6D. 7 SIMULATION AND VALIDATION OF SEA SURFACE TEMPERATURE AT THE MAIN DEVELOPMENT REGION FOR TROPICAL CYCLONES IN EASTERN NORTH PACIFIC OCEAN

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Compare with other global climate models (GCMs), the Canadian GCM has been attributed with the least error in simulating global and tropical sea surface temperature, an important variable in determining tropical cyclone maximum potential intensity. This paper addresses the ability of Canadian GCMs to simulate historical (1971-2000) sea surface temperature, focusing at the main development region for tropical cyclones in the eastern North Pacific basin. The feasibility of CGCM to model sea surface temperature in the region is statistically validated. The main development region, when subdivided longitudinally, shows a regional difference in the historical trend of tropical cyclone activity and has comparable correlation with SST in both the observed and modeled datasets.

1. INTRODUCTION:

Challenges arise when determining major long term trend of tropical cyclone frequency considering 1) there is a lack of consistent TC intensity measurement prior to 1970s; 2) the relationship is depends on the selection of period and 3) the presence of basin-specific inter-annual to inter-decadal variations (Webster et al., 2005; Wu & Wang, 2008) may mask the actual tendency of TC genesis. These concerns are partly addressed through the use of fine-scaled Global Climate Models (GCMs) to generate aspects of TC characteristics over a long period of analysis (Henderson-Sellers et al., 1998). Confidence of TC simulation depends on the accuracy of GCM-forced boundary conditions.

Environmental conditions such as sea surface temperature (SST) is directly related to the relative humidity in the lower troposphere (Knutson & Tuleya, 2004; Trenberth, 2005) and is theoretically considered as the limiting thermodynamic factor in regulating the strength of TC when other factors are controlled. Previous studies have relied on the climatology of GCM-generated SST as one of the main source to simulate TC record in models with a higher resolution (Lavender & Walsh, 2011). Their results mostly agree the highest TC intensity will strengthen in the future (Knutson & Tuleya, 2004; Lavender & Walsh, 2011). Through applications of the ensemble approach (Knutson et al., 2007), the bias associated with the downscaled SST has been minimized. However, there still remains the question of how realistic GCMs can accurately simulate SST conditions that are critical to TC development.

The third generation of Canadian GCMs (CGCM3) has been applied to simulate TC potential intensity based on the result of the validated CO_2-enhanced SST (Yu et al., 2010). Though CGCM3 has made the least error in historical SST simulation, results are based on global and tropical scales that are not basin specific.

Our study will simulate and validate SST using CGCM3 in the Main Development Region (MDR) of the eastern North Pacific (ENP) basin through statistical measures. Modeled SST and observed TC measures will be subdivided into western (WDR) and eastern (EDR) developing regions from MDR and correlated (Figure 1).

2. DATA AND METHODOLOGY:

Annual TC track record, including 6-hourly track positions, maximum surface wind speed and TC intensity measures, is obtained from the hurricane best track data of Unisys Weather http://weather.unisys.com/hurricane/e_pacific/index.php. TC seasonal record (May 15-November 30) is assembled for 1971-2000. Though the Dvorak intensity scheme has started since 1972 (Collins, 2010) and annual TC data is extended to the current date, the analysis period is selected in congruent with the availability of modeled SST data. TC data are classified into named storms (NS), named storm days (NSD), hurricanes (H), hurricane days (HD), major hurricanes (MH) and major hurricane days (MHD) according to the Net Tropical Cyclone (NTC) activity index according to Ralph & Gough (2009); tropical depression events are not included in the study to exclude unreliable TC data in the early record.

Observed monthly SST data within the physical boundary of 10-20°N and 85-140°W are retrieved from the British Atmospheric Data Center's HadISST1.1, which has a data specification of a 1° by 1° gridded scale. Limitation of model simulation only enable the comparison of observed and modeled SST data from 1971-2000. To validate model performance in simulating historical SST, data output with the same spatial and temporal boundary is obtained from CGCM3 version T63 with an ocean solution of 1.4° latitude by 0.9° longitude. Simulated SST data is spatially re-sampled to confer with grid scale of observed dataset using the interpolation method of Kriging. This method considers the six nearest measurements of the modeled dataset while placing more weights on data points that are closer to the intended 1° by 1°grid cells within the physical boundary. Re-sampled data are statistically tested for CGCM's accuracy in simulating SST in the observational period (1971-2000), using a paired-t test over MDR, WDR and EDR.

Both the observed and modeled SST and measures of TC activity in MDR are longitudinally are subdivided at 112°W into WDR 10-20° N and 85-

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112°W and EDR 10-20° and 112-140°W. Spearman rank correlation coefficient is chosen to perform at comparing correlations of the two SST datasets and TC activity because of the non-normal distribution of TC data.

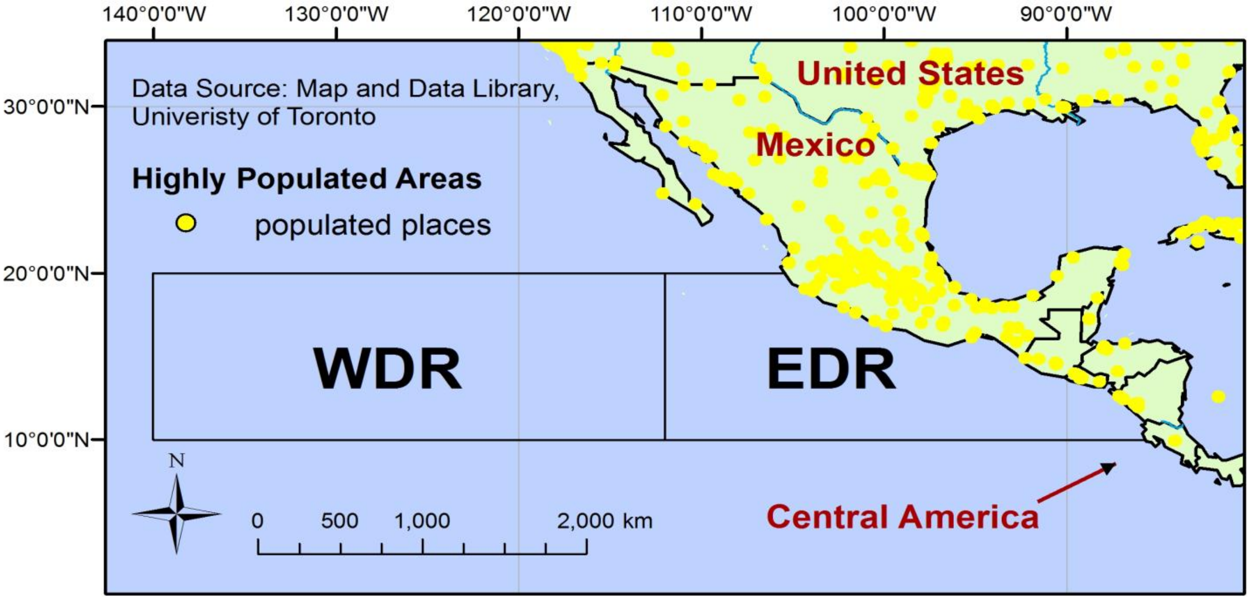

Figure 1: MDR is being divided into WDR and EDR at 112°W at ENP basin where the density of TC activity is the highest of all major TC development regions (Collins, 2010).

3. RESULTS:

From 1971-2000, the annual rate of TC genesis in MDR of ENP basin has been constant with a minute positive trend, while TC originated from EDR (WDR) has experienced a small but decreasing (increasing) trend of a similar magnitude (Figure 2a). A small gain in TC frequency in MDR is mostly a result of increasing MHs (Figure 2b), balancing the opposing effect of TS and H. Even though MH shows a decreasing pattern leading up to 2011, a significant difference in MH activity is noted between both periods when MDR is subdivided at 112° W into western and eastern portions (Figure 1). The eastern boundary of MDR is adjacent to highly populated areas where recurving TCs land and natural disasters occur on a seasonal basis.

When the analysis period is divided into an equal fifteen-period interval (1971-1985; 1986-2000), consistent contrasting directions of TC frequency are evident in MDR and its subdivisions. During the former (latter) half of the 30-year period, TC frequencies in MDR, EDR and WDR show an increasing (decreasing) pattern (Figure 2c,d), an evidence of decadal fluctuation that is commonly observed at other TC developing basins. A greater SST warming and more favourable thermodynamic (low to mid level relative humidity) and dynamic (wind shear, low-level relative vorticity) factors in the earlier period may have contributed to a positive response in TC frequency; while the opposite can be true in the latter period.

CGCM3-modeled SST has shown a thirty-year average of 29.5°C, compared with the observed dataset of 28.0°C. A paired t-test to verify the model's ability to simulate historical SST data in MDR fails with a $p<0.05$ over 63890 paired samples. Significant difference of SST between the two datasets cautions the reliability of simulated TC measures due to modeled-SST forcings. This explains why previous attempts to simulate TC measures in the historical period have either bias-corrected modeled SST or applied the observed SST climatology.

Changes to the six measures of NTC activity have been linked with SST as a controlling factor, in particular at WDR where observed SST is below the threshold (26.5°) for TC genesis (Gough & Ralph, 2009). Though the statistical test fails, the use of CGCM3 to show spatiotemporal changes of SST has been consistent with the observed result obtained from Ralph and Gough (2009). For instance in Figure 3 (a) and (b), the modeled data accurately simulated SST to warm from July, 1971 to July, 2000. Warming is most convincing at EDR, near the western shoreline of Mexico, where SST is already above the threshold for TC formation. Hence, further warming may not cause substantial increases in TC activity. On the other hand, warming in WDR is not as prominent as EDR considering only gradual warming is visible from the change in the colour intensity at the southeastern corner of WDR. As a result of a combined SST change in EDR and WDR, it is possible to rationalize only minute increase in TC frequency (Figure 1a) is observed from 1971-2000. However, it is important to realize TC frequency has decreased when the analysis period extends from 2000 to 2010. Temporal simulation CGCM may be needed to be extended to test if SST is positively correlated with the recent downturn of TC frequency.

Spearman correlation values between modeled SST and the six NTC measures are different from Ralph & Gough (2009). Our result shows HD and modeled SST in MDR has the highest correlation (r=0.43) where $p<0.05$. Though the same attribute of HD-SST relationship is present in WDR (r=0.39) and EDR (r=0.35), statistical significance is not shown at EDR. This underlines the influence of SST, and perhaps other thermodynamic factors, over TC development in WDR (Collins & Mason, 2000; Ralph & Gough, 2009).

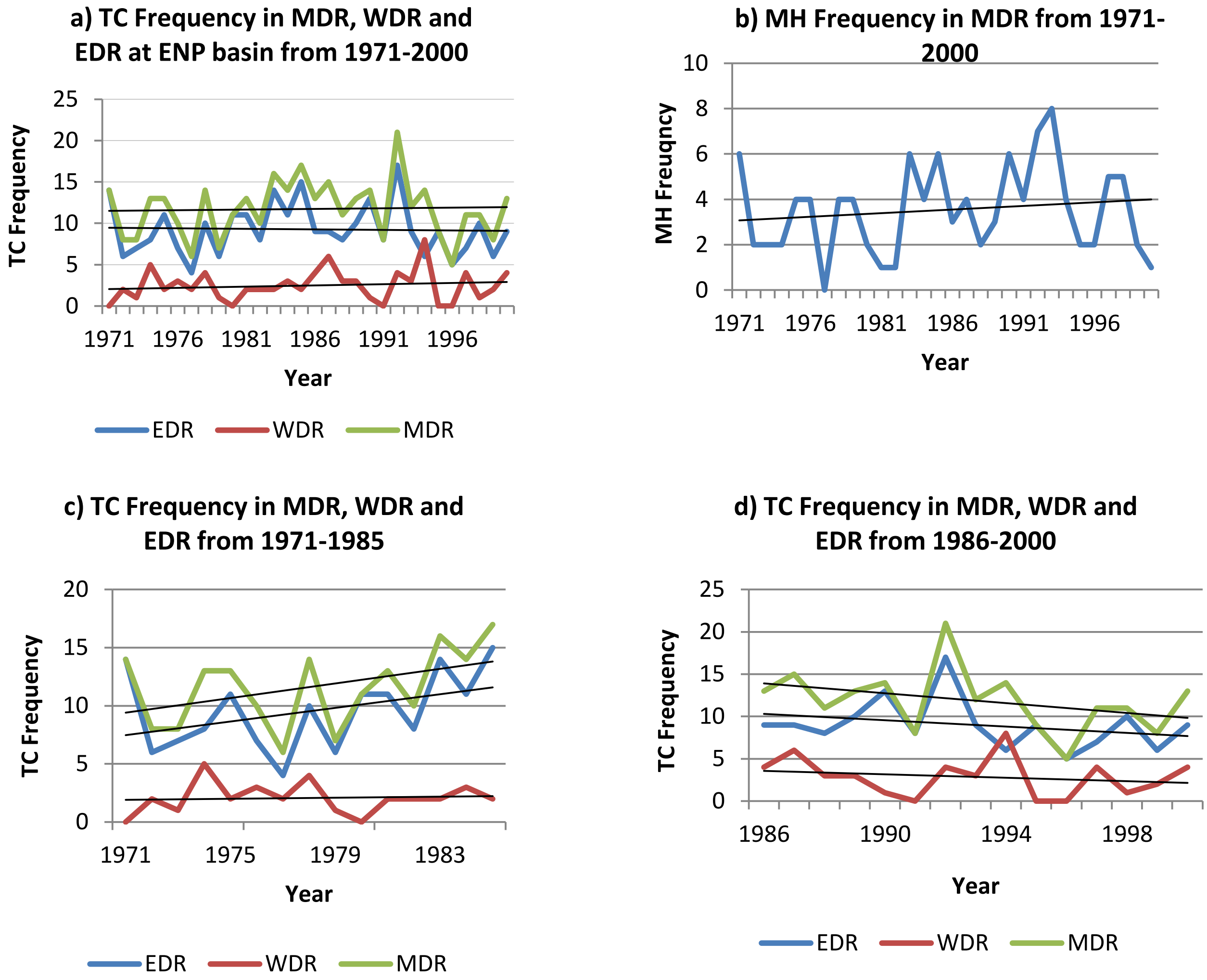

Figure 2: Temporal trend of a) TC frequencies in MDR, EDR and WDR and b) MH frequency in MDR from 1971-2000. TC frequency when temporally divided is showing trends with opposite directions in all developing regions.

4. CONCLUSION:

We have reviewed the relationship of the observed measures of NTC activity index with the model-simulated warming of SST in ENP basin. In particular, SST warming from 1971-2000 at the subdivisions of MDR shows a more favourable thermodynamic condition for TC development, assuming all other factors are controlled. Further work is needed to investigate the accuracy of other model-simulated environmental factors in triggering TC development. Mid-level relative humidity in WDR had been statistically associated to interact with TC measures in a significant way; while the same is not found in EDR (Collins, 2010). This allows for further comparison between modeled and observed dataset in their association with measures of TC activity to justify the capability of GCM to simulate climate conditions that are essential to project future TC record.

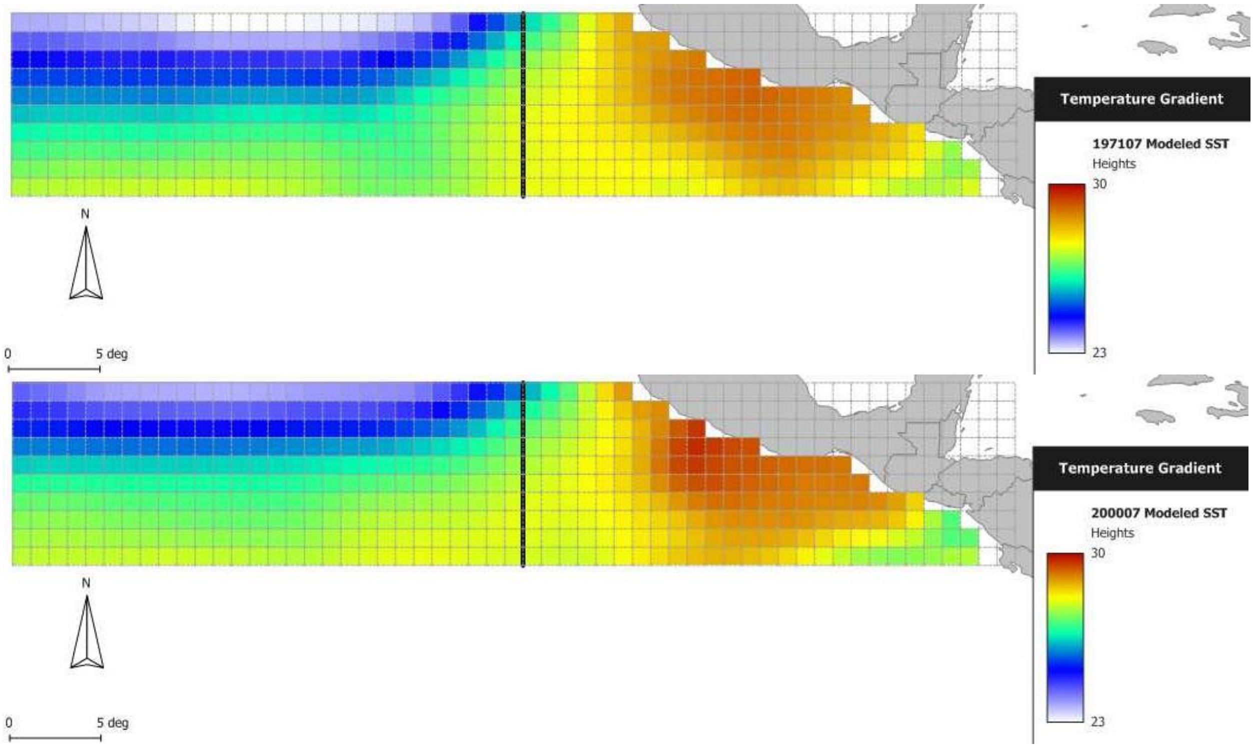

Figure 3: Raster images of CGCM3-modeled SST temperature (°C), showing gradient differences form July, 1971 (top) to July, 2000. Modeled SST has been re-gridded according to the resolution of the observed dataset at 1° by 1° basis. Longitudinal boundary is drawn to show the division of MDR into EDR and WDR.

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