Water Availability and Global Land Use Change

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Based on joint work with
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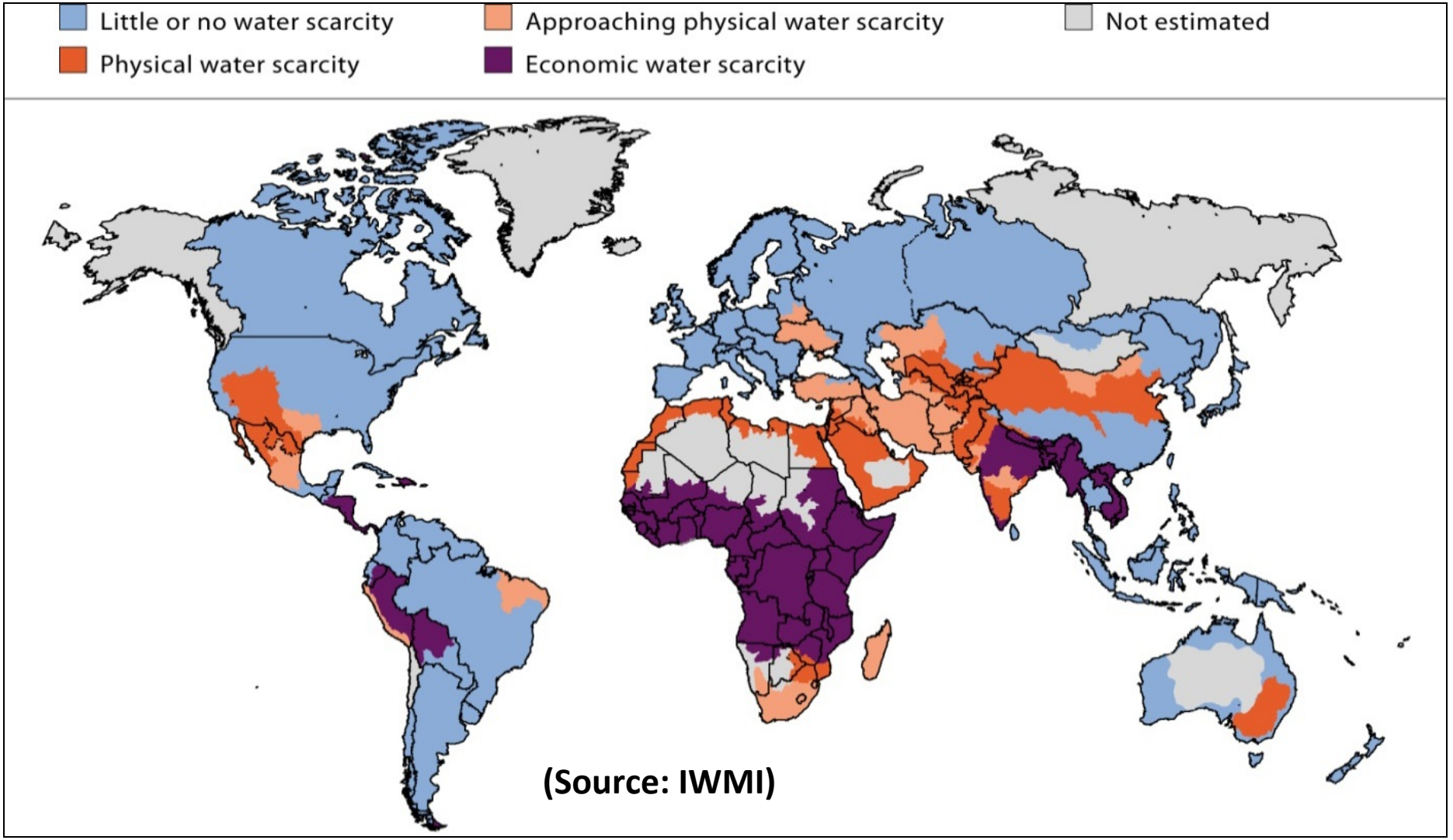
Background (1)

- **Water resource challenge**
  - **Demand for water will outstrip capacity to provide it**
    - **Existing reliable supply: 4.2 (trillion m^3)**
    - **2030 estimated demand: 6.9 (trillion m^3)**

      (Source: *2030 Water Resources Group)*

Global Water Scarcity



(Source: IWMI)

Background (1)

- Water resource challenge
  - Demand for water will outstrip capacity to provide it
    - Existing reliable supply: 4.2 (trillion m^3)
    - 2030 estimated demand: 6.9 (trillion m^3)

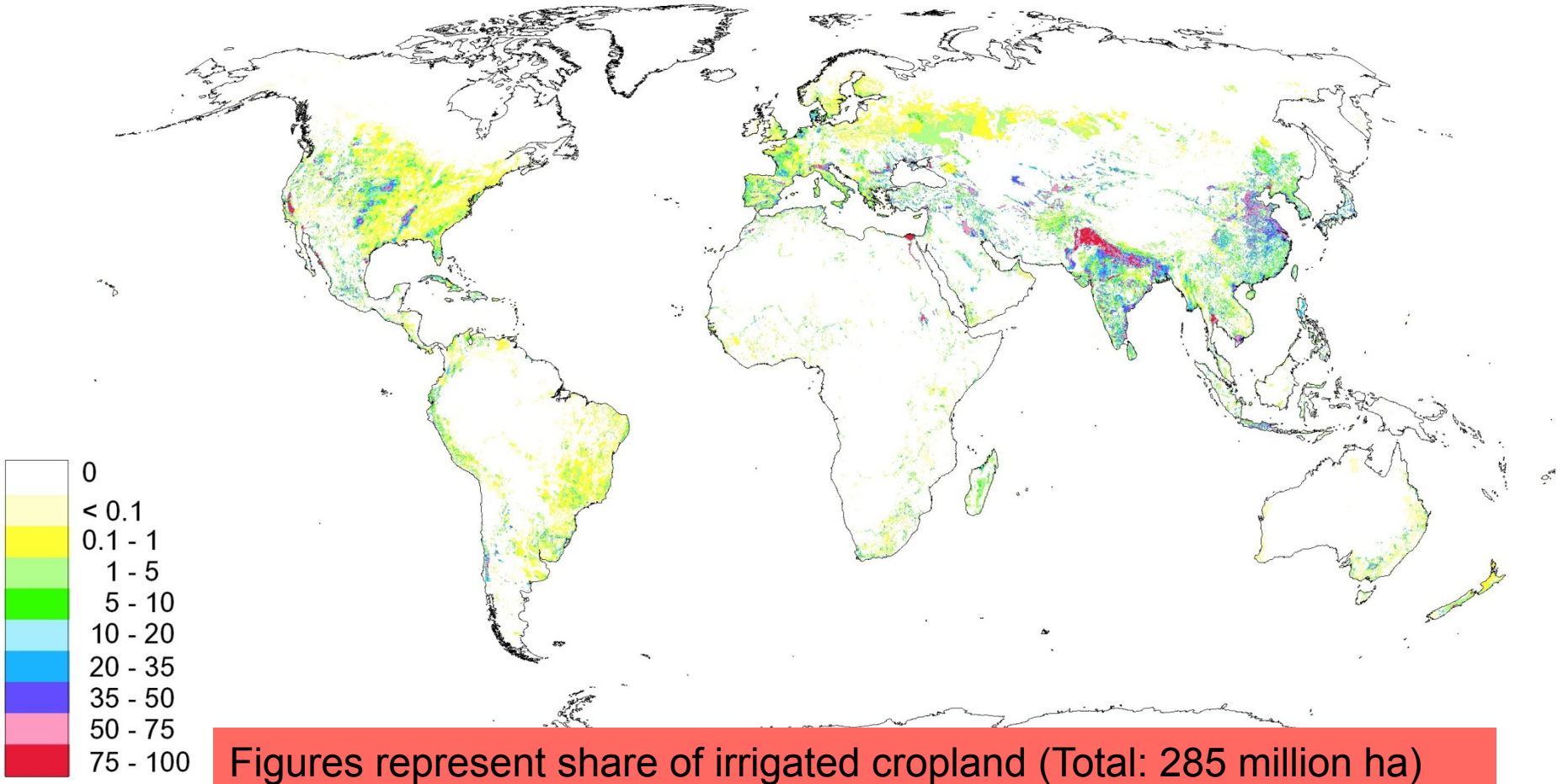
      (Source: *2030 Water Resources Group)*
  - **Climate-induced water variability may exacerbate the stress**
    - **Changes in precipitation and temperature**
    - **More extreme wet and dry days**
    - **Seasonal variation**

Background (2)

- **Our focus is on water for irrigated agriculture**
  - **Agriculture relies heavily on irrigation:**
    - **Accounts for 40% of global production (20% of harvested area)**
    - **Irrigated crop yields avg 2.3 times higher than rainfed yields**
    - **Agriculture in arid regions is impossible without irrigation**

Role of irrigation in agriculture

Irrigated area in 2000

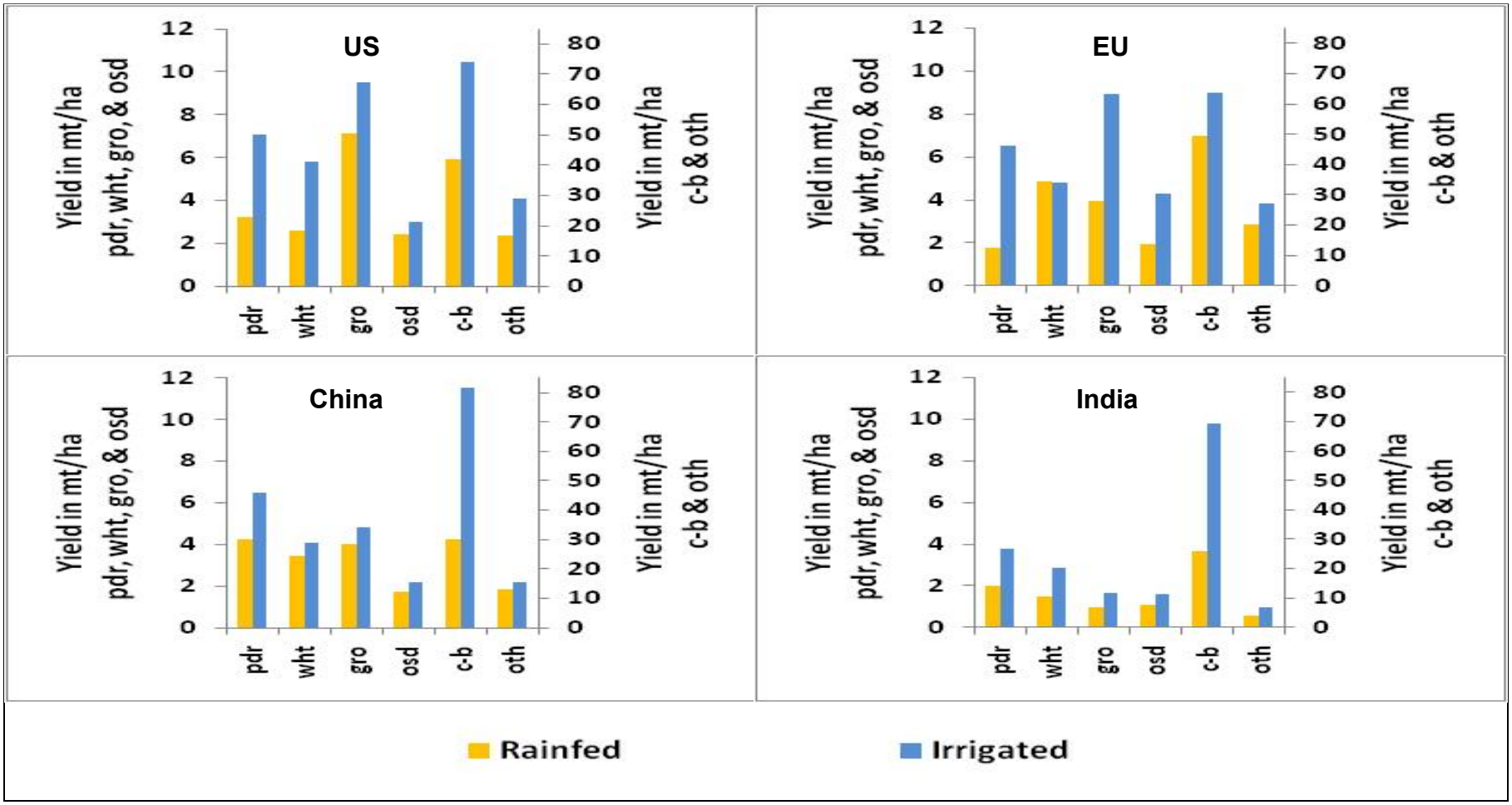


Figures represent share of irrigated cropland (Total: 285 million ha)

Source: Siebert et al., 2006

Role of irrigation in agriculture

Irrigated & rainfed yields by crop types for selected regions



Irrigated yields are generally much higher than rainfed

Background (2)

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  - Agriculture relies heavily on irrigation:
    - Accounts for 40% of global production (20% of harvested area)
    - Irrigated crop yields avg 2.3 times higher than rainfed yields
    - Agriculture in arid regions is impossible if without irrigation
  - **Agriculture tends to be a large, low-priority user compared to civilian and industrial uses**
    - **Accounts for 70% of global fresh water withdrawals**
    - **In areas where water shortages arise, solution is often to remove it from agriculture (e.g., US Southwest)**
    - **What if the projected water gaps in future are closed by cutting down irrigation?**
  - **Irrigation constraints will alter the pattern of land use in the wake of increased demands (e.g., for biofuels)**

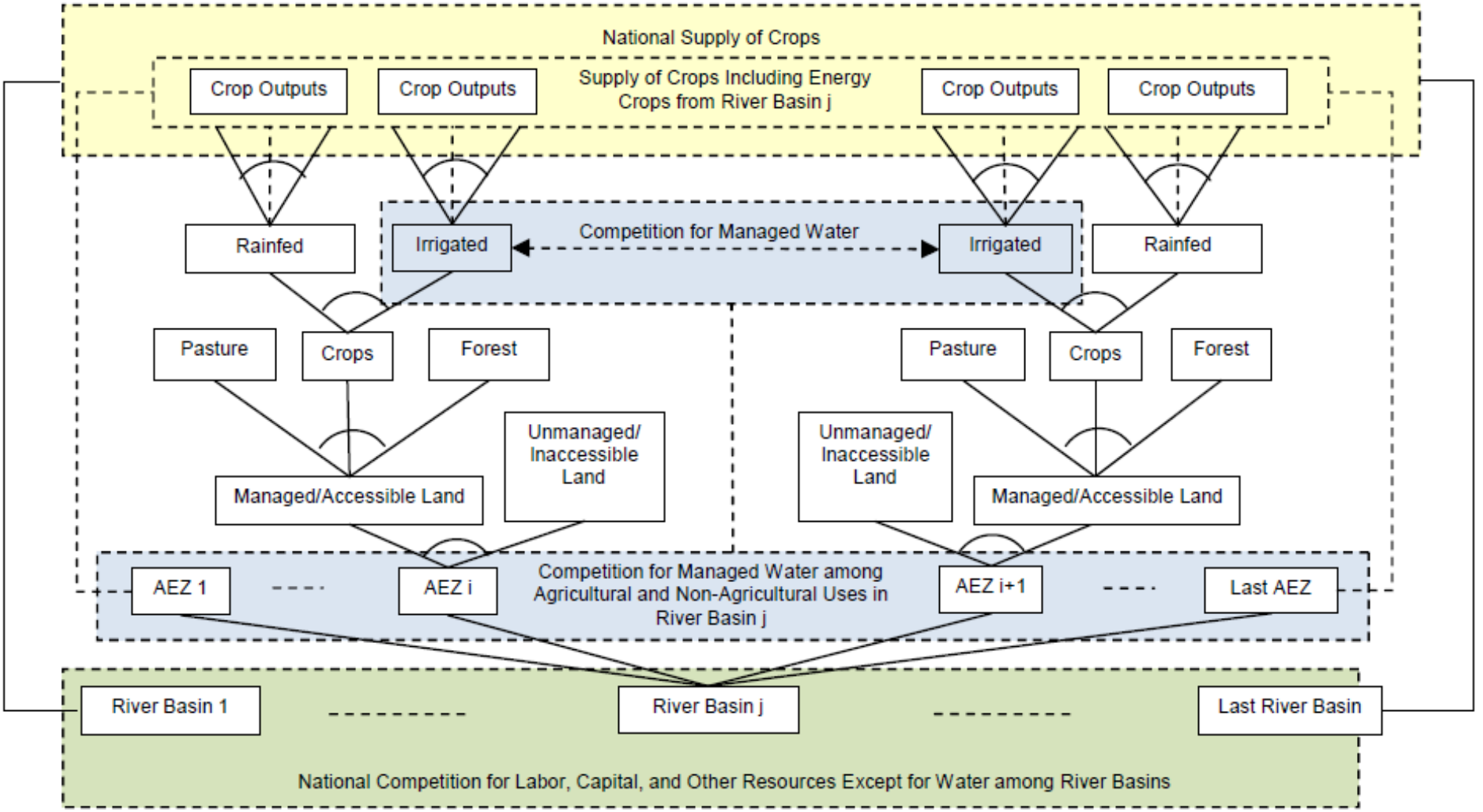
Water-Land cover-Trade Nexus

- Water stress suppresses expansion of irrigated area
- Crop production shifts towards rainfed agr, but expanded production through non-irrigated production entails more area than if could expand both irrigated and rainfed areas together
- Rainfed areas are also more carbon-rich, so not only need more land conversion, but more emissions/ha converted
- Future water scarcity may have far reaching consequences:
  - reshaping global distribution of crop production
  - Changing trade patterns likely

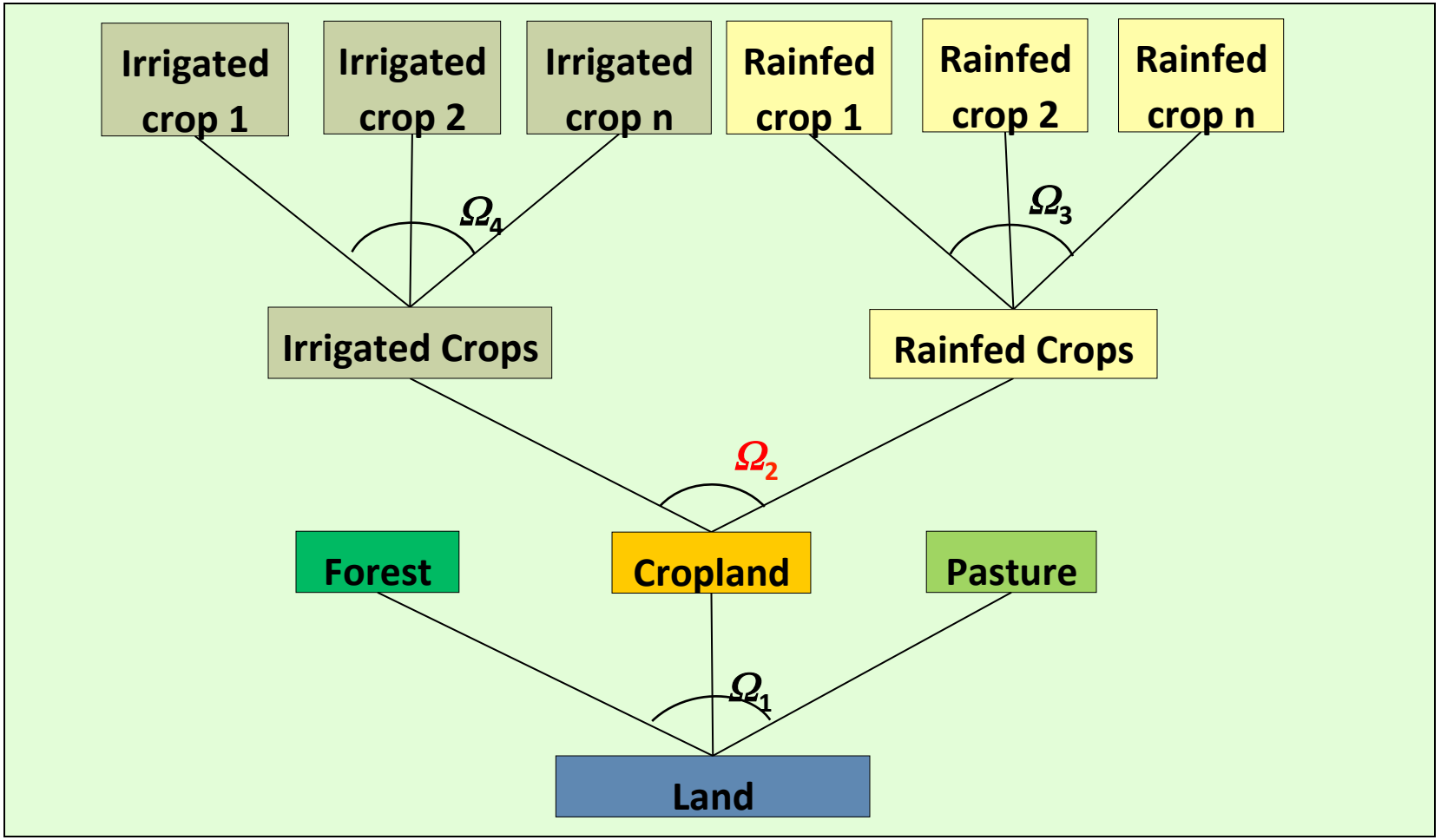
Preliminaries: The Data Gap

- **In order to address this issue, need a global scale, spatial data base which reports yields and harvested area for rainfed and irrigated agriculture at the grid cell, at global scale**
- **Many groups working on this issue spend the majority of their time on data creation, minority on modeling and analysis; final data products are non-comparable and inferior to what could be produced by data base originators if they were to collaborate**
- **As with others working in this area, we merged multiple inconsistent data bases for this work.**
- **GEOSHARE aims to remedy this... More on this tomorrow**

Method: Modeling Framework



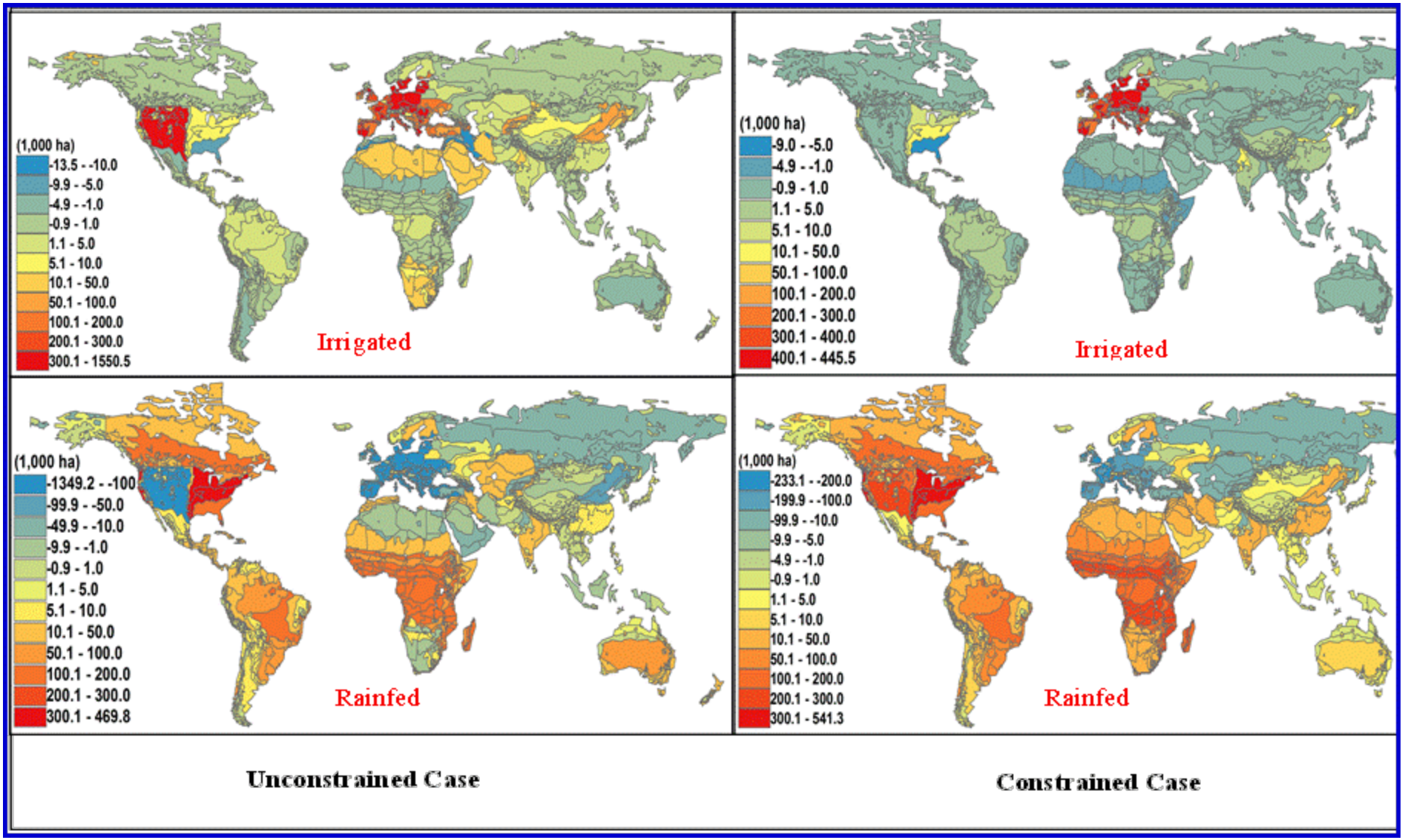
Zoom in: Land supply structure



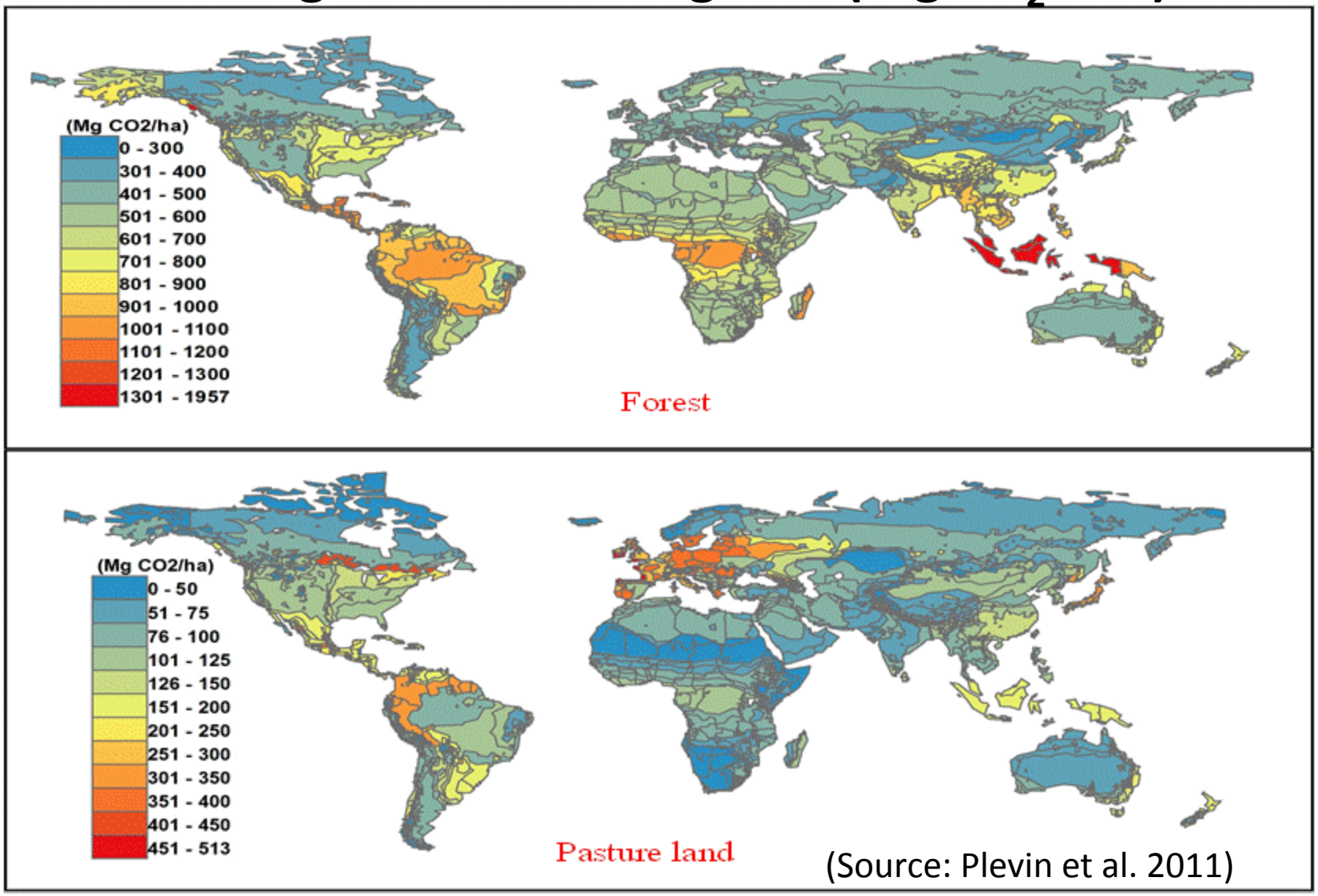
Methods: Part I

- Taheripour, Hertel and Liu (2011) introduced rainfed and irrigated agriculture into GTAP-BIO model: Water is an implicit input in irrigated agriculture
- Key distinction is between high productivity irrigated crop production and lower productivity rainfed production
- Taheripour, Hertel and Liu (2011) investigate how irrigation constraints alter the pattern of land use in the face of biofuels expansion

Pattern of land use change is altered by irrigation constraints



Carbon fluxes due to conversion of natural land to cropland are larger in rainfed regions (Mg CO_2 ha^{-1})



(Source: Plevin et al. 2011)

So the presence of irrigation constraints boosts the ILUC emissions from biofuel expansion

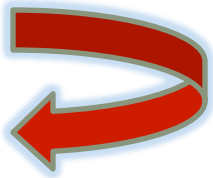
Simulations	Ethanol Production (billion gallons)	Annualized ILUC Emissions	
		(gCO_2eMJ^{-1})	Deviation from Baseline (%)
Unconstrained	13.23	35.60	0.05
Baseline	13.23	35.62	0.00
Constrained	13.23	45.43	27.5

Methods: Part II

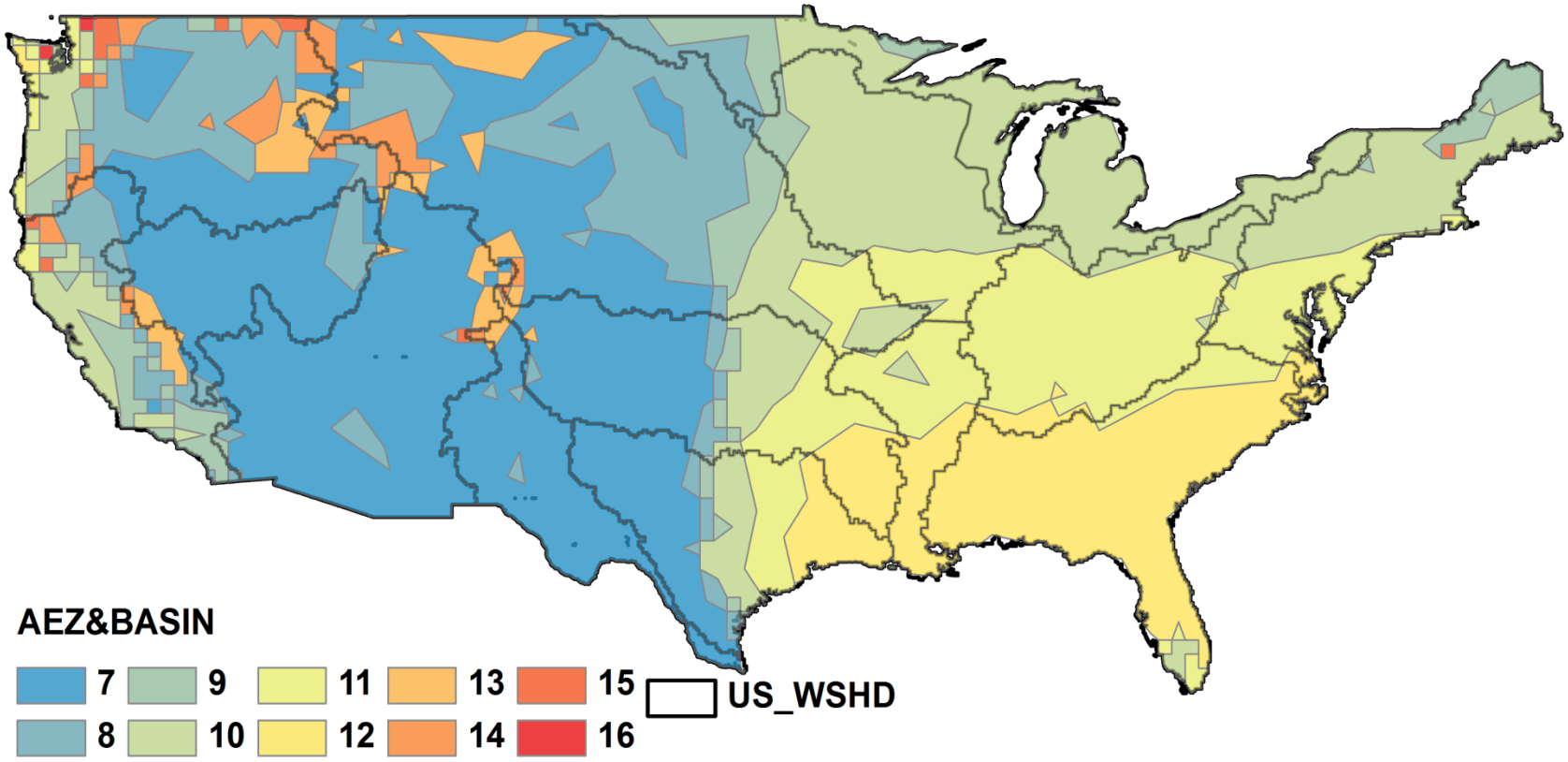
- In this work, water is introduced as an explicit input
- Water and land are complementary inputs in irrigated agriculture at basin-AEZ level
- Irrigation water is a mobile input for irrigated crops and can move across AEZs within a river basin
- Supply of water is fixed at river basin level; leading to intense competition for irrigation water
- Irrigated and rainfed croplands continue to compete with other land uses, including forestry and pastures

Method: Data

- **Grid-based data (Siebert and Döll, 2010) REG_AEZ_BASIN (in physical terms)**
  - **area, output and water use by crop and irrigation condition**
  - **tell apart irrigated and rainfed agriculture**
- **Determine value added of land & water (in value terms)**
  - **yield differences at grid cell attributed to application of irrigation water**
- **6 Crops, 19 Regions, 18 AEZs, 20 Basins**
  - **Now we keep track of production at Basin/AEZ level**



River Basins often cut across AEZs

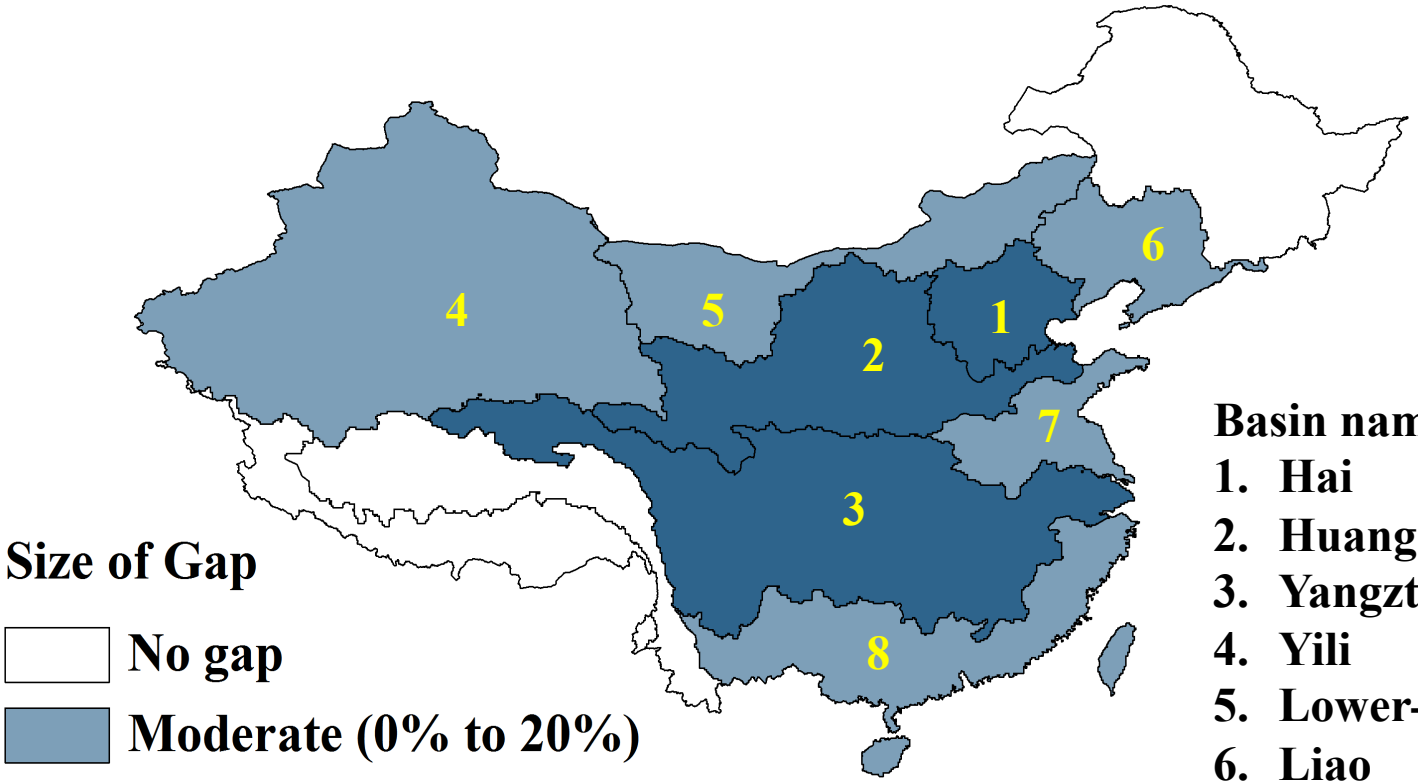


Black lines outline the River Basins

A case study: Projected water shortage in China in 2030

- China is a key country in global crop production and trade
- Heavy use of irrigation; irrigation water productivity appears to be low:
  - 44.8% of the harvested area is irrigated, generating 44.2% of the total crop output
  - US 15.9% vs. 33.2%, EU 9.4% vs. 16.5%
- Severe water shortages in some basins due to urbanization and industrialization; depletion of groundwater

Water gap between existing supply and projected demand in 2030



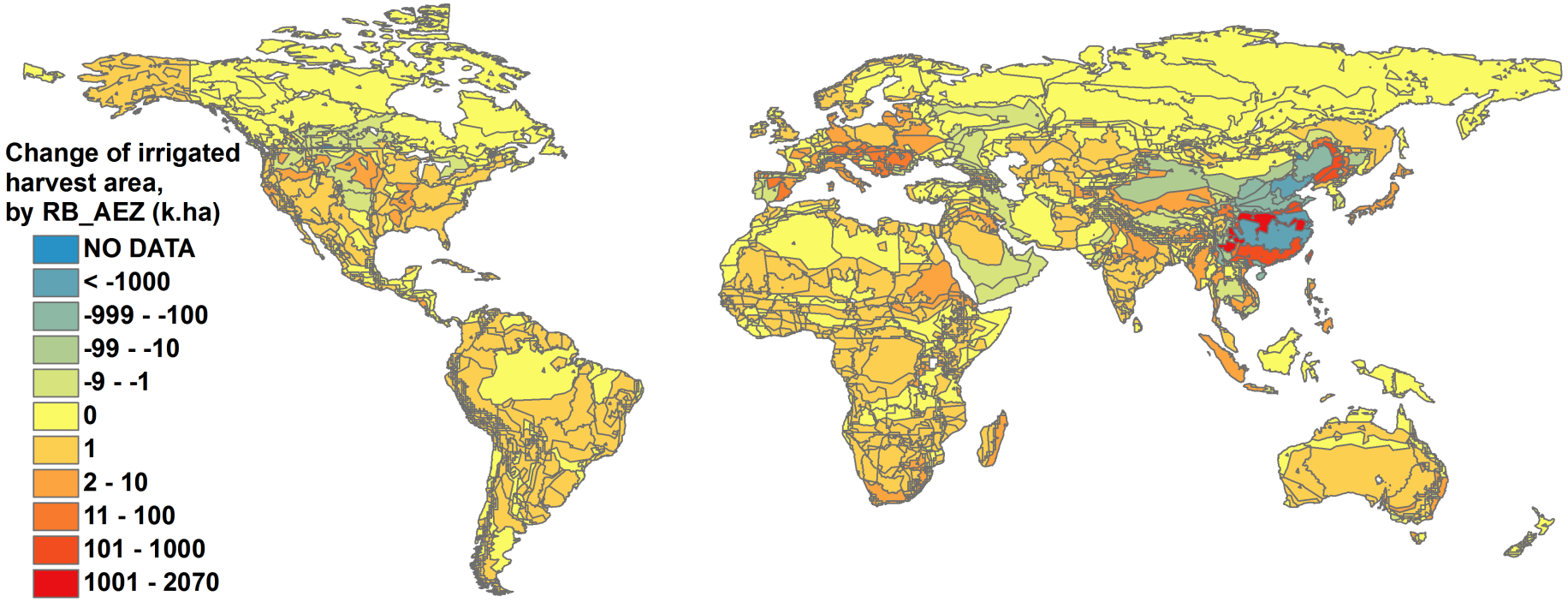
Source: Charting Our Water Future - McKinsey & Company

Experiment

- Water supply fixed in non-China regions
- Rising non-agricultural water demand ⟷ limited supply of irrigation water
- Shocks to available water supply:
  - Yangtze, Huang and Hai Basin by 50%
  - Huai, Liao, Lower-Mongolia, Yili and Pearl Basin by 10 %
- No other exogenous shock; water efficiency is unchanged: impacts will be outer bound

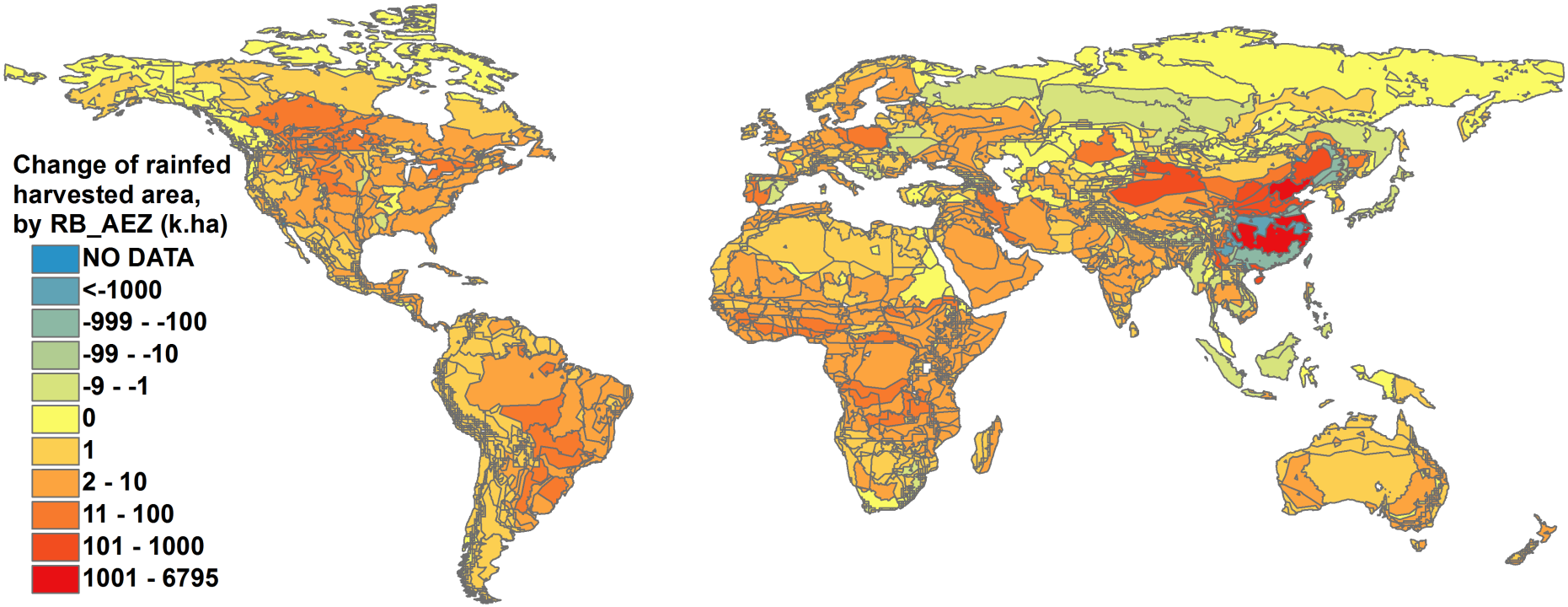
Results

Irrigated area contracts in water scarce regions, expands elsewhere



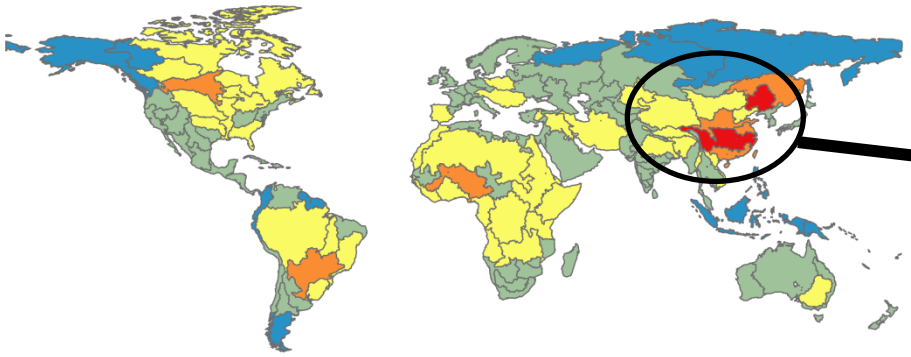
Polygons represent AEZ-intersected BASINs. When water stress arises, AEZs within the basin compete for water (e.g. Yangtze basin in China).

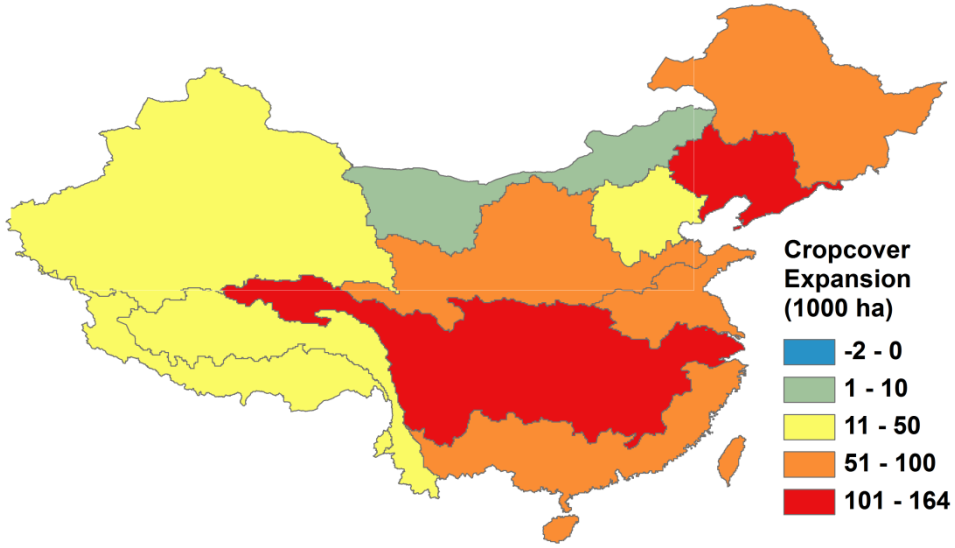
Rainfed area expands in water scarce regions, contracts elsewhere in China



Harvested area expands globally (1000 ha)

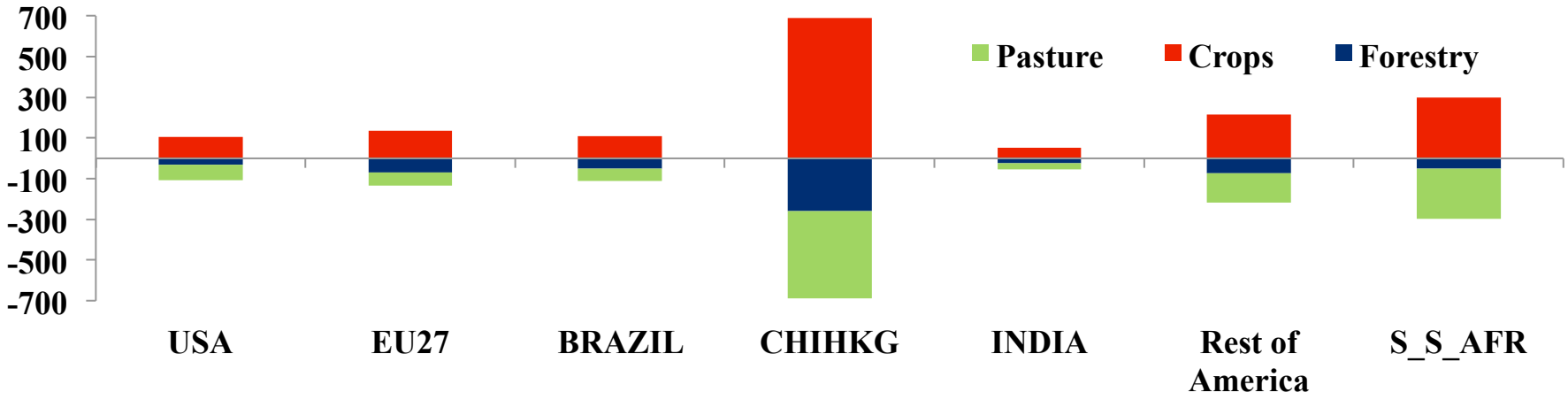
Crop	USA	EU27	Brazil	CHIHKG	INDIA	World
Irrigated crops	21	32	1	-7539	12	-7400
Rainfed crops	85	103	109	8228	40	9214
Total	107	135	109	689	53	1814





- Largest land use change occurs in China
- Yield difference is not very big in China, except for sugar
  - Sugar crops: 1.7 times higher
  - Other crops: 20-50% higher

Land Cover Change (1000 ha)



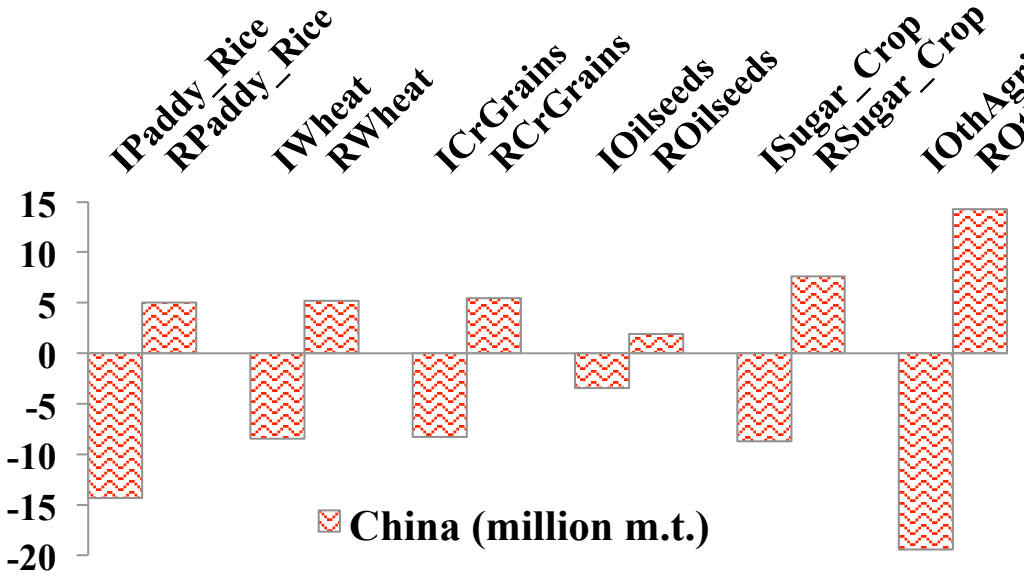
- **Globally,**
  - **Cropland +1.81**
  - **Forests - 0.48**
  - **Pasture - 1.34 (mill. ha)**

Global Crop Cover Expansion

- **More area but less output, because newly converted land is less productive due to absence of irrigation (unit: m.t./ha)**

Crop	Yield before	Yield after
Paddy_Rice	3.91	3.88
Wheat	2.75	2.74
CrGrains	3.09	3.07
Oilseeds	2.52	2.51
Sugar_Crop	58.69	58.72
OthAgri	10.40	10.37

Crop Production Change (1000 m.t.)



- **Irrigated production decreases, rainfed production increases.**
- **Crop output falls in China, slightly rises in other regions.**

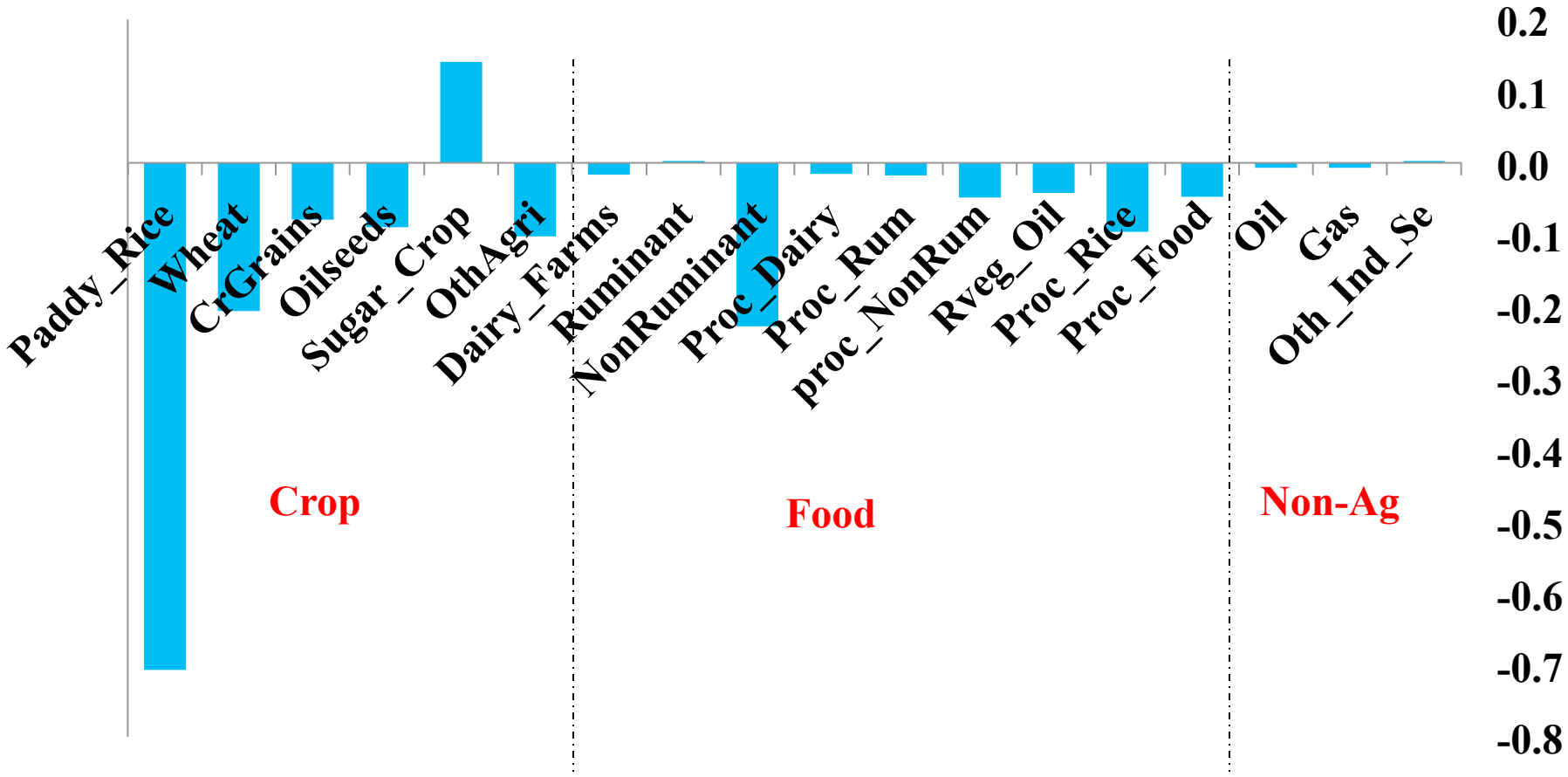
Crop	USA	EU27	CHINA	INDIA	ROW	World
Paddy_Rice	27	31	-9362	83	346	-8875
Wheat	103	111	-3275	53	332	-2675
CrGrains	529	86	-2784	7	478	-1684
Oilseeds	354	129	-1496	12	762	-240
Sugar_Crop	0	28	-1098	-35	-230	-1334
OthAgri	325	1198	-5210	195	1788	-1704

Other Commodity outputs also affected (% chng)

Crop	USA	EU27	BRAZIL	CHINA	INDIA
Dairy_Farms	-0.02	0.01	0.01	**-0.27**	-0.04
Ruminant	0.04	0.07	0.02	**-0.75**	0.18
NonRuminant	0.12	0.09	0.17	**-0.94**	0.002
Proc_Dairy	-0.01	0.01	-0.01	**-0.54**	-0.02
Proc_Rum	0.02	0.02	-0.05	**-0.68**	0.32
proc_NonRum	0.07	0.05	0.22	**-1.94**	0.51
Rveg_Oil	0.09	0.01	-0.05	**-1.10**	-0.06
Proc_Rice	1.04	1.10	0.00	**-1.25**	0.07
Proc_Food	0.03	0.03	0.00	**-1.44**	0.09
Oil	-0.01	-0.01	-0.02	**0.12**	-0.01
Gas	-0.02	0.01	-0.03	**0.22**	-0.01
Oth_Ind_Se	-0.003	-0.01	-0.02	**0.17**	-0.03

Lstk outputs also contract due to higher priced feed and more intense competition for land; Non-agr output expands to deliver needed exports

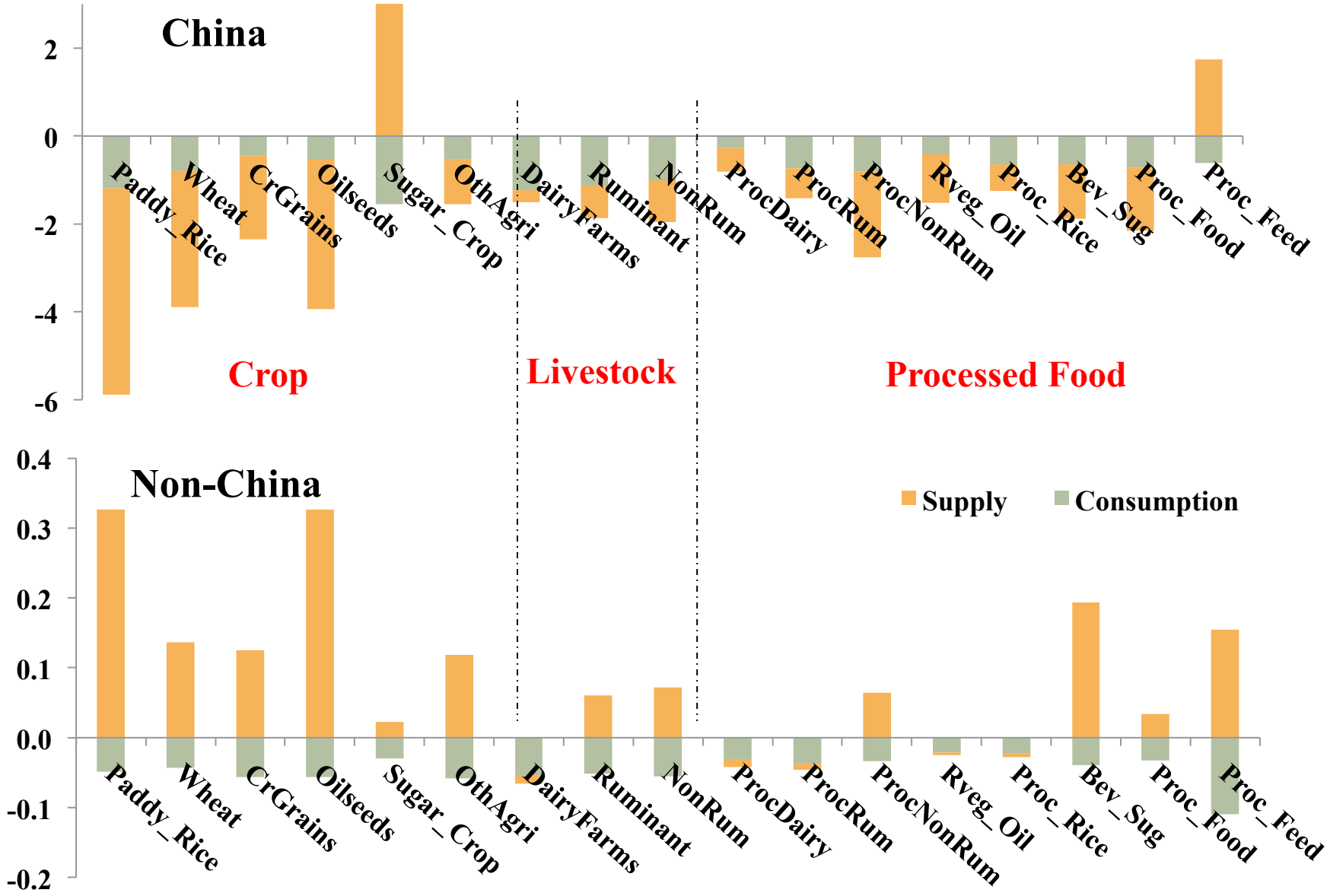
With fewer resources, global output contracts (% change index of world output, by sector)



Dirving up crop prices, particularly in China

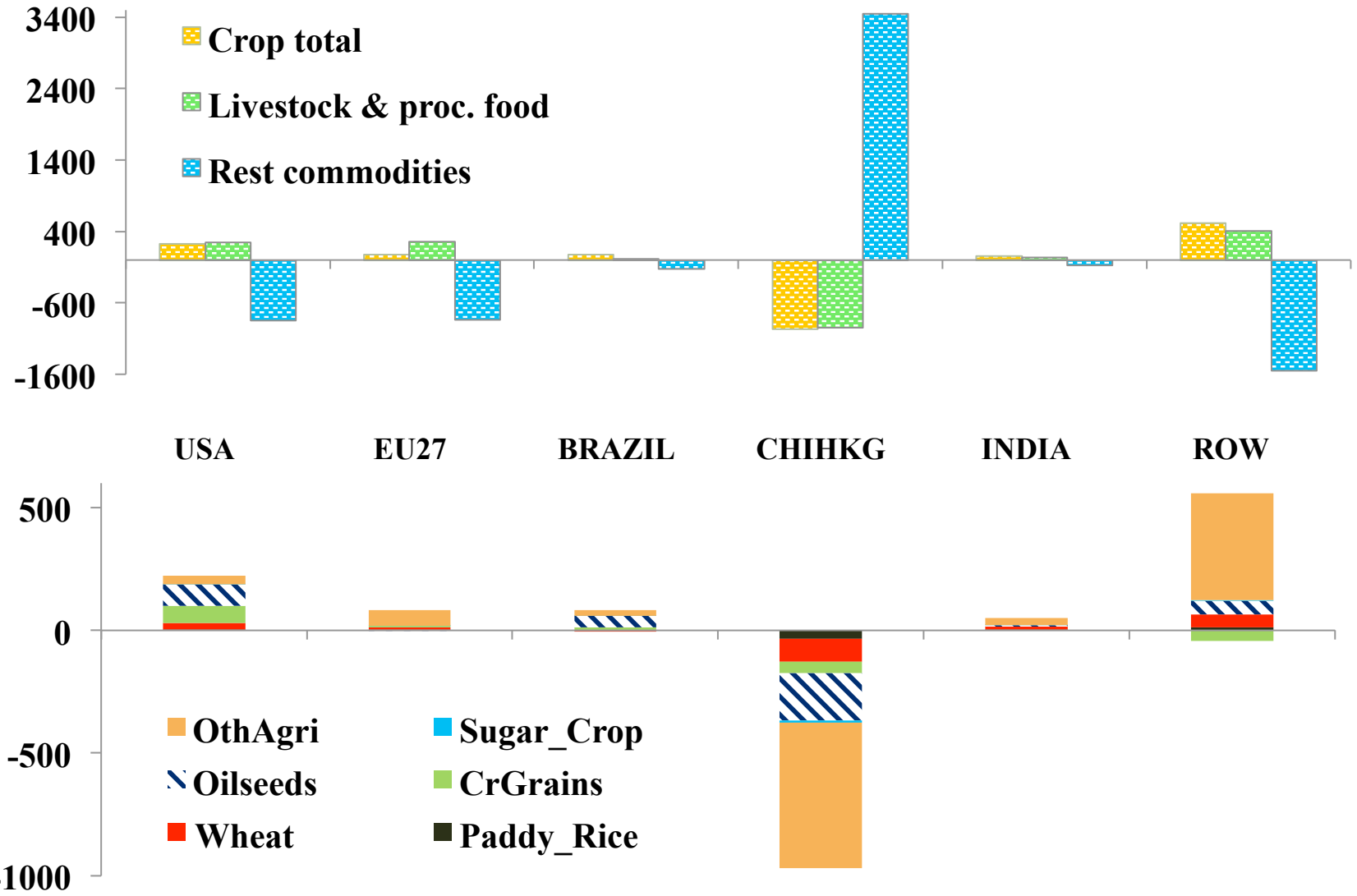
Crop	USA	EU27	BRAZIL	CHIHKG	INDIA
Paddy_Rice	0.5	0.2	0.4	15.3	0.3
Wheat	0.5	0.3	0.4	8.4	0.2
CrGrains	0.5	0.3	0.5	7.7	0.2
Oilseeds	0.6	0.4	0.5	5.6	0.2
Sugar_Crop	0.6	0.2	0.4	22.0	0.3
OthAgri	0.5	0.3	0.4	3.9	0.3

So food consumption contracts globally, with largest reductions in China



Significant Changes in Trade Balance ($US mill):

- Rate of return falls in China, causing dTBAL >0
- China exports more non-agr, imports more agr



Conclusion

- **Reduction in supply of water for irrigation could cause land use changes and affect other economic variables; *estimates at upper bound due to fixed water efficiency***
- **Crop production competes with land from forestry and livestock sectors**
- **International trade buffers the shock of variable regional water supply, but the spillover effects cause worldwide crop land expansion**
- ***Question: What happens when other regions ALSO experience similar water shortages?***
- **There is no interoperable, internally consistent, spatially explicit, global data base for rainfed and irrigated yields and harvested area; discuss this challenge tomorrow in context of GEOSHARE project**