Consistent changes in twenty-first century daily precipitation from regional climate simulations for Korea using two convection parameterizations

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Abstract

We present an analysis of the projected daily precipitation over Korea from regional climate change scenarios (1971–2080) implementing different convection schemes (Grell vs. MIT-Emanuel) within the RegCM3 double-nested system. Daily precipitation characteristics are investigated in terms of the normalized frequency and amount of precipitation and the extreme precipitation above the 95th percentile. For reference period (1971–2000), the MIT-Emanuel simulation is superior to the Grell simulation for daily precipitation regardless of frequency and intensity. However, future changes tend to be similar. This behavior can be explained partly by a constraint on the normalized distribution of precipitation that separates increasing from decreasing contributions to the normalized spectrum. Precipitation with intensity above the 50th percentile tends to increase its contribution to total precipitation while precipitation of lower intensity tends to yield a reduced contribution. The change signal of winter precipitation is clearer, showing a well-defined pattern of more intense precipitation.

Keywords

Daily precipitation, Climate change scenario, Convection parameterization

Disciplines

Atmospheric Sciences | Climate

Comments

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[1] We present an analysis of the projected daily precipitation over Korea from regional climate change scenarios (1971–2080) implementing different convection schemes (Grell vs. MIT-Emanuel) within the RegCM3 double-nested system. Daily precipitation characteristics are investigated in terms of the normalized frequency and amount of precipitation and the extreme precipitation above the 95th percentile. For reference period (1971–2000), the MIT-Emanuel simulation is superior to the Grell simulation for daily precipitation regardless of frequency and intensity. However, future changes tend to be similar. This behavior can be explained partly by a constraint on the normalized distribution of precipitation that separates increasing from decreasing contributions to the normalized spectrum. Precipitation with intensity above the 50th percentile tends to increase its contribution to total precipitation while precipitation of lower intensity tends to yield a reduced contribution. The change signal of winter precipitation is clearer, showing a well-defined pattern of more intense precipitation. **Citation:** Im, E.-S., W. J. Gutowski Jr., and F. Giorgi (2008), Consistent changes in twenty-first century daily precipitation from regional climate simulations for Korea using two convection parameterizations, *Geophys. Res. Lett.*, *35*, L14706, doi:10.1029/2008GL034126.

1. Introduction

[2] Various climate change studies based on observations and modeling have shown that the intensity and frequency of extreme precipitation events tend to increase under global warming conditions [*Intergovernmental Panel on Climate Change (IPCC)*, 2007; *Emori et al.*, 2005; *Kripalani et al.*, 2007]. However, precipitation extremes may have a complex regional and seasonal dependence [*Kitoh et al.*, 2005], which makes understanding the characteristics of their change difficult. A systematic investigation of daily precipitation is thus needed to understand extreme events and their application to impact assessment [*Seth et al.*, 2004].

[3] In this study, we assess two simulations made with the RegCM3 double-nested system using two different convective parameterization schemes (CPS), namely, the Grell scheme (Grell [*Grell*, 1993]) and the MIT-Emanuel scheme (EMU [*Emanuel*, 1991]). Using the Grell CPS, we have already investigated several features, such as the model performance for the reference period (1971–2000) [*Im et al.*, 2007a], the changes in surface climate variables for the period of 2021–2050 [*Im et al.*, 2008a], and the interdecadal variation of the projected temperature and precipitation [*Im et al.*, 2007b]. Using this well-diagnosed suite of simulations, we evaluate here how daily precipitation may change under projected global warming for the Korean peninsula.

[4] The Grell simulation during the reference period had seasonal precipitation biases averaged over South Korea that were one half to one fifth the magnitude of the parent GCM's biases relative to precipitation observed at 57 stations. Consequently, the Grell simulation's annual cycle of precipitation had an amplitude within 15% of the observed cycle, whereas the amplitude of GCM's annual cycle was less than half the observed amplitude [*Im et al.*, 2007a]. However, limitations were revealed especially in summer, indicating an underestimation of the intensity of daily precipitation events in the mid to high range (approximately more than 30 mm/day). Because the simulation of extreme precipitation can be highly CPS-dependent [*Emori et al.*, 2005; *Kimoto et al.*, 2005], a comparison between two simulations using different CPSs could promote further understanding of precipitation characteristics and provide increased confidence in the projected future changes due to increased greenhouse gas (GHG) forcing.

[5] Our analysis focuses on daily precipitation in terms of the amount and frequency as a function of intensity, as well as the extreme events above the 95th percentile. We analyze daily precipitation from the Grell and EMU simulations, both carried out at a grid spacing of 20 km over Korea. The analysis covers the present day (1971–2000) and future climatic conditions (2021–2050/2051–2080) during the winter and summer seasons.

2. Model and Observation Data

[6] For simulating fine-scale climate change scenarios focusing on the Korean peninsula, the ECHO-G (ECHAM4/HOPE-G) global climate model [*Min et al.*, 2005] under the SRES B2 GHG emission forcing [*IPCC*, 2000] supplied lateral boundary conditions for temperature, horizontal wind, specific humidity and surface pressure to the RegCM3. Simulations with RegCM3 using this source of boundary conditions have already been extensively analyzed [*Im et al.*, 2007a, 2007b, 2008a], providing a foundation for the analyses here, as already discussed above. Temperature and precipitation changes simulated by ECHO-G, particularly the increase in the East Asia monsoon precipitation, are in line with those found in other global model simulations [*Giorgi and Bi*, 2005]. Thus, we can use

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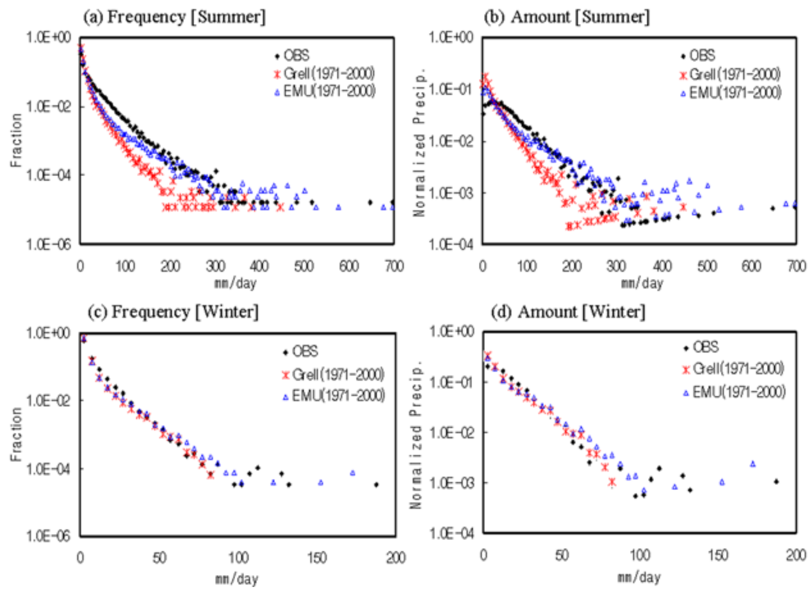

Figure 1. (a, c) Normalized frequency and (b, d) amount of precipitation as a function of daily intensity for observation and the Grell and EMU reference simulations during summer and winter.

the ECHO-G B2 experiment as a representative climate change simulation for the region.

[7] The RegCM3 is run in double (one-way) nested mode, following the standard procedures used for RegCM3 [*Pal et al.*, 2007]. The mother domain covers East Asia at 60 km grid spacing while the nested domain focuses on the South Korean peninsula at 20 km grid spacing. In this study, we analyze daily precipitation from the inner nested domain. The integration spans a 110-year period from January 1971 to December 2080. The analysis focuses mostly on the periods 1971–2000 (the reference climate) and 2051–2080. For the Grell experiment, the temperature change over Korea gradually increases to 3.2 K by the 2070s. Precipitation in the future periods is larger than in the reference period but with substantial interdecadal fluctuations. Further details appear in work by *Im et al.* [2007a, 2007b, 2008a]. See *Im et al.* [2008b] for the sensitivity of the RegCM3 East Asian climate simulation to the switch between the Grell and EMU convective schemes when using NCEP/NCAR reanalyses as boundary conditions. Since the RegCM3 has only recently included the EMU CPS, its performance has not been tested extensively over different regions to date.

[8] For the validation of the reference simulation, we use daily precipitation from 57 stations maintained by the Korea Meteorological Administration (KMA) during the 30-yr period 1975–2004 over southern Korea. We compare simulated daily precipitation with individual station values using the grid points closest to the stations. The relatively high model resolution justifies the comparison between station data and closest grid point model data [*Im et al.*, 2007a]. For the future period, we again pooled together and analyzed daily precipitation at the 57 grid points closest to the South Korean observation stations.

3. Analysis Methods

[9] In this study, we use two analysis methods to estimate possible future changes in the daily precipitation characteristics projected by the RegCM3 modeling system: (1) histograms of normalized precipitation frequency and amount versus intensity and (2) trends in 95th percentile precipitation. The analysis is divided into winter (DJF) and summer (JJA) seasons to investigate the seasonal characteristics of the changes.

3.1. Normalized Frequency and Amount of Precipitation as a Function of Daily Intensity

[10] For precipitation frequency and amount versus intensity, we define a precipitation event as a daily precipitation value greater than or equal to 1.0 mm. We analyze precipitation events at all observing stations and all grid points closest to the station locations. We specify histogram bin widths (5 mm/day) that satisfy the minimum width criteria suggested by *Wilks* [1995] for avoiding excessively fine and potentially noisy gradations. We then normalize the two distributions (Figures 1 and 2) according to *Gutowski et al.* [2007] (hereinafter referred to as G07). This normalization is performed because the observed and simulated data have different numbers of precipitation events. Equally important, G07 showed a possible constraint on changes in the precipitation distribution under climate change that is more robust for normalized distributions. The constraint identifies a precipitation percentile (roughly 60%) that separates portions of the distribution giving increasing and decreasing contributions to the normalized distribution, irrespective of precipitation mechanisms, so long as the distribution is well approximated by a gamma distribution. We normalize the frequency versus intensity distribution by dividing the event count for each bin by the total number of precipitation events in all the samples contributing to the distribution. We normalize the precipitation amount versus intensity distribution by dividing the amount for each bin by the total precipitation accumulated over all the sampling sites over Korea.

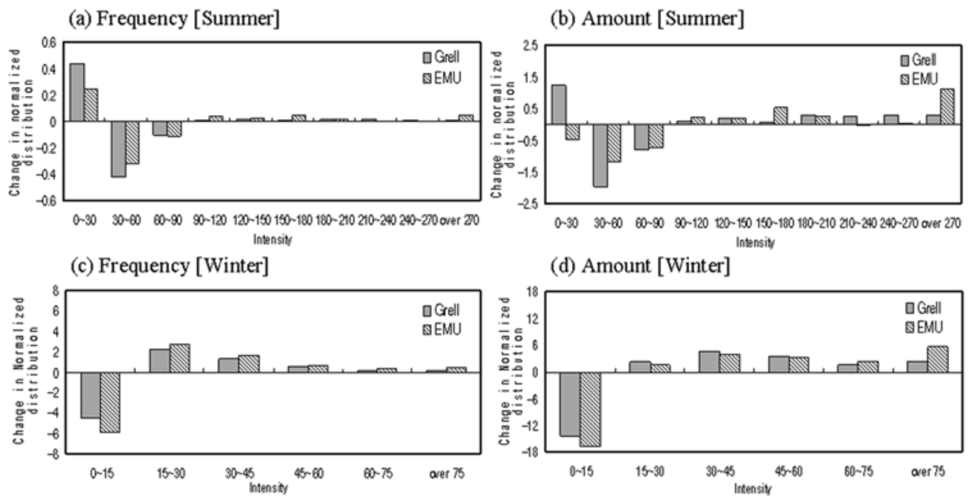

Figure 2. Changes (2051–2080 with respect to 1971–2000) in the normalized distribution of (a, c) frequency and (b, d) amount of precipitation for the Grell and EMU simulation during summer and winter.

3.2. Trend of Extreme Precipitation Change Above the 95th Percentile

[11] To examine trends in extreme precipitation, we calculate the interannual variation in the projected precipitation that exceeds the 95th percentile determined for the reference period's summer and winter seasons. First, we compute the 95th percentile threshold for summer and winter in the observations and in the two simulations (Table 1). We then compute for each year in both the reference and future scenario periods the average of all daily precipitation events occurring above that threshold, producing what we term "extreme precipitation" in this study. Finally, we obtain yearly anomalies in the extreme precipitation by subtracting the average of the extremes for the reference period, and then dividing by the average for the reference period to obtain a percentage change (Figure 3).

4. Results

[12] Figure 1 shows the normalized frequency and amount of precipitation as a function of daily intensity during the reference period in the Grell and EMU simulations and in the observations from the 57 Korean stations. We first find that the simulations show a CPS sensitivity with seasonal dependence. In winter, precipitation is produced mainly by large-scale systems under strongly baroclinic conditions, whereas moist convection plays a major role in determining precipitation during summer [*Im et al.*, 2008b]. Thus, in winter, the results are not sensitive to the CPS scheme, whereas pronounced CPS dependence occurs in summer. For summer, the EMU distribution is much closer to the observed precipitation distribution than the Grell distribution. In particular, the EMU distribution has a longer tail at the high intensity range while the Grell simulation fails to capture precipitation events for intensities greater than 450 mm/day. The normalized amount of precipitation (Figures 1b and 1d) shows the same characteristics as the frequency distribution (Figures 1a and 1c).

[13] The behavior of the simulations using different CPSs is the same as found in simulations using NCEP-reanalysis boundary conditions [*Im et al.*, 2008b]. Convective precipitation is a major contributor to the model's performance in summer over Korea. In the Grell simulation using NCEP boundary conditions, the atmospheric moisture was lower and its convective stability was greater than in the EMU simulation. This meant that the EMU simulation had greater moist static energy than the Grell simulation and thus an environment more favorable for activating convection.

[14] The frequency distributions in Figure 1 are fairly well approximated by an exponential function, similar to what was found in G07. This means that the precipitation amount versus intensity is approximated by a form of the gamma distribution, a common feature in precipitation data [*Wilks*, 1995]. This distribution will help to explain some of our later results.

[15] We follow G07 and assess the projected changes in normalized distributions. Figure 2 shows the difference between the future (2051–2080) and reference simulations averaged over bins with an interval of 30 (15) mm/day for the summer (winter) season. Despite the large differences in

Table 1. Average of Daily Precipitation Events in the Summer and Winter Seasons[a]

	OBS		Grell		EMU	
	JJA	DJF	JJA	DJF	JJA	DJF
			Reference(1971–2000)			
+95% ave (mm/day)	121.5	30.2	59.0	27.1	97.3	30.0
95th level (mm/day)	82.0	21.2	35.9	18.9	50.8	21.1
			Change(Fut.-Ref.)			
+95% ave (%)			5.4	40.6	4.0	53.0
95th level (%)			−1.9	37.6	3.5	47.4

[a]Values given are above the 95th percentile (+95% ave) and at the 95th percentile (95th level).

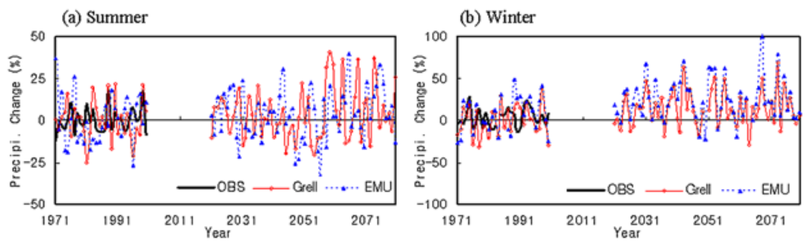

Figure 3. Interannual variations in the simulated and observed (reference period only) precipitation anomaly above the 95th percentile for the (a) summer and (b) winter seasons.

the reference simulations, the changes show a similar pattern and sign. The changes thus are insensitive to the characteristics of the reference climate and show a rather robust feature when viewed as anomalies with respect to their respective reference climates. This result is partly due to the cancellation of systematic errors in the underlying model when taking the difference between future and reference climates [*Hagemann and Jacob*, 2007; *Sushama et al.*, 2006]. This common difference pattern is also consistent with the explanation offered by G07 based on normalized changes when precipitation follows a gamma distribution. Moreover, three of the four differences in Figures 2b and 2d (EMU summer amount, Grell and EMU winter amount) have transitions between decreasing and increasing contributions to the total precipitation at about the 50th percentile. The consistent behavior is emblematic of the theory presented in G07, who also showed that normalized distributions adhering to a gamma function should have a transition at about the 55th–65th percentile if the frequency of precipitation does not change. The fairly close agreement in change distributions and transition percentiles are thus consistent with G07. The one change pattern that does not match well with the theory of G07 is from the Grell summer simulation (transition percentile = 72%). In this case, the precipitation amount versus intensity does not match a gamma distribution as well and, more important, the change distribution is departs from that given by changing a gamma distribution (G07).

[16] An important feature of the change distributions in Figure 2 is that they show increased contributions to total precipitation from high intensity events. Table 1 presents the average of the precipitation above the 95th percentile and the value of the 95th percentile for the reference period and the changes in both of these quantities in the future scenario. The differences between simulations in Figure 1 are reinforced in the extreme case. The Grell simulation tends to underestimate the precipitation intensity in both the 95th percentile and the average precipitation above the 95th percentile compared to observations. The EMU simulation agrees better with observations, though it still produces less than the observed amounts. In spite of the fairly large difference in the average values above the 95th percentile between both the reference simulations, the change percentages are not very different. Thus, the two scenario simulations produce robust changes in precipitation, including changes in extremes.

[17] Change behaviors in time-series of extreme precipitation also show a seasonal dependence (Figure 3). In both simulations, the summer precipitation in the reference period has larger interannual variability than the observed extremes. This is a typical behavior of regional-scale precipitation variability [*Giorgi*, 2005], and points to the need for carefully evaluating individual climate change simulations to ensure that the change signal is greater than the "noise" induced by interannual and interdecadal unforced, or natural, variability. The multi-decadal length of our simulations allows us to examine both unforced variability and trends of the climate change signal. Projections derived from a short future period could produce erroneous interpretations of the results because the projected change could be skewed by unrecognized unforced variability [*Im et al.*, 2007b]. For example, the summer projections during the 2040s and 2050s show a decreasing trend in extreme precipitation while enhanced extreme precipitation is discernible after the 2060s in spite of the substantial interannual variability. Due to this variability in summer, a well-defined regular trend is not certain in the future projection. A different situation is found for winter precipitation, which has larger values of extreme precipitation than those in the reference simulations. The extreme episodes in winter precipitation increase by more than 50% under global warming.

[18] To diagnose the statistical significance of these changes, we perform a two-tailed t-test assuming unequal variances (Welch's t-test). The p-values obtained from this statistical test represent the probability that the absolute value of the test statistic exceeds that calculated for the future and reference scenario by chance. For both simulations, the summer change as shown by Figure 3 is not significant at the 5% level due to the dominant interannual variability. The change in extreme precipitation after 2060 appears to exceed the noise of interannual variability. However, when viewed in the context of decadal scale variability from 2021 onward, the significance of the change become less certain. In contrast, the change in extreme precipitation for winter is significant at the 5% level or lower ($p < 0.05$) for 2021–2050 (Grell = 0.015, EMU = 0.013) and for 2051–2080 (Grell = 0.004, EMU = 0.003).

5. Conclusion and Discussion

[19] To estimate possible future changes in the daily precipitation characteristics over Korea, we have analyzed two regional climate change scenarios produced by the RegCM3 double-nested system implementing the Grell and EMU CPSs.

[20] Comparison of the simulations for the reference period with observations shows the superiority of the EMU simulation over the Grell simulation for daily precip-

itation from medium to high intensities. For extreme precipitation above the 95th percentile, the EMU simulation agrees better with observations than the Grell simulation, particularly during summer.

[21] Despite these different performances, we observe a consistency of the normalized changes in projected daily precipitation. In our simulations, the changes between future and reference simulations tend to be insensitive to the characteristics of the baseline climate, in part due to the canceling of systematic error when producing change signals. In addition, the change pattern from normalized precipitation versus intensity distributions shows common features when using either CPS because of the constraint identified in G07. Thus, the behavior of the changes appears to be consistent across the two CPSs despite differences in the control climates. Common features in both projections include an enhancement of relatively high intensity precipitation and a reduction of weak intensity precipitation. The increase in intensity and extremes of winter precipitation are much more strongly supported as a consequence of climate change in these simulations, being statistically significant at the 95% confidence level.

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