# MARINE GEODESY

by James C. Tison, Jr.
Director, U.S. Coast and Geodetic Survey

Reprinted, by kind permission, from "Bulletin Géodésique, being the Journal of The International Association of Geodesy", No. 88, 1 June 1968.

## FOREWORD

Perhaps the most lucrative field for exploration and exploitation remaining in the world today consists of the vast ocean expanses which cover nearly three-fourths of the surface of the globe. The importance of marine science cannot be overstated. It involves observation, description and understanding of physical, chemical and biological phenomena of the marine environment. The value of the potential resources of the sea is incalculable. And the study of the phenomena of the sea, coupled with meteorology and solid-earth geophysics could very well result in long-range environmental prediction and modification. Thus marine geodesy was born of necessity.

## GENERAL STATEMENT

The practice of marine geodesy is in its infancy and, thus, from lack of experience, no authoritative statements can be made as to the best methods and the accuracies obtainable for the determination of positions and elevations at sea. This paper, therefore, contains material more of a speculative nature and admittedly raises more problems than it solves. But as in any venture which must involve new approaches, it is well to consider established instrumentation and methods presently in use, assess the accuracies which have been attained and consider any refinements that may be reasonably expected in the future extension of geodetic control over the ocean areas.

## GEODETIC POSITIONING AT SEA

To proceed in an orderly manner, we might consider this problem as it applies to an ascending order of distances out from the coastline. First, we shall consider only those distances which can be surveyed by direct line of sight using shore-borne instrumentation. This would include distances up to perhaps 5 nautical miles from the coastline along which there are no topographic elevations to perhaps 30 or 40 nautical miles from a coastline which does have high eminences that permit longer lines of sight.

One of the important requirements in the United States will be the delineation of state boundaries as these are extended seaward. Once such a boundary has been legally defined and accepted by the two states involved, the problem is to either physically define the boundary by bottom markers or to devise a method by which a ship can be placed on boundary as it is legally defined. As the resources of the continental shelf are developed, the question of state boundaries will become of extreme importance. In as much as these boundaries extend only three nautical miles from the ordinary low water line, accurate positioning can be obtained by the use of shore-borne equipment; that is, by triangulation, electronic distance measurements, or a combination of both. Accuracies obtainable should be under one foot which is probably far better than bottom markers can be placed or a ship can be manœuvred directly over a bottom marker or into a predefined position.

The production of oil in the waters off the Gulf coast has already demanded high accuracy positioning at sea. The Bureau of Land Management has layed out a system of lease tracts consisting generally of 5 000-acre squares which form the basis for the division of royalties realized from the production of oil. Actually in this area classical triangulation has been used to extend control. This is possible because of drilling platforms on which theodolites can be mounted for the triangulation observations. This work has been carried out as far as 60 or 70 miles from the coastline.

As the development of the continental shelf proceeds further out to sea beyond the line of sight from the shore, other methods for positioning must be considered. There are many types of electronic fixing devices which will produce accuracies under optimum conditions of at least 100 feet at distances up to 100 nautical miles from the coastline. It is estimated that by exercising particular care, these systems might be capable of position accuracy of the order of 50 feet. The two greatest sources of position error of the electronic fixing method are the geometry of the system, i.e. the angle of intersection of the lines of position, and the variation in the propagation velocity.

Some existing electronic positioning systems will provide control of as far as 1 000 nautical miles, but of course the accuracy at these ranges falls off considerably, principally because of the propagation velocity problem.

For areas of great distances of several hundred up to two thousand nautical miles from the coastline, resort may have to be made to observations of artificial earth satellites such as in the Navy Navigation Satellite System. This system uses satellites which are in approximate circular polar orbit at an altitude of roughly 1 100 kilometres. It is planned that enough of these satellites will be put into orbit to provide roughly 10 to 15 opportunities for positioning per day at any point in the ocean areas. The estimated total error of the system is 100 metres standard deviation. This does not include the error in determining the navigator's velocity, but a total error of one-tenth nautical mile is presently contemplated. The system is based on Doppler frequency measurements and the fixes resulting are related to an adopted earth centered ellipsoid and, therefore, not to any particular geodetic datum. It should be pointed out here that upon completion of the world satellite triangulation network, it will be possible to place all land masses on a single geodetic datum. This will be a boon to all worldwide position fixing systems.

There are certain applications of underwater acoustic positioning which depend on a series of arrays of active bottom markers. This method of positioning will permit high relative accuracies of a few metres in limited areas anywhere in the ocean, but the absolute positioning of this system will have to be provided by other means, such as the Navy Navigation Satellite System or some long-range electronic fixing system.

## ELEVATIONS AT SEA

The idea of elevations at sea at first thought appears to be on the ridiculous side in that the elevations on land are usually defined as heights above mean sea level, but the problem is not that simple.

Mean sea level is defined by geodesists as the equipotential surface which the oceans would assume if the only forces acting upon them were the earth's gravitational force and the centrifugal force set up by the earth's rotation. Unfortunately there are many other forces, such as the tidal forces of the sun and the moon and the meteorological forces such as wind, atmospheric pressure and others which vary from time to time and place to place. These produce an ever changing surface of the sea which is very difficult to relate to the ideal equipotential surface of the geodesist's mean sea level. It is true that the differences between the actual surface of the sea and the equipotential surface are of a rather small order, probably only a few metres at most, still some oceanographers are interested in what they call the slope of the sea and its position above or below the equipotential surface at any given time at a given place. No solutions to this problem are offered, but in the run of time we can hopefully expect that some method will be devised by which this problem can be solved.

## GRAVITY MEASUREMENTS AT SEA

Such measurements have been made since the early 1920's which at that time required the use of submarines. However, the past decade or so has seen the development of surface seaborne gravity meters which have a potential instrumental accuracy of ± 3 mgals under ideal operating conditions. This might be considered the standard deviation to be expected in open ocean surveys. However, uncertainty in ship's velocity required for the Eotvos correction indicates that this value should be increased to ± 5 or ± 7 mgals.

Improved underwater meters indicate surveys can be conducted to depths of 1 000 metres with accuracy of 0.02 mgal. Even under the most adverse conditions, accuracy of 0.1 mgal is feasible. The difficulty here is reducing these data to sea level. The lack of adequate tidal and depth information, coupled with errors in determining the position of the submerged meter, and knowledge of the true gravity gradient are some of the principal problems.

Effective use has been made of underwater gravity meters on the continental shelf for mineral exploration and for establishing reference ranges for evaluation of underway shipboard systems. Recently the Coast and Geodetic Survey, as well as others, established such gravity ranges on the continental shelf of both the east and west coast.

One of the greatest lacks of geodetic data is that of gravity values over the open ocean in order to define the geoid-spheroid relationship. It has been proposed that orbiting satellites with ranging equipment might determine the shape of the ocean surface by continuous ranging between the satellite and the ocean surface. It is estimated that accuracies of the order of 5 or 10 metres might be expected as a mean error in determining the surface of the ocean by combining the known altitude of the satellite at any given time with the range requirements.

## DEFLECTIONS OF THE VERTICAL AT SEA

Astro-geodetic deflections of the vertical were determined aboard ship traversing the Puerto Rico Trench. The astronomical observations were made by the Geon System which includes a kind of stabilized platform, and geodetic positions were determined by electronic navigation.

The Geon System can indicate the gravity vertical at sea with a standard error of about 15 seconds of arc. This, coupled with the geodetic determination, will furnish deflections of a sort, but the accuracy which is partially dependent upon the geodetic position is hardly enough to be of much value. Hopefully a much more refined method of astronomic determinations of positions will be developed in the future, as well as that of geodetic positioning, particularly far out to sea. Such observations are required in determining the geoid-ellipsoid relationship at sea with much greater detail than that produced by dynamic observations on an earth satellite.

## SUMMARY

This discussion only scratches the surface of the subject of marine geodesy. Its sole purpose is to bring into focus some of the problems and the requirements which will arise as a result of the exploration of the sea. It seems clear at least at this time that the geodetic accuracies obtainable over the ocean areas in general will be at least one or two orders of magnitude less than those obtainable on land. But modern science which has produced the atom bomb, artificial satellites, soft landings on the moon, and other highly sophisticated accomplishments, might be expected in the future to provide some means of obtaining much higher geodetic accuracies at sea than can now be foreseen.

## REFERENCES

[1] Panel on Oceanography, President's Science Advisory Committee, Effective Use of the Sea, Superintendent of Documents, June 1966.

[2] Hickley, T.J., R.R. Ross and A.A. Ferrara : Shore-based Electronic Systems for Marine Geodesy. Proceedings, First Marine Geodesy Symposium, Columbus, Ohio, September 1966.

[3] Orlin, H. : Marine Gravity Surveying Instruments and Practice. Proceedings, First Marine Geodesy Symposium, Columbus, Ohio, September 1966.

[4] Spiess, F.N. : Navigation using Underwater Acoustics. Proceedings, First Marine Geodesy Symposium, Columbus, Ohio, September 1966.

[5] Newton, R.R. : The Navy Navigation Satellite System. Proceedings, First Marine Geodesy Symposium, Columbus, Ohio, September 1966.

[6] Arx, W.S. von : Level-surface Profiles across the Puerto Rico Trench. *Science*, December 30, 1966.