Application of Representative Concentration Pathways Scenarios on Streamflow Impact Assessment

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Outline

- Introduction
- Statistical downscaling data from TCCIP
- Using model performance metric to select GCMs
- Climate change assessment on stream flow
- Results and discussions
- Summary and conclusion

Introduction(1/2)

- Most General Circulation Models (GCMs) indicated that global **temperature** should **increase** significantly, and **annual dry days** probably **increase**, too. Water resource management problems might become harder under climate change.
- The study aims on **estimation impacts of water resources** due to climate change through simulating stream flow in wet and dry spell. GCMs' projections could not be used to evaluate the impact of climate change directly.
- IPCC provided projection results of GCMs for different Representative Concentration Pathways (RCPs), **each GCM projection is one possible result**.

Introduction(2/2)

- The researchers of impact assessment are usually limited by the **excessive number of GCMs and scenarios** and could not evaluate impacts one by one. It is also **hard to make adaptation** policy from all GCMs projects.

- How to apply projections data of **all GCMs and selecting few GCMs** to assess climate change impacts is a importance issue.

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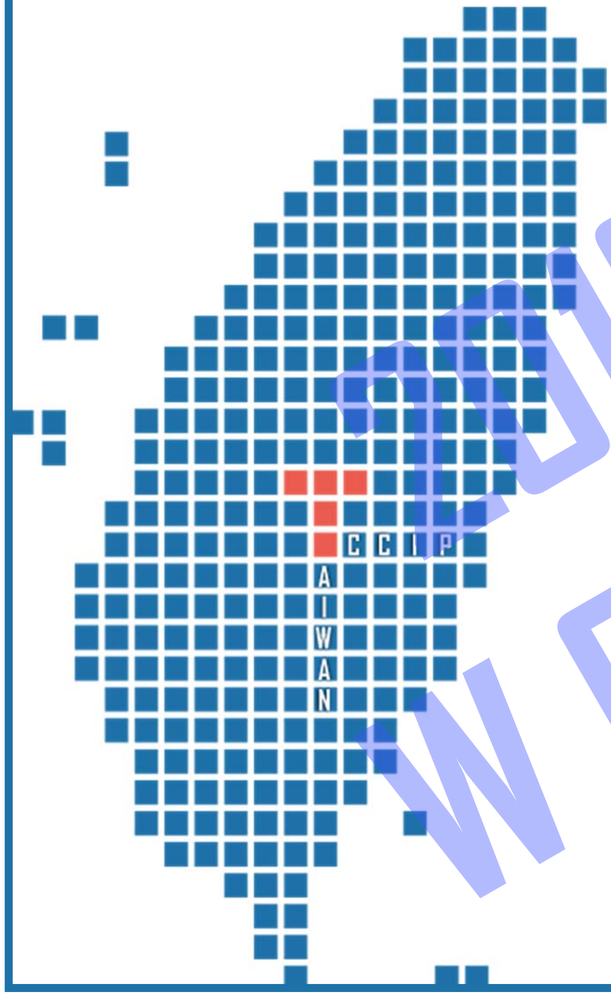
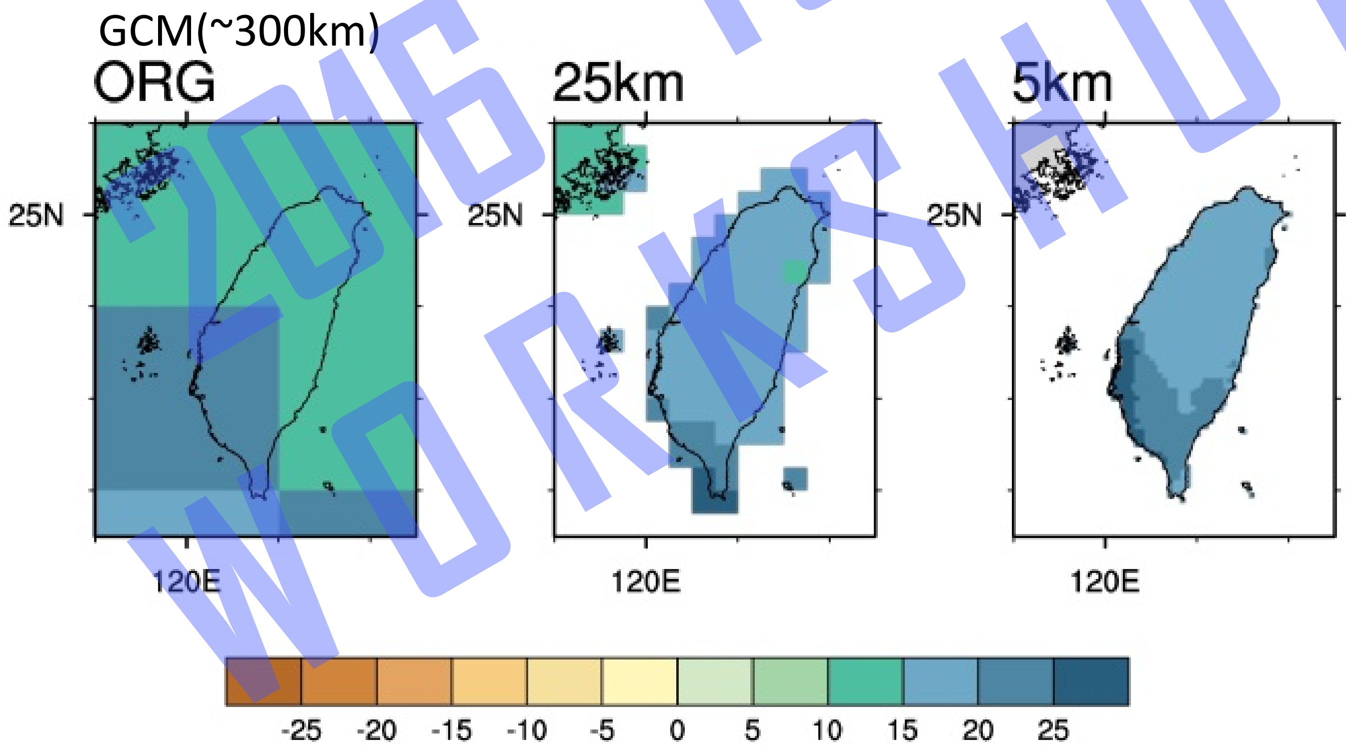


2. Statistical downscaling data from TCCIP

Why do we need downscaling?

- GCM too coarse for local assessment
- GCM biases in climatology(spatially and temporally)
- Regional climate change variability (topography, surface landscapes, coastlines)



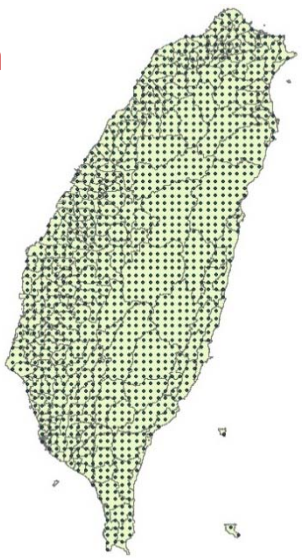
Statistical Downscaling

- Bias correction statistical downscaling method (SDSM)
- Spatial coordination: 5Km resolution
- Four emission scenarios, 126 GCMs

Scenario	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Number of GCM	26	38	21	41

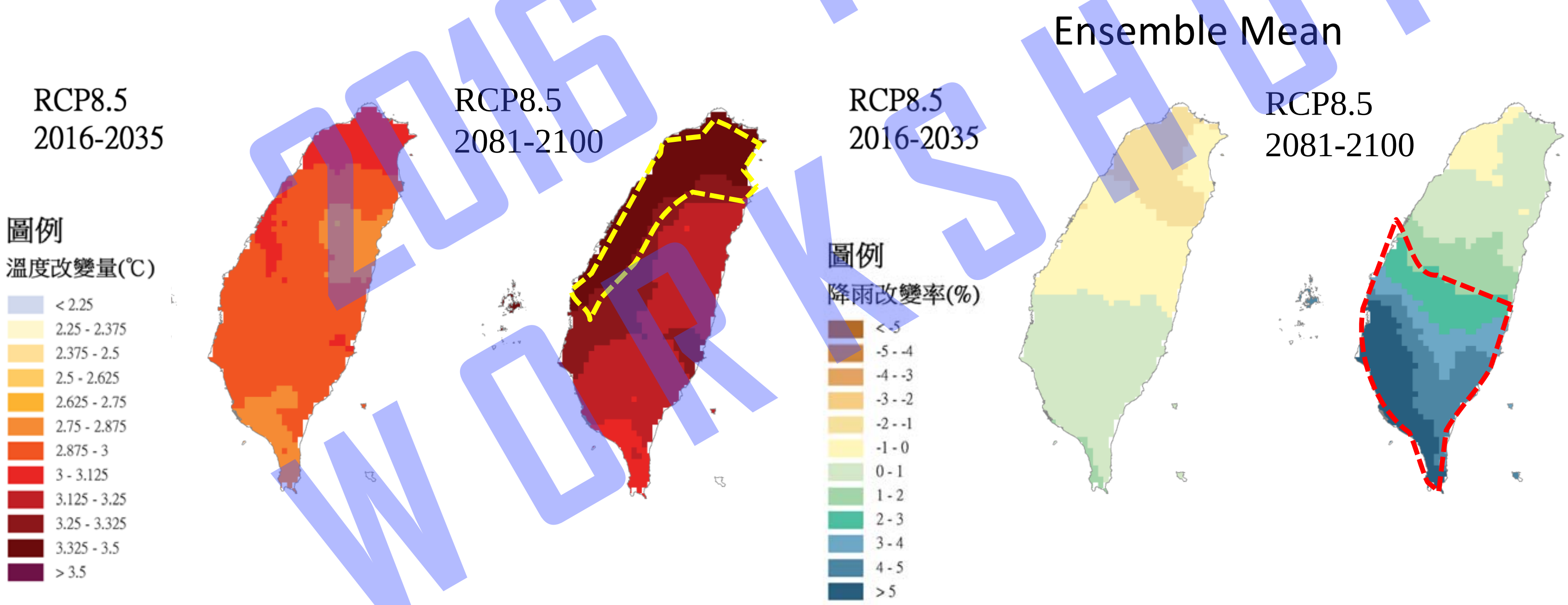
- Projection period
  - 1986~2005(baseline)
  - 2016~2035 (near future)
  - 2081~2100(end of century)

Distribution of Grid after Statistical Downscaling



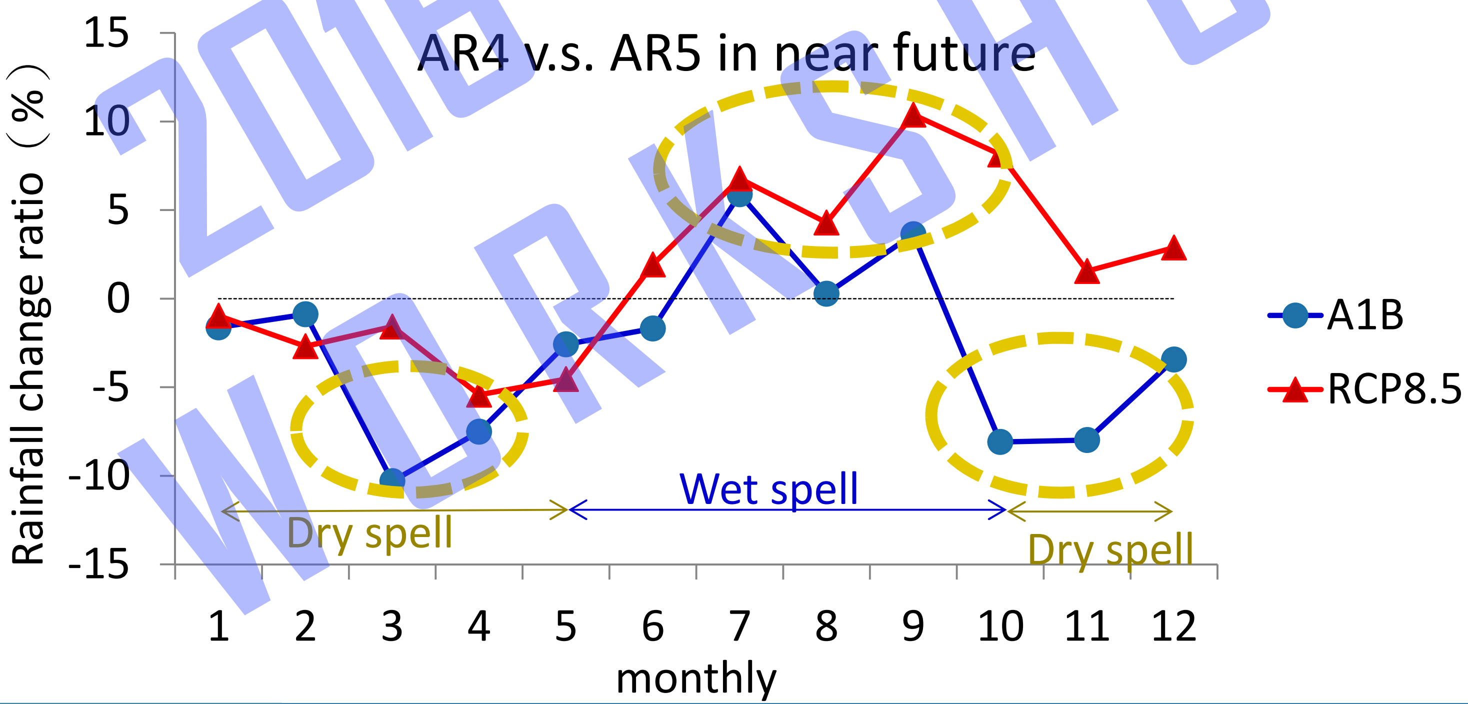
Trend of Future Climate Projection

➲ **Temperature would rise about 4℃, and rainfall would increase obviously in central and south Taiwan during the end of the century in RCP 8.5.**



Multi-Model Ensemble(MME)

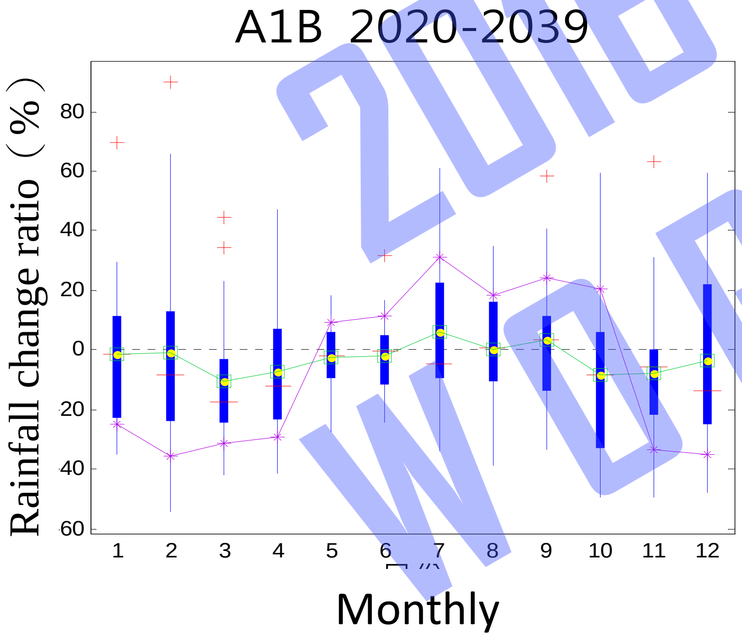
- Rainfall change ratio in wet spell in AR5 scenarios is greater than its in AR4, while the decreased trend of rainfall is more insignificance in dry spell.
- The **difference of rainfall change in between wet and dry spell** in AR4 is more obvious than in AR5.



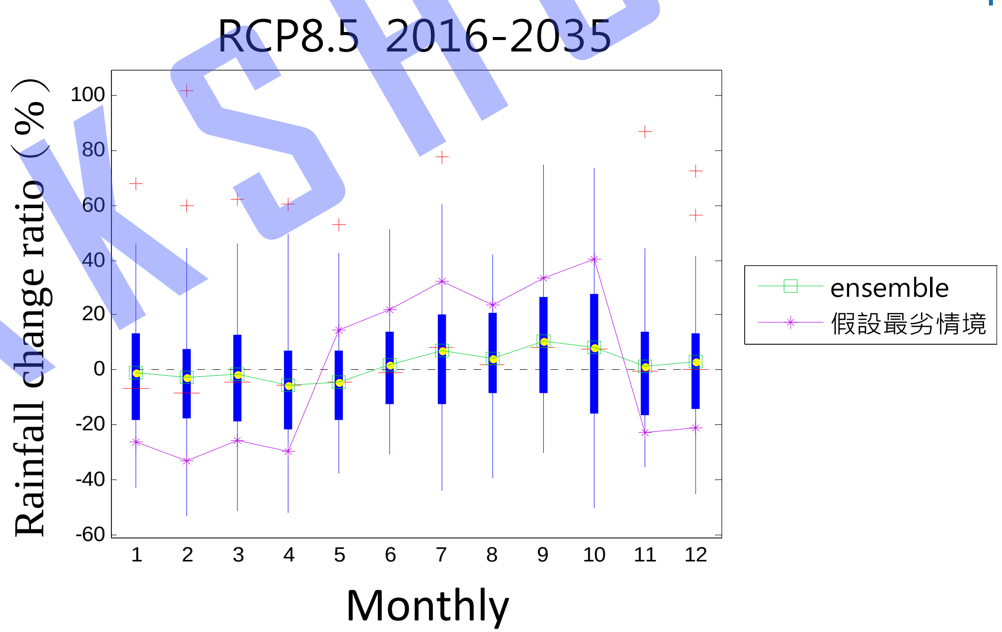
Box plot of monthly rainfall change ratio

- **The variance of monthly rainfall change ratio in AR5 scenarios are great than in AR4 scenarios.**
- **AR5 scenarios could cause more severe impacts of water resource.**

AR4



AR5

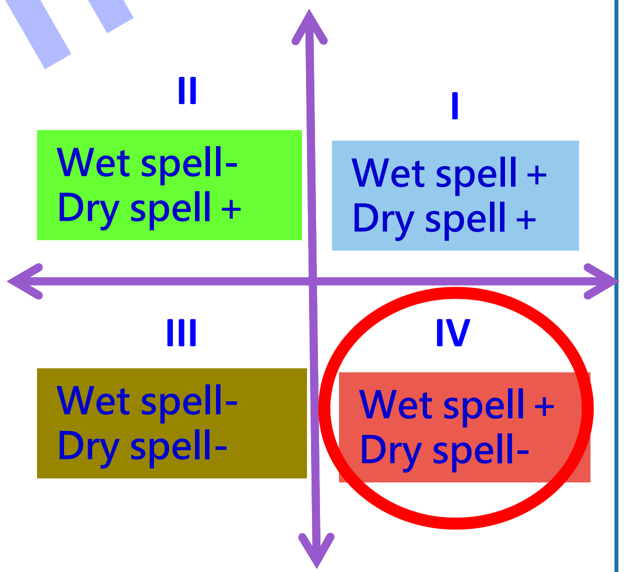


Rainfall characteristic of GCM in wet and dry spells

➲ **There are 73 GCMs that precipitation increased in the wet period and decreased in the dry period.**

(including RCP4.5 and RCP8.5 scenarios in two future period from projection data of all Taiwan grids).

	I	II	III	VI
Near future	21	11	17	30
Far future	21	7	8	43



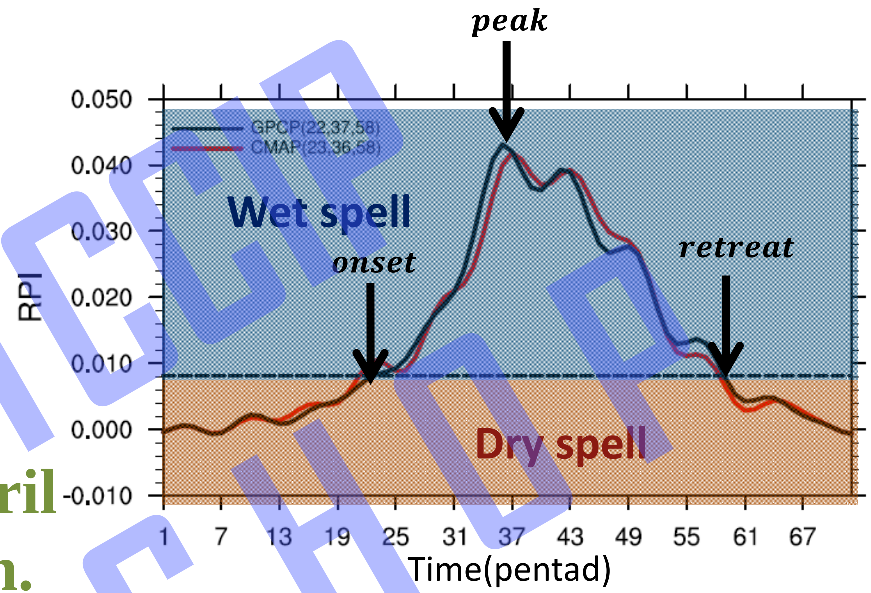
3. Selection GCMs based on performance of Monsoon onset

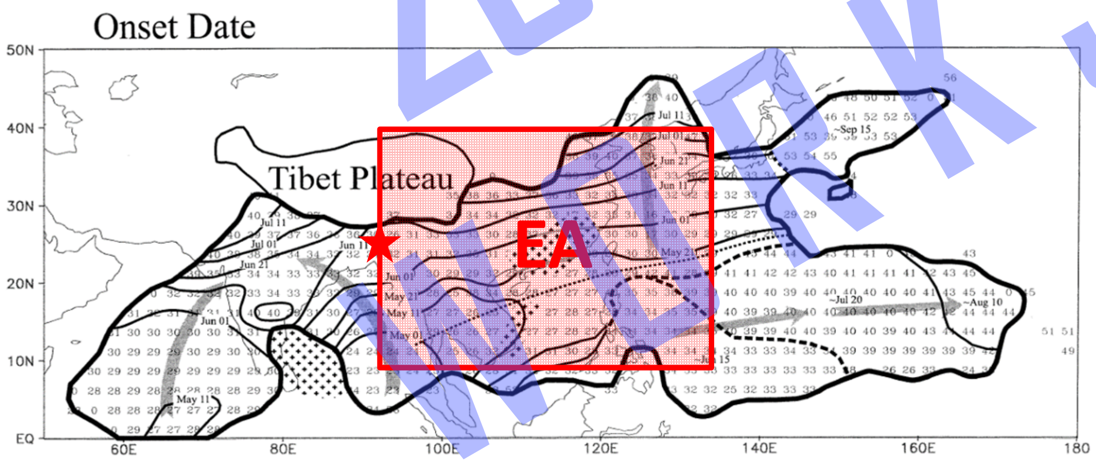
Analysis of performance metrics

- The **performance metrics of summer monsoon season** in East Asian area were used to select the GCMs.
- The Taylor Skill Scores meta-analysis is evaluated the performance of each model.
- According to the T-Skill Scores, the **better GCMs** (TOP 5) and the **worse GCMs** (LAST 5) were selected to assess the streamflow impact and compared with impacts of all GCMs due to climate change, respectively.

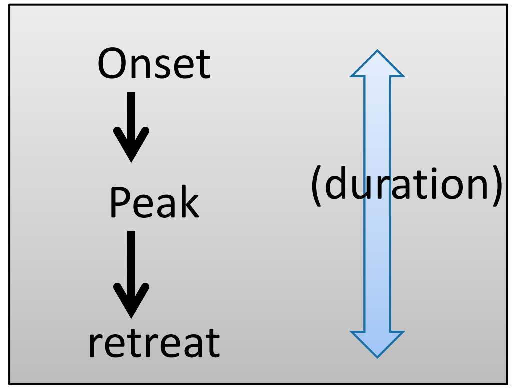
Monsoon onset

- The summer monsoon rainfall starts around the **beginning of May and continues until September or October.**
- It is **consistent with** the wet season of May to October and dry season of November to April in **term of hydrology** in Taiwan.





Summer Monsoon period



- East Asia Monsoon(EA) –90°E-135°E, 10°N-40°N

Assessment of performance metrics

- The characteristic of the GCMs has better performance on simulating the summer monsoon period as **the basis for GCM selection**.
- The **daily rainfall data** of 18 GCMs from the CMIP5 project is used to evaluate time series of summer monsoon.
- The 1981 to 2000 daily rainfall CPC Merged Analysis of Precipitation (CMAP) by NASA GPCP(Global Precipitation Climatology Project) is applied to **verify the performance of GCM models** and evaluate the **accuracy of summer monsoon rainfall onset and retreat time** during GCMs simulation.

Taylor Skill Score

- Kitoh (2006) uses **pattern correlation coefficient** and **root mean square error** to analyze the statistical correlation of monsoon rainfall timing changes between different models and observation data by Taylor Skill Score (2001).

$$S = \frac{4(1+R)^4}{\left(\hat{\sigma}_f + 1/\hat{\sigma}_f\right)^2 (1+R_0)^4}$$

- $\hat{\sigma}_f$ is **normalized standard deviation** between models and observed fields(σ_f/σ_r)
- R is **correlation coefficient** between model and observed fields
- R_0 is **maximum correlation** attainable(R_0=1)

The phenomena matrix of monsoon for CMIP5 models

Table of EA Taylor skill score(CMIP5)

	OS (Onset)	RT (Retreat)	DR (Duration)
(1)CMAP	0.71	0.82	0.78
(2)ALLENS	0.39	0.7	0.61
(3)TOP5ENS	0.43	0.65	0.68
(4)LAST5ENS	0.3	0.52	0.45
(5)ACCESS1-0	0.32	0.61	0.37
(6)bcc-csm1-1	0.3	0.48	0.5
(7)BNU-ESM	0.32	0.5	0.45
(8)CanESM2	0.24	0.44	0.46
(9)CCSM4	0.24	0.4	0.36
(10)CESM1-BGC	0.23	0.64	0.49
(11)CNRM-CM5	0.31	0.57	0.48
(12)CSIRO-Mk3-6-0	0.26	0.29	0.41
(13)FGOALS-g2	0.13	0.33	0.28
(14)GFDL-ESM2M	0.36	0.52	0.49
(15)HadGEM2-ES	0.51	0.62	0.5
(16)inmcm4	0.11	0.64	0.29
(17)IPSL-CM5A-MR	0.27	0.55	0.54
(18)MIROC5	0.21	0.61	0.43
(19)MIROC-ESM-CHEM	0.14	0.48	0.34
(20)MPI-ESM-LR	0.36	0.47	0.51
(21)MRI-CGCM3	0.21	0.48	0.35
(22)NorESM1-M	0.29	0.57	0.53

- **Poor skill score of onset timing**
- **2 items above 0.5, at least**

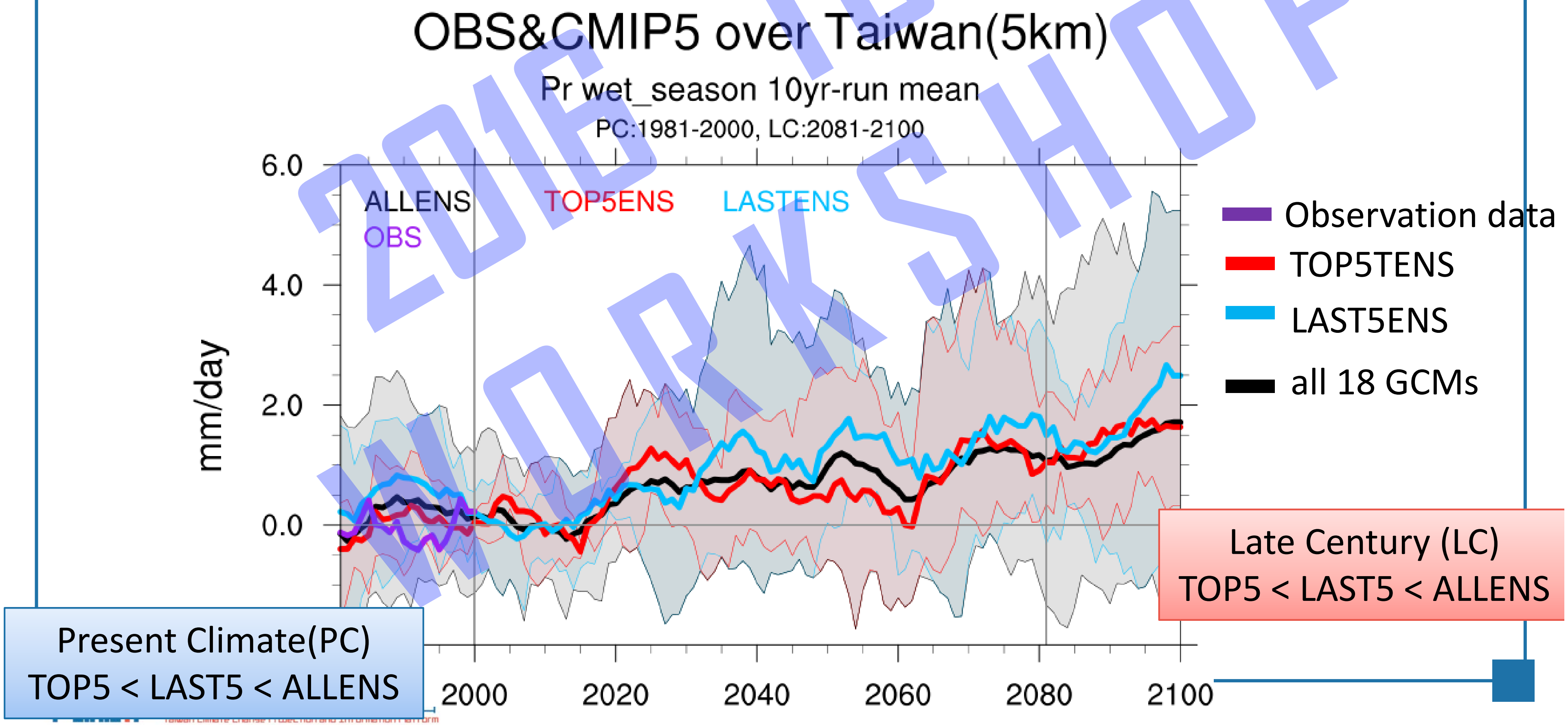
OS(Onset of monsoon)
RT(Retreat of monsoon)
DR(Duration of monsoon)

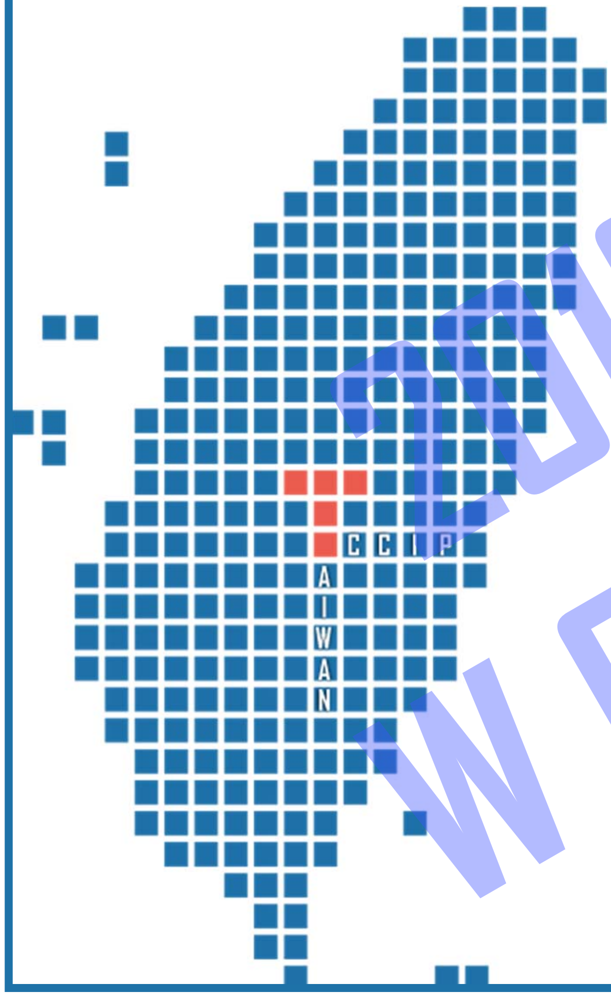
TOP5 (Best5)
- bcc-csm1-1
- HadGEM2-ES
- IPSL-CM5A-MR
- MPI-ESM-LR
- NorESM1-M

LAST5 (Worst5)
- CSIRO-Mk3-6-0
- FGOALS-g2
- MIROC-ESM-CHEM
- MRI-CGCM3
- CCSM4

Uncertainty of GCMs

- **The 20-year moving average for climate variations from now until the end of the century.**
- **The TOP5 models are having the minimum distribution range (smaller uncertainty), while the LAST5 models mainly distribute at maximized ranges of the all models, so it can be considered the worst scenario.**





4. Assessment of stream flow impact

Assessment of streamflow impacts

Bias correction statistical downscaling (BCSD)
(Monthly climatic data, 5km*5km)

↓

Weather Generator
(Daily rainfall and temperature)

↓

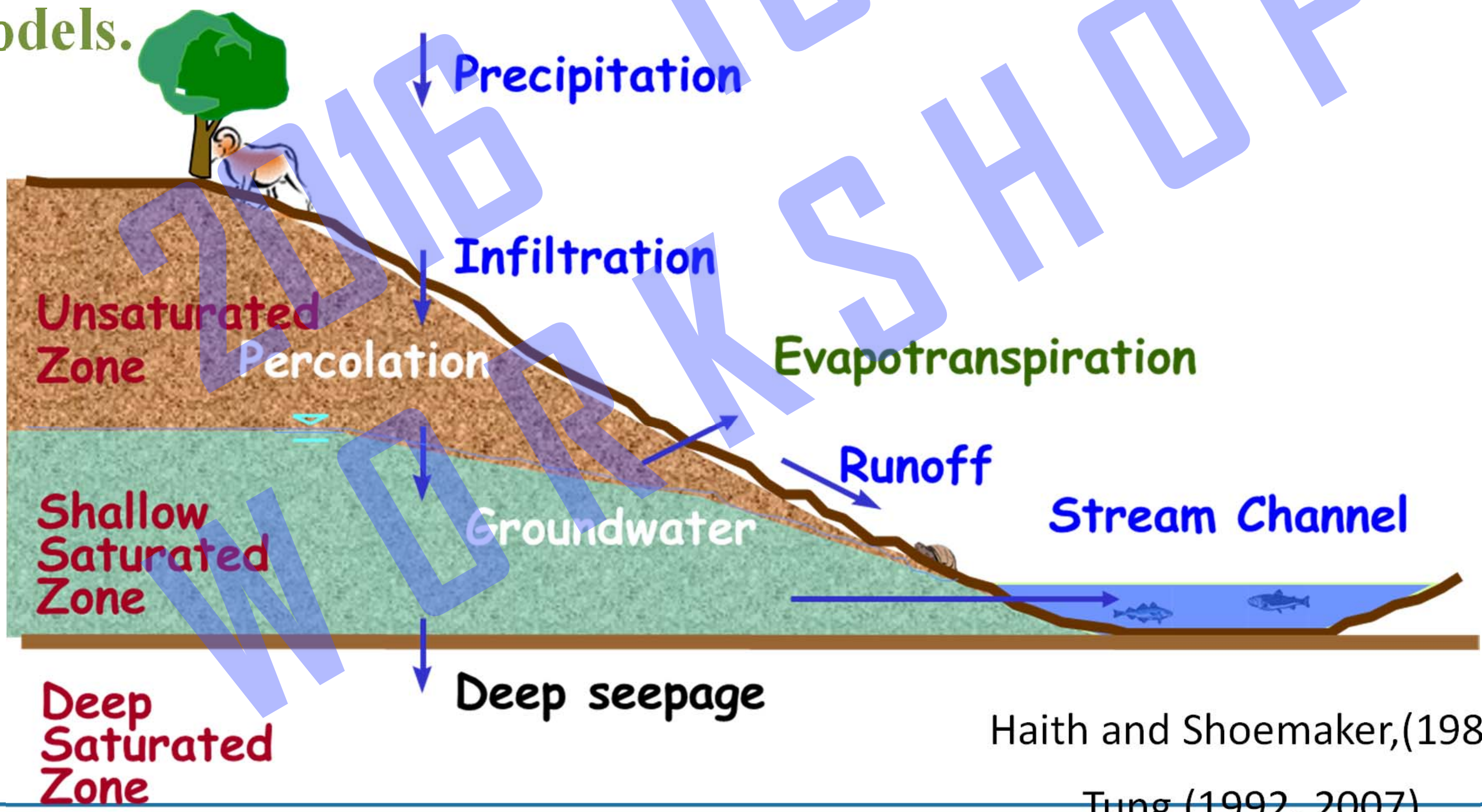
Simulate streamflow by hydrology model
(GWLF)

↓

Compare streamflow characteristics
(Change ratio with baseline and projection period)

The GWLF model

- GWLF (Generalized Watershed Loading Functions) , a **lump hydrological model**, is used to assess streamflow.
- The parameters are based on the physical properties of the watershed, so the uncertainty is less than other complex models.

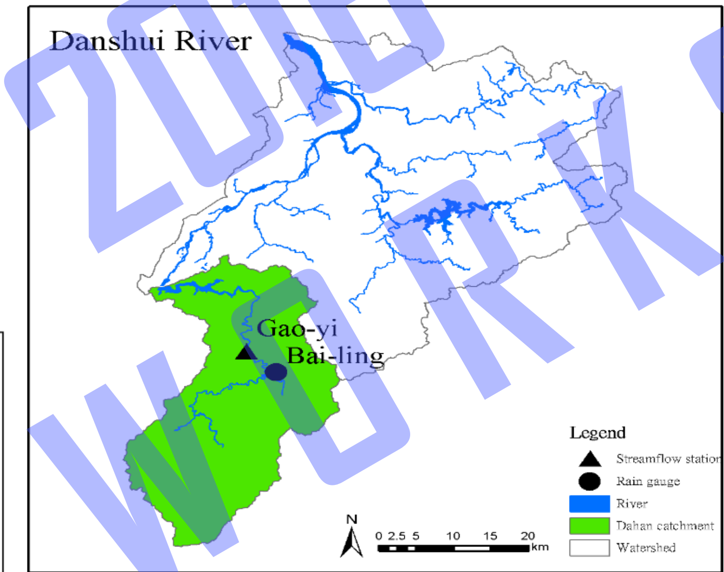


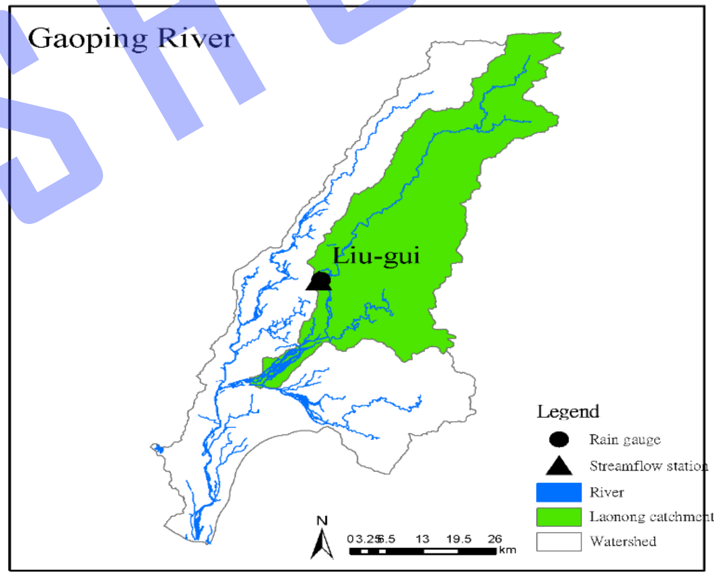
Haith and Shoemaker,(1987)

Tung (1992, 2007)

Study area

- The **Danshui river** and **Gaoping river** are chosen for assessing the impacts of streamflow, and located in Northern and Southern Taiwan, respectively.
- These two rivers are very important water resources that supply drinking water to New Taipei City and Kaohsiung City.

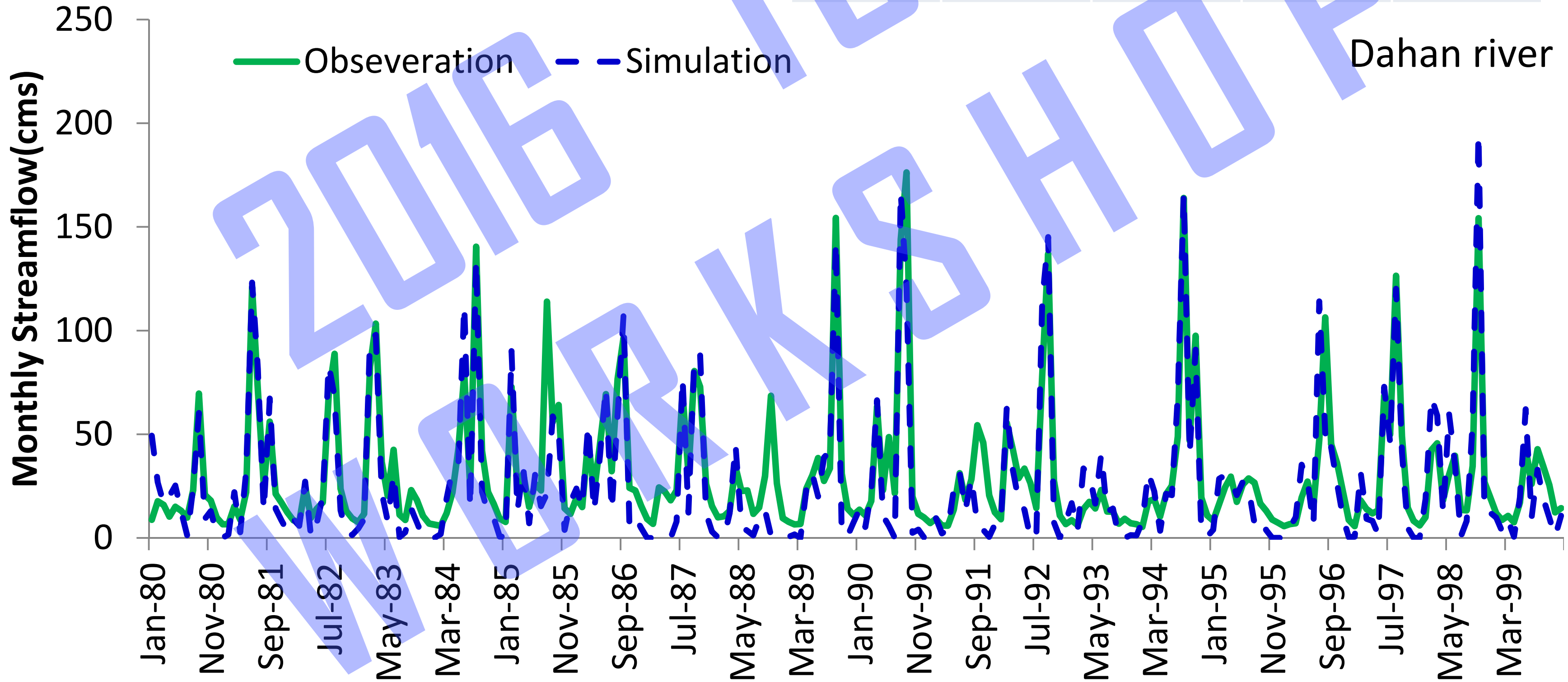


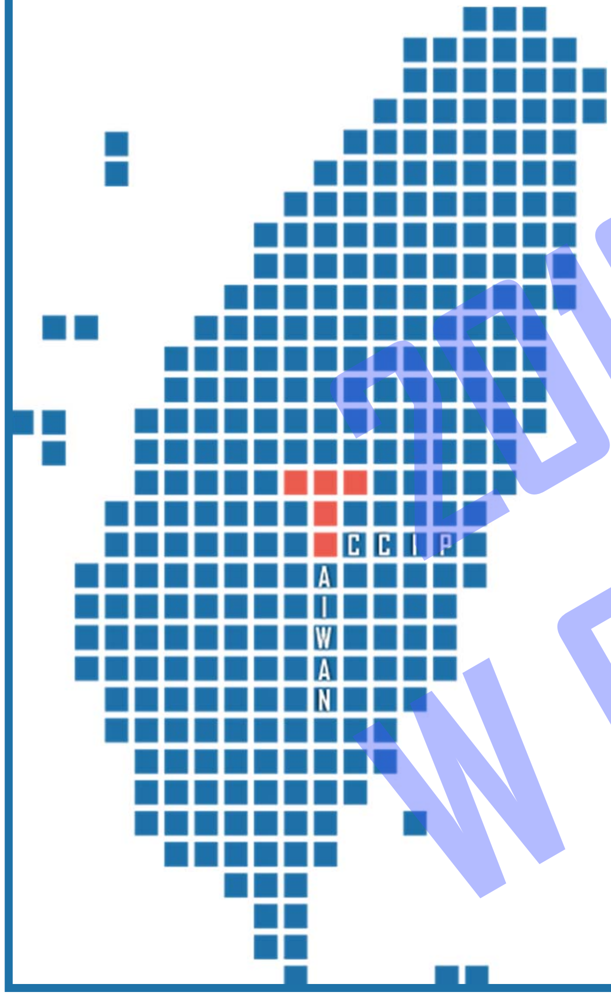


GWLF model verification

- The parameters, evapotranspiration cover coefficients, are required to verify.
- GWLF model was able to predict the monthly stream flow with good accuracy.

Index	R	NSE	ME_{ratio}	RMSE
Value	0.89	0.84	0.9	7.88

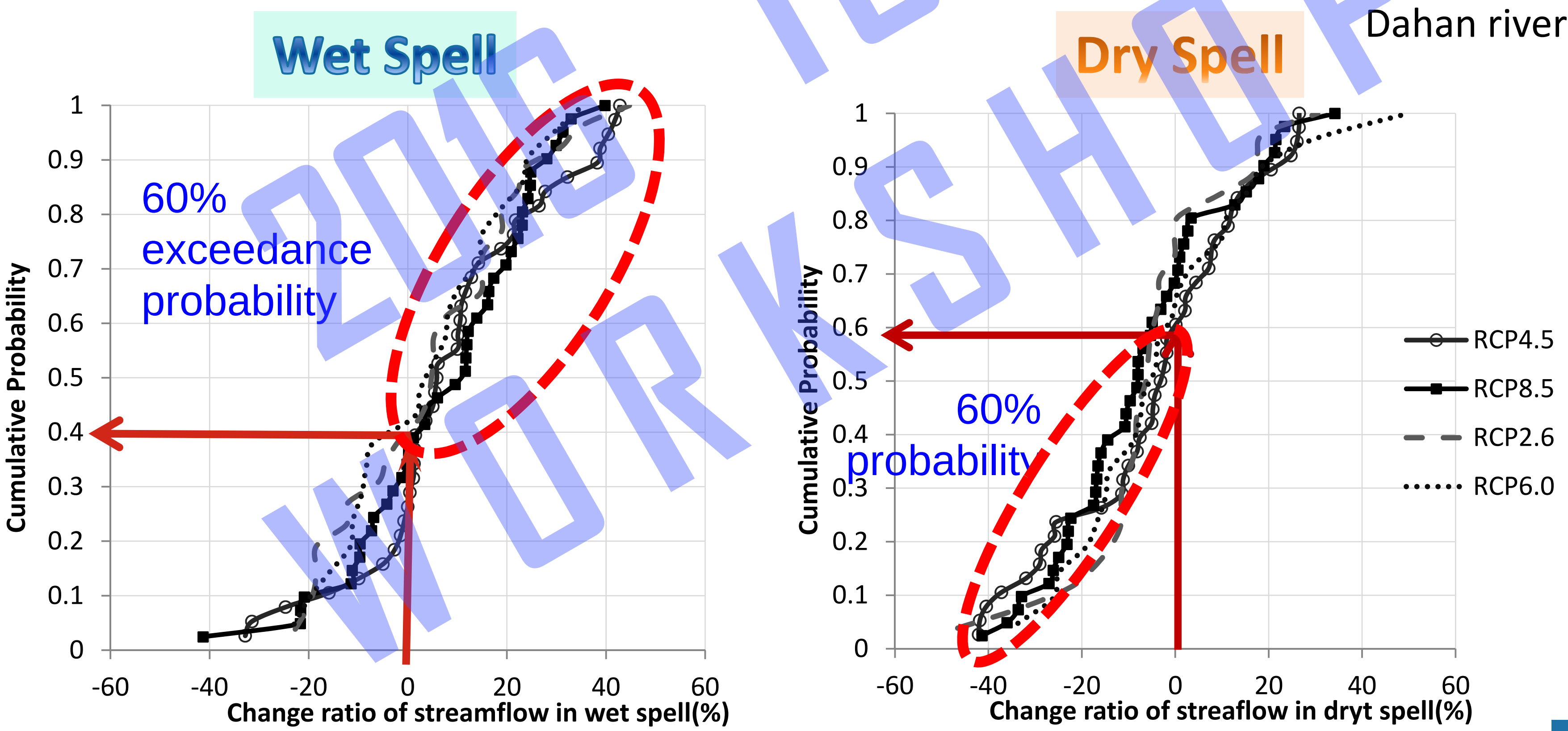




5. Result of streamflow impact

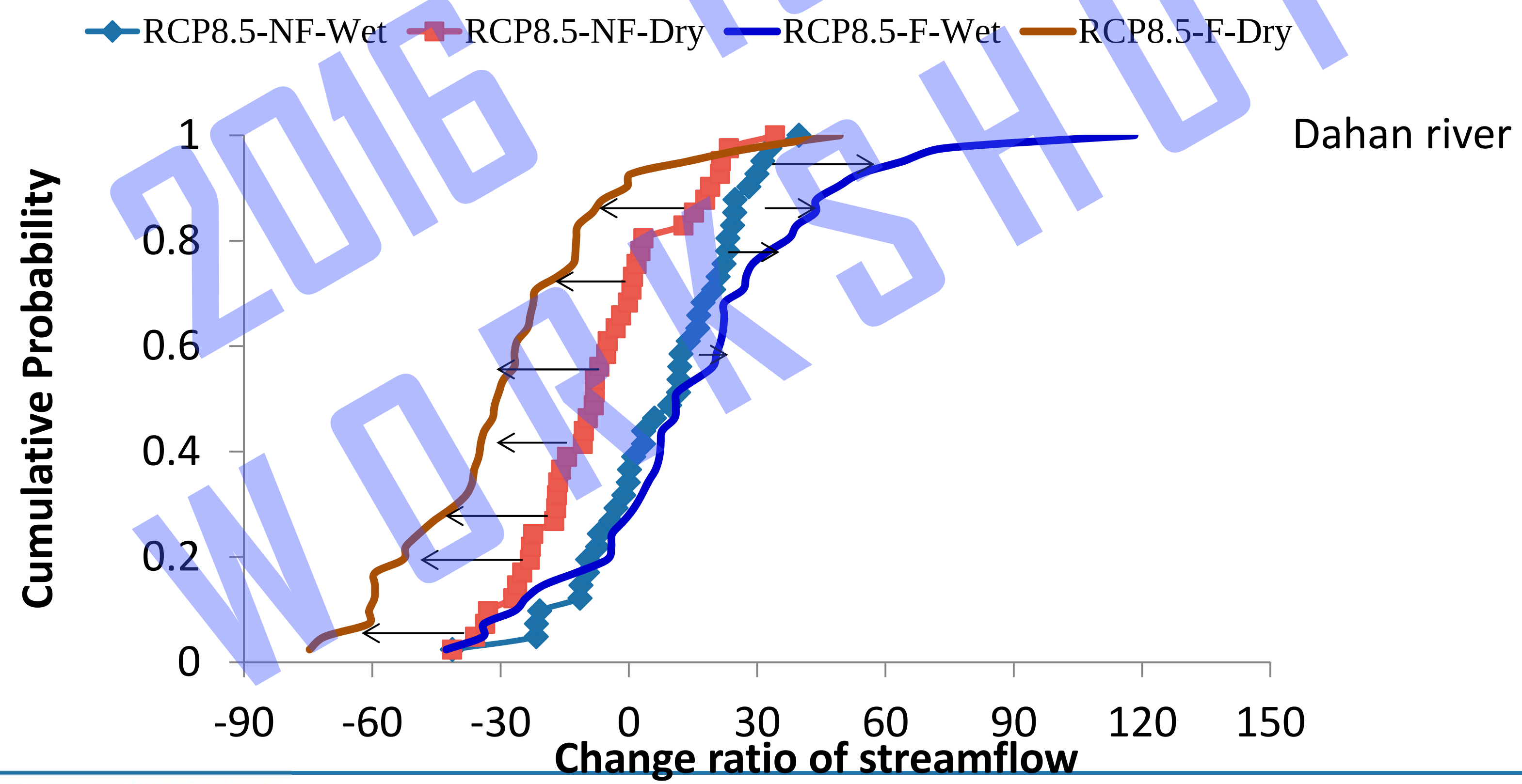
Change rate of streamflow

- The more 60% of all GCMs are shown stream flow increase in wet spell and decrease in dry spell in near future.
- Range of change rate of stream flow is -40~40% and -40~50% in wet and dry spell, respectively.



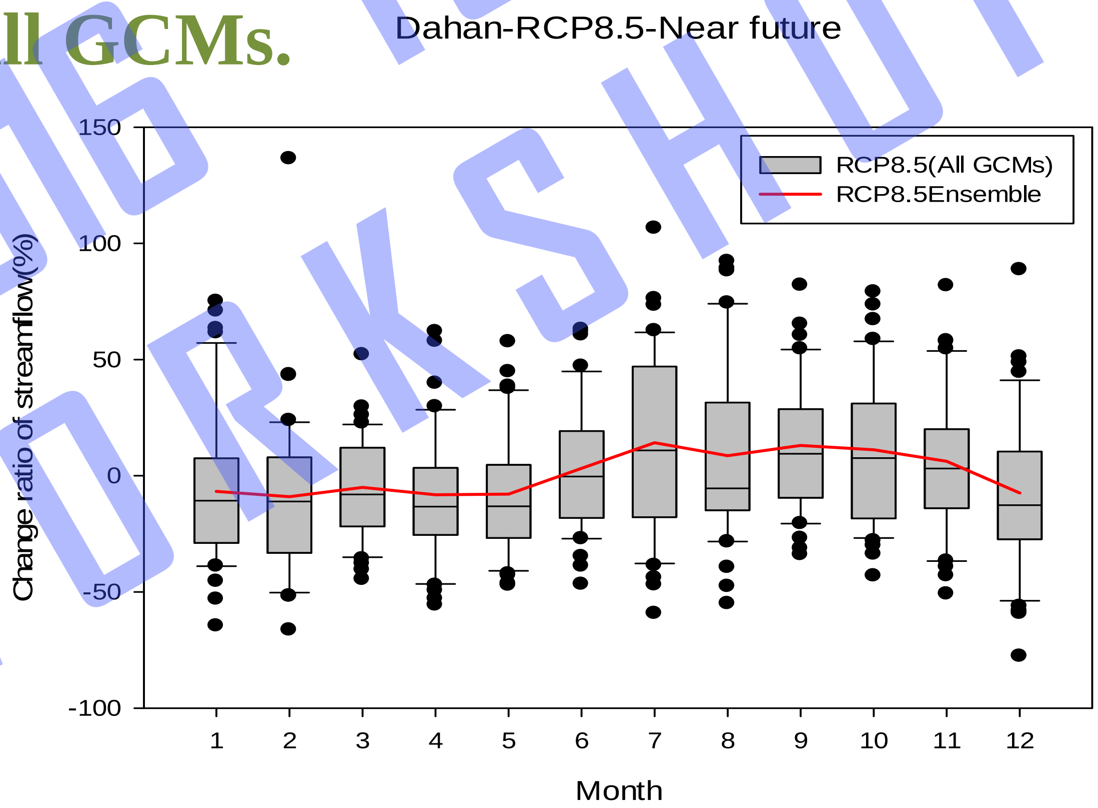
Change rate of streamflow in different projection period

- The stream flow impact is merely more serious in end of century. The change ratio is **-40~120%** in wet spell, and **-80~50%** in dry spell in more than 80% of GCMs projection.



Impacts of monthly stream flow

- The box size represents the variance in monthly stream flow change ratio. The **variability** in **July and August** are greater.
- The result of MME is smaller when comparing with that of all GCMs.

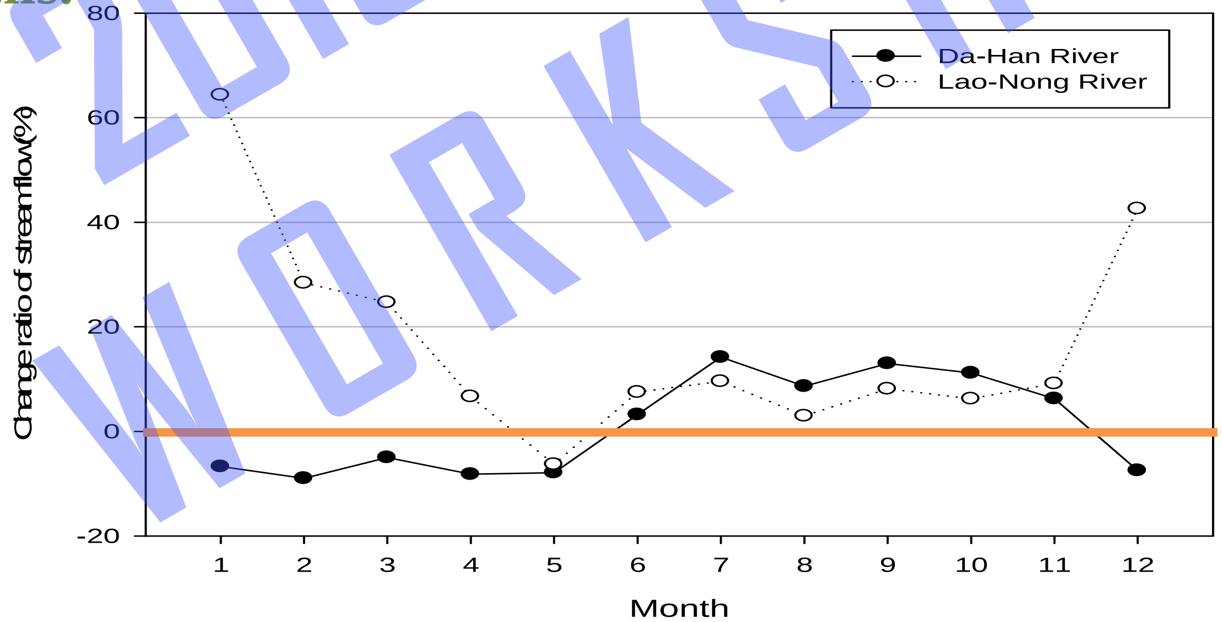


Box plots

- Maximum
- Upper quartile
- Median
- Lower quartile
- Minimum
- Dots are outliers

The ensemble mean result

- To reduce the uncertainty of different GCMs, Knutti (2010) recommended MME, so as to eliminate the climate system deviation of the climate models.
- The variation of streamflow in MME between two catchments during June to November was closer.
- The variation was significant different in December to April the next year. The Laonong River stream flow increases for wet and dry spells.



The change ratio of streamflow in different intervals

- The **25 GCMs** exhibited **0~30%** change ratio of streamflow in the wet spell and **-30%~-1%** change ratio in the dry spell.
- The decision makers could build adaptation strategies to deal with a 30% increase in a wet spell and a 30% decrease in a dry spell for stream flow.

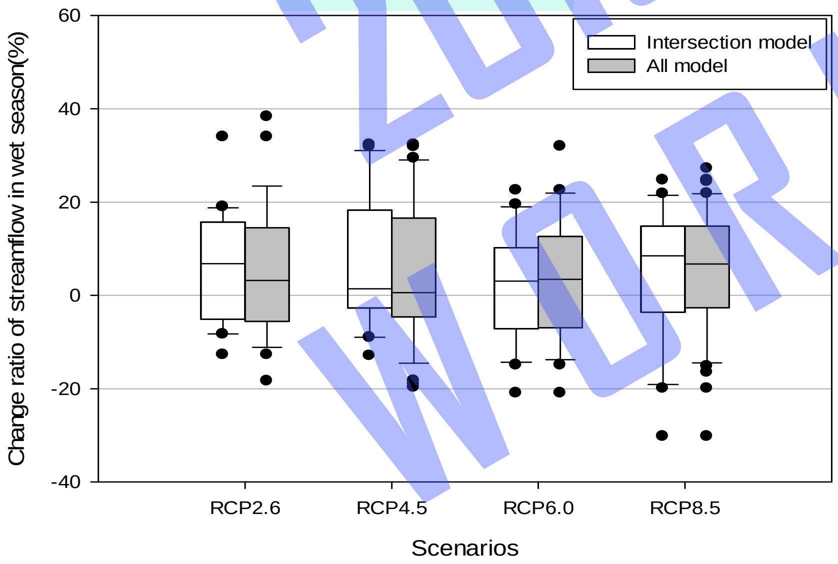
Change Ratio Interval		Change ratio of streamflow in dry spell(%)					
		>60	31~60	0~30	-1~-30	-60~-31	<-60
Change ratio of streamflow in wet spell(%)	>60	0	2	1	1	2	0
	31~60	0	1	4	4	5	0
	0~30	0	7	14	25	18	4
	-1~-30	0	0	9	22	2	1
	-60~-31	0	0	1	1	2	0
	<-60	0	0	0	0	0	0

Dahan River in the end of century

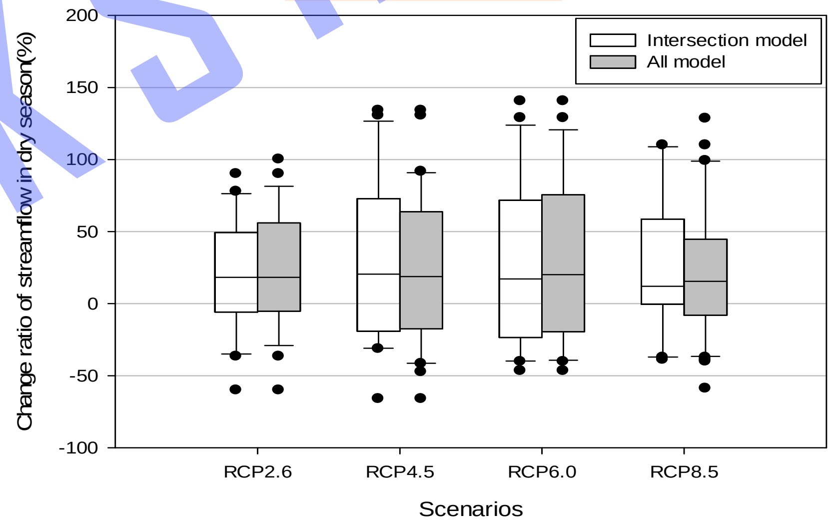
Comparisons of all GCMs and some models

- These **20 GCMs** with four scenarios are selected to compare with all GCMs.
- The user can apply the 20 GCMs to assess climate change impacts, based on the **variance** between all models and the 20 GCMs are **close**.

Wet Spell

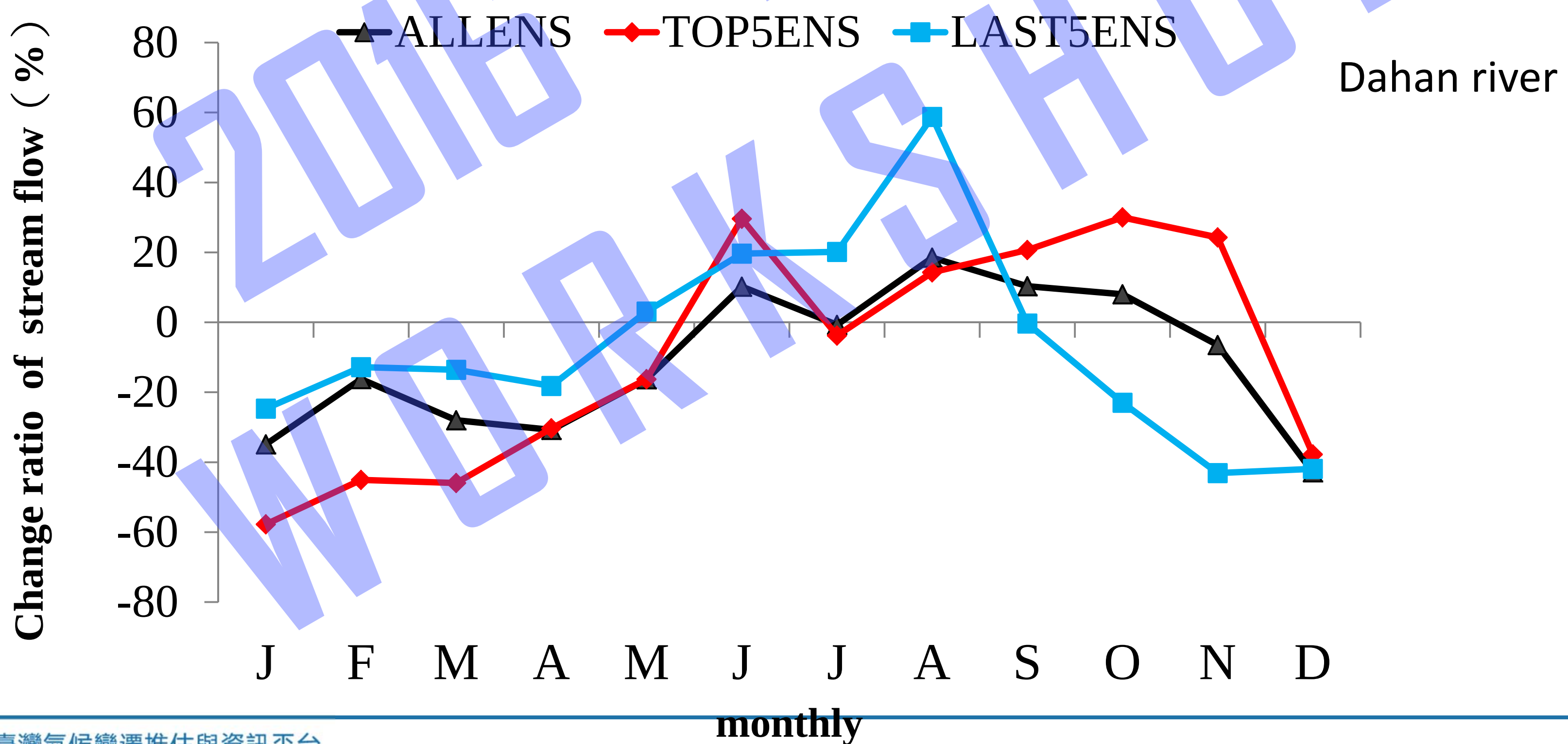


Dry Spell Laonong River



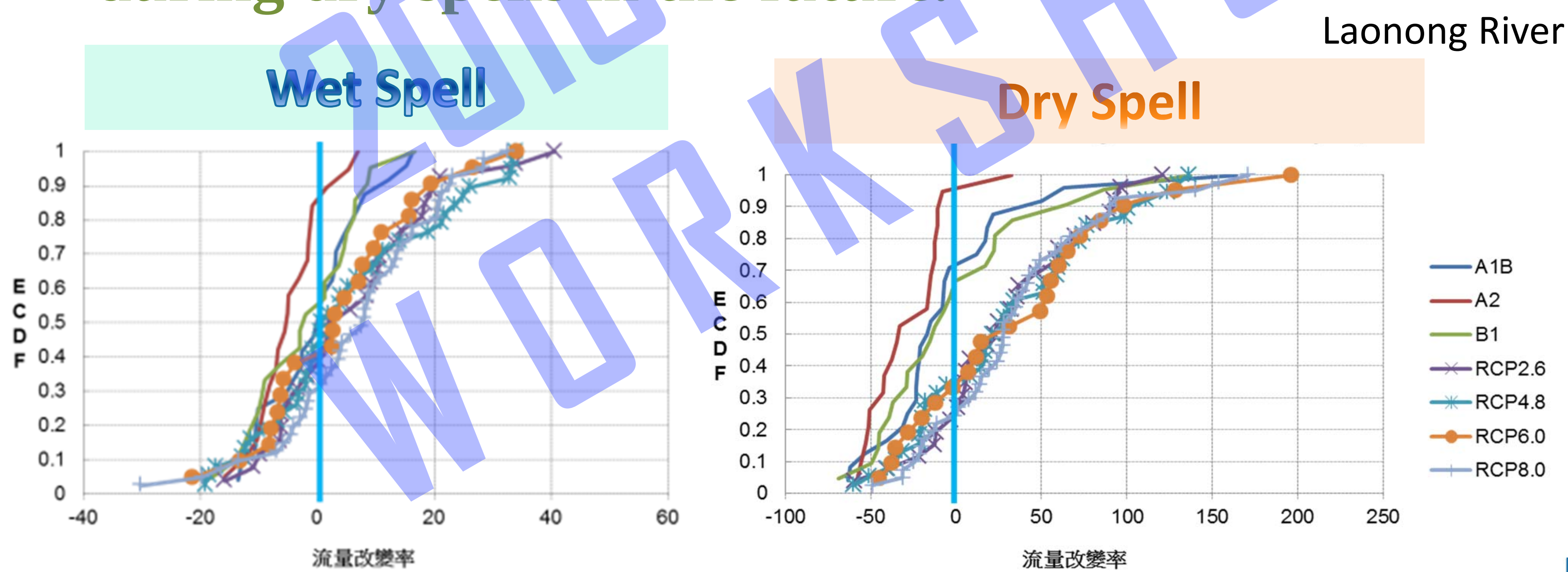
Streamflow impact with selected models

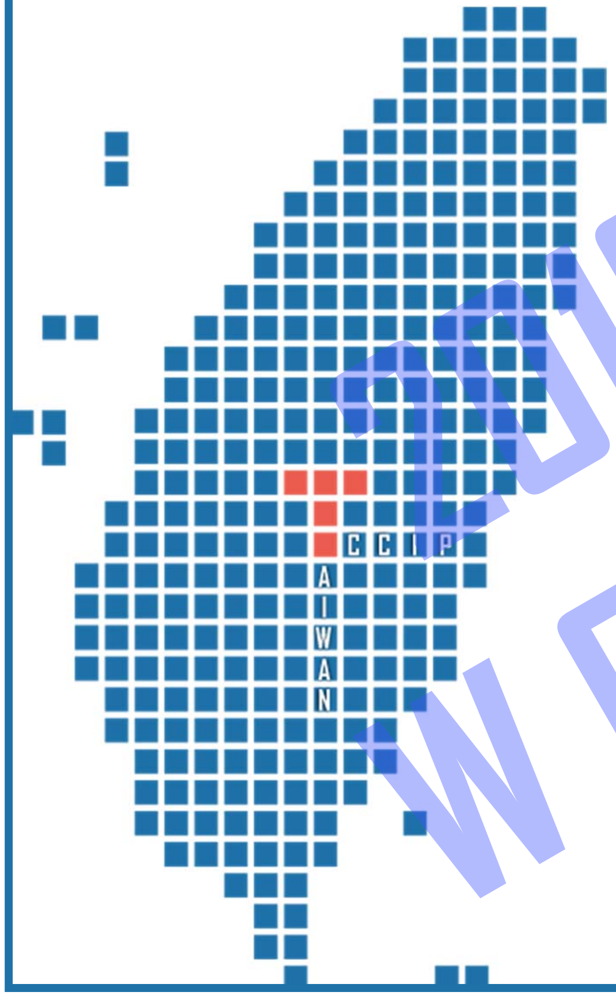
- The monthly streamflow change between ALLENS and TOP5ENS are relatively closer.
- The LAST5ENS is greater, streamflow increases 20~60% in wet season and decrease 20~40% in dry season.



Comparison between AR4 and AR5 data

- Most GCMs show streamflow will increase in wet and dry spell in Laonong River in AR4.
- There is **more serious in wet spell**, but **more wet in dry spell** in AR5. The more flexible strategies for water resource management will be necessary during dry spells in the future.





6. Summary and Conclusion

Summary(I)

- Based on the rainfall of GCMs projection, **the wet spell becomes wetter and dry spell becomes drier** in Taiwan in the future.
- The box-and-whisker plot is used to present the results of streamflow impacts, the decision-makers can evaluate the **uncertainty** to take appropriate adaptation strategies.
- This study had shown that stream flow would **increase in wet spell (+40%)**, and **decrease in dry spell (-40%)** in near future about more than 60% GCMs projections.

Summary(II)

- The five better GCM models are **BCC-CSM1.1, HadGEM2-ES, IPSL-CM5A-MR, MPI-ESM-LR and NorESM1-M** based the **onset and retreat of monsoon** in East Asia region.
- The user can applied the 20 GCMs to assessment climate impact, based on the **variation between all models and the 20 GCMs are close.**
- There is **more serious in wet season**, but **more wet in dry season** in AR5 in Southern Taiwan river. The more flexible strategies for reservoir operations and water deployment will be necessary during dry spells in the future.

TCCIP 臺灣氣候變遷推估與資訊平台
Taiwan Climate Change Projection and Information Platform

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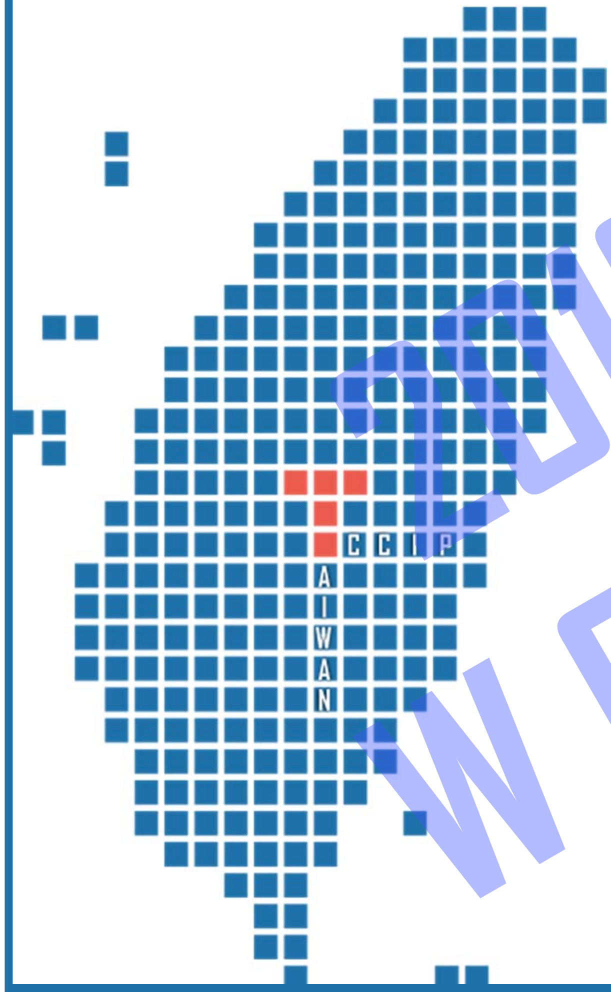

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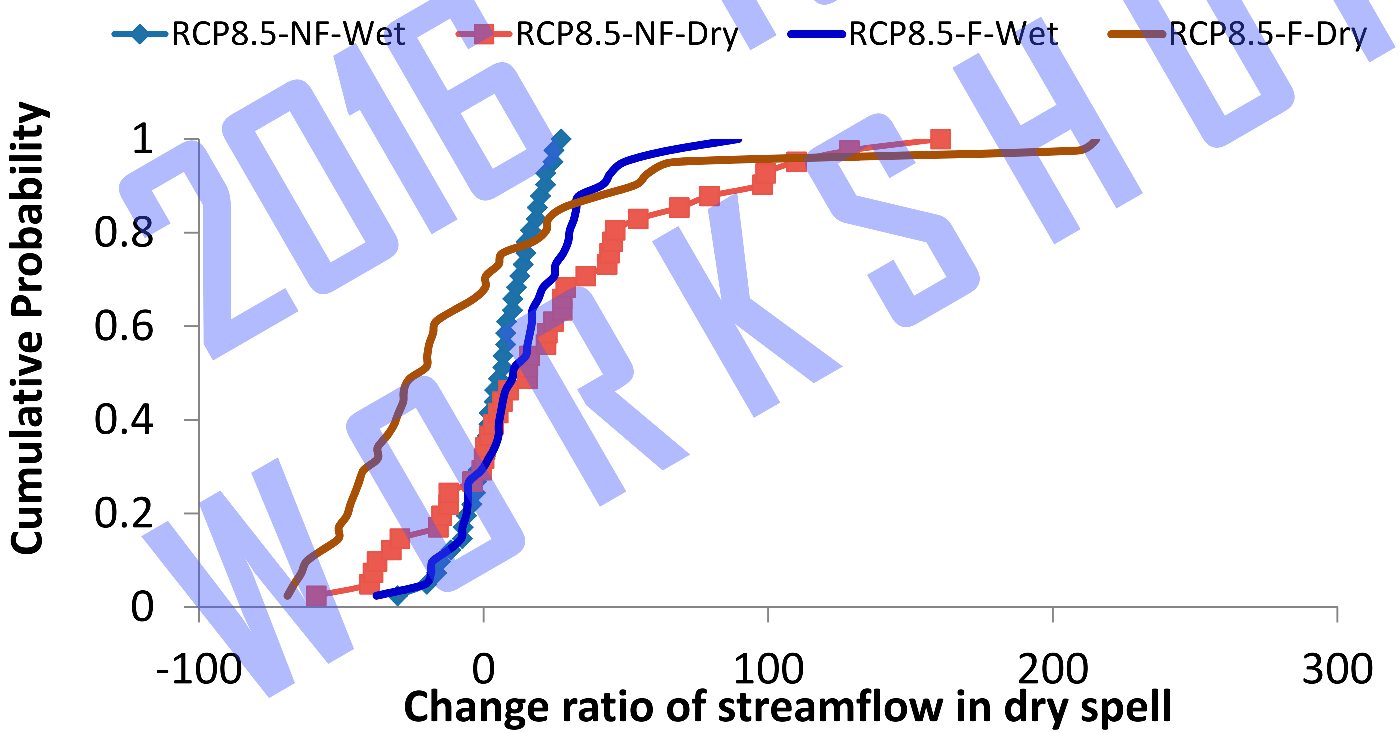
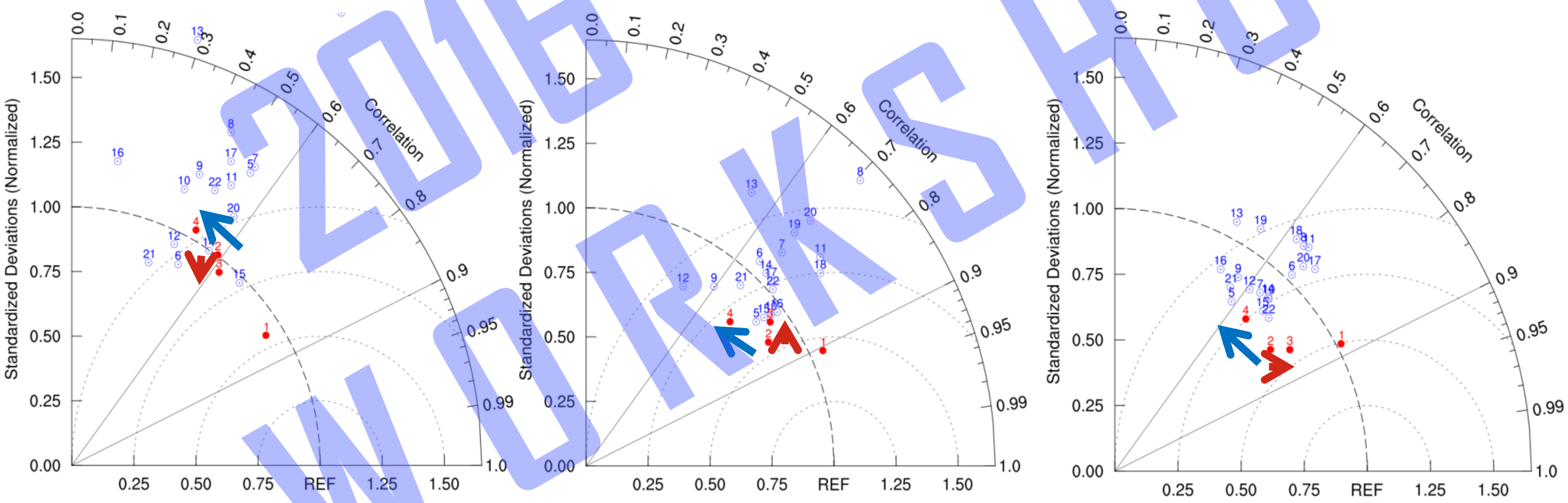
Change rate of streamflow in different projection period



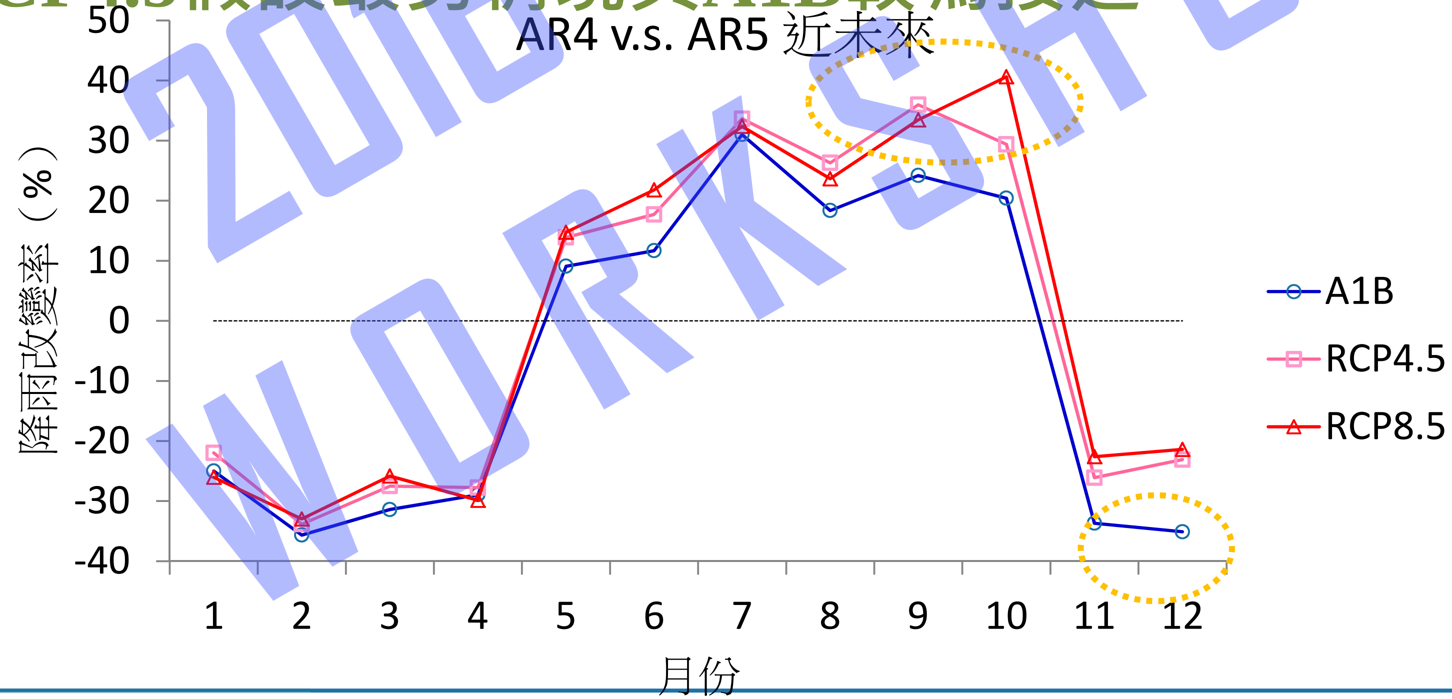
Onset | Retreat | Duration



TOP5 advancement → LAST5 advancement →

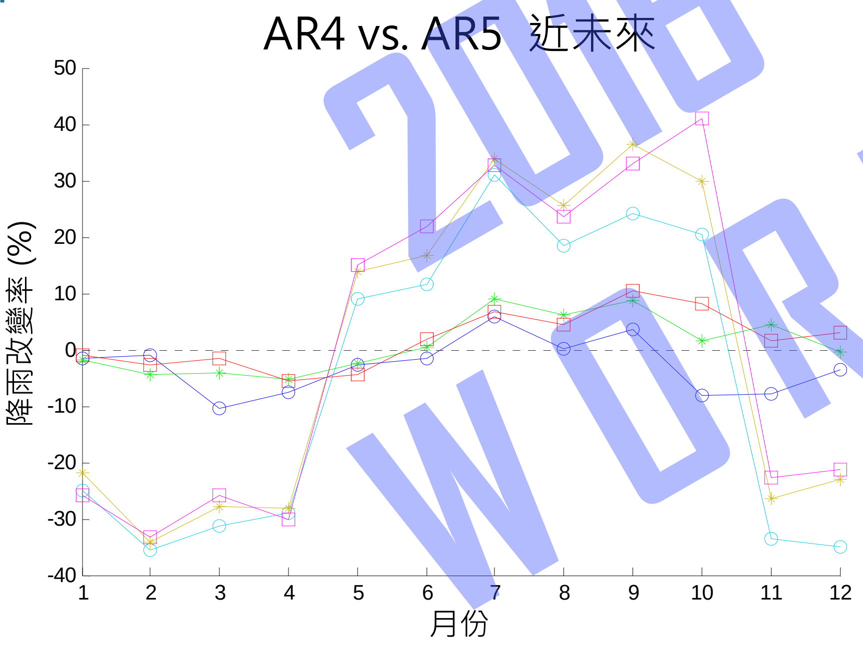
AR4與AR5之假設最劣情境

- 整體上AR4與AR5差異不大改變率約-30~30之間。
- AR4於11月與12月降雨衝擊量較AR5大
- AR5則是在豐水期降雨量改變率增加量較大（8~10月）
- RCP4.5假設最劣情境與A1B較為接近



近未來與世紀末比較

- AR5世紀末的衝擊大於近未來，其豐增枯減趨勢更為明確。



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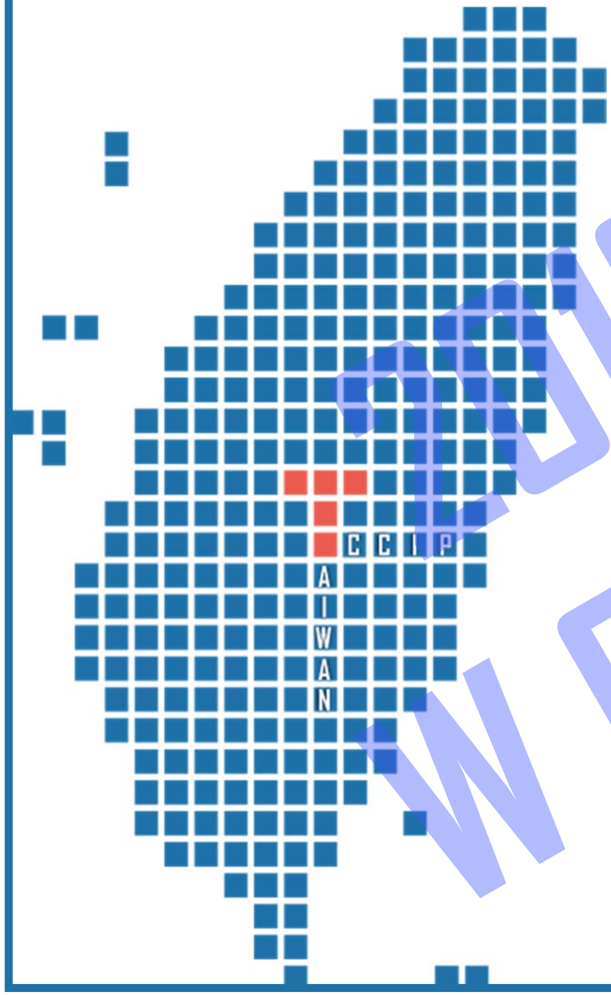


過去的挑選模式

AR4、AR5的日雨量資料

↓

類神經網路判讀模式
(學習降雨特性)

↓

序率暴雨模式

↓

hourly rainfall data

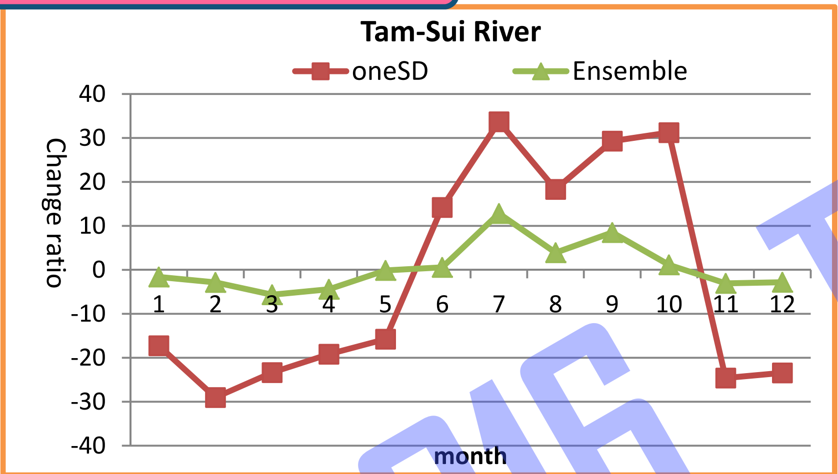
Data application

hydrological scenarios

Flood Control and Sediment Management due to Climate Change

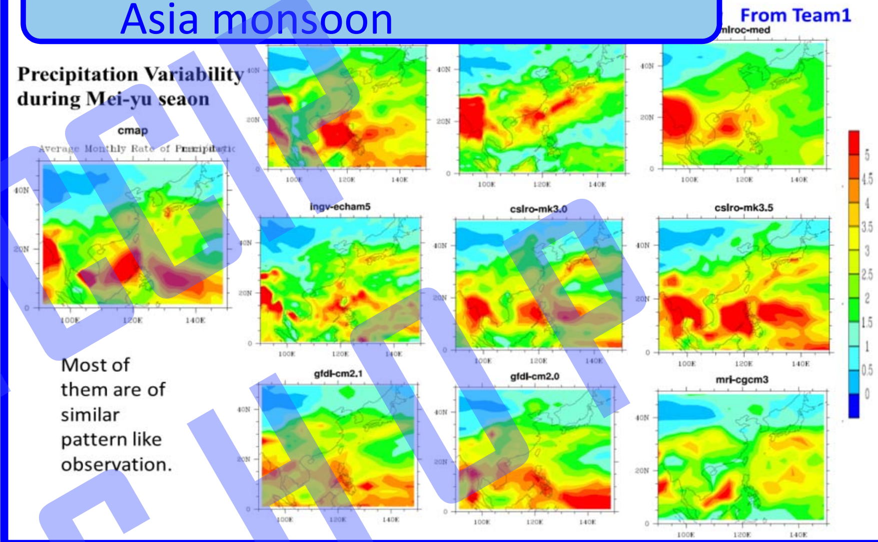
Selection of GCMs for impact studies of water resources

① Artificial worse case



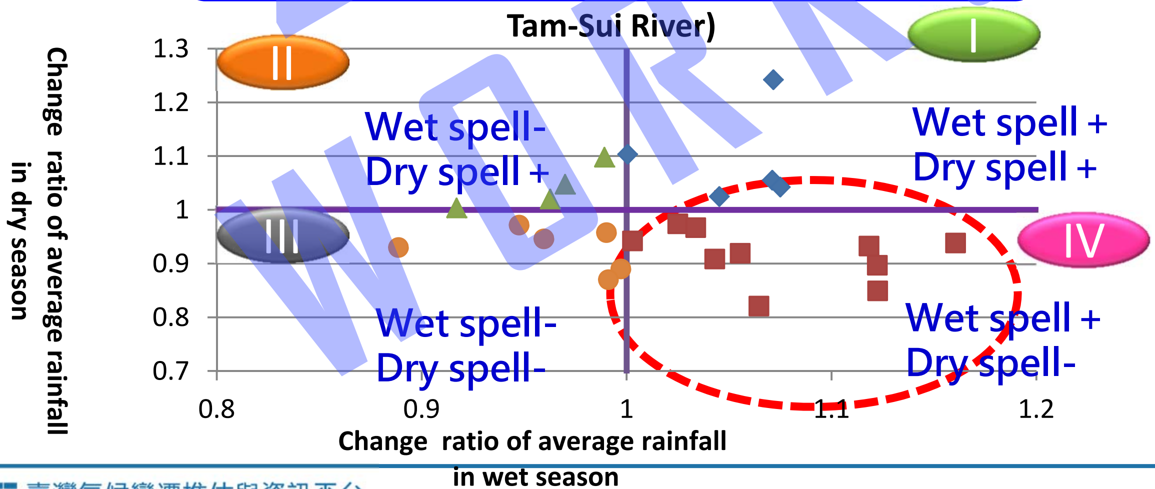
Multi-model ensemble + one time standard deviation

② GCMs' performance of East Asia monsoon



Most of them are of similar pattern like observation.

③ Based on characteristic of rainfall change rate in wet and dry spell

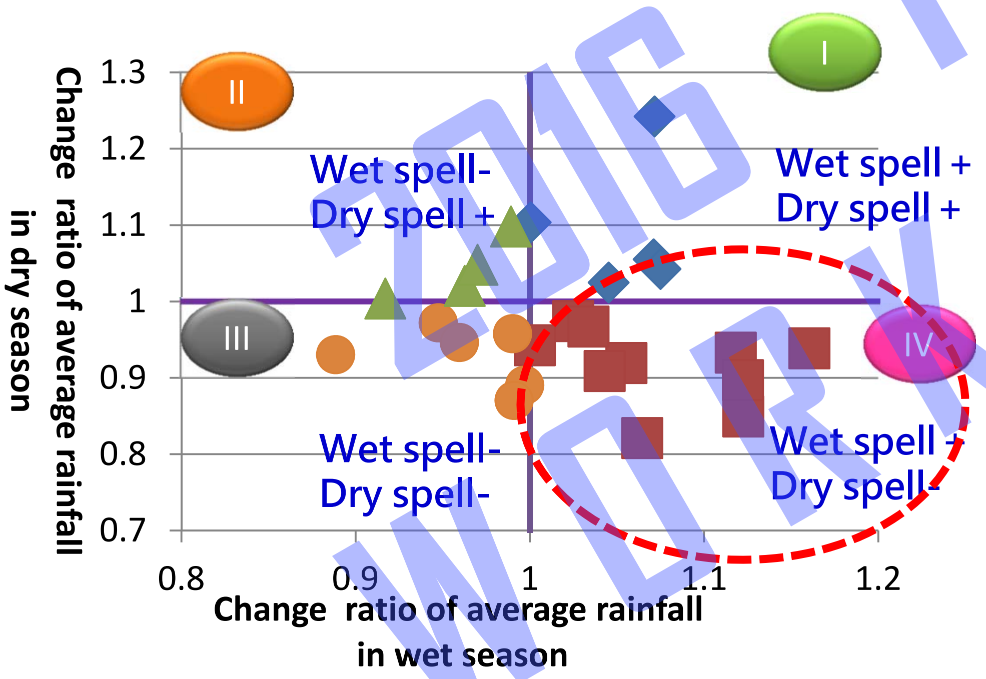


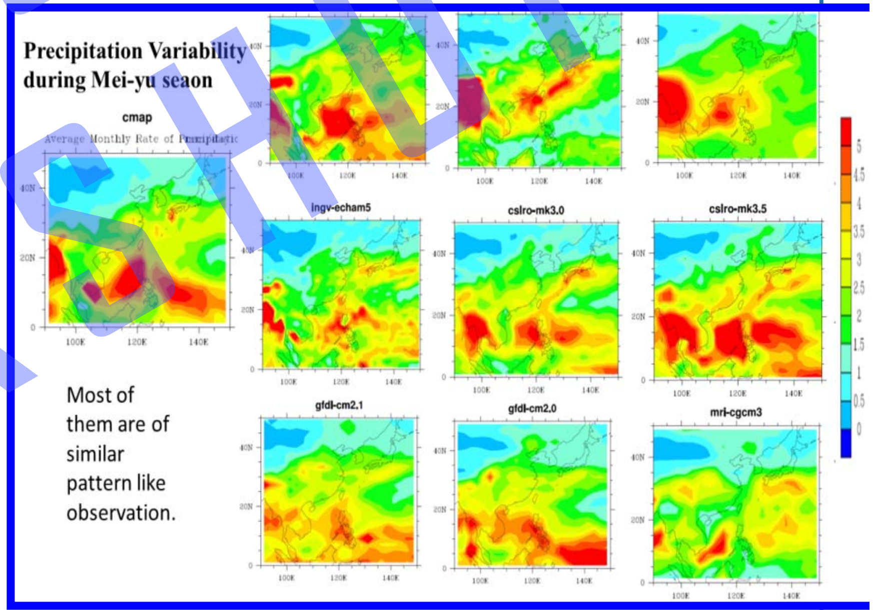
Different Strategies are made for Application of Water resource using Projection data of Statistical Downscaling concerning Climate Change

Method of Selection GCM model

① **Based on characteristic of rainfall change rate in wet and dry spell**

② Using performance of East Asia monsoon by GCM simulation result





AR4資料應用情形

水利署研究計畫名稱	氣候變遷情境應用
氣候變遷水文情境評估研究 氣候變遷對水旱災衝擊影響 氣候變遷對防洪與土砂災害衝擊影響	多模式平均 假設最劣情境 空間解析度:5km
臺灣北、中、南、東部地區氣候變遷對水資源衝擊評估計畫	挑選「全年少雨」與「全年多雨」之等5個GCM模式。 空間解析度:25km

narios

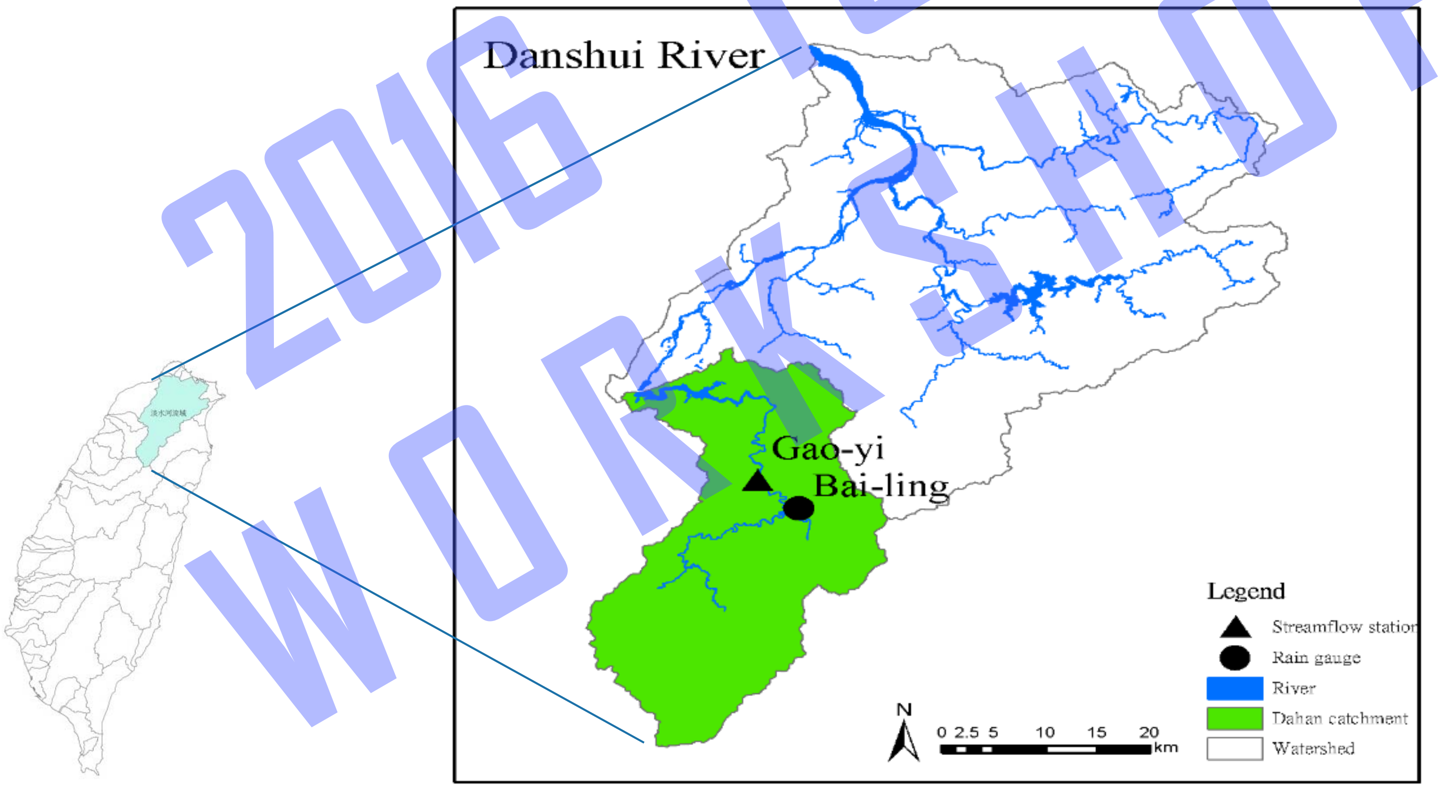
Flood Control and Sediment Management due to Climate Change

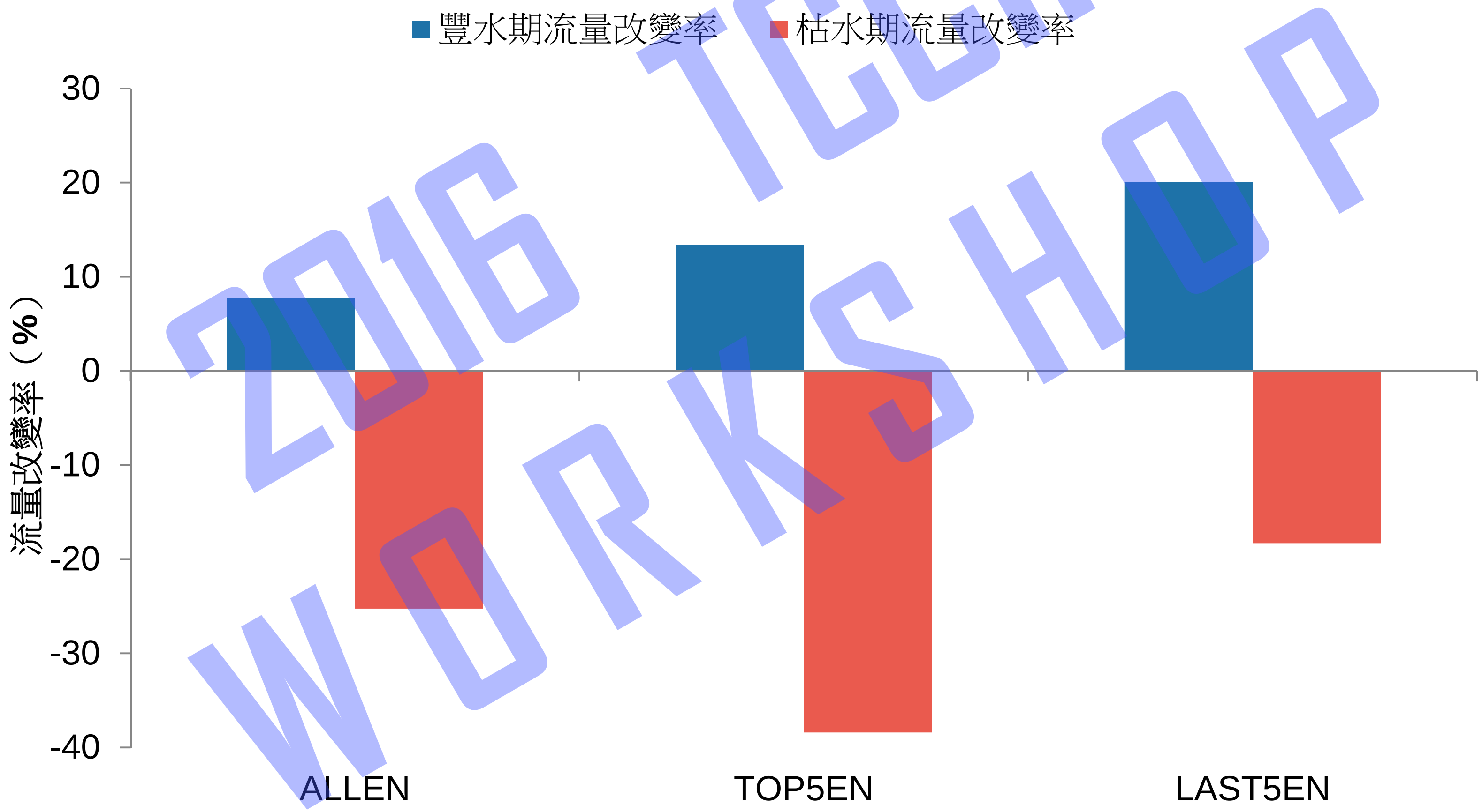
esults and discussions

- **Stream flow impact in wet and dry spell in near future**
- **Comparison of various variables**
  - Selected GCMs
  - Selected girds and rainfall stations
  - Rainfall distributions of weather generation
  - Comparison between natural variability and GCMs uncertainty
  - Downscaling-spatial resolutions

Study area

- The Danshui river is chosen for assessing the impacts of streamflow and located in Northern Taiwan.
- This rivers is very important water resources that supply drinking water to New Taipei.




豐水期流量改變率
枯水期流量改變率
流量改變率（%）
30
20
10
0
-10
-20
-30
-40
ALLEN
TOP5EN
LAST5EN