Statistical versus Dynamical Downscaling for Hydrologic Analysis

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1. INTRODUCTION

The spatial resolution of General Circulation Models (GCMs) is too coarse to represent regional climate variations at the scales required for environmental impact assessments. Two techniques have been developed that counter this deficiency: semi-empirical (statistical) downscaling (SDS) of GCM outputs, and regional climate models (RCMs) nested within a GCM. Here we compare two approaches focusing on hydrological responses a river basin. For the basin studied, the SDS gives a more accurate hydrologic simulation. Results also show how the nonlinear response of surface hydrology amplifies and diminishes errors in either method and indicate site-specific features of such a comparison.

Several features distinguish SDS and RCM approaches to regional climate simulation. Statistical approaches are relatively fast, allowing the user to develop ensembles of climate realizations and thus obtain confidence interval estimates. Robust SDS typically strives for succinct representation of physical features that control the region's climate. Because any simplified representation of regional physics is likely incomplete, stochastic variability is generally added to account for missing physics. RCMs are based on fundamental conservation laws for mass, energy and momentum and thus contain more complete physics than SDS. However, the more complete physics evokes a significant computational cost that limits RCM simulation. Thus, typical RCM studies use only a single realization of a climate.

2. METHODS AND DATA

The comparison focuses on the Animas River basin, which has a drainage area of 1820 km^2 and is located in southwestern Colorado, a state in the U.S. Rocky Mountains. Observations of daily precipitation (P) and minimum and maximum temperature (TMIN, TMAX) produced by snow telemetry (SNOTEL) and U.S. National Weather Service (NWS) stations provide the basis for calibrating the SDS and for evaluating SDS and RCM simulations. River discharge from the basin, measured by the U.S. Geological Survey (USGS) provides additional observations for model evaluation. Both the SDS and the RCM used NCEP/NCAR reanalyses (Kalnay et al., 1996) for driving data sets. RCM boundary conditions also used observations of water-surface temperature in the Gulf of California and the North American Great Lakes, which are under-resolved in the reanalysis.

The SDS method in this study uses step-wise multiple linear regression to identify parsimonious sets of atmospheric variables in gridded, large-scale analyses that are used to predict local daily TMIN, TMAX and P (Wilby et al., 1999). The SDS uses separate regression equations for each climatological season and output variable. RCM output comes from RegCM2 (Giorgi et al., 1996), which simulated a continental U.S. domain at approximately 50 km resolution. At this resolution, the Animas basin is marginally resolved by three gridpoints. However, temperature and precipitation comparisons for the larger San Juan River basin, which includes the Animas give essentially the same results. TMIN, TMAX and P output from both models was also fed into a the USGS Precipitation-Runoff Modeling System (PRMS; Leavesley et al., 1983**)** to compute snowpack and river disharge for the Animas.

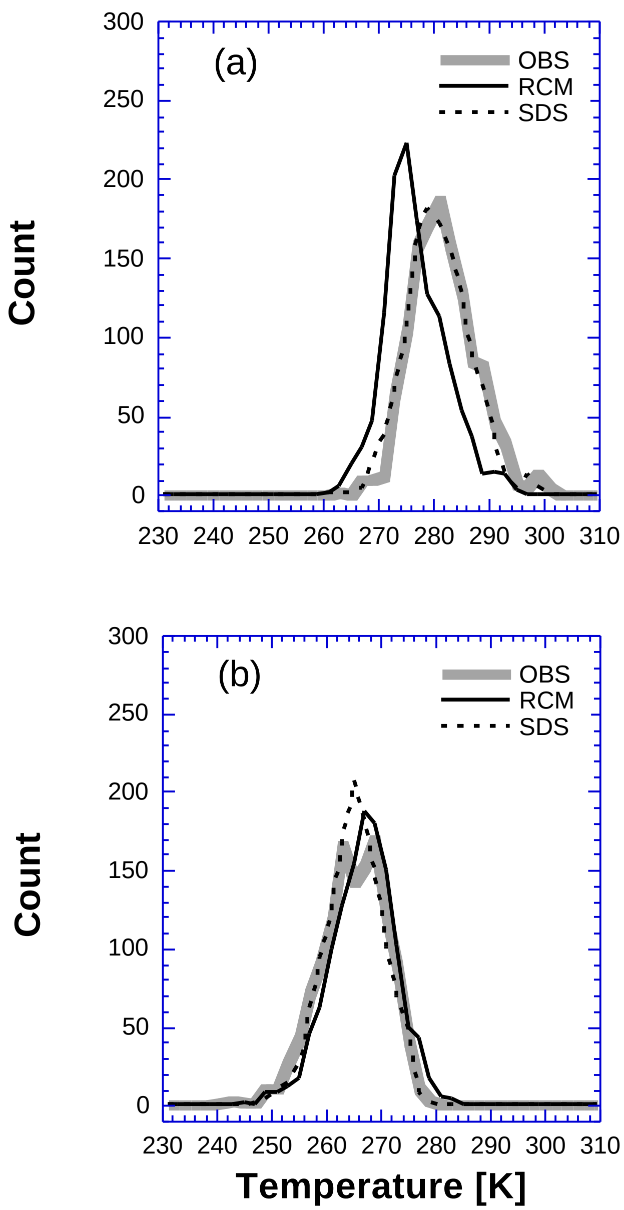
The SDS was calibrated using observations for the water years 1987-1995. The RCM simulated the calendar years 1979-1988. Comparison of SDS and RCM output uses the water years 1980-1986.

3. RESULTS

The RCM has low precipitation (2.3 mm/d) versus observations (2.7 mm/d). The SDS precipitation (2.6 mm/d) is only slightly less than observed. Both techniques give about the same temperature distribution as observed. Cold season (October-March) temperatures are especially important for this region, as they affect the development of snowpack. The RCM has a cool bias in TMAX during this half of the year (Fig. 1a) that averages over 4.5˚C. SDS on the other hand has only a small cold bias in TMAX (~0.5 ˚C). Both techniques have a small warm bias in TMIN during the cold season (Fig. 1b).

PRMS simulations using either source of input give slightly less annual average discharge (RCM: 24.5 m^3/s, SDS: 25.0 m^3/s) than observed (26.7 m^3/s). They also give the strong annual cycle of observed discharge that results from a cycle of snowpack accumulation and melt (Fig. 2). However, interannual variability in each case is less than observed. Furthermore, the RCM-driven run's peak discharge tends to lag observations substantially (Fig. 2). This results from its cool bias in TMAX: cooler temperatures delay spring snowmelt and hence the annual discharge peak. The delay also causes larger snowpack accumulation and, hence, larger peak runoff.

FIGURE 1 - Frequency distribution of daily (a) TMAX and (b) TMIN during the cold season. SDS values are from an ensemble average of 20 realizations.



4. CONCLUSIONS

Both SDS and RCM methods reproduce general features of the statistics of precipitation and temperature in the Animas basin. Both do display some bias with respect to observations: too much light precipitation (both), warm TMIN bias (both), and cool TMAX bias (RCM). For the Animas basin hydrology simulation, the most important bias is the RCM's cool TMAX (even after effective elevation adjustment) which delays spring snowmelt. The hydrology simulation is relatively insensitive to SDS and RCM warm TMIN biases. Also, because the accumulated snowpack governs the annual discharge cycle, the hydrology simulation is insensitive to simulation biases in precipitation intensity distribution.

These results are dependent on the climatology of the basin simulated. One could easily imagine alternative situations where cool TMIN bias (e.g., initiating snowpack accumulation too early) or P bias would govern error in discharge simulation.

5. ACKNOWLEDGEMENTS

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FIGURE 2 – Average annual cycle of runoff. SDS curves bound the runoff range runoff in the twenty realizations.