Global water scarcity assessment under RCP-SSP scenarios

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Outline

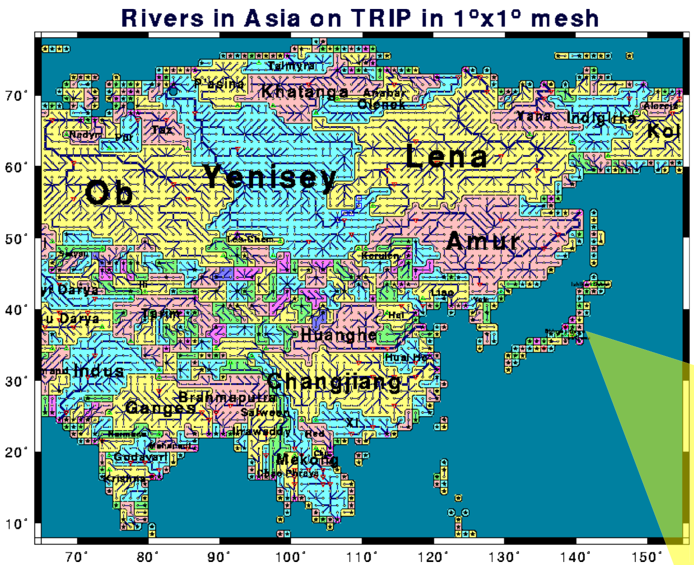
- **Global** impact assessment on water resources
- Interaction between **IAM and IAV**

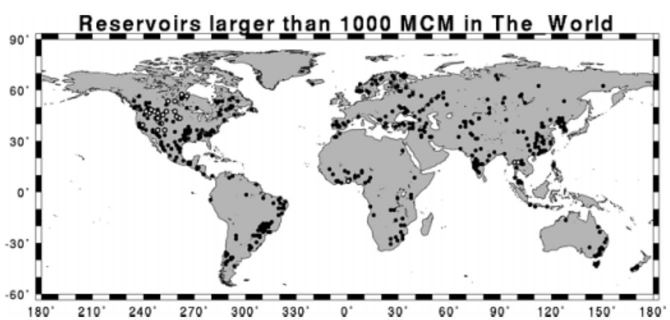
1. Background & Objective
2. Methodology
3. **SSP compatible global water use scenarios**
4. Results
5. Summary

Background & Objective

- Assessment of CC impact and adaptation on water resources
- Hundreds of reports & papers have been published (TAR, AR4, SREX, Arnell, 2004; Alcamo et al., 2003,2007, …)
- Shortcomings of earlier works
    1. Annual basis assessment (neglecting variations of water availability and use)
    2. Fix non-climate variables/factors (inconsistent with socio economic/emission scenarios)
    3. Based on SRES (RCP and SSP are readily available)
- Objective: overcome above three issues

H08 model

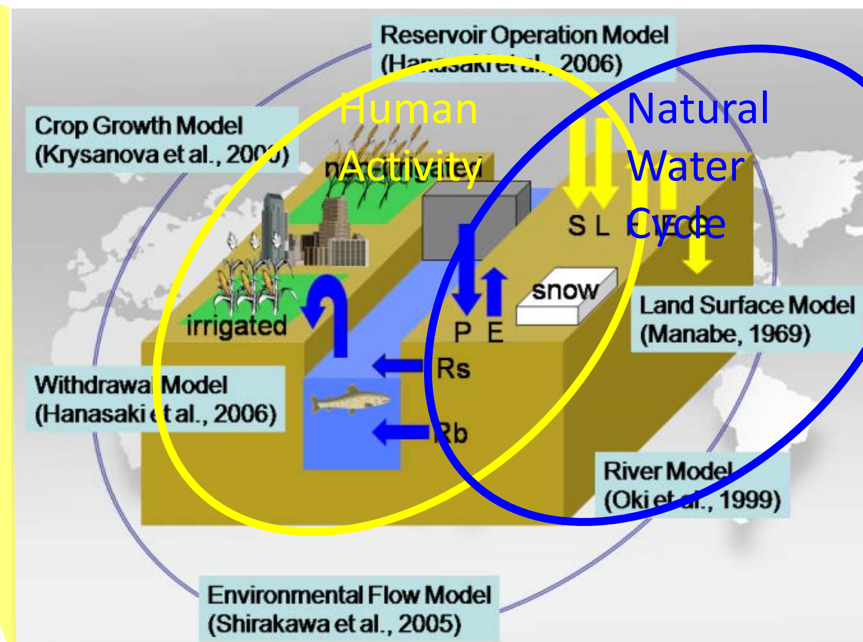




452 reservoirs, 4140 km^3

- 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

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	Future ?
Shortwave radiation	-GCM
Longwave radiation	-Bias correction
Precipitation	-Downscale

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

Future

?

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

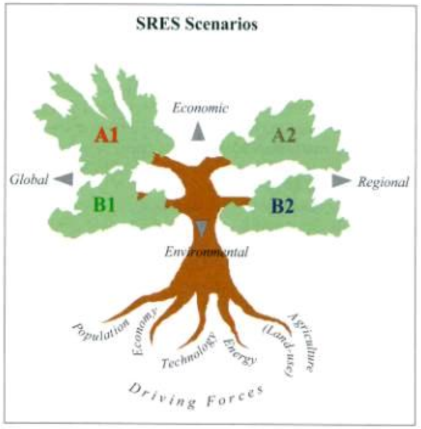
IPCC Scenarios

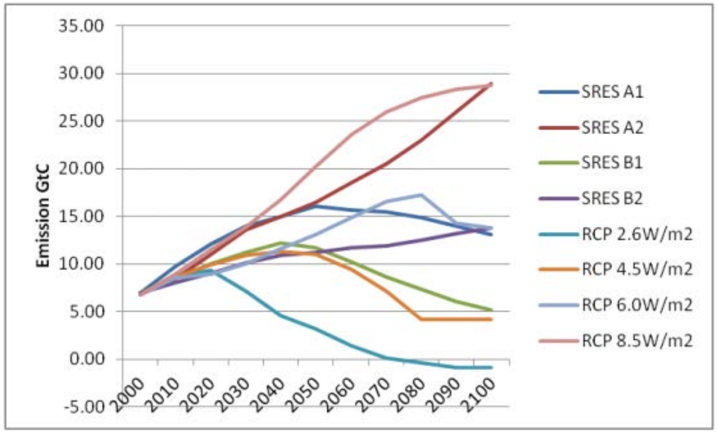
SRES

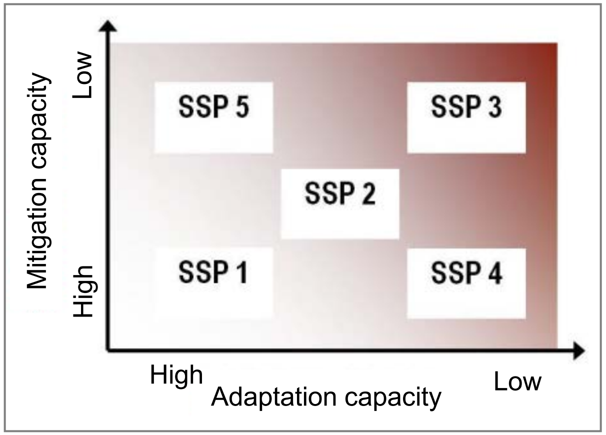
- 4 emission and socio-economic composite scenarios
- 9 variables, 4 regions, 10-yearly
- http://sres.ciesin.columbia.edu/

RCP & SSP (AIM Interim)

- 4 emission scenarios (RCP) x 5 socio-economic scenarios (SSP)
- 6 variables?, **12** regions, **yearly**
- http://www-iam.nies.go.jp/aim/aimssp/







Simulation settings

Socio-economic Scenario

SSP1: Low population, High income

SSP3: High population, Low income

Emission scenario

With climate policy
STaBilize at 4.5W/m²

No climate policy
Business As Usual

Climate Scenario

CanESM2
RCP4.5 (r1i1p1)

CanESM2
RCP 8.5 (r1i1p1)

		Population	GDP (2005 USD)
CTR	2005	6.51×10^{9}	45.7×10^{12}USD
SSP1	2055	8.08×10^{9}	212.9×10^{12}USD
SSP3	2055	11.10×10^{9}	140.7×10^{12}USD

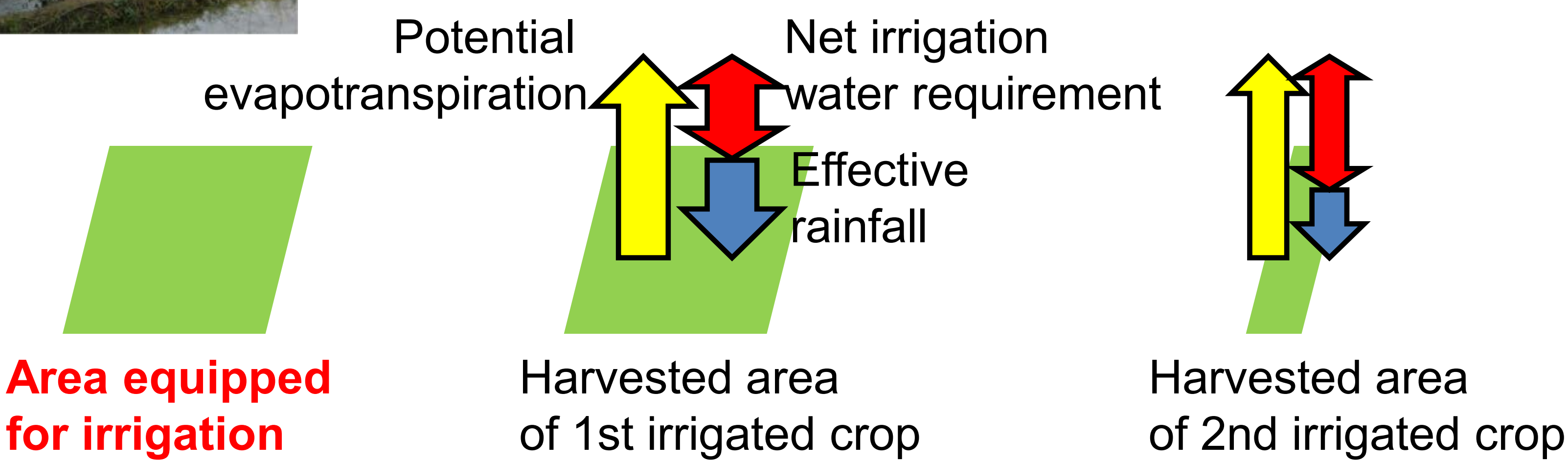
+Electricity generation

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

H08 additionally needs water specific scenarios.

Agricultural (=irrigation) water withdrawal modeling

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



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

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	0.2	0.15
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

Medium variant

Low variant

Industrial & domestic water withdrawal modeling

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

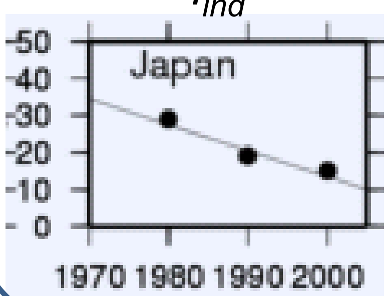
More flexible model is needed for scenario study.

Industrial water withdrawal

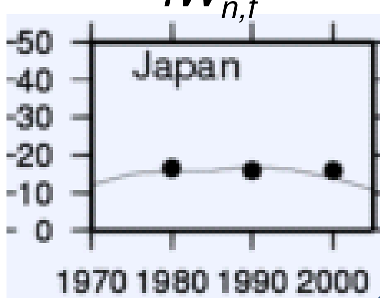
$$IW_{n,f} = i_{ind} \times ELC_{n,f}$$

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

i_{ind}



$IW_{n,f}$

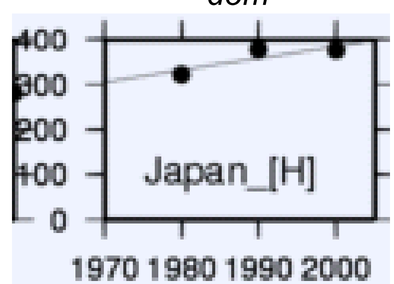


Domestic water withdrawal

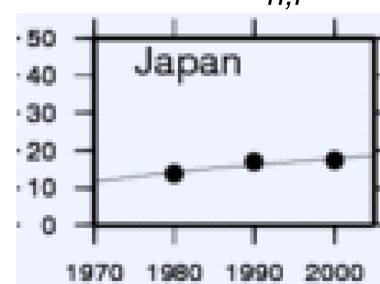
$$DW_{n,f} = i_{dom} \times POP_{n,f}$$

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

i_{dom}

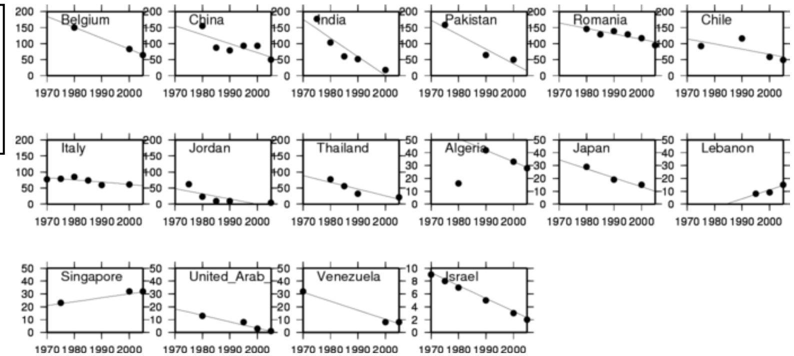


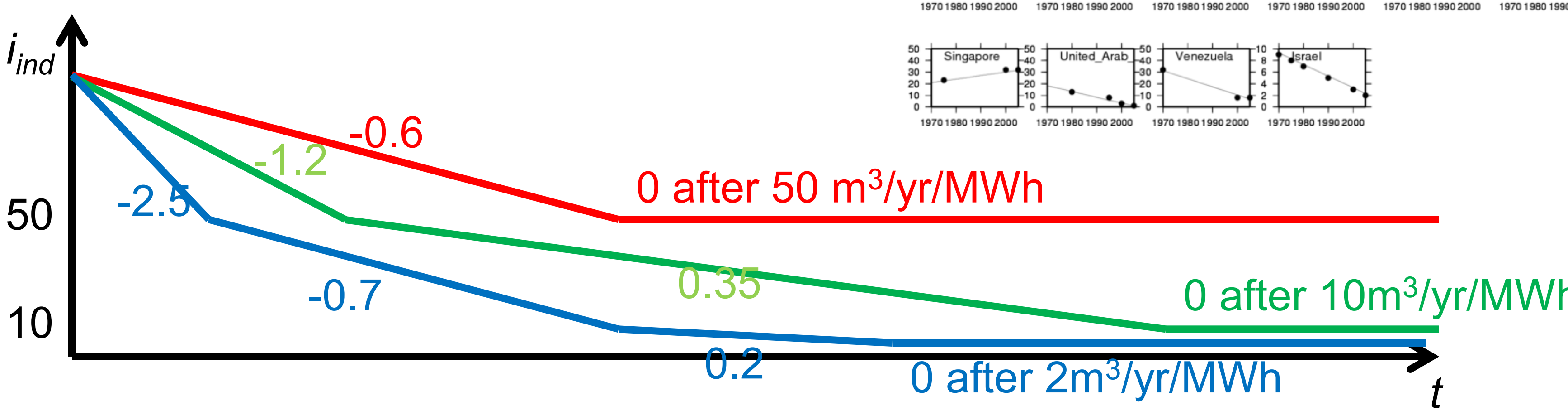
$DW_{n,f}$

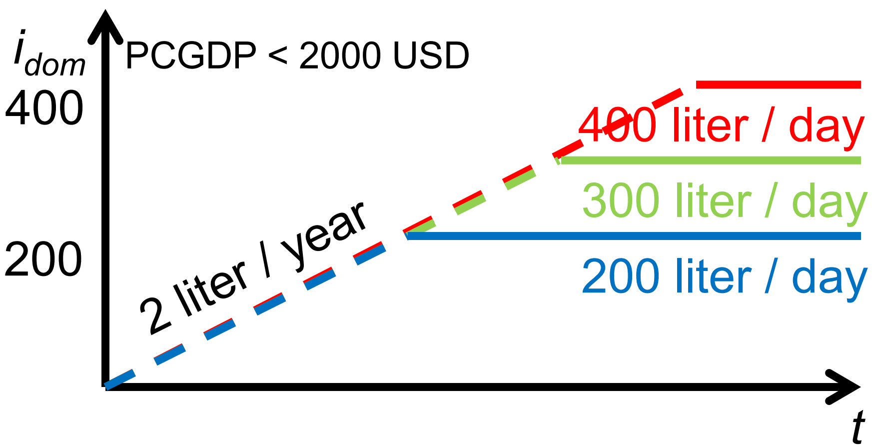


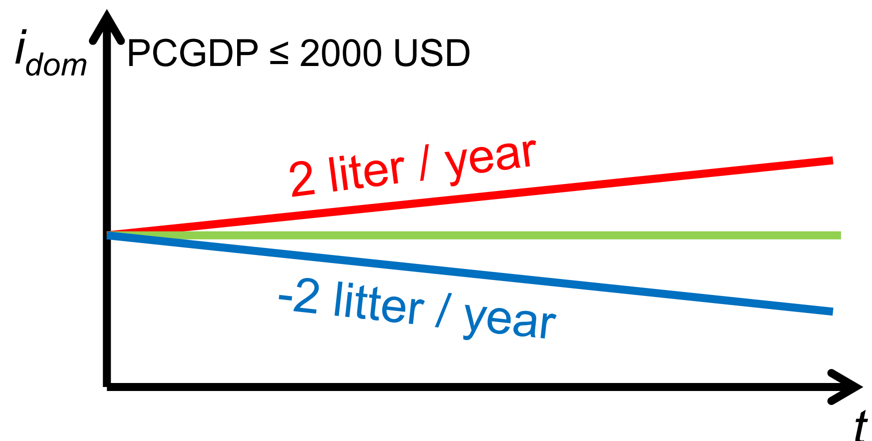
Industrial/Domestic intensity scenario

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

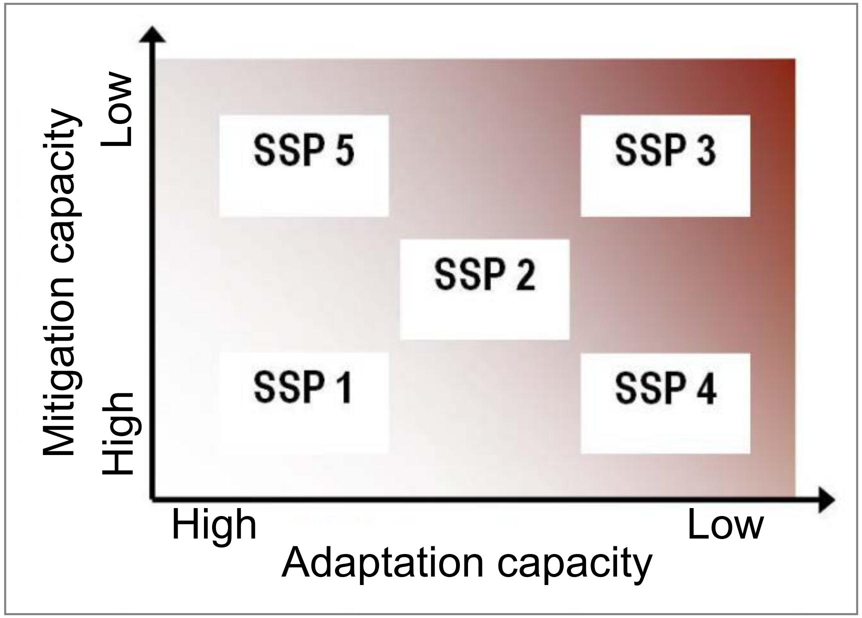








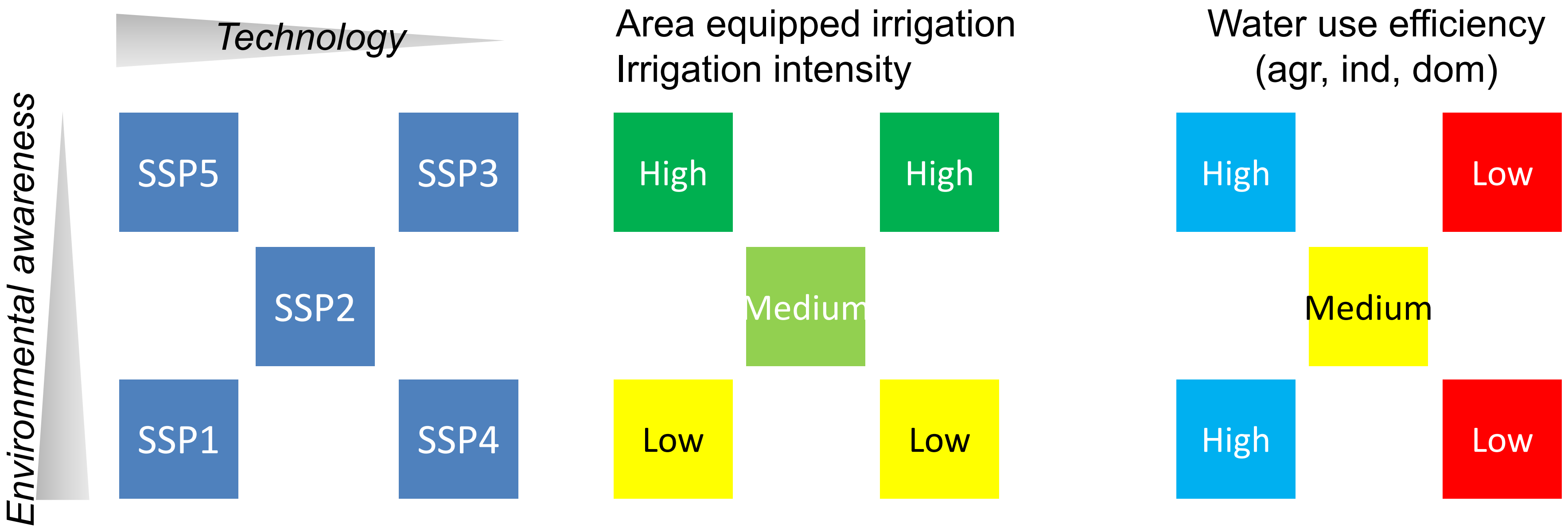
Revisiting concept of SSP



Narrative scenario of SSP

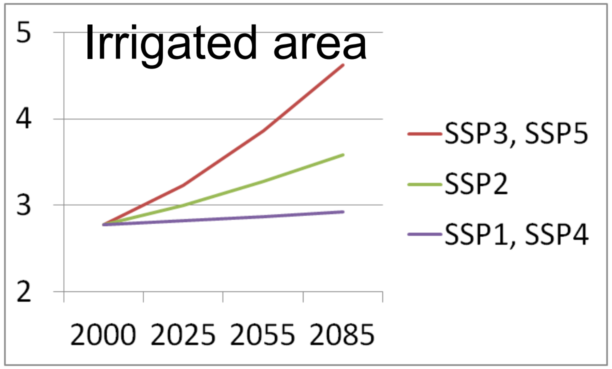
SSP1	Sustainable world High international cooperation High technological improvement High environmental awareness
SSP2	Middle of the road in between SSP1 and SSP3
SSP3	Fragmented world Low international cooperation Low technological improvement
SSP4	Divided in rich & poor Low international cooperation High technological improvement
SSP5	Coal gas powered growth High international cooperation High technological improvement Low environmental awareness?

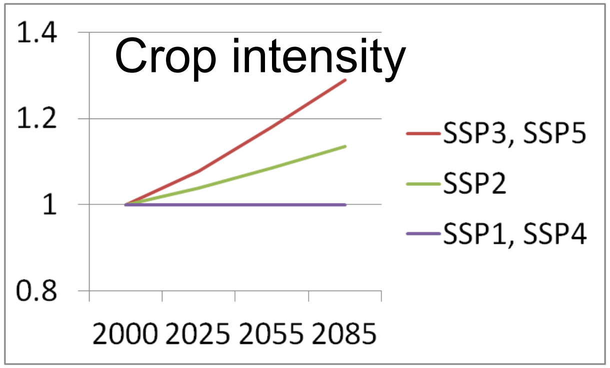
SSP interpretation

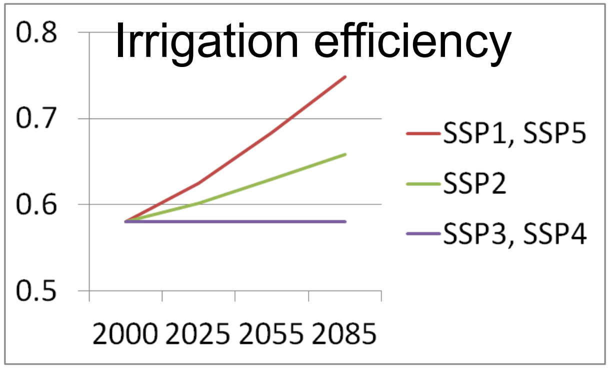


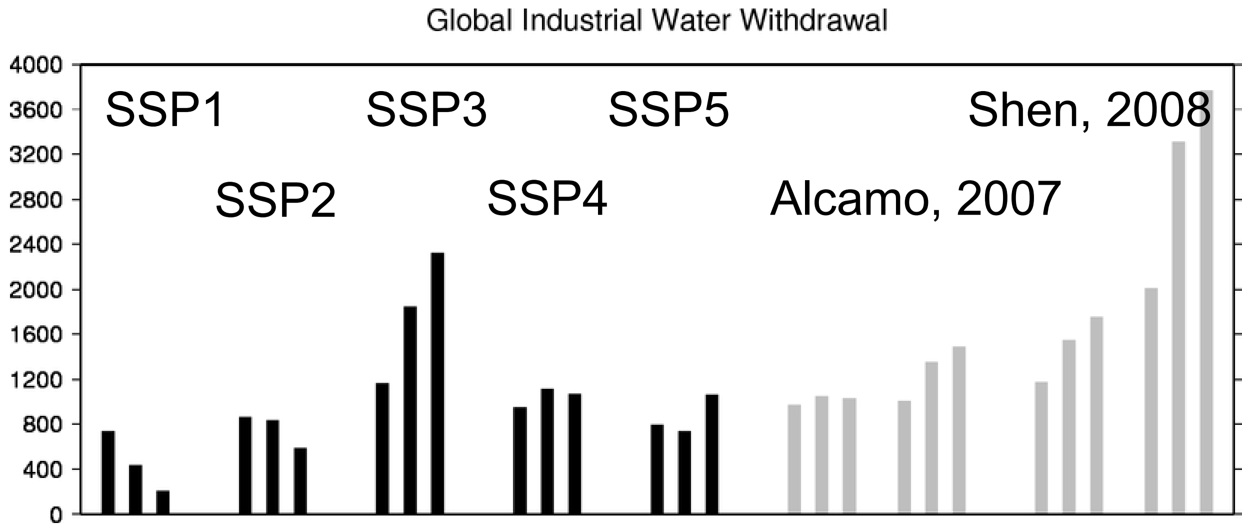
	in a word	Area	intensity	A eff.	I eff.	D eff.
SSP1	Sustainable world	0.06	0.15	0.3	HE	HE
SSP2	middle of the road	0.3	0.2	0.15	ME	ME
SSP3	Fragmented world	0.6	0.4	0	LE	LE
SSP4	Divided in rich & poor	0.06	0.15	0	LE	LE
SSP5	Coal gas powered growth	0.6	0.4	0.3	HE	HE

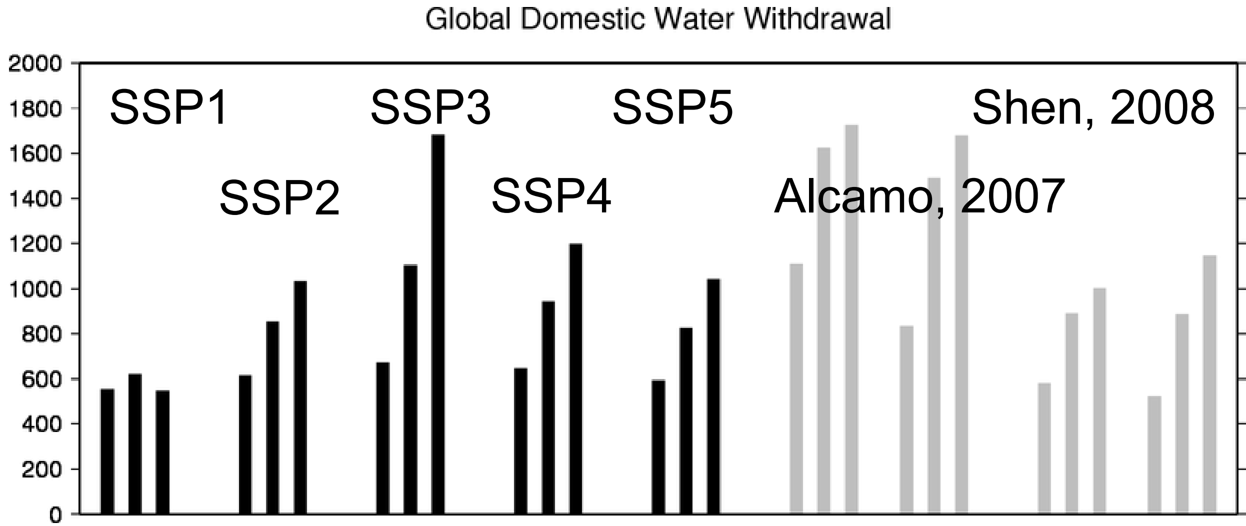
SSP compatible water scenarios!



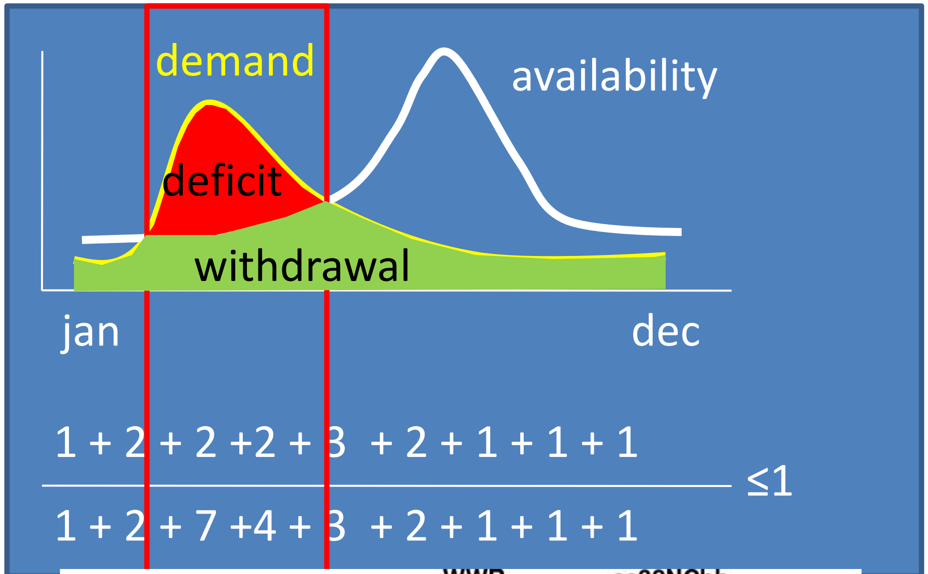








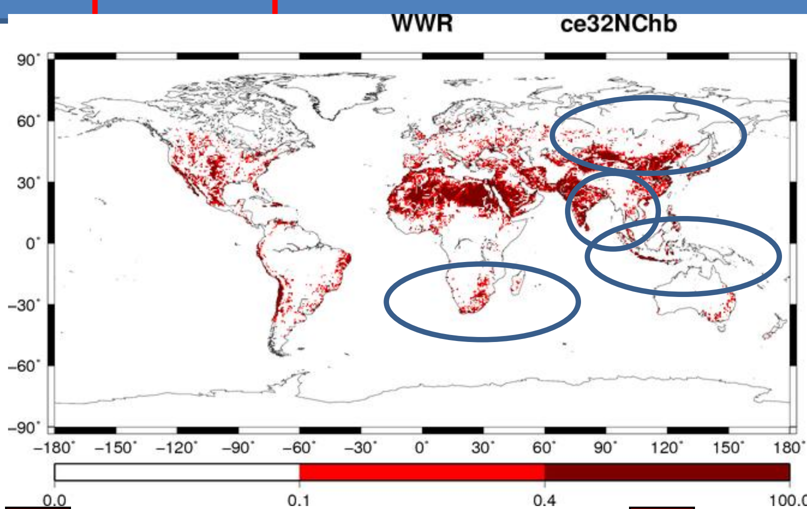
Water resources assessment

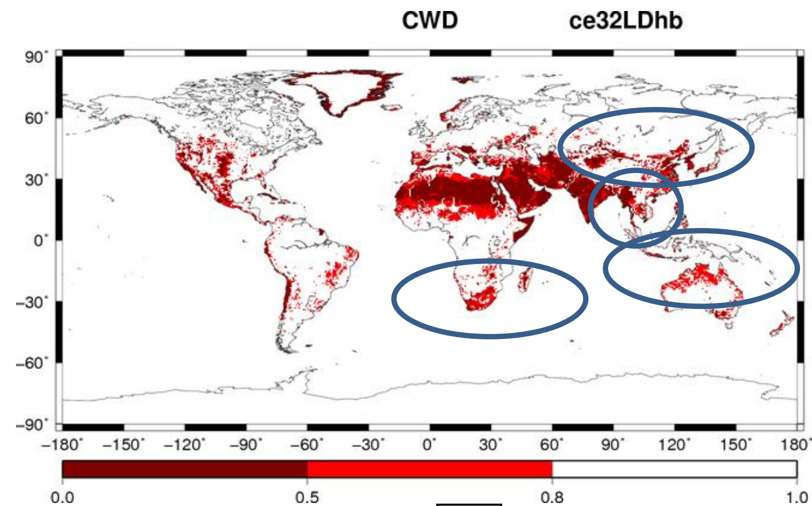


Daily basis

$$\text{Index}=\frac{\sum \text{daily withdrawal (simulated)}}{\sum \text{daily demand (simulated)}}$$

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

		CWD	WWR
CTR	2000	1.61×10^9 (G)	1.94×10^9 (G)
SSP1-BAU	2041-2070	2.76×10^9 (G)	2.62×10^9 (G)
SSP1-STB	2041-2070	2.64×10^9 (G)	2.57×10^9 (G)
SSP3-BAU	2041-2070	4.06×10^9 (G)	3.90×10^9 (G)
SSP3-STB	2041-2070	3.97×10^9 (G)	3.86×10^9 (G)
Alcamo et al., 2007	2055 (B2)	N.A.	$5.15\text{-}5.24\times10^9$ (B)

Hanasaki et al. in prep

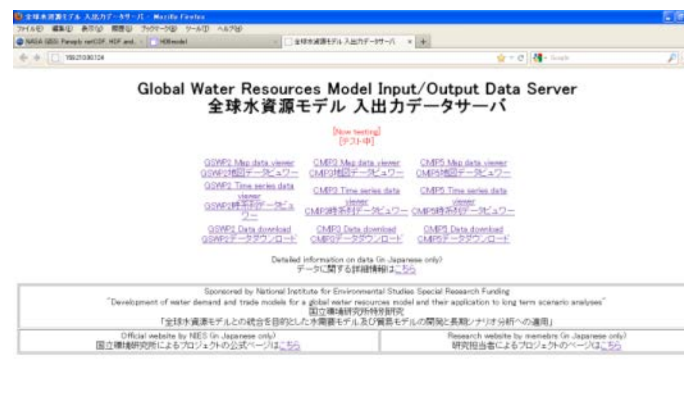
- Water stressed population in the middle of the 21st century
  - SSP1 << SSP3, STB < BAU
- Socio-economic scenario has larger sensitivity than climate policy scenario → **<u>Socio-economic scenario matters.</u>**
- Water availability impacts economic activities? → **<u>Consistent scenario links IAM and IAV modeling.</u>**

Summary

- Summary
  - RCP/SSP based simulation using H08.
  - Proposal of SSP compatible water use scenarios
  - **<u>Socio-economic scenario matters</u>** to global CC water resources assessment.
  - **<u>Consistent scenario links IAM and IAV modeling</u>**. Further collaboration needed for better modeling & understanding.
- Future works
  - Polish models, scenario interpretation
  - Examine other scenarios, period
  - Regionally/Temporally detailed analyses

Advertisement: H08 is freely available

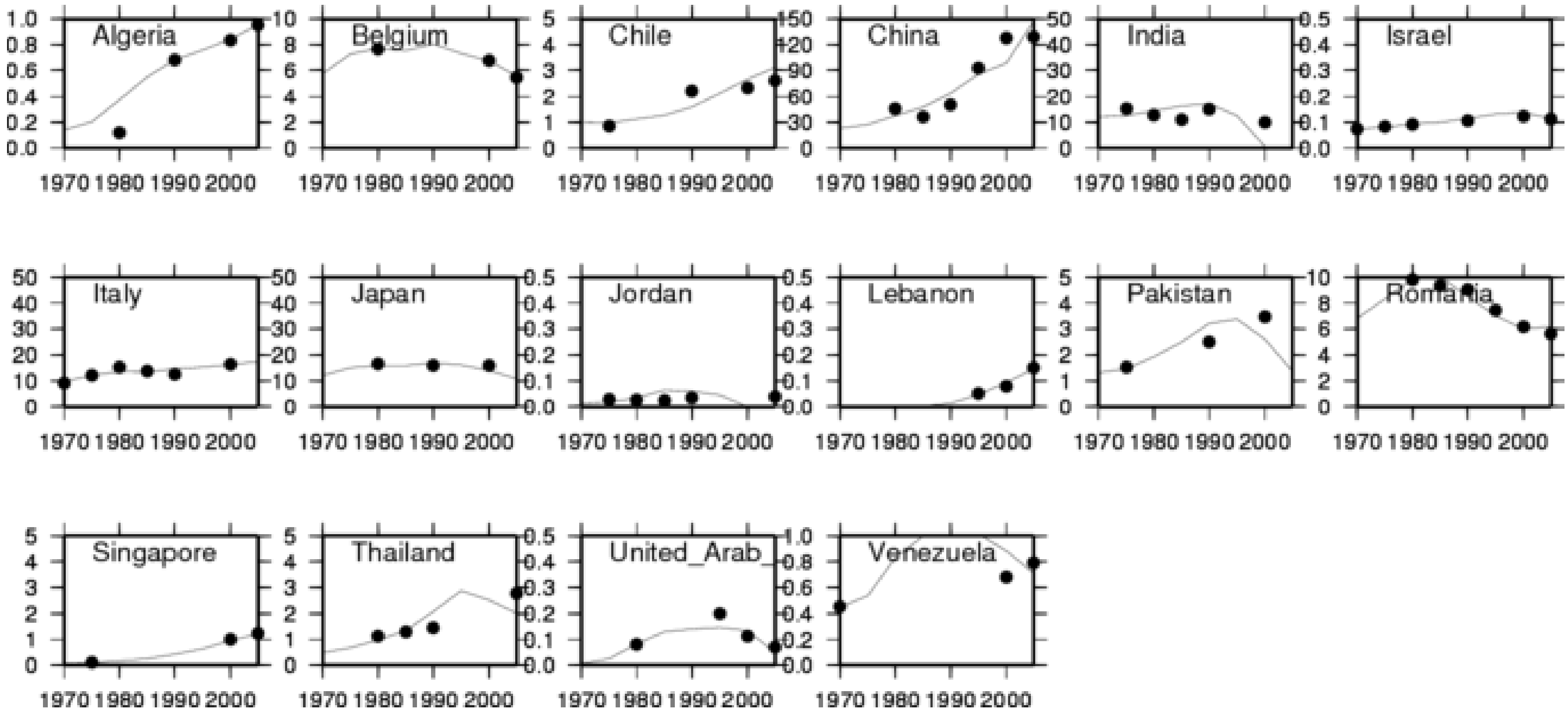
- H08 web site
  - https://sites.google.com/site/h08model/
  - Source code and manual
- Input & Output data server
  - http://158.210.90.124/ (available soon)
  - Including CMIP3 & CMIP5 data
- Recent papers
  - Virtual water and complex network theory (Konar et al., 2011; Suweis et al. 2011)
  - Intl. model intercomparison (Haddeland et al., 2011)
  - H08 in MIROC earth system model (Pokhrel et al. 2012)



Industrial water withdrawal

x: year, y: total withdrawal[km^3/yr]

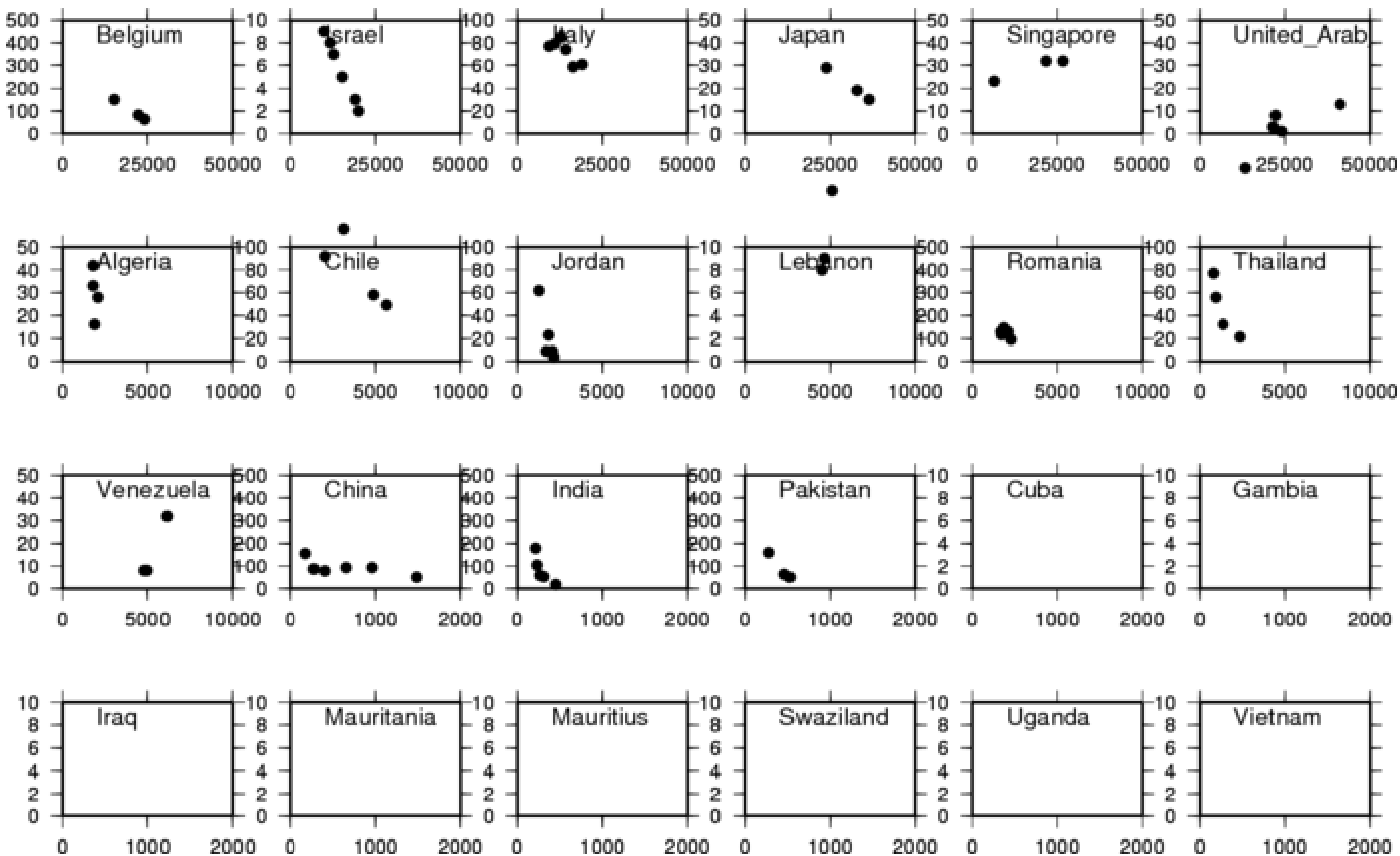
Hanasaki et al. in prep



Industrial water withdrawal

x: GDPPC, y: intensity [m^3/yr/MWh]

Hanasaki et al. in prep



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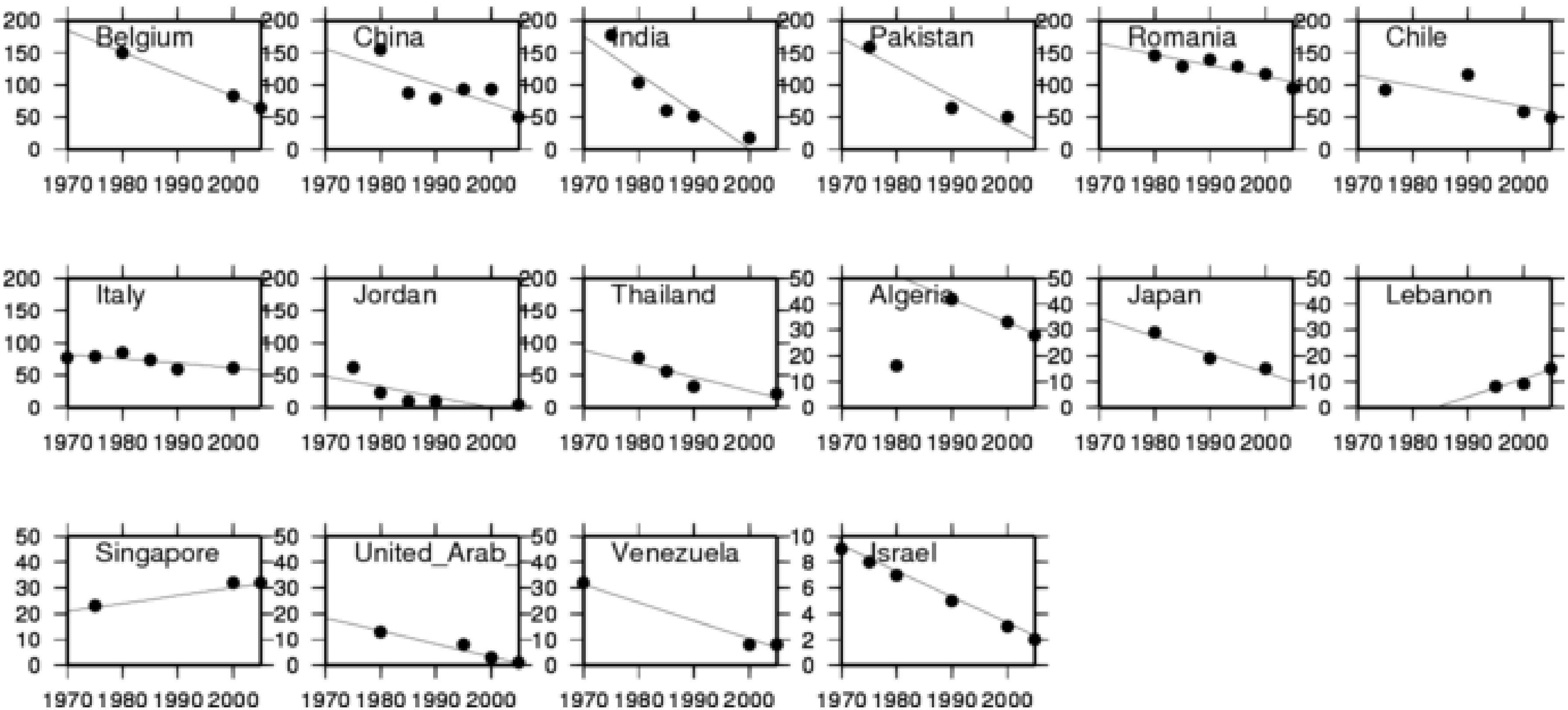
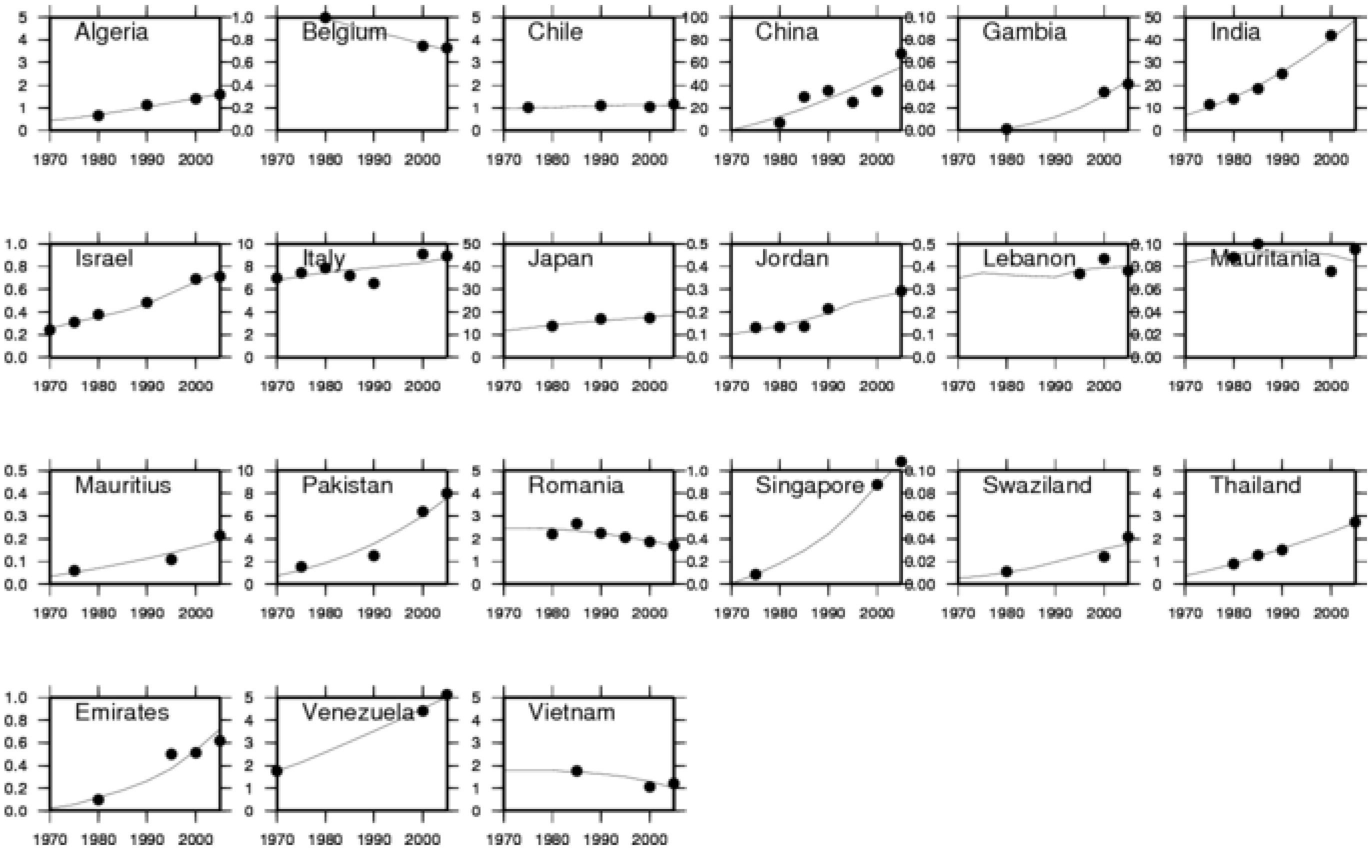


Domestic water withdrawal

x: year, y: total withdrawal [km^3/yr]

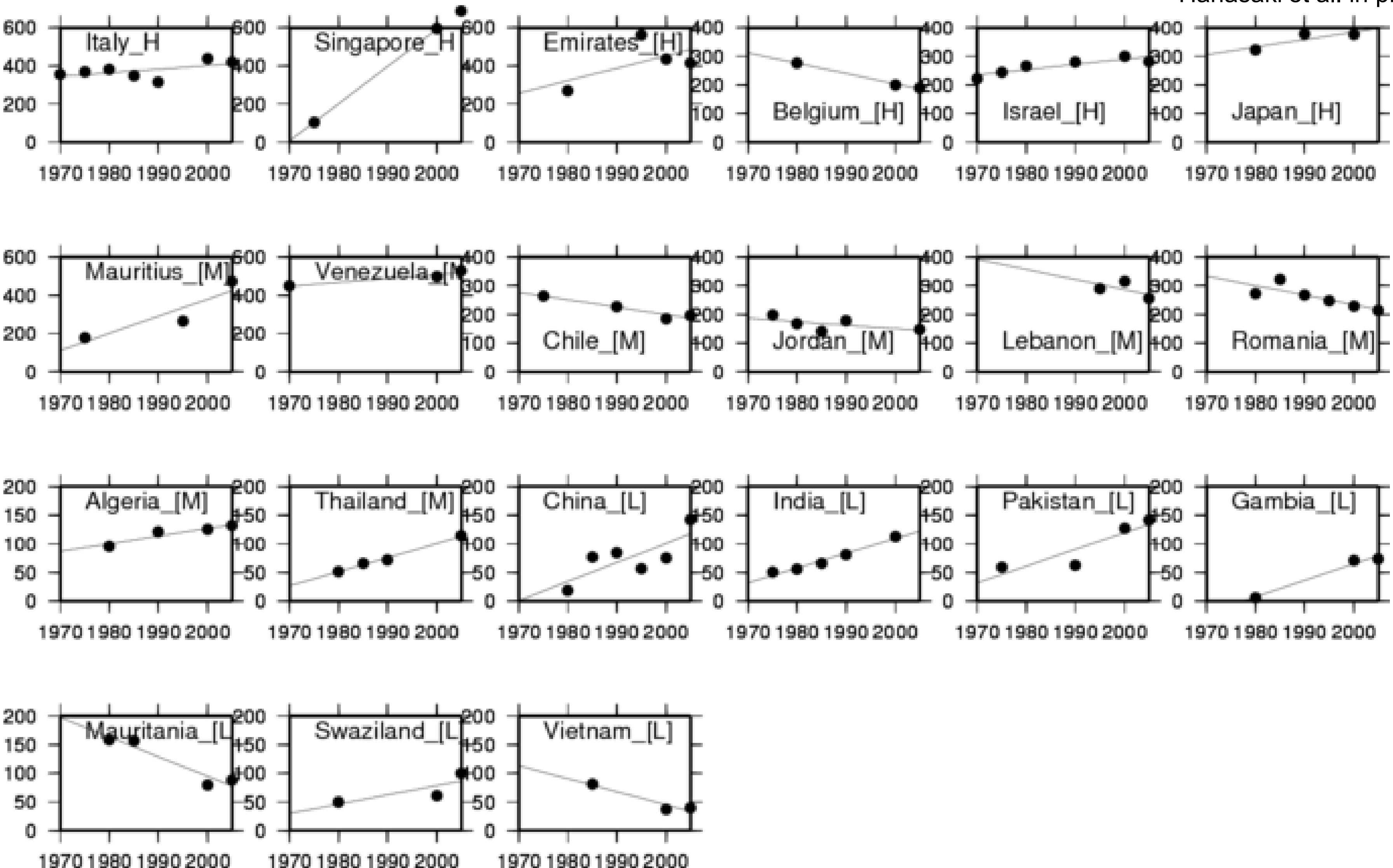
Hanasaki et al. in prep



Domestic water withdrawal

x: GDPPC, y: intensity [litter/day/person]

Hanasaki et al. in prep



Hanasaki et al. 2010

Water withdrawal