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Tropical Cyclone Modelling with TELEMAC-2D

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***Abstract*—Model testing has shown that the use of schematic wind models can reproduce well the observed rotating wind field in a tropical cyclone. Imposing the wind field and air pressure field in TELEMAC-2D has been found to give good results in comparison with observed storm surge levels at tide gauges during a cyclone.**

The purpose of this study was to validate the capability of TELEMAC-2D to model the storm surge due to a tropical cyclone. These storms are also referred to as hurricanes and typhoons in different parts of the world. The surge arises as a result both of the pressure drop in the middle of the cyclone and also because of the resulting rotating wind. The effects on the flows of the wind and the atmospheric pressure variation are included in TELEMAC-2D. Storm surge is important as flooding is often the greatest danger to life due to a cyclone.

Because of the large amount of data available, cyclone Yasi (Australia, Queensland, 2011) was selected for this study. Available data included wind speed and direction at 12 sites near to the cyclone's track measured throughout the cyclone's passage. Tide gauge data at a number of ports was also available (see Fig. 1).

Data from the Australian Bureau of Meteorology included the cyclone's track, and the central pressure and maximum wind speed during the storm's passage. Cyclone Yasi had a track (see Fig. 1) making landfall near Clump Point. A minimum pressure of 929mB was measured at Clump Point and a maximum wind speed of 57m/s was estimated. The maximum recorded storm surge was 5.33m at Cardwell.

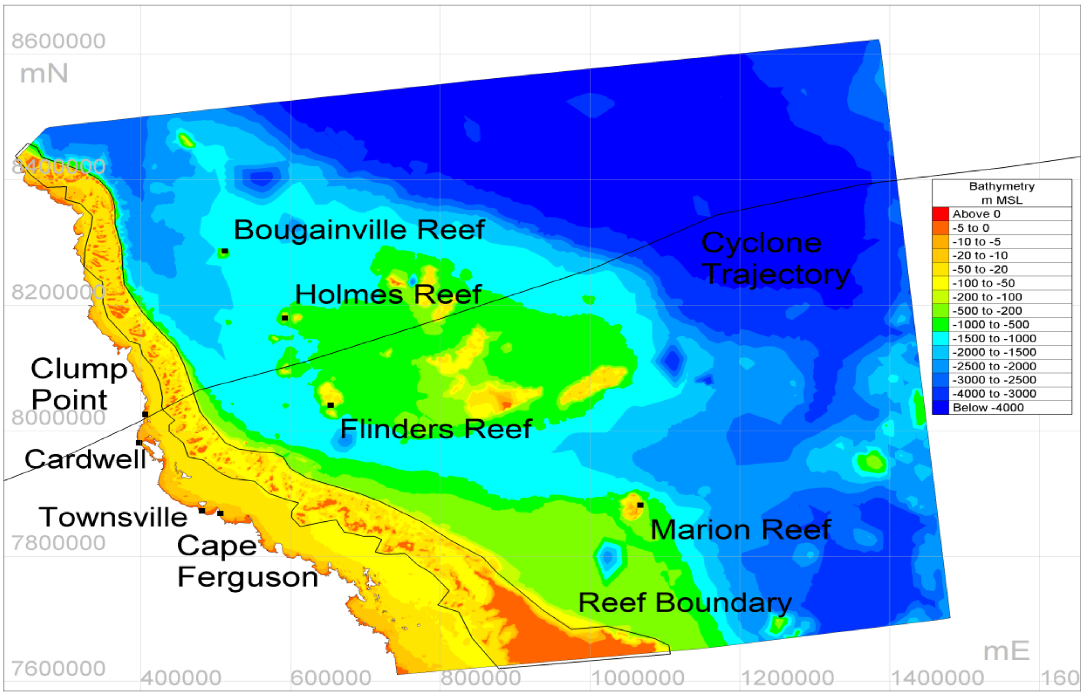

Figure 1. Observation locations (wind and surge).

Tropical cyclones are characterised by a strong, circular wind field that can be represented approximately in a 1D model as the wind and pressure vary mostly in the radial direction. The atmospheric pressure is a minimum at the centre of the storm.

The available information on a cyclonic storm is likely to include that given above (track, central pressure, maximum wind speed and sometimes radius to maximum wind speed) although the radius to maximum wind is not always known. Under these circumstances it is usual to create a schematic wind and pressure model and compare it as far as is possible with any wind and pressure data that are available. Another possibility could be to use a detailed atmospheric model to simulate the wind and pressure fields, but that was not the method chosen in this case.

Flow model simulations carried out included the following:

- *Using a wind field from Holland (1980) or Jelesnianski and Taylor (1973)*

At each location in each wind field, the wind speed was determined based on the parameters of the cyclone at the time and the distance of the point from the centre of cyclone. Both Jelesnianski and Taylor (1973) and Holland (1980) formulations were implemented in the model.

The relation used from Jelesnianski and Taylor (1973) is:

$$U_i = \frac{2rR_{\max}}{r^2 + R_{\max}^2} U_{\max} \tag{1}$$

where U_i (m/s) is the speed at location i, r is the distance of i (km) from the centre of the cyclone, U_{max} is the maximum wind speed (m/s) and R_{max} is the radius of the maximum wind speed (km).

The wind velocity given in Holland (1980) is:

$$U_i^2 = U_{\max}^2 \exp\left(1 - \frac{R_{\max}^\beta}{r^\beta}\right)\frac{R_{\max}^\beta}{r^\beta} \tag{2}$$

The β coefficient is calculated from the central pressure drop P_{drop} (Pa) and the maximum wind velocity U_{max} (m/s) as:

$$\beta = U_{\max}^2 \rho e / P_{drop} \tag{3}$$

with ρ is density of air and e the base of natural logarithms.

The representation of the wind was best achieved using the Holland (1980) wind formulation (see Fig. 2). This is partly because the Holland beta coefficient allows for reproducing different profile shapes of the radial wind speed distribution.

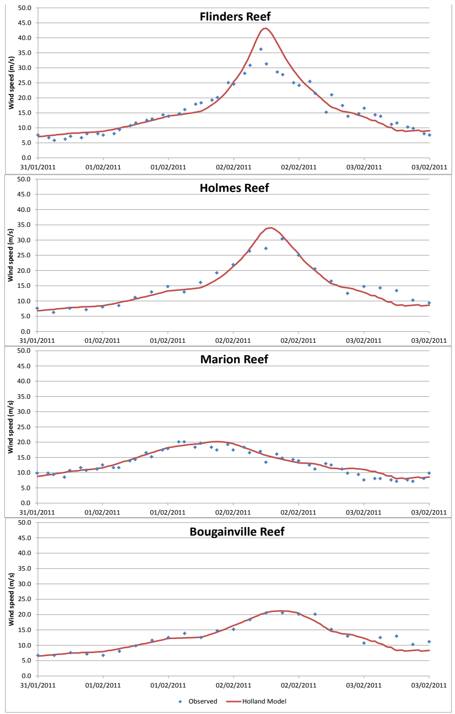

Figure 2. Comparison of modelled and observed wind speed time histories.

- *Including/excluding the forward tracking speed in computing the wind field*

The forward tracking speed of the cyclone is added into the cyclone wind field based upon a formulation of McConochie et al (2004). This method allows the contribution of the forward tracking speed to decrease with increasing distance from the centre of the storm. By adding in the forward tracking speed the wind speed on one side of the cyclone is increased and that on the other side decreased so the cyclone is no longer circularly symmetric.

- *Including/excluding the inward angle of the wind*

It is expected that the wind close to the ground will have a component of flow towards the centre of the cyclone driven by the low pressure there.

The winds circulate clockwise around a southern hemisphere cyclone. The direction of the wind is assumed to be close to a circular wind field but with an inflow angle dependent on the distance from the centre. The wind inflow angle, β, follows the relation:

$$\begin{array}{ll} 0 \le r < R\max & \beta = r/R\max \times 10° \\ R\max \le r \le 1.2\,R\max & \beta = 10° + 5(r/R\max - 1) \times 15° \\ r > 1.2\,R\max & \beta = 25° \end{array} \tag{4}$$

- Including/excluding the effect of the tide

The TELEMAC-2D simulation shows a large surge spread along the coast (Fig. 3). The surge was strong due to the particularly high speed cyclone winds and the broad continental shelf. At Cardwell which lies close to where the wind was strongest the surge was also enhanced by constriction of the surge within the bay.

In the case of cyclone Yasi the best schematic wind representation was using the Holland (1980) model with time varying beta value. The best simulation of the peak surge levels (Fig. 4) at the tide gauge locations included:

- adding the forward tracking speed of the storm (so the wind field is not symmetrical)
- an inward angle of the wind near the ground.
- The flow modelling included the tide (but it did not make a great difference if the tide was not modelled)
- an enhanced friction at the location of the Great Barrier Reef (location shown in Fig. 1).

In this best simulation the mean value over 7 tide gauges of the absolute error in the predicted peak storm surge was 0.33m.

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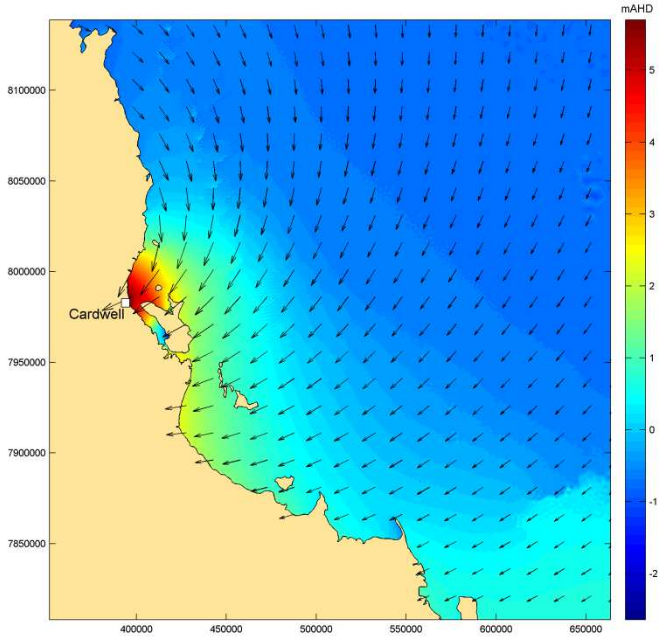

Figure 3. TELEMAC-2D simulation of water level due to Cyclone Yasi at the time of maximum surge at Cardwell. The arrows show wind vectors.

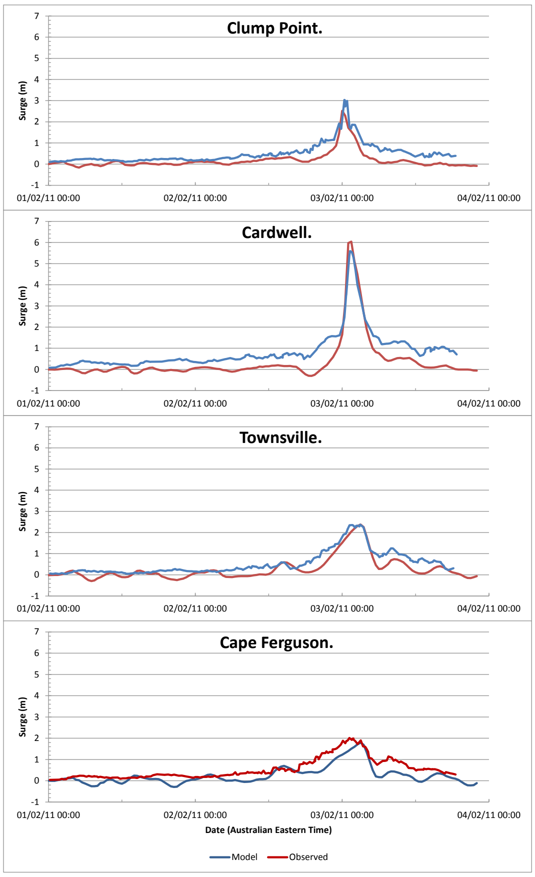

Figure 4. Comparison of modelled and observed storm surge water levels.