mean sea level observed in 1994/95 at 6 GMT, 12 GMT and averaged (B).

No strong tidal effects are to be observed in FJL and characteristics of the tide are rather uncomplicated. The height of tides in the archipelago ranges from 0.5 m (improper semi-diurnal tides in the western and eastern parts of FJL) to 0.6 m (semi-diurnal tides in the central part of FJL, including Wilczek Land, McClintock, La Ronciere, Ziegler, Wiener Neustadt, Hayes, Salisbury, Champ and Luigi islands), but in narrow bays and straits under heavy winds and low barometric pressure it can exceed 1 m. Systematic observations show, however, that seaonal variations in sea level, with lower water in the cold period, do not exceed 20-30 cm. Multi-year, annual and monthly values of the Barents Sea mean level are graphically represented in Figure 11 (Kostka & Sharov 1996). The age of semi-diurnal high tide in the FJL region is 2 days.

In the AMETHYST frameworks, major attention will be paid to the central part of FJL and basic key sites are planned in Wilczek Land and Hall Island. In 1993, the glacier area of Hall Island was equal to 907 km^2. Ice volumes, measured and calculated for the same year, were equal to 134.7 and 148.4 km^3 correspondingly, and the maximum ice thickness was equal to 290 m. There is one apron glacier known in Hall Island. In 1993 its area was equal to 0.49 km^2 and volume – to 0.01 km^3 (Macheret et al., 1999). The total area of Wilczek Land was equal to 2054 km^2; and glacier area – 1906 km^2 (Govorukha, 1989). According to (Macheret et al., 1999), the total glacier area in 1993 was equal to 1855.3 km^2, measured and estimated ice volumes were 346.6 and 374.9 km^3 correspondingly, and measured maximum ice thickness was equal to 383 m. There are 17 apron glaciers in Wilczek Land. Their total area in 1993 was equal to 7.78 km^2, and the ice volume - to 0.156 km^3.

Severnaya Zemlya (SZ)

Severnaya Zemlya (SZ) is an archipelago consisting of 5 large islands (October Revolution, Bol'shevik, Komsomolets, Pioneer, Shmidta) and many smaller ones situated in the north-eastern part of the Kara Sea. The total area of Severnaya Zemlya is 36 766 km^2, of which 18 325 km^2 (50%) is covered by glaciers. The SZ coastline stretches for 3 498 km and the specific length of the coastline is 0.095 km^{-1} (that translates to 10.5 km^2 per 1 km of the coastline), i.e. 3 times smaller than in FJL. The total length of ice coasts is 500.8 km (14%), of which 191.5 km (5.5%) corresponds to fronts of outlet glaciers and can be considered as unstable coastline (Atlas of the Arctic 1985).

The glaciation index increases northwards from 31% for Bol'shevik to 58% - for October Revolution, 68.5% - for Komsomolets and to 99.7% for Shmidta islands (Vinogradov, 1980). The average ice thickness and the total ice volume are equal to 300 m and 5500 km^3, correspondingly. The maximum ice thickness at Academy of Science Ice Cap, the largest glacier complex in SZ with the total area of 5860 km^2 and the ice volume of about 2,184 km^3, extends 800 m. About 50% of the glacier bed is below sea level, and there is a clearly-defined subglacial valley running from the east the to west beneath this ice cap. The minimum bedrock elevations are about - 200 m on the east side and lower than - 300 m in the south-west. Academy of Sciences Ice Cap is characterised by the slow flow in the interior parts and the faster motion at margin, marked by four fast-flowing ice streams with lateral shear zones and maximum velocity of 140 m yr^{-1}. These ice streams stretching for 17-37 km originate from the slower-moving ice within 5-10 km of the ice-cap crest, their width ranges from 4 to 8 km. Mass flux from these ice streams makes up to almost 0.4 km^3 yr^{-1} and 1 km-long tabular icebergs were observed in coastal waters to the east of Red Army Strait (Alexandrov, Kolatschek, 1997). The average annual glacier outflow in SZ reaches 6.5-7.5 km^3, of which only 0.5 km^3 is related with calving (Govorukha 1989).

Floating ice shelves were indicated in three regions of Severnaya Zemlya: in the eastern part of Academy of Science Ice Cap, in Marat Fjord (October Revolution Island) and Matusevich Ice Shelf in Matusevich Fjord (October Revolution Island). The total area of Matusevich Ice Shelf, which is formed by nine confluent outlet glaciers flowing down from Karpinskogo and Russanova ice caps, exceeds 240 km^2 (Vinogradov, 1980). This is the most prominent ice shelf in the Eurasian Arctic.

The interpretation of aerial photographs from successive surveys since the 1930-s, showed the general glacier retreat of in SZ, linked to the termination of the Little Ice Age, as indicated by ice-core records. The loss of about 500 km^2 of ice-covered area in SZ in the course of 1931-1984 has been reported in (Govorukha et al. 1987), although V.Koryakin (1988) suggests that this may be an over-estimate resulting from errors in the interpretation of aerial photographs. The mass-balance measurements for Vavilov Ice Cap, an ice cap with 1,820 km^2 area in October Revolution Island, indicate that the mean net balance was slightly negative between 1974 and 1988 (-0.03 m yr^{-1} water equivalent), although the high interannual variability (standard deviation ±0.36 m yr^{-1}), makes the mean value indistinguishable from zero (Barkov et al., 1992).

Different types of the ice-free coastline occur in SZ. Coasts of glacier-tectonic type (fiord-skerry?) prevail in the western part of Bolshevik Island, along Shokalsky Strait and in the eastern part of the Red Army Strait. Deposition coasts with dead cliffs and contemporary marine terraces are situated in the eastern part of October Revolution Island near Matusevitch Fjord, and in Komsomolets Island to the north of Red Army Strait. Erosion-deposition coasts are typical for the western part of Pioneer Island and can be found in the western part of October Revolution Island. Sandy coasts are typical in Komsomolets Island. Deposition and erosion marine terraces with heights up to 200 and 350 m a.s.l. respectively are usual in SZ due to multiple marine transgressions of Taimyr-Severnaya Zemlya region

(Bolshiyanov 1996). The SZ coastline is characterised by rather fast gradation from one geomorphic type to the other, straight rocky coasts and low-lying coastal plains with simple outlines occur along with highly indented coastlines. The western coastline is mostly low-lying and highly indented by multitude armlets and lagoons. Rectilinear outlines, and high and steep bank vaults are typical for the Shokalsky Strait coastline, some parts of which are also indented by fjords.

The glacioisostatic uplift of Severnaya Zemlya could take place in the past. In the present time, only the tectonic uplift with velocities much less than in the western part of the Arctic was observed. The northernmost part of Komsomolets Island was probably formed due to the rise of the ocean bottom. On the other hand, some parts of Severnaya Zemlya are found to be subsiding, e.g. at the eastern coast of Komsomolets Island. Formation of Coastlands with isolated lagoons and marine sediments are typical in Pioneer and Komsomolets islands. In Pioneer, October Revolution and Komsomolets islands, estuaries of small streams are blocked by sand-silty walls, forming shallow flood near the mouth. This process is favoured by gentle slopes of erosion coasts and intensive accumulation of alluvium in river mouths. Intensive accumulation and deposit of alluvium results in a multiple distributaries, bifurcation and divagation of rivers that are clearly visible in wide (up to 100-200 m) flood-lands at Komsomolets and October Revolution islands.

Some fjords are known in SZ that include half-closed desalinated lake-sea basins with original limnological conditions. For instance, Krasnaya Bay in Matusevich Fjord represents hydrological features being typical for a glacier lake. The coastline location in this area changed significantly as the lake became shallow due to the alluvial deposition by Ushakova River (Govorukha 1989). Fjord Lake with freshwater and the depth of 100 m was formed approximately 100 years ago, when Marat Fjord was cut from the sea by two confluent outlet glaciers flowing down from Karpinskogo and Universitetskogo ice caps.

During winter, SZ is surrounded with fastice. The vast area of fastice in the eastern part of the Kara Sea stretches from the mainland to the northern part of Komsomolets Island. To the east from Severnaya Zemlya this area is rather narrow. Main straits of the archipelago - Vilkitsky, Shokalsky and Red Army straits - are also covered by fastice. In Vilkitsky Strait, the fastice is usually destructed in late July – early August, but, sometimes, this can be delayed until late August. Even in late August the average sea ice concentration in SZ region amounts to 50-60 %. Surface currents near SZ both in the Kara and Laptev seas are of northward direction with velocity of less than 2 cm/s near October Revolution island and up to 2-5 cm near Komsomolets island. Eastward current, with velocity of 5-10 cm/s, persists in the northern part of Vilkitski Strait. In the southern part, the current with a velocity less than 2 cm/s directs westward. The eastward current with velocity of 2-5 cm/s persists in Shokalski Strait. Improper semi-diurnal tide of 0.2-0.4 m range is typical for SZ region (Atlas of the Arctic Ocean 1980).

Mean annual temperatures in Severnaya Zemlya are about –15°C, compared with about –12°C in Franz Josef Land and –9°C in Novaya Zemlya. Precipitation increases from about 0.25 to 0.45 m yr^{-1} (water equivalent) between the sea level and the summits of major ice caps (Bryazgin & Yunak 1988). This is important because the meteorological conditions being favourable for the glacier nourishment are not quite suitable for the remote sensing studies and field works. Our key sites in SZ are situated at the southern coastline of Komsomolets Island and in the northern part of October Revolution Island.

Novaya Zemlya (NZ)

The Novaya Zemlya (NZ) archipelago represents a natural boundary between Barents and Kara seas, which stretches from the north to the south like an arch of 1000-km length and 25-30 to 145-km width. NZ consists of two large islands: Northern Island (47 230 km^2) and Southern Island (33 960 km^2) separated by Matochkin Shar Strait. Both large islands have a complicated coastline pattern of fjords, bays, inlets and capes with many small islands around, especially in the southern part of Southern Island. Mezhdusharskiy Island in the southernn part and Pankrat'eva Island in the northern part of the archipelago are also quite large though they are much smaller than 2 main islands.

From geological point of view the NZ archipelago is considered as a continuation of Urals Mountains. The main part of the archipelago is occupied by longitudinal mountain chains. The transverse valleys dissect the mountain chains in separate massifs. Some valleys make cross gaps from the Barents to the Kara coasts. Coastal plains, plateaus and mountains are the main features of the NZ landscape. Undulating coastal plains rise up to the foot of mountains at 80-100 m asl. The 20-30 m cliff is typical for coastal plains. It is known that, in the present time, the glacioisostatic uplift of NZ takes place.

24300 km^2 of the NZ area is covered by glaciers. The largest glaciated area of Northern Ice Cap and Main Ice Sheet 20520 km^2 of total area is situated in Northern Island. There are more than 60 outlet glaciers draining ice from the ice sheet, most of them reach the sea level and produce icebergs. 44 outlet glaciers with the total ice front of 117 km flow into the Barents Sea, and 22 outlet glaciers with the total ice front of 77 km discharge into the Kara Sea. Besides, southwards from the ice sheet there are 5 glaciers (with the total front of 8 km) that reach the Barents Sea, and 2 glaciers (total ice front of 6.4 km) that reach the Kara Sea (Chizhov et al. 1968, Koryakin 1988). There are few glaciers with the total area of 600 km² in Southern Island and none of them reaches the sea. Thus, the total length of ice coast in Novaya Zemlya is 208 km.

There is no significant asymmetry in glacier location: 12 660 km^2 of glaciers are oriented towards the Barents Sea, and 11 130 km^2 – to the Kara Sea. The present tendency of glacier recession in NZ is adopted by all arctic scientists, although several advancing glaciers occur. The size of Petersen and Shokalsky glaciers slightly increased in 1930-s – 1940-s. Kropotkin Glacier is characterised by more or less stationary regime during relatively long period. Ice velocity measurements at Shokalskiy Glacier with the total front of 3.4 km allows the calving rate to be estimated at 16x10 km^2/yr. It is worth to note that the first observations of Shokalskiy Glacier motion was made by Yermolayev in 1932-33 by studying the deformation of fastice at the glacier front. The very approximate assessment of the total ice calving for NZ gives 2 km^3 of ice per year (Chizhov et al, 1968). The average annual glacier outflow in Novaya Zemlya is about the same, as for Severnaya Zemlya and FJL – approximately 6.5-7.5 km^3.

Northern Island of NZ is of the highest interest for the AMETHYST project and main key sites are situated in the northernmost part of this island poleward of latitude 76° N. According to our rough planimetric estimations the coastline of Northern Island stretches for about 4000 km. The northernmost coast of Novaya Zemlya near Cape Zhelaniya is of deposition type with died cliffs and contemporary marine terraces (Figure 12, b). The gravel and boulder beaches occur up to 20 m asl. Buried ice was found in some coastal areas north from Russian Harbour and around Glazova, Mashigina and Krestovaya bays. Permafrost is common in the area near Cape Zhelanya. The ground ice was observed near Cape Zhelanya and in some terraces of Litke peninsula. Large massifs of ground ice have been discovered in moraines of submountain glaciers to the north of Russkaya Gavan. Lagoons, separated from the sea by series of coastal walls, are typical. Due to the long-term disconnection from the sea and repeated desalination by the inflow of fresh water the water mineralization in these lagoons does not exceed 300-400 mg/l. Disastrous debacles of lagoon lakes happened near Russkaya Gavan'.

There are 17 outlet glaciers situated at the NZ western coast to the north from 76° N including Bunge, Pavlova, Petersena and Inostrantseva glaciers. At the eastern coast the northernmost outlet Roze Glacier is located just at 76° N. The map of iceberg distribution in the Barents Sea for the period 1933-1990 shows the maxim concentration of icebergs northward of latitude 76 N° (Abramov, 1992). It should be noted, however, that the most of icebergs melt in fjords of NZ and, therefore, they can not be observed in the open sea. During winter the narrow stripe of fastice is formed along the northern part of the NZ coastline. In the northern part of Novaya Zemlya, sea ice melts usually in early August. By the end of August the average concentration of thick first-year ice amounts to 1-3 /10^{th}.

Strong surficial coastal currents towards the northeast with velocity of 10-25 cm/s have been registered at the Barents Sea coast of NZ. In the Kara Sea, coastal currents with mean velocity of 2-5 cm/s direct to the southwest. The largest part of the NZ coastline is characterised by semi-diurnal tides. The height of tides reaches 0.5 m at the northern coast of Southern Island and ranges from 0.6 m at the northernmost coast to 0.8 m and 1.0 m for the mid and the southern part of Northern Island respectively (Atlas of the Arctic 1985). Improper semi-diurnal tides are typical for the southern part of Southern Island.

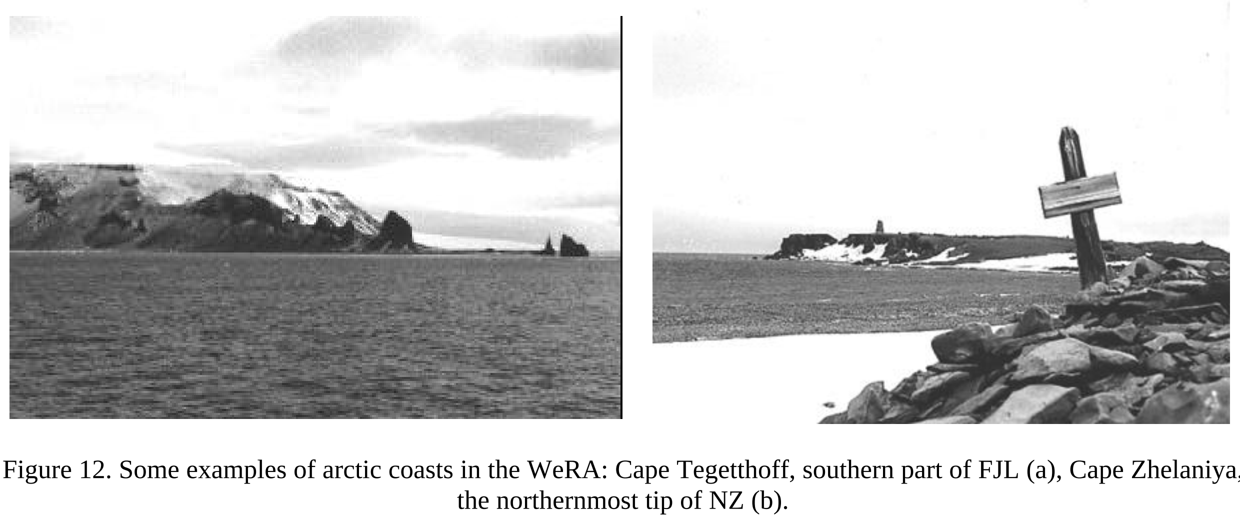

Figure 12. Some examples of arctic coasts in the WeRA: Cape Tegetthoff, southern part of FJL (a), Cape Zhelaniya, the northernmost tip of NZ (b).

Baydaratskaya Bay (BB)

Baydaratskaya Bay (*Guba* in Russian) is a large gulf between Yugorskiy and Yamal peninsulas in the south-western part of the Kara Sea. Our test site includes the largest part of the BB coastline enclosed between Amderma town at the west and Cape Kharasavey at the east. For the most part, the BB coastline is represented by margins of an extensive accumulative lowland plain. This site could play the key role in understanding coastal erosion / deposition processes in the WeRA.

A small fragment of deposition coast can be found nearby Amderma town. Further eastwards the coastline is substantially graded by thermal abrasion. 30 km to the east from Rusanovo settlement, there is again a small portion of deposition coast formed due to the river sedimentation. Thermal abrasion coast appears again by moving to the east. There is wide spit nearby the entrance to Kara Bay resulted from the alongshore flux of river sediments in the south-eastern direction. Further to the east, there is a 20-km long thermoabrasion coast, which indicates that the Kara River sedimentation is wholly downloaded at the coast of Kara Mouth. of Torasavey and Levdiev islands nearby the eastern coast of Yugorskiy Peninsula are the largest accumulative landforms (bars) in the western part of BB. The total length of Torasavey Bar including Torasavey Island is about 50 km. Its western part is attached to the continental coast and the narrow lagoon between this bar and the mainland is very shallow.

The western Yamal coastline to the south from Cape Kharasavey is considered as abrasion-accumulative coast, which is described as a coast of grading type in the classification by (Ionin at al. 1961). In Morrasale area, coastal prominences are graded by erosion, which is quite essential due to unlithified material of coasts and thawing permafrost. Marine terraces in this part of BB are composed of frozen sandy-clayey sediments. These frozen sediments contain ice-wedges and tabular ground ice. It is interesting to note that there is no direct dependence between the rate of coastal thermoerosion and the coastal lithology. Also, there is no distinct correlation between this rate and the mean summer air temperature, with the exception of abnormally warm years (for example 1990) when high mean summer air temperature coincided with increased amount of coastal destruction.

The high level of correlation (more than 0.65) was determined between the ice content in sediments and the rate of coastal retreat (Vasiliev, 1999). It was revealed that the increase of the total ice content in coastal sandy-clayey sediments from 10 to 60% of their volume results in approximately two-fold increase of the retreat rate (Vasiliev, Leibman, 1999). The highest retreat rate is typical for the sites enclosing massive (tabular) ground ice. The rate of coastal retreat in the western Yamal ranges from 0.8 m/year (1997) to 3.3 m/year (1990) and the average for 20 years is 1.7 m/year. The analysis of 20-year observations on thermoerosion in BB shows that the process of coastal destruction in western Yamal has a cyclic character with the complete cycle duration of 18–20 years. The periods with low rate of destruction are gradually replaced by the periods with high rate. On the basis of the available data it is possible to suggest that the cyclicity of coastal thermoerosion is probably typical for the entire Arctic and could be related with cycles of arctic atmospheric and oceanic processes. In this context, it would be interesting to reveal the conformity of such cycles in various sectors of the Arctic (Vasiliev 1999).

Fine sediments are transported outside the coastal zone being the source for wide-spread mud deposits. The low and flat coast with tidal mud occurs to the north from Morrasale. Coarser sediments are transported along the shore both to the south and north, thus contributing to the spit development to the south and to the north of Morrasale. The more intensive southward sediment flux served as on origin to the group of accumulative islands called Morrasal’skiye Koshki. Quite large Litke Island is the residual tundra plain separated from the Yamal mainland due to thermal erosion (Suzdalsky, 1974). Coasts of Sharapov Shar Bay are also considered to be of thermoabrasional origin. The advancing deltas of Mordyakha and Nodoyakha rivers are important coastal features in the area.

The innermost (southernmost) part of Baydaratskaya Bay near the mouth of Baydarata River is very shallow along the distance of more than 150 km and there are no erosion cliffs, nor deposition coasts. This is a typical tideflat with uncertain coastline. Mud deposits are mostly accumulated in this part of BB. The spring tide in BB is less than 0.5 m and the coast slope is very gentle. That is why, the surface of mud flats is mostly shaped by winds, which are quite strong here (mean velocity of 9.1 m/s) especially in the cold season.

For most of the year BB is covered by sea ice, but fastice is formed only close to the coast. In this part of the Kara Sea, fastice is finally formed by the end of December. The external boundary of fastice passes in close vicinity to the 10-15 m isobath (Borodachev 1998). Fastice at the western coast of BB is often fractured and separate floes are usually drawn into the central part of the aquatory. In some years, the stable fastice is not observed in BB during the whole winter season. Fracturing of fastice near the Yamal coast is rear and happens only in the period of ice formation (Bondarev et al. 1995).

BB is characterised with slow (less than 2 cm/s) northward surficial currents. The tidal pattern is quite complicated. Semi-diurnal tides and improper semi-diurnal tides of 0.5 m range are typical for the southern and central part of BB, correspondingly. In the northern part, the range of semi-diurnal tides varies from 0.7 m at the eastern coast to 1.0 m at the western shore.

Varandey (V)

The Varandey (V) test site includes the continental coast of the Barents Sea and islands between Petchora Mouth and Khaipudyrskaya Bay. This south-eastern shallow part of the Barents Sea is, sometimes, called as Pechora Sea. In the V test site, the coastline stretches from Indiga Mouth in the west along the coastland of Malozemelskaya Tundra, Pechora Bay and coastal area of Bol'shezemelskaya Tundra to Khaypudyrskaya Bay in the east. Some parts of large islands Kolguyev and Vaygatch are also included. Pechora, Korotaikha and Chornaya are the largest rivers in this area.

From geomorpholological point of view our test site is an accumulative lowland plain. This area is a part of Pechora plate, where the basement is overlaid by thick cover of Paleozoic and Mezozoic rocks, with uppermost Quaternary sequence of marine and glacial deposits. The late Pleistocene and Holocene deposits are exposed along the most part of the shore.

In Pechora Bay, main coastal elements are Pechora delta and low tundra cliffs with marine deposits and peat developed in late Pleistocene and Holocene. The coastline to the east from Pechora Bay is represented with alternating portions of accumulative and thermal abrasion. Muddy and sandy shores with large littoral zone are typical in the western part of the test site, and deposition coasts with dead cliffs and contemporary marine terraces – in the eastern part. Gently sloping shore favours the development of tideflat and small submarine ridges in bays and at the lee side of accumulative islands and spits. There are several large isolated accumulative landforms, such as Pesyakov Island and Medynskiy Zavorot Bar, and small spits. The group of islands Matveyev, Golets, Dolgiy, Zelentsy is possibly a large sand ridge originated from the sedimentation by tidal currents ant emerged above the sea level. There is, however, other interpretation stating that this group of islands corresponds to remnants of the early Holocene coastline (Kaplin et al. 1991).

The coastline is dislocated by the erosion, which, in spite of some protection by the sea ice, is quite significant due to strong winds, intensive wave action and permafrost. The eustatic transgression and tectonic subsidence also cause the spread of the sea over land along a subsiding shoreline. The direct mechanical impact of waves on permanently frozen ground is not remarkable, but both, disintegration and solifluction is activated due to the heat exchange. Deep wave-cut notches stimulate the intensive collapsing and recession of permafrost coasts. Submarine permafrost that widely occur in bottom sediments of Kara and Pechora seas down to the depth of 100 below sea level is an important feature that might influence the coastal development. The upper boundary of frozen layer varies from 4,5 to 43 m below the sea bottom and the thickness of submarine permafrost is usually more than 50 m. Gas pockets are often found under this layer. Large icy and ice-sedimentary columns of 15-17 m relative height and 100-300 m width, which were found recently at the bottom of Pechora Sea might originate from thermal effects of gas flowing through the permafrost layer (Mel'nikov et al. 1998).

In winter, Pechora Sea is covered by sea ice. In April, the ice thickness can reach 120 cm, but the average thickness of sea ice is about 70 cm. The ice surface is usually quite rough and, in coastal regions, 80 - 100% of the total ice area is covered with ridges and hummocks (Golovin et al. 1996). In Khaipudyrskaya Bay and around Matveev and Dolgiy islands, grounded hummocks of 10-12 m high form typical chains along coastal shoals at depths of 30 m and more. Bottom ploughing by their subwater parts lead to the formation of furrows as deep as 10 m. In August - September Pechora Sea is mostly released from its ice cover.

Surficial currents in Pechora Sea with velocity of 2-10 cm/s are directed to the east. The tide in V is of semi-diurnal type excepting the eastern coast of Khaibudyrskaya Bay where improper semi-diurnal tides are recorded. Tides in Pechora Bay are rather high reaching 1.5 m. At the open coast the height of tides ranges from 0.3 to 0.8 m, but it can exceed 3 m under strong barometric changes and heavy winds.

Since the 1970-s, Varandey Island was subjected to significant antropogenic impacts. Extensive excavation of sand from the beach took place near to the cliff edge, which underwent significant deformations due to the road construction and other engineering activities in the coastland. As a result, the erosion rate increased abruptly in the mid of 1970-s from 1-2 to 7-10 m/year. After some protectional activities were undertaken, the rate of coastal retreat decreased to 1.5-2.5 m/year during the period of 1981-1987. Recent studies showed, however, that in the course of 1988-2000 it increased again to a 3-4 m/year. The rate of coastal erosion near Old Varandey village increased to 4-6 m/year that is also considered to be related with technogenic disturbances (Ogorodov et al. 2000).

General remark

The total and specific length of the coastline as well as the length of ice coasts and glacier fronts (in km and % of the total length) in main test areas as they are specified in available cartographic publications (Atlases and Catalogues of Glaciers) are summarised in Table 6 for the purpose of comparison.

Table 6. The coastline length in main test areas

Test area \ Parameter	Total length, km	Specific length, km^{-1}	Ice coast, km	Glacier fronts, km
Franz Josef Land	4425	0.19	2650 (59.4%)	1570 (35.5%)
Severnaya Zemlya	3498	0.095	500.8 (14%)	191.5 (5%)
Novaya Zemlya, North. Isl.	4000	0.085	208 (5.2%)	< 200 ?

5.4 History of hydrographic surveys in test sites

According to the thorough review made by R. D. Parry and C. R. Perkins, the Russian Federation produced the most extensive range of topographic maps and hydrographic charts of the Arctic, both in sheet and atlas form. As has been demonstrated the whole territory of the Russian Arctic is covered by map series down to a scale of 1:100 000. There are also series of maps at 1:50 000 and 1:25 000 covering individual areas and a few sheets at 1:10 000. These cartographic sources are undoubtedly important for any environmental study in the WeRA, but their use for precise up-to-date hydrographic determination is only possible on the basis of a thorough understanding of all natural changes having occurred in those lands since the last surveys. Besides, available topographic maps and hydrographic charts of the region are dispersed among many national agencies and cannot be readily compiled for analysis. Therefore, the present phase in the development of arctic hydrography is mainly focussed on the revision of available maps, the creation of generally-accessible detailed cartographic products, the modelling of current geophysical processes and the mapping of coastal changes on an economical basis by resurvey from aircrafts and automatic polar-orbiting satellites carrying high-resolution instruments.

FJL

Early general topographic maps at 1:1 000 000 scale for the whole FJL archipelago (3 sheets with sketched contours) were published by GUGK (Chief Administration for Geodesy and Cartography) in 1944. A marine navigation chart at 1:700 000 scale was published in 1939 after explorations had been carried out by the Arctic Research Institute in 1930-1937 with some subsequent editions performed in 1953 after field campaigns in 1947-1949. No aerial photographs were available, although the first aerial survey of a large part of the archipelago was successfully performed in the scope of the international arctic expedition by the airship "Earl Zeppelin" (commander G. Eckener, scientific leader R. Samoylovitch) in summer 1931.

The next aerial survey of the whole FJL archipelago was carried out in 1952-1953 by the "Arktikrazvedka" Trust and repeated over several islands in 1958 by the "Soyuzmorniiproekt" Establishment. 12 astronomic stations provided the horizontal control for aerial surveying. Permanent records from several tide gauges served for the vertical control, which is referred to mean sea level. Extensive geodetic and hydrographic works in FJL including third-order triangulation and leveling, sea-level measurements, bathymetric determinations, etc., were performed in 1954-1960 by the N10 expedition of the Hydrographic enterprise of St. Petersburg. Large-scale aerial photographs of geodetic signals erected by the N10 hydrographic expedition were taken for photogrammetric reference in 1962.

The incorporation of the local insular geodetic net into the Russian state triangulation net was performed twice - during the periods of 1961-1967 and 1974-1977 - by establishing an intermediate trilateration net based on airborne geodetic measurements using radio-range finders. The accuracy of geodetic determinations in FJL in relation to the continental network was enhanced from 40-50 meters at the beginning to up to 10 meters in the second campaign.

A controlled photomosaic at 1:500,000 scale and the large standard map series covering the whole area of the archipelago were photogrammetrically compiled in the following years. The present map series range in scale from 1:1000 000, 1:500 000, 1:200 000 and 1:100 000 down to 1:50 000 and 1:25 000. A series of topographic maps at a basic scale of 1:100,000 was created in the 1950s by means of stereophotogrammetric plotting. It includes 71 map sheets in Gauss-Krüger projection with standardised information content. Dimensions of the ellipsoid of Krassovskiy were used. Astronomic stations served as a plane basis. Elevations were given with reference to the mean level of the Barents Sea. The relief is presented by contour lines in combination with spot heights and symbols not true to scale. Bathymetric marks are given as well. 25 sheets of the 1:200,000 map, each covering a latitude of 0°40' and a longitude of 3°, were compiled by generalising the 1:100,000 map, and were printed in 1957 (western and central part of FJL), 1965 and 1971 (south-eastern part of the archipelago). The system of sheet lines of the 1:200 000 map series is given in Figure 13. Apart from the geographical co-ordinates, these maps also include the values of a geodetic co-ordinate system. Further notes, however, are missing (Kostka, Sharov 1996).

Small-scale topographic maps of FJL at 1:1000 000 scale (3 sheets, each map sheet covering a geographical latitude of 4° and a geographical longitude of 24°) and 1:500 000 scale (4 sheets with 2° by 12° geographical coverage per sheet) were published and republished in 1957, 1963, 1989, 1990 and 1991 being based on the same surveys. Both geographic and geodetic co-ordinate systems are applied, and values of magnetic declination are present.

In 1977-78 "Soyuzmorniiproekt" successfully used aerial photos taken in 1952-53 for producing 246 large-scale map sheets pasted on metallic plates. 143 map sheets were issued for the whole archipelago at 1:50 000 scale with a contour interval of 10 meters, and 143 map sheets were published at 1:25 000 for the coastal and ice-free areas of FJL covered by the conditioned aerial survey. There are no basic differences in map contents. Maps are based on the geodetic network of 1954-1959, which enables coastal areas and navigation spots to be represented with standard accuracy. These maps served as a topographic basis for revising older marine maps published in 1961 at 1:200,000 scale and for editing new marine maps, some of them published in 1985. Moreover, cartometric investigations of large-scale topographic maps provided valuable spatial information about the glaciological environment of the archipelago, which was included in the Catalogue of Glaciers in FJL (Vinogradov, Psaryova 1965).

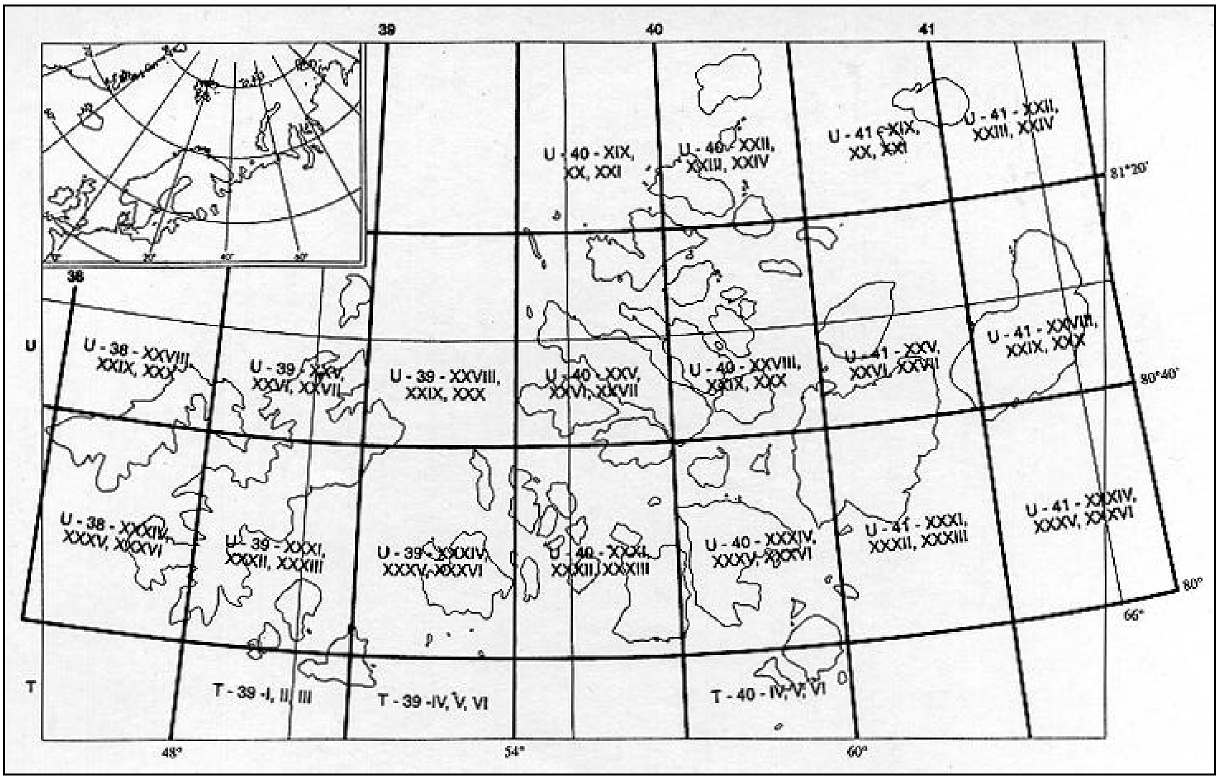

Figure 13. Sheet lines of map series 1:200 000 in FJL region

SZ

In 1913 the Russian hydrographic expedition led by B.A.Vilkitskiy discovered the SZ archipelago and made the first sketches of the southern and eastern coasts. First detailed observations in Severnaya Zemlya were made in 1930 - 1932 during the extensive field campaign led by G.A.Ushakov and N.N.Urvantsev. This expedition undertook the geographical and geological survey of the whole archipelago and compiled one geographical map of SZ at 1:750 000 scale and geological map at 1:500 000 scale.

First extensive aerial survey of the SZ archipelago was performed in July 1931 from the airship LZ-127 Graf Zeppelin. Several maps of SZ, e.g. geographic map of October Revolution Island at 1:400 000 scale and topographic map of Matusevich Ice Shelf at 1.25 000 were generated by Dr. O.v.Gruber and Dipl. Ing. Aschenbrenner on the basis of those images (Samoylovich 1933, Gruber 1933).

In 1948-1951 the geological survey of the archipelago was made and a 1:1 000 000 geological map was compiled. After the field studies in 1950-1951, N.G.Zagorskaya generated the first geomorphological map of the archipelago. The data on glacier front position collected by I.S.Mikhaylov at Bol'shevik Island in 1956-1957 allow the glacier change in that area to be assessed.

The aerial photographic survey of the whole Severnaya Zemlya archipelago was carried out in 1952 and the large-scale map series were produced. In 1975, some areas of SZ were covered again by aerial survey, and at the beginning of 1980-th the aerial survey of the whole Severnaya Zemlya archipelago was carried out by the GUGK. The results were used for publishing the contemporary large-scale map series.

In 1962, the Arctic and Antarctic Research Institute (AARI) began diverse geographical studies of the archipelago that include meteorology and climatology, hydrology, botany, soil and permafrost studies, zoology and glaciology. Glaciological studies included mass-balance measurements, radio-echo sounding and deep ice drilling at Vavilov and Academy of Sciences ice caps. The perennial scientific base on Vavilov Ice Cap worked until 1989. Beginning from 1975 the "Sevmorgeologiya" started the extensive geological survey of SZ and produced geological and geomorphological maps at 1:200 000 scale for the islands. The results of field studies and analysis of large-scale topographic maps were integrated in the Catalogue of Glaciers of Severnaya Zemlya published in 1980 (Vinogradov 1980). Extensive airborne radio-echo sounding of the archipelago was made by the Bristol Glaciological Centre and the Institute of Geography, Moscow in 1997. The new ongoing project related with deep drilling at Academy of Sciences Ice Cap was started in 1999-2000 by the Alfred Wegener Institute (Germany) and AARI.

NZ

Novaya Zemlya archipelago has a long history of studies and the list of available cartographic and hydrographic materials is quite long. Norwegian maps from the second half of the XIX-th century and maps compiled by V.N.Veber (1908), V.A.Rusanov (1907-1911), G.Ya.Sedov (1912-1913) are less accurate than desired and might be used for revealing only substantial changes. The topographic maps resulted from the AARI expeditions (P.A.Lavrova) have much better accuracy and the comparison with contemporary maps revealed rather good correspondence for the steady locations on hard rock outcrops. The mean square error in the horizontal position was ± 158 m and in the vertical position - only ± 5.3 m (Chizhov et al. 1968).

Present cartography of the Novaya Zemlya archipelago is also based on the materials of aerial surveys performed in the 1950s, but very little is yet known to the authors on the elements of coastal hydrography in those islands. Some notions on the glacial topography and coastal environment of Novaya Zemlya can be found in the comprehensive publication by V.Koryakin (1988).

The list of topographic / geographic maps and hydrographic charts, which could provide an interest for the project work includes:

- historical maps e.g. the map attached to the “Zapiski po gidrographii”, vol.43 (1918), the map from Report of the Scientific Results of the Norwegian Expedition to Novaya Zemlya, 1921 (ed. Olaf Holtedahl), the map attached to the “Trudy po izucheniyu Severa” issue 40 (1929), maps from “Sailing Directions of Kara Sea”, part 2, Kara Sea and Novaya Zemlya, 1935, the map in “Trudy Arkticheskogo Instituta”, vol. 57 (1936);
- contemporary map series by the GUGK and the Hydrographic Department, the Chief Administration of the Northern Sea Route.

Besides, it should be noted that a large number of both regional and general, topographic and thematic maps of all our test areas are contained in three great Russian atlases of the Arctic, namely, the Atlas of the Arctic Ocean published by the Chief Administration for Navigation and Oceanography in Leningrad, 1980, the Atlas of the Arctic published in Moscow in 1985 by GUGK and the World Atlas of Snow and Ice resources published by the Russian Academy of Sciences in Moscow, 1997. It is also worth to note that there is a Digital Database on massive Ground Ice (DBGI) being currently under construction at the Moscow State University (Streletskaya, Ukraintseva, Drozdov 1999). The database contains the information on ground ice covering 133 sites in the arctic coastal zone, 108 located in Russia. The bibliographical list includes 400 titles, 87 of which are foreign publications. It includes the results from different studies of massive ground ice in the Arctic during the last century and describes morphology and morphometry of ground ice deposits, lithology, ice content, lateral and coastal erosion. The DBGI holds plans and location maps of Russian Arctic coasts.

Additional historical facts on hydrographic studies in two other test sites (BB and V) are not given here due to the lack of place and the lower priority of those sites. Nevertheless, all necessary historical data will be additionally provided by the NIERSC, if such a necessity arise during the practical work in the AMETHYST project.

6. Identification of information needs. User requirements. Tools, available and upcoming

The identification of information needs and user requirements will be provided by the NPOM before the first Progress Meeting (April 2001) as a separate deliverable including the “User Requirements Document” (URD) and the “Software Requirements Document” (SRD). The question on how consumer demand is helping our research is answered in the “Working Concept of the ARCTUR administrative software and databank” (Igor V.Elizavetin, NPOM) that should be considered as a working plan of the programming group. Please, refer to footnote 8[8]. Detailed description of available and upcoming software, platforms and devices for the collection and processing of hydrographic data, both image and non-image, will be presented in the final version of the scientific report.

7. Data requirements. Inventory of resources

All data requirements should be based on the leading *principle of meaningful performance instead of maximum performance.* The attempt to get all and the best data available for monitoring project may lead to unsatisfactory results with regard to costs and time planning, and may require to vary the approach until both cost and duration of the project are within the set limits (*economic concept of monitoring*). On the other hand, basic images ordered for actual change detection should have a wide dynamic range, high ground resolution, small or well-known geometric distortion and should allow three-dimensional modelling of the study area. They should be obtained in appropriate terms. The most sophisticated tricks during image processing won’t help if the quality of the original imagery is inadequate.

[8] Term “information” should not be mixed with “data”, the latter stands usually for the input to be processed in the monitoring system; the former implies rather output results of monitoring.

The identification of all basic data and corresponding services needed for the successful project performance is given in the Annex 5 (Data Delivery Plan). In the Annex 5 all data are arranged in two groups:

- cartographic and geographic data;

- remote sensing image and non-image data.

In the following, a concise evaluation appraising the value of different data sources is given.

7.1 Cartographic and geographic data

Early Russian topographic maps of the WeRA made before 1950-s , e.g. those of FJL published by GUGK in 1944, are generally unreliable and incorrect in detail. These maps were merely based on terrestrial observations without basic geodetic control. All contemporary topographic maps and hydrographic charts containing major spatial information about Russian Arctic coasts of standard quality were mostly created through materials of the last aerial and geodetic-hydrographic surveys carried out in the 1950-s. Those hydrographic charts are, however, often inaccurate or out of date in portraying the coastline, especially where it is low-lying and the nearshore zone broad and shallow. Coastlines are usually more accurate on topographic maps, but these may be unreliable in showing inter-tidal features and potential hazards to shipping.

In the AMETHYST project, *traditional contemporary topographic maps of coastlands at 1:200 000 scale will be applied to the coastline change detection & measurement, and hydrographic charts shall be used as a source of additional semantic information.* Ancillary cartographic materials, such as meteorological or glaciological maps, and geographic-hydrographic publications containing tide-gauge data, oceanographic parameters of coastal waters (salinity, currents, surges, waves), hydrological data (river discharge), statistical data on the production / distribution of icebergs, mass-balance data for outlet glaciers etc. will be used for selecting and pre-processing image data, planning field work and prospective hydrographic modelling. Data on the distribution and main parameters (thickness, density, surface characteristics) of the coast ice could provide a valuable information with respect to studying coastline changes, especially along ice coasts. A wide range of historical maps, paleogeographical and geomorphological data might be used for the assessment of long-term coastal changes.

7.2 Remote sensing data

The full list of available/ordered remote sensing image and non-image data with their parameters is given in Table 7[9]. In the AMETHYST project, ERS-1/2-INSAR image pairs are the basic remote sensing data of the highest priority. All other RS data will play a subsidiary role. First, spaceborne SAR images constituting INSAR image pairs should be ordered and pre-processed. Then optical imagery obtained from Resource-F and LANDSAT satellites covering all gaps, both spatial and temporal, in the INSAR coverage should be additionally acquired.

Table 7. Description of available remote sensing image data

Priority	System	Image /data type	Date of survey	Swath, km / resolution, m	Quantity
1	ERS-1/2-INSAR, SAR	SLCI, PRI	1995, 1996 1991, 1993	100 / 40, 25 – 30	50
2	KATE-200	Multispectral, stereo	1978, 1993	225 / 24	25
3	LANSAT, TM	MS	?	185 / 30	?
4	NOAA	Bispectral	1990-s	280 / 1100	?
5	CORONA, KH-4(A)	Panoramic, stereo	1962, 1964	25 / 4 – 8	30
6	AFA-TE100, aerial	Panchromatic, stereo	1953, 1958	5.4 / 0.7	100
7	Zeiss-Aerotopograph	Panchromatic, stereo	1931	? / ?	?
8	RES data, aerial	-	1994, 1997	- / ?	?
9	ERS-1/2 radar altimeter	RAW, ?	?	- / 350	?
Reserve	MK-4	MS, stereo	?	120 / 8	?
Reserve	KFA-1000	Panchromatic, stereo	1993	80 / 5	15

How do we judge on the image quality of different sensors? Keeping this question in mind, a *concept of effective image scale* was developed by G.Gonin (1989). Effective image scale is defined as the original image scale multiplied with a useful enlargement factor and can be expressed mathematically as follows

[9] Data from upcoming satellite systems, e.g. ENVISAT and ALOS, is not included.

$$\frac{1}{m_e} = \frac{R}{R_v} \cdot \frac{1}{m} \, , \qquad (5)$$

where m is the original image scale, R and $R_v \cong 5$ lines/mm are resolving powers of the imaging system and human vision respectively.

The equation (5) can be re-written as

$$m_e = 2AR_v\sqrt{dD} \, , \qquad (6)$$

where dD - optical contrast of an object in the original image.

This concept appears to be a good measure to compare the applicability of different image data for monitoring purposes. Effective scale values for basic satellite image data are given in Table 8 under the supposition of medium contrast (dD = 0.5).

An inventory of resources specifying the data in our possession will be generated and attached later on after all necessary data will be acquired.

Table 8. Effective image scale of spaceborne imagery

Image type	**Original scale**	**Effective scale**
NOAA (APT-format)	1:25 000 000	1:7 800 000
KATE-200 (1st channel)	1:1 250 000	1:130 000
ERS-1/2-SAR (PRI scenes)	1:500 000	1:180 000
MK-4 (1st channel)	1:800 000	1:60 000
KFA-1000 (panchromatic)	1:250 000	1:40 000

8. Output products and services

The main output service of the AMETHYST project is related to the support of natural exploration, maritime operations and environmental protection in the WeRA with reliable up-to-date hydrographic information in the form of regional coastal reference database (RECORD).

The RECORD database includes several basic sub-systems (Figure 14), namely

- Coastal hydrographic inventory ARCHIVE or simply ARCHI showing the present state of ice shores in the WeRA;
- Arctic regional topographic information system ARTIST, which represents coastlines as they are given in available and already obsolete topographic maps;
- AMETIST metainformation system representing real and potential changes of the coastline in the WeRA;
- ARCTUR administration software and databank with interactive viewing / processing / analysing functionalities.

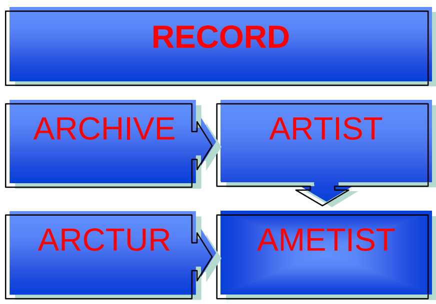

Figure 14. Basic output products

Each of the ARCHIVE, ARTIST and AMETIST basic sub-systems will contain several information layers including new satellite image-based maps at different scales ranging from 1:1000 000 to 1:100 000, reference fragments from available topographic / thematic maps, hydrographic models and documentation on detected coastal processes / changes, tabular descriptions of selected coastal units, etc. These all together will be our main output products and we think that they could find their users or even customers among those specified in the following list.

9. List of potential users and applications

Implementation of the AMETHYST output products and their rational exploitation at regional, national and international level is foreseen considering the following potential users:

- Federal Service of Land Cadastre, Federal Mining and Industrial Control, other ministries (Minpriroda, Mintrans, Goskomstroy);
- State Geodetic and Cartographic Administration, State Department of Oceanography and Navigation, National State Cartographic Programme “SEVER”;

- Glaciological / Permafrost Association, Environmental Protection Board, FJL Natural Reserve Administration;
- NSR Administration, shipping companies, insurance companies, tourist agencies;
- hydrometeorological centres, image processing centres (ALMAZ, NERSC, NSIDC, Rosgidromet);
- research and educational institutions (AARI, IGRAS, MIIGAiK, MMBI, NIERSC, VNIIOceangeologia);
- international databanks and monitoring networks (AEDD, AMAP, GRID, IBCAO, IPCC, LOICZ, RAISE, WCMC, WVS);
- other programmes and projects (ACD, CAFF, COP, GTOS, IDNHR, INSROP, IASC, ICEMASS, WCRP).

The utility assessment for the coastal hydrographic metainformation derived in the AMETHYST frameworks is tentatively given in Table 9. Further developments will be focussed so to ensure the conformity of the main AMETHYST products to international standards and to satisfy the broad spectrum of user needs.

Table 9. Potential utility of the AMETHYST coastal hydrographic information (H = high, M = moderate, L = low)

Potential Utility of	**Map Data**	**Digital Data**	**Tables**	**Physical Boundaries**	**Error Estimation**
Technical review	M	M	L	L	L
Modelling	M	M	L	L	L
Hazard Response	H	H	L	L	L
Policy	L	L	H	H	H
Management / Planning	H	H	H	H	H
Research / Education	H	H	M	M	H
Citizens	H	L	L	L	L
Industry / Commerce	H	H	L	L	H

10. Principles and conditions of the implementation

The analysis of principles and conditions of the implementation including the detailed list of potential users and the general structure of marketing system is performed by I.Elizavetin and included in the separate report that can be find in the project web-site. The letter of intent by the general users (Russian Academy of Sciences, NPOM) will be provided at the first progress meeting in Moscow (April 2001).

11. Analysis of perspectives for the collaboration with related projects

New co-operative agreements have been proposed in order to ensure closer interactions with several related research projects, both ongoing and potential, including

- the Arctic Coastal Dynamic Project (ACD) established by the International Arctic Science Committee and the International Permafrost Association and recently started with the overall aim to improve the understanding of circum-arctic coastal dynamics as a function of environmental forcing, coastal geology, geomorphology and cryology (Potsdam, 2000). Several particular ACD objectives aimed at establishing the rates and magnitudes of erosion and deposition at Arctic coasts, developing a network of long-term monitoring sites, producing series of thematic and derived maps, and developing empirical models to assess the sensitivity of Arctic coasts to environmental variability and human impacts show some thematic overlaps with the AMETHYST specific tasks and indicate promising opportunities for the ideas / data / information exchange and integration, and the distribution of products;

- the "Operational Monitoring of European Glacial Areas (OMEGA)" EU Project (EESD Research Programme) devoted to the development of new long-term observation capacity for several alpine and polar glaciers. Due to the high similarity of the remote sensing methods used, quite high potential for synergy can be expected by clustering the AMETHYST and OMEGA projects in the terms of joint technical solutions, e.g. in the INSAR data processing and the design of algorithms for change detection, spatial extrapolations, numerical modelling and glaciological data analysis / representation;

- collaboration with several ENVISAT and RADARSAT AO / PI projects launched by the European Space Agency is quite important for collecting remote sensing data, transferring new information technologies and controlling the accuracy.

Therefore, clustering the AMETHYST project with these projects might serve a good base for the development of the long-term operational monitoring network (hydrographic, hydrological, oceanographic) at the European scale or / and circumpolar level. The joint organisation of field campaigns in the test areas of mutual interest is also very expedient since interdisciplinary thematic investigations can be carried out, some logistical problems can be settled and rather high costs of works can be shared.

12. Curriculum of monitoring

Somebody, who will find it too boring to read the whole 40 pages of the present concept, is advised to read only this section providing an alternative opportunity to get all basic ideas of coastal hydrographic monitoring in the Western Russian Arctic (WeRA) without significant efforts.

TITLE:	COASTAL HYDROGRAPHIC MONITORING
FUNCTIONAL TYPE:	REGULATORY
COMPLEXITY:	COMPLEX
TECHNOLOGICAL SCHEME:	PROSPECTIVE
METHODOLOGY, BASIC:	SATELLITE RADAR INTERFEROMETRY (INSAR)
RESERVE:	SATELLITE PHOTOGRAMMETRY, DATA FUSION
TERRESTRIAL SCALE:	REGIONAL & LOCAL
TIME SCALE:	LAST 50 YEARS OF THE PAST CENTURY
WORKING SCALE, BASIC:	1:100 000
RESERVE:	1:200 000, 1:500 000, 1:1000 000, 1:2 500 000
BEGIN:	OCTOBER 1, 2000
FREQUENCY:	5 – 7 YEARS
STUDY REGION:	WERA
SIZE:	2 000 000 KM^2
TEST AREAS:	FJL, SZ, NZ, BB, V
SIZE:	7 000 – 23 000 KM^2
KEY SITES:	TO BE DEFINED
OBJECT:	ARCOS
SUBJECT:	RECORDING COASTLINE CHANGES
MAIN TASK:	CHANGE DETECTION, ANALYSIS AND DOCUMENTATION
KINDS OF CHANGES:	TYPICAL, STEADY, SIGNIFICANT
OUTPUT PRODUCTS, GENERAL:	RECORD
SPECIFIC:	ARCHIVE, ARTIST, AMETIST, ARCTUR
TOOLS:	ARCTUR
USERS:	TO BE DEFINED
END:	?

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