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CYCLONIC STORM SURGES AS A HAZARD
 TO NORTH QUEENSLAND AND THE GULF OF CARPENTARIA

A storm surge is the rapid rise in water, over a few hours, caused by the falling barometric pressure, together with the strong onshore winds associated with tropical cyclones. Wind speeds and the forward movement of the cyclone are critical factors determining the maximum surge height. If the cyclone's landfall occurs where there is a partially enclosed bay, shallow water offshore, or an estuary, these will tend to amplify the 'inverted barometer wave'. However, if strong offshore winds occur, as in the forward right quadrant of a cyclone, it is possible that water may be moved away from the land, causing a negative surge.

Cyclonic storm surges can be a natural hazard of major proportions, especially where densely populated lowland areas are exposed to the risk of surges such as in the Bay of Bengal. In 1737, 300,000 lives were lost in the Ganges Delta after a cyclone hit the area with an associated storm surge of 12.2 metres, and again in 1970, a 3.7 metre surge resulted in the death of 300,000 people on the Delta. Similar disasters caused by storm surges have occurred in other parts of the world.

In north east Australia the importance of the storm surge as a natural hazard is of somewhat lesser proportion, mainly owing to the sparsely populated cyclone prone area. To date, there has been a comparatively small loss of life from storm surges in north east Australia. The majority of those killed were at sea, for example, the pearling fleet in 1899 (307 killed), the crew of the *Douglas Mawson* in 1923 and the 75 lives lost on the sea during the 1934 cyclone. The greatest loss of life on the land was in the Mackay cyclone of 1918 where the storm surge of 3.66 metres inundated low lying parts of the city and there were thirty people killed.

Although there is a relative paucity of literature on cyclonic storm surges in Australia compared with the U.S.A., most of this has come from Queensland. The reasons for the lack of studies on storm surges could probably be attributed to the less populated area of north east Australia, to the less reliable cyclone tracking prior to 1940, and to the relatively wide spacing of tide gauges in the area.

The earliest reference to storm surges in Queensland appears to have been made in 1884 following the cyclone which hit Bowen on the 30th January in that year. Mr Christisen, the manager of the Poole Island Meat Freezing Works, wrote in a local paper,

"a strong wind rose from a point S.25°W increasing in velocity and pursuing a complete circle. When it reached S.45°E, about one a.m. on Wednesday it blew with terrific violence, the sea rising fully ten feet higher than any drift marks previously seen upon the island".

Between 1867-1899 many intense cyclones appear in the literature, although no reference to storm surges is made, except that cyclone Sigma (central pressure 991 mb) which hit Townsville in 1896 caused many suburbs to be flooded, the lower parts of the town to a depth of 1.83 metres. However, it is hard to ascertain how much of this was due to the

Ross River bursting its banks.

In 1899 the highest storm surge recorded in Australia hit Bathurst Bay north of Cooktown. Cyclone Mahina with a central pressure of 914 mb passed over Bathurst Bay in March 1899 with an associated storm surge reported to be 12.2 metres. Constable J.M. Kenny of Cooktown with four native troopers had camped on a beach ridge over 12 metres above sea level and about 800 metres from the beach, with scrub and a high sand ridge between the camp and the beach. He reported

"At 5 a.m. it (the wind) shifted to the N.E. and if possible, blew harder than ever, with torrents of rain. Shortly after the wind shifted to the N.E. an immense tidal wave swept inshore, and reached waist deep on the ridge with the camp on it....Here the wave stretched between 2 and 3 miles inland".

Cyclone Mahina destroyed a pearling fleet which had anchored in the bay. Three hundred and seven lives were lost from the fleet and a number of aborigines were taken by the sea whilst they were assisting shipwrecked men out of the water.

Cyclone Leonta (960 mb) in 1903 hit Townsville at 64 kph coming from the north east. An eye-witness report indicated that a negative surge occurred. According to the Townsville *Bulletin*, the wind was seen to move water away from the shore causing the tide to recede much further than at the lowest spring tides.

In January 1918 Mackay was hit by a cyclone from the north east with a central pressure of 932 mb. 30 lives were lost and an estimated \$1,000,000 worth of damage was done at Mackay where a "tidal wave" occurred. The storm surge was recorded as 3.66 metres although one eye-witness reported that

"a wall of water twenty-five feet high swept over the beaches, through the city over the flat countryside carrying with it masses of debris it had gathered in its path. On low-lying flats the rush of water was so sudden that homes were overwhelmed in moments".

A few months later in March a cyclone from the east crossed Cape York Peninsula, doing a great deal of damage to Innisfail, Cairns, Cardwell, Ingham and Dunk Island. The barometer fell to 944 mb at Innisfail and there was a 3.05 metre storm surge on the coast. Again in 1920 Cairns was damaged by a cyclone and a 1.22 metres of water was reported to have swept over the esplanade.

The first report of a storm surge in the Gulf of Carpentaria was that associated with the Douglas Mawson cyclone in March 1923, (named after the ss. *Douglas Mawson* which sank without trace). At Burketown the tide rose 2.74 metres above normal. An eye-witness reported a surge 5.5 metres above spring tides in the Vanderlin Island/Port McArthur area. However, another eye-witness suggested this should have been 2.5 metres. He reported

"the wave went back to sea in a few hours and the next day the highest flood seen in McArthur came down".

At Groote Eylandt the water level rose to the second storey of the Mission house, a height of 7 metres above normal river level.

In March 1934 a storm surge was reported from the Low Isles (Port Douglas). An intense cyclone (982 mb) in the Coral Sea, moved west and caused torrential rain and gales. A storm surge at Almason ruined banana plantations.

"Huge breakers, seen only on such occasions in these protected waters, smashed in foaming masses on the reef and added to the din. But stranger still was the considerable

rise in the tide. The waters were now approximately 4' higher than at 6 a.m. so that 6' is a conservative estimate of the extra rise".

Fourteen years later in February 1948, Bentinck Island in the Gulf of Carpentaria was more than half covered by a storm surge which was stated as being the indirect cause of the death of many Islanders and the abandonment of their island home. The aborigines described the tide as covering all but the highest parts of the island. Tindale surveyed the island in 1960 and from physical effects still visible at the time he managed

"to ascertain that the rise was to 12' above the highest normal tide mark. It flooded all but the highest parts of the island. As much as 50% of the land area of Bentinck Island temporarily must have been covered by sea-water including the parts most intensively used by the people".

A year later, in early March, Gladstone was badly damaged by a cyclone and the storm surge was reported to be over 1.22 metres.

"The maximum water surface rose well above the jetty level by wave action; the waves being 6-7' high. Mean level of this water surface is deduced as 16-17'".

Predictions show

"mean high water springs which was 12.6' on the morning of this occurrence, thus suggesting a surge of between 3.4' and 4.4' in the port".

It is also apparent from this report that a negative surge occurred earlier.

In 1956 cyclone Agnes tracked westward towards Mackay and swung north to hit Townsville with an associated storm surge of 0.79 metres. However a maximum surge of 1.4 metres occurred further south at Mackay. Agnes, with a central pressure of 961 mb, damaged Townsville badly, and also Bowen which experienced damaging cyclones again in 1958 and 1959. The 1958 cyclone had a central pressure of 968 mb with wind gusts exceeding 179 kph and a storm surge of 1.5 metres or more.

From 1956 onwards the reports of storm surges tend to be more consistent owing to the cyclone summaries published in the Australian Meteorological Magazine for the cyclone seasons up to 1962/1963 and from then onwards published as a separate summary by the Bureau of Meteorology. In 1964 there were reports of three surges in the Gulf of Carpentaria. Cyclone Audrey on 10th January was centred over Edward River Mission and south east to south west winds over the whole of the southern and western Gulf caused a negative surge at Karumba of about 0.3 metres.

"The main storm surge occurred on 11th January. When the astronomical tide is subtracted from the marigram it is found that an almost linear, surge results between 101800-110300Z amounting to just over 5'".

Only a month later cyclone Dora tracked down from the north west of the Gulf to cross the coast south of the Mitchell River affecting the coast to the north of its centre. The Superintendent of the Edward River Mission stated, "The sea came right over the beach ridge, a rise of approximately 18'". Karumba experienced negative tidal anomalies before the 4th February but a pronounced positive deviation on the 8th also occurred at Mornington Island.

At the start of the next cyclone season in the same year, yet another report came from the Gulf. In December a cyclone tracked from the south west to south east of the Gulf causing higher than normal tides at Burketown and a surge, near Inkerman Station, which was amplified by the

funnelling effects of the nearby creek. An eye-witness stated

"The sea came up the creek with a terrific rush. The bridge weighing approximately 2 tons and situated 10 miles from the mouth was lifted and carried upstream about $\frac{1}{2}$ a mile and dumped approximately 100 yds up on a ridge. The bridge must have been carried on top of the surge as no drag marks were visible on the ground".

On 16th February 1971 cyclone Gertie (983 mb) moved north west, parallel to the Queensland coast, causing a storm surge from Mackay to Cardwell. It then crossed Cape York Peninsula, redeveloped into Fiona causing an even larger surge in the Gulf, and then tracked back inland of the Queensland coast and eastwards to New Caledonia. Cyclone Gertie produced a 0.6 metre surge at Lindeman Island and Cardwell and a 0.3 metre surge at Townsville and Mackay. When Gertie redeveloped in the Gulf as Fiona it deepened to 960 mb and produced a 4.5 metre surge at Inkerman Station and between Edward River Mission and the mouth of the Coleman River.

Perhaps the most important cyclone as far as the literature on storm surges is concerned was cyclone Althea which hit Townsville in December 1971 with a central pressure of 952 mb. A great deal of storm surge literature was produced after Althea, and from this, original work emerged on the scientific analysis of the storm surge components. Cyclone Althea crossed the north Queensland coast at 0900 hours E.S.T. near Rollingstone, 48 km north of Townsville, on 24th December.

"The maximum height above predicted (3.6 mm) occurred at Toolakea, 25 km south of where the eye crossed the coast. Surge levels were reduced rapidly to the north but less so to the south, giving the typical asymmetric profile associated with the wind pattern. The maximum surge recorded on a tide gauge was 2.85 metres at Townsville".

A separate cyclone Althea report was published by the Bureau of Meteorology, and a paper was presented by the Co-Ordinator General's Department on the Althea storm surge. In August 1972 Dr D. Hopley presented a paper on storm surges associated with cyclones Althea and Emily to A.N.Z.A.A.S. and in late 1972 the James Cook University published 'Cyclone Althea Part II - Storm surges and coastal effects', the sections on storm surges and coastal effects also by Dr Hopley.

The first analytical work on storm surges in north east Australia is documented in the Australian Geographical Studies 1974. A report on the cyclone Althea surge indicates the apparent success of harmonic analysis as a means of surge component identification. Work has also started on the probability of surges in north east Queensland, and on computer modelling of these surges. However, this work is oriented to long term planning rather than analysis of storm surges.

In April 1972 cyclone Emily, central pressure below 945 mb, approached the central Queensland coast from the north east. A surge of 1.8 metres occurred around Bustard Head and levels of 0.9 metres were recorded at Gladstone and Bundaberg.

Literature on more recent storm surges in north east Australia is associated with cyclones Madge and Una in 1973. Madge moved from the Coral Sea on a west south westerly course to cross the coast 56 km north of Cooktown on the afternoon of the 4th March, with a central pressure of 988 mb. The resultant surge was 1 metre high at Cape Flattery and Cooktown. Tides at Lizard Island remained high all day, and to the south, Cairns had a deviation of 0.42 metres in the early hours of the 4th. In December, cyclone Una had a similar approach to cyclone Althea of 1971. Una with a central pressure of 988 mb approached Townsville at 25 kph on the 18th but changed course 65 km from Townsville, crossing the coast in Bowling Green

Bay on the 19th. The surge peaked at Bowen with a height of 0.72 metres, falling away to 0.35 metres at Mackay. Townsville which was closest to the eye experienced a negative surge as Una passed just to the south. Dr Hopley in a paper on the cyclone Una storm surge examines the surge components, using harmonic analysis techniques and also refers to the forecasting of storm surges.

Given accurate tidal data, the complex series of oscillations representing the storm surge lend themselves to harmonic analysis. By the superimposition of a number of simple component waves it is possible to identify or filter out the dominant periodicities in order to explain the composition of the storm surge.

Finally the most recent literature on north east Queensland storm surges analyses the surges associated with cyclones Wanda, Pam and Zoe of 1974. Three papers were submitted jointly by Dr Hopley and N. Harvey to the Harbours and Marine Beach Protection Authority in 1975. The storm surges associated with all three cyclones had a maximum on the southern Queensland coast causing extensive damage to the beaches. Cyclone Pam which was one of the largest cyclones ever recorded in the Coral Sea region, came no closer than 450 km to the coast and yet produced tidal anomalies from Cairns to the south Queensland coast.

Much of the literature on storm surges in north east Australia tends to be descriptive and often inaccurate. Reports of surge heights in many cases are personal accounts of past events, and are of variable reliability. These reports supplement accurate measurement out of necessity, when no tide gauges were operating in earlier years and where the present system of gauges is inadequate.

However, from the literature a number of observations can be made. The majority of storm surges referenced are perhaps those associated with a high absolute water level. The reason for this is that these surges are more spectacular and often associated with the greatest damage, although they need not necessarily be the highest surges, since high surges occurring at low tide will not produce noticeably abnormal water levels. Every cyclone will produce a storm surge of some magnitude, but many of the surges occurring at lower absolute water levels are probably absent from the literature.

Another observation can be made upon the relative frequency and magnitude of the surges referenced. South of Mackay the frequency of storm surges appears to be least, and rarely are there any reports of surges greater than 1 metre in height. North of Mackay is the region most affected by cyclones and consequently the majority of storm surge reports have come from this stretch of coast, a number being over 3 metres in height. However, it is from the Gulf in the last decade that reports of high surges have emerged, some greater than 4.5 metres.

Whilst the greater occurrence of storm surges north of Mackay appears to be related largely to the greater cyclone activity in this area, the occurrence of high surges in the Gulf of Carpentaria is greatly influenced by the shallow submarine floor within the partially enclosed basin of the Gulf. The Bureau of Meteorology (1966) noted that with cyclone Audrey in 1964 "the level of the Gulf water at Karumba is very sensitive to atmospheric disturbances". The bathymetry together with the peculiar tidal characteristic and coastal configuration of the Gulf appear to have a major influence upon the occurrence of high storm surges in the Gulf.

Since the probability of storm surge inundation is highest north of Mackay, this has obvious implications for planning. In north east Australia there is already an expansion of residential zones into land less than 1 metre above high tide in cities such as Cairns, Townsville and Mackay.

However, the more immediate problem is to ensure that there is a minimum loss of life and property from storm surges where the potential

already exists. This necessitates a greater understanding of storm surges in north east Australia and a refinement of storm surge forecasting techniques.

It is only in the past few years, specifically since cyclone Althea that any analytical work on storm surges has been carried out using accurate data, but with the imminent installation of a more detailed network of tide gauges along the coast more analytical work will be possible and a greater understanding of north east Australian storm surges should begin to emerge.

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