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Review of Ice Movement Buoys for Tracking Oil Spills

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REVIEW OF ICE MOVEMENT BUOYS FOR TRACKING OIL SPILLS

by

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for the

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ABSTRACT

In the event of an oil spill in Arctic waters, oil may be trapped under ice for a period of time. Thus, the tracking of the oil during this time may be accomplished by following the movements of the ice under which the oil is located. This report reviews the various techniques by which ice movements might be remotely monitored or determined. These techniques are divided into two regimes: "macro" systems for tracking ice over great distances and "micro" systems using short-range homing systems for the accurate location of specific sites.

On the basis of the review, recommendations are made on the configurations of equipment for each system. The macro system would use a small transmitter which reports to the TIROS-N (ARGOS) satellite. The position of the transmitter is calculated from Doppler shift measurements. It is recommended that the micro system consist of a combination of a VHF-pulsed transmitter and a Luneberg lens radar reflector. The range of this system would be approximately 30 km and the station could be located with an accuracy of a few tens of meters. An air-droppable penetrometer-type package is proposed for both macro and micro systems.

RÉSUMÉ

Advenant un déversement d'hydrocarbures dans l'océan Arctique, il se peut qu'une partie de la nappe de pétrole soit emprisonnée sous les glaces pendant un certain temps. On pourrait alors dépister ces hydrocarbures en suivant les mouvements des glaces sous lesquelles ils se trouvent. Le présent rapport passe en revue les diverses méthodes de contrôle et de télé-détection du mouvement des glaces. Ces méthodes sont de deux catégories: celles qui font appel aux "macrosystèmes" pour suivre les glaces sur de grandes distances et celles qui font appel aux "microsystèmes" de radiogoniométrie à courte distance pour localiser exactement les emplacements.

En s'appuyant sur cet examen, le rapport présente des recommandations quant aux types d'instruments à utiliser pour chacun des systèmes. Le macrosystème utiliserait un petit émetteur communiquant avec le satellite TIROS-N (ARGOS). La position de l'émetteur serait déterminée au moyen de mesures de l'effet Doppler-Fizeau. Le microsystème comprendrait un émetteur d'impulsions à hyperfréquences, combiné à un réflecteur radar à lentille Luneberg. Ce système aurait une portée d'environ 30 km et la station pourrait être localisée à quelques dizaines de mètres près. Le rapport recommande l'usage d'un pénétromètre largable d'un avion pour les deux systèmes envisagés.

FOREWORD

Innovative Ventures Ltd. conducted this study under contract to the Department of Fisheries and the Environment. Mr. P.J. Blackall of the Department's Environmental Emergency Branch, Edmonton, Alberta, acted as scientific authority on this project.

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1 INTRODUCTION

Offshore drilling for oil and gas is currently underway in the Beaufort Sea and in the high Arctic. Drilling is scheduled to begin in the Labrador Sea and in the Davis Strait-Lancaster Sound area of the eastern Arctic (Figure 1). Much of this drilling is taking place or will be taking place in regions where the water surface is covered by ice in winter. If a well blowout were to occur and continue throughout the winter, much of the oil would be trapped in or under the ice cover.

Depending upon the ice type, oil under ice will migrate through the brine channels in the spring or fall of the next year. The oil arriving at the surface of the ice in this manner might be disposed of by burning. Thus, countermeasures for oil under ice depend on knowing the location of the oil-contaminated ice. This report addresses the problem of tracking ice floes in the Canadian Arctic.

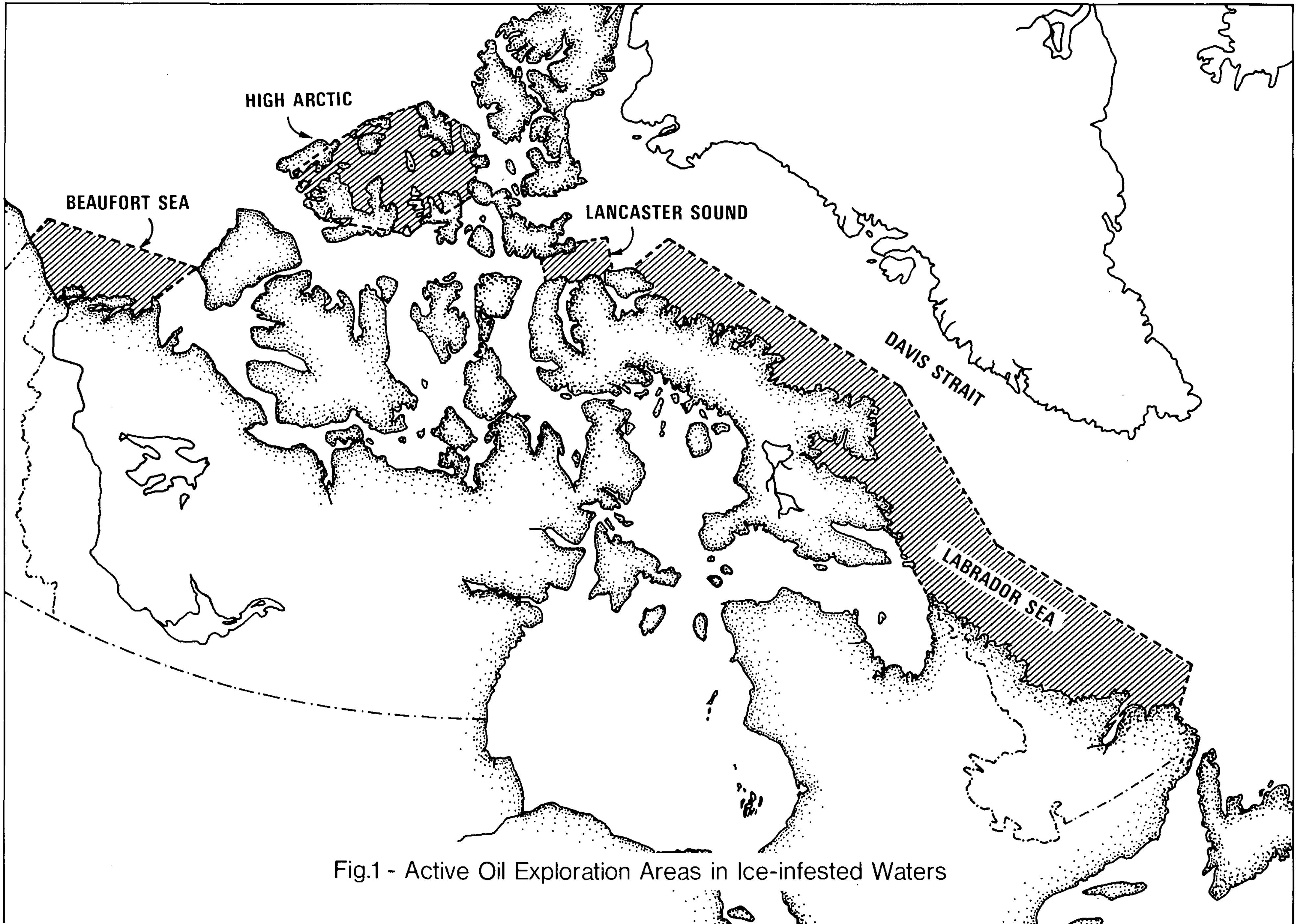


Fig.1 - Active Oil Exploration Areas in Ice-infested Waters

2 PROBLEM DESCRIPTION

Tracking oil slicks in ice-infested waters is difficult using existing remote-sensing technology. Research has shown that oil quickly couples to the undersurface of the ice and remains immobilized, moving with the ice pack.

The width of a slick is expected to be about 100 meters, while the length is the distance covered by the ice pack over a winter season. This may be up to a few hundred kilometres, depending on the region. Tracking an oil slick is therefore reduced to monitoring the ice from the spill area (Lewis, 1976).

2.1 Ice Floe Tracking and Motion

The motion of the Arctic ice pack has been studied extensively under project AIDJEX, and a model of ice motion has been developed as a result of these experiments. The principal forces on an ice floe (which cause ice motion) are wind shear, ocean currents, Coriolis force, sea tilt and internal strain. The first three dominate in most situations. For practical purposes, one need consider only wind and Coriolis force, since the surface ocean currents are wind-induced.

This theory of ice motion, first proposed by Nansen as a result of the 'Fram' drift (Nansen, 1902), indicated that wind stress is the principal driving force governing ice motion, with the ice moving at two percent of wind speed at 30° to the right of wind direction. The 30° deviation is due to the Coriolis force. Zubov (1945) devised an empirical formula for ice motion as a result of observations made from the Soviet icebreaker SEDOV (Zubov's rule):

$$V = \alpha \Delta \rho \qquad (1)$$

where V = ice drift velocity in km/month

$\Delta \rho$ = barometric pressure gradient in millibars/km

α = a coefficient, typically 9-12 x 10^3

The motion is along the isobars in Arctic areas, since the rotation of the geostrophic wind and the Coriolis force approximately cancel (Zubov, 1945).

Brown and Crary (1958) and Reed and Campbell (1960) examined the drift motion of ice station 'Alpha', an ice island trapped in the Beaufort Sea pack ice. These observations showed that for winds of less than 10 km/h, the ice moves at about three percent of wind speed at an angle of 45^{o} to the right, while for stronger winds (30 km/h) the ice moves at two percent of wind speed at an angle of 30^{o} to the right.

From the data collected in the Arctic, the Labrador Sea and the Gulf of St. Lawrence, it is clear that wind and the Coriolis force dominate the motion of ice floes. Therefore, it might be possible to predict the motion of ice floes (and an oil slick) from a knowledge of the meteorological conditions in a given area. This, however, is not practical since the motion may be out to sea where there are few, if any, weather observations. In addition, the theory is not adequately developed to predict movement over long periods of time.

Thus, for the foreseeable future it will be necessary to monitor ice motion using one or more locating systems. The following discusses the applicability of various devices that will achieve results at a reasonable cost. Since the problem here is similar to that of tracking ocean currents, the term 'buoys' will be used to describe motion-measuring packages. Investigation has revealed that at present a single system does not exist to give accurate positional information over the predictable range of ice motion. The tracking of ice floes may therefore be divided into two parts:

1. Macro (large-scale) motion
2. Micro (small-scale) motion

2.2 Macro Ice-Motion

The macro ice-motion tracking system must operate over a period of 10 months and be capable of tracking over distances of a few hundred kilometres. Should shore-based facilities be considered, they must have a range of several hundred kilometres in the event that ice floes move offshore. The position accuracy should be a factor of five less than the range of the micro tracking system, that is, in the order of 10 km.

2.3 Micro Ice-Motion

The macro system provides information on the general motion of the ice; to find a narrow (100 m wide) slick, a micro system must be employed. Buoys satisfying this requirement will have a short range (30 km), but a high position accuracy. Their location will be determined using instruments installed in search aircraft.

It is possible to use satellite navigation equipment to determine the precise location of any platform, anywhere in the world. However, these data are of no value to the search aircraft since existing navigation instruments have accuracies of approximately one to two kilometers. For this reason, the use of homing techniques to locate these buoys becomes necessary.

The units must be air-droppable and capable of operating in the Arctic for 10 months. Since cleanup procedures will take place in daylight (spring), the micro positioning buoys would not be required to operate during the dark period; this will extend the batteries' lifetimes.

3 SOLUTIONS

There are commercially available systems that can be adapted to ice floe tracking. Operation under Arctic conditions has been demonstrated for some systems and methods for adaptation to this environment are well understood. Techniques for air deployment are not as well developed and will require some investigation.

3.1 Macro Systems

Two systems are considered:

1. Satellite systems
2. Radio ranging systems.

3.1.1 Satellite Systems. Two broad classes are available:

1. Polar orbiting satellites
2. Geostationary satellites.

The geostationary systems are useful for data retransmission only, while the polar orbiting satellites can be used for both data retransmission and position determination.

3.1.1.1 Polar orbiting satellites. LANDSAT (formerly ERTS) is a polar orbiting, image collecting satellite with limited data retransmission capabilities. It does not have position determination capability.

The NIMBUS 6 (Kerut and Haas, 1975) contains a data retransmission and Doppler positioning facility known as RAMS (Cote and Julian, 1975). It was launched in May 1975, with an anticipated lifetime of two years. Since the system is still in operational use, it is apparent that the lifetime specification was conservative. The NIMBUS 6 is an experimental program designed to evaluate various sensors to be used in the TIROS-N satellite (ARGOS program).

The ARGOS program, which is to replace NIMBUS 6, will consist of the TIROS-N and NOAA-A through NOAA-G satellites. These satellites will be launched at regular intervals so that two remain in orbit at all times. The first launch was in May 1978 and the system is now operational. The eight satellites, each with a design lifetime of two years, should provide an operational system until 1985 (Taillade, 1977).

The satellites will be in a near polar orbit (98.7^{o} inclination) and at an altitude of 750 to 900 km. One orbit will be at 08:00 $\pm$ 2 hours local time and the other at 16:00 $\pm$ two hours local time. The orbital period will be 101 minutes. Position is determined by

Doppler shift measurements of a precise-frequency oscillator located in the ground station.

The Doppler Vector equation is:

$$\left(\frac{c}{\Delta+\gamma}\right)\left(\Sigma-\Delta\right) - \frac{\left(\vec{N}\bullet\vec{R}\right)\ \left(\dot{\vec{N}}-\vec{R}\right)}{\left|\vec{N}-\vec{R}\right|} - \frac{\vec{R}\bullet\vec{V_e}}{\left|\vec{N}-\vec{R}\right|} \qquad (2)$$

where

γ	=	satellite oscillator frequency	
Σ	=	buoy oscillator frequency	
c	=	speed of light	
Δ	=	observed Doppler shift	
$\vec{N}$	=	buoy position on earth	
$\dot{\vec{N}}$	=	buoy velocity on earth	
$\vec{R}$	=	spacecraft position	orbital definition
$\dot{\vec{R}}$	=	spacecraft velocity	orbital definition
$\vec{V_e}$	=	rotational velocity of earth at platform	
$\left\|\vec{N}-\vec{R}\right\|$	=	short range (buoy to spacecraft)	

The quantities $\vec{N}$, $\dot{\vec{N}}$, and Σ are unknown and are, in general, changing with time. If it is assumed that:

- buoy motion is in the form of a great circle between and during passes
- speed is constant during a pass
- buoy oscillator (Σ) is stable during a pass
- altitude is known (sea level) and constant,

then in two successive passes it is possible to determine:

- platform velocity
- longitude of platform at first pass
- oscillator biases during first and second pass (these should be the same).

If only one pass is made, there is ambiguity in position, which is symmetrical about the satellite orbit. The correct position is uniquely determined from a second pass or by trajectory plotting, assuming a reasonable and likely motion (Figure 2). Such interpolation is not necessary, since two passes are normal in Arctic regions.

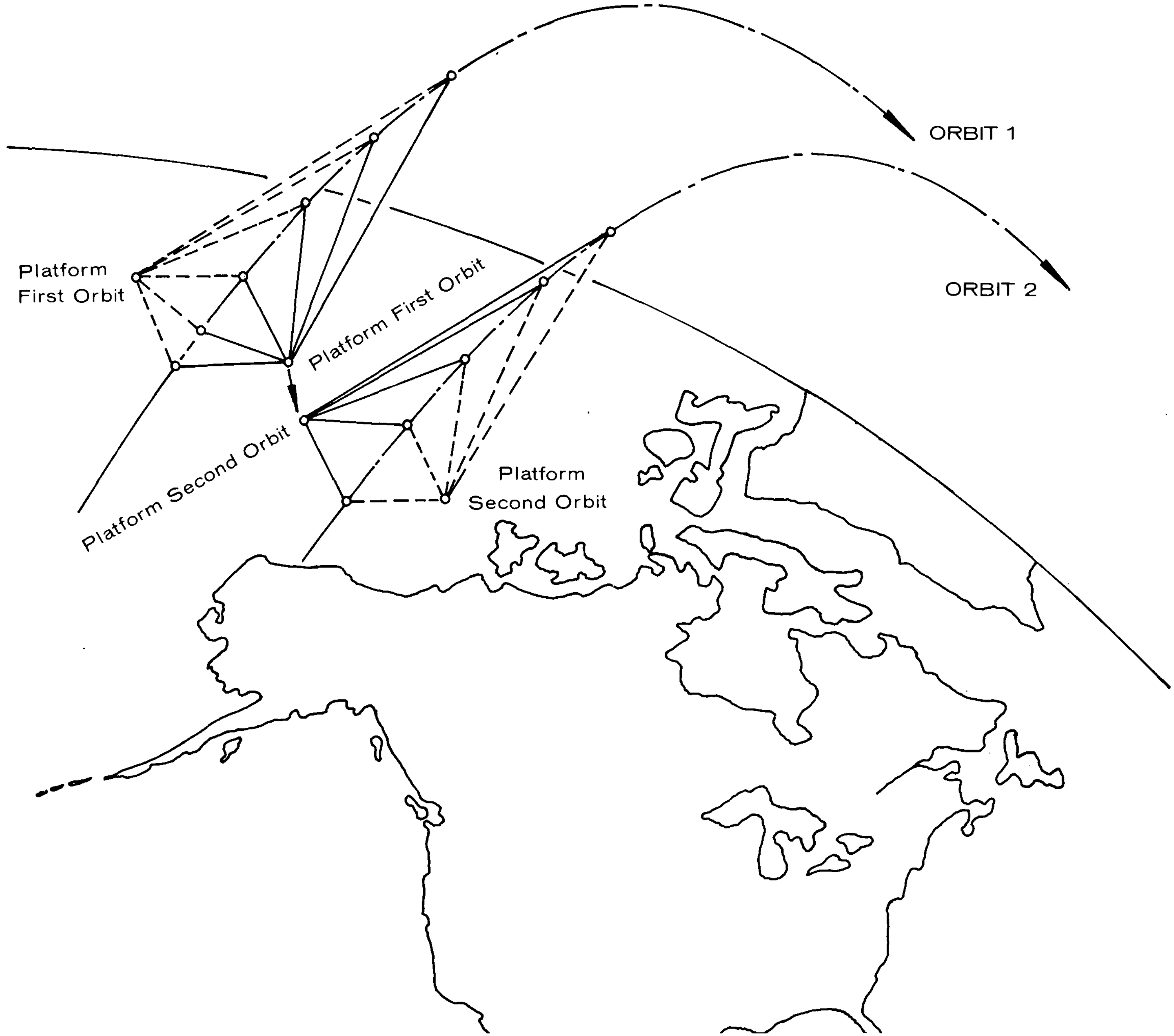


Fig.2 - Location Measurement using Satellite Doppler Positioning

The error of position determination is due to the root mean sum of errors of all the parameters of Equation 2. The orbit of the satellite is measured using Doppler effect measurements of the satellite using special 'Orbitography Platforms'. Ten such platforms are distributed around the globe at geodesic markers so that during each satellite pass at least one station is in view (Figure 3). The orbit is determined once a day for each satellite.

The accuracy of the orbital determination is 500 m along the path of the orbit and 150 m in a perpendicular direction. These errors determine the precision of $\vec{R}$ and $\dot{\vec{R}}$. $\vec{V}_e$ does not contribute to the overall errors. A major error contribution is the medium-term stability (20 minutes) of the buoy oscillator: the error in Σ. Figure 4 is a plot of position accuracy as a function of short-term stability.

The number of positions per day is a function of buoy location. In the region between 40^{o}N and 40^{o}S latitude, it is not possible to see two successive passes of the same satellite. North or south of this, successive passes of one satellite are common, and in the area of interest for ice-floe tracking, two passes can always be achieved. Figure 5 shows a plot of the number of location determinations (two passes) as a function of latitude. North and south of 60^{o}N and 60^{o}S respectively, the location is calculated using measurements taken by two satellites. Should this fail, an attempt is made to calculate position using two successive passes from one satellite. The dip in coverage in the area of 82^{o} is due to the 98^{o} inclination of the satellite orbit.

Data received by the satellite is combined with other sensor data in a unit called TIP (Tiros Information Processor). The TIP data is broadcast in real time with a VHF link (136.77 or 137.77 MHz) and is also stored in a GTR (Global Tape Recorder). The GTR is dumped at Command and Data Acquisition Stations (CDA) located at Wallops Island, Maryland; Gilmore Creek, Alaska; and Lannion, France. These telemetry receiving stations transmit the data to the National Environment Satellite Service (NESS) of NOAA in Suitland, Maryland. The ARGOS data is separated at Suitland and transmitted to the ARGOS processing centre in Toulouse, France, via a 7,200-baud data link (Figure 6).

The ARGOS data centre computer calculates the buoy position using the most recent orbitographic information, which is then passed on to the user. ARGOS-user communications are typically via telex, dedicated lines or modem phone terminals.

Since new data arrive once every 50 minutes (two satellites, each with a 101-minute orbital period), processing by the ARGOS centre must, of course, be faster. The time from reception by the satellite to availability in the ARGOS telemetry station varies between zero and 100 minutes, depending on buoy location; transmission from the

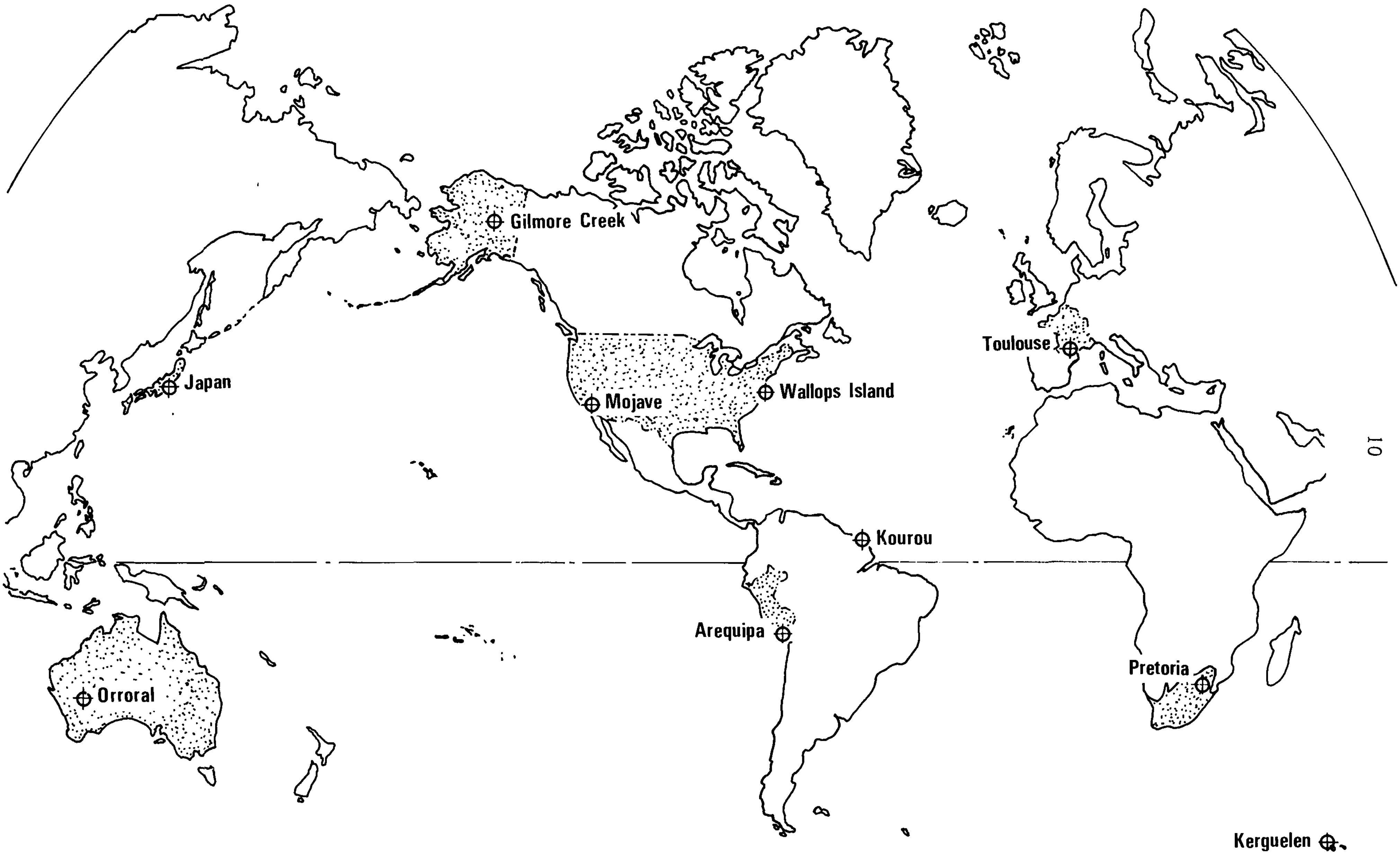


Fig.3 - Position of Orbitography Platforms for Service Argos

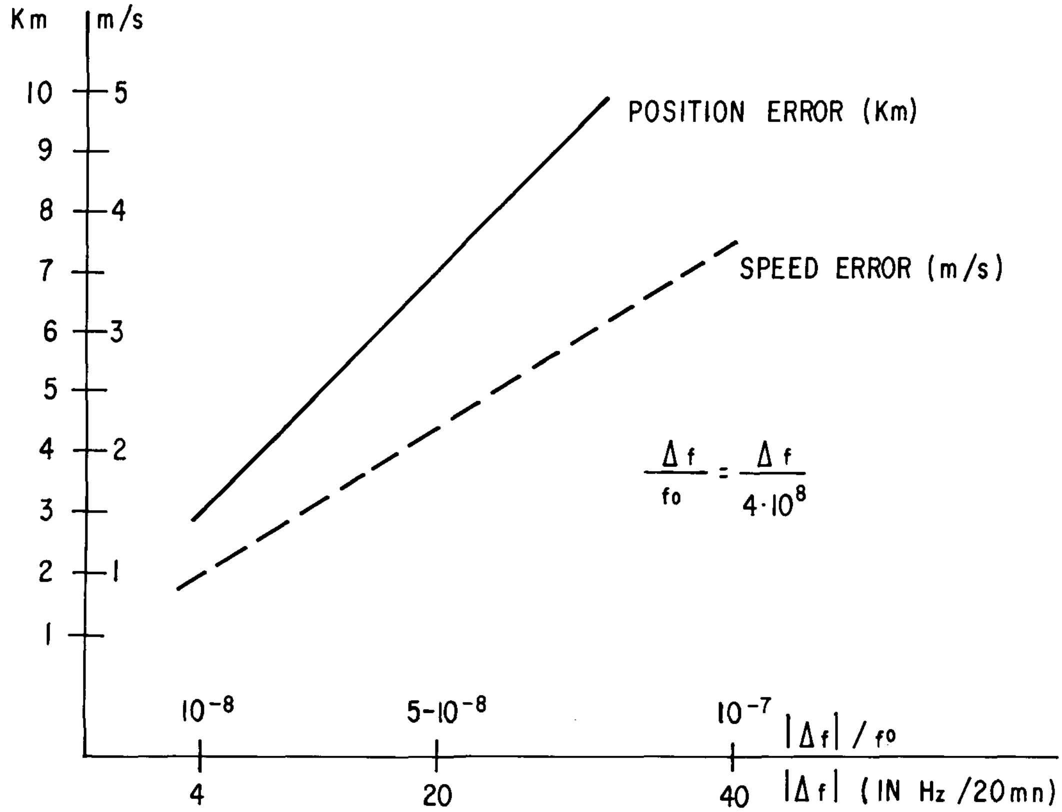


Fig.4 - Position Accuracy as a Function of Short-term (20 minutes) Oscillator Stability

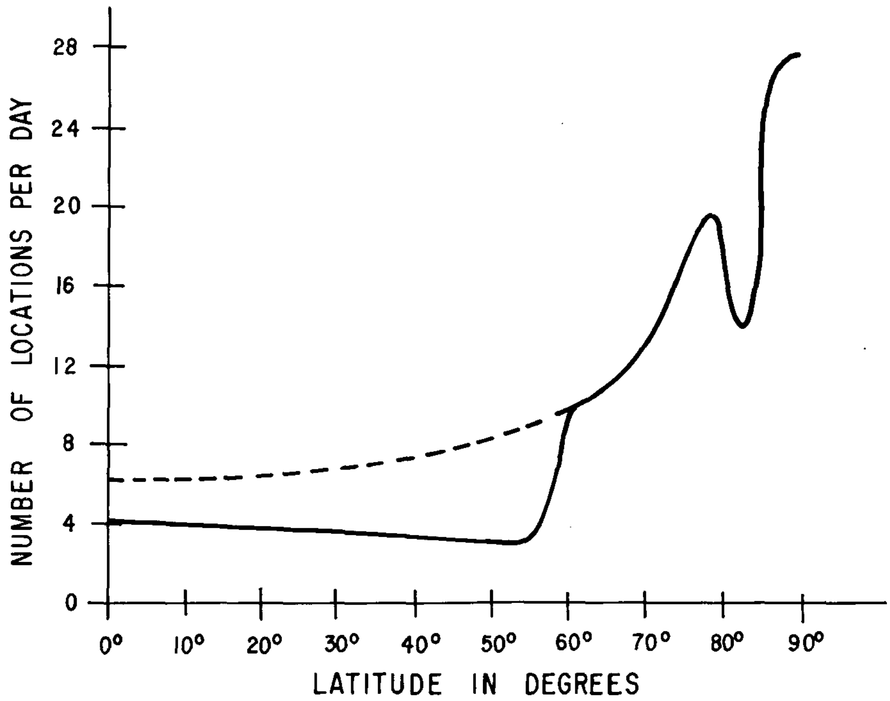


Fig.5 - Number of Locations Per Day Versus Latitude

Fig.6 - Data Link for Service Argos

telemetry station to NOAA centre and processing of data take 45 minutes; the ARGOS data are transmitted from the NOAA centre to ARGOS Toulouse in 20 minutes. The processing time in Toulouse is 40 minutes, resulting in a total delay of between 105 and 205 minutes (Figure 7). ARGOS anticipates achieving this processing time 75 percent of the time.

In summary, the TIROS-N will give position accuracies of three kilometers, with a maximum delay of 205 minutes. This assumes a 20-minute oscillator stability of 10^{-8}, which is typical of commercial electronic systems (Livingston et al, 1975).

3.1.1.2 Geostationary satellites. Geostationary or geosynchronous satellites are positioned in orbit above a given point on the equator. They are useful for data retransmission; but, unlike polar orbiting satellites, they cannot be used for Doppler positioning since they have a fixed position with respect to the earth. Therefore, in solving the ice tracking problem, an independent location system must be used, the output of which is transmitted via the geostationary satellite.

The required range of tracking eliminates most conventional survey techniques; a global positioning system must be used. Two such systems are applicable:

1. VLF phase-comparison electromagnetic system (OMEGA) (Broughton, 1977)
2. Navigation satellite system (NAVSAT) (Stansell, 1971).

The VLF positioning technique measures the phase difference between low-frequency electromagnetic transmitters located at known positions on the earth. These operate in phase coherence, established by atomic clocks, at locations shown in Figure 8. The OMEGA stations operate at a frequency of 13.6 KHz (wavelength: 22 km). Thus, a simple measurement of phase will give the position to 22 km and other means must be used to determine the position more precisely.

The global surface is effectively divided into a series of lanes 22 km wide, and a VLF receiver determines the location within a four-sided area. The lane ambiguity can be resolved by using data from other stations or by counting lanes from a known starting location. In the case of a slowly moving object such as an ice floe, the general trajectory can be used to determine lane position, since it is unlikely that the floe will move more than one lane between observations.

Since the propagation velocity and, hence, the phase are affected by the electrical characteristics of the earth, the accuracy of VLF systems is a function of global location. Typical accuracies of two kilometers have been observed in Arctic regions. In order to improve the accuracy of position determination, a differential

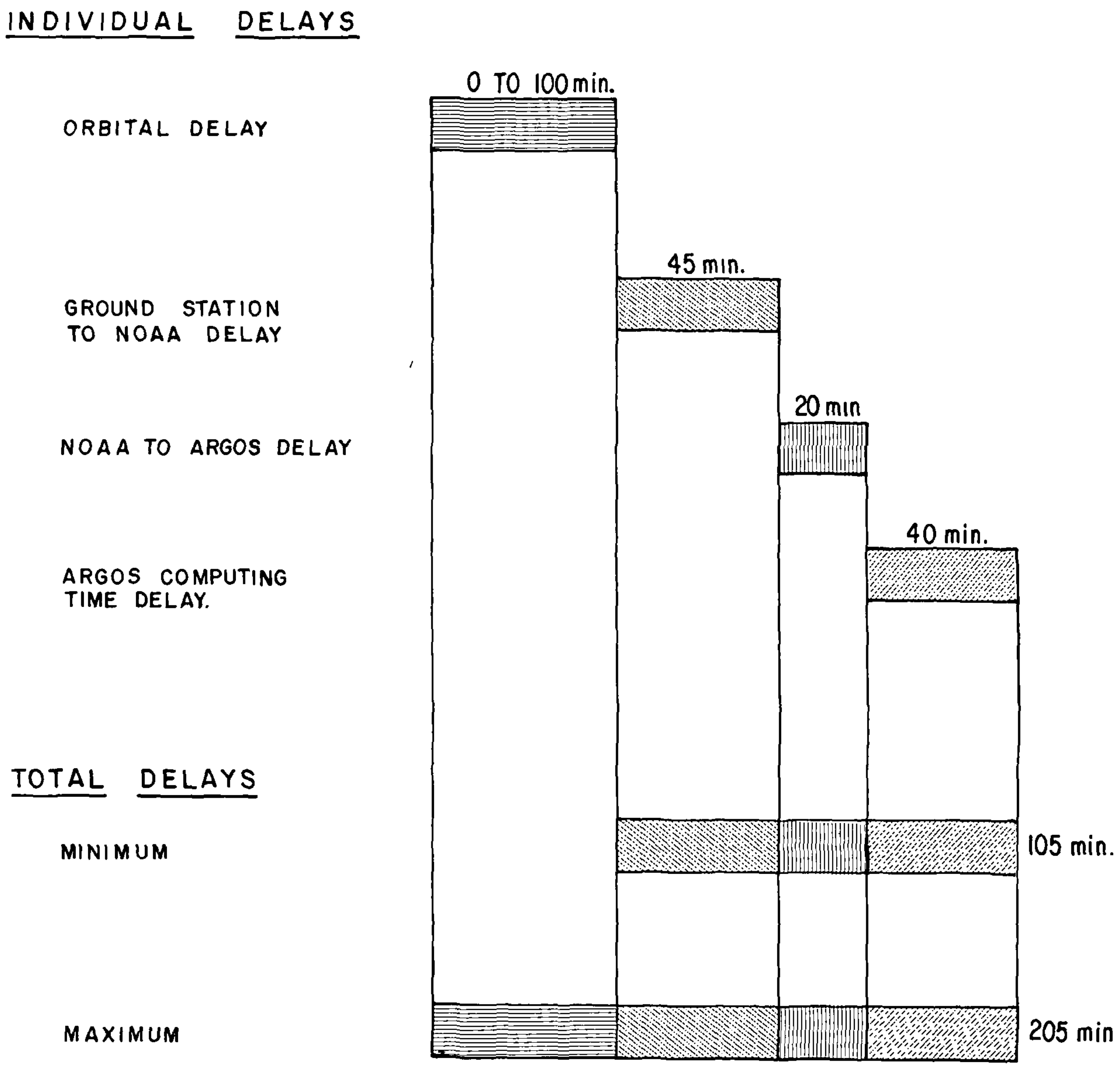


Fig.7 - Processing Time for Service Argos Data

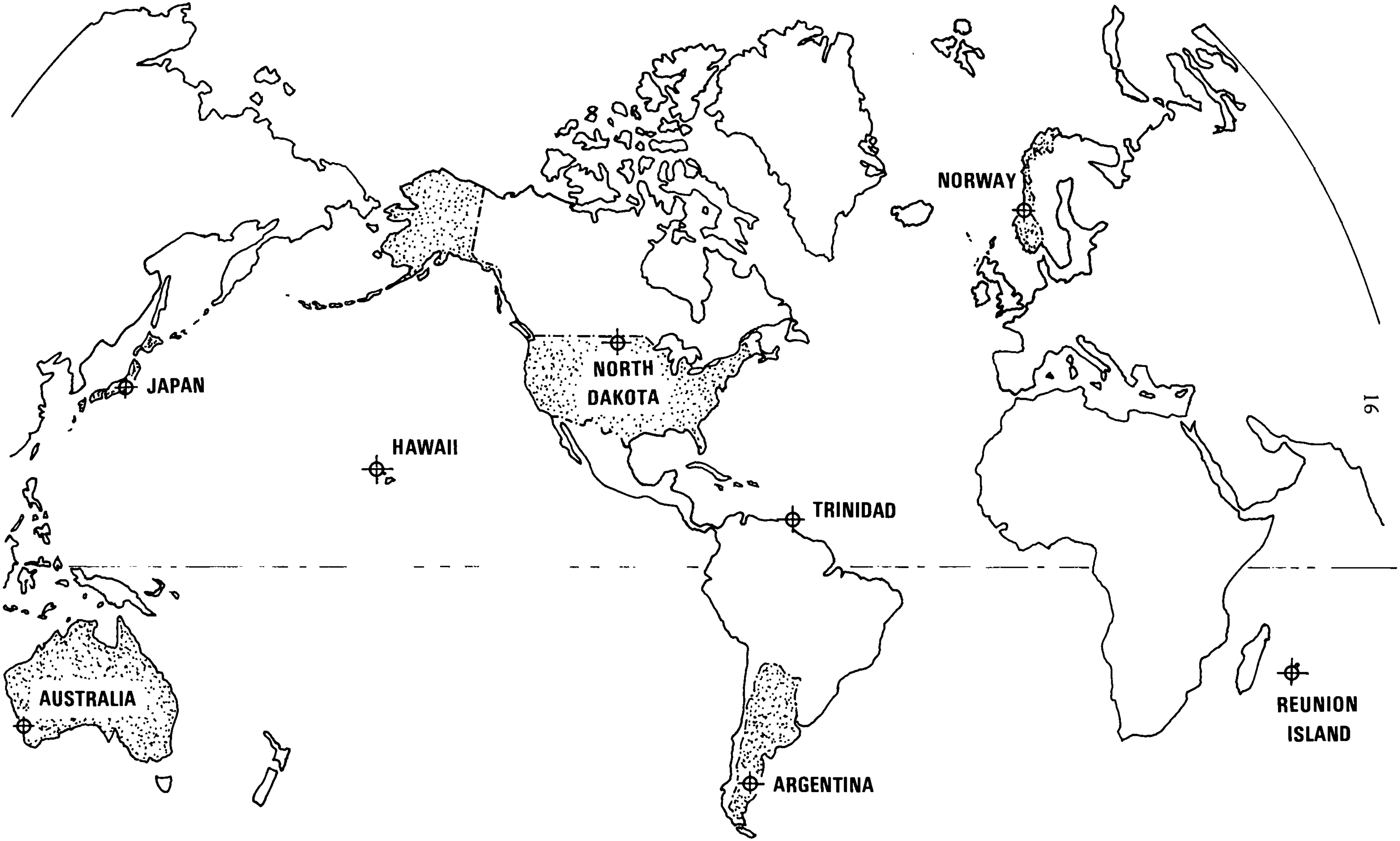


Fig.8 - Location of Omega Transmitters

OMEGA system can be used. This employs at least two VLF receivers, one at a known site and the other at a remote location. By comparing the phase differences between these receivers, first-order phase-shift errors can be cancelled out, with typical error reductions of a factor of 10 to 20. VLF systems work well in the Arctic and in the Labrador Sea, but the effect of the Greenland Ice Cap limits application in the Baffin Island region.

A number of polar-orbiting navigation satellites, which emit a precise frequency detectable by a ground-based receiver, have been launched by the U.S. Navy (U.S. Navy Navigation Satellite System). The ground unit measures the Doppler shift and computes the position in a manner essentially the same as the ARGOS system. The orbital parameters of the satellite are encoded in the satellite transmission. Accuracies in position in the order of 100 m are achievable and several position determinations per day are possible in polar regions.

Accuracy is limited by atmospheric effects and orbital uncertainties. By using two receivers in a differential mode (translocation), similar to OMEGA, it is possible to reduce errors to a few metres. By using satellite positioning, accuracies of 100 m are possible in stand-alone mode and one to two metres in translocation mode.

Position information can therefore be provided by the OMEGA or NNSS systems and the data transmitted via the GOES (Geostationary Operational Environmental Satellite) system. The position and coverage of the two satellites presently in use are shown in Figure 9. The map shows the 5^{o} (horizon) contour; this is approximately the limit of most available transmission systems.

A remote station for GOES consists of a 10 to 40 watt transmitter; frequency is derived from a stable, temperature-compensated crystal oscillator (Figure 10). The satellite receiver operates over a band of 401.7 to 402 MHz; this is divided into 99 channels which are further time-multiplexed to ensure optimal user performance.

The GOES retransmits the signal to a ground station, such as the Canadian receiving station recently established at Prince Albert, Saskatchewan, by the federal Department of Fisheries and the Environment. Permission to use the GOES satellite and the allocation of channel assignments and time slots is controlled by NESS. The program using GOES must involve the observations of natural events and be of an environmental nature.

TELESAT is a government-operated commercial communications company which offers, on a common-carrier basis, satellite (ANIK) data links (Forcina and Smalley, 1977). This system's principle of operation is similar to GOES', except the frequency is

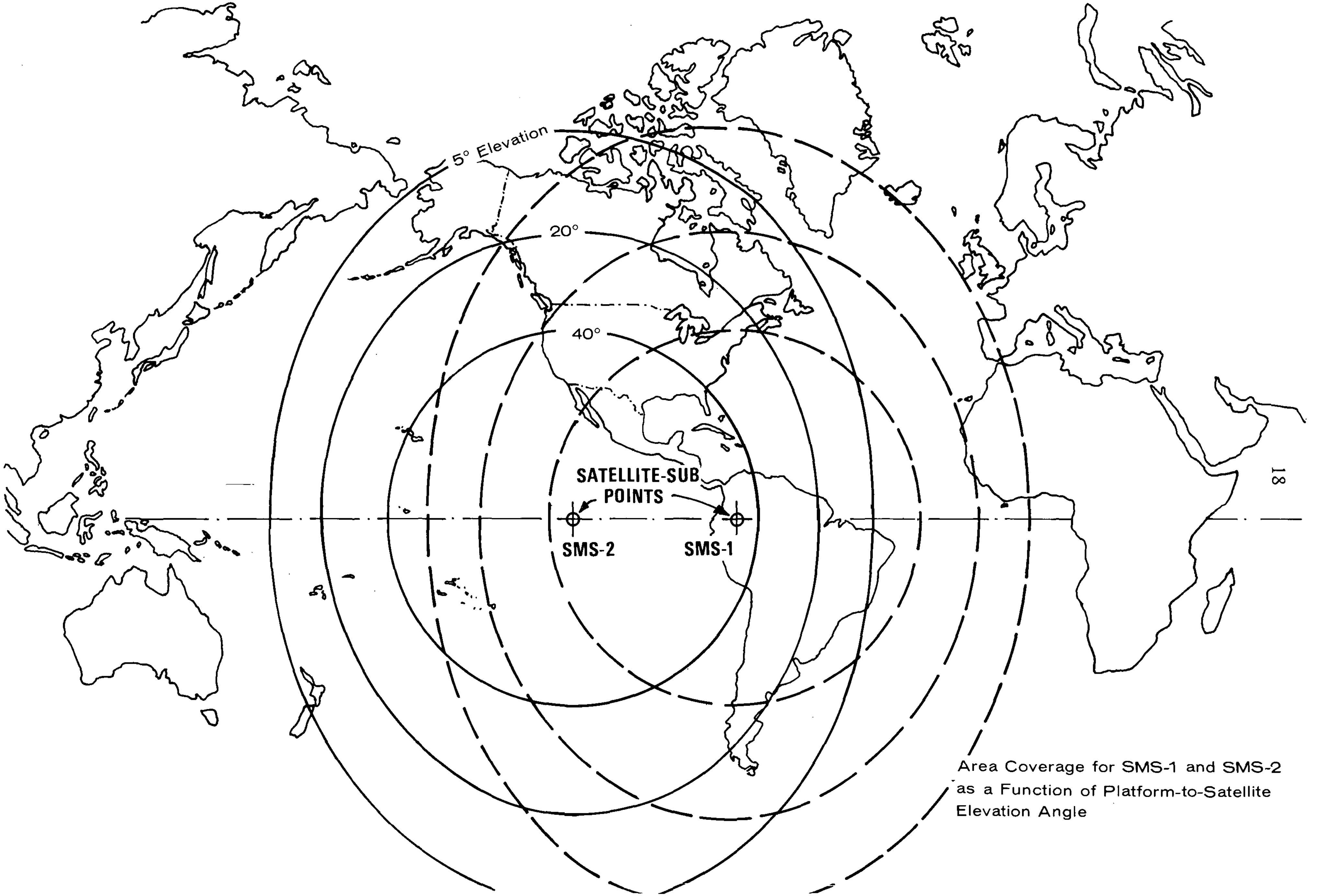


Fig.9 - GOES Geostationary Satellite Positions

Fig.10 - A Ball Bros. Ltd. GOES Transmitter

5950 MHz and the basis of service is on a user-fee concept. ANIK has similar limitations to GOES in terms of global coverage, but the transmitter and antenna are more complex.

In summary, platforms may be deployed on the ice which will determine position using either OMEGA or NNSS. While the data provided has an accuracy which is comparable or better than the position information given by a TIROS-N buoy, there are two distinct drawbacks to their use:

1. The cost of remote platforms is high
2. The position information is more accurate than the best aircraft navigation equipment.

Knowing the precise location of a buoy from satellite retransmissions via GOES does not improve the capability of relocating specific sites. The accuracy of position determination need not be better than the best performance of the navigation equipment aboard the surveillance aircraft (which will be ultimately responsible for location of oil slicks).

3.1.2 Radio ranging systems. A possible alternative to satellite positioning would be the use of land-based radio direction systems to determine position by triangulation. Such a means has been used for tracking drifting buoys in oceanographic programs, and offers the advantage of collecting real-time information by way of an independent, self-contained operational system.

A small, high-stability high-frequency transmitter is installed on an ice floe and tracked by two land-based receivers, as shown in Figure 11 (Murray et al, 1975). The angular measurements, which are accurate to a few degrees, allow determination of the buoy position. The accuracy is a function of receiver geometry and range. The prime drawbacks to this system are the limited range, distortion due to atmospheric effects and the cost of maintaining a manned station on shore.

Variations of this concept are possible however. A narrow band, high-frequency link can be used to retransmit OMEGA data from an ice floe. The HF signal is decoded using a standard OMEGA receiver at a base station. This technique has been used by Canadian Marine Drilling Ltd. for tracking ice floes near drilling locations in the Beaufort Sea.

The use of VHF rather than HF as the telemetry or ranging system would improve the signal to noise ratio, and hence the system accuracy. However, the range of VHF transmissions is limited to line-of-sight and is therefore not useful for macro ice-floe tracking.

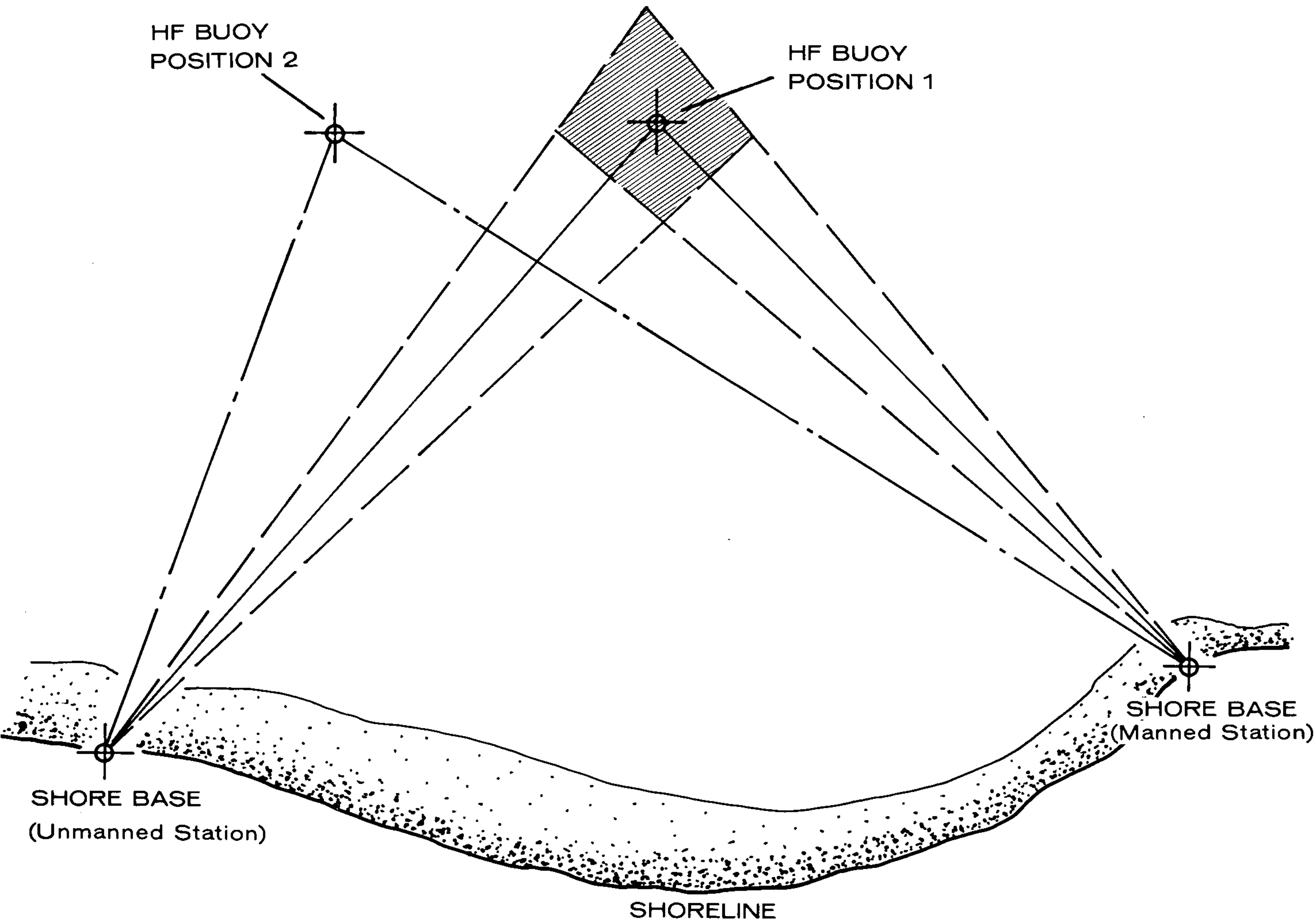


Fig.11 - High-Frequency Radio Tracking

3.2 Micro Systems

To allow a surveillance aircraft to find the exact position of ice floes and accompanying oil slicks, a homing device is required. Two systems are discussed:

1. HF and VHF beacons
2. Radar reflectors.

3.2.1 HF and VHF Beacons. High-frequency homing beacons have been developed to track drifting buoys and recover current meters in oceanographic programs. These beacons operate in the 27 MHz citizens' band at a power level of 100 mW. The detector consists of a directional loop, a receiver and a relative bearing indicator mounted on an aircraft. These systems have a range of 10-50 km, depending on flight altitude.

While the 27 MHz systems are the most common, similar beacons have been developed to operate at VHF (150 MHz) and at UHF (420 MHz). These newer systems are slightly more complex and suffer from range problems at low flight levels. They are, however, less susceptible to interference than the units which operate in the popular and crowded citizens' band frequencies.

Fig.12 - VHF Homing Beacons at a Remote Site in the Canadian Arctic

3.2.2 Radar Reflectors. A passive radar reflector is essentially a radar antenna which resonantly reflects X or C band radiation. The standard system is a corner reflector which has an effective albedo of 2.5 as compared with that of a typical semi-infinite specular reflector. While no power source is required, the size and shape of the elements are critical; consequently, performance will be seriously degraded by accumulation of ice and snow.

A recent development uses a Luneberg lens (Skolmak, 1962) which is more rugged and suitable for this application. A 30-cm sphere has an effective radar cross-section of 10 m^2; the reflector works like a Koster prism (Figure 13). The newness of this system makes capability assessment difficult.

Active radar transponders function in a fashion similar to passive reflectors, but provide additional signal strength. The units consist of a radar receiver, delay, and a radar transmitter. The delay allows a common antenna and similar frequencies to be used for receive and transmit functions. These units require power at the remote location, but give a much better signal-to-noise ratio for the return; problems of antenna icing and snow accumulation are therefore not as critical as they are for passive reflectors.

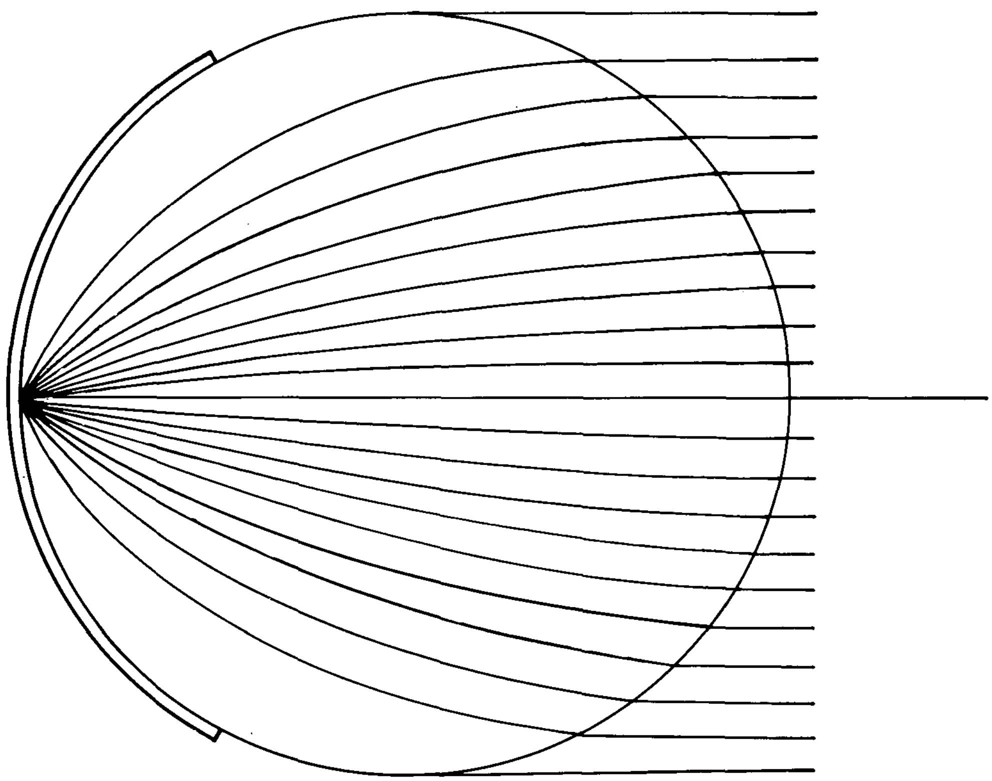


Fig.13 - Orbit in the Luneberg Lens

4 DEPLOYMENT TECHNIQUES

Since both the macro and micro buoys will be used offshore in Arctic areas, the only practicable deployment techniques will require the use of aircraft. In most instances, the buoys will be placed at the well site; as the ice moves (and the oil with it), other units will be deployed at the well site. Over the period of the winter, a line of buoys will mark the trajectory of the slick.

The traditional and well-proven technique for deployment and recovery of equipment from the Arctic ice pack is the use of helicopters. This is expensive at any time, but since the anticipated time of deployment will be during the dark period, a twin-engined, IFR-equipped machine will be mandatory; this requirement increases costs considerably. While it is quite possible that helicopters will be used from time to time, it is important to consider other, less expensive techniques. In addition, the use of helicopters is very weather-dependent, and range is limited to approximately 400 km.

The increased range and lower operating costs of a fixed-wing aircraft make this an attractive vehicle for buoy deployment. However, since landing of fixed-wing aircraft would be made impossible under many conditions (light, weather, ice), an air-droppable system becomes necessary. There are two possible methods of air deployment:

1. 'Soft' drop, using a parachute
2. 'Hard' drop, using a high 'g' missile.

An air-droppable, satellite-reporting (to NIMBUS 6) buoy (ADRAMS) was developed by Polar Research Laboratories for project AIDJEX. This is a 'soft' drop system using a parachute which detaches after landing. The electronics package is gimbal mounted to preserve antenna and sensor orientation, independent of the characteristics of the terrain. The operational life of an ADRAMS buoy is approximately nine months (limited by battery capacity).

Various military systems developed for precision bombing use air-droppable radio beacons. It has not been possible to obtain adequate information on these systems to evaluate their potential for ice-floe tracking.

An alternative to the 'soft' drop parachute system is a free-falling missile. Early U.S. Coast Guard studies (McIntosh et al, 1973) show the use of penetrometers in ice were successful. The USCG system contained a VHF telemetry capability to transmit deceleration data; it is quite reasonable to assume that a transmitter compatible with Service ARGOS could be constructed using the same technology. A penetrometer will increase the probability of firm mounting in the ice and not require a gimbal assembly.

The depth of penetration can be calculated by considering the energy transfer to the ice. Assuming a terminal velocity of 100 m/sec. (typical of a free-falling missile) and a weight of 25 kg, the penetrometer will have an energy of 1.25×10^5 joules. The specific cutting energy of ice is 6.6×10^6 joules/m^3; so that 1.89×10^{-2} cubic metres of ice will be removed. If the missile has a diameter of 0.1 m, it will penetrate 2.4 m; this assumes no frictional losses.

It is clear from the foregoing that a collar and/or aerodynamic retardation is required. To penetrate 0.2 m, the impact velocity should be reduced to less than 50 m/sec., or dissipate half of the energy in a retarding collar (with a diameter of 30 cm). The choice between these is a function of penetrometer design. Figure 14 is an artist's conception of a microsite containing a pulsed VHF transmitter and a Luneberg lens radar reflector.

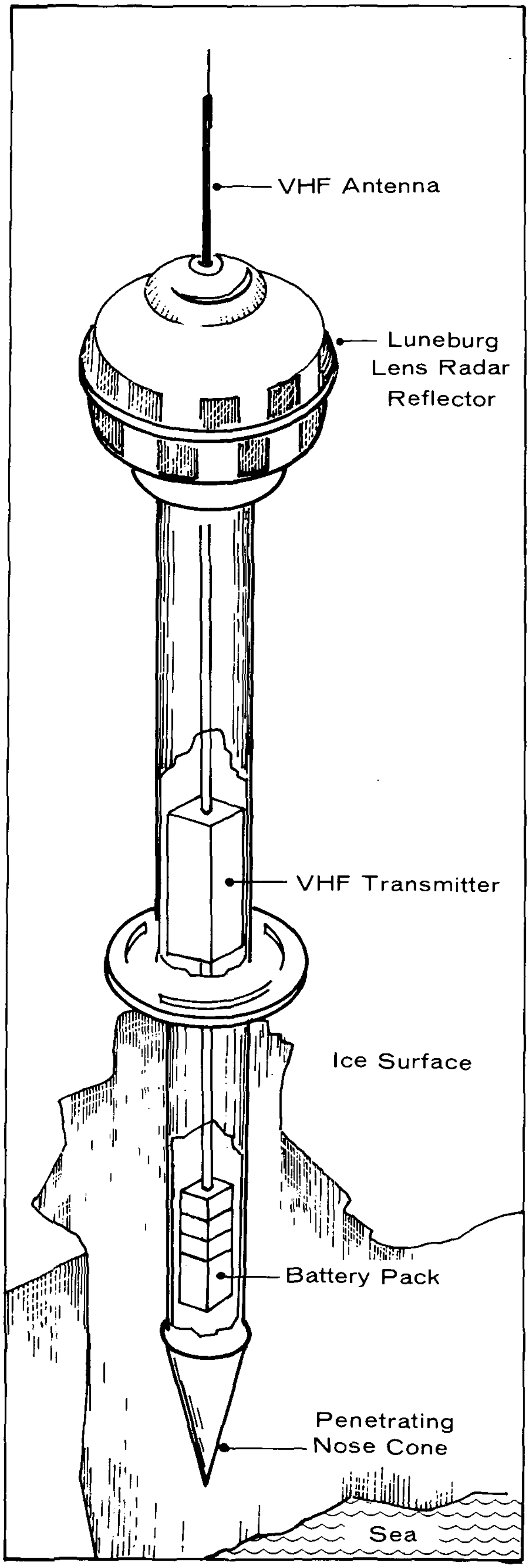
4.1 Aircraft Tracking

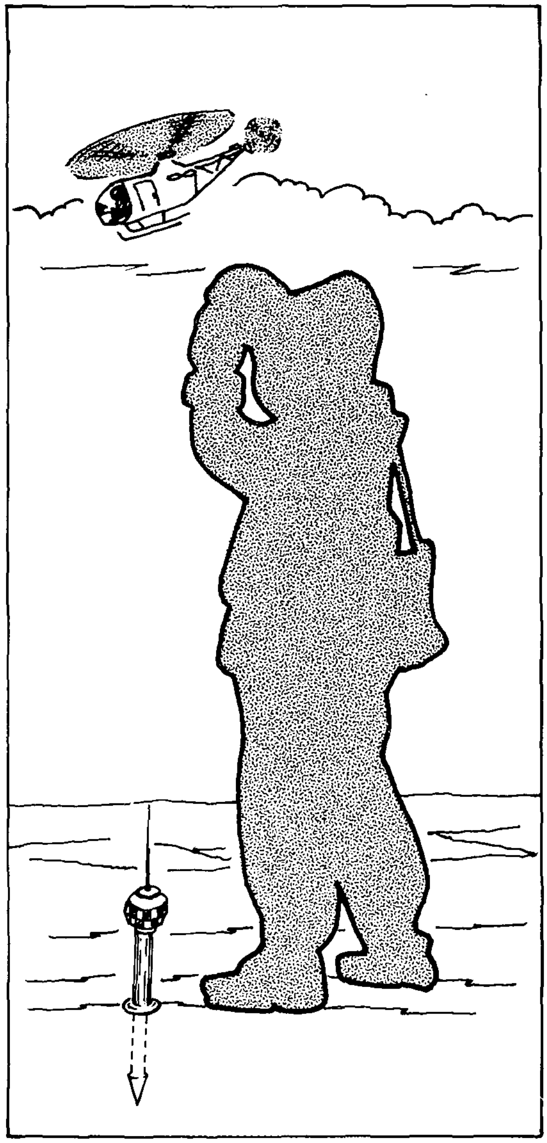
Homing into a specific site requires a set of detecting equipment on the aircraft. There are two sources of aircraft: government and private sector.

Two DND aircraft likely to be used are the "Tracker" and the "Argus"; both are equipped with a surveillance radar and hand-held cameras. The Argus uses an INS navigation system; and by the summer of 1978, OMEGA navigation equipment will be available on the Tracker.

The Atmospheric Environment Service (AES) operates two Ice Reconnaissance "Electra", each equipped with a laser altimeter, infrared line scanner and radiation thermometer (in addition to cameras and radar). One aircraft will have a side-looking radar system which produces real-time hard-copy images.

Most commercial aircraft, particularly those with STOL characteristics, are not highly instrumented; any equipment would have to be installed for an ice floe tracking program. Since missions of this type will be conducted in the spring, however, ample preparation time will be available.





Sketch showing relative size

Fig.14 - Typical Microsite

5 RECOMMENDED SYSTEM

Selection of the most appropriate system requires balance between cost, accuracy and reporting time. The operational use will define the specifications; if incorrect assumptions are made about the requirements, the recommendations will be questionable.

5.1 Macro System

It is assumed that the macro system will be used for general tracking of an oil slick path by monitoring ice floe trajectory and that the buoy will be installed at or near the well site. The position accuracy should be a few kilometres, with at least three reliable positions given per day. Delays of 24 hours in reporting are acceptable.

It is clear that the most appropriate system will use Service ARGOS and the series of TIROS-N and NOAA satellites. OMEGA or NNSS devices retransmitting position data to the GOES or ANIK will improve reporting time, but this is not a significant benefit when compared with the high cost and complexity of these systems.

Table 1 summarizes the costs of the various macro systems. ANIK is not included because the buoys will require a high-power transmitter; and because of the complexity of the antenna, their use for air deployment is precluded.

Satellite-reporting buoys are available from a number of U.S. manufacturers. Units from Handar, Polar Research Laboratories (Figure 15) and American Electronics Laboratories will operate at low temperatures, although they are not built to specifications appropriate for a penetrometer design. If ice floe tracking is required before developmental work can be undertaken, however, instruments can be deployed by helicopter.

5.2 Micro System

The choice of a micro system is less definite over the choice of a macro system. Some systems of this type have yet to be proven reliable in an Arctic environment; however, the Luneberg lens is most attractive because of its low cost, rugged design, and because most of the larger surveillance aircraft are equipped with radar equipment which is directly compatible with the lens. Detection of conventional radar reflectors in rough ice has been particularly unsuccessful, but the Luneberg lens has an effective cross-section which is a factor of five larger than conventional designs and has, as a result, definite merit for this application.

TABLE 1 MACRO SYSTEMS - COST SUMMARY

		ARGOS	GOES NAVSAT	GOES OMEGA
Buoy & Penetrometer Cost:	10	$6,000	$32,000	$14,000
	100	3,500	28,000	10,000
	1000	2,000	24,000	8,000
Ground costs:		$20/interrogation	$500/yr.	
Ground Station Costs:		$50,000	$150,000	
Dimensions:		Cylinder, 1 m long x 10 cm diameter	Cylinder, 8 m long x 20 cm diameter	
Weight:		25 kg	50 kg	
Lifetime - deployed:		12 months	12 months	
- shelf:		Battery limited; otherwise infinite	Battery limited; otherwise infinite	
Permit:		From NESS & ARGOS Environmental sensing	From NESS Environmental sensing	
Deployment:		Air-droppable	Helicopter	
Recovery:		Probably not cost-effective; would require landing on ice	Helicopter	

Two proven systems for micro ice-floe tracking are the pulsed HF or VHF transmitters and the radar transponder. The latter is expensive (approximately $3,000) but is directly compatible with standard surveillance radar. The HF or VHF-pulsed transmitters require a special receiver and antenna to be installed in the aircraft, but the buoy cost is low ($500 including the cost of a penetrometer).

It appears that the best system would incorporate a Luneberg lens and an HF or VHF-pulsed transmitter into a penetrometer design. This will provide redundancy, is compatible with a wide variety of aircraft, and has a low unit cost (approximately $700).

For both the macro and micro systems, the package can be either 'soft' or 'hard' drop. There are distinct advantages with the penetrometer design in terms of simplicity of the missile and position stability of the buoy. While high 'g' transmitters have been routinely used in sonobuoy applications, there is considerable design work required for the ice floe tracking application.

Fig.15 - A Polar Research Laboratories Ltd. NIMBUS 6 Transmitter

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APPENDIX A

OIL SPILL TRACKING BUOYS - MANUFACTURERS AND SPECIFICATIONS

APPENDIX A: OIL SPILL TRACKING BUOYS - MANUFACTURERS AND SPECIFICATIONS

Based on the findings of this report, certain firms have been recognized as having the capability to develop macro and micro tracking systems for use with ARGOS Services and VHF transmitters, respectively. Several of these firms are listed, as well as the specifications of several direction tracking devices presently manufactured.

1 MANUFACTURERS

Ranked in the order of estimated capability, the following firms are those which could undertake the development of a macro buoy system using ARGOS Services:

Orion Electronics Limited
P.O. Box 58, Saulnierville
Digby County, Nova Scotia

Hermes Electronics Ltd.
40 Atlantic Street
Dartmouth, Nova Scotia

Briston Aerospace Ltd.
P.O. Box 874
Winnipeg, Manitoba

The following are the firms capable of undertaking the development of a micro tracing system using a VHF transmitter recommended to operate at 150 MHz:

Orion Electronics Limited
(address previously given)

Hermes Electronics Ltd.
(address previously given)

Davtron
Minneapolis, Minnesota
U.S.A.

Ocean Applied Research Corporation
10447 Roselle Street
San Diego, California
U.S.A. 92121

Sandia Laboratories
Albuquerque, New Mexico
U.S.A.

Luneberg lenses can be purchased from:

Maritime Facilities Co. Ltd.
31, Nishi-Gotanda 1-chome
Shinagawa-ku
Tokyo 141
Japan

2 SPECIFICATIONS

General specifications of a free-fall or parachute-retained ice-penetrating marker are as follows:

Frequency	150 MHz
Range	20 km (power out 100 mW)
Lifetime	9 months or more
Temperature	$60^{o}C$ to $40^{o}C$
Modulation	Pulsed, 100 mS on, 500 mS off
Air drop	Up to 500 meters onto ice (2000 G for 10 mS)

It is assumed that the satellite transmitter unit could be built in approximately the same configuration as the marker, but larger in scale.

Orion Electronics Limited presently produces and markets oil spill tracking buoys: a basic O.S.T. buoy with internal antenna for light oils and a heavy O.S.T. buoy with internal antenna for heavy oils; the receivers developed by Orion to track and locate these transmitters are the R8 and R9 models. The specifications are as follows:

Size	R8	4.5"L x 3.5"W x 3"H	(hand-held, compact folding antenna)
	R9	7.5"L x 5.25"W x 6.25"H	(rugged version of R8, seamless drawn aluminum carrying case, large and easy-to-read meter, remote audio and metering, several antenna packages)
Type		Crystal controlled, double conversion super-hetrodyne	
Frequencies		120 MHz - 310 MHz	
Channels		R8 - Maximum of 4 R9 - Maximum of 6	
DF Indication		Left/Right or signal strength	
Power		Internal - Two 9 V dry batteries	

External - 10-30 V negative ground, internal regulation; 22 mA low volume, 130 mA maximum volume

Options include:

Narrow filter ± 2.8 KHz installed in R8/R9

Waterproof, fixed antenna

Antenna rotator (120VAC)

High gain yagi antenna

Other special antennas for aircraft, helicopter and vehicle

Special buoy frequencies

Maritime Facilities Co. Ltd. makes available the Luneberg lens which is manufactured by Tokyo Keiki Co. Ltd. Performance characteristics and specifications are shown below:

1. Detectable Range

	Lens height from sea surface	On calm sea (miles)	On rough sea (miles)
12" Type	2 m (6.7 ft.)	5.5 ~ 6.0	4 ~ 5.0
	5 m (16.7 ft.)	7 ~ 8	4 ~ 5.5
8" Type	2 m (6.7 ft.)	4 ~ 4.5	3 ~ 3.5
	5 m (16.7 ft.)	5 ~ 5.5	4 ~ 4.5

2. Reflectivity

Horizontal Plane	360^{o} (360^{o})
Vertical Plane	approx. 40^{o} (35^{o})
Upward Direction	50^{o} (none)
Radar Cross-section	more than $10m^2$ (more than $2m^2$)

The LENSREF has no relation with polarization plane of the radar wave.

Note: Parentheses indicate 8" type

3. Weight

12" Type	less than 6.5 kg (14.4 lb.)
8" Type	less than 2.5 kg (5.5 lb.)