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Division of Environment and Sustainability




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Projections of rising heat stress over the western Maritime Continent from dynamically downscaled climate simulations

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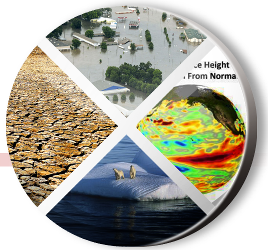
ABSTRACT

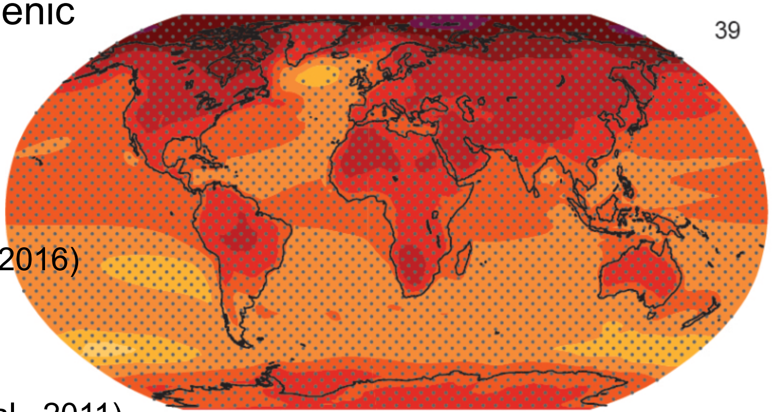
This study assesses the future changes in heat stress in response to different emission scenarios over the western Maritime Continent. To better resolve the region-specific changes and to enhance the performance in simulating extreme events, the MIT Regional Climate Model with a 12-km horizontal resolution is used for the dynamical downscaling of three carefully selected CMIP5 global projections forced by two Representative Concentration Pathway (RCP4.5 and RCP8.5) scenarios. Daily maximum wet-bulb temperature (TW_{max}), which includes the effect of humidity, is examined to describe heat stress as regulated by future changes in temperature and humidity. An ensemble of projections reveals robust pattern in which a large increase in temperature is accompanied by a reduction in relative humidity but a significant increase in wet-bulb temperature. This increase in TW_{max} is relatively smaller over flat and coastal regions than that over mountainous region. However, the flat and coastal regions characterized by warm and humid present-day climate will be at risk even under modest increase in TW_{max}. The regional extent exposed to higher TW_{max} and the number of days on which TW_{max} exceeds its threshold value are projected to be much higher in RCP8.5 scenario than those in RCP4.5 scenario, thus highlighting the importance of controlling greenhouse gas emissions to reduce the adverse impacts on human health and heat-related mortality.

High Susceptibility to Global Warming



❖ High signal-to-noise ratio for changes in surface temperature

- The temperature increase expected from anthropogenic emission forcing is large relative to the model uncertainty and the natural variability.
- The background "noise" induced by internal variability is lower in the tropics than elsewhere around the world. (Hawkins & Sutton 2009; Harrington et al. 2016)
- The low-latitude countries around tropical areas exhibit *the most imminent and robust emergence of hot temperature extremes*. (King et al., 2015; Mahlstein et al., 2011)



[Adapted from IPCC AR5]

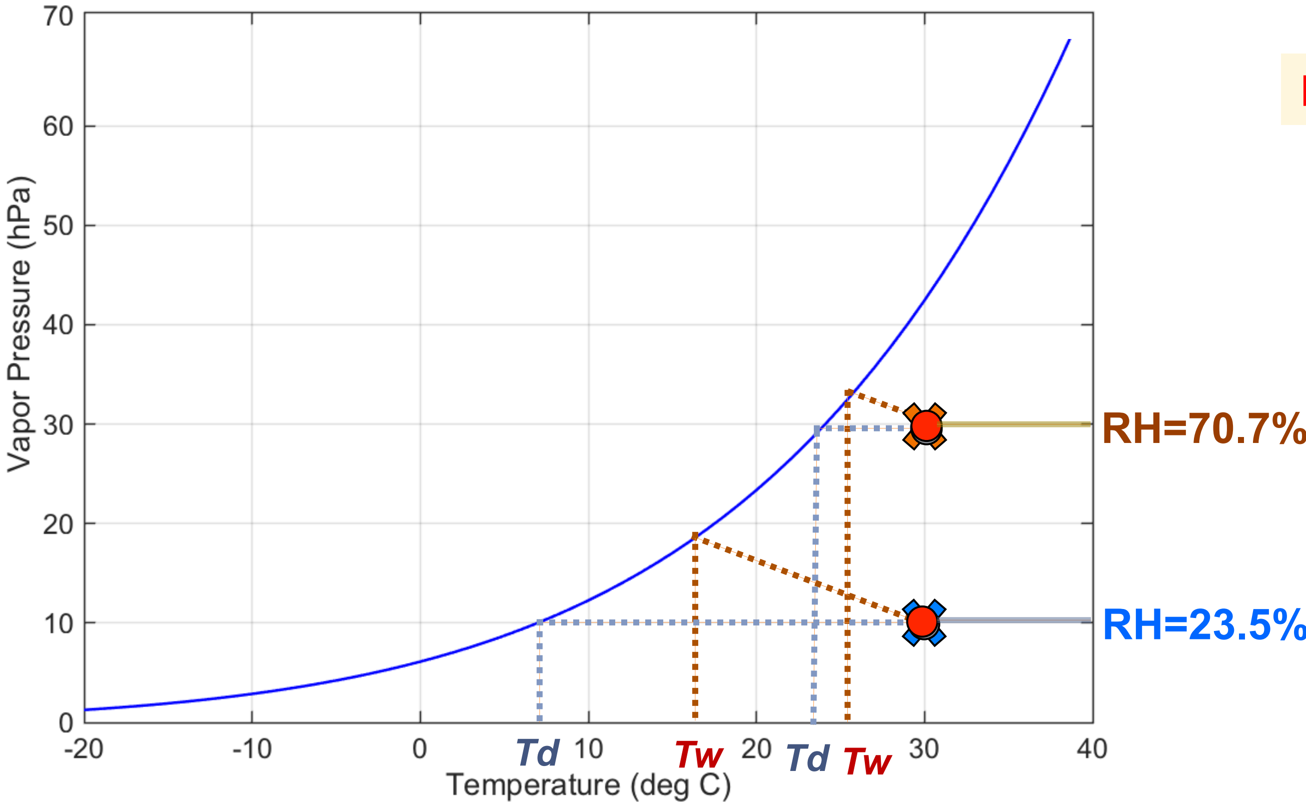
❖ Humid and hot climate in the present day

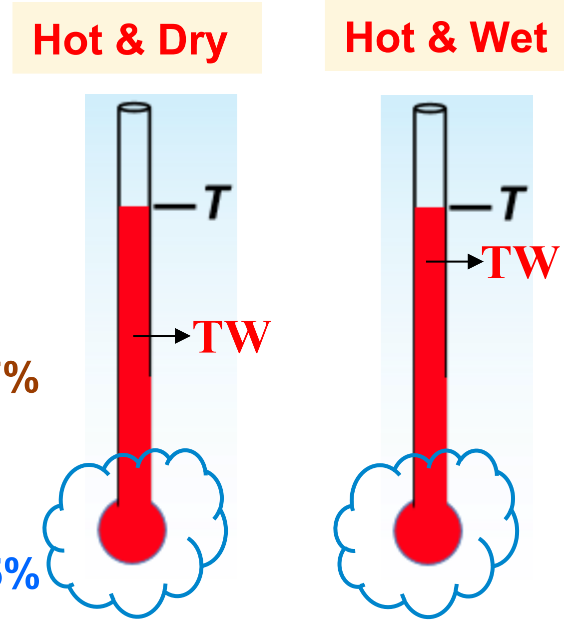
- The humid and hot tropical climate is particularly vulnerable to the increasing temperature because even *modest warming may exceed the critical level of heat stress* and become more dangerous and intolerable.
- Heat events may worsen more in humid tropical regions even if it warms less than the global average, due to greater absolute humidity increases.

❖ Low socioeconomic status

- Poor populations in areas of low socioeconomic status will be more likely to be adversely affected by extreme heat events.
- The *capacity to adopt and manage the risks of extreme heat is often limited* in the tropics.

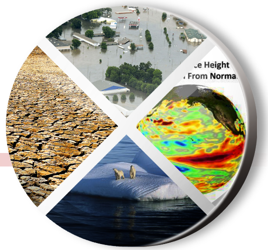
Concept of Wet-Bulb Temperature





- Wet-bulb temperature is particularly useful in human health applications associated with heat stress, because evaporation is the primary means by which bodies cool in hot environments; thus, when Tw is high, evaporative cooling is restricted and the body core temperature may rise (Davis et al. 2016).
- ***35°C*** is the threshold value of TW beyond which any exposure for more than 6-hour would likely be intolerable even for the fittest of humans resulting in hyperthermia. In current climate, TW rarely exceeds ***31°C***.

Various Metrics of Moist Temperature



❖ Wet-bulb temperature (T_w)

- Tw is the temperature at which air becomes saturated by evaporation at constant pressure.
- Tw is empirical value to which a wetted thermometer will drop under vaporation.
- Tw is particularly useful in human health applications associated with heat stress, because evaporation is the primary means by which bodies cool in hot environments.

$$T_w = T\,\mathrm{atan}[0.151\,977(\mathrm{RH\%} + 8.313\,659)^{1/2}] + \mathrm{atan}(T + \mathrm{RH\%}) - \mathrm{atan}(\mathrm{RH\%} - 1.676\,331) + 0.003\,918\,38(\mathrm{RH\%})^{3/2}\,\mathrm{atan}(0.023\,101\mathrm{RH\%}) - 4.686\,035.$$

[From Stull 2011]

$$T_w = T - (T - T_d) * (0.12 + 0.008 * T)$$

[From Anderson 1968]

❖ Apparent temperature (T_{app})

- T_{app} combines temperature and humidity into a single index for the assessment of human comfort in the warm season.

$$T_{app} = 2.719 + 0.994T_a + 0.016(T_d)^2$$

(where, T_a dry-bulb temperature)
(where, T_d dew-point temperature)

❖ Wet-bulb globe temperature (WBGT)

- WBGT is the empirical combinations of T_w, T_a, and T_g to measure heat stress.

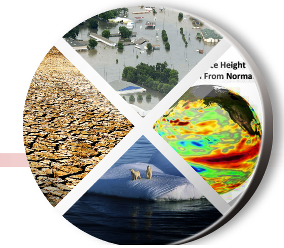
$$\mathrm{WBGT} = 0.7T_W + 0.2T_g + 0.1T_a$$

(where, T_g globe thermometer temperature)
(where, T_w wet-bulb temperature)

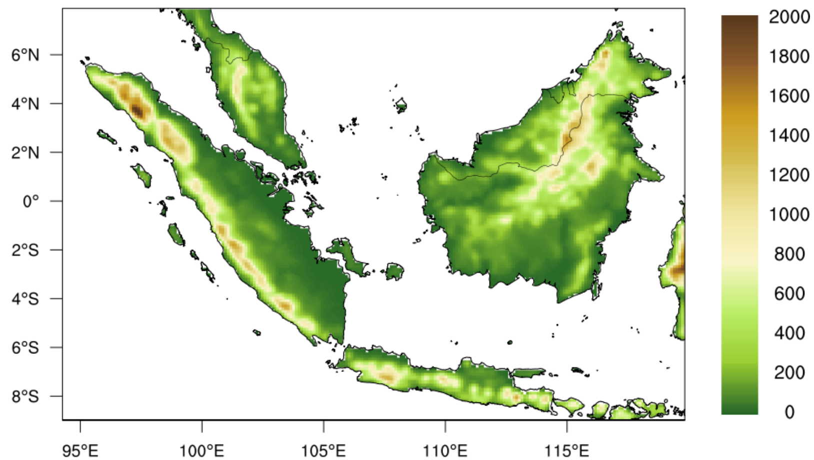
$$\mathrm{WBGT} = 0.567T_a + 0.393e + 3.94$$

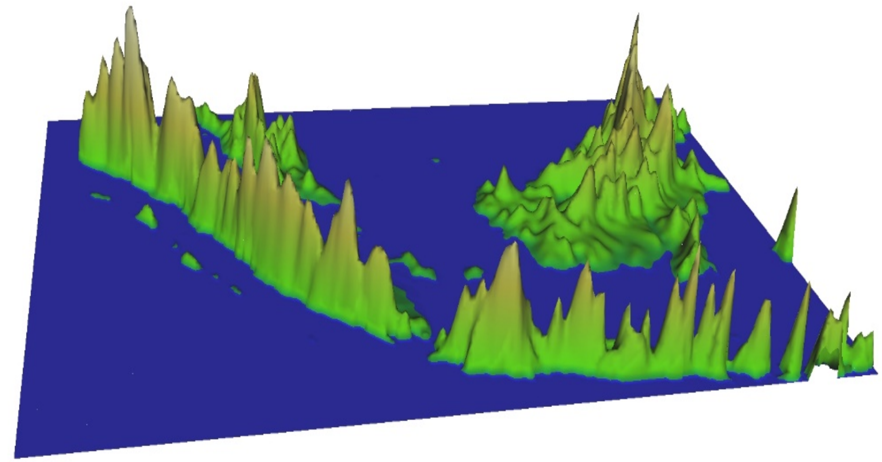
(where, e: vapor pressure)

Experimental Design



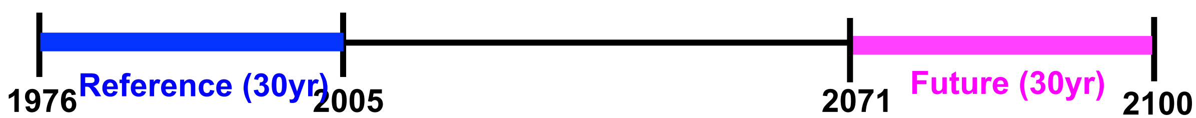
❖ MIT Regional Climate Model (MRCM) with 12 km





❖ Integration Period : Reference Climate (1976-2005:30yr) - Historical

: Future Climate (2071-2100:30yr) – RCP4.5 and RCP8.5



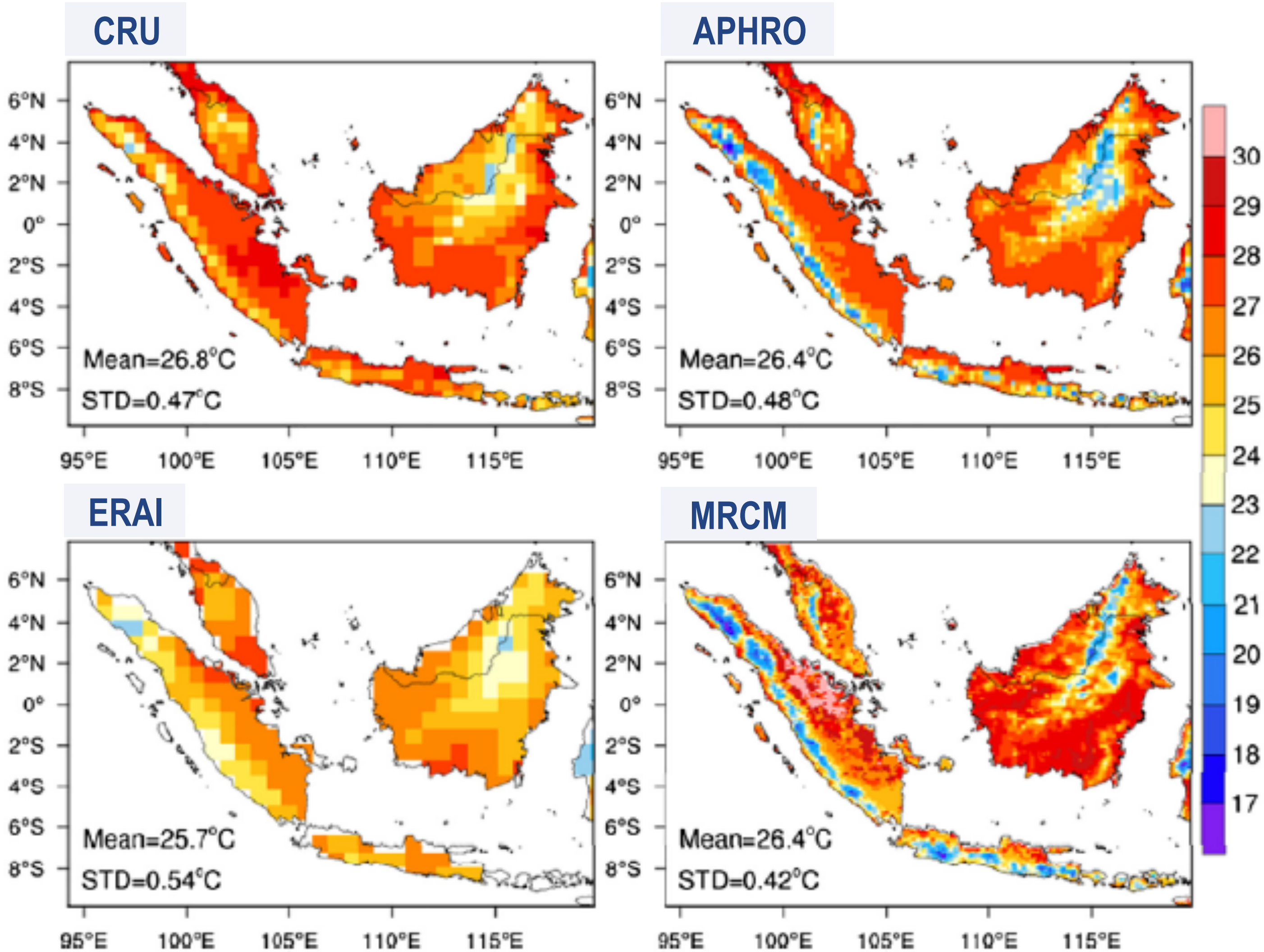
❖ Initial & Boundary Condition: CCSM4, MPI-ESM-MR and ACCESS

CCSM	MPI	ACCESS
Reference	Reference	Reference
RCP4.5	RCP4.5	RCP4.5
RCP8.5	RCP8.5	RCP8.5

- 19 GCMs selection based on overall performance metrics over the continental-scale regions including Southeast Asia [McSweeney et al. 2015]
- Evaluation of how reasonably the models simulate rainfall, temperature, wet-bulb temperature, and humidity.

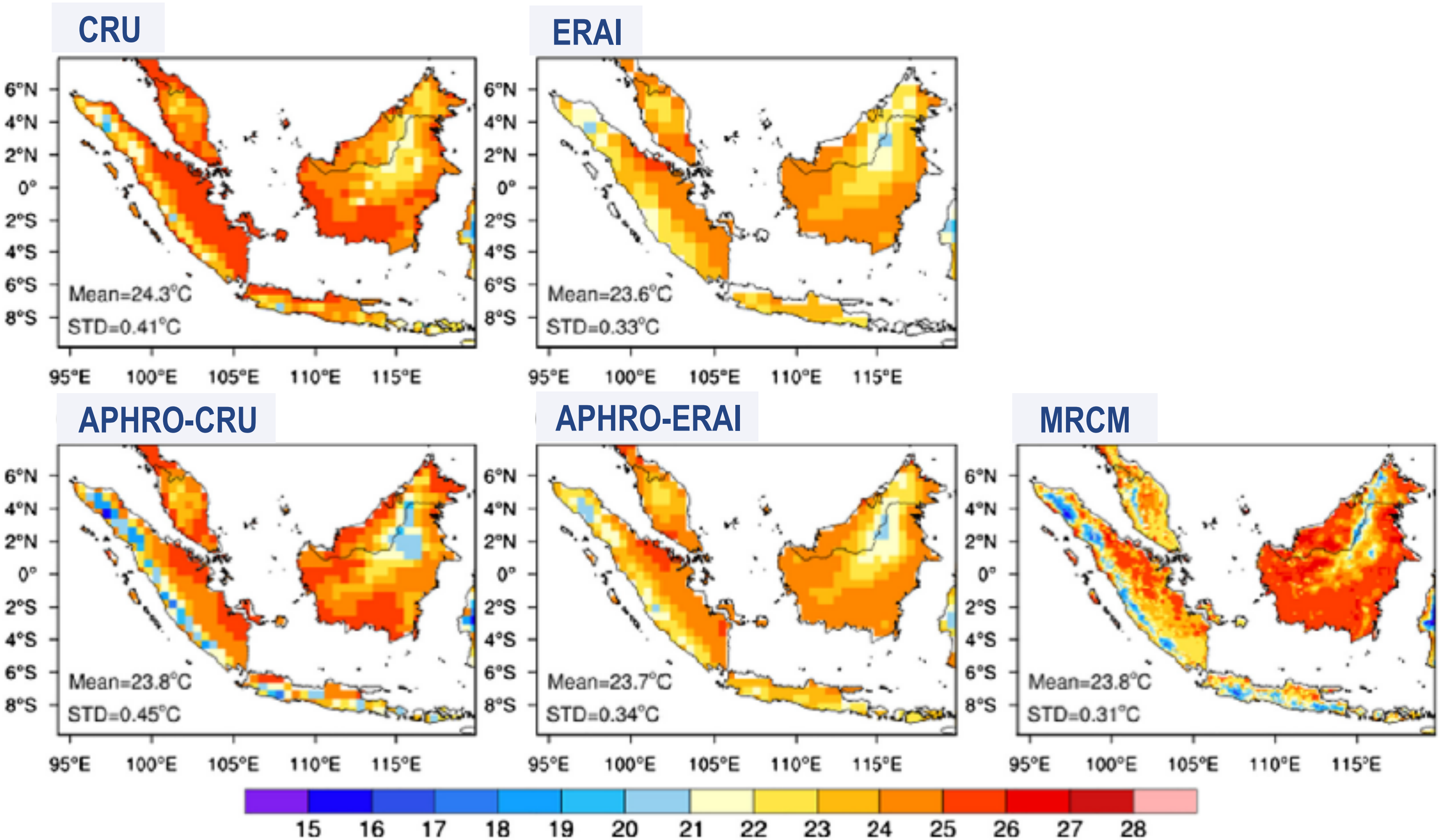
MRCM Validation: Mean Temperature in May

❖ Spatial distribution of 30-year climatological mean temperature in May



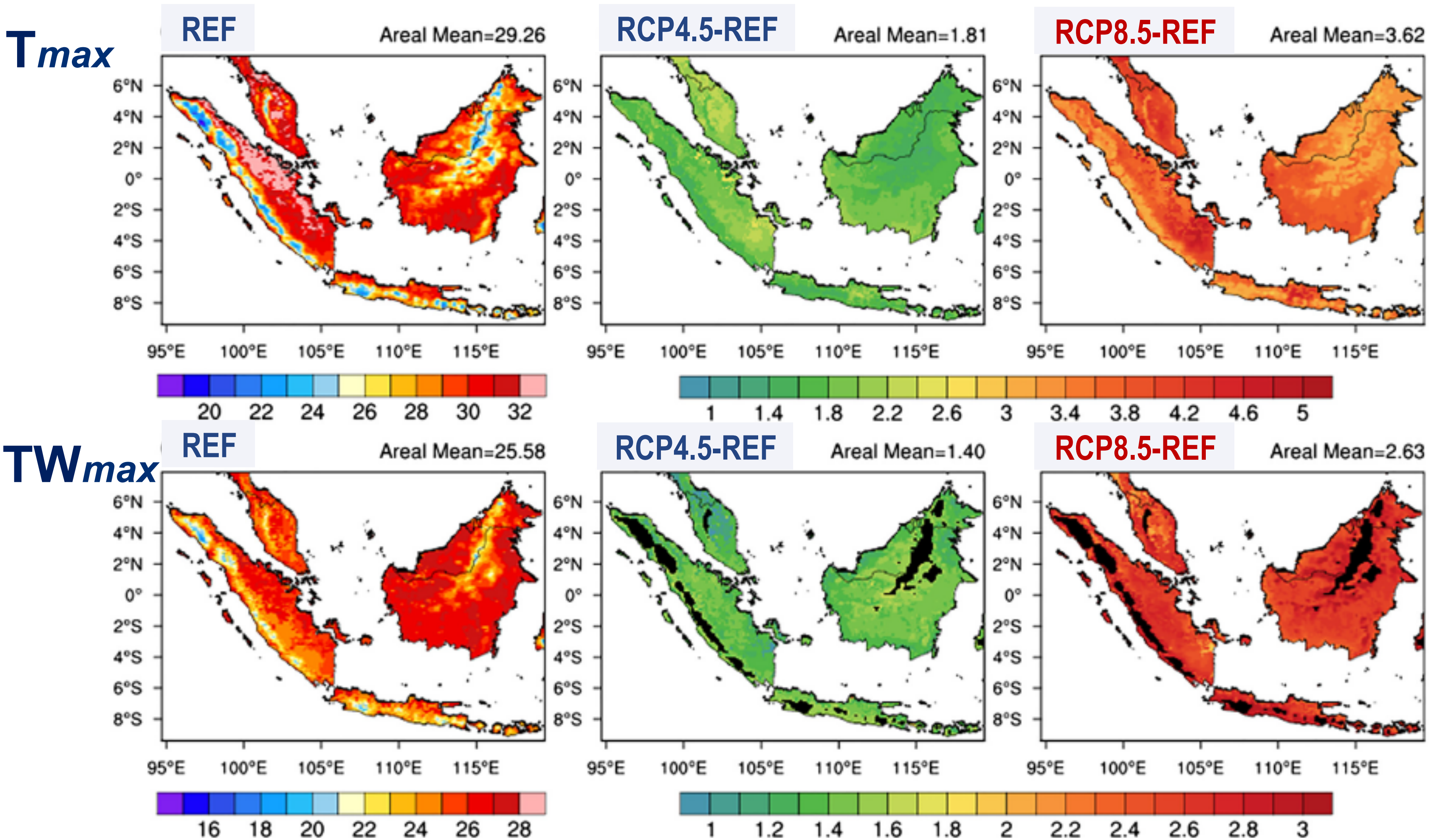
MRCM Validation: Mean Wet-bulb Temp. in May

❖ Spatial distribution of 30-year climatological mean wet-bulb temperature in May



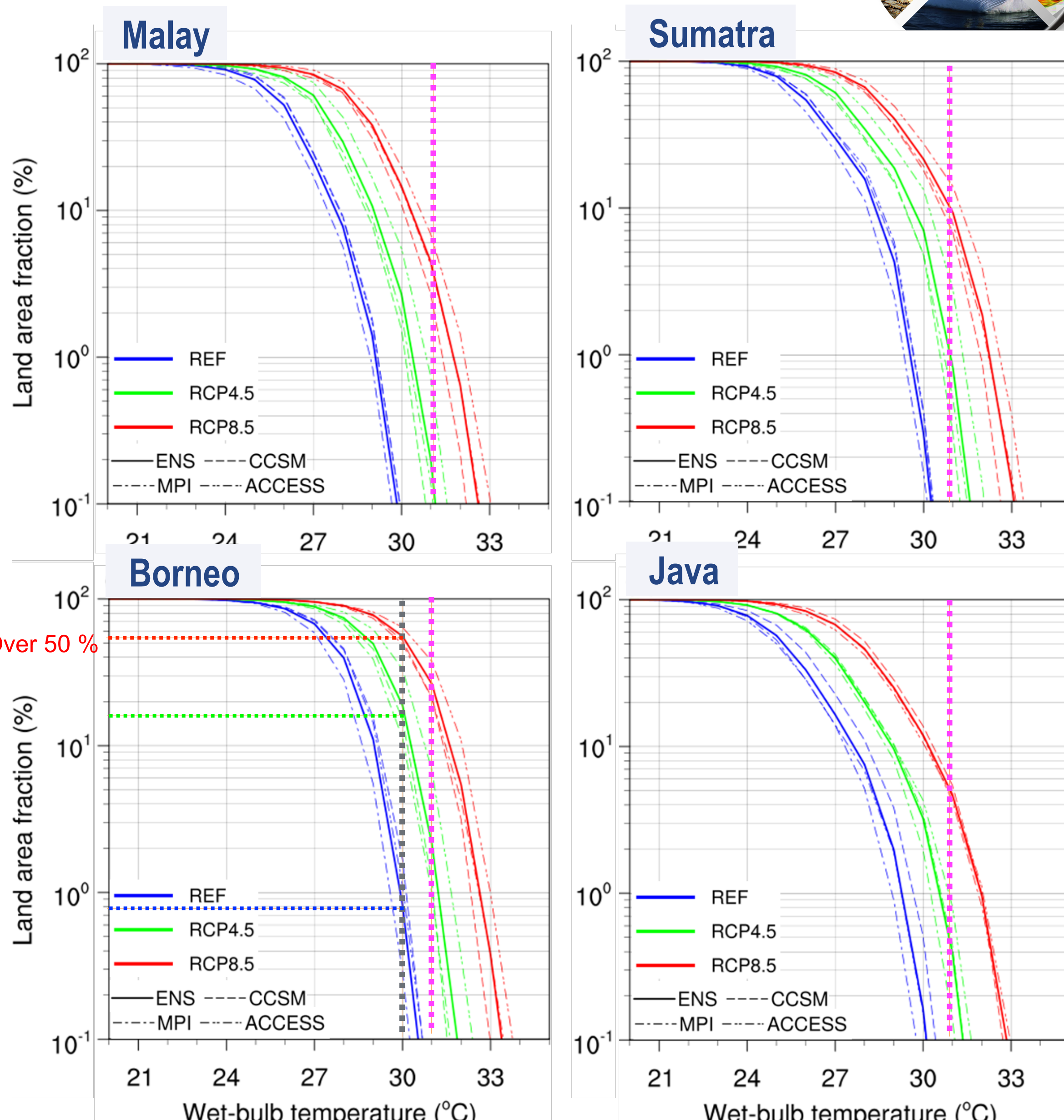
Changes in T_{max} & TW_{max} in May

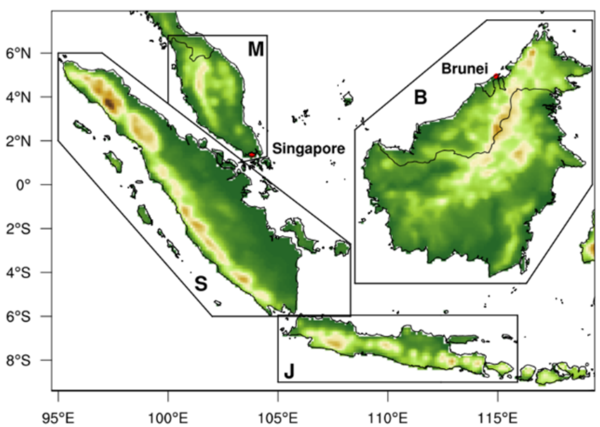
❖ Spatial distribution of 30-year climatological mean wet-bulb temperature in May



Land Area Fractions Exposed to TW*max*

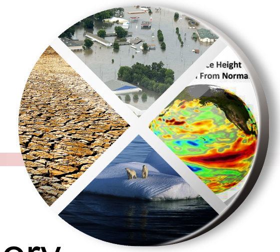
- Land area fractions (%) exposed to TW*max* values at least once during reference and future period.





[Maskout the regions above 650m]

Likelihood of Heat Risk: TW*max*



- Global warming pushes TW*max* into an area of severe risk level.
- Borneo island under RCP8.5 scenario appear in the “extreme danger” risk category.

Malay

Temperature

°C	28.9	30.0	31.1	32.2	33.3	34.4	35.6
°F	84	86	88	90	92	94	96
65	23.2	24.2	25.2	26.2	27.3	28.3	29.3
70	24.0	25.1	26.1	27.2	28.2	29.2	30.3
75	24.8	25.9	27.0	28.0	29.1	30.1	31.2
80	25.6	26.7	27.8	28.9	30.0	31.0	32.1
85	26.4	27.5	28.6	29.7	30.8	31.9	32.9
90	27.2	28.3	29.4	30.5	31.6	32.7	33.8
95	27.9	29.0	30.1	31.2	32.4	33.5	34.6

Relative Humidity(%)

Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Borneo

Temperature

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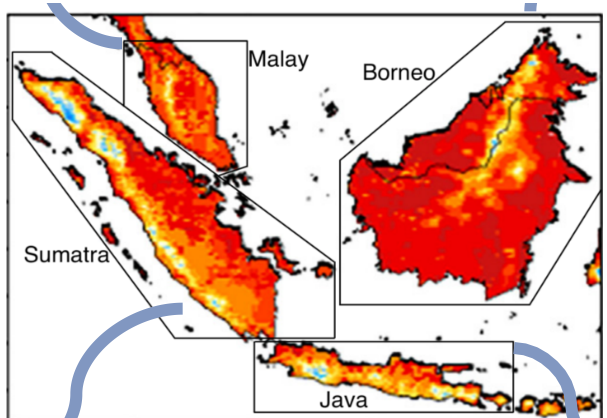
Relative Humidity(%)



Sumatra

Temperature

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Relative Humidity(%)

Caution
Extreme Caution
Danger
Extreme Danger

Ref
RCP4.5
RCP8.5

Java

Temperature

°C	28.9	30.0	31.1	32.2	33.3	34.4	35.6
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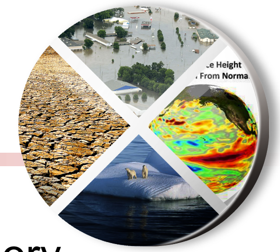
Relative Humidity(%)



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Relative Humidity(%)

Borneo

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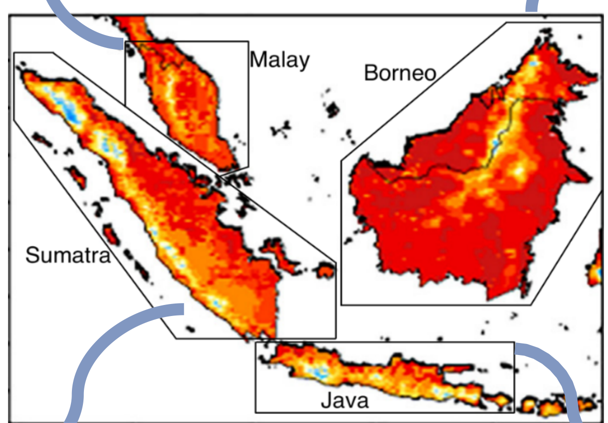

Sumatra

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Relative Humidity(%)

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Relative Humidity(%)

Caution
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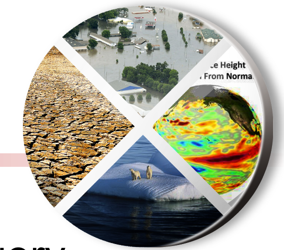
Extreme Danger

Ref
RCP4.5
RCP8.5

Likelihood of Heat Risk: TW*max*



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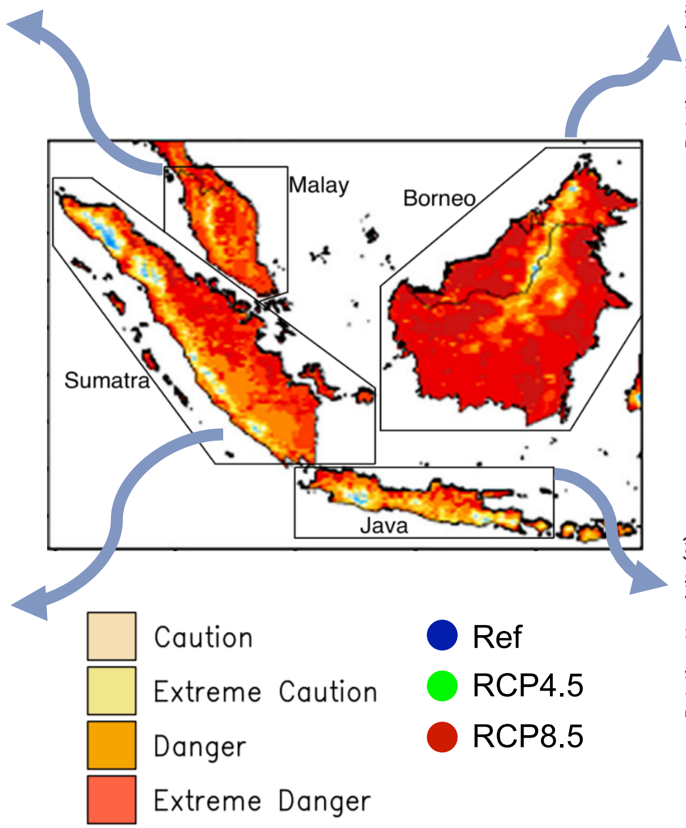

Sumatra

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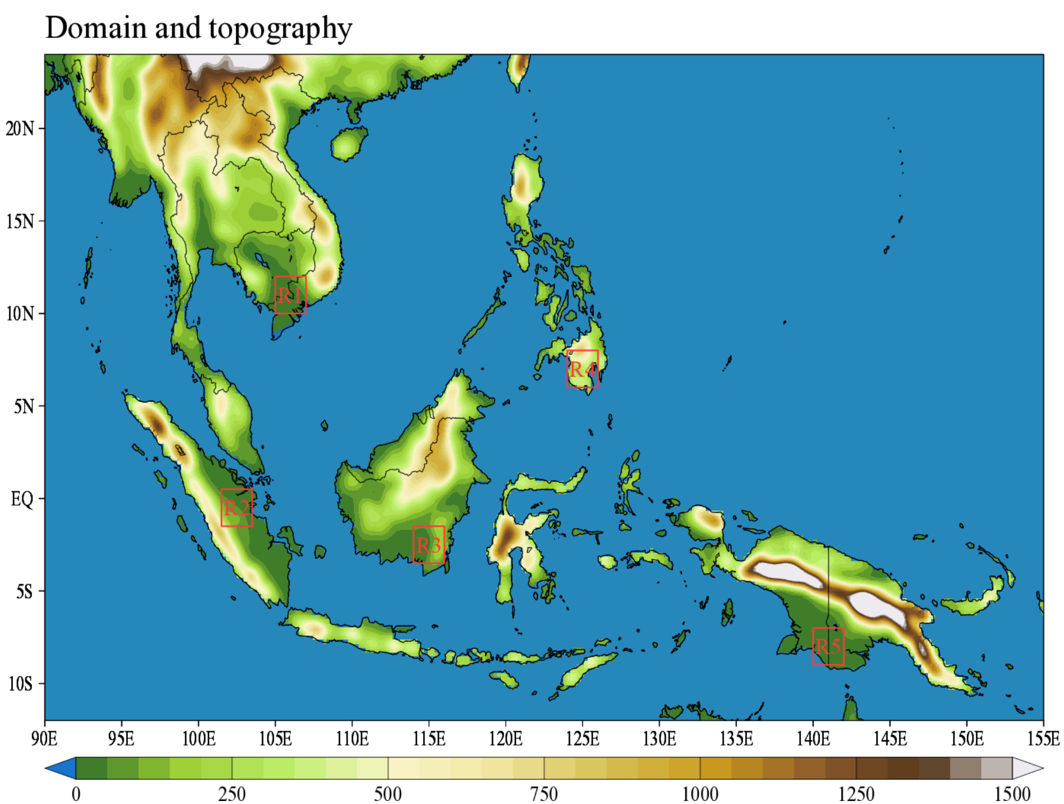
Basic Performance of CORDEX-CORE Simulation over Southeast Asia♪



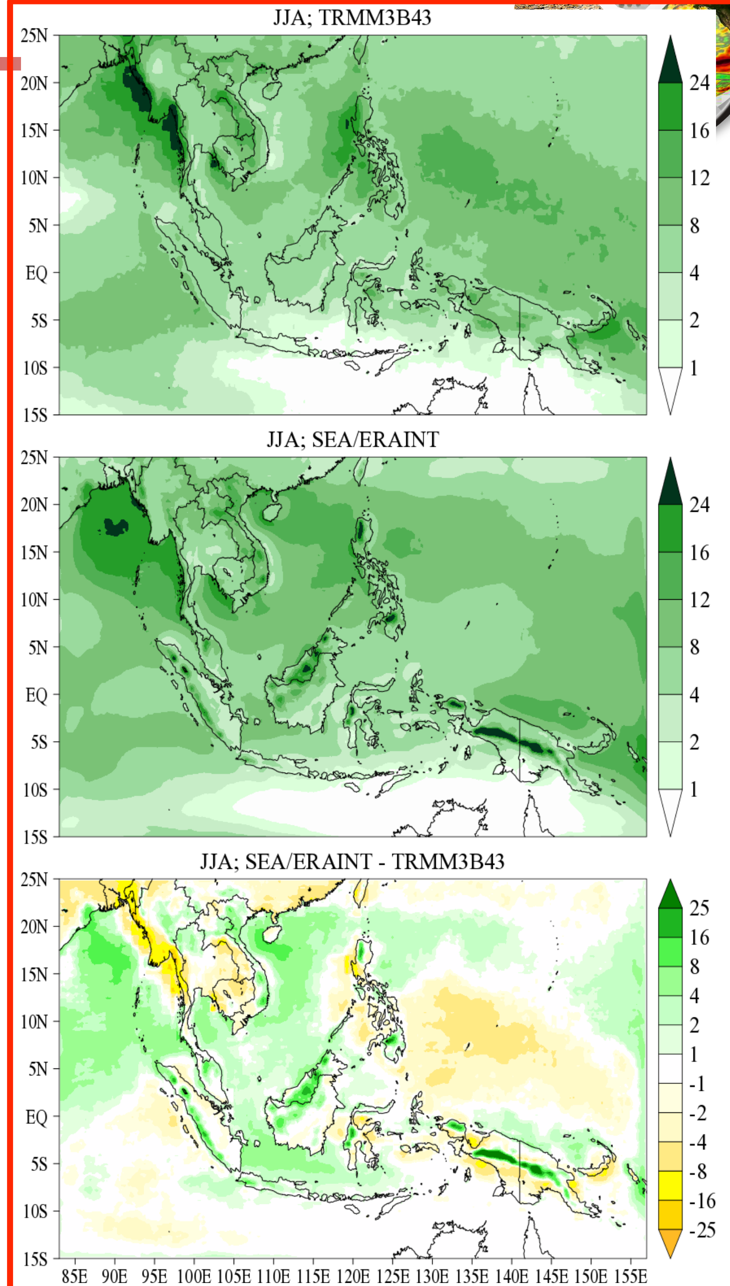

Domain & Topography

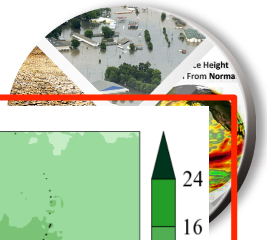


❖ Three GCMs Reference simulation (1970-2005)

: NorESM, MPI-ESM-MR, HadGEM

ICBC: ERAInterim



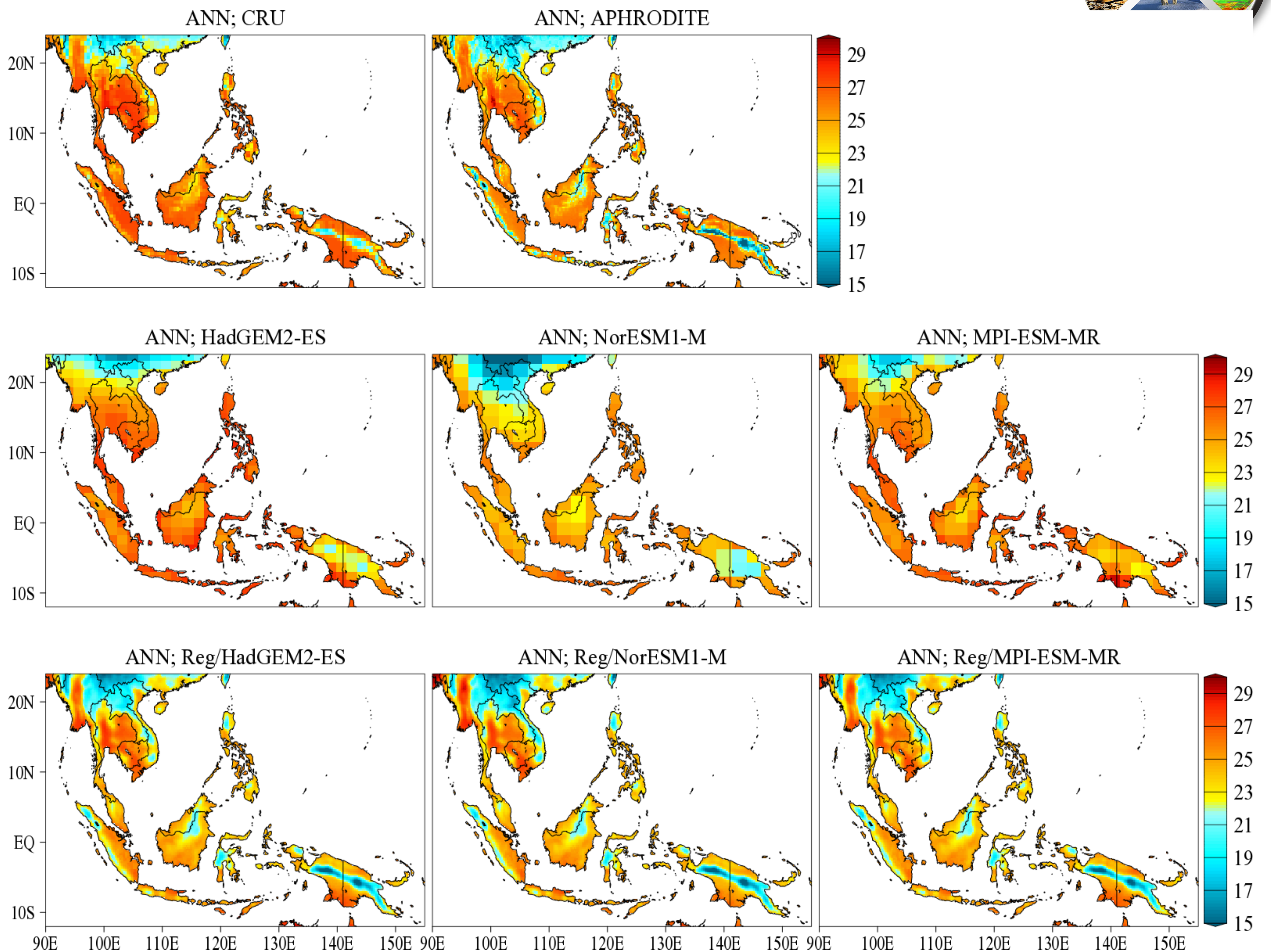


ANN Temperature

OBS

GCM

RegCM



ANN Precipitation

OBS

GCM

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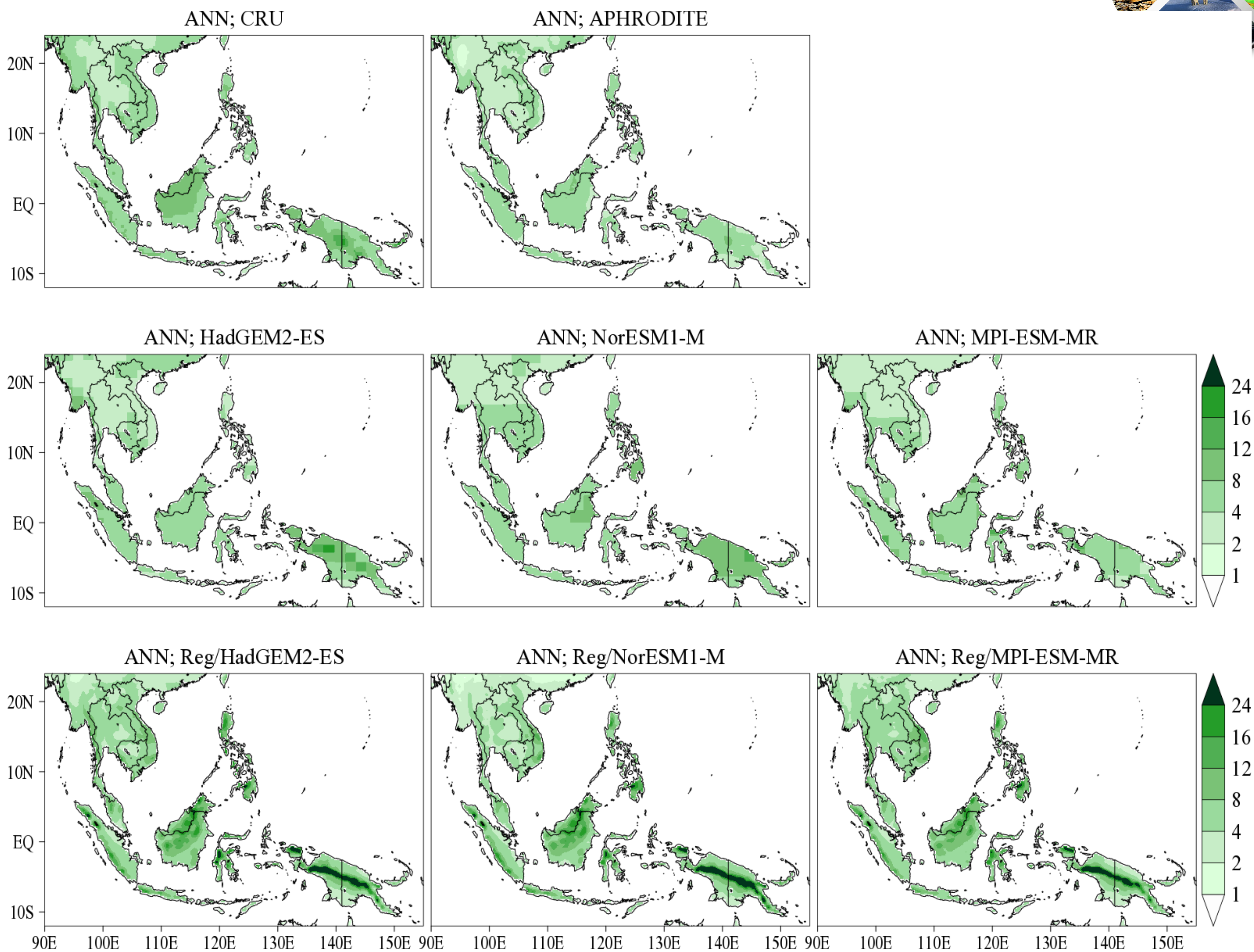
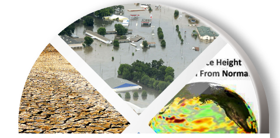


DJF & JJA Precipitation

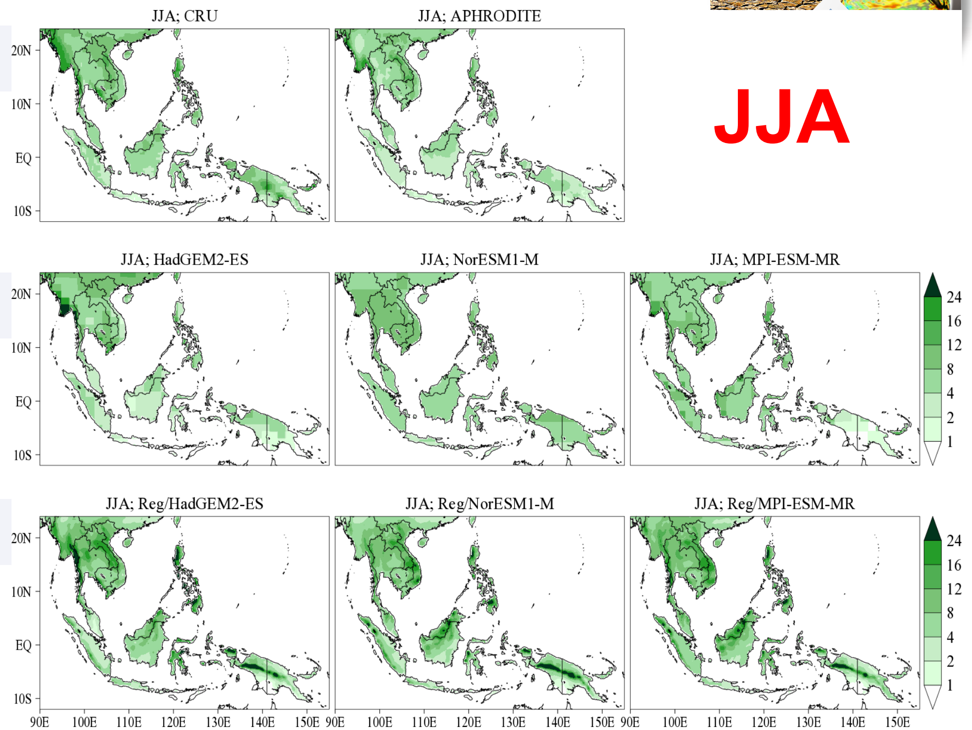


OBS

GCM

RegCM

JJA



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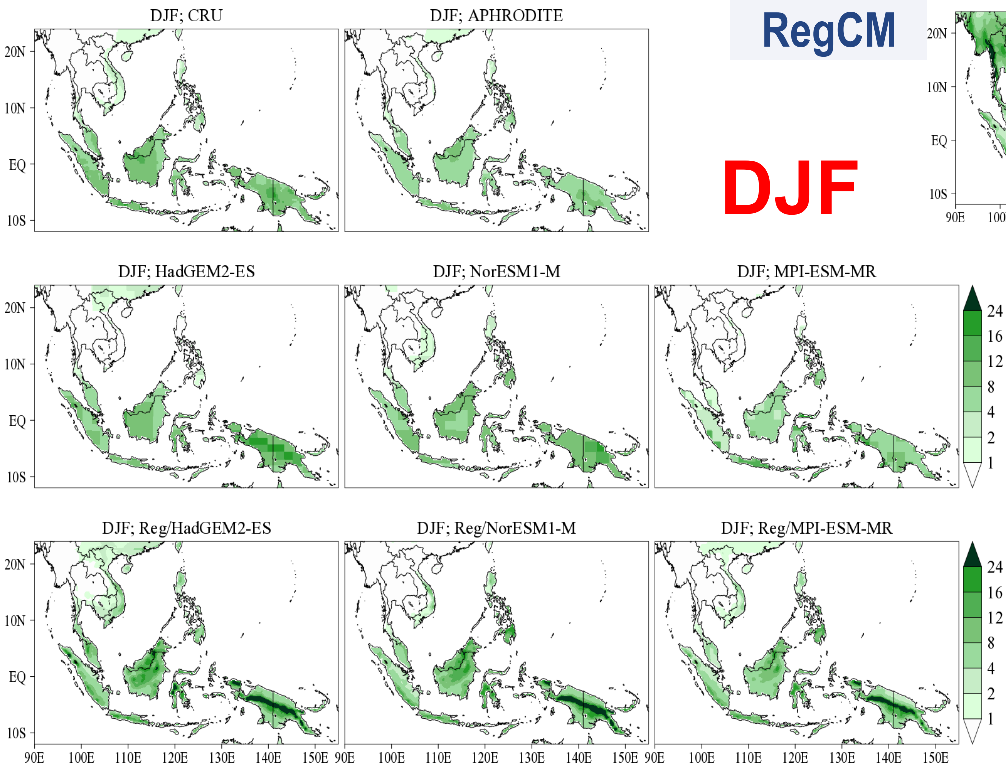
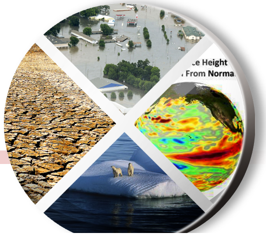
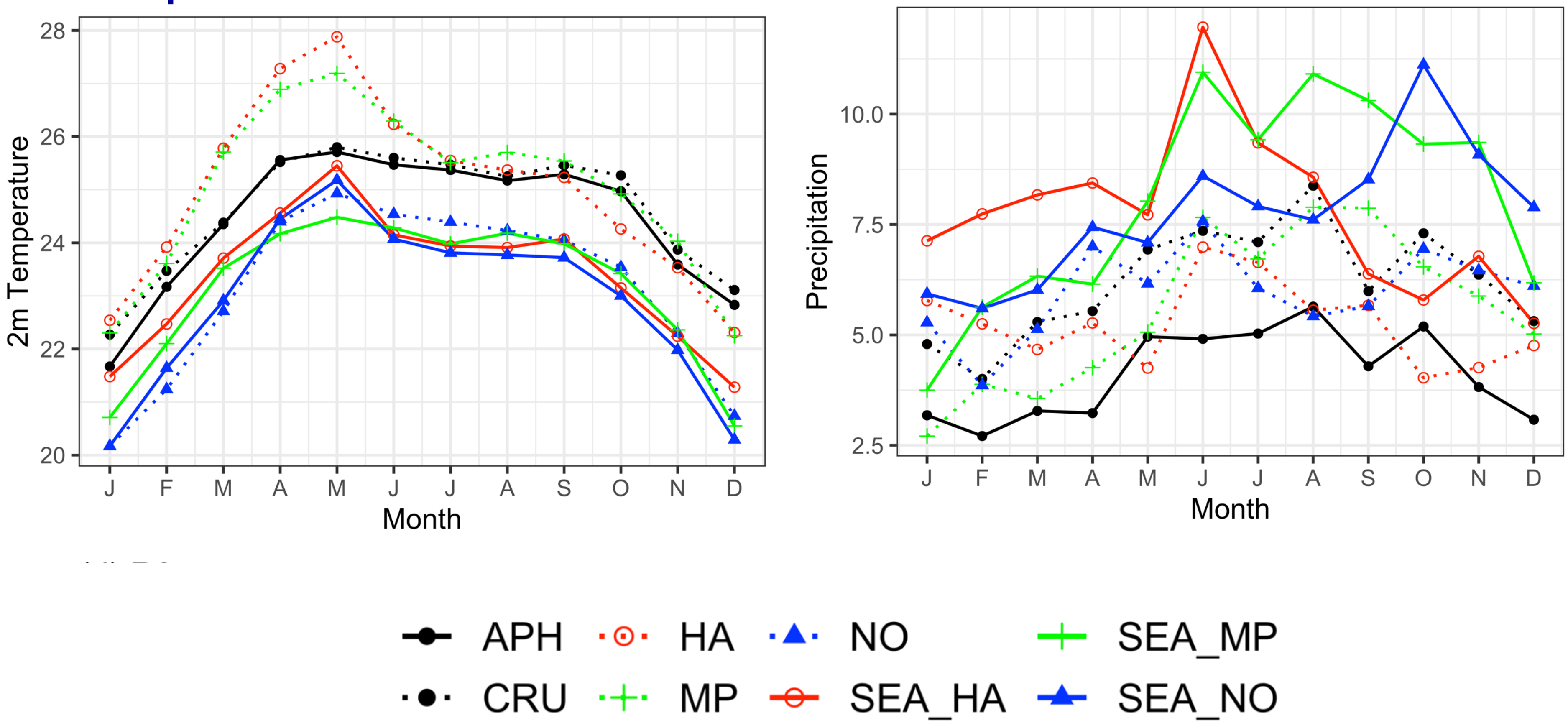


Annual Cycle of Temp. & Preci. over Land

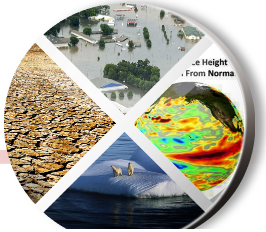


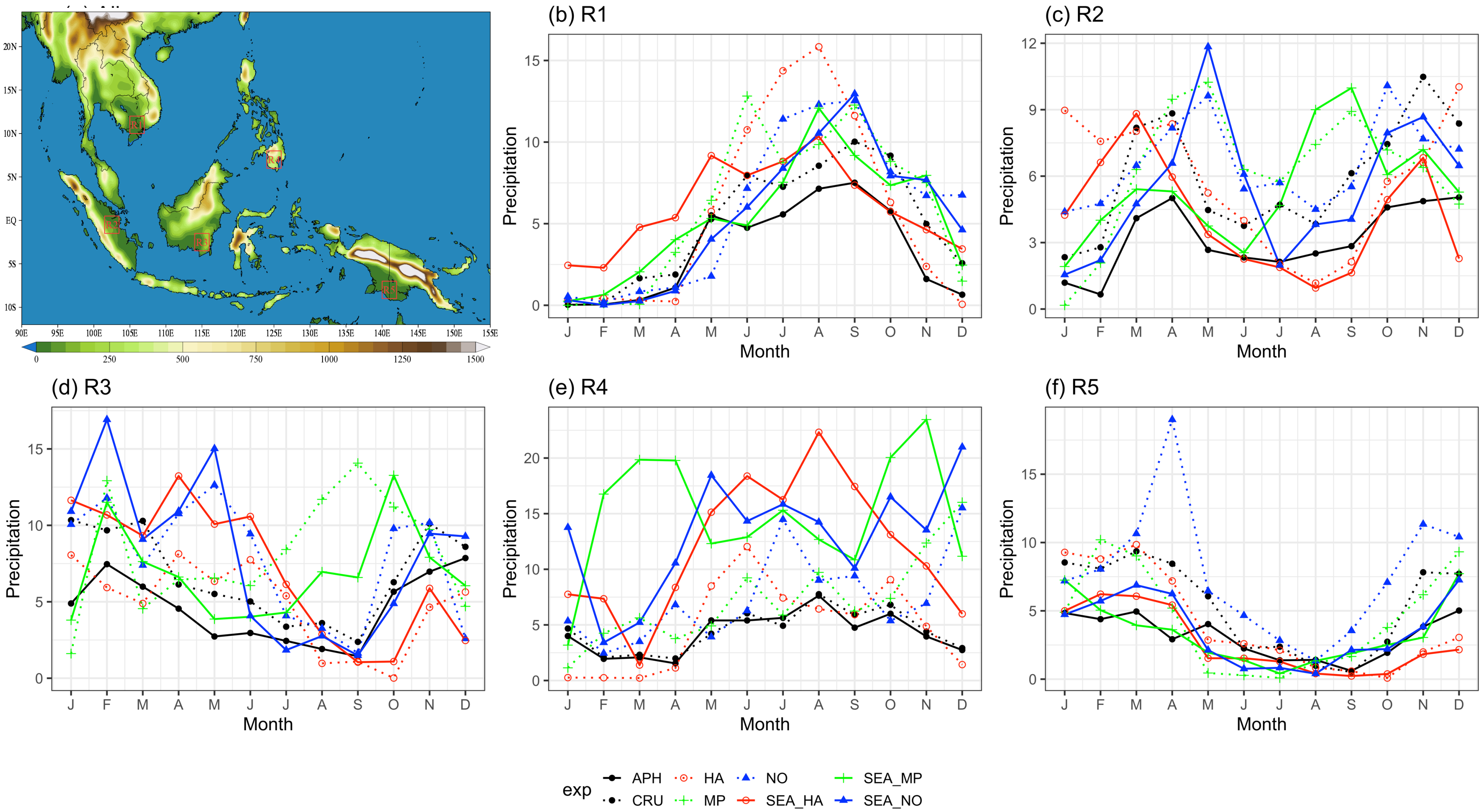
Temperature

Precipitation



Annual Cycle of Precipitation over Sub-Regions





Thank you for your attention!♪