The Dependence of Future Projected Changes in Tropical Cyclones to the Tropical Cyclone Detection and Tracking Criteria

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Abstract

The activities of tropical cyclones (TCs) has been simulated in CMIP5 models in historical, Rcp4.5 and Rcp8.5 scenarios before. However, such the results are tested by global climate models and the resolution of these models are quite low so that the wind speed and the intensity simulated are also under-estimated. The decision to the detection scheme used in the model are thus critical to simulate the typhoon's activities. Therefore, we are curious about the results if any threshold is "tuned." Because over 30% $\sim$ 40% of typhoons originates from northwestern Pacific ocean, which is representative enough, we will focus our examinations on cyclones' activities in this region in this study. We first tune each variable separately to find how NTC changes, then we adjust our criteria in order to fit the observations. Finally, we put the detection scheme we have found at last into Rcp8.5 scenario for each model to see the future TC activities. By such the systematic way, we can make sure that the thresholds would be more objective and convincing and so do the results. By the test, we found there isn't significant increase – even slight decrease – in the NTC tested by 9 detection schemes in Rcp8.5 scenario for MRI-CGCM3 model, which is different from Camargo's prediction of a great increase in NTC. In MPI-ESM-LR, the NTC decreases in the future in most cases, also different from Camargo's study. GFDL-CM3 models shows an significant decrease in Rcp85 compared with historical scenario, which is consistent with Camargo's results. However, its characteristics of seasonal cycle is abnormal. This problem may be because the threshold is not good or simply because the simulation bias of GFDL CM3 model. Because we are able to simulate different results of TC's activities with different model, the selection of detection become an important issue. On the other hands, the resolution of the model can also be critical for us to choose the detection scheme for these thresholds are resolution-dependent so that we cannot simply apply the same criteria to a different model. Therefore, we can see the importance of the selection of detection scheme, and we have to determine more carefully before we do further studies about TC's future activities.

Keywords: tropical cyclones, CMIP5 models, detection scheme, resolution.

1 Introduction

In IPCC AR5 (Intergovernmental Panel on Climate Change, Fifth Assessment Report), it predicted the future activities of tropical cyclones (TCs) in Western North Pacific (WNP) region (Fig.1). It is agreed that the total number of TCs would decrease but the number of severe storms would increase. However, this is constructed based on the global climate models. The resolution of these models are usually low so that the intensity and the wind speed simulated of the typhoons are also under-estimated. In order to fit the observations, the detection criteria should not be too strict anymore. Therefore, the results will also depend on the detection schemes we choose. It may greatly influence the future simulations.

The phase 5 of the Coupled Model Intercomparison Project (CMIP5) is an extension of the analysis of AMIP to coupled models. CMIP models are of the atmosphere and ocean that includes interactive sea ice and simulate the physical climate system (McGuffie 2013). Camargo (2013) has used TC detection and tracking algorithm improved by Camargo and Zebiak (developed by Vitart (1997, 2003) at first) to test the TC-like storms in CMIP5 models. He examined the ability of the models to simulate TC-like storms and the statics of TC-like storms generated by models and analyze the changes in large-scale variables (Camargo 2013). His test results are shown in Fig. 2. But now, we want to know how does the detection scheme effect the results. Therefore, here are what we are going to study: can we tune the various thresholds used in the schemes to obtain better model TC statistics? What are the influences from individual criteria and thresholds? Can the same scheme applied to different model simulations? We are curious about the result if tested by another "reasonable" criteria.

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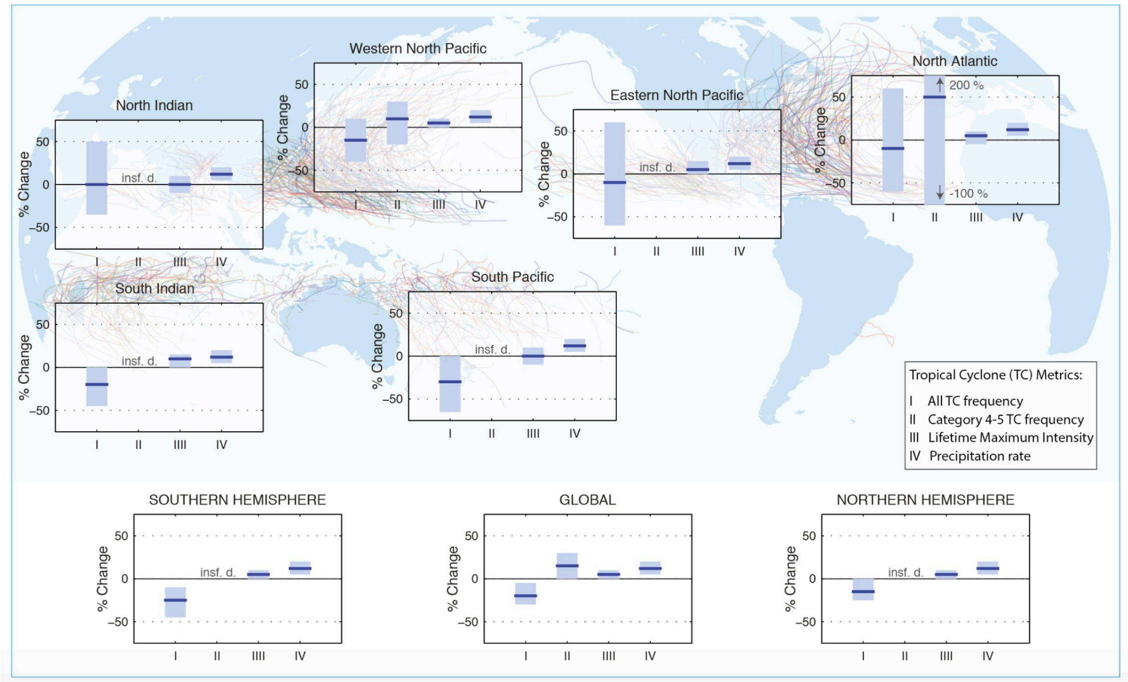

Figure 1: IPCC AR5 (2013) evaluations of TCs' future activities. I represents all TC frequency, II stands for category 4-5 TC frequency, III is the lifetime maximum intensity, and IV is the precipitation rate. In most study, we find that the all TC frequency would decrease in the future, but the sever storms would increase.

Therefore, in this article we will focus on the influence to the future changes in TC activities if different "test matrices" of detection are applied. We will test the TC activities with different thresholds in 3 models, MRI-CGCM3 (M13), MPI-ESM-LR (M12), GFDL CM3 (M5). There are two reasons to choose these models, according to Camargo (2013): (1) They simulate more storms than others; (2) NTC increases in Rcp85 scenario in two of them and another decreases. We will explore the NTC change for tuning single threshold to see the influences. Then, we want to apply it to Rcp8.5 scenario to find the future change in NTC. We hope that we can find the characteristics and importance on the threshold we use and therefore improve the TC detection and tracking technique.

2 Models, Data, and Methods

2.1 CMIP5 Models

We choose 6-hourly MRI-CGCM3, MPI-ESM-LR, GFDL CM3 models for this studies. However, it remains a restriction, that is, the lack of lots of variables. The Vitart algorithm (Knutson 2007) requires environmental variables such as vorticity at 850 hPa, temperature, geopotential, wind speeds on various pressure levels, and sea level pressure. But the CMIP models doesn't provide geopotential data and wind speed at sea level, we are going to skip the thickness criteria in the algorithm (in Sec. 2.2) and replace surface wind by 850-hPa wind.

Furthermore, the data is accessible for specific scenarios, including a historical simulation and two future warming scenarios. The historical simulation is forced with observed atmospheric conditions (including natural and anthropogenic parts) (Camargo 2013). The historical simulations are available from 1950 to 2005, and future simulations are from 2006 to 2100. The future simulations we chose is called "representative concentration pathways (RCPs)." In our study, we chose only historical run and Rcp8.5 from 1981 to 1990 and 2081 to 2090, relatively. In table 1 we list the models we used in this study.

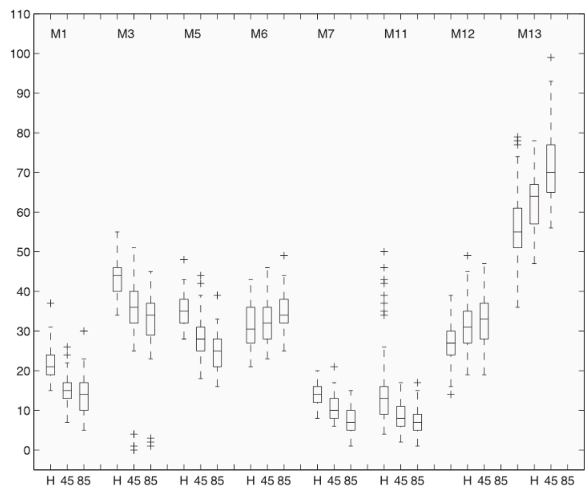

Figure 2: Global test results in CMIP5 models. Camargo (2013) provided examinations on historical and two future warming scenarios. We can find that some models show significant increase in future simulations, some show decrease and the other's changes are not so significant. It may be related to the determination of detection schemes.

Table 1: CMIP5 models we used to analysis in our study. (Taylor et al. 2012, Camargo 2013)

Acronym	Model name	Number [1]	Modeling center	Resolution
GFDL CM3	Geophysical Fluid Dynamics Laboratory Climate Model, version 3	M5	NOAA/Geophysical Fluid Dynamics Laboratory	$2.5° \times 2.0°$
MPI-ESM-LR	Max Planck Institute Earth System Model, low resolution	M12	Max Planck Institute for Meteorology	$1.9° \times 1.9°$
MRI-CGCM3	Meteorological Research Institute Coupled Atmospheric-Ocean General Circulation Model, version 3	M13	Meteorological Research Institute	$1.1° \times 1.2°$

2.2 Detection and Tracking Algorithm

To objectively determine the TCs by dynamic and thermodynamic theories, there has been lots of works and applications (Bengtsson 1982; Vitart 1997, 2003; McDonald 2005). We would apply Vitart's (1997, 2003) detection and tracking algorithm to our study.

There are two parts of the algorithm. The first one is detection part. The program loops over the grids and looks for storms (the length of half side of the checking grids is set to 500 km). First, the program checks for vorticity maximum and that should exceed a specified threshold value. Next, it locates the local sea level pressure minimum, which would be defined as the center of the storm. The center must exist within a specified radius (also designated by user) of the vorticity maximum. Also, the pressure gradient around the storm must satisfy the specified condition. Thirdly, the program checks for presence of a warm core. The closest local maximum in temperature averaged between 200 hPa and 500 hPa is defined as the 1st center of the warm core. The temperature gradient around the storm also have to exceed the threshold value. Finally, it checks for 2nd center of the warm core, which is the the closest local maximum in thickness averaged between 200 hPa and 1000hPa. However, we don't have geopotential data in 6-hourly CMIP5 models, so we skip this step. If all the criterion are satisfied, we have a tropical storm (Fig. 2).

The second part, tracking part, includes two sections. First, for a given storm, the program examines whether there are storms that appear on the following timestep (6 hours) at a distance of less than 400 km. Secondarily, the storm must satisfy a maximum wind velocity and warm core at the same time for several times during total life time. All the threshold values are specified by user.

According to Camargo's (2013) test results of the CMIP5 models, he applied another way to detect and track the cyclones. The improved method, Camargo-Zebiak algorithm (2002), is based on Vitart's studies. This program looks for typhoons using a 7×7 box. It examines if 850-hPa relative vorticity exceeds the vorticity threshold at first. Secondarily, it checks if the maximum surface wind speed in a centered box exceeds the wind speed threshold. Thirdly, it find the minimum of the sea level pressure in a centered 7×7 box. Finally, the program checks if the temperature anomaly averaged over the box and three pressure levels (300, 500, and 700 hPa) exceeds the temperature anomaly threshold. However, for the accessibility of the program, we still use Vitart's algorithm instead of the Camargo-Zebiak algorithm.

2.3 Determining Detection Schemes Objectively

The issue aroused here is because Camargo (2013) used only one detection scheme to test for each model (Table 2). We are curious about the difference of the results due to the adjustments to each threshold value. Therefore, we try to be more systematic to test the storms with different detection schemes. By those adjustments, we look forward to acquiring a better scheme which best fits the observation – 27 cyclones per year and 14 cyclones in summer, July, August and September, in northwestern Pacific region.

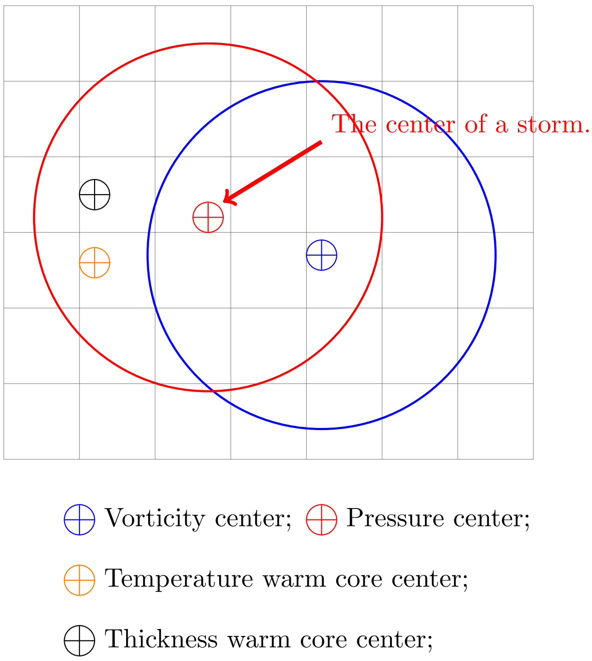

Figure 3: The locations of vorticity, pressure, temperature warm core, and thickness warm core center for a detected storms. The center of the storms is regarded as the pressure center. We don't find thickness center for the restriction of CMIP5 6-hour data.

Table 2: Thresholds used for vorticity (10^{-5} s^{-1}), 850-hPa wind speed (m s^{-1}), and vertical integrated temperature (i.e. the sum of 3 temperature level, 850, 500, and 300 hPa) anomaly (K) for defining TC-like storms in Camargo's (2013) study in the western North Pacific. The relaxed vorticity (10^{-5} s^{-1}) listed in the last column is for global threshold.

Model	Thresholds			
	Vorticity	Wind Speed	Temperature	Relaxed Vorticity
GFDL CM3 (M5)	3.4	13.4	2.0	2.0
MPI-ESM-LR (M12)	3.6	12.8	1.9	3.5
MRI-CGCM3 (M13)	4.7	13.9	2.0	3.5

According to Vitart's algorithm, there are several criterion like vorticity, sea level pressure, temperature warm core, and wind speed, etc, used to detect and track typhoons. Given an appropriate default detection scheme (based on model's resolution), and then we takes turns adjusting each criteria with different threshold values and calculate its yearly average and JAS average of NTCs within 1981 and 1990 (historical scenario). Then we can pick up a suitable scheme to fit the observation. Simultaneously, we test in Rcp8.5 scenario with all the test matrices we used in historical run and compare the results. It would help us to find the relationship between our adjustments to the detection criterion and the change trends of the NTCs. We will show the whole process in the following section.

3 Results

We will test in the historical scenario to find the ideal detection scheme to fit the observation of NTC for each model, and then we will check the future trend of the TC activities also.

3.1 Historical Scenario

3.1.1 MRI-CGCM3

Chen's group has tested some spectral models in prior studies, so we applied their detection scheme to our studies. Noticed that the resolution of this model is $1.1° \times 1.2°$, we use detection scheme used in T106 model for the "default" detection scheme in this model. That is, the vorticity threshold at 850 hPa is set to 3.5×10^{-5} s^{-1} in a radius of 2°, the minimum sea level pressure must increase by 2 hPa in all directions from storm center to 3° radius, and the temperature must decrease by at least 0.2 K in all directions from the temperature warm core center to 3° radius. The result is shown in Fig. 3.

Now, we adjust vorticity threshold in historical scenario at first. We put 3.5×10^{-6}, 1.8×10^{-4}, and 3.5×10^{-4} s^{-1} into vorticity threshold, with other criterion stay unchanged. Then we returned the vorticity threshold to the initial value, and adjust the temperature warm core threshold to 0.1, 0.5 K (of course, within the range of 3°). Next, return the temperature criteria to initial value and adjust pressure gradient threshold to 1 and 3 hPa, with others unchanged. Finally, we test maximum wind speed from 5 to 25 interval 5 m s^{-1} used in the trajectory threshold. All the testing results are shown in Fig. 3 and Table 3.

From Fig 3 and Table 3, we can find some characteristics of this model. The result using default detection scheme shows that the NTC mostly ranges from 10 to 13, and yearly average within 10 years is about 12, which is not enough in order to fit the observations. Furthermore, the default threshold values of vorticity, temperature warm core are close to the lowest critical values so that the results do not change even if we lower the threshold. The only way to raise the NTC is to lower the pressure gradient threshold. However, there would be a problem in seasonal cycle – in October, the NTC is under-estimated. Finally, we use 3.5×10^{-5} s^{-1} for critical vorticity threshold (in 2° radius), 0.2 K of temperature warn core threshold and 1.5 hPa of pressure gradient threshold within a radius of 3° for our final detection scheme.

Next, we take a look at the passage frequency of TCs simulated in Fig 6(b). Fig. 6(a) is the observation data from IBTrACS (International Best Track Activity for Climate Stewardship) data Basically, the distribution of the TC's activity is acceptable, but the frequency is under-estimated. In short, the simulation ability of this model is good for considering the TC statistics, seasonal cycle, and the passage frequency.

3.1.2 MPI-ESM-LR

The resolution of this model is $1.9° \times 1.9°$, much lower than that in MRI-CGCM3. If we apply the same default detection scheme used in MRI-CGCM3, we will get very few cyclones, that is, the yearly average during $1981 \sim 1990$ is 1.7. Therefore, we have to give a different default detection scheme for this model to detect storms. These criterion are listed below:

Table 3: The test results of MRI-CGCM3 model in historical scenario. We adjust the threshold values for each criterion – vorticity, temperature warm core, pressure gradient, and wind speed.

Scenario	Average	Vorticity criteria (10^{-5} s^{-1})			Temperature warm core criteria (K)			Pressure gradient criteria (hPa)			Wind speed cirteria (m/s)			Final Scheme
		3.5, 0.35	18	35	0.1	0.2	0.5	1	2	3	5, 10 15	20	25	
Historical	JAS	12.2	8.5	1.2	12.5	12.2	7.9	15.1	12.2	7.7	12.2	10.9	7.1	14.4
	Yearly	22.7	17.5	2.5	23.8	22.7	14.9	30.2	22.7	16	22.7	20.5	12.1	26.8

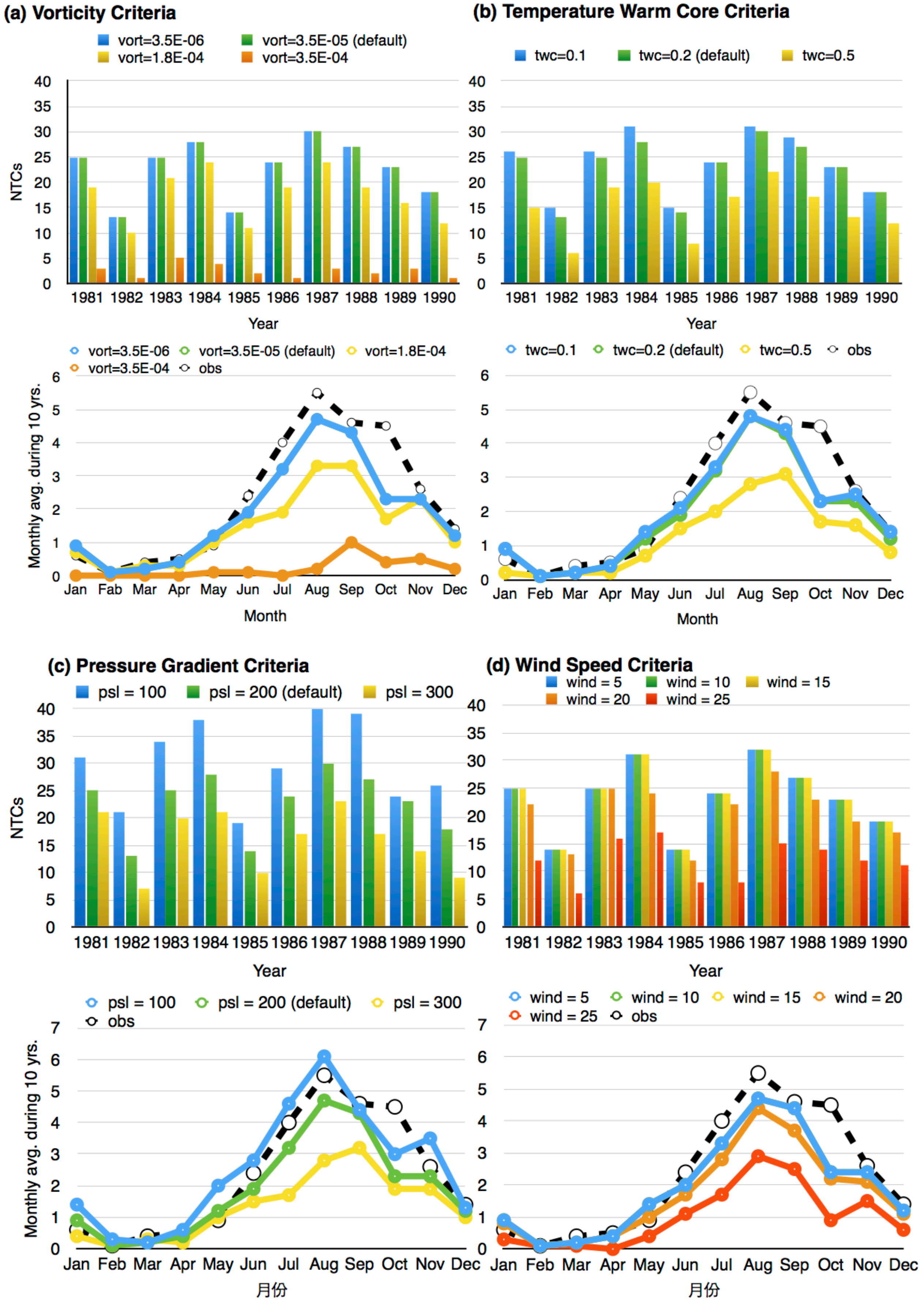

Figure 4: The test results in both historical scenario of MRI-CGCM3 model. NTCs in 10 years and monthly average for 10 years diagram are shown. We adjust different threshold values for each criteria, such as (a) vorticity threshold criteria, (b) temperature warm core criteria, (c) pressure gradient criteria, and (d) wind speed criteria.

Table 4: The test results of MPI-ESM-LR model in historical scenario. We adjust the threshold values for each criterion – vorticity, temperature warm core, pressure gradient, and wind speed.

Scenario	Average	Vorticity criteria (10^{-5} s^{-1})			Temperature warm core criteria (K)			Pressure gradient criteria (Pa)			Wind speed cirteria (m/s)			Final Scheme
		0.34	3.4	7	2.5 $\times 10^{-8}$	2.5 $\times 10^{-2}$	2.5	0.25	2.5 25	250	10	15	20	
Historical	JAS	11.3	10.9	8.5	10.9	10.4	7.8	10.9	10.6	5.5	18.3	12.8	8.3	10.9
	Yearly	27.5	26.7	21.1	26.7	25.4	19	26.6	25.3	12.7	45.7	33.3	19.3	27.1

1. Local relative vorticity maximum at 850hPa should exceed 3.4×10^{-5} s^{-1}.
2. The center of the storm must exist within a 3° radius of the vorticity maximum.
3. We don't set a default threshold value for pressure gradient criteria in this model. Actually, in order to run the program smoothly, we still set a very small threshold value as 2.5×10^{-8} Pa.
4. We don't set a default threshold value for temperature warm core criteria. A very small value 2.5×10^{-8} K is specified.

Although the NTC in this model tested by default detection scheme well fits the observation, but we still want to find suitable threshold values for pressure gradient and temperature warm core criterion instead of specifying a very small value. Therefore, we still do our tests. As well as the way we have used in MRI-CGCM3, we first adjust the vorticity threshold values to 3.4×10^{-6}, 3.4×10^{-5}, and 7.0×10^{-5} s^{-1} with other criteria staying unchanged. Then, we returned vorticity threshold to default value and adjust temperature warm core criteria to 0.025, 2.5 K, with the radius of 3°. The NTC doesn?t change until we set the temperature gradient to 0.025 K. Next, we adjust pressure gradient threshold to 0.25, 2.5, 25, 250 Pa within the radius of 3° after returning the temperature warm core threshold to default values. NTC changes until we set threshold value to 2.5 Pa. Finally, we test maximum wind speed from 5 to 25 interval 5 m/s used in the trajectory threshold. We find that it's very sensitive. These results are shown in Fig. 4 and Table 4. So the ideal detection scheme to fit the observation of NTC is keep the vorticity to the default value, 3.4×10^{-5} s^{-1}, and adjust the pressure gradient criteria and temperature criteria to the lowest critical value, 0.25 Pa and 0.25 K, and slightly lower the wind speed to 12 m/s. The yearly average of NTC is thus 27.1.

After the test, we find some characteristics of the model. NTCs in winter are usually over-estimated in the winter but under-estimated in the summer compared with the observations. Finally, we take a look at the passage frequency (Fig. 6(c)), we can find that the frequency is well fit with IBTrACS data, and the distribution is also acceptable. In general, though there is a defect in seasonal cycle, the model is still acceptable.

3.1.3 GFDL CM3

The method we used to test the model is very similar to the others, so we will not describe it repeatedly. The detection scheme and all the results will be shown in Fig. 5 and Table. 5. We use the same default detection scheme as MPI-ESM-LR model. However, the default scheme for this model is not strict at all. It generates too many TCs. Therefore, we use the same method mentioned before to find a suitable detection scheme.

By these test results, we can observe some characteristics of the model. The cyclones detected in winter is much more than in summer. However, if we check its generic point, none of them is extratropical cyclone. It is great probably because of the behavior that the model simulates. In these tests, we found that the problem in seasonal cycle is difficult to be solved, therefore we choose a final detection whose JAS average would underestimated but yearly NTC fits the observations. Finally, we use 3.5×10^{-5} s^{-1} for critical vorticity threshold (in $3°\times3°$ box), 0.15 K of temperature warn core threshold and 5 Pa of pressure gradient threshold within a radius of 4° for our final detection scheme. At last, we take a look at the passage frequency (Fig 6(d)), we found that the distribution of TC's tracks are concentrated between 0° $\sim$ 30° N, and the frequency is underestimated.

In summary, we have tried to define a TC-like storms in each model, and we did find a ideal detection and trajectory scheme for each model that fits the observation of yearly NTCs. And from so many simulations by several test matrices, we found that the results may be different if adjusting our ideal threshold values. However, there are great uncertainties between different models such as the detection scheme we used, the simulating bias of the model, etc.

Table 5: The test results of GFDL CM3 model in historical scenario. We adjust the threshold values for each criterion – vorticity, temperature warm core, pressure gradient, and wind speed.

Scenario	Average	Vorticity criteria (10^{-5} s^{-1})			Temperature warm core criteria (K)			Pressure gradient criteria (Pa)			Wind speed cirteria (m/s)			Final Scheme
		0.34	3.4	17	5 $\times 10^{-8}$	0.1	0.2	2	20	200	10	15	20	
Historical	JAS	16.9	14.6	0.1	14.6	10.9	6.7	14.2	12.5	1.5	14.7	8.8	1.9	8.1
	Yearly	53.1	46.1	0.3	46.5	34.3	21.7	45.3	32.8	5.7	46.7	31.5	10	26.6

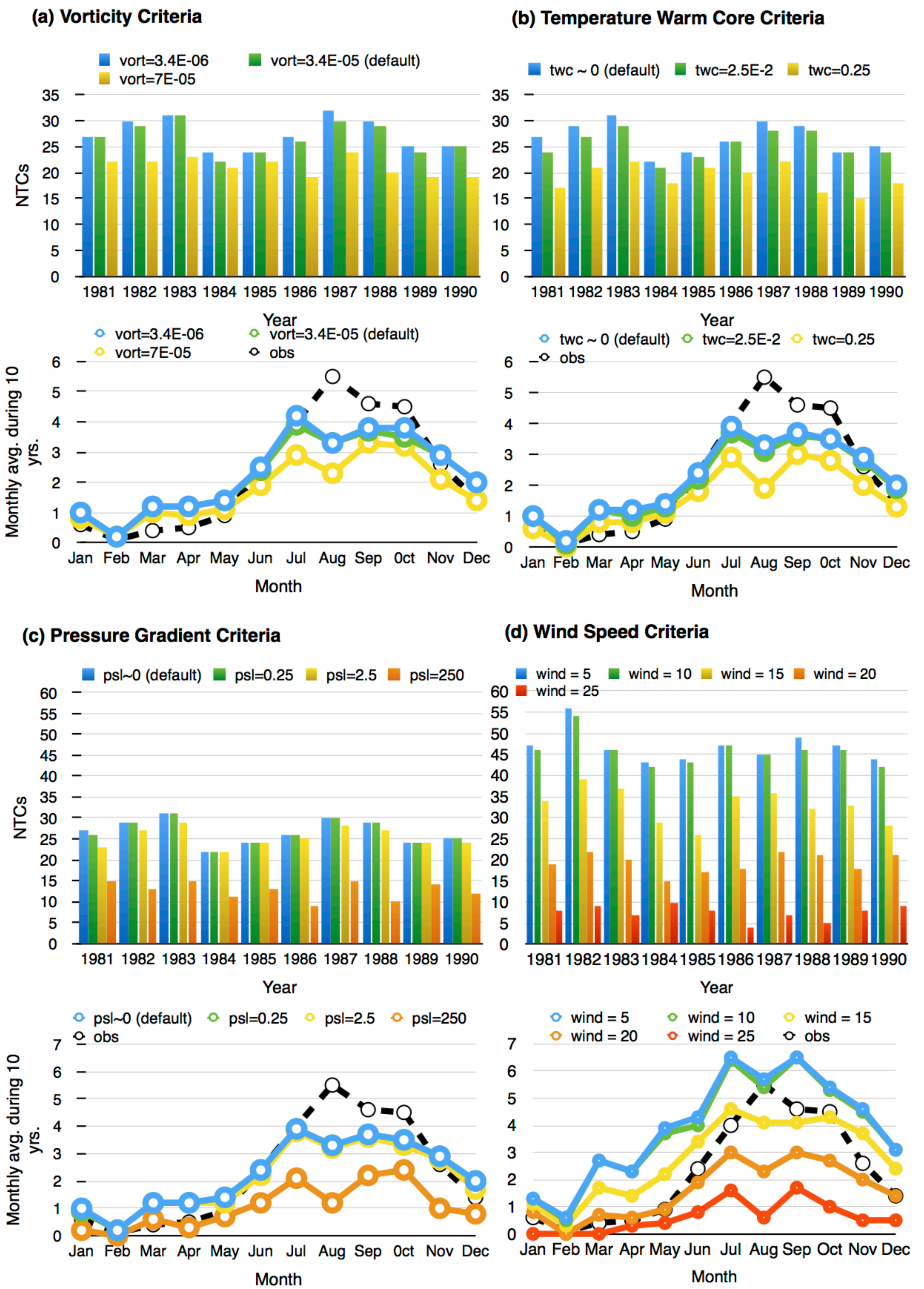

Figure 5: The test results in both historical scenario of MPI-ESM-LR model. NTCs in 10 years and monthly average for 10 years diagram are shown. We adjust different threshold values for each criteria, such as (a) vorticity threshold criteria, (b) temperature warm core criteria, (c) pressure gradient criteria, and (d) wind speed criteria.

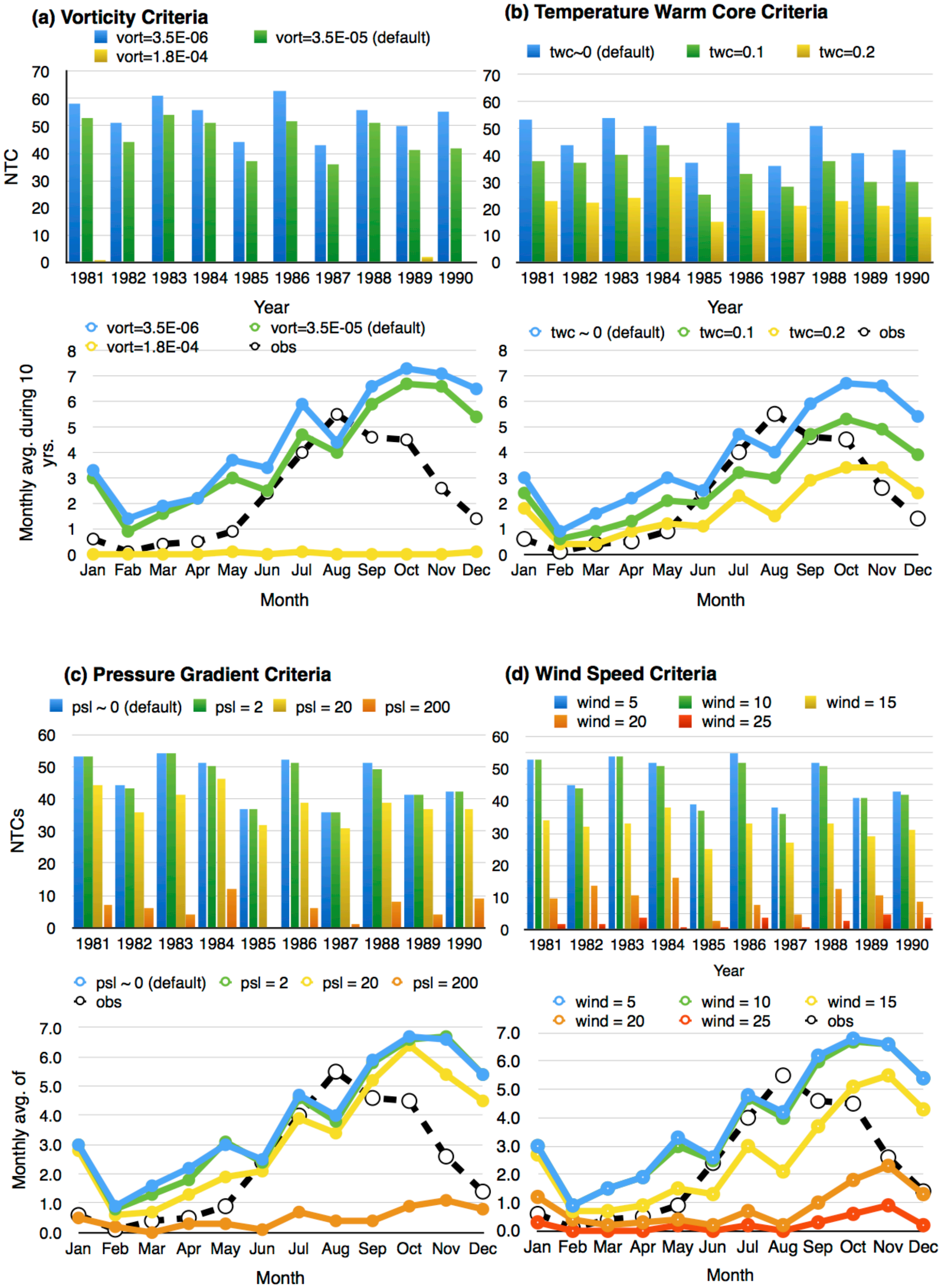

Figure 6: The test results in both historical scenario of GFDL CM3 model. NTCs in 10 years and monthly average for 10 years diagram are shown. We adjust different threshold values for each criteria, such as (a) vorticity threshold criteria, (b) temperature warm core criteria, (c) pressure gradient criteria, and (d) wind speed criteria.

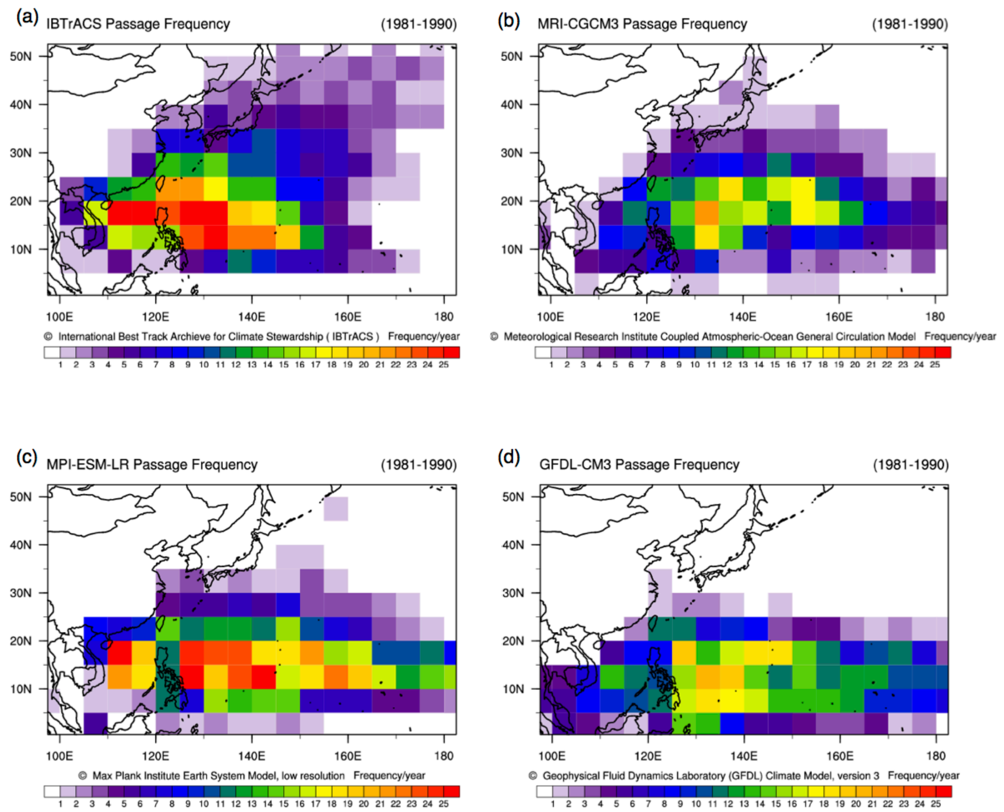

Figure 7: The passage frequency of the 3 models in historical scenario, 1981 to 1990. (a) Observation data from IBTrACS (International Best Track Activity Climate Stewardship); (b) MRI-CGCM3; (c) MPI-ESM-LR; (d) GFDL CM3.

3.2 Rcp8.5 Scenario

After the historical run, we also examine the results in Rcp8.5 scenario with all the test matrices used in historical scenario. Finally, we take a look at the future change signals in the three model. The results are shown in Fig. 8. We applied all the test matrices to Rcp8.5 scenario. In MRI-CGCM3, we found that the changes in future are not obvious, even if some increase and the other decrease. Neither do MPI-ESM-LR. With different criteria is used, the future change is not apparent. But in GFDL-CM3 model, the trend is clear. We can easily observe that the NTC in future decrease in all test matrices. In short, the adjustment of threshold values does have great influence on the climate change signals.

Now compare the future change in three models, as shown in Fig. 9. We find that though the three model simulates well in number of TCs, but it doesn't necessarily means that the simulating behavior is also good. In MRI-CGCM3 model, we find that the seasonal cycle model is good except the defect in October, and its change rate is -0.033, not significant. But it shows a slight decrease instead of a great increase like Camargo's studies. In MPI-ESM-LR, though there is a defect in seasonal cycle, but it's still acceptable. It predicts the NTC will decrease, this is also different from Camargo's study. Finally, there is big problem in seasonal cycle in GFDL CM3 model. Though it predicts a change similar to previous study, we still doubt that the climate change signal exists great uncertainties. Although we compared our results with Camargo's, we should notice that Camargo used 55-year data for both historical and Rcp8.5 scenario.

Table 6: The final detection and trajectory schemes of the three models and their test results. (Change rate is defined as the difference in yearly NTC in Rcp8.5 and historical scenario over the yearly NTC in historical scenario.)

			MRI-CGCM3 (M13)	MPI-ESM-LR (M12)	GFDL CM3 (M5)
Final detection criterion	Vorticity (10^{-5} s^{-1})		3.5	3.4	3.5
	Radius range		2°	3°	3°
	Temperature warm core (K)		0.2	0.25	0.15
	Radius range		3°	5°	5°
	Pressure gradient (Pa)		100	0.25	5
	Radius range		3°	5°	5°
	Wind speed (m/s)		15	12	10
Test results	Historical	JAS avg.	14.4	10.2	8.1
		Yearly avg.	26.8	27.1	26.6
	Rcp8.5	JAS avg.	16.3	8.6	8.6
		Yearly avg.	25.9	20.1	18.6
	Change rate		−0.0336	−0.258	−0.301

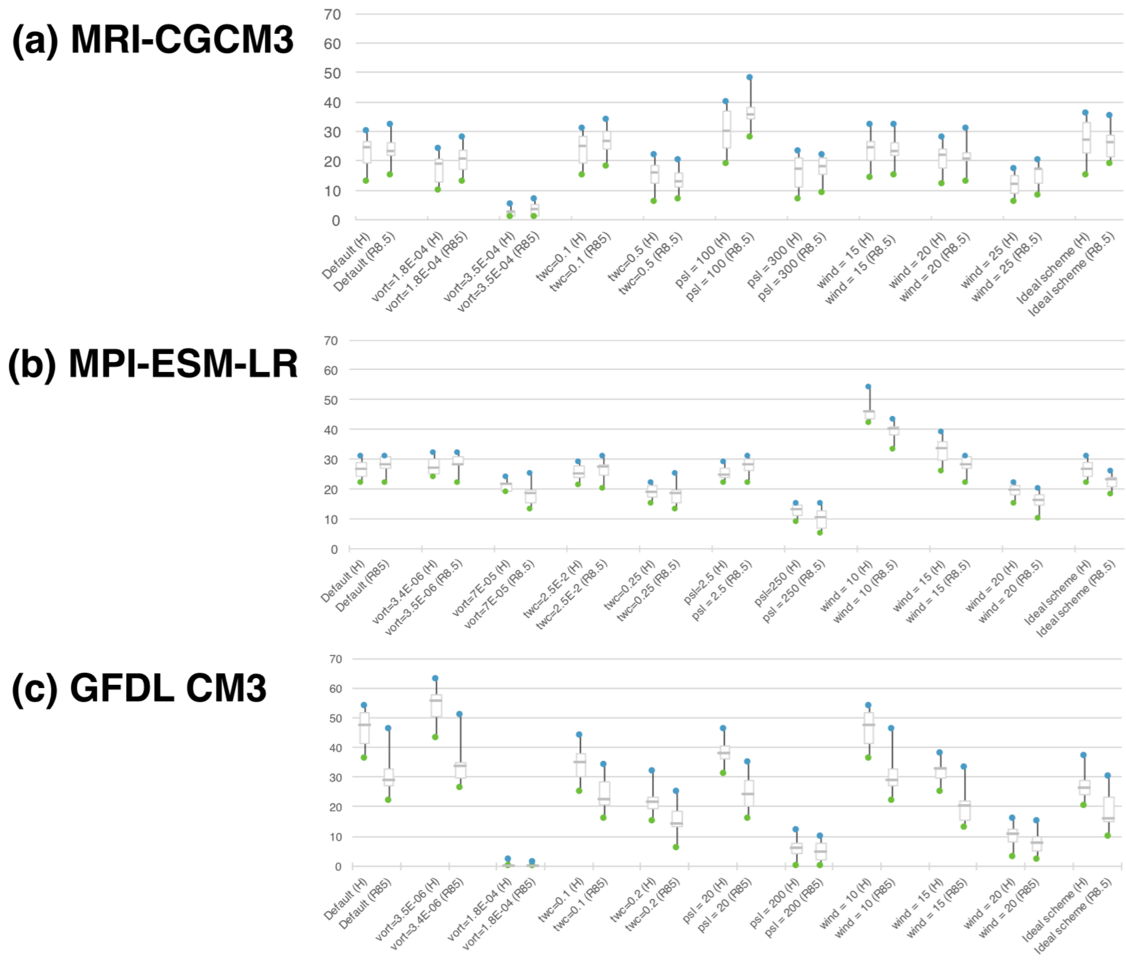

Figure 8: Climate change signals in every test matrices for each model. (a) is MRI-CGCM3, and the changes are not significant. (b) is MPI-ESM-LR. Though there are increase signals in some detection scheme, but there are also decrease signals in the others. But in general, the change is more obvious than MRI-CGCM3. (c) is GFDL CM3 model. NTCs have great decrease in every matrices test.

Finally, we examine the change in spatial distribution of passage frequency. Red blocks means that the region TC activity would be intensified and that would be weaken in blue blocks. In general, the TC activity does weaken in most region, this is consistent with our studies. Compared with IPCC AR5, our results is also consistent with their conclusion – the yearly NTC will decrease in the future.

4 Discussion

The study didn't aim at giving a certain answer about how TC activities would change in the future but give some informations about the influence to the results due to adjusting detection and trajectory criteria. The results simulated by the three model are not completely the same. It may because of the detection schemes we use or simply the simulating bias of the model. For example, the results in historical scenario well fits the observations in MRI-CGCM3 model, but the climate change signal are different from Camargo's results. At this time, this may be because of the detection scheme we use is different from his so that the result also changes. Also, in MPI-ESM-LR model, the results also change with the adjustments of the threshold values. Therefore, the climate change signal is related to the detection scheme we choose. But in GFDL CM3 model, we can find that though the climate change signal of our result is consistent with Camargo's, but there is bias existing in the seasonal cycle. Therefore, we think that there are great uncertainties in the model. Therefore, it may not so appropriate to simulate the TC activities with this model. In addition to these reasons, it may also because of the algorithm are also different from Camargo's, and the time range of the data we use is only 10 years in both historical model and Rcp8.5 model. These factors may also effect the simulations. However, how each factor effects the results should be discussed in the future.

Another issue is that is detection scheme resolution dependent? We tried to apply the default detection scheme used in MRI-CGCM3 in both MPI-ESM-LR and GFDL CM3 and found that very few cyclones detected in MPI-ESM-LR model (1.7 for yearly average) and no typhoon detected in GFDL CM3 model. This means that the lower the resolution is the model, the easing the criterion should be. This may be consider if there is future work for simulations.

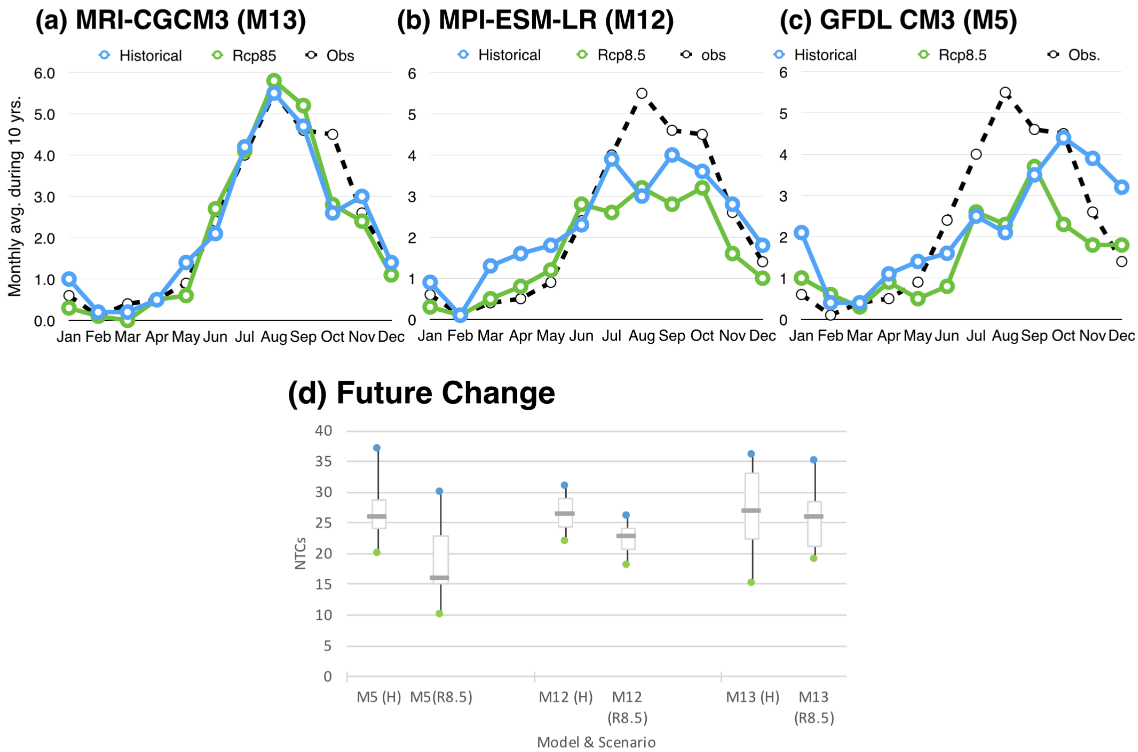

Figure 9: The comparison of the future TC activities between the three models. (a), (b), (c) shows the seasonal cycle in historical scenario and Rcp8.5 scenario for each model and the observation data. (d) is the box diagram of NTCs in 1981 ∼ 1990 and 2081 ∼ 2090 of three models.

The detection and tracking technique is aimed at climate predictions. Is the skills we have enough to forecast TC's activities next month, next year, or even next 10 years? Maybe there is still have rooms for improvement. Because there are too many possible detection and tracking schemes, whose test results of NTC may fit the observations but other characteristics may not necessarily be reasonable (e.g. GFDL CM3), we still have to study how to select the best detection scheme in more detailed and more systematical methods. Besides, resolution also plays a critical role in the selection of detection criterion. Definitely, we need easier threshold values for models in lower resolution. But how do we quantize? Could we decide the detection scheme directly by some specific way? These questions shows how important we study the dependence of TC activities to the detection and trajectory criteria. On the other hands, comprehensive criterion may help us to estimate TC's activities more precisely. For example, we mainly define a spinning object with low pressure center as our "tropical cyclones", but maybe such the system didn't form clouds, which should not be regarded as a TC. How do we know if this is a rotor cloud or not? For this consideration, we may use water vapor amount as our additional detection criteria. Another one is that we use wind field to compute the vorticity, but we don't know whether the system is spinning or not. In short, we still have to develop more and more criteria to fit the structure of TCs so that it can be applied to future climate forecasting.

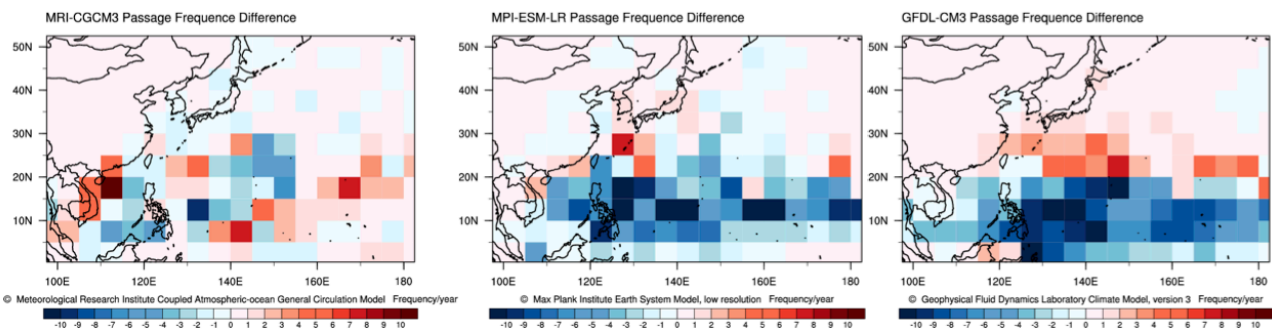

Figure 10: The difference of passage frequency in historical scenario (1981 ∼ 1990) and rcp8.5 scenario (2081 ∼ 2090). In most regions, we can find that the TC frequency decreases.

5 Summary

In this study, we try to develop a systematic way to detect and track the cyclones. We examined the characteristics of test results with different TC detection and criterion separately. We are able to find an ideal detection scheme for each model to fit the observation in yearly average of NTCs. However, the simulating ability is different from one another. In MRI-CGCM3, the seasonal cycle well fits the observation except a defect in October. MPI-ESM-LR is also acceptable exclusive of the over-estimation in winter and the under-estimation in summer. There is a serious problem in GFDL CM3 that the NTC in winter is much more than that in summer. We think that it may because of the bias of the model. In Rcp8.5 scenario, we test the climate change signal with all the test matrices and find that the results are not totally consistent with Camargo's study. In MRI-CGCM3, the change is not significant. There are increase signals when tested by some of the detection scheme but there also decrease signals if other schemes are used. Therefore, we can say that the results are influenced by the conditions we defined. Though the change in NTC in Rcp8.5 scenario for GFDL CM3 model is consistent with Camargo's studies, but there might be great uncertainties in the models. That is, that the simulated climate change may also depend on model?s bias. Therefore, we have to select the detection scheme more carefully to evaluate future climate change in advance.

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