Future Change of North Atlantic Tropical-Cyclone Tracks: Projection by a 20-km-mesh Global Climate Model.

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1.Purpose

Future changes in tropical-cyclone (TC) tracks, affected by global warming, have not been well investigated. These changes as well as intensity changes are important for socioeconomic damage in the future. However, most studies used coarse resolution models (e.g. 60-120 km mesh) for multi-year climate simulations. The low resolution deteriorates not only TC structures and intensity, but also real distributions of TC tracks and genesis positions.

In this study, we conducted multi-year climate simulations with a 20km-mesh Meteorological Research Institute and Japan Meteorological Agency AGCM (MRI/JMA AGCM) in order to investigate future change in TC tracks over the North Atlantic. The projection periods are from 1979 to 2003 for a present day simulation (PD) and from 2075 to 2099 for a global warmed future simulation (GW), which is based on the IPCC A1B scenario.

2.Experimental design

20km-mesh MRI/JMA AGCM

	20 km mesh global climate model
Horizontal Grids	1920x 960
Vertical Layers	60
Truncation Wave	TL959
Grid Spacing	20km
Top Layer Pressure	0.4hPa
Dynamical frame	Semi-Lagrangian scheme
Radiation Process	Shibata et al. (1999) Solar (every hour) Infrared (3 hourly)
Precipitation Process	Prognostic Arakawa-schubert Large-scale condentation Prognostic cloud water
Gravity wave drug	Iwasaki et al (1989)
Land surface	Simple Biosphere(SiB) model
PBL and surface fluxes	Mellor-Yamada level 2 Moni-Obukhov similarity

Integration Periods

Present day (PD) : 1979-2003 (25 years)
Future (GW): 2075-2099 (25 years)

Lower Boundary Conditions

For PD run:
The Hadley Centre Sea-Ice and Sea-Surface Temperature data set version 1 (HadISST1)

For GW run:
SST and sea ice are prescribed by the CMIP3 multi-model ensemble mean based on IPCC SRES A1B scenario. Interannual variation by observation are also included by following Mizuta et al. (2008).

Observation Data

Tracks:
A global TC best-track data provided by Unisys Corporation Website (http://weather.unisys.com/hurricane/)

Detection method for TC

The method for TC identification involves the six sets of criteria described in Oouchi et al.(2006).

2. Overall result of simulated TC number for each basin

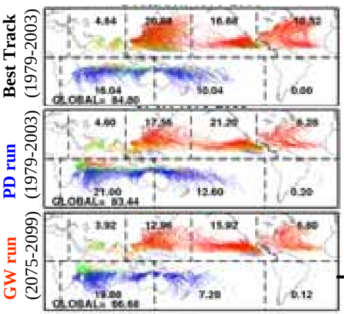


Fig.1 All tracks for (a) Best track, (b) PD run, and (c) GW run. Blue (JFM), Green (AMJ), Red (JAS), Orange (OND). Numbers mean annual averaged TC number.

Tab.1 Statistics of annual mean TC numbers for each simulation.

Region	Observation	PD	GW	GW-PD
Global	84.80	83.44	66.68	-16.76
N.Hemisphere	58.72	49.64	39.36	-10.28
S.Hemisphere	26.08	33.76	27.24	-6.52
North Indian	4.68	4.60	3.92	-0.68
western North Pacific	26.84	17.56	12.96	-4.60
eastern North Pacific	16.68	21.20	15.88	-5.32
North Atlantic	10.52	6.28	6.60	0.32
South Indian	16.04	21.00	19.84	-1.16

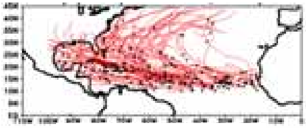
#Green columns mean 99% statistical significance for the future difference.

Reductions in TC frequency are seen for the most basins except for the North Atlantic.

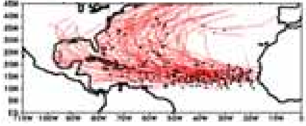
4. Track change over the North Atlantic

Change in tracks

(a) PD run (TC tracks, 1979-2003, JASO)



(b) GW run (TC tracks, 2075-2099, JASO)



(c) GW - PD (frequency of TC occurrence, JASO)

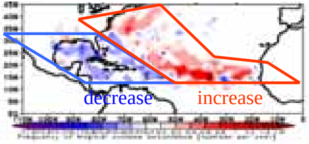
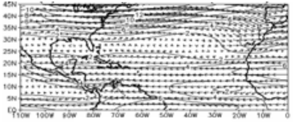


FIG. 3 Total TC tracks over North Atlantic in July-Ougust for (a) PD, and (b) GW run. Difference in frequency of occurrence is shown in (c).

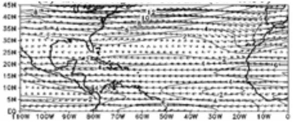
TC tracks show a significant eastward shift in future, resulting in a reduced probability of TC landfall over North America.

Change in large-scale flow

(a) PD run (1979-2003, JASO)



(b) GW run (2075-2099, JASO)



(c) GW - PD (JASO)

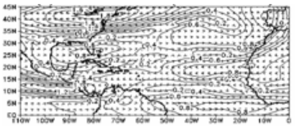
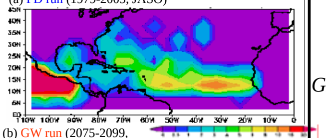


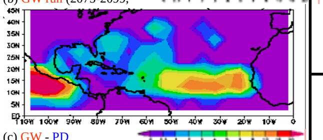
FIG. 4 Simulated large-scale steering flows (m/s) for the peak cyclone season of July–October (JASO) for (a) the PD run, (b) the GW run, and (c) the difference between the GW and PD runs.
Large-scale steering flows were defined as pressure weighted mean flows from 850 to 300 hPa.

Change in large-scale flow does not explain TC track changes.

(a) PD run (1979-2003, JASO)



(b) GW run (2075-2099,



(c) GW - PD

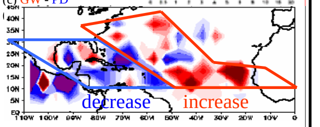


FIG. 5 Simulated frequency of tropical cyclone genesis for the peak cyclone season of July–October (JASO) for (a) the PD run, (b) the GW run, and (c) the difference between the GW and PD runs.

These changes appear to be consistent with the predicted change in frequency of TC occurrence (Fig. 3c), thereby indicating that the change is caused mainly by the change in frequency of genesis.

Why did TC tracks shift eastward?

Large-scale flow changed? ***NO***

Genesis locations changed? ***YES***

5. Genesis Potential Index (GPI)

To determine the factors behind such genesis changes, we used a Genesis Potential Index (GPI) by Emanuel and Nolan (2004) with some modifications.
The formulation is as follows;

$$GPI' = \left|10^5\eta\right|^{\frac{3}{2}}\left(\frac{RH}{50}\right)^3\left(\frac{V_{pt}}{70}\right)^3(1+0.1V_s)^{-2}\left(\frac{-\omega+0.1}{0.1}\right), \quad (1)$$

Absolute Vorticity at 850hPa	Relative Humidity at 700hPa	Maximum Potential Intensity	Vertical Wind Shear (850-200hPa)	Vertical Wind Velocity at 500hPa

6. Reasons for future change in genesis location

6.a) GPI analysis

Above, we found that future changes in the frequency of TC occurrence arise from changes in the frequency of genesis rather than changes in large-scale flows. Here, we investigate the reason for such changes in frequency of genesis, based on the modified GPI.

The GPI can be used to determine which of the GPI elements contribute most to its future change. Here, we assign the future value to one of the five GPI elements in Eq. (1); the other elements are kept at the present-day values, as used in the PD run.
The virtual GPI value is then subtracted from the present-day GPI value. In the case of a large difference, the assigned GPI element is considered an influential factor in terms of GPI change.

It is clear that changes in the maximum potential intensity and omega terms make the dominant contribution to the increase in the GPI within the eastern North Atlantic, whereas the relative humidity and omega terms make the largest contribution to the decrease in the GPI within the western North Atlantic.

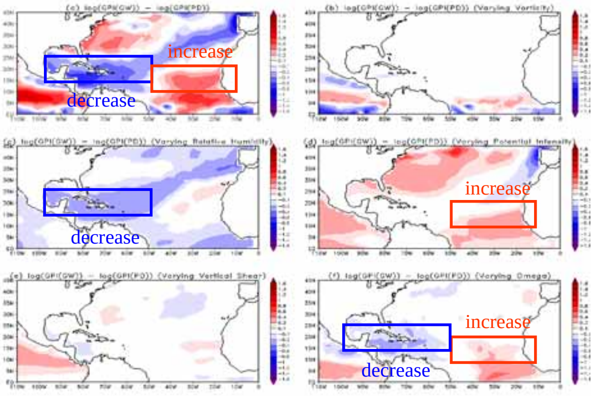


FIG. 7. Future change in the GPI during July–October (JASO) over the North Atlantic for (a) non-varying GPI (i.e., difference in GPI between the GW and PD runs), and for GPI changes obtained by varying (b) vorticity, (c) relative humidity, (d) maximum potential intensity, (e) vertical shear, and (f) omega, where in each case the other variables were those of the PD run. Gray shading indicates positive values.

6.b) Eastern North Atlantic

The GPI increase in the eastern NA is largely due to change in large-scale vertical motion and maximum potential intensity, which appear to be related to enhanced convective activity in the ITCZ. Figure 8 shows changes in July-October mean vertical velocity at 500 hPa in the NA. It is clear that upward motions are enhanced in the region offshore from West Africa. These changes are consistent with a predicted increase in precipitation (Fig. 9).
In addition, prescribed future SST (Fig.10) is relatively higher at the eastern North Atlantic. Overall, these favorable environmental conditions for convective activity promote TC genesis near the eastern Atlantic ITCZ.

6.c) Western North Atlantic

In contrast to the findings for eastern NA, increased subsidence (Fig. 8c), decreased relative humidity, and reduced precipitation (Fig. 9c) can be seen in the western NA. The increase in vertical motions in the eastern NA and eastern Pacific acts to enhance zonal circulation, which results in turn in the suppression of convective activity over the western NA. Note that precipitation is reduced in the western NA (Fig. 9c) despite an increase in SST (Fig. 10c). The distribution of the SST anomaly is important not only for local TC genesis, but also for remote TC genesis in the NA.

(a) PD run (1979-2003, JASO) (b) GW run (2075-2099, JASO) (c) GW - PD (JASO)

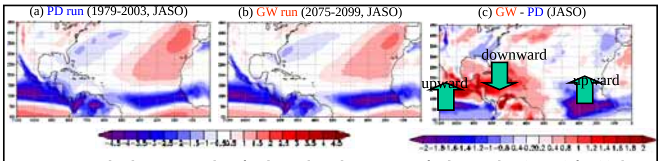


FIG. 8 Vertical velocity at 500 hPa for the peak cyclone season of July–October (JASO) for (a) the PD run, (b) the GW run, and (c) the difference between the GW and PD runs. Unit is 10^-2 Pa/s.

(a) PD run (1979-2003, JASO) (b) GW run (2075-2099, JASO) (c) GW - PD (JASO)

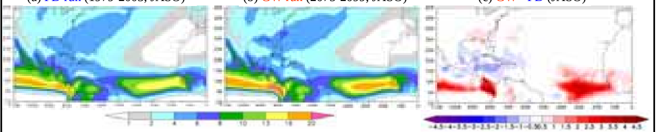


FIG. 9 Same as Fig. 8, but for precipitation [mm/day].

(a) PD run (1979-2003, JASO) (b) GW run (2075-2099, JASO) (c) GW - PD (JASO)

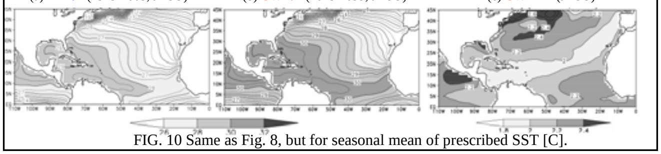


FIG. 10 Same as Fig. 8, but for seasonal mean of prescribed SST [C].

7. Conclusion

We conducted a pair of 25-year climate simulations for the present day (1979–2003, PD) and the last quarter of the 21st century (2075–2099, GW), based on the A1B scenario using a MRI/JMA 20-km-mesh high-resolution atmospheric general circulation model. The analysis focused on tropical cyclone (TC) activity, especially TC tracks, over the North Atlantic (NA).

Concerning future change, the change in frequency of TC occurrence was spatially inhomogeneous, with a marked decrease in the western NA and an increase in the eastern NA.
A comparison of large-scale flows between the PD and GW runs reveals no significant change. In contrast, we found a marked change in the locations of TC genesis between the PD and GW runs; therefore, change of genesis locations is the major reason for the predicted change in frequency of occurrence and TC tracks.

The signal of TC location shifts is well captured by Emanuel and Nolan's Genesis Potential Index (GPI) change. The main factors contributing to the predicted future increase in TC genesis in the eastern NA were changes in maximum potential intensity and vertical motion, which are related to the enhanced convective activity in the eastern Atlantic ITCZ. The decrease in TC genesis in the western NA was related mainly to reduced relative humidity and increased subsidence. Although, the prescribed sea surface temperature (SST) showed increase in the western NA, convective activities were decreased by the unfavorable environmental factors. It is inferred that the increase in convective activity in the eastern NA or in the eastern Pacific was sufficiently large to result in enhanced Hadley circulation in the NA. In turn, this led to a subsidence anomaly over the western NA, which suppressed convective activity and resulted in a decrease in TC genesis over this region.