METEOROLOGICAL SERVICE SINGAPORE
Centre for Climate Research Singapore

GENERATING CLIMATE CHANGE PROJECTIONS FOR SINGAPORE: A TALE OF SCALE

Dr Bertrand Timbal

Senior Principal Research Scientist

With contributions from many in CCRS

Is it useful ?

Relevance of the Climate Science

Centre for Climate Research Singapore (CCRS) work supports

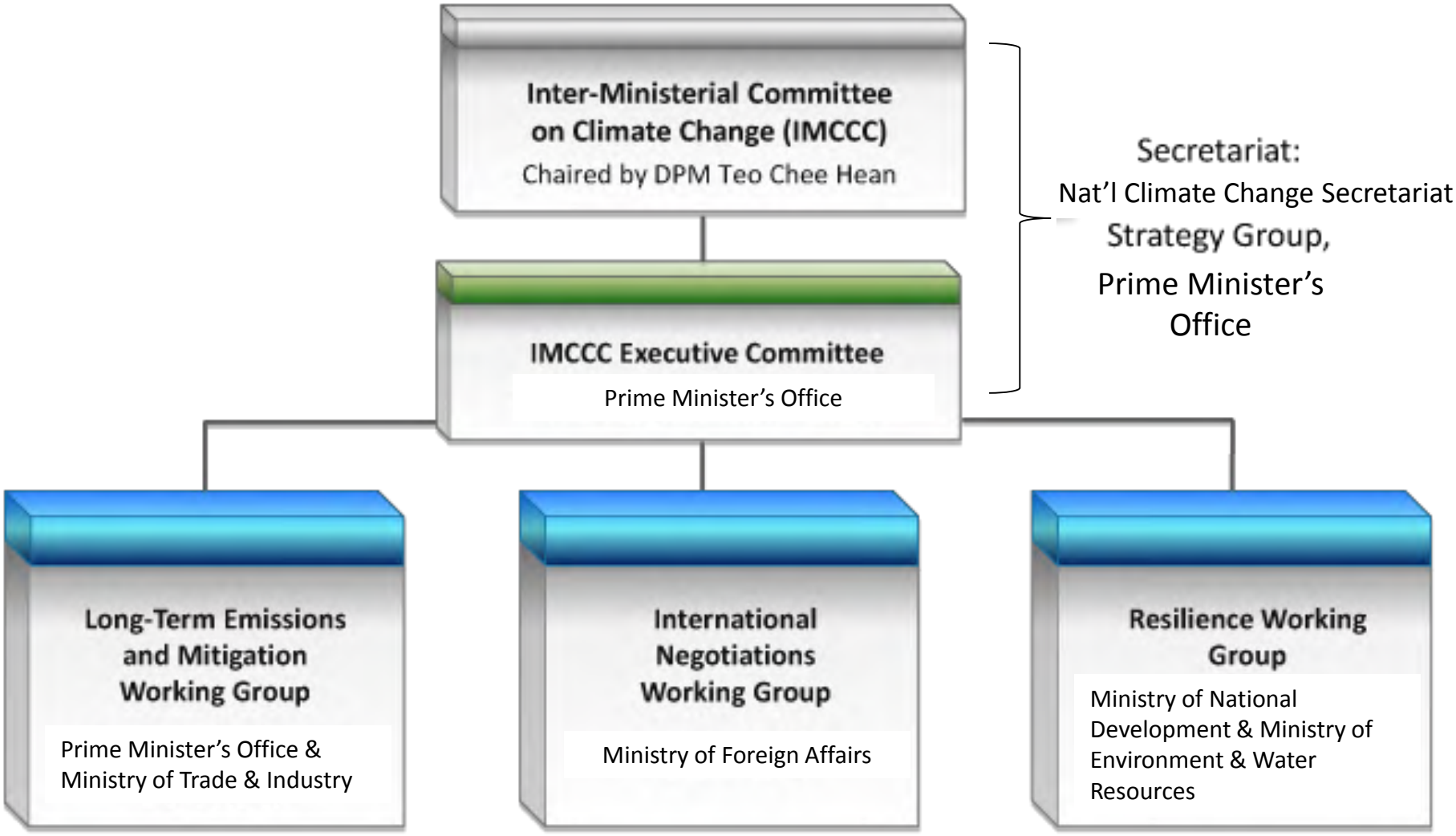
- the Inter-Ministerial Committee on Climate Change (IMCCC)
- & its Resilience Working Group (RWG)

RWG is tasked to develop a risk assessment framework & long-term plans for infrastructure adaptation

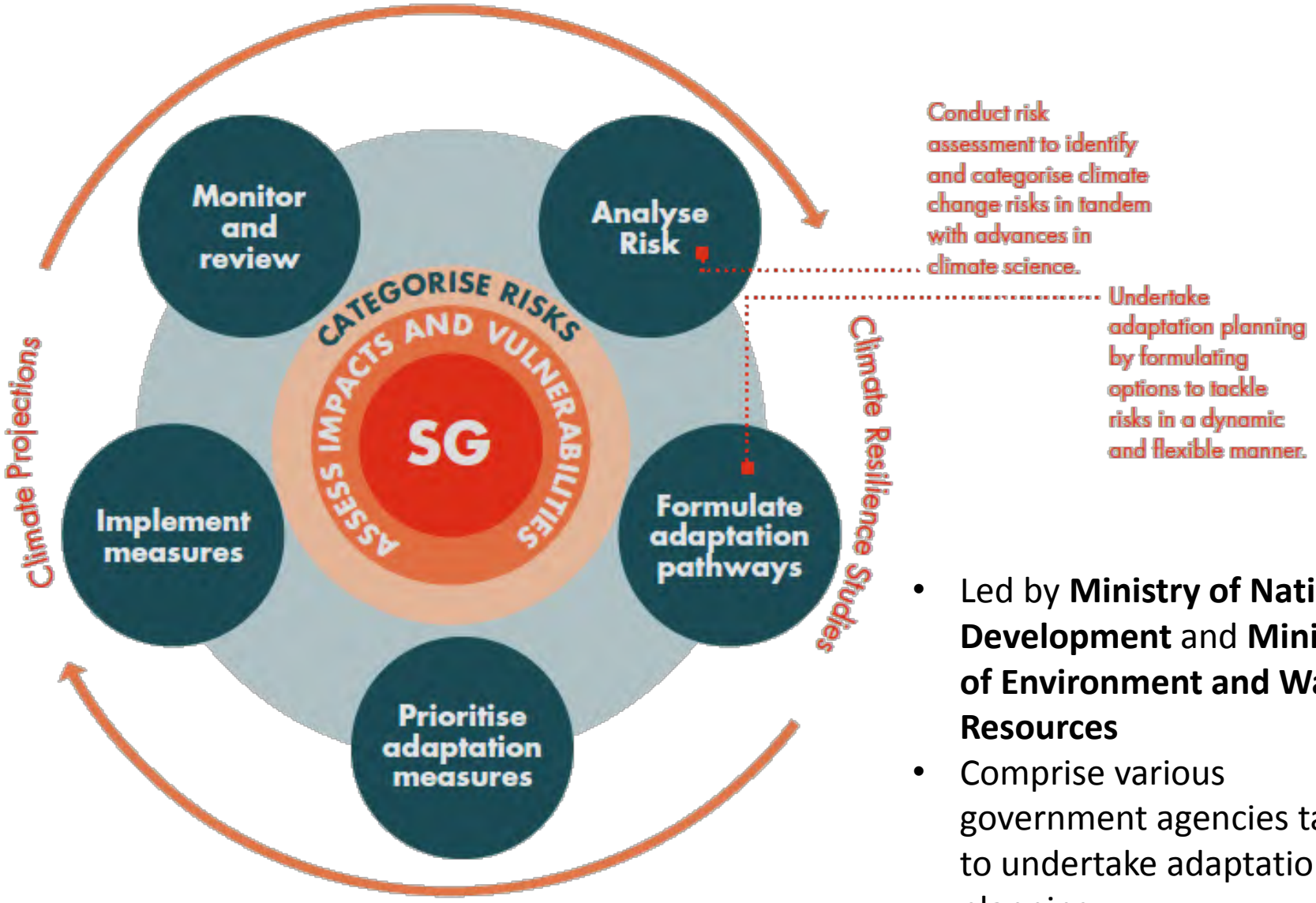
Singapore 2nd National Climate Change Study was released in 2015

Learning about future climate change helps us to prepare for and respond to future change (**adaptation**) as well as understand the benefits of reducing climate change (**mitigation**)

Inter-Ministerial Committee on Climate Change

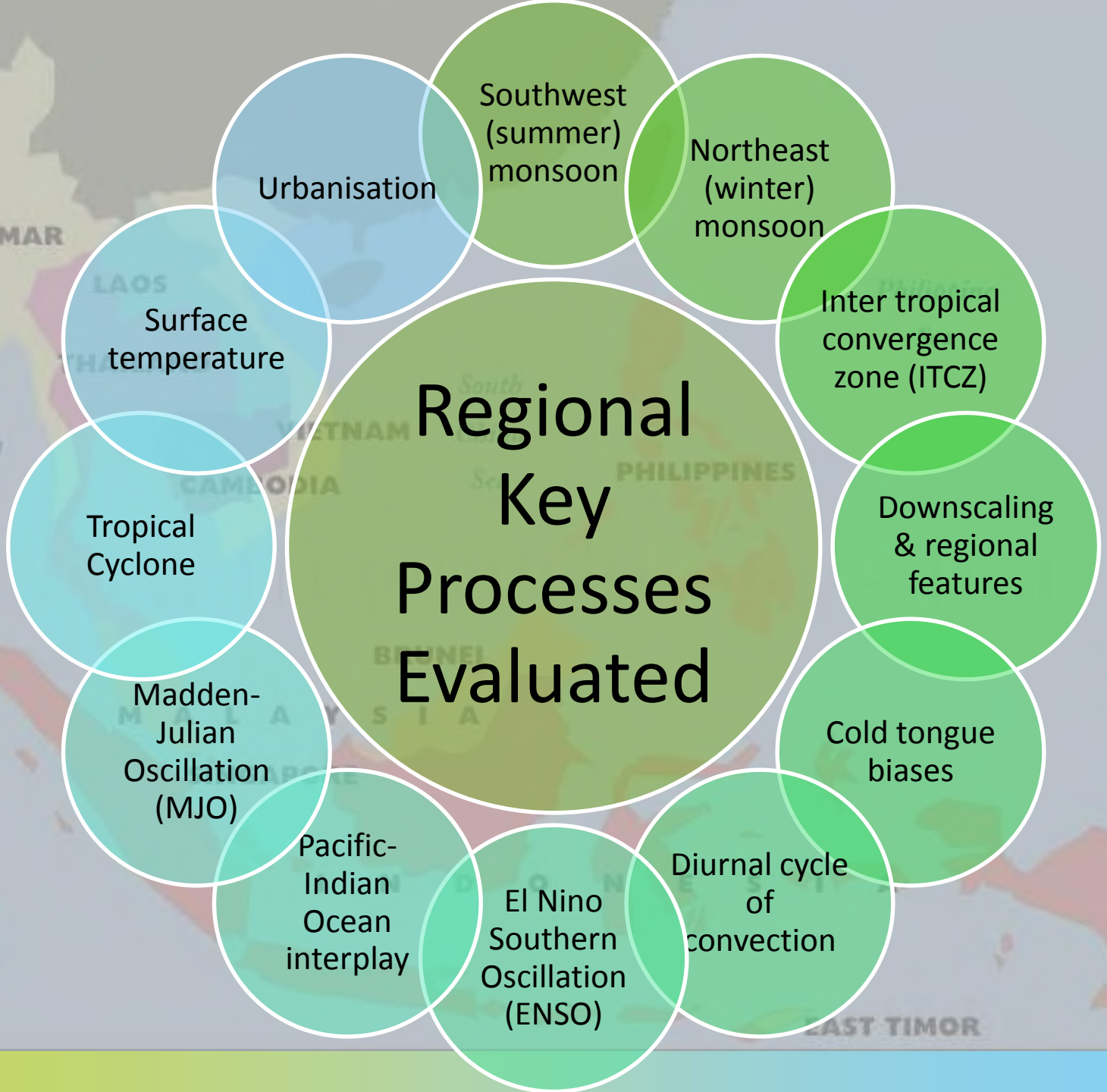


Singapore's Climate Resilience Framework

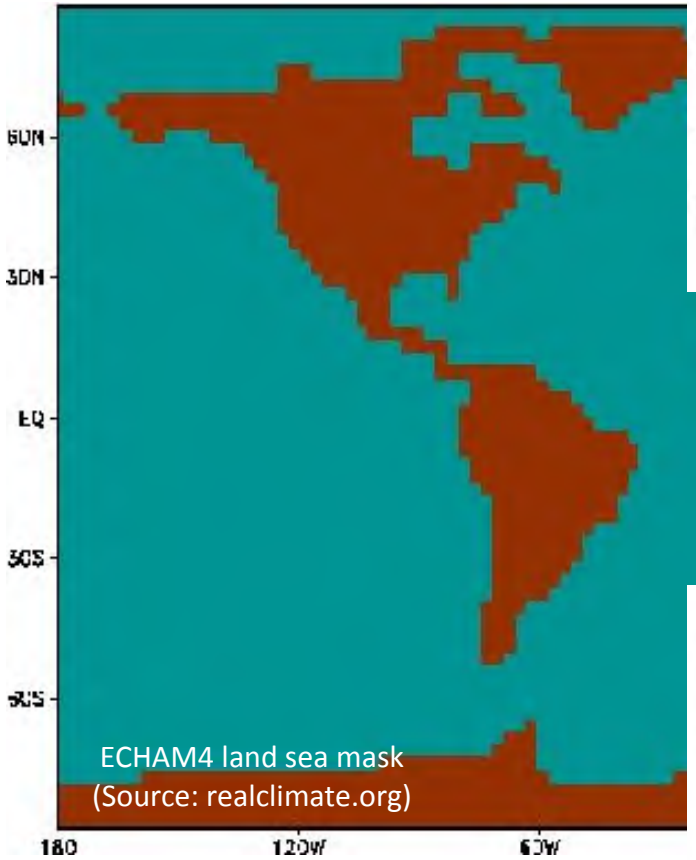


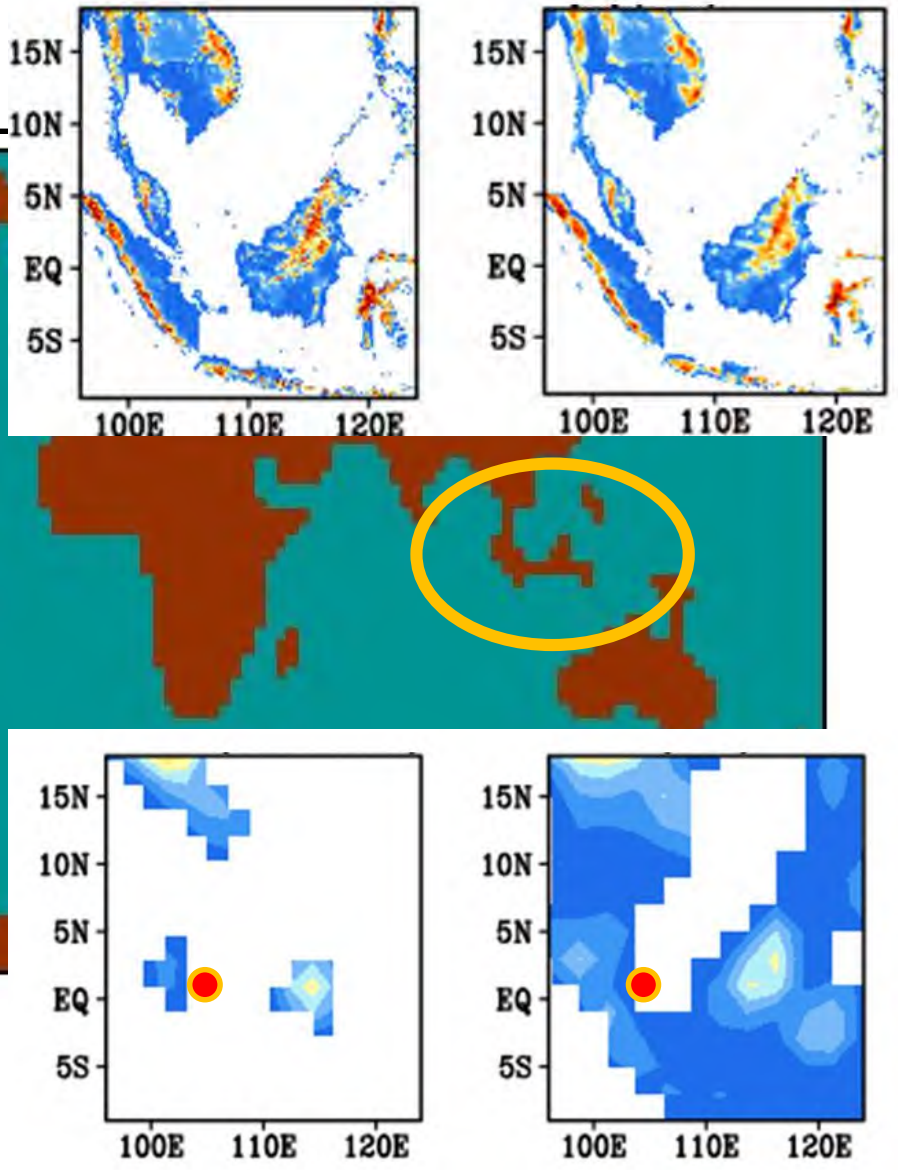
- Led by **Ministry of National Development** and **Ministry of Environment and Water Resources**
- Comprise various government agencies tasked to undertake adaptation planning

Is it easy ?


Regional Key Processes Evaluated
Southwest (summer) monsoon
Northeast (winter) monsoon
Inter tropical convergence zone (ITCZ)
Downscaling & regional features
Cold tongue biases
Diurnal cycle of convection
El Nino Southern Oscillation (ENSO)
Pacific-Indian Ocean interplay
Madden-Julian Oscillation (MJO)
Tropical Cyclone
Surface temperature
Urbanisation

GCMs cannot



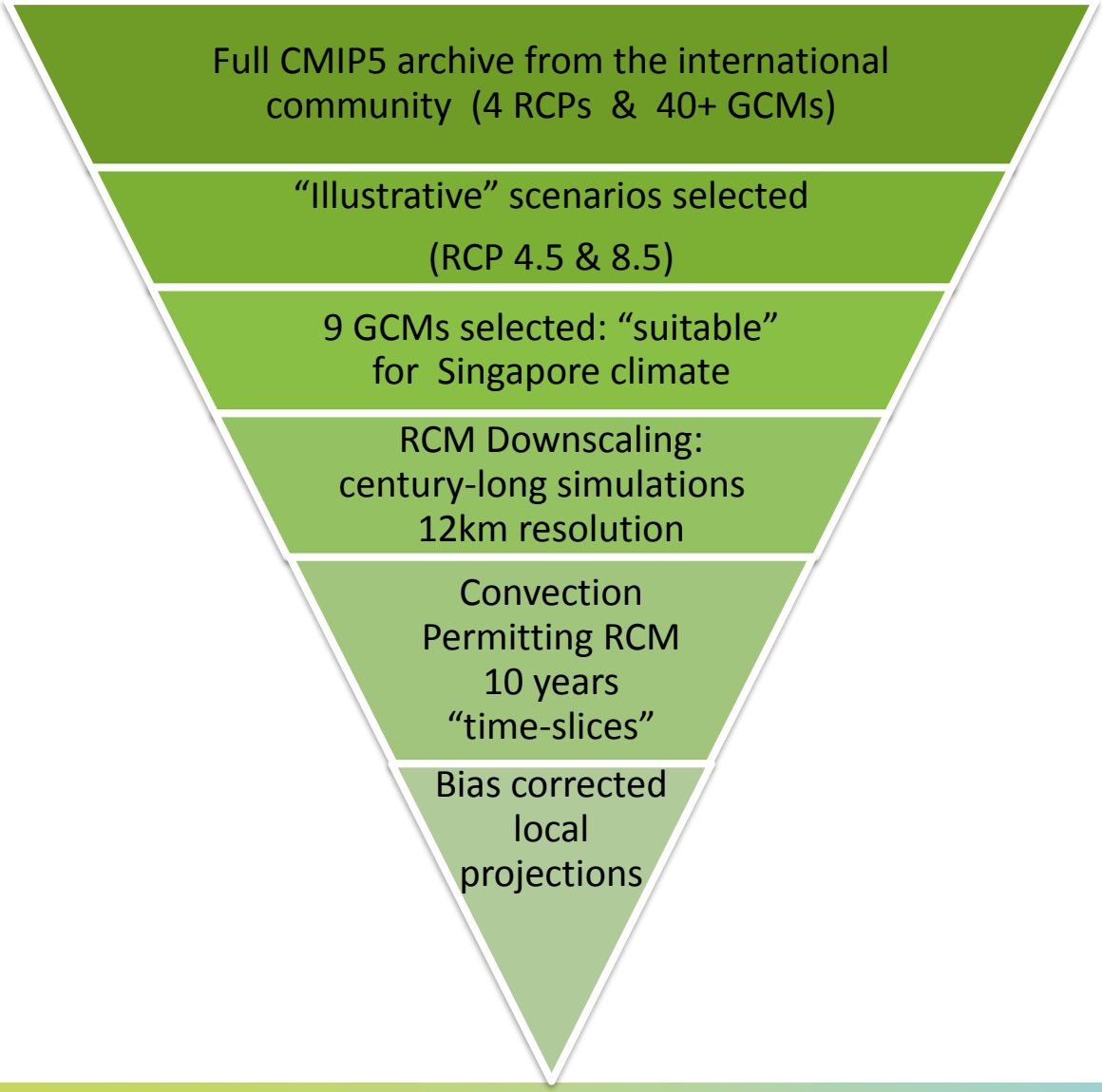


GCM's views of the **continents**

South-East Asia is not realistic:

Red dot (**Singapore)** is not on the map (examples from @ state-of-the-art GCMs)

Numerical Modelling Tools



Uncertainties Considered

- **Anthropogenic forcing**: Plausible future paths of socio-economic development
- **Global Climate System**: Different modelled responses to the anthropogenic forcing
- **Downscaling linkage**: Response of the regional climate to global climate change(s)
- **Convective Process resolved**: Response of localized weather systems to regional climate change
- **Local Information:** Statistical adjustments to provide local information for quantities of relevance to users

Singapore 2nd National Climate Change study

2nd Singapore Climate Change Study

CCRS has completed the **2nd National Climate Change Study** (2015)

- Based on the latest models used in the IPCC 5th Assessment Report (AR5)
- Undertaken as a joint project between CCRS and the UK Met Office

Provides climate projections for key variables:

- **Temperature**, **Rainfall**, Humidity, Wind and **Sea-level**
- Change in **mean** and **extremes**
- Trajectories of changes **up to 2100** and beyond

Climate Projections jointly by CCRS & UK Met Office

Climate Impacts Assessment by Infrastructure Agencies

Model evaluation & Downscaling

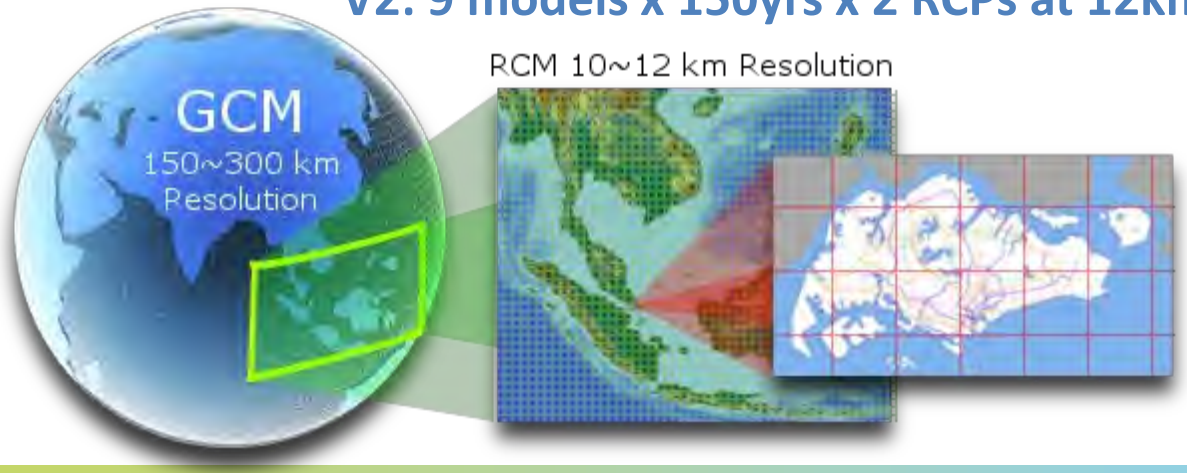
CMIP5: 38 models x 150yrs x 2 RCPs
Results reported in IPCC AR5

Strategic sub-sampling:
- Span uncertainty
- Use most skilful models
- Most efficient use of resources

V2: extension

3 x 10yrs time-slices @ 1.5km

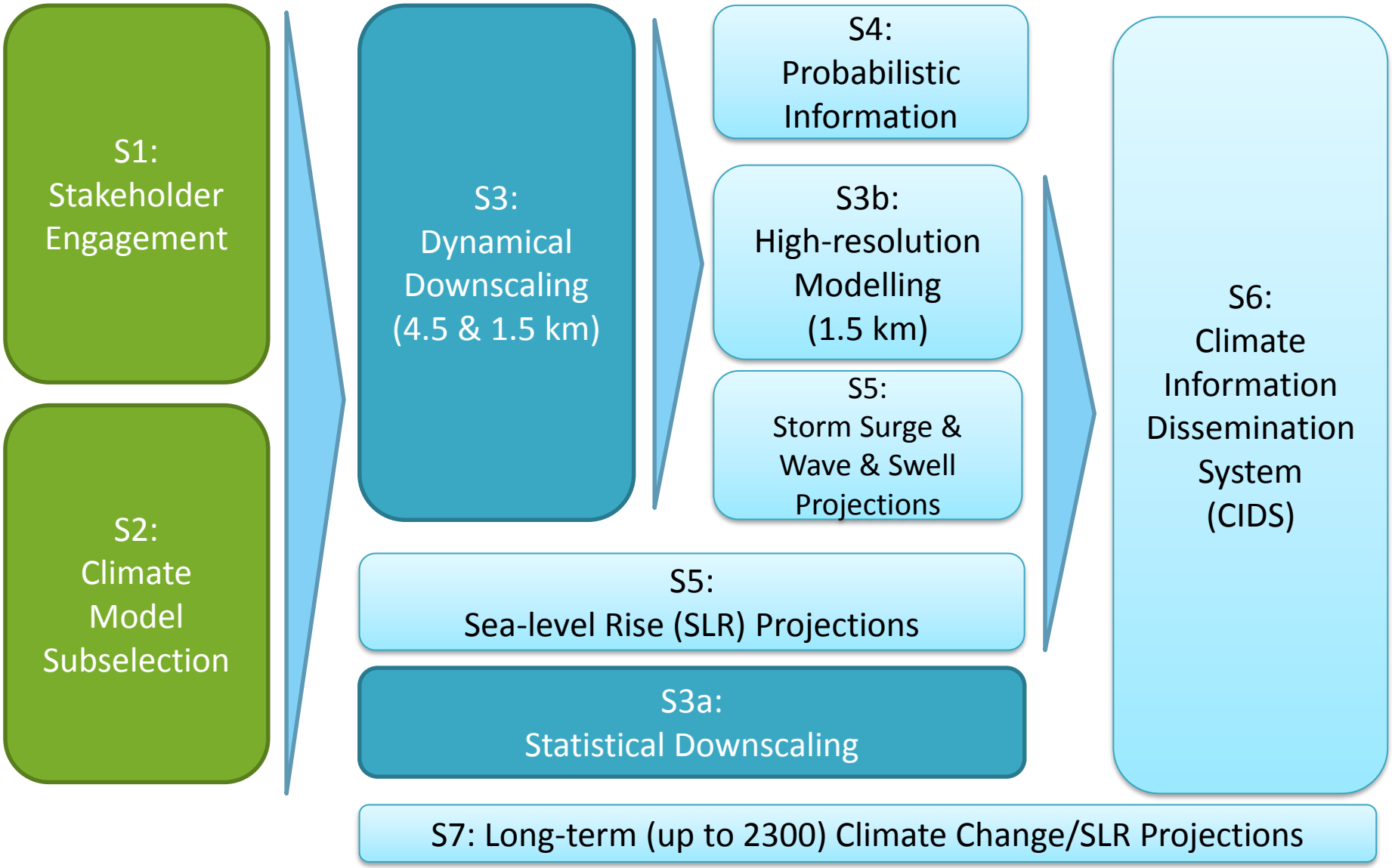
V2: 9 models x 150yrs x 2 RCPs at 12km



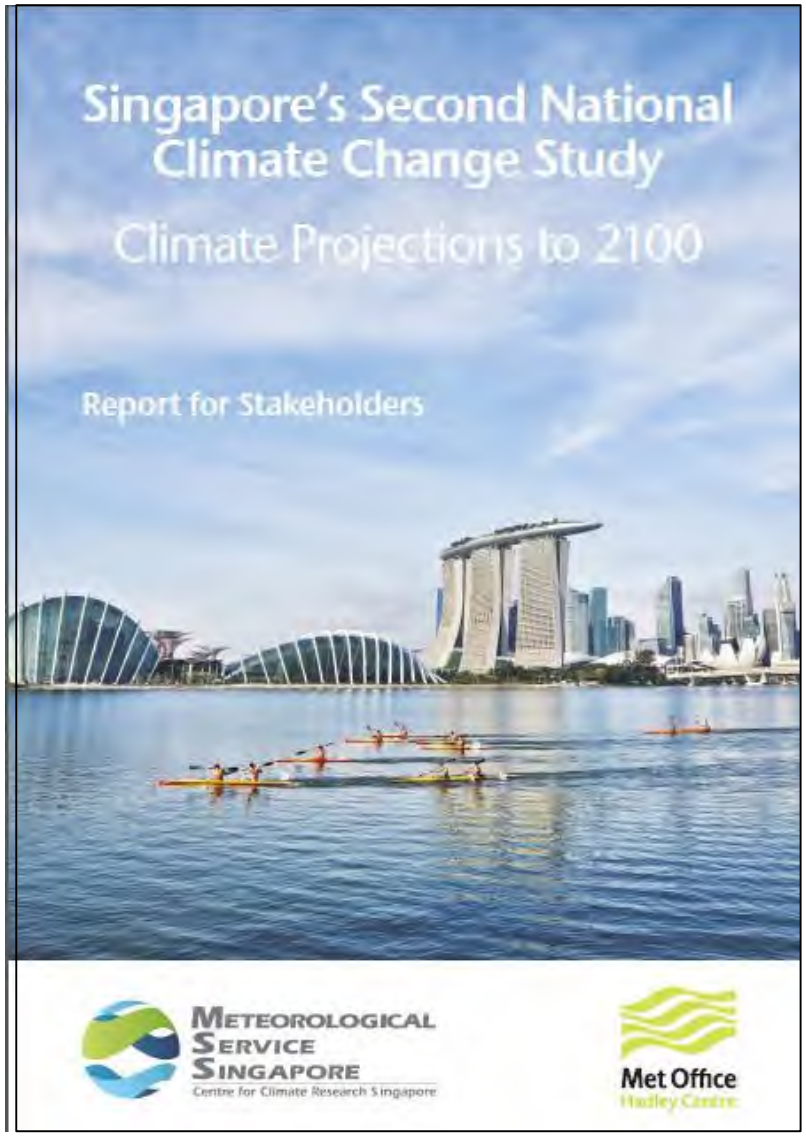
Bias correction

CIDS

Project Stages



2nd National Climate Change Study



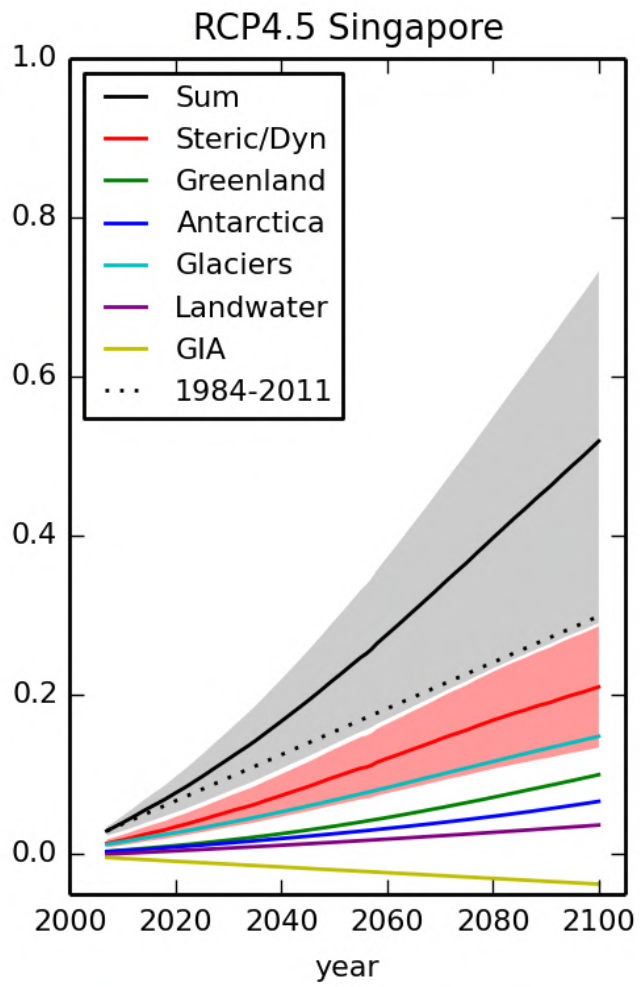
Two reports have been produced:

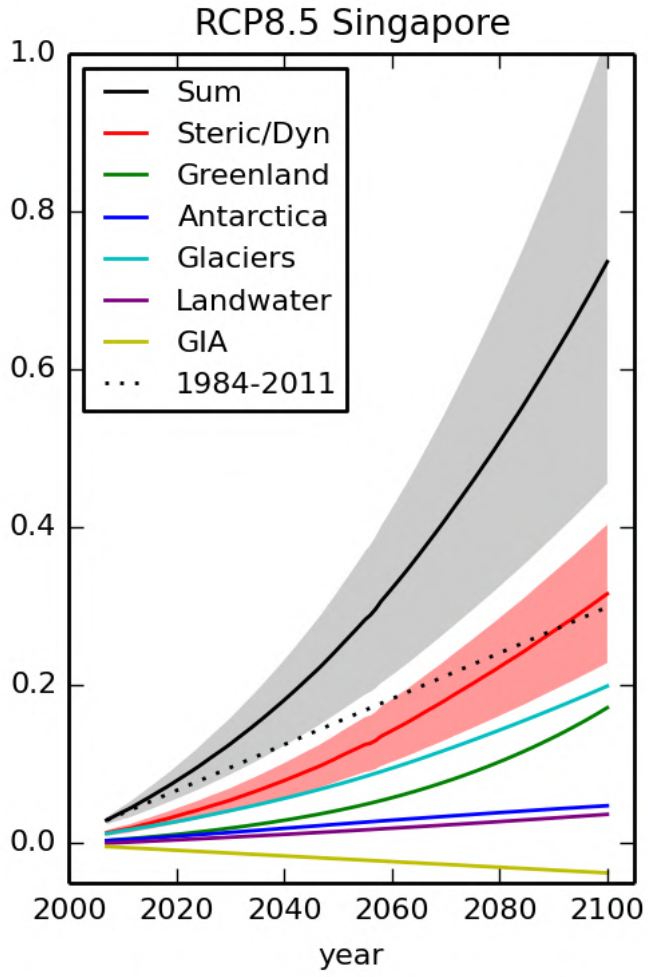
The Stakeholder Report
(Summary of key results)

The Science Report

Both available at:
http://ccrs.weather.gov.sg/publications-listing-page/

2nd National Climate Change Study



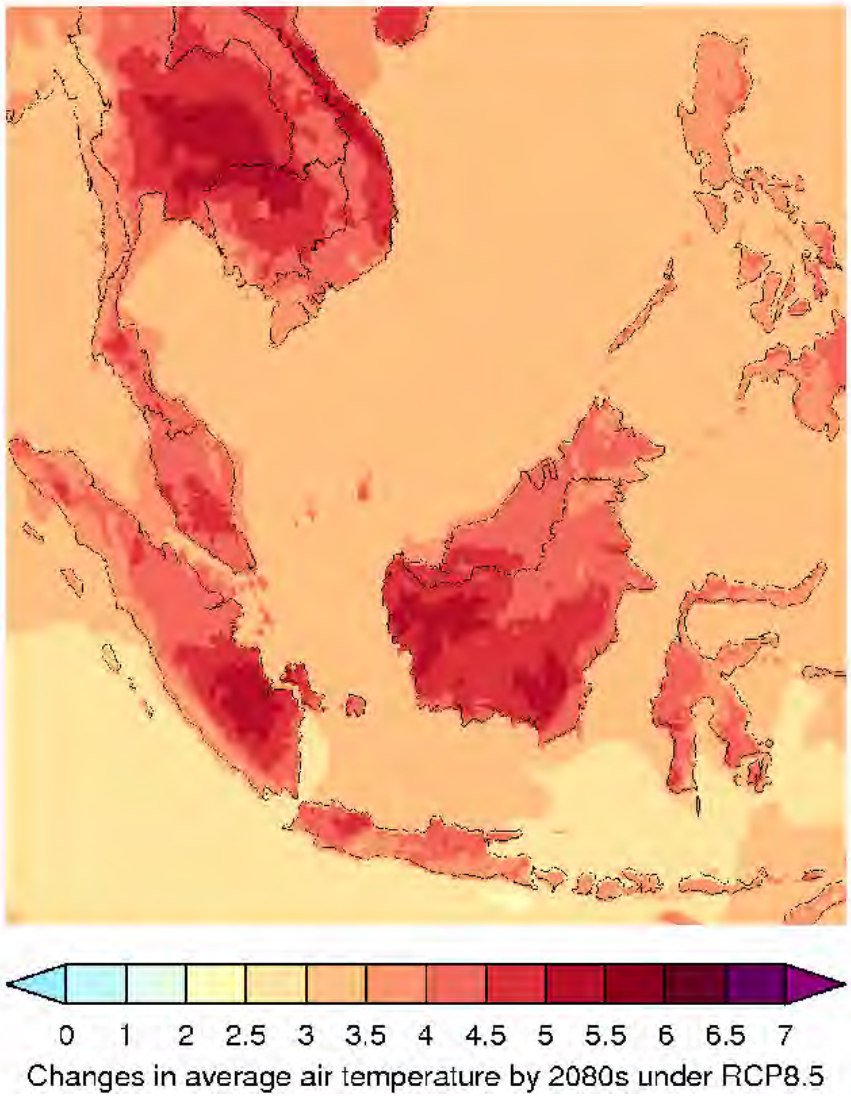


Sea level rise from various sources (e.g. glaciers) with the total rise in black

Projections of **sea level rise**

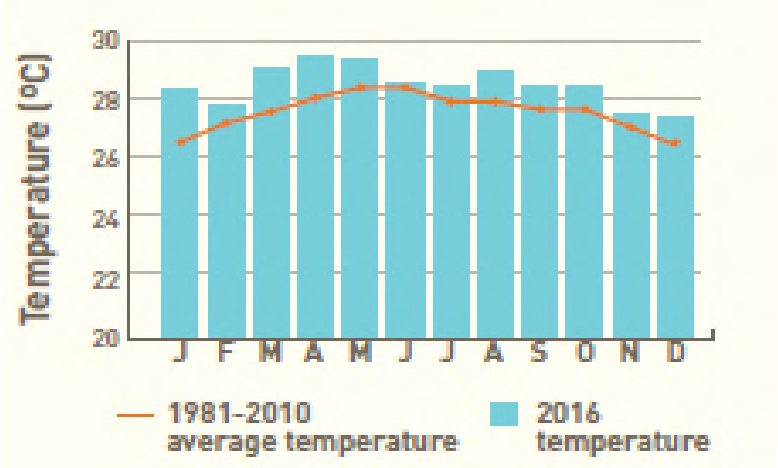
- Scenario dependent
- No significant positive change for storm surge and waves
- Large uncertainties for GSLR
- Critical issue for adaptation planning in Singapore

2nd Singapore Climate Change Study



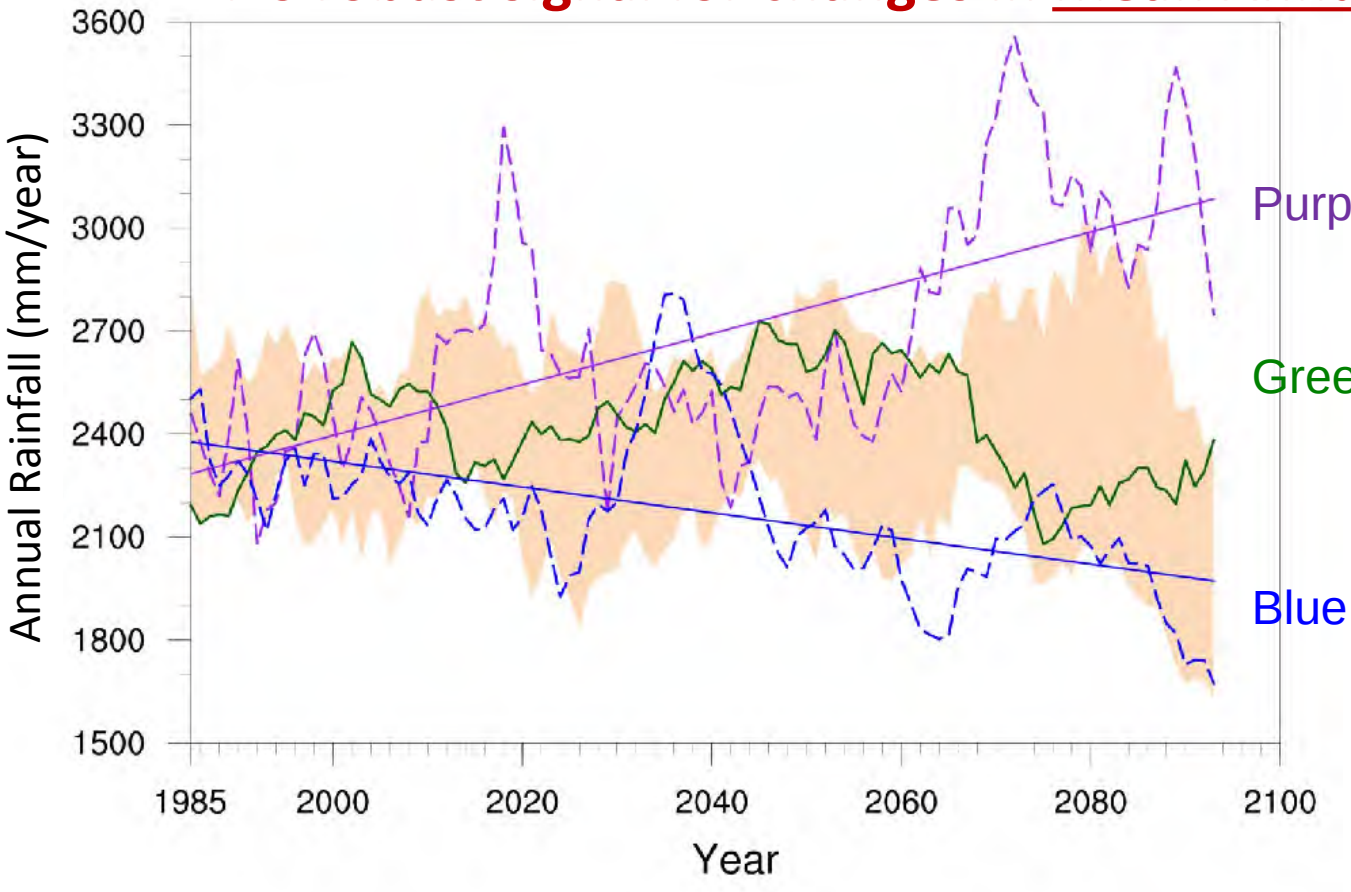
SE Asian mean temperature (T) rise during SW Monsoon (°C):

- June-August 2m T for 2070-2099 vs. 1980-2009 under RCP8.5
- More warming over land than ocean (3 – 5°C across the region)
- Much larger than annual cycle of T in Singapore, or recent anomalies



2nd Singapore Climate Change Study

No robust signal for changes in Mean Annual rainfall



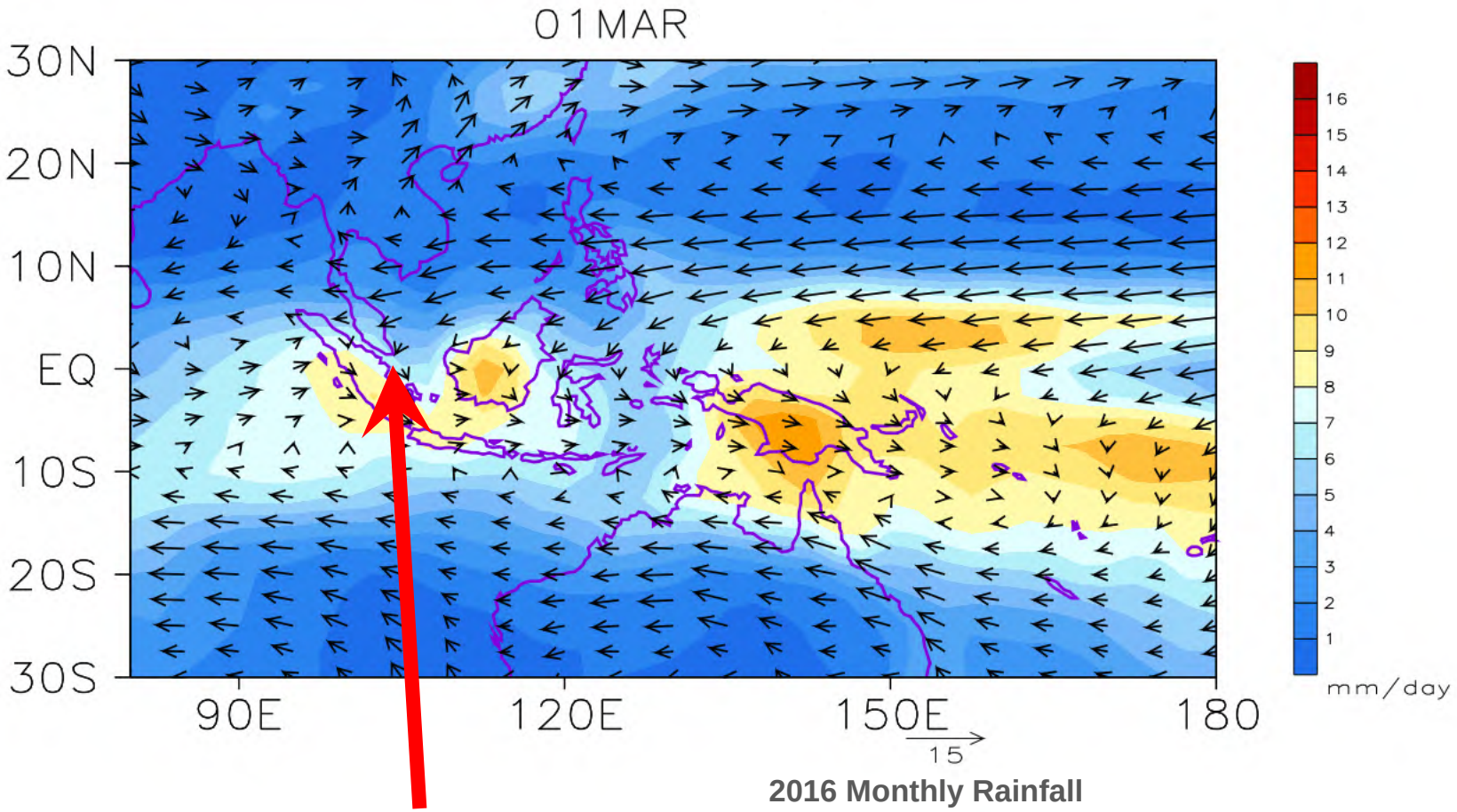
Purple max upward **trend**

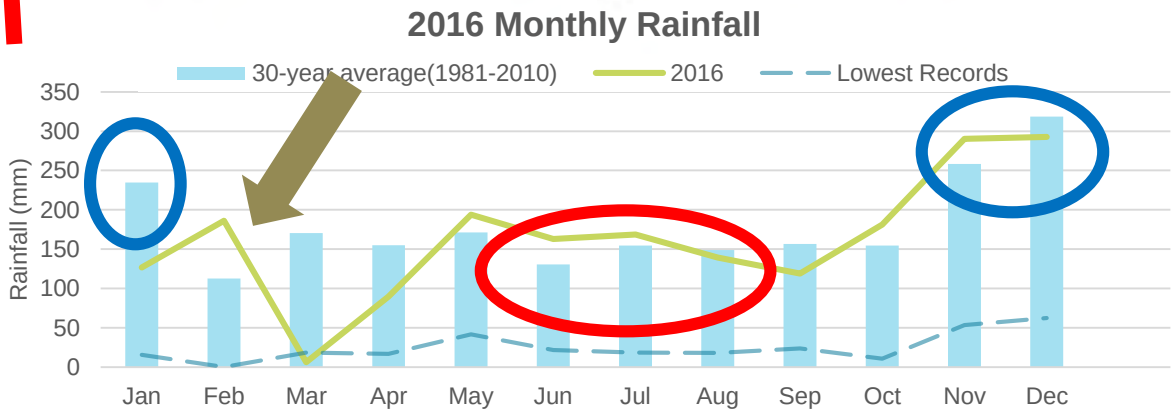
Green – median **trend**

Blue – max downward **trend**

At any particular time in the future, the projections are a **combination** of **natural climate variability** and **anthropogenic climate change**

Understanding the projections

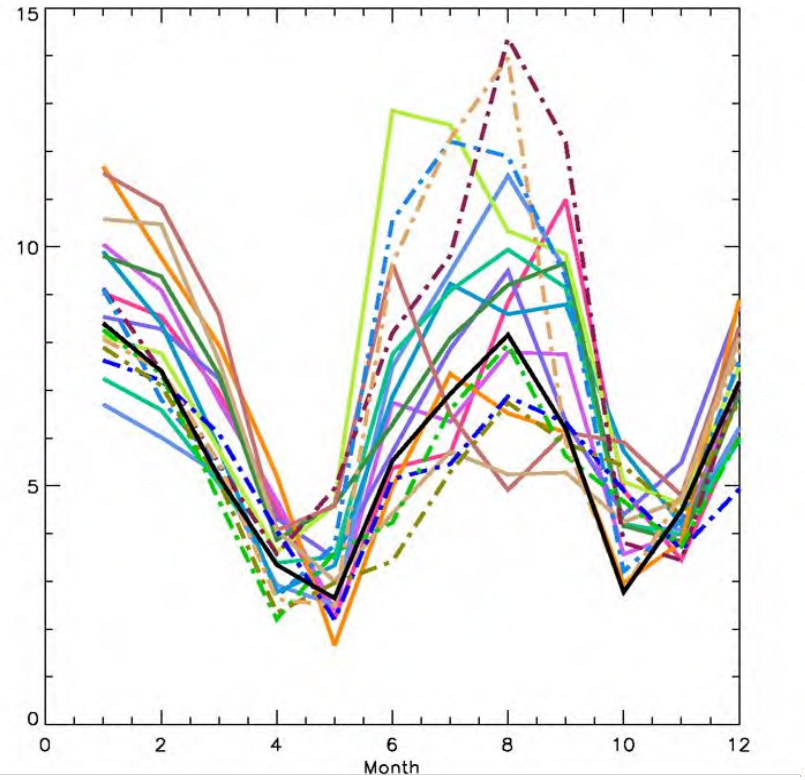

01MAR
30N
20N
10N
EQ
10S
20S
30S
90E
120E
150E
180
15
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
mm/day

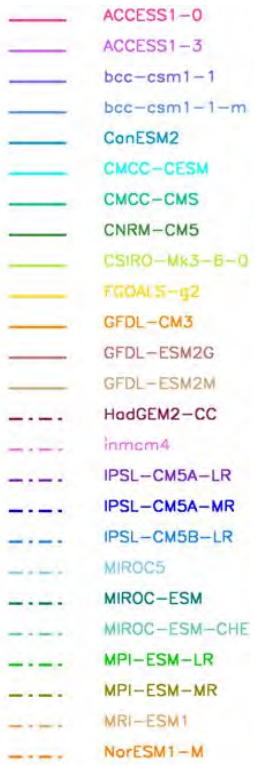

2016 Monthly Rainfall
30-year average(1981-2010)
2016
Lowest Records
Rainfall (mm)
350
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Circulation vs. Precipitation

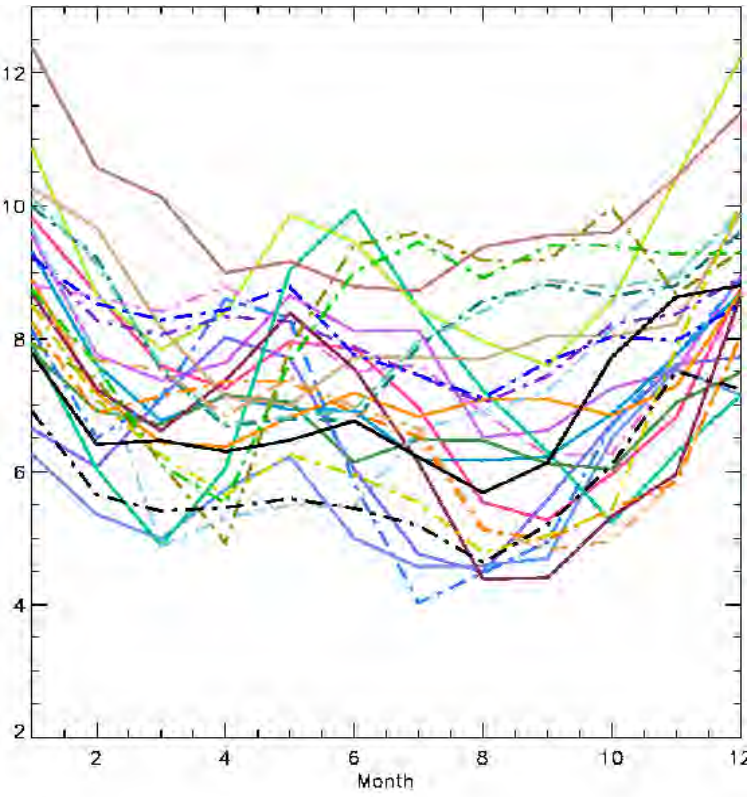
5-10N, 107-115E

Wind Speed (850 hPa)





Precipitation

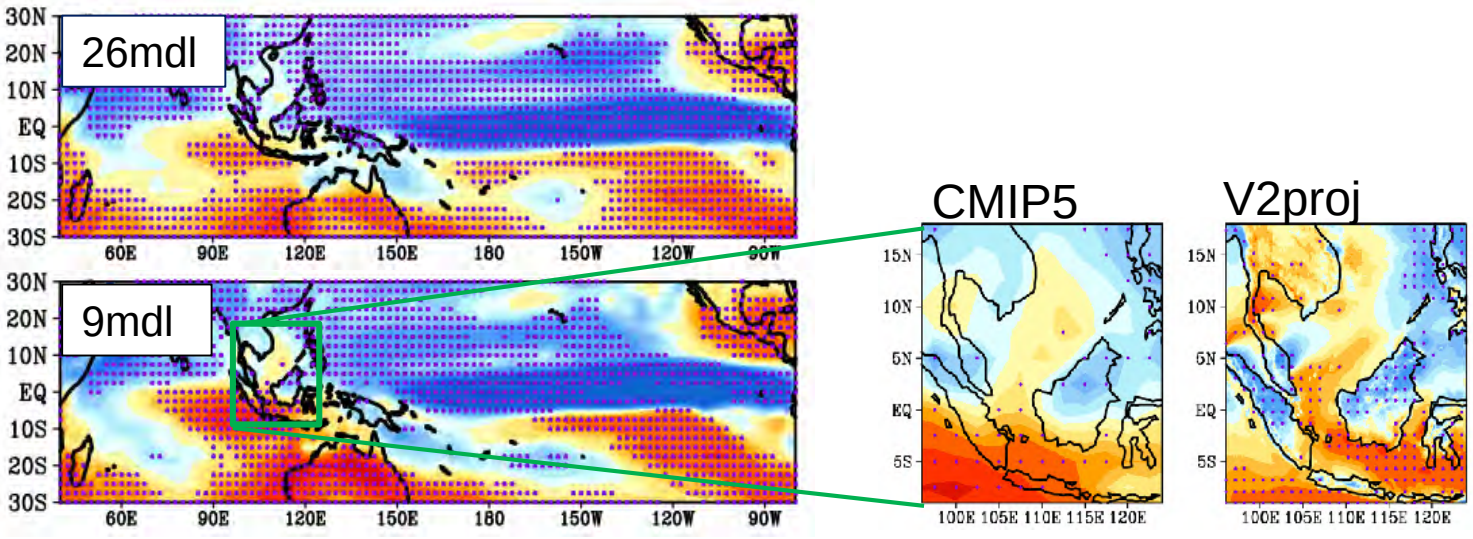


Estimate of the truth: ERA-I

Estimate of the truth: GPCP & TRMM

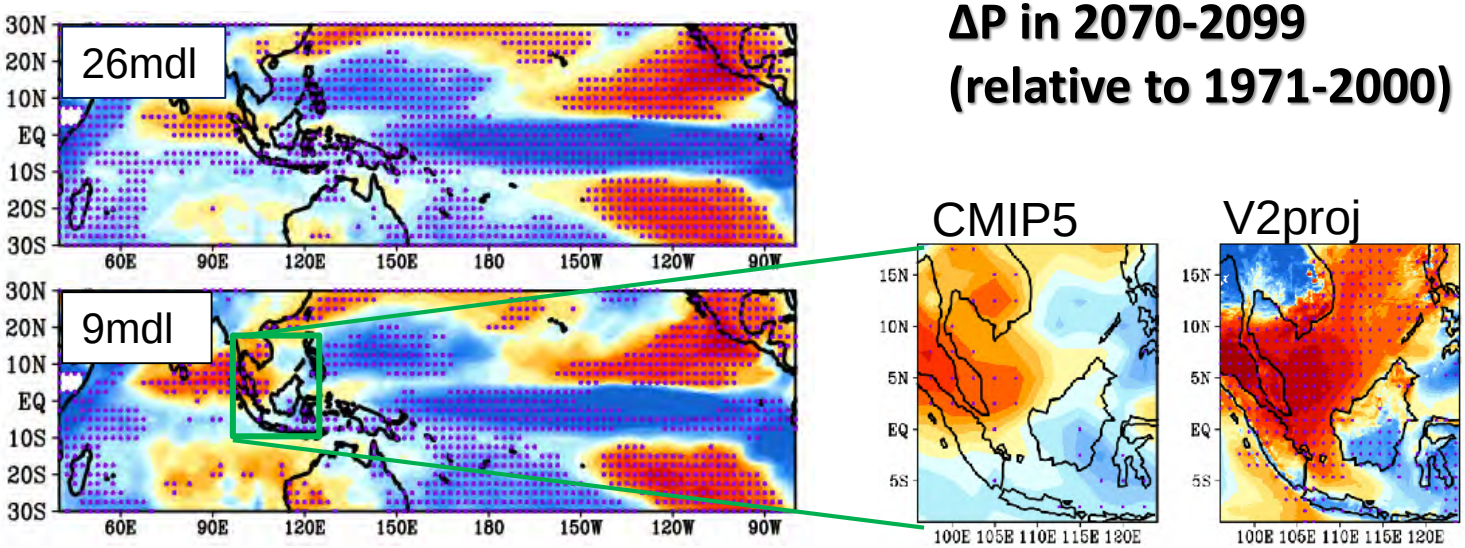
Seasonal rainfall projected changes

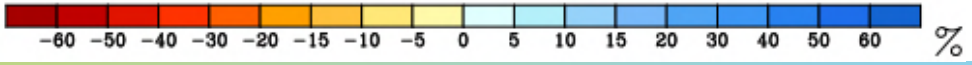
JJAS



ΔP in 2070-2099
(relative to 1971-2000)

FEB

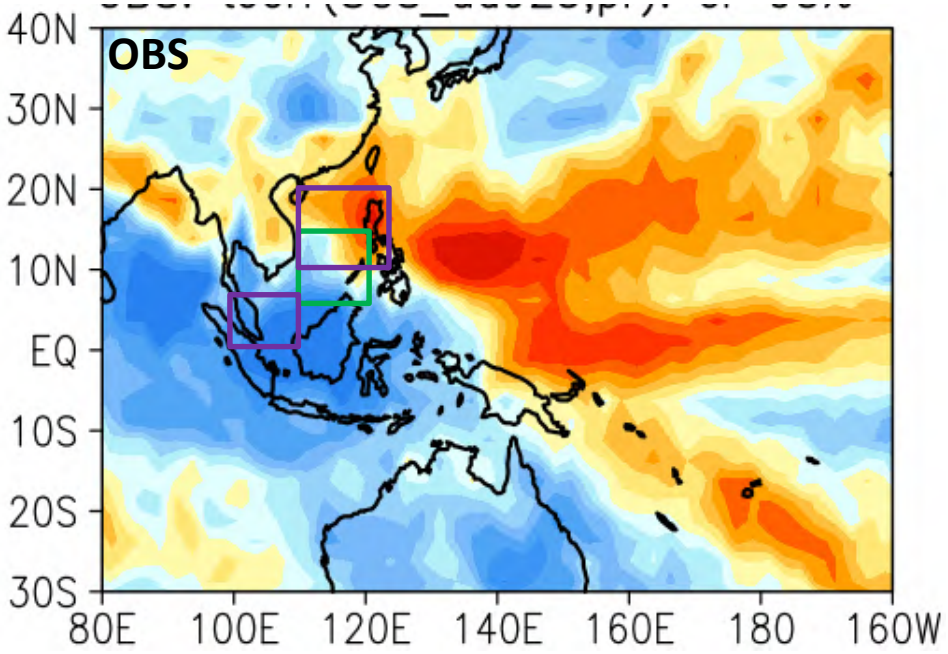




cl=90%

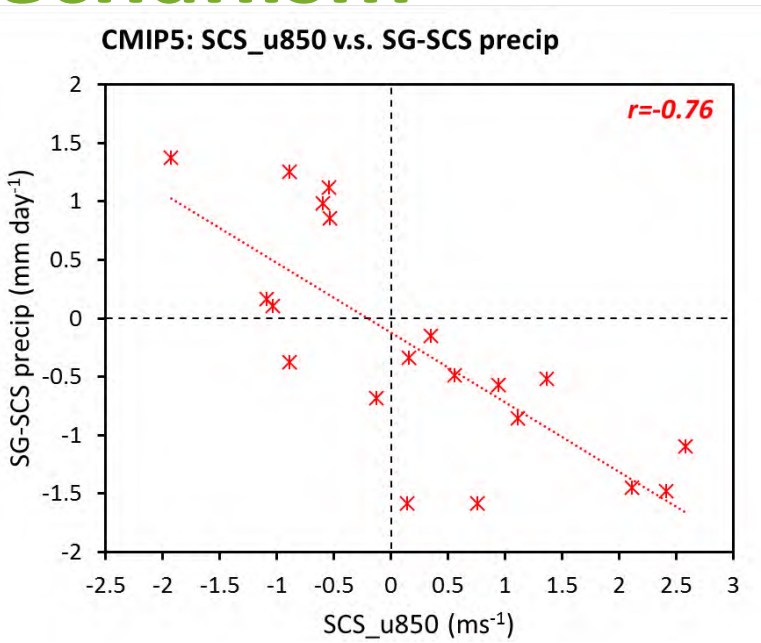
SW Monsoon rainfall: mechanism

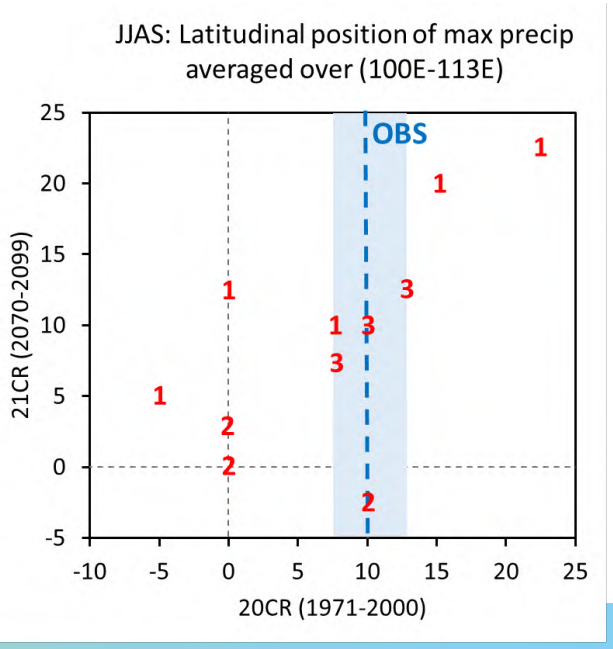
Corr (low level wind, precip)



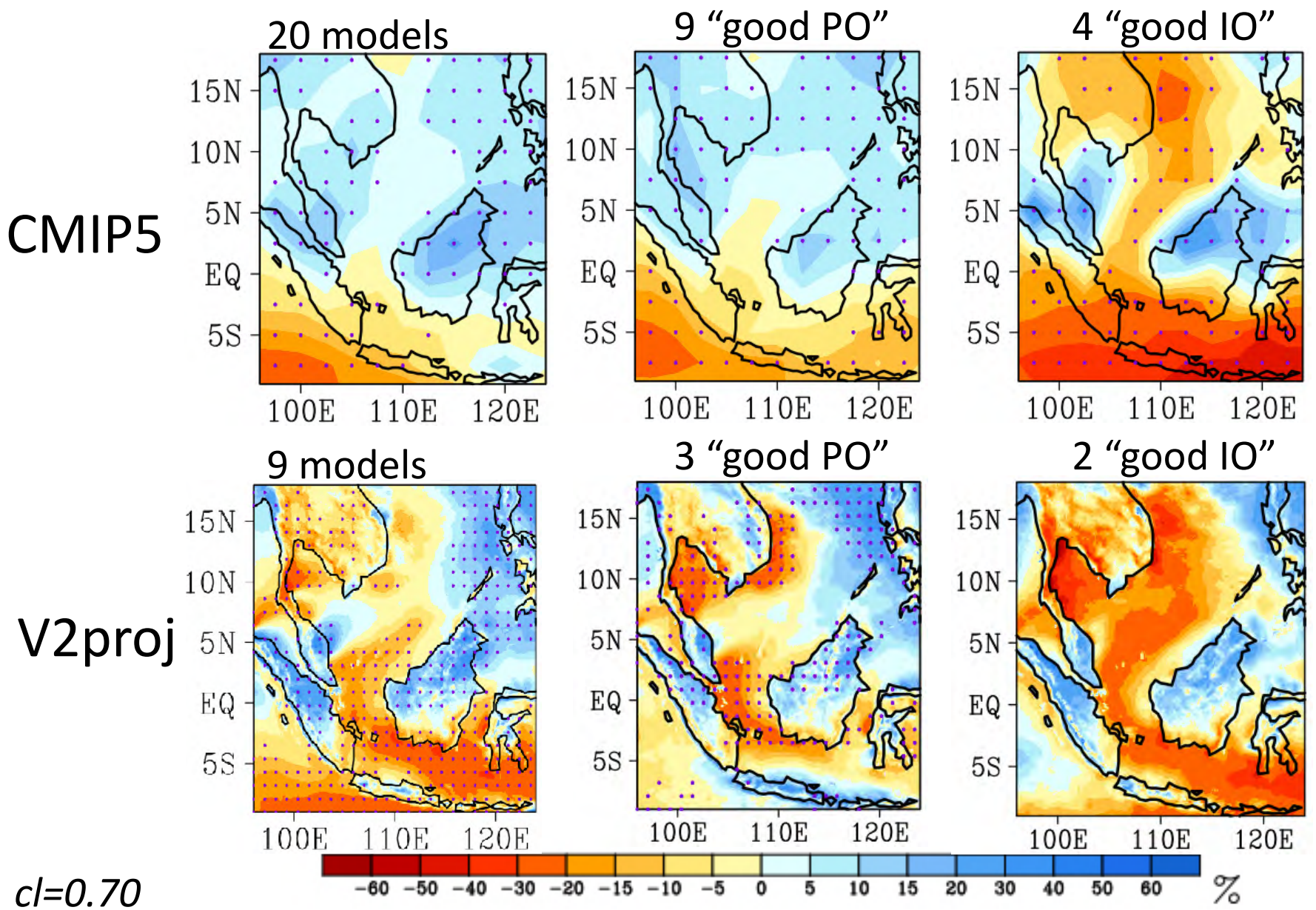
SCS_u850 : 5-15N, 110-120E (Wang et al 2004)

SG_pr : 1.5S-7N, 100-113E
SCS_pr : 10-20N, 110-125



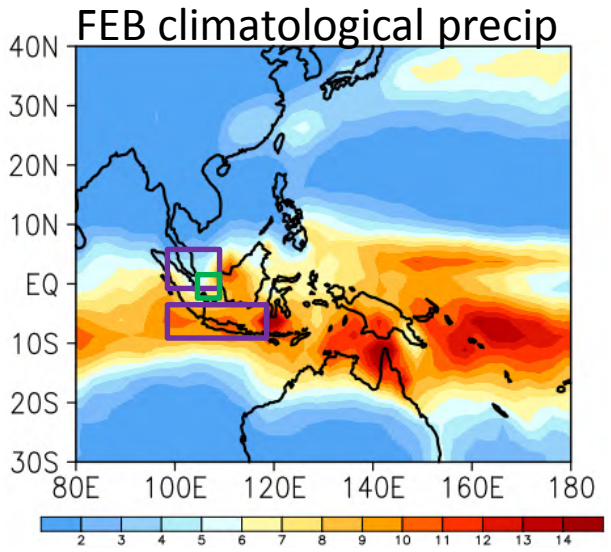


SW Monsoon rainfall: increase robustness



cl=0.70

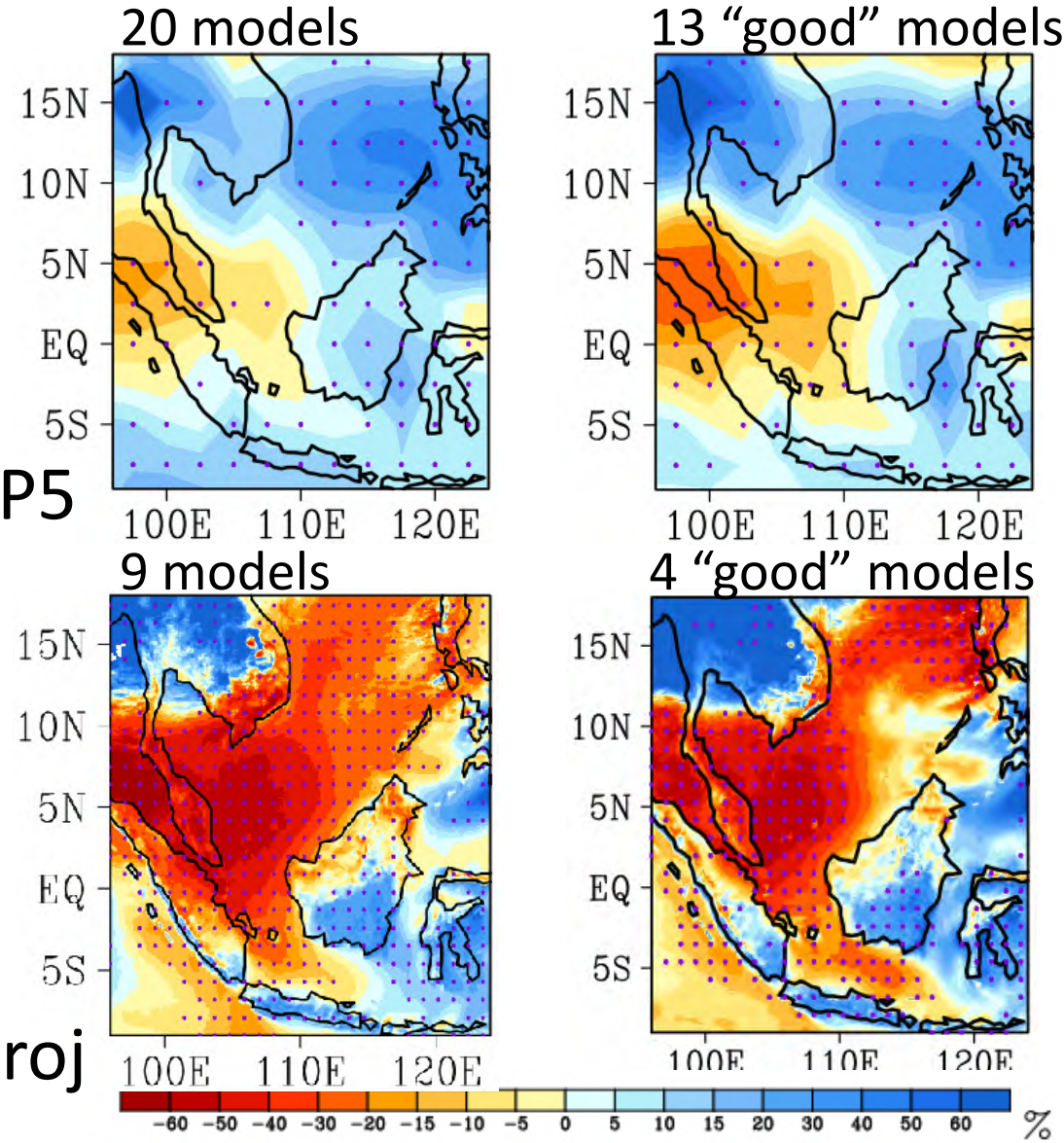
NE Monsoon dry-spell: mechanism



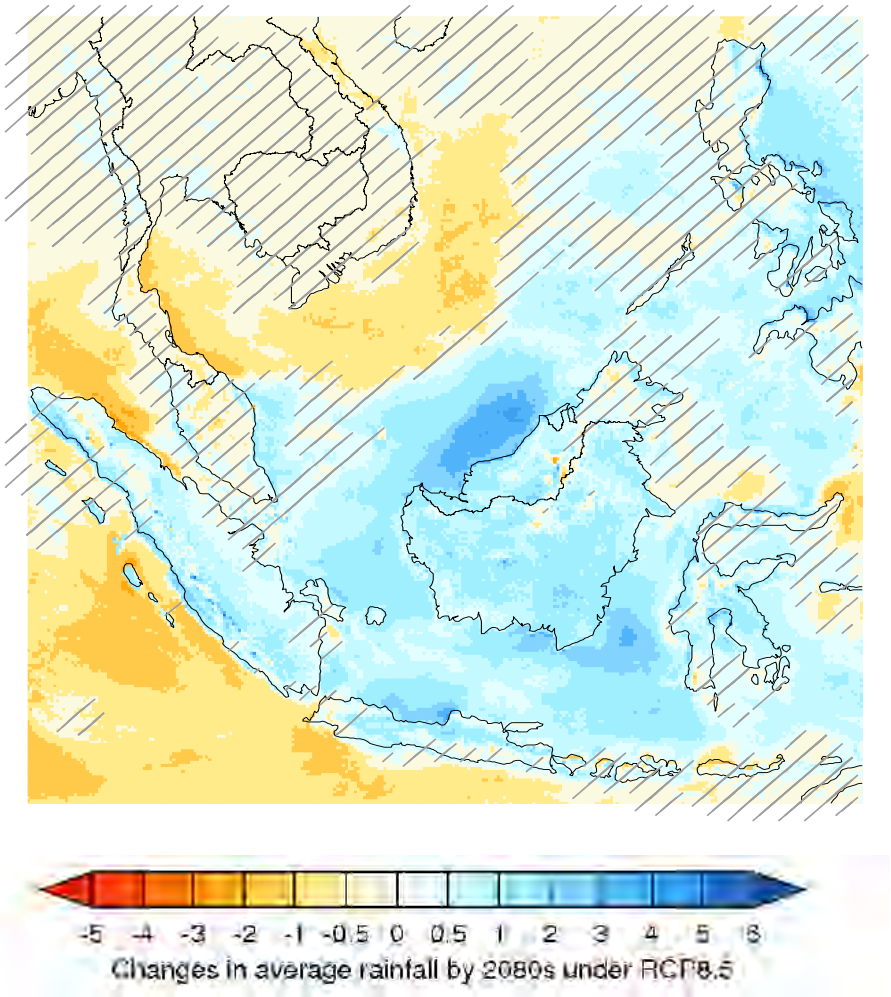
Cross-Equatorial Northerly Surge, CENS : v925 over 5S-EQ, 105-115E (Hattori et al 2011)

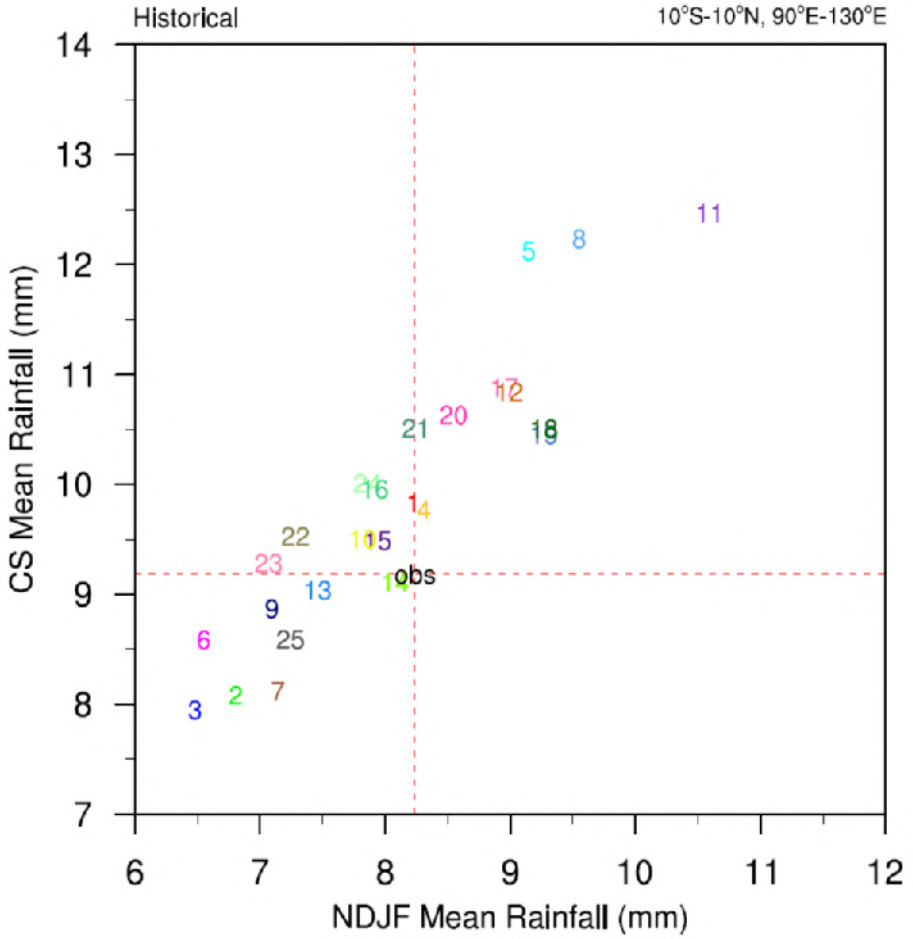
SG_pr: 1.5S-7N, 100-113E

Java_pr : 5-12S, 100-120E



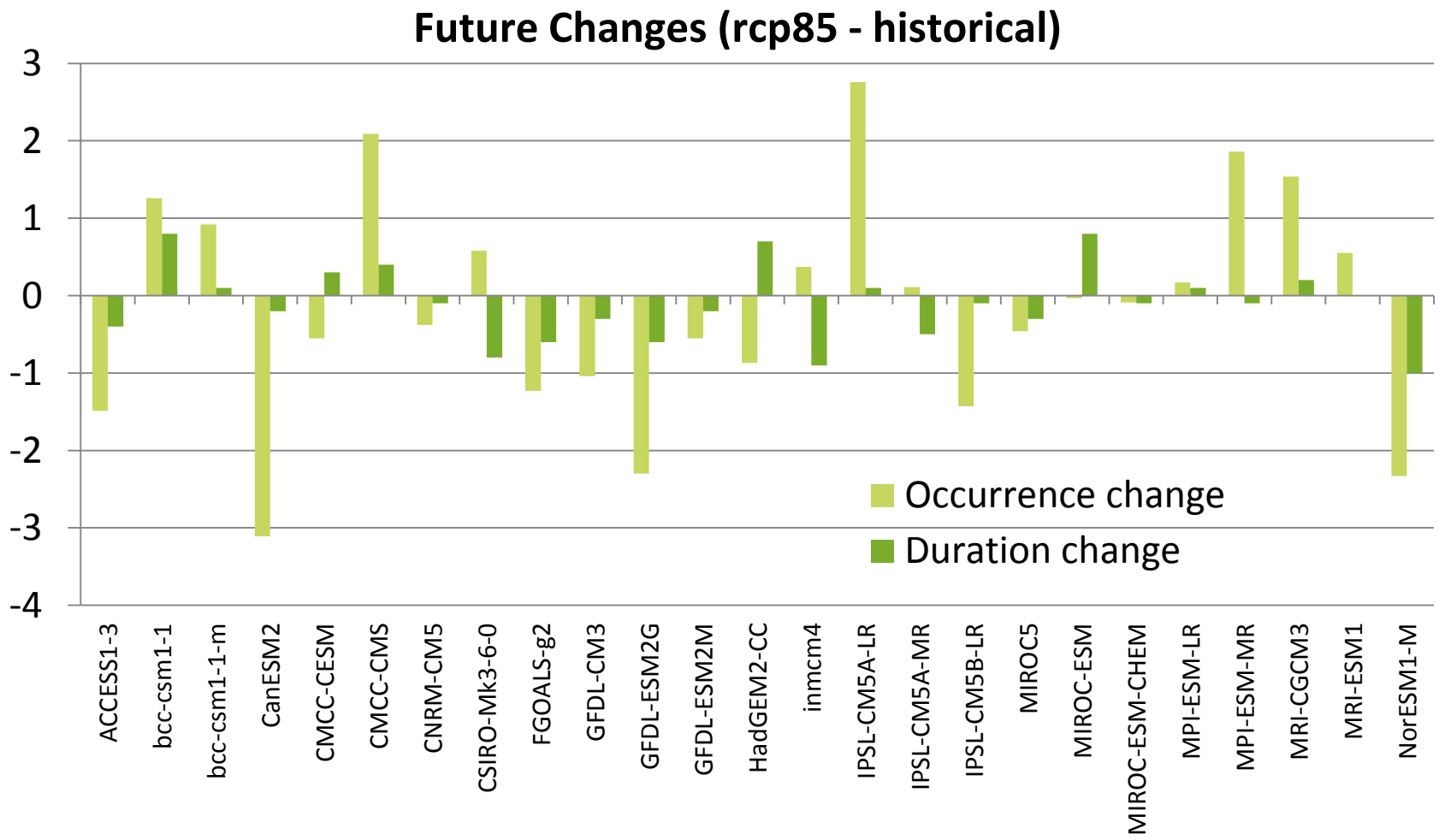
NE Winter Monsoon: Cold Surges



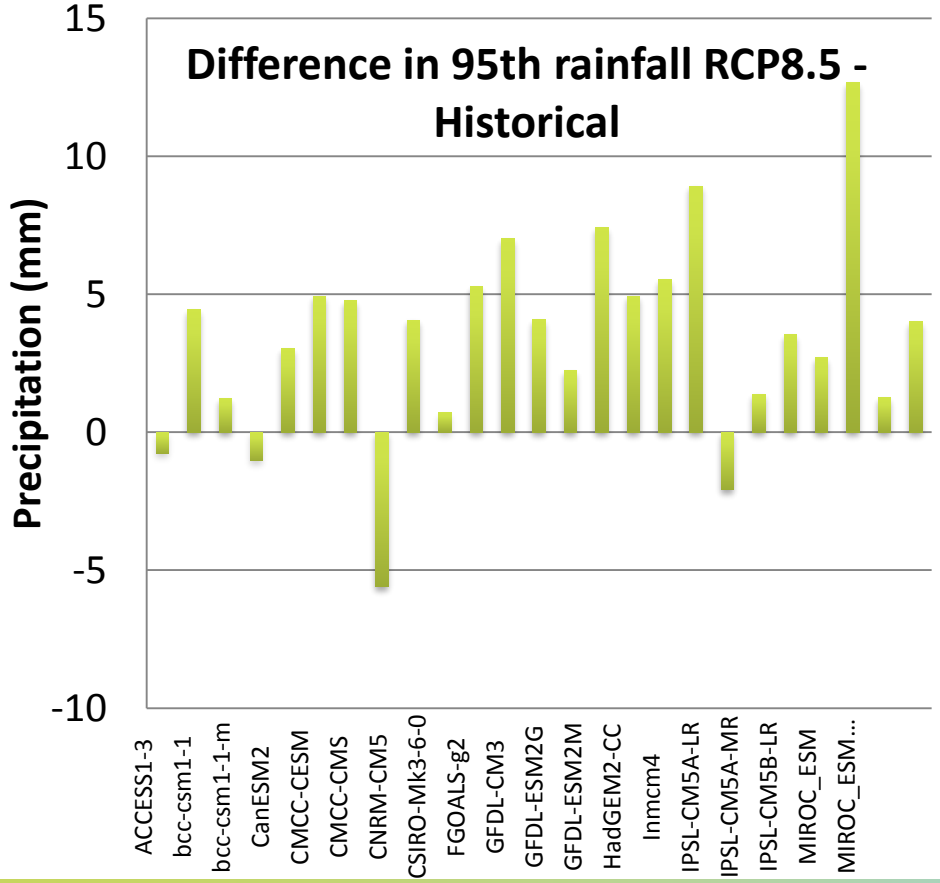


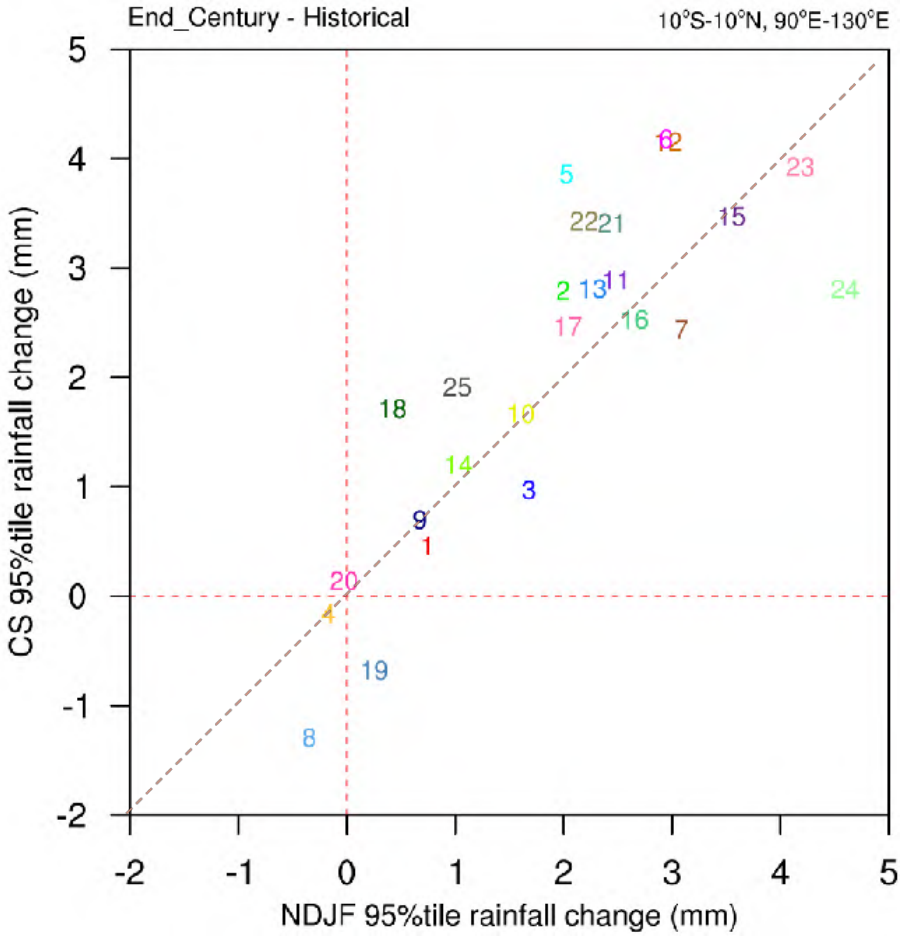
Cold Surge Index:
Lim et al., 2017, *J. of Clim.*

NE Winter Monsoon: Cold Surges changes



NE Winter Monsoon: Extreme Rainfall

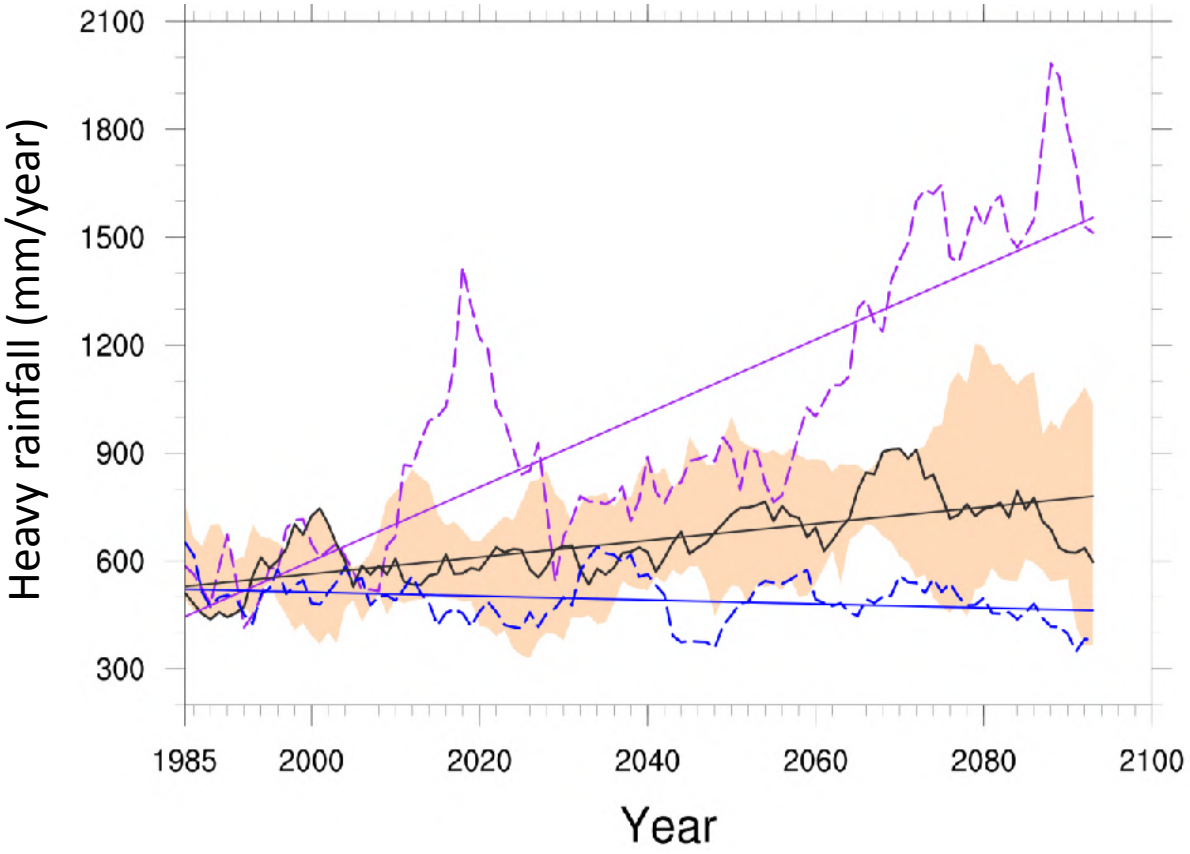




Extreme rainfall

2nd Singapore Climate Change Study

Projected increase in heavy rainfall



Purple max upward **trend**

Green – median **trend**

Blue – max downward **trend**

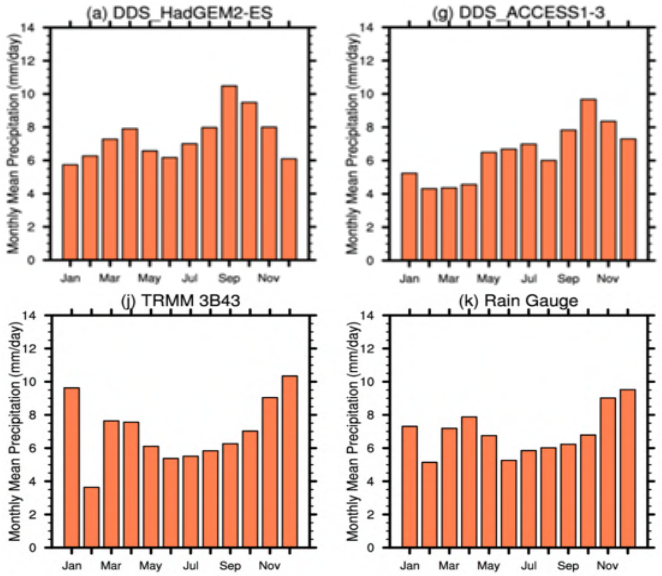
Contribution to annual rainfall total from **very wet days (**rainfall >95th percentile in the current climate: 56 mm/day).

Issues: Realism of key characteristics

- V2 RCM over land regions covering Singapore struggle with:
  - The seasonal cycle
  - Extreme rainfall

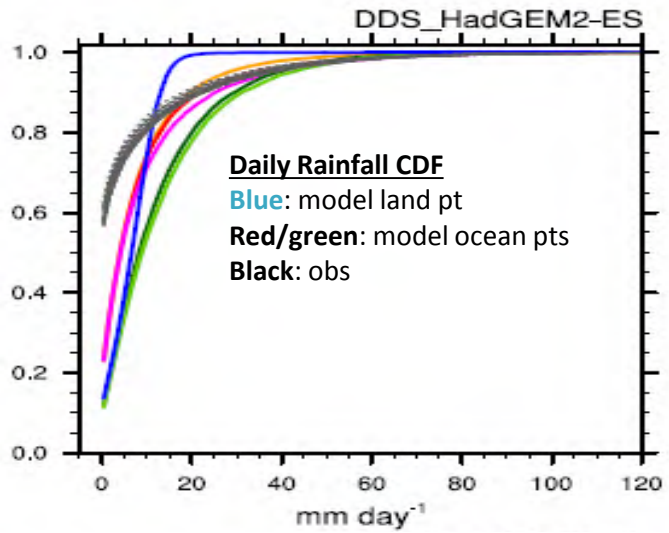
model

obs



Too little heavy rain

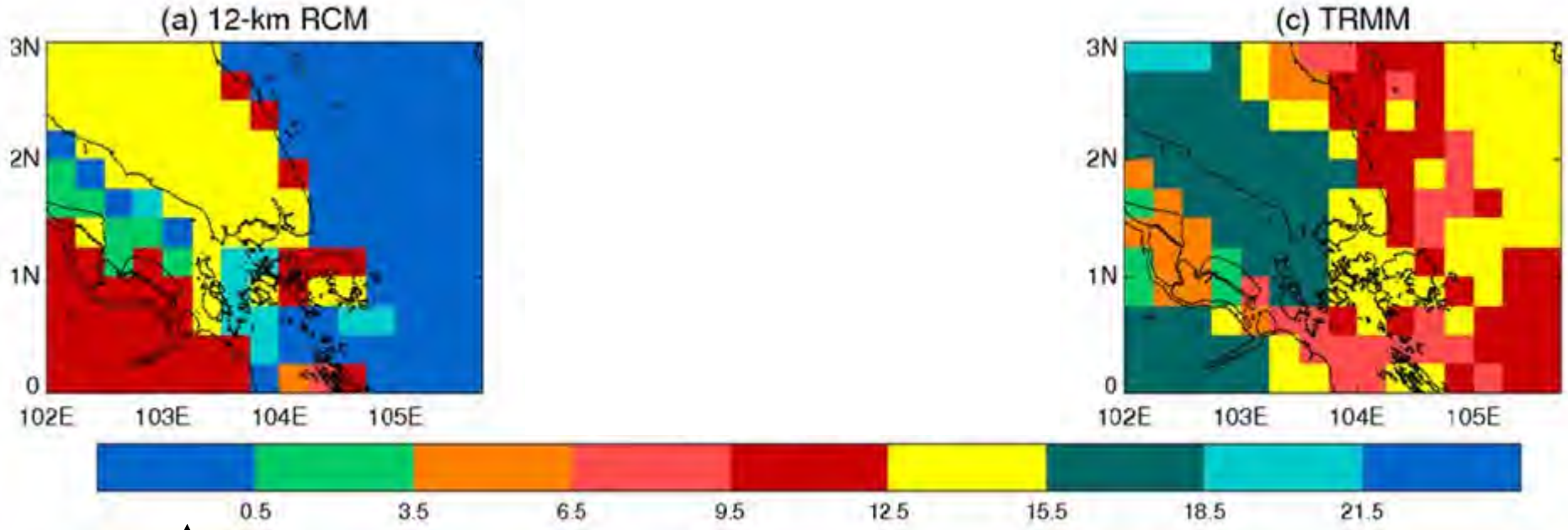
Too much light rain

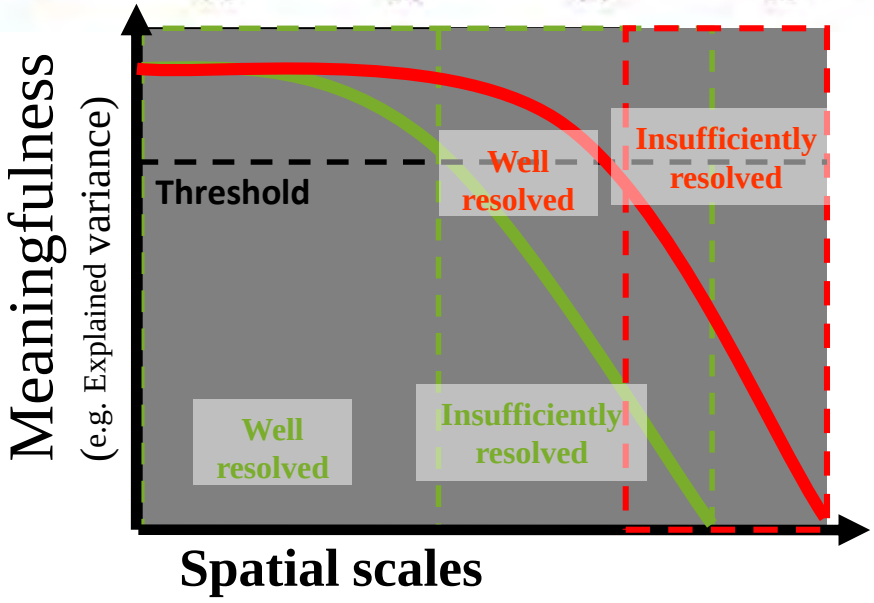


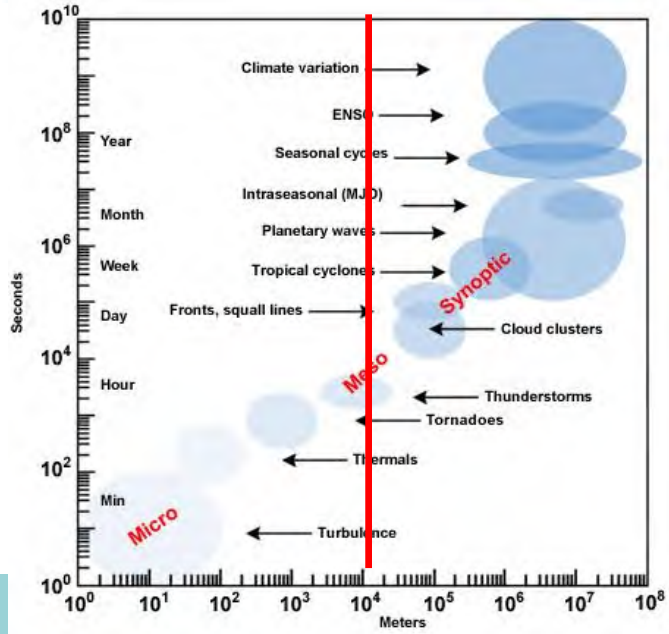
Monthly Rainfall

- Poor simulation of precipitation over land & sharp land-sea contrast ➔ Scale of weather processes
- For 12 km simulations – bias-correction performed

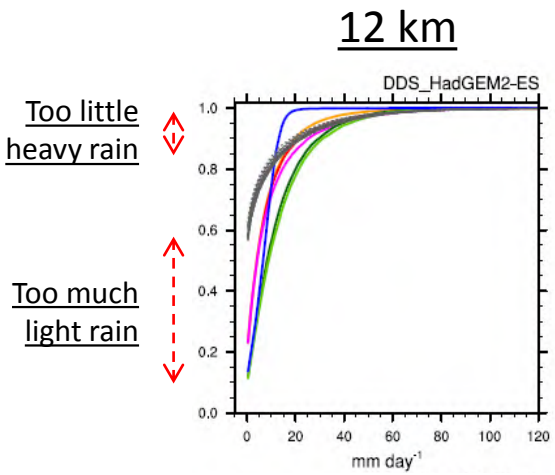
Issues: Diurnal cycle of convection





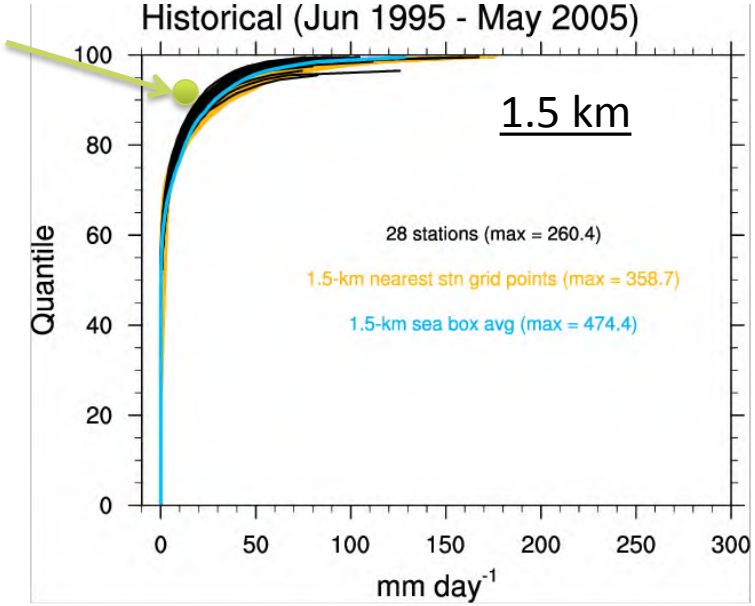


Improved simulation of rainfall extremes

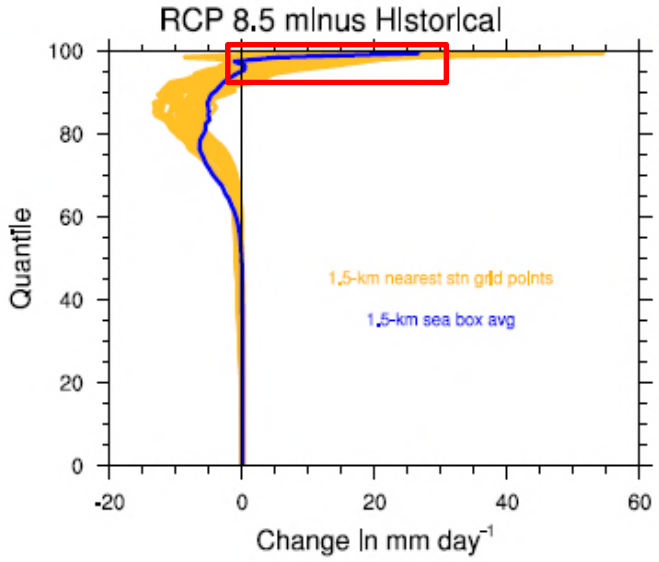


Blue: model land pt
Red/green: model ocean pts
Black: obs

12km RCMs Cut off here



1. Results demonstrate **better agreement** between obs and the 1.5 km simulations



2. The projected changes in rainfall extremes from this simulation are broadly in agreement with those from the 12 km bias-corrected results (i.e. increase in extreme rainfall projections)

Decadal variability in the simulations (which were for 10 years) prevents precise comparisons.

What we would like to improve upon?

Issues arising from the projections:

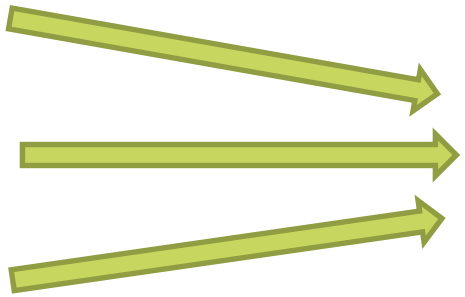
1) Better modelling of extreme rainfall (will build on the weather prediction work)
2) Treatment of the urban environment (with NUS)
3) Inclusion of man made (e.g. greenhouse gas and urban) climate changes and natural climate variability
4) Updated projections on sea level rise

Improved models

Global – natural variability

Regional – better treatment of aerosols and air sea interaction

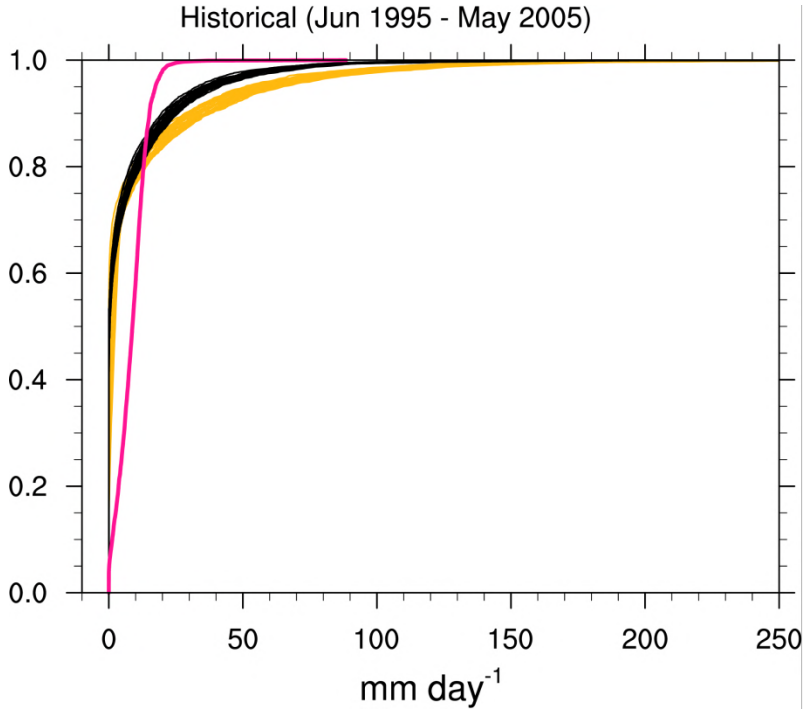
Local – inclusion of urban effects



More reliable climate projections to underpin adaptation planning

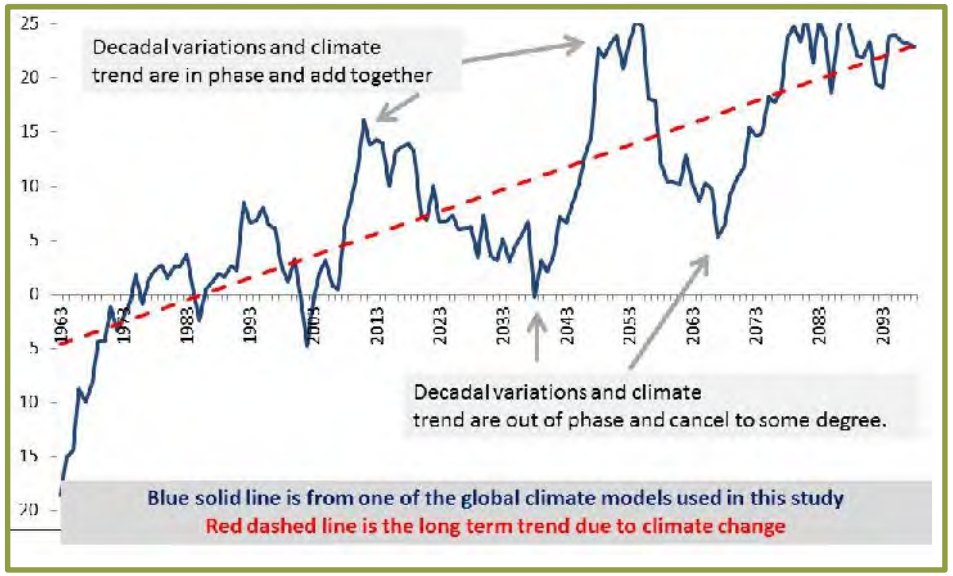
Two high priority issues for CCRS

The Cumulative distribution function of daily rainfall



Improved representation of convective rainfall

Annual daily maximum rainfall time series as a percentage change from current values

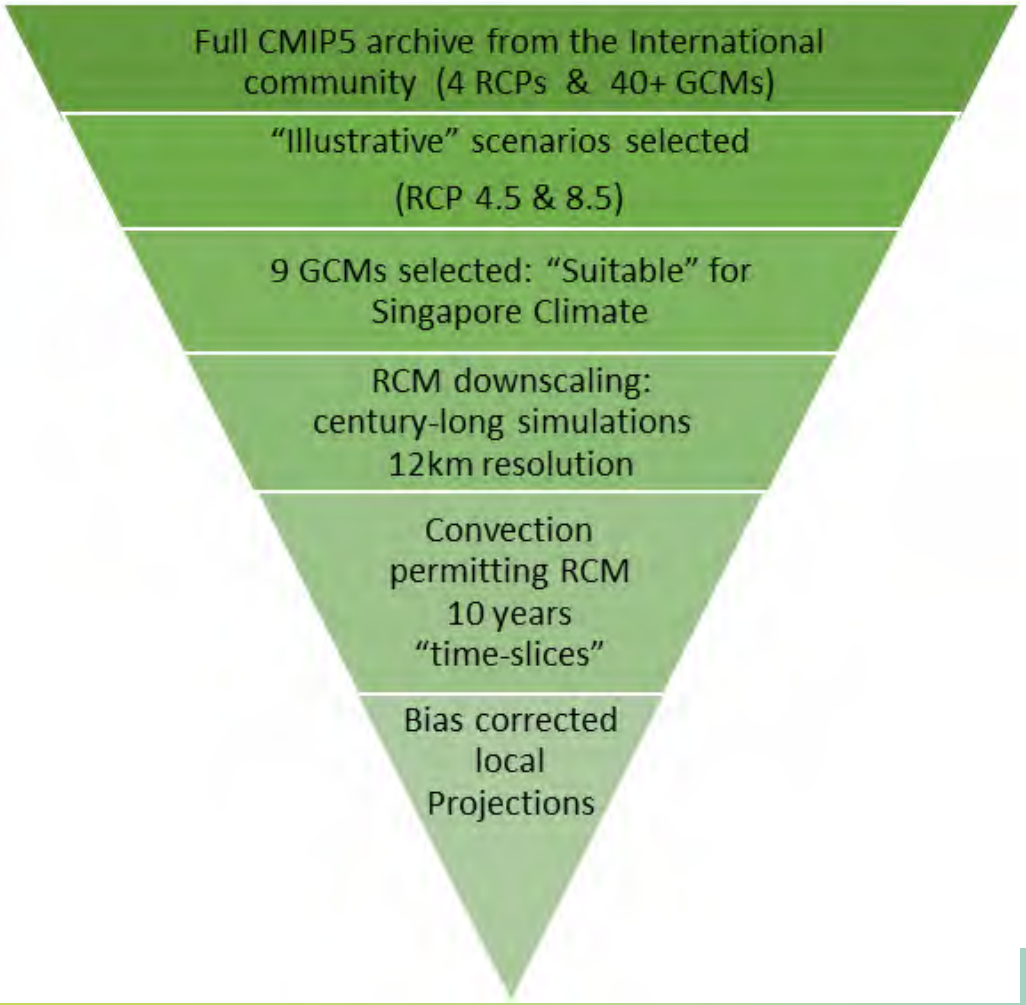


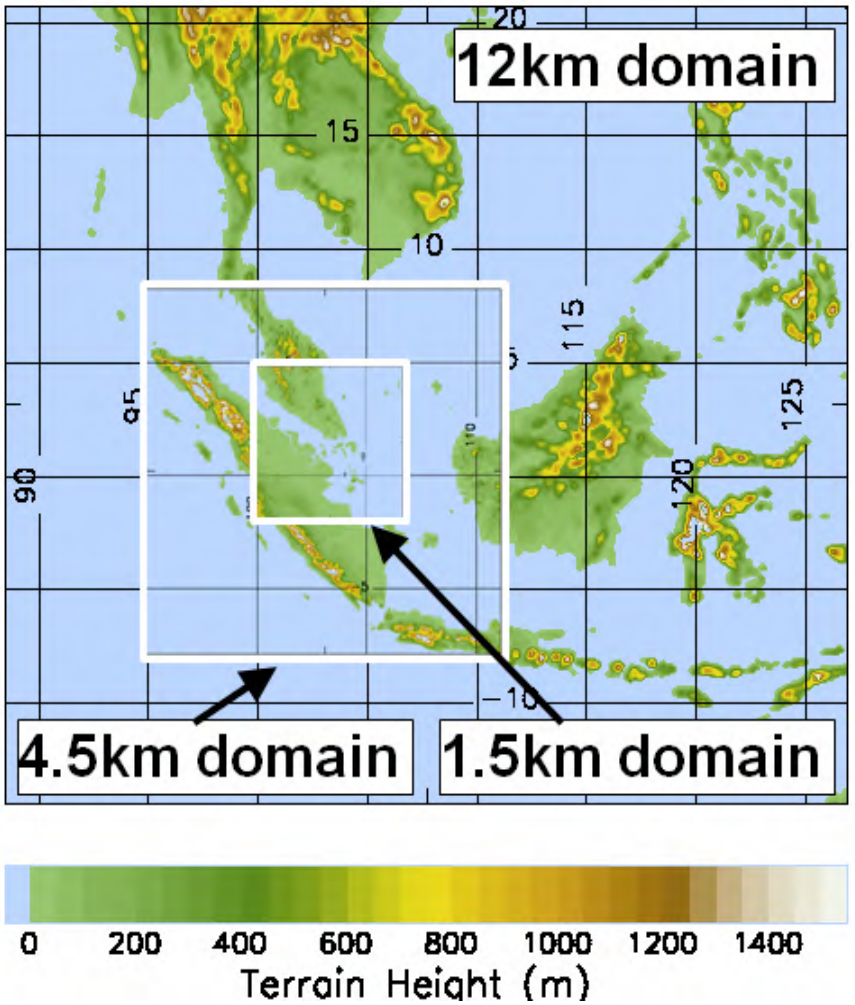
Improved understanding and modelling of natural decadal variability

Next Frontier in RCM: km-scale modelling

Convective-scale modelling:

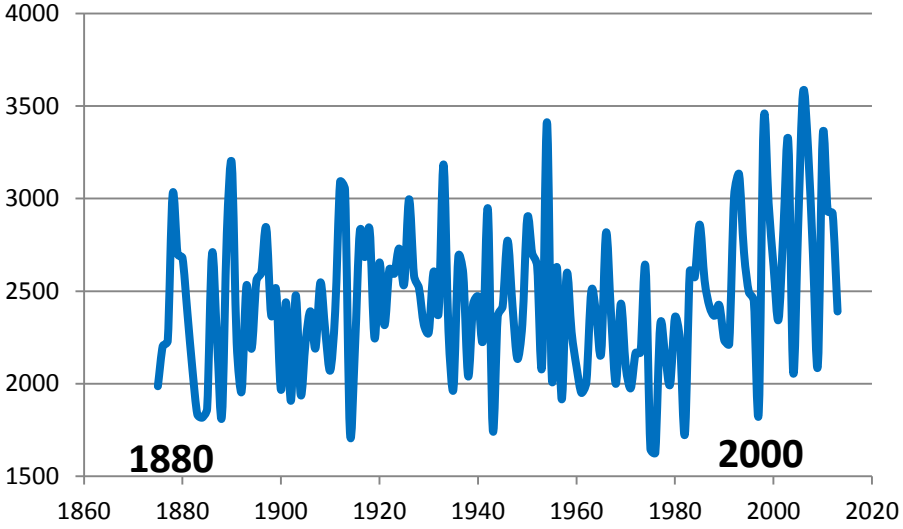
- Relevant for high impact weather?
- Evaluate 12 km bias correction





Man-made climate change and natural variability

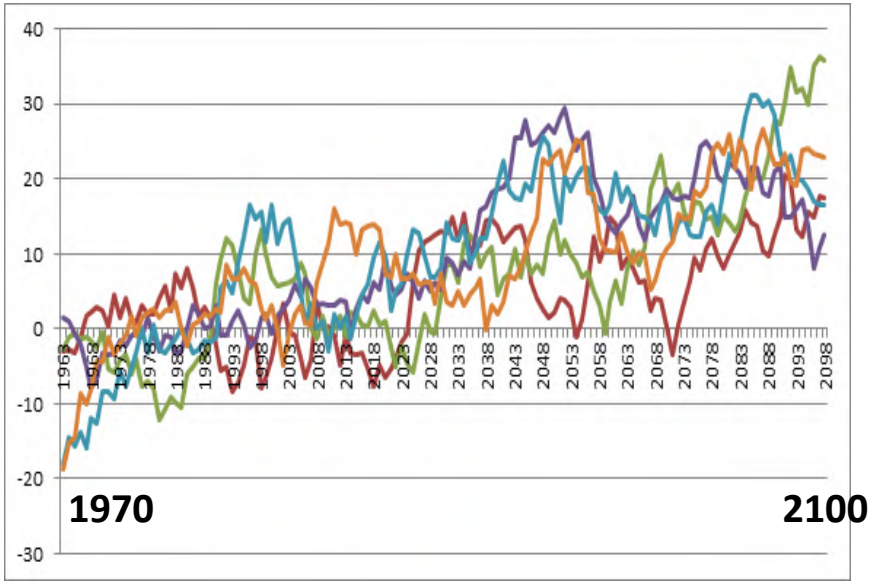
MacRitchie Reservoir observations
Annual rainfall: May to April



There are clear and large amplitude decadal variations

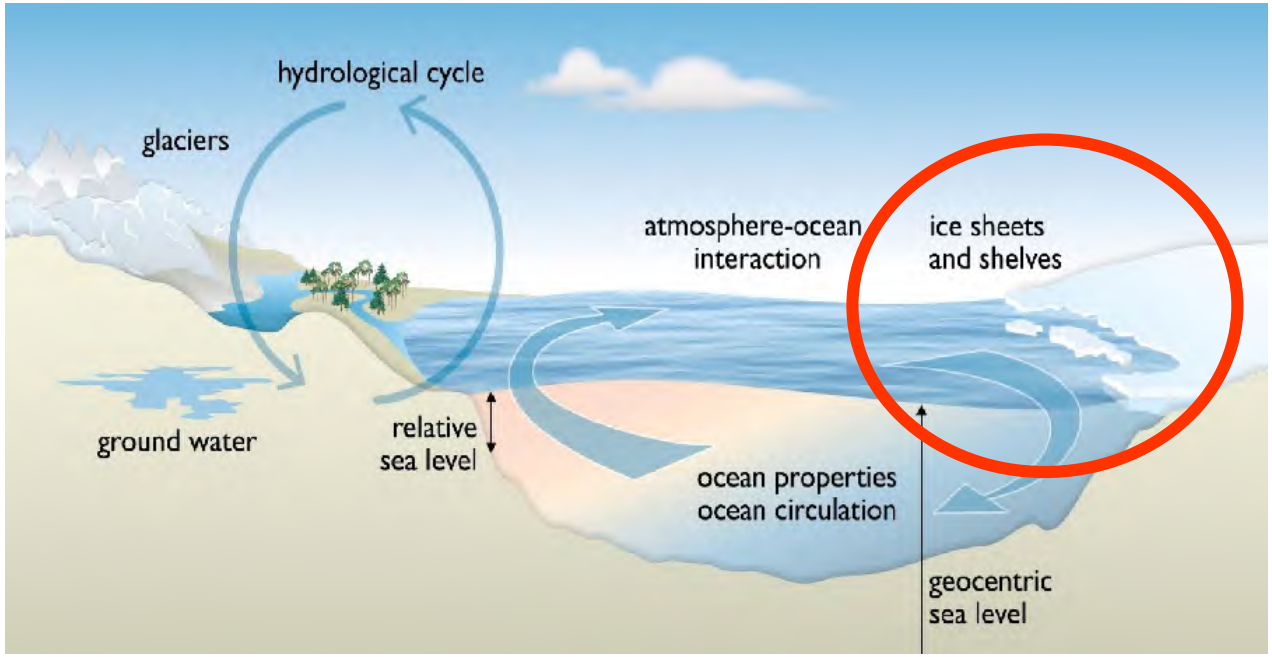
Why this matters for climate change projections:

Region near Singapore, one climate model and 5 realizations with a 'butterfly ' in 1850



For mid-century adaptation to changing rainfall, man made climate change and natural variability are both important

Global Sea Level Rise Science



Projections of **sea level rise**

- Possibility of much higher GSLR
- Special treatment in V2 **H++ scenario**
- Rapidly evolving science: **ice sheets dynamic**

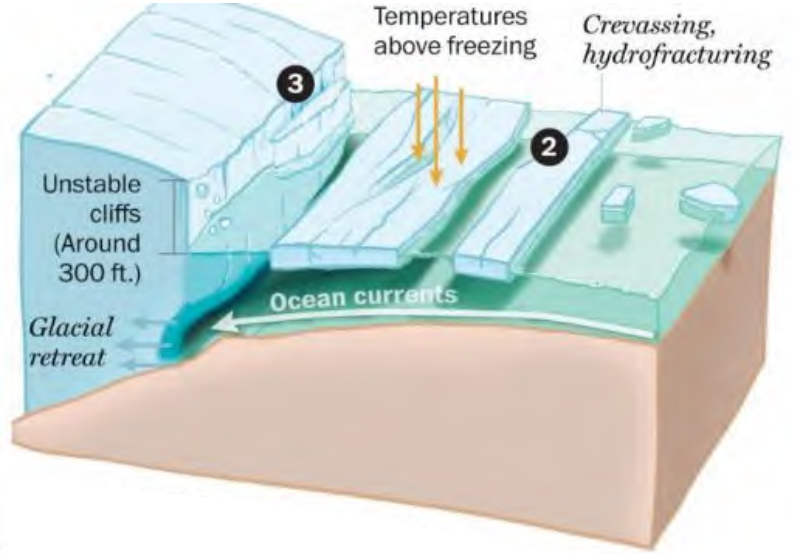
Singapore Sea Level rise using various methods:

	2100		2200		2300	
	Lower	Upper	Lower	Upper	Lower	Upper
RCP4.5 IPCC AR5 Method	0.29	0.73 m	-	-	-	-
RCP8.5 IPCC AR5 Method	0.46	1.02 m	-	-	-	-
RCP4.5 "low sensitivity"	0.19	0.65 m	0.30	1.42 m	0.36	2.10 m
RCP8.5 "high sensitivity"	0.47	1.29 m	0.88	3.57 m	0.94	5.48m
Hi-end "H++" scenario	1.00	2.00 m	2.00	4.00 m	3.00	6.00m

Source: IPCC AR5

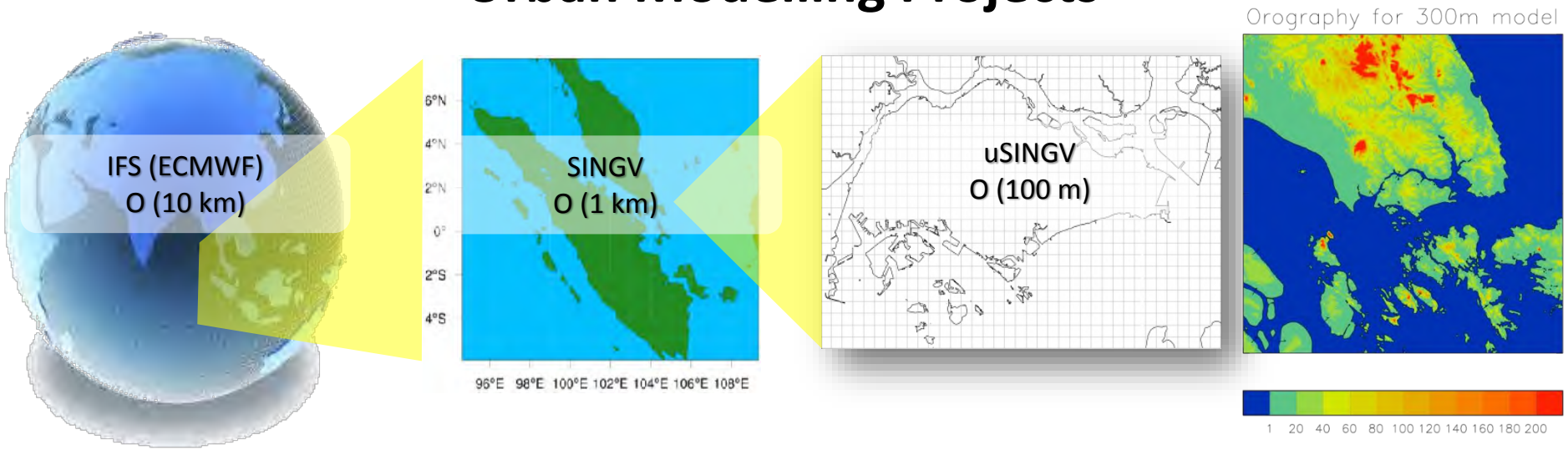
Evolving Scientific Consensus & New Science

- IPCC **AR4** (2007): uncertainty in **ice sheet dynamics** not addressed
- IPCC **AR5** (2015): "collapse of marine-based sectors of Antarctic ice-sheet… cause global mean sea-level to rise substantially… "
- Rapidly advancing science since AR5:
  - Better representation:
    - Ice-shelves break-up
    - Collapse of ice-cliff
  - Increased risk for *upper-end* of SLR
    - By 2100 to be *over* 1 m
    - Additional 1 m from Antarctic
  - E.g. study giving indication of 1/1000 chance of SLR > 2.45 m



De Conto & Pollard (2016)

MSS (CCRS) – NUS (Geography Dept.)
Urban Modelling Projects



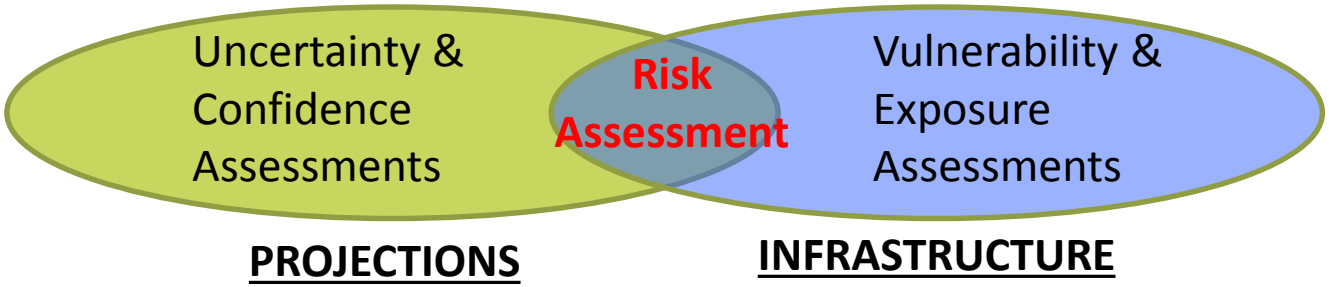
- Robust and reliable urban modelling system *uSINGV*
- Model domain is 200 km x 200 km in horizontal and extends up to 40 km up in the atmosphere. Grid resolution is 300 m in horizontal and 5 m in vertical near the surface
- Urban morphology from high resolution building database from SLA
- High resolution (300m) in-house landuse generated using ESA-CCI landuse product

Communication

Purpose of Confidence Information

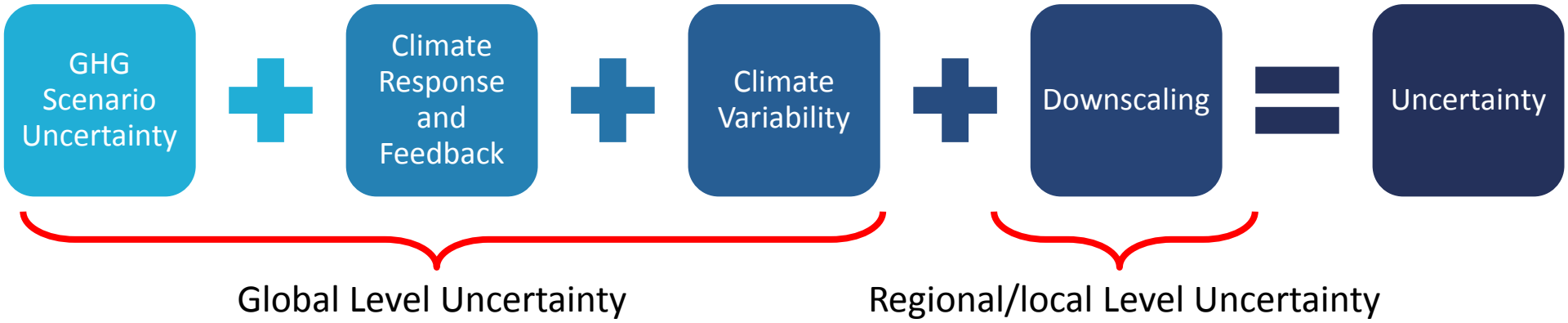
Provide guidance on the confidence that can be placed arising from the uncertainties in the key findings of V2

- Science: Informs future studies by **identifying gaps**. Mark as research priority to improve understanding.
  - E.g. Mechanisms for projected drying, latest science for ice-sheet melt
- Applications: allows agencies to factor in uncertainty in decision-making and planning. E.g. focus on **highly-vulnerable areas** with reasonable levels of confidence



Uncertainties: “range of possible future projections”

Sources of Uncertainty



Uncertainty and confidence information:

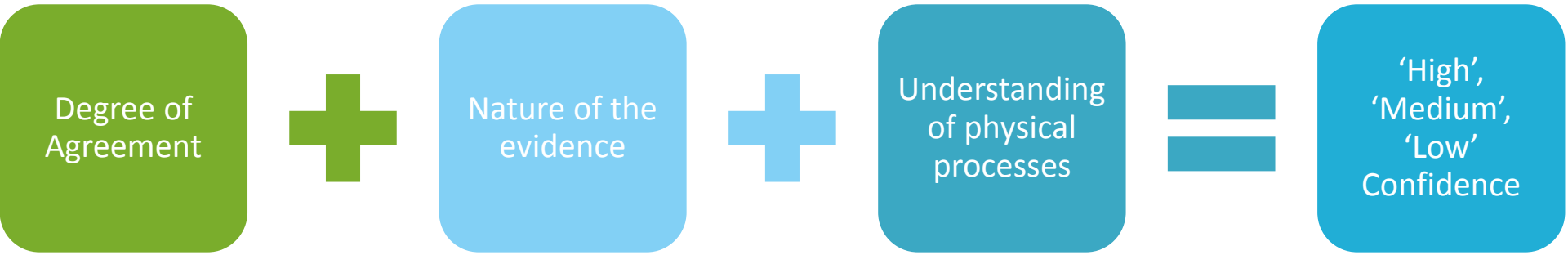
- Provides measure of validity of climate change findings
- Communicated during stakeholder engagement sessions
- Avoids quantitative models results being regarded too literally (e.g. level of precision ≠ better certainty), and being reduced to a single number

Use of Confidence Information

Current projections represents 'best estimate' based on **modelling evidence** and ***current*** **scientific understanding**

- As the science develops, possible for future projections may challenge the current range
- Therefore, important for the climate science community not to reduce the estimation of the range
- Hence, information on assessment of confidence is **as important** as the projection itself

Following IPCC



Low Confidence

- Projected range in **extreme** rainfall
- Increase in NE Monsoon Wind Speed
- Projected upper limit in mean SLR

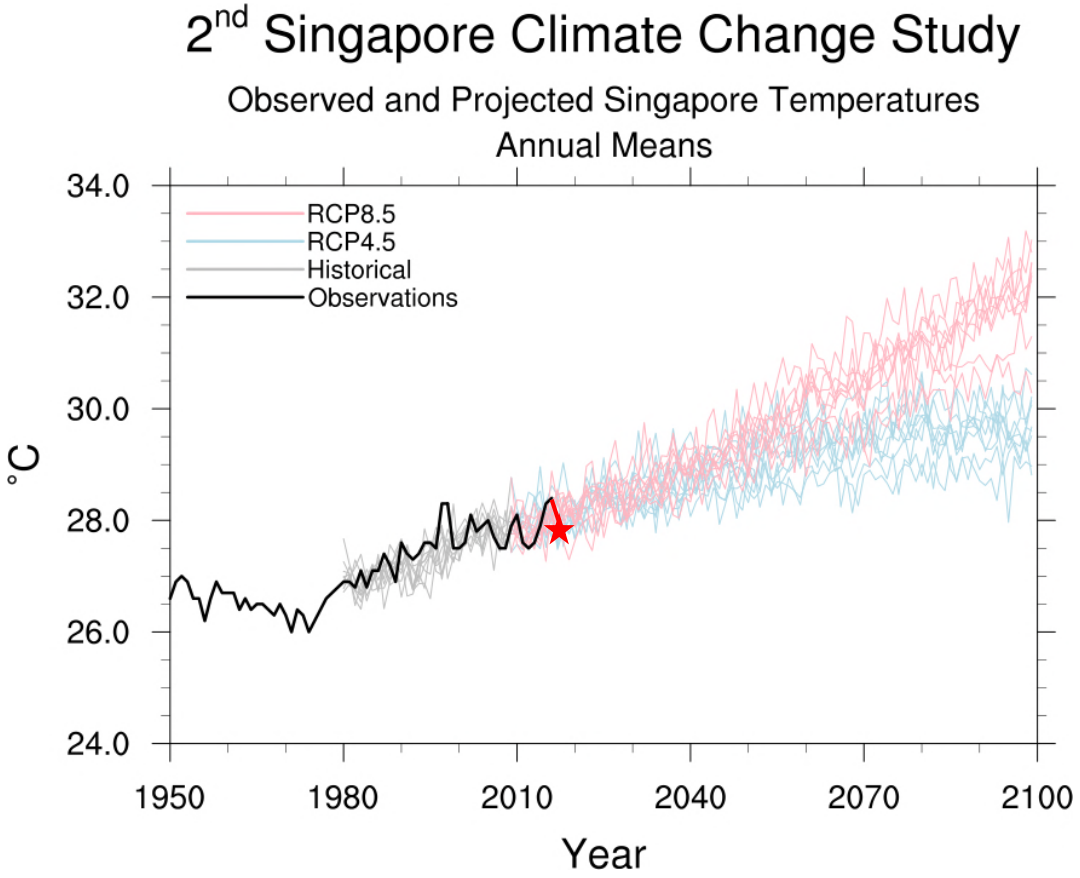
Medium Confidence

- Projected range in temperature
- Annual **average** rainfall not expected to change significantly
- Feb, SW Monsoon getting drier
- No significant change in **extreme** sea-level
- Upper limit of mean sea-level at least 0.76m, lower limit at least 0.35m

High Confidence

- Increase in temperature
- Increase in heavy rain frequency/intensity
- Increase in **mean** sea-level

Dashboard: Singapore temperature



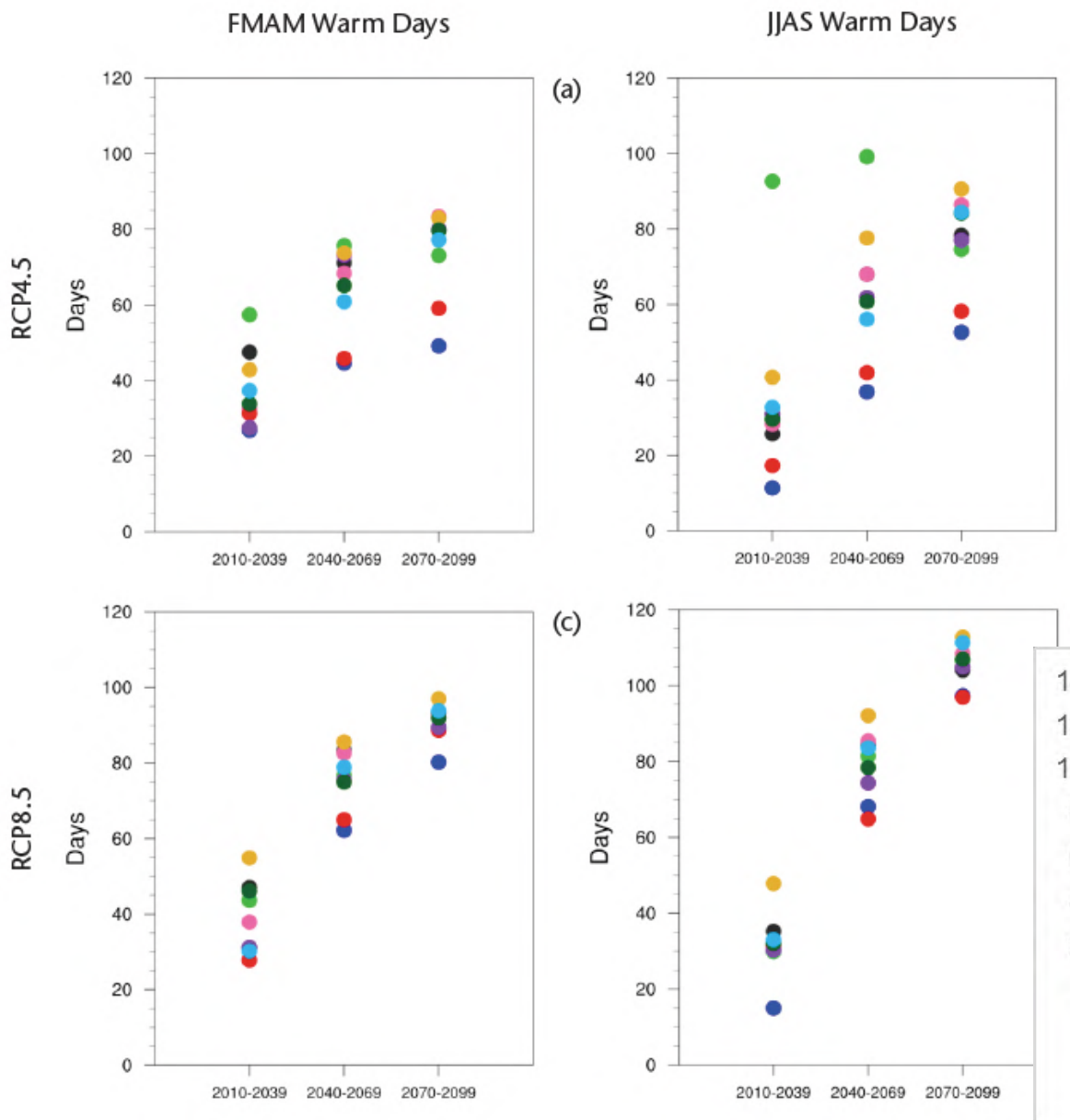
What scenario are we tracking?

- No significant difference between RCP 4.5 & 8.5 until ~2070
- Not expecting to answer this question during my life time!
- Key point: Natural variability when not spatially averaged is larger

Possible to do more on this:

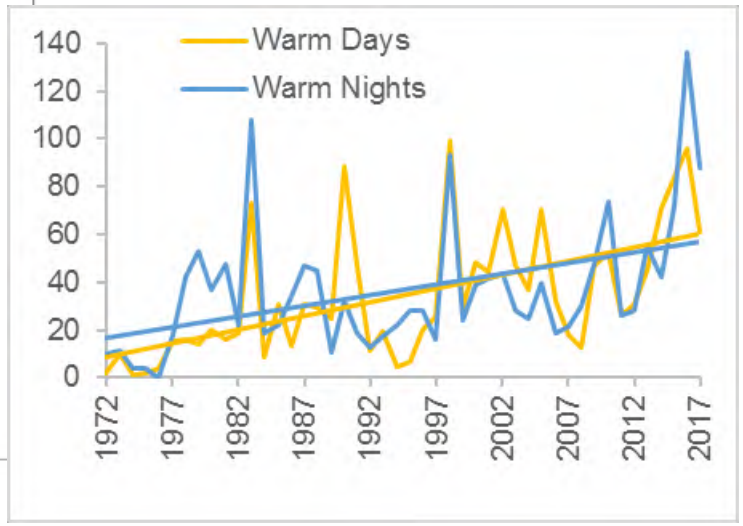
- Smooth out some of the "known" natural variability (e.g. ENSO)
- Unlikely to be meaningful for mean rainfall ….
- Extremes (rainfall, temperature) more likely to be meaningful

Change of extreme temperature



Extreme temperature:

- More significant to population
- More significant (risk)
- How climate change is starting to be experienced



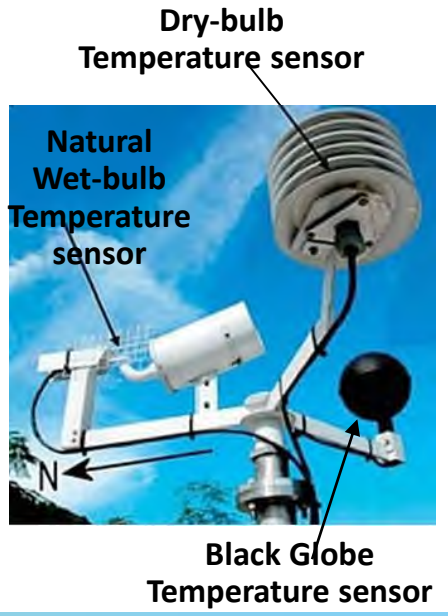
Heat Stress and Heat Injury

- **Heat Stress** is a measure of the effect of heat that generates discomfort on the human body
- Increasing levels of heat stress can induce spectrum of heat injuries

- One Heat Stress indicator used to measure the risk of heat injury is the Wet Bulb Globe Temperature (WBGT)

WBGT is a composite temperature to estimate the effect of **temperature, humidity, wind speed** and **solar radiation** on humans

- A measure of a person's perspiration rate and thus an indicator of human comfort
- Used as a guide in managing strenuous activity in hot and humid environments



Conclusions (I)

1. Future rainfall changes across Western Maritime Continent (including Singapore) will be a consequence of changes in Monsoonal circulation

2. Mean rainfall projected changes is uncertain and innocuous (no trend)

3. Devils are in the details:
   - Possible increase in decadal variability
   - Dry spells (SW monsoon JJAS and NE monsoon Feb) likely to become drier
   - Extreme rainfall event during the wettest part of the year (Cold surges during NE monsoon) likely to increase
   - Implications for adaptation planning in Singapore

4. Extreme rainfall:
   - Confidence in the physical understanding
   - But limited confidence in climate model results
   - Pushing into CRM simulations

Conclusions (II)

1. Real uptake of the climate change science and projections by the WOG approach of the Singaporean government

2. Mean Sea Level Rise is critical issue for Singapore – National SL Program

3. Natural Variability and Climate Change:
   - Endless communication issue: “Is it due to climate Change?”
   - How to monitor climate change?
   - Multi decadal naturally occurring climate variability

4. Importance of communication:
   - Relevance of the science
   - Integrity of the science
   - Communication of uncertainties

Centre for Climate Research Singapore (CCRS)

http://ccrs.weather.gov.sg

Meteorological Service Singapore (MSS)

www.weather.gov.sg

METEOROLOGICAL SERVICE SINGAPORE

Email

Bertrand_Timbal@nea.gov.sg

Web page

ccrs.weather.gov.sg/bertrand-timbal/

Google Scholar / ResearchGate