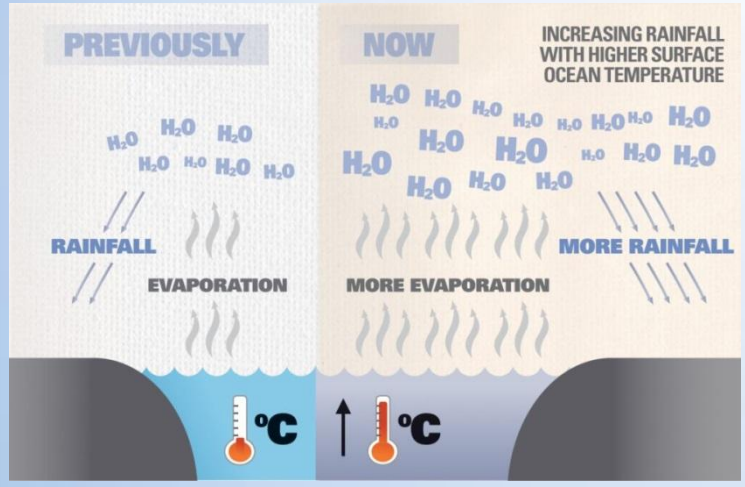
Rainfall projection for Hong Kong in the 21st century

M S Cheung, H S Chan & H W Tong

Hong Kong Observatory

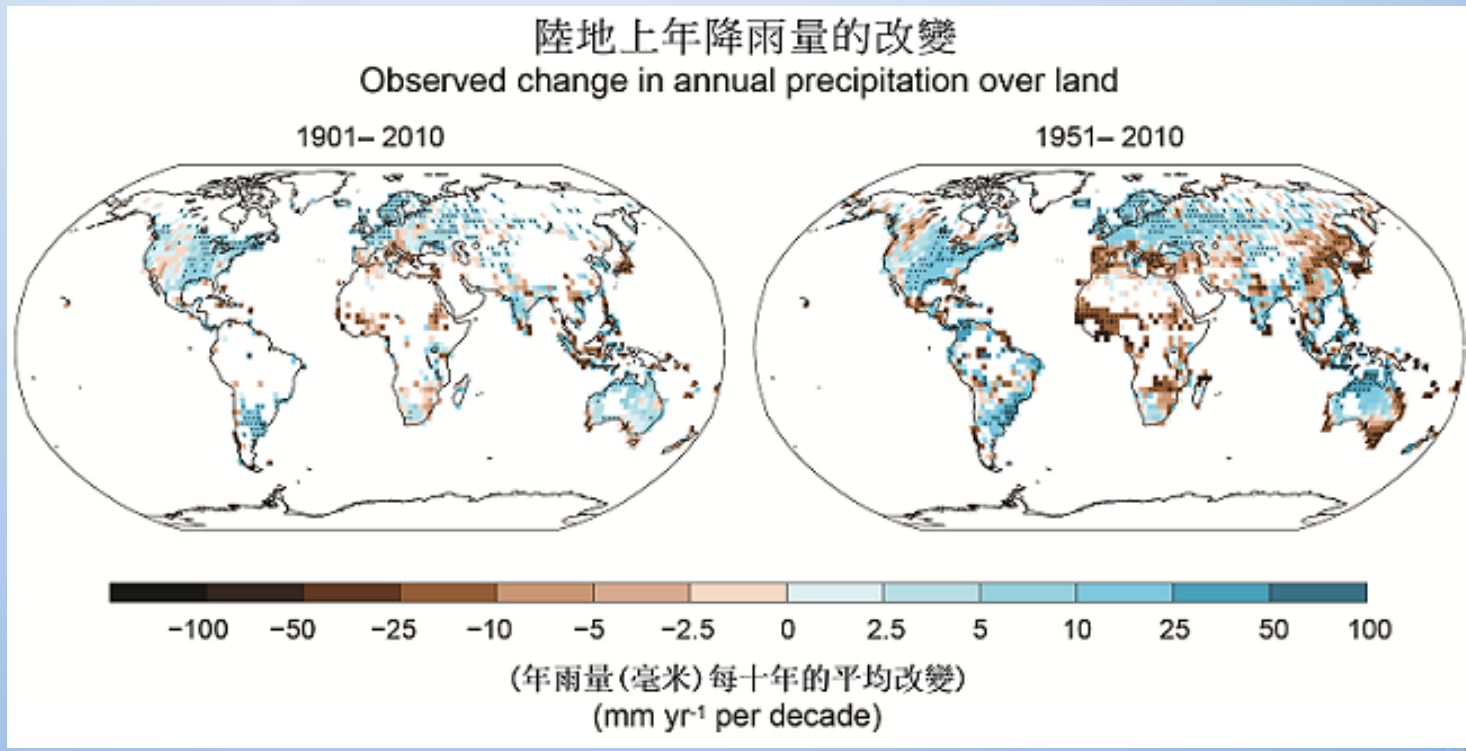
12 Nov 2014

Enhanced water cycle



Source: Climate Commission, Australia

- Higher sea surface temperature increases evaporation
- A warming atmosphere can hold more water vapour
- Annual precipitation increases in some places



Source: IPCC AR5

Impact on Hong Kong

- Landslides
- Flooding
- Drought

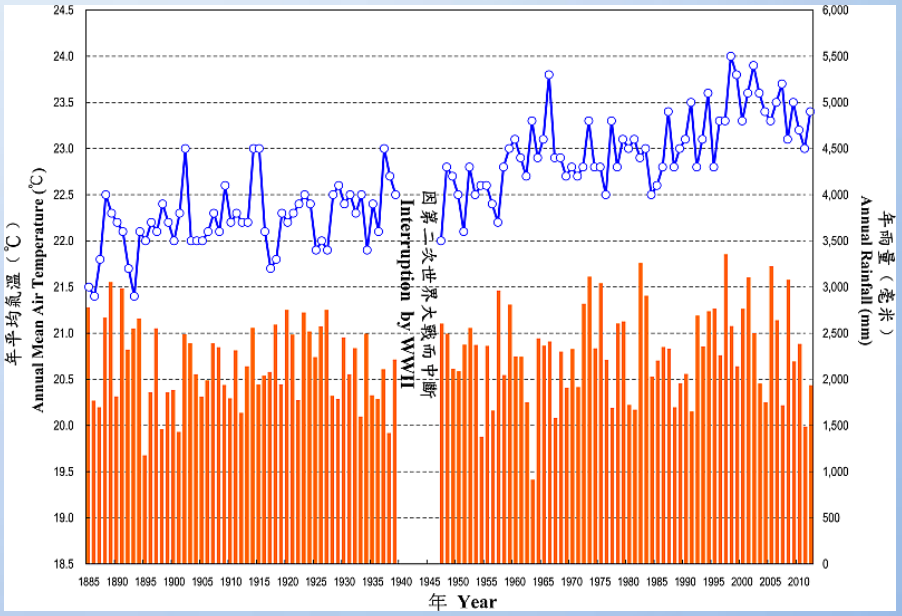
Hong Kong Observatory

- Regular meteorological observations commenced in **1884**, including temperature, rainfall, pressure, sunshine duration, wind speed/direction, etc.
- **130 years** of climate data serve as valuable resources for climate change studies and provide scientific basis to support the formulation of mitigation and adaptation measures of climate change.

1st AWS at Shatin

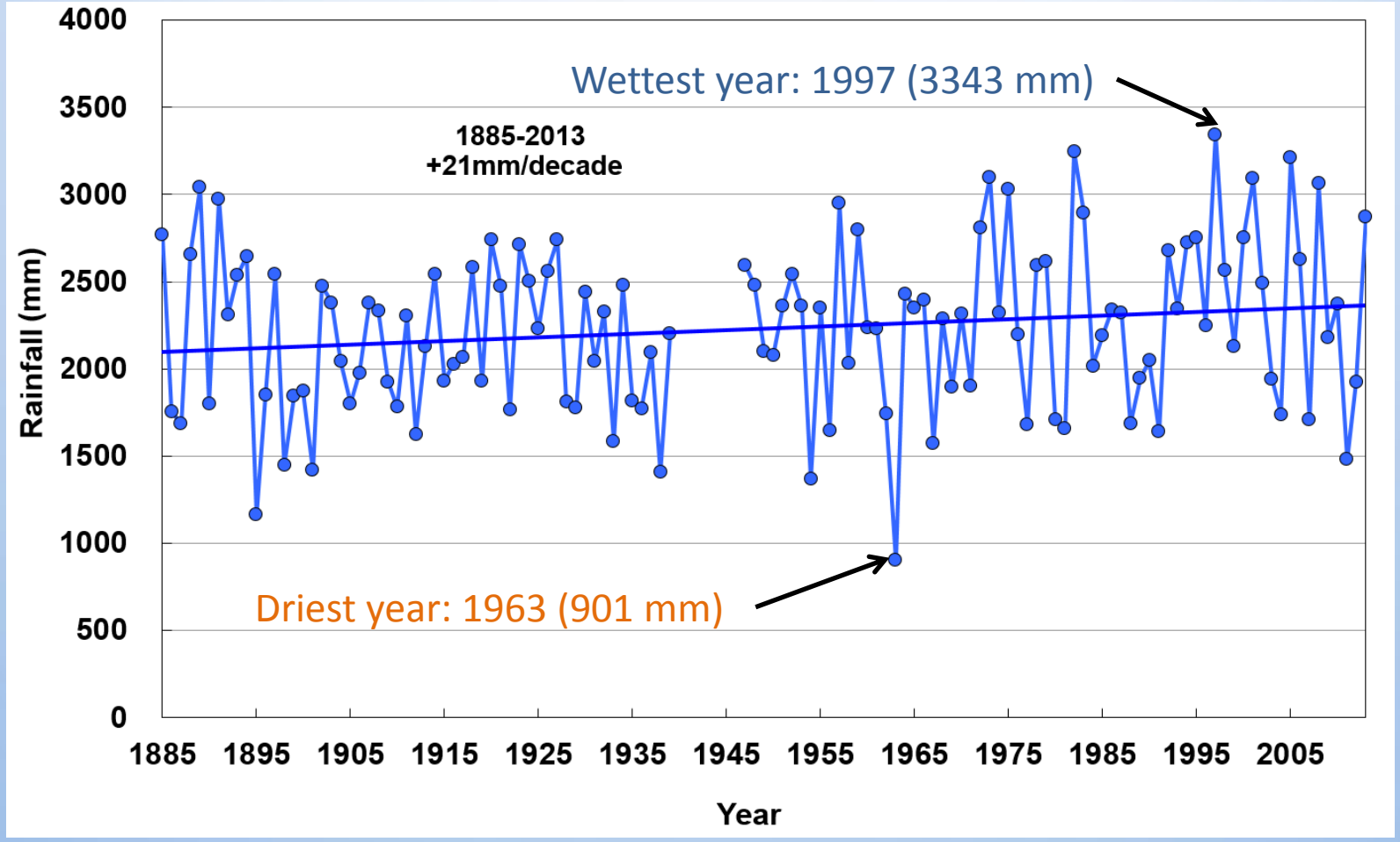
HKO Headquarters

King's Park (since 1950s)



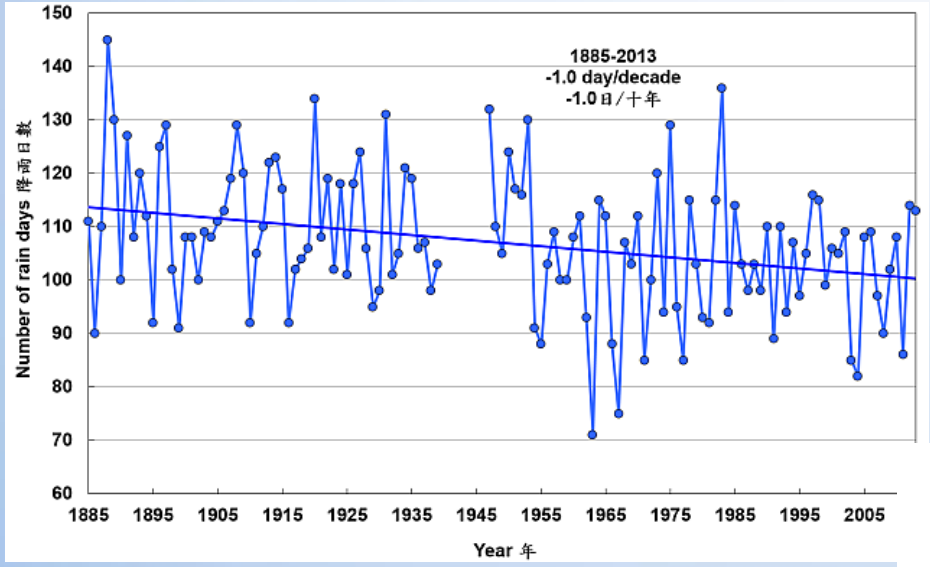
香港天文台
HONG KONG OBSERVATORY

Annual rainfall recorded at Hong Kong Observatory (1885-2013)

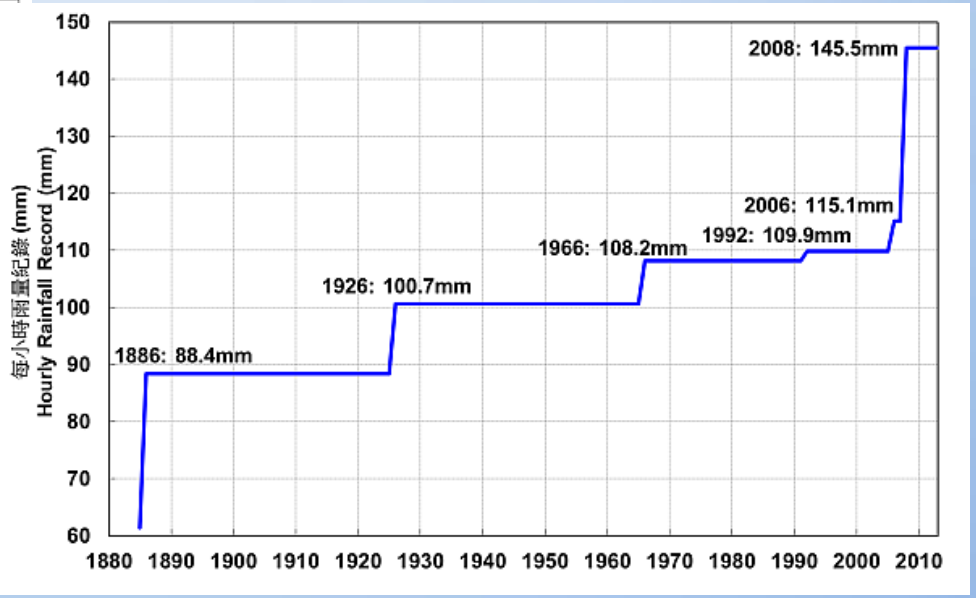


- A weak rising trend
- The annual rainfall trend is small compared to the year-to-year fluctuation

More frequent heavy rain



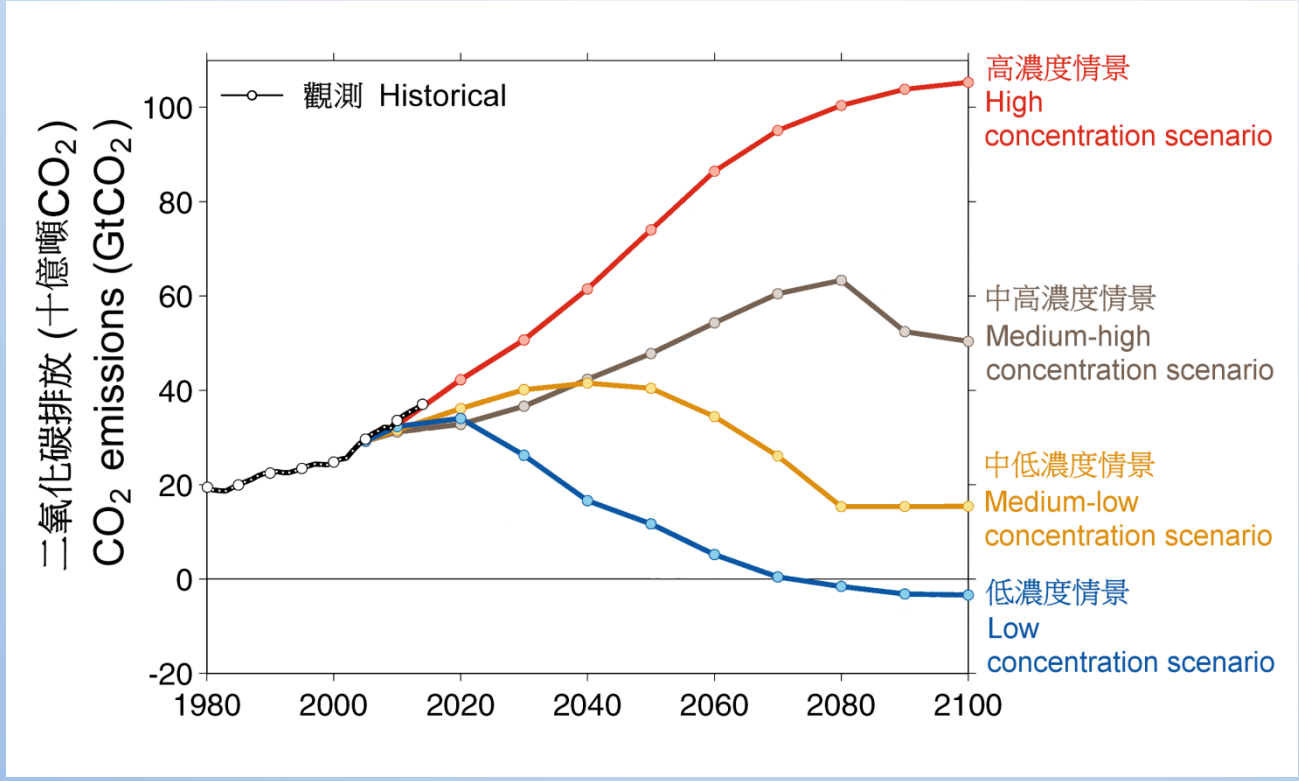
Number of rain days declines



More frequent record breaking extreme rainfall

Greenhouse gas concentration scenarios

- 4 RCPs: RCP2.6, RCP4.5, RCP6.0, RCP8.5
- Indentified by the radiative forcing in year 2100 relative to 1750: 2.6 Wm^{-2} for RCP2.6, 4.5 Wm^{-2} for RCP4.5, etc.



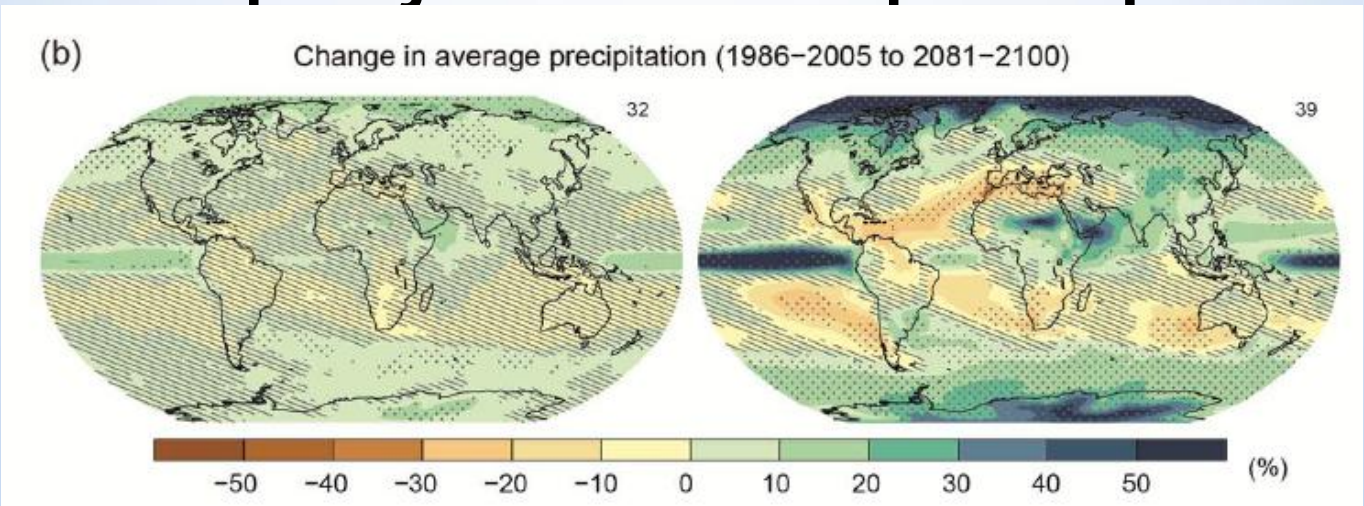
Source: globalcarbonproject.org

RCP8.5 – high concentration/ emission scenario

RCP2.6 – low concentration/ emission scenario

The emission is tracking along the RCP8.5 !

Global projection of precipitation

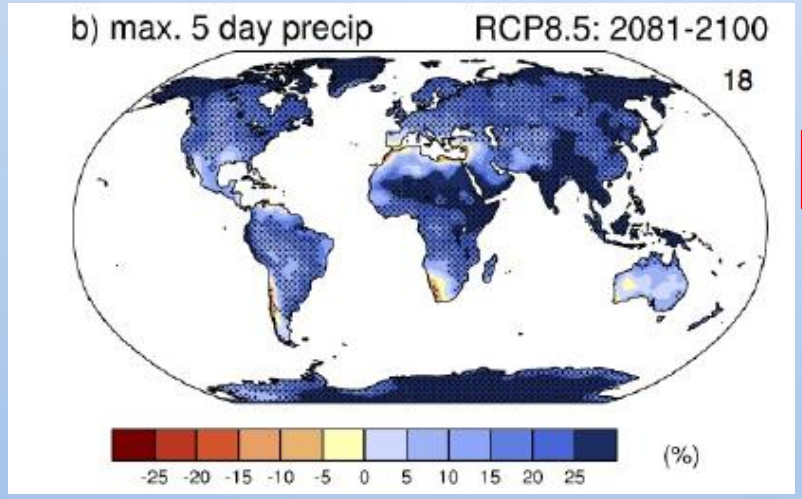


Source: IPCC AR5

Low greenhouse gas concentration scenario

High greenhouse gas concentration scenario

Precipitation generally increases over East Asia under high greenhouse gas scenario

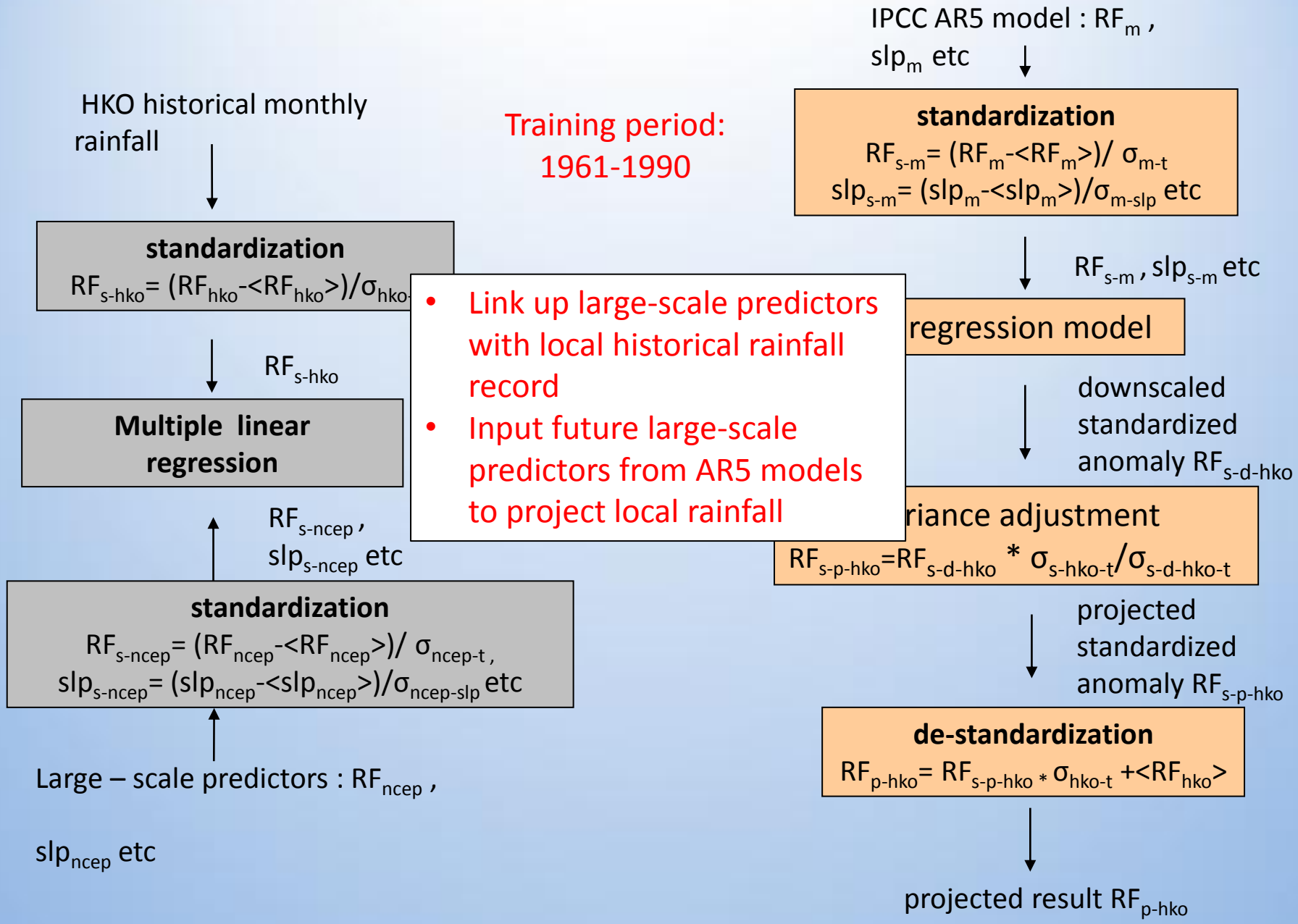


More frequent extreme rainfall

Source: IPCC AR5

Downscaling

- Horizontal resolution of global climate models are generally too coarse
- Typical resolution of a global climate model: 150-300 km.
- We need to “zoom in”
- Two approaches:
  - Dynamical downscaling using regional climate model
  - Statistical downscaling


IPCC AR5 model : RF_m , slp_m etc
HKO historical monthly rainfall
Training period: 1961-1990
standardization
$RF_{s-m}= (RF_m-<RF_m>)/ \sigma_{m-t}$
$slp_{s-m}= (slp_m-<slp_m>)/\sigma_{m-slp}$ etc
RF_{s-m} , slp_{s-m} etc
standardization
$RF_{s-hko}= (RF_{hko}-<RF_{hko}>)/\sigma_{hko-}$
regression model
RF_{s-hko}
downscaled standardized anomaly $RF_{s-d-hko}$
Multiple linear regression
riance adjustment
$RF_{s-p-hko}=RF_{s-d-hko} * \sigma_{s-hko-t}/\sigma_{s-d-hko-t}$
RF_{s-ncep} , slp_{s-ncep} etc
projected standardized anomaly $RF_{s-p-hko}$
standardization
$RF_{s-ncep}= (RF_{ncep}-<RF_{ncep}>)/ \sigma_{ncep-t}$,
$slp_{s-ncep}= (slp_{ncep}-<slp_{ncep}>)/\sigma_{ncep-slp}$ etc
de-standardization
$RF_{p-hko}= RF_{s-p-hko} * \sigma_{hko-t} +<RF_{hko}>$
Large – scale predictors : RF_{ncep} ,
slp_{ncep} etc
projected result RF_{p-hko}
• Link up large-scale predictors with local historical rainfall record
• Input future large-scale predictors from AR5 models to project local rainfall

Dataset

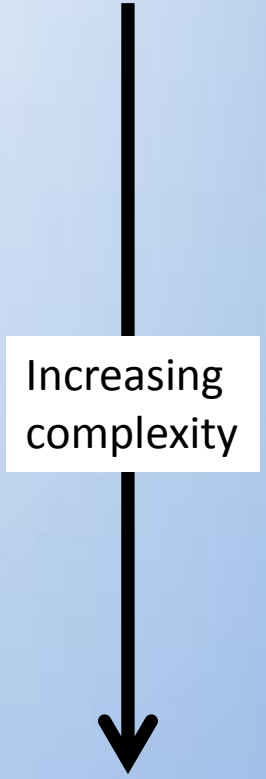
Dataset	Period	Purpose
HKO monthly rainfall	1961-1990 & 1991-2005	Building the stat. model & validation
NCEP 20th century reanalysis dataset	1961-1990 & 1991-2005	Building the stat. model & validation
IPCC AR5 model data	2006-2100	Projection

Model	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
ACCESS10	×	✓	×	✓
BCC-CSM1-1	✓	✓	✓	✓
BNU-ESM	✓	✓	×	✓
CanESM2	✓	✓	×	✓
CCSM4	✓	✓	✓	✓
CNRM-CM5	×	✓	×	✓
CSIRO-Mk36	×	✓	✓	✓
GFDL-ESM2G	✓	✓	✓	✓
GFDL-ESM2M	×	✓	✓	✓
FGOAL_Sg2	✓	✓	×	✓
GISS-E2-H	✓	✓	✓	✓
GISS-E2-R	×	✓	✓	✓
HadGEM2-AO	✓	✓	✓	✓
HadGEM2-CC	×	✓	×	✓
HadGEM2-ES	✓	✓	✓	✓
INM-CM4	×	✓	×	✓
IPAL-CM5A-LR	✓	✓	✓	✓
IPSL-CM5A-MR	✓	✓	✓	✓
IPSL-CM5B-LR	×	✓	×	✓
MIROC5	✓	✓	✓	✓
MIROC-ESM	✓	✓	✓	✓
MIROC-ESM-CHEM	✓	✓	✓	✓
MRI-CGCM3	✓	✓	✓	✓
Nor-ESM-1M	✓	✓	✓	✓
Nor-ESM1-ME	✓	✓	✓	✓
Total	17	25	17	25

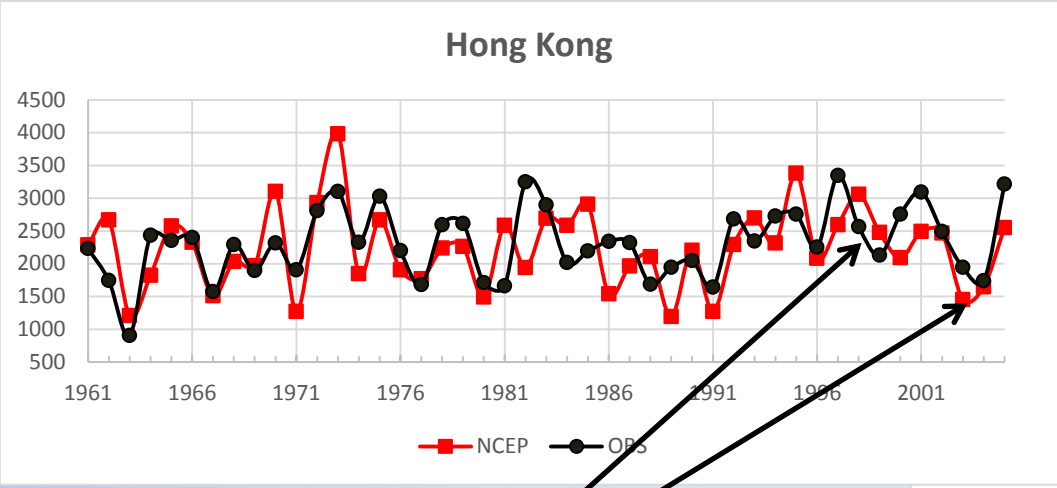
- 25 models for RCP4.5 and RCP8.5
- 17 models for RCP2.6 and RCP6.0
- All downloaded from pcmdi9.llnl.gov

Predictor sets

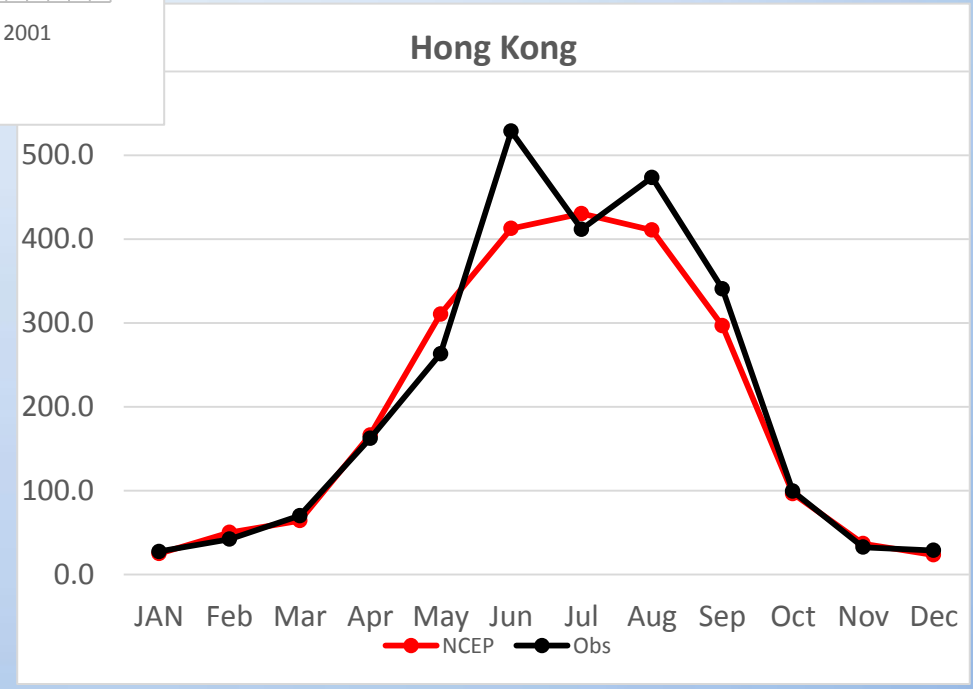
Predictor Set	Large-scale predictors (spatial average of 20-30N, 105-120E)
Set 1	Rainfall
Set 2	Set 1 + Mean sea level pressure
Set 3	Set 2+ 850 hPa relative humidity
Set 4	Set 3+ 850 hPa zonal wind and 850 hPa meridional wind
Set 5	Set 4 + 500 hPa zonal wind and 500 hPa meridional wind



Validation (1991-2005)



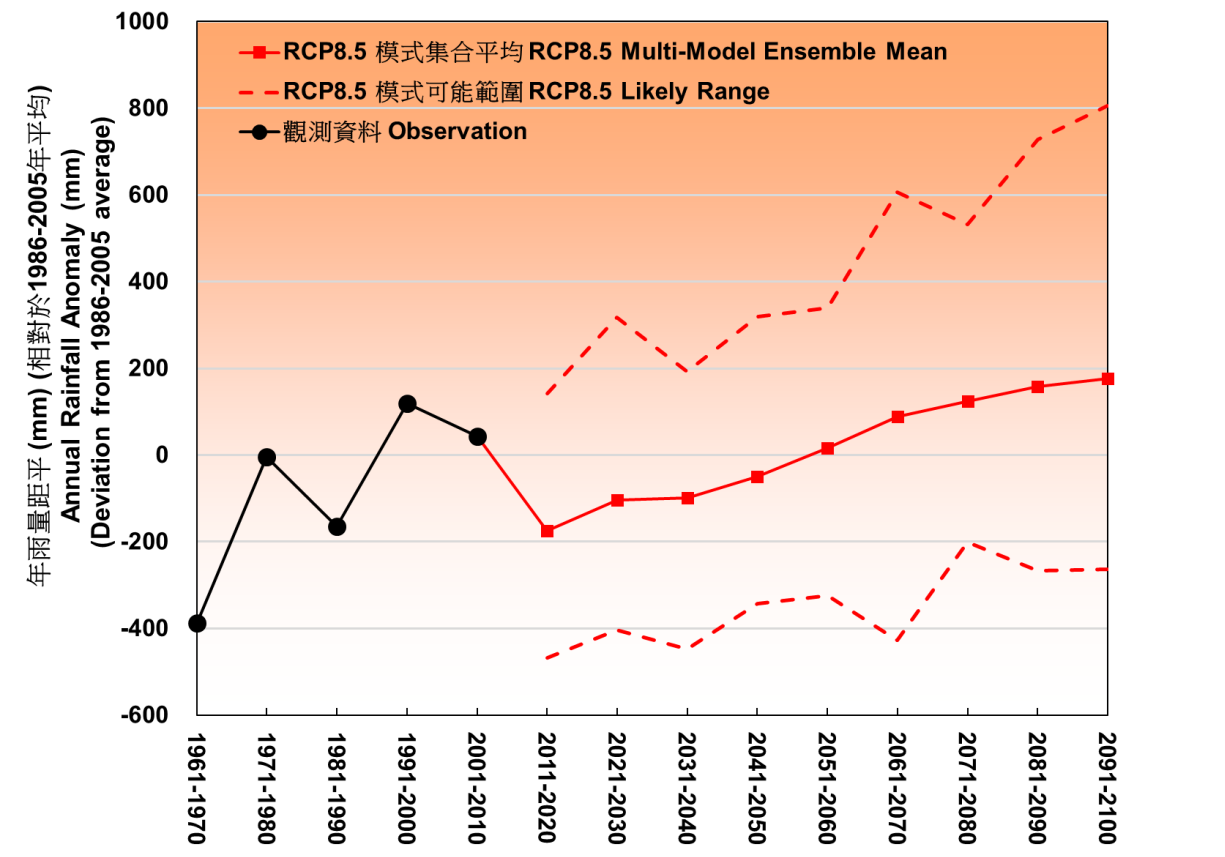
Wet period and dry period are reasonably reproduced during the validation period



Annual cycle in 1991-2005

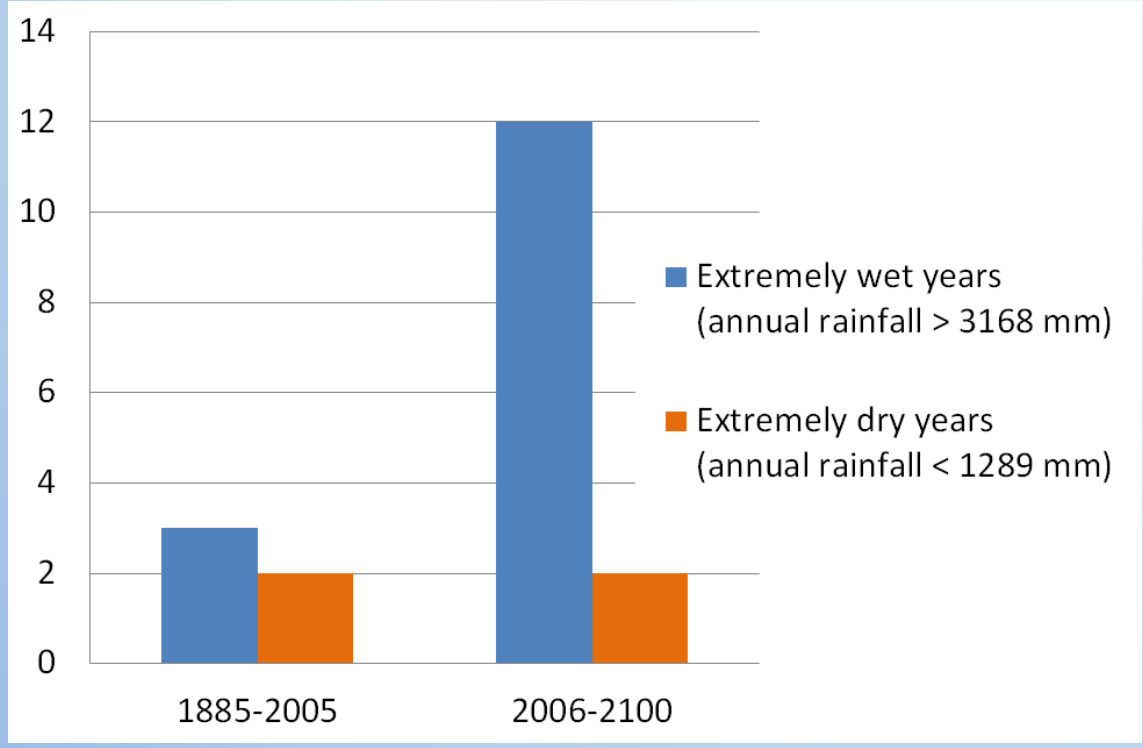
Projections for 21st century under RCP8.5

- Relative to average of 1986-2005
- Likely range = 5th and 95th percentile of the spread of downscaled rainfall



- Annual rainfall is expected to increase towards the end of the this century
- Inter-model variation is still large

Number of extremely dry and extremely wet years



Criteria of extremely wet/dry years:

- Extremely dry year: Average rainfall in 1885-2005 minus 2 standard deviation (1289 mm)
- Extremely wet year: Average rainfall in 1885-2005 plus 2 standard deviation (3168 mm)

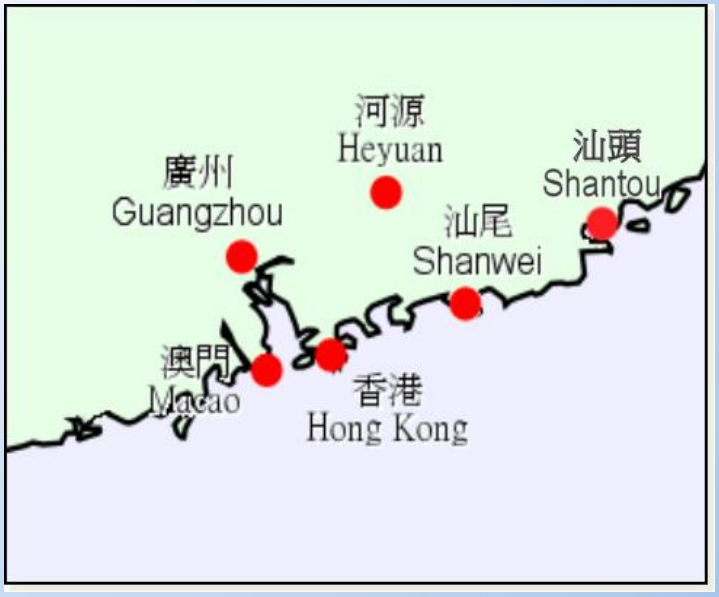
- Significant increase in the number of extremely wet years
- On the other hand, risk of drought cannot be totally ruled out

Source of uncertainty

- Future greenhouse gas emissions
- Ability of climate models to simulate physical processes
- Downscaling methodology
- Stability of the statistical downscaling relationship in future

Apply the same methodology to 5 southern China stations

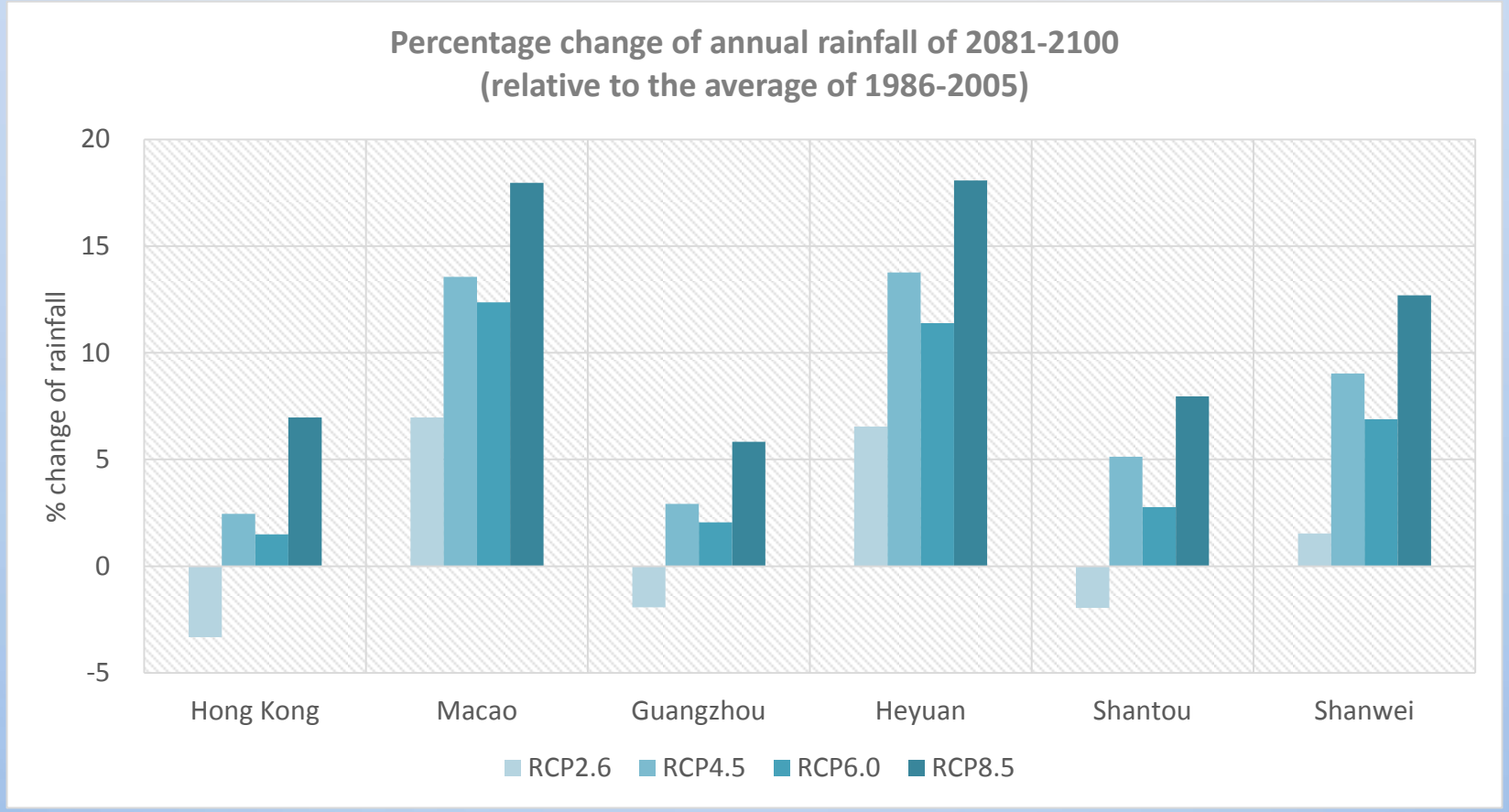
- Macao, Guangzhou, Shanwei, Shantou and Heyuan



- For Guangzhou, Shanwei, Shantou and Heyuan, historical monthly data are available only from 1961

- Definition of extremely wet/dry year is slightly modified to be: ± 2 s.d. of the average of 1961 - 2005 rainfall of the corresponding station

Projections for Hong Kong and 5 southern China stations



- Increasing trend for RCP4.5, RCP6.0 and RCP8.5

Number of extremely dry years and wet years

No. of Years		Macao		Guangzhou		Heyuan		Shantou		Shanwei	
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1961-2005 (45 years)	Observations	1	1	0	2	1	1	0	3	1	2
2006-2100 (95 years)	RCP2.6	1.4	5.6	2.8	4.7	2.2	7.8	3.0	6.5	1.9	5.0
	RCP4.5	1.2	7.3	2.4	6.6	2.2	10.4	2.6	9.0	1.6	7.2
	RCP6.0	1.5	6.6	3.2	5.7	2.7	8.8	3.6	7.4	2.2	6.5
	RCP8.5	1.4	9.8	3.0	8.7	2.2	13.0	2.9	11.4	1.9	9.7

It is not a fair comparison as the projection period is much longer than the baseline period

No. of Years (every 45 yrs)		Macao		Guangzhou		Heyuan		Shantou		Shanwei	
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1961-2005	Observations	1	1	0	2	1	1	0	3	1	2
	Historical	0.7	1.2	1.4	1.2	1.1	1.9	1.5	1.7	1.0	1.0
Projection period (x * 45/95)	RCP2.6	0.7	2.6	1.3	2.2	1.1	3.7	1.4	3.1	0.9	2.4
	RCP4.5	0.6	3.4	1.1	3.1	1.0	4.9	1.3	4.3	0.7	3.4
	RCP6.0	0.7	3.1	1.5	2.7	1.3	4.2	1.7	3.5	1.0	3.1
	RCP8.5	0.7	4.6	1.4	4.1	1.0	6.2	1.4	5.4	0.9	4.6

No. of extremely wet/dry years every 45 years.

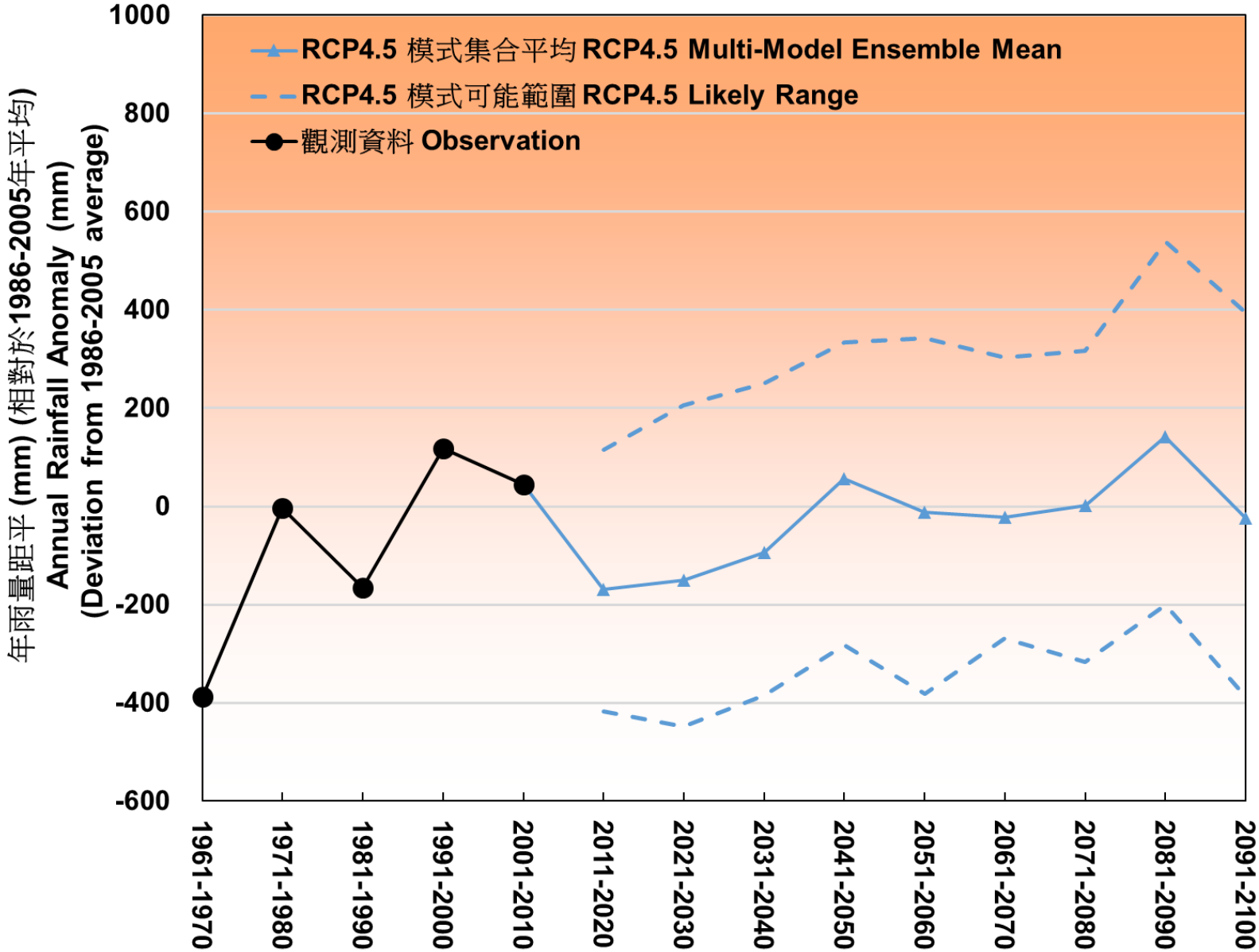
Works in progress

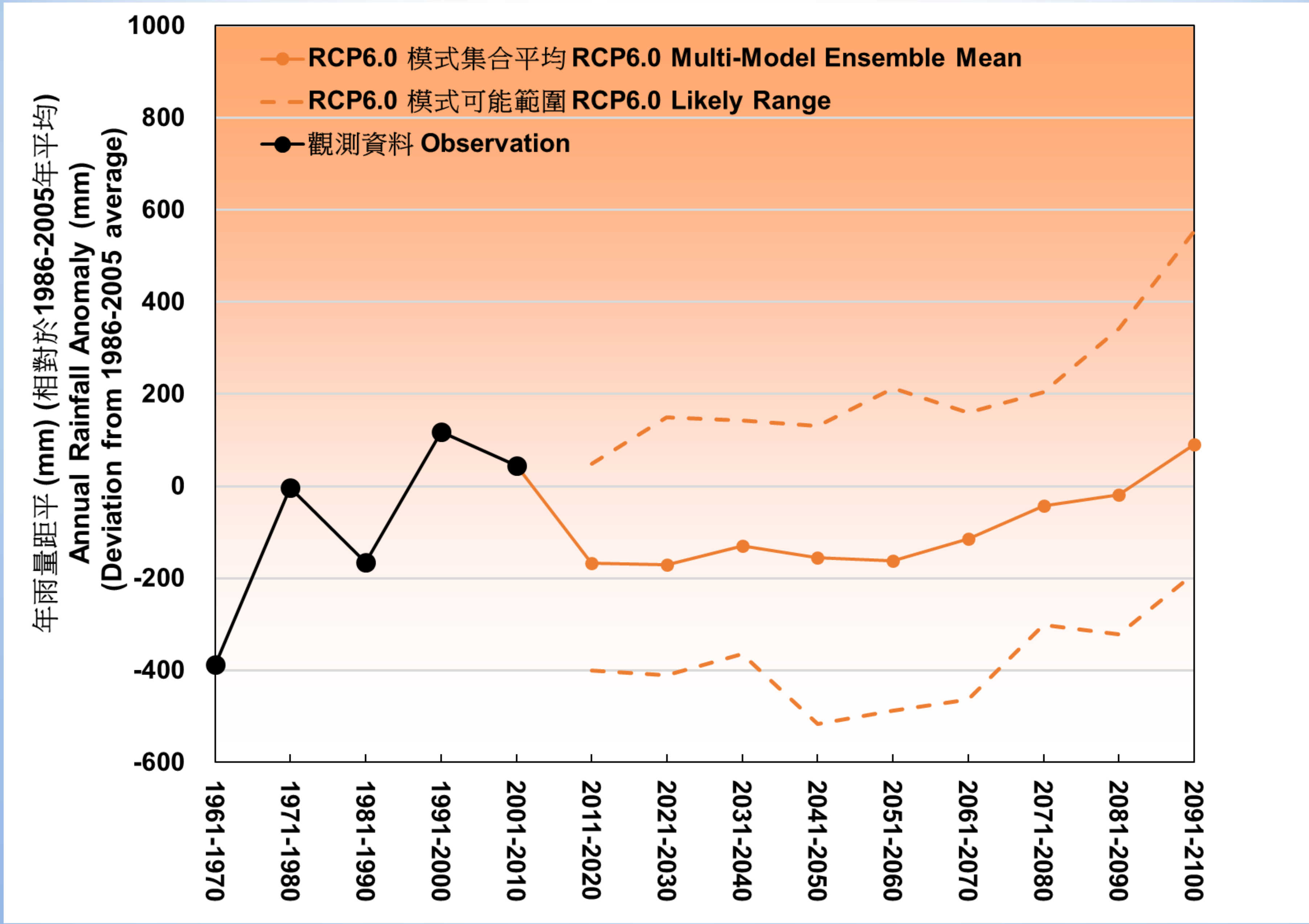
- Using AR5 model daily data to project number of rain days, number of extreme rainfall days, etc
- Projections of drought index, e.g. standardized precipitation index (SPI)
- Comparison between other downscaling methods (e.g. dynamical downscaling)

Summary

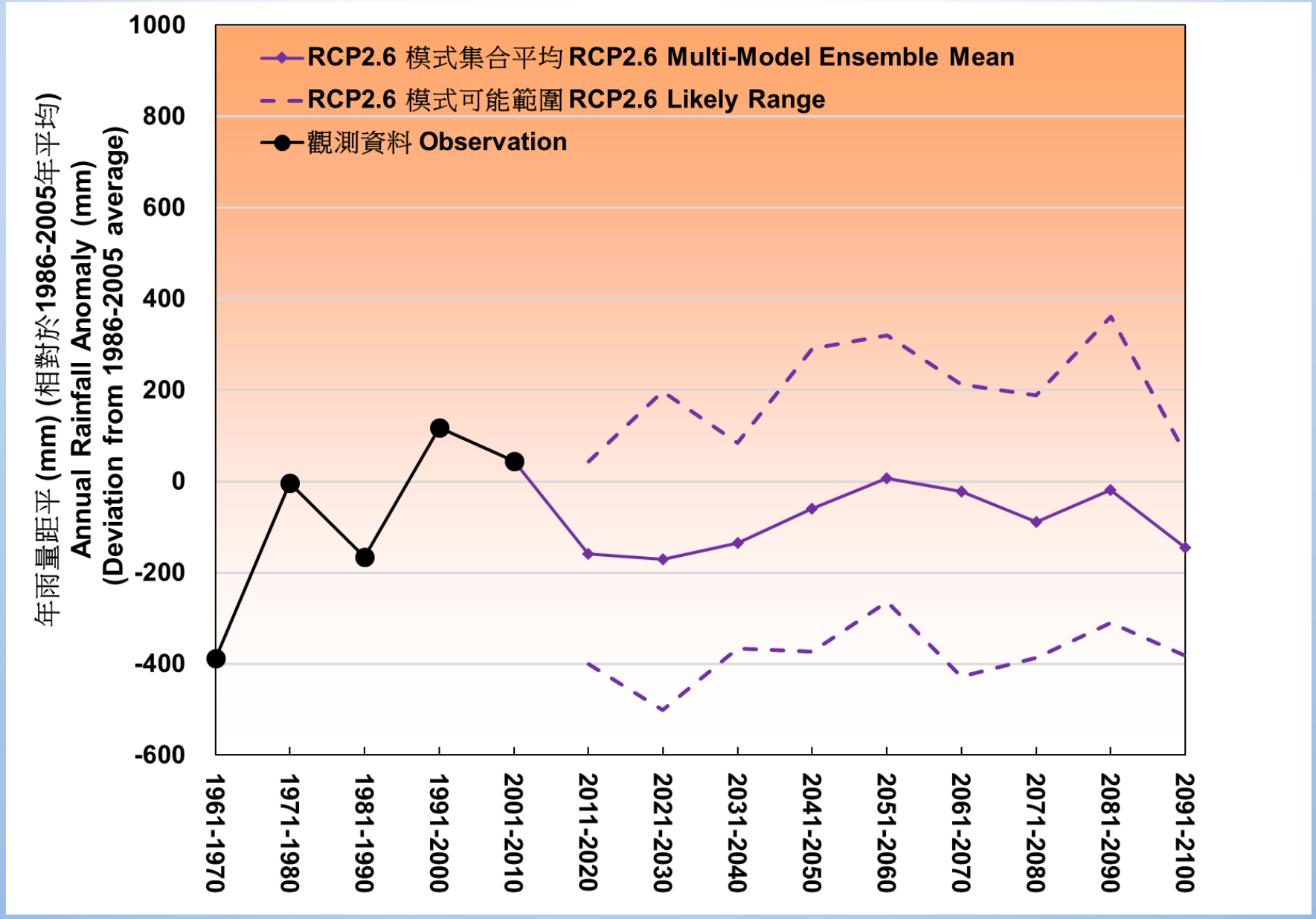
- Under the high greenhouse gas concentration scenario (RCP8.5), the annual rainfall of Hong Kong would increase towards the end of this century.
- Number of extremely wet years would increase from 3 to 12.
- Number of extremely dry years would remain at 2. Risk of drought cannot be totally ruled out
- Large inter-model variations still exist, reflecting the uncertainty of the projections to some extent.
- Similar pattern could be found over other southern China stations.

Thank you


RCP4.5 模式集合平均 RCP4.5 Multi-Model Ensemble Mean
RCP4.5 模式可能範圍 RCP4.5 Likely Range
觀測資料 Observation
年雨量距平 (mm) (相對於1986-2005年平均)
Annual Rainfall Anomaly (mm)
(Deviation from 1986-2005 average)
1000
800
600
400
200
0
-200
-400
-600
1961-1970
1971-1980
1981-1990
1991-2000
2001-2010
2011-2020
2021-2030
2031-2040
2041-2050
2051-2060
2061-2070
2071-2080
2081-2090
2091-2100



RCP6.0 模式集合平均 RCP6.0 Multi-Model Ensemble Mean
RCP6.0 模式可能範圍 RCP6.0 Likely Range
觀測資料 Observation
年雨量距平 (mm) (相對於1986-2005年平均)
Annual Rainfall Anomaly (mm)
(Deviation from 1986-2005 average)
1000
800
600
400
200
0
-200
-400
-600
1961-1970
1971-1980
1981-1990
1991-2000
2001-2010
2011-2020
2021-2030
2031-2040
2041-2050
2051-2060
2061-2070
2071-2080
2081-2090
2091-2100


RCP2.6 模式集合平均 RCP2.6 Multi-Model Ensemble Mean
RCP2.6 模式可能範圍 RCP2.6 Likely Range
觀測資料 Observation
年雨量距平 (mm) (相對於1986-2005年平均)
Annual Rainfall Anomaly (mm)
(Deviation from 1986-2005 average)
1000
800
600
400
200
0
-200
-400
-600
1961-1970
1971-1980
1981-1990
1991-2000
2001-2010
2011-2020
2021-2030
2031-2040
2041-2050
2051-2060
2061-2070
2071-2080
2081-2090
2091-2100