SEA-SURFACE TOPOGRAPHY AROUND AUSTRALIA

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Abstract. The sea-surface topography, as represented by the separation between the ocean surface and a level surface, is viewed as a problem involving and concerning both geodesy and physical oceanography. The determination of this topography by *geodetic levelling* processes, in conjunction with tide-gauge observation, is examined. Sources of error, difficulties, estimates of accuracies, and actual results are mainly related to the third-order Australian levelling net, which has indicated a sea-surface topography variation, with position, of 2 m, with a standard deviation estimated to be about 30 cm. The expected *oceanographic* influences on the sea-level are described, the individual contributing factors being discussed separately. Around Australia, differences in water density can account for an estimated 60 cm of the above mentioned 200 cm sea-level variation, while the air-pressure effect appears to account for another 10 cm only. The wind influence undoubtedly also contributes to the sea-surface topography but it is presently virtually impossible to provide a suitable figure. Some discussion is given to the apparent differences between the results from these separate sources, for this continent.

1. Introduction

The topographical shape of the surface of the ocean is a subject of interest in the seemingly unrelated fields of oceanography and geodetic surveying. It is intended here to discuss the phenomenon in terms of both geodetic and oceanographic knowledge, particularly on the basis of information which has been gathered around Australia, and to explain the relationship between the two approaches to the problem.

The sea-surface topography is represented by the vertical separation between the ocean surface and the geoid. The scalar values form a set of results in three-dimensions, two relating to position on the geoid, and the third being time. In practice, it is convenient to discuss *mean* values over given areas of ocean and over specified periods of time. Although it may be apparent that the mean sea-surface topography varies with position, it should be recognised that both the epoch and the time *interval* of the sea-surface topography may also be significant.

The above definition of the topography is, of course, dependent on the particular equipotential surface which is accepted as being the reference level. In geodesy, where *differences* in the sea-surface topography, particularly with position, are important, this choice of reference level is not significant. The divergence of two equipotential surfaces which are near sea-level is not large enough to cause concern.

If the oceans consisted of a still, homogeneous liquid, unaffected by any forces except those due to a time-invariant gravity field about the Earth, then the ocean surface would coincide with a level surface, according to the basic laws of hydrostatics. The sea-surface topography would be constant, independent of time and position. However, there are a number of phenomena of oceanographic interest, such as tides,

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currents, and wind set-up, which do give rise to a time and position dependent sea-surface topography, and, as might be expected, oceanographic knowledge can be used to make estimates of the shape of the sea-surface.

It is also possible to estimate the sea-surface topography at the coast, using geodetic levelling connections between tide-gauges. The gauges, which must all be operated over the same time interval, provide the level of the local sea-surface, which can then be related to a single equipotential surface by the levelling. Another, as yet unverified, technique for surveying this topography will be mentioned in Section 4.

Although oceanographic and geodetic methods can be used to provide estimates of the sea-surface topography, the converse of this situation is also true. Knowledge of the topography can be of value in testing and developing oceanographic theory, and, in surveying, it can be utilized to check observations and could be incorporated into survey techniques. Specifically, geodetic interest lies in the possibility of determining the basic reference surface, the geoid, given the position of the ocean surface and a knowledge of its topography. This would be useful mainly for *elevation* determinations, but would also be of value in accurate determination of *horizontal* position. For example, height determinations by levelling may be *checked* by reference to the sea-surface, at tide-gauges, if the topography is known. Height networks may, alternatively, be *extended*, particularly across oceans and seas. The use of sea-surface topography has been discussed as a method for connecting level nets in France and England (with doubtless application to the construction of an English Channel tunnel). International connections could also be useful in satellite tracking, by enabling obervational stations on opposite sides of the Earth to be related to the same reference surface. With satisfactory ocean data, future applications could include the determination of the heights of ship-borne instruments, notably gravimeters, above the geoid, and the orthometric height (above the geoid) of a satellite equipped with an altimeter capable of measuring the separation distance between the spacecraft and the ocean surface.

It is suggested that, although both oceanographic and geodetic techniques are capable of providing an estimate of the sea-surface topography, the two fields of study could certainly benefit from further data. Comparisons of results given by the two methods have been reported, particularly as the result of attempts to verify unexpected levelling results, e.g., in the United States (Sturges, 1967, 1974), in the United Kingdom (Hollwey, 1974) and in Australia (Hamon and Greig, 1972; Mitchell, 1974).

The U.S. experience, as reported by Braaten and McCombs (1963) as well as by Sturges, based on the levelling used in the 1963 adjustment by the U.S. Coast and Geodetic Survey, indicated that the sea-surface slopes upward from south to north by about 70 cm along both the Pacific and Atlantic coasts. At a given latitude the Pacific Ocean appears 60 cm higher than the Atlantic Ocean, the probable error in the levelling being estimated as 6 cm. Sturges (1974) concludes that the longitudinal variation does agree with oceanographic data, but that the meridional change along each coast does not.

In the most recent report of levelling in the U.K., Hollwey (1974) describes both time and position variations in sea-level. In 1968, the sea-surface topography was estimated to vary 21 cm over 440 km on the east coast of England.

Rodriguez (1970) reported that, according to the Brazilian first-order levelling, the sea-level variation is 40 cm between Rio de Janeiro and Fortaleza. Sturges' (1974) data suggests that this meridional variation agrees with approximate oceanographic expectations.

Apparently, levelling results from some networks have not been compared to oceanographic estimates of the sea-surface topography.

Levelling in the United European Levelling Network, as reported by Levallois (1960) showed some variation between sea-level and levelled heights. If the levelling heights were assumed to be correct, then sea-level had an apparent elevation of +28 cm at Kemi, Finland, an apparent elevation of +14 cm at Cascais, Portugal, and −34 cm at Genoa in the Mediterranean Sea. Generally, sea-levels had apparent elevations of the order of ±10 cm in this network. More recently, from the same area, the first order levelling net of France of 1969 indicated that differences in sea-level around the coastline were up to half a metre, 30 cm of which appeared to be concentrated across the Straits of Gibraltar.

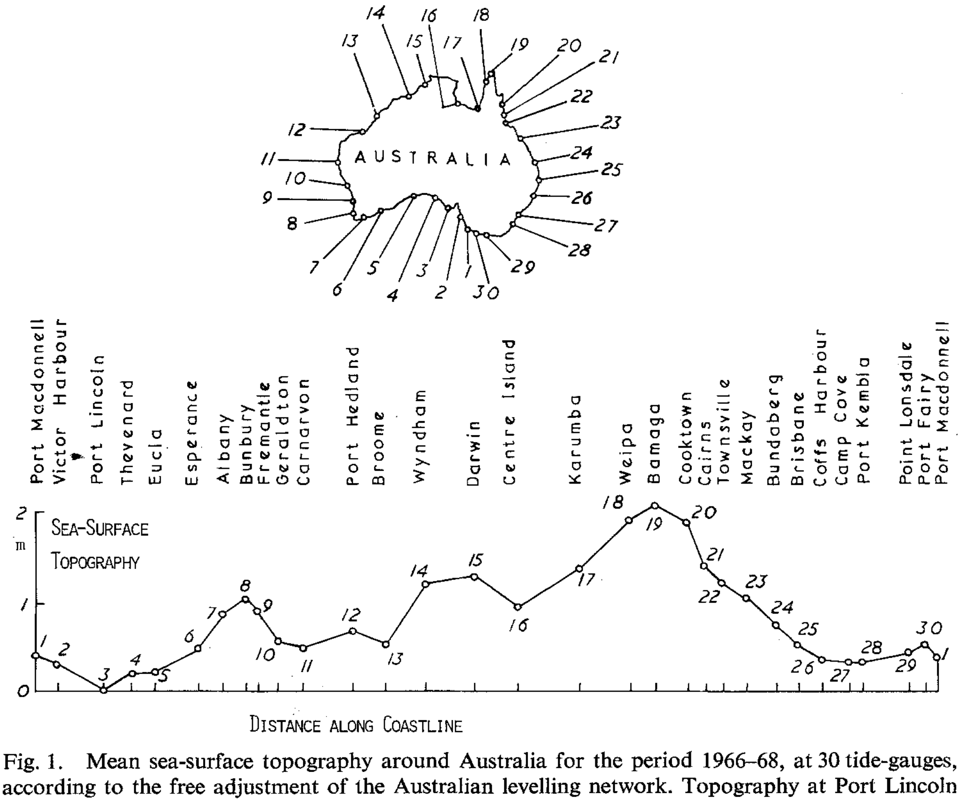

Fig. 1. Mean sea-surface topography around Australia for the period 1966–68, at 30 tide-gauges, according to the free adjustment of the Australian levelling network. Topography at Port Lincoln assumed to be zero. Adapted from Roelse *et al.* (1971).

A levelling net in *Australia* has suggested that the sea-surface topography varies, around the continent, up to the order of 2 m. Details of the apparent topography are given by Roelse *et al.* (1971), while the result is summarized in Figure 1. A maximum level of the sea-surface above the geoid at Cape York, the northern tip of eastern Australia, is about 2 m above the minimum level at Port Lincoln, near Adelaide, in the Great Australian Bight. The relationship between the apparent sea-surface topography and latitude is shown in Figure 2, which illustrates an approximate latitude dependence of the sea level.

The remainder of this article discusses the sea-surface topography, particularly around Australia, on the basis of two estimates: one given by an observational technique using levelling and tide-gauge records, the second an indirect method based on

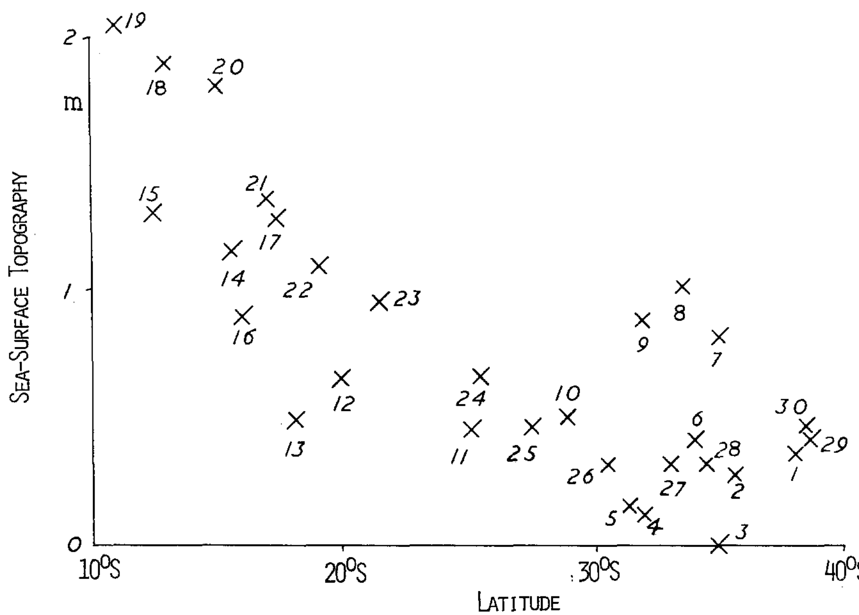

Fig. 2. Relationship between latitudes of tide-gauges and the apparent sea-surface topography given in Figure 1. Gauge numbers as in Figure 1.

oceanographic and meteorological data. The position-dependent, rather than time-dependent, sea-surface topography is investigated.

2. Estimates of the Sea-Surface Topography by the Levelling Network

Since 1945, 160 000 km of levelling has been undertaken over Australia, under the direction of the Division of National Mapping for the National Mapping Council of Australia. This network is described by Leppert (1970) and by Roelse *et al.* (1971). During this survey, connections were made to about 30 tide-gauges spaced around the Australian coastline. The intention was to connect various local datums based on

Mean Sea Level (Roelse *et al.*, 1971). The results also provide the estimate of the sea-surface topography on the coast around this continent as described in the preceding section.

This sea-surface topography result must be viewed in the light of:

(i) the *validity* of the assumption that levelling can determine heights, with respect to the geoid;

(ii) the *accuracy* of the resulting topography estimate;

(iii) the ability of tide gauges to determine the position of the sea-surface in the vertical sense, and the accuracy of this determination.

Two causes for concern about the ability of a levelling net to provide orthometric heights over the continent, and, therefore, to measure the elevations of the sea-surface as given by tide-gauges at the coastline, are:

(i) non-parallelism of the equipotential surfaces;

(ii) the time variations of the spatial positions of both the equipotential surfaces and the physical surface of the Earth.

Such problems are of particular interest in a network covering an area as large as the Australian continent. Although the levelling is not actually related to the true sea-surface topography, a discussion of the network in this article is considered to be justified by the extensive use of levelling to estimate the sea-surface topography. Some insight should thus be given to the validity and accuracy of a topography result obtained by this technique.

2.1. Non-parallelism of the equipotential surfaces

The levelling instrument used during the survey is aligned to the local equipotential surface. As the survey is extended across the physical surface of the Earth, the level is, by necessity, aligned to equipotential surfaces at different elevations. If these surfaces are not parallel, the resultant effect is equivalent to using different reference planes for different areas of the survey. If the level was referred to only one equipotential surface, or if all the equipotential surfaces were parallel, this effect would be eliminated. In practice, some attention must be paid to this aspect of the levelling.

Generally, correction terms are applied to the levelling results. The orthometric corrections are based on the expected divergence of equipotential surfaces, the divergence being a function of the gravity and elevation values at the point of observation.

Before their adjustment of the results from the Australian network, the Division of National Mapping applied correction terms which were based on the theoretical value of gravity given by Reference System 1967 (Roelse *et al.* 1971, p. 65). The magnitudes of the corrections, which were calculated for every length of observed levelling between bench-marks, were generally only 0.3 mm or less.

As an alternative to the method of applying orthometric corrections, the leveled height differences may be converted into geopotential differences based on normal gravity. In terms of potential, the equipotential surfaces are, of course, parallel. Without entering into a theoretical derivation, it may still be appreciated that the results given as geopotential differences should then, theoretically, be free from the influence of the non-parallelism of the equipotential surfaces.

With an additional refinement of using observed gravity, instead of normal gravity, the observed height differences in the Australian network have been transformed into differences in geopotential (Mitchell, 1974). Geopotential differences, ΔW, between bench marks in the levelling were formed from the observed height differences, Δh, using the relation:

$$\Delta W = \tfrac{1}{2}(g_1 + g_2)\ \Delta h,$$

where g_1 and g_2 are the gravity values at the bench marks which were at an average spacing of the order of 3 km. The gravity values were interpolated from surrounding observed gravity, which was available at a 0.1 deg spacing about the levelling.

The geopotential differences and height differences were compared by calculating the sea-surface topography in terms of both adjusted potential and height differences. Despite the theoretical difficulties of comparing the dimensionally different results in potential and height differences, it was obvious that the geopotential calculation had not altered the apparent sea-surface topography by an amount which was significant to the 2 m maximum variation. Details of the conversion and comparison are given by Mitchell (1974).

The small magnitude of the changes to the network produced by conversion to potential differences, as well as by the application of orthometric corrections, suggests that the divergence of the equipotential surfaces has not significantly influenced the sea-surface topography result.

2.2. Changes in the Shape of the Earth and Geoid

The possibility that error in the levelling results may be caused by changes in the shape of the physical surface of the Earth and in the shape of the equipotential surfaces during the time of the survey has been recognised. The former are due to Earth tides and the 'loading tide', resulting from the variations in the amount of water on the continental shelf during the ocean tide cycle. The latter are due to tides of all the equipotential surfaces resulting from the varying gravitational attractions of the Sun and Moon and due to the gravity variation resulting from ocean tides. However, simple calculations using estimates of the Earth tide magnitudes (e.g., Melchior, 1966) and using formulas for geoid tide corrections, given by Jensen (1950), show that the variations should not affect the levelling results by more than a few cm.

Only two tide-gauges in Australia have operated for a length of time which is suitable for determination of the secular variation of sea-level. The apparent rise in sea-level, estimated from approximately 50 yr of records at these sites, is of the order of 0.5 mm/yr. The figure suggests that sinking and uplifting of the land masses is not a cause for concern in the Australian sea-surface topography result.

2.3. Accuracy of the Levelling

The accuracy of the levelling in the Australian network has been studied by Roelse *et al.* (1971) who, in their report on the adjustment, note that "... most of the levelling in the network was observed to third order standard", (p. 75). This standard requires that two levellings of any section between bench-marks must not differ by more than $12\sqrt{K}$ mm where K is the distance, in kilometres, between the bench-marks. Roelse *et al.* (p. 76) have adopted a value of approximately $8\sqrt{K}$ mm for the precision of the *adjusted* orthometric levelling. It is estimated (*ibid.* Annexure F) that the standard deviation of a height at the coastline when referred to a height at an origin towards the centre of the continent is of the order of 30 cm. The estimate of the standard deviation of the adjusted geopotential difference between Cape York and Port Lincoln was 3 $m^2 \cdot s^{-2}$ (Mitchell, 1974). This is considerably less than the 20 $m^2 \cdot s^{-2}$ variation in sea-level which has been shown by the levelling results. Thus, the existence of the sea-surface topography cannot be attributed to the error expected from the type of levelling survey carried out in Australia.

Systematic errors could exist undetected, to produce an apparently large sea-surface topography, but discussion on this would, at the moment, seem to be largely speculative.

2.4. The tide-gauges

The tide-gauges are an integral part of the measurement of the sea-surface topography. Records from the gauges are used in defining the vertical position of the sea-surface, which can then be given a height value by connection into the levelling network. This elevation at any gauge is assumed to represent the level of the sea-surface for the length of coastline around the gauge, for the time period over which the gauge was operated. For each gauge utilized in the result mentioned in Section 1, mean values were taken from hourly readings over the same three years, 1966–68, to provide sea-levels. Thus the heights of the sea-surface, at each gauge, all represent the same time interval and epoch.

Gauge recording faults, such as disturbance of the gauge level during its operating life, as described in the reports of the gauges and their operation (Easton, 1968, 1970; Easton and Radok, 1970) are not considered here to contribute to any sea-surface topography effect which varies regularly with position. Nevertheless, it is recognised that *individual* gauge results may be affected by some error. Similarly, river flow past gauges, a number of which are situated in rivers or near their mouths, (Easton, 1968) is expected to only introduce, in the topography, an error which is randomly distributed with respect to the gauge positions.

2.5. Summary of the levelling network

The non-parallelism of the equipotential surfaces and of time variations in the shape of the physical and equipotential surfaces are not considered to have significantly influenced the sea-surface topography around Australia, as indicated by the levelling connections between tide-gauges. The random error in the result, due to the levelling, is illustrated by a standard deviation of 30 cm between the most widely separated coastal points. Gauging errors are discounted as likely contributors to a position-dependent sea-surface effect. The adopted result is, therefore, as given in Section 2 with an error estimated to be a maximum of 30 cm between any two gauges.

3. Estimation of the Sea-Surface Topography by Oceanographic Means

In this section the aim is to discuss the sea-surface topography at the tide-gauges around the coastline of Australia, as would be expected from oceanographic data. The sum of the various known sources of separations between the sea-surface and an equipotential surface should be obtained for the years 1966 to 1968. This topography should then be directly comparable with that given by the combination of the levelling with the tidegauge recording.

3.1. Sea and swell

Sea waves under development in a wind field and swell, propagating out of the generating area, produce short period sea-surface variations. Because of their high frequency, these waves are generally considered to be filtered by the mechanisms of the tide-gauges, from the records. Thus, the state of the sea and swell should provide no contribution to the sea-surface topography on the Australian coastline. However, the existence of waves which contribute to the instantaneous sea-surface topography cannot always be disregarded.

3.2. Tides

Large values of geoid/sea-surface separation are also caused by ocean tides, whose influence is composed of a large number of sinusoidal components with different magnitudes, periods, and phases. By studying the effect of a three year mean on each component, it can be shown that the total influence at any site is reduced to a few centimetres, either as a result of the high frequency or low magnitude of each contributing component. However, it must be remembered that over a period less than three years, the simple mean may not satisfactorily eliminate the tidal influence, and other filtering techniques may be required. It is also difficult to subtract the tide effect by using a combination of the appropriate amplitudes and phases, as these can only be determined using past records; the analyzed components may then be contaminated by other variations of the sea-level.

Unoki and Isozaki (1965) have discussed the *position* dependent tidal influence on sea-surface topography within bays and harbours, although the order of magnitude of this effect was only centimetres. Little other mention has been found, in the literature, on the position dependent effect of tides. It has been concluded for this study that the tidal contribution to the sea-surface topography is nil.

3.3. Water density and ocean currents

Two oceanographic phenomena which significantly affect the sea-surface topography are the distribution of water density and the existence of ocean currents. However, they are closely related and may be discussed simultaneously. Theoretically, the value of the sea-surface topography at a given time and place depends on the average density in a column of water between the surface and a specified equipotential surface deep in the ocean. Density is a function of salinity and temperature, which are measurable, and of pressure, which depends on the dynamic depth. Variations in the sea-surface topography with time and position due to this effect may therefore be calculated from differences in densities. The surface of less dense water is higher, with respect to the geoid, than that of more dense water.

Ocean current positions are also indicative of the density-induced portion of the sea-surface topography. The currents arise as a result of the pressure differences, which in turn result from the density distribution. Their flow is modified by the Coriolis effect, so that, for example, currents in the southern hemisphere circulate in an anticlockwise direction around areas of high topographical level. The situation is analogous to the relationship between atmospheric winds and barometric pressure differences.

Thus, the sea-surface topography can be estimated by steric levelling, (based on density values calculated from temperature and salinity observations) or by geostrophic levelling, (based on current velocities, positions and breadths of flow). The complete theory of ocean water densities and currents and their relationships to sea-level is complex, but is covered in many works on currents (e.g. Neumann, 1968) or on general oceanography (e.g. Dietrich, 1963, pp. 291 *et seq.*).

The relationships between ocean currents, density, and sea-level in practical cases have also been considered in many articles, including Lisitzin (1965) and Sturges (1967, 1974); see also a review by Hamon (1970). Lisitzin (1965, p. 16) and Stommel (1964) have produced a world map of density effects on the sea-surface, showing the expected variation in sea-surface topography around the Australian coastline to be of the order of 80 cm. Numerous publications indicating sea-surface topography values in waters around Australia, due to the density-current effect, have been based on density data which has been collected by the Division of Fisheries and Oceanography of the C.S.I.R.O., Australia. The data shows a contribution of about 60 cm to the apparent variation of sea-surface topography between Port Lincoln and Cape York (Mitchell, 1974). The existence of time variations in the height of the sea surface

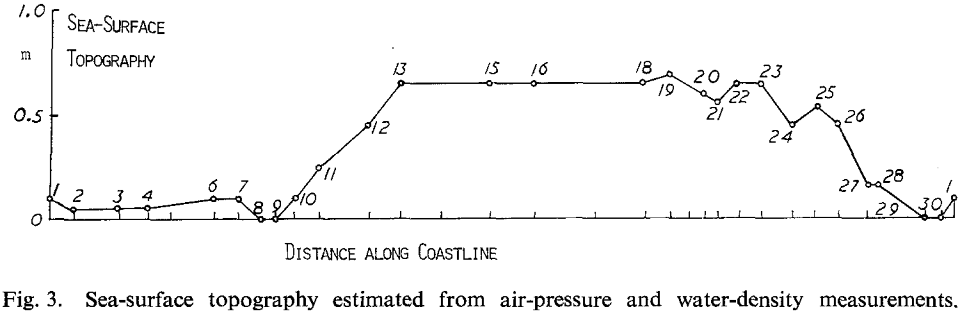

Fig. 3. Sea-surface topography estimated from air-pressure and water-density measurements. Gauge numbers as in Figure 1.

is illustrated by changes in the positions of the ocean currents around Australia, but a lack of complete data makes it difficult to estimate these fluctuations.

The accuracy of the estimate of the density/current effect on sea-level depends directly on the availability of salinity, temperature and current data. It can be concluded, however, that this effect is one of the principal contributors to variable sea-surface topography, and is of the order of 60 cm around Australia; see Figure 3.

3.4. Atmospheric action

Interaction between the atmosphere and the oceans produces a number of variations of sea-surface topography with both position and time. The portion of observed sea-level Δh due to barometric pressure is generally given by the linear relationship

$$\Delta h = \alpha \, \Delta p ,$$

where Δp is the deviation of the atmospheric pressure from a standard value which is independent of time and position, usually about 101.3 kPa and where α is a constant. Theoretically, α has a value of 10.1 $\text{cm} \cdot \text{kPa}^{-1}$. Actually there is doubt as to the value of α, as analyses of sea-level records in conjunction with air-pressure records has not always produced the factor quoted above. However, using a value of 10.1 $\text{cm} \cdot \text{kPa}^{-1}$ and air pressure observations from the Bureau of Meteorology, Australia, the corrections needed to reduce all mean sea-levels, at the tide-gauges in the Australian survey, to a standard atmospheric pressure have been calculated (Mitchell, 1974). The corrections were equivalent to a variation in sea-surface topography around Australia of the order of 10 cm.

Another atmospheric action on sea-level, often operating simultaneously with barometric pressure, is wind. The magnitude of the influence is dependent on the depth and width of the continental shelf and on the velocity of the wind acting along the shelf or towards the shore. Various formulae have been used to estimate the wind set-up and pile-up effects. Theoretically, the influence of winds on a long term mean of sea-level is negligible. Observational evidence of wind effects around Australia is scarce. Studies of the tide-gauges used in the Australian survey and of their records (Easton, 1968, 1970; Easton and Radok, 1970) have produced some information and the most noteworthy is evidence of a persistent 15 cm effect at Mackay (Easton, 1970, pp. 47 and 252).

3.5. Summary of the oceanographic estimate

The current and water-density effect is undoubtedly the primary cause of the sea-surface topography. Existing data suggests that the position dependent variation around this continent is at least 60 cm. Atmospheric influences are secondary, with a calculated 10 cm air pressure effect and a wind influence which is, as yet, unestimated. An estimate of the error in the above density air-pressure effects is unfortunately virtually impossible with existing data. Wave influences have been discounted, and tide effects accepted as non-existent. The sea-surface topography difference between Cape York and Port Lincoln is considered to be 70 cm as a minimum.

4. Discussion

In Sections 2 and 3, it has been suggested that the two estimates of the sea-surface topography disagree, one estimate of the total difference being of the order of twice the other.

Hamon and Greig (1972) have studied the relationship between mean sea-level and the Australian levelling result, discussing mainly the same items mentioned in this article, but with an emphasis of the water density effect. Regarding the discrepancy between the two sets of results, they conclude 'that no satisfactory explanation for the discrepancies can be put forward at present'.

It would seem at the moment that only some sort of systematic error could possibly cause an erroneous estimate of the elevations of the sea-surface at the tide-gauges as given by the levelling. Nevertheless, a latitude dependent systematic error of the order of only 0.3 mm per km would virtually explain the difference in the estimates by the two methods.

The oceanographic estimate of the sea-surface topography provides some areas for speculation when considering possible sources of error.

The largest contributing cause to the sea-surface topography, the density/current effect, seems to suggest itself as the most disputable area of concern. It is credible that its contribution may be larger than indicated in the above discussion. It seems plausible that the relationship between the measured densities at sea and the sea-surface topography is imperfect, being affected, for example by sea-bed topography, ocean current eddies, or friction to an extent which may be presently underestimated.

Attention could be paid to wind effects on the sea-surface. Although not expected to produce a full metre variation in sea-level, their contribution could nevertheless be significant. Extensive study should at least prove conclusively that the wind effects are not significant or that they are worthy of further study. The vast areas of shallow water less than 200 m deep in the Gulf of Carpentaria, Arafura Sea and Torres Strait regions arouses interest.

The possibility of a position dependent tidal influence could be examined.

Estimates of the effect of river flow past tide-gauges and of recording errors in Australia would reduce the uncertainty in present values of the sea-surface topography at the coastline.

Investigation into the differences between the sea-surface topographies estimated by the levelling and oceanographic methods would presumably be assisted by a third, independent, measure of this topography. In recent years, there have been proposals for the use of a new geodetic method of determining the topography (Apel, 1971). The method is a reversal of one of the uses of knowledge of the sea-surface topography in geodesy, as mentioned in Section 1, namely, the determination of satellite heights. Basically the method is to relate the satellite position to the geoid and to obtain the satellite height with respect to the geoid by an altimeter carried in the spacecraft. The system is complex and involves consideration of the accuracies and abilities of determining the satellite height with respect to the geoid and with respect to the sea-surface. To be useful, the method needs to be refined until its accuracy is compatible with the conventional methods for determining the sea-surface topography. It must also be noted that the technique would provide values of the sea-surface topography over the open ocean where conditions may not be the same as on the coastline if the sea-surface topography is influenced by the continental shelf.

5. Summary

The topographical shape of the sea-surface, with respect to an equipotential surface, varies with both time and position. Knowledge of the relationship between the two surfaces would be of immense value in practical geodesy by providing the position of the geoid in terms of the sea-surface position. The topography is also a factor of interest in the study of oceanographic phenomena. The sea-surface topography can presently be estimated by two methods. Firstly, direct measurement, by using geodetic levelling to relate the levels of the sea-surface as given at tide-gauges, can provide the sea-surface profile along a coastline. Secondly, the topography may be estimated by the less direct method using results based on oceanographic and meteorological conditions. An estimate around Australia, by the former method, of an ocean topography variation with position of about 2 m does not appear to suffer unduly from random levelling errors, from the effects of the non-parallelism of equipotential surfaces, nor from the Earth and geoid tides. The second method, applied around the same coastline, produces a variation of sea level approaching only one metre. This result is based principally on steric levelling, using ocean density data, other influences appearing comparatively slight. However, the accuracy of the result would undoubtedly be improved with further data, particularly wind-effect and water density observations. Differences in the estimates of the topography around Australia, from oceanographic and geodetic data, suggest that further knowledge of sea-surface topography is required before full use can be made in geodetic techniques. It seems that further investigation, particularly through the application of satellite altimetry, will produce an improved understanding of the problem. This will require the co-operation of geodetic and oceanographic workers, both of whom would benefit from the knowledge which should be ultimately gained.

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