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DESKTOP HURRICANE-WAVES RESONANCE MODELING AT THE CANADIAN HURRICANE CENTRE: OUTPUT IN LESS THAN 60 SECONDS

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1. INTRODUCTION

Waves in the forward right quadrant of translating tropical cyclones (TC) have one spectral mode (Bowyer and MacAfee, 2004). Accordingly, single spectrum wave generators, such as first generation wave growth equations, are sufficient for producing accurate wave height forecasts when waves-storm resonance exists.

Depending on translation speed, wind speed, and storm-relative fetch length, the effective fetch for wave growth can be either an enhancement or a reduction of the storm-relative fetch (MacAfee and Bowyer 2000a). The sensitivities of these parameters within transitioning tropical cyclones can be challenging to forecast, with Phadke et al. (2003) noting that engineers and scientists often resort to parameterizing the winds in TC because they are among the most difficult phenomena in the atmosphere to fully describe and predict.

The Canadian Hurricane Centre (CHC) began modeling TC waves-storm resonance in 2000 to answer the questions: when, where, and how big will the biggest TC-waves be? The CHC used a parametric hurricane wind model to drive a Lagrangian-based wave model which parameterized storm-relative fetches in 6-hourly time-steps over a limited area grid (MacAfee and Bowyer, 2000b). This presentation highlights significant improvements made to the *trapped-fetch wave* (TFW) model (MacAfee and Bowyer 2004) and validation through case-studies. A companion presentation outlines improvements made to the parametric hurricane wind model (MacAfee 2004).

2. METHODOLOGY

Following MacAfee and Bowyer (2004), TC waves-storm resonance is modeled by: converting the six hourly HURDAT track to one-hour track locations (TL) using linear interpolation; constructing an offset modeling grid at each TL (Fig. 1a), computing a wind field at grid points (Fig. 1b), and employing a Lagrangian-based method for calculating TFW.

A reference line A_o extends right of TL, orthogonal to the storm motion $\mathbf{V_{st}}$. Each grid row perpendicular to A_o represents a set of points from which trajectories can be computed. Initial wave calculation points for each TL are determined using the winds. Along each grid row across A_o, the winds forward of A_o are examined and points satisfying the condition: wind direction-$\mathbf{V_{st}}$ difference criterion (D_{CRIT}) of < 30^o are retained (Saville 1954). Strong wind shifts ahead of A_o (Fig. 1b) preclude

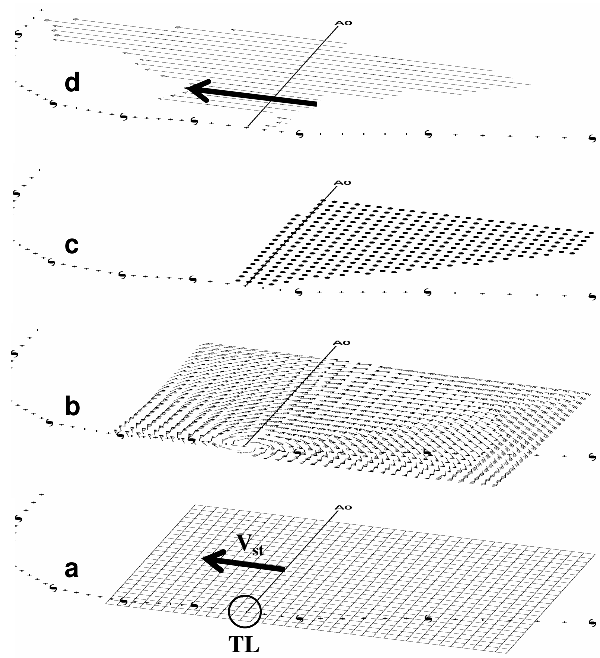

Fig. 1. Schematic diagram showing the successive steps in defining initial wave calculation points at a track location (circled and labeled TL): (a) construct a model grid right-of-track, oriented parallel to storm motion $\mathbf{V_{st}}$, locating the reference line A_0; (b) create a wind field using a parametric model; (c) apply criteria to select initial wave calculation points; the TFW model output for the selected points is displayed as trajectories in (d); the dominant trajectory for the TL is denoted by the heavy arrow.

the need for a wind speed criterion as D_{CRIT} will always be satisfied first. Similarly, points trailing A_o are retained if the preceding D_{CRIT} is met and the wind speed (component along $\mathbf{V_{st}}$) at a point is within 75% of the A_o wind. The wind speed threshold of 75% was established to reduce computational time and was determined through extensive testing. Fig. 1c illustrates the reduced, non-interacting initial wave point calculation set achieved by applying these criteria.

Consider a grid row across A_o and the initial wave calculation points along that row. At T_0, at each of these points, the local wind speed component along $\mathbf{V_{st}}$ and an initializing unlimited fetch (simulated by 2000 n mi) are input to the wave growth equations (Bretschneider 1970) to generate significant wave height and period, and equivalent fetch values, for a time-step duration of one hour. During the time step, waves from the initial calculation points travel an *equivalent fetch* along the

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row. At their new position, these waves are subjected to the newly determined local wind field of the next TL. Using D_{CRIT}, the new wind direction is tested against $\mathbf{V_{st}}$ at T_0. If D_{CRIT} is not satisfied, the waves are flagged as having reached their TFW limit and are no longer computed. Otherwise, the potential for further growth is compared against the limit of fully-developed seas. As long as all criteria are satisfied for at least one point, the calculations are repeated through successive time steps until there are no remaining points in a row. The highest waves for the row are then recorded as a trajectory. In turn, each row for a given TL is processed before proceeding to the next initiating TL where another independent set of initial wave calculation points seed a new set of iterations.

The trajectories of Fig. 1d are the set generated for a single TL. Wave calculation points are non-interactive and the waves generated from an earlier TL do not pre-condition downstream initial wave calculation points. Because of this complexity model output displays the trajectory which represents the dominant TFW (shown by the heavier arrow in Fig. 1d).

3. APPLICATION

Using HURDAT for TC track and intensity, the TFW model was run for a selection of Atlantic TC and also for South Pacific Cyclone Heta (2003). These case studies will be presented.

Fig. 2 shows output for Hurricane Juan, a category 2 storm approaching Nova Scotia, Canada. Shown are dominant wave trajectories for each TL. Typically, resonance waves track parallel to their generating storm (Bowyer and MacAfee 2004), however, Juan's

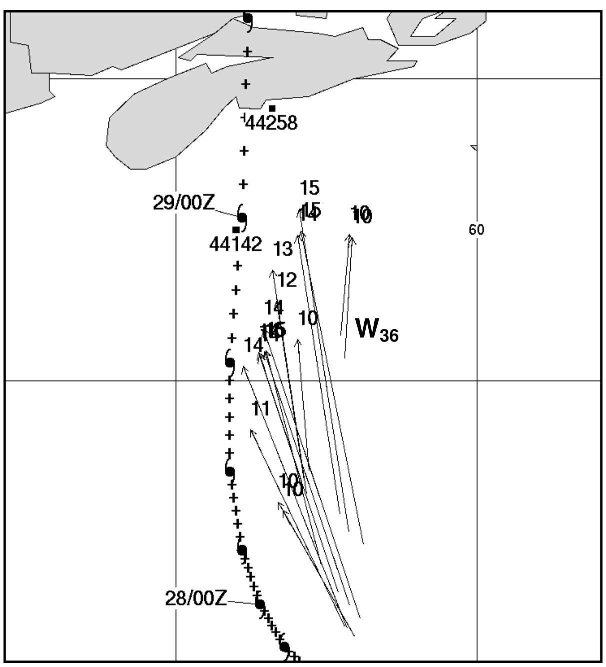

Fig. 2. TFW model output for Hurricane Juan (2003) showing dominant wave trajectories for each TL ≥ 10 m. The W_{36} denotes the CMC 36-h WAM forecast of 6 m.

trajectories were oriented across-track. This indicates that significant wave growth began before Juan turned more northward and that sufficient wave energy was maintained in the initial direction of motion to allow this set of TFW to dominate. Adjusted buoy data showing H_{SIG} of 14.1 m (44142) and 10.8 m (44258) confirm that Juan was a highly resonant hurricane. The Canadian Meteorological Centre's (CMC) operational wave model (WAM) 36-h forecast valid 00Z September 29 2003 had a maximum H_{SIG} of 6 m (denoted by W36 in Fig. 2).

4. THE NEED FOR SPEED

The TFW model runs on a Linux platform forecaster workstation, allowing forecaster intervention in the hurricane parameters. Following intervention, the model can be rerun to generate new wave trajectories that incorporate the refined storm parameters, such as track, wind speed, and central pressure. Operational runs to generate maximum H_{SIG} and trajectories for each hour through a storm's evolution, or forecast, require less than 60 seconds. This affords the operational advantage of making storm-parameter adjustments, hence, wave prediction changes, close to bulletin deadlines.

5. REFERENCES

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