

Precipitation change over Taiwan area: results of dynamical downscaling using MRI-JMA AGCM output

Chao-Tzuen Cheng¹, Yi-Yin Lin¹, Dan-Rong Chen¹, Chen-Ta Chen², and Masato Sugi³

1: National Science and Technology Center for Disaster Reduction, Taiwan

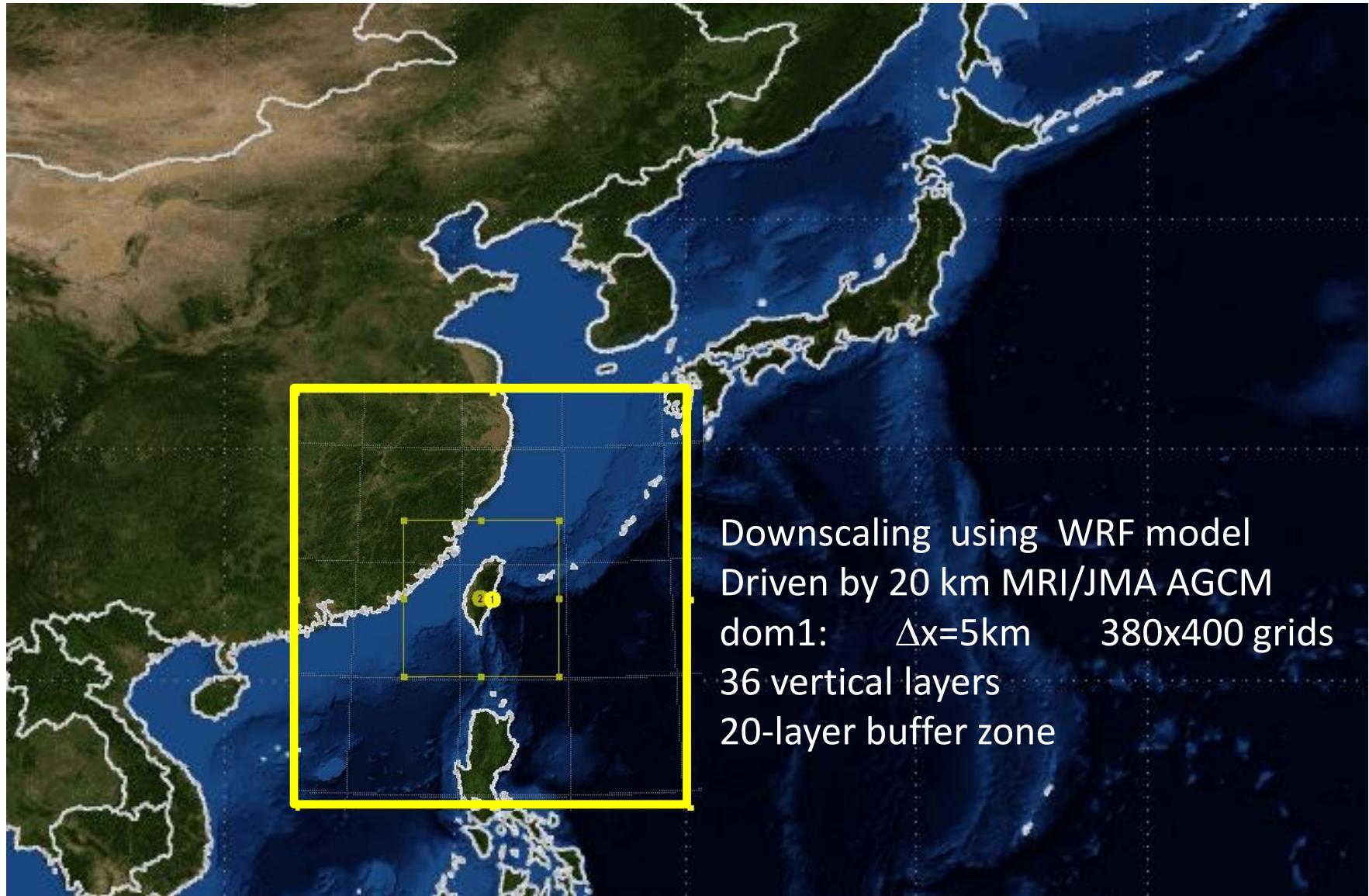
2: Department of Earth Science, National Taiwan Normal University, Taiwan

3: JAMSTEC, Japan

Outline

- Methodology
- Typhoons and their response to global warming in MRI AGCM
- Results of dynamical downscaling
 - Evaluation
 - Projection
- Summary

RCM for dynamical downscaling: WRF



Typhoon detection

Tropical Storm Detection and **Tracking** Scheme (following Vitart et al. 1997)

- Local relative vorticity maximum exceed threshold,

$$\xi_{\max} \text{ at } 850 \text{ hPa} > 2 \times 10^{-4} \text{ s}^{-1}$$

- Local sea level pressure minimum nearby (SLP_{min} within 1° radius of ξ_{max}) and defined as storm center,

$$SLP_{\text{environment}} - SLP_{\min} > 5 \text{ hPa} \quad (\text{within } 4^\circ \text{ radius of center})$$

- Local upper level warm core near storm center:

$$T_{200-500\text{hPa}} - T_{\text{environment}} > 1 \text{ K} \quad (\text{within } 4^\circ \text{ radius of center})$$

- Local maximum thickness near storm center:

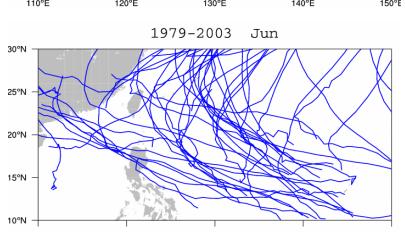
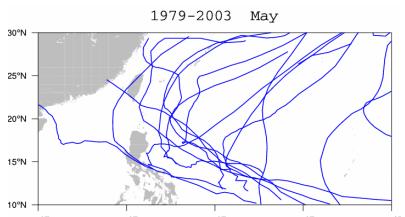
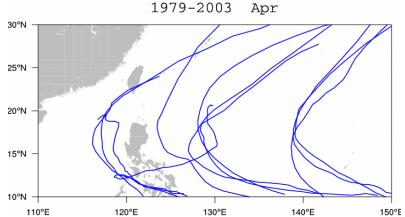
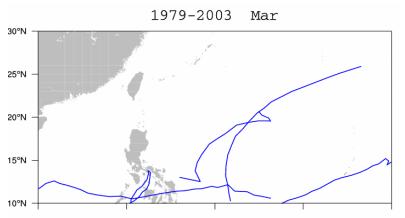
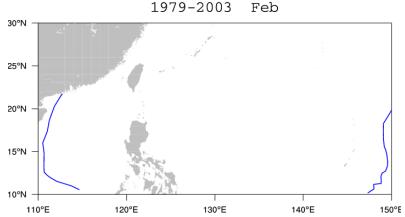
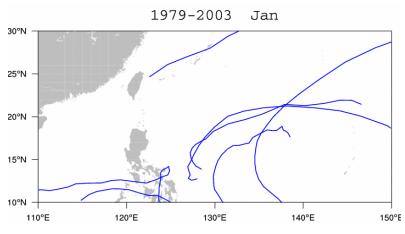
$$Z_{200-1000\text{hPa}} - Z_{\text{environment}} > 200 \text{ m} \quad (\text{within } 4^\circ \text{ radius of center})$$

- Trajectory stopped if there is no storm on the next time step (6hr) within 400 km.

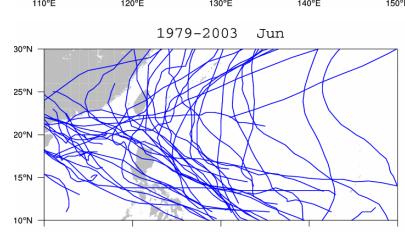
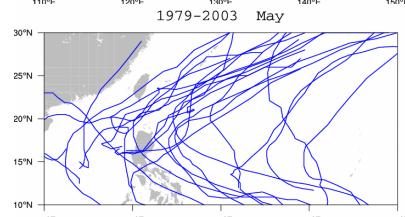
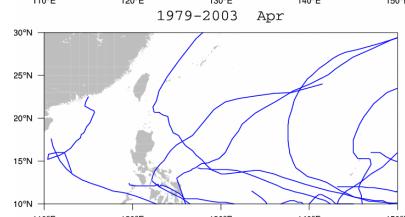
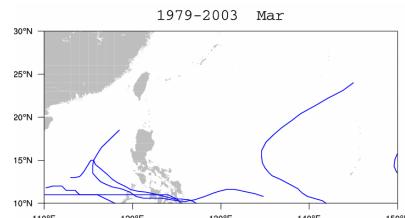
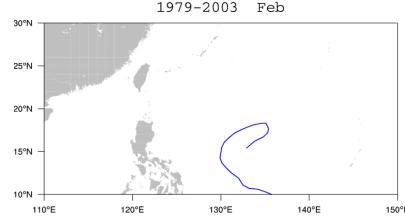
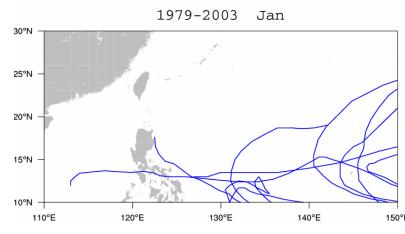
- Trajectory must last at least 1.5 days and have lowest model level wind velocity > 17 m/s during at least 1.5 days (not necessarily consecutive)

Typhoons and their response to global warming in MRI AGCM

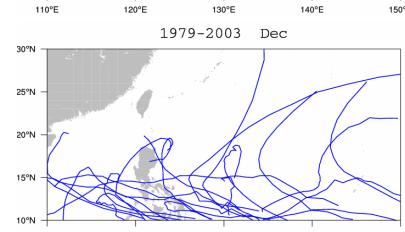
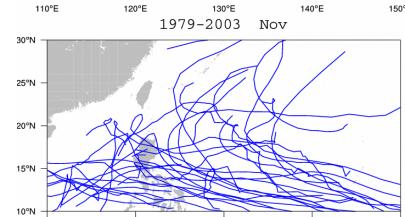
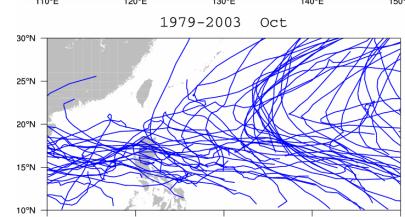
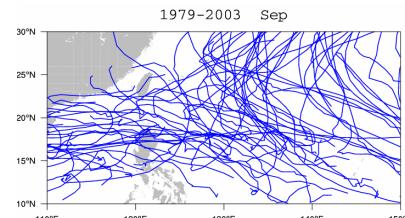
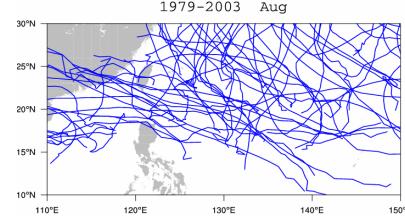
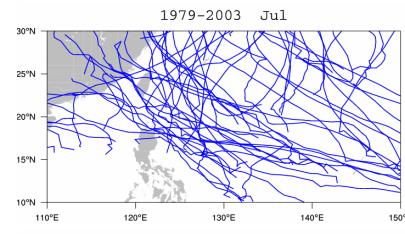
MRI 1979-2003



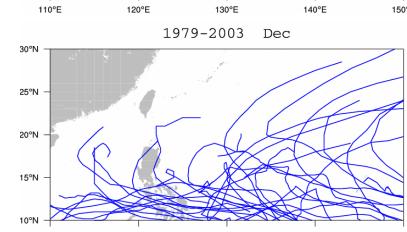
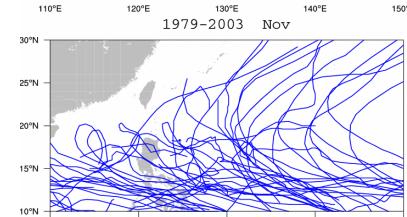
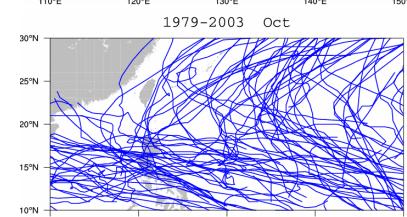
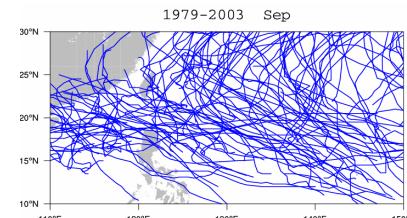
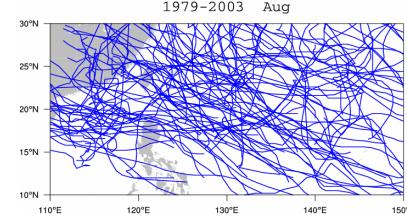
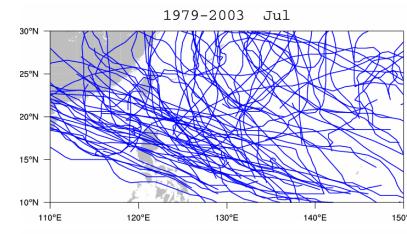
OBS 1979-2003



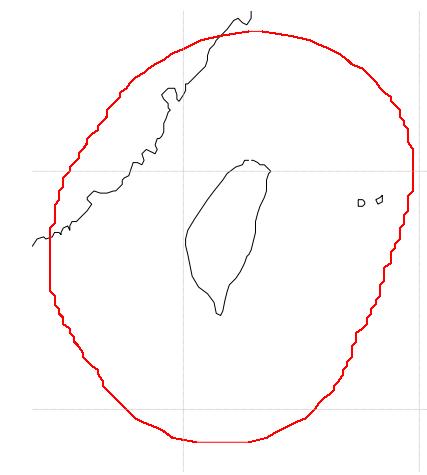
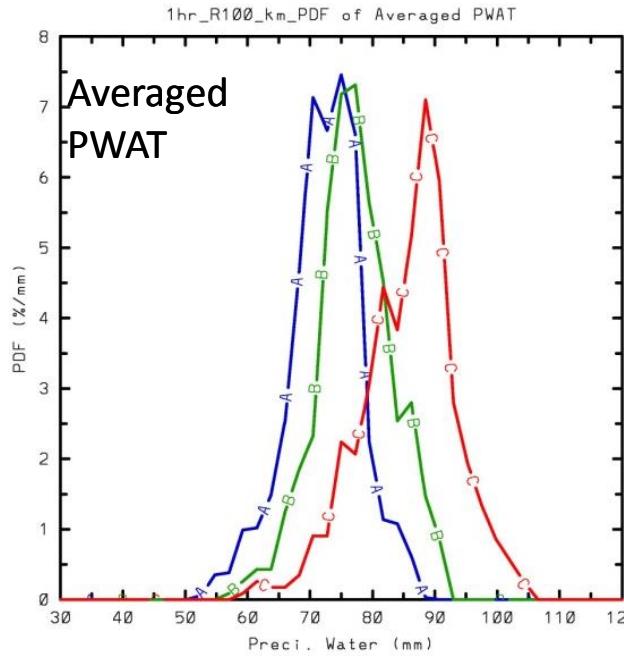
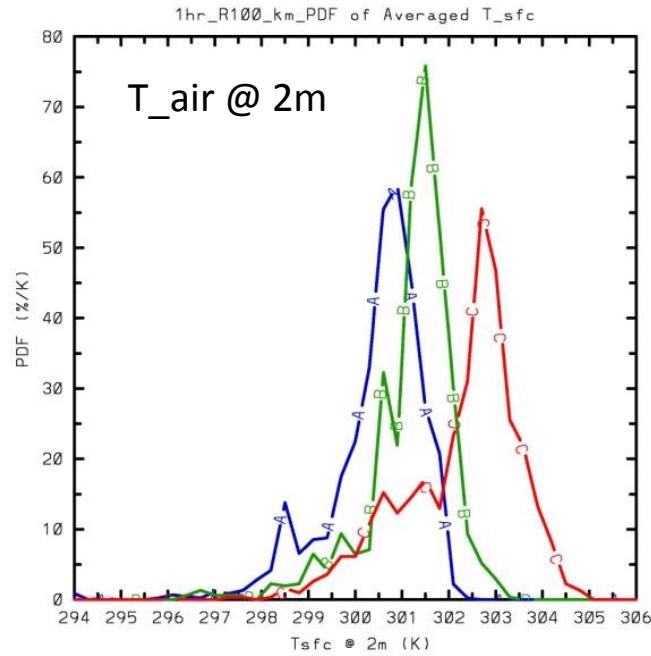
MRI 1979-2003



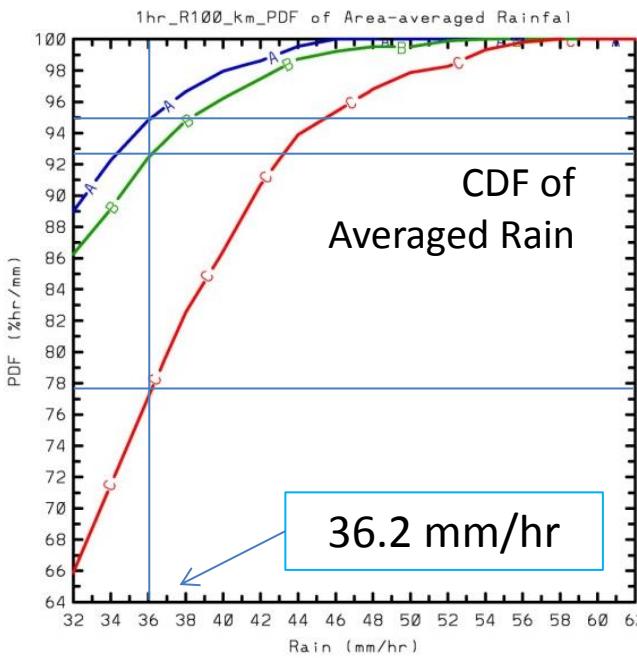
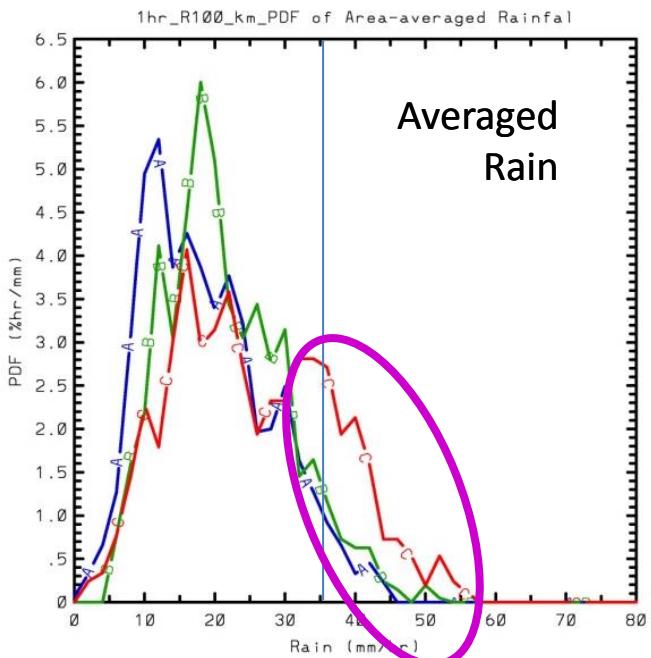
OBS 1979-2003



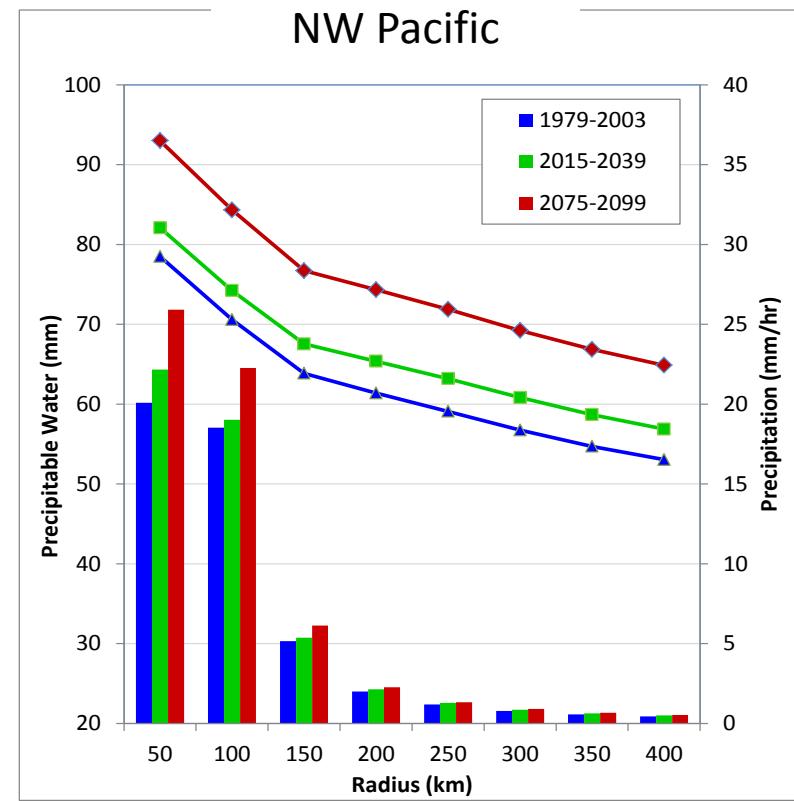
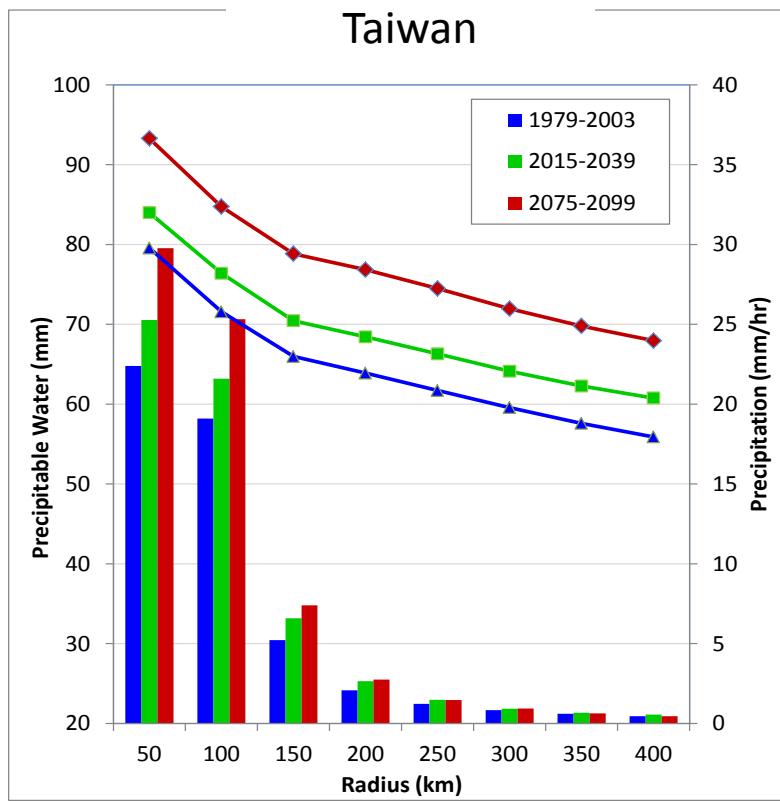
PDF or CDF for R=100 Km for typhoon near Taiwan



- Changes in vapor and T in good agreement



- Probability of typhoons with strong rainfall rate increases significantly in the end of 21 century



Precipitation (bars, right vertical axis, mm/hr) and precipitable water (lines, left vertical axis, mm) as function of radius (km)

Changes of vapor and precip. as function of radius of typhoon in end of 21st century

	Radius (km)	0~50	50~100	100~150	150~200	200~250
PWAT	NWP	18.5%	19.5%	20.2%	21.1%	21.7%
	Taiwan	17.2%	18.4%	19.5%	20.3%	20.7%
Precip.	NWP	29.0%	20.2%	18.9%	13.5%	12.1%
	Taiwan	33.0%	32.5%	41.8%	32.9%	19.0%

- Vapor increase ~ 20% for SST+2.4°C
- Preci. Increase > 30% near typhoon center

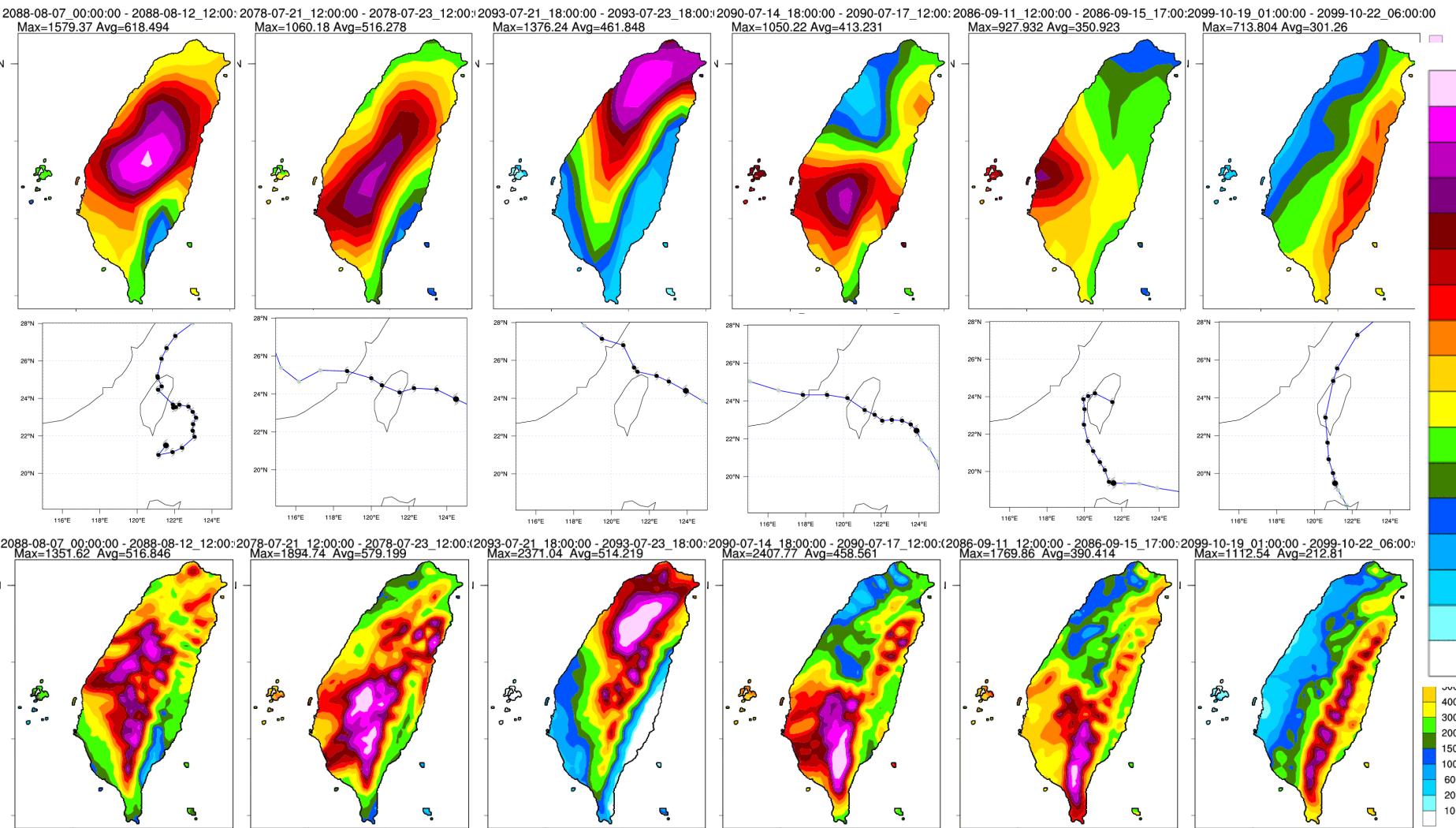
Life span of typhoon (hour), and ratio of life span in the future

Strength		TS +	Cat 1 +	Cat 3+
NW Pacific	Near Future	50360 (0.87)	26877 (0.90)	13048 (0.90)
	End of century	39433 (0.68)	20817 (0.70)	10978 (0.75)
Near Taiwan	Near Future	2166 (0.79)	1033 (0.68)	453 (0.78)
	End of century	2046 (0.75)	1032 (0.68)	462 (0.80)

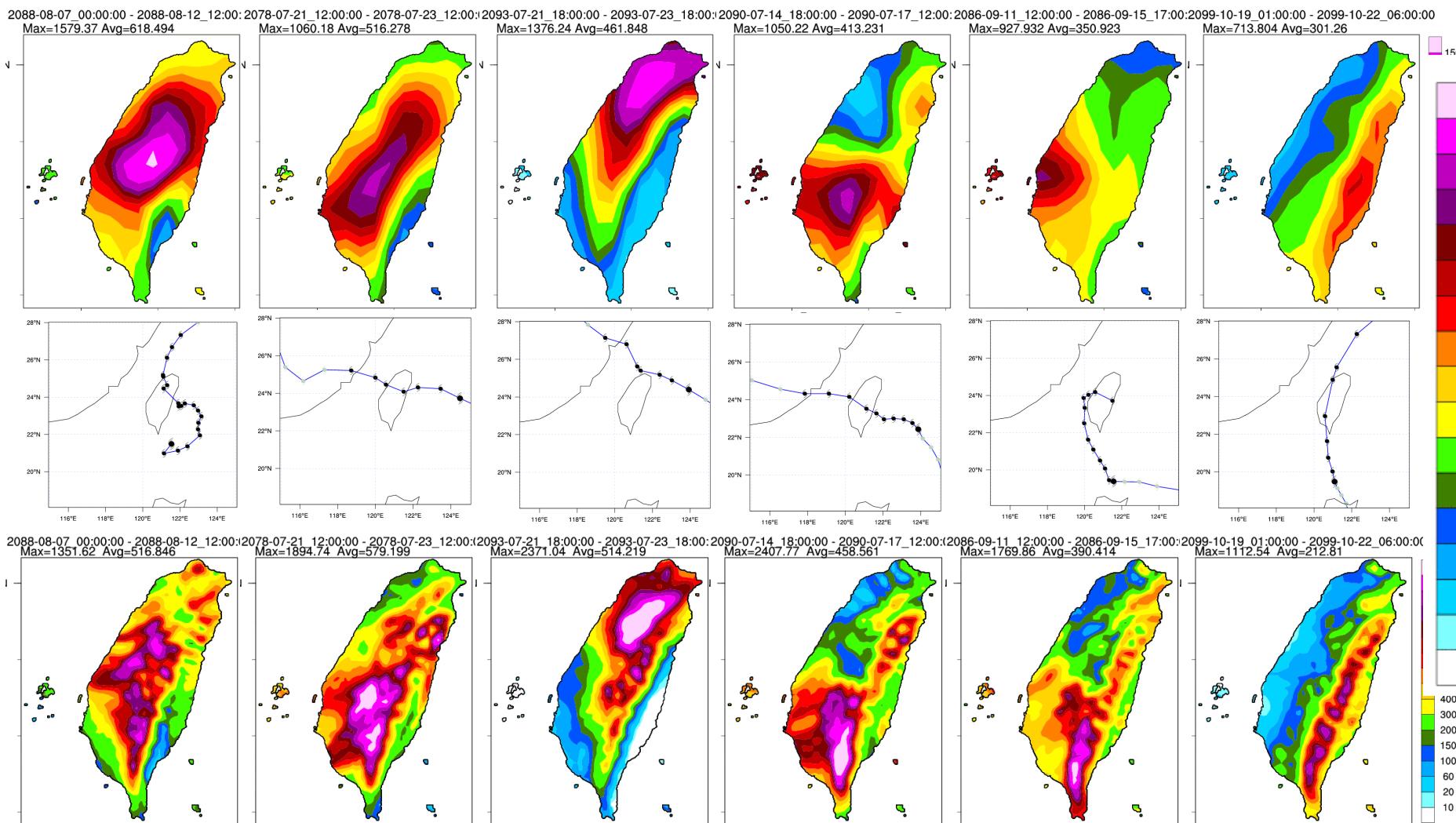
Influencing time of typhoon (TS+) decreases by 21~25%

Results of dynamical downscaling

Precipitation of top 6 typhoons in 1979-2003



Precipitation of top 6 typhoons in 2075-2099



1979-2003

2015-2039

2075-2099

TY num	Max		Avg	
	MRI	MRI-WRF	MRI	MRI-WRF
199702	1173.10	2770.13	623.86	707.57
199203	1129.01	1693.58	426.26	459.63
199603	972.68	1432.27	302.01	340.79
198802	872.61	1162.29	256.02	240.05
200303	776.79	1844.31	247.74	307.47
200302	1178.90	1182.66	246.59	274.71
198103	542.91	745.00	244.28	239.49
199102	634.90	1070.16	220.56	253.85
199303	577.79	1263.96	211.87	303.57
198404	582.74	1043.17	207.18	235.46
200203	640.82	703.04	206.58	162.55
198406	505.50	2252.02	202.54	323.1
198005	561.46	1189.58	200.38	281.28
199902	547.62	1029.72	175.42	204.98
199104	256.55	389.58	146.3	144.12
199204	572.78	764.08	144.41	221.44
200102	368.65	409.47	133.91	119.35
199201	493.03	1094.81	131.29	189.31
199402	484.35	805.43	130.18	117.66
198105	440.84	431.54	117.51	112.55

TY num	Max		Avg	
	MRI	MRI-WRF	MRI	MRI-WRF
201701	768.86	1675.62	480.72	471.32
202305	299.53	446.15	360.84	435.69
202301	384.55	303.79	350.63	369.05
202103	450.36	996.87	281.75	349.26
203202	110.96	211.25	268.24	387.56
203203	110.52	167.42	240.14	325.09
203003	127.76	73.32	205.25	256.36
202105	436.80	588.69	204.45	201.98
202702	188.61	116.66	201.34	203.34
202002	462.98	936.58	197.26	251.82
203004	127.61	108.66	197.15	236.55
203702	29.76	67.89	192.41	199.38
202403	257.01	263.00	192.23	189.52
203204	92.59	279.83	191.7	227.46
203101	117.42	112.77	188.06	186.02
201903	470.72	463.51	184.66	279.56
202304	303.83	779.99	183.98	178.39
202801	148.40	191.58	160.48	197.25
201804	574.04	1149.27	159.37	170.93
203501	51.71	83.86	158.45	201.79

TY num	Max		Avg	
	MRI	MRI-WRF	MRI	MRI-WRF
208802	1579.37	1351.62	618.49	512.03
207803	1060.18	1894.74	516.28	596.98
209302	1376.24	2371.04	461.85	491.17
209004	1050.22	2407.77	413.23	490.13
208603	927.93	1769.86	350.95	434.9
209902	714.20	1190.80	301.53	297.54
208503	610.42	683.35	296.81	209.03
209901	607.06	1227.66	295.61	363.16
207503	649.60	1122.94	289.96	310.77
209304	650.64	1673.10	288.7	348.46
208504	607.90	669.56	281.55	193.15
207603	818.55	1111.46	266.38	254.63
209001	655.19	1132.60	242.86	271.08
209601	587.28	1116.60	240.97	272.61
209402	747.65	865.35	238.15	210.78
209002	670.29	744.91	235.79	199.26
209701	553.13	1000.38	224.19	299.09
209703	551.50	1174.95	192.24	246.91
209501	594.07	858.75	178.07	180.2
208303	487.49	997.22	162.54	168.35

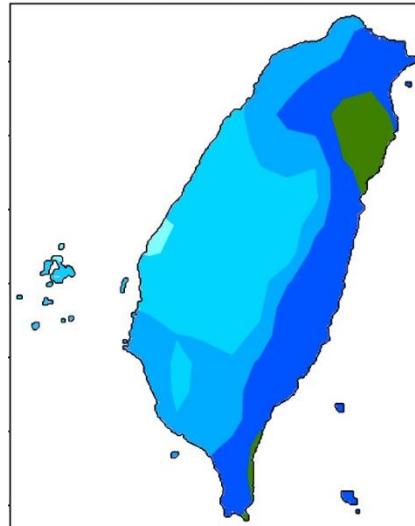
- * Maximum increase remarkably
- * Area averaged preci. increase (not much) in most cases.

SDII (Simple Daily Precipitation Intensity Index)

$$SDII = \frac{\text{日降雨} \geq 1 \text{ mm 的總累積雨量}}{\text{降雨} \geq 1 \text{ mm 的總降雨日數}}$$

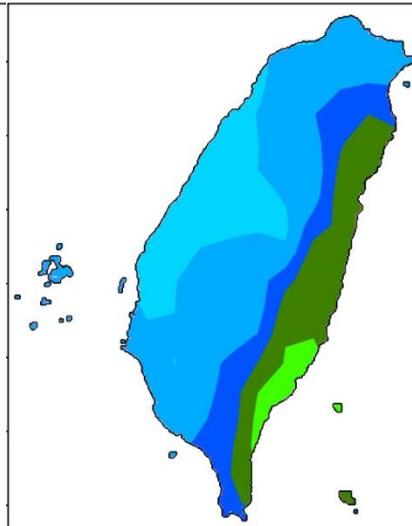
1979-2003

SDII (1979-2003) MRI



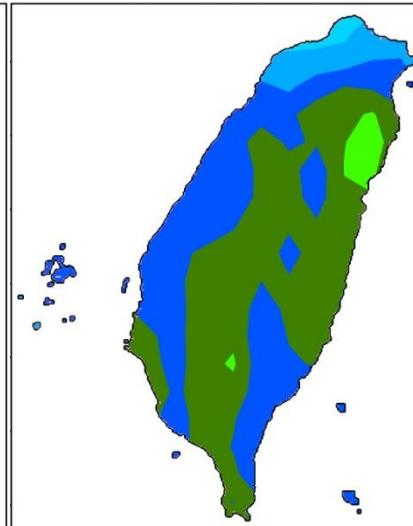
2015-2039

SDII (2015-2039) MRI

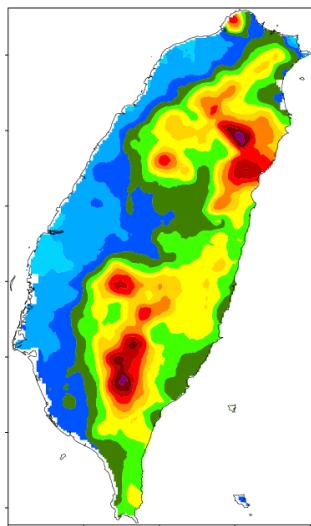


2075-2099

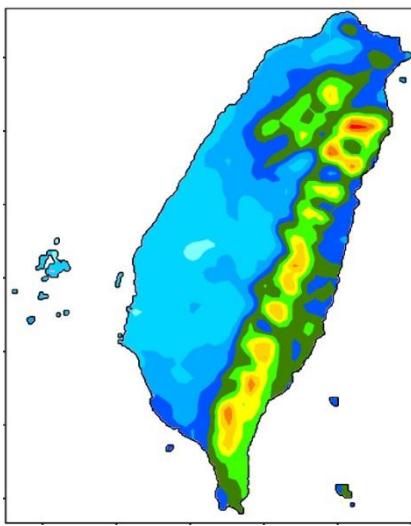
SDII (2075-2099) MRI



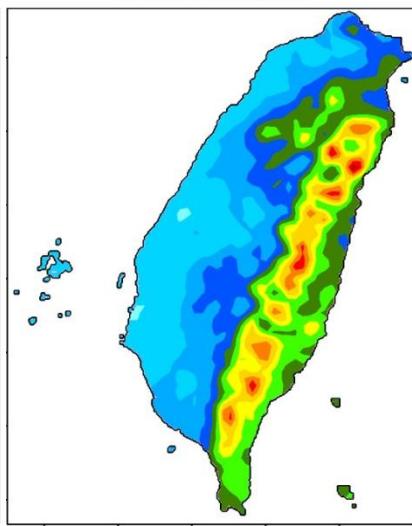
SDII (1992 - 2010) OBS



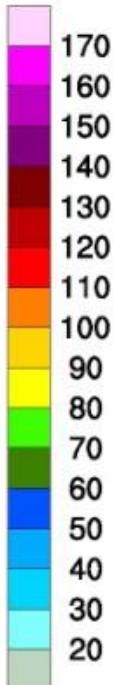
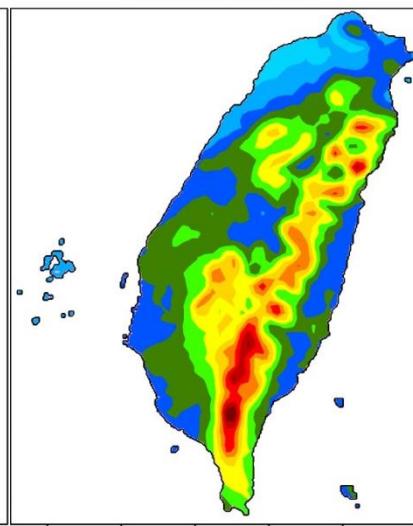
SDII(1979-2003) WRF



SDII(2015-2039) WRF

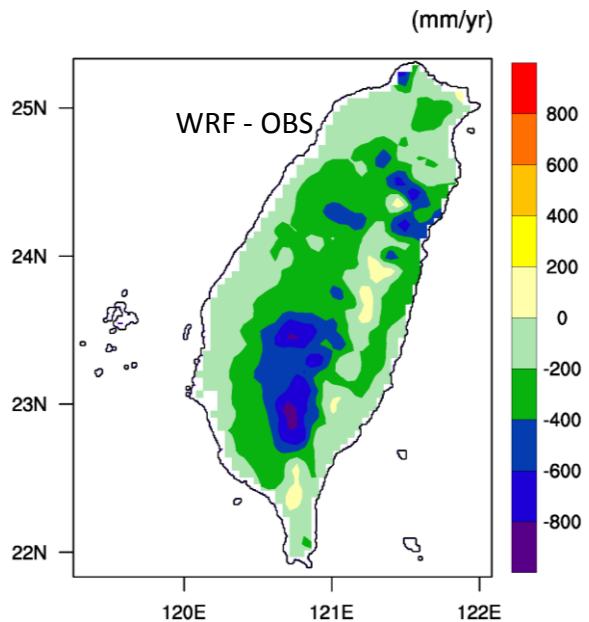


SDII(2075-2099) WRF



Dry bias

Bias between OBS(1992-2010) and WRF(1979-2003)



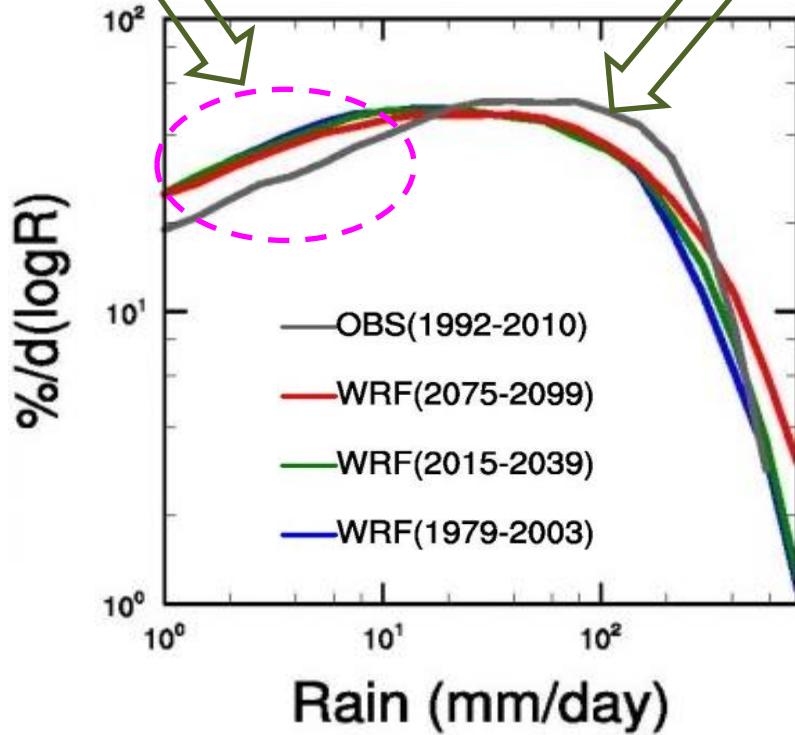
Simulation
underestimates typhoon
precipitation for present
day

PDF (Probability Density Function)

Overestimate

Taiwan

Underestimate



Life span of typhoons in MRI AGCM

Total hours of Tropical Cyclone's life span during 1979-2003

Percentage in brackets : the ratio of the life span to the life span of all TCs

Strength		Category 0 and above	Category 1 and above	Category 3 and above
West North Pacific	Observation	84393 (100%)	32958 (39.1%)	3441 (4.1%)
	MRI	57782 (100%)	29878 (51.8%)	14561 (25.2%)
Affecting Taiwan	Observation	16812 (100%)	6033 (35.9%)	612 (3.6%)
	MRI	2725 (100%)	1526 (56.0%)	580 (21.3%)

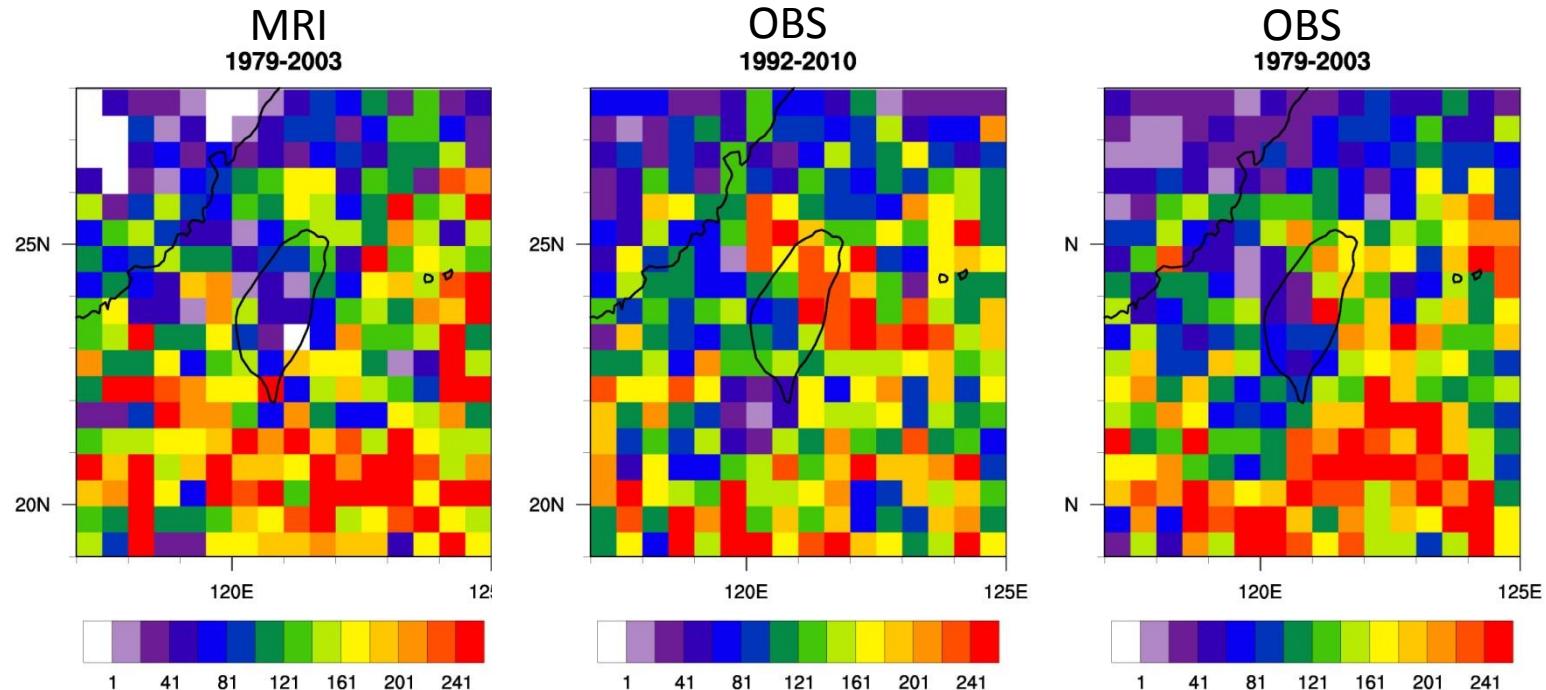
$$\frac{2725}{16812} \sim \frac{1}{6}$$

$$\frac{1526}{6033} \sim \frac{1}{4}$$

In term of life span

- There are too many strong tropical cyclones in simulation
- There are too few tropical cyclones affecting Taiwan in simulation

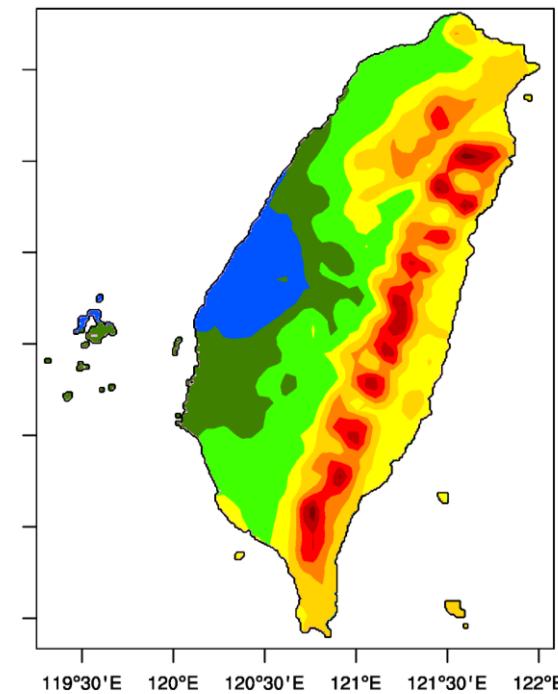
Track density (10 min sample)



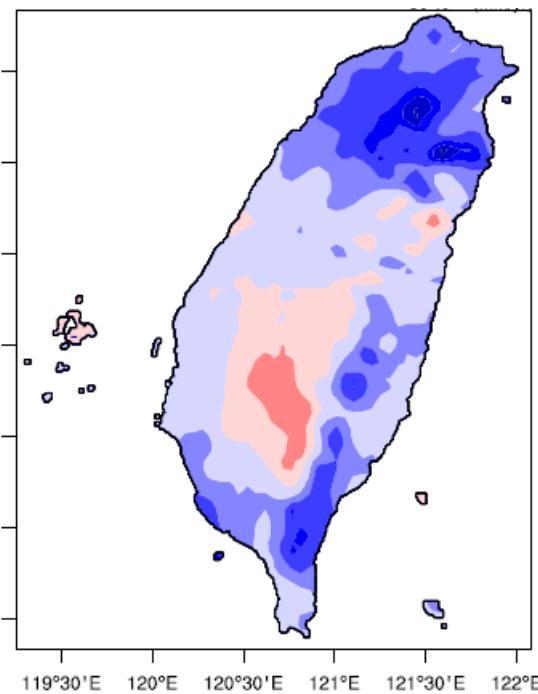
- Typhoons with track type 2 & 3 are common in observation
- More typhoons in 1992-2010 (vs. 1979-2003 obs)
- Typhoons avoid make landfall in MRI simulation, track bias

Annual Typhoon Precipitation (mm/year)

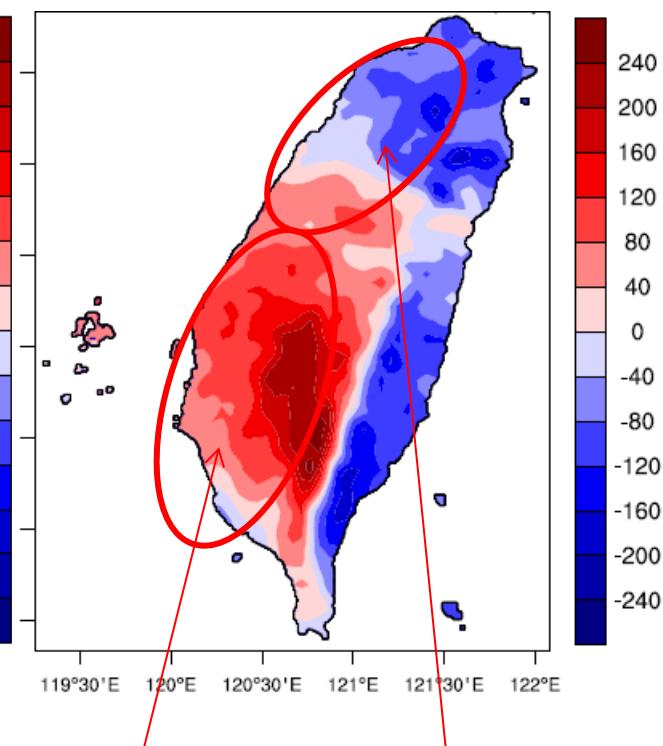
Present Day



Changes in Near Future



Changes in the End of Century



Typhoon

342.7 mm/yr

-10.9%

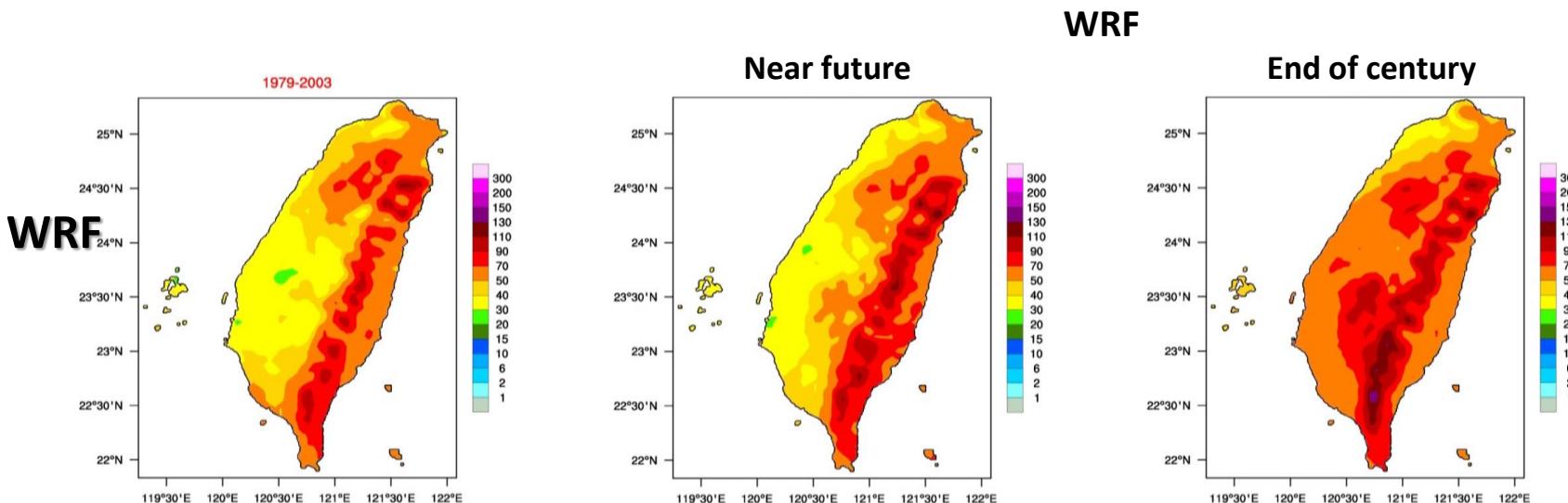
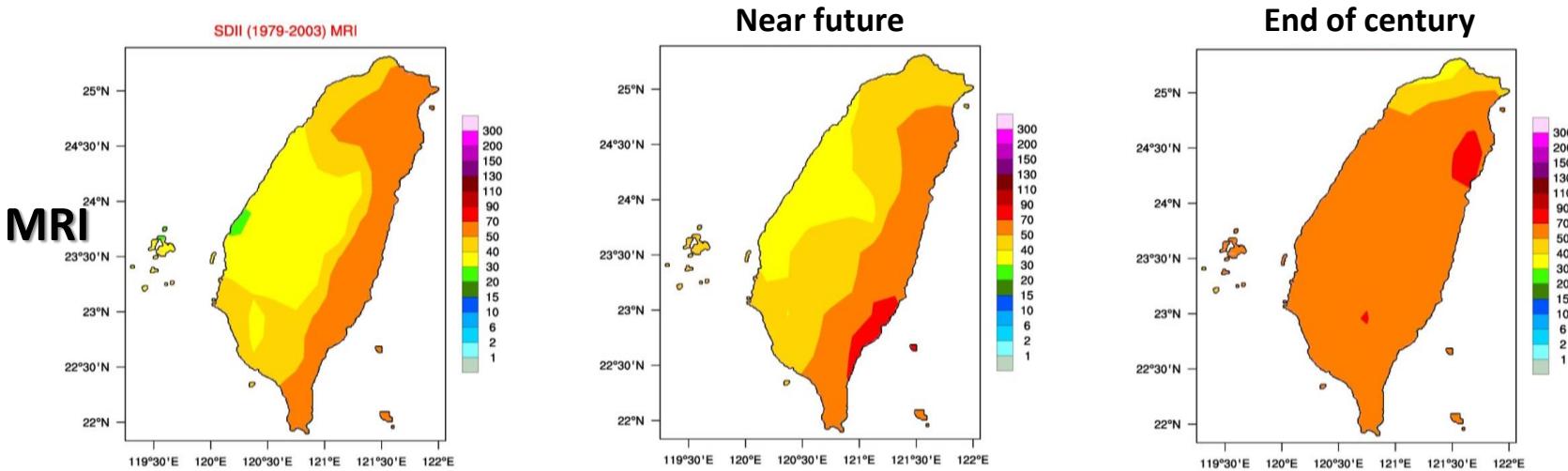
2.8%

Increase

decrease

Change in Precipitation Intensity

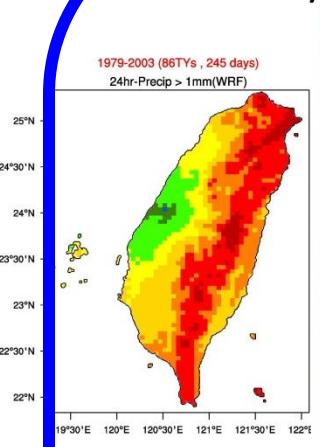
SDII (precipitation/rain days)



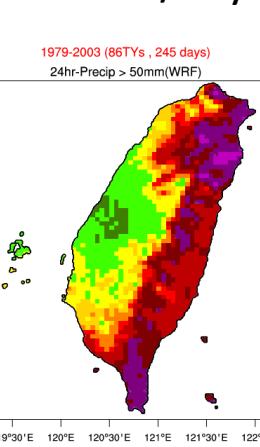
Occurrence of days with heavy precipitation (days)

Present

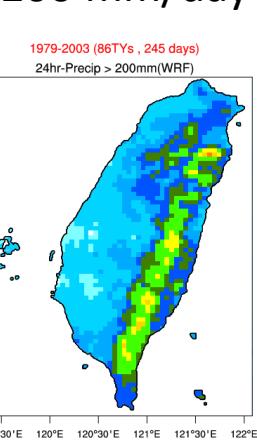
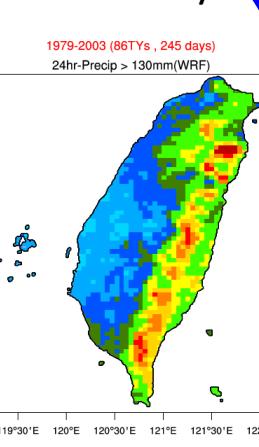
> 1 mm/day



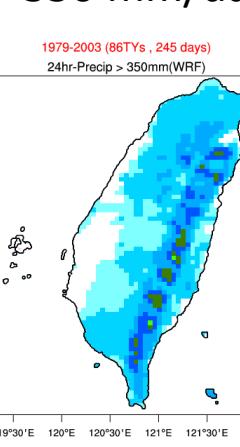
> 50mm/day



> 130 mm/day



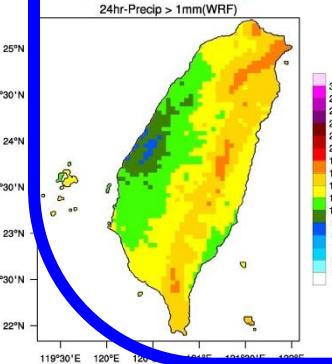
> 350 mm/day



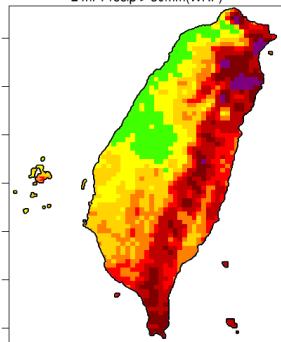
130
110
90
70
60
50
45
40
35
30
20
15
10
6
2
1

End of century

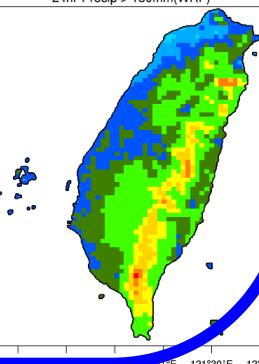
2075-2099 (73TYS , 201 days)



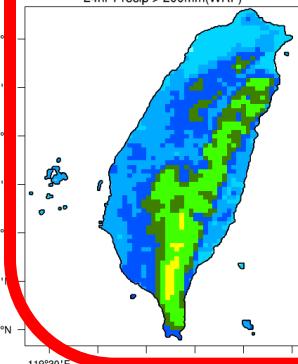
2075-2099 (73TYS , 201 days)



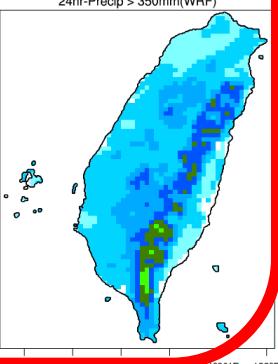
2075-2099 (73TYS , 201 days)



2075-2099 (73TYS , 201 days)



2075-2099 (73TYS , 201 days)



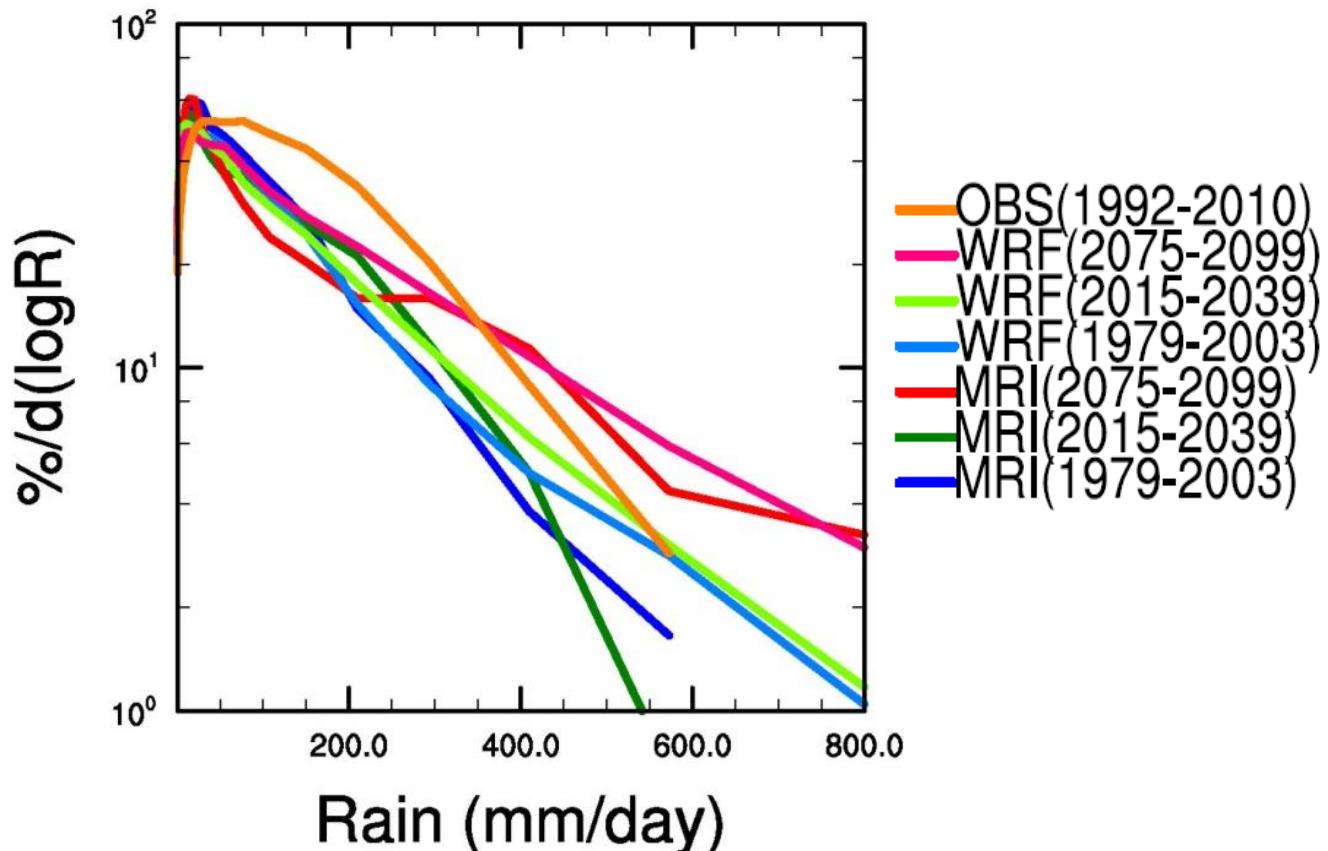
130
110
90
70
60
50
45
40
35
30
20
15
10
6
2
1

decrease in the future

increase in the future

Probability density of typhoon precipitation over Taiwan

Taiwan

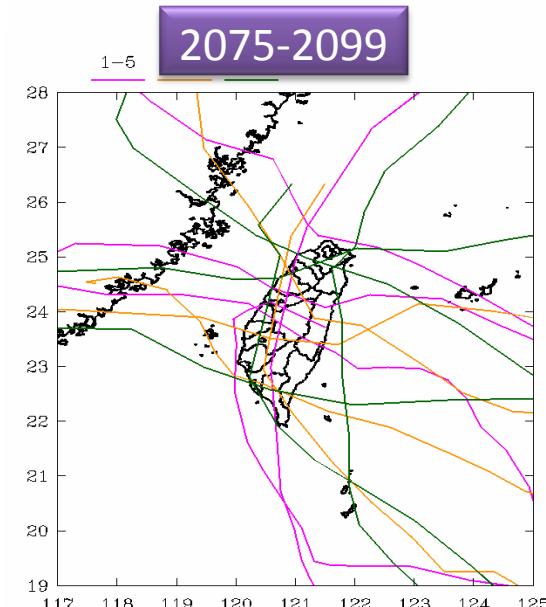
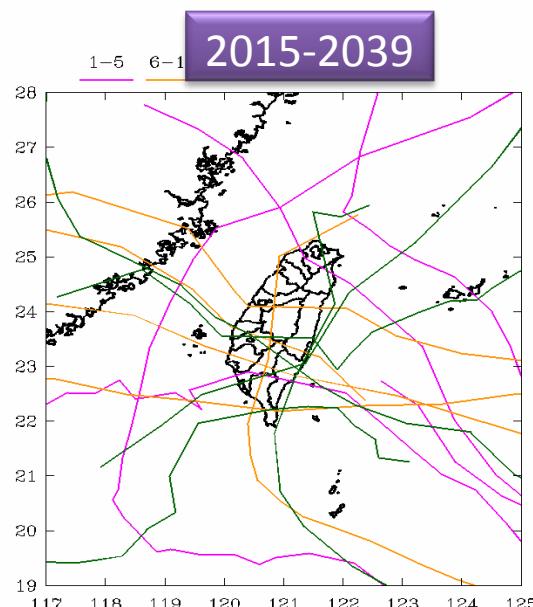
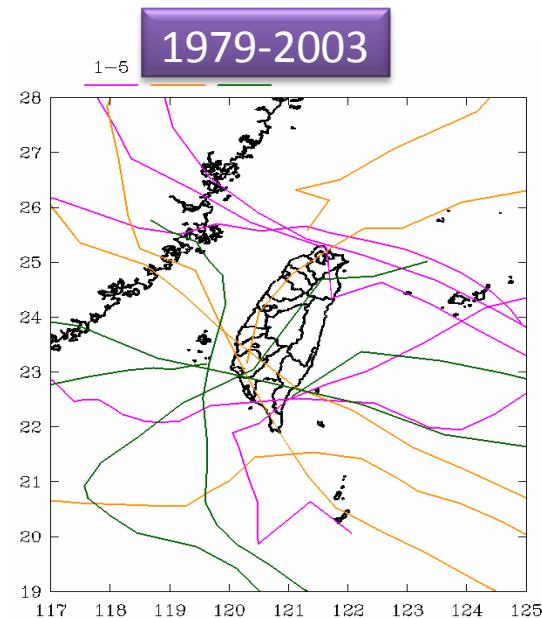
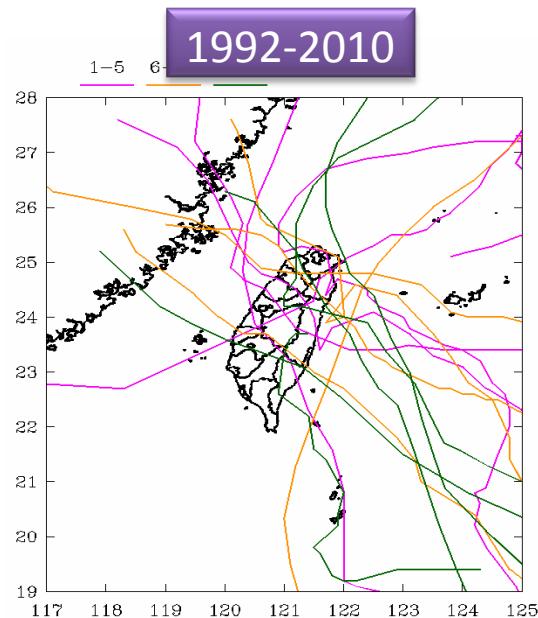


- Intensity increase after downscaling
- Intensity increase after warming
- Biases (present day) :
 - Incorrect modes in models
 - Weaker intensity in simulation

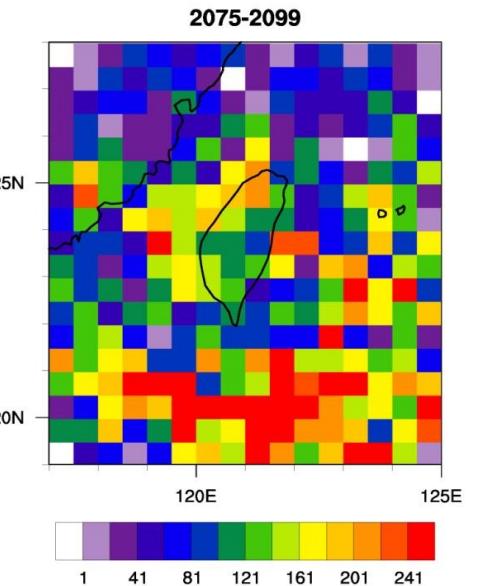
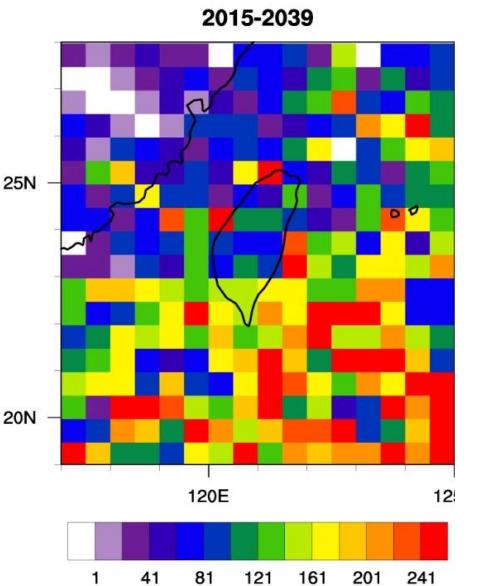
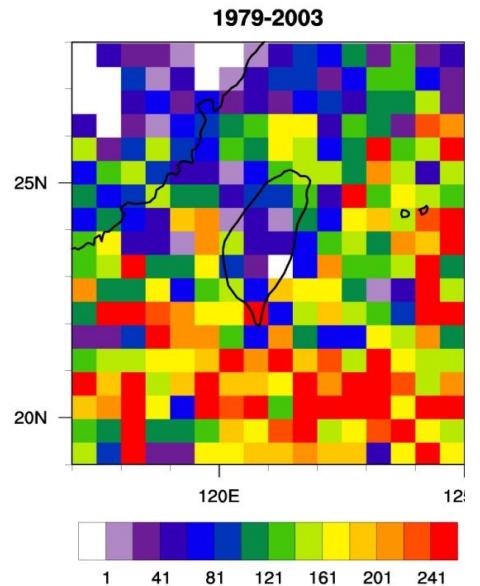
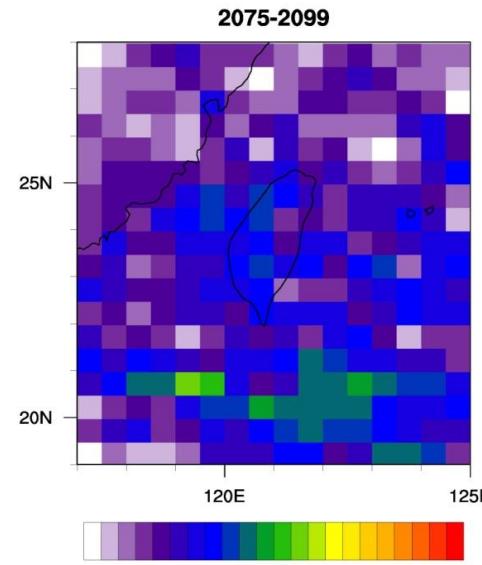
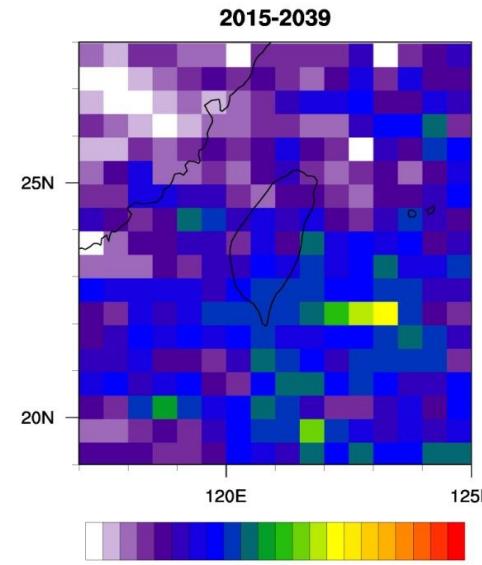
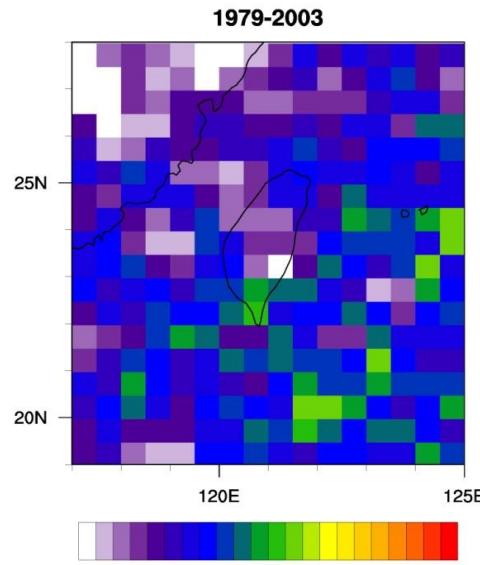
Change in Typhoon frequency and tracks

	Per Year
1992-2010	5.36
1979-2003	3.44
2015-2039	3.16
2075-2099	2.92

- Fewer tropical cyclones (-36%)
- Number decrease ~15% by the end of 21st century



Track Density



Summary

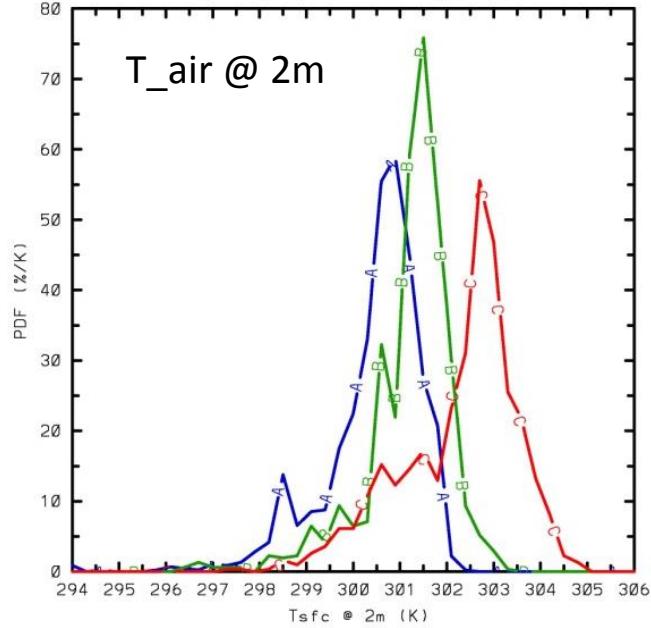
- MRI AGCM can generate typhoons with reasonable statistic numbers in west North Pacific basin. However, the duration of Taiwan affected by typhoons are underestimated way too much ($\sim 1/6$).
- In the end of 21 century, the number and affecting time of typhoons decrease. Vapor amount increases by $\sim 20\%$ and precip. increases by $\sim 30\%$ near typhoon centers.
- Dynamical downscaling improves typhoon precipitation in term of spatial distribution and intensity. After downscaling, values of maximum preci. are close to reality.
- Intensity of typhoon precipitation increases in the future. The frequency increases for preci. $> 200 \text{ mm/day}$ and decreases for preci. $< 200 \text{ mm/day}$.
- Due to the increase in preci.intensity, decrease in frequency, and change in popular tracks,typhoon precipitation decreases in near future by 10.86%, but increase 2.76% in the end of 21st century.
- Biases in tracks and frequency may cause large uncertainty to these result.

Thank you for your attention!

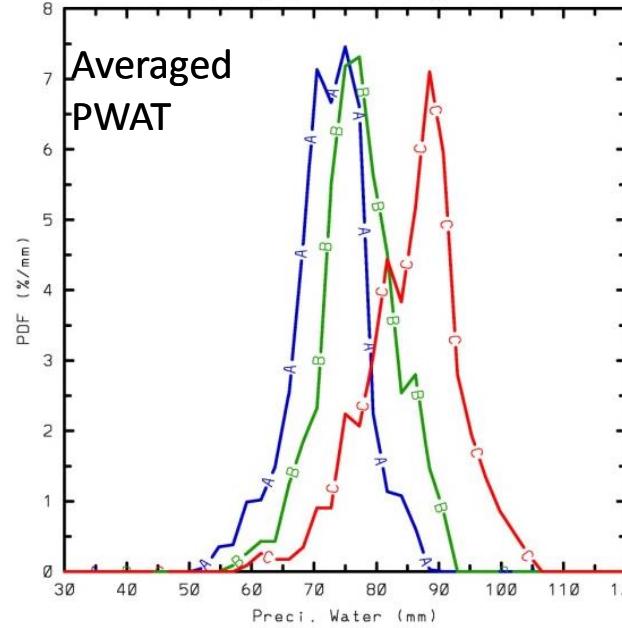
Effect of global warming on
vapor and precipitation of
typhoon

PDF or CDF for R=100 Km for typhoon near Taiwan

1hr_R100_km_PDF of Averaged T_sfc

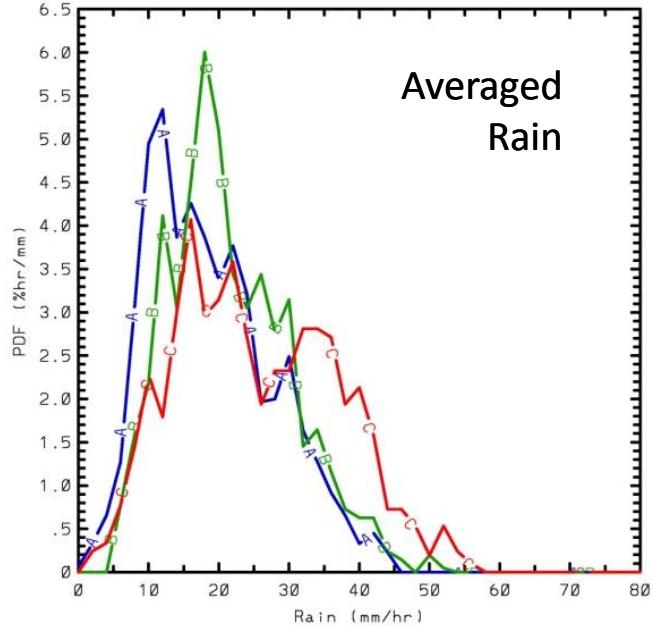


1hr_R100_km_PDF of Averaged PWAT

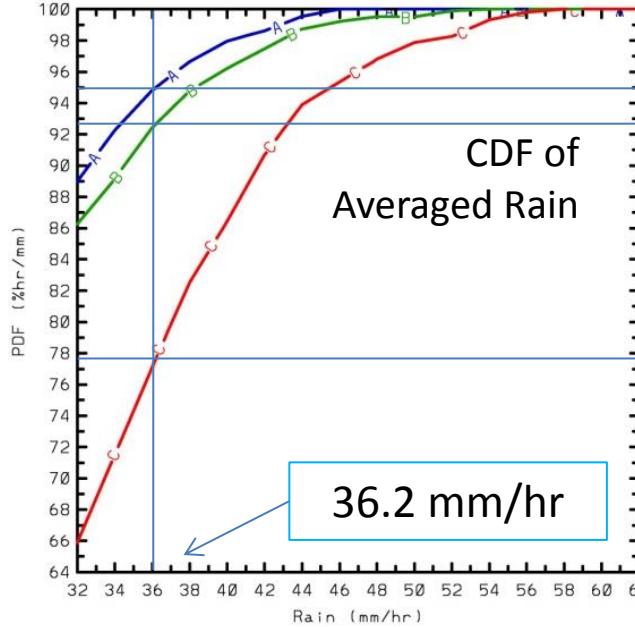


- Sampled from area averages at different time

1hr_R100_km_PDF of Area-averaged Rainfall



1hr_R100_km_PDF of Area-averaged Rainfall

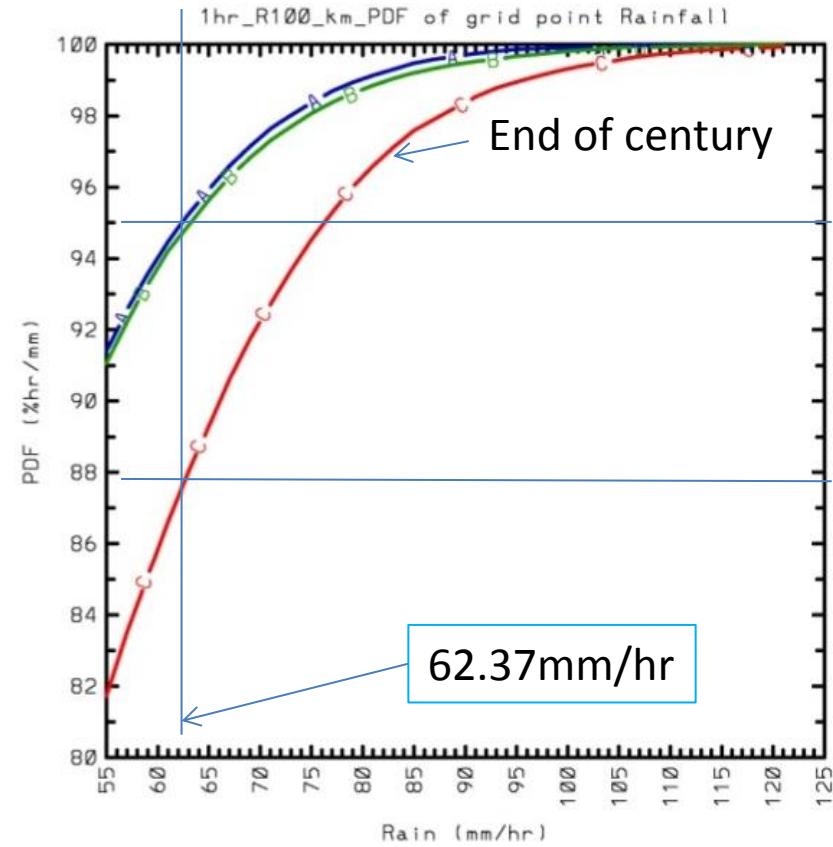
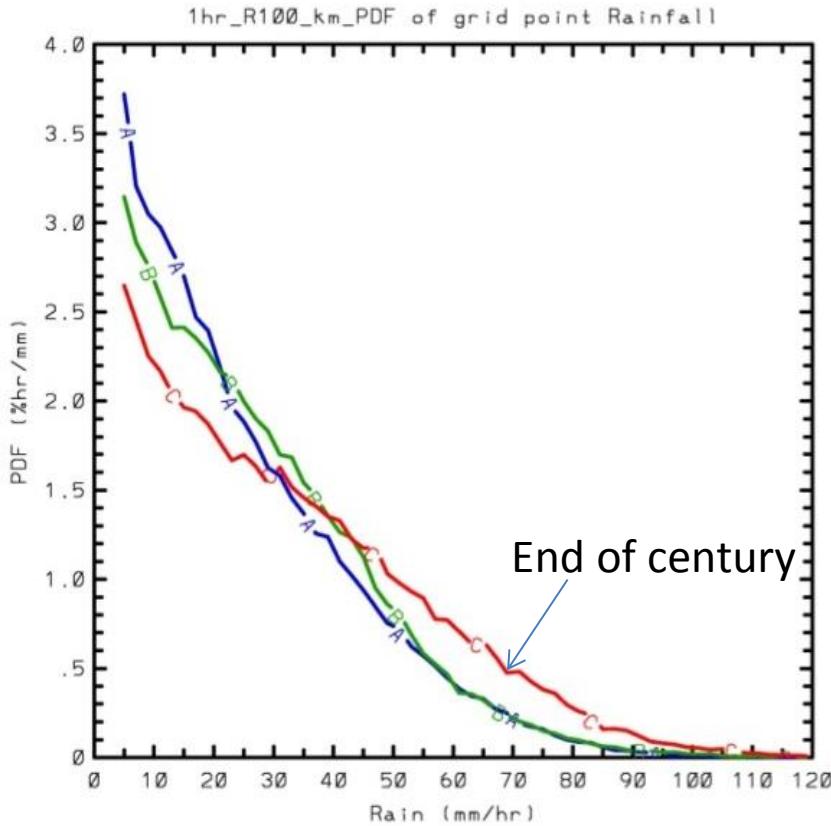


Ratio of typhoon occurrence = 1:0.68:0.68

$$(1 \times 5\%) : (0.68 \times 7.33\%) : (0.68 \times 22.34\%) = 1 : 0.99 : 3.02$$

Changes in the occurrence of extreme events (top 5%) over Taiwan

PDF & CDF for hourly rainfall at grid points
within R<=100 Km when typhoon near Taiwan



Ratio of sampled grid point numbers = 1 : 0.81 : 0.74
(1x5%) : (0.73x5.3%) : (0.71x12.4 %) = 1 : 0.77 : 1.76

Occurrences of extreme precipitations and extreme typhoons (criterion defined by the top 5% of present day) increase in the end of 21st century

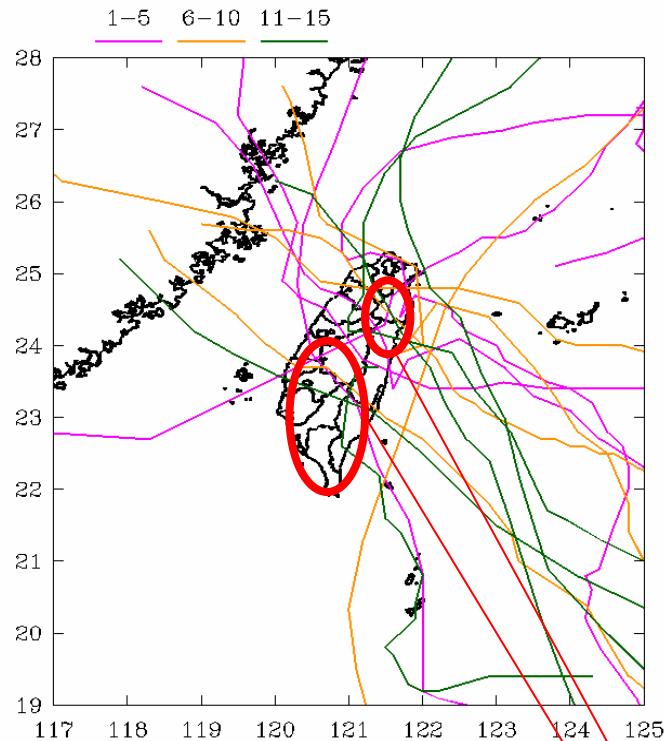
Ratio of occurrence	From Grid Points (for extreme Precipitation events)			From Area Means (for extreme Typhoon events)		
	1979-2003	2015-2039	2075-2099	1979-2003	2015-2039	2075-2099
R<100km NW Pacific	1	1.17	1.58	1	1.34	2.59
R<100km Taiwan	1	0.77	1.76	1	0.99	3.02

Bias in Typhoon frequency and tracks

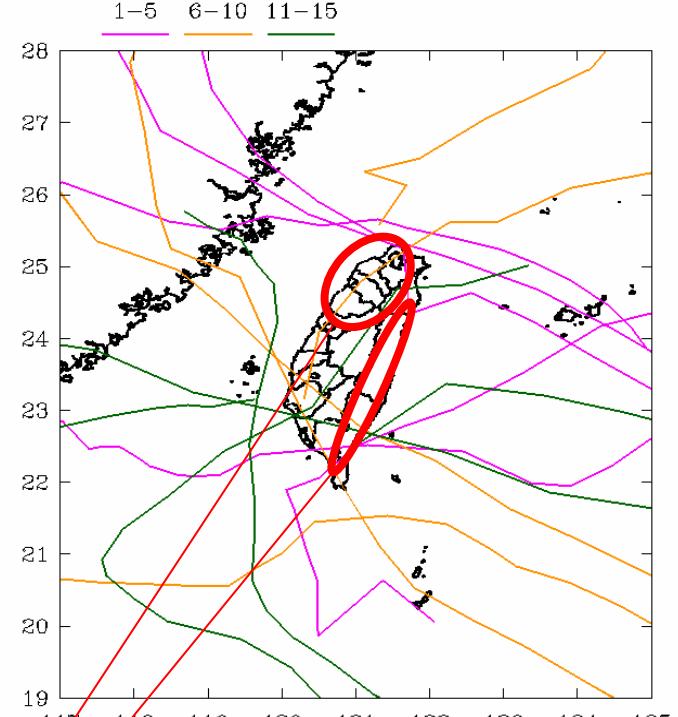
Tracks of Typhoons with heavy precipitation (top 15)

	Per Year
1992-2010	5.36
1979-2003	3.44
2015-2039	3.16
2075-2099	2.92

Observation 1992-2010



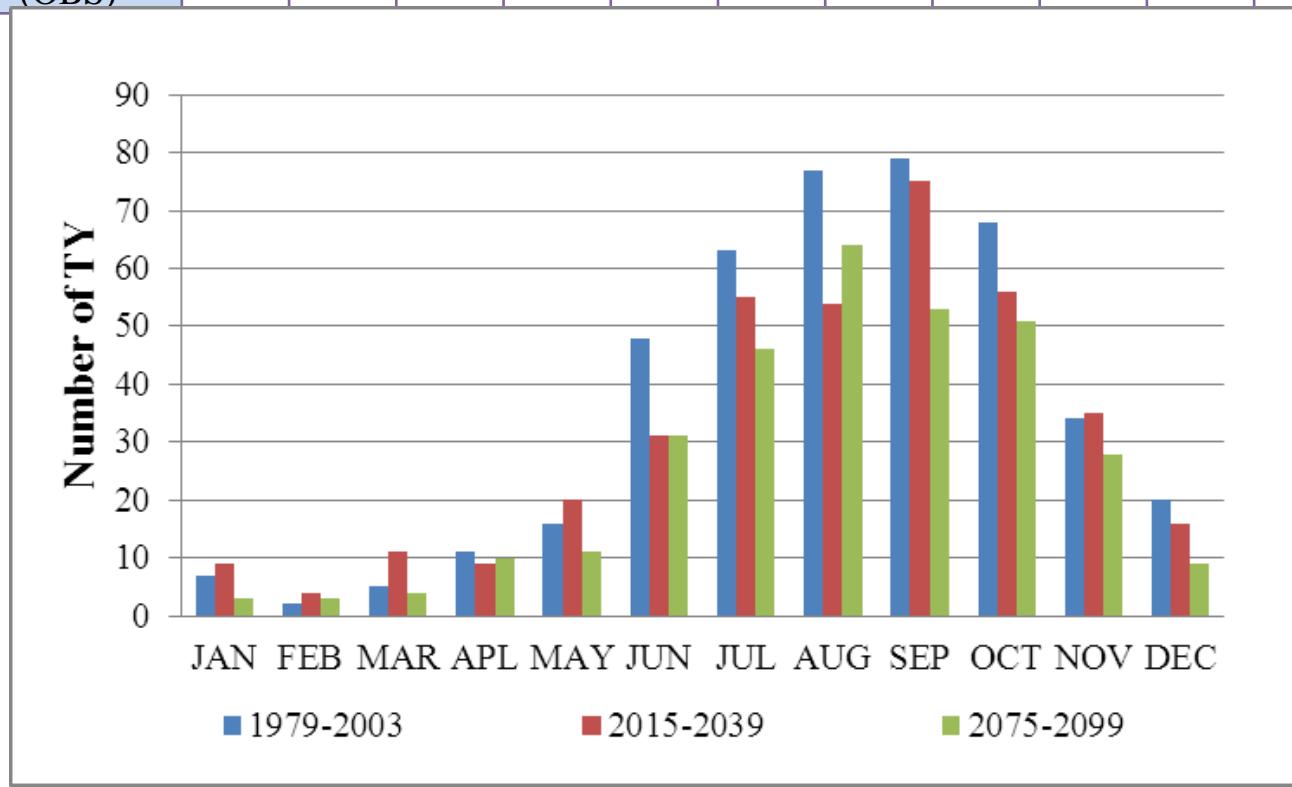
Simulation 1979-2003



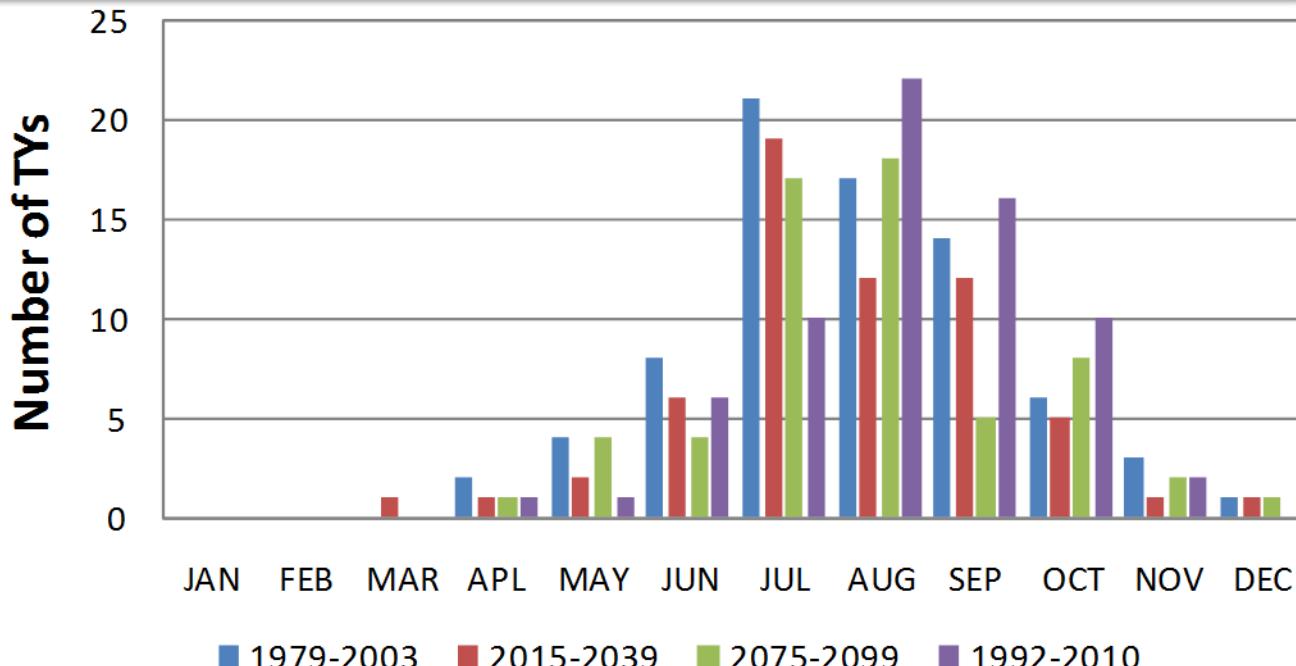
Precipitation hot spots

西北太平洋

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total	Per Year
1979-2003 (OBS)	10	3	8	17	26	41	92	135	125	93	58	33	641	25.64
1979-2003	7	2	5	11	16	48	63	77	79	68	34	20	430	17.2
2015-2039	9	4	11	9	20	31	55	54	75	56	35	16	375	15
2075-2099	3	3	4	10	11	31	46	64	53	51	28	9	313	12.52
	-0.57	+0.5	-0.2	-0.09	-0.31	-0.35	-0.27	-0.17	-0.33	-0.25	-0.18	-0.55	-0.27	
1992-2010 (OBS)	4	2	3	12	23	26	65	112	92	65	40	20	464	24.42

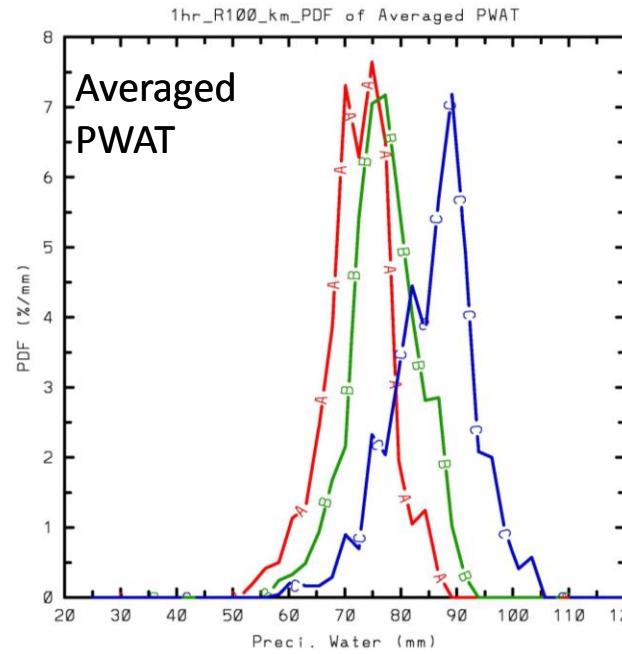
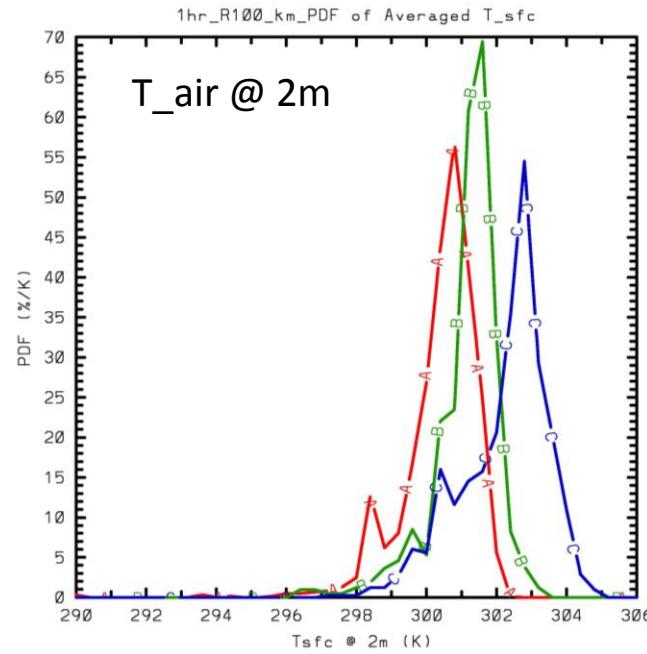


中度颱風以上影響台灣颱風個數統計

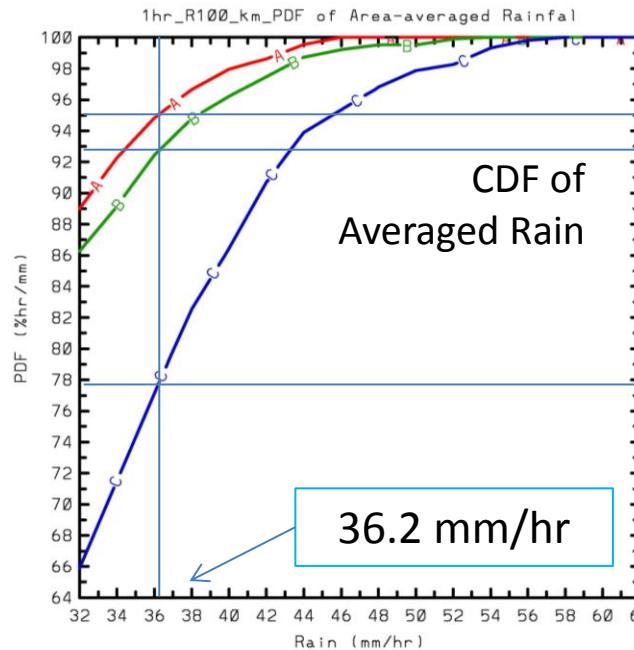
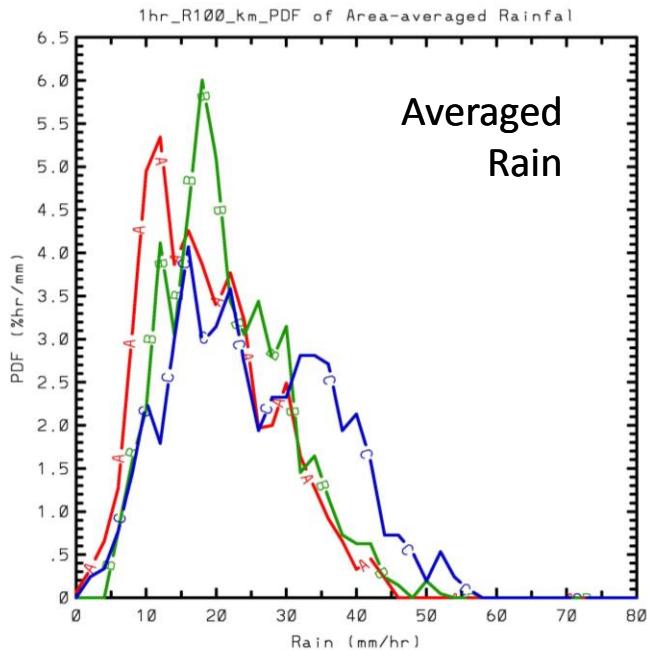


	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total	Per Year
1992-2010	0	0	0	1	1	6	10	22	16	10	2	0	68	3.7
1979-2003	0	0	0	2	4	8	21	17	14	6	3	1	76	3.04
2015-2039	0	0	1	1	2	6	19	12	12	5	1	1	60	2.4
2075-2099	0	0	0	1	4	4	17	18	5	8	2	1	60	2.4
				0	0	-0.50	-0.19	+0.06	-0.64	+0.33	-0.33	0		

PDF or CDF for R=100 Km for typhoon near Taiwan

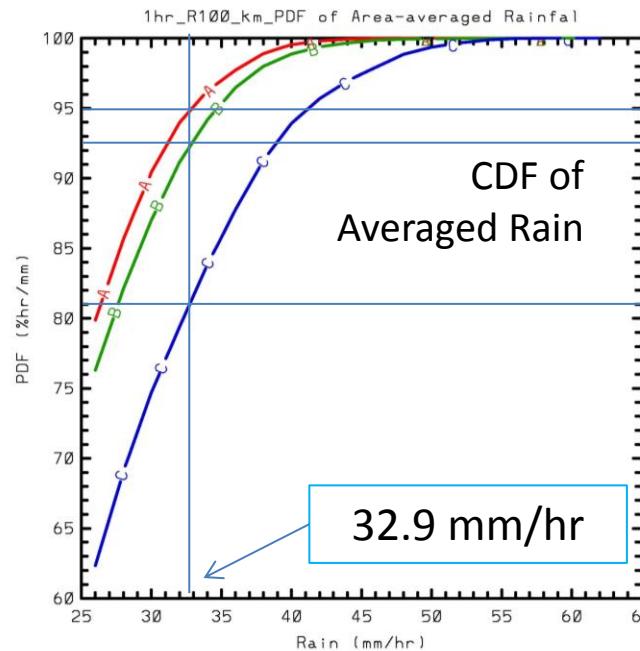
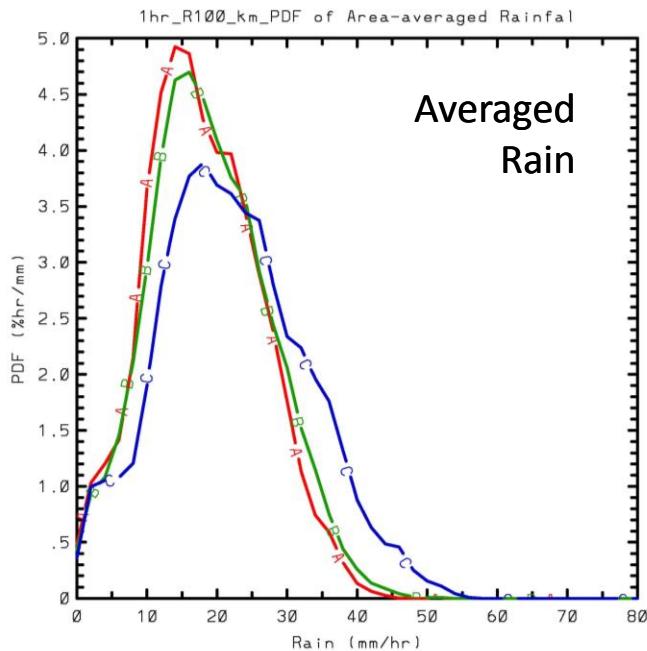
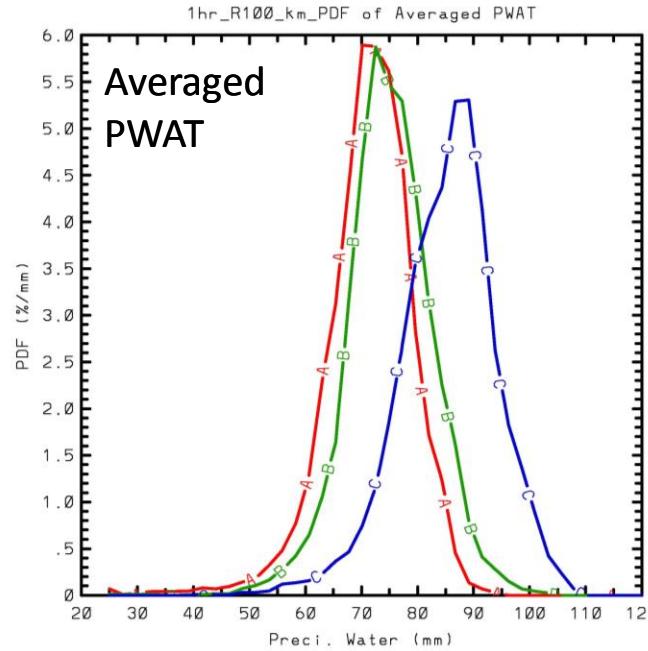
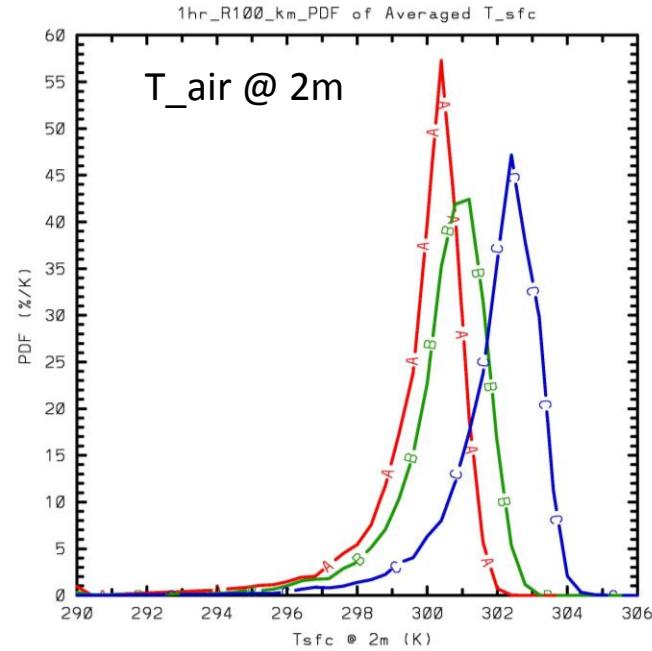


- Sampled from area averages at different time



Ratio of typhoon occurrence = 1:0.68:0.68
 $(1 \times 5\%) : (0.68 \times 7.33\%) : (0.68 \times 22.34\%)$
 $= 1 : 0.99 : 3.02$

PDF or CDF for R=100 Km



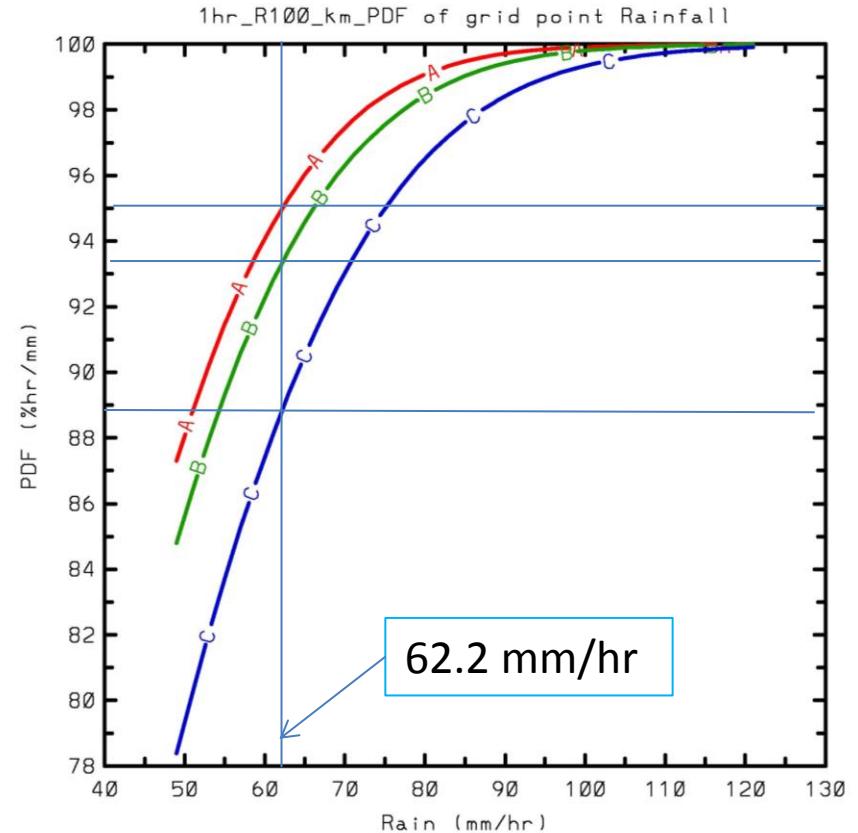
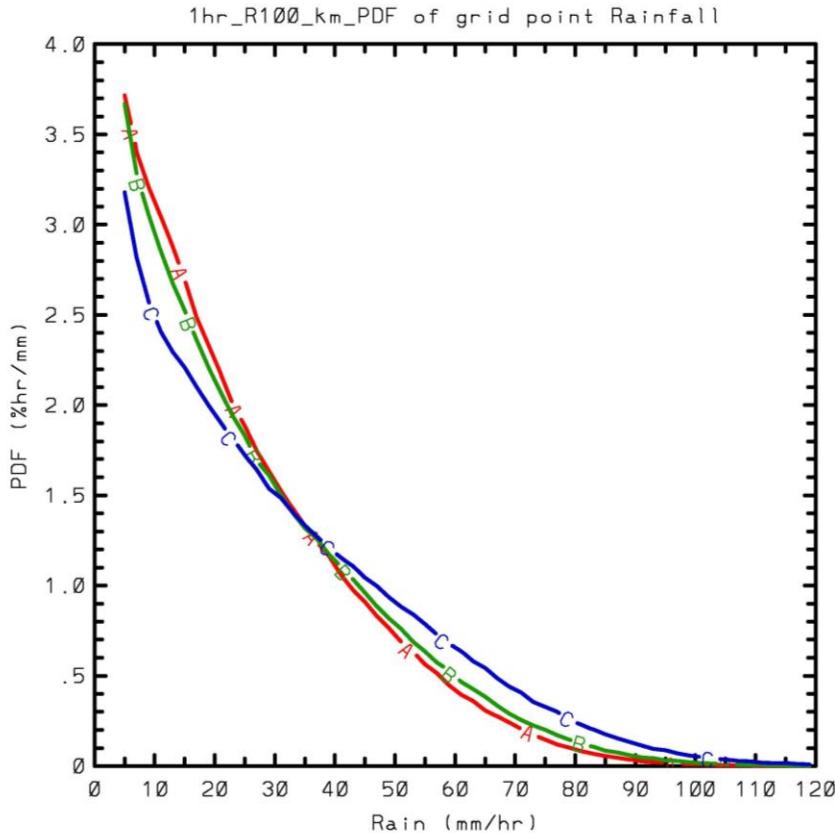
- 樣本取自所有颱風(中度以上)在生命期間, 颱風半徑<100km圈內的區域平均值

Ratio of Cat1 and greater
= 1:0.90:0.70

(1x5%) : (0.9x7.48%) :
(0.7x18.6%)
= 1 : 1.34 : 2.59

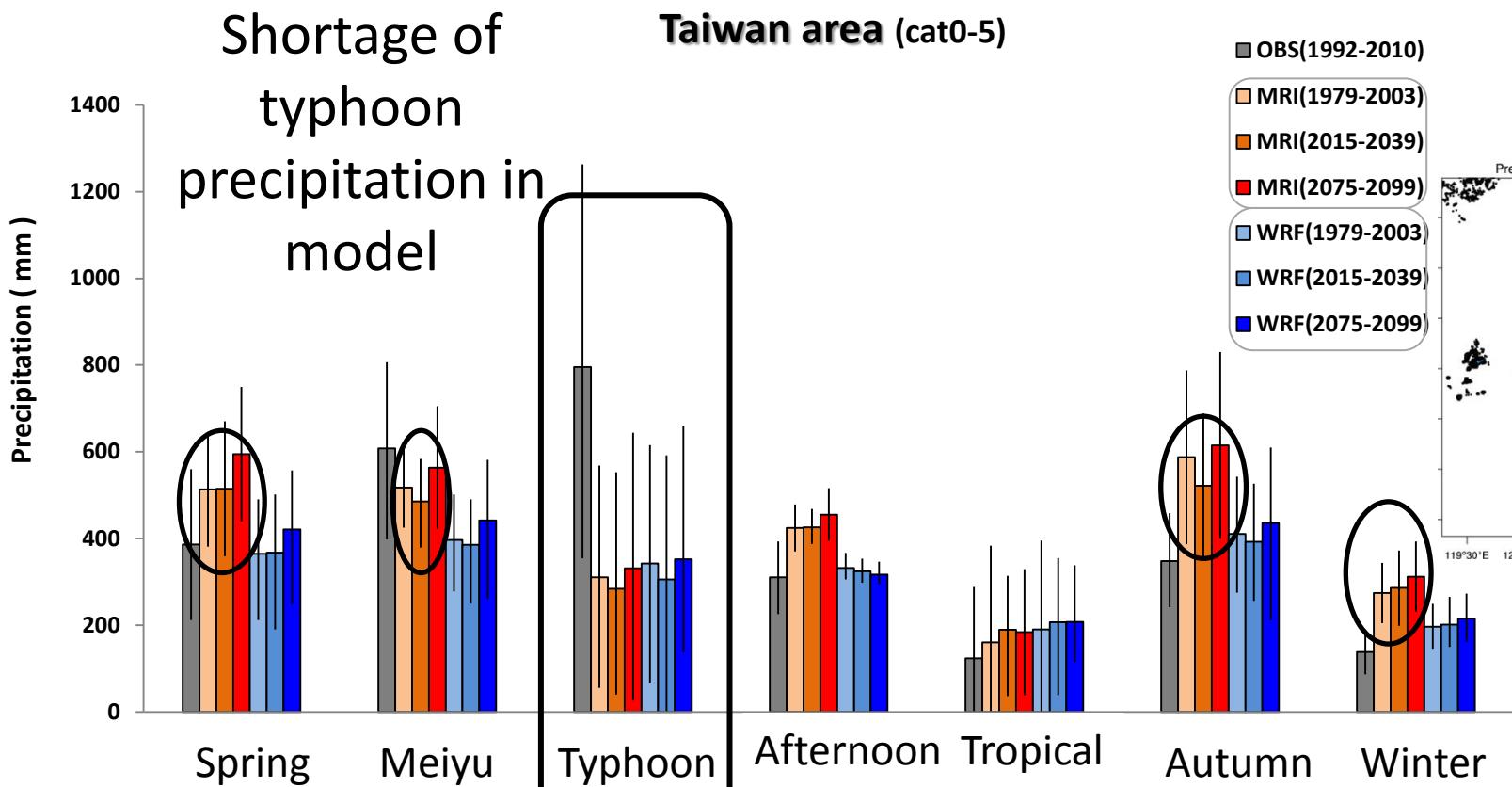
PDF & CDF for hourly rainfall at grid points

within R<=100 Km • 樣本取自颱風圈內的所有格點



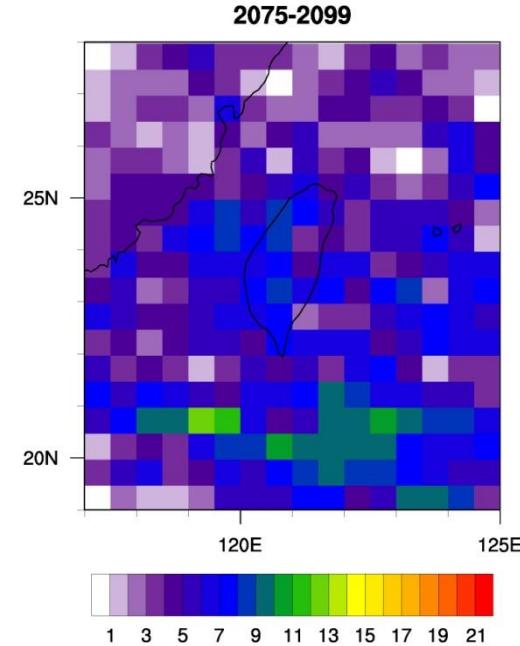
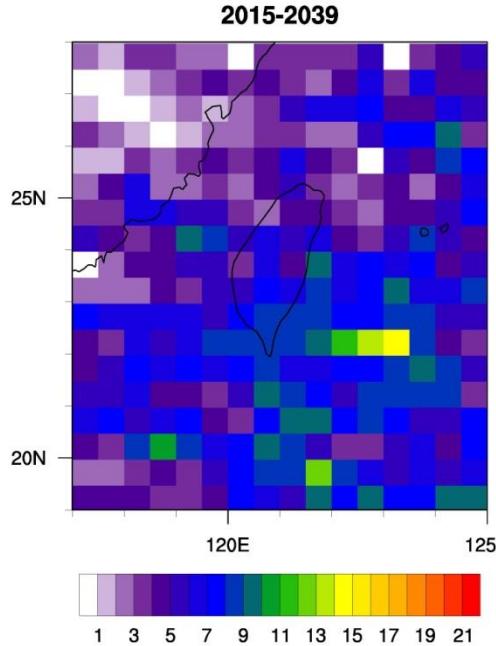
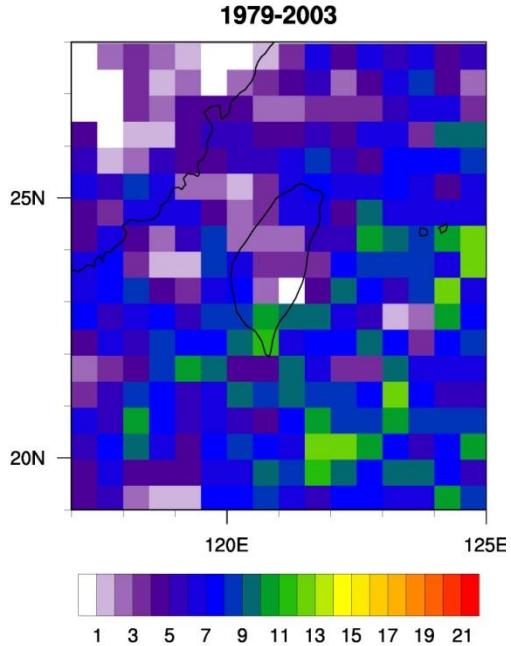
$$\text{Ratio of samples} = 1 : 0.89 : 0.71$$

$$(1 \times 5\%) : (0.89 \times 6.65\%) : (0.71 \times 11.14\%) = 1 : 1.18 : 1.58$$

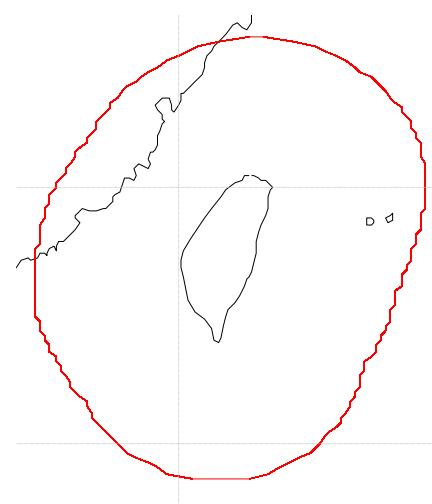
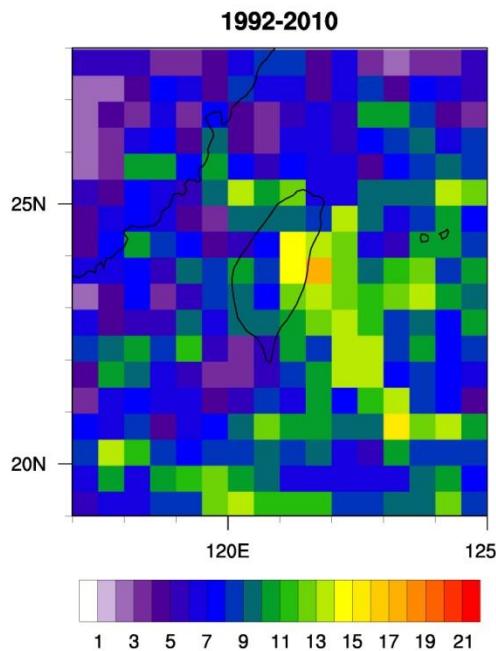
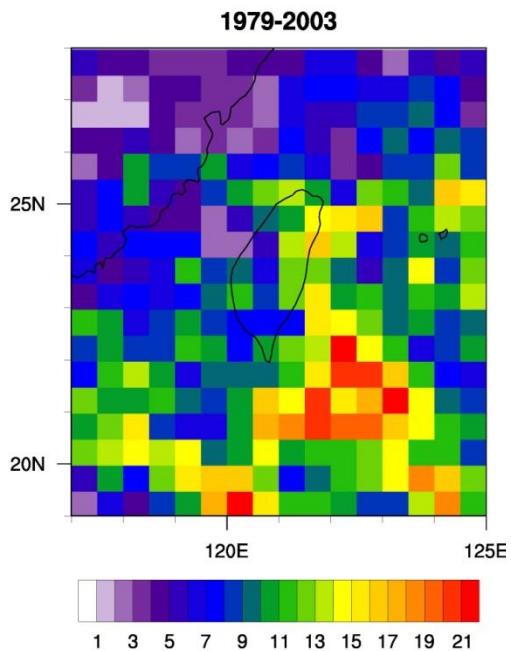


Mean Precipitation (mm/year)	MRI	WRF	OBS
Present	2728.6	2173.6	2709.6
Near future	2642.9	2125.2	
End of century	2953.6	2288.6	

MRI



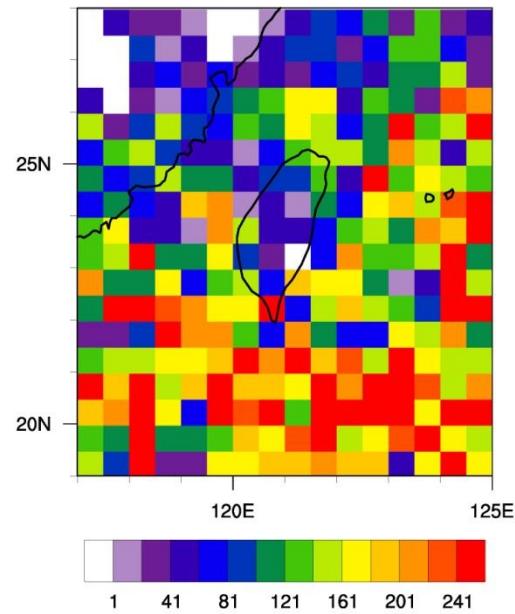
OBS



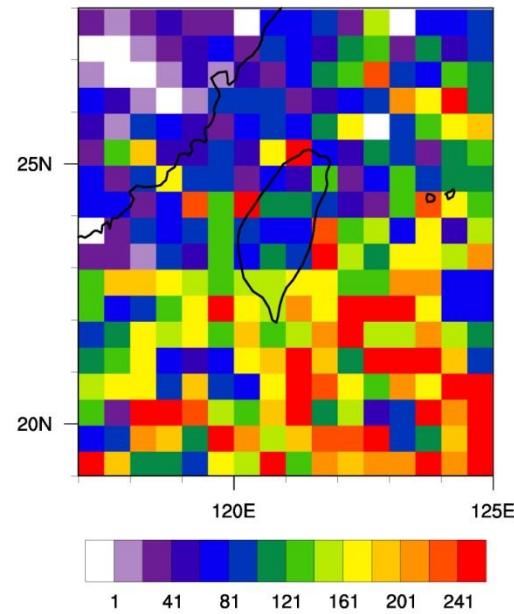
10 min

重覆計算

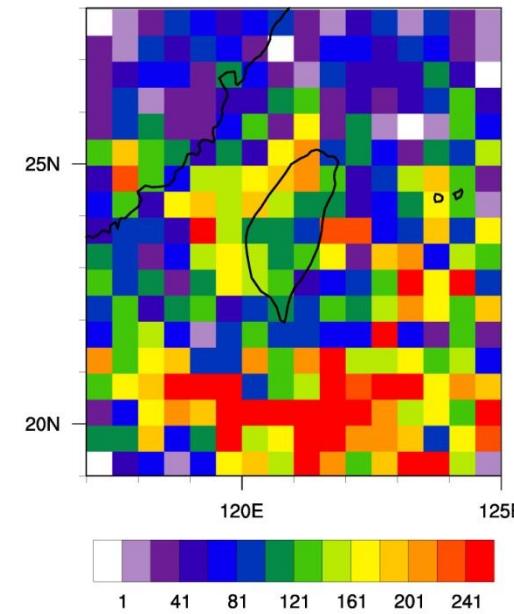
1979-2003



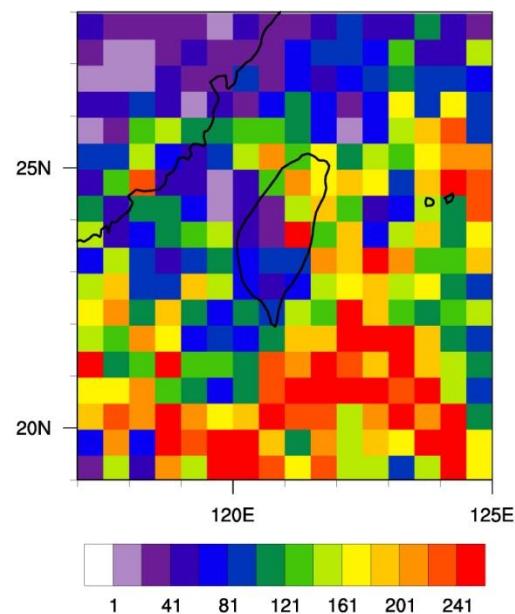
2015-2039



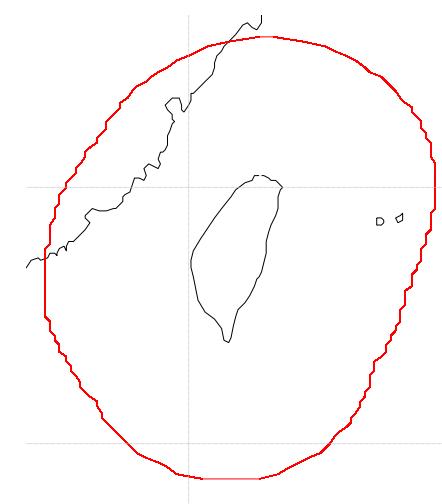
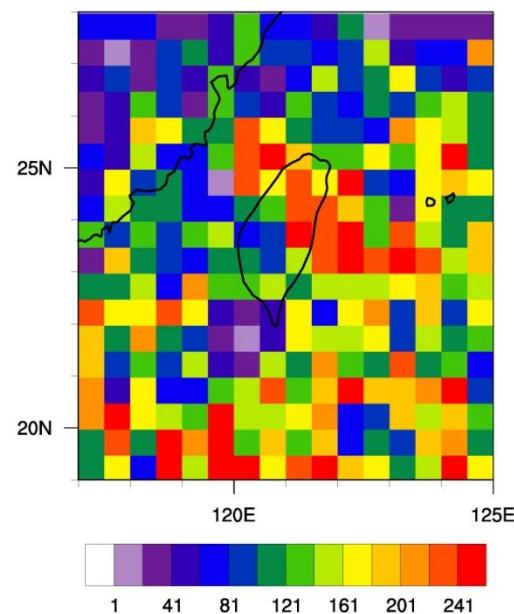
2075-2099

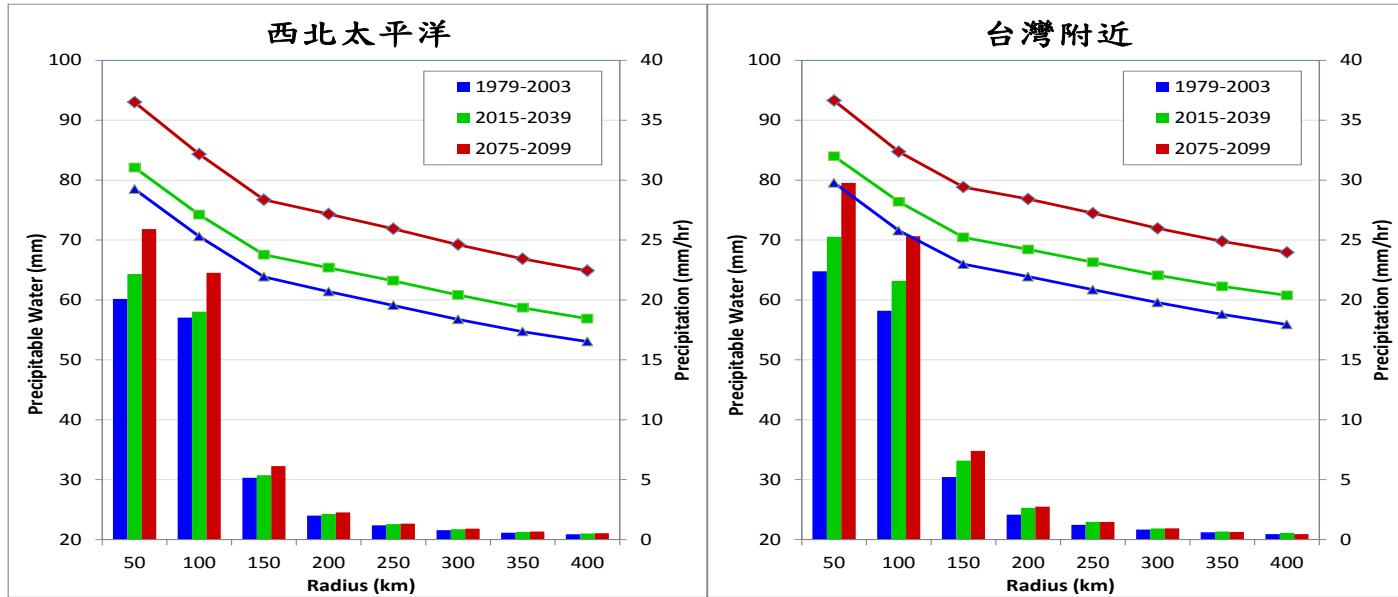


1979-2003



1992-2010





各時期的颱風內平均降水強度及水汽含量在颱風中心徑向上的分布。折線圖表示可降水量(左縱軸，單位：mm)、柱狀圖表示降水(右縱軸，單位：mm/hr)，橫軸表示距颱風中心的距離(單位：km)。

與現在時期相較模式推估未來西北太平洋以及臺灣附近的颱風內平均降水強度及水汽含量的改變在颱風中心徑向上的分布

		Radius (km)	0~50	50~100	100~150	150~200	200~250
PWAT	NWP	Near Future	4.6%	5.2%	5.8%	6.5%	6.9%
		世紀末	18.5%	19.5%	20.2%	21.1%	21.7%
	Taiwan	Near Future	5.6%	6.7%	6.8%	7.1%	7.4%
		世紀末	17.2%	18.4%	19.5%	20.3%	20.7%
Precip.	NWP	近未來	10.3%	2.7%	4.3%	6.6%	8.2%
		世紀末	29.0%	20.2%	18.9%	13.5%	12.1%
	Taiwan	近未來	12.8%	13.1%	26.2%	27.7%	20.6%
		世紀末	33.0%	32.5%	41.8%	32.9%	19.0%