"SOUSEI" is a Japanese word which means "generation" or "creation".

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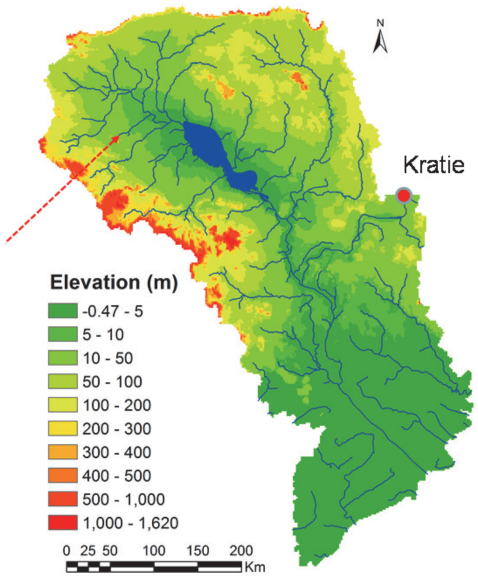
気候変動リスク情報創生プログラム

Flood Risk Assessment under Climate Change in Asia



Lower Mekong River Version

International Centre for Water Hazard and Risk Management under the auspices of UNESCO (ICHARM),

Public Works Research Institute (PWRI), Japan

United Nations Educational, Scientific and Cultural Organization

SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

Contents

1. Background

SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

Three Key Global Agendas in 2015

Understanding | Governance | Investment | EW/BBB

March 2015 — Sendai Framework on Disaster Risk Reduction

September 2015 — Sustainable Development Goals

December 2015 — Paris Agreement (COP 21)

Concerted Action is Required

- Reducing Current Risk
- Preventing Future Risk
- Adaptation & Recovery

Building Resilience

Sustainable Development

1. Background

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CMIP5 (Coupled Model Intercomparison Project Phase 5)

CMIP5 Coupled Model Intercomparison Project
WCRP World Climate Research Programme

http://cmip-pcmdi.llnl.gov/cmip5/

- At a September 2008 meeting involving 20 climate modeling groups around the world agreed to promote a new set of coordinated climate model experiments.
- These experiments comprise the fifth phase of the Coupled Model Intercomparison Project (CMIP5).
- More than 50 General Circulation Model (GCM) datasets for IPCC AR5 studies.

Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR5) (2013)

✓**RCP (Representative Concentration Pathway)**

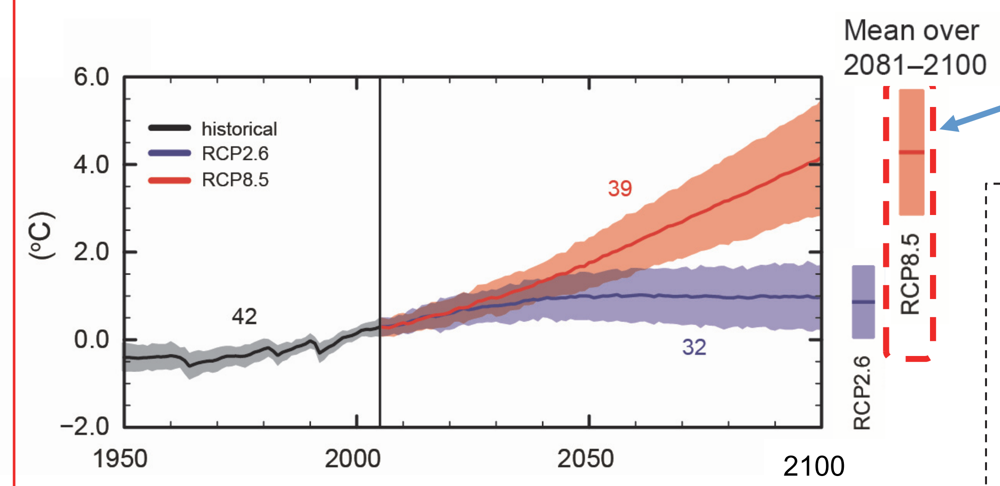

Fig. Global average surface temperature change (in AR5)

RCP8.5: Business as usual scenario with highest GHG emission in RCPs.

RCP 2.6:Global annual GHG emissions peak between 2010-2020, with emissions declining substantially thereafter.
RCP 4.5: GHG emissions peak around 2040, then decline
RCP 6 : GHG emissions peak around 2080, then decline
RCP 8.5, emissions continue to rise throughout the 21st century

2. Outline of SOUSEI Program (1/2)

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Objectives

To create new basic information required for managing water-related disaster risks resulting from climate change in the river basin scale.

Outline

- The program is a five-year (2012-2016) research program funded by MEXT (Ministry of Education, Culture, Sports, Science and Technology, Japan).
- Co-workers are Kyoto Univ., Yamanashi Univ., etc., and the research collaborators in relative governments.

Basic technologies to develop

1. Prediction of the change of rainfall under the climate change,
2. Development of hydrological model,
3. Flood/Drought hazard analysis for future condition using hydrological model,
4. Flood/Drought risk assessment on socio-economic activities for future condition,
5. Promotion of adaptation measures against the climate change

2. Outline of SOUSEI Program (2/2)

SOUSEI Program for Risk Information on Climate Change
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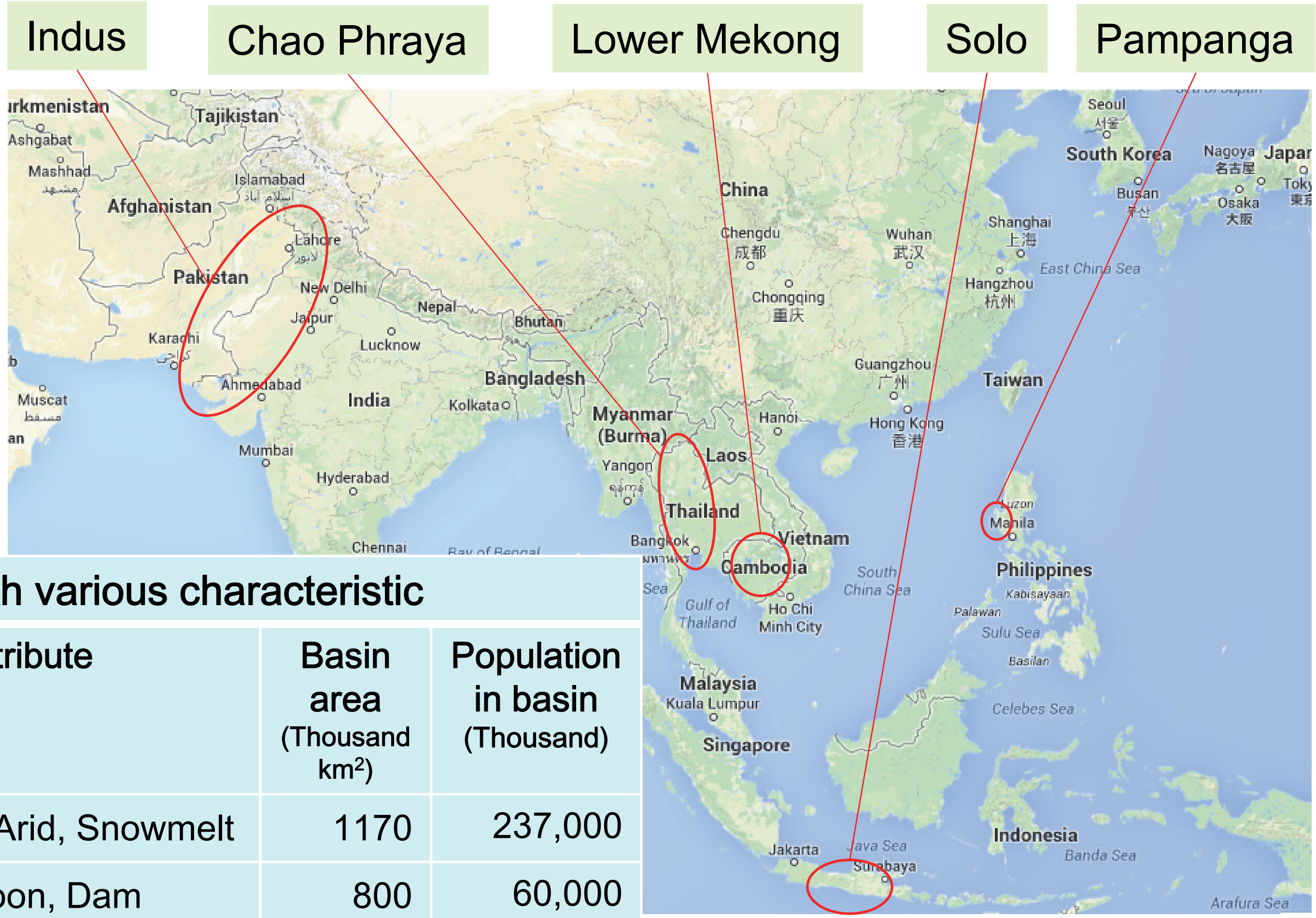
Target River Basins (5 basins)



River basins with various characteristic			
River	Attribute	Basin area (Thousand km²)	Population in basin (Thousand)
Indus	Continent, Semi-Arid, Snowmelt	1170	237,000
Mekong	Continent, Monsoon, Dam	800	60,000
Chao Phraya	Continent, Monsoon, Dam	160	28,000
Solo	Islands, Volcano, No Typhoon	16	17,000
Pampanga	Islands, Volcano, Typhoon	11	5,800

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3. Research Methodology (1/2)

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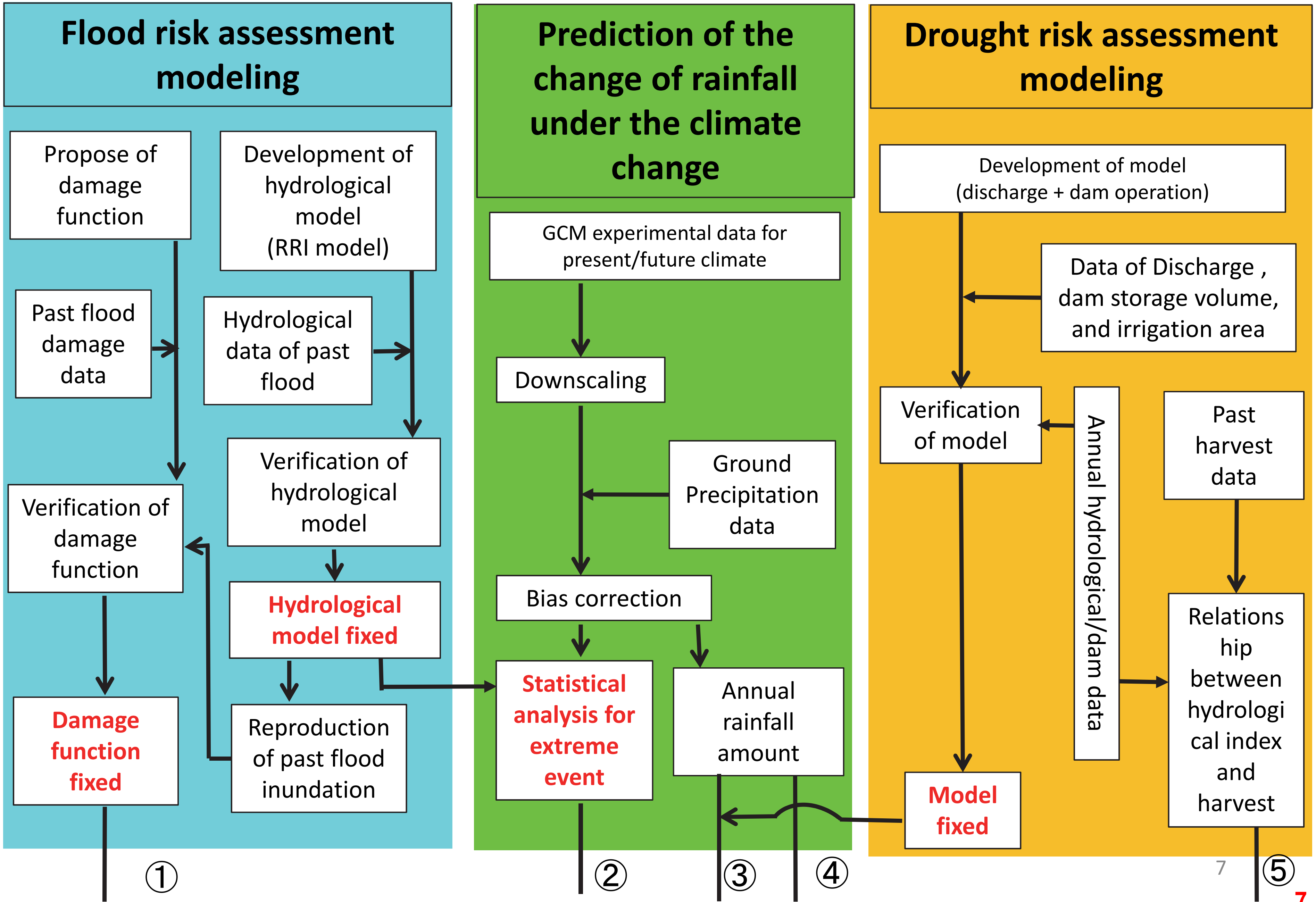

3. Research Methodology (2/2)

SOUSEI Program for Risk Information on Climate Change
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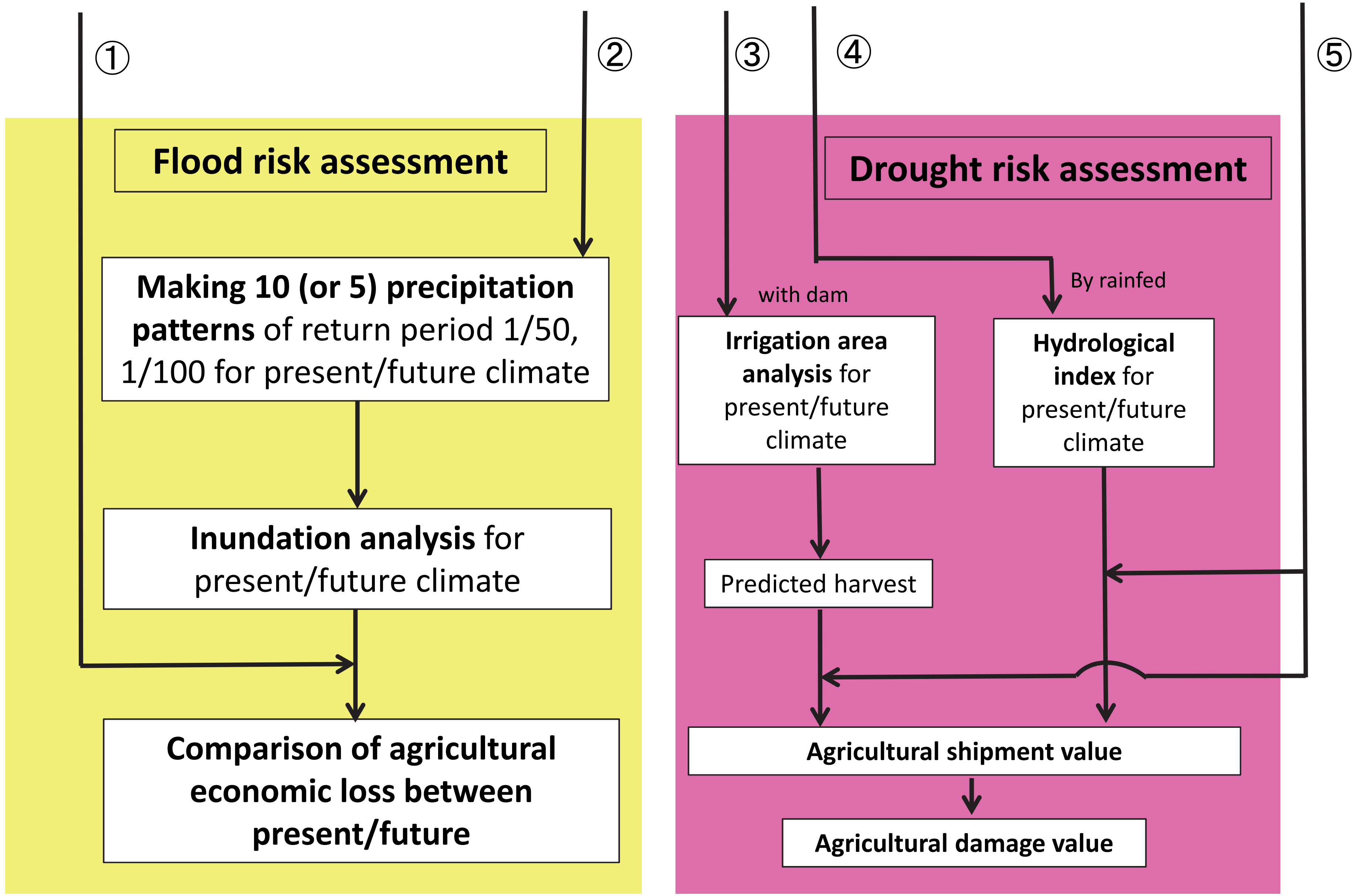

3. Research Methodology 3.1 Rainfall change assessment

SOUSEI Program for Risk Information on Climate Change
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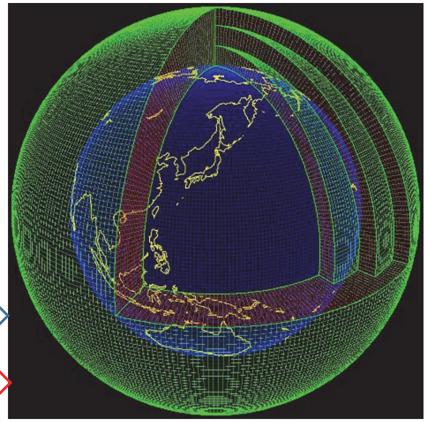
GCM experimental data for present/future climate

Input data:
CMIP5 dataset, etc.

Present Climate Experimental Data (1979-2003)
1 pattern
Initial/Boundary Conditions:
Green house gas (GHG), Sea surface temperature (SST), sea ice, etc.,
based on the observation

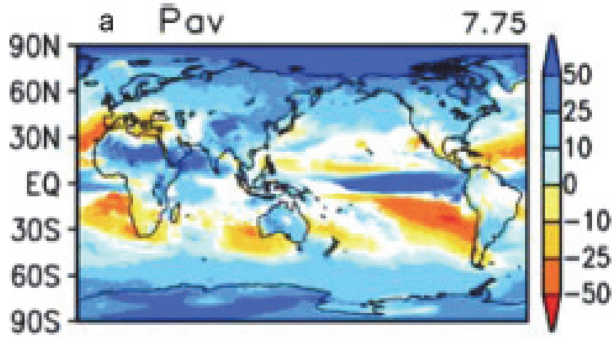
Future Climate Experimental Data (2075-2099)
4 patterns (MME, C1, C2, C3)
Initial/Boundary Conditions:
GHG (RCP8.5), etc.,
4 types of SST & sea ice fields based on 28 GCMs in CMIP5 RCP8.5 experiment (MME, C1, C2, C3)
[Refer next slide]

Atmospheric General Circulation Model:
MRI-AGCM 3.2S



Output:
Precipitation change

Hydrological Effect of Global Warming



(Kitoh & Endo, 2016 WCE)

Merits of MRI-AGCM:
✓Horizontal resolution is higher (20km) than those of coupled GCMs (CGCMs) in CMIP5 (100+km)
→ **Better precipitation (topography, TCs, etc.)**
✓Uncertainty in CGCMs can be separated:
➢Uncertainty of model physics
➢**Uncertainty of SST distribution**

Reference:
✓*Kitoh, A. and H. Endo (2016) Changes in precipitation extremes projected by a 20-km mesh global atmospheric model, Wea. and Clim. Extremes, 11, 41-51, DOI:10.1016/j.wace.2015.09.001.*
✓*Mizuta, R., H. Yoshimura, H. Murakami, M. Matsueda, H. Endo, T. Ose, K. Kamiguchi, M. Hosaka, M. Sugi, S. Yukimoto, S. Kusunoki and A. Kitoh (2012) Climate simulations using MRI-AGCM3.2 with 20-km grid, J. of Meteor. Soc. of Japan, 90A, 233-258, DOI:10.2151/jmsj.2012-A12.*
✓*Mizuta, R., O. Arakawa, T. Ose, S. Kusunoki, H. Endo and A. Kitoh (2014) Classification of CMIP5 future climate responses by the tropical sea surface temperature changes, SOLA, 10, 167-171, DOI:10.2151.sola.2014-035.*

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4 types of Sea Surface Temperature (SST) & sea ice fields based on 28 GCMs in CMIP5 RCP8.5 experiment (MME, C1, C2, C3)

Cluster 1 (C1):

8 MRI-AGCM3.2S models with nearly uniform warming in the both hemispheres

Cluster 2 (C2):

14 models with a larger warming over the central equatorial Pacific (so-called El Niño-like pattern)

Cluster 3 (C3):

6 models with a larger warming in the Northern Hemisphere than in the Southern Hemisphere.

The mean of these 28 CMIP5 models (MME):

a baseline future precipitation while C1, C2 and C3 cases represent climate change uncertainty.

Reference:

✓*Mizuta, R., O. Arakawa, T. Ose, S. Kusunoki, H. Endo and A. Kitoh (2014) Classification of CMIP5 future climate responses by the tropical sea surface temperature changes, SOLA, 10, 167-171, DOI:10.2151.sola.2014-035.*

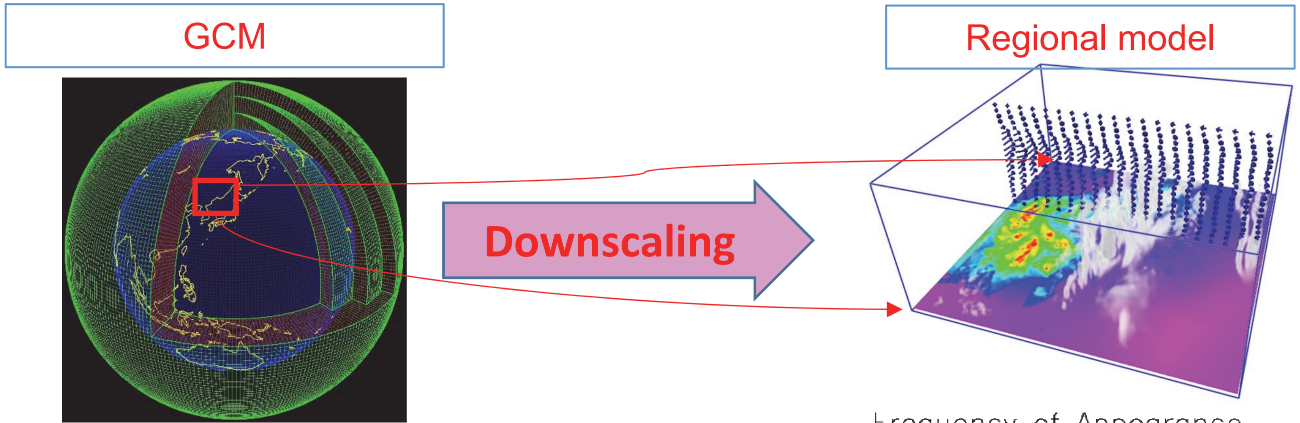
3. Research Methodology

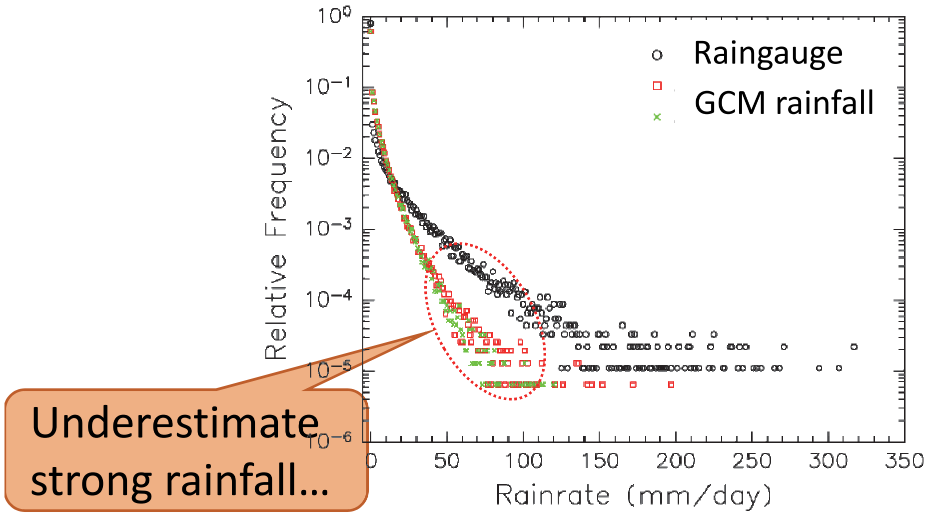
3.1 Rainfall change assessment

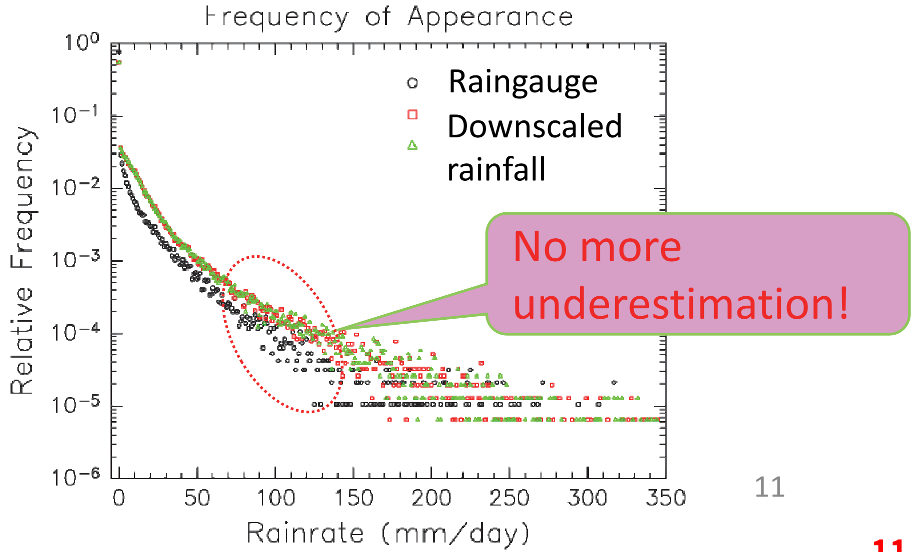
SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

Dynamic downscaling

- General Circulation Model (GCM) is **too coarse** to compute precipitation processes in typically 20-30 km size clouds with the effect of complex terrains.
- Dynamic downscaling by a regional model reproduces **more accurate** rainfall via realistic representation with high resolution model in a limited area.







3. Research Methodology

3.1 Rainfall change assessment

SOUSEI Program for Risk Information on Climate Change
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Bias correction

✓ **Climate models exhibit systematic errors (biases) in their output.**

These errors can be due, among others, to:

- Limited spatial resolution (horizontal and vertical)
- Simplified physics and thermodynamic processes
- Numerical schemes
- Incomplete knowledge of climate system processes

- **Initial GCM result should be tuned to the observation data by bias correction.**
- **The ratio can be used to get bias corrected GCM future value.**

The main assumptions of bias correction methods are:

- Quality of the observations database limits the quality of the correction.
- It is assumed that the bias behaviour of the model does not change with time.
- Limitation: Temporal errors of major circulation systems can not be corrected.

Reference: IS-ENES project Web site *https://climate4impact.eu/impactportal/help/faq.jsp?q=bias_correction*

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3. Research Methodology

3.1 Rainfall change assessment

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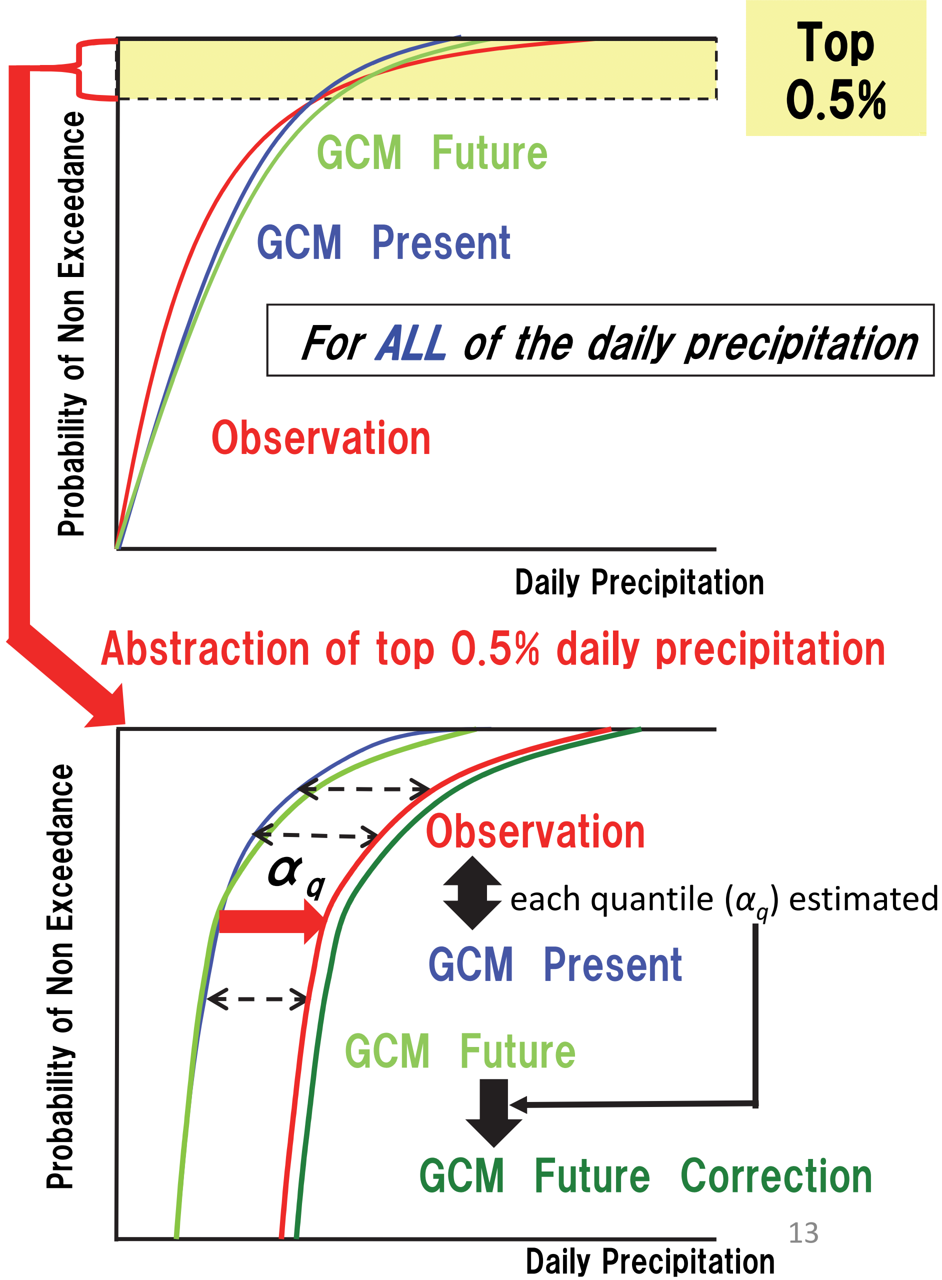
Concept of bias correction method for GCM -Hybrid Method- (1/2)

A) Extreme Value
⇒The samples in top 0.5% of prob. of non exceedance are considered.
B) Other value
⇒They are divided into each month.

①The samples in top 0.5% on probability of non exceedance for observation, GCM Present and GCM Future are abstracted.

②The ratio for each quantile (α_q) between observation (Red line) and GCM Present (Blue line) is estimated.
α_q is regarded as a correction coefficient for each quantile and multiplied to the value of GCM Future (Light Green line) of same quantile and corrected value (Dark green line) is obtained.



Reference:
Inomata, H., K. Takeuchi and K. Fukami (2011) Development of a statistical bias correction method for daily precipitation data of GCM20, J. of Japan Soc. of Civil Engineers, Ser. B1 (Hydraulic Engineering), 67, I_247-I_252, DOI:10.2208/jscejhe.67.I_247.

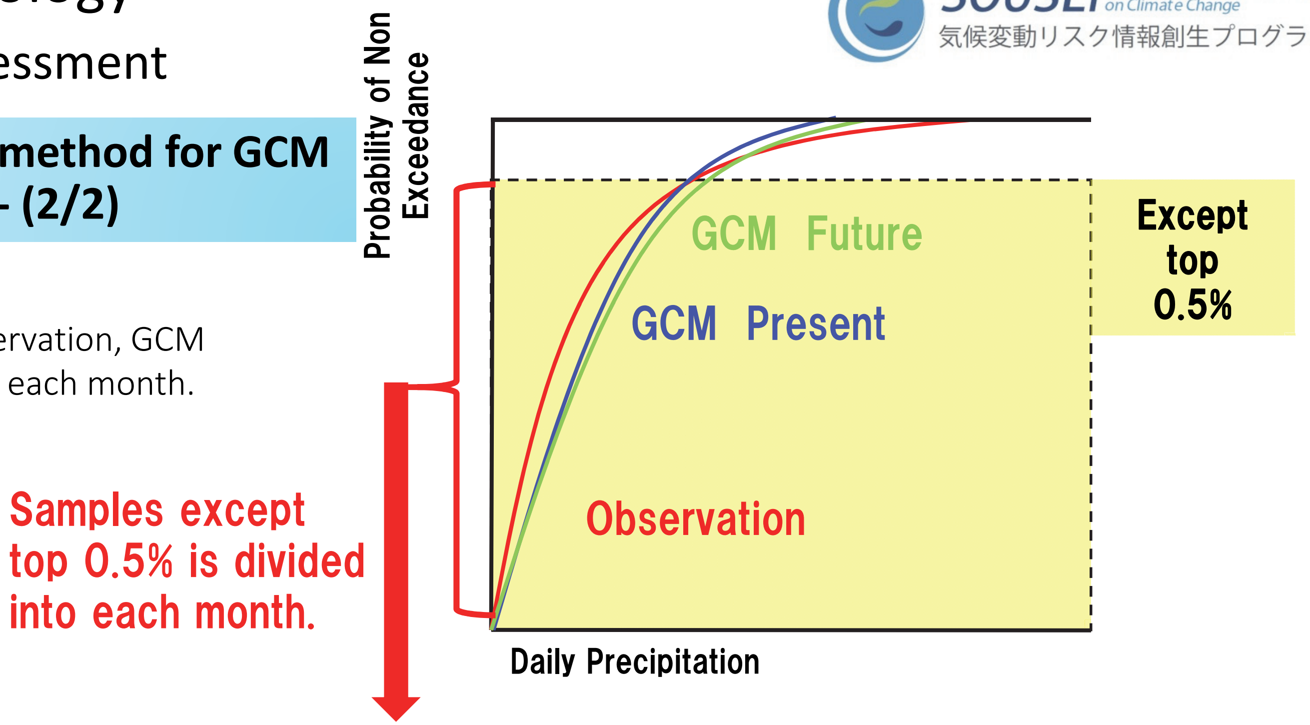
3. Research Methodology

3.1 Rainfall change assessment

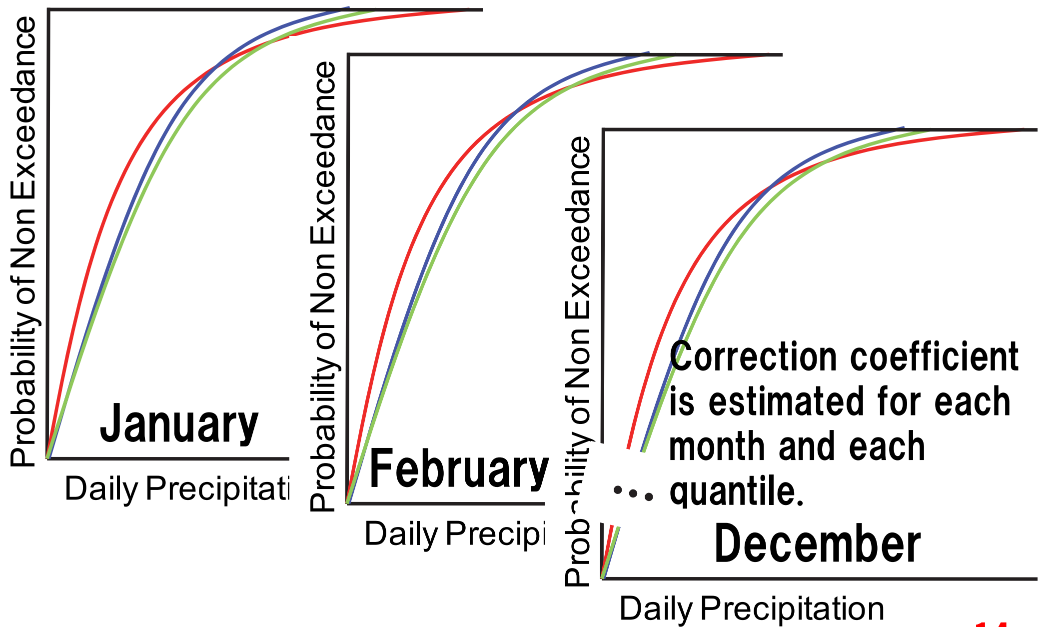
SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

Concept of bias correction method for GCM -Hybrid Method- (2/2)

③Samples except top 0.5% on observation, GCM Present and Future are divided into each month.



④The ratio between observation (**Red line**) and GCM Present (**Blue line**) is estimated <u>for each month</u> and each quantile (α_{m_q}).
α_{m_q} is regarded as correction coefficient and multiplied to GCM Future of same month and same quantile (**Light Green line**) and corrected value is obtained.



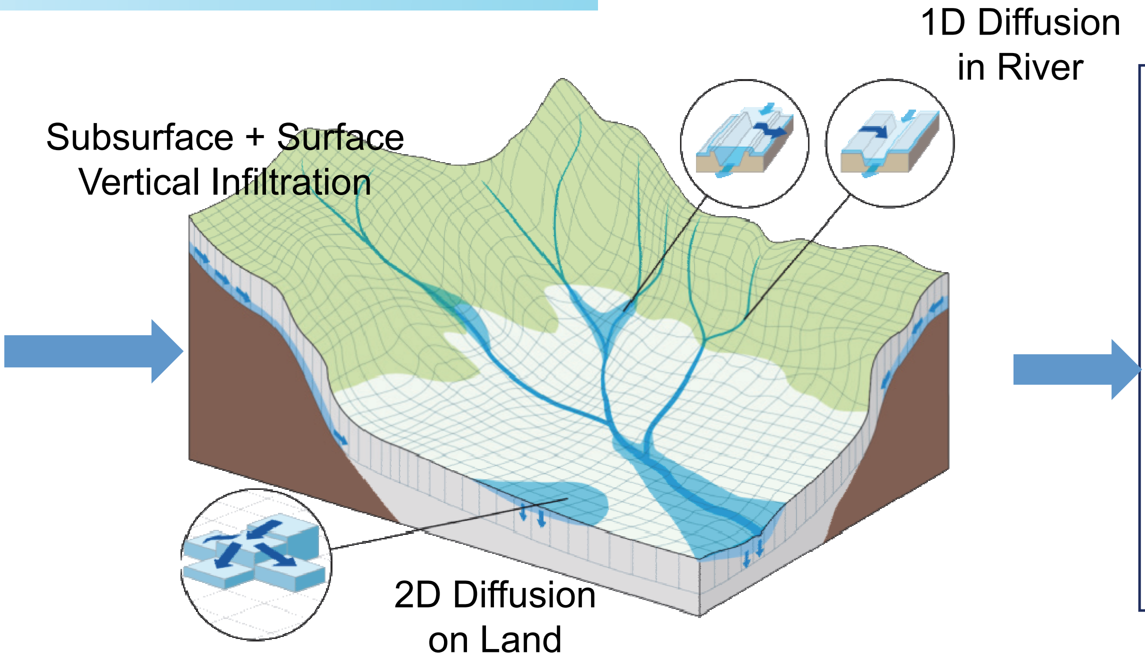
Reference:
Inomata, H., K. Takeuchi and K. Fukami (2011) Development of a statistical bias correction method for daily precipitation data of GCM20, J. of Japan Soc. of Civil Engineers, Ser. B1 (Hydraulic Engineering), 67, I_247-I_252, DOI:10.2208/jscejhe.67.I_247.

3. Research Methodology 3.2 Flood risk assessment

Rainfall-Runoff-Inundation Model (RRI model)

Input

- Rainfall
- DEM
- Land Cover
- Cross Sec.



Output

- Discharge
- W. Level
- Inundation

- Two-dimensional model capable of simulating rainfall-runoff and flood inundation simultaneously
- The model deals with slopes and river channels separately
- At a grid cell in which a river channel is located, the model assumes that both slope and river are positioned within the same grid cell

Reference:
Takahiro Sayama, Go Ozawa, Takahiro Kawakami, Seishi Nabesaka & Kazuhiko Fukami et al.: Rainfall-Runoff-Inundation Analysis of Pakistan Flood 2010 at the Kabul River Basin, Hydrological Sciences Journal, 57(2), pp. 298-312, 2012.

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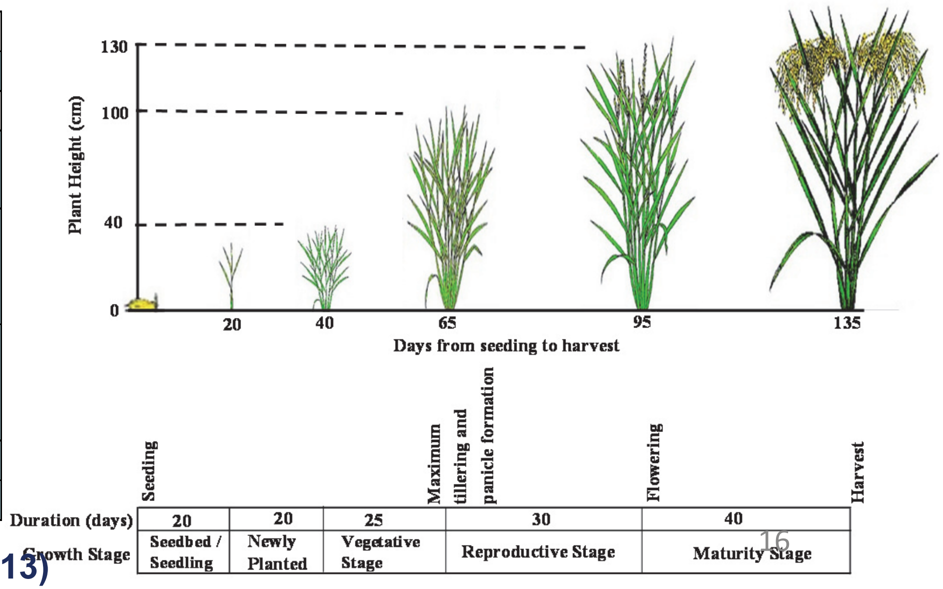
Process of Damage Assessment (Damage to Rice-Crops)

Growth Stage of Rice	Calculation Method
Seedbed / Seedling 20 days from palay germination	***Value of production losses*** = Area affected x Cost of input / hectare x yield loss
Newly Planted Stage 1-20 days after sowing	
Vegetative Stage (21-45 days)	
Reproductive Stage (46-75 days)	***Value of Production Losses*** = Volume of losses x most recent farm gate price ***Volume of losses*** = Most recent yield/hectare x area damaged x Yield loss
Maturing Stage (76-115 days)	

Flood damage matrix: Rice-crops Damage

Growth stage	Days of submerge			
	1-2	3-4	5-6	7
	Estimated yield loss (%)			
Vegetative stage: Minimum Tillering /Maximum Tillering	10-20	20-30	30-50	50-100
Reproductive Stage: Panicle Initiation/Booting Stage (Partially Inundated)	10-20	30-50	40-85	50-100
Reproductive Stage: Panicle Initiation/Booting Stage (Completely Inundated)	15-30	40-70	40-85	50-100
Maturity Stage: Flowering stage	15-30	40-70	50-90	60-100
Ripening Stage	5	10-20	15-30	15-30

Days and plant height of rice crops at its each stage



Source: Bureau of Agricultural Statistics, Philippines (2013)

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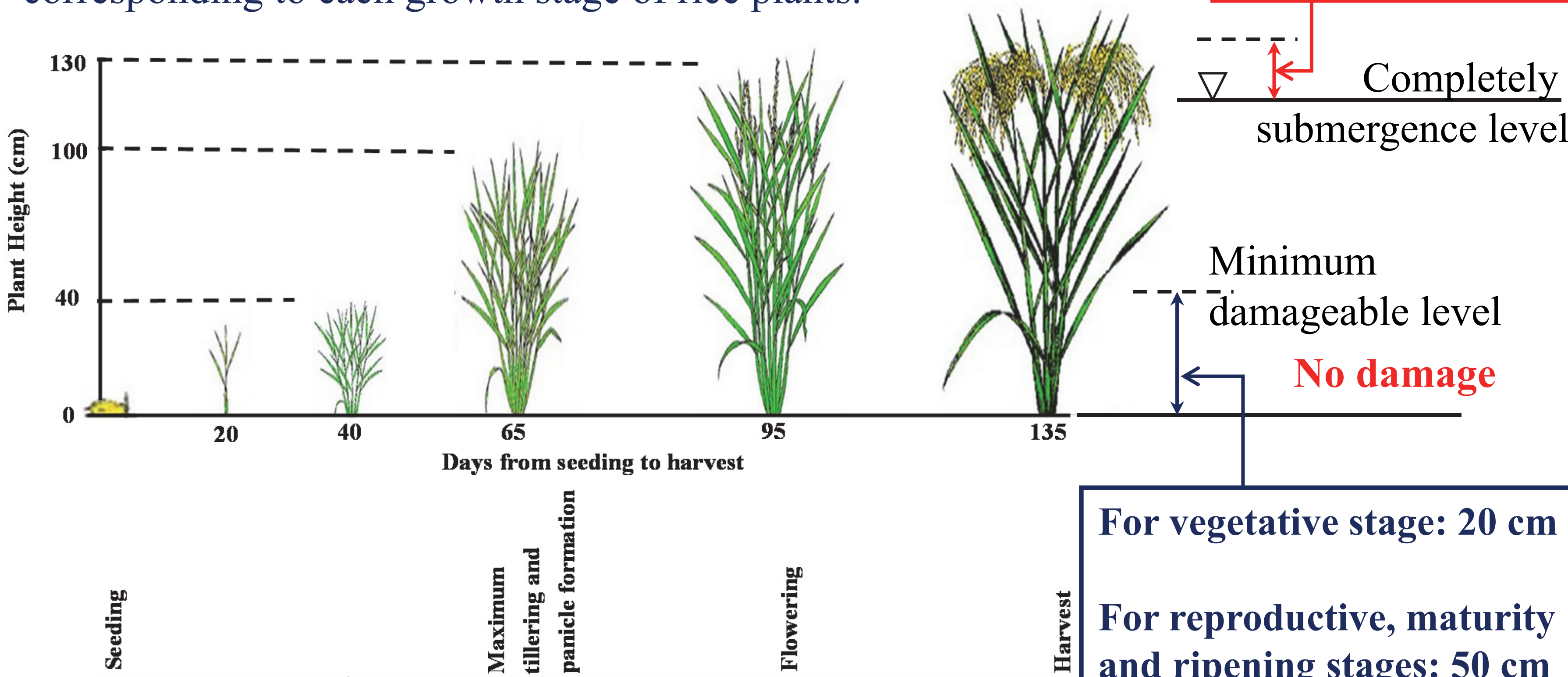
Development of Flood Damage Curves (Rice-Crops)

- Flood damage curves as a function of flood depth and duration are proposed based on linear interpolation of flood damage matrix data by introducing minimum damageable flood depth and by considering partial or complete submergence water surface levels corresponding to each growth stage of rice plants.

Assumed: 10 cm (9 to 15 cm, BAS, 2013)



For vegetative stage: 20 cm

For reproductive, maturity and ripening stages: 50 cm

Duration (days)	20	20	25	30	40
Growth Stage	Seedbed / Seedling	Newly Planted	Vegetative Stage	Reproductive Stage	Maturity Stage

Source: International Rice Research Institute (IRRI, 2009)

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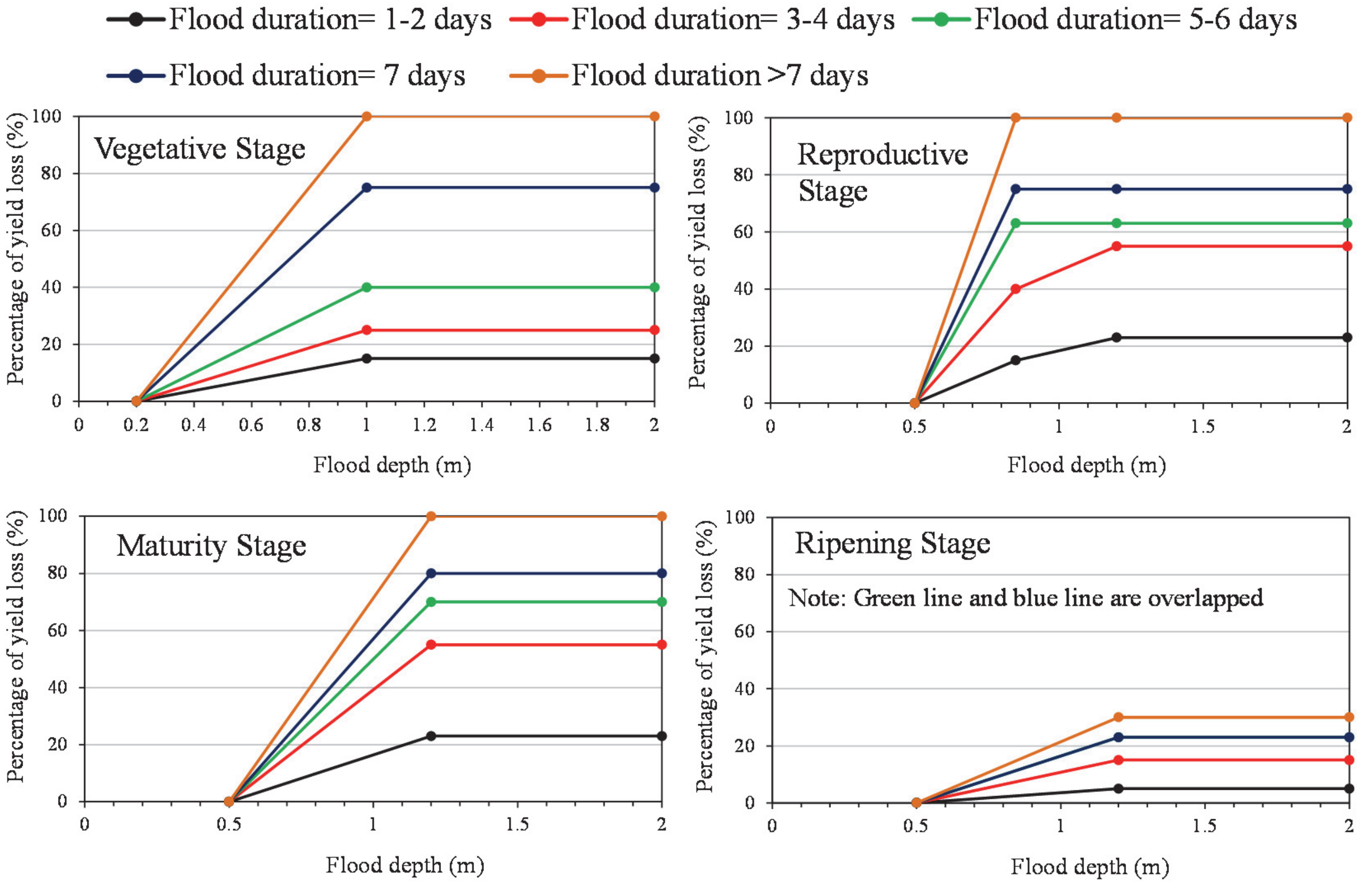
Development of Flood Damage Curves (Rice-Crops) (Cont.)

ICHARM's Damage Curve

The damage curve can consider growth stage, flood depth, and flood duration.

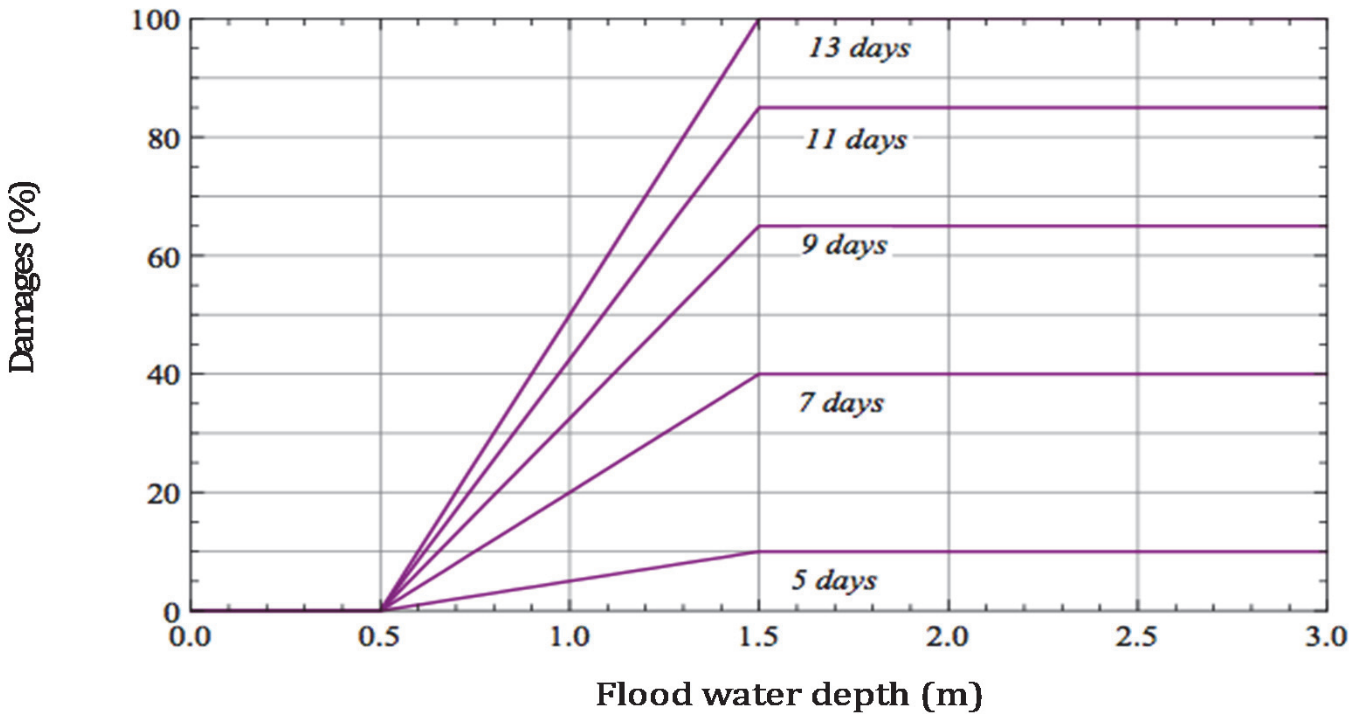


Reference: *Shrestha, B. B., Okazumi, T., Mamoru, M. and Sawano, H.: Flood damage assessment in the Pampanga river basin of the Philippines, Journal of Flood Risk Management, Vol. 9, No. 4, pp.355-369, 2016. DOI: 10.1111/jfr3.12174*

Application of another agricultural damage curves by MRC

For flood risk assessment in the Lower Mekong River, we applied two different damage curve (by MRC and by ICHARM) and compared.

Rice crop flood damage curve, Mekong River Commission Secretariat



Note: If the inundation duration is lower than 4 days, no inundation damage occurs

Source: FMMP (2010): Flood damages, benefits and flood risk in focal areas, Flood Management and Mitigation Programme. Component 2: Structural Measures and Flood Proofing in the Lower Mekong Basin, Report, Vol. 2C.

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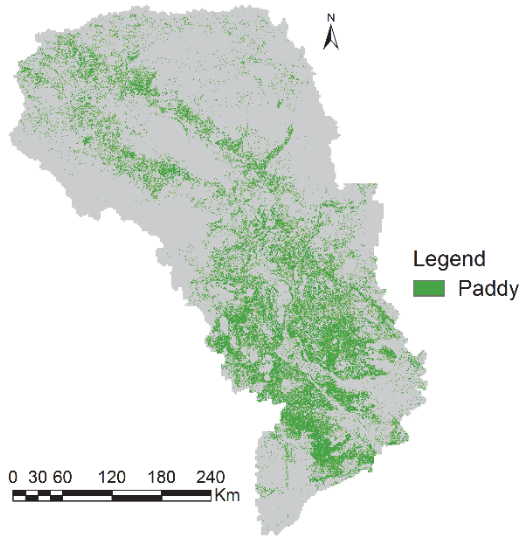
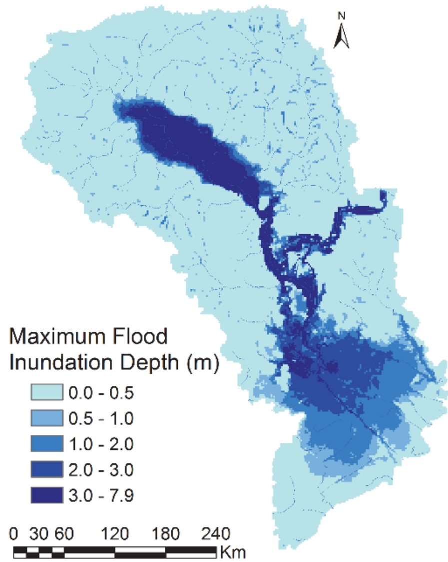
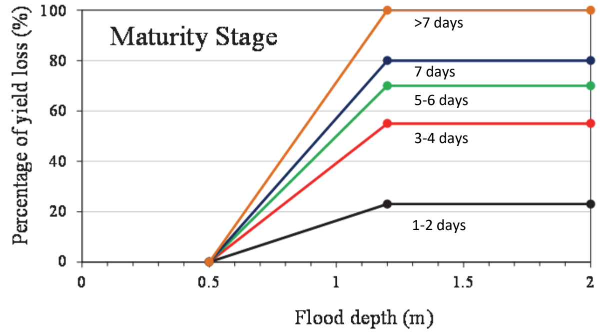
Schematic of agricultural damage value calculation (Rice production)

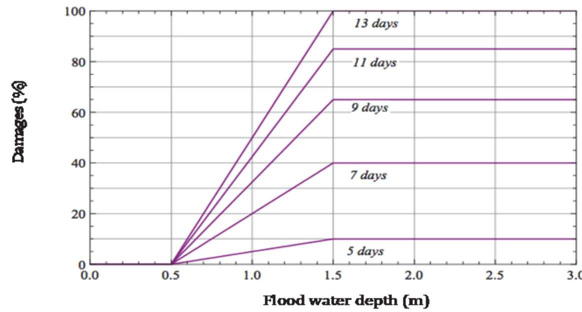




ICHARM's Damage Curve



MRC's Damage Curve



Paddy field area (Global data)

Inundation area, depth, duration by RRI model

Damage curve for rice production

Value of farm gate price (924 Riel/kg)*

Rice yield (2,500 kg/ha)**

Agricultural economic loss

Sources:
. Department of Rice Crop, Cambodia, 2013*

4. Research Result

4.1 Rainfall change assessment

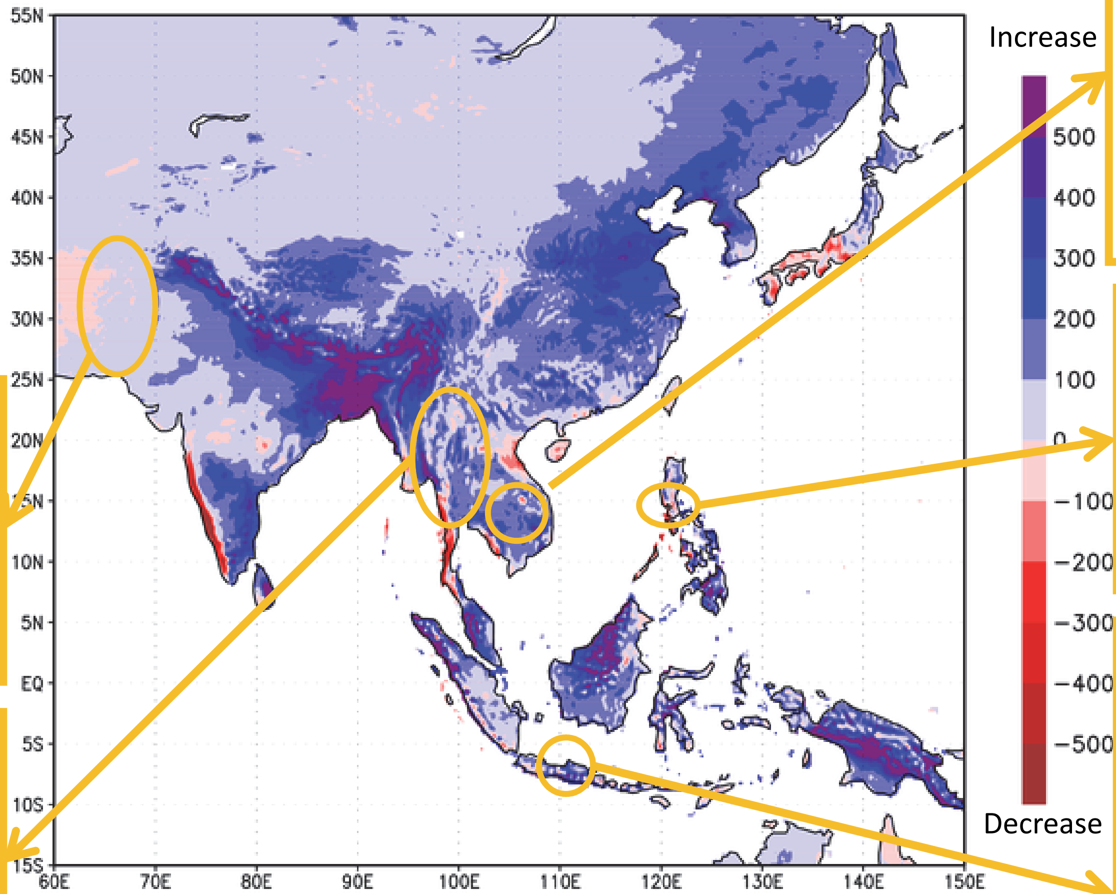
SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

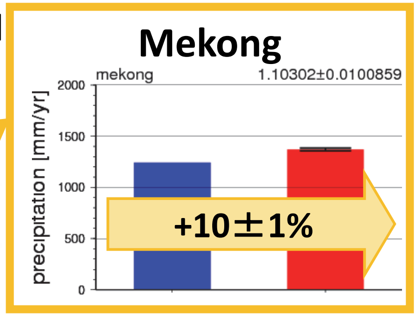
Analysis result –Comparison of 5 river basin- (1/2)

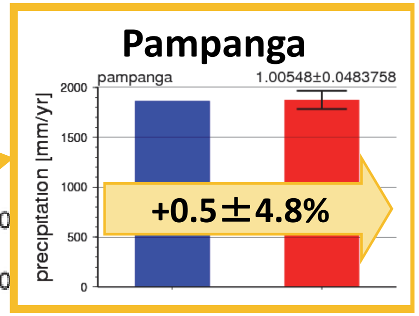
Difference in <u>average yearly precipitation</u> between present and future climate for 4 Sea Surface Temperature (SST) patterns (MME, C1, C2, and C3)

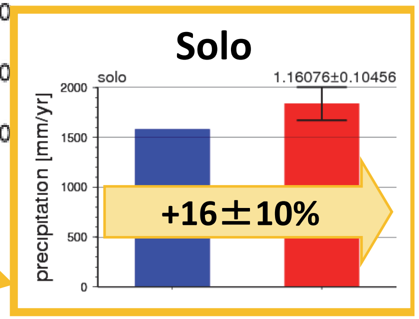
Basin average yearly precipitation
- **Present Climate (1979-2003)**
- **Future Climate (2075-2099)**

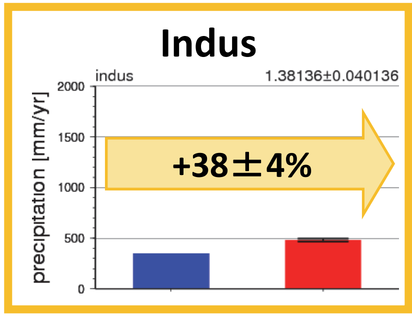
Average and standard deviation in 4 SSTs

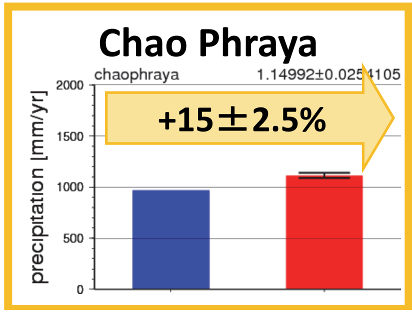












4. Research Result

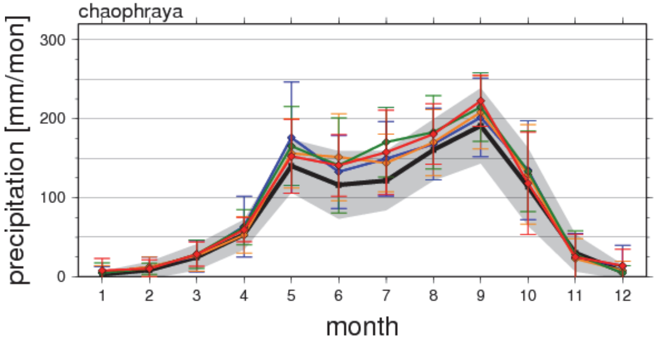
4.1 Rainfall change assessment

SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

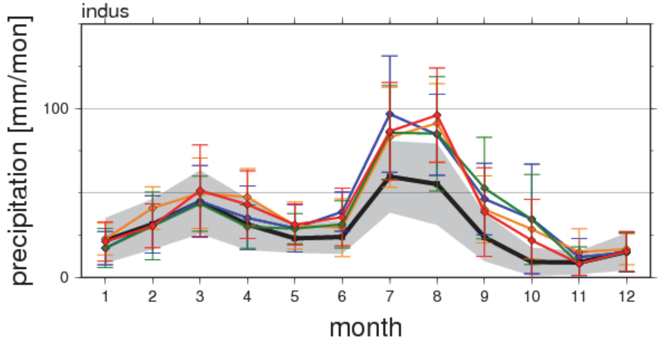
Analysis result –Comparison of 5 river basin- (2/2)

Comparison of average monthly precipitation between present and future climate or 4 SST patterns (MME, C1, C2, and C3)

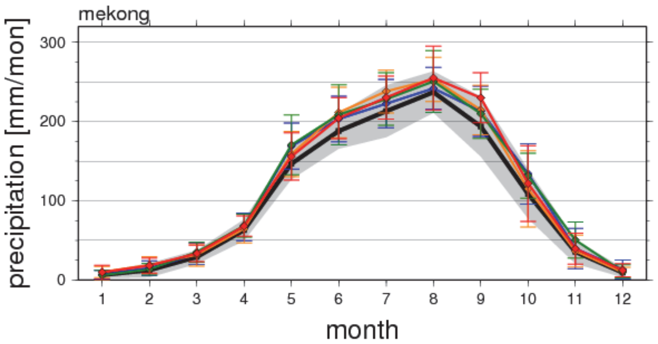
Chao Phraya



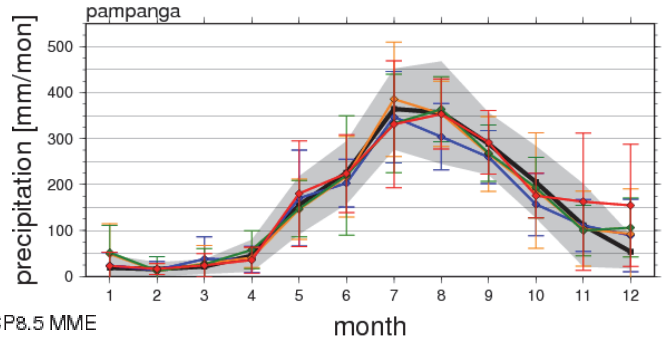
Indus



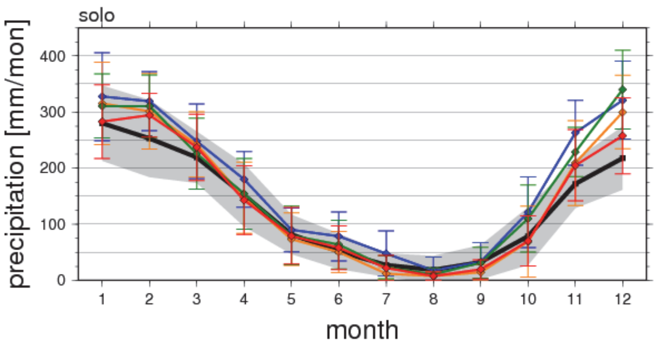
Mekong

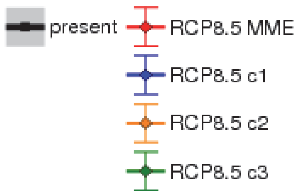


Pampanga



Solo





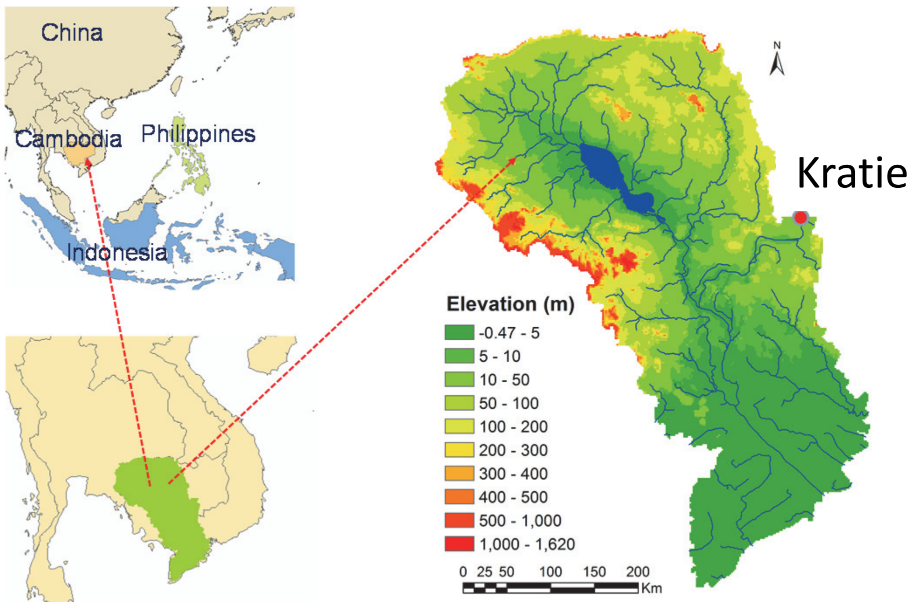
Reference: *Iwami et al, Comparative study on climate change impact on precipitation and flood in the Asian river basins (2016), HRL*

4. Research Result

SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

Lower Mekong River Basin: General Features

Location of study area (151,408 km^2)

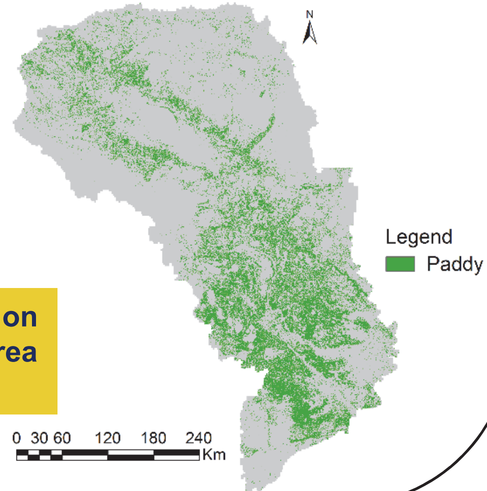


Lower Mekong Basin in Cambodian Floodplain

Paddy field area

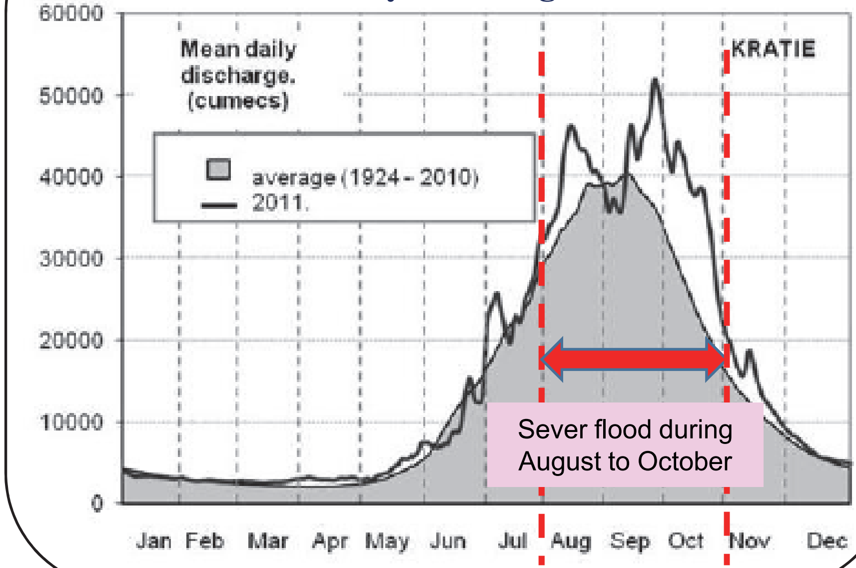
Data Source: Global Land Cover (GLCNMO),
International Steering Committee for Global Mapping
(Resolution: 15 arc-second)

Total paddy area based on GLCNMO in the study area =2,959,639 ha

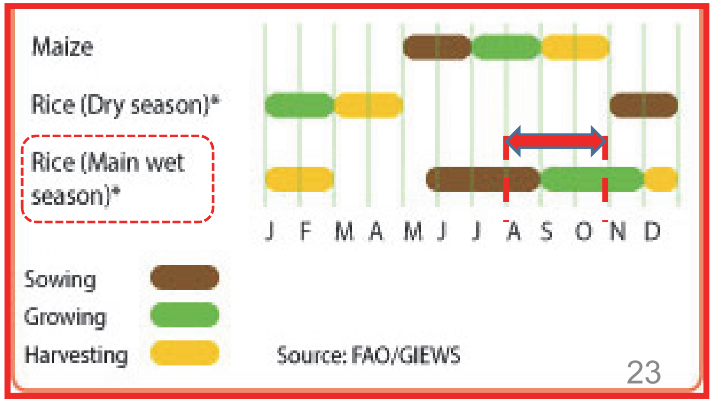


2011 Flood

Mean daily Discharge at Kratie



Cambodia Cropping Calendar



4. Research Result

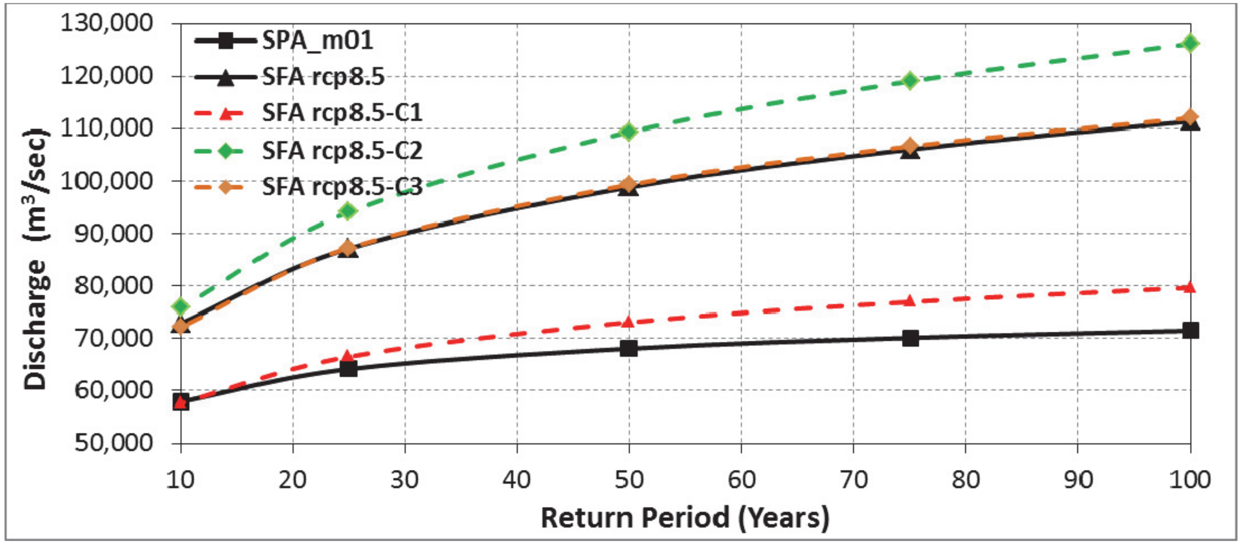
4.1 Rainfall change assessment

SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

Table: Summary results of frequency analysis

MRI-AGCM Experiment	50 year return period rainfall (mm/4 months)	100 year return period rainfall (mm/4 months)
Present	40.6	41.9
Future (RCP8.5 MME)	45.3	46.3
Future (RCP8.5 C1)	42.4	43.6
Future (RCP8.5 C2)	45.4	46.6
Future (RCP8.5 C3)	45.6	47.3

Figure: Return periods for Kratie discharges for climatic experiments based on GEV distribution



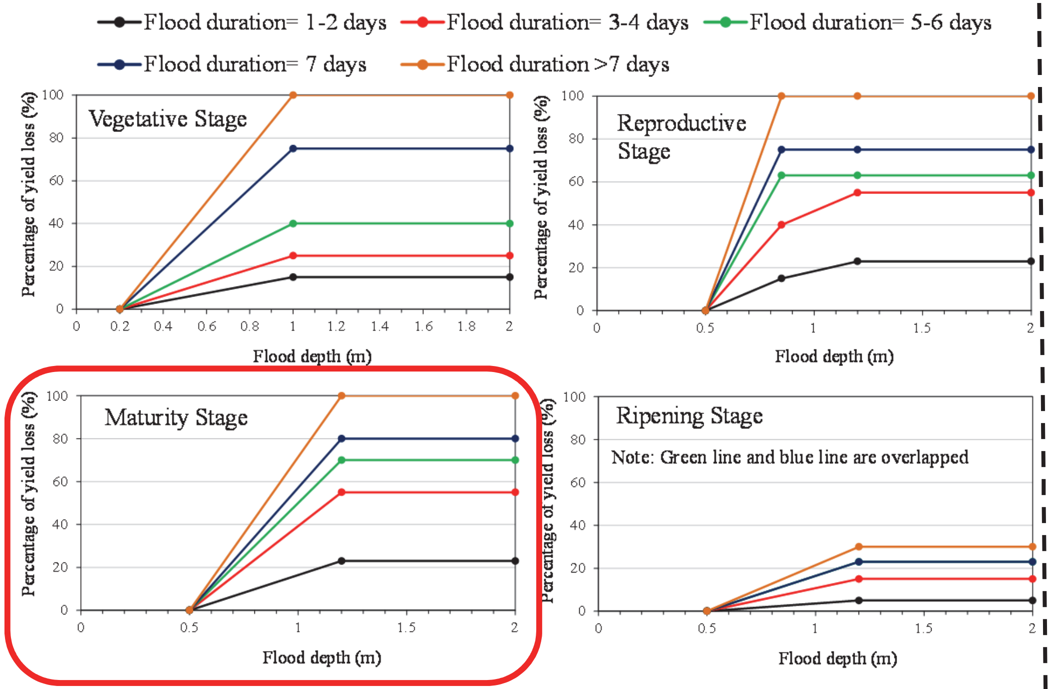
4. Research Result

4.2 Flood risk assessment

SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

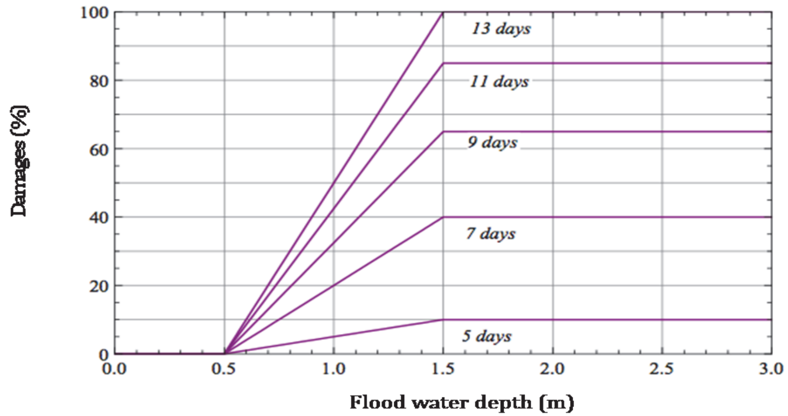
For flood risk assessment in the Lower Mekong River, we applied two different damage curve (by MRC and by ICHARM) and compared.

ICHARM's Damage Curve



Based on the severe flood period (Aug. – Oct.) and the cropping calendar, the damage curve of "Maturity stage" is applied.

MRC's Damage Curve



<u>*Note: If the inundation duration is lower than 4 days, no inundation damage occurs*</u>

4. Research Result

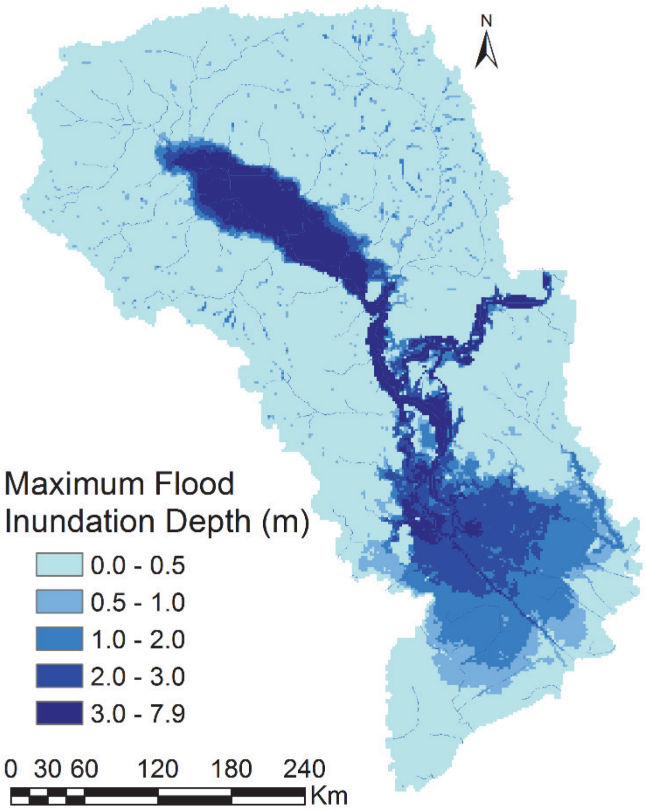
4.2 Flood risk assessment

SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

Verification of reproduction of past flood inundation by RRI Model

Flood event: 2011 (Largest Recorded Flood Event)

Composite of Maximum Flood Inundation Depth calculated by RRI Model



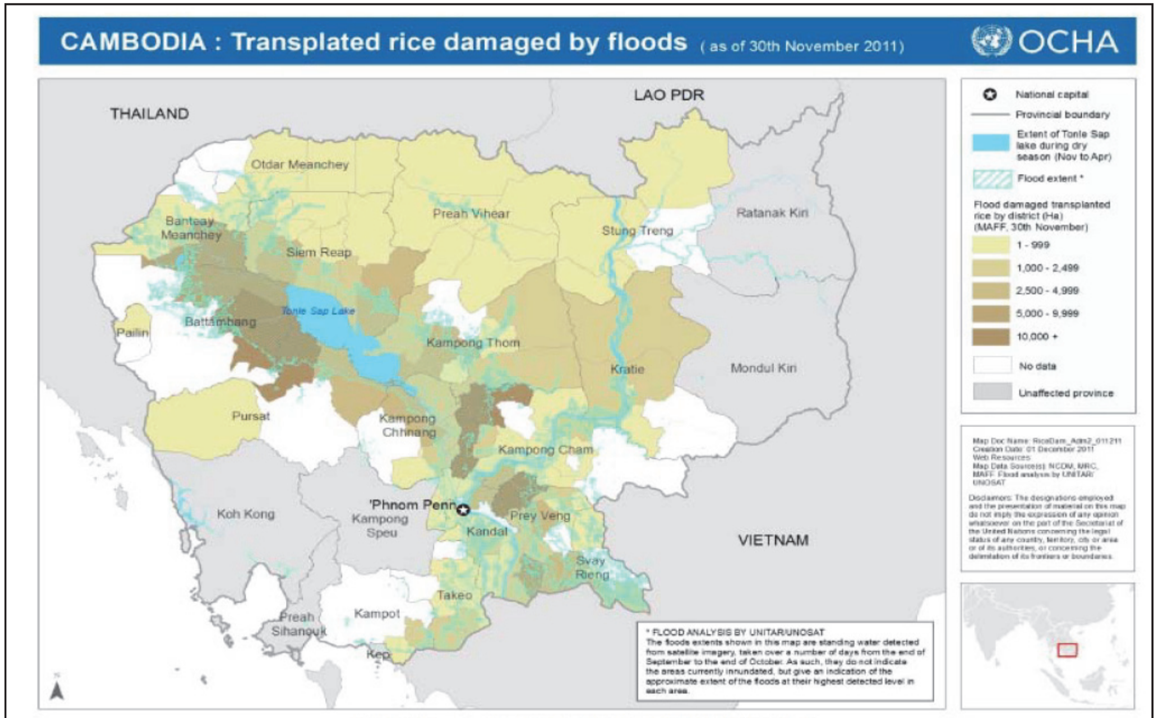


Figure 6. Damaged transplanted rice by district (MAFF, 30 Nov)

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4. Research Result

4.2 Flood risk assessment

SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

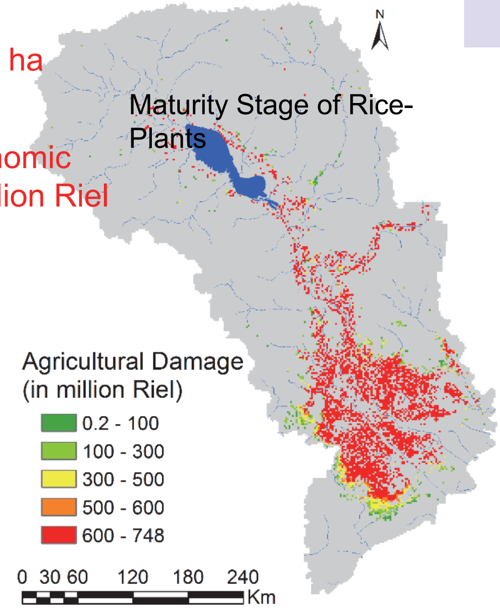
Estimation of 2011 flood damage using 2 different damage curve

2011 Flood

By ICHARM's Damage Curve

Damage area:1,314,144 ha

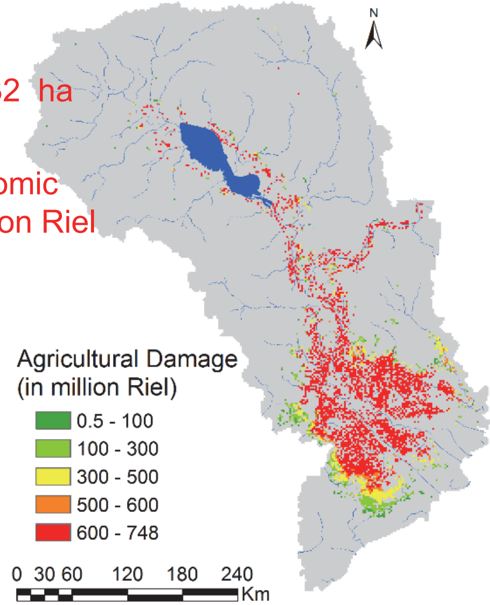
Estimated economic loss: 2637.3 billion Riel



By MRC's Damage Curve

Damage area:1,285,632 ha

Estimated economic loss: 2468.3 billion Riel



Rice Crop Damages in Cambodian Floodplain (million USD)		
Reported[#1]	Calculated Using ICHARM's Damage Curve	Calculated Using MRCS's Damage Curve
178.8	**189.1**	**178.0**

[#1] "Flood Damage Emergency Reconstruction Project, Preliminary Damage and Loss Assessment", ADB, 2012

Yield = 2500 kg/ha (source: Department of Rice Crop, Cambodia)
Farm get price = 924 Riel/kg (source: Department of Rice Crop, Cambodia)

4. Research Result

4.2 Flood risk assessment

SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

Estimation of 2011 flood damage using 2 different damage curve (Cont.)

Comparison of calculated damage area with reported data (Cambodian Floodplain)

Province	Reported damage area (ha)			Calculated damage area (using ICHARM's Damage Curve)	Calculated damage area (using MRCS's Damage Curve)
	MRC#1	ADB#2	Average		
Banteay Meanchey	18894	2000	**10447**	1620	1620
Battambang	35000	51000	**43000**	14580	13284
Kampong Cham	20049	23000	**52698**	58320	57996
Kampong Chhnang	11166	8000	**9583**	33048	33048
Kampong Thom	69396	36000	**52698**	30780	22356
Kampot	3254	-	**3254**	648	648
Kandal	5770	5000	**5385**	69984	68688
Kratie	5191	5000	**5096**	7452	7452
Phnom Penh	681	-	**681**	2268	1944
Pursat	17940	15000	**16470**	10368	8424
Prey Veng	47268	50000	**48634**	75816	75492
Siem Reap	15120	16000	**15560**	20412	18468
Svay Rieng	7761	10000	**15560**	12960	11016
Takeo	5566	5000	**5283**	44712	43416
Preah Vihear	2018	3000	**2509**	5832	2592

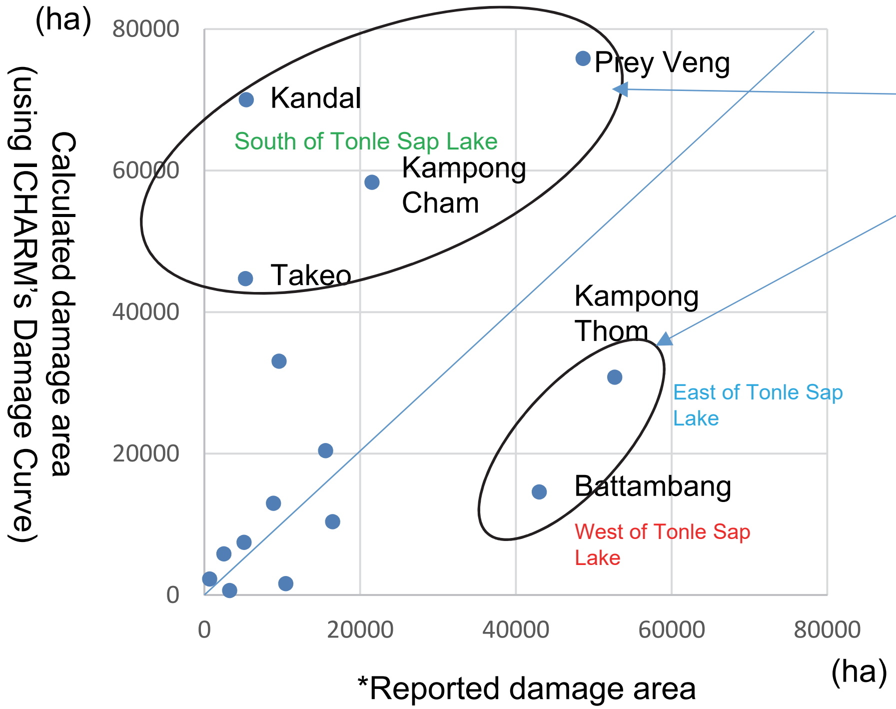
#1 "Annual Mekong Flood Report 2011", Flood Management and Mitigation Programme, MRC, 2014
#2 "Flood Damage Emergency Reconstruction Project, Preliminary Damage and Loss Assessment", ADB, 2012

4. Research Result

4.2 Flood risk assessment

Estimation of 2011 flood damage using 2 different damage curve (Cont.)

Comparison of calculated damaged area (by ICHARM's curve) and reported flood damaged area



- The south provinces of the Tonle Sap Lake are <u>overestimated</u>
- The east and west provinces of the Tonle Sap Lake are <u>underestimated</u>

(Reference: Rice damaged area by flood (ha) for each district Including inundation area)

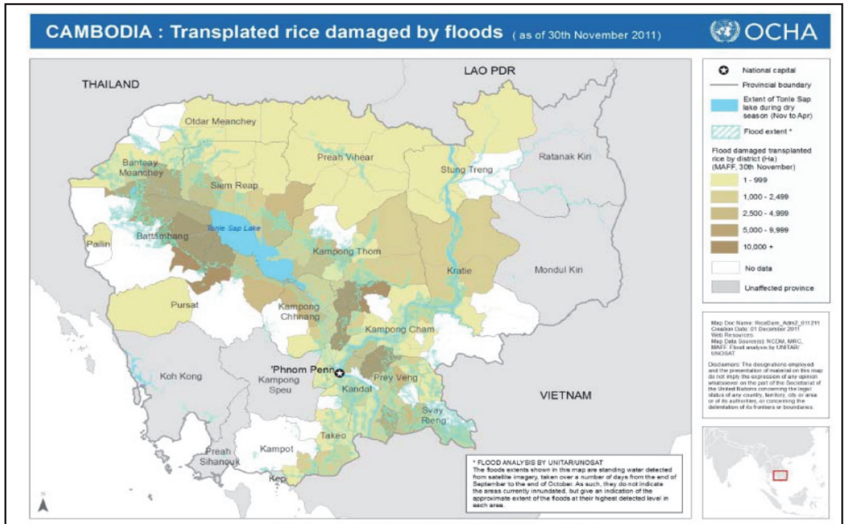


Figure 6. Damaged transplanted rice by district (MAFF, 30 Nov)

*Reported damage area is average of the following two report;

- [#1] "Annual Mekong Flood Report 2011", Flood Management and Mitigation Programme, MRC, 2014
- [#2] "Flood Damage Emergency Reconstruction Project, Preliminary Damage and Loss Assessment", ADB, 2012

4. Research Result

4.2 Flood risk assessment

SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

Estimation of 2011 flood damage using 2 different damage curve (Cont.)

Comparison of calculated damaged area (by ICHARM's curve) and reported flood damaged area

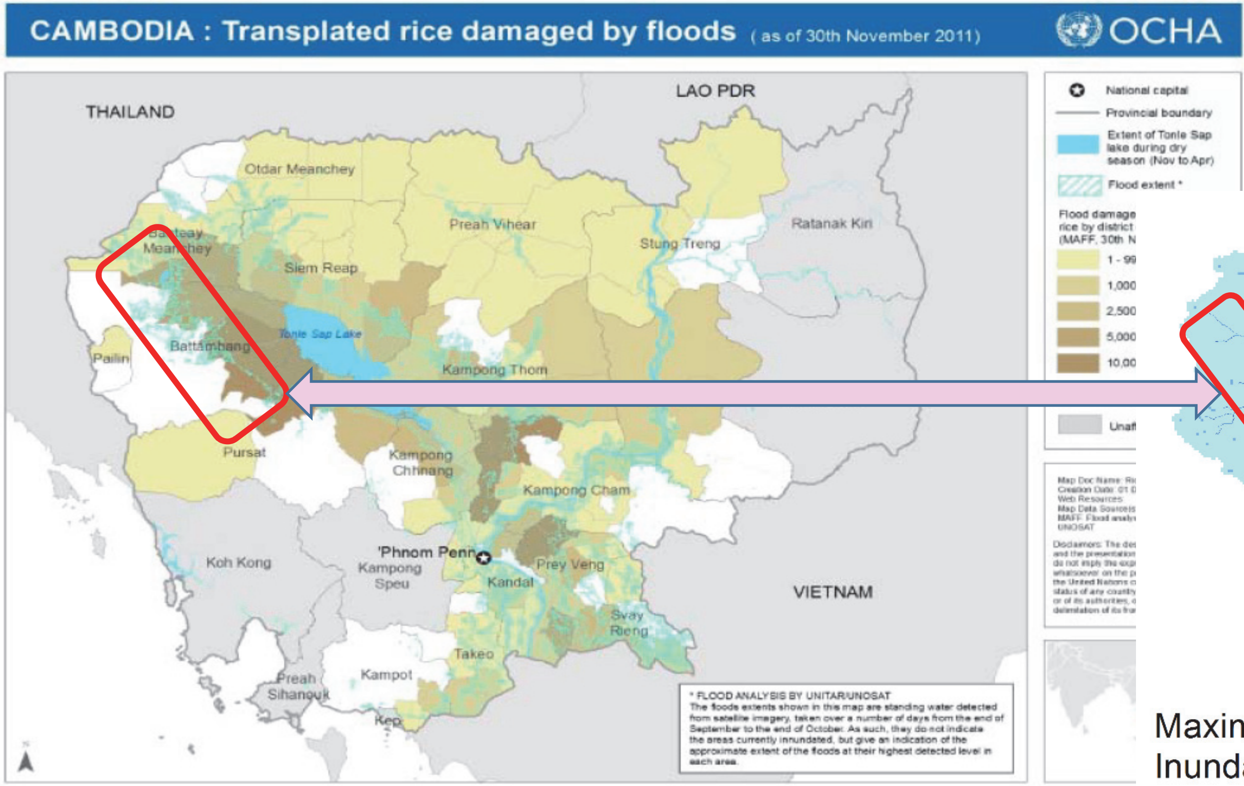
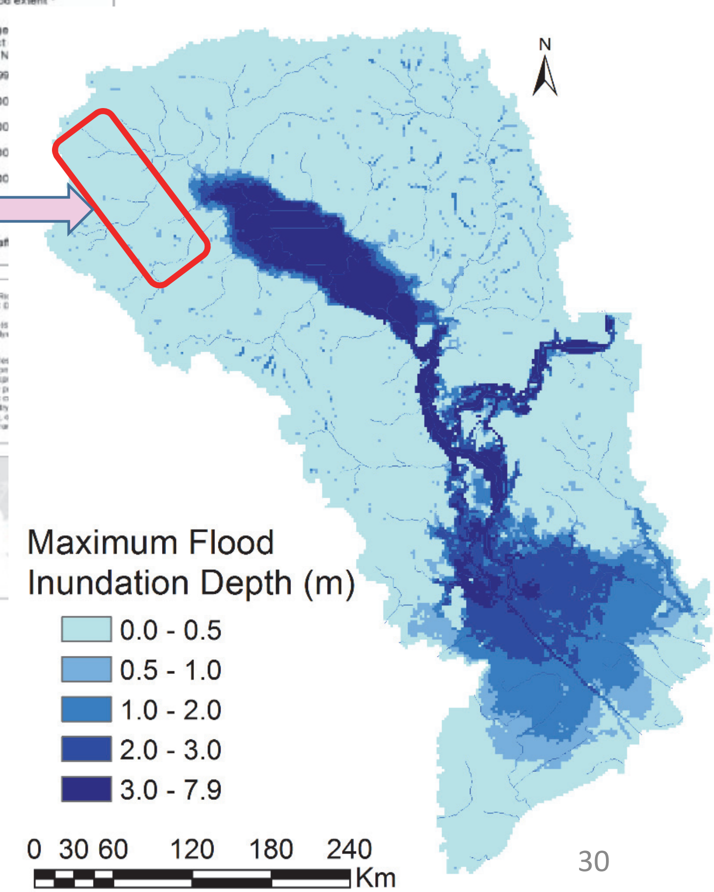


Figure 6. Damaged transplanted rice by district (MAFF, 30 Nov)

Rice damage by flood for each district Including inundation area

RRI simulation result



Actual inundation area is not reproduced by RRI model well

Methodology of flood risk assessment considering various hazard patterns for present/ future climate

Lower Mekong Version

Step 1: Reproduction of daily rainfall patterns for present/future 25 years.

Step 2: Calculation of accumulated basin rainfall volume for fixed flood period (Lower Mekong: 4 months) .

Step 3-1: Abstraction of 5 rainfall patters with 5 highest daily precipitation from each climate data

Step 3-2: Calculation of the accumulated rainfall volume for 50-year and 100- year return period.

Step 4: Extension of the each 5 abstracted rainfall patterns to the level which rainfall amount is equal to the calculated ones by Step 3-2.

Step 5: Inundation analysis by RRI model for each extended rainfall patterns.
(for 50-year and 100-year return period, for present and future (totally 5 patterns × 5 climate (Present, Future MME, Future C1, Future C2, Future C3) × 2 (return period) =50 inundation area

Step 6: Calculation of damaged agricultural areas and agricultural economic loss considering each maximum inundation areas.

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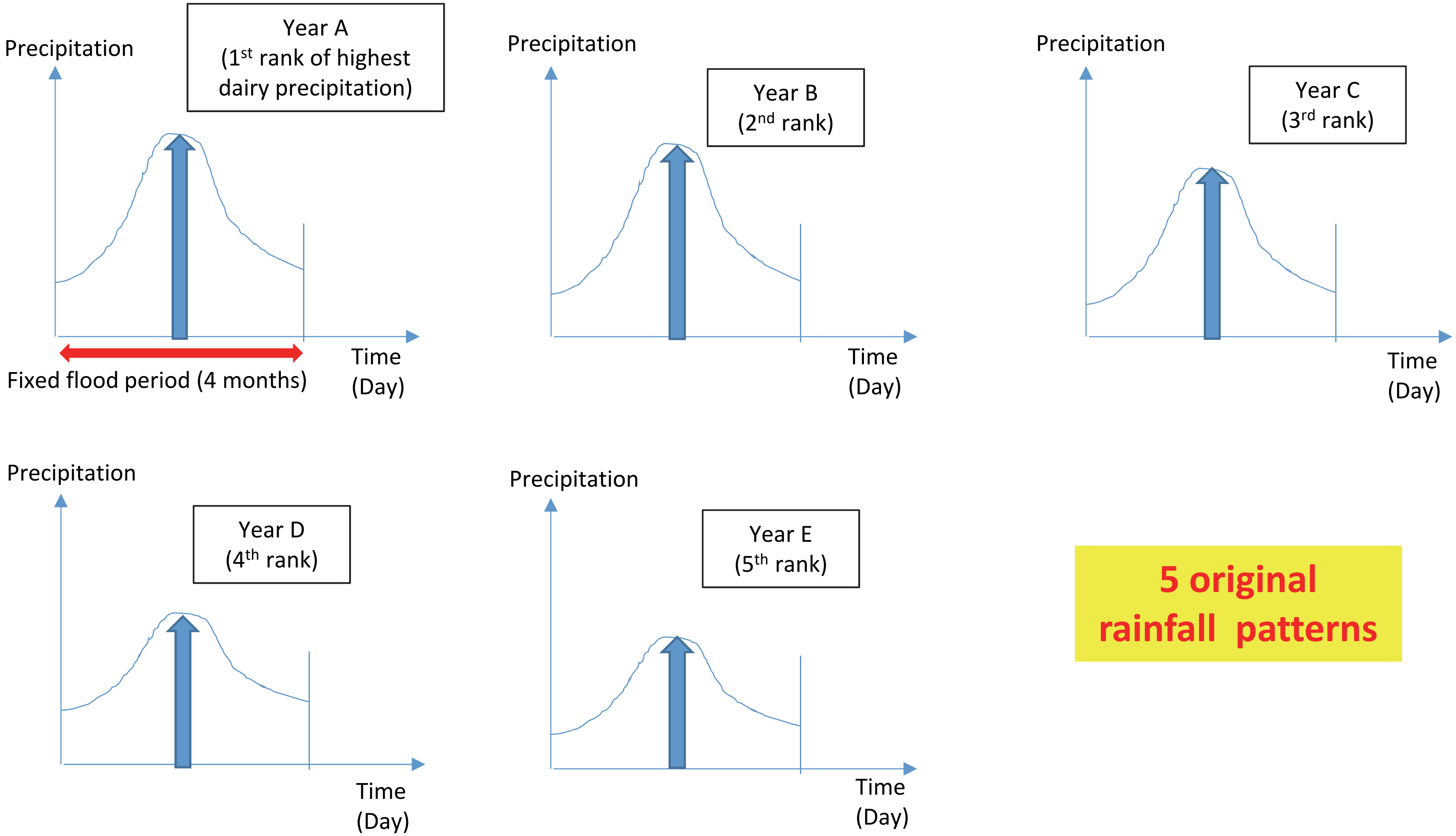
4. Research Result 4.2 Flood risk assessment

SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

Methodology of flood risk assessment considering various discharge patterns for present/ future climate

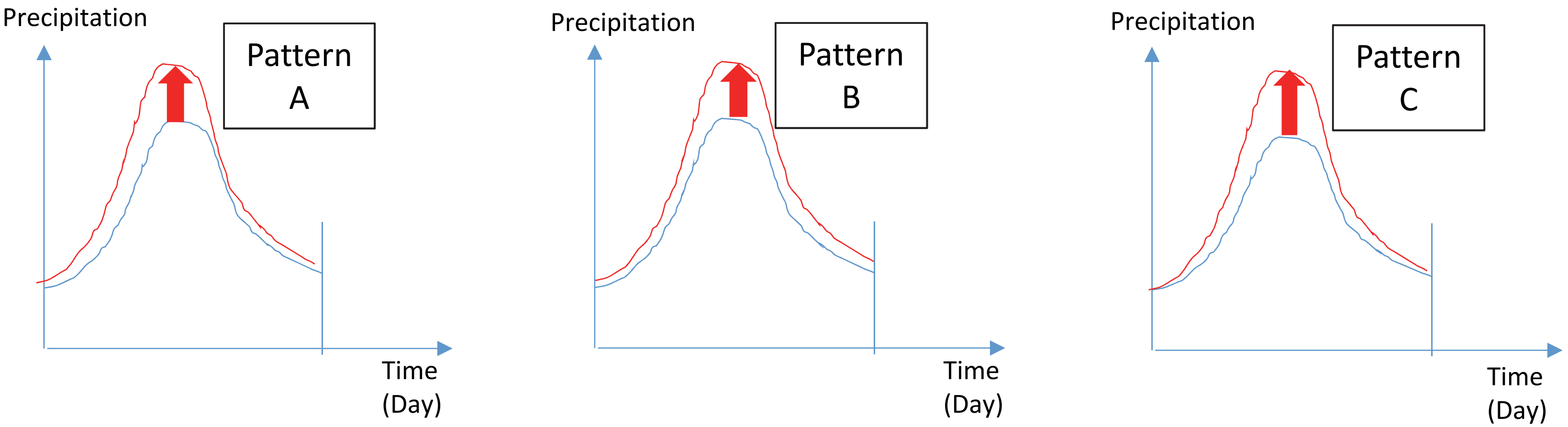
Step 3-1:
Abstraction of 5 rainfall patters with 5 highest dairy precipitation

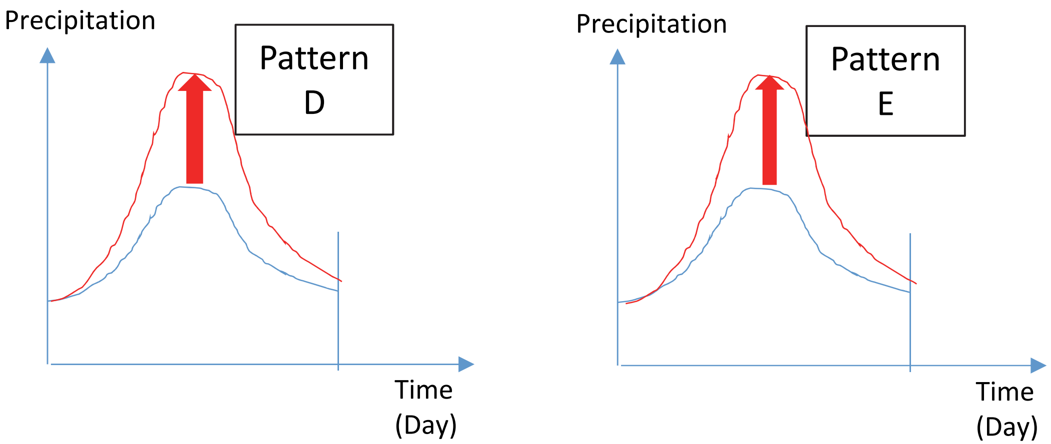


4. Research Result 4.2 Flood risk assessment

Methodology of flood risk assessment considering various precipitation patterns for present/ future climate

Step 4:
Extension of the each 5 abstracted rainfall patterns to the level which rainfall amount is equal to the calculated ones by Step 3-2.





Different 5 rainfall patterns corresponding to same rainfall volume

4. Research Result

SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

4.2 Flood risk assessment

Agricultural damage assessment: with 5 different rainfall patterns chosen from each climate (Original Rainfall)

Present Climate: (1979-2003)

Rainfall pattern	4-month rainfall value (mm)	Damaged agricultural area (ha)	Agricultural economic loss (billion Riel)
A	41	**1128492**	**2231.8**
B	38	1056240	2001.1
C	37	1020924	1910.5
D	37	951588	1604.3
E	37	935388	1575.3
Average	38	1018526.4	1864.6

Future Climate: RCP 8.5 MME (2075-2099)

Rainfall pattern	4-month rainfall value (mm)	Damaged agricultural area (ha)	Agricultural economic loss (billion Riel)
A	44	1236384	2476.2
B	43	1309932	2660.3
C	43	1230876	2484.1
D	42	**1315116**	**2688.5**
E	41	1122984	2194.7
Average	43	1243058.4	2500.7

Future Climate: RCP 8.5 C1 (2075-2099)

Rainfall pattern	4-month rainfall value (mm)	Damaged agricultural area (ha)	Agricultural economic loss (billion Riel)
A	41	**1158300**	**2263.9**
B	39	1130760	2220.8
C	39	1145016	2251.8
D	39	1127196	2176.1
E	38	1125252	2123.5
Average	39	1137304.8	2207.2

Future Climate: RCP 8.5 C2 (2075-2099)

Rainfall pattern	4-month rainfall value (mm)	Damaged agricultural area (ha)	Agricultural economic loss (billion Riel)
A	43	**1232496**	**2436.4**
B	43	1195236	2308.7
C	42	1078272	2062.3
D	41	1061100	2028.9
E	41	1099656	2139.1
Average	42	1133352.0	2195.1

Future Climate: RCP 8.5 C3 (2075-2099)

Rainfall pattern	4-month rainfall value (mm)	Damaged agricultural area (ha)	Agricultural economic loss (billion Riel)
A	45	1203984	2394.8
B	44	1058184	2033.0
C	42	**1340712**	**2583.6**
D	41	1110996	2173.7
E	41	1091880	2095.0
Average	43	1161151.2	2256.0

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4. Research Result

SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

4.2 Flood risk assessment

Agricultural damage assessment: with 5 different rainfall patterns chosen from each climate (50-Year Flood)

Present Climate: (1979-2003)

Rainfall pattern	4-month rainfall value (mm)	Damaged agricultural area (ha)	Agricultural economic loss (billion Riel)
A	40.6	1111968	2189.0
B		1120068	2205.7
C		**1140804**	**2258.0**
D		1116828	2170.3
E		1099656	2131.7
Average		1117865	2191.0

Future Climate: RCP 8.5 MME (2075-2099)

Rainfall pattern	4-month rainfall value (mm)	Damaged agricultural area (ha)	Agricultural economic loss (billion Riel)
A	45.3	1282068	2589.4
B		1374084	2817.8
C		1294704	2631.2
D		**1430784**	**2950.4**
E		1269432	2576.5
Average		1330214	2713.1

Future Climate: RCP 8.5 C1 (2075-2099)

Rainfall pattern	4-month rainfall value (mm)	Damaged agricultural area (ha)	Agricultural economic loss (billion Riel)
A	42.4	1283364	2572.6
B		1266840	2565.5
C		**1328724**	**2694.8**
D		1228608	2379.1
E		1231200	2394.7
Average		1267747	2521.3

Future Climate: RCP 8.5 C2 (2075-2099)

Rainfall pattern	4-month rainfall value (mm)	Damaged agricultural area (ha)	Agricultural economic loss (billion Riel)
A	45.4	**1306692**	**2610.2**
B		1277532	2509.0
C		1197828	2375.8
D		1231524	2463.9
E		1261980	2564.9
Average		1255111	2504.8

Future Climate: RCP 8.5 C3 (2075-2099)

Rainfall pattern	4-month rainfall value (mm)	Damaged agricultural area (ha)	Agricultural economic loss (billion Riel)
A	45.6	1269432	2570.6
B		1178388	2343.4
C		**1492344**	**2948.3**
D		1275264	2587.3
E		1305072	2626.2
Average		1304100	2615.2

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4. Research Result

4.2 Flood risk assessment

SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

Agricultural damage assessment: with 5 different rainfall patterns chosen from each climate (100-Year Flood)

Present Climate: (1979-2003)

Rainfall pattern	4-month rainfall value (mm)	Damaged agricultural area (ha)	Agricultural economic loss (billion Riel)
A	41.9	1171584	2330.0
B		1169640	2326.3
C		**1189404**	**2378.9**
D		1168668	2306.0
E		1156032	2265.0
Average		1171066	2321.3

Future Climate: RCP 8.5 MME (2075-2099)

Rainfall pattern	4-month rainfall value (mm)	Damaged agricultural area (ha)	Agricultural economic loss (billion Riel)
A	46.3	1316736	2672.0
B		1403568	2893.8
C		1323540	2699.8
D		**1464480**	**3021.7**
E		1304424	2648.6
Average		1362550	2787.2

Future Climate: RCP 8.5 C1 (2075-2099)

Rainfall pattern	4-month rainfall value (mm)	Damaged agricultural area (ha)	Agricultural economic loss (billion Riel)
A	43.6	1325484	2670.6
B		1310904	2668.8
C		**1373112**	**2799.6**
D		1257120	2462.0
E		1258740	2477.2
Average		1305072	2615.6

Future Climate: RCP 8.5 C2 (2075-2099)

Rainfall pattern	4-month rainfall value (mm)	Damaged agricultural area (ha)	Agricultural economic loss (billion Riel)
A	46.6	**1362096**	**2731.9**
B		1324512	2614.7
C		1234440	2486.0
D		1272996	2577.5
E		1307016	2671.6
Average		1300212	2616.4

Future Climate: RCP 8.5 C3 (2075-2099)

Rainfall pattern	4-month rainfall value (mm)	Damaged agricultural area (ha)	Agricultural economic loss (billion Riel)
A	47.3	1320624	2683.0
B		1229580	2484.2
C		**1546776**	**3070.7**
D		1328724	2707.8
E		1359504	2764.4
Average		1357042	2742.0

4. Research Result

4.2 Flood risk assessment

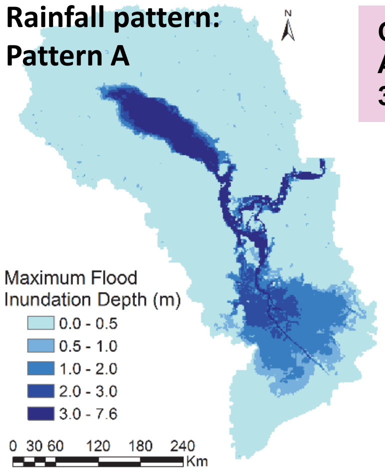
Comparison of Rice Crop Damage under Present/future Climate

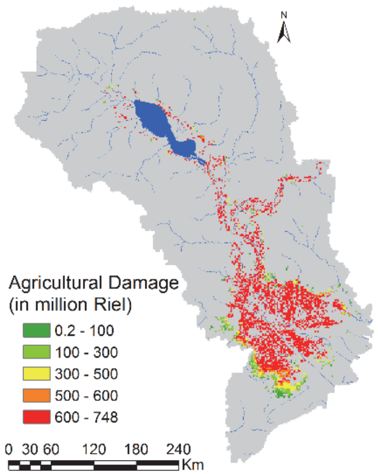
Worst Cases in terms of Agricultural Damage Area: Original Rainfall

Present Climate (1979-2003)

Rainfall pattern: Pattern A

Composite of Inundation Area (>50 cm depth)= 34,710.1 km2





Damage area= 112,849,2 ha
Estimated Damage= 2,231.8 billion Riel

Inundation area increased by 20 %

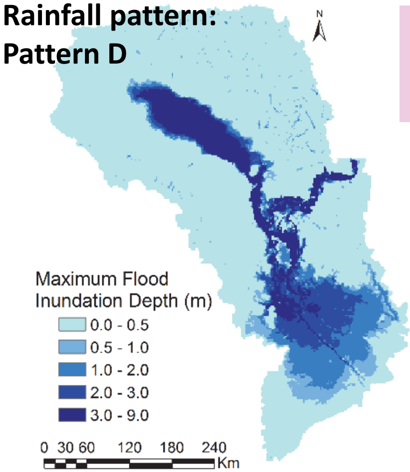
Damage area increased by 17 %

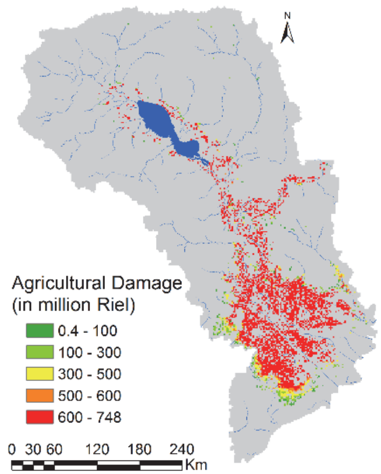
Damage value increased by 20 %

Future Climate (2075-2099): RCP 8.5 MME

Rainfall pattern: Pattern D

Composite of Inundation Area (>50 cm depth)= 41,776.5 km2





Damage area= 131,511,6 ha
Estimated Damage= 2,688.5 billion Riel

4. Research Result

4.2 Flood risk assessment

SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

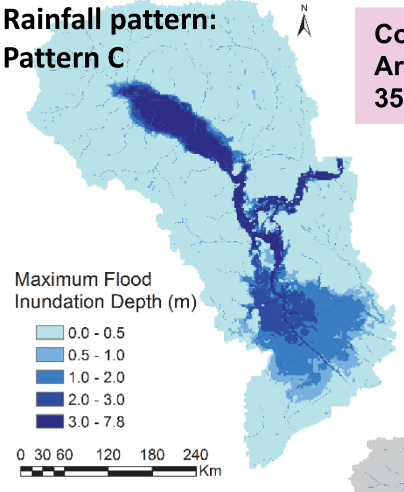
Comparison of Rice Crop Damage under Present/future Climate

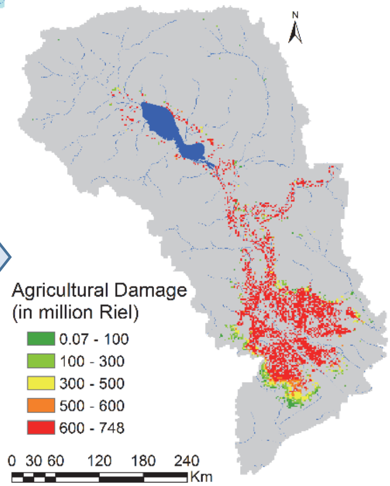
Worst Cases in terms of Agricultural Damage Area: 50-Year Flood

Present Climate (1979-2003)

Rainfall pattern: Pattern C

Composite of Inundation Area (>50 cm depth)= 35,134.5 km2





Damage area= 114,080,4 ha
Estimated Damage= 2258.0 billion Riel

Inundation area increased by 30 %

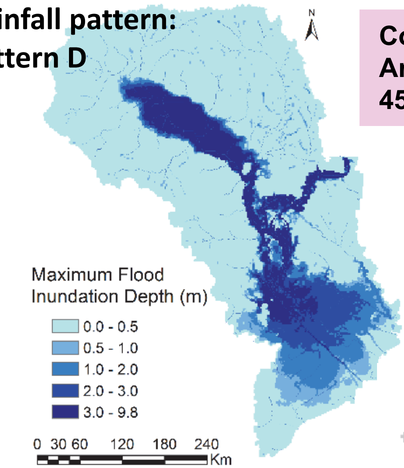
Damage area increased by 25 %

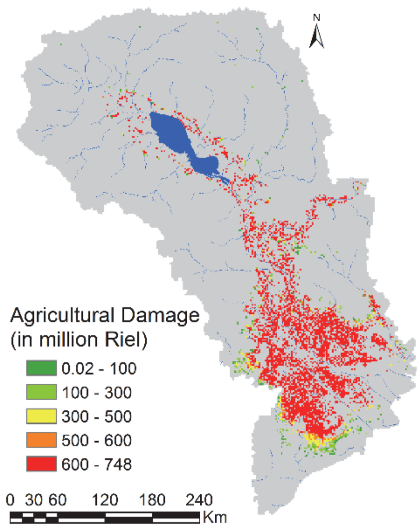
Damage value increased by 31 %

Future Climate (2075-2099): RCP 8.5 MME

Rainfall pattern: Pattern D

Composite of Inundation Area (>50 cm depth)= 45,551.1 km2





Damage area= 143,078,4 ha
Estimated Damage= 2950.4 billion Riel

4. Research Result

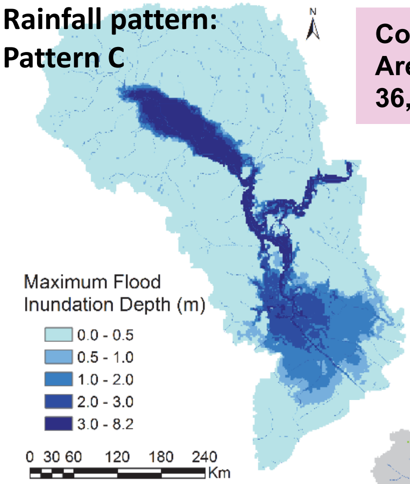
4.2 Flood risk assessment

Comparison of Rice Crop Damage under Present/future Climate

Worst Cases in terms of Agricultural Damage Area: 100-Year Flood

Present Climate (1979-2003)

Rainfall pattern: Pattern C

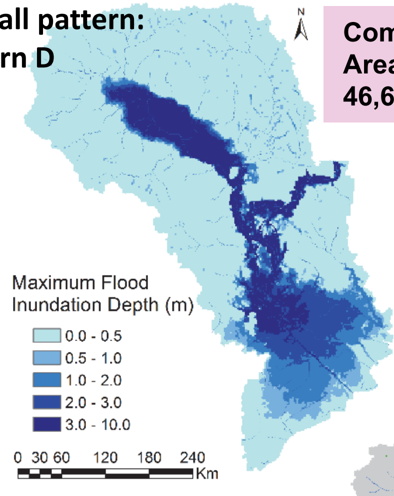


Composite of Inundation Area (>50 cm depth)= 36,725.4 km2

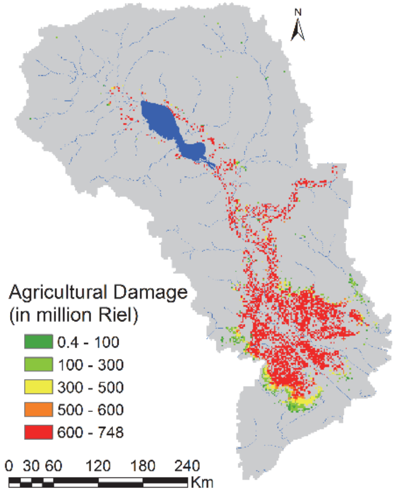
Inundation area increased by 27 %

Future Climate (2075-2099): RCP 8.5 MME

Rainfall pattern: Pattern D

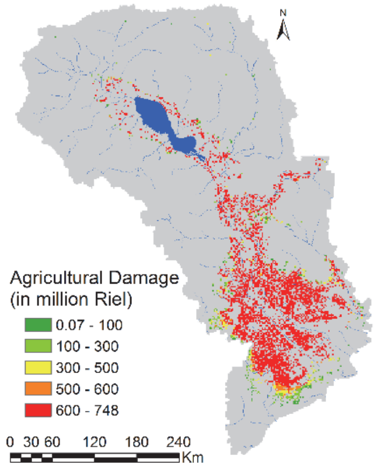


Composite of Inundation Area (>50 cm depth)= 46,620.4 km2



Damage area increased by 23 %

Damage value increased by 27 %



Damage area= 1,189,404 ha
Estimated Damage= 2378.9 billion Riel

Damage area= 1,464,480 ha
Estimated Damage= 3021.6 billion Riel

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4. Research Result

4.2 Flood risk assessment

Summary : Comparison with average agricultural damage area case

Rainfall Conditions	Present Climate		Future Climate		% Increased	
	Agricultural damage area (ha)	Agricultural economic loss (bil. Riel)	Agricultural damage area (ha)	Agricultural economic loss (bil. Riel)	Agricultural damage area	Agricultural economic loss
Original	101,852,6.4	1864.6	124,305,8.4	2500.7	22	34
50-Year Return Period	111,786,5	2191.0	133,021,4	2713.1	19	24
100-Year Return Period	117,106,6	2321.3	136,255,0	2787.2	16	20

Summary : Comparison with worst agricultural damage area case

Rainfall Conditions	Present Climate		Future Climate		% Increased	
	Agricultural damage area (ha)	Agricultural economic loss (bil. Riel)	Agricultural damage area (ha)	Agricultural economic loss (bil. Riel)	Agricultural damage area	Agricultural economic loss
Original	112,849,2	2231.8	131,511,6	2688.5	17	20
50-Year Return Period	114,080,4	2258.0	143,078,4	2950.4	25	31
100-Year Return Period	118,940,4	2378.9	146,448,0	3021.7	23	27

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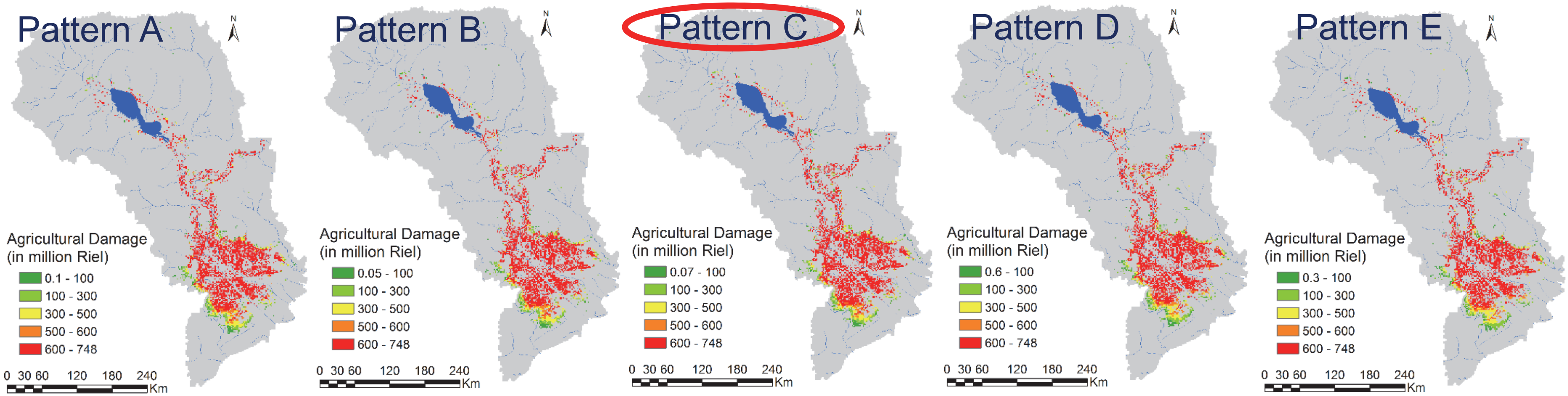
Agricultural damage assessment by conducting hazard analysis using 5 different precipitation patterns with rainfall amount of 50 year return period

50-Year Flood

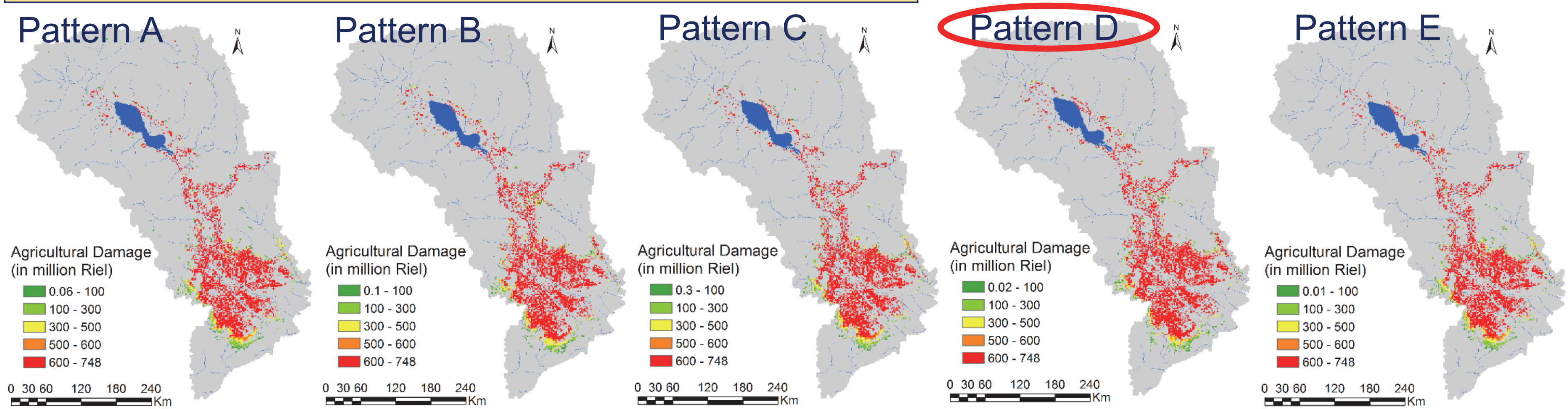
Present Climate (1979-2003)

Rainfall pattern with Largest damaged agricultural area



Future Climate (2075-2099): RCP 8.5 MME

Rainfall pattern with Largest damaged agricultural area



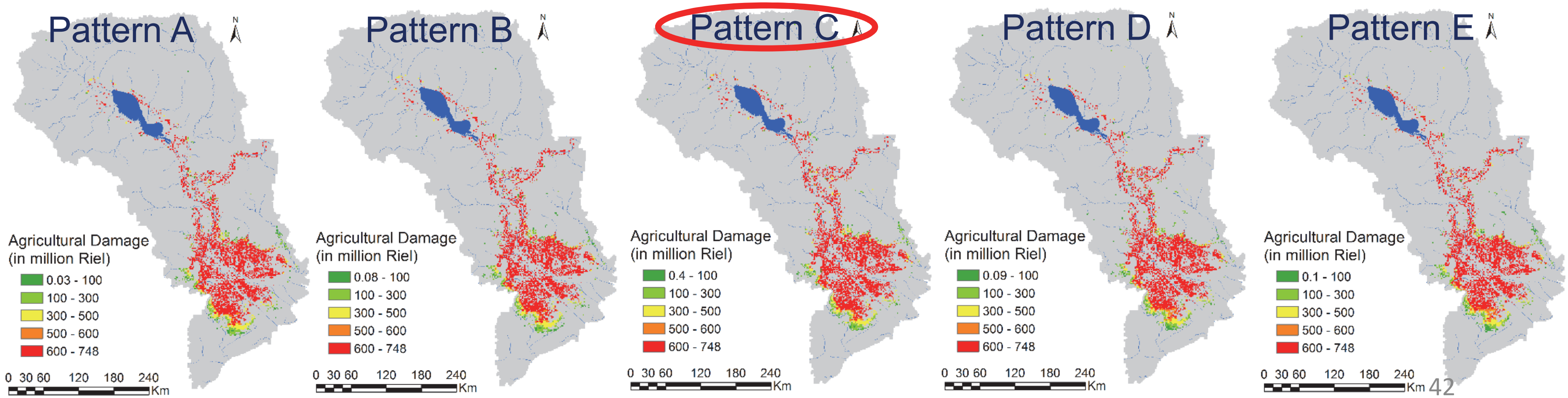
4. Research Result 4.2 Flood risk assessment

Agricultural damage assessment by conducting hazard analysis using 5 different precipitation patterns with rainfall amount of 100 year return period

100-Year Flood

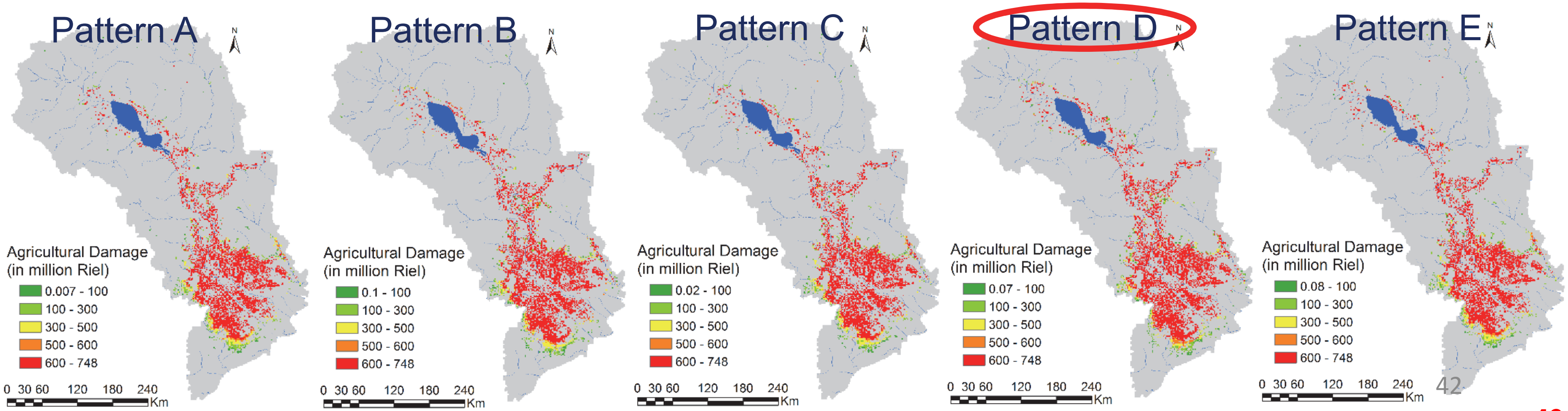
Present Climate (1979-2003)

Rainfall pattern with Largest damaged agricultural area



Future Climate (2075-2099): RCP 8.5 MME

Rainfall pattern with Largest damaged agricultural area



4. Research Result 4.2 Flood risk assessment

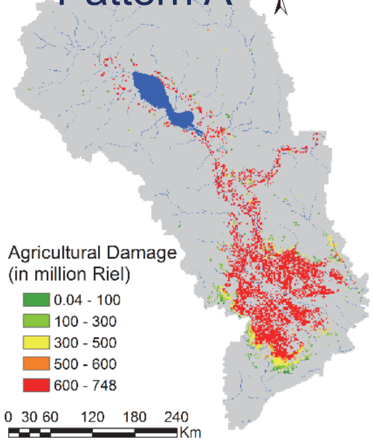
(Reference)

Future Climate (2075-2099): RCP 8.5 C1

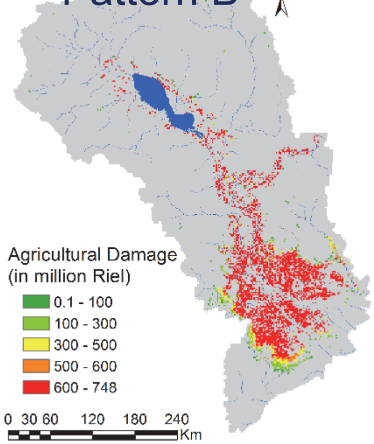
50 Year Flood

Rainfall pattern with Largest damaged agricultural area

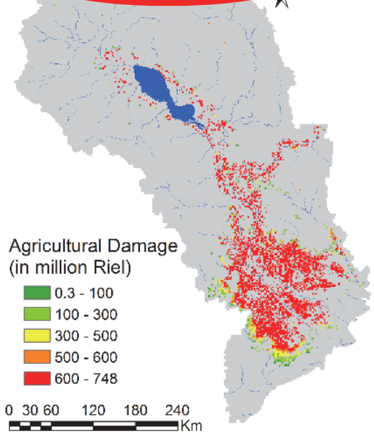
Pattern A



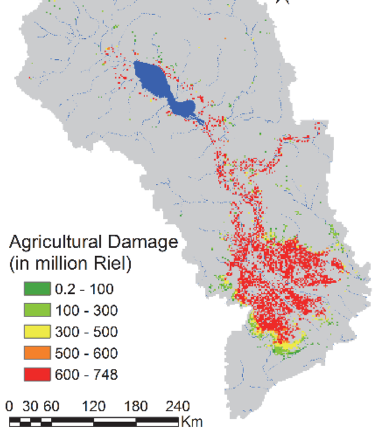
Pattern B



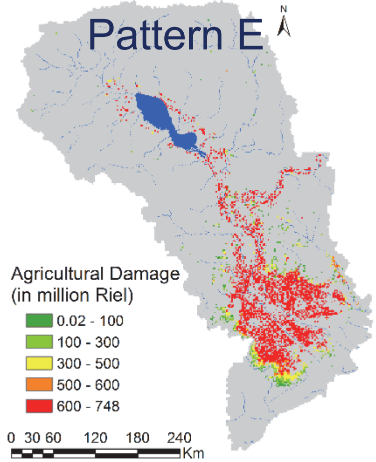
Pattern C



Pattern D



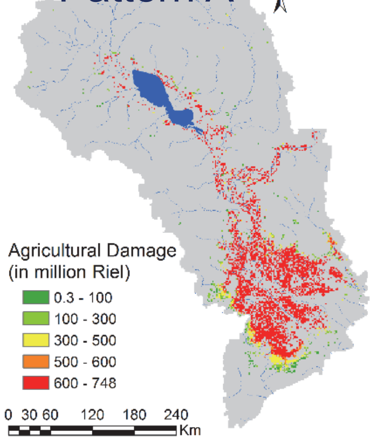
Pattern E



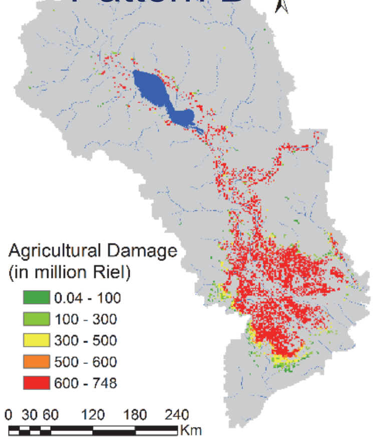
100 Year Flood

Rainfall pattern with Largest damaged agricultural area

Pattern A



Pattern B



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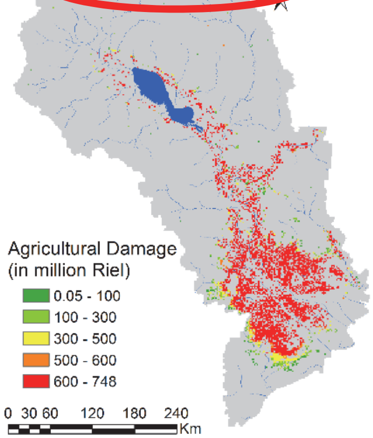

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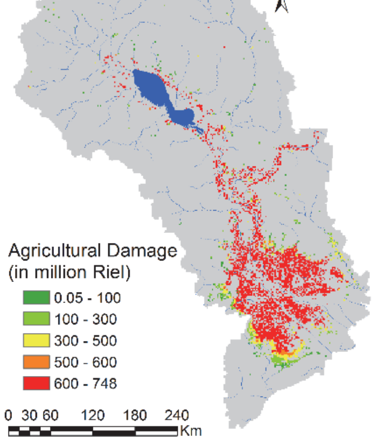

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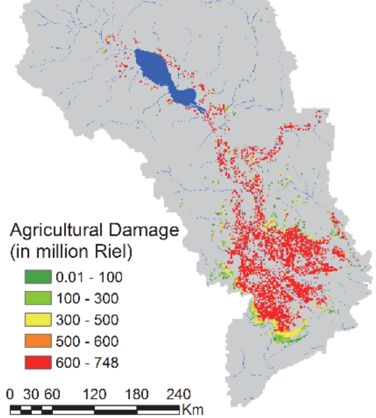


43

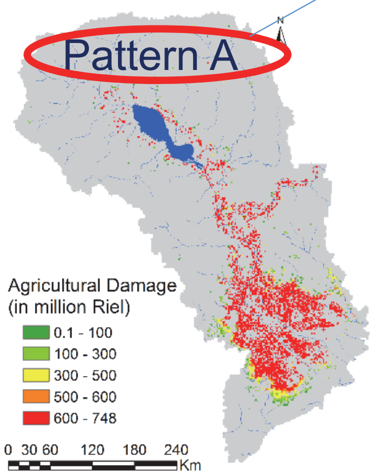
4. Research Result 4.2 Flood risk assessment

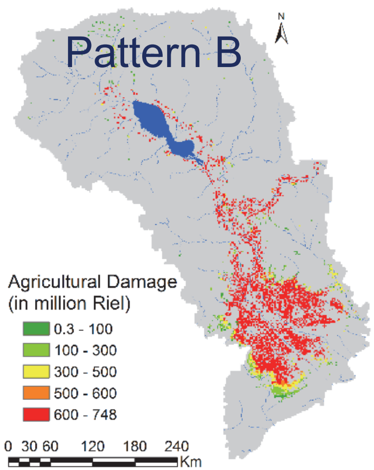
(Reference)

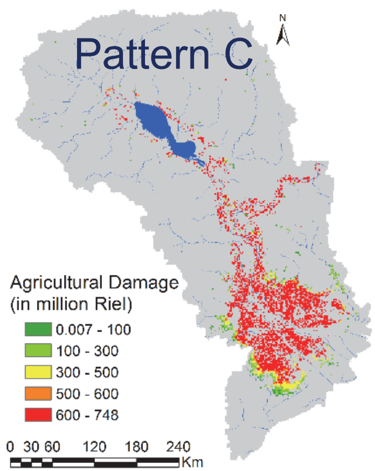
Future Climate (2075-2099): RCP 8.5 C2

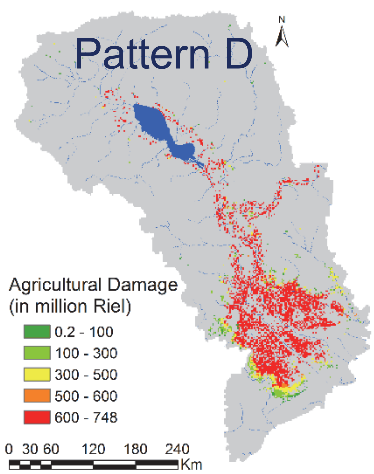
50 Year Flood

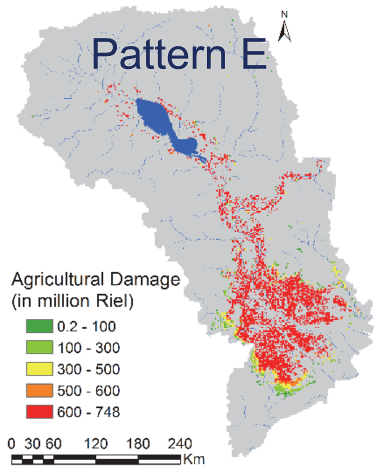
Rainfall pattern with Largest damaged agricultural area





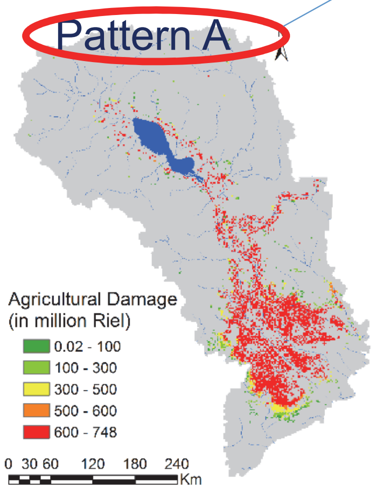


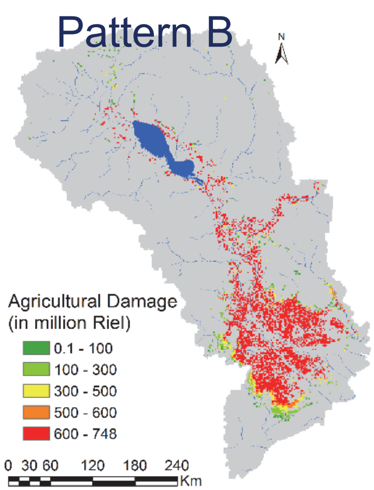


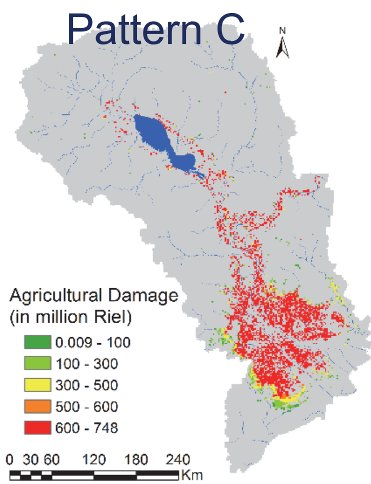


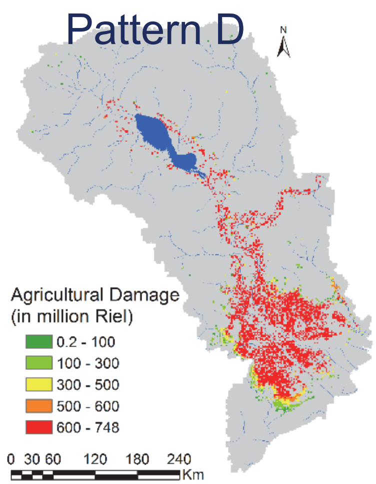
100 Year Flood

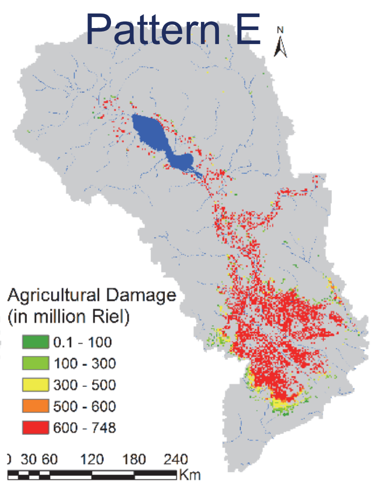
Rainfall pattern with Largest damaged agricultural area











4. Research Result 4.2 Flood risk assessment

SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

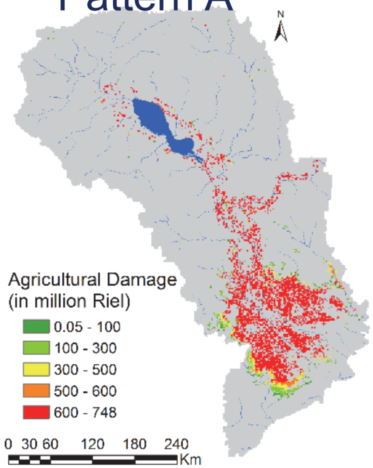
(Reference)

Future Climate (2075-2099): RCP 8.5 C3

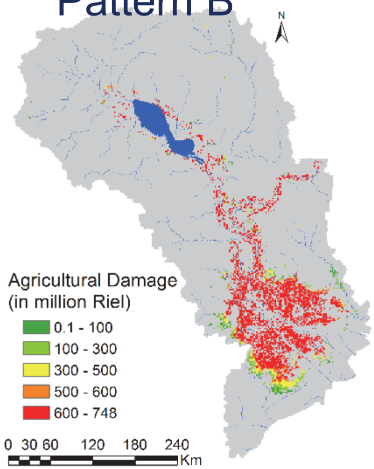
50 Year Flood

Rainfall pattern with Largest damaged agricultural area

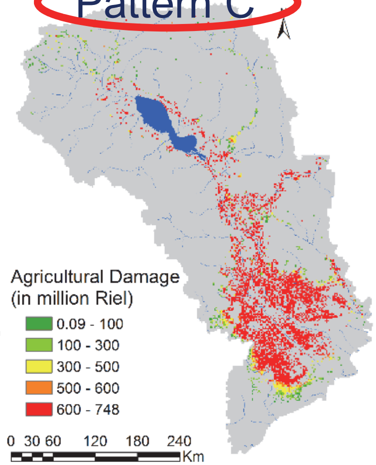
Pattern A



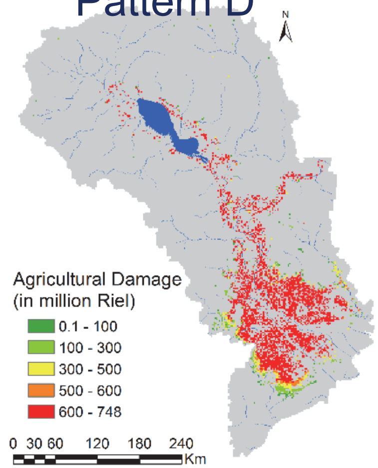
Pattern B



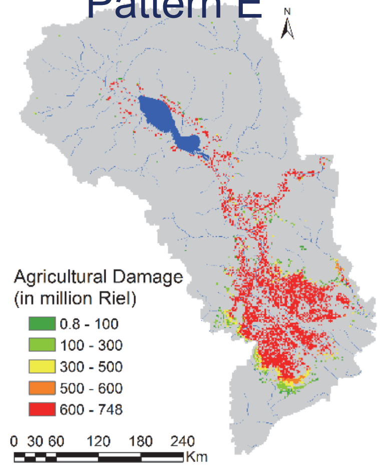
Pattern C



Pattern D



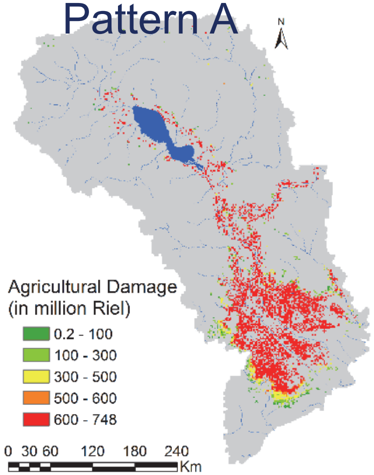
Pattern E



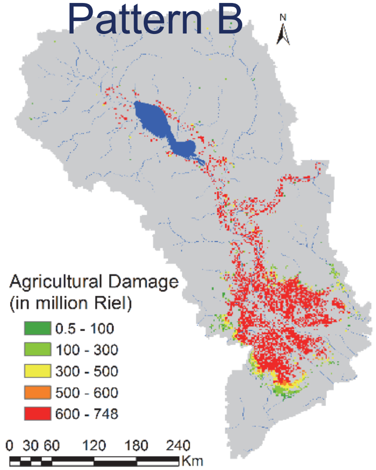
100 Year Flood

Rainfall pattern with Largest damaged agricultural area

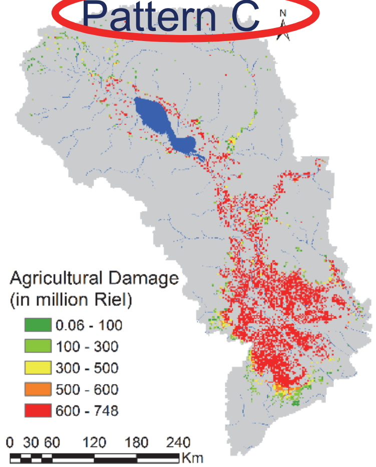
Pattern A



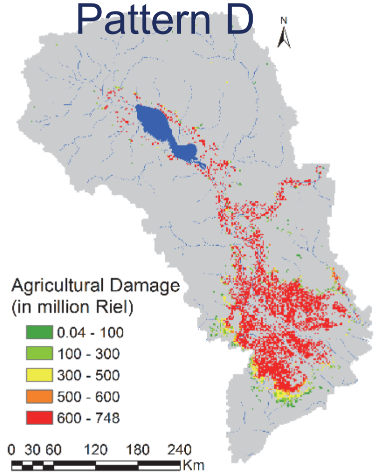
Pattern B



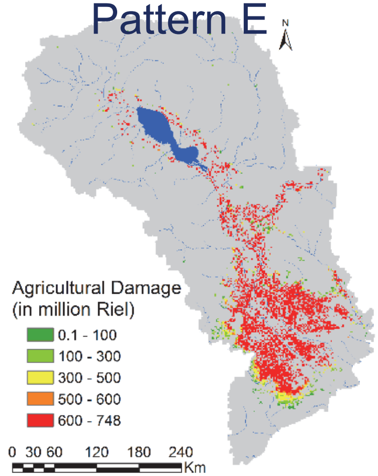
Pattern C



Pattern D



Pattern E



5. Summary

- The average yearly precipitation between in future climate can be increased by 10 %, especially the average monthly precipitation during flood season (May-September) can be increased.

- 50-year rainfall (mm/4 months) can be increased by about 10%.

- Agricultural economic loss to rice-crops can be increased by 25 % in the case of 50-year flood and 23 % in the case of 100-year flood.

Feb. 25, 2017

Drought Risk Analysis of Mekong River Basin

(North East Thailand)

Strategy for Analysis

Object :

- Predict Rice production in future in North East Thailand to investigate socio-economic impact of drought

Difficulty :

- There is not an appropriate reservoir related to irrigation area downstream. So, we need to build or find a predicting model for rice planted area.

Methodology :

- Apply Prediction model of IRE *2 for Rice Planted Area Prediction*1 and validate with Past Rice Planted Area data and Rainfall data.
- After validation, apply IRE model to predict Rice Planted Area using future rainfall data.

*1) TANIGUCHI, MASUMOTO et al: Development of a Distributed Water Circulation Model Incorporating Various Paddy Water Uses, PART1: A Model for Estimating Cropping Area and Pattern, Journal of Japan Society of Hydrology and Water Resources, Vol. 22, No.2 Mar.2009

*2) Institute of Rural Engineering, National Agriculture and Food Research Organization(NARO)

Obtained Data for Analysis

Item	Resolution	Duration	Reference
Planted Area of Rice	Each Province, every year, Major(Wet season) and 2nd Rice(Dry season)	1980-2013	Agriculture Economic Agency, Ministry of Agriculture and Cooperation
Harvested Area of Rice	Each Province, every year, Major(Wet season) and 2nd Rice(Dry season)	1980-2013	Agriculture Economic Agency, Ministry of Agriculture and Cooperation
Rice Production	Each Province, every year, Major(Wet season) and 2nd Rice(Dry season)	1980-2013	Agriculture Economic Agency, Ministry of Agriculture and Cooperation
Rainfall	15 arc minute 20km	Past(1950-2007) Future	APHRODITE(for Past) MRI-AGCM3.2(for Future)
Land Use for Crops	5 arc minute Each month, Rainfed area and Irrigate area	Average of Duration from1998 to 2000	MIRCA2000

THAILAND Source: Agricultural Statistics of Thailand

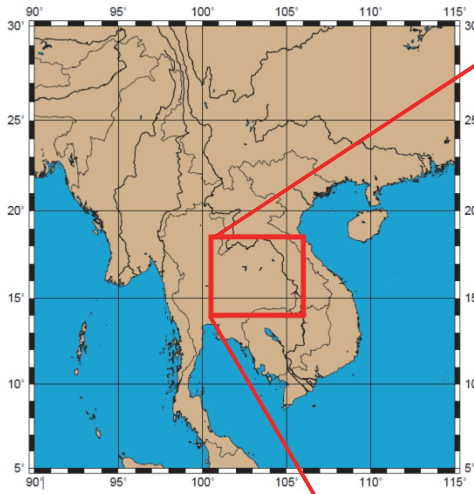
Irrigated crop calendar **2007**

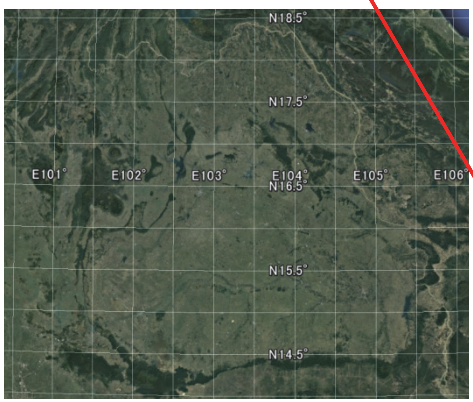
Irrigated crops		Area	Crop area as percentage of the full control actually irrigated area by month											
		1000 ha	J	F	M	A	M	J	J	A	S	O	N	D
Rice one	SECOND RICE(Dry Season)	2 327	46	46								46	46	46
Rice two	MAJOR RICE(Wet Season)	3 941					78	78	78	78	78			

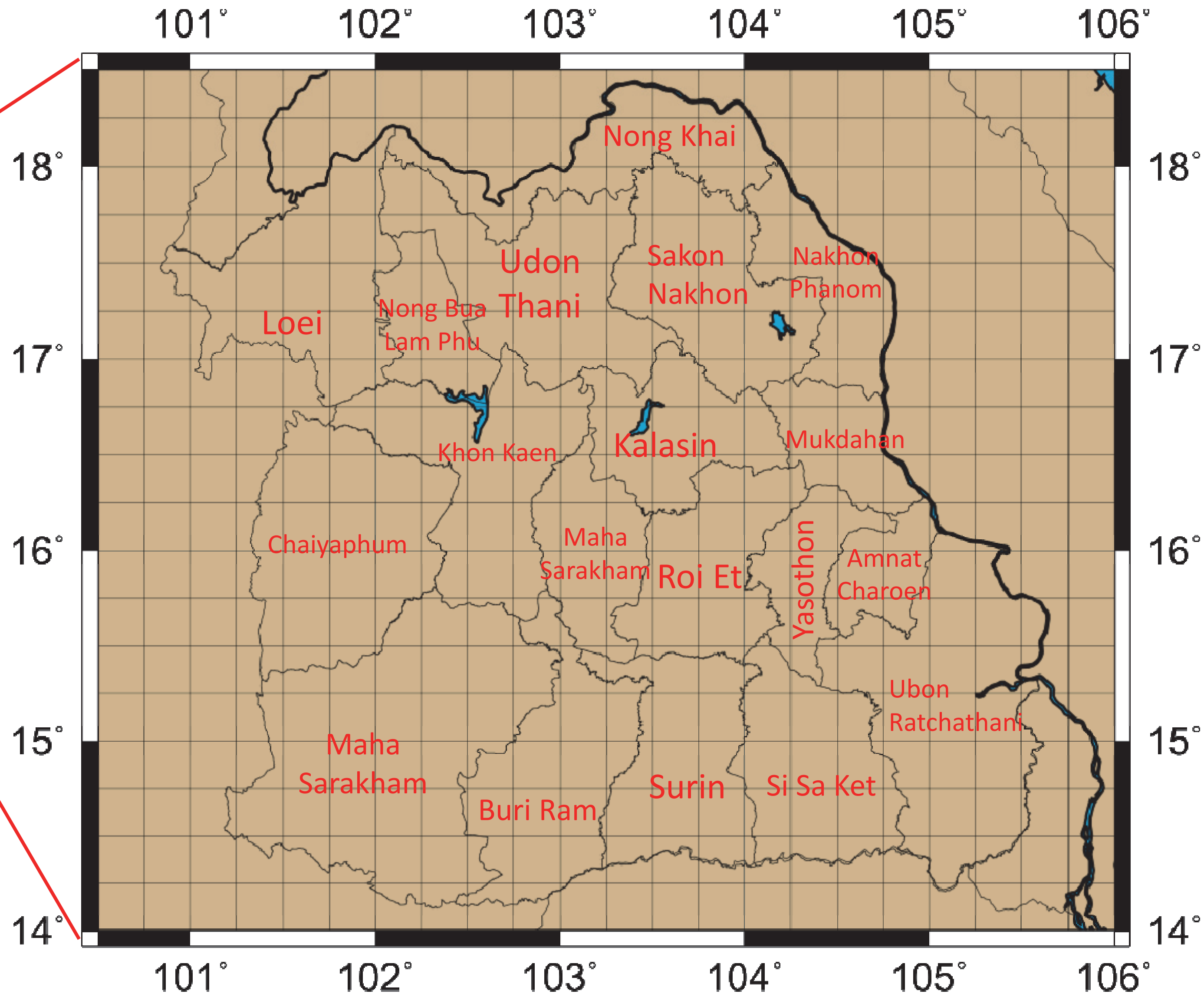
References

FAO. 2012. AQUASTAT, FAO's global information system on water and agriculture. http://www.fao.org/nr/aquastat

Overview of Target Area(Location)

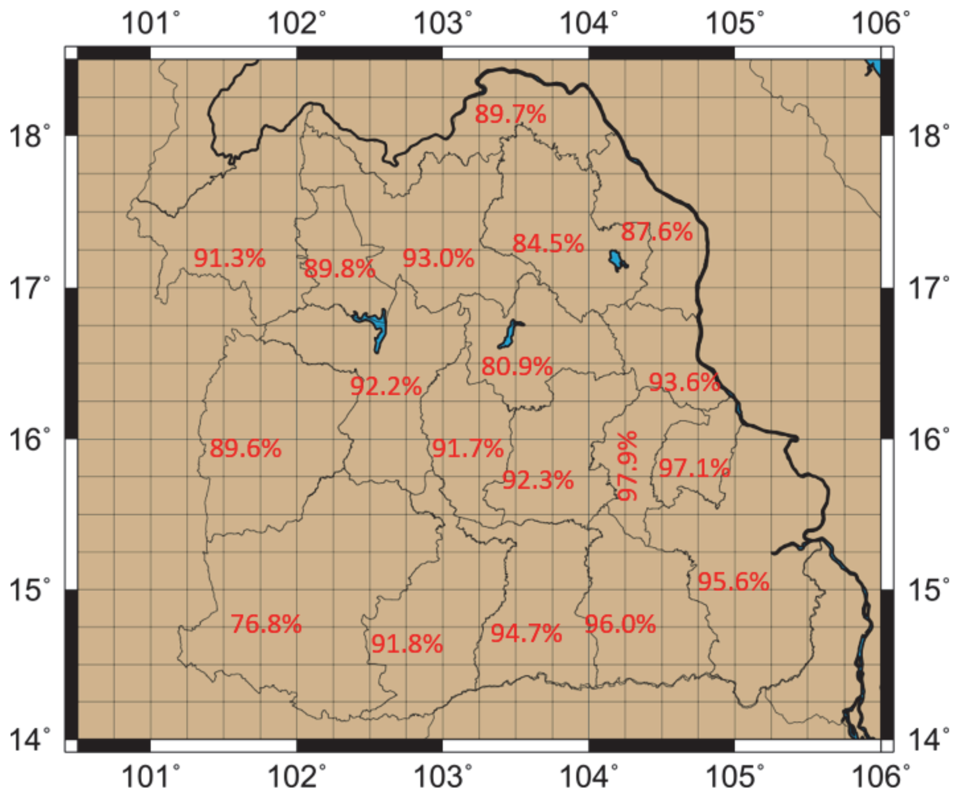






Northeast Thailand (19 Provinces)

Overview of Target Area(Type of Rice Field)



Proportion of Area of Rainfed Rice Field in Rice Filed in each province

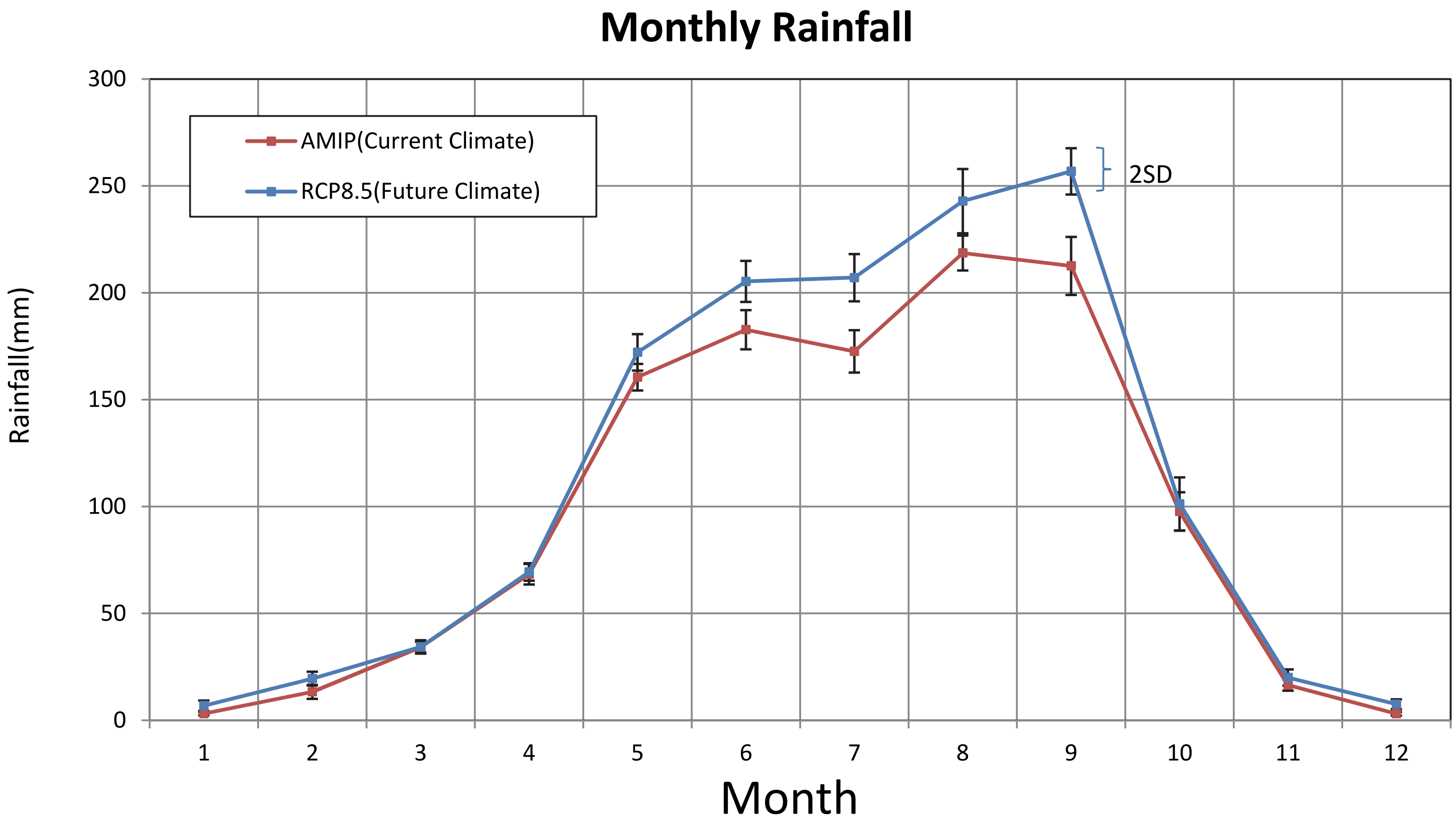
Rainfed Rice field dominates in this area compared to irrigated Rice field.
That is why we focus on Wet Season.

THAILAND
Irrigated crop calendar **2007**

Irrigated crops	Area	Crop area as percentage of the full control actually irrigated area by month											
	1000 ha	J	F	M	A	M	J	J	A	S	O	N	D
Rice one	2 327	46	46								46	46	46
Rice two	3 941					78	78	78	78	78			

References
FAO. 2012. AQUASTAT, FAO's global information system on water and agriculture. http://www.fao.org/nr/aquastat

Overview of the Target Area(Rainfall)

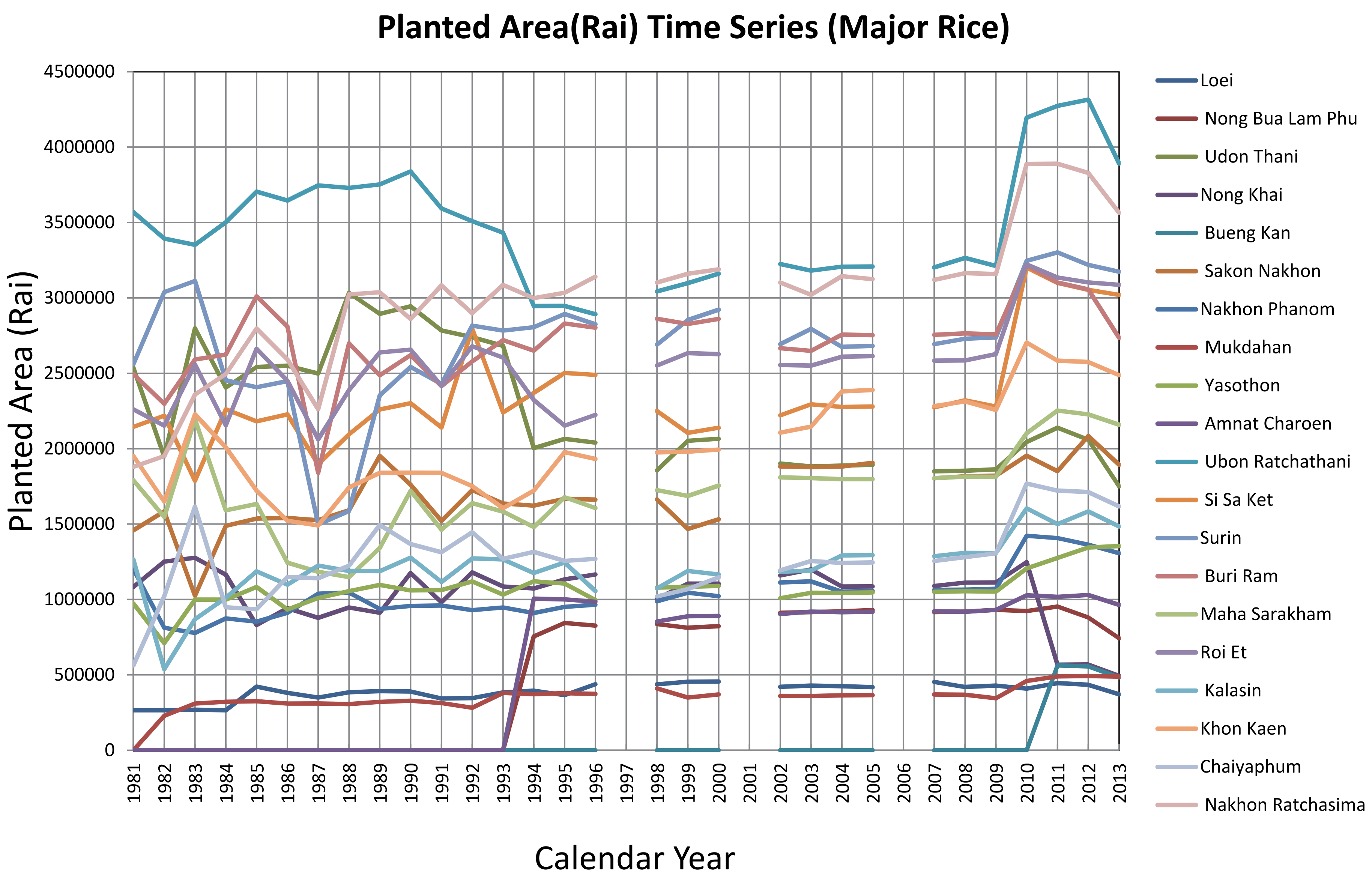


Annual Average Rainfall

AMIP(Current Climate)	1183 mm
RCP8.5(Future Climate)	1343 mm

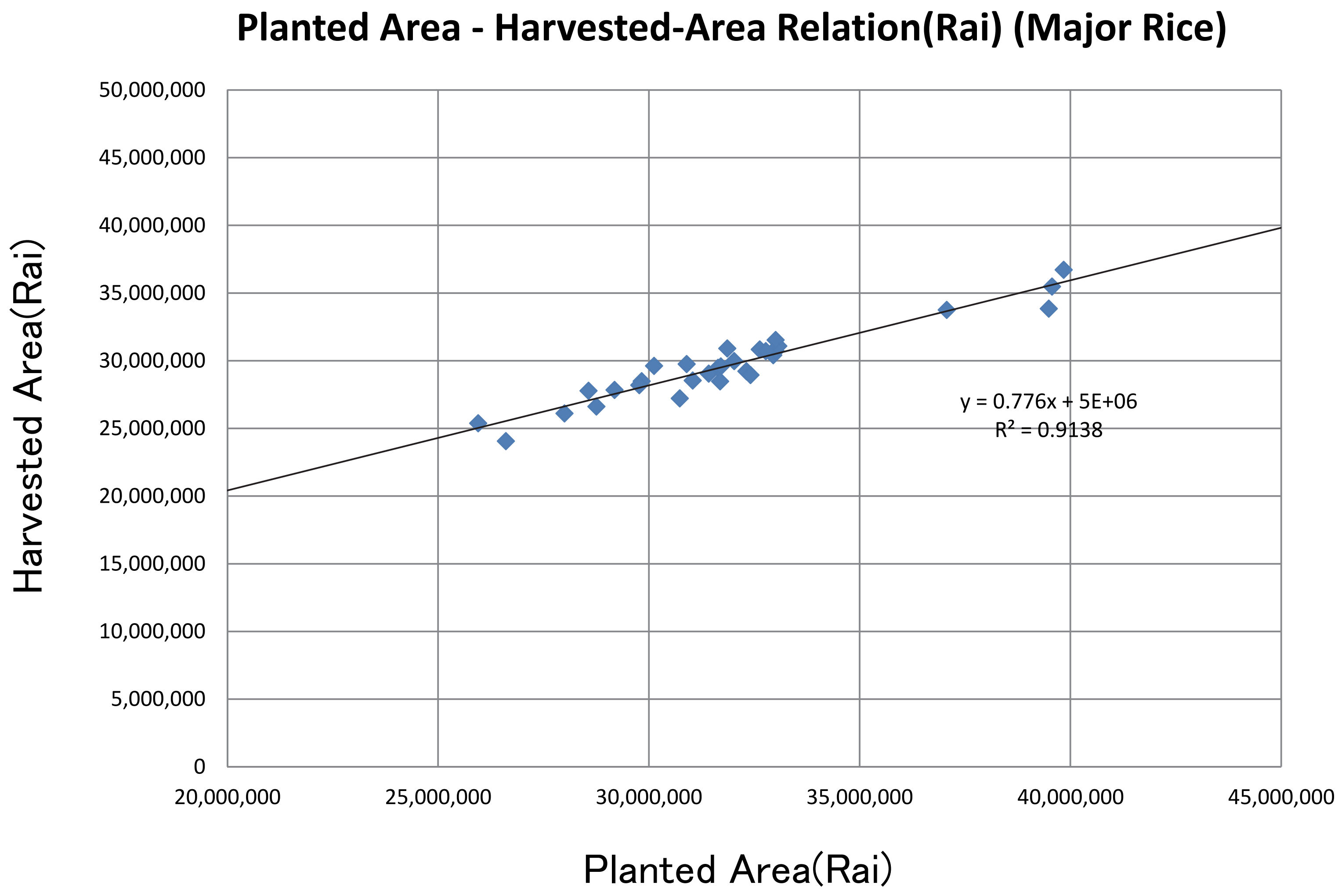
Average Rainfall in Mekong River Basin (North East Thailand)

Time Series of Planted Area of Rice in Wet Season



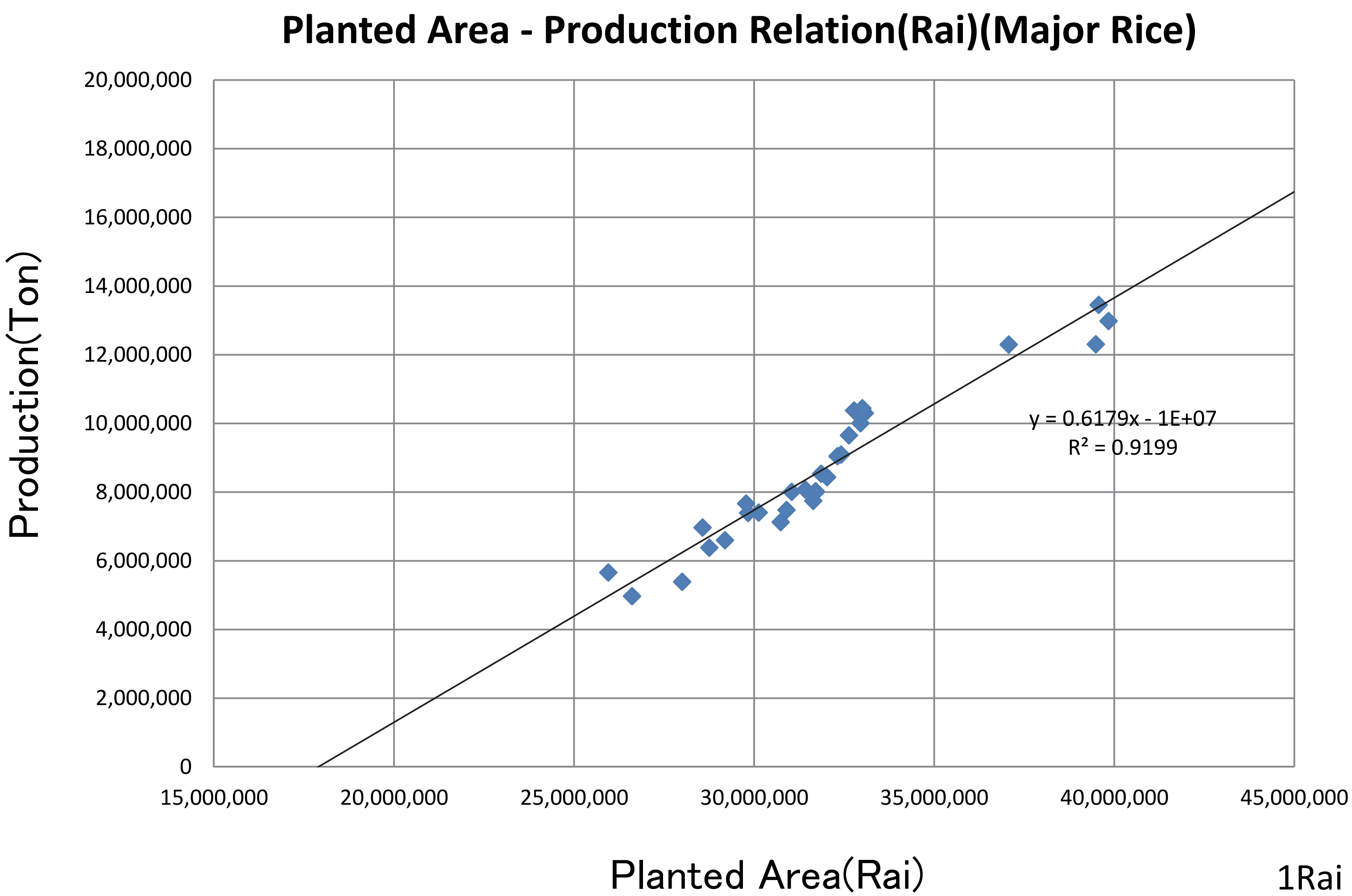
1 Rai = 0.16ha

Relationship between Planted Area and Harvested Area in Wet Season



1Rai = 0.16ha

Relationship between Planted Area and Rice Production in Wet Season



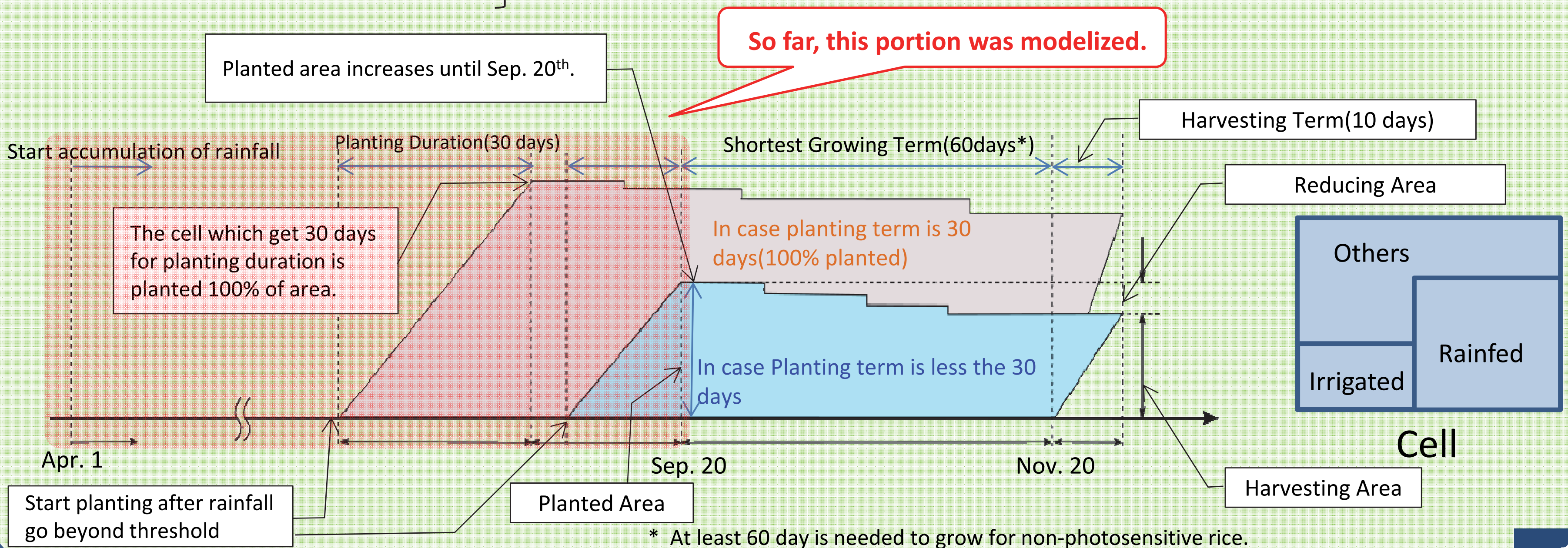
1Rai = 0.16ha

High correlation between planted area and rice production was found.

Applied IRE Model (Wet Season)

- Divide whole basin into cells. Allocate area of irrigated field and rainfed field to each cell.
- Calculate accumulation of rainfall from Apr. 1st. Set threshold of accumulated rainfall for start planting for each type of filed(Irrigated, Partial Rainfed Full Rainfed). In case accumulation of rainfall surpass the threshold, it start planting.
- Planting term for 100% planting is 30 days.
- Planted area increases by 1/30 area per day until Sep 20th. Planting stop on Sep 20th to ensure growing time -60 days. So that Planted Area at the date of Sep. 20th is the planted area in that year.
- Threshold of Accumulated Rainfall for Start Planting

Irrigated:	500mm	Set by existing survey
Partial Rainfed:	341mm	Set based on threshold value of Irrigated rice filed using ratio of Partially Rainfed and Full Rainfed.
Full Rainfed:	625mm	

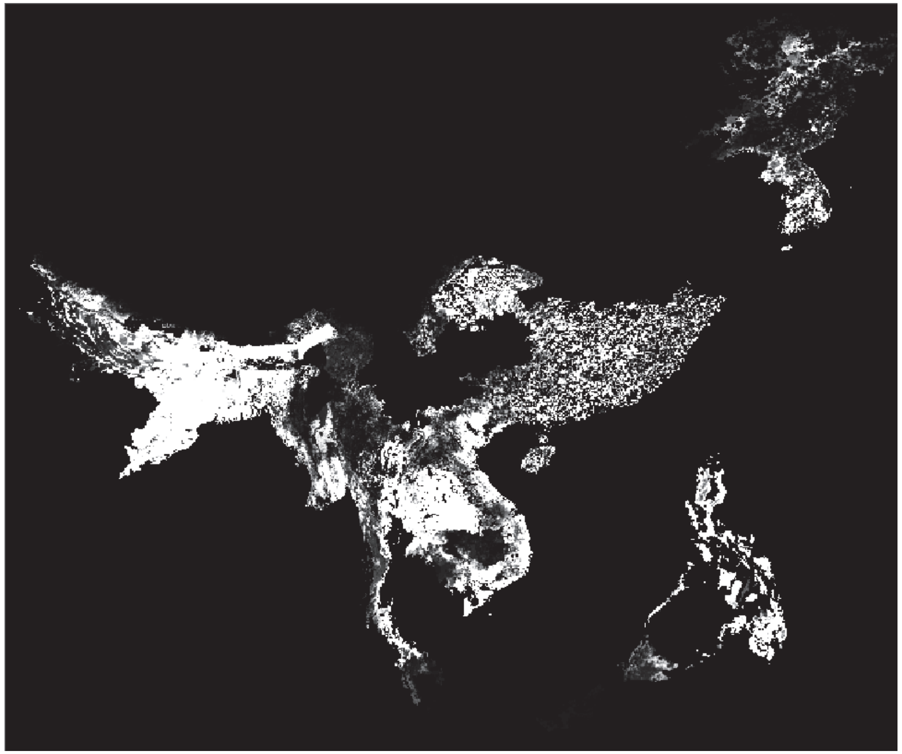


* At least 60 day is needed to grow for non-photosensitive rice.

Land Use Classification(Allocation of Maximum Planted Area)

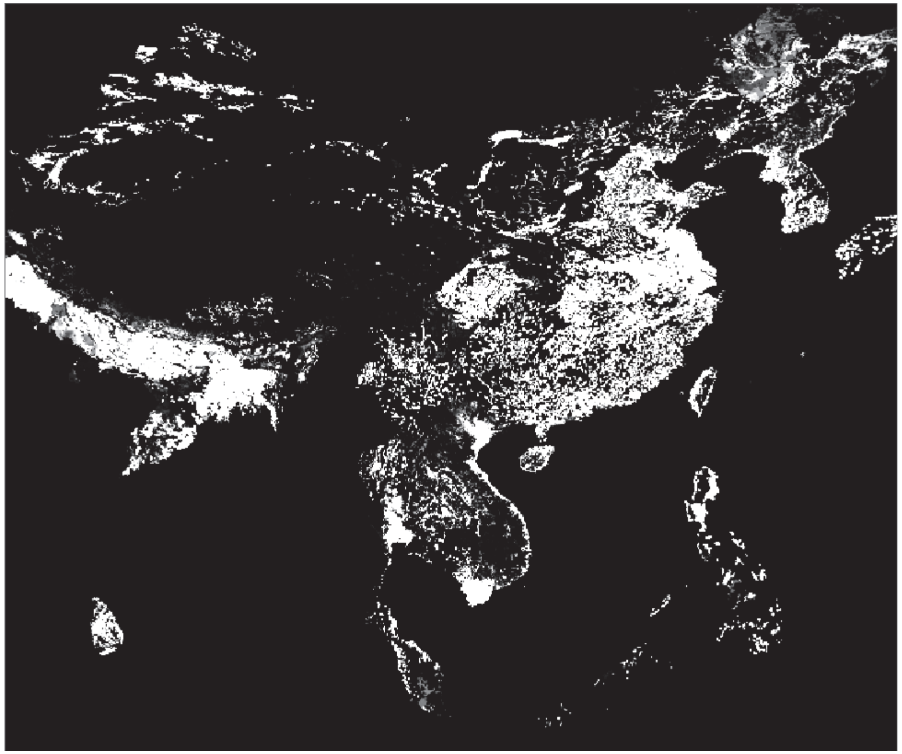
MIRCA2000：

Resolution: 5 arc sec (9.2km on equator)
Each sell store irrigated rice field and rainfed rice field of each month around year 2000(average of 1998-2002)
Calculate Maximum Planted Area for irrigated and rainfed rice field.



Distribution of Rainfed (June)

Value
High : 7206
Low : 0 (Hectare)



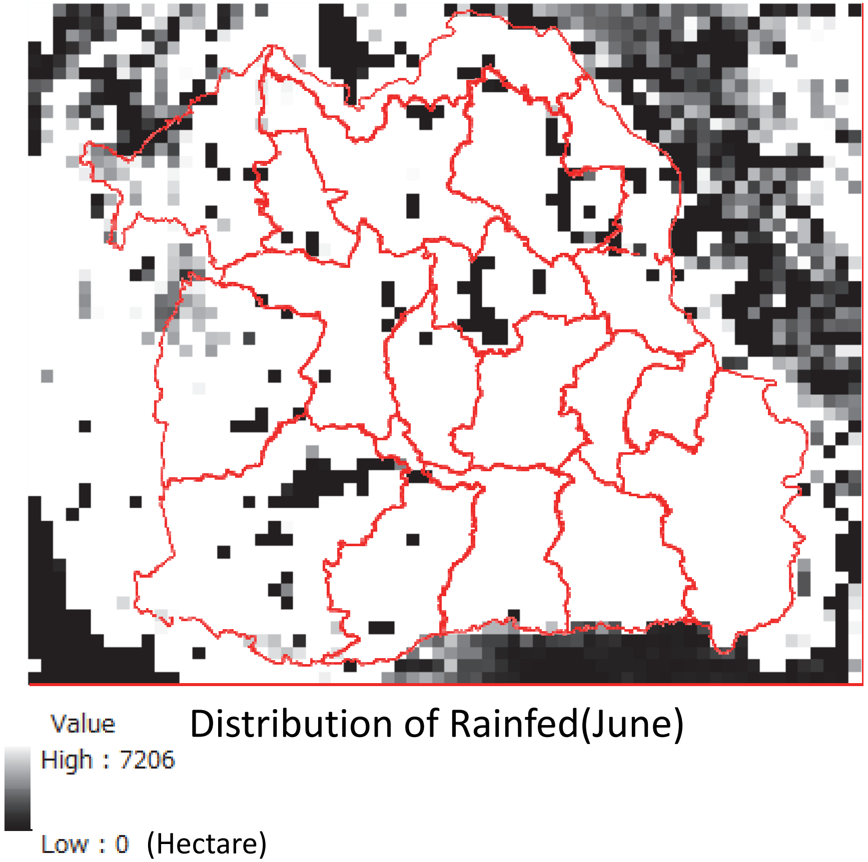
Distribution of Irrigated(June)

Value
High : 8227
Low : 0 (Hectare)

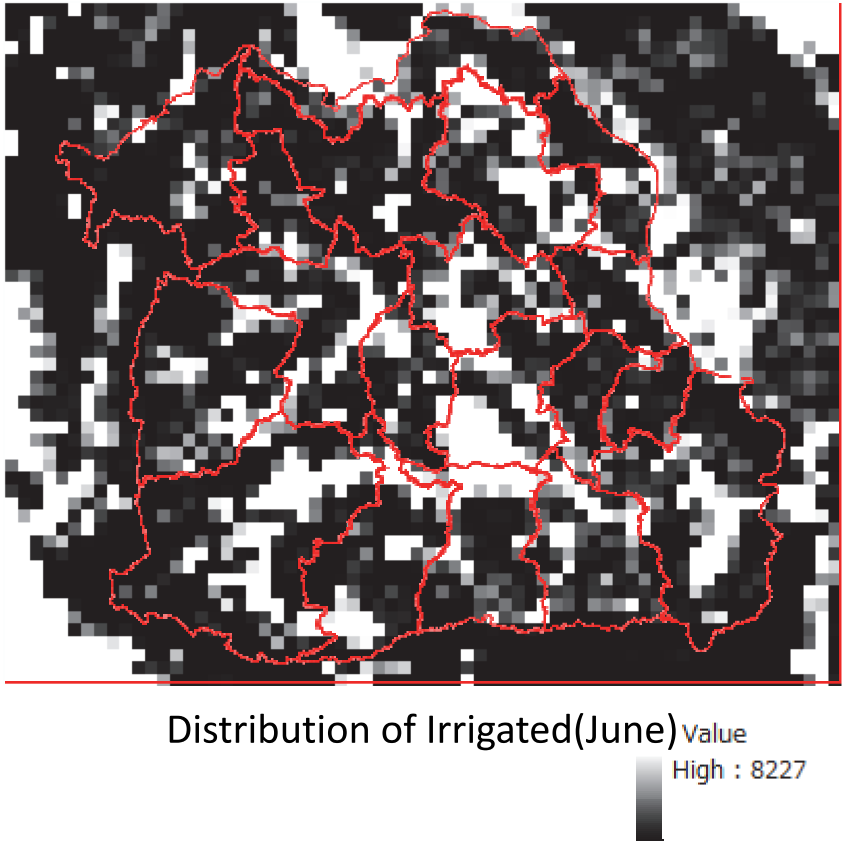
Land Use Classification(Allocation of Maximum Planted Area)

Allocating Rainfed Area and Irrigated Area for each cell

Allocate Maximum Planted Area of Each Province so as to fit calculated planted area with observed average planted area from 1981 to 2013. Use proportion of irrigated area and rainfed from MIRCA2000 to allocate irrigated and rainfed area each.

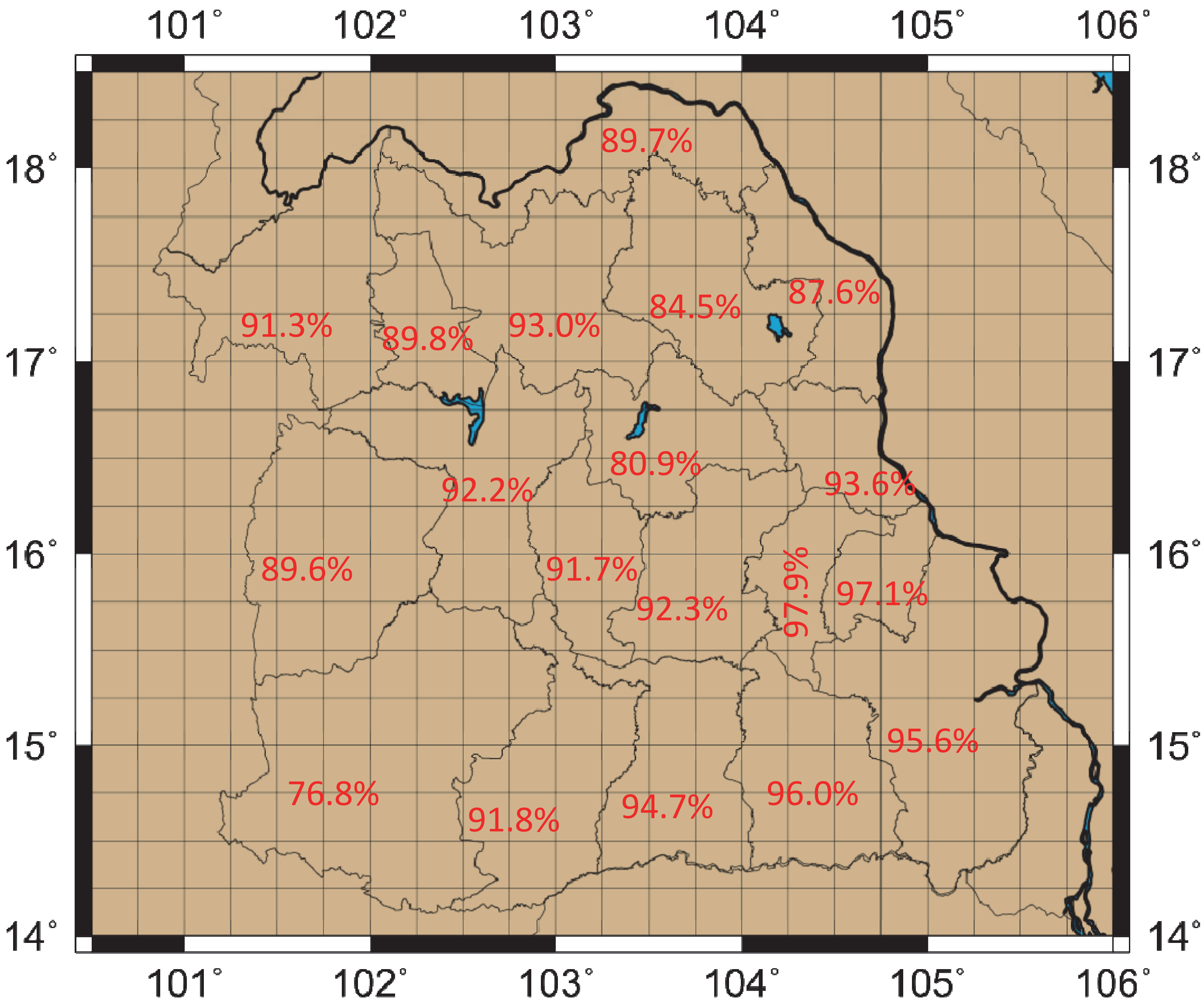


Distribution of Rainfed(June)



Distribution of Irrigated(June)

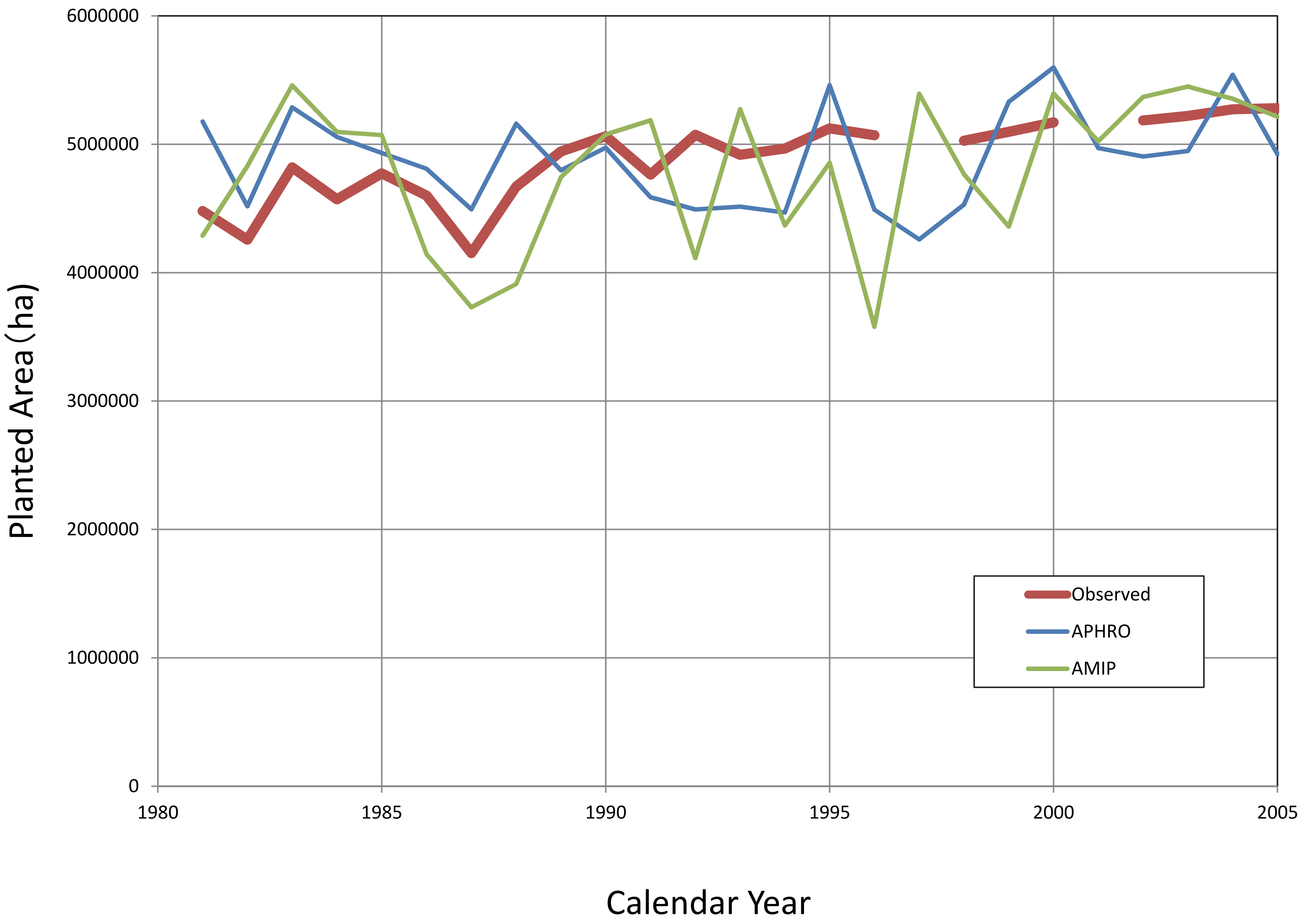
Land Use Classification(Allocation of Maximum Planted Area)



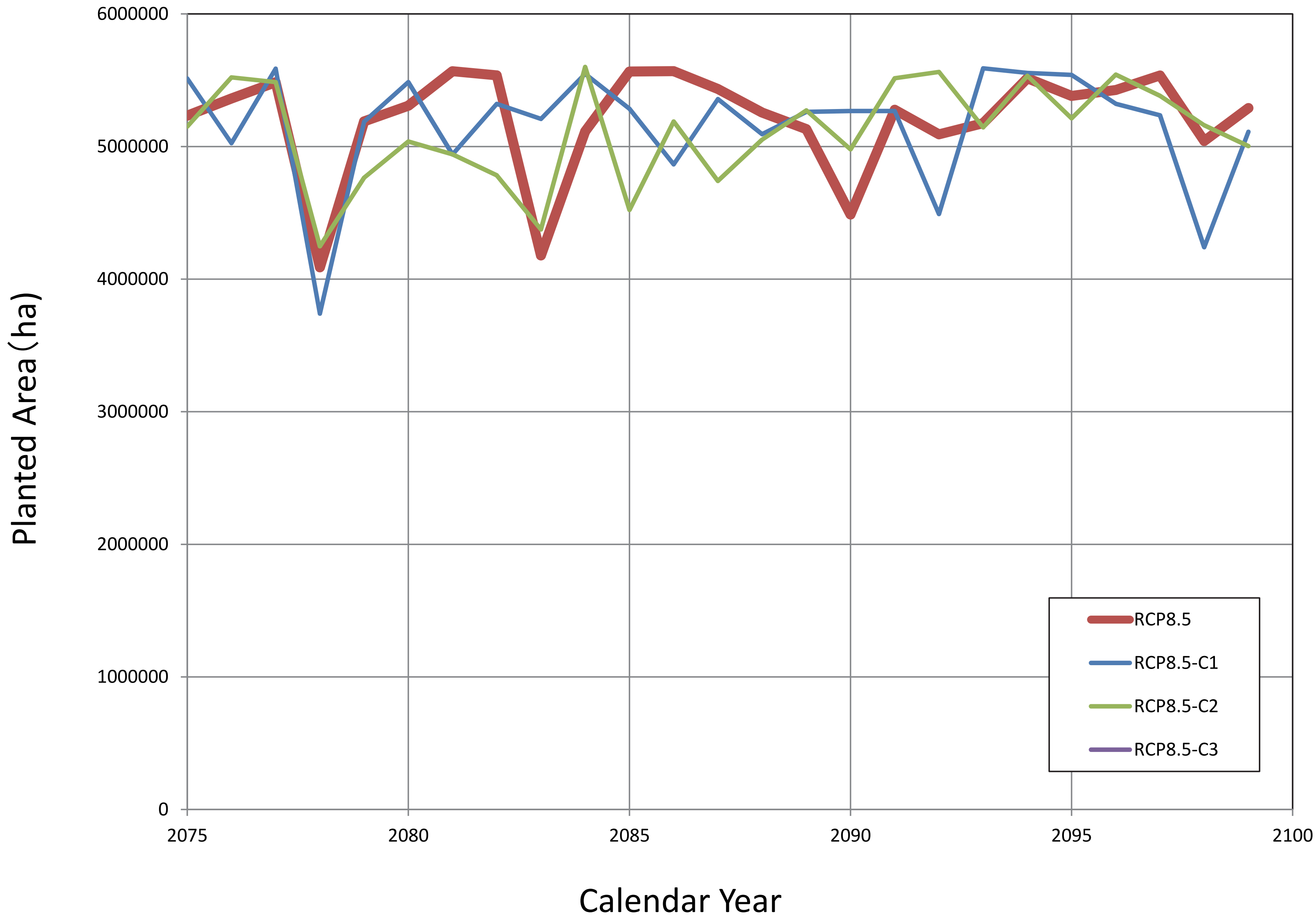
Proportion of Area of Rainfed Rice Field in Rice Filed in each province

Interval of meridian is 15’ same as resolution of rainfall data. Resolution of Land Use data is 3 times finer than that of rainfall data.

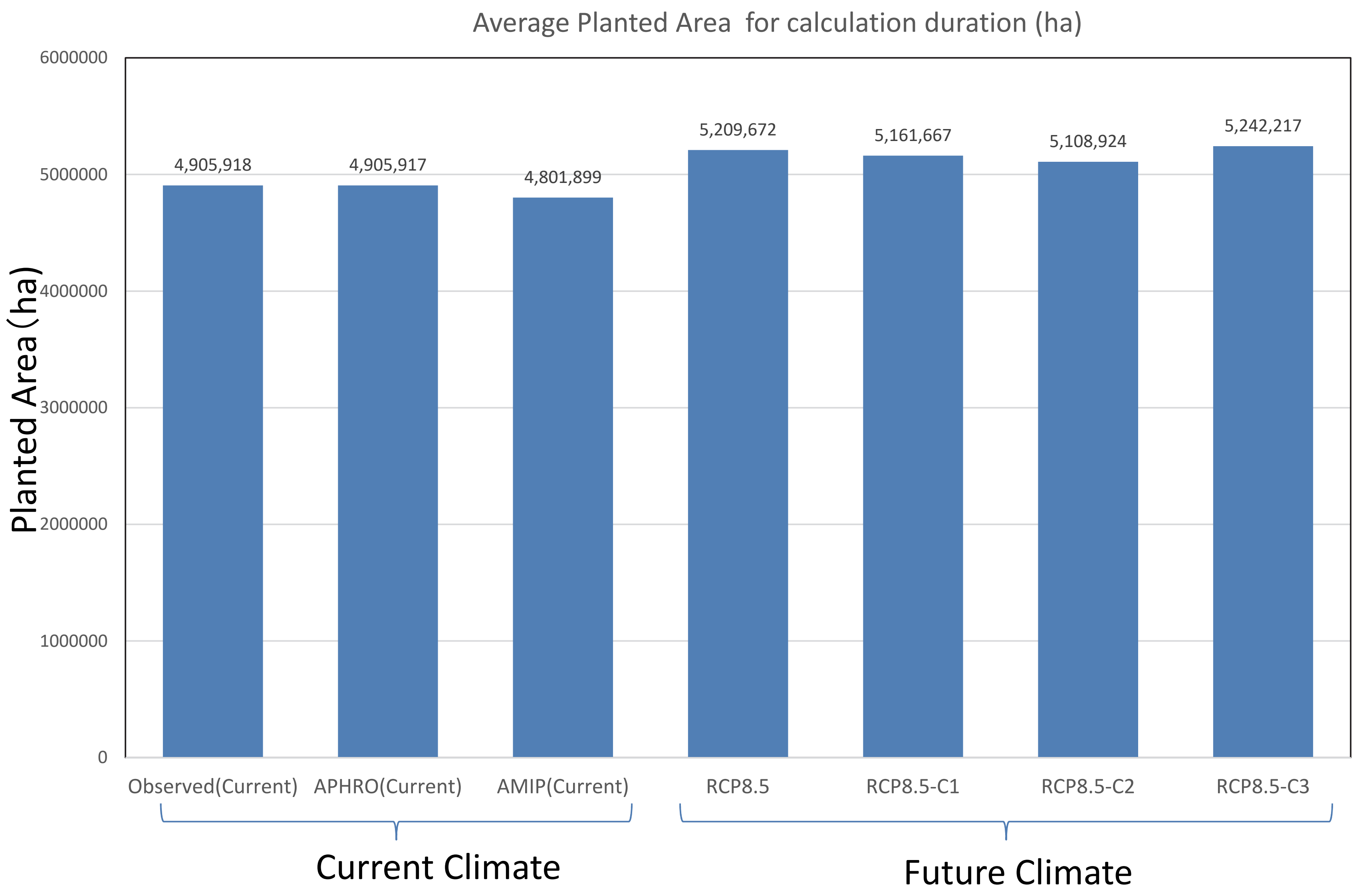
Calculation Result (Wet Season - Current Climate)



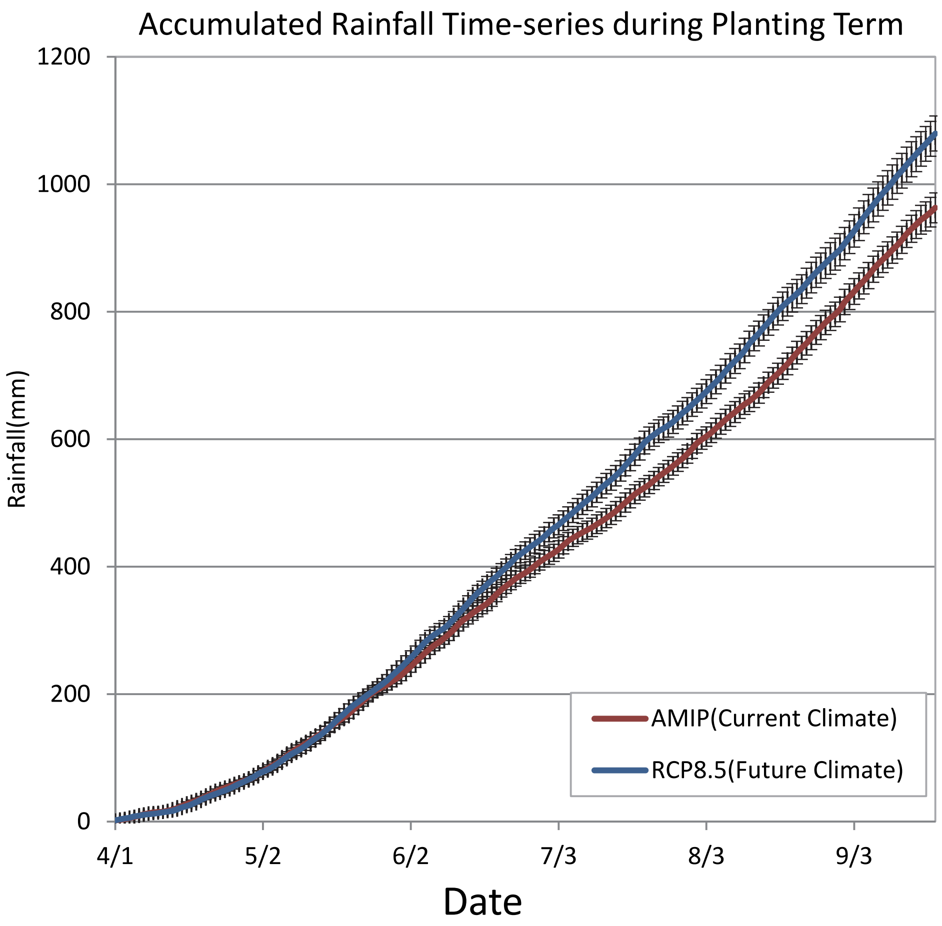
Calculation Result (Wet Season – Future Climate)

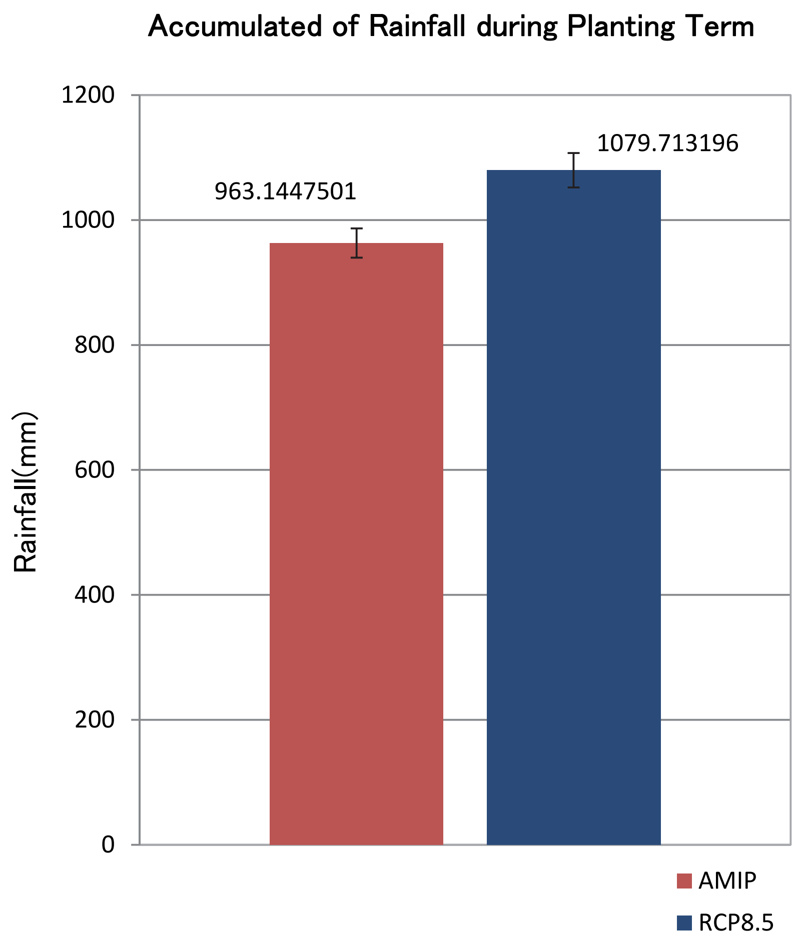


Calculation Result (Present– Future Comparison)



Difference of Rainfall between Current Climate and Future Climate





Conclusion

1. We applied IRE Model for Rice Planted Area Prediction. In case of the current climate, it turned out that this model reproduces current annual rice planted area time series well.

2. We got the result that Rice Planted Area will increases by approximately 6 to 9 % in future.

3. The reason why planted area will increase in future is that rainfall in planting duration increases so that farmers get to start planting early compared to current climate.

4. Above shown results are based on the assumption that reducing proportion of planted area after complete of planting is not changed.

Next Step

1. Calculation harvesting Area of Rice. It needs to build a model for reducing paddy area after planted.

2. Calculation harvesting Area of Rice in Dry Season.