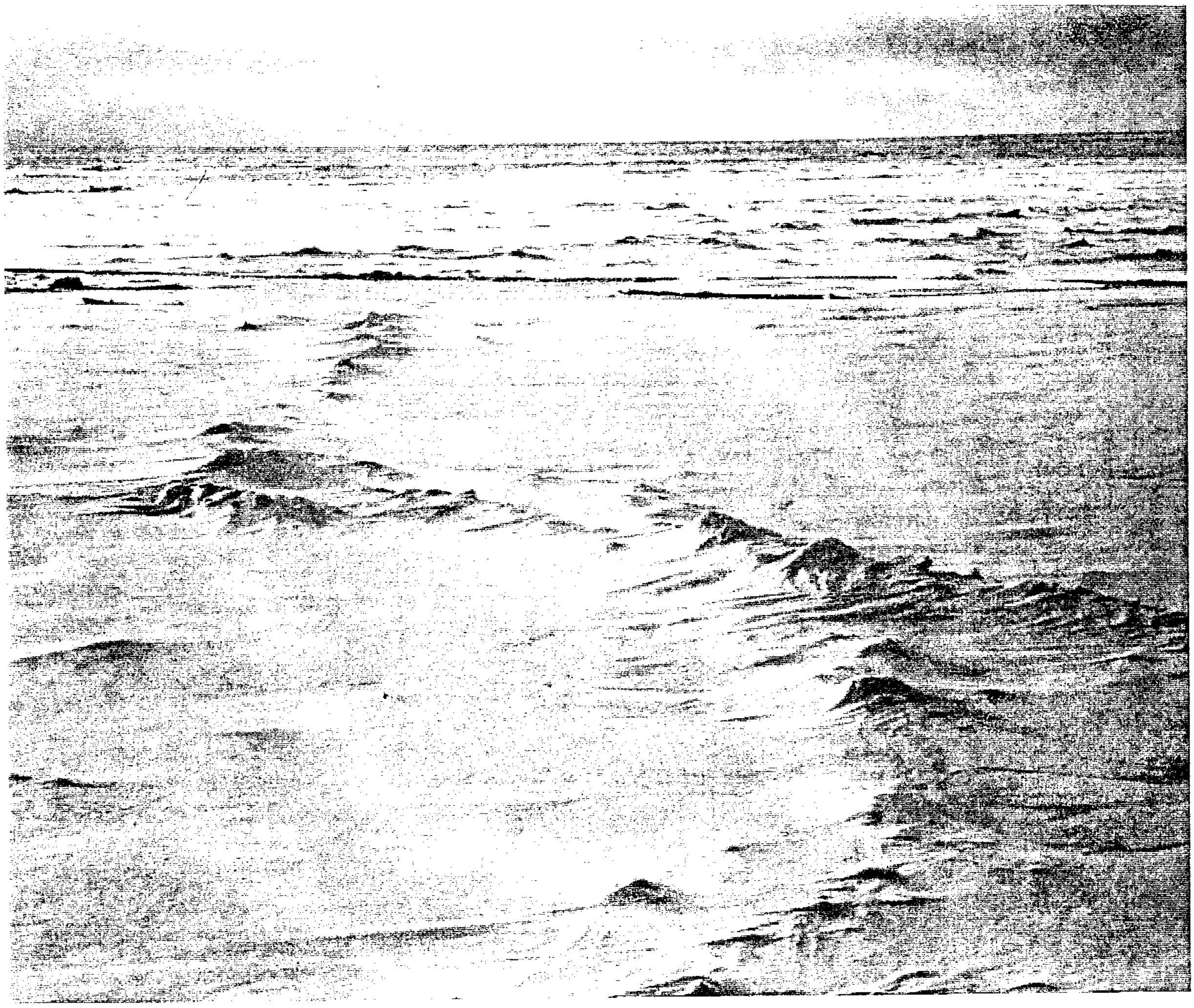
HOVERCRAFT IN THE ARCTIC: A COST EFFICIENT PLATFORM FOR SCIENCE

A research proposal to

MAST III Marine Science and Technology

Research Area C: Marine Technology



by

University of Bergen, Bergen, Norway (coordinator)

Alfred Wegener- Institute of Marine and Polar Research, Bremerhaven, Germany

Scott Polar Research Institute Cambridge, UK

Nansen Environmental Remote Sensing Centre, Bergen, Norway

GEOMAR Kiel, Germany

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EXECUTIVE SUMMARY

The advance of scientific research in the Euroarctic sector of the Arctic Ocean is limited by high logistics costs. Sea ice roughness in the Transpolar Drift north of Svalbard is less severe the in other parts of the Arctic Ocean north of Greenland, Canada and the United States, and available documentation strongly suggest that a hovercraft with surface clearance of 1.5 m would be effective.

Rieber Shipping A/S, Bergen, Norway with extensive polar experience and a fleet of polar vessels, will consider acquiring a suitable hovercraft (1.25 M ECU) to be operated out of Svalbard on a year-around basis at a day rate of approx. 2.5k ECU provided there is a sufficient basis for an initial trial period and outlook for future long term use (Appendix).

This proposal for research area C: Marine Technology is for a 2 month operation in 1996 (fall) and 2 month in the late winter in early 1997 for an in-depth assessment of hovercraft as a scientific platform in oceanography, sea ice research and marine geophysics. If successful, this platform will open new and cost efficient opportunities for the polar research programmes established on Svalbard by several EU-member nations (France, Germany, Italy, Sweden, Netherlands). Similarly, it would greatly increase the efficiency of activities under the Arctic Ocean Grand Challenge initiative in the subsequent years and facilitate studies of larger parts of the seasonal cycle in environmental parameters than possible today.

1. OBJECTIVE

Medium sized (payload 5 ton) hovercrafts are considered to have a good potential as a cost effective research platform with a range of 350 km or more from northern Svalbard. It can serve as a moving laboratory for all standard type oceanographic, sea ice, marine biological and geological studies. The overall objective is:

- to investigate the performance and practical use of medium sized hovercraft as a platform for scientific research in the Arctic Ocean during different parts of the year, operating out of Svalbard where a number of EU-member nations have established research facilities.

2. WORK CONTENT

Introduction

The increasing awareness of the importance of the Arctic Ocean in the context of the global environment require we search for logistic alternatives other than costly icebreakers to support the wide range of scientific experiments which does not involve heavy equipment items. This proposal seeks to investigate the feasibility of hovercraft as a platform for science in the polar packice by carrying out a series of scientific experiments on sea ice and in the water column over a period that cover the full annual cycle. The project is divided into tasks as shown in Fig. 1

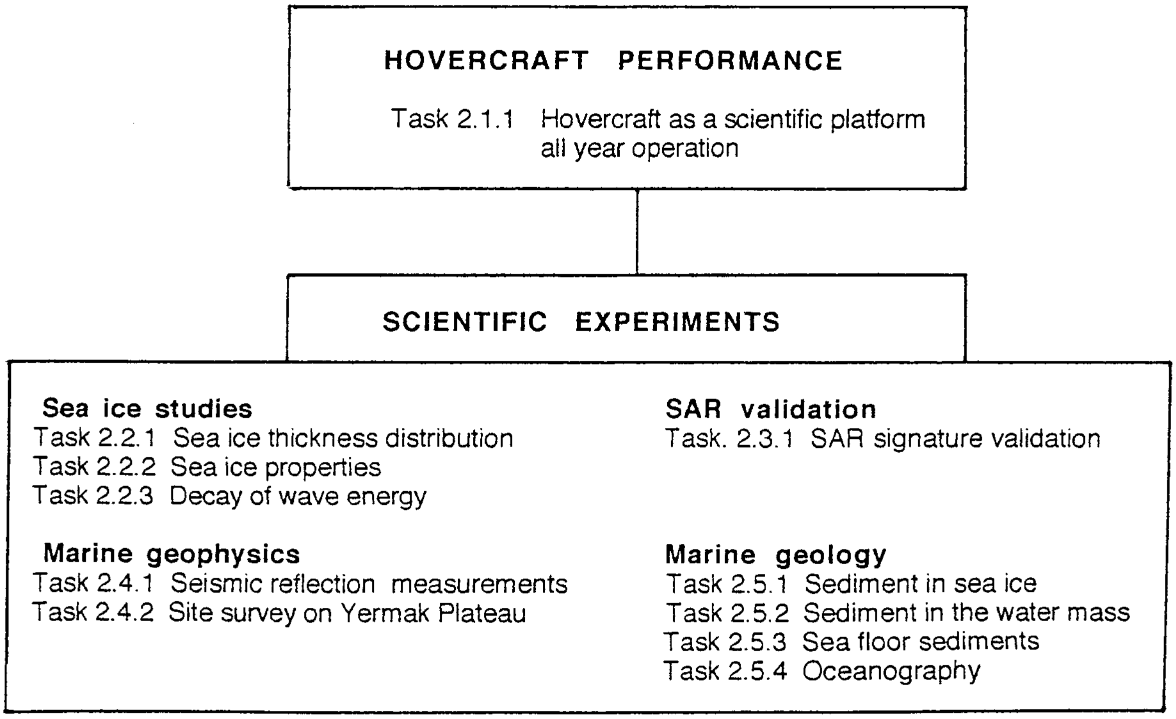


Fig. 1 Work organization

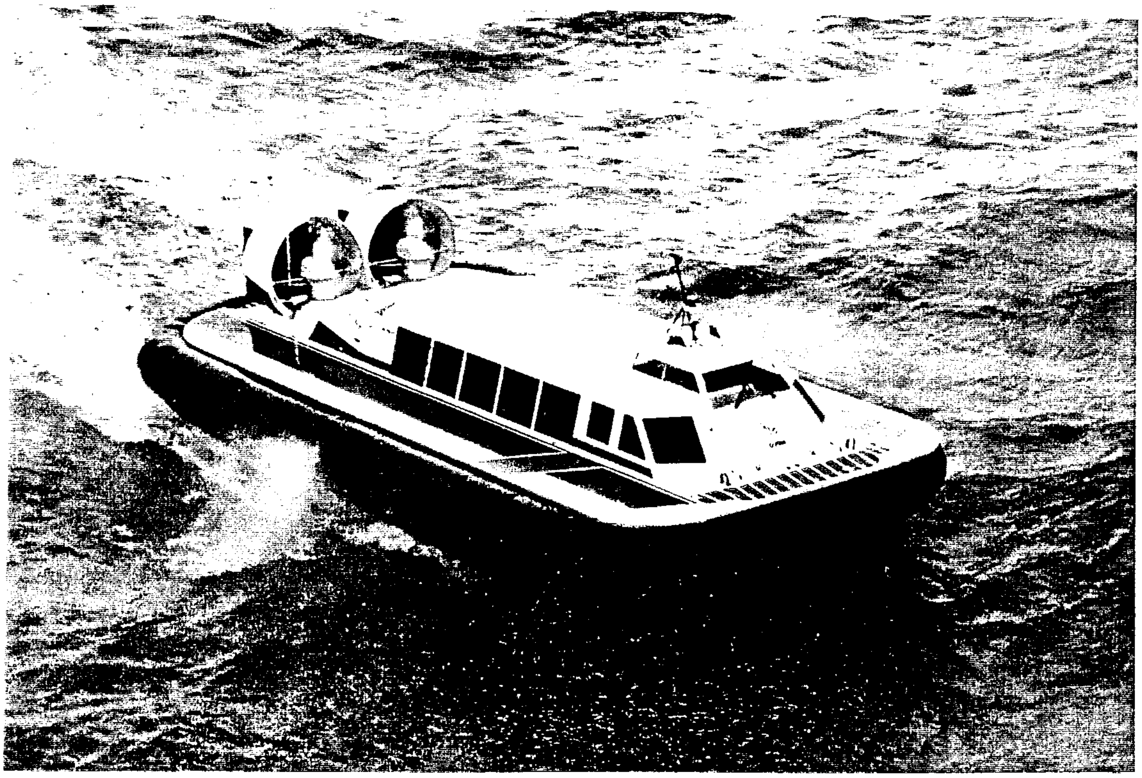


Fig. 2 Diesel driven hovercraft at cruise speed. An upgraded version of this craft can carry a payload of 5 tons and has surface clearance of 1.4 m.

2.1 ASSESSMENT OF HOVERCRAFT AS AN ARCTIC SCIENCE PLATFORM

Hovercrafts are mainly used for passenger traffic across shorter open water areas, for search and rescue, coastal hydrographic work and seismic surveys in swamps and large river delta plains, and as military landing crafts. Initially, the technology for air cushion vehicles was adapted from aircraft industry and still is for the larger crafts, but use of light weight diesel engines in small and medium sized crafts after 1986 represented a major reduction in operating costs.

2.1.1 The hovercraft

A hovercraft is classified as a vessel (Fig. 2). The hull construction is made of marine grade aluminium with beams alongships and cross ribs covered by 1.6-3-0 mm plate. Bottom tanks provide 300% reserve bouancy and form a double hull. Hovercrafts are classified by Lloyds Register of Shipping and other national classification agencies.

The flexible skirt is made of neophrene or rubber coated canvas and consists of an upper part which is continuous and a lower part of more than hundred individual segments. 15% of the segments can be damaged without the lift capacity of the craft being significantly impaired. Rubber skirts have proven flexible in polar operations down to minus 50 centigrades.

The propulsion system include two air-cooled diesel engines which each power a lift fan and a propeller. The power is distributed roughly as 1/3 for lift and 2/3 for propulsion. A twin-engine craft can continue on a single engine in an emergency situation.

Braking of the craft in motion is done by reversible propellers and ground friction. Steering is by air rudders augmented by restraining the lower edge of the skirt such that the craft is tilted in the turning direction.

A hovercraft is very stable against accidental roll-over due to the low center of gravity and relatively large width. Hover height is 15-20% of the width of the craft.

The noise level inside the cabin and at 25 m distance for a twin-engine medium sized craft is 78 dB

2.1.2 Hovercraft as a scientific platform

A hovercraft of suitable size with 5 ton payload has a cabin area of more than 45 sq. m. (Fig. 2). For scientifc use the cabin may be converted into 20 sq.m. of living space and the rest into laboratory and work space for cruises of a duration of several days to weeks.

The craft should be fitted with a hydro hole through the hull of minimum 0.7 m x 0.7 m so oceanographic equipment can be operated from inside the cabin when the craft is resting in the water or parked over a hole on an ice floe. The laboratory facilities will make it possible to rig and test out equipment before departure on a cruise.

A.C. power (230 volt) is available from the main power plant during cruise, and from an auxiliary generator at other times. Hydraulic pressure may be used to power an oceanographic winch with kevlar cable.

A hovercraft is considered suited for the following scientific tasks:

Disipline	Equipment	Remarks
Oceanography	CTD, water sampling, current meters, floats, thermistor strings	CTD with internal data logger. More efficient operation than large icebreaking vessel, good mobility for regional surveys such as detection of meso-scale eddies.
Sea ice research	temperature data logger, stakes for snow depth, local and regional deformation networks, E.M. equipment for ice thickness measure-ments.	Well suited for deployment and maintenace visits of data loggers for temperature, radiation measurements, positioning of deformation networks, ice coring and ice thickness measurements.
Marine biology	plankton nets, water sampler, diving gear, sampler for surface sediments.	Ample laboratory space for treatment of samples.
Remote sensing (ground truth)	scatterometer, radiometer, ice thermometer, conductivity measurements	Validation studies of satelitt data over a regional area throughout **most** of the annual cycle.

Meterology	automatic weather stations	Well suited for deployment and maintenance of automatic stations.
Energy exchange	radiometer, CTD, thermistor chains	Well suited for experiments to assess the ocean-atmosphere energy exchange throughout most of the annual cycle.
Ocean tomography	acoustic source and receiver	Deploy acoustic source and receivers for seasonal measurements of long range sound propagation as a measure of the integrated temperature state as a climatic indicator of the Arctic Ocean.
Marine geology	light sediment corer, sediment traps. pumping equipment	Studies of suspended material in the water mass and upper sea floor sediments.
Marine geophysics	seismic source (air gun), short hydrophone cable, snow streamer	High resolution seismic studies in leads during summer and on ice with snow cable during winter time.

2.1.3 Past applications of hovercraft in the Arctic Ocean

The Canadian government carried out six tests of hovercrafts during the years 1966-68. The first test was from the village of Tuktoyaktuk where the Mackenzie River enters the Arctic Ocean in the Beaufort Sea. The test included maximum speed over ice, crossing of ice ridges, driving over snow covered tundra and a 700 km trip up the river during the spring break-up. The SR.N5 craft with a hover height of 1.2 m traversed ice ridges up to 1.7 m height, and it is evident from the film documentation that high speed reveiced much attention. The conclusion in the Defence Research Board Report (DR 182) was:

> "In general this hovercraft (SR.N5) could negotiate all surface conditions encountered in these areas. It has been shown that hovercraft have a considerable potential as a transport medium in Northern Canada."

At this time the philosophy behind hovercraft construction and operation was aerospace technology. The power unit was gas turbine and high operating costs limited practical use of the craft.

A Canadian built craft began operating for the Canadian Coast Guard in 1971 and was stationed in Montreal from 1973. Three more crafts were commissioned later. Until recently, two crafts has been in operation on the west coast and one on the east coast of Canada. Northern Transportation Company, Calgary, operated in 1973-1976 two older hovercrafts (SR.N5 and SR.N6) for supply service to drilling platforms in the Beaufort Sea and the Finnish built hover ferry "Laurus" was operated by Arctic transportation Ltd., Calgary out of Tuktoyaktuk in 1986-1988.

The Swedish Coast Guard has recently acquired three small hovercrafts (0.4 m and 0.8 m hover height, 2 ton payload) and the Finnish Coast Guard two crafts for coastal surveillance during the winter when Gulf of Bothnia is frozen.

A natural impediment for use of hovercrafts out from Alaska is the wide zone of high ridges with ice rubble which develop in a shear zone offshore between landfast ice and drifting ice.

2.1.4 Sea ice morphology and hovercraft trafficability

Drag forces from winds and currents keep the ice in continuous motion. Local areas of tension open leads and compression create pressure ridges. newly frozen leads most often give way and ice ridges are often blocks of relatively thin ice (<1 m) forming long ridges.

The drifting sea ice is a mosaic of smooth surfaces of dimensions tens of meters to kilometers surrounded by ridges of different ages. The surfaces can be newly frozen leads or multi-year ice where old ridges are smoothed to a gently rolling landscape by the summer melt and innfilled by snow drifts. Laser measurements from aircraft and heliopter show that about 80% of the ridges are less than 1.5 m high (Tucker and Taylor, 1989; Wadhams, 1976 and 1980). During the summer melt season (medio June-medio August), the ridges become rounded off and up to 50% of the ice surface can be covered by knee-deep meltwater ponds. Leads that open up do not refreeze and the amount of open water increase during this period until middle of August. Characteristic features of the ice surface is shown in figure 3.

Regional variations in sea ice surface roughness in the Arctic Ocean can be related to the large scale pattern of ice drift and the interaction with the surrounding land masses. The area of open water north of Svalbard represent a free boundary and does not constrain the ice motion. Convergence of ice towards land in the Canadian Arctic Islands creates a hummocky terrain of ice ridges near the coast. Similarly, the shear zone between landfast ice and longshore drifting sea ice off the coast of Alaska creates a wide zone of rubble and hummocks.

Sea ice roughness: Laser profiling from aircraft along an 850 km long profile from north of Svalbard (Fig. 4) in northwest direction shows that the main variations in surface roughness of the first 350 km from the ice edge in the Transpolar Ice Drift is mainly of 1 m height or less with an increase in the number of higher ridges north of Greenland. Other laser measurements from helicopter over an 8 km distance in the Transpolar Drift indicate that 70% of ice ridges over 0.8 m were less than 1.4 m high (Futterer, 1992).

Trafficability: A theoretical estimate of the trafficability of hovercrafts in the Arctic Ocean for different hover heights has been attempted by Tucker and Taylor (1989). Trafficability is expressed as the relation between the actual distance a craft has to travel to get from point A to point B and the straight line between A and B. The basis was a study by Hibler and Ackley (1973) where they showed that trafficability was simply a function of the number of ridges over a spesific height pr. km distance and the relation between the first and second moment in the statistical distribution of ridge lengths. The latter was given an assumed value and the distribution of ridge heights taken from laser measurements from aircrafts. The location of the points of laser information are shown in figure 5 and the trafficability estimates in figure 6. We note however, that there is practically no data from the Transpolar Drift used in their study.

For a hover height of 1.5 m, the *theoretical* trafficability have high values in the area north of Greenland and the islands in the Canadian Arctic as a result of the general ice drift pattern (Tucker and Taylor, 1989). Areas with theoretical trafficability of 10 should in practical terms be impossible to traverse. We note that this is a theoretical excercise not yet validated in any way. The conditions experienced by several surface expeditions from the Canadian coast to the North Pole demonstrate that these numbers are much too high for at least the northern 2/3 of the way (Thorset, 1982; Kagge, 1990). The dogsled expedtion of W. Herbert in 1968 from Alaska to Svalbard travelled a total distance of 1.752 times the great circle route (Herbert, 1970).

Fig. 3a. Pressure ridge formed by closing of newly frozen lead. Ridge height ca. 1.8 m . After Tucker and Taylor (1989).

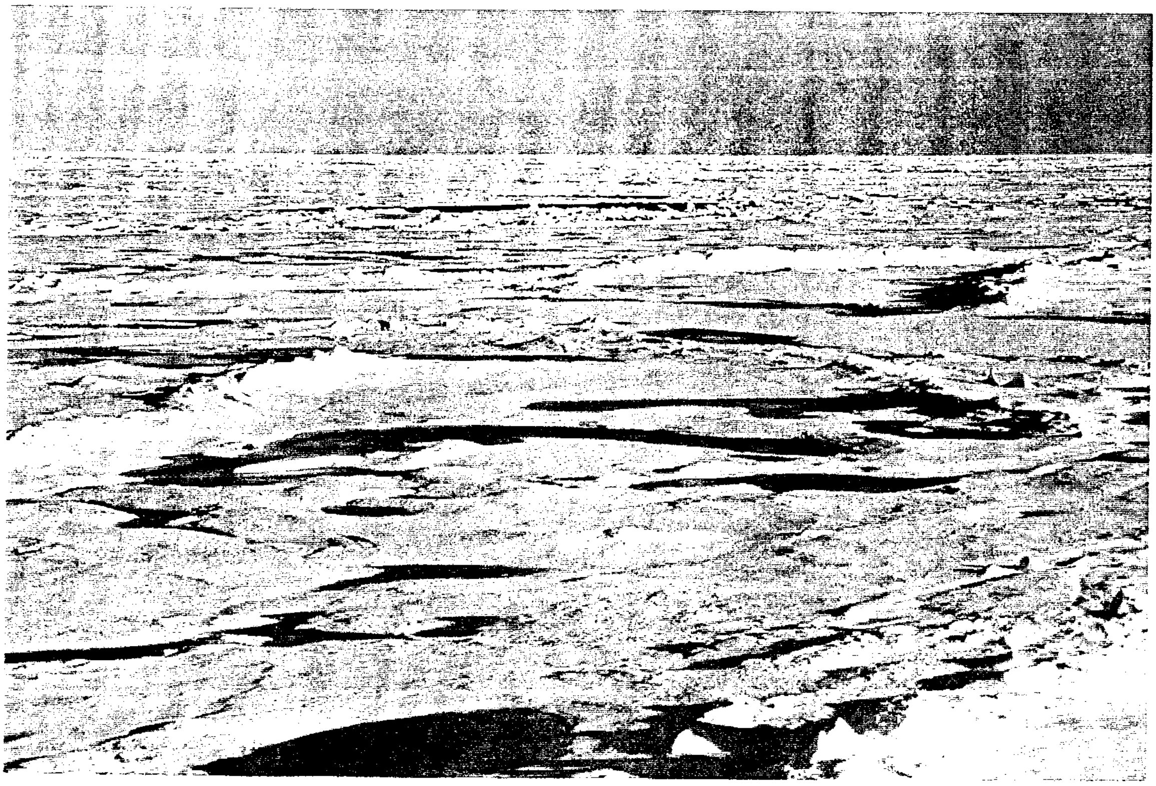


Fig. 3 b. Older pressure ridges in multi-year ice with meltwater ponds. Ridge height ca. 1.5 m over level ice. Position 84 30´N, 05 00`W, 22 September 1991.

Fig. 3 c. Uneven surface of first year ice in the background. Roughness of the order of 1 m. Position 84 30`N, 05 00`W , 22 September 1991.

Fig. 3 d. Overview which characterize ice conditions frequently encountered during the cruise with icebreakers "Polarstern" and "Oden" to the North Pole in 1991. Position¨ 85 30´N, 10 00´W , 16 September 1991.

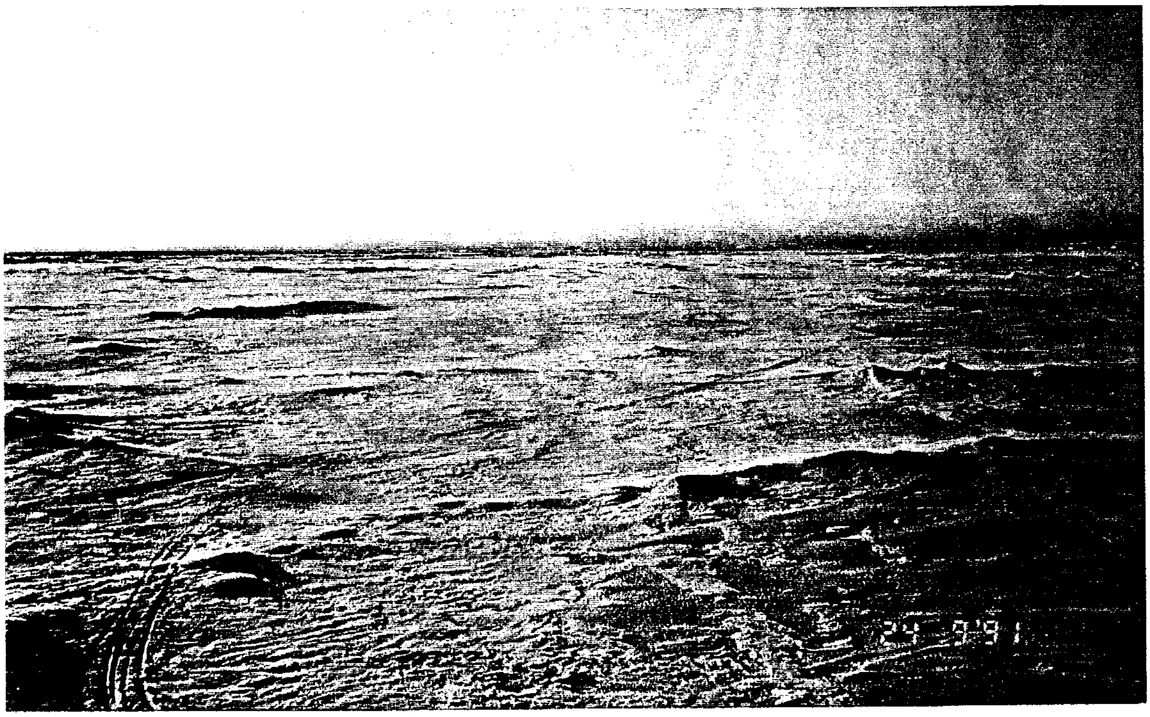


Fig 3 e. Smoothe surface of multi-year ice. Note tracks of snow scooter in left foreground. Position 83 30´N, 05 00´E, 24 September 1991.

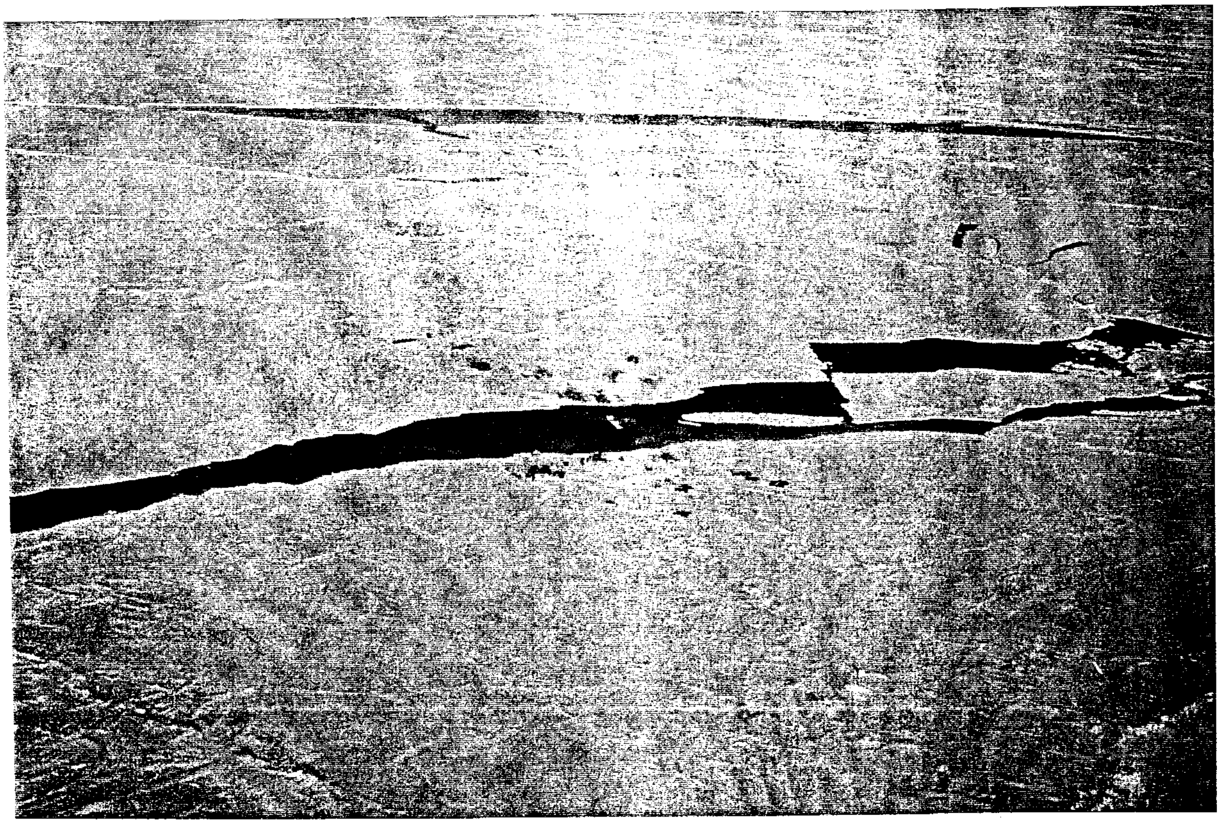


Fig. 3 f. Overview of the ice surface in the vicinity of ice station FRAM-IV, 10 April 1979 after breakup of a large flow of multi-year ice. Position 84 N, 12 W.

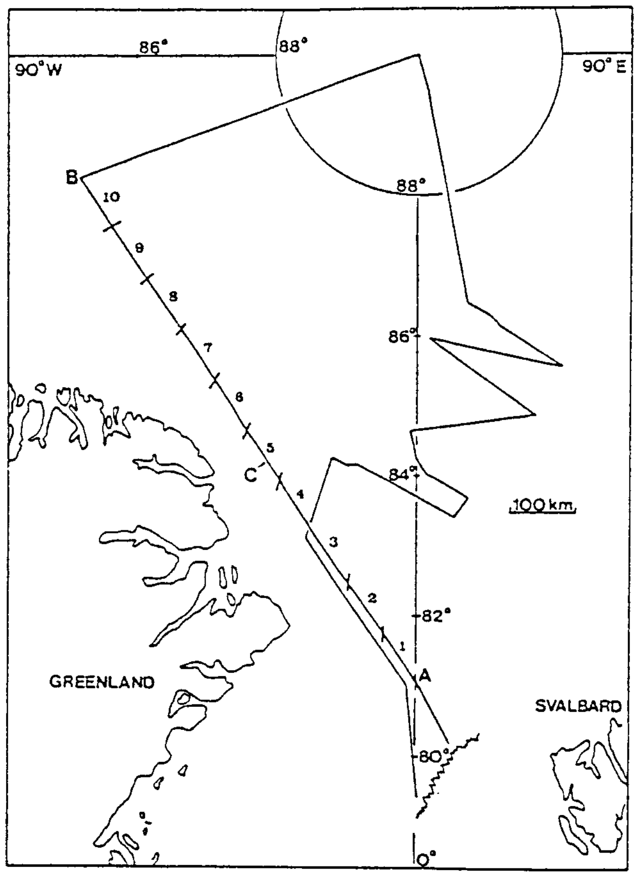


Fig. 4 a. Flight track (A-B) with laser profile carried out by the Canadian Maritime Patrol Oct. 1 976. The line is divided into segments and the height distribution of ice ridges within each segment is shown below. After Wadhams (1980).

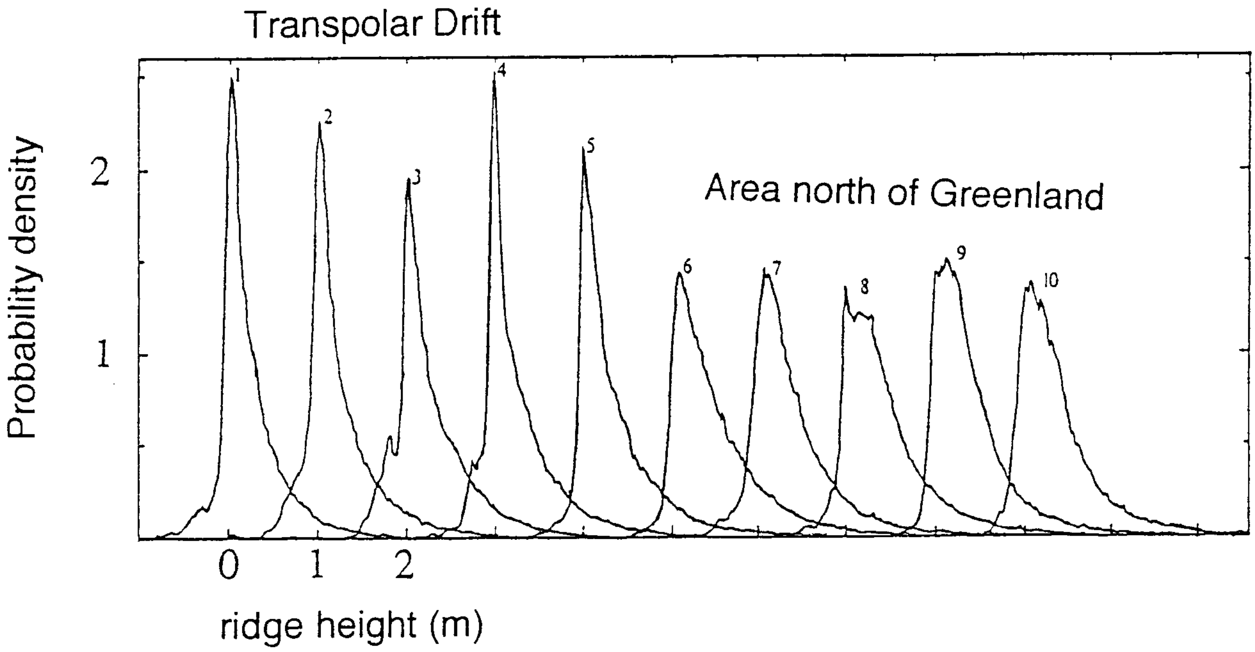


Fig. 4 b.
Height distribution of ice ridges along different segments of flight track A-B expressed as probability density. Zero level is the smooth ice. Each curve is displaced 1 m to the right with respect to the curve for the neighbouring segment. The first five segments are in the Transpolar Drift and show generally smaller ice ridges than ice in the area north of Greenland . After Wadhams (1980).

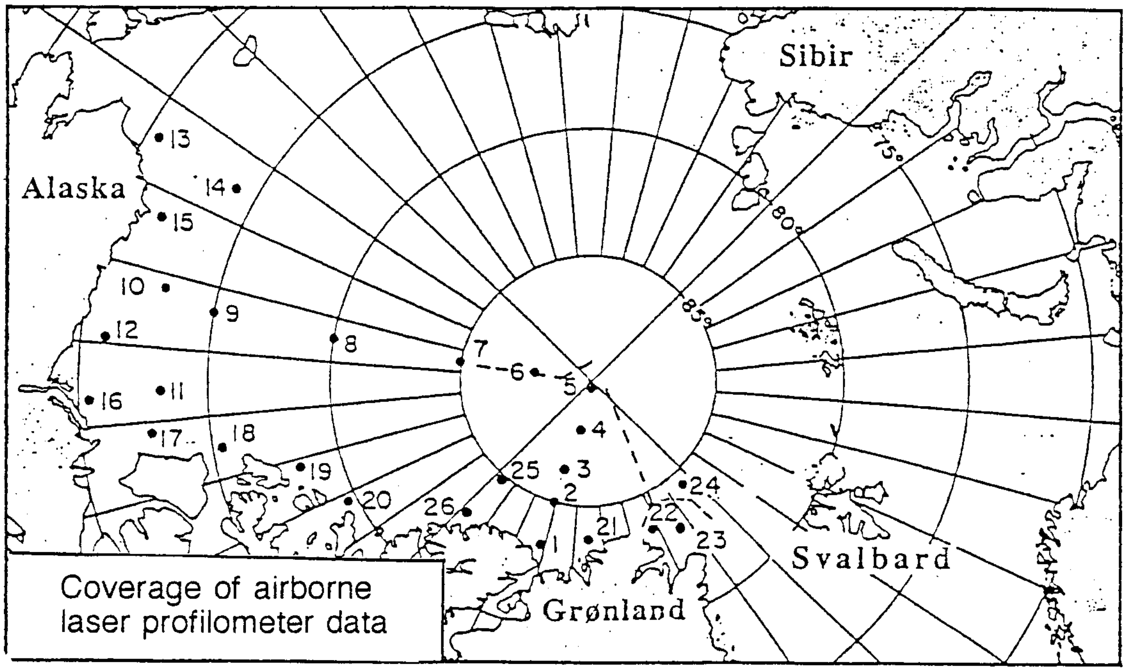


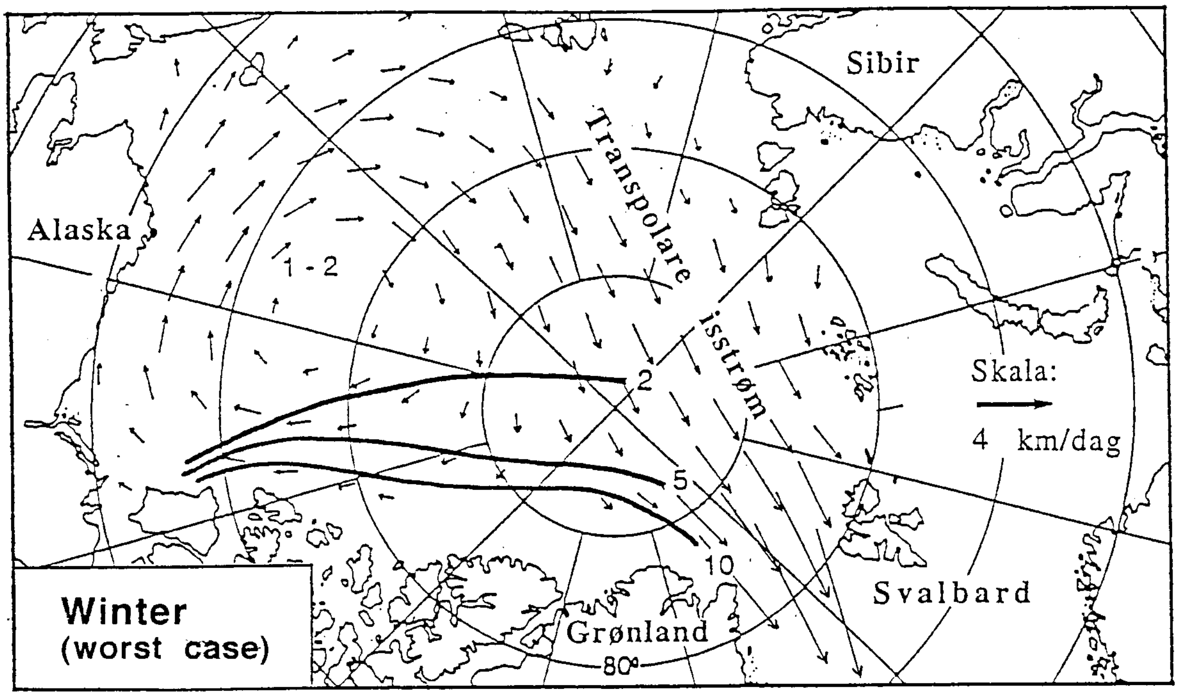
Fig. 5. Coverage of laser measurements of ridge heights used as basis for Tucker and Taylor's (1989) statistical estimate of trafficability of air ccushion vehicles in the Arctic Ocean.

Continous video recordings of the ice surface at 50 m flight altitude was made over a 250 km line north of Svalbard to 83 30′ N (April 1994) as part of a feasibility study for hovercraft operation (Kristoffersen, 1994). Video documentation was also made at 82 30′ N from R/V Polarstern in 1991 over a 50 km distance as well as visual observation of surface roughness during the transit from Svalbard to the North Pole and return on the same trip. An assessment of the video documentation yields a trafficability factor of 1.3 in terms of distance and 1.5 in terms of time. Video documentation reveals the options for minor course changes to avoid obstacles which is not evident from laser profile measurements of ridge heights.

In conclusion, the drifting sea ice in the Euroarctic sector of the Arctic Ocean is part of the Transpolar Drift and characterized by rigde heights which are generally smaller than in other parts of the polar ocean basin. A surface clearance of ca. 1.5 m is likely to be sufficient for efficient passage of a craft.

2.1.5 Safety

A hovercraft of suitable size can operate over open water in wave heights of 1.5 m at cruise speed (30 knots). Transit north to the ice edge should follow the coast of Svalbard. For safety reasons we consider an average speed of 25 km/hour (40% of cruise speed) as satisfactory progress over the ice. The low center of gravity and large width (8 m) of the craft give good stability. A twin-engine craft can proceed on a single engine if needed.



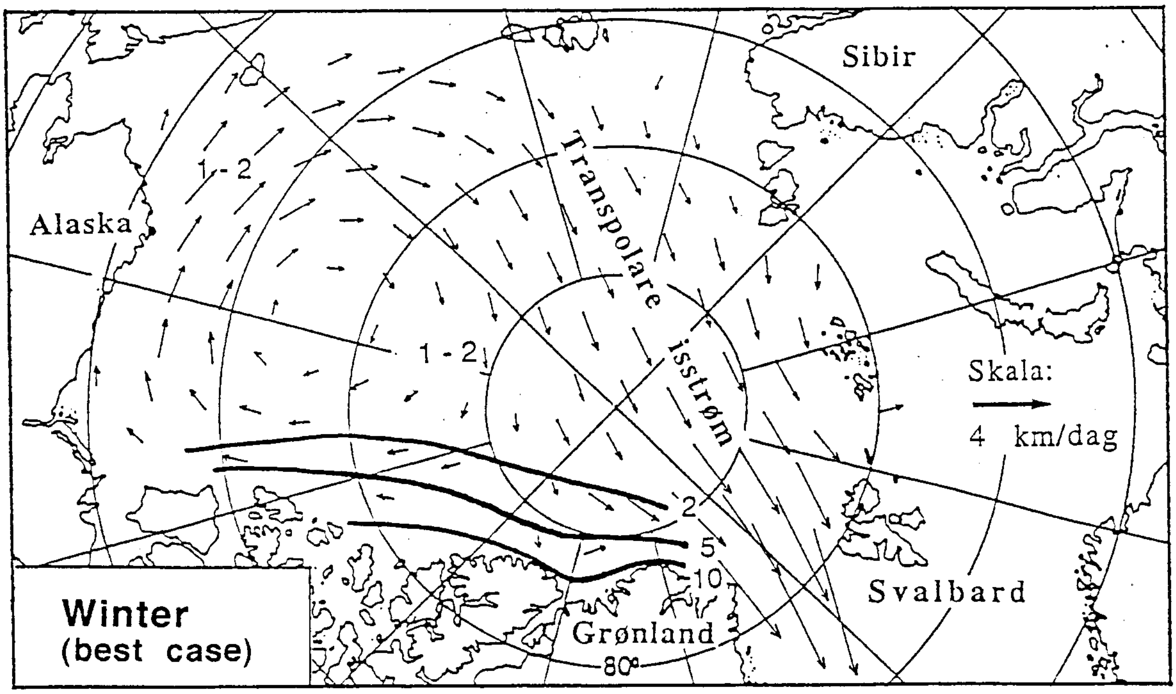
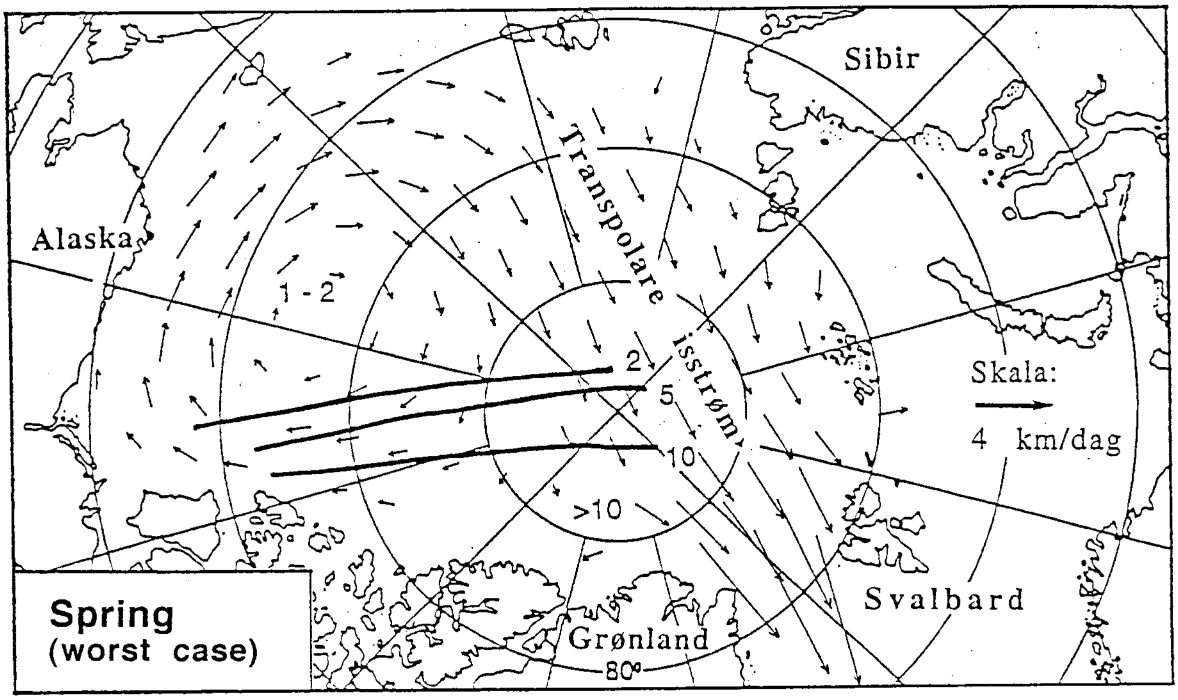


Fig. 6 a.
Tucker and Taylor's (1989) estimate of trafficability for 1.5 m surface clearance during the winter in the Arctic Ocean between Alaska and Greenland based on different assumptions about the probability for long ridges crossing each other. Small arrows indicate mean ice drift velocity based on ARGOS buoys during the period 1979-90 (from ARGOS Newsletter No. 44).



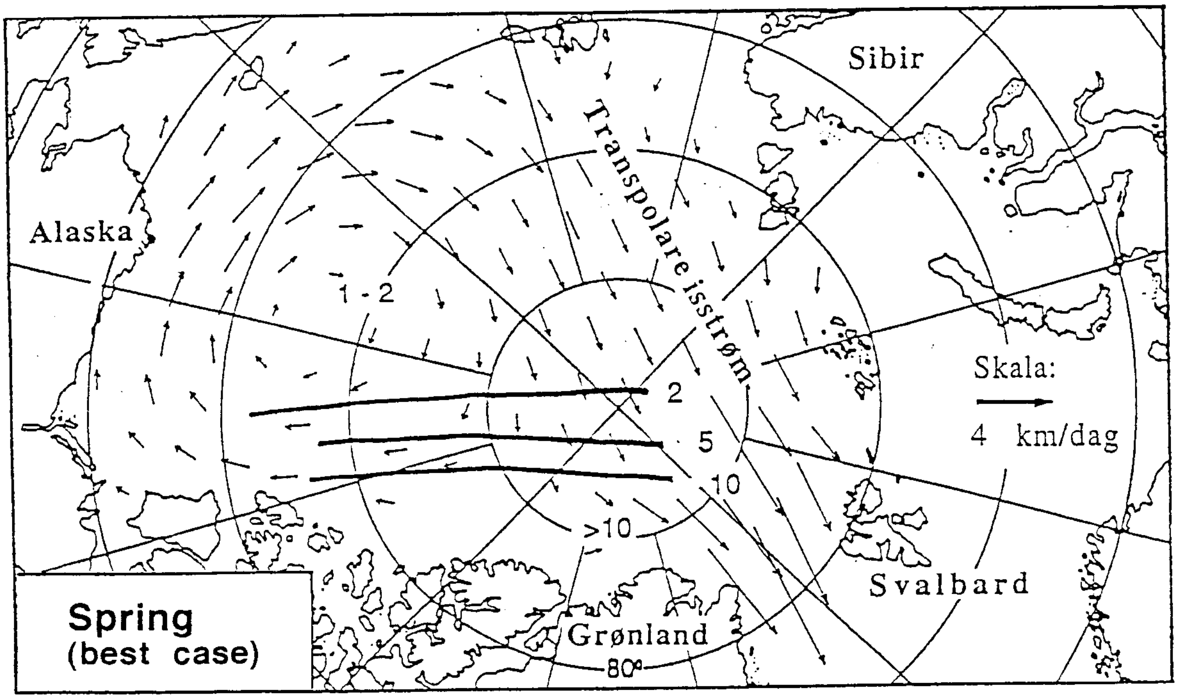


Fig. 6 b.
Tucker and Taylor's (1989) estimate of trafficability for 1.5 m surface clearance during the spring in the Arctic Ocean between Alaska and Greenland based on different assumptions about the probability for long ridges crossing each other. Small arrows indicate mean ice drift velocity based on ARGOS buoys during the period 1979-90 (from ARGOS Newsletter No. 44).

2.1.6 Environmental concerns

Measured noise levels from a hovercraft of suitable size is 78 dB at 25 m under full power and may be compared to the noise of a helicopter at 200 m distance (96 dB at 25 m). We note that the maximum acceptable noise limit for a snow scooter is 85 dB at 15 m according to EFTA regulations.

Operation of a hovercraft out of Svalbard is principally for transportation over snow and ice covered areas. During the summer season, landing on terra firma should be limited to the beach zone for embarkation/disembarkation and supply to avoid surface disturbance. The ground pressure of the air cushion is about 1/20 of an adult person.

The Arctic environment is in many ways vulnerable to human activities and large parts of Svalbard have been designated national parks. A major concern of the Norwegian authorities is to keep the effect of tourism at a level which is considered acceptable to the environment. Introduction of a hovercraft as a mean of transportation should at this stage be done with a clear understanding that this is a platform intended for a wide range of scientific experiments.

2.1.7 Range and period of operation

Range is dependent of ice conditions, wind, visibility and light conditions. Fuel consumption of a suitable craft at 25 km/hour with full payload is estimated at 110 liter pr. hour. A 2 ton scientific payload, will yield an endurance of 42 hours plus 25% reserve. If we take into account a trafficability factor of 1.5 in time as estimated from the video documentation, *effective* range out of Svalbard becomes 350 km as illustrated in figure 7.

A hovercraft of suitable size can operate in wind speeds up to 30 knots and experience from Antarctica show that this is a realistic number (Cook, 1989). Skirts made out of rubber perform well in temperatures down to minus 50 degrees Celsius.

Icing on the underside of the hull from crossing open water leads in low temperature do not seem to be a problem under winter operations in Gulf of Bothnia. Crossing of a lead is however, a controlled operation and the number of crossings can be reduced to a minimum if this is a problem.

It is considered highly likely that a hovercraft of suitable size can operate in the coastal areas of Svalbard all year around, but the feasibility of operations in the polar pack ice north of Svalbard during the period of full darkness (November-February) can only be assessed from future operational experience.

Approach:

All the above issues regarding the performance of hovercraft as a scientific platform will be addressed in the following task:

Task 1.1 Hovercraft as a scientific platform for all year operation
Task leader: UiB

Hover height and low temperature performance are the most important parameters for practical and efficient use of hovercraft. Information on sea ice roughness in the Transpolar Drift and estimates of practical trafficability require a hover height of about 1.5 m which is

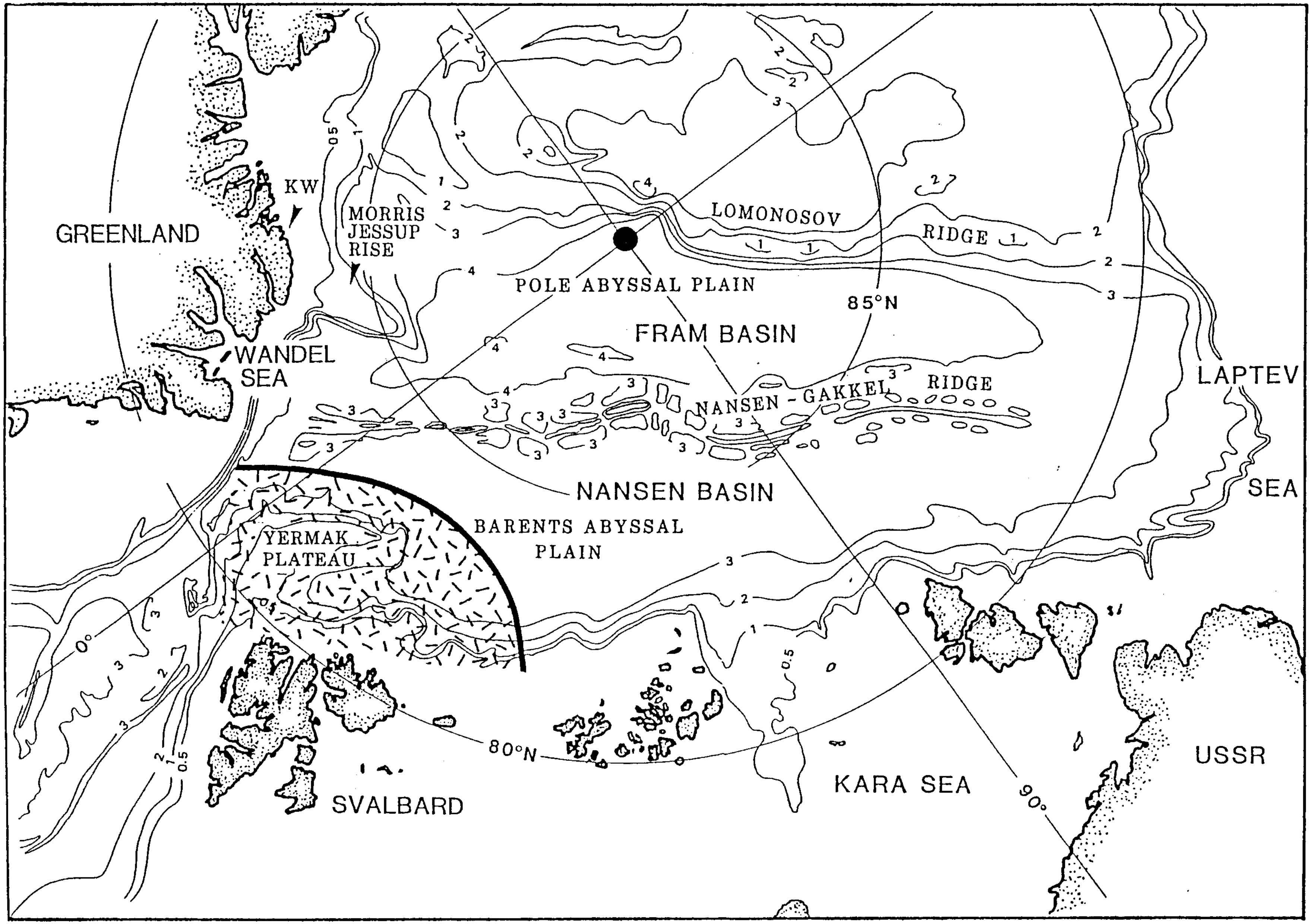


Fig. 7. Calculated *effective* operating range for a hovercraft as research platform with 2 ton payload (scientist and scientific equipment) from a fuel depot in northern Spitsbergen. Endurance is 42 hours at designated cruise speed with additional 25% reserve.

within the capabilities of modified versions of current hovercraft design using diesel engine power plants and well tested open loop skirts.

In the early phase, this task is consemed with providing realistic input of the needs of the different scientific disiplines which require modification in the construction of a hovercraft for scientific applications; particularly major items such as a hydro hole through the hull for operation of sampling equipment from inside the cabin, and strengthening of the hull for winches and small outrigger booms.

Hovercraft performance and progress over different types of ice, weather and light conditions, and during different the seasons of the year need to be documented and quantified.

As field experience accumulates, the scientific needs for improvement of equipment and procedures have to be coordinated and implemented without delay.

SCIENTIFIC EXPERIMENTS

2.2 Thickness and properties of sea ice exported through the Fram Strait

Ocean-atmosphere interaction in the polar regions is to a large extent controlled by the thickness and properties of the sea ice cover (Wadhams,1994). Furthermore, numerical model experiments indicate that the ice thickness distribution in the Arctic Ocean is sensitive to climate change. Such changes would in turn affect the climate of the northern hemisphere. Roughly nine tenths of the ice produced over the shallow Eurasian shelves and within the Transpolar Drift are exported from the Arctic Basin through the Fram Strait. Sea ice studies focussing on the downstream cross-section of the Transpolar Drift would hence provide extremely valuable data about the integrated history of the ice during its drift of 2 to 3 year duration (Colony and Thorndike, 1985). Furthermore, such data are of great interest with respect to the freshwater budget of the Greenland Sea, which is crucial in controlling the extent of deep convection in the North Atlantic.

Specific objectives:

* *Sea ice thickness distribution:* To implement instrumentation for continuous ice thickness measurements by electromagnetic induction/ laser techniques from a hovercraft platform to improve constraints on estimates of total ice mass flux through Fram Strait as measured by satellite imagery and moored upward-looking sonars.

* *Sea ice properties:* To validate ice types and their relative contribution to the total ice mass flux through the strait.

* *Decay of wave energy in sea ice fields:* To investigate the control of incident wave energy on the morphology of the sea ice field.

Key Research Issues:

Sea ice thickness distribution: For the last four years the ice transport through Fram Strait has been monitored by the deployment of a line of moored upward-looking sonars across the ice-covered part of the Strait at 79 degrees North. Support for this work has come from EC via EPOCH and MAST-2 contracts, with the participants being Norwegian Polar Research Institute (NPRI), AWI and SPRI. It is hoped that this monitoring will continue during 1996-1998 using doppler sonars that give ice velocity as well as ice draft, thus yielding ice flux directly (the ESOP-2 proposal to MAST-3, with NPRI being the task leader). Otherwise it is possible that monitoring will continue using normal upward looking sonars provided either by NPRI or AWI. The problems with monitoring the ice transport through Fram Strait in this fashion alone, without validation, are:

1. The sonars tells us nothing about the ice types involved. It would be very useful to validate ice type as observed directly against thickness or roughness parameters obtained from the sonar.

2. Estimates of the total ice mass flux through Fram Strait depend on interpolating mean thicknesses between sonars, and beyond the extreme sonars westward (coast) and eastward (MIZ). It is not clear how this interpolation may be done in an unbiased way.

3. Derivation of ice draft from the sonar record involves using appropriate values for sound velocity in the uppermost 50 m of the ocean, which are dependent on temperatur-salinity structure.

Sea ice properties: The physical properties of sea ice reflects its growth history constrained by mass balance factors. Ice exported through the Fram Strait is mainly multi- and first year ice from the Transpolar Drift, but also older multi-year ice entrained from the Beaufort Gyre. The relative contributions from the various parts of the age spectrum of ice in the total flux need to be better validated. Also ice core obtained during the winter season would be of particular interest because methodical problems encountered during the warmer seasons could be minimized.

Decay of wave energy in sea ice fields: Wave energy is generated by wind action over the open ocean and ice and penetrate into the sea ice field. Penetrating waves break up the continuous ice field into floes, whose diameter increases with distance from the ice edge. The ice morphology in the outermost 100 km or so of the ice field (a substantial fraction of the width of the ice field in Fram Strait) is probably controlled by waves. Much theory and experimental data exist (e.g. Wadhams, 1986) relating floe size distribution to incident wave field, but observations are needed to investigate how deeply into the ice pack a significant wave influence extends.

Approach:

We propose that the research effort towards quantifying the total ice flux through the main gateway from the Arctic Ocean can be efficiently enhanced by use of hovercraft as a platform. The overall sea ice programme will be carried out jointly between AWI, Bremerhaven (Dr. H. Miller, Dr. H. Eicken) and UCAM-SPRI (Dr. P. Wadhams) with use of AWI- and NERC facilities at Ny-Ålesund, Svalbard.

Task/Subtask	Leader
2.2.1 Sea ice thickness distribution	**AWI**
2.2.2 Sea ice properties	**AWI**
2.2.3 Decay of wave energy in sea ice fields	**SPRI**

Task 2.2.1 Sea ice thickness distribution............Leader: AWI

For the task of continuous measurements of ice thickness along the cruise track, we will employ an electromagnetic induction device (EMI) which provide high resolution (<5 m lateral, <0.2 m vertical resolution) thickness data. The EMI would be operated jointly with a laser altimeter. The instrument has been used successfully both for ground and ship-based measurements during the summer and winter season (Eicken et al., 1994; Haas, 1994). Because of its moderate speed and low cruising altitude, a hovercraft is considered an ideal platform for EMI-based ice thickness measurements, superior to airborne measurements with respect to vertical and lateral resolution. The projected hovercraft range would allow measurements across the entire width of the Transpolar Drift and all the way across the Fram Strait. Transects across the Strait will be done at 79 degrees North to cover the line of sonars, or shifted farther north if required by operating conditions.

Task 2.2.2 Sea ice properties...............................Leader: AWI

This task will provide information on the ice type by taking ice cores to obtain parameters related to ice growth history and mass balance (microstructure, salinity, stable isotopes, tracer- and biota analysis). In-situ measurements of ice conductivity is also required for calibration and interpretation of EMI ice thickness data.

When over the sonar sites shallow CTD measurements will be done with a Seacat portable CTD using a small winch. This is to check the average sound velocity over the site. CTD information would also show depth to the pycnocline as well as near-surface fine structure due to freeze or melt. The measurements would be undisturbed by the influence of the hull of a large ship.

Task 2.2.3 Decay of wave energy in sea ice field...Leader: SPRI

The directional wave spectrum as a function of distance from the ice field margin can be observed by deployment of a heave-tilt sensor array on the ice for periods of the order of an hour at each observation point. In the outer part of the marginal ice zone, navigating between ice floes, the hovercraft can deploy a small wave bouy (the "Seadisc", designed by SPRI) in the water instead of the heave-tilt array on the ice. This wave energy decay information will be combined with ice field flow size distribution obtained from satellite imagery to estimate the disintegration of the ice field with wave energy.

2.3 Synthetic Aperture Radar (SAR) validation studies

Satellite remote sensing is an extremely powerful way of monitoring changes in the polar environment.Ice classification can be achieved through radar backscatter data from ERS-1/2 and RADARSAT SAR using appropriate ice classification algoritms constrained by ground truth information. However, ice properties change with the season and algoritms need to be validated for the full annual cycle

Specific Objective:

* Improve predicitive capabilities of SAR imaging of sea ice in key regions of the Arctic ocean at different times of the year.

Key Research Issues:

The physical characteristics of snow and ice determine how the microwaves are scattered and reflected to the SAR receiver. The important microwave parameters are wavelength, polarization and angle of incidence. The interaction with the snow cover, which is usually found on the top of the ice, depends on parameters such as temperature, water content and grain structure. While dry snow is nearly transparent to microwaves, scattering starts to become important when the snow temperature approaches zero degrees centigrade or there are snow layers which impact on the wave propagation. As the microwaves hit the ice surface, the scattering is determined by ice salinity, brine volume, ice structure and surface roughness. These ice parameters change considerable during growth and decay of the ice through the seasons. The main challenge is to quantify the effect of the various snow and ice parameters on the SAR backscatter, so that the integrated effect on the SAR signal become known. This work is in good progress, but considerable work still remains before the SAR signature from different seasons and regions are sufficiently well known. Correlation of in-situ measurements of physical snow and ice parameters from field experiments with SAR data combined with development of scattering models are important ativities in this research. The main difference in backscatter signature between multi-year ice, first-year ice and some new ice types have been established in previous theoretical and observational investigations. However, several problems remain, such as:

1. uncertainties in the changes in backscatter signature for various stages of new ice (grese ice, nilas, pancake ice, etc.), including the effect of the physical conditions of ice formation;

2. seasonal and regional vaiability of these signatures;

3. realistic theoretical modelling studies of the SAR backscatter from snow and ice.

□he seasonal evolution of active and passive microwave ice signatures have been studied, though primarily during the summer melt period. Recent investigations of the seasonal and regional variability in ERS-1 SAR backscatter in the Beaufort Sea during the winter show that significant variability was found. There have been neither systematic theoretical nor observational studies of such properties in the Eurasian Arctic, although a large number of SAR data exist from this region.

Task 2.3.1 SAR signature validation.............Leader: NERSC

The objective of this task is to obtain microwave backscatter data over different ice types and roughness combined with in-situ data of ice types, ridges leads, thickness, snow cover, temperature and brine volume. A scatterometer will be mounted on the hovercraft for surveys within a 50 x 50 km area. These observations will be coordinated with overflying SAR satellites ERS-2 and Radarsat. The SAR data, obtained in real time from Tromsø Satellite Station, will be used to locate interesting ice phenomena such as ridges, leads, etc. The hovercraft will be directed to these positions to collect in-situ data and offer a unique opportunity to systematically samle a large area essential to validation of SAR data. It will be important to perform the experiment in different seasons because the ice characteristics varies considerably with time. In this task the test area needs to be covered at least twice.

The final product will be a complete mapping of the ice characteristics in a test area from both SAR and in-situ measurements.

2.4 Marine geophysics; A site survey for scientific drilling

The Arctic Ocean has a history of a land-locked basin from its formation in the late Jurassic/early Createaceous except for pre-early Tertiary shallow seaways into Siberia and North America (Green and Kaplan, 1982). From plate tectonic considerations, we infer that surface and deep water communication between the Arctic "mediterranean" Ocean and lower latitude water masses became established through the Fram Strait gateway probably in the early Neogene at about 20-15 Ma, after the global cooling trend was initiated (Kristoffersen, 1990).
At the beginning of the Oligocene (Chron 13), a regime of oblique spreading was initiated between Svalbard and Greenland (Talwani and Eldholm, 1977). Other important factors for seaway development were progradation of the shelves bounding the proto- Fram Strait and subsidence of the Yermak Plateau.

Yermak Plateau is a complex geologic structure; its northeastern part is a volcanic constructional feature indicated by associated large amplitude magnetic anomalies (Feden et al., 1979). For the southwestern part, a smooth magnetic signature argue in favour of crustal material of continental affinity (Jackson et al., 1984). The elevation of the northern part of Yermak Plateau and its conjugate feature, Morris Jesup Rise suggest that these features may have been at or near sea level during their formation if we account for the subsequent subsidence of the surrounding oceanic crust. The record of the subsidence history of the plateau is contained in the geologic record (attidude of sediment layers, fossil content and sediment type) of the sediment cover on the ridge. The ice cover render only the area up to 81 30´ N accessible by shipborne surveys in good ice years, unless icebreakers are used.

Specific objectives:

* Investigate the practical use of hovercraft as a vehicle for seismic reflection surveys in ice covered areas during various times of the year;

* carry out regional reconnaissance and detailed site surveys for optimum targets for future international scientific drilling efforts such as the Nansen Arctic Drilling initiative.

Key Issues:

Hovercraft and seismic reflection measurements: Seismic reflection measurements is the primary remote sensing tool for studies of the layered sub-bottom sediments. Seismic reflection measurements in ice covered waters pose considerable practical problems. An icebreaker used during the summer season, is largely constrained to follow open leads in order to make continuous progress. A hovercraft may be used in a similar way for towing a marine seismic streamer of suitable length, but considerable thought and experiments has to go into the seismic source arrangement and its operation.

During the winter season with very little open water, an over ice snow streamer will be more useful. An explosive source is probably required and the number of shot points and data redundancy will be reduced. The operation at this time of the year is not constrained by the distribution of open leads.

If it proves practical to carry out seismic reflection measurements from a hovercraft, it will represent a very cost effective approach within its geographical range of operation.

Site survey for Arctic gateway scientific drilling: The importance of the consept of Arctic gateways for oceanic circulation and climate history is underscored by the fact that two recent drilling legs (two months each) of the international Ocean Drilling Programme (Leg 151 in 1993 and Leg 162 in 1995) are devoted to drilling in the open water north and west of Svalbard and in the Norwegian-Greenland Sea. Leg 151 drilling north of Svalbard was unable to penetrate the thick (>500 m) glacial sediments. The Nansen Arctic Drilling initiative with links to ODP envision drilling from alternative platforms, taking advantage of simpler solutions from relaxed requirements for any heave compensation in this environment. A pioneer experiment for drilling in 1000 m water depth on Lomnosov Ridge near the North Pole, is planned for the Swedish Arctic Expedition in 1996.

Approach:

The versatility of hovercraft as a platform for seismic reflection experiments will be assessed through the following tasks:

Task 2.4.1 Seismic reflection measurements from hovercraft
Leader: UoB

This task involves definition of requirements and implementation of constructional details which will provide for subsequent experiments with seismic reflection measurements from the hovercraft, both for towing a seismic cable and operating a seismic source (airgun).

We consider seismic reflection measurements clearly feasible during the summer season in the presence of frequent open leads in a similar way as for a marine survey from an icebreaker. Strictly speaking, the only space required between ice floes are for lowering a single air gun into the water. Winter operation will be tested with a snow streamer available to University of Bergen from the oil company Norsk Hydro.

Task 2.4.2 Site survey on Yermak Plateau.......Leader: UoB

The objective of this task will be to carry out a regional reconnaissance survey of the northern part of the plateau based on the available geophysical information. The regional data set will be subject to interpretation and definition of optimum locations for further detailed surveys to be carried out in a second field effort.

Only short fragments of seismic reflection data exist on northern slope of Yermak Plateau (Kristoffersenand Husebye, 1985; Futterer, 1992), a few heat flow measurements and short sediment cores (Jackson et al., 1984).

2.5 Marine geology; Sediment transport by sea ice.

Arctic sea ice strongly influence the global climate through the albedo. The Siberian shallow shelves are the main source areas of Arctic sea ice which subsequently enters the Transpolar Drift and exits the Fram Strait after 2-3 years. In contrast to Antarctica, sea ice in the Arctic plays an important role for particle transport. Large amounts of lithogene and biogene particulate matter are incorporated into the ice as it forms on the shelves, and sediment transport by and deposition from particle-laden sea ice largely offset the reduced input from biogenic production compared to an ice-free ocean situation.

Specific objectives:

* investigate the importance of drifting sea as a mechanism for sediment transport and redistribution.

Key research Issues:

Some of the most important issue for future research are:

- the influence of particulate matter in the ice on the melting process and albedo;
- sediment redistribution within the ice during melting;
- comparison of lithogenic and biogenic characteristics of clastic inclusions in the ice and the question of source region;
- net bulk sediment accumulation and the relative importance of sea ice t ransported sediments.

Approach:

A comprehensive study of particulate matter in the ice, the water mass and the surficial sediments on the sea floor will be achieved in the following tasks:

Task 2.5.1 Sediment in sea ice..................Leader: GEOMAR

Quantitative and qualitative characterization of sea ice sediments is obtained through mapping of lithological composition, biogenic content (ice algae; diatoms and dino-flagellates), clay minerals and aeolian components. Several sampling cruises throughout the year are required to estimate variability of the sediment content.

Task 2.5.2 Sediment in the water mass.........Leader: GEOMAR

This task require installation of moored sediment traps below the ice cover to determine sedimentation rates and and sediment composition.

Task 2.5.3 Sediments on the sea floor..........Leader: GEOMAR

A small box corer will be used to obtain sediment from the sea floor to study net accumulation.

Task 2.5.4 Oceanography........................Leader: GEOMAR

Properties of the water masses obtained by CTD measurements are required for understanding the hydrological regime which determine particle transport.

3. PROJECT MILESTONES AND DELIVERABLES

The significant project milestones are the following:

1995

November-December	If proposal for support of trial of hovercraft for scientific application is approved, Rieber Shipping A/S may place contract for building a craft for arctic use. Construction time is 7-10 months.

1996

March	Planning meeting for field experiments in 1996 and 1997.
July	Complete operational plan for 1996 and 1997
August/ September	Delivery of craft to Svalbard and outfitting for scientific experiments.
September-November	Hovercraft field cruises across the Fram Strait and north of Svalbard
December	Semi-annual reports of field experiments and preliminary analysis.

1997

March-June	Hovercraft field cruises across Fram Strait and north of Svalbard. **End of field experiment phase.**
July	Complete final report on hovercraft evaluation
December	Complete report on scientifc results

The project will generate the following deliverables:

Operational plan: Outline a stepwise strategy for outfitting and testing of scientific equipment mounted on the hovercraft, coordinated field experiments, laboratory work, data analysis and integration between all activities.

Cruise report: Each field experiment will be documented by a description of activities and summary of data collection by the scientist in charge.

Semi-annual report: Progress report of hovercraft capability, field experiments and preliminary data analysis.

Data: Data from the field investigations will be made available to participants and to other scientists through the data management system implemented for Arctic Ocean Grand Challenge.

Publications: The scientific results including information of hovercraft performance will be published 1-2 years after conclusion of the field experiments.

4. BENEFITS

A cost effective platform for scientific experiments in the ice covered Arctic Ocean, available all year around for short term hire would open up new opportunities for the research programmes established on Svalbard by several EU-member mations (England, France, Germany, Italy, Sweden, Netherlands). Another very important point is that research expeditions by icebreakers do only take place during the summer season and is therefore able to capture a very limited part of the annual cycle and variability in environmental parameters. Hovercraft as a platform for science would provide possibilities for:

- support of small research projects which are elements in a larger effort to cover the annual cycle in environmental parameters
- deployment of automatic recording systems which can remain unattended for weeks or months for monitoring of parameters relevant to air-ice-ocean interaction and export of sea ice out of the Arctic Ocean.

5. ECONOMIC AND SOCIAL IMPACTS

The user evaluation programme proposed here will be a major component in the descision making process of Rieber Shipping Company to accquire a hovercraft. We stress the importance of a hovercraft being considered purely a platform for scientific experiments at this point. If proven as a reliable vehicle for transportation over ice covered areas around Svalbard, it opens for alternative applications such as for example tourism; an issue which needs prior consideration by Norwegian environmental authorities.

6. PROJECT MANAGEMENT STRUCTURE

Based on past effort in investigating the potential of hovercraft for arctic use, the project coordinator will be:

Professsor Yngve Kristoffersen,
Institute of Solid Earth Physics, Univ. of Bergen/
Institute of Biology and Geology, Univ. of Tromsø,
Norway

7. THE PARTNERSHIP

Coordinator: University of Bergen, Bergen, Norway (UoB)

The Institute of Solid Earth Physics and Geophysical Institute, University of Bergen have for almost three decades had a major part of the reseach activity in the polar regions; Weddell Sea, Antarctica and in the north the Norwegian-Greenland Sea and the Arctic Ocean.

UiB will resume responsibility for providing realistic input of the needs of the different scientific disiplines which require modification in the construction of a hovercraft for scientific applications.

Professor Yngve Kristoffersen has a research interest in marine geophysics and 17 years of polar field experience ranging from responsibility as co-chief scientist on two drifting ice stations (3 months) supported by the United States (1979, 1982), participation on "Polarstern" expedition to the North Pole to member of the Norwegian Antarctic Research Expeditions in 1978/79 and 1984/85. He has carried out pioneer multichannel seismic reflection experiments from ice stations and icebreakers. He is involved in the international initiative for scientifc drilling in the Arctic Ocean (Nansen Arctic Drilling). At the request of the Norwegian Research Council, he undertook a feasibility study of the use of hovercraft as a scientific platform (Kristoffersen, 1994), including a test north of Svalbard of a craft (hover height 0.4 m) chartered from England (Kristoffersen, 1992). Dr. Kristoffersen has represented the ESF Consortium for Ocean Drilling (ESCO) on several Ocean Drilling Program thematic panels (1985-1988 and 1992-95) and has been a member (1986-91) of the U.S. Polar Research Board Ad hoc Committee on "Arctic Geoscience for Year 2000".

Dr. Kristoffersen has published nearly 70 scientific papers on topics which include geophysical studies of the continental and oceanic crust, the plate tectonic, palaeoceanographic and glacial history of the polar regions.

The proposed project is consistent with the research policy of UiB, and particulaly the quest for cost effective research logistics.

Partner 2: A. Wegener-Institute for Marine and Polar Research (AWI)

AWI coordinates the German polar research activities and has been heavily involved internationally both in Arctic and Antarctic research for the past decade. AWI operates the icebreaker "Polarstern", one of the most capable research vessels in polar and marine research.

Professor Heinz Miller is director of the Department of Geophysics and Glaciology at AWI. He has more than 15 years of experience in polar research focussing on marine geophysics and glaciology, and has led several expeditions to the Arctic and Antarctic. He serves in the steering committees of a number of international projects and associations, including the Greenland Ice Core Porject (GRIP) and heads the SCAR Working Group on Glaciology.

Dr. Hajo Eicken has taken part in seven expeditions to both polar regions and been leading the sea ice group at AWI for the last three years. Recent work by this group includes successful employment of EMI techniques for ice thickness determinations (including continuous shipborne EMI/laser altimeter measurements) as well as a program on thickness, structure and properties of sea ice in the central Arctic.

AWI carries out research in both polar regions with increasing focus on Arctic problems. The Physics department is especially interested in the observation and modelling of atmosphere-ice-ocean interaction in the context of climate studies. The proposed project represent an important addition to AWI-funded projects since it provides the data base for the distribution of ice thicknesses in the Eurasian Arctic in the context of climate and meterological studies and provides a linkage between geophysical , glaciological and ocean research at AWI. It furthermore ties in with other proposed projects in the Arctic (Artic Ocean Grand Challenge) and in the Greenland Sea (deployment of moored upward looking sonars and analysis of satellite data).

Partner 3: Scott Polar Research Institute, Cambridge, U.K. (UCAM-SPRI)

Scott Polar Research Institute (SPRI), founded in 1920 as the world´s first bipolar research institution, has been a leading academic research organization in both polar regions for many decades. Its experience in sea ice research includes pioneer work on mapping Arctic ice thickness from submarines (from 1971 onwards); measuring and understanding problems of wave propagation in icefields; working on marginal ice zone dynamics, properties and energy interactions (including planning and participatory role in the MIZEX series of Greenland Sea ice edge experiments 1983-1987); the first work on Antarctic ice properties in mid-winter; and studies on icebergs, ice mechanisms and sea ice modelling. SPRI houses the world´s largest polar library, the World Data Centre "C" for Glaciology, and the secretariat for Scientific Committee for Antarctic Research. As a Department of Cambridge University it benefits from an environment of valuable interdepartmental cross-fertilization characteristics of the distinguihed university, and is also accustomed to EC programme participation, having been involved in two EPOCH programmes, one MAST-2 and one Environment (P. Wadhams, Co-ordianator for the latter two).

Dr. Peter Wadhams has 25 years of experinece of working on sea ice research in the Arctic and Antarctic and has published over 150 papers. He has led 28 field operations involving work from submarines, icebreakers, ice camps, aircraft and helicopters, working on ice mechanics, properties and dynamics, ice-ocean interactions, wave-ice processes and icebergs. He is founder and leader of the Sea Ice Group at SPRI and was Director of SPRI itselv for five years (1988-1992). Specifically to this project, he has taken part in three submarine cruises to the Arctic Ocean, has analysed and published all ice thickness data collected by UK submarines from 1971 to date, and has been a partner in the 1993-1995 Sea Ice Mechanics Initiative programme in the Beaufort Sea. The 1987 submarine experiment which he organized involved concurrent remote sensing observations of sea ice made by several platforms simultanously (submarine, aircraft and satellite) in order to validate sensors (including SAR) over different ice types. In 1990 he was awarded the Italgas Prize for Environmental Sciences (Turin) and in 1994 an honorary Doctor of Science degree (Cambridge University).

A central thrust of research at SPRI, both in oceanography and in terrestrial glaciology, is to carry out geophysical research to understand cryospheric processes in both polar regions. The present project is fully consistent with this policy.

Partner 4: Nansen Environmental and Remote Sensing Centre (NERSC)

NERSC is a non-profit research organization founded in 1984 and affiliated with University of Bergen. Its primary focus is studies of the polar environment particulaly in the fields of oceanography and remote sensing.

NERSC has extensive experience in Arctic field experiments, such as coordination of NORSEX, MIZEX and SIZEX. The centre has high competence in numerical modelling and data assimilation activities. Important climate related processes studied by NERSC are deep water formation and ice edge processes in the Greenland Sea/Fram Strait area, coupling of physical and biological processes in numerical models, ocean circulation modelling in the Arctic Ocean and adjacent seas, modelling of deep sea gravity currents along continental slopes, and in trend analysis of global ice extent by remote sensing data. The scientific staff has considerable experience in mesoscale ocean process studies using satellite remote sensing methods and modelling techniques.

Professor Ola M. Johannessen has been chief scientist on 22 experiments/ expeditions, e.g. the large international experiments such as the Norwegian Remote Sensing Experiment (NORSEX) '79; Marginal Ice Zone Experiment (MIZEX) 1983-84-87; the Seasonal Ice Zone Experiment (SIZEX) 1989-92; and CO2 and Deep Water Formation (CARDEEP), 1993-95. Dr. Johannessen has served on different committees and working groups such as the NASA NIMBUS-7 team, the ESA EOPAG and EOSTAG Committees, the CEC Remote Sensing Review Committee, the Nato Remote Sensing Working Group, chairman of the MIZEX Scientific Committee, chairman of the International Society of Photogrammetry and Remote Sensing Group on Ice; Japanese MOS Team, and the Norwegian WOCE and HOV committees. He was the chairman of the International Space Year program "Ocean Variability and Climate" in 1992. Presently Dr. Johannessen is a member of the CEC/ESF European Committee on Ocean and Polar Sciences (ECOPS), the Arctic Ocean Science Board, the US/French Topex/Poseidon team, the Japanese JERS-1 Team.

Dr. Johannessen has published more than 120 scientific articles and is frequently used as referee for international scietific journals and research programmes. He has been the organizer/co-organizer of 15 international conferences and workshops.

Dr. Stein Sandven is director of research with responsibility for the remote sensing group at NERSC. He has been in charge of several research projects and participated in a number of Arctic field experiments and published on internal waves, mesoscale eddies, ice dynamics, polar oceanography and remote sensing.

Partner 5 GEOMAR

The Department of Palaeoceanology at GEOMAR has a major part of its research effort devoted to the Arctic Ocean. GEOMAR coordinates on behalf of the German BMFT a bi-lateral Russian-German program, the "Laptev Sea System". Scientists from GEOMAR have participated in all geoscience oriented expeditions of R/V Polarstern to the Arctic Ocean.

Professor Jørn Thiede is the Director of GEOMAR and has extensive experience in Arctic marine geological research. He has been chief scientist on a number of cruises including the ARK II, III and IV of R/V Polarstern (1983, 1984, 1987) as well as Ocean Drilling Program Leg 151 which drilled north of Svalbard.

Dr. Heidemarie Kassens has specialized in studies of the palaeoenvironmental signals in physical and sedimentological properties of glaciomarine sediments from the Nordic Seas and the Arctic Ocean. Her recent work is devoted to the environmental geosystem on the Siberian shelves.

8. FINANCIAL INFORMATION

Budget (kECU)	Partner 1 UoB	Partner 2 AWI	Partner 3 SPRI	Partner 4 NERSC	Partner 5 GEOMAR
Scientific personnel	35	55	36	87	280
Travel & meetings	10	3	11	5	40
Durable equipment	30		16	5	36
Consumables	30		19	3	44
Subcontracting	372*				
Administration	0	0	0	0	0
Overhead	70	6	16.4	incl.	60
Total	552	64	98.4	100	460
Total from MAST III	**522**	**64**	**98.4**	**50**	**460**
Own institution	30	0	0	50	0

Grand total requested from MAST III is: 1194.4 kECU

* Charter of hovercraft is estimated at Nok. 25k/day or 3.1kECU/day or 93 kECU/mont
Charter for science applications: 2 months in the fall 1996 and 2 months in early 1997
Total cost of charter 4 months is ECU 372 k.

9. EXPLOITATION PLANS

Results will be made available immediately to all participants in the project for use in overall data reduction and analysis, and will be logded in appropriate data centres after the project for completely open dissemination. Results will be published in scientific journals.

10. ONGING PROJECTS AND PREVIOUS PROPOSALS

None

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APPENDIX

OPERATED BY:
RIEBER
SHIPPING A/S

Damsgårdsgt. 125
P.O. Box 990
N-5002 Bergen · NORWAY

Telephone: + 47 5 34 28 00 (+ 47 55 34 28 00)
Telefax: + 47 5 34 30 04 (+ 47 55 34 30 04)
Telex: 42017 rieco n
Bus. reg. No. 5855813

Prof.Yngve Kristoffersen
Universitetet Bergen
Allegt. 41
N-5007 Bergen

Bergen, 6th March 1995.

Dear Sir,

Re.: Amphibious Hover craft in Arctic.

We refer to a pleasant and interesting meeting the 2nd of March regarding purchase and operating of a Hover craft specially built for use in Polar areas. As we mentioned we consider seriously to purchase such a craft already for the season 1996 provided that we will obtain sufficient operating days in time. If so, our intention is that this craft will be owned and operated by our company Rieber Shipping Svalbard A/S partly from Longyearbyen and Ny Ålesund. We look forward to hearing from you.

Best regards

Rieber Shipping A/S

Leif H. Sørensen - director