Coupling for ESM: CESM and iPETS

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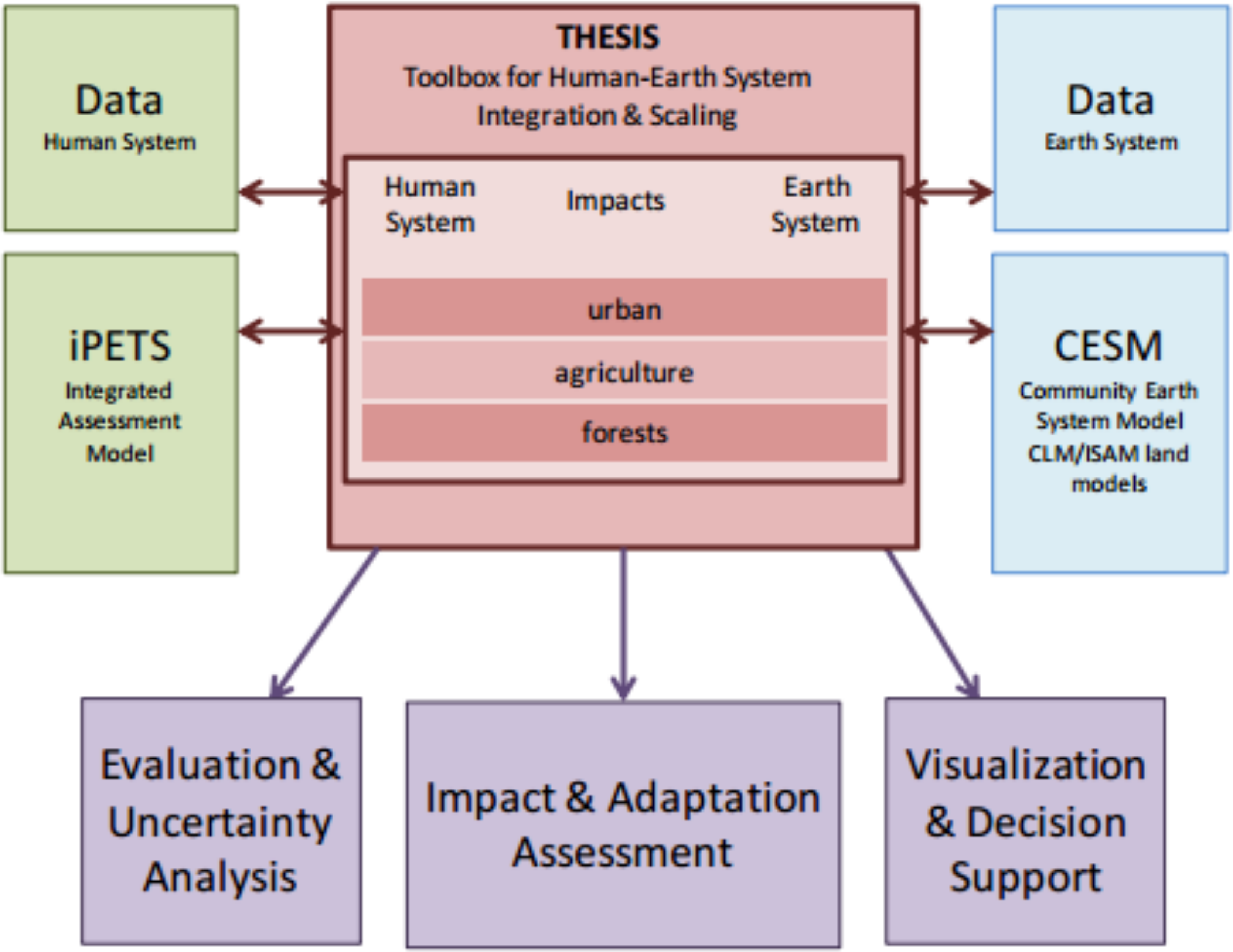
THESIS Soft Coupling of iPETS to CESM



iPETS coupled to CLM Crop Yield Tool Investigation

1. Assess the avoided crop yield impacts of RCP 4.5 compared to RCP 8.5 in the SSP3 and SSP5 scenarios

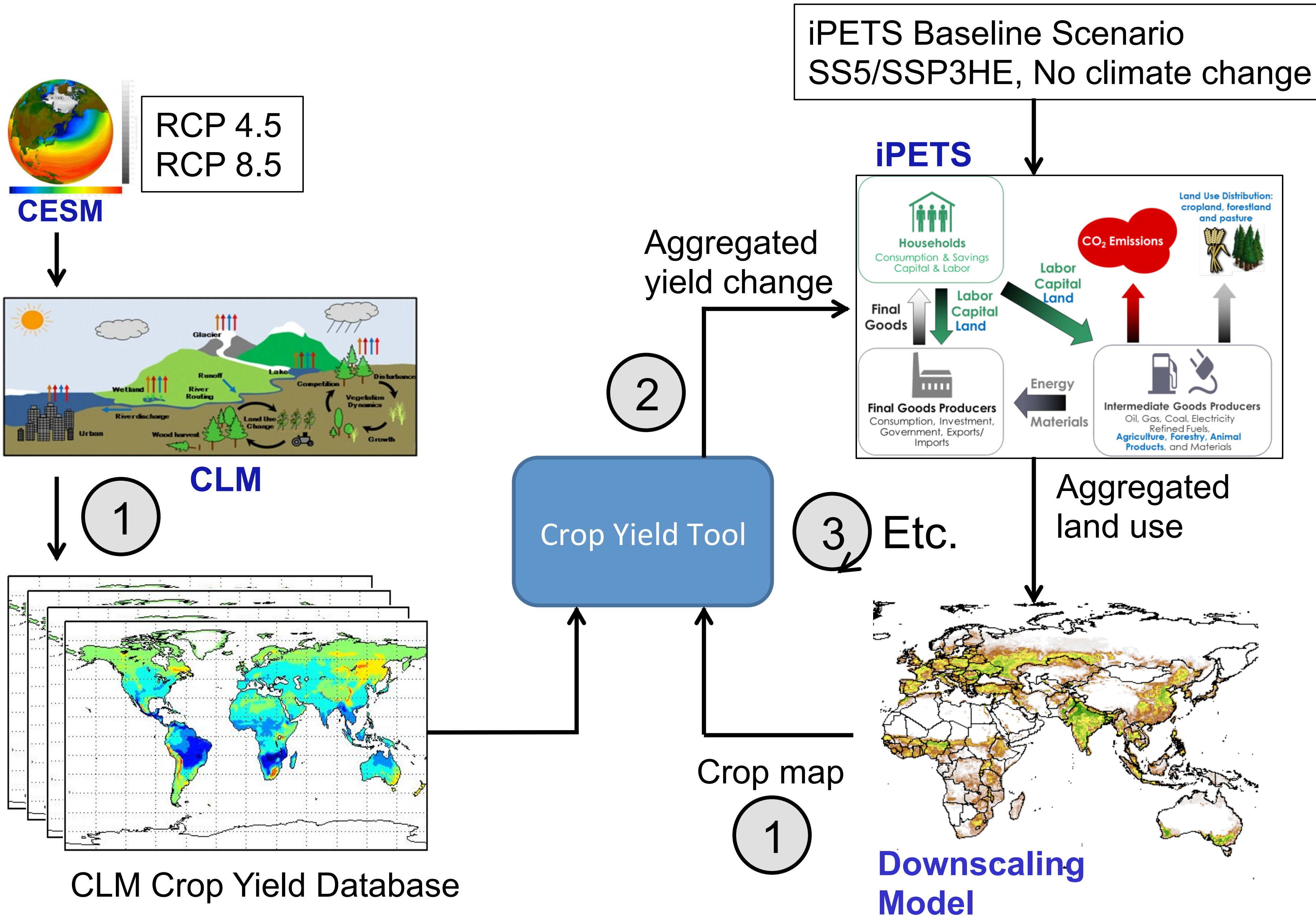
2. iPETS baseline SSP3 (high population with lower tech change)
   baseline SSP5 (lower population with higher tech change)

3. The climate impacts on crop production for each SSP scenario are evaluated with the RCP 4.5 and RCP 8.5 climate. iPETS produces:
   SSP3HE-RCP4.5 SSP3HE-RCP8.5 SSP5-RCP4.5 SSP5-RCP8.5

4. The climate impacts on crop production are evaluated using the CLM Crop Yield Tool for each of the scenarios using crop and pasture demand downscaled to individual crops at 0.5 degrees globally

5. The climate impacts on crop yield are returned to iPETS to adjust the crop productivity in each SSP – RCP combination scenario. iPETS then produces new Crop and Pasture demand which is evaluated in the CLM Crop Yield Tool until they are consistent

THESIS Agricultural Demand iPETS to CESM Crop Yield



THESIS Crop and Pasture Demand in iPETS

Inputs → iPETS Model → Outputs

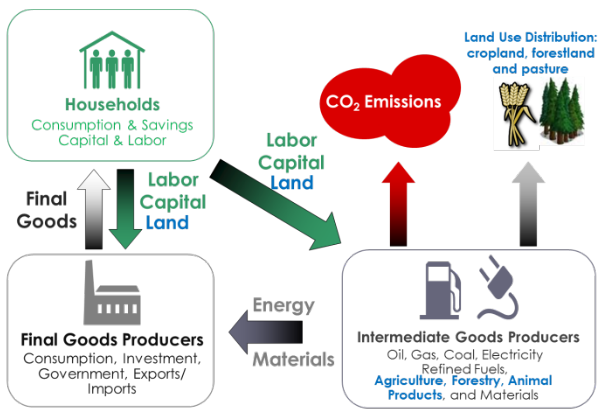
Inputs

Economic **initial conditions** (region, sector)

Projected **population**

Technological progress: projected productivity of land, energy, labor

Policies (carbon tax, emissions permits, subsidies, etc.)



Outputs

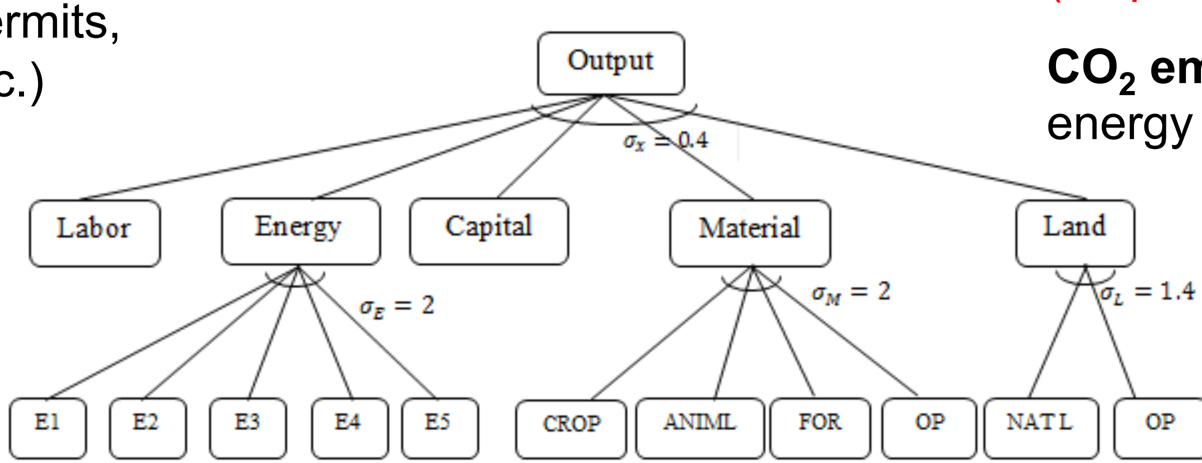
Total **economic output** (GDP)

Quantities of goods produced and consumed (energy, food)

Prices of goods (energy, food)

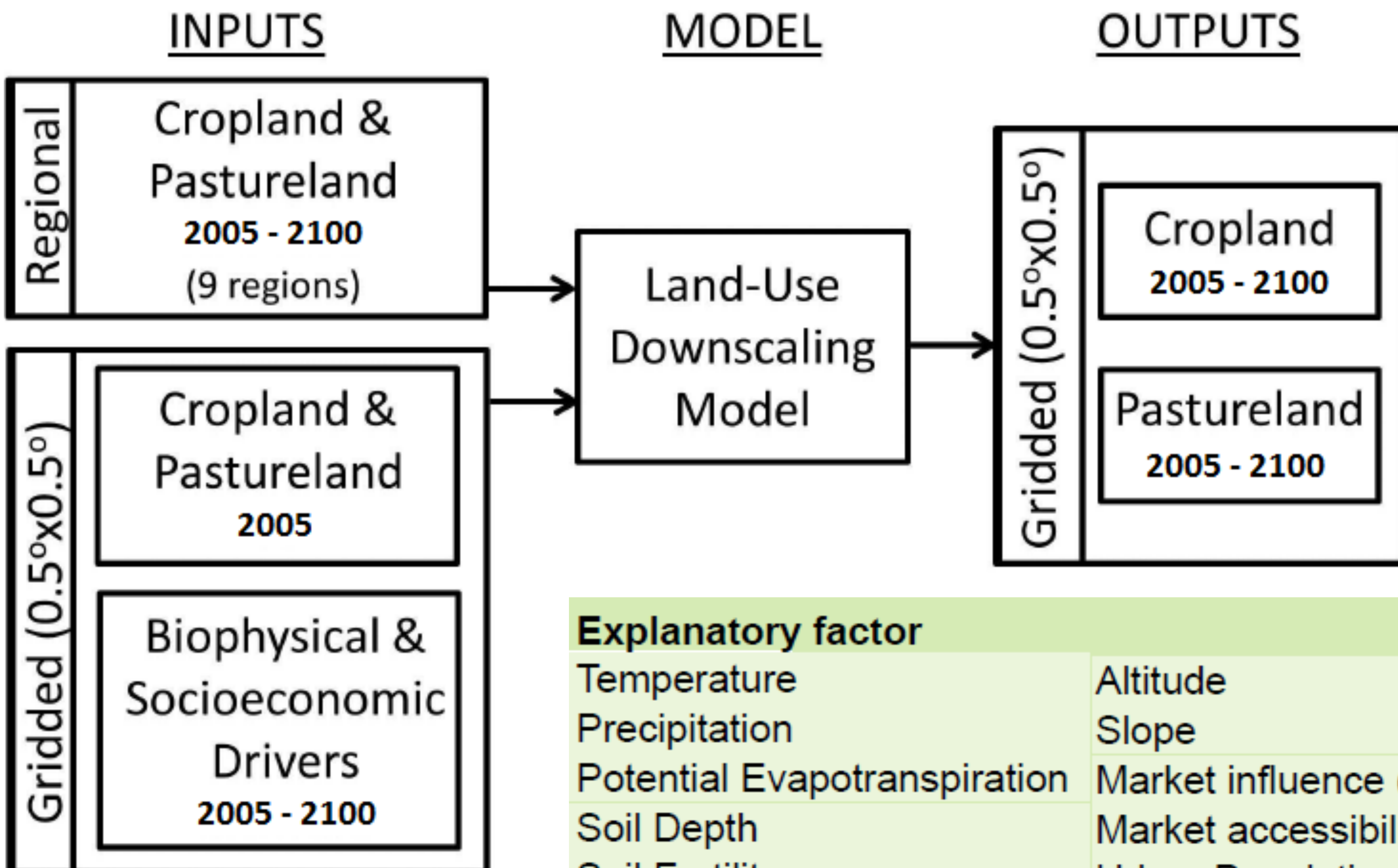
Aggregate **land use** (cropland, pasture)

CO_2 emissions from energy use



THESIS Crop and Pasture Downscaling – Meiyappan 2014

Annual regional demand for crop and pasture land for 2005 – 2100 from iPETS for each SSP – RCP scenario to generate 0.5 degree maps

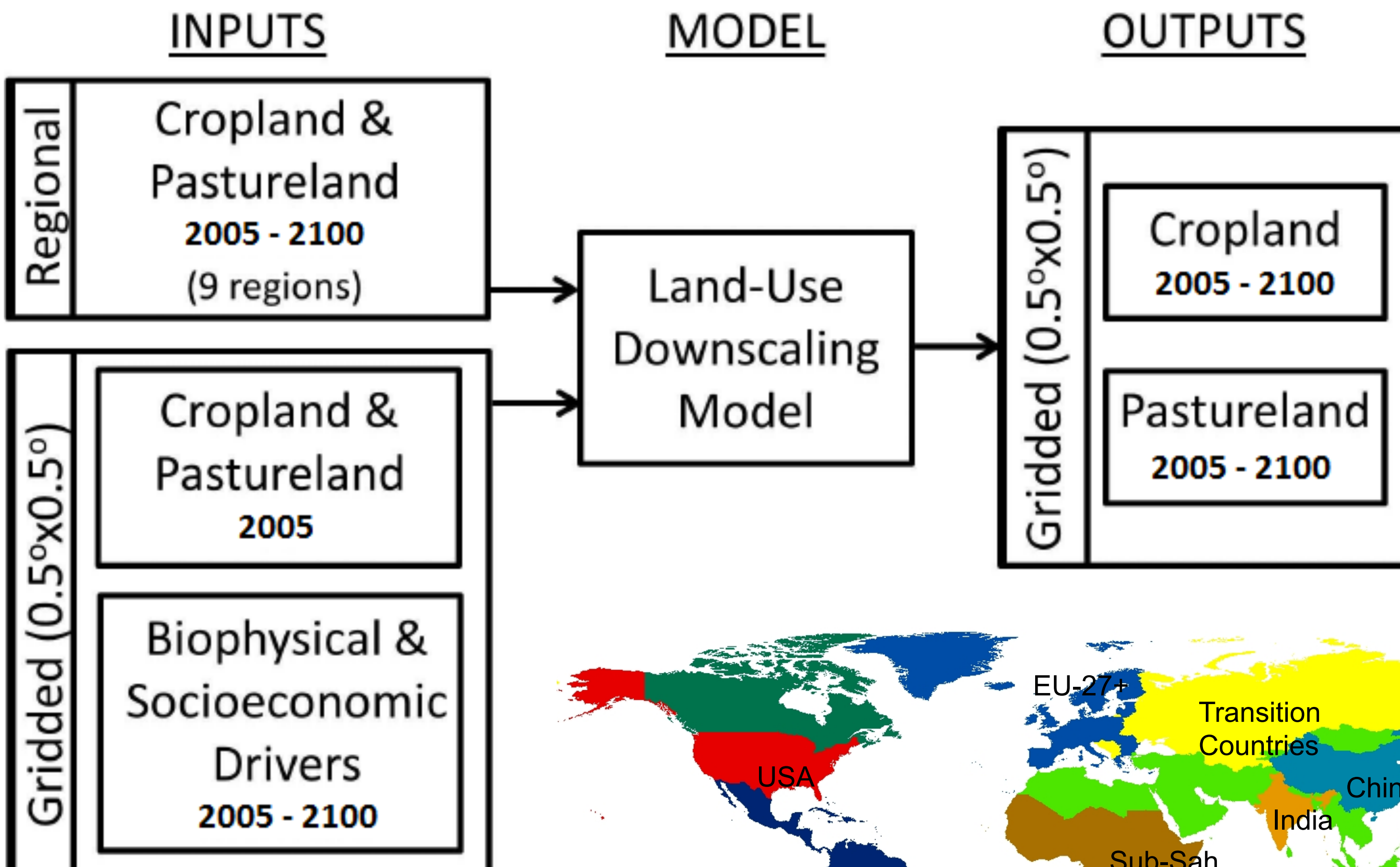


$$Min \sum_{i=1}^{2} \sum_{j=1}^{M} (F_{ij} - F'_{ij})^2$$

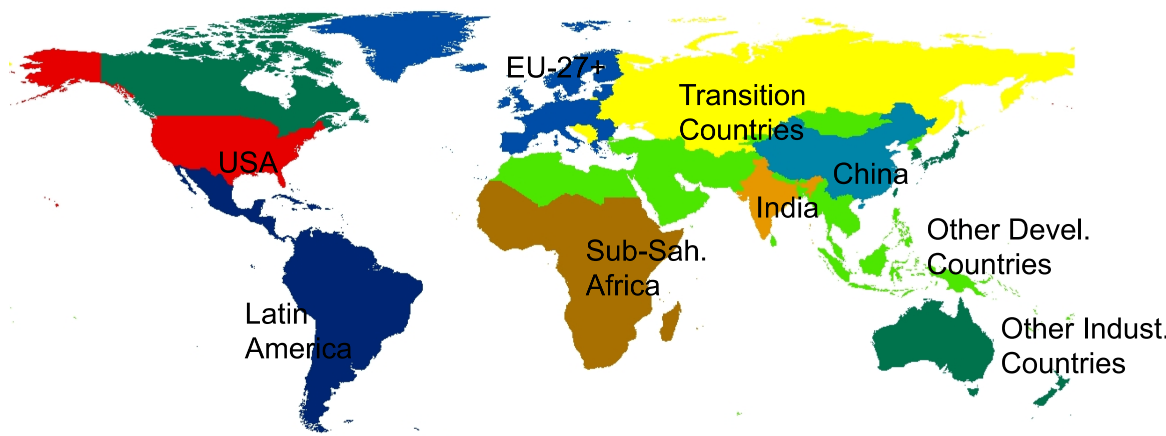
Explanatory factor	
Temperature	Altitude
Precipitation	Slope
Potential Evapotranspiration	Market influence (GDP)
Soil Depth	Market accessibility
Soil Fertility	Urban Population density
Soil Drainage	Rural Population density
Soil Texture	Urban/Bulit-up land
Soil Chemical Composition	Area Equipped for Irrigation

THESIS Crop and Pasture Downscaling – Meiyappan 2014

Annual regional demand for crop and pasture land for 2005 – 2100 from iPETS for each SSP – RCP scenario to generate 0.5 degree maps



$$Min \sum_{i=1}^{2} \sum_{j=1}^{M} (F_{ij} - F'_{ij})^2$$



CLM Crop Idealized Crop Simulations

Following the AgMIP GGCMI protocol we performed a series of idealized CLM Crop simulations for Historical and Future RCP cropping

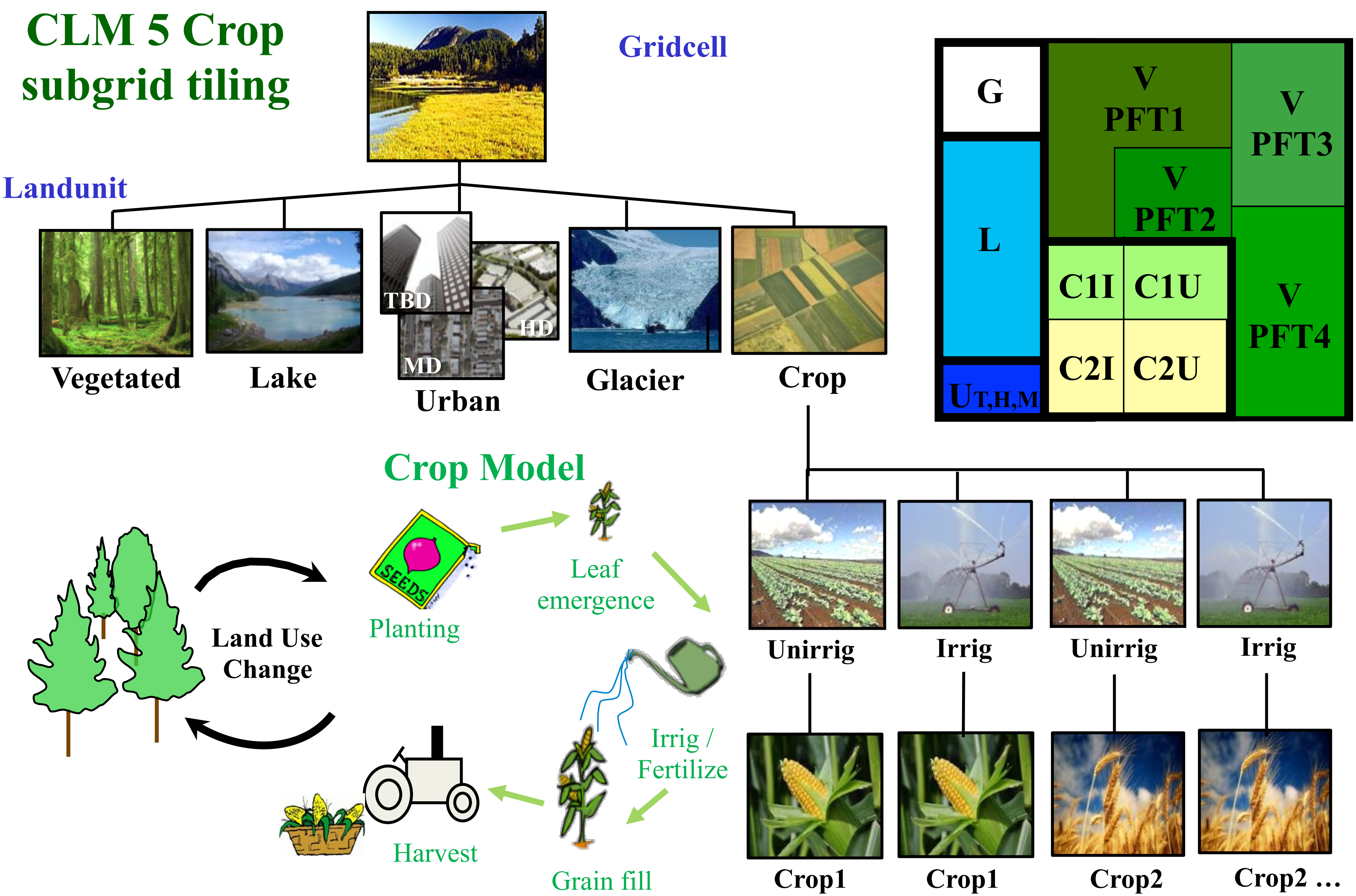
1. Run globally with Wheat, Maize, Soy, Rice, Sugarcane, Cotton in every vegetated land grid cell and with meteorology and CO_2 from Community Earth System Model simulations from CMIP5 (AR5)

   – Historical 1901- 2005
   – RCP 4.5 medium CO_2 and warming scenario 2006 - 2100
   – RCP 8.5 high CO_2 and warming scenario 2006 - 2100

2. We simulated the CLM-Crop model with variations in irrigation, N fertilizer, climate change, and atmospheric CO_2 change for each of these climate runs.

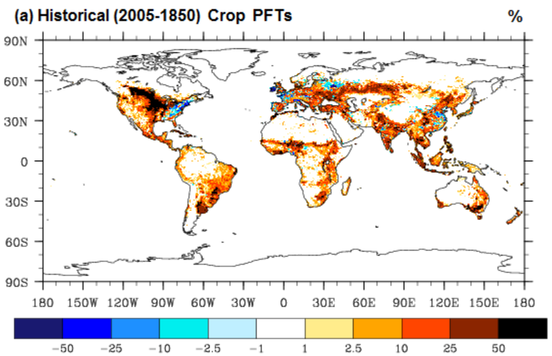
3. UNFAO Data 1961 – 2013 had been compiled at country level for:

   Crop Area – Irrigation Fraction – N Fertilizer – Production/Yield

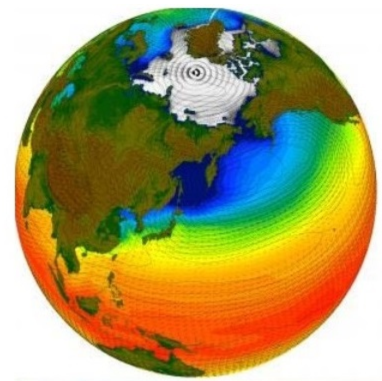

CLM 5 Crop subgrid tiling
Gridcell
Landunit
Vegetated
Lake
TBD
HD
MD
Urban
Glacier
Crop
G
L
UT,H,M
V PFT1
V PFT2
V PFT3
V PFT4
C1I
C1U
C2I
C2U
Crop Model
Planting
SEEDS
Leaf emergence
Irrig / Fertilize
Grain fill
Harvest
Land Use Change
Unirrig
Irrig
Unirrig
Irrig
Crop1
Crop1
Crop2
Crop2 …

Historical and RCP Global Crop Simulation Database

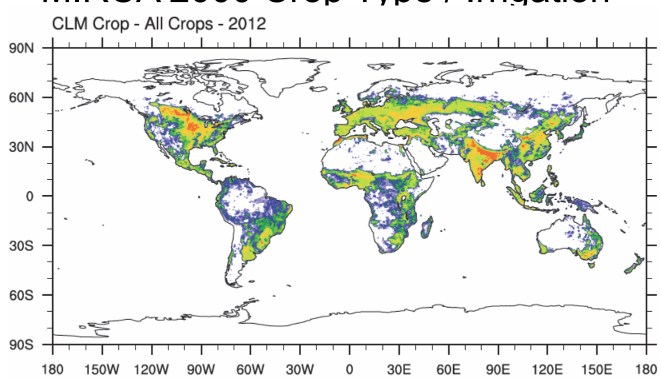
Crop Area time series from THESIS Downscale

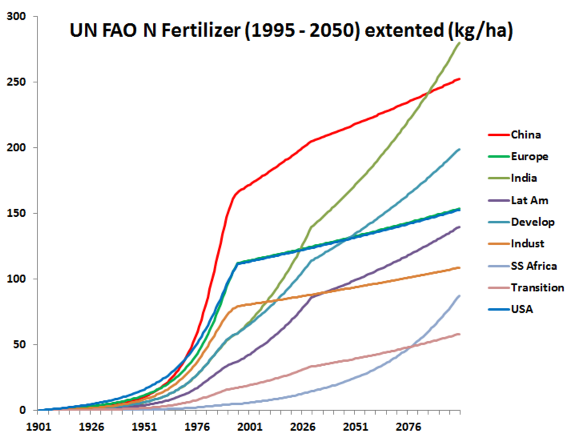


CESM Climate / CO_2 Scenario – Hist/RCP4.5/RCP8.5



MIRCA 2000 Crop Type / Irrigation





All Crops grown in every vegetated grid cell

Global CLM Crop Simulation Database

- Scenario
- Crop
- Year
- Area

- Yield
- Fertilizer
- Irrigation

- Temp.
- Precip.
- Solar
- CO_2

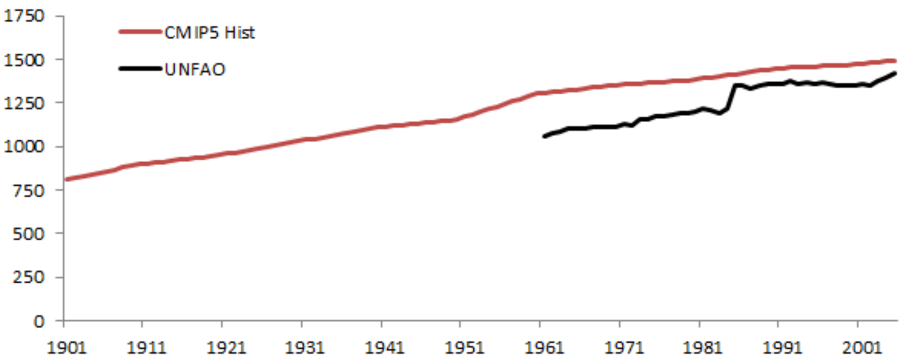
Global Idealized CLM Crop Simulation Database

For Historical, RCP4.5 and RCP8.5 time series and for each crop

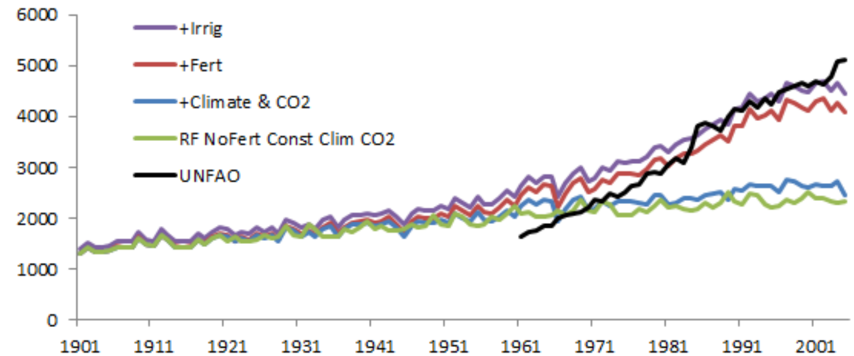
Rainfed / Irrigated	N Fertilizer	CO2 Concentration	Climate
Irrigated	UNFAO Fertilizer	Transient	Transient
Rainfed	UNFAO Fertilizer	Transient	Transient
Irrigated	No/Const Fertilizer	Transient	Transient
Rainfed	No/Const Fertilizer	Transient	Transient
Irrigated	UNFAO Fertilizer	Constant	Transient
Rainfed	UNFAO Fertilizer	Constant	Transient
Irrigated	No/Const Fertilizer	Constant	Transient
Rainfed	No/Const Fertilizer	Constant	Transient
Irrigated	UNFAO Fertilizer	Constant	Constant
Rainfed	UNFAO Fertilizer	Constant	Constant
Irrigated	No/Const Fertilizer	Constant	Constant
Rainfed	No/Const Fertilizer	Constant	Constant

Global Historical Analysis UNFAO Area, Yields, N Fert

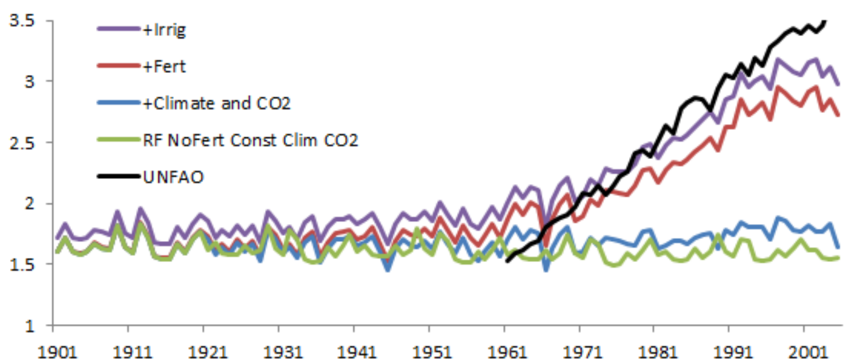
Historical Global Crop Area (millions hectares)



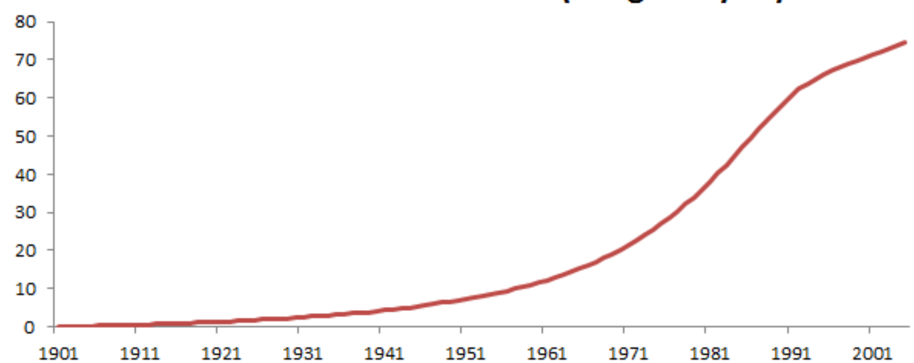
Historical Global Production (millions tonnes)



Historical Global Crop Yield (tonnes/ha)



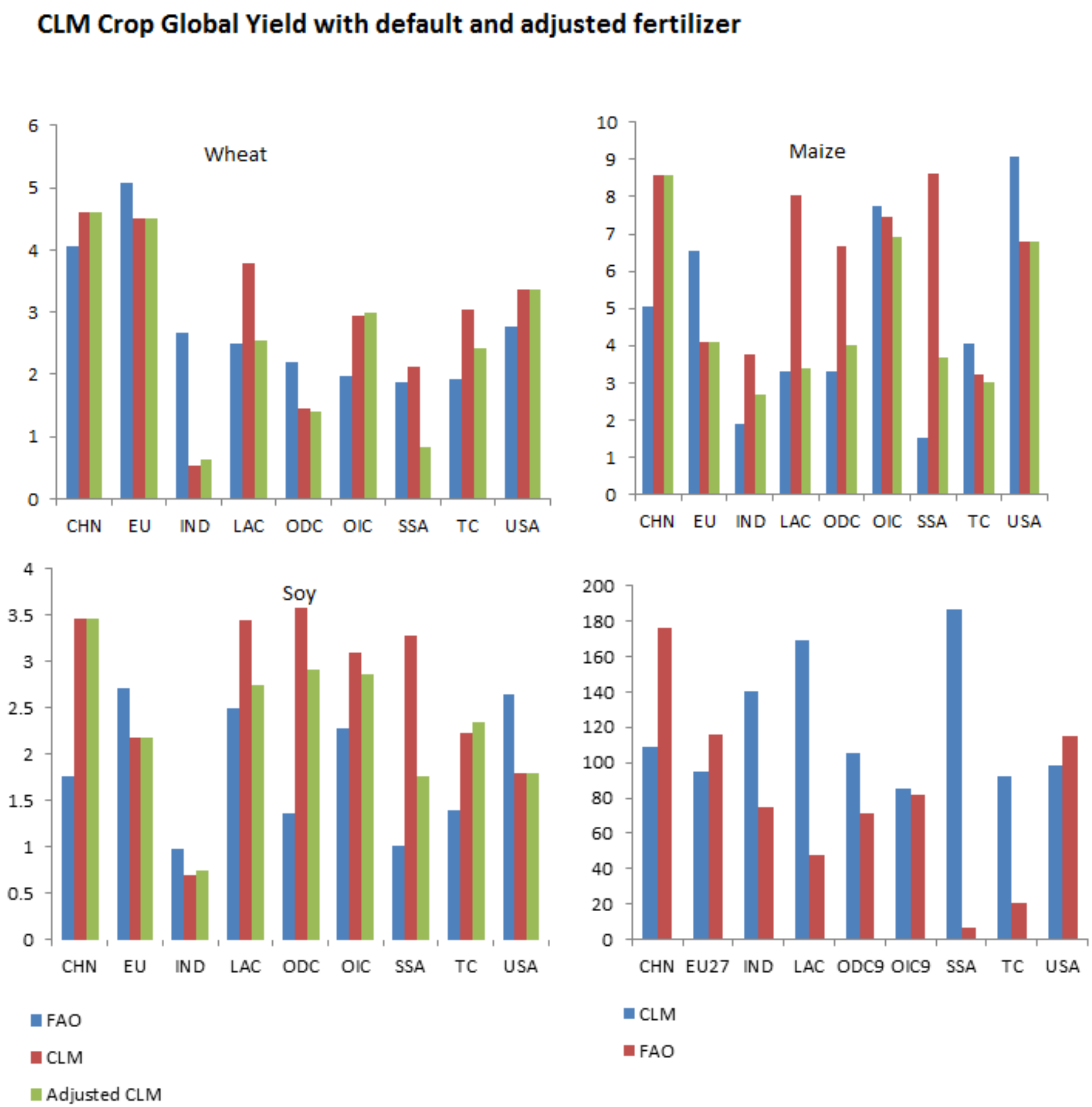
Historical Global N Fertilizer (kilograms/ha)



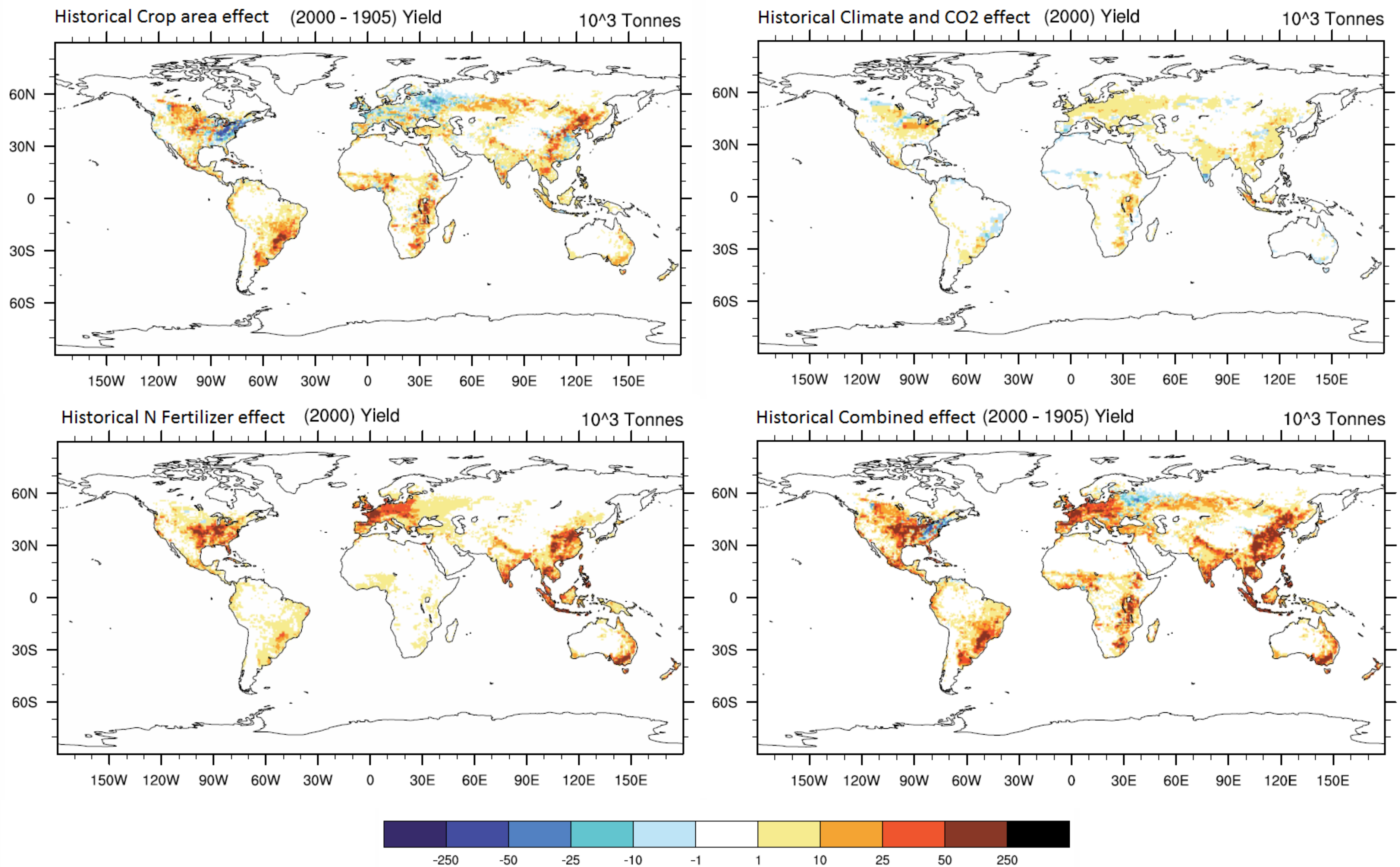
Area Effect	Climate & CO2	N Fert Effect	Irrig Effect	Total Effect
+77.2%	+5.8%	+65.6%	+9.5%	+226.8%

*UNFAO only using Yields for CLM Crop Types over All Crop Areas

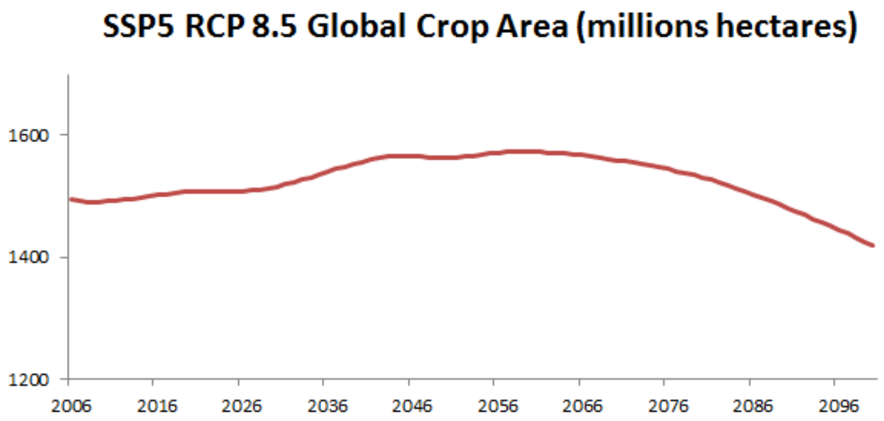
Global Historical Analysis (All Crop) Yield and N Fertilizer

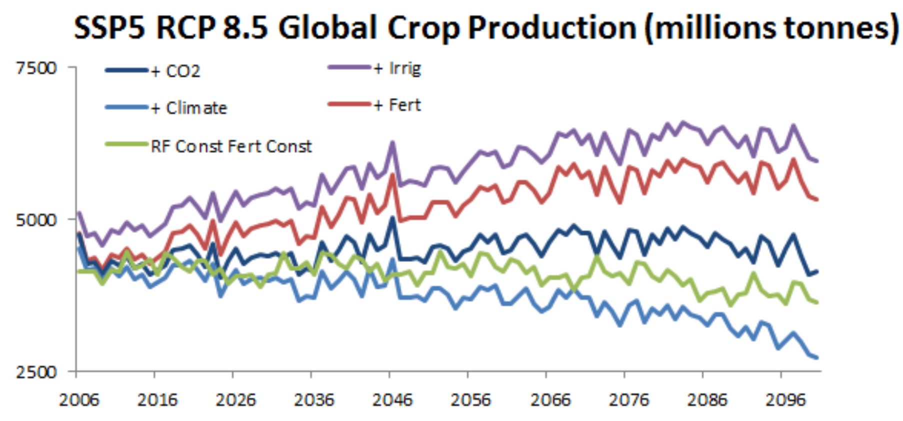


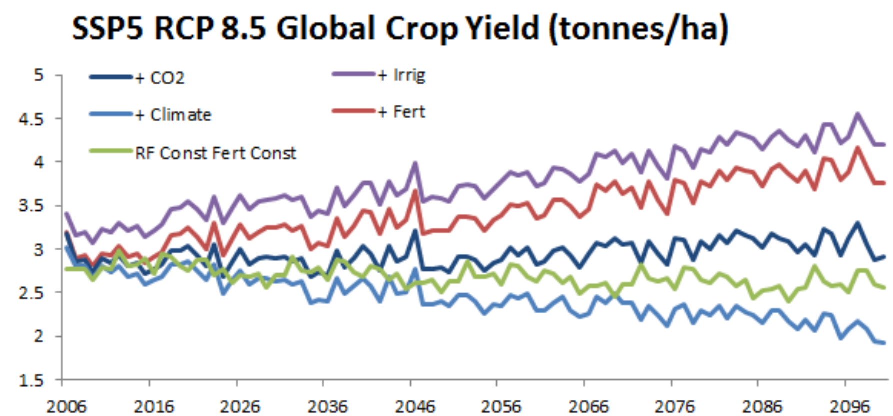
Global Historical Analysis (All Crop) Production

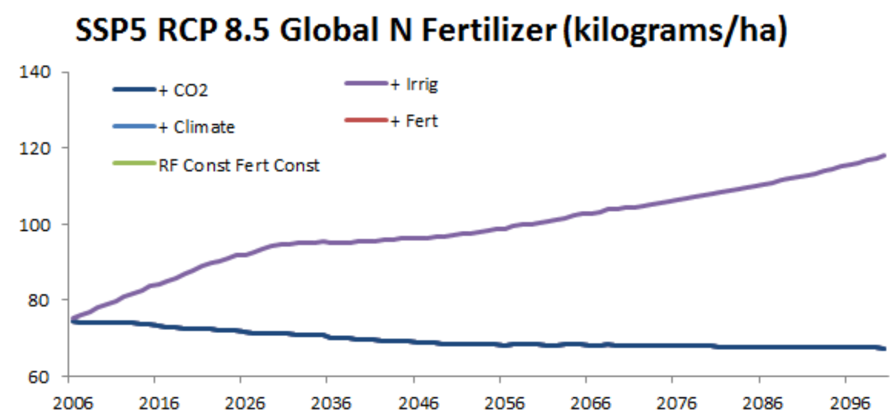


Global SSP5 RCP 8.5 Analysis (All Crops) Area, Yield, N





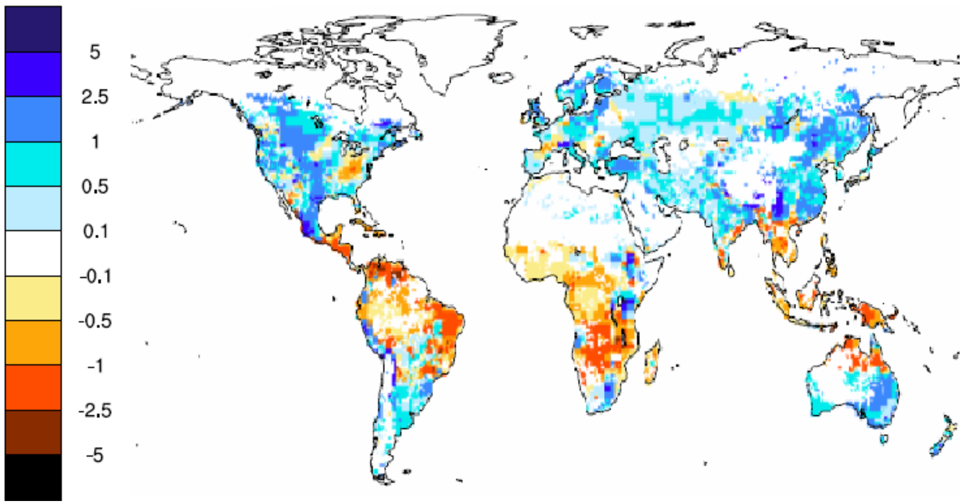




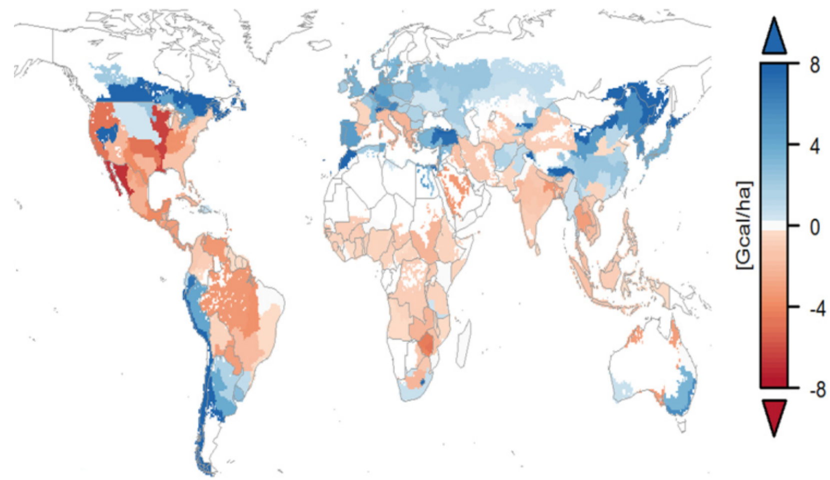
Area Effect	Clim Effect	CO2 Effect	N Fert Effect	Irrig Effect	Total Effect
-9.1%	-20.4%	+46.0%	+27.3%	+10.7%	+49.0%

CLM Crop versus AgMIP changes for RCP 8.5 to 2100

CLM crop yield changes (Tonnes/Ha)

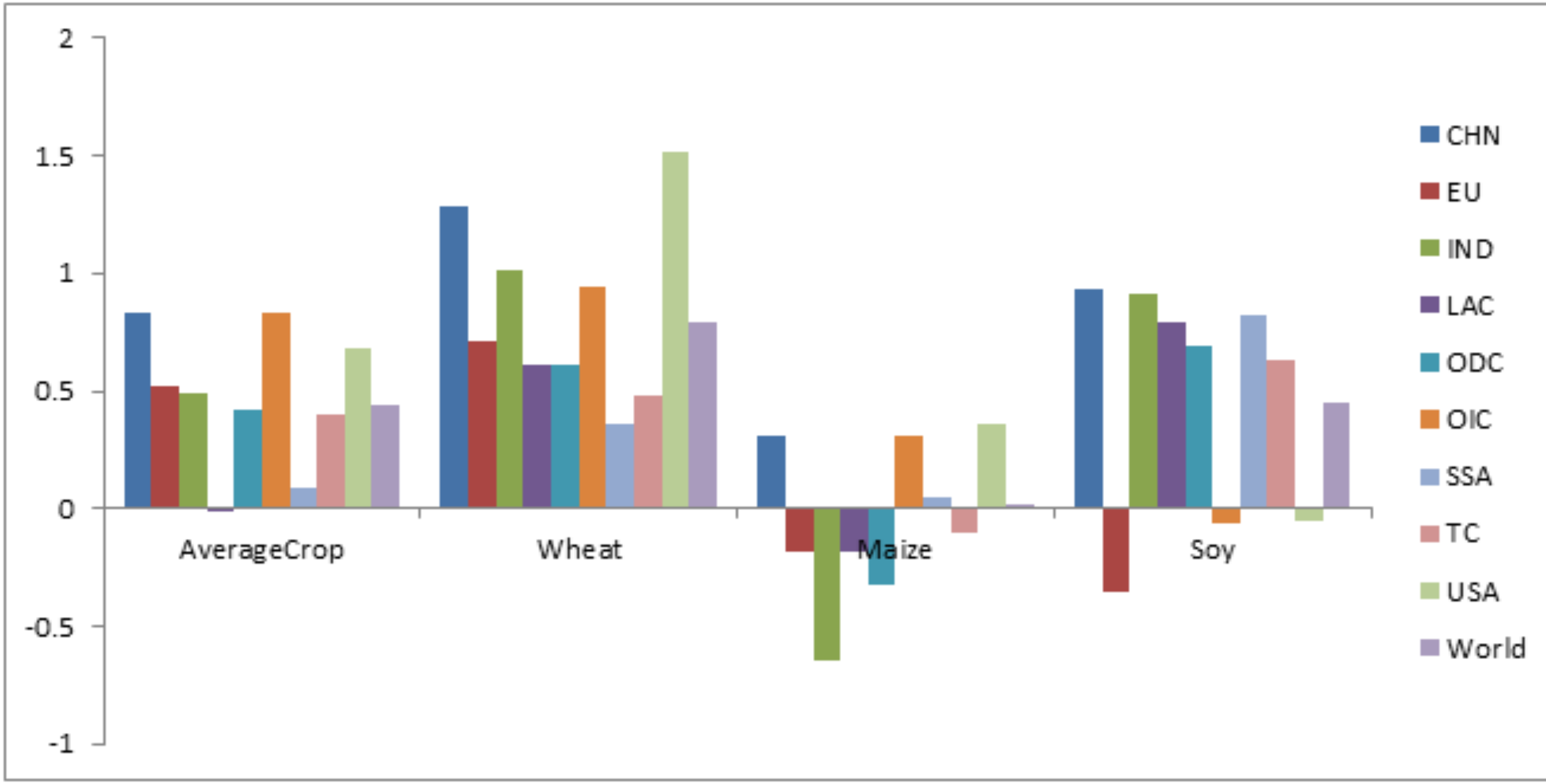


AgMIP productivity changes (Gcal/ha)



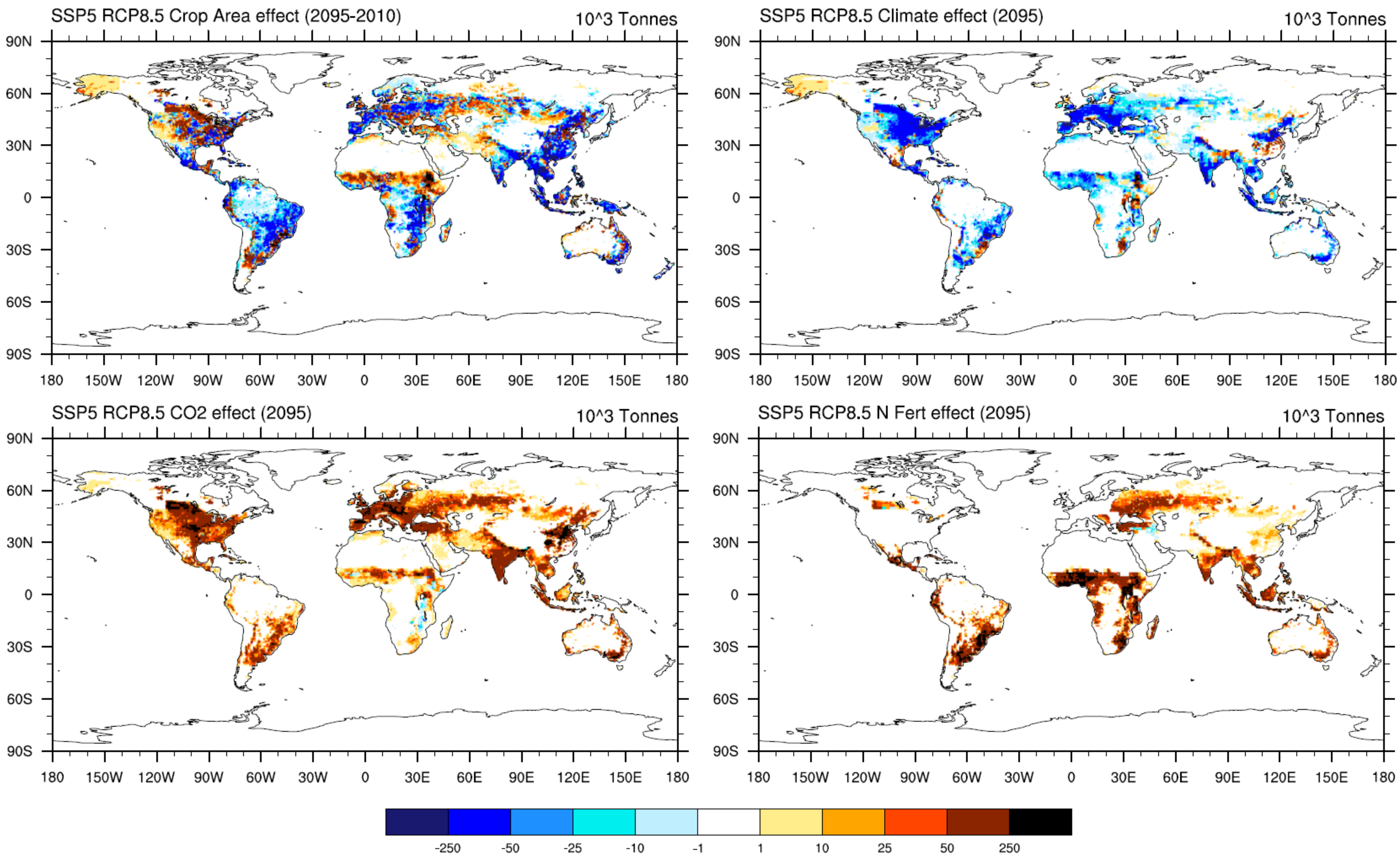
Change under RCP 8.5 climate with CO_2 fertilization for average crop. AgMIP results are median change of all GGCM×GCM combinations (n=30) (From Müller et al. 2015). Cropping areas, fertilizer and irrigation are held constant at 2005 values for both results.

CLM Crop and iPETS changes for SSP 5 RCP 8.5 to 2100

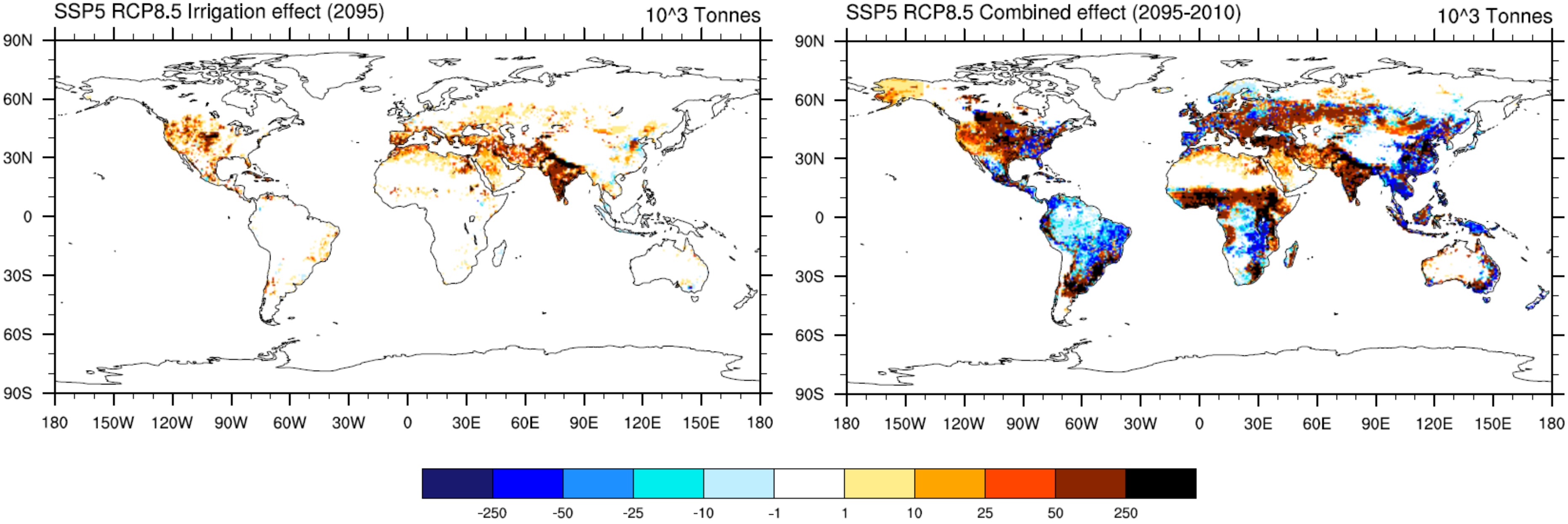


Change under RCP 8.5 climate with CO_2 fertilization for average and individual crops. Cropping areas, fertilizer and irrigation are held constant at 2005 values for both results.

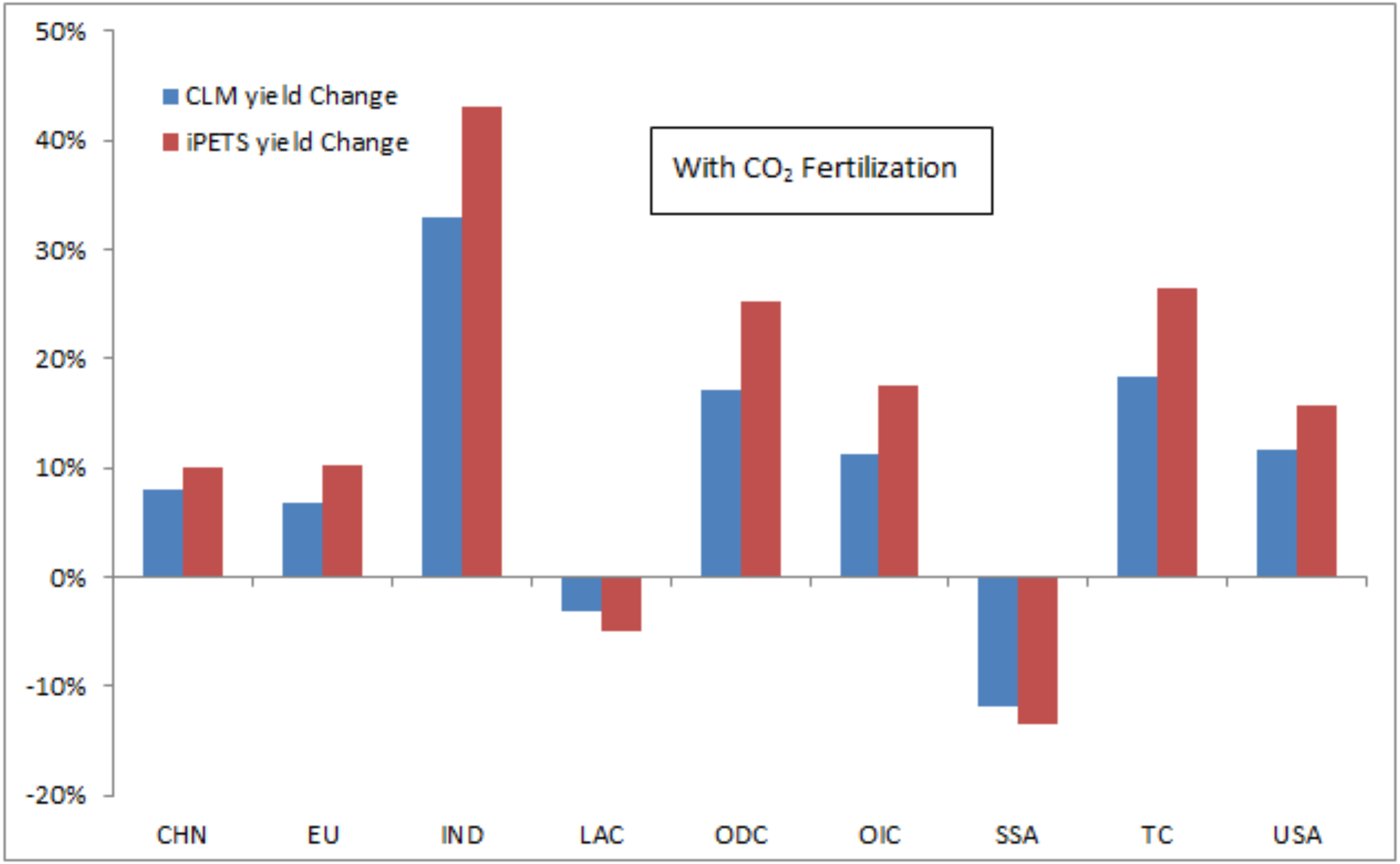
Global SSP5 RCP 8.5 Analysis (All Crop) Production



Global SSP5 RCP 8.5 Analysis (All Crop) Production

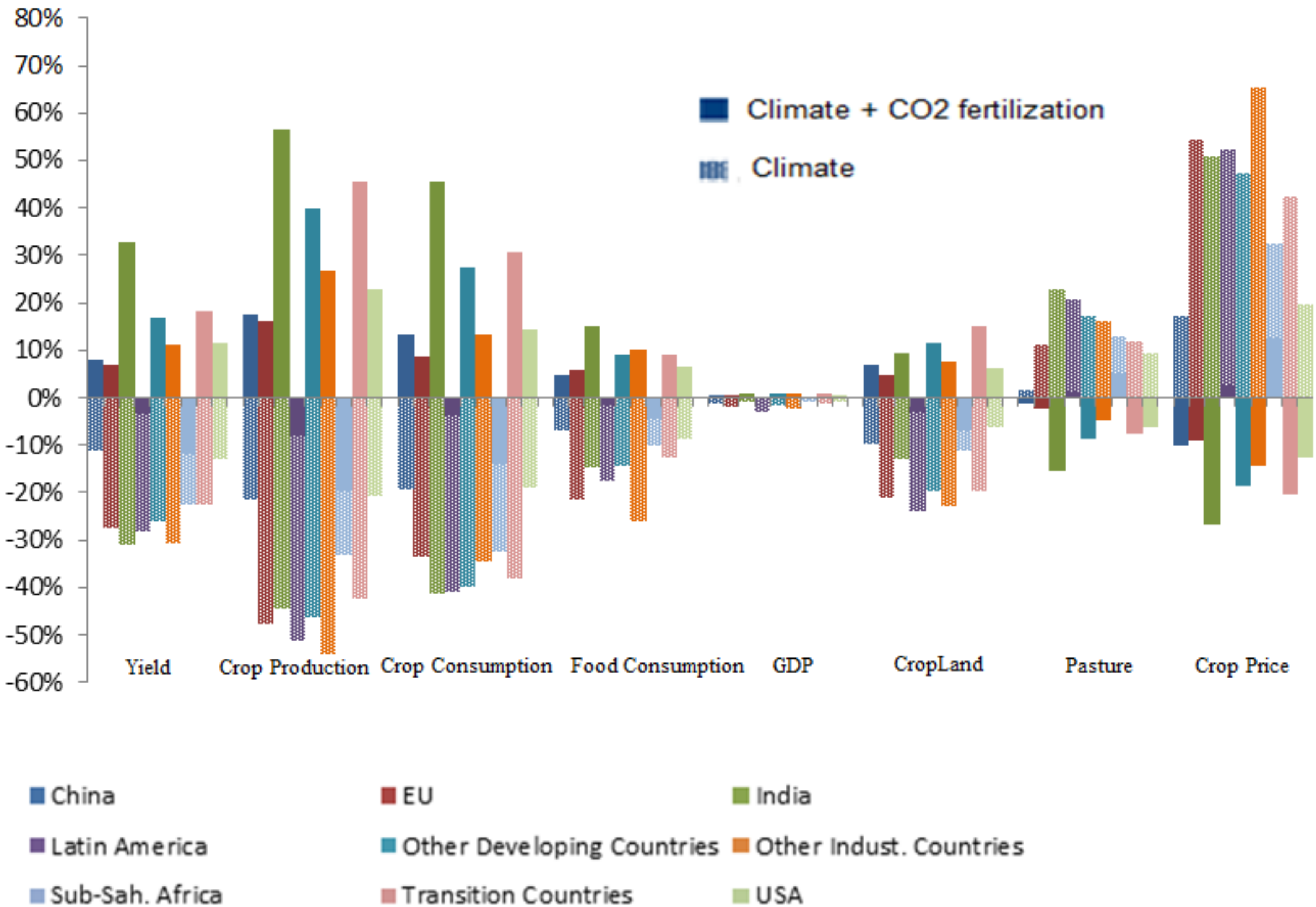


CLM Crop and iPETS changes for SSP 5 RCP 8.5 to 2100



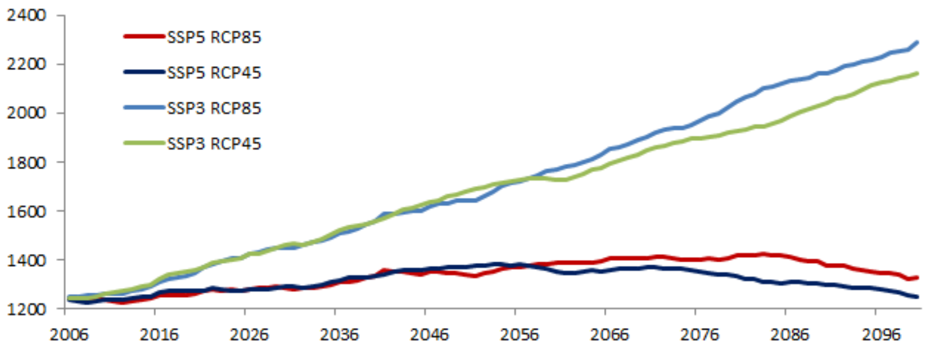
Change under RCP 8.5 climate with CO_2 fertilization for average and individual crops. Cropping areas, fertilizer and irrigation are held constant at 2005 values for both results.

iPETS for SSP 5 RCP 8.5 vs no Climate Change at 2100

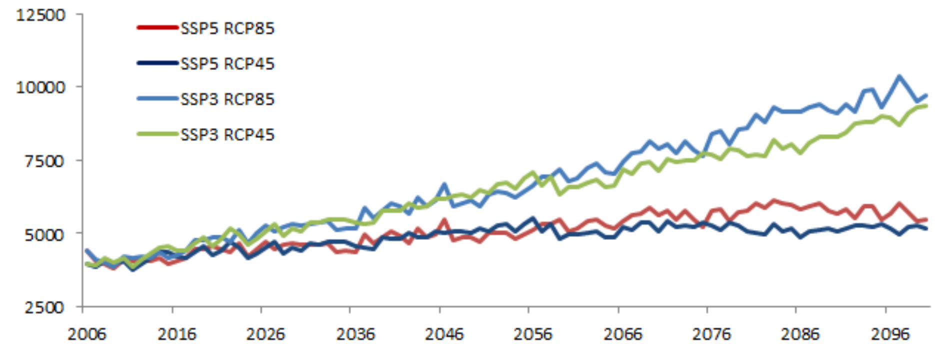


Global SSP RCP Final Analysis (All Crop*) Area, Yield, N

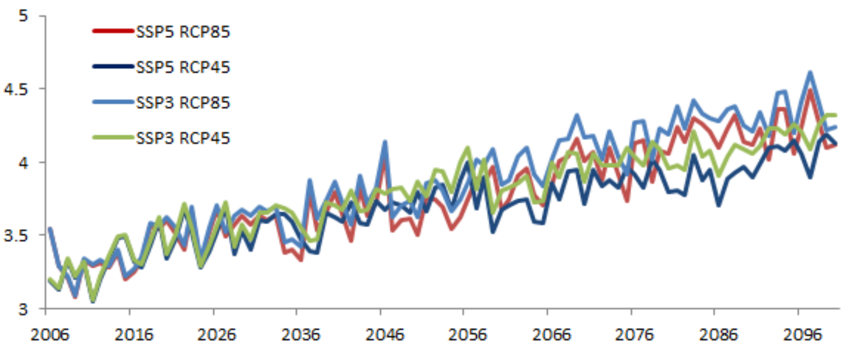
Final Global Crop Area (millions hectares)



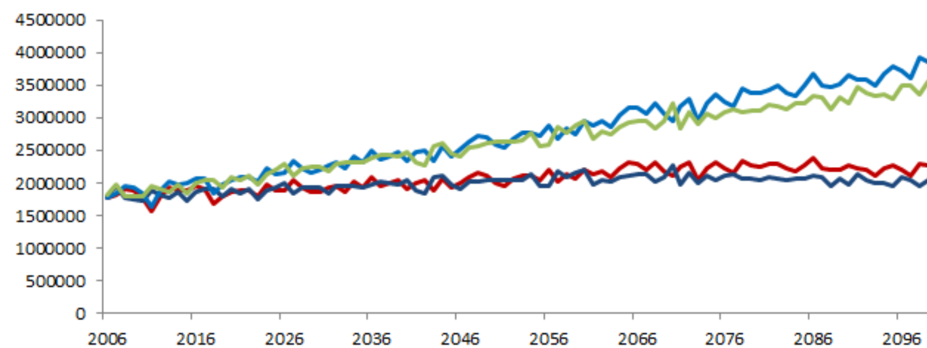
Final Global Crop Production (millions tonnes)



Final Global Crop Yield (tonnes/ha)



Final Global Irrigation (m^3)



SSP3 RCP 4.5	SSP3 RCP 8.5	SSP5 RCP 4.5	SSP5 RCP 8.5
+114.5%	+132.2%	+28.6%	+40.1%

* All Crops without rice

iPETS coupled to CLM Crop Yield Tool Investigation

1. THESIS tools allow us to link iPETS to the CLM Crop Yield Tool to introduce Climate and Management impacts on Crop Yields

2. CLM Crop performs reasonably well compared to FAOSTAT Yield and Area data once N Fertilizer accounted for

3. CLM Crop Yield Tool allows attribution of yield impacts to changes in: 1. area and crop composition; 2. climate change; 3. CO_2 fertilization; 3. N Fertilizer; and 4. Irrigation.

4. For Final SSP – RCP the Crop Yield Tool production impacts of:

SSP3 RCP 4.5	SSP3 RCP 8.5	SSP5 RCP 4.5	SSP5 RCP 8.5
+114.5%	+132.2%	+28.6%	+40.1%

5. iPETS crop productivity feedbacks have large impacts on Crop production, consumption, price, and area but very little impact on GDP. CO_2 fertilization is the biggest factor