Convection-permitting scale simulations reduce precipitation bias over North America

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Motivation

Deep convection is a key process in climate systems and the main source of precipitation, which is a vital component of the water cycle. Precipitation intensity is increasing across the Contiguous United States (CONUS) (Fig 1). This increase is robust — it is seen in observation data, model simulation outputs at convective parameterized (Chang et al. 2016) and convective permitting simulations (Chen et al. 2020); it is also seen in both summer and winter. In order to represent the water cycle in the state-of-the-art earth system models (ESMs), the deep convection has to be parameterized due to the coarse grid spacing of the ESMs. However, the sub-grid deep convection parameterization is a major source of uncertainty and model bias. In addition, coarse grid spacing is not able to capture fine-scale features of topography and results in underestimation of rainfall and snowfall over mountain regions. When the grid spacing goes to 4 km or less, the ESMs can solve the convection explicitly, so model bias and uncertainty in the water cycle can be significantly reduced, and the predictability of hydrological extremes can be improved. We refer to this scale of simulation as convection-permitting scale (C-P hereafter). We have conducted short-term 4km simulations over contiguous United States (CONUS) and found that, compared to our previously generated 12km simulations, the C-P simulation significantly reduced the bias in precipitation size and intensity, diurnal variations, as well as snowfall and snowpack.

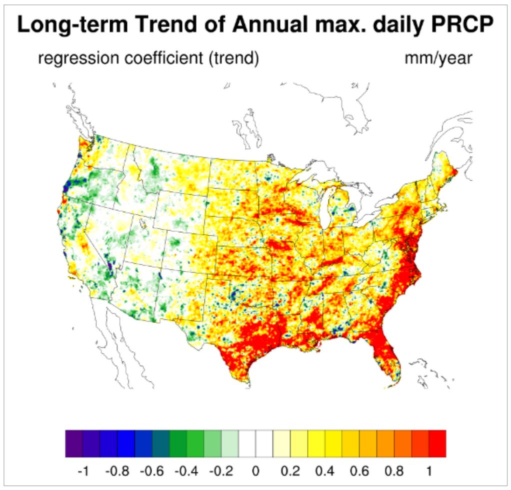

Figure 1. Long-term trend of annual maximum precipitation intensity based on 37 year of data from 1981 to 2017. The data is an observation-based gridded dataset on spatial resolution of 4km, called PRISM.

Model description: We conducted a suite of model runs at 4km horizontal resolution (C-P) using the Weather Research and Forecasting Model (WRF-ARW) version 3.3, with National Centers for Environmental Prediction Reanalysis II (NCEP) reanalysis for boundary and initial conditions. Simulation domains span most of North America, and the results shown here are for summer, 2005, June-August. The physics parameterizations used are WSM6 (WRF single-moment 6-class) microphysics (Hong and Lim 2006); Spectral nudging is applied above 850 hPa to wavelengths around 1200 km, with a nudging coefficient of $3\times10^{-5}s^{-1}$. We compare these 4km runs with the same setup but 12km with Grell–Devenyi convective scheme (GD) (Grell and Dévényi 2002) and Kain–Fritsch convective scheme (Kain 2004).

Results: The table below decomposed factors explaining precipitation bias for the model cases at 12km using GD and KF convective schemes, expressed as % anomaly vs stage IV (a gridded observation dataset). Precipitation distributions in both 12km simulations using GD (*2nd* column in the Table) and KF (*3rd* column in the Table) convective schemes are dominated by low-intensity and large-size rainstorm. The bias averaged over entire CONUS (compared with Stage IV observations) are 13% and 21% lower in intensity; and 150% and 220% higher in size. The explicit-convection 4 km reduces the wet bias in amount, and has a stronger mean intensity as well as a more accurate rainstorm size. While the model bias at monthly scale are similar between 12km and 4km resolution, the 4km capture better the smaller scale features, such as single severe storms (Fig. 2a) as well as diurnal variation (Fig. 2b), which is very important to describe the precipitation pattern in US, especially in warm season. Compare to observation data averaged over entire CONUS, all the models capture the diurnal cycle with peak in afternoon or evening, but 12km simulations generate too large and too regular peaks; and they also show an earlier minimum in the midnight. Specifically, over central great plains, all 12km simulations show early morning peaks while the observed peak is in late evening (not shown here). The 4km reduces the wet bias during the afternoon peak averaged over entire CONUS and is able to capture the diurnal curves over central great plains (not shown here).

Storm property	12km, GD	12km, KF	4km, C-P
Amount	58	68	29
Intensity	-13	-21	30
Size	150	220	33
Duration	-9	-4.6	-0.01
Num. of storms	-19	-42	-20

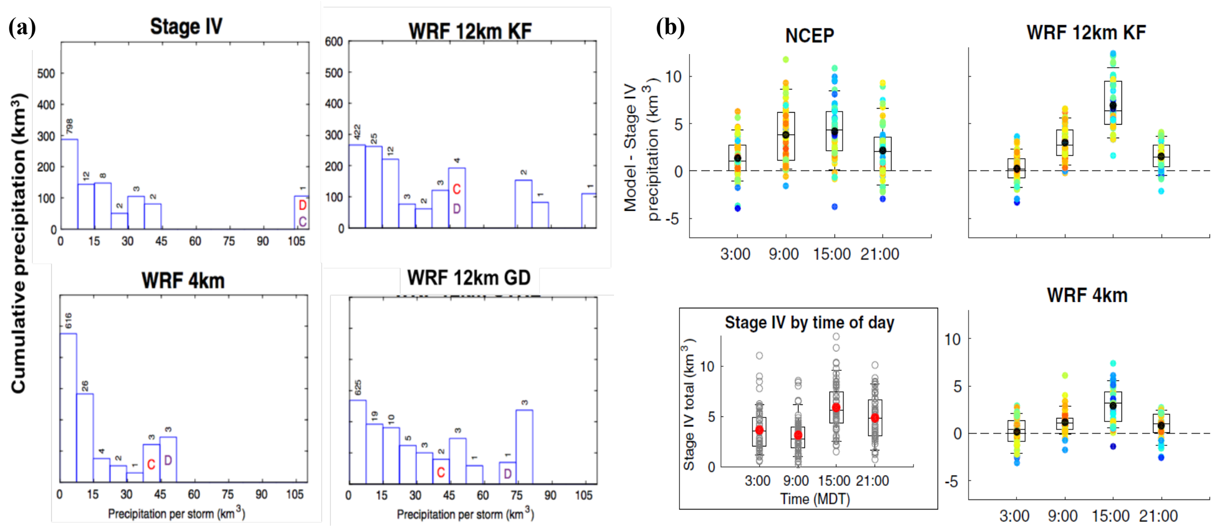

Figure 2 (a) Event-based precipitation distributions classed by individual storm precipitation amount. Numbers above each bar give the number of individual storms in each size bin. Labels 'C' or 'D' on a bin indicate the largest storm identified as part of Hurricanes Cindy or Dennis. (b) Box-Whisker plots of bias in diurnal cycle: absolute bias in domain-aggregated precipitation by time of day (mountain daylight time) for all model runs and for comparison, diurnal cycle in Stage IV observed precipitation. X-axis labels mark center of 6-h time intervals. and 9th and 91st percentiles of each distribution. Color code in the bias plots indicates the total observed precipitation in each time step. All downscaled model runs show an amplified diurnal cycle, though using explicit rather than parametrized convection appears to moderate this effect.

Simulations in progress: We use the WRF with the ARW core, version 4.3.1. The simulation domain is centered at 38.4°N and 98°W and has dimensions of 2050 (west-east) × 1750 (south-north) × 61 (vertical) grid points with grid spacing of 4 km, covering most North America including Alaska, Canada as well as Puerto Rico. A large ensemble simulation will be conducted using reanalysis as well as GCMs from CMIP6. The simulation will include: (1) 20 years (2000-2019) of simulation forced by reanalysis data ERA5; (2) 20 years of historical and future simulations for mid and end of 21st century, respectively using three GCMs from CMIP6 to cover the range of uncertainty of all the CMIP models to CO2 doubling. Uncertainty due to internal variability and physics sensitivity will be also assessed as we did for the 12km simulations. We expect this dataset to improve on the Wang and Kotamarthi (2014) and Zobel et al. (2017) downscaled dataset.

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