Developing Global Water Models for Assessing Water-Food Nexus under Climate Change : Limitations and Opportunities

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Motivation Questions

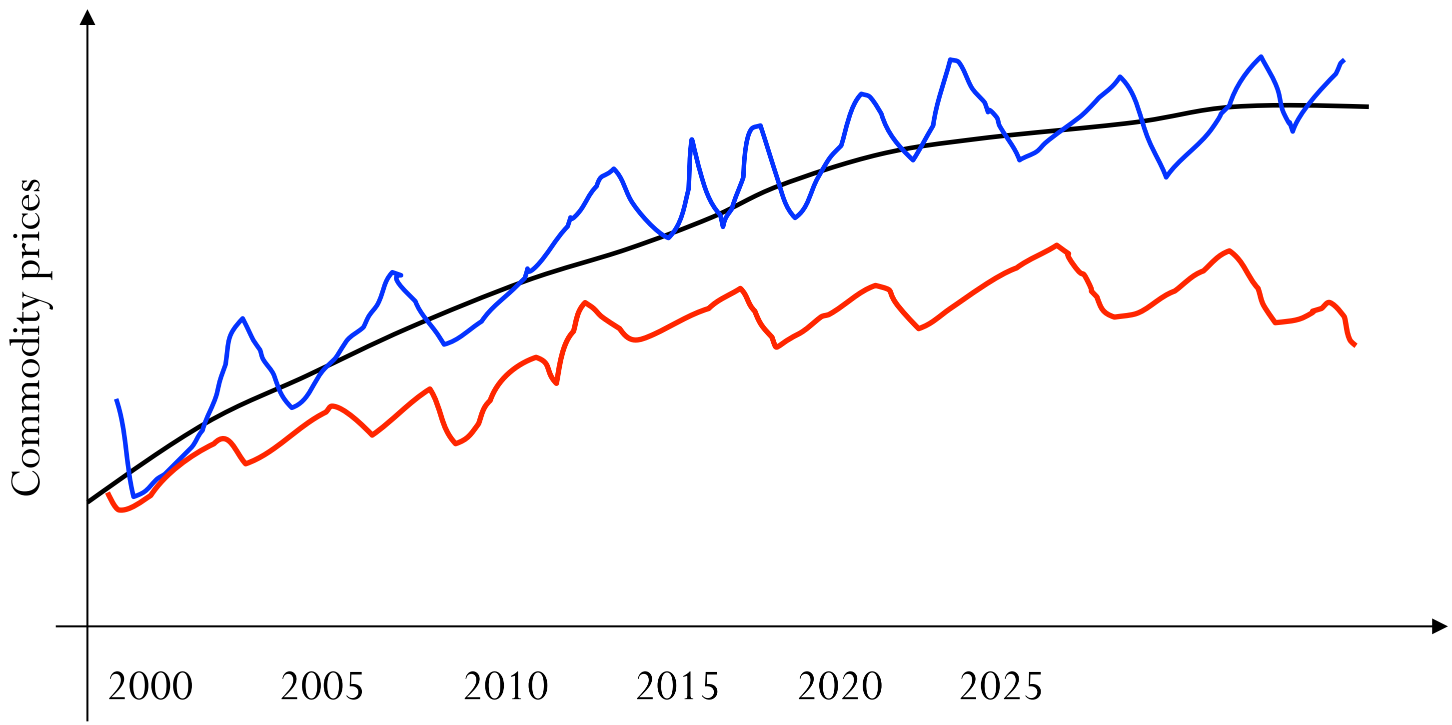
What progresses can be used to enhance the modeling exercise?

What issues are likely to be too tough to deal with at global scale?

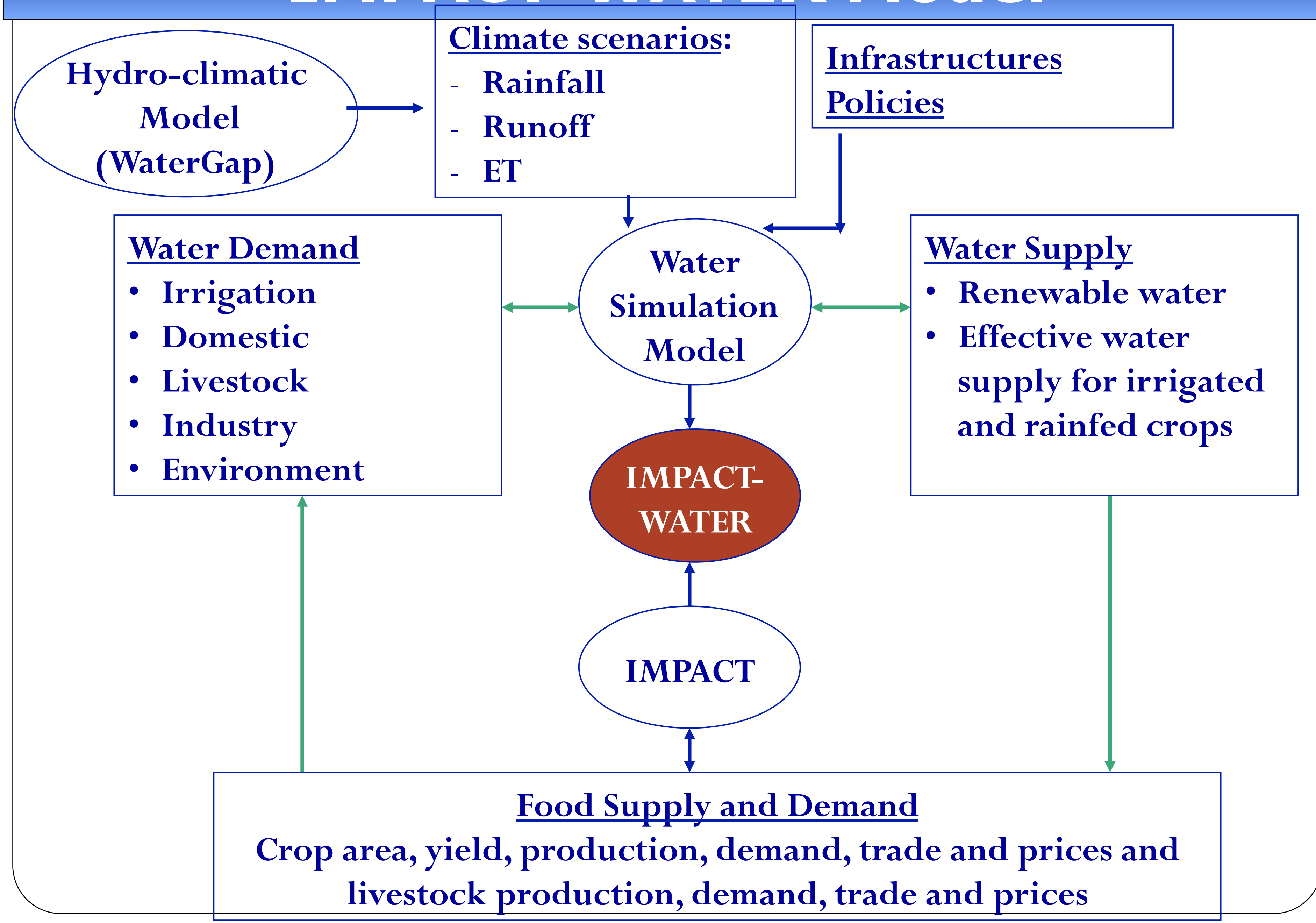
What are reasonable goals for the IAM community to set in this area?

Where will the investment of additional resources yield the highest payoff?

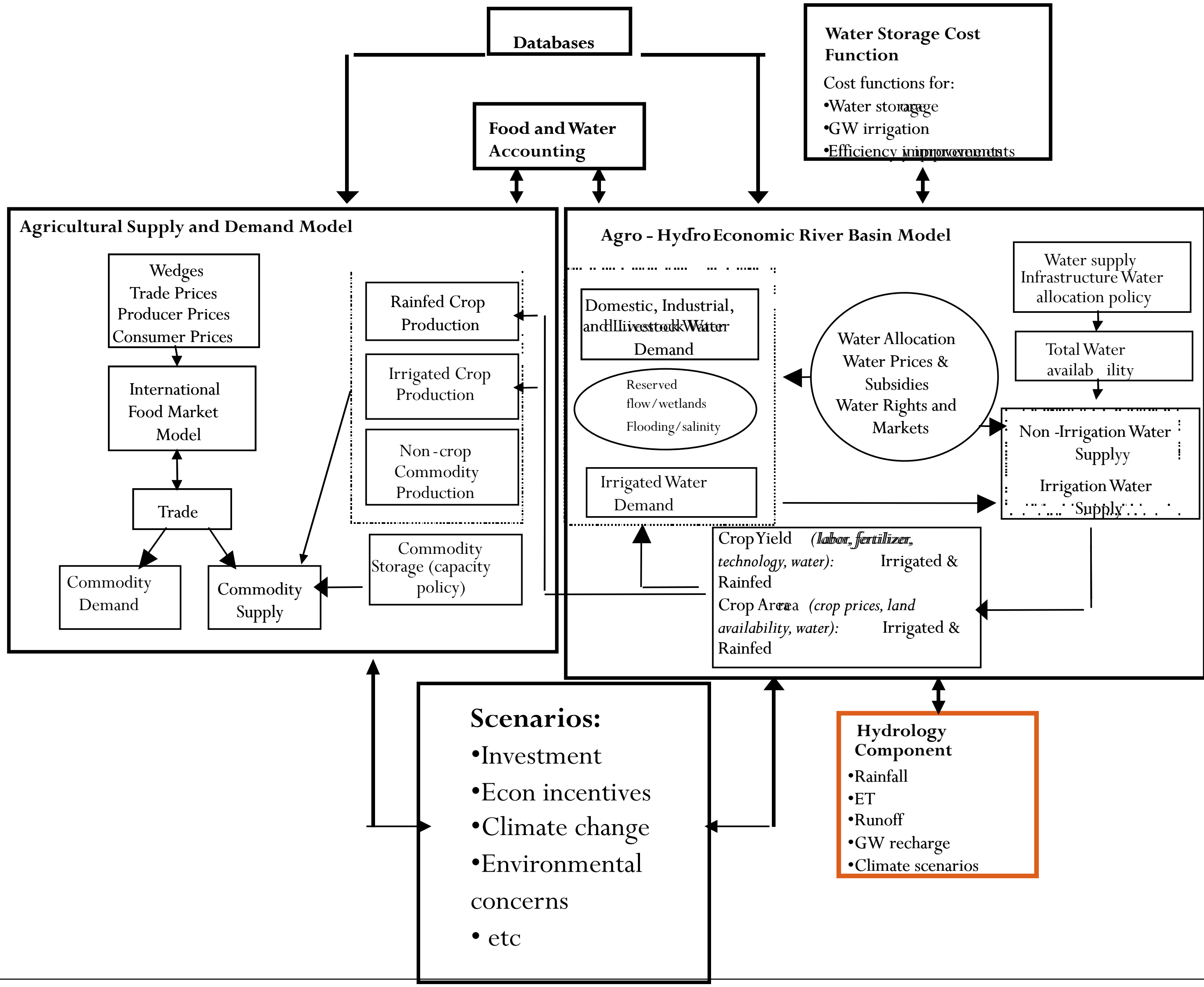
Motivation for IMPACT-WATER: What should the result look like?



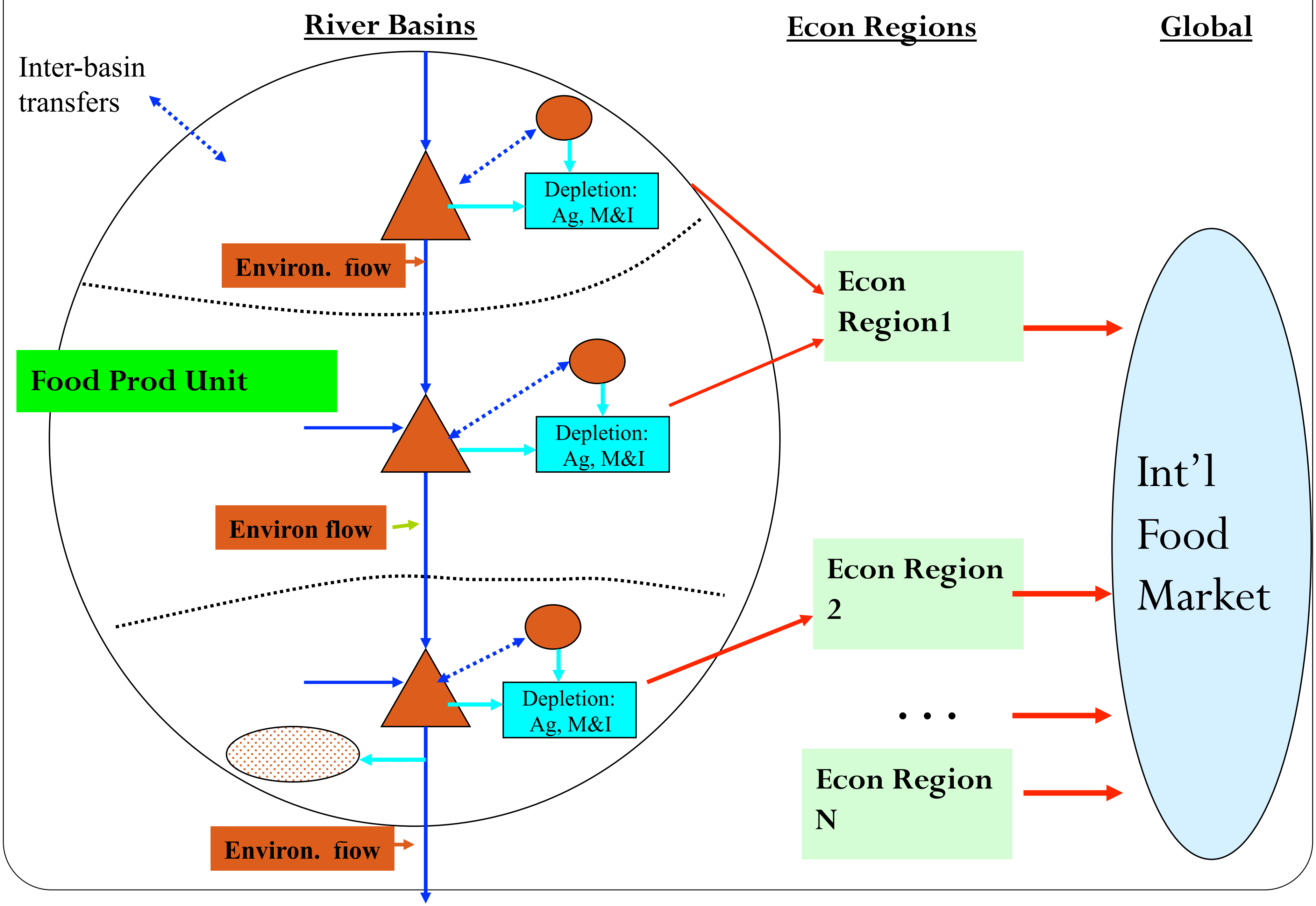
IMPACT-WATER Model



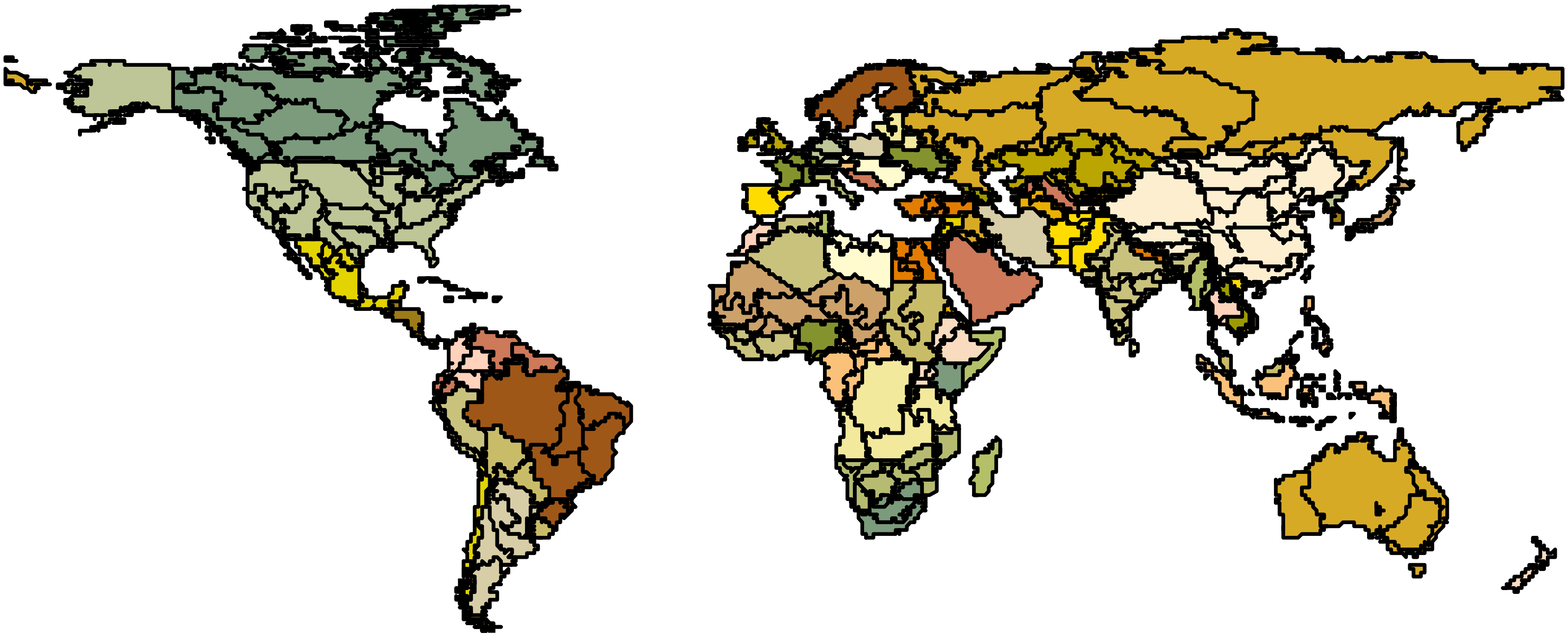
IMPACT-WATER Model



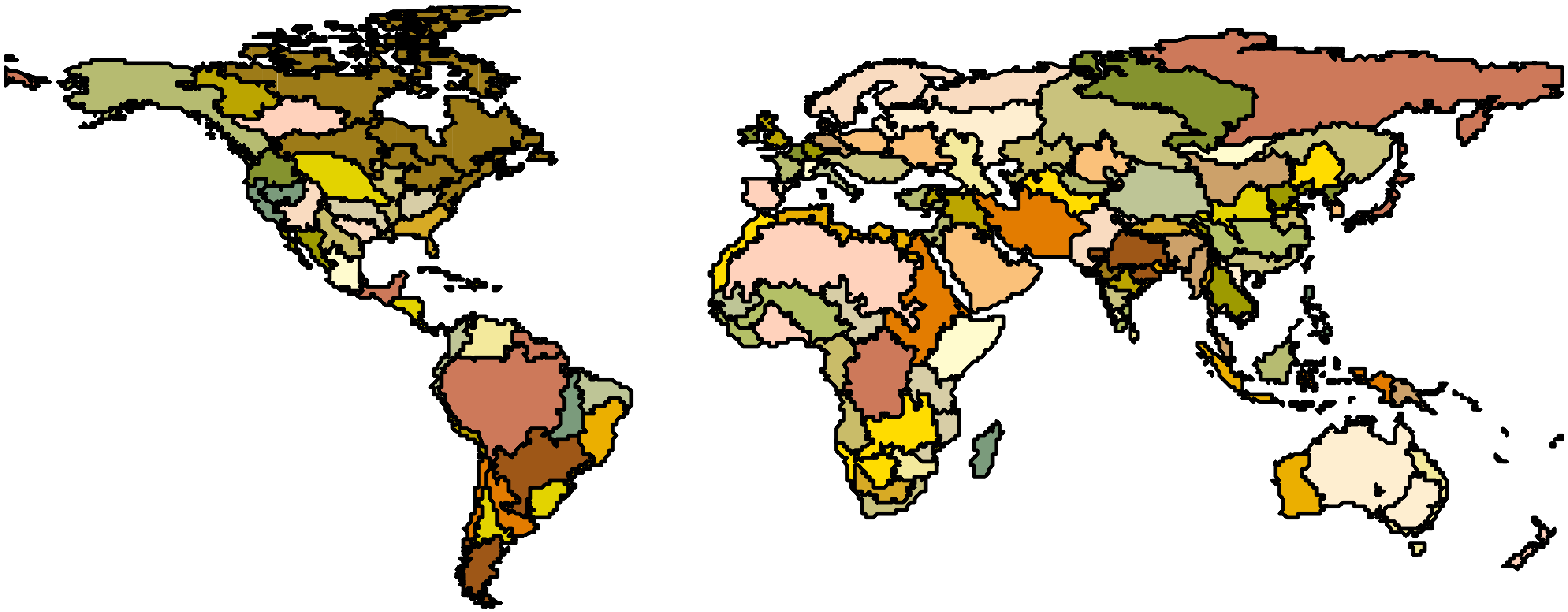
Scale-coupling in the water and food model



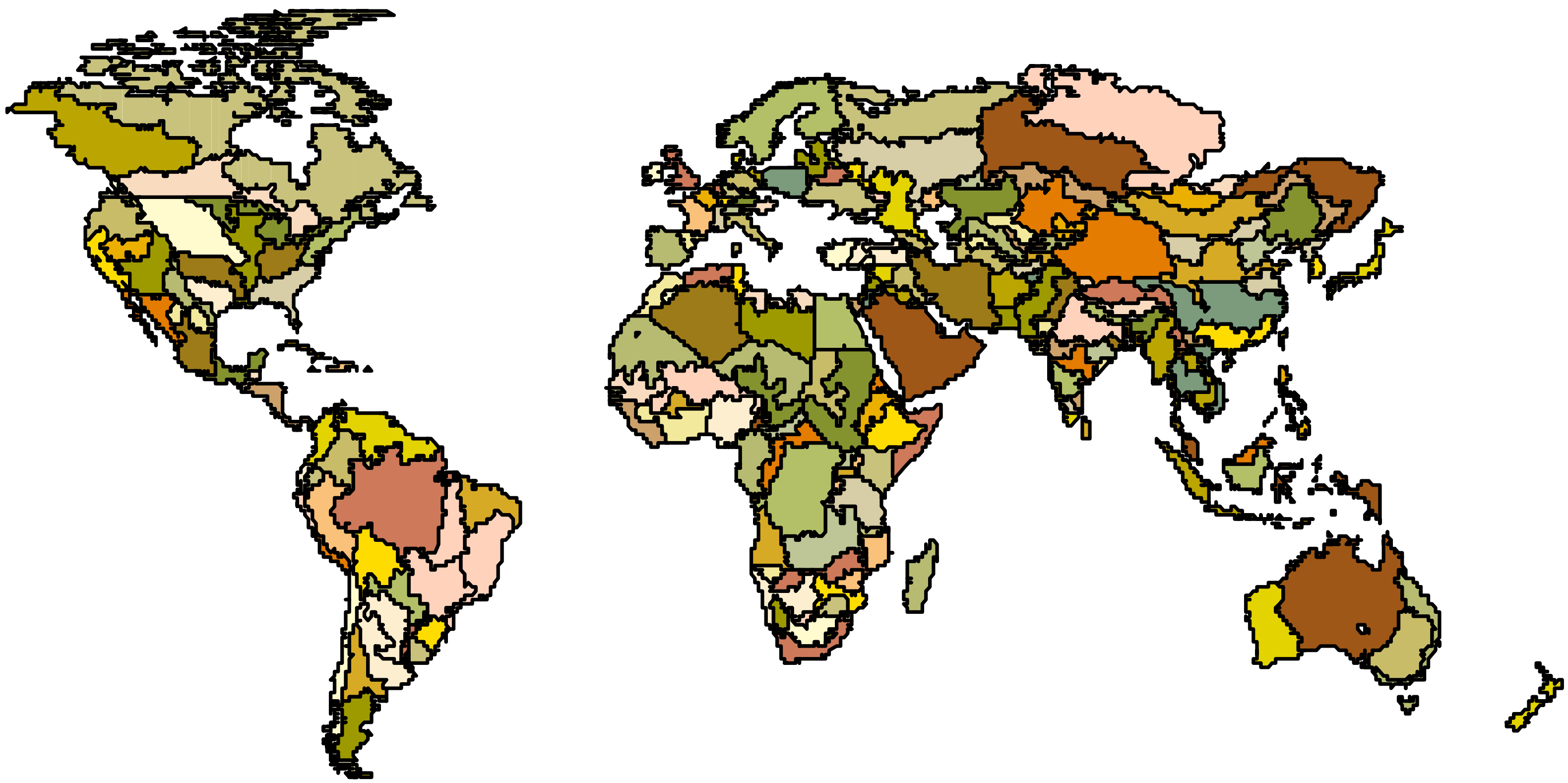
Spatial Units: 79 Economic Regions



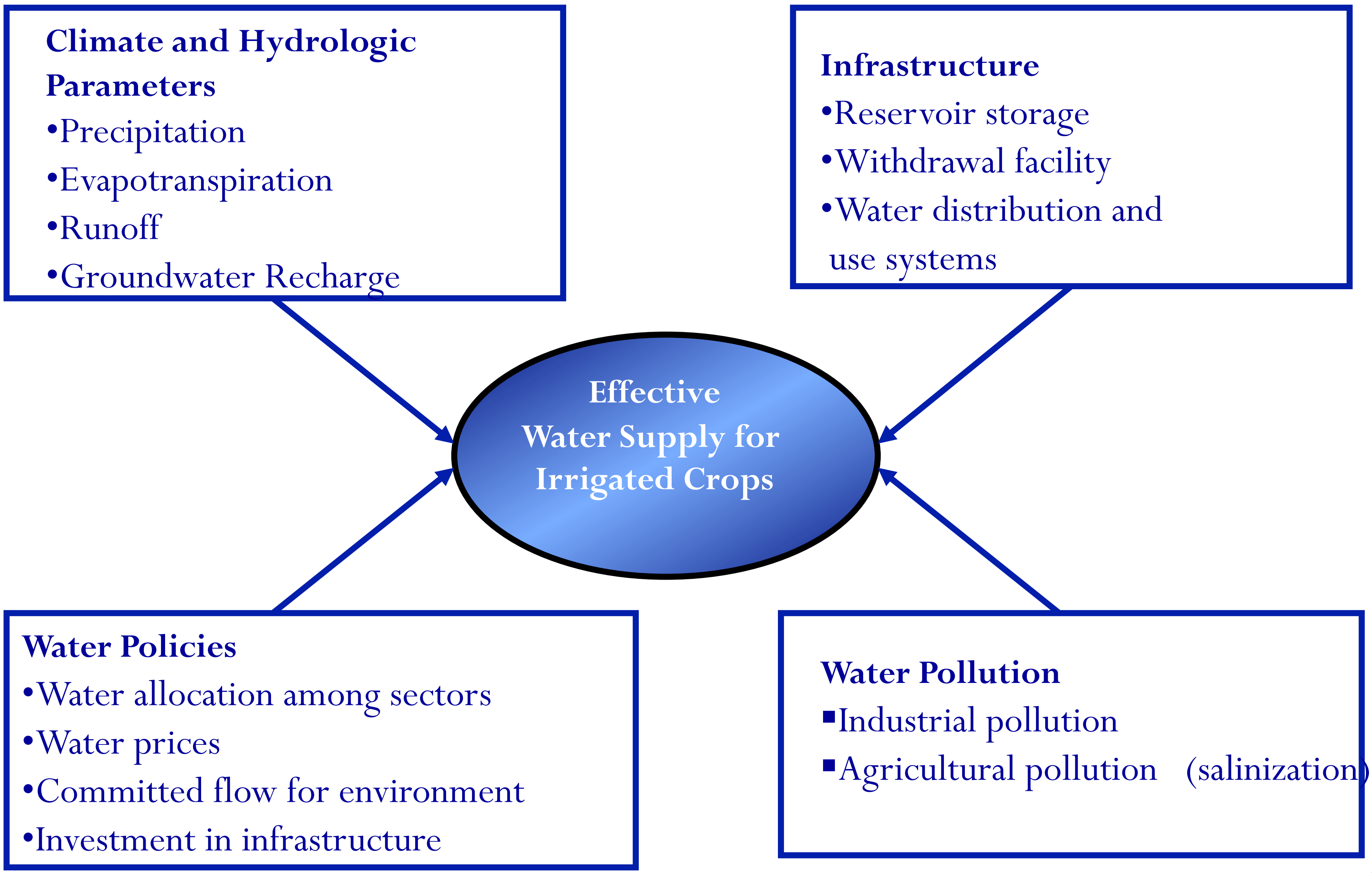
Spatial Units: 128 River Basins



Spatial Units: 255 Food Production Units



Variables Influencing Agricultural Water Supply



Data Requirements

CATEGORY	ITEMS
INFRASTRUCTURE	Reservoir storage Withdrawal capacity Groundwater pumping capacity Water distribution, use and recycling
HYDROLOGY	Watershed delineation Precipitation & Effective Precipitation Potential evapotranspiration Runoff Groundwater recharge Water pollution (salinity) Committed outflow

Data Requirements

CATEGORY	ITEMS
AGRONOMY	Crop growth stages Crop evapotranspiration-coefficient (kc) Yield-water response coefficient (ky)
CROP PRODUCTION	Crop harvested area Irrigated and rainfed crop area Irrigated and rainfed crop yield
NON-IRRIGATION WATER DEMAND	Industry Domestic Livestock
POLICY	Committed flow, Water demand growth Investment, Int. water sharing agreements

Opportunities: Data Sources

<u>Remote sensing data sources</u>

• Land use and land cover with resolution of 30 arc-seconds, derived from IGBP, MODIS, GLC, and UMD (Biradar et al. , 2009)

• Global real-time actual and potential evapotranspiration
  - University of Washington (Tang et al., 2009)
  - University of Montana (Zhang et al., 2010)

• GRACE for water balance (Güntner et al., 2006)

Biradar et al. (2009), *Int. J. Appl. Earth Obs. Geoinf.* 11: 114-129.
Güntner et al. (2006), *Geophysical Research Abstracts*, Vol. 8, 03429
Zhang, K., et al. (2009) *J Hydrol*, *379*(1-2), 92-110
Tang, Q., et al. (2009) *Journal of Geophysical Research*, *114*, D05114

Opportunities: Data Sources

<u>Other data sources</u>

- Global rainfed/irrigated area and yield by crop (Portmann et al., 2010)
- Irrigation requirement change under climate change (under working)
- Crop land availability assessment (Cai et al., 2011)
- Crop land availability change under climate change (Zhang and Cai, 2011)
- Crop yield change under climate change (Lobell and Field, 2007; Lobell et al. 2011)
- Others

Portmann et al. (2010) *Global Biogeochem. Cycles*, 24, GB1011.

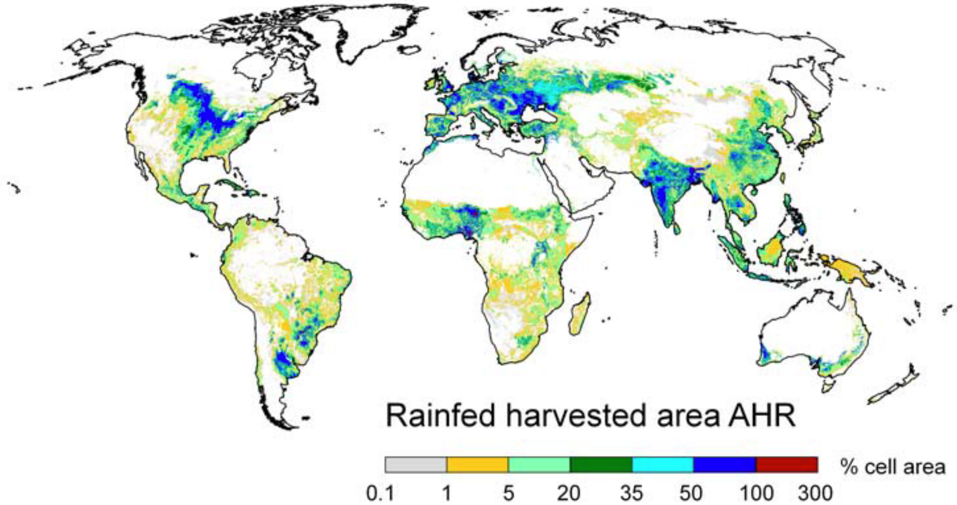
Cai et al. (2011). *Environ. Sci and Tech*. 2011, 45 (1), pp 334–339.

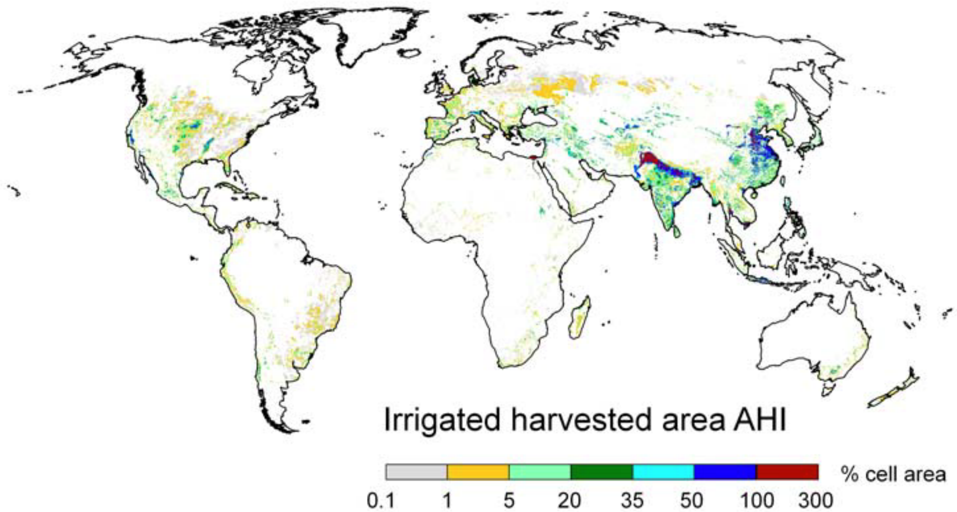
Zhang and Cai (2011). *Environ. Res. Lett*. 6 014014.

Lobell and Field (2007), *Environ. Res. Lett*. **2** 014002.

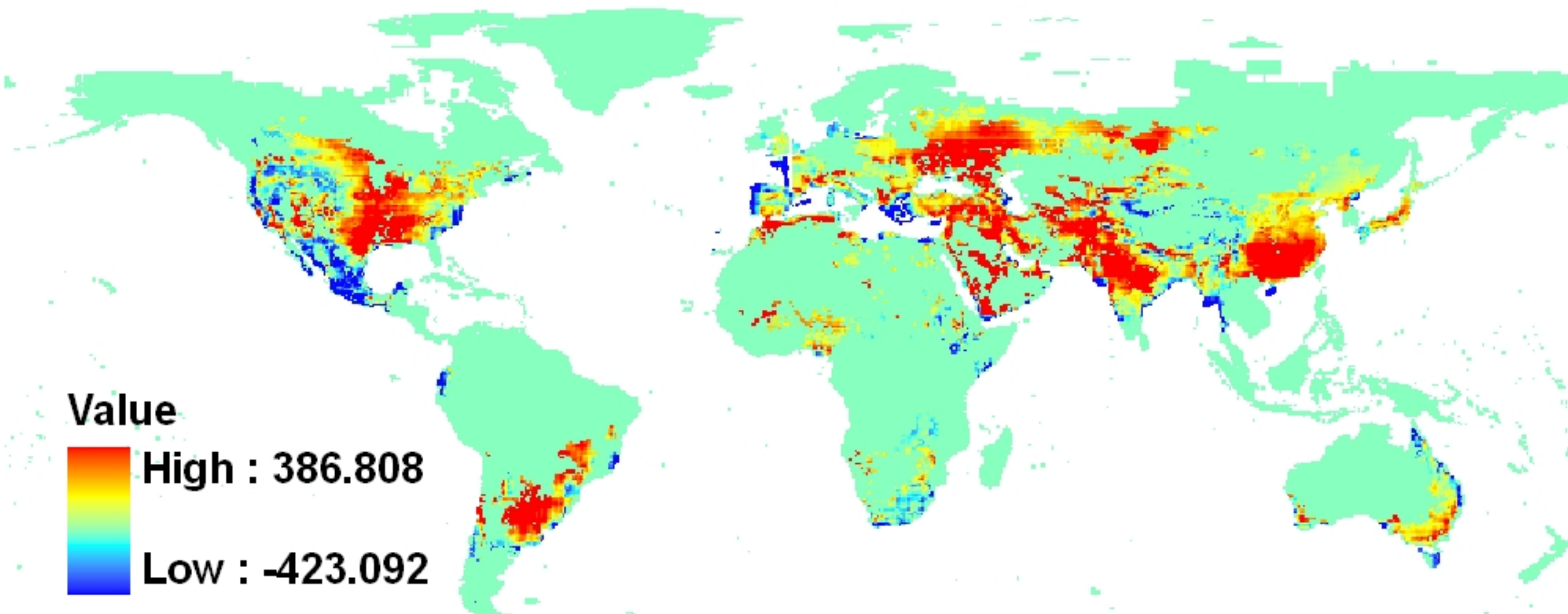
Lobell et al. (2011), *Science DOI: 10.1126*

Opportunities: Data Sources

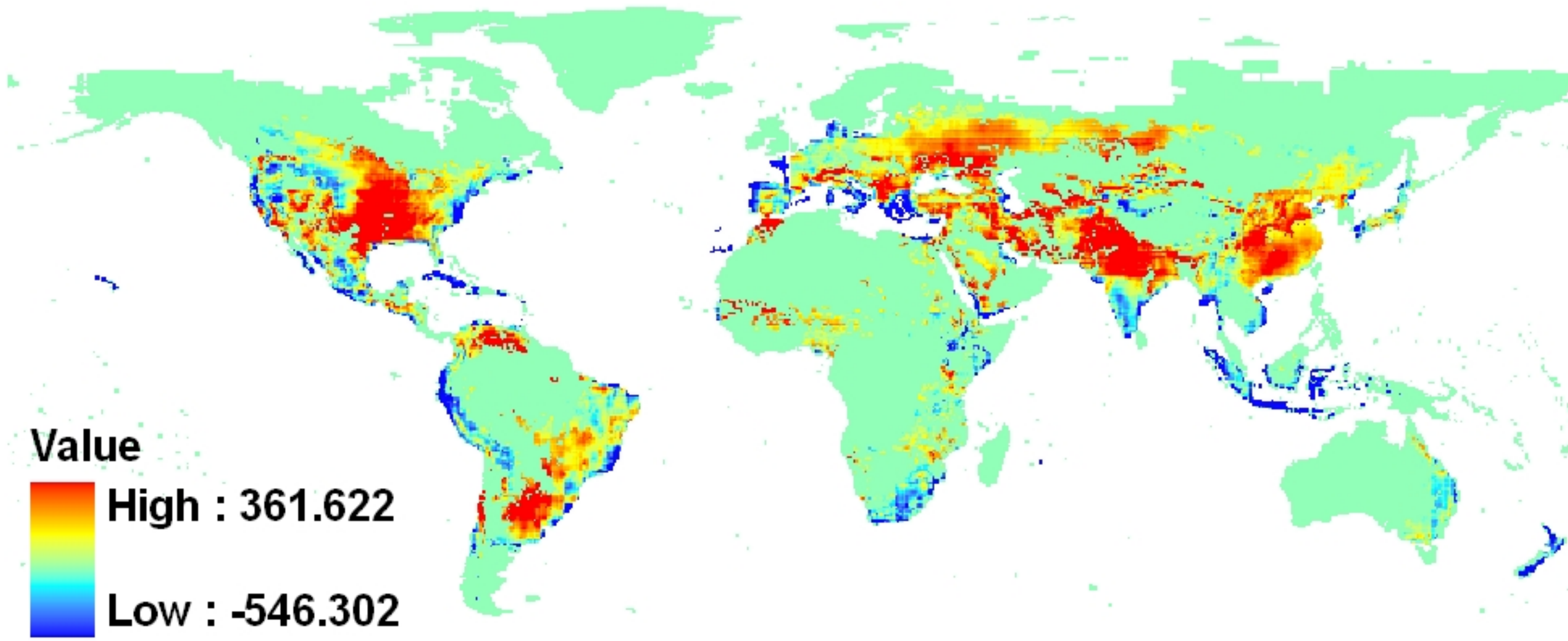




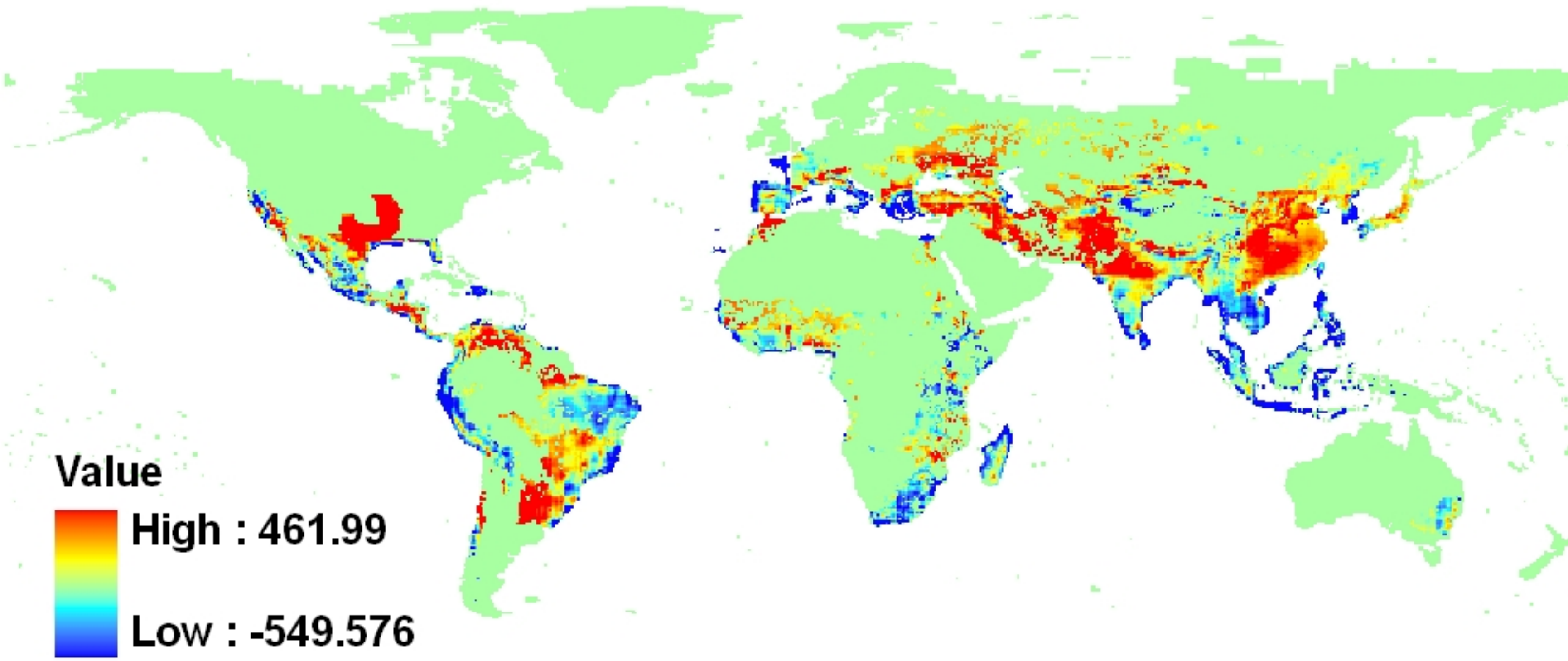
Source: Portmann et al. (2010)



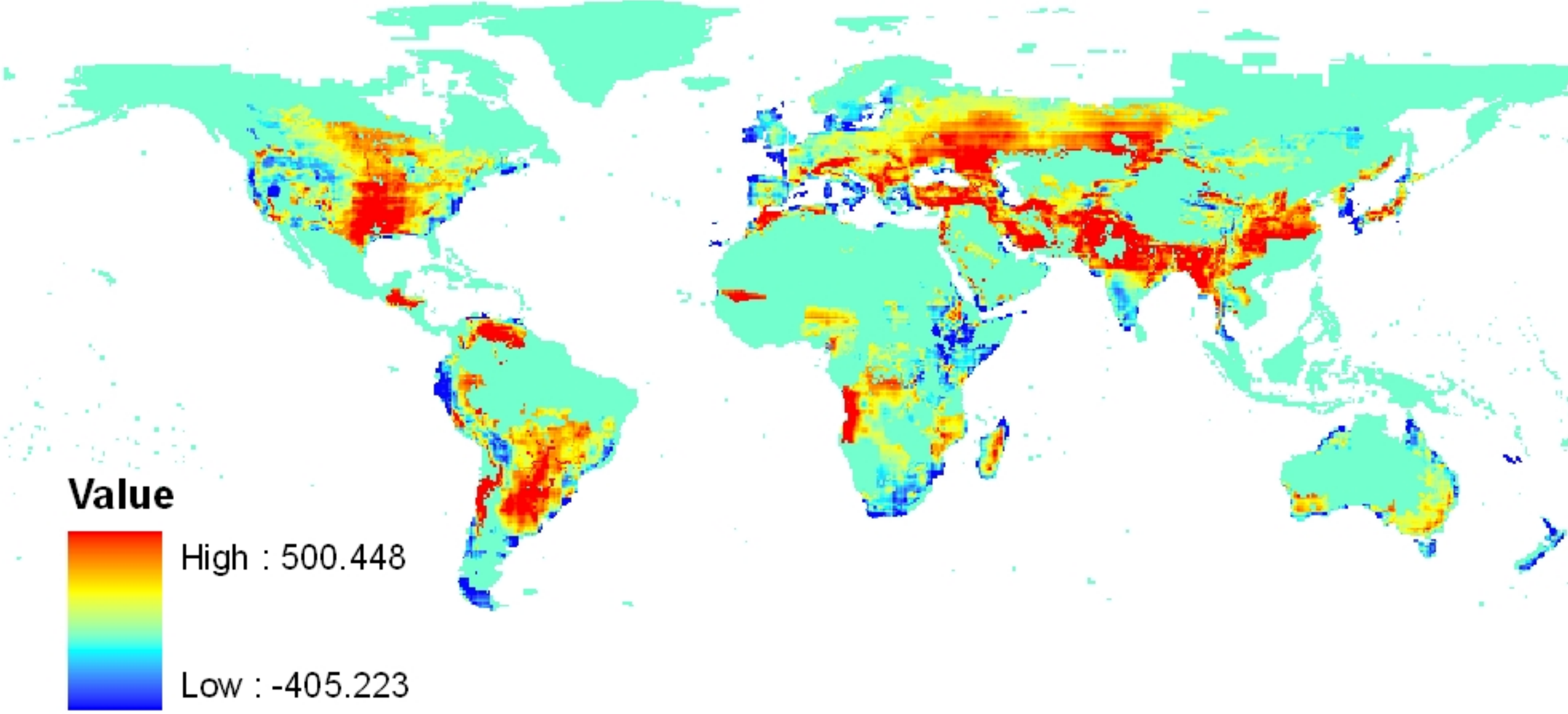
Annual irrigation requirement change of wheat under A1B scenario(mm) (under working)



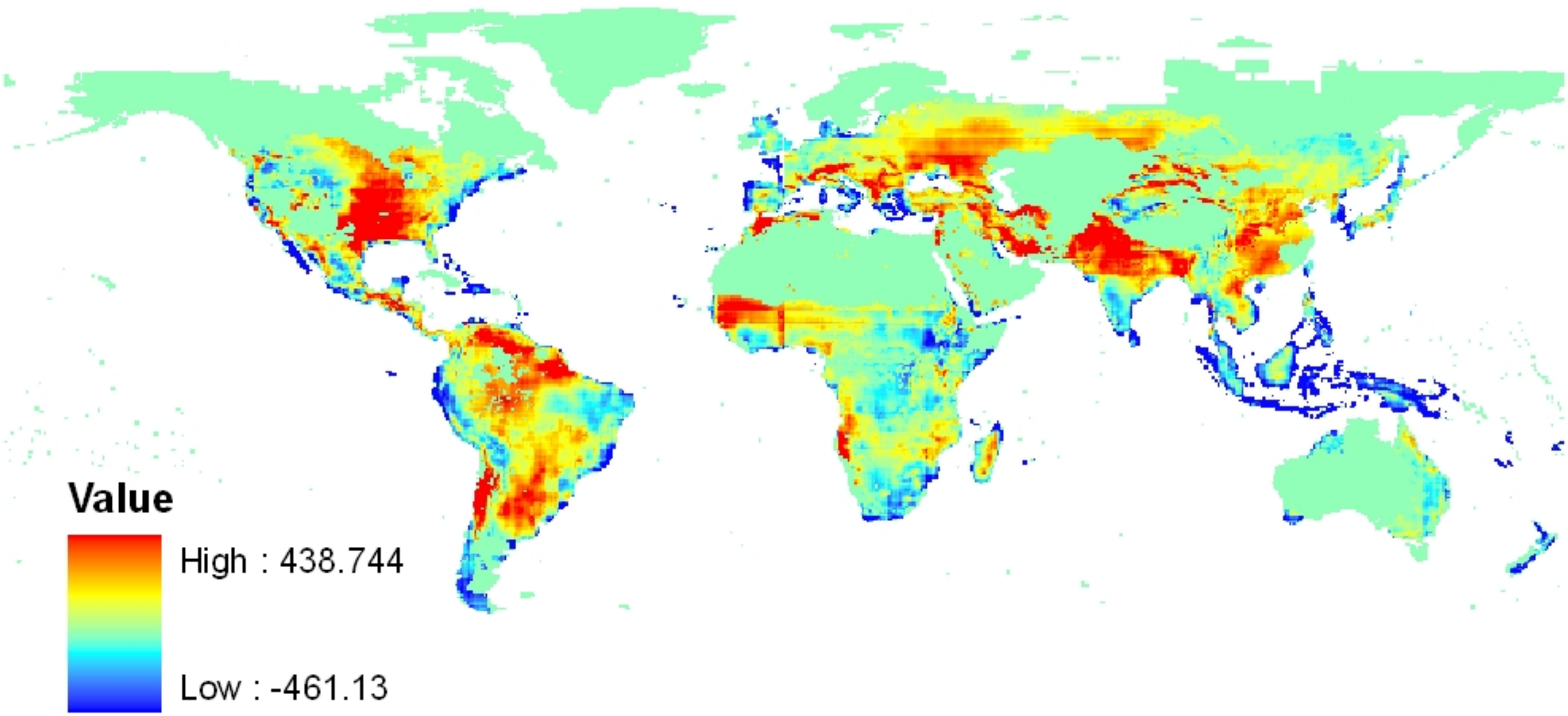
Annual irrigation requirement change of maize under A1B scenario (mm) (under working)



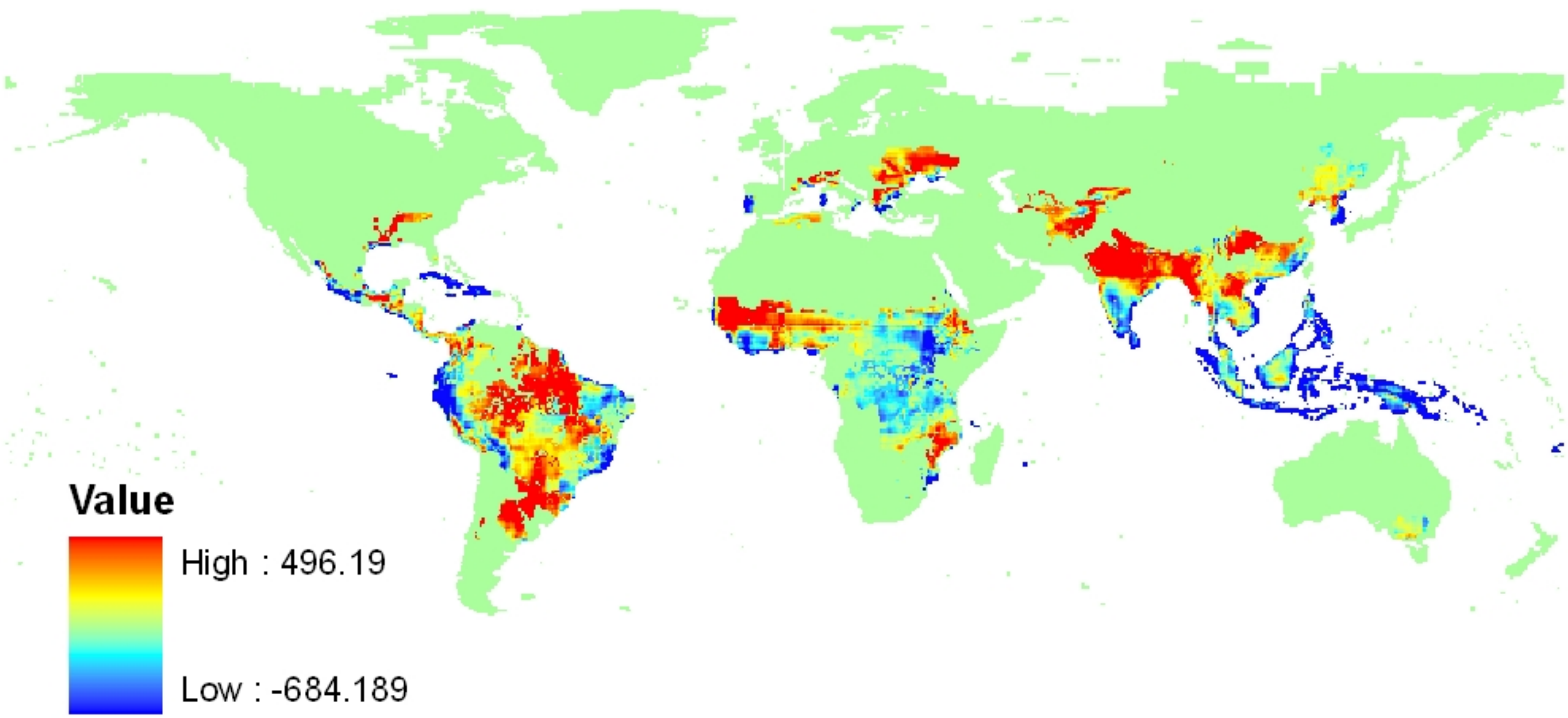
Annual irrigation requirement change of rice under A1B (mm)
(under working)



Annual water deficit change of rainfed wheat under A1B scenario(mm) (under working)



Annual water deficit change of rainfed maize under A1B scenario(mm) (under working)



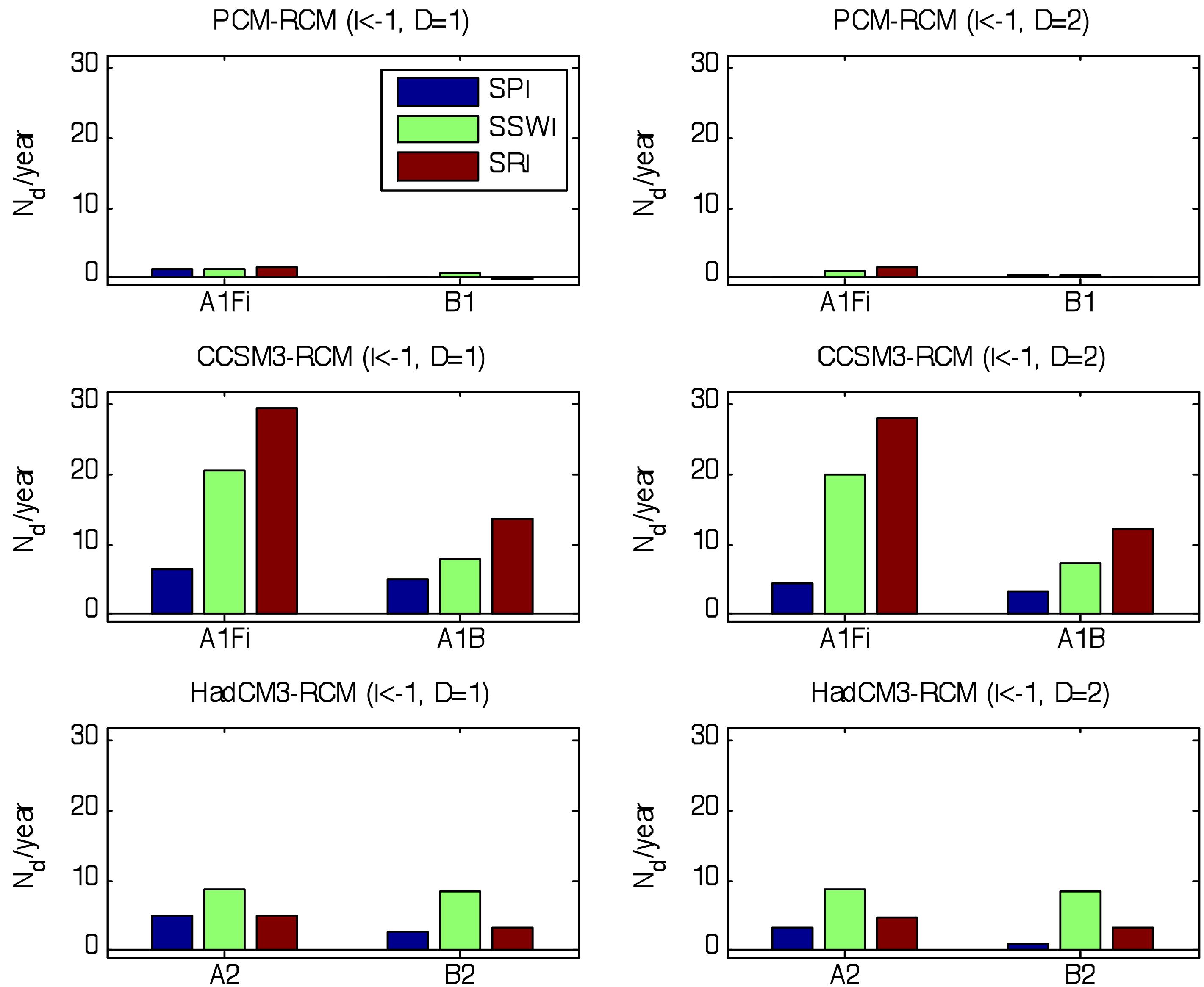
Annual water deficit change of rainfed rice under A1B scenario(mm) (under working)

Water requirement increase on irrigated (up) and rainfed (down)crop land (million m3)

Crop	Scenario	Africa	China	Europe	India	South America	United States	Global
Wheat	**A1b**	275	144	209	366	254	562	3,147
	B1	251	124	194	373	240	533	2,971
Maize	**A1b**	302	307	349	156	554	1,002	4,027
	B1	234	284	347	143	499	935	3,777
Rice	**A1b**	471	468	294	350	654	437	4,010
	B1	401	439	283	342	569	410	3,797

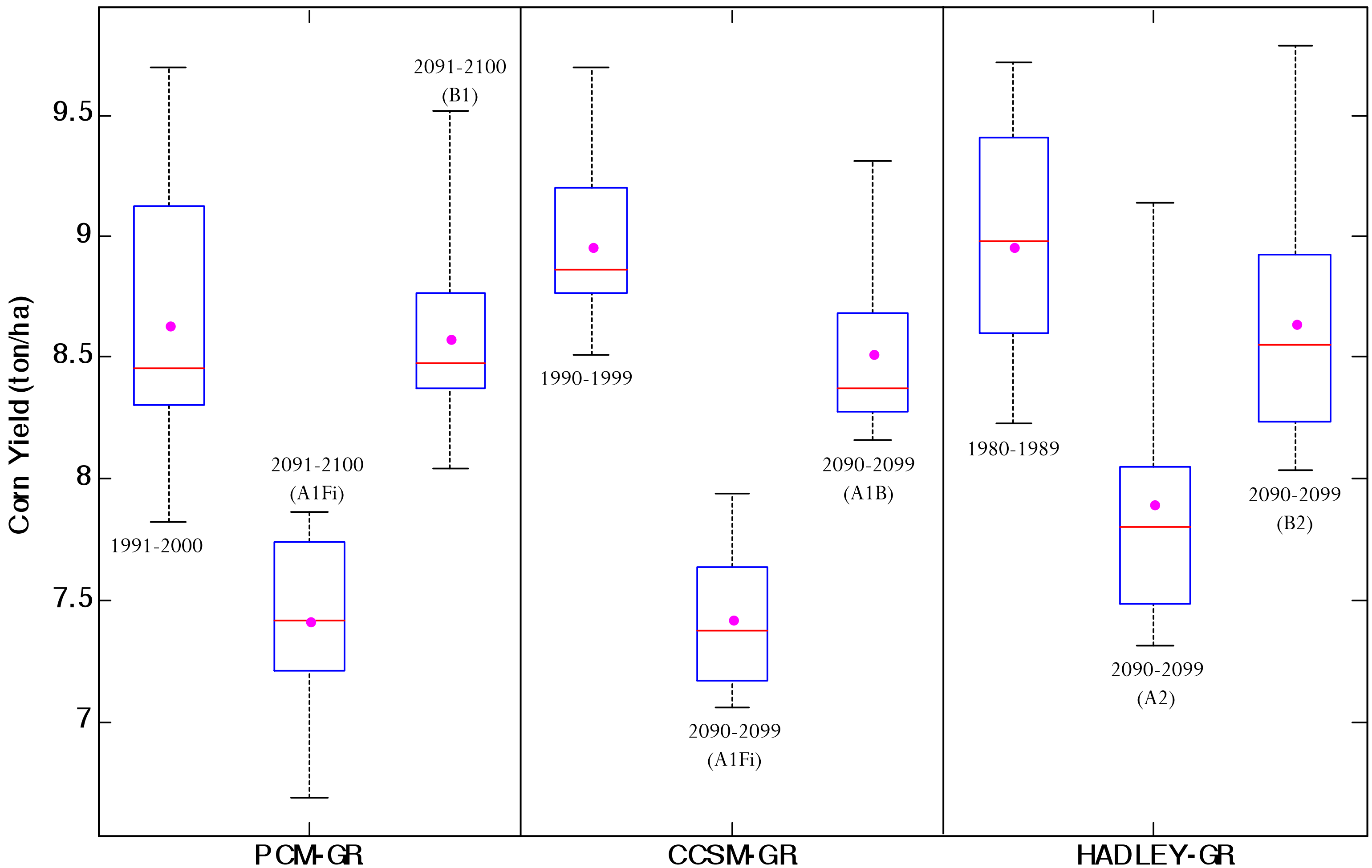
Crop	Scenario	Africa	China	Europe	India	South America	United States	Global
Wheat	**A1b**	672	146	298	129	498	608	4,051
	B1	589	119	291	134	401	585	3,727
Maize	**A1b**	938	406	392	173	766	871	5,109
	B1	717	366	386	162	614	822	4,630
Rice	**A1b**	889	119	193	186	1014	60	2,785
	B1	691	107	198	172	881	59	2,514

Change of drought event number in Central IL

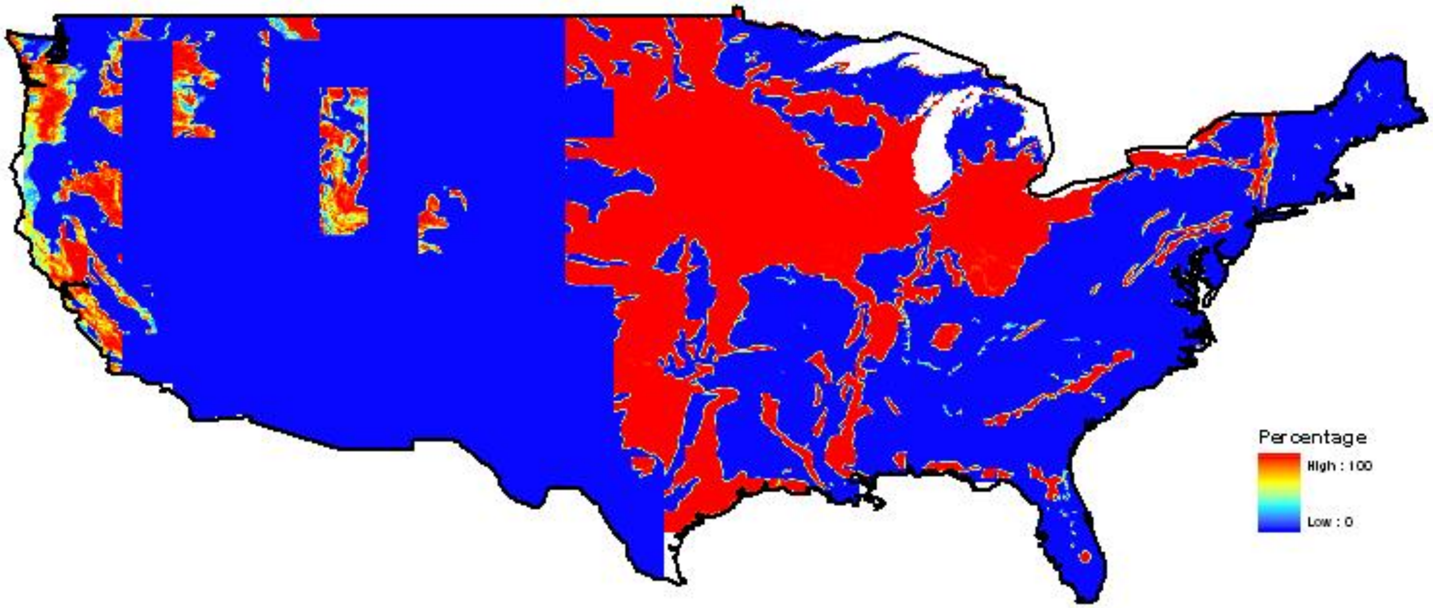


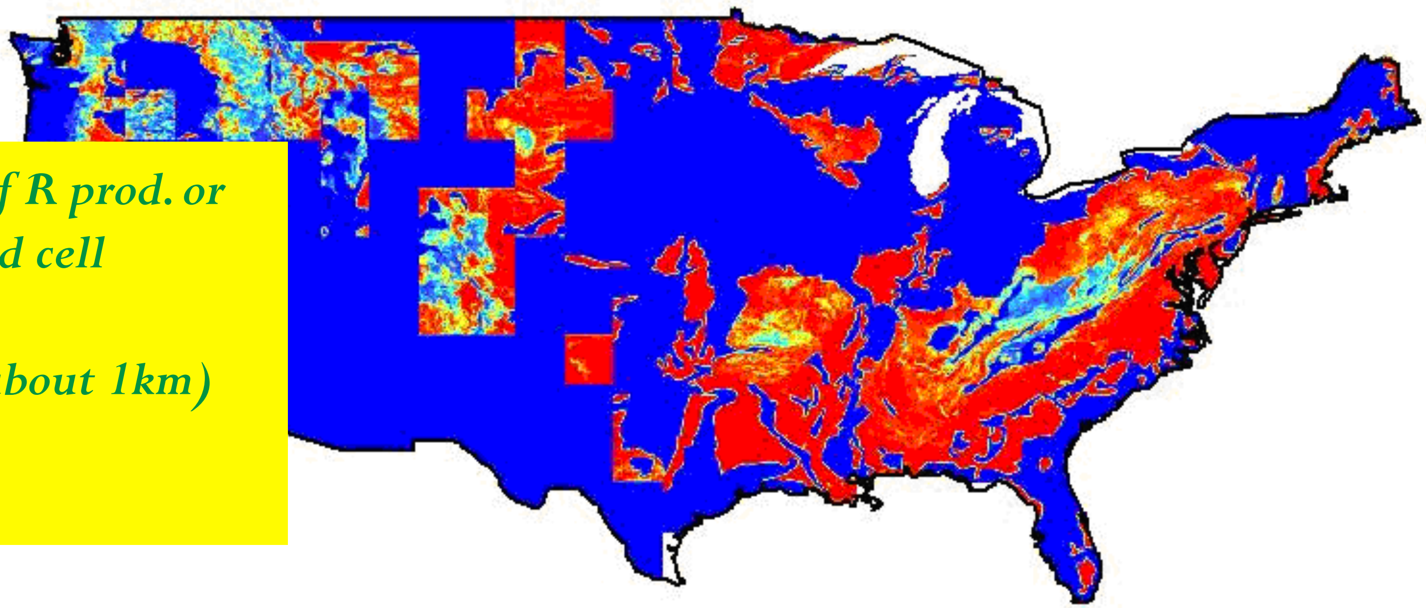
Source: Wang et al. (2011), *Wat. Resou. Res.* under review

Impacts on Corn yield



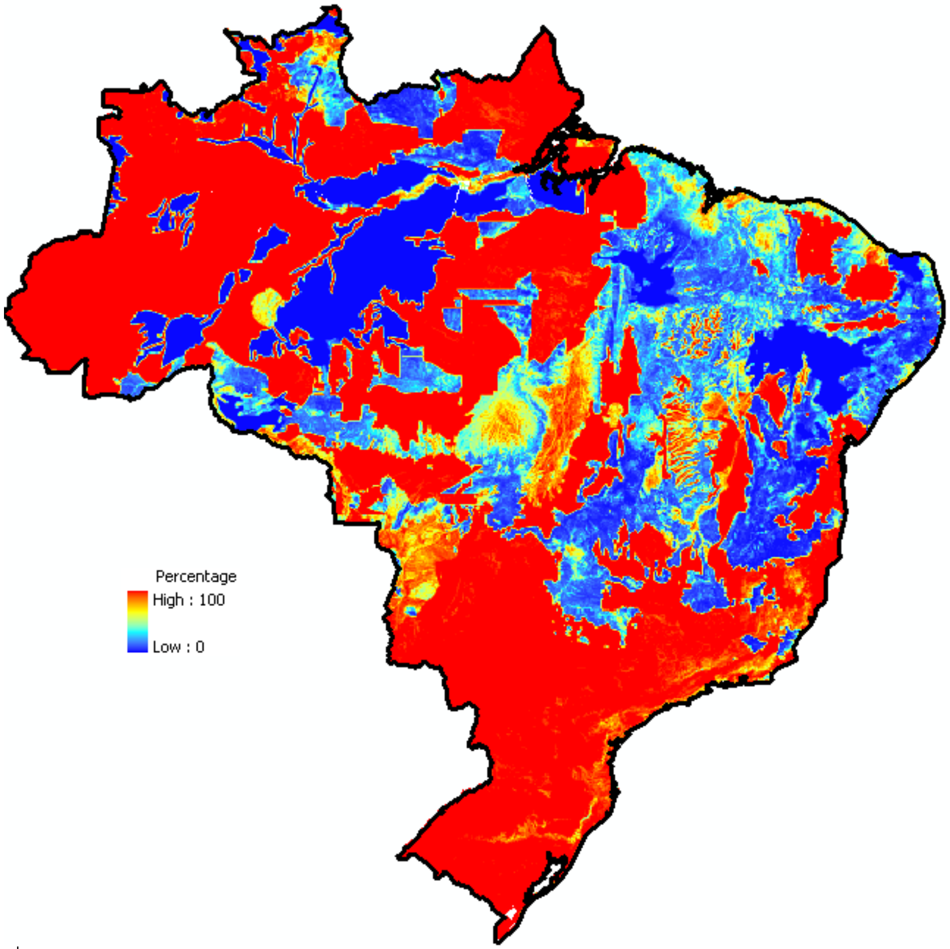
Source: Wang et al. (2011), *Wat. Resou. Res.* under review

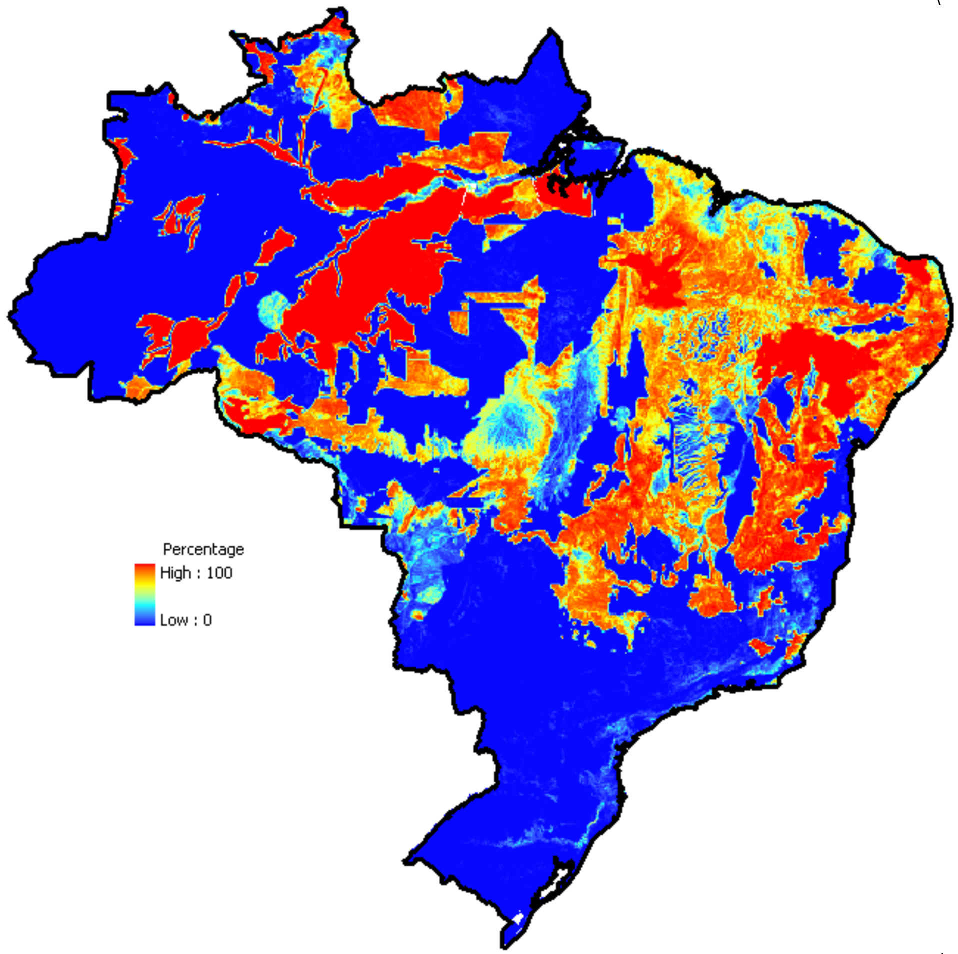




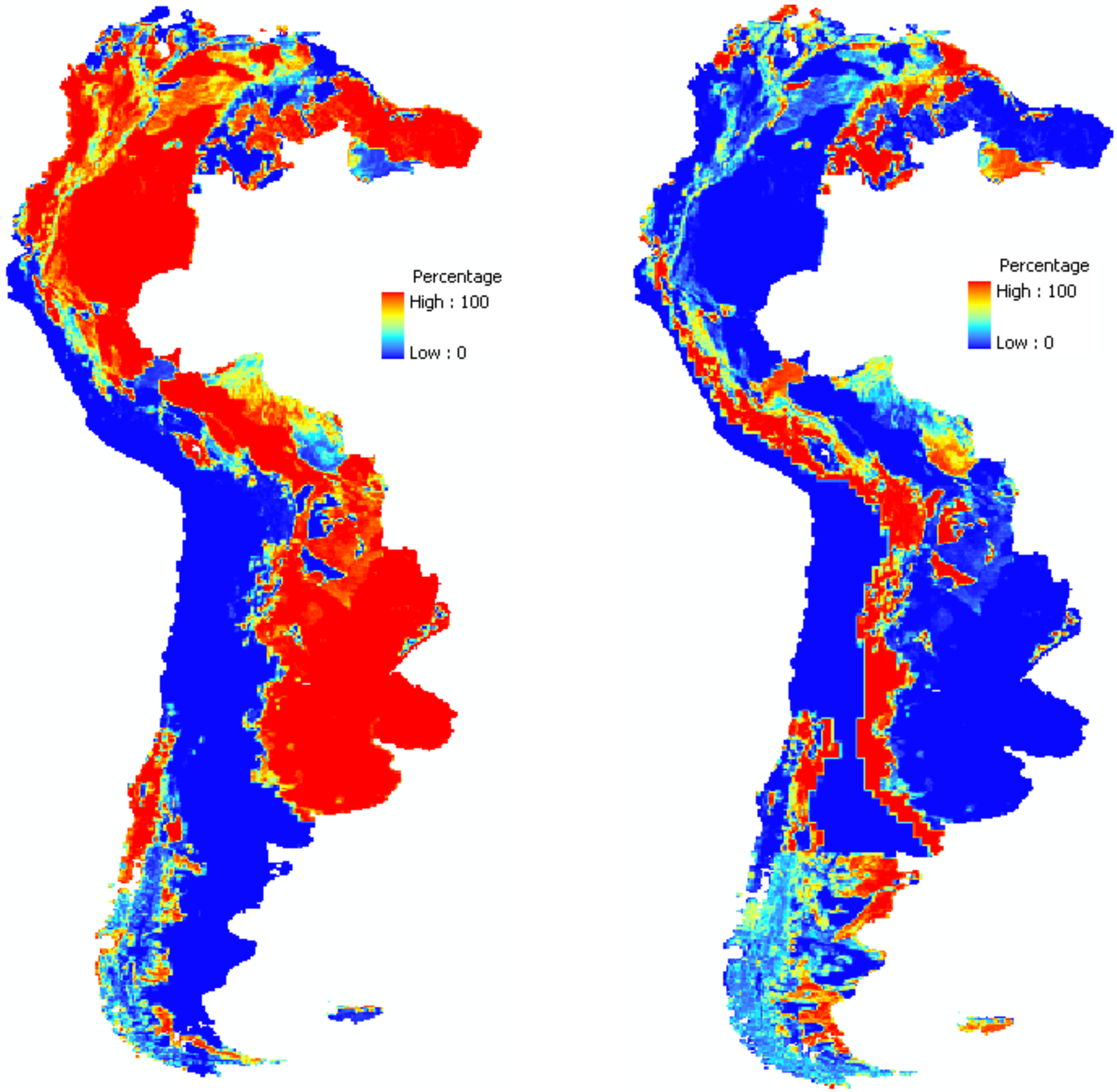
Colors show % of R prod. or M prod. of a land cell
Resolution-
30 arc second (about 1km)

Regular /Marginal productivity land in continental USA

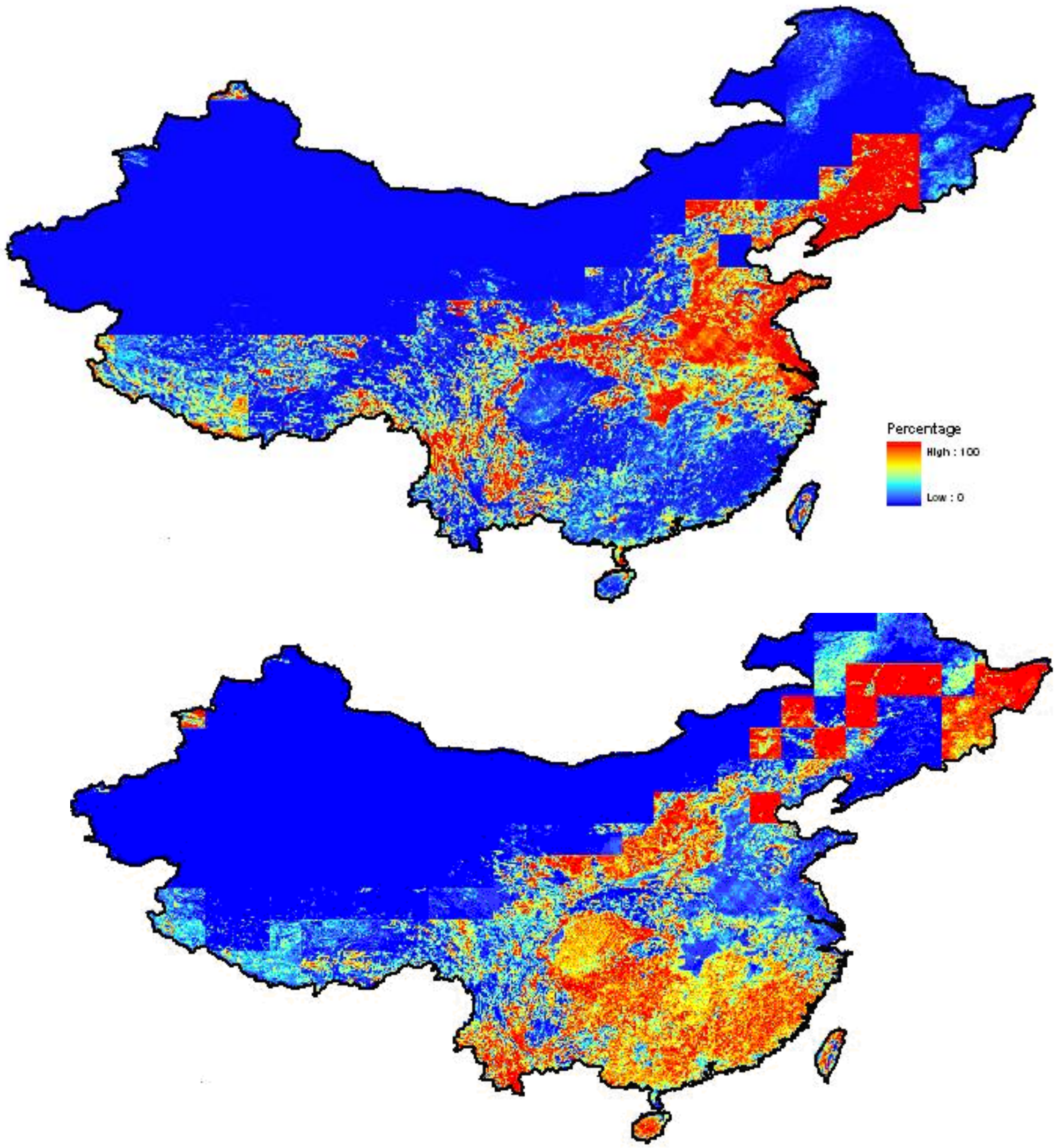




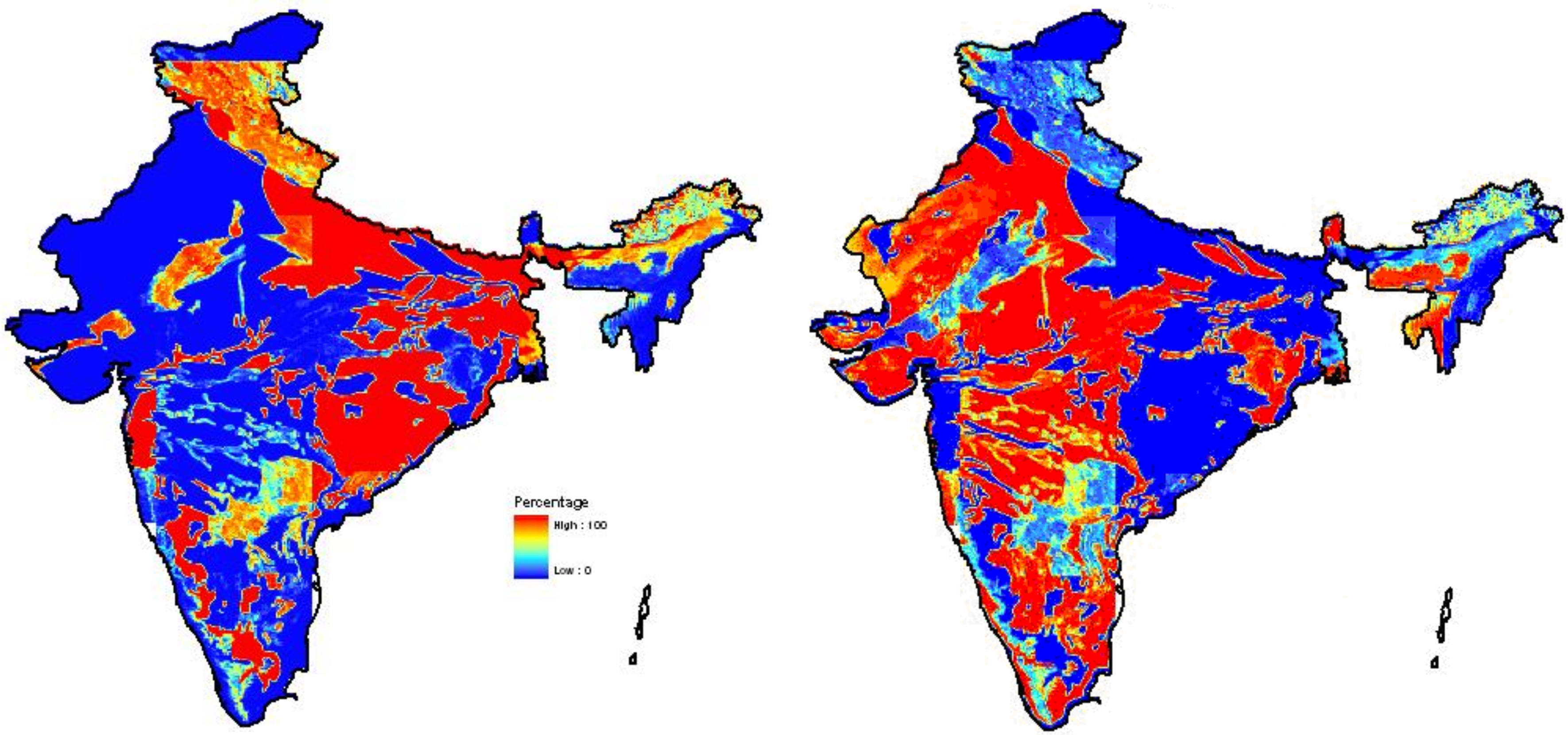
Regular /Marginal productivity land in Brazil



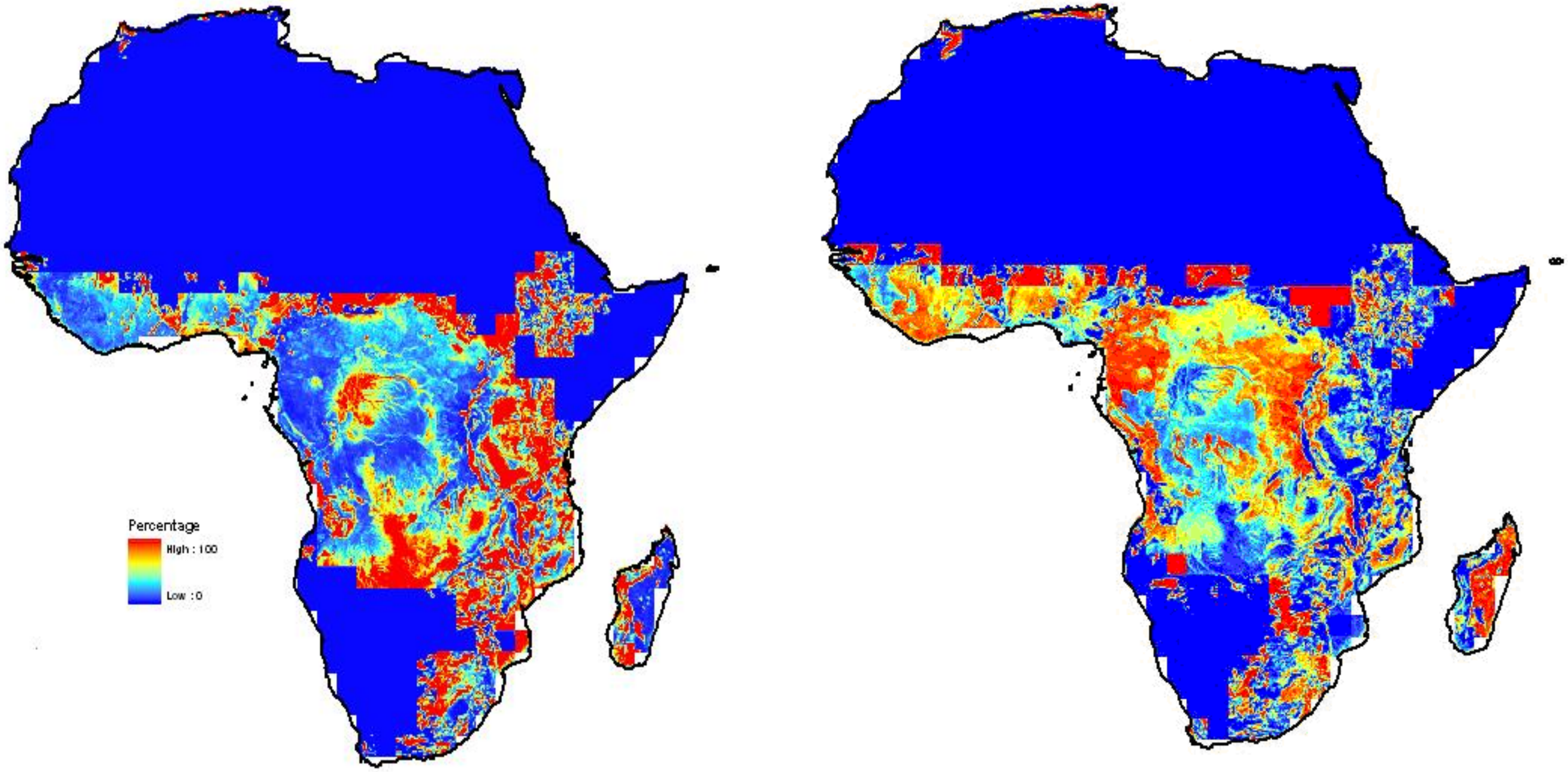
Regular / Marginal productivity land in South America (Ex. Brazil)



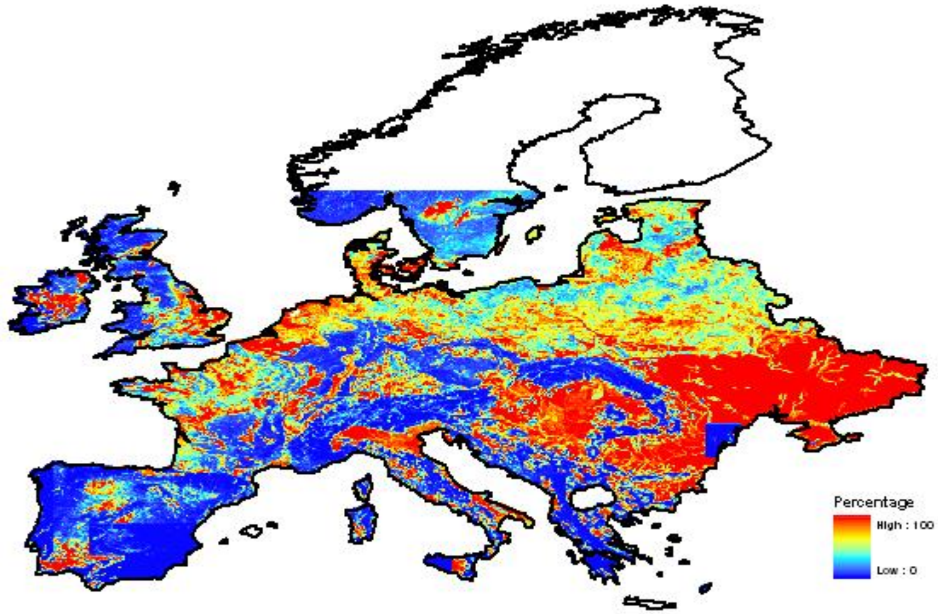
Regular/Marginal productivity land in China

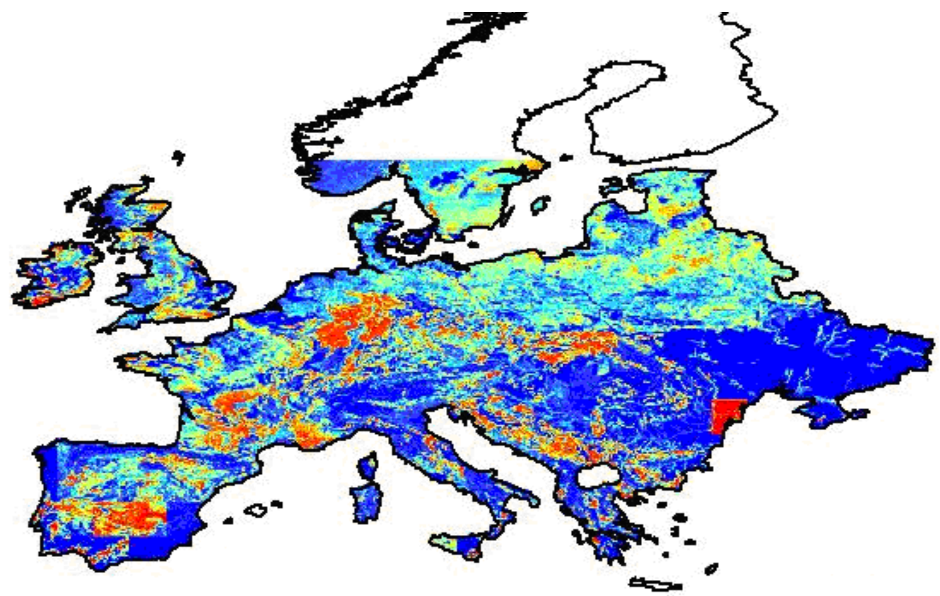


Regular/Marginal productivity land in India



Regular/Marginal productivity land in Africa





Regular/Marginal productivity land in Europe

Scenarios of Land Use for Bioenergy Production (Cai et al. 2011)

S1 – *Marginal mixed crop and vegetation land* - part of abandoned cropland

S2 – S1 and *marginal cropland* - abandoned and degraded cropland

S3 – S2 and *marginal* grassland, savanna and shrubland
(S2+ low-input high-diversity LIHD land for mixed natural perennials **Tillman et al., 2006, 2008**)

S4 – All *mixed crop& vegetation land, marginal cropland* and all *grassland, savanna, and shrubland* discounted by pastureland
(S2+LIHD land without affecting current pasturing)

	Land by regions (mha)						
	Africa	**China**	**EU**	**India**	**S. Am.**	**US**	**Total**
S1	66	52	33	18	108	43	322
S2	132	134	102	110	156	68	702
S3	481	213	109	138	343	127	1411
S4	314	152	111	151	256	123	1107

Other potentials

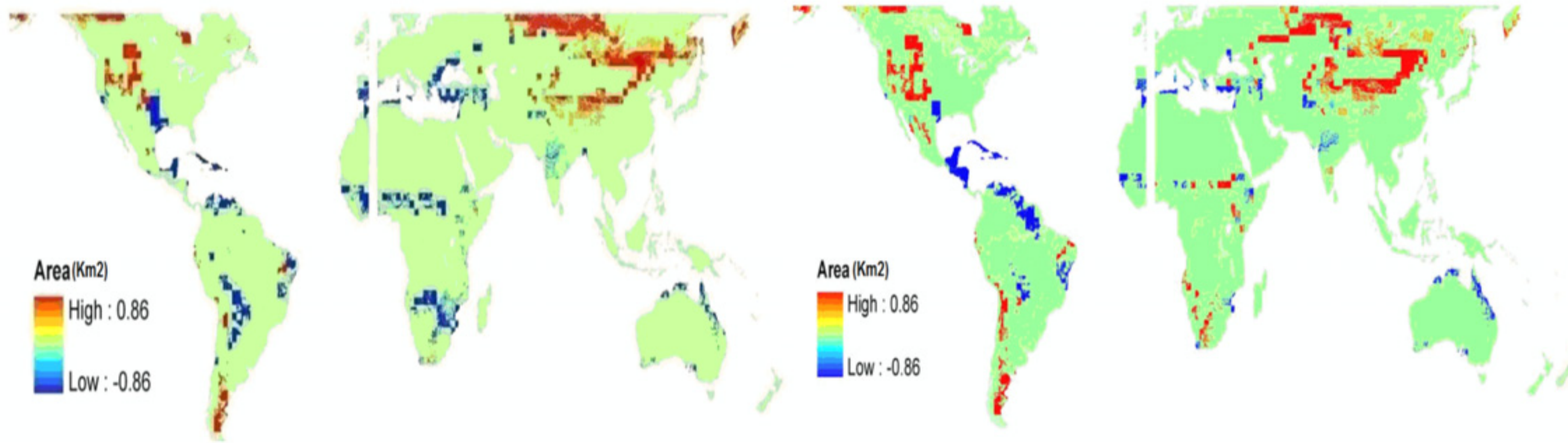
- Forestland ??? Exchange between forestland and cropland?
- Rotation between food, fiber and energy croplands?

Estimates of Net Energy Gain under Land Use Scenarios

- Wide range of NEG for both LIHD prairies and the ... iofuel feedstocks (Davis et al., 2009).
- The range of NEG for LIHD biomass is 17.8 ~ ... *et al.*, 2003; Hamelinck, 2004)
- The range of NEG of the 2nd generation cellulosic ... ate range based on published studies (Schmer, et al., 2008; Fischer et al., 20... Schmidt, 2006; Collura et al., 2006; Angelini et al., 2009).
- The world liquid fuels consumption in 2006 is $1.9*10^{11}$ GJ (Int'l Ene... Outlook).

Planting Lignocellulosic crops on cropland and LIHD prairies on grasslands

Scenarios	Total land available (mha)	Lignocellulosic	
		NEG ($GJ*10^9$)	% to liquid Fuel consump.
S1	**322**	19~45	10~24
S2	**702**	42~98	22~52
S3	**1411**	55~118	29~62
S4	**1107**	49~110	26~58



(a) (b)

Changes of potential arable land under emission scenarios (a) A1B and (b) B1 (Source: Zhang and Cai 2011)

Table 2. Net potential arable land areas and change percentages under historic and projected scenarios

	Africa		China		India		Europe		Russia		South America		US		Global	
	Mkm^2	(%)	Mkm^2	(%)	Mkm^2	(%)	Mkm^2	(%)	Mkm^2	(%)	Mkm^2	(%)	Mkm^2	(%)	Mkm^2	(%)
Baseline	10.33		3.79		2.33		3.11		1.96		8.82		3.24		41.32	
A1b-SAM	8.47	−18	5.28	39	2.00	−14	2.45	−21	2.71	38	5.65	−36	3.46	7	38.05	−8
A1b-RMSEMM	7.14	−31	4.77	26	2.02	−13	2.43	−22	3.05	56	6.76	−23	3.20	−1	37.62	−9
B1-SAM	9.26	−10	5.09	34	2.05	−12	2.65	−15	2.35	20	7.16	−19	3.78	17	40.62	−2
B1-RMSEMM	7.99	−23	4.68	24	2.05	−12	2.65	−15	2.66	36	7.48	−15	3.57	10	39.46	−5

Opportunities: Updated and New Models

- WaterGap 2.1, WaterGap-N (Univ of Kassel and Univ of Frankfurt)

- VIC model (nearly real-time for U.S., Africa and other regions, Princeton and U. of Washington)

- Coupled Common Land Model (CLM) and a 3-dimensional volume averaged soil-moisture transport (VAST) model (Univ. of Illinois)

- More …

Limitations: Water Infrastructure and Water Use Data

- Reservoir storage
- Water withdrawal capacity
- Surface water versus groundwater
- Water consumption versus water withdrawal
- Water use efficiency
- Agricultural versus non-agricultural water use
- Water quality and its impact on food production
- Instream flow requirements

These items have limited data sources from FAO, IWMI, IFPRI, Pacific Institute and other agencies mainly at the country and regional level

Limitations: Modeling Issues

- Small scale versus large scale
- Uncertainty with both natural and human factors
- Physically-based model versus empirical model
- Retrospective analysis versus prediction
- Model coupling (scales, uncertainties, result interpretation etc.)

Some Comments

- A "white model" of water availability at sub-basin scale is still difficult given the limited data (especially with human factors) and the limited model validation with both natural and human parameters

- Conduct experiments on scale /complexity / uncertainty using observation

- Use observation to verify the prediction made 10-15 years ago

- Build on testbeds at the country or regional level

- Target at a plausible trend from now to the future based on those from history