Projection of Extreme Rainfall Trend and Mean Sea Level Rise in Hong Kong for the 21st Century

S. M. Lee

Hong Kong Observatory

DSD R&D Forum 2016
Striving Innovation in Sustainable Stormwater Drainage
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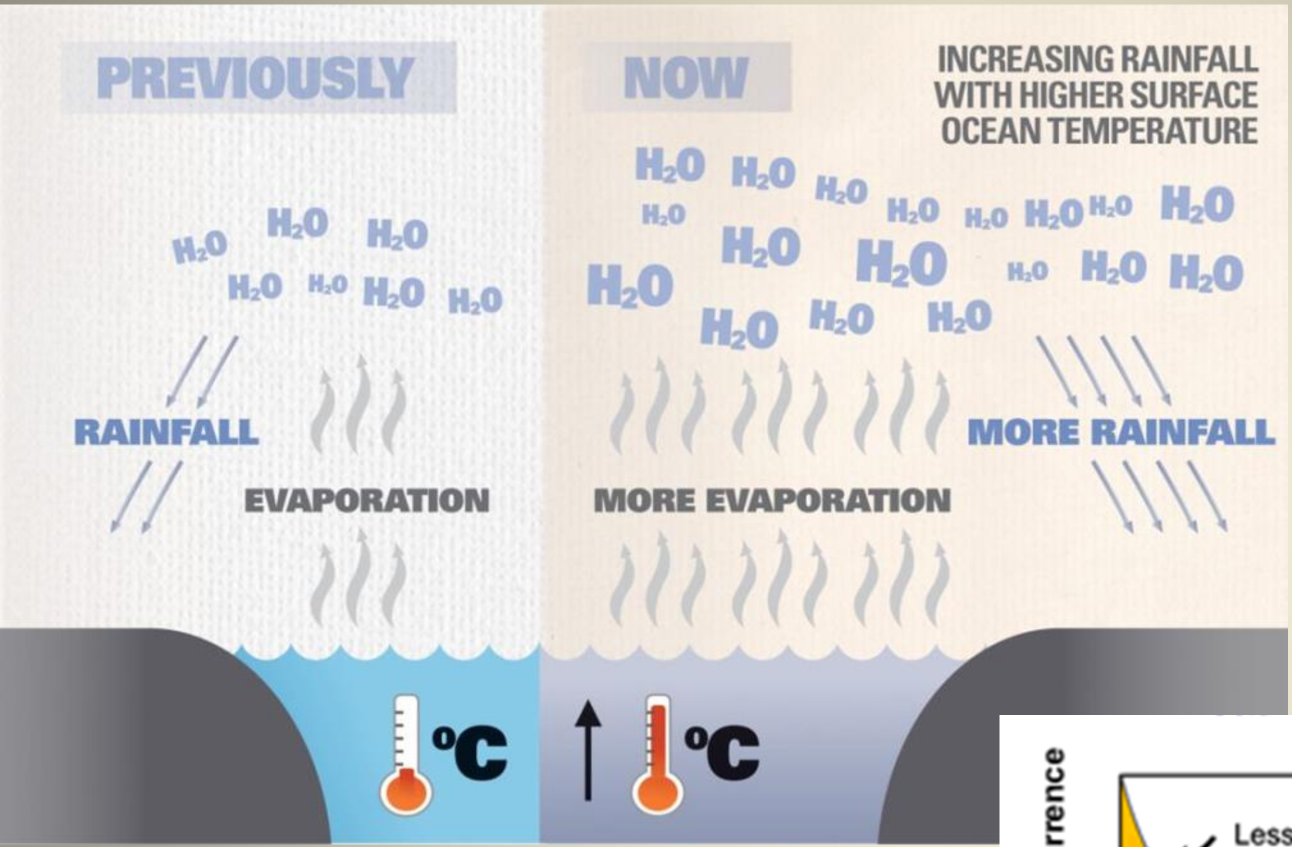
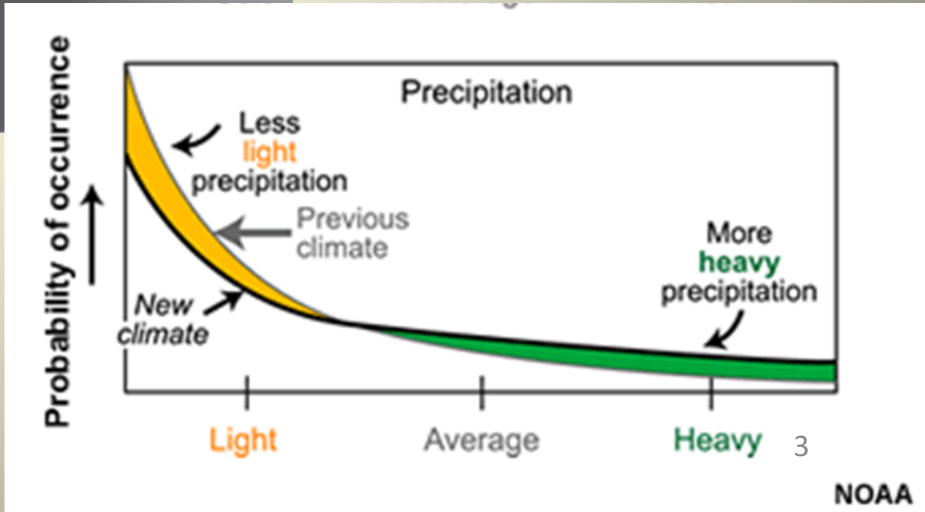
Projection of Extreme Rainfall Trend

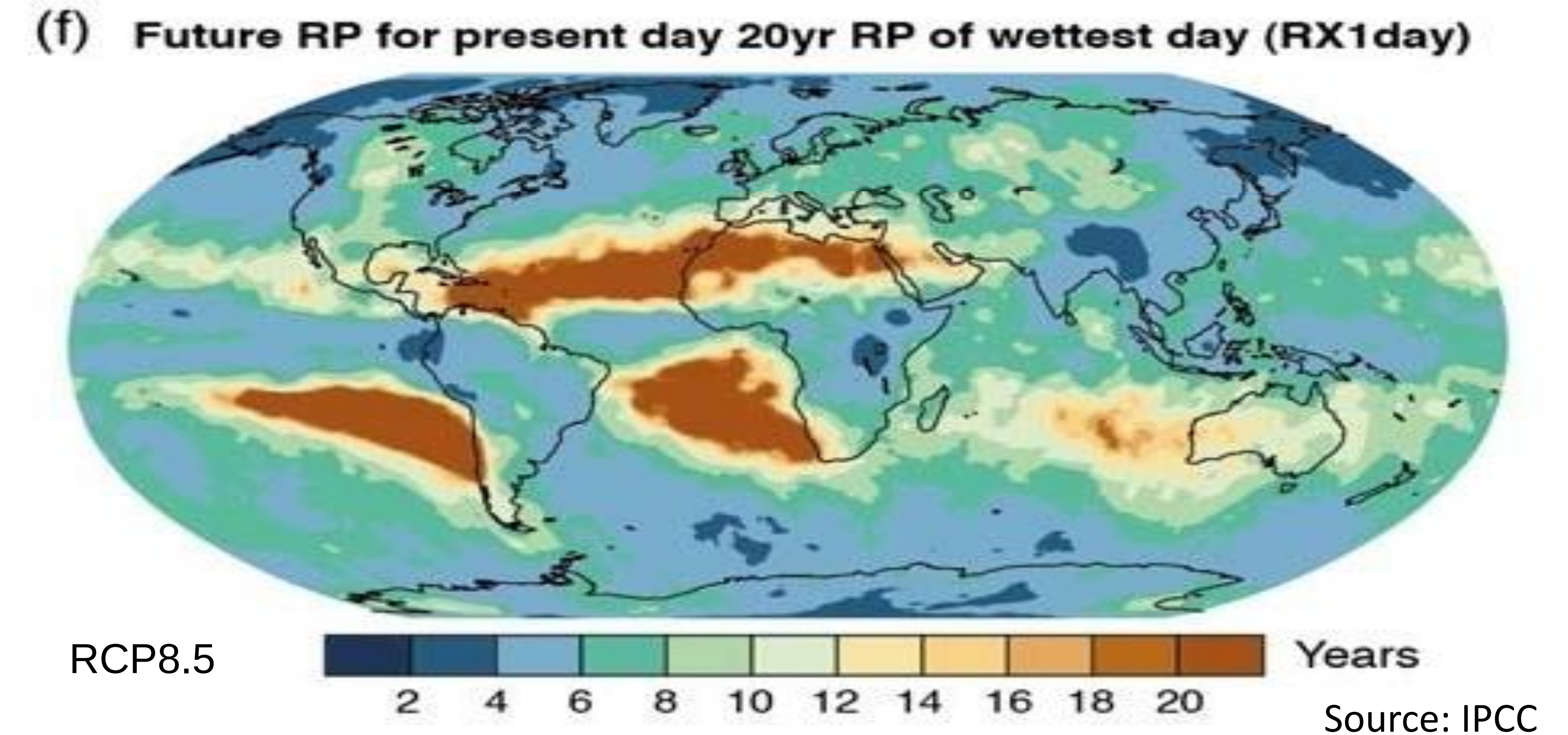
Climate Change and Extreme Rainfall





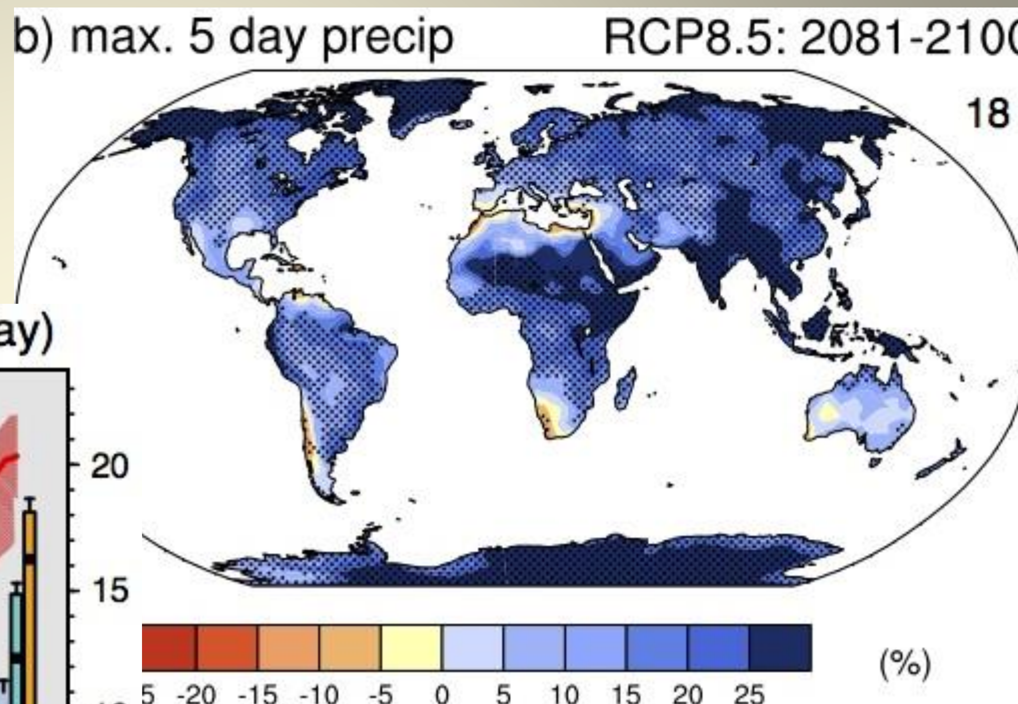
The 2081–2100 Return Period (RP) of a 1-in-20 year Extreme Daily Precipitation Event in 1986–2005

1-in-20 year event in 1986-2005 → More/less frequent in 2081-2100?

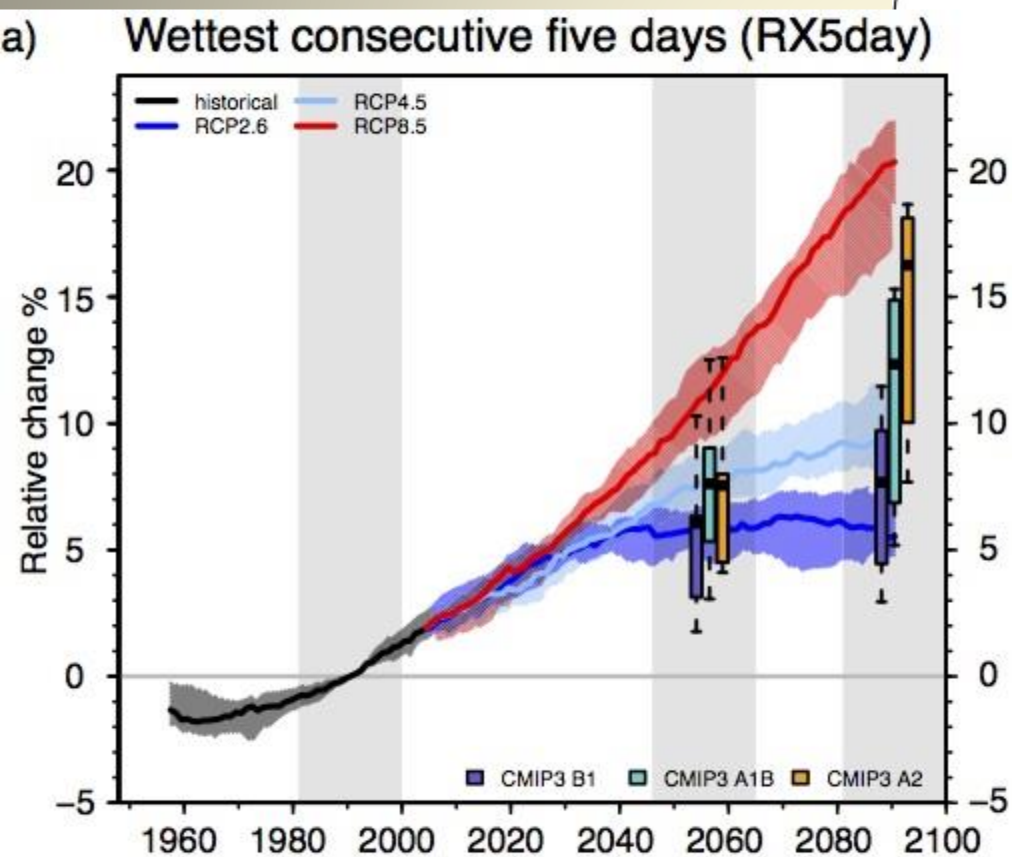


Source: IPCC

Projected Percentage Change (relative to 1981-2000) in the Annual Maximum 5-day Precipitation



Global average over land regions



Source: IPCC

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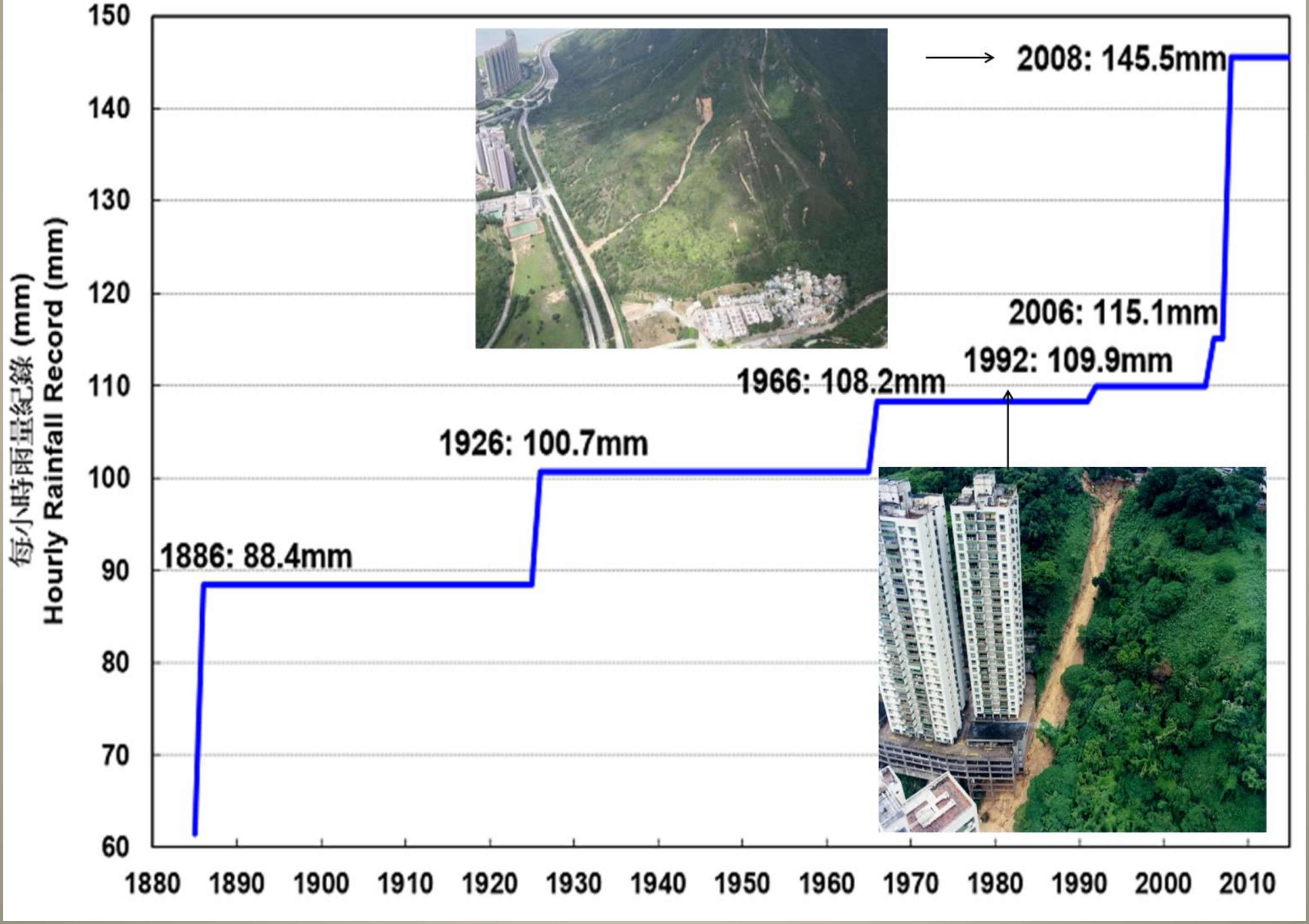
Observed Extreme Rainfall Trend in Hong Kong



Data

- 1966-2005 HKO daily rainfall as training dataset
- 1966-2005 southern China averaged (108-120E, 16-30N) NCEP20th re-analysis data as predictors
- 2006-2100 CMIP5 models for projections

CMIP5 Models

Model	Center	RCP4.5	RCP8.5	RCP2.6	RCP6.0
ACCESS1-0	CSIRO	✓	✓		
BCC-CSM1-1	BCC	✓	✓	✓	✓
BNU-ESM	BNU	✓	✓	✓	
CanESM2	CCCma	✓	✓	✓	
CNRM-CM5	CNRM	✓	✓	✓	
CSIRO-Mk3-6-0	CSIRO	✓	✓	✓	✓
GFDL-ESM2G	NOAA GFDL	✓	✓		✓
GFDL-ESM2M	NOAA GFDL	✓	✓		✓
HadGEM2-CC	UKMO Had	✓	✓		
IPSL-CM5A-LR	IPSL	✓	✓	✓	✓
IPSL-CM5A-MR	IPSL	✓	✓	✓	✓
IPSL-CM5B-LR	IPSL	✓	✓		
MIROC5	MIROC	✓	✓	✓	✓
MIROC-ESM	MIROC	✓	✓		
MIROC-ESM-CHEM	MIROC	✓	✓	✓	✓
MPI-ESM-LR	MPI	✓	✓	✓	
MRI-CGCM	MRI	✓	✓		✓
Nor-ESM1-M	NCC	✓	✓	✓	✓
MPI-ESM-MR	MPI	✓	✓	✓	
ACCESS1-3	CSIRO	✓	✓		
BCC-CSM1-1-m	BCC	✓	✓	✓	✓
CMCC-CMS	CMCC	✓	✓		
CMCC-CM	CMCC	✓	✓		

Rainfall Occurrence Model

HKO daily rainfall
1966 -2005

↓

Binarization 1=occur,0=not occur

↓

Multiple logistic regression

↑

Standardization

↑

NCEP Predictors
1966-2005

Multiple logistic regression → Regression model

CMIP5 model predictors
2006-2100

↓

Standardization

↓

Regression model

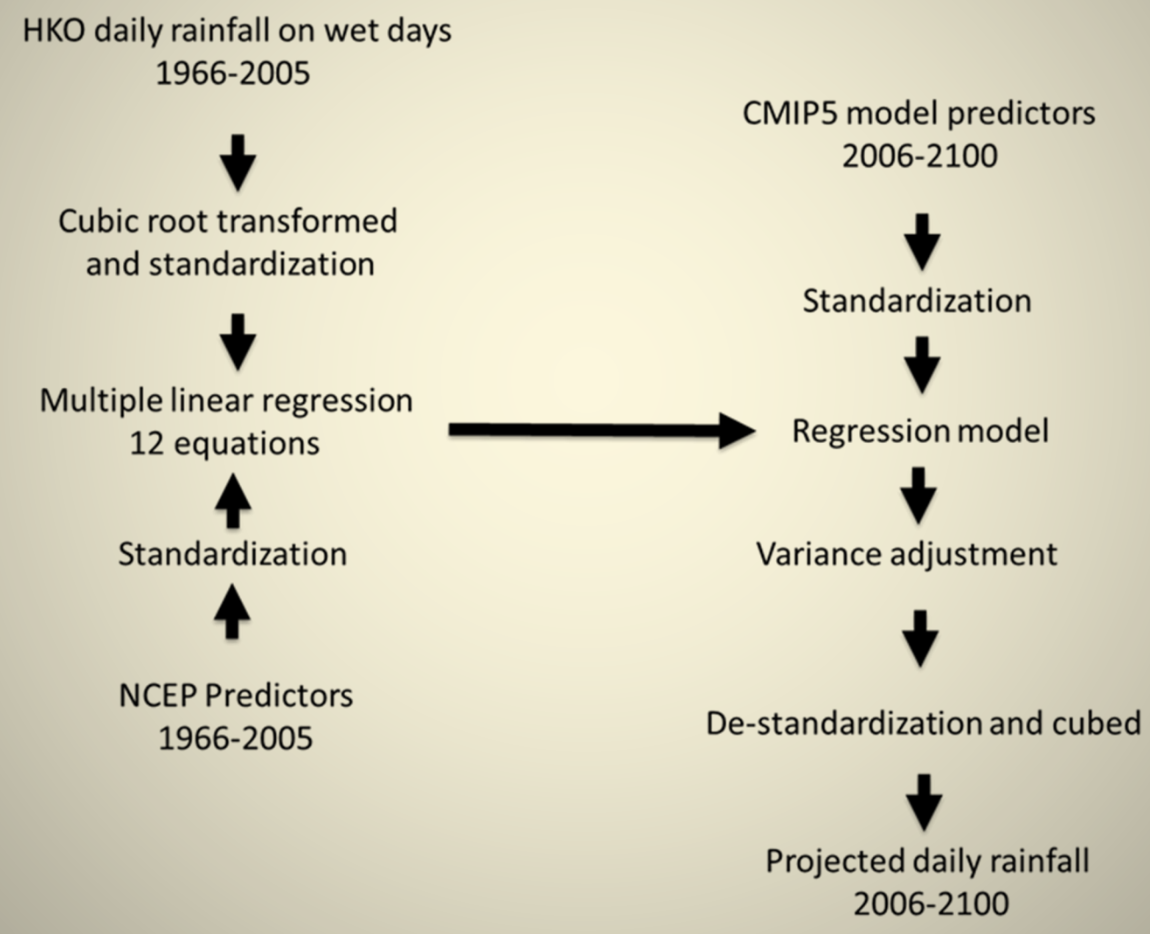
↓

Matching the climatological rainfall occurrence

↓

Rainfall occurrence

Rainfall Amount Model

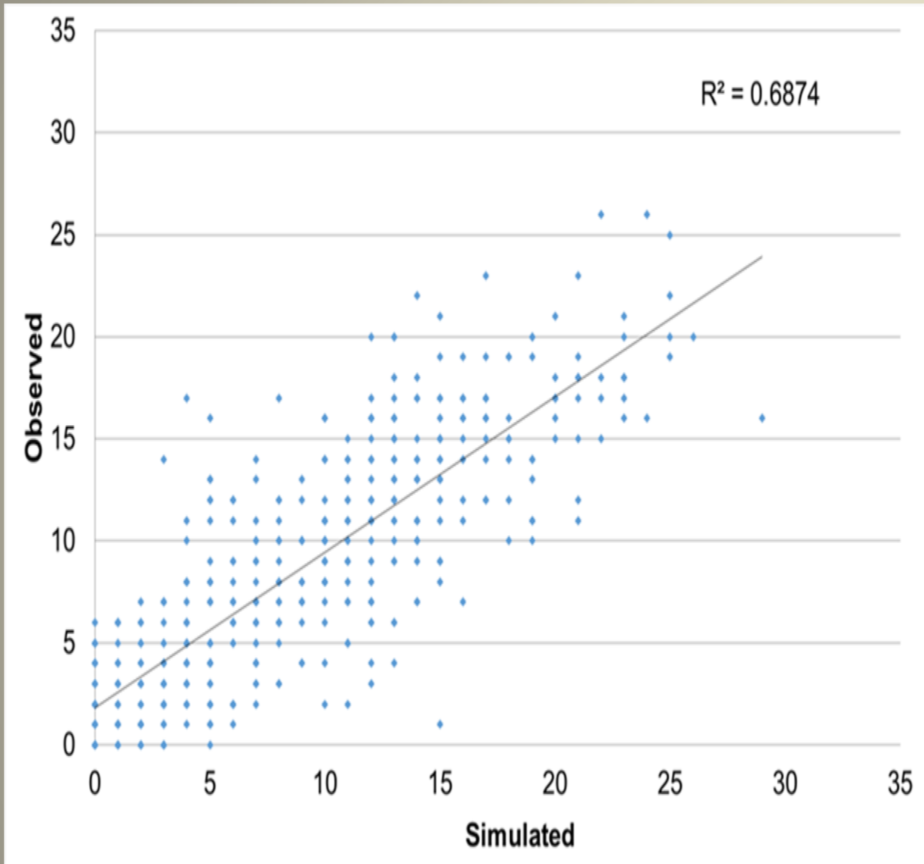


Predictor Sets

Six predictor sets are used for the statistical models in this study to generate ensembles of projections under different RCP scenarios:

Set 1: Rainfall
Set 2: Rainfall, MSLP
Set 3: Rainfall, MSLP, 850-hPa RH
Set 4: Rainfall, MSLP, 850-hPa RH, 850-hPa U & V
Set 5: Rainfall, MSLP, 850-hPa RH, 850-hPa U & V, 500-hPa U & V
Set 6: Stepwise regression of Set 5

Model Validation



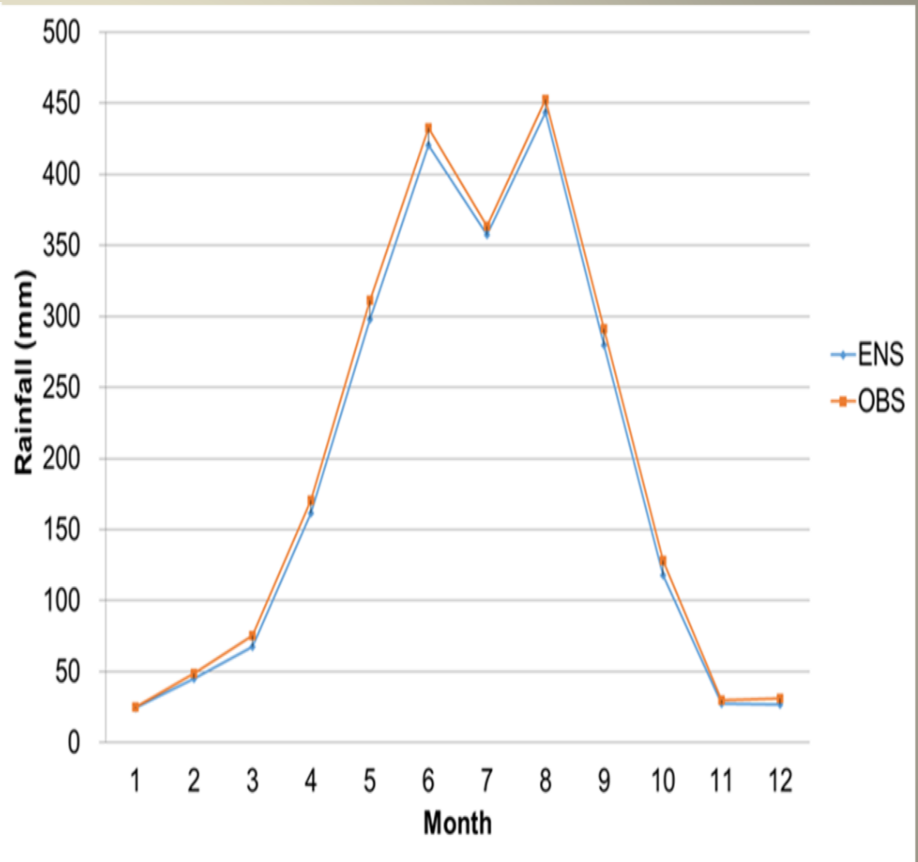


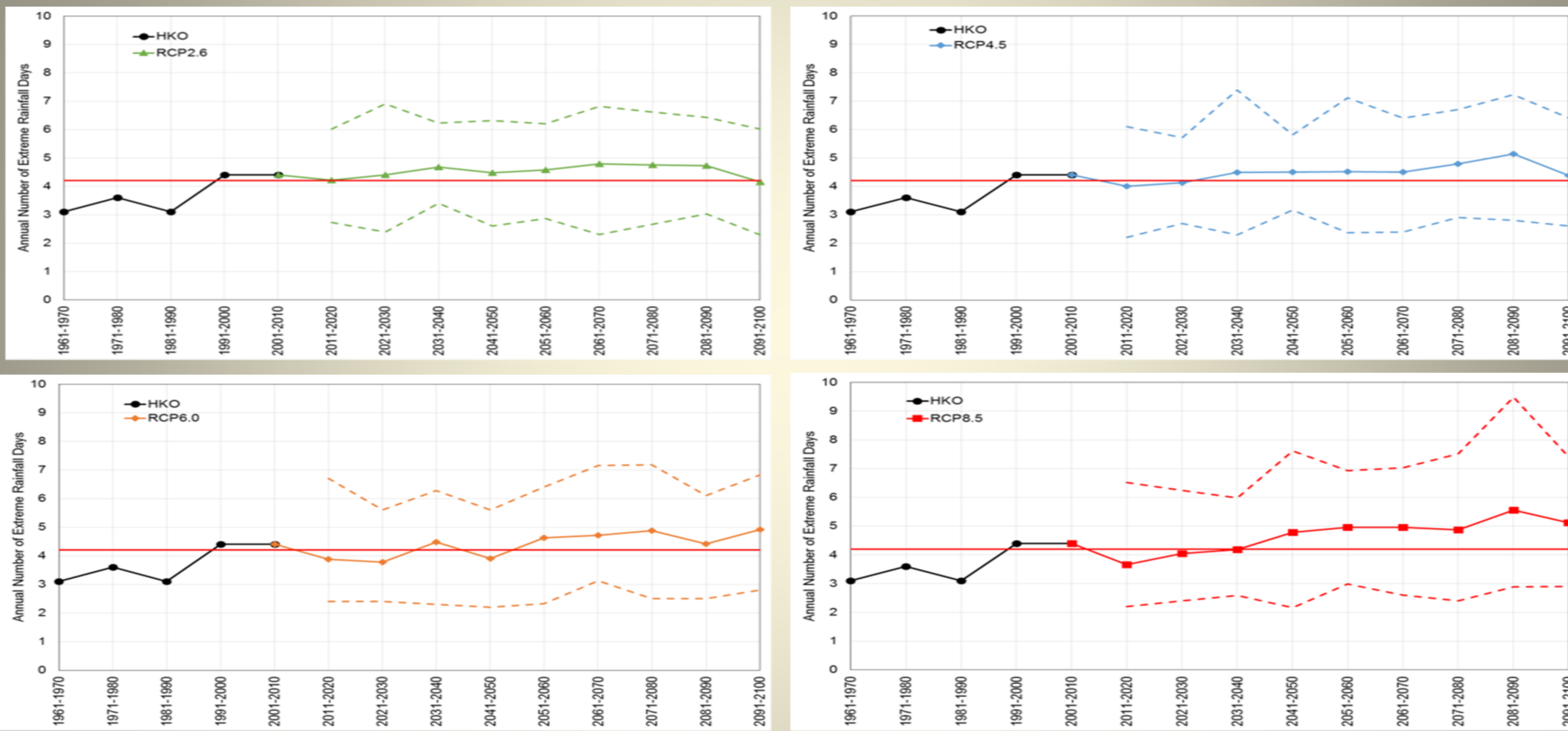
Figure 2. Predicted (using the cross-validation approach) and observed monthly number of rain days during 1966-2005.

Figure 3. Predicted (blue line, using the cross-validation approach) and observed (orange line) annual cycle of monthly rainfall during 1966-2005.

Evaluation using CMIP5 Historical Runs

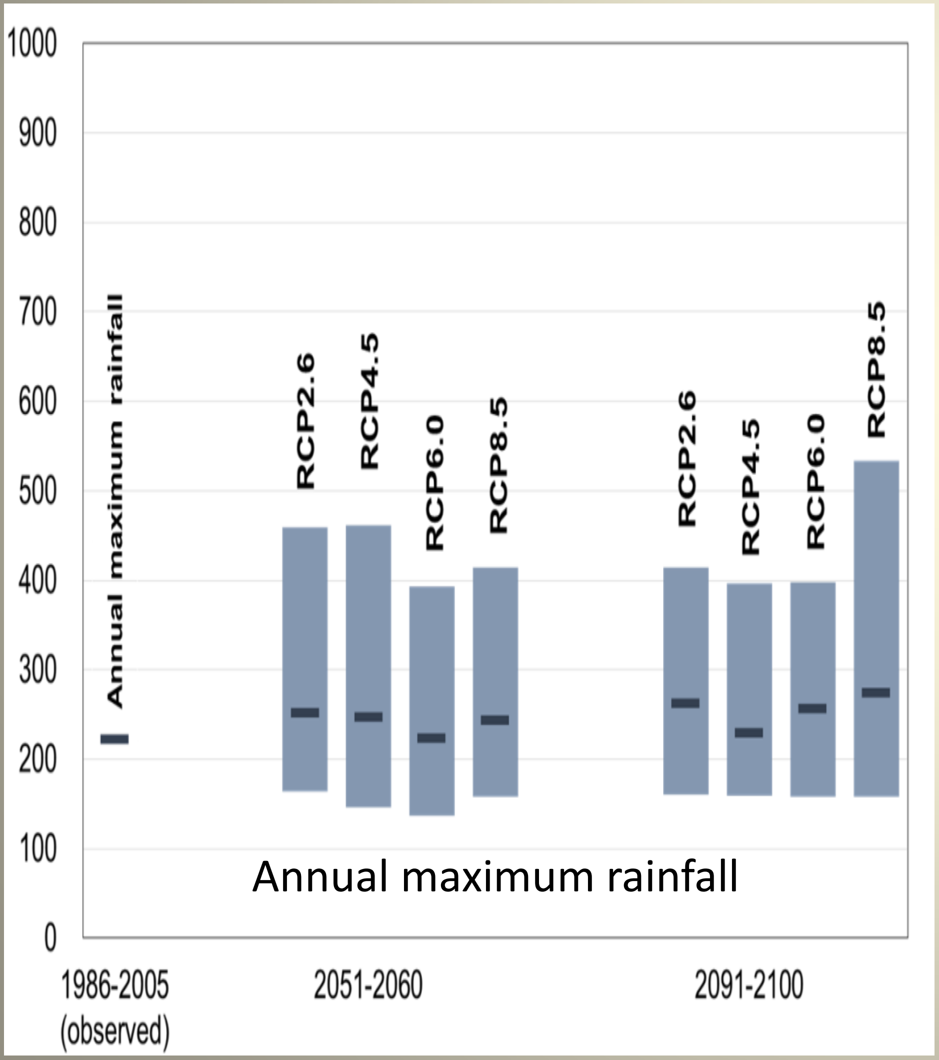
	Mean annual rainfall (mm)	Daily rainfall intensity (mm/day)	Annual number of extreme rainfall days	Annual number of rain days
Downscaling result	2324	22.7	3.7	102.3
Observation	2361	23.0	3.9	102.4
Standard deviation of observation	493	3.4	2.0	12.6

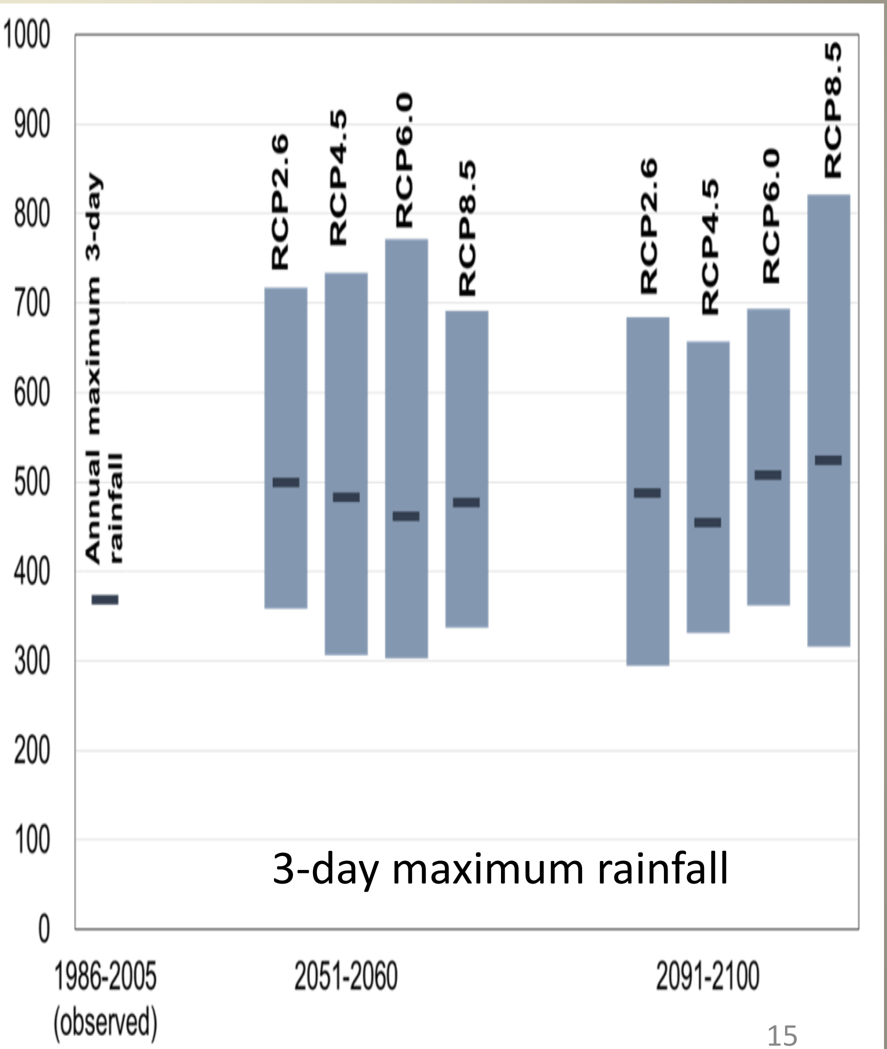
Projection of Extreme Rainfall Days (daily rainfall >= 100 mm)



The red horizontal line shows the 1986-2005 average of 4.2 days. Occurrence of extreme rainfall is expected to increase in all scenarios with the increasing trend more prominent in the RCP8.5 scenario.

Projection of Annual Maximum and 3-day Rainfall





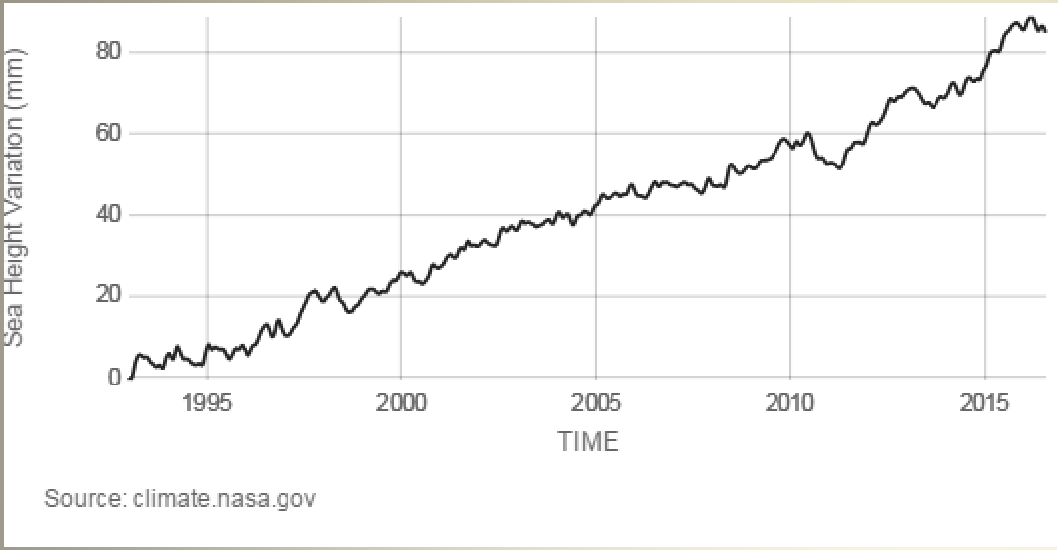
Projections for Other Parameters

	1986-2005 Actual	2091-2100 Projection	2091-2100 Projection	2091-2100 Projection	2091-2100 Projection
Greenhouse gas concentration scenario	--	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Annual maximum number of consecutive dry days	46	54	52	53	59
Annual number of rain days	102	102	102	102	97
Average rainfall intensity (mm/day)	23.4	23.9	24.0	25.5	26.7

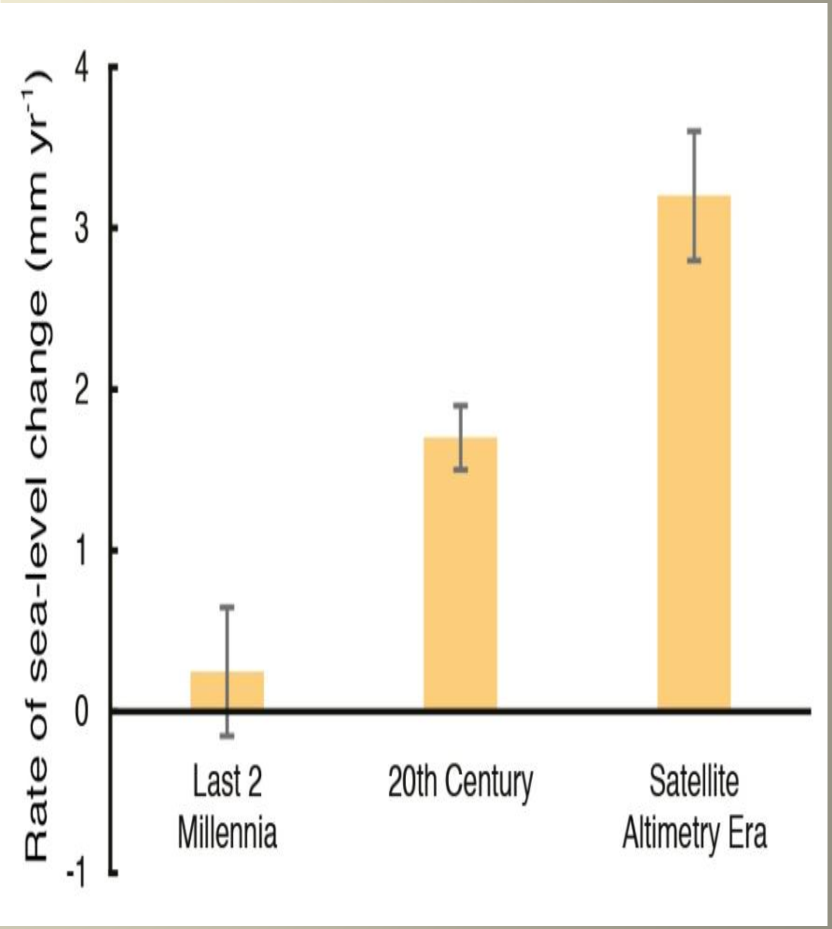
- Changes in annual number of rain days (daily rainfall ≥ 1 mm) are not prominent for RCP2.6, RCP4.5 and RCP6.0. Annual number of rain days is expected to decrease under RCP8.5
- Annual maximum number of consecutive dry days and average rainfall intensity (annual rainfall divided by annual number of wet days) are projected to increase in all scenarios

Projection of Mean Sea Level Rise

Global Mean Sea Level Rise



Source :NASA



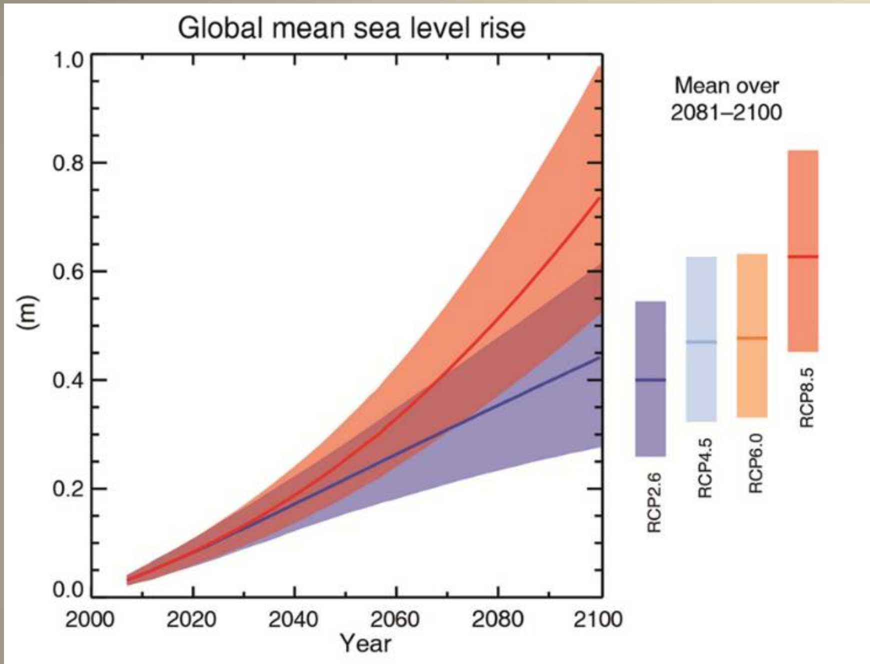
Mean sea level rise is accelerating!

1.7 mm/year (1901 – 2010)

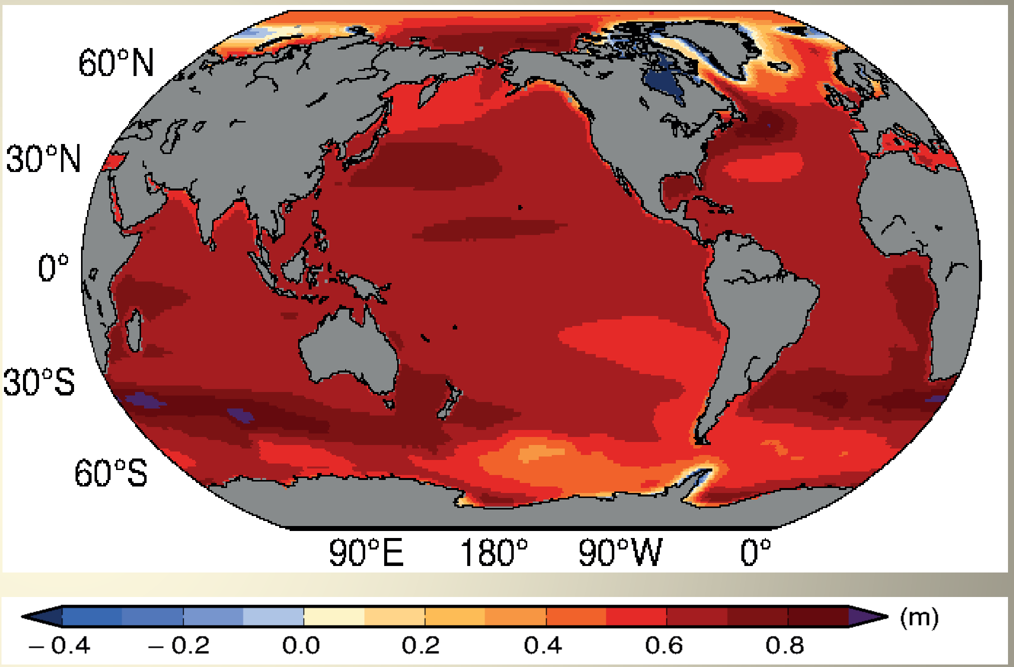
3.2 mm/year (1993 – 2010)

Source: IPCC

Global and Regional Sea Level Rise

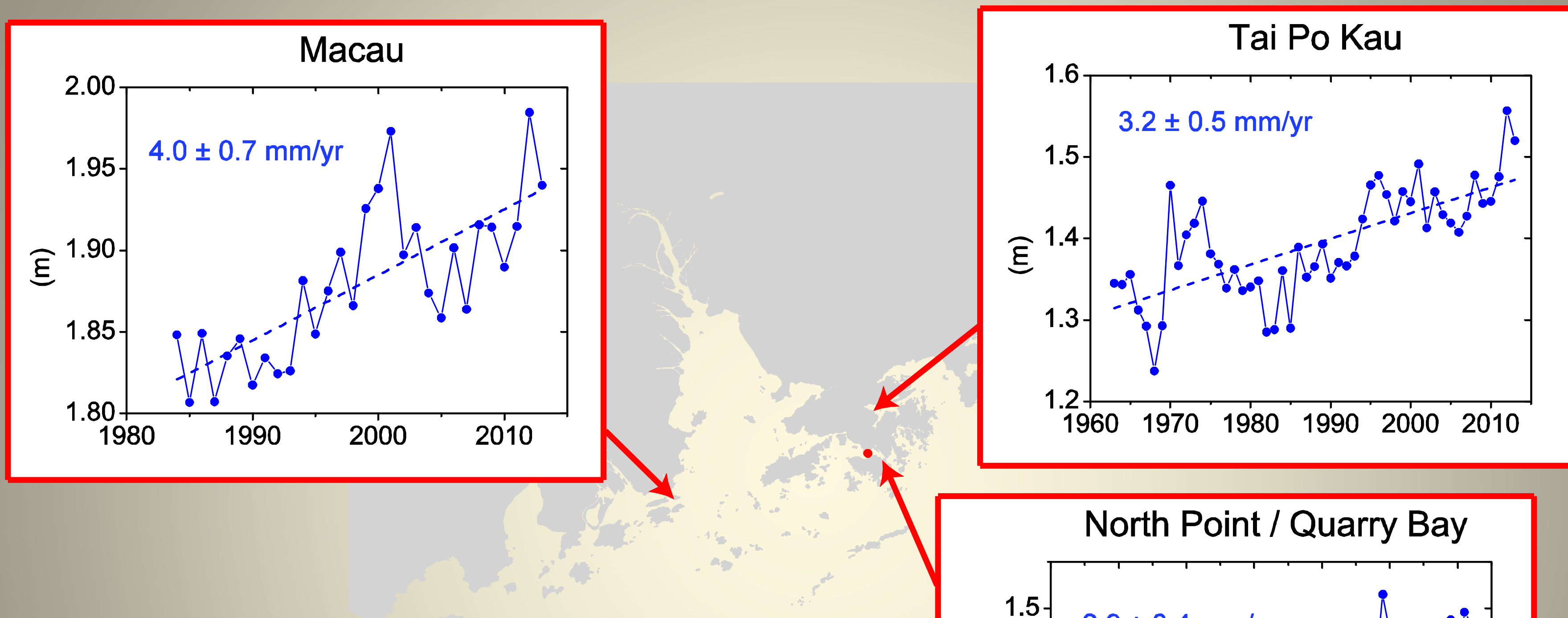


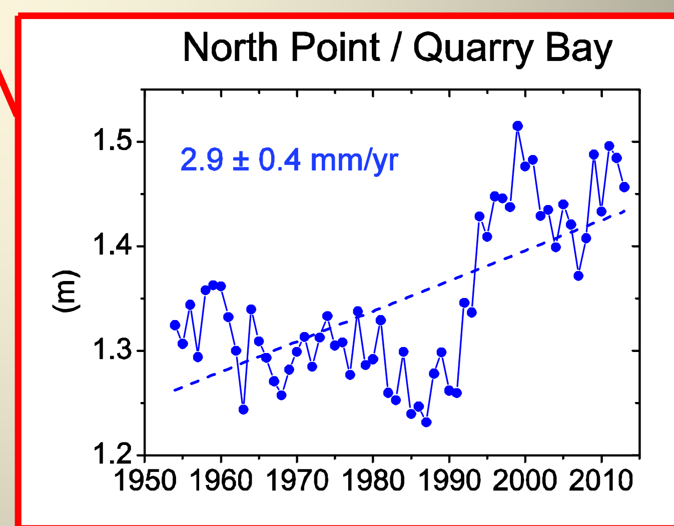
Projections of global mean sea level rise over the 21st century (relative to 1986-2005)

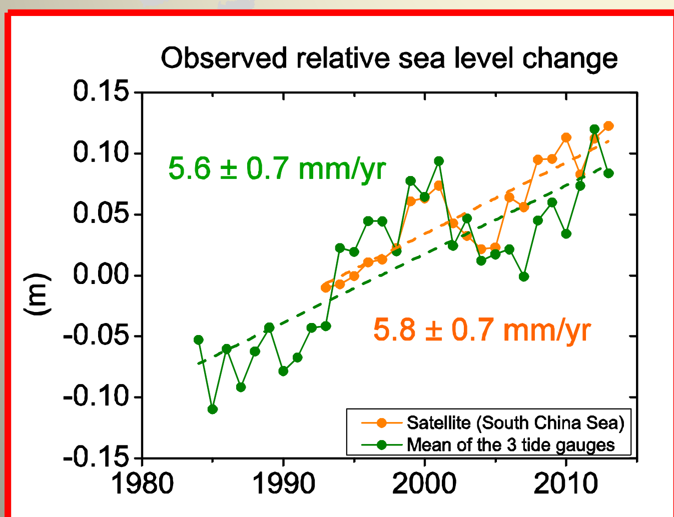


Ensemble mean regional relative sea level change evaluated from 21 CMIP5 models between 1986-2005 and 2081-2100 for RCP8.5.

Observed Sea Level Change around Hong Kong







The 3-station averaged sea level change is used to represent the sea level change of Hong Kong and its adjacent waters

Causes of Regional Variation of Sea Level Change

- Ocean dynamics such as dynamical re-distribution of water masses due to changes in ocean circulations and surface winds

- Regional steric effect, or changes in water density, induced by spatial variations in the ocean heat content or salinity

- Changes in Earth's gravitational field and ocean floor height resulted from water mass exchanges between land and the ocean

- Regional atmospheric mass loading (inverse barometer effect) due to changes in atmospheric surface pressure (considered negligible: -0.002/-0.006 m for RCP4.5/8.5 by end of 21st century)

- Vertical land movement resulted from long term glacial isostatic adjustment or other non-climatic factors such as tectonic activities, sediment transfer and compaction, and ground water depletion

Components of Local Sea Level Changes

- Global-ocean thermal expansion (*zostoga*)
- Local steric and dynamic effect (*zos*)

Explicitly simulated by CMIP5 models

- Land ice (Glaciers & Ice-sheets)
- Land water storage

Global-estimations given by IPCC AR5
Then scaled by regional factors

- Vertical land movement

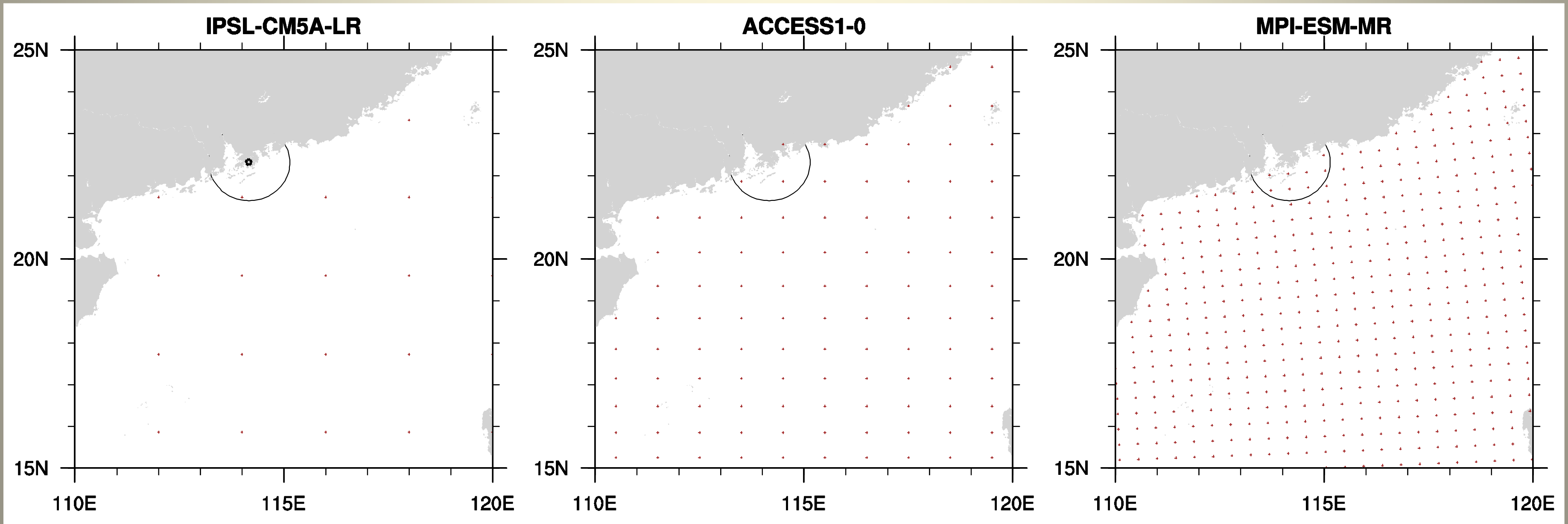
Continuous high precision GPS measurements

19 CMIP5 Climate Models

Model	Centre	Country
ACCESS1-0	CSIRO and BOM	Australia
ACCESS1-3	CSIRO and BOM	Australia
CanESM2	CCCma	Canada
CNRM-CM5	CNRM and CERFACS	France
CSIRO-Mk3-6-0	CSIRO and QCCCE	Australia
GFDL-CM3	NOAA GFDL	USA
GFDL-ESM2G	NOAA GFDL	USA
GFDL-ESM2M	NOAA GFDL	USA
GISS-E2-R	NASA GISS	USA
HadGEM2-CC	UKMO Hadley	UK
HadGEM2-ES	UKMO Hadley	UK
INM-CM4	INM	Russia
IPSL-CM5A-LR	IPSL	France
IPSL-CM5A-MR	IPSL	France
MPI-ESM-LR	MPI-M	Germany
MPI-ESM-MR	MPI-M	Germany
MRI-CGCM3	MRI	Japan
Nor-ESM1-M	NCC	Norway
Nor-ESM1-ME	NCC	Norway

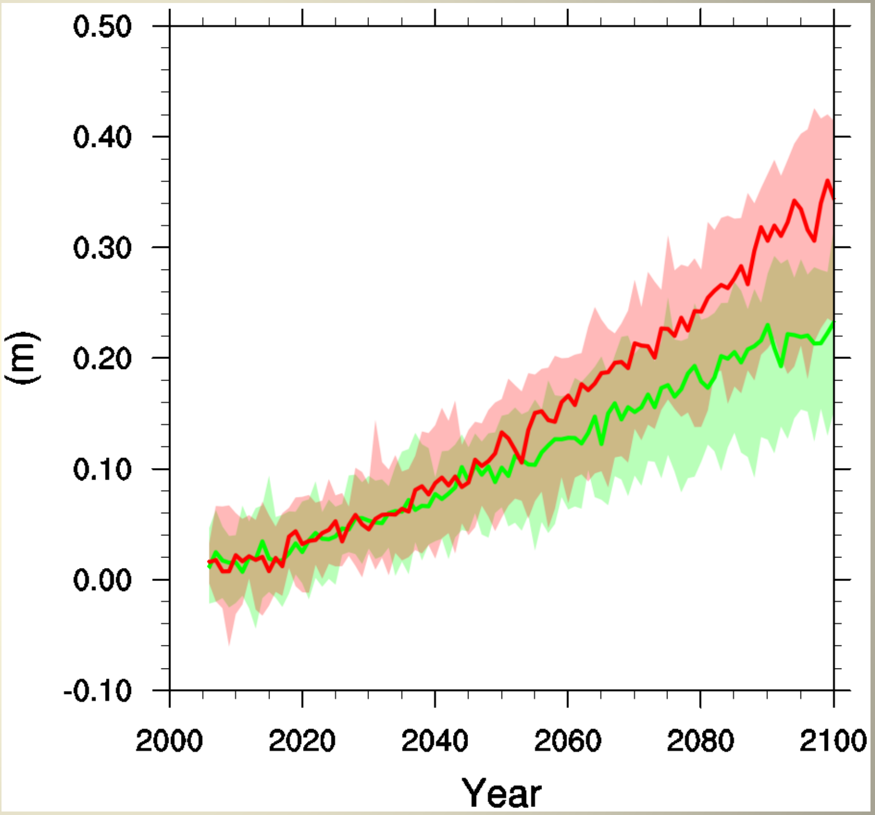
Model Grids for Hong Kong and its Adjacent Waters

- Hong Kong and its adjacent waters is defined as the sea area within 100 km of HKO Headquarters
- Number of grid point within the area ranges from 1 to 8
- Grid points within the specified area were averaged to represent the sea level change in Hong Kong and its adjacent waters



Combined Ocean Circulation and Heat Uptake Contribution (*zostoga and zos*)

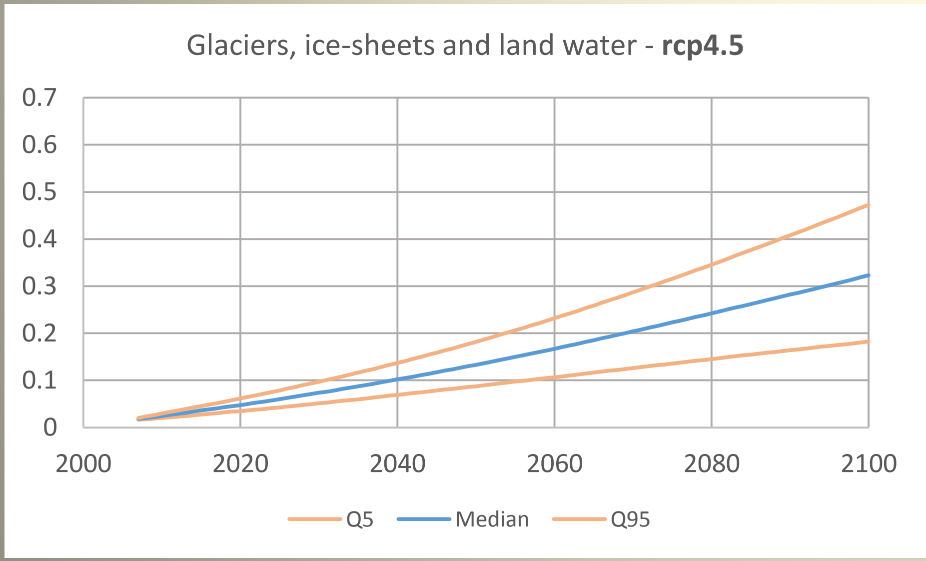
- Simulated sea level rise for 2081-2100 relative to 1986-2005
- 0.30 [0.20 to 0.37] m (RCP8.5)
- 0.21 [0.13 to 0.27] m (RCP4.5)
- Slightly higher than the global mean value projected in AR5

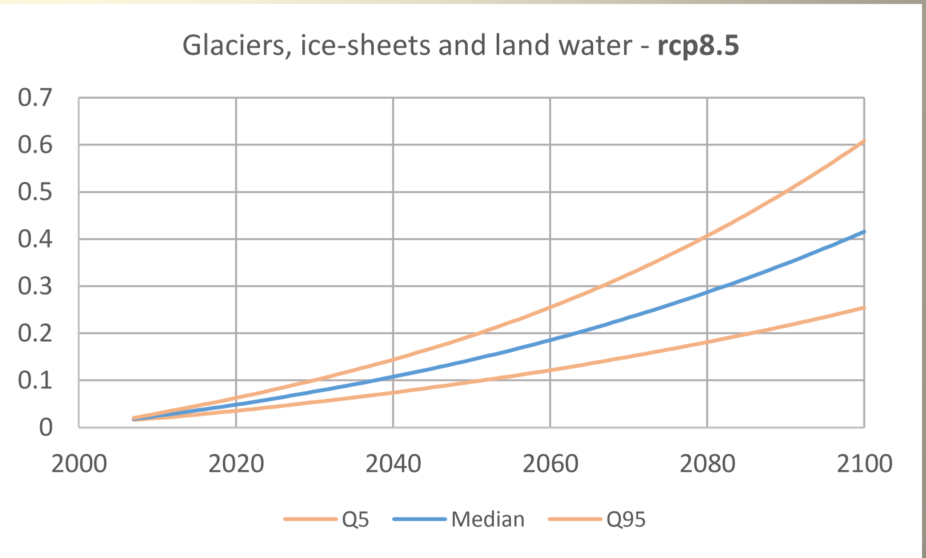


Median and 90% confidence limits (5th percentile and 95th percentile)

Land Ice and Land Water Storage

- Global-averaged time series given by IPCC AR5. These are global estimates of the following contributions:
  - Glaciers
  - Ice-sheets (Greenland and Antarctic)
  - Land water storage

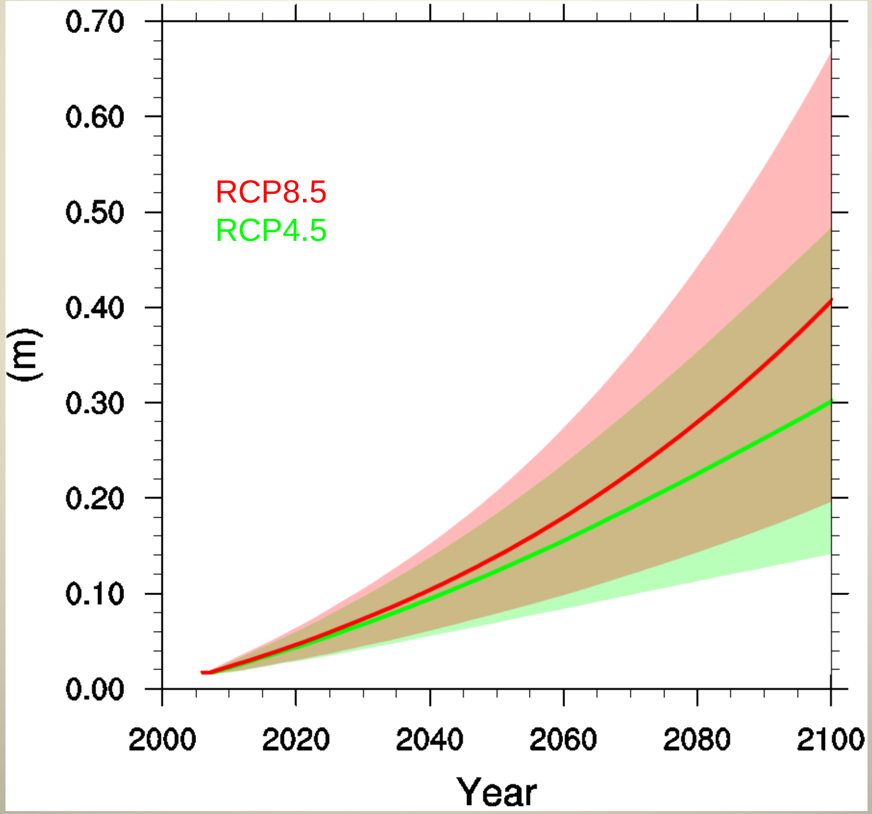




Median and 90% confidence limits (5th percentile and 95th percentile)

Land Ice and Land Water Storage

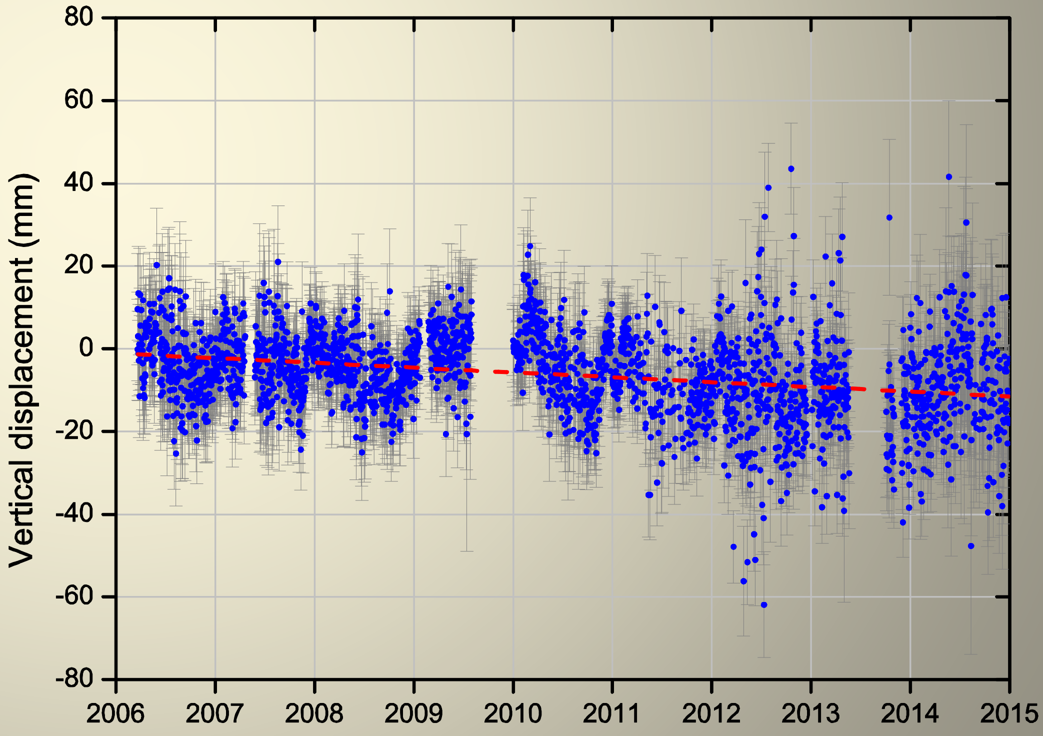
- The regional sea level changes due to land ice and land water storage are determined by scaling the global estimation with published data on regional sea level changes.
- Scaling factors extracted from results of Slangen *et al.* (2014).



Slangen ABA, Carson M, Katsman CA, van de Wal RSW, Köhl A, Vermeersen LLA, Stammer D (2014), Projecting twenty-first century regional sea-level changes, Clim. Change, 124, 317-332.

Vertical Land Movement in Hong Kong

- Glacial isostatic adjustment is considered very small in the vicinity of Hong Kong (Church *et al.*, 2013)
- Observation of crustal movement using continuous high precision GPS station at Tate's Cairn
- A subsidence trend of 1.99 ± 0.31 mm/yr

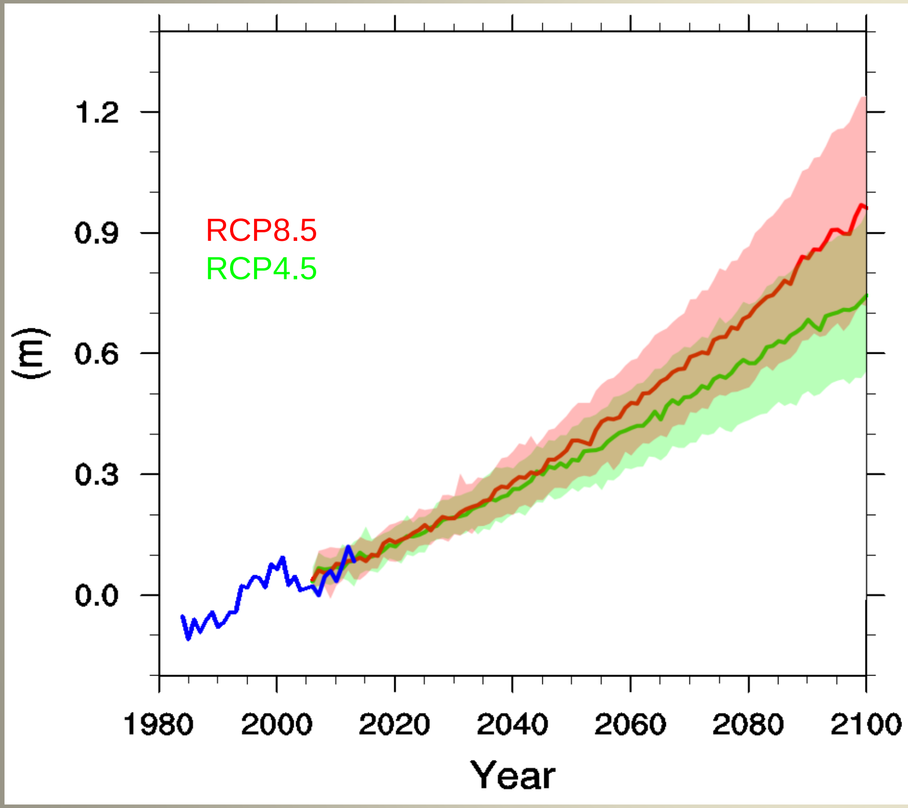


D.S. Lau and W.T. Wong, 2010: 利用GPS監測香港地殼移動的初步結果, HKO Reprint 876

Vertical Velocity of Shanghai

- Located within the same Eurasia plate
- Observations of Shanghai GPS from 1995 to 2013: -1.40 ± 0.32 mm/yr
- Very long baseline interferometry measurements at Shanghai from 1988 to 1998: -1.86 ± 0.83 mm/yr
- Subsidence rate at Shanghai is believed to be slightly smaller than that of Hong Kong

Sea Level Rise in the vicinity of Hong Kong (assuming long-term subsidence rate of 1.99 ± 0.31 mm/yr)



		Sea level rise in Hong Kong and its adjacent waters
RCP4.5	2081-2100	0.67 [0.50 to 0.84]
	2100	0.74 [0.56 to 0.95]
RCP8.5	2081-2100	0.84 [0.63 to 1.07]
	2100	0.96 [0.72 to 1.24]

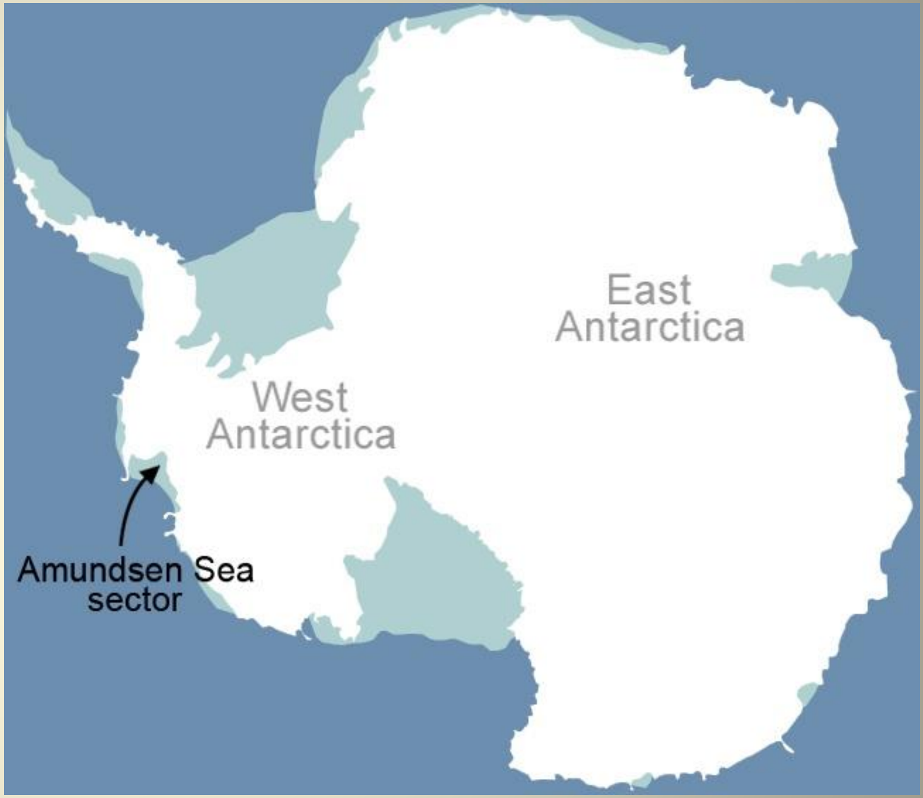
Summary of Results

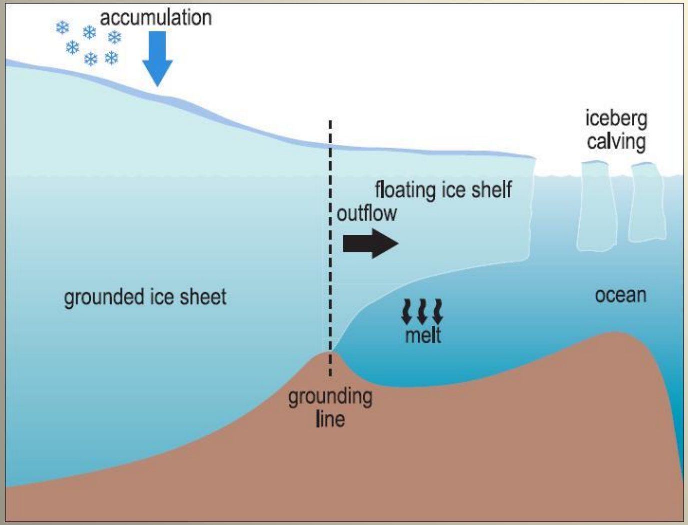
Components	2046-2065		2081-2100	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Steric and dynamic effect	0.11 [0.06 to 0.16]	0.14 [0.07 to 0.19]	0.21 [0.13 to 0.27]	0.30 [0.20 to 0.37]
Surface mass balance (glaciers + ice-sheet)	0.07 [0.02 to 0.13]	0.09 [0.03 to 0.16]	0.13 [0.03 to 0.25]	0.19 [0.05 to 0.38]
Ice-sheet rapid dynamics	0.06 [0.02 to 0.10]	0.06 [0.03 to 0.10]	0.12 [0.03 to 0.21]	0.13 [0.04 to 0.22]
Land water storage (*)	0.01 [0.00 to 0.02]	0.01 [0.00 to 0.02]	0.02 [-0.01 to 0.05]	0.02 [-0.01 to 0.05]
Vertical land movement (*)	0.12 [0.09 to 0.15]	0.12 [0.09 to 0.15]	0.19 [0.14 to 0.24]	0.19 [0.14 to 0.24]
Total (with land movement)	0.38 [0.29 to 0.47]	0.43 [0.32 to 0.53]	0.67 [0.50 to 0.84]	0.84 [0.63 to 1.07]
Total (without land movement)	0.26 [0.17 to 0.34]	0.31 [0.20 to 0.40]	0.48 [0.32 to 0.64]	0.65 [0.44 to 0.87]

(*) independent of RCP scenarios

Bad news from West Antarctica: some glaciers have passed the point of no return

NASA (May 2014): The melting of this sector of glaciers could cause a global sea level rise of 1.2 metres





More bad news!

- Potsdam Institute for Climate Impact Research (Feb 2015): Local destabilization can cause complete loss of West Antarctica's ice masses (3 m of sea level rise in centuries)

- U of Massachusetts Amherst and Pennsylvania State University (Mar 2016): Sea-level rise could nearly double over earlier estimates in next 100 years

Storm Surge

Challenges to Drainage System

Date (Oct 2016)	Rainfall (mm)
18	178.7
19	223.4

Normal rainfall in October (1981-2010) = 100.9 mm

October 2016 rainfall is more than SIX times the normal

今日
Today

50年一遇

1 in **50** years

21世紀末

Late 21st century