NW ATLANTIC WAVE ESTIMATES AND CLIMATE CHANGE

[1,2]Will Perrie, [1,3]Jing Jiang, [1,2]Zhenxia Long, [1]Bechara Toulany, and [1,2]Weiqing Zhang

[1]Fisheries & Oceans Canada, Bedford Institute of Oceanography
1 Challenger Dr., Dartmouth, Nova Scotia, Canada
[2]Dept. Engineering Math, Dalhousie Univ., Halifax, Canada
[3]Department of Atmospheric Sciences, Nanjing Univ., Nanjing, China

1. INTRODUCTION

This is a study of the possible impacts of climate change on ocean waves. Global climate models (GCMs) provide simulations of the present climate conditions, as well as possible conditions that may occur under global warming scenarios, resulting from enhanced greenhouse gas levels. Several recent studies have used GCM outputs to drive wave models and estimate the impacts on the wave climate resulting under these climate change scenarios. Notable examples are Wang and Swail (2001, 2002), Wang et al. (2004). These studies show that important changes did occur in winter and fall seasonal means and extremes for significant wave heights during 1958-1997, and they are also projected to experience further important changes in the 21st century under accepted global warming scenarios produced by the Canadian coupled climate model (CGCM2). In this paper we consider this problem from the point of view of downscaling the CGCM2 outputs by using finer-resolution regional models. Two approaches are considered.

In one approach, we nest the Canadian Regional Climate Model (CRCM) on 30km resolution, within the CGCM2 simulations, following similar methodology of Walsh and Katzfey (2000, J. Climate) and Walsh and Ryan (2000, J. Climate). Simulations are conducted for winter storms (December – February) for present (1975-1994) and a climate change scenario (2041-2060). Results, showing that while the total number of storms in the NW Atlantic decreases slightly, the weaker storms (with lower waves) become fewer, whereas the total number of strong storms (with higher waves) become more numerous, will be presented at the Workshop.

In a second approach, we objectively select all the autumn storms (September – October) from the CGCM2 outputs, for the present and climate change scenario years defined above, and nest a mesoscale atmospheric model (the Canadian Mesoscale Community Compressible model MC2) on 0.25^{o} resolution, within the CGCM2 simulations. This follows the approach of Knutson et al. (1998, 2001) and Knutson and Tuleya (1999). Simulations for 72 storm cases for the present climate and 66 storm cases for the climate change scenario years were completed.

Quantitative assessment and analysis of results on wave estimates for both the present climate conditions, and the climate change scenario will be presented at the Workshop. Waves are simulated using the operational NCEP WaveWatch II (hereafter WW3, Tolman, 2002) wave model. This is a third generation spectral wave model. Section 2 describes the setups of the models, following the 'second approach' described above, using MC2 – the Canadian mesoscale compressible community atmospheric model (Tanguay et al., 1990). Section 3 gives the storm cases and results, and Section 4 gives conclusions. We show that, for the cases considered, strong storms become more intense, with higher waves. Very minor changes seem to occur to storm tracks and maximum wave regions, particularly for storms occurring in the early autumn.

2. MODEL SETUPS

MC2 is a fully-elastic non-hydrostatic model based on a semi-implicit semi-Lagrangian time scheme. Implemented on a limited-area Cartesian domain, it uses a staggered grid with uniform horizontal and non-uniform vertical resolution, and orography introduced using Gal-Chen vertical coordinates. MC2 has been shown successful in simulating extratropical cyclones (Benoit et al. 1997; McTaggart-Cowan et al. 2001), which are the focus of this paper. The domain is the Northwest Atlantic and most of the North America continent (79.5°-29.75°W, 20.5°-65.25°N, with 0.25° resolution, 30 vertical layers, and 600s time steps. Initial and lateral conditions are from CGCMII. Additional studies, where we consider coupling to ocean circulation models such as POM and sea spray or air-sea flux parameterizations, are also possible.

The WaveWatch-III (hereafter WW3: Tolman, 2002) wave model was implemented for a corresponding Northwest Atlantic 0.25^o grid, using Etopo2 bathymetry. Regarding further set up details, f_{low}, f_{high} are the lowest, highest frequencies, set to 0.0412, 0.4060, respectively. The number of frequency points f is 25, number of angle bins θ, 24, $f_{i+1}/f_i = 1.1$, respectively. Six-hourly winds are used to drive the wave model.

3. STORM CASES

Archives of marine storms were selected from two 20-year periods output data from CGCM2. This consists of the period 1975-1994, representing the current climate, and 2040-2059, the future climate, with higher greenhouse gases such as CO_2, as described by Boer et al. (2000). Storms were selected used a storm detection algorithm. Details are presented by Jiang et al. (2004), and Long et al. (2004). Criteria include a local minima of surface level pressure (SLP), less than 1005mb, with at least 24h lifecycle and southwest to northeast track. Thus, archives of 72 present climate autumn storms (Sept.–Oct.) and 66 future climate storms were obtained. These storms were simulated using MC2 to provide driving wind fields for WW3.

4. RESULTS

Figures 1 and 2 respectively give the maximum Hs tracks for the storms in the current and future climates, as defined in this study. The two families of Hs storm tracks show some variation, with the future climate tending to suggest a slightly higher density of Hs tracks near the North American coastline, than the present climate. Results for associated comparisons of storm tracks and intensity from MC2 simulations, when compared with those of GCM simulations as well as the NCEP reanalysis data are presented by Jiang et al. (2004), and show that while MC2 simulations are basically realistic in terms of storm tracks and intensities, they are more intense than those of NCEP reanalysis data, or CGCM2 estimates.

As a preliminary estimate of the impacts on ocean waves, Fig. 3 gives locations of maximum significant wave heights Hs, for all storms in current and future archives of this study. A more quantitative understand is underway and will be reported at the Workshop. In the autumn, in midlatitudes, large ocean waves are generated when accelerating extratropical hurricanes propagate at a speed that matches the group velocity of the dominant wave, and if storm lifecycles encompass greater oceanic fetch. Thus the impact of climate change would be felt in ocean waves if storm propagation speeds change to match group velocities of the dominant wave, and if they cover longer fetches when this matching occurs, even if surface winds did not change. Of these two factors, a modest increase in the number of storms propagating at speeds matching the dominant wave speeds would have more impact on maximum Hs than an increase in effective ocean fetch occurring when the storm 'decouples' from the waves, in the sense of not matching the dominant wave group speed.

Distributions of % number of storms with $Hs_{MAX} > Hs$ as a function of Hs, for current and future climates are shown in Fig.4. This shows that for moderate and low Hs values, current and future storm archives are about the same. However, for very high Hs values, there is a slight increase for future climate, in the number of storms having increased Hs values, relative to the current climate. This is in agreement with implications of the impacts of climate change on storm intensities, by Knutson and Tuleya (2004) and Lambert (2004).

As a further demonstration of the trend for increased maximum waves in the largest storms in future climate, compared to present climate, Figs. 5 and 6 give respective distributions of Hs as a function of time, for all the storms of these archives. These plots show very slight trends in the future climate for higher maximum waves in the biggest storms, and longer durations of storms. Further analysis will consider factors related to coupling between storm propagation speed and dominant wave group velocity.

5. CONCLUSIONS

Preliminary analysis of the results from this study suggest that the impact of climate change is to slightly enhance the maximum wave heights occurring in the largest storms, while the effect of waves occurring in moderate and low intensity storms seems to experience little change. This result is consistent with recent studies by Lambert (2004) and Knutson and Tuleya (2004) suggesting that intensities of the strongest storms should increase in CO_2 – warmed future climate. Ongoing analysis focuses on determination of the role of enhancements to the coupling between waves and winds, in the sense of matching between the storm speeds and dominant wave speeds, as well as increases in the effective fetch for wave growth. Additional concern relates to possible slight shifts in the location of maximum waves and storm tracks, related calculations using outputs for winter storms, determined from the CRCM model, and quantitative statistical analysis of all results.

Acknowledgements

Support for this research comes from Canadian Panel on Energy Research and Development (PERD - Offshore Environmental Factors Program), ONR (US Office of Naval Research) through GoMOOS – the Gulf of Maine Ocean Observing System, Petroleum Reseach Atlantic Canada (PRAC).

6. References

Benoit, R., M. Desgagné, P. Pellerin, S. Pellerin, Y.Chartier, S. Desjardins, 1997, The Canadian MC2: a semi-Lagrangian semi-implicit wide-band atmospheric model suited for fine-scale process studies and simulation, *Mon. Wea. Rev.,* **125,** 2382-2414.

Boer, G.J., G. Flato, M.C. Reader and D. Ramsden, 2000: A transient climate change simulation with greenhouse gas and aerosol forcing: experimental design and comparison with the instrumental record for the twentieth century. *Climate Dynamics*, **16**, pp. 405-425.

Jiang, J., Perrie, W., Ren, X., Zhang, W., and Long, Z., 2004: Estimate of impacts of climate change on North Atlantic extratropical hurricanes. To be submitted to Geophys. Res. Letters.

Knutson, T.R., Tuleya, R.E. and Kurihara, Y., 1998: Simulated increase in hurricane intensity in a CO_2 -warmed world. *Science*, **279**, 1018-1020.

Knutson, T.R. and Tuleya, R.E., 1999: Increased hurricane intensities with CO_2-induced warming as simulated using the GFDL hurricane prediction system. *Clim. Dyn.*, **15**, 503-519.

Knutson, R.E., Tuleya, R.E., Shen, W. and Ginis, I., 2001: Impact of CO_2 - induced warming on hurricane intensities as simulated in a hurricane model with ocean coupling. October issue of *J. Climate*.

Knutson,T.R. and Tuleya,R.E. 2004: Impact of CO2-Induced warming on simulated hurricane intensity and precipitation: Sensitivity to the choice of climate model and convective parameterization. *J. Climate* 17:3477-3495.

Lambert, S. 2004: Changes in winter cyclone frequencies and strengths in transient enhanced greenhouse warming simulations using two coupled climate models. *Atmosphere-Ocean* 42(3): 173-181.

Long, Z., and Perrie, W., 2004: Estimated impacts of climate change on North Atlantic winter storms. To be submitted to Geophys. Res. Letters.

McTaggart-Cowan, R., J. R. Gyakum, M. K. Yau, 2001, Sensitivity testing of extratropical transitions using potential vorticity inversions to modify initial conditions: Hurricane Earl case study. *Mon. Wea. Rev.,* **129,** 1617-1636.

Tanguay, M., A. Robert, R. Laprise, 1990, A semi-implicit semi-Lagrangian fully compressible regional forecast model. *Mon. Wea. Rev.,* **118,** 1970-1980.

Tolman H.L., 2002: User Manual and system documentation of WAVEWATCH-III Version 2.22. Technical Note. U.S. Department of Commerce.

Walsh, K.J.E. and Katzfey, J.J., 2000: The impact of climate change on the poleward movement of tropical cyclone-like vortices in a regional climate model. *J. Climate***, 13**, 1116-1132.

Walsh, K.J.E. and RyanB.F., 2000; Tropical cyclone intensity increase near Australia as a result of climate change. *J. Climate***, 13**, 3029-3026.

Wang, X. L. and V. R. Swail, 2002: Trends of Atlantic wave extremes as simulated in a 40-year wave hindcast using kinematically reanalyzed wind fields*. J. Clim.* **15**(9), 1020-1035.

Wang, X. L. and V. R. Swail, 2001: Changes of Extreme Wave Heights in Northern Hemisphere Oceans and Related Atmospheric Circulation Regimes. *J. Clim.*, **14**, 2204-2221.

Wang, X. L., F. W. Zwiers and V. R. Swail, 2004: North Atlantic Ocean Wave Climate Change Scenarios for the 21st Century. *J. Clim*. (in press)

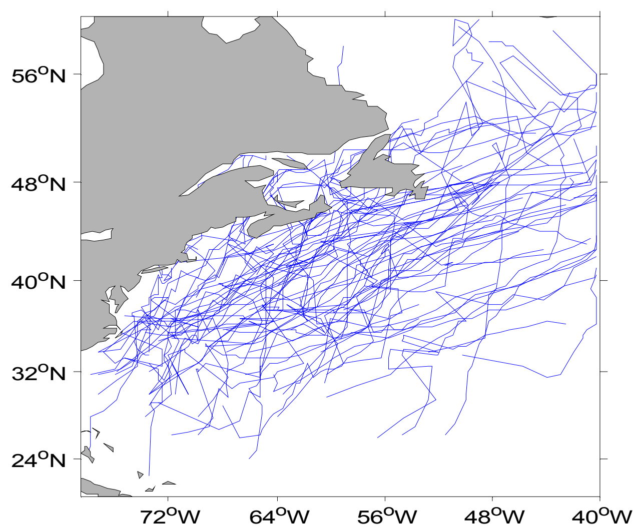

Figure 1: Tracks of maximum Hs for current climate 1975-1994.

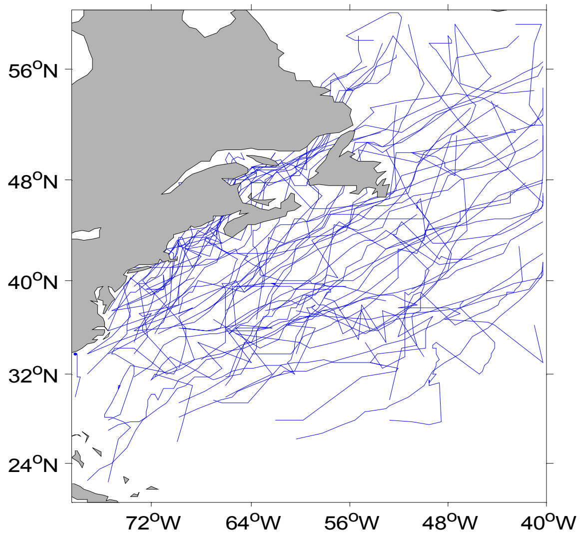

Figure 2: As in Fig. 1 for for future climate 2040-2059.

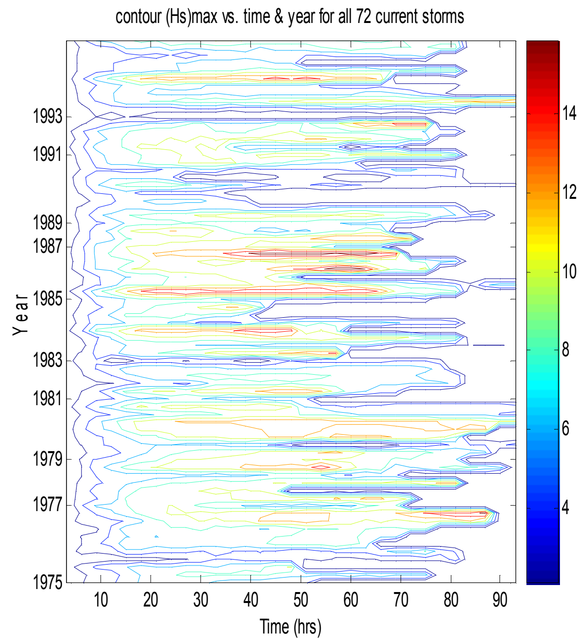

Figure 5: Hs contours as a function of time, for all storms in the current climate.

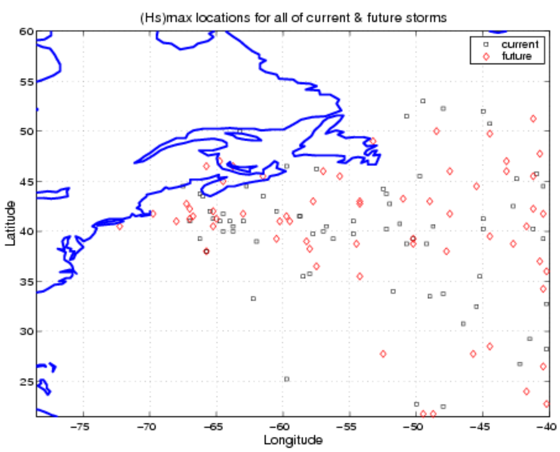

Figure 3: Locations of maximum waves for current and future climates.

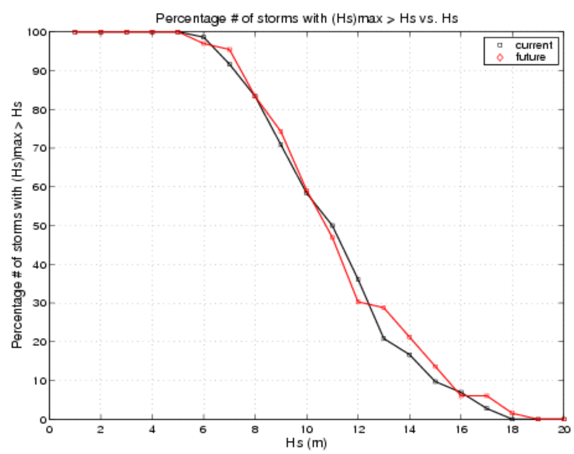

Figure 4: Comparison of Hs for current and future climates.

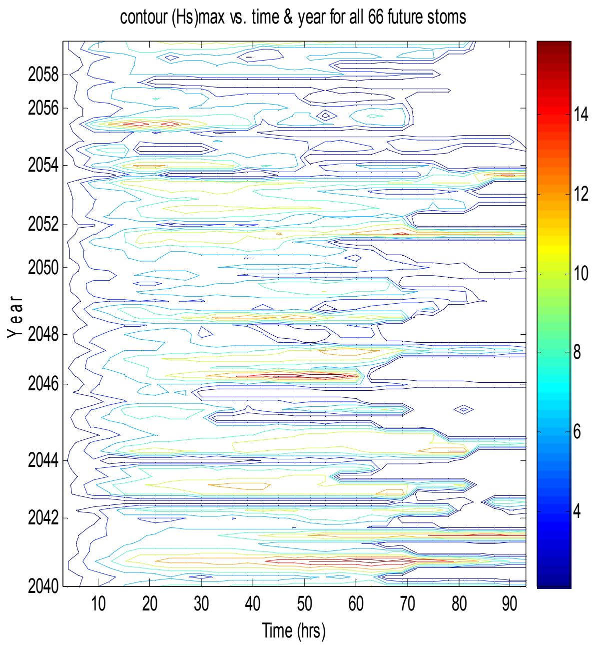

Figure 6: As in Fig. 5 for future climate.