Application of AIM (Asia-Pacific Integrated Model) toward new socio-economic scenario development integrating climate change mitigation, impact and adaptation

T. Masui, S. Fujimori, T. Hasegawa, N. Hanasaki,

Y. Shin, K. Takahashi, Y. Hijioka, M. Kainuma

The 5th IAMC Annual Meeting

Utrecht, Netherlands

12 November 2012

This research was supported by the Environment Research and Technology Development Fund (A-1103 and S-10) of the Ministry of the Environment, Japan, and Climate Change Research Program and research project on development of water resource model of NIES.

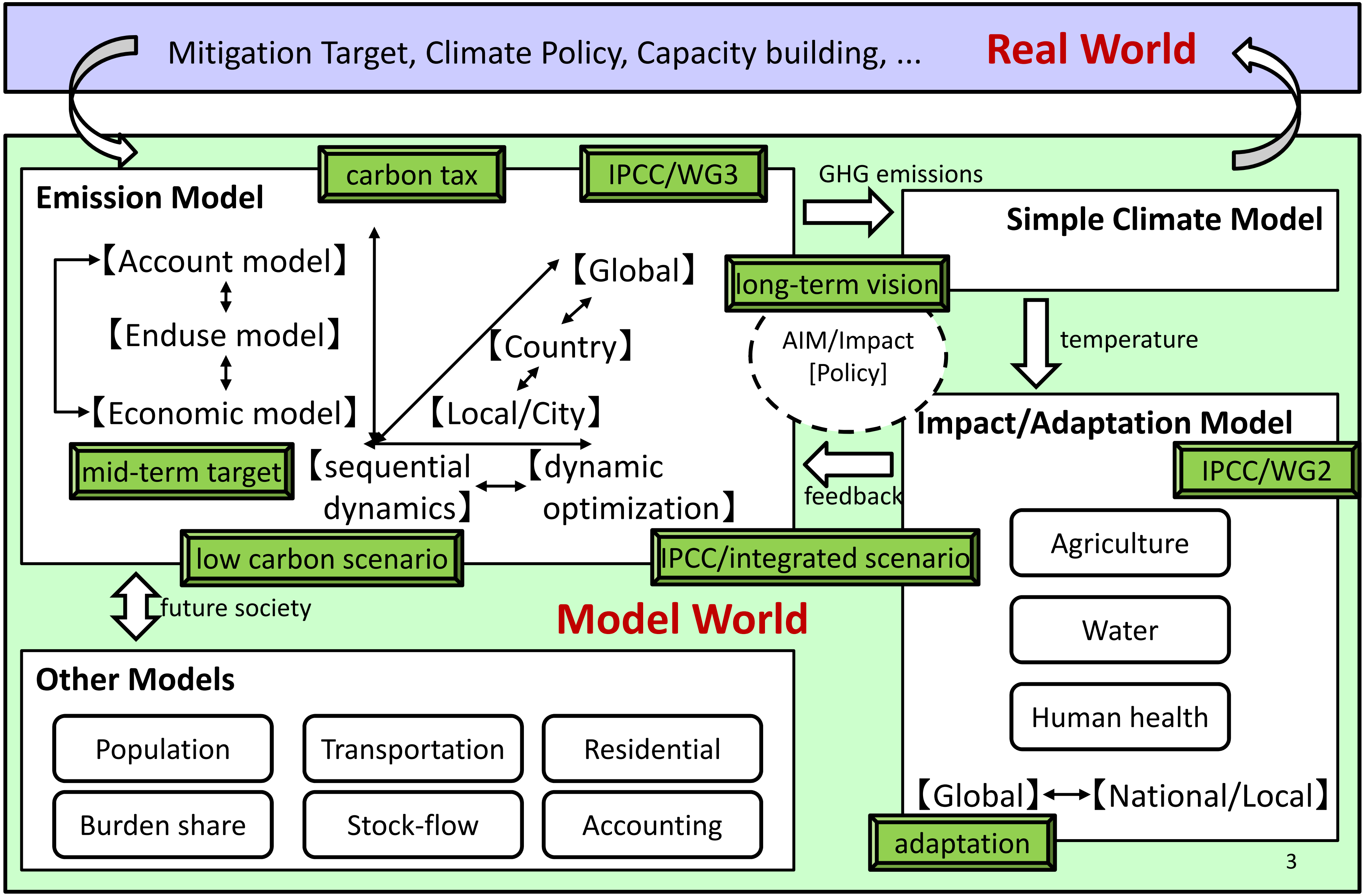
AIM (Asia-Pacific Integrated Model)

- AIM is an integrated assessment model to assess mitigation options to reduce GHG emissions and impact/adaptation to avoid severe climate change damages.
- The model is now extended to sustainable development.
- http://www-iam.nies.go.jp/aim/

at the 17th AIM International Workshop (NIES, 2012)

ASIA-PACIFIC INTEGRATED MODEL

Contents of Present AIM

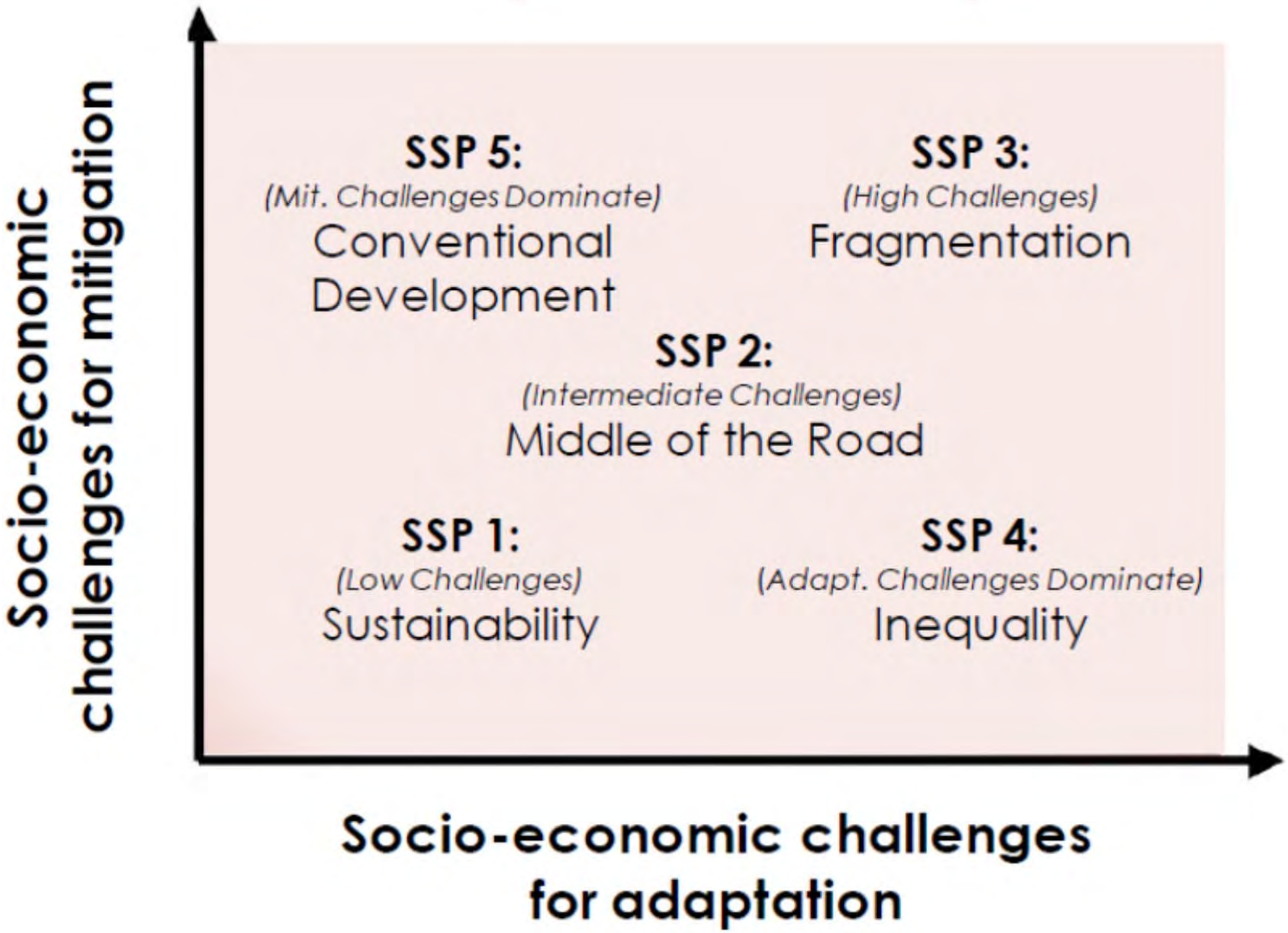


Integrating IAM (Integrated Assessment Model) and IAV (Impact, Adaptation and Vulnerability)

- SSPs (Shared Socio-economic Pathways) are trial to integrate IAM and IAV.
- AIM team is trying to assess future scenarios using IAM and IAV models
  - Water stress
    - Reflecting variations of water availability and use consistent with socio-economic scenarios
    - Taking into account future climate
  - Food demand/supply
    - Crop yield change, including adaptation, due to climate change and socio-economic condition

ASIA-PACIFIC INTEGRATED MODEL

Idea of SSPs



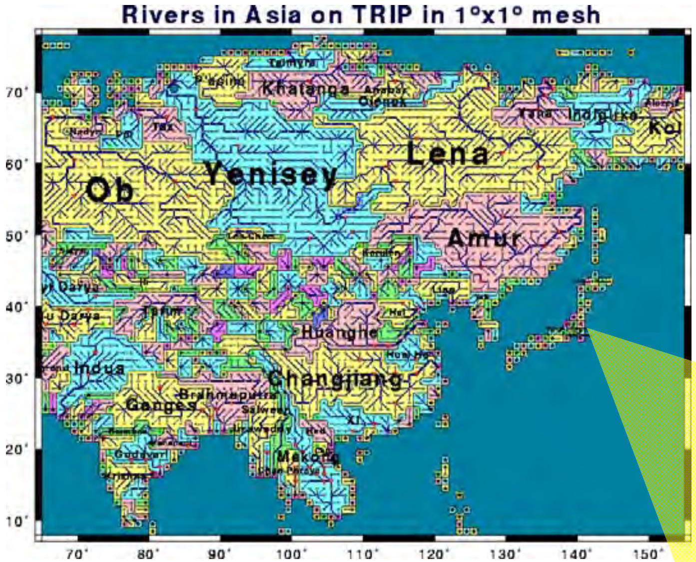
ASIA-PACIFIC INTEGRATED MODEL

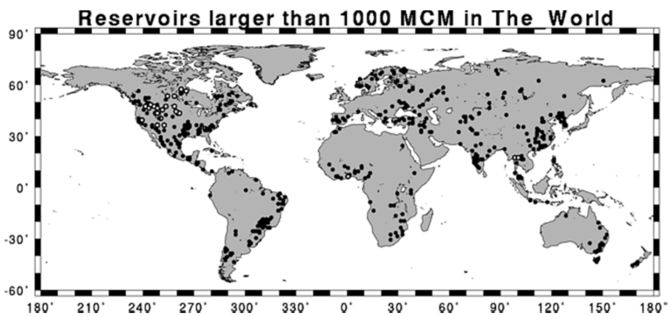
Integrating IAM (Integrated Assessment Model) and IAV (Impact, Adaptation and Vulnerability)

- SSPs (Shared Socio-economic Pathways) are trial to integrate IAM and IAV.
- AIM team is trying to assess future scenarios using IAM and IAV models
  - Water stress
    - Reflecting variations of water availability and use consistent with socio-economic scenarios
    - Taking into account future climate
  - Food demand/supply
    - Crop yield change, including adaptation, due to climate change and socio-economic condition

AIM
ASIA-PACIFIC INTEGRATED MODEL

H08 model

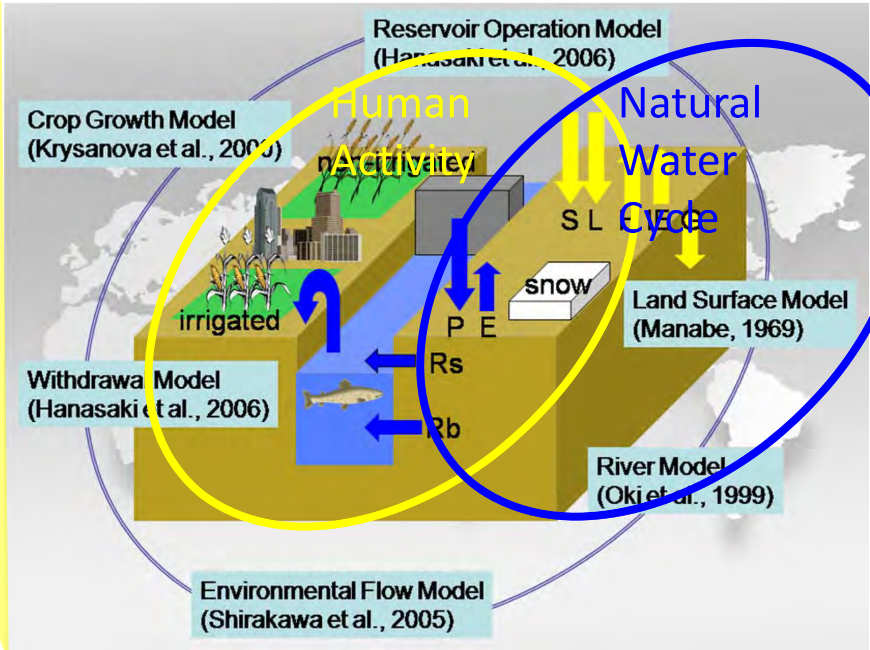




452 reservoirs, 4140 km^3

- Characteristics

1. High spatial resolution (0.5° × 0.5°, total 66,420 grid cells)
2. Simulate both water availability (streamflow) and water use at daily-basis
3. Deal with interaction between natural hydrological cycle and anthropogenic activities



Hanasaki et al., 2006, J. of Hydrol.
Hanasaki et al. ,2008a,b, Hydrol. Earth Sys. Sci.
Hanasaki et al., 2010, J. of Hydrol

AIM ASIA-PACIFIC INTEGRATED MODEL

Input and Output

Meteorological (0.5°×0.5°, 6hourly, 1971-2000)	
Air temperature	WATCH Forcing Data (Weedon et al., 2011)
Specific humidity	
Air pressure	
Wind speed	
Shortwave radiation	
Longwave radiation	
Precipitation	

Geographical/other (0.5°×0.5°, circa 2000)	
Cropland area	Ramankutty et al. 2008
Irrigated area	Siebert et al., 2005
Crop intensity	Döll and Siebert, 2002
Irrigation efficiency	Döll and Siebert, 2002
River map	Döll et al., 2003
Reservoir map	Hanasaki et al. 2006
Industrial water dem.	FAO, 2011
Domestic water dem.	FAO, 2011

H08

Output (0.5°×0.5°, daily, 1971-2000)	
Land sub-model	Evapotranspiration
	Runoff
	Soil moisture
	Snow water equivalent
	Energy term
River sub-model	Streamflow
	River channel storage
Crop growth sub-model	Planting date
	Harvesting date
	Agricultural water dem.
	Crop yield (not used)
Reservoir sub-model	Reservoir storage
	Reservoir outflow
Withdrawal sub-model	Agri. water withdrawal
	Ind. water withdrawal
	Dom. water withdrawal
Environmental flow	Env. flow requirement

Simulation settings

Socio-economic Scenario		Emission scenario		Climate Scenario
SSP1: Low population, High income	×	With climate policy stabilizing at 4.5W/m^2	—	CanESM2 RCP4.5 (r1i1p1)
SSP3: High population, Low income		No climate policy Business as Usual	—	CanESM2 RCP 8.5 (r1i1p1)

		Population	GDP (2005 USD)
CTR	2005	6.51x10^9	45.7x10^{12}USD
SSP1	2055	8.08 x10^9	212.9 x10^{12}USD
SSP3	2055	11.10 x10^9	140.7 x10^{12}USD

+Electricity generation

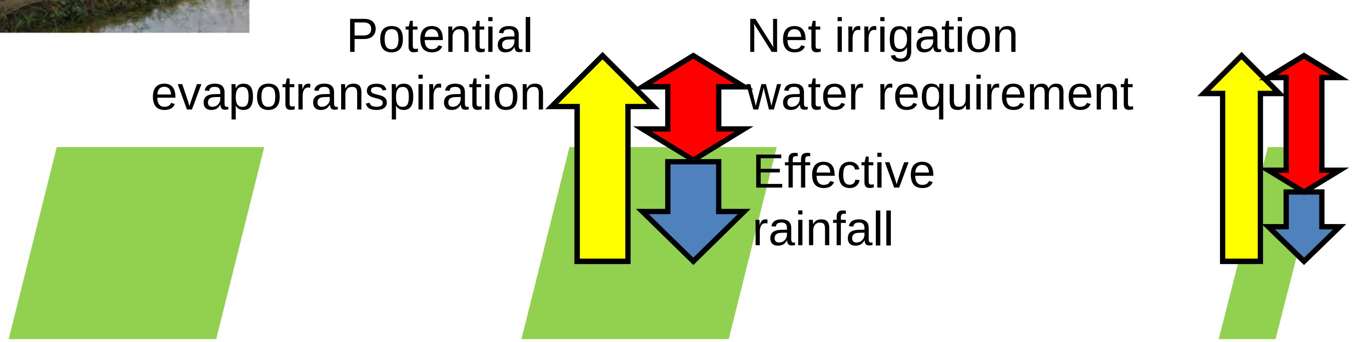
		ΔT	ΔP
CTR	1961-1990		
RCP4.5	2041-2070	+3.1K	+3.7%
RCP8.5	2041-2070	+4.1K	+4.7%

H08 also needs scenarios for irrigated area, crop intensity, irrigation efficiency, industrial/domestic water withdrawal !

AIM ASIA-PACIFIC INTEGRATED MODEL

Agricultural (=irrigation) water withdrawal modeling

$$\frac{\text{Net irrigation water requirement}}{\textbf{Irrigation efficiency}} = \textbf{Irrigation water withdrawal}$$



Area equipped for irrigation

Harvested area of 1st irrigated crop

Harvested area of 2nd irrigated crop

$$\frac{\text{Harvested area of 1st and 2nd irrigated crop}}{\text{Area equipped for irrigation}} = \textbf{crop intensity}$$

How should we set up scenarios for these factors?

Irrigated area, crop intensity, irrigation efficiency scenarios

Reference	Population	GDP	Irrigated area (10^{6}ha)			Irrigated area growth rate (%/yr)	Crop intensity growth rate (%/yr)	Irrigation efficiency growth rate(%/yr)
			2000	2030	2050			
Rosegrant et al. 2002	UN 1998 med	IFPRI	*375 (1995)*	*441 (2025)*				
Bruinsma , 2003 (Faures et al., 2002)	UN 2001 med	WB 2001	271 202 257	324 242 341	(365)	0.60	0.4	0.3
Alcamo et al., 2005 MA-Techno Garden	MA-TG	MA-TG	239		252	0.11		
de Fraiture, 2007 CA-Irrig area expansion	MA-TG	MA-TG	340		450	0.60		
CA-Comprehensive	MA-TG	MA-TG			394	0.30		
CA-Irrig yield improve	MA-TG	MA-TG			370	0.15		
CA-rain area expansion	MA-TG	MA-TG			340	0		
CA-rain yield improve	MA-TG	MA-TG			340	0		
CA- trade	MA-TG	MA-TG			340	0		
Rosegrant et al., 2009	UN 2005 med	MA-TG	*433*	*478 (2025)*	*473*	0.06	0.15	0

High variant	0.6	0.4	0.3
Medium variant	0.3	0.2	0.15
Low variant	0.06	0.15	0

ASIA-PACIFIC INTEGRATED MODEL

Industrial & domestic water withdrawal modeling

Earlier studies developed multi-regression models but,
- parameters are highly unstable
- parameters are unique: not suited for scenario study.

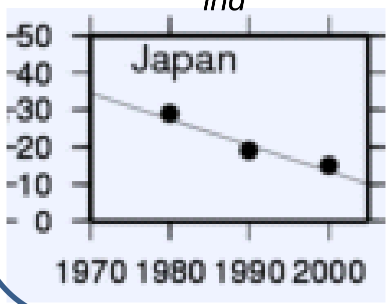
More flexible model is needed for scenario study.

Industrial water withdrawal

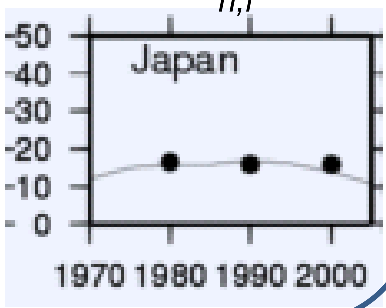
$$IW_{n,f} = i_{ind} \times ELC_{n,f}$$

$$i_{ind} = i_{ind,0} + s_{ind}(t - t_0)$$

i_{ind}



$IW_{n,f}$

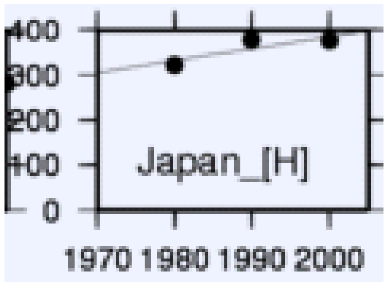


Domestic water withdrawal

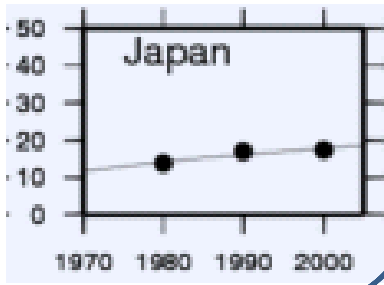
$$DW_{n,f} = i_{dom} \times POP_{n,f}$$

$$i_{dom} = i_{dom,0} + s_{dom}(t - t_0)$$

i_{dom}



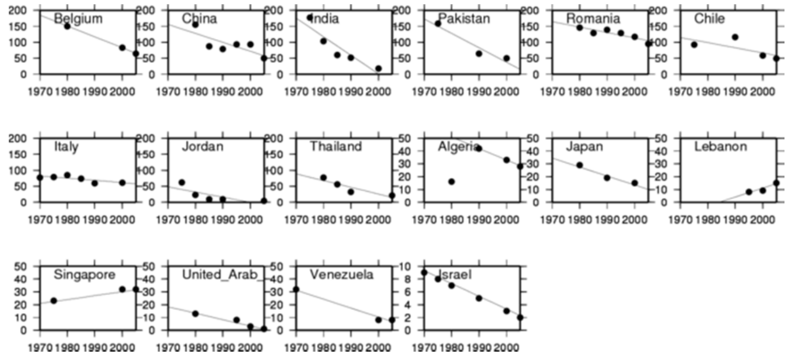
$DW_{n,f}$

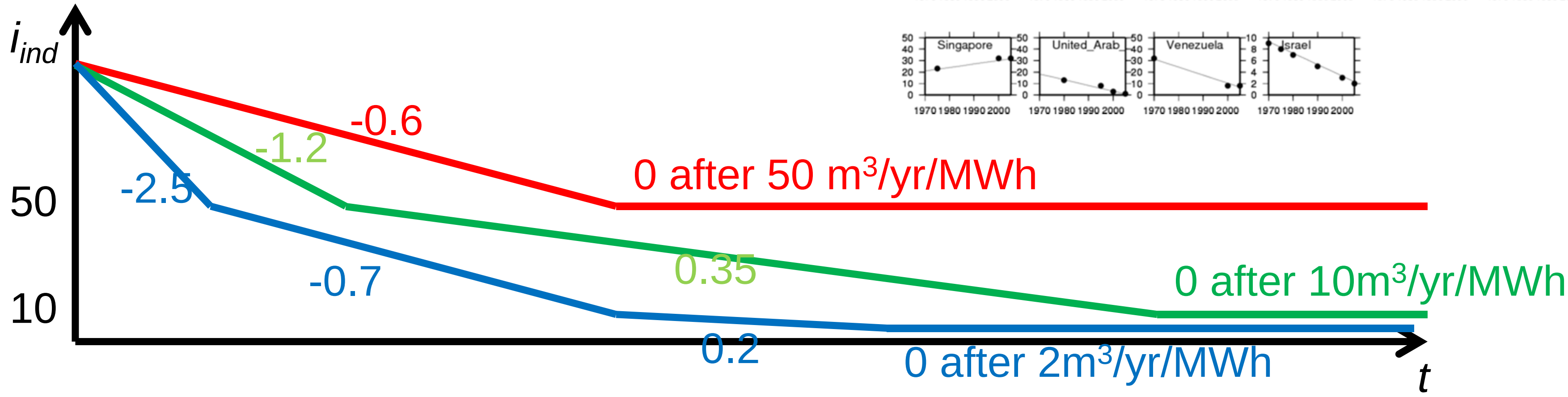


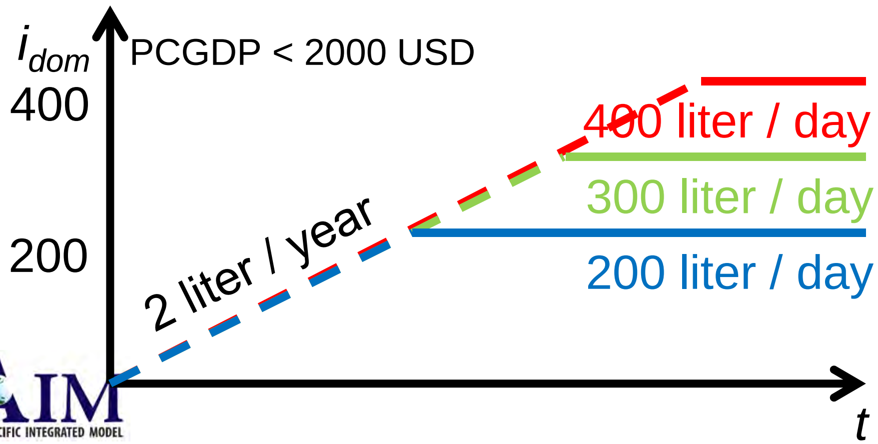
AIM
ASIA-PACIFIC INTEGRATED MODEL

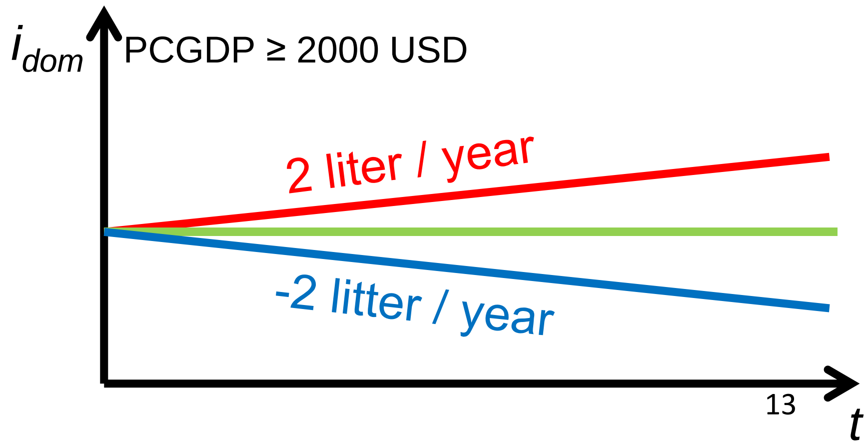
Industrial/Domestic intensity scenario

Set three scenarios for i_{ind} and i_{dom}
High, Medium, Low Efficiency

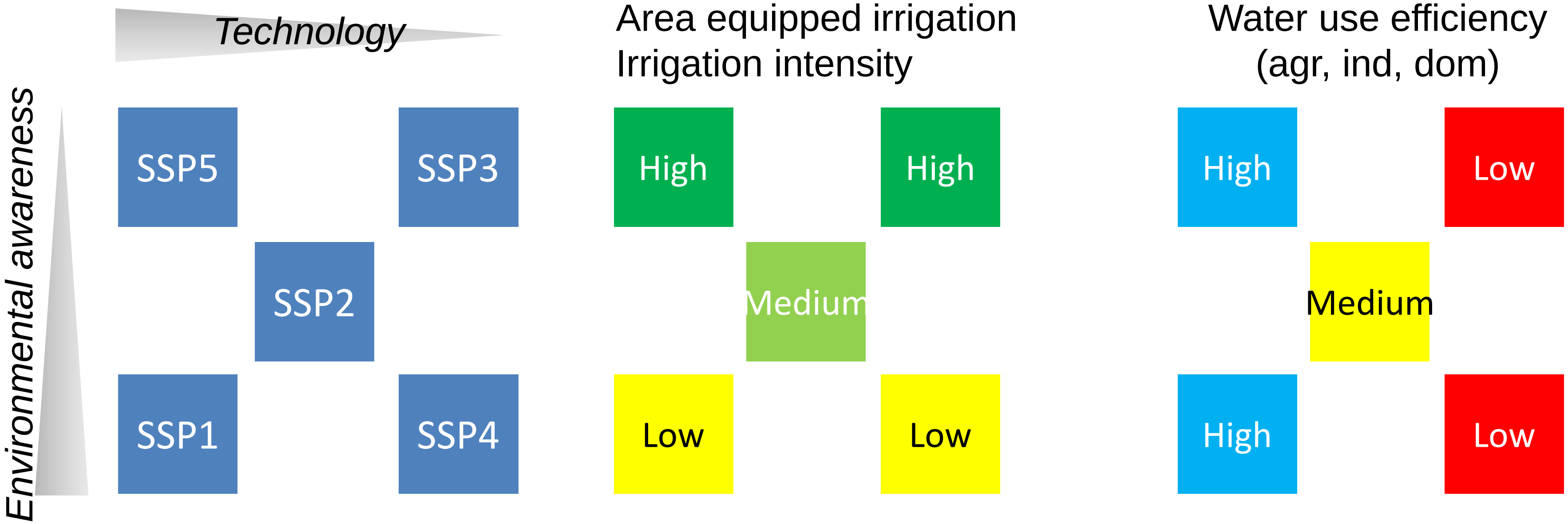






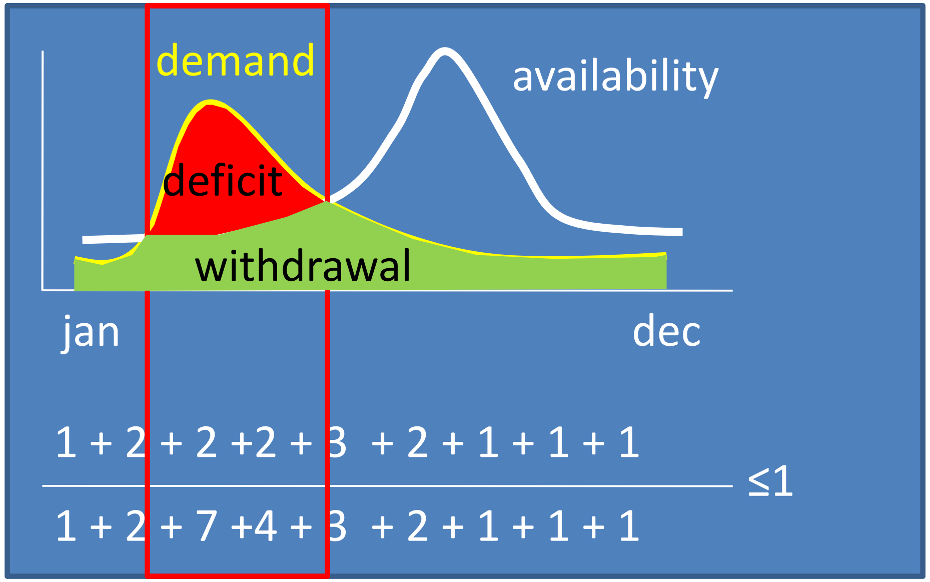


SSP interpretation



	Storyline	Area	intensity	A eff.	I eff.	D eff.
SSP1	Sustainability	0.06	0.15	0.3	HE	HE
SSP2	Middle of the road	0.3	0.2	0.15	ME	ME
SSP3	Fragmented world	0.6	0.4	0	LE	LE
SSP4	Inequality	0.06	0.15	0	HE/LE	HE/LE
SSP5	Conventional Development	0.6	0.4	0.3	HE	HE

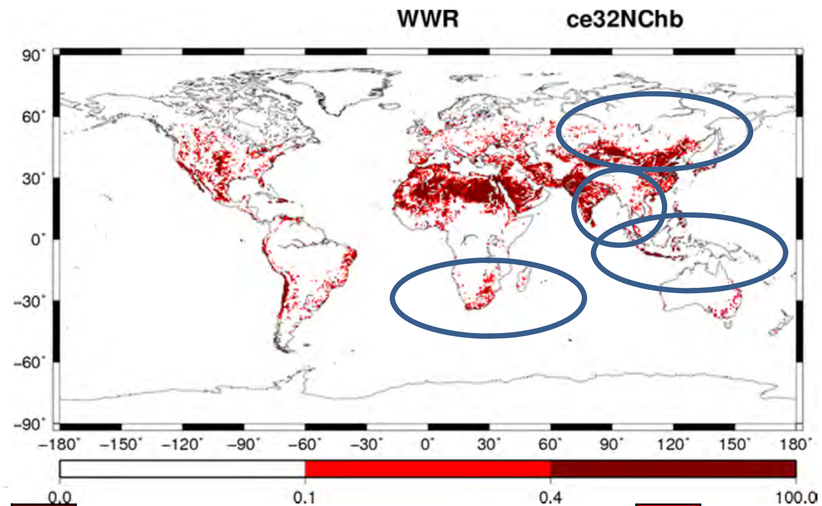
Water resources assessment

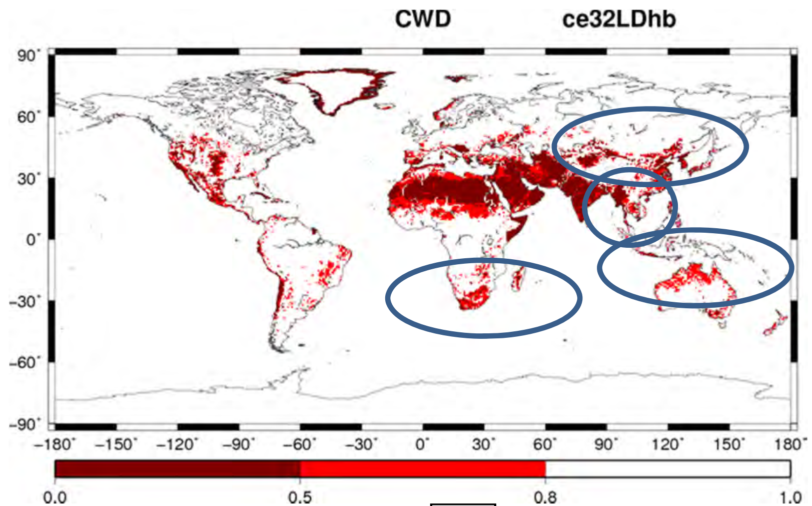


Daily basis

Index= ∑daily withdrawal (simulated) / ∑daily demand (simulated)

High stress	Index<0.5
Medium stress	0.5≤index<0.8
Low stress	0.8≤Index





High Stress

Medium Stress

Low Stress

Water stressed population

Global total number of people living under the each condition

Scenarios	Period	Index 1 $\frac{\text{Annual water withdrawal}}{\text{Annual river discharge}} > 0.4$	Index 2 $\frac{\sum \text{daily water withdrawal}}{\sum \text{daily water demand}} < 0.5$
Present	2000	1.61×10^9	1.94×10^9
SSP1-RCP8.5	2041-2070	2.76×10^9	2.62×10^9
SSP1-RCP4.5	2041-2070	2.64×10^9	2.57×10^9
SSP3-RCP8.5	2041-2070	4.06×10^9	3.90×10^9
SSP3-RCP4.5	2041-2070	3.97×10^9	3.86×10^9

Hanasaki et al. in prep

- Water stressed population in the middle of the 21st century
  - SSP1 << SSP3, RCP4.5 < RCP8.5
- Socio-economic scenario has larger sensitivity than climate policy scenario → **Socio-economic scenario matters.**
- Water availability may impact economic activities?
  → **Need to link IAM and IAV models.**

AIM
ASIA-PACIFIC INTEGRATED MODEL

Simulation settings

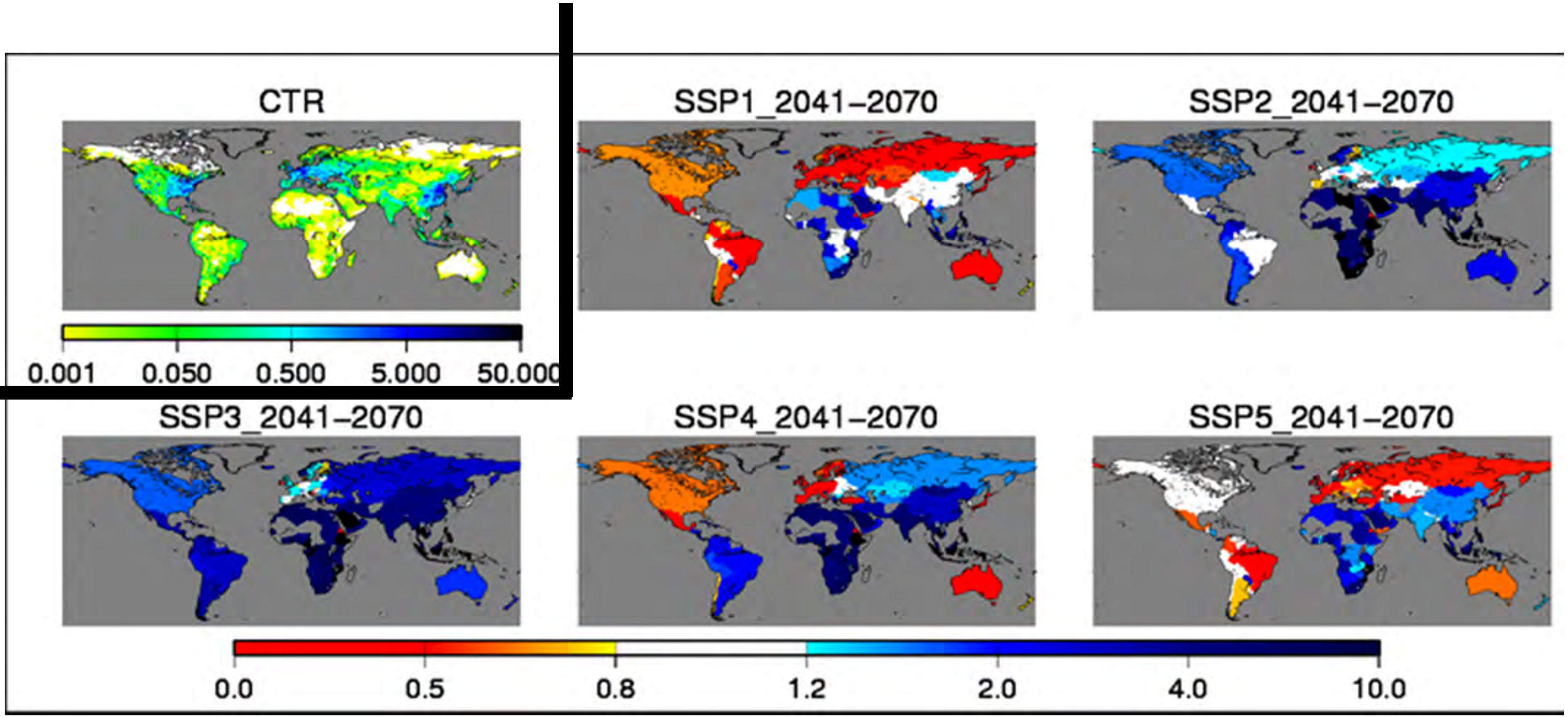
Preliminary Scenario Matrix

	RCP2.6	RCP4.5	RCP6.0	RCP8.5
SSP1	SSP1 policy		SSP1 BAU	
SSP2		SSP2 policy		SSP2 BAU
SSP3			SSP3 policy	SSP3 BAU
SSP4	SSP4 policy		SSP4 BAU	
SSP5			SSP5 policy	SSP5 BAU

CMIP5 GCMs

- MIROC-ESM-CHEM
- GFDL-ESM2M
- HadGEM2-ES

Industrial water withdrawal（2041-2070）



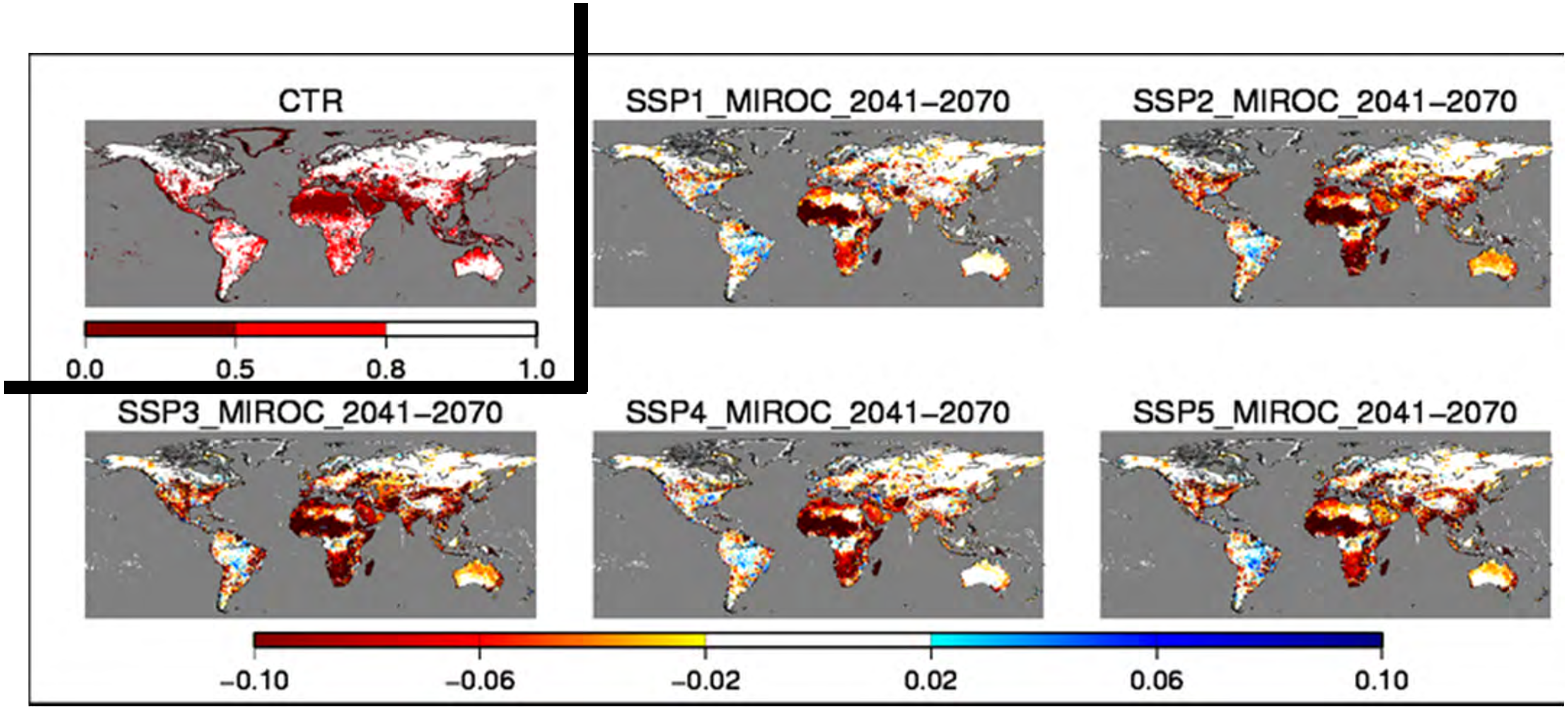
increasing slowly

increasing rapidly

AIM ASIA-PACIFIC INTEGRATED MODEL

Water stress (index 2)

- Reference case

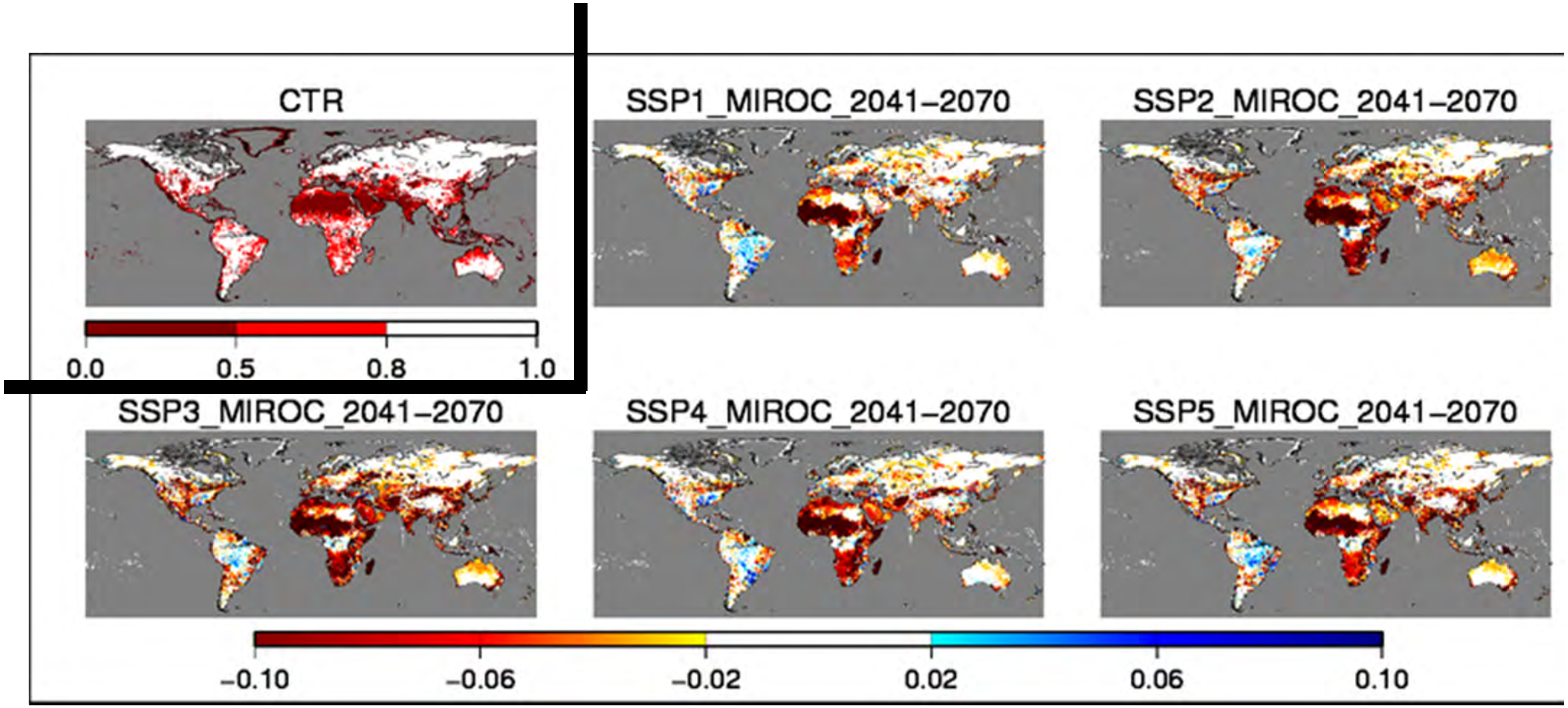


Worse improvement

AIM ASIA-PACIFIC INTEGRATED MODEL

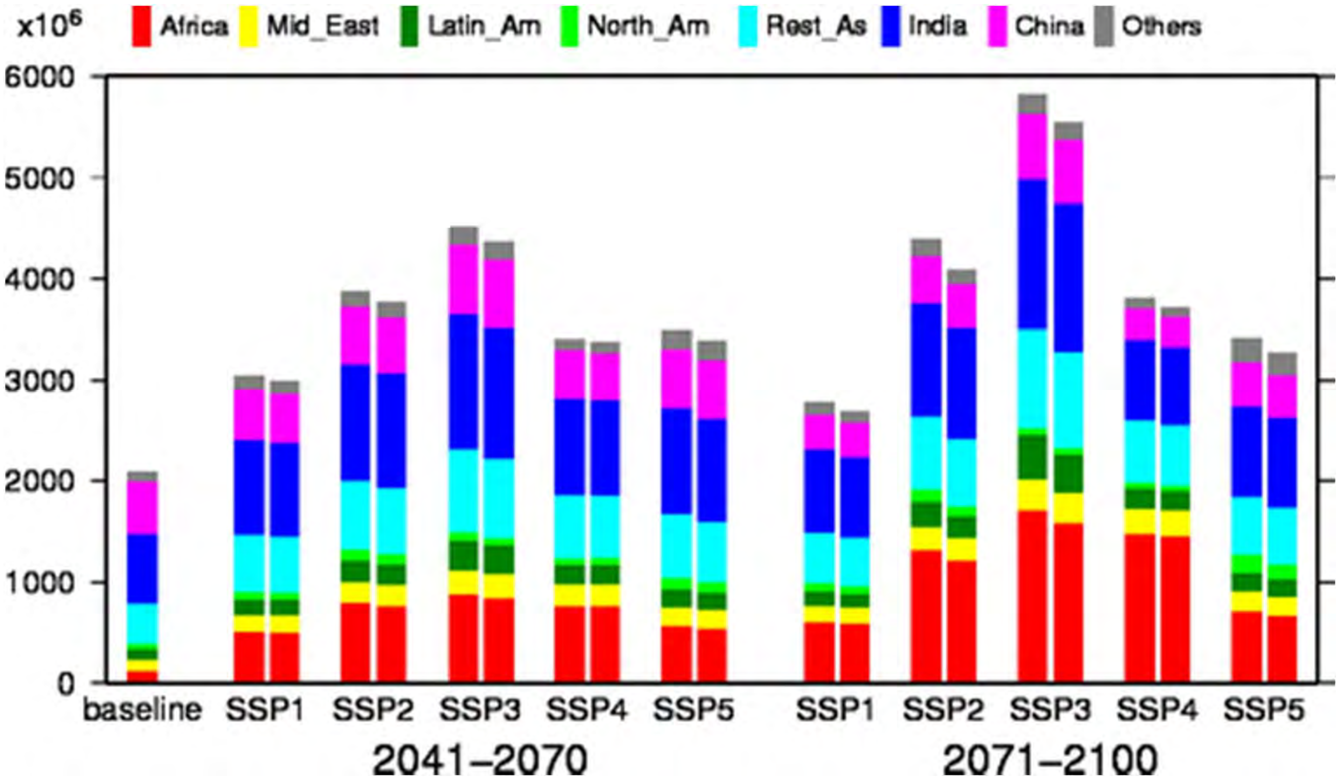
Water stress (index 2)

- Effectiveness of climate policy



Worse improvement

Water stressed population



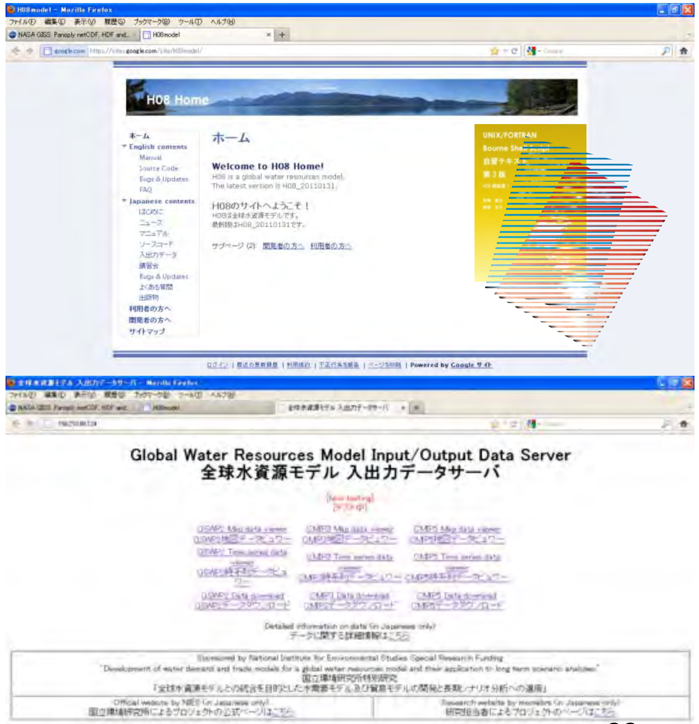
CAUTION: now fixing a minor problem.

- Water stressed population in the middle of the 21st century
  - Effect of Climate Policy << Difference of SSP
- Socio-economic scenario has larger sensitivity than climate policy scenario → **Socio-economic scenario matters.**
- Water availability impacts economic activities? → **Consistent scenario links IAM and IAV modeling.**

ASIA-PAC

Advertisement: H08 is freely available

- Discussion paper available soon online
  - Hanasaki, N., et al.: A global water scarcity assessment under Shared Socio-economic Pathways: Part 1 Water use scenario, Hydrol. Earth Syst. Sci. Discuss., 2012.
  - Hanasaki, N., et al.: A global water scarcity assessment under Shared Socio-economic Pathways: Part 2 Water availability and scarcity, Hydrol. Earth Syst. Sci. Discuss., 2012.
- H08 web site
  - https://sites.google.com/site/h08model/
  - Source code and manual
- Input & Output data server
  - http://158.210.90.124/
  - Including CMIP3 & CMIP5 data

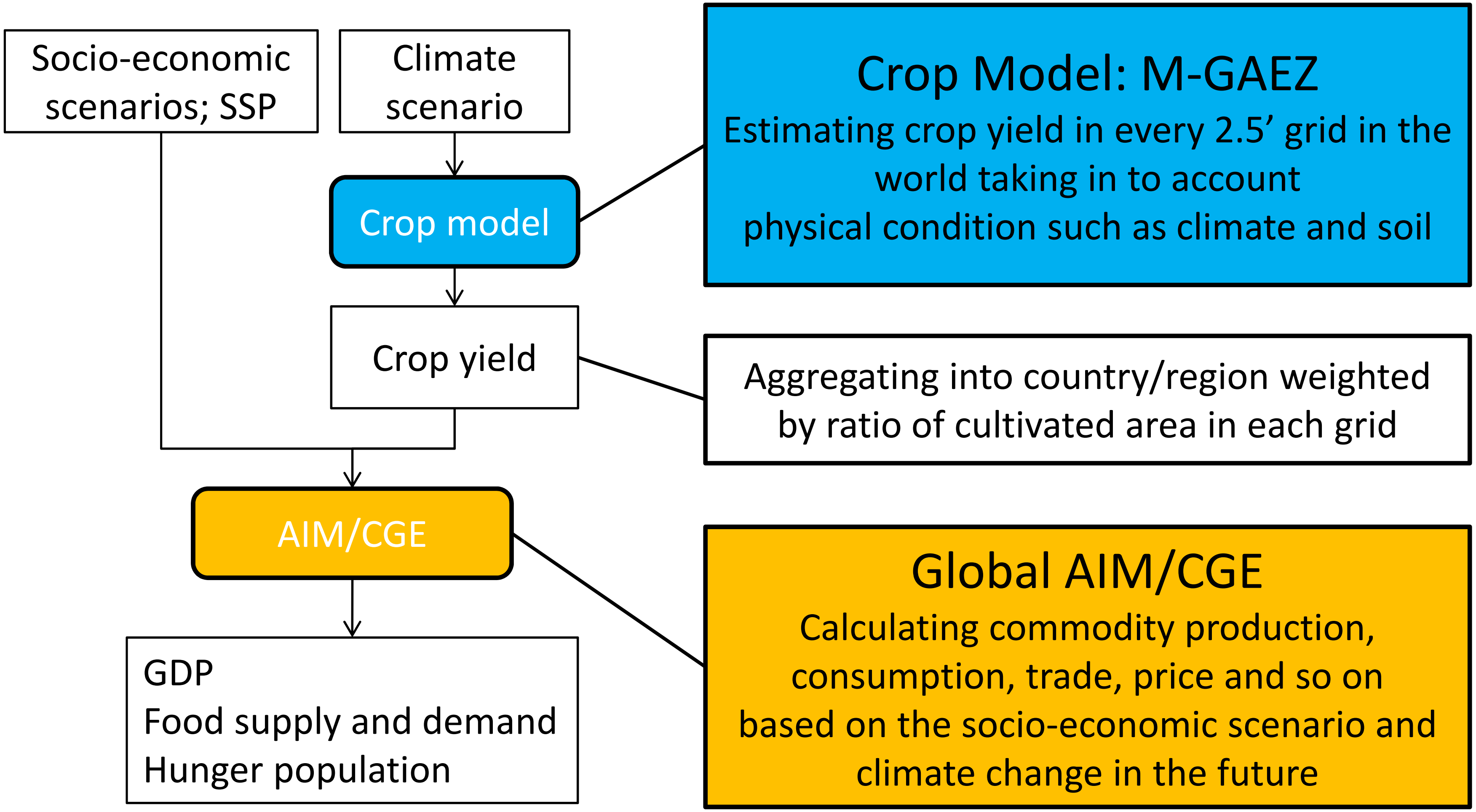


Integrating IAM (Integrated Assessment Model) and IAV (Impact, Adaptation and Vulnerability)

- SSPs (Shared Socio-economic Pathways) are trial to integrate IAM and IAV.
- AIM team is trying to assess future scenarios using IAM and IAV models
  - Water stress
    - Reflecting variations of water availability and use consistent with socio-economic scenarios
    - Taking into account future climate
  - Food demand/supply
    - Crop yield change, including adaptation, due to climate change and socio-economic condition

AIM
ASIA-PACIFIC INTEGRATED MODEL

Framework for taking into account crop yield



ASIA-PACIFIC INTEGRATED MODEL

Future scenarios

	Optimistic society (Medium economic growth, medium population growth) **Based on SSP2**	**Pessimistic society (low economic growth, high population growth)** **Based on SSP3**
Without-climate-change		
With-climate-change (assuming condition in RCP8.5)	adaptation in developing countries will be implemented	adaptation in developing countries will **not** be implemented

Adaptation

- Developed countries will be able to introduce adaptation in pessimistic scenario.
- Treated crops: rice, wheat and maize
- Adaptation: (1) Breed improvement (2) Planting date change

AIM
ASIA-PACIFIC INTEGRATED MODEL

Global CGE model

17 regions

Japan
China
India
South East Asia
Other Asia
Oceania
25 countries in EU
Other Europe
Former Soviet Union
Turkey
Canada
USA
Brazil
Other Latin America
Middle East
North Africa
Other Africa

Agricultural products in the model

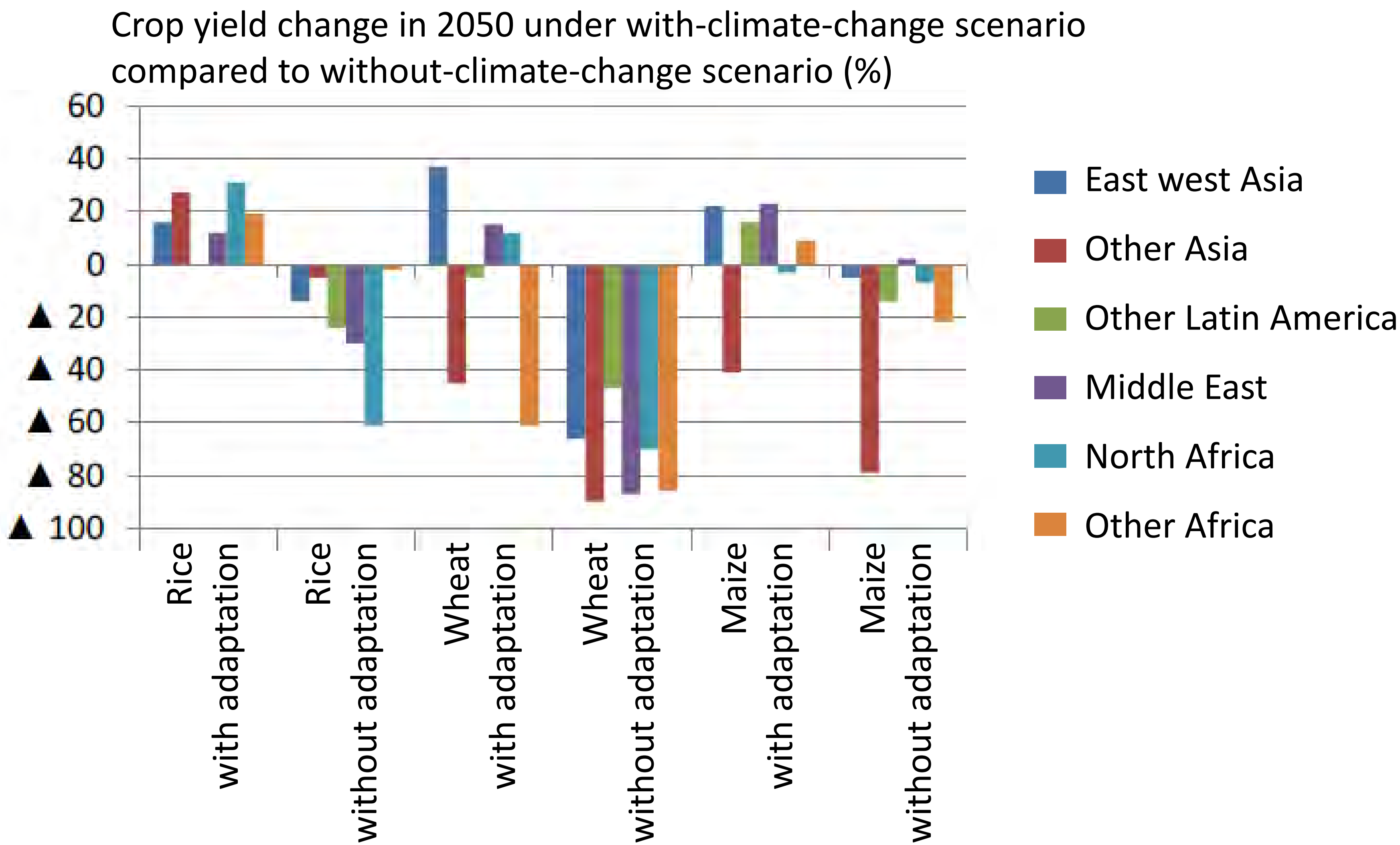
rice
wheat
maize and others
oil crops
sugar crops
other crops
beef cattle
dairy cattle
other livestock
fishery

Total 26 commodities are treated in the model.

Benchmark year: 2005
Base model: Fujimori et al. (2012)
http://www.nies.go.jp/social/dp/pdf/2012-01.pdf

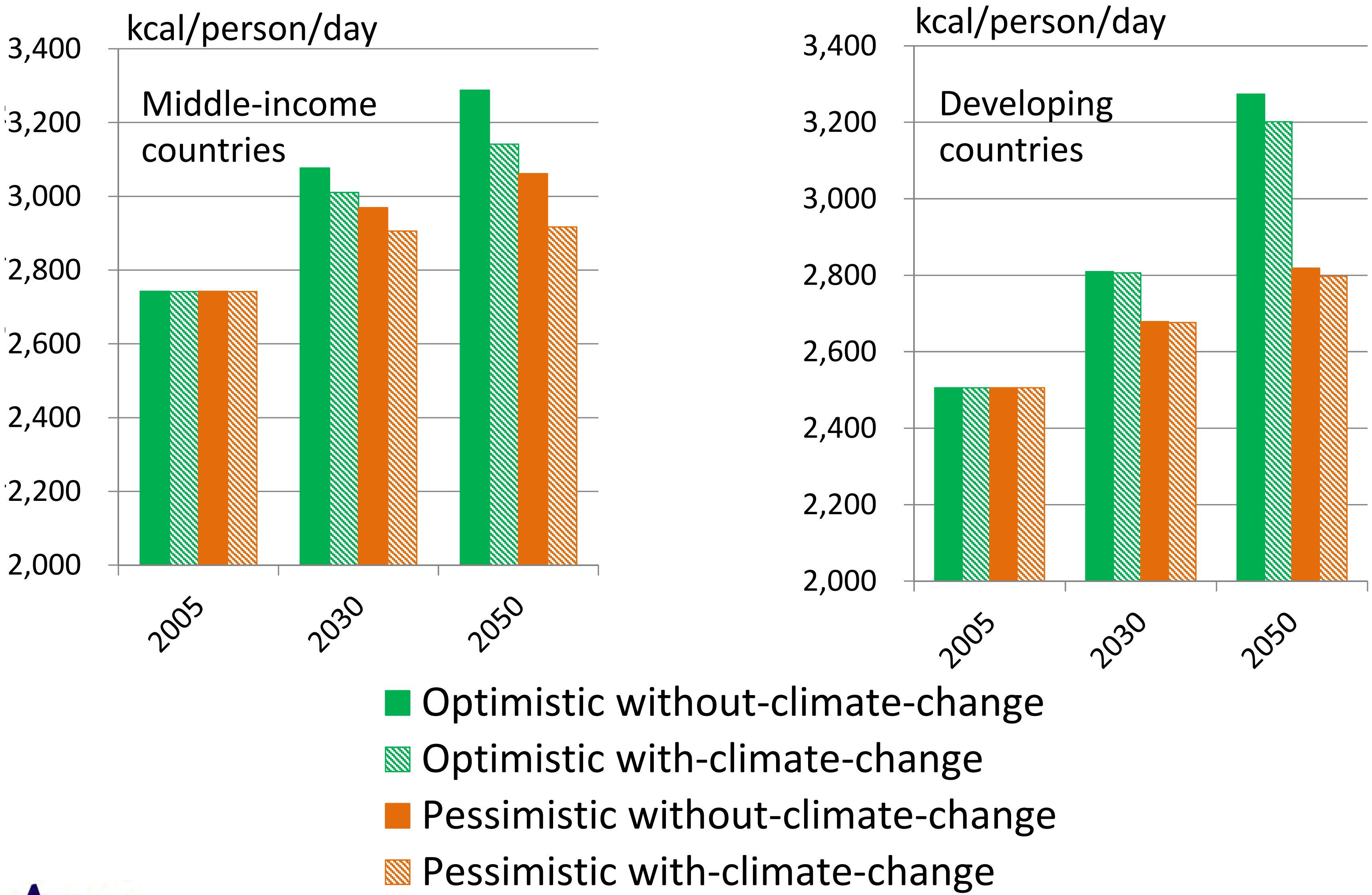
ASIA-PACIFIC INTEGRATED MODEL

Assumption of crop yield



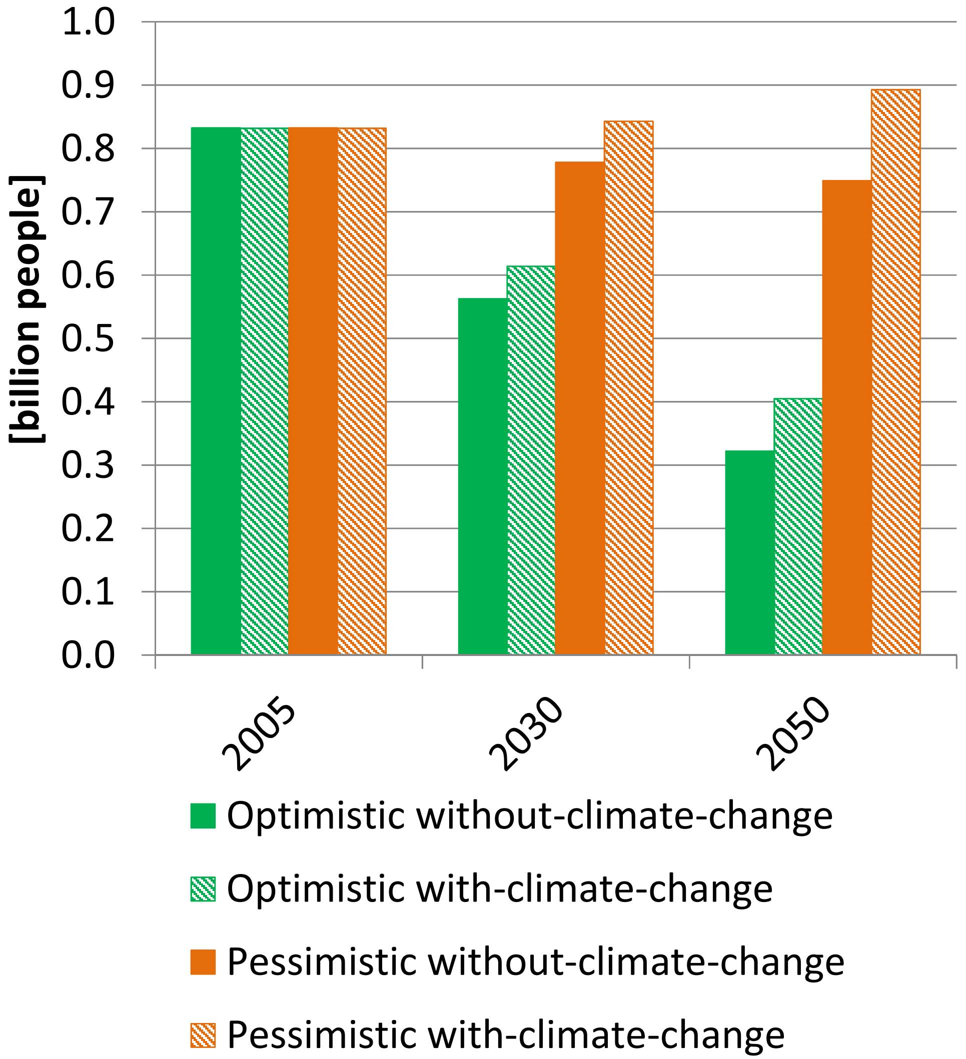
In without-climate-change scenario, assuming numbers from existing literatures.
In with-climate change scenario, following results of M-GAEZ (Masutomi el al.(2009)).

Result: Food consumption (Per capita Calorie)
(Median value among 12GCMs with RCP8.5)



Hasegawa et al., submitted

Result: Hunger population in the world
(Median value among 12GCMs with RCP8.5)



Hasegawa et al., submitted

Conclusion

- We are trying to integrate IAM (socio-economic scenarios including GHG emissions) and IAV (climate change impacts).
- In the area of water and food, influence of socio-economic scenario is larger than the climate change impact.
  - In SSP3, which shows the less economic growth and the more rapid population growth, water stress population and hunger population will be the severest.
- But the climate change impact cannot be neglected.
  - This suggests the necessity of implementing adaptation measures.
- For future works,
  - Full coupling IAM and IAV models to quantify the feedback effects on socio-economic scenarios and consistent socio-economy/GHG emissions/impact scenario.
  - Treatment of other issues such as biomass energy.
  - More comprehensive scenario development which covers all elements.

AIM
ASIA-PACIFIC INTEGRATED MODEL

Contact persons

- Water
  - Dr. Naota Hanasaki hanasaki@nies.go.jp

- Food
  - Dr. Tomoko Hasegawa hasegawa.tomoko@nies.go.jp
  - Dr. Shinichiro Fujimori fujimori.shinichiro@nies.go.jp
  - Dr. Kiyoshi Takahashi ktakaha@nies.go.jp

AIM
ASIA-PACIFIC INTEGRATED MODEL