Sensitivity of the North American Monsoon to Antecedent Rocky Mountain Snowpack

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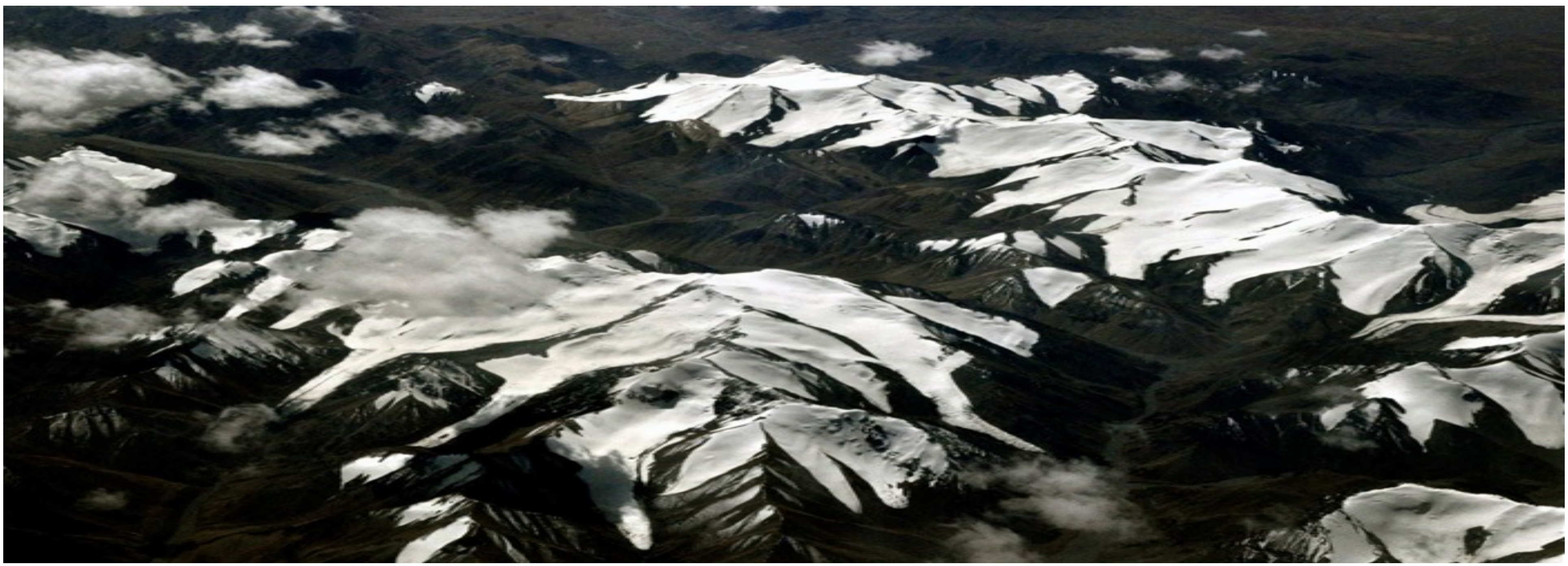
Funding: NOAA CPPA, DOE NICCR

NCSA / University of Texas (Teragrid)

Snow-Monsoon Relationship over Eurasia

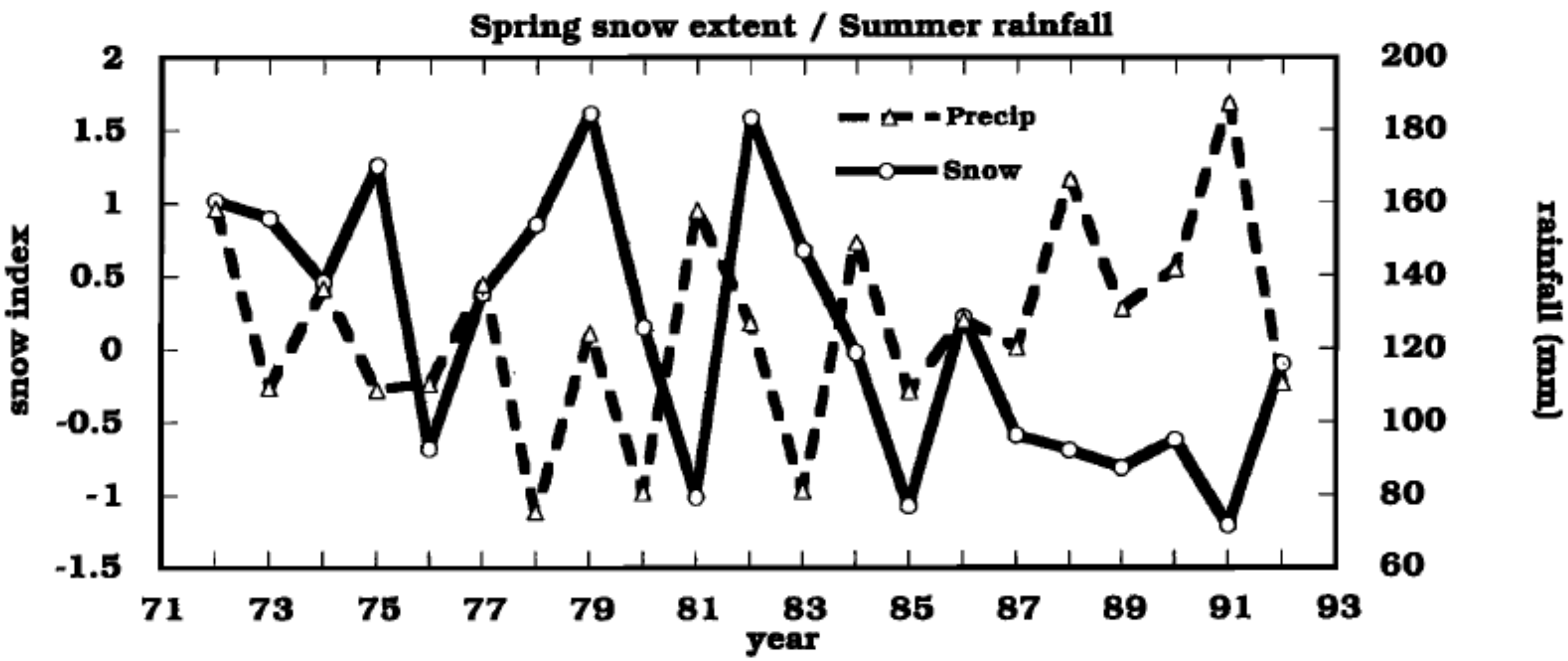
An observational study by Zhao et al. (2007) found that anomalously extensive Tibetan snowpack can enhance springtime soil moisture and lead to a weaker subsequent East Asian summer monsoon, with shifts in China's rainfall patterns.

Numerous observational studies (e.g. Hahn and Shukla, 1976) revealed that anomalously high winter/spring Eurasian snow cover can lead to reduced rainfall in the subsequent Indian summer monsoon. Extensive snow cover through spring favors wet soils and cool conditions that diminish the ocean-land temperature contrast and dampen the subsequent monsoon circulation.



Snow-Monsoon Relationship over North America

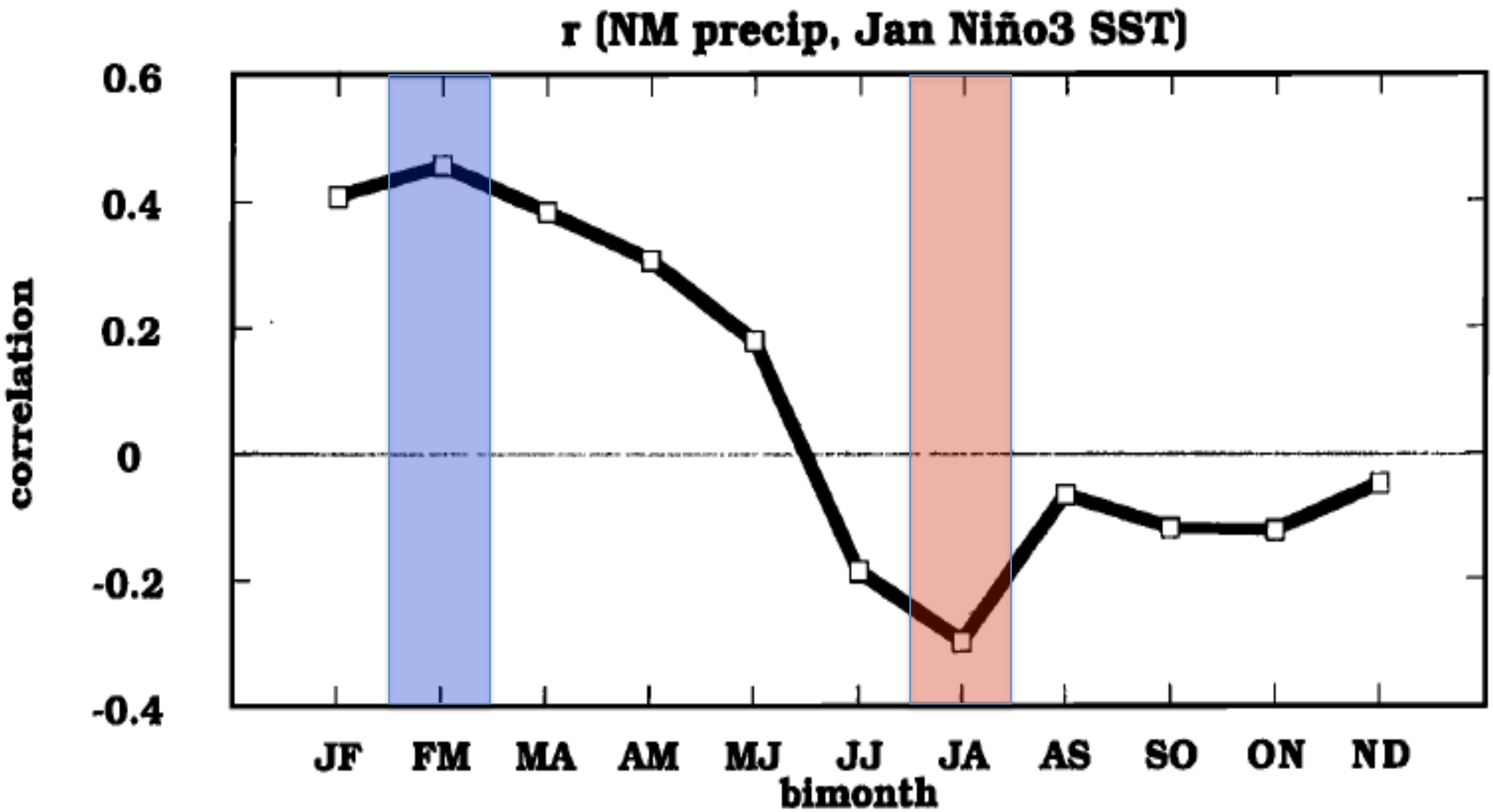
Gutzler and Preston (1997) identified observational evidence of a potential negative relationship between spring snow extent across the west-central United States and subsequent summer (July-August) monsoon rainfall over the American Southwest (esp. New Mexico). This is consistent with the Eurasian snow-monsoon relationship.



r = -0.37, 5 of the 7 wettest summers preceded by negative snow index;
5 of the 7 driest summers preceded by positive snow index

Snow-Monsoon Relationship over North America

The approach of observational correlations, as used by Gutzler and Preston (1997), does not exclude ocean influences, including ENSO. So is this snow-monsoon relationship real?



METHODS

Abdus Salam International Centre for Theoretical Physics
Regional Climate Model Version 4 (ICTP RegCM4)
(Pal et al. 2007; Elguindi et al. 2011)

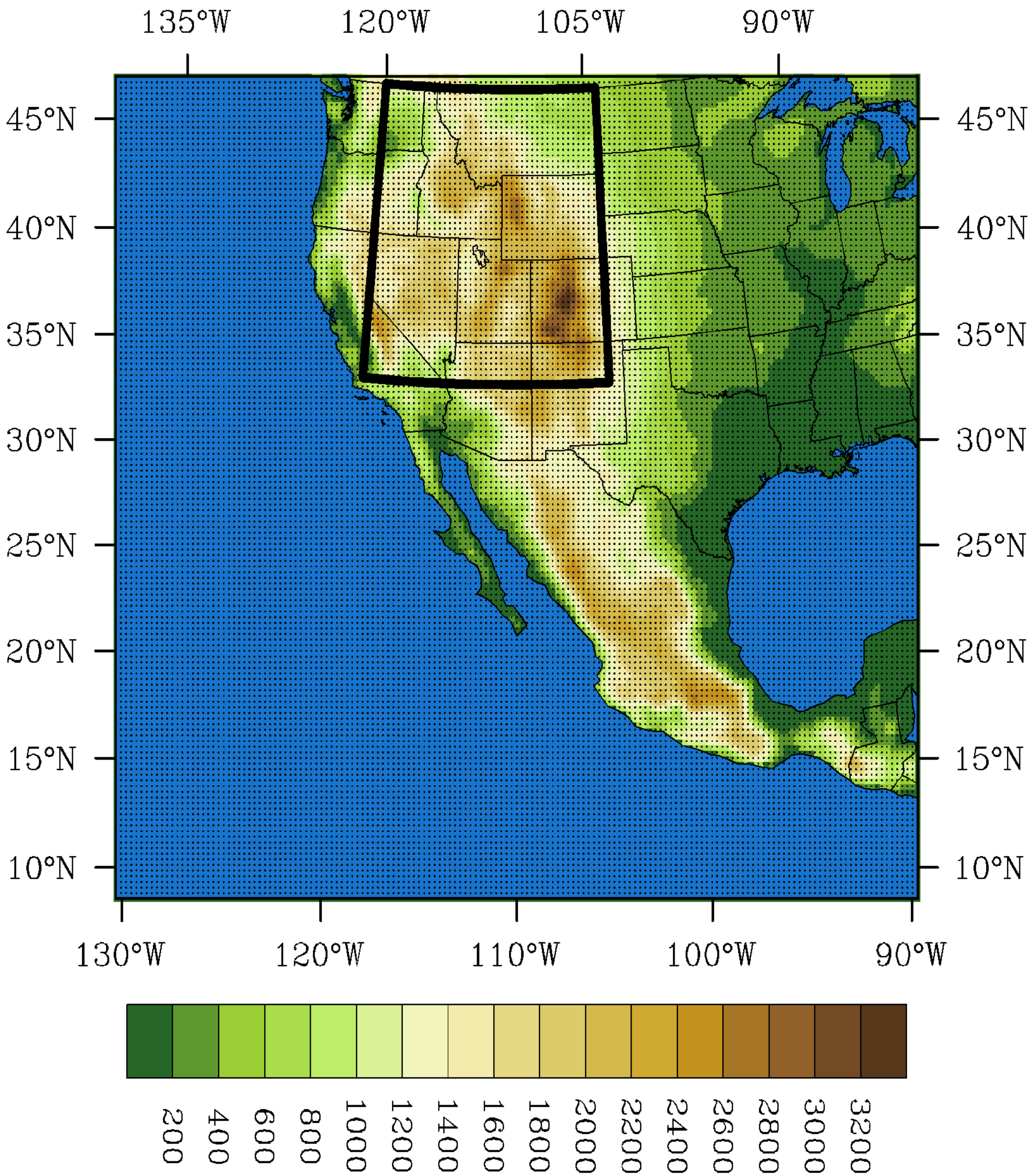
30-km grid spacing, 18 sigma levels

Coupled to Biosphere-Atmosphere Transfer Scheme (BATS)
(Dickinson et al., 1993)

Grell (1993) convective scheme

Initial and Lateral Boundary Conditions:
NCEP-NCAR Reanalysis (Kalnay et al., 1996)
NOAA Optimum Interpolation SSTs (Reynolds et al., 2002)

Control Simulation: 1991-2000



Model Domain

Shading = Elevation (m)

Dots = Grid cells

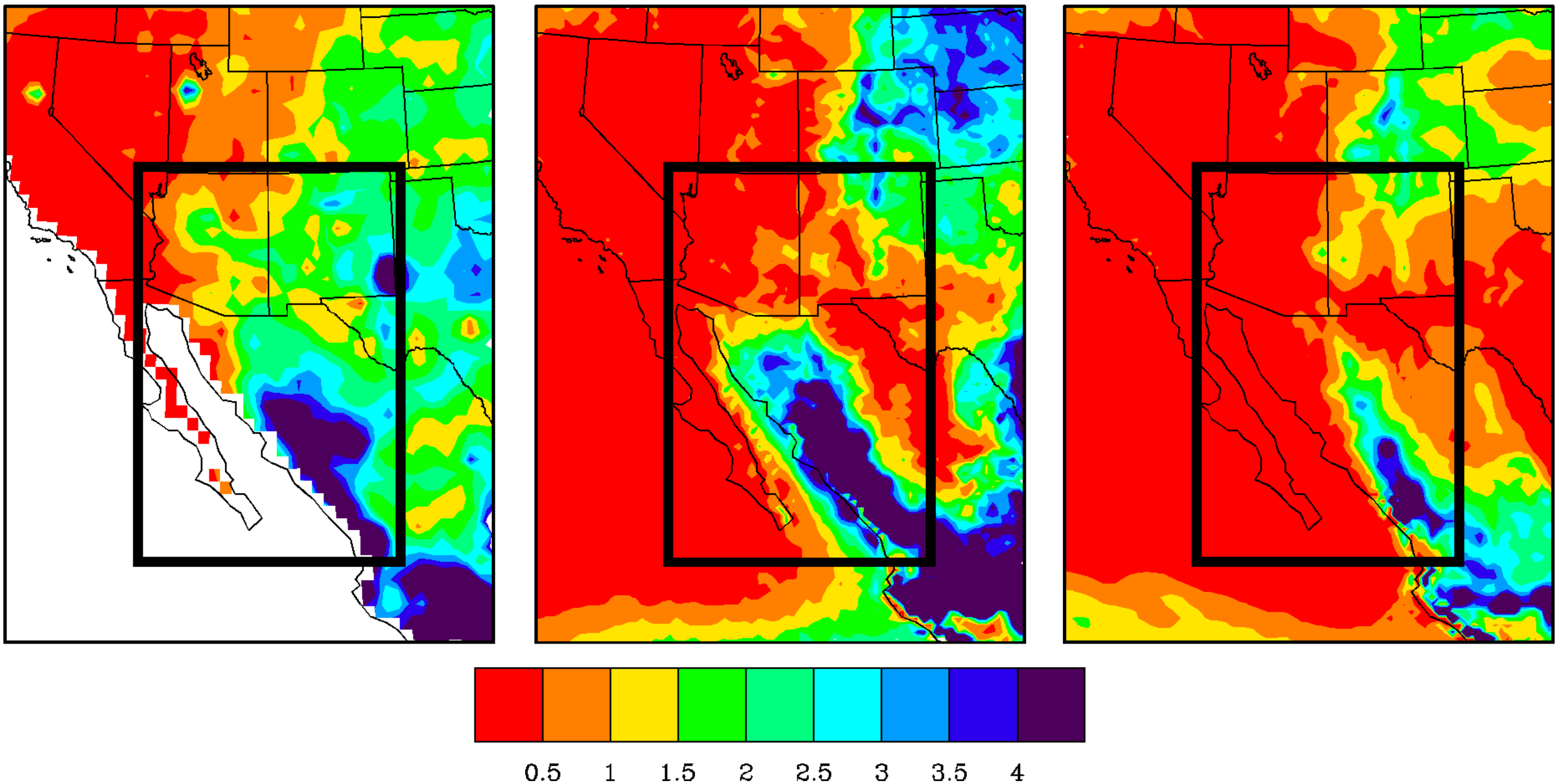
Box = Rocky Mountain region

Grell vs. Kuo Convective Scheme

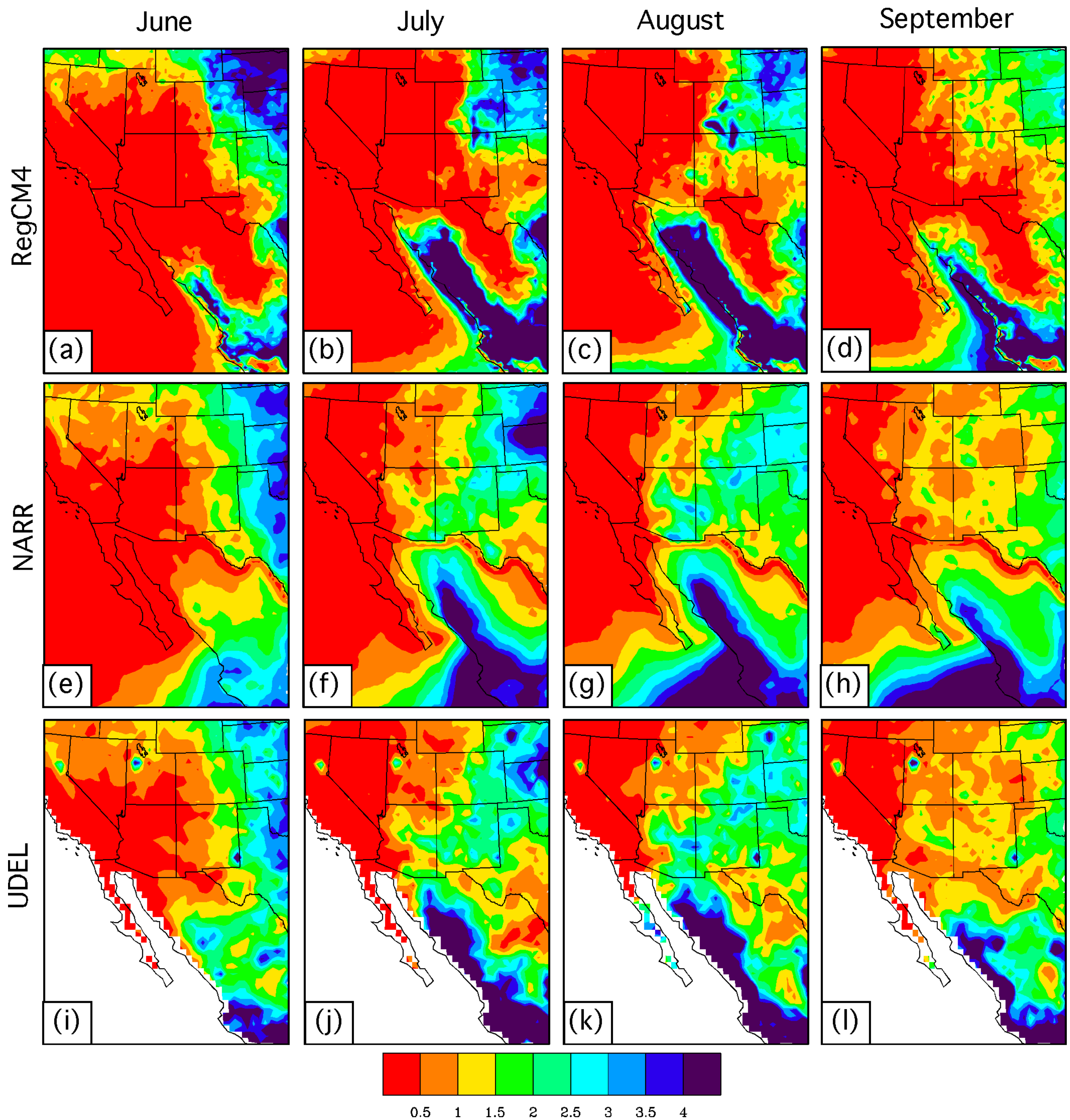
a) Observed

Bias: -22%,
Spatial r = 0.63
b) Simulated (Grell)

Bias: -56%
Spatial r = 0.57
c) Simulated (Kuo)



Mean precipitation (mm/day) during JJAS 1990-1991 from Willmott-Matsuura observations and RegCM4 with Grell or Kuo



Seasonal evolution of the monsoon in RegCM4, North American Regional Reanalysis (NARR), and University of Delaware observations

Precipitation (mm/day)

Experimental Design

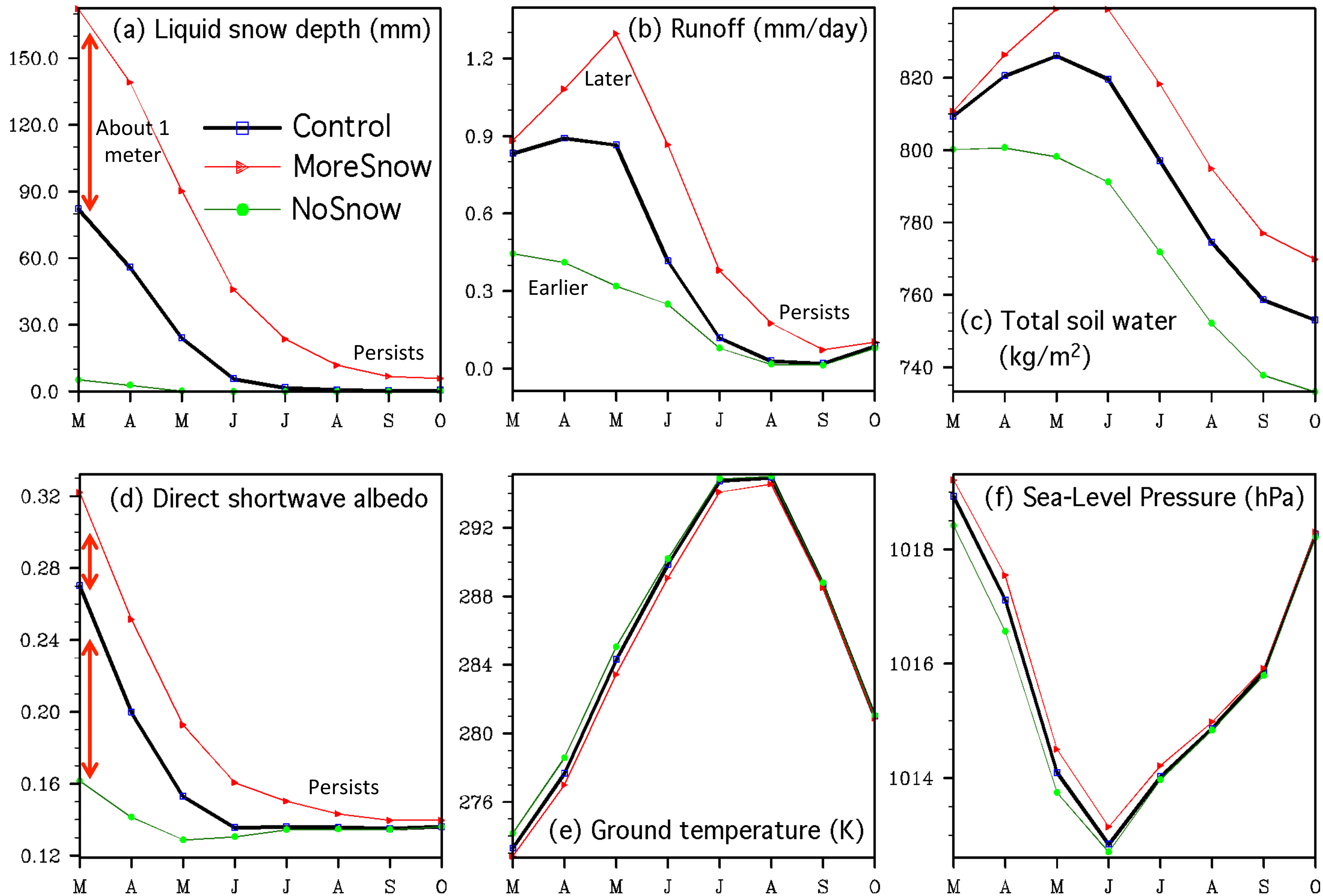
CTL = Control experiment for 1991-2000

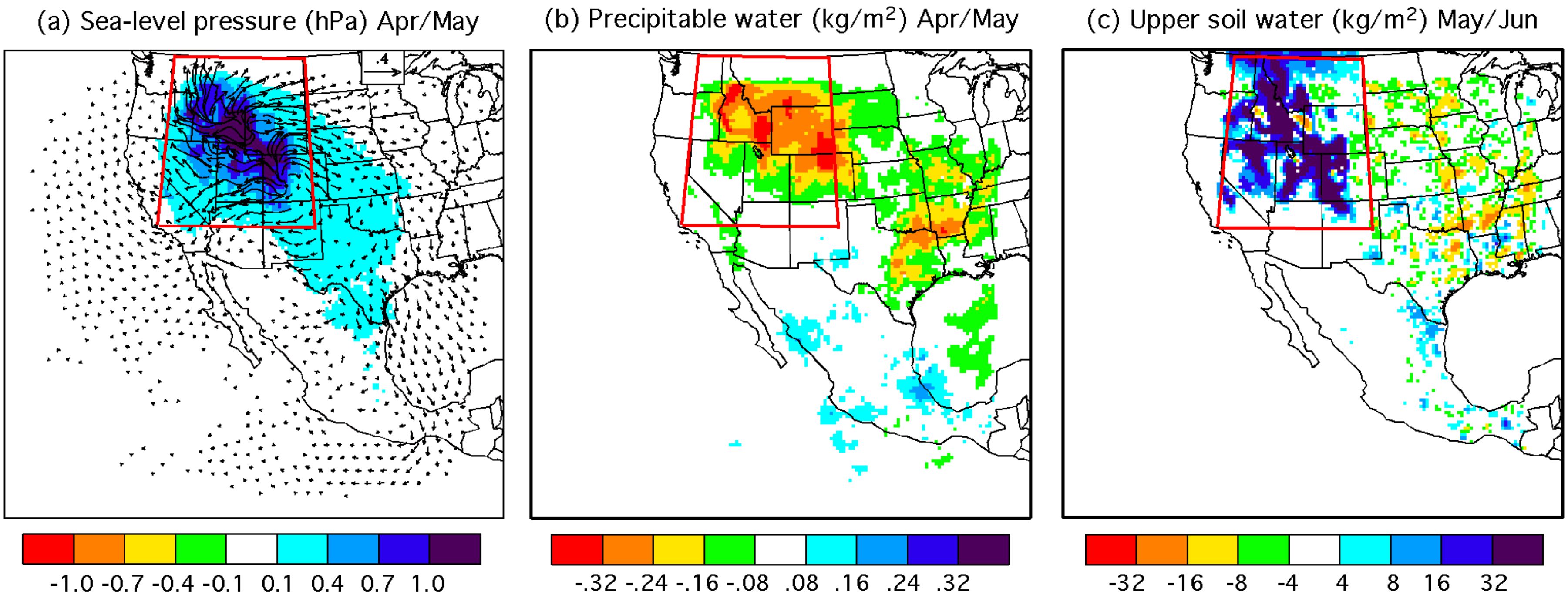
10 ensemble members (MoreSnow) are run for March-October using March 1st restart files from each of 10 years in CTL and doubling the snow depth across the Rocky Mountains region (35-49°N, 120-104°W).

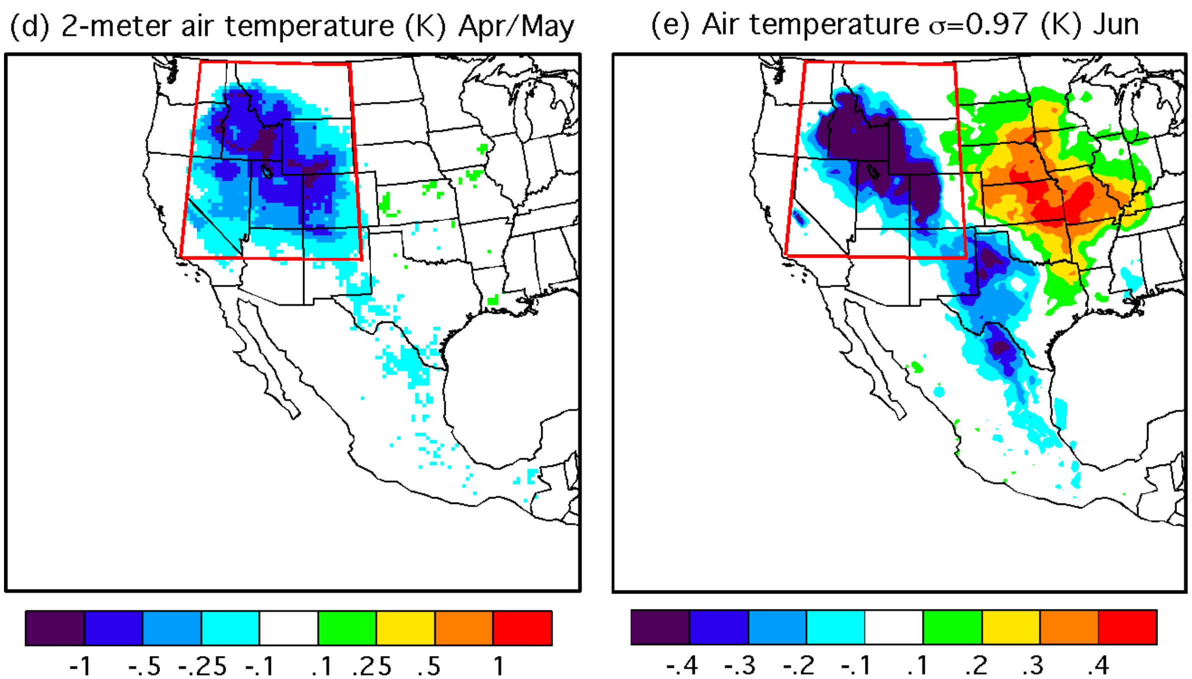
10 ensemble members (NoSnow) are run for March-October using March 1st restart files from each of 10 years in CTL and setting the snow depth across the Rocky Mountains region to zero.

The snow depth is altered in both ensemble sets, prior to the MAM snowmelt season, to assess the climatic response of anomalous snowpack both locally in the Rocky Mountains and remotely across the North American monsoon region and much of the United States.

Local Response over the Rocky Mountains Region



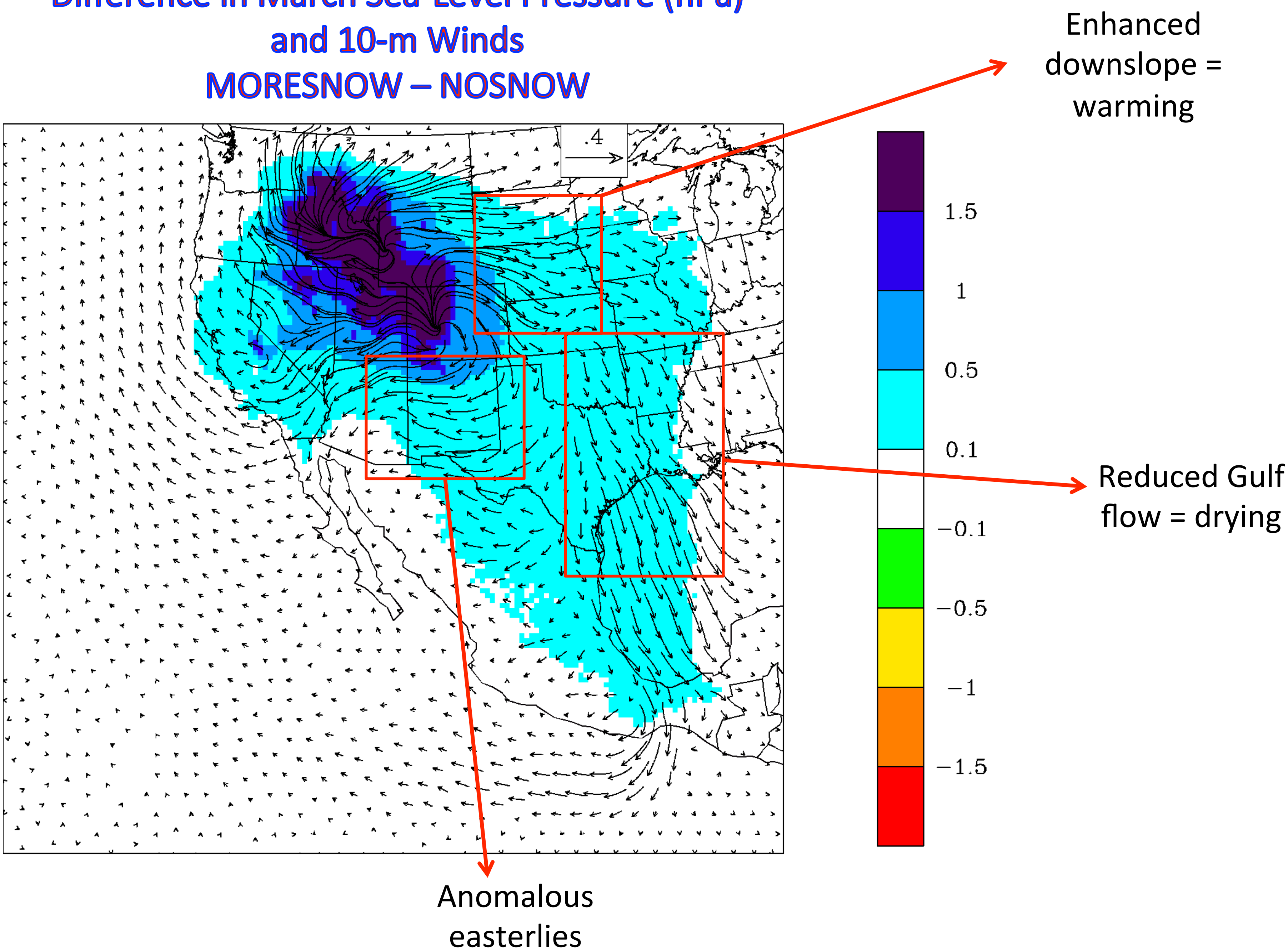




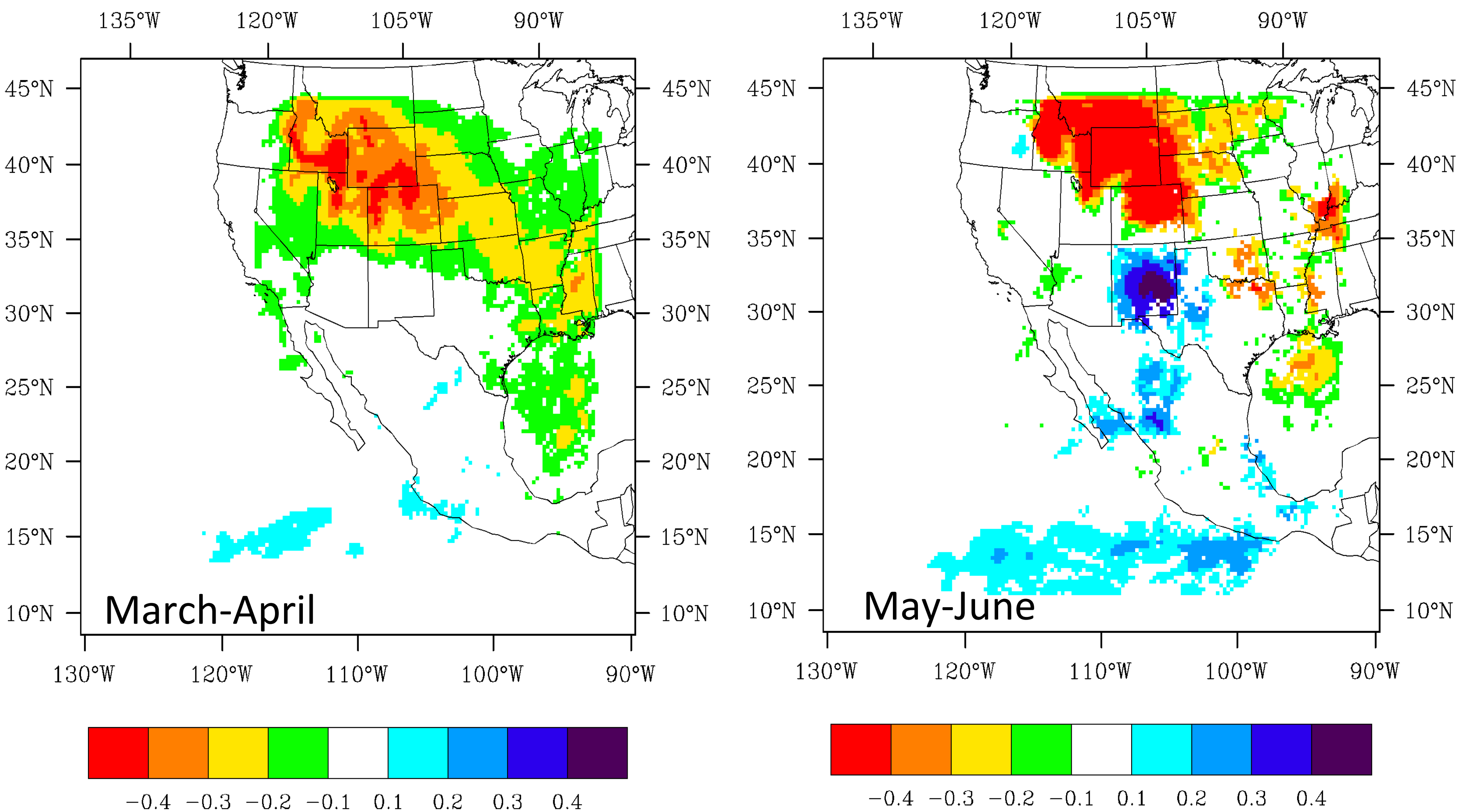
Local and Remote Responses to Elevated Snowpack (MoreSnow-CTL)

Consistent with Vavrus et al. (2007) -> cooler, wetter soil

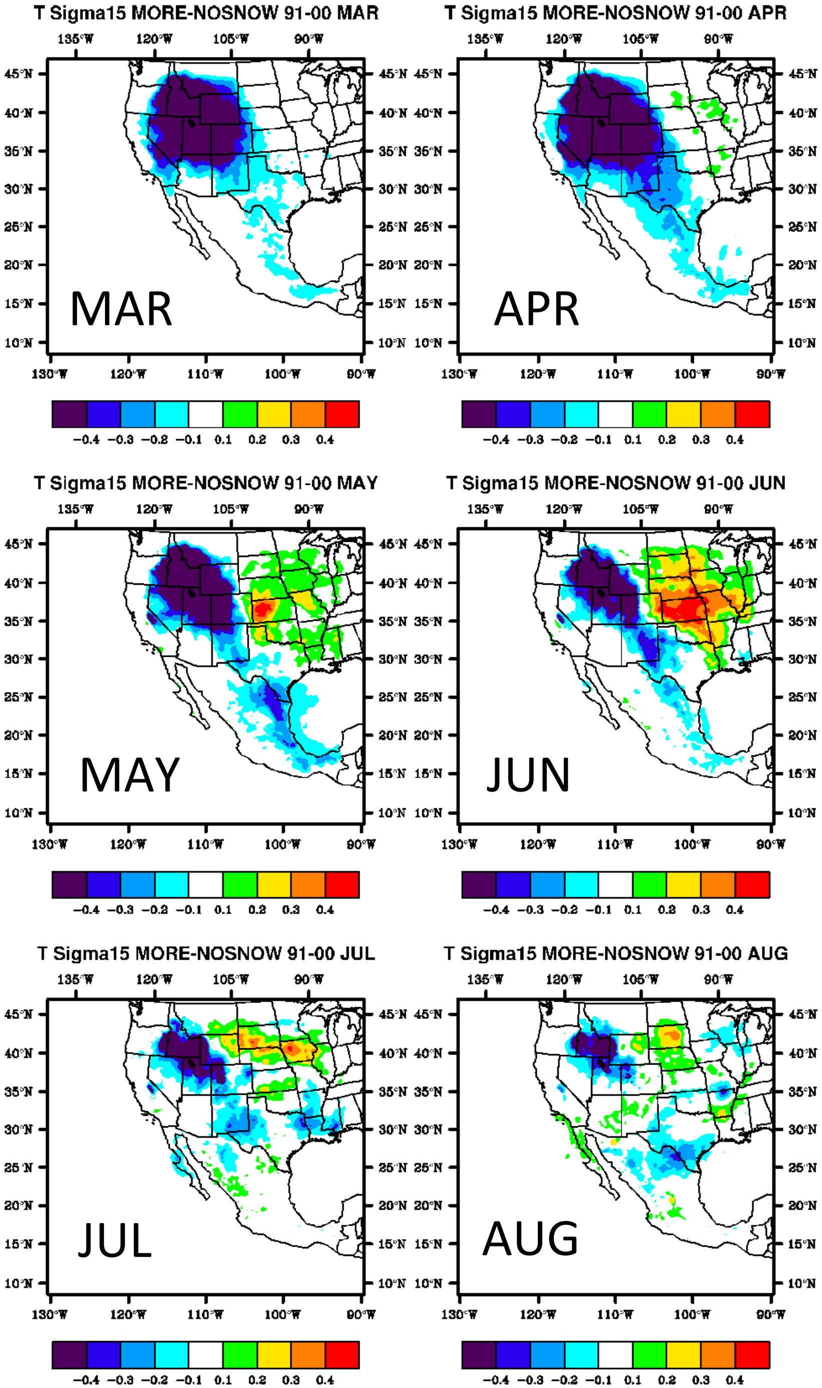
Difference in March Sea-Level Pressure (hPa) and 10-m Winds
MORESNOW – NOSNOW

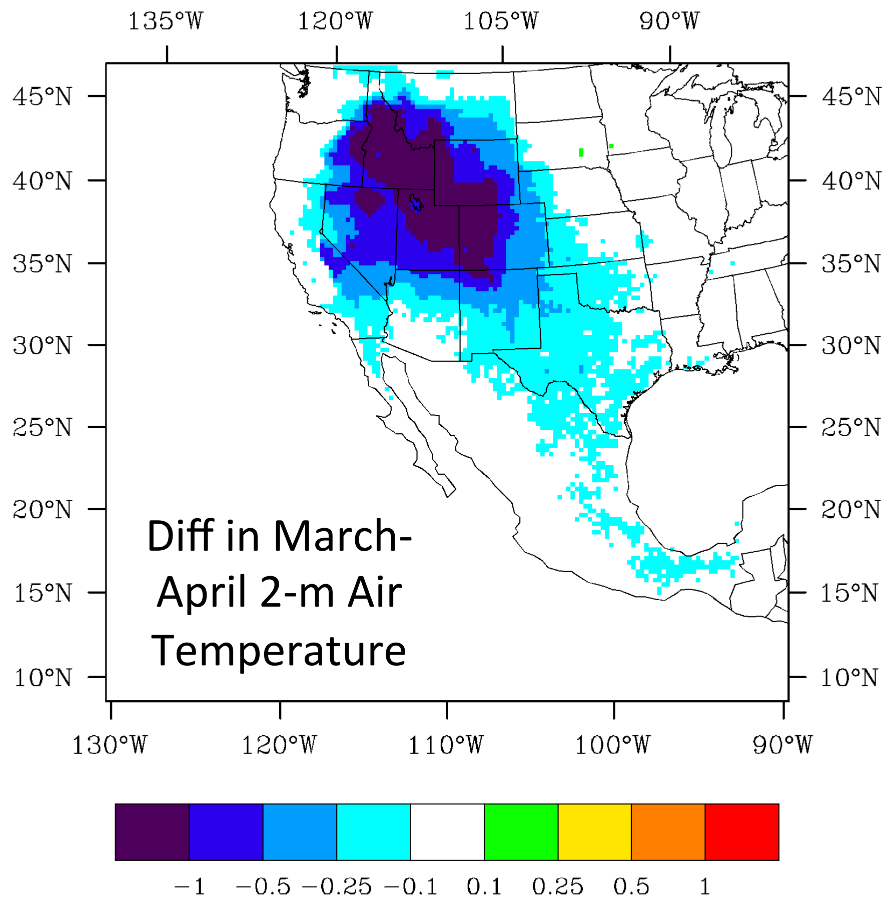


Difference in Precipitable Water (kg/m²)
MORESNOW – NOSNOW

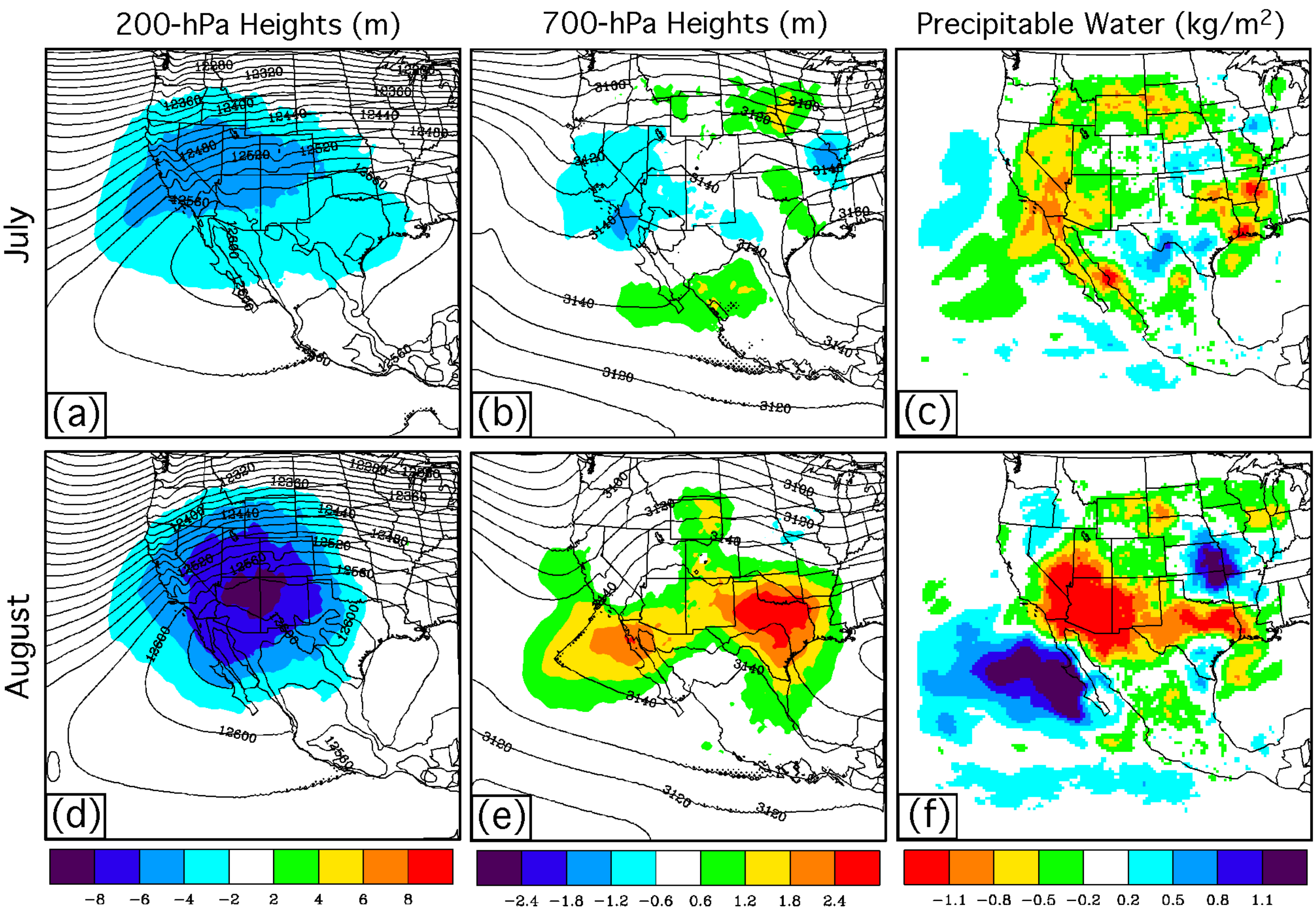


Difference in Temperature (°C) at σ = 0.97 (MORESNOW-NOSNOW)

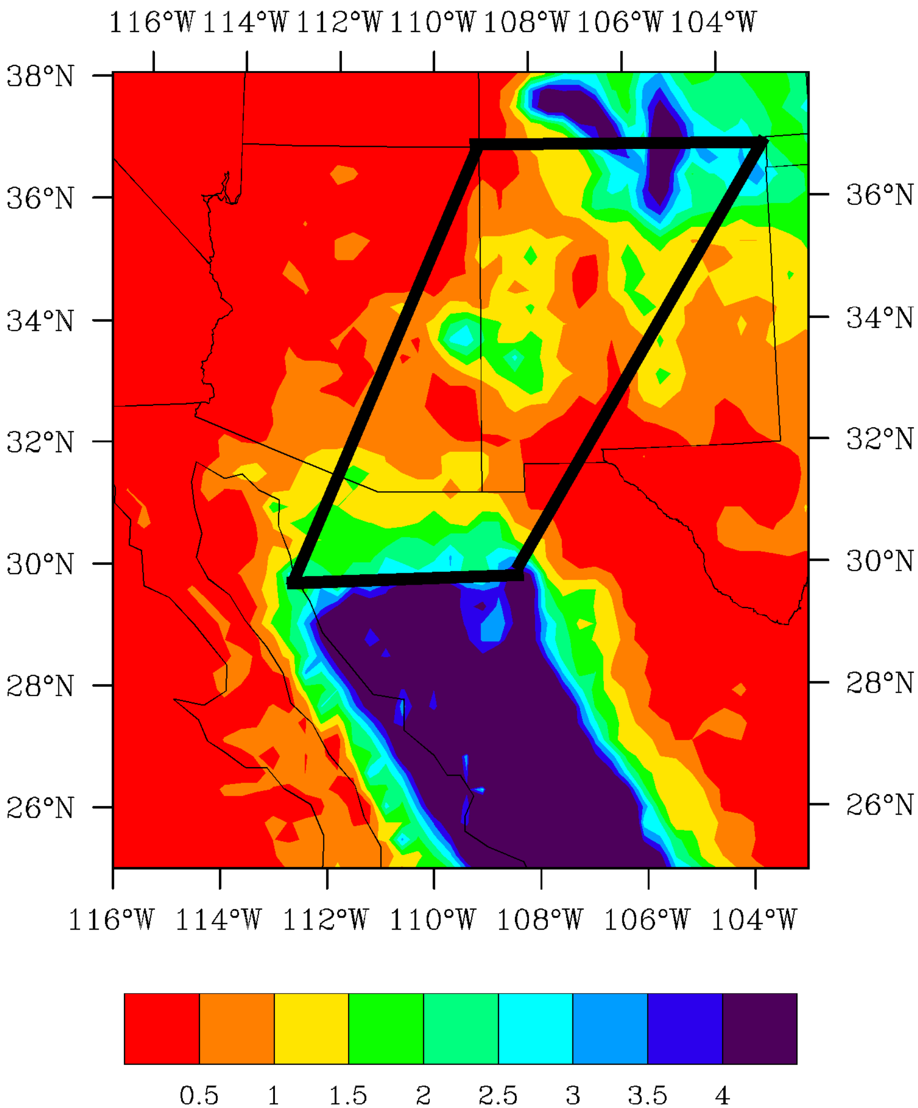




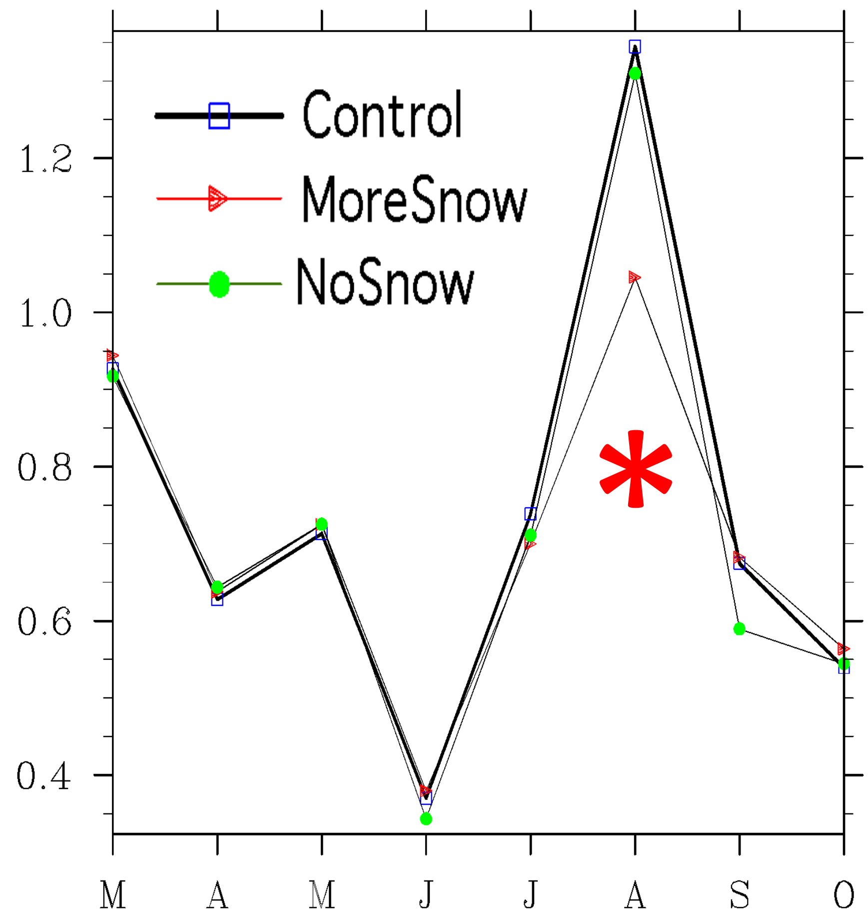
Impact of Elevated Snowpack on Jul-Aug Circulation and Moisture (MoreSnow-CTL)



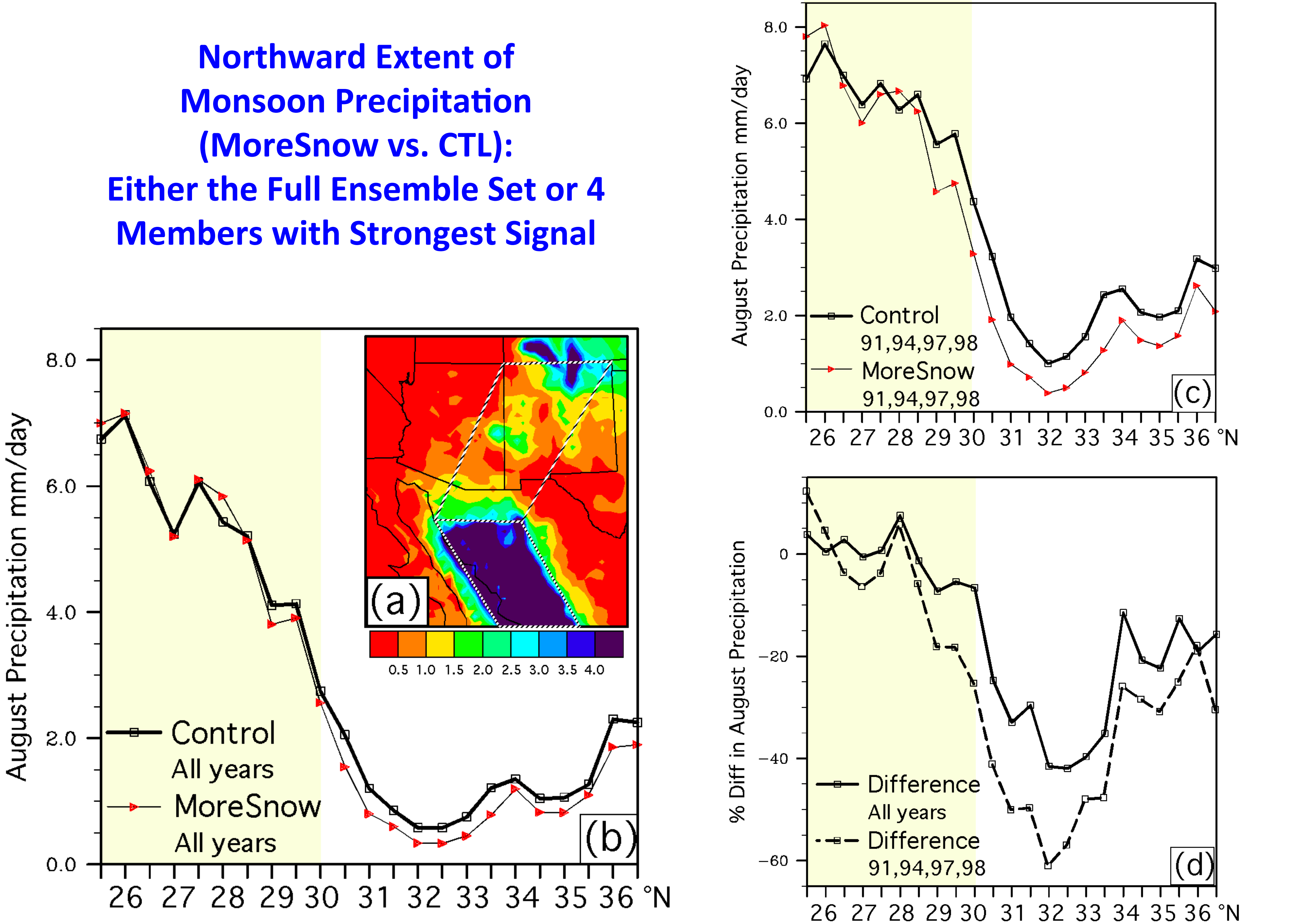
Model Climatology of August Precipitation (mm/day)



Monthly Precipitation in Parallelogram (mm/day)



Northward Extent of Monsoon Precipitation (MoreSnow vs. CTL): Either the Full Ensemble Set or 4 Members with Strongest Signal



CONCLUSIONS AND DISCUSSION

RegCM4 experiments suggest that the monsoon over the American Southwest is sensitive to antecedent snowpack over the Rocky Mountains, with a response that is consistent with the Eurasian snow-monsoon mechanism.

A deep snowpack and delayed snowmelt produce a higher surface albedo and wetter soils into summer, both which produce cooling. Anomalously low tropospheric temperatures over land weaken the northward advance of monsoon precipitation into AZ-NM.

The results are not definitive and the relationship is modest, but any increase in seasonal predictability across this complex region is vital.

Notaro, M., and A. Zarrin, 2011: Sensitivity of the North American monsoon to antecedent Rocky Mountain snowpack. Geophysical Research Letters, 38, L17403.