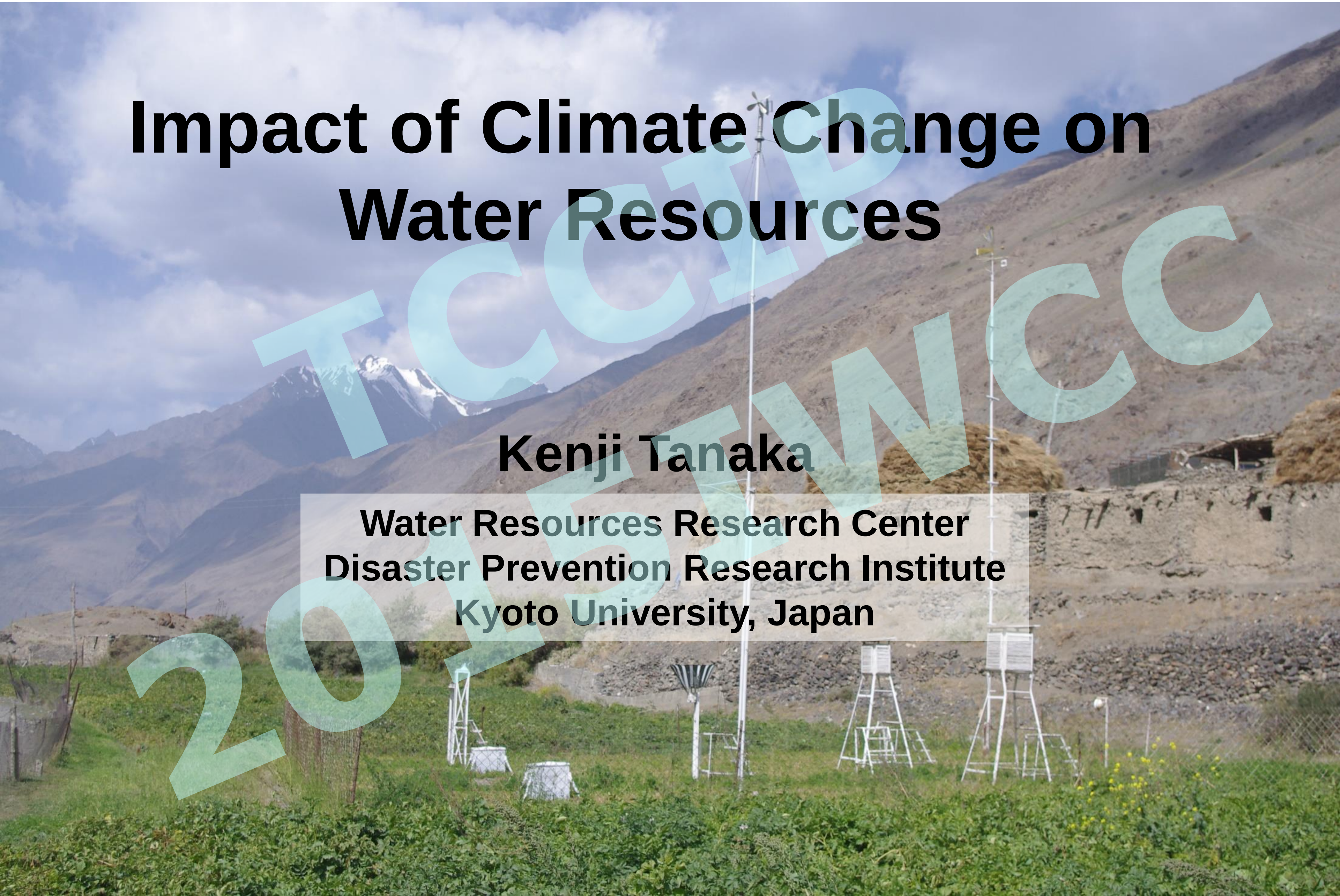
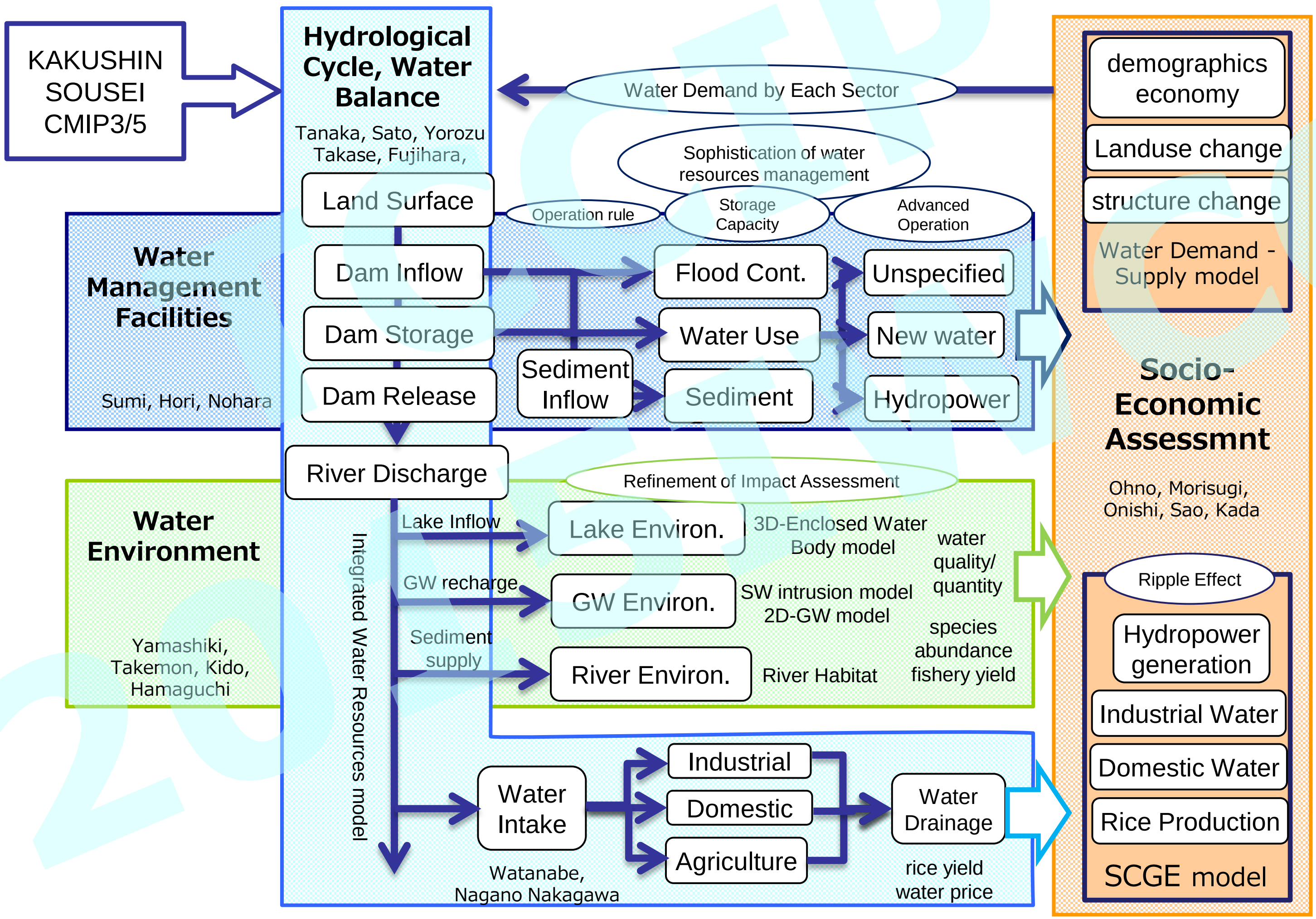


Impact of Climate Change on Water Resources

Kenji Tanaka

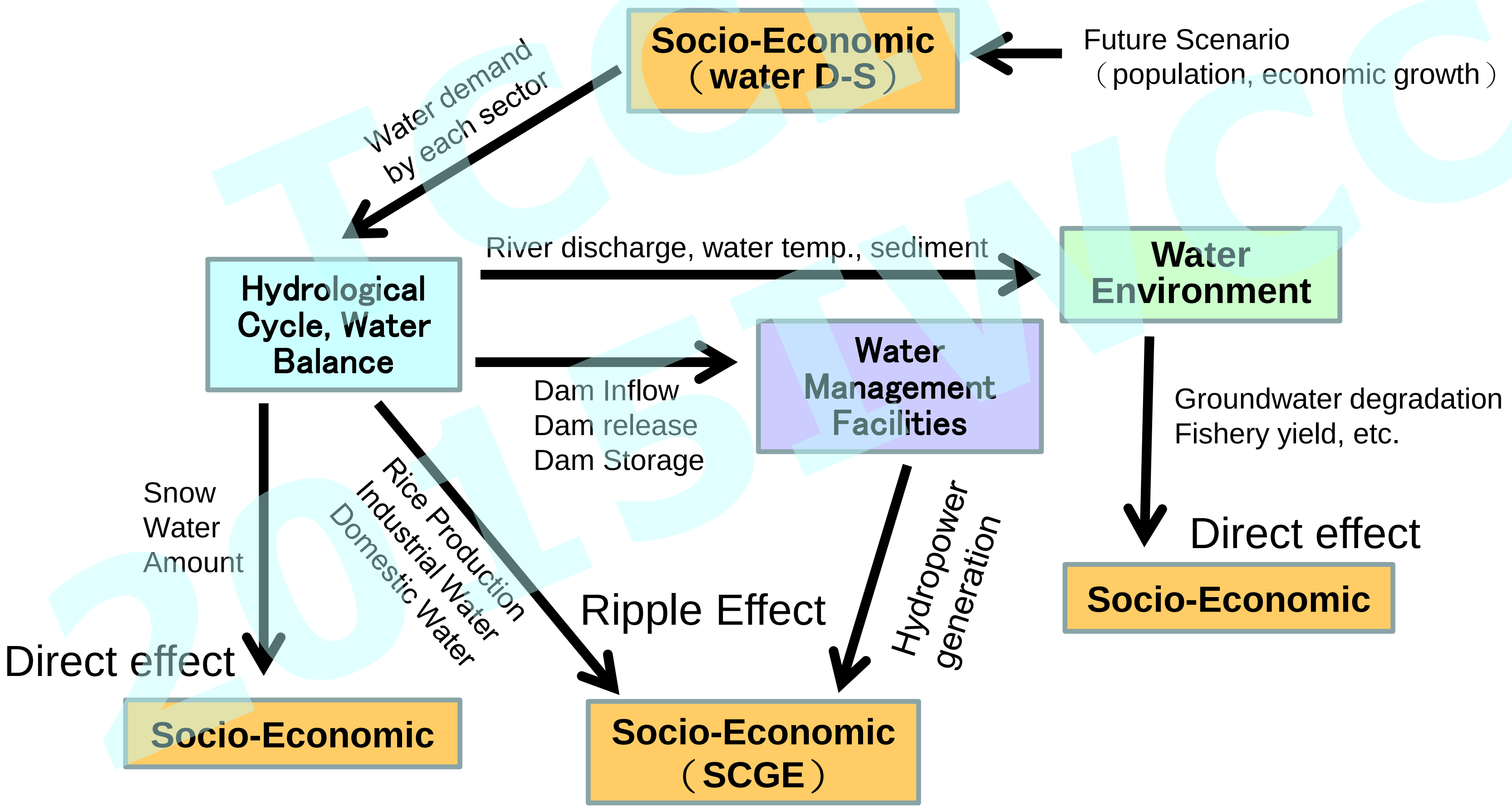
Water Resources Research Center
Disaster Prevention Research Institute
Kyoto University, Japan

Climate Change Impacts on Water Resources Team (a)



Tanaka, K.

Important Collaboration between sub-Group



Contents

1. **Projection of Future Change in Aridity Index & Evaporation Ratio**

    Global, land surface model

    climate change tendency (positive, negative)

2. **Projection of Future Change in Available Water Resources in Japan**

    Japan, Integrated model

    river discharge, water stress, snow

    adaptation strategy for rice production

Background 1 (evapotranspiration)

Annual evapotranspiration approaches annual precipitation in arid and semi-arid regions where the available energy greatly exceeds the amount required to evaporate annual precipitation.

Evapotranspiration is a key information for water management in the region where available water resources are limited.

Aridity Index

Energy balance

$$\frac{R_{net}}{L\,P}$$

5	< AI < 12	Arid
2	< AI < 5	Semi Arid
0.75	< AI < 2	Sub Humid
0.375	< AI < 0.75	Humid

(Ponce et al. 2000)

Evaporation Ratio

Water balance

$$\frac{E}{P}$$

R_{net}: annual mean net radiation
P : annual precipitation
L : latent heat of vaporization
E : annual evapotranspiration

Land Surface Processes

Energy balance eq.

$$\Delta M = Rn - H - \lambda E - G$$

地表面熱貯留 / 純放射量 / 顕熱 / 潜熱 / 地中熱流量

Radiation balance eq.

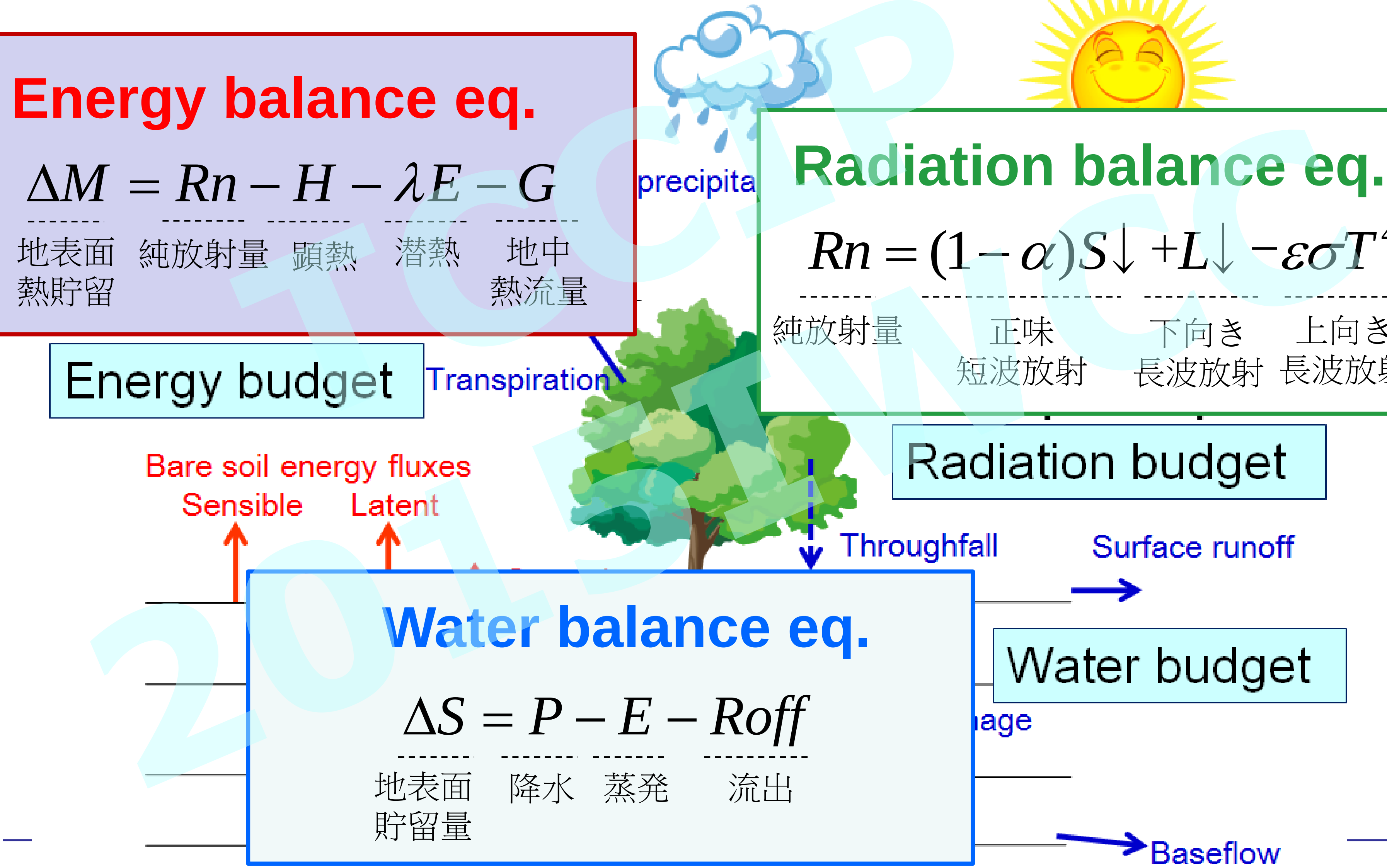
$$Rn = (1-\alpha)S\downarrow + L\downarrow - \varepsilon\sigma T^4$$

純放射量 / 正味短波放射 / 下向き長波放射 / 上向き長波放射

Water balance eq.

$$\Delta S = P - E - Roff$$

地表面貯留量 / 降水 / 蒸発 / 流出



Land Surface (SiBUC)

Grid box is divided into three landuse categories

1. Green Area
2. Urban Area
3. Water Body

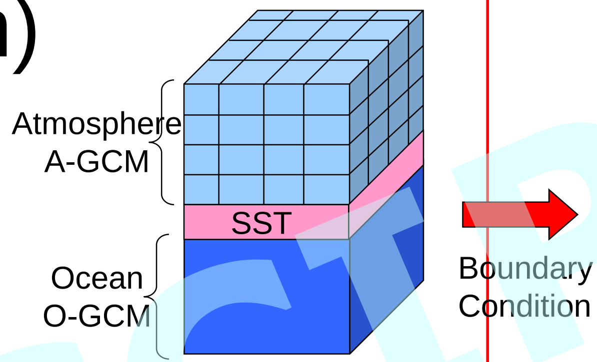
1 · Broadleaf-evergreen trees
2 · Broadleaf-deciduous trees
3 · Broadleaf and needle leaf trees
4 · Needle leaf-evergreen trees
5 · Needle leaf-deciduous trees
6 · Short vegetation/C4 grassland
7 · Broadleaf shrubs with bare soil
8 · Dwarf trees and shrubs
9 · Farmland (non-irrigated)
10. Paddy field (non-irrigated)
11. Paddy field (irrigated)
12. Spring wheat (irrigated)
13. Winter wheat (irrigated)
14. Corn (irrigated)
15. Soybean (irrigated)
16. Cotton (irrigated)
17. Other crops (irrigated)

MRI-AGCM3.2S (20km resolution)

Surface meteorological elements are provided with high spatial and temporal resolution.

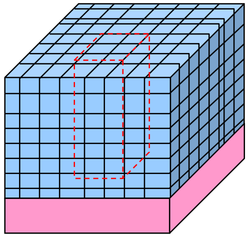
1hr : Prec, Tair, Wind
3hr : Qair, SWdown, LWdown, Psfc

General Circulation Model
(Global: AOGCM)

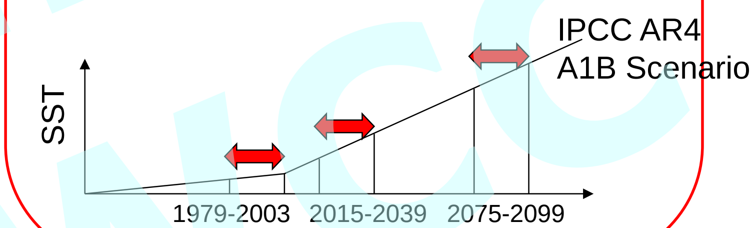


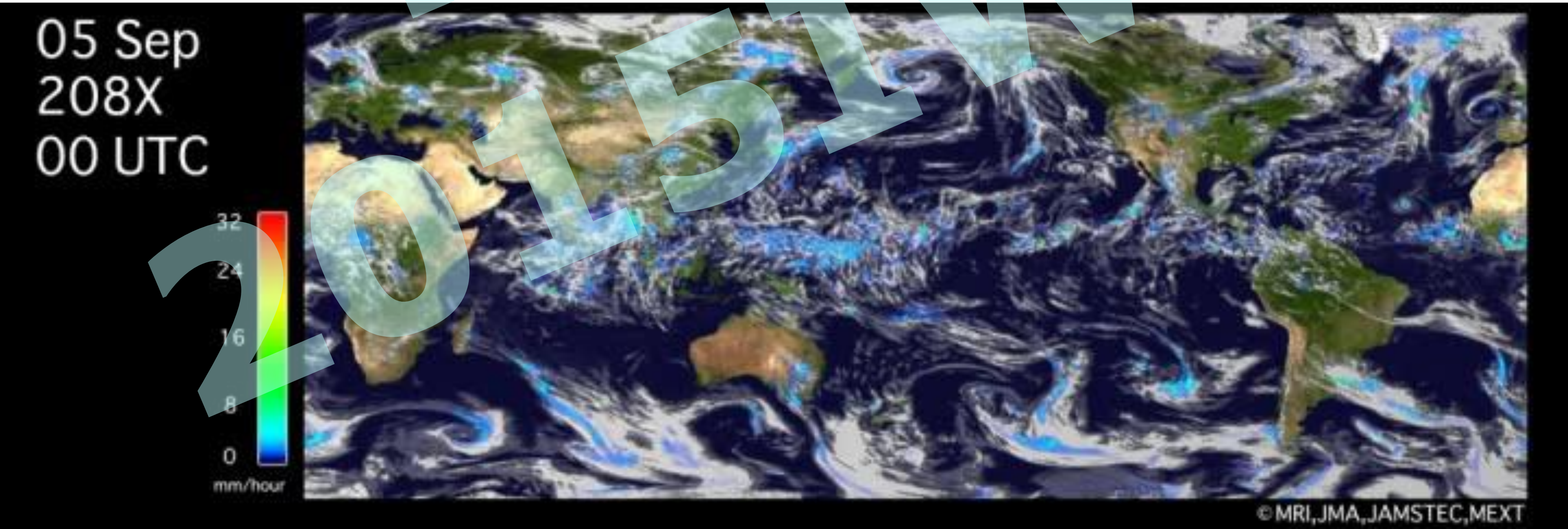
KAKUSHIN

Super high-resolution GCM
(Global: AGCM)

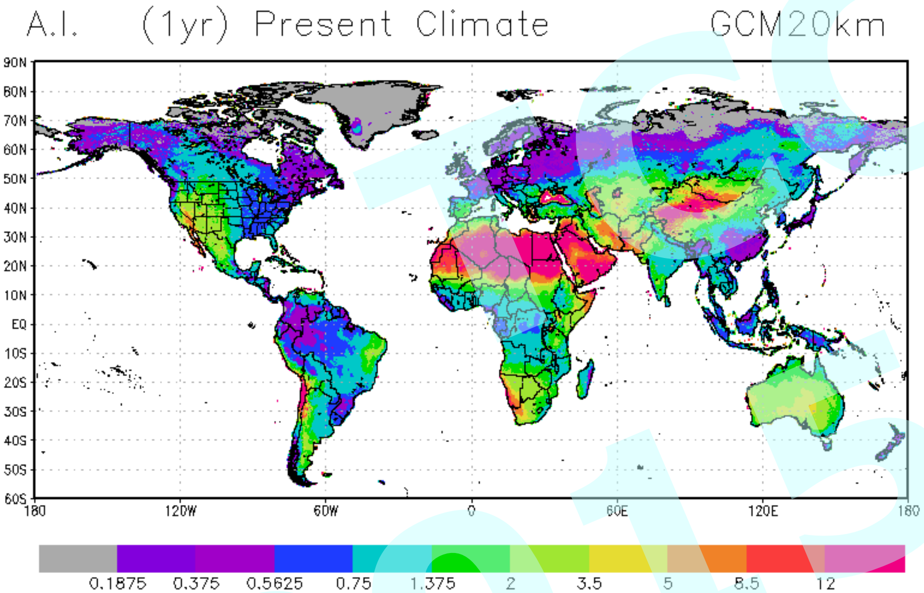


MRI-TL959(1920 x 960 x 60)
Horizontal resolution: 20 km
Vertical: 60 layers

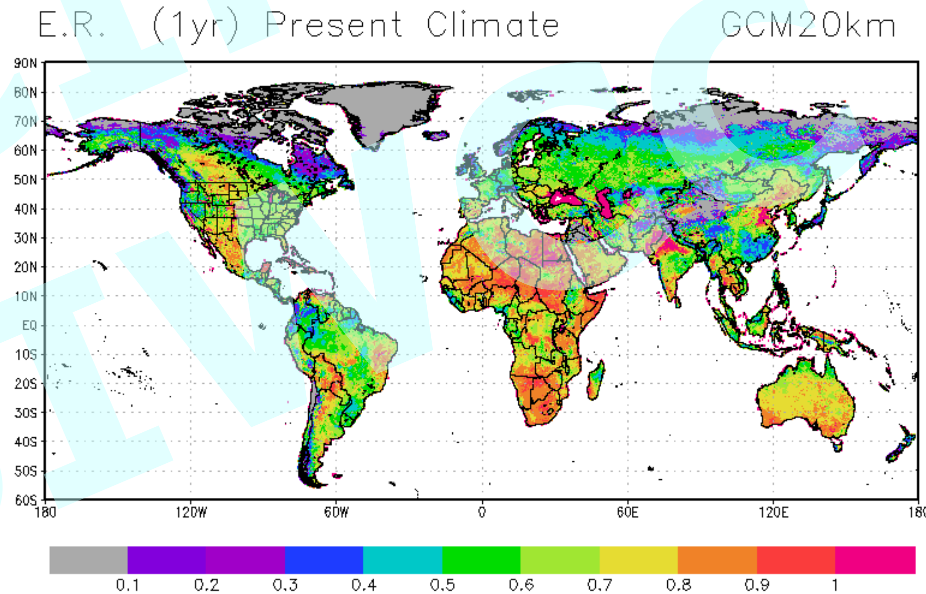




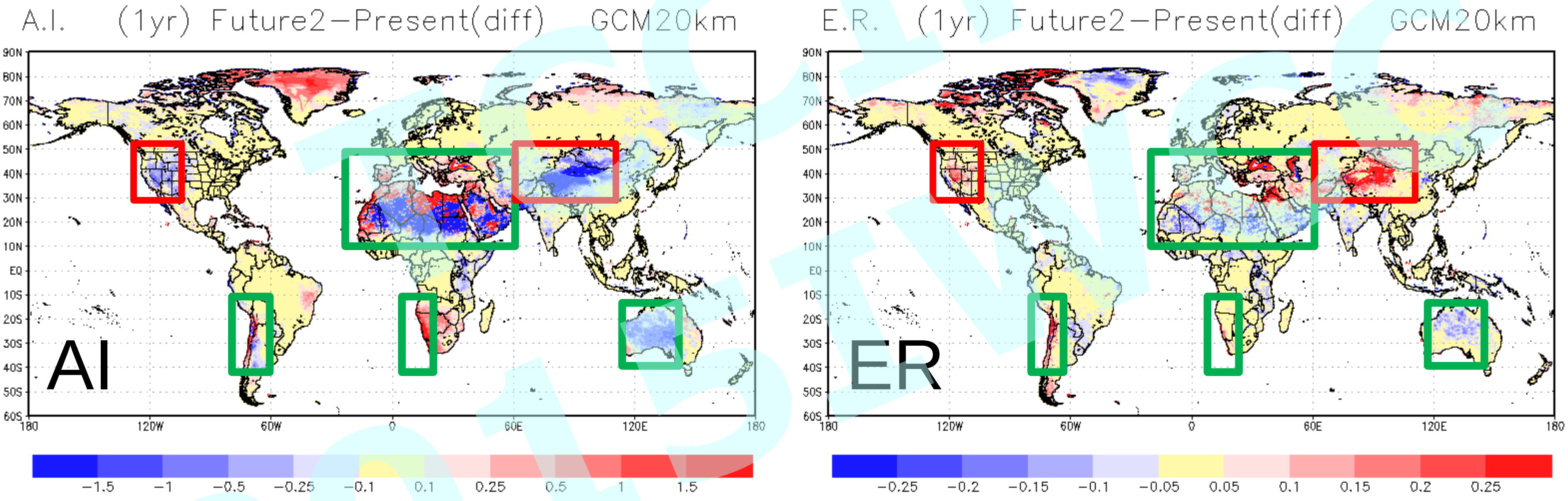
Aridity Index (Present)



Evaporation Ratio (Present)



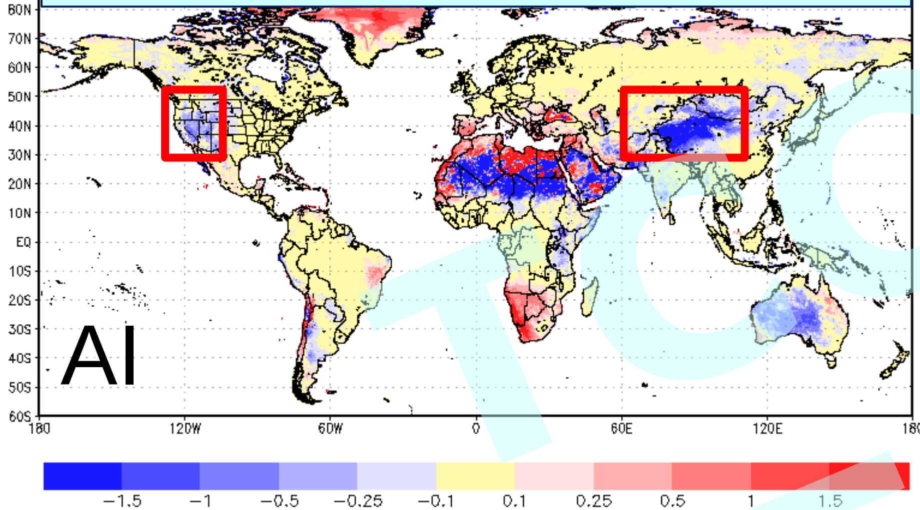
The climate change signals for AI and ER are generally same.
(Ex.) Atacama desert, Sahara desert, Namib desert,
Arabian Peninsula, and Australia.

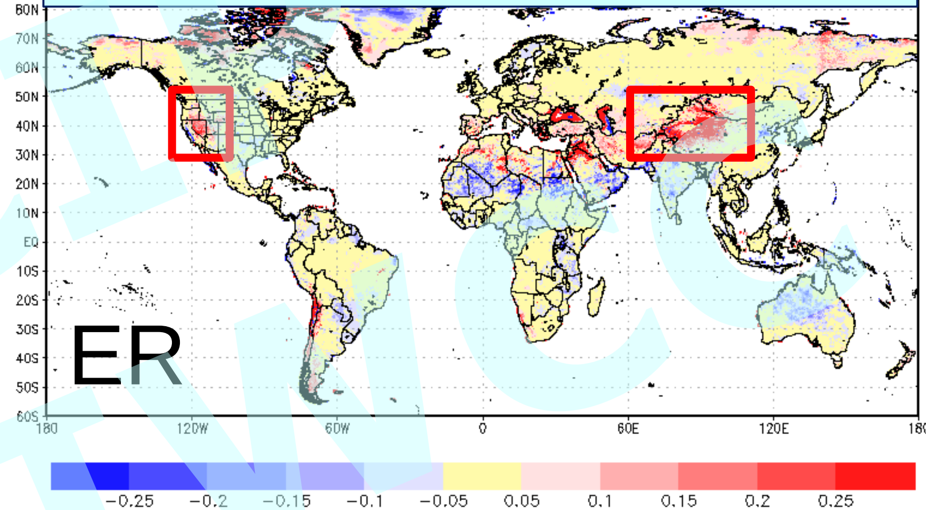


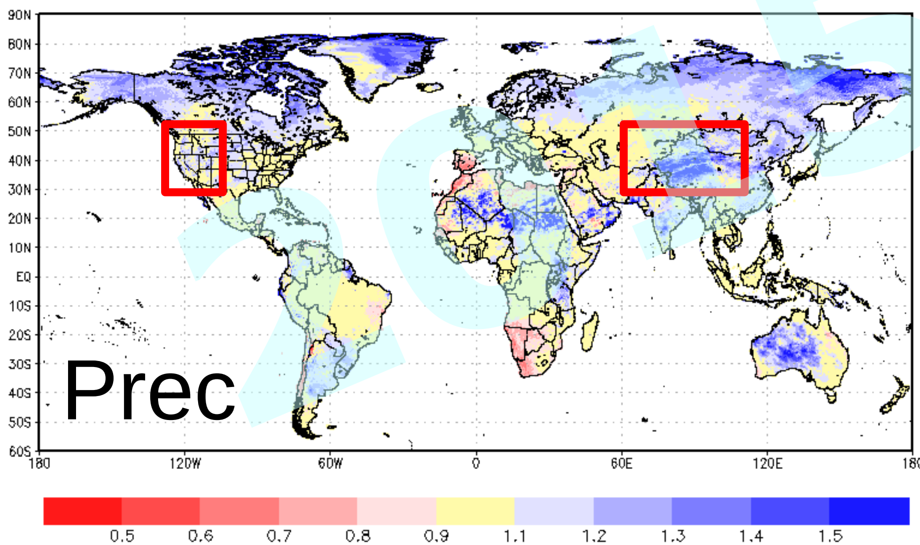
Some regions have negative impact on AI and positive impact on ER.
(Ex.) California, Tibetan Plateau, and Gobi desert,

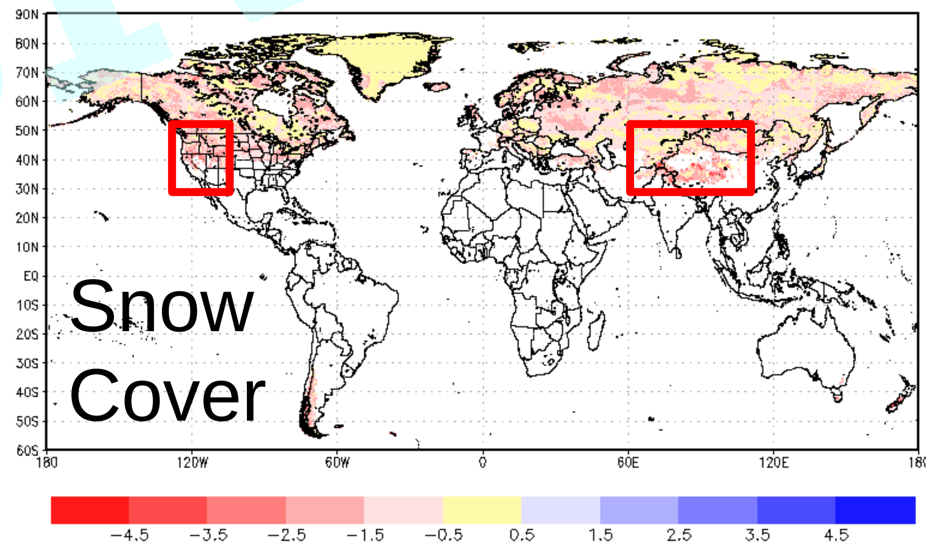
Negative impact on AI is basically consequence of the increased precipitation.

Positive impact on ER can be explained by the decreased snow-covered period.



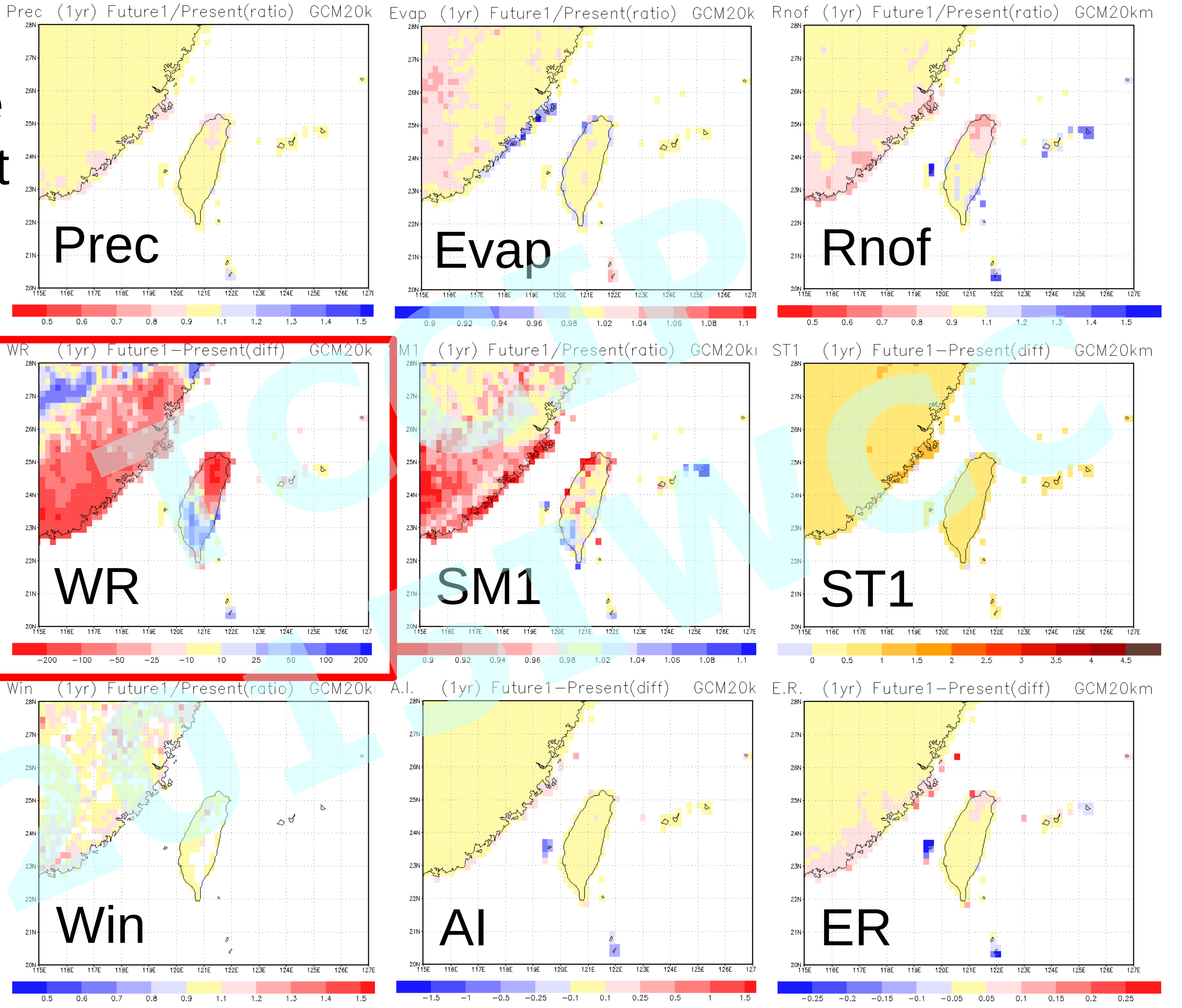




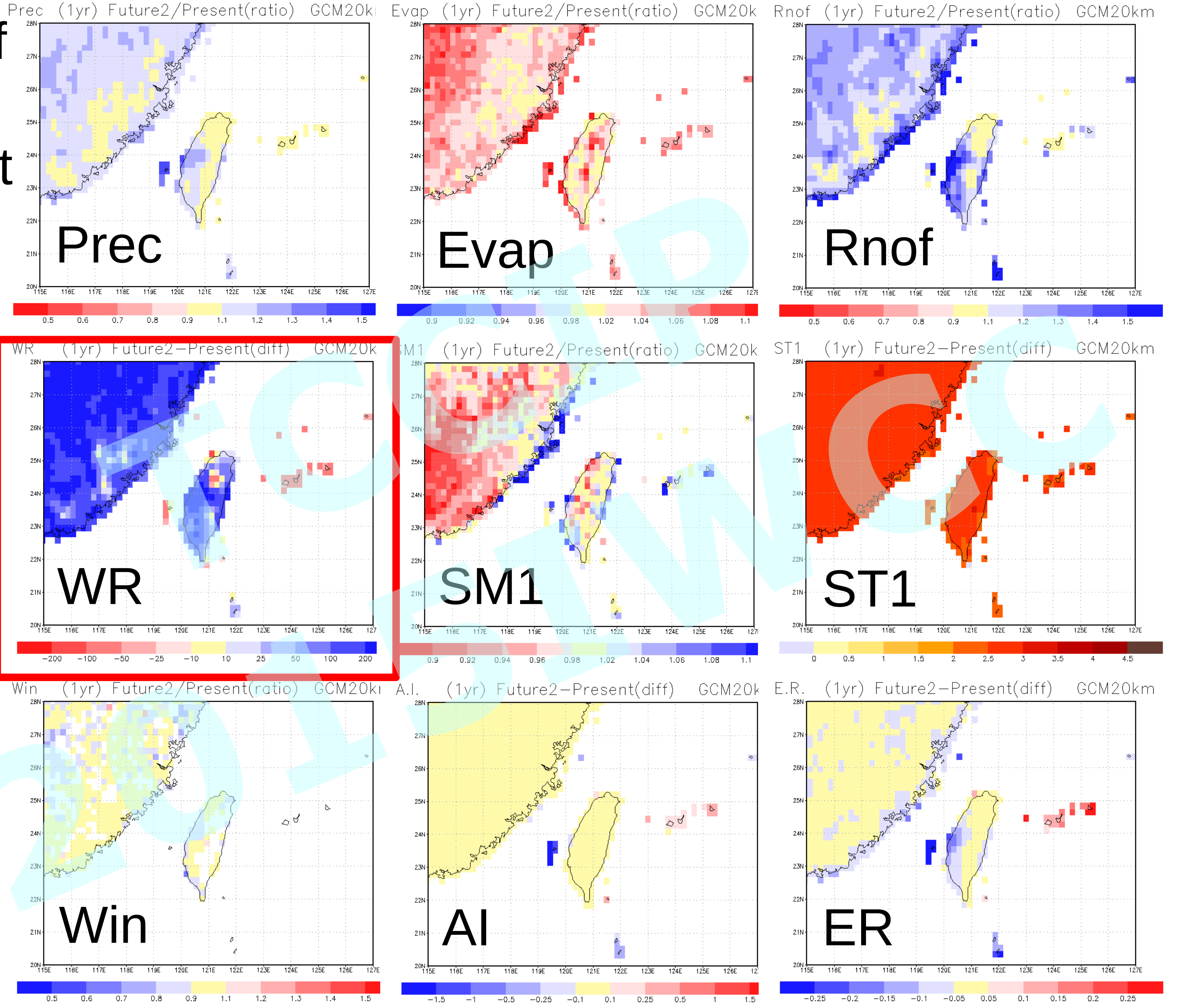


Some Close-up images for Taiwan

Near Future Impact



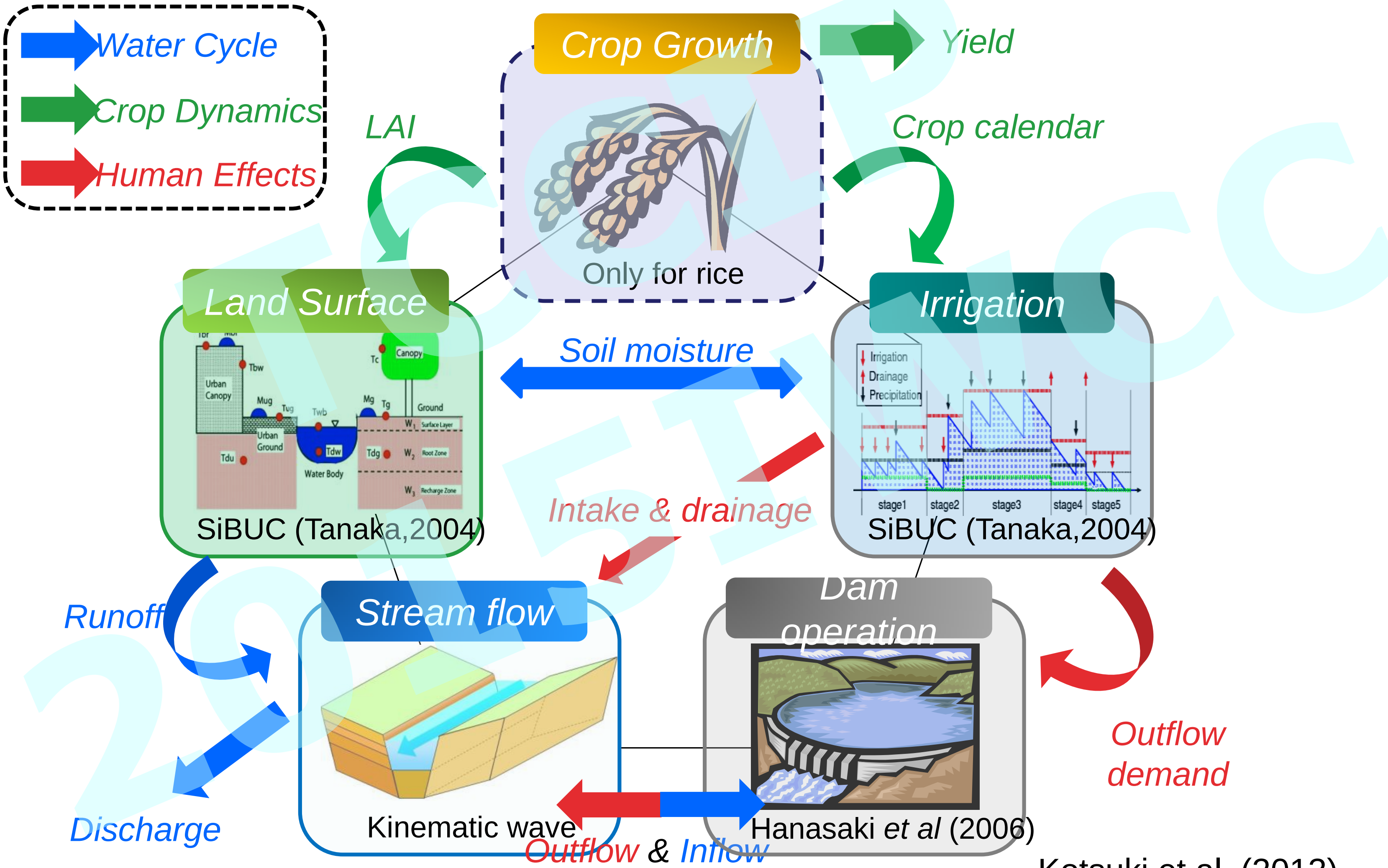
End of 21st C Impact



Summary (part 1)

- Future projection of change in Aridity Index (AI) and Evaporation Ratio (ER) using super high-resolution global climate model and land surface model with 20km resolution.
  + present climate (1979-2003)
  + future climate (2075-2099)
- In general, AI and ER show same climate change tendency
  Atacama desert, Sahara desert, Namib desert,
  Arabian Peninsula, Australia
- In some region, AI and ER show opposite climate change tendency
  California, Tibetan Plateau, Gobi desert
  + Negative impact on AI : increased precipitation
  + Positive impact on ER: decreased snow-covered period

Integrated water resources model



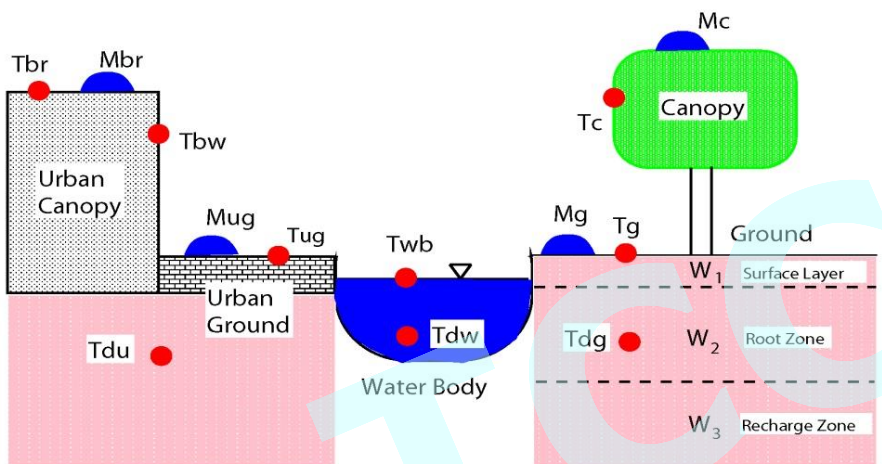
Kotsuki et al. (2013)

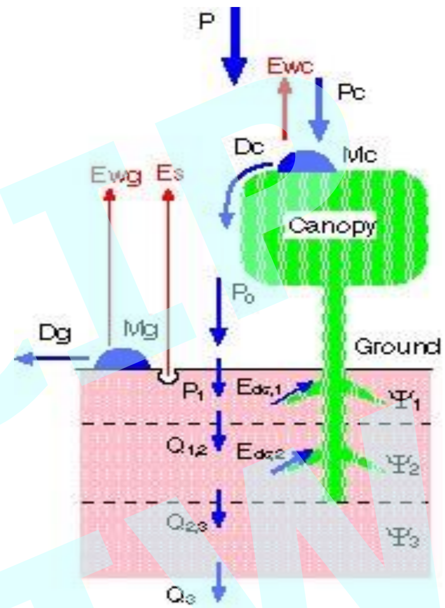
Percentage of water withdrawal by each sector (AQUASTAT)

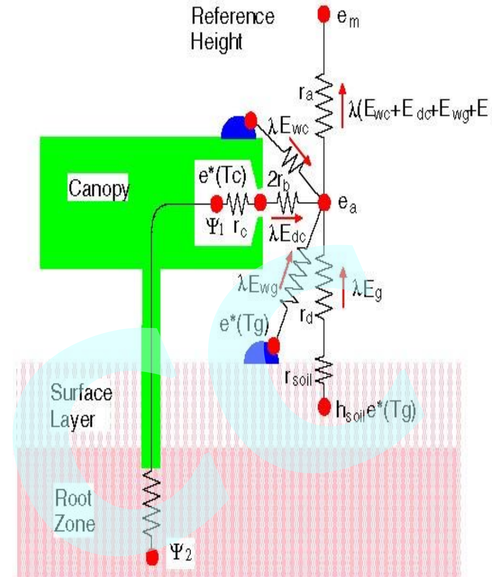
	Agricultural	Municipal	Industrial
Canada	11.77	19.56	68.67
USA	41.49	13.48	45.03
Italy	45.00	18.19	36.71
Japan	62.45	19.68	17.87
France	9.81	15.72	74.47
Russia	19.94	20.24	59.82
Germany	2.94	14.94	82.12
UK	2.94	21.70	75.36

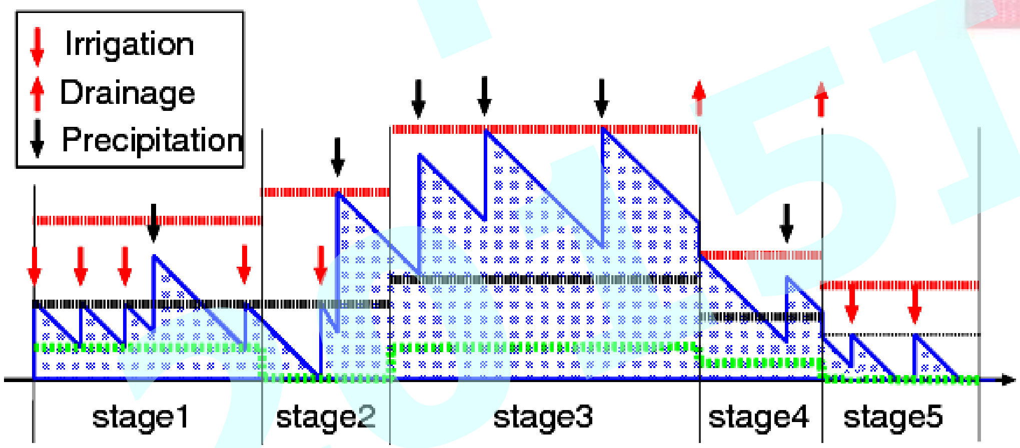
Most of the agricultural water use in Japan is for rice paddy field

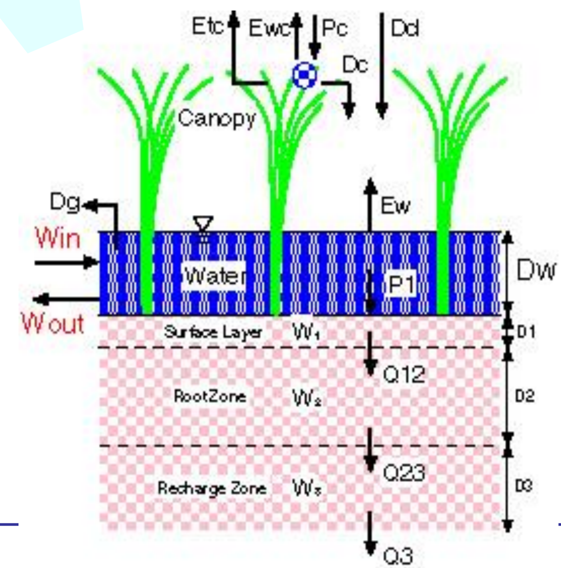
Land surface model SiBUC paddy field model











Basic concept is to maintain water depth/ soil moisture within appropriate ranges for optimal crop growth

Tanaka, K.

S I M R I W

Simulation **M**odel for **Ri**ce-**W**eather relations

Horie (1986)

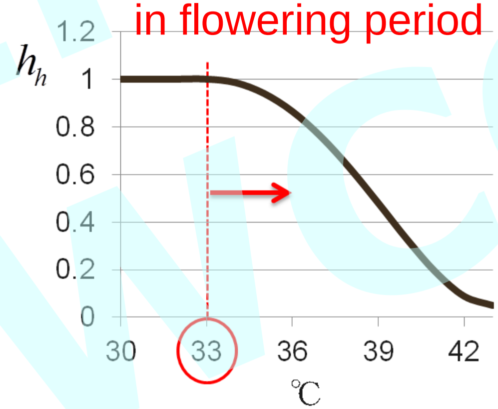
$$Y = \tau \cdot h_h \cdot W$$

Yield Harvest Index Dry weight

$$h_h = h_m(1-0.95\gamma_h);$$

$$\begin{cases} \gamma_h = \left[\left(\frac{\overline{T}_{max}-T_b}{T_o-T_b}\right)\left(\frac{T_c-\overline{T}_{max}}{T_c-T_o}\right)^{\frac{T_c-T_o}{T_o-T_b}}\right]^{C_{cool}} & for \quad \overline{T}_{max} > T_o \\ \gamma_h = 0 & for \quad \overline{T}_{max} \le T_o \end{cases}$$

High temperature stress in flowering period



LAI growth

$$\Delta LAI_j = LAI_j \cdot A \cdot 1-\exp\left[-K_f(T-T_{cf})\right]\left\{1-\left(\frac{LAI_j}{LAI_{max}}\right)^k\right\}$$

Empirical equation

Solar absorption

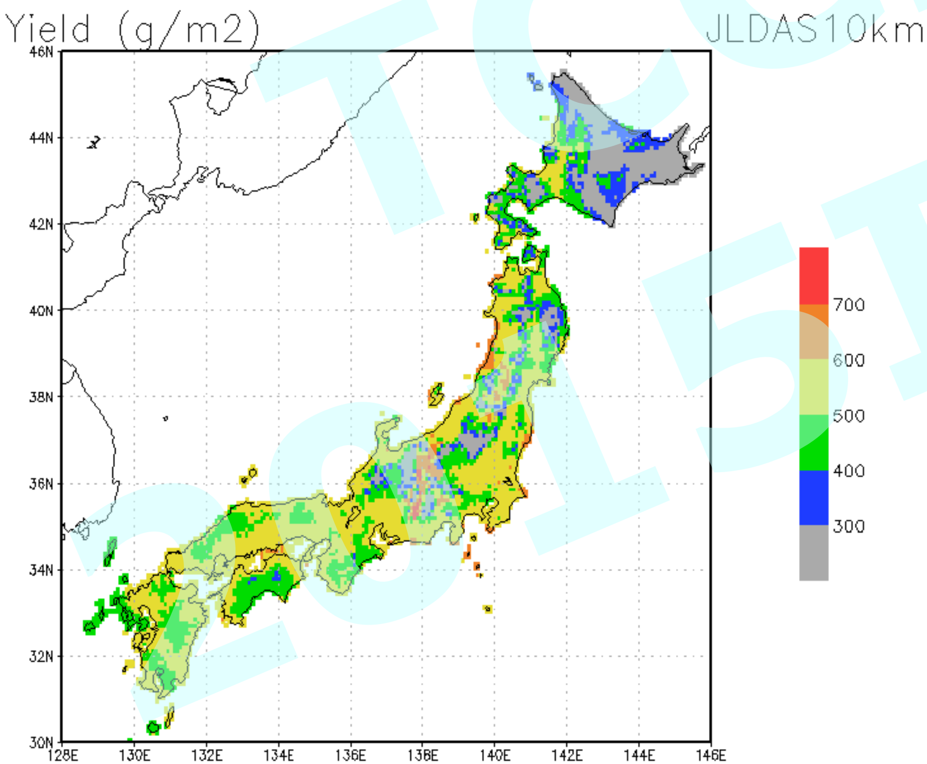
$$S_s = S_0\left[1-r-(1-r_0)\exp\{-k(1-m)LAI\}\right]$$

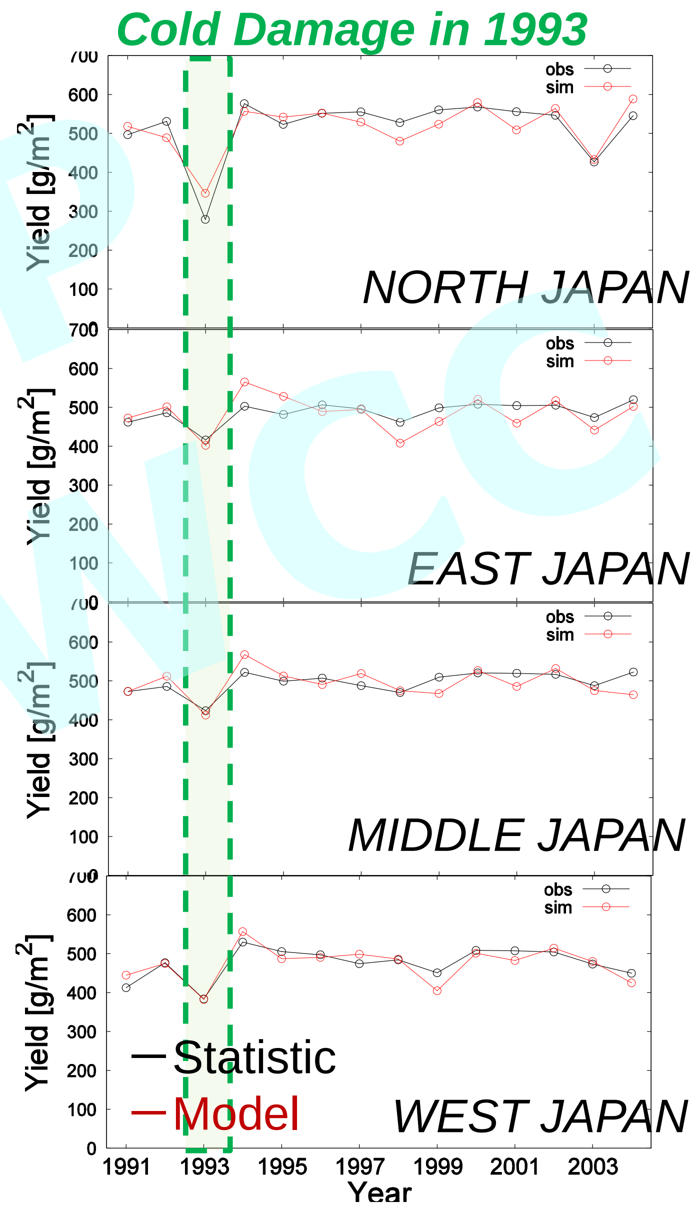
Carbon production

$$\Delta DW_j = S_s C_s, \quad C_s = \begin{cases} C & for\ 1 < DVI < 2 \\ \frac{C(1+B)}{1+B\exp b}, \quad b = \frac{DVI-2}{t} & for\ 2 < DVI < 3 \end{cases}$$

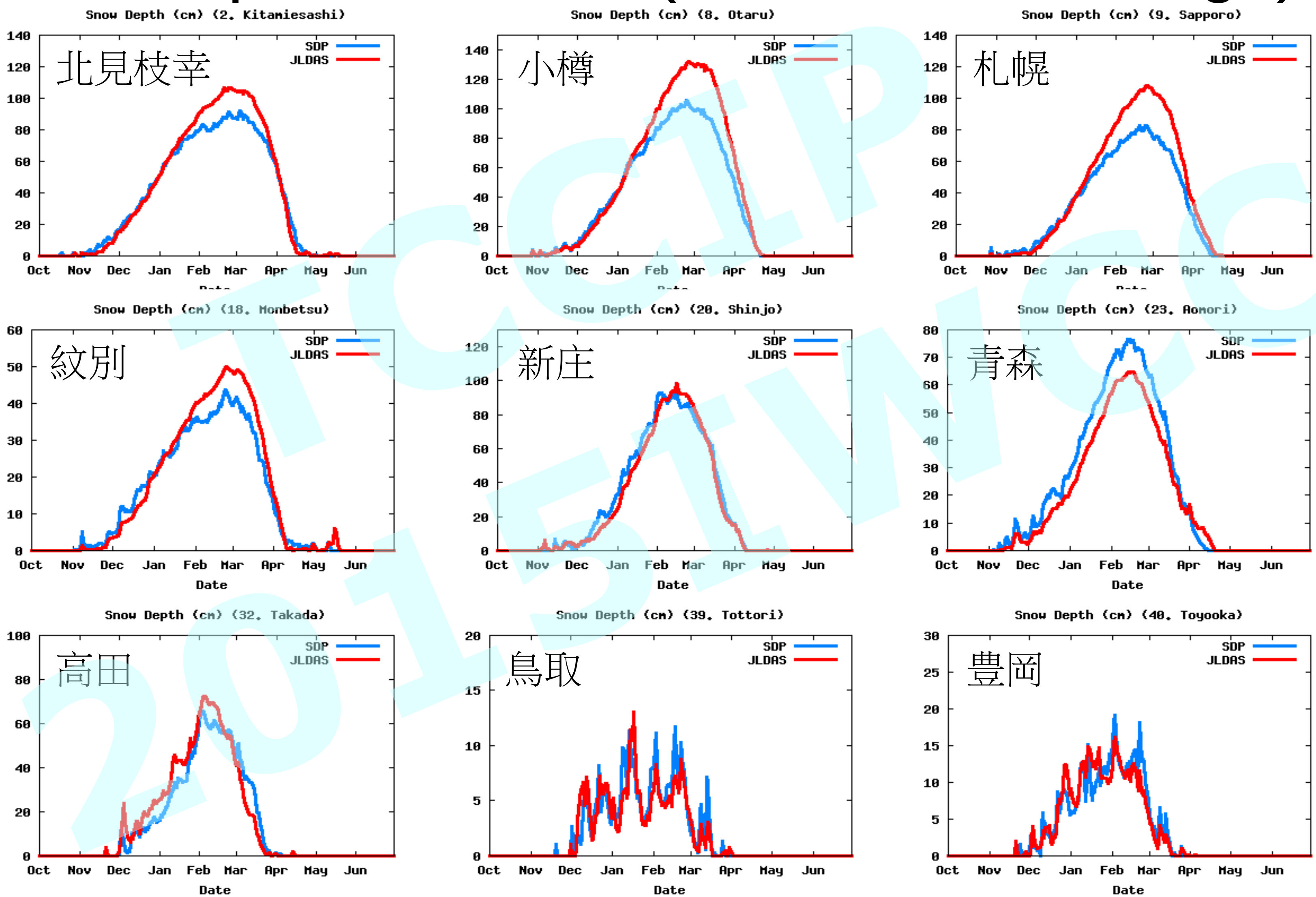
Validation of rice yield

Inter-annual variation of rice yield is reproduced well



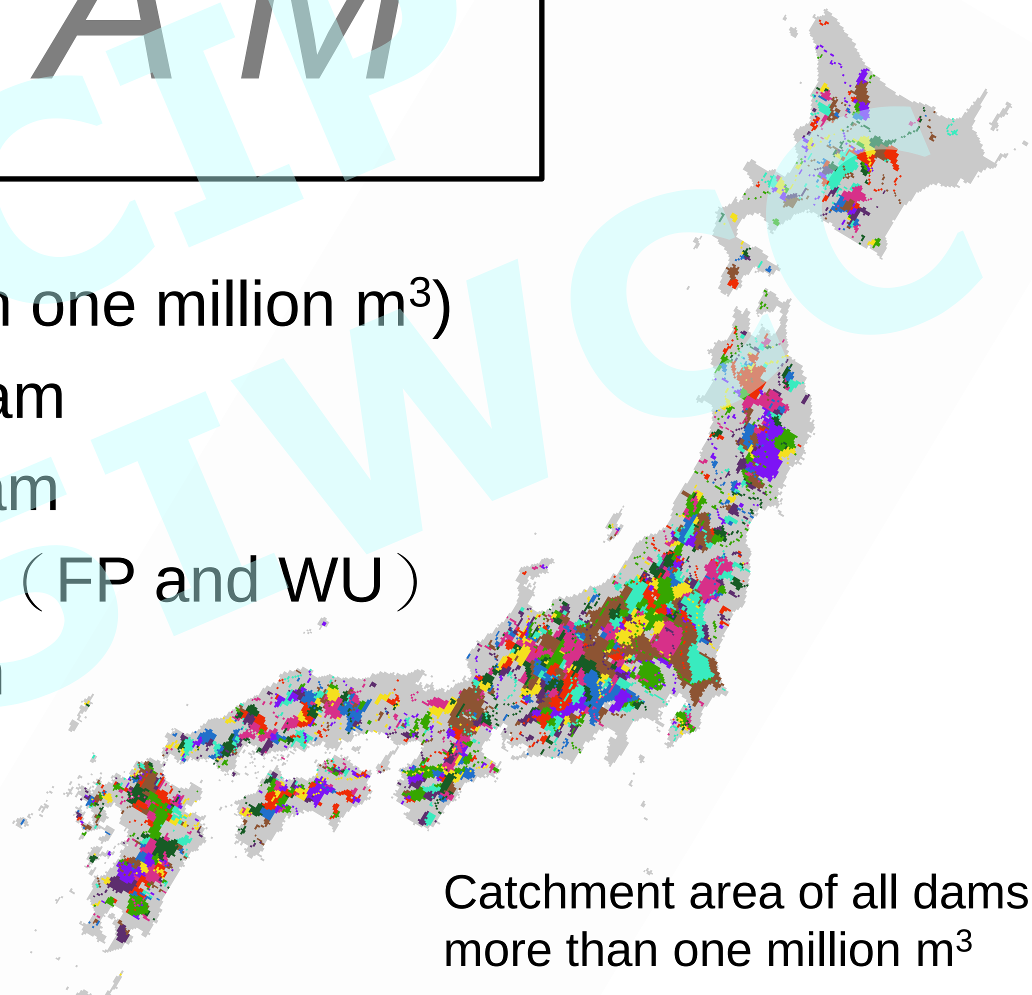


Snow depth validation (1991-2008 average)



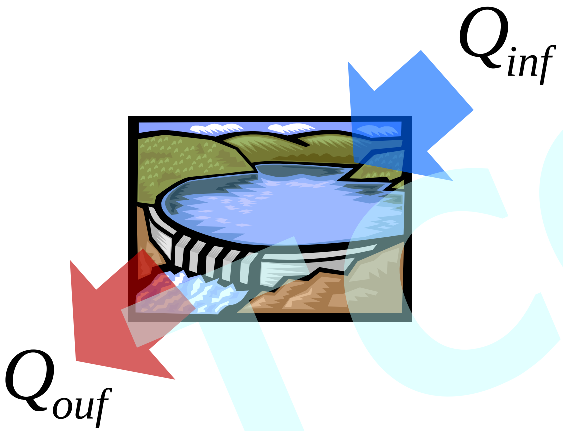
D A M

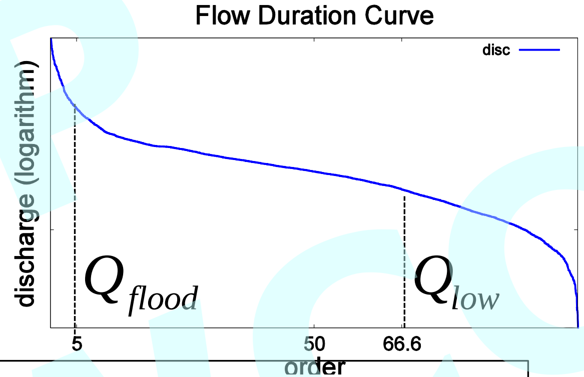
- 1231 dams (more than one million m^3)
  - Flood protection dam
  - Water utilization dam
  - Multi purpose dam（FP and WU）
- Dynamic coupling with river routing model



Catchment area of all dams more than one million m^3

Basic Operation

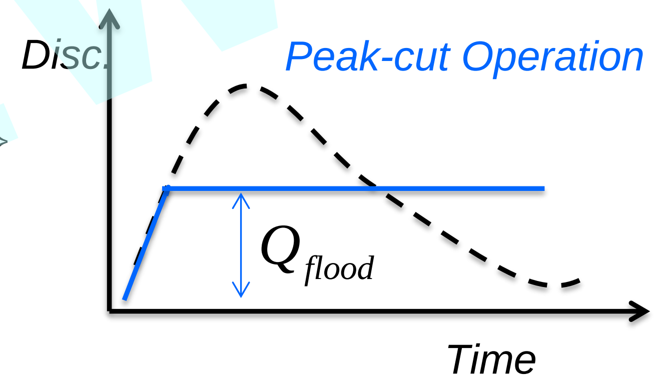




Flood flow rate and normal flow rate are set from flow duration curve

1. Flood protection operation

$$Q_{base} = \begin{cases} Q_{flood} \\ Q_{norm} \end{cases} when \begin{cases} Q_{inf} > Q_{flood} \\ else \end{cases}$$

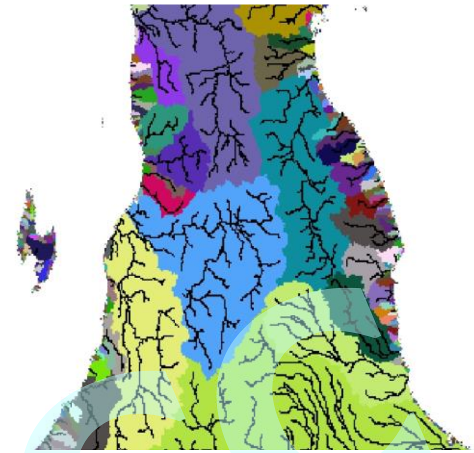


2. Water utilization operation

$$Q_{ouf} = \max\{Q_{base}, Q_{req}\}$$

Release the demand from downstream
Demand can be estimated from irrigation Model and statistics

Discharge



- 20 first rank rivers 1994-2003年（SDP, AMeDAS）
- Correction of raingauge under-catch rate

No.	River	Station	Budget[%]	Nash
1	Teshio	Maruyama	-8.7	0.436
2	Ishikari	Ishikari	+13.5	0.117
3	Tokachi	Moiwa	-2.0	0.855
4	Mogami	Sagoshi	-10.0	0.849
5	Omono	Tsubakigawa	-11.2	0.847
6	Kitakami	Tome	-14.6	0.812
7	Yoneshiro	Futatsui	-13.3	0.868
8	Abukuma	Tateyama	-13.7	0.843
9	Shinano	Ojiya	-18.2	0.726
10	Agano	Maoroshi	-14.2	0.783

No.	River	Station	Budget[%]	Nash
11	Tone	Kurihashi	+12.7	0.873
12	Naka	Noguchi	-8.7	0.842
13	Fuji	Kitamatsuno	+59.1	0.619
14	Tenryu	Kashima	+0.4	0.873
15	Kiso	Inuyama	+0.3	0.911
16	Katsura	Katsura	+9.0	0.734
17	Kizu	Yawata	-22.3	0.782
18	Gono	Kawahira	-20.2	0.660
19	Yoshino	Ikeda	+10.6	0.871
20	Chikugo	Senoshita	-14.9	0.940

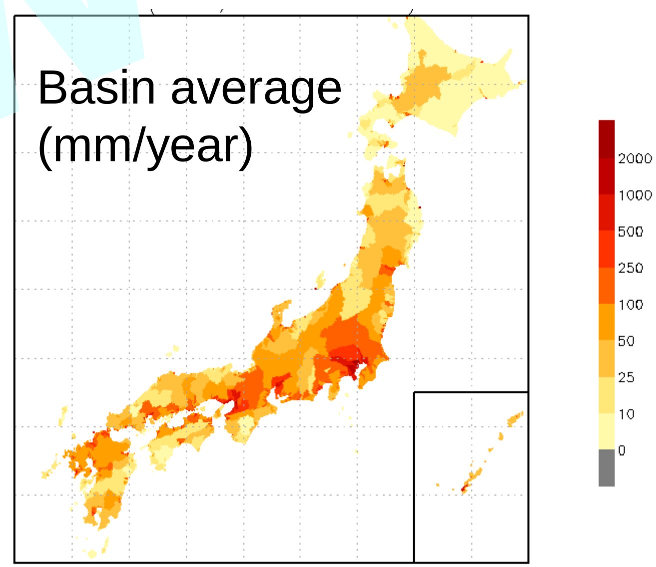
Water stress analysis

Water Stress

- Water stress for each river basin （16,000 rivers）
- Water demand from each sector
  - agriculture: irrigation model (SiBUC)
  - industrial and domestic:

National Land Numerical Information Download Service
Report of Japanese Water Resources in 2011 (MLIT)

Total water demand



Water Stress Index

Water withdrawal to total runoff

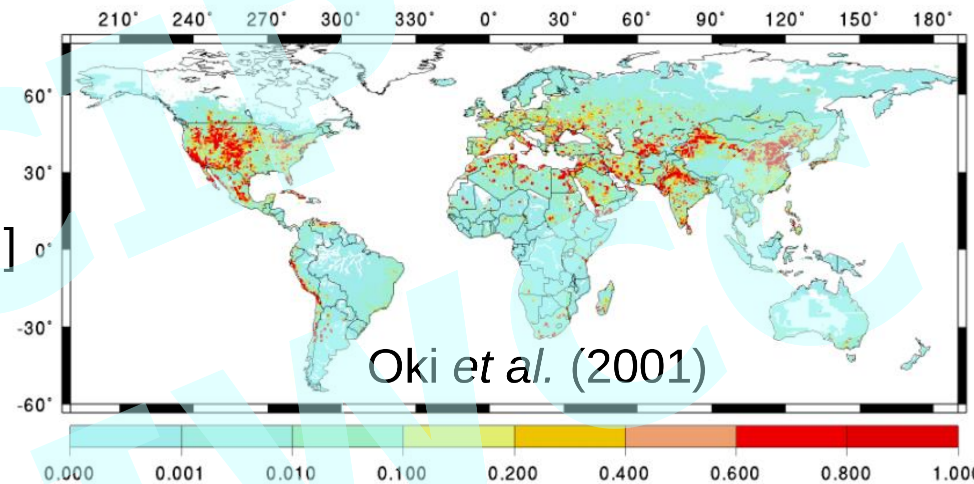
$$WWR = \sum W_i / \sum Q_i$$

Raskin, 1997

W: daily water withdrawal [MCM]

Q: daily discharge [MCM]

⇒annual water stress



Oki *et al.* (2001)

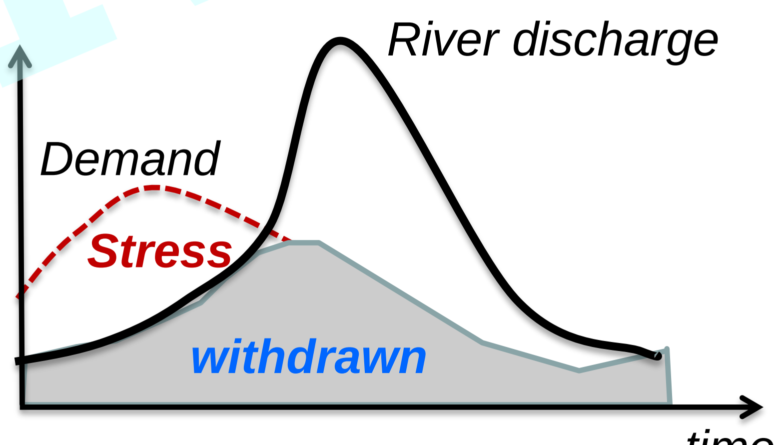
Cumulative withdrawal to demand ratio

$$CWD = \sum (W_i / D_i)$$

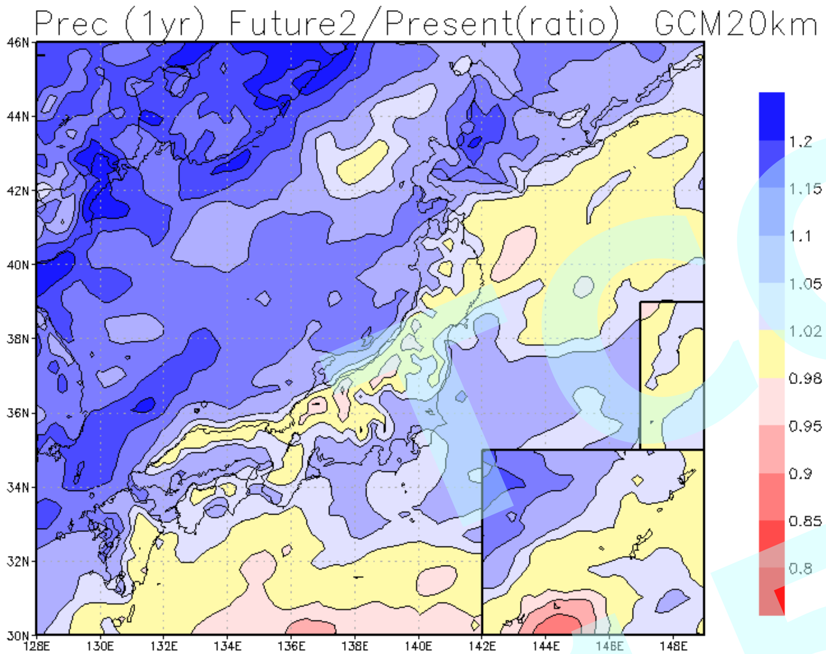
Hanasaki (*HESS*, 2008)

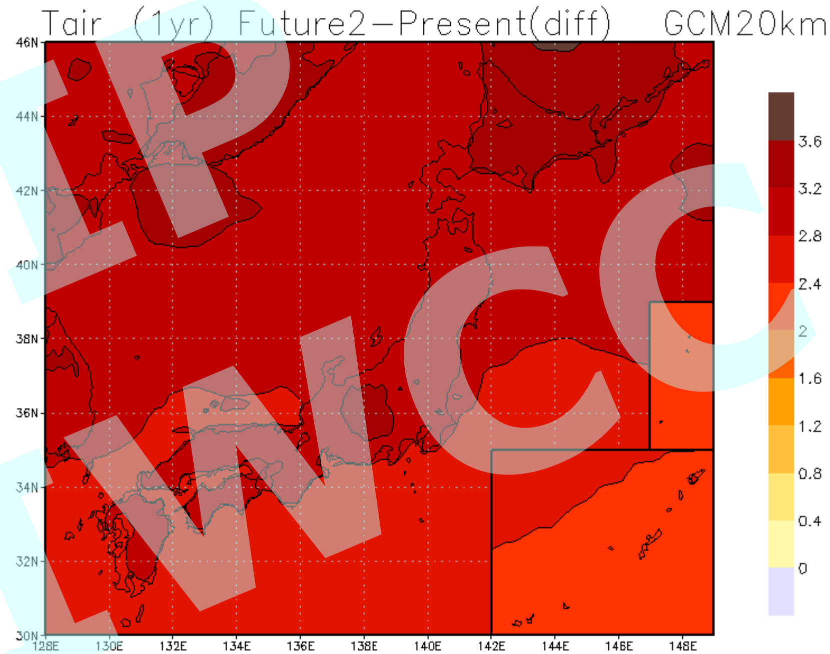
D: daily demand [MCM]

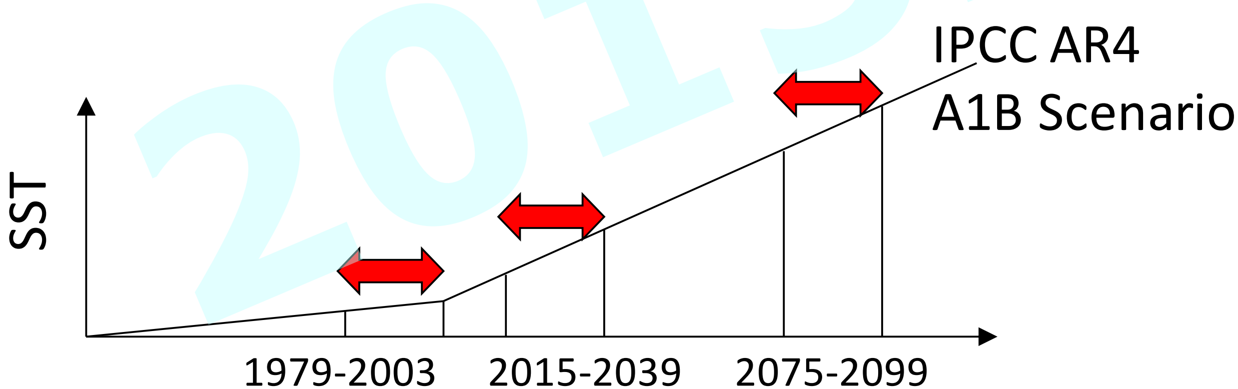
⇒seasonal water stress

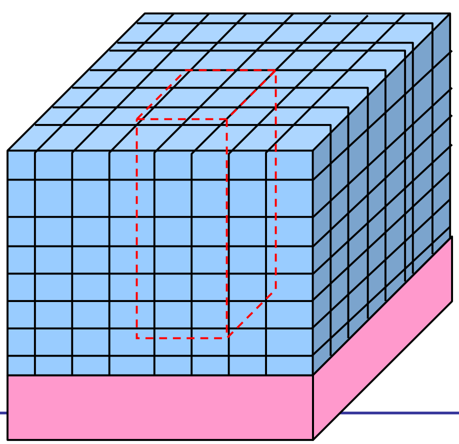


Climate change projected by MRI-AGCM3.2S









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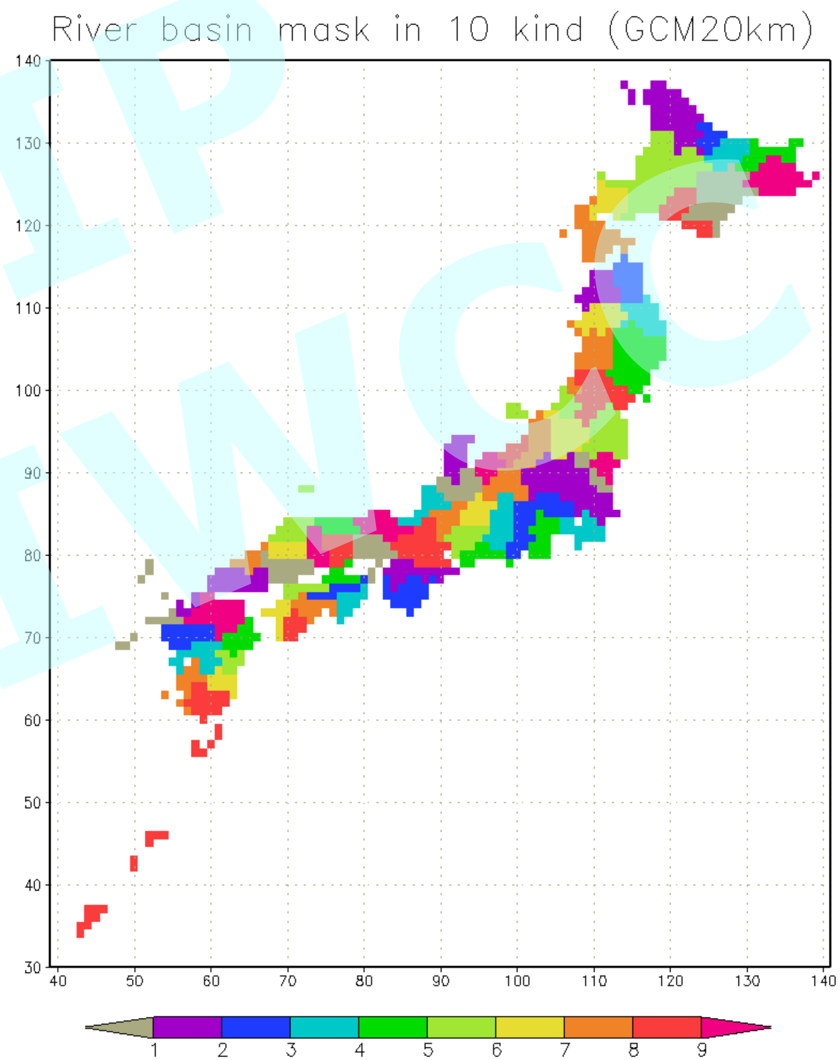
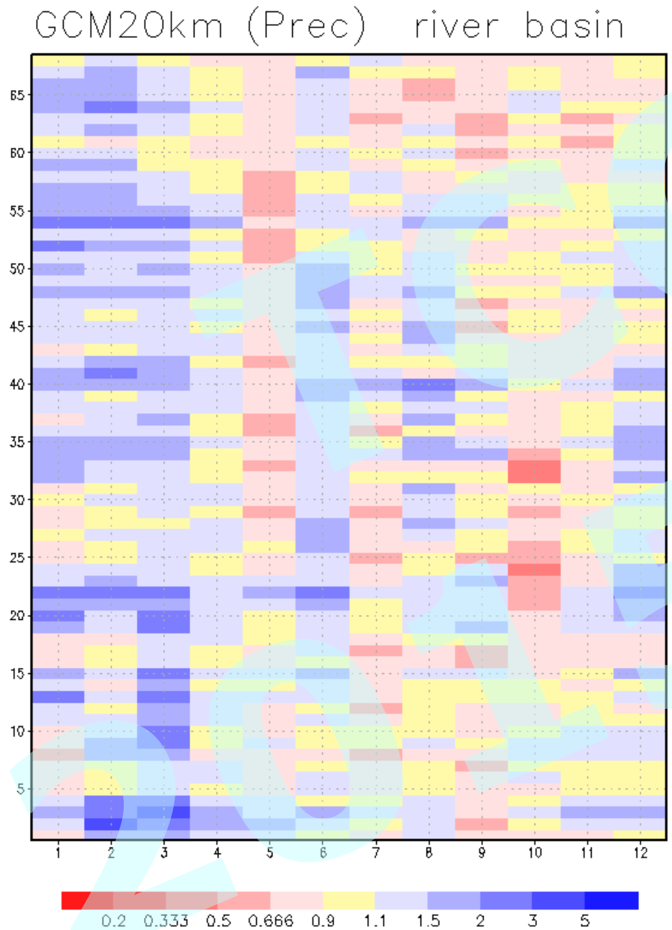
Bias detection/correction for each river basin

1	Teshio	天塩川	35	Yahagi	矢作川
2	Shokotsu	渚滑川	36	Kiso	木曽川
3	Tokoro	常呂川	37	Nagara	長良川
4	Abashiri	網走川	38	Yodo	淀川
5	Ishikari	石狩川	39	Yura	由良川
6	Shiribetsu	尻別川	40	Kako	加古川
7	Shiribeshi	後志利別川	41	Kino	紀の川
8	Saru	沙流川	42	Kumano	熊野川
9	Kushiro	釧路川	43	Kuzuryu	九頭竜川
10	Tokachi	十勝川	44	Sendai(Chu)	千代川
11	Iwaki	岩木川	45	Hii	斐伊川
12	Takase	高瀬川	46	Gouno	江の川
13	Mabechi	馬淵川	47	Takatsu	高津川
14	Kitakami	北上川	48	Yoshii	吉井川
15	Abukuma	阿武隈川	49	Takahashi	高梁川
16	Yoneshiro	米代川	50	Oota	太田川
17	Omono	雄物川	51	Saba	佐波川
18	Mogami	最上川	52	Yoshino	吉野川
19	Kuji	久慈川	53	Naka(Shikoku)	那賀川
20	Naka(Kantou)	那珂川	54	Toki	土器川
21	Tone	利根川	55	Shigenobu	重信川
22	Ara(Kantou)	荒川	56	Hiji	肱川
23	Tsurumi	鶴見川	57	Niyodo	仁淀川
24	Sagami	相模川	58	Shimanto	四万十川
25	Ara(Hokuriku)	荒川	59	Chikugo	筑後川
26	Agano	阿賀野川	60	Matsuura	松浦川
27	Shinano	信濃川	61	Kase	嘉瀬川
28	Seki	関川	62	Kikuchi	菊池川
29	Hime	姫川	63	Kuma	球磨川
30	Jintsu	神通川	64	Gokase	五ヶ瀬川
31	Oyabe	小矢部川	65	Omaru	小丸川
32	Fuji	富士川	66	Ooyodo	大淀川
33	Tenryu	天竜川	67	Sendai(Kyu)	川内川
34	Toyo	豊川	68	Kimotsuki	肝属川

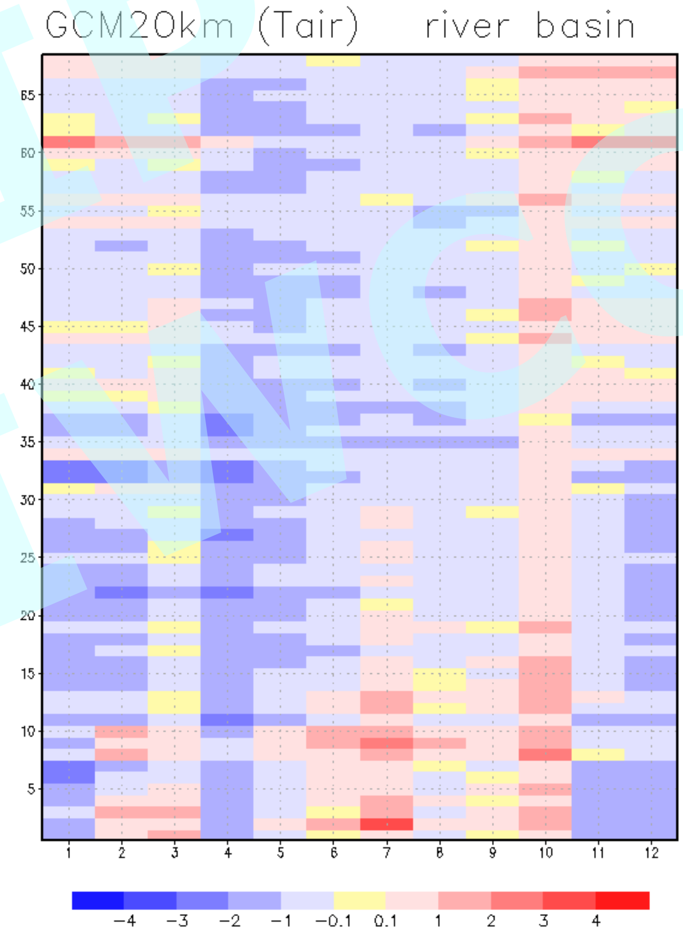


Model bias of MRI20kmGCM（river basin）

Precipitation

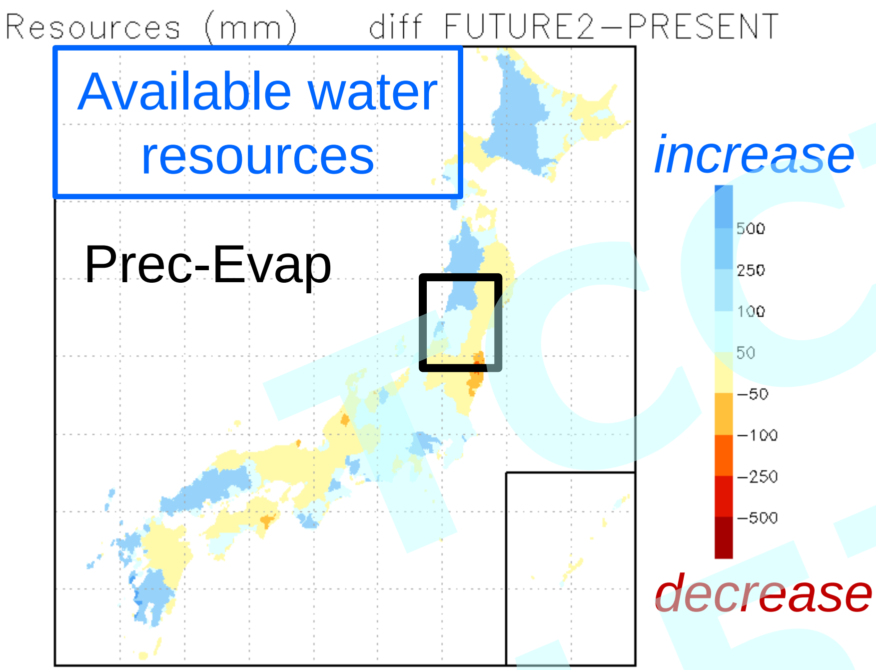


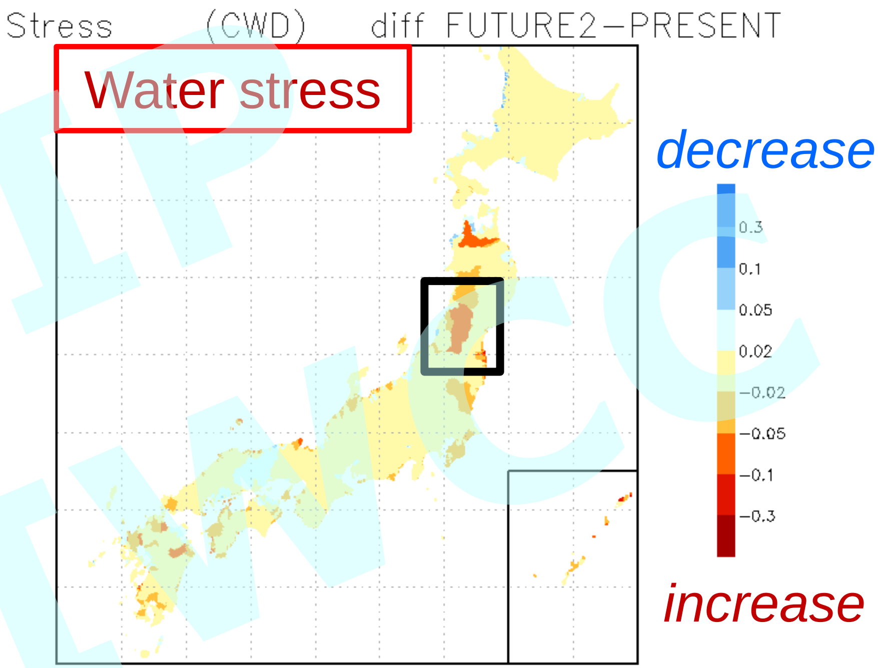
Air temperature



Horizontal: month vertical: number of river basin

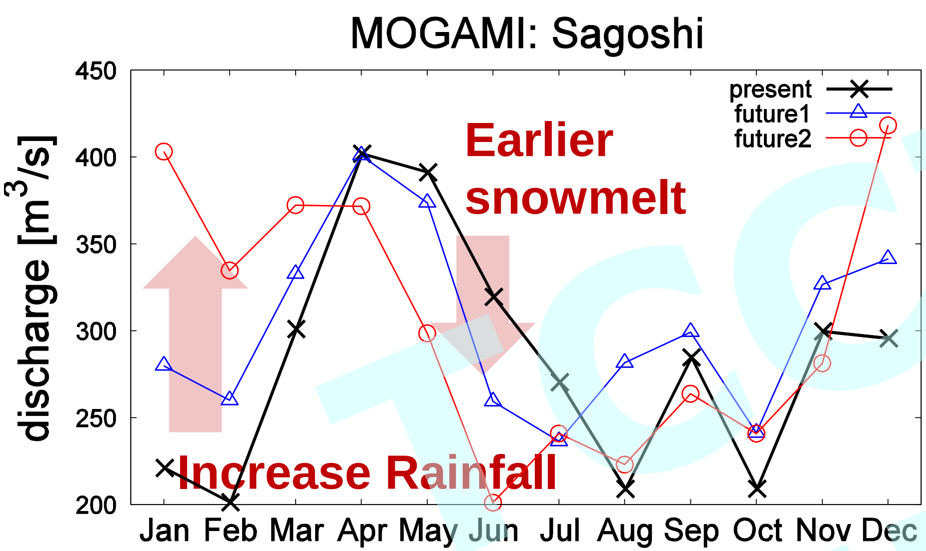
Impact on available water resources and water stress

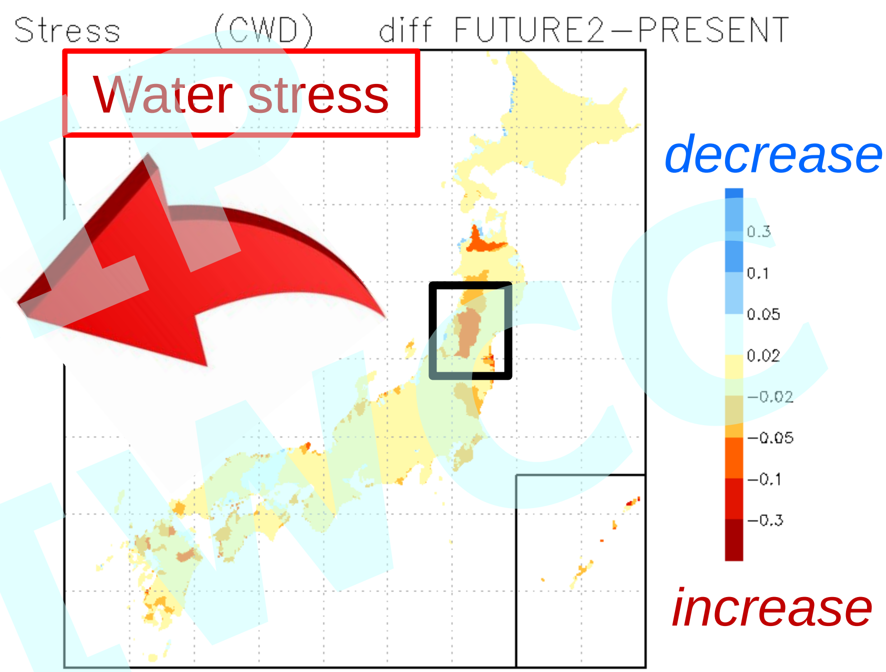




Accelerated hydrological cycle, reduction of snowfall

In spite of the increase in available water resources, water stress will increase in Tohoku region



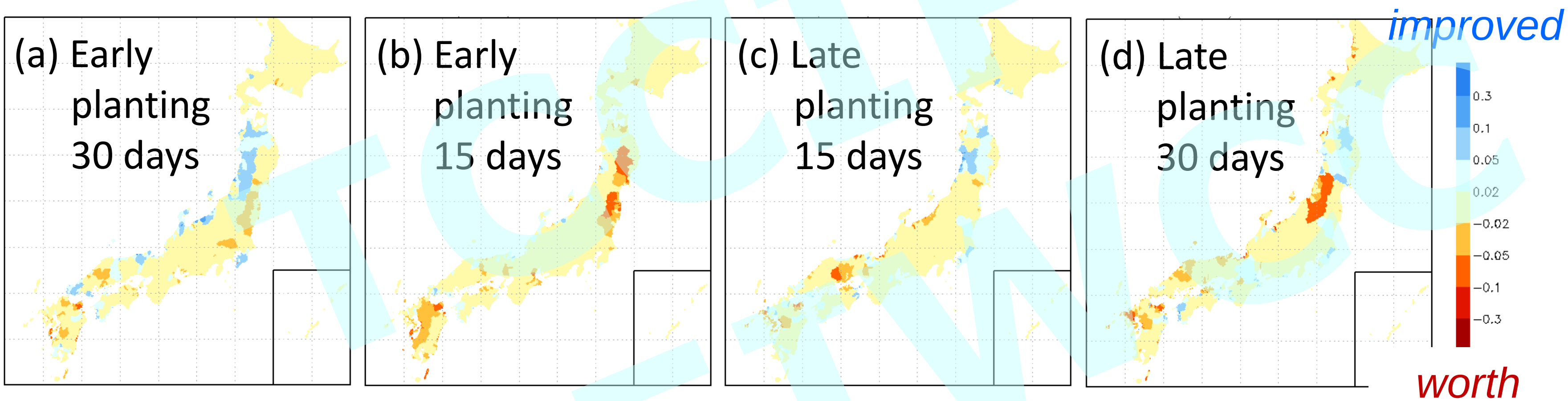


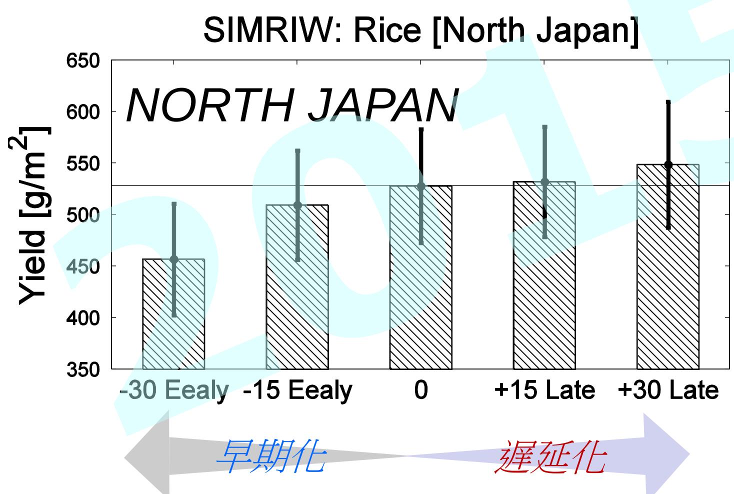
— Present
— Near future
— end of 21 C

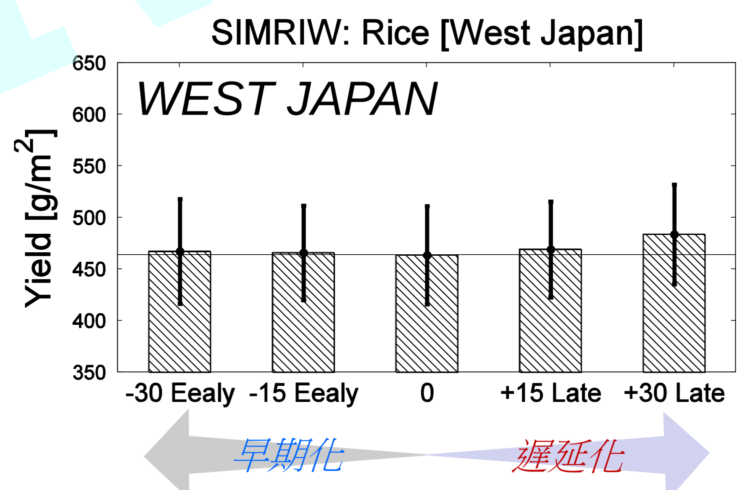
Due to the temperature rise, phase change of winter precipitation (snowfall → rainfall)
→ Increase of runoff in winter
Reduction of snowmelt runoff in spring to summer
→ difficult to meet the water demand for rice field

How adaptation strategy affects on water stress?

（change the agricultural water demand period）







Summary (part 2)

1. Integrated water resources model in Japan
   - Dynamic coupling of hydrological cycle and agricultural activity
   - Validation of rice yield, Snowdep, river discharge
2. Estimating the climate change impact
   - Change in flow rate, water stress, rice yield
   - Evaluate the adaptation strategy (planting date)

   Adaptation strategy should be proposed considering both rice yield and water stress

Ski resort in Nagano Prefecture