Introducing the MIT Regional Climate Model (MRCM)

&

Application to climate change studies over the Maritime Continent & West Africa

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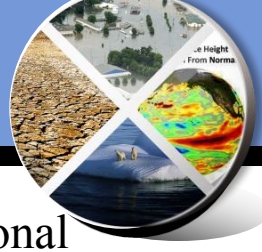
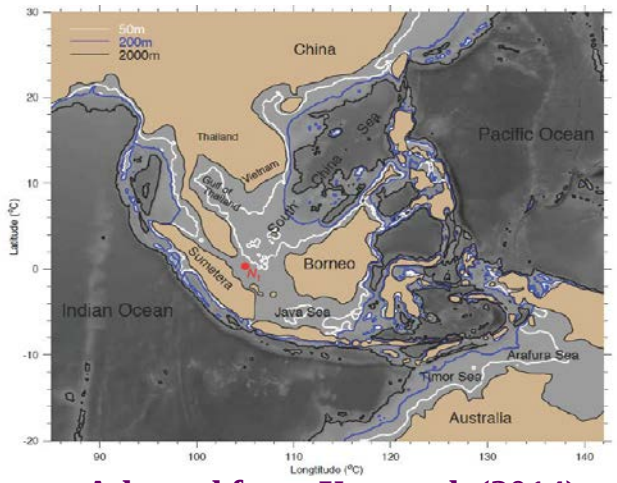
PICES S10: Regional Climate Modeling in the North Pacific

SMART Climate Project Overview



❖ The objective of research is to improve our ability to predict the local and regional climate change and associated impact over the Maritime Continent

	Global Projection	**Regional Projection**	**Local Projection**
Team	MIT Dr. Wang Group	MIT Prof. Eltahir Group	NUS Prof. Liong Group
Model	CESM AOGCM based on emission scenarios using MIT Integrated Global System Model (IGSM)	MRCM	CWRF
Resolution	1.875X2.5 degree	About 30km	Less than 5km



Adapted from Xue et al. (2014)

OASIS3 Coupler

MIT Prof. Paola Rizzoli Group
FVCOM (Finite Volume Coastal Ocean Model)

MIT Regional Climate Model (MRCM)

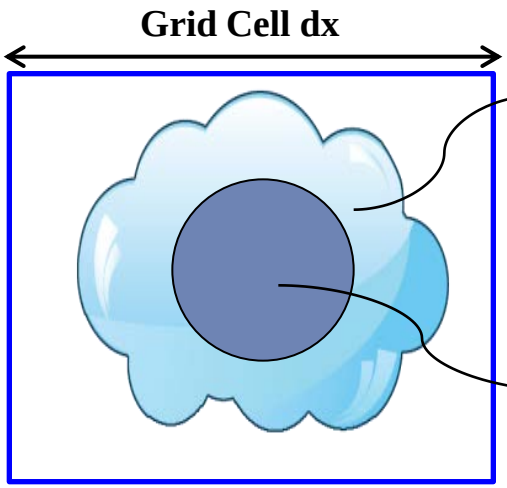
RegCM3 upgraded by MIT Eltahir Group

Physics	New Features	Key References
Aerosols & Chemistry	New treatment of lateral boundary for mineral aerosol	Marcella & Eltahir 2010
	Sub-grid variability of dust emission	Marcella & Eltahir 2011
Convective Cloud & Rainfall	New convective cloud fraction scheme	Gianotti & Eltahir 2014
	New convective rainfall autoconversion scheme	Gianotti & Eltahir 2014
	Modified boundary layer height & boundary layer cloud scheme	Gianotti 2012
Land Surface	Integrated Biosphere Simulator (IBIS) Land Surface Scheme	Winter et al. 2009
	New surface albedo assignment	Marcella & Eltahir 2012
	New irrigation module within IBIS	Marcella & Eltahir 2014 Im & Eltahir 2014

→ **MIT Regional Climate Model (MRCM)**

- Im, E.-S. et al, 2014: Improving simulation of the West African monsoon using the **MIT Regional Climate Model**. J. Climate, 27, 2209-2229.

Modified Convective Parameterization (I)



$$\mu = \frac{\overline{R}}{R_{\text{clim}}} = f_r \text{FC}_{\text{cnv}}$$

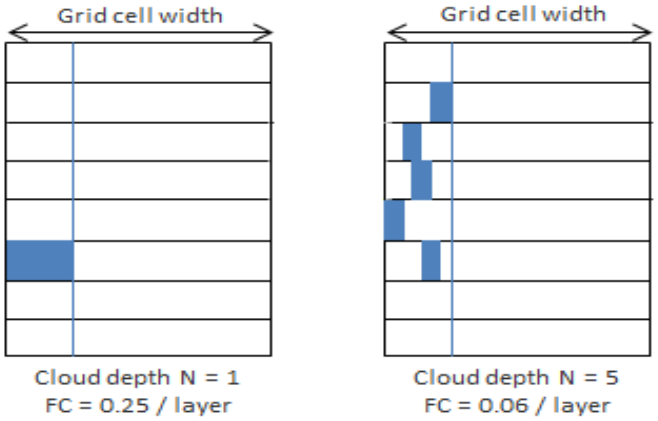
$\overline{R}$: grid-average rainfall
R_{clim} : climatological rainfall intensity
f_r : fraction of total cloudy area that is raining

From Eltahir & Bras (1993)
Gianotti & Eltahir (2014b)

RegCM3

$$\text{FC}_{\text{cnv}} = 1 - 0.75^{1/N}$$

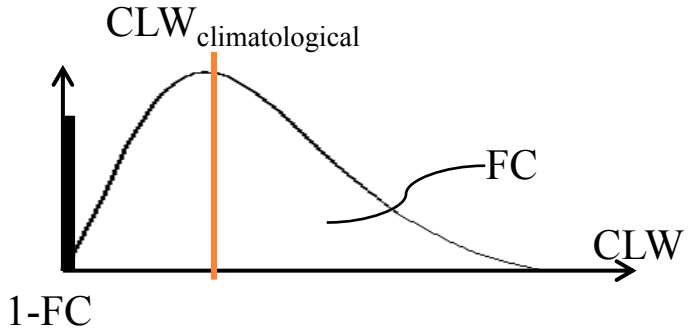
N: number of layer between cloud top and cloud base



MRCM

$$\text{FC}_{\text{cnv}} = \frac{\overline{\text{CLW}}}{\text{CLW}_{\text{clim}}}$$

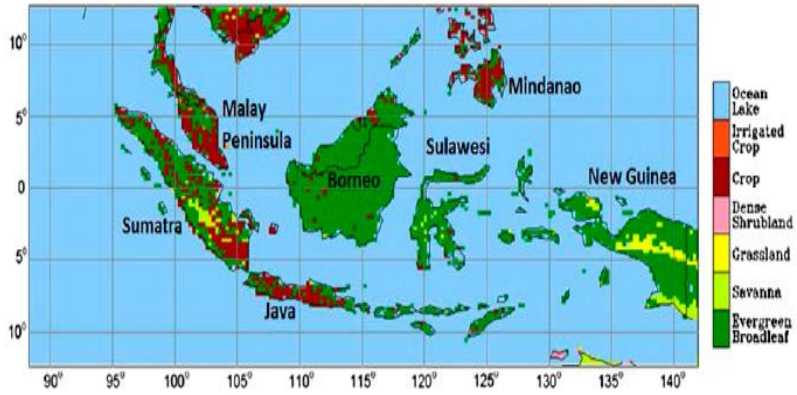
CLW : cloud liquid water



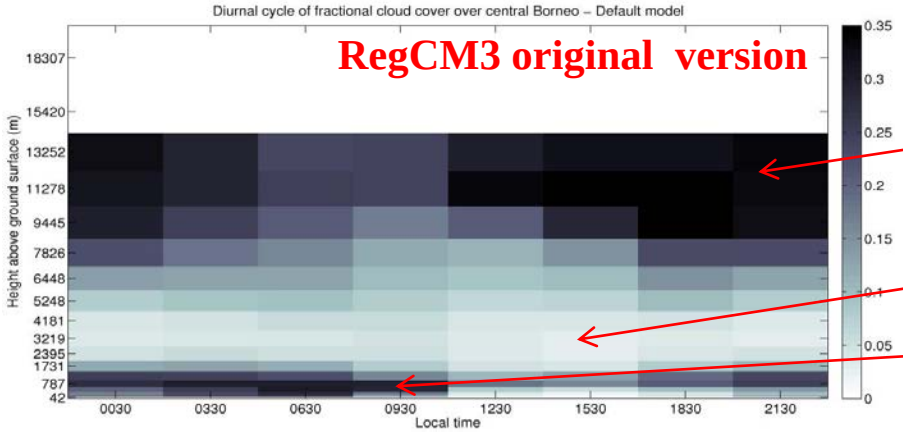
Adapted from Gianotti (2012) and Gianotti & Eltahir (2014a,b)

Modified Convective Parameterization (II)

- Resolution: 30 km
- Integration Period: 1998-2001 (4yr)
- Initial & Boundary: ERA40 Reanalysis (2.5X1.875)



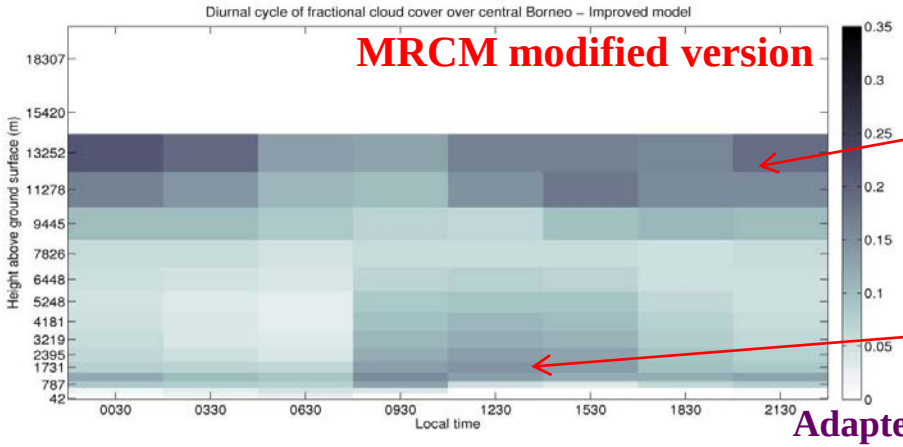
Diurnal cycle of cloud fraction over Borneo



High cloud too dense

Convective cloud missing

Low cloud too dense



Nighttime cloud more realistic

Representation of afternoon convective cloud

Adapted from Gianotti (2012) and Gianotti & Eltahir (2014a,b)

Irrigation Module within IBIS (I)

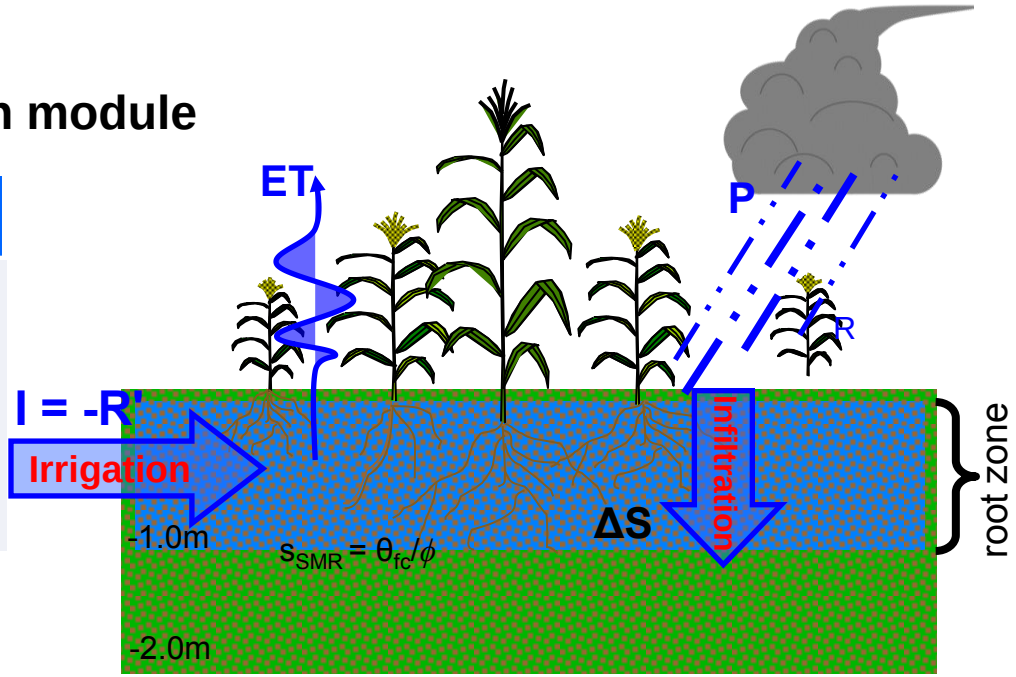
❖ Coupling of Integrated Biosphere Simulator (IBIS)

- The simulations over **North America**, the **Maritime Continent**, **Southwest Asia**, and **West Africa** demonstrate that the use of IBIS results in better representation of surface energy and water budget in comparison to RegCM3's native land surface scheme, Biosphere-Atmosphere Transfer Scheme (BATS)

❖ Implementation of new irrigation module

$$\Delta S = P - R - \mathrm{ET} + I - D$$

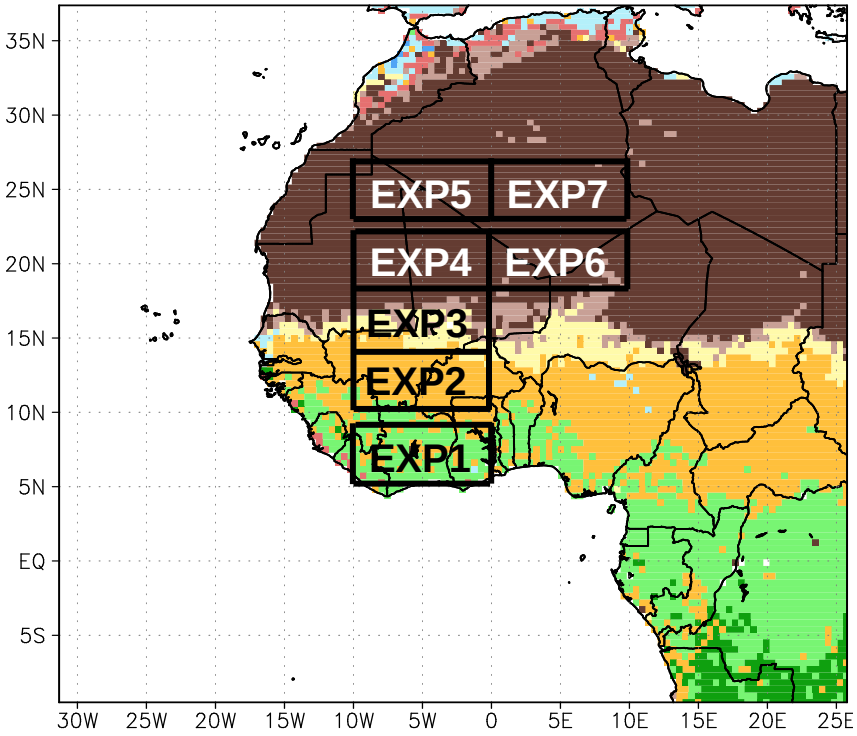
Here, ΔS: Changes in storage of soil moisture
P: Precipitation
R: Runoff
ET: Evapotranspiration
I: Irrigation water
D: Drains into deeper layer

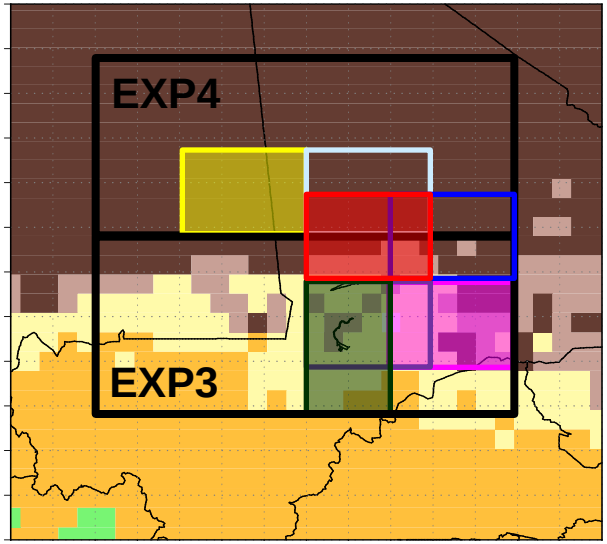


- Add anthropogenic land cover, irrigated cropland biome to IBIS
- Root zone soil moisture is forced to relative field capacity
- "Negative runoff" to supply water and conserve water balance
- Useful tool for the impact studies of anthropogenic land use change due to human activity

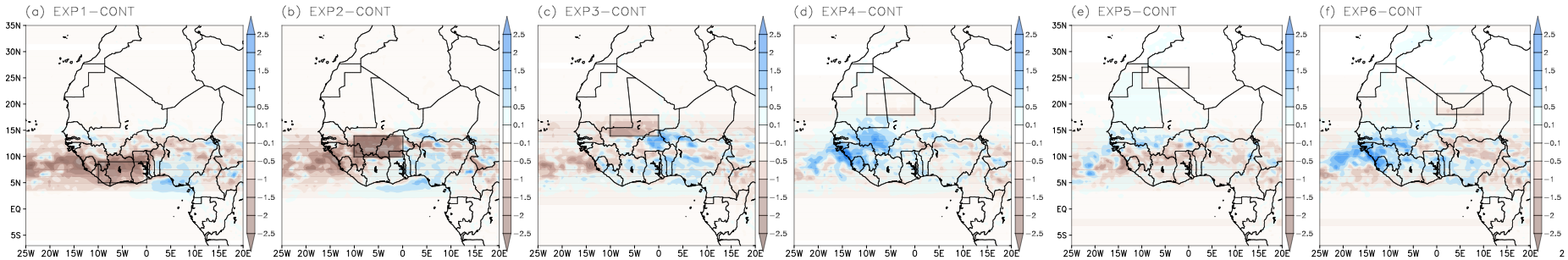
Adapted from Marcella & Eltahir (2014) and Im et al. (2014)

Irrigation Module within IBIS (II)





Rainfall Changes

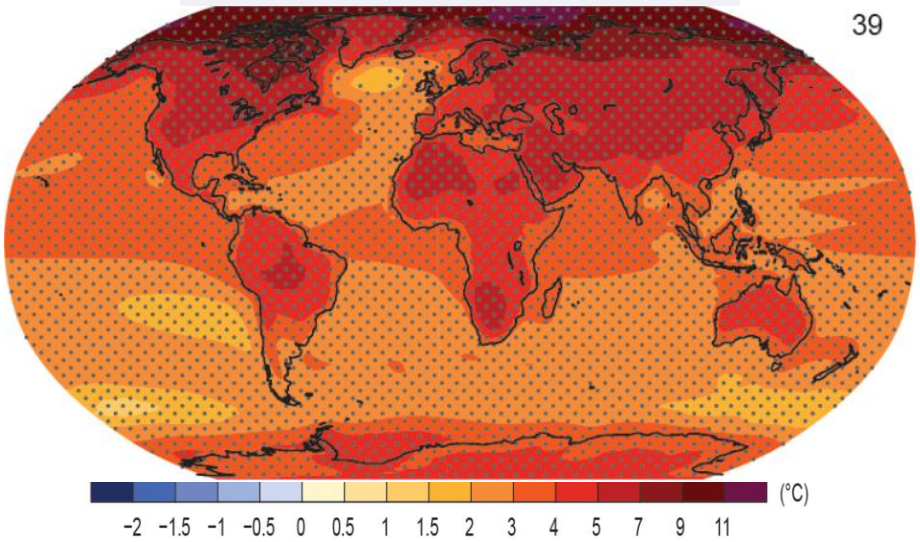


Adapted from Im et al. (2014) and Im & Eltahir (2014)

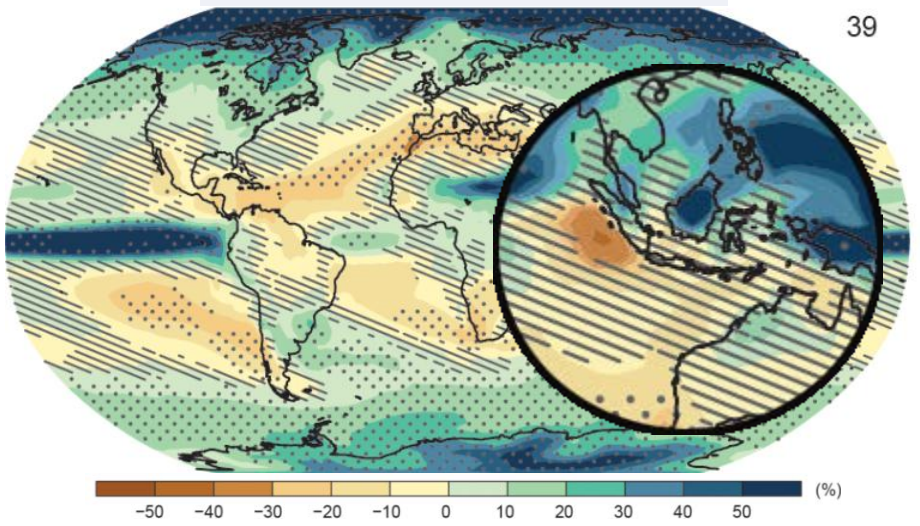
Regional Climate Modeling over the Maritime Continent

RCP8.5 Projection (2081-2100)

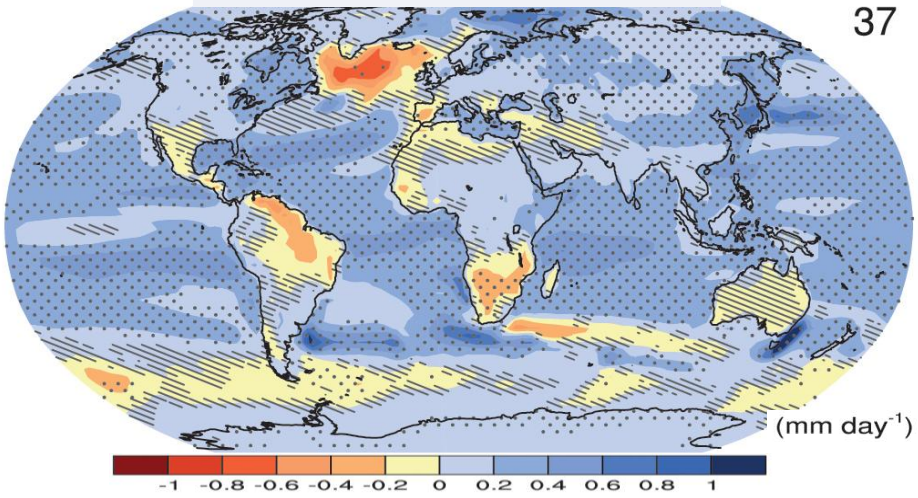
Changes in Temperature



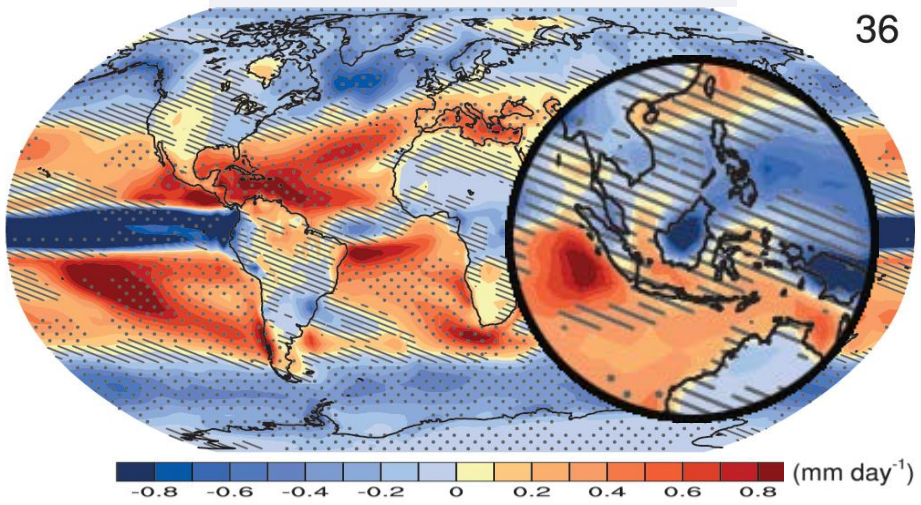
Changes in Precipitation



Changes in Evaporation

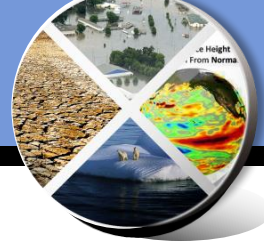


Changes in Eva.-Pre.



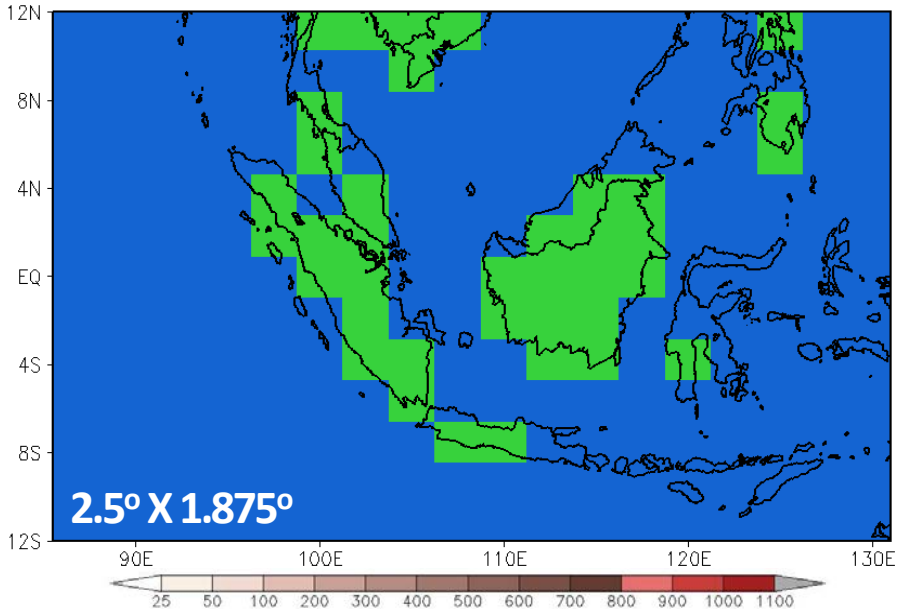
Adapted from IPCC AR5

MRCM of the Maritime Continent

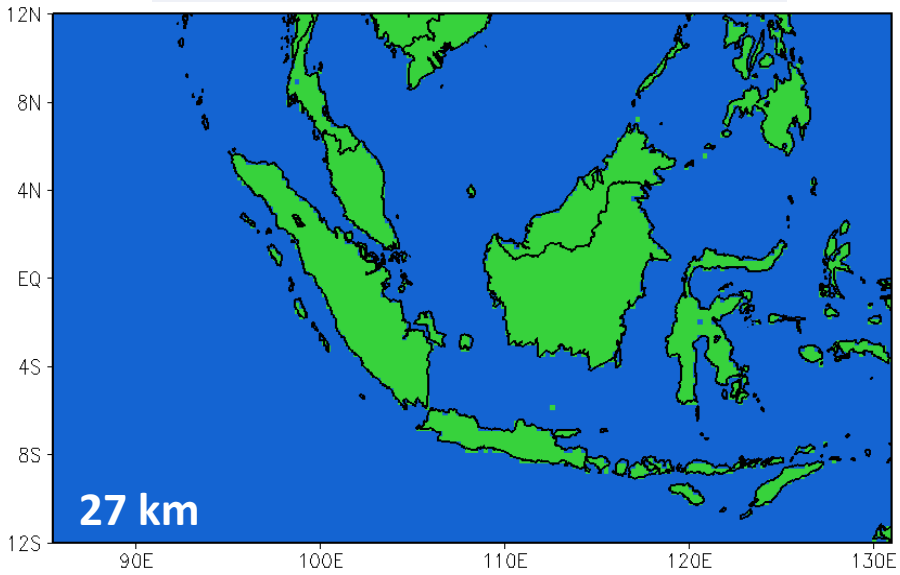


❖ MRCM Domain and Topography (27km)

CESM: Land-Sea Mask

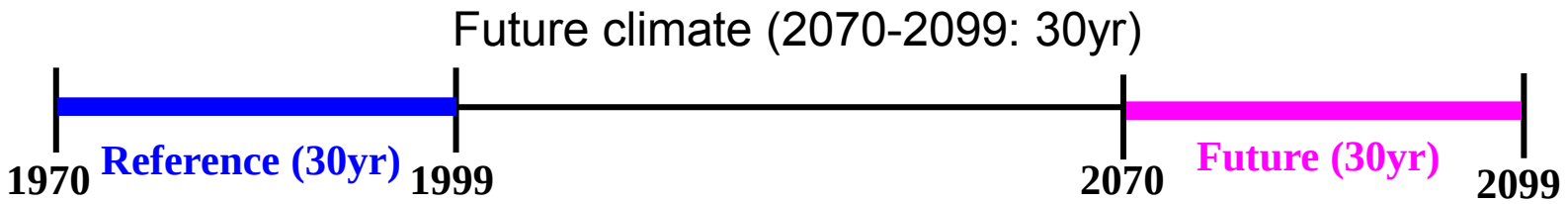


MRCM: Land-Sea Mask



Climate Change Experiments Design

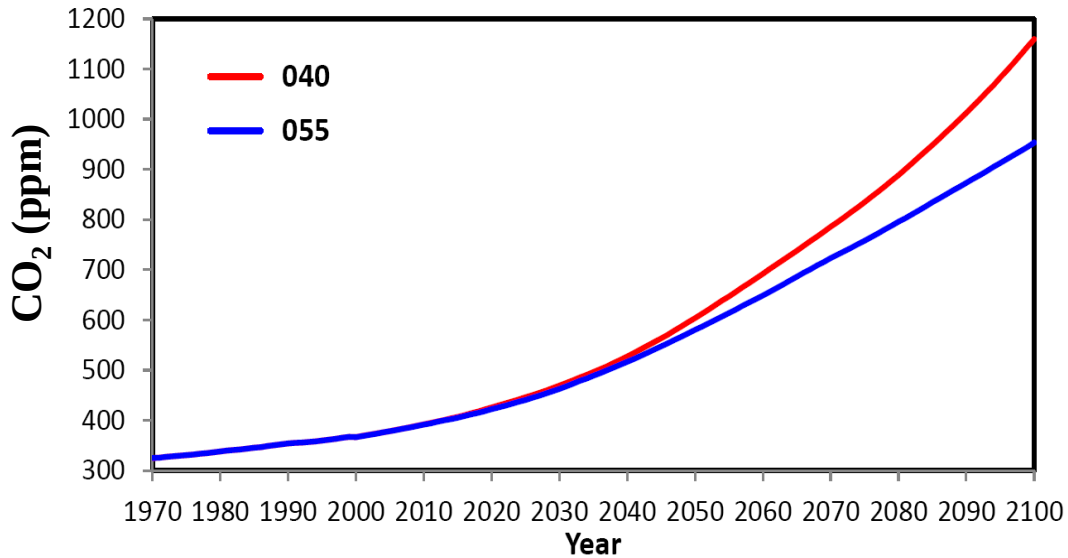
- MRCM Resolution: 27 km
- Initial & Boundary: Community Earth System Model (CESM) (2.5X1.875deg)
- Integration period: Reference climate (1970-1999: 30yr)



Future change signal = Future Simulation – Reference Mean

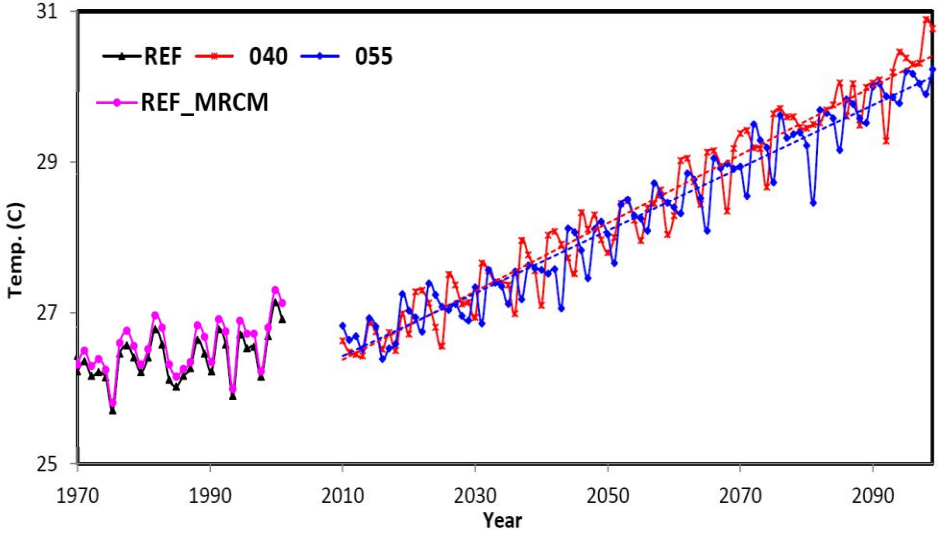
- Emission scenario : **040** & **055** from MIT Integrated Global System Model (IGSM)

[Sokolov et al. 2009]

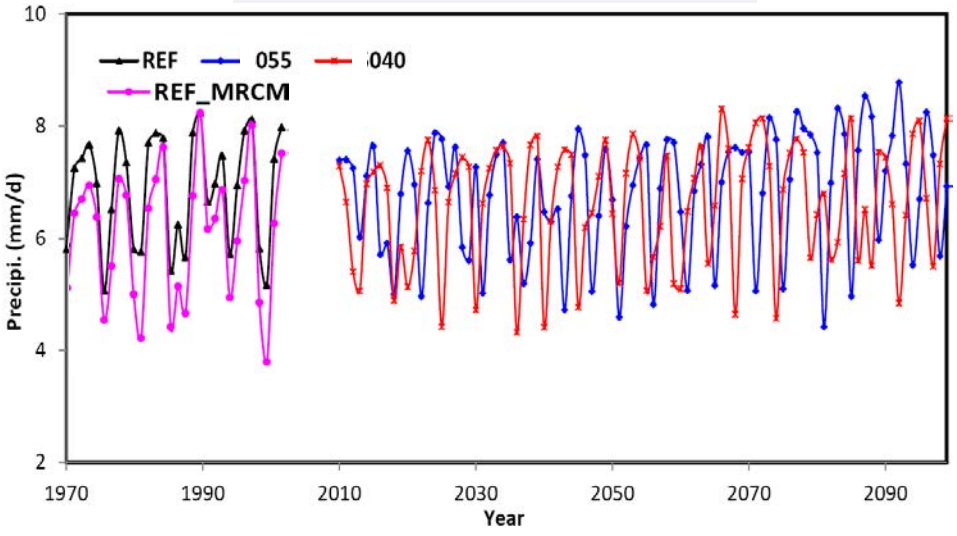


Temp. & Preci. Long-term Trend over MC

Temperature

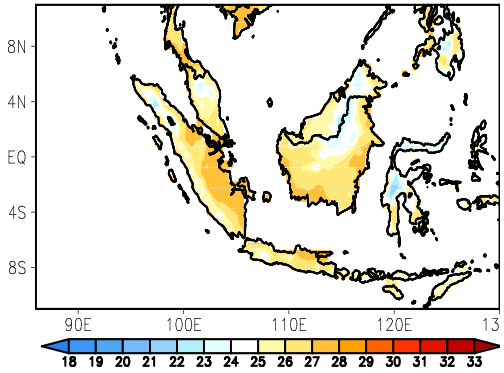


Precipitation

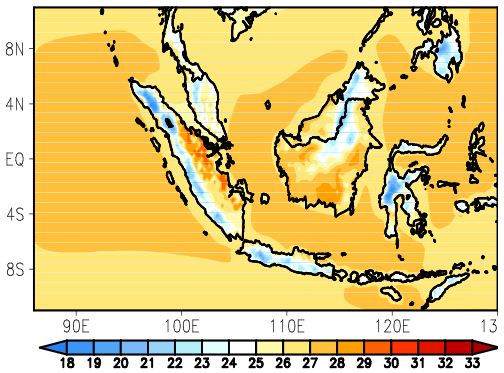


ANN Temp. & Preci. [Reference]

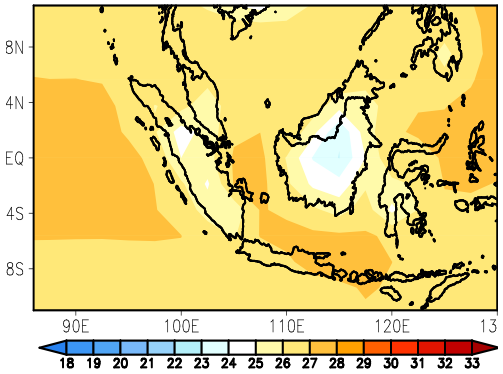
CRU [T]



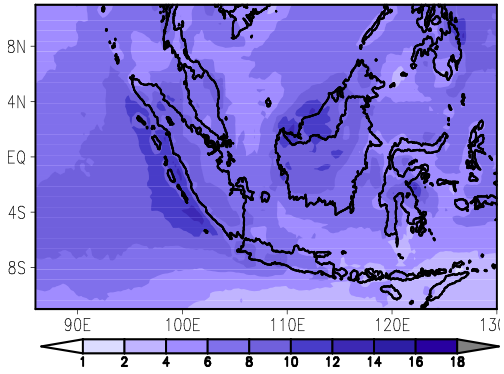
MRCM [T]



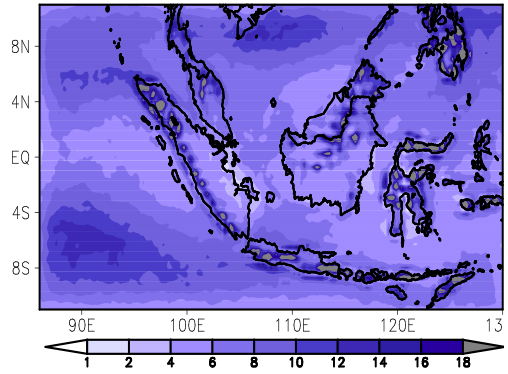
CESM [T]



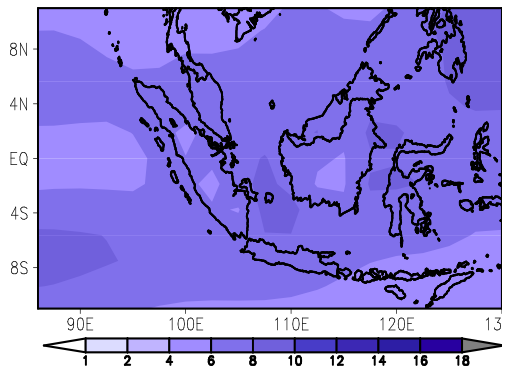
TRMM [P]



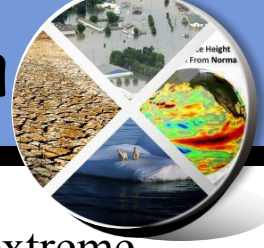
MRCM [P]



CESM [P]

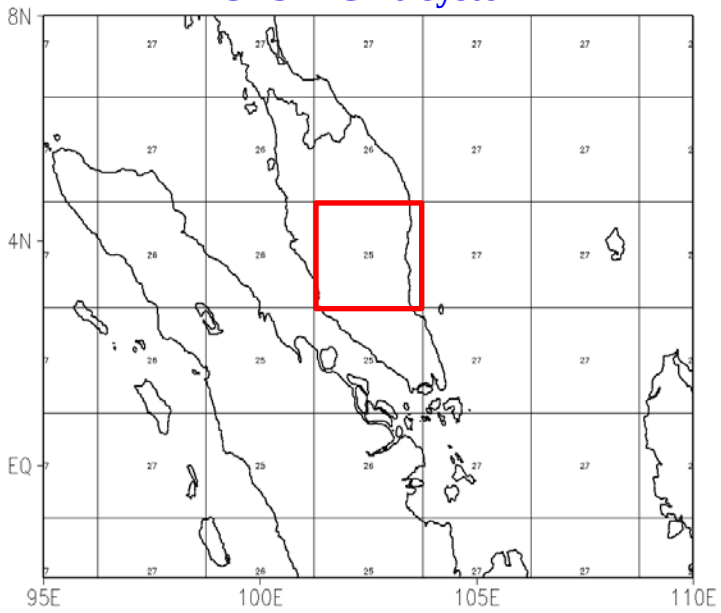


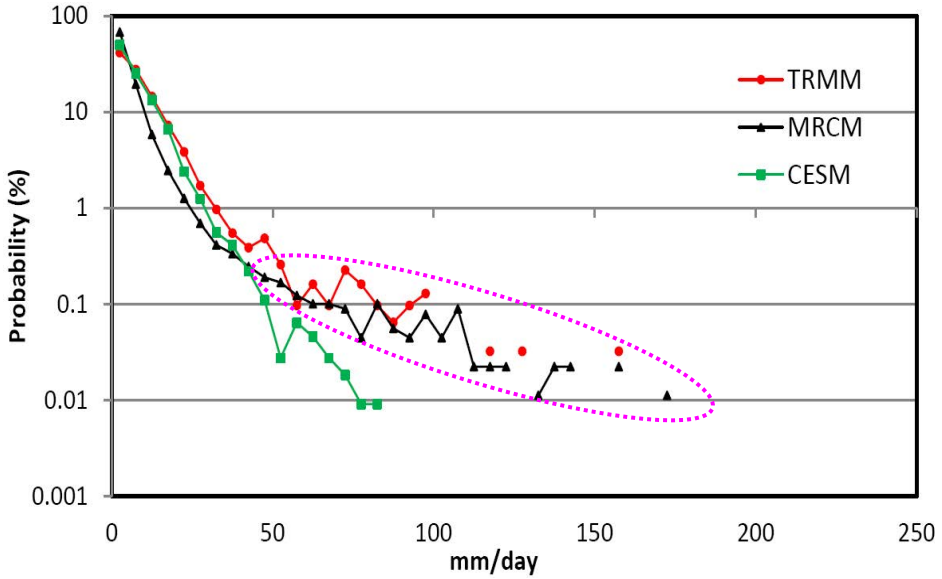
Frequency Distribution of Daily Precipitation



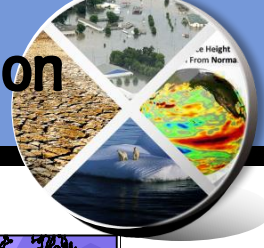
- Daily precipitation from MRCM driven CESM is capable of capturing some extreme values closer to TRMM observation compared CESM used as boundary condition.

CESM Grid system



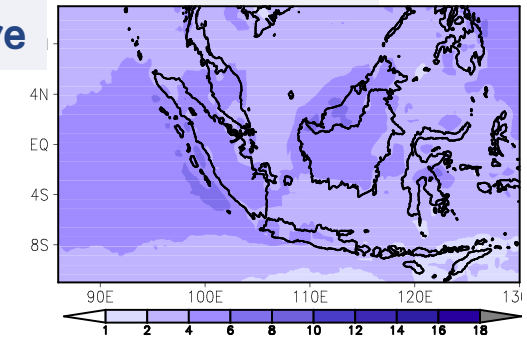


Physical Realism: Convective vs. Large-scale Precipitation

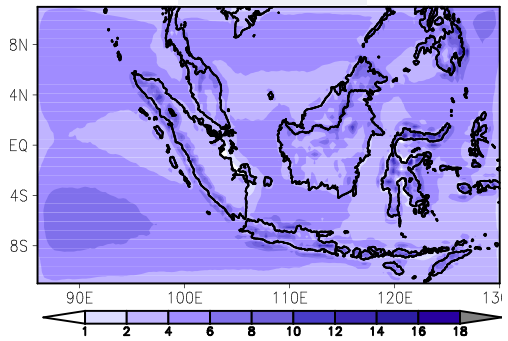


Convective

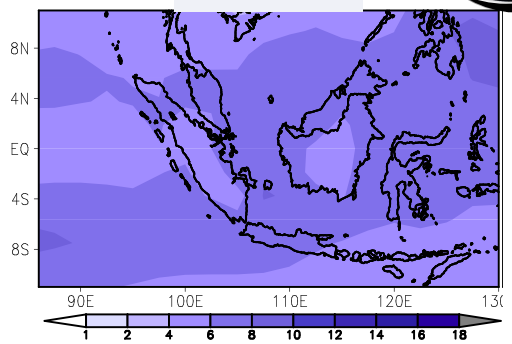
TRMM



MRCM

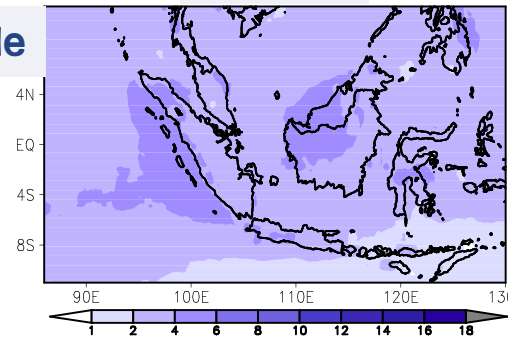


CESM

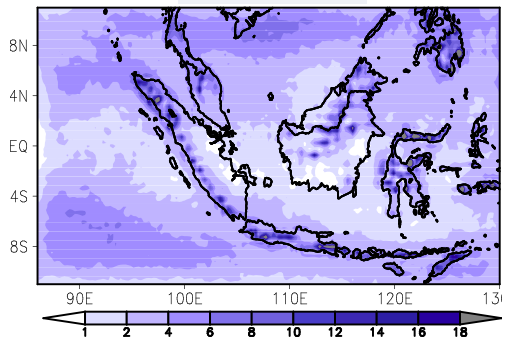


Large-scale

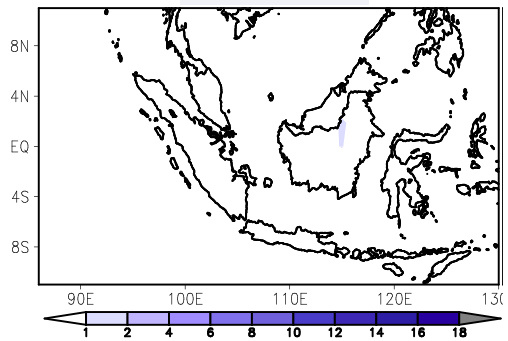
TRMM



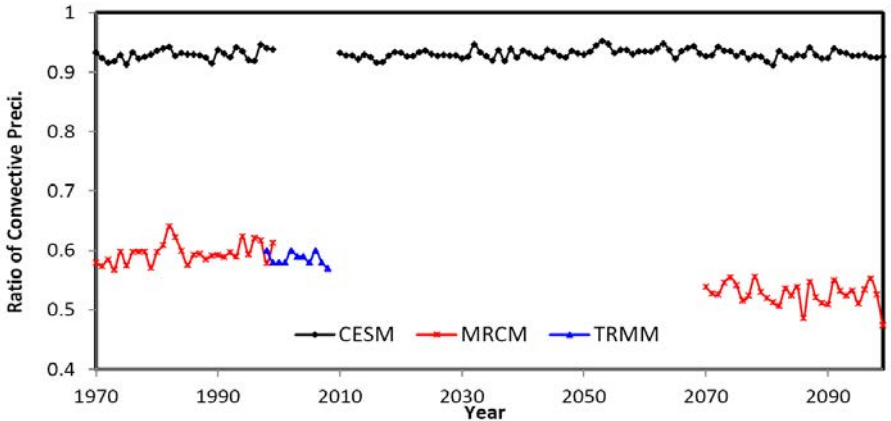
MRCM



CESM

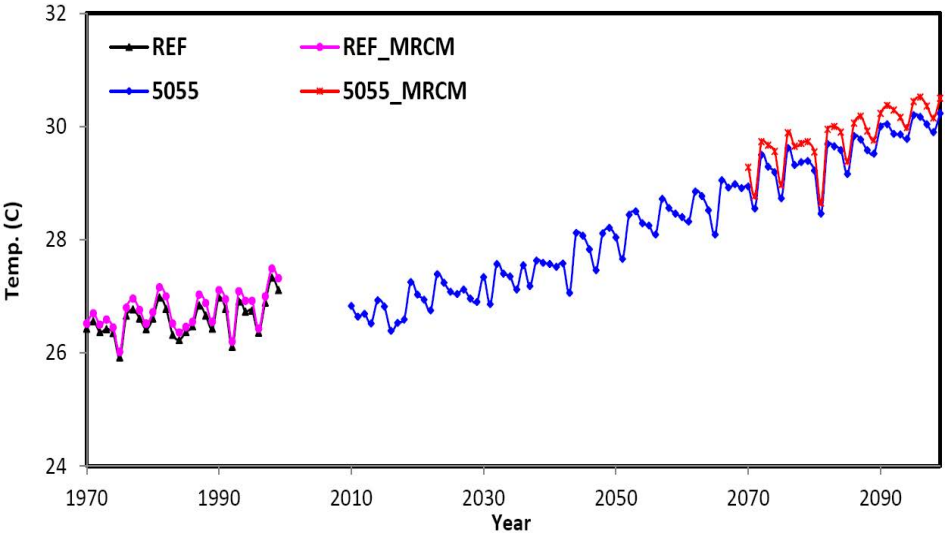


Annually area-averaged ratio of convective precipitation

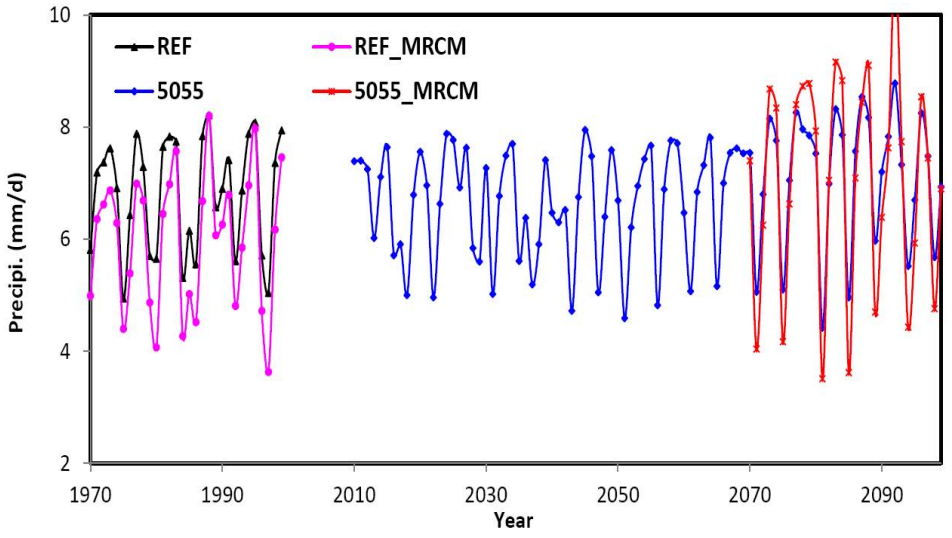


Temp. & Preci. Long-term Trend over MC

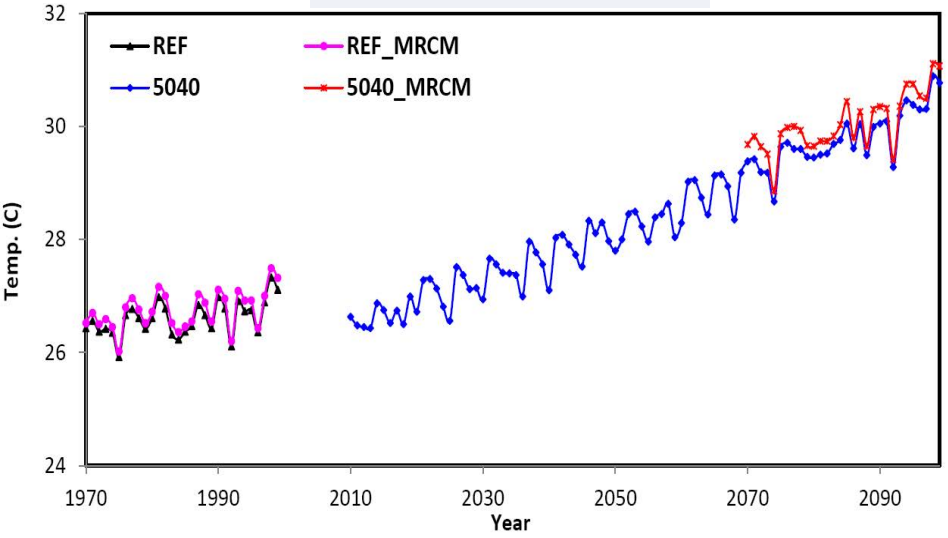
Temp. [055]



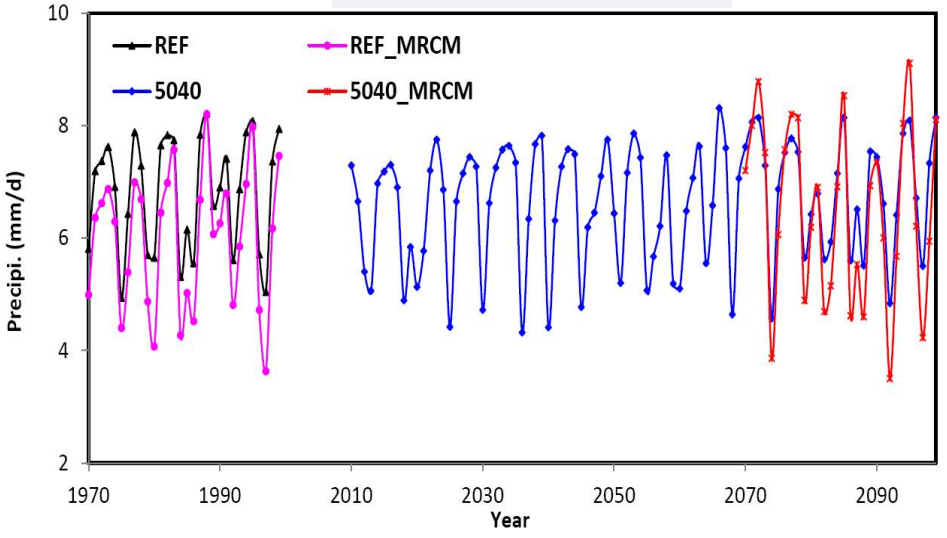
Preci. [055]



Temp. [040]



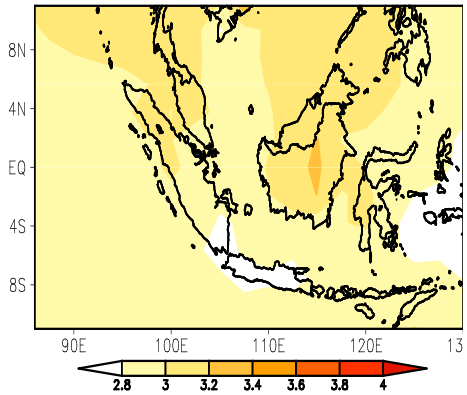
Preci. [040]



ANN Temp. & Preci. Changes

➢ CESM global projection

Temp. [055]



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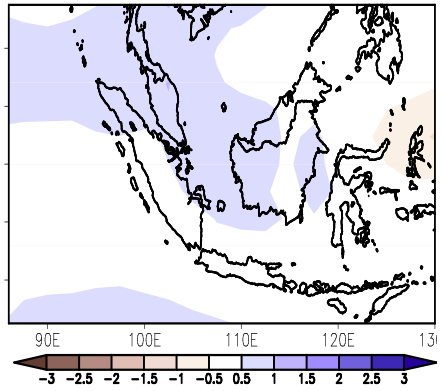
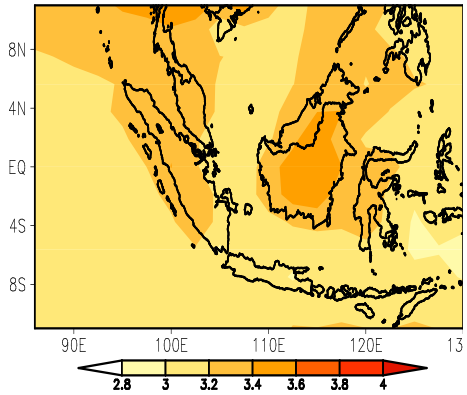
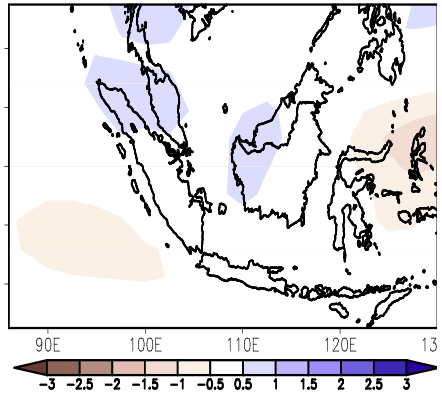


Temp. [040]

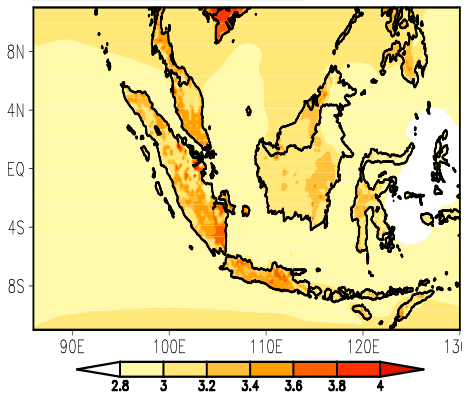


Preci. [040]

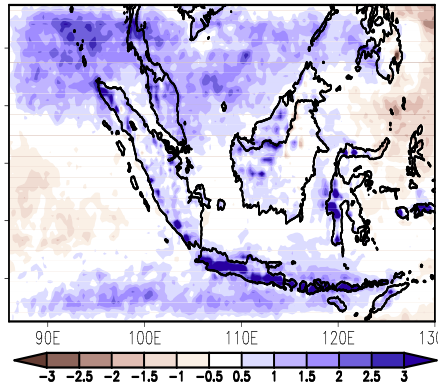


➢ MRCM regional projection

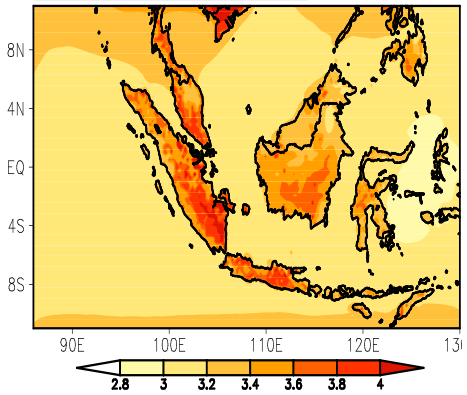
Temp. [055]



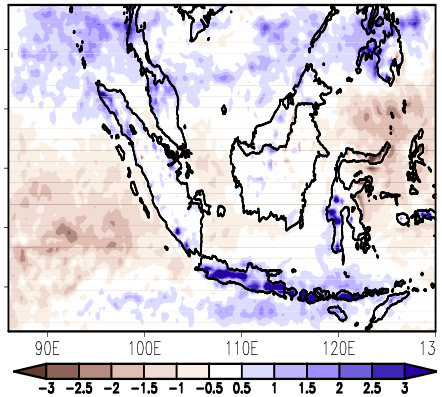
Preci. [055]



Temp. [040]



Preci. [040]



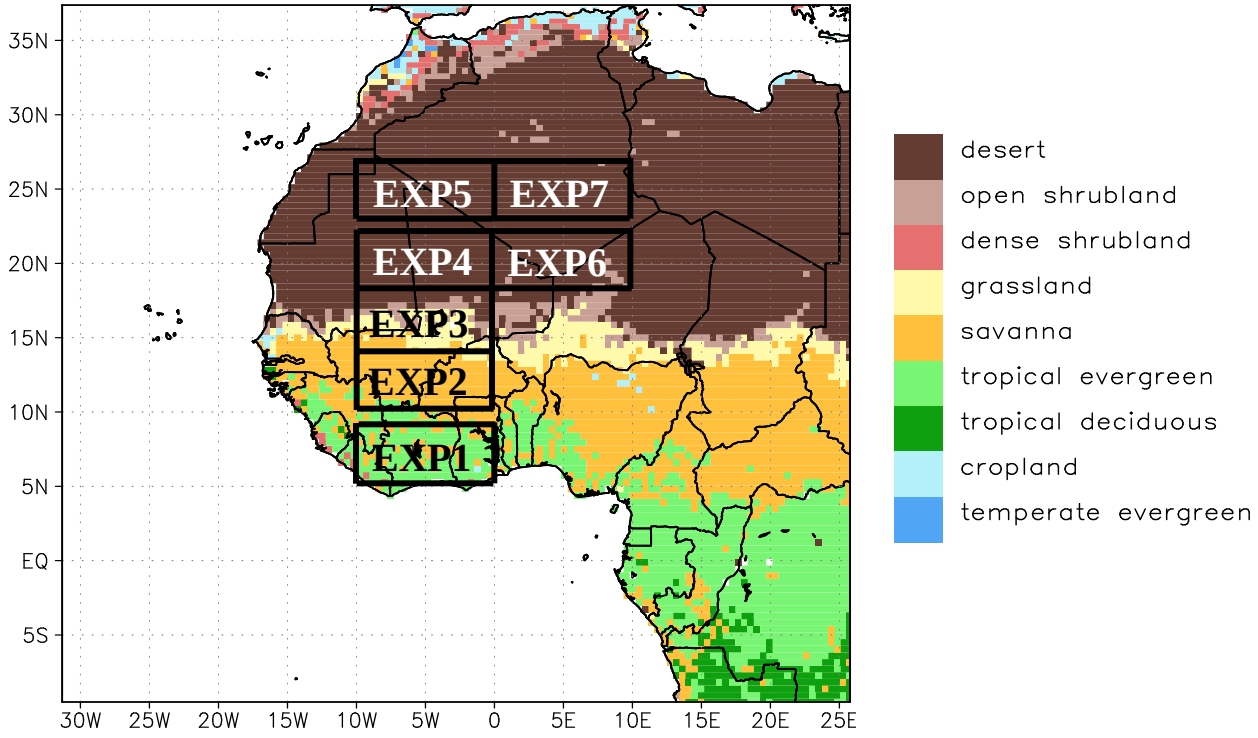
Regional Climate Modeling over West Africa

: Focus on the impact of irrigation on the West African Monsoon

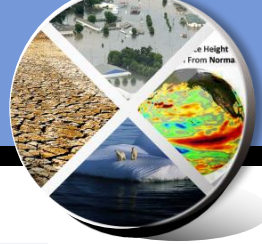


Experiment Design

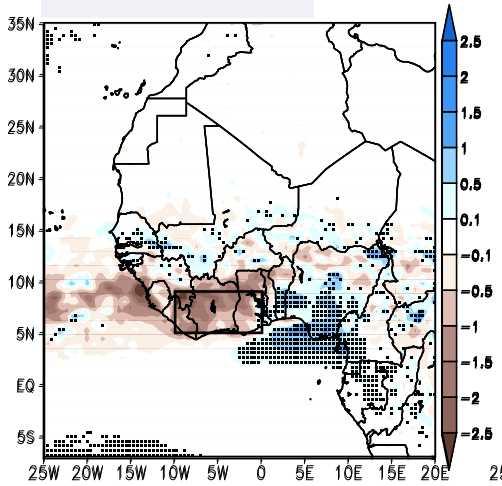
- Resolution: 50km
- Integration Period: 1989-2008 (20yr)
- Initial & Boundary Conditions: ERAInterim (1.5deg)



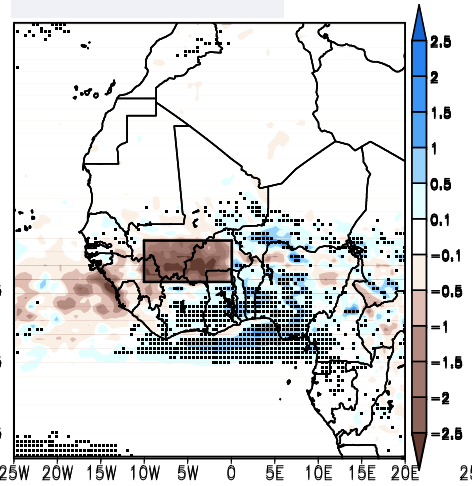
Rainfall Change (May-Sep)



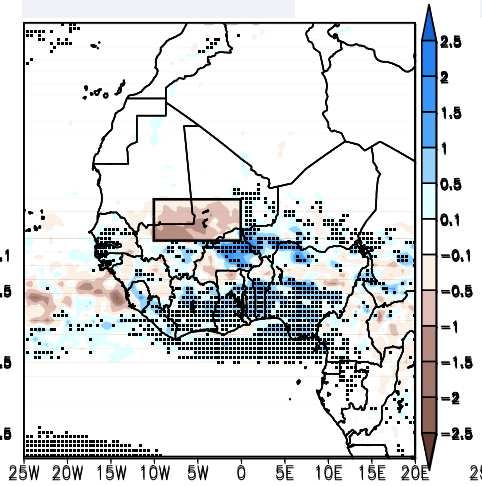
EXP1-CONT



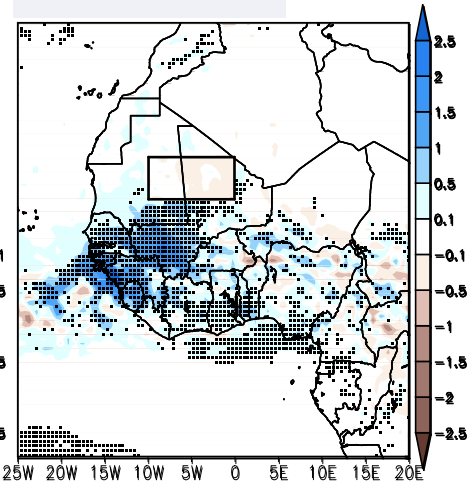
EXP2-CONT



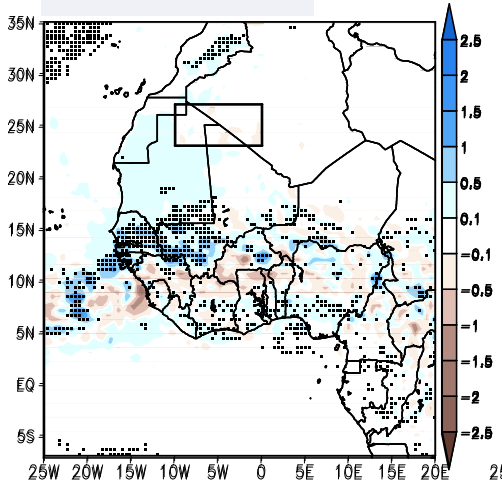
EXP3-CONT



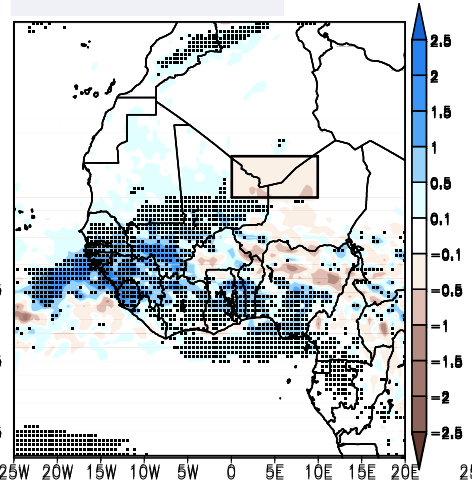
EXP4-CONT



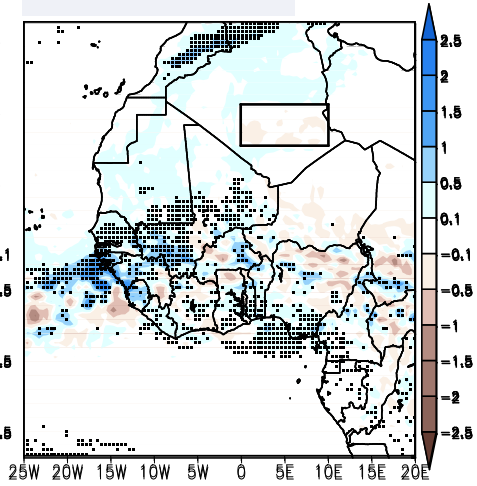
EXP5-CONT



EXP6-CONT



EXP7-CONT

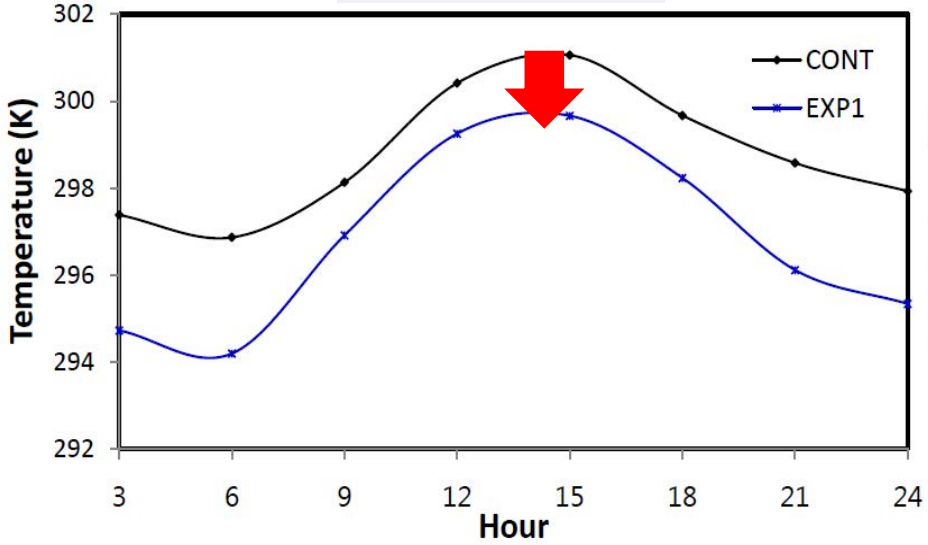


- Dotted area

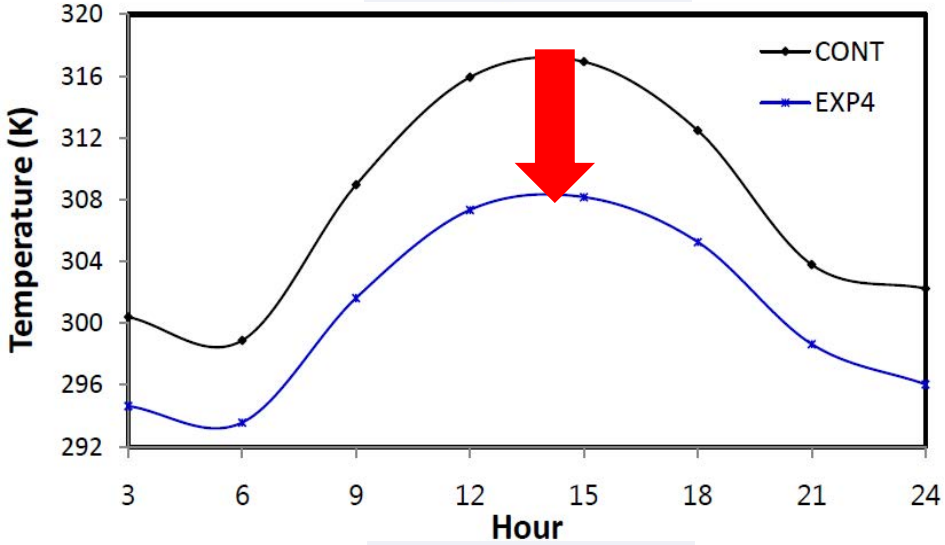
: **Significance of rainfall increase**

Mechanism of Local Response

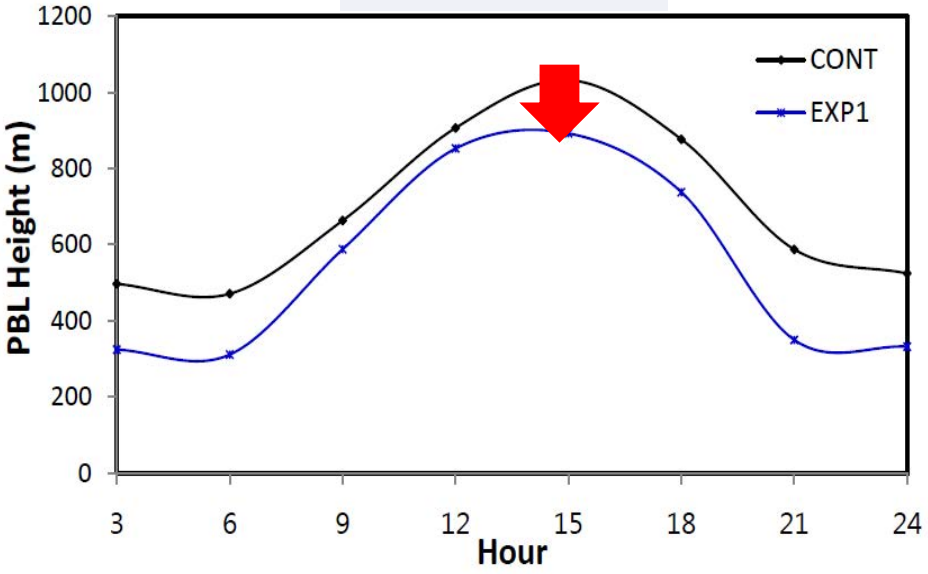
Temperature



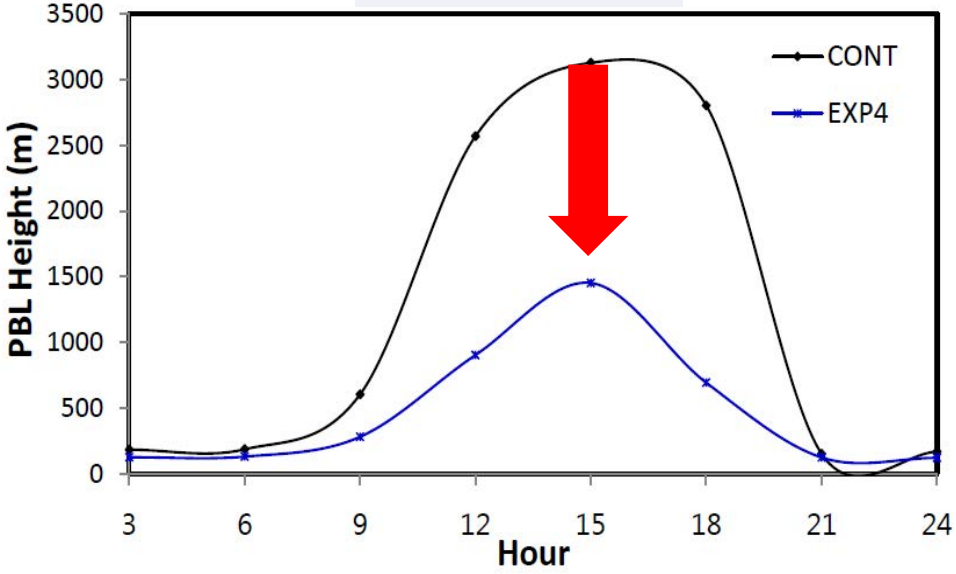
Temperature



PBL Height

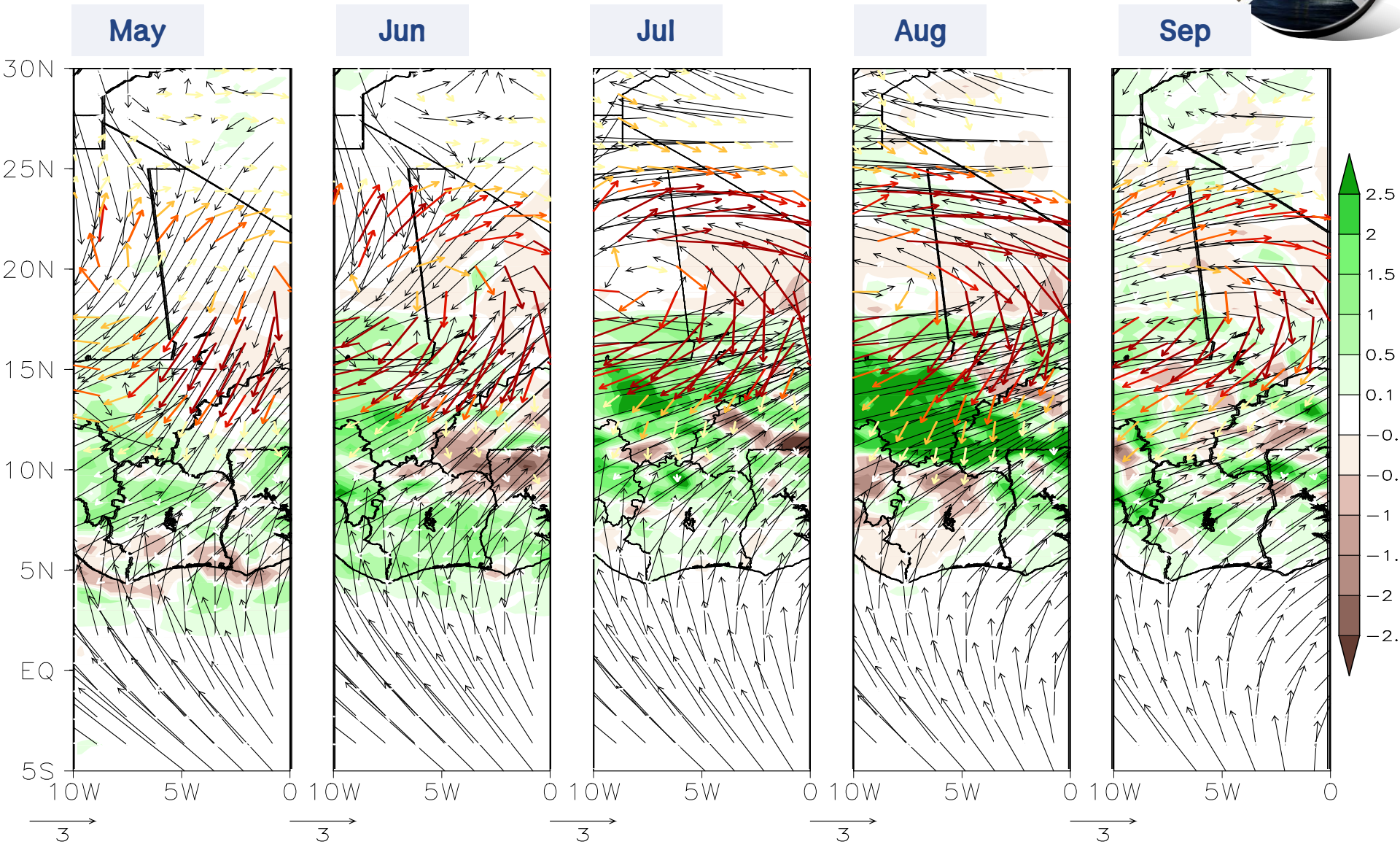


PBL Height

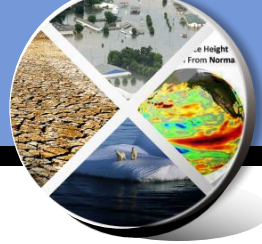


Remote Effect

- Black arrow : CONT monsoon flow
- Red gradient arrow: Anomalous flow



Local vs. Remote Response



Wet soil moisture due to irrigation

↓

Surface cooling

↓

Suppression of PBL height

↓

Reduced triggering of convection

↓

Local rainfall decrease

Local Response

Remote Response

↓

Anomalous descending motion

↓

Anti-cyclonic circulation

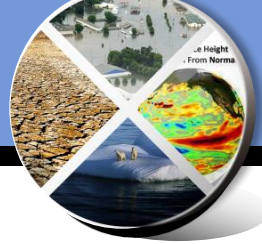
↓

Convergence between prevailing monsoon flows and anomalous outflows

↓

Remote rainfall change

Take Home Message



MRCM Development :

- Improvement of the model physics
- Development of a new integrated modeling system that couples climate processes
  - across different domains (atmosphere, ocean, land-surface incorporating groundwater)
  - across different scales (local to global)

MRCM Application :

- Dynamical downscaling of global projections for climate change assessment (e.g. over the Maritime Continent)
- Process study of physical mechanism shaping the climate over particular region (e.g. land-atmosphere interaction over West Africa)

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Thank you for your attention!

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