11B.4 INTERANNUAL VARIABILITY OF TROPICAL CYCLONE FREQUENCIES IMPLIED FROM AN ENSEMBLE CLIMATE SIMULATION WITH THE NCAR COMMUNITY ATMOSPHERE MODEL

Junichi Tsutsui*, Hiroaki Hatsushika, and Hideyuki Kitabata
Central Research Institute of Electric Power Industry, Abiko, Japan

1 INTRODUCTION

The motivation of this study arises from some uncertainties about interannual variations of tropical cyclone (TC) activity, such as the mechanism of the variability, contributory factors, and impacts of anthropogenic climate change. All these uncertainties are not only scientifically interesting, but also socially important issues. Probably, there are some keys to clarify these uncertainties. For example, observed records show some modulated TC activity due to El Niño-Southern Oscillation (ENSO), and generally the variability is different from basin to basin (e.g., Gray, 1984; Wang and Chan, 2002). Then, it is suggested that sea surface temperature (SST) variations play a role in TC activity through large-scale flow fields.

Although a general circulation model is becoming a promising tool to study climatological aspects of TCs, it is often pointed out that credibility of modelling studies is lost due to large model-to-model differences. Thus, we're conducting this study with the following two objectives using several versions of the NCAR Community Atmosphere Model. The first one is to verify the model's performance regarding TC simulations focusing on the sensitivity to moist convection schemes and spatial resolutions; the second one is to investigate SST-forced impacts on TC activity with an emphasis on differences between two major TC basins, the western North Pacific and the North Atlantic.

2 NUMERICAL EXPERIMENTS

The model we used in this study is mostly based on the NCAR CCM3.6 with some modifications in physics parameterizations and with different horizontal resolutions in the range from T42 to T341. The most important modification is an implementation of an inhibition mechanism using relative humidity (RH) threshold in the boundary layer, to which simulated TC activity is very sensitive. Other modifications include changes in cloud diagnostics parameters, which are tuned in higher resolution models so as to keep simulated radiation properties similar to those for the standard resolution (T42). So far, the highest resolution (T341) is experimental due to some difficulties in this tuning. The results from the latest model, the Community Atmosphere Model (CAM), will also be presented.

We conducted some sensitivity experiments with four different resolution models, and long-term (1979 to 2000) ensemble climate simulations with T42 and T170 models using observed SSTs as boundary condition data. The number of ensemble members is nine and six for the T42 and T170 model runs, respectively. We examined simulated TC activity based on total storm days, where a simulated TC is defined as a low over the ocean between 40°N to 40°S, with a significant pressure gradient at sea level and a warm core structure in the upper troposphere. The critical sea level pressure gradient for qualified TCs depends on the model's horizontal resolution considering pressure deepening affected by numerical truncation.

*Corresponding author address: Junichi Tsutsui, Central Research Institute of Electric Power Industry, 1646 Abiko, Abiko-city, Chiba 270-1194 Japan; e-mail: tsutsui@criepi.denken.or.jp.

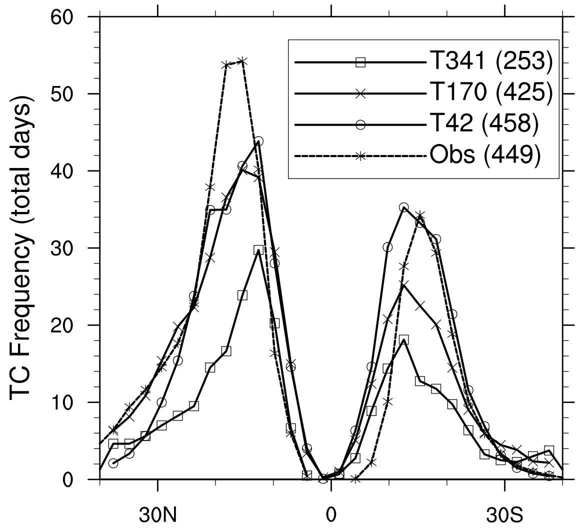

Figure 1: Zonally summed TC frequencies from the T42, T170, and T341 models and observation.

3 RESULTS

3.1 Sensitivity Experiments

Figure 1 shows zonally summed TC frequencies from three different resolution models and observation, where the frequency is evaluated as annual storm days at each T42 grid point. The models employ RH threshold of 85% in the convective inhibition scheme. The CCM3 has a deficiency of weak tropical variability, and virtually no tropical cyclones are generated with the original configuration. It is realized that the original model tends to generate convection to maintain the convective available potential energy (CAPE) within a small value. The convective inhibition is beneficial to increase the CAPE with reasonable variability. From the sensitivity experiments, it is found that the model with 85% RH threshold simulates TC frequencies comparable to observation.

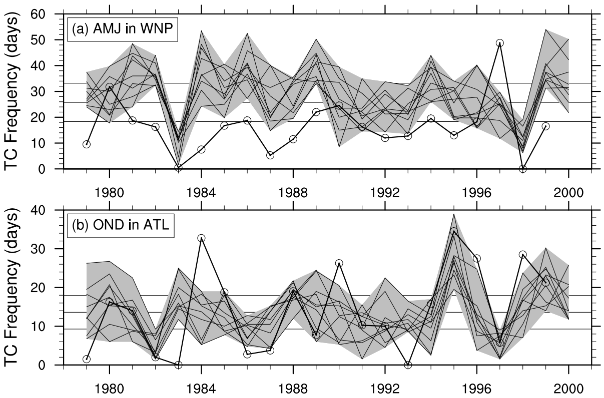

Figure 2: Interannual variations of seasonal TC frequencies from the T42 model ensemble. Thin solid lines with shading denote ensemble member variations, thick solid line with markers of open circle denotes observation. Three horizontal lines indicate ±1 standard deviation range from a long-term run using climatological SST.

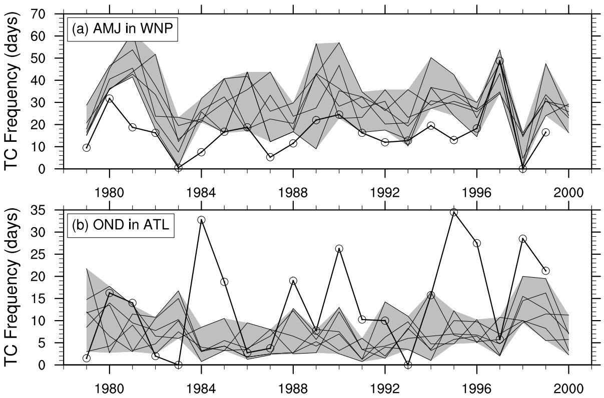

Figure 3: Same as in Figure 2, except for the T170 model ensemble without standard deviation range.

Although simulated TC frequencies are very sensitive to the threshold, they do not much depend on horizontal resolutions. Simulated large-scale properties are mostly similar among the four different resolution models. While a simulated TC by lower resolution models is somewhat like a tropical depression rather than a tropical storm, it becomes realistic with higher resolution models in terms of horizontal scale, intensity, and motion. Although even the highest resolution model cannot well represent inner-core structures of TCs, consistent TC activity among different resolution models suggests that simulated TC frequencies reflect a kind of TC genesis potential.

3.2 Ensemble Simulations

Generally, observed interannual variations of annual TC frequencies are not very well simulated by the models, and higher resolution models are not very capable to produce TCs in the North Atlantic. However, some of the variations of seasonal TC frequencies are successfully simulated in specific regions. Figures 2 and 3 show remarkable time series of the early season (April to June) frequencies in the western North Pacific and the late season (October to December) frequencies in the North Atlantic from the two sets of ensemble simulations. The simulation period includes two strong El Niño events of 1982-1983 and 1997-1998, in which SST anomalies rapidly changed from strong warm phase to cold phase in a similar way. During these events suppressed TC activity was both observed and simulated in the late season in the first year in the North Atlantic, and in the early season in the second year in the western North Pacific. In particular, late 1990s active period in the North Atlantic (Goldenberg et al., 2001) modulated by the 1997-1998 event was realistically simulated by the T42 model. In the western North Pacific the T170 model shows better capability regarding the 1997-1998 modulation.

These suppressed TC activity is consistent with large-scale fields associated with tropical cyclogenesis in each TC basin. One of the good indicators for TC activity is upper-level velocity potential for the western North Pacific, and vertical shear of zonal wind for the North Atlantic. For example, during the 1997-1998 event in the western North Pacific, simulated large-scale fields show an eastward shift of convection area associated with the warm phase, which returns to the normal position with enhanced convection responding to the cold phase. During this transition in the second year, convection is still suppressed in the early season, but somewhat enhanced in the mid season. These large-scale fields are consistent with simulated TC activity. However, in reality, convection was still suppressed in this mid season, and resulted in the record-breaking low activity in the year (Nakazawa, 2001).

Results from the ensemble climate simulations in this study imply that SST-forcing is partly responsible for interannual variations of observed TC frequencies. Further investigation is needed for other factors that affects TC activity as well as the model's errors.

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