Modeling the Impact of Irrigation on Precipitation in the Great Plains

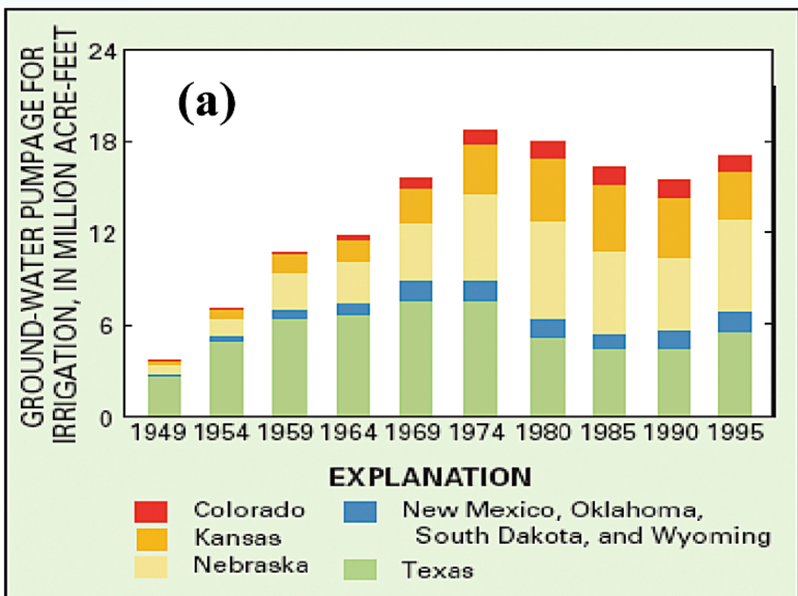
Keith J. Harding
Peter K. Snyder

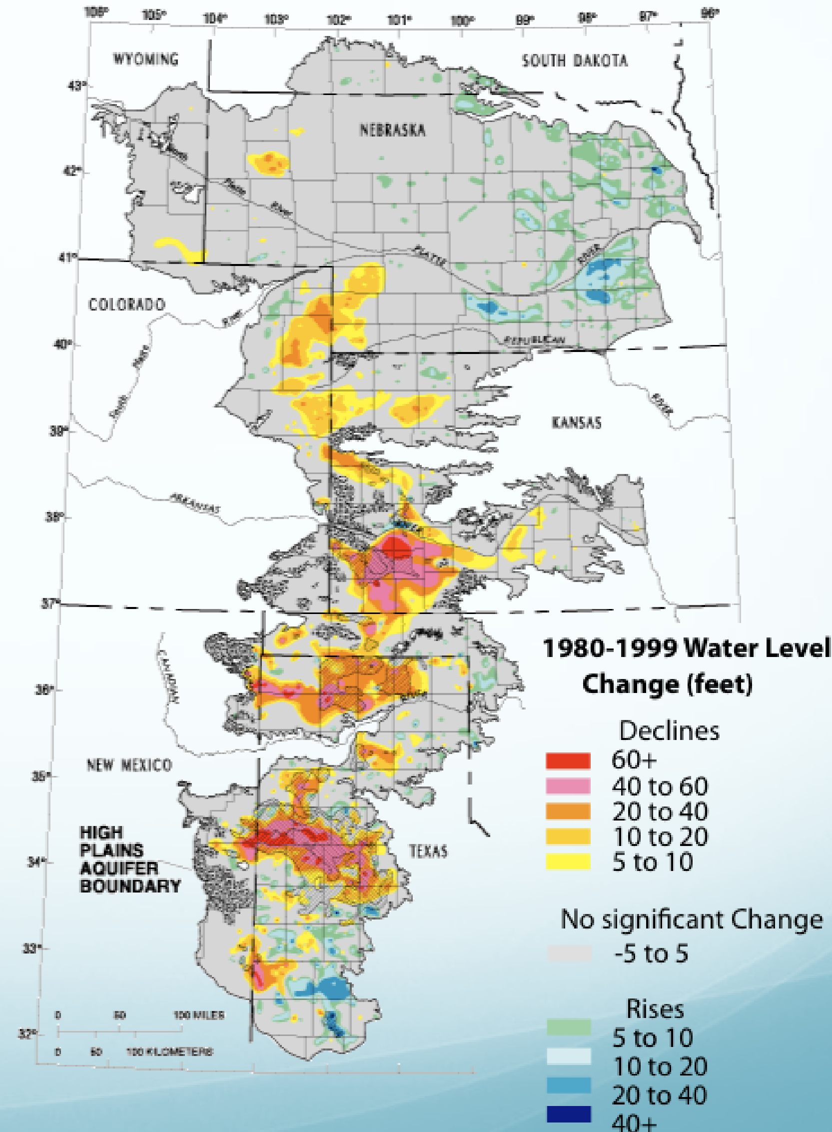
University of Minnesota
Department of Soil, Water, and Climate



Why is this important?

- Irrigation has rapidly expanded since WWII
  - Increased withdrawals of groundwater
    - Ogallala Aquifer stressed
    - Current groundwater extraction rates are unsustainable
  - Important to know the amount of irrigated water that is returned to the region through precipitation





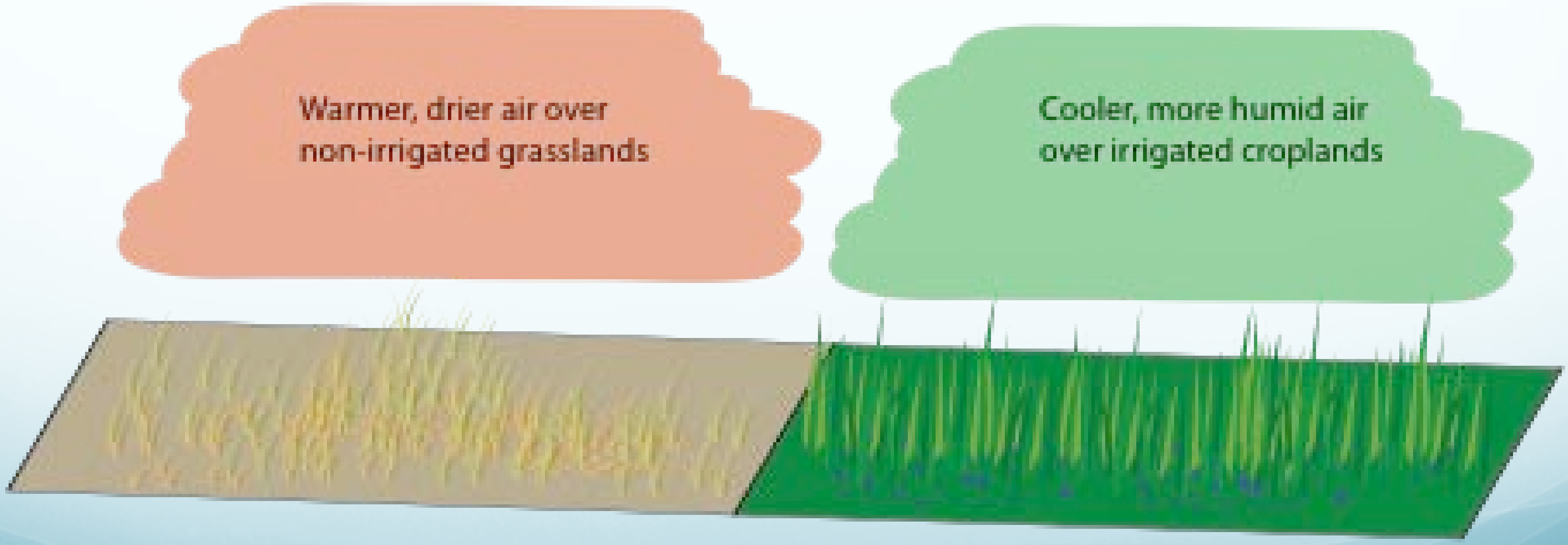
DeAngelis et al. (2010), McGuire (2001)

Why is this important?

- Climate Change
  - Increased drought prevalence and severity expected
    - Accelerated stress on Ogallala Aquifer
      - Groundwater withdrawals more costly
- Great Plains are one of the most productive agricultural regions in the world
  - Food scarcity
  - Instability related to food prices

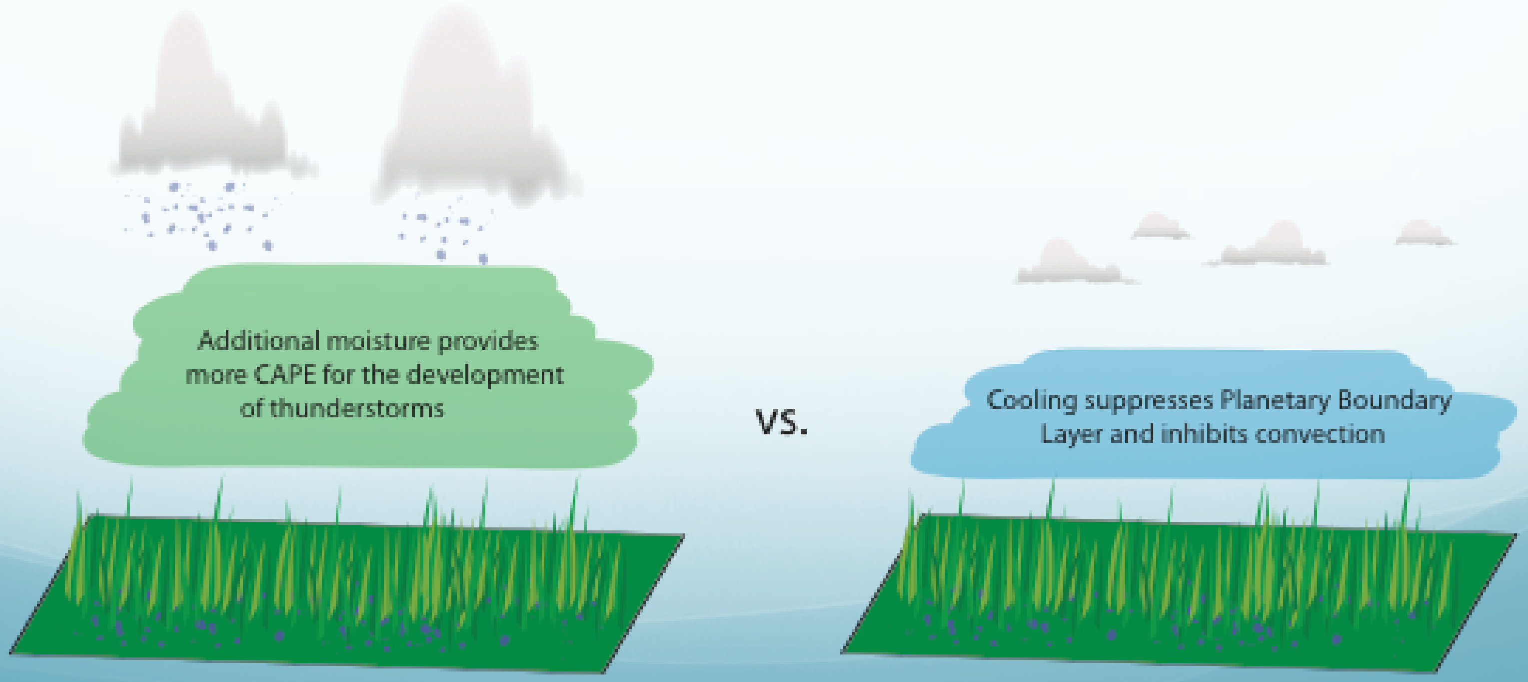
Biophysical Impacts of Irrigation

- Increased latent heat flux over irrigated areas
  - Drives cooler temperatures and higher humidity at the surface



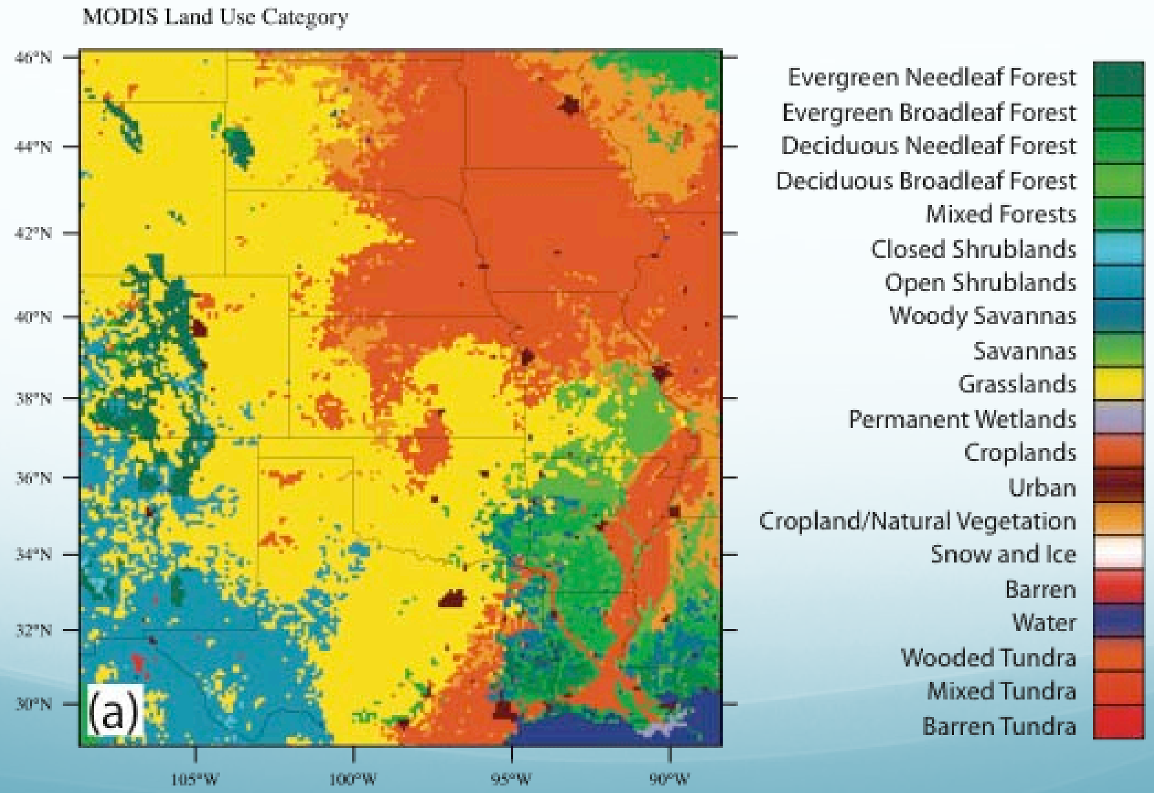
Effect of irrigation on convection

- Irrigation drives competing effects on thunderstorm development
  - Increased moisture increases Convective Available Potential Energy (CAPE)
  - Decreased temperatures suppress the Planetary Boundary Layer, inhibiting convection



Experimental Setup

- Weather Research and Forecasting (WRF) Model
  - 10 km resolution
  - 30-second time step
  - No cumulus parameter
  - Noah Land Surface Model
  - Morrison Microphysics
  - YSU PBL Scheme
  - RRTM Longwave Scheme
  - Dudhia Shortwave Scheme



Skamarock et al. (2008)

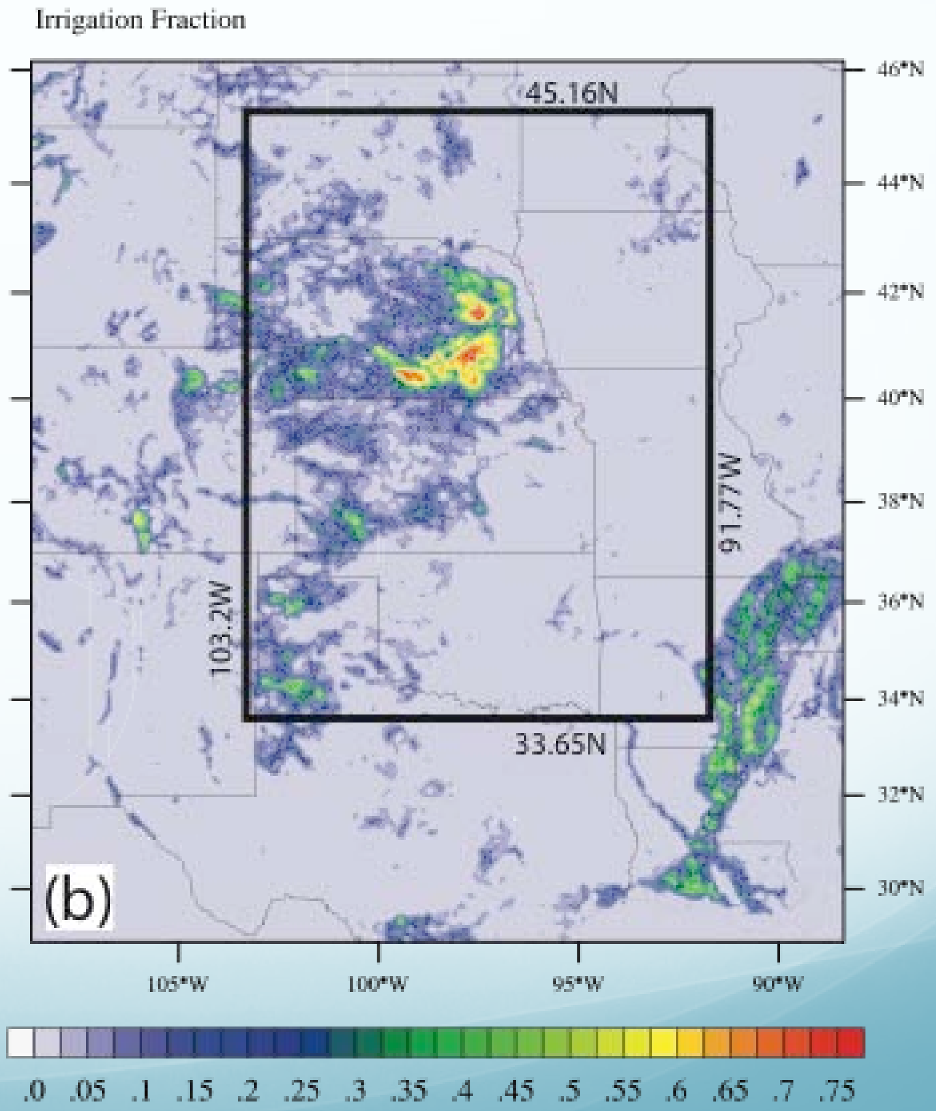
Experimental Setup

- Simulations of 9 different years
  - 3 drought years, 3 normal years, and 3 pluvial (flood) years
  - 3 El Niño years, 3 neutral years, and 3 La Niña years
  - Full spectrum of climate conditions
- Each year simulated with and without irrigation

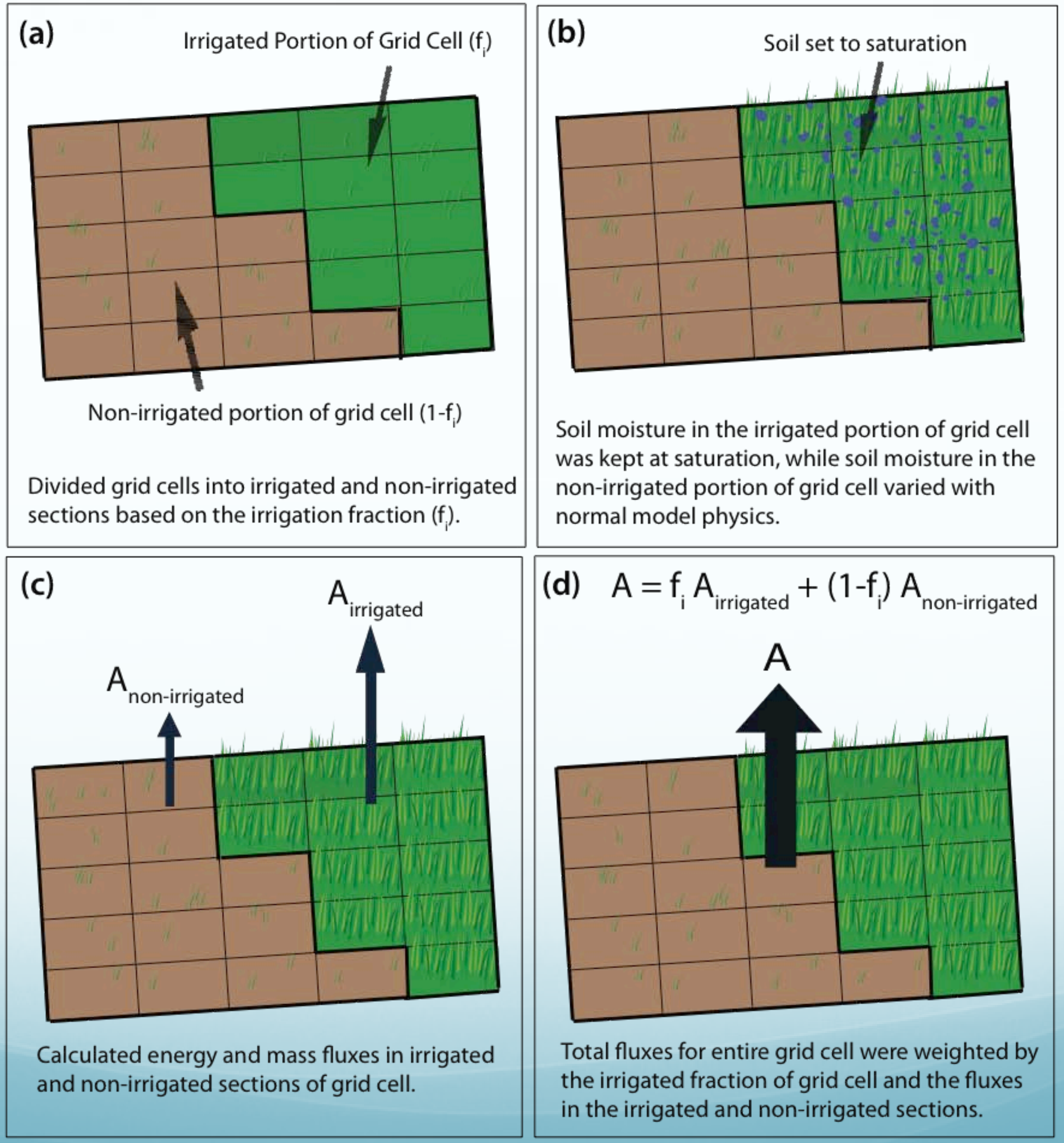
	Drought	**Normal**	**Pluvial**
Current Vegetation, Irrigated	El Niño: 1983 Neutral: 2000 La Niña: 1988	El Niño: 1997 Neutral: 1990 La Niña: 1985	El Niño: 1993 Neutral: 2008 La Niña: 2007
Current vegetation, non-irrigated (control)	El Niño: 1983 Neutral: 2000 La Niña: 1988	El Niño: 1997 Neutral: 1990 La Niña: 1985	El Niño: 1993 Neutral: 2008 La Niña: 2007

Experimental Setup

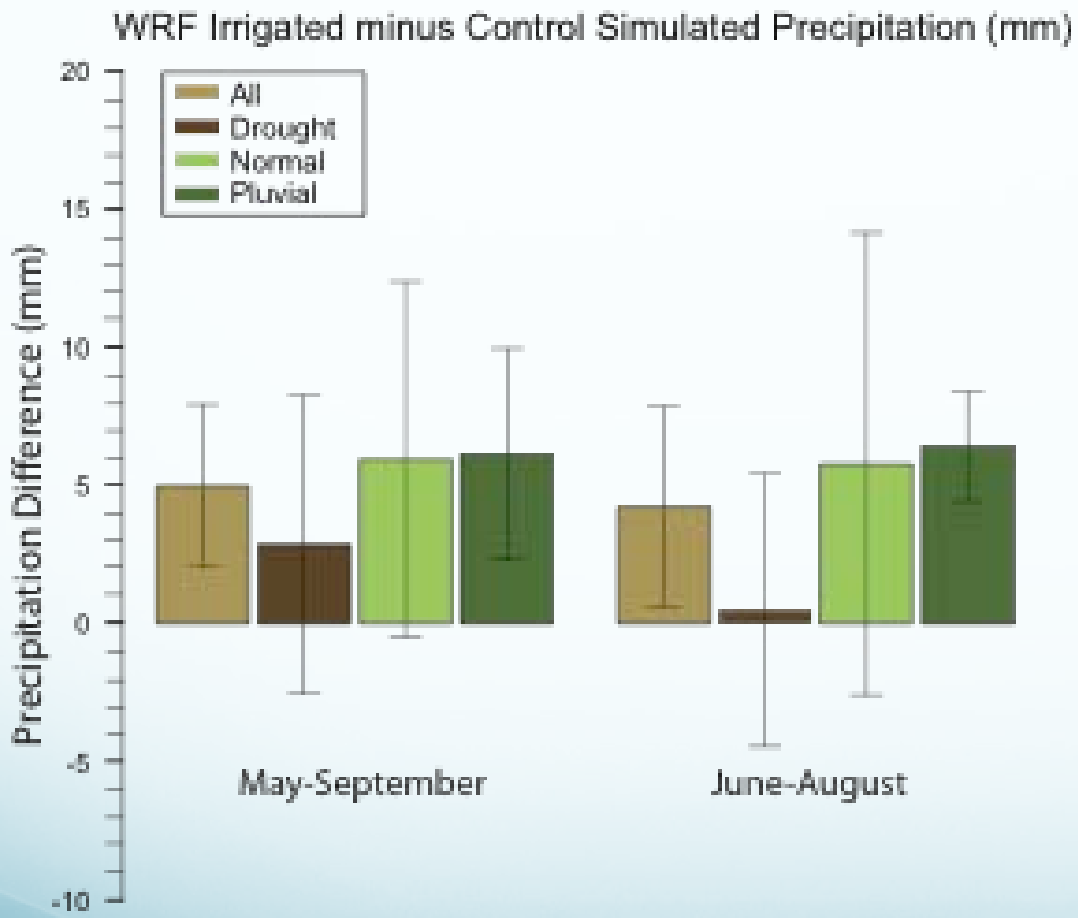
- 500 m resolution MODIS irrigation fraction dataset from Ozdogan and Gutman (2008)
- Uses differences in NDVI between different wavelengths to determine irrigation fraction

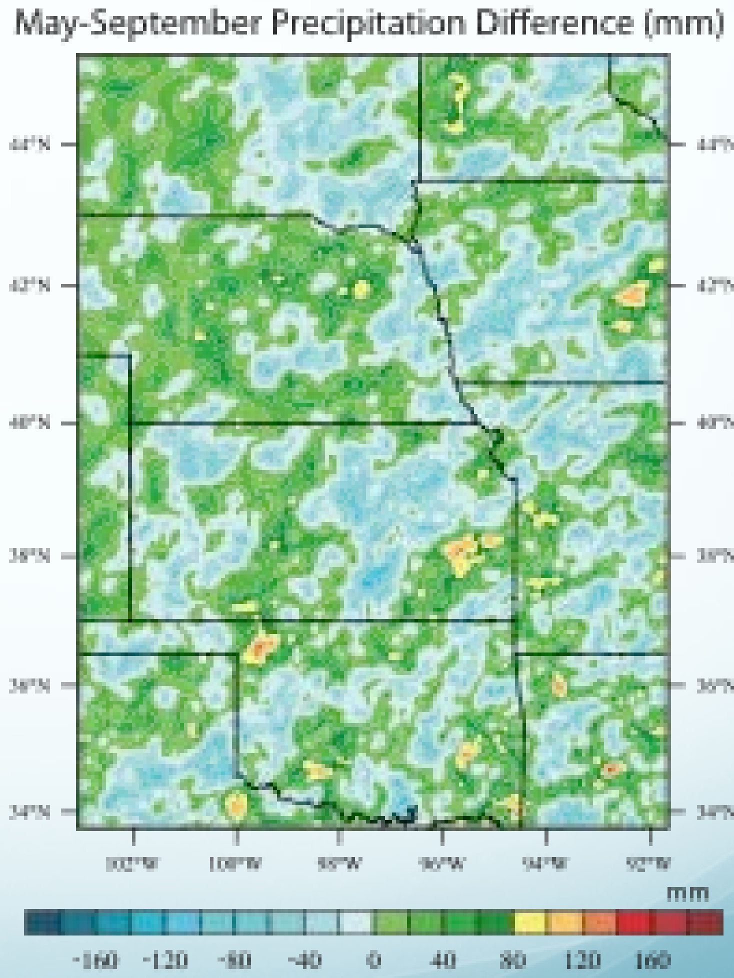


Irrigation Representation in WRF



Model Results





Model Results

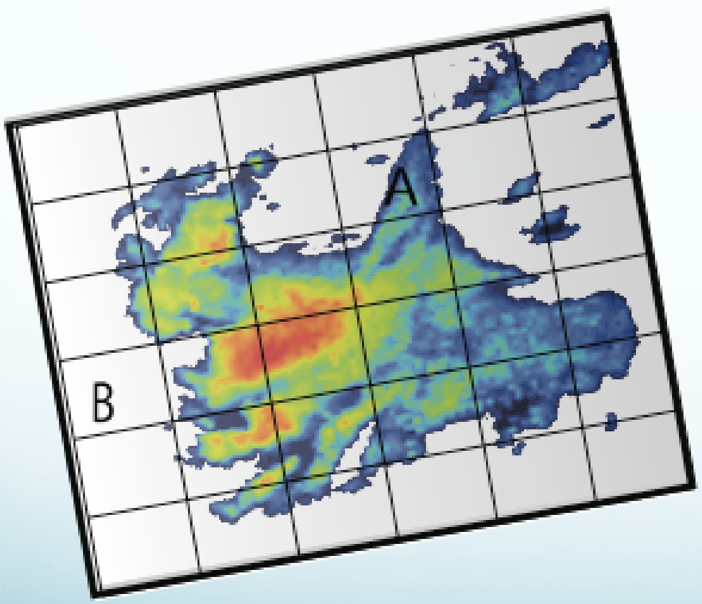
- Irrigation results in a 1% increase in precipitation over the Great Plains ($p < 0.05$)

Forcing for increased convection from additional CAPE	>	Forcing for suppression of convection from decreased boundary layer

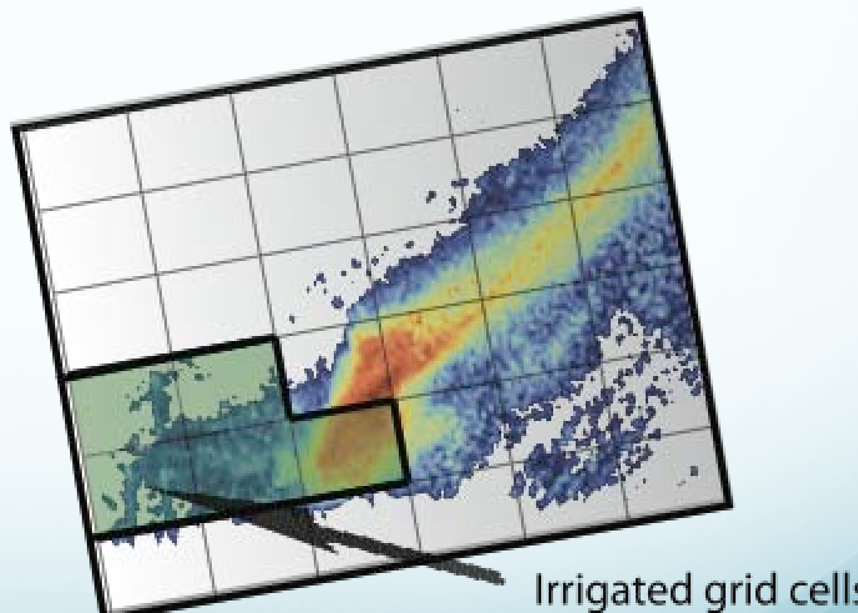
- Smallest precipitation increase during drought years
  - Due to greatest decrease in planetary boundary layer height
  - Decrease over irrigated areas
- What is the source of the increase in precipitation?
  - Evapotranspiration (ET) over irrigated areas?
  - Additional advection of moisture from external sources (e.g. Gulf of Mexico)?

Determination of Irrigation-Induced Precipitation

- Backward trajectory analysis determines source of precipitation
- Derived from backward trajectory analysis of Brubaker et al. (2001)

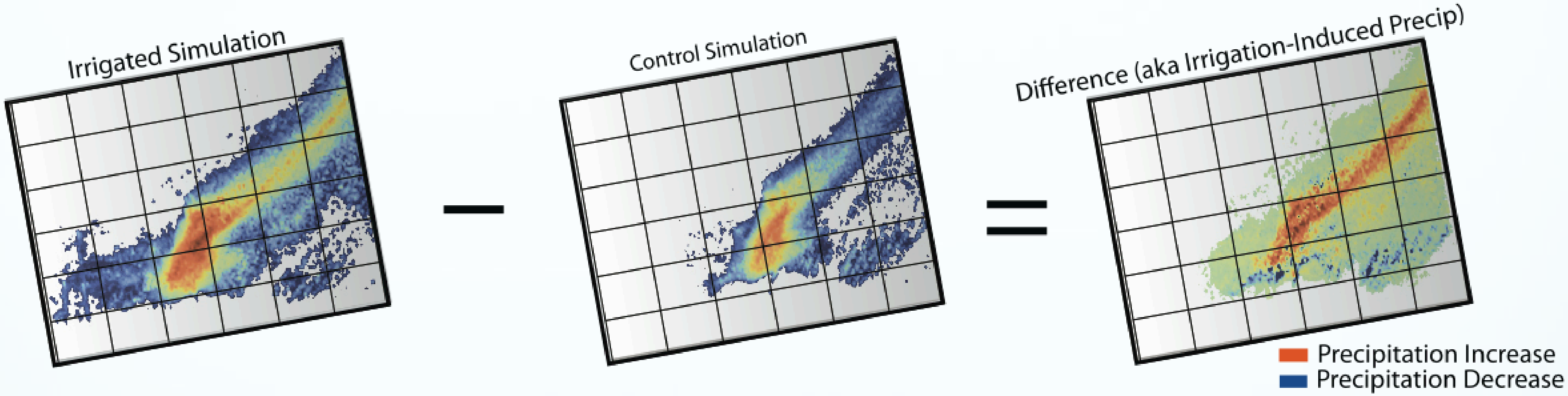


Precipitation from Individual Grid Cell



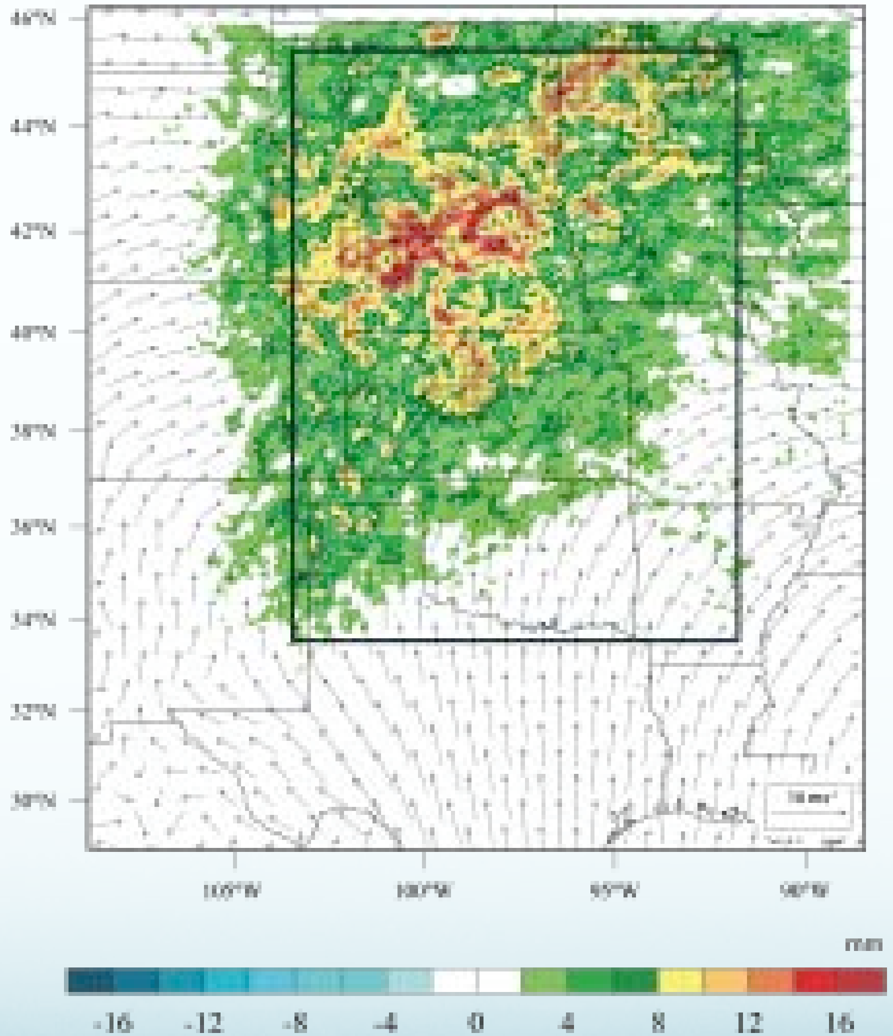
Precipitation from Irrigated Grid Cells

Determination of Irrigation-Induced Precipitation



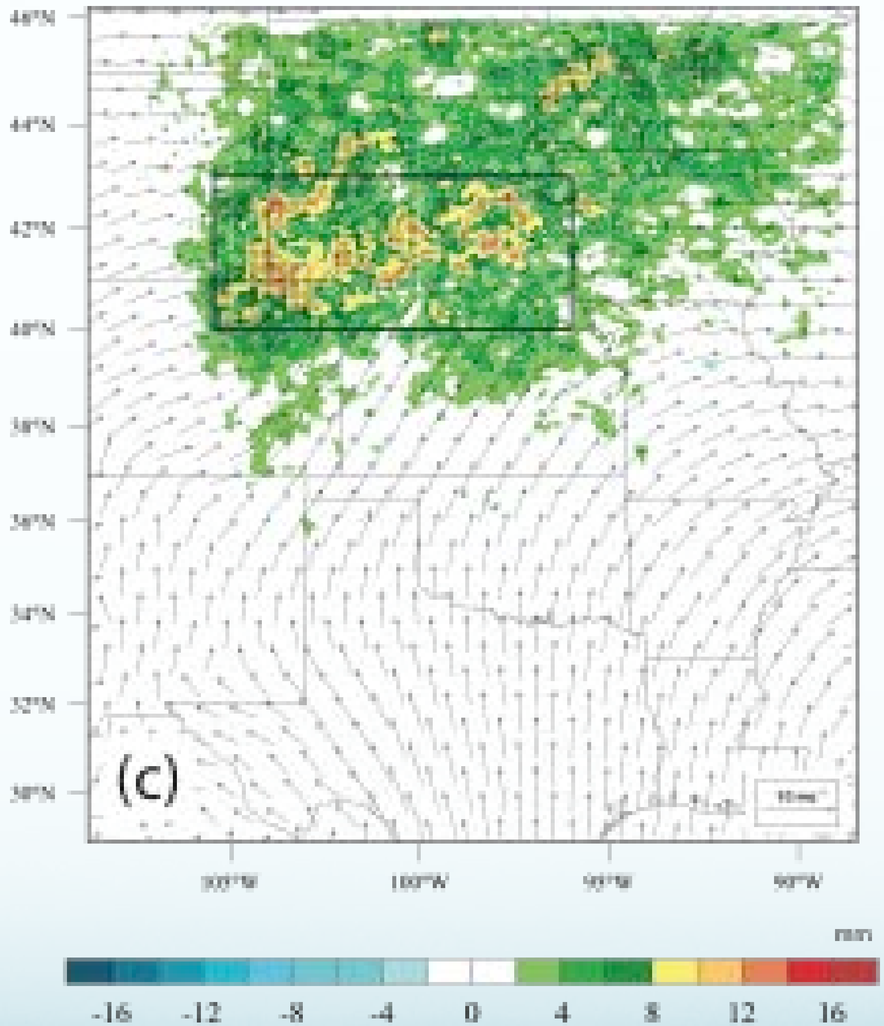
- Performed for irrigated and control simulations
- Difference is the precipitation of water from ET over irrigated fields (aka irrigation-induced precipitation)

Irrigation-Induced Precipitation



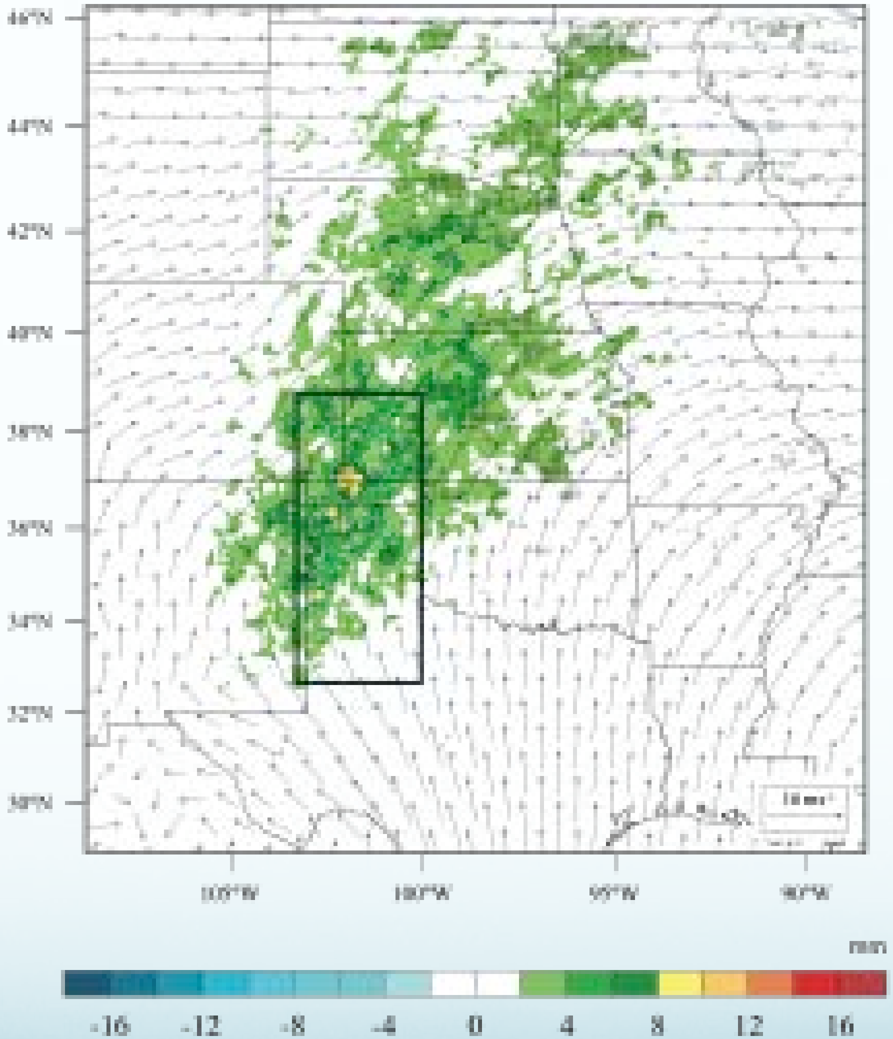
May-September irrigation-induced precipitation (mm) and moisture-weighted wind vectors for all simulated years from grid cells with at least 10% irrigation within box

Irrigation-Induced Precipitation



May-September irrigation-induced precipitation (mm) and moisture-weighted wind vectors for all simulated years from grid cells with at least 10% irrigation within box

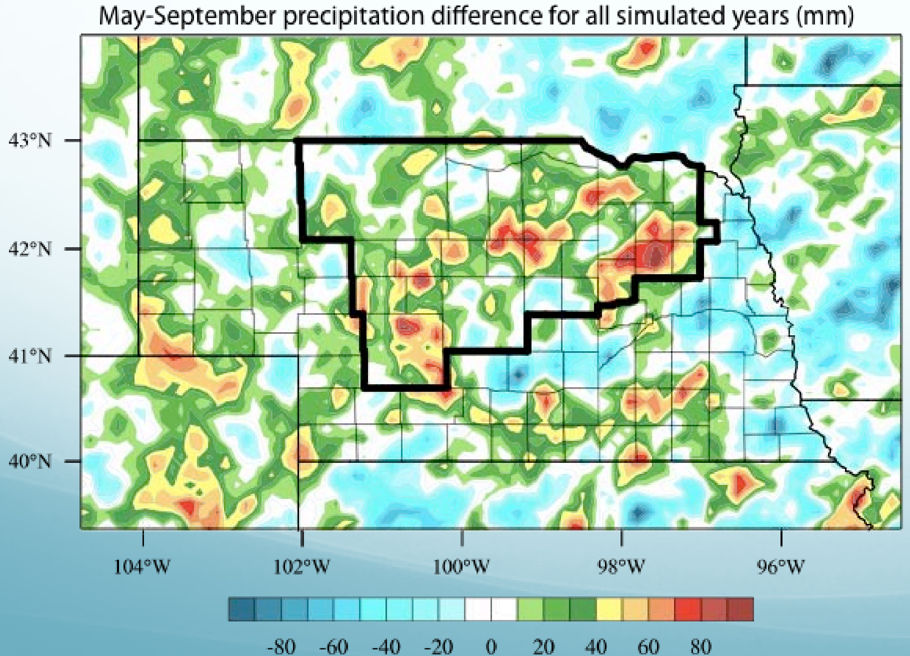
Irrigation-Induced Precipitation

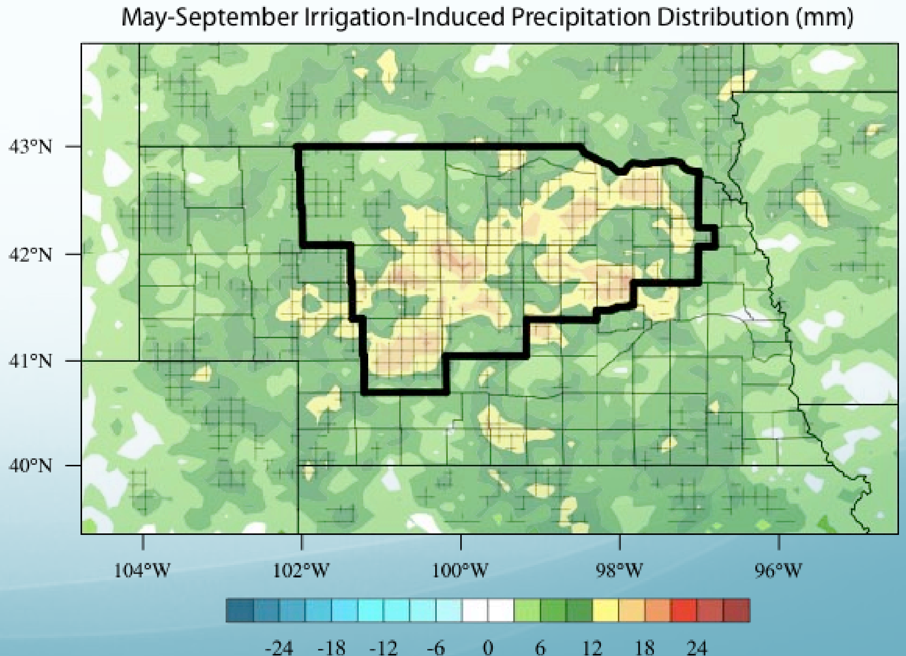


May-September irrigation-induced precipitation (mm) and moisture-weighted wind vectors for all simulated years from grid cells with at least 10% irrigation within box

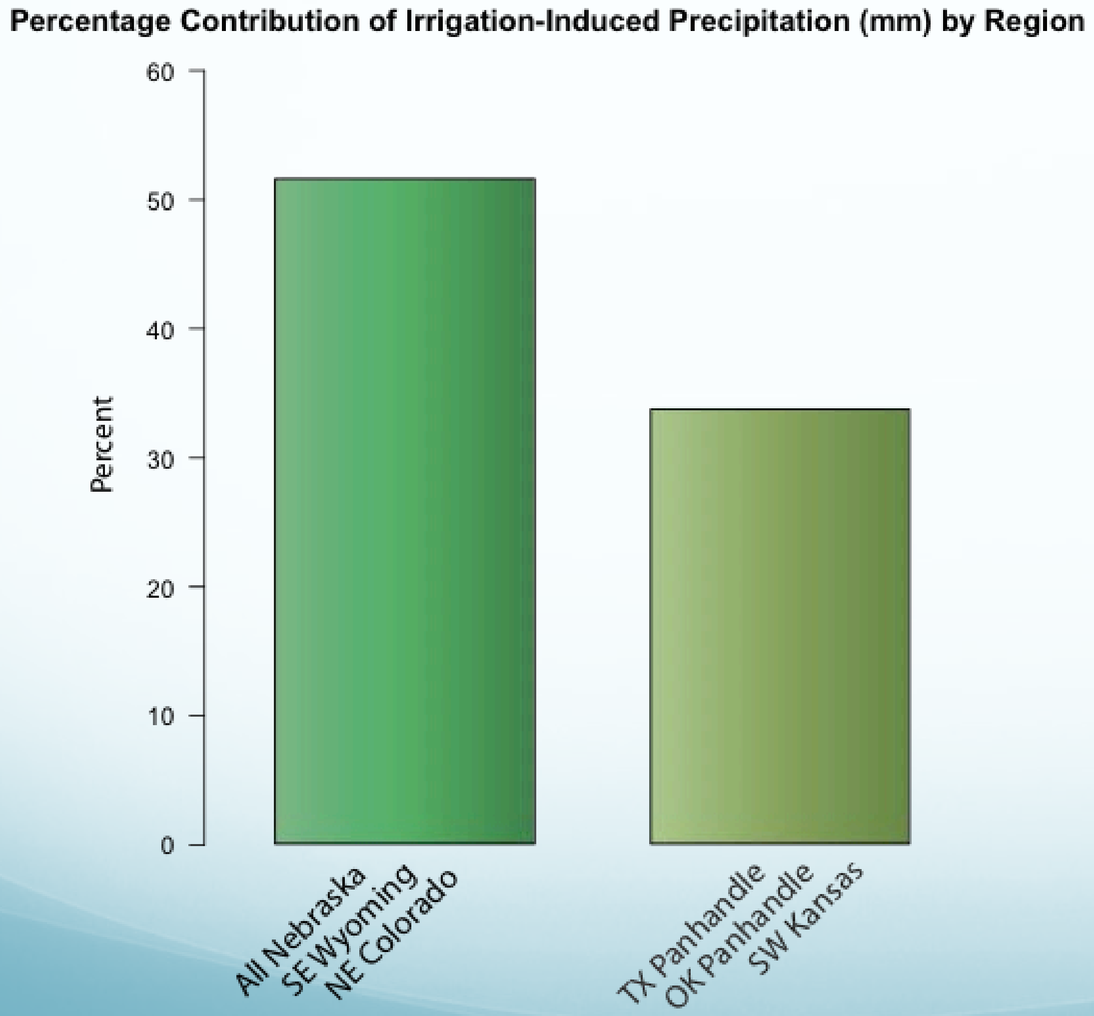
Irrigation-Induced Precipitation

- Heaviest irrigation-induced precipitation coincident with simulated precipitation increases
  - 8.96 mm simulated total precipitation change
  - 9.11 mm of irrigation-induced precipitation
- Irrigation-induced precipitation responsible for simulated precipitation increase
- Coincident with observed precipitation increases after irrigation

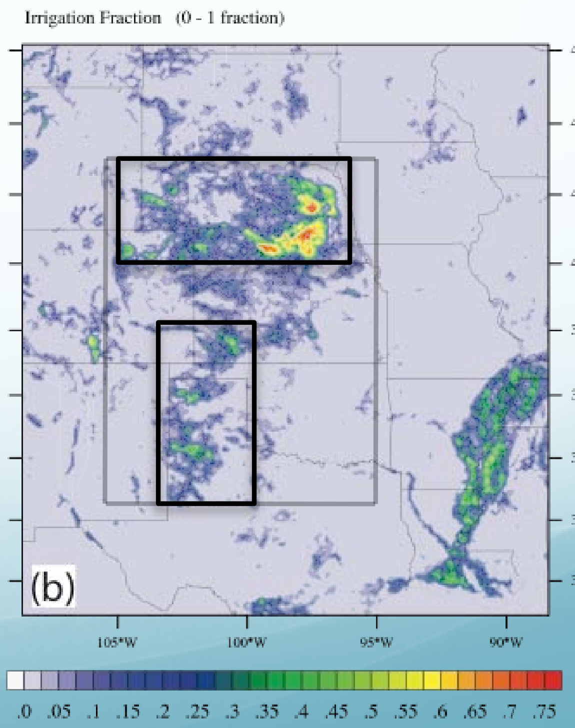




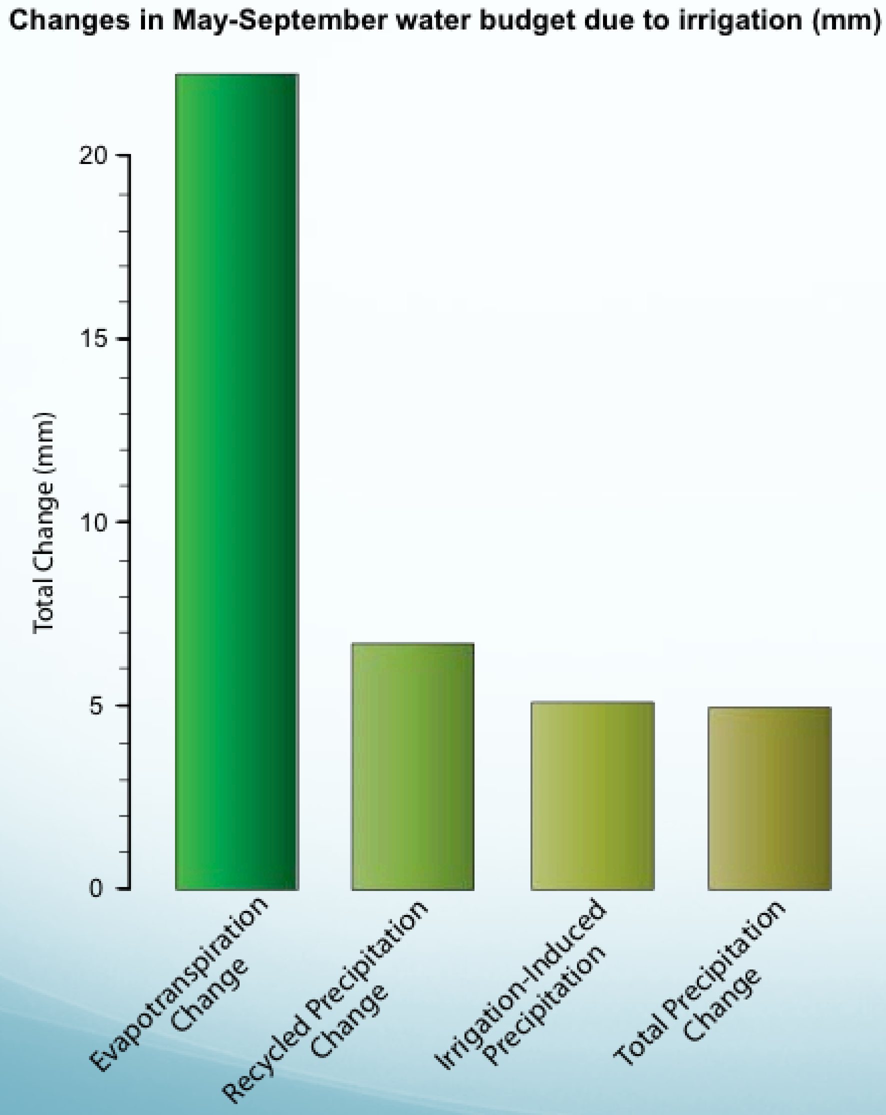
Irrigation-Induced Precipitation



- Majority comes from irrigated areas in the northern High Plains
- Smaller amount from the southern High Plains



Effect on Water Budget



- Evapotranspiration increase greater than precipitation increase
  - Irrigation results in a net loss of 17.7 mm (0.7”) during the warm season
  - Only 15% of evapotranspired water from irrigation returns to the region
- Irrigation-induced precipitation ≈ total precipitation change
  - Additional precipitation due to evapotranspiration over irrigated fields

Conclusions

- Irrigation results in a small increase in rainfall (1%) over the Great Plains
  - Can be traced to ET over irrigated fields
  - Largest increase in precipitation during flood years
- Change in evapotranspiration > precipitation increase
  - Irrigation results in a net loss of water during the warm season
    - Most magnified during drought years
      - Smallest increase in precipitation
      - Largest increase in ET
    - Future Consequences
      - Increased drought frequency with climate change
      - Expect greater water loss due to irrigation

Acknowledgments

Tracy Twine

Stefan Liess

Jarod Bryant

Hong Xu

Pete Boulay, Minnesota Department of Natural Resources

Francina Dominguez, University of Arizona

Mutlu Ozdogan, University of Wisconsin-Madison

University of Minnesota Supercomputing Institute (MSI)

UNIVERSITY OF MINNESOTA

Driven to Discover℠

References

Brubaker, K. L., P. A. Dirmeyer, A. Sudradjat, B. S. Levy, and F. Bernal, 2001: A 36-yr climatological description of the evaporative sources of warm-season precipitation in the Mississippi River basin. *J Hydrometeorol*, **2,** 537-557.

DeAngelis, A., F. Dominguez, Y. Fan, A. Robock, M. D. Kustu, and D. Robinson, 2010: Evidence of enhanced precipitation due to irrigation over the Great Plains of the United States. *J Geophys Res-Atmos*, **115.**

McGuire, V. L: Water-Level Changes in the High Plains Aquifer, 1980 to 1999, 2001: U.S. Geological Survey Fact Sheet 029-01. Reston, VA.

Ozdogan, M., and G. Gutman, 2008: A new methodology to map irrigated areas using multi-temporal MODIS and ancillary data: An application example in the continental US. *Remote Sens Environ*, **112,** 3520-3537.

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang, and J. G. Powers, 2008: A description of the Advanced Research WRF Version 3.