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Interactive comment on "Development and comparative evaluation of a stochastic analog method to downscale daily GCM precipitation" *by* S. Hwang and W. D. Graham

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——— Comment on temporal scale (daily in our study): In many cases, daily data offer insufficient temporal resolution (e.g. for urban hydrological modeling, daily data are far too coarse; the same can be said for many soil loss and erosion models, which require at least hourly data). Likewise, the lengths of wet and dry spells are very coarse measures of a precipitation time series. Importance attaches to other aspects of such a record, including rainfall rates and rainfall event properties.

Response: We agree with the reviewer that the appropriate spatiotemporal resolution

at which climate variability and change (and their impacts) are assessed, and thus the choice of a particulardownscaling method, are dependent on the research or management question being asked. We understand that some hydrologic applications, such as storm event modeling and soil erosion simulation, may require precipitation intensity data at finer-temporal resolution than daily (e.g.,15 minute or hourly). However, the ultimate goal of our research is to provide useful climate information for assessing impacts of climate variability and climate change on the availability of surface water and groundwater for regional public water supply. For assessing water availability on a regional scale, monthly or weekly scale water-balance models have been found to be useful for identifying the hydrologic consequences (i.e. changes in seasonal streamflows changes in groundwater elevations, changes in drought frequency or duration) of changes in temperature and precipitation (Xu and Singh, 1998). Furthermore, statistical downscaling approaches are often applied at a temporally aggregated scales (e.g., daily, monthly or seasonally) rather than at sub-daily time scales due to the limited availability, lower reliability and larger biases of GCM at sub-daily time scales (Maurer and Hidalgo, 2008, Ines and Hansen, 2006). While several researchers have published papers evaluating the skills of hourly GCM and RCM outputs to reproduce diurnal cycles of temperature and precipitation (e.g. Braganza et al., 2004), we are not aware of any research that has directly used hourly climate model outputs for hydrologic applications. Using hourly GCM results generated at 200km space-scales for hydrologic applications would likely lead to unreliable results. Instead, if the research or management application requires higher temporal resolution data, it may be more appropriate to spatially downscale daily data or monthly GCM data and then temporally disaggregate the downscaled results into hourly or sub-hourly data using a weather generator or historical hourly or sub-hourly precipitation patterns. We will revise the manuscript to include a discussion of issues regarding the relevance of daily climate data for hydrologic applications and alternative methods for temporally disaggregating daily data if finer temporal resolution is needed. Furthermore in the discussion section we will emphasize that the BCSA approach can be used to spatially downscale GCM predictions at any time scale for which the GCM predictions are deemed reliable and observational data are available.

——– Comment: The authors present no discussion of sensitivity of hydrological models to the kinds of discrepancies between various existing downscaling methods, and thus make no compelling case that a better method is needed. The kinds of hydrologic questions that can be answered from daily precipitation data may well not require high precision in the data. In other words, is the few percent improvement in the accuracy of downscaled data achieved by the authors actually significant?

Response: As the reviewer correctly points out, the need to accurately represent the spatial variability and temporal patterns of precipitation at any particular scale depends on the research question, water management problem, or hydrologic model being assessed. For low-relief, rainfall-dominated watersheds the spatiotemporally variability of precipitation is known to be an important factor for predicting spatial variability in streamflow and groundwater response to climatic forcing. For example, spatially uniform lower intensity rainfall generally produces more evapotranspiration and less streamflow and groundwater recharge than more spatially distributed concentrated storms with the same total volume. We are currently conducting a follow-on study to evaluate the hydrologic importance of spatiotemporal variability of statistically downscaled climate model outputs. However presentation of these hydrologic implications would unreasonably increase the length and number of figures required for this manuscript.

——– Comment on evaluation criteria (e.g., 50th and 90th percentile): Would it be more important that a downscaling method has good success in predicting the 99th percentile, for instance, in relation to flood inundation damage or other management issues?

Response: The spatial distributions of 50th and 90th percentile of daily precipitation were mapped to illustrate how the downscaled results using each method reproduce

the daily precipitation cumulative distribution function at the local scale. We showed that BCSD and BCCA underestimated 90th percentile (Figure 7) and overestimated 50th percentile (Figure 8). The point is that the cumulative distribution function and thus variability of daily precipitation at the downscaled resolution is not necessarily reproduced by bias-correction at the GCM grid scale. The underestimation shown in the maps for the 90th percentile of daily precipitation will be similar, or perhaps more severe, for the 99th percentile rainfall event. To clarify this point, the revised manuscript will provide comparison of the full CDFs of daily precipitation downscaled using each method and will replace the 90th percentile map with the 99th percentile map. Furthermore we will augment the discussion of the manuscript to justify the importance of understanding changes the frequency and duration of multi-day wet-spells and dry-spells for water supply planning.

——– Comment on observation data used in the study: An issue that I felt warranted more attention was the nature of the observational data from Florida. These were apparently gridded to a regular spatial resolution, and I was not sure how much bias might have been introduced during the gridding process. This is potentially important since it is the gridded data that are used to bias-correct the downscaled GCM data.

Response: The daily gridded observations that we used were derived directly from observations by Maurer et al. (2002) and are available across the entire United States. These data are spatially averaged across each grid cell and were used to derive the BCSD and BCCA downscaling results we compare with (Maurer et al., 2010). Additionally they have been used to assess hydrologic implications of the differences among the downscaling methods (i.e., BCSD, CA (constructed analog), and BCCA) using the Variable Infiltration Capacity (VIC) hydrologic model (Liang et al., 1994). We assessed the Maurer et al (2002) data against locally available gage observations where available (http://gis.tampabaywater.org/rainfall/) as well as PRISM (Oregon State University, (http://prism.oregonstate.edu) and NLDAS (NASA GES DISC, (http://mirador.gsfc.nasa.gov/)) data and found them to be unbiased (compared to these other gage and gridded products) in Florida. Furthermore in our study, it was necessary to use the same observation data for all downscaling methods so that we could consistently evaluate the results across the methods. More explanation regarding the accuracy of the gridded data and reasons for its choice will be included in the revised manuscript. As we discuss in section 5.3 of the present manuscript, the BCSA method can be applied to downscale coarse resolution climate data into any temporal (e.g., monthly, daily, sub-daily) and spatial scale (e.g., gridded or irregularly distributed points) wherever observations are available to estimate the cumulative distribution functions and spatial correlation structure of precipitation. The purpose of this manuscript was to compare the BCSA method to other commonly used downscaling methods over the state of Florida, independent of application. However for hydrologic applications the target resolutions for downscaling will dependent on the particular research question or management issue. If the primary goal of downscaling is to run a particular hydrologic model that has been calibrated using dense spatially distributed precipitation station data, these data can be used in BCSA to bias-correct and downscale GCM data directly onto the model domain.

——— Comment on GCMs used in the study: Likewise, I was somewhat concerned by the use of somewhat old GCM output, since there have been significant advances in GCMs in recent years.

Response: We used 4 GCM results from CMIP3 (Coupled Model Inter-comparison Project phase 3) referenced in IPCC Forth Assessment Report (AR4). These datasets have provided important inputs for climate change impact assessment by many researchers and were used in the US Global Change Research Program's National Climate Assessment Report (http://ncadac.globalchange.gov/) that was released in early 2013. We are aware that CMIP5 multi-model datasets that use improved GCMs have recently become available for use and will be incorporated into the forthcoming IPCC AR5. Comparative evaluations of CMIP3 vs. CMIP5 predictions are currently being conducted by the climate science community to evaluate the degree of improvement

they provide (e.g., Dufresne et al., 2013). However, while improvements in the GCMs will (hopefully) reduce the need for bias-correction, downscaling of the GCMs for local hydrologic applications will still be required. The goal of our study was to compare the spatiotemporal characteristics of precipitation produced using a variety of statistical downscaling methods with a consistent set of GCMs. The significant differences we found in the spatial patterns of downscaled precipitation among the methods will be exhibited regardless of the GCM predictions used, or the degree of bias-correction needed. Thus use of improved GCMs would not change the major findings of the study: that interpolation based spatial disaggregation methods produce downscaled precipitation field that are significantly more spatially uniform than observed precipitation fields, and therefore should not be used for applications where reproducing spatial variability of rainfall is important. We will revise the conclusions section of the manuscript to include a discussion of these issues.

——— Other specific comments

= For the Figure 3 though Figure 8, the maps will be enlarged as much as space permits in the revised manuscript.

= Too many "Note that ...." (7 times through the manuscript): These sentences will be rephrased.

= Generally GCM stands for either 'General Circulation Model' or Global Climate Model'. However we used the former and 'global circulation model' in the Abstract was an error and will be replace by General Circulation Model.

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We thank the reviewer for his/her constructive review and comments.

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