Assessing current and future storm surge risk for the South Pacific and Australia

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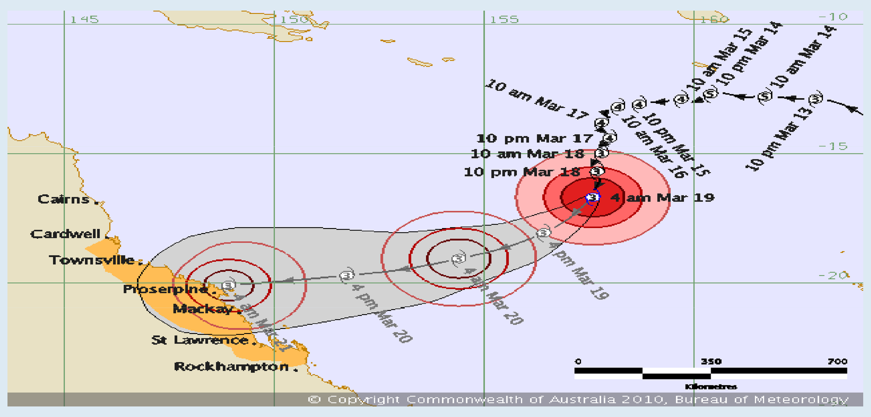
Introduction

Current and future sea level rise poses a major threat on low-lying coastal communities. Most significant impacts may arise from short lived storm surges and extreme wave events. These are superimposed on the slower sea level trend and hence are likely to become more frequent in the future. Climate change may also affect atmospheric conditions leading to extreme sea level events and the effect of climate change on these meteorological drivers also needs to be studied. Physical impacts of extreme sea levels at the coast include coastal inundation and accelerated erosion. Quantifying these impacts poses challenges that are partly rooted in a lack of observations but also in the need for significant computational resources to simulate processes at the localized/ regional scale. Projects like the Australian/ Pacific Climate Change Science Project are contributing to greater understanding of these issues and provide the underlying climate science that is needed for Australia to manage climate change.

Causes of extreme sea levels

- Extreme sea level events occur during storms and high tide events
- **Storm surges** are temporary increases in coastal sea levels caused by the falling atmospheric pressure and severe winds during storms
- Storm surges may be accompanied by an additional increase in water level due to breaking waves on the open coast producing **wave setup**
- The magnitude of the wave setup is related to the height of the offshore waves and is usually much smaller than the storm surge.
- **Wave run-up** is the maximum inland penetration of water that is caused by the breaking of individual waves at the coast



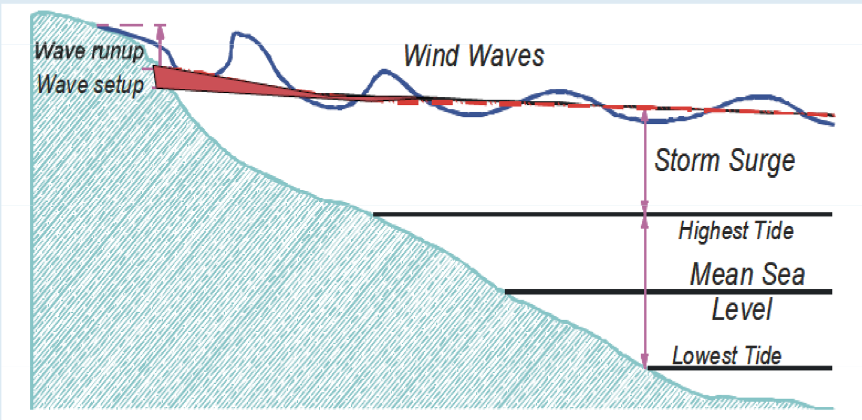


Figure 1: **Upper:** Projected path of a recent cyclone passing northeast Australia. Causing potential extreme sea levels. **Lower:** **C**auses of coastal sea level elevation

Methods to assess extreme sea level events

To date hydrodynamic models have been used to explore the impact of climate change on extreme sea level events using three different approaches

1.Direct nesting approach: Model is forced with atmospheric conditions derived from simulations of either a global or a regional climate model for current and future time periods

2.Perturbed historical baseline approach: A hydrodynamic model is used to simulate past climate from which extreme sea level recurrence intervals can be evaluated to which perturbations related to future mean sea levels and/ or meteorological conditions can be applied

3.Statistical dynamical approach: In the tropics, due to the relative infrequency of tropical cyclones in the historical record, a statistical model of cyclones is developed to enable a large sample of plausible cyclones histories to be developed for a location of interest. Simple cyclone models are then used to generate the surface wind and pressure fields necessary to force the hydrodynamic model

Extreme surge events along Victoria's coast

- **Perturbed historical baseline approach** (McInnes et al., 2009)
- Extreme sea levels along the Victorian coast often result from the combination of tides with storm surges producing a coherent signal along large parts of the coastline
- This enables tide gauge records to be used to identify a population of significant storm surge events to be modelled with a hydrodynamic model
- Climate change effects are taken into account by applying perturbations to variables that contribute to extreme sea levels to represent plausible future climate conditions

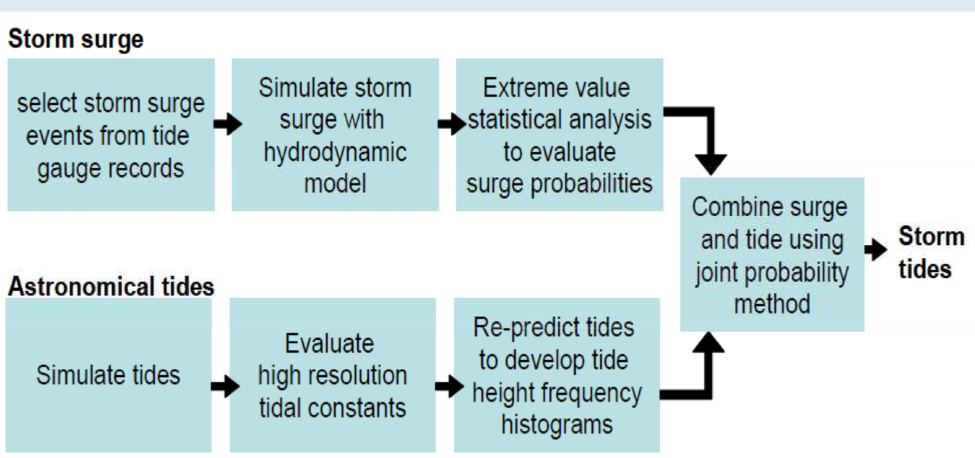


Figure 2: Methodology used to calculate return periods of extreme sea level events

- Storm surges and tides are calculated Separately
- Wave related sea level changes are not taken into account
- Non-linear tide surge interactions are neglected
- Ocean model used is GCOM2d. (Hubbert and McInnes, 1999)

Results

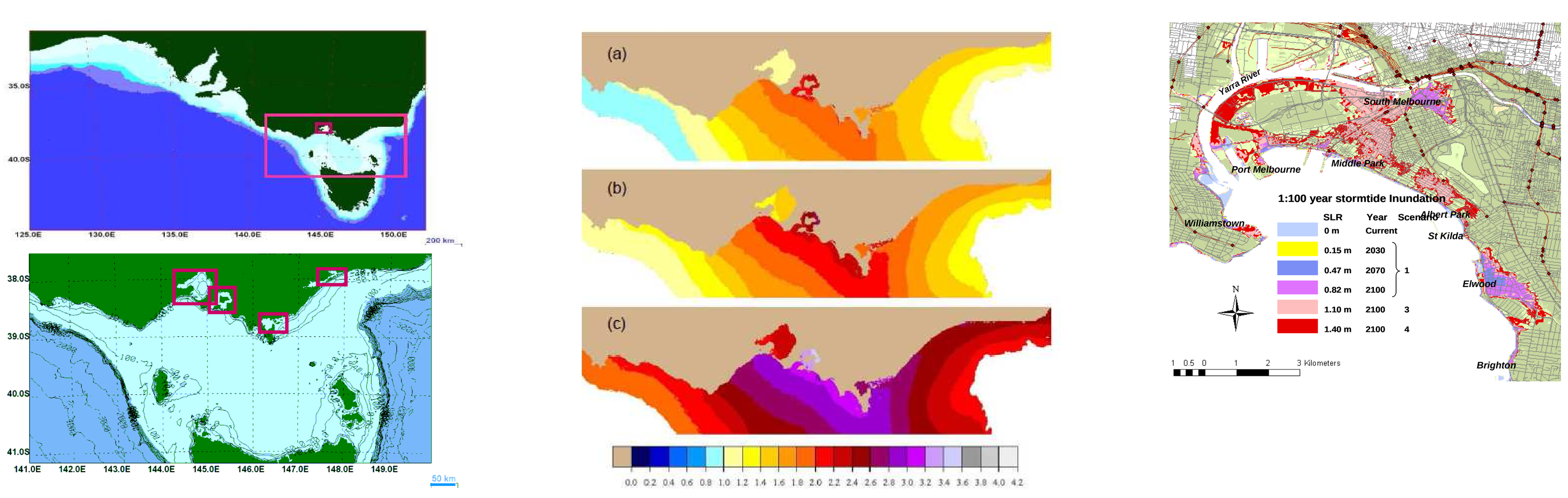


Figure 3: **Left**: Model domain and nesting strategy. The outer/ inner/ most inner grid have a resolution of 5km/ 1km/ 100m, respectively. **Middle**: The spatial pattern of 1 in 100 year storm tide heights for the Victorian coast under (a) late 20th Century climate conditions, (b) wind speed increases for 2100 without sea level rise, (c) all included 2100. Values are in metres relative to late 20th Century mean sea level. **Right:** Land vulnerable to inundation during a 1 in 100 year storm tide under current climate conditions and various scenarios of future sea level rise for the St Kilda region.

Extreme sea levels: Australia and the South Pacific

- For large parts of the southern Australian coastline and Tasmania passing fronts are the dominant weather systems affecting sea level height
- Tropical cyclones are the dominant driver of extreme sea levels for northeast Australia and the Pacific Island's region
- Climate modes such as ENSO and SAM impact differently on different regions. Their effect can be considered as direct and indirect.
- For example: ENSO is associated with sea level elevation of up to half a meter in parts of the South Pacific region but may also act as to modify frequency and/ or intensity of Tropical cyclones (see **Figure 4**) thereby exerting an indirect effect on extreme sea levels

Figure 4: **Left:** Map of Austral-Asian region. **Right:** **Top:** Variation of tropical cyclone incidence in the Australian/ South Pacific region. **Middle:** average incidence during La Nina, **Bottom:** El Nino years (taken from Walsh, 2009).

Storm surge impact on Cairns, Australia

- **Statistical dynamical approach** to study storm surges associated with tropical cyclones at Cairns (McInnes et al., 2003)
- Approach necessary as meteorological archives cannot provide adequate sample of tropical cyclones due to low frequency and localised influence
- Statistical cyclone model is developed and used to force the ocean model (GCOM2d)
- Potential effects of climate change are studied by changing (a) cyclone characteristics such as intensities and frequencies and (b) mean sea-level

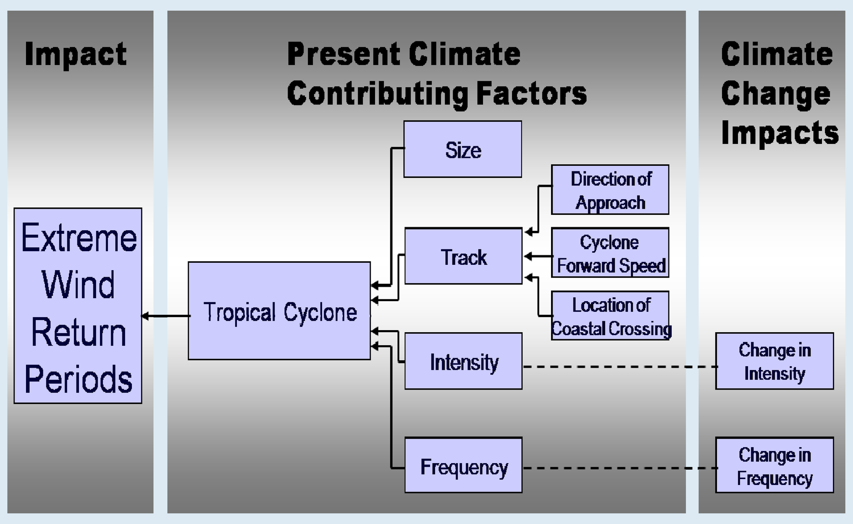


Figure 5: Key factors affecting storm tide return periods under present and enhanced greenhouse climate conditions

- Range of plausible cyclone characteristics is derived from an analysis of the historical cyclone record in the region
- Monte-Carlo approach is used to randomly select cyclone characteristics from which hundreds of storm tide simulations are performed
- This produces a synthetic record of extreme sea-level events that are analysed to produce return periods (**Figure** below)

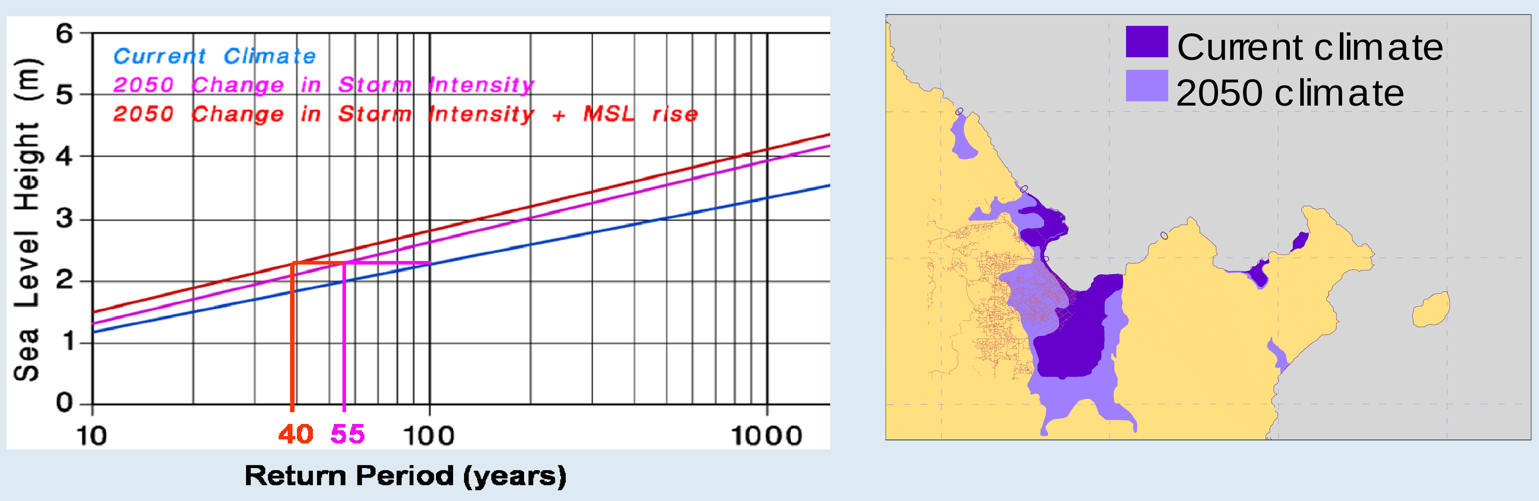


Figure 6: **Left:** Return periods for storm tides at Cairns under present and enhanced greenhouse climate conditions. **Right:** The inundation produced by the top 5% of storm surge model simulations (100 year return period and greater) under current climate conditions and conditions assuming a 10% increase in tropical cyclone intensity by 2050. The road network of Cairns is shown in red to highlight the impact of the inundation.

Future work

- Future work includes using ROMS (2d) in a **direct nesting approach** to analyse current and future extreme events for Tasmania and southern Australia
- Explore potential wave impacts on low lying Pacific Islands (Atolls) using ROMS
- Undertake high resolution coastal modelling to further develop methods for quantifying potential inundation and wave setup in coastal extreme sea level assessment

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