Tropical Storms in Atmospheric Global Circulation Models

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1. Introduction

The possibility of using climate dynamical models to forecast seasonal frequency of tropical cyclones has been explored by various authors [1, 2]. In this paper, the variability of tropical storms frequency and genesis position is studied in simulations from three low-resolution atmospheric global circulation models. The AGCMs used are ECHAM3, ECHAM4.5, and NSIPP. The first two models were developed at the Max-Planck Institute for Meteorology, Hamburg, Germany [3, 4] and the third one was developed at NASA Goddard at Maryland (NASA Seasonal to Interannual Prediction Project) [5]. The model integrations used in this study were performed using observed sea surface temperature with the number of ensemble members, period and output frequency given in Table 1.

To obtain accurate frequency values in these models, objective algorithms for detection and tracking of individual model tropical cyclones were developed, based substantially on prior studies [2, 6]. Making the tropical storms detection algorithm basin and model dependent leads to better simulation of the seasonal cycle and interannual variability. More realistic tracks are provided by new tracking algorithm. Here we describe these algorithms and show the variability of these AGCMs when they are applied. The three models are found to have better tropical storm simulation skill in the ocean basins where ENSO has an important role.

2. Detection and Tracking Algorithms

Previous studies [2, 6] used detection algorithms based on fixed meteorological criteria. Since dynamic and thermodynamic variables of different basins and models have quite different biases, using fixed criteria leads to the failure to detect tropical cyclones in many cases that simple visual inspection suggests should be identified. Tropical storms in our study are therefore identified using criteria that are objectively defined for each basin and model according to the model variable statistics. A detailed description of the detection algorithm can be found in Ref. [7].

After the model tropical cyclones are detected, they are connected from one time step to the next, and counted as tropical storms if they last at least 1.5 days. Previously cyclone tracks were obtained by simply connecting the points on which the storm was detected. The new tracking algorithm tracks model cyclones backward and forward in time using lower threshold values than in the detection algorithm and calculates their position using the low-level vorticity centroid, tracking storm formation and disappearance. Details of the tracking algorithm can be found in Ref. [7]. This tracking procedure produces longer and more realistic tracks which could be used in landfall statistics studies. Figure 1 shows the old and new tracks for a ECHAM3 model cyclone.

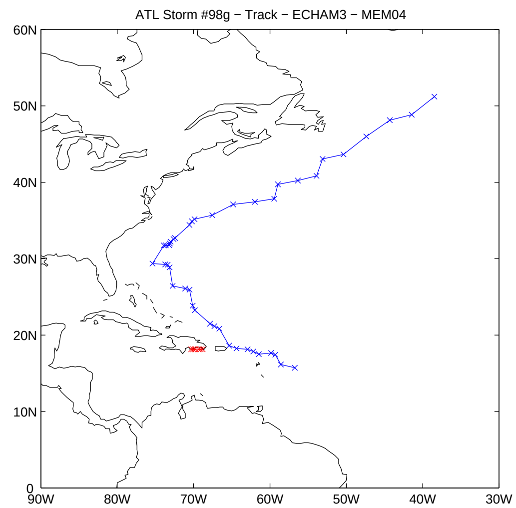

Figure 1: Comparison of the original (red) and new (blue) track of a tropical cyclone in the ECHAM3 model in the Atlantic.

3. Annual Cycle and Interannual Variation

The annual cycle of tropical storm frequency simulated by the AGCMs was compared to the observed number of named storms per month in each ocean basin. In most cases, the peak of the tropical cyclone activity is correctly simulated by the AGCMs. However, the models do not create enough tropical storms in the most active periods of the year.

Figure 2 shows the annual cycle of the three models in the Western North Pacific. When ECHAM4.5 daily averaged output was used instead of a daily snapshots, fewer storms were detected in the peak of the season, probably due the smoothing caused by averaging. In the North Indian Ocean (not shown) the three models do not reproduce two peaks in May and October but have an annual cycle similar to the Western North Pacific. The number of storms simulated in the models has a large deficit in the Atlantic and the Eastern North Pacific basins, though the two ECHAM model annual cycles have the right timing in the Atlantic.

In Fig. 3 the average monthly genesis position for the

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Model	ECHAM4.5	ECHAM4.5(L)	ECHAM3	NSIPP
Period	1979-1995	1950-2000	1949-2000	1961-2000
Ens. Size	13	17	10	09
Output Type	DS	DA	SH S	DS

Table 1: Notation: daily snaphots (DS), daily averages (DA), six-hourly snapshots (SH S), long (L).

Basin	Season	ECHAM3	ECHAM4.5	ECHAM4.5(L)	NSIPP
SI	JUL-JUN	0 (0.2)	-0.2	-0.1 (**0.3**)	-0.4 (0)
SI	DJFMA	-0.2 (0.1)	-0.1	-0.2 (0.1)	-0.3 (0)
AUS	JUL-JUN	-0.3 (-0.4)	**0.7**	0.2 (0)	0 (0)
AUS	DJFMA	-0.3 (-0.4)	**0.7**	**0.3** (0.2)	0.1 (0.1)
SP	JUL-JUN	**0.6** (**0.8**)	0.2	**0.4** (**0.6**)	**0.6** (**0.7**)
SP	DJFMA	**0.5** (**0.6**)	0.1	**0.3** (**0.5**)	**0.4** (**0.5**)
NI	JAN-DEC	-0.3 (-0.3)	-0.2	-0.1 (0.1)	-0.3 (-0.3)
NI	MJSON	-0.1 (**0.3**)	-0.1	-0.2 (0.1)	-0.2 (0)
WNP	JAN-DEC	**0.4** (**0.4**)	0.2	**0.3** (**0.4**)	0.2 (0.2)
WNP	JJASO	**0.3** (**0.3**)	0.0	**0.3** (**0.4**)	0.1 (0.2)
ENP	JAN-DEC	0.1 (0.2)	**0.6**	0.2 (**0.4**)	-0.3 (-0.3)
ENP	JJASO	0.2 (0.1)	**0.5**	0.2 (**0.3**)	-0.4 (-0.5)
ATL	JAN-DEC	0.2 (**0.4**)	**0.6**	**0.3** (**0.6**)	0.2 (0.2)
ATL	JJASO	0.2 (**0.3**)	**0.6**	**0.4** (**0.5**)	0.2 (**0.4**)

Table 2: Correlations of the simulated number of storms per year (or season) with observations, for each of the three models.

ECHAM4.5 in the Western North Pacific is shown, where each number corresponds to a month. In the winter (December, January, February and March) the average genesis position is near 10N and moves northward in the spring, reaching its maximum northward displacement in August (around 20N). In the Fall the average genesis position moves equatorward again.

The AGCMs best simulate interannual tropical storm variability in the ocean basins where ENSO has an important impact on tropical storm variability: the Atlantic, Eastern North Pacific, Australian and the South Pacific regions. The model bias-corrected interannual variability for the Atlantic, Eastern North Pacific, Western North Pacific and Australian basin is shown in Fig. 4. In some periods, the variability of the models follows quite well the observed variability, while in others it does not, suggesting that other signals are not being correctly simulated in the models and are influencing the observed variability.

Table 2 shows the correlations of the number of storms in the different models with observations. The ocean basins considered are South Indian (SI), Australian (AUS), South Pacific (SP), North Indian (NI), Western North Pacific (WNP), Eastern North Pacific (ENP) and Atlantic (ATL). In the Northern Hemisphere the correlations are calculated either for the calendar year: January to December (JAN-DEC) or only during the the hurricane/typhoon season June to October (JJASO), with the exception of the North Indian Ocean for which the tropical cyclones season used is May, June, and Septe'mber to November (MJSON). In the Southern Hemisphere, the correlation for the months July to the following June (JUL-JUN) and the tropical cyclone season December to April (DJFMA) is considered. Two values of the correlation were calculated, taking the whole period that the model integrations were calculated and only considering the period of 1971-2000, if appropriate. One can note that the correlations in most cases improve when only the latter period is considered, perhaps attributable to better observational data, especially in ocean basins other than the Atlantic. There is large variation of skill among the different models, but in general the ENSO influence seems to be the source of the skill in the ocean basins where the correlations are significant.

4. ENSO impacts on model tropical storms

Some of the known effects of ENSO on observed tropical cyclones appear in the ECHAM3 and ECHAM4.5 simulations. Figure 5 shows the genesis positions of Atlantic and Eastern Pacific model storms for El Niño (red) and La Niña years for ECHAM4.5(L). Though the bias of low number of tropical storms in these basins is clear, one can see that in El Niño years the number of model tropical storms is reduced in the Atlantic, with the opposite happening in La Niña years, as happens in observations [8]. In the Eastern North Pacific, the genesis locations of model storms are more widely spread to the West in El Niño years and the number of storms is larger than in La Niña years.

Figure 6 shows that the ECHAM4.5(L) model average genesis location has a northwest - southeast shift according to the ENSO phase, similar to the observed shift [9].

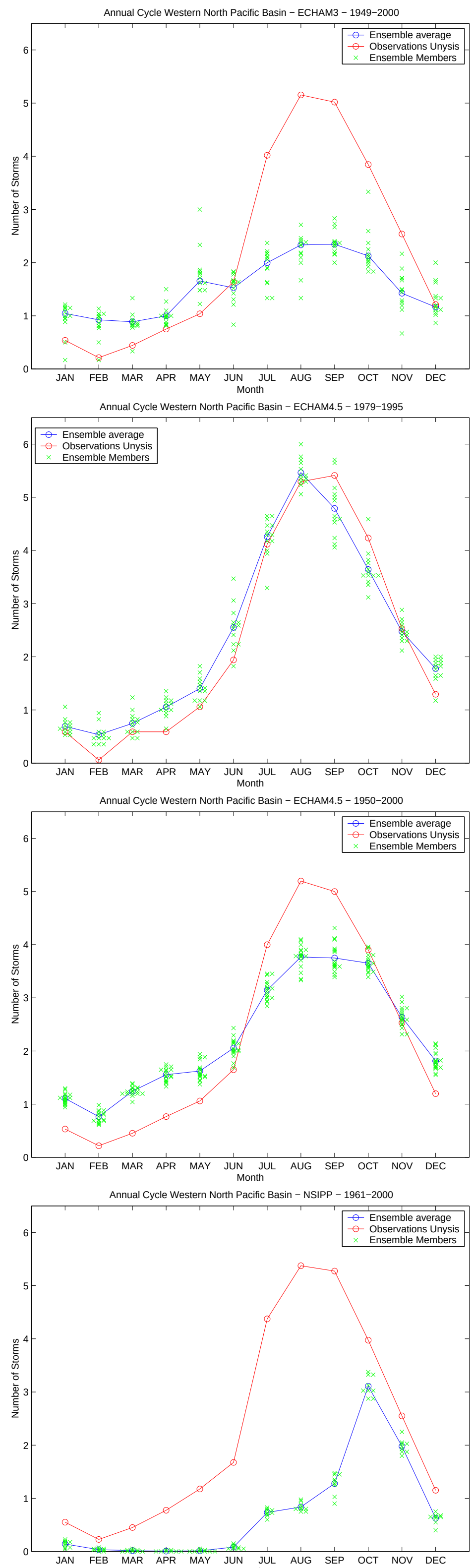

Figure 2: Annual Cycle in the Western North Pacific (WNP) for the different models.

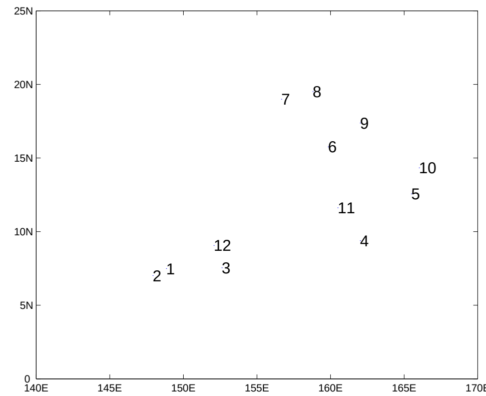

Figure 3: Average monthly genesis positions in the ECHAM4.5(L) model tropical storms in the Western North Pacific. Each number is located at the average first position of the corresponding month.

The monthly displacement of the average genesis position in latitude in observations [9] is very well captured in the ECHAM4.5(L) model, with a correlation of 0.98 with observational data.

In the South Pacific, the model also is able to capture the shift of tropical storms in El Niño and La Niña years. Figure 7 separates model tracks in the South Pacific by ENSO phases. In El Niño years ECHAM4.5 model and observed storms [10] tend to occur nearer the equator and more in the central South Pacific.

5. Conclusions

The AGCMs analyzed have some skill in simulating seasonal frequency and location of tropical storms in some ocean basins. ENSO influence on tropical cyclones seems to be the largest source of skill in simulating intreannual variability. The ECHAM models simulate cyclone frequency variability in the Atlantic and Eastern Pacific due to ENSO, in spite of their large mean bias. In the Eastern Pacific this bias could be related to the low resolution of the models, which leads to poor representation of the mountains in Central and South America and and poor simulation of Atlantic easterly waves reaching the Eastern Pacific and producing hurricanes. The ECHAM models also have skill over the Western North and South Pacific, and are able to simulate the shift of genesis and track location related to different ENSO phases. The ocean basin in which all the models are least successful simulating cyclone activity is the North Indian Ocean, probably due to failure of the models to properly represent the summer Indian monsoon and its relation to tropical cyclones.

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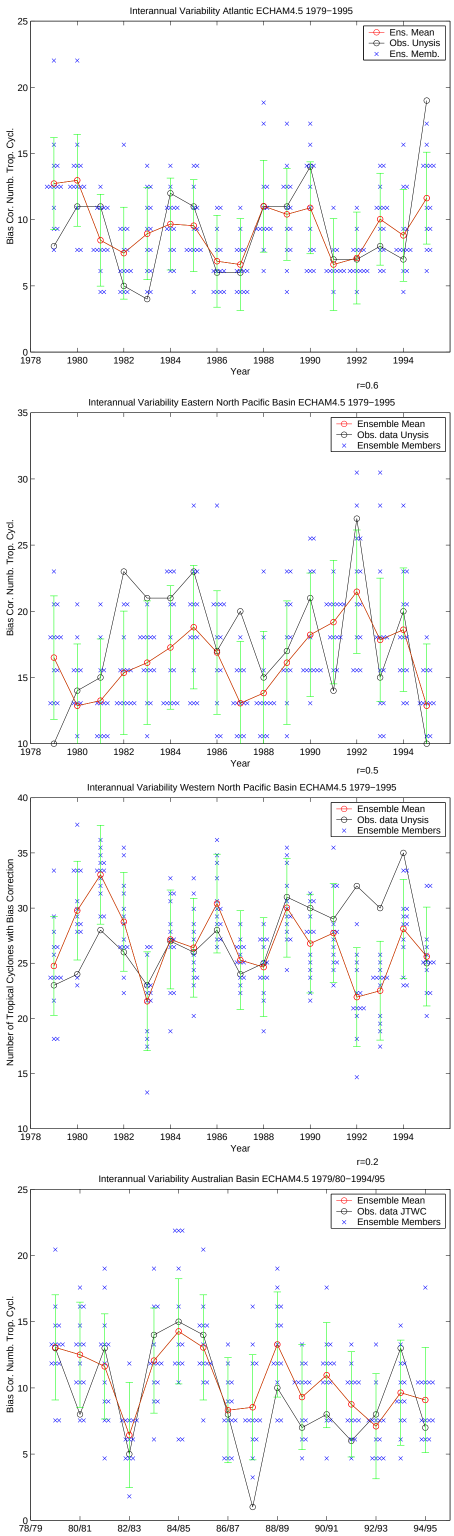

Figure 4: Bias corrected interannual Variability of the ECHAM4.5 storm frequency in the Atlantic, Eastern North Pacific and Australian region.

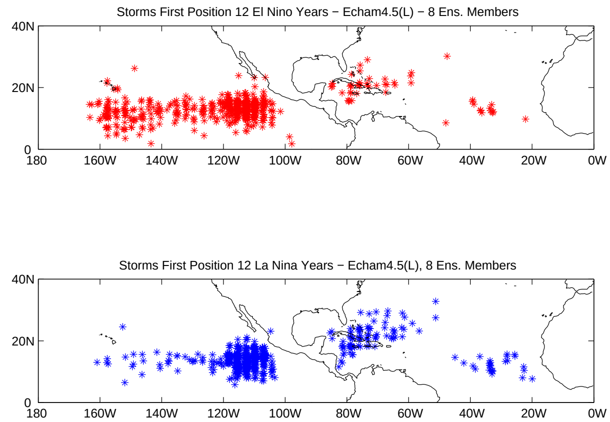

Figure 5: Genesis positions in the ECHAM4.5(L) model tropical storms in El Niño, La Niña in the Atlantic and Eastern North Pacific.

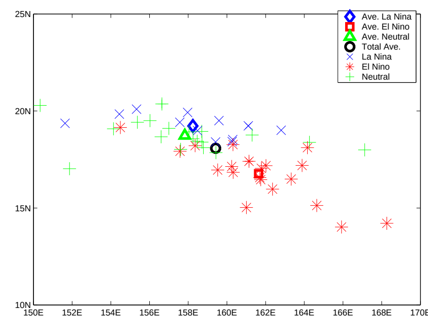

Figure 6: Average genesis position of ECHAM4.5(L) model tropical storms in El Niño, La Niña and Neutral years in the Western North Pacific.

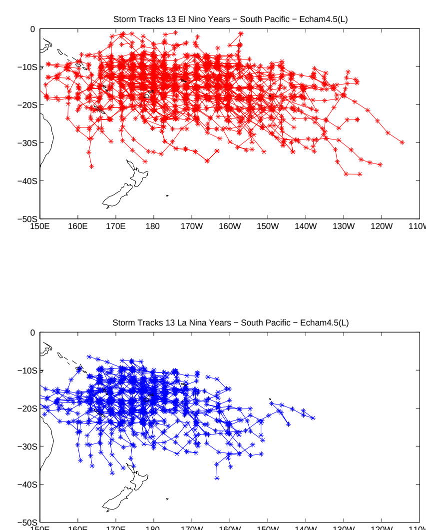

Figure 7: ECHAM4.5(L) model tropical storms tracks in the South Pacific in El Niño (red) and La Niña (blue) years.

References

[1] L. Bengtsson, H. Bötter and M. Kanamitsu, Simulation of hurricane-type vortices in a general circulation model, *Tellus* **34**, 440 (1982).

[2] F. Vitart, J.L. Anderson, and W.F. Stern, Simulation of interannual variability of tropical storm frequency in an ensemble of GCM integrations, *J. Climate* **10**, 745 (1997).

[3] Model User Support Group, ECHAM3 - Atmospheric General Circulation Model, *Das Deutshes Klimarechnenzentrum, Report No* **6** (1992).

[4] E. Roeckner, K. Arpe, L. Bengtsson, *et al.*, The atmospheric general circulation model ECHAM-4: Model description and simulation of present-day climate, *Max Planck Institute for Meteorology, Report No* **218** (1996).

[5] M.J. Suarez and L.L. Takacs, Documentation of the Aries/GEOS dynamical core Version 2, *NASA Technical Memorandum* **104606, 5** (1995).

[6] L. Bengtsson, M. Botzet and M. Esh, Hurricane-type vortices in a general circulation model, *Tellus* **47A**, 175 (1995).

[7] S.J. Camargo and S.E. Zebiak, Improving the detection and tracking of Tropical Storms in Atmospheric General Circulation Models, in preparation (2002).

[8] W.M. Gray, Atlantic Seasonal Hurricane Frequency 1. El-Niño and 30-MB Quasi-Biennial Oscillation Influences, *Mon. Wea. Rev.* **112**, 1649 (1984).

[9] H.H. Chia and C.F. Ropelewski, The Interannual Variability in the Genesis Location of Tropical Cyclones in the Northwest Pacific, submitted to *J. Climate* (2001).

[10] R.E. Basher and X. Zeng, Tropical Cyclones in the Southwest Pacific - Spatial Patterns and Relationships to Southern-Oscillation and Sea-Surface Temperature, *J. Climate* **8**, 1249 (1995).