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POSITION FIXING FOR MARINE AREAS OF VICTORIA— MULTIDISCIPLINARY UTILISATION

By G. L. Benwell

Department of Surveying, University of Melbourne, Parkville, Victoria 3052

INTRODUCTION

Many users of the seas require accurate position fixing facilities. This paper examines the survey requirements of a large scientific marine study, in particular the position fixing methods and equipment. The depth of discussion is such that the material can be of general use to both surveyor and scientist.

In North America, Europe, South Africa, New Zealand and elsewhere, continental shelves have received considerable scientific attention in keeping with their increasing utilisation and with growing awareness of their potential. Despite the vast area of the continental shelf around Australia, very little coordinated research has been undertaken to date. In light of the scientific complexity of Bass Strait its resource potential both living and non-living, and its central position in relation to major population centres and shipping lanes, the Victorian Institute of Marine Sciences (VIMS) initiated a major study (VIMS 1978).

Early in 1978 VIMS set about to establish a Study Planning Committee to formulate proposals for such study. An invitation to participate in the project was extended to a wide number of organizations, institutions and individuals. The status of the responses varied substantially.

Significant study areas were outlined (VIMS 1978) as

1, bathymetry (1:250 000 mapping). 2, geological evolution and materials. 3, water movements and circulation. 4, atmospheric interactions. 5, chemical processes and transport. 6, sediment transport and geomechanics. 7, (a) continental shelf ecosystem—Plankton; (b) continental shelf ecosystem—benthic studies; (c) continental shelf ecosystem—fisheries. 8, coastal zone interactions. 9, the Bass Strait Islands. 10, continental shelf management and utilisation. 11, community interests and education.

For all topics except 1, 10 and 11 (for obviously different reasons) position fixing is an adjunct to the main task not an end in itself, and so should not dominate the operation. An ideal system would be one which covers the whole area of operations at all times, gives location to an accuracy that will satisfy the most exacting user, be largely automatic in operation and be of little cost.

EXISTING FACILITIES (Table 1)

Traditional navigational aids (navaids), such as lead lights, radio direction finding (RDF), celestial navigation, radar and dead reckoning have been chosen not to be the subject of this paper. Bass Strait is well served for traditional shipping (Navigational Aids Systems Inquiry 1974) by these navaids and placed in skilled hands are accurate. Within Bass Strait there are four radio beacons, Cape Otway, Cape Schanck, Cape Wickham and Gabo Island as well as 29 attended and unattended lights. (Navigational Aids Systems Inquiry 1974).

The oil exploration industry has self contained Decca Trisponder, Motorola Miniranger systems to service its own requirements. The coverage is shown in Fig. 1.

Global navigation systems such as Omega (and hybrids) and satellite systems may be considered as existing facilities but are discussed further below.

ALTERNATIVES

Traditional position fixing systems have been broadly classified (Ingham 1974) into

1, short range (25 to 100 km), 2, Medium range (150-1200 km), and 3, long range (>2000 km).

Many other classifications are possible; frequency, vertical (i.e. below surface, surface, airborne) or lattice propagation type. In this paper the latter classification is preferred.

TABLE 1
EXISTING FACILITIES WITHIN BASS STRAIT*†

VICTORIA	TASMANIA
Manned Lighthouses	
Cape Otway	Low Head
Cape Schanck	Swan island
Wilson's Promontory	Eddystone Point
Deal Island	
Point Hicks	
Gabo Island	
Unattended Lights	
Cape Wickham	Three Hummock Island
Currie Harbour	Hunter Island
Stokes Point	Highfield Point
Cumberland	Rocky Cape
Councillor Island	Table Cape
Split Point	Round Hill Point
Cape Liptrap	Mersey Point
Citadel Island	Waterhouse Island
Cliffy Island	Cape Barren
Hogan Island	Goose Island
	Cat Island
	Holloway Point

* Information derived from Commission of Inquiry into the Maritime Industry. Report of navigational aid systems. 1974. Parliamentary Paper No. 319.

† The State division is one from the above Inquiry and not the geographical State boundary.

As an introduction to the basic principles of electromagnetic position fixing (EPF) this section is devoted to an explanation under:

1. Range-Range systems; 2. Rho-Rho systems; 3. Hyperbolic systems; 4. Satellite systems.

RANGE-RANGE (Table 2)

This is the most accurate mode (to this day) due to the strong geometry of the pattern of intersecting circles (Fig. 4). It must be pointed out however, that less accurate fixing may eventuate if the geometry is allowed to degenerate. A typical system consists of a ship borne master and antenna (R/T unit) propagating a microwave which is received by a shore station (slave unit or remote) and retransmitted back to the master. The round trip travel time is converted to a distance and two such distances define the ship's position. A limited number of vessels can use the same remote, generally one to five. The number of remotes is also restricted varying from manufacturer to manufacturer.

For Bass Strait the range-range solution is unfortunately manpower intensive. From tests conducted in February 1979, aboard the M.V. Cape Don three remote stations covered less than 1/6 of Bass Strait. The remotes were deployed at Arthur's Seat, Bass Hill and Mount Oberon (Wilson's Promontory). All range-range systems depend on line of sight conditions and range is proportional to elevation of both remote and master (R/T unit). It is not always possible (time and expense wise) to occupy the highest peak and a six hour rough walk (with remote and 3 12V DC batteries) into Mt. Latrobe was the reason for selecting Oberon. (See Fig. 2).

For a scientific study, range-range systems are not attractive unless the study is confined, laterally along the shoreline or to a limited distance from remotes (i.e. < 150 km). The expected coverage of a range-range system in Bass Strait is shown in Fig. 3. The coverage shown in Fig. 3 requires the occupation of 27 stations, 2 or 3 at any one time. An additional disadvantage of the range-range system is that the pattern cannot be monitored, although traditional surveying methods may be used to calibrate remotes. It is recommended that this calibration be carried out within the study area and over the approximate range of the survey. Dynamic test measurements have been proposed by others (Ridge 1973) as a method to lessen the effect of unknown refractive index and propagation speed.

RHO-RHO (Table 3)

These systems do not require the ship to carry a transmitter. Instead, the shipboard receiver and both shore transmitters are controlled by precise atomic frequency standards. Once synchronised in both rate and epoch with the shore transmitters, the receiver monitors phase change due to ship movement, which in turn is converted to change in range (which is added to the initial synchronised range). The measurement of range change, is, in this case, achieved proportional to a full wavelength change whereas in range-range systems it is half of a wavelength. Measurement accuracy may be slightly inferior to range-range because of very small differences in frequency of the atomic standards. Such systems are in world wide use particularly Loran-C and Decca Lambda. The pattern can be monitored at a stationary receiver on shore.

A draw back of this system, particularly with Telecom installations at Arthur's Seat and Mt. Oberon, lies in the several frequencies used. It has

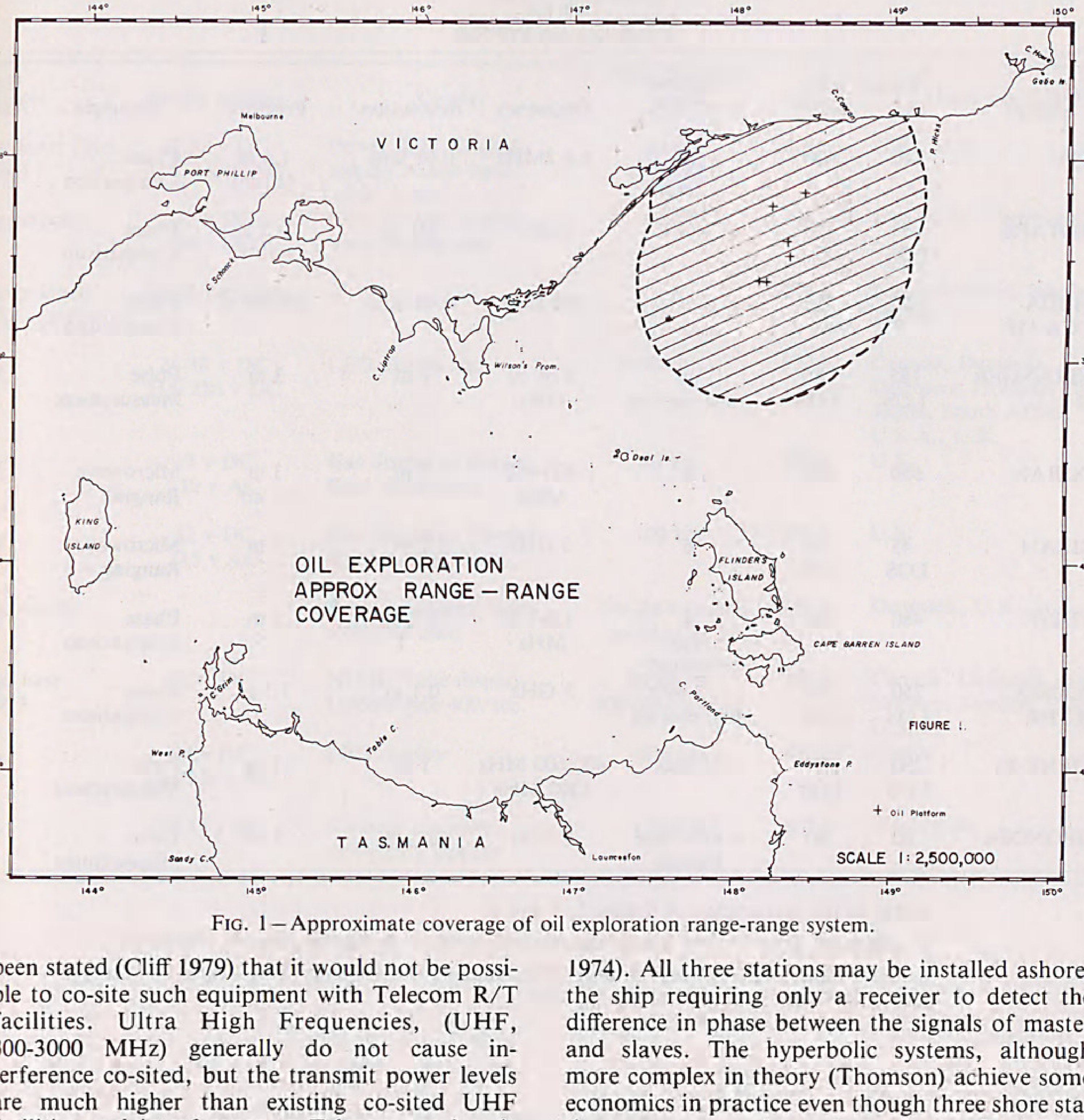

FIG. 1 – Approximate coverage of oil exploration range-range system.

been stated (Cliff 1979) that it would not be possible to co-site such equipment with Telecom R/T facilities. Ultra High Frequencies, (UHF, 300-3000 MHz) generally do not cause interference co-sited, but the transmit power levels are much higher than existing co-sited UHF facilities and interference to Telecom services is possible. Equipment operating at High Frequencies (HF, 3-30 MHz), as a general policy, is not permitted at R/T stations. Operation of any system at "reasonable" separation from Telecom R/T sites would of course be satisfactory. Preference for Telecom sites is inferred here, due to geographic location and elevation, though the latter is of less importance.

HYPERBOLIC (Table 4)

In many ways similar to Rho-Rho and others have grouped them together (Leahy 1979, Ingham 1974). All three stations may be installed ashore, the ship requiring only a receiver to detect the difference in phase between the signals of master and slaves. The hyperbolic systems, although more complex in theory (Thomson) achieve some economics in practice even though three shore stations, a master and two slaves are involved. They are intrinsically multiuser systems. Position of constant phase difference for ranges from any set of master and slave units lie on a hyperbola. A family of these curves can be established (as with sextant graph sheets) and forms a "lattice" (for production of lattices, Royal Australian Survey Corps 1978), on which the ship's position can be tracked. The "lane" width of the lattice is not constant as can be seen from Fig. 4. The precision will deteriorate with lane width, which occurs with increase in distance from the shore stations. The pattern geometry is weak (intersection angle varies

TABLE 2
RANGE-RANGE SYSTEMS

System	Range (km) Day	Night	Number of uses	Frequency	Resolution	Precision	Principle	Used in Australia
ARGO	740	400	12	1.6-2MHz	0.01 lane	1.4 m (10 m)	Phase Comparison	Yes
AUTOTAPE	150 LOS	150 LOS	Single	3GHz	0.1 m	0.5 m $\pm 10^{-6}$	Phase Comparison	No
LAMBDA DECCA 12f	650	350	Single	150 KHz	0.01 lane	30-100 m	Phase Comparison	No
MINIRANGER III	185 LOS	185 LOS	10 time sharing	5 or 10 GHz	1 m	3 m	Pulse Measurement	Yes
MAXIRAN	650	650	6	420-450 MHz	1 m	3 m (11 m)	Microwave Ranging	No
MINIRAN	45 LOS	45 LOS	6	3 GHz	1 m	2 m	Microwave Ranging	Yes
RAYDIST	480	280	4 (Hyp. unlimited)	1.6-3.3 MHz	0.5 m	3 m	Phase Comparison	Yes
TELLURO-METER	250 LOS	250 LOS	1, 3 with time sharing	3 GHz	0.1 m	$1.5 \pm 3 \times 10^{-6}$	Phase Comparison	No
TRIDENT III	250 LOS	250 LOS	50 Max	400,600 MHz 1300 MHz	1 m	3 m	Pulse Measurement	No
TRISPONDER	80	80	4 with time sharing	9 GHz	0.5 m	3 m	Pulse Measurement	Yes

NOTE: In the preparation of Tables 2, 3 and 4:

1. Precision figures taken from manufactures notes. User figures given in (brackets).
2. Information derived from: Eaton 1975; Haugh 1975; Ingham 1974; Leahy 1979; Thomson; U.S. Department of Commerce, 1977.

TABLE 3
RHO-RHO SYSTEMS

System	Range (km) Day	Night	Number of uses	Frequency	Resolution	Precision	Principle	Used in Australia
LORAN-C	2000	2000	Unlimited	100 kHz	25 m	150 m	Pulse and CWPC	No
OMEGA	Complete		Unlimited	10-30 kHz	500 m	2-4 km (4-10 km)	CWPC	Yes

Decca 12 F Lambda and Miniranger III may also be used in Rho-Rho mode.
CWPC = Continuous Wave Phase Comparison.

TABLE 2 *(continued)*
RANGE-RANGE SYSTEMS

Notes	Supply voltage	Display	Max. platform speed	Cost	Users world wide
94 m lanes Hyp. ptional)	22-32 v DC 115/230 v AC	Power light. Digital display Alarm light. 24 hr. clock	20 kts or 80 kts (opt)	$140 k	U.K., U.S.
so hyperbolic	12 v DC 24 v DC	NIXIE Tube display Vary display rate	160 kts	$90 k	Iran, U.S., Venezuela
0-600 m lanes o-Rho – unlimited ers	Diesel powered			$250 k	North Atlantic, North Pacific
	24-30 v DC 115/230 v DC	LED display etc.	>Mach 1	$27 k	Canada, Denmark, Finland, Germany, Holland, Italy, Japan, South Africa, U.S.A., U.K.
	12 v DC 110 v AC	Gas discharge display Rack mountable	80 kts	$76 k	U.S.
	12 v DC 115 v AC	Gas discharge Display Update rate 10/sec.	130 kts	$28 k	U.S.
so hyperbolic		Power indicator lights Rotating dials	No limit (tested to MACH 2)	$70 k	Denmark, U.K., U.S.
eased here ne 1979	12 v DC	NIXIE Tube display Update rate 400/sec.	30 kts or 500 kts (option)	$30 k	Canada, Denmark, Nigeria, Norway, Sweden, U.K., U.S.A.
	24 v DC 110/220 v AC	LED display	600 kts	$90 k	France
	22-32 v DC	Variable intensity numertron display	>Mach 1	$27 k	Worldwide

TABLE 3 *(continued)*
RHO-RHO SYSTEMS

Notes	Supply voltage	Display	Max. platform speed	Cost	Users world wide
vt. maintained	110/220 v AC			Variable due to coverage	North Atlantic & North Pacific
o hyperbolic	110/220 v AC	Alarm, chart & roller lane count	500 kts	$3 k (receiver)	Global

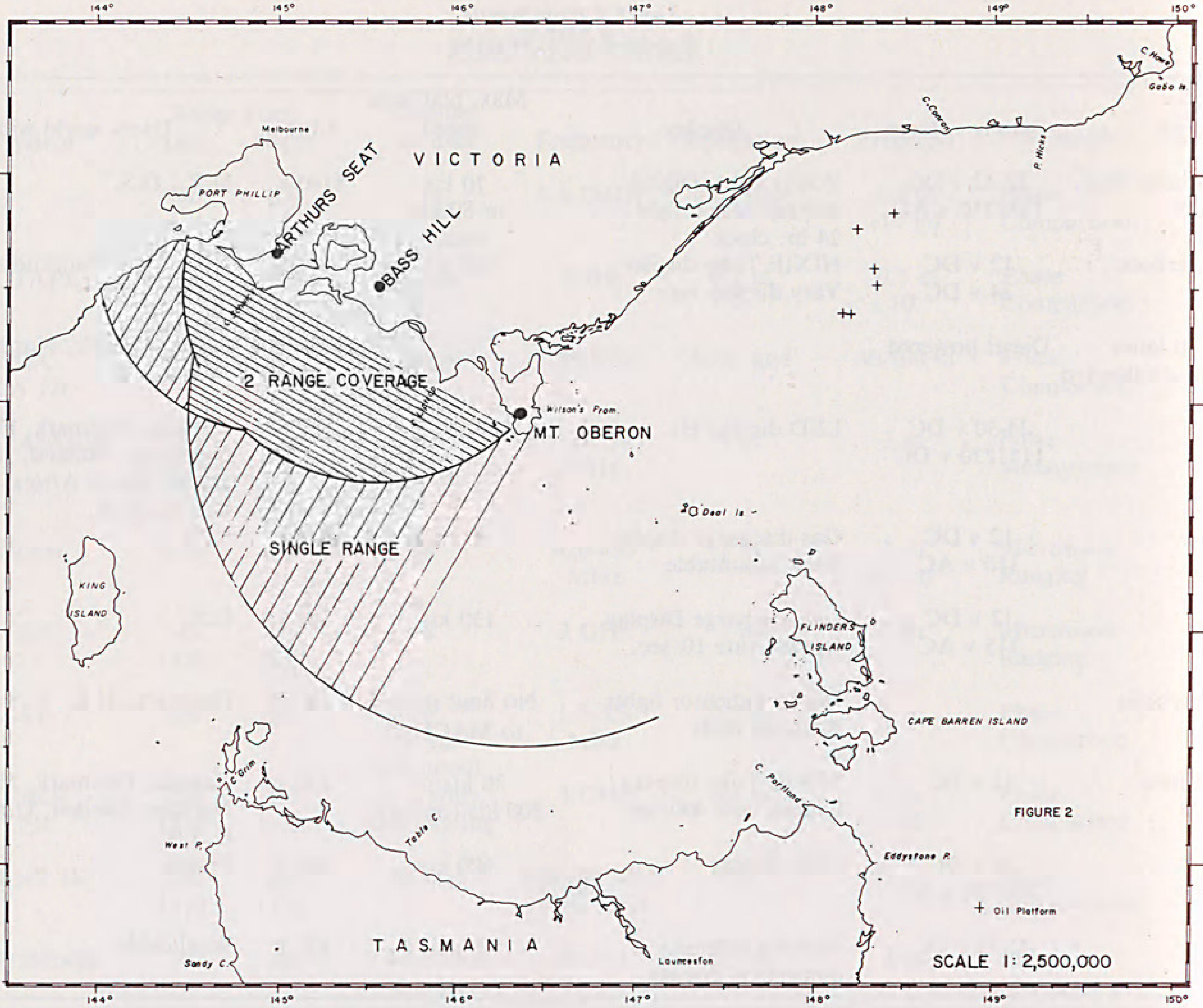

FIG. 2—Range-Range coverage with 3 remotes, VIMS cruise February 1979.

rapidly), but there is no limit to the number of users, and the receiver is much less expensive than a Rho-Rho receiver. All Medium Frequency (M.F., 300 KHz-3 MHz), Low Frequency (L.F., 30-300 KHz), and Very Low Frequency (V.L.F., 10-30 KHz) systems can be used in hyperbolic mode.

Omega possibly has the longest range of the hyperbolic systems. The seven existing Omega installations are in:

Argentina, Japan, Liberia, La Reunion (a French Island off the East Coast of Africa), Norway, Hawaii, U.S.A.—North Dakota. Construction of the eigth and final installation in East Gippsland is due to commence soon. The transmitted signals from one of the Omega stations can be visualised as a series of concentric circles or lanes. If it is assumed that at each of these circles the phase angle of the received Omega signal is the same as the phase of the signal at the station transmitter, then the distance between the circles is proportional to the wavelength (16 nmi, for a 10.2 KHz transmission). One position fixing technique computes a position fix by intersecting the measured position within three such lanes from three Omega transmitters. In order to navigate, the Omega receiver must know the correct land number of each received Omega transmission.

"The stated accuracy goal of the Omega system is 1 nmi root mean square error (rms) probability during day conditions and 2 nmi rms at night" (Herbert 1977, Maenpa 1978). Navigation accuracy is often much less than this goal but it forms a very useful system, alone or as a satellite/Omega hybrid.

SATELLITE

There are essentially three satellite navigation or positioning methods in use today (Hart 1968).

The Doppler method as developed for the U.S. Navy Navigation Satellite System. The system depends upon measurement of Doppler shift of a received satellite signal to produce a fix and the basis of the initial calculations is on an assumed position. The resultant precision is dependent upon the knowledge of orbital parameters on the first hand, while antenna placement, ship motion and reflected wave may also lead to a decrease in precision. Typical of the Doppler satellite navigators are those produced by Magnavox (Stansell 1978) and Decca.

Visual methods were also used, primarily for ground surveying and it is not expected that such will be used extensively in any marine scientific study.

The third basic method is that of ranging or trilateration between ground positions and the satellite. The U.S. Army's Sequential Coalition of Range (SECOR) (5) system requires specialized equipment but at this time is not planned to be used at sea.

All field operations of the navigators are extremely simple and the equipment consists of master unit (a receiver) and antenna/preamplifier. Geocentric coordinates are derived from doppler shift via the broadcast ephermeris (WGS72 datum). It will be recommended later that the Australian Map Grid (AMG) be the adopted coordinate datum for the study and consequently conversion from WGS72 to Australian Geodetic Datum (AGD) (hence AMG) must be known. Such conversions are available (Natmap 1978).

During the scientific cruise in February 1979 (Fig. 5) a Magnavox MX1107 was tested. Time in-

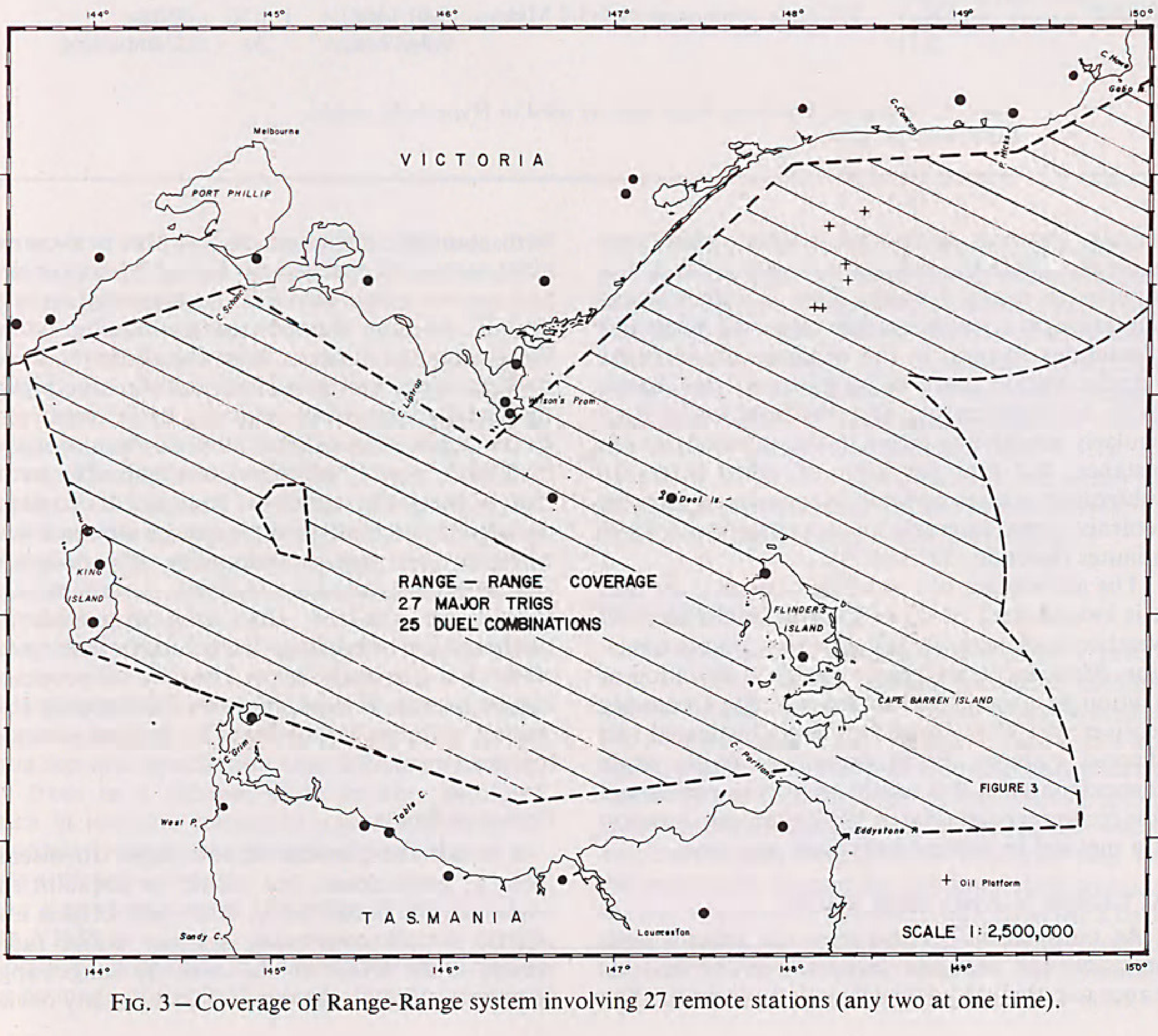

FIG. 3 – Coverage of Range-Range system involving 27 remote stations (any two at one time).

TABLE 4
HYPERBOLIC SYSTEMS

System	Range (km) Day	Night	No. of uses	Frequency	Resolution	Precision	Principle	Used Aust
HI-FIX/6	350	350	Unlimited	1.6-5 MHz	0.01 lane	5 m	Phase Comparison	Ye
HYDROTRAC	450	220	Unlimited	1.6-3 MHz	0.8 m 0.01 lane	?	Phase Comparison	No
LORAC	480	160	Unlimited	1.6-2.5 MHz	0.001 lane	20-40 m	Phase Comparison	No
OM1 System	480	280	Unlimited	1.6-1.8 MHz	0.001 lane 0.2 m	1 m	Phase Comparison	No
SYLEDIS	120 LOS	120	Unlimited	420 MHz	0.1 m	1 m	Pulse Comparison	No
TORAN	550	250	Unlimited	1.6-3.0 MHz	0.01 lane 0.4-0.9 m	1 m	Phase Comparison	No

Raydist, Decca 12f Lambda, Argo may be used in Hyperbolic mode.
LOS = line of sight.

tervals between acceptable passes, which are generally related to latitude, ranged from a few minutes to nearly 7 hours. This can place severe limitation on scientific sample rates and times. For continuous fixation in the dynamic situation the velocity vector must be supplied to the master (with microprocessor) and the solution is particularly sensitive to errors in this information for instance, 0.2 nmi per knot of speed error. In subsequent cruises updated Magnavox equipment returned time intervals of approximately 70-90 minutes (latitude, 39°S-40°S).

The advantages of a satellite navigator are that it is independent of shore stations, multi-user, all weather and with reasonably predictable precision. Manufacturers claim a standard deviation of fixation of around 100 m for a single frequency receiver and 37 m for the more sophisticated two channel systems. From experience (with single channel systems) this would seem very optimistic. It is recommended (Hatch 1976) that translocation is a method to achieve improved precision.

ACCURACY AND PRECISION

As outlined earlier the scientists require both precision and accuracy; accuracy in the first instance and thereafter for relocation precision. The term standard deviation of location is a convenient means of comparison (bring both precision and accuracy into account). As a general "rule of thumb" for any shore-based positioning system the greater the distance from the shore the lower both accuracy and precision, and thus the higher the standard deviation. This can be demonstrated by the application of error ellipses. An alternative method is to plot "contours" of predictable errors (for a particular constant multiple of standard deviation). Such an example can be seen in Fig. 6 where in this case the reliability of a proposed Decca Navigator chain can be determined. It should be realized that this approach of mathematical modelling lends itself, with great ease, to a pre-analysis of a survey or proposed survey system. It does, however, presuppose that sources of error can be made to fit such a model (or vice versa).

CAUSES OF ERROR

It is not the purpose of this paper to discuss these in great detail, but rather to acquaint the reader, in the broad sense, with their origins and effects. As all positioning systems utilise radio waves, from UHF in the case of range-range systems to VLF in the case of Omega, any devia-

TABLE 4 *(continued)*
RHO-RHO SYSTEMS

Notes	Supply voltage	Display	Max. platform speed	Cost	Users world wide
lanes also e-Range	22-32 v DC	Power lights. Alarm lights. Filament type numeric indicator	460 kts	$80 k	U.K., U.S., Canada, Finland, Germany, N.Z., Norway, Poland, Sweden, U.S.S.R.
developed	22-30 v DC 115/230 v DC	Power lights. Digital display. Alarm, Hold, selected display	38 kts	$80 k	U.K., U.S.
Range-Range lanes	115 v DC	Power lights, drum display long/lat direct	80 kts	$185 k	U.K., U.S.
Range-Range	12 v DC 24 v DC	Power lights. Panel illumination.	80 kts 160 kts (opt)	$150 k	New System—introduction
	22-30 v DC	LED display	190 kts	$53 k	Denmark, France, Holland, Italy, Singapore, Spain, South Africa, U.K.
	22-30 v DC 110/220 v AC	NIXIE tube display Alarm lights	270 kts	$60 k	Denmark, France, Iceland, U.K.

tion in wave path will adversely affect the measurement accuracy. In line of sight equipment (mostly range-range systems) this deviation is usually ground reflected waves. This will cause errors due to longer path length and/or cause the signal to be blanked out (often referred to as range holes). With long range systems it is the upper atmosphere and the so called skywaves that are important. Diurnal change in the ionosphere and the nightly disappearance of an absorbing layer just below it, cause significant interference problems to lower frequency radio measuring systems. This is apparent from Table 4 where most equipment has a diminished range at night.

As electromagnetic waves travel at the speed of light (i.e. 299, 792 ± 12 m sec^{-1} in a vacuum 1974) it is important to know or at least be able to determine this velocity. The velocity is affected by attenuation and retardation (the difference in velocity from in a vacuum to in another medium) which in turn are related to upper atmospherics (particularly the troposphere) and surface conductivity (refractive index).

As a consequence of the author's involvement with VIMS it is hoped that measurements of the velocity of propagation and/or related variables can be made in the field season, January to April 1980. Additional, but not all, sources of error are: a, Phase lag (for HF bands when paths are over land and sea); b, Ill directed antennae (Very High Frequency (V.H.F., 30-300 MHz); c, equipment with sector antennae); d, Ambiguities (hyperbolic systems); e, Solar radiation; f, Predicted Propagation Correction (PPC) (Omega); g, Velocity vector and orbital parameters (satellite sec. 4.6.7); h, Reliability of control coordinates; i, Accuracy of propagation frequencies; j, Zero or index error; k, Precision of lattice charts and corrections.

THE REQUIREMENTS

Scientists have varying requirements on precision. However studies within the water column must eventually be closely related to bathymetry. The surveyor would be negligent if he did not attempt to achieve a precision such that bathymetric data is of use to both scientist and hydrographer (Cooper 1969). During the collection of water temperature and salinity data, precision may be less important. During the February 1979 cruise it was not uncommon to collect such data for 2 to 3 nautical miles. It was subsequently considered to have come from a point location. In dynamic mode this sampling continued around the clock.

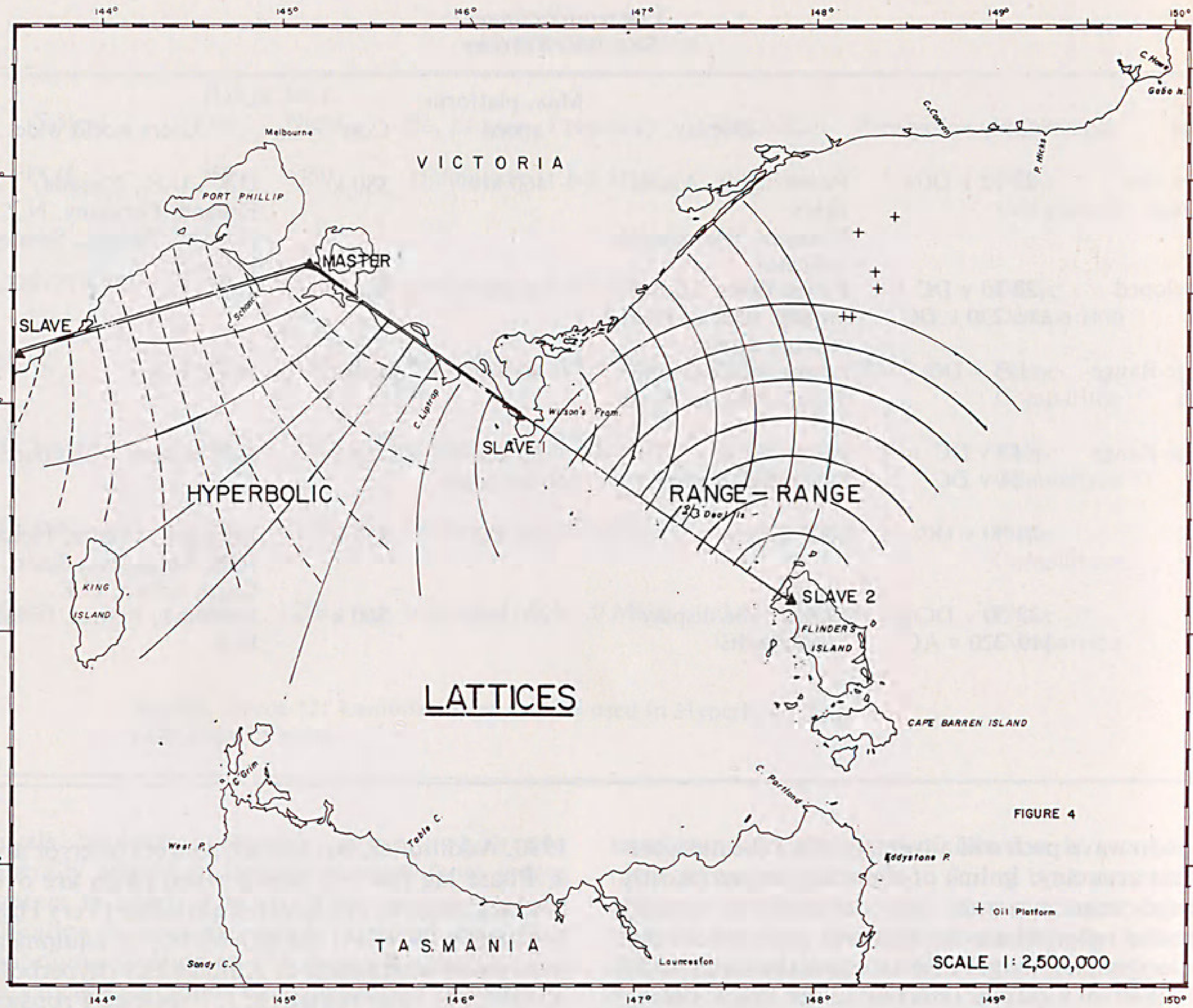

FIG. 4—Examples of Hyperbolic and Range-Range lattices.

The study (VIMS Report 1) ranges from the Victorian to Tasmanian coasts, from King to Flinders Islands. Coastal environments and island ecosystems will also form an important part of the study. For core and grab sampling, vertical water column sampling, sediment transport and others, precision in relocation will be of prime importance. For relocation and grid plotting real time coordinate determination is also important.

Therefore, the surveyor will have to provide a system (or hybrid system/s) that in turn provides the highest possible precision, 24 hour coverage, total area coverage, precision relocation and real time solutions. In more general terms (Thomson) the surveyor must consider;— a, the position accuracy required; b, the area in which the study is to be carried out (distance from shore, approximate depth of water, size of vessel likely to be used, etc.); c, dynamic and/or post-mission positioning requirements; d, availability of shore control; e, interfacing requirements with other instrumentation (e.g. echo-sounder, side scan sonar, sub-bottom profiler, gravimeters, magnetometers, etc); f, position methods (e.g. geometry, quantities to be measured); g, duration of surveying operation and periods during which positioning is required (e.g. 24 hrs/day, all weather); h, the availability of necessary measurement instrumentation; i, the availability of necessary computational devices to compute positions (and plot them) and/or accuracy estimates; j, cost, both capital and running.

THE FUTURE

The system that is finally adopted will more than likely be determined from a compromise between cost and efficiency. Up to now positioning has been determined by satellite navigator (kindly lent by Hawker Pacific Pty. Ltd.) but even here the scientists have reservations. To quote a VIMS report (79-K-1):

'The Sat Nav system still requires manual velocity and heading input, and is thus open to errors arising from lack of communication or corrupted data. An automatic log/gyro system would function more reliably. Some parts of Bass Strait experience very strong tidal streams. It is pointed out that no Sat Nav system (without Doppler Sonar) can allow for these disturbances continuously. Accordingly, optimum position location requires some long distance range-range system (ARGO or DECCA Navigator). The ultimate would be a network chain of some kind but in the current political and economic climate this utopia is beyond the horizon. In the meantime, a range-range system (VIMS and the University of Melbourne now jointly own a Miniranger III with processing and plotting facilities) could be used for close in shore details and the Satellite navigator could be used (updated and automated) for general positioning and longer range work.'

The VIMS report (79-K-1) continues: 'For navigation the ship's navigator used AUS 358 Wilson's Promontory to Point Hicks and Flinders Island, published by the Hydrographic Service R.A.N. This chart has spot soundings in fathoms and a scale of 1:300 000. Some of the data on this chart are inaccurate, particularly in depths greater than 100 fm.'

If the data collected on VIMS cruises is to be used by others it is essential that a data bank be established. The value of same is well known. It

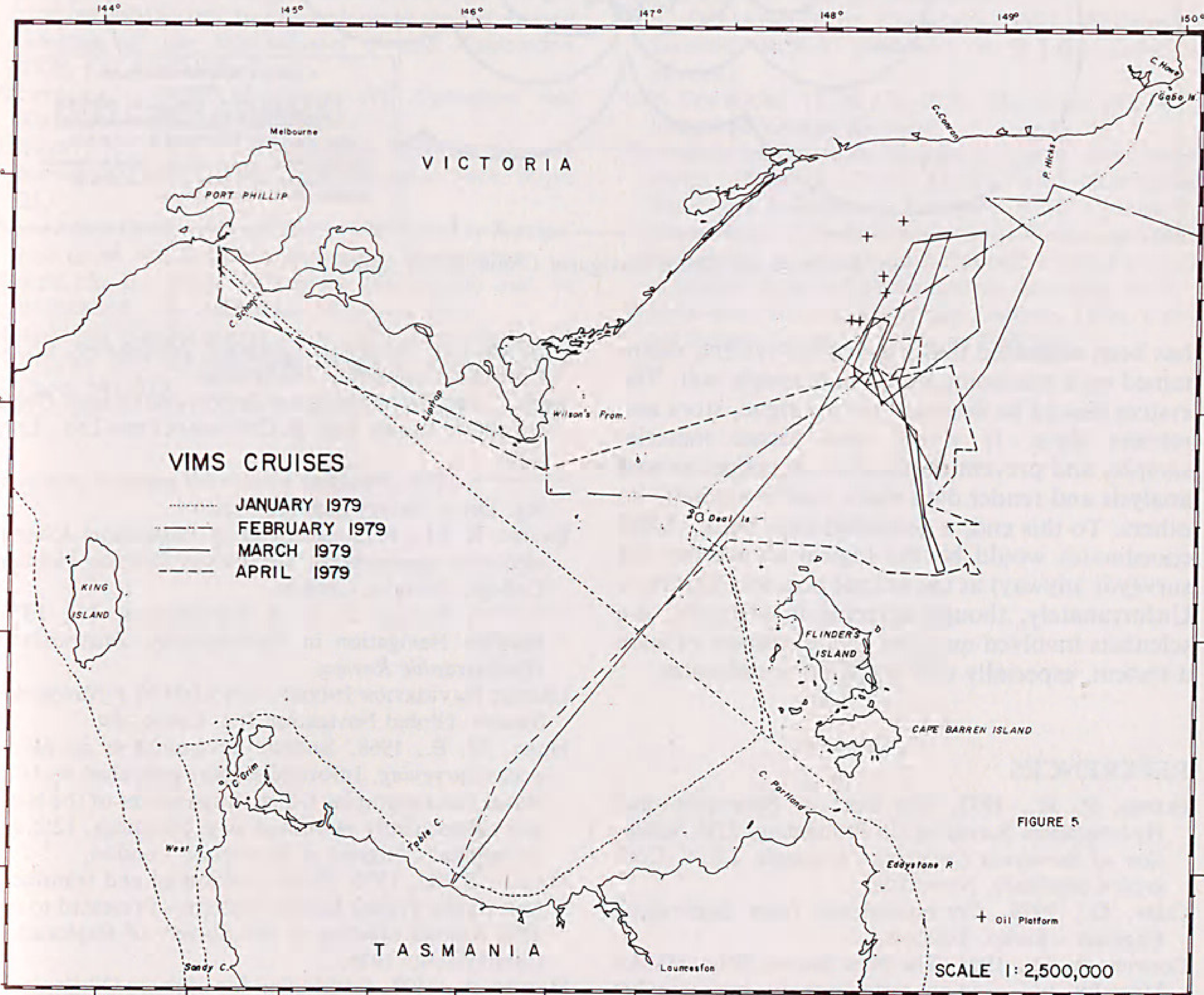

FIG. 5—VIMS cruise patterns 1979.

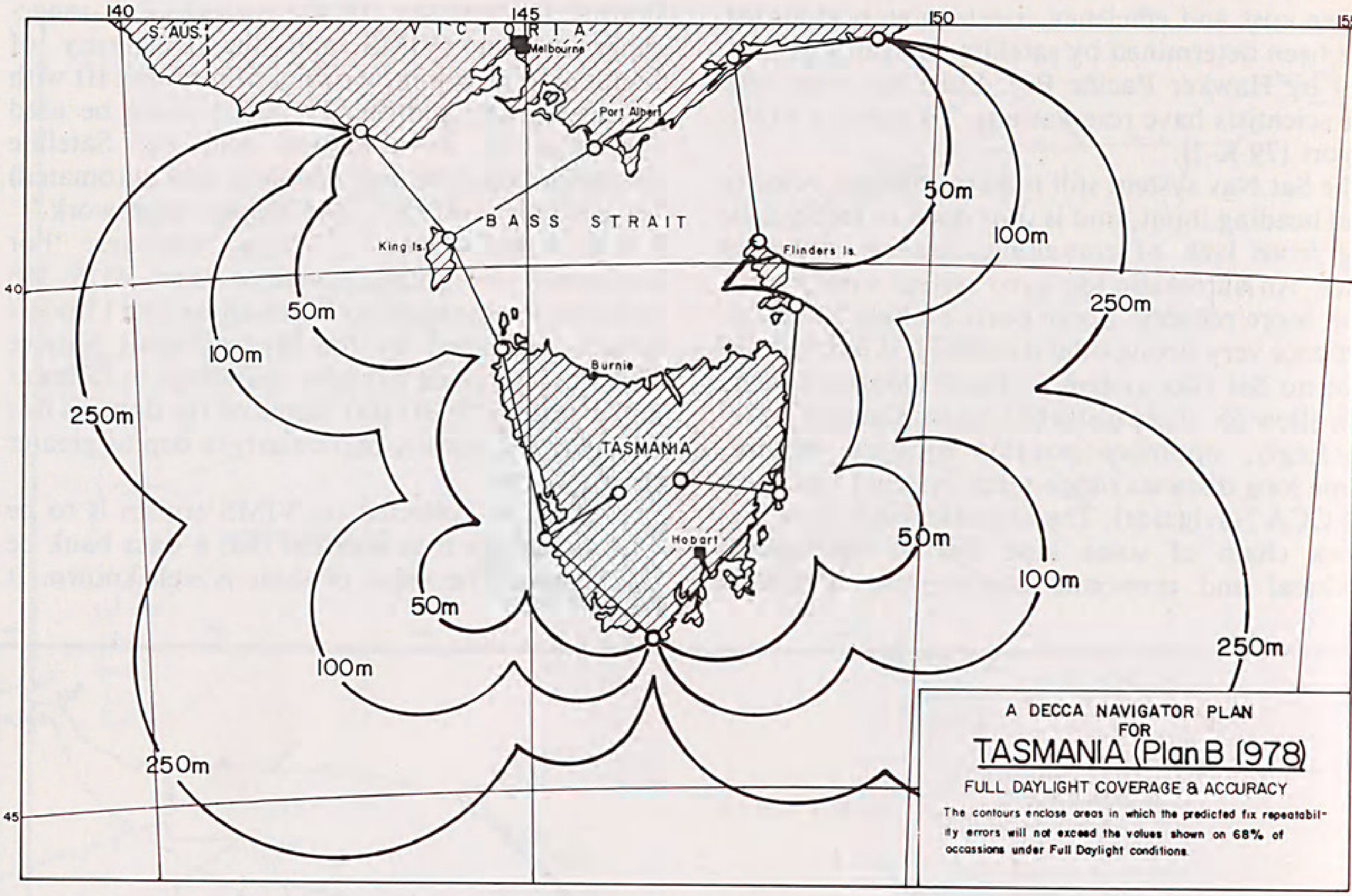

FIG. 6—Proposed Decca Navigator Chain. Error Quantities.

has been suggested that a geocoded system, maintained on a minicomputer, would amply suit. The system should be designed to catalogue, store and retrieve data. It would also locate material samples and prevent duplication of collection and analysis and render data more readily available to others. To this end, a geocoded data bank, AMG coordinates would be the logical choice (by the surveyor anyway) as the unique position identifier. Unfortunately, though agreeing in principle, the scientists involved question the usefulness of such a system, especially one based on coordinates.

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