Regionalization and Uncertainty of Future Taiwan Climate Change Projection Based on CMIP5 Statistical Downscaling:

From Mean Climate States to High-Impact Weather and Climate Extreme

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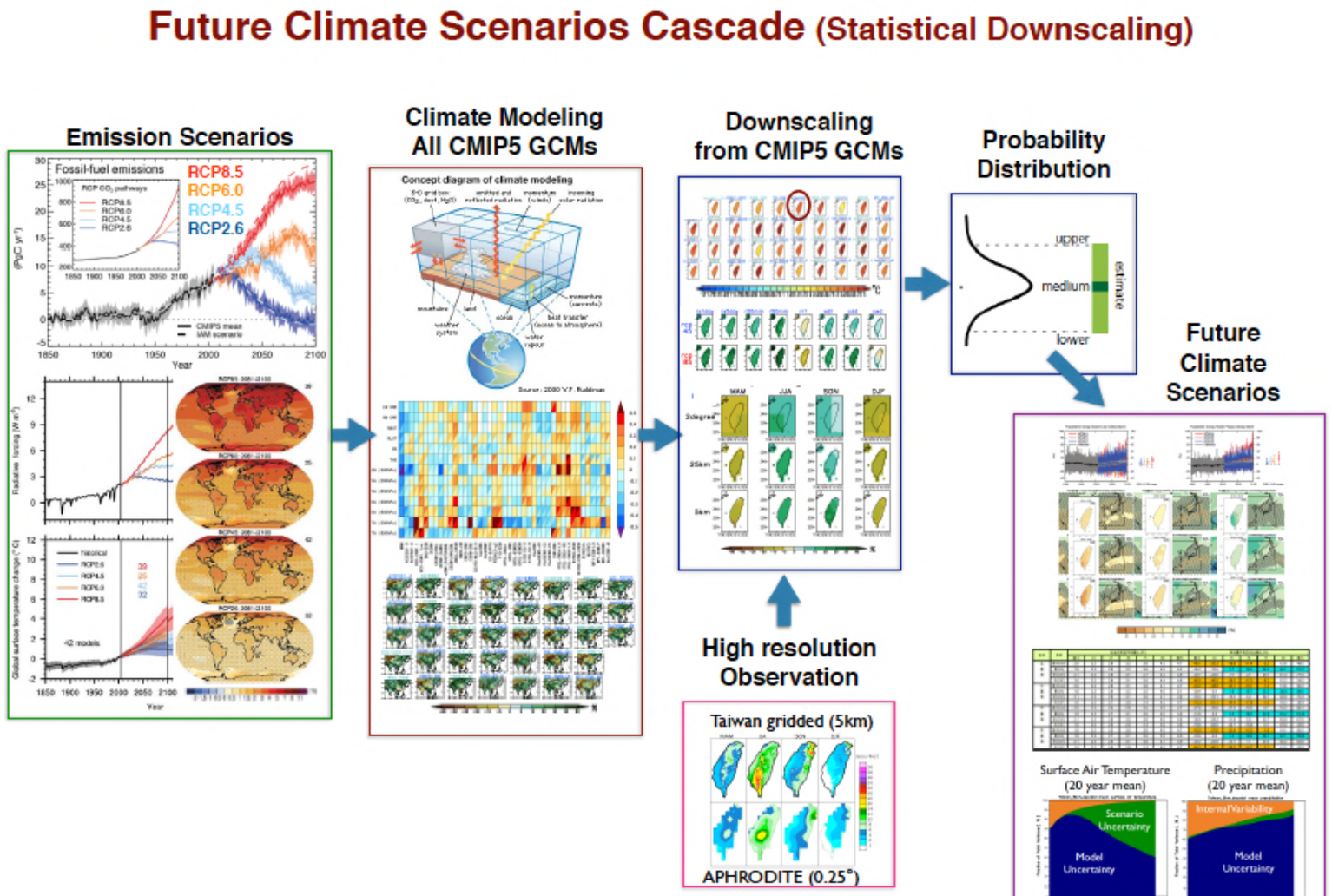
NCDR Taiwan Climate Change Projection and Information Platform Project Team



- Why do we need regionalization ?
- Why statistical downscaling and How?
- Projection uncertainties and sources
- Update with CMIP5
- Downscale monthly mean statistics
- Downscale extreme indices
- Downscale daily statistics

Why do we need downscaling?

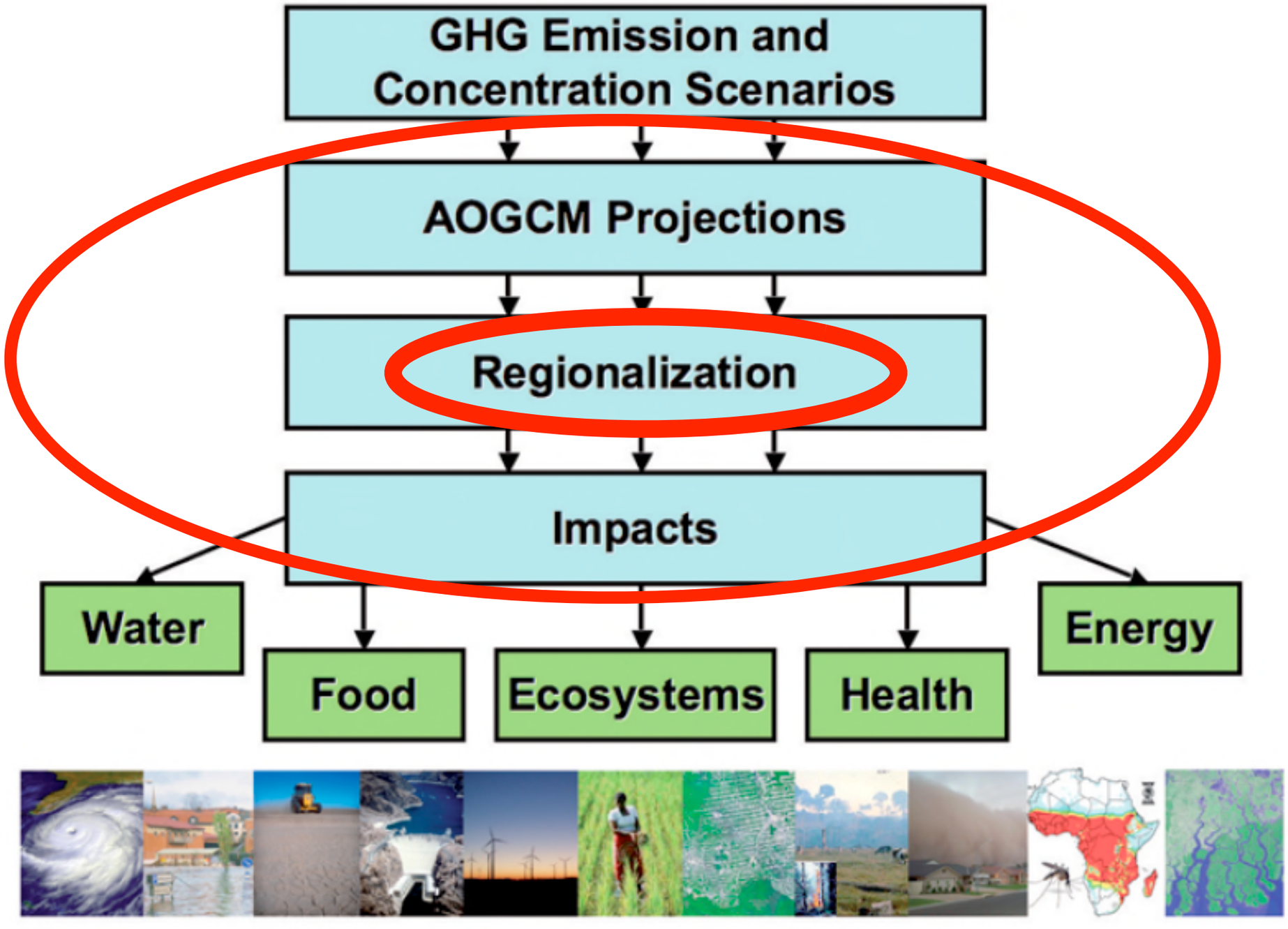
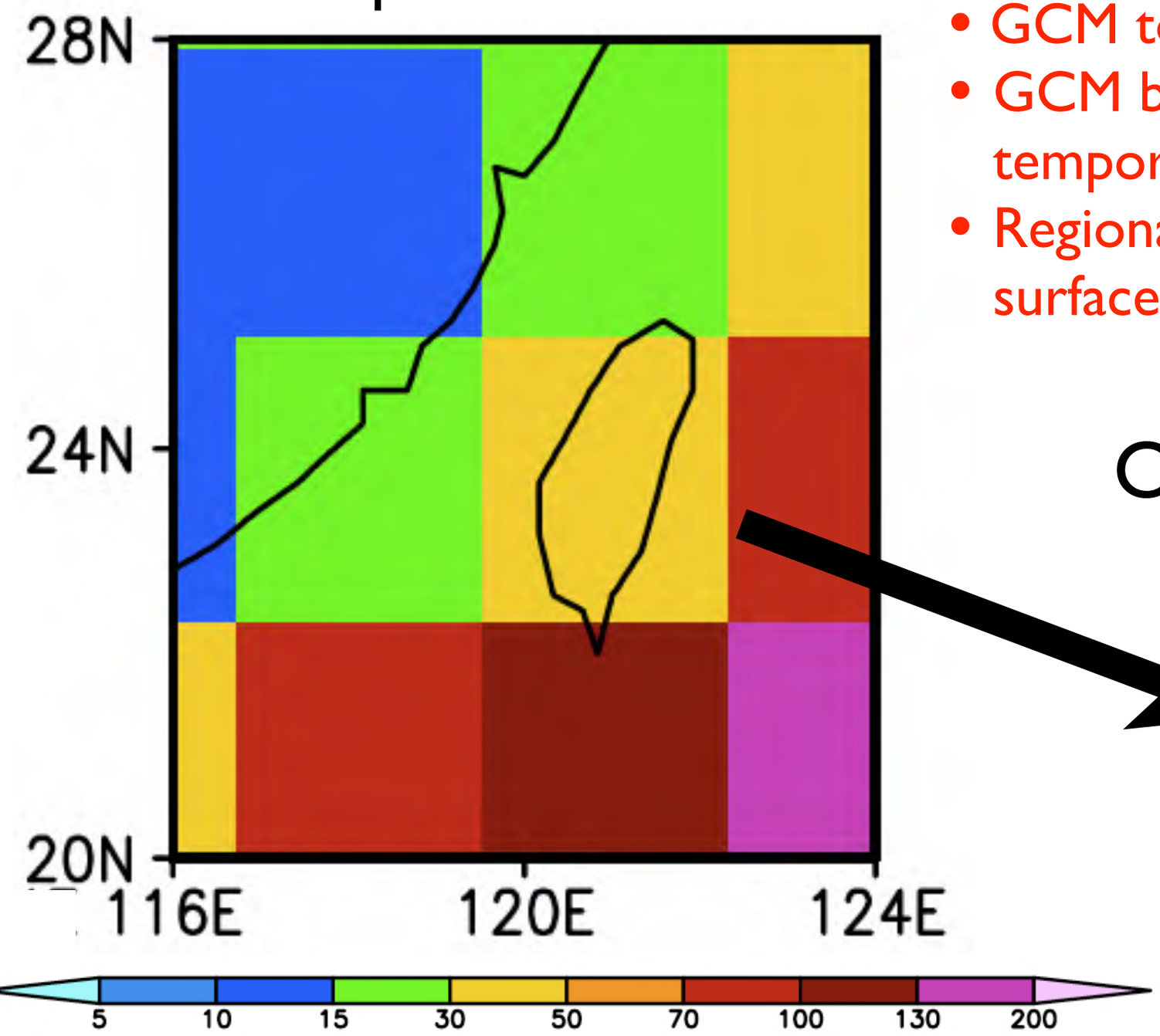


Figure 3 — Schematic depiction of the steps involved in the production of climate change information usable for impact assessment work via regionalization methods

Source: Giorgi (2008)

Why do we need downscaling?

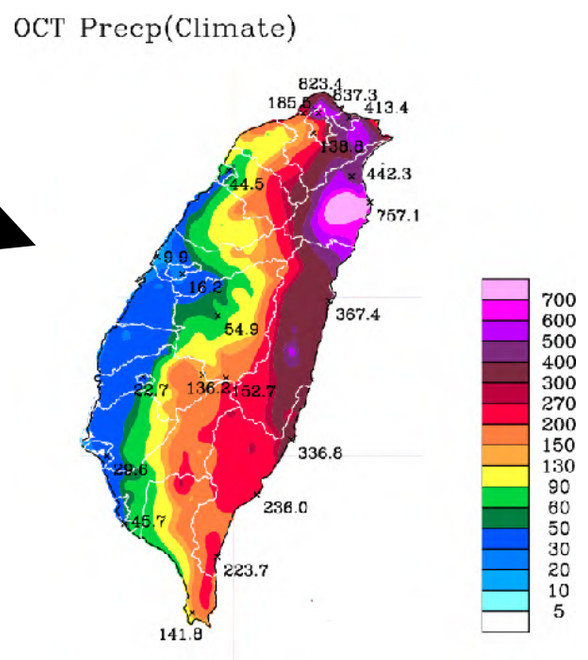
GCM (~300 km)
Precipitation October



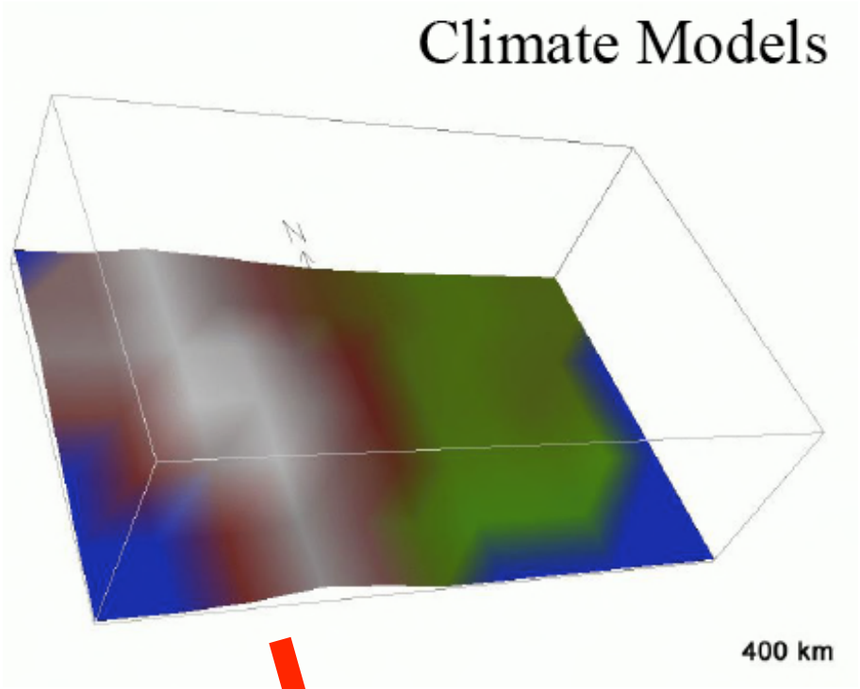
Problems:

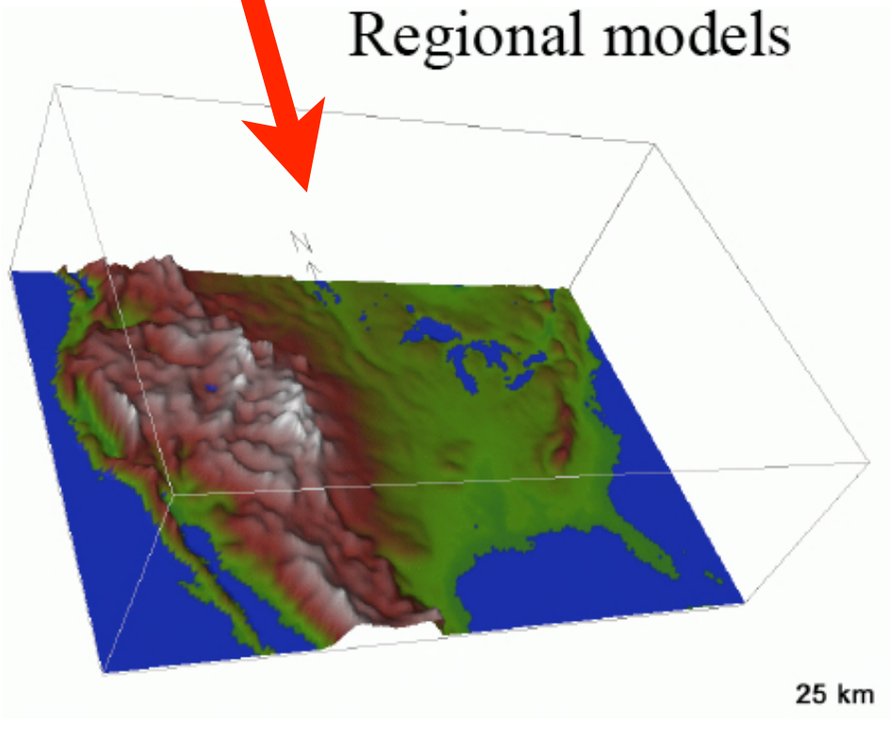
- GCM too coarse for local assessment
- GCM biases in climatology (spatially and temporally)
- Regional climate variability (topography, surface landscapes, coastlines)

Observation (~5km)



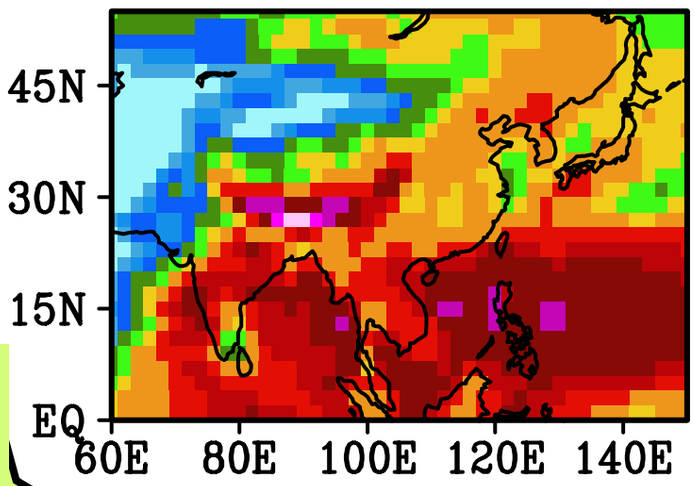
Dynamical Downscaling



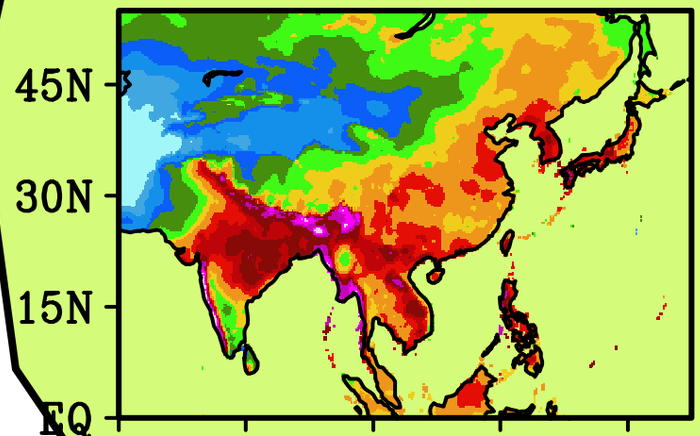


Statistical Downscaling

Climate Model

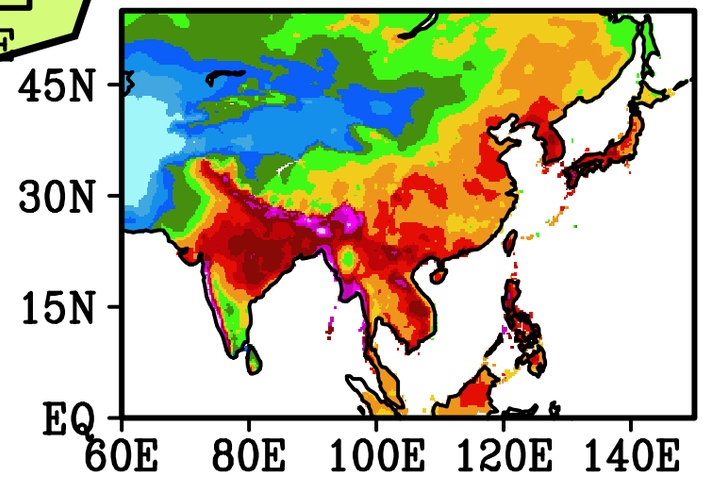


High Resolution Observation



Develop transfer function

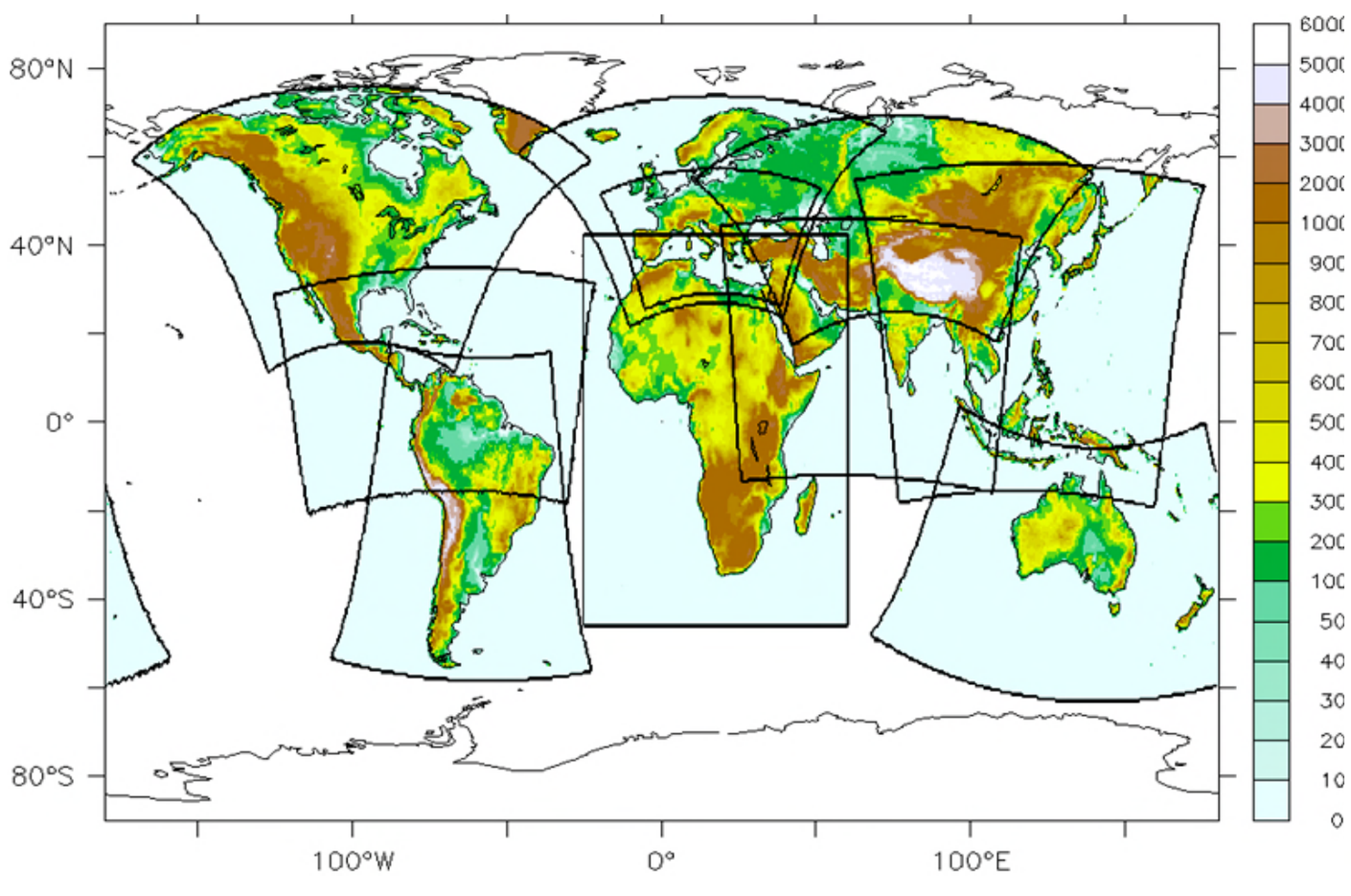
Downscaled

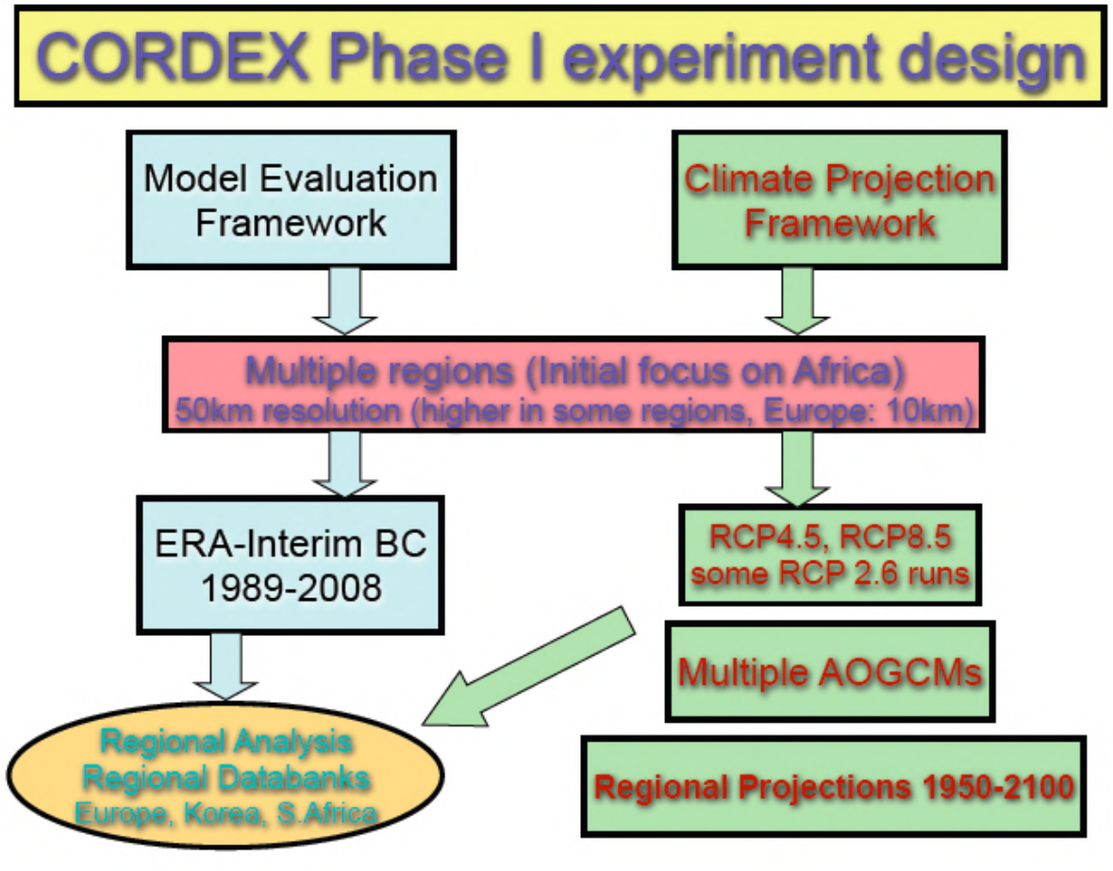


Dynamical downscaling (RCMs)

Dynamical downscaling required large resources to cover all scenarios, different GCM/RCM sensitivity

WCRP CORDEX





Why statistical downscaling?

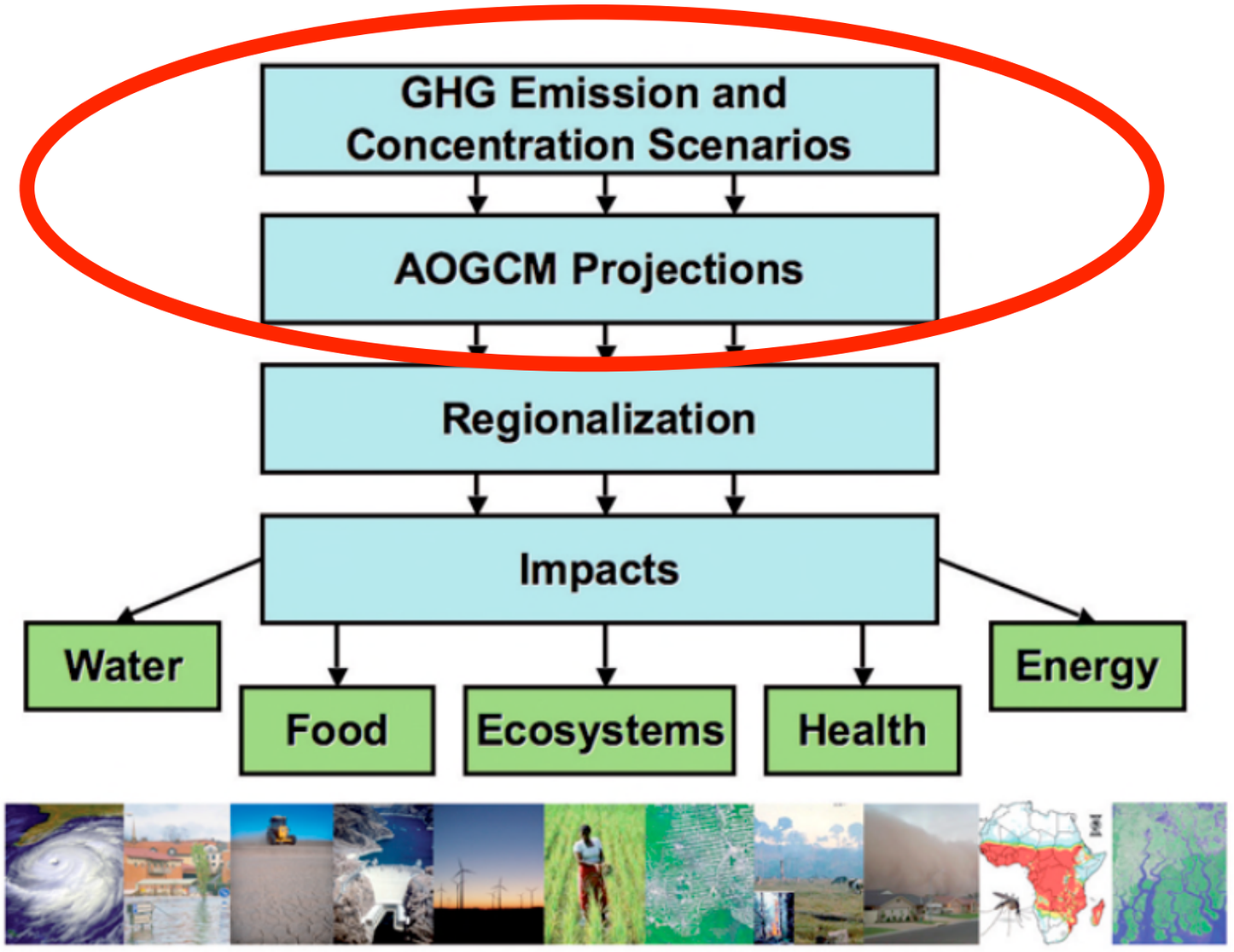
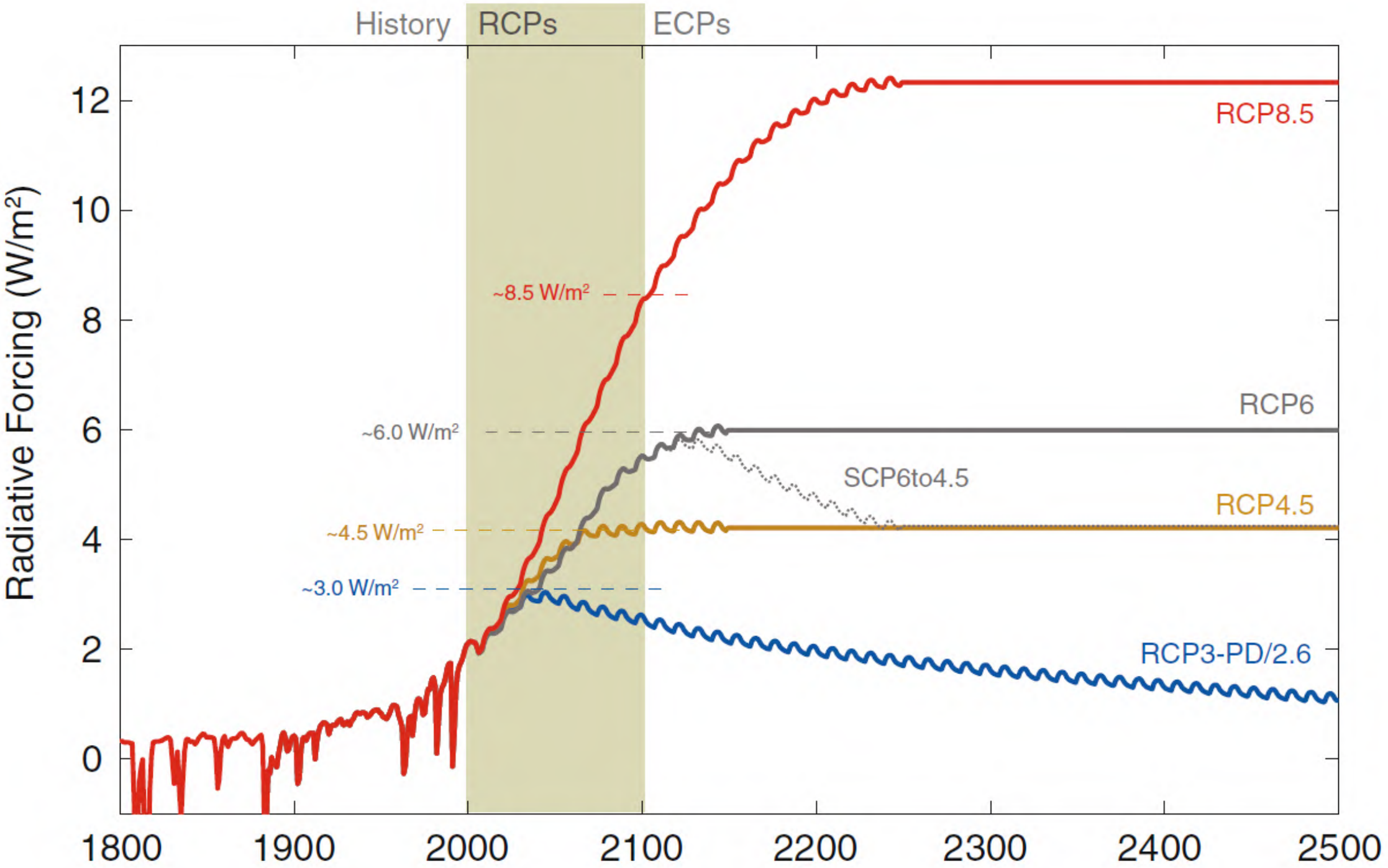


Figure 3 — Schematic depiction of the steps involved in the production of climate change information usable for impact assessment work via regionalization methods

Source: Giorgi (2008)

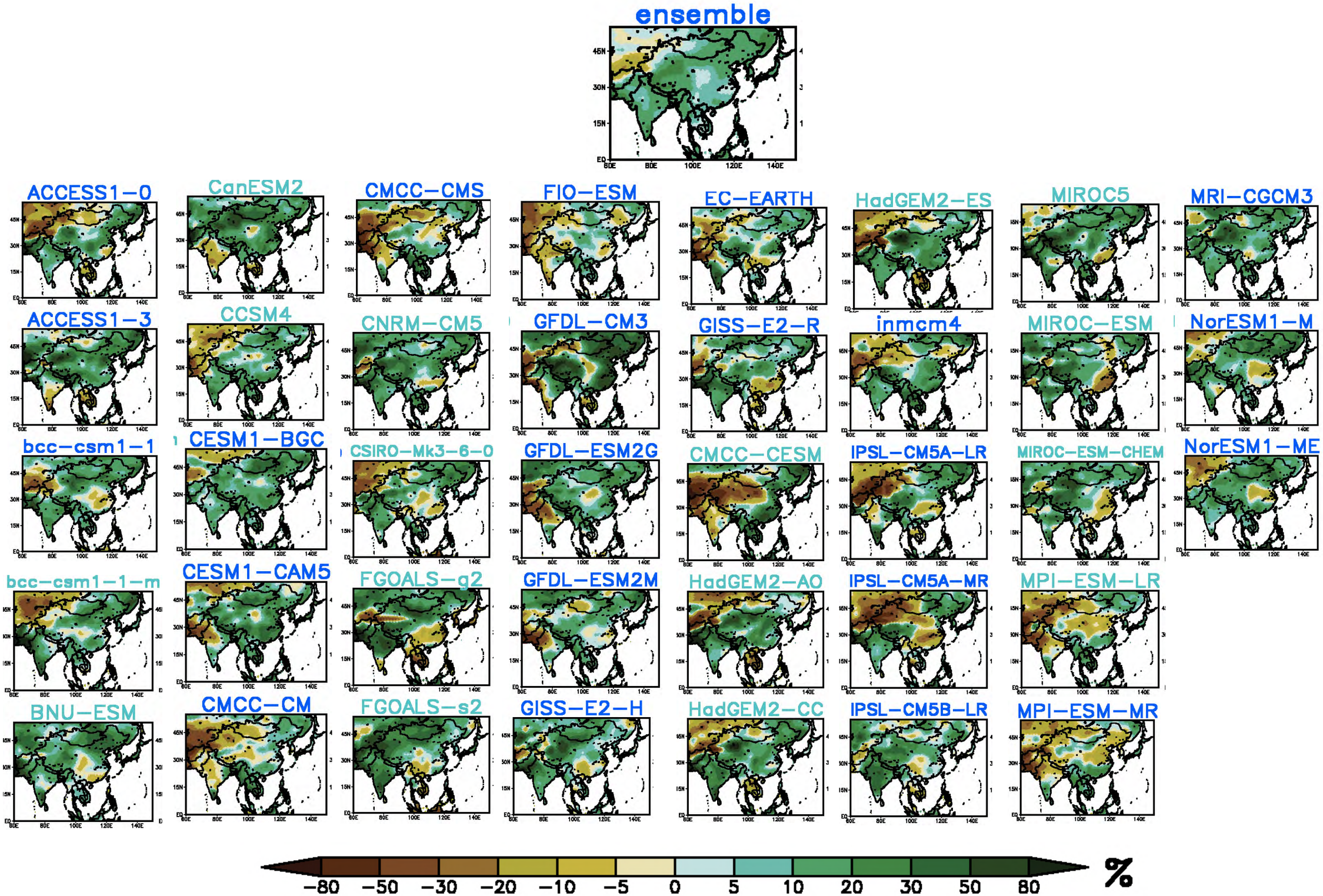
- Uncertainties in future greenhouse gas and aerosol emissions
- Uncertainties in global and regional climate sensitivity, due to differences in the way physical processes and feedbacks are simulated in different models
- Regionalization with statistical approach doesn't need extensive resources and, therefore, possible to cover all the uncertainties and produce probabilistic projection.

Uncertainty from AR5 Emission Scenarios



Uncertainty from Global Climate Models

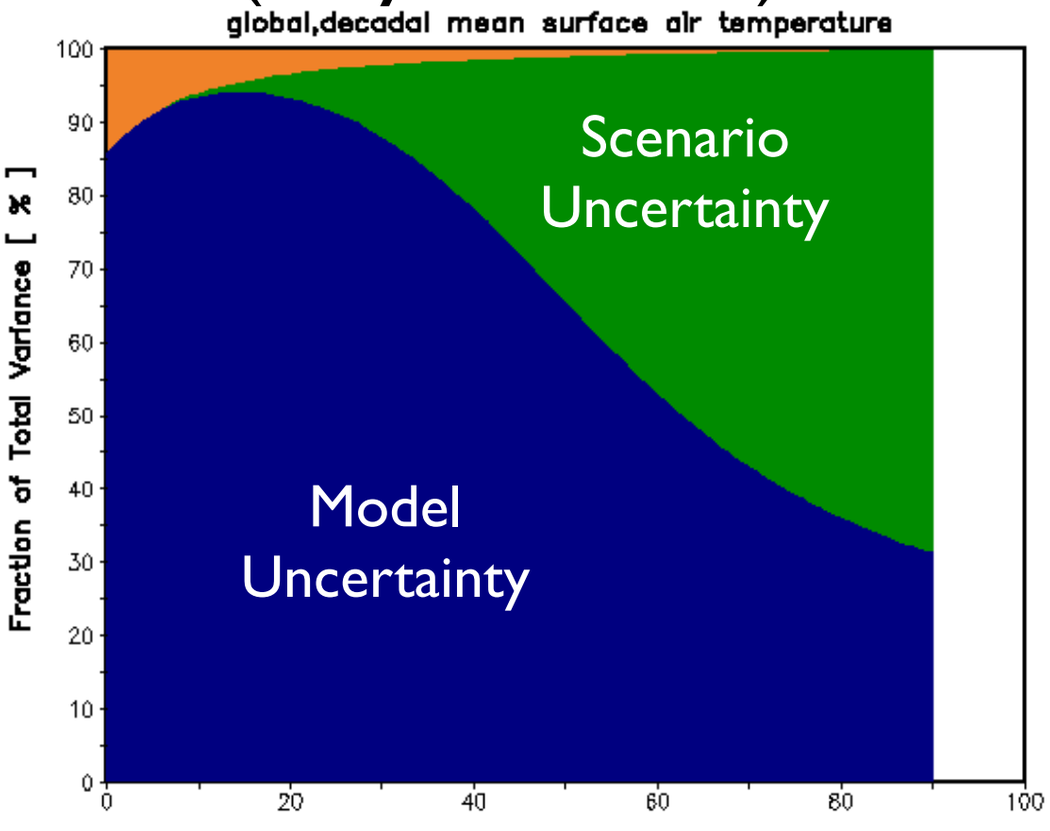
Summer precipitation change(%) with CMIP5 models under RCP8.5 scenario



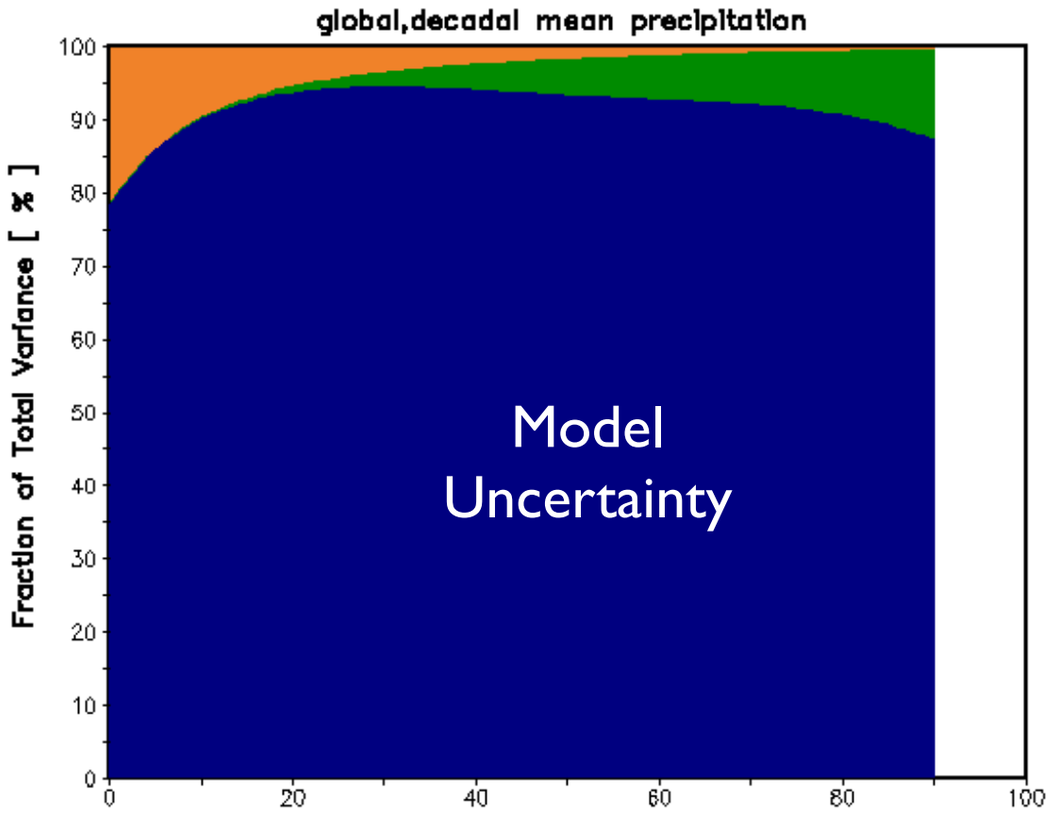
Uncertainties Assessment (Hawkin and Sutton, 2009)

Fraction of Total Variance Plot (Scenario, Model, Internal Variability)

Global mean
Surface Air Temperature
(20 year mean)



Global mean
Precipitation
(20 year mean)



(Dynamical-) Statistical Downscaling

Simple Statistical Downscaling:
Bias Correction Spatial Downscaling (BCSD)

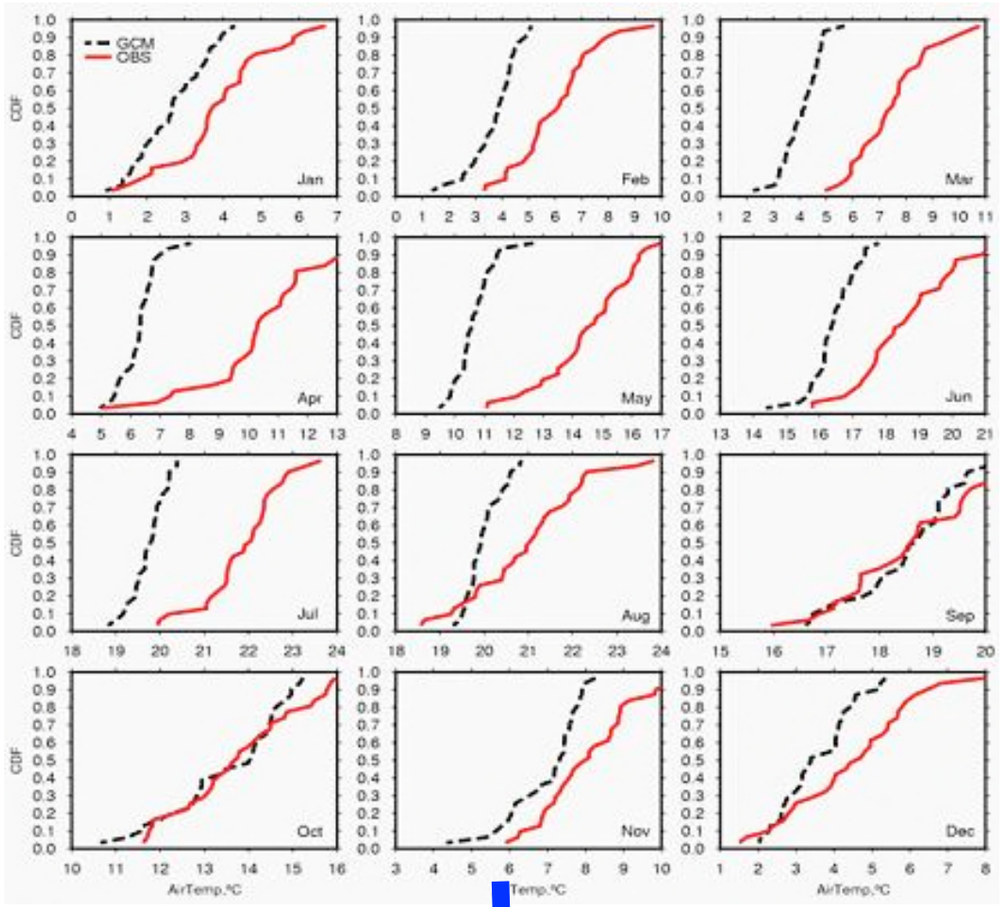
Wood et al. 2004, and Maurer 2007

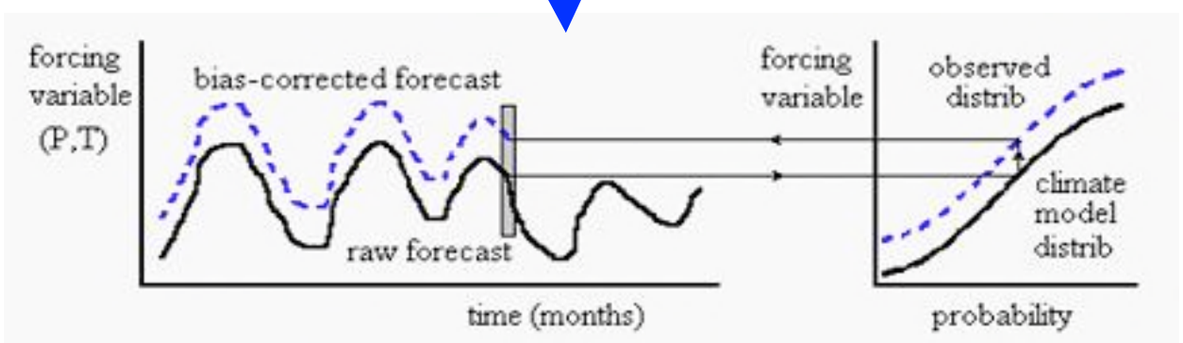
- Aggregate gridded OBS to GCM resolution
- Remove trend (if the trend is significant)
- Generate CDF of observed and GCM data
  - Q-Q mapping approach
  - limitation on extrapolation
- Add trend back in
- Resample/interpolate to finer resolution
- Apply spatial factor to account for subgrid topography

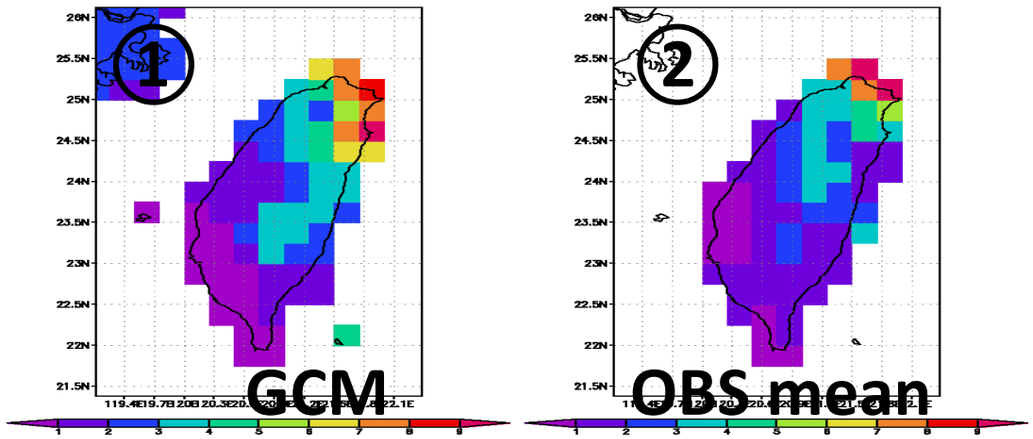
(Dynamical-) Statistical Downscaling

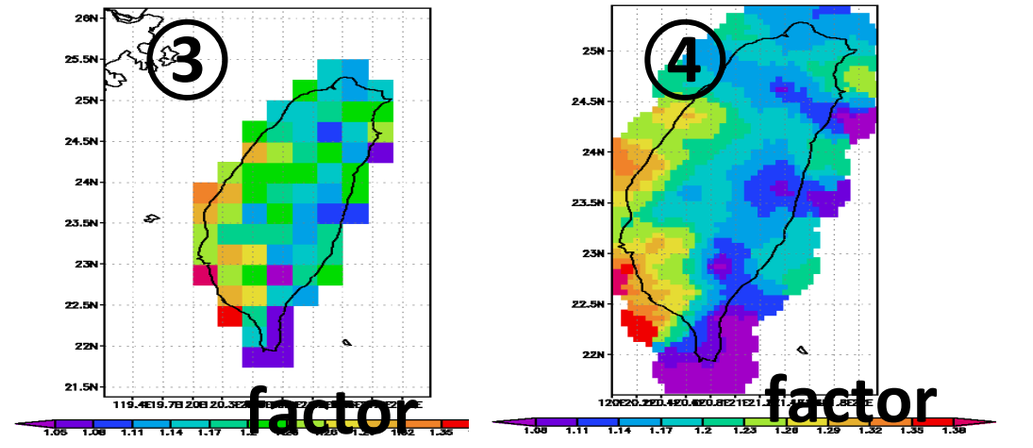
Statistical downscaling and bias correction by cumulative distribution function and interpolation

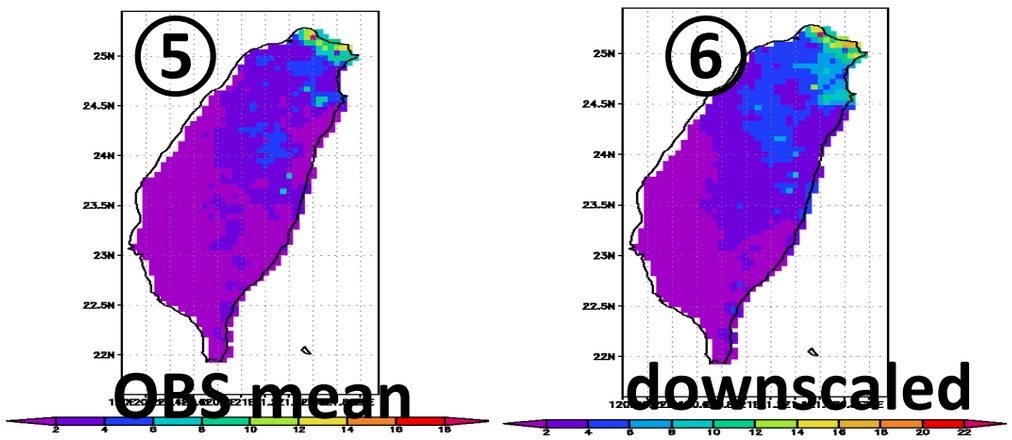
Wood et al. 2004, and Maurer 2007











CMIP5 experiments

historical

RCP2.6, 4.5, 6.0, 8.5

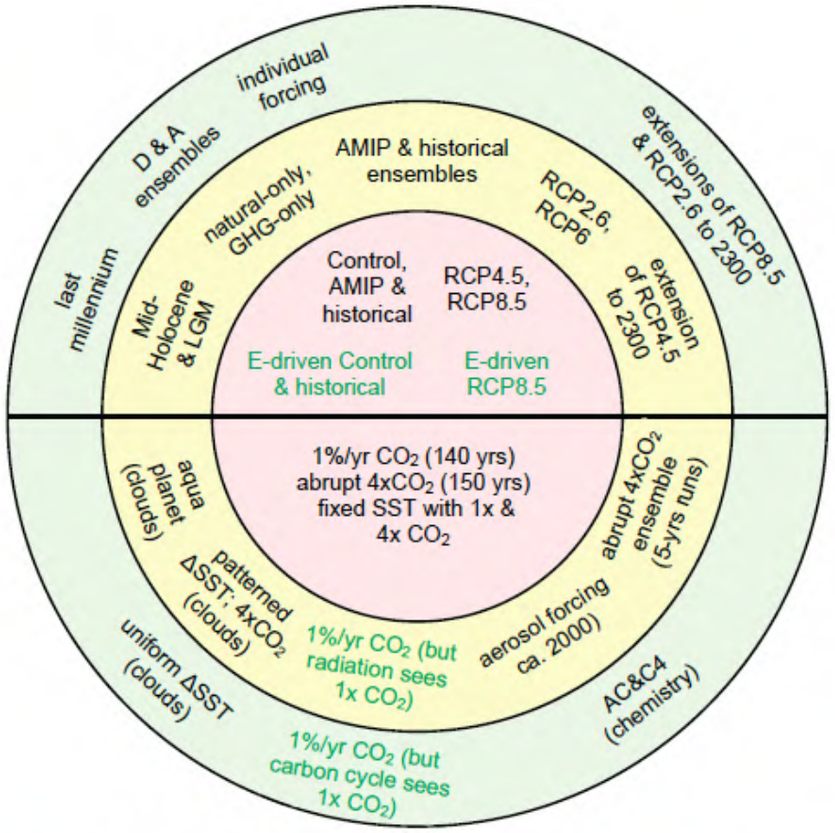


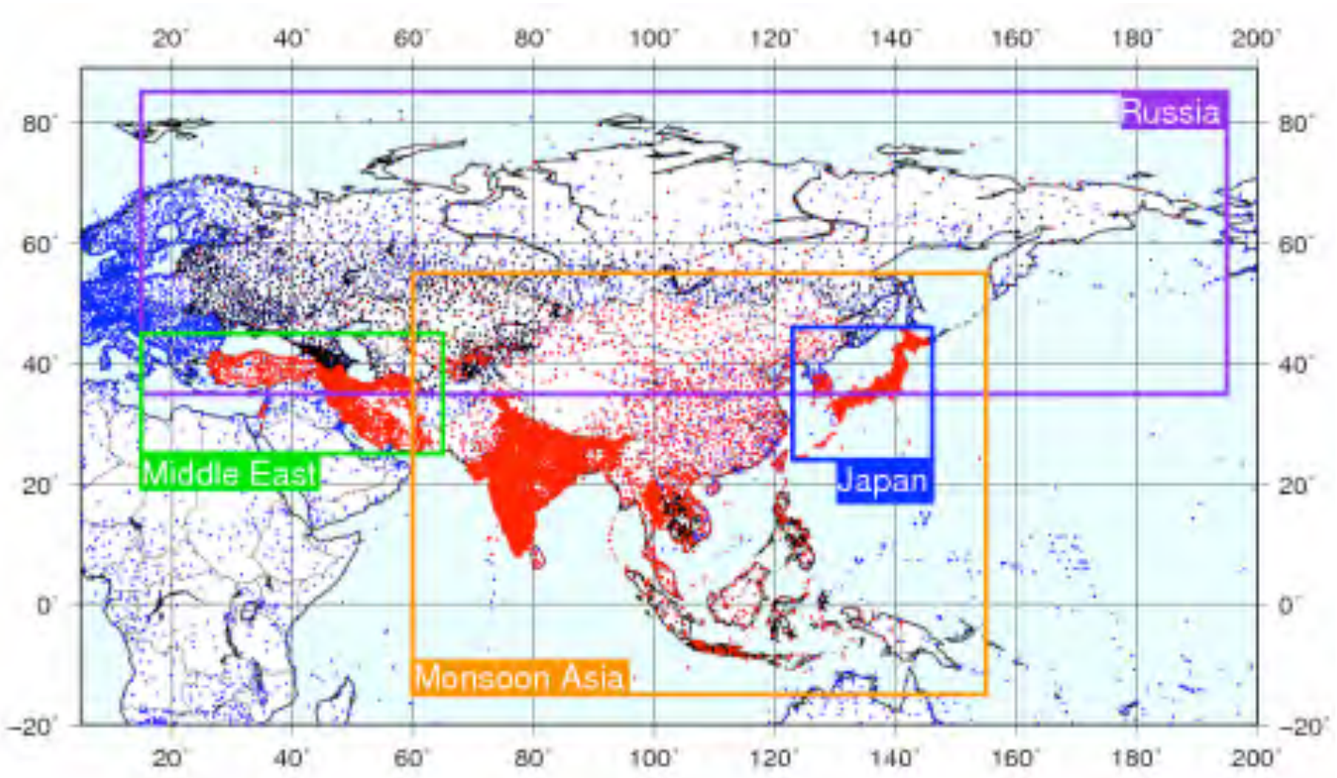
FIG. 2. Schematic summary of CMIP5 long-term experiments with tier 1 and tier 2 experiments organized around a central core. Green font indicates simulations to be performed only by models with carbon cycle representations. Experiments in the upper hemisphere are suitable either for comparison with observations

CMIP5 models (29 centers, >50 model versions)

Modeling Center	Model	Institution	terms of use
BCC	BCC-CSM1.1 BCC-CSM1.1(m)	Beijing Climate Center, China Meteorological Administration	unrestricted
CCCma	CanAM4 CanCM4 CanESM2	Canadian Centre for Climate Modelling and Analysis	unrestricted
CMCC	CMCC-CESM CMCC-CM CMCC-CMS	Centro Euro-Mediterraneo per I Cambiamenti Climatici	non-commercial only
CNRM-CERFACS	CNRM-CM5	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique	non-commercial only
COLA and NCEP	CFSv2-2011	Center for Ocean-Land-Atmosphere Studies and National Centers for Environmental Prediction	unrestricted
CSIRO-BOM	ACCESS1.0 ACCESS1.3	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)	non-commercial only
CSIRO-QCCCE	CSIRO-Mk3.6.0	Commonwealth Scientific and Industrial Research Organisation in collaboration with the Queensland Climate Change Centre of Excellence	non-commercial only
EC-EARTH	EC-EARTH	EC-EARTH consortium	non-commercial only
FIO	FIO-ESM	The First Institute of Oceanography, SOA, China	non-commercial only
GCESS	BNU-ESM	College of Global Change and Earth System Science, Beijing Normal University	unrestricted
INM	INM-CM4	Institute for Numerical Mathematics	unrestricted
IPSL	IPSL-CM5A-LR IPSL-CM5A-MR IPSL-CM5B-LR	Institut Pierre-Simon Laplace	unrestricted
LASG-CESS	FGOALS-g2	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences; and CESS, Tsinghua University	unrestricted
LASG-IAP	FGOALS-gl FGOALS-s2	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences	unrestricted
MIROC	MIROC-ESM MIROC-ESM-CHEM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	non-commercial only
MIROC	MIROC4h MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	non-commercial only
MOHC (additional realizations by INPE)	HadCM3 HadCM3Q HadGEM2-A HadGEM2-CC HadGEM2-ES	Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)	unrestricted
MPI-M	MPI-ESM-LR MPI-ESM-MR MPI-ESM-P	Max Planck Institute for Meteorology (MPI-M)	unrestricted
MRI	MRI-AGCM3.2H MRI-AGCM3.2S MRI-CGCM3 MRI-ESM1	Meteorological Research Institute	non-commercial only
NASA GISS	GISS-E2-H GISS-E2-H-CC GISS-E2-R GISS-E2-R-CC	NASA Goddard Institute for Space Studies	unrestricted
NASA GMAO	GEOS-5	NASA Global Modeling and Assimilation Office	unrestricted
NCAR	CCSM4	National Center for Atmospheric Research	unrestricted
NCC	NorESM1-M NorESM1-ME	Norwegian Climate Centre	unrestricted
NICAM	NICAM.09	Nonhydrostatic Icosahedral Atmospheric Model Group	non-commercial only
NIMR/KMA	HadGEM2-AO	National Institute of Meteorological Research/Korea Meteorological Administration	unrestricted
NOAA GFDL	GFDL-CM2.1 GFDL-CM3 GFDL-ESM2G GFDL-ESM2M GFDL-HIRAM-C180 GFDL-HIRAM-C360	Geophysical Fluid Dynamics Laboratory	unrestricted
NSF-DOE-NCAR	CESM1(BGC) CESM1(CAM5) CESM1(CAM5.1, FV2) CESM1(FASTCHEM) CESM1(WACCM)	National Science Foundation, Department of Energy, National Center for Atmospheric Research	unrestricted

Require long-term high-resolution observations

APHRODITE (0.25°)



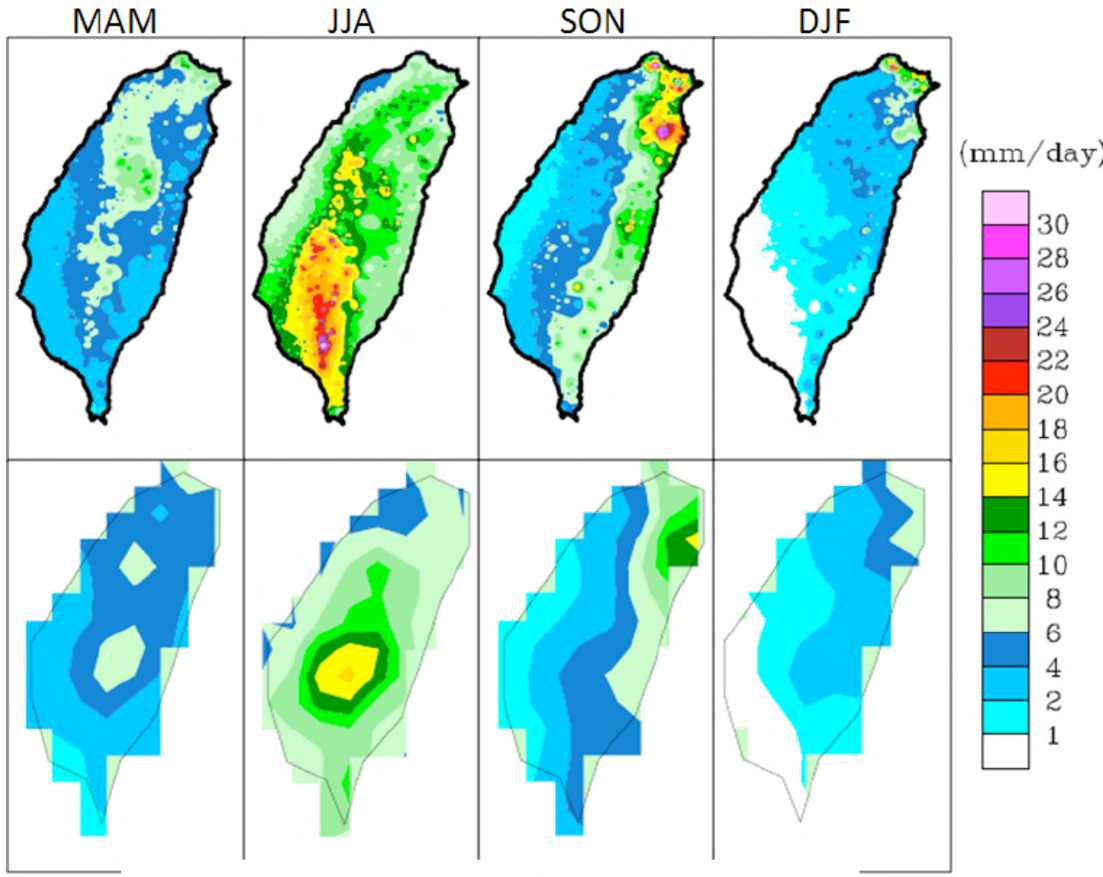
Current version, with Rain/Snow discrimination: V1101R2 Download
»Readme

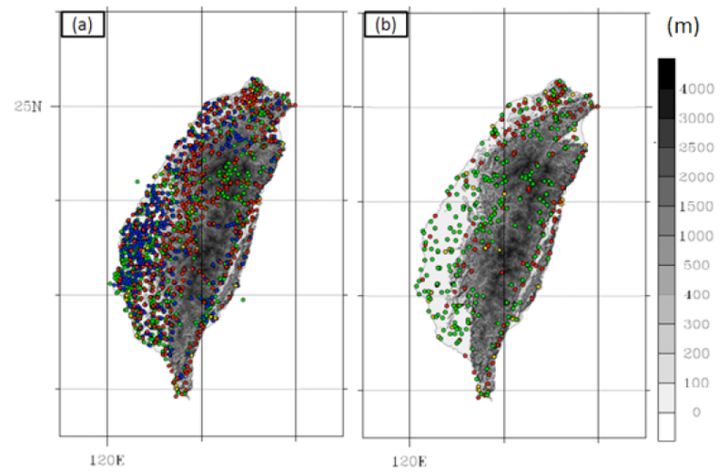
Name	Domain	Resolution	Period
Monsoon Asia (MA) (Yasutomi et al. 2011)	60°E-150°E, 15°S-55°N	0.5° and 0.25°, daily	1961-2007

AphroTemp Current version: V1204R1 Download **»Readme**

Name	Domain	Resolution	Period
Monsoon Asia (MA) (Yasutomi et al. 2011)	60°E-150°E, 15°S-55°N	0.5° and 0.25°, daily	1961-2007

New high-resolution (1~5km) gridded climate data over Taiwan

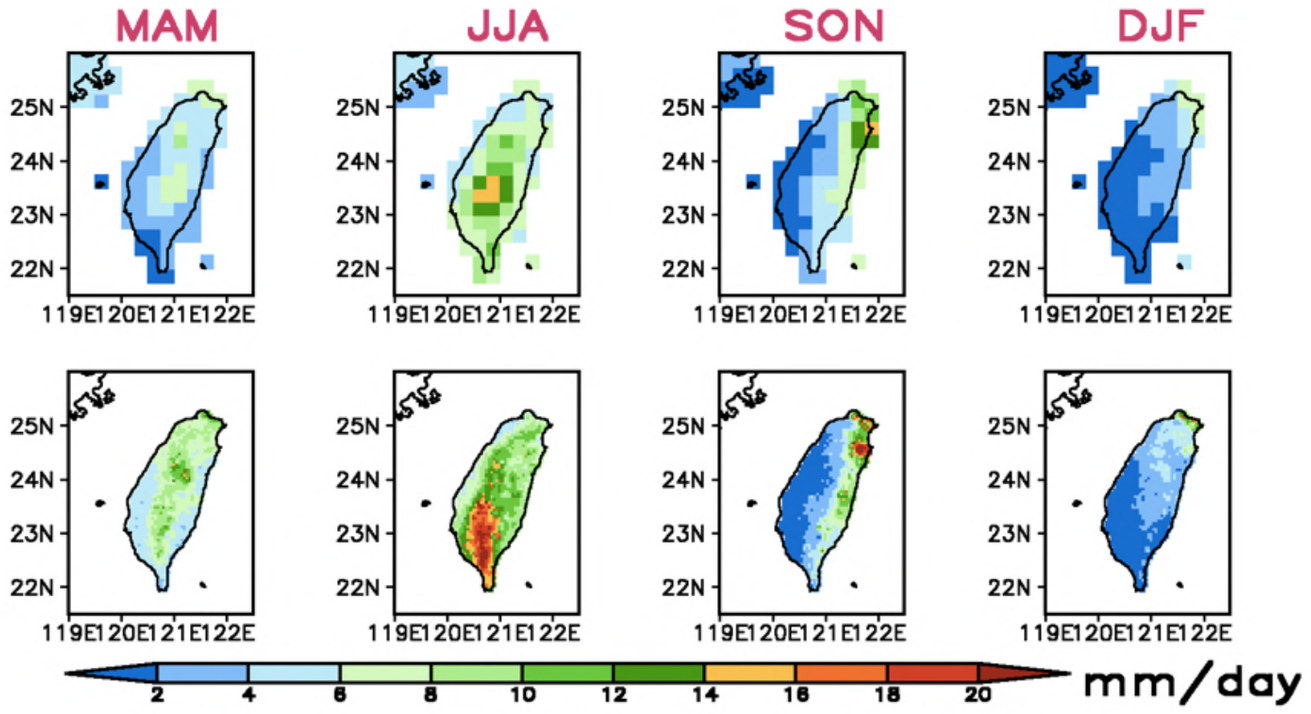




2-stages: (1) GCM ⇒0.25° (2) 0.25°⇒ 5 km

Aphrodite 0.25°

Taiwan gridded 5km



CMIP5 Model Projected Future Change in Precipitation (%) RCP8.5

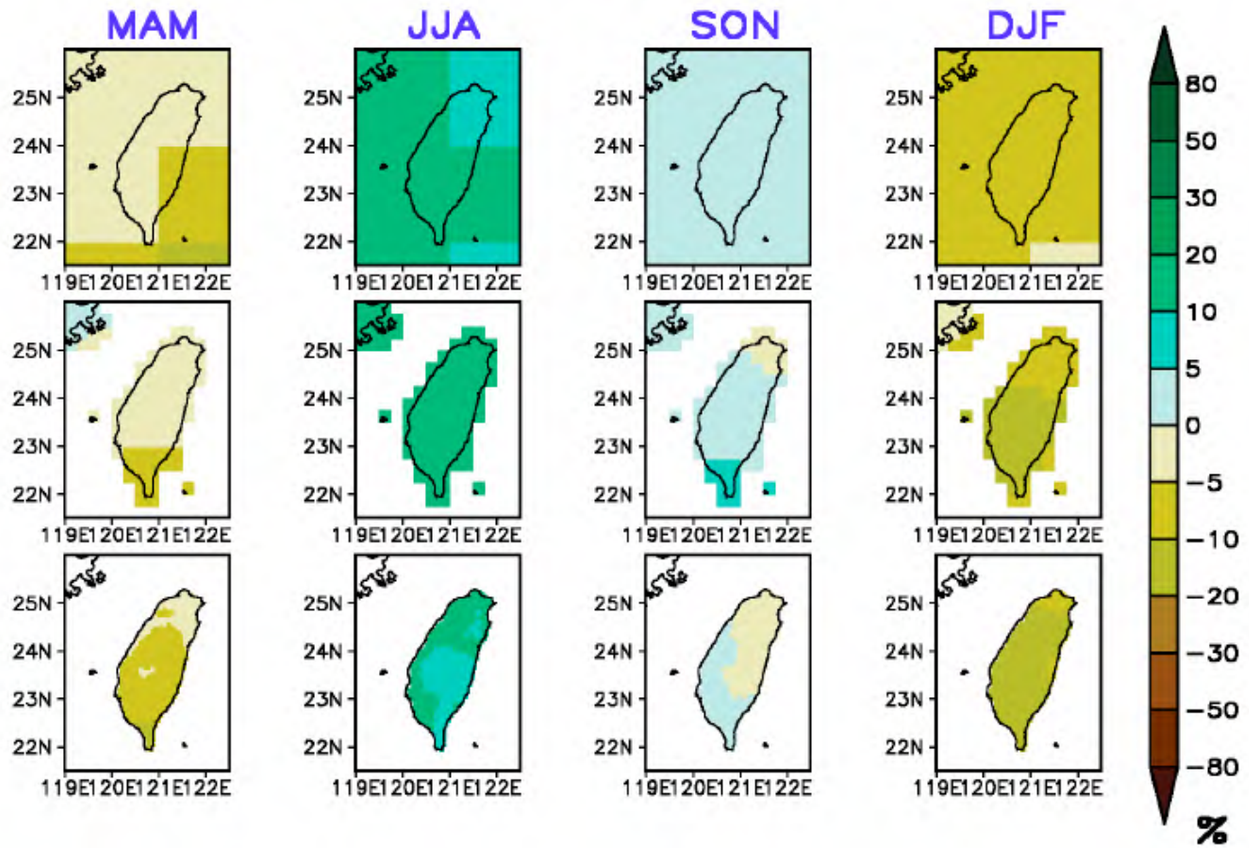
(1)

(2)

Model Resolution

25 km

5 km



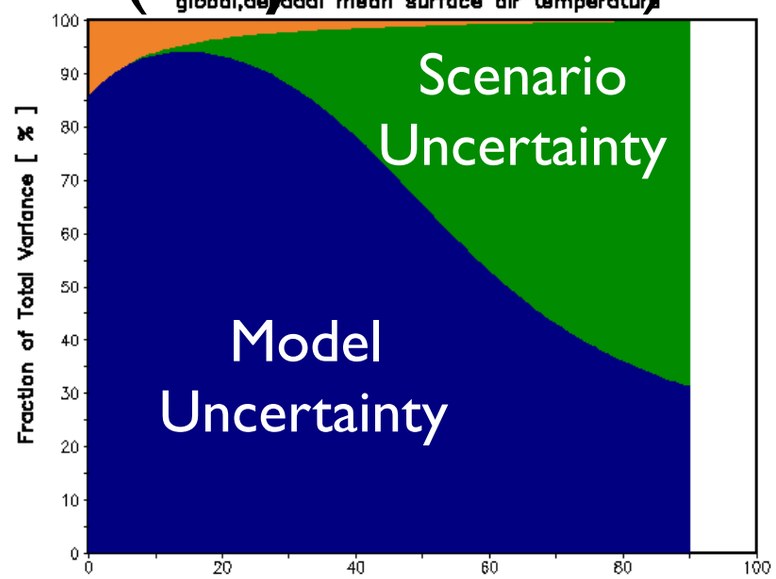
Uncertainties Assessment (Hawkin and Sutton, 2009)

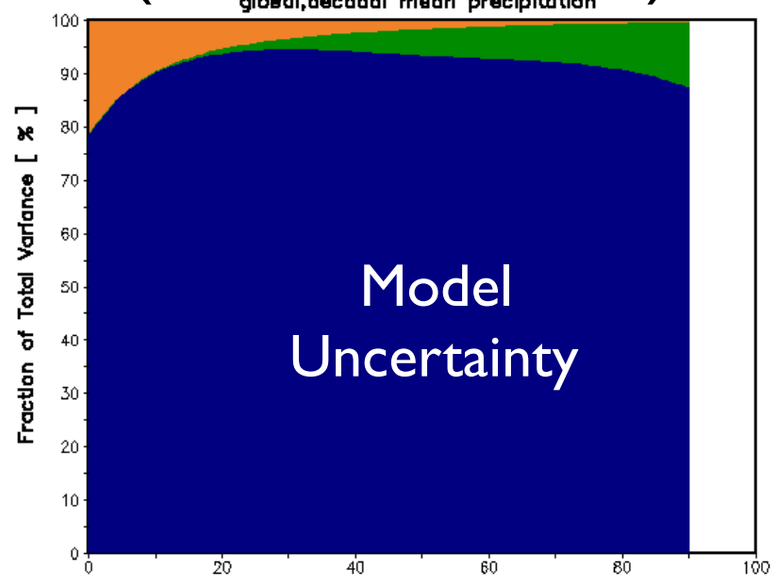
Fraction of Total Variance Plot (Scenario, Model, Internal Variability)

Surface Air Temperature (20 year mean)

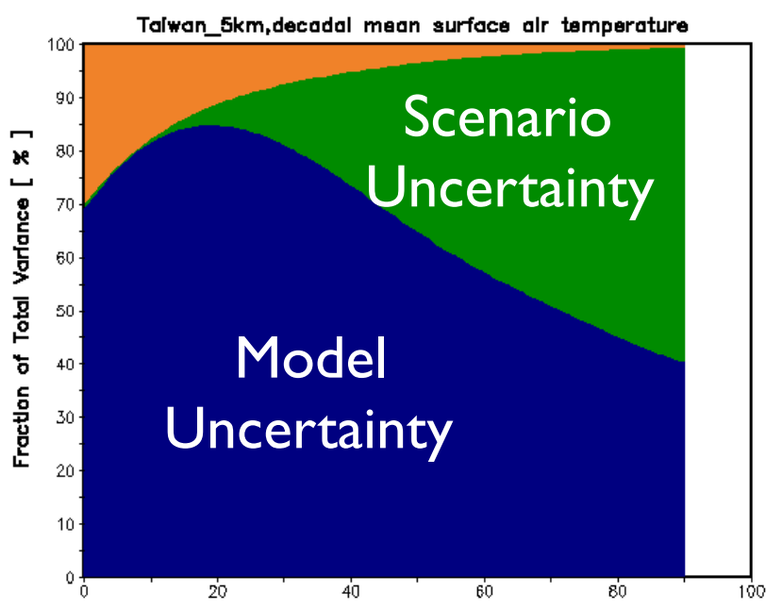
Precipitation (20 year mean)

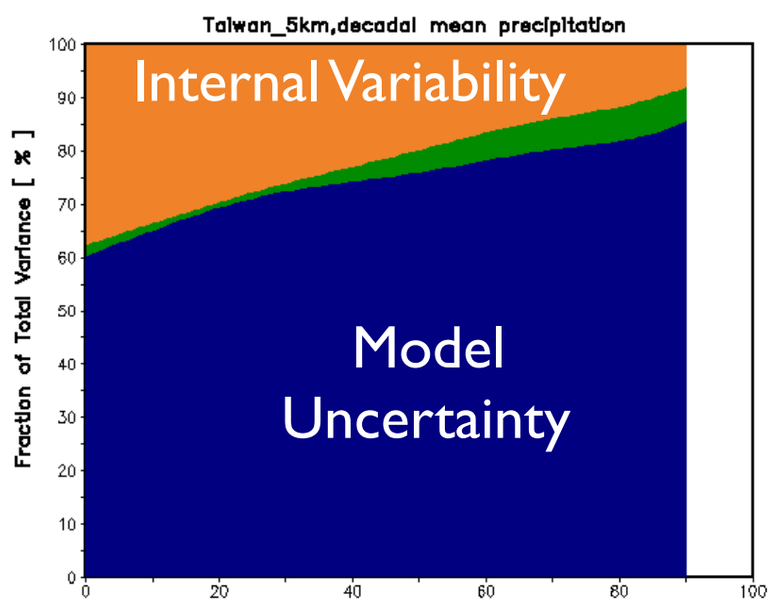
Global





Taiwan





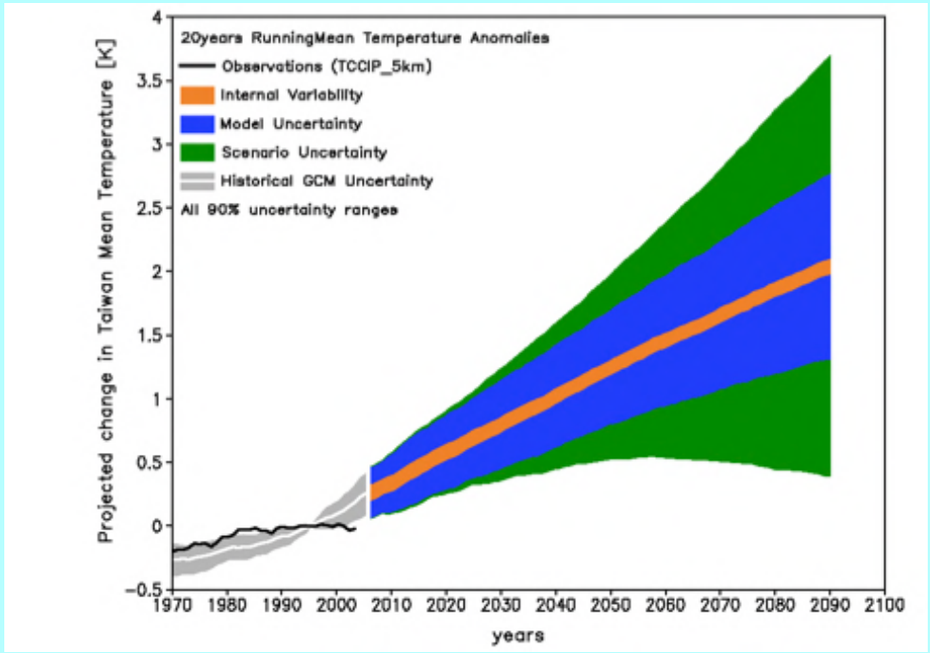
Uncertainties Assessment (Hawkin and Sutton, 2009)

Time series of projected change and associated uncertainties due to Scenario, Model, Internal variability

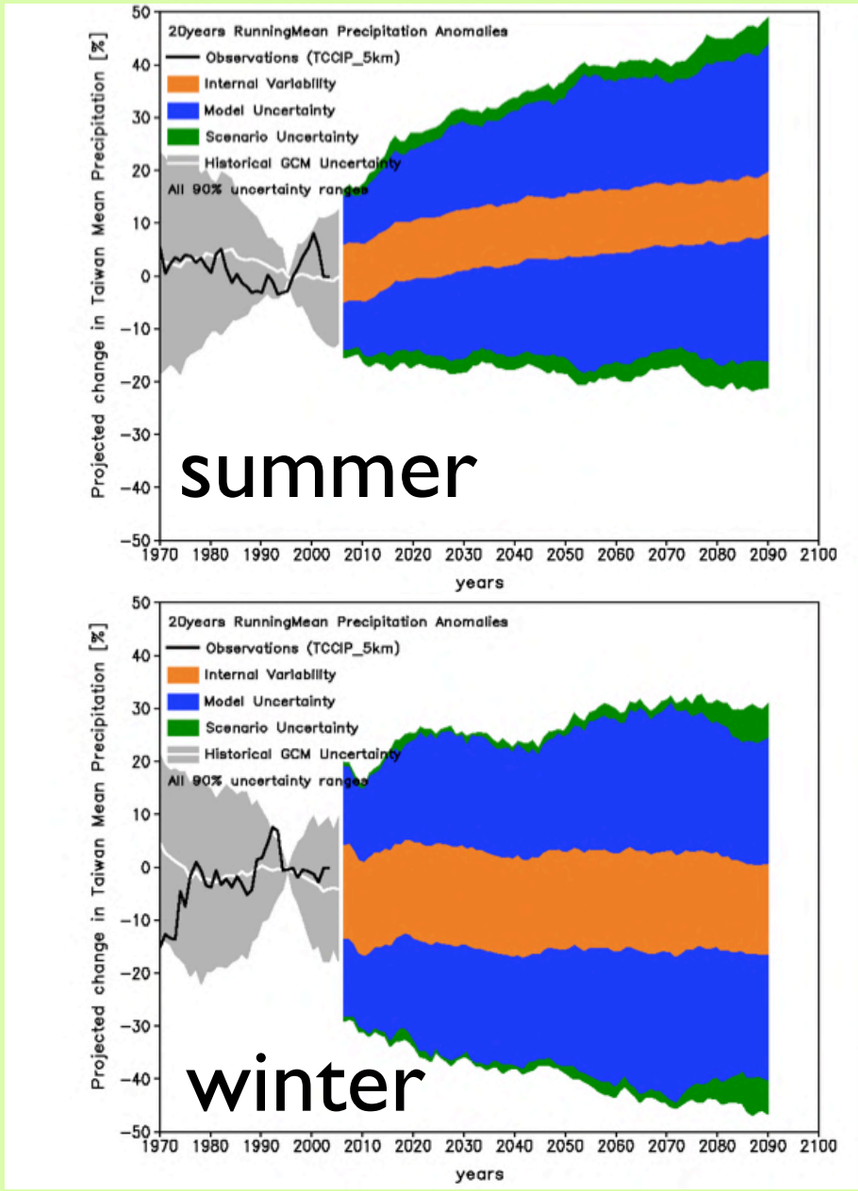
Taiwan

Surface Air Temperature (20 year mean)

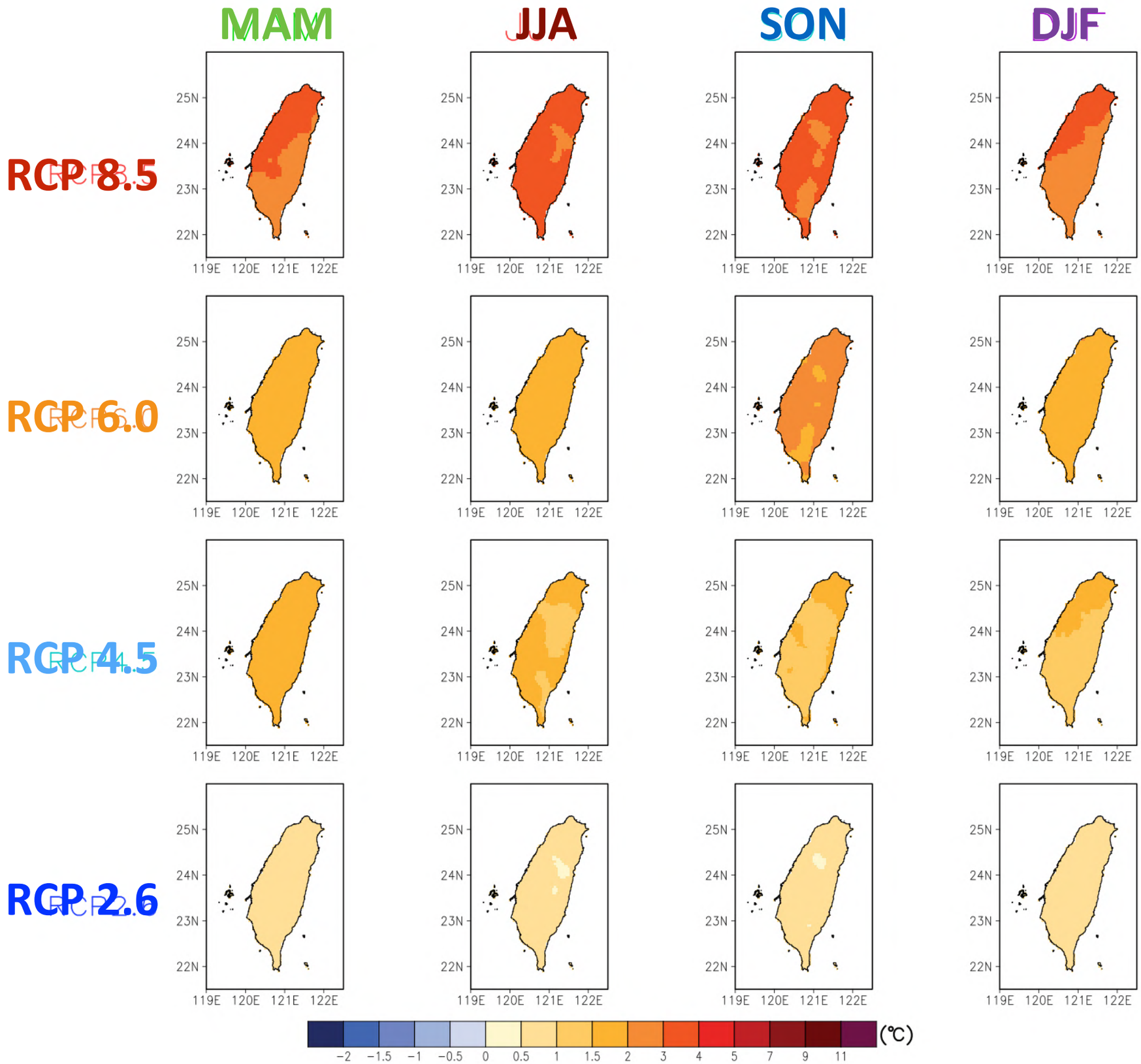
annual mean



Precipitation (20 year mean)



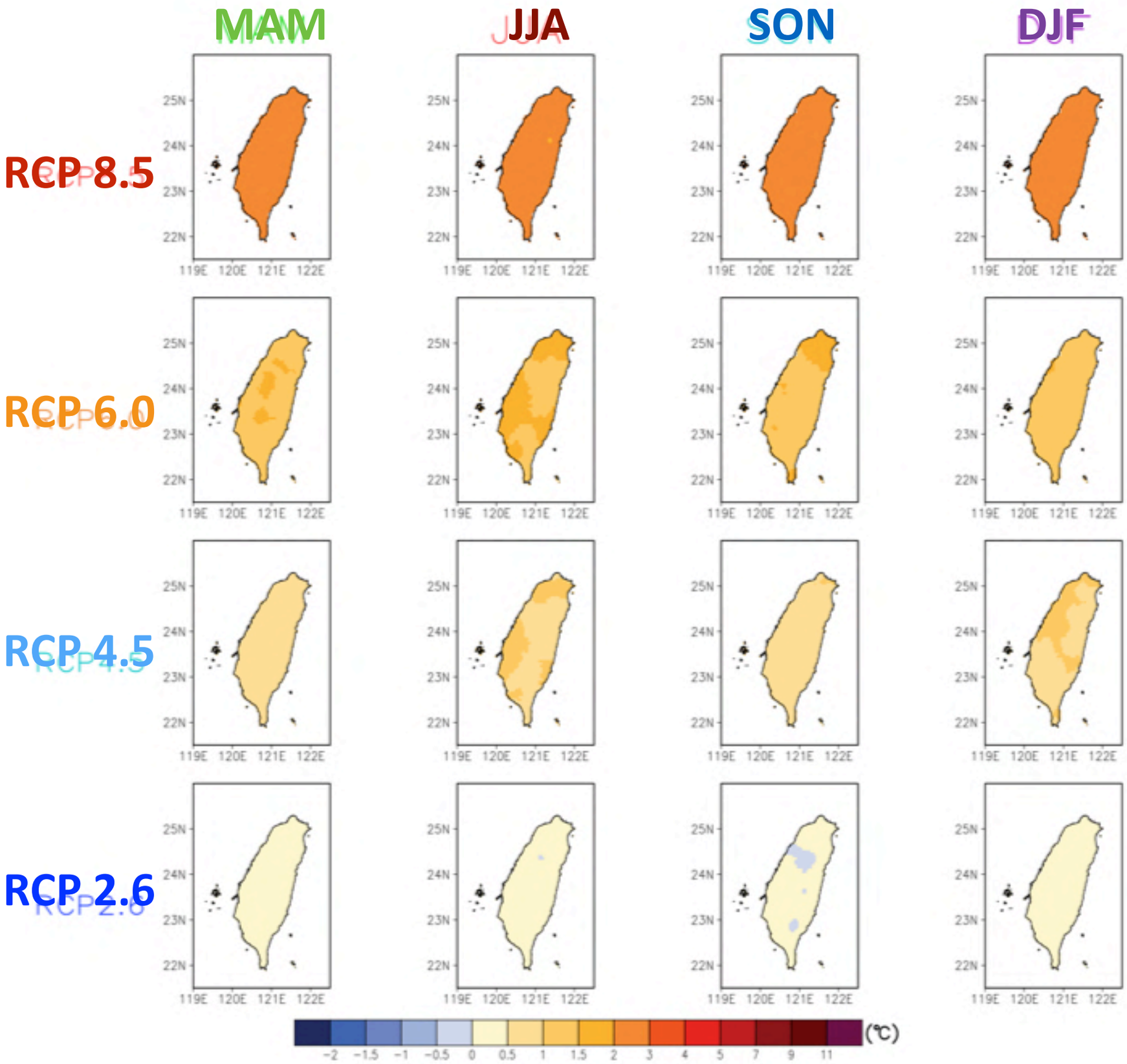
Projected model median surface air temperature change (°C)



more likely than not

多半可能

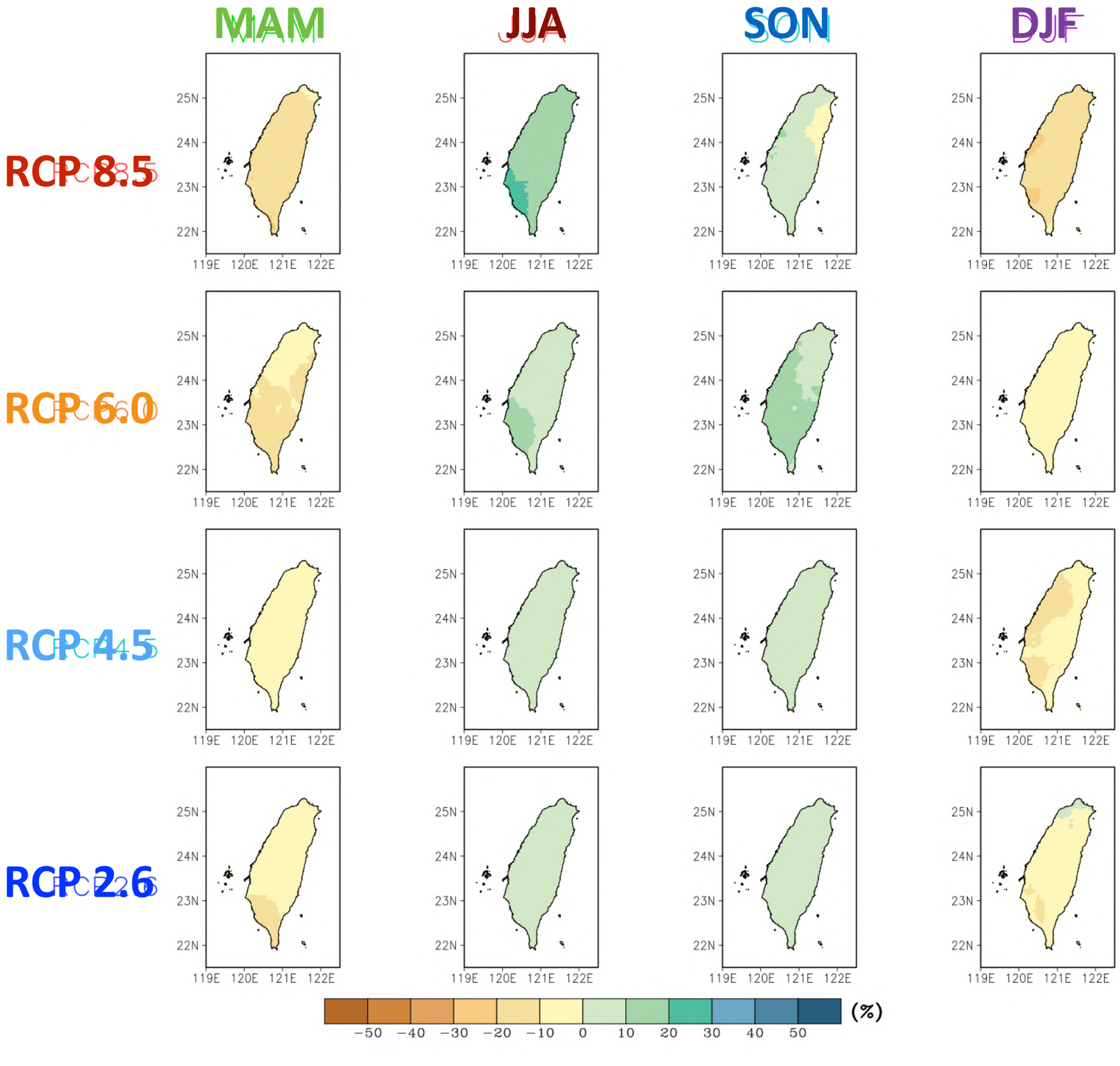
Projected model 10 percentile surface air temperature change (°C)



very likely

很可能

Projected model median precipitation change (%)

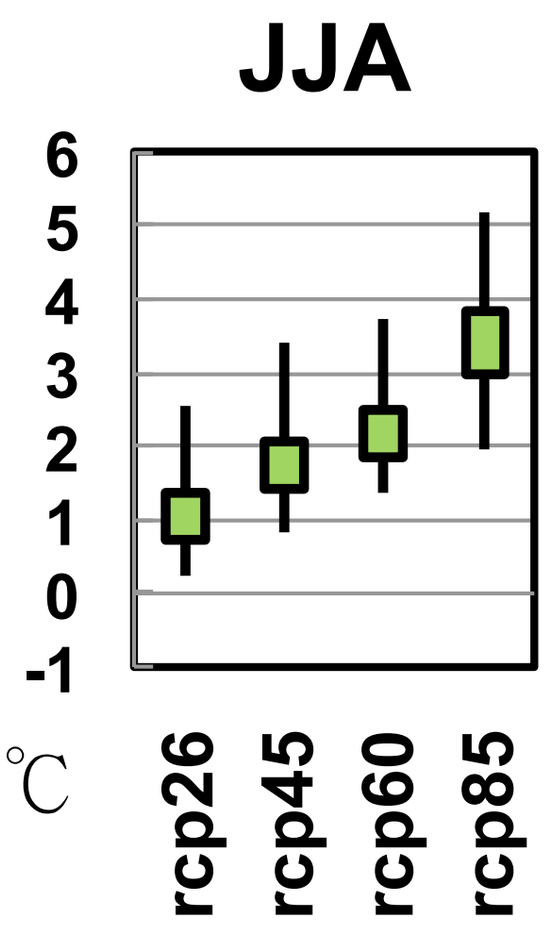


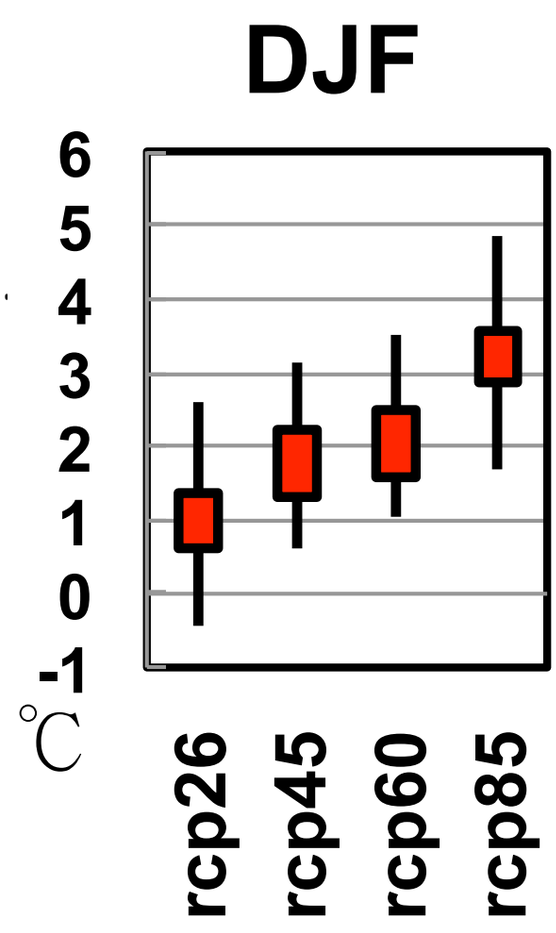
more likely than not

多半可能

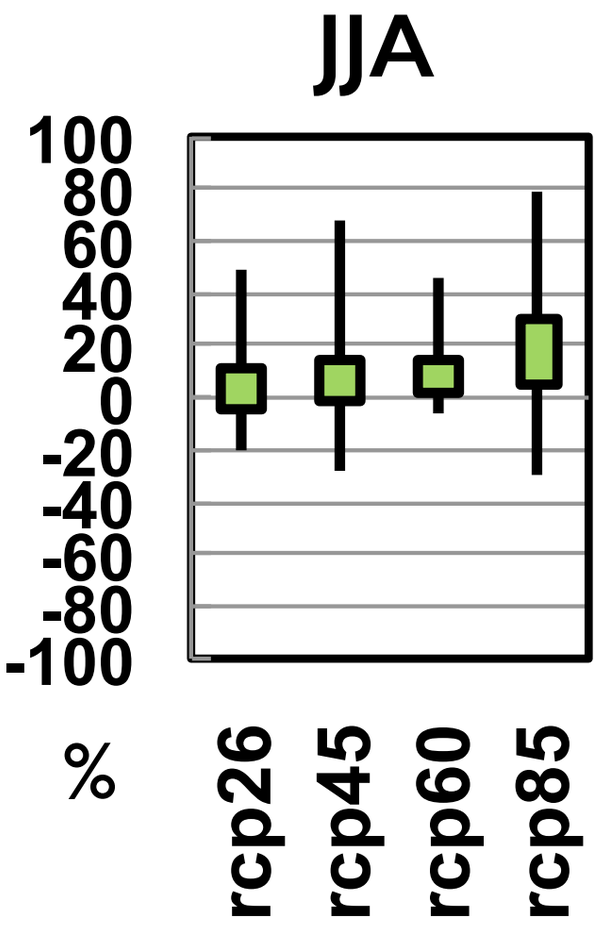
Box-Whisker Plots of CMIP5 Model Projected Taiwan Mean Future (2080-2099) Climate Change with RCP8.5 scenario

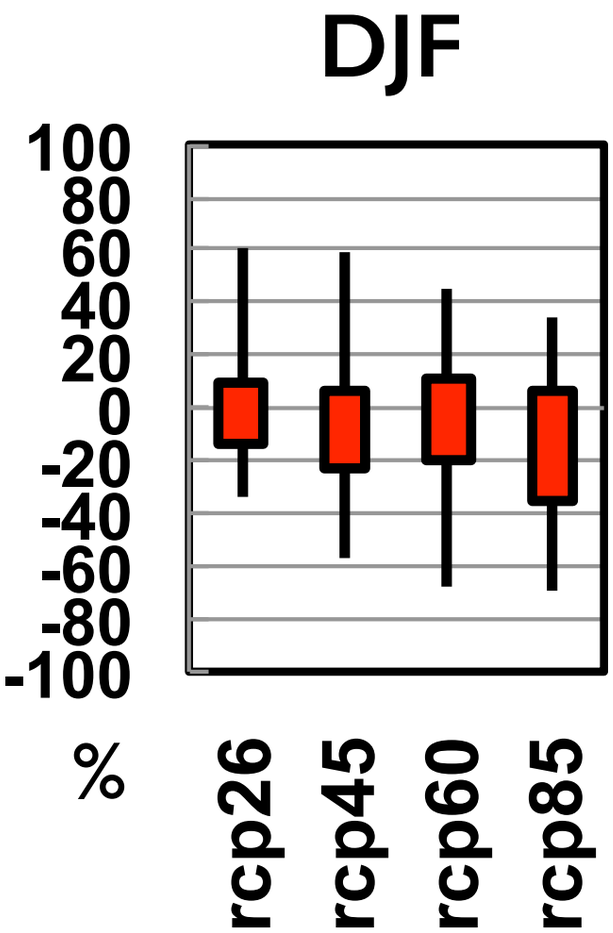
Taiwan Mean Temperature Change



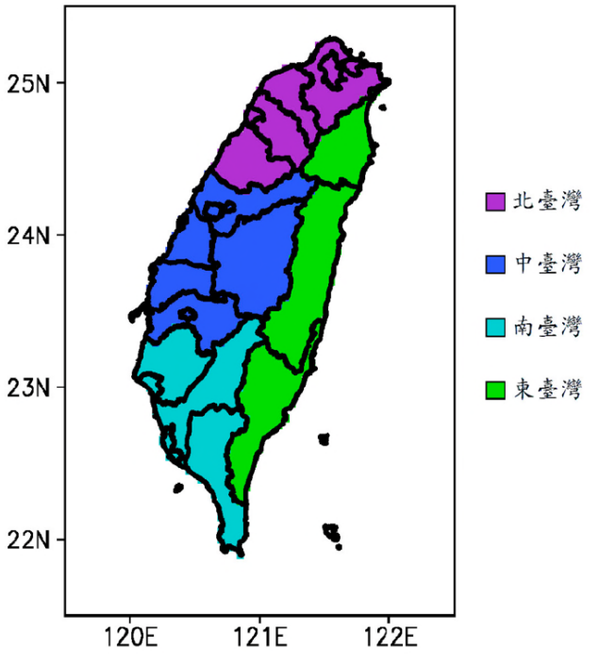


Taiwan Mean Precipitation Change



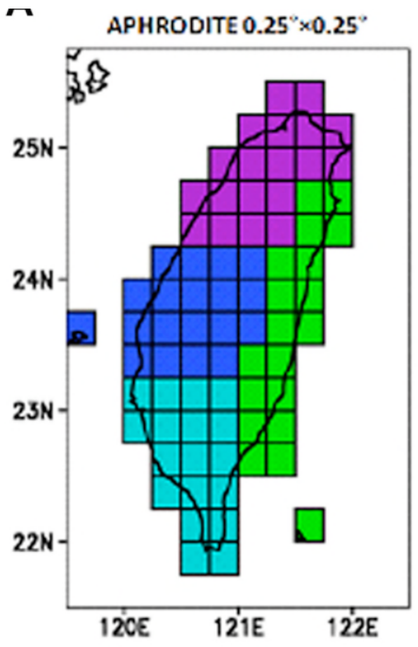


CMIP5 RCP8.5 (2081-2100)-(1986-2005)



區域	季節	近地表氣溫平均變化 (℃)							降水量平均百分比變化 (%)						
		最小	10	25	50	75	90	最大	最小	10	25	50	75	90	最大
北臺灣	春(MAM)	2.0	2.2	2.6	3.2	3.6	4.3	4.7	-40.1	-25.3	-18.8	-11.4	-3.2	12.6	49.5
	夏(JJA)	1.8	2.3	2.8	3.2	3.6	4.0	5.2	-35.2	-12.5	0.7	15.3	26.2	46.1	114.7
	秋(SON)	2.1	2.3	2.8	3.1	3.7	4.2	4.9	-32.7	-24.5	-7.7	2.7	20.1	41.3	77.2
	冬(DJF)	1.5	2.2	2.8	3.1	3.5	4.4	4.8	-60.5	-40.5	-28.3	-17.3	-5.2	12.2	24.2
中臺灣	春(MAM)	2.0	2.2	2.6	3.1	3.6	4.1	4.7	-43.2	-28.0	-23.1	-15.1	-1.4	13.6	56.2
	夏(JJA)	1.8	2.3	2.8	3.2	3.5	4.0	5.1	-29.4	-9.1	1.6	15.7	25.2	38.9	98.6
	秋(SON)	2.1	2.3	2.8	3.1	3.6	4.1	4.8	-34.4	-23.1	-10.4	5.5	26.1	48.8	75.3
	冬(DJF)	1.5	2.2	2.7	3.0	3.4	4.2	4.7	-70.3	-51.1	-34.4	-17.8	-1.5	18.2	38.4
南臺灣	春(MAM)	2.0	2.3	2.5	2.9	3.5	3.9	4.7	-47.6	-32.6	-27.3	-18.3	0.7	15.2	56.1
	夏(JJA)	1.9	2.3	2.7	3.1	3.5	4.0	4.9	-31.8	-6.3	2.3	19.3	32.6	43.2	114.8
	秋(SON)	2.1	2.3	2.8	3.0	3.6	4.0	4.8	-30.4	-24.2	-11.8	5.6	22.7	43.9	67.0
	冬(DJF)	1.5	2.2	2.6	2.9	3.3	3.9	4.6	-79.6	-55.0	-34.7	-16.9	0.3	23.9	43.8
東臺灣	春(MAM)	1.9	2.2	2.5	3.0	3.6	4.0	4.7	-43.0	-27.6	-22.9	-15.3	-1.9	14.1	50.5
	夏(JJA)	1.8	2.3	2.7	3.1	3.5	3.9	5.0	-33.5	-8.3	2.4	15.9	26.1	42.1	105.8
	秋(SON)	2.1	2.3	2.8	3.1	3.6	4.1	4.9	-32.2	-22.8	-12.1	1.1	20.4	40.2	63.8
	冬(DJF)	1.4	2.2	2.6	2.9	3.3	4.0	4.7	-64.2	-40.2	-26.3	-14.7	-2.7	12.5	25.0

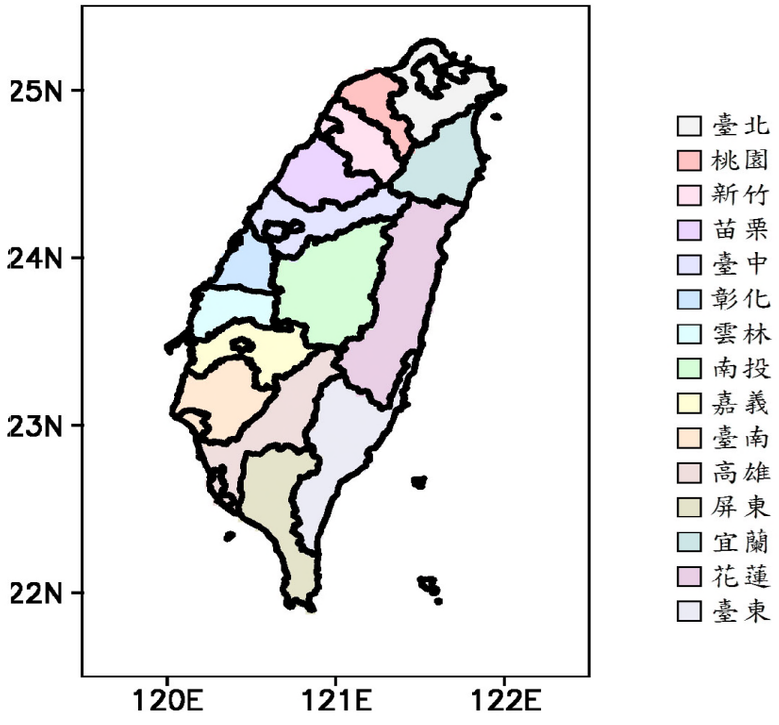
CMIP3 A1B (2081-2100)-(1981-2000)



區域	季節	近地表氣溫平均變化 (℃)							降水量平均百分比變化 (%)						
		最小	10	25	50	75	90	最大	最小	10	25	50	75	90	最大
北臺灣	冬(DJF)	1.1	1.4	1.9	2.4	2.9	3	3.7	-39	-34	-21	-13	0	6	30
	春(MAM)	1.6	1.7	1.9	2.3	2.6	2.7	3.5	-24	-23	-15	-3	8	13	20
	夏(JJA)	1.2	1.4	1.9	2.3	2.6	3	3.6	-12	-10	-3	13	26	36	43
	秋(SON)	1.3	1.4	2	2.2	2.7	3	3.5	-25	-23	-12	-3	11	14	38
中臺灣	冬(DJF)	1.1	1.3	1.8	2.3	2.7	3.1	3.4	-41	-38	-22	-15	0	6	34
	春(MAM)	1.6	1.6	1.9	2.3	2.6	2.8	3.5	-27	-26	-18	-3	8	11	29
	夏(JJA)	1.2	1.4	1.9	2.2	2.6	3	3.6	-9	-8	-4	15	28	34	47
	秋(SON)	1.3	1.4	2	2.2	2.7	2.9	3.4	-26	-20	-11	-2	14	18	47
南臺灣	冬(DJF)	1	1.4	1.8	2.2	2.5	2.9	3.2	-37	-35	-23	-16	-2	6	35
	春(MAM)	1.5	1.6	1.8	2.2	2.4	2.7	3.3	-31	-29	-22	-7	4	10	35
	夏(JJA)	1.2	1.3	1.9	2.1	2.5	2.9	3.7	-16	-14	-3	19	28	34	52
	秋(SON)	1.2	1.4	1.9	2.1	2.6	2.8	3.4	-25	-20	-9	-1	15	22	55
東臺灣	冬(DJF)	1	1.3	1.9	2.3	2.7	2.9	3.5	-37	-34	-20	-15	-1	6	26
	春(MAM)	1.6	1.6	1.8	2.2	2.6	2.7	3.5	-27	-26	-19	-4	6	10	28
	夏(JJA)	1.2	1.3	1.9	2.2	2.6	2.9	3.7	-14	-12	-3	16	28	33	43
	秋(SON)	1.2	1.4	2	2.2	2.7	2.9	3.5	-24	-21	-11	-3	13	18	48

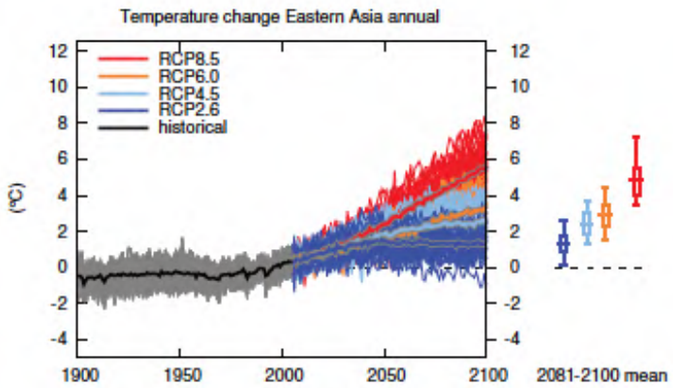
3.1 °C : 2.2 °C

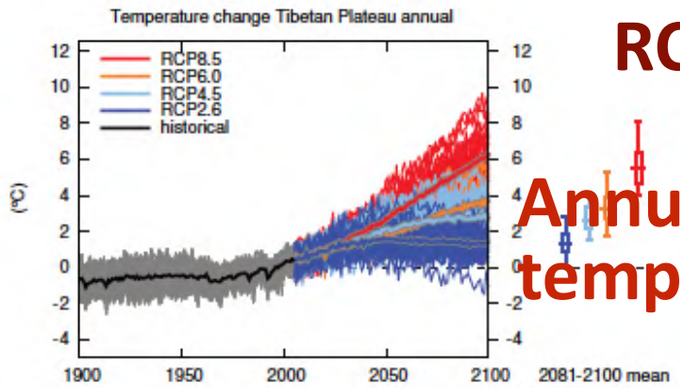
8.5 Wm^{-2} : 6.0 Wm^{-2}



區域	季節	近地表氣溫平均變化(℃)							降水量平均百分比變化(%)						
		最小	10	25	50	75	90	最大	最小	10	25	50	75	90	最大
臺北	春(MAM)	2.0	2.2	2.6	3.2	3.7	4.3	4.7	-36.3	-22.2	-16.7	-10.5	-2.9	10.5	43.2
	夏(JJA)	1.8	2.4	2.8	3.3	3.6	4.1	5.2	-34.9	-12.1	-0.4	15.9	25.1	43.9	117.8
	秋(SON)	2.1	2.4	2.9	3.2	3.7	4.3	4.9	-27.4	-19.8	-7.8	1.0	15.1	31.4	58.3
	冬(DJF)	1.5	2.2	2.8	3.1	3.5	4.4	4.9	-53.2	-34.3	-24.9	-15.2	-4.5	8.1	15.9
桃園	春(MAM)	1.9	2.2	2.6	3.2	3.6	4.3	4.7	-42.3	-26.0	-19.3	-11.1	-2.9	12.8	51.0
	夏(JJA)	1.8	2.4	2.8	3.3	3.6	4.1	5.3	-36.4	-12.8	-0.3	14.7	26.3	47.5	117.3
	秋(SON)	2.1	2.4	2.9	3.2	3.7	4.3	4.9	-33.1	-23.6	-8.0	1.8	19.7	39.5	75.6
	冬(DJF)	1.5	2.2	2.8	3.1	3.6	4.4	4.8	-60.3	-40.1	-27.6	-17.7	-5.4	11.9	22.2
新竹	春(MAM)	2.0	2.2	2.6	3.2	3.6	4.3	4.7	-41.7	-26.7	-20.0	-11.7	-3.4	13.7	52.0
	夏(JJA)	1.8	2.3	2.8	3.2	3.6	4.0	5.2	-35.6	-12.6	1.5	15.0	26.9	47.4	112.4
	秋(SON)	2.1	2.3	2.8	3.1	3.7	4.2	4.8	-34.1	-25.5	-8.0	2.9	20.7	42.8	81.6
	冬(DJF)	1.5	2.2	2.8	3.1	3.5	4.4	4.8	-63.2	-42.2	-28.7	-18.2	-5.7	13.6	27.1
苗栗	春(MAM)	1.9	2.2	2.6	3.2	3.6	4.3	4.7	-42.2	-27.7	-20.2	-12.4	-3.6	14.4	54.7
	夏(JJA)	1.7	2.3	2.7	3.1	3.6	3.9	5.1	-34.4	-12.6	2.1	15.1	27.1	47.0	110.8
	秋(SON)	2.1	2.2	2.8	3.0	3.6	4.2	4.8	-38.1	-30.2	-7.1	5.4	26.4	53.9	99.2
	冬(DJF)	1.5	2.2	2.8	3.1	3.6	4.4	4.8	-67.9	-47.5	-32.8	-19.0	-5.6	16.4	34.0
臺中	春(MAM)	2.0	2.2	2.6	3.2	3.6	4.2	4.7	-43.2	-27.2	-21.7	-13.7	-3.2	13.9	54.7
	夏(JJA)	1.7	2.2	2.7	3.1	3.5	3.9	5.1	-33.1	-12.2	2.2	16.1	26.4	44.8	110.7
	秋(SON)	2.1	2.2	2.8	3.0	3.6	4.1	4.8	-36.8	-26.8	-8.3	5.5	26.5	52.3	87.2
	冬(DJF)	1.5	2.2	2.8	3.1	3.5	4.4	4.8	-68.7	-50.2	-33.4	-18.8	-3.8	16.8	38.1
彰化	春(MAM)	2.0	2.3	2.6	3.1	3.6	4.2	4.7	-44.3	-28.8	-24.1	-14.2	-0.3	14.5	65.5
	夏(JJA)	1.9	2.5	2.9	3.3	3.6	4.1	5.2	-30.0	-10.4	0.9	16.8	25.4	40.3	104.5
	秋(SON)	2.1	2.3	2.9	3.1	3.7	4.2	4.9	-40.8	-25.8	-10.6	9.3	35.9	65.4	91.5
	冬(DJF)	1.5	2.2	2.8	3.1	3.5	4.3	4.7	-75.5	-58.6	-37.4	-20.1	-0.4	19.7	45.3
南投	春(MAM)	2.0	2.2	2.6	3.0	3.6	4.1	4.7	-41.7	-27.0	-22.6	-14.8	-2.0	13.1	50.0
	夏(JJA)	1.7	2.2	2.7	3.1	3.5	3.9	5.0	-28.3	-7.9	1.9	14.0	22.8	36.5	87.4
	秋(SON)	2.1	2.2	2.7	3.0	3.6	4.1	4.8	-30.3	-20.1	-9.8	3.2	20.9	39.1	62.4
	冬(DJF)	1.5	2.2	2.7	3.0	3.4	4.1	4.7	-66.1	-46.2	-31.3	-16.4	-2.5	15.8	32.7
雲林	春(MAM)	2.0	2.3	2.6	3.1	3.6	4.2	4.7	-45.5	-29.6	-24.1	-16.3	0.7	14.1	67.3
	夏(JJA)	1.9	2.4	2.9	3.3	3.6	4.1	5.1	-28.5	-9.2	1.6	17.5	26.9	38.0	103.4
	秋(SON)	2.1	2.3	2.9	3.1	3.7	4.2	4.9	-39.6	-24.4	-12.9	8.1	34.0	59.4	85.3
	冬(DJF)	1.5	2.1	2.7	3.0	3.5	4.2	4.7	-75.2	-57.4	-39.4	-19.2	2.0	21.6	44.7
嘉義	春(MAM)	2.0	2.3	2.6	3.0	3.6	4.1	4.7	-44.2	-29.4	-24.5	-17.3	-0.2	13.4	58.0
	夏(JJA)	1.9	2.4	2.8	3.2	3.6	4.1	5.1	-27.9	-7.1	0.9	17.0	27.8	36.9	101.7
	秋(SON)	2.1	2.3	2.8	3.1	3.7	4.1	4.8	-33.1	-22.7	-11.9	6.4	25.6	48.8	72.8
	冬(DJF)	1.5	2.2	2.7	3.0	3.4	4.1	4.7	-74.9	-54.0	-36.8	-17.3	0.0	21.7	42.4
臺南	春(MAM)	2.0	2.3	2.6	3.0	3.6	4.0	4.7	-48.4	-32.8	-27.6	-19.0	0.5	15.9	60.8
	夏(JJA)	1.9	2.4	2.8	3.2	3.5	4.0	5.0	-32.8	-7.9	2.5	20.4	34.7	44.7	127.6
	秋(SON)	2.1	2.3	2.8	3.1	3.7	4.1	4.8	-33.4	-27.2	-12.8	6.8	25.7	49.1	73.3
	冬(DJF)	1.5	2.1	2.6	2.9	3.4	4.0	4.7	-81.0	-57.5	-39.8	-18.4	-0.2	26.3	48.2
高雄	春(MAM)	2.0	2.3	2.6	3.0	3.6	4.0	4.7	-45.5	-30.8	-26.2	-17.4	-0.4	14.5	53.6
	夏(JJA)	1.8	2.3	2.7	3.1	3.5	4.0	5.0	-31.8	-6.1	2.3	19.6	32.7	42.7	114.9
	秋(SON)	2.1	2.2	2.7	3.0	3.6	4.0	4.8	-29.2	-23.4	-11.6	4.4	21.2	41.0	63.4
	冬(DJF)	1.5	2.2	2.6	2.9	3.3	3.9	4.6	-79.3	-55.0	-35.3	-17.8	-0.8	23.4	42.8
屏東	春(MAM)	1.9	2.2	2.5	2.9	3.5	3.9	4.7	-49.3	-34.3	-28.3	-18.7	1.9	15.4	55.1
	夏(JJA)	1.8	2.3	2.7	3.1	3.5	3.9	4.9	-31.0	-5.2	2.3	18.0	30.7	42.5	104.4
	秋(SON)	2.1	2.2	2.7	3.0	3.5	3.9	4.8	-29.3	-22.8	-11.4	6.0	21.8	43.0	66.1
	冬(DJF)	1.5	2.2	2.6	2.8	3.3	3.8	4.6	-78.9	-53.0	-29.9	-14.6	1.9	22.6	41.3
宜蘭	春(MAM)	1.9	2.2	2.6	3.1	3.6	4.1	4.7	-39.2	-24.3	-20.1	-12.6	-3.1	12.5	49.1
	夏(JJA)	1.8	2.3	2.7	3.2	3.5	4.0	5.1	-35.4	-11.4	2.5	17.5	27.0	46.3	118.0
	秋(SON)	2.1	2.3	2.8	3.2		4.2	4.9	-29.4	-21.9	-9.3	-2.2	16.8	32.6	54.1
	冬(DJF)	1.5	2.2	2.7	3.0	3.4	4.3	4.8	-60.9	-36.6	-26.2	-16.9	-4.7	8.5	19.9
花蓮	春(MAM)	1.9	2.2	2.5	2.9	3.6	4.0	4.7	-43.4	-27.6	-23.1	-15.5	-2.0	15.0	51.6
	夏(JJA)	1.7	2.2	2.7	3.1	3.5	3.8	5.0	-34.1	-8.4	2.8	15.0	24.5	42.4	104.3
	秋(SON)	2.1	2.3	2.8	3.1	3.6	4.1	4.9	-32.7	-23.4	-12.8	0.0	20.4	39.6	63.3
	冬(DJF)	1.4	2.2	2.6	2.9	3.3	4.0	4.6	-58.9	-36.4	-25.2	-14.3	-2.9	11.2	23.3
臺東	春(MAM)	1.9	2.2	2.5	2.9	3.5	3.9	4.7	-45.2	-29.8	-24.7	-16.8	-0.8	14.0	49.9
	夏(JJA)	1.8	2.3	2.7	3.1	3.5	3.9	4.9	-31.2	-6.2	1.9	16.1	27.8	38.8	99.5
	秋(SON)	2.1	2.2	2.7	3.0	3.6	4.0	4.8	-33.5	-22.4	-13.1	5.0	22.9	46.1	71.1
	冬(DJF)	1.5	2.2	2.6	2.9	3.3	3.9	4.6	-73.8	-48.0	-27.8	-13.9	-1.1	17.1	30.8
澎湖	春(MAM)	2.0	2.3	2.6	3.1	3.6	4.2	4.7	-42.7	-26.9	-21.6	-11.6	1.5	13.9	64.8
	夏(JJA)	1.9	2.5	2.9	3.3	3.6	4.1	5.1	-29.4	-10.4	1.8	16.7	31.4	42.7	119.4
	秋(SON)	2.1	2.4	2.9	3.2	3.9	4.3	4.8	-36.8	-25.4	-12.5	7.7	29.2	51.7	75.8
	冬(DJF)	1.5	2.1	2.7	3.0	3.4	4.2	4.7	-67.8	-52.0	-33.6	-17.3	1.9	16.4	39.0

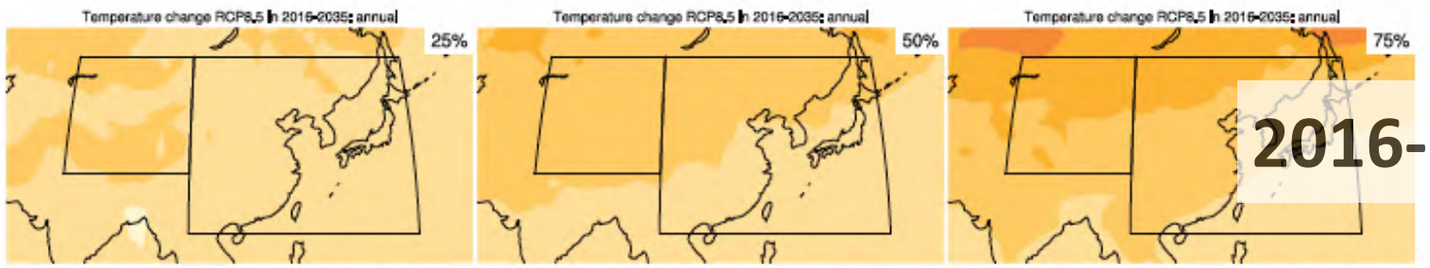
IPCC AR5 Atlas



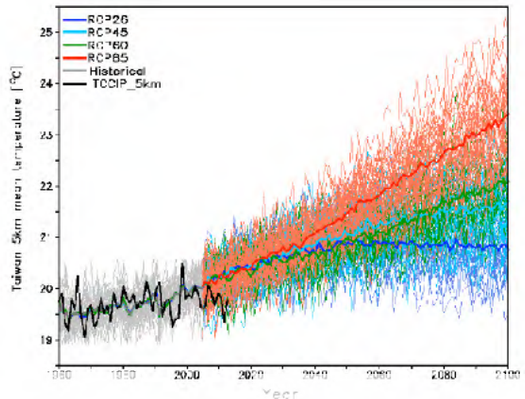


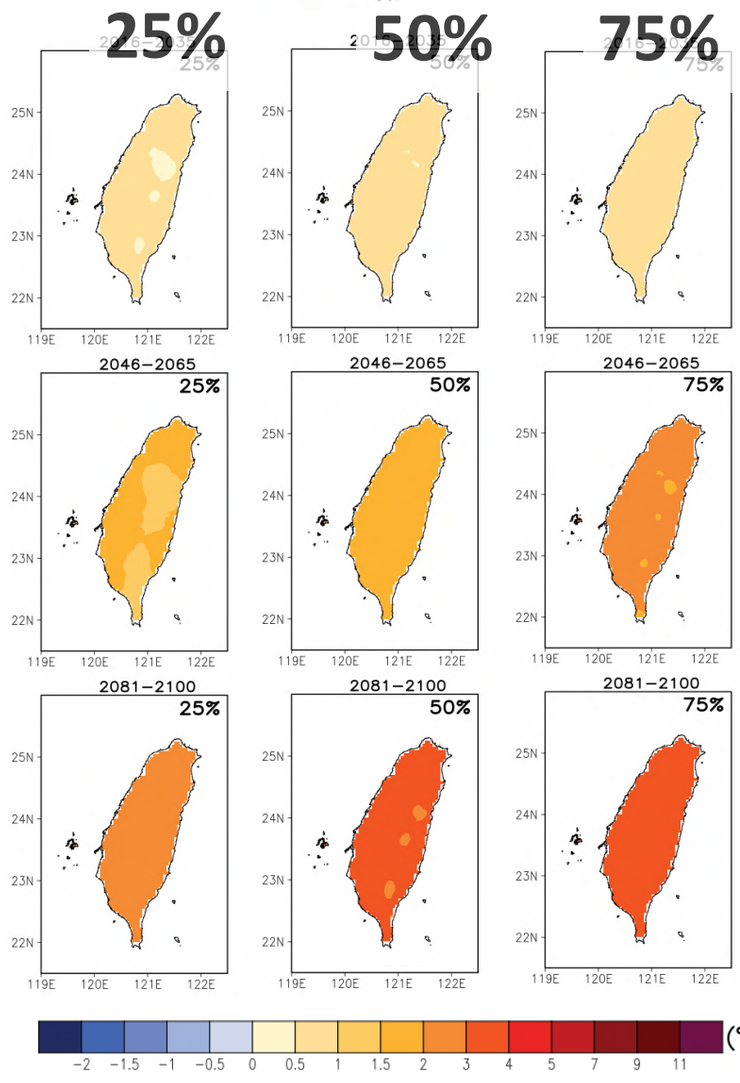
RCP 8.5

Annual mean temperature



TCCIP Atlas

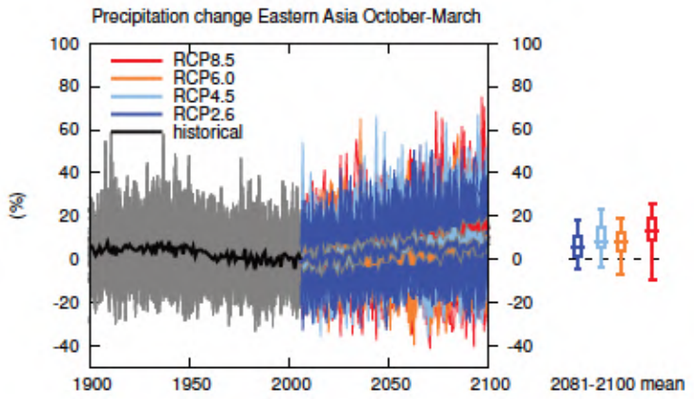


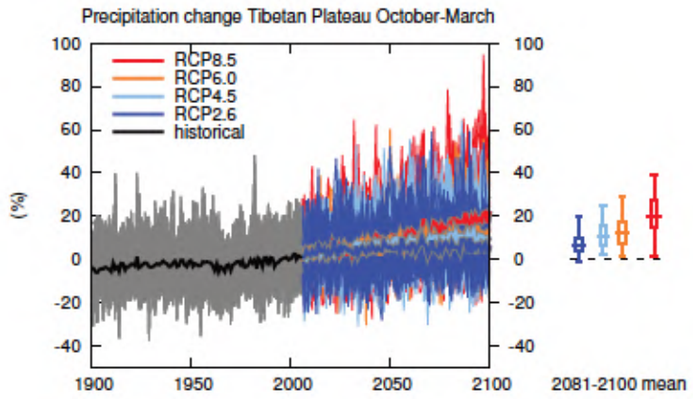


RCP 8.5

ONDJFM mean precipitation

IPCC AR5 Atlas





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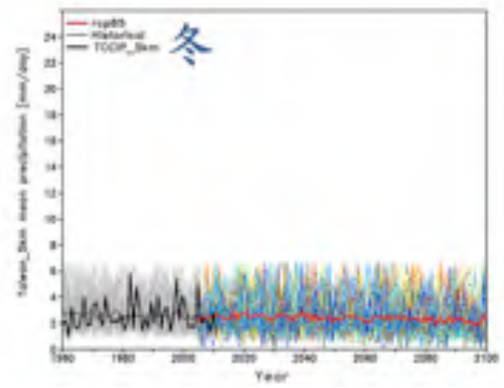
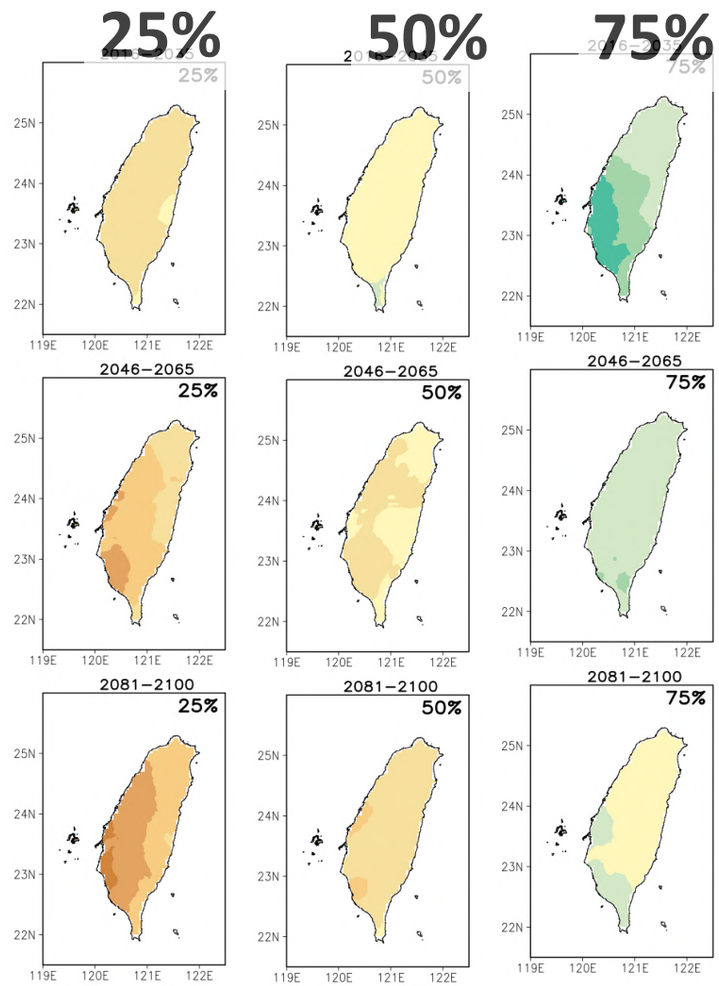
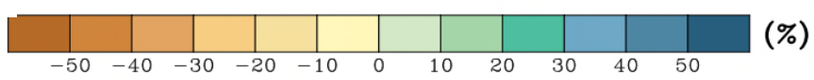
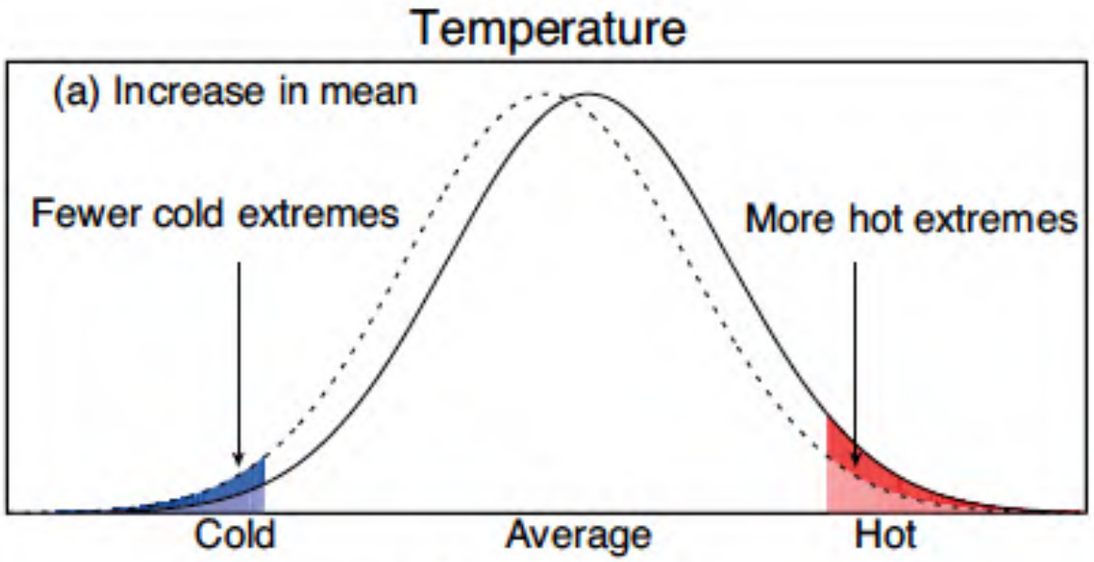
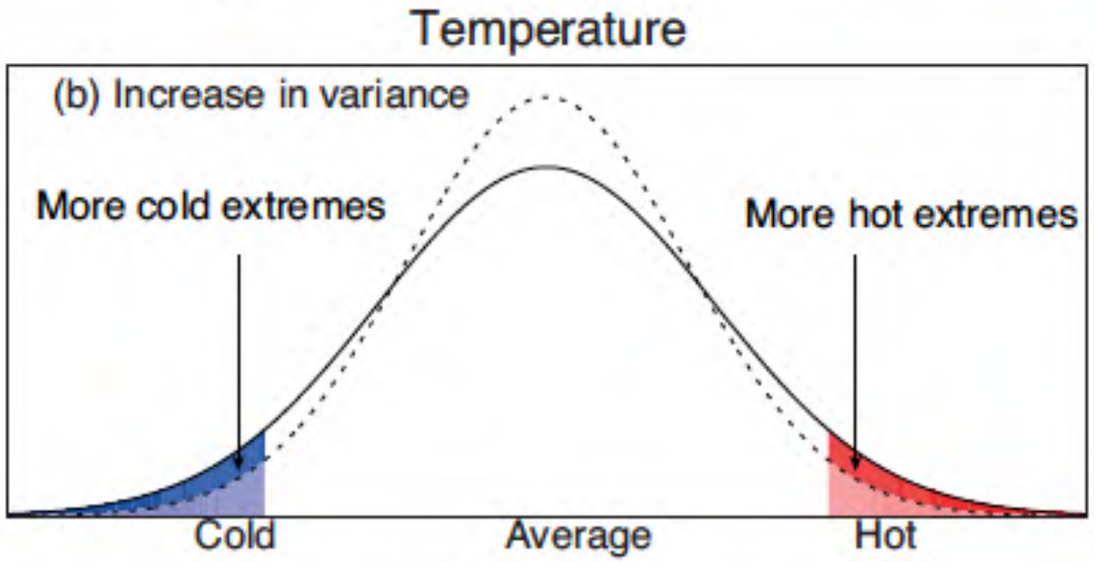
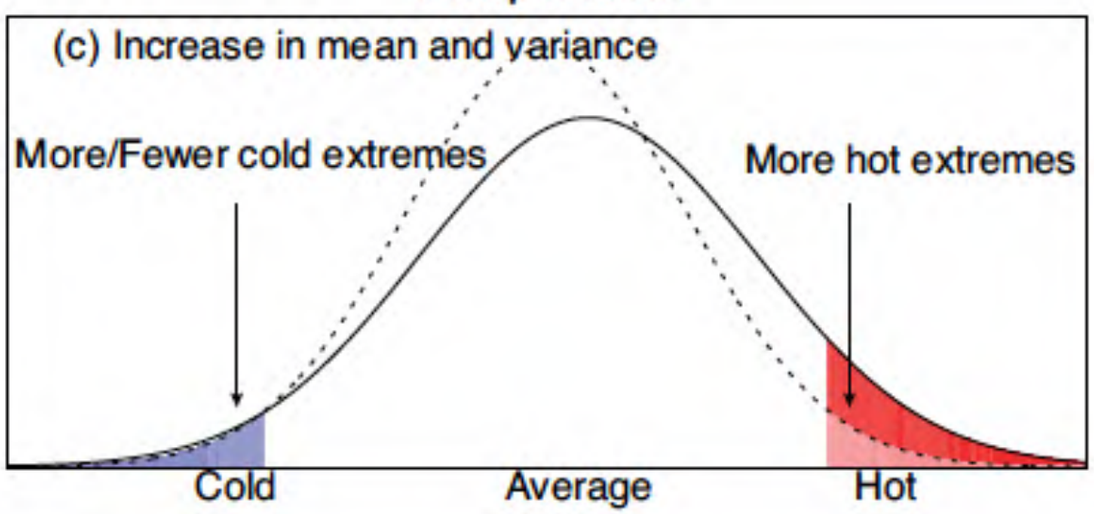






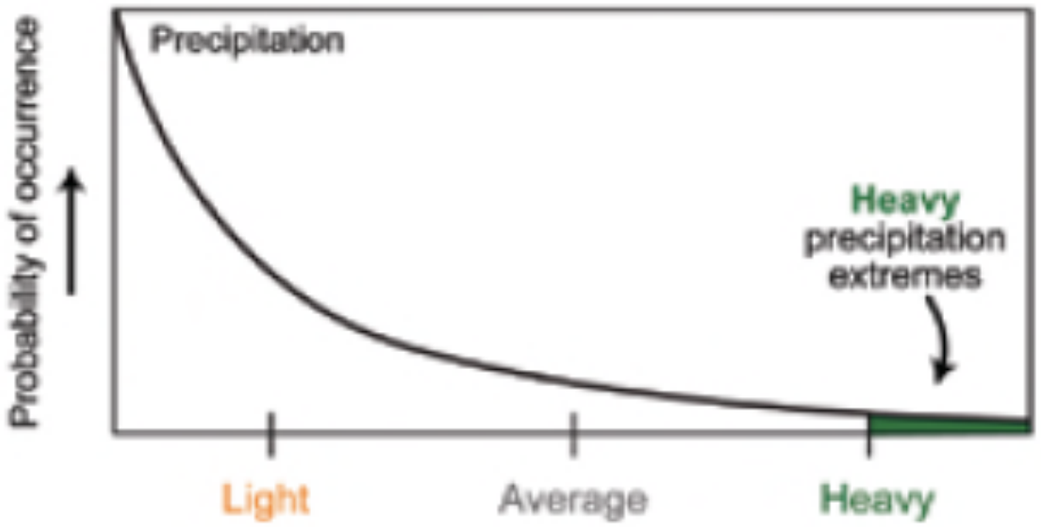




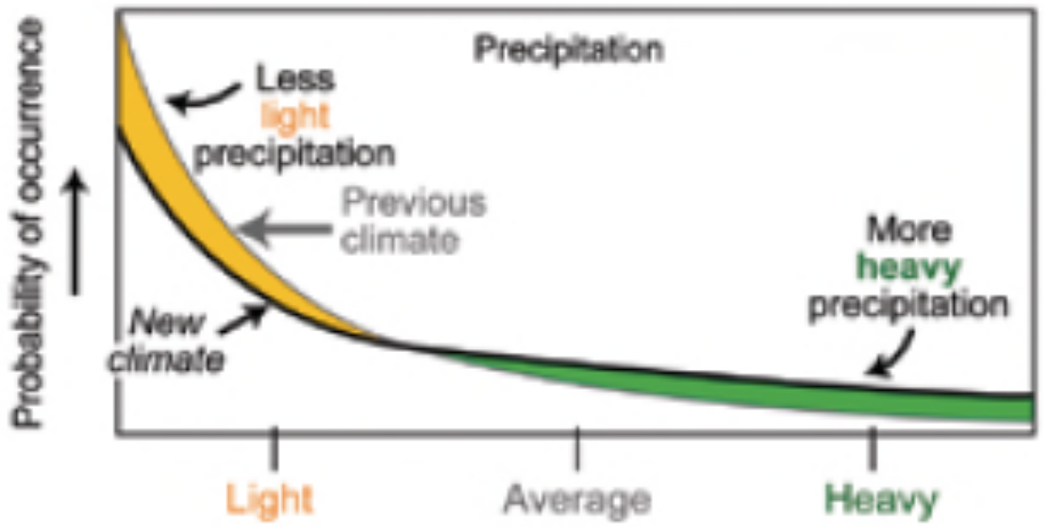


More heat waves
Less cold surges

What is extreme?

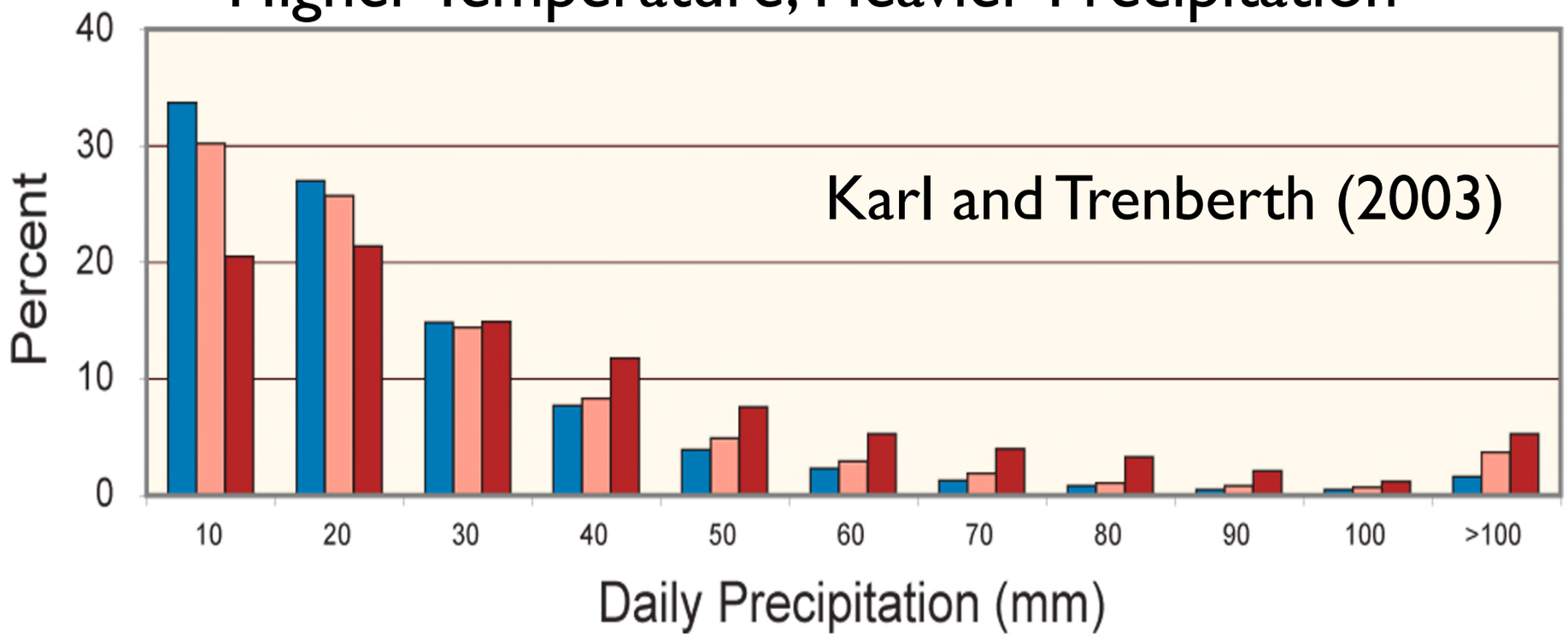


Change in probability of extremes



US Climate Change Science Program (2008)

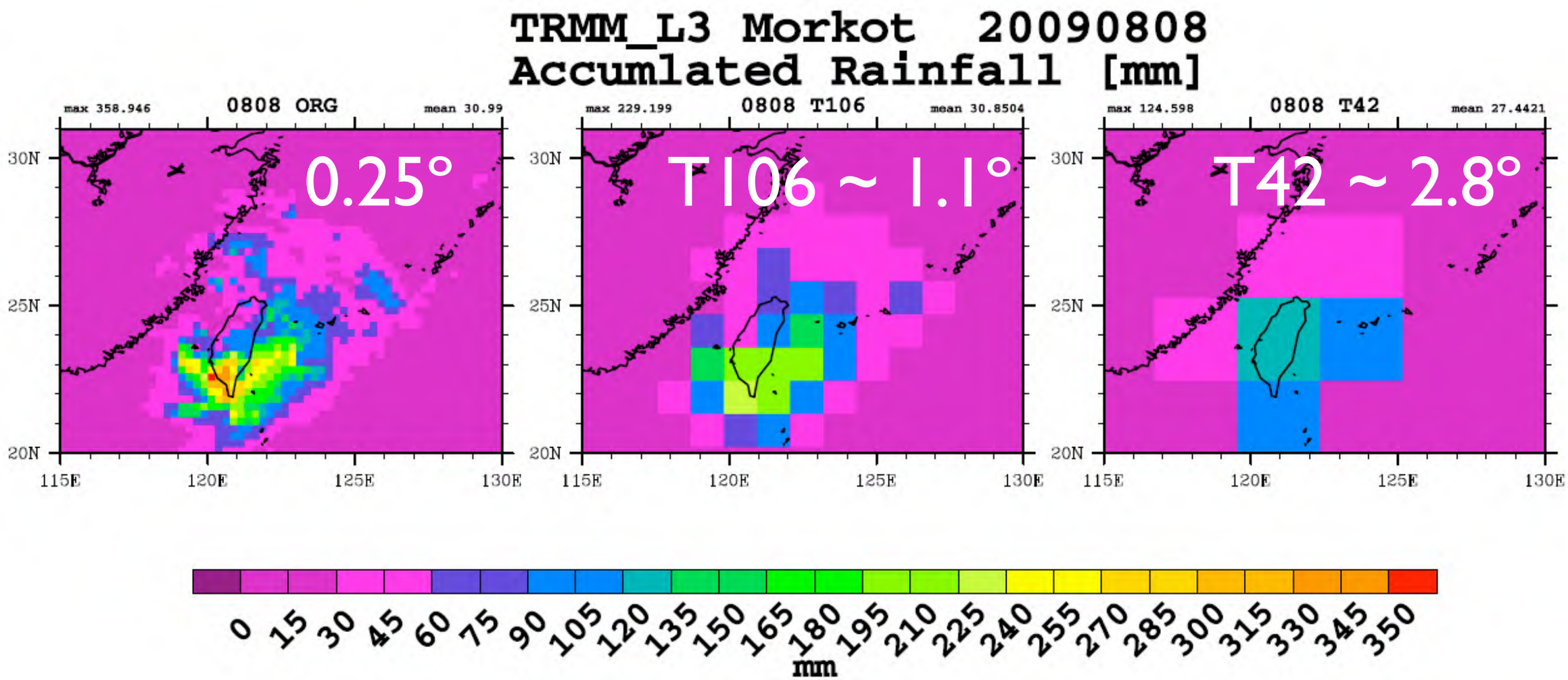
Higher Temperature, Heavier Precipitation



Percent of total seasonal precipitation for stations with 230mm±5mm falling into 10mm daily intervals based on seasonal mean temperature. Blue bar -3°C to 19°C, pink bar 19°C to 29°C, dark red bar 29°C to 35°C, based on 51, 37 and 12 stations

Statistical downscaling for the extremes?

High resolution observed daily rainfall analysis
regrid to typical model resolution

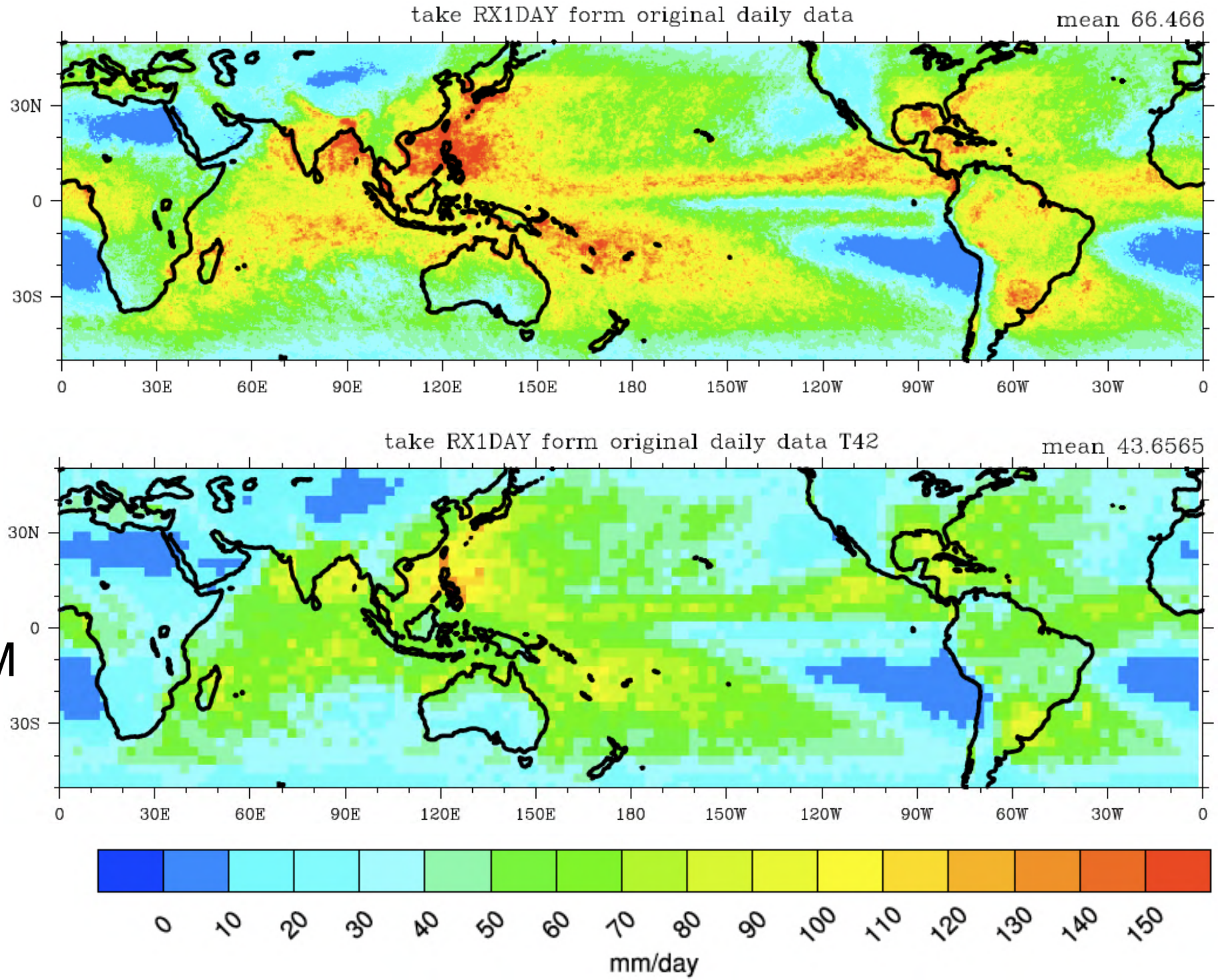


	Extreme Index	unit
RX1DAY	Highest one day precipitation amount per time period	mm/day
RX5DAY	Highest five-day precipitation amount per time period	mm/day
R10MM	Heavy precipitation days index per time period	day
R20MM	Very heavy precipitation days index per time period	day
RR1	Wet days index per time period (RR>1mm)	day
SDII	Simple daily intensity index per time period(RR>1)	mm/day
CDD	Consecutive dry days index per time period	day
CWD	Consecutive wet days index per time period	day
R95pTOT	Annual total PRCP when RR > 95p	mm/day
R99pTOT	Annual total PRCP when RR > 99p	mm/day
PRCPTOT	Annual total precipitation in wet days (RR>1mm)	mm/day

CCI/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices, ETCCDI

Deriving high-impact weather extremes at different spatial resolutions using observational estimates

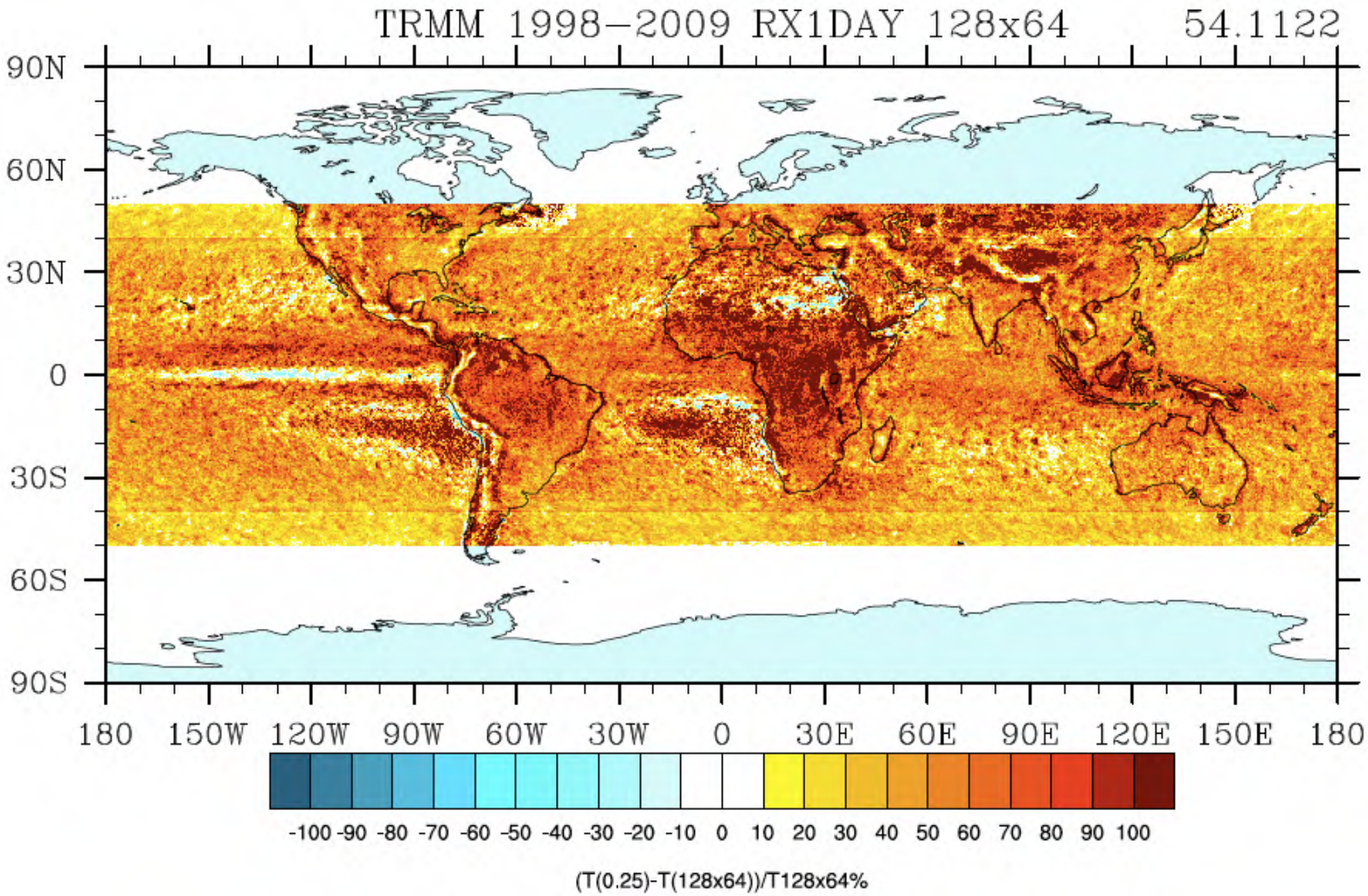
Annual maximum daily rainfall (Rx1day) at 0.25° resolution derived from TRMM (1998-2009)



Annual maximum daily rainfall (Rx1day) at T42 derived from TRMM

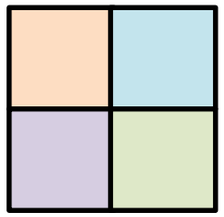
Correct the Spatial Scale Dependence of high-impact weather extremes using observational estimates

Enhancing factor (%) from T42 to 0.25° resolution [P(0.25°)-P(T42)]/P(T42)



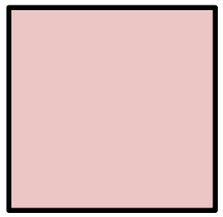
OBS

A



remap

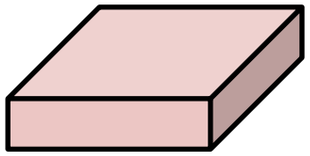
C



rx1day

rx1day

D



remap

E

B

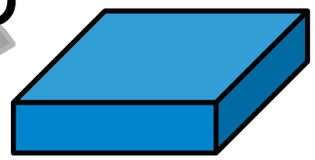
$$\Delta R_i = \frac{B_i}{E_i}$$

Model

α

Bias correction

β

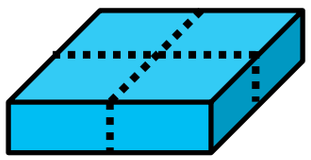


rx1day

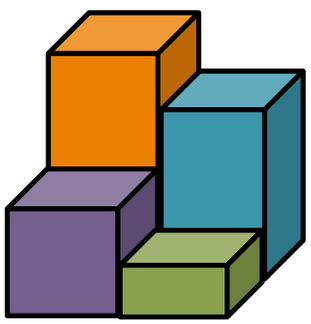
γ

remap

δ



ε

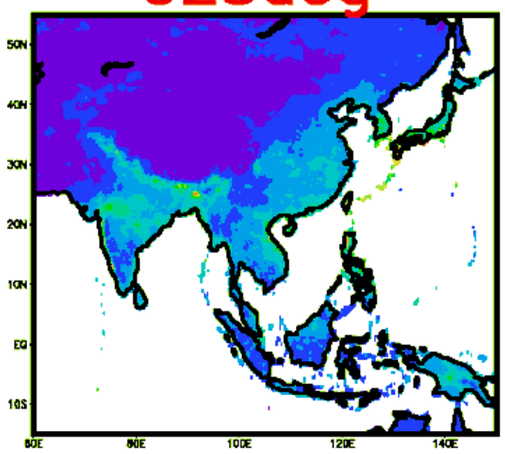


$$\varepsilon_i = \delta_i \times \Delta R_i$$

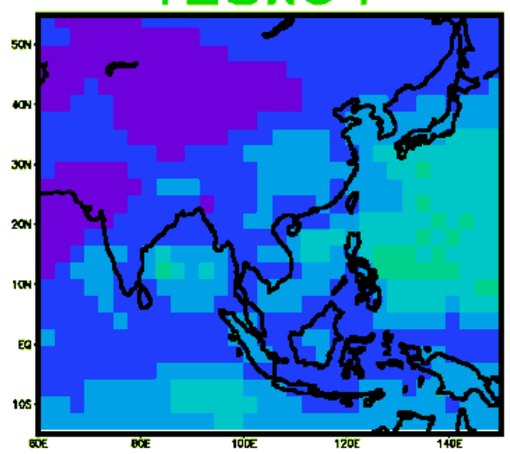
(1961-2000)

rx1day mri_cgcm2_3_2a

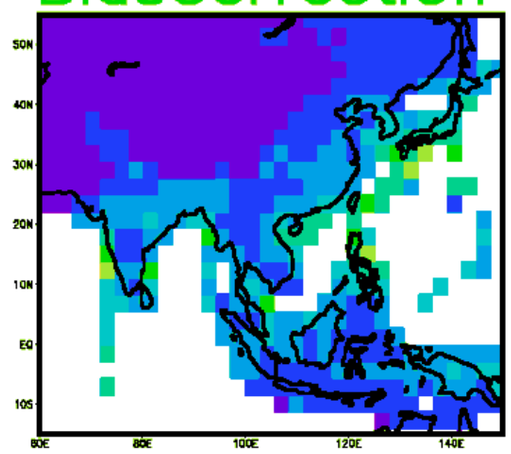
obs(1980~1999)
025deg



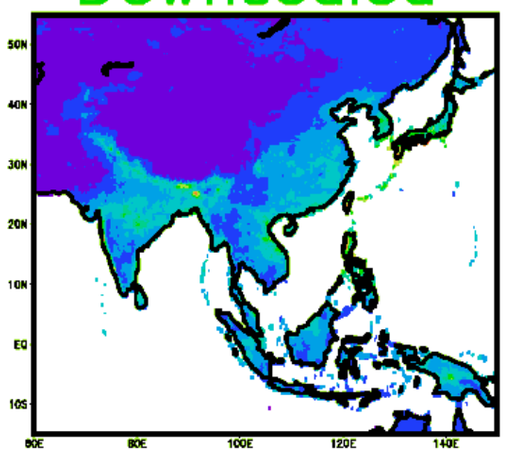
20c3m(1980~1999)
128x64



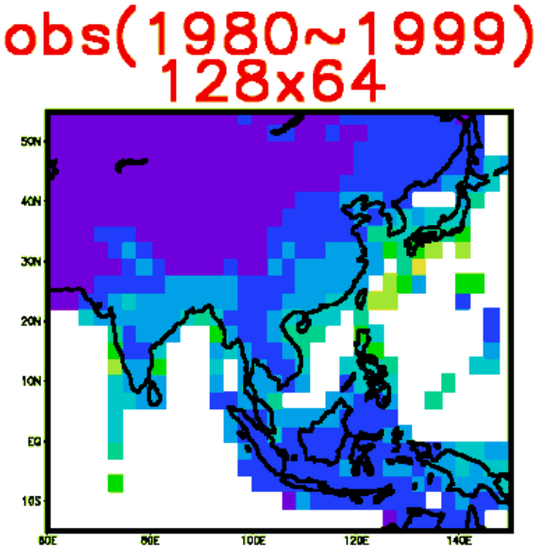
20c3m(1980~1999)
BiasCorrection



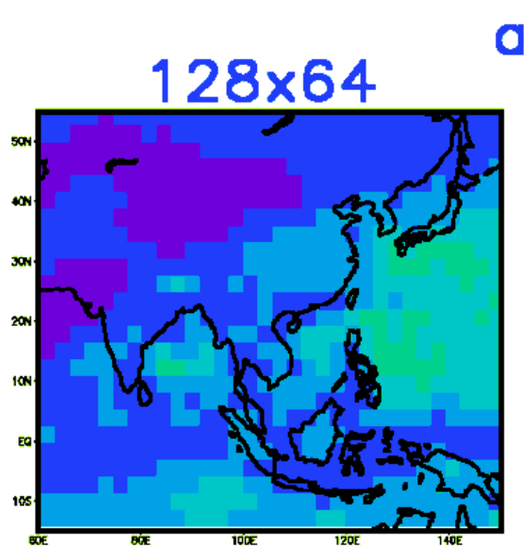
20c3m(1980~1999)
Downscaled



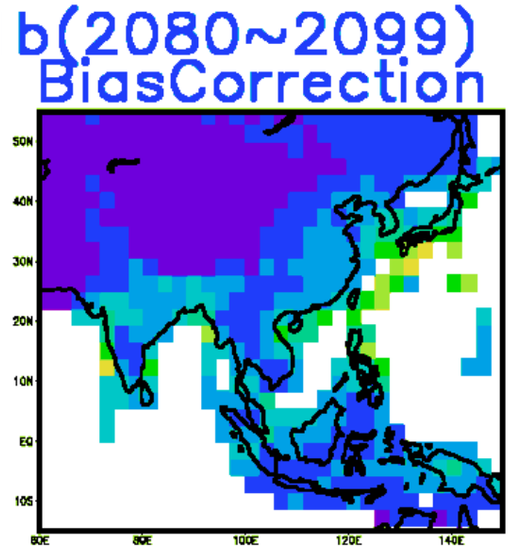
obs(1980~1999)
128x64



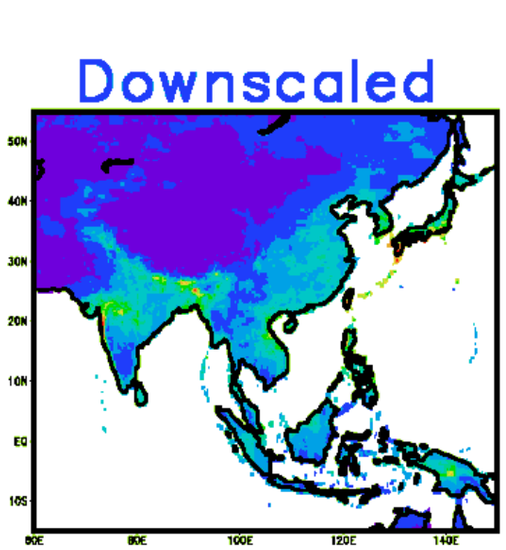
a1b(2080~2099)
128x64

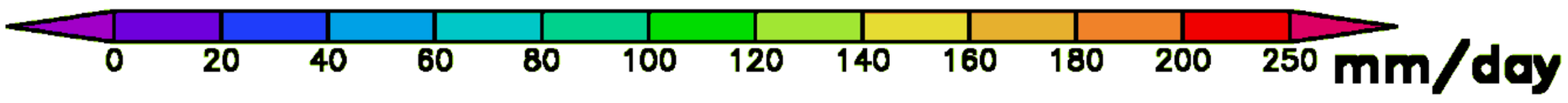


a1b(2080~2099)
BiasCorrection

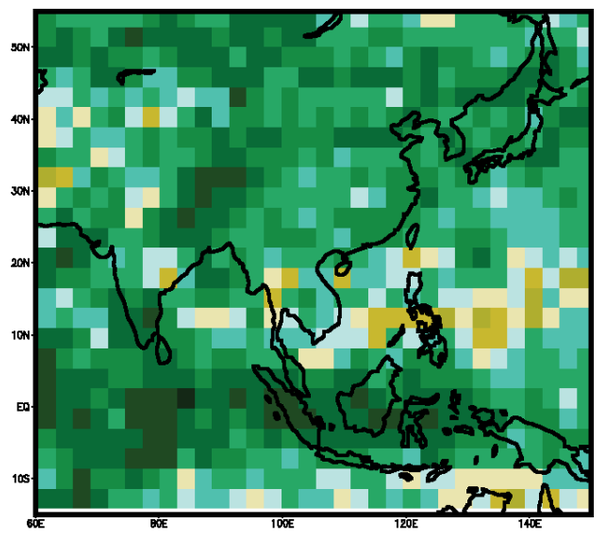


a1b(2080~2099)
Downscaled

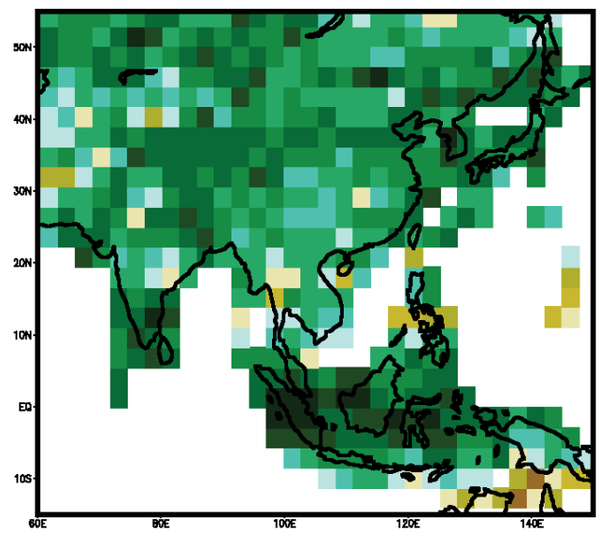




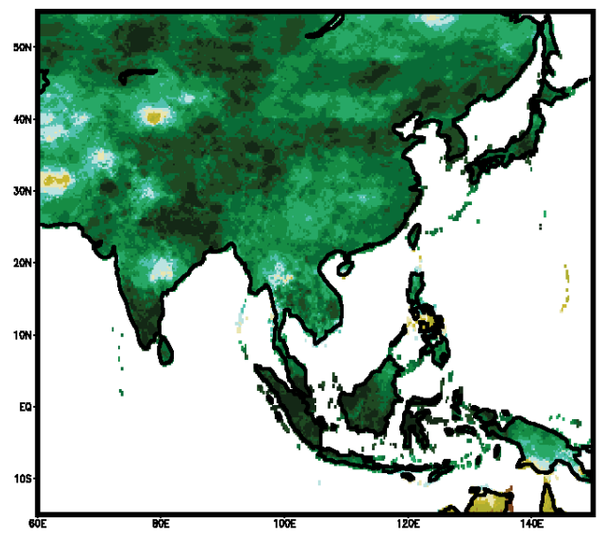
miroc3_2_medres rx1day Change (%)



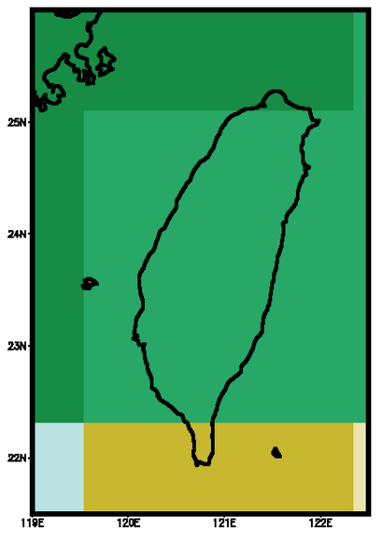
Original
128x64

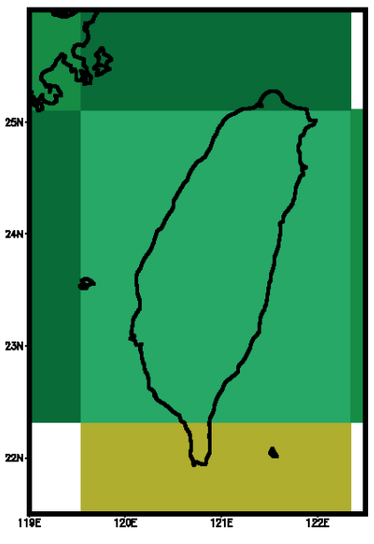


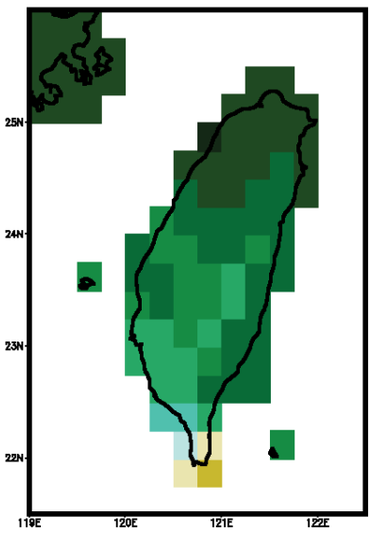
BiasCorrection
128x64

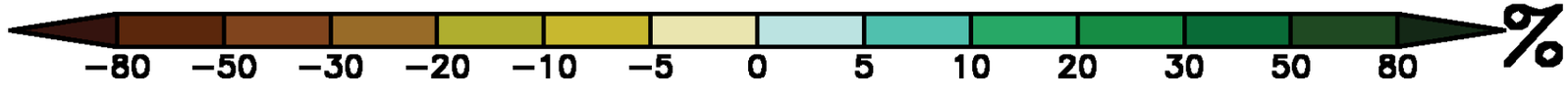


Downscaled
025deg



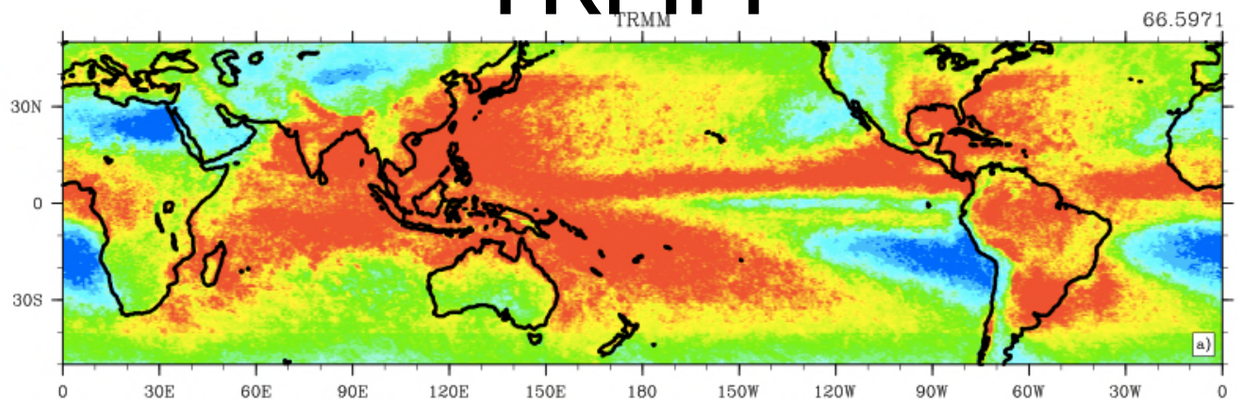




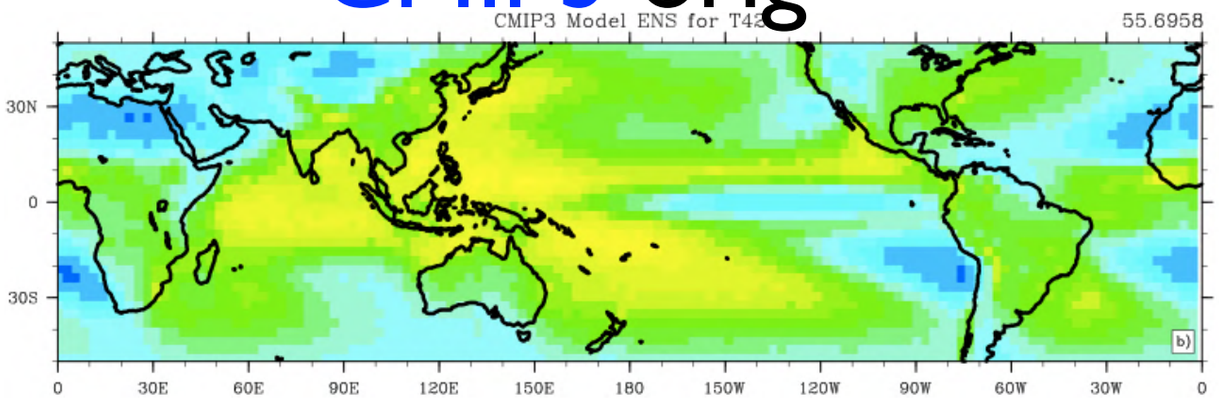


Downscaled model ensemble mean RX1day

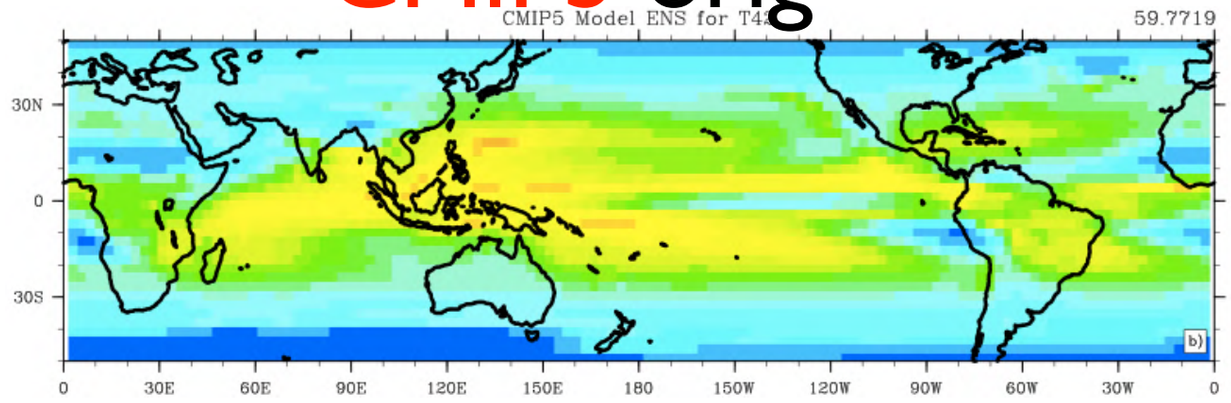
TRMM



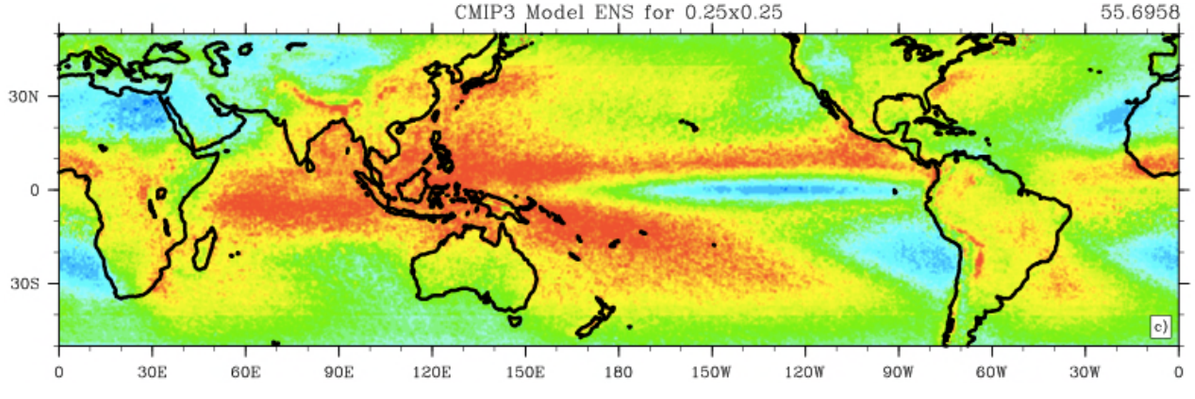
CMIP3 orig



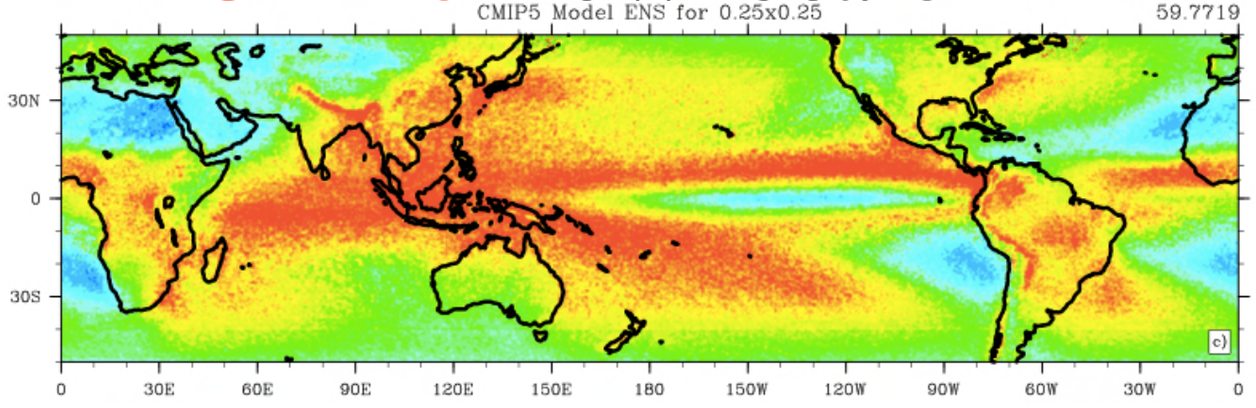
CMIP5 orig

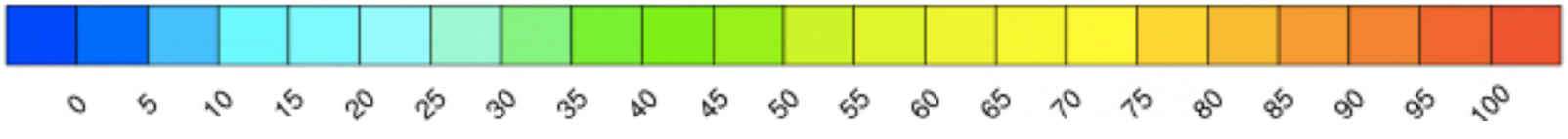


CMIP3 downscaled

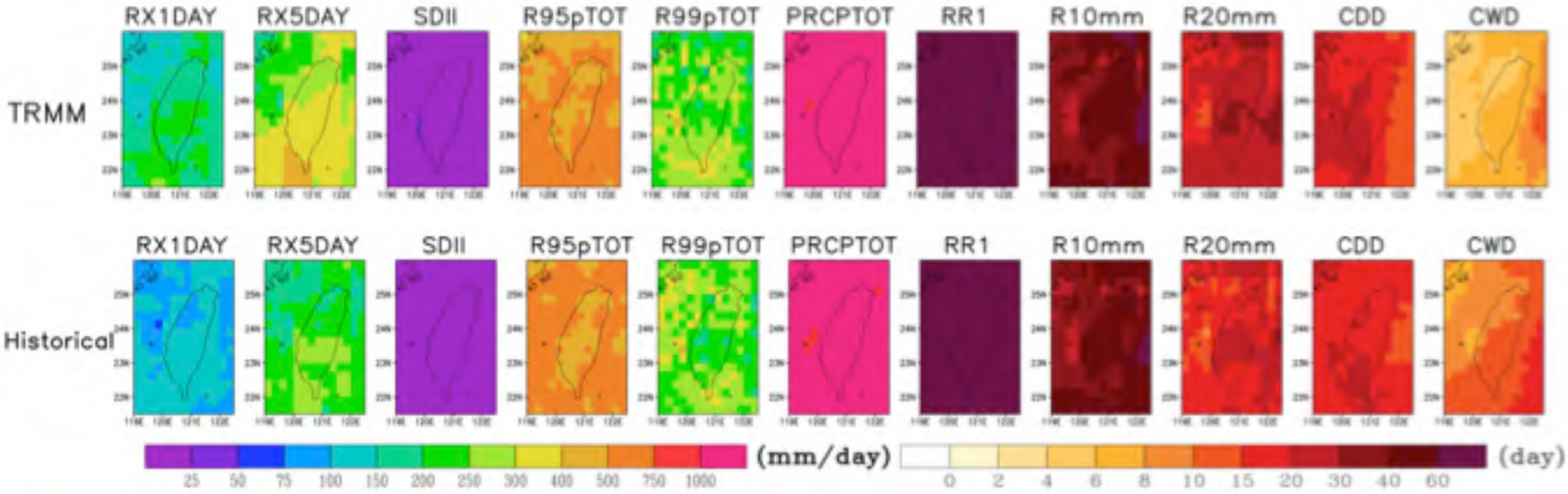


CMIP5 downscaled



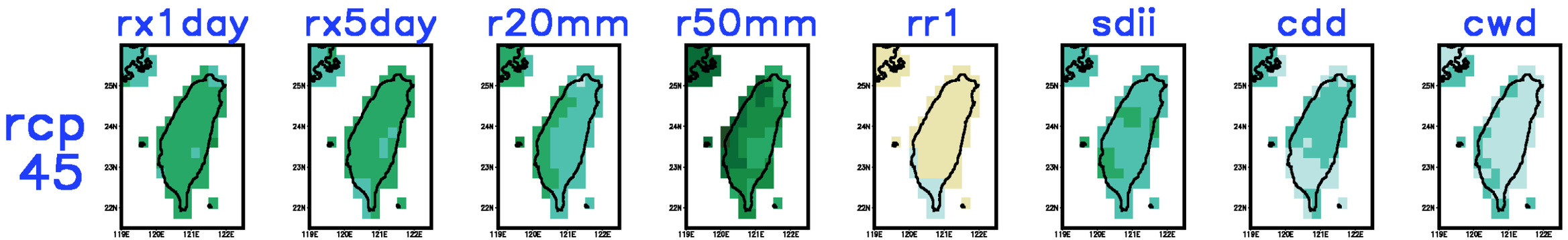


Downscaled CMIP5 Model Ensemble Median in Rainfall Extreme Indices



氣候指標	Min	25th%	Median	75th %	Max	Mean	TRMM	單位
rx1day	49.3	87.7	111.6	140.5	191.2	114.3	196.2	mm
rx5day	124.8	182.6	233.4	278.2	368.5	235.3	334.3	mm
sdii	10.0	12.2	15.6	18.1	22.4	15.5	20.4	mm
rr1	74.1	95.1	105.6	121.5	162.9	109.3	94.1	day
r10mm	23.2	33.6	42.1	49.3	62.6	41.7	42.7	day
r20mm	5.6	14.1	19.9	25.8	39.2	20.1	26.4	day
cdd	9.2	15.2	18.6	22.6	31.8	19.3	19.5	day
cwd	5.5	8.0	10.2	13.8	29.8	11.7	6.3	day
r95ptot	319.6	437.5	508.0	572.3	745.9	509.3	506.8	mm
r99ptot	124.7	211.8	249.5	289.0	446.7	256.2	261.6	mm
prcptot	1035.7	1353.0	1636.1	1896.3	2489.8	1656.7	1902.1	mm

CMIP5 Model Ensemble Median
Projected Future Change in Extreme Climate Indices (%)



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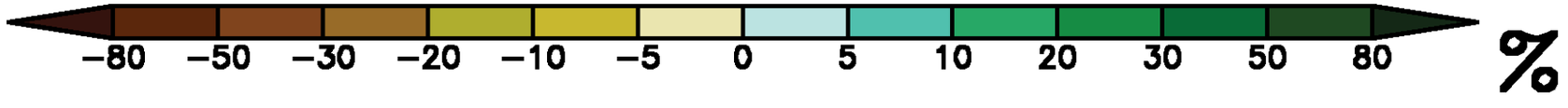

Extreme Index (2081~2100-1986~2005)/(1986~2005)

Projected Change in Taiwan

氣候指標	Min	25th%	Median	75th %	Max	Mean	TRMM	單位
rx1day	49.3	87.7	111.6	140.5	191.2	114.3	196.2	mm
rx5day	124.8	182.6	233.4	278.2	368.5	235.3	334.3	mm
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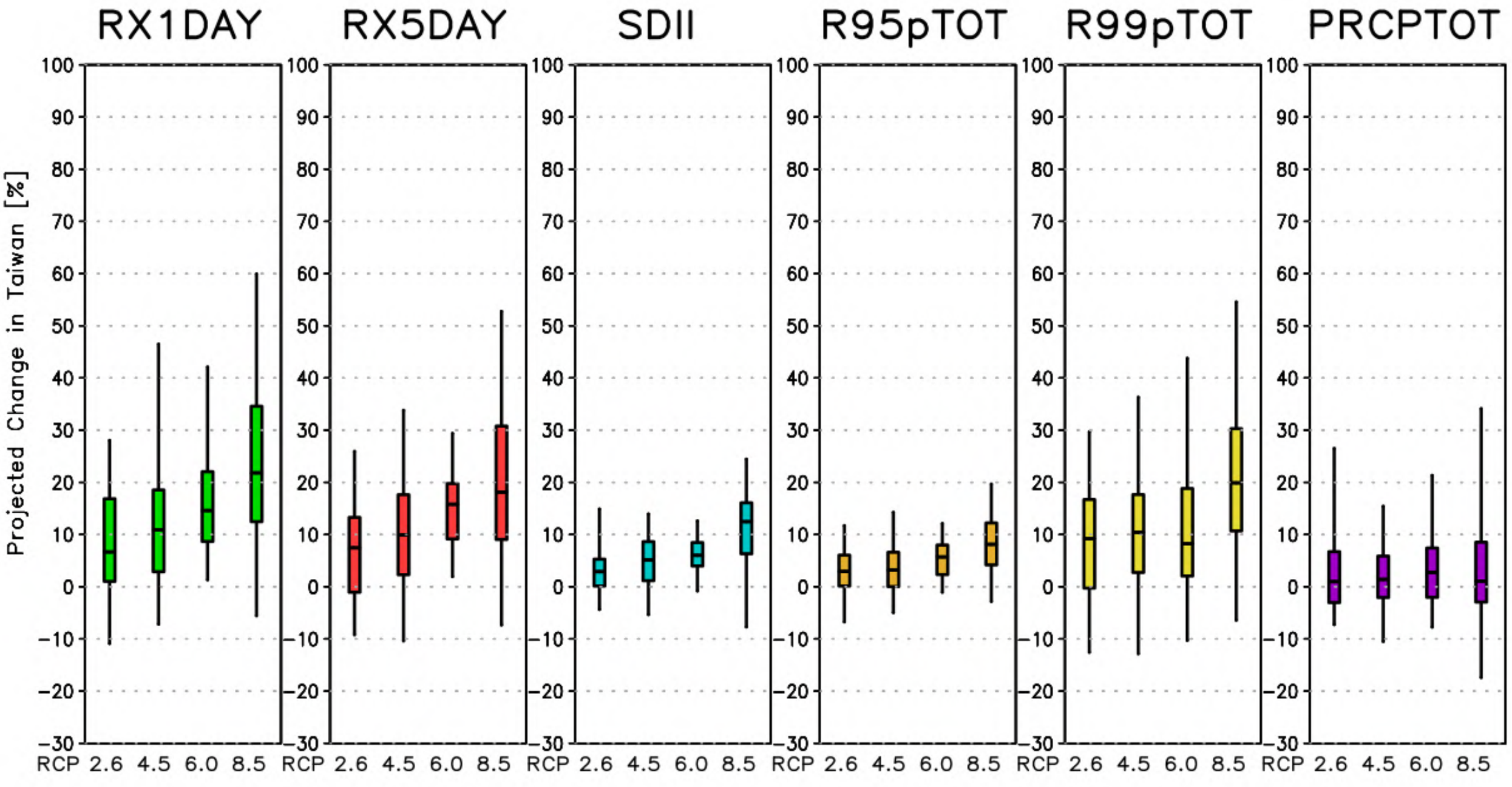

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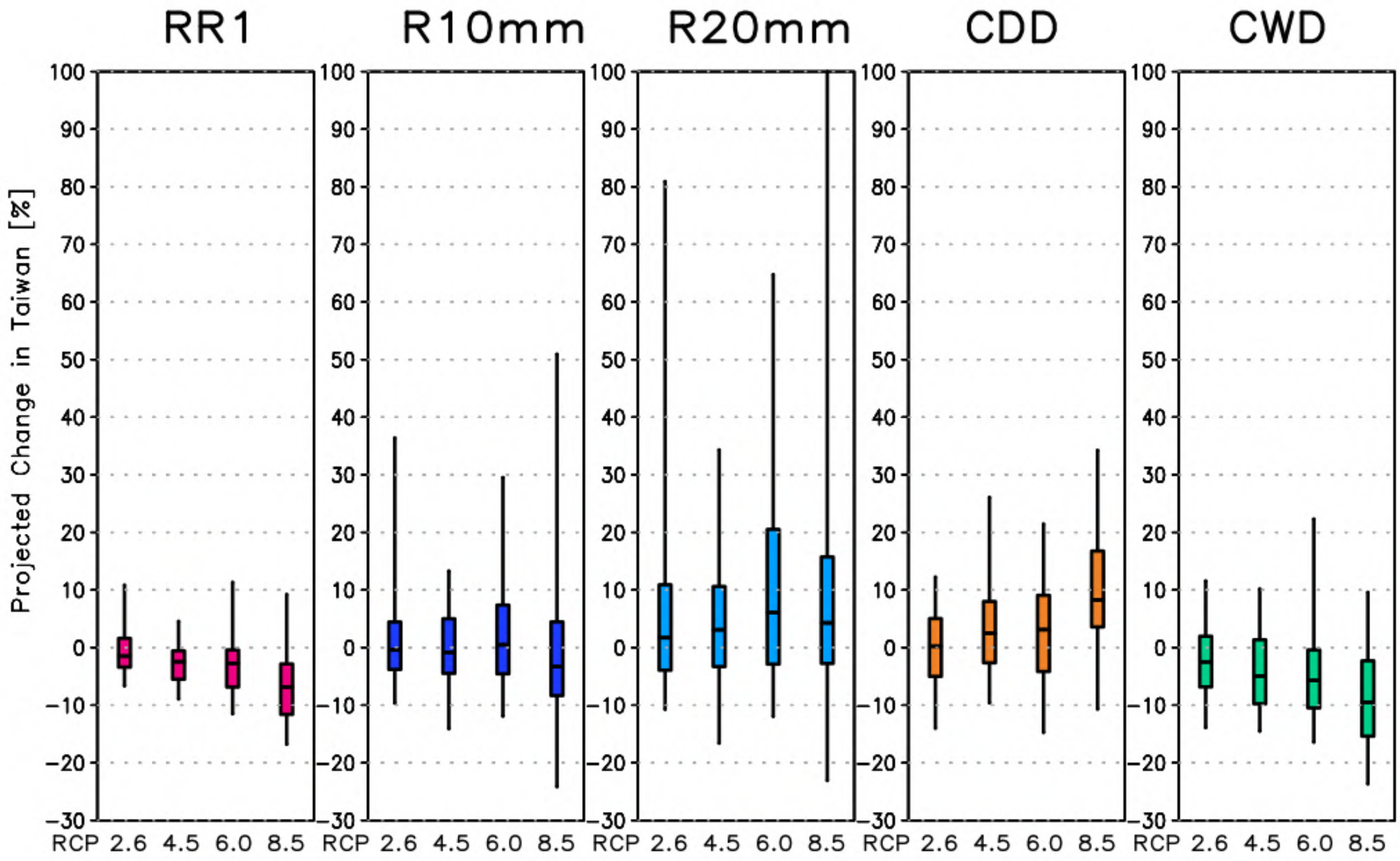
rr1	74.1	95.1	105.6	121.5	162.9	109.3	94.1	day
r10mm	23.2	33.6	42.1	49.3	62.6	41.7	42.7	day
r20mm	5.6	14.1	19.9	25.8	39.2	20.1	26.4	day
cdd	9.2	15.2	18.6	22.6	31.8	19.3	19.5	day
cwd	5.5	8.0	10.2	13.8	29.8	11.7	6.3	day
r95ptot	319.6	437.5	508.0	572.3	745.9	509.3	506.8	mm
r99ptot	124.7	211.8	249.5	289.0	446.7	256.2	261.6	mm
prcptot	1035.7	1353.0	1636.1	1896.3	2489.8	1656.7	1902.1	mm

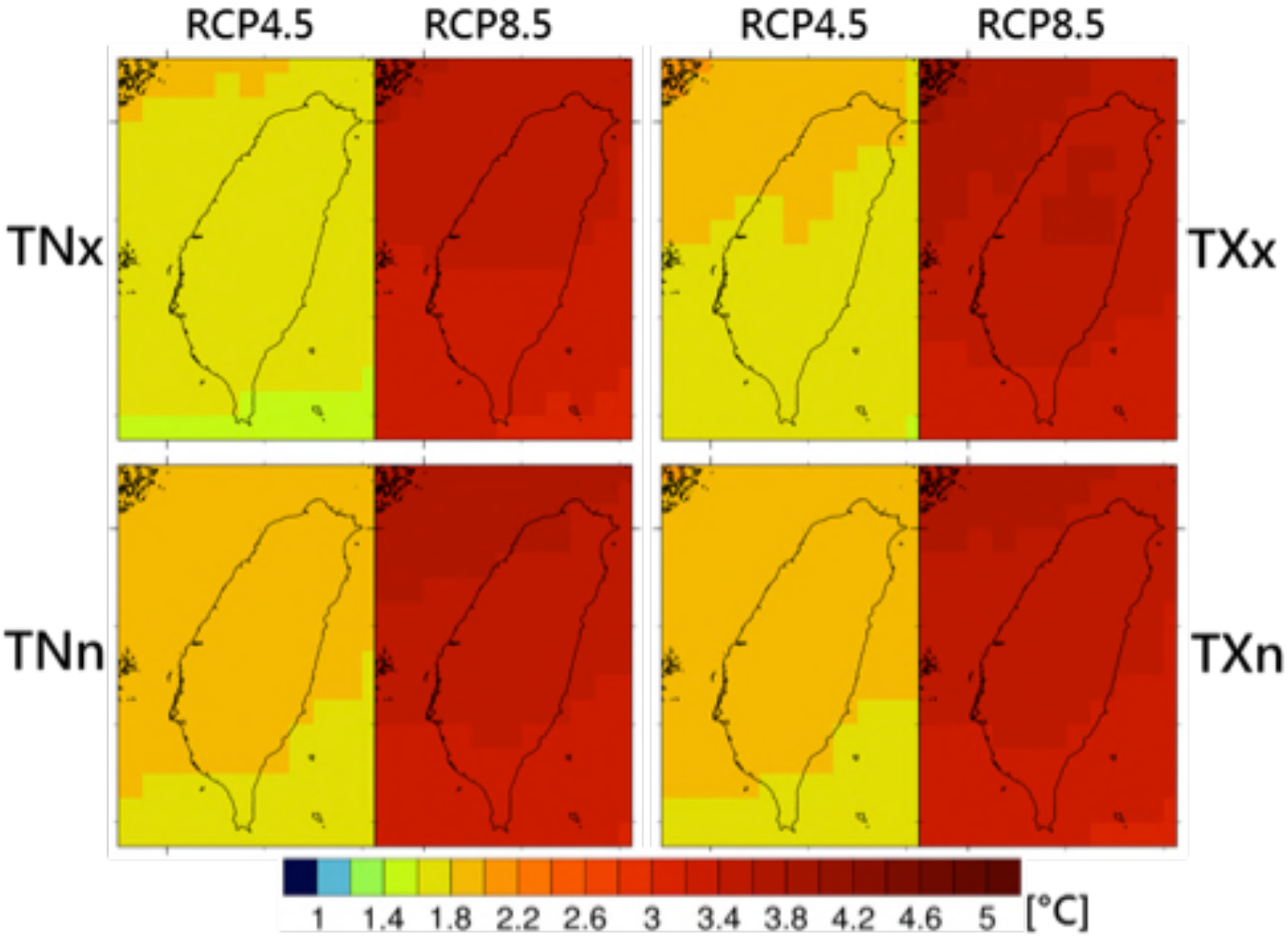
Projected Change in Taiwan



	Temperature Extreme Index	*unit*
DTR	*Daily temperature range (TX - TN)*	℃
TXx	*Yearly maximum value of daily maximum temperature*	℃
TNx	*Yearly maximum value of daily minimum temperature*	℃
TXn	*Yearly minimum value of daily maximum temperature*	℃
TNn	*Yearly minimum value of daily minimum temperature*	℃
TN10p	*Percentage of days when TN < 10th percentile of 5-day window*	day
TX10p	*Percentage of days when TX < 10th percentile of 5-day window*	day
TN90p	*Percentage of days when TN > 90th percentile of 5-day window*	day
TX90p	*Percentage of days when TX > 90th percentile of 5-day window*	day
HWDI	*Heat wave duration index (TX > 93th percentile of all data 持續3天)*	day
CWDI	*Cold wave duration index (TX < 2th percentile of all data 持續2天)*	day

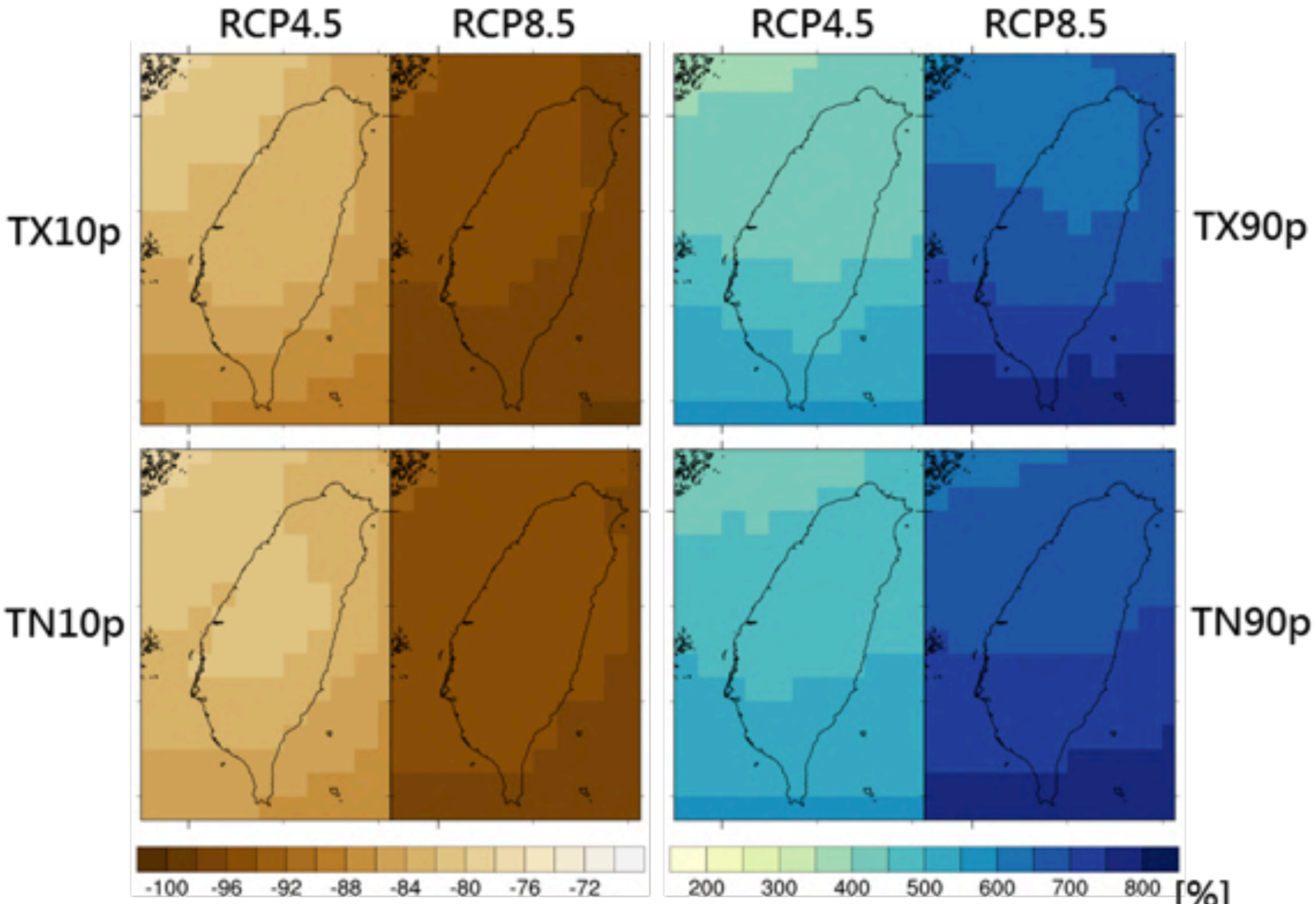
CCI/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices, ETCCDI

CMIP5 Model Ensemble Median
Projected Future Change in Extreme Climate Indices (%)

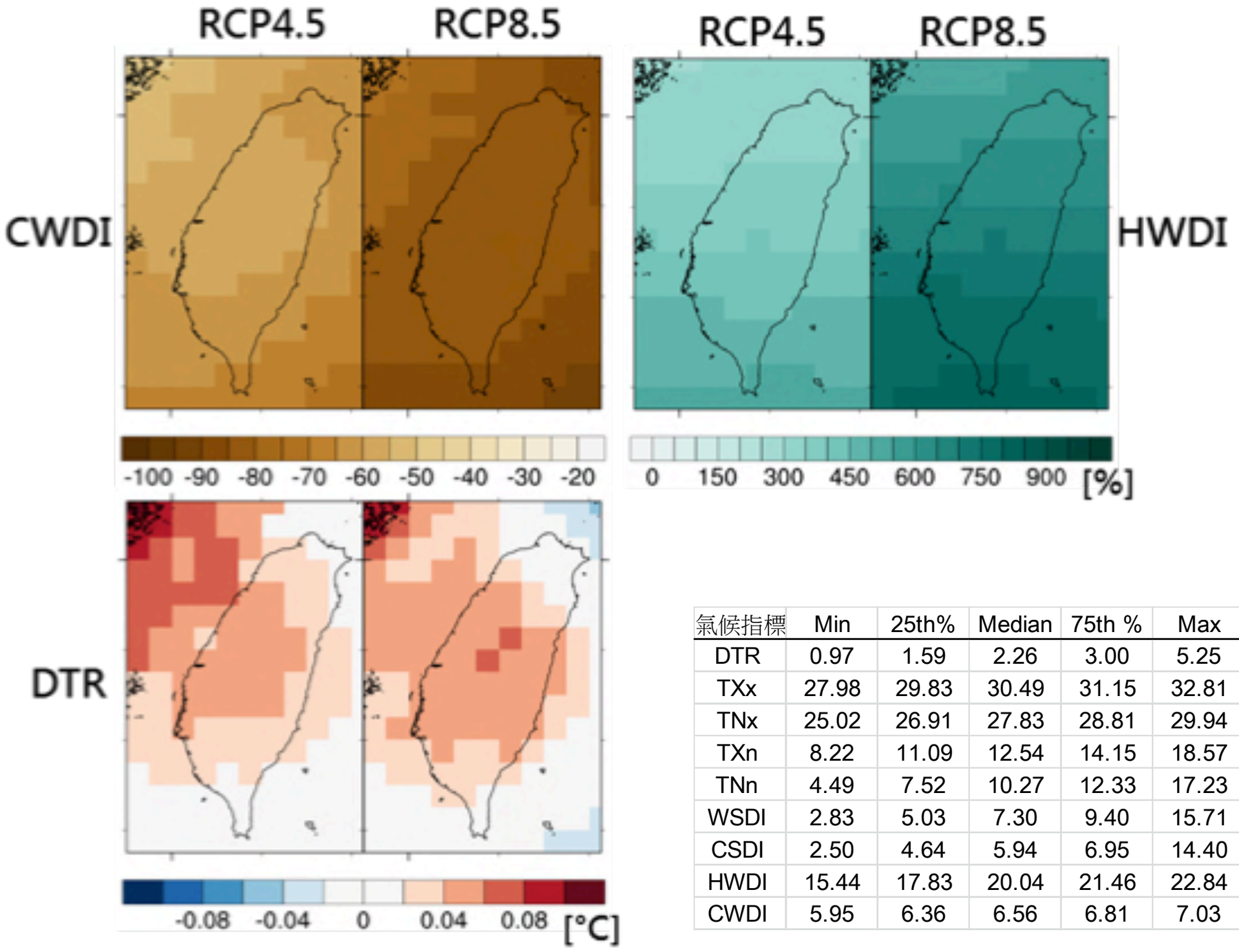


氣候指標	Min	25th%	Median	75th %	Max	Mean	單位
DTR	0.97	1.59	2.26	3.00	5.25	2.35	℃
TXx	27.98	29.83	30.49	31.15	32.81	30.50	℃
TNx	25.02	26.91	27.83	28.81	29.94	27.82	℃
TXn	8.22	11.09	12.54	14.15	18.57	12.73	℃
TNn	4.49	7.52	10.27	12.33	17.23	10.20	℃

CMIP5 Model Ensemble Median
Projected Future Change in Extreme Climate Indices (%)



CMIP5 Model Ensemble Median
Projected Future Change in Extreme Climate Indices (%)



氣候指標	Min	25th%	Median	75th %	Max	Mean	單位
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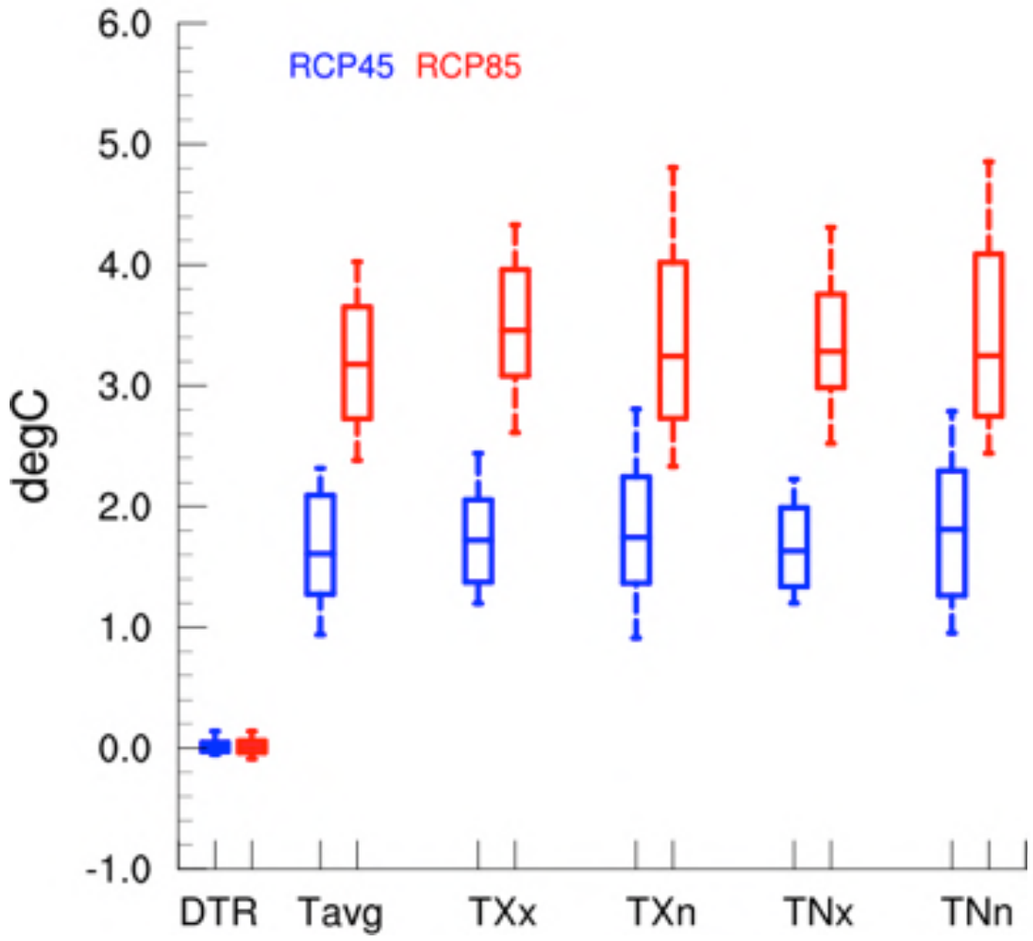
TXx	27.98	29.83	30.49	31.15	32.81	30.50	℃
TNx	25.02	26.91	27.83	28.81	29.94	27.82	℃
TXn	8.22	11.09	12.54	14.15	18.57	12.73	℃
TNn	4.49	7.52	10.27	12.33	17.23	10.20	℃
WSDI	2.83	5.03	7.30	9.40	15.71	7.58	day
CSDI	2.50	4.64	5.94	6.95	14.40	6.17	day
HWDI	15.44	17.83	20.04	21.46	22.84	19.65	day
CWDI	5.95	6.36	6.56	6.81	7.03	6.56	day

CMIP5 Model Ensemble Median
Projected Future Change in Extreme Climate Indices (%)



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DTR	0.97	1.59	2.26	3.00	5.25	2.35	℃
TXx	27.98	29.83	30.49	31.15	32.81	30.50	℃
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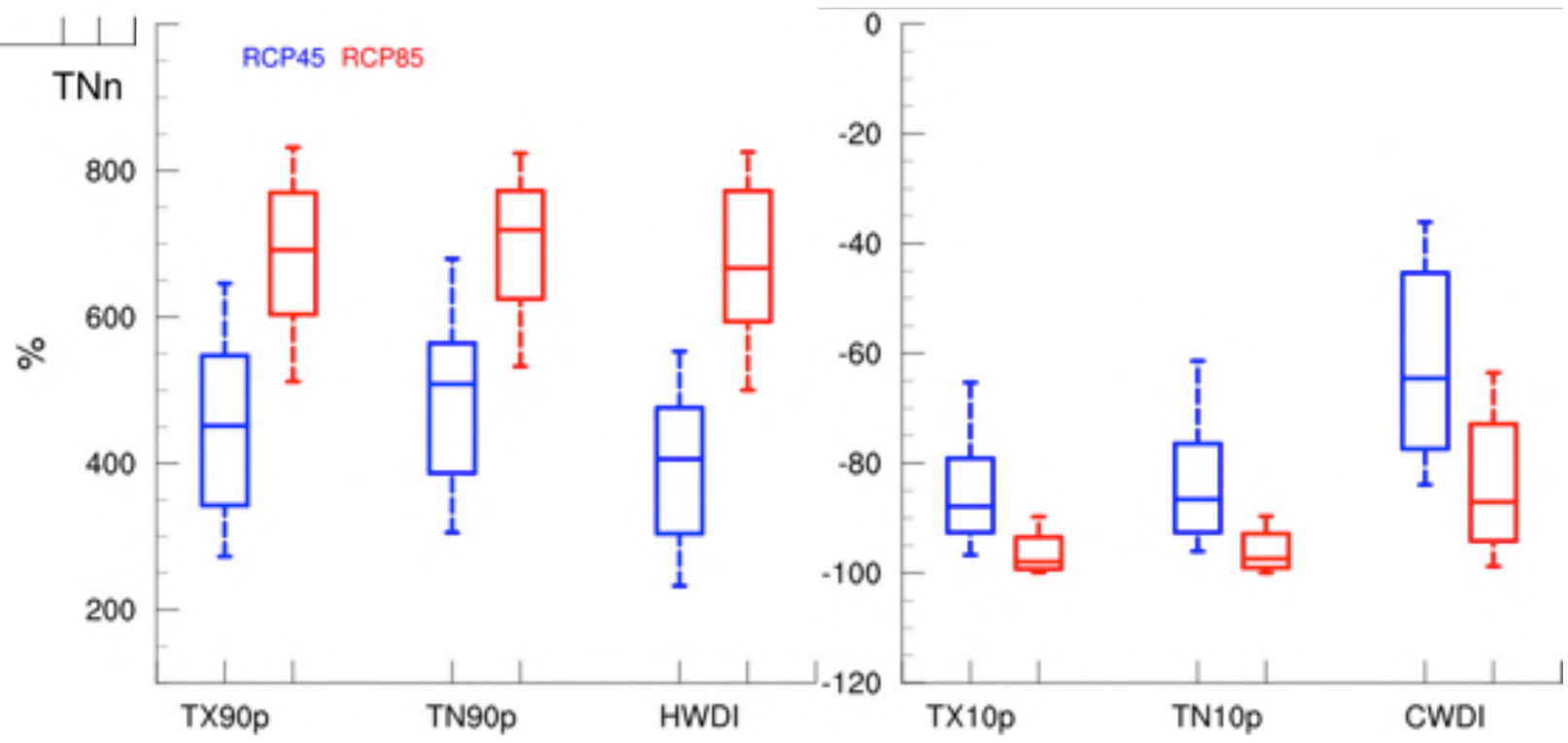
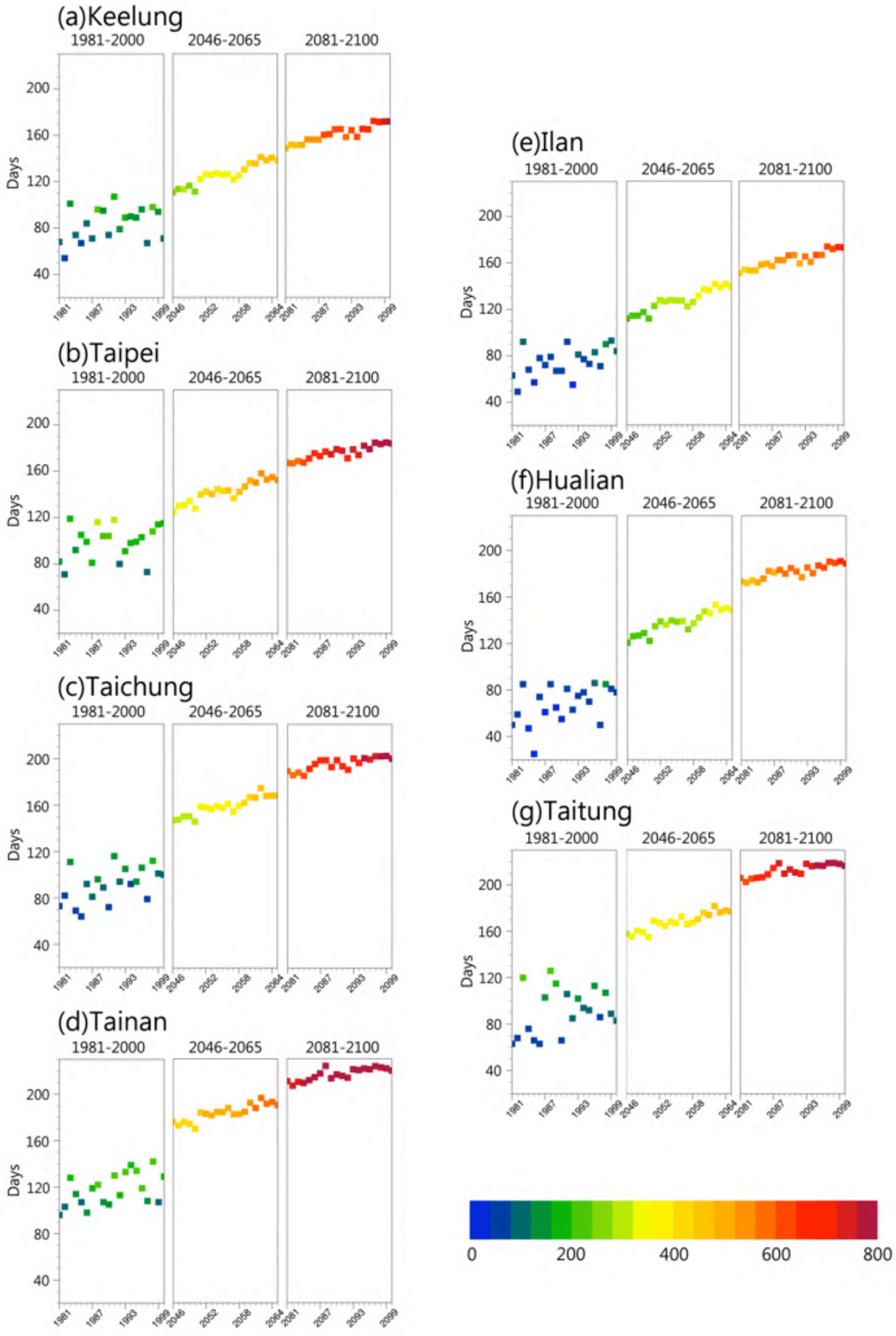
HWDI	15.44	17.83	20.04	21.46	22.84	19.65	day
CWDI	5.95	6.36	6.56	6.81	7.03	6.56	day



RCP8.5

臺灣地區氣溫高於28°C的日數年變化及CDD值的年變化圖。

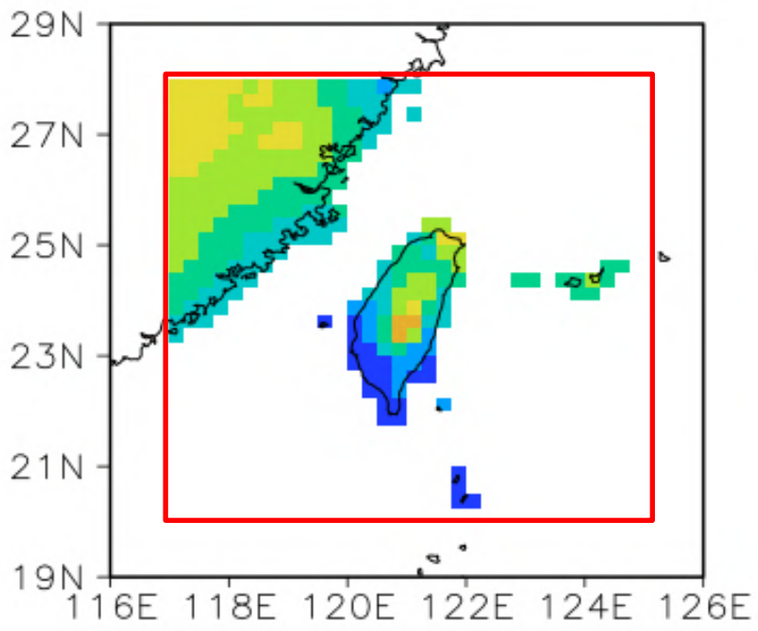
X軸為時間；Y軸為氣溫高於28°C的日數；色階為CDD值。



Daily Downscaled

- OBS:Aphrodite(V1101R2)1961~2007
- Model:CMIP5 Daily
  - Historical(34) 1961~2005
  - rcp26(22)、rcp45(30)、rcp60(17)、rcp85(33)
- Daily Downscaled
  - Step 1：Interpolation
  - Step 2：Bias Correction

Lon:117~125
Lat:20~28



CMIP5	Daily	Atmosphere						
Model	Institute	RES.	calendar	historical	rcp26	rcp45	rcp60	rcp85
ACCESS1-0	CSIRO-BOM	192x145	**standard**	○		○		○
ACCESS1-3		192x145	**standard**	○		○		○
bcc-csm1-1	BCC	128x64	**365**	○	○	○	○	○
bcc-csm1-1m		320x160	**365**	○	○	○	○	○
BNU-ESM	BNU	128x64	**365**	○	○	○		○
CanESM2	CCCMA	128x64	**365**	○	○	○		○
CCSM4	NCAR	288x192	**365**	○	○	○	○	○
CESM1-BGC	NCAR	288x192	**365**	○		○		○
CESM1-CAM5		288x192	**365**	○	○	○	○	○
CMCC-CESM	CMCC	96x48	**standard**	○				○
CMCC-CM		480x240	**standard**	○		○		○
CMCC-CMS		192x96	**standard**	○		○		
CNRM-CM5	CNRM-CERFACS	256x128	**standard**	○	○	○		○
CSIRO-Mk3-6-0	CSIRO-QCCCE	192x96	**365**	○	○	○	○	○
EC-EARTH	ICHEC	320x160	**standard**	○				○
FGOALS-g2	LASG-CESS	128x60	**365**	○	○	○		○
GFDL-CM3	NOAA-GFDL	144x90	**365**	○	○		○	○
GFDL-ESM2G		144x90	**365**	○	○	○	○	○
GFDL-ESM2M		144x90	**365**	○		○	○	○
HadGEM2-AO	MOHC	192x145	**360**	○	○	○	○	○
HadGEM2-CC		192x145	**360**	○		○		○
HadGEM2_ES		192x145	**360**	○	○	○	○	○
inmcm4	INM	180x120	**365**	○		○		○
IPSL-CM5A-LR	IPSL	96x96	**365**	○	○	○	○	○
IPSL-CM5A-MR		144x143	**365**	○	○	○	○	○
IPSL-CM5B-LR		96x96	**365**	○		○		○
MIROC5	MIROC	256x128	**365**	○	○	○	○	○
MIROC-ESM		128x64	**standard**	○	○	○	○	○
MIROC-ESM-CHEM		128x64	**standard**	○	○	○	○	○
MPI-ESM-LR	MPI-M	192x96	**365**	○	○	○		○
MPI-ESM-MR		192x96	**365**	○	○	○		○
MRI-CGCM3	MRI	320x160	**standard**	○	○	○	○	○
MRI-ESM1		320x160	**standard**	○				○
NorESM1-M	NCC	144x96	**365**	○	○	○	○	○
			Total :	34	22	30	17	33

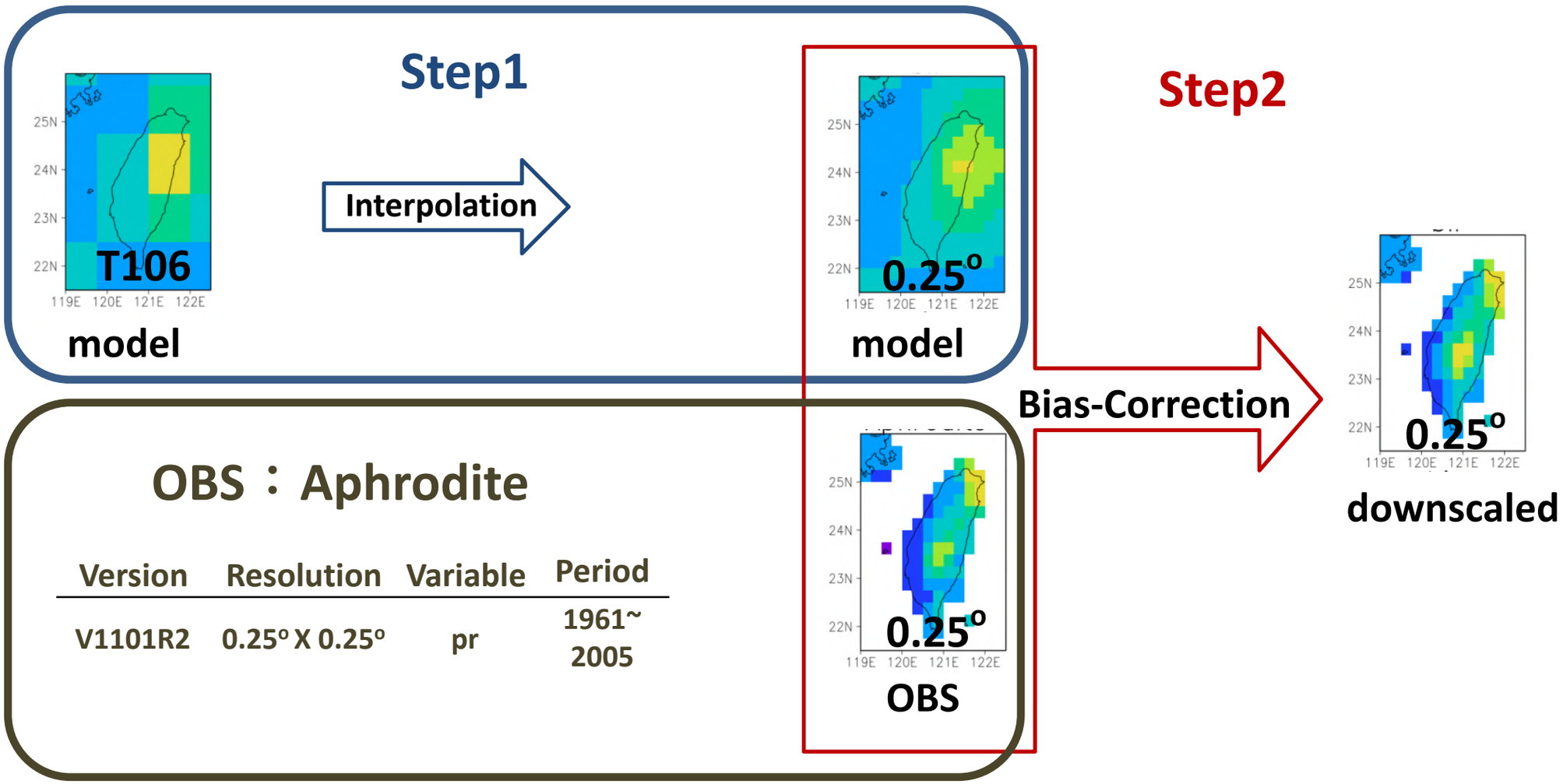
日降尺度流程圖

Step 1：Interpolation

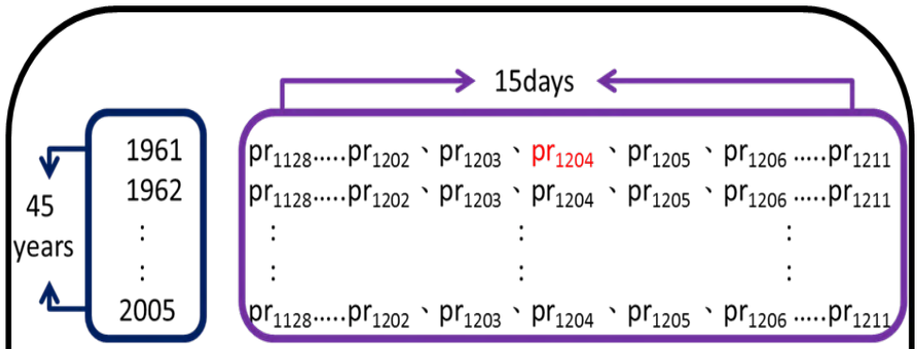
- Bilinear interpolation
- Model resolution → 0.25 deg

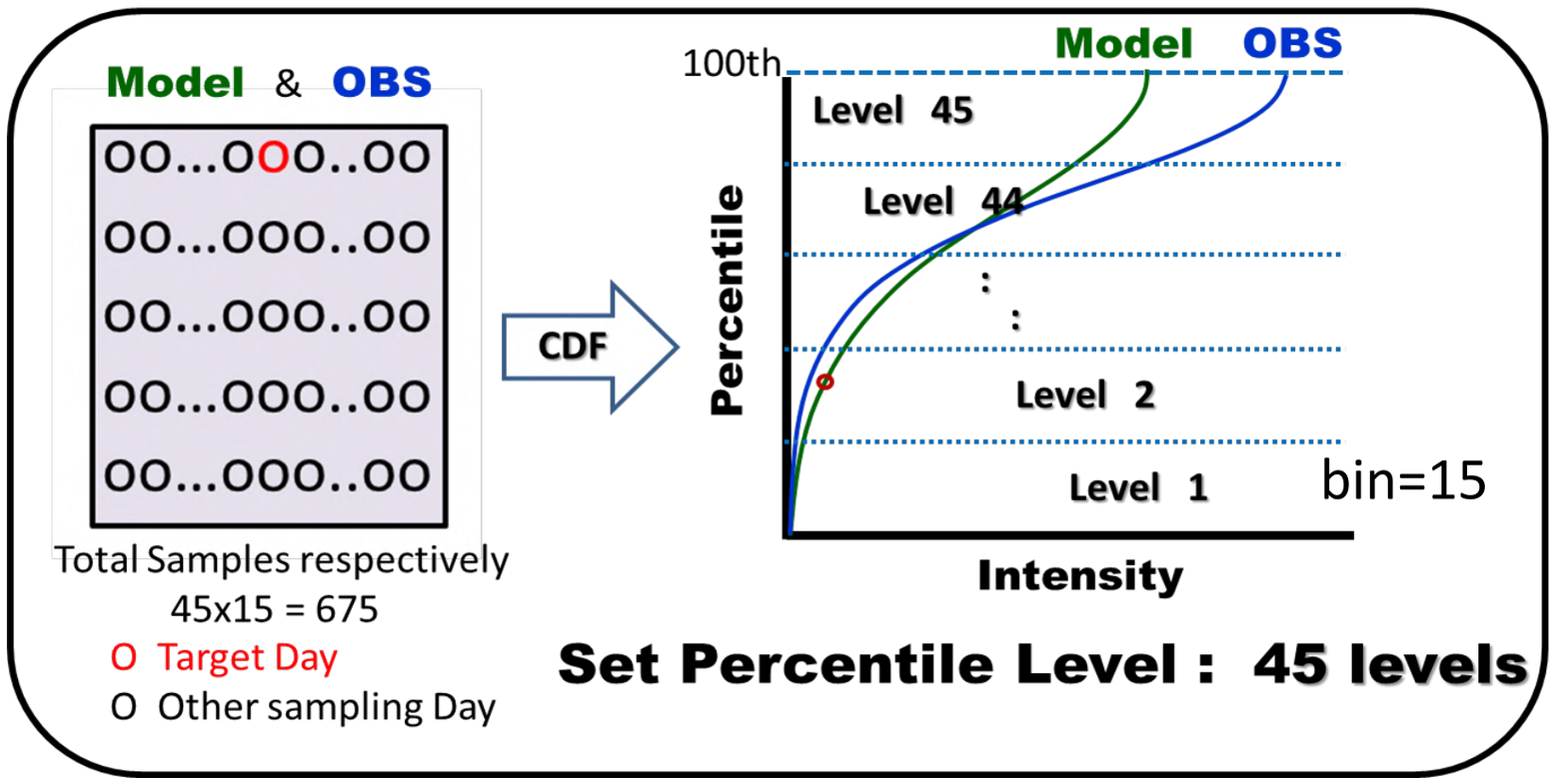
Step 2：Bias-Correction

- Set time window 15 days
- Set percentile level 45



Bias-Correction流程圖





OBS_{lv2} Total pr = $\sum Pr_{obs}$ (Level 2)

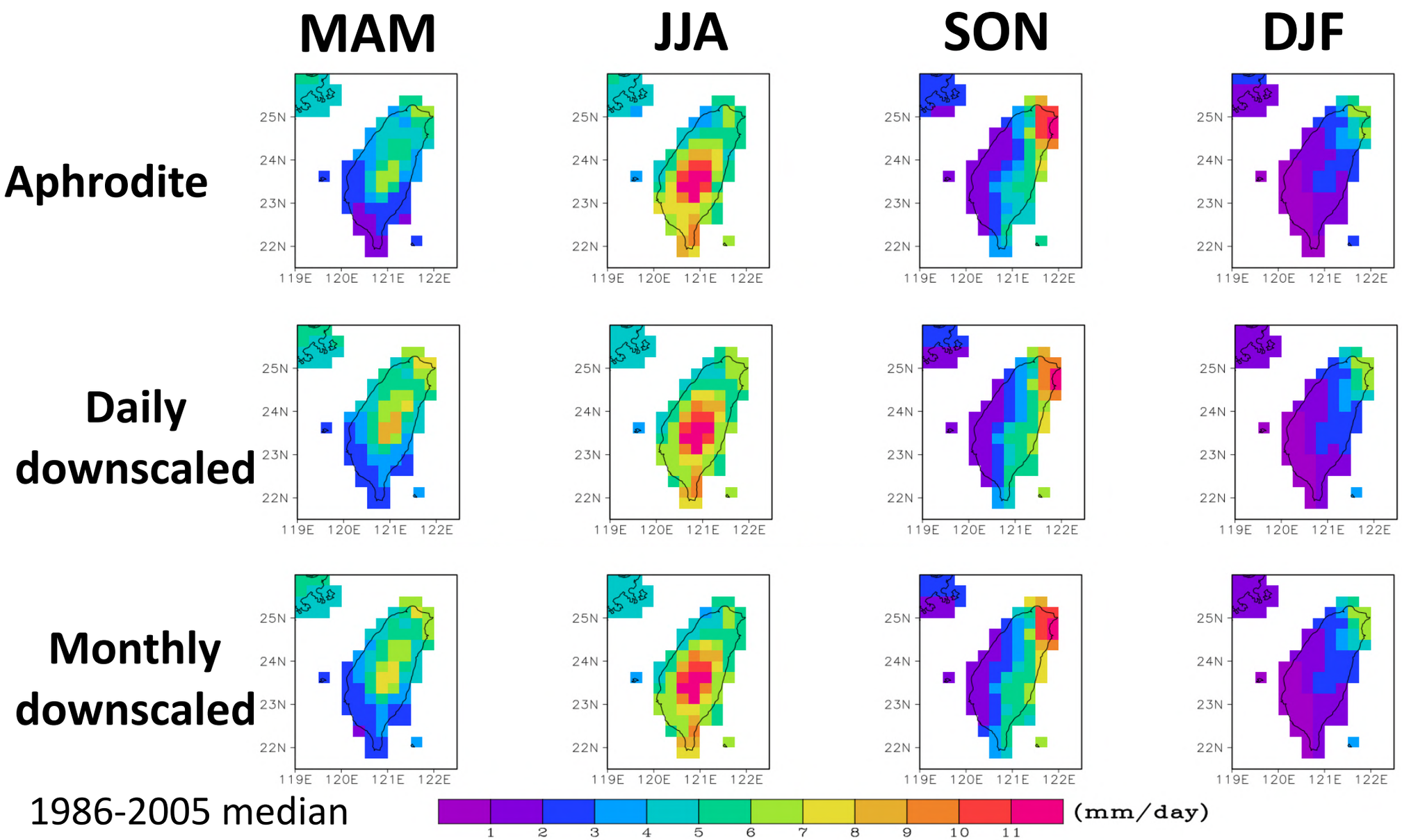
$Model_{lv2}$ Total pr = $\sum Pr_{model}$ (Level 2)

1. window=31
2. bin=10

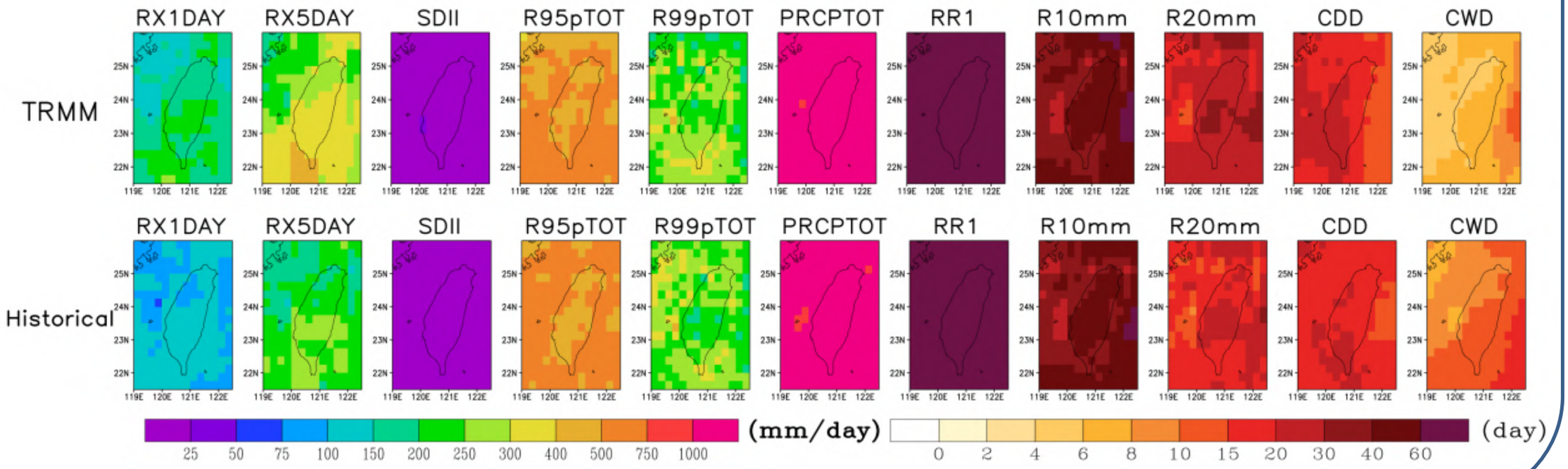
Target Day 1961 12/4 Model Bias Correction

$$Model\_BC_{pr_{1204}} = (Model_{pr_{1204}} \times OBS_{lv2} / Model_{lv2})$$

月與日降尺度在四季節之比較

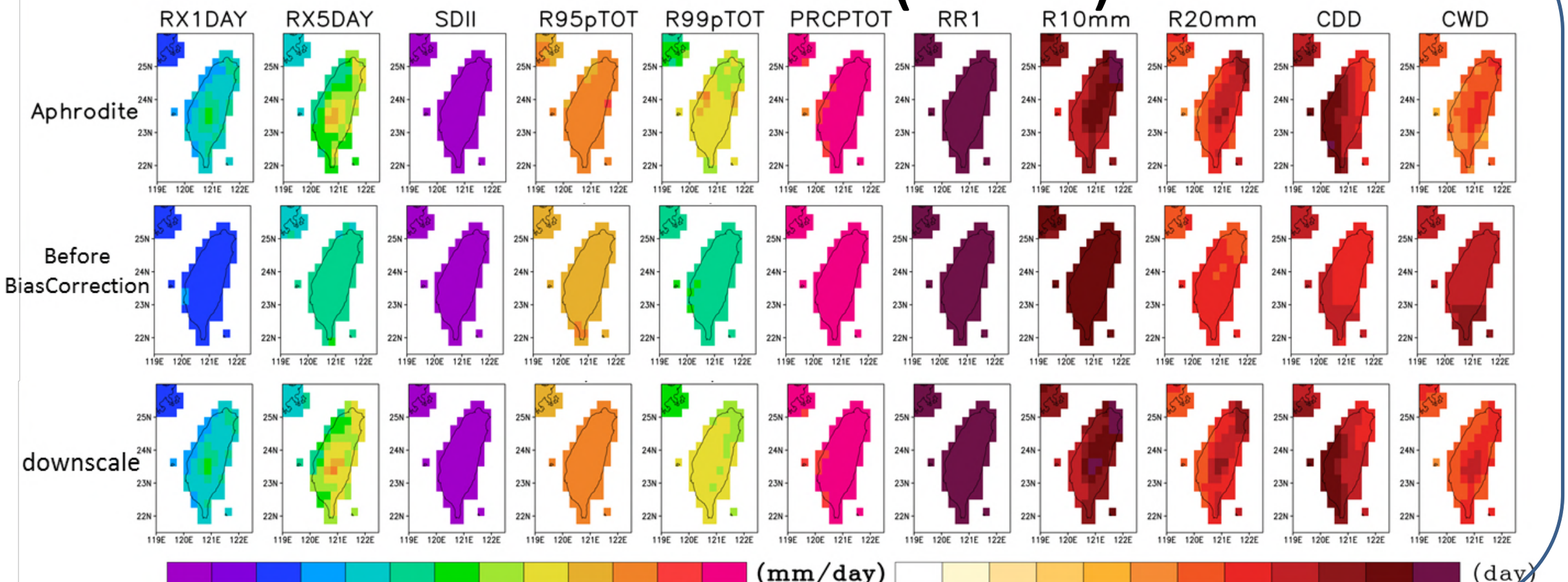


Extreme indices (2014)

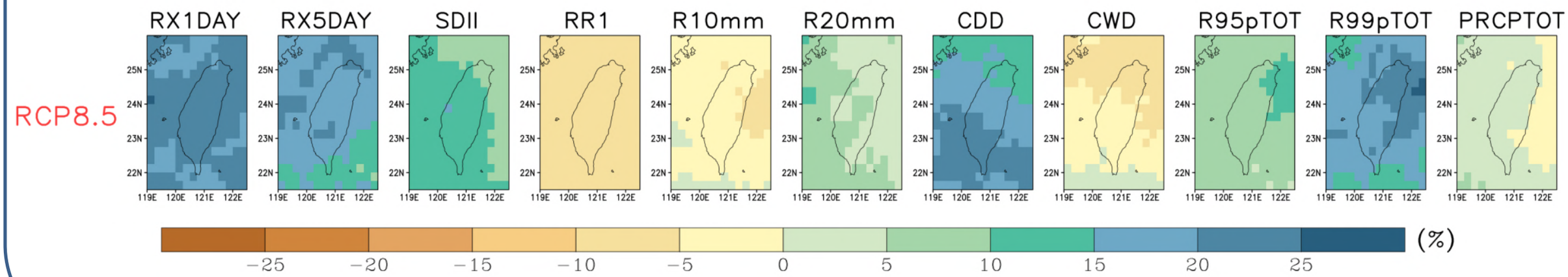


1986~2005 median

Extreme indices (2016)

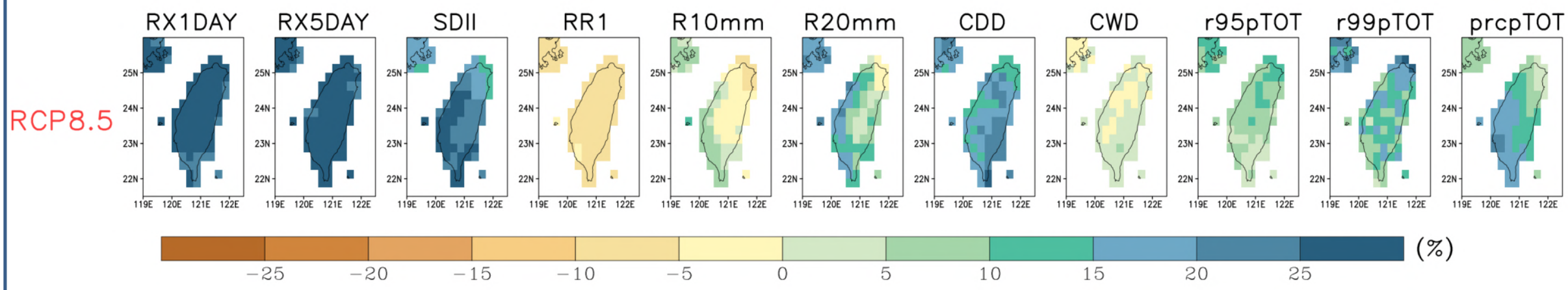


Extreme indices (2014)



2081~2100 change ratio median

Extreme indices (2016)



附錄A window bin之挑選

- 測試5種window 、4種bin ，共20個case

	w07	w15	w21	w31	W45
b05	w07b05	w15b05	w21b05	w31b05	w45b05
b10	w07b10	w15b10	w21b10	w31b10	w45b10
b15	w07b15	w15b15	w21b15	w31b15	w45b15
b20	w07b20	w15b20	w21b20	w31b20	w45b20

- 測試方法：
  - 在Historical方面
    - 各極端氣候指標模式與觀測相近
  - 在未來推估方面：
    - 降尺度前後之各指標世紀末變化率表現相近

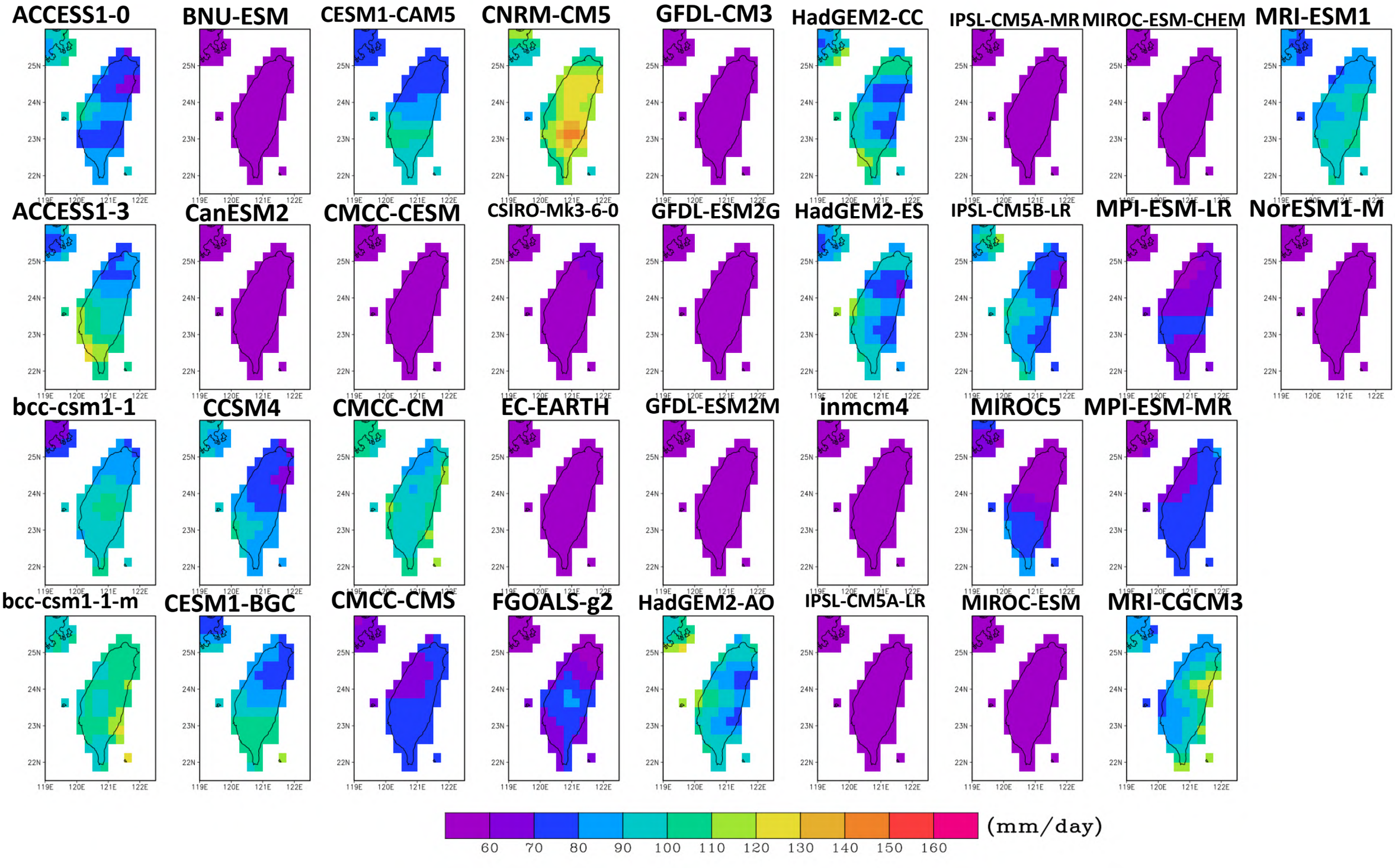
EXTREME INDEX 1986~2005(Interpolation)

Index	10th %	25th%	Median	75th %	90th %	Mean	Aphrodite	unit
rx1day	46.706	54.577	79.279	103.55	114.99	79.957	131.4	mm/day
rx5day	113.32	136.23	185.85	222.79	266.51	186.79	253.9	mm/day
sdii	6.4611	7.3849	8.5655	10.353	12.252	8.9413	11.9	mm/day
rr1	143.64	160.14	179.8	197.64	220.32	183.06	124.7	day
r10mm	31.323	36.417	45.515	55.098	63.658	46.897	38.7	day
r20mm	8.7316	12.532	17.595	23.647	29.581	18.455	19.6	day
cdd	14.196	17.137	21.024	24.983	30.324	21.469	31.9	day
cwd	15.258	17.322	21.622	30.91	39.138	26.311	11.8	day
r95pTOT	393.41	425.9	498.22	588.66	643.49	506.68	610.4	mm/day
r99pTOT	146.31	171.57	204.32	250.88	276.3	212.84	338.5	mm/day
prcpTOT	1161.1	1294.7	1534	1865.9	2181.5	1615.7	1508.0	mm/day

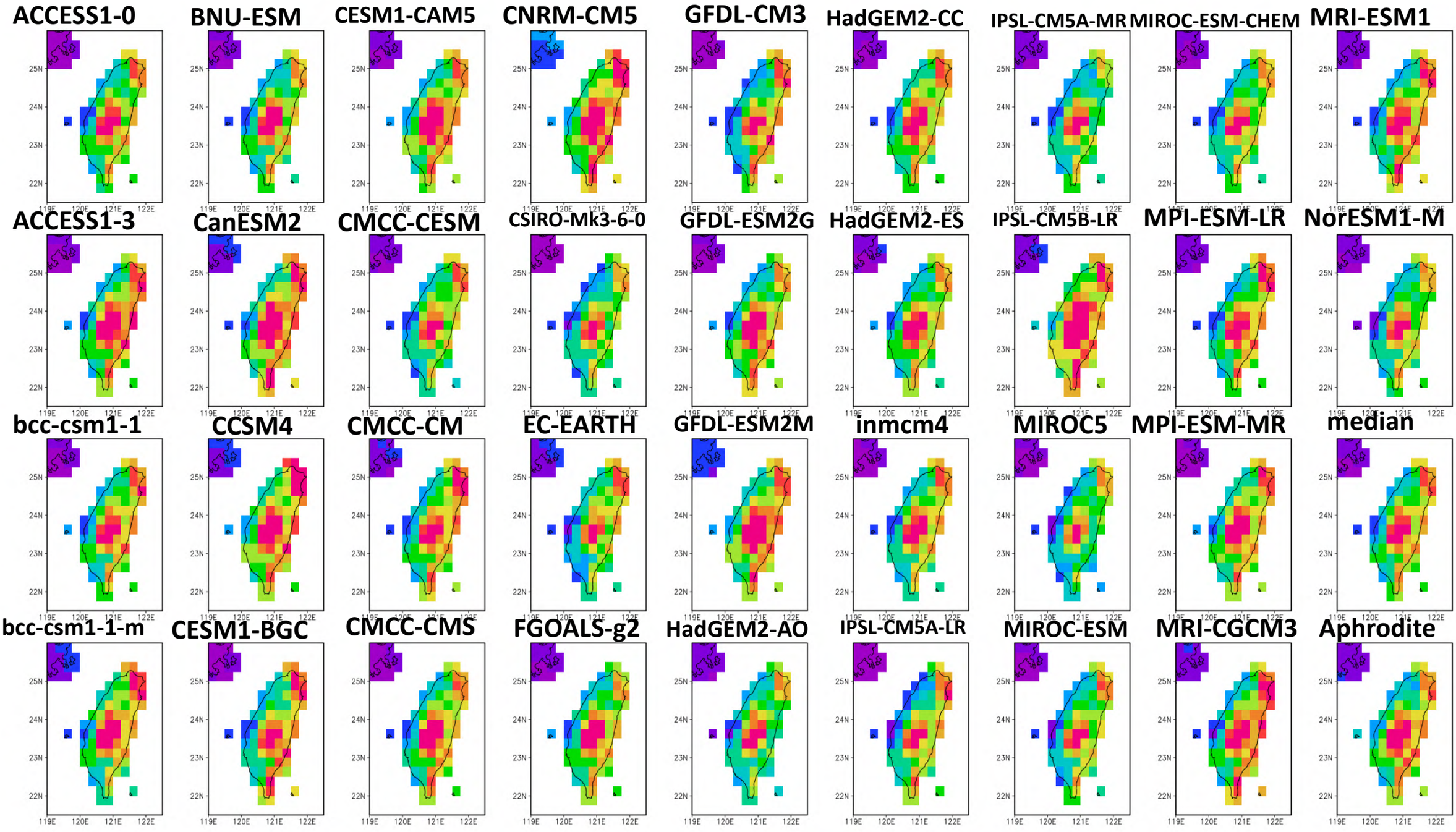
EXTREME INDEX 1986~2005(w31b15)

Index	10th %	25th%	Median	75th %	90th %	Mean	Aphrodite	unit
rx1day	114.65	120.11	126.49	134.64	141.36	127.47	131.4	mm/day
rx5day	255.99	271.5	295.67	323.9	341.76	299.03	253.9	mm/day
sdii	11.62	11.872	12.145	12.504	12.929	12.214	11.9	mm/day
rr1	129.76	131.63	133.56	135.47	137.08	133.52	124.7	day
r10mm	39.857	40.694	41.74	42.832	44.056	41.813	38.7	day
r20mm	19.947	20.51	21.208	22.145	23.02	21.375	19.6	day
cdd	27.718	29.61	31.675	34.396	36.615	32.087	31.9	day
cwd	12.51	14.069	15.593	17.459	18.653	15.732	11.8	day
r95pTOT	597.67	610.64	627.61	645.42	662.06	629.1	610.4	mm/day
r99pTOT	273.19	291.99	315.7	345.77	373.29	321.07	338.5	mm/day
prcpTOT	1545.2	1588.7	1630.8	1685.4	1755.8	1641.9	1508.0	mm/day

Historical Model Interpolation RX1DAY

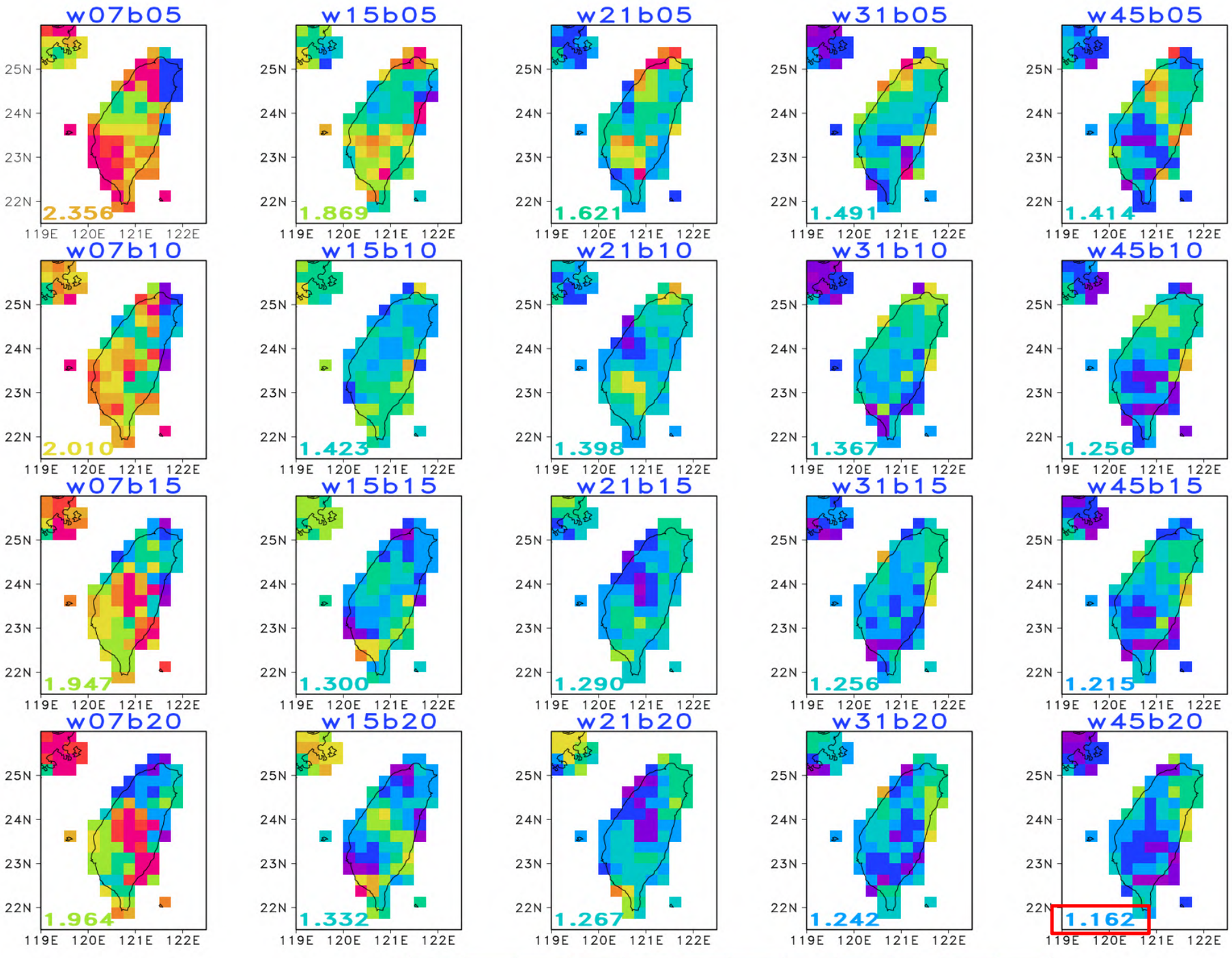


Historical Model Interpolation RX1DAY w31b15

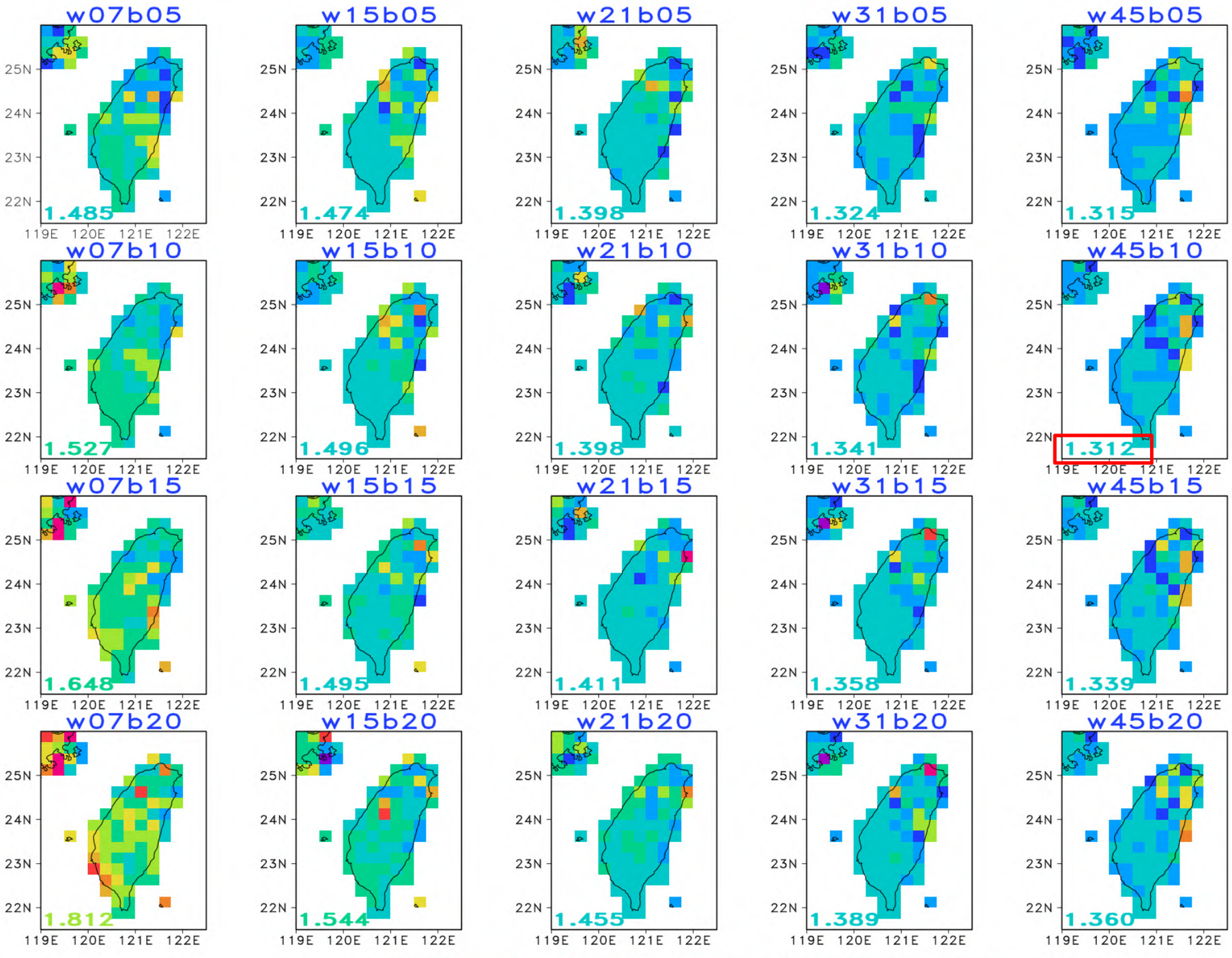


- $X_{vm} = (BC_{vmt} - OBS_{vt})$, $t=\overline{1986\sim2005}$
- $Y_{vm} = (I_{vmt} - BC_{vmt})$, $t=\overline{2081\sim2100}$
- $R^2{}_{vm}=(X_{vm}/\overline{|X_{vm}|}^{c})^2+(Y_{vm}/\overline{|Y_{vm}|}^{c})^2$
- $R = \overline{R_{vm}}^{vm}$
    - I : $Before\ Bias\_Correction$
    - BC : $After\ Bias\_Correction$
    - v : Extreme index
    - m : $model$
    - c : 20 $case$

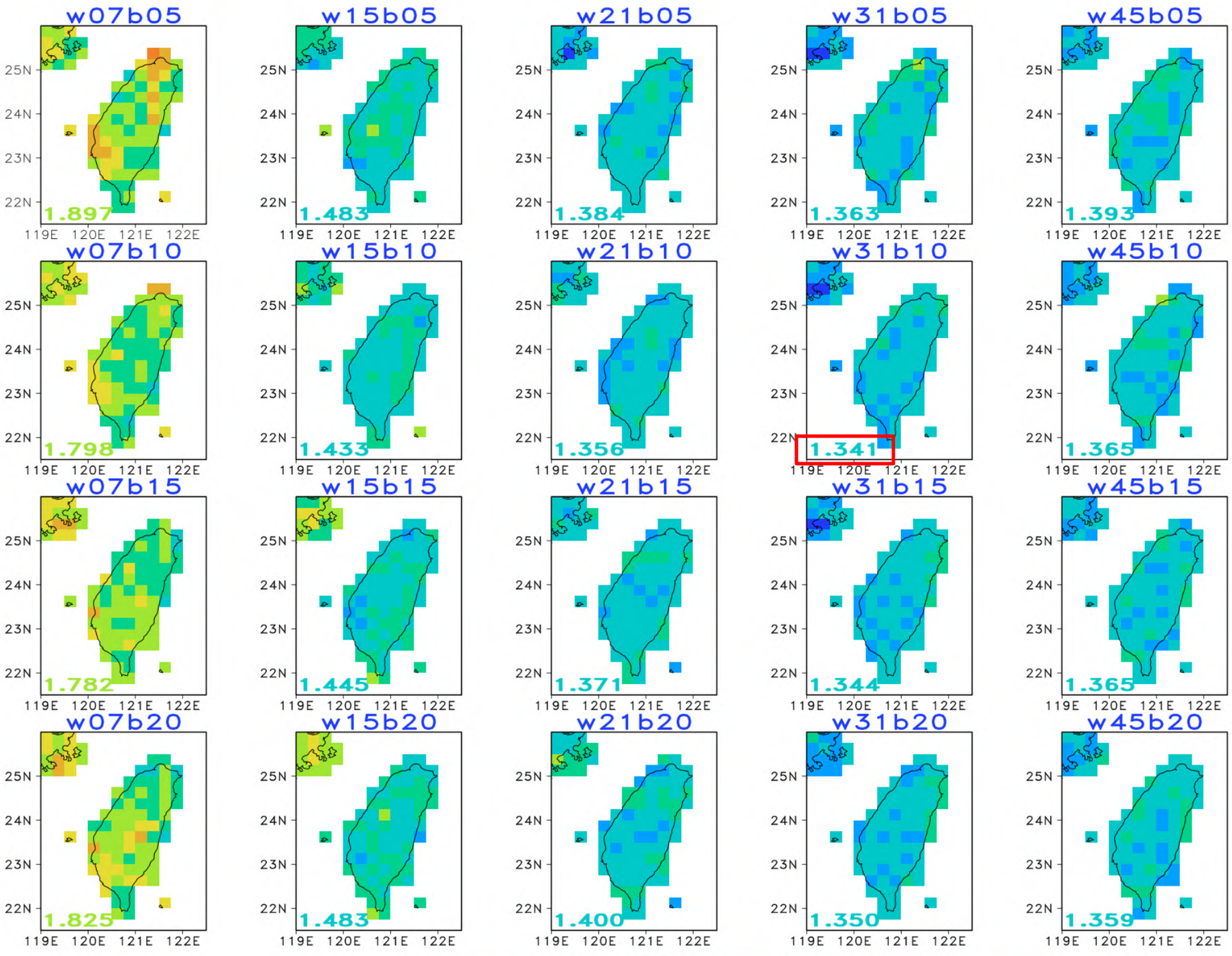
rcp85 , $R_{v,m}$,v=Rx1day,m=MRI-CGCM3



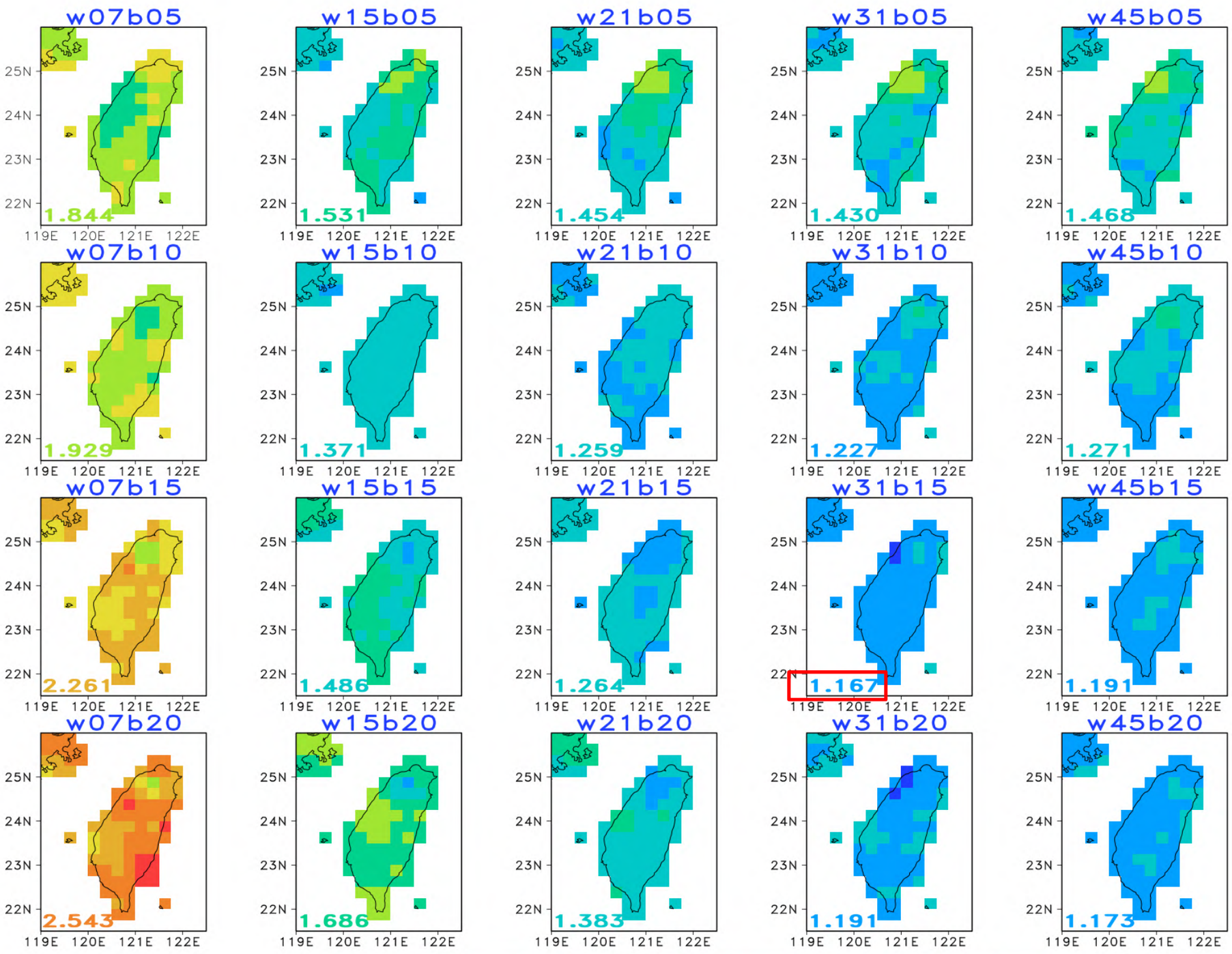
rcp85 , $R_{v,m}$,v=rr1,m=MRI-CGCM3



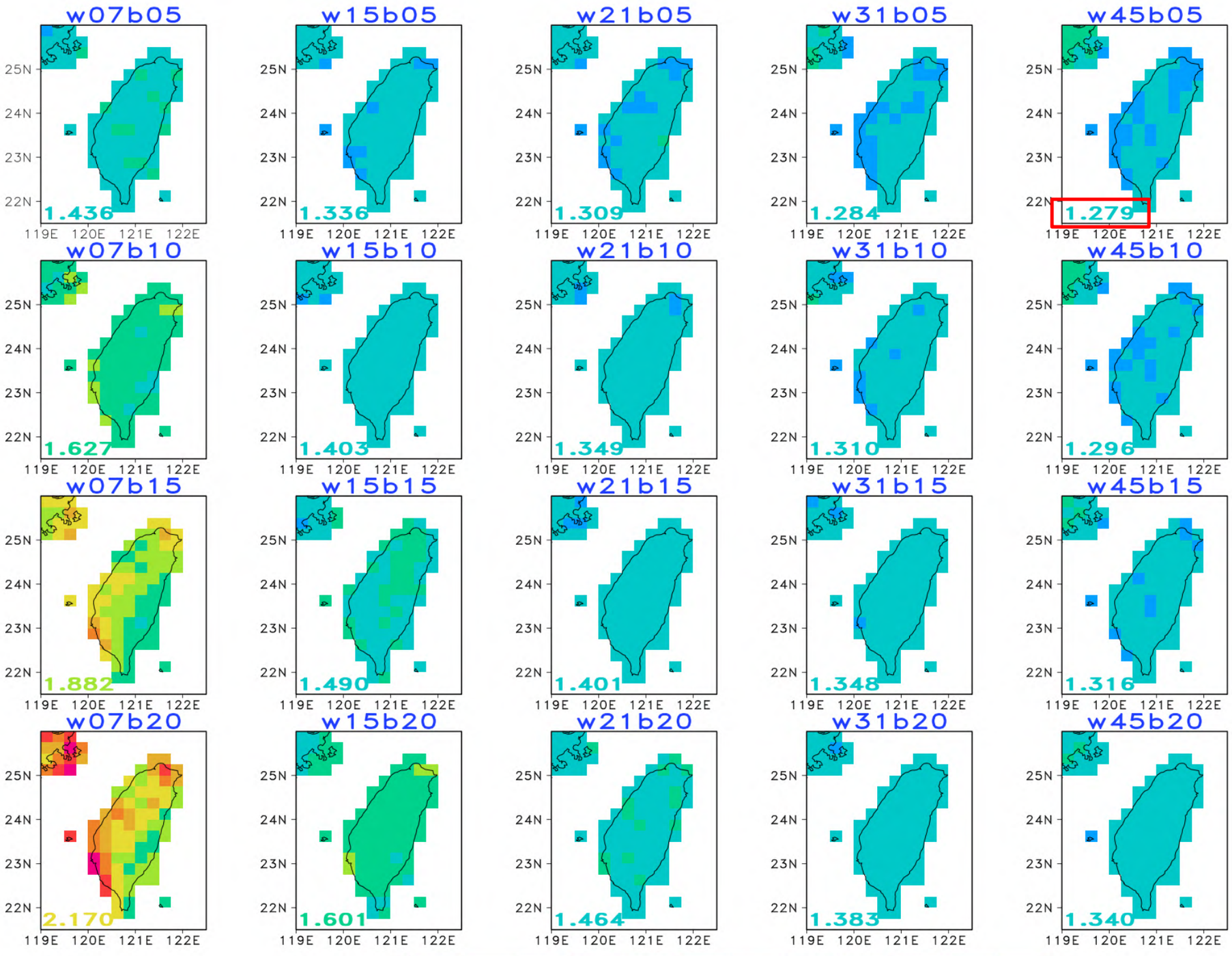
rcp85 , R_m ,v=11 indices mean,m=MRI-CGCM3



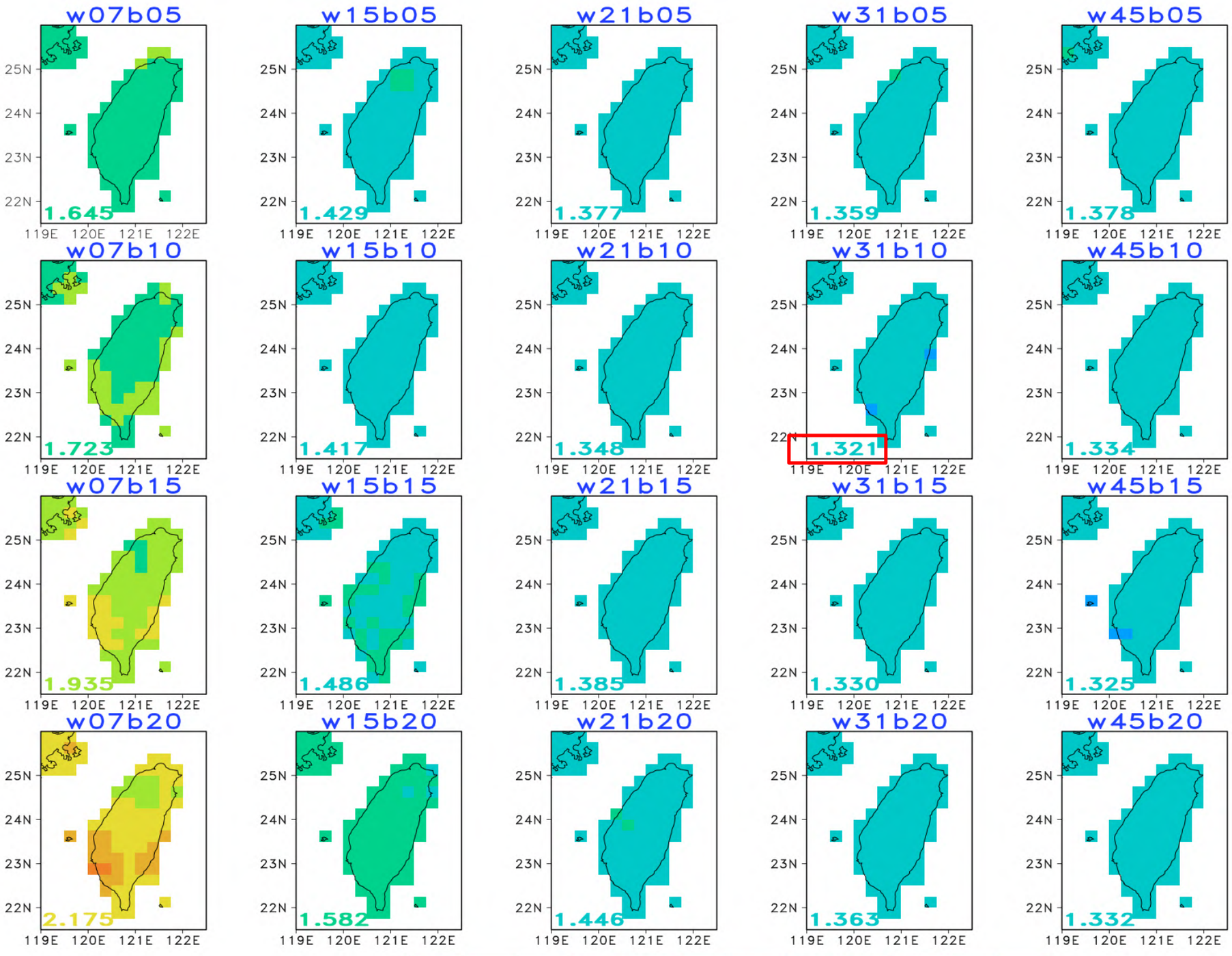
rcp85 , R_v ,v=Rx1day,m=ensemble mean



rcp85 , R_v ,v=rr1,m=ensemble mean



rcp85 , $R_{v,m}$,v=11 indices mean,m=ensemble mean



R	rcp26		rcp45		rcp60		rcp85		MEAN	
w7b5	1.698	17	1.700	17	1.664	17	1.645	17	1.677	17
w7b10	1.779	18	1.782	18	1.739	18	1.723	18	1.756	18
w7b15	2.004	19	1.989	19	1.953	19	1.934	19	1.970	19
w7b20	2.258	20	2.222	20	2.208	20	2.175	20	2.216	20
w15b5	1.430	13	1.432	13	1.421	13	1.429	13	1.428	13
w15b10	1.412	12	1.420	12	1.408	12	1.417	12	1.414	12
w15b15	1.489	15	1.488	15	1.470	15	1.486	15	1.483	15
w15b20	1.591	16	1.583	16	1.567	16	1.582	16	1.581	16
w21b5	1.383	10	1.368	10	1.384	10	1.377	9	1.378	10
w21b10	1.350	8	1.349	8	1.351	6	1.348	6	1.349	7
w21b15	1.385	11	1.384	11	1.381	9	1.385	11	1.384	11
w21b20	1.447	14	1.443	14	1.440	14	1.446	14	1.444	14
w31b5	1.329	6	1.341	7	1.357	7	1.359	7	1.347	6
w31b10	1.305	1	1.313	3	1.320	1	1.321	1	1.315	1
w31b15	1.321	5	1.328	5	1.328	2	1.330	3	1.327	4
w31b20	1.355	9	1.364	9	1.360	8	1.363	8	1.360	9
w45b5	1.343	7	1.330	6	1.386	11	1.378	10	1.359	8
w45b10	1.310	2	1.298	1	1.343	5	1.334	5	1.321	3
w45b15	1.310	3	1.303	2	1.337	3	1.325	2	1.319	2
w45b20	1.319	4	1.319	4	1.340	4	1.332	4	1.328	5

結論

- 綜合各氣候指標與模式之平均，Window=31、Bin=10為最佳Bias-Correction之方法
- 以此做日降尺度