WRF ensemble dynamical downscaling of precipitation over China using different cumulus convective schemes

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Abstract

Ensemble dynamical downscaling of precipitation over China was conducted based on simulations of the Weather Research and Forecasting model using both Kain–Fritsch and Grell cumulus convective parameterization schemes. The simulations were driven by ERA-Interim reanalysis data with 25-km horizontal resolution for the period 1980–2015. Results indicated that superior performance was achieved by the ensemble based on the two different schemes because certain observed signals were captured complementarily by each scheme over distinct regions. For climatological mean precipitation, the ensemble improved the annual mean pattern, probability distribution, and seasonal evolution of precipitation. With regard to interannual variation, the ensemble showed the highest skill in representing the series of precipitation anomalies at regional scales for all subregions. Improvement was also evident in the spatial patterns of the dominant precipitation variability modes and the corresponding temporal variations. For extreme precipitation, several indices were selected, and the ensemble was better able to capture the main features with higher spatial pattern correlations and closer magnitudes. The advantages of the ensemble are due to its appropriate regime specific weights derived from the Kain–Fritsch and Grell schemes.

Introduction

The Coordinated Regional Climate Downscaling Experiment (CORDEX), is a program under World Climate Research Program (WCRP) with the vision to advance and coordinate the science and application of regional climate downscaling worldwide (Giorgi et al., 2012; Lake et al., 2017; Dai et al., 2020).

China's regional climate is controlled primarily by the East Asian summer monsoon (EASM), which is one of the most complex circulation systems modeled (Lin et al., 2008; Gao et al., 2008; Zou et al., 2010). In addition, complex characteristics of surface topography and vegetation distribution also increase the difficulty of accurate precipitation simulation for RCMs. Previous studies have shown that systematic errors and large uncertainties in prediction of precipitation over China are associated with the choice of cumulus convective parameterization (CUP) scheme (Lee and Suh, 2000; Lee et al., 2005; Fu and Zheng, 1998; Fu et al., 2005; Kang and Hong, 2008; Pal et al., 2007; Zhang et al., 2015).

Although numerous CUP schemes exist, no single scheme has been proven to systematically outperform the others over targeted regions. Therefore, an ensemble of multiple CUP schemes is often used to reduce model uncertainties and improve the overall performance of precipitation simulation (Liang et al., 2007; Liu et al., 2009; Qiao and Liang, 2017).

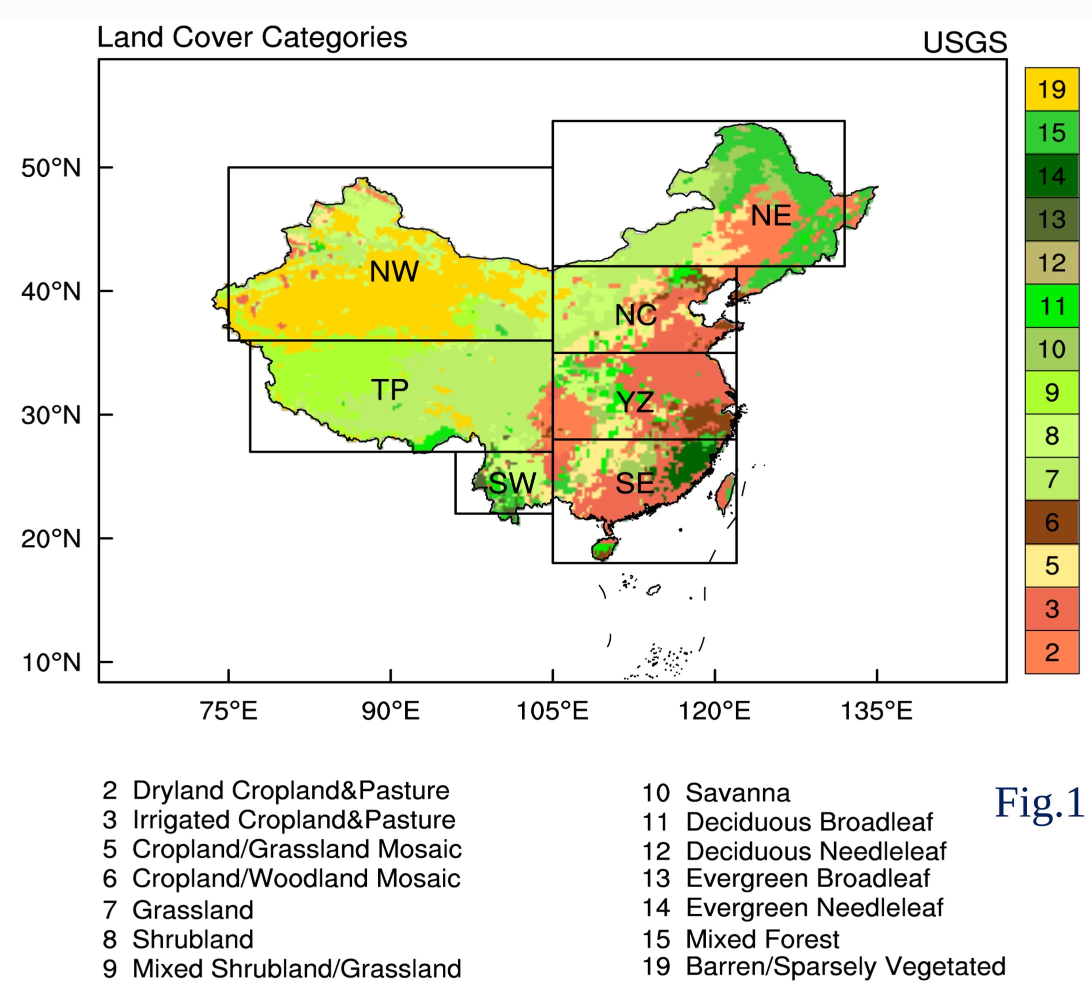
Experimental design

The WRF model version 3.9 (Skamarock et al., 2008), developed at the National Center for Atmospheric Research, was used as the RCM in this study.

A high-quality gridded daily analysis of precipitation with 0.25° × 0.25° horizontal resolution, based on in situ measurements at 2416 stations throughout mainland China (1961–2015), was used as the observational data (Wu and Gao, 2013).

Two WRF experiments configured with the KF and GR schemes were conducted. Both simulations were initialized on October 1, 1979 and terminated on December 31, 2015. The first three months were regarded as the spin-up period.

Considering the topographic characteristics and land cover specifications, we divided China into seven subregions: Northeast China (NE), Northwest China (NW), North China (NC), the Yangtze River (YZ), Southeast China (SE), Southwest China (SW), and the Tibetan Plateau (TP) (Yang et al., 2016; Gao, 2020). These regions also roughly coincide with the major climatic regions of China.



To reduce the uncertainties of the WRF simulation associated with the two CUP schemes, the Feasible Sequential Quadratic Programming method (Zhou et al., 1997) was used to estimate the weights assigned to the different CUP schemes for each grid point.

Fig.1 The WRF computational domain

Results

●Precipitation mean climatology

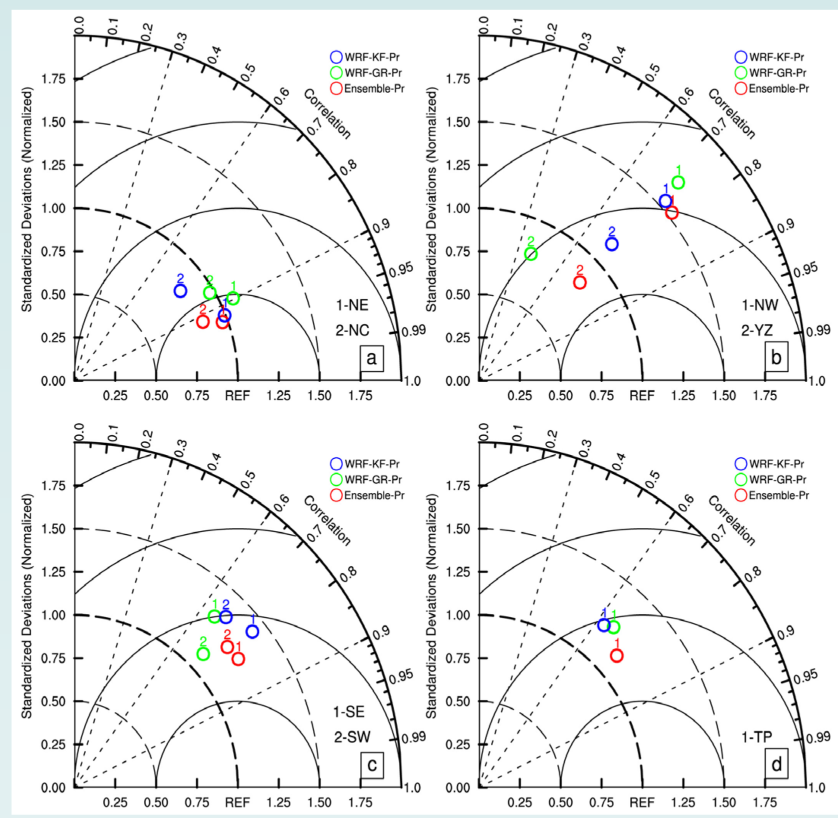


Fig.2 Taylor diagrams for the annual mean precipitation

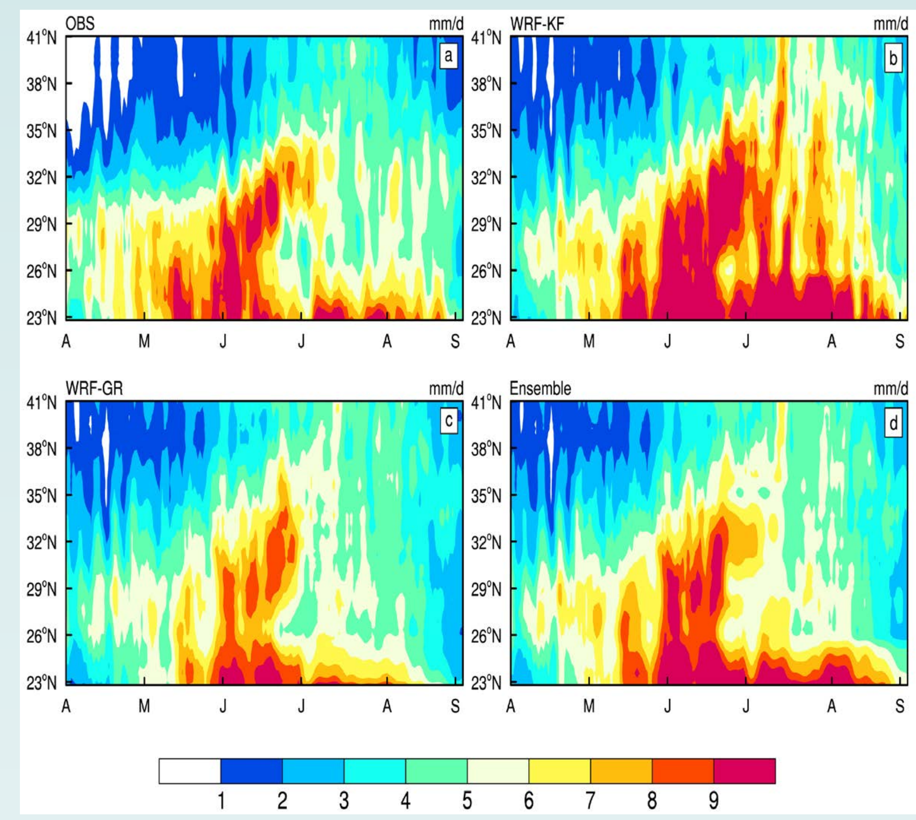


Fig.3 Latitude-time cross-sections of the averaged between 105°E and 122°E

●Interannual variation of precipitation

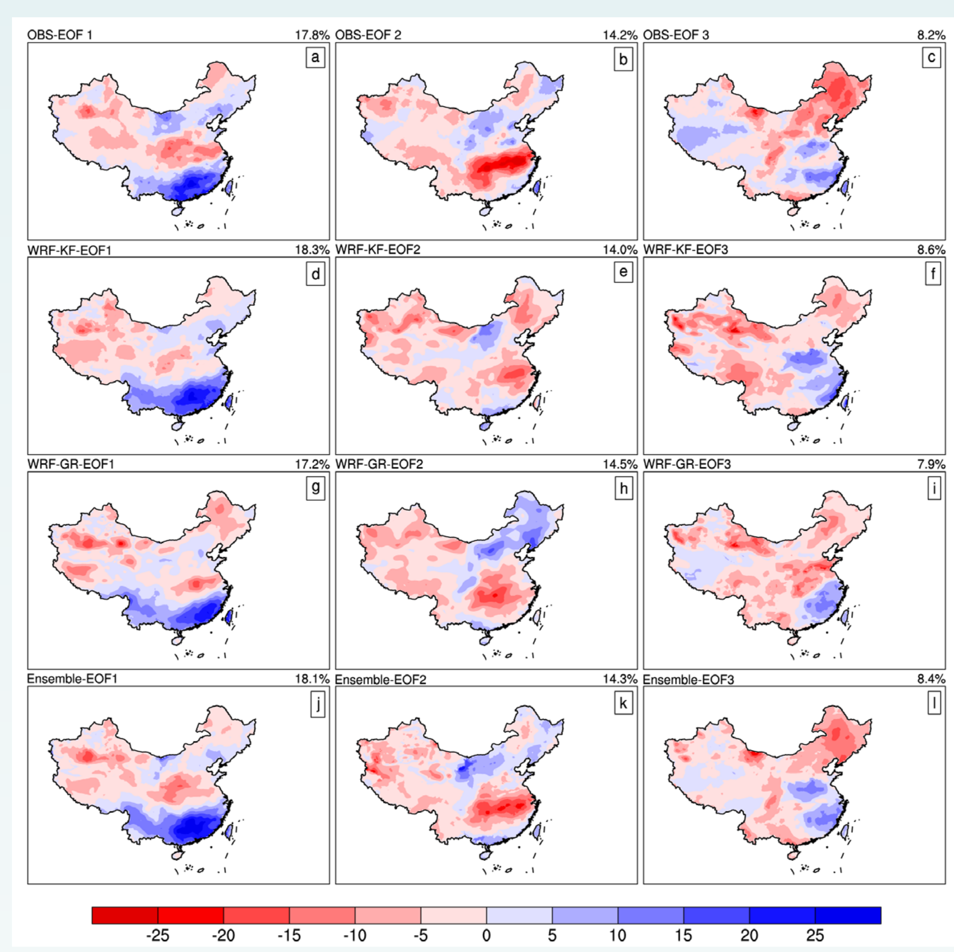


Fig. 4. The first, second and third leading modes of summer mean precipitation

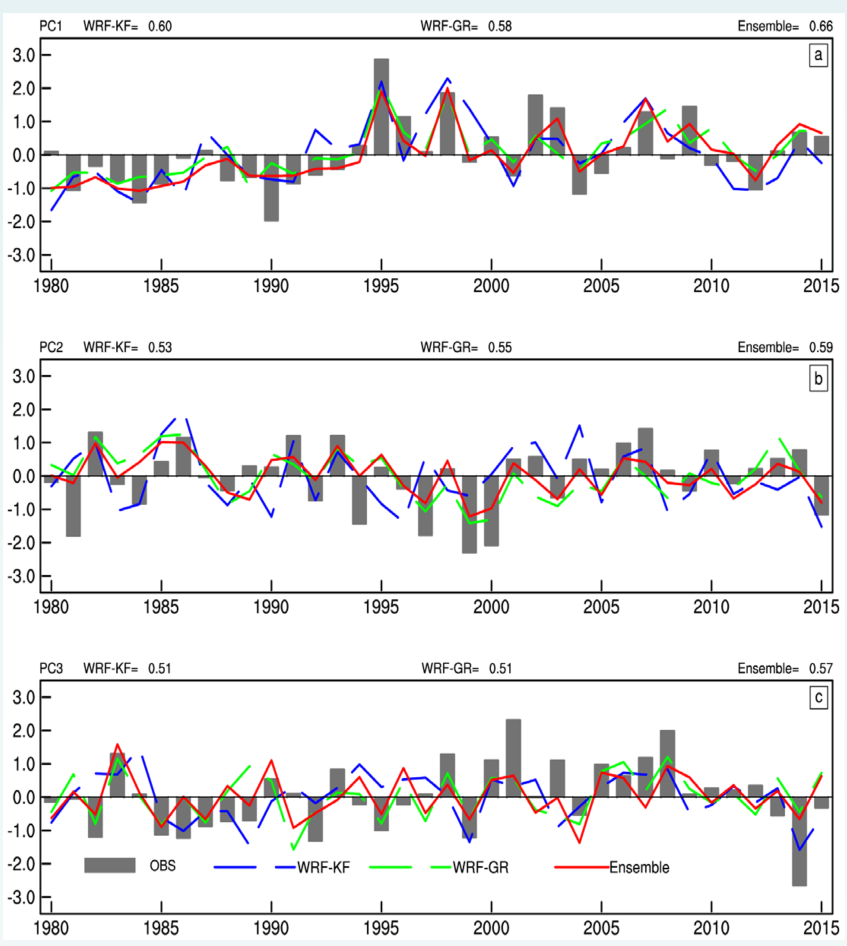


Fig. 5. Normalized PCs corresponding to the first , second and third leading modes

●Extreme precipitation

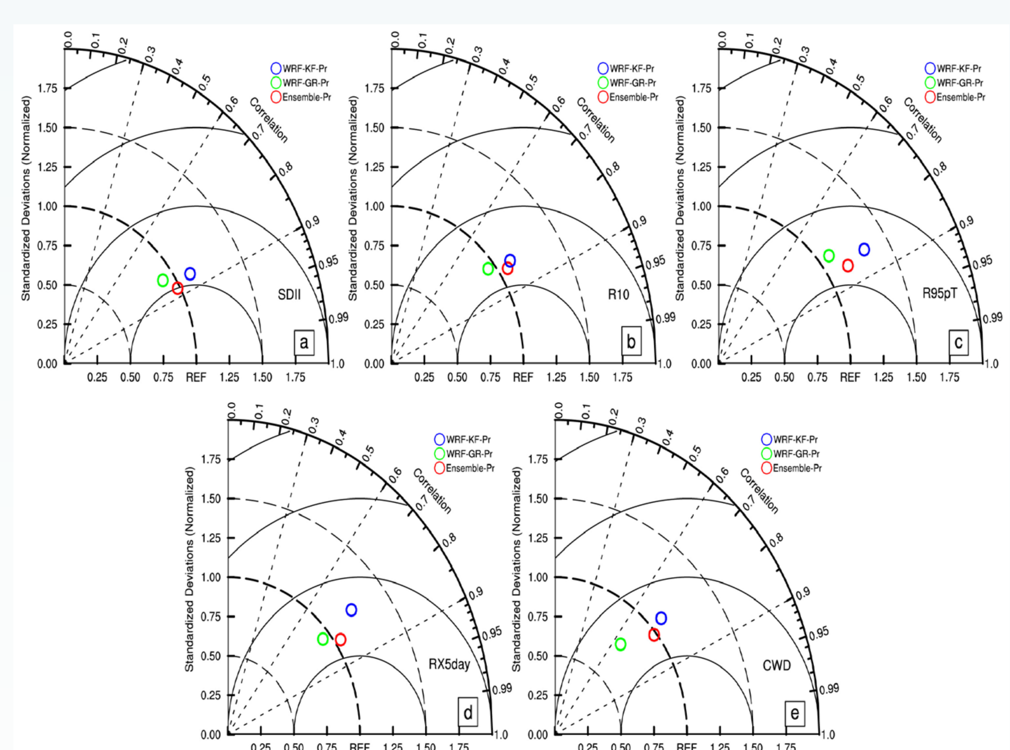


Fig. 6. Taylor diagrams for summer mean SDII, R10, R95pT, RX5day and CWD

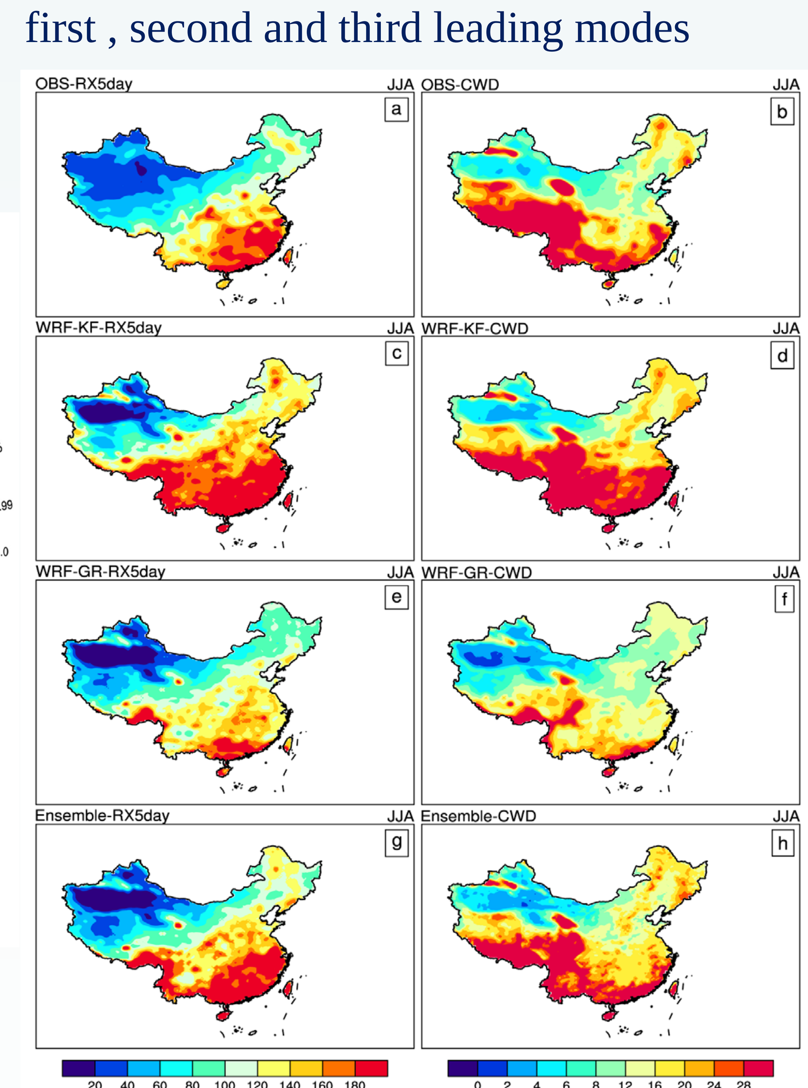


Fig. 7. Spatial distributions of summer mean RX5day and CWD over China

Conclusions

- The ensemble simulation improved the distribution of precipitation and reduced the RMS difference from both KF and GR schemes, because there exist distinct regions where one scheme is persistent with more skills than the other.
- When compared to the KF and GR schemes, the ensemble more realistically reproduced the spatial structures and temporal evolution of summer monsoon precipitation.
- The three dominant modes and their associated temporal variations were captured well by the ensemble, and they were more realistic than those associated with the KF and GR schemes individually.
- For extreme precipitation, the ensemble revealed obvious improvements by compensating the inherent biases of the individual CUP schemes.
- The observed spatial distributions of the extreme precipitation indices (i.e., RX5day, and CWD) were simulated well by the ensemble, with closer magnitudes and higher spatial pattern correlations exhibited