SUPPLEMENT TO PREDICTING STORM-TRIGGERED LANDSLIDES

BY DIANDONG REN, RONG FU, LANCE M. LESLIE, AND ROBERT E. DICKINSON

This document is a supplement to "Predicting Storm-Triggered Landslides," by Diandong Ren, Rong Fu, Lance M. Leslie, and Robert E. Dickinson (*Bull. Amer. Meteor. Soc.*, **92,** 129–139) • ©2011 American Meteorological Society • *Corresponding author:* Diandong Ren, Australian Sustainable Development Institute, Curtin University of Technology, GPO Box U1987 Perth, Western Australia 6845 • E-mail: dd_ren@jsg.utexas.edu • DOI:10.1175/2010BAMS3017.2

APPENDIX. To show the Intergovernmental Panel on Climate Change (IPCC) projected changes of precipitation frequency over the Asian monsoon region, the recurrence frequency during 1971–2000 (horizontal axis in Fig. S1) are plotted against the 2071–2100 period (vertical axis). Eight models are represented by eight dots in this plot, for each category. For example, the cyan dots represent the >500-mm category or, according to the traditional approach, >50 mm day^{-1} extreme rainfall for this region of warm temperate mixed forest.

All eight models successfully simulated the event frequencies for precipitation intensity less than 50 mm day^{-1} events. The hatched dots derived from the observational data are surrounded tightly by the models (numbers of the same color). Hence, there is no clear overestimation or underestimation tendency among the models. There is, however, a clear tendency to underestimate the extreme events [e.g., the Max Planck Institute (MPI) and the third climate configuration of the Met Office Unified Model (HadCM3) Twentieth-Century Climate in Coupled Models (20C3M) even fail to identify events with intensities greater than 100 mm day^{-1}; those in the 50–500 mm day^{-1} category actually are within the 50–100 mm day^{-1} category], clearly indicated by the fact that all blue numbers lie to the left of the blue dot (observed occurrence frequency). For rainfall intensity > 50 mm day^{-1}, however, all of the models indicate an increased tendency over time (the blue numbers lie above the diagonal line in Fig. S1a). That all climate models shown here underestimate the observed high-end precipitation occurring frequency may imply that their predictions of future increase in extreme events may also be an underestimation of reality, for the reasons cited in Allen and Ingram (2002). These findings are consistent with many previous studies (Chen et al. 1996; Dai et al. 1999), which conclude that precipitation occurs too frequently at reduced intensity in climate models. In addition, we find that, for a given climate model, increases of severe precipitation scale with the emission scenario, in that the greatest increases are achieved under the Special Report on Emissions Scenarios (SRES) A2, a high emissions scenario, and that the smallest increase occurs under SRES B1, a lower emissions scenario than SRES A1B.

We now examine the precipitation according to independent rain events (i.e., we classify the rain events into five categories according to total rainfall amount; Fig. S1b). Although light rainfalls are close to each other, the extreme rainfalls stand out separately in the lower-left corner. Except for the ECHAM model, all models indicate an increase in extreme rain events (>500 mm). Thus, either examining the problem from the rain intensity histogram or the distribution of rain events according to total precipitation, the models have converged on increasing extreme precipitation as the climate warms. That models differ only quantitatively indicates that the primary mechanism may be the increase in vapor concentration, as described in O'Gorman and Schneider (2009). Fractional changes in extreme precipitation occurrence (changes of recurrence frequency compared with recurrence frequency extracted from the 1971–2000 period) scale with changes in area-mean surface air temperature. When scaled with warming, there is little intermodel scattering in the selected region of interest.

Compared with observations, three coupled global ocean–atmosphere models (CGCMs)—the Community Climate System Model, version 3 (CCSM3), the Commonwealth Scientific and Industrial Research Organisation Mark version 3.0 (CSIRO Mk3.0), and ECHAM—stand out closely simulating the extreme rainfall historical occurrence frequency (the *x* axis of the cyan numbers in Fig. S1b is close to the cyan dot), whereas the remaining five models significantly overestimate the extreme rainfall's occurrence frequency (as large as two orders of magnitudes for INM CM3.0). The models tend to underestimate extreme rainfall intensity; however, when divided into individual rainfall events, they also tend to overestimate the rainfall amount of extreme events. Clearly, work is needed in this vital research area. Generic over all climate models is an overestimation in the observed high-end precipitation occurring frequency. The truly large (100 times for some models) magnitude of overestimation indicates that the limited observational period (30 years) is not a reason for the low realization of the extreme rainfall events observed in the real world. Coarse grid spacing is also unlikely as an explanation because our region of interest involves at least 10 CGCM grids, and the extreme rainfalls show extraordinarily strong spatial coherence over the region. This shared deficiency, fortunately, may not be an indictment of the CGCMs, and it is still a valid conclusion that future extreme rainfall events will occur more frequently.

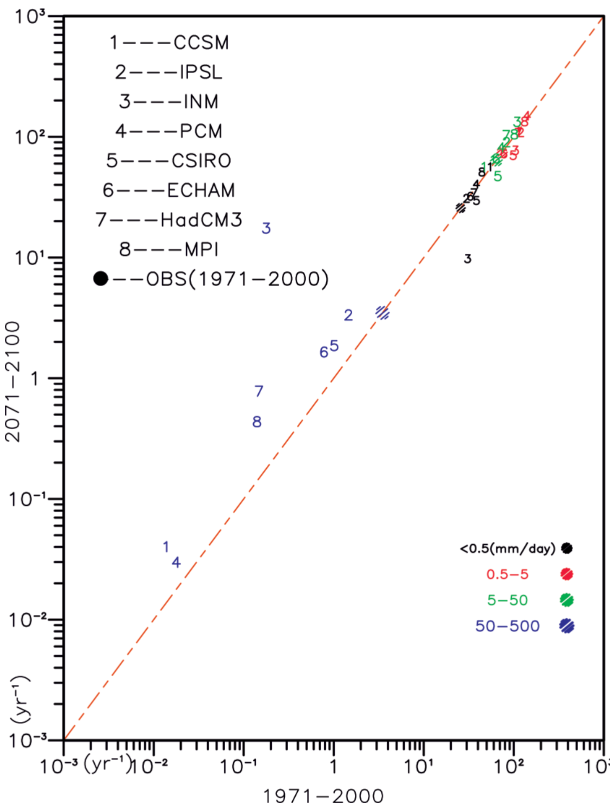

FIG. S1. Simulated rain occurrence frequency (yr^{-1}) from eight CGCMs, for five different categories, <0.5, 0.5–5, 5–50, 50–500, and >500 mm day^{-1}, in interested Asian monsoon region (the framed area near point A in Fig. 4). Values inferred from 1971 to 2000 are used as *x* coordinates, whereas the vertical axis corresponds to the 2071–2100 period (based on the SRES A1B scenario). In each category, estimations based on observations are hatched (the null hypothesis is that there is no change in recurrence frequency, thus all observed lie on the diagonal line). (a) Based on the traditional classification of one day for each rainfall event; (b) based on "super-rain event" classification. Model expansions not included in the text are L'Institut Pierre-Simon Laplace Coupled Model (IPSL) and Parallel Climate Model (PCM).

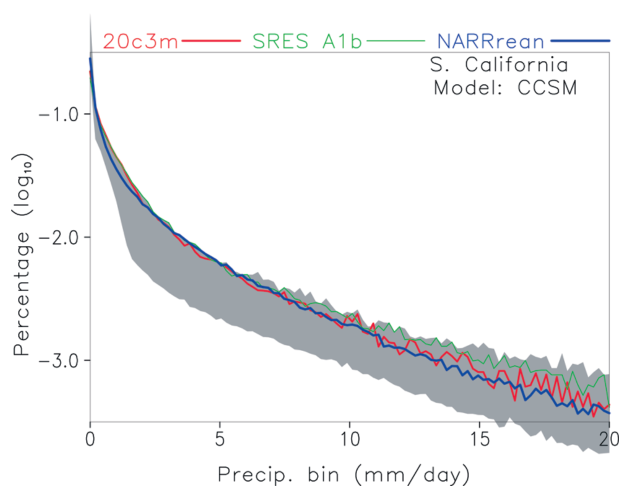

FIG. S2. The CCSM-simulated precipitation morphology change over Southern California: 2011–2040 (SRES A1B scenario runs) compared with 1971–2000 (20C3M runs). The thick blue curve is derived from NARR data for the 1979–2008 period. We use 101 linear bin levels of 0.2 mm day^{-1} interval to subdivide the 0–20 mm day^{-1} band, resulting in a nearly continuous histogram of daily precipitation. Model scatter is shown as gray shading.

Simulation of the precipitation for the Mediterranean climate zones poses less challenge to CGCMs. There is no systematic overestimations/underestimations for both viewing angles. Some models show great ability in simulating the rainfall morphology. For example, even at a fine bin size of 0.2 mm day^{-1}, the CCSM3, a coupled climate model of relatively high horizontal resolution of ~1.4° latitude × ~1.4° longitude, accurately captures each bin level, compared with the North American Regional Reanalysis's (NARR's) same period observations (Fig. S2). For this Mediterranean climate region, precipitation totals greater than 15 mm day^{-1} (or total amount greater than ~50 mm) should be viewed as extreme precipitation. The model shows a clear increase in its occurring frequency as climate warms. Considering that the model's 20C3M simulation is close to observations at each bin level (blue and red lines in Fig. S2), it is highly likely that the increasing trend is viable. The spread in the climate models seems random (the gray shading brackets the blue line). Although some models are not as "accurate" as the CCSM3 in simulating the present rainfall histogram, the shared feature of all eight (climate models) is that extreme heavy precipitation will be more frequent as the climate warms.

REFERENCES

Allen, M., and W. Ingram, 2002: Constraints on future changes in climate and the hydrologic cycle. *Nature,* **419,** 224–232.

Chen, M., R. Dickinson, X. Zeng, and A. Hahmann, 1996: Comparison of precipitation observed over the continental United States to that simulated by a climate model. *J. Climate,* **9,** 2223–2249.

Dai, A., F. Giorgi, and K. Trenberth, 1999: Observed and model-simulated diurnal cycles of precipitation over the contiguous United States. *J. Geophys. Res.,* **104,** 6377–6402.

O'Gorman, P., and T. Schneider, 2009: The physical basis for increases in precipitation extremes in simulations of 21st-century climate change. *Proc. Natl. Acad. Sci. USA,* **106,** 14 773–14 777.