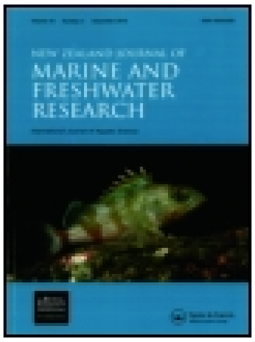

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PHASE DISTRIBUTION OF TIDAL CONSTITUENTS AROUND NEW ZEALAND

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ABSTRACT

The phase distributions of the M_2, S_2, K_1, and O_1 tidal constituents around New Zealand are plotted from existing harmonic analyses of tidal heights. Both semi-diurnal constituents exhibit a complete 360° range of phase around New Zealand, with complex areas of rapid phase change through or near the strait separating the two main islands. The K_1 amphidrome and that for O_1, which previously were thought to be centred on New Zealand, are shown to be located east of New Zealand. The distributions plotted highlight areas where tidal observations are lacking.

INTRODUCTION

Time series of tidal elevations and currents can be decomposed by harmonic analysis into the discrete frequency components of the forcing functions, arising from clearly defined motions of the Earth-Moon-Sun system. The contribution of each tidal constituent to the total tidal elevation is given by $f\,H \cos(E + u - g)$ where g is the phase lag of the constituent of amplitude H behind the corresponding tide raising force at Greenwich, $E + u$ is a regularly increasing phase angle, and f is a slowly varying factor which takes account of the 18.6 y periodicity in the moon's orbit. The two main semi-diurnal and diurnal tidal contributions come from the principal lunar (M_2) and solar (S_2) semi-diurnal constituents, with angular speeds of 28.984 and 30.000 degrees per solar hour respectively, and the two diurnal lunar declinational constituents (K_1, O_1), with angular speeds of 15.041 and 13.943 degrees per solar hour respectively.

Oceanic-scale charts of the tidal phase distribution for these constituents exhibit interesting features near New Zealand. For example Dietrich's phase chart for M_2 (in Defant 1961) shows a complete 360° phase range around New Zealand, with an amphidrome south-east of New Zealand, and his chart for K_1 shows New Zealand appearing at the centre of an amphidrome. Apart from brief references to these features as part of oceanic-scale studies (e.g., Defant 1961, Hendershott 1973) and recent studies of the M_2 tide around New Zealand (Bye & Heath 1975) and in Cook Strait (Heath 1974), the phase distributions have not been further defined in any detail. Distributions for some of the adjoining areas have been given by Easton (1970) for parts of the Australian coast and Luther & Wunsch (1975) for the central Pacific Ocean. As a first

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step in future tidal research in the area, the phase distributions of the M_2, S_2, K_1, and O_1 tidal constituents in the region surrounding New Zealand from 10° S to 55° S and from 150° E to 160° W are presented and briefly discussed.

PHASE DISTRIBUTIONS

Contours of equal phase have been drawn at 30° intervals using tidal constants presented in the Admiralty Tide Tables (Hydrographic Department 1970), supplemented in Cook Strait by constants kindly made available by the New Zealand Navy Hydrographic Service. Both phases and amplitudes upon which the contouring is based are shown. Tidal admittance diagrams for both the diurnal and semi-diurnal constituents are presented for several New Zealand ports, the admittance being taken as the ratio of the observed to the equilibrium tidal amplitude for each constituent, the equilibrium constituents used being those given by Doodson & Warburg (1941).

M_2 TIDE

The M_2 tide around New Zealand (Fig. 1) is notable in that the phase embraces the complete 360° range. Bye & Heath (1975) explained this situation in two alternative ways: either New Zealand is under the influence of three separate clockwise-rotating tidal systems (one each on the southern and south-western coasts, the east coast, and the west coast) (see, e.g., Hendershott 1973, fig. 5), or the extensive New Zealand bathymetric platform traps the tidal wave, giving rise to the observed situation. The maxima in the tidal admittance curves, the occurrence of a large age of the tide (the phase difference between the M_2 and S_2 constituents) (Fig. 2), and the close fit of a symmetrical analytical solution to the observed tides suggest the trapping mechanism is important.

The complete phase range around New Zealand of the M_2 tide leads to a difference in phase through Cook Strait of 140° (between New Plymouth and Wellington: Hydrographic Department 1970) of which 118° takes place through the narrows of Cook Strait between Wellington and Makara (Fig. 3), a distance of only 28 km. This region of rapid phase change in the narrowest part of Cook Strait has been found to be consistent with two overlapping standing waves (Heath 1974) resulting from reflection of the tidal waves advancing from the north-west and south-east.

The rapid change in phase through Foveaux Strait results from the slow progress of the long wave over the relatively shallow Campbell Plateau rather than from the effect of the strait itself; this slow progress is evident in the numerical model of the M_2 tide of Bye & Heath (1975) (in which Foveaux Strait itself is not represented).

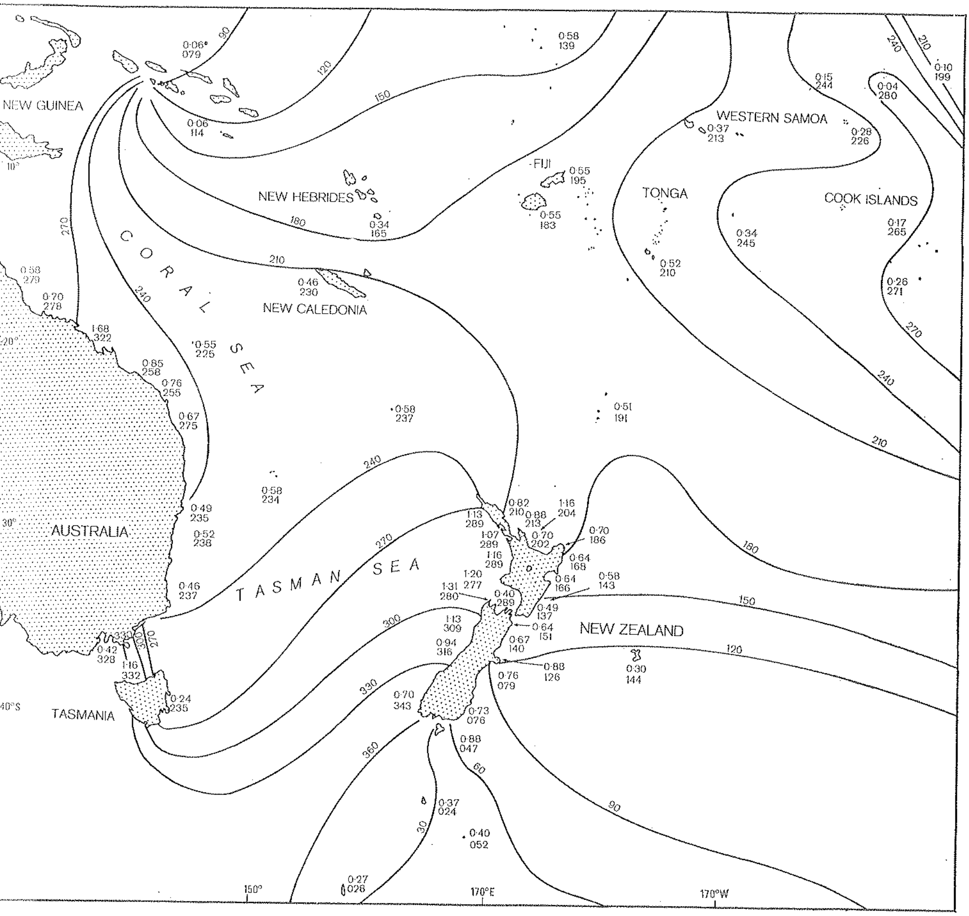


FIG. 1—Contours of the observed phase of the principal lunar semi-diurnal tidal constituent (M_2) around New Zealand. The observed values of the amplitude (m) and phase (°) are also shown.

S_2 TIDE

The phase distribution of the S_2 tide around New Zealand (Fig. 4) is similar to that of M_2, embracing the complete 360° range. The age of the tide is not, however, constant, but varies significantly from one section of coast to the next (see Bye & Heath 1975, table 1). They suggested that these variations in phase difference result from the progressive M_2 and S_2 tidal waves approaching New Zealand from different directions.

The semi-diurnal tidal admittance is substantially less at the S_2 than at the M_2 frequency (Fig. 2); the admittance reaches an observed

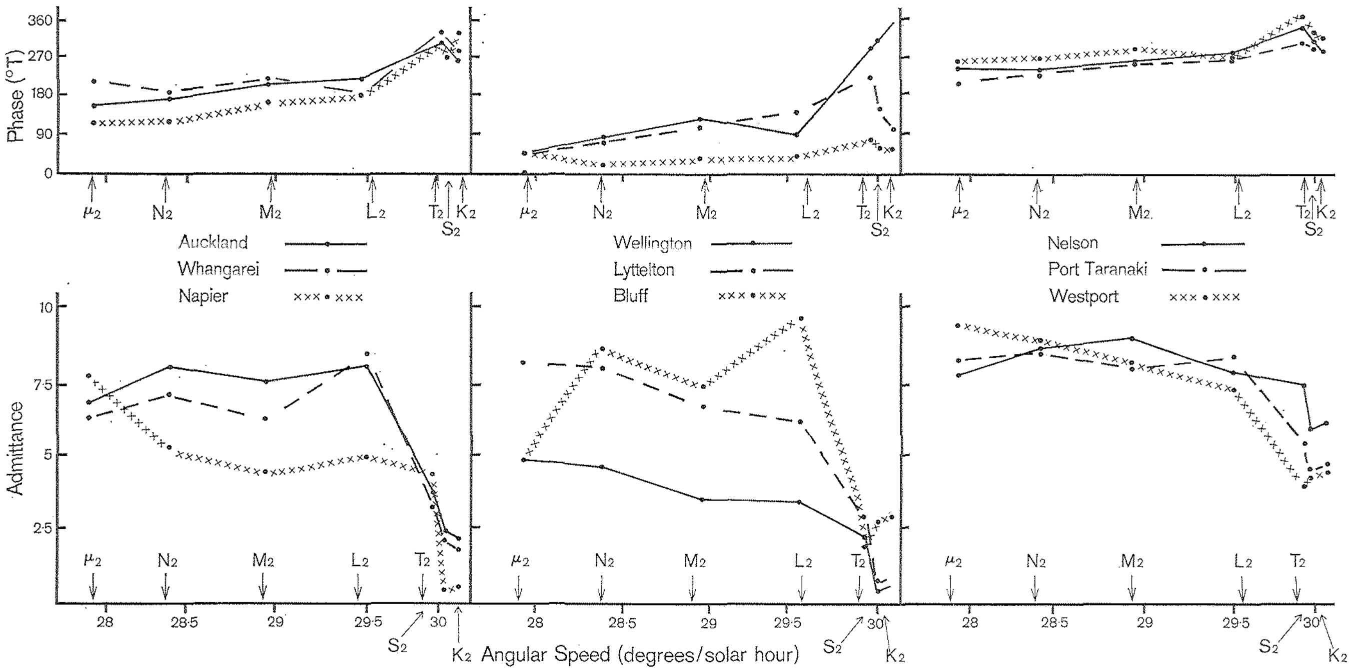
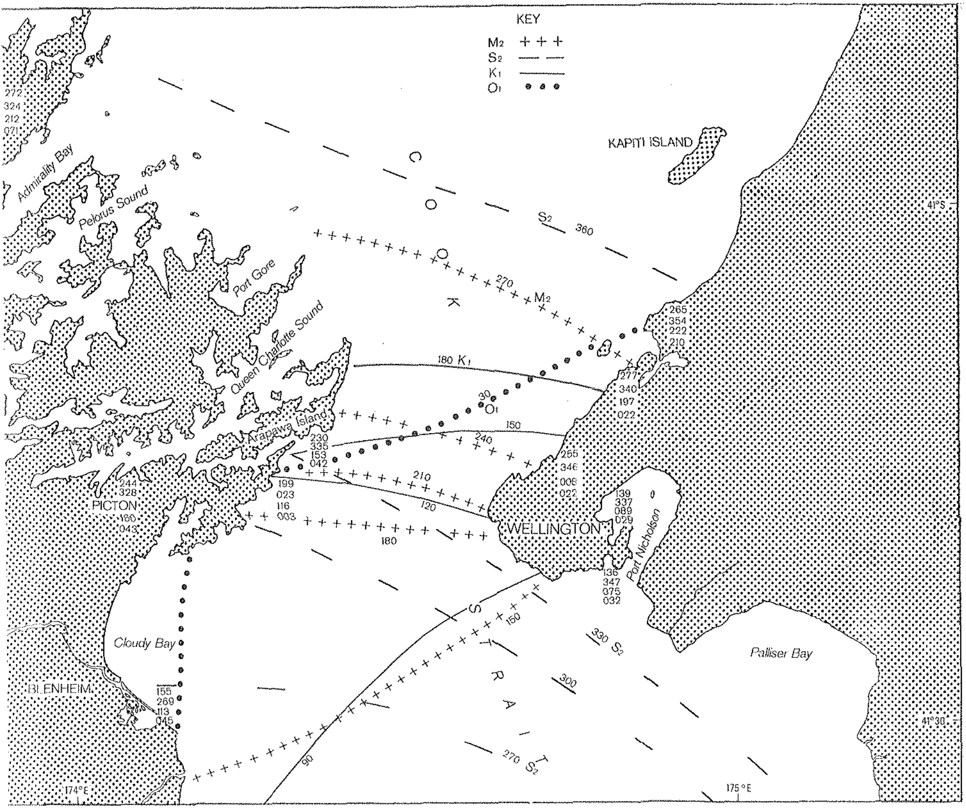


FIG. 2—Admittance and phase of the semi-diurnal tidal constituents for nine New Zealand ports.



IG. 3—Contours of the observed phase of the M_2, S_2, K_1, and O_1 tidal constituents in Cook Strait. The observed values of the phase (°) for these components are also shown in that order.

maximum at 29.528 degrees per solar hour, the angular speed of the L_2 tidal constituent. The amplitudes of both S_2 and M_2 are larger on the west coast than on the east coast of New Zealand.

The ratio of the tidal amplitudes (S_2 : M_2) in western Cook Strait is much larger than on the east coast between Kaikoura and Napier (Figs 4 & 5). Probably, this relative dominance of the S_2 tide advancing from the west through Cook Strait over that on the east coast leads to the area of rapid phase change and small S_2 tidal amplitudes occurring between Kaikoura and Napier, rather than in the narrows of Cook Strait where the rapid phase change occurs for the M_2 tide. Perhaps the form of the S_2 tides near Cook Strait is better explained by separate progressive waves entering the strait from either side without significant reflection. The detailed phase distribution for S_2 off the east coast near Cook Strait is difficult to define, however, because the amplitudes are small and therefore the phases calculated by harmonic analysis may be unreliable.

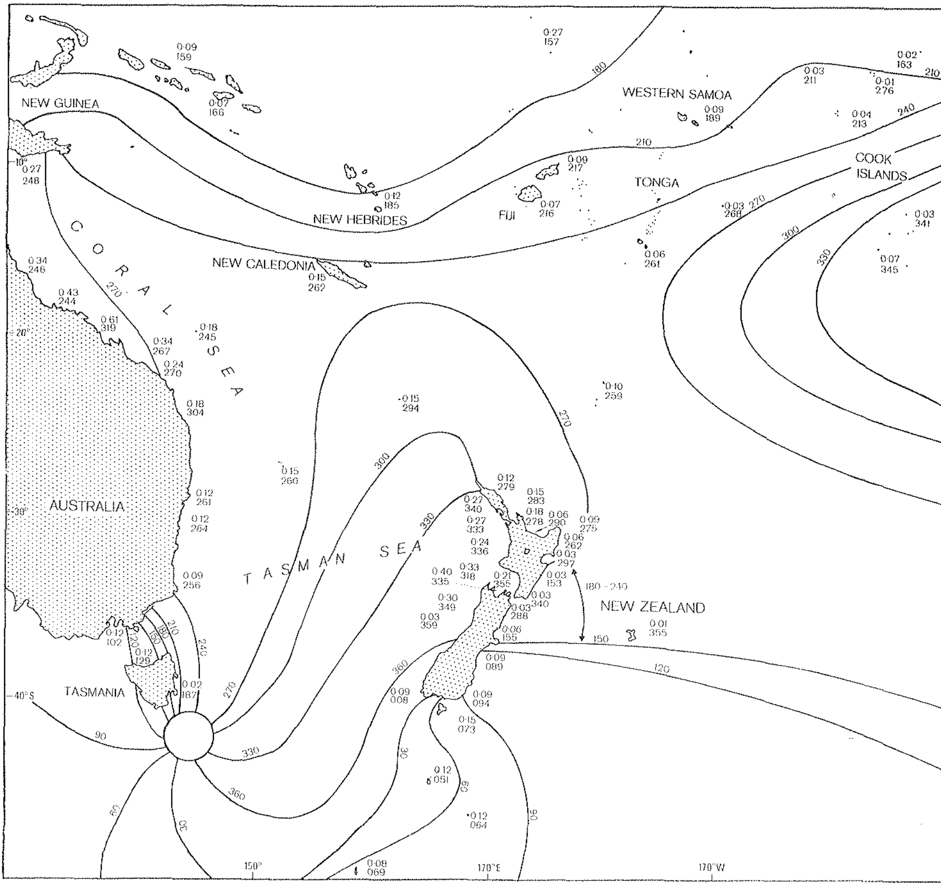


FIG. 4—Contours of the observed phase of the principal solar semi-diurnal tidal constituent (S_2) around New Zealand. The observed values of the amplitude (m) and phase (°) are also shown.

K_1 TIDE

Defant (1961, p. 492) mentions an amphidrome for the K_1 tide centred on New Zealand with a complete rotation of 360° clockwise around both islands. The phase on the north-east coast of New Zealand (Fig. 5) is not, however, consistent with this pattern, although the low K_1 tidal admittance around New Zealand (Fig. 6) confirms the near presence of an amphidrome (Fig. 5). The phase observations are consistent with a K_1 amphidrome situated in the Hikurangi Trench east of New Zealand (Fig. 5).

There is a large K_1 phase change through Cook Strait (Fig. 3), with the most rapid region of change being in the narrows of Cook Strait, a dynamic situation presumably similar to that for the M_2 tide.

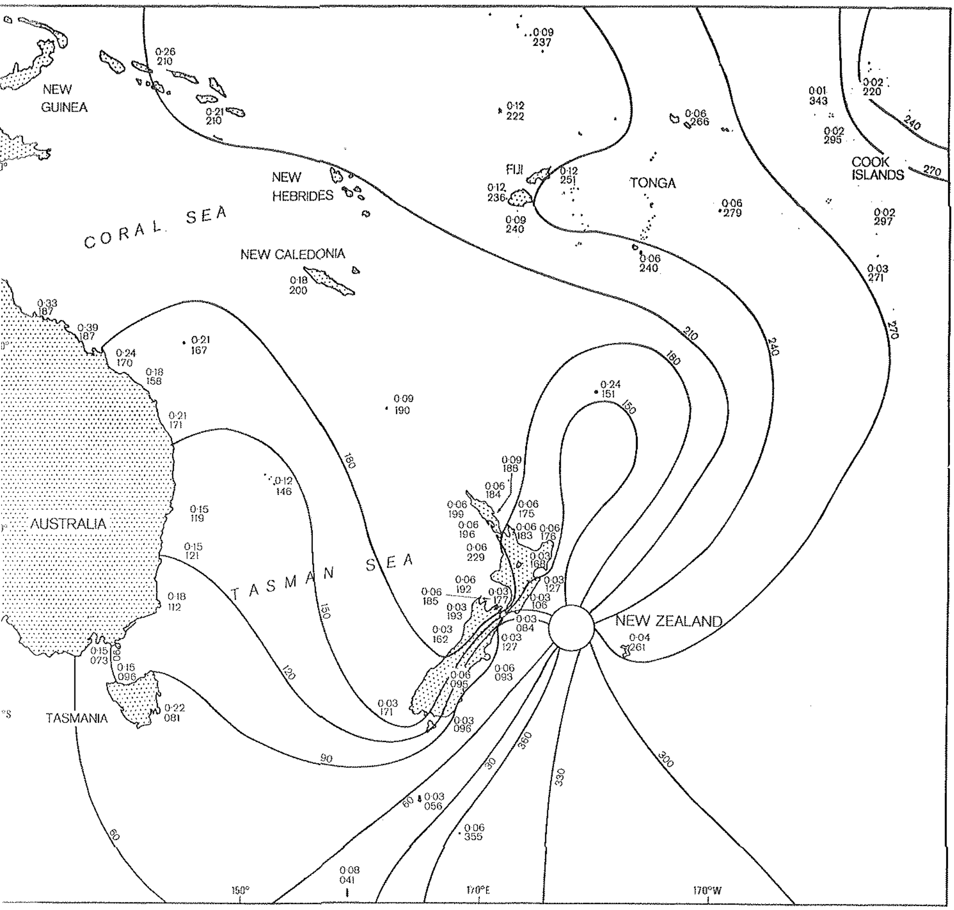


FIG. 5—Contours of the observed phase of the lunar declinational constituent (K_1) around New Zealand. The observed values of the amplitude (m) and phase (°) are also shown.

O_1 TIDE

The O_1 and K_1 tides are the diurnal oscillations due to variations in the moon's declination to earth's axis, one arising from adding the frequency of the moon's orbit to the earth's angular frequency (K_1), and the other from subtracting it (O_1). As would be expected with these components only varying slightly in frequency, the phase distribution is very similar (Figs 5 & 7). O_1 also has an amphidrome situated east of New Zealand and consequently very low amplitudes around New Zealand. The O_1 amphidrome appears to be located further north than that for K_1, east of Hawke Bay as opposed to Cook Strait. Also, there does not appear to be the rapid change in phase through the narrows of Cook Strait that occurs for K_1.

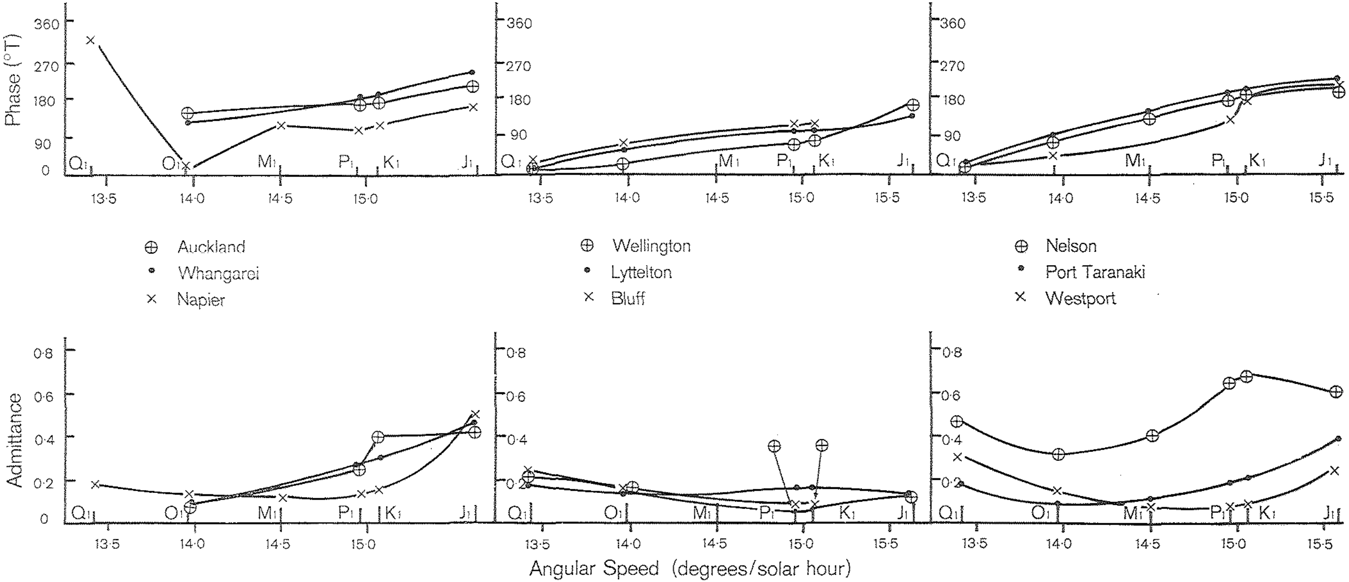
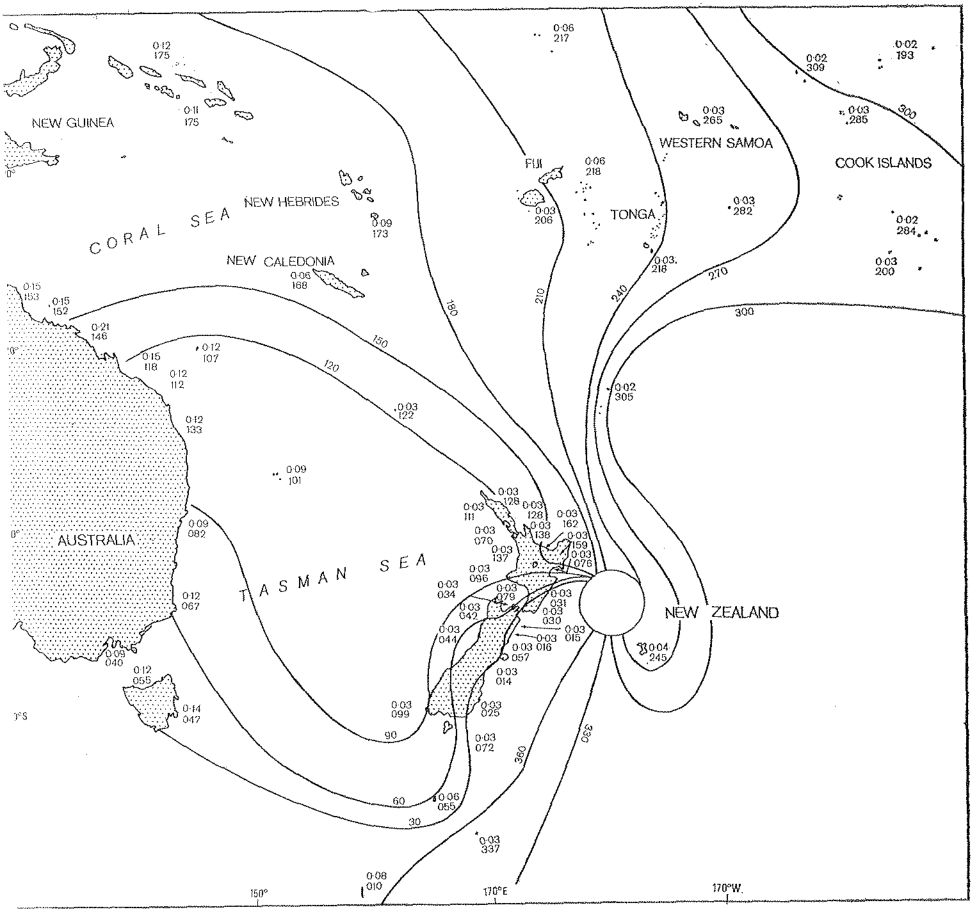


FIG. 6—Admittance and phase of the diurnal tidal constituents for nine New Zealand ports.



IG. 7—Contours of the observed phase of the lunar declinational constituent (O_1) around New Zealand. The observed values of the amplitude (m) and phase (°) are also shown.

CONCLUSIONS

The phase distributions presented clearly indicate regions in which further tidal elevation observations are required to allow better definition. For M_2, measurements in the area of rapid phase change around the top of the North Island (Fig. 1) and at the entrance to the Marlborough Sounds (Fig. 3) are needed. For S_2, long term (annual) tidal elevations in the region of small amplitude off the east coast between Christchurch and Gisborne might allow the phase distribution to be defined in more detail; a check on the S_2 constants at Kaikoura and Castlepoint would be valuable. Deep sea tidal elevations in the region of the K_1 and O_1 amphidromes east of New Zealand would allow the position of the amphidromes to be defined in more detail. Further measurements in the areas of rapid phase change for the diurnal constituents, near Hawke Bay for O_1, and in Cook Strait for K_1, are needed before the respective distributions can be defined in any detail.

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