TCCIP 臺灣氣候變遷推估資訊與調適知識平台
Taiwan Climate Change projection and adaptation Information Platform

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

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

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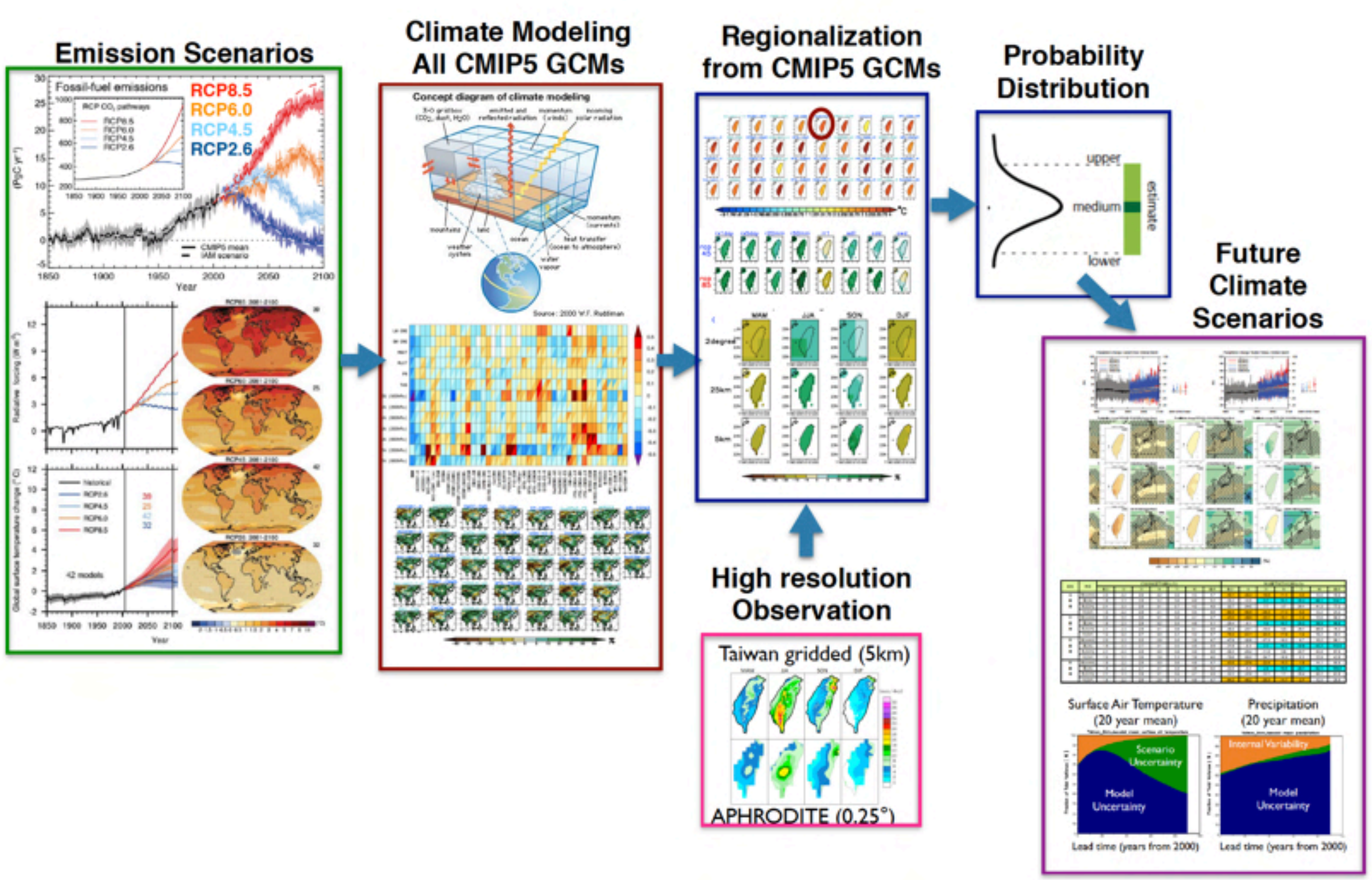
Future Climate Scenarios Cascade (Statistical Downscaling)



tccip.ncdr.nat.gov.tw

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

Why do we need downscaling?

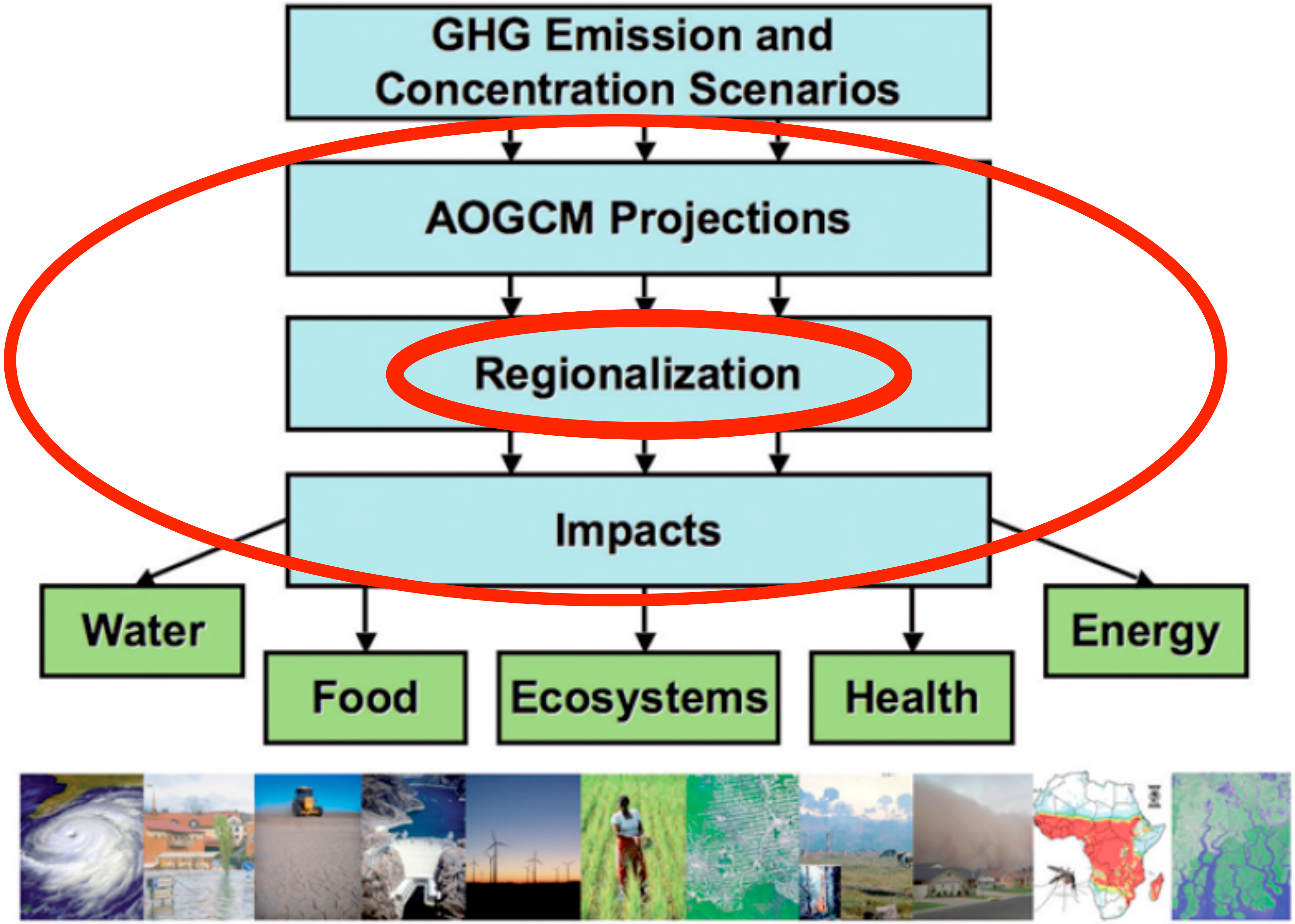
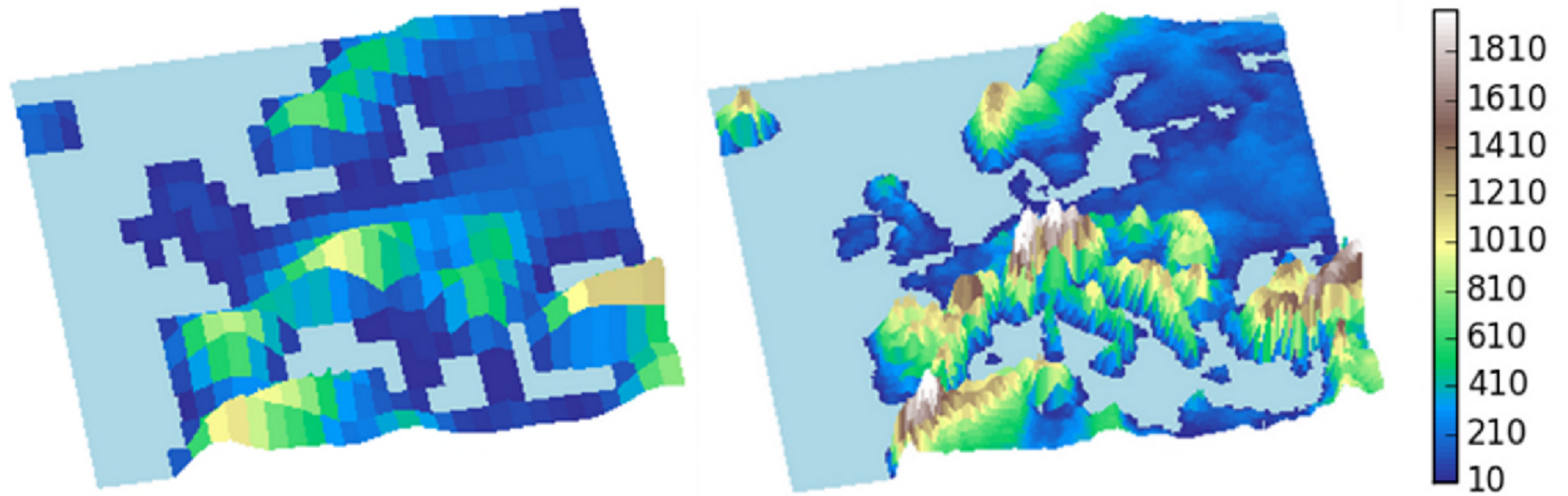
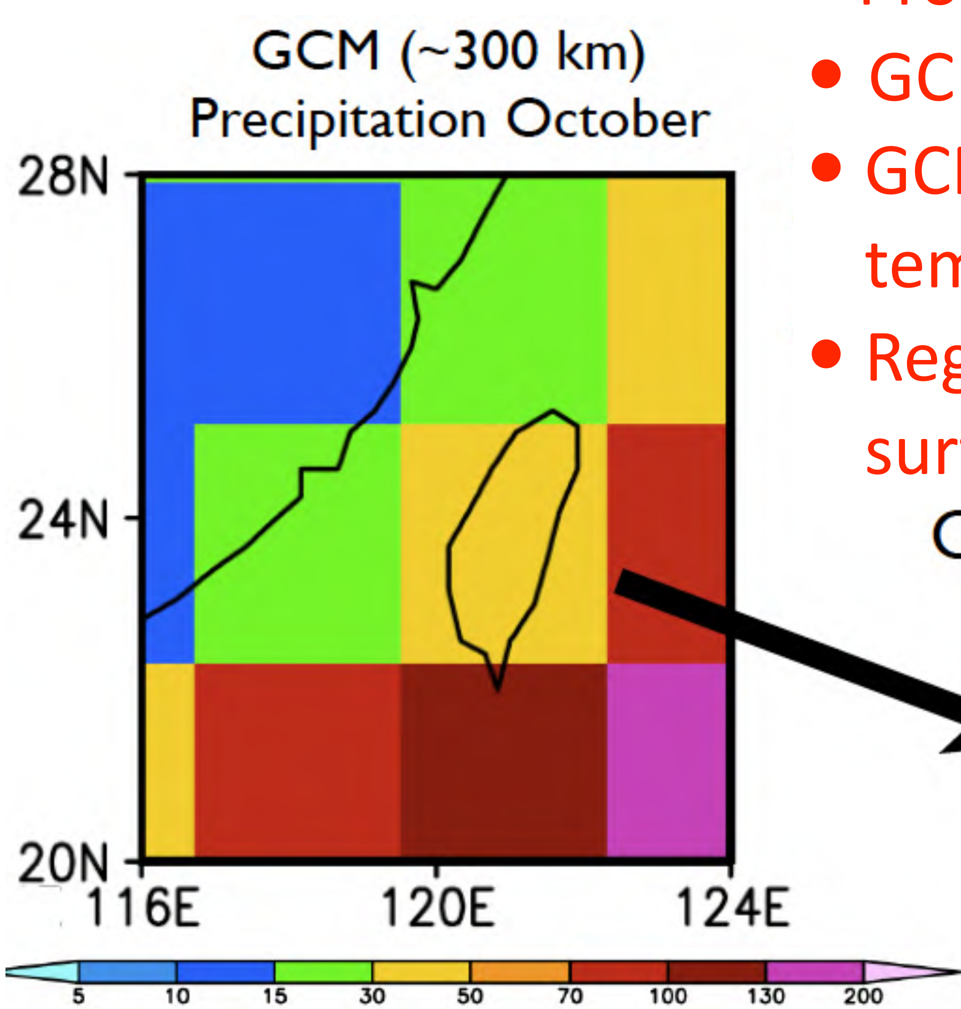


Figure 3 — Schematic depiction of the steps involved in the production of climate change information usable for impact assessment work via regionalization methods

Source: Giorgi (2008)

Why do we need downscaling?

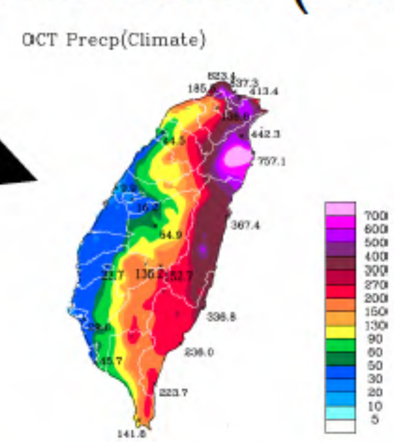




Problems:

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

Observation (~5km)



Why statistical downscaling?

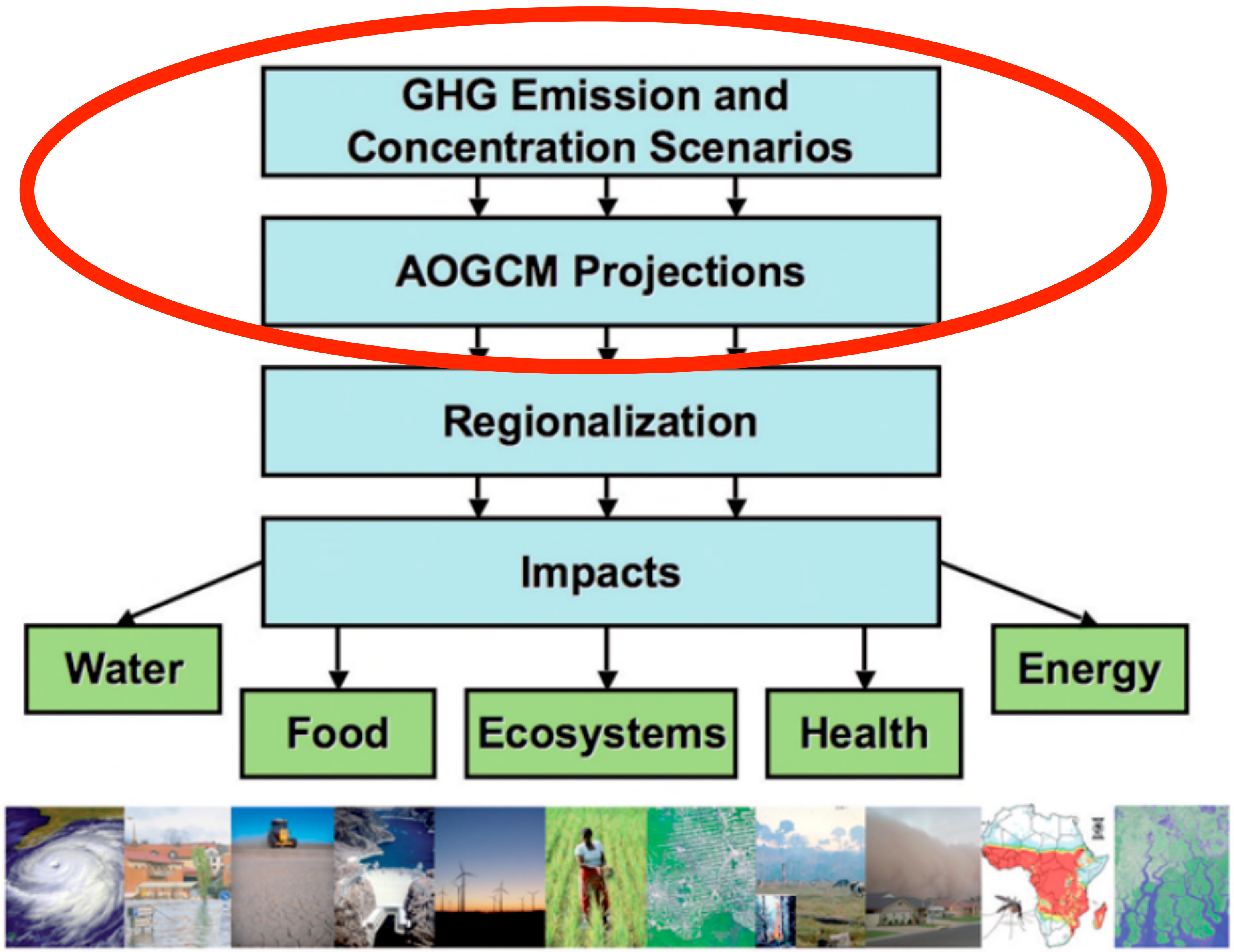


Figure 3 — Schematic depiction of the steps involved in the production of climate change information usable for impact assessment work via regionalization methods

Source: Giorgi (2008)

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

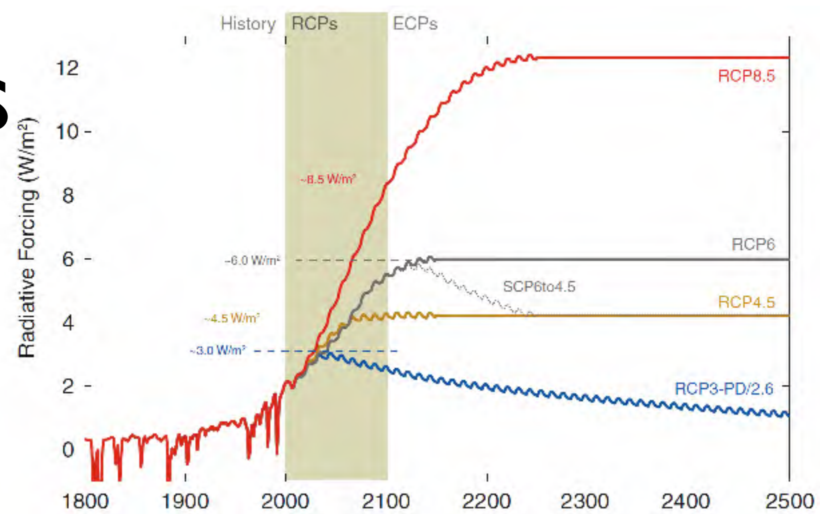
Why statistical downscaling?

CMIP5 experiments

historical

RCP 2.6, 4.5

RCP 6.0, 8.5



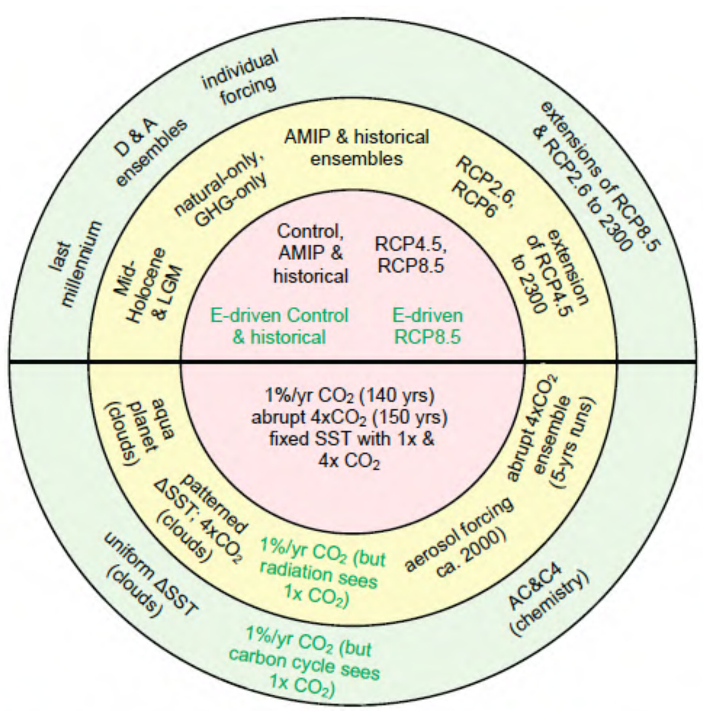


Fig. 2. Schematic summary of CMIP5 long-term experiments with tier 1 and tier 2 experiments organized around a central core. Green font indicates simulations to be performed only by models with carbon cycle representations. Experiments in the upper hemisphere are suitable either for comparison with observations

CMIP5 models (29 centers, >50 model versions)

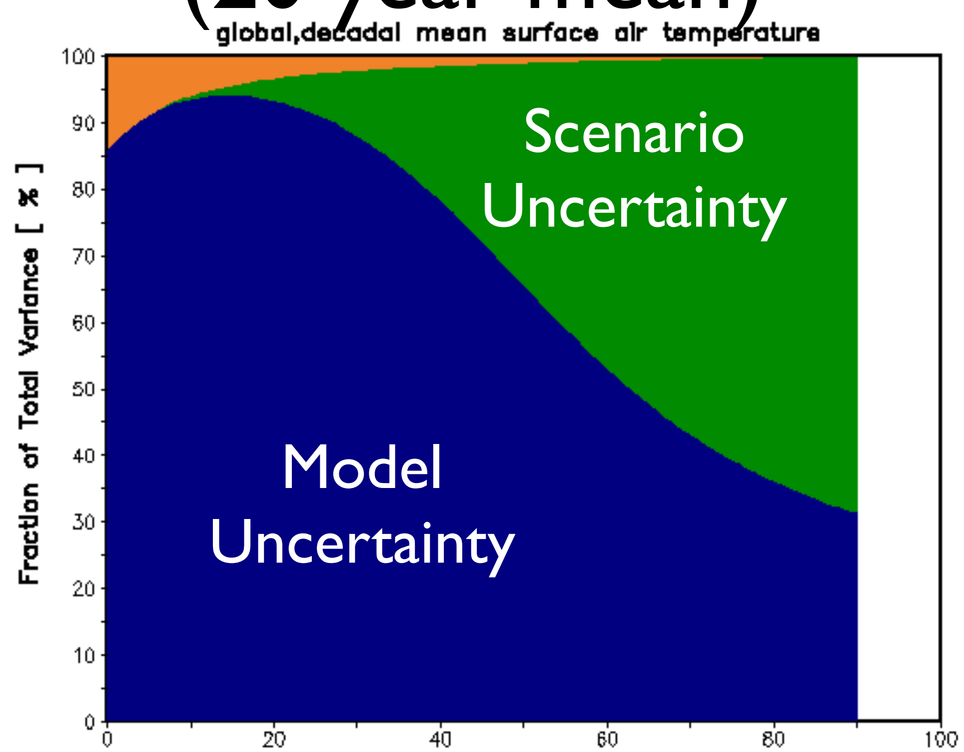
Modeling Center	Model	Institution	terms of use
BCC	BCC-CSM1.1 BCC-CSM1.1(m)	Beijing Climate Center, China Meteorological Administration	unrestricted
CCCma	CanAM4 CanCM4 CanESM2	Canadian Centre for Climate Modelling and Analysis	unrestricted
CMCC	CMCC-CESM CMCC-CM CMCC-CMS	Centro Euro-Mediterraneo per 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

Why statistical downscaling?

Uncertainties Assessment (Hawkin and Sutton, 2009)

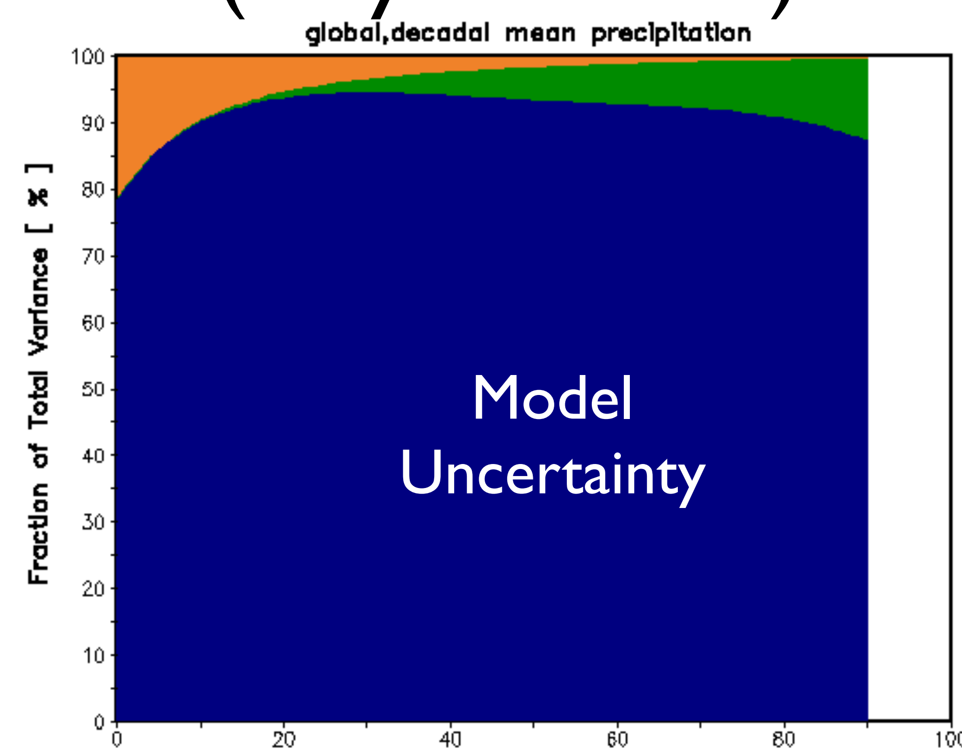
Fraction of Total Variance Plot (Scenario, Model, Internal Variability)

Global mean Surface Air Temperature (20 year mean)



Lead time (years from 2000)

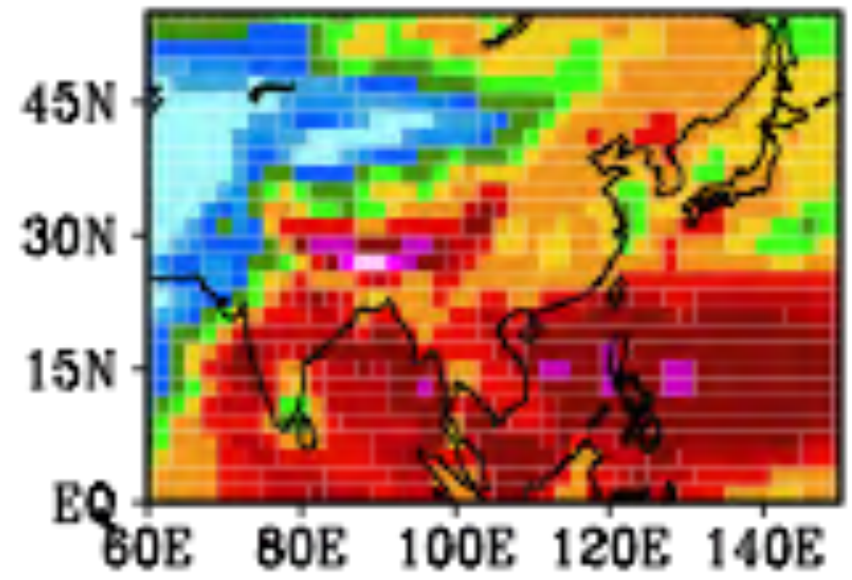
Global mean Precipitation (20 year mean)



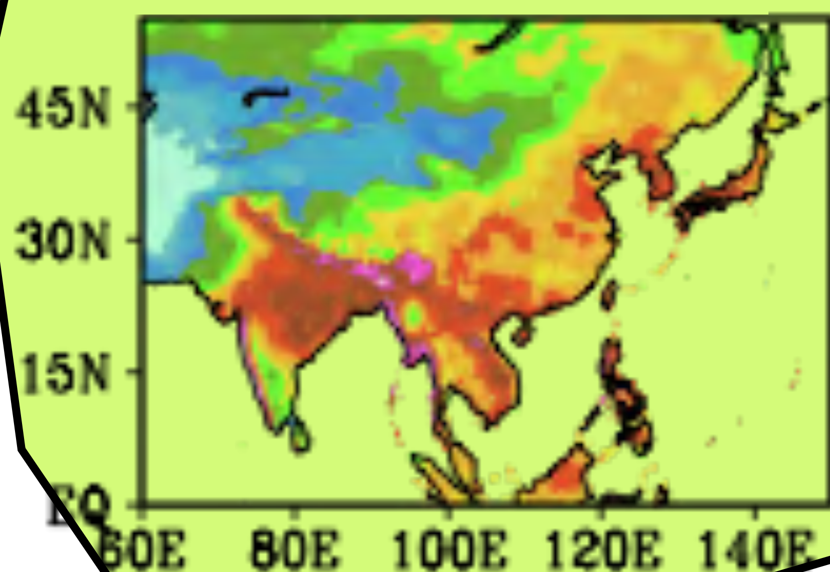
Lead time (years from 2000)

Statistical Downscaling

Climate Model

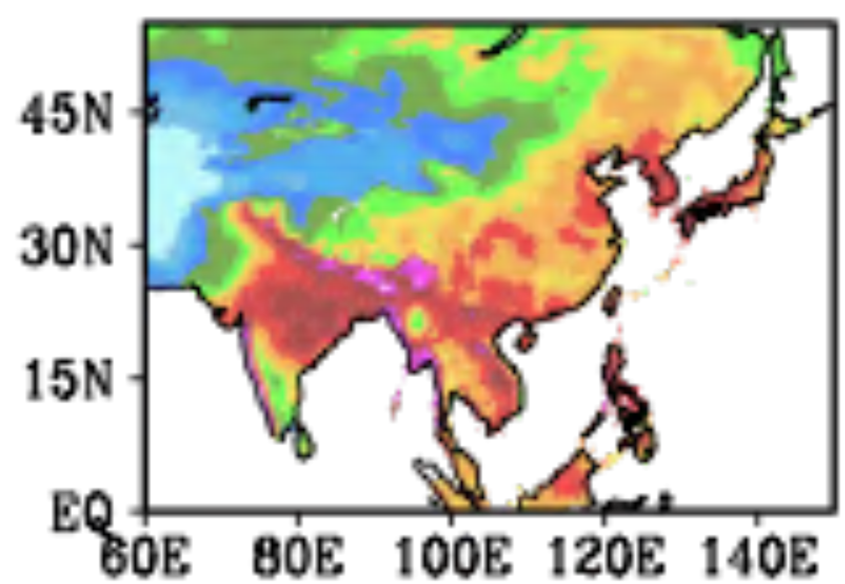


High Resolution Observation



Develop transfer function

Downscaled



Statistical Downscaling

Simple Statistical Downscaling:
Bias Correction Spatial Downscaling (BCSD)

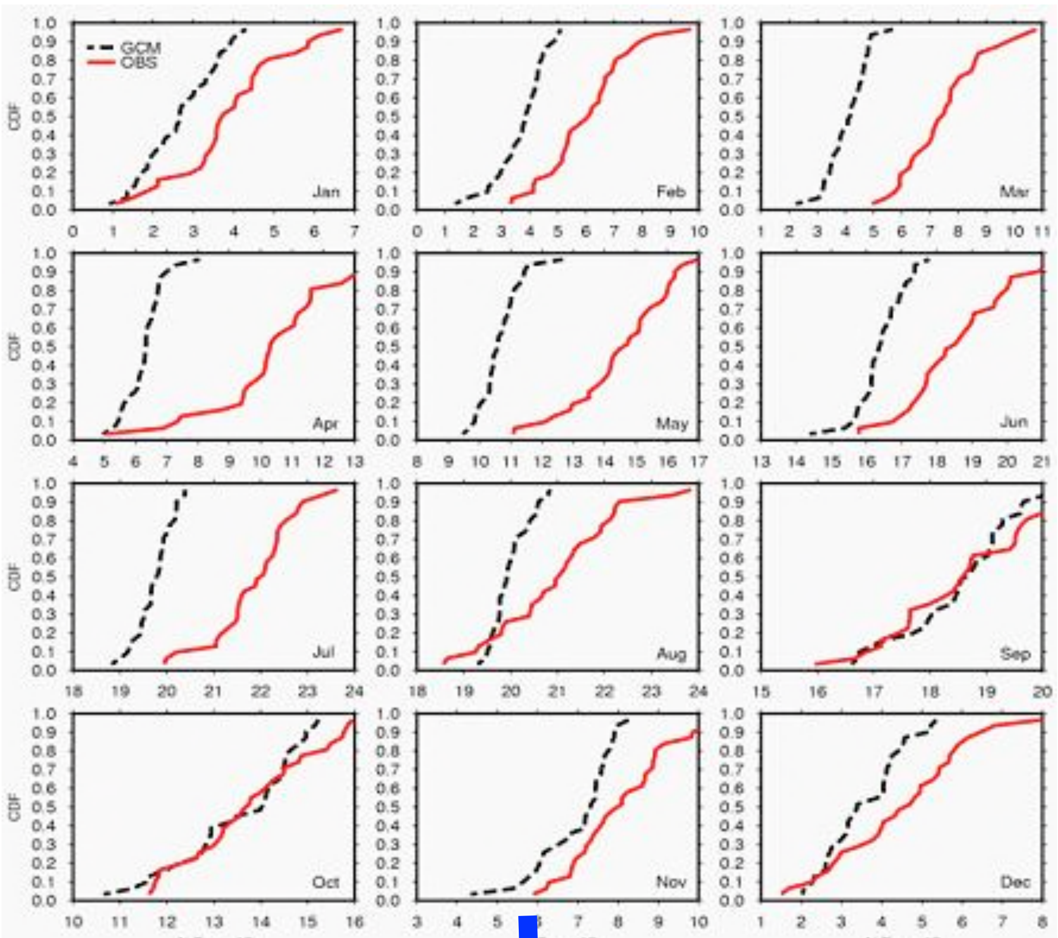
Wood et al. 2004, and Maurer 2007

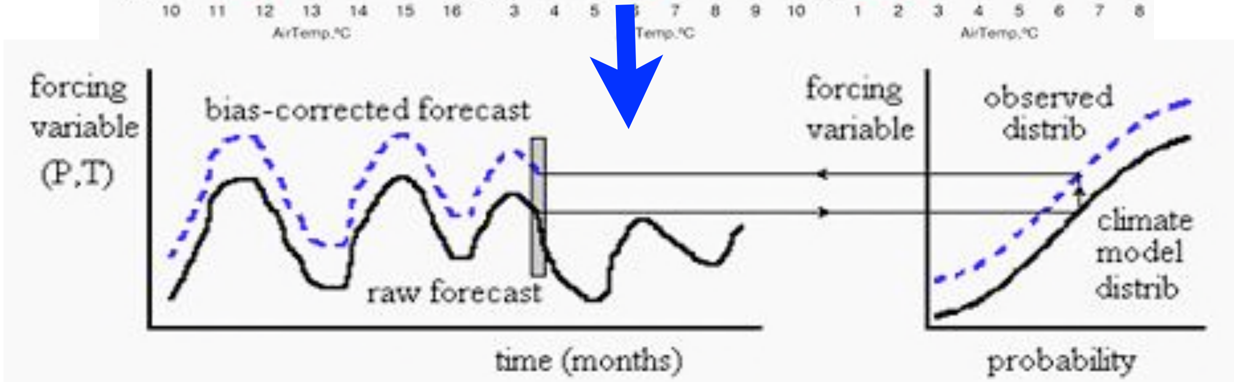
- Aggregate gridded OBS to GCM resolution
- Remove trend (if the trend is significant)
- Generate CDF of observed and GCM data
  - Q-Q mapping approach
  - limitation on extrapolation
- Add trend back in
- Resample/interpolate to finer resolution
- Apply spatial factor to account for subgrid topography

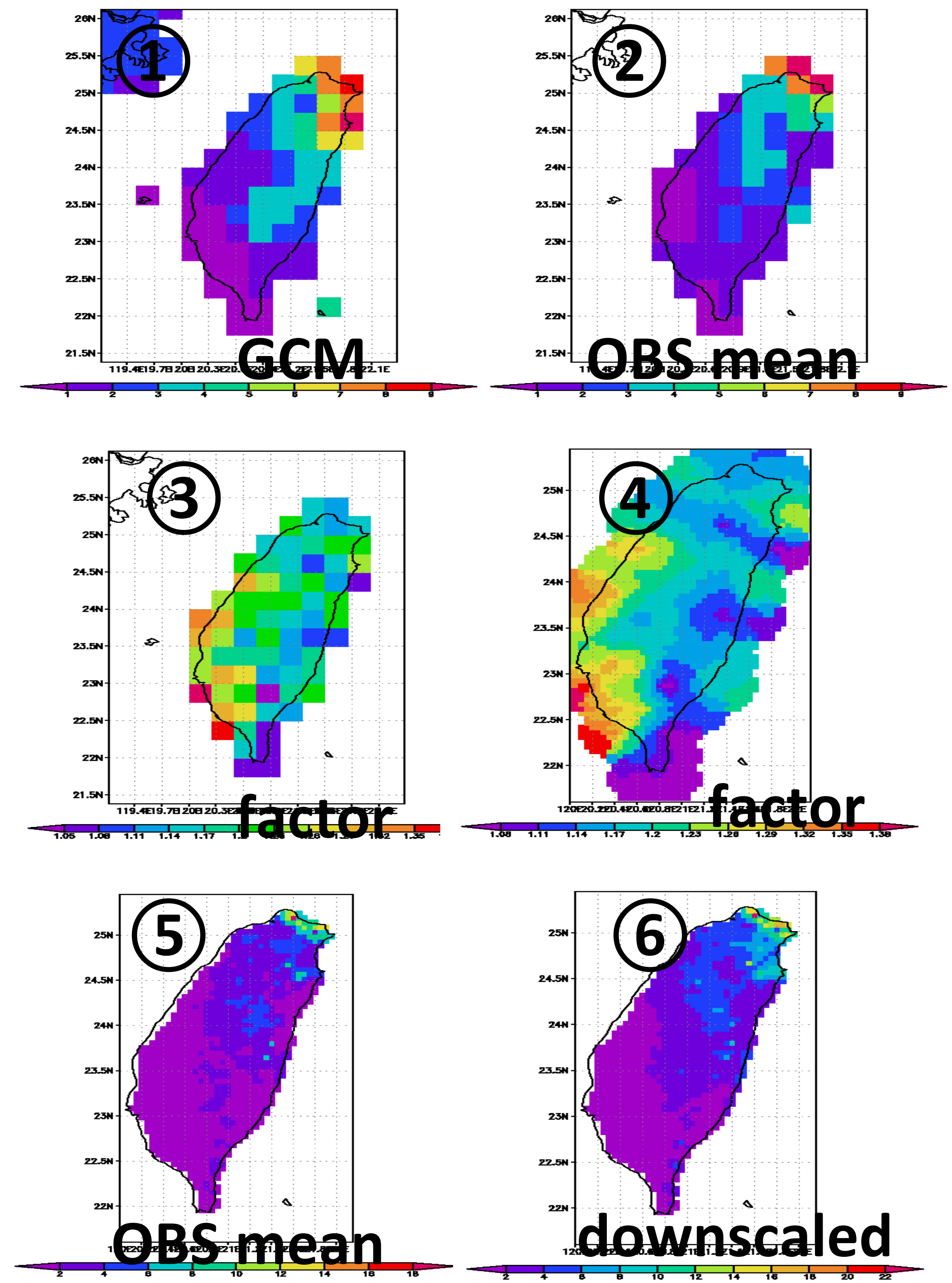
Statistical Downscaling

Statistical downscaling and bias correction by cumulative distribution function and interpolation

Wood et al. 2004, and Maurer 2007

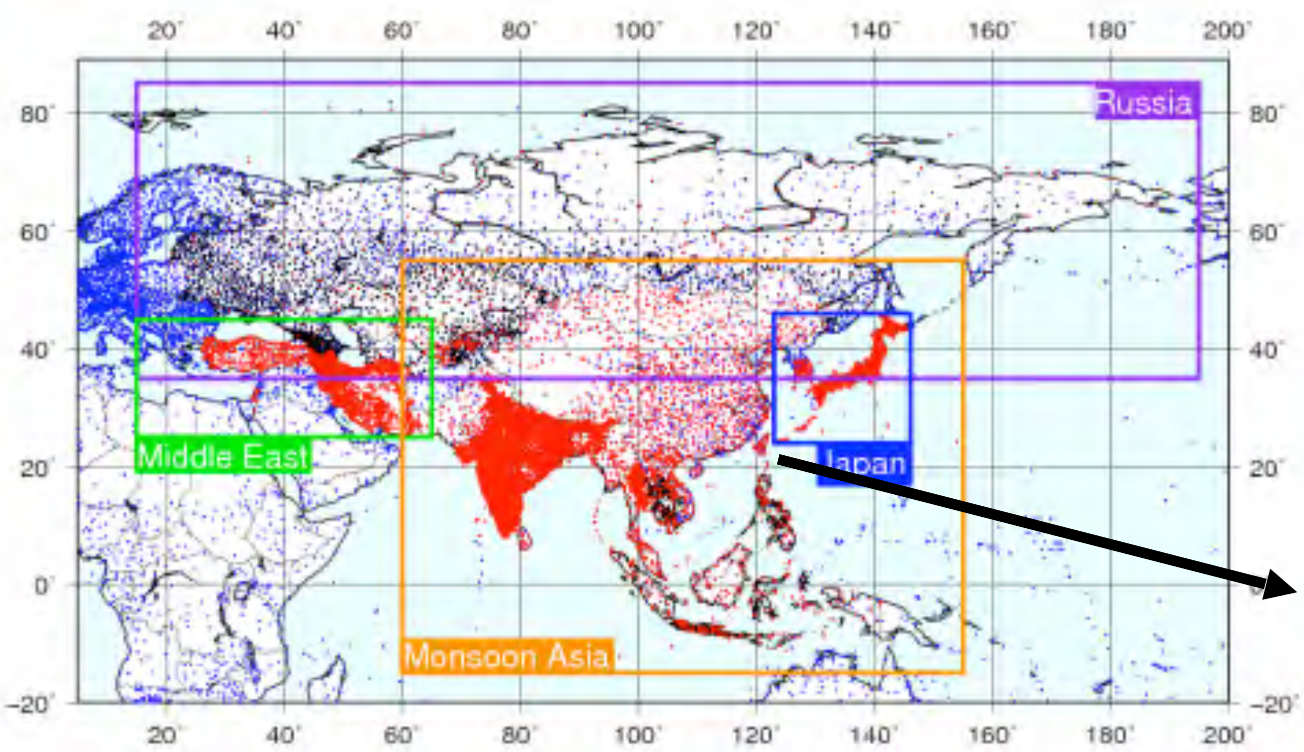






Require long-term high-resolution observations

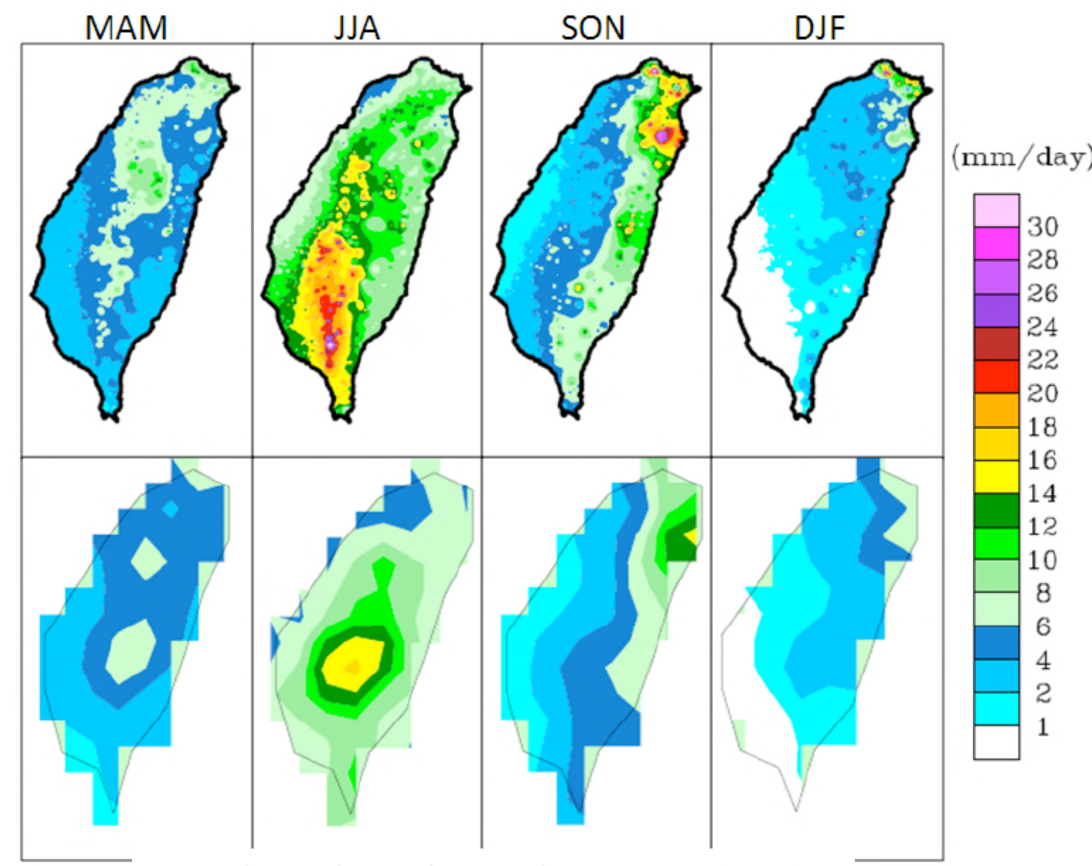
APHRODITE (0.25°)

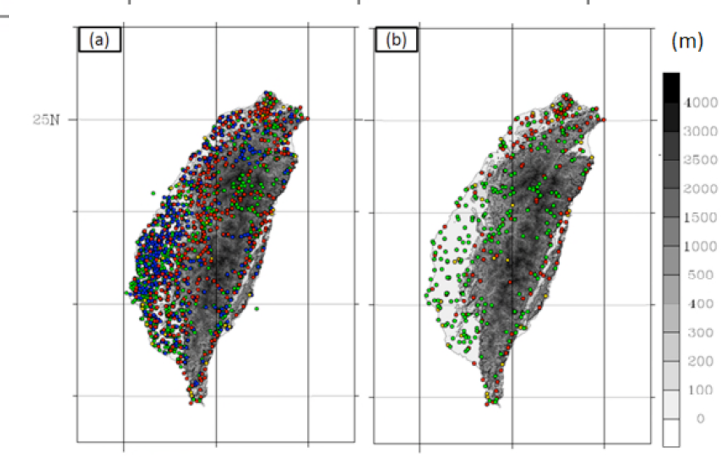


Current version: V1003R1 Download »Readme »Errata

Name	Domain	Resolution	Period
Monsoon Asia (MA)	60°E-150°E, 15°S-55°N	0.5° and 0.25°, daily	1951-2007
Middle East (ME)	15°E-65°E, 25°N-45°N		
Russia (RU)	15°E-165°W, 34°N-84°N		

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





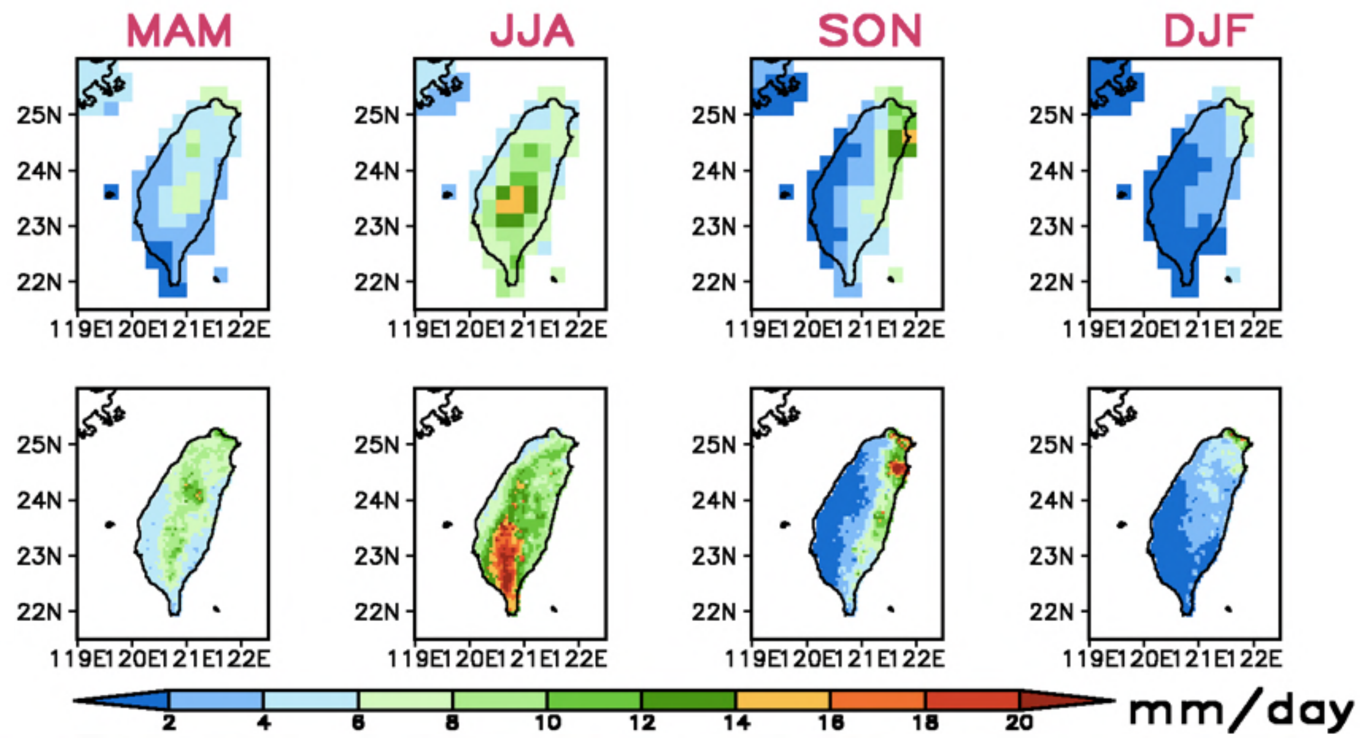
TCCIP, Weng and Yang (2015)

Two Steps Approach

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

Aphrodite 0.25°

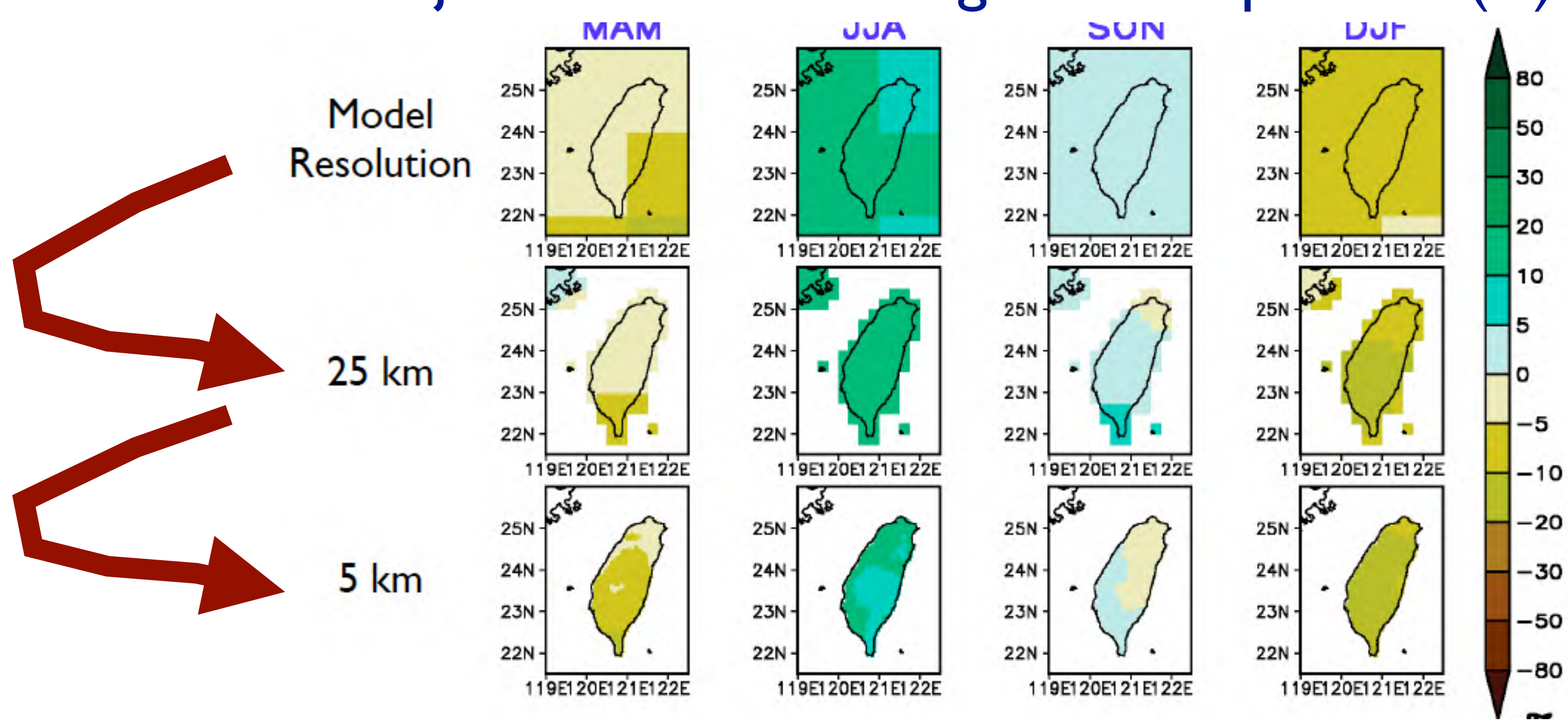
Taiwan gridded 5km



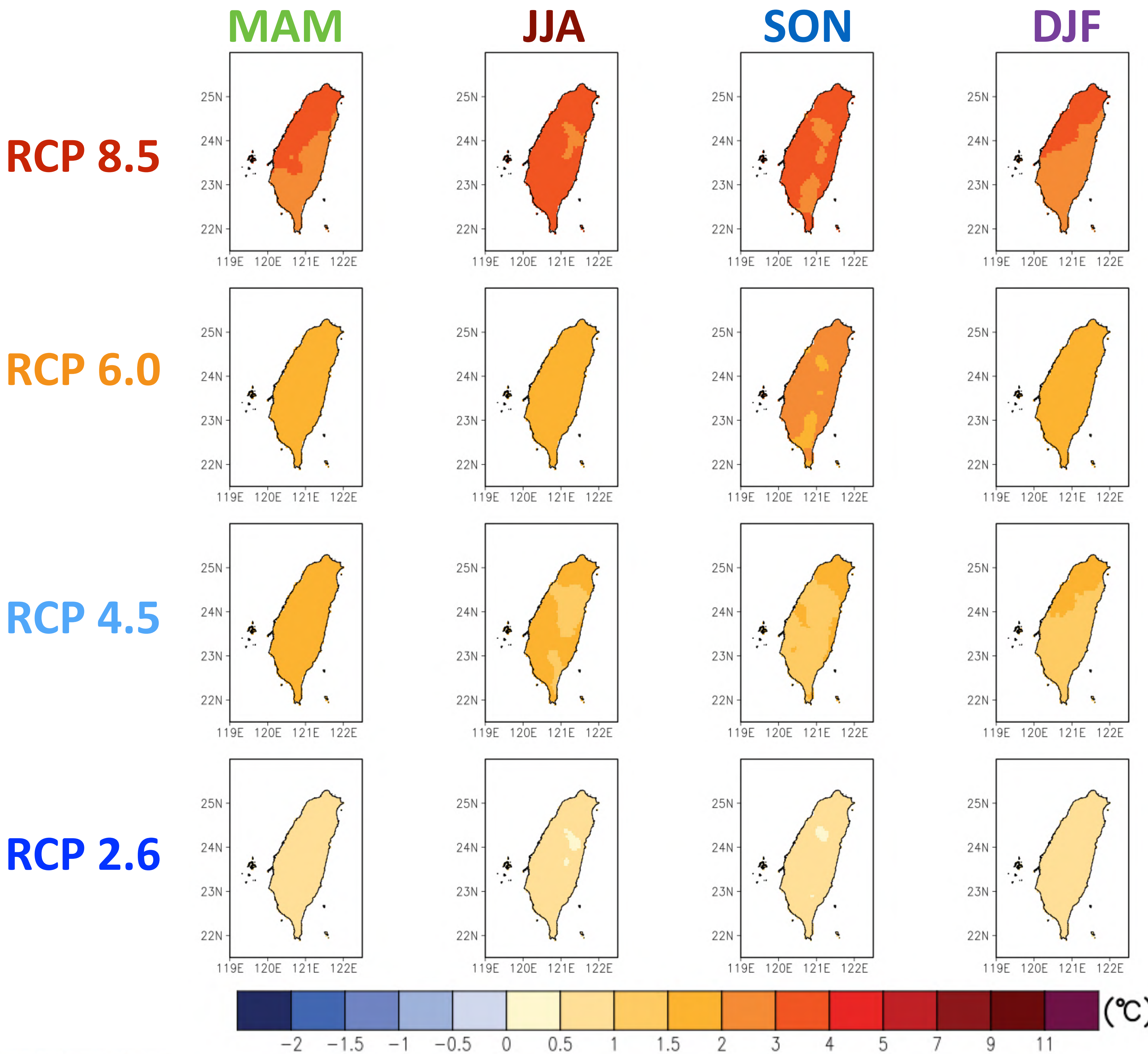
CMIP5 Model Projected Future Change in Precipitation (%) RCP8.5

(1)

(2)



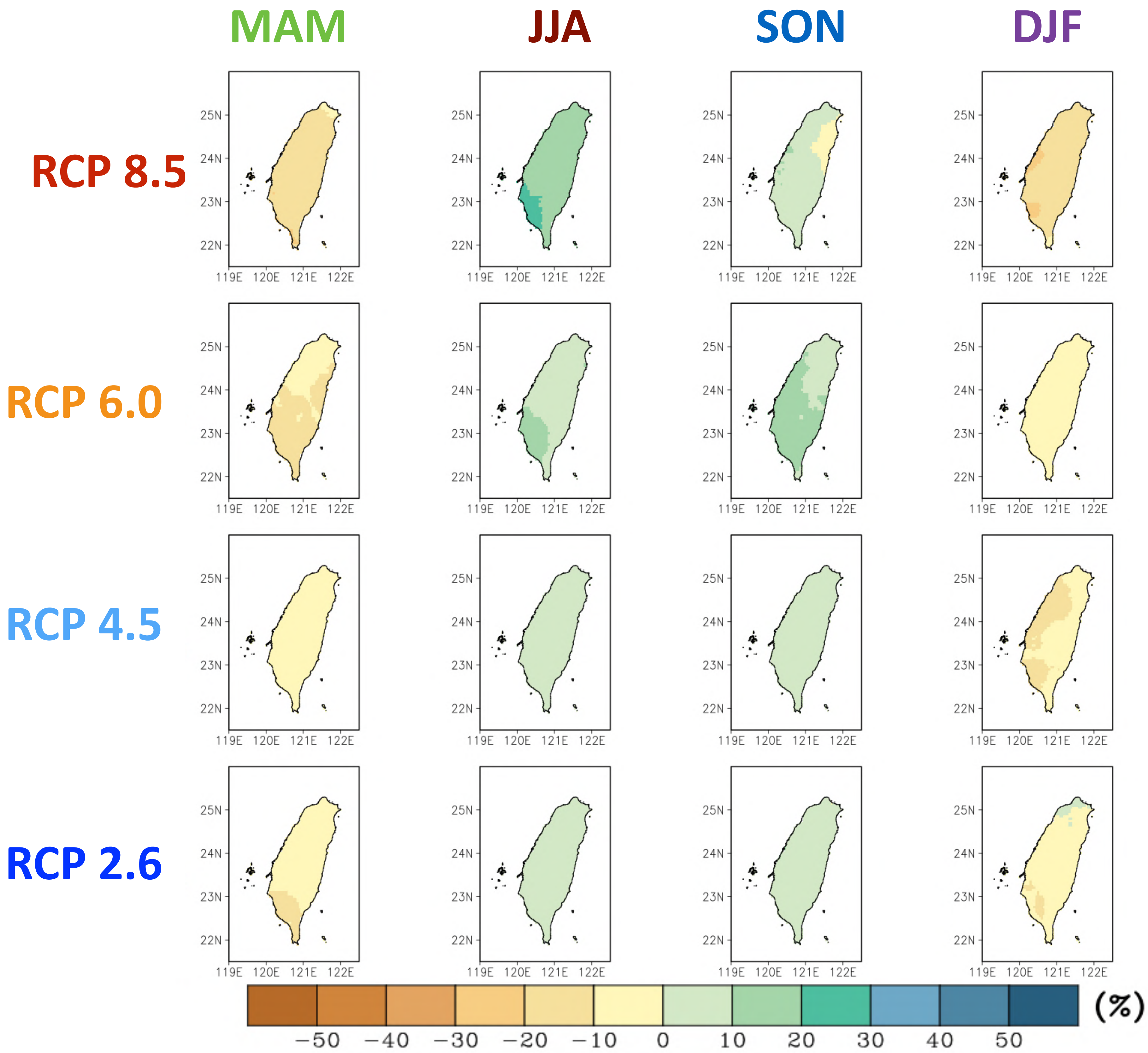
Projected model median surface air temperature change (°C)



more likely than not

多半可能

Projected model median precipitation change (%)



more likely than not

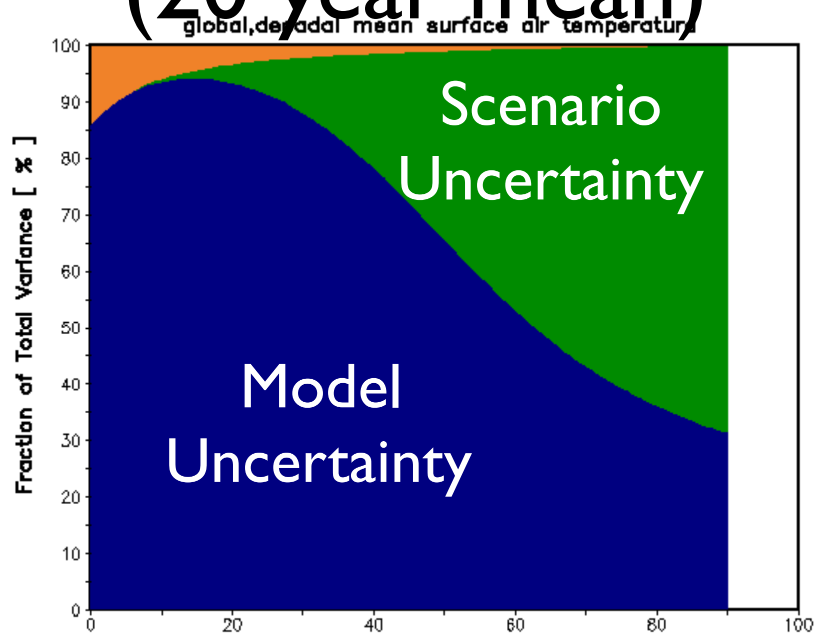
多半可能

Uncertainties Assessment (Hawkin and Sutton, 2009)

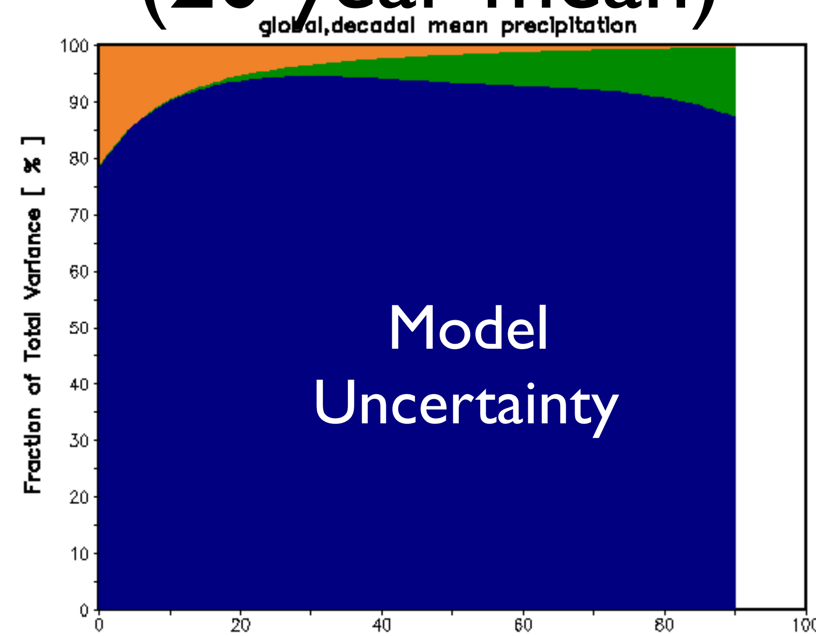
Fraction of Total Variance Plot (Scenario, Model, Internal Variability)

Surface Air Temperature (20 year mean) | **Precipitation (20 year mean)**

Global

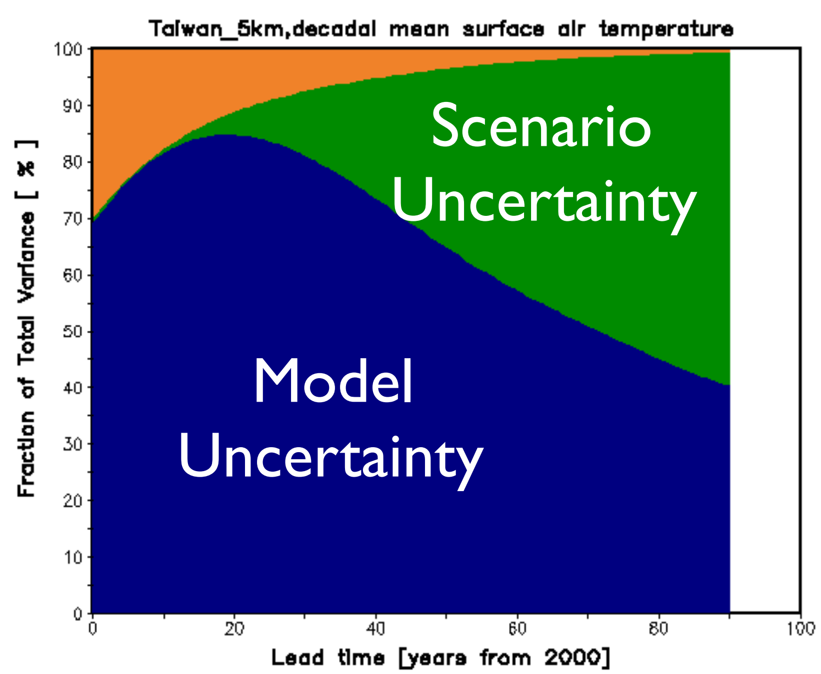


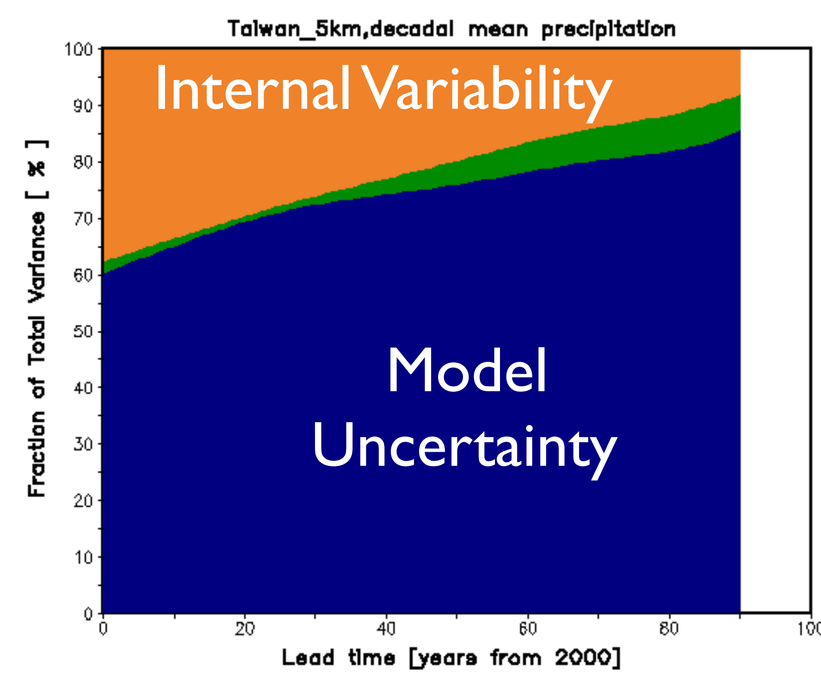
Lead time (years from 2000)



Lead time (years from 2000)

Taiwan





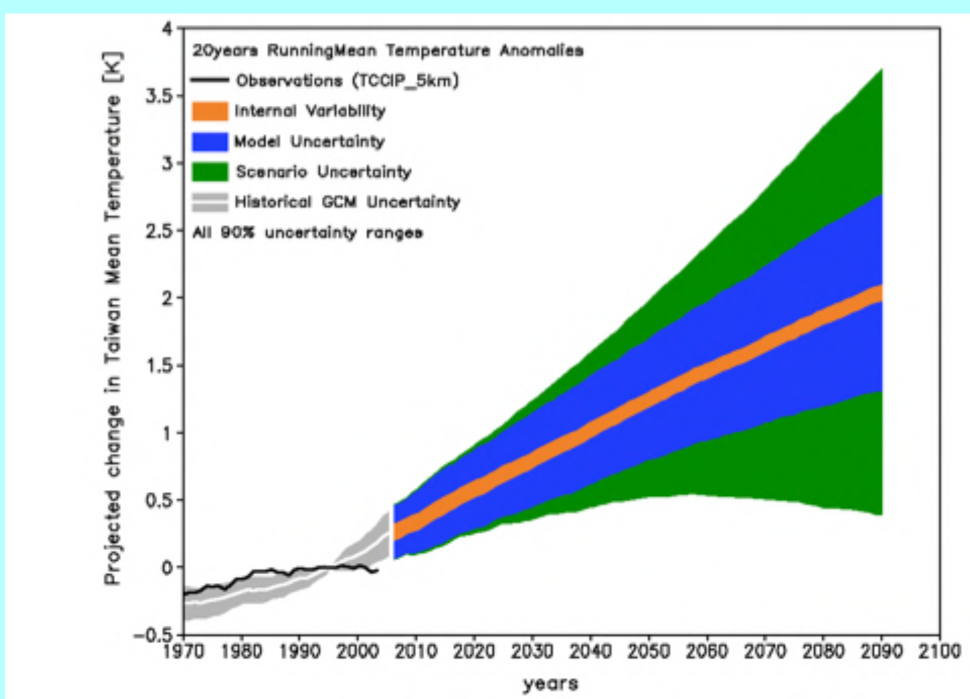
Uncertainties Assessment (Hawkin and Sutton, 2009)

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

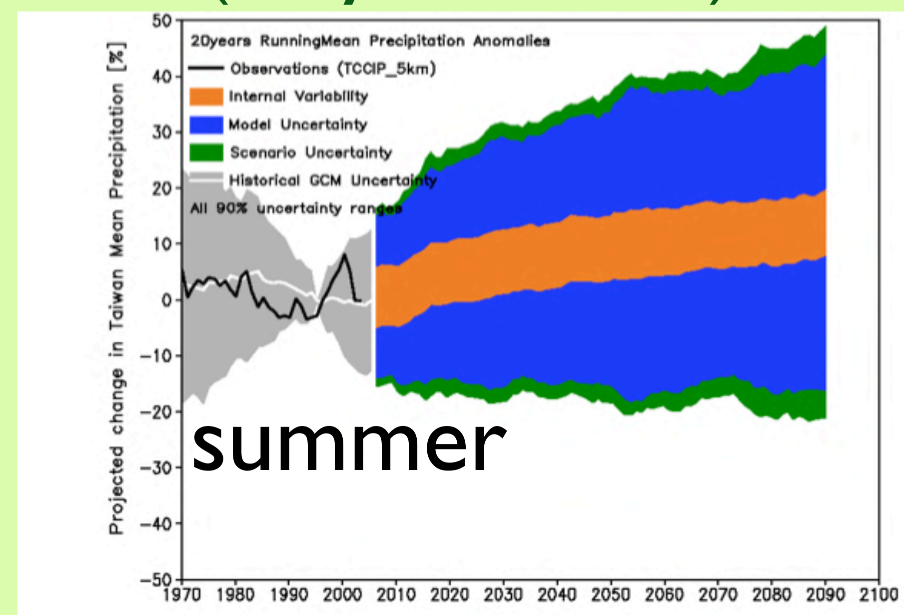
Taiwan

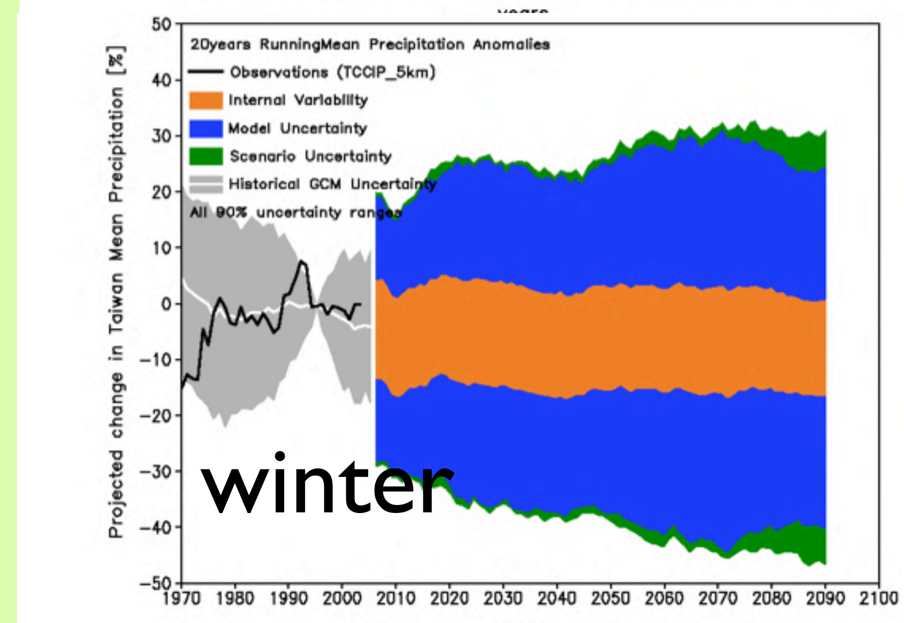
Surface Air Temperature (20 year mean)

annual mean



Precipitation (20 year mean)



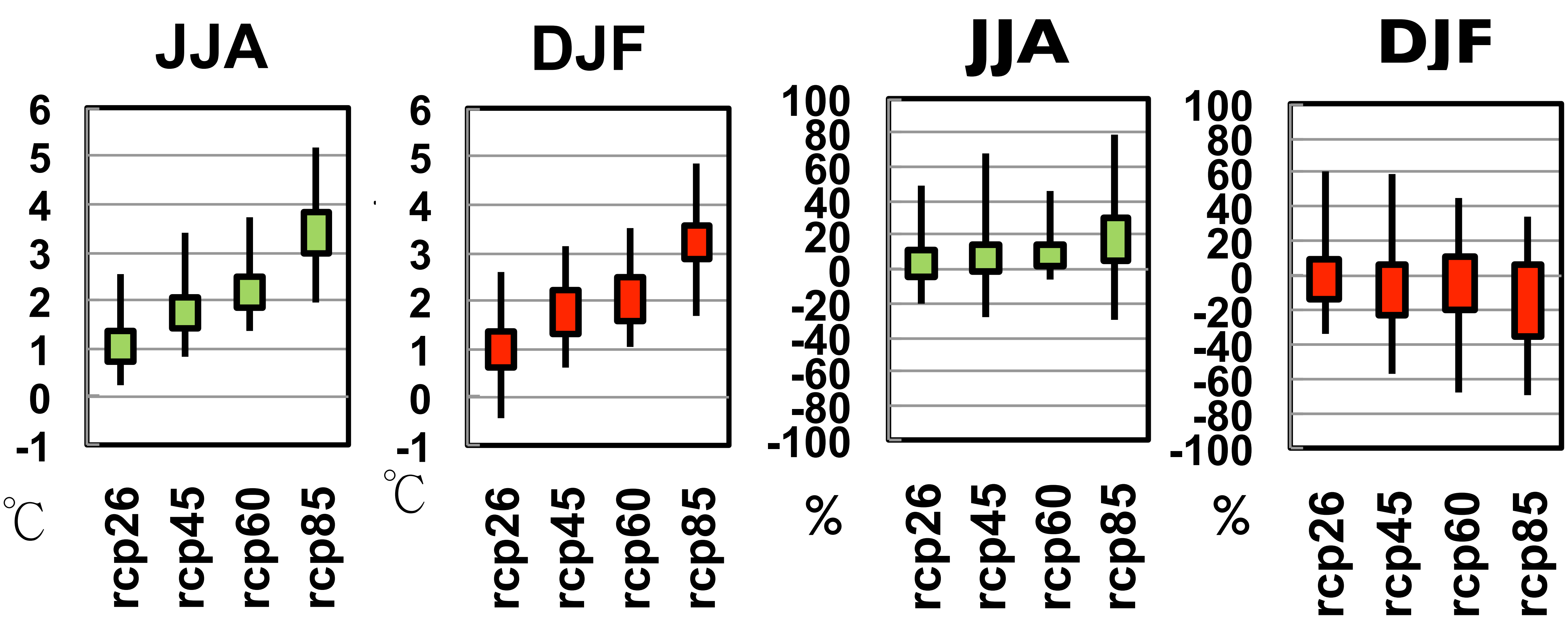


Seasonal future climate change range with different RCPs

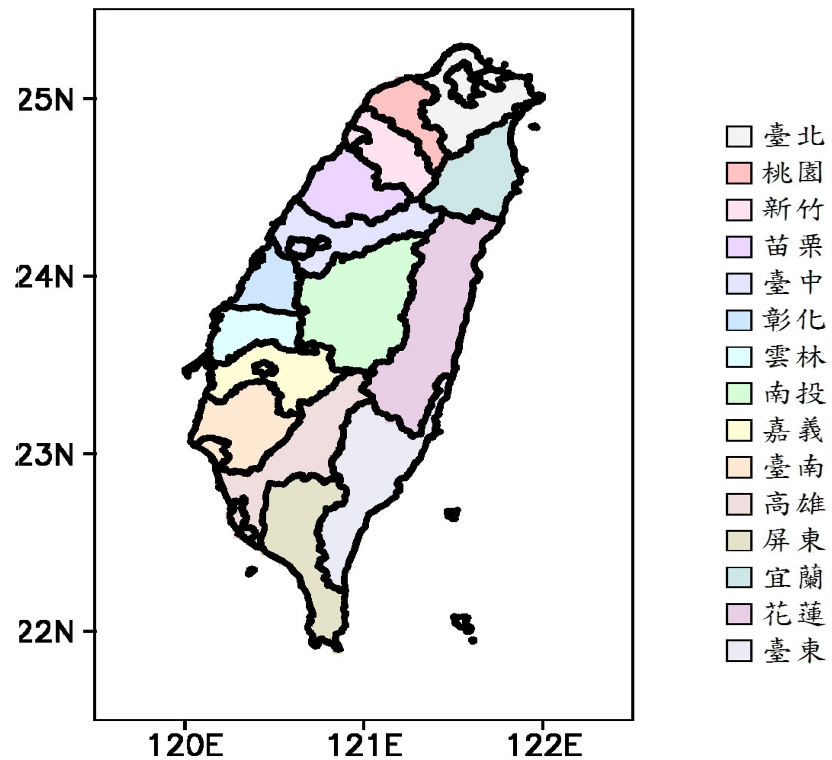
Box-Whisker Plots of CMIP5 Model Projected Taiwan Mean Future (2080-2099) Climate Change with RCP8.5 scenario

Taiwan Mean Temperature Change

Taiwan Mean Precipitation Change



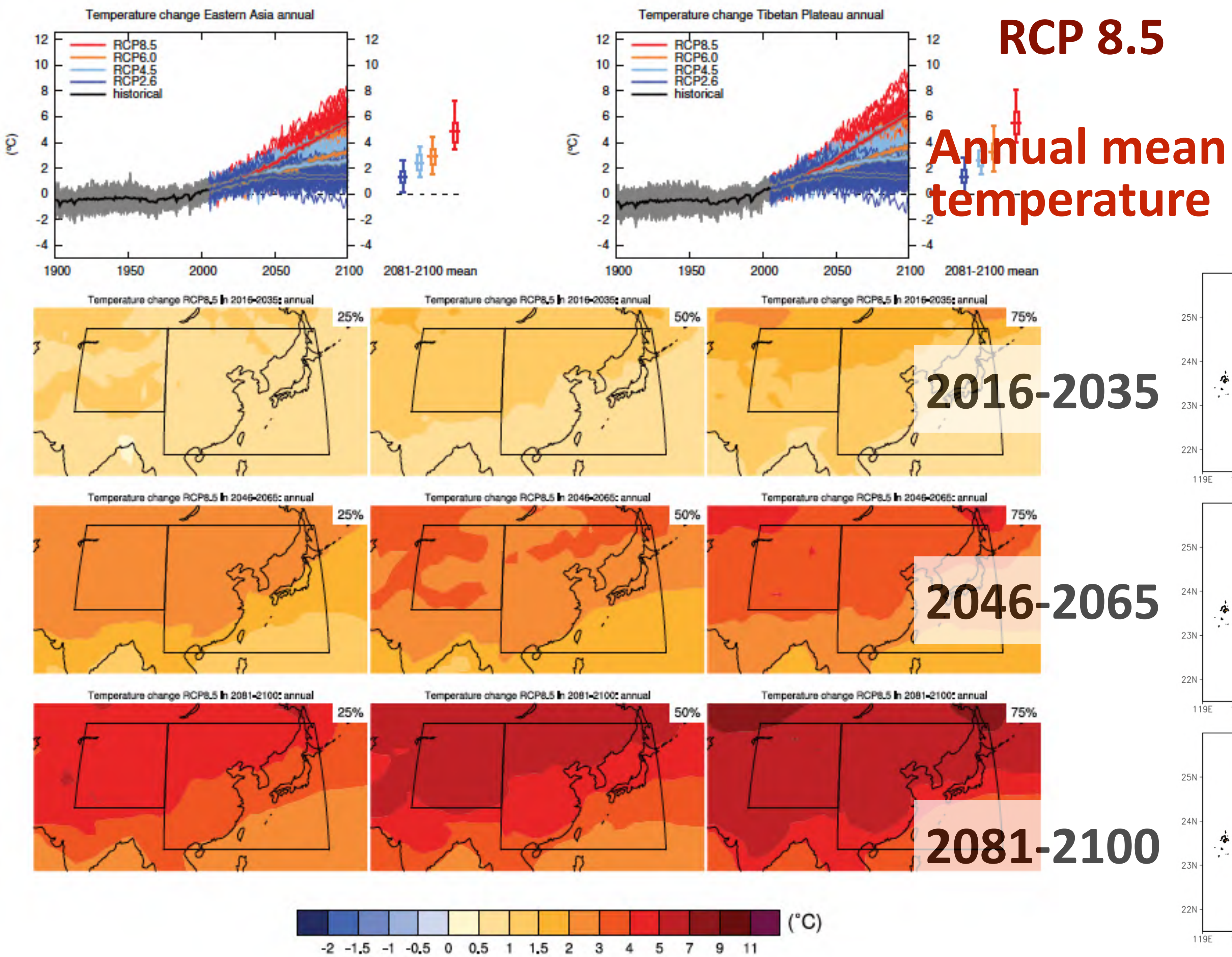
Downscaled future climate change range to counties



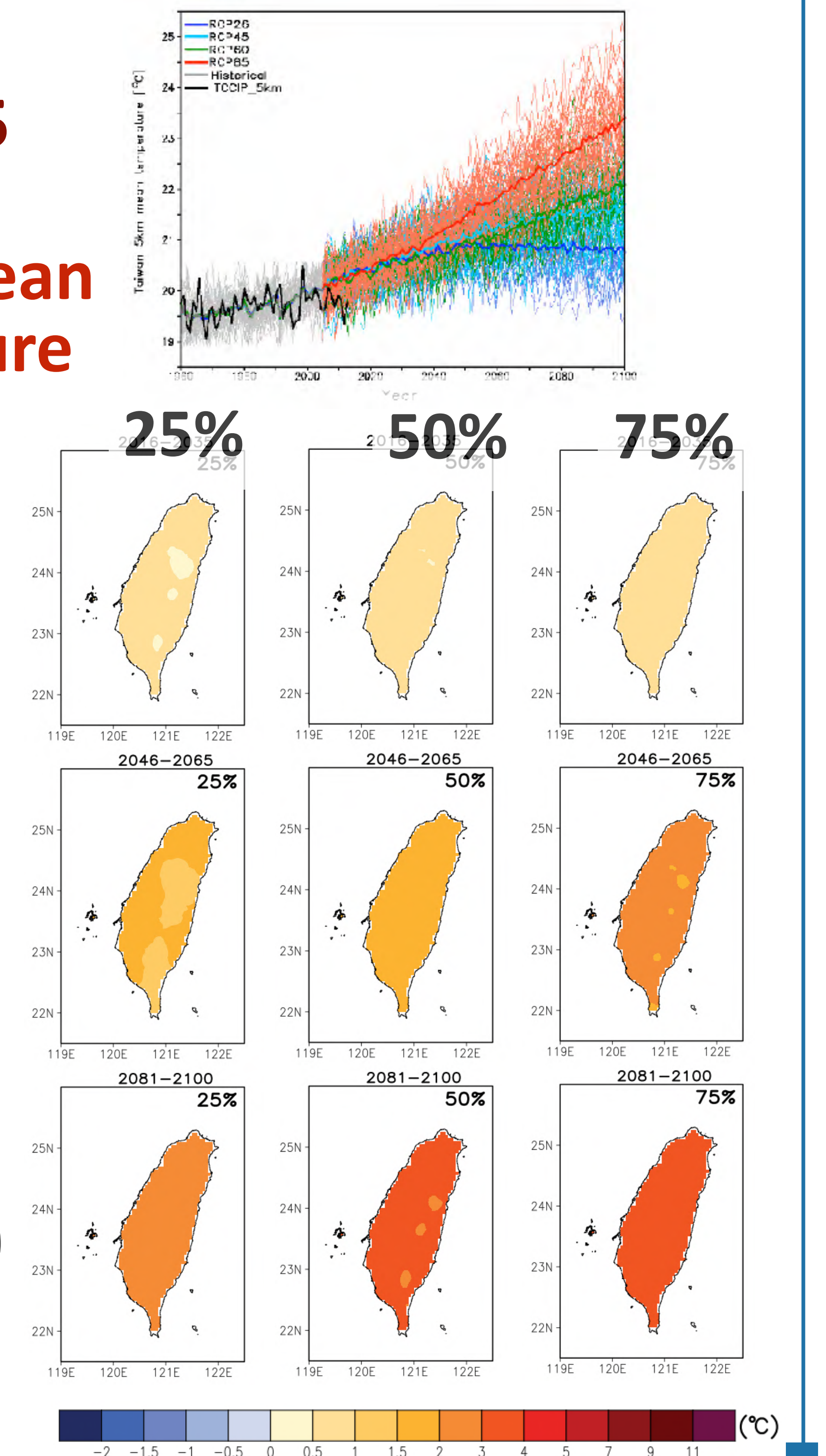
區域	季節	近地表氣溫平均變化 (°C)							降水量平均百分比變化 (%)						
		最小	10	25	50	75	90	最大	最小	10	25	50	75	90	最大
北北基	春(MAM)	2.0	2.2	2.6	3.2	3.7	4.3	4.7	-36.3	-22.2	-16.7	-10.5	-2.9	10.5	43.2
	夏(JJA)	1.8	2.4	2.8	3.3	3.6	4.1	5.2	-34.9	-12.1	-0.4	15.9	25.1	43.9	117.8
	秋(SON)	2.1	2.4	2.9	3.2	3.7	4.3	4.9	-27.4	-19.8	-7.8	1.0	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	3.7	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

Future Annual Mean Temperature Change Atlas (RCP8.5)

IPCC AR5 Atlas



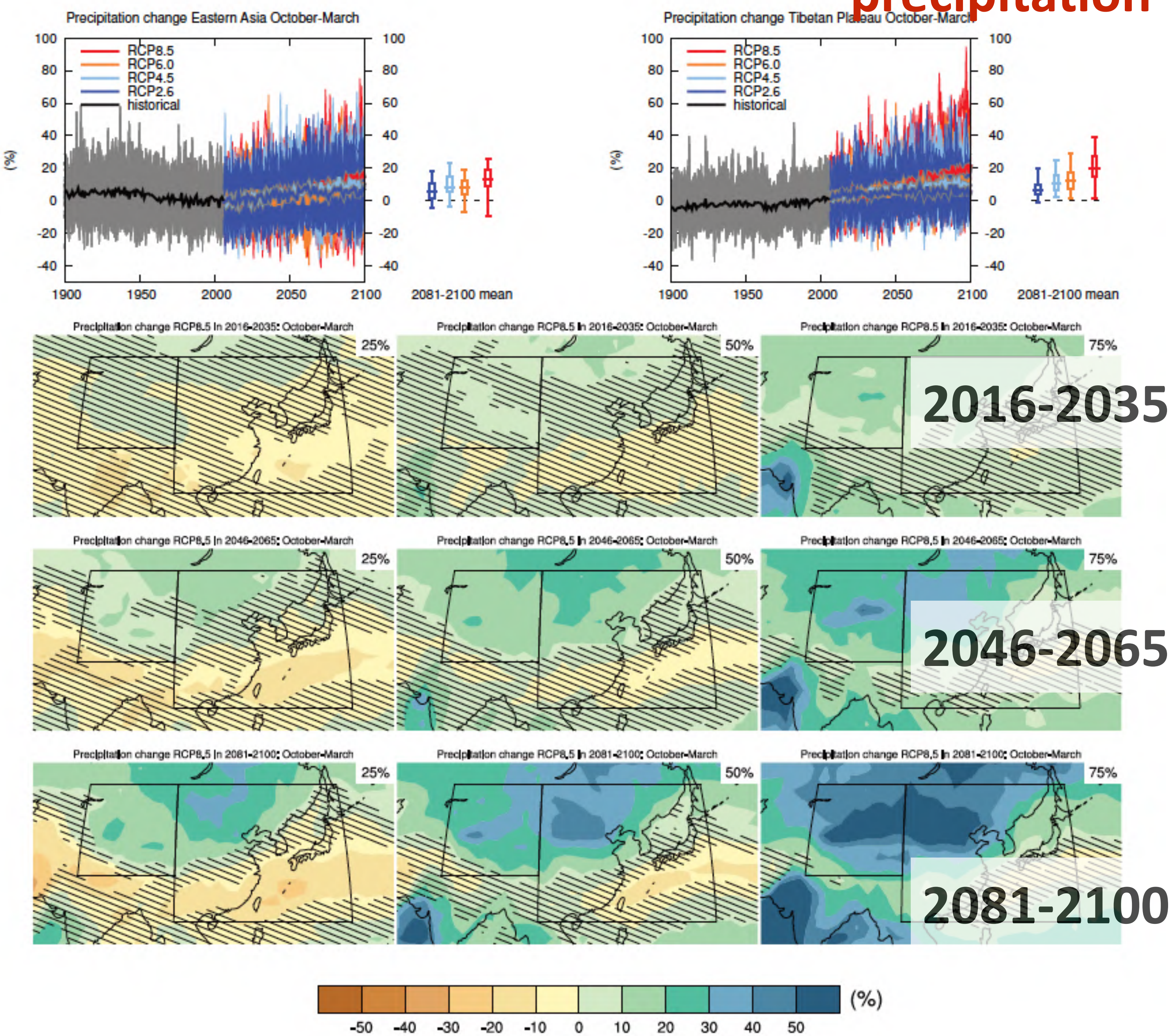
TCCIP Atlas



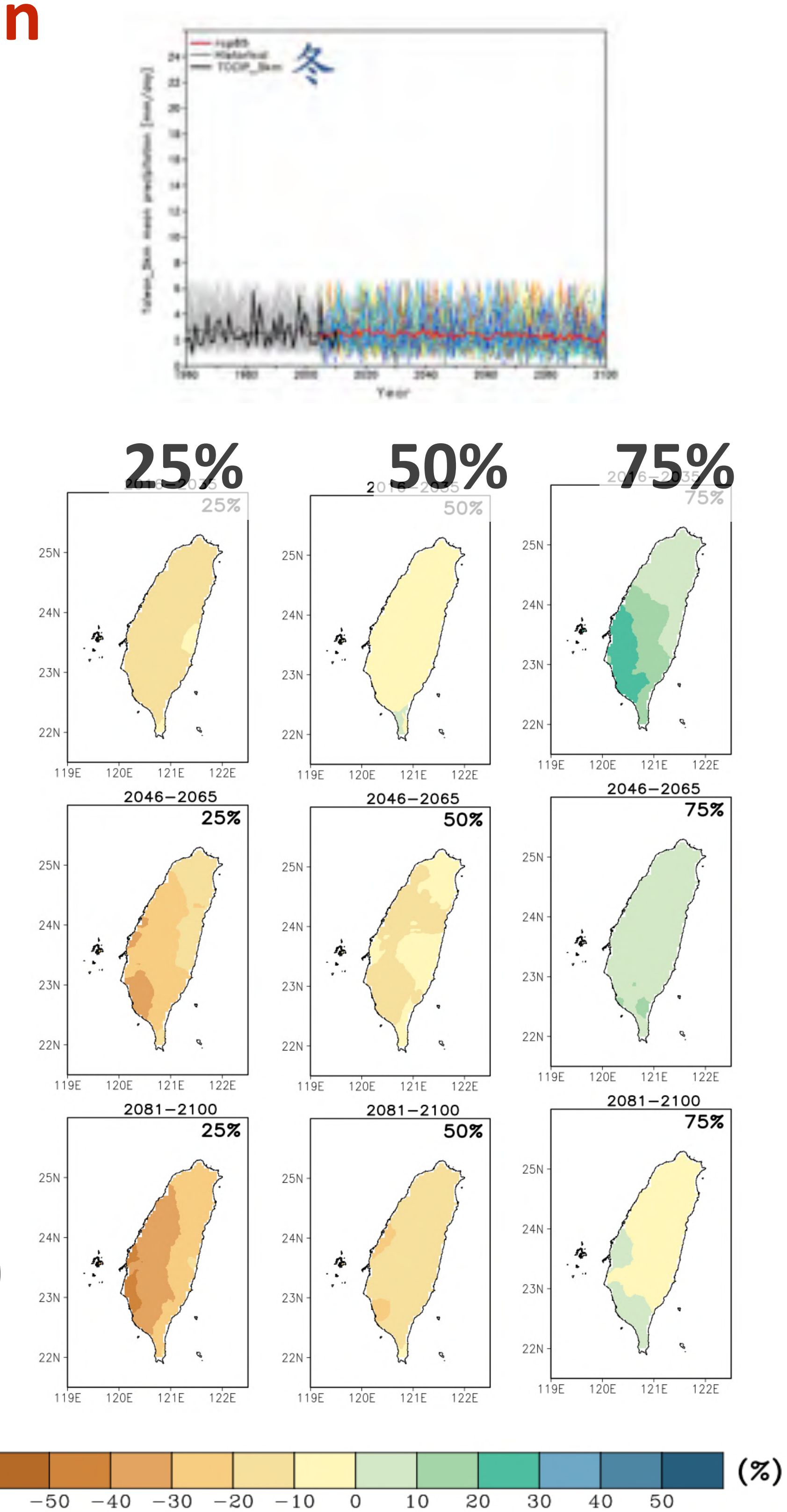
Future ONDJFM Mean Precipitation Change Atlas (RCP8.5)

IPCC AR5 Atlas

RCP 8.5
ONDJFM mean precipitation



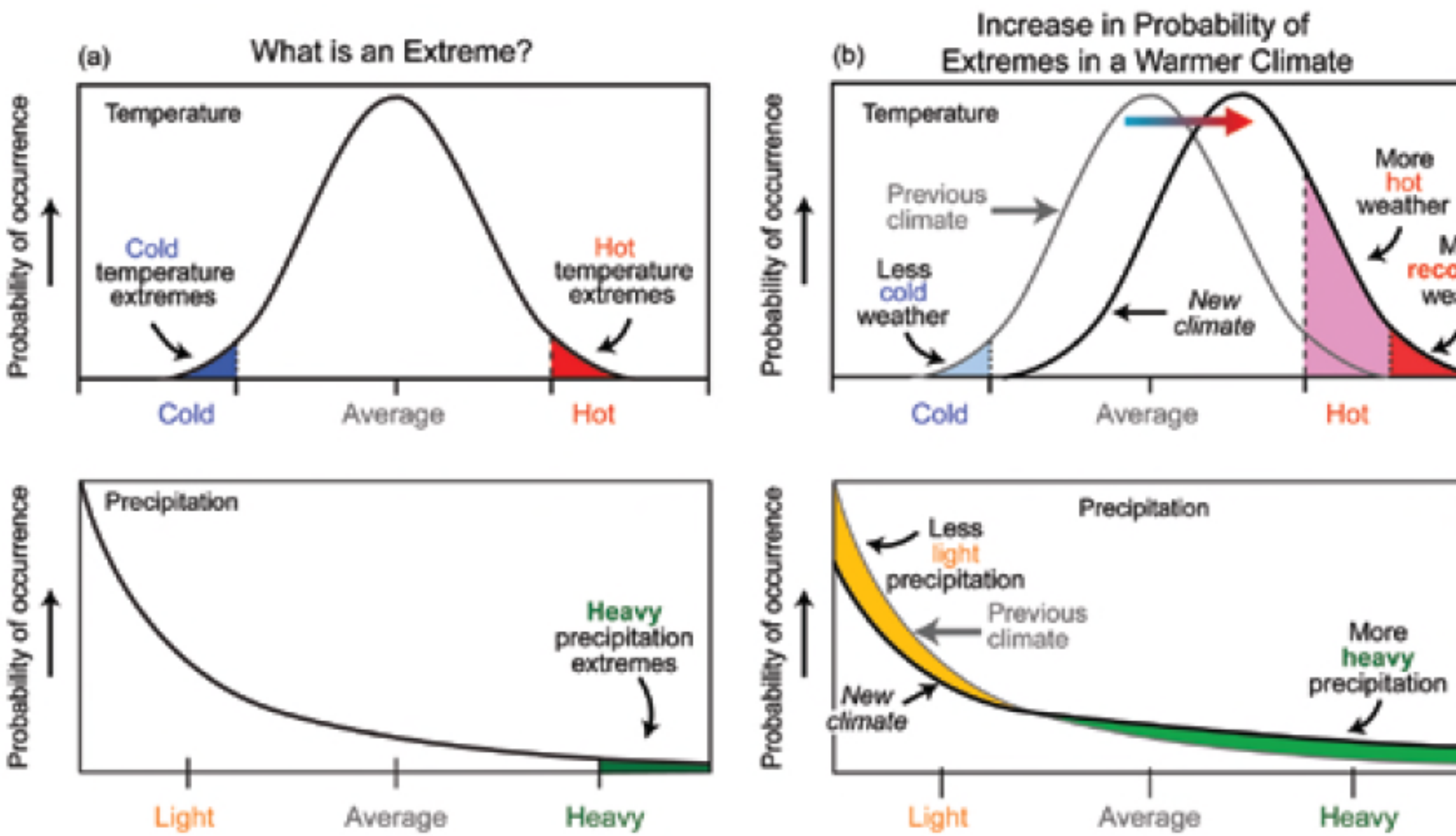
TCCIP Atlas

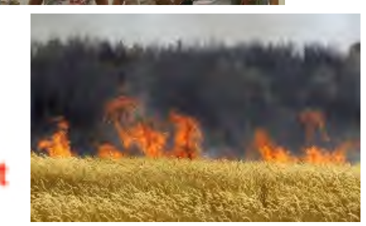


Projection of extreme events

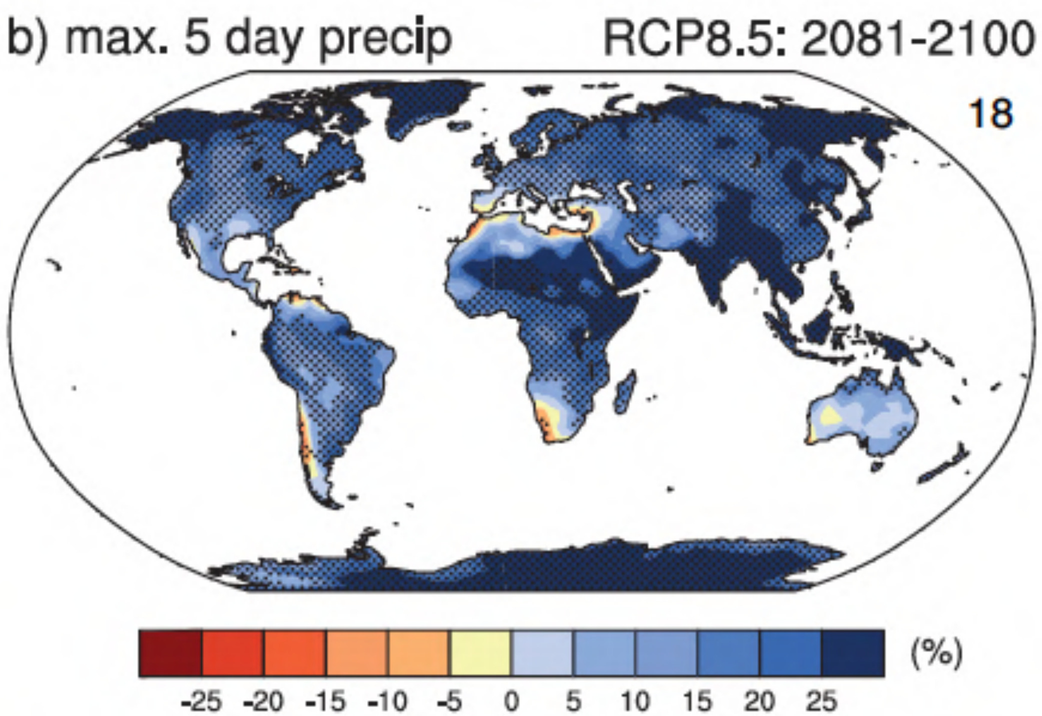
High-impact and high-resolution climate information needed for:

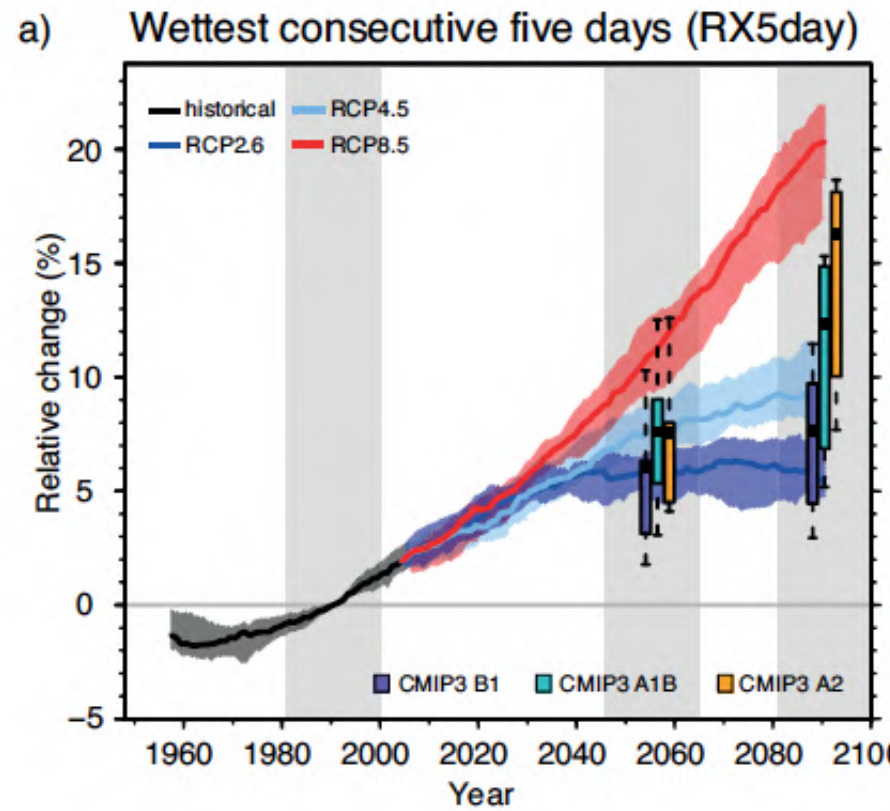
- assessing environmental and societal relevant climate change impacts
- developing adaptation strategies and mitigation efforts



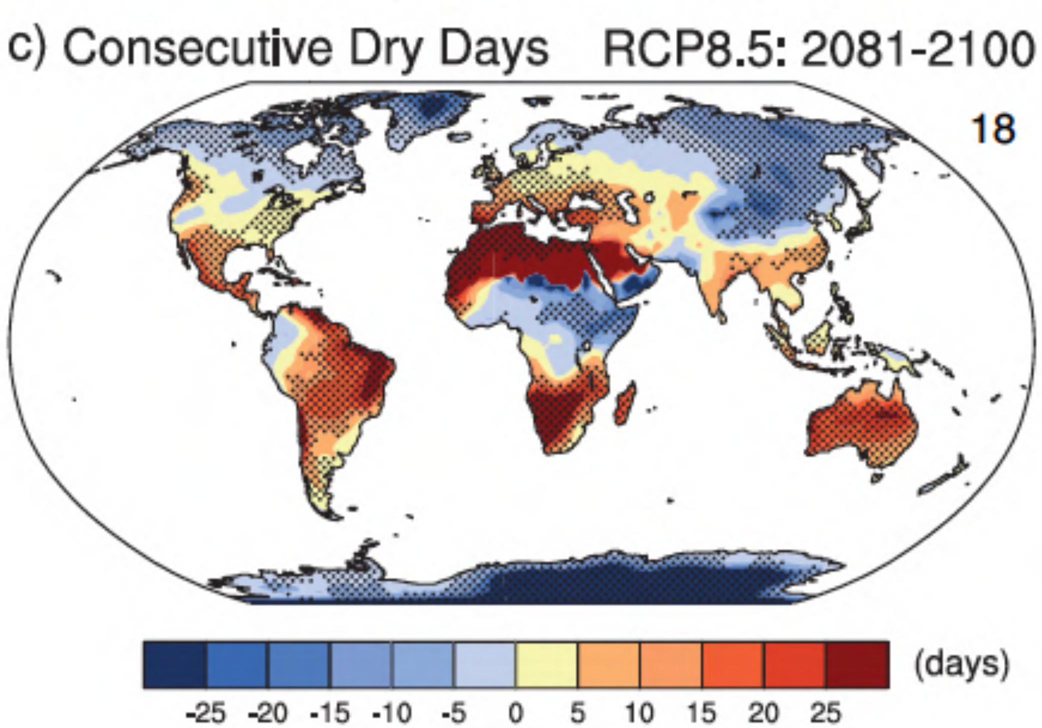


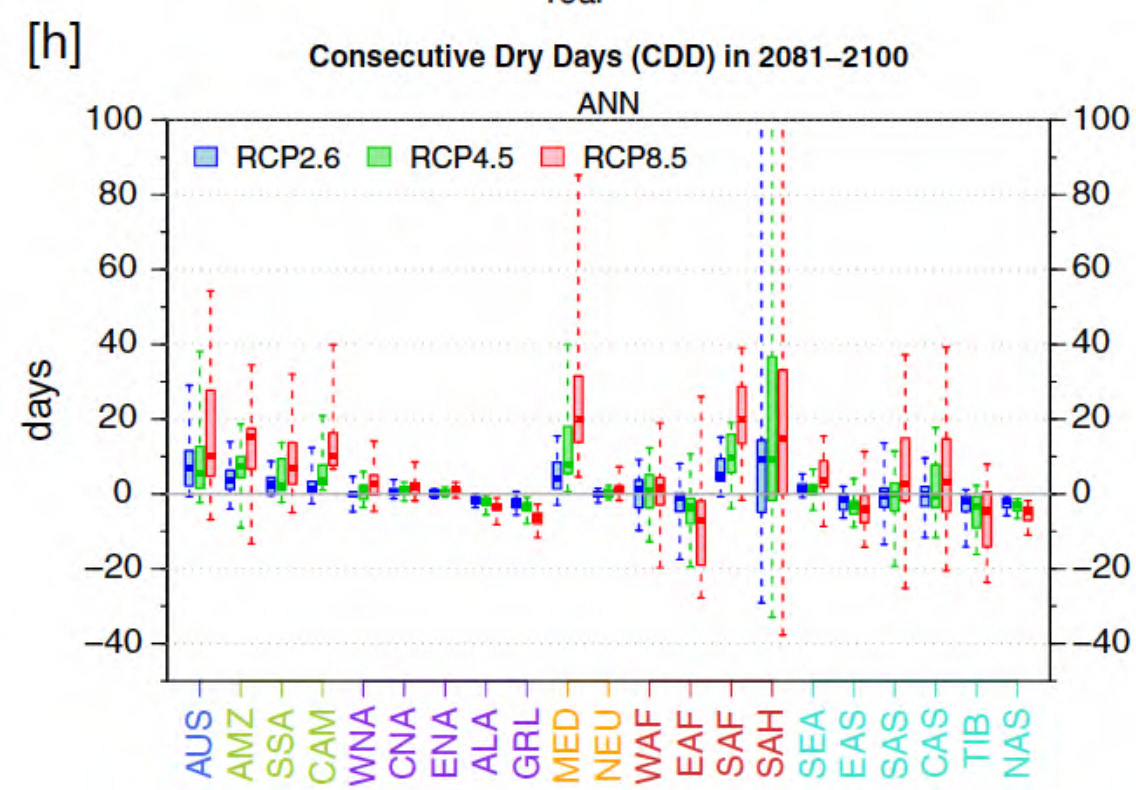
Wet Get Wetter and the Dry Drier





RX5day



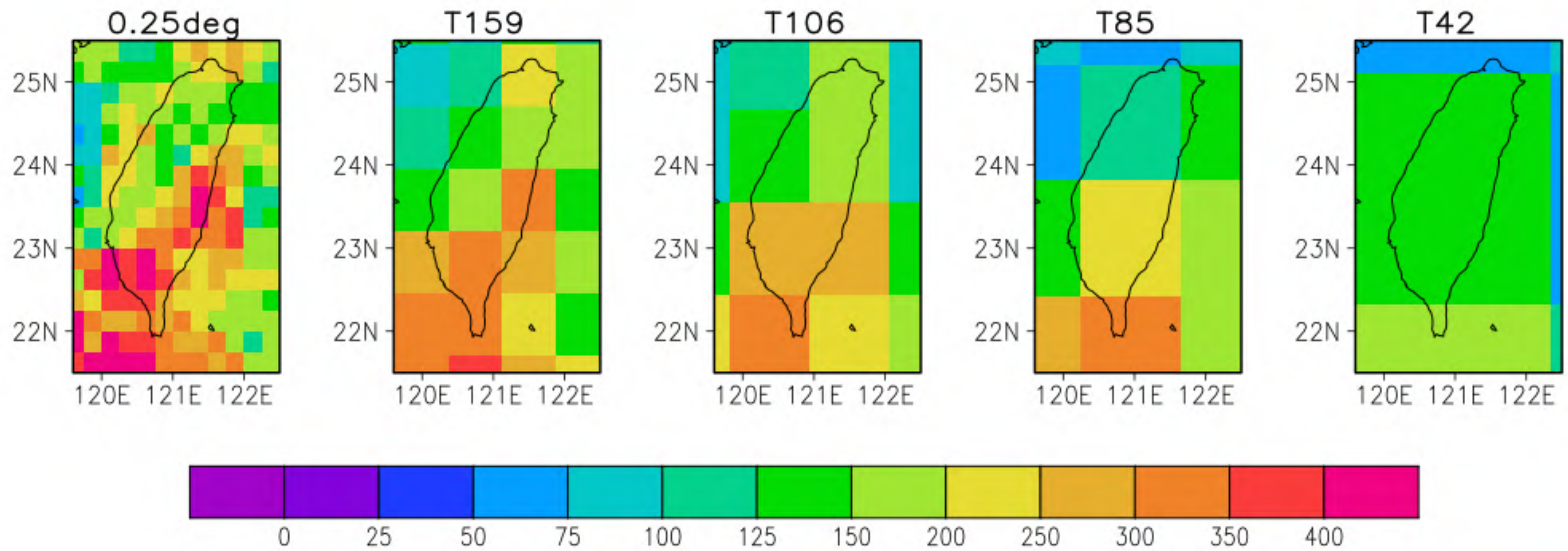


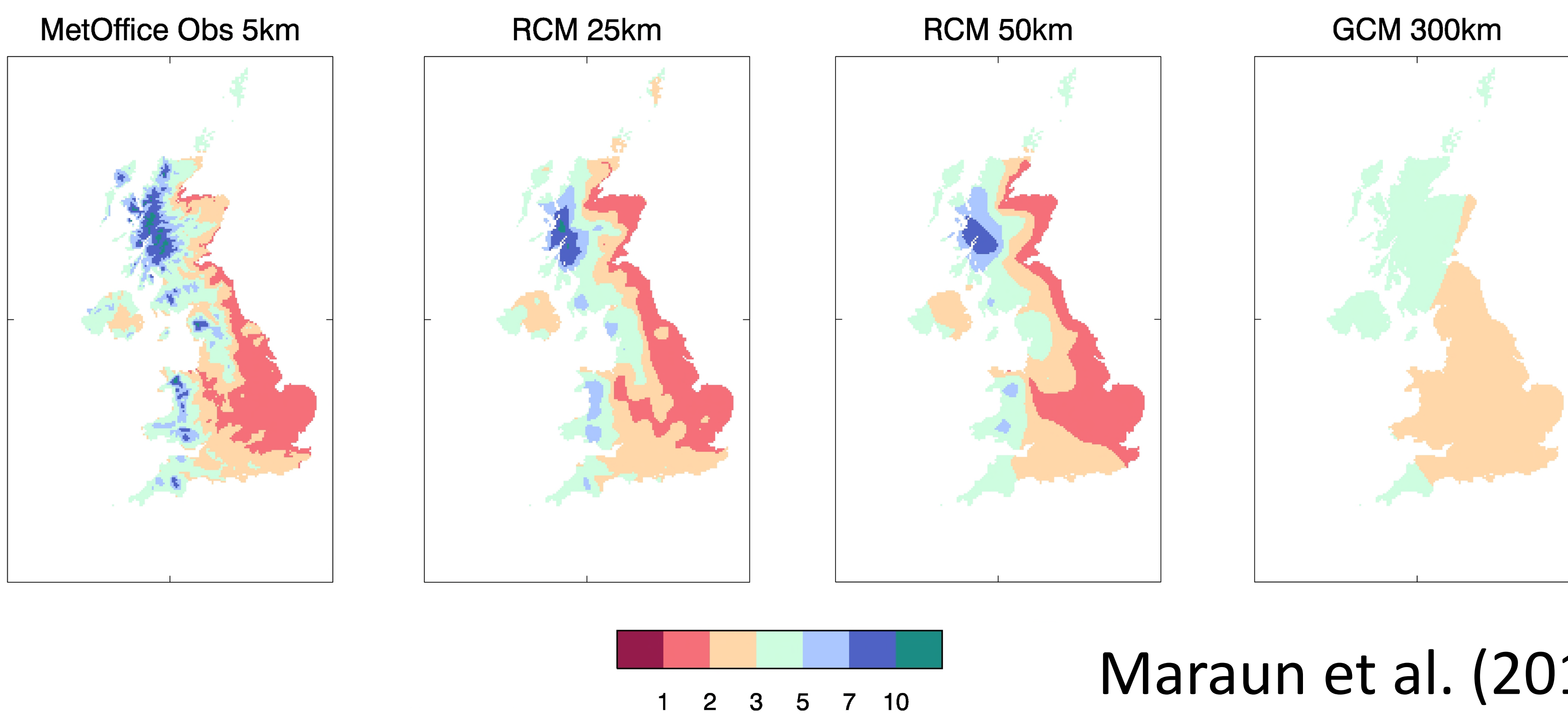
CDD

IPCC AR5, 2013

Spatial scale dependence of extreme events

TRMM
Rx1day





Maraun et al. (2010)

CMIP5 models for Daily data downscaling

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**	○	○	○	○	○
				~				
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

Daily Data Downscaling Procedure

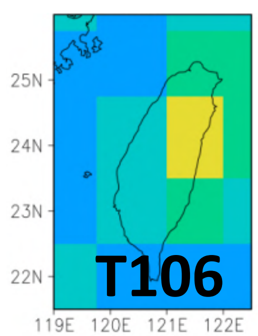
Step 1：Interpolation

- **Bilinear interpolation**
- **Model resolution → 0.05 deg**

Step 2：Bias-Correction using Quantile mapping

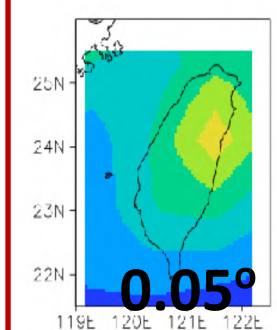
- **Set time window ±15 days**
- **Set bin size 10**

Step1



model

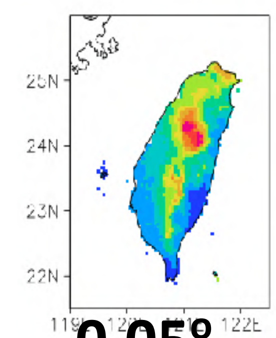
Interpolation



model

Step2

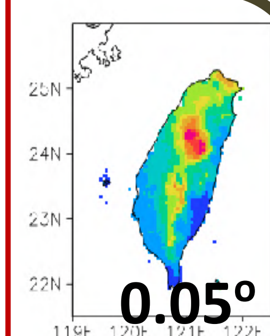
Bias-Correction



downscaled

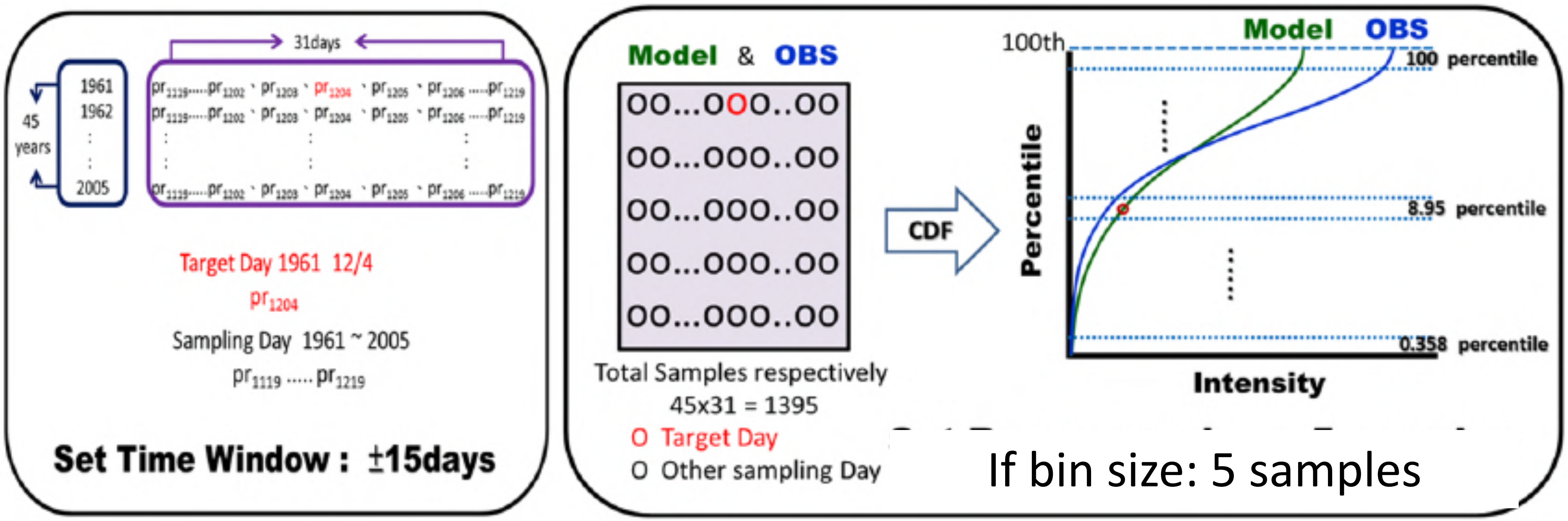
OBS：TCCIP_5km

Version	Resolution	Variable	Period
V2	0.05º X 0.05º	rainfall	1960~ 2005



OBS

Daily Data Bias Correction (Quantile Mapping)



$$OBS_{8.95p} = \sum Pr_{obs121st\text{-}125th} / 5$$

$$Model_{8.95p} = \sum Pr_{model121st\text{-}125th} / 5$$

Target Day 1961 12/4 Model Bias Correction

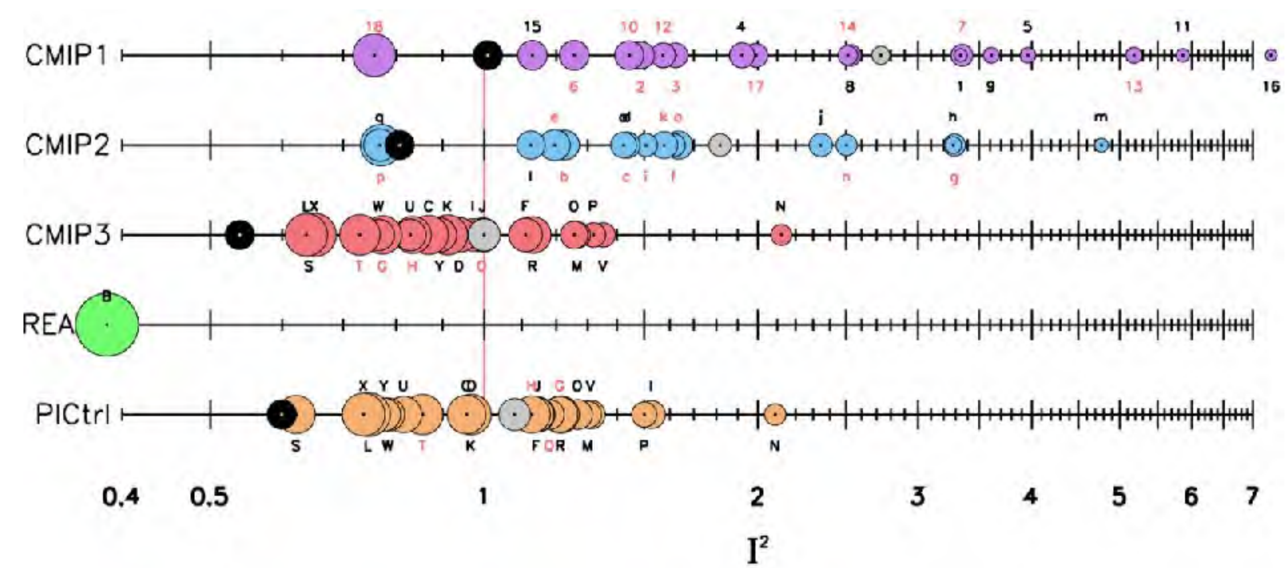
$$Model\_BC_{pr_{1204}} = (Model pr_{1204} \times OBS_{8.95p} / Model_{8.95p})$$

※ $$Model\_BC_{T_{1204}} = (Model T_{1204} - Model_{8.95p} + OBS_{8.95p})$$

How to decide the window and bin size?

	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

- $X_{vm} = (BC_{vmt} - OBS_{vt}),_{\overline{t=1979\sim2003}}$
- $Y_{vm} = (I_{vmt} - BC_{vmt}),_{\overline{t=2075\sim2099}}$
- $R^2{}_{vm} = (X_{vm}/\overline{|X_{vm}|}^{c})^2 + (Y_{vm}/\overline{|Y_{vm}|}^{c})^2$
- $R = \overline{R_{vm}}^{vm}$
  - I : $Before\ Bias\_Correction$
  - BC : $After\ Bias\_Correction$
  - v : Extreme index
  - m : $model$
  - c : $16\ case$



Reichler and Kim (2008, BAMS)

CMIP5 Model (Interpolated Only)

← Model Range of Extremes → Observation

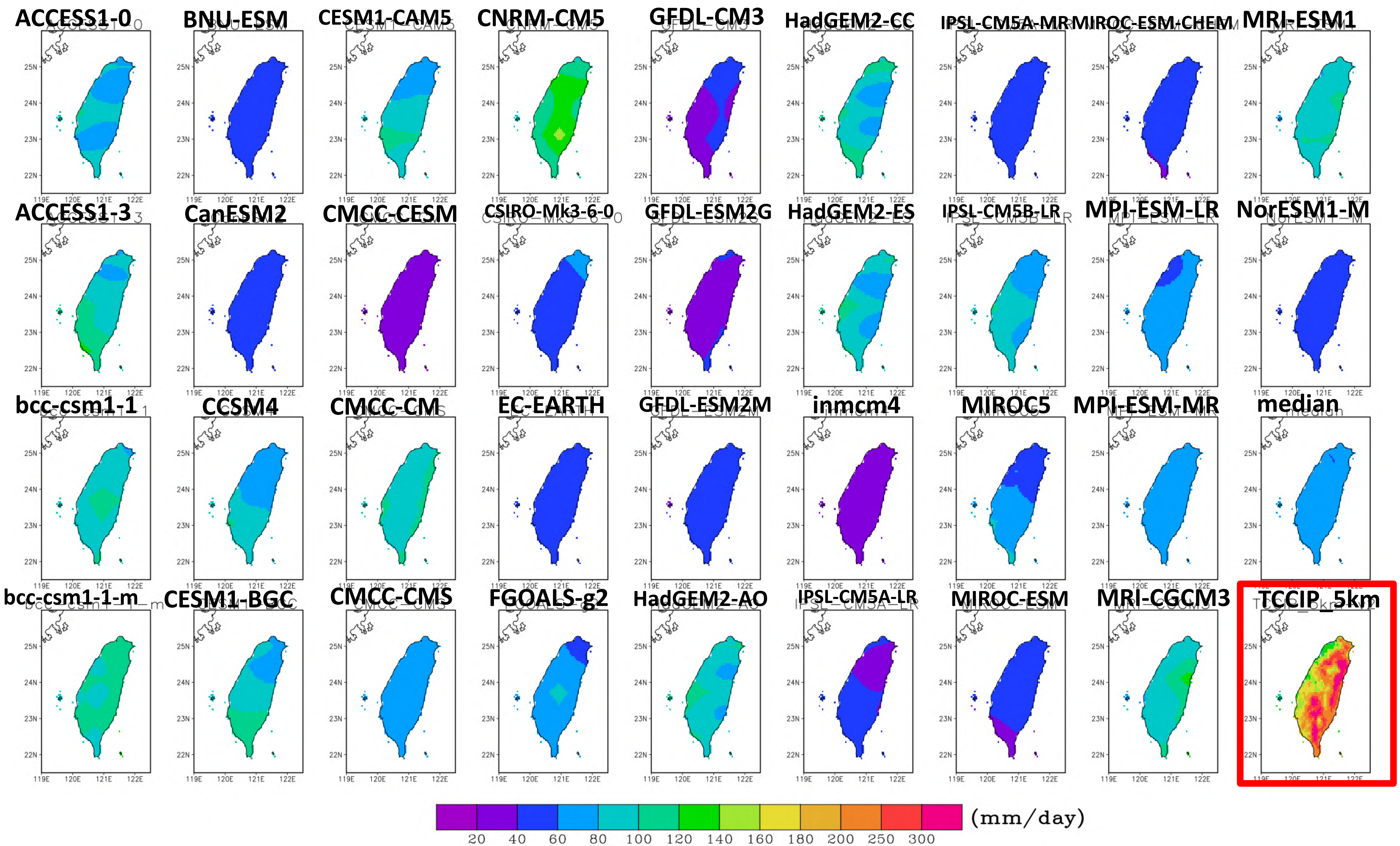
Index	10th %	25th%	Median	75th %	90th %	Mean	TCCIP	unit
rx1day	38.7	46.7	69.4	88.5	99.9	69.0	**220.2**	mm/day
rx5day	102.4	122.1	170.9	204.3	227.0	168.3	**406.4**	mm/day
sdii	5.7	6.6	7.6	9.0	10.5	7.9	**21.4**	mm/day
rr1	163.9	183.9	199.3	218.6	235.6	203.0	**89.8**	day
r10mm	29.5	36.9	45.0	53.7	62.7	45.9	**43.0**	day
r20mm	6.5	9.9	16.0	21.9	27.3	16.4	**25.4**	day
cdd	12.9	16.2	18.9	22.2	25.7	19.1	**46.1**	day
cwd	18.8	21.7	27.7	37.4	53.7	33.0	**9.0**	day
r95pTOT	371.8	407.2	479.1	543.1	585.9	480.2	**678.6**	mm/day
r99pTOT	135.7	151.1	183.1	216.6	250.5	189.8	**424.5**	mm/day
prcpTOT	1165.8	1304.2	1527.9	1809.4	2084.1	1589.7	**1926.8**	mm/day

CMIP5 Model (Downscaled)

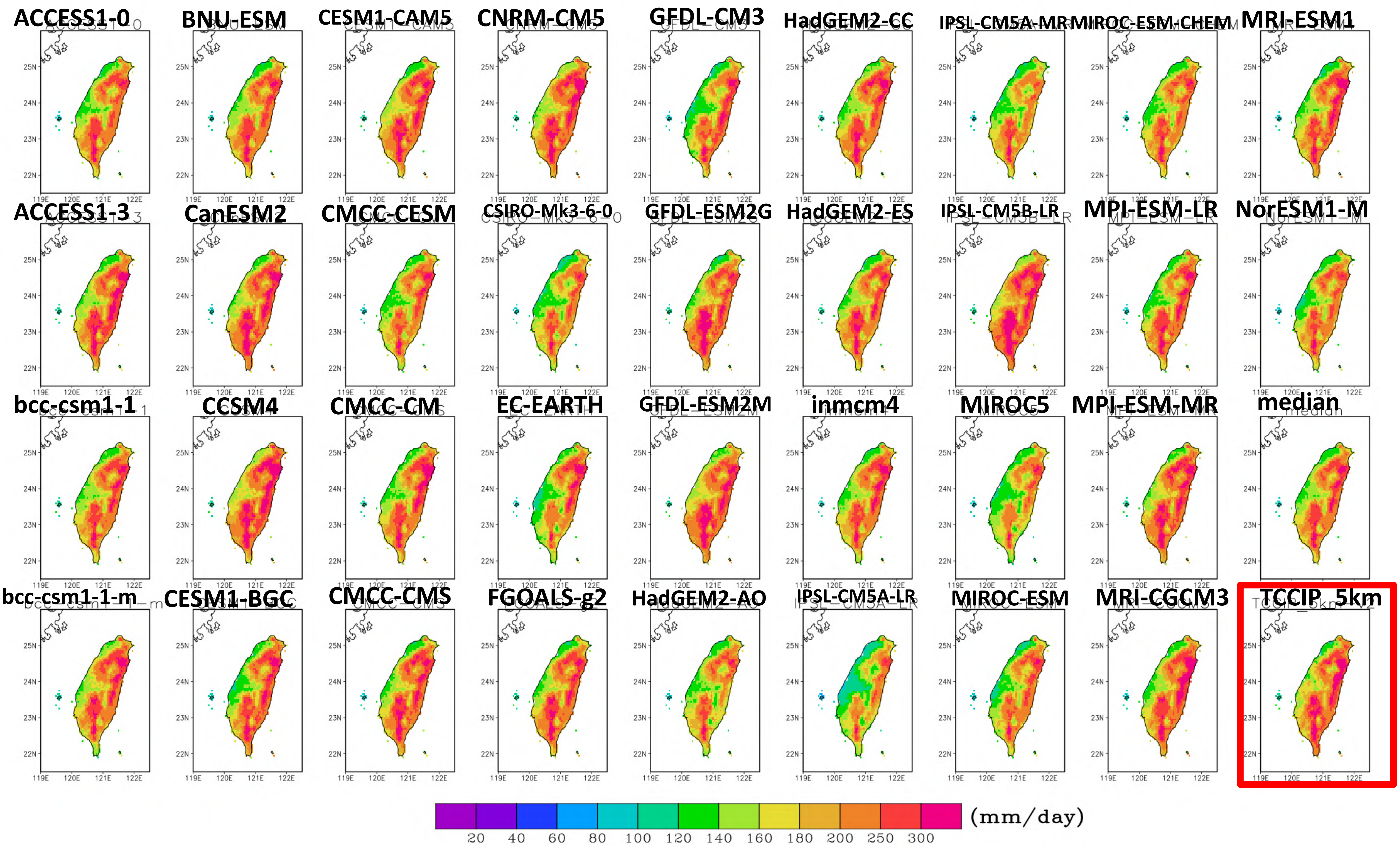
← Model Range of Extremes → Observation

Index	10th %	25th%	Median	75th %	90th %	Mean	TCCIP	unit
rx1day	179.5	192.4	204.5	218.4	228.3	204.8	**220.2**	mm/day
rx5day	383.0	405.1	439.2	485.5	517.3	447.6	**406.4**	mm/day
sdii	19.8	20.5	21.2	21.9	22.6	21.2	**21.4**	mm/day
rr1	89.0	90.3	92.1	93.8	95.0	92.0	**89.8**	day
r10mm	41.0	42.0	43.1	44.2	45.1	43.1	**43.0**	day
r20mm	23.5	24.3	25.1	26.0	26.8	25.1	**25.4**	day
cdd	40.5	42.9	46.0	49.7	52.7	46.5	**46.1**	day
cwd	9.1	10.2	11.3	12.7	13.8	11.4	**9.0**	day
r95pTOT	619.4	640.0	661.0	687.1	711.5	664.4	**678.6**	mm/day
r99pTOT	340.5	365.2	396.6	438.9	478.9	405.1	**424.5**	mm/day
prcpTOT	1782.5	1864.1	1927.1	2006.0	2095.6	1936.1	**1926.8**	mm/day

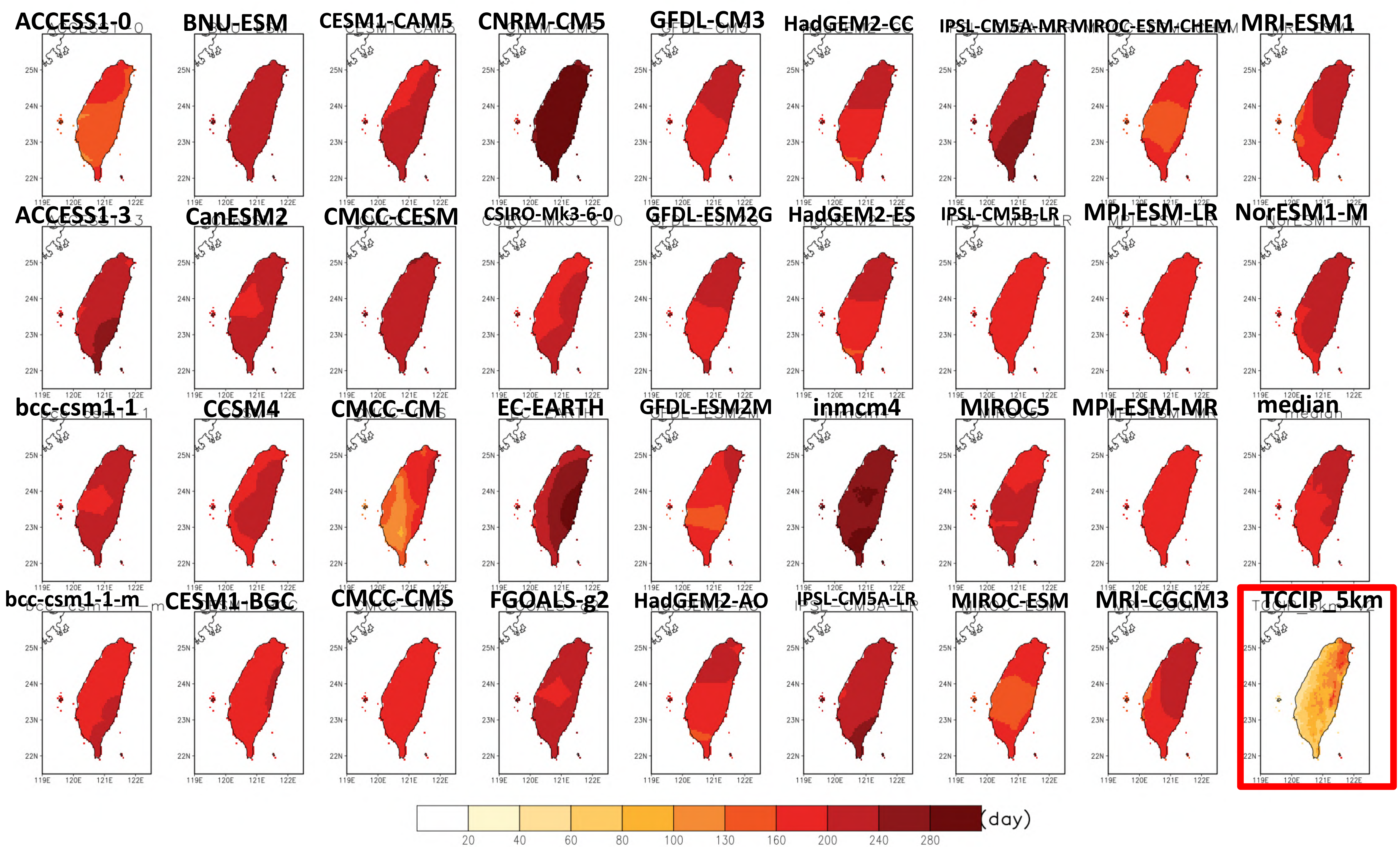
Interpolated CMIP5 Projection: RX1DAY



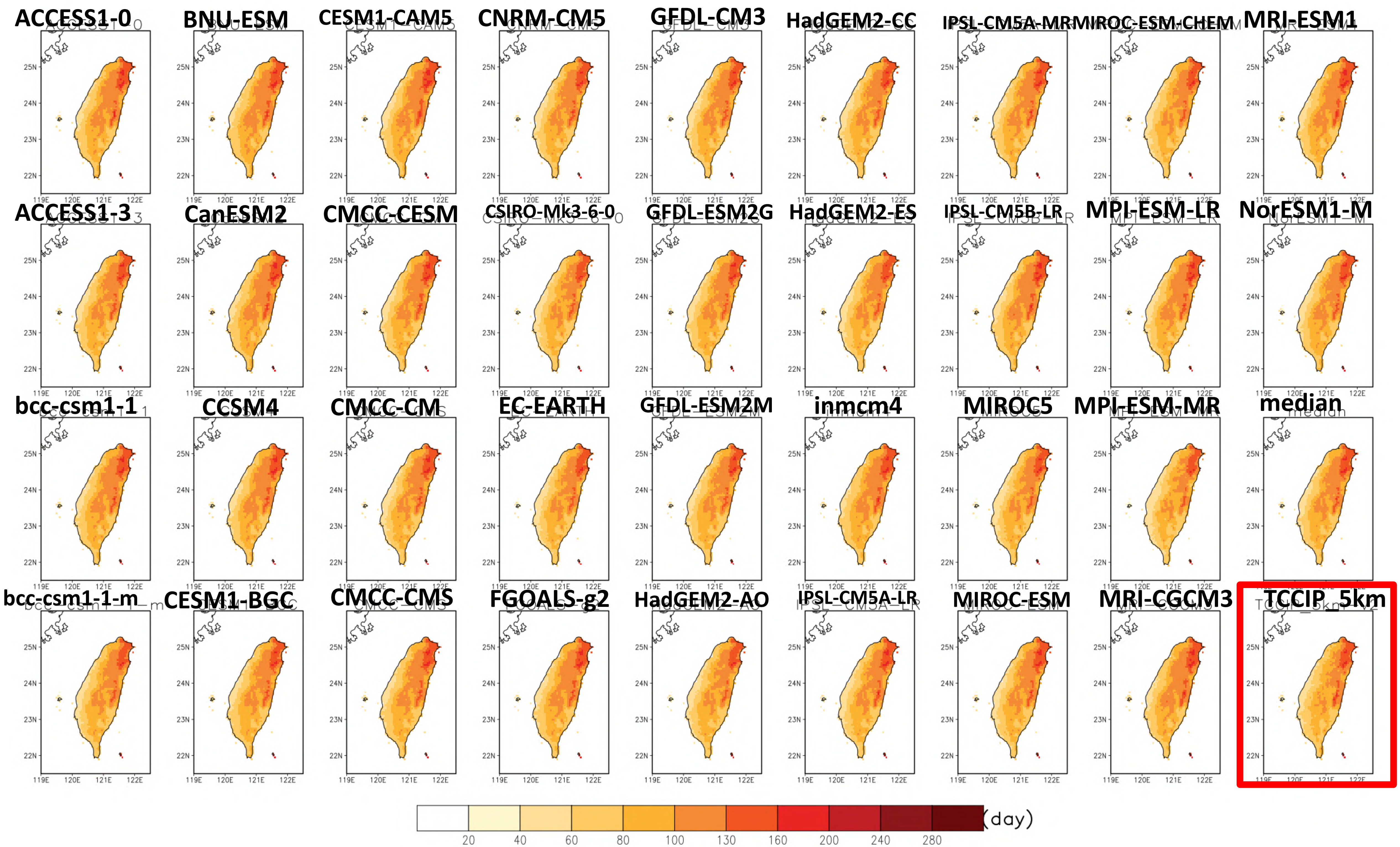
Downscaled CMIP5 Projection: RX1DAY



Interpolated CMIP5 Projection: RR1 (wet day freq.)

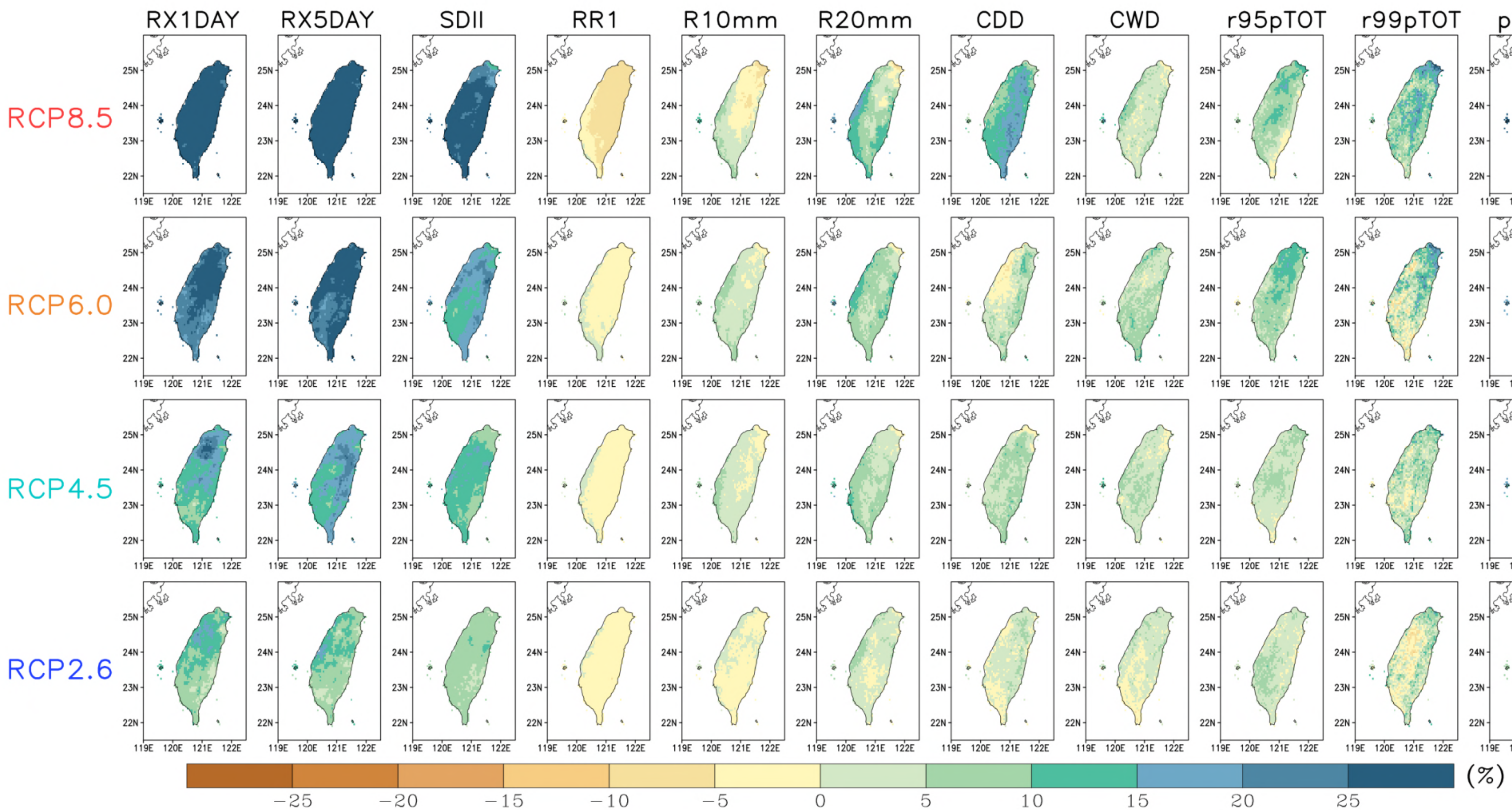


Downscaled CMIP5 Projection: RR1 (wet day freq.)

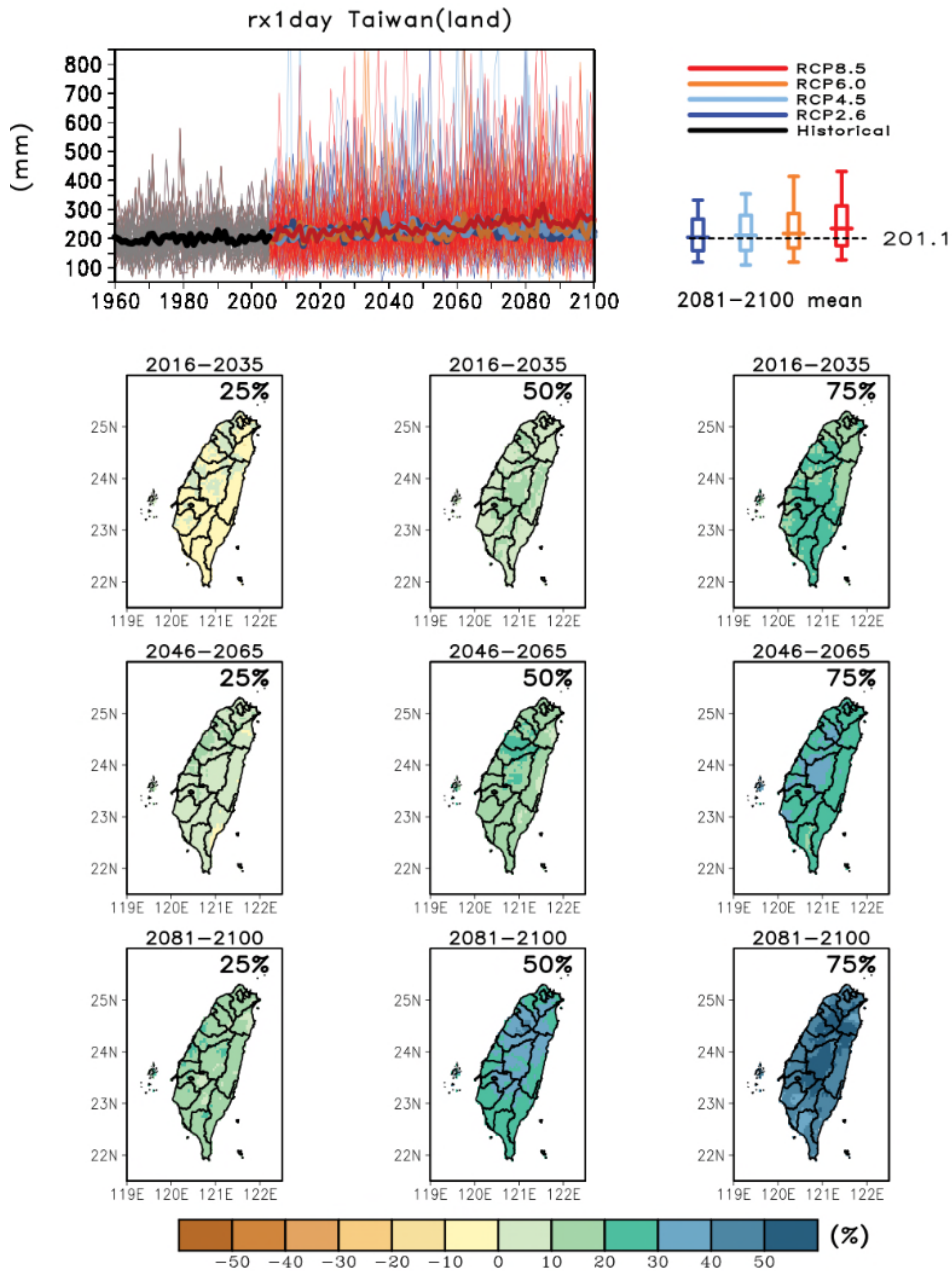


Downscaled Projection Changes in Rainfall Extremes

CMIP5 Model Projected Future Change of Rainfall Related Extreme Indices (Model Median, 2081-2100) Based on Downscaled Daily Data



Atlas and Table for Future Change of Rainfall Extreme (Rx1day)



區域	情境	世紀末 rx1day 百分比變化 (%)						
		最小	10	25	50	75	90	最大
北北基	rcp26	-12.8	-6.0	0.1	10.5	24.5	29.4	34.7
	rcp45	-10.1	-4.5	4.8	17.1	27.9	35.9	51.4
	rcp60	-3.7	1.6	15.9	24.9	33.6	49.2	65.7
	rcp85	-16.6	0.1	13.1	29.1	45.3	66.8	118.6
桃園	rcp26	-20.2	-3.0	3.9	12.5	22.0	28.6	39.0
	rcp45	-11.6	-5.4	7.0	19.2	29.4	36.9	43.1
	rcp60	1.5	6.1	15.8	26.7	33.2	45.0	64.4
	rcp85	-21.5	6.3	17.1	29.2	48.0	65.9	139.6
新竹	rcp26	-24.6	-1.3	5.2	15.3	24.0	32.8	50.9
	rcp45	-12.4	-5.7	5.5	20.7	34.1	41.5	54.5
	rcp60	3.0	9.3	19.2	29.7	36.2	53.8	64.4
	rcp85	-22.1	2.3	14.2	34.5	52.5	76.4	153.7
苗栗	rcp26	-27.3	-0.5	5.3	13.6	23.7	35.1	51.2
	rcp45	-11.4	-6.3	3.0	17.3	34.1	41.6	54.1
	rcp60	6.5	10.1	18.8	28.1	36.1	51.0	54.8
	rcp85	-23.1	-2.4	15.5	35.9	50.7	71.7	138.1
臺中	rcp26	-23.6	0.6	5.0	11.4	25.1	32.3	42.7
	rcp45	-11.6	-6.0	2.7	12.7	33.9	41.4	55.0
	rcp60	4.7	9.1	19.5	27.1	36.3	45.4	50.2
	rcp85	-23.8	-3.3	17.8	32.7	49.6	72.2	117.8
彰化	rcp26	-20.6	-0.5	2.9	10.5	22.2	34.8	41.6
	rcp45	-17.9	-3.8	3.1	11.1	28.6	39.3	44.9
	rcp60	1.8	3.6	16.1	22.3	32.4	43.8	46.8
	rcp85	-24.5	-3.7	19.5	28.8	45.1	75.2	105.4
南投	rcp26	-19.1	-0.7	4.7	10.9	25.5	35.0	43.3
	rcp45	-13.6	-5.5	3.4	12.9	33.9	43.2	57.4
	rcp60	3.4	8.5	18.6	28.0	35.8	46.3	49.9
	rcp85	-19.8	-2.8	16.1	31.7	53.6	79.8	106.7
雲林	rcp26	-15.6	-1.7	4.6	9.3	21.6	34.6	40.6
	rcp45	-16.2	-5.3	2.3	10.5	25.2	40.7	50.5
	rcp60	-4.1	0.3	13.4	20.6	32.1	46.6	50.6
	rcp85	-23.8	-5.5	18.1	28.7	44.9	78.3	100.6
嘉義	rcp26	-15.2	-2.0	3.8	8.7	24.9	33.4	39.3
	rcp45	-13.3	-4.3	3.4	11.3	27.5	40.1	52.2
	rcp60	-6.7	-2.2	12.9	22.4	31.7	45.0	49.4
	rcp85	-21.5	-4.7	13.3	31.0	48.7	80.7	100.8
臺南	rcp26	-11.0	-2.0	2.2	6.6	21.7	32.5	37.9
	rcp45	-13.5	-3.4	2.4	9.9	21.1	36.9	49.2
	rcp60	-11.4	-7.4	14.2	21.4	29.9	41.0	45.5
	rcp85	-23.1	-2.3	16.1	28.1	42.1	68.8	99.3
高雄	rcp26	-11.7	-4.9	1.6	6.1	22.7	32.7	43.0
	rcp45	-12.1	-6.6	0.0	7.9	21.8	35.4	52.4
	rcp60	-9.8	-3.1	11.6	22.6	29.6	38.9	41.0
	rcp85	-24.1	-2.3	13.2	28.7	45.3	64.3	90.8
屏東	rcp26	-12.9	-3.9	1.1	7.2	22.2	32.6	39.7
	rcp45	-15.4	-9.0	1.0	9.6	20.6	36.1	53.9
	rcp60	-10.3	-0.1	11.3	21.1	28.4	35.2	39.4
	rcp85	-26.2	3.9	15.7	26.4	40.7	57.4	79.3
宜蘭	rcp26	-12.4	-3.1	1.1	7.9	25.3	30.3	38.3
	rcp45	-9.8	-4.9	3.3	14.0	28.1	35.1	64.4
	rcp60	-5.8	0.4	16.5	25.3	33.7	50.1	59.5
	rcp85	-21.0	-4.8	10.6	30.0	48.9	75.6	100.3
花蓮	rcp26	-11.2	-3.5	1.7	8.3	23.6	30.6	39.6
	rcp45	-15.7	-5.4	4.2	14.1	29.3	40.3	62.6
	rcp60	-3.1	3.8	16.6	25.5	35.9	51.7	57.9
	rcp85	-19.7	-1.5	13.5	30.8	47.9	74.1	95.7
臺東	rcp26	-9.4	-5.6	-0.6	6.4	22.5	31.2	39.5
	rcp45	-20.3	-7.3	1.7	9.7	26.5	37.7	47.8
	rcp60	-3.4	3.4	9.5	19.8	31.0	41.6	67.0
	rcp85	-21.7	2.3	13.5	27.1	45.1	61.2	81.3
澎湖	rcp26	-10.3	-4.2	3.1	12.3	21.7	32.4	39.8
	rcp45	-6.2	-2.3	6.8	11.3	20.2	36.3	45.4
	rcp60	-10.8	0.6	11.8	20.4	35.2	42.6	53.1
	rcp85	-18.8	2.8	20.6	29.2	45.2	68.5	120.5

Test Stationarity Assumption

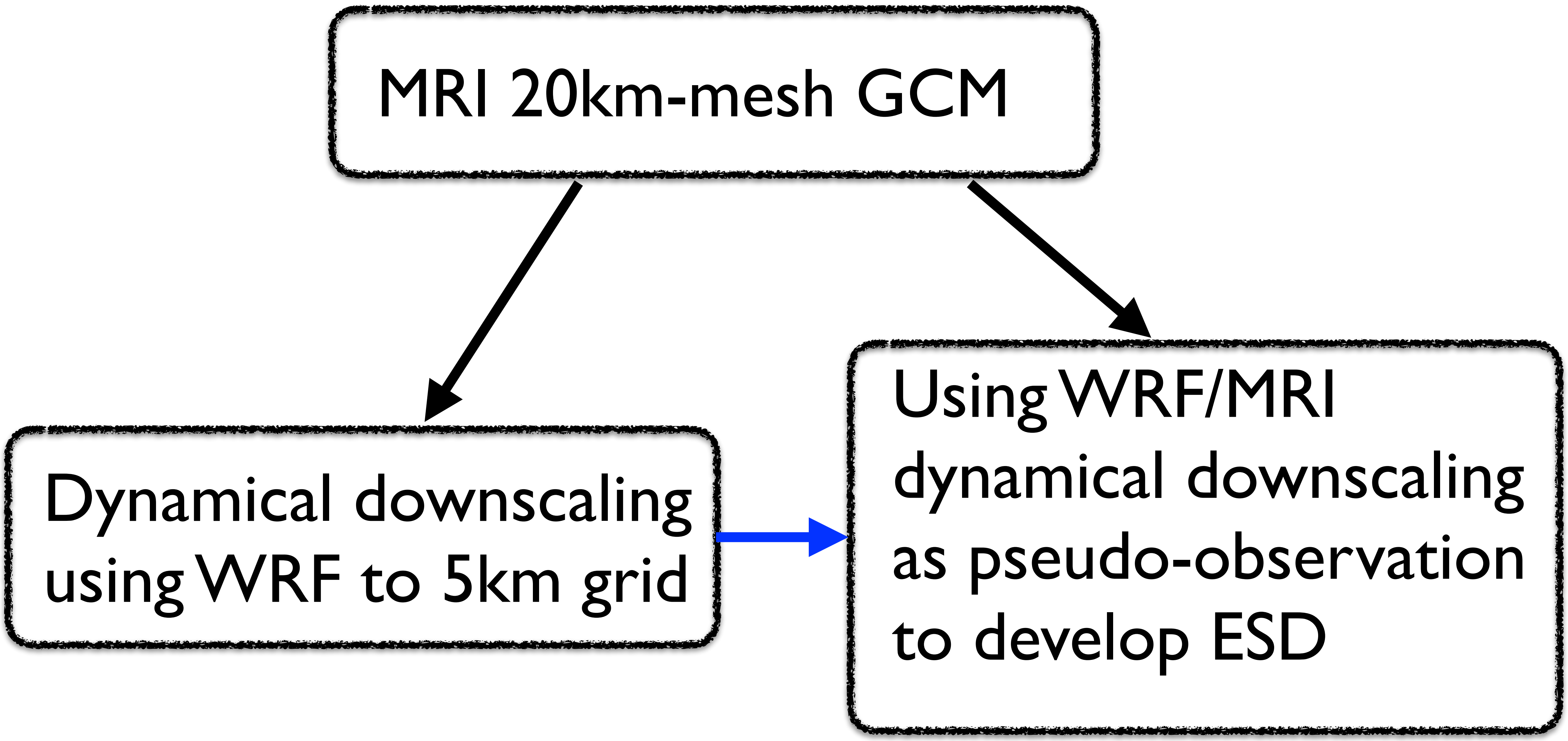
"Stationarity Assumption"

All ESD methods assume:
historical relations ⇒ valid in future
(climate has changed!)

Using WRF/MRI dynamical downscaling as pseudo-observation

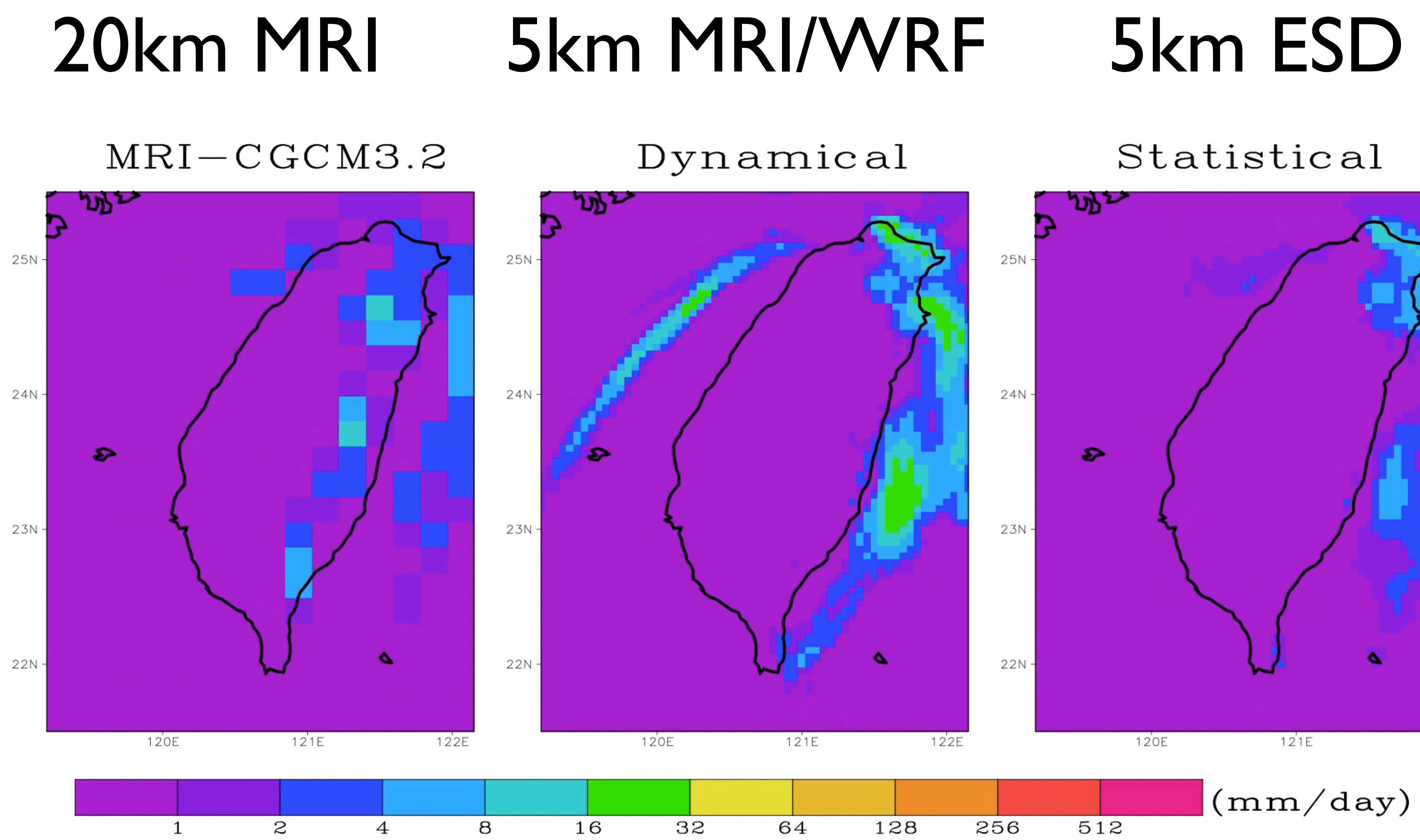
Dynamical vs. Statistical downscaling

Dynamical downscaling vs. Statistical downscaling



Dynamical vs. Statistical downscaling

Comparison of 1994 daily rainfall evolution



Dynamical vs. Statistical downscaling

historical(1979~2003)		
Index	Dynamical	Statistical
rx1day	223.4	231.5
rx5day	389.9	398.0
sdii	17.4	17.6
rr1	130.4	132.4
r10mm	51.8	53.4
r20mm	30.8	31.8
r80mm	5.1	4.7
r200mm	0.8	0.8
cdd	34.0	34.1
cwd	14.9	13.4
r95pTOT	642.0	627.0
r99pTOT	395.8	376.0
prcpTOT	2337.5	2356.5

rcp8.5(2075~2099)		
Index	Dynamical	Statistical
rx1day	243.1	351.1
rx5day	420.5	558.0
sdii	19.1	20.8
rr1	125.0	130.2
r10mm	50.9	54.1
r20mm	31.1	33.2
r80mm	5.7	5.7
r200mm	0.8	1.2
cdd	32.5	32.8
cwd	15.1	14.4
r95pTOT	721.6	803.8
r99pTOT	409.6	509.7
prcpTOT	2400.2	2655.5

Summary

- Large resources are needed for dealing with all the uncertainties using dynamical downscaling approach. Statistical approach is a relatively simple and cheap alternative..
- Statistical downscaling methods for daily data have been developed and applied to CMIP5 data archive. Quantile mapping with proper selection of data time window and number of quantile bins can effectively remove the model bias and adjust spatial scale dependence of extreme indices.
- Using dynamical downscaling result as surrogate observation for daily data statistical downscaling, model project future changes in extreme rainfall tends to be larger than those from dynamical downscaling