4C.4 TRENDS IN LARGE-SCALE CIRCULATIONS AND THERMODYNAMIC STRUCTURES IN THE TROPICS DERIVED FROM ATMOSPHERIC REANALYSES AND CLIMATE CHANGE EXPERIMENTS

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1 INTRODUCTION

In recent years, the frequency of natural disasters due to tropical cyclones tends to increase, which raises questions about possible changes in tropical cyclone activity under global warming. Although recent observational and modeling studies suggest an increased intensity and a decreased frequency of tropical cyclones in a warmed climate (Emanuel, 2005; Knutson and Tuleya, 2004; Oouchi et al., 2006), there is considerable uncertainty about climatological behaviors of tropical cyclones including their large natural variability.

The objective of this study is to accumulate scientific knowledge about future changes in tropical cyclone activity based on tendencies in tropical large-scale conditions, which presumably are dominant factors that affect tropical cyclone activity. As the first step toward this objective, multiple climate data are compared in terms of large-scale tropical circulations and thermodynamic structures.

2 CLIMATE DATA

Climate data used in this study are three reanalyses of the global atmosphere, JRA-25 (Onogi et al., 2006), ERA-40 (Uppala et al., 2004), and NCEP R-1 (Kalnay et al., 1996), and climate model experiments for the upcoming IPCC Fourth Assessment Report (AR4). The JRA-25 is the first Japanese long-term reanalysis, conducted jointly by Japan Meteorological Agency (JMA) and Central Research Institute of Electric Power Industry. The JRA-25 deals with reanalysis from 1979, when an advanced satellite observing system was established. Many kinds of observation data, including special data prepared for the JRA-25 such as retrieved winds near tropical cyclones (Fiorino, 2002), are assimilated by a three-dimensional variational scheme based on a version of the JMA's operational scheme. The JRA-25 reanalysis has satisfactory quality in general and indicates better quality in some aspects such as the spatial distribution of precipitation rates than the other reanalyses.

The model experiments are ensemble simulations by the Community Climate System Model version 3 (CCSM3, Collins et al., 2006a) and Community Atmosphere Model version 3 (CAM3, Collins et al., 2006b). The CCSM3 is one of the most advanced atmosphere-ocean coupled climate models, and the CAM3 is the atmosphere component of the CCSM3. The CCSM3 data are a subset of multi-century ensemble simulations over the period from 1870 through the middle of the 25th century under various natural and anthropogenic forcings (Tsutsui et al., 2006). The CAM3 data are ensemble simulations over the period 1950-2000 with prescribed annual cycles of observed sea surface temperature (SST) and sea ice distributions under the same forcings as used in the CCSM3 simulations. Other model experiments for the IPCC AR4 are being used for comparison. The period 1979-2001 is focused in this extended abstract.

3 RESULTS

3.1 Large-scale tropical circulations

To examine tendencies in large-scale tropical circulations, intensities of Hadley, Walker, and monsoon circulations are defined using a monthly mean velocity potential at the 200-hPa level according to the methodology by Tanaka et al. (2004). In this methodology, the velocity potential is decomposed into zonal mean (1) and deviation from it, and the latter is further decomposed into 12-month mean (2) and deviation from it (3). These components (1–3) represent, respectively, Hadley, Walker, and monsoon circulations, which are primarily driven by meridional differential heating, different SSTs along the equatorial tropics, and heat contrast induced by the land-sea distributions. Although this representation is too simple to discuss complex behavior in tropical circulations, it is useful to identify a large fraction of the tropical circulations from a global perspective and to discuss their trend and interannual variability.

Figure 1 illustrates the three components of the velocity potential averaged over the period 1979-2001 from the JRA-25. The Hadley and monsoon circulations are examined in December-February (DJF) and July-August (JJA) seasons. Following Tanaka et al. (2004), the intensity of each circulation is measured by a peak value in each distinctive area, as marked in the figure.

Figure 2 summarizes the variability as well as the climatology of the tropical circulations over the period 1979-2000 from the all climate data. Although there are some systematic biases, the relation of the intensities of the three circulations is mostly consistent across the data, that is, ranked as the Walker, monsoon, and Hadley in descending order. In this period, consistent trends are found across the three reanalyses; the DJF Hadley circulation increases, and the Walker and DJF monsoon circulations decrease. However, the model experiments indicate no such trends.

The results from the CCSM3 show smaller intensities in the JJA Hadley and JJA monsoon circulations and smaller variability in the Walker circulation. These biases are related

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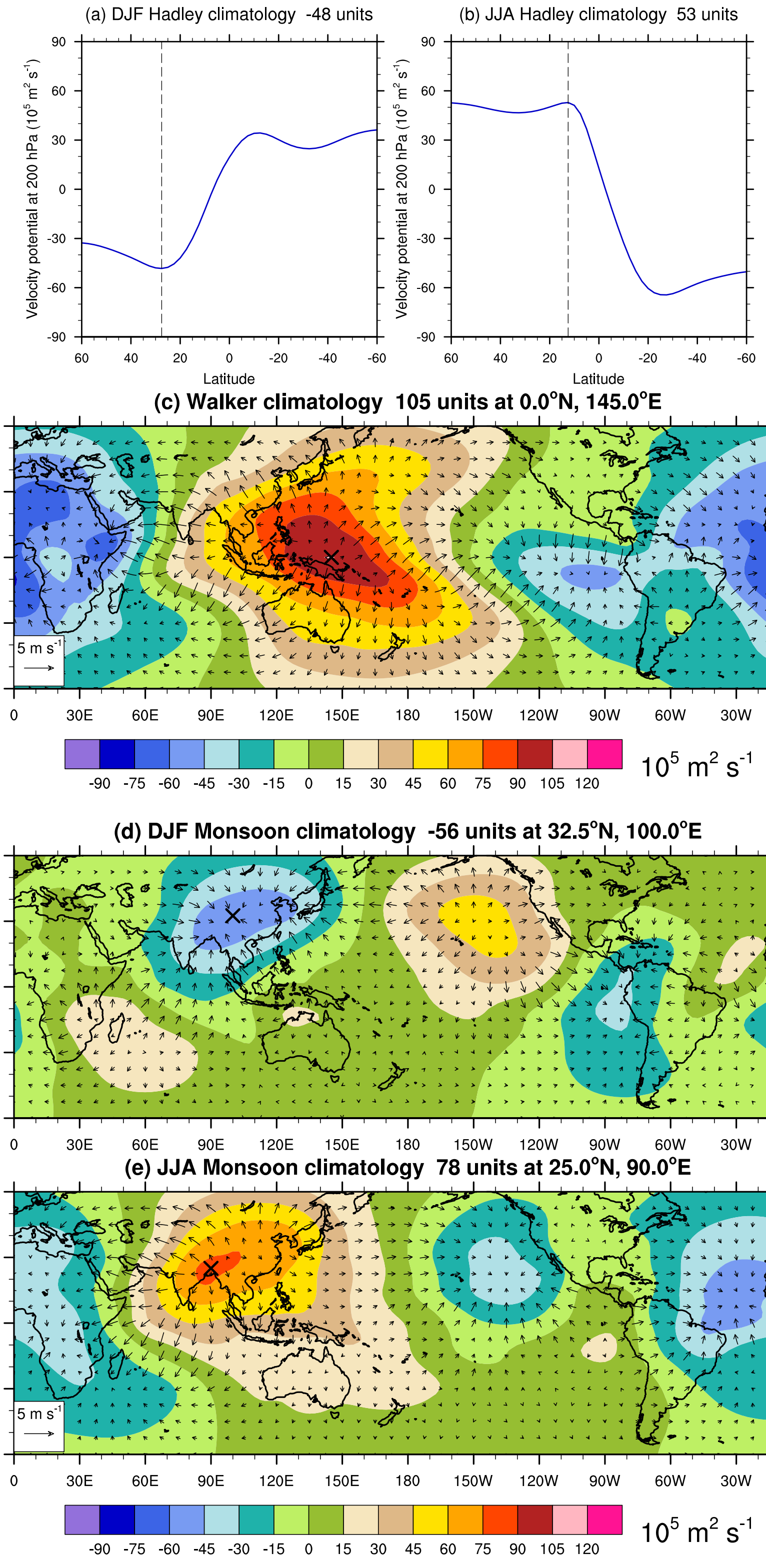

Figure 1: Spatial distributions of decomposed 200-hPa velocity potential from the JRA-25 reanalysis. Panels a–e represent circulations regarding DJF Hadley, JJA Hadley, Walker, DJF monsoon, and JJA monsoon. The intensity of each circulation is defined as a peak value in each distinctive area, which is marked by a vertical dashed line in panels a–b and by a cross (×) in panels c–e.

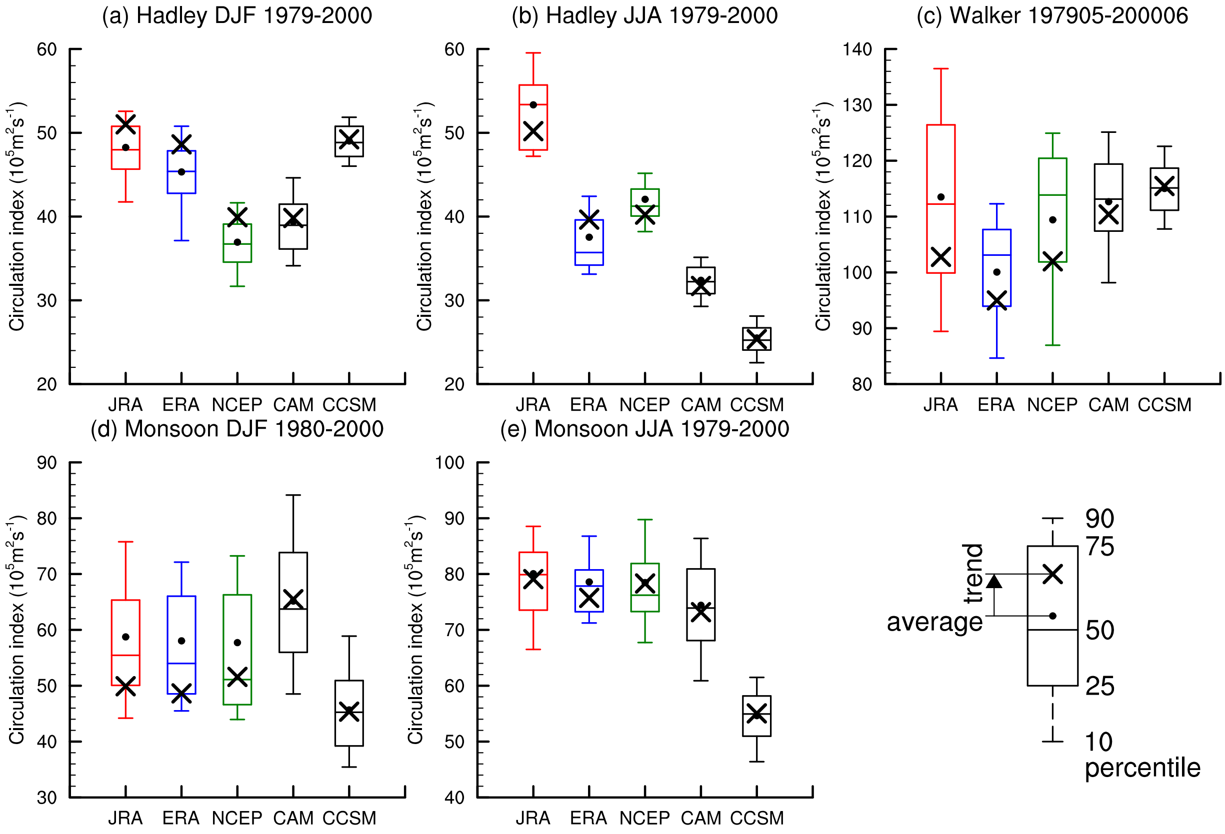

Figure 2: Comparison of tropical circulation intensities among the reanalyses and climate experiments. The variability of each circulation intensity is represented by percentiles and linear trend in units of $10^5 \mathrm{m}^2\mathrm{s}^{-1}$ per decade as denoted by the legend.

to the model's systematic errors, such as "double intertropical convergence zone" and weak tropical variability (Collins et al., 2006a). Some of these biases are reduced in the results from the CAM3 because it is driven by observed SSTs. Nevertheless, all the CAM3 trends are close to zero, which does not approve the trends identified in the reanalyses.

It has been pointed out that the quality of reanalyses in the tropics is affected by data assimilation systems, and that existing reanalyses have different characteristics in the tropics (Newman et al., 2000; Bengtsson et al., 2004). Although the JRA-25 has an advantage of better spatial distributions of precipitation rates, it does not necessarily have better quality in all of the other aspects. Also, changes in observation systems and their influences on the quality of tropical circulations should be taken into account. In the JRA-25, for example, some discontinuous changes are identified in reanalysis of year 1987, corresponding to the first use of precipitable water data retrieved from Special Sensor of Microwave Imager. Similar discontinuous characteristics could be included in the other reanalyses.

3.2 Tropical thermodynamic structure

Only temperature changes are mentioned in this extended abstract. Figure 3 shows linear trends over the period 1979-2001 (1979-2000 for the CAM3 data) of zonal mean monthly temperature anomalies from the climate data. Each anomaly is defined as the deviation from an average over the period 1979-2001 except for the CAM3 data, for which 1971-2000 averages are used. In general, the reanalyses and the model experiments show typical tendencies, such as warming in the lower troposphere in the Northern Hemisphere and cooling in the stratosphere, in particular, in high latitudes in the Southern Hemisphere. Note that decreased stratospheric ozone is considered as boundary data in the reanalyses and the model experiments.

Although these general tendencies are common, there are large discrepancies among the climate data in the tropics and most latitudes in the Southern Hemisphere, where conventional observations used in the reanalyses are sparse. In the results from the two climate experiments, a similar warming pattern is observed, suggesting that given forcings such as increased greenhouse gases are responsible for the tropospheric warming, and that the ocean conditions do not much affect the warming pattern. This simulated warming pattern, however, is very different from any of the three reanalyses, in particular, in the tropics.

Figure 4 shows vertical profiles of the linear trends averaged over 20S-20N latitudes. In the model experiments, the temperature trends are positive throughout the troposphere and increase from the surface to about the 250-hPa level. This profile is more or less observed in other global warming

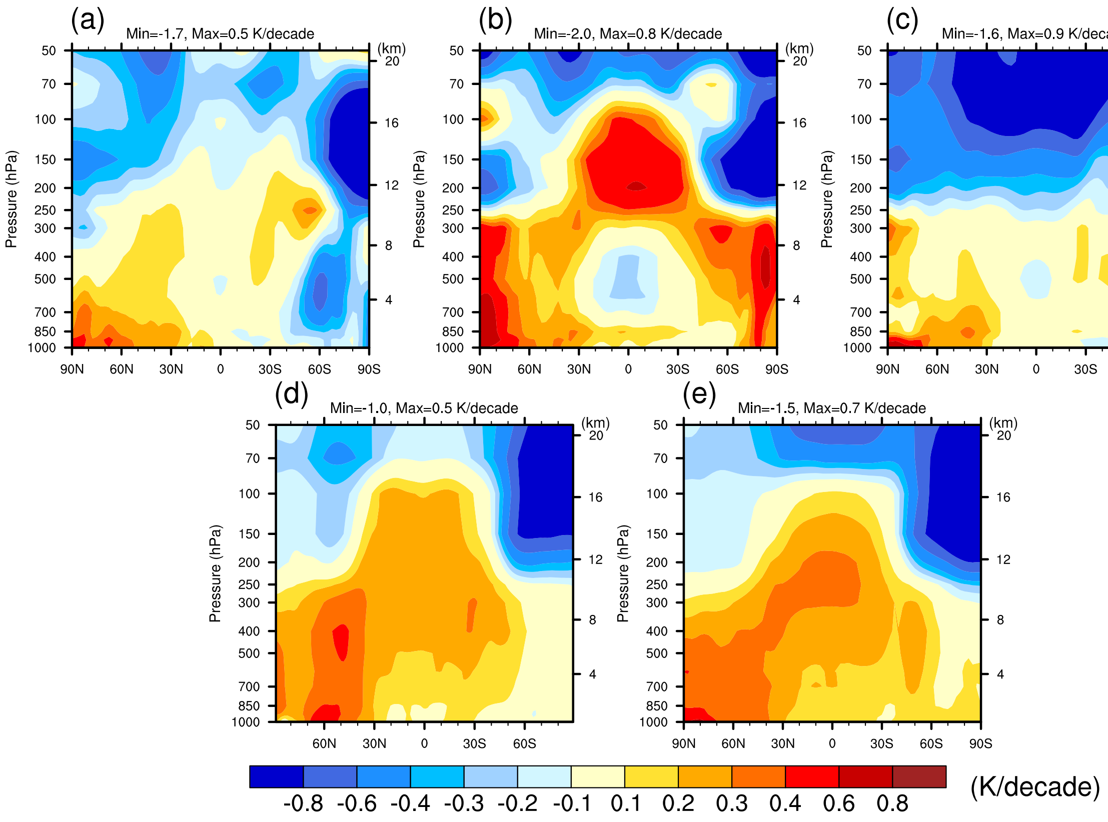

Figure 3: Pressure-latitude distributions of linear trends in units of K per decade over the period 1979-2001 (1979-2000 for the CAM3 data) of zonal mean monthly temperature anomalies from the JRA-25 (a), ERA-40 (b), NCEP R-1 (c), CAM3 (d), and CCSM3 (e).

experiments (e.g., Hansen et al., 2002), implying the beginning of anthropogenic global warming in the late 20th century. Contrastingly, the trends from the JRA-25 and NCEP R-1 are close to zero below the 300-hPa level. Although the profile from the ERA-40 has a similar characteristics to those from the model experiments, the trends are much greater in the upper troposphere and negative in the middle troposphere, in which the latter seems to be compensation for the former.

There are some uncertainties to be considered regarding the temperature trends in the tropical troposphere. The greater warming in the upper troposphere in the models is fundamentally related to the moist adiabatic ascent of convective air parcels (Hartmann, 1994). However, the amount of tropical upper-tropospheric warming generally depends on physical processes in climate models, typically convection scheme. The formulation of physical processes is developed based on the knowledge of the present climate and is not necessarily applicable to warmed climate in the future.

The trends in the reanalyses basically represent time changes in temperatures observed by radiosonde and atmospheric sounding systems carried on polar-orbiting satellites. Also, the trends can be affected indirectly by time changes in water vapor observations through physical processes in a data assimilation system. In general, radiosonde observations are spatially inhomogeneous, and satellite observations include significant biases (Mears et al., 2003; Christy et al., 2003). Therefore, it should be recognized that the trends in the reanalyses are more or less influenced by such insufficient observations.

4 CONCLUDING REMARKS

Tendencies in the tropical circulations and thermodynamic structures are basic information for understanding of recent changes in tropical cyclone activity and the projection of future changes. At this moment, however, these tendencies are not necessarily consistent across multiple reanalyses and climate model experiments. The identification of these tendencies involves difficulties associated with uncertainties of observation biases and physical processes in climate models. Multiple climate data including other model experiments should be further investigated from various aspects to assess each reliability.

The production of the JRA-25 reanalysis is in a final stage, and the reanalysis data is being provided to research community. Currently, none of the all reanalyses including the JRA-25 is better than the others. At least, this new long-term reanalysis would be beneficial to climate studies as one of the standard reference data.

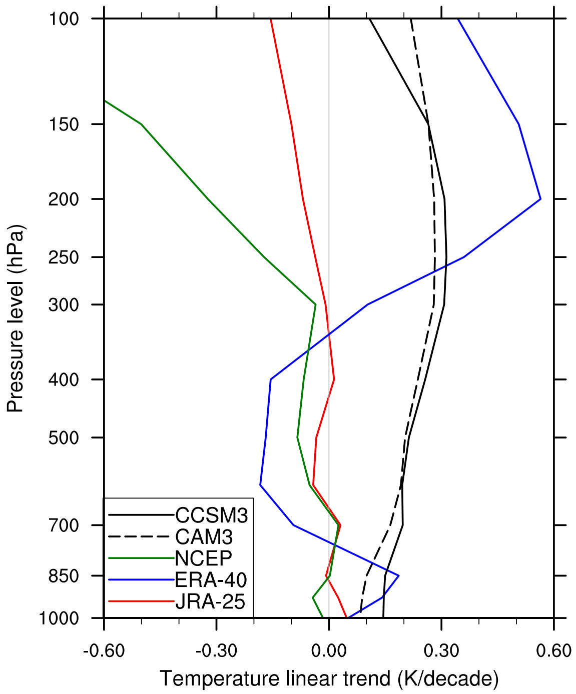

Figure 4: Vertical distributions of linear trends of zonal mean monthly temperature anomalies averaged over 20S-20N latitudes. The definition of the trend is the same as in Figure 3.

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