Downscaling of Typhoon precipitation over Taiwan in climate projection

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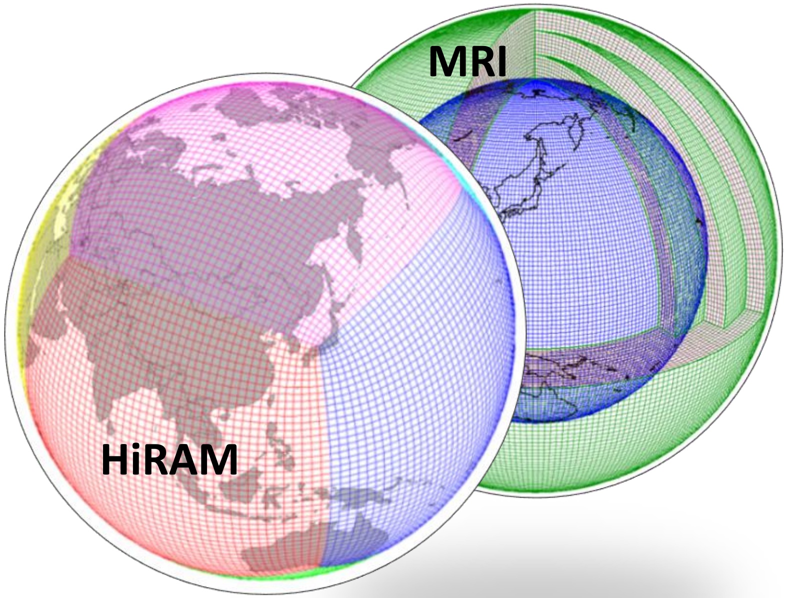
Out line of presentation

1. Dynamical Downscaling & Tropical cyclones (TCs)
2. Bias Correction of TC precip
3. Statistical Downscaling of TC precip

2-Tier Dynamical Downscaling in TCCIP

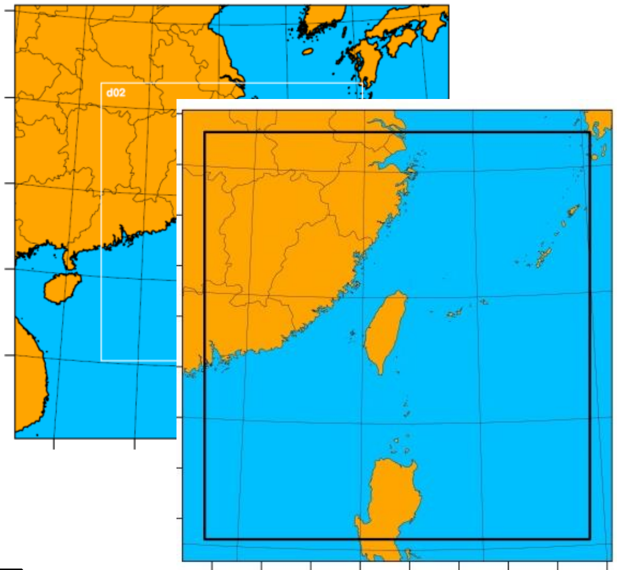
1. **High-Res AGCM simulation, driven by CMIP ensemble mean SST**
2. **High-Res RCM (WRF 5km) driven by high-res AGCM ensemble**

High-Res AGCM ⇨ 5 km RCM (WRF)



Projected circulation and SST

Initial, Lateral & Lower B.C.



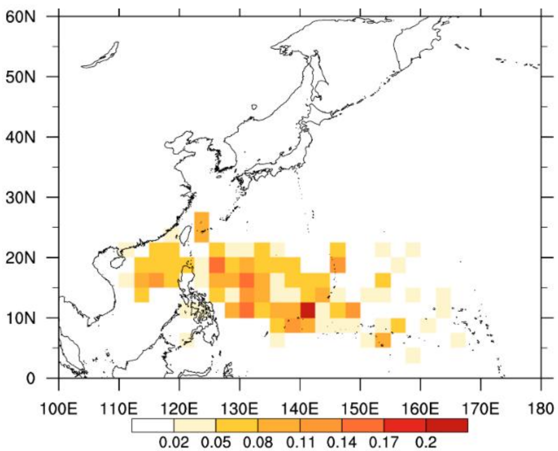
- ❑ Projections of time slices, 1979-2003, 2040-2065 and 2075-2099

- ❑ 1~2 nested domain.
- ❑ ΔX=15, **5** km
- ❑ Spectral nudging in D01 only
- ❑ **Cumulus in D01 only**
- ❑ **Ocean ML for TC simulation**

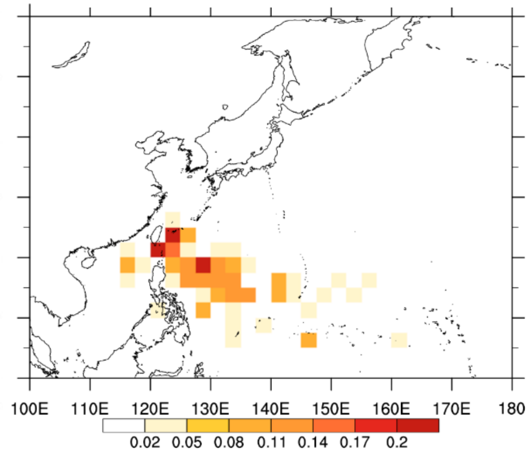
TCCIP MOST NCDR

Genesis of TCs affecting Taiwan

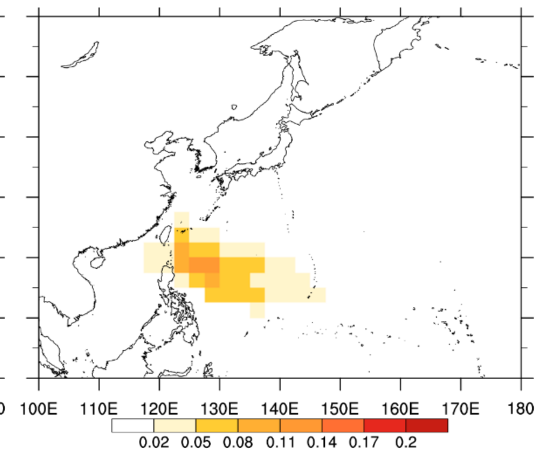
OBS IBTrACS

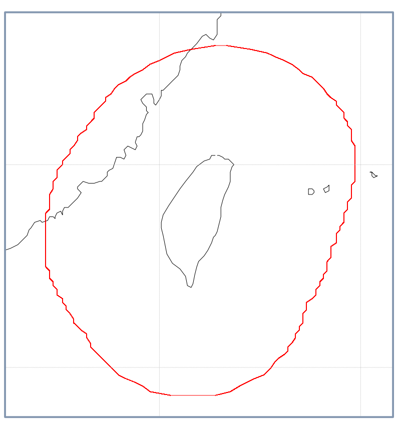


MRI-AGCM3.2S

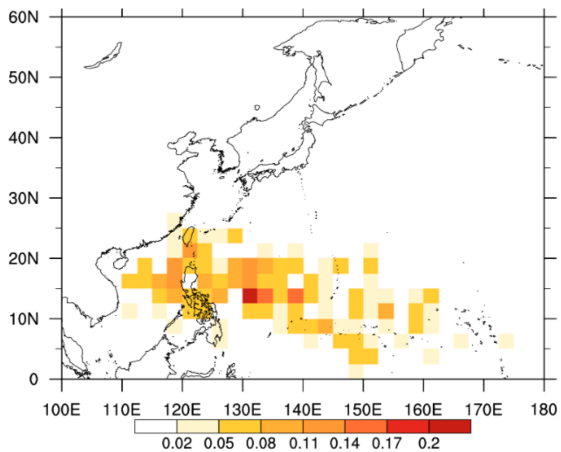


MRI-AGCM3H.2 D4PDF

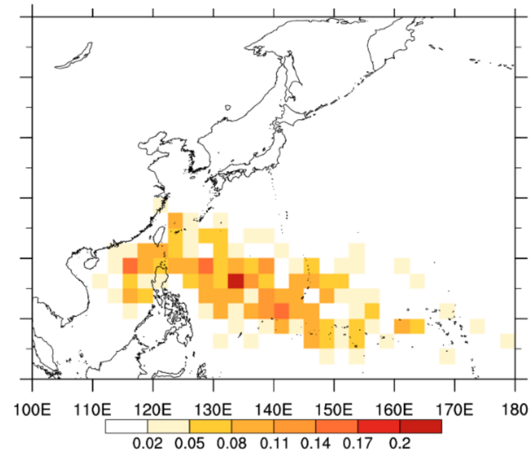




HIRAM C384



HIRAM C192



Genesis of TCs affecting Taiwan

TC Ann. Freq.	OBS 1979 2015	MRI-AGCM (20km) 1979 2003	MRI-AGCM (60km) 1981 2010	HiRAM C384 (25km) 1979 2015	HiRAM C192 (50km) 1979 2015
# per year	4.7	3.2 (-32%)	3.1 (-34%)	4.7 (-)	5.3 (+13%)

- Annual Freq and genesis areas in HIRAM were reasonably simulated.

- In MRI-AGCM, gensis area is smaller, and annual freq were underestimated by 30 %

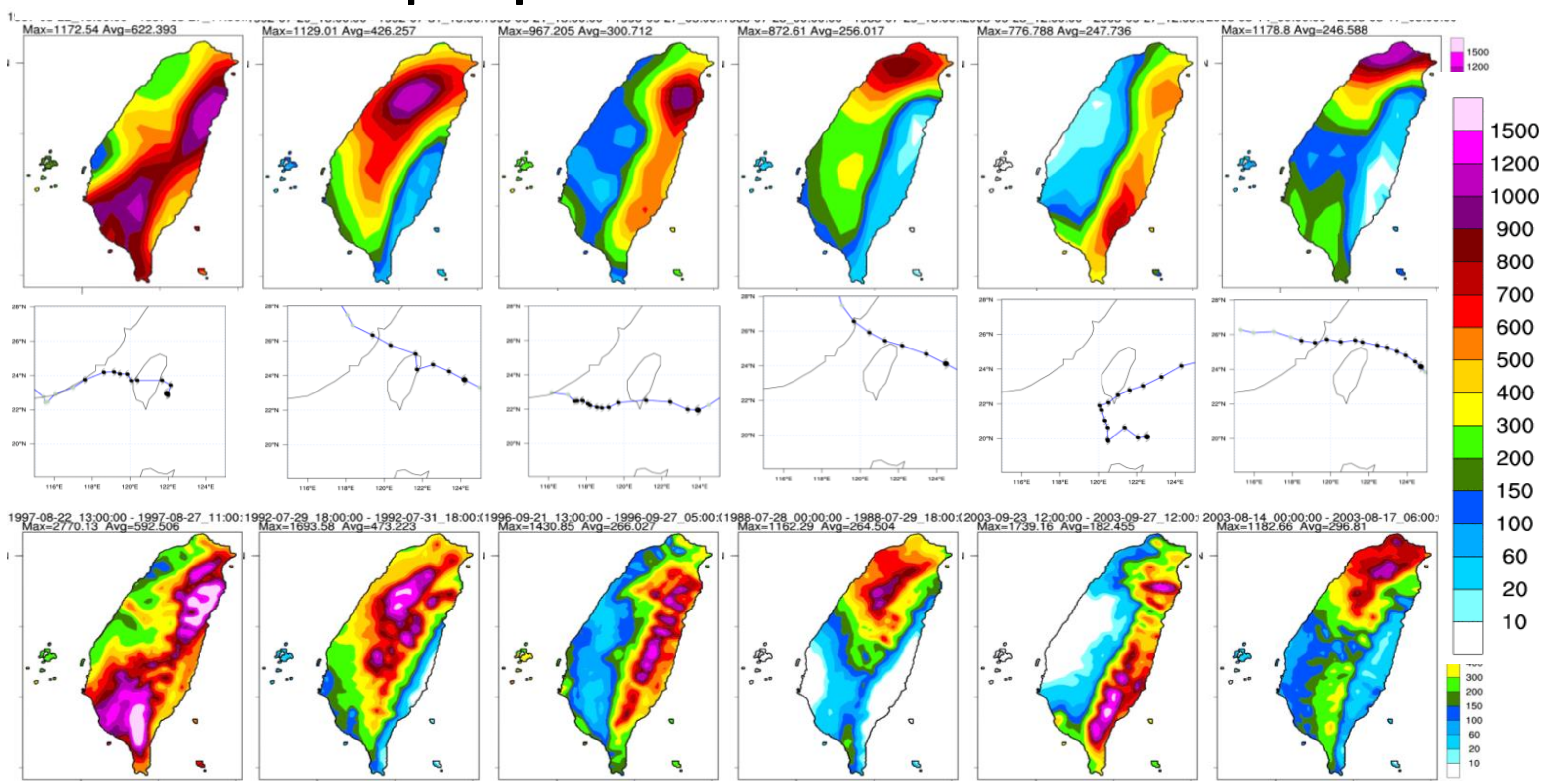
Simulated TC precip over Taiwan

- High-res. AGCM looks good, RCM does better job, giving more realistic rainfall. RCM also fix the TC intensity overestimation by MRI and underestimation by HIRAM

TC precip. of MRI-AGCM3.2S and WRF

MRI-AGCM
3.2S

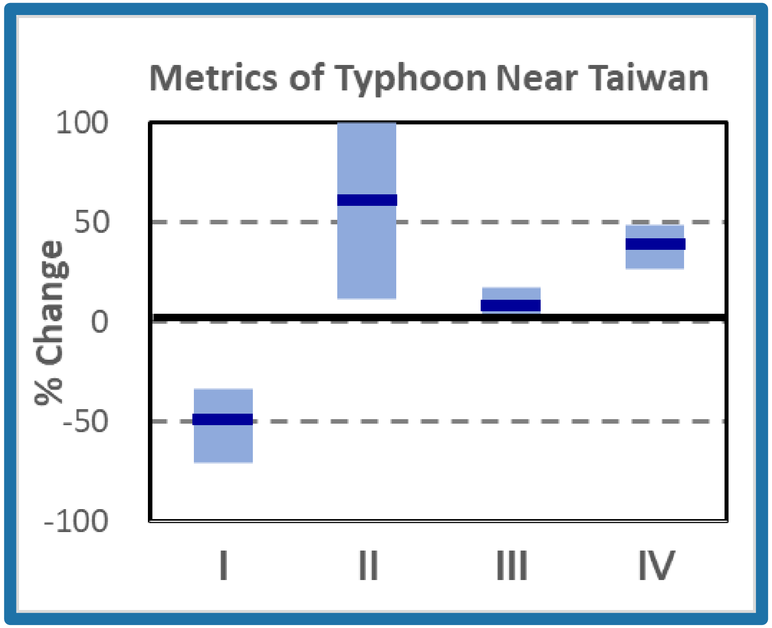
WRF
5km



Future changes of TC projected by MRI-WRF ensemble

- Through WRF downscaling, simulations of TCs were improved
- With the help of 4-member ensemble, 4 metrics for TCs affecting Taiwan can be calculated

Metrics @ Lifetime Max. Intensity

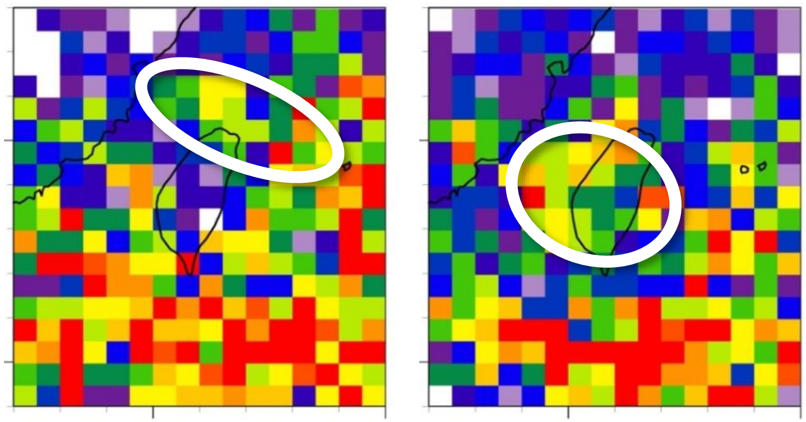


- (I) annual freq., -49%
- (II) freq. of Cat. 4&5, +61%
- (III) mean Max. Int. +8%
- (IV) precip within 200 km +39%

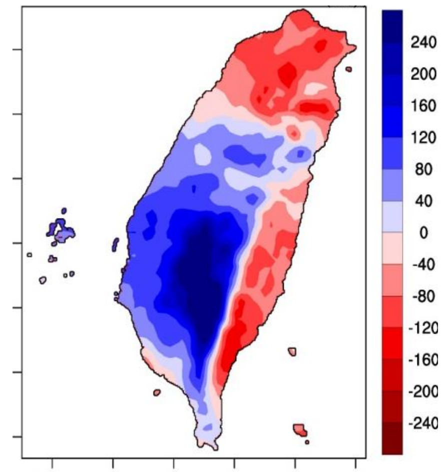
Issue of track projection & local TC precip changes

TC center Track Density

1979-2003 2075-2099



TC rainfall Change (%) in
2075-2099 vs. 1979-2003



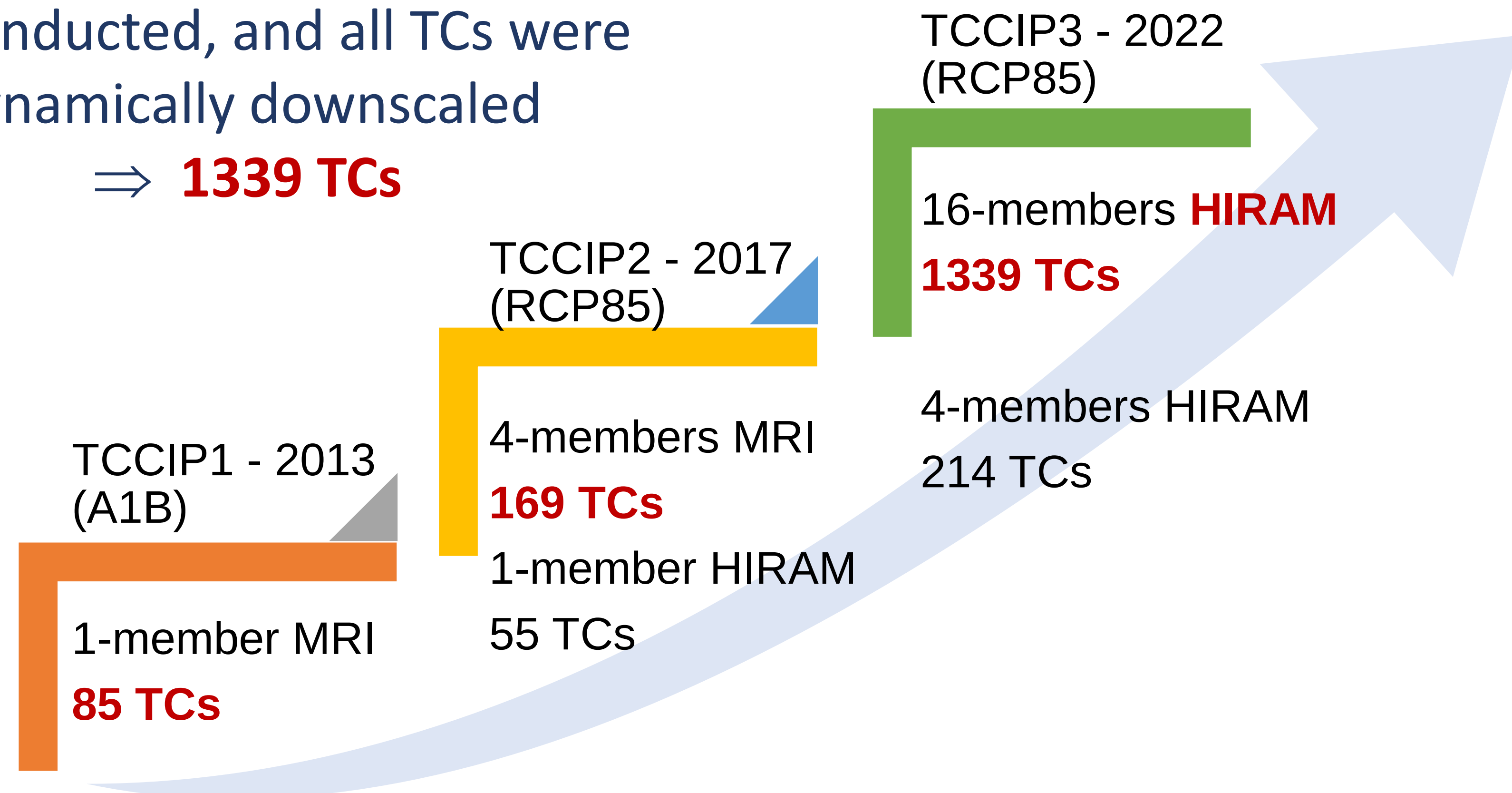
- Highly uncertain TC track changes may dominate the precip changes, and obscure the effect of warming on precip

- A large TC sample to analysis is what we pursuit in TCCIP, it not only gives us more reliable results it also help to minimize the influence of track difference

Task 1: increasing TC number

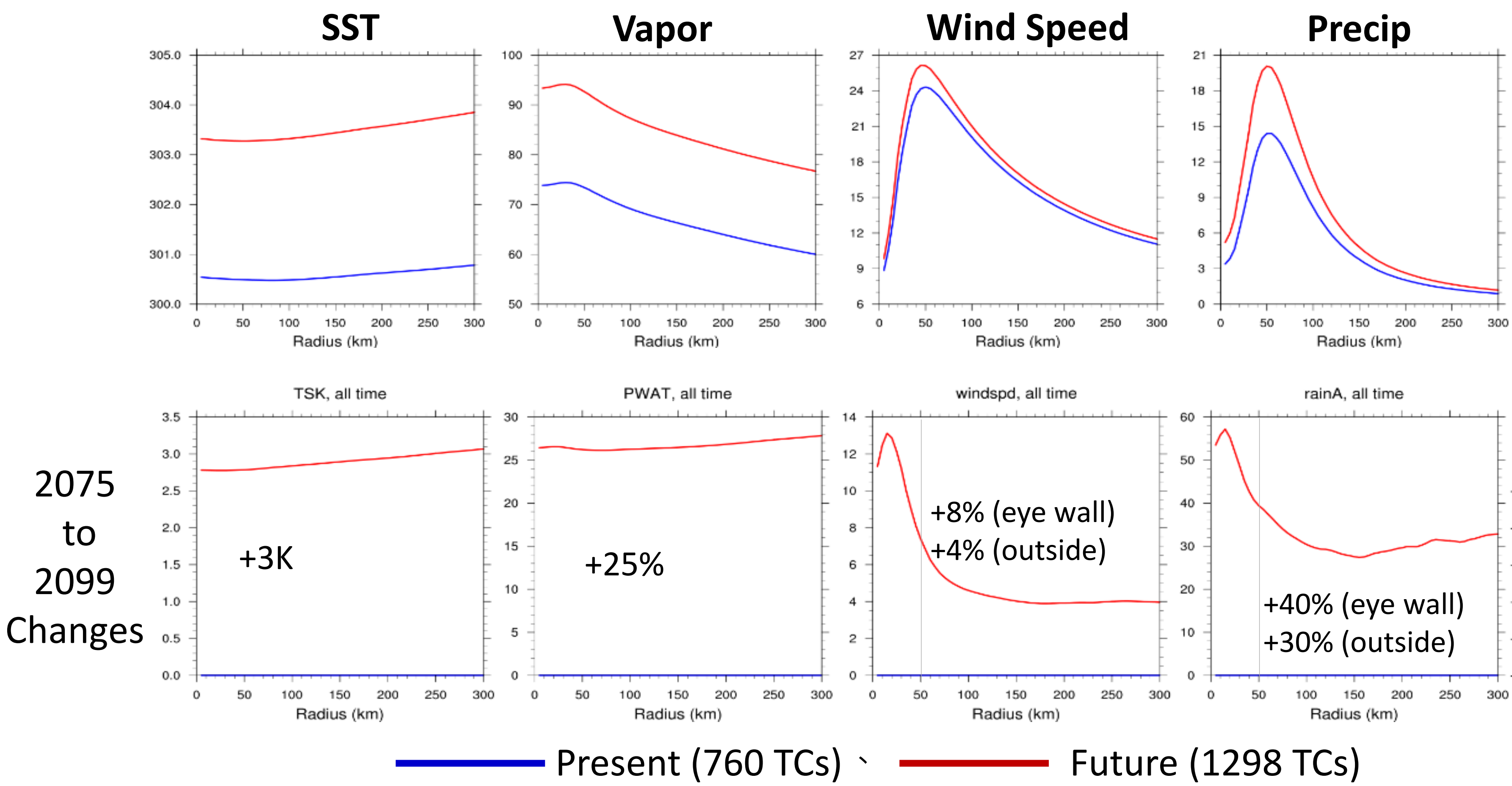
- To have more TCs, 4/16-member ensemble simulations were conducted, and all TCs were dynamically downscaled

  ⇒ **1339 TCs**



TC # available for analysis keeps increasing

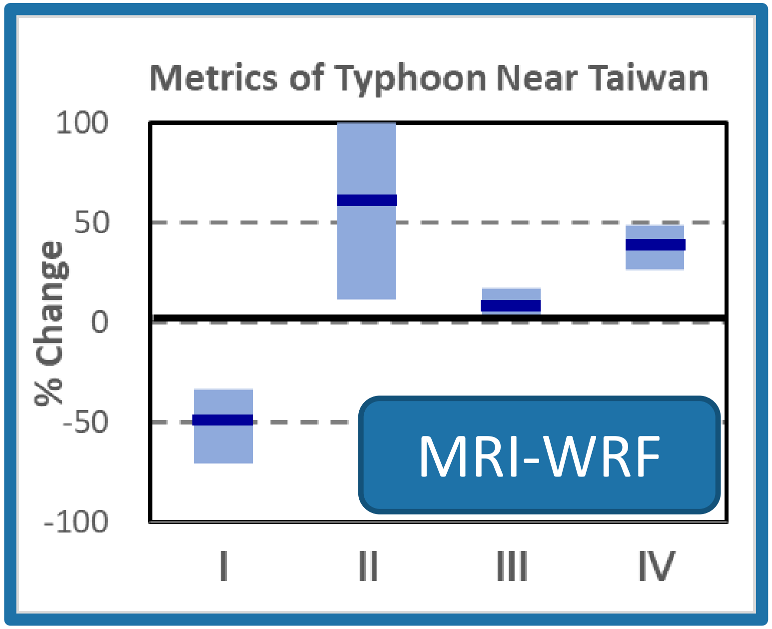
Climatology and changes of TCs structure in HiRAM-WRF



- SST +3K, Vapor +25%, Wind +4~8%, precip +30~40%

Metrics of TC changes in HiRAM-WRF

Metrics @ Lifetime Max. Intensity



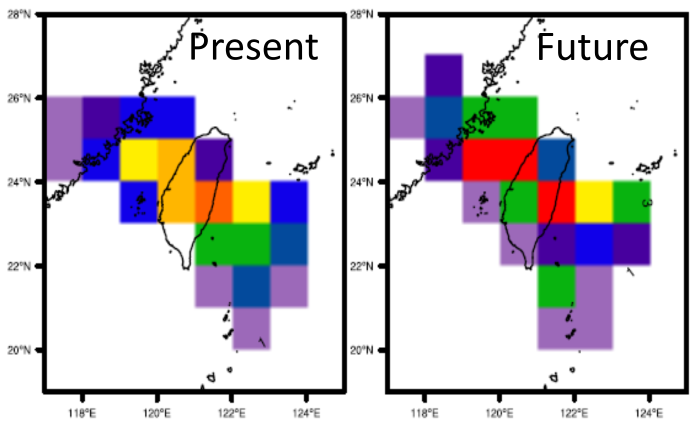
Changes	MRI-WRF	HiRAM-WRF
I. Freq.	-49%	-43%
II. Freq. of Cat 4-5	+61.1%	+124%
III. Max Intensity	+8.4%	+7.6%
IV. Precip of Max. Int	+38.5%	+28.7%

- 760/1300 TCs in HIRAM-WRF ensemble have similar tendencies of TC metrics as in MRI-WRF ensemble.
- HiRAM-WRF has higher change in the Freq. of Cat 4-5 TCs

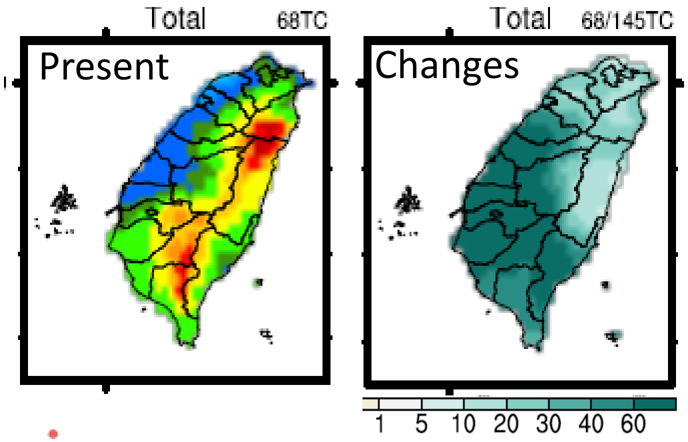
TCCIP MOST NCDR

Classification of TC as 9 types

Type-3 TC Track density
With good similarity



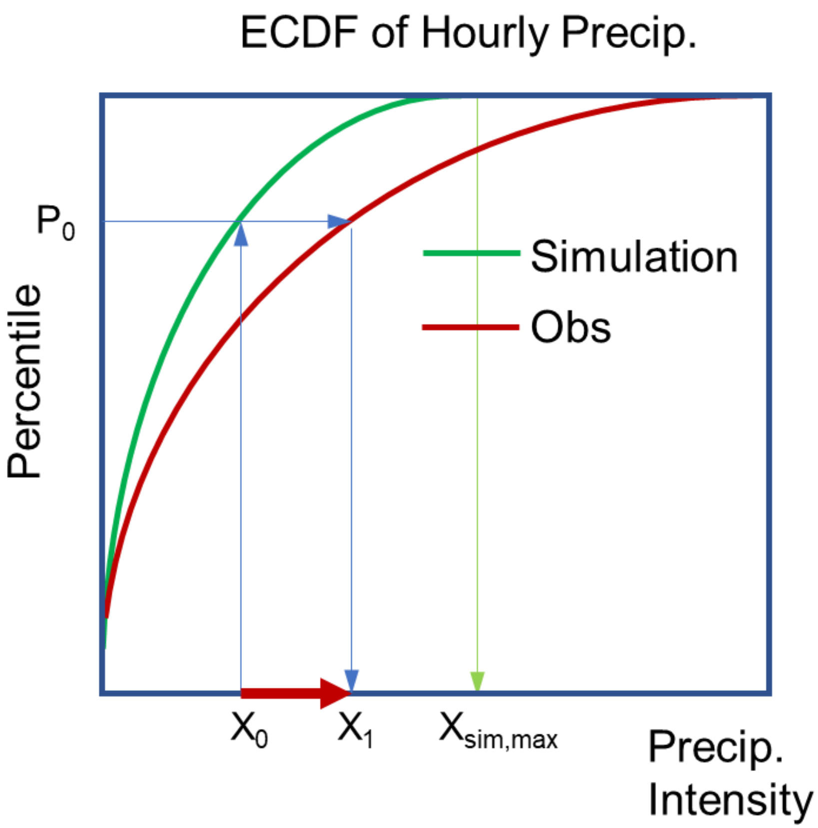
Precip (mm/hr) & Changes (%)



- Based on tracks, TCs from HiRAM-WRF were classified as 9 different types.
- With similar tracks, fair comparison of TC precip were expected
- Large sample size give us more liable results
- For type-3 TCs, future TC precip increase for the whole island.

TCCIP MOST NCDR

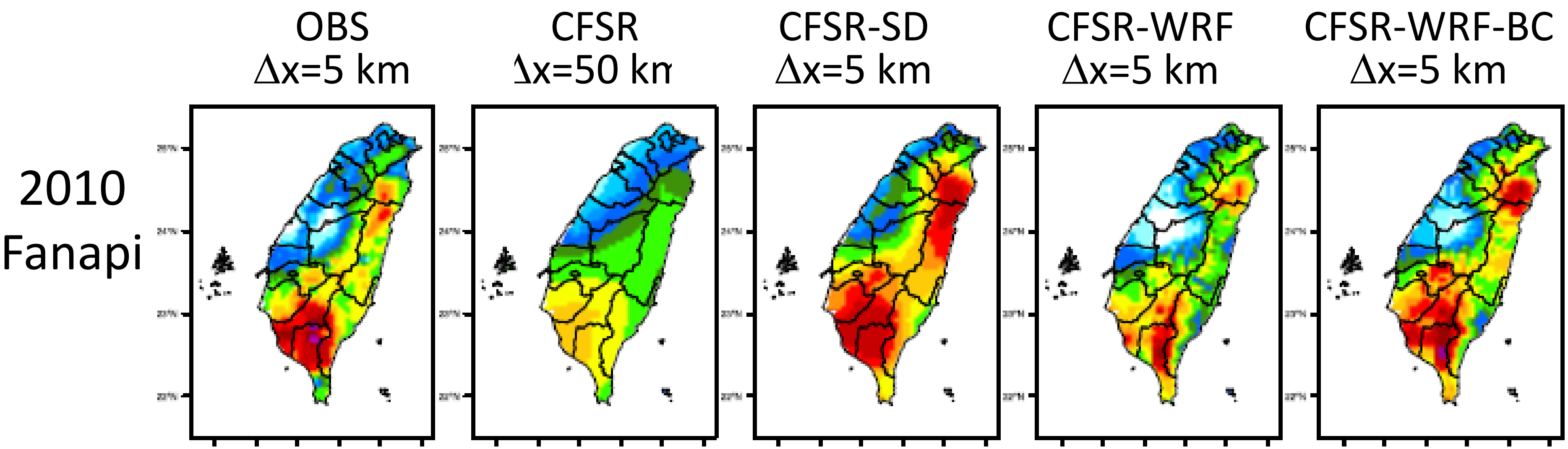
Bias Correction (BC) of hourly TC precip.



Transfer function $T(X_0) = X_1 \div X_0$

- For better impact assessment, a BC module considering locations of grid points and locations of TC center, were developed.
- Quantile mapping the ECDF of hourly precip approach was adopted.
- Transfer function is linearly decreased to 1 to a preset maximum value when extrapolation is needed ($x > X_{sim,max}$).

Test BC on CFSR-WRF and CFSR-SD.

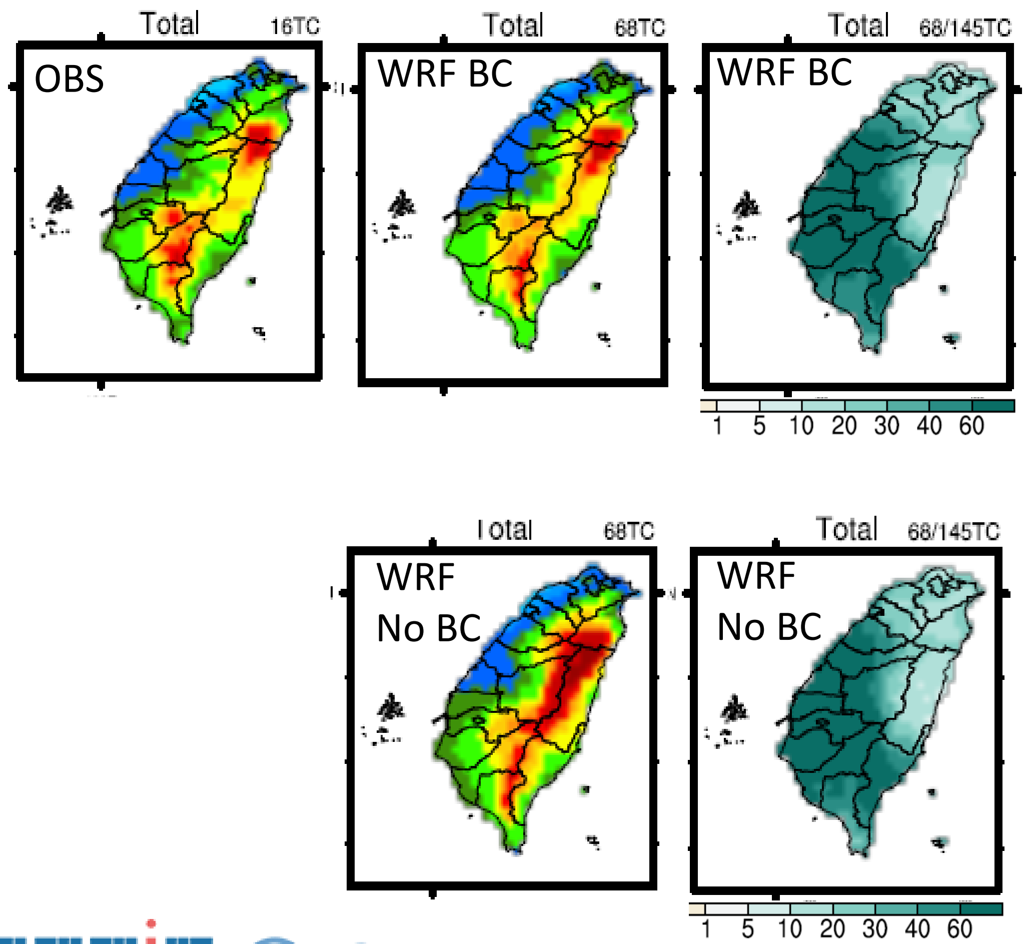


- BC can adjust rainfall intensity, getting better result
- BC can’t fix everything when difference is big.

Changes in local TC precip of 9 types

Type-3 TCs

Precip (mm/hr) & Changes (%)

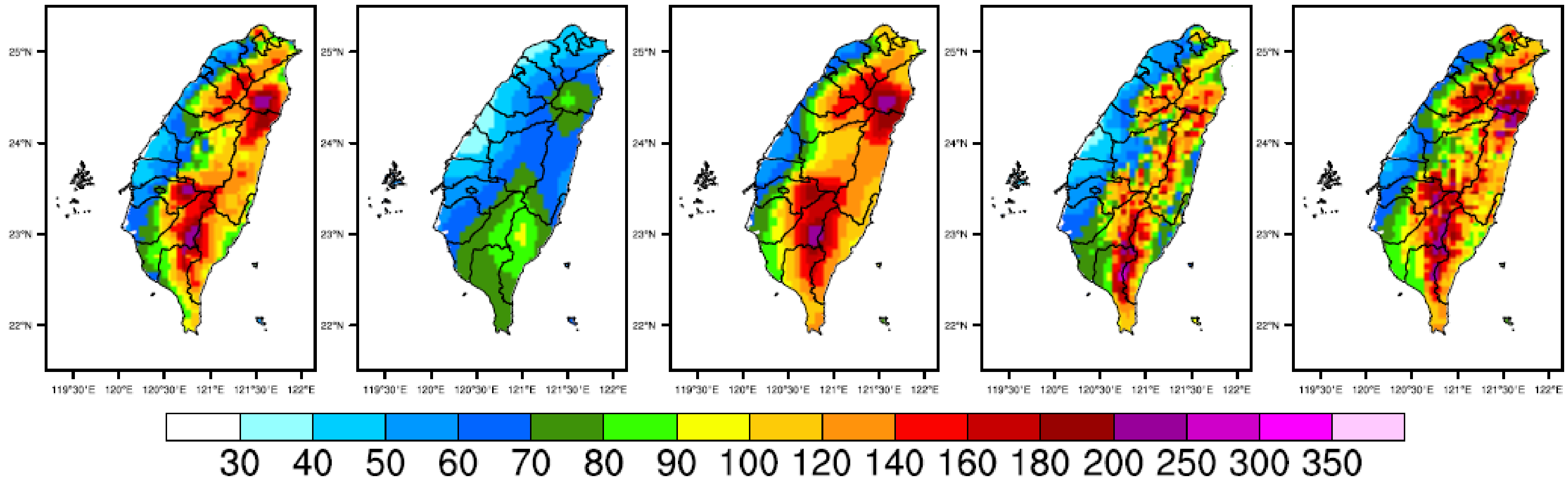


- BC gives us better results
- BC results in minor effect on future change rates

Climatology of Obs and downscaled TC precip.

Mean precip of historical TCs since 1992-2010 (mm/event)

OBS CFSR CFSR-SD CFSR-WRF WRF-BC

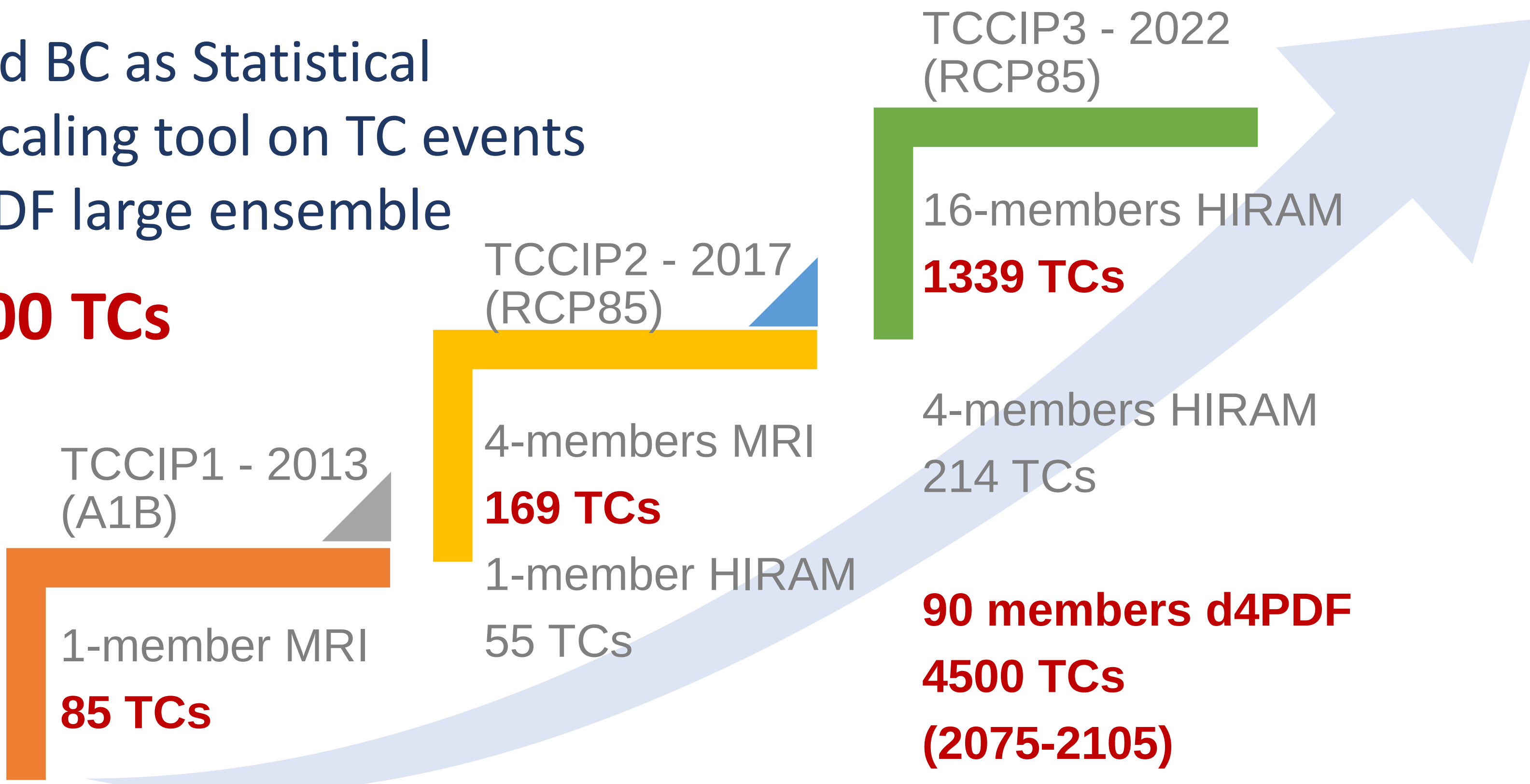


- BC can adjust rainfall intensity to proper values
- BC can’t fix much when the origin is poor
- Using BC as a S.D. Tool on GCM data seems to work well

Using TC precip BC as a SD tool

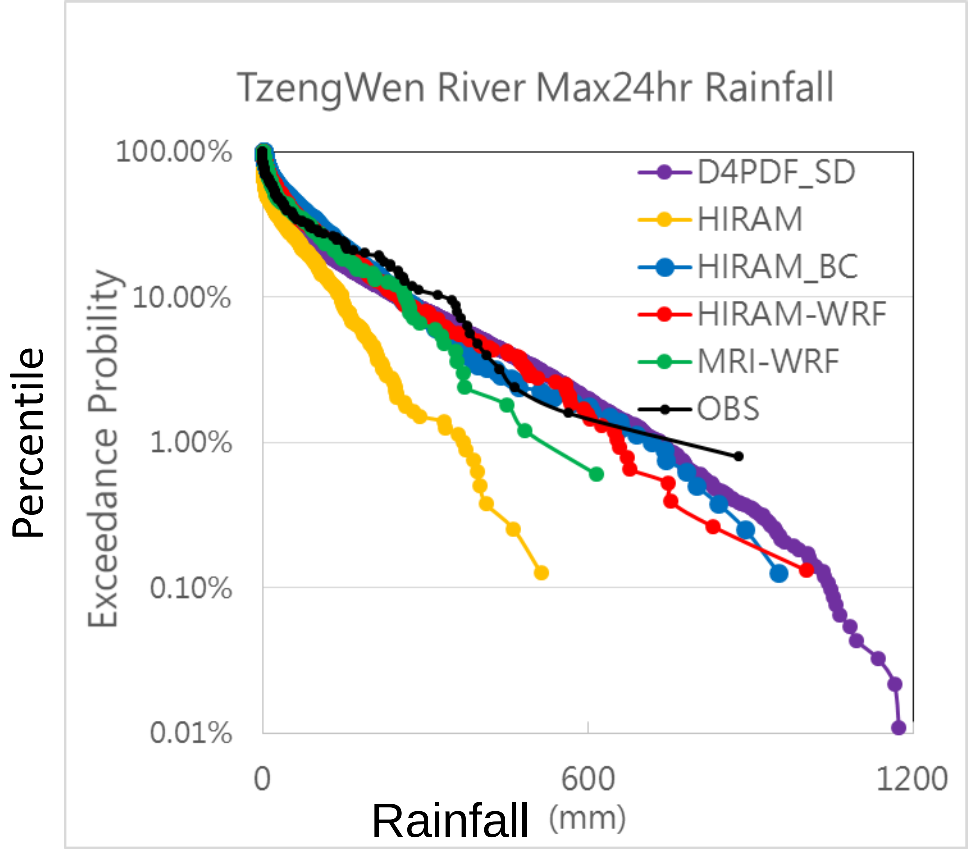
- TOUGOU-C provided TC tracks and hourly precip. of D4PDF
- Applied BC as Statistical Downscaling tool on TC events of D4PDF large ensemble

⇒ **4500 TCs**



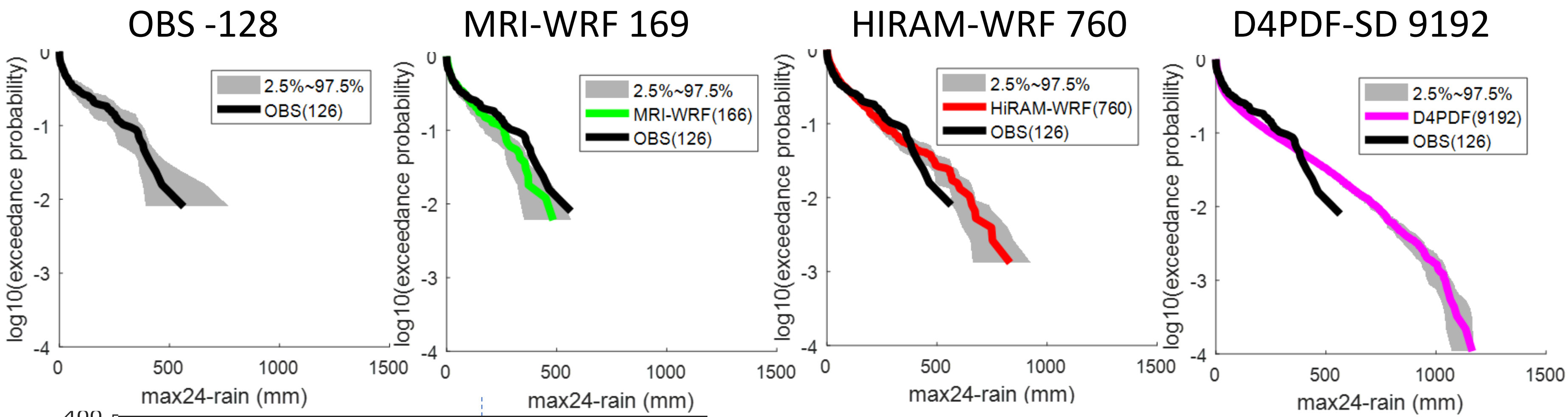
TC # available for analysis keeps increasing

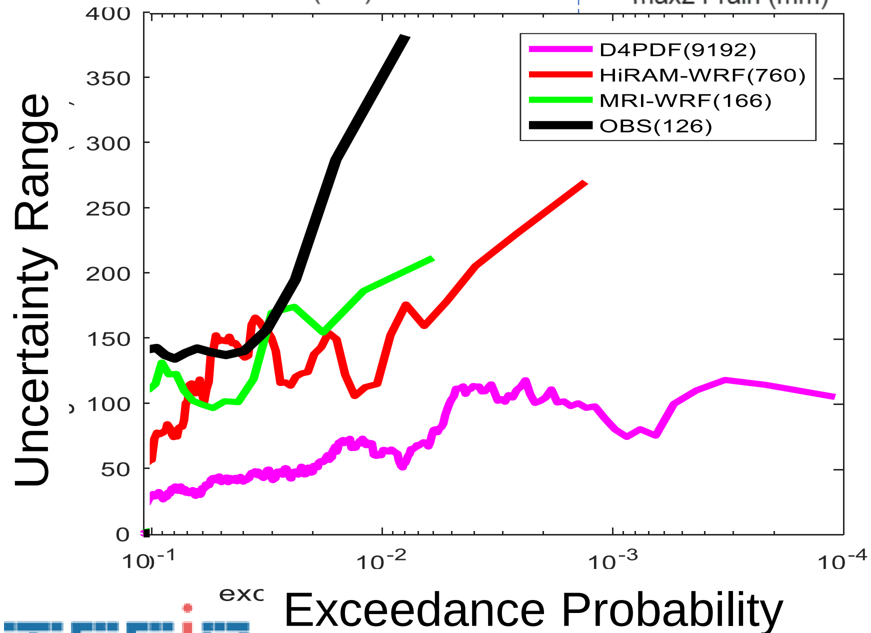
Frequency analysis of Local Impact with larger TC sample



- Taking Max24hr area-averaged TC precip of Tzengwen River basin as example
- All BC TC precip have similar exceedance probability distribution
- D4PDF allow us to explore the impact of more extreme events

Estimate the confident levels of different data





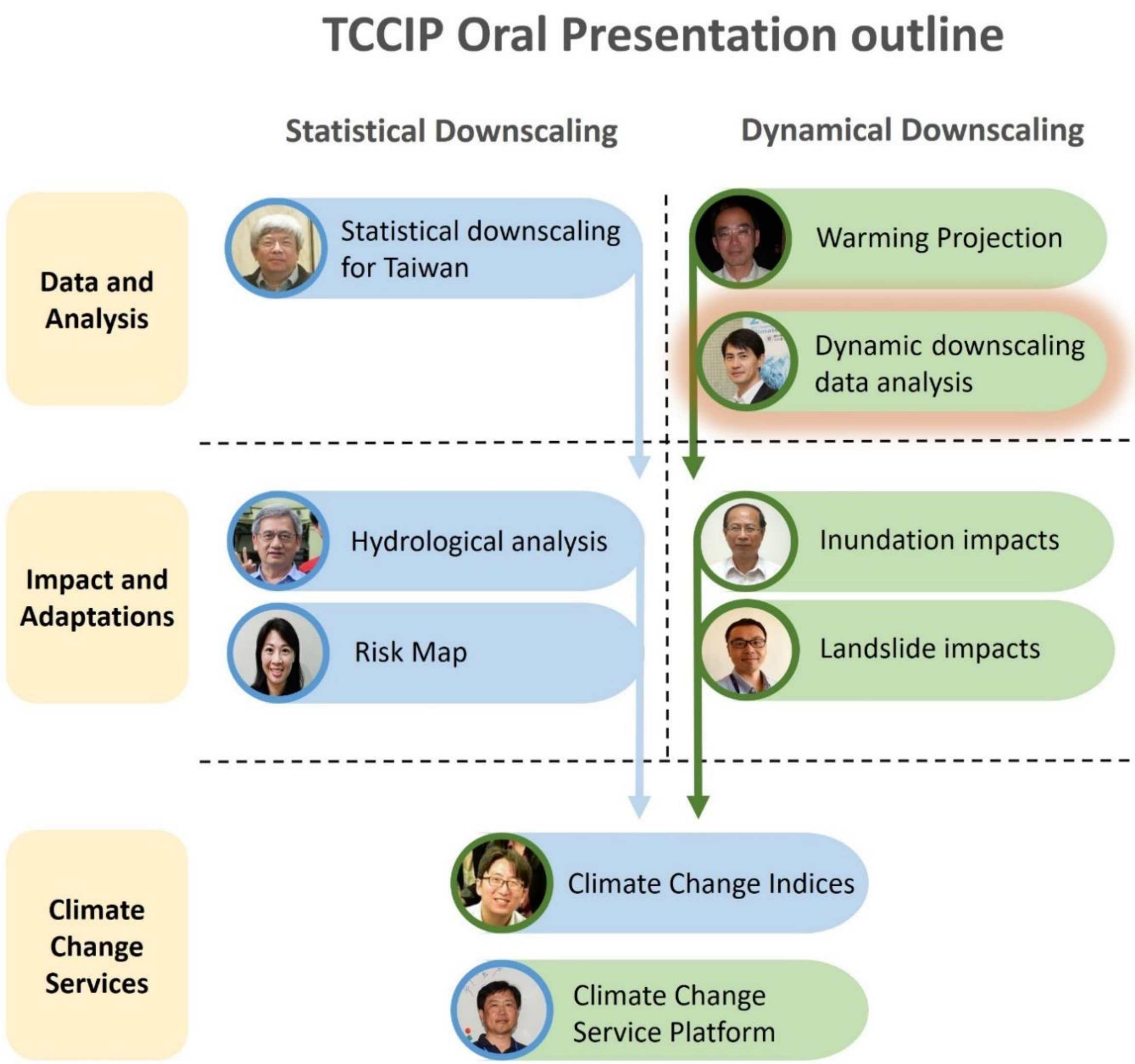
- Bootstrap, resampling 1000 times to estimate 95% confident interval as uncertainty range.
- Extremes with lower exceedance probability is with larger uncertainty
- The longer the data records, the smaller the uncertainty range

Conclusion

- With Dynamical Downscaling, a larger number of high-resolution TC data were produced (166/169 TCs from MRI ensemble, 790/1339 TCs from HIRAM ensemble). On averages, SST +3K, Vapor +25%, wind +4~8%, precip + 30~40 % for future TCs

- With help of Bias Correction, TC precip can be adjusted to proper values, suitable for impact assessment. It has minor effect on future changes. It can be used as a statistical downscaling tool

- Statistical Downscaling on precip of 9200/4500 TCs from D4PDF large ensemble is doable, giving us another way to produce a large sample TC data. More reliable hydrology frequency analysis for local impact study can be expected.

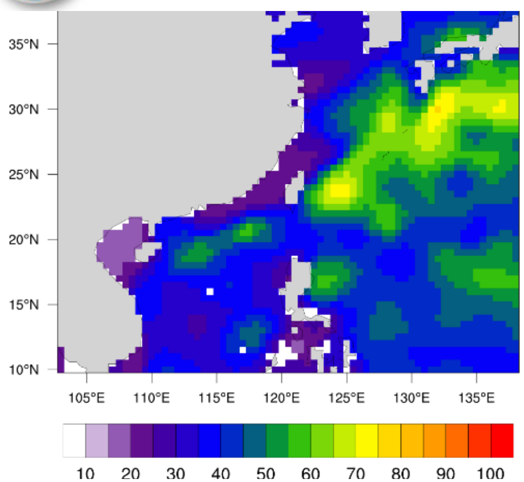


In Prof. Yeh's and Dr. Li's presentations, TC precip of MRI-WRF ensemble were used in their study.

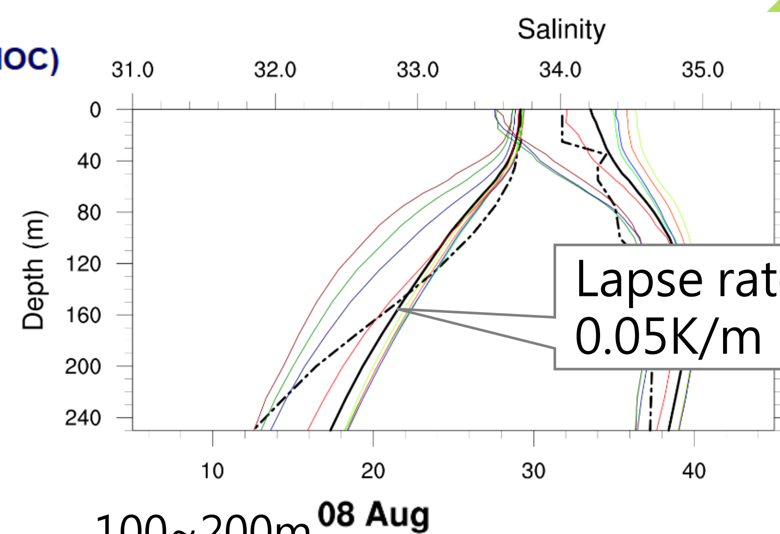
Thanks for your attention!

WRF Ocean Mixed Layer OML module

Monthly Isopycnal & Mixed-layer Ocean Climatology (MIMOC)

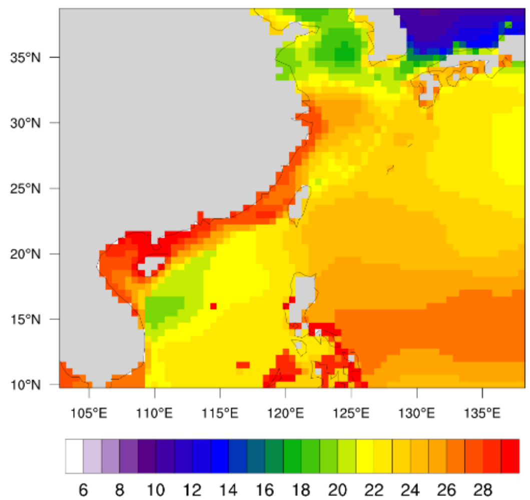


Depth of ML (-5% @ end of 21st century)



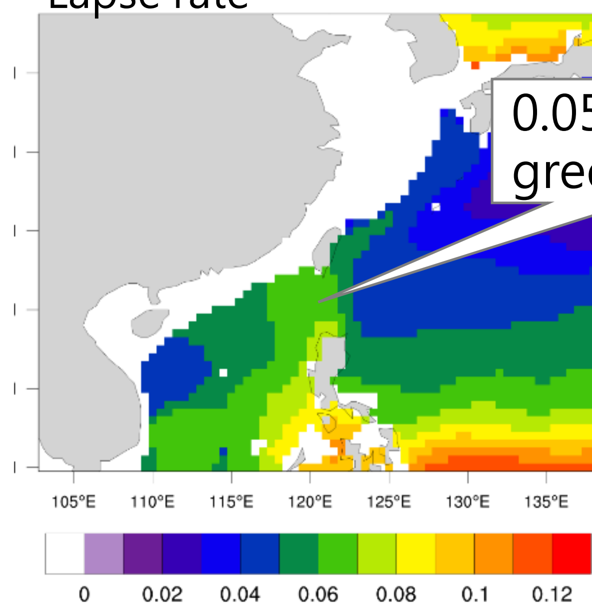
Lapse rate ~ 0.05K/m

100~200m Lapse rate



Mean T @ 0~200M

Climatology of monthly an area mean T is used



0.05K/m in green shade

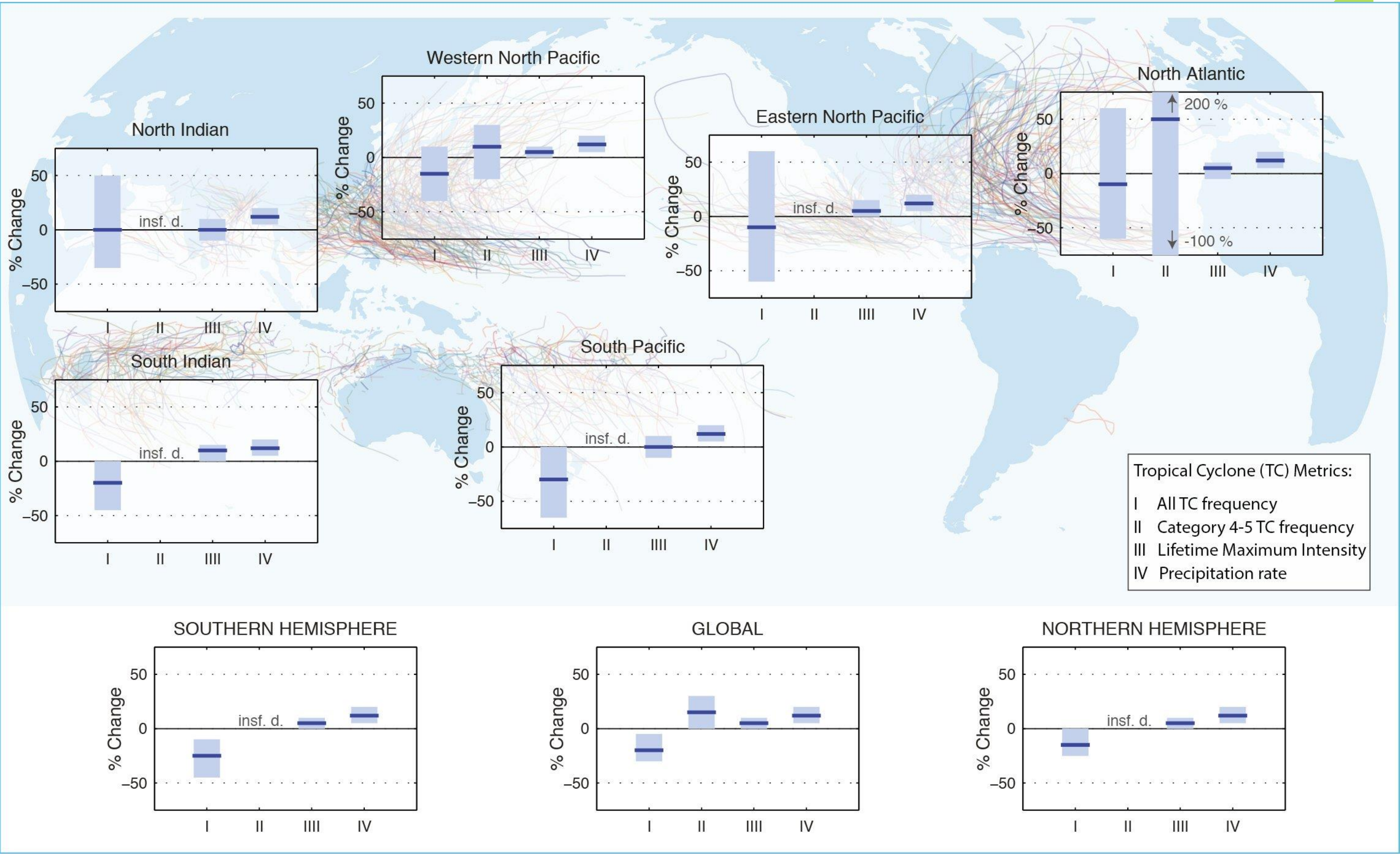
Freq. of TCs of 9 different tracking types

Type	OBS 1958-2015 (191)		MRI 1979-2003 (166)		HiRAM 1979-2015 (790)		WHIRAM 1979-2015 (760)	
	#	%	#	%	#	%	#	%
Type-1	22	12%	14	8%	155	20%	113	15%
Type-2	30	16%	20	12%	71	9%	88	12%
Type-3	28	15%	8	5%	54	7%	68	9%
Type-4	16	8%	18	11%	71	9%	50	7%
Type-5	29	15%	26	16%	120	15%	114	15%
Type-6	29	15%	28	17%	85	11%	68	9%
Type-7	8	4%	6	4%	29	4%	29	4%
Type-8	5	3%	13	8%	101	13%	82	11%
Type-9	16	8%	17	10%	78	10%	100	13%
Type-Special	8	4%	16	10%	26	3%	48	6%

Typhoon Rainfall Statistical Downscaling (TR-SD)

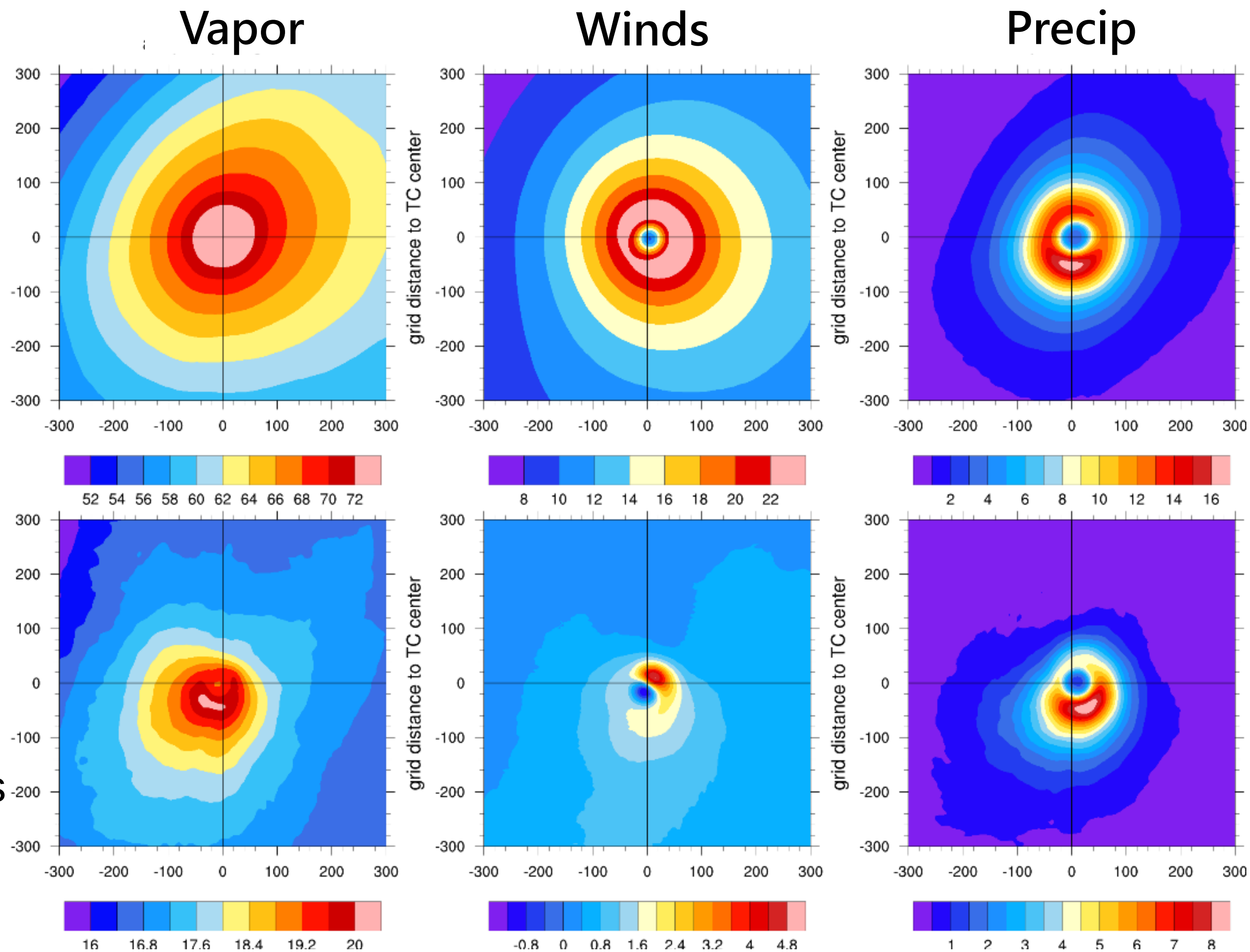
- Apply typhoon rainfall bias correction to GCM hourly rainfall, ⇒ 5km TR-SD
- Appling TR-SD to d4PDF data gives ~10000 typhoons

GCM	Resol. (km)	Period	Simulation years	Typhoon Number
CFSR	50	1979-2010	32	151
HIRAM-C384	25	1979-2015*1	37	173
		2039-2065*4	108	473
		2075-2099*4	100	214
HIRAM-C192	50	1979-2015*4	148	790
		2039-2065*16	432	TBD (~2000)
		2074-2099*16	416	1360
MRI-AGCM3.2S	20	1979-2003*2	50	166
		2075-2099*4	100	169
D2/4PDF	60	1951-2010*100	6000	TBD (~20K)
		2031-2090*(9*6)	3240	TBD (~10K)
		2051-2110*(15*6)	5400	TBD (~10K)



Western North Pacific
North Atlantic
200 %
-100 %
Eastern North Pacific
North Indian
South Indian
South Pacific
insf. d.
% Change
50
0
−50
I
II
IIII
IV
SOUTHERN HEMISPHERE
GLOBAL
NORTHERN HEMISPHERE
Tropical Cyclone (TC) Metrics:
I All TC frequency
II Category 4-5 TC frequency
III Lifetime Maximum Intensity
IV Precipitation rate

Climatology and changes of TCs structure



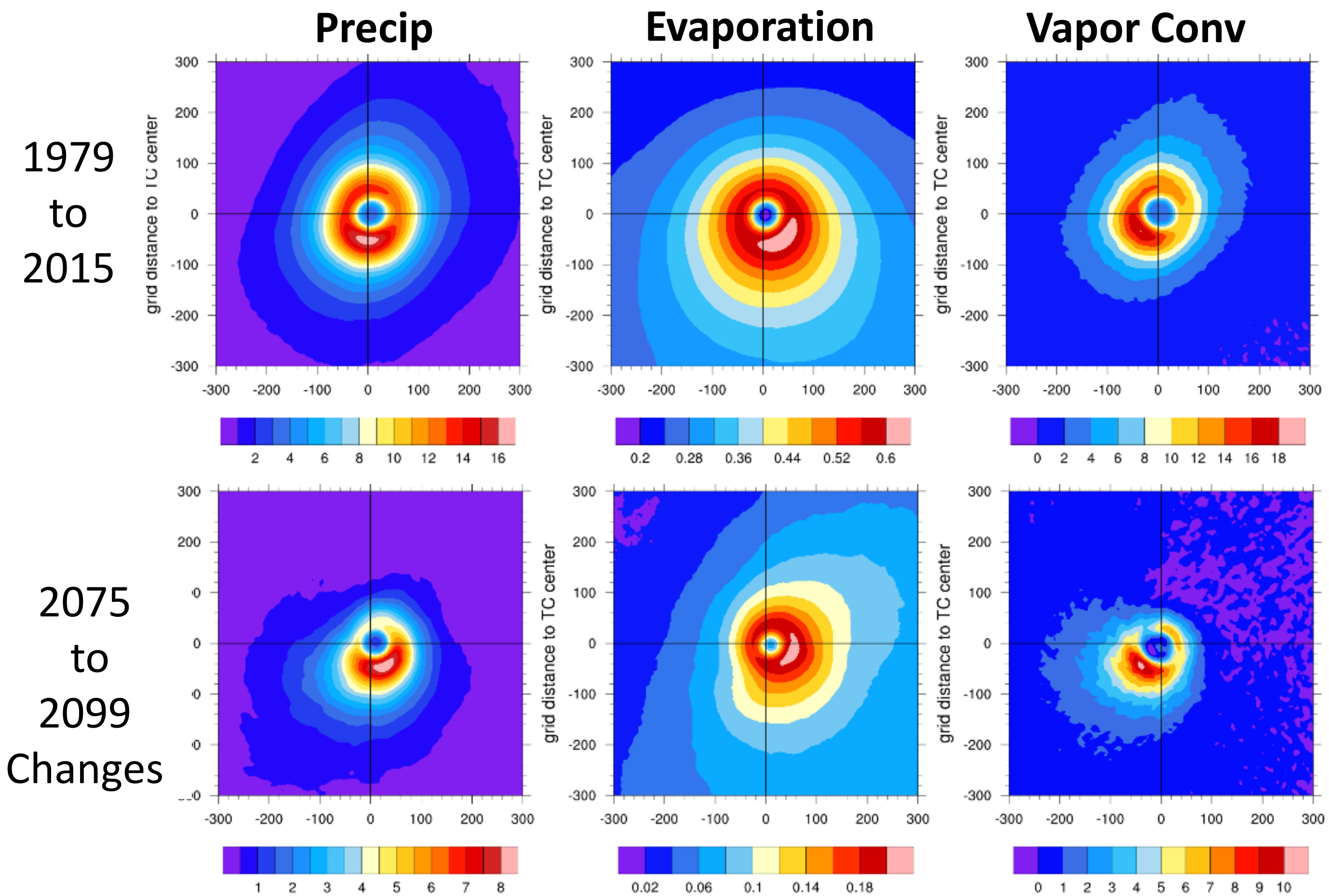
1979 to 2015

2075 to 2099 Changes

Present (760 TCs) Future (1298 TCs)

TCCIP MOST NCDR

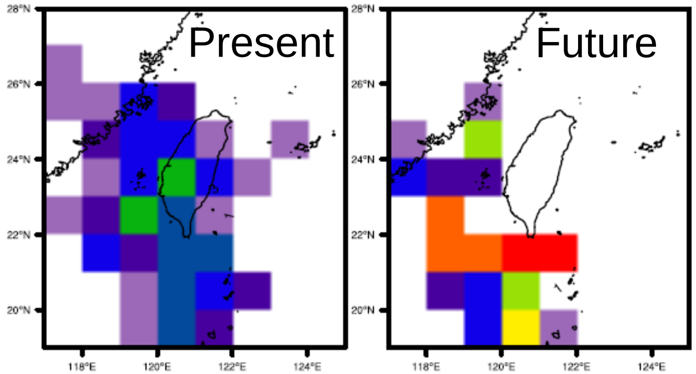
Water budget & changes in HiRAM-WRF



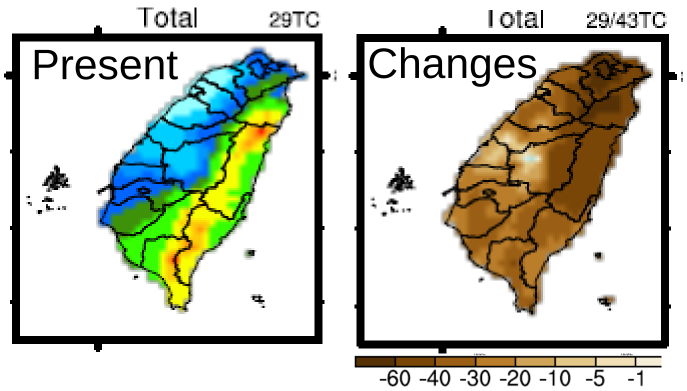
- Precip & Vapor conv. dominate the water budget balance.
- Changes in evaporation is 50 times smaller

Deal with trouble of track bias to local impact – 9 track types

Type-7 TC Track density
With poor similarity



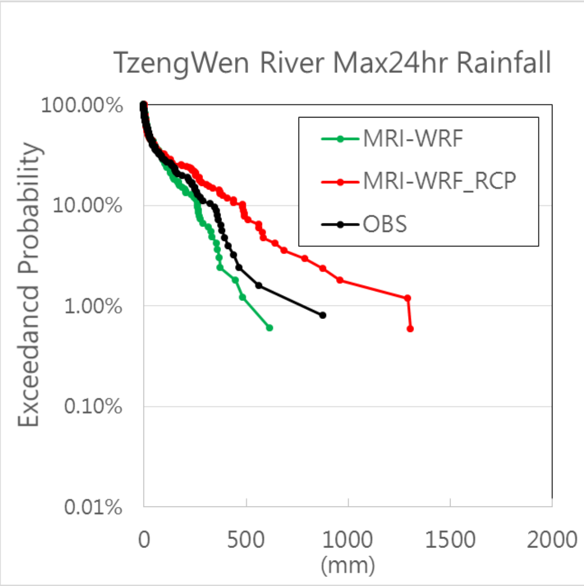
Precip (mm) & Changes (%)



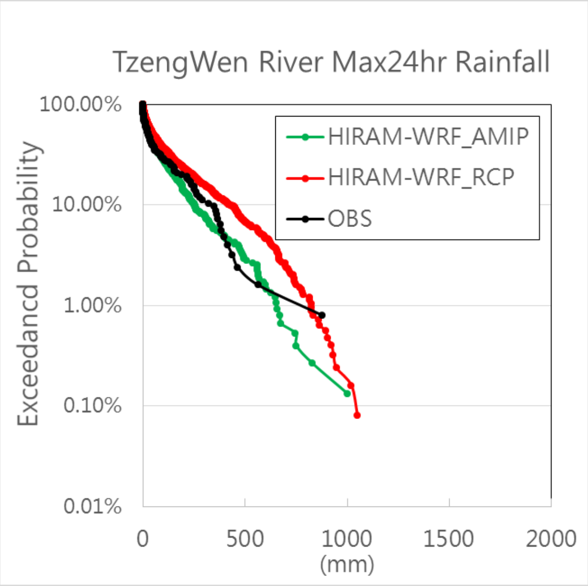
- For type-7 TCs, future TC precip. decrease for the whole island???
- Similarity in track is still poor
- Sample size is smaller.
- Sample size still play an import role to give you better track similarity and reliable result.

Future Changes of Local Impact

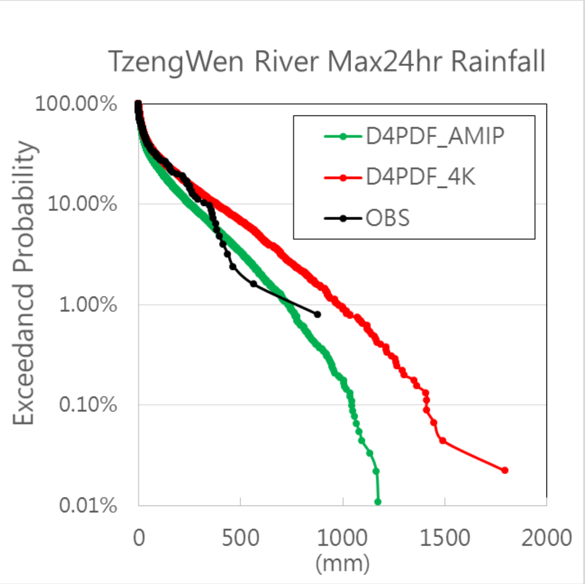
MRI-WRF



HIRAM-WRF



D4PDF-SD

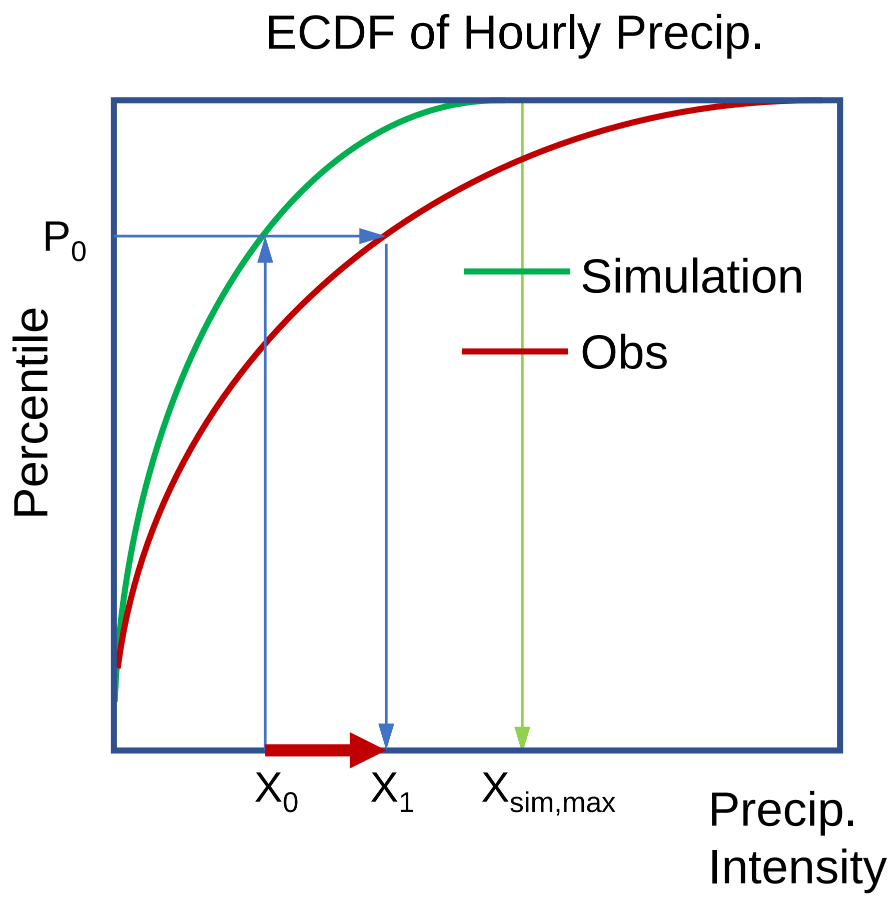


- Need to take into account the future reduction of TC frequency by ~50%, when return period is discussed.
- Uncertainty of track projection may still dominate the underestimation. So are the estimation of future changes

Freq. of TCs of 9 different tracking types

Type	OBS 1958-2015 (191 TCs)	MRI 1979-2003 (166 TCs)		WHIRAM 1979-2015 (760 TCs)	
	Present %	Present %	Future %	Present %	Future %
Type-1	12%	8%	9%	15%	15%
Type-2	16%	12%	7% (-5%)	12%	10% (-2%)
Type-3	15%	5%	11% (+6%)	9%	12% (+3%)
Type-4	8%	11%	9%	7%	8%
Type-5	15%	16%	19%	15%	13%
Type-6	15%	17%	12%	9%	10%

- Track type-3 is the most threatening TCs for Tzengwen River basin. Both MRI and HIRAM underestimate its freq.


ECDF of Hourly Precip.
P0
Percentile
Simulation
Obs
X0
X1
Xsim,max
Precip.
Intensity