The development of WRF-Noah-Mosaic-Irrigation framework and its application in regional climate modeling

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Literature Review on Irrigation Modeling

- **Global Scale** (Boucher et al. 2004; Sacks et al. 2009; Puma and Cook

Local Effects:
Increased LH; Decreased SH; Increased SMOIS; Decreased Temperature

al. 2014);

Regional Effects: Complicated and Subject to different Climate Regime
soil moisture alters precipitation via multi-scale processes:
local secondary atmospheric circulations driven by the heterogeneity of the irrigated and non-irrigated land
long-distance water vapor transport
long-term (seasonal to interannual scale) memories

- **HeTao, China** (Kawase et al. 2008)

The Development of a Coupled Regional Climate-Irrigation Model

- Realistic Irrigation Approach
- Accurate Irrigated Acres Information Nationwide
- Irrigation's impacts on the regional water cycle and large-scale circulations
- Effects of irrigation over summer precipitation

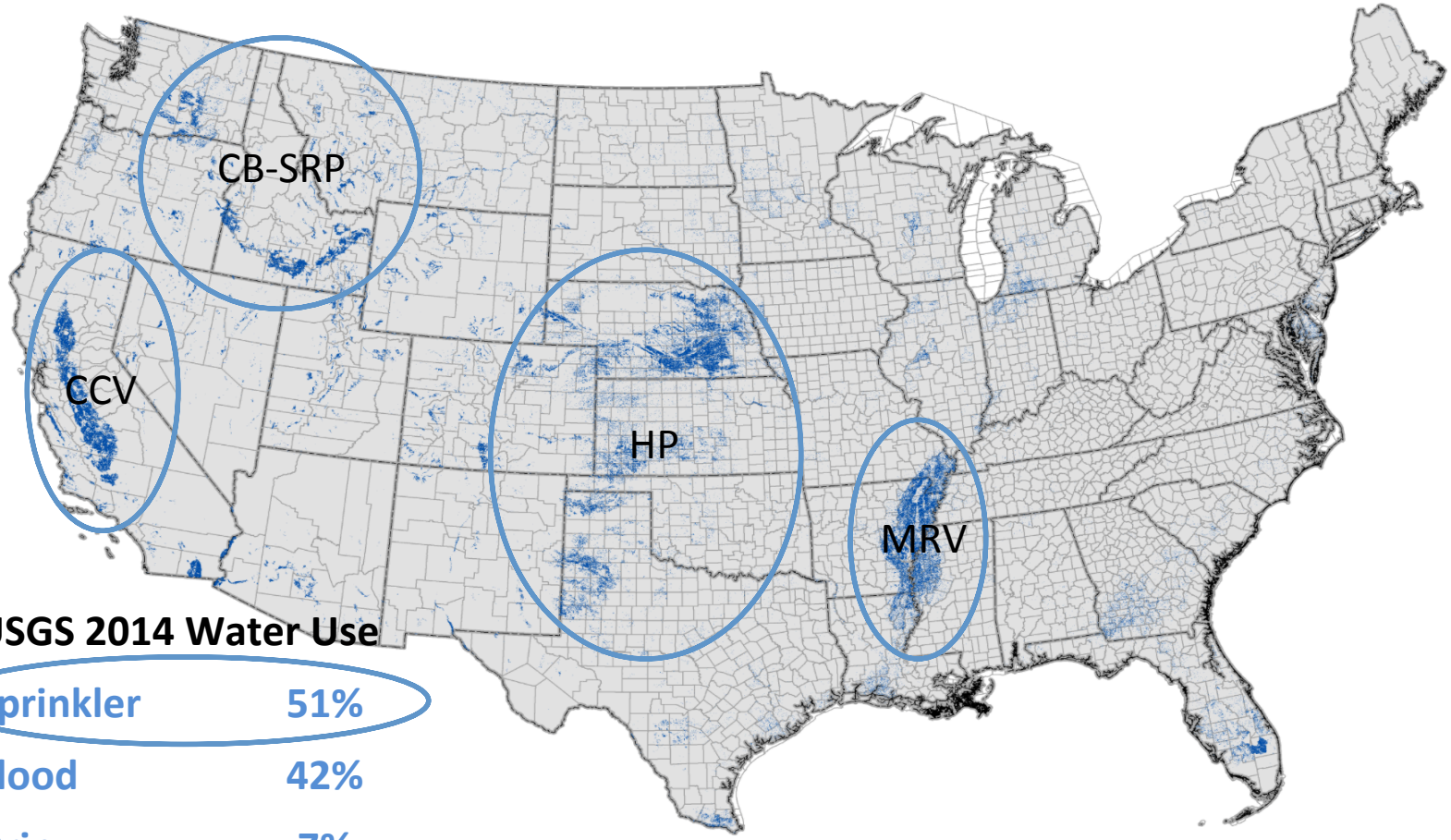
High Plains: Center Pivot Irrigation

(Images from Internet)






2012 MODIS Irrigated Agriculture Data for CONUS -- Version 1



USGS 2014 Water Use

Sprinkler	51%
Flood	42%
Drip	7%

Noah-Mosaic (Li et al., 2013, JGR DOI:10.1002/2013JD020657)

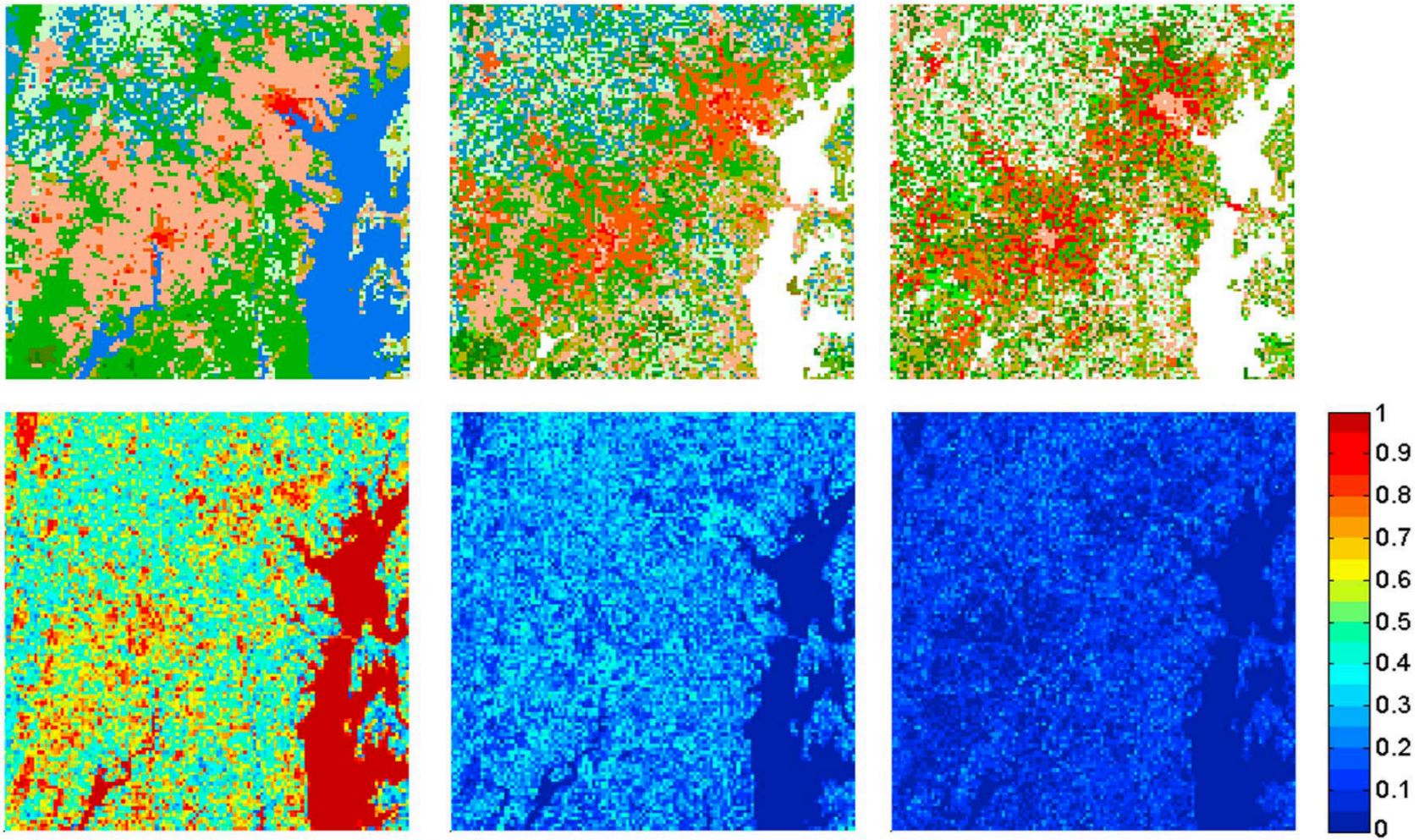
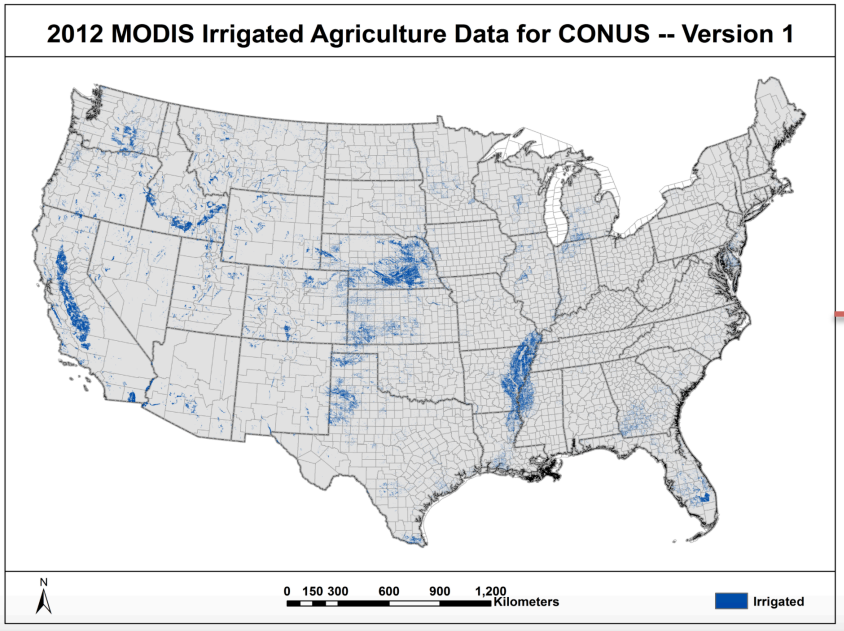
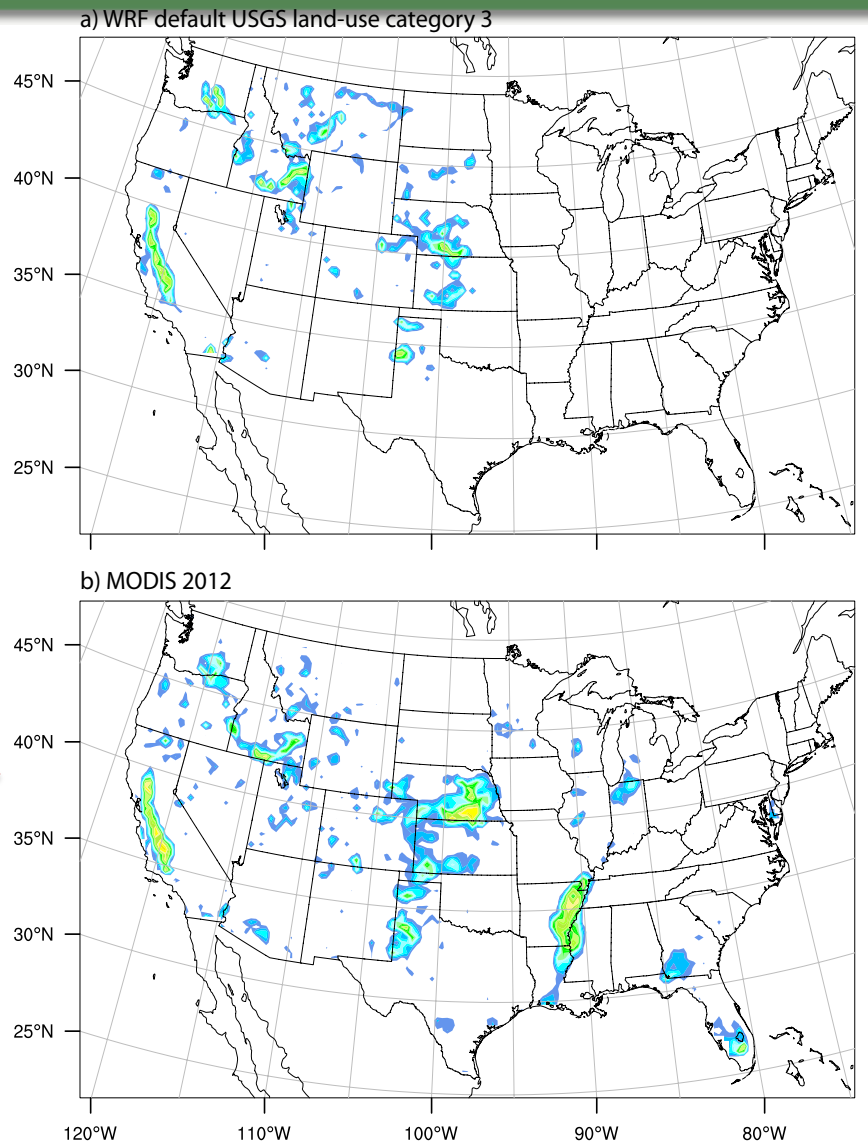
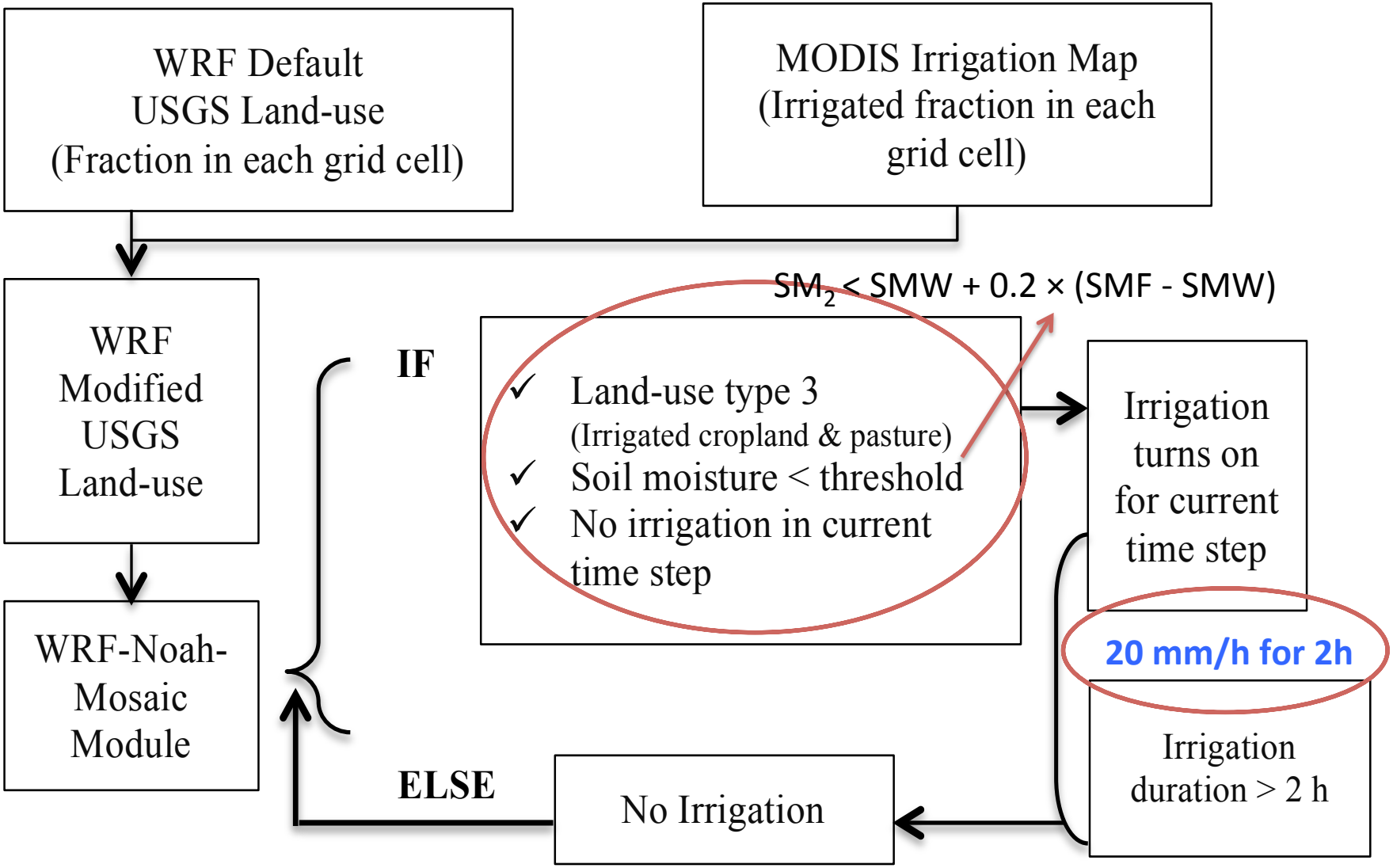


Figure 3. (top) The land cover types of the three dominant tiles within each grid cell in the 1 km domain 3 (the legend for land cover types follows the one used in Figure 1; blank areas indicate that there are no second or third tiles). (bottom) The area fractions of these three dominant tiles within each grid cell in domain 3.

WRF Default USGS land-use Category 3: Irrigated Cropland and Pasture

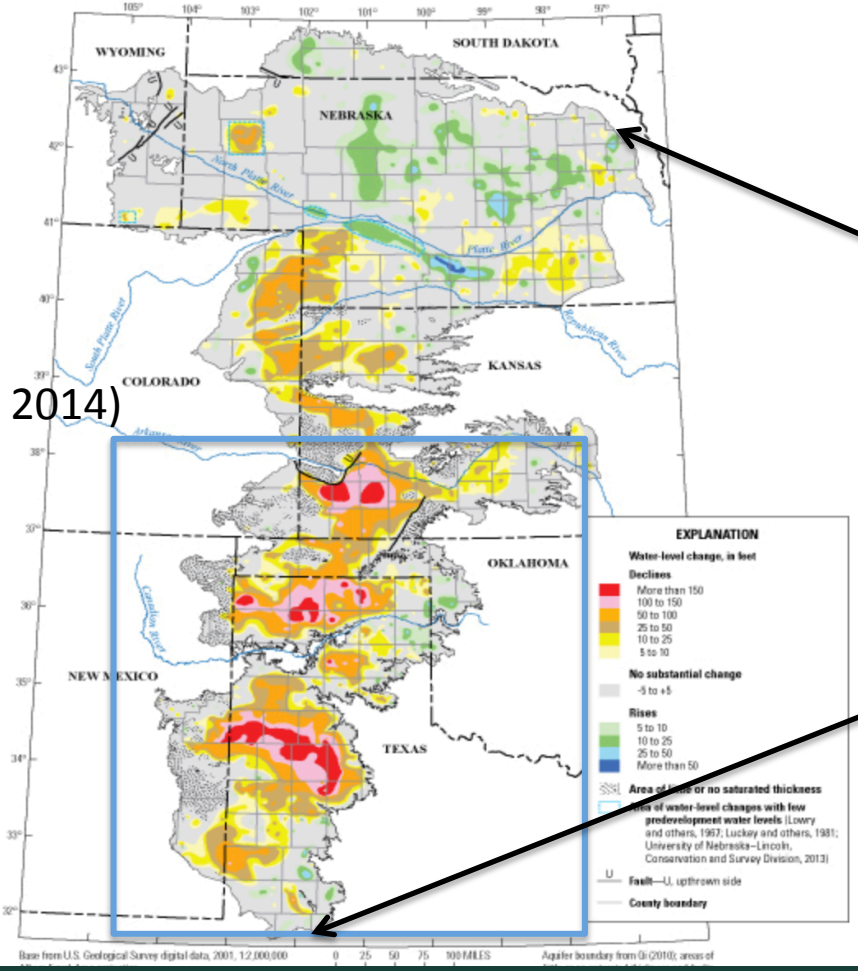





WRF Default
USGS Land-use
(Fraction in each grid cell)
MODIS Irrigation Map
(Irrigated fraction in each grid cell)
WRF
Modified
USGS
Land-use
WRF-Noah-
Mosaic
Module
IF
$SM_2 < SMW + 0.2 \times (SMF - SMW)$
✓ Land-use type 3
(Irrigated cropland & pasture)
✓ Soil moisture < threshold
✓ No irrigation in current time step
Irrigation turns on for current time step
20 mm/h for 2h
Irrigation duration > 2 h
ELSE
No Irrigation

NSF: *Toward Sustainability of the **High Plains Aquifer** Region: **C**oupled **L**andscape, **A**tmosphere, and **S**ocioeconomic **S**ystems (**CLASS**)*

(USGS 2014)



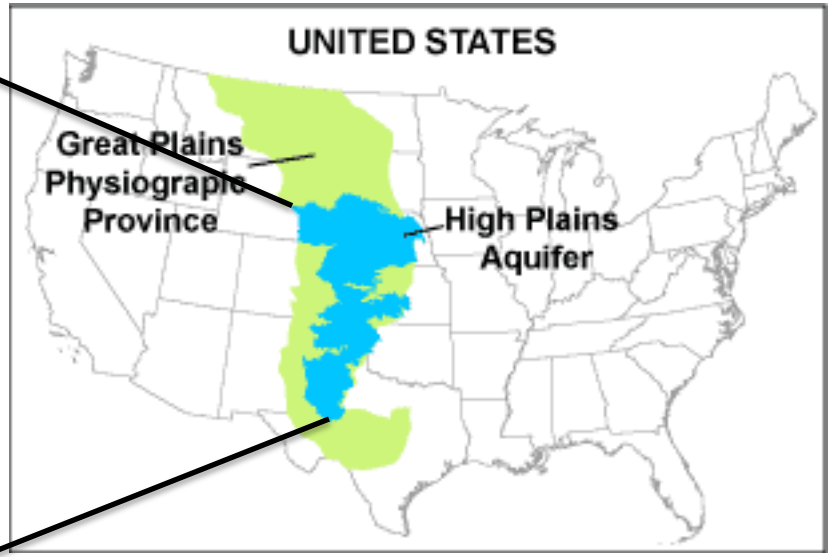


Image by ne.water.usgs.gov

1. A typical center-pivot system irrigates a 1/4 section field, a section is 1 square mile, so the radius of a 1/4 section field is 1/4 of a mile, or 402.4 m For a field of this size, the center pivot system completes a full rotation in approximately 5-7 days

Size

2. Given this, the outer tip of the center pivot is traveling at 15.04 to 21.06 meters/hour, halfway in the center pivot, the system is traveling at half that rate, so 7.52 - 10.53 m/hr

Rotation Speed

3. Not all center pivot systems are identical, but modern lower-pressure spray designs have a spray width of between 2-3 meters, and higher-pressure sprayers on older systems between 3-7 meters

Spray Width

4. This means that at the outer tip of the system, water is applied to a given spot on the field in less than half an hour, while halfway in the water is applied in approximately one hour, even further in, the application times are longer. That is where the time range of **1-2 hours** came from.

Applying Duration

According to the Realistic Practice over the High Plains Aquifer

1. Application amounts can be more variable. Farmers will apply between 12 and 24 inches of water to their fields in most years, or 30.48 to 60.96 cm.

Annual Irrigation Water Amount

2. If farmers start irrigating on May 1st, and irrigate through the end of August, there are 123 days in the growing season, if they irrigate at most every 7 days then there are 17 opportunities to irrigate during the growing season.

Number of Annual Irrigation Event

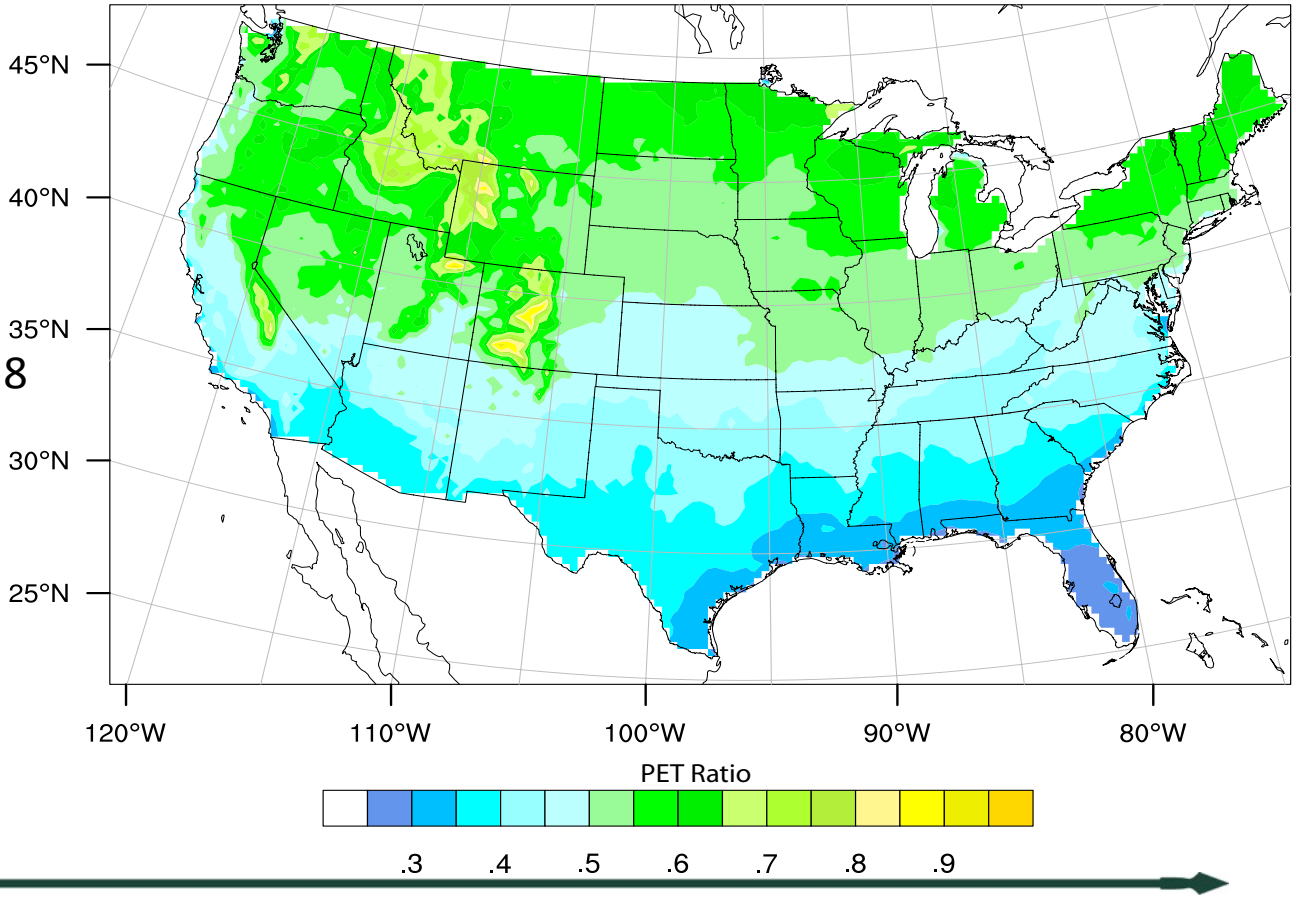
3. This means that, in order to apply the typical amounts of water, the minimum irrigation amount **per irrigation event must be between 1.79 and 3.58 cm**. However, most farmers do not start irrigating this early, nor do they irrigate that often, so a more reasonable estimate of per-event irrigation would be higher than that.

Calculate Irrigation Water Amount Per Event

USGS 2010 County-level Water Use Data (Million Gallon Per Year)

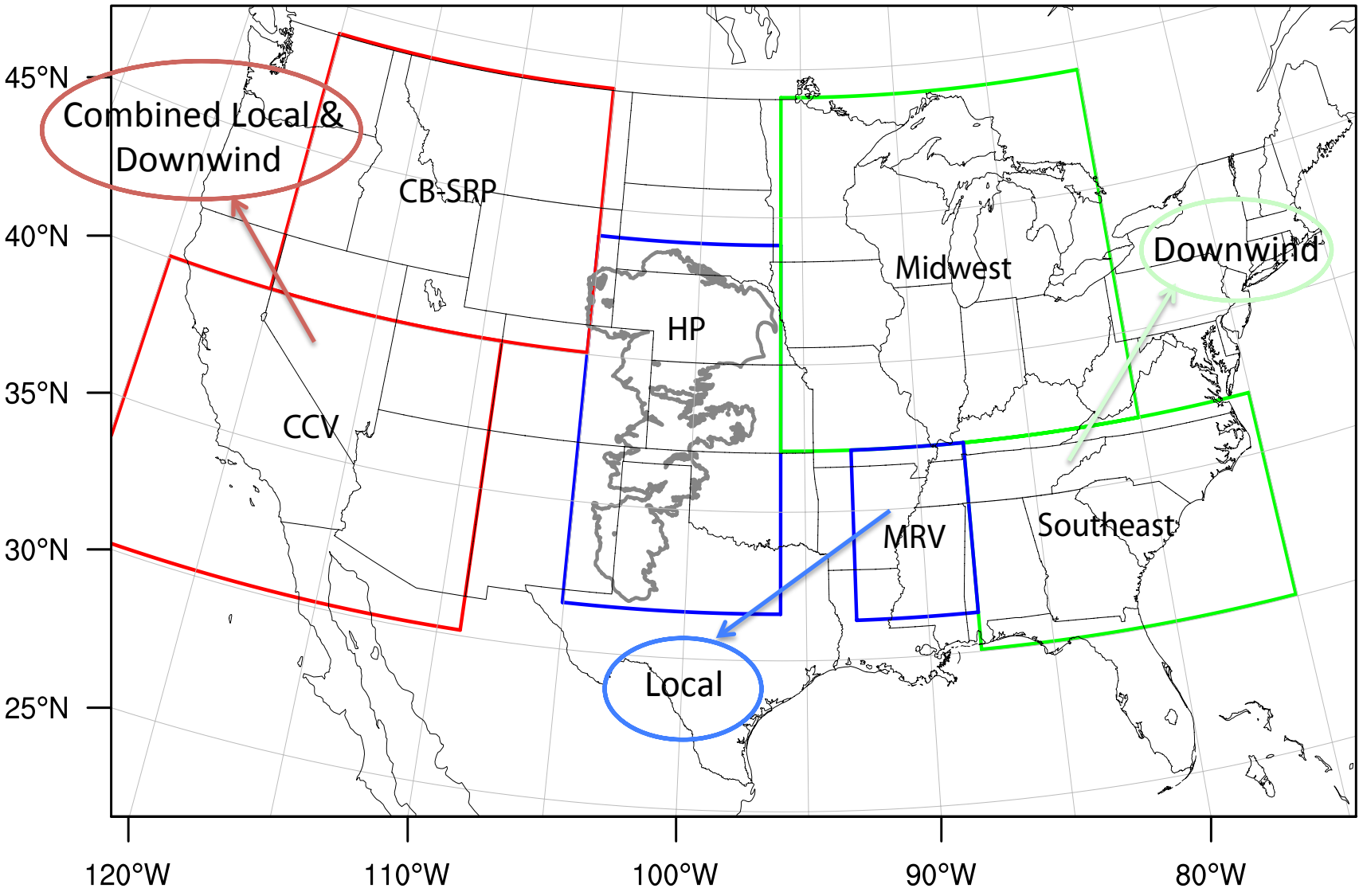
- In the South : 0.25
- In the North: 0.5
- In the Intermountain: > 0.8

Potential Evapotranspiration Ratio
(PET Ratio of JJA to whole growing season)

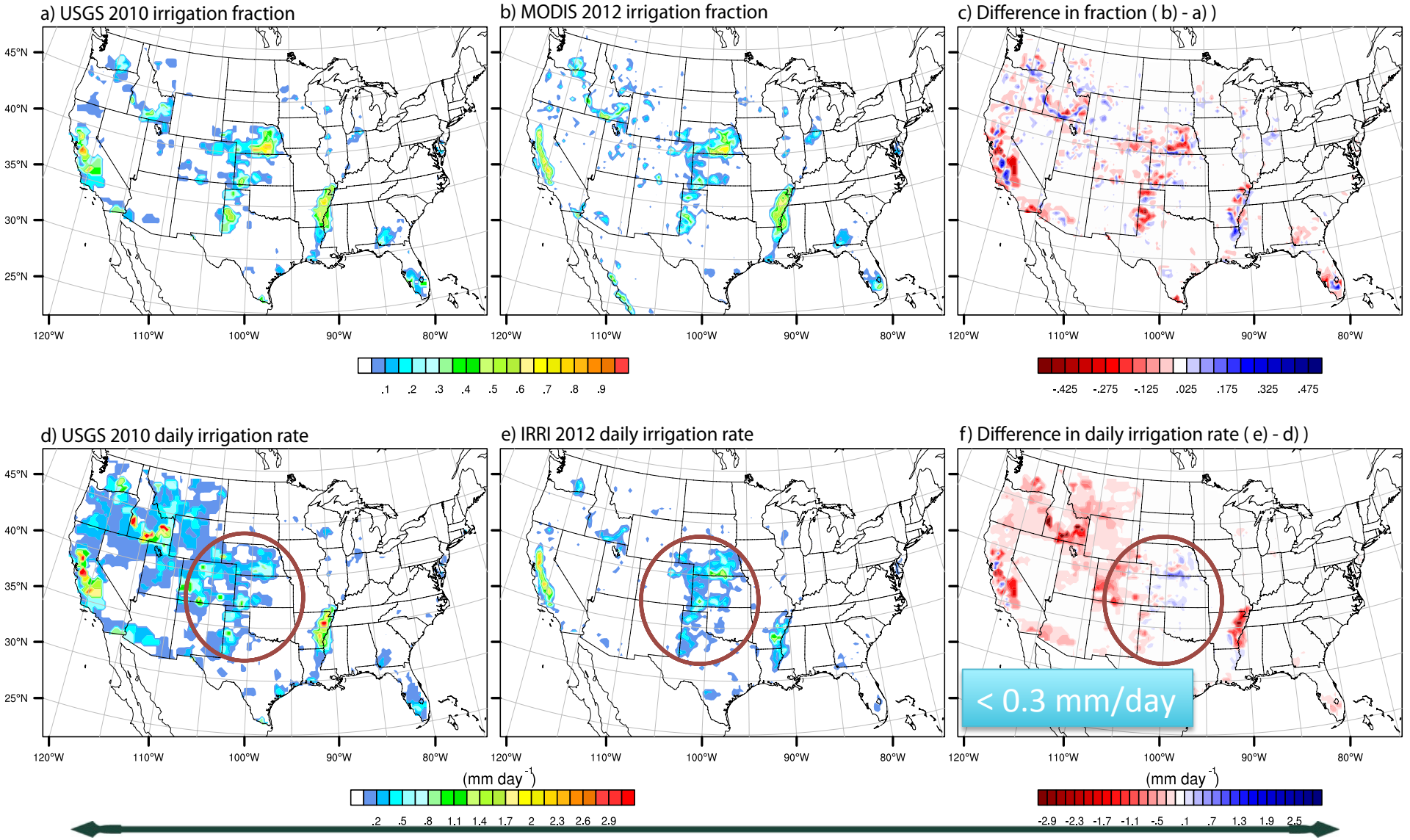


Model Configuration

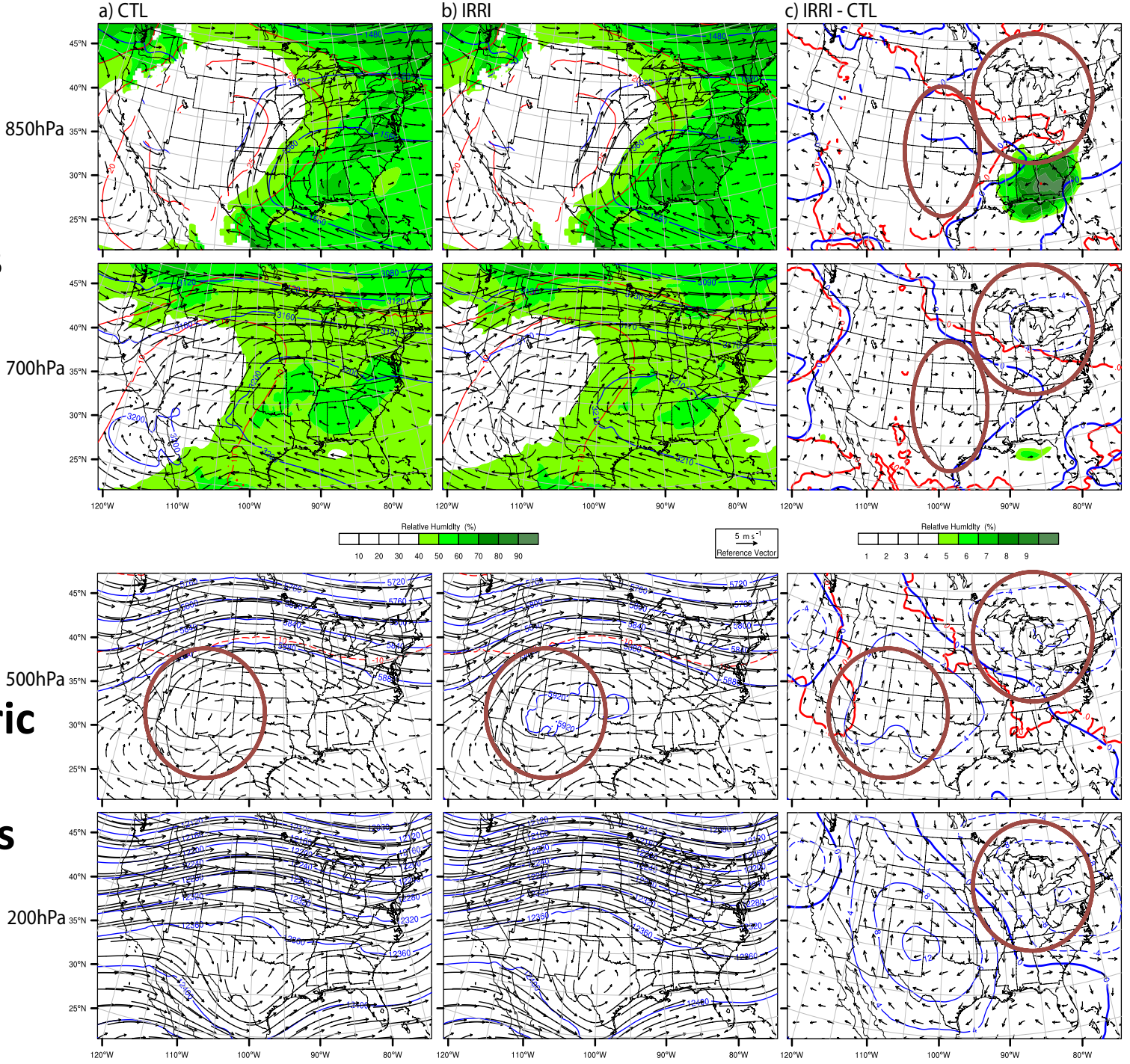
- JJA 2012 --- Driest summer for the central United States since 1895 (Hoerling et al. 2014)
- Single mesh in 30-km resolution, driven by NARR with 1-month spin-up
- Kain-Fritsch cumulus parameterization
- WSM6 6-class momentum scheme for resolved rainfall
- YSU for PBL
- Dudhia shortwave radiation
- RRTM longwave radiation


Combined Local & Downwind
CB-SRP
HP
CCV
Midwest
Downwind
MRV
Southeast
Local
45°N
40°N
35°N
30°N
25°N
120°W
110°W
100°W
90°W
80°W

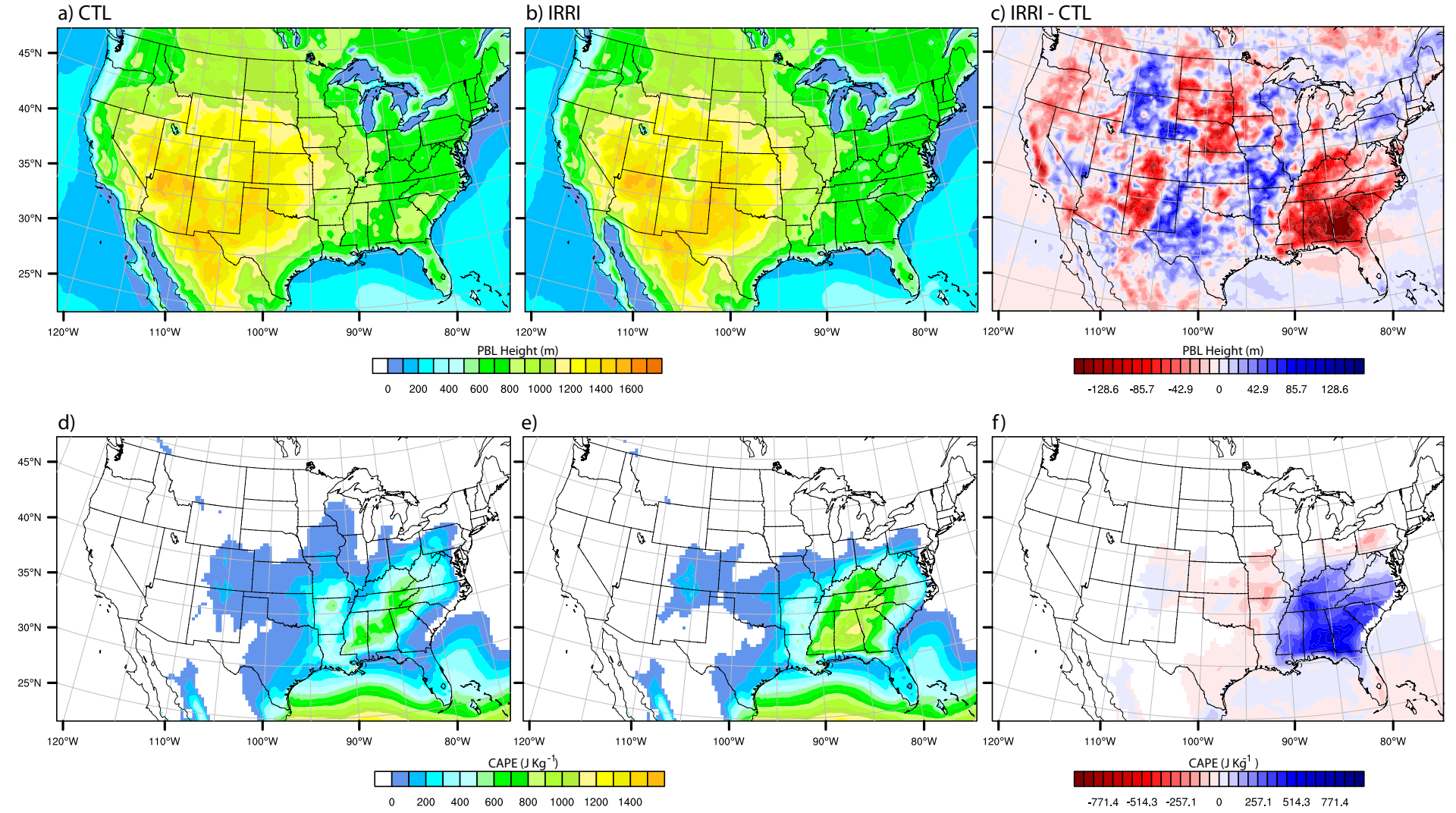
Simulated Irrigation Rate for 2012 JJA



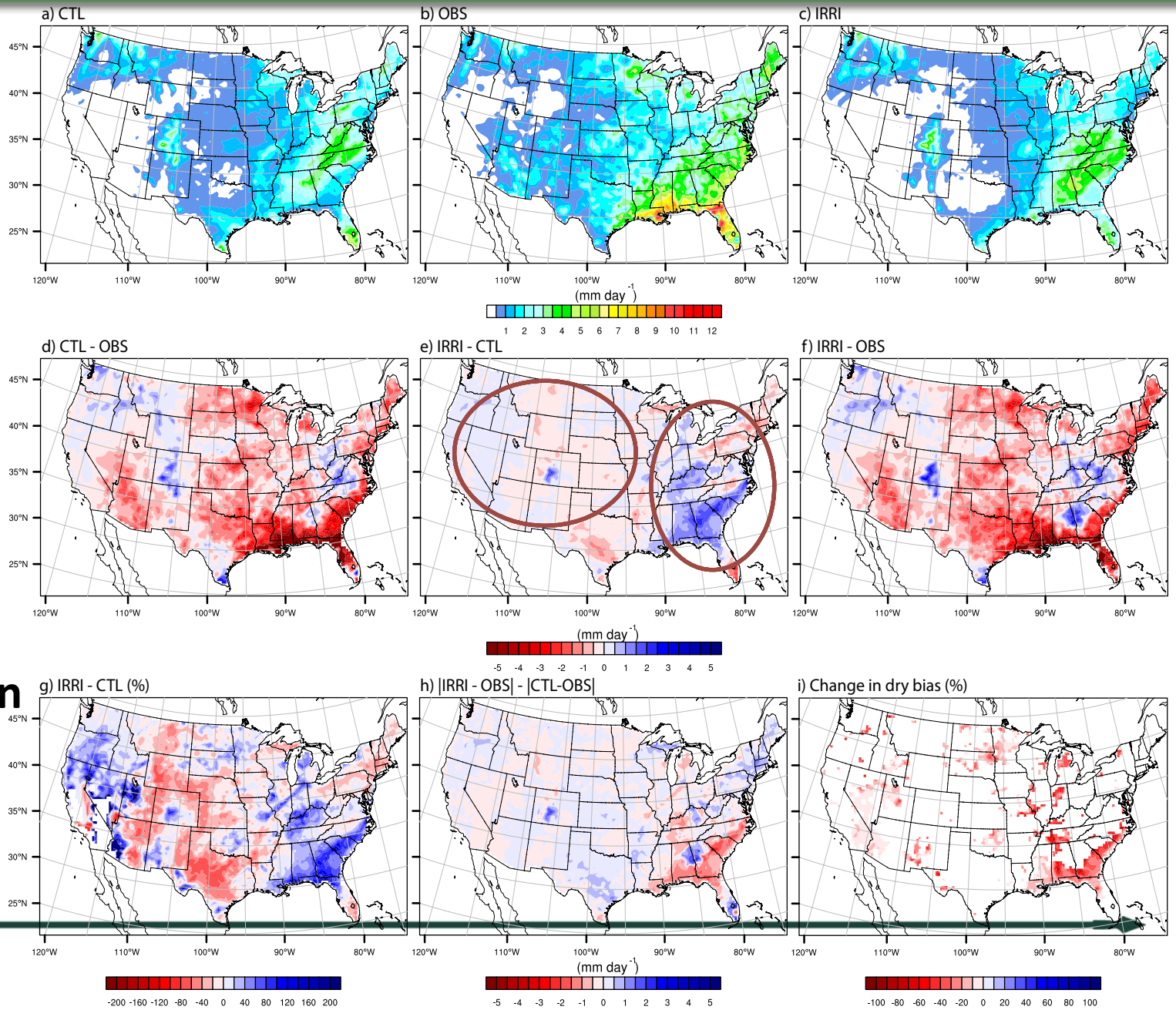
Irrigation's effect on large-scale atmospheric circulations



Irrigation's effect on PBL and CAPE



Irrigation's effect on summer precipitation



* Journal of Hydrometeorology 2015 ; e-View
doi: http://dx.doi.org/10.1175/JHM-D-14-0115.1

Observational evidence that Great Plains irrigation has enhanced summer precipitation intensity and totals in the Midwestern US (over last century)

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Improved Simulation Skill in the Summer Precipitation over the United States

	U.S.		CCV		CB-SRP		HP		MRV		Midwest		Southeast	
	CTL	IRRI	CTL	IRRI	CTL	IRRI	CTL	IRRI	CTL	IRRI	CTL	IRRI	CTL	IRRI
Mean Bias ($mm\ day^{-1}$)	-0.71	-0.68	-0.54	-0.57	0.01	-0.01	-0.53	-0.69	-1.73	-1.72	-0.77	-0.65	-1.81	-0.98
RMSE ($mm\ day^{-1}$)	0.97	0.92	1.17	1.17	0.81	0.61	1.65	1.61	5.72	5.93	2.38	2.36	3.81	3.62
R	0.41	0.51	0.13	0.13	0.65	0.81	0.13	0.25	0.16	0.05	0.27	0.34	0.40	0.38

Improvements mainly occur in the downwind areas

Conclusions

- Confidence in WRF model's capability in dynamically simulating the irrigation water demand
- Irrigation over the HPA might have helped worsen the 2012 summer drought over the central U.S.
- Downwind effects more significant than local impacts
- Uncertainties in the PBL dynamics
- Future improvement in the irrigation scheme

Thank You!