Mechanism of Tropical Cyclone Frequency Changes Due to Global Warming

Masato Sugi[1], Hiroyuki Murakami[1] and Jun Yoshimura[2]

1 Japan Agency for marine-Earth Science and Technology, Yokohama, Japan

2 Meteorological Research Institute, Tsukuba, Japan

msugi@jamstec.go.jp

Introduction

Recent high resolution models consistently show that the global tropical cyclone (TC) frequency will decrease in the future due to global warming, while there is a large uncertainty in the projected regional TC frequency changes (Knutson et al. 2010). The mechanism of the changes in global and regional TC frequency is not yet fully understood, although some hypotheses are proposed. Sugi et al. (2002) suggested that the reduction of global TC frequency is closely related to a weakening of tropical circulation (upward mass flux). Emanuel et al. (2008) suggested that the reduction of global TC frequency is closely related to an increase in mid-troposphere saturation deficit.

Hypothesis

Previous studies proposed the following hypothesis (Table 1) as a mechanism of the global and regional TC frequency changes (Sugi et al. 2002, Sugi and Yoshimura 2004, Yoshimura and Sugi 2005). We consider two effects: CO2 effect and SST effect. In the CO2 effect, the overlap of CO2 and water vapor long wave absorption bands is playing an important role. The atmospheric cooling will decrease due to the overlap effect when CO2 is increased, leading to a reduction of precipitation, upward mass flux and global TC frequency. On the other hand, in the SST effect the static stability change is playing an important role. From thermodynamic equation, we can derive the following relation between the rate of change in precipitation (P), upward mass flux (ω) and dry static stability (S):

$$\frac{\Delta\omega}{\omega} \approx \frac{\Delta P}{P} - \frac{\Delta S}{S}$$

When SST is increased, atmospheric temperature and moisture will increase, leading to an increase in precipitation. However, as the rate of increase in stability (S) is larger than that of precipitation (P), the upward mass flux (ω) in the tropics will decrease, leading to a decrease in global TC frequency.

Model and Experiment

In order to further clarify the mechanism of global and regional TC frequency changes due to global warming, five 25-year runs have been conducted using the MRI-AGCM3.2 at 60km resolution (Fig.1). For the present climate run (HPA run), observed sea surface temperature (SST) and atmospheric concentration of GHG including CO2 and aerosols are prescribed, while for the future climate run (HFA run), the CMIP3 mean SST anomaly is added to the observed SST and GHG and aerosols at the end of 21st century of IPCC A1B scenario is prescribed. In addition, for the uniform SSTA run, uniform 1.83K (global mean of CMIP mean SSTA) is added to the present observed SST.

Results

Main results of this study are reported in Sugi et al. (2012). The global TC frequency in HFA run is 25% less than that of HPA experiment, while the global TC frequencies in CO2F run and SSTF run are 9% and 18% less than that of HPA run, respectively. These results are basically consistent with previous studies (Yoshimura and Sugi, 2005, Held and Zhao 2011), although the CO2 effect is smaller compared with the previous studies due to the effect of other GHG. It should be noted that the effect of other GHG is opposite to that of CO2, because atmospheric cooling generally increases when GHG is increased, but it decreases only when CO2 is increased due to the overlap effect of CO2 and water vapor.

Figure 2 shows the uniform SSTA effect and non-uniform SSTA effect in the changes in TC frequencies. As indicated in Fig.2, non-uniform SSTA does not change the global TC frequency, but it causes only a shift of active deep convection area and significantly affects the regional TC frequency changes.

Figure 3 shows the CO2 effect and SST effect in the changes in TC frequency, precipitation, upward mass flux, vertical shear and saturation deficit. The effect of CO2 increase is to decrease precipitation, upward mass flux and TC frequency. On the other hand, the effect of SST increase is to increase precipitation but to decrease upward mass flux and TC frequency. Despite the opposite sign of the changes in precipitation, both CO2 effect and SST effect decrease upward mass flux and reduce TC frequency. We note, however, in some regions the SST effect on upward mass flux do not agree well with that on TC frequency. Such disagreement may be explained to some extent by the changes in vertical shear or saturation deficit in the SSTF run.

Summary

Global TC frequency reduction

- CO_2 effect and uniform SSTA effect are responsible for the reduction of global TC frequency in the future GHG warmed climate.
- CO_2 effect is a result of overlap effect of CO_2 and water vapor long wave absorption bands, while uniform SSTA effect is a result of increased dry static stability.
- Both CO_2 effect and uniform SSTA effect cause a reduction of upward mass flux, leading to the reduction of global TC frequency.
- Most important remaining question is how the reduction of upward mass flux causes the reduction of TC frequency.

Regional TC frequency change

- Non-uniform SSTA effect (effect of SSTA relative to the tropical mean SSTA) is mainly responsible for the regional TC frequency.
- Non-uniform SSTA effect causes shift of active convection area, leading to the shift of TC genesis area. It causes little change in global TC frequency.

Acknowledgement

This work was conducted under the framework of the ”Projection of the Change in future Weather Extremes using Super-high-resolution Atmospheric Models” supported by the KAKUSHIN Program of the Ministry of Education, Culture, Sports, Science, and Technology (MEXT). The calculations were performed on the Earth Simulator.

References

Emanuel, K., R. Sundararajan and J. Williams, 2008: Hurricanes and global warming: results from downscaling IPCC AR4 simulations. *Bull. Amer. Meteor. Soc.*, pp. 347–367.

Held, I. M. and M. Zhao, 2011: The response of tropical cyclone statistics to an increase in CO_2 with fixed sea surface temperatures. *J. Climate,* in press.

Knutson, T., J. McBride, J. Chan, K. Emanuel, G. Holland, C. Landsea, I. Held, J. P. Kossin, A. Srivastava and M. Sugi, 2010: Tropical cyclones and climate change. *Nature Geoscience*, p. doi:10.1038/ngeo0779.

Sugi, M., A. Noda and N. Sato, 2002: Influence of the global warming on tropical cyclone climatology: An experiment with the JMA Global Model. J. Meteor. Soc. Japan, **80**, 249-272.

Sugi, M., H. Murakami, J. Yoshimura, 2012: On the mechanism of tropical cyclone frequency change due to global warming. *J. Meteor. Soc. Japan*, 90A, 399-410.

Sugi, M., and J. Yoshimura, 2004: A mechanism of tropical precipitation change due to CO_2 increase. J. Climate, **17**, 238-243.

Yoshimura, J. and M. Sugi, 2005: Tropical cyclone climatology in a high-resolution AGCM -Impacts of SST warming and CO_2 increase. *SOLA*, **1**, 133–136, doi:10.2151.

Table 1 Hypothesis for the mechanism of global and regional TC frequency changes.

Effect		Global change					Regional change
		radiative cooling	precipitation	stability	upward massflux	TC frequency	TC frequency
CO2	CO2	Decrease	Decrease		Decrease	Decrease	
	GHG	Increase	Increase		Increase		
SST	Uniform SSTA	Increase	Increase	Increase	Decrease	Decrease	
	Non-uniform SSTA						Shift

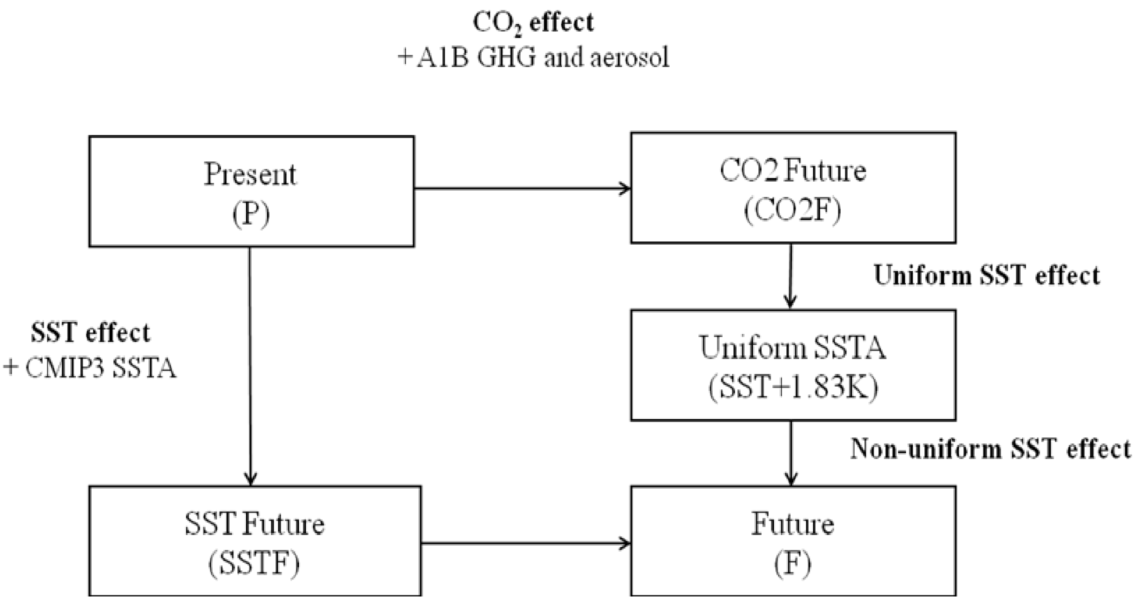

Fig.1 Experiment

Uniform SSTA effect
83.5 → 64.1
(–23.2%)

Non-uniform SSTA effect
64.1 → 63.6
(–0.8%)

Total SSTA effect
83.5 → 63.6
(–23.9%)

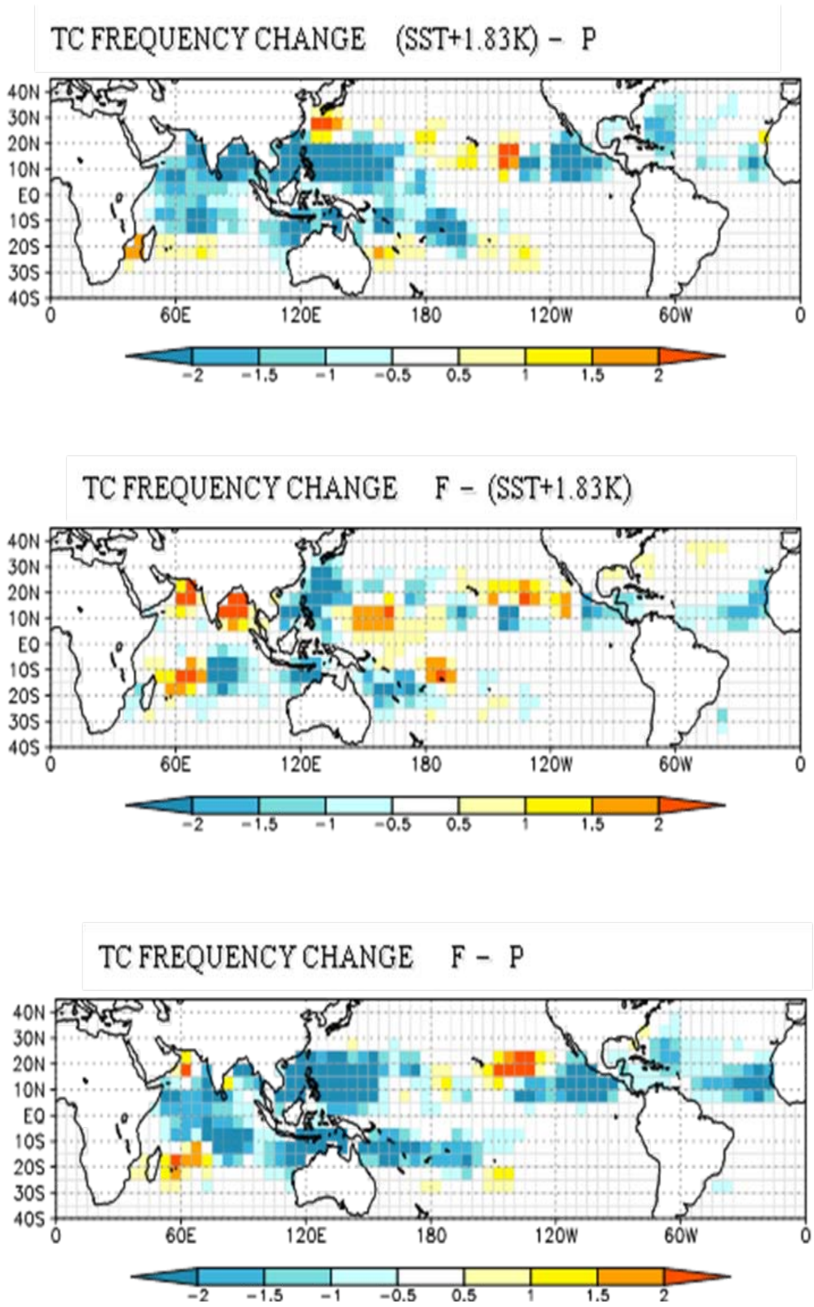

Fig.2 Changes in TC frequency. Uniform SSTA effect including CO2 effect (top), non-uniform SSTA effect (middle) and total SSTA effect including CO2 effect (bottom).

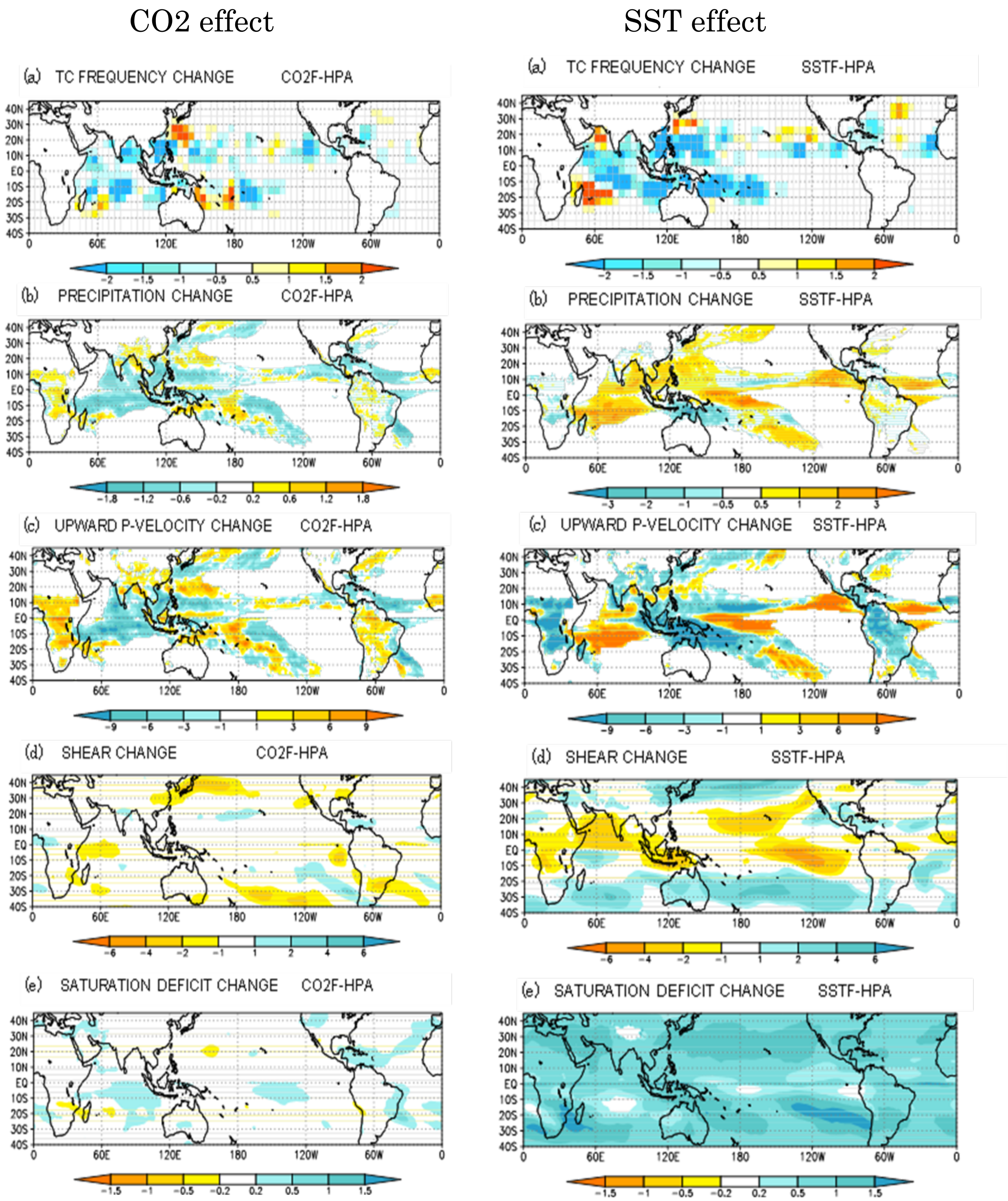

Fig.3 Left: CO_2 effect. Right: SST effect. Changes in (a) TC frequency, (b) precipitation, (c) Upward mass flux (vertical p-velocity at 500hPa), (d) Vertical shear between 200hPa and 850hPa, (e) Saturation deficit at 600hPa.