# Oscillations of the Gulf of Carpentaria

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## ABSTRACT

Analysis of sea level residuals at ports in the Gulf of Carpentaria reveals resonent oscillations of the Gulf at periods of 10.6 and 16.0 h, which are close to those predicted by a theory of Williams (1972). Further activity at periods of 30–40 h is also present. The evidence suggests that the resonant oscillations may be caused by disturbances in the Indian Ocean and Coral Sea as well as by local meteorological conditions. The analysis also shows considerable residual activity in the ter-diurnal tidal band, this being consistent with the occurrence of resonance and nonlinear tidal interactions in this period range.

## 1. Introduction

A recent theoretical model of the Gulf of Carpentaria-Arafura Sea system (Williams, 1972; Buchwald and Williams, 1975), shown in Fig. 1, predicts that the Gulf resonates at periods of 7.9, 10.4 and 16 h. Although the model assumes a highly idealized geometry, these periods are found to change by only 1% for changes of approximately 10% in the dimensions of the model, and can be regarded as reasonable estimates of the expected resonant periods.

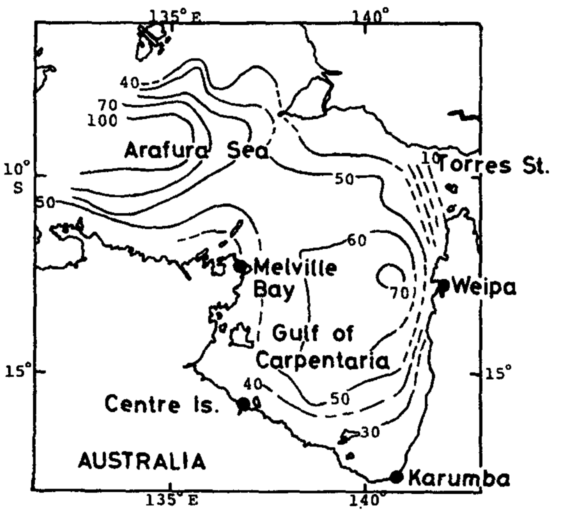



Fig. 1. The Gulf of Carpentaria-Arafura Sea region with depth contours in meters (after Rochford, 1966).

Previous harmonic analyses of tidal records from Weipa, Karumba, Centre Island and Melville Bay (Table 1) show large ter-diurnal tides, amounting to a total possible amplitude of approximately 10 cm at Weipa and Karumba. This is consistent with a resonance of the Gulf at 8 h. However, an alternative explanation of the large ter-diurnal tides at these two ports could be the position of the gages in shallow estuaries.

The Gulf is shallow, having a maximum depth of about 70 m, so that bottom friction may be large, possibly preventing the establishment of significant resonant oscillations, especially at higher frequencies. In

Table 1. The amplitudes (mm) of the major diurnal, semi-diurnal and ter-diurnal tides as computed by the Liverpool Tidal Institute (Karumba, Weipa) and Flinders University (Centre Island, Melville Bay).

| | $O_1$ | $K_1$ | $M_2$ | $S_2$ | $MO_3$ ($2MK_3$) | $M_3$ | $SO_3$ | $MK_3$ | $SK_3$ |
|---|---|---|---|---|---|---|---|---|---|
| Centre Island | 352 | 421 | 395 | 104 | 16 | 6 | 13 | 22 | 12 |
| Karumba | 664 | 909 | 168 | 37 | 33 | 9 | 28 | 38 | 30 |
| Melville Bay | 207 | 259 | 800 | 256 | 23 | 5 | 9 | 19 | 7 |
| Weipa | 312 | 457 | 362 | 50 | 34 | 9 | 17 | 35 | 20 |

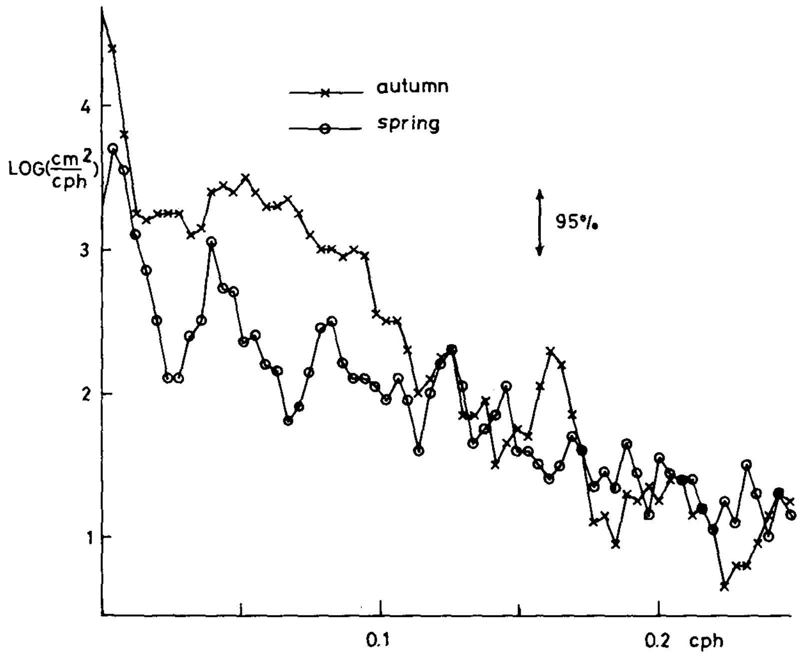



FIG. 2. Residual spectra at Centre Island for autumn and spring 1967 (bandwidth = 0.0005 cph).

order to determine whether the predicted oscillations actually take place, corresponding tide-gage records from Centre Island (1 January 1966–3 January 1970), Melville Bay (6 October 1965–17 August 1972) and Weipa (1 January 1966–2 September 1973) were analyzed. The records from these three locations were the only ones available over sufficiently long concurrent periods. However, their spacing around the Gulf was considered to give a satisfactory coverage of the area.

## 2. Results

### *a. Residual spectra*

Residuals were calculated by subtracting predictions, based on standard tidal constants for the corresponding period (or nearest possible), from the full tide-gage records. Seasonal spectra of the residuals were computed and these showed considerable variation from season to season. The spectra for autumn and spring, 1967, at Centre Island are shown in Fig. 2. The spring spectrum shows peaks of residual energy in the tidal bands possibly due to nonlinear tidal and tide-surge interaction. The autumn spectrum is qualitatively different with a large increase in energy in intertidal bands leading to a broad plateau for the periods 10–100 h. The ratio of $E_{max}/E_{min}$ at Centre Island for the seasons in the period 1 December 1966–30 November 1969 is shown in Fig. 3. There are peaks in the tidal bands—at 15.1 and 11.1 h near the predicted resonances and a further local max-

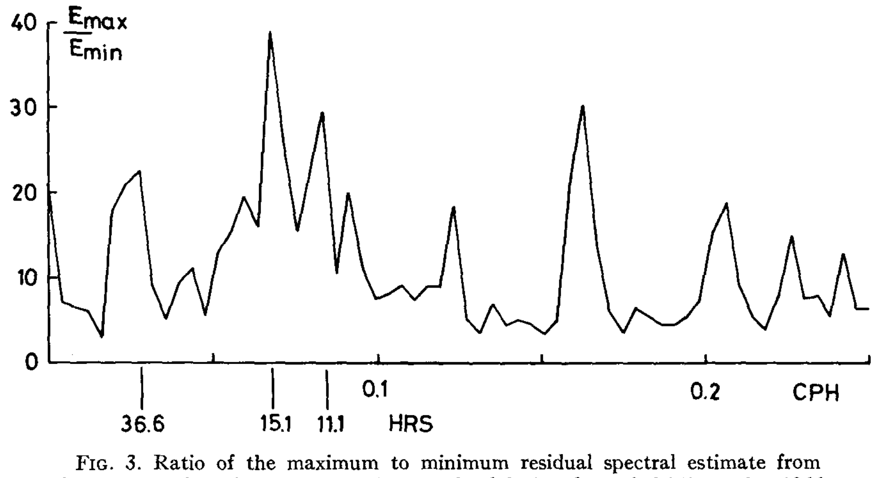



FIG. 3. Ratio of the maximum to minimum residual spectral estimate from the 12 seasonal residual spectra at Centre Island during the period 1 December 1966 to 30 November 1969.

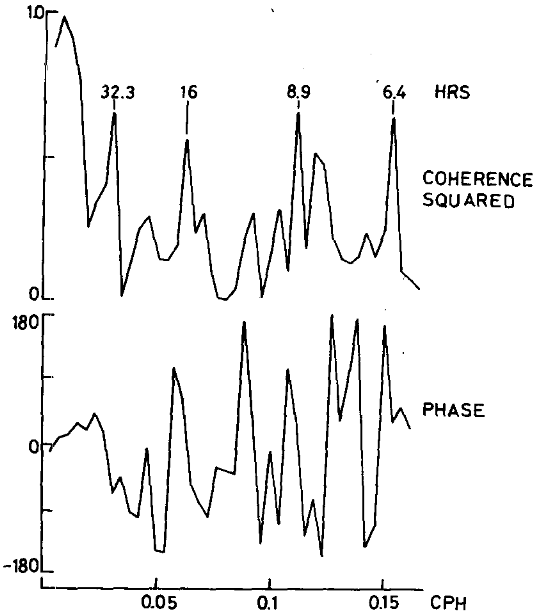



FIG. 4. Squared coherence and phase between Weipa and Melville Bay for the six weeks beginning 5 March 1967.

imum in the neighborhood of 40 h. In each case $E_{max}$ occurred in the summer or autumn of 1966–67. The same periods were prominent for Weipa and Melville Bay and, while the maxima did not all occur in those particular seasons, all were in either summer or autumn. These are the seasons for tropical cyclones and the 1966–67 season was particularly active with 15 reported in the Australian region (Coleman, 1972). Moreover, this region is generally under the influence of the inter-tropical convergence with its marked N–S fluctuations during the months November to March, and the changes in wind direction may provide another source of energy input.

### b. *Coherence and phase*

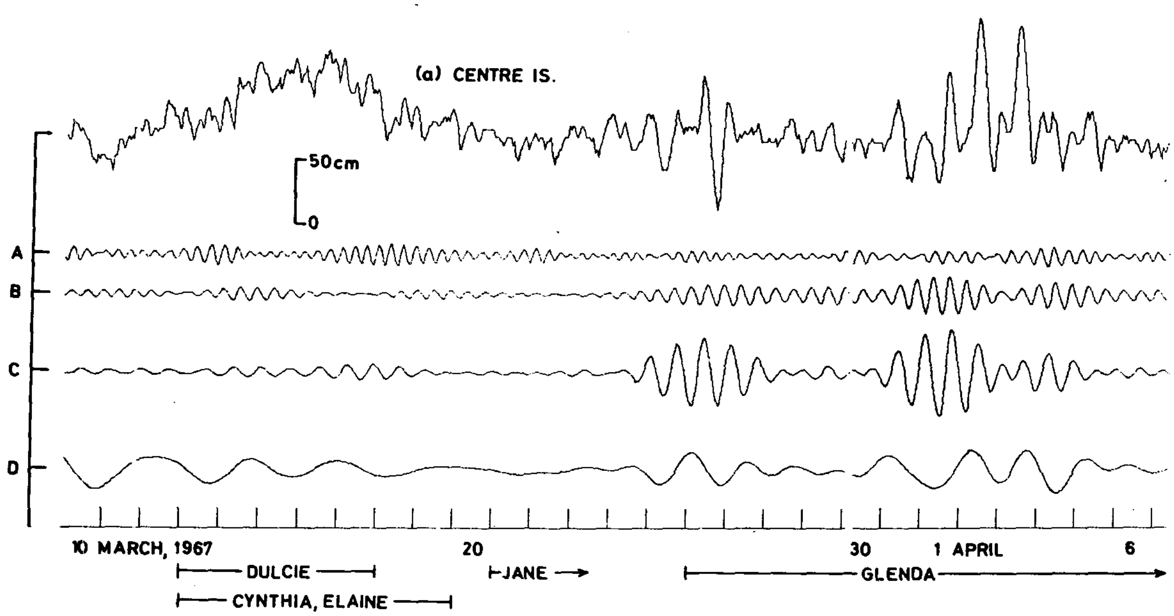
The squared coherence and phase between the residuals at Weipa and Melville Bay were computed for the six weeks beginning 5 March 1967, during which there was almost continuous cyclonic activity. In Fig. 4 the residuals are shown to be strongly coherent at 6.4, 8.9, 16 and 32.3 h. The phase at 16 h agrees well with the prediction of Williams. This is the only predicted resonant period for which a direct comparison is possible.

The coherence of the residuals between Centre Island and Weipa, and Centre Island and Melville Bay, for the same period, showed peaks in the neighborhood of 16, 8 and 6 h and in addition one at 10.7 h.

### c. *Analysis of events during March–April, 1967*

Visual inspection of the residual records indicated the presence of significant transient "events" at each port. In order to further examine these events the residuals were bandpass filtered with filter A passing periods 6.5 to 9.4 h, B (9.1–11.0 h), C (14.3–19.4 h), and D (30.0–80.0 h). A, B and C covered the expected resonant periods, and D those longer periods showing significant spectral variation (Fig. 3). Fig. 5 shows the residual sea levels and outputs of the four filters, for Centre Island and Weipa for the period 10 March 1967 to 6 April 1967. Also recorded in the figure are the periods and locations of cyclones in the Australian Region at the time.[1] The corresponding filter outputs at Melville Bay, which are

[1] Tropical Cyclones in the Northern Australian Regions 1966–67 Season. Australian Bureau of Meteorology, May 1969.



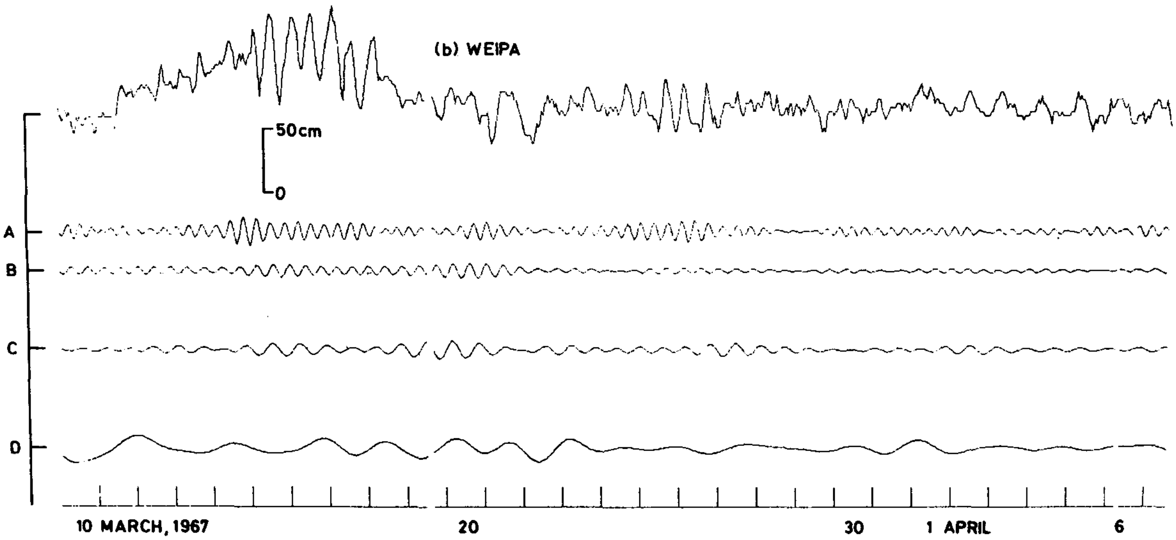



FIG. 5. Residual sea level series at Centre Island (a) and Weipa (b) and filter output for the period 10 March 1967 to 6 April 1967. Filter A passes periods 6.5–9.4 h, B (9.1–11.0), C (14.3–19.4), D (30.0–80.0). The tropical cyclones in the Australian region during this time were Jane in the Indian Ocean, Cynthia in the Gulf, and Dulcie, Elaine and Glenda in the Coral Sea.

not shown, are generally comparable in magnitude to those at Weipa.

One feature of interest in both residual records is the storm surge of around 60 cm, due to cyclone Cynthia, persisting for a period of some 6 days. The residuals at Weipa during this period shows a semi-diurnal component which is most likely due to tide-surge interaction.

The output of filter A shows a fairly constant oscillation of amplitude around 5–10 cm, of the same order as the maximum combined magnitude of the ter-diurnal tides given in Table 1. These oscillations are probably caused either by the resonance, predicted by Williams, or by nonlinear interactions to which standard harmonic analysis is not applicable.

The output from filter C shows large oscillations of period 16 h at Centre Island on 24–28 March (X) and 1–4 April (Y). There is some evidence that X was caused by a front passing across the Gulf. Event Y coincides with an intense cyclone, Glenda, in the Coral Sea. According to Williams' model, the amplitude of the 16 h resonance is three times as large at Centre Island as a Weipa so the comparatively small response at the latter is not surprising. However, at other times significant oscillations at 16 h are present at Weipa or Melville Bay and not at Centre Island. We have no explanation of this.

Filter B shows strong oscillations of period 10.6 h during Y at Centre Island with a lesser response at

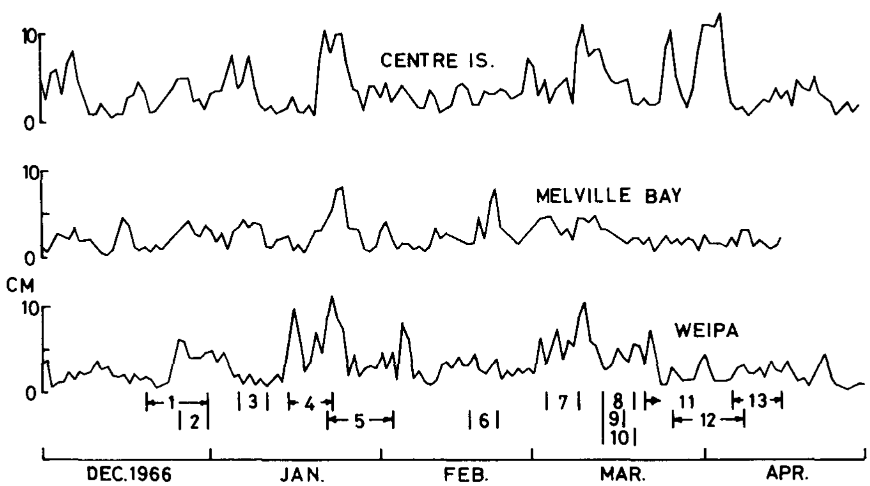



FIG. 6. Daily rms output of filter D at the three ports during summer and autumn 1966–67. Numbers refer to cyclones listed below according to their location: Indian Ocean (1–4, 7, 11, 13); Gulf of Carpentaria (8); Coral/Tasman Seas (5, 6, 9, 10, 12).

Weipa. This again is consistent with the theoretical model.

The outputs of filter D show significant oscillations at both ports. While more than one frequency is present, a period of about 40 h is the most obvious. A possible explanation, which is supported by dimensional estimates, is that the whole Arafura Sea-Gulf system has one or more resonant frequencies in this range. Further support is provided in Fig. 6 where the daily root mean square outputs of filter D at the three ports are plotted, together with information on cyclones in adjacent tropical waters during the 1966–67 season. There is clearly a strong correspondence between local maxima of the rms signals and the occurrence of cyclones. In particular, the increase in the long-period oscillations at all three ports after cyclones Elsie and Gwen is noteworthy. These cyclones are the only two which occurred during this period in the Indian Ocean close to the northwest Australian continental shelf. In particular, Elsie travelled along a path parallel to the coast for approximately 6 days.

## 3. Discussion

The frequencies of the observed resonant oscillations at 10.6 and 16.0 h agree well with those predicted by Williams, so that the value of his model is established. The total amplitudes can be quite large with the result that on frequent occasions in the summer and autumn seasons sea level predictions based on standard harmonic analysis may be very misleading.

Further discrepancies in predicted sea level are due to the fact that the observed oscillations in the ter-diurnal range do not correspond to the predicted tidal constants.

In addition to these predicted resonances, there were unexpected and highly coherent oscillations of periods 30–40 h, with indications that in this range more than one resonant period is present. Further theoretical work on the Arafura Sea-Gulf system, as well as a geographically more extensive analysis of sea level records, is needed to gain a better understanding of this phenomenon.

The observed oscillations could be caused by cyclones in the Indian Ocean and Coral Sea, or by meteorological conditions local to the Gulf. In particular, there is evidence that 1) oscillations caused by cyclones in the Coral Sea may propagate into the Gulf through the Torres Strait and 2) cyclones on the northwest Australian continental shelf force long-period oscillations of the Arafura Sea-Gulf System.

A likely local cause appears to be the sporadic N–S movement of the intertropical convergence. The possibility of comparing significant oscillations of the Gulf with available meteorological data is being investigated.

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