Towards Improvement in Seasonal Forecasting in the Southwest United States using a Regional Climate Product at the Convective Permitting Scale

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Introduction

Accurate regional and local scale information about seasonal climate variability and its impact on water availability is important in many practical applications like agriculture, water resource planning, and emergency hazard management. The need for improved seasonal forecasts during the warm season (May to September) in the United States is particularly urgent. During this time of year, "billion-dollar disaster events" as caused by severe weather, heat waves and drought, wildfire, and flooding are likely becoming more extreme in an anthropogenically-driven warming global climate (e.g. Meehl et al. 2000; Min et al. 2011). The warm season climate is becoming more extreme in conjunction with large-scale atmospheric circulation (or teleconnection) patterns that are the primary drivers of continental-scale variations in wet and dry conditions on seasonal timescales (e.g. Chang et al. 2015, Coumou et al. 2014). North American monsoon precipitation in the Southwest U.S. is influenced by both synoptic-scale variability in atmospheric circulation and localized convection, which requires a climate model configuration with sufficient spatial resolution and reliable atmospheric forcing to better capture the seasonal variability. The current North American Multi-Model Ensemble (NMME) global climate models used for operational sub-seasonal to seasonal (S2S) forecasting has very limited forecasting skill for the warm season, in part due to the poor representation of the convective precipitation (Kirtman et al. 2014). The NMME models, however, may have some skill in deterministically representing the synoptic-scale atmospheric circulation at S2S timescales. **The main research objective is to generate a regional climate model simulation for the Southwest at convective-permitting spatial resolution by downscaling a retrospective atmospheric reanalysis, in order to explicitly represent monsoon thunderstorms in the simulation**. Use of regional model adds value in terms of better spatial and temporal representation of precipitation (e.g Prein et al. 2015, Liu et al. 2016) and is a necessary initial step towards eventually dynamically downscaling S2S forecasts that would be provided from NMME global forecast models.

Data and Methodology

Convective-permitting Regional Climate Modeling (CPM):
The Weather Research and Forecasting- Advanced Research WRF (WRF-ARW 3.5.1) model (Skamarock et al., 2005) is configured with two nested domains at 12 and 3km resolution centered over the Southwest and upper and lower Colorado River Basins (UCB, LCB, see Fig. 1). Reanalysis data from Climate Forecast System Reanalysis (CFSR, Saha et al. 2010) provides the WRF initial and boundary conditions at a 6-hourly time interval. A continuous WRF CPM simulation has been completed from 2001 to 2011.

Observation for Model Validation:
To evaluate the WRF simulations, we use two sources of gridded daily precipitation data available within the contiguous U.S.: **1)** Parameter-elevation Regressions on Independent slopes model (**PRISM**) data at one-sixteenth degree resolution was used to validate the RCM simulations at the daily scale. **2)** Quality-controlled **Stage IV data** is used to compare observed precipitation to WRF-modeled precipitation on the CPM simulation domain at the sub-daily scale. Stage IV data has some problems with respect to estimating precipitation in complex terrain, due to issues of lack of rain gauge observations and radar beam blockage (Adams et al. 2014; Minjarez-Sosa 2016).

Seasonal Precipitation Analysis:
Monthly precipitation is evaluated for both warm (June to September) and the cool (November to April) season June to September. A Generalized Pareto Distribution (GPD) is used to characterize the amount of precipitation at which the threshold (95th percentile) is exceeded. Events within the tails of the distribution above this threshold are considered as the extremes

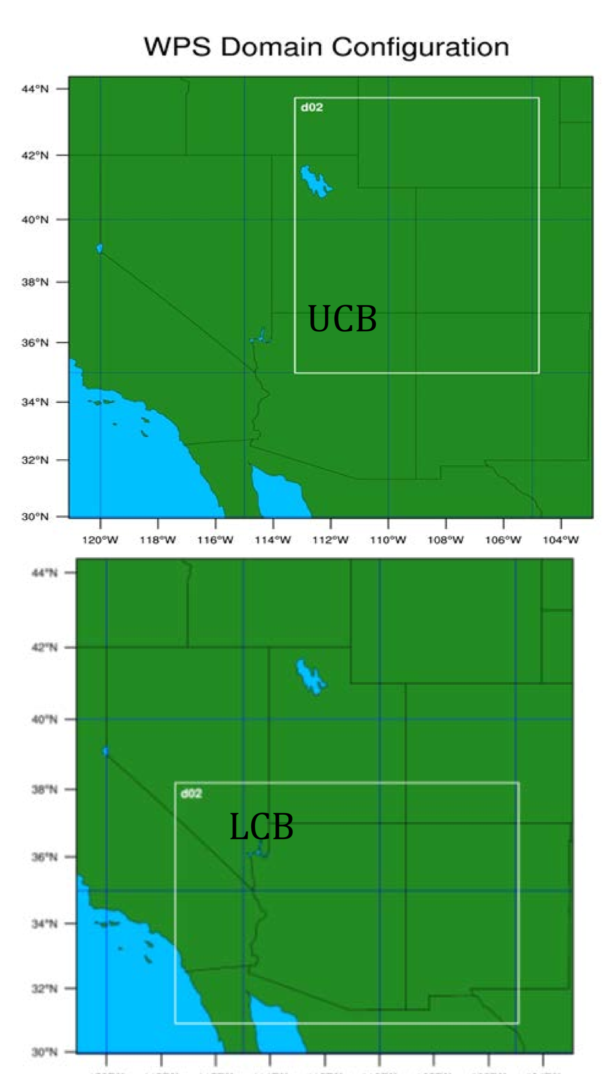
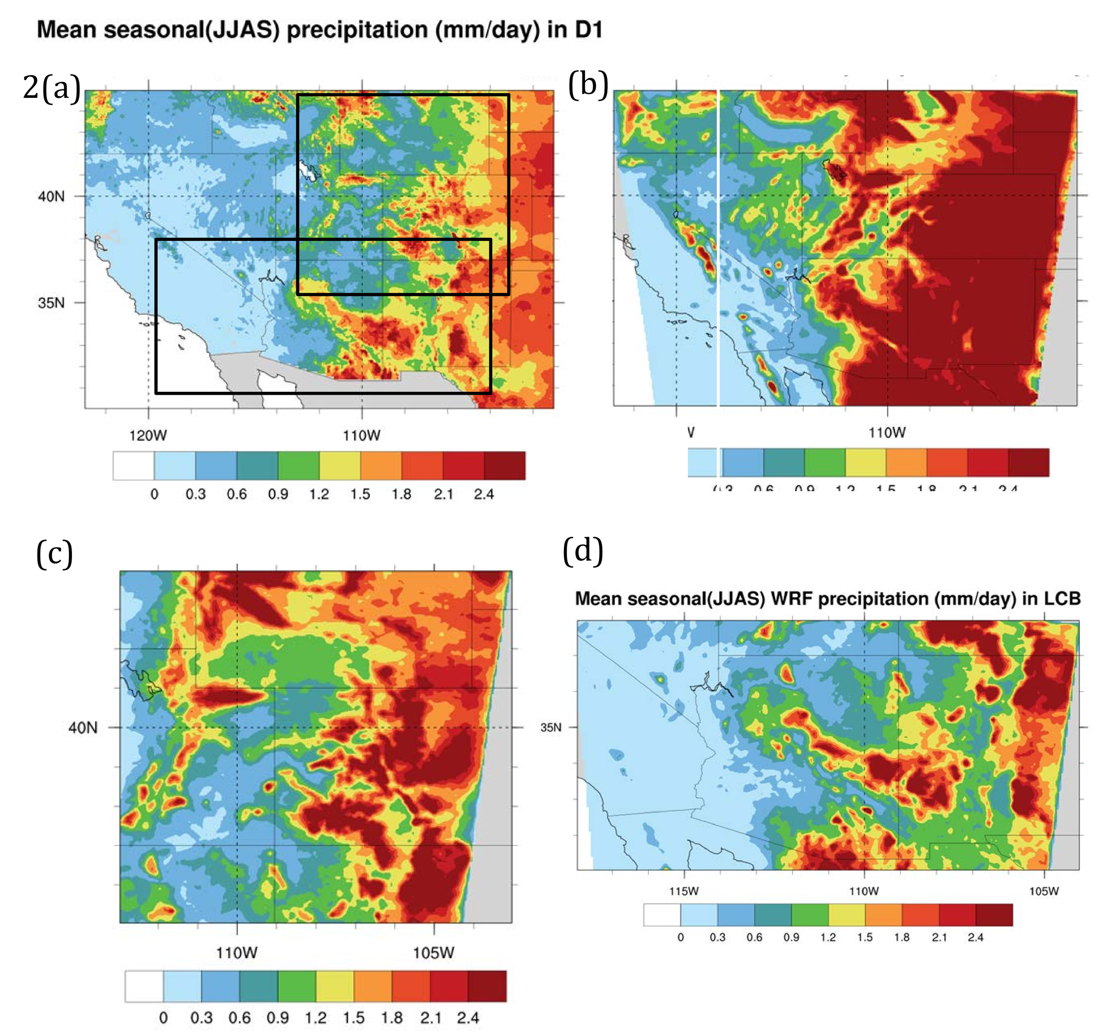


Fig. 1.WRF domains used for convective-permitting regional climate simulations

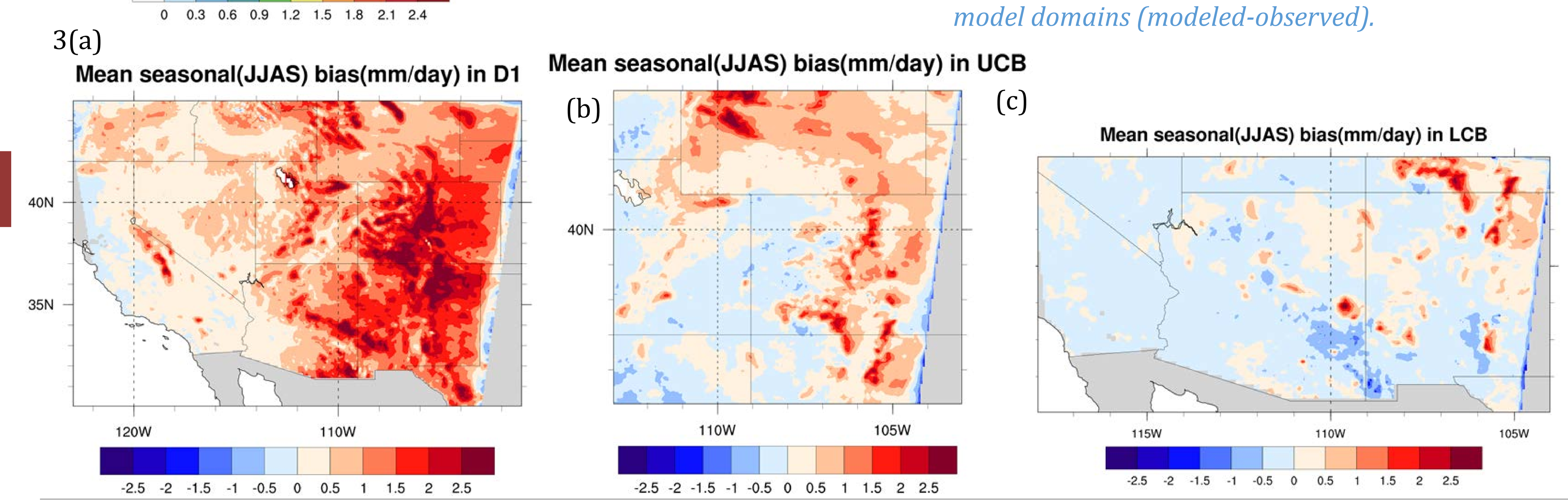
Simulation of mean climate in warm and cool seasons

1. Mean Warm Seasonal Precipitation (JJAS, 2000-2011)

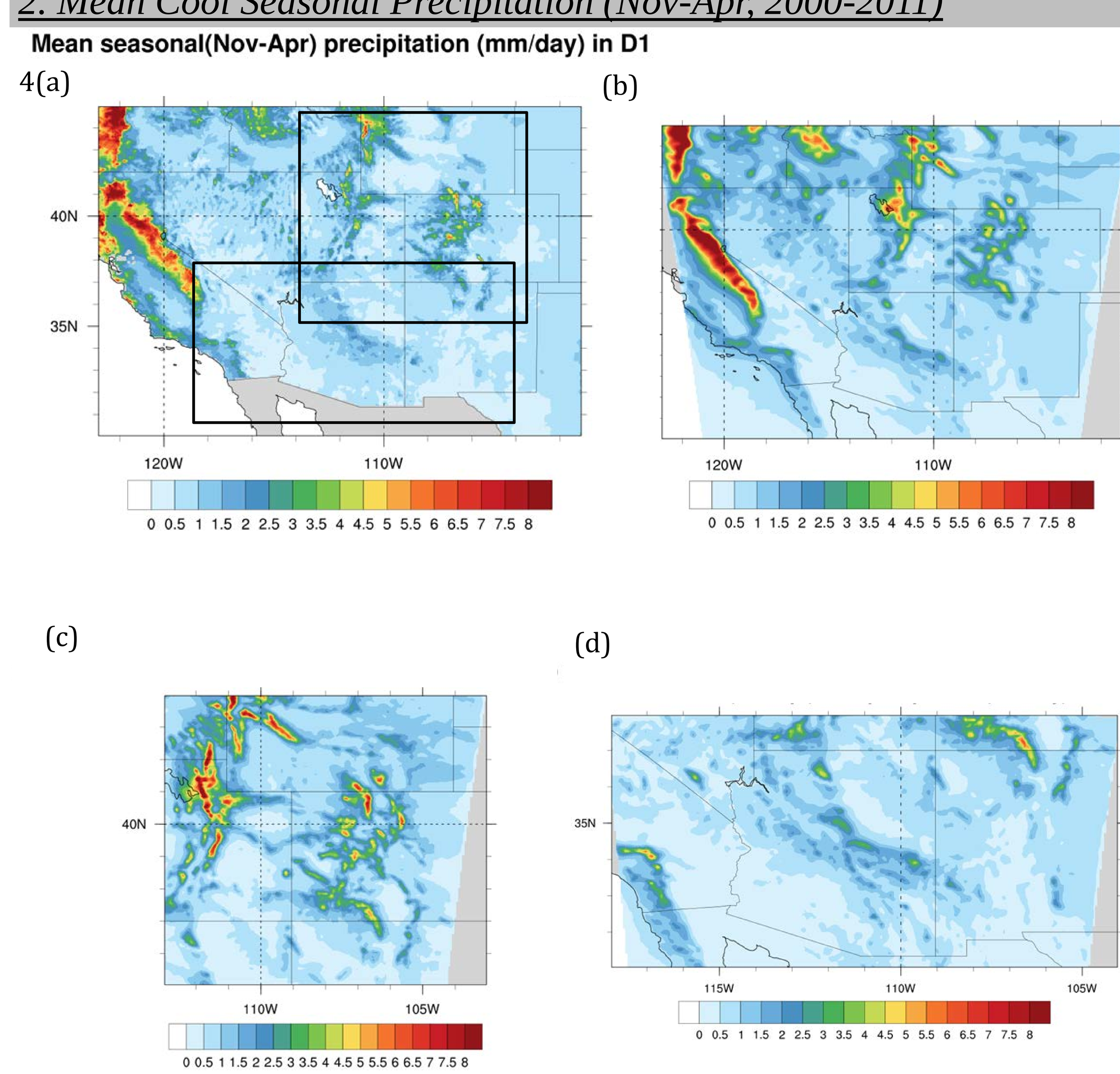


Value added of CPM in warm season precipitation simulation:
Precipitation is first examined during warm season between observations (Fig. 2a) and WRF coarse and CPM domains. The precipitation intensity and distribution is overestimated within the WRF coarse domain (12km resolution, Fig. 2b), especially in areas of complex terrain. The wet bias is greatly reduced within convective-permitting domains (Figs 2c, 2d). The magnitude of the precipitation bias in the CPM simulations is in the order of +/- 0.5 mm/day (Figs 3b, 3c). In contrast, the WRF simulation at coarser resolution generates widespread positive bias (Fig. 3a), with largest wet bias in the mountainous regions > 2.5 mm/day. Summertime precipitation in this region is associated with monsoonal convective activity as a result of complex interaction between synoptic and mesoscale atmospheric circulation features and local topographic variation, which is better resolved in a CPM (e.g Prein et. al, 2015).

Fig. 2.(a-d) Mean precipitation climatology for warm season (JJAS) represented by observed(a), WRF coarse resolution domain(b), CPM in UCB (c) and LCB (d).
Fig. 3.(a-c) Corresponding bias in precipitation for all model domains (modeled-observed).



2. Mean Cool Seasonal Precipitation (Nov-Apr, 2000-2011)



Cool season performance:
A similar seasonal precipitation comparison for the cool season (November to April) reveals that WRF is able to reasonably capture the precipitation characteristics in both coarser and CPM domains. (Fig 4). Negligible bias is seen in both the domains (not shown) which agrees with previous studies (Kirtman et al 2014). Winter precipitation, though influenced by local topography, is mostly dependent on synoptic scale variability, which is captured well by both domains of the WRF due to the fact that spectral nudging implemented in the coarser domain.

Fig. 4 (a-d). Mean precipitation climatology for cool season (Nov-Apr) represented by observed(a), WRF coarse resolution domain(b), UCB(c) and LCB (d).

CPM to represent extremes and demonstration for S2S forecasting

3. Warm Season (JJAS, 2000-2011) Extreme Precipitation

The GPD analysis shows that the pattern of extreme precipitation pattern from the WRF simulation generally follows the mean precipitation. At coarser resolution, precipitation maxima is found over mountainous regions (Fig. 5b) with a wet bias as compared to observation (Fig. 5a). The CPM simulations (Figs. 5c, 5d) have a more realistic representation of daily 20-year return period extreme precipitation (mm/day) which matches the spatial representation of the equivalent observations. Within the lower Colorado River Basin (Fig. 5d) the CPM accurately captures extreme rainfall in southwest Arizona associated with organized mesoscale convective systems during the North American monsoon, and this critical feature is not present in the coarser resolution simulation.

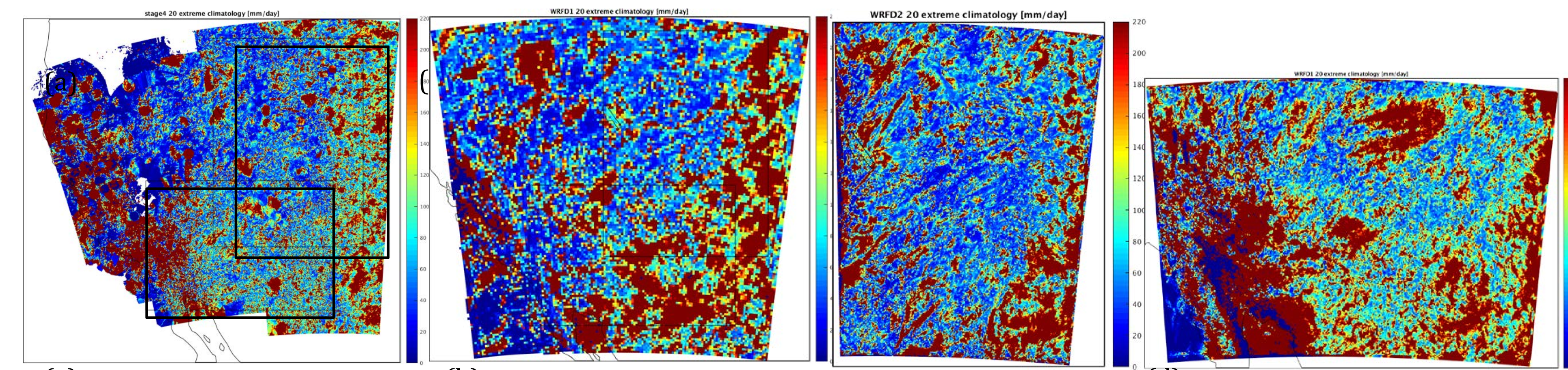


Fig.5. Warm season daily extreme precipitation (mm/day) analysis using GPD 20-year return values. Observation (a), coarse resolution WRF simulation (b), UCB (c), and LCB (d).

4. Subseasonal to Seasonal CPM simulation: Preliminary Results

Use of a dynamically downscaled WRF CFSR simulation shown in previous sections highlighted the value added using CPM to improve warm season convective precipitation, with respect the climatological representation of mean and extreme precipitation. Our next step is to demonstrate the value added of CPM in dynamically downscaling retrospective NMME reforecast data. S2S warm season simulations are currently underway using CFSv2 seasonal forecast ensembles from NMME. NMME models are relatively more skillful during the cool season, with comparatively little if any skill during the warm season. If this lack of skill is due at least part to the representation of precipitation processes in the NMME models, CPM may be extremely valuable. Figure 6b is the preliminary result from WRF CPM simulation forced by one CFSv2 ensemble member for 2006. Comparing it with gridded observation from CPC (Fig. 6a), WRF CPM has reasonable precipitation representation for the Southwest U.S.

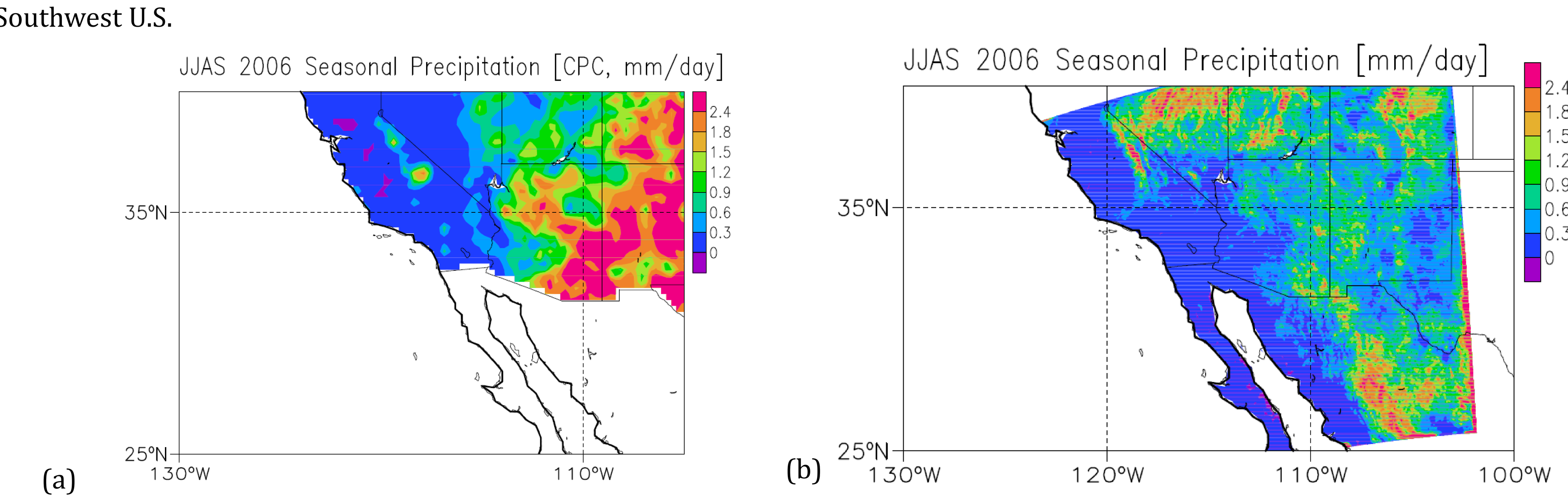


Fig.6. 2006 Warm season mean precipitation (mm/day): CPC gridded observation (a) and WRF CPM simulation driven by CFSv2 (b)

Summary and Conclusions

- **Current seasonal forecasts for the Southwest U.S. are not satisfactory, especially during warm season when severe events during the North American monsoon occur. Improving the representation of this type extreme weather in the western United States within S2S forecasts should be a priority.**
- **A regional climate model at a convective permitting scale adds substantial value to the representation of warm season precipitation due to its better representation of monsoon thunderstorms, especially mesoscale convective systems.**
- **High resolution RCM products are useful and add value to simulating mean daily, extreme daily and sub-daily precipitation, to improve decision making capability.**
- **It is now technically possible to dynamically downscale retrospective WRF-CFSv2 reforecasts to demonstrate the potential value added of convective permitting modeling for S2S forecasting in the western United States, across a continuum of timescales.**

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