The construction of Taiwan climate datasets in the TCCIP project:

the Taiwan Rainfall Index
and
the Rainfall/Temperature Datasets with 1-km Gridded Resolution

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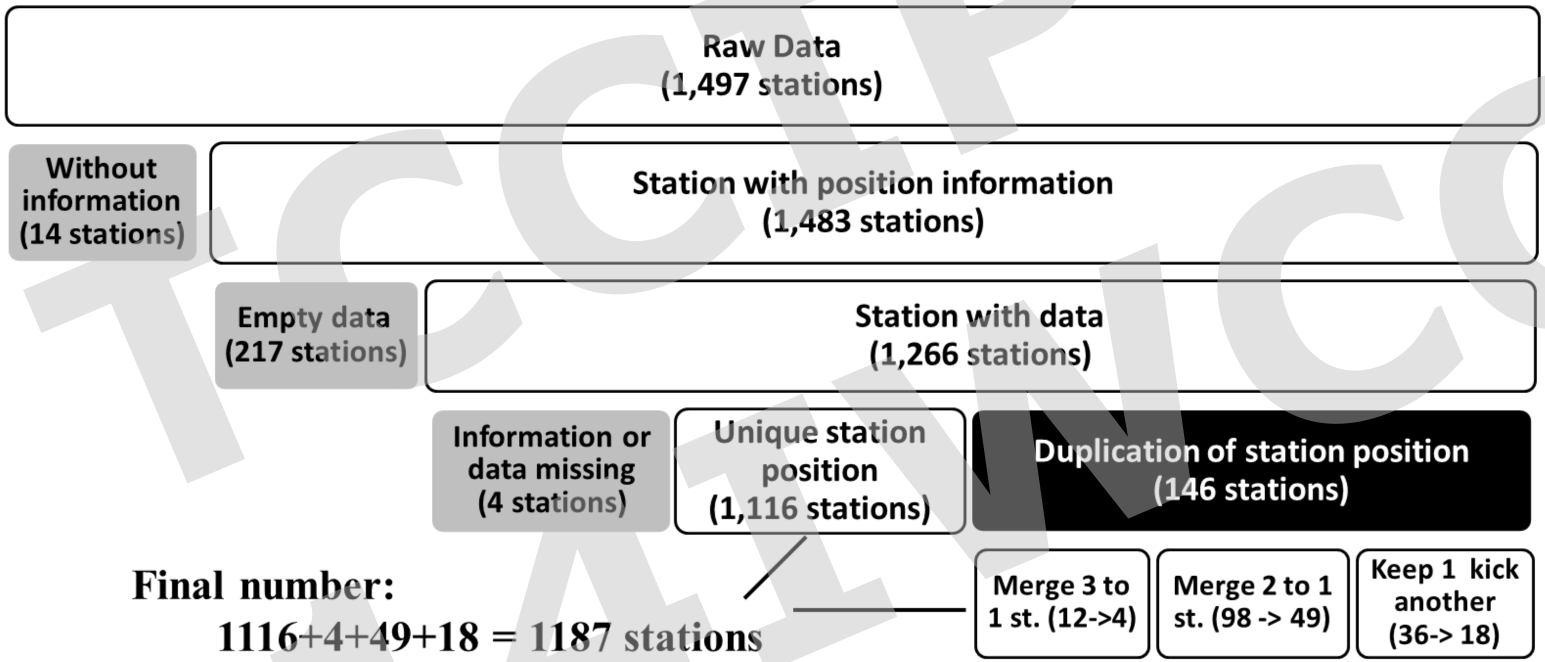
Taiwan Rainfall Index (TRI)

The diagram for the processing of the Taiwan Rainfall Data (TRD)



The gray blocks represented the deleted stations

The black blocks represented the processes for duplicated-data stations

The white blocks represented the kept stations

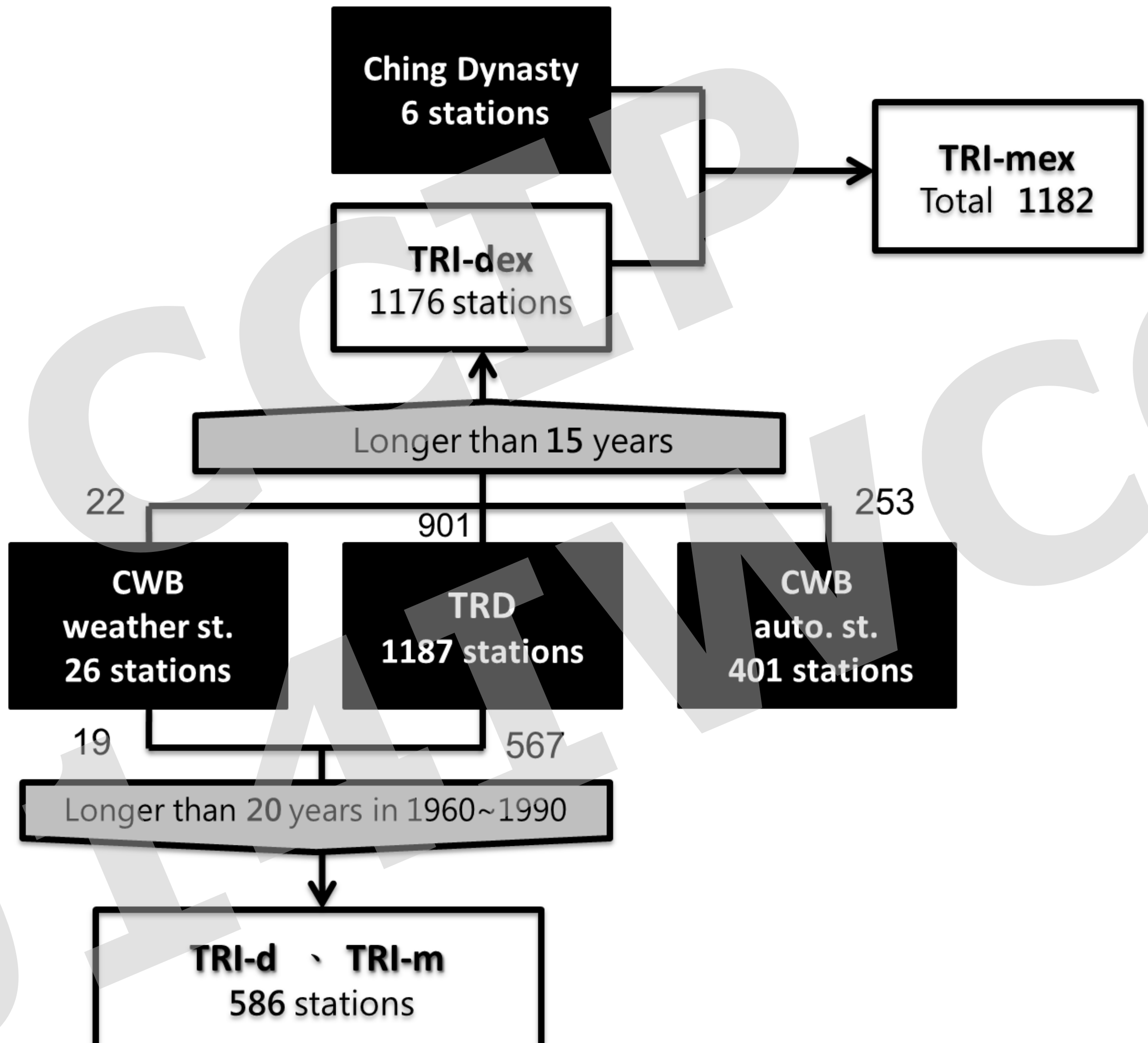
The final number of used stations is **1,187**.

Data sources:

CWB weather stations、Taiwan Rainfall Data (TRD, under TCCIP), and CWB auto stations

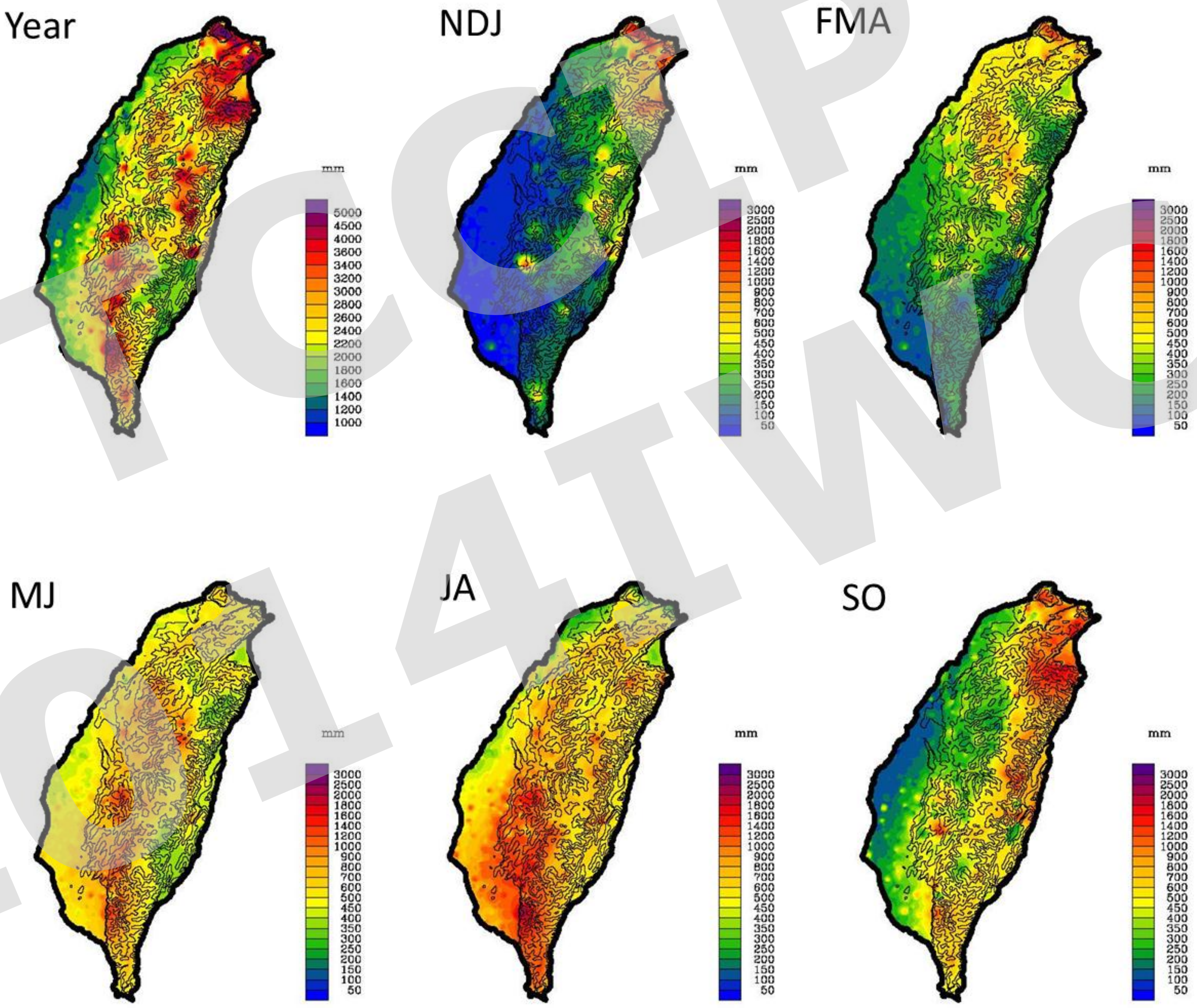
The resources of TCCIP-TRD are:

臺灣糖業公司 (294站)、經濟部水利署 (251站)、臺灣電力公司 (94站)、行政院農委會林務局 (67站)、菸酒公賣局 (22站)、臺灣製鹽總廠 (18站)
嘉南農田水利會 (96站)、雲林農田水利會 (57站)、彰化農田水利會 (33站)、桃園農田水利會 (21站)、高雄農田水利會 (17站)、農業改良場 (17站)、行政院農委會農委會糧食局 (15站)、行政院農委會林業試驗所 (14站)、屏東農田水利會 (14站)、苗栗農田水利會 (13站)、臺中農田水利會 (13站)、行政院退輔會 (10站)、宜蘭農田水利會 (10站)、臺東農田水利會 (10站)、臺鳳公司 (9站)、南投農田水利會 (8站)、行政院農委會農業試驗所 (7站)、臺北翡翠水庫管理局 (7站)
臺灣大學 (7站)、石門農田水利會 (6站)、茶業改良場 (6站)、高速公路局 (6站)、花蓮農田水利會 (5站)、新竹農田水利會 (5站)、土地銀行 (3站)、行政院農委會 (3站)、畜產試驗所 (3站)、中興大學 (2站)、水產試驗所 (2站)、屏東科技大學 (2站)、中央大學 (1站)、水利署 (1站)、台灣糖業 (1站)、竹林國小 (1站)、竹南農田水利會 (1站)、自來水公司 (1站)、私立中國文化大學 (1站)、亞洲蔬菜研究發展中心 (1站)、青果運銷合作社 (1站)、財團法人農業工程研究中心 (1站)、彰化師大 (1站)、臺中港務局 (1站)、臺灣鹼業公司 (1站)、瑠公農田水利會 (1站)



Numbers of stations to calculate TRI daily (TRI-dex, TRI-d) and TRI monthly data (TRI-m, TRI-mex)

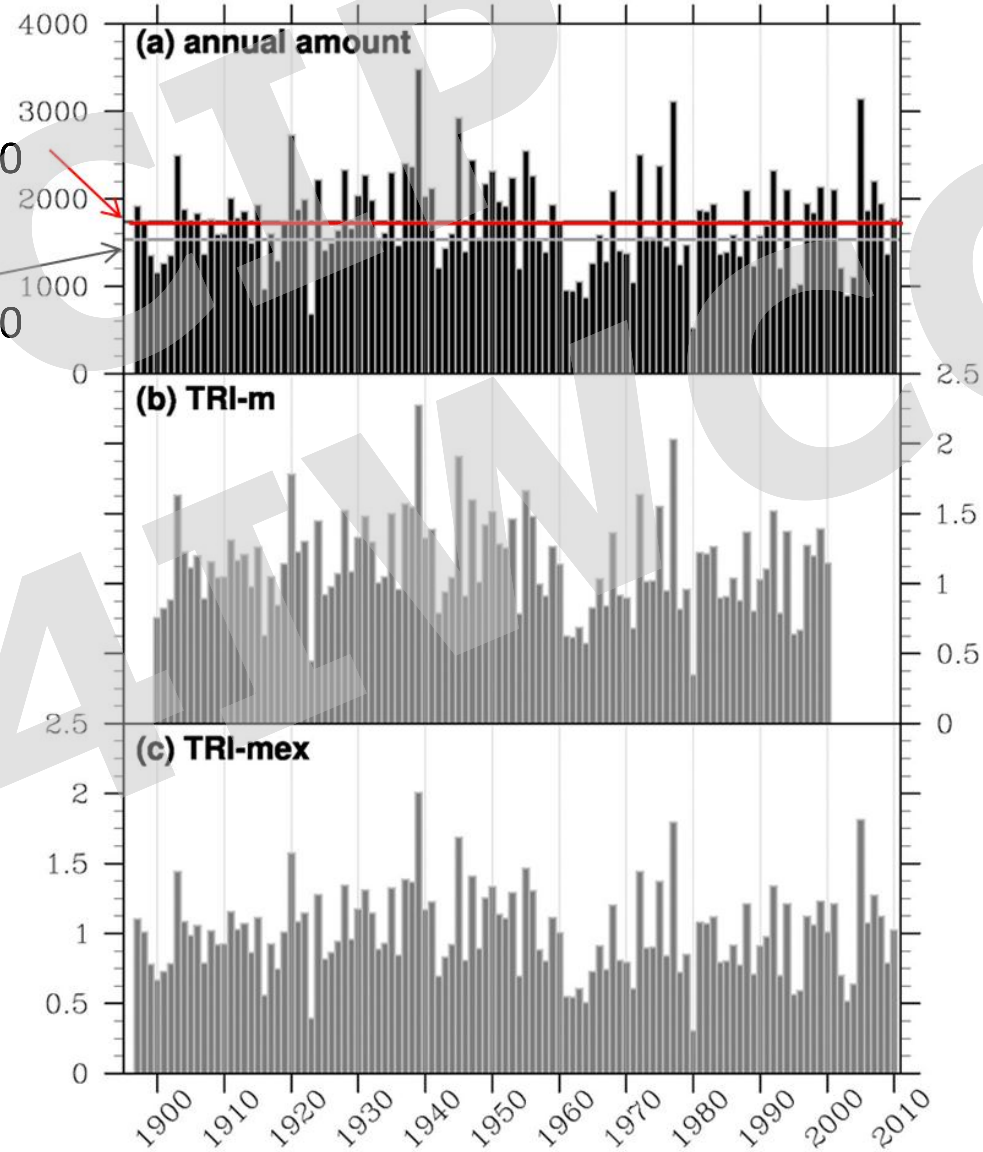
The climatology of Taiwan rainfall (1897-2010)



The process of making TRI (using CWB Tainan station as an example)

Red line is the mean of 1897～2010

Gray line is the mean of 1961～1990

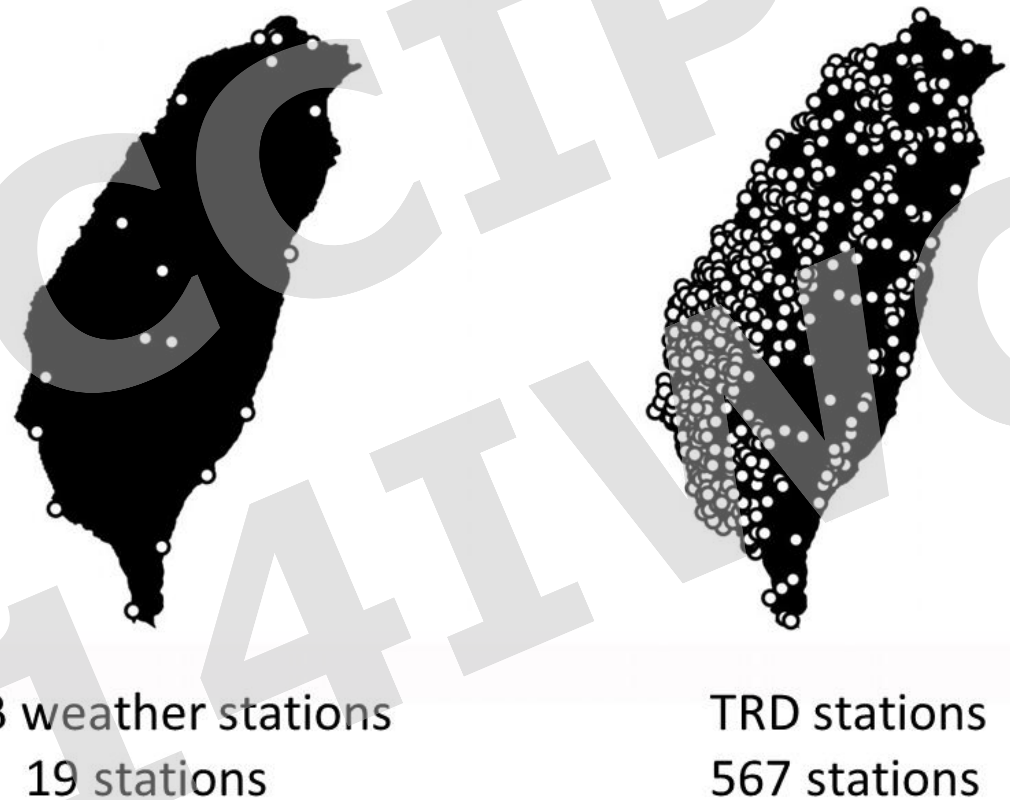


(a) The red line is the mean of Annual rainfall from 1961 to 1990.

(b) TRI-m: rainfall divided by the value of the Gray Line in (a).

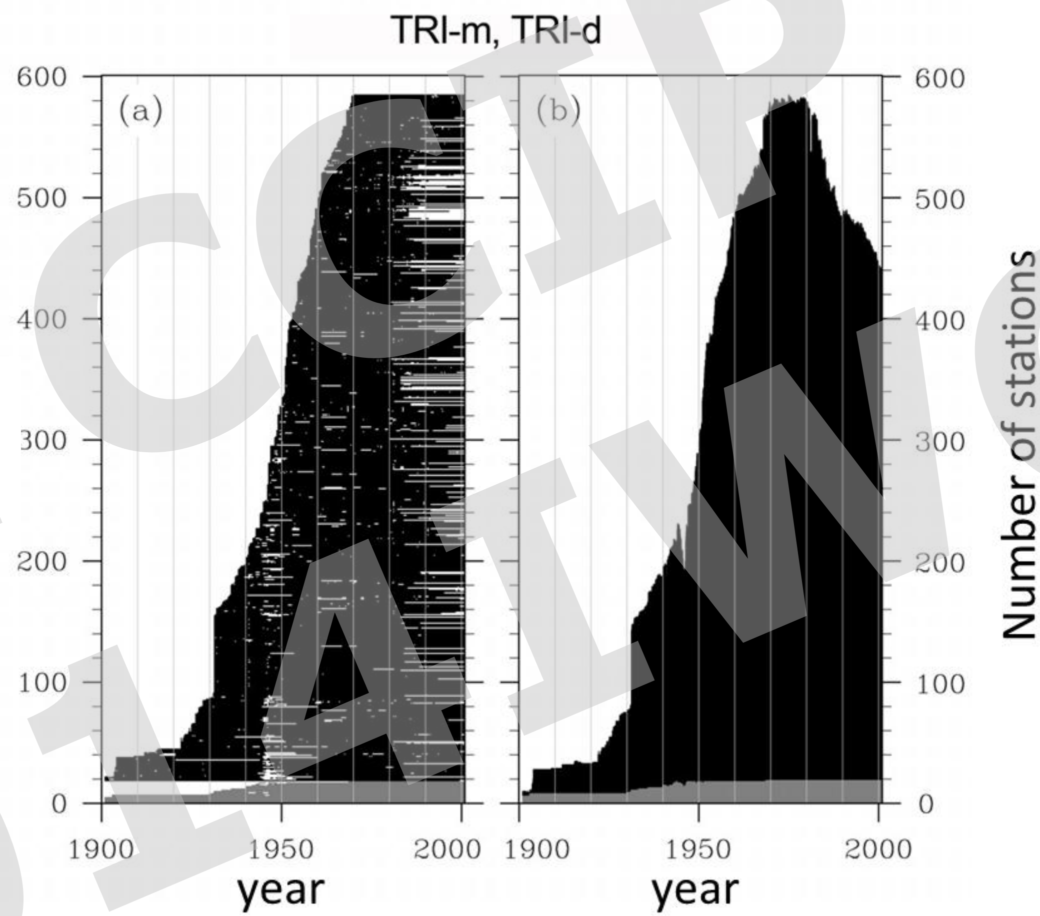
(c) TRI-mex: rainfall divided by the value of the Red Line in (a).

The locations for stations included in TRI-m and TRI-d



Distribution of stations used in TRI-m and TRI-d: the total number is 586. The left 19 stations are CWB weather stations, and the right 567 stations are stations of TRD.

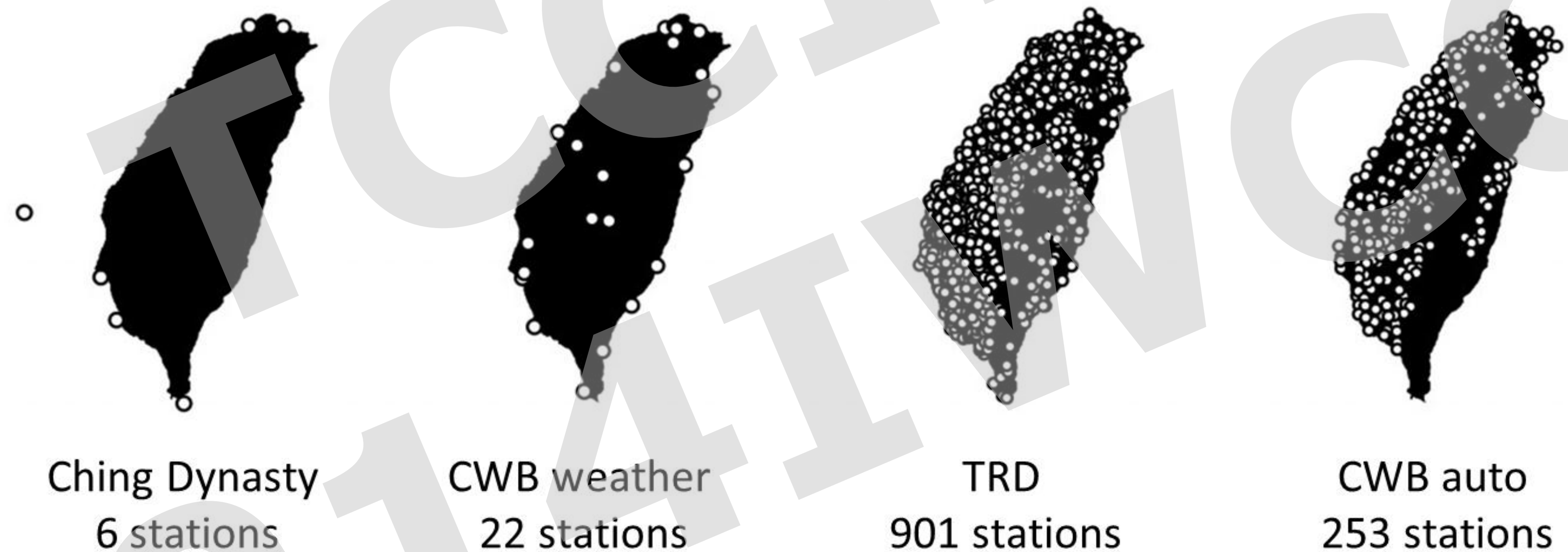
The data period and total number used for TRI-m and TRI-d



(a) This figure shows the lack of data of stations of all 586 stations to calculate TRI-m and TRI-d 586. The gray color stands for CWB weather stations, and the black color stands for TRD dataset. White color stands for lack of data.

(b) numbers of summaries in fig.(a).

The locations for stations included in TRI-mex



The distribution of total 1,182 stations used in TRI-mex. The white spots stand for stations.

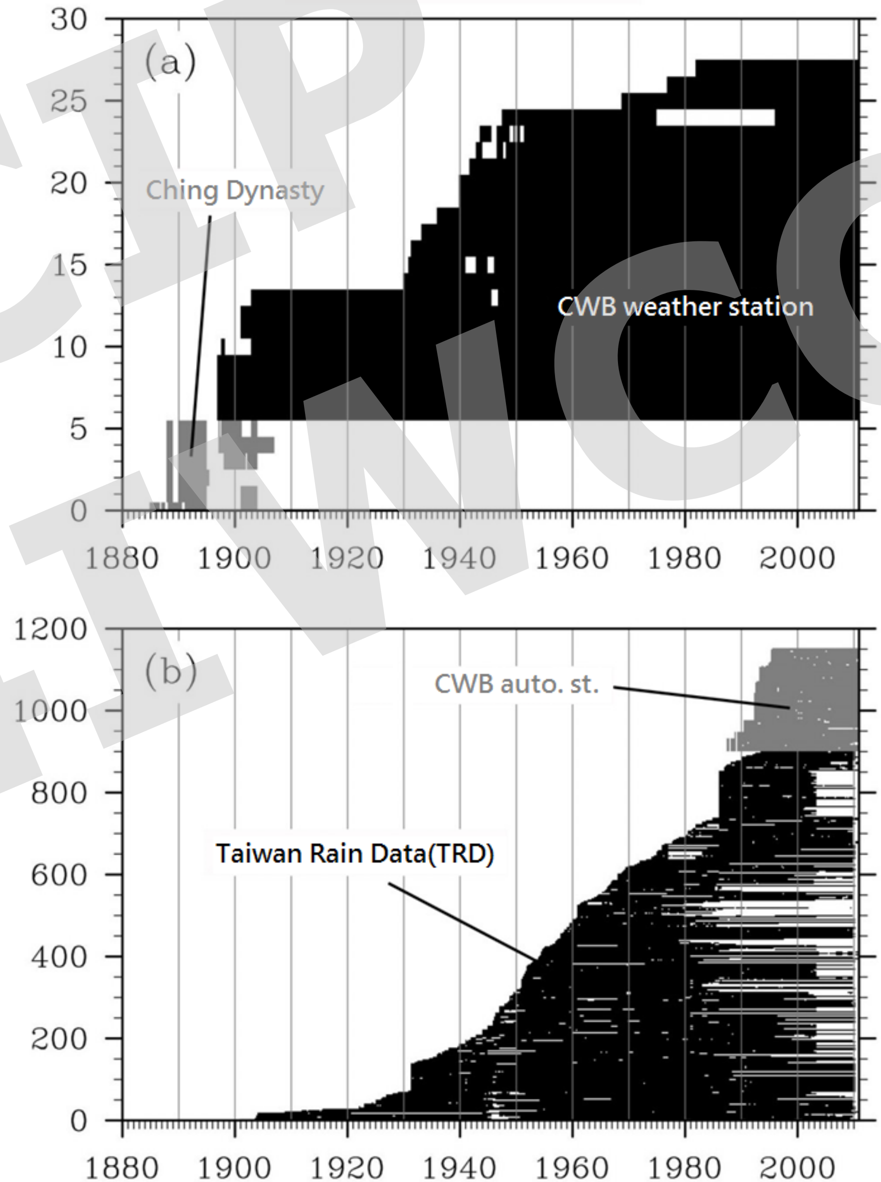
The data period of the original stations used in TRI-mex

This figure shows the lack of data of stations of all 1,182 stations used in TRI-mex.

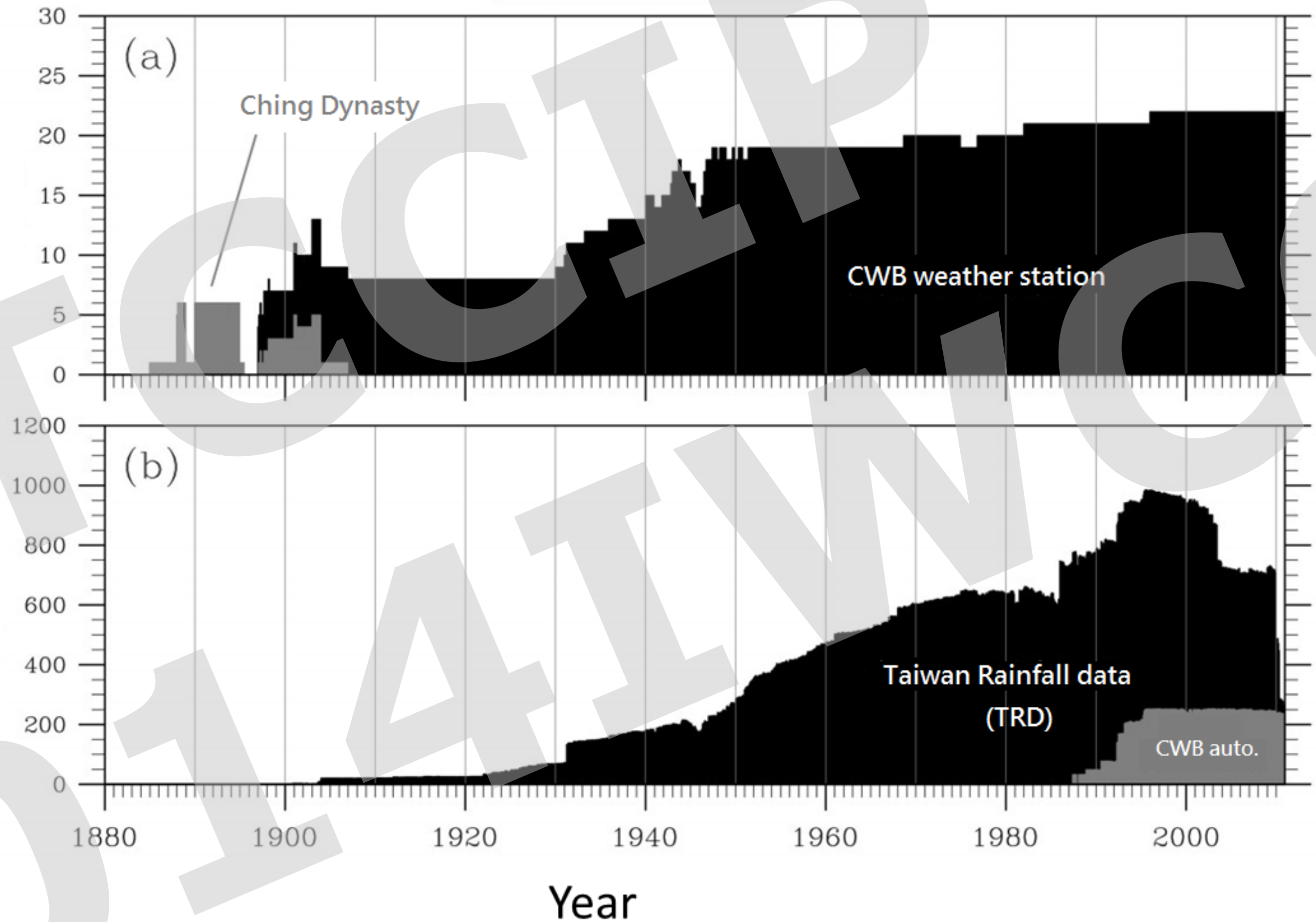
(a) The gray color stands for the Ching Dynasty stations(6 stations). The black color stands for the CWB weather stations(22 stations).

(b) The gray color stands for the CWB auto stations(253 stations). The black color stands for the TRD stations(901 stations).

White color stands for lack of data.



The data number of the original stations used for TRI-mex

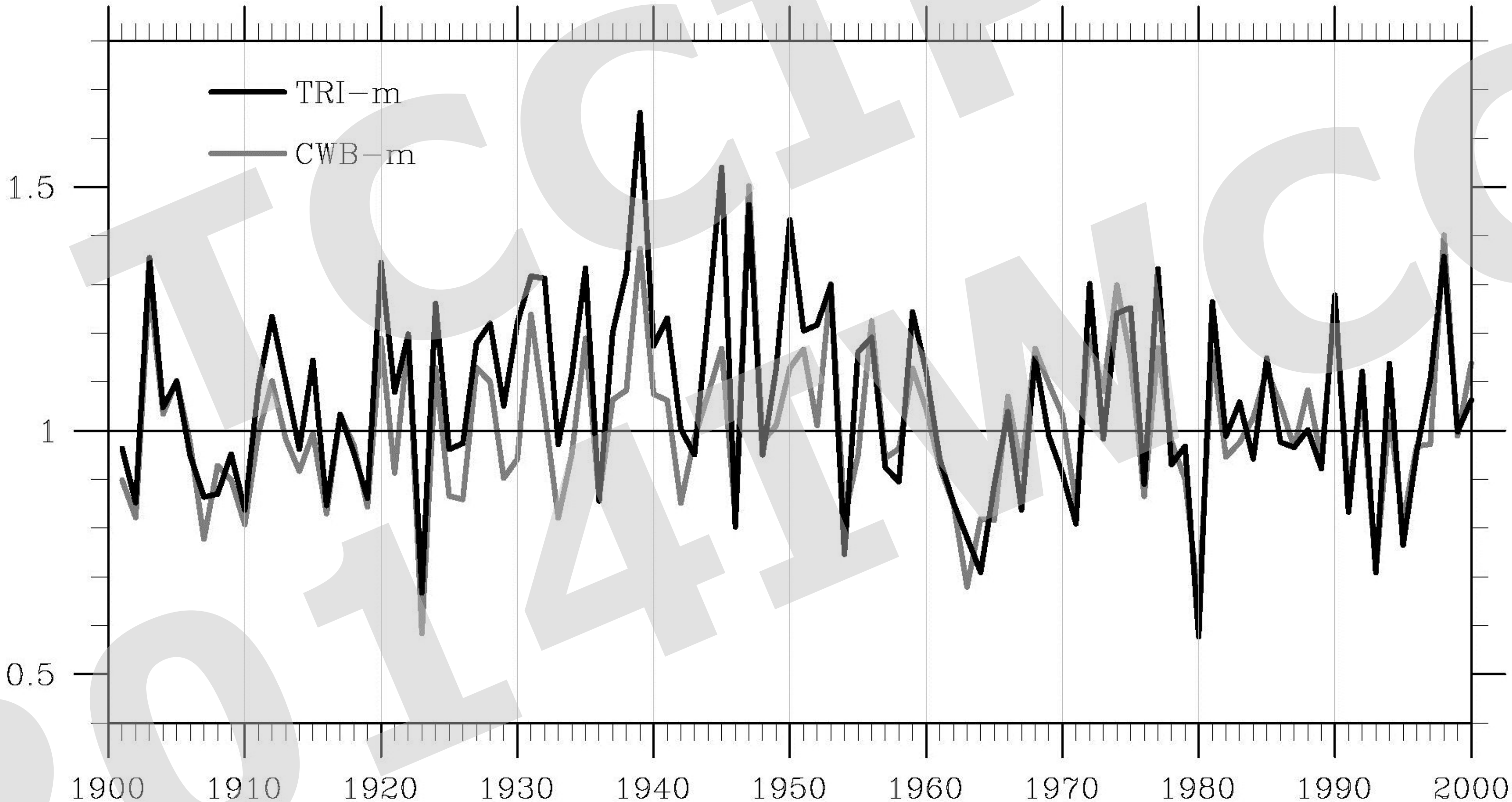


Numbers of stations to calculate TRI-mex:

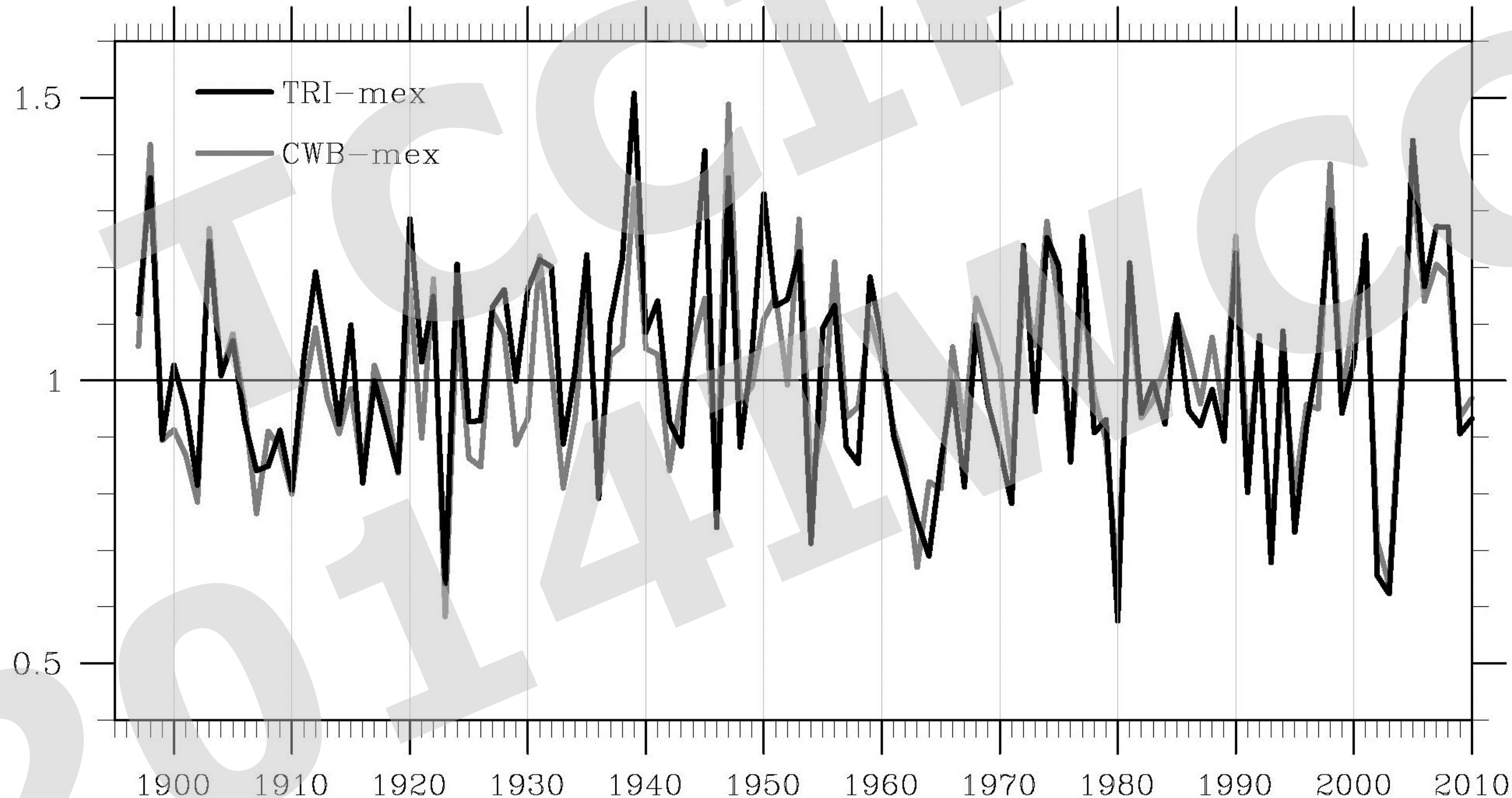
(a) Gray color stands for Ching Dynasty stations, and Black color stands for CWB weather stations.

(b) Gray color stands for CWB auto stations, and Black color stands for TRD stations.

Comparison between TRI-m and the similar index constructed only with CWB conventional stations



Comparison between TRI-mex and the similar index constructed only with CWB conventional stations

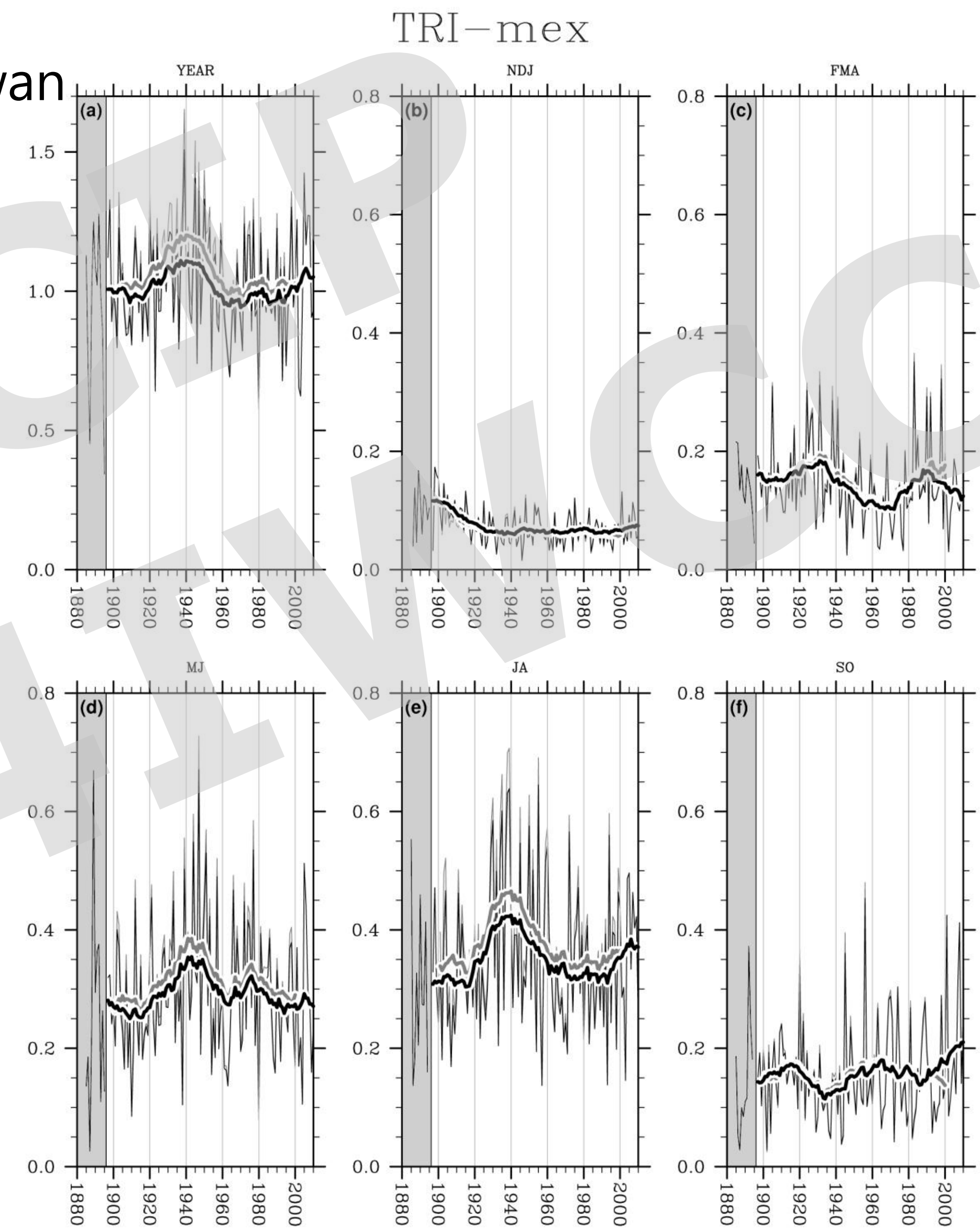


The interannual and inter-decadal variations of the Taiwan rainfall in various seasons

Summaries of each season of TRI-mex:
(a) yearly (YEAR)
(b) Winter (Nov-Jan，NDJ)
(c) Spring (Feb-Apr，FMA)
(d) Mei-Yu (May-Jun，MJ)
(e) Summer (Jul-Aug，JA)
(f) Autumn (Sep-Oct，SO)

Black : TRI-mex
Gray: TRI-m
Thin line: monthly data
Fat line: 21-year running mean

The gray shadow marks these data are just for reference cause of the such small group of stations before 1895 in Ching Dynasty.



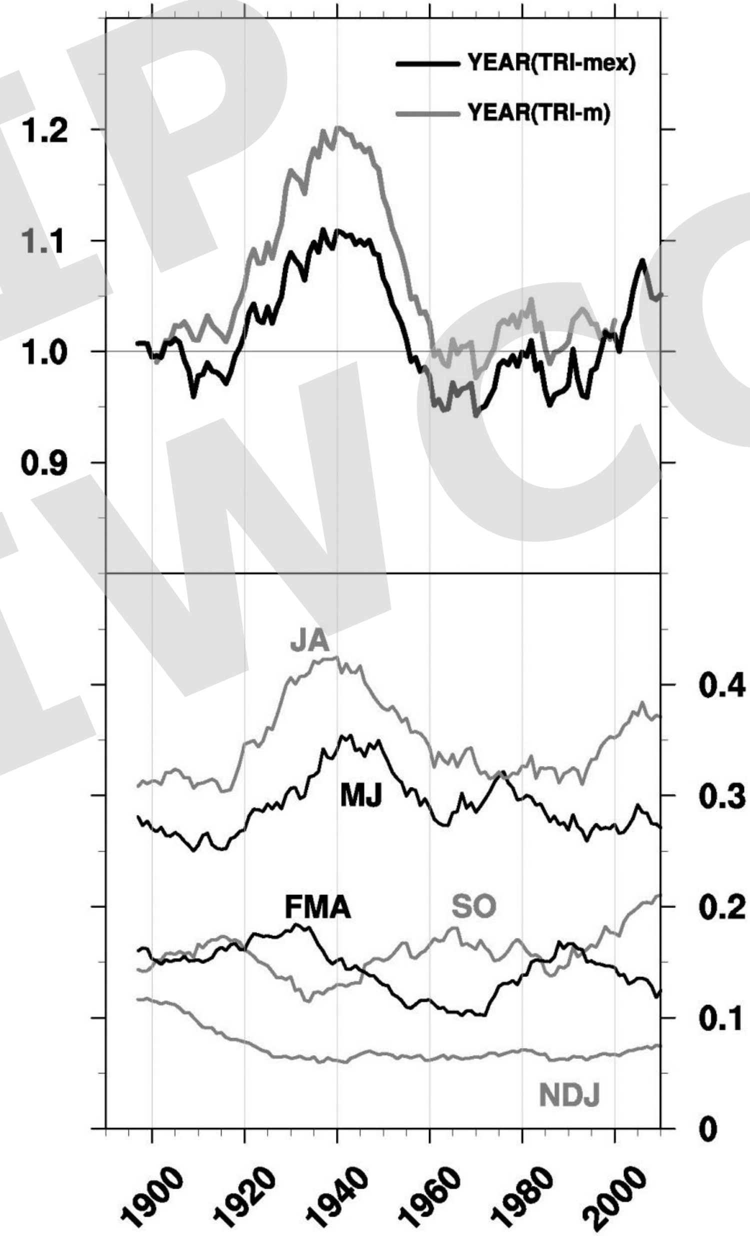
The decadal variations of each natural season based on the TRI-mex

Upper figure:

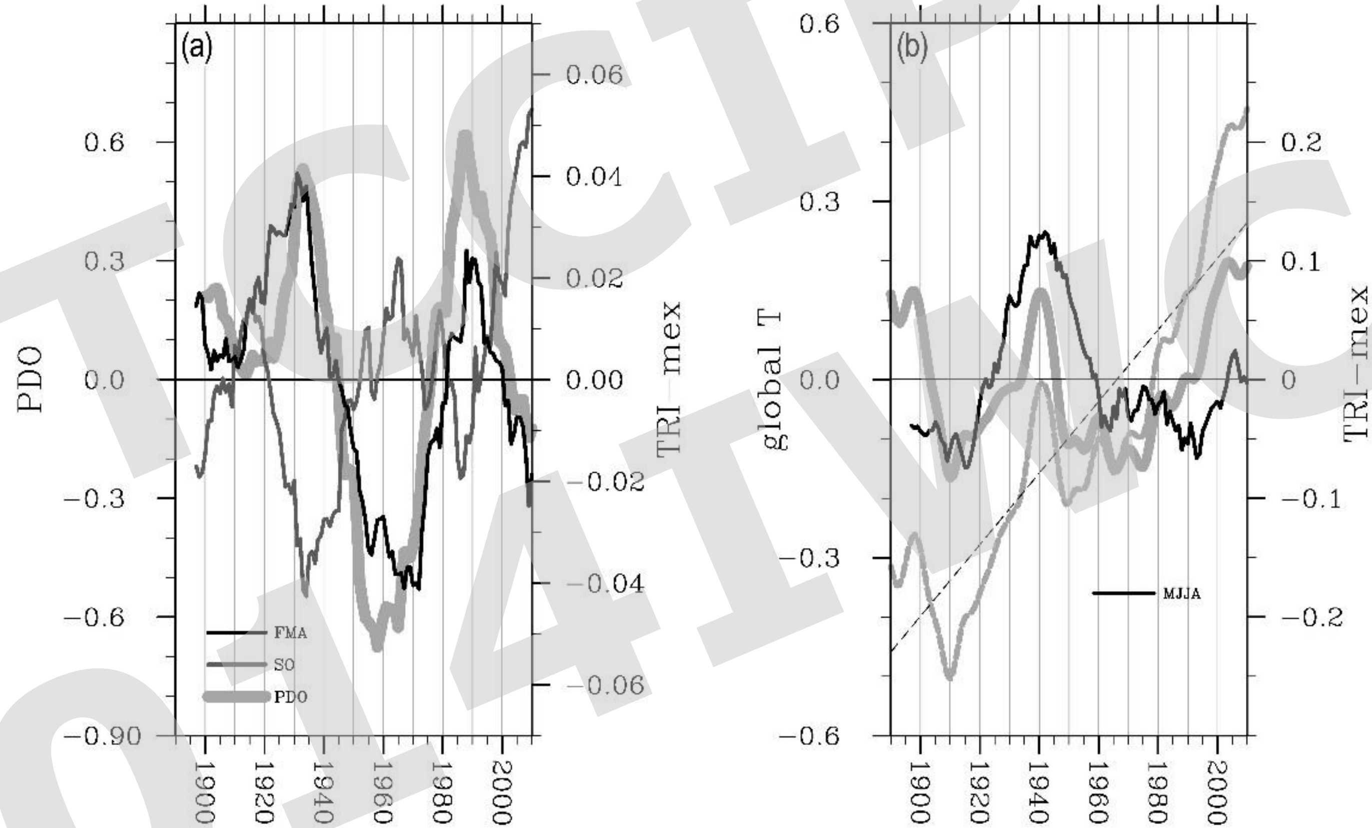
Black: annual mean of TRI-mex
Gray: annual mean of TRI-m

Lower figure:
Summarized TRI-mex of each season:
Nov-Jan (NDJ)
Feb-Apr (FMA)
May-Jun (MJ)
Jul-Aug (JA)
Sep-Oct (SO)

All of them are 21-year running mean



The decadal variations of TRI-mex, PDO, and global temperature in each season



(a) The black line stands for summary of TRI-mex from Feb to Apr(FMA) . The thin gray line stands for summary of TRI-mex from Sep and Oct(SO). The fat gray line stands for PDO index.
(b) The black line stands for the summary of TRI-mex from May to Aug(MJJA). The gray dashed line stands for anomalous global temperature mean. The dark gray straight line is the trend of anomalous global temperature mean . The fat gray line is the result of anomalous global temperature mean minus its trend. The calculations above were processed after 21-year running mean.

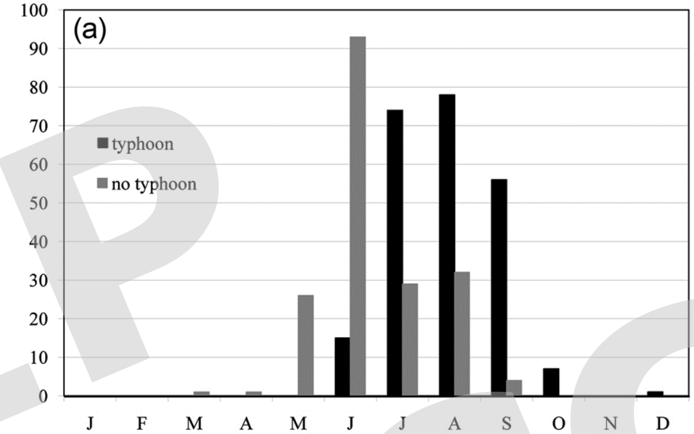
The characteristics of the first 1% extreme cases from TRI-dex during 1897-2010

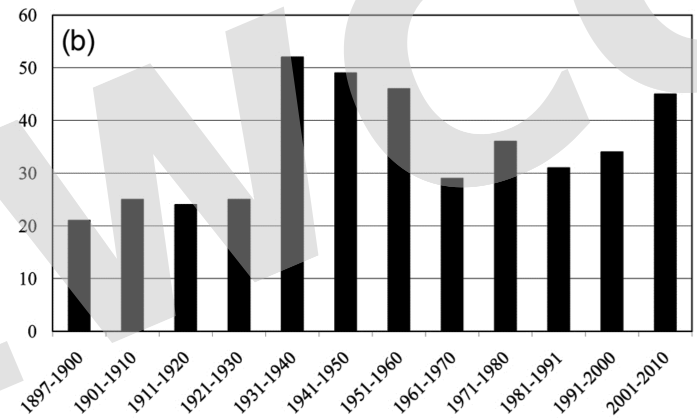
(a) The monthly distribution of the first 1% extreme cases from TRI-dex . The black bars stand for typhoon cases, and the gray bars stand for no typhoon cases.

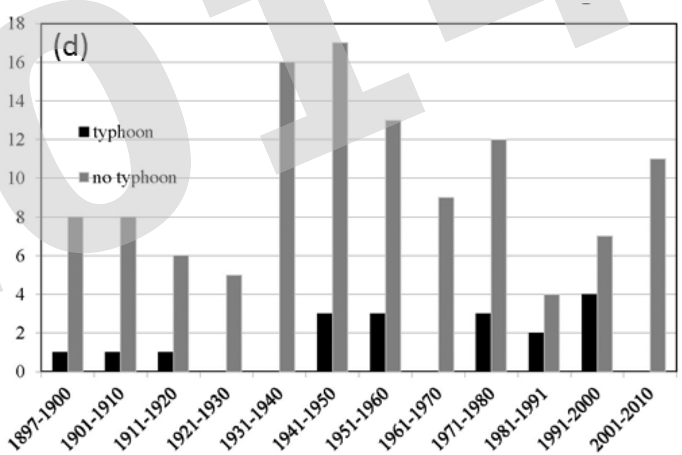
(b) The decadal distribution of the first 1% extreme cases from TRI-dex .

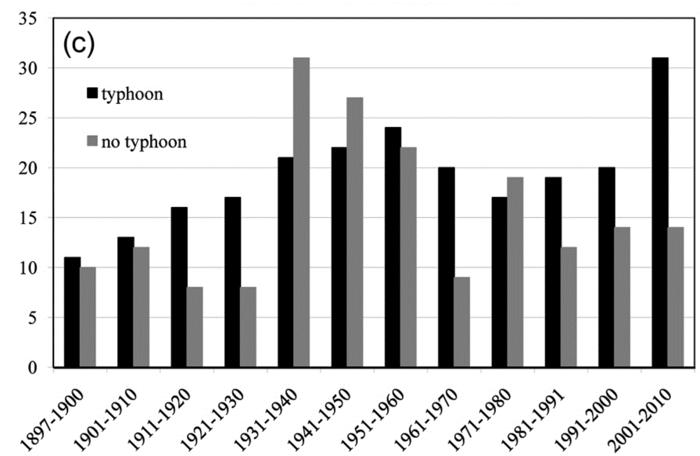
(c) The decadal distribution of the first 1% extreme cases from TRI-dex . The black bars stand for typhoon cases, and the gray bars stand for no typhoon cases.

(d) The monthly distribution of the first 1% extreme cases from TRI-dex (only during Mei-Yu season). The black bars stand for typhoon cases, and the gray bars stand for no typhoon cases.









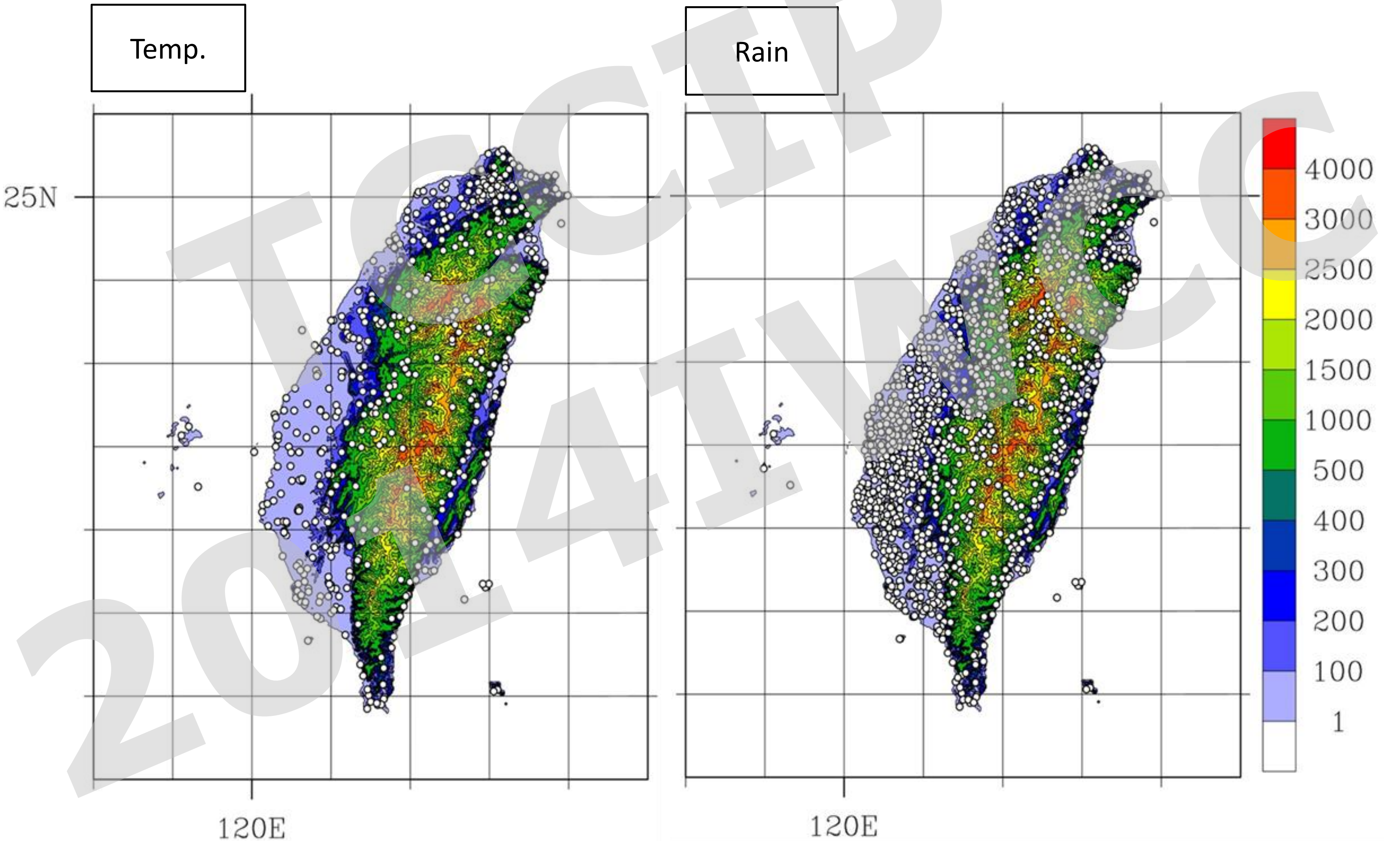
Summary

A TCCIP Taiwan Rainfall Index (hereafter TRI), the longest rainfall index in the Taiwan meteorological history, is constructed in this study. The TRI is based on the richest data from observational stations in Taiwan. More than 1,500 stations are used including observations during the Ching dynasty, the conventional weather stations, the newly acquired Taiwan Rainfall Data (from 51 different sources, including the major contributors as the Water Resources Agency, Irrigation Associations and Taiwan Power Company), and Central Weather Bureau's automatic rainfall station data. The TRIs have daily and monthly versions. The longest index starts from 1885 and ends in 2010. Similar to the well-known "All India Monsoon Rainfall Index", the TRIs represent the variations of Taiwan rainfalls and can be used for many different research purposes.

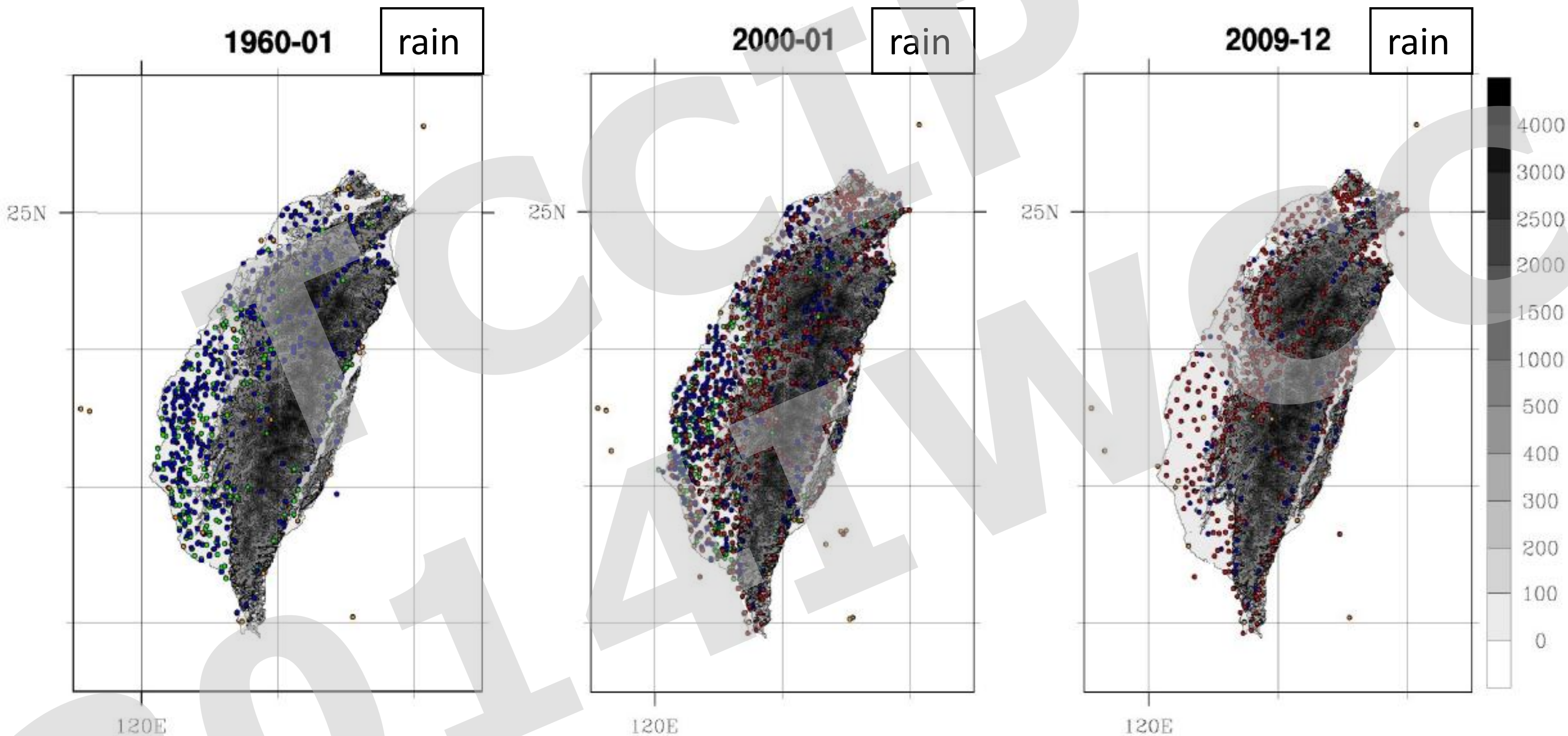
Using the TRI, the long-term rainfall variability in Taiwan is studied. Results show that there were more rain in 1920-1960s, less rain in 1960-1990s, and more rain again after mid-1990s (especially after 2000) with respect to the long-term climatology. These decadal variations are found in both yearly sum of rainfall amount and the number of extreme events. This study further analyzes the decadal to inter-decadal variations of rainfalls in each natural season. Results show that (1) the spring rain is highly correlated with the Pacific Decadal Oscillation, (2) the spring rain and autumn rain are negatively correlated, and (3) the decadal variations of rainfalls between Mei-yu (May-June) and early summer season (July-August) are related to the global temperature change in which the long-term warming trend is removed.

Introduction on the TCCIP 1-km gridded data

Geographical distribution of overall (T, P) stations



Inhomogeneous space-time distribution



紅色圓點:氣象局自動雨量測站

綠色圓點:農業測站

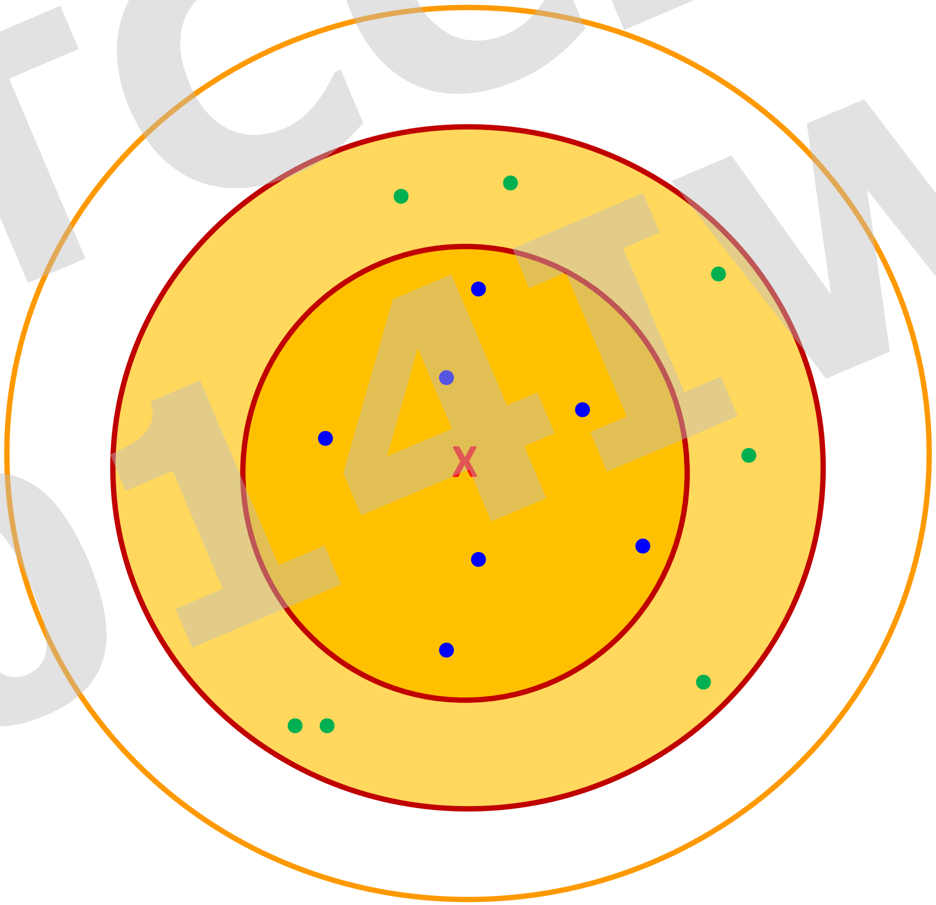
金色圓點:氣象局局屬測站+空軍測站+民航局測站

藍色圓點:水利署測站

The number of agricultural stations (green dots) is largely decreasing after 1990s, which is somewhat remedied by the increasing CWB/ARMTS stations (red dots).

Missing data imputation (Simolo et al. 2010, IJOC)

Using station geographical information (latitude, longitude, elevation difference, and relative azimuth between target station and reference stations) to compute the weightings (distance, elevation, azimuth) of reference stations.



X: target station

•: reference stations

•: reference stations

Missing data imputation (Simolo et al. 2010, IJOC)

1

$$w_i^d(x,y) = \exp\left(-\frac{d_i^2(x,y)}{c_d}\right) \quad ; \quad c_d = \frac{\overline{d^2}}{\ln 2}$$

2

$$w_i^h(x,y) = \exp\left(-\frac{\Delta h_i^2(x,y)}{c_h}\right) \quad ; \quad c_h = \frac{\overline{h^2}}{\ln 2}$$

- $w_i^d(x,y)$:**distance weight parameter**
- $d_i(x,y)$:**the distance between the target and reference stations *i-th***
- $\overline{d^2}$:**search radius (d)**
  (in this radius most have more then 20 reference stations)

$w_i^h(x,y)$: **height weighting parameter**

$\Delta h_i(x,y)$: **the** elevation difference **between the target and reference stations *i-th***

c_h : **constant**

$\overline{h^2}$: **h = 0.35km (Simolo et al.(2010))**

3

$$w_i^{ang}(x,y) = 1 + \frac{\sum_{j \neq i} w_j^d(x,y) w_j^h(x,y)(1-\cos\theta_{(x,y)}(j,i))}{\sum_{j \neq i} w_j^d(x,y) w_j^h(x,y)}$$

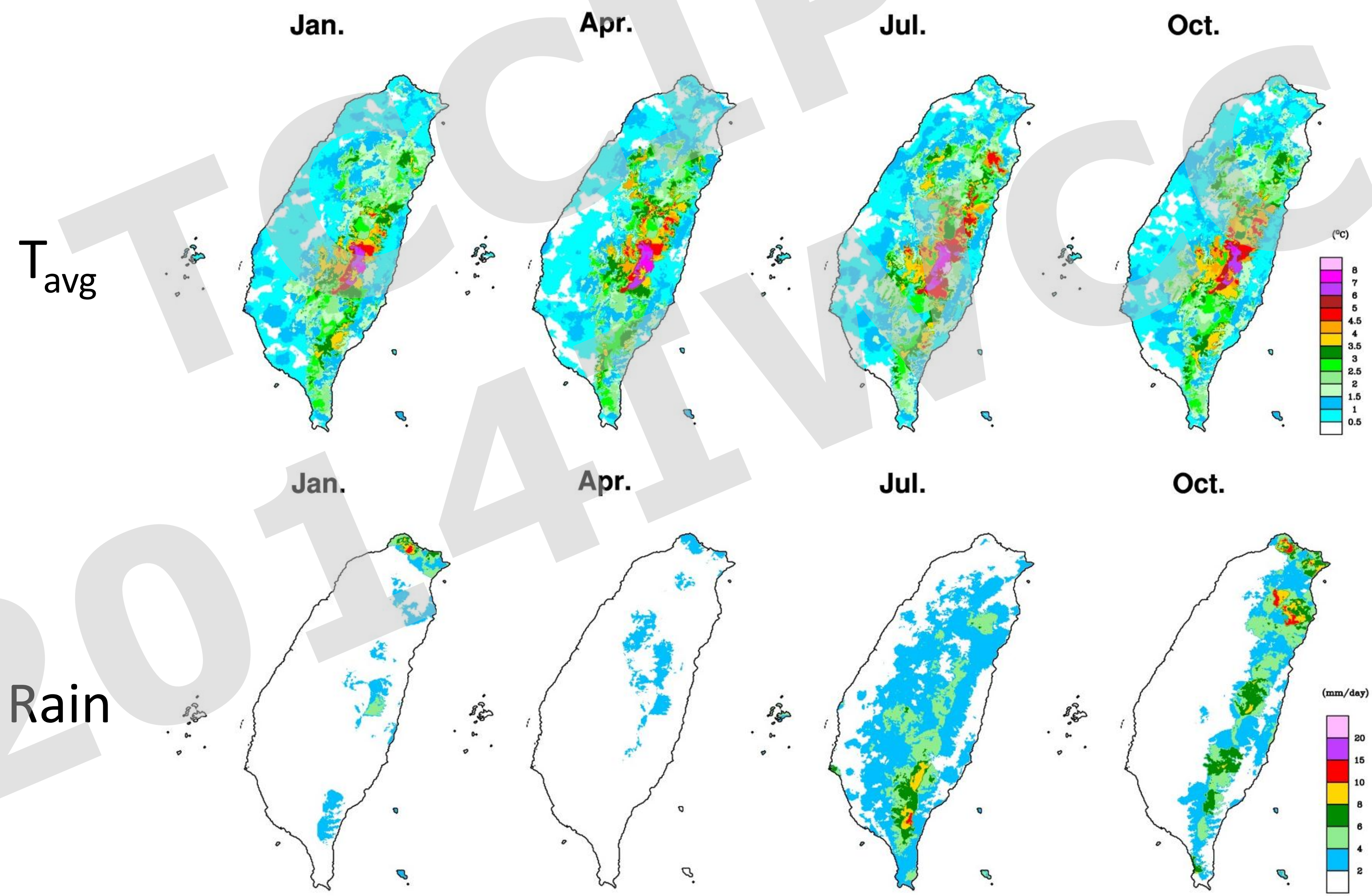
- the indices *i* and *j* are the reference stations
- $w_i^{ang}(x,y)$:azimuth separation **weighting parameter**
- *ϑ(x,y)(j, i)* :the azimuth separation between the *j* -th and *i*-th reference station with respect to the target station *(x, y)*.

4

$$w_i(x,y) = w_i^d(x,y) w_i^h(x,y) w_i^{ang}(x,y)$$

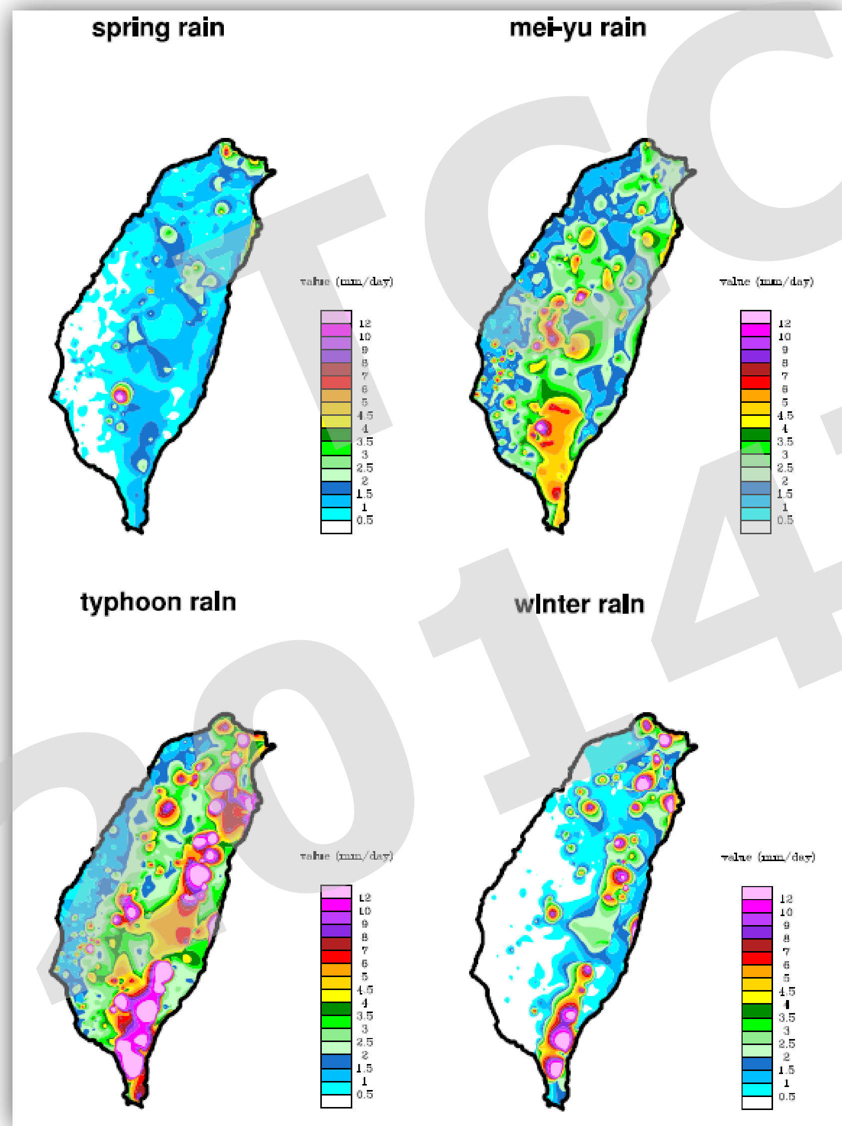
Final weighting is the product of (distance, elevation, azimuth) weightings

Uncertainty analysis: gridded s.t.d. of reference stations' (T, P)

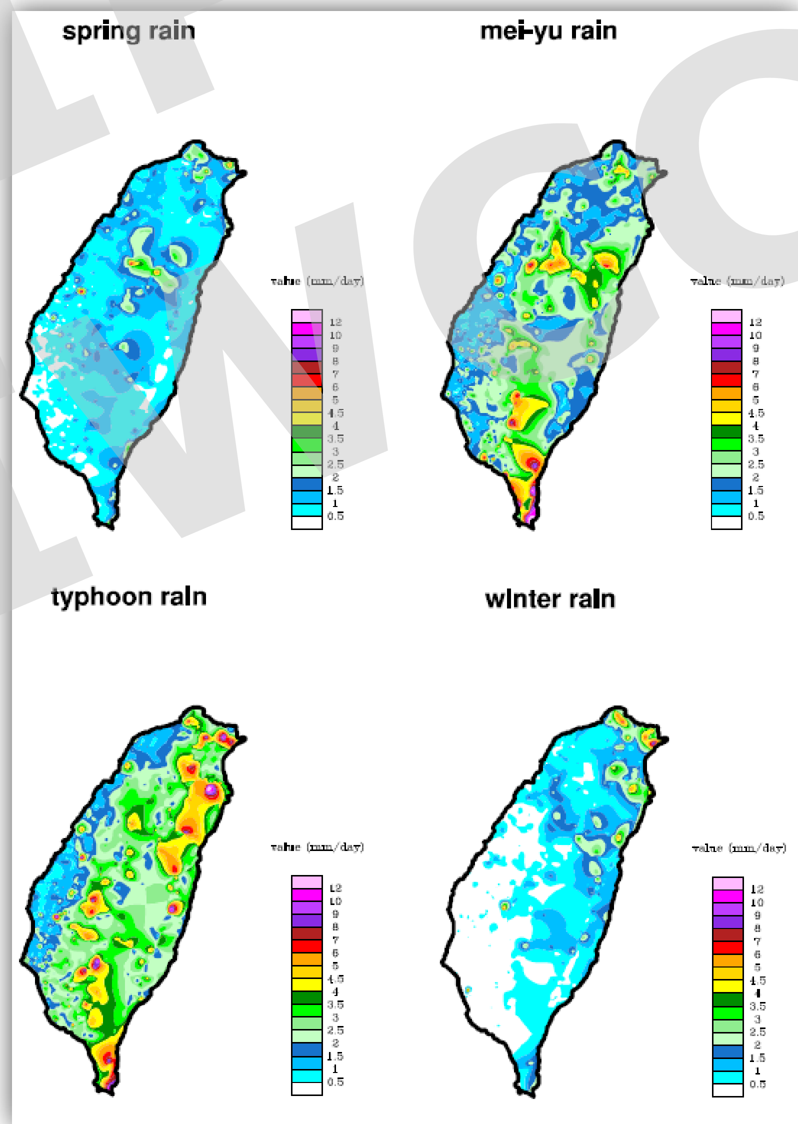


Uncertainty analysis of rainfall: RMSE (Jacknife's 'take-one-out' procedure)

1970~1979 (worst)

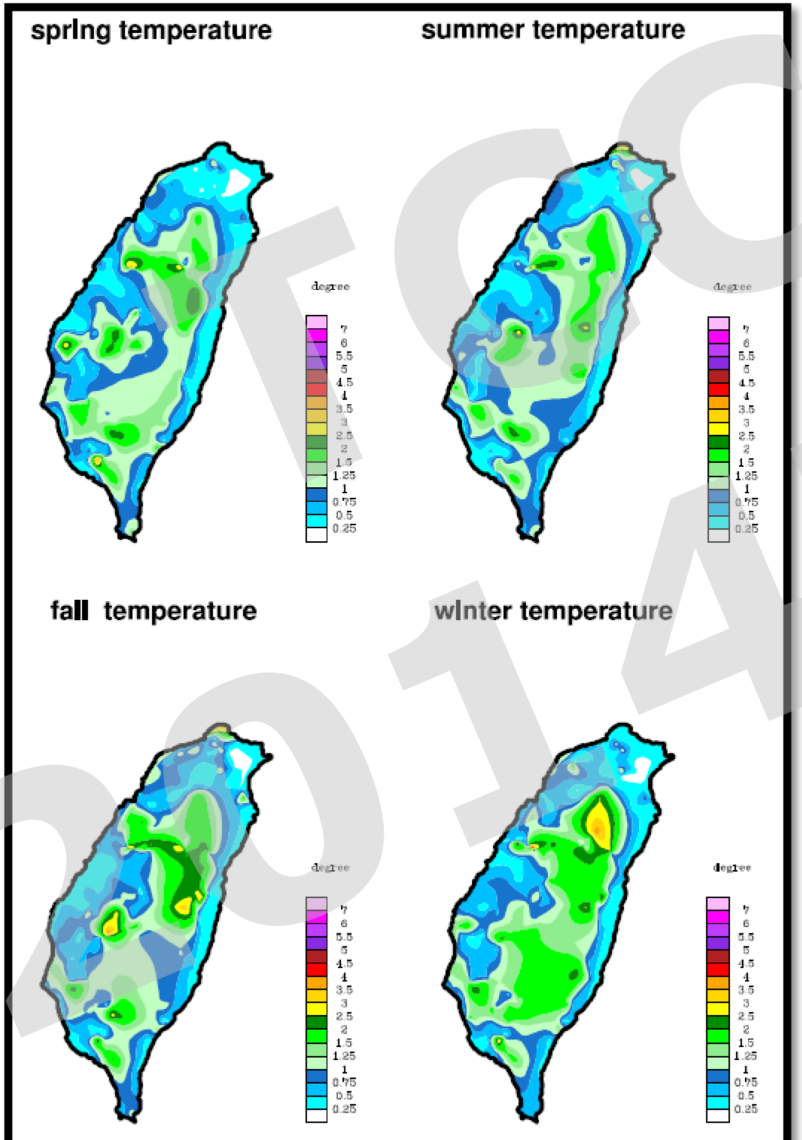


1990~1999 (best)

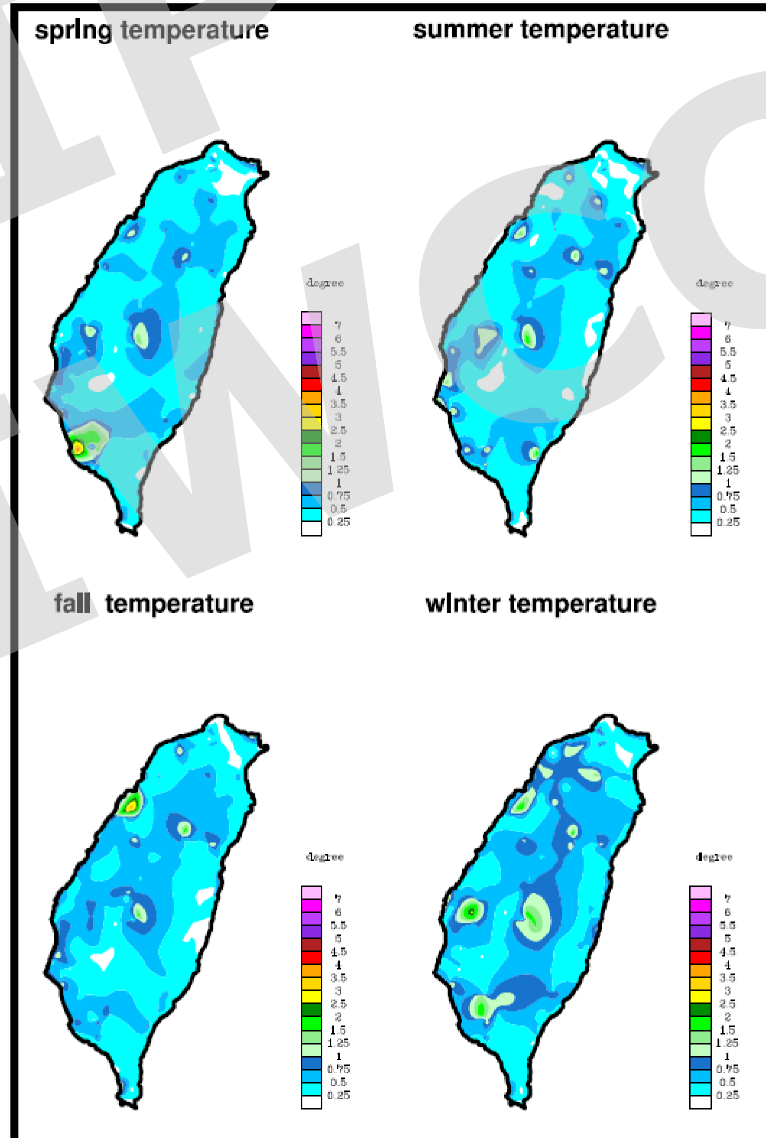


Uncertainty analysis of Temp: RMSE (Jacknife's 'take-one-out' procedure)

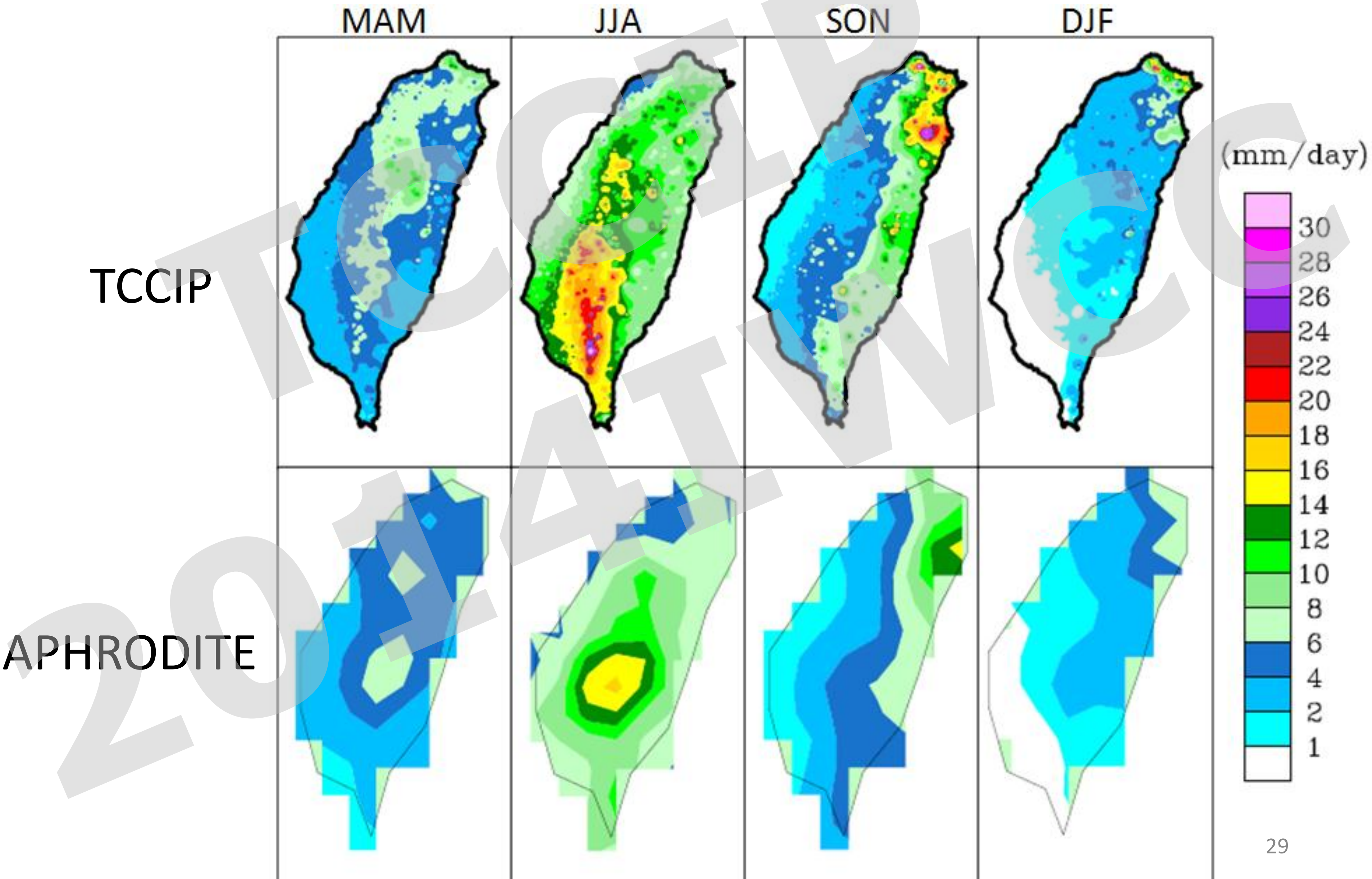
1980~1989 (worst)



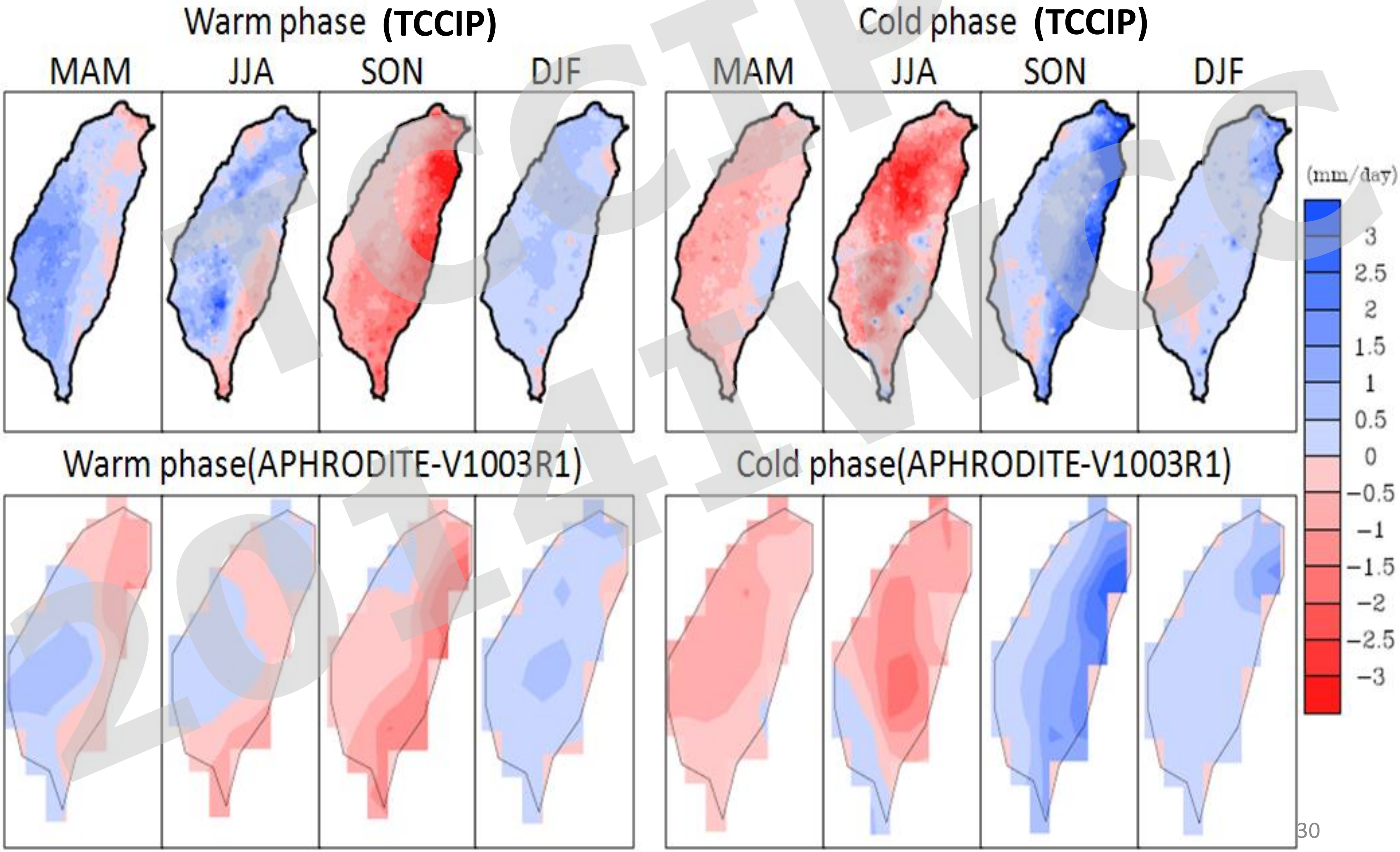
2000-2009 (best)



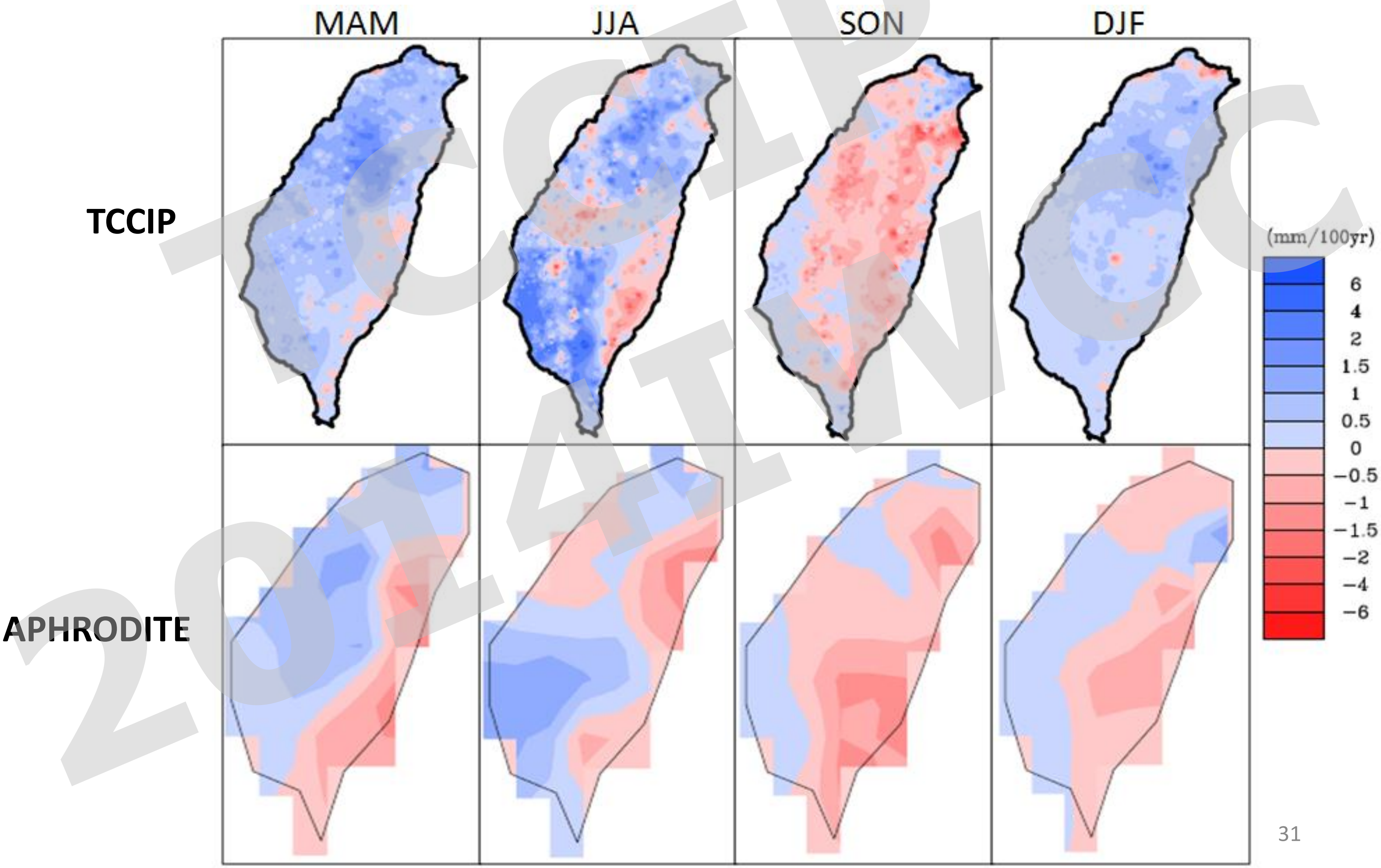
Rainfall climate comparison



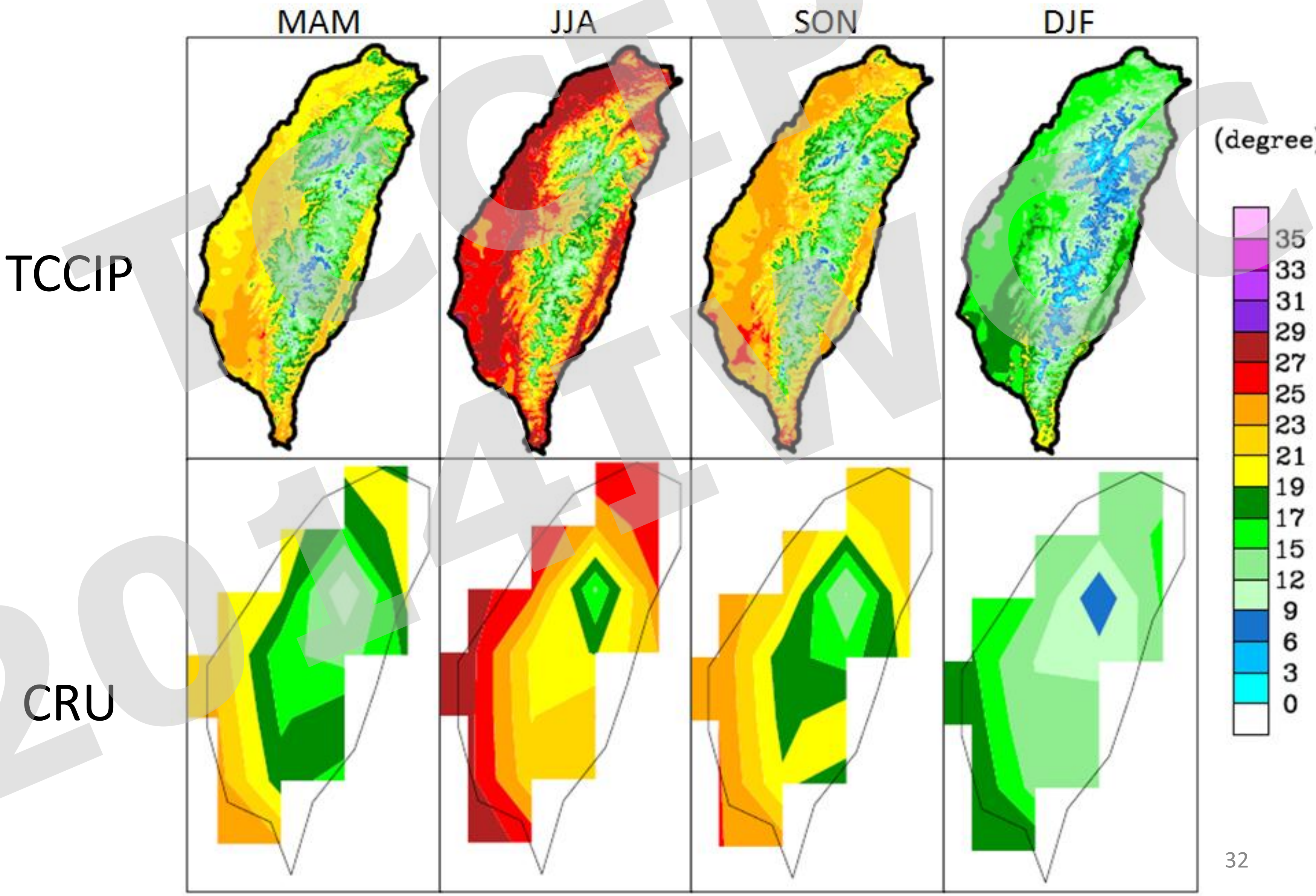
ENSO-related seasonal rainfall variability



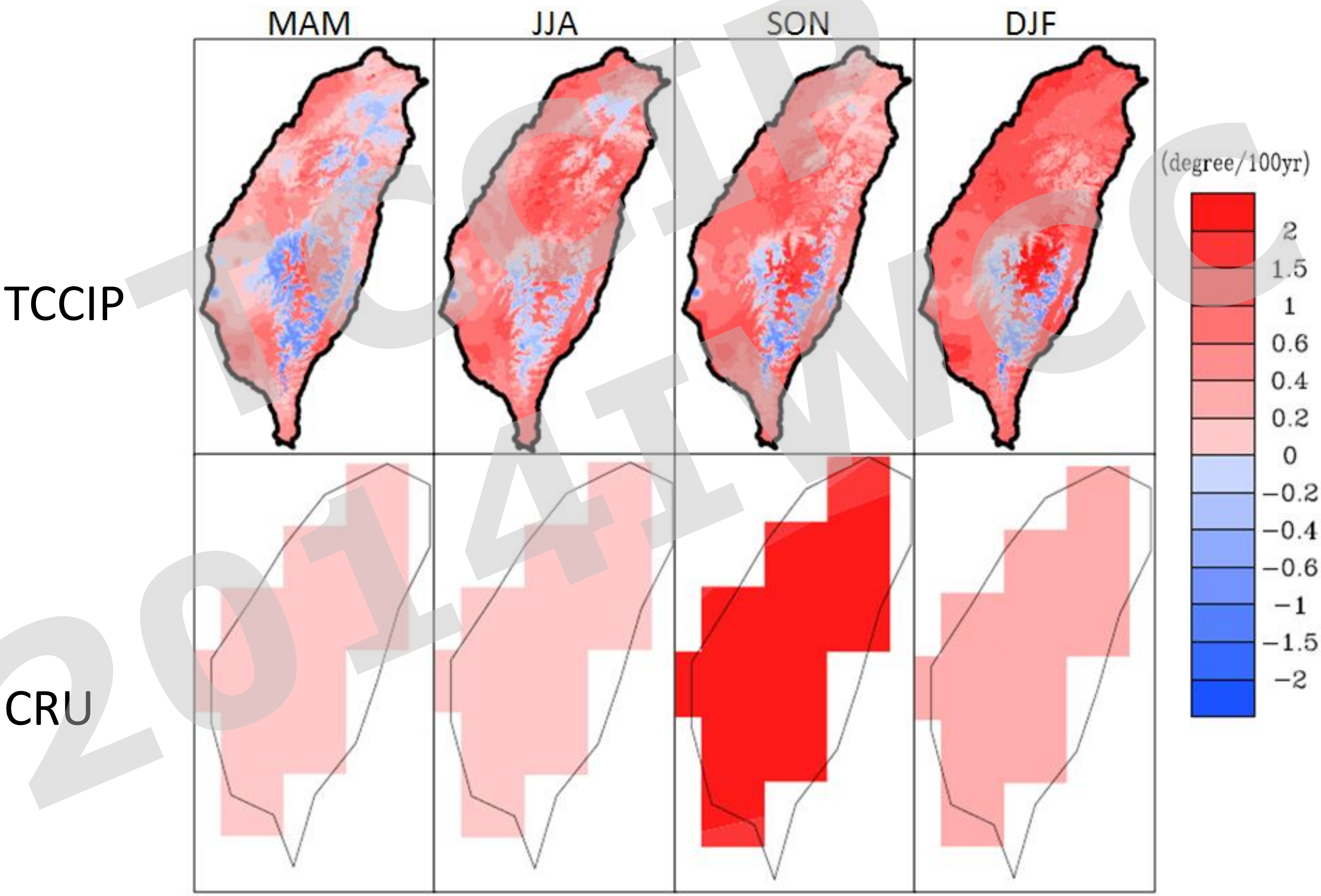
Comparison on the long-term rainfall trend



Temp climate comparison



Comparison on the long-term temp trend



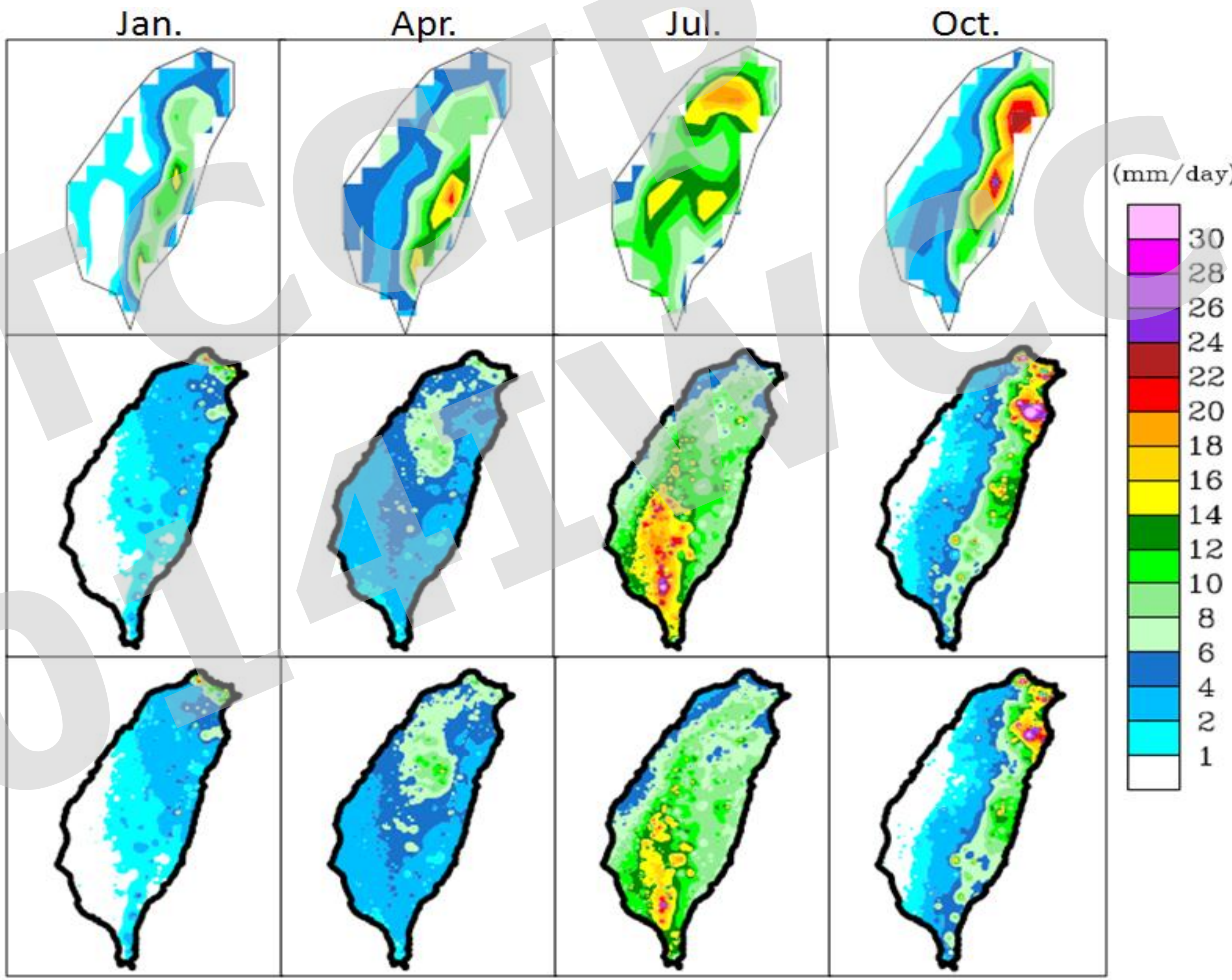
Application: serve as the basis for the statistical downscaling and future projection

Rain

MRI-20km model output (1979-2003)

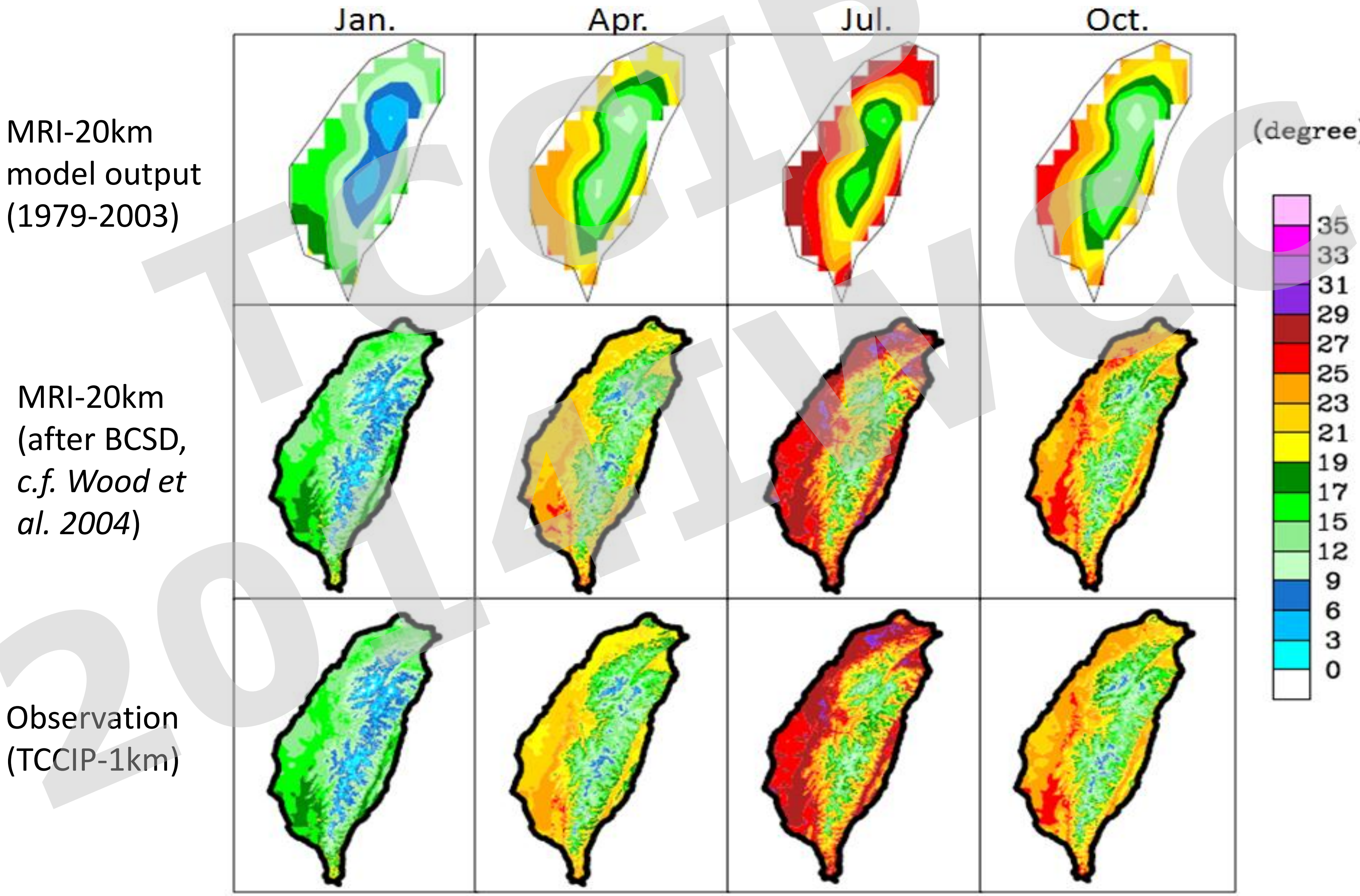
MRI-20km (after BCSD, c.f. Wood et al. 2004)

Observation (TCCIP-1km)

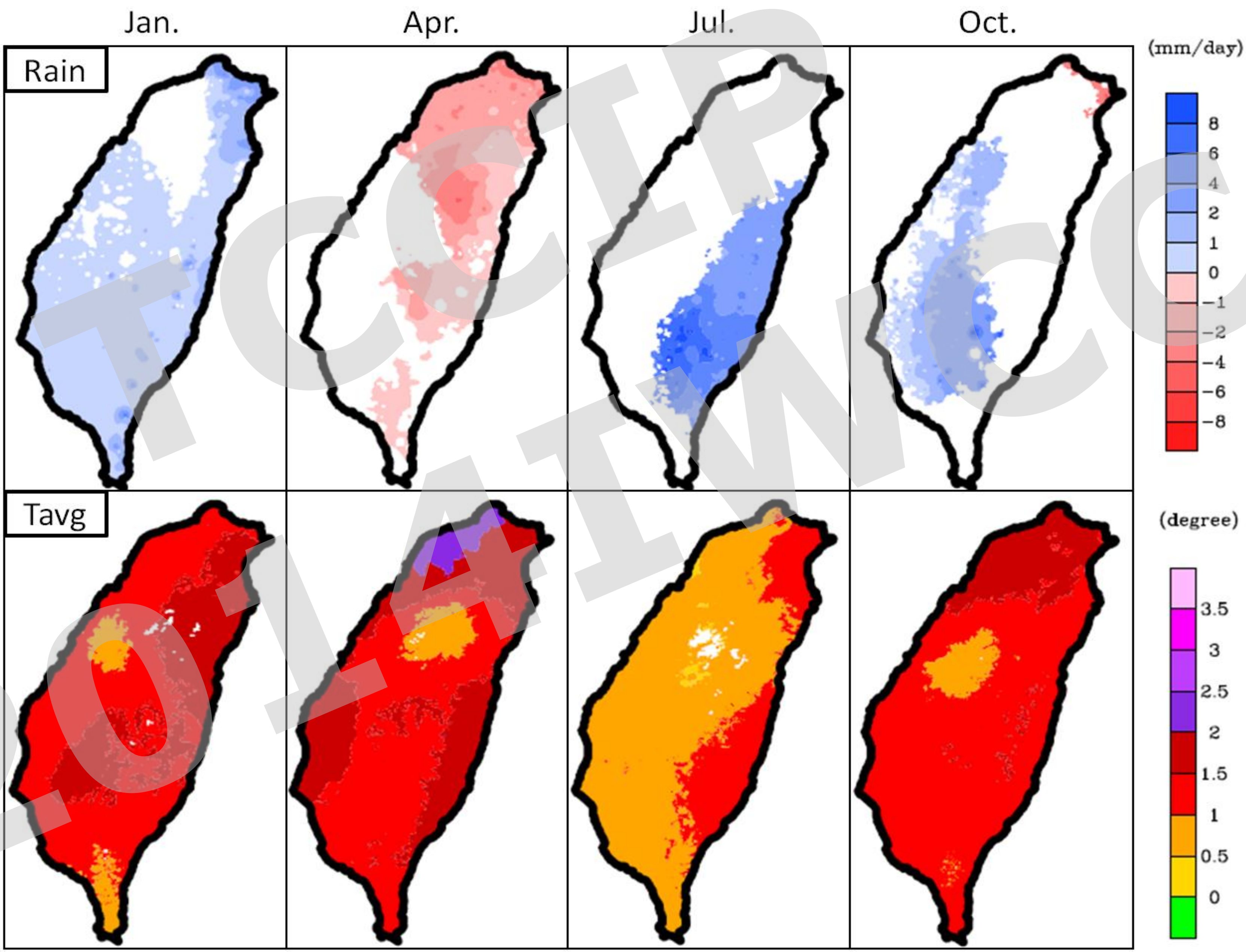


Application: serve as the basis for the statistical downscaling and future projection

Temp



Projection of trends in the near future (2015-2039)



Summary

1. A Long-term (January 1960 – December 2012) and complete monthly rainfall and temperature datasets with a 1-km horizontal resolution have been constructed in TCCIP.
2. The depicted seasonal climatology, interannual, and long-term trend are analyzed and compared with the coarser APHRODITE rainfall (0.25^0 by 0.25^0) and CRU temperature (0.5^0 by 0.5^0) datasets.
3. Using the historical (1979-2003) and projected (2015-2039) products simulated by the Japanese MRI/JMA regional climate model (with a 20-km resolution) as an example, the TCCIP 1-km gridded databank can serve as the basis (with a BCSD statistical downscaling method) to statistically evaluate the future rainfall and temperature changes.
4. There exists a significant decreasing (increasing) trend in the springtime (summertime) **rainfall** over northern (southern) Taiwan.
5. There exists an increasing **temperature** trend island-wide, especially in the northwestern area during the springtime.