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Climate Change and Water Use Efficiency in Field Crops: Implications for Agricultural Adaptation in the U.S.

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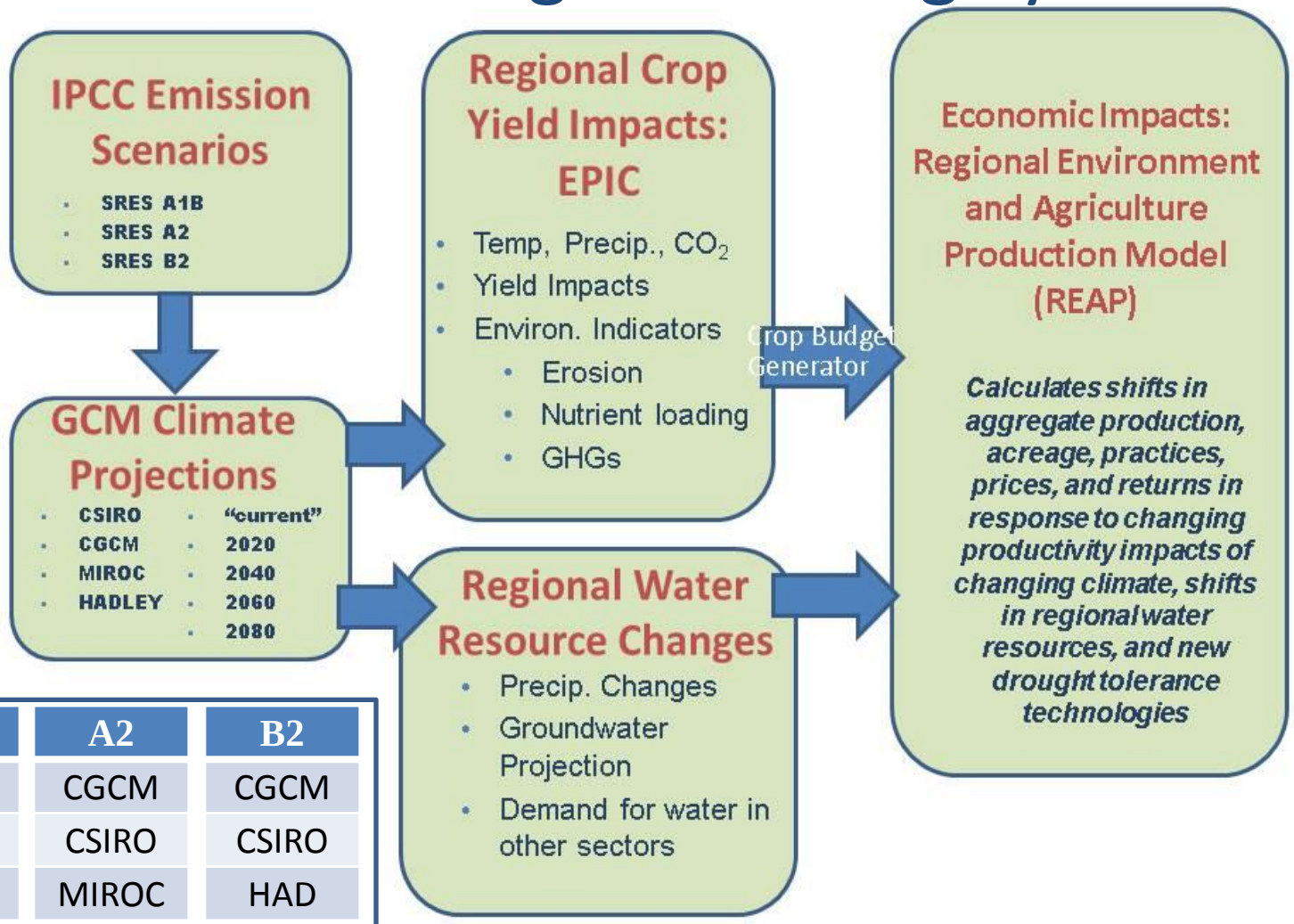
Research Questions

- What are the impacts of climate change on plant water use efficiency of field crops in the United States?
  - biophysical effects on crop yields (precipitation, temperature, CO_2)
- How do adjustments in water use efficiency affect irrigation demand under changing growing conditions?
  - Regional farmer adaptation
  - Irrigation as an adaptive response
- How might shifting water regimes under a warming climate affect water-supply availability for irrigation?
- To what extent is irrigation a constraint to adaptation and national production under climate change?
  - Regional variation

Climate Change Modeling System



A1B	A2	B2
CGCM	CGCM	CGCM
CSIRO	CSIRO	CSIRO
MIROC	MIROC	HAD

Climate Change Modeling System

IPCC Emission Scenarios

- SRES A1B
- SRES A2
- SRES B2

GCM Climate Projections

- CSIRO
- CGCM
- MIROC
- HADLEY
- reference
- 2020
- 2040
- 2060
- 2080

A1B	A2	B2
CGCM	CGCM	CGCM
CSIRO	CSIRO	CSIRO
MIROC	MIROC	HAD

Regional Crop Yield Impacts: EPIC

- Temp, Precip., CO_2
- Yield Impacts
- Environ. Indicators
  - Erosion
  - Nutrient loading
  - GHGs

Crop Budget Generator

Regional Water Resource Changes

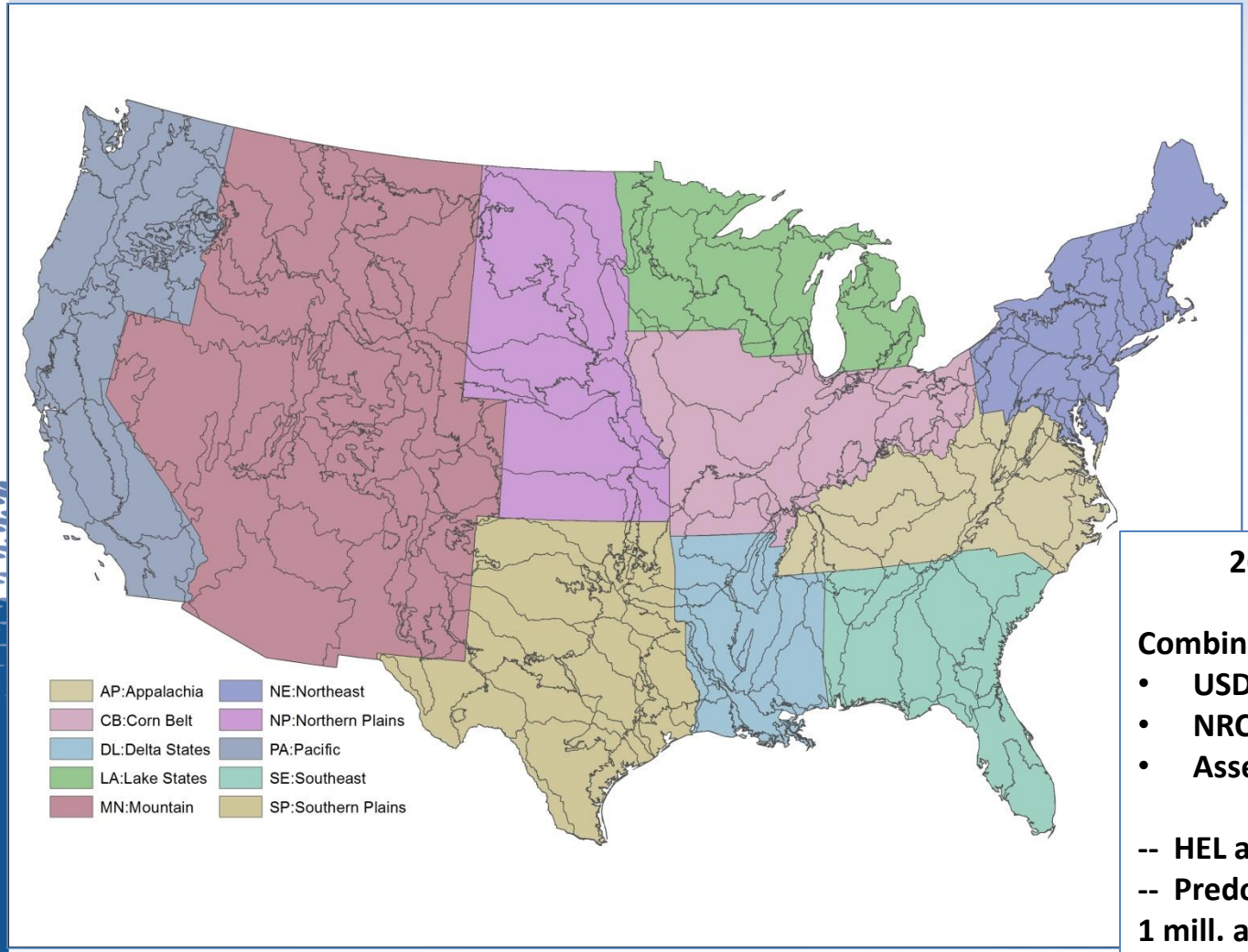
- Precipitation patterns and amount
- Surface-water and groundwater supplies

Shortage Estimates

Economic Impacts: Regional Environment and Agriculture Programming Model (REAP)

- *shifts in production, acreage, practices, prices, and returns*
- *shifts in regional water resources, agricultural use and irrigation constraints*

REAP Model Production Regions



267 Model Regions

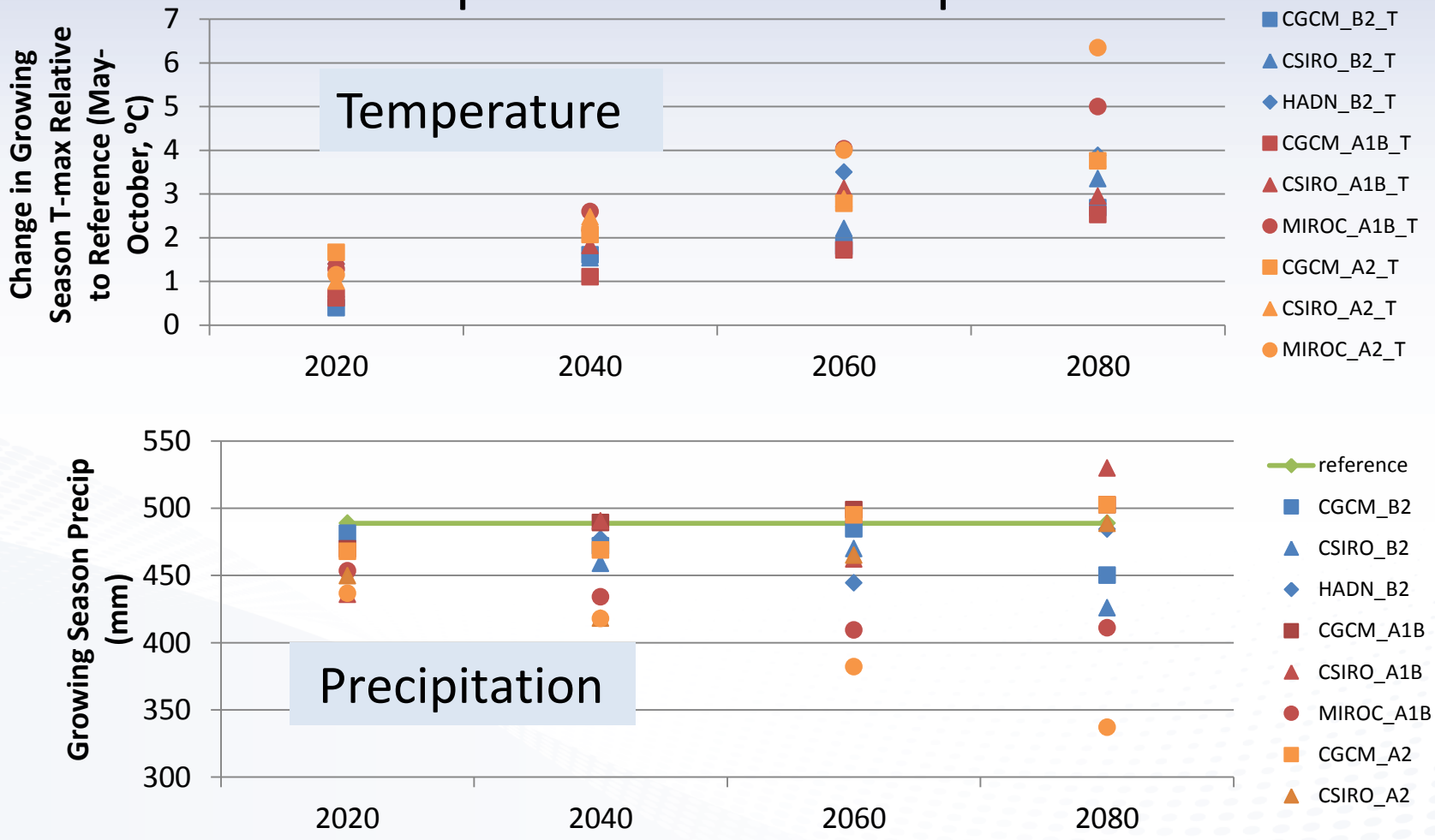
Combination of:

- **USDA Farm Production Regions**
- **NRCS Land Resource Regions**
- **Assessment Sub-Regions (ASRs)**

-- HEL and NHEL land types (NRI)
-- Predominant soil type per roughly 1 mill. acres by land type (SSURGO)
-- Tiled and non-tiled

U.S. Climate Projections

Temperature and Precipitation



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Factors Driving Productivity Impacts

- **Moisture stress**
  - Increased moisture stress where rising evapotranspiration (ET) demands are not satisfied.
  - Reduced stress where higher precipitation offsets rising ET demand.

- **Temperature stress**
  - Reduced biomass and grain-yield production where temperature exceeds optimal growing conditions; offsetting decline in crop ET demand.

- **Atmospheric CO_2**
  - Increased plant-water use efficiency, reducing crop ET demands.
  - Increased yield through photosynthesis on C_3 crops (wheat, hay, cotton, rice, soybeans); yield effect for C_4 crops (corn, sorghum) more limited.

Corn Yields, 2060

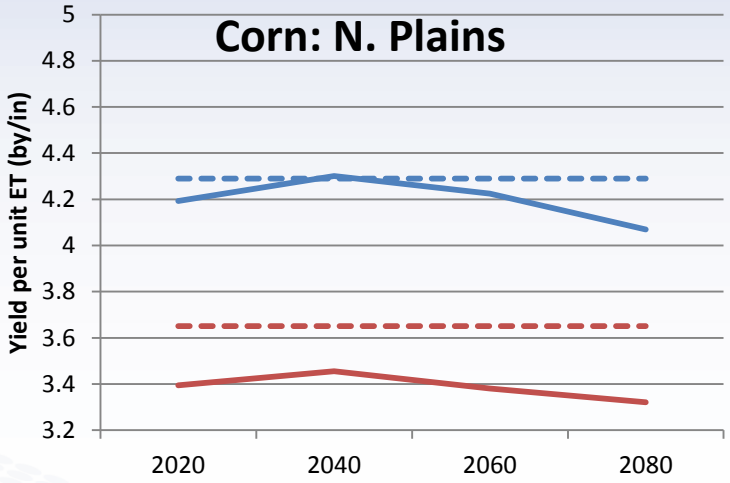
			Percent Change in Corn Yields, 2060									
FPR	IRR	Ref (bu/ac)	CGCM_ B2	CSIRO_ B2	HADN_ B2	CGCM_ A1B	CSIRO_ A1B	MIROC_ A1B	CGCM_ A2	CSIRO_ A2	MIROC_ A2	AVG
CB	D	208.6	-1.7	-10.8	-22.3	7.8	-22.1	-14.2	-8.7	-15.6	-22.7	-12.3
CB	I	258.8	-5.6	-10.8	-21.1	-2	-18.8	-21.4	-19.6	-20.1	-23.9	-15.9
DL	D	208.6	-2.1	1.4	-11.5	-2.6	-11.3	-22.3	-16.6	-10.3	-36.8	-12.5
DL	I	235.7	1	2.9	-1.4	-0.1	7	-3.2	-5.5	0.5	-8.7	-0.8
LA	D	228.5	4	-12.3	-14.6	2.7	-13.7	-13.4	-1.7	-8.1	-16.1	-8.1
LA	I	286.1	-0.8	-9.7	-10.3	-1.5	-15.4	-11.8	-7.3	-11.8	-10.6	-8.8
MN	D	95	4.4	-1.3	-31.6	26.6	-19.8	-21.5	-8.3	-3.6	-29.5	-9.4
MN	I	280.7	-5.4	-3.8	-22.7	-1.6	-20.4	-23.8	-15.6	-12.8	-25.5	-14.6
NP	D	141.3	2.7	-23.9	-33.5	18.1	-23.4	-22.2	7.1	1.8	-19.2	-10.3
NP	I	285	-4.2	-10.4	-31.1	1.4	-22.3	-25.7	-17.4	-13.6	-26	-16.6
PA	D	80.9	12.6	91.1	1.5	14.7	10.8	22	22.2	30	14.6	24.4
PA	I	301.9	-10	-16.8	-22.6	-16.3	-10.2	-17	-14	-8	-14.5	-14.4
SP	D	149.5	6.3	10.4	-17.3	4.2	-1.9	-30.1	-10.5	-19.7	-30.7	-9.9
SP	I	216.9	1.6	2.8	-10.7	-2.4	-0.7	-6.5	-8.7	-6.4	-15.3	-5.1

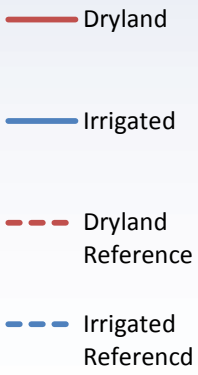
Wheat Yields, 2060

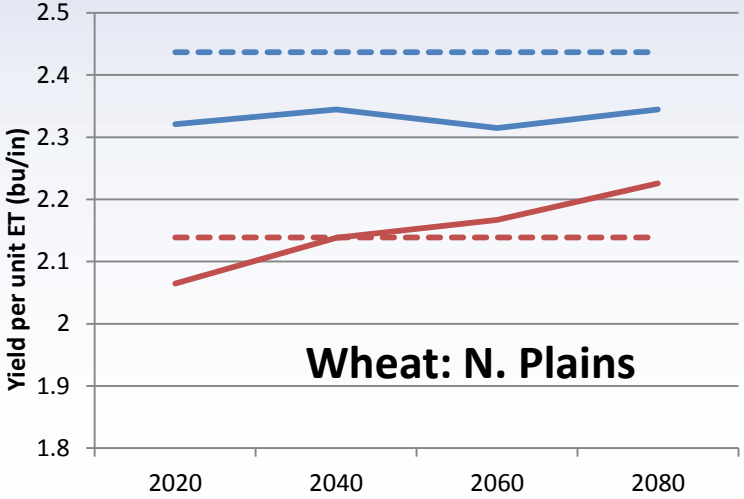
			Percent Change in Wheat Yields, 2060									
FPR	IRR	Ref (bu/ac)	CGCM_ B2	CSIRO_ B2	HADN_ B2	CGCM_ A1B	CSIRO_ A1B	MIROC_ A1B	CGCM_ A2	CSIRO_ A2	MIROC_ A2	AVG
CB	D	67.2	-1	7.4	-2.7	7.9	-10.9	3.6	0.6	-0.4	-2.8	-1
CB	I	68.3	-5.7	11.4	3.8	3.8	-2.2	8.3	1.8	0.9	5.3	-5.7
DL	D	65.1	-7.7	12.7	5.4	7.4	-2.6	2.3	2.5	10.9	2.5	-7.7
DL	I	60.9	-6.6	17.6	3.9	5.1	-1	-0.3	-1.3	10.2	5.3	-6.6
LA	D	67.6	3.1	-0.1	-9.5	9	-17.3	-5.8	0.6	-2.2	-0.6	3.1
LA	I	77.3	2.1	3.4	-9.2	3.4	-5.8	-0.3	-6.6	-6	3.2	2.1
MN	D	39.6	14.4	8.1	-14.4	33.6	-9.3	-0.5	33.1	22.7	0.8	14.4
MN	I	103.9	5.7	4.1	-5.4	8.8	-1.7	7.5	5.3	7.1	5.6	5.7
NP	D	44.5	8.8	-7	-12.6	23.6	-20.9	-14.4	16.6	13.9	3.1	8.8
NP	I	74.7	3.6	2.3	-8.2	5.5	-7.1	-2.9	-1.3	4.6	2.4	3.6
PA	D	59.9	24	35.2	23.2	44.9	32.9	67.9	67.3	61.1	48.7	24
PA	I	162	3.7	8.4	9	11.2	7.6	7.2	-0.5	19.4	10.1	3.7
SP	D	33.1	8.5	0.3	-11.2	25.1	-1.5	-18.4	14.2	3.3	-16.3	8.5
SP	I	53.4	0.7	-1.1	2.2	9	-1.3	2.1	-1.1	9.4	5.4	0.7

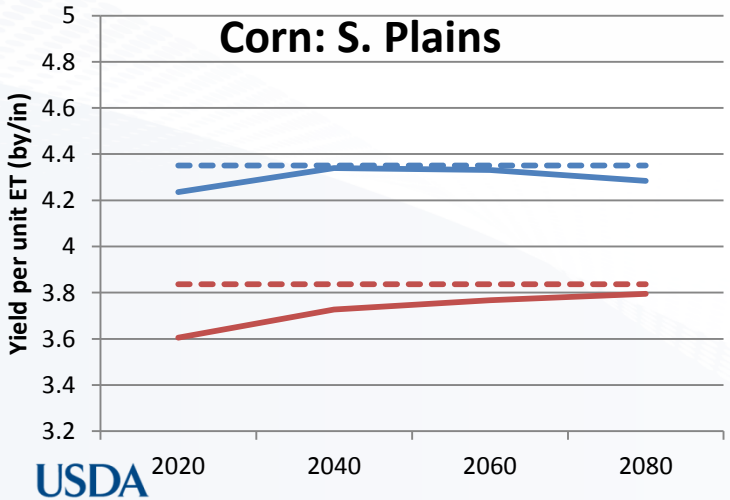
Crop Water Use Efficiency

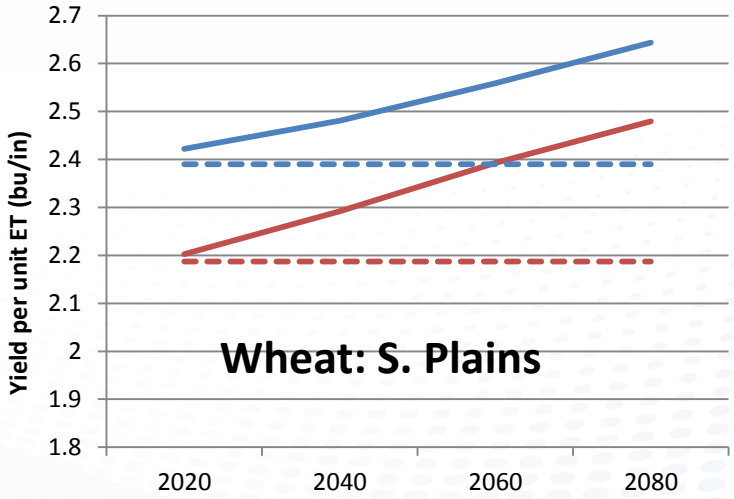
Yield per unit ET (bu./in.)











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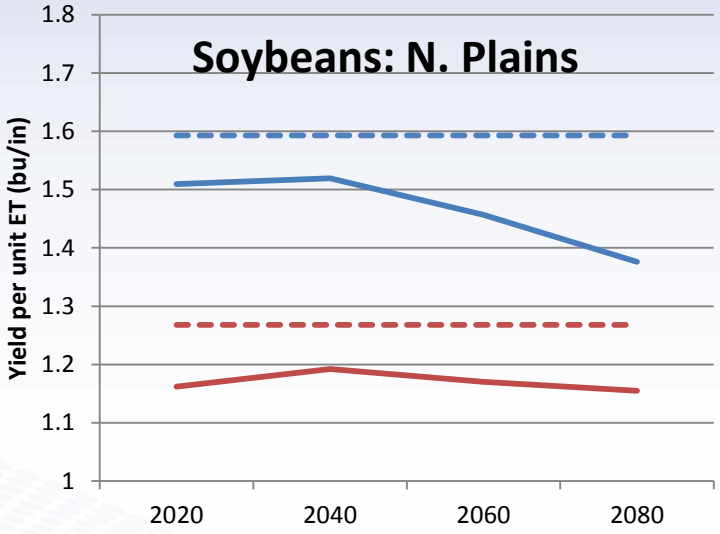
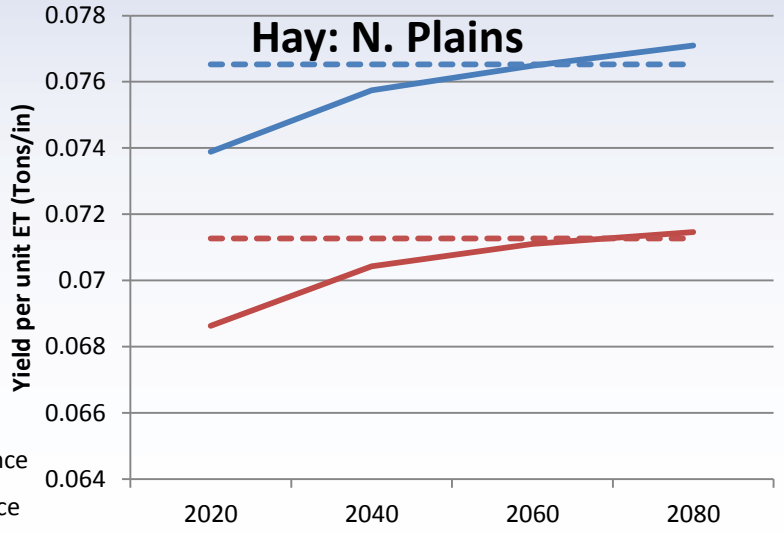
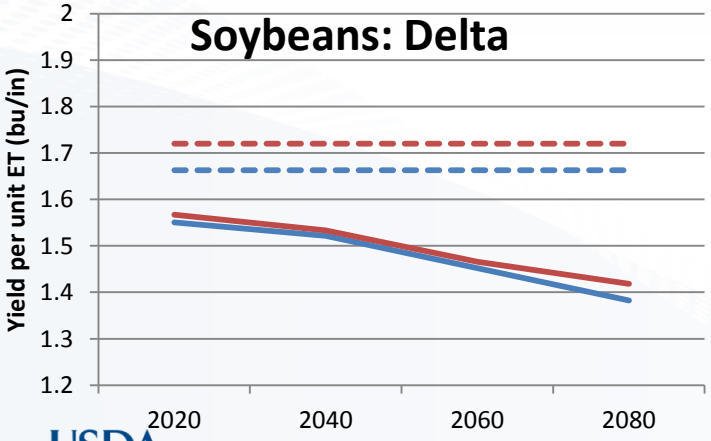
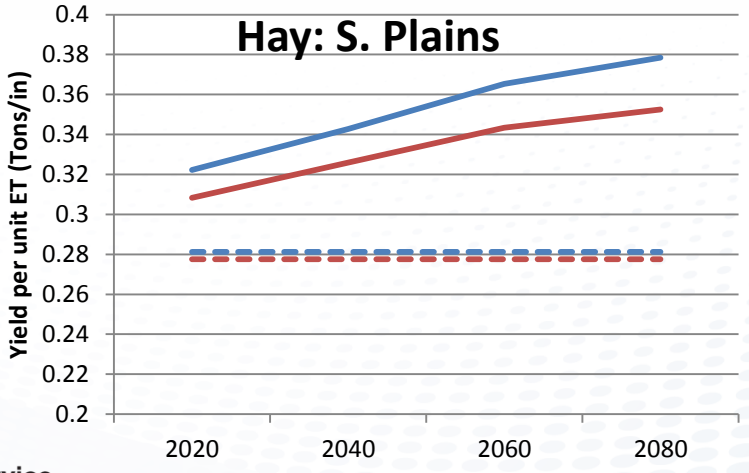
Crop Water Use Efficiency

Yield per unit ET (bu./in.)









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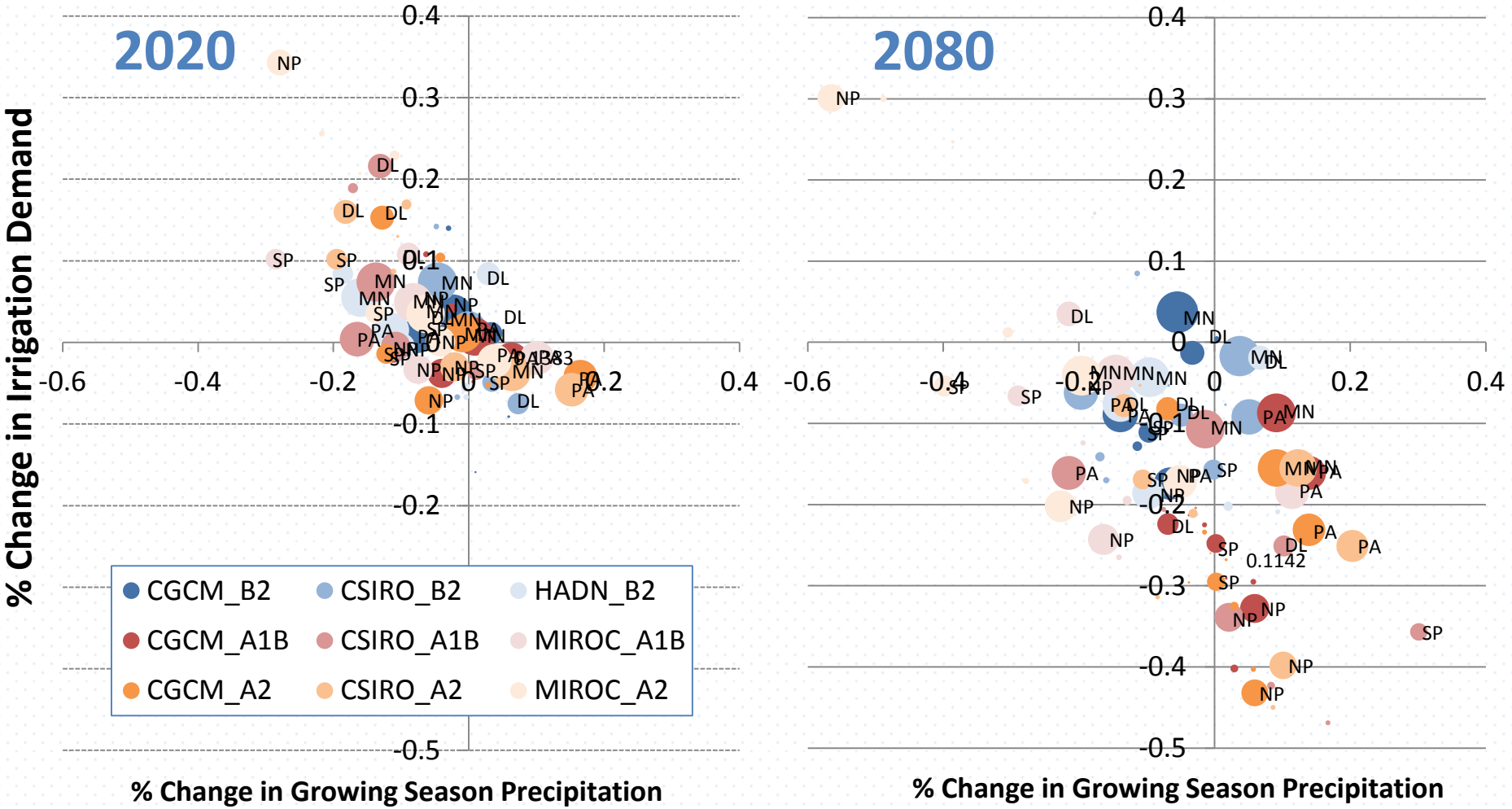
Precipitation and Irrigation Demand



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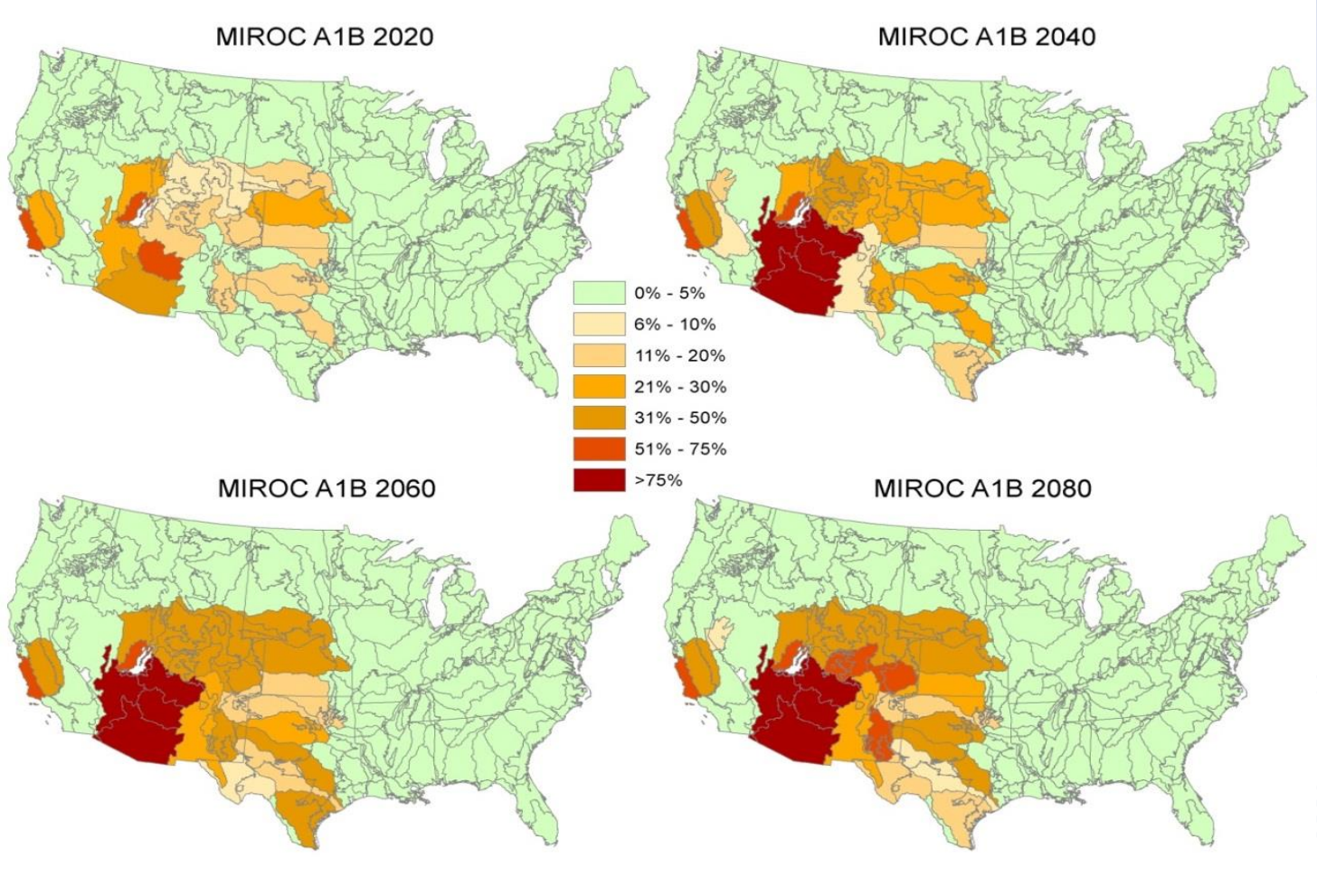
Factors Driving Adaptation Response

- **Changing patterns of relative profitability among crops, crop systems, and production systems under climate change**
  - Irrigation returns may be more sensitive than dryland systems to % declines in crop yields; yield premiums are required to cover higher-cost irrigated production systems.
- **Possible constraints on adaptation due to irrigation shortages**
  - Irrigation demand depends on changing patterns of precipitation as well as adjustments in crops grown and changing levels of crop water demand
    - changing extent and intensity of irrigation
  - **Irrigation supply**
    - **Surface water supplies under climate change:** 2010 Resources Policy Act (RPA) National Assessment produced projected water shortages by hydrologic sub-basin
      - Water yield, routing/storage models
      - Water demand by sector
    - **Groundwater supplies: not climate-related**

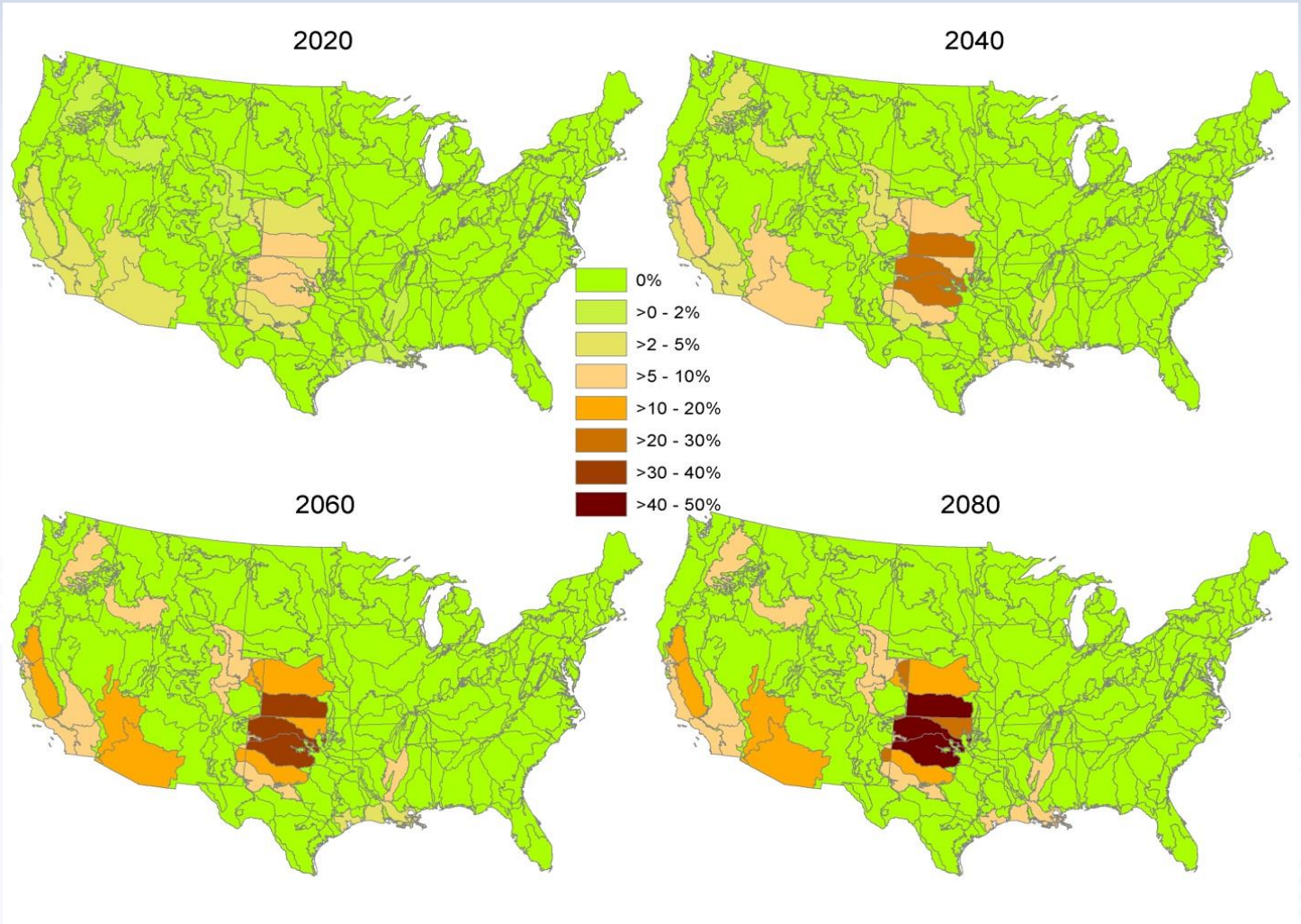
Shifting Relative Profitability of Irrigated Production, 2060

	% change in ratio of returns to irrigated versus dryland production									
	CGCM_B2	CSIRO_B2	HADN_B2	CGCM_A1B	CSIRO_A1B	MIROC_A1B	CGCM_A2	CSIRO_A2	MIROC_A2	AVG
AP	1.6	0.8	-2.6	-3.2	-0.6	-2.5	-8.7	1.4	-2.9	-1.9
CB	-4.3	-2.9	0.4	-1.9	4	-8.3	-10.9	-6.3	-1.9	-3.6
DL	4.5	-2.3	13.5	21.4	17	41.5	41.3	16.1	65.2	24.2
LA	-5.5	1.8	6.6	-8.1	-0.2	1.1	-6	-1.9	6.9	-0.6
MN	-35	-21.9	96.9	-43.8	-11.2	-14.7	-27.1	-26.2	-9.9	-10.3
NP	-7.2	36.5	16.4	-22.4	2.6	-4.1	-26.4	-16.1	-10.3	-3.4
NE	-3.9	0.8	1.9	-4.9	0.1	4.4	0.7	4.1	11.8	1.7
PA	-2.1	-17.9	1.3	-1.2	-19	-20.4	-1.2	-7.8	1.2	-7.5
SE	17.5	3	-17.6	-18.3	-1.3	-27.3	-7	-8.2	34.2	-2.8
SP	-8.5	-27.2	-6.3	-22.3	-32.9	32.5	-19.9	5.4	17.4	-6.9

Surface-water Shortages

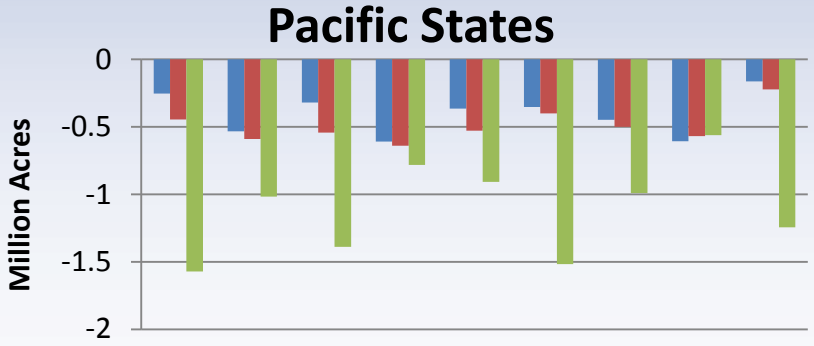


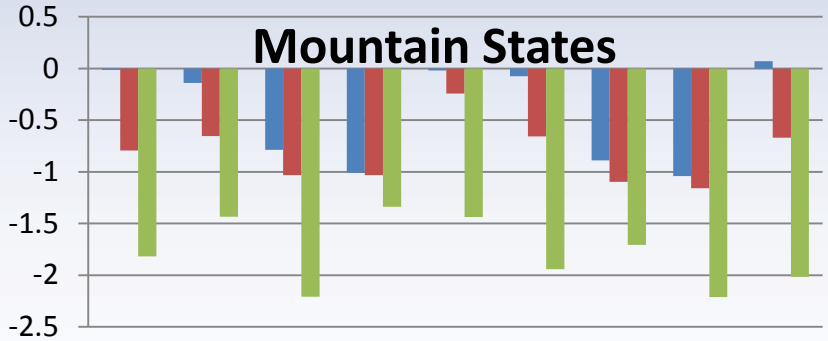
Groundwater Withdrawal Reductions

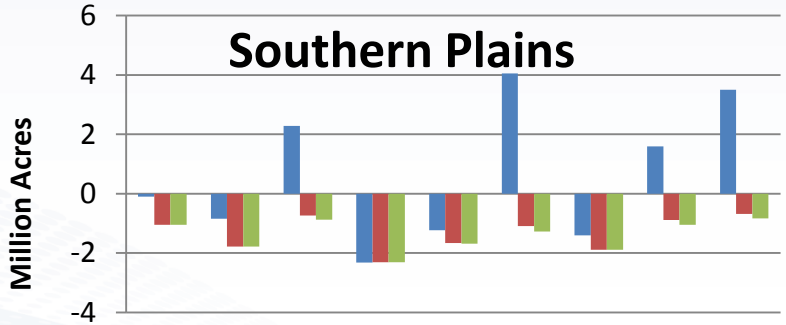


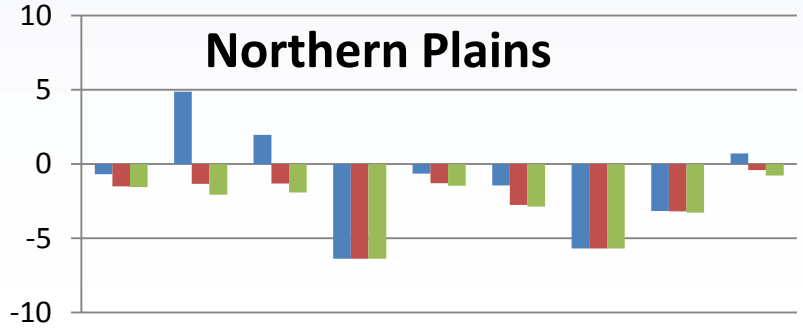
Change in Irrigated Acreage

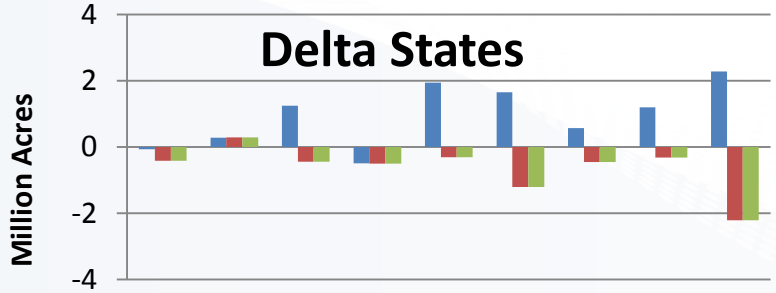
(from Reference Case), 2060











- w/o water-supply constraints
- w/GW constraints
- w/ surface-water constraints

Order of Columns
CGCM_B2
CSIRO_B2
HADN_B2
CGCM_A1B
CSIRO_A1B
MIROC_A1B
CGCM_A2
CSIRO_A2
MIROC_A2

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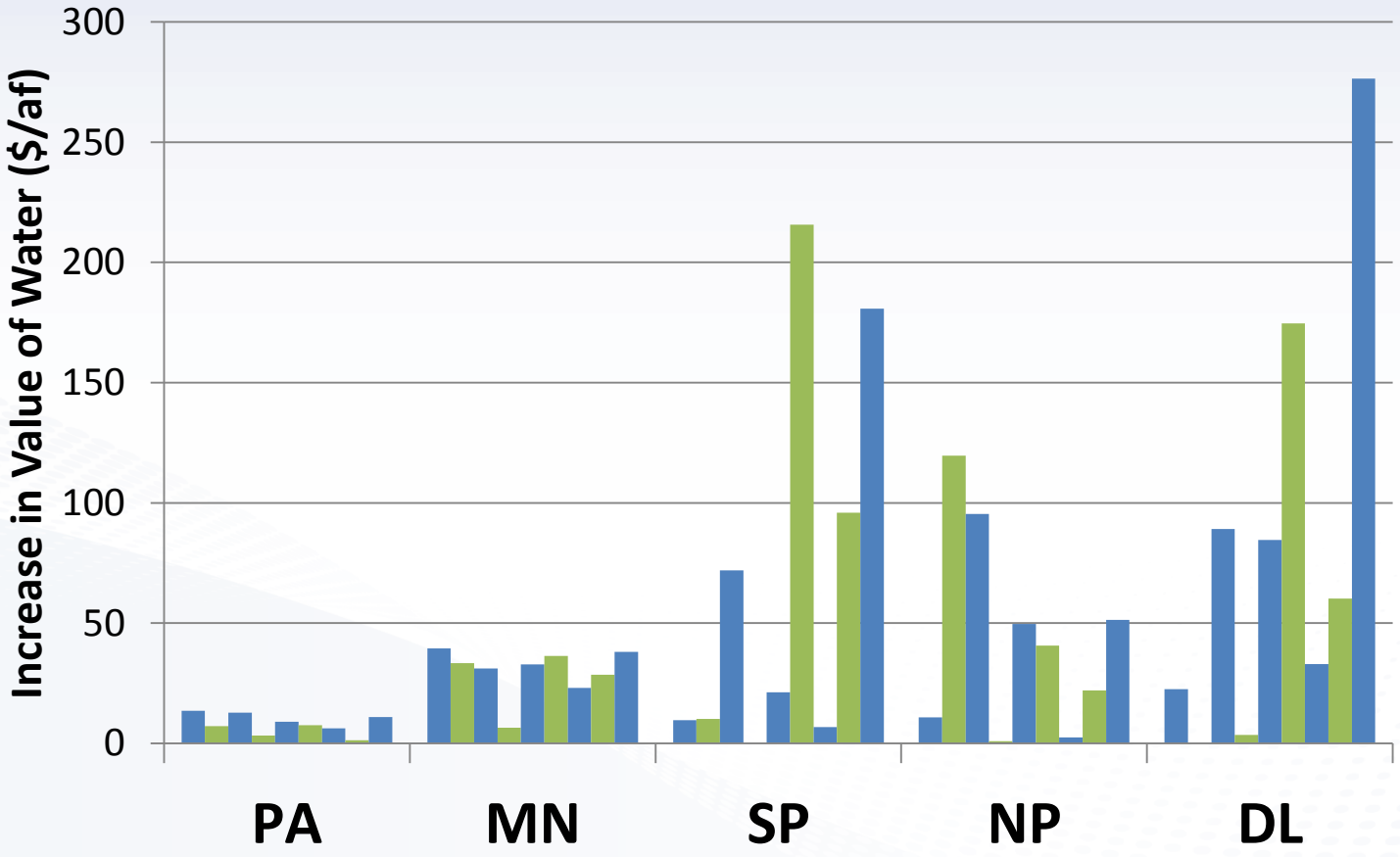
Increase in Value of Water Under Climate Scenarios ($/af)



Order of Columns
CGCM_B2
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CGCM_A1B
CSIRO_A1B
MIROC_A1B
CGCM_A2
CSIRO_A2
MIROC_A2

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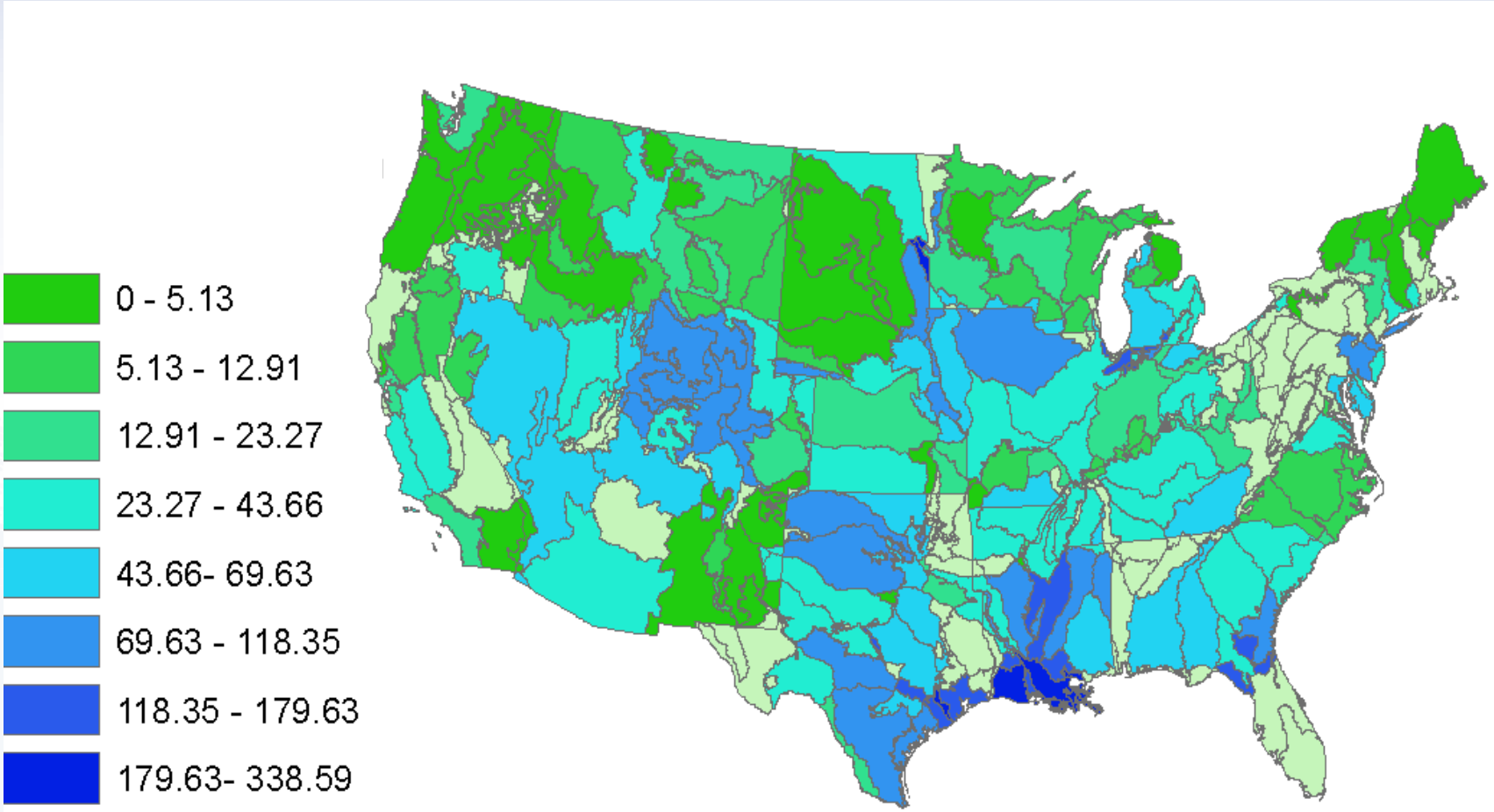
Regional Change in Value of Water ($/af)

(average over climate futures)



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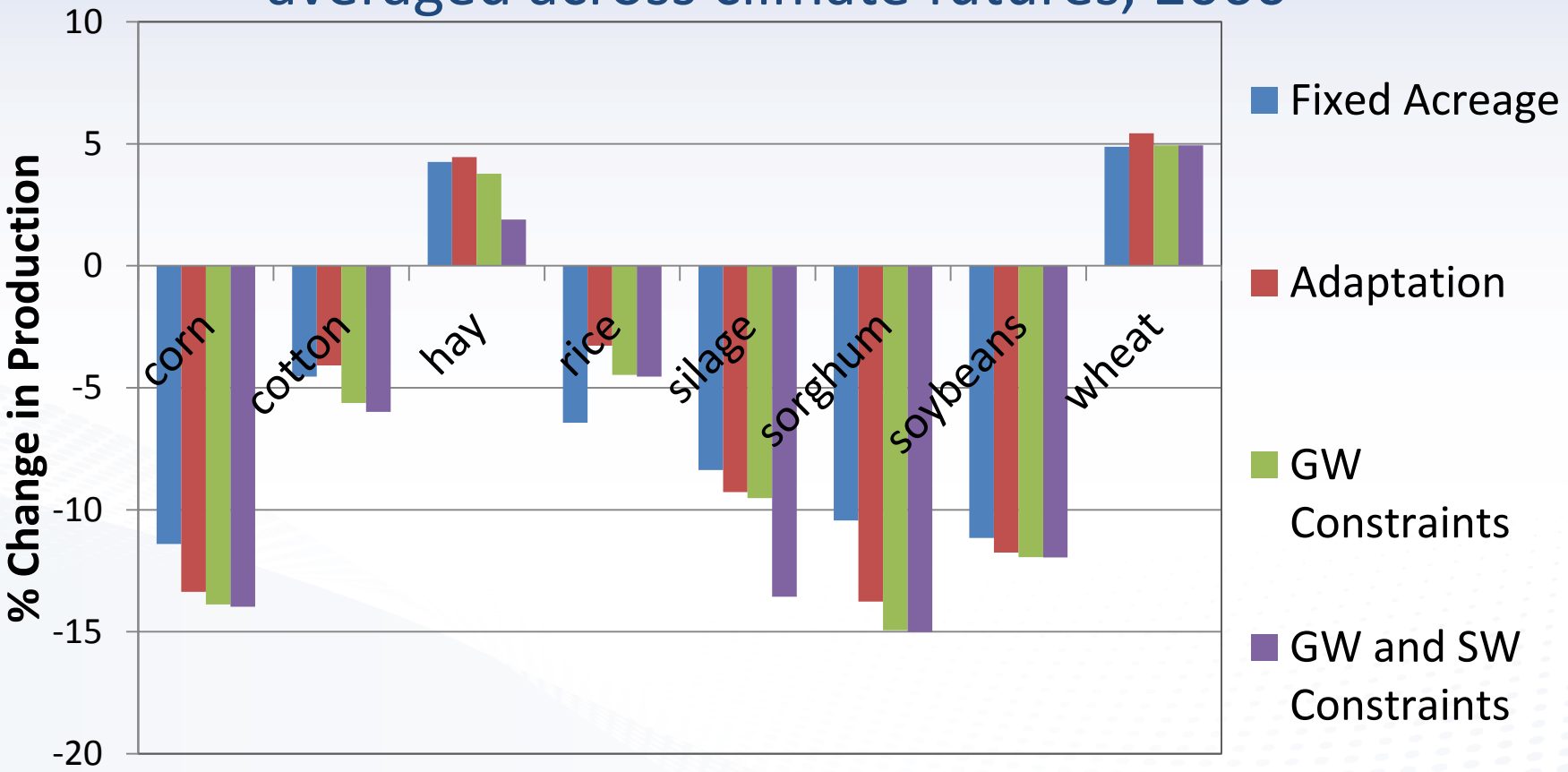
Change in National Production

(relative to reference production levels)

averaged across climate futures, 2060



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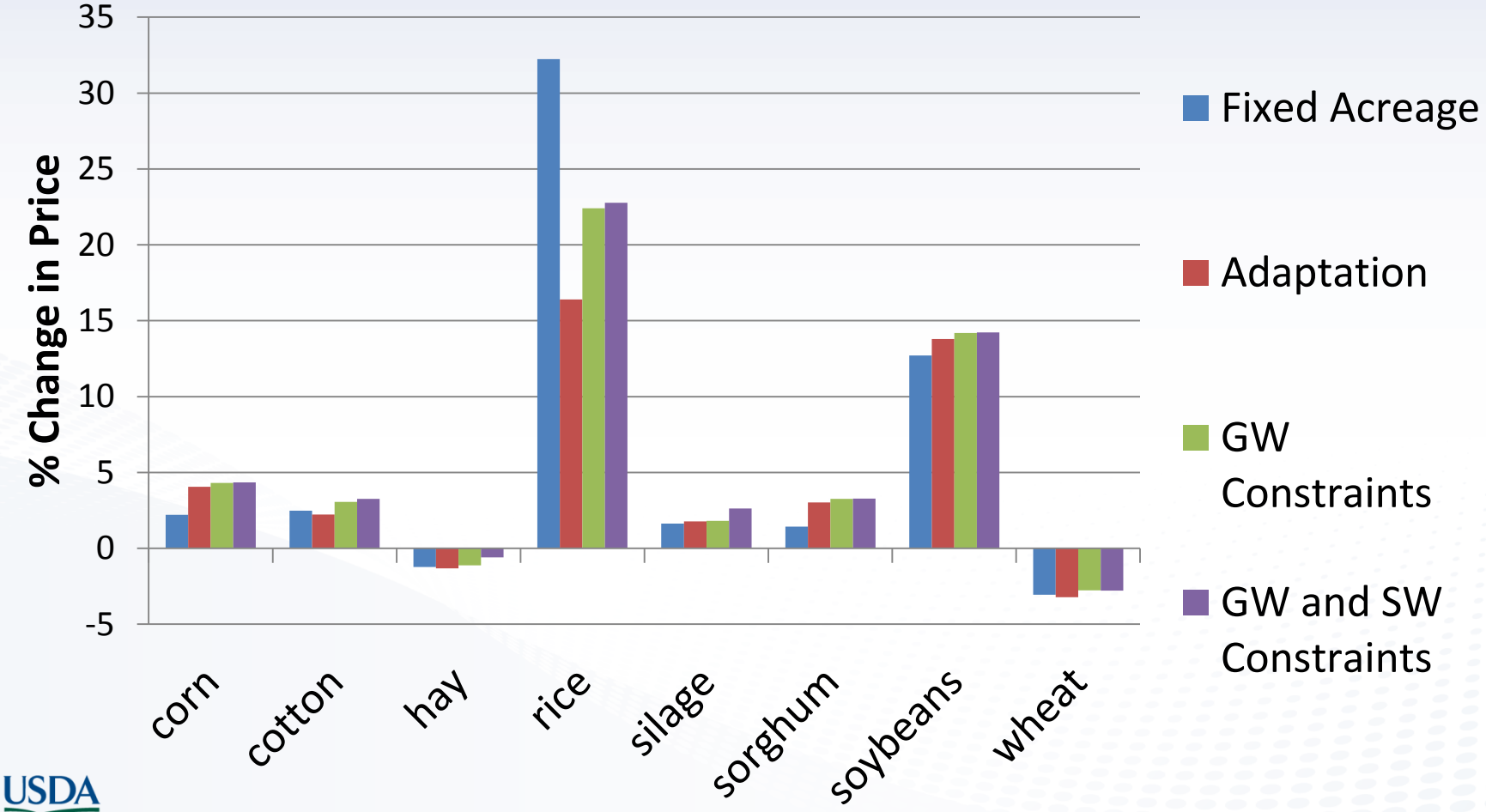
Change in Commodity Prices

(relative to reference price levels) averaged across climate futures, 2060



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Conclusions

- Differential yield impacts across dryland and irrigated production:
  - Precipitation patterns, moisture stress, and irrigation requirements;
  - Temperature, biomass heat stress, and ET response;
  - CO_2, water-use efficiency, and yield of C_3 crops;
- Irrigation demand declines beyond mid-century (relative to reference case), due in part to shifting water productivity in crop production.
- Relative importance of climate impacts on irrigation varies regionally:
  - Surface-water shortages restrict irrigated area in PA, MN regions;
  - Relative profitability of irrigation the primary driver elsewhere.
- Price and production impacts of surface-water supply reductions small relative to initial biophysical impacts of changing climate conditions.