Frontiers of global hydrological modeling, water scarcity assessment, and water-energy nexus study

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Outline

- Part 1: Frontiers of global hydrological modeling and water scarcity assessment
- Part 2: Frontiers of Water-Energy Nexus studies

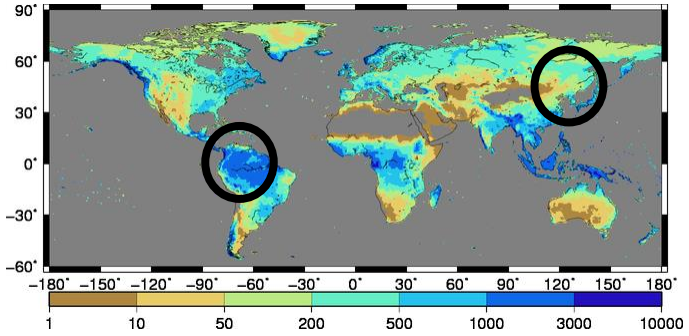
Part 1:
Frontiers of global hydrological modeling and water scarcity assessment

Background

Three primary causes of water scarcity in the world

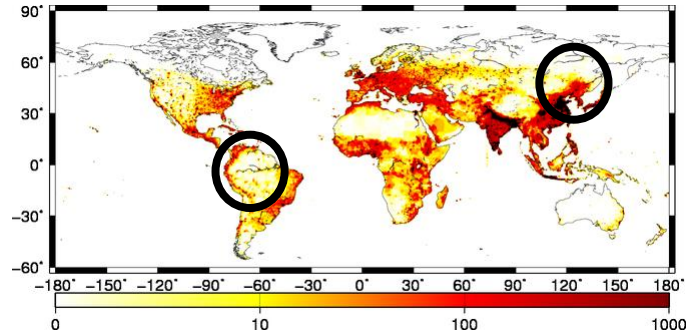
1. Uneven geographical distribution

Mean annual runoff



Hanasaki et al., 2013a

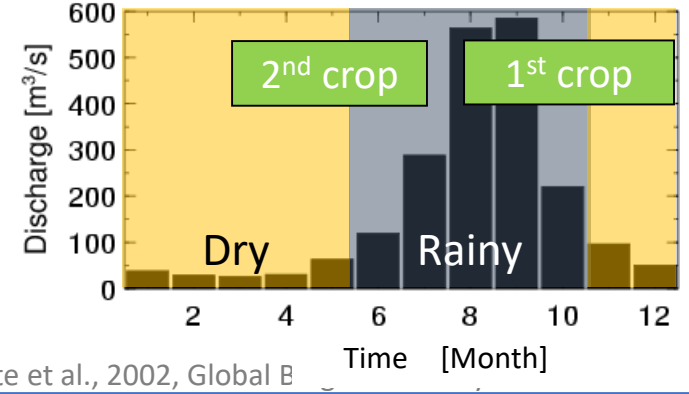
Population



http://sedac.ciesin.columbia.edu/gpw

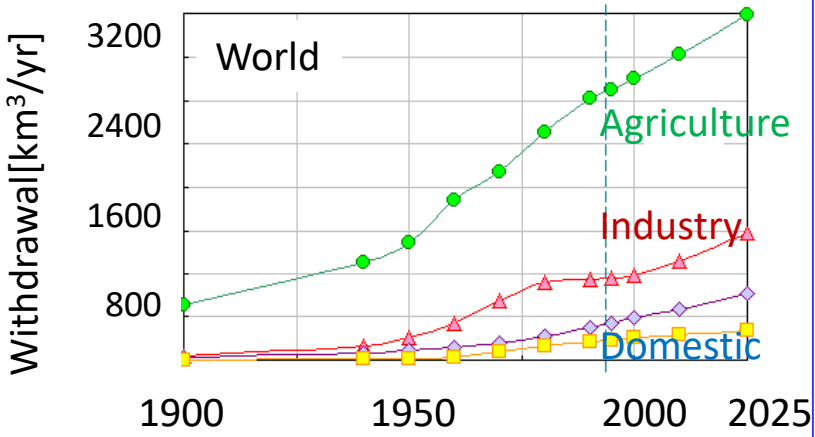
2. Uneven temporal distribution

Monthly river discharge in Thailand



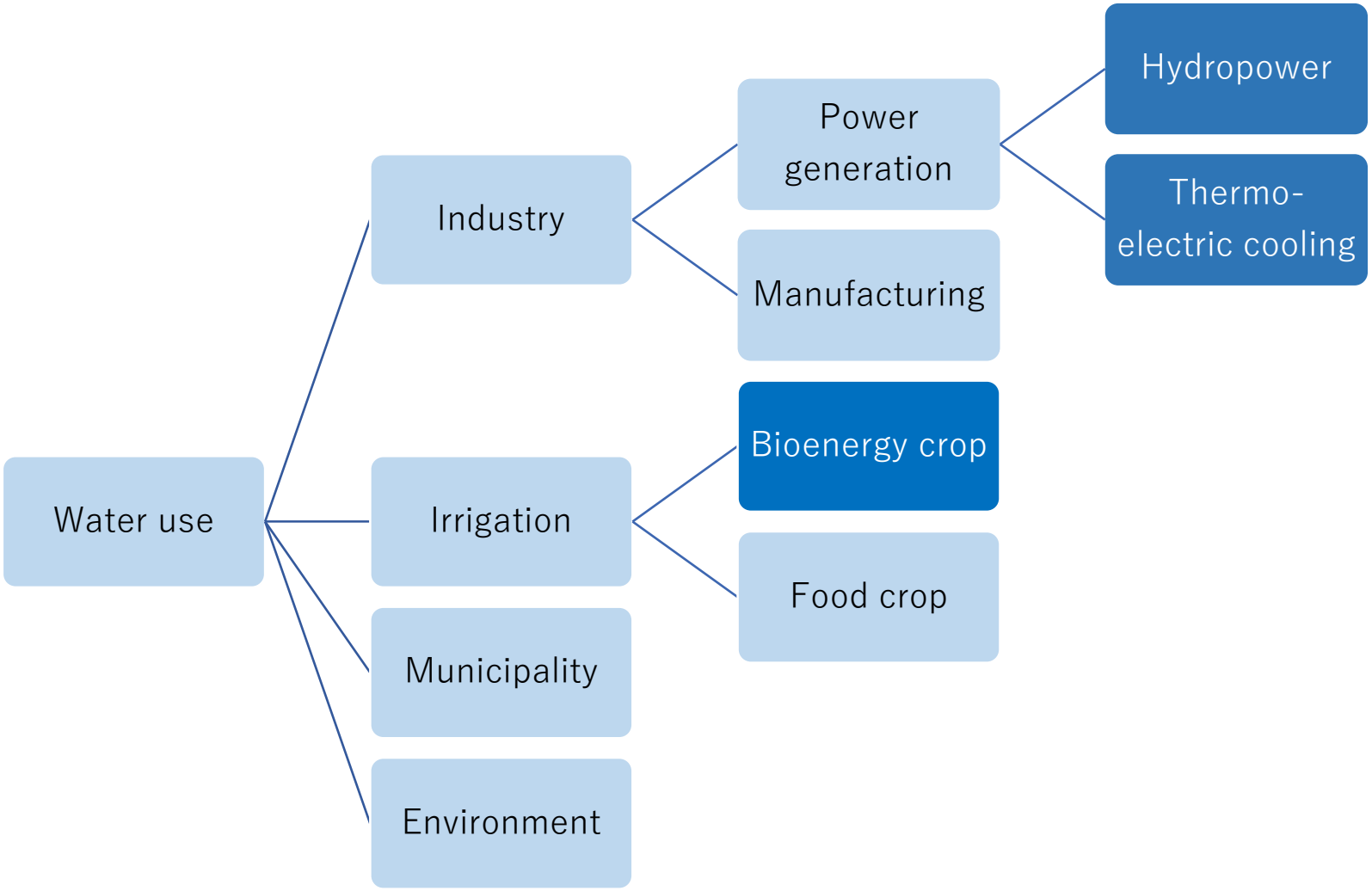
Fekete et al., 2002, Global B

3. Increasing human water use



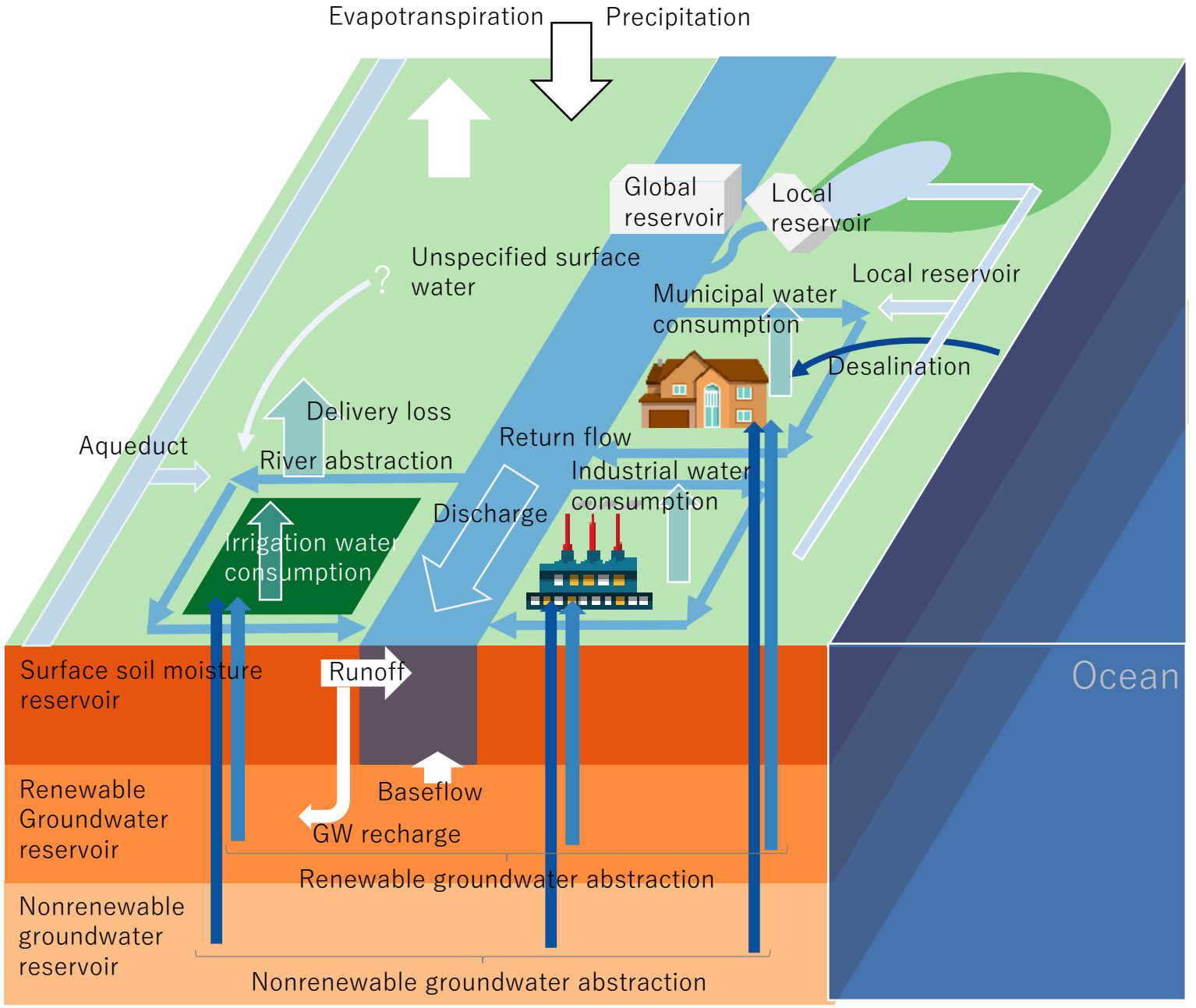
Shiklomanov, 2000, Water Int.

Water use


Water use
Industry
Power generation
Hydropower
Thermo-electric cooling
Manufacturing
Irrigation
Bioenergy crop
Food crop
Municipality
Environment

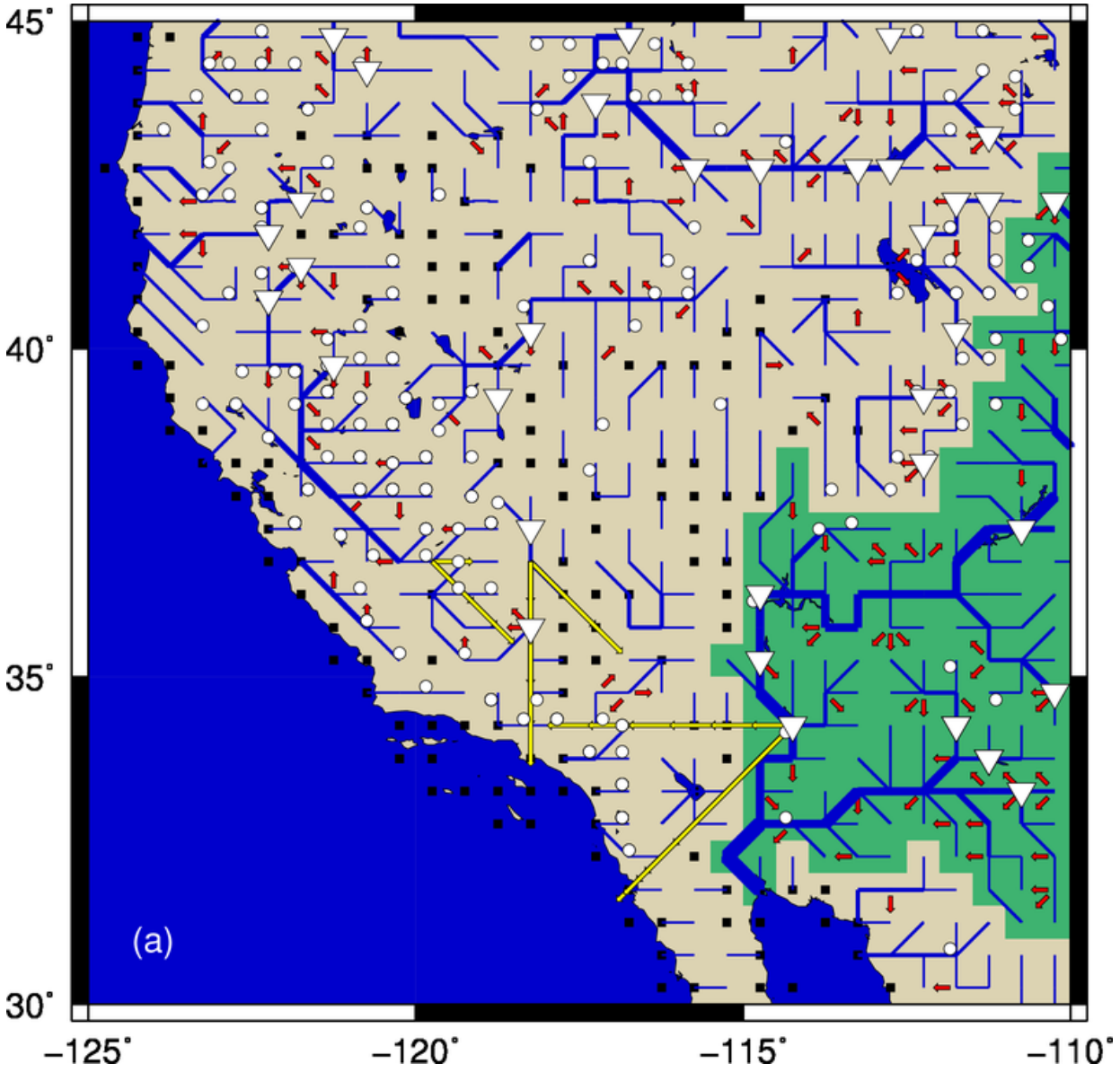
Global hydrological model H08

- Model=Computer software
- Grid-based model,
  Standard spatial resolution:
  50km x 50km
- Standard temporal resolution: a day
- Three water use sectors,
  Seven water sources
- Interaction between natural hydrology and human activities



Hanasaki et al. 2008ab, 2010, 2016, 2018

Map in H08



Global reservoirs
(on the major rivers)

Local reservoirs
(off the major rivers)

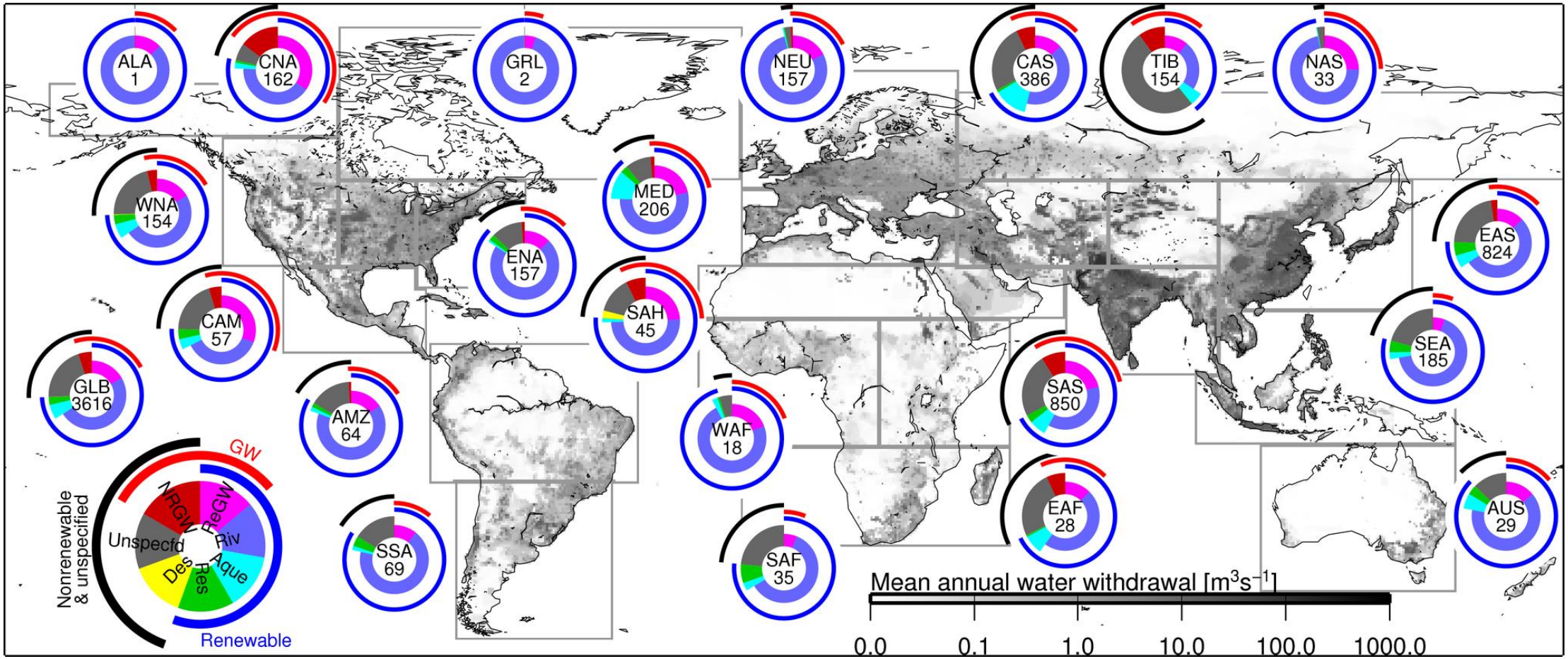
“Explicit” aqueducts
(confirmed by literature)

“Implicit” aqueducts
(inferred by geographical conditions)

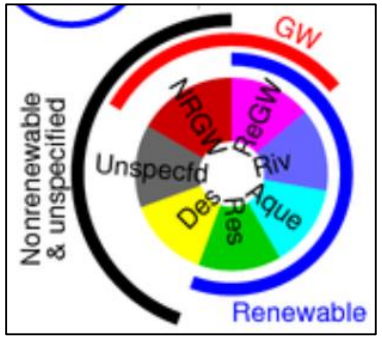
Terminal of rivers

Hanasaki et al. 2018, HESS

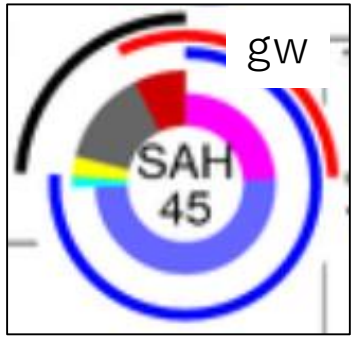
Regional water sources



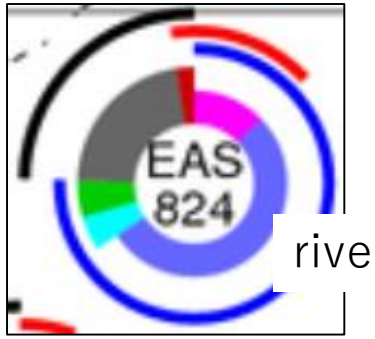
Legend: fraction of water source



Sahara; groundwater +desalination

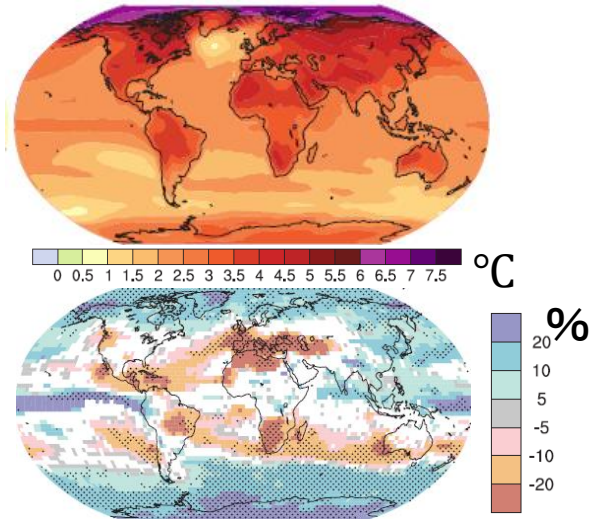


East Asia: surface water dominated



Hanasaki et al. 2018, HESS

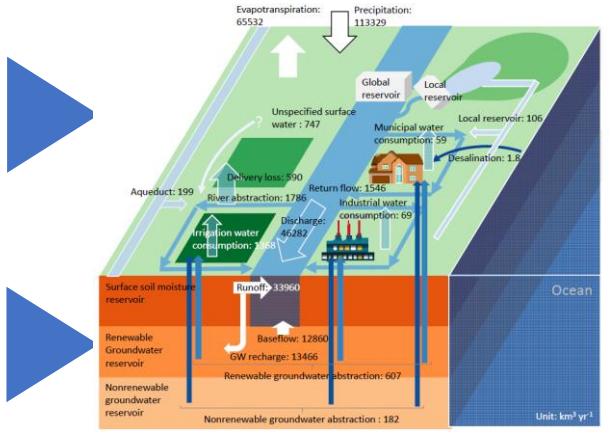
Climate change and water scarcity



Future climate

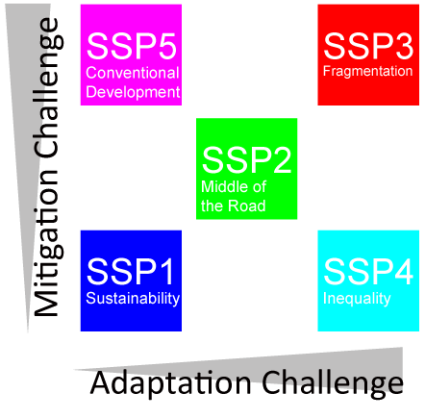
Socio-economic scenarios

↳ Future water use



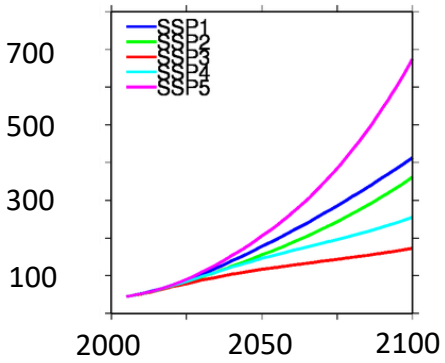
Water resources

Socio economic scenarios: Shared Socio-economic Pathways (SSP)

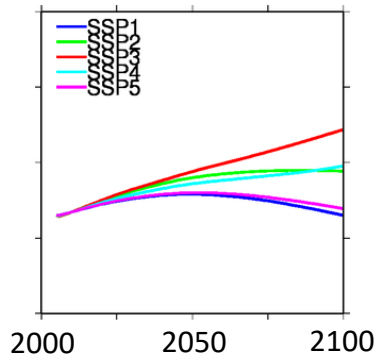


SSP	Description of the world
SSP1	Sustainability
SSP2	Middle of the Road
SSP3	Fragmentation
SSP4	Inequity
SSP5	Conventional Development

Total GDP (trillion USD)



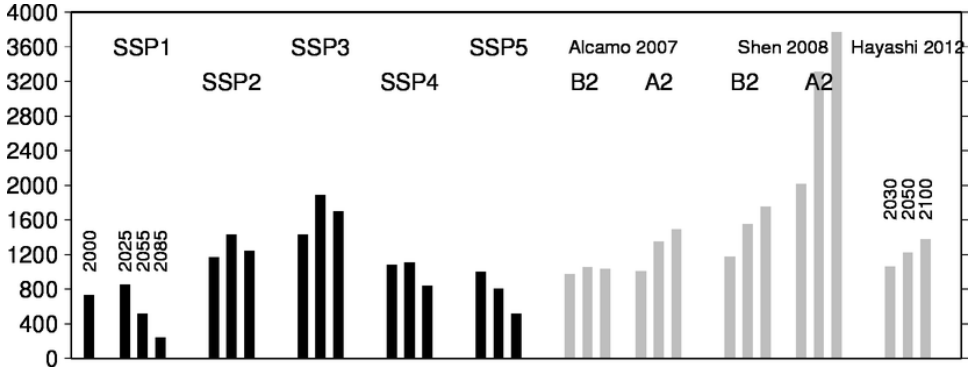
Population (billion person)

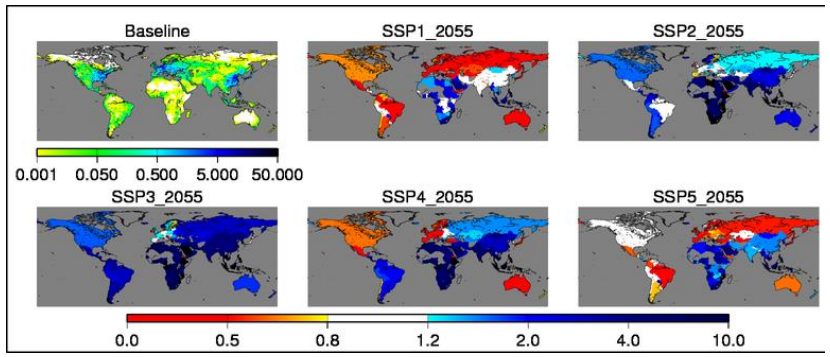


Hanasaki et al. 2013ab, HESS

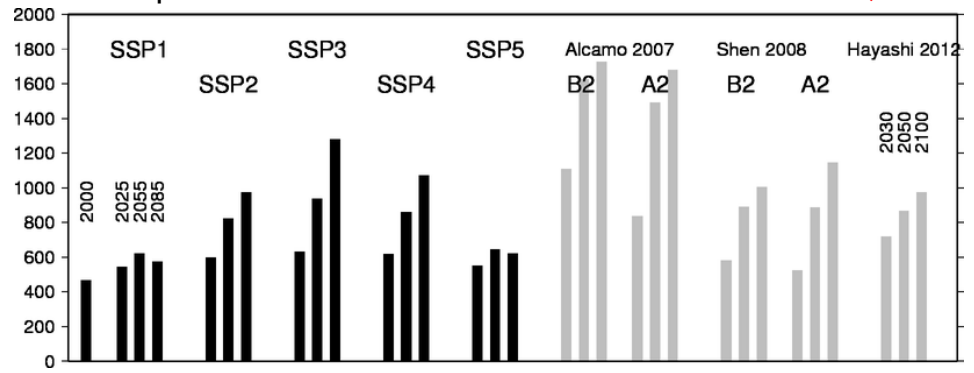
Projecting future water use

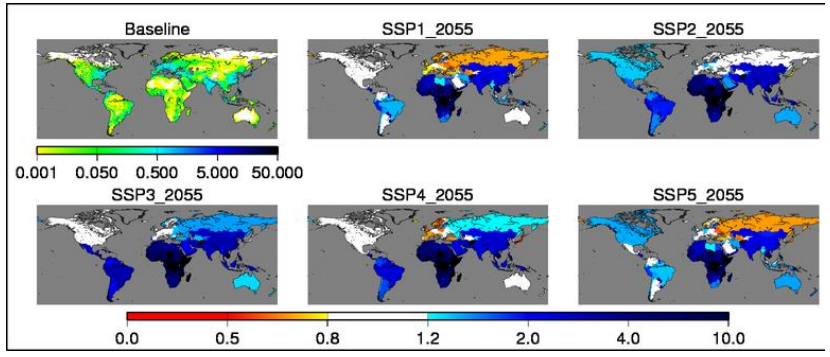
Industrial water withdrawal scenarios (based on regression analysis)



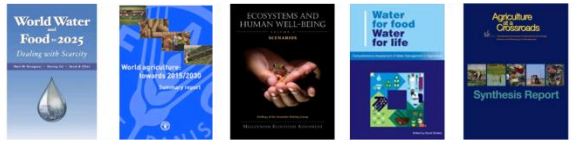


Municipal water withdrawal scenarios (based on regression analysis)

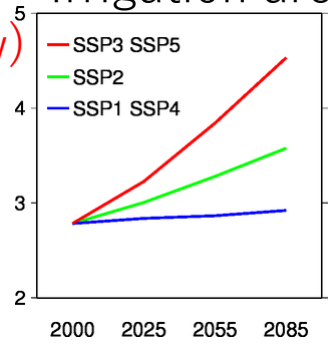




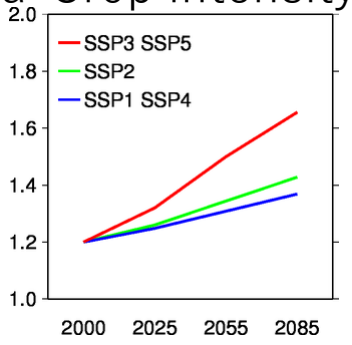
Irrigation scenarios:
(based on literature review)



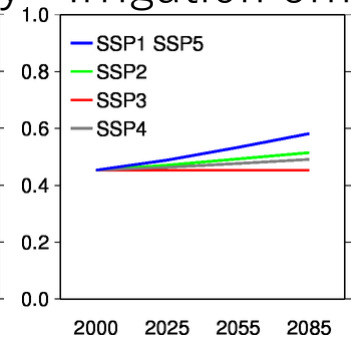
Irrigation area



Crop intensity



Irrigation efficiency



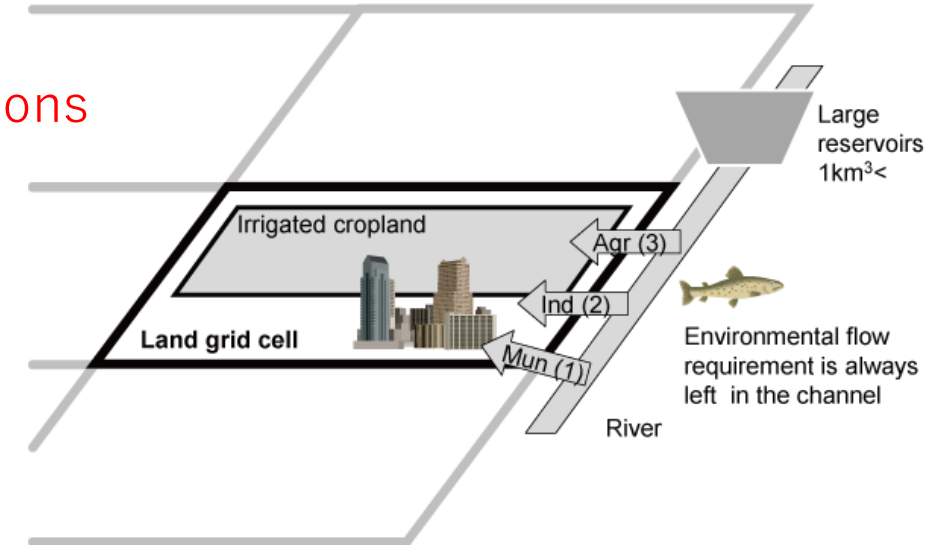
Hanasaki et al. 2013ab, HESS

Definition of “water scarcity”

Method used in this study

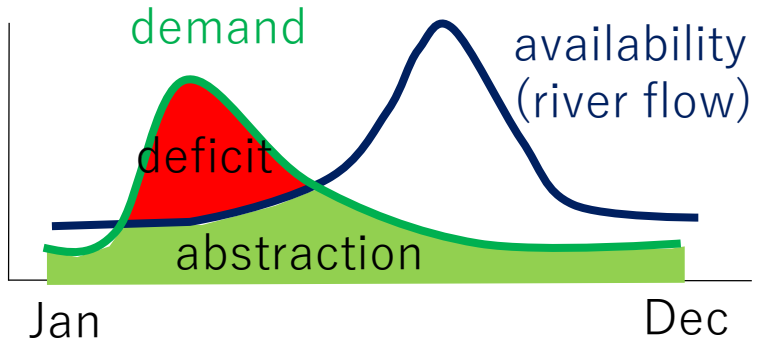
Water abstraction simulations

- Abstract only from river at a daily interval
- Rivers can be depleted and abstraction can fall below requirement



Water scarcity index: Cumulative Abstraction to Demand Ratio

$$CAD = \frac{\sum_{DOY=1}^{365} abstraction_{DOY}}{\sum_{DOY=1}^{365} demand_{DOY}}$$



Change in water scarcity: Change in CAD

Water stressed regions: CAD<50%

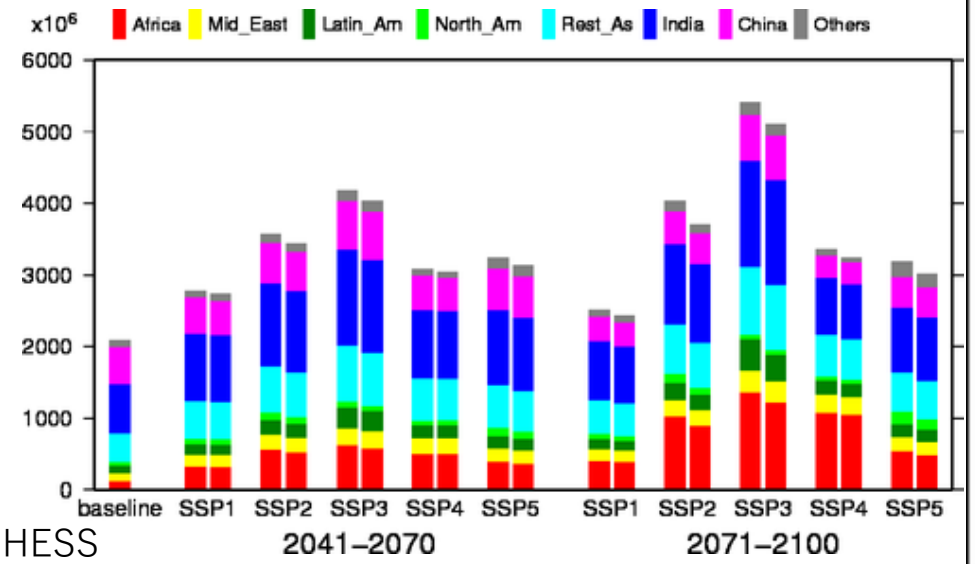
Hanasaki et al. 2013ab, HESS

Projecting future water scarcity

Change in water scarcity
(availability of water when needed)
→Africa is most vulnerable

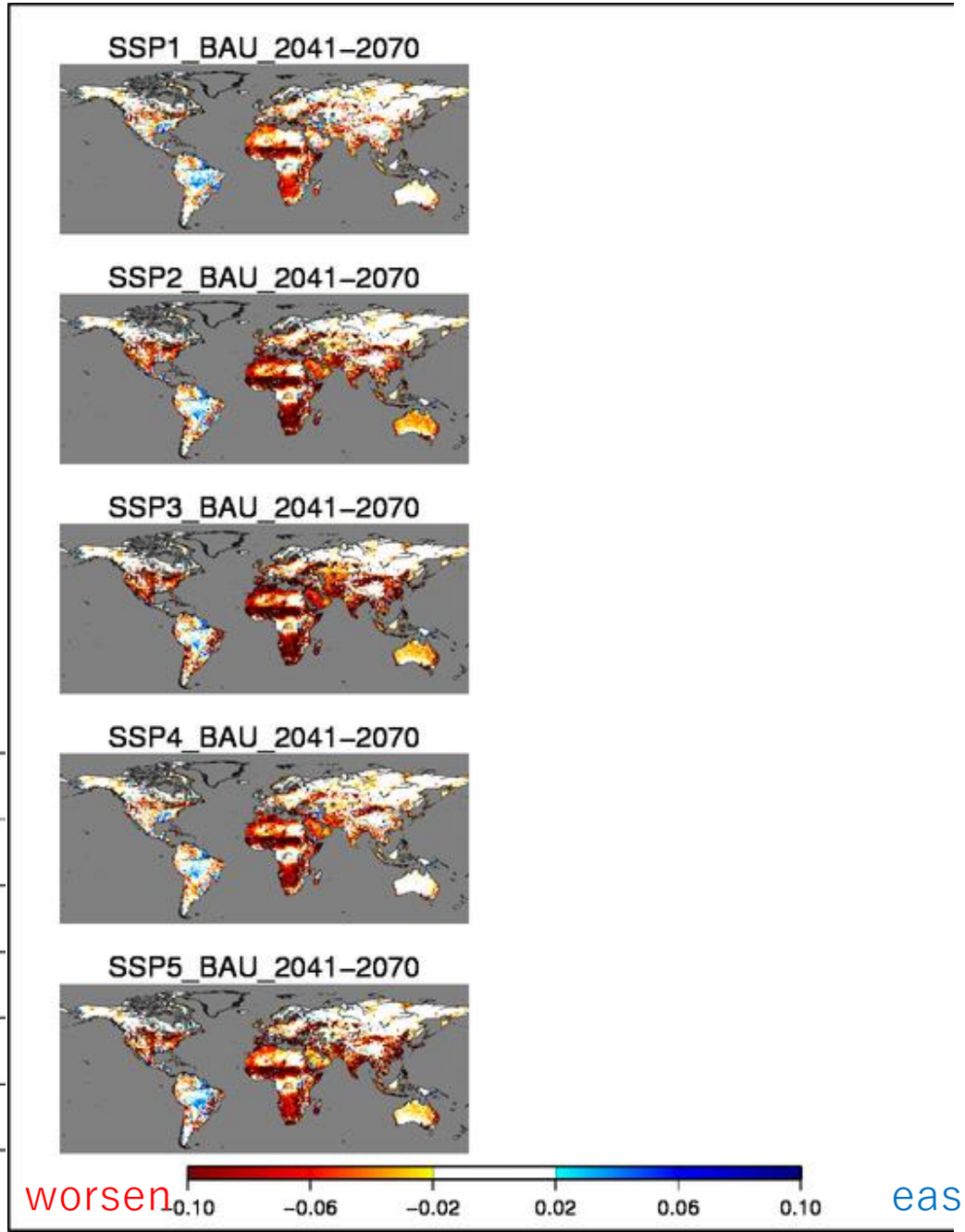
SSP	Description of the world
SSP1	Sustainability
SSP2	Middle of the Road
SSP3	Fragmentation
SSP4	Inequity
SSP5	Conventional Development

Water stressed population
(Population living in grid cells with water stressed regions)



BAU (No stringent GHG emission reduction)

With stringent GHG emission reduction



Hanasaki et al. 2013ab, HESS

Part 2:
Frontiers of Water-Energy Nexus studies

Water-energy Nexus

Water-Energy Nexus

- Water for energy production
- Energy for water supply/treatment

- Usually, the nexus is hardly noticed.
- It emerges in some extreme events. (e.g. Heatwave in Europe in 2003)
- Climate change will increase the intensity & frequency of extreme events.

Climate change and W-E Nexus

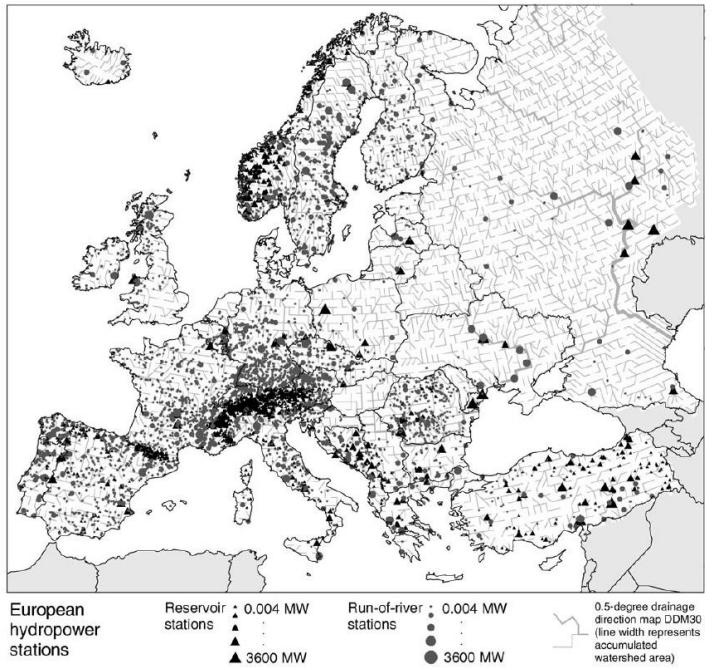
- Hydropower
  - Streamflow
- Thermoelectric cooling
  - Streamflow
  - Stream temperature (environmental regulation)
- Irrigation for bioenergy crop
  - Water availability
  - Irrigation water requirement
  - Yield response to water

Progress of Hydropower W-E Nexus Studies

Step 1: Estimation of Theoretical Hydropower Potential (THP)
Step 2: Estimation of Economically Exploitable Capability (EEC)
Step 3: Integrated assessment (hydrology + energy economic models)

Lehner et al. 2005, Clim Chang

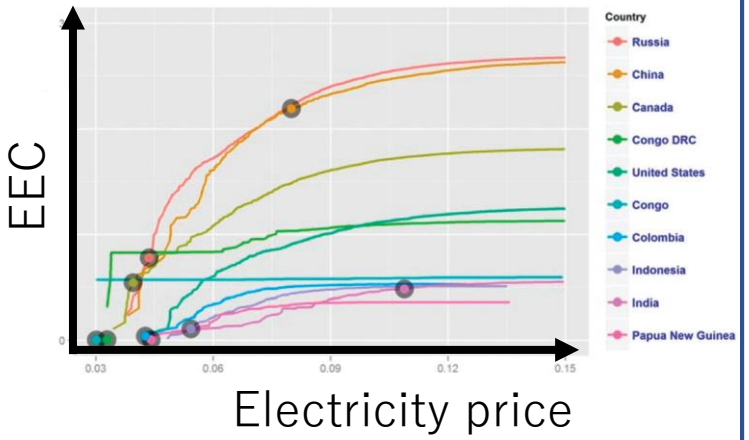
Estimating THP from global hydrological model



Zhou et al. 2015, EES

Estimating EEC from dam construction cost

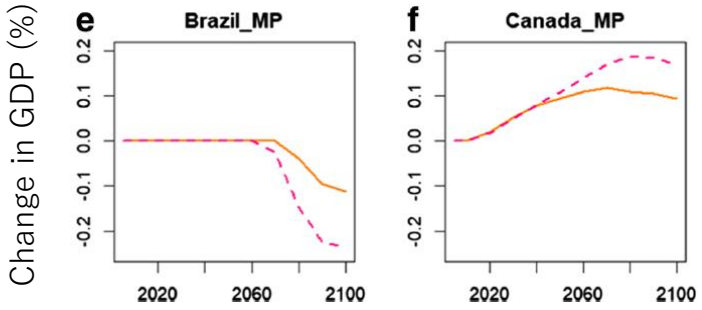
EEC increases by electricity price



Zhou et al. 2018, Clim Chang

Economic consequence of THP change

Economic impact in Brazil and Canada estimated by a computable general equilibrium model



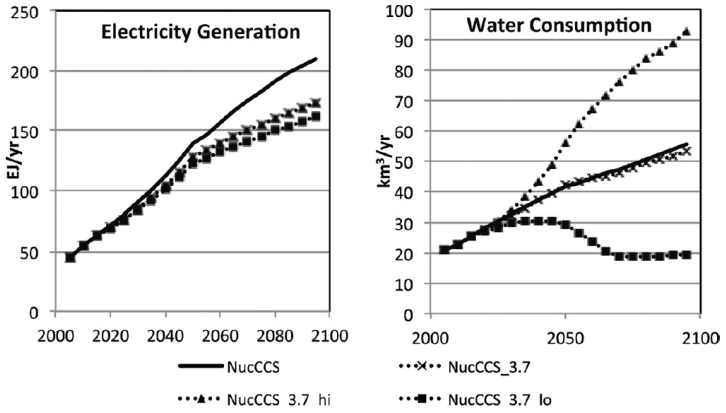
Progress in Thermoelectric cooling W-E Nexus Studies

Step 1: Estimation of cooling water demand (energy-economic perspective)
Step 2: Estimation of cooling water availability (under streamflow and temperature constraint)
Step 3: Integrated assessment (hydrology + energy economic models)

Kyle et al. 2013, IJGGC

Cooling water demand estimation considering technological options

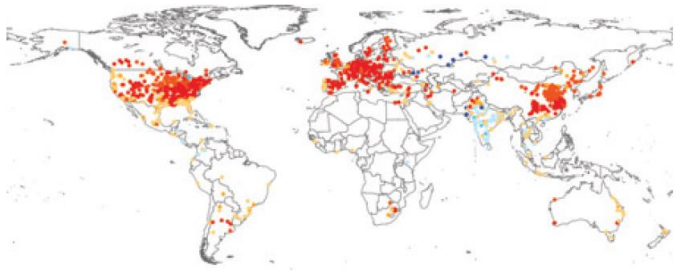
Electricity generation and water consumption



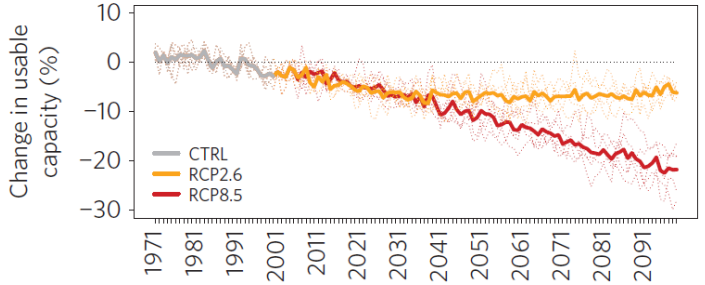
Van Vliet et al. 2016, NCC

Cooling water availability using hydrological model

Cooling water requirement



Change in usable capacity



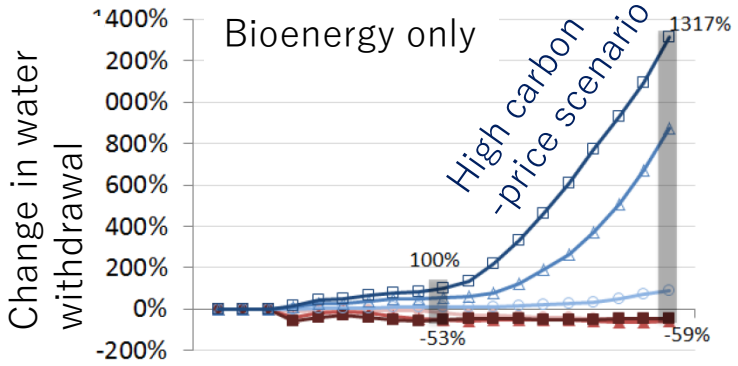
Step 3 forthcoming

Progress in Bioenergy W-E Nexus Studies

Step 1: Estimate irrigation water demand for bioenergy (energy-economic perspective)
Step 2: Estimate irrigation water demand for bioenergy (hydro-agronomical perspective)
Step 3: Trade-off analysis among planetary boundary components

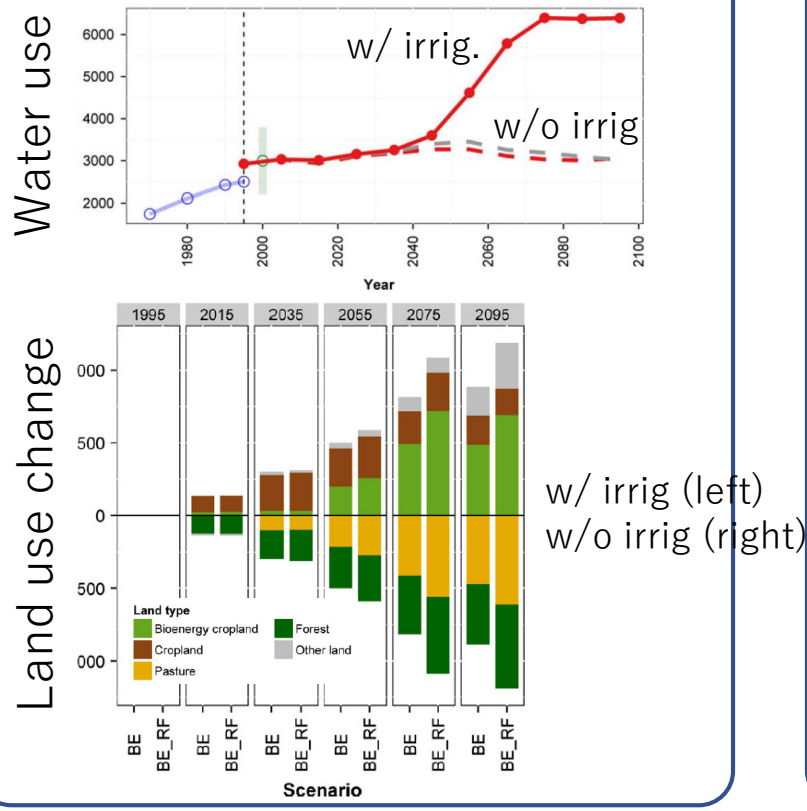
Hejazi et al. 2014, HESS

Irrigation water would be inflated when carbon price was high



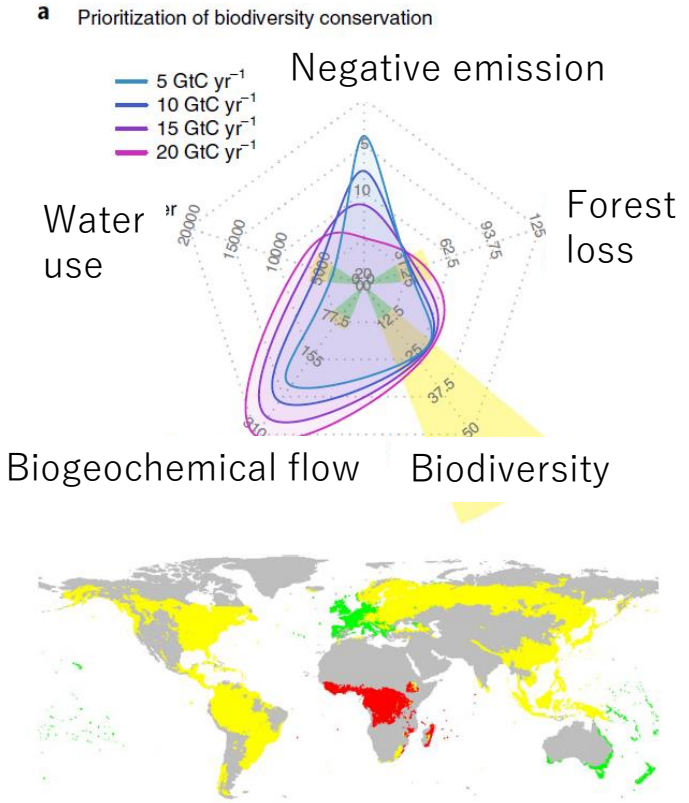
Bonsch et al. 2016, GCB

Land saving by irrigation



Heck et al. 2018, NCC

Planetary Boundary



Summary

Frontiers remain but progress is being made

- **Hydrological modeling**
  - Latest models deal with multiple water sources and water use sectors
  - High spatio-temporal resolution outlines the key causes of water scarcity

- **Water scarcity assessment**
  - Latest assessments use shared socioeconomic pathways
  - General increase in water stress under all scenarios
  - Socioeconomic effects outweighs climate effects (scenario-dependent)

- **Water-energy nexus**
  - Excellent studies from either/both energy-economic and hydrological perspectives
  - Climate change could magnifies the nexus

Thank you for your attention

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