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ON ANOMALOUS TIDES IN AUSTRALIAN WATERS

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Abstract

The Coral Sea has been identified as the location of an anomaly in the semi-diurnal tidal band with an apparently sharp local resonance in the vicinity of the frequency of L_2. It is here shown that such a simple resonance does not exist but that the anomaly has a gravitational origin which may indicate a more complex mechanism.

Long spans of tidal observations from Cairns, Townsville and nearby ports are analysed in an attempt to estimate the frequency response of the gravitational tide across the semi-diurnal spectral band. The identification of the response function is assisted by the treatment of perturbing energy from non-gravitational sources, in particular those associated with shallow water non-linear interaction. At both stations two terms emerge which are seen to be greatly amplified, one with an argument number (2-10000) is very close to N_2 in the frequency spectrum while the other (210000) is near to L_2. Together they form a conjugate pair of tidal lines about M_2 and they are separated from their more conventional neighbours by only one cycle in 8.85 years, the period of the lunar perigee.

The anomaly is discussed, and the suggestion is made that the amplification of these terms, (2±10000), may be due to their spatial distribution which is different from those of the principal tides, so exciting specific forcing functions in the response of the oceanic scale system.

INTRODUCTION

In recent works, WEEB (1973) and LENNON (1980), some anomalies are noted in the tidal response function which links the tide-generating potential with the semi-diurnal tides observed in Australian waters. The difficulties encountered in

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identifying the gravitational response function are well-known. A significant number of the tidal lines suffer from multiple forcing functions involving mechanisms of atmospheric origin in addition to the gravitational tide, and the non-linear interaction associated with shallow-water hydrodynamics. Consequently, there is a severe limitation on the selection of tidal constituents to which the response function may be fitted without special treatment. The aim here is to take advantage of long data sets so as to achieve better separation of tidal lines in the spectrum, and to attempt to quantify energy from non-gravitational sources so that an optimum fit of the gravitational response function may be made. In this way, it is planned to examine the fine structure of the spectrum with particular reference to the behaviour of the semi-diurnal tide in the Queensland region.

TIDAL DISCRIMINATION

The tide generating potential of the Moon and the Sun can be expanded in terms of periodic functions of their orbital elements τ, s, h, p, N and P_1.

where τ = local mean lunar time in angular measure
s = the mean longitude of the Moon
h = the mean longitude of the Sun
p = the mean longitude of the Moon's perigee
N = the mean longitude of the ascending node of the Moon
P_1 = the mean longitude of the Sun's perigee.

These parameters are arranged in ascending order of period as follows:

τ = lunar day (24.84 hours = 1.035 mean solar days)
s = 27.32 mean solar days
h = 365.22 mean solar days
p = 8.85 mean solar years
N = 18.61 solar years
P_1 = 201 Julian centuries

It follows that the resolution of a tidal analysis is dependent upon the relationship between the above periods and the length of the observed time series. For practical reasons data sets submitted to analysis seldom exceed one year in duration. In consequence such analyses are able to discriminate only between tidal lines which are separated in the frequency spectrum at least by one cycle in periods τ, s, or h.

Pairs of tidal lines whose synodic period exceeds h, that is periods associated with cycles determined by p, N or P_1, cannot be identified individually and consequently tend to be merged in a time-dependent cusp of energy. In practice since Nodal variations, associated with N, are of the order of ±3%, they are commonly given special treatment through the application of amplitude and phase correction terms, f and u respectively, based upon a consideration of the equilibrium tidal relationships. Rare attempts have been made (AMIN, 1976) to effect nodal splitting in a fine resolution of tidal harmonics through the treatment of data sets extending over 19 years. Clearly, it is impractical to investigate variations due to the Sun's perigee and also features associated with the Moon's perigee have been largely ignored except in so far as their treatment has been automatic in the nodal exercises. Special attention is given here to tidal discrimination at the level of one separation cycle in the period of the lunar perigee, i.e. a discrimination of 0.0046° per mean solar hour. For each tidal line, it is then proposed to compare the observed amplitude response, H, with the amplitude for the same line computed from the equilibrium tide, H(e), over the semi-diurnal tidal band and also to compare the observed phase lag on the equilibrium constituents, g, with its neighbours in the spectrum. In this way the attempt is made to identify the frequency dependent response function across the semi-diurnal tidal band which links the astronomical tide-generating potential with the actual response of the ocean. In the real ocean, hydrodynamical effects modify the equilibrium characteristics and it is this modification which is the subject of interest. Given the physical case of the world ocean and the resonant mechanisms which control its response to tidal forcing, one has reason to expect that the response characteristics will emerge as a smooth function which varies slowly with frequency.

SOURCE DISCRIMINATION

In attempting to identify the semi-diurnal gravitational response function linking the observed with the equilibrium tide, the first priority is to achieve a fine resolution of the tidal lines as discussed in the previous section. However, this is not the only problem to be solved in the present context. More intractable is the problem of multiple sources, whereby one tidal line may comprise responses to more than one stimulus. In general this can occur within the gravitational tide more than one stimulis. In general this can occur within the gravitational tide itself though the problem is not serious in the semi-diurnal band. What is more serious is the response to atmospheric or radiational features at, or near, the frequency of the solar tide, S_2. Again the non-linear terms of the hydrodynamical equations, associated with friction in shallow water, allow interaction between the gravitational terms such that new tidal constituents emerge whose speeds are equal to sums and differences of the interacting gravitational lines. Since the orbital elements are few in number and their combinations are complex, it is not surprising that non-linear terms can coincide with each other in the spectrum and, in particular, it is possible for them to coincide with gravitational lines. The latter feature is of considerable significance in the present task. In fitting a gravitational response function to the results of analysis of observations, one has to be aware of the fact that most of the tidal constituents receive contributions from multiple sources so that they cannot be used directly. This being so, every attempt must be made to isolate the gravitational contribution for fitting purposes, by the elimination of terms arising from atmospheric or non-linear sources.

The problem is non-trivial since a closer inspection reveals that all the major tidal constituents which we would wish to select for response function fitting suffer perturbation from sources other than the gravitational tide to some degree as seen in Table 1.

The end result will be to introduce a cyclic variation in the results for H and g giving values disposed on either side of their real values. On a phasor polar plot all results would be confined within a finite sector.

However, where $\frac{H_1}{H} \geq 1$, then U or α will assume all values in the range $(-\pi, \pi)$ depending on the value of p. It is therefore possible to conclude from the results of Table 2 and Figure 1 that, at Cairns and Townsville, L_2 is being perturbed by another harmonic term and furthermore that the second term is significantly larger than L_2 itself.

Therefore in the L_2 case $\frac{H_1}{H} >> 1$

Examination of N_2 variations suggests the operation of a similar harmonic perturbation where, in this case, the perturbing term is significanlty smaller than N_2.

Here $\frac{H_1}{H} << 1$

THE ANALYSIS OF LONG PERIOD OBSERVATIONS

Although a qualitative estimate of anomalous terms in the vicinity of N_2 and L_2 can be obtained from the apparent temporal variations in the conventional constituents, it is essential to resolve these terms numerically if quantitative evaluation is desired. It would have been helpful to have had available observations from the site covering the nodal cycle of 18.61 years, in which case the inaccuracies of the inputs of f and u would have been avoided and the resolution of the analytical procedure would have been more than adequate for the problem in hand. However the available observed records from Cairns and Townsville are much shorter than the nodal cycle, nevertheless near-continuous time series of nine years duration were available at each station clearly exceeding the period of the perigean cycle. Consequently, it is possible to resolve directly terms differing by p (1 cycle in 8.85 years) in argument number and this may be achieved without the need to input f and u for these terms.

The results of the harmonic analysis are given under the label 'Observation' in Table 3 for both Cairns and Townsville with particular reference to the semi-diurnal tidal band. The coherence of the tidal signal over some 300 km of the Northern Coastal Lagoon is clearly demonstrated. However, the aim is to fit to the results the gravitational response function $(\frac{H}{H^{(e)}})$, the amplitude ratio of observed to equilibrium tide. For this purpose, it is desirable to identify and quantify any energy arising from non-gravitational sources by anticipating a smoothly varying function over frequency span of tidal species insofar as the gravitational response is concerned. Any departure which cannot be explained by a known forcing function is consequently of considerable interest and requires interpretation as a finely-tuned resonant phenomenon or as an anomalous wave. The absolute values may then be used to quantify the associated energy.

Table 2

Tidal constituents resolved from one year observations

CAIRNS TIME ZONE G.M.T. UNITS - METRES

	1967		1968		1969		1970		1971		Sept 71 Aug 72		Sept 72 Aug 73		1973		1974		1975		Previous Analysis 1966-67	
	H	G°	H	G°	H	G°	H	G°	H	G°	H	G°	H	G°	H	G°	H	G°	H	G°	H	G°
A_0	1.407		1.443		1.441		1.450		1.414		1.422		1.477		1.493		1.476		1.479		1.406	
O_1	.152	13.8	.150	14.4	.155	14.9	.155	14.4	.152	14.4	.153	15.1	.155	14.9	.157	14.8	.150	13.9	.151	12.4	.152	13.5
K_1	.310	40.3	.312	41.2	.310	41.4	.310	40.8	.312	40.9	.314	40.9	.313	41.3	.313	41.2	.313	41.0	.311	40.8	.310	39.9
M_2	.571	346.8	.572	348.0	.563	348.9	.571	346.4	.567	347.2	.566	347.3	.556	347.4	.557	347.1	.567	347.6	.573	346.2	.577	346.7
S_2	.338	305.7	.338	307.5	.341	308.2	.337	306.8	.340	307.3	.342	306.7	.350	307.4	.345	307.7	.345	307.1	.347	307.0	.334	306.6
L2	.025	177.6	.013	166.3	.009	188.4	.016	136.0	.023	64.8	.016	2.2	.013	319.8	.013	314.8	.019	262.2	.024	219.3	.032	201.3
P_1	.093	36.9	.091	38.9	.094	38.3	.096	37.6	.092	39.0	.095	37.3	.097	38.5	.098	39.5	.098	37.6	.096	36.7	.092	36.1

Table 2 (cont.)

Tidal constituents resolved from one year observations

TOWNSVILLE TIME ZONE G.M.T. UNITS - METRES

	1966		1967		1968		1969		1970		July 70 June 71		Aug 71 July 72		1972		1973		1974	
	H	G°	H	G°	H	G°	H	G°	H	G°	H	G°	H	G°	H	G°	H	G°	H	G°
A_0	1.669		1.616		1.608		1.624		1.587		1.580		1.605		1.619		1.668		1.667	
O_1	.162	12.1	.163	12.9	.162	13.6	.160	12.8	.163	12.3	.164	12.5	.163	12.1	.165	12.9	.165	11.9	.164	12.0
K_1	.335	37.8	.336	37.8	.337	37.9	.332	38.1	.338	38.0	.340	37.9	.340	38.1	.338	38.0	.338	37.8	.340	38.2
M_2	.723	350.9	.723	348.9	.725	349.0	.723	350.7	.725	348.6	.722	347.9	.730	349.2	.732	350.1	.726	349.1	.727	349.7
S_2	.423	306.8	.416	307.4	.422	306.2	.425	307.3	.423	307.2	.424	306.7	.427	307.0	.427	307.0	.428	307.1	.426	307.9
L_2	.025	259.0	.011	149.0	.012	146.0	.013	148.8	.027	128.4	.034	100.4	.030	7.5	.025	347.3	.021	323.3	.016	276.0
P_1	.097	35.5	.102	33.0	.101	34.6	.095	33.6	.101	33.0	.100	33.1	.102	31.3	.099	32.1	.099	32.5	.103	32.1

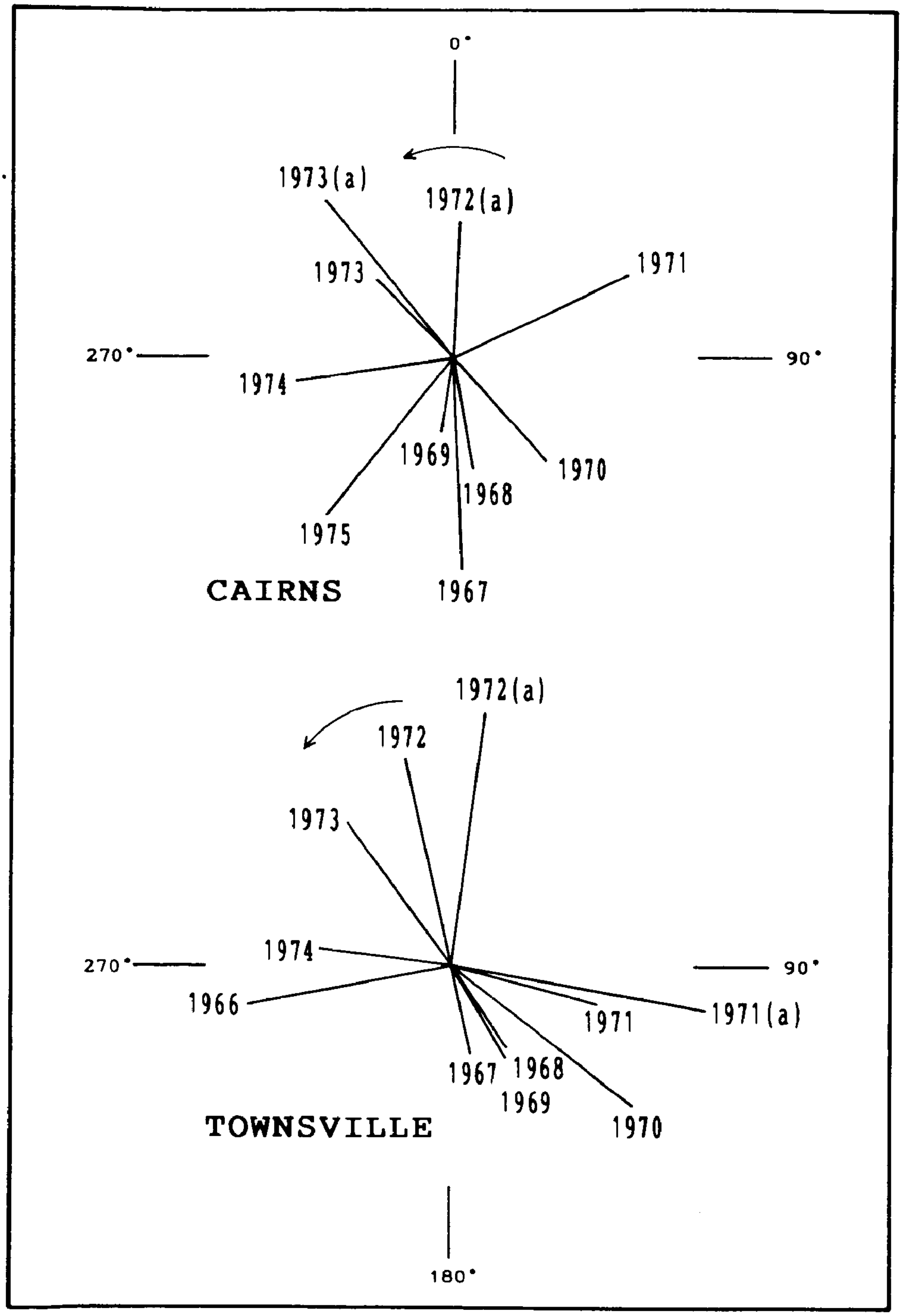

FIG. 1.- 1. Phasor diagram of constituent L_2 as obtained from analyses of one-year sets of Cairns and Townsville observations.
(a) indicates that observations started from 1st September of previous year.

Table 3

Constituents resolved by analysing long period observations and those estimated indireclty.

Constituent									Cairns				Townsville			
									Observation		Estimated		Observation		Estimated	
Argument No.							Speed	Name	H (mm)	g (deg.)	H (mm)	g (deg.)	H (mm)	g (deg.)	H (mm)	g (deg.)
1	0	0	-1	0	0	90	14.4874103		6	170.03			8	159.88		
1	0	0	0	0	0		14.4920521	M_1	4	265.70			3	274.85		
1	0	0	1	0	0	90	14.4966939		14	179.23			14	176.73		
							27.4238337	MNS_2	9	217.15			11	204.15		
							27.8860712	$2MK_2$	2	197.05			4	174.61		
2	-2	0	2	0	0		27.8953548	$2N_2$	26	241.57			33	239.89		
2	-2	2	0	0	0		27.9682089	μ_2	38	224.69	μ_2=30	233.50	47	218.37	μ_2=38	232.20
											$2MS_2$=9	194.00			$2MS_2$=14	174.00
2	-1	0	-1	0	0		28.4304458		1	276.23			1	11.81		
2	-1	0	0	0	0		28.4350877	Ms_2	13	284.65			18	281.55		
2	-1	0	1	0	0		28.4397295	N_2	190	256.52			236	257.32		
2	-1	0	2	0	0		28.4443713		3	263.98			1	234.69		
2	-2	2	-1	0	0		28.5125831	ν_2	33	263.83			43	265.06		
2	0	0	0	0	0		28.9841042	M_2	566	276.93			726	279.22		
2	1	-2	1	0	0	180	29.4556253	λ_2	7	68.87	λ_2=2	274.90	8	46.16	λ_2=3	282.63
											SNM_2=9	78.05			SNM=10	60.62
2	1	0	-2	0	0		29.5238371		1	151.31			1	305.87		
2	1	0	-1	0	0	180	29.5284789	L_2	5	148.10	L_2=8	278.98	2	357.91	L_2=11	281.07
											$2MN_2$=12	117.53			$2MN_2$=11	89.13
2	1	0	0	0	0		29.5331207	Ms_2	14	167.28			18	164.69		
2	1	0	1	0	0		29.5377626		5	227.77			8	210.35		
2	2	-3	0	0	0		29.9589333	T_2	23	221.00			29	213.12		
2	2	-2	0	0	0		30.0	S_2	341	246.77			423	247.08		
2	2	0	0	0	0		30.0821373	K_2	95	243.25			116	243.69		
2	3	-2	-1	0	0		30.5443747	MSN_2	8	332.90			9	313.25		
2	4	-4	0	0	0		31.0158958	$2SM_2$	6	290.87			4	285.44		

Notwithstanding earlier discussion it may be stated that in non-linear tidal regimes, there are four tidal constituents: N_2, ν_2, λ_2, L_2 and S_2 in this context because of their corruption by extraneous contributions. It will be noted that the length of the observed time series at Cairns and Townsville provides some relief. For example it has been possible to resolve $2MK_2$ (2-20000) from $2N_2$(2-20200). This in turn allows an estimation of the magnitude of $2MS_2$ (2-22000) which coincides in speed with the gravitational constituent μ_2, as in AMIN (1982). By this means two additional discrete lines $2N_2$ and μ_2 were made available for functional fitting.

At this stage a decision must be made as to the basic form of the function to be fitted. If the response across the tidal band is considered to be nearly linear then a 2nd degree polynomial may be satisfactory.

In the case of Queensland it was prudent to select a 3rd degree polynomial presentation

$$R(\sigma)=\sum_{k=0}^{3} C_k Q_k(\sigma) \tag{6}$$

where $R(\sigma) = H/H^{(e)}$ is the response function, to be estimated in terms of a linear combination of the orthogonal polynomials with the assistance of a knowledge of certain discrete values corresponding to the speeds of principal constituents.

$Q_K(\sigma)$ are orthogonal polynomials defined by the recurrence relationship as:

$$\begin{aligned} &Q_0(\sigma)=1, Q_1(\sigma)=\sigma-a_1 \\ &Q_k(\sigma)=(\sigma-a_k)Q_{k-1}(\sigma)-b_kQ_{k-2}(\sigma),\ k\geq 2 \end{aligned} \tag{7}$$

Equation (6) is solved for C_k such that

$$\sum_i W_i[R_i-\sum_{k=0}^{3} C_kQ_k(\sigma_i)]^2$$

is a minimum.

Summation is effected over the constituents previously identified for inclusion with weights, W, chosen to give more influence, perhaps related to constituent amplitude, to those constituents which are large and pure. In this way large departures may be allowed only near to small and doubtful constituents. Constituents with serious contamination e.g. S_2 can be neglected or used with reduced weights.

In the case of phase lags a similar functional estimate can be obtained through the replacement of R by g in the above expression.

Response functions computed by this technique are shown in Figure 2. These identify a general pattern of response varying with frequency, which will be maintained despite reasonable changes in the selection of polynomials and the skeletal framework.

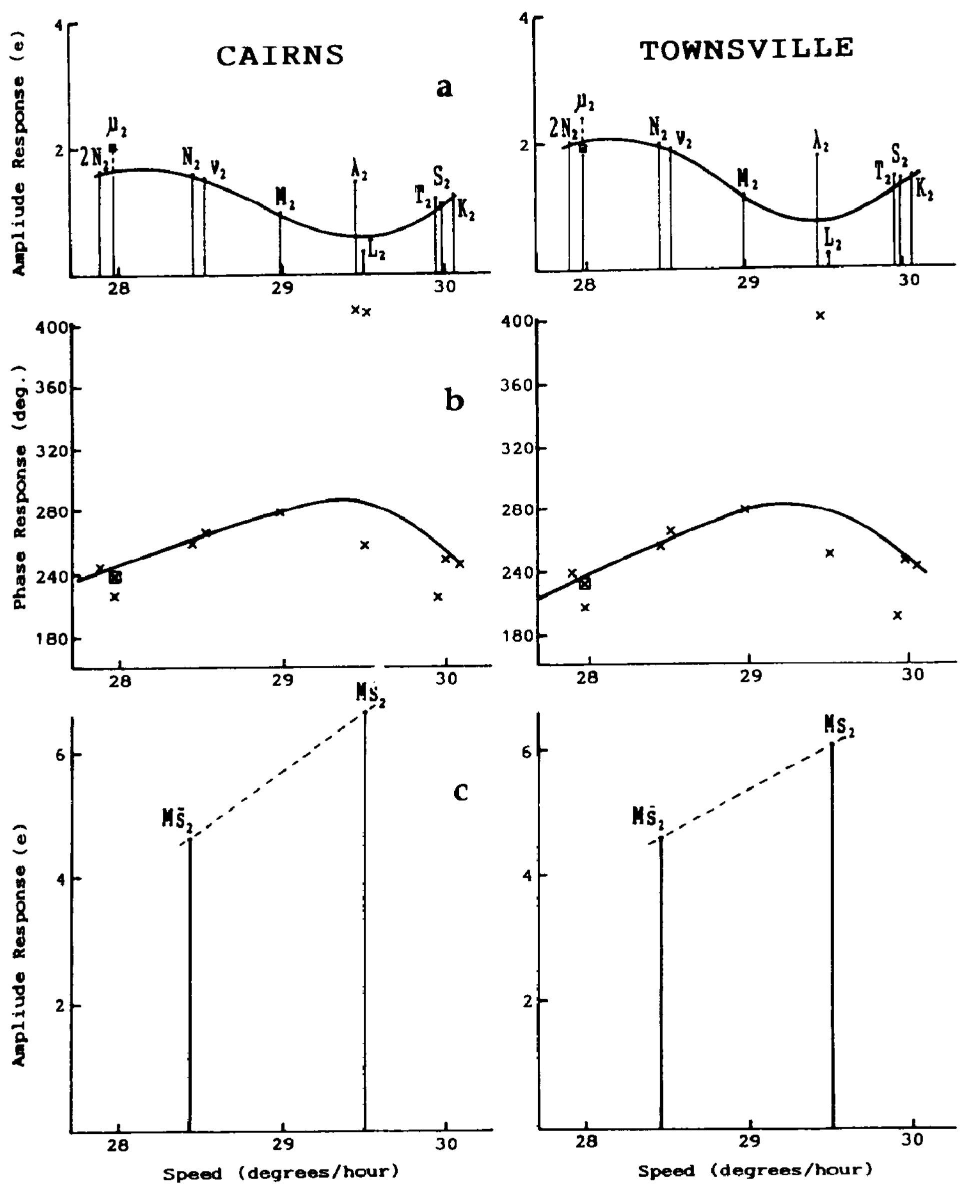

FIG. 2.- Response functions of Cairns and Towsville tide as fitted to constituents resolved from nine years observations:
a. amplitude response $(H/H^{(e)})$ of principal tides; b. phase response; c. amplitude response of tides due to third degree terms in the tide generating potential. □ is the corrected value of μ_2 after removing $2MS_2$.

DISCUSSION OF RESULTS

The response curves which emerge from both Cairns and Townsville show remarkable similarity suggesting a real tidal phenomenon of regional coherence.

In particular, departures from the response curve suggest the presence of additional and therefore non-gravitational energy at, or near, the frequencies of $2N_2$, λ_2, L_2, T_2 and S_2. Each of these tidal lines requires careful attention.

In the case of S_2 additional energy is expected to arise from solar radiation, perhaps linked with the atmospheric tide. It has been shown (CARTWRIGHT, 1968 and ZETLER, 1971) that in the coastal zones of the central Pacific, North America and elsewhere a radiational S_2 might assume a magnitude of 20% of the gravitational S_2. Evidence now exists that this condition is also true of the deep ocean (CARTWRIGHT, personal communication). The physical mechanism, however, remains somewhat obscure. The nature of the Australian environment would argue for a radiational tide at least as large as this but it is difficult to quantify the effects precisely since there are non un-perturbed gravitational constituents present in the vicinity on which to fix the gravitational response function. Again, since the radiational forcing function is less rigorously periodic than the astronomical equivalent, the resultant temporal variability manifests itself as a spread of energy over a frequency band in the form of a cusp. Furthermore annual perturbations of M_2, due to seasonal changes in weather, were shown to exist by CORKAN (1934). Recently similar perturbation of S_2 were also identified by AMIN (1982). Such features are however masked by the gravitational constituents T_2 and R_2, both of which separate from S_2 by one cycle in one year. Even K_2, separated from S_2 by one cycle in six months, may be degraded by a spread of solar radiational energy around S_2. This being so, the fit of the response function in the vicinity of S_2 is somewhat questionable implying difficulty in discrimination between gravitational and radiational origins. This uncertainty applies both to the amplitude and phase diagrams of Figure 2.

More assurance is provided concerning the residual range of frequency in the semi-diurnal band. In the first place, it is helpful to consider the harmonic terms arising from the interaction of M_2, S_2 and N_2 in shallow water. Three terms are so generated: MNS_2 (2-32100), MSN_2 (23-2-100) and SNM_2 (21-2100). Of these, two, namely NMS_2 and MSN_2, have an unambiguous source in that coincidence is not expected with another interactive term, neither is there a gravitational term at the same frequency. In consequence, the two terms can be resolved directly and, it will be noted in Table 3 that they are seen to be in the amplitude range of 9 mm to 10 mm. On this basis, it may be assumed that SNM_2 is also of similar magnitude, say 10 mm. However, SNM_2 coincides exactly in frequency with λ_2 and may be taken to account for the apparent additional energy displayed at the λ_2 frequency. It is against this background that attention is directed towards the spectrum in the neighbourhood of N_2 and L_2. In the latter case again special consideration is required. At the frequency of L_2 one may anticipate a contribution from the shallow water term $2MN_2$ so that the displacement of the L_2 plot from the smooth response curve is not unexpected. It would appear that $2MN_2$ has an amplitude of 12 mm approximately. It is difficult to be precise since the minimum of the response curve occurs in this vicinity leaving some ambiguity in its fitting in the absence of known discrete values nearby.

Having identified the perturbations it is then appropriate to examine the marine response to the gravitational forcing function in the vicinity of N_2 and L_2. A preliminary comment must be that the response is much more complex than was anticipated. In particular there emerge two strong tidal lines at speeds (2±10000) to which appropriate names might be given as Ms_2 and $M\bar{s}_2$. The characteristics of these tidal lines are as follows:

(a) They form a conjugate pair equally spaced in frequency about M_2.
(b) In the equilibrium tide there exist two small harmonic terms at these frequencies arising from 3rd degree terms in the expansion of the tide generating potential.
(c) There are no shallow-water terms expected at these frequencies and, in association with the above considerations, their origin is clearly gravitational.
(d) In an absolute sense the amplitudes of 14 mm and 20 mm are not very large but, relative to the equilibrium tide, their amplitudes are very significant.
(e) The terms are consistent in amplitude and phase at two ports, indicating a real signal over a broad region.
(f) They are separated in frequency from the conventional terms N_2 and L_2, by only one cycle in 8.85 years indicating a very fine resolution in the mechanism which selects $M\bar{s}_2$ and Ms_2 for amplification.
(g) In fact Ms_2 is greater in absolute magnitude than its neighbour L_2, thereby producing the anomaly which initiated the present study. The constituent, $M\bar{s}_2$ is considerably smaller than N_2 and consequently could not create significant temporal disturbances in analytical results for N_2.

THE REGIONAL SCALE

Although long sea level time series are not generally available, and certainly not along the Queensland coast north of Cairns, it is possible to examine the spatial extent of the anomaly southwards. It would of course be extremely interesting to investigate the situation to the east along the reef fringe of the coastal lagoon and indeed in the deeper waters of the Coral Sea, however, such work is precluded by the complete absence of long data sets.

In this context, the treatment applied to the cases of Cairns and Townsville has also been given to data from Mackay, Bundaberg, Newcastle and Ft. Denison (Sydney Harbour) so effectively covering a length of coastline in excess of 2,000 km. Throughout this region there is a clear anomalous signature with the new constituents, $M\bar{s}_2$ and Ms_2, clearly identifiable although the signal becomes progressively smaller towards the south. This feature is shown in Figure 3 which may be interpreted in an identical manner to that of Figure 2.

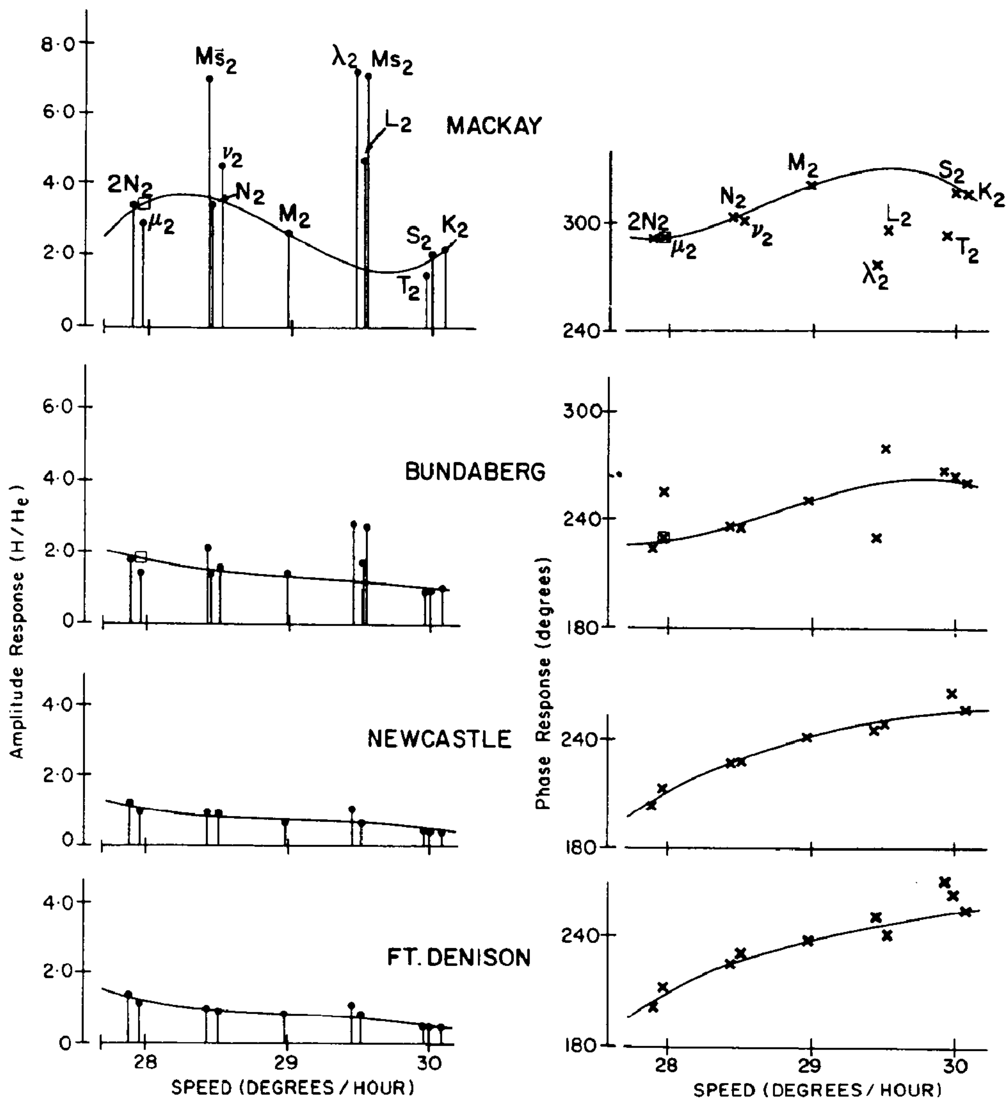

FIG. 3.- Response functions of Mackay, Bundaberg, Newcastle, and Fort Denison tides.

Meanwhile the entries of Table 4 give numerical values to both amplitudes and phase lags of the relevant constituents. One may note that from Mackay southwards, the perturbing tidal line Ms_2 is already less in magnitude than the conventional L_2 tidal constituent.

The three northern stations show progression and a coherence which is convincing although the pattern to the south becomes confusing. Newcastle and Ft. Denison are mutually reinforcing and although they are only 130 km apart their agreement suggests reality. However, there seems to exist a boundary in the vicinity of Mackay/Bundaberg from which differences in phase between the northern and southern section increase. Table 4 also includes the values of M_2 which demonstrate a similar pattern of tidal progression.

Table 4

	M_2	$M\bar{s}_2$	N_2	L_2	$2MN_2$	Ms_2
CAIRNS	566(277)	13(285)	190(257)	8(279)	12(118)	14(167)
TOWNSVILLE	726(279)	18(282)	236(257)	11(281)	11(89)	8(165)
MACKAY	1652(323)	27(300)	412(305)	30(334)	62(282)	24(193)
BUNDABERG	852(251)	8(230)	178(236)	21(264)	19(202)	9(75)
NEWCASTLE	472(241)	3(94)	101(227)	-	-	5(20)
FT.DENISON	509(237)	4(101)	114(224)	-	-	6(19)

13 may be interpreted as
H in mm = 13
g in degrees referred to local time GMT - 1000 = 285°.

CONCLUDING REMARKS

The analyses of large spans of tidal observations and the subsequent treatment of non-gravitational terms provide a framework upon which the response function of the gravitational tide can be fitted. This definition of the characteristics of the response function makes it possible to draw certain inferences with respect to the tidal anomalies of the region.

At both Cairns and Townsville, the L_2 constituent is seen to be suppressed. Here it is difficult to be precise in one's interpretation, however, it can be stated that the response function has a regional minimum in this vicinity and the coincidence of the non-linear tide $2MN_2$ may explain the problem.

What is very clear is that two new tidal constituents of gravitational origin have been identified and these are seen to be very close to N_2 and L_2, respectively, and are subject to a mechanism which nevertheless selects the new constituents, rather than their neighbours, for amplification.

Previously, the explanation of the anomalous behaviour of L_2 had rested with simple resonance. Now rather complex problems are seen. For example:

(i) When other terms ($2MN_2$, Ms_2) are separated from the L_2 tide, the changes in the response function around the L_2 frequency band are smooth and similar to those observed at many other ports.

(ii) The amplification of the 3rd degree terms ($M\bar{s}_2$ and Ms_2) is much greater than that of the principal tides in the semi-diurnal band. Nevertheless, the change in the response over a wide frequency band ($M\bar{s}_2$ - Ms_2) is small and can be considered as smooth. This suggests that a physical process which can discriminate between forcing functions, so close in frequency as to be separated by one cycle in 8.85 years, exists.

(iii) Whatever mechanism is invoked to explain the Ms_2/L_2 anomaly must also explain the $M\bar{s}_2/N_2$ anomaly in another part of the spectrum.

Since the response of the ocean depends on the spatial distribution of the forcing function, it does not seem to be illogical that the responses of $M\bar{s}_2$ and N_2 on the one hand, and Ms_2 and L_2 on the other, are not the same. In the gravitational tide, the terms Ms_2 and $M\bar{s}_2$ originate from 3rd degree terms in the expansion of the tide-generating potential. The spatial distribution of the latter terms is quite different from that which gives rise to N_2 and L_2. In illustration it may be noted that all the principal conventional tides progress from North to South whereas Ms_2 and $M\bar{s}_2$ progress in the opposite direction. It may be relevant also to note that oceanic normal modes of 12.1 hour and 12.5 hour periods (PLATZMAN et al., 1981), are very close to the periods of N_2 and L_2. The propagation of these modes are such that they favour the progression of Ms_2 and $M\bar{s}_2$ and make selective amplification possible; CARTWRIGHT (1975) used similar principles in explaining the large magnitude of M_1 in European waters.

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