Mid- 21st Century Warming in the Southern Colorado Rocky Mountains from "NARCCAP" Models

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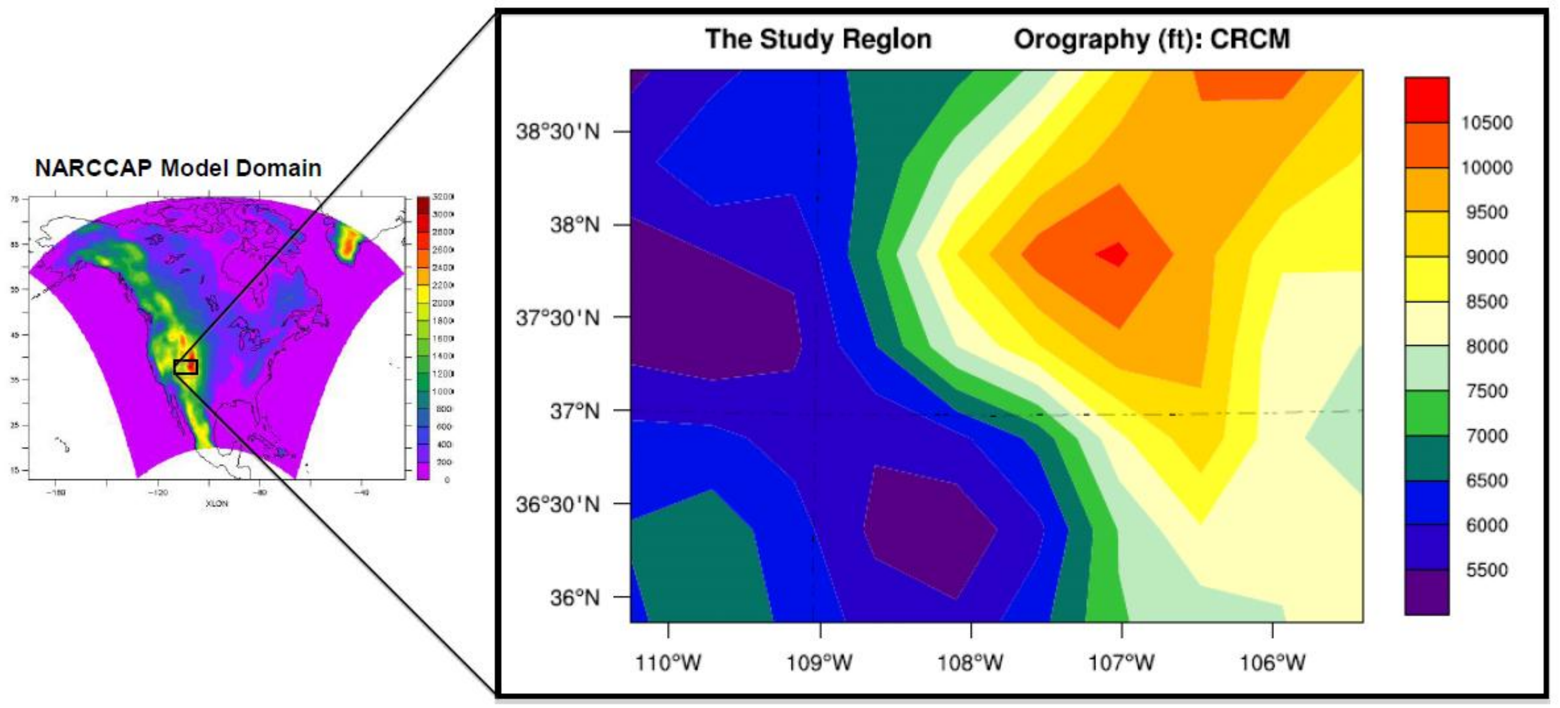
The Study Region

Between 36.0°-38.5°N latitude and 105.5°-110°W longitude, the region encompasses the San Juan Mountains and the Four Corners Region, containing in excess of 60 grid cells.



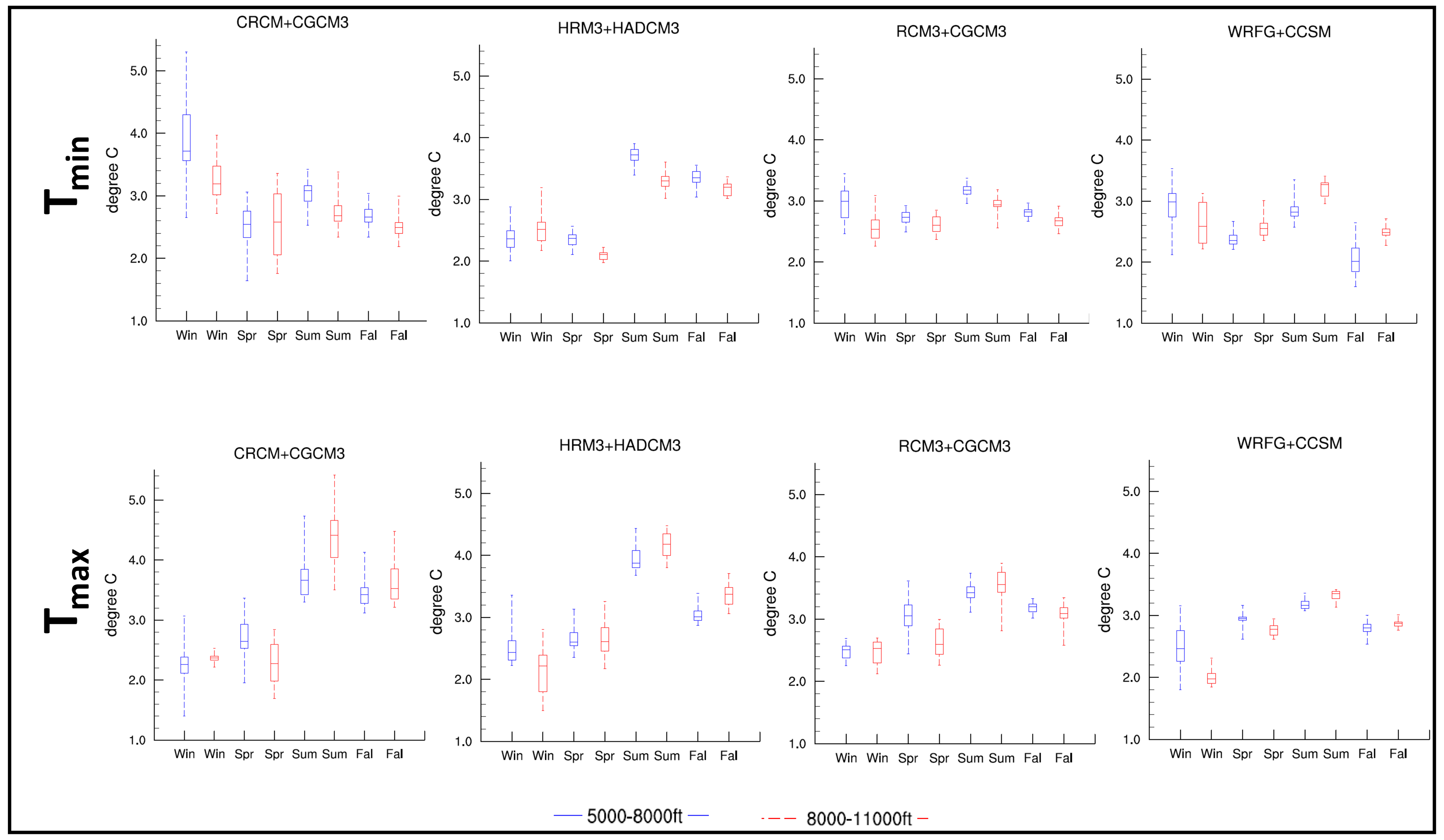
Mid-century Changes in T_{min} and T_{max}

Analysis: Mean change* (°C) in T_{min} and T_{max} between 1971-2000 and 2041-2070 periods for two different surface elevation ranges: 5000-8000ft and 8000-11000ft.

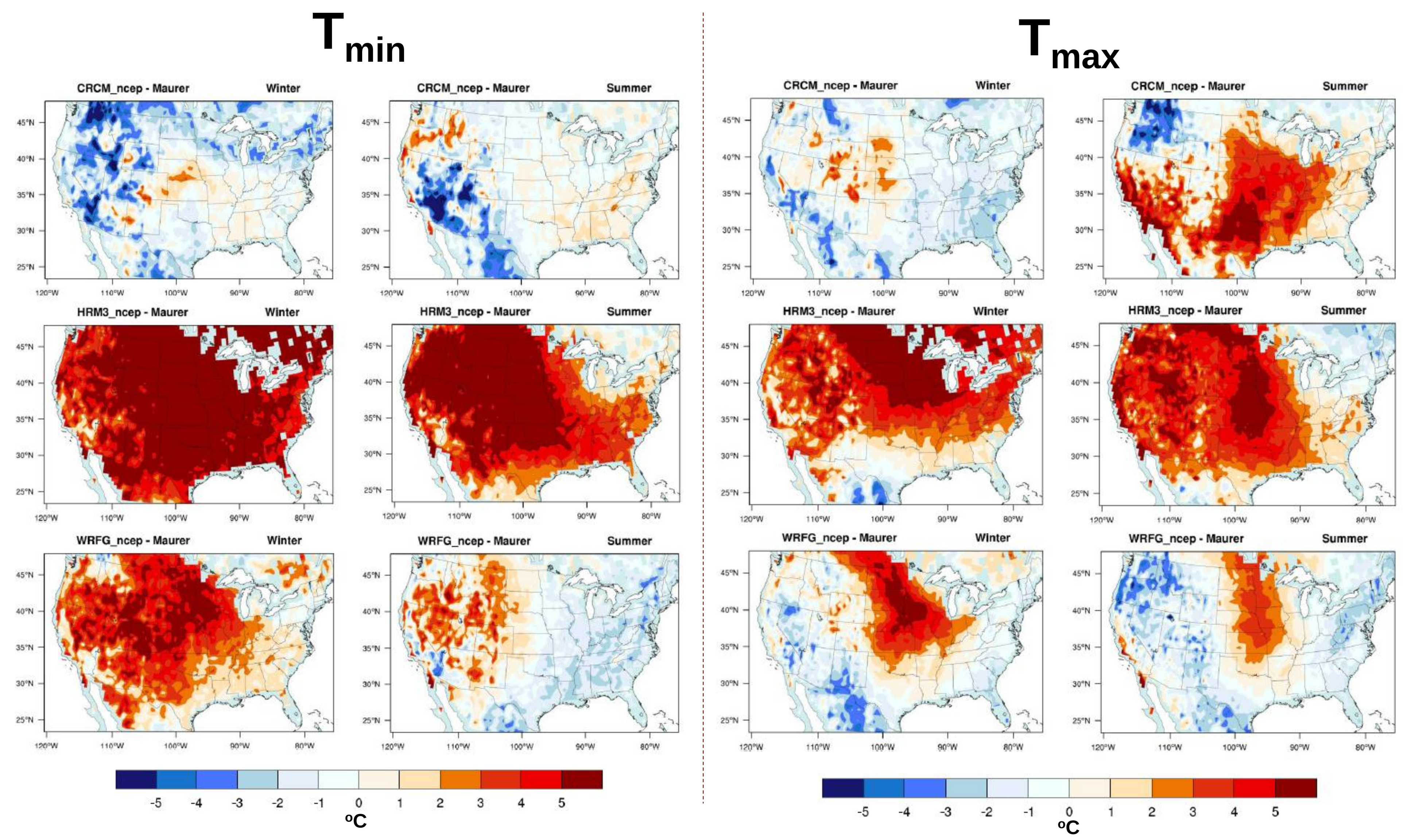
NARCCAP models analyzed: 1. CRCM+CGCM3, 2. HRM3+HADCM3, 3. RCM3+CGCM3, 4. WRFG+CCSM

- **Relative large increases (> 3°C) in T_{max} during summer at higher elevation, and in T_{min} during winter at lower elevations**
- T_{max} increases during summer are associated with decreases in soil moisture and large reductions in latent heat fluxes .
- T_{min} increases during winter are associated with decreases in surface snow cover and increases in soil moisture and surface specific humidity.

*The boxplots describe the mean change. The boxes show 25th and the 75th percentile values, the dark line within the box is the median value and the error bars stretches to the minimum and maximum values.

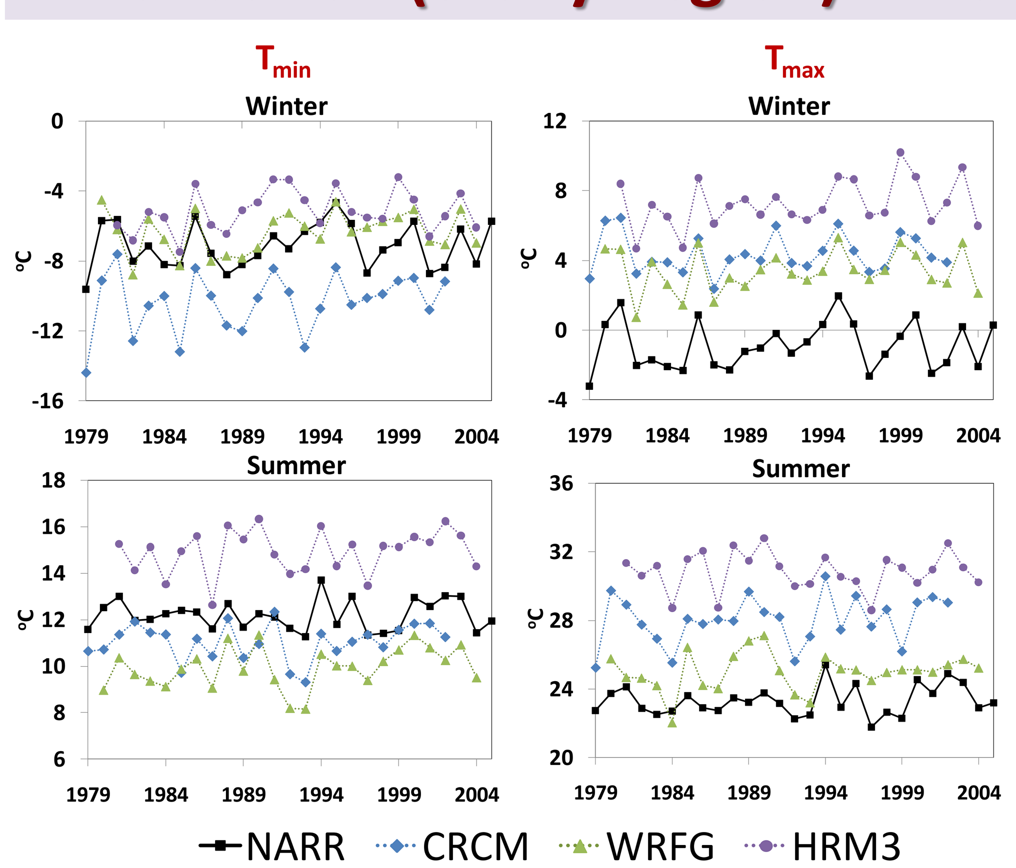


Validation (U.S.): RCM Biases in T_{min} and T_{max}



Biases are calculated relative to the Maurer (2002) gridded data. HRM3 has large warm biases in both T_{min} and T_{max} for most of the US. All models show large warm biases in summer time T_{max} for the mid-western US; HRM3 and WRFG also have such a bias in T_{min} and T_{max} during winter. For winter, CRCM show a strong cold bias in T_{min} for several regions of the western US, including our study region.

Validation (Study Region): Anomaly Correlation with NARR



Plots show a comparison of T_{min} and T_{max} time series for winter and summer from three NCEP forced RCMs (CRCM*, WRFG & HRM3) and NARR**.

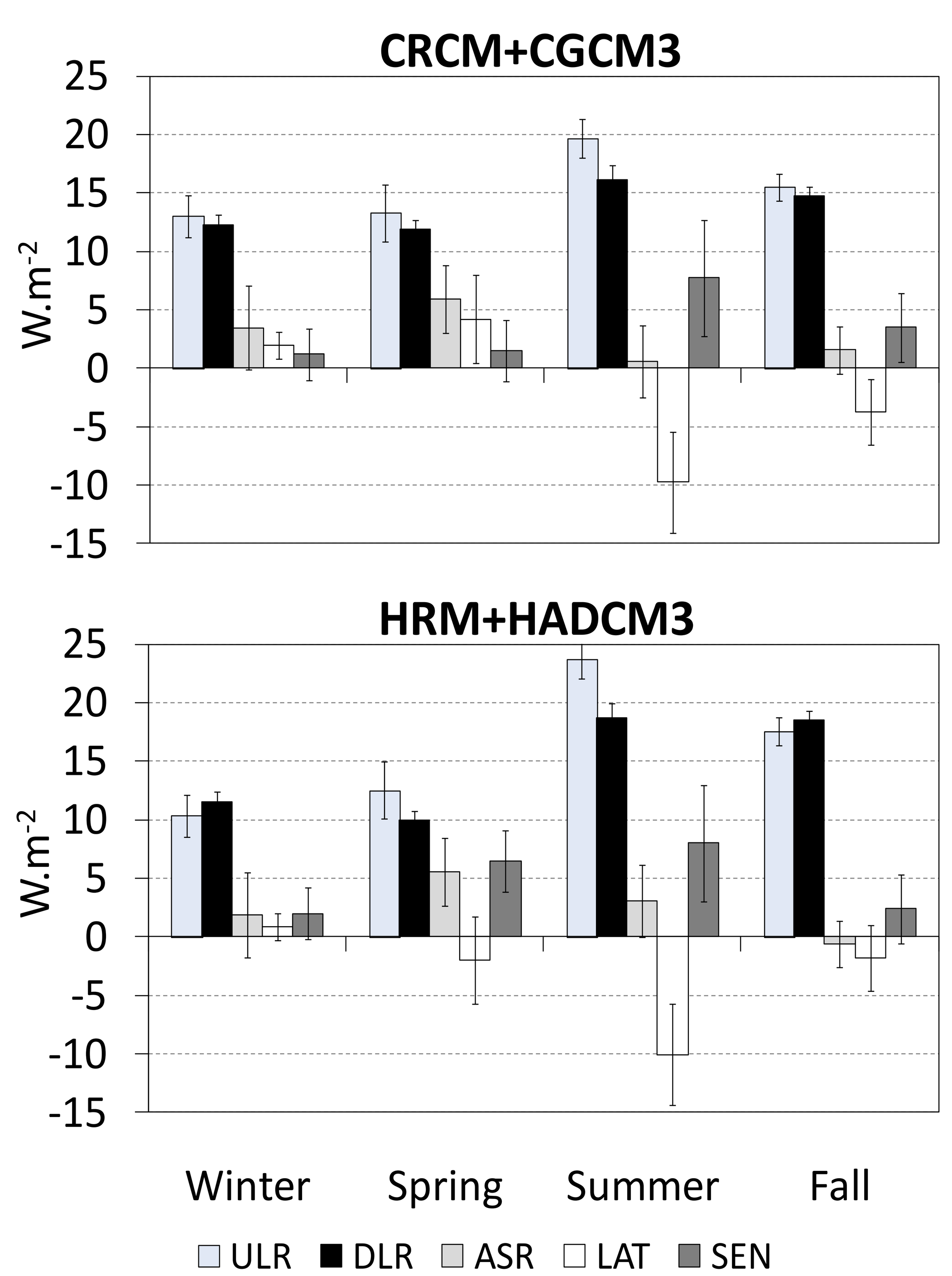
Generally, a **high correlation (r = 0.5-0.8) between the RCMs and NARR** time series of T_{min} and T_{max}. The **correlation is higher in winter relative to summer.**

*CRCM uses large scale spectral nudging.
** NCEP North American Regional Reanalysis (http://www.emc.ncep.noaa.gov/mmb/rreanl/); it is appropriate for comparison with NARRCAP RCMs because of similar spatial resolution.

Changes in Surface Energy Fluxes

Analysis: Mean seasonal changes in the components of surface energy fluxes between 2041-2070 and 1971-2000 periods

- **Large decreases in latent heat fluxes** (10 $W.m^{-2}$) **and increases in sensible heat fluxes** (8 $W.m^{-2}$) **in summer.**
- **Increases in absorbed solar radiation** (3-6 $W.m^{-2}$) **in spring and winter.**
- Proportionally **greater increases in downwelling longwave radiation during winter relative to upwelling longwave radiation.**



ULR = Upwelling Longwave Rad.; **DLR** = Downwelling Longwave Rad.; **ASR** = Absorbed Solar Rad.; **LAT, SEN** = Latent & Sensible Heat Fluxes

Table 1. Seasonal correlation (r) of Tmin and Tmax with precipitation, soil moisture, cloud cover, specific humidity and the components of surface energy fluxes from two RCM simulations for the 2041-2070 period. Bold values are significant at 5% level.

		Tmin				Tmax				
		Winter	Spring	Summer	Fall		Winter	Spring	Summer	Fall
HRM3+HADCM3	DLR	**0.91**	**0.75**	**0.63**	**0.77**	DLR	**0.43**	0.19	0.12	0.25
	ASR	-0.22	0.05	0.18	0.20	ASR	**0.45**	**0.63**	**0.64**	**0.73**
	LAT	0.31	0.05	-0.33	-0.12	LAT	-0.19	**-0.52**	**-0.74**	**-0.61**
	SEN	**-0.68**	0.12	0.29	0.23	SEN	-0.33	**0.65**	**0.70**	**0.67**
	Precipitation	0.30	0.01	-0.36	-0.11	Precipitation	-0.29	**-0.58**	**-0.77**	**-0.62**
	Soil Moisture	**0.39**	-0.18	-0.25	-0.18	Soil Moisture	-0.06	**-0.62**	**-0.47**	**-0.59**
	Cloud Cover	**0.52**	0.16	0.19	-0.12	Cloud Cover	-0.09	**-0.37**	-0.23	**-0.54**
	Sp. Humidity	**0.90**	**0.42**	-0.03	0.30	Sp. Humidity	**-0.83**	**-0.73**	-0.15	**-0.72**
		Winter	Spring	Summer	Fall		Winter	Spring	Summer	Fall
CRCM+CGCM3	DLR	**0.64**	**0.78**	**0.83**	**0.85**	DLR	**0.47**	0.29	0.10	0.21
	ASR	0.32	0.30	**-0.38**	0.12	ASR	**0.47**	**0.78**	**0.40**	**0.78**
	LAT	**0.54**	0.36	-0.13	-0.08	LAT	**0.36**	-0.12	**-0.75**	**-0.71**
	SEN	-0.03	0.05	-0.06	-0.04	SEN	0.01	**0.59**	**0.66**	**0.61**
	Precipitation	-0.10	0.07	0.20	-0.07	Precipitation	-0.27	**-0.49**	**-0.57**	**-0.59**
	Soil Moisture	-	-	-	-	Soil Moisture	-	-	-	-
	Cloud Cover	-0.02	-0.04	0.27	0.05	Cloud Cover	-0.32	**-0.59**	-0.34	**-0.66**
	Sp. Humidity	**0.89**	**0.93**	**0.83**	**0.71**	Sp. Humidity	**-0.52**	**-0.84**	0.22	**-0.54**

Table 2. Mean percent changes by mid-21st century in precipitation, soil moisture, cloud cover, specific humidity and the components of surface energy fluxes from two RCM simulations.

HRM3+HADCM3					CRCM+CGCM3				
	Winter	Spring	Summer	Fall		Winter	Spring	Summer	Fall
DLR	5	4	6	7	DLR	6	5	6	6
ASR	2	3	1	0	ASR	4	3	0	1
LAT	5	-5	-18	-6	LAT	36	13	-23	-18
SEN	-10	20	16	10	SEN	9	4	11	10
Precipitation	4	-11	-20	0	Precipitation	4	-7	-25	-9
Soil Moisture	2	0	-1	0	Soil Moisture	-	-	-	-
Cloud Cover	-3	-3	-6	5	Cloud Cover	0	-5	3	-3
Sp. Humidity	14	7	4	18	Sp. Humidity	25	18	14	17

Summary

All four RCMs project 2°C or higher increases in T_{min} and T_{max} for all seasons. However, there are much greater (> 3°C) increases in T_{max} during summer at higher elevations and in T_{min} during winter at lower elevations. T_{max} increases during summer are associated with decreases in soil moisture and large reductions in latent heat fluxes. This occurs in part from decreases in precipitation and early snowmelt,. T_{min} increases during winter are, in part, associated with decreases in surface snow cover and increases in soil moisture and specific humidity. In winter, increased moistening of the land and near-surface atmosphere facilitates a greater diurnal retention of the increases in daytime solar heating of the surface because of snow cover reductions. This daytime retained heat in the land surface positively feedbacks on the longwave heating of the land surface at night.

Western Water Assessment

Postdocs Applying Climate Expertise Fellowship Program

References

1. Maurer, E., et al. (2002), A Long-Term Hydrologically Based Dataset of Land Surface Fluxes and States for the Conterminous United States, *Journal of Climate*, *15*(22), 3237-3251.

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