Impact of irrigation over the California Central Valley on regional climate

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Science Question:

– What is the role of irrigation over the California Central Valley (CCV) on regional climate?
- a. Can model performance be improved by inclusion of a realistic irrigation scheme?
- b. What is the impact of CCV irrigation on local and regional climate?
- c. Can we distinguish the direct and indirect impacts of irrigation on local and regional climate?

Methods:

– Use Weather Research and Forecasting (WRF) coupled with a realistic irrigation scheme to represent irrigation over the CCV, the coupled model is driven by NARR data as atmospheric forcing.

– Use a Water Vapor Tracer Scheme in WRF to differentiate between the direct and indirect impacts of the CCV on local and regional climate.

Experiment Design

Two sets of simulations: IRR (with irrigation) and CNTL (without irrigation)

- Resolution: 20 km
- Study period: JJA in three dry years (2002,2007, 2013), three wet years (2005, 2006, 2010).
- Atmospheric forcing: NARR data
- Three ensemble members initiated at: 1st April, 10th April, 15th April.
- Physical Parameterization: Noah LSM, WSM 6-class microphysics parameterization, RRTM radiative transfer model, YSU boundary layer parameterization, Kain-Fritsch (KF) convection scheme.
- OBS: California Irrigation Management Information System (CIMIS) and PRISM data.

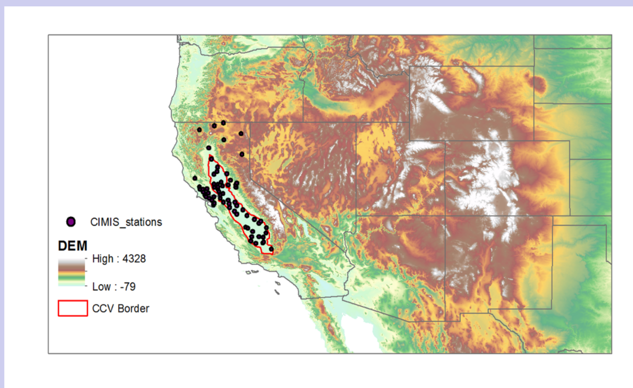


Figure 1: *Model domain, CIMIS stations, and areas equipped with irrigation.*

Kain-Fritsch scheme Calibration

Default KF scheme tends to overestimate precipitation over the domain, we calibrated the KF scheme following *Yang et al. 2012.

Table 1: *Modified KF scheme parameters.*

Parameter	Description	Def./Mod.	Range
Pd	Coefficient related to downdraft mass flux rate	0/0.852	[-1, 1]
Pe	Coefficient related to entrainment mass flux rate	0/-0.316	[-1, 1]
Ph	Starting height of downdraft above updraft source layer (USL) (hPa)	150/331	[50, 350]
Pt	Maximum turbulent kinetic energy in sub-cloud layer (m^2s^{-2})	5/4.62	[3,12]
Pc	Average consumption time of convective available potential energy (CAPE) (seconds)	2700/3386	[900, 7200]

Simulation for July 2006:

- Default KF scheme clearly overestimates precipitation and temperature.
- Calibrated KF scheme effectively reduces the wet bias and warm bias.

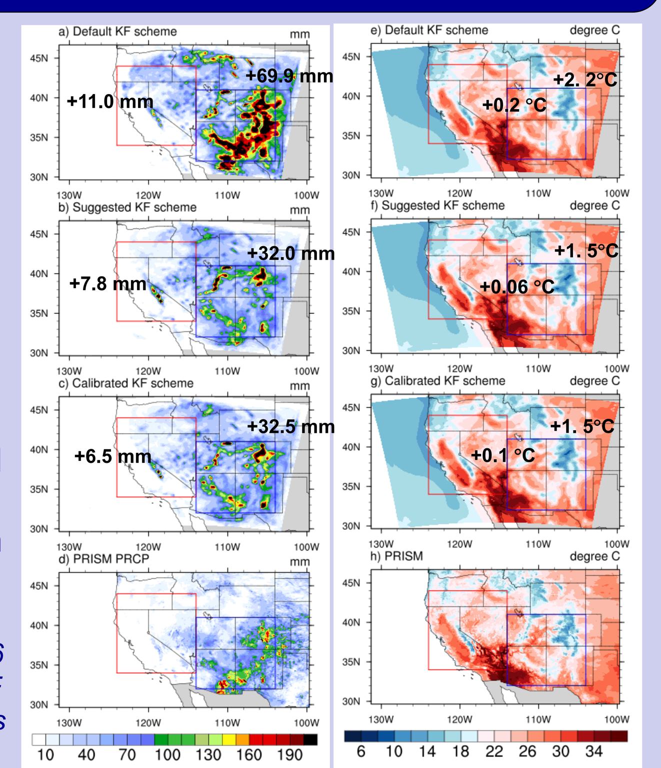


Figure 2: *On the left, model simulated July total precipitation spatial pattern for 2006 with a) default KF scheme, b) previously suggested KF scheme, c) our calibrated KF scheme. Observational data are shown in d). The red box encircles California and its nearby region is defined as CNR and the blue box delineates the Colorado River Basin (CRB). On the right, same as the left but for surface air temperature.*

Water Vapor Tracer Scheme & Irrigation scheme

Water Vapor Tracer Scheme:

- Tracks the evapotranspirated water that arises from a pre-defined source region.
- Tags the water vapor and tracks its movements in space and time.
- Enables us to differentiate between direct and indirect impacts of the source region.

Irrigation Scheme: Where? When? How much to irrigate?

- Where? The CCV. Irrigation data obtained from the Food and Agriculture Organization (FAO).
- When? 1) Growing season, 2) Soil moisture is below than the defined Moisture Availability (MA).

$$MA = \frac{SW - SW_{WP}}{SW_{FC} - SW_{WP}}$$

SW is the soil moisture, SW_{WP} is the soil moisture content at wilting point, SW_{FC} is the maximum amount of soil that hold against gravity.

- How much? Once irrigation is triggered, irrigated water is added at uniform rate during 0600 to 1000 LT, until soil moisture reaches its field capacity. Adjust the MA value to ensure the irrigation over the CCV is around 350 mm in the growing season.

*Yang, B., Y. Qian, G. Lin, R. Leung, and Y. Zhang, 2012: Some issues in uncertainty quantification and parameter tuning: a case study of convective parameterization scheme in the WRF regional climate model. Atmospheric Chemistry and Physics, 12, 2409–2427, doi:10.5194/acp-12-2409-2012

Irrigation impact over the CCV

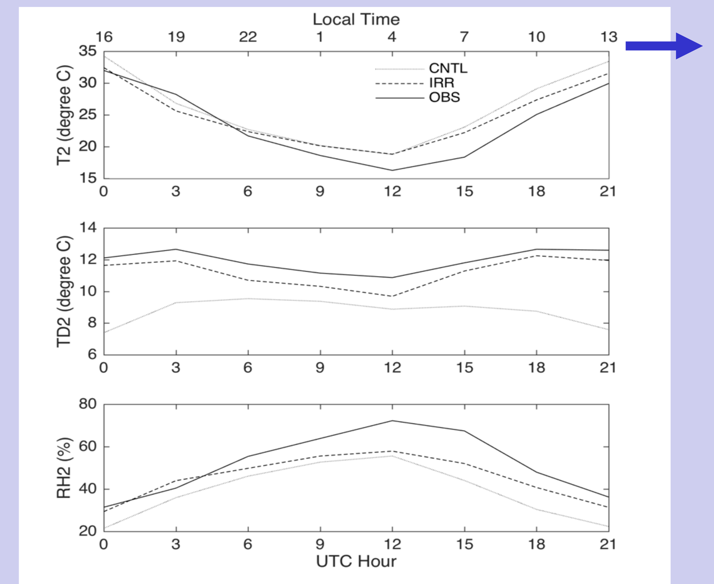


Figure 3: *Diurnal cycle of 2 m air temperature (T2), dew point temperature (TD2) and relative humidity (RH2) from the CIMIS observations, the CNTL and IRR simulations.*

Diurnal cycle:

- In the IRR simulations, surface air temperature (T2) is better represented from 0700-1600 LT, but slightly worse from 1700-2100LT.
- Diurnal cycles of dew point temperature (TD2) and relative humidity (RH2) are much improved in IRR simulations when compare to the CIMIS data.
- Mean absolute bias:
  - TD2, 3.2 °C in CNTL, 0.7 °C in IRR.
  - RH2, 13.3% in CNTL, 7.7% in IRR.
  - T2, bias reduced by 1.6 °C in daytime (from 0700-1900LT).

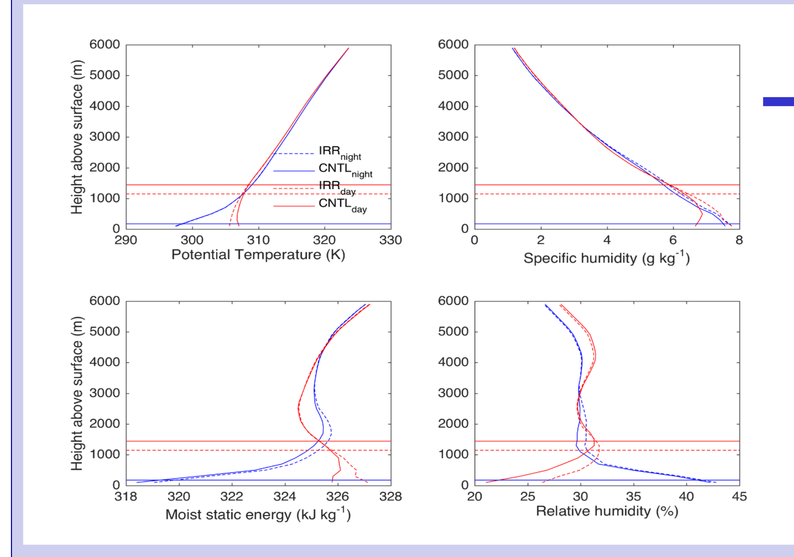


Figure 4: *Vertical profiles of potential temperature (K), specific humidity (g kg-1), moist static energy (kJ kg-1) and relative humidity (%) in the daytime (red) at 1300 LT and night time (blue) at 0100 LT from IRR (dash line) and CNTL (solid line) simulations. Horizontal lines represent the planetary boundary layer height.*

Vertical Profiles:

Daytime, irrigation induced:

a) increase in moist static energy and relative humidity.
b) decrease in the planetary boundary layer height.

Nighttime,

a) potential temperature and specific humidity are similar in IRR and CNTL simulations.
b) difference in MSE and relative humidity in the residual layer between elevation of 1000 to 3000m.
c) moisture is transported upward during the daytime and remains in the residual layer during the night time.

Changes in variables by irrigation:

- Latent heat flux is doubled and increases by 32.10 Wm^{-2}. Sensible heat flux decreases by 23.80 Wm^{-2} (22.4%).
- Specific humidity increases by 0.68 gkg^{-1}.
- Surface air temperature is decreased by 0.39 °C.
- PBL height is decreased by 103.2 m.
- Lifting condensation level is decreased by 179.2 m.
- Level of free convection is decreased by 526.8 m.
- CAPE is increased by 58.89 Jkg^{-1}.

LCL-crossing and **increase in CAPE** suggest that it is more likely to form precipitation in the IRR simulations over the CCV. However, as shown later there is no significant change in precipitation over the CCV.

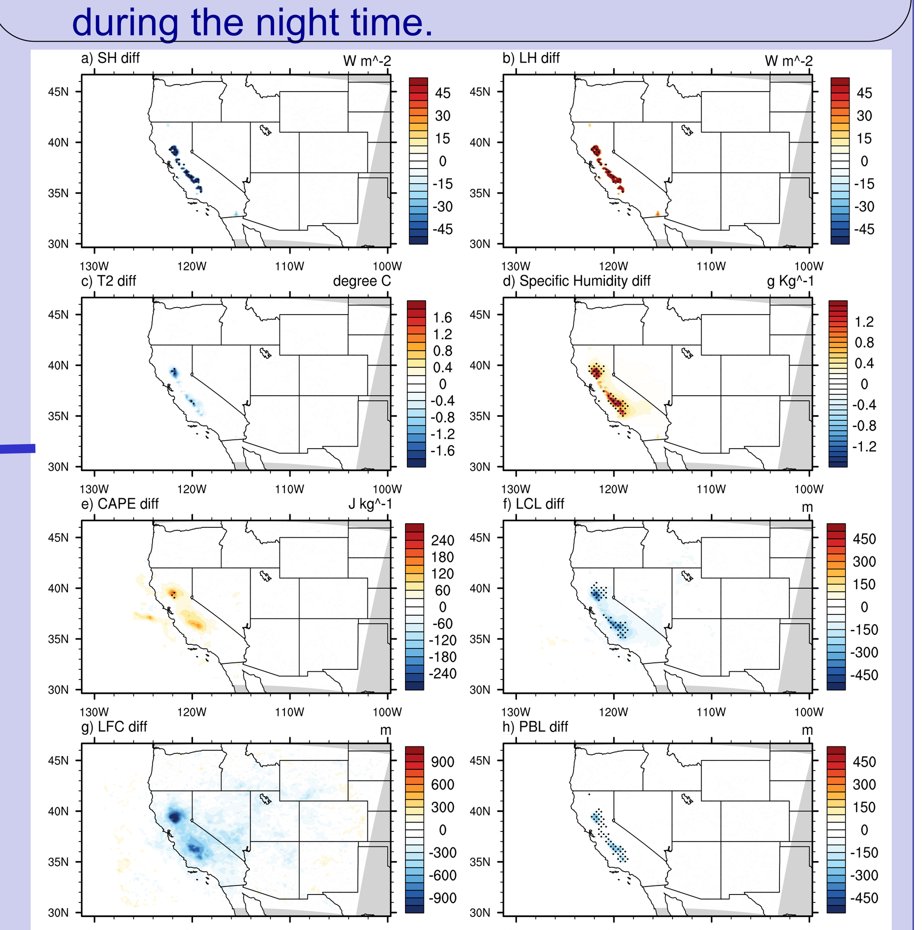
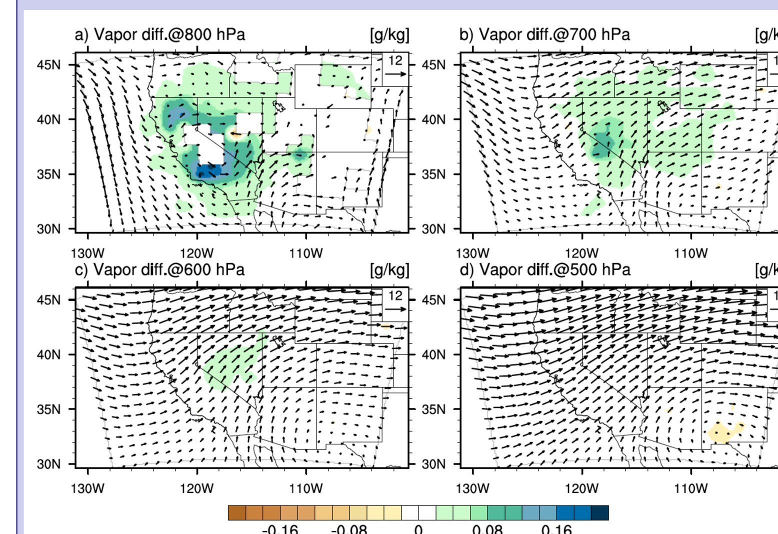


Figure 5: *Simulated differences between the IRR and CNTL simulations in a) sensible heat flux (W m-2), b) latent heat flux (W m-2), c) surface air temperature (°C), d) specific humidity (g kg-1), e) convective available potential energy (CAPE, J kg-1), f) PBL height (m), g) lifting condensation level (LCL, m) and h) level of free convection (LFC, m). Stippled areas indicate that differences between IRR and CNTL are statistically significant using the two sample t test at P = 0.05.*

Irrigation impact on regional precipitation



Water vapor mixing ratio difference:

- Water vapor differences mainly exist in the low levels. Difference is negligible above 600 hPa.
- Bermuda high induces southwesterly, southerly flows and leads to a positive anomaly in water vapor downwind, in Nevada, Utah, and southern Idaho.
- Southern Colorado River Basin (CRB) is not affected.

Figure 6: *Shaded regions indicate the water vapor mixing ratio (g kg-1) difference between the IRR and CNTL simulations at different levels ranging from 800 hPa to 500 hPa in a) through d). Vectors indicate the winds at each level.*

Local convergence difference (direct):

- Irrigation induces strong divergence over the CCV during the JJA months
- Divergence over the CCV generates outflows to the west and east.
- The moist eastward flow has a potential to rise orographically along the Sierra Nevada Range and induce topographic precipitation.

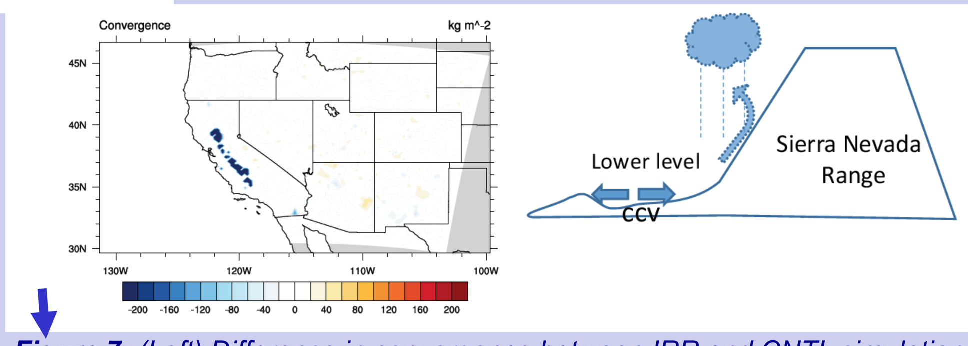
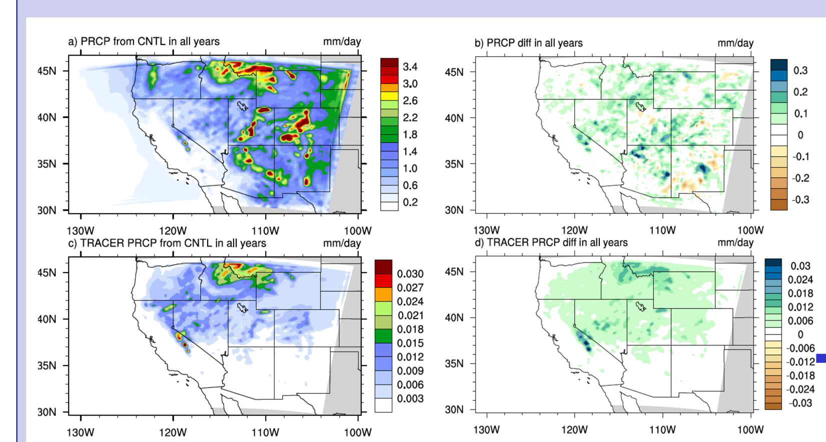


Figure 7: *(Left) Difference in convergence between IRR and CNTL simulations for JJA months (see details in Schmitz and Mullen (1996), negative values indicate divergence). (Right) A schematic depiction of how divergence over CCV may affect the upwind side of the Sierra Nevada.*



Precipitation and Tracer precipitation:

- Irrigation increases precipitation almost over the entire domain (direct + indirect).
- Consistent increase over the windward side of the Sierra Nevada (both wet & dry years, not shown).
- Tracer precipitation increase is confined to northern CRB, cannot explain precipitation increase over the entire CRB.

Figure 8: *a) Simulated average precipitation from all years in CNTL simulations; b) simulated precipitation difference between IRR and CNTL for all years; c) and d) are the same as a) and b) but for tracer precipitation, respectively (mm/day).*

Indirect impact of irrigation on precipitation over the CRB:

- 500 hPa geopotential height difference shows a wave pattern when precipitation difference is above 75th percentile over the CNR.
- Geopotential height pattern draws moisture from the Gulf of California or the core of monsoon region and induces thunderstorm events in the southern CRB.

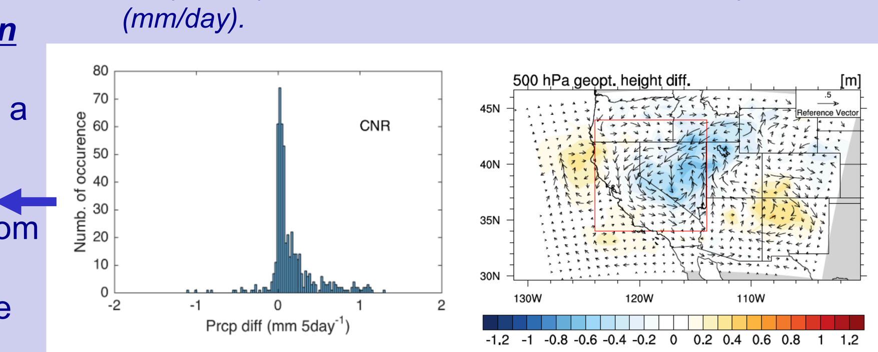


Figure 9: *On the left, distribution of 5-day precipitation difference (IRR-CNTL) over CNR for all years and all ensemble members. The positive skew indicates that precipitation increase over this region. On the right, 500 hPa geopotential height difference between the IRR and CNTL simulations at pentads when precipitation difference over the CNR (left) is above 75th percentile of its time series. Vectors indicate the wind anomalies at 500 hPa level.*

Conclusion

- ✓ Calibration of the KF scheme has improved model performance in precipitation and temperature.
- ✓ Irrigation has improved performance of surface temperature, relative humidity, and dew point temperature; leads to changes in local climatic variables, however, such changes do not induce changes in local precipitation over the CCV.
- ✓ Irrigation increases precipitation through different mechanisms, including: induces local divergence and increases precipitation at the windward side of the Sierra Nevada Range; direct moisture contribution at downwind region; induces wave pattern in geopotential height that leads to precipitation over the CRB.

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