Regional Climate Projection

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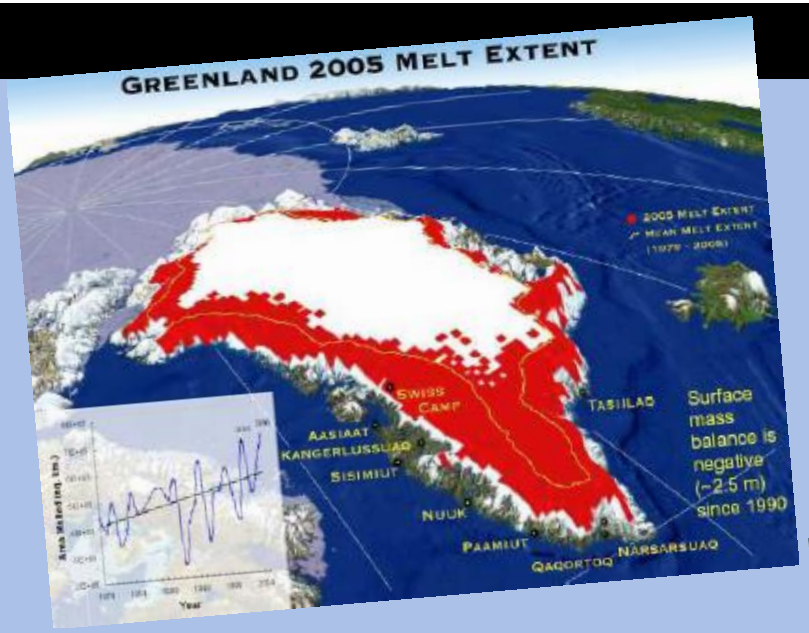
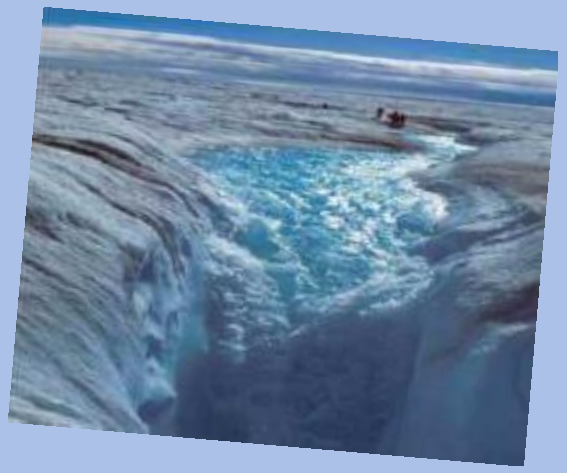
APEC Climate Center Training Program 2015

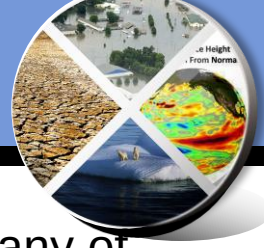
Review of 5th Assessment Report (AR5) Intergovernmental Panel on Climate Change (IPCC)

Global Warming Reality or Science fiction ???

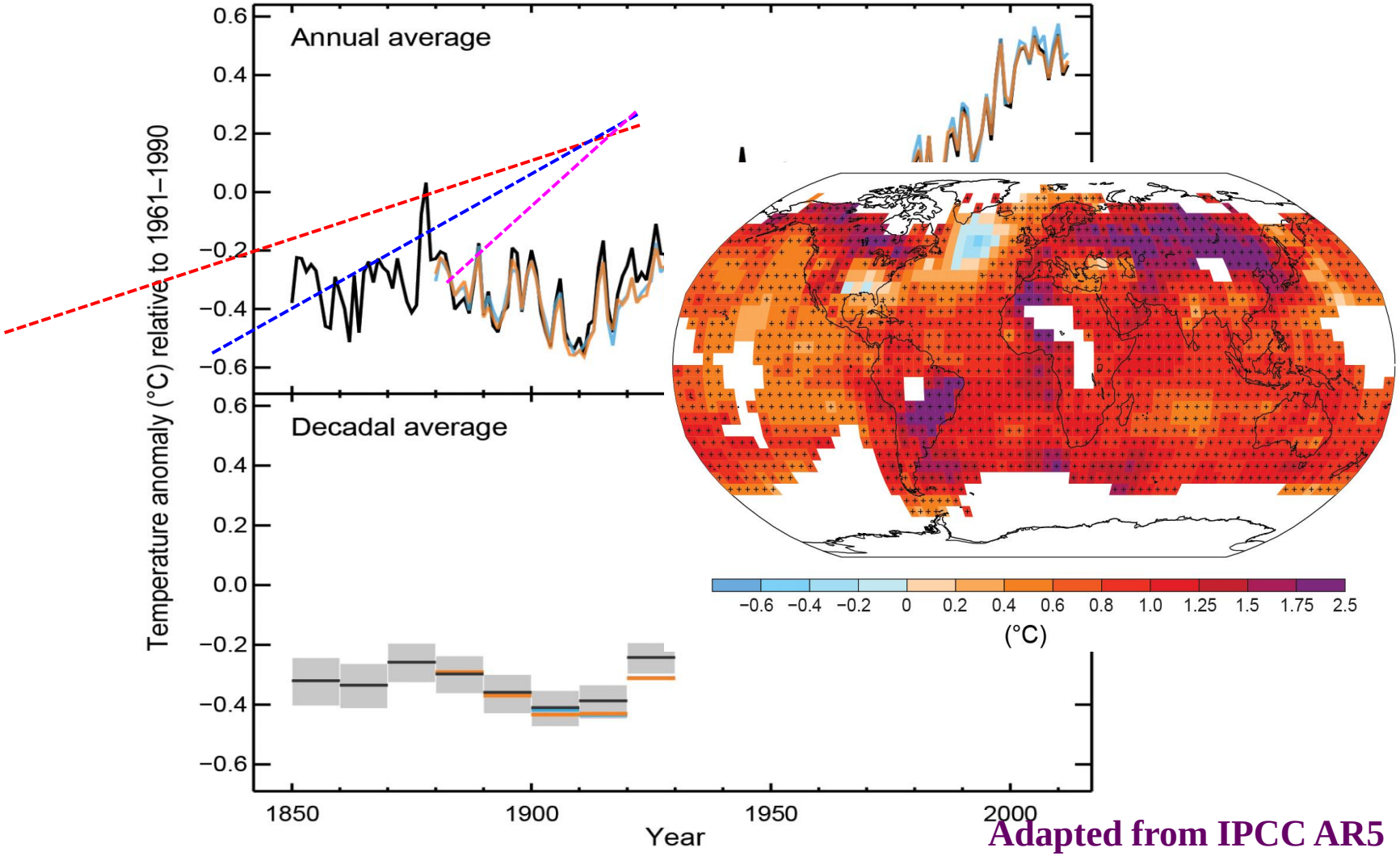




Observed Global Temperature Anomaly

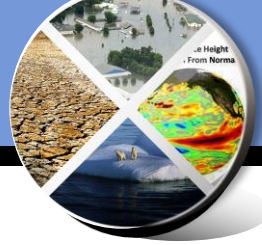


- Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia ecosystem



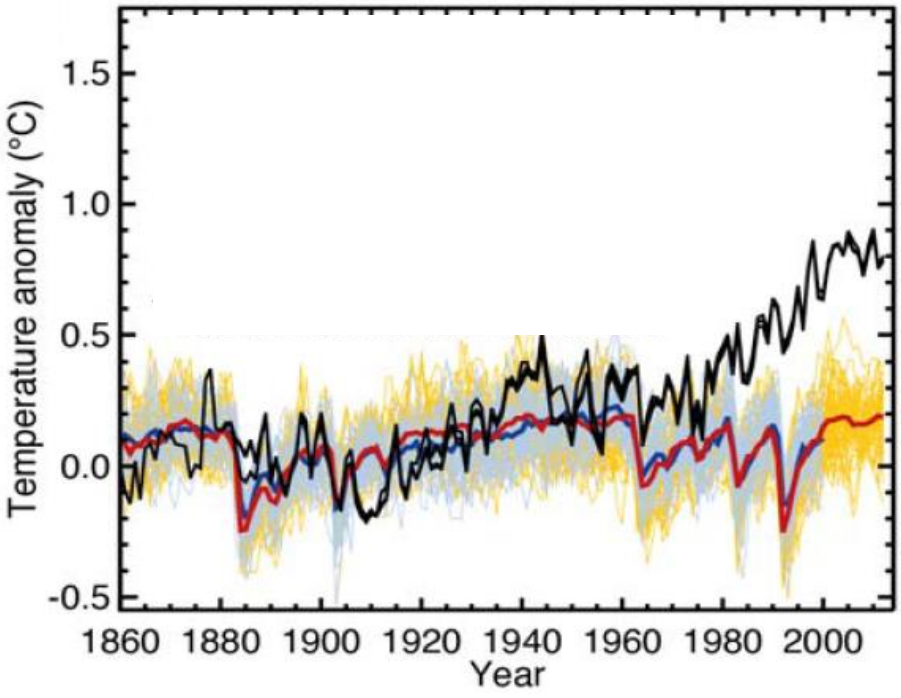
Adapted from IPCC AR5

Anthropogenic Warming

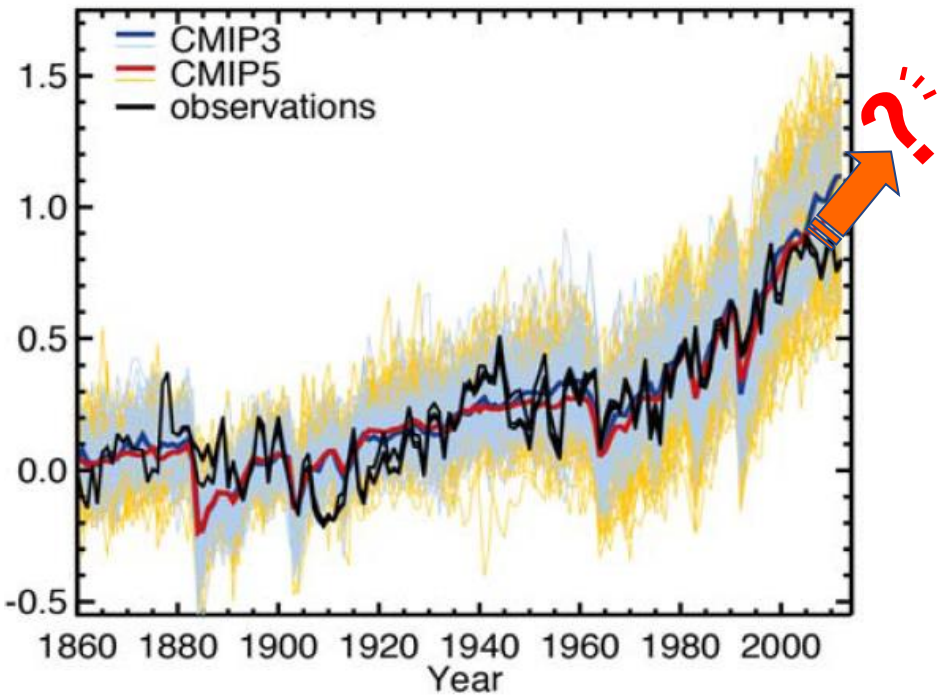


- There is significant anthropogenic warming over the past 50 years.
- It is "extremely likely" that human influence has been the dominant cause of observed warming since the mid 20th century.
- The global mean surface temperature response simulated by CMIP3 and CMIP5 models is very similar, both in mean and variability.

Natural Forcings



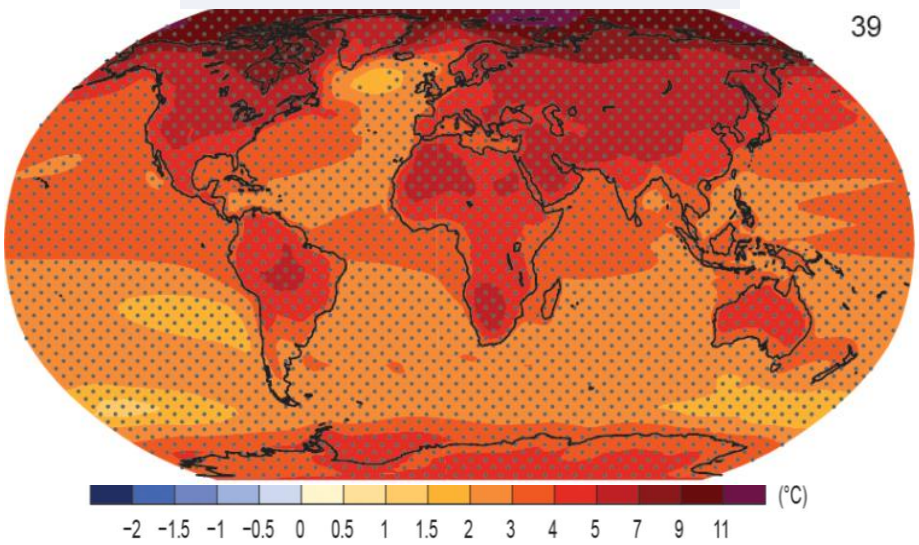
Natural + Anthropogenic Forcings



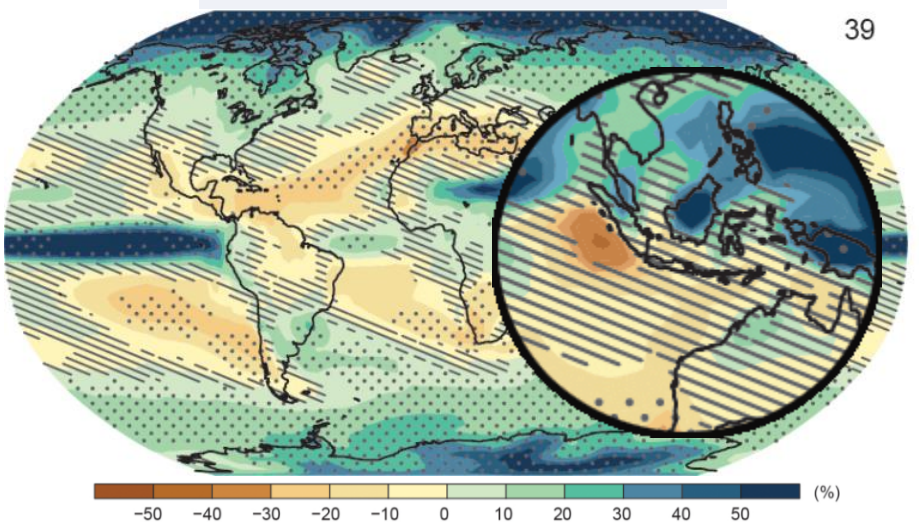
Adapted from IPCC AR5

RCP8.5 Projection (2081-2100)

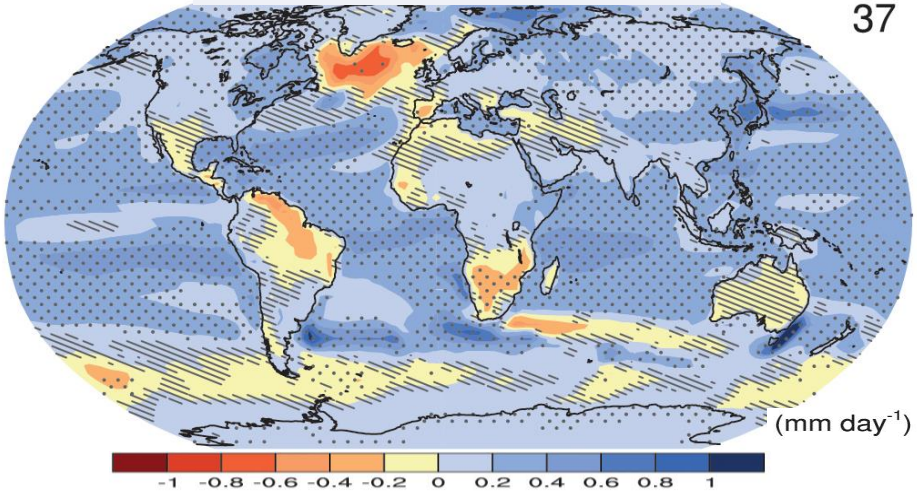
Changes in Temperature



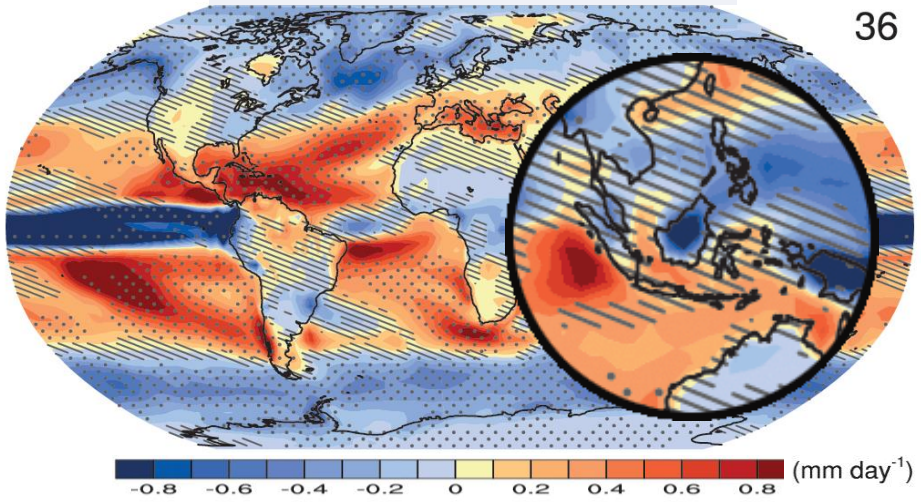
Changes in Precipitation



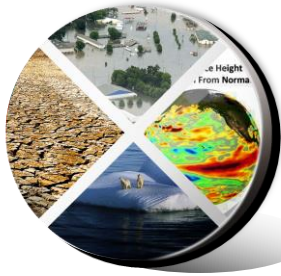
Changes in Evaporation



Changes in Eva.-Pre.



Adapted from IPCC AR5



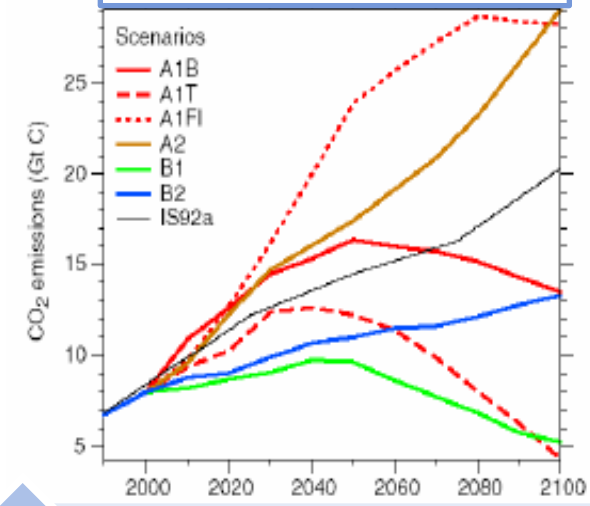
IPCC AR4 (CMIP3) vs. IPCC AR5 (CMIP5)

- Coupled Model Intercomparison Project (CMIP) coordinated by the World Climate Research Programme.

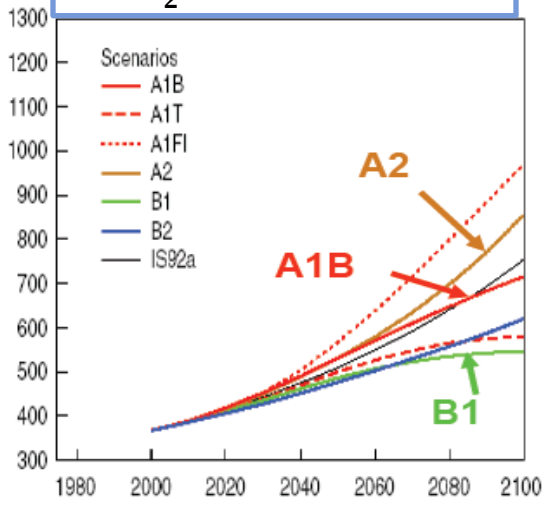
IPCC AR4 & AR5 Emission Scenario

SRES : Special Report on Emission Scenario

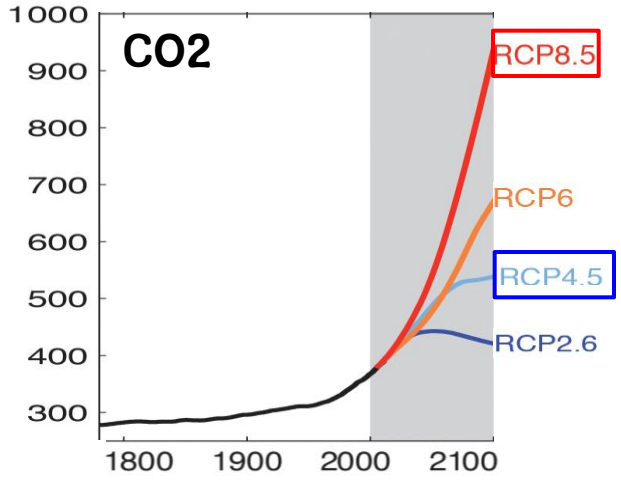
CO_2 Emission Scenario

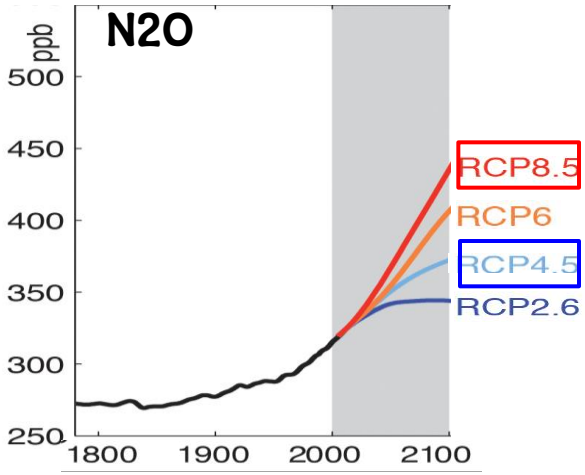


CO_2 Concentrations



RCP : Representative Concentration Pathways

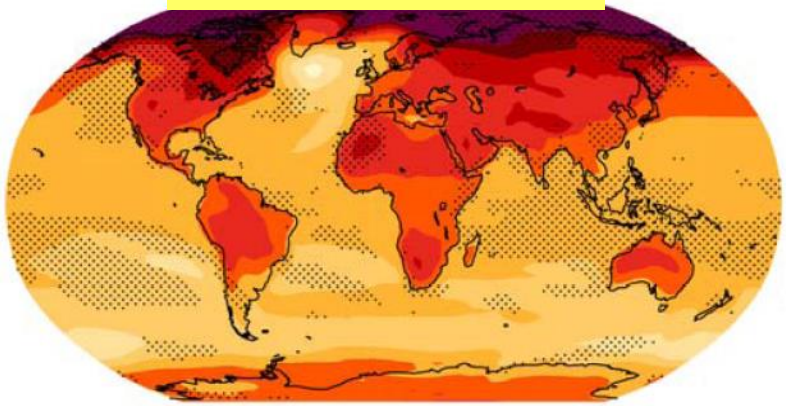




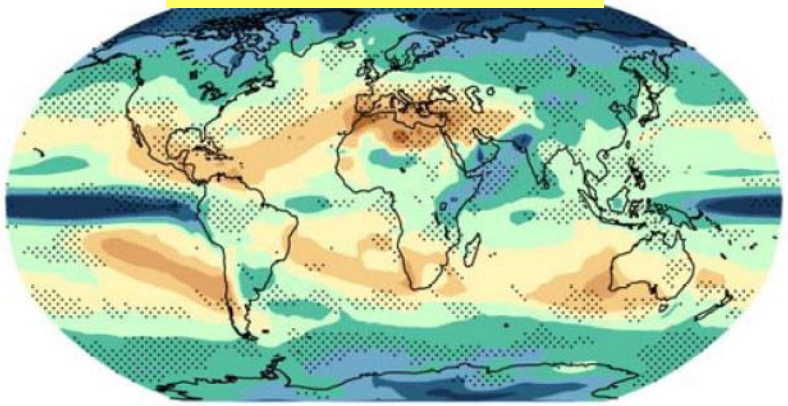
CMIP3 vs. CMIP5 Projection

Temp. & Preci. Change (2080-2099)

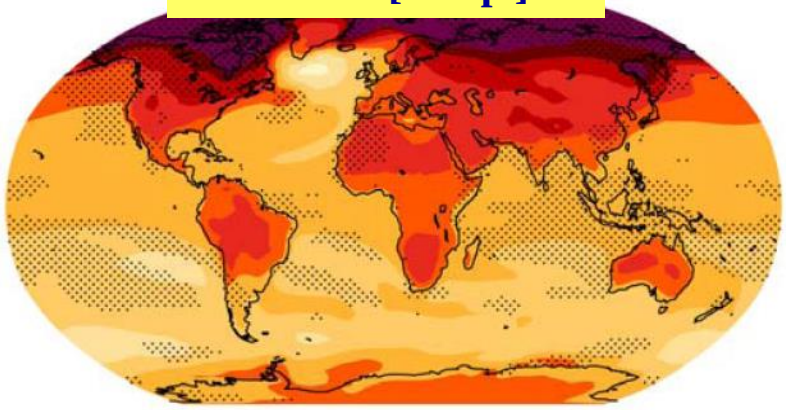
CMIP3 [Temp.]



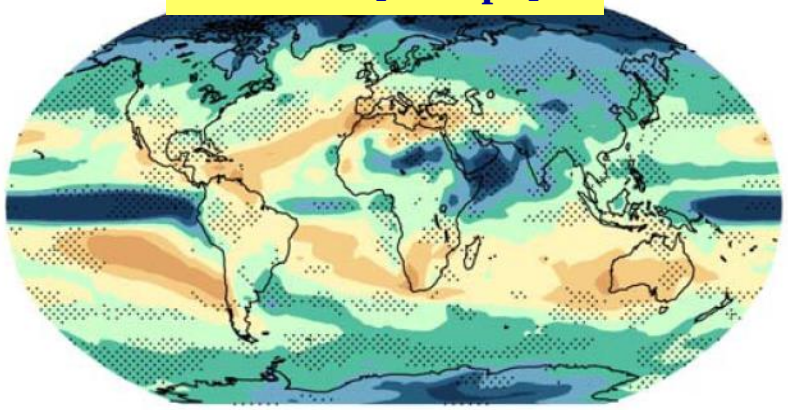
CMIP3 [Precipi.]

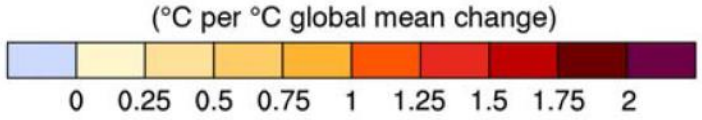


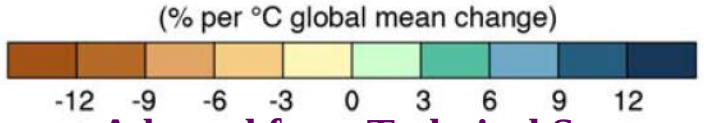
CMIP5 [Temp.]



CMIP5 [Precipi.]

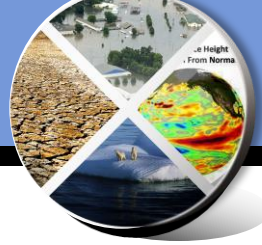






Adapted from Technical Summary of AR5

Anthropogenic Warming



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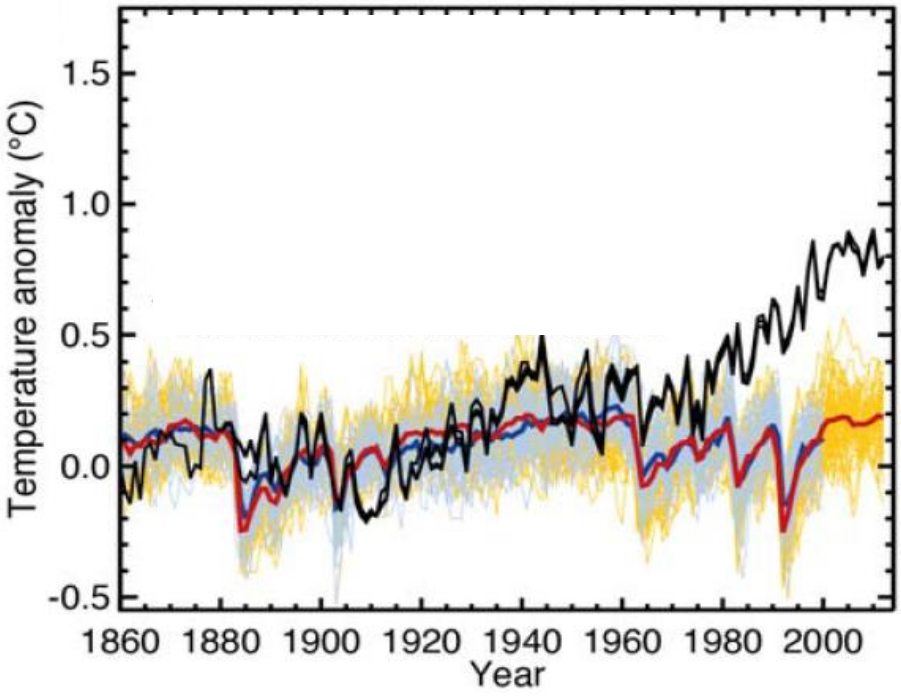
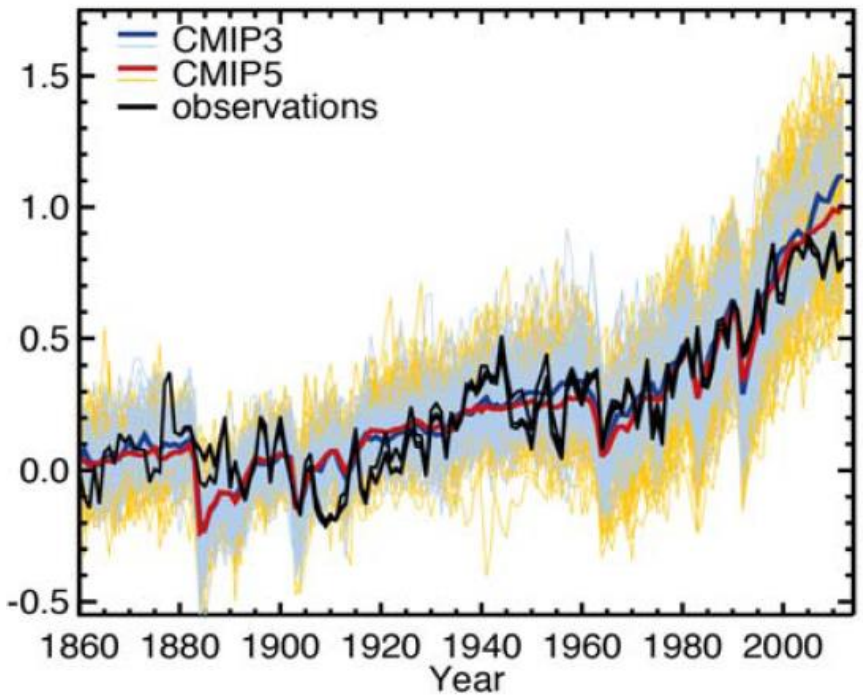


Natural + Anthropogenic Forcings



Adapted from IPCC AR5

Assessment of Reliability

Three Evidences for Assessing Reliability

- **How to estimate the reliability of simulations of future climate change?**

1 Comparison of simulated present-day climate with observations

2 Simulation of past (20th century and earlier) climate changes

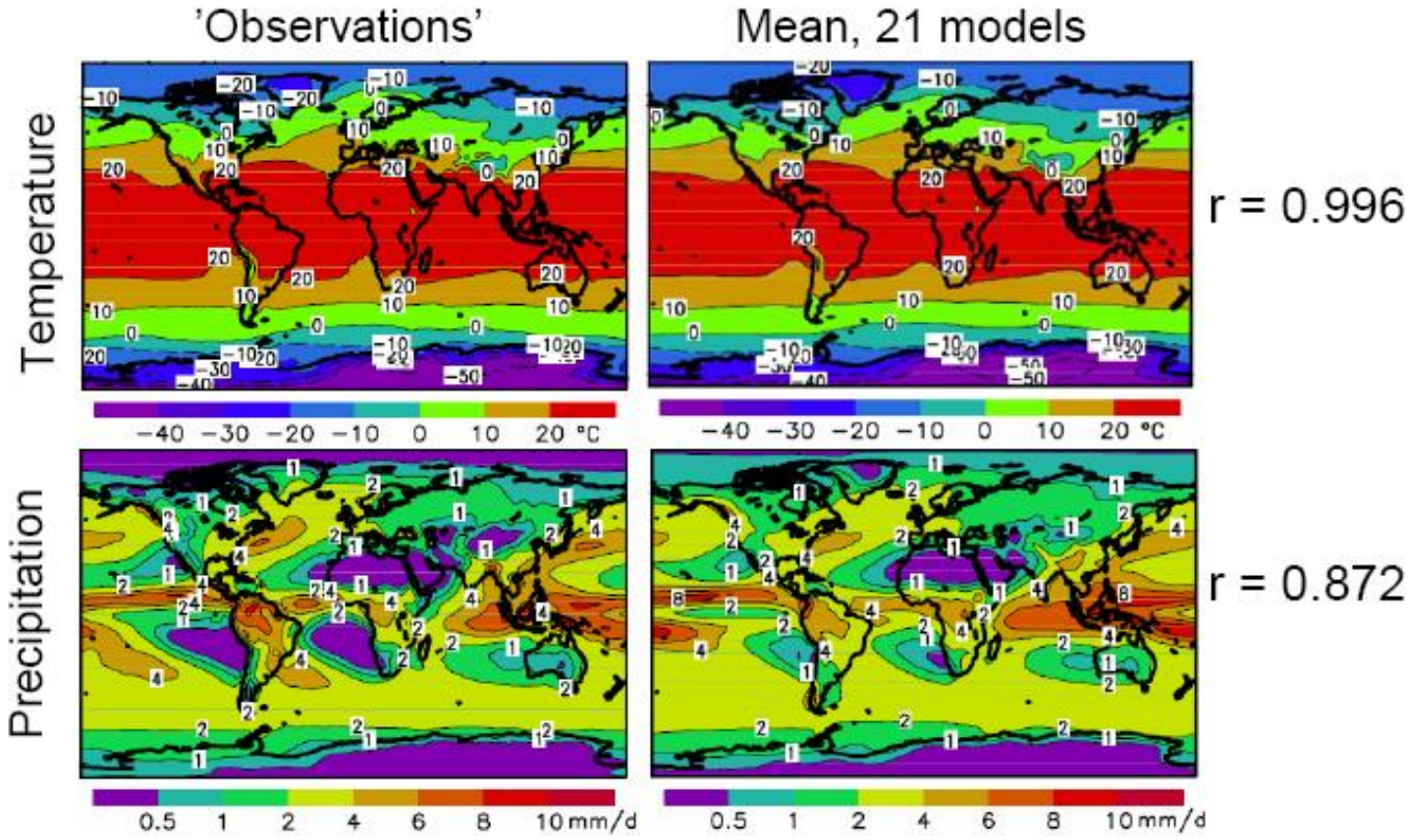
3 Intercomparison of climate change simulations between different models

Assessment of the reliability of climate change projection

Reliability Criteria I

Verification of Present-day Climate

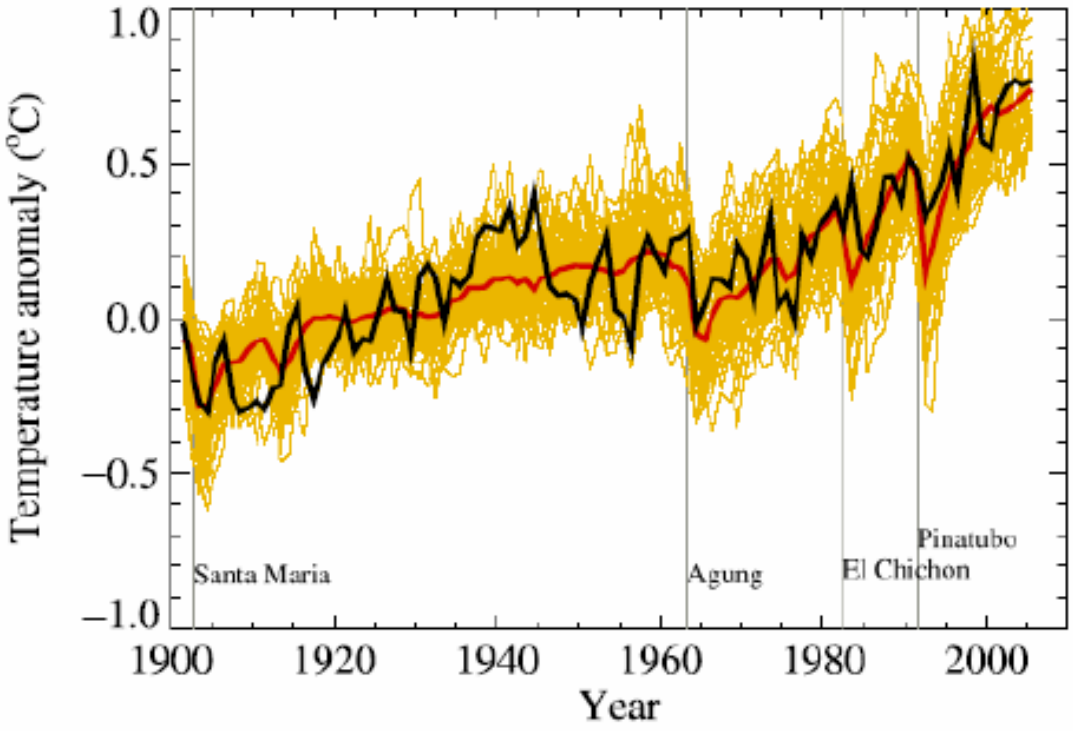
- Observed vs. Simulated annual mean temperature and precipitation
- Model distribution well captures observed large scale patterns.



Reliability Criteria II

Estimation of Past Climate Change

- The performance of past climate change can be the most objective test
- Models have successfully simulated general warming trend with similarity to observation.



Black: observations

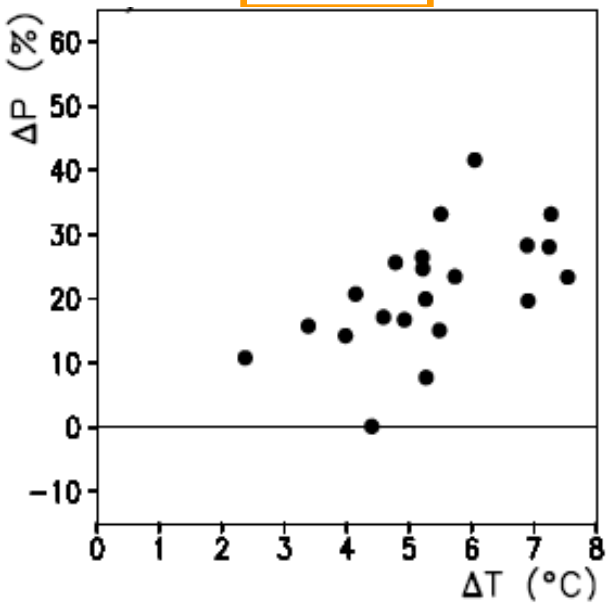
Red and **yellow**: mean and variability of 58 simulations by 14 CMIP3 models, including both natural and anthropogenic forcing.

Reliability Criteria III

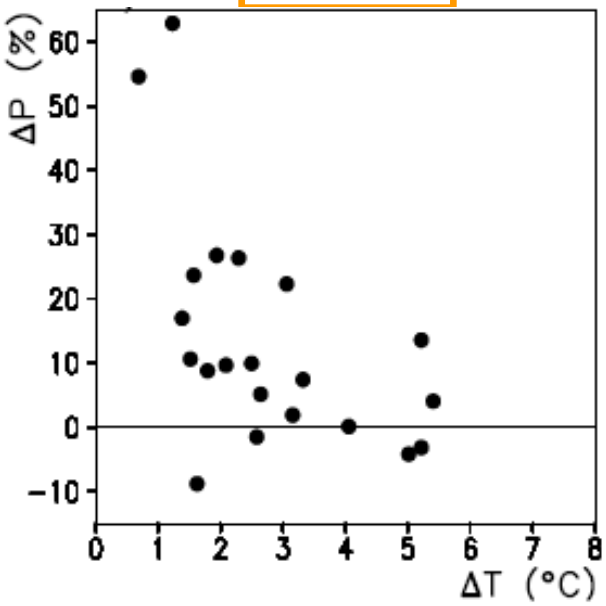
Intercomparison of Models

- Intercomparison of climate change between different model gives a quantitative estimate of uncertainty.
- Changes in temperature and precipitation by 21 IPCC AR4 models (Finland)
- There are general agreement of change sign, toward increase direction.

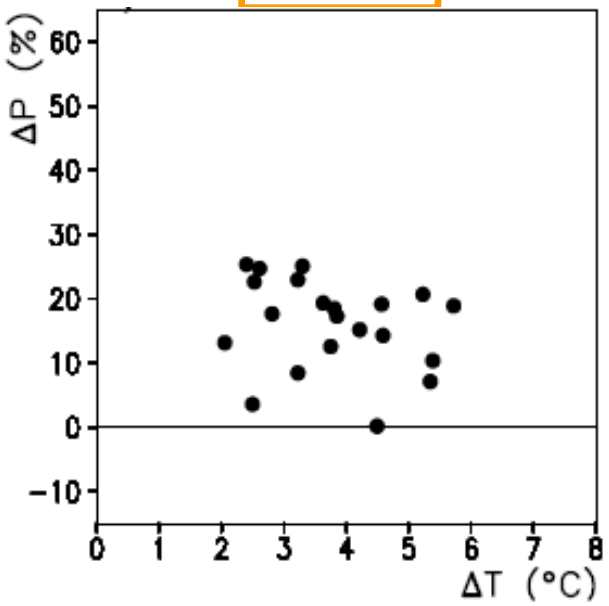
Winter



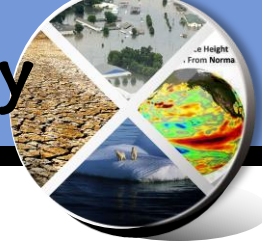
Summer



Annual



RCM Experiment Step for Climate Change Study



STEP I

Perfect LBC Experiment

- IC and BC from analysis observation (NCEP/NCAR, ECMWF . . .)
- Validation of the model performance against observation

STEP II

GCM-driven Reference Exp.

- IC and BC from GCM simulation of present-day climate
- Assessment of added fine scale information provided by RCM

STEP III

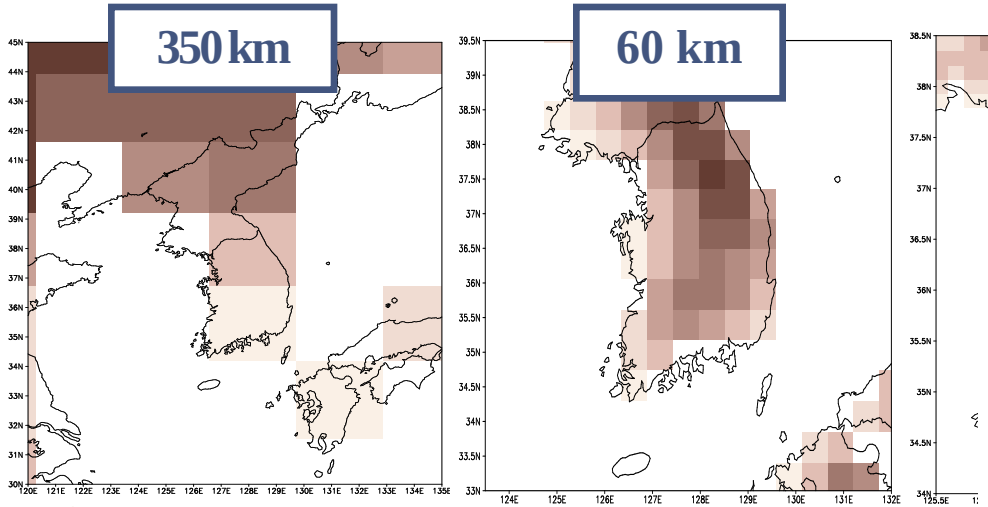
GCM-driven Future Exp.

- IC and BC from GCM simulation of future climate
- Comparison of future and present climate statistics in order to identify the change signal

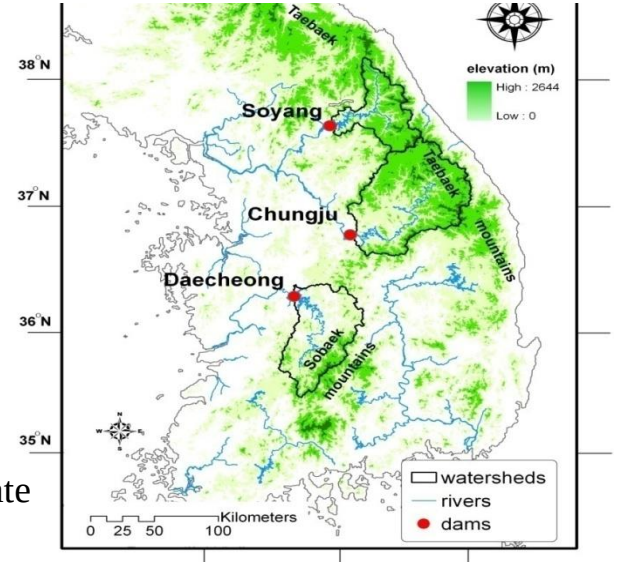
RCM Necessity for Climate Change Study I

Successful linkage between climate and impact sector

- It is needed to bridge scaling gap between the climate models and various impact assessment models because the impact assessments are mostly valid in regional and local sector.



Basin level for hydrology model



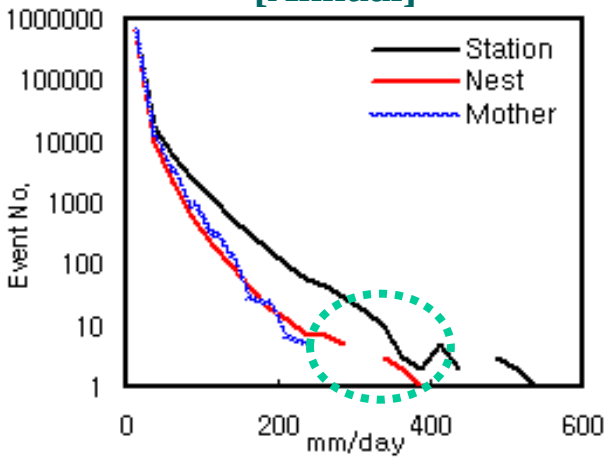
Im et al. 2010: Hydrometeorological response to dynamically downscaled climate change simulations for Korean basins. **[Climatic Change]**

RCM Necessity for Climate Change Study II

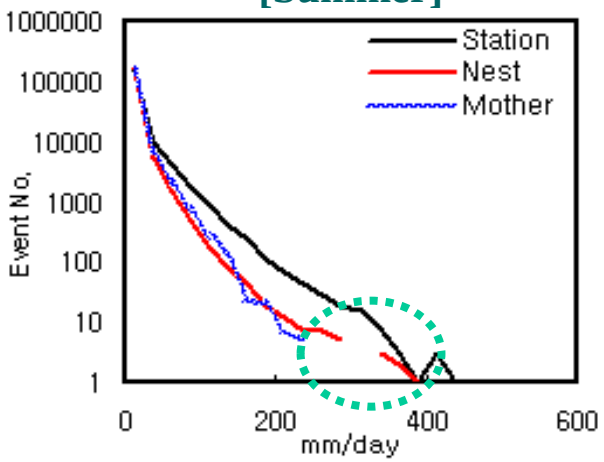
Improving the simulations of extremes

- By comparison between the nested and mother domain simulations, for low to mid-intensities the two frequency distributions are essentially the same. However, the nested domain frequency distribution has a longer tail at the high intensity range.
- In other words, only nested domain simulation is capable of producing extreme precipitation episodes and this result supports the use of finer scale models to simulate extreme events.

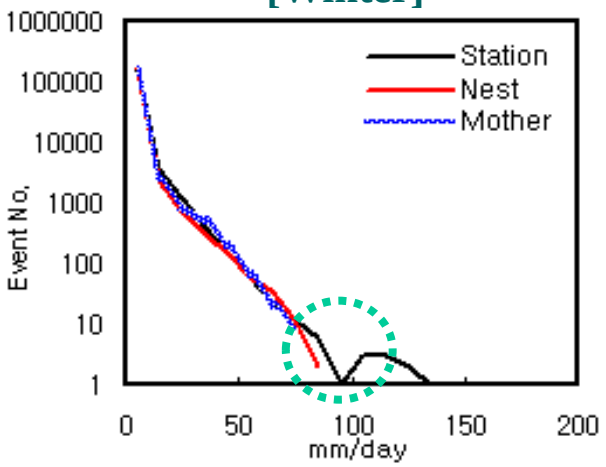
[Annual]



[Summer]



[Winter]



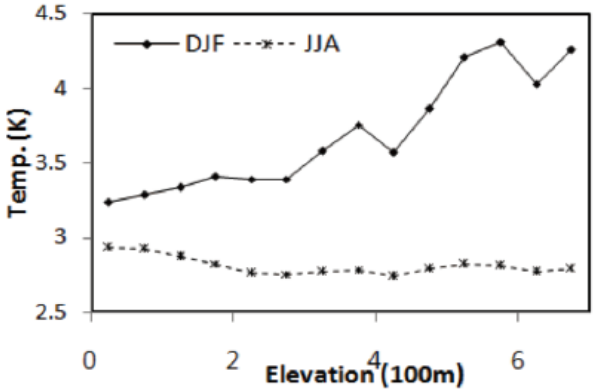
Im et al. 2008: Multi-decadal scenario simulation over Korea using a one-way double-nested regional climate model system. **[Climate Dynamics]**

RCM Necessity for Climate Change Study III

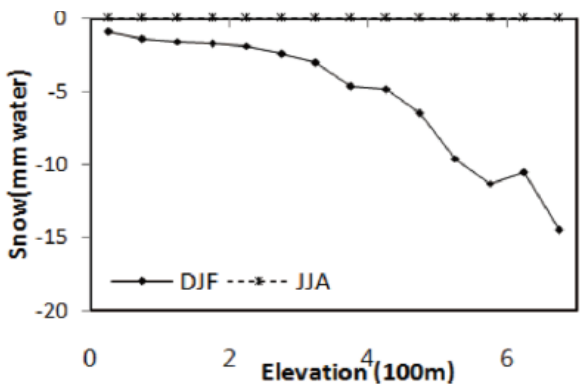
Elevation-Dependency of Climate Change Signal

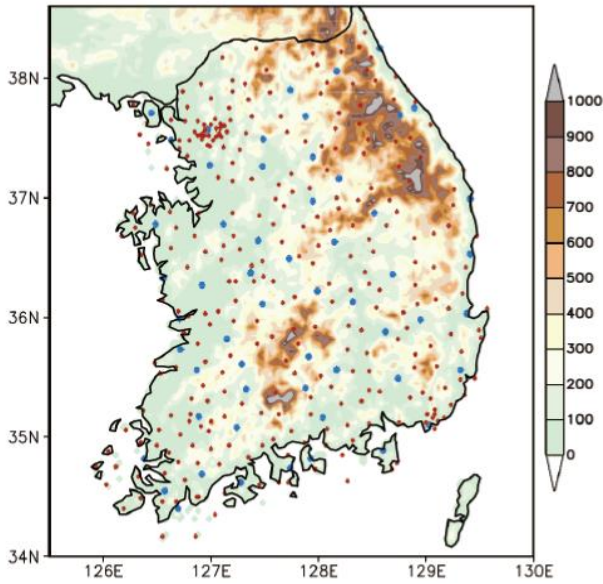
- ❖ High elevation area tends to be more enhanced response due to global warming
- ❖ The detailed topographic forcing in the climate model is essential for climate change simulation

[Tmin]



[Snow]





Im & Ahn, 2011: On the elevation dependency of present-day and future climate simulations from a high-resolution regional climate model. [**J. Meteorol. Soc. Japan**]

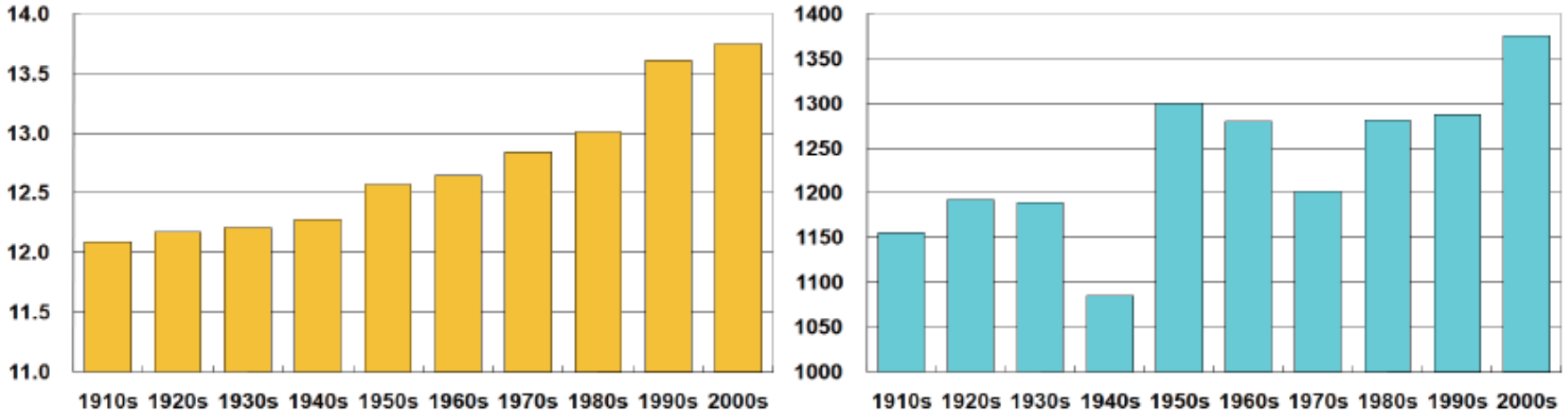
Im et al., 2010: Local effects of climate change over the Alpine region. [**Geophy. Res. Lett.**]

Climate change simulation over Korea from a RegCM3 double-nested system

Climate Change over Korea

Long-term Trends of Temperature & Precipitation

- 6-station mean temperature and precipitation (1912-2008)



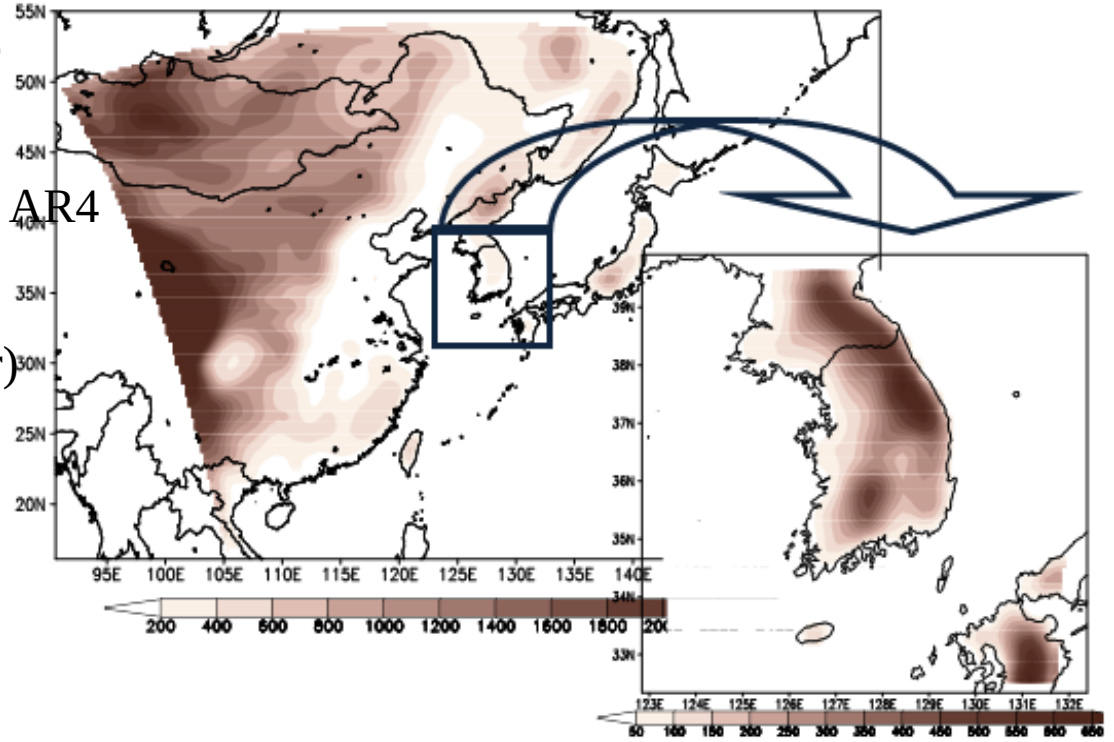
[Adapted from 기후변화 이해하기 II]

- The climate of Korea has experienced a gradual warming throughout the 20th century.
- It is reasonable to expect that Korea will be strongly vulnerable to climate change.

RegCM3 one-way double-nested system

Model Configuration

- ICTP Regional Climate Model Ver. 3
- Resolution: Mother domain – 60km / Nested domain – 20km
- Physical parameterization
  - MIT Emanuel Convection Scheme
  - BATS Land Surface Scheme
- Initial & Boundary :
  - ECHAM5 A1B(1.875)-IPCC AR4
- Integration Period :
  - [Reference] 1971-2000 (30yr)
  - [Future] 2000–2100 (100yr)



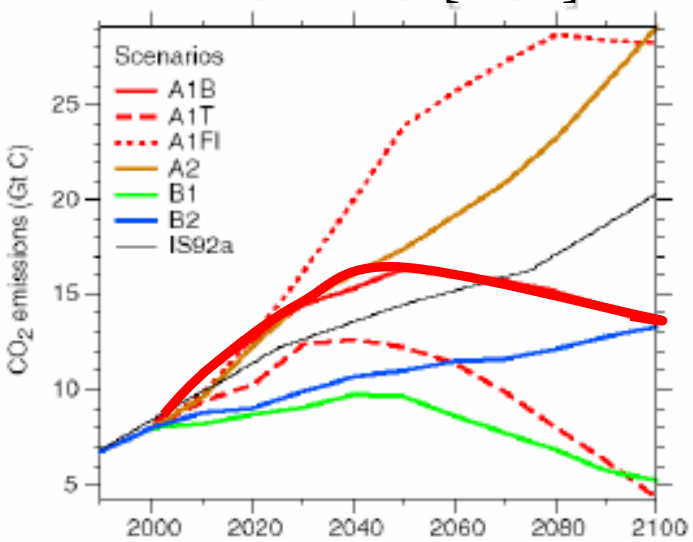
Experiment Design

Initial & Boundary Condition

- **ECHAM5/MPI-OM A1B (1.875)**

  : State-of-the art coupled GCM, which was used to conduct ensemble simulations for th forth assessment report of the IPCC (AR4)

- IPCC SRES [CO2]



Integration Period: 130year

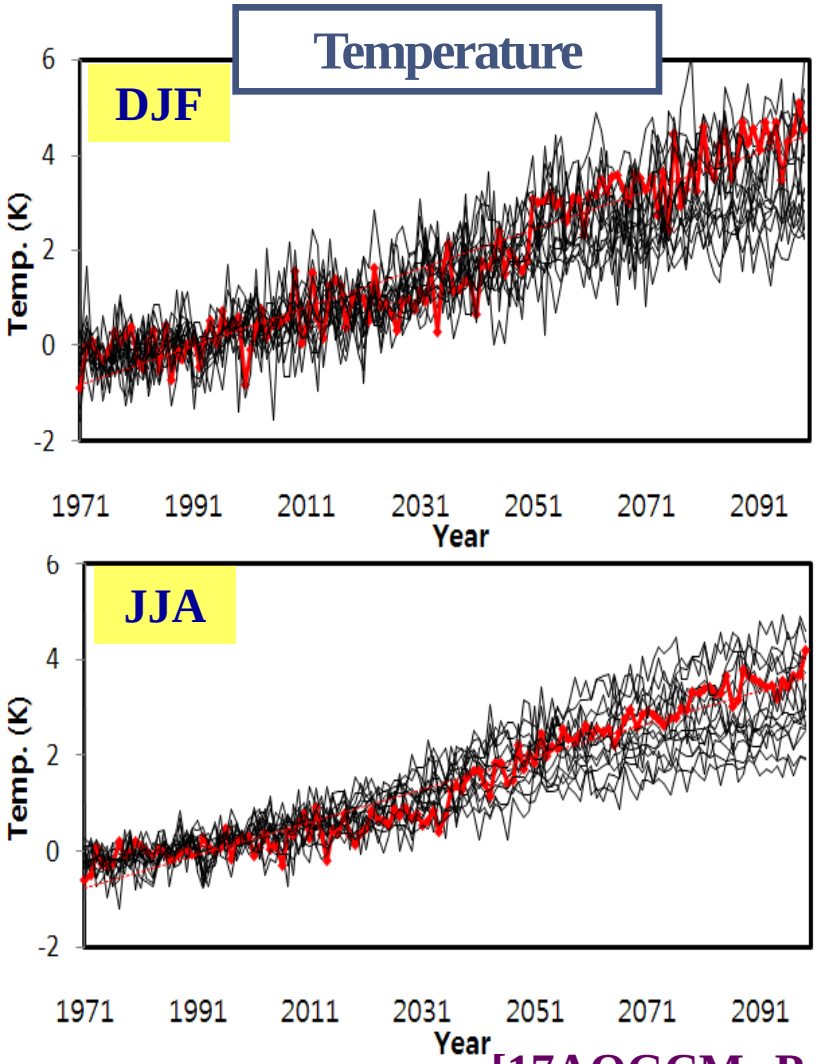
- Reference climate: 1971-2000, 30yr
- Future climate: 2000-2100, 100yr

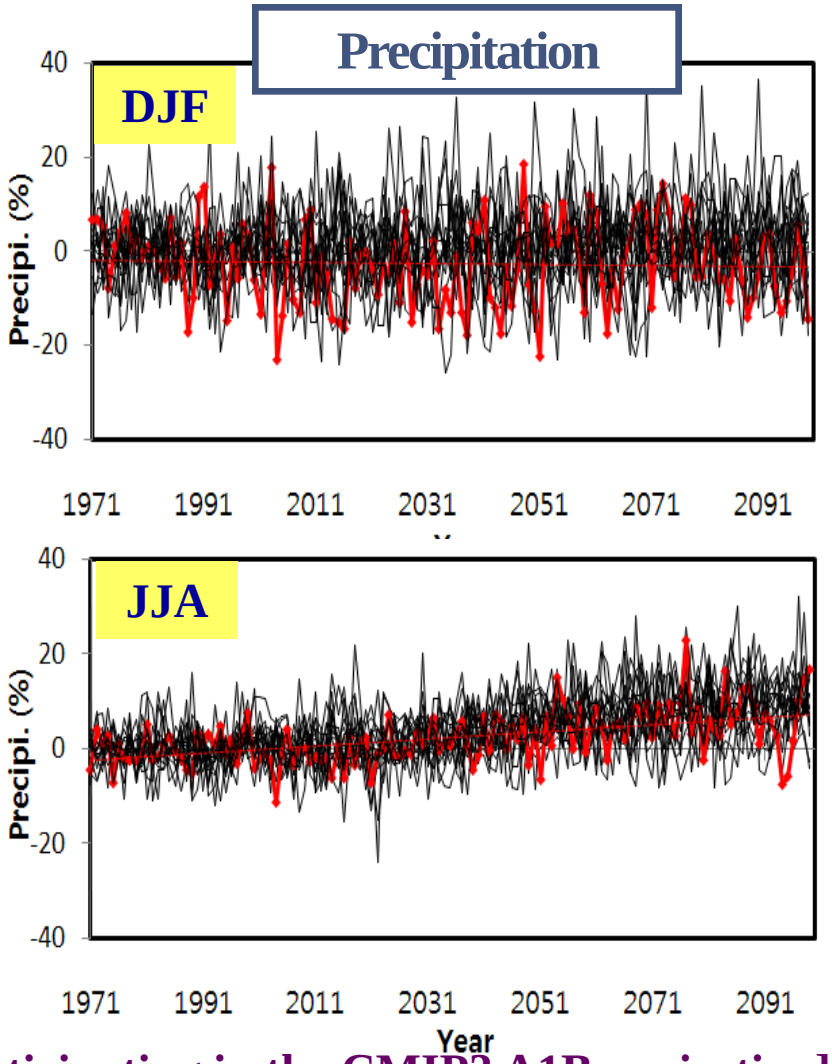
1971 Reference (30yr) 2000 Future (100yr) 2100

Future change signal = Future Simulation – Reference Mean

Reliability of ECHAM5 Projection

Inter-Model Variability

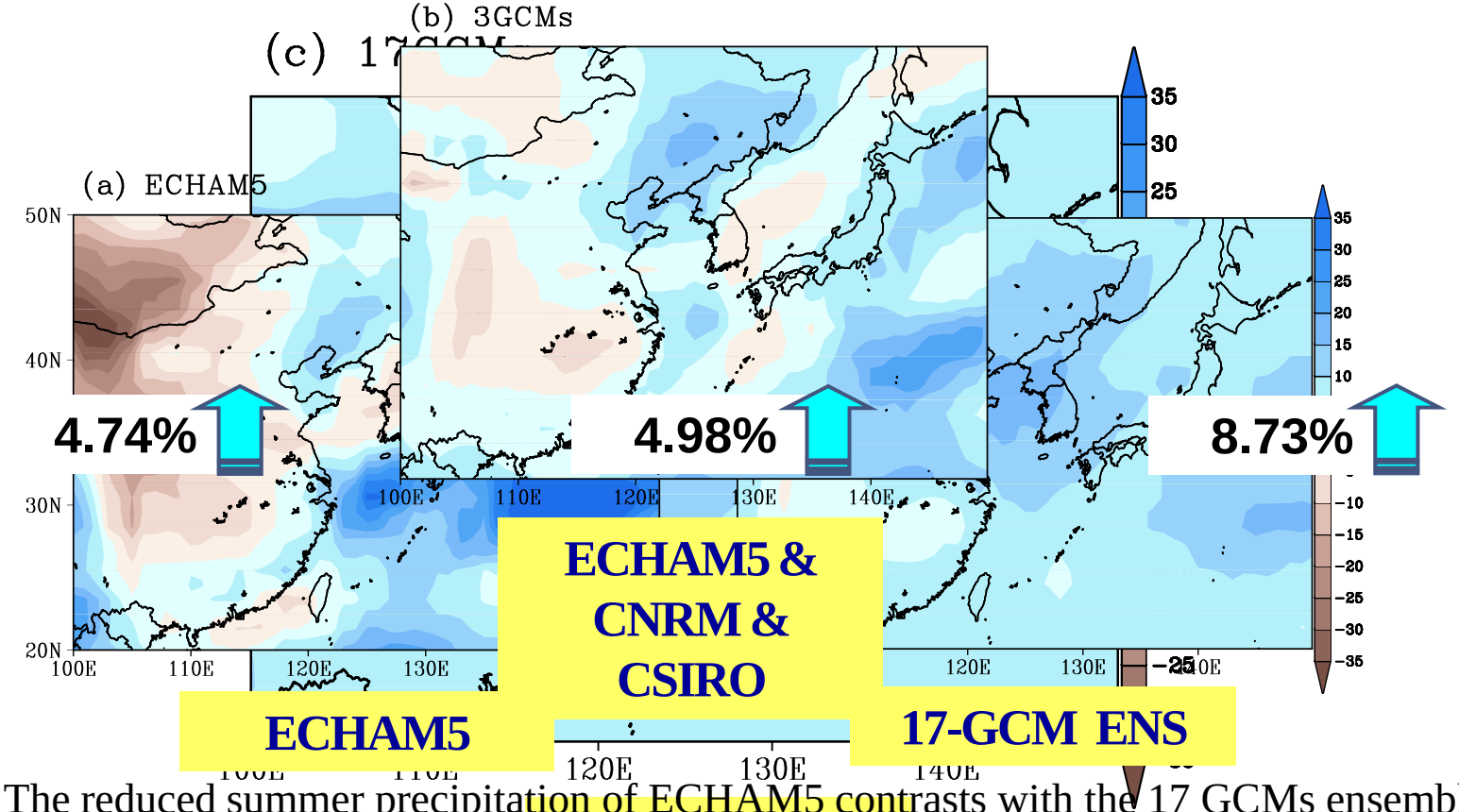




[17AOGCMs Participating in the CMIP3 A1B projection]

Uncertainty of GCMs Projections

JJA Precipitation Change (2071-2100 minus 1971-2000)



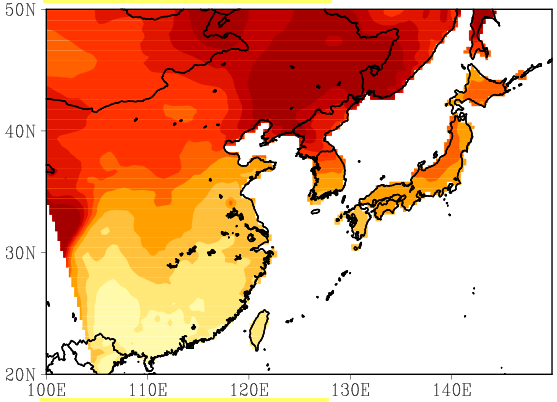
- The reduced summer precipitation of ECHAM5 contrasts with the 17 GCMs ensemble average. But, there is a large possibility of misinterpretation from the GCM projections over a narrow peninsula such as Korea.
- In the three GCMs (including ECHAM5) with the relatively high resolution (1.875˚), the negative areas are more expended mostly over the land compared to ENS average pattern .

Temp. & Preci. Change

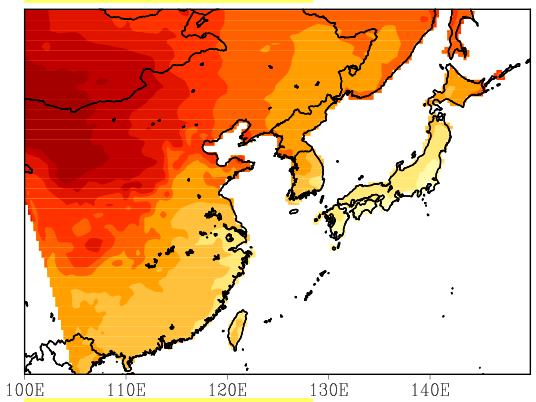
Mother domain simulation (2071-2100)

- The downscaled results generally follow the behavior of ECHAM5, but substantial fine-scale details are found in the spatial pattern, and the change signal becomes more enhanced at the local scale.

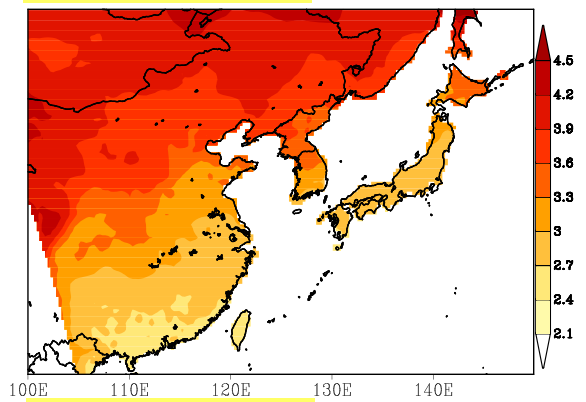
Temp. [DJF]



Temp. [JJA]



Temp. [ANN]



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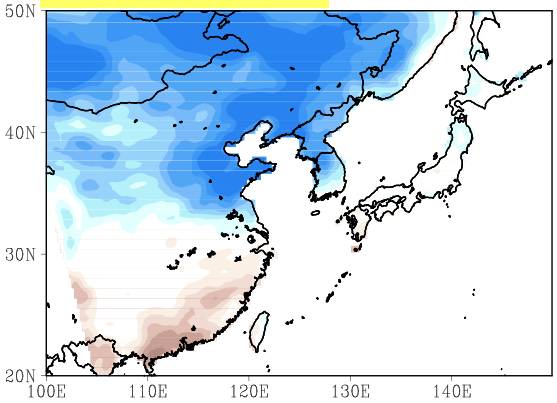

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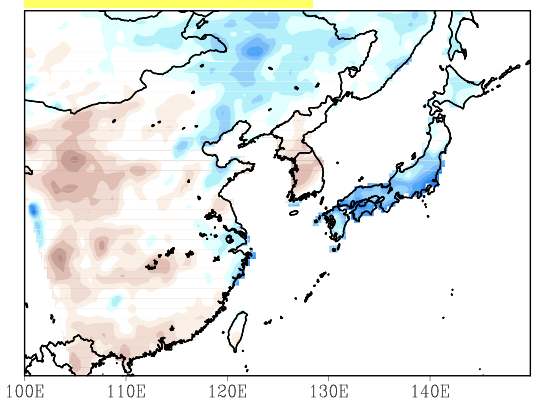

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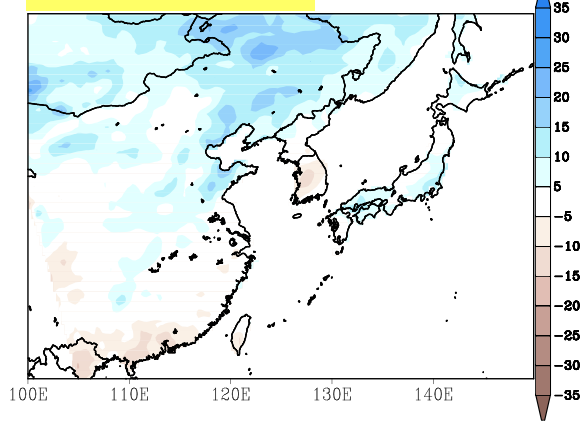
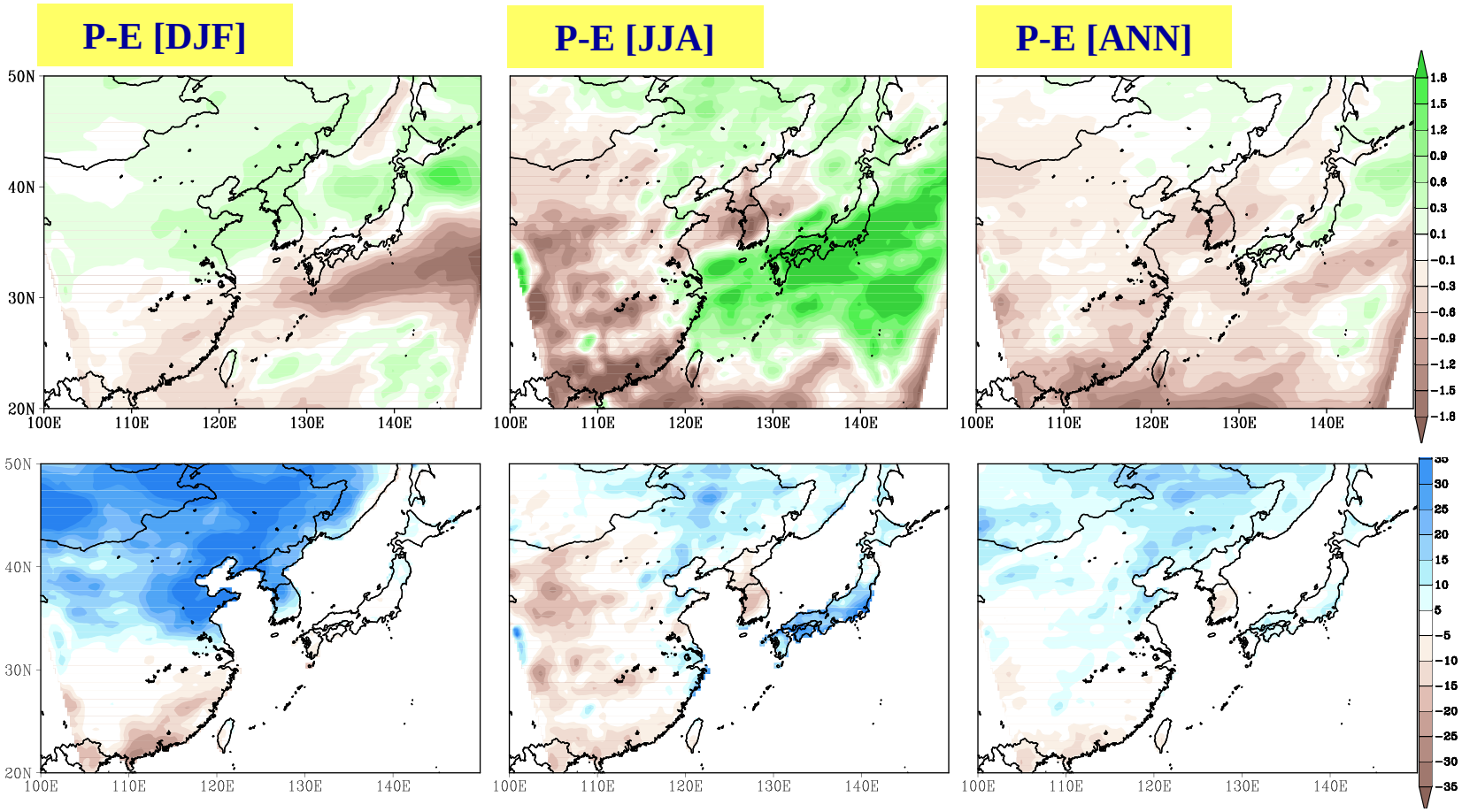


Future Dryness

Precipitation - Evapotranspiration

- Moisture deficit = Evapotranspiration > Precipitation. (Negative sign)
- Water stress becomes more pronounced in the warmer climate due to enhanced evaportranspiration.



Assessment of Drought

self-calibrated Palmer Drought Severity Index (PDSI)

- PDSI is the most prominent index of meteorological drought, which is measured by cumulative effect of atmospheric moisture supply and demand.
- PDSI incorporates both precipitation and temperature as inputs.
- Drought is shown in terms of a negative number.

  For example, PDSI < -3 is severe drought.

Relative Departure of Moisture

$$D = P - P^* = P - (PE^* + PR^* + PRO^* - PL^*)$$

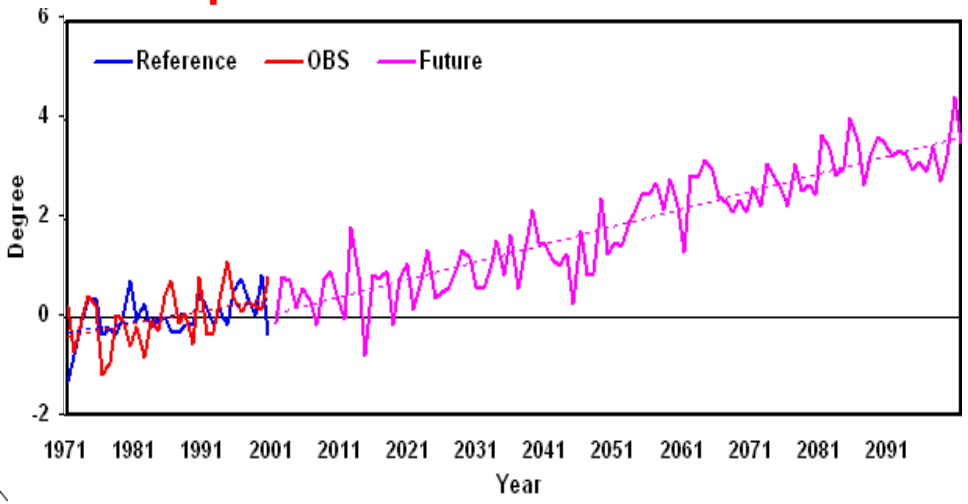
[PE: Potential Evapotranspiration / PR: Potential Recharge / PRO: Potential Runoff / PL: Potential Loss]

- The moisture departure, d, is the excess or shortage of precipitation compared to the CAFEC (climatically appropriate for existing conditions).

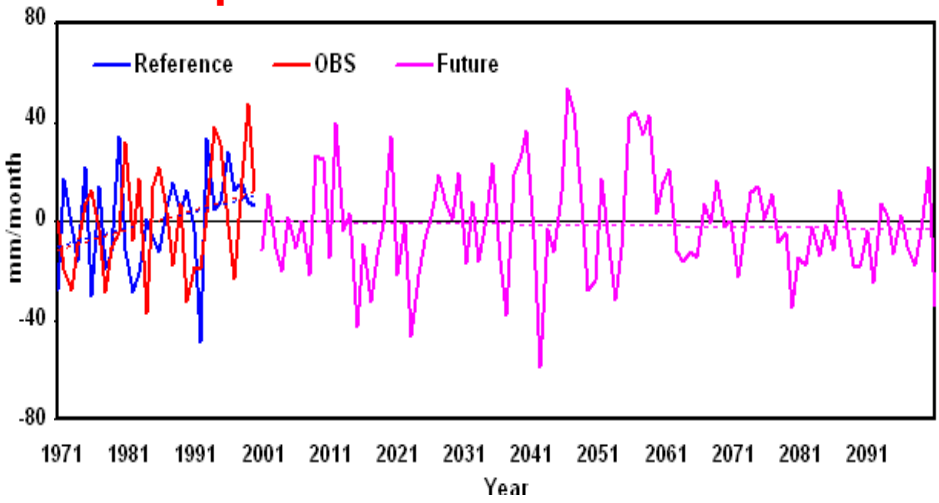
Future Drought

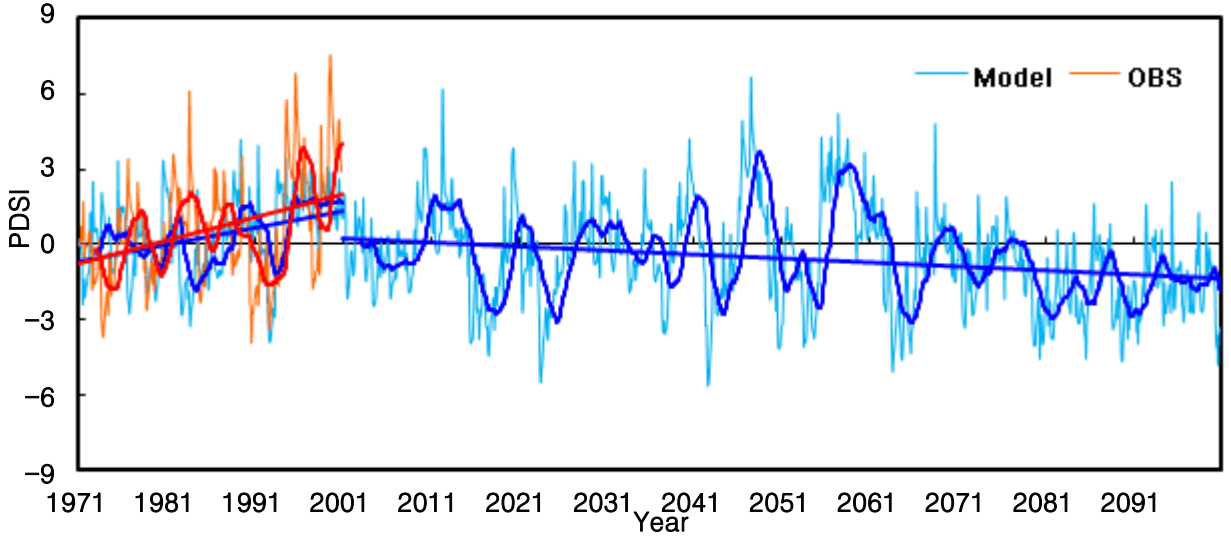
Long-term Trend of Temperature & Precipitation & PDSI

Temperature



Precipitation

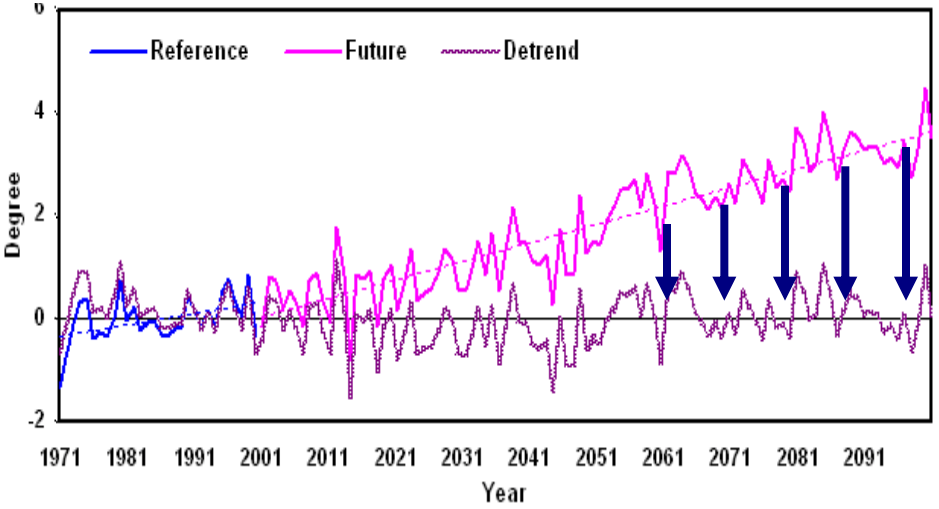




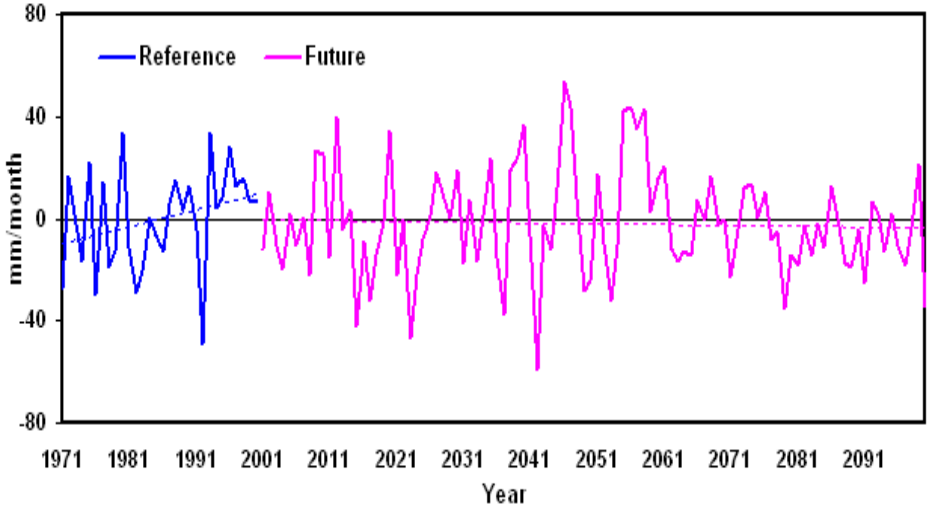
Effect of Temperature on Drought

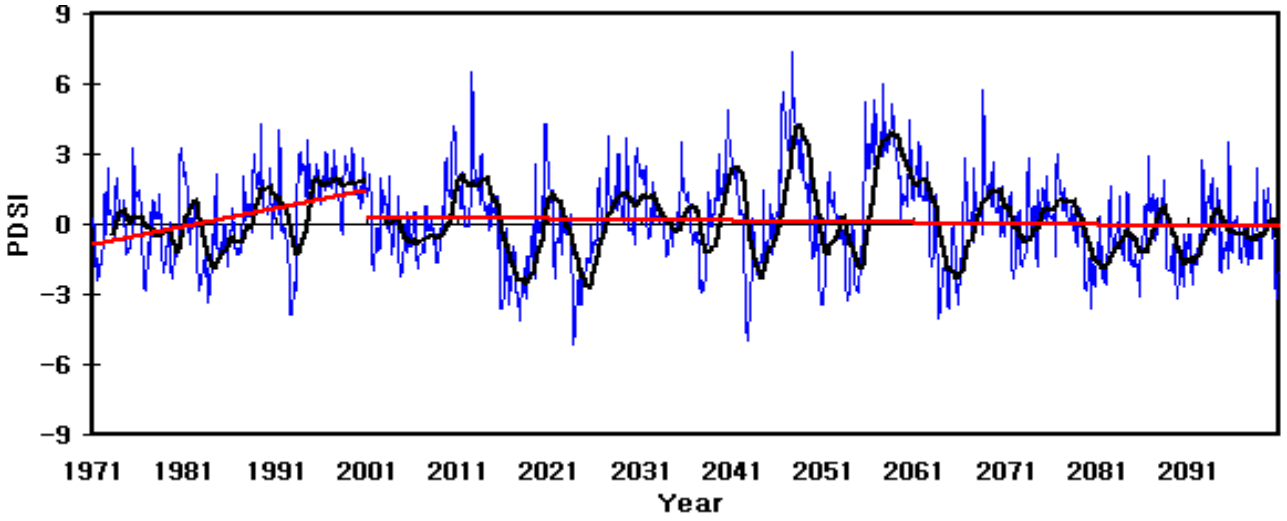
PDSI derived by detrended Temperature

Temperature (Detrended)



Precipitation





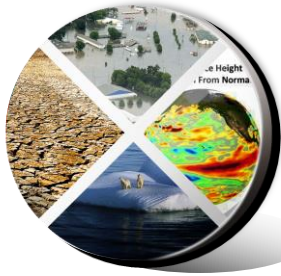
Summary

Change of precipitation characteristics

- Global warming enhances the hydroclimatic intensity, through increased heavy precipitation and reduced light precipitation.
- Change in the total mean precipitation does not necessarily mean that drought will become more or less common.

Enhanced water stress due to temperature increase

- The increase of temperature enhances the evapotranspiration, and hence the water stress becomes more pronounced in the warmer climate.
- Decreasing PDSI trend is primarily due to the increasing temperature trend.
- However, the variation of drought is mainly determined by the variation of precipitation.

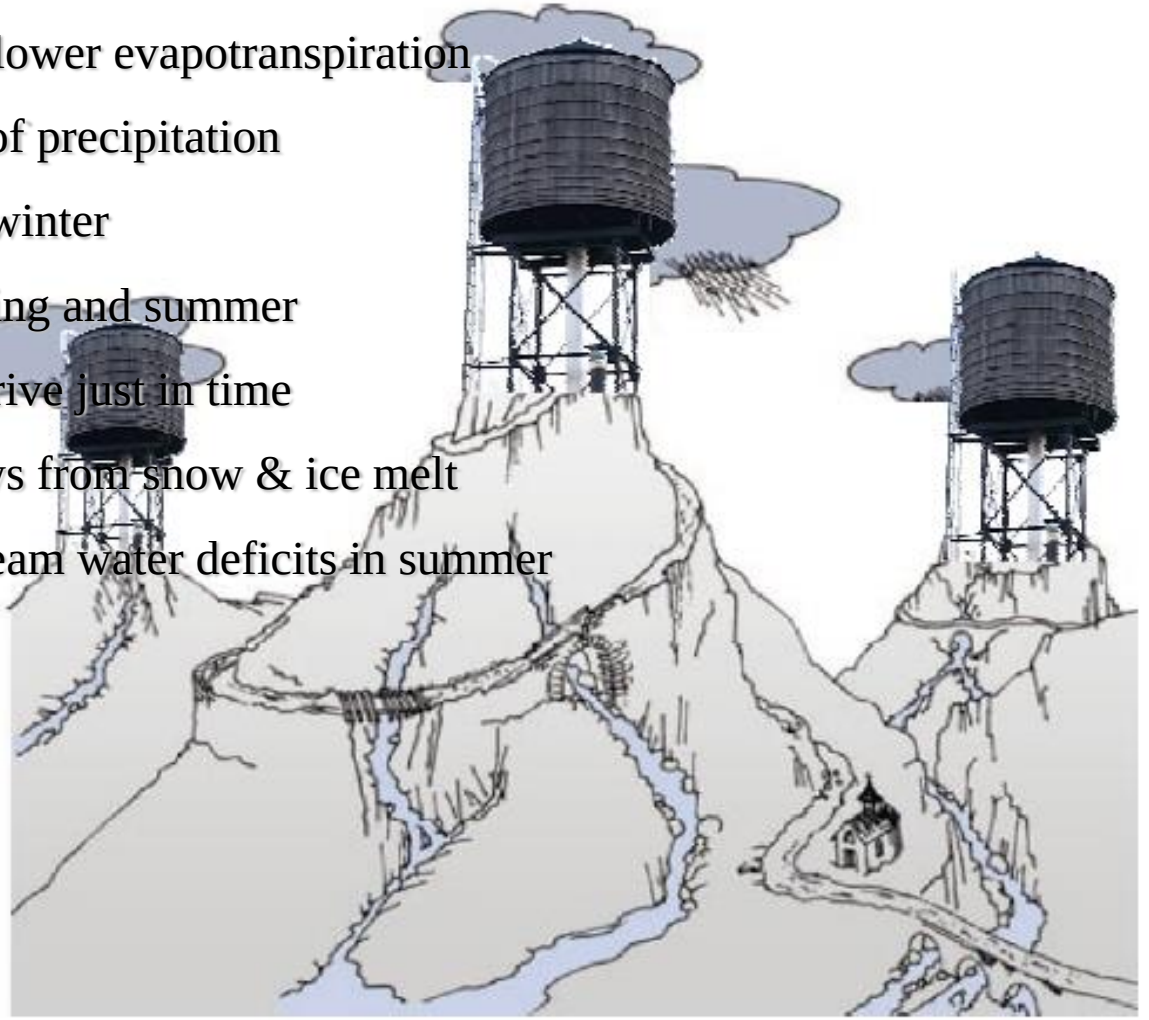


Climate change simulation over Alps from Sub-BATS simulation

Why Alps??

The Alps Water Tower of Europe

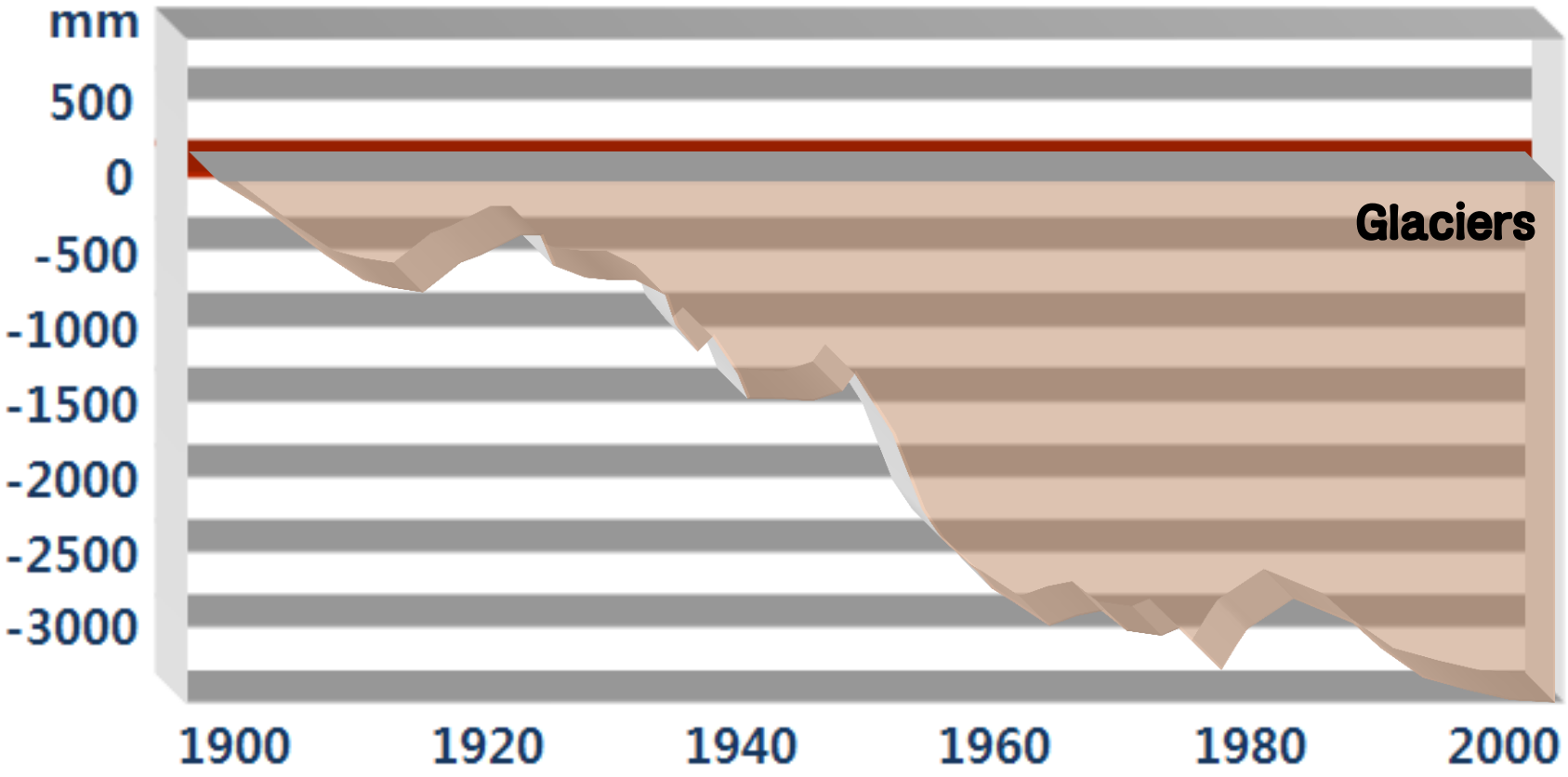
- ❖ Superior water supply
  - higher precipitation & lower evapotranspiration
- ❖ Seasonal redistribution of precipitation
  - snow accumulation in winter
  - snow & ice melt in spring and summer
- ❖ Highly reliable flows arrive just in time
  - highly dependable flows from snow & ice melt
  - attenuation of downstream water deficits in summer



Vulnerability to Global Warming

Global vs. Alps Warming Trend

- Global warming depends on elevation associated with snow-albedo feedback.
- The warming signal at high elevation region would be more significant than low elevation region.



Experiment Design

ECHAM5-MPI/OM A1B Global Simulation (1.8 deg)

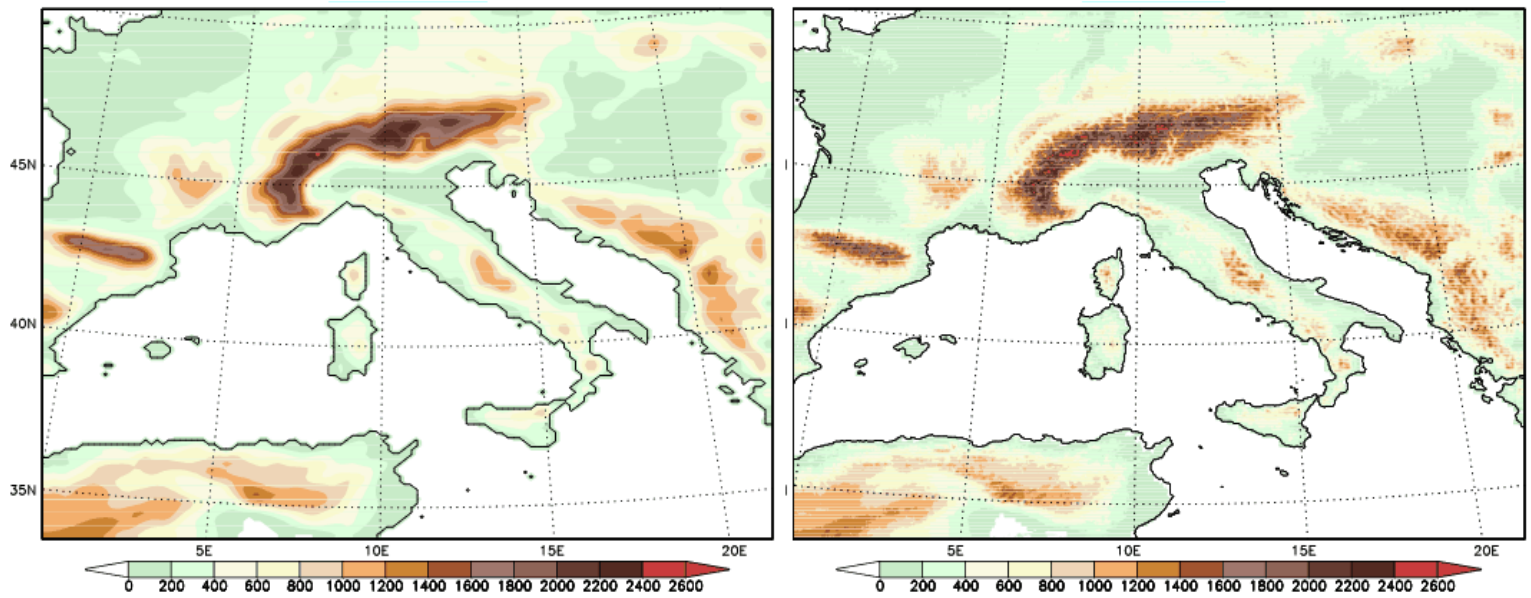
↓ **Dynamical Downscaling**

RegCM3 Whole Europe A1B simulation (25km)

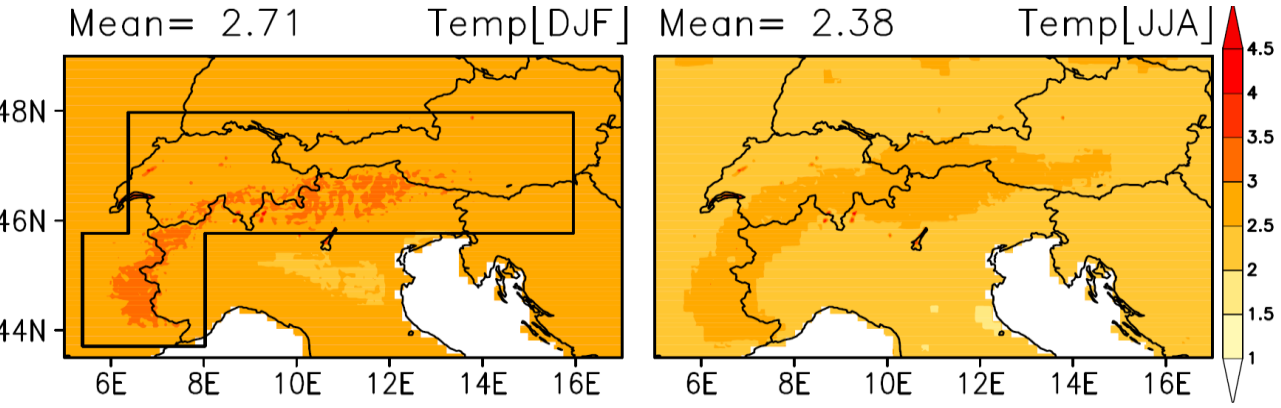
↓ **Dynamical Downscaling**

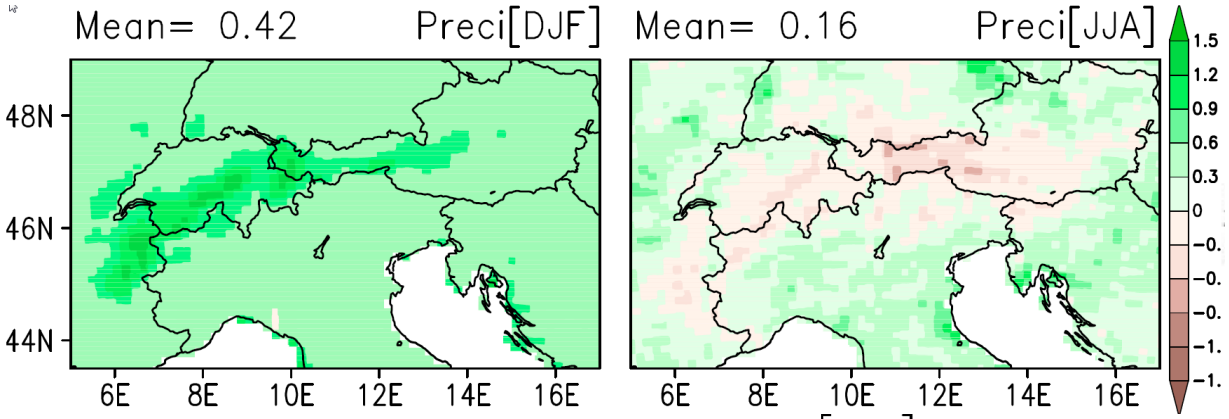
RegCM3 SUB-BATS System (15km & 3km)

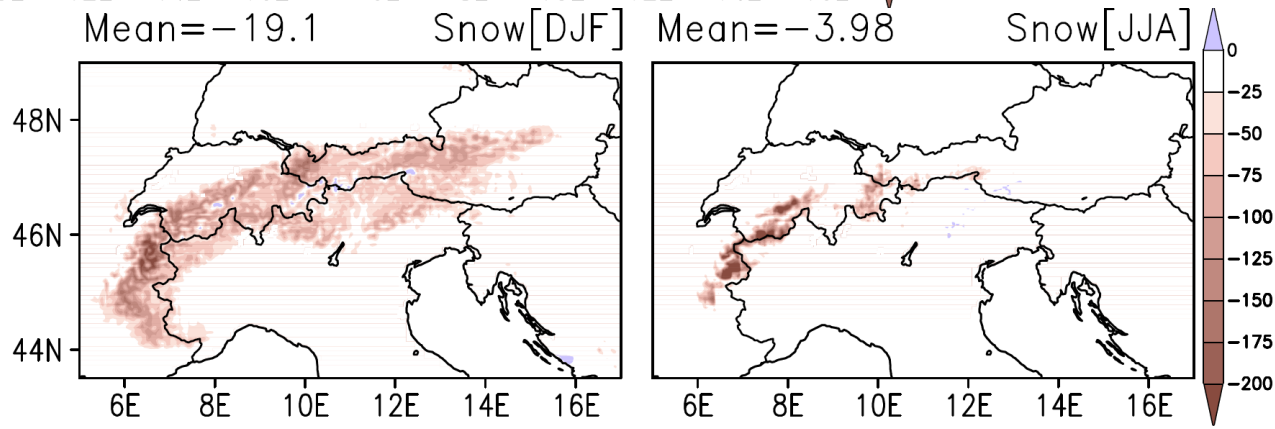
- Reference:1971-2000
- Future: 2071-2100



Climate Change Signal

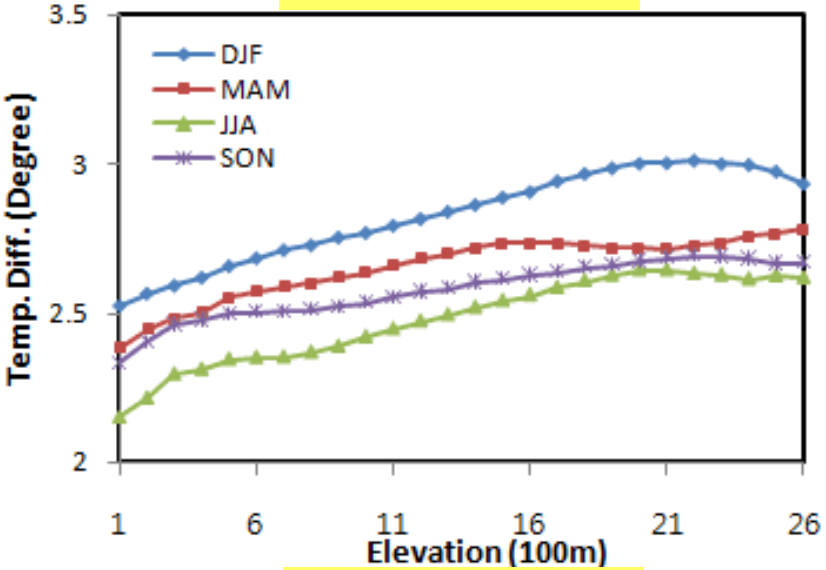




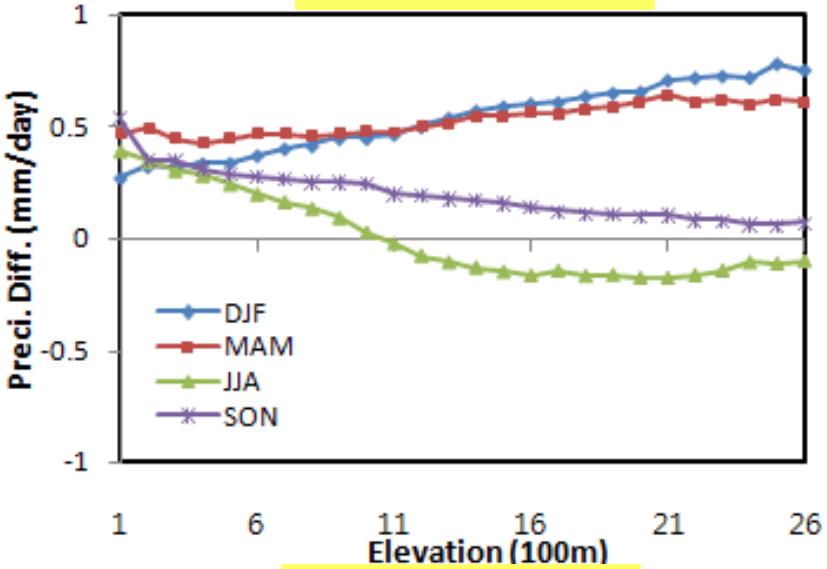


Elevation Dependency

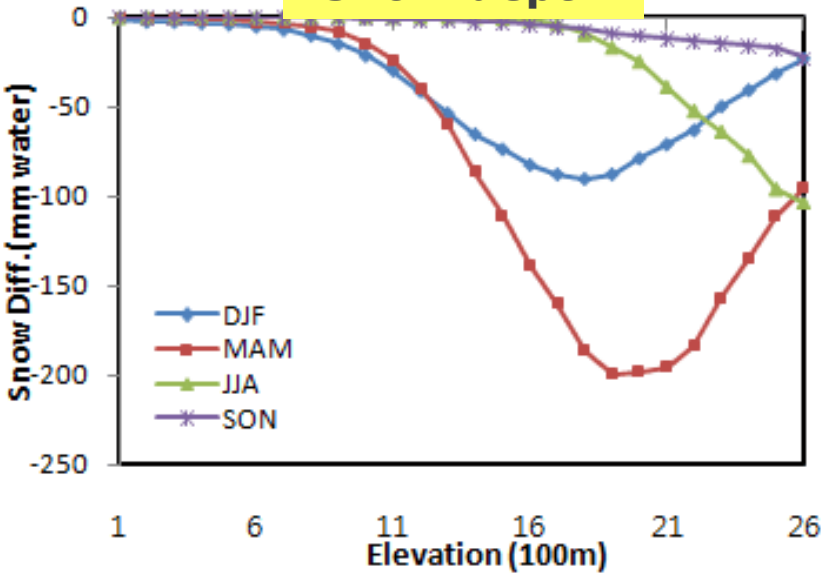
Temperature



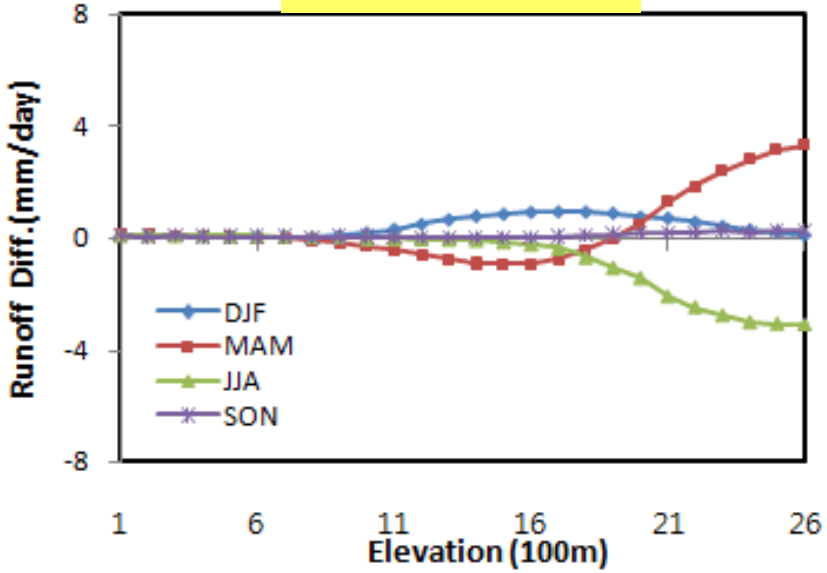
Precipitation



Snow depth



Runoff



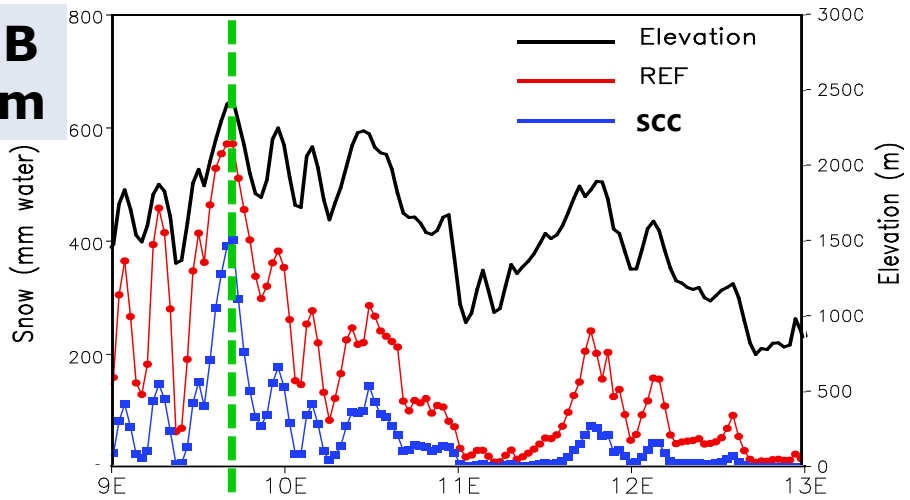
Topography Effect

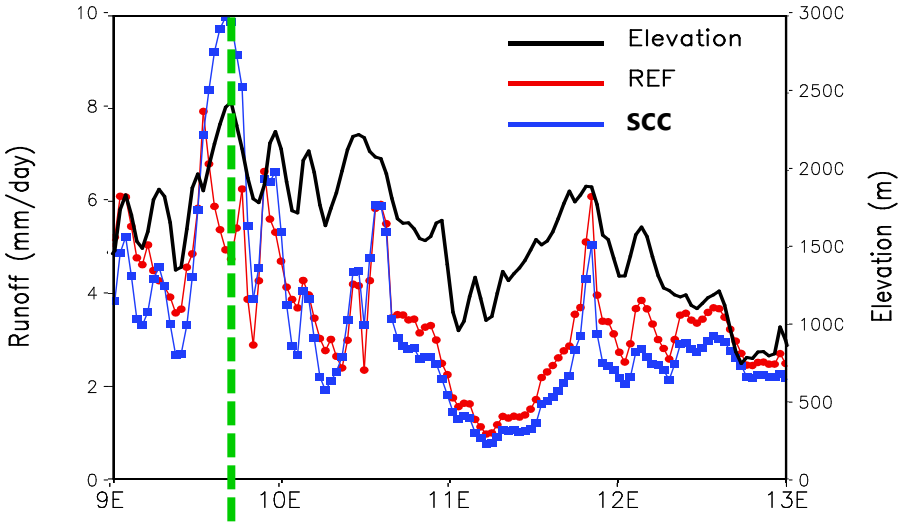
Eastwest Transects (Lat: 46.3N)

Snow Depth [MAM]

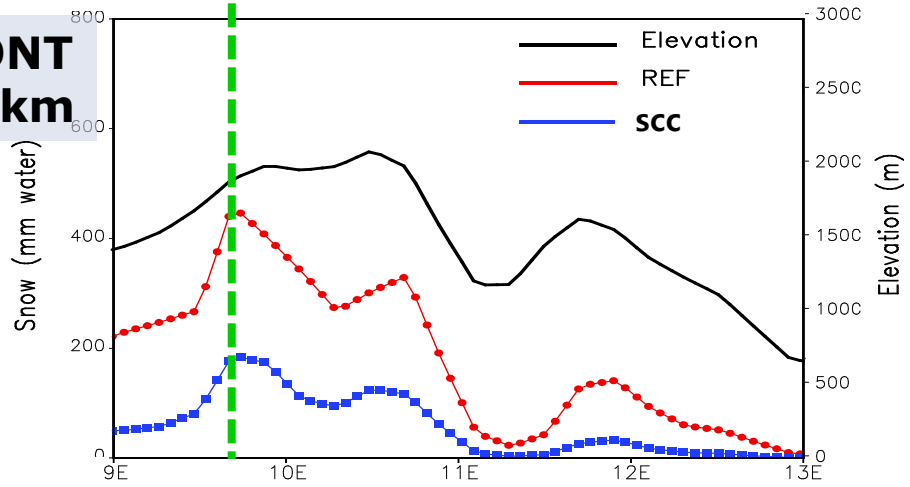
Runoff [MAM]

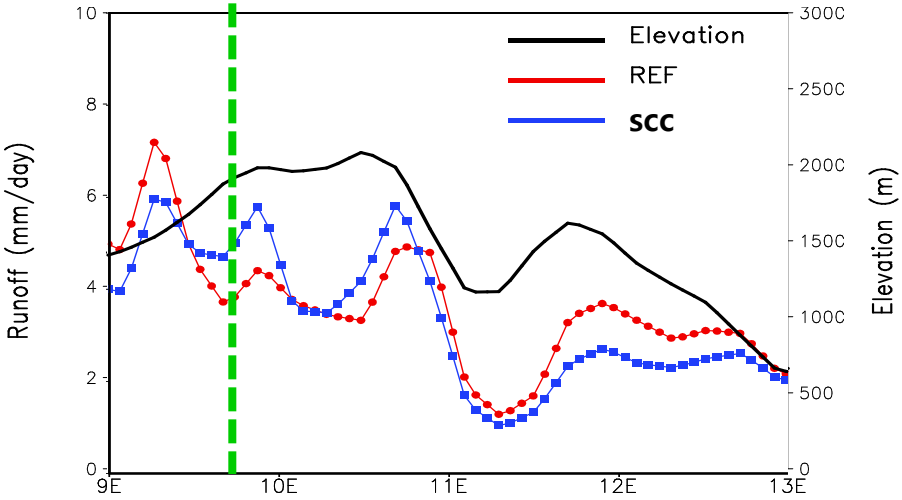
SUB 3km

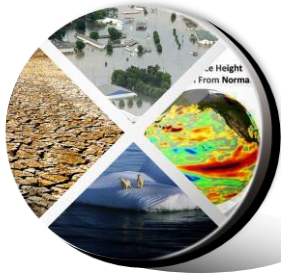




CONT 15km



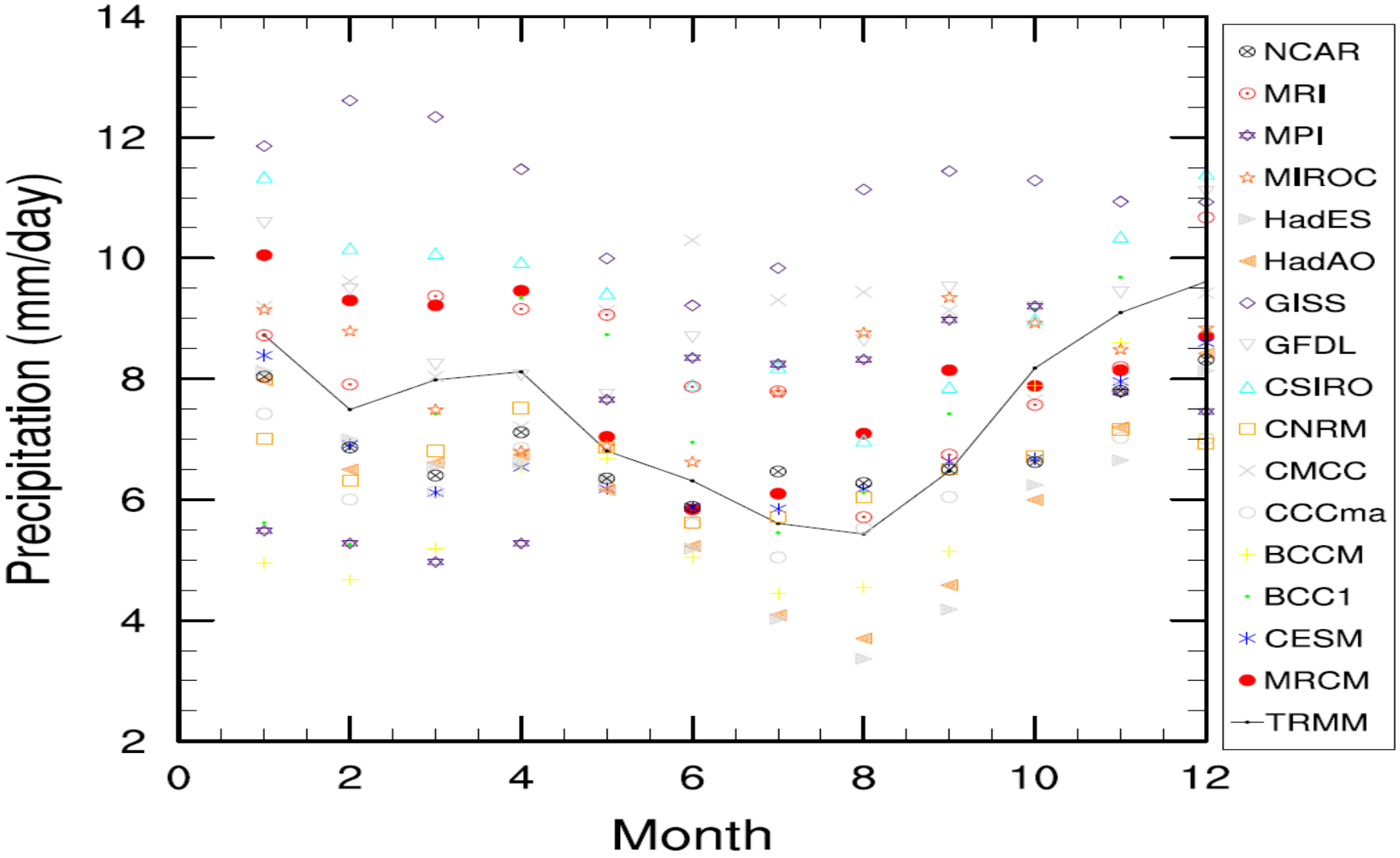




Climate change simulation over the Maritime Continent

Uncertainty of GCMs (CMIP5)

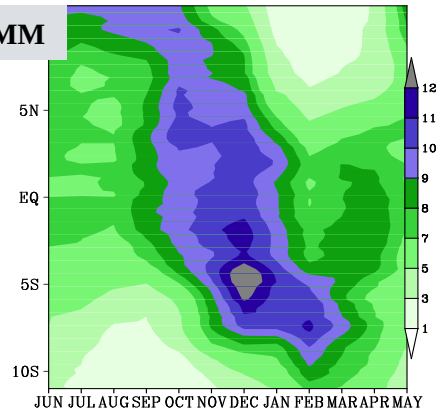
❑ **Rainfall seasonal cycle (averaged 86-130E & 11S-11N)**



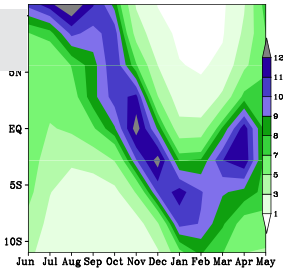
Uncertainty of GCMs (CMIP5)

❑ Latitude-Time cross section (averaged 90-120E)

TRMM



1 BCC1



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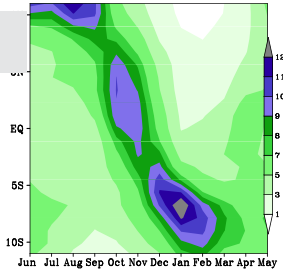

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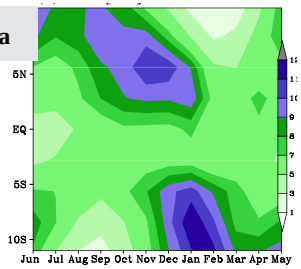
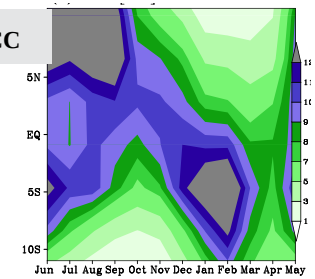
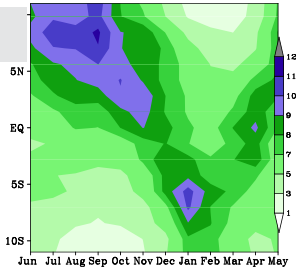


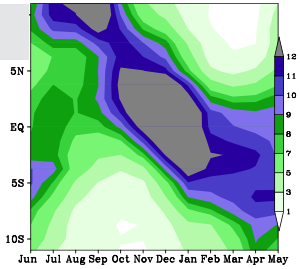
4 CMCC



5 CNRM



6 CSIRO



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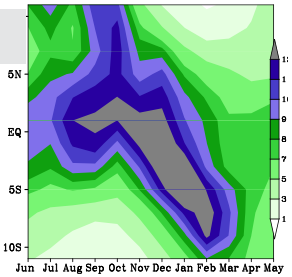

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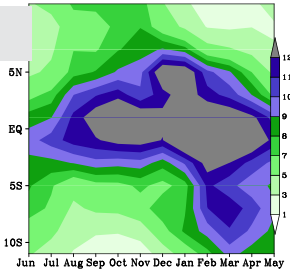
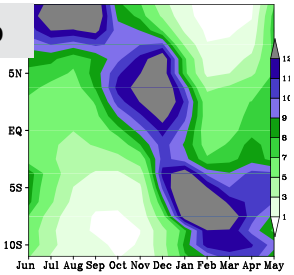
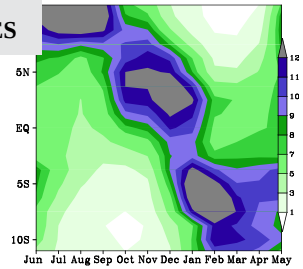


9 Had AO



10 Had ES



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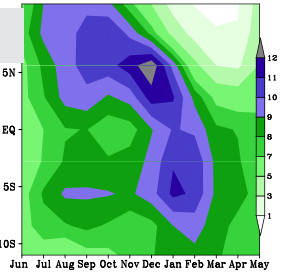
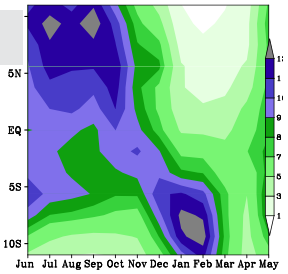


12 MPI



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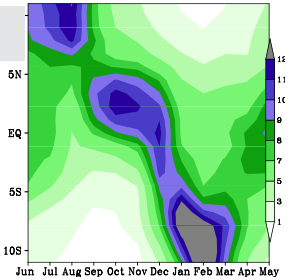
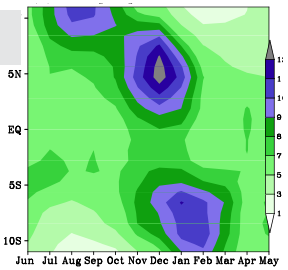


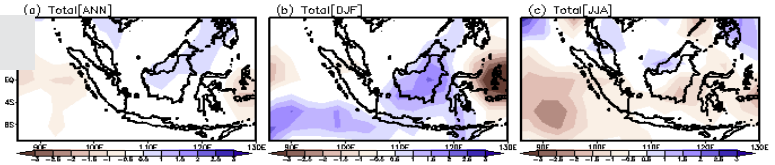
14 NCAR



Uncertainty of GCMs (CMIP5)

❑ Future Change of Rainfall

1 BCC1



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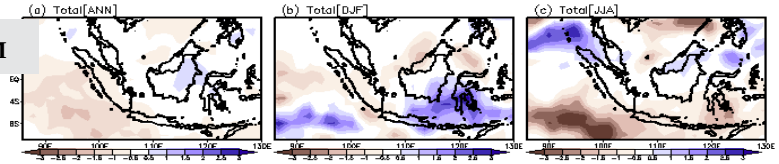
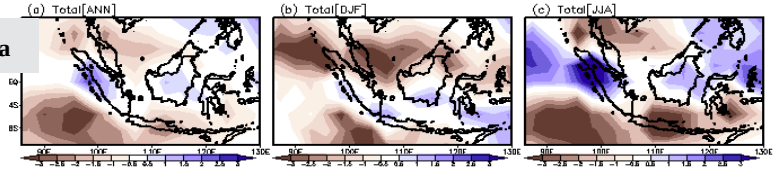


3 CCCma



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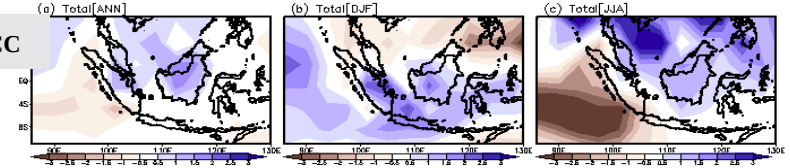
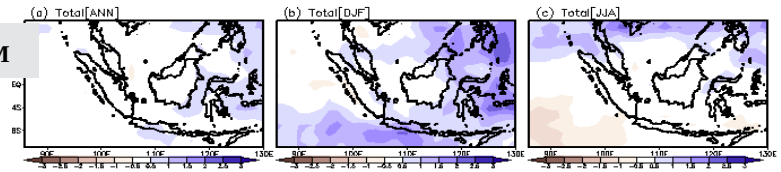
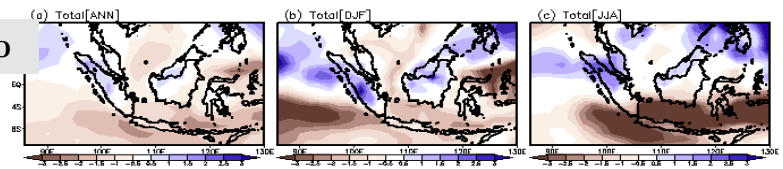


5 CNRM



6 CSIRO



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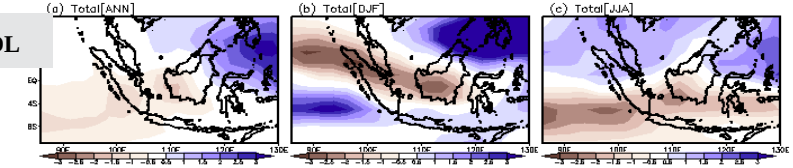

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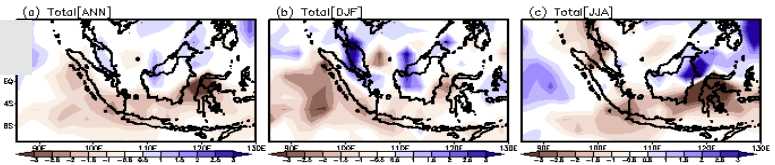
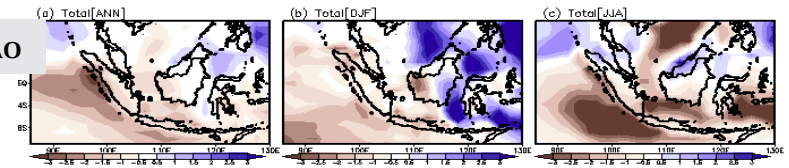


9 Had AO



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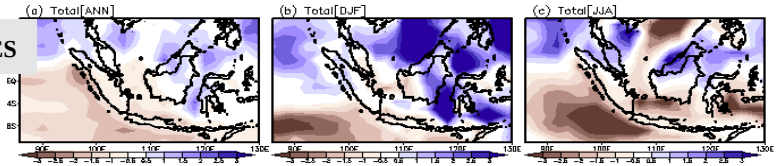
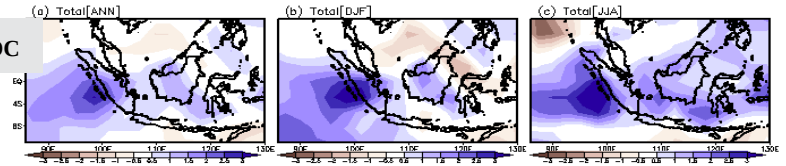
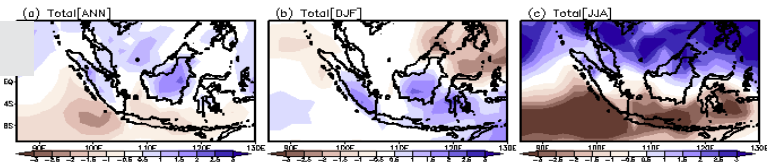


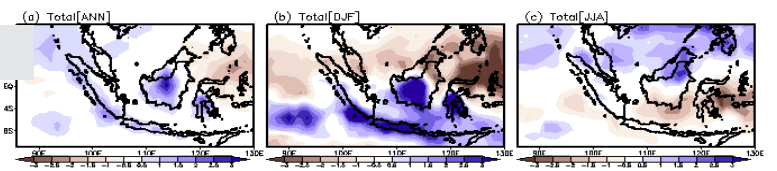
11MIROC



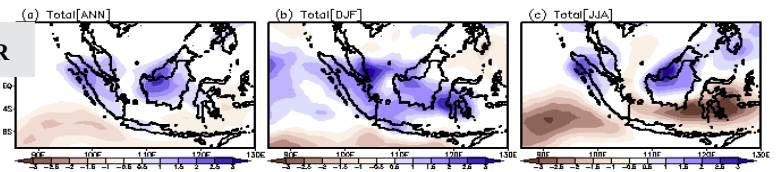
12 MPI



13 MRI



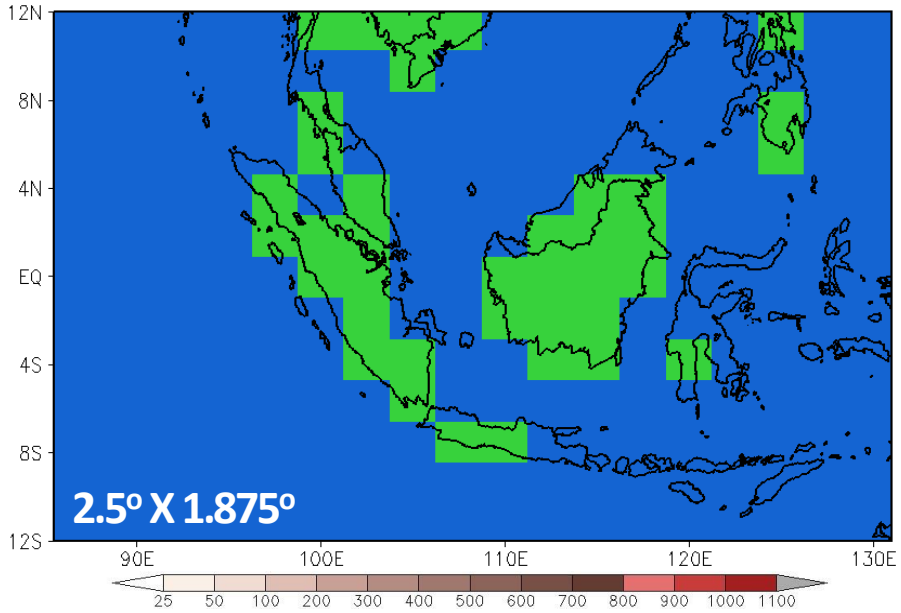
14 NCAR



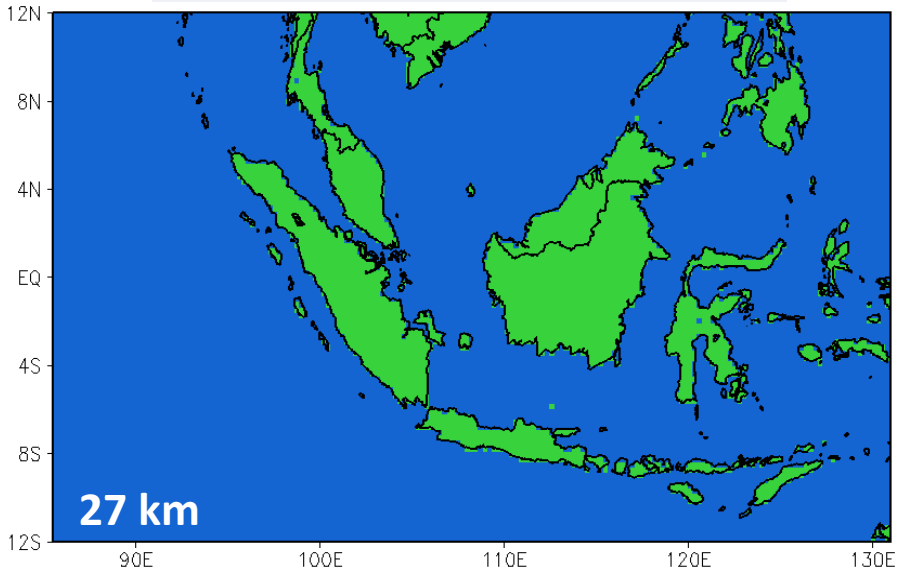
MRCM of the Maritime Continent

- MRCM Domain and Topography (27km)

CESM: Land-Sea Mask

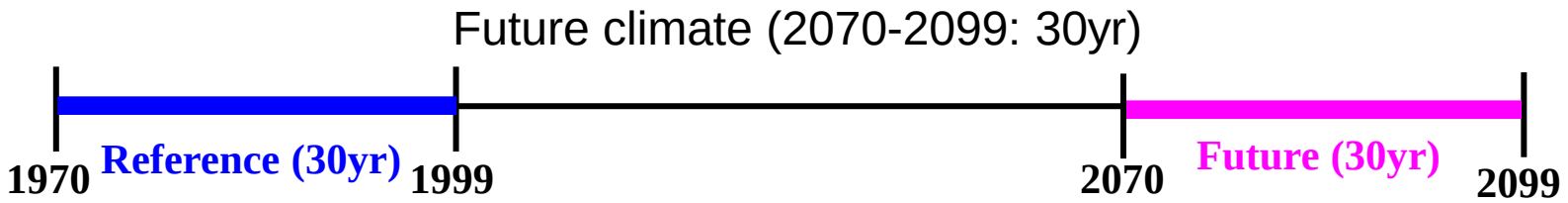


MRCM: Land-Sea Mask



Climate Change Experiments Design

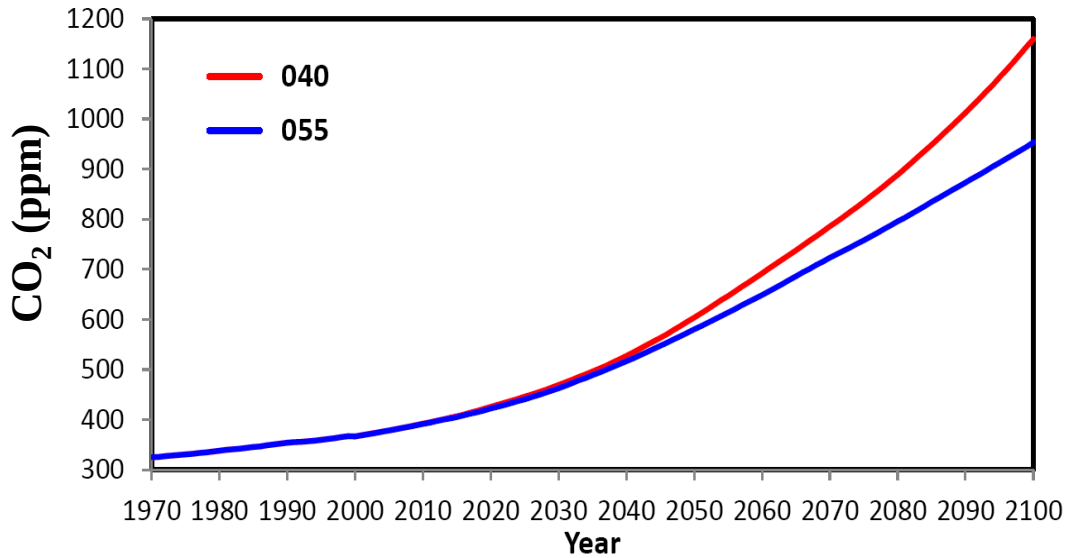
- MRCM Resolution: 27 km
- Initial & Boundary: Community Earth System Model (CESM) (2.5X1.875deg)
- Integration period: Reference climate (1970-1999: 30yr)



Future change signal = Future Simulation – Reference Mean

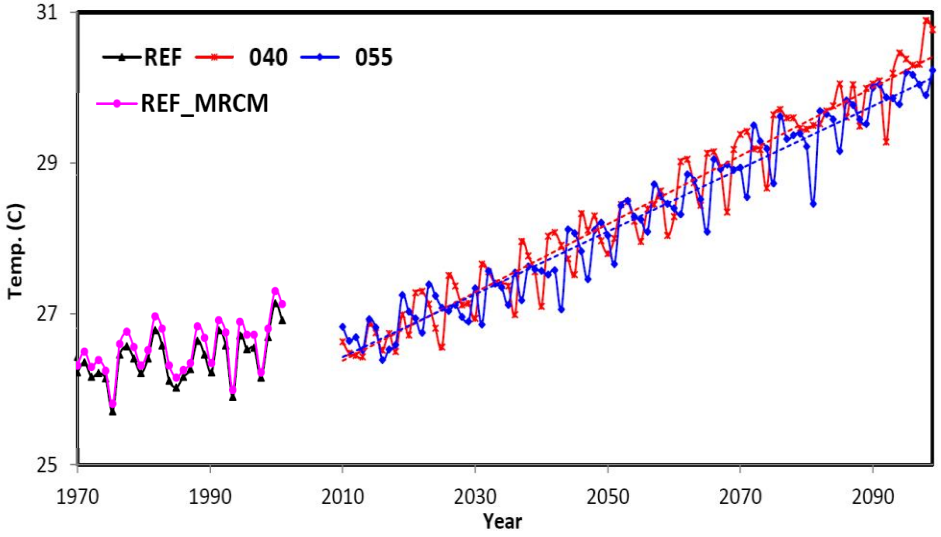
- Emission scenario : **040** & **055** from MIT Integrated Global System Model (IGSM)

[Sokolov et al. 2009]

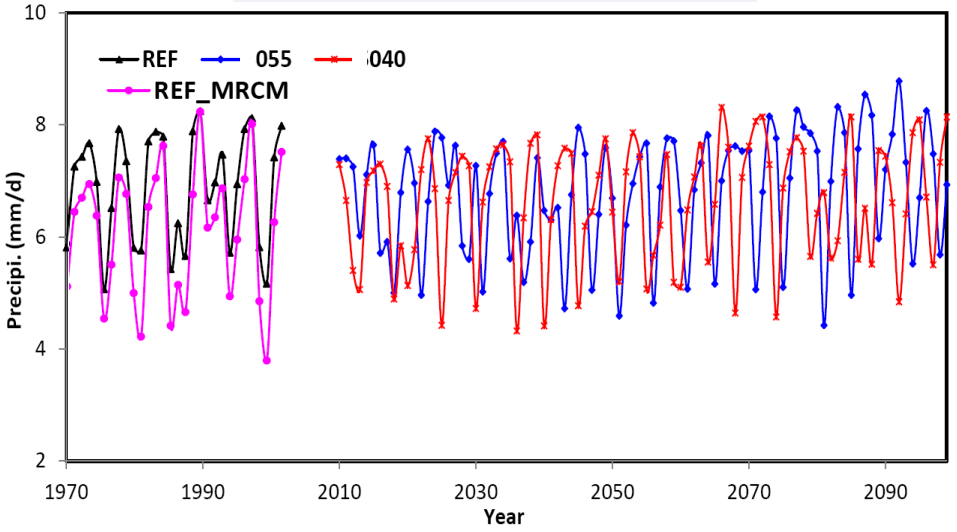


Temp. & Preci. Long-term Trend over MC

Temperature

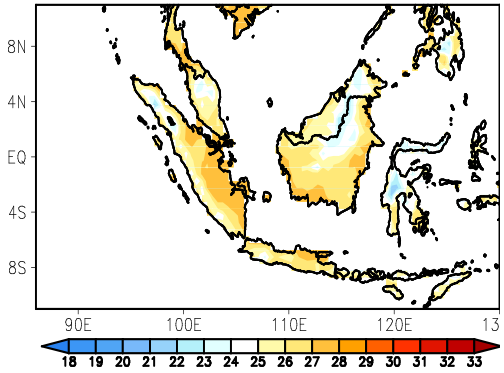


Precipitation

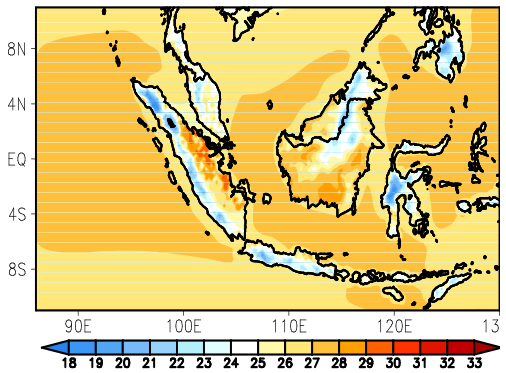


ANN Temp. & Preci. [Reference]

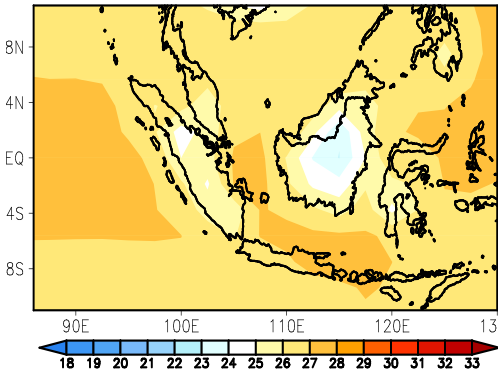
CRU [T]



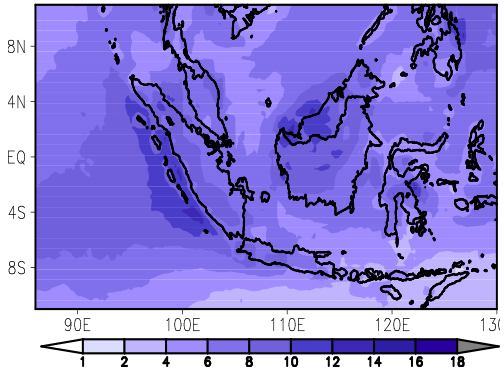
MRCM [T]



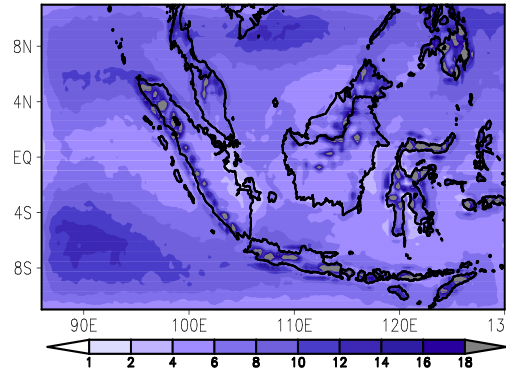
CESM [T]



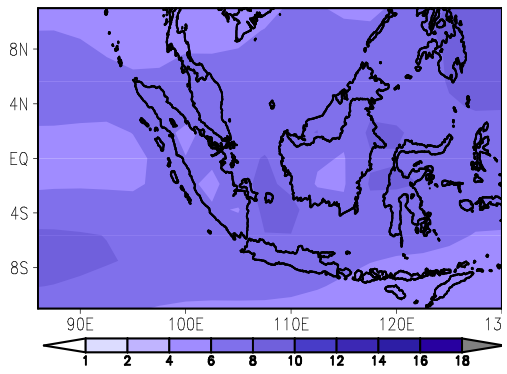
TRMM [P]



MRCM [P]



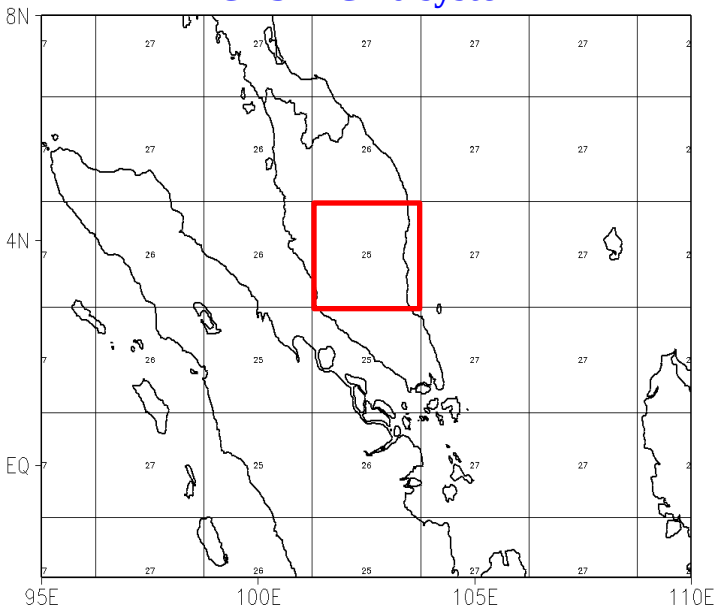
CESM [P]

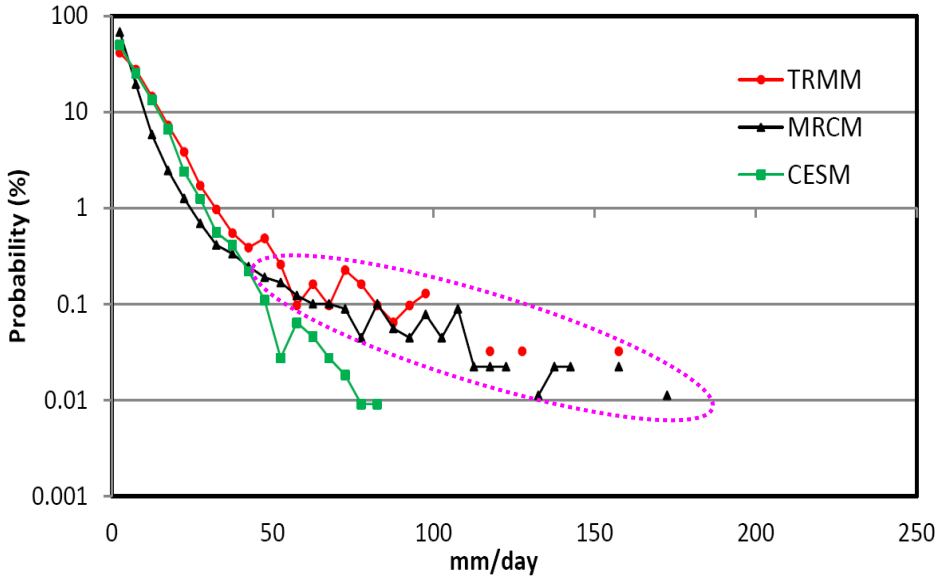


Frequency Distribution of Daily Precipitation

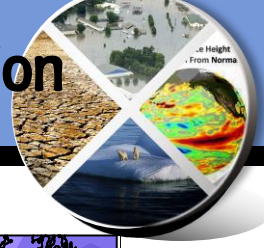
- Daily precipitation from MRCM driven CESM is capable of capturing some extreme values closer to TRMM observation compared CESM used as boundary condition.

CESM Grid system



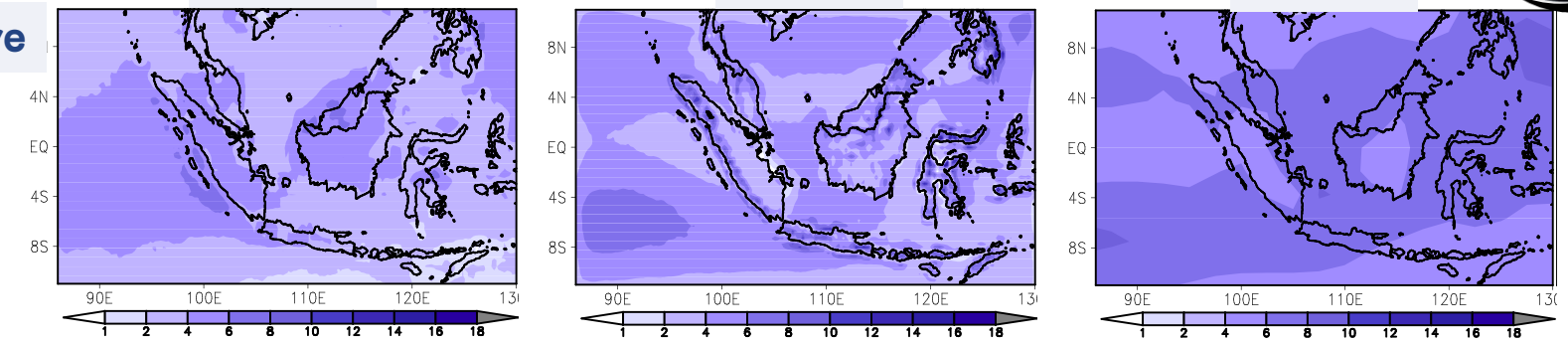


Physical Realism: Convective vs. Large-scale Precipitation



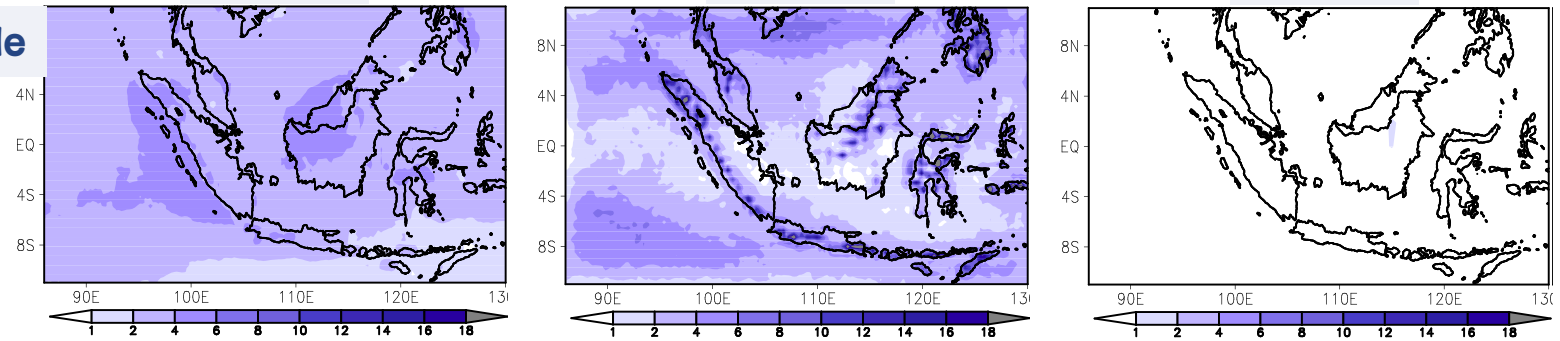
TRMM **MRCM** **CESM**

Convective

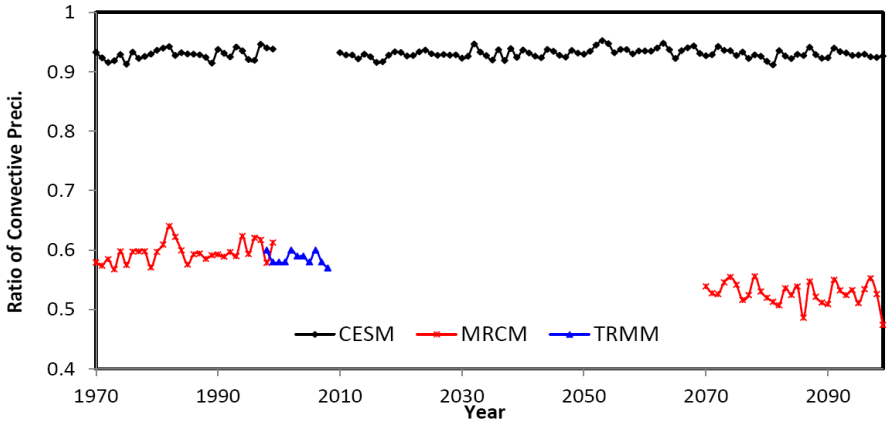


TRMM **MRCM** **CESM**

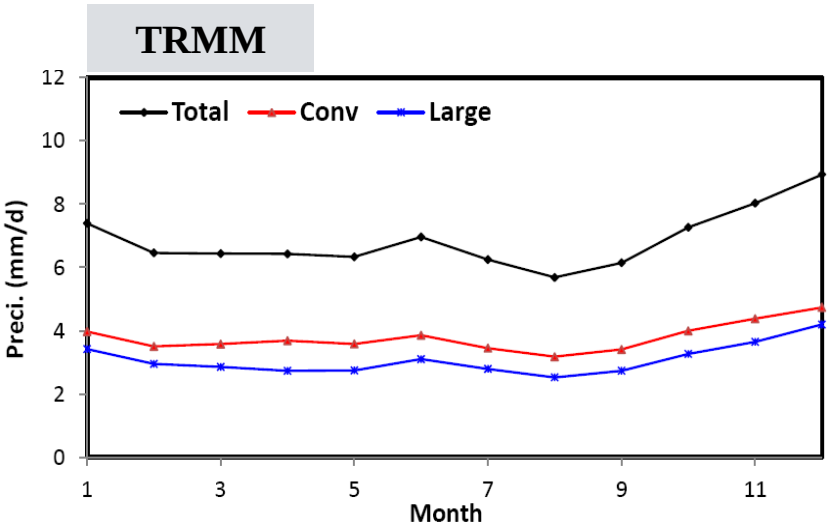
Large-scale

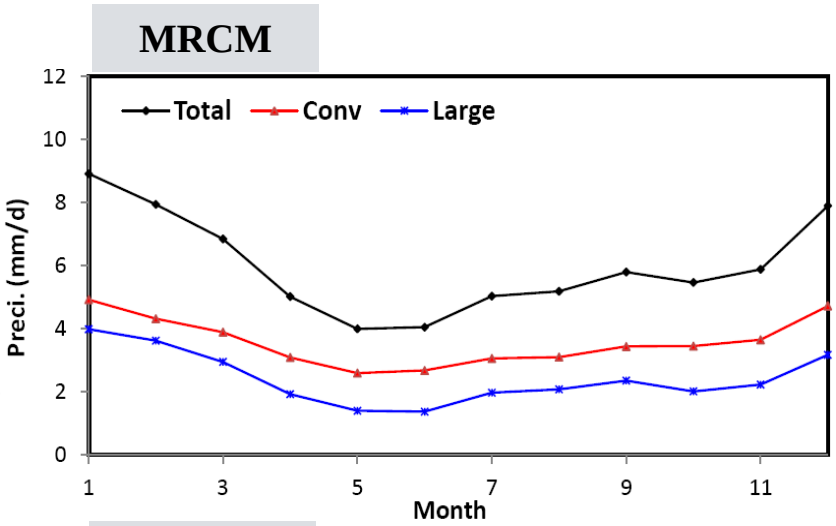


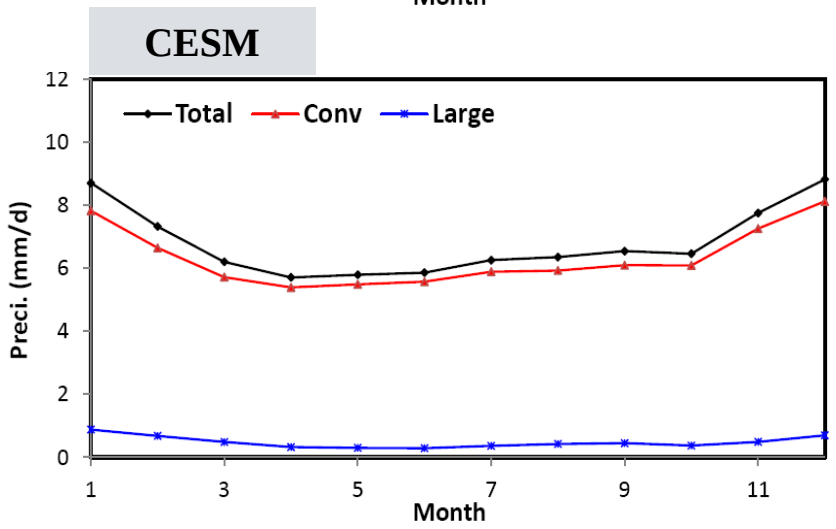
Annually area-averaged ratio of convective precipitation



Monthly Variation of Total & Convective & Large-scale P

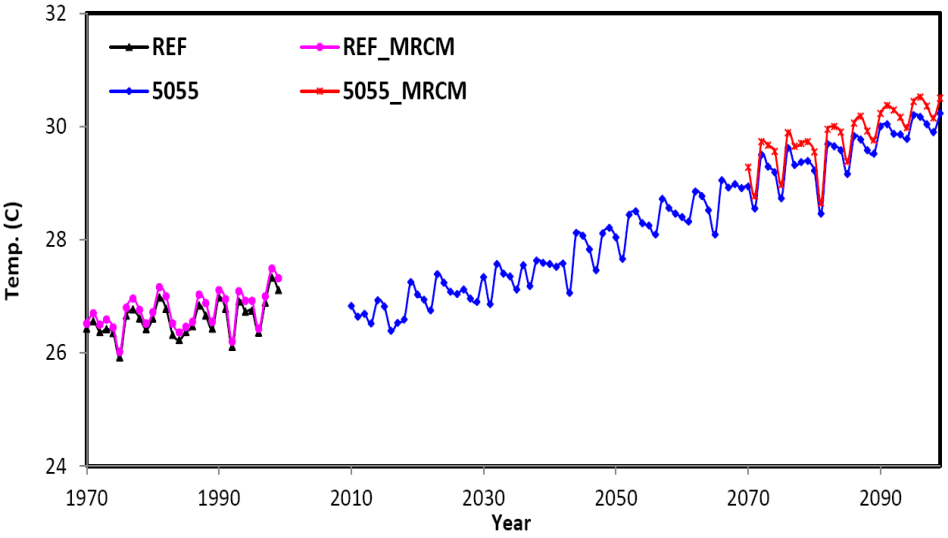




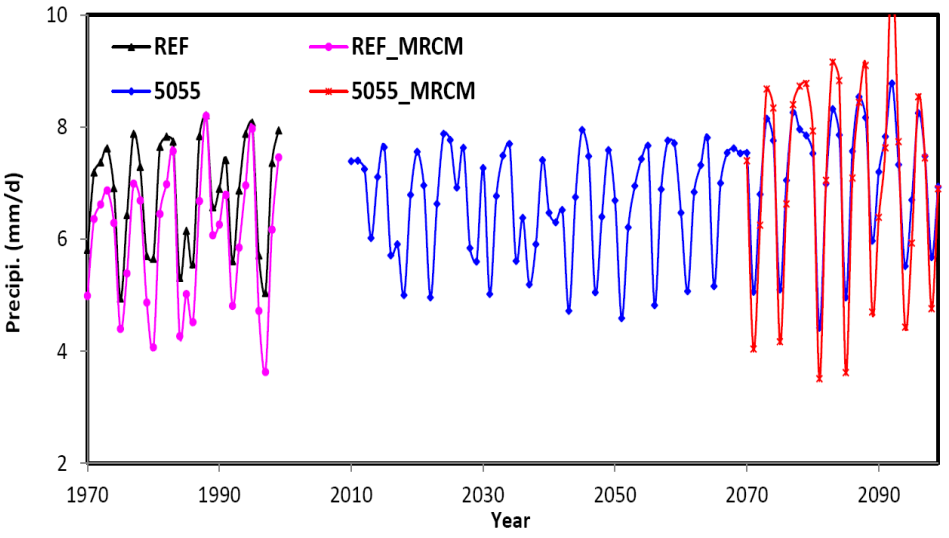


Temp. & Preci. Long-term Trend over MC

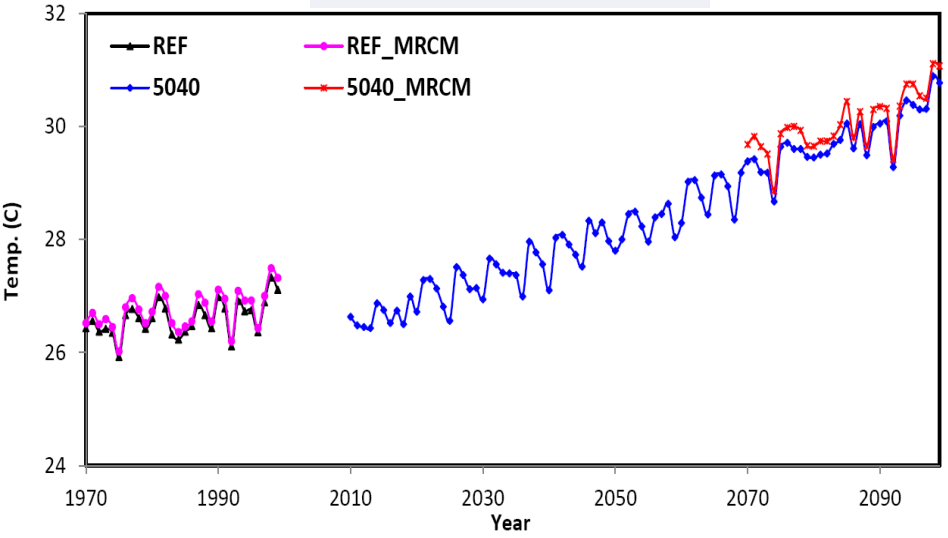
Temp. [055]



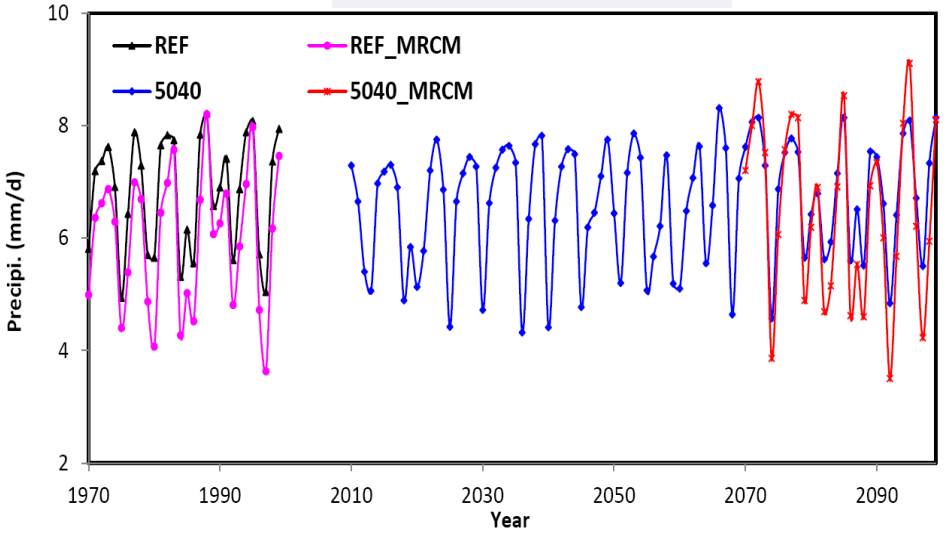
Preci. [055]



Temp. [040]



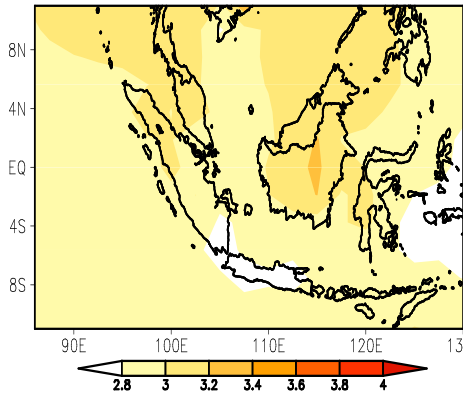
Preci. [040]



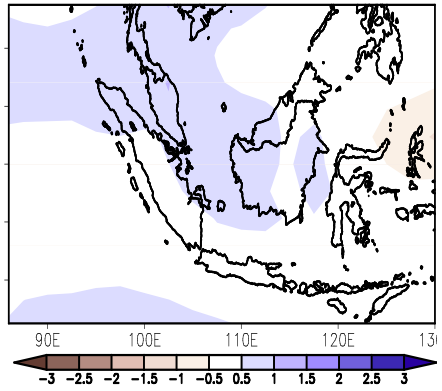
ANN Temp. & Preci. Changes

➢ CESM global projection

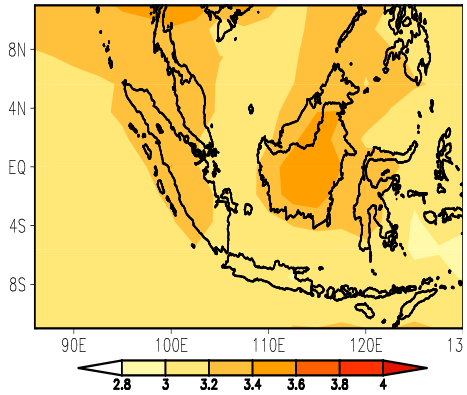
Temp. [055]



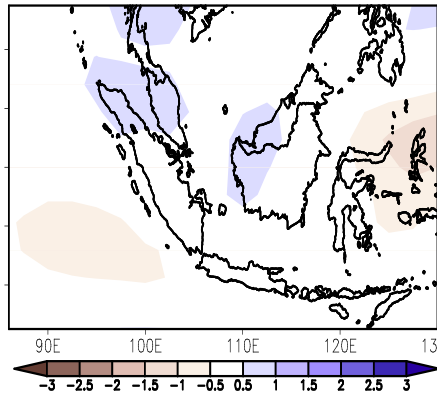
Preci. [055]



Temp. [040]

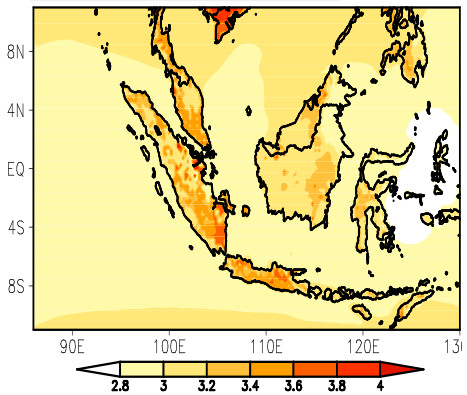


Preci. [040]

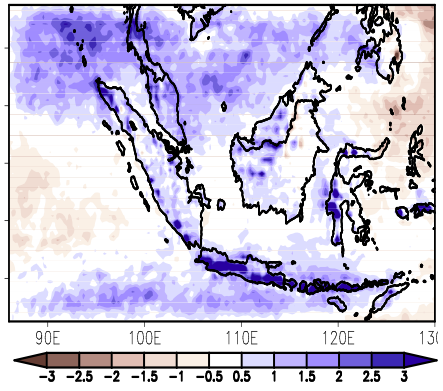


➢ MRCM regional projection

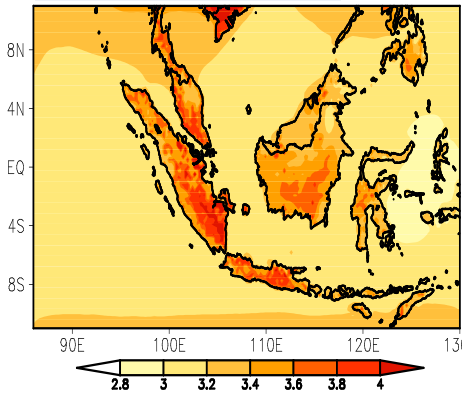
Temp. [055]



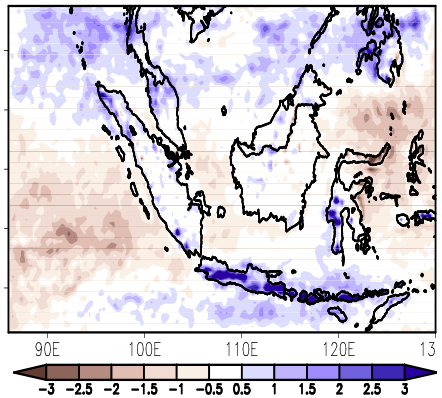
Preci. [055]



Temp. [040]



Preci. [040]



Frequency Distribution of Daily Precipitation

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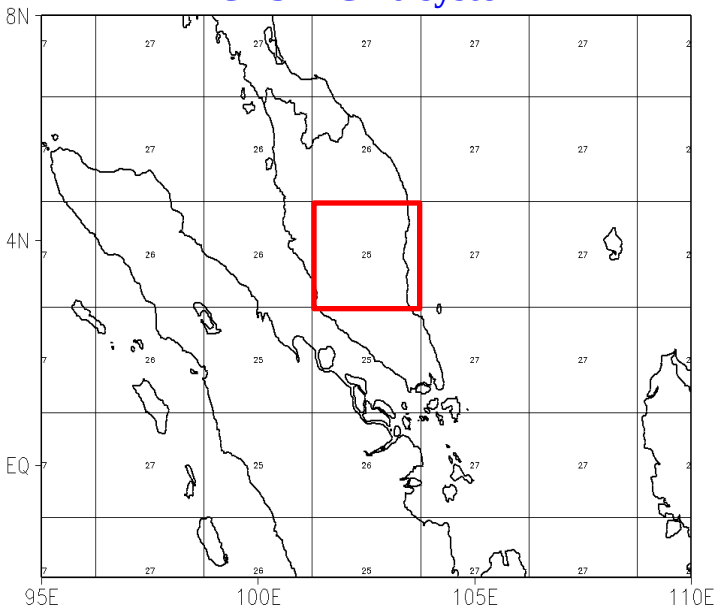
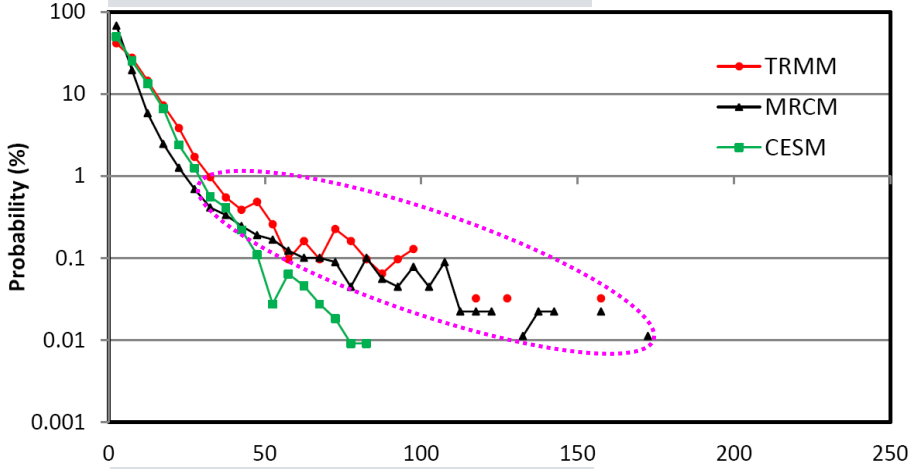
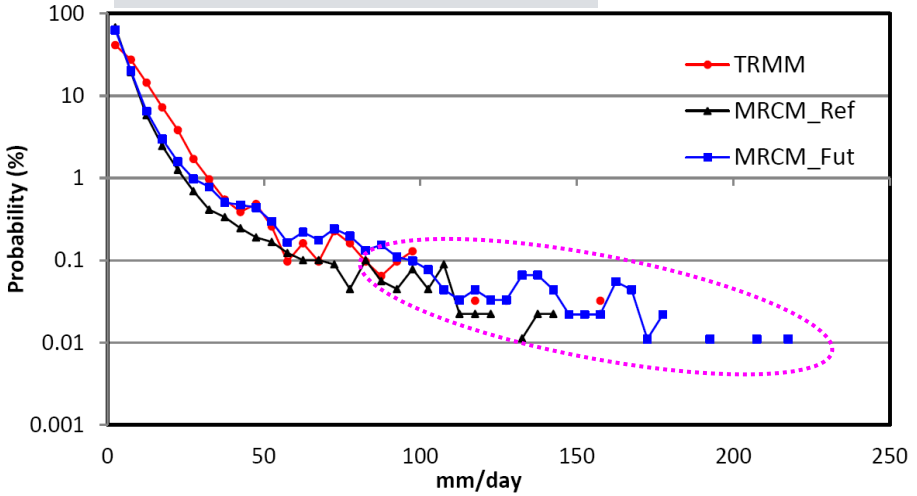
CESM Grid system



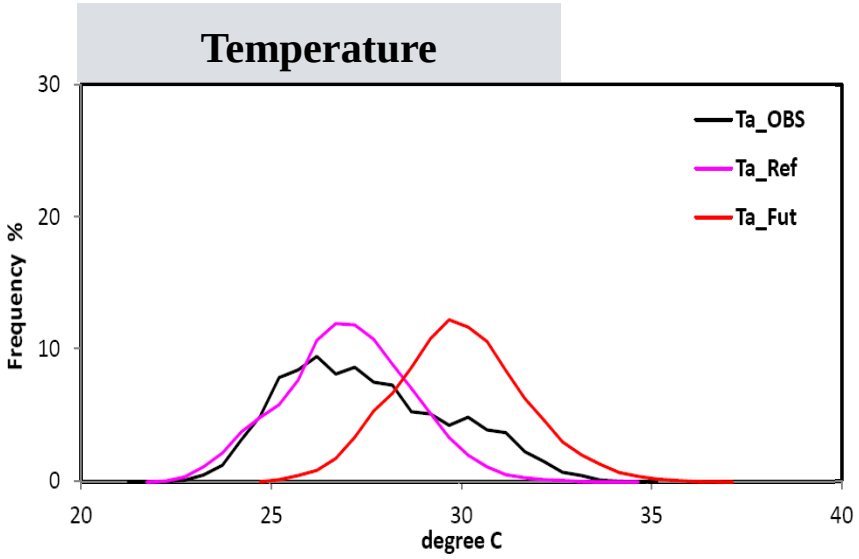
Reference [1970-1999]

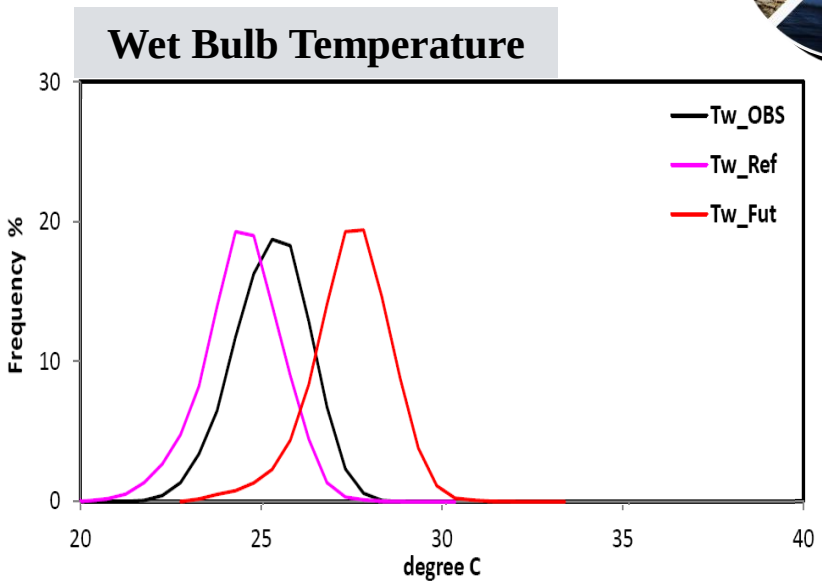


Future [2070-2099]



Frequency Distribution of 3-hour T and Wet Bulb





- Wet-bulb temperature is used as the indication to measure heat stress.
- The distribution shape of wet bulb temperature is narrower and more peaked than surface temperature with lower mean value. MRCM is capable of capturing these characteristics.
- In the future, both distributions are shifted toward warmer climate. This shift has an important implication because it accompanies the changes in the extreme events due to changes in the upper and lower tail bounds.