Land, water and ecosystem nexus for climate risk management

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6th Dec 2013, ICA-RUS workshop

Contents

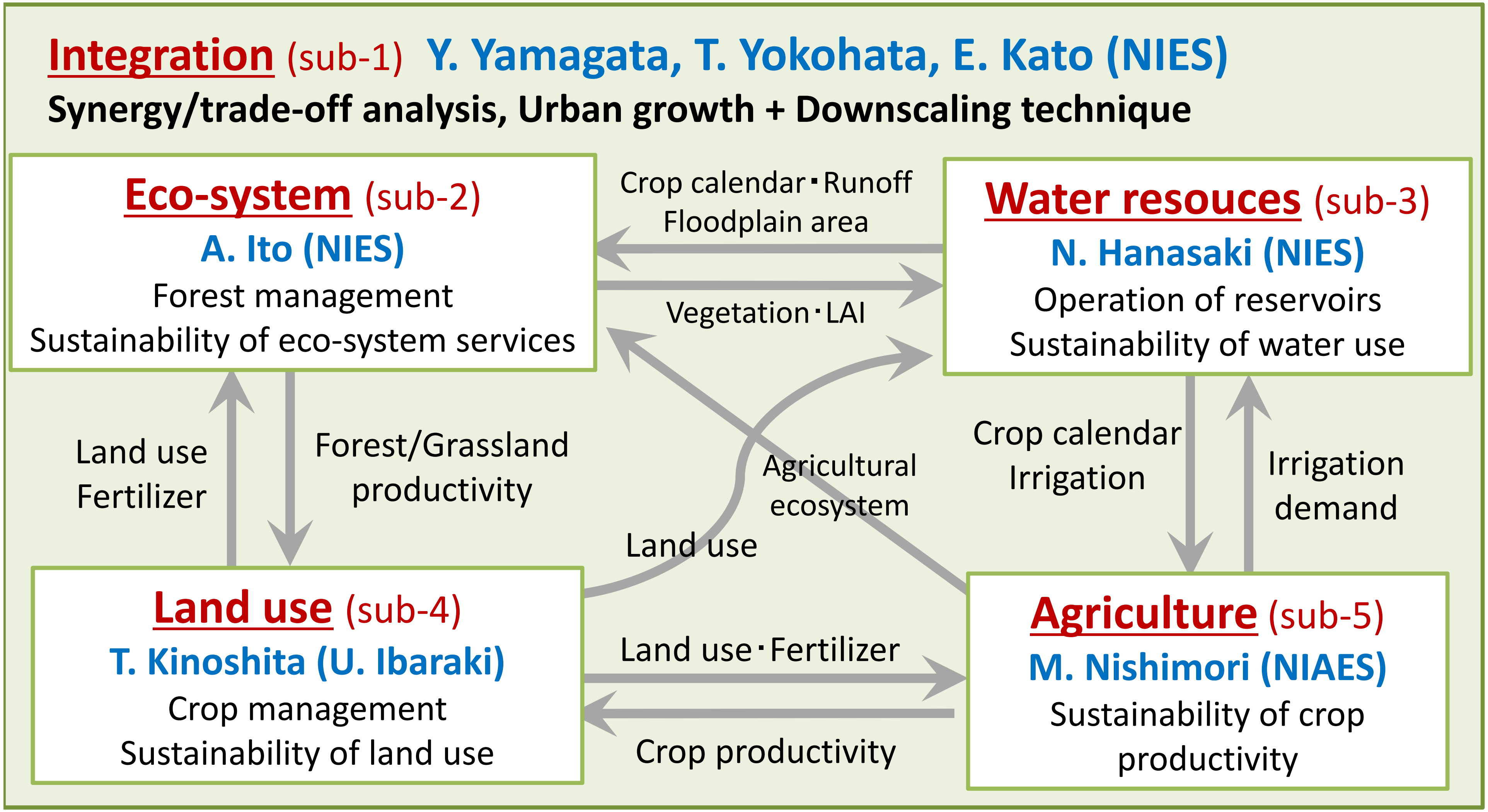
- **<u>Background, scope and objective</u>**
  - **Land-Water-Ecosystem “nexus” approach**
- **<u>Status and key findings</u>**
  - **Land**: Land use change, down scaling
  - **Water:** Future water scenario, water scarcity
  - **Ecosystem:** Model uncertainty, global crop yield
- **<u>Challenges for the future</u>**

Land, water, ecosystem "nexus"

- **Land**
  - A basis for **human life** (agricultural/urban area) and **ecosystem** (forest etc)
  - Land use change affects/controls **climate change**
- **Water**
  - Used for **food** (agriculture etc), **energy**, and **human life**
  - Water resources is affected by **climate change**
- **Ecosystem**
  - Provides **food** (agriculture etc) as well as **energy** (bio crop)
  - Ecosystem (vegetation etc) affects/controls **climate change**

"Nexus approach" (trans-sectoral, multi-scales) is essential for climate risk management

Our “nexus” approach



Model input: Socio-economic scenario (RCP, SSP etc.), climate scenario (CMIP4/5)

Population, GDP, future “story-line”, changes in climate (temperature, precipitation etc)

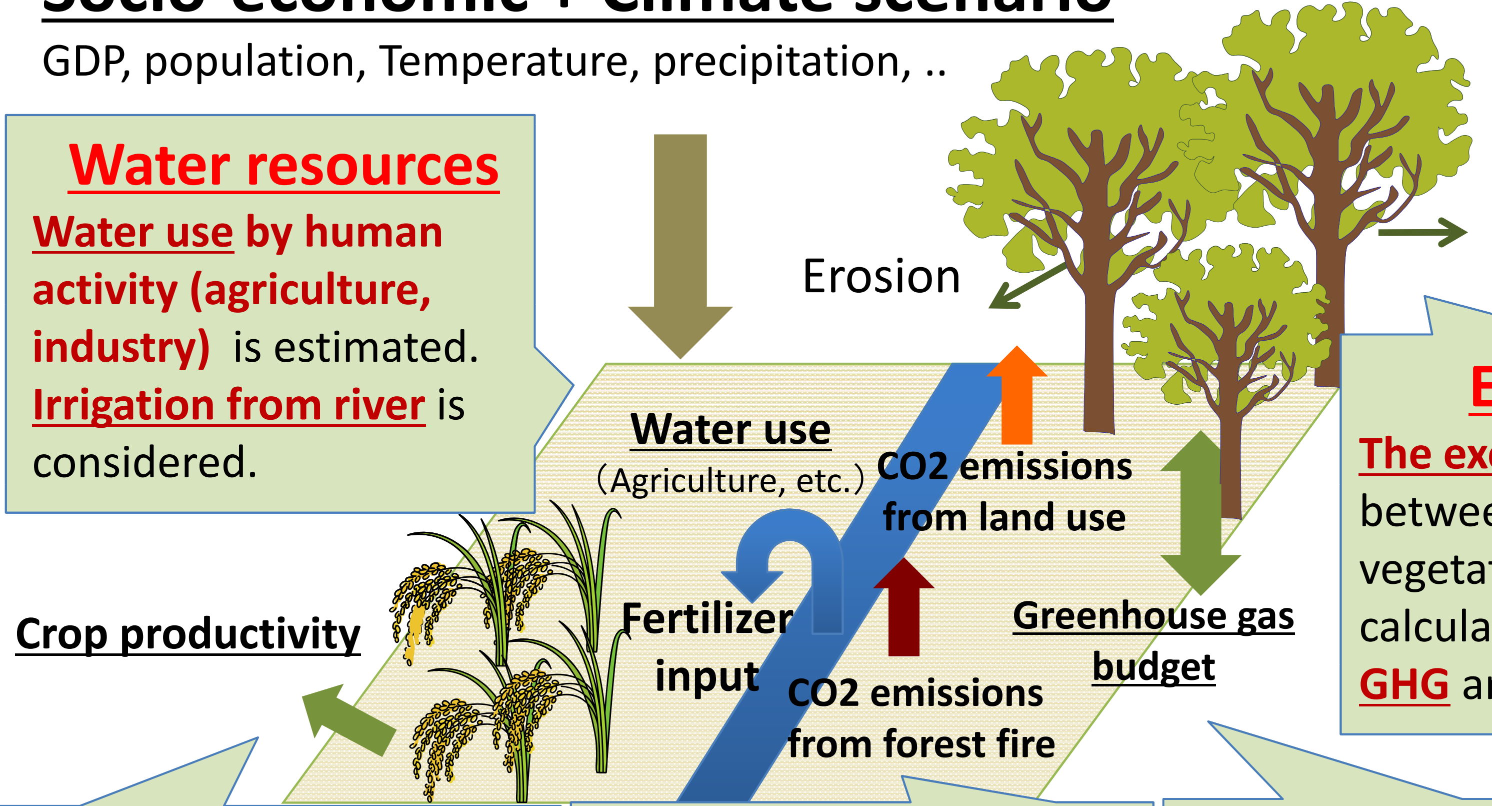
Objectives

- **Low-carbon scenario?**
  - Sustainability of intensive mitigation/adaptation options, such as **negative emission?**
  - **Potential of future Bio-Energy Carbon Capture and Storage (BECCS) and 2 degree target: by E. Kato**
- **Business as usual (high-carbon) scenario?**
  - Interaction between land, water, ecosystem?
  - "Climate Boundary": how resilient are we?
- **Development of models and data-bases**
  - Coupling of land-water-ecosystem models

Development of "Integrated terrestrial model"

Socio-economic + Climate scenario

GDP, population, Temperature, precipitation, ..



Water resources

Water use by human activity (agriculture, industry) is estimated. Irrigation from river is considered.

Eco-system

The exchange of C and N between atmosphere-vegetation-soil is calculated. Changes in GHG are estimated.

Agriculture

Crop productivity is estimated . The production of bio-energy crop for mitigation option is considered.

Land（MATSIRO）& Climate（MIROC）

Soil water, temperature are calculated based on the water-energy budget.

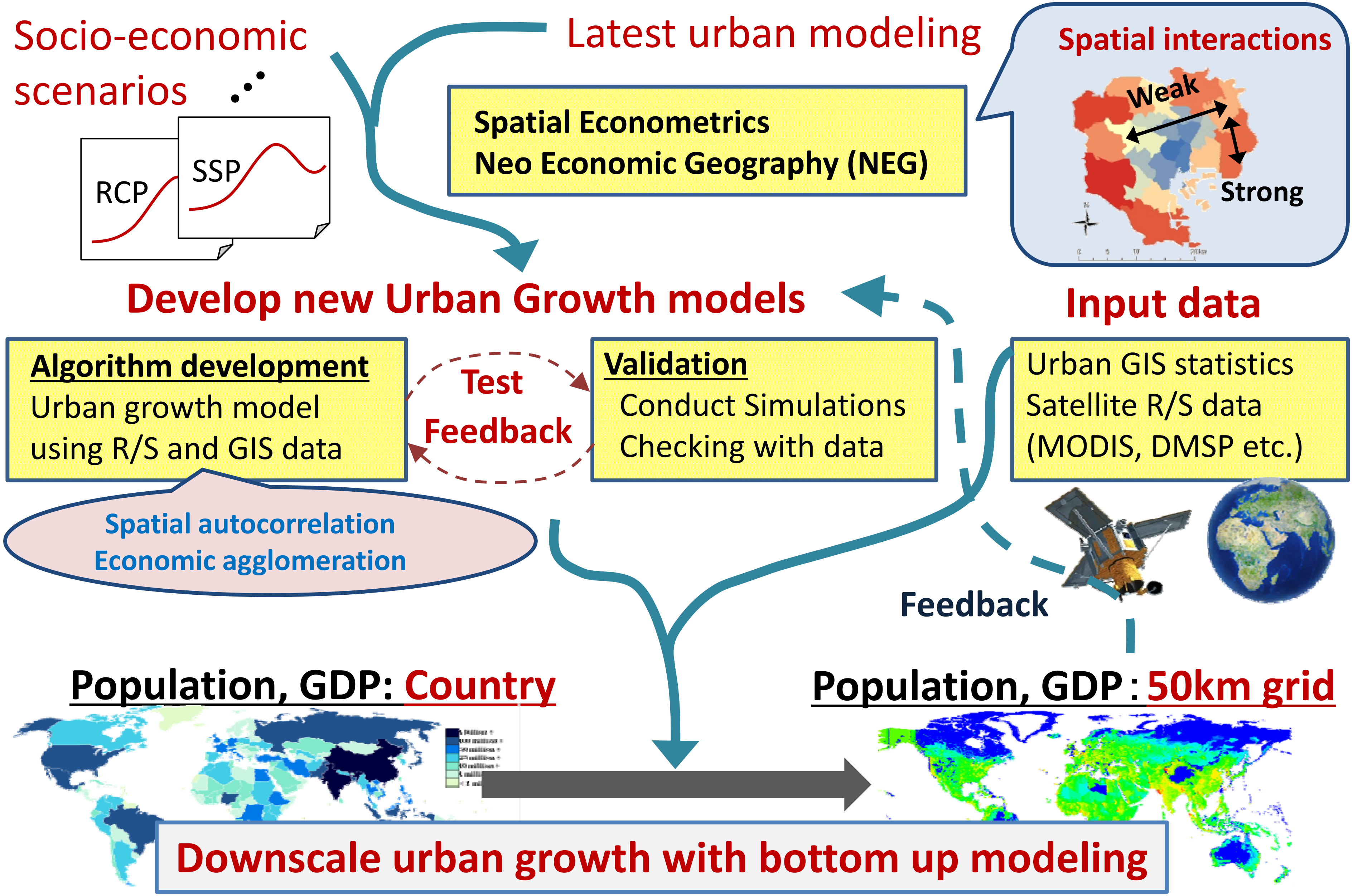
Land use

Land-use change (cropland-forest) is calculated based on future socio-economic scenarios. Economic (e.g., trade) +natural (e.g. inclination) factors are considered.

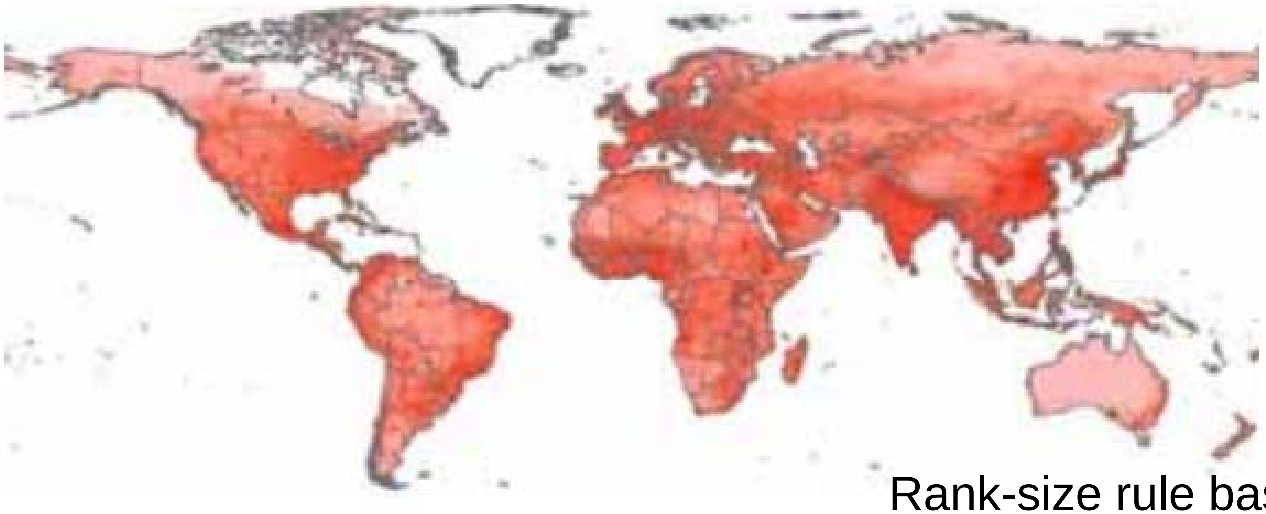
Land

Modelling of land use change,
Development of down scaling method

Spatially explicit urban growth model

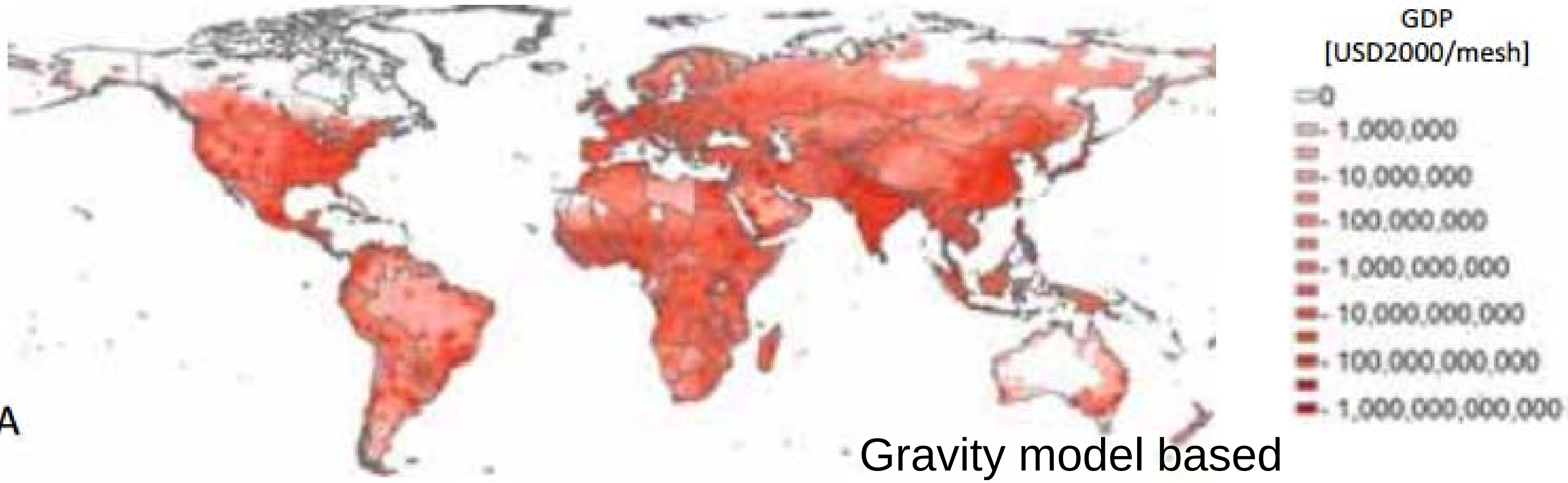


Creation of future gridded population and GDP of the world



NIES

Rank-size rule based



IIASA

Gravity model based

Database for gridded population

Table 1 Gridded population datasets and their characteristics

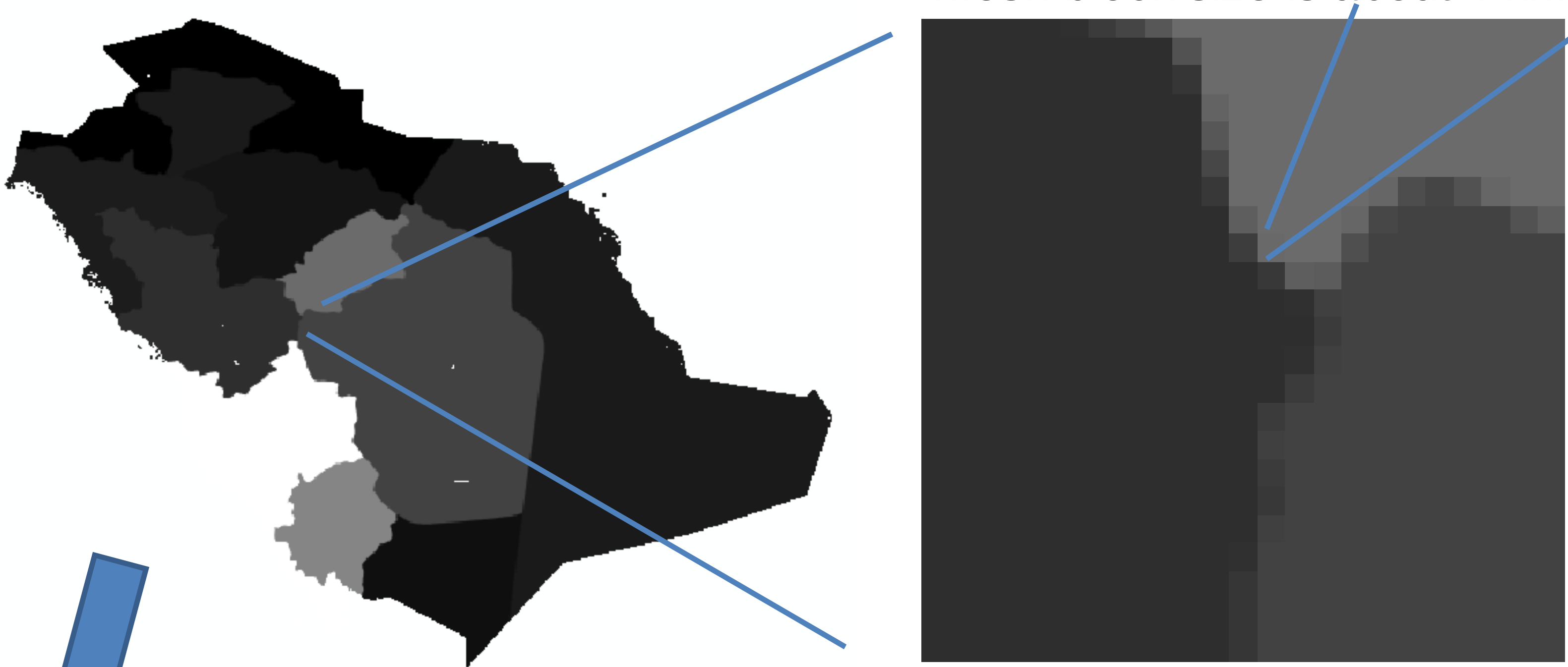
Dataset	Year(s) represented	Spatial resolution	Input data used	Data source for national pop total adjustments	Source
LandScan	2008	30 arcseconds (~1 km)	Census, land cover, elevation, slope, roads, populated areas/ points	CIA [23]	[11]; http://www.ornl.gov/sci/landscan/
Gridded Population of the World (GPW)	1990/1995/ 2000/2005/ 2010/2015	2.5 arcminutes (~5 km)	Census, water bodies (for masking)	UNPD [22]	[12]; http://sedac.ciesin.columbia.edu/gpw/global.jsp
Global Rural Urban Mapping Project (GRUMP)	1990/1995/ 2000	30 arcseconds (~1 km)	Census, populated areas, water bodies (for masking)	UNPD [22]	[13]; http://sedac.ciesin.columbia.edu/gpw/global.jsp
United Nations Environment Programme (UNEP) Global Population Databases	2000	2.5 arcminutes (~5 km)	Census, populated points, roads	UNPD [22]	[14]; http://na.unep.net/siouxfalls/datasets/datalist.php

Tatem, A. J., Campiz, N., Gething, P. W., Snow, R. W., & Linard, C. (2011). The effects of spatial population dataset choice on estimates of population at risk of disease. *Population health metrics*, *9*(1), 4.

➡ Population Count Grid v3（PCGv3）by SEDAC is freely available, and most widely used.

Problem of SEDAC population database

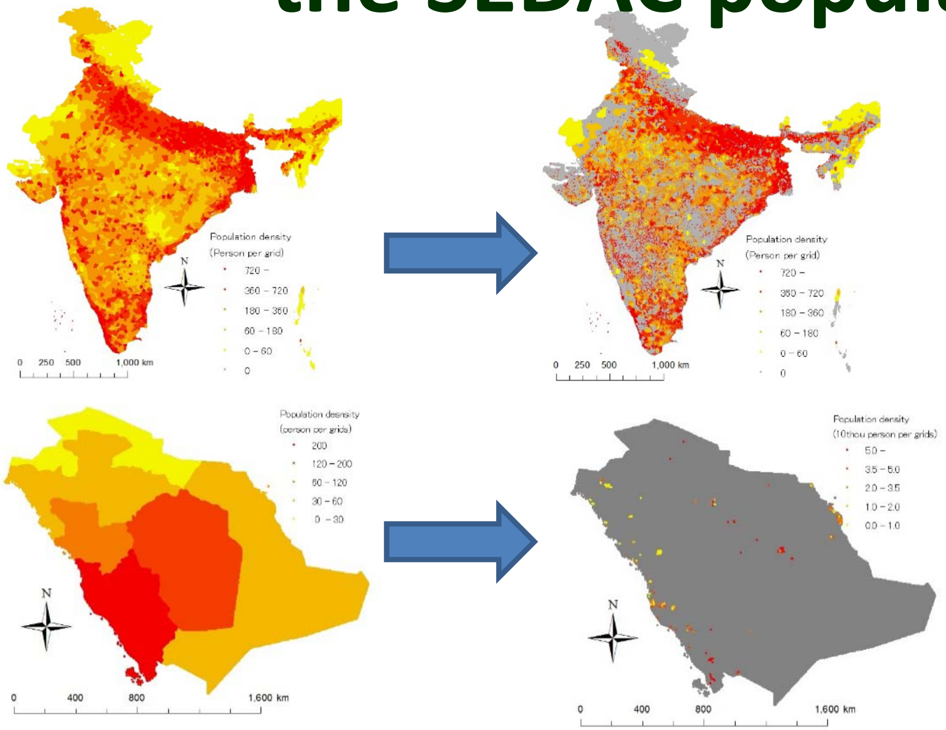
Mesh block size is about 4 km x 4km



Saudi Arabia, 2000

Creating using areal weighting, and overly smoothed. First of all, we have tried to build a spatial statistical model to refine this data set.

New method application to the SEDAC population database



New spatial statistical downscaling method

Yamagata, Seya, and Murakami (2013)

$$\hat{\boldsymbol{y}} = \boldsymbol{\mu} + \boldsymbol{N}'(\boldsymbol{N}\boldsymbol{N}')(\bar{\boldsymbol{y}} - \boldsymbol{N}\boldsymbol{\mu})$$

$$[\boldsymbol{\mu}]_i = [\boldsymbol{x}_i' \ \boldsymbol{\beta}_i]$$

$$\hat{\boldsymbol{\beta}}_i = (\bar{\boldsymbol{X}}_i'(\boldsymbol{N}\boldsymbol{N}')^{-1}\bar{\boldsymbol{X}}_i)^{-1}\bar{\boldsymbol{X}}_i'(\boldsymbol{N}\boldsymbol{N}')^{-1}\bar{\boldsymbol{y}}_i$$

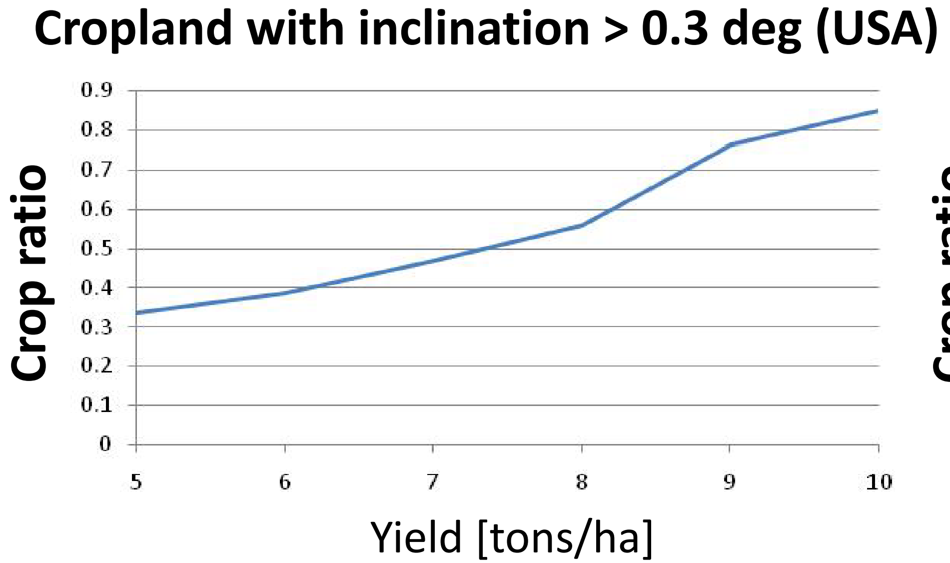
$$s.t. \quad \boldsymbol{N}\boldsymbol{y} = \bar{\boldsymbol{y}} \quad \hat{\boldsymbol{y}} > \boldsymbol{0}$$

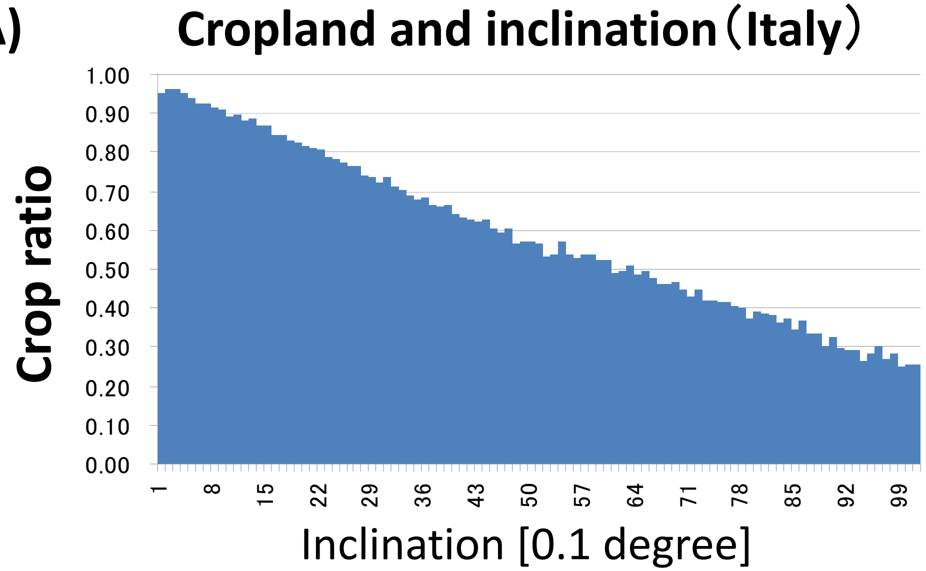
	Explanatory variable	Spatial autocorrelation
Areal weighting	Area	×
Allocation by land use	Land use	×
ArcGIS10.2 (A-to-P kriging)	NA	○
Regression based	Arbitrary (possibly plural)	×
New method	**Arbitrary (possibly plural)**	○

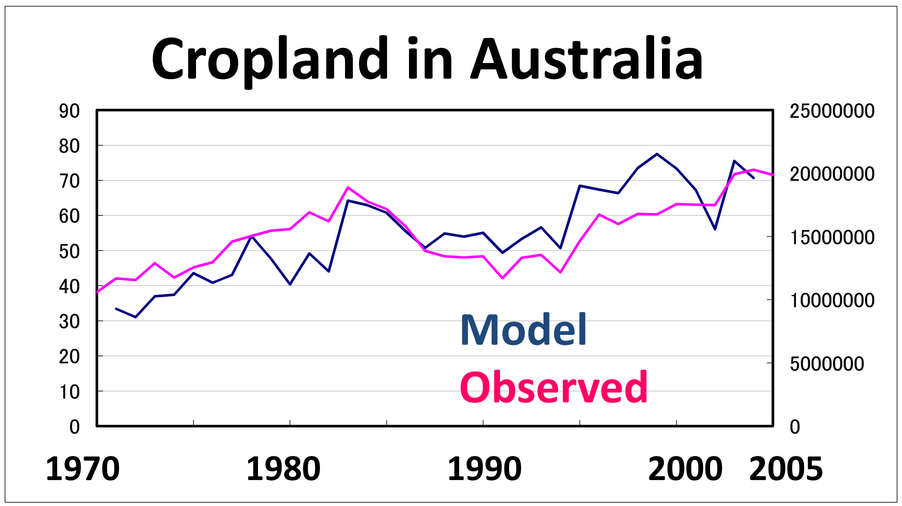
Using PCGv3 Without refinement may leads to biased results, including future estimates.

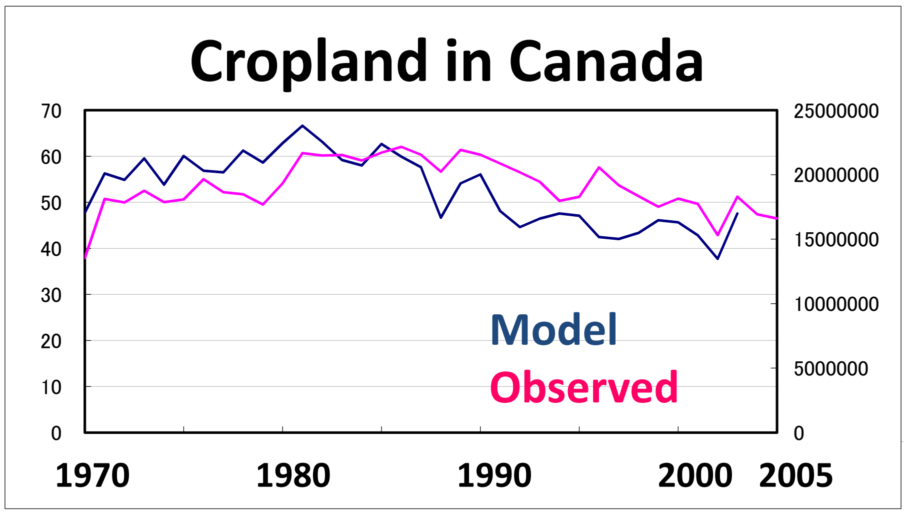
Our new method drastically improve the downscaling accuracy.

Land use model: Constraint by yield, inclination









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Water

Future scenario of water use,
water scarcity

Global water scarcity assessment

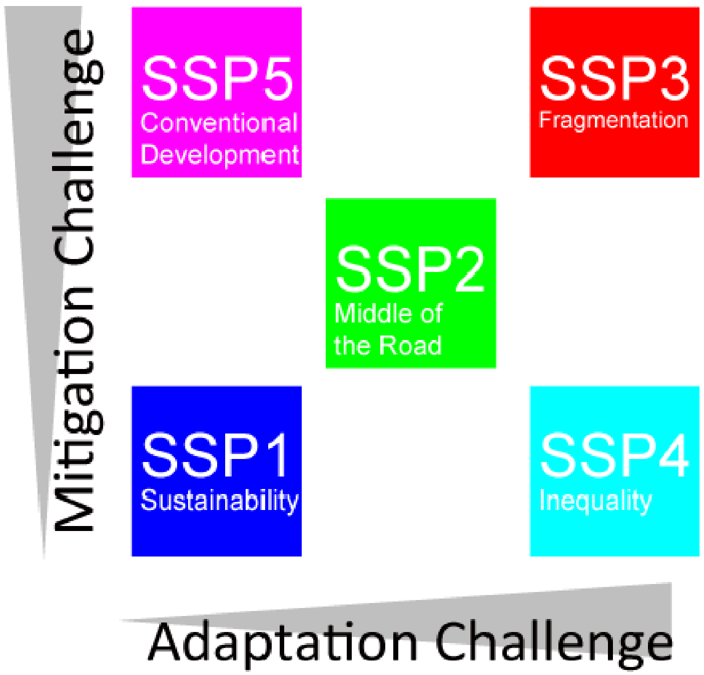
Global hydrological model with human activities

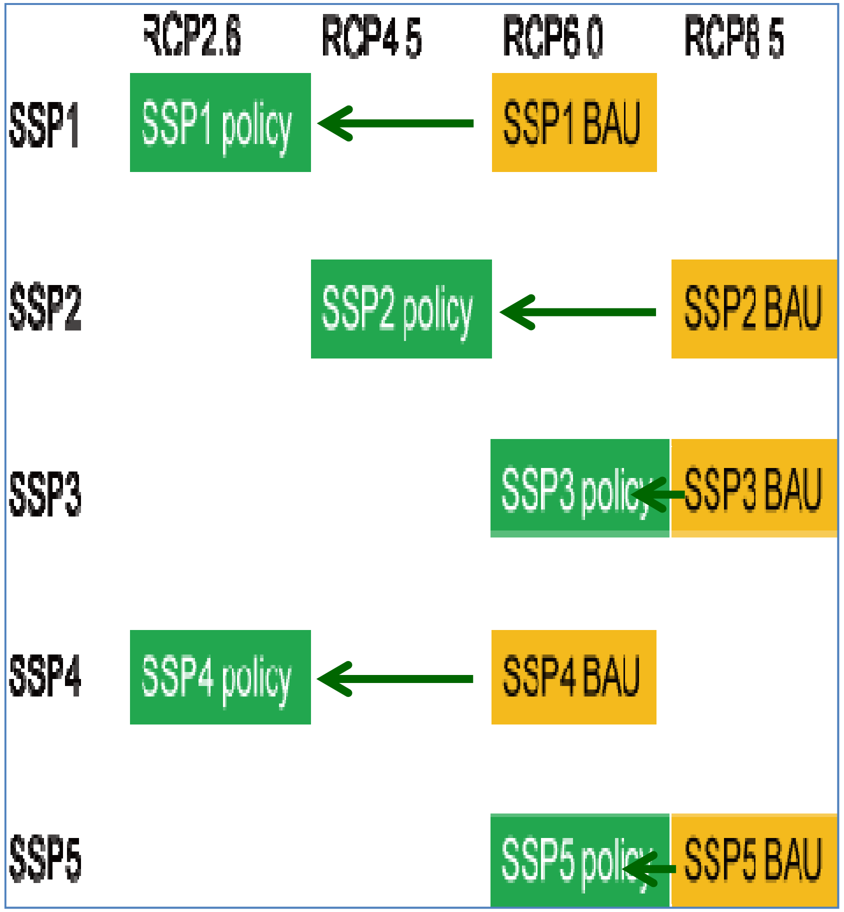
H08 An open source global hydrological model with human activities

SSP: Shared Socioeconomic Pathways

- SSP is **a global socio-economic scenario,** the successor of SRES. **Five different views of the world** are depicted.
- SSP doesn't include scenarios on water. We developed **a compatible water use scenario**.

We also **developed a scenario matrix of SSP and RCP.** We analyzed the results **with/without climate policy.**

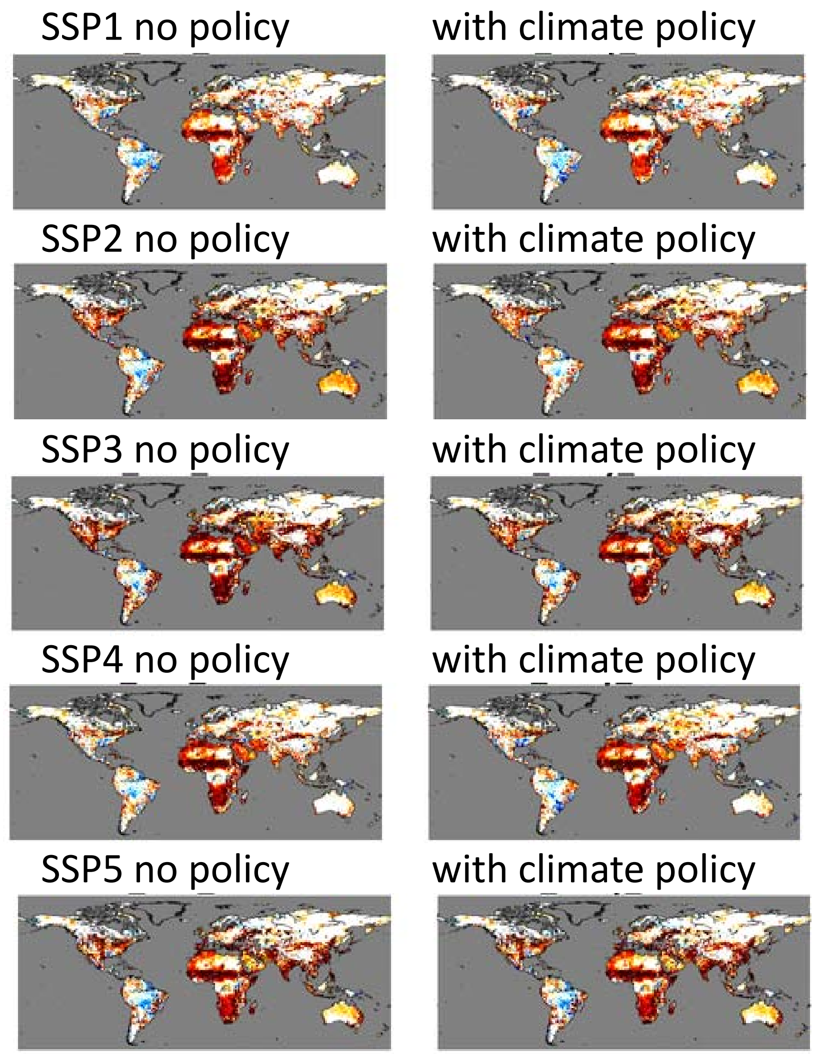




Hanasaki et al. 2013a,b,
Hydrology and Earth System Sciences

Global water scarcity assessment

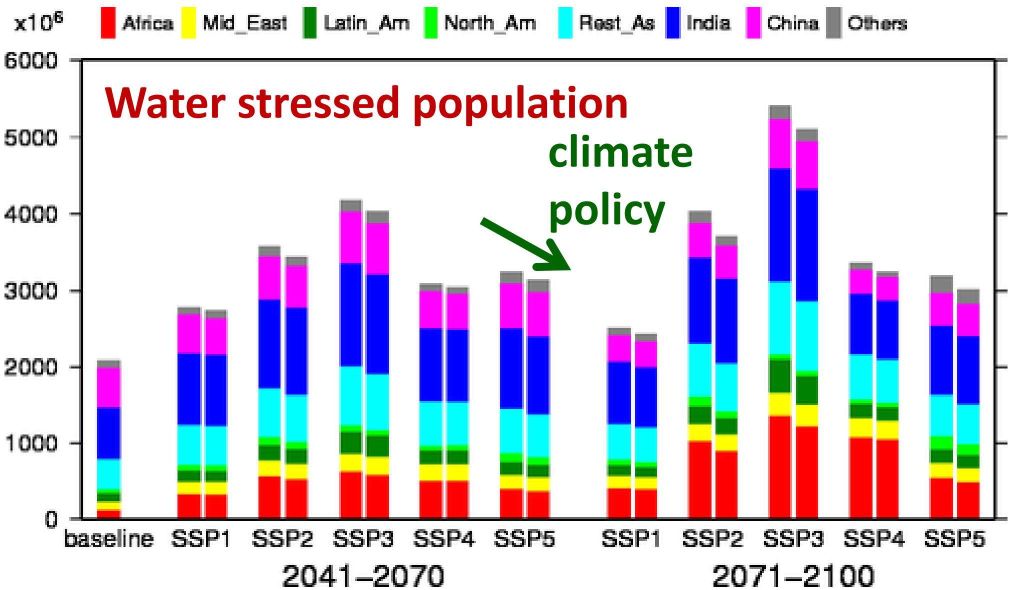
2041-2070, difference from present



Water stressed population, **RED=worse**

Water resources assessment

- **Water availability and use was simulated** at daily interval, at spatial resolution of 0.5 deg x 0.5 deg.
- **A new index for water scarcity** was used to evaluate whether water is available when it is needed.



- **Ten sets of comprehensive global water scenarios** have been developed.

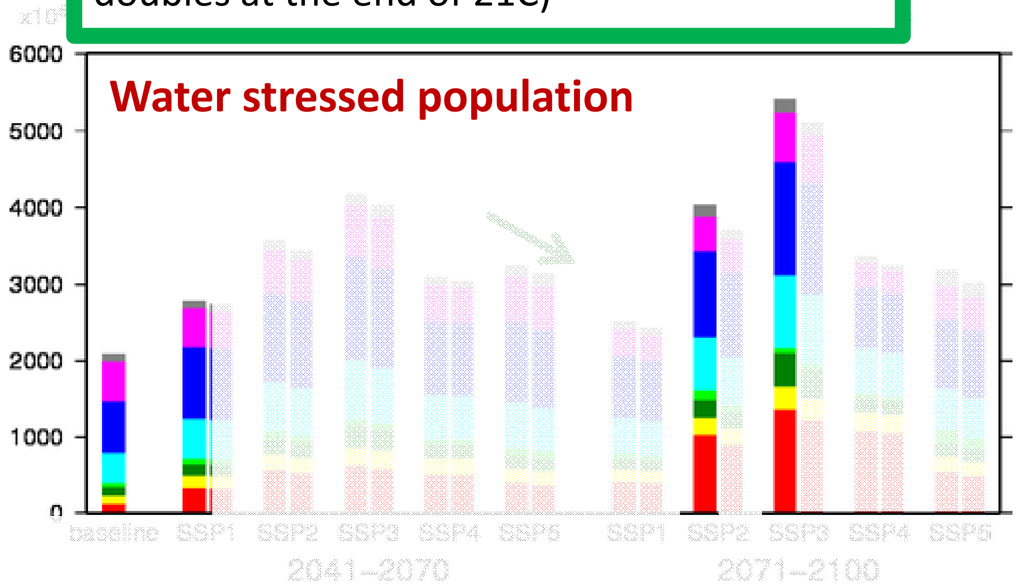
Hanasaki et al. 2013a,b, Hydrology and Earth System Sciences

Global water scarcity assessment

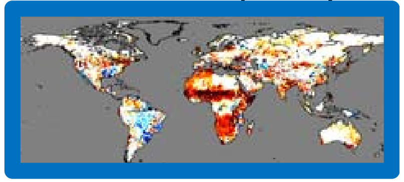
2041-2070, difference from present

Best scenario
-Sustainable society
-Efficient climate policy
-Water stress stabilizes except Africa

BAU scenario
-Middle of the road
-Moderate climate policy
-Water stress increases (stressed population doubles at the end of 21C)



with climate policy



SSP2 no policy

SSP3 no policy

Worst scenario
-Low technological change and low environmental consciousness
- High birth rate and low income
-Water stress heavily increases (stressed population triples at the end of 21C)

- **Ten sets of comprehensive global water scenarios** have been developed.

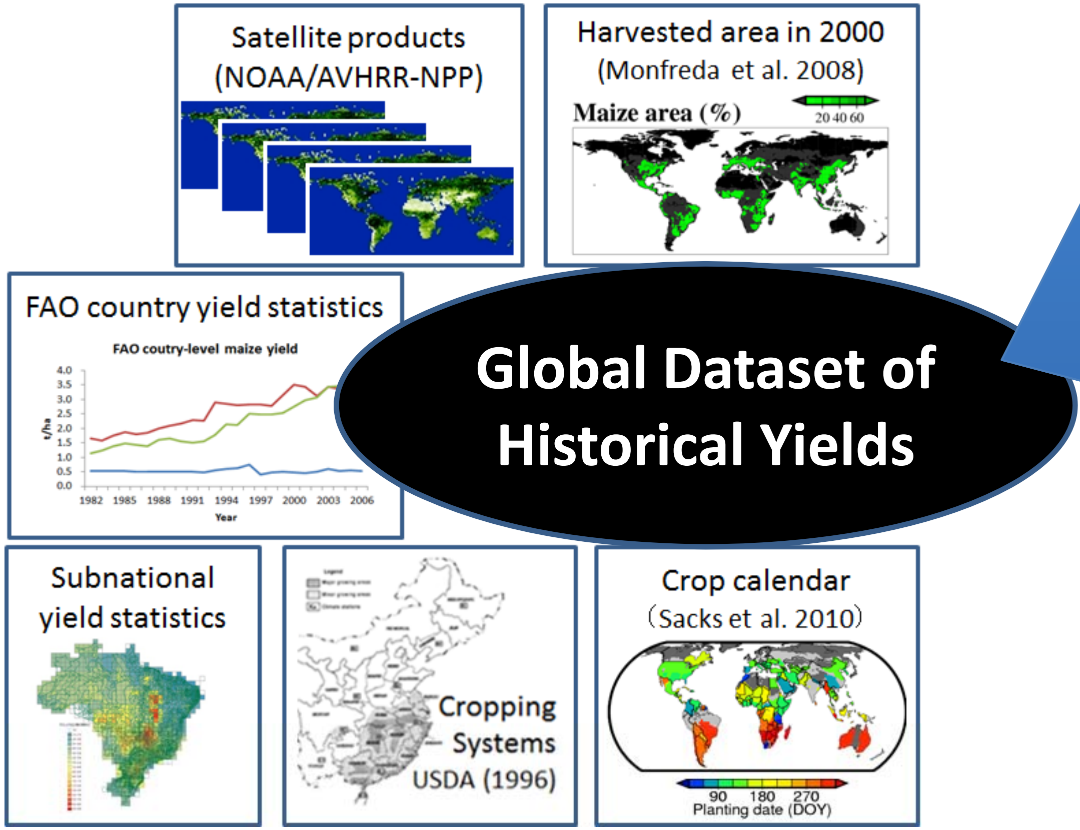
Hanasaki et al. 2013a,b, Hydrology and Earth System Sciences

Ecosystem

Global crop yield and climate change

Uncertainty in ecosystem models

Dataset of historical changes in global yields

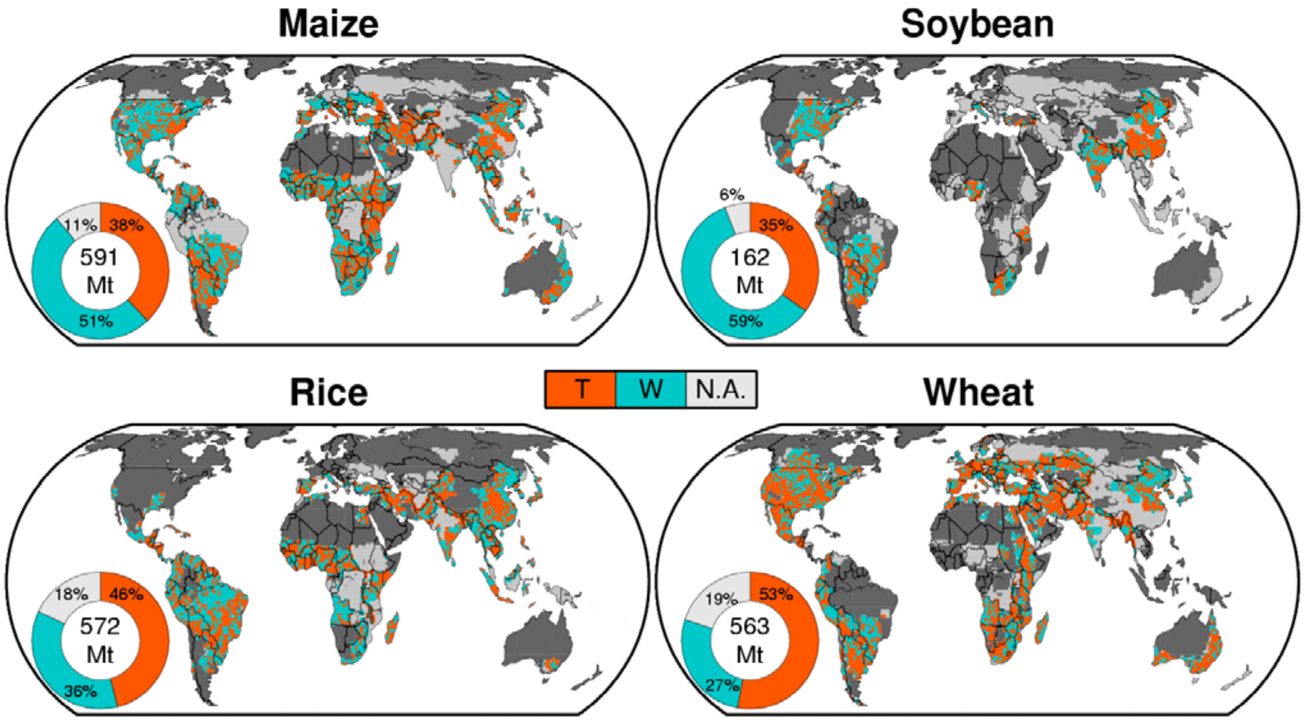


Iizumi *et al.* (2013) *Glob Ecol & Biogeogr*

By combining global agricultural datasets related to crop calendar and harvested area in 2000, country yield statistics, and satellite-derived net primary production

- **During 1982-2006** with **a resolution of 1.125° × 1.125°**
- **Maize, soybean, rice, and wheat**.

Dominant climatic factors affecting year-to-year variations in the yield



$\delta Yield_t =$
$a_1 \Delta T_t + a_2 \Delta W_t + \varepsilon$

Temperature

Soil moisture

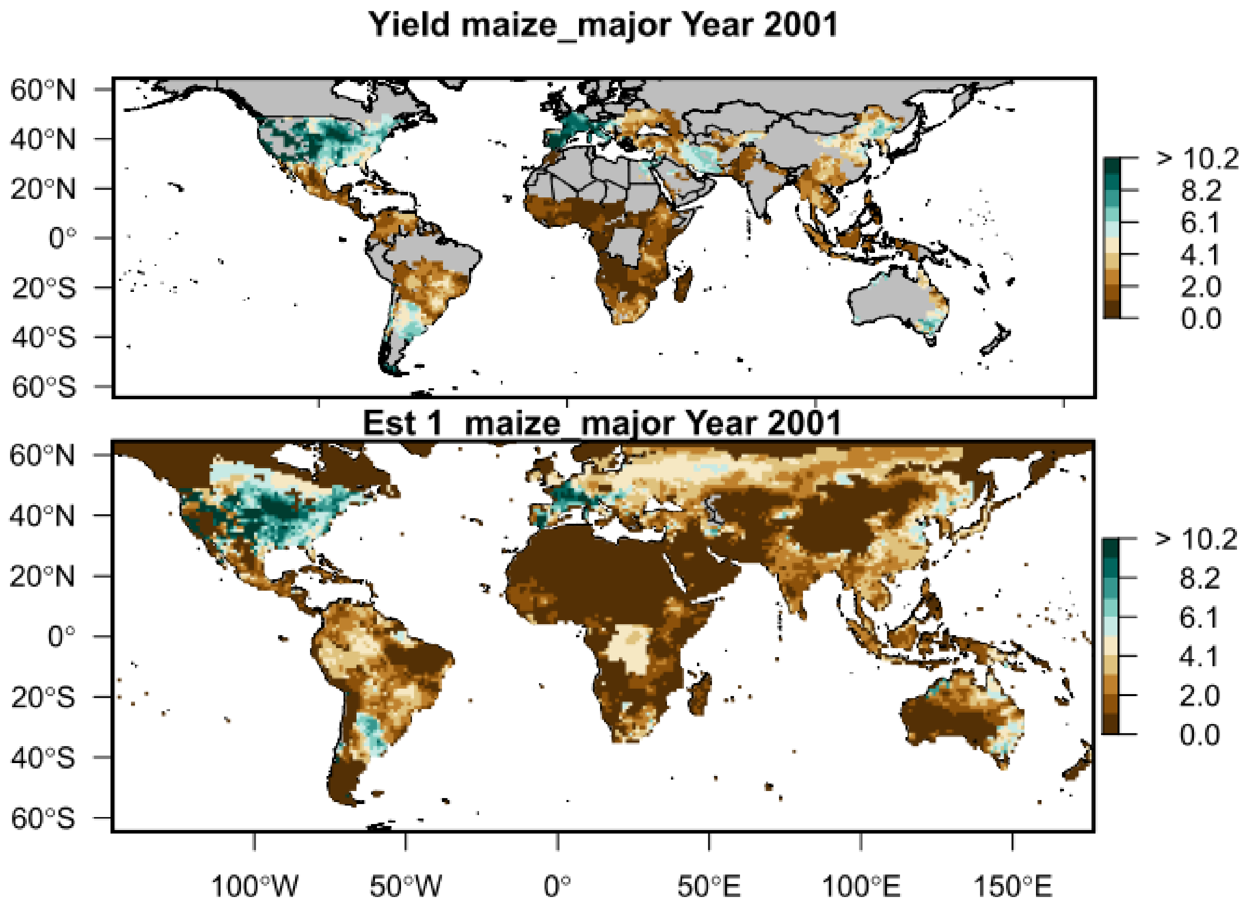
Iizumi *et al.* (2013) *Nature Climate Change*

- **Dominant factors (temperature , soil moisture)** are different among crops and regions.
- **Climatic constrains** -> **Future climate change impacts**

Improved Process-based Regional-scale crop Yield Simulator with Bayesian Inference (PRYSBI2)

Global yield of maize in 2001
(Iizumi et al 2013)

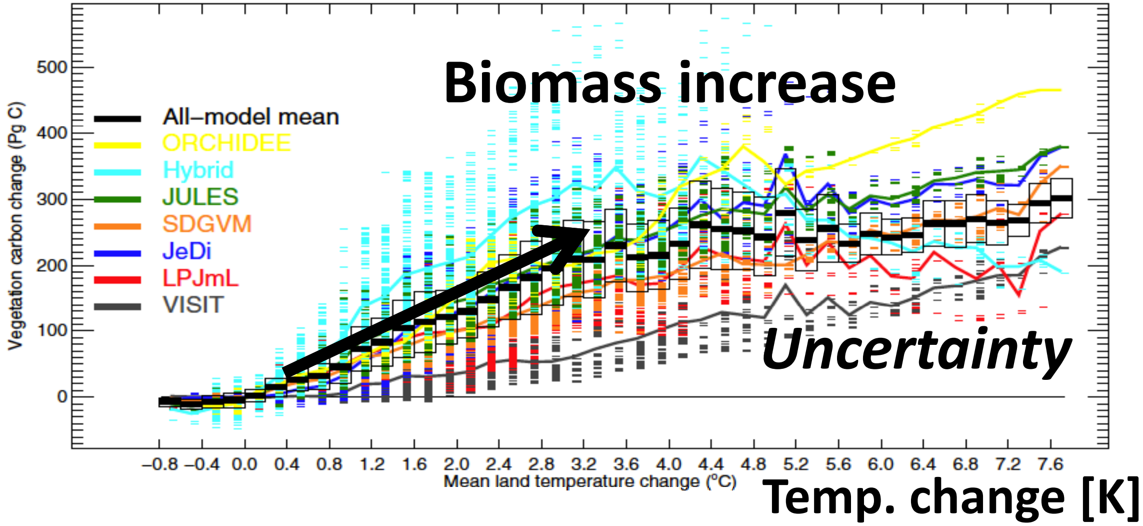
Estimated yield of maize in 2001 By PRISBI2
Calibrated by Even-numbered years



- **Process-based, regional-scale crop model**
- **Predictability for global scale** (maize, soybean, rice, wheat)

Uncertainty in terrestrial ecosystem models

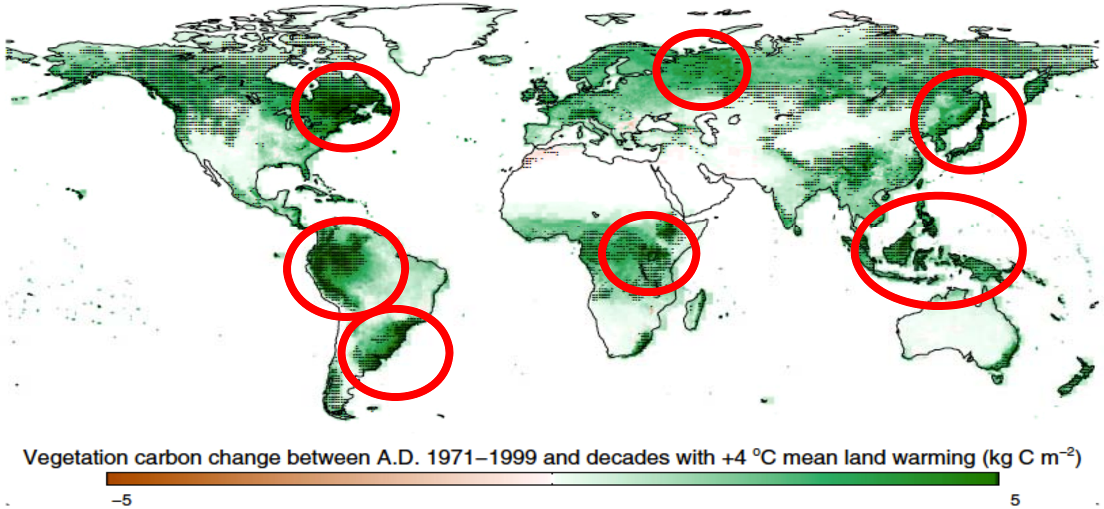
ISI-MIP analysis on carbon response



Contribution to "ISI-MIP":

Inter-sector Impact Model Inter-comparison Project

Hot spots [areas] in carbon change



Friend et al. 2013, in press, PNAS

Impact assessment by

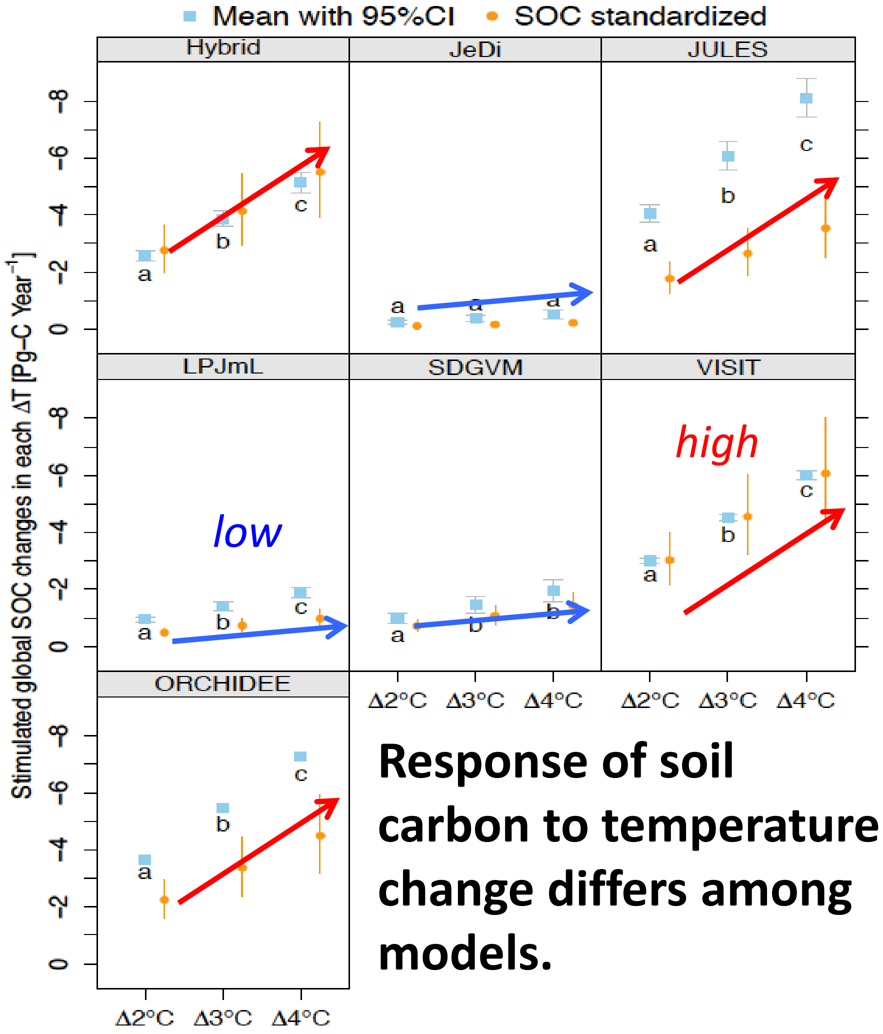
4 RCPs

x 5 climate models

Uncertainties in **socio-economic and climate scenario**

Uncertainty in terrestrial ecosystem models

ISI-MIP analysis on soil carbon response



Response of soil carbon to temperature change differs among models.

Nishina et al. (submitted to Earth System Dynamics)

Future challenges

Coupling of land-water-ecosystem models

Future risks under climate change

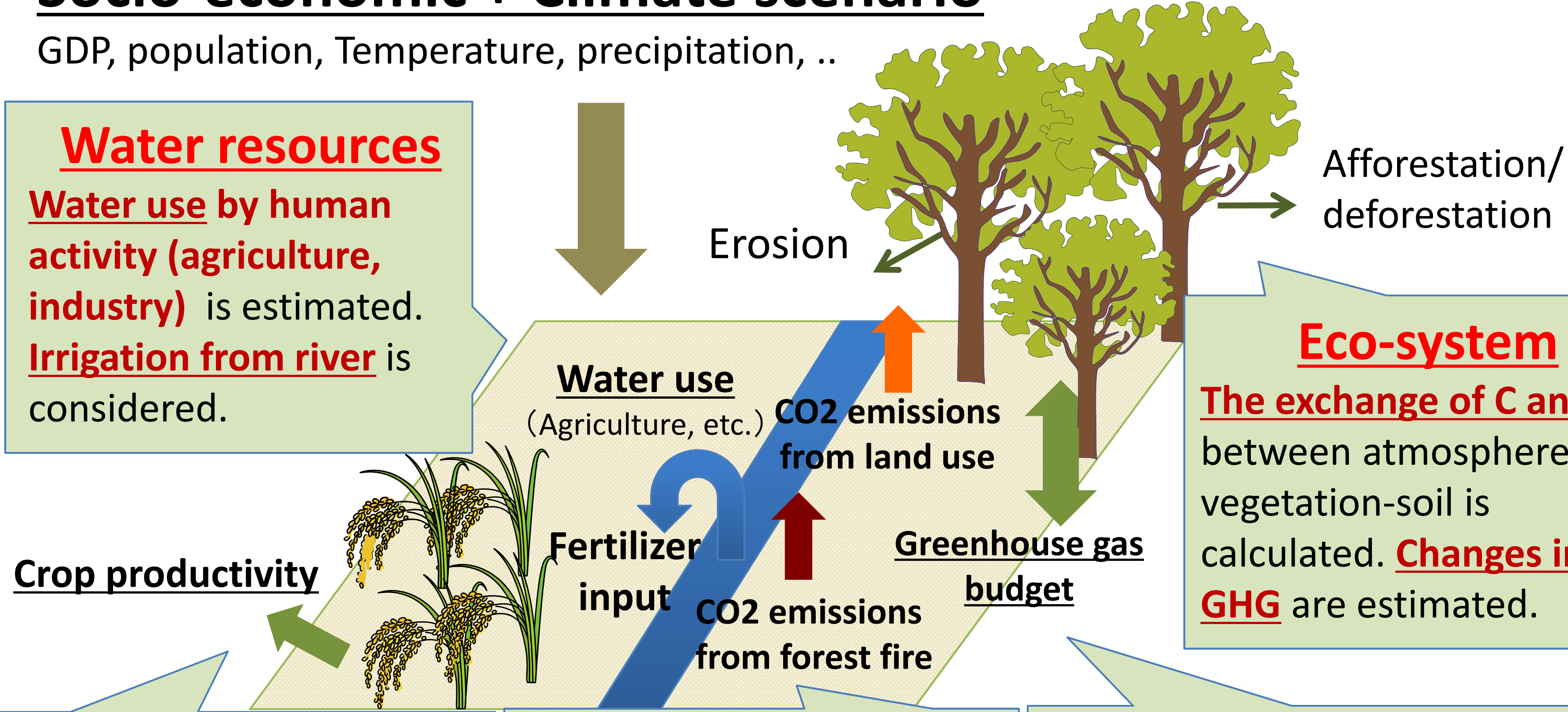
Nexus approach by “Integrated terrestrial model”

Socio-economic + Climate scenario

GDP, population, Temperature, precipitation, ..

Water resources

Water use by human activity (agriculture, industry) is estimated. **Irrigation from river** is considered.



Eco-system

The exchange of C and N between atmosphere-vegetation-soil is calculated. **Changes in GHG** are estimated.

Agriculture

Crop productivity is estimated . **The production of bio-energy crop** for mitigation option is considered.

Land& Climate

Soil water, temperature are calculated based on the water and energy budget. Atmospheric processes (precipitation etc) is option.

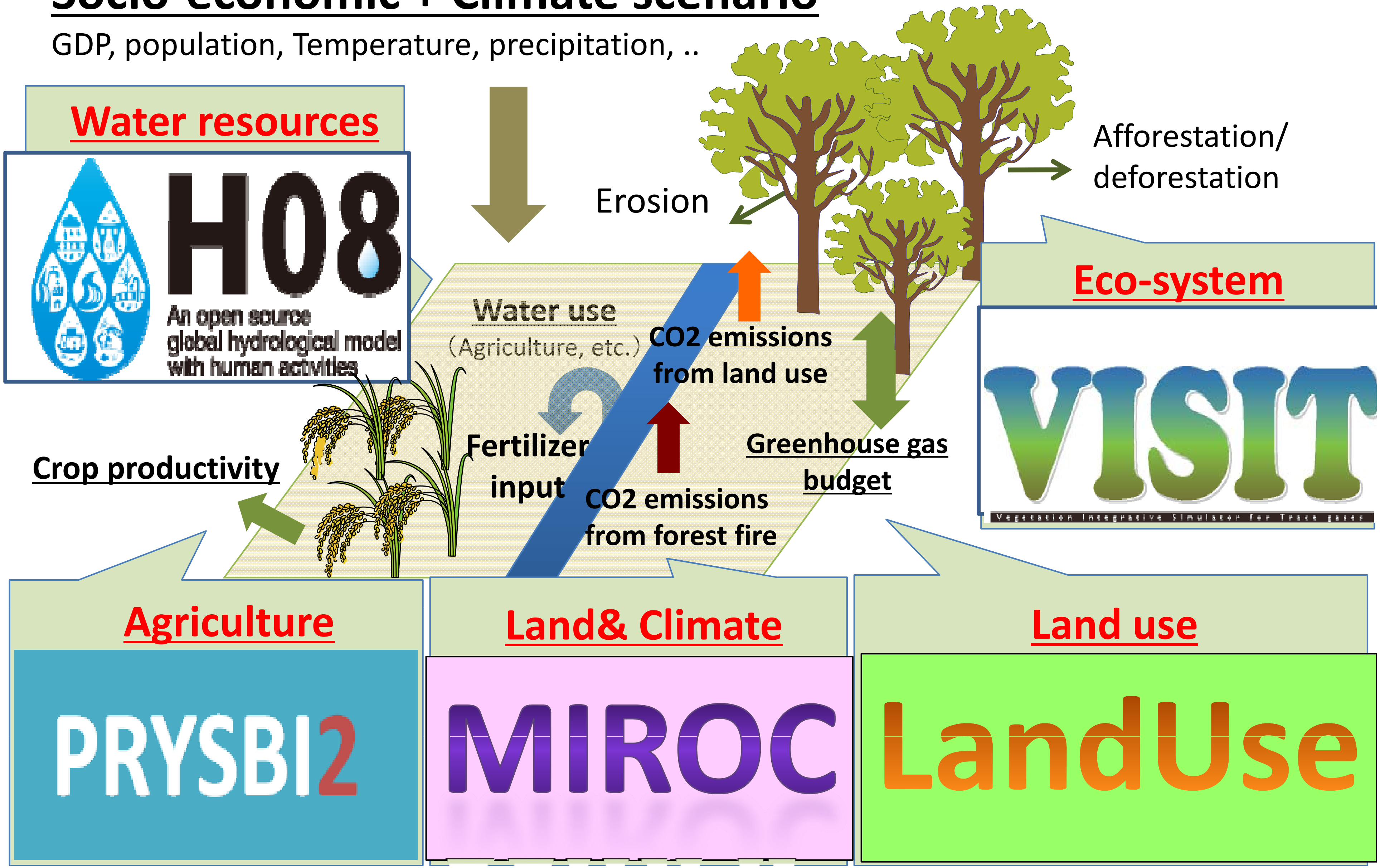
Land use

Land-use change (cropland-forest) is calculated based on future socio-economic scenarios. **Economic (e.g., trade) +natural (e.g. inclination) factors** are considered.

Nexus approach by "Integrated terrestrial model"

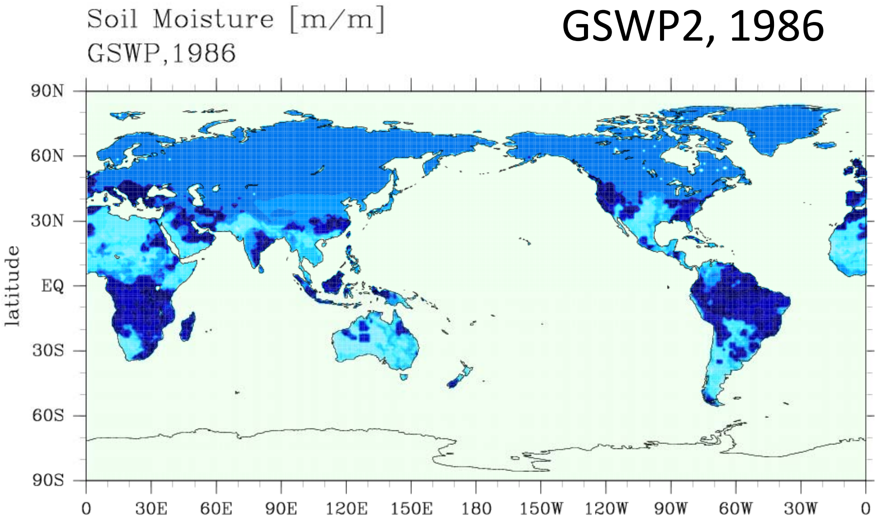
Socio-economic + Climate scenario

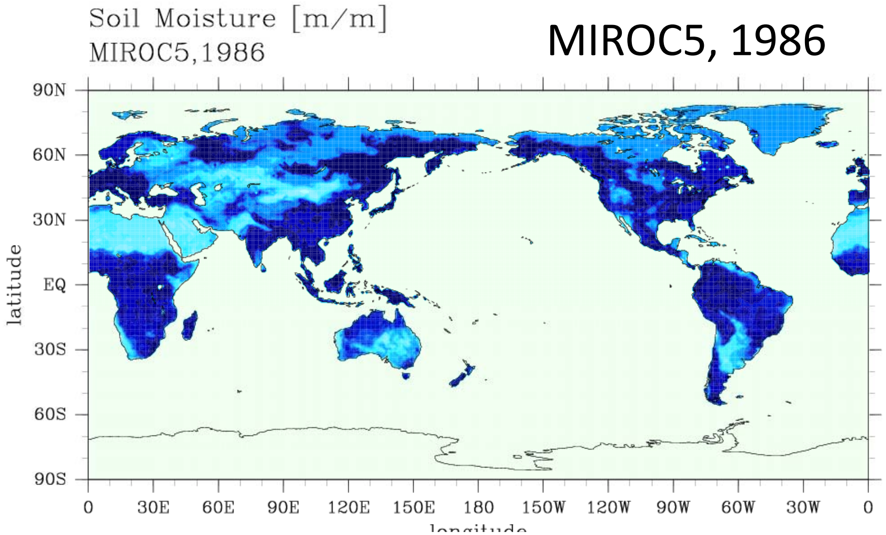
GDP, population, Temperature, precipitation, ..

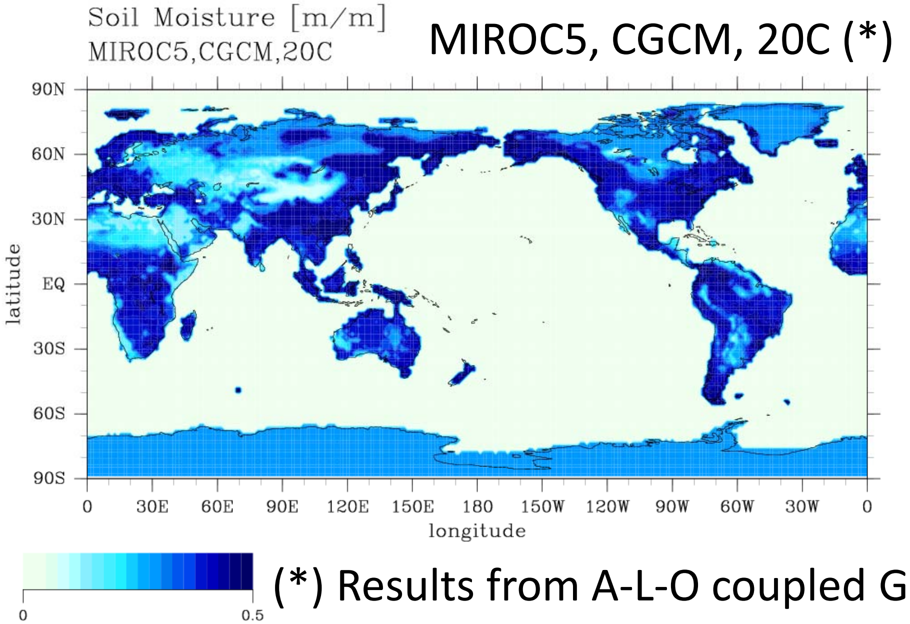


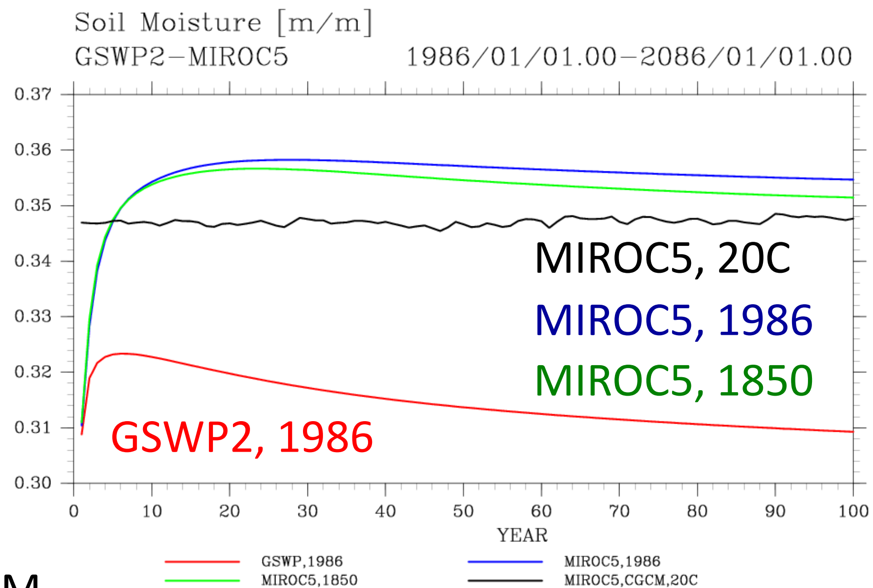
Soil moisture

“Forcing”: SAT, precipitation, etc
GSWP2 (obs), MIROC (model)



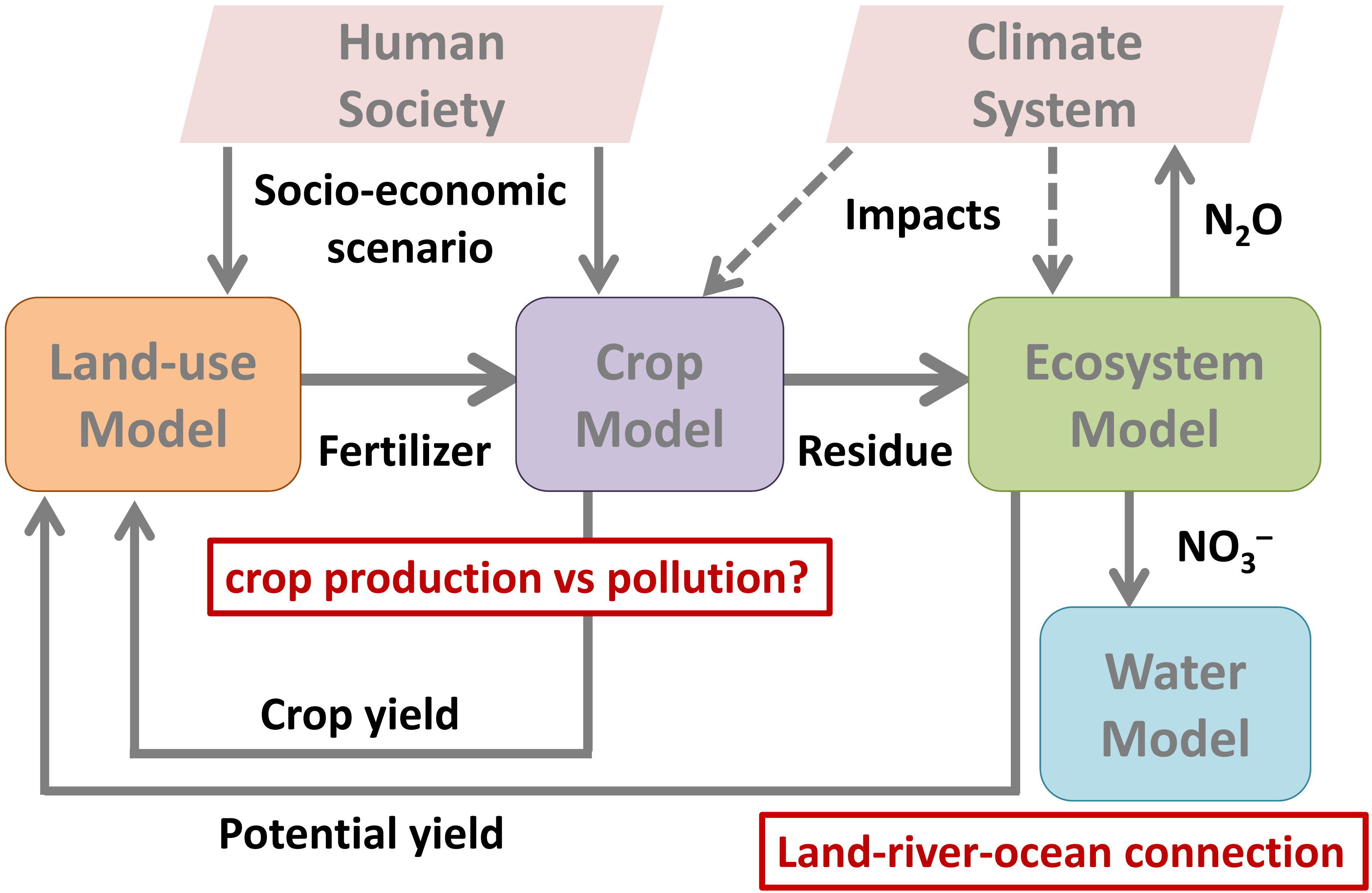






(*) Results from A-L-O coupled GCM

Future challenge: “Nitrogen nexus”



Future scenarios on nitrogen fertilizer

Calculation for potential yield and its quantity of nitrogen fertilizer

↓

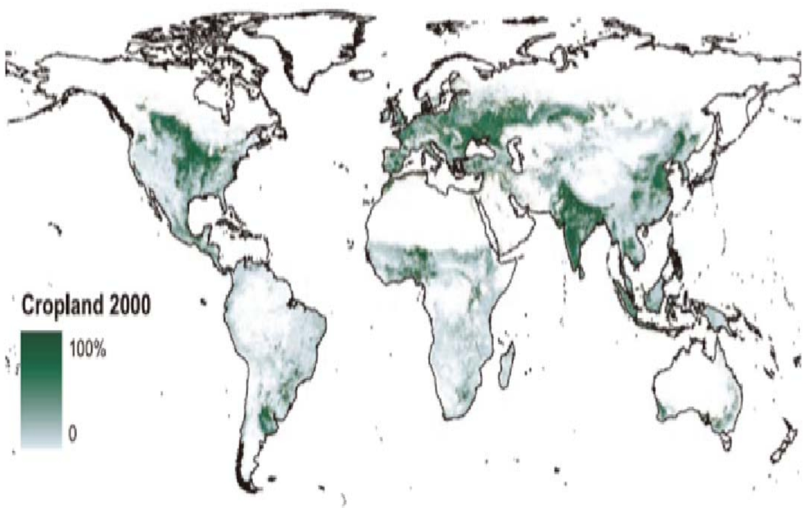
Trend estimation for the variety of nitrogen fertilizers in the past

↓ ← **production function**

Nitrogen fertilizer scenarios

10 crops: Maize, Rice, Soybean, Springbarley, Springwheat, Winterbarley, Winterrye, Winterwheat, Sugarbeet, Sugercane

4RCP × 5 climate models



Cropland（Ramankutty et al. 2008）

Future scenarios on nitrogen fertilizer

Calculation of potential yield under nitrogen fertilizer input

↓

Estimation of the variety of nitrogen fertilizers in each grid point

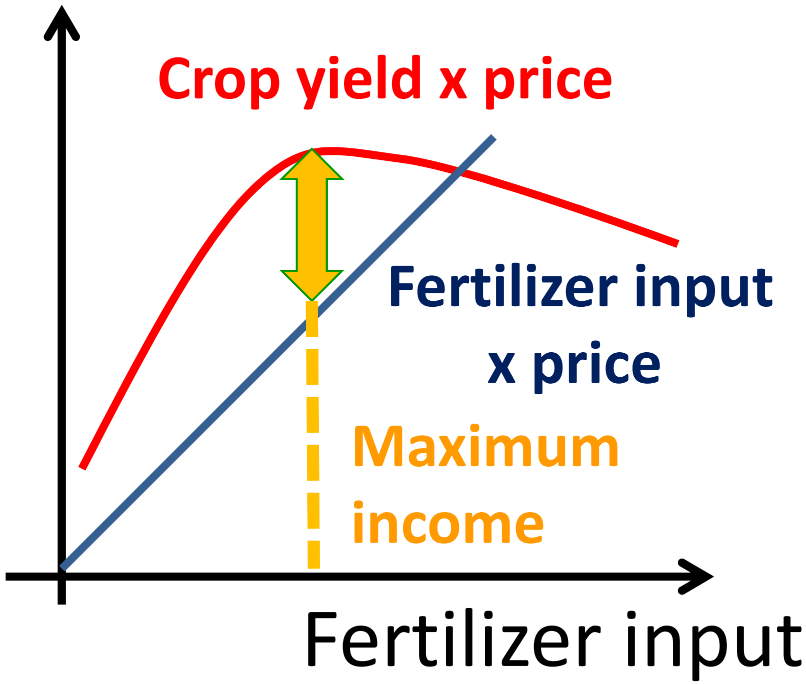
← **production function**

↓

Nitrogen fertilizer scenarios

10 crops: Maize, Rice, Soybean, Springbarley, Springwheat, Winterbarley, Winterrye, Winterwheat, Sugarbeet, Sugercane

4RCP × 5 climate models



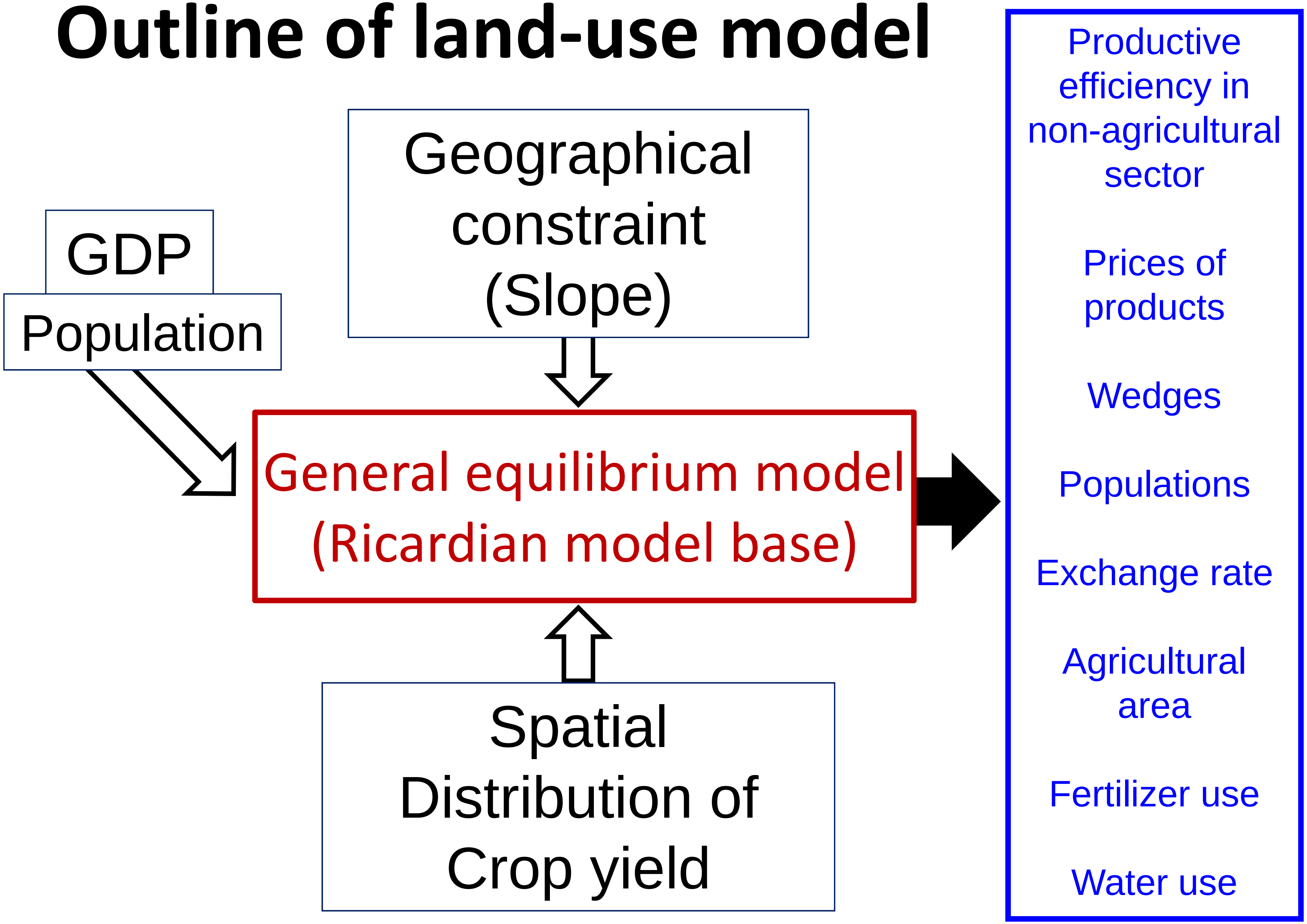
Summary and next step

- **Land**
  - **Land use modelling**, **downscaling + urban growth**
- **Water**
  - Future scenario, water scarcity -> Evaluation of **future adaptation strategy (water saving etc)**
- **Ecosystem**
  - Good model for the past, uncertain for the future
  - **Management options (geo-engineering, REDD+ etc)?**
  - **Future crop yield (fertilize input, climate change)?**
- **"Nexus approach"** by integration of models
  - **Analysis of risk trade-offs** (low-carbon vs high-carbon)

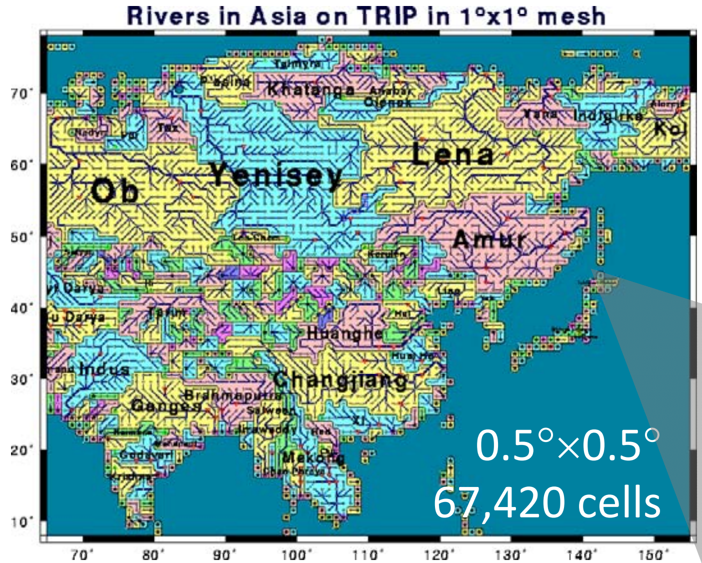
Appendix

Model Description

Outline of land-use model

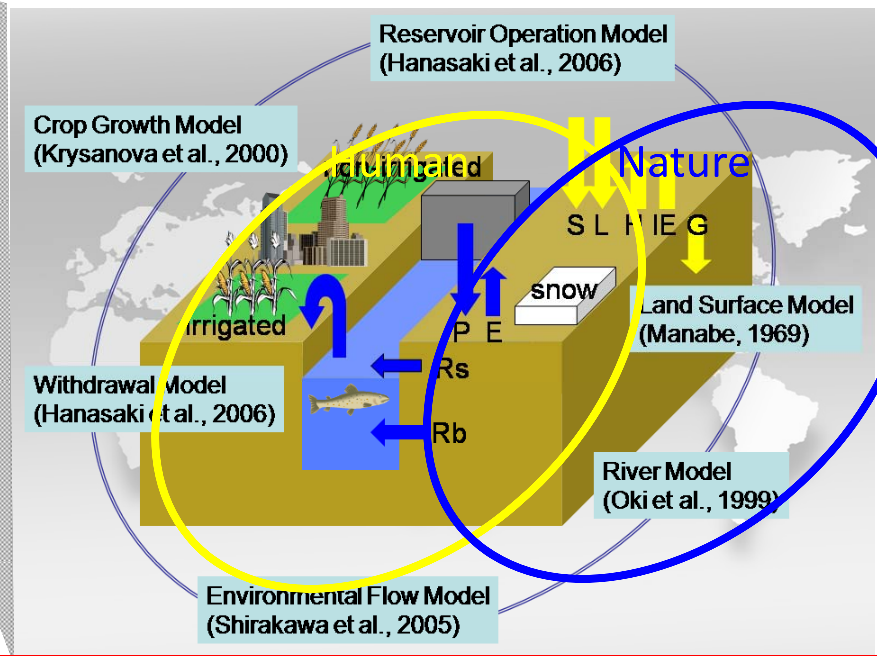


Global water resources model H08



1. High spatial resolution (0.5deg)
2. High temporal resolution (daily)
3. Interaction between natural water cycle and human activities

H08
An open source global hydrological model with human activities



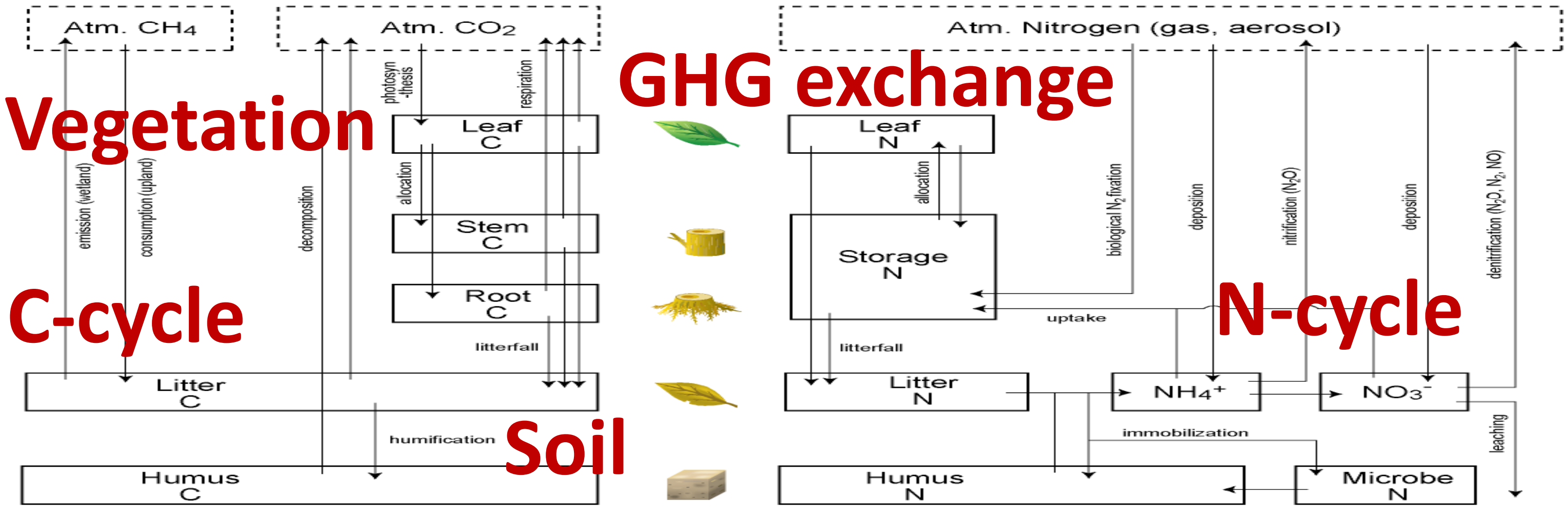
Details in http://h08.nies.go.jp/h08/index.html

Ecosystem model

VISIT

Vegetation Integrative Simulator for Trace gases

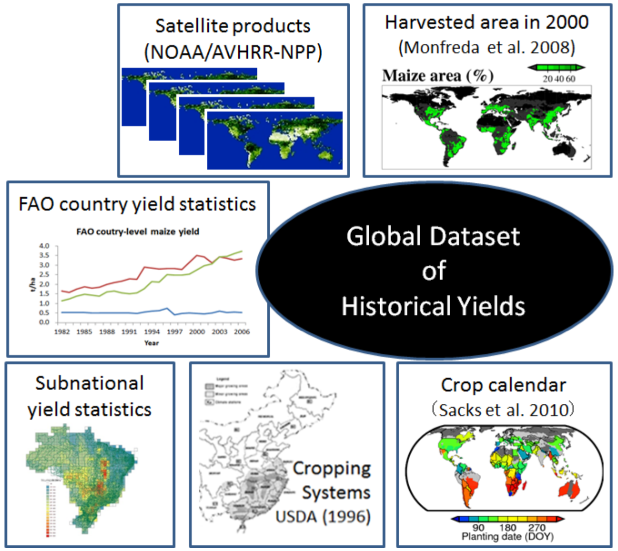
Vegetation Integrative Simulator for Trace gases



- C budget : stock and flows
- GHG exchange : CO_2, CH_4, N_2O
- Simple bio-physical & hydrological scheme
- Disturbance : fire, land-use change etc.
- Management options
- Vegetation dynamics (under development)

Data assimilation of yield data set into process-based crop model

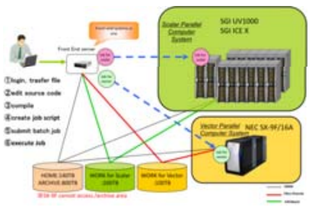
Global yield data base



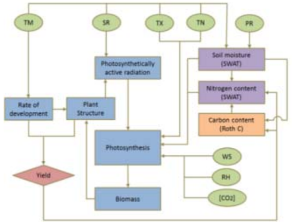
Iizumi *et al.* (2013) *Glob Ecol & Biogeogr*

Technical coefficient
Trend of technical coefficient
Temperature sensitivity
Total heat unit
Leaf structure

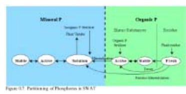
MCMC for each grid

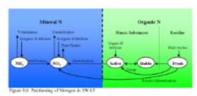


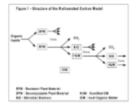
Crop growth model



PRYSBI2







SWAT Soil & Water Assessment Tool

RothC

- Global yield data set was assimilated into process-based model using a Bayesian method for maize, soybean, rice, and wheat.