Recent Advances in Storm Tide Modelling in Australia

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1 Introduction

An overview is provided of a number of tropical cyclone storm tide studies from around Australia and extending to the Indian and Pacific Oceans. The studies have either been completed in the past few years or are still underway and present some new methodologies that may have useful application to other regions. The studies to be presented address both planning and warning strategies. In the planning context, increased emphasis is placed on the representation of the landfalling climatology. In the warning context, emphasis is on the variance in the forecast parameters and possible tidal interactions. However, both requirements rely on shared methodologies and the presentation will discuss effective approaches to address both the strategic and tactical aspects of the problem. Special consideration is given to the task of estimating breaking wave setup in different environments (beach *vs* reef) and some emerging issues in regard to inundation modelling will be discussed. The role of storm tide hindcasting in re-assessing storm intensity and structure is introduced and aspects of climate change are also addressed. The presentation will focus on the study design and meteorological issues rather than details of the hydrodynamics.

2 Cocos (Keeling) Islands – SE Indian Ocean

This study (Harper *et al.* 2001a) addressed the need for setting the elevation for storm tide shelters on the main southern island group, a protectorate of Australia situated 1000 km SW of Indonesia in the South East Indian Ocean (12.1˚S, 96.8˚E). The southern group forms a typical small to medium sized coral atoll system in which a large lagoon is surrounded by an enclosing intertidal reef on which the various islands are located. Most of the land area of 12 km^2 is between 3 and 4 m above Mean Sea Level (MSL).

The study methodology consisted of assembling the regional climatology and hindcasting a number of the more significant tropical cyclones that had affected the island in recent history to justify the choice of wind field model. The average frequency of occurrence is about 2.5 storms per annum within 500 km but there have been 8 storms within 100 km since 1960. The good quality 50 y wind data record from the airport was used to calibrate a climatological model, which was then used to generate storm tide events (surge, wave, tide and lagoon setup).

The principal storm tide threat to the island was determined to be the breaking wave setup component, which was considered capable of exceeding 3 to 4 m MSL at the 0.1% pa frequency level. An overview of the simulation methodology combining tide, outer reef processes, inner lagoon processes and wave setup will be presented.

3 Queensland Climate Change Project - Australia.

The *Queensland Climate Change and Community Vulnerability to Tropical Cyclo*nes project (QCCP) was instigated in 1999/2000 through the combined efforts of the Bureau of Meteorology in Queensland and various State Government agencies. The project was designed to update and extend the understanding of the threat of storm tide inundation in Queensland on a state-wide scale, including the effects of extreme wave conditions in selected areas, and estimates of potential enhanced Greenhouse climate impacts.

The project proceeded within the context of an initial technical blueprint that set out the essential methodologies and data requirements for a state-of-the-art assessment of the ocean hazards from tropical cyclones. This stage (Harper 2001b) identified the need for improved climatological descriptions of the tropical cyclone threat, the application of proven hydrodynamic models and a robust statistical methodology, within which climate change impacts could be realistically embedded. The advantages of providing integrated planning and warning systems were also examined based on a parametric modelling approach. The entire 3,600 km of the Queensland coast was subdivided into 12 numerical domains at a base resolution of 2.8 km (Figure 1), extending to 560 m in selected areas.

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The highly-developed James Cook University storm surge model MMUSURGE (Bode and Mason 1994), with its ability to accurately model coral reef regions, was then applied to a number of historical cyclone events to demonstrate the deterministic accuracy possible with such a model, subject to good representation of the cyclone winds. Subsequent stages of the study have progressed the original recommendations, leading to the adoption of an advanced synthetic cyclone track population model and the inclusion of simultaneous spectral wave modelling (Hardy *et al.* 2004) for estimating breaking wave setup in specific areas. Some results will be presented from the summary report (SEA 2004) comparing and contrasting statistical estimates of extreme storm tide assuming both present climate and enhanced Greenhouse scenarios.

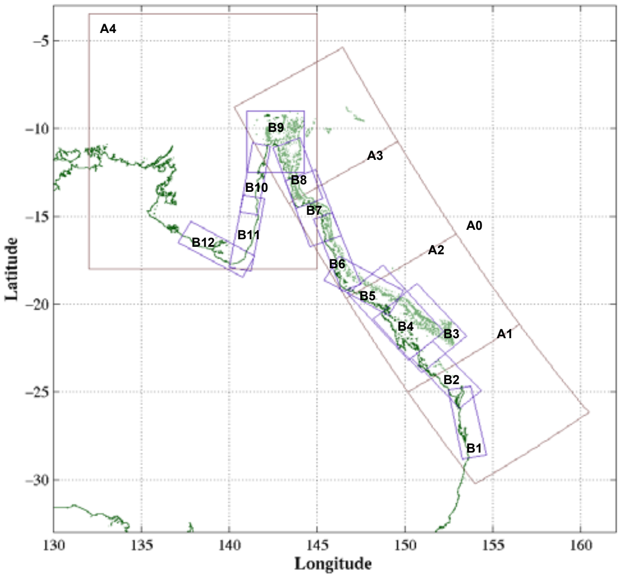

Figure 1 Numerical storm tide model coverage of the Queensland coast.

4 Whitsunday coast - Queensland

This was the first study (Fryar *et al.* 2004) to apply the form of parametric storm tide modelling recommended under the QCCP project for providing a potentially integrated planning and warning context. Of particular interest in this region of the Central Queensland coast is the large variation in tidal range, which increases southwards from 2 m to 3.5 m over a distance of 100 km. This localized study extended the QCCP study by considering the breaking wave component of the storm tide.

The study area comprised a series of mainland islands with relatively deep but sometimes narrow passages and the storm tide threat was determined to vary largely as a function of distance offshore and wave exposure. These two effects were found to counteract in such a way as to form a relatively constant threat throughout the main towns and resorts of this popular tourist area. In addition to the study outcomes setting long term planning levels, the modelling could now be used to study response and evacuation scenarios in a warning context, allowing the realistic combination of wind, tide, wave and surge time histories for a range of locations.

5 Rarotonga , Cook Islands – South Pacific

This coastal protection study (GHD-SEA 2005a) has similarities to the Cocos Island study, although Rarotonga (21.2˚S, 159.8˚W) does not have a lagoon system. Instead, interest centred on the effects of breaking wave induced inundation near the harbours of Avatiu and Avarua on the northern coast. Again, a climatological model was calibrated against long term airport winds and hindcasts of storms of record used to prove the deterministic aspects of the models. *Sally* in 1987 was a pivotal calibration storm where rare wave buoy data was obtained and photographic evidence of inundation was available. Recently, *Meena* struck a glancing blow that caused similar levels of inundation and video footage of this event will be shown.

6 Townsville – Thuringowa coast - Queensland

This study (GHD-SEA 2005b) is similar to that undertaken for the Whitsunday area in that it is a more detailed local analysis of the storm tide threat that considers breaking wave setup and coastal inundation. The study is still ongoing but examples of wind model and tide gauge calibration for severe tropical cyclones *Althea* and *Aivu* will be presented to demonstrate typical wind, surge and wave model performance. Examples of parametric storm surge model performance will also be shown. The threat of inundation of suburban areas is significant in this project and extended work is planned to better investigate the relative contributions to damage by waves and storm surge impinging on domestic structures.

7 Northern Territory Storm Tide Prediction System - Australia

The NT storm tide prediction system (SEA 2004b) for the Bureau of Meteorology in Darwin is nearing completion and follows the QTCC proposal for a parametric modelling approach. It will enable forecasters to make allowance for variability in the forecast storm parameters and include that uncertainty directly in the prediction of the storm tide. The resulting prediction will then contain a range of potential outcomes, each with an associated probability. Decision makers may then use the full range of predictions, including the maximum predicted inundation level if necessary, to decide the level and timing of warnings and emergency response.

This predictive capability is achieved through the combination of a number of numerical models of tropical cyclone wind fields, storm surge and waves that have been established over seven separate geographical regions starting from the Queensland border west to the Kimberley coast of Western Australia (Figure 2). Many thousands of potential tropical cyclone scenarios have then been constructed in order to determine the storm tide response in each region as a function of the many possible incident storm parameters. This information is then summarised into a further numerical parametric model for each region that enables very rapid retrieval of storm tide response information within the context of a forecast and warning environment (Figure 3).

In support of the above, a statistical analysis has been undertaken of the historical tropical cyclone activity in the region. The purpose of that analysis has been to provide guidance in the selection of scenarios so as to concentrate on the most likely situations. Notwithstanding this, the scenarios have been extended to cover very extreme, low probability events, including tropical cyclones that have reached their maximum potential intensity in the region. To underpin the technical quality of the study, two demonstration tropical cyclones have been included, namely *Tracy* (1974) and *Kathy* (1984), which together illustrate the potential accuracy of the predictive system. An example from the demonstration cyclones will be shown that illustrates the value of using storm tide impacts to re-assess the estimates of storm intensity and structure.

8 Conclusion

There has been an upsurge in activity in Australia over the past five years in undertaking detailed storm tide risk assessment studies and also emerging interest in neighbouring regions as the threats become better understood. The studies discussed here are only those familiar to the author and the interested reader will find other examples that may be relevant to other situations. The examples here illustrate the importance of choosing wisely from the available range of methodologies to best represent risks within a specific geographical region and illustrate the importance of model calibration and validation. The identified roadblocks to further refinement of storm tide risks are seen to be mainly meteorological in nature. These include (deterministically) tropical cyclone windfield structure, surface boundary layer representation and (probabilistically) the need to revise and correct many historical best track data sets to ensure uniformity and remove potential intensity and scale biases.

9 References

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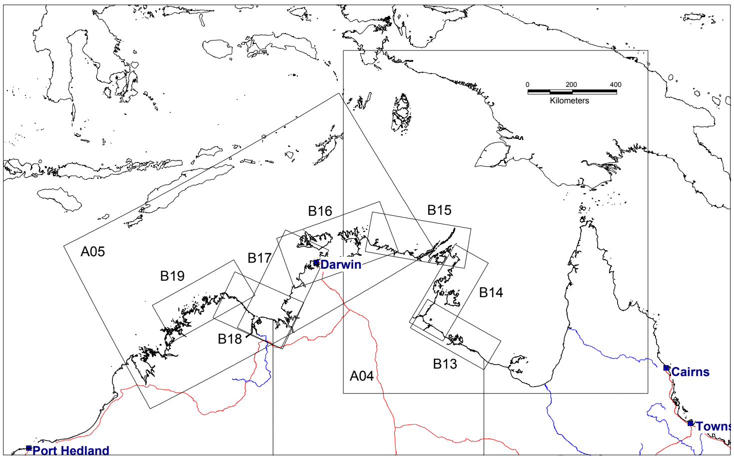

Figure 2 Numerical storm tide model coverage of the Northern Territory coast.

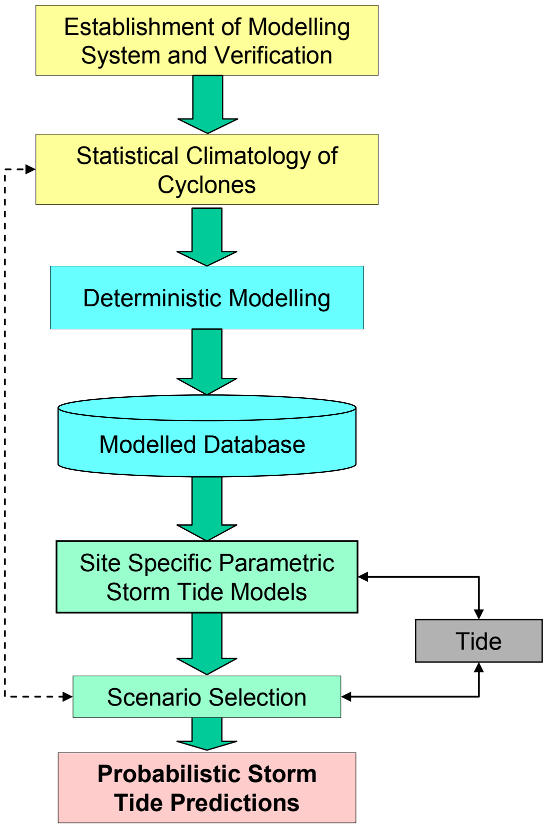

Figure 3 Northern Territory storm tide prediction system.