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IMPROVED MODELING OF EXTREME STORM SURGES AND WAVES ALONG THE AUSTRALIAN COAST

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Ivica Janekovic, Yasha Hetzel and Charitha Pattiaratchi
University of Western Australia
Bushfire and Natural Hazards CRC

Corresponding author: ivica.janekovic@uwa.edu.au

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SUMMARY

More than 85% of Australians live near the coast resulting in a high density of coastal infrastructure and a population exposed to the destructive effects of extreme sea levels caused by storms. Successfully building resilience to, and planning for disasters when they occur requires accurate knowledge and prediction of extreme sea levels and areas susceptible to erosion and inundation. Recent advancements in numerical models now provide coastal planners and emergency managers with invaluable tools, such as inundation maps, to better prepare for and deal with disaster related to surges in sea level. Here we present results from state of the art storm surge modeling experiments and present a case study of a 'worst case scenario' storm, highlighting some modeling challenges and the improvements gained when waves are included in an advanced coupled storm surge model.

INTRODUCTION

Recent technological advances allow for realistic high-resolution numerical models capable of analysing dynamics to better understand how storms will impact the coastline through erosion and inundation and even predict such events. One of the most destructive storms in Western Australia was Cyclone Alby in 1978 that caused an estimated $50 million dollars in damage and killed five people. Large waves and extreme surges caused coastal erosion and inundation across the southwest of the state [1].

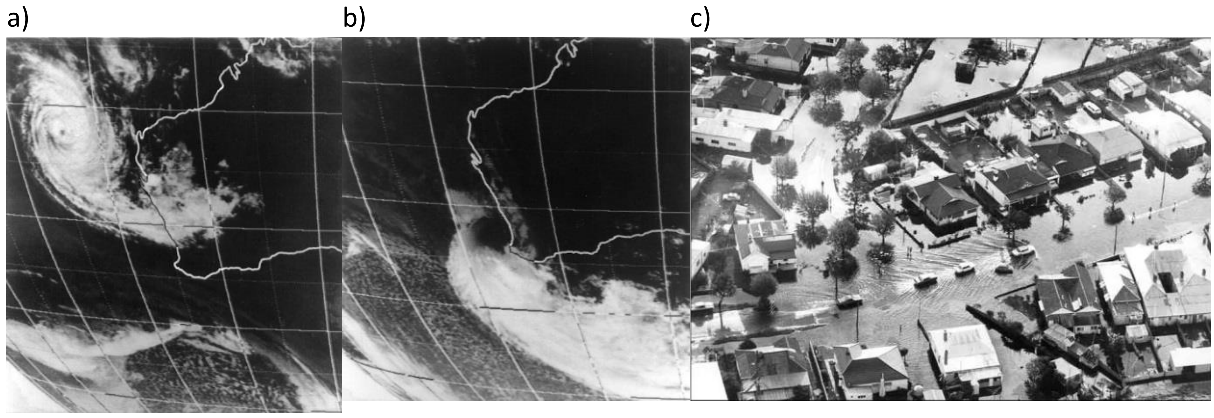

Figure 1. Satellite imagery of Cyclone Alby demonstrating the transition from tropical cyclone (a) to extratropical storm (b). Photograph of inundation in Bunbury, 200 km south of Perth caused by Alby (c). Source: http://www.bom.gov.au/cyclone/history/wa/alby.shtml#photos

Alby was not a typical tropical cyclone. As Alby moved south out of the tropics it violently interacted with an approaching cold front and became a hybrid storm transitioning from tropical to extra tropical in nature. The storm increased in speed, became spatially distorted with an extremely broad area of northerly winds along the coast, causing it to become a 'worst case scenario' for the southwest of the state due to the extreme waves and storm surge created [2]. Atmospheric models struggle to reproduce the dynamics of these transitioning storms [3] and historically simulations of the storm surge created by Alby and used to plan for future emergency situations have been limited to simplified wind models that treat Alby as a standard tropical storm. Here, we applied a recently released atmospheric hindcast dataset that has been shown to more accurately reproduce the dynamics of such storms than what has previously been available [4]. This in turn forced a state-of-the-art storm surge model.

METHODS

NUMERICAL MODEL SETUP

A realistic simulation of cyclone Alby was undertaken using the high resolution 3D finite element SELFE/SCHISM hydrodynamic modeling system that has successfully been applied to simulate storm surges in a broad range of coastal environments [5, 6, 7]. Model resolution increased toward the coast to as fine as 100 m. The model was forced with wind and pressure fields from the JRA-55 reanalysis (see below) and was two-way coupled with the WWMIII spectral wave model [8]. The coupled model better represented wind stress over the sea taking into account wave surface roughness and dynamics. Multiple model runs were undertaken with the coupling switched on/off to determine the effects of including waves. Model results were compared against measurements at available sites and the magnitude and timing of the surge matched well at Perth, Bunbury, and Busselton.

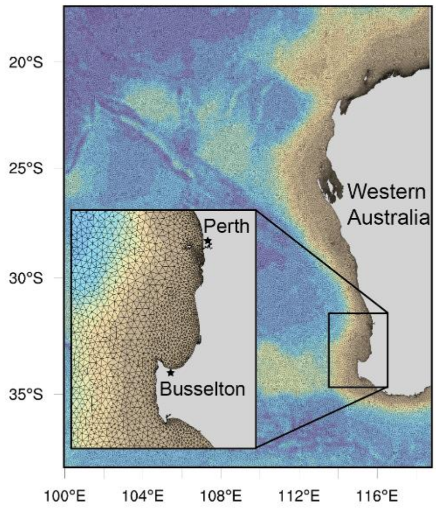

Figure 2. The model grid showing the study site and the unstructured mesh. Resolution increased from ~2000 m offshore to 100 m at the coastline.

The recently released Japanese Reanalysis JRA-55 reanalysis atmospheric model [9] provided wind and pressure fields on 1.25 degree resolution at 6 hourly intervals that were used to force the hydrodynamic model. This dataset has been shown to successfully capture the structure of storms transitioning from tropical to extratropical [4]. An advantage of the dataset is its vortex relocation algorithm that uses cyclone track data to ensure that the simulated storm follows an accurate trajectory.

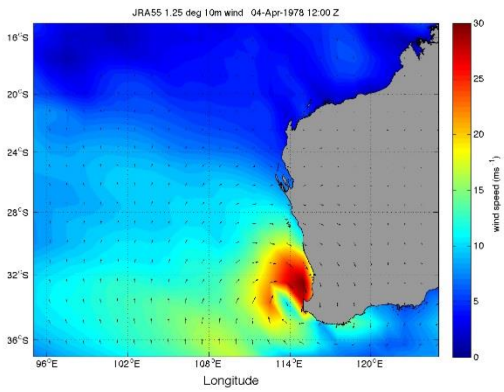

Figure 3. Snapshot of JRA-55 model wind speeds for cyclone Alby on 4 April 1978 used to force the hydrodynamic/surge model. Intense winds over a broad area created extreme surges along the SW Australian coastline.

RESULTS

Significant waves in the storm region were around 10m which agreed with ship observations (Fig. 4a). The two-way coupled modeling approach better represented wind stress over the sea taking into account wave surface roughness and dynamics. Including waves in the model also provided data on how waves acted to elevate water levels near the coast. The results revealed a closer fit with observed water levels compared with other commonly applied storm surge models. The predicted onset, magnitude, and duration of the surge event were similar to reported values. The surge from Alby peaked at 1.1 m in Busselton, with approximately 10% of the height resulting from wave effects included in the model (Fig 4b, 5). Highest water levels and the strongest currents occurred in Geographe Bay around Busselton in line with with observations during the night of 4 April 1978 (Fig 4b). In protected waters at Perth the storm surge created by model runs including wave effects reached 0.75 m whilst without waves the surge was only 0.44 m (Fig. 5). The difference here indicated that the wave effects could account for up to an astounding ~58% of the surge.

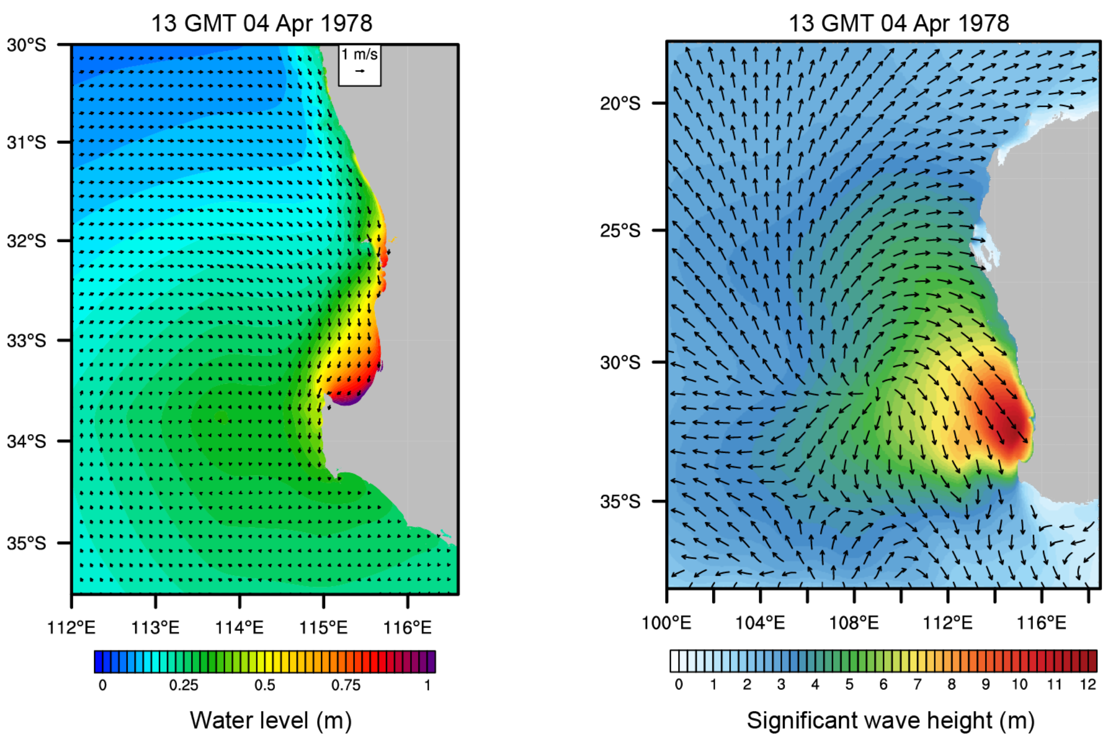

Figure 4. Model results from the coupled wave (a) and hydrodynamic (b) model. Colour background represents wave height in (a) and storm surge in (b). Vectors show wave direction and water transport respectively.

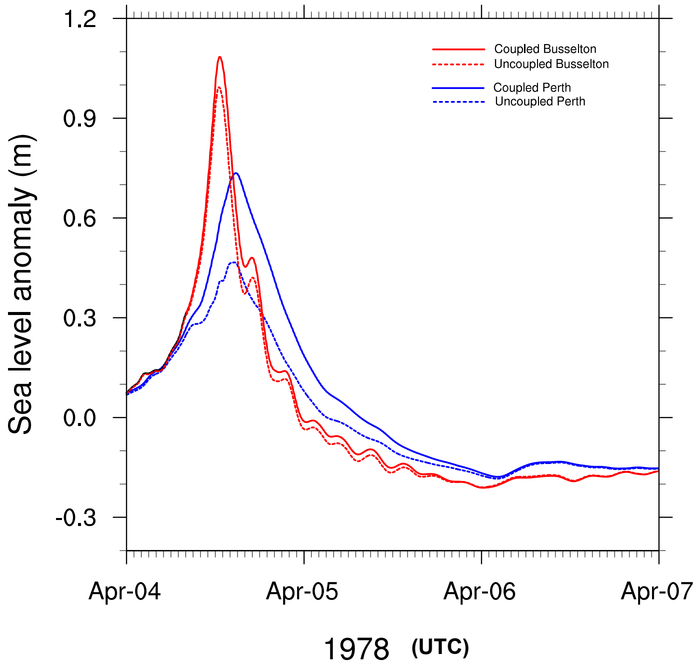

Figure 5. Modeled storm surge time series of water levels for the passage of Alby in Perth and Busselton for model runs with (solid line) and without (dashed line) the effects of waves included.

DISCUSSION

Cyclone Alby is presented here as a case study of a worst case scenario extreme event that is extremely challenging to model due to the nature of the storm and the lack of observations for this region and time period. In contrast to other comparable studies for cyclone Alby that used idealised cyclone wind fields we applied more realistic atmospheric forcing and modeled a storm surge comparable with observations at tide gauges. An additional benefit arising from the coupled hydrodynamic-wave modeling system was the ability to determine the relative contribution of waves to the surge. Storm surges are created by wind stress acting on the ocean surface allowing for setup at the coast and as a result the surge height is sensitive to the way that surface stress is quantified. The coupled model leads to a more realistic representation of stress causing an increased sea level response and higher storm surges. A secondary effect was an increase in water levels near the coast due to the presence of waves. In this case the increase in surge due to the inclusion of waves was between 10% and 58%. A benefit of the unstructured grid used here is the ability to simulate with extremely high resolution near the coastline, a requirement for inundation studies of land areas.

The successful application of this coupled model offers encouraging potential for improving predictions of a range of storm surge events along the coast. Ongoing work will expand to other parts of Australia to simulate other devastating storms and will also investigate inundation of land areas. The results will improve understanding of what conditions combine to produce damaging events and ultimately will contribute to improving preparedness for catastrophic storm events.

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