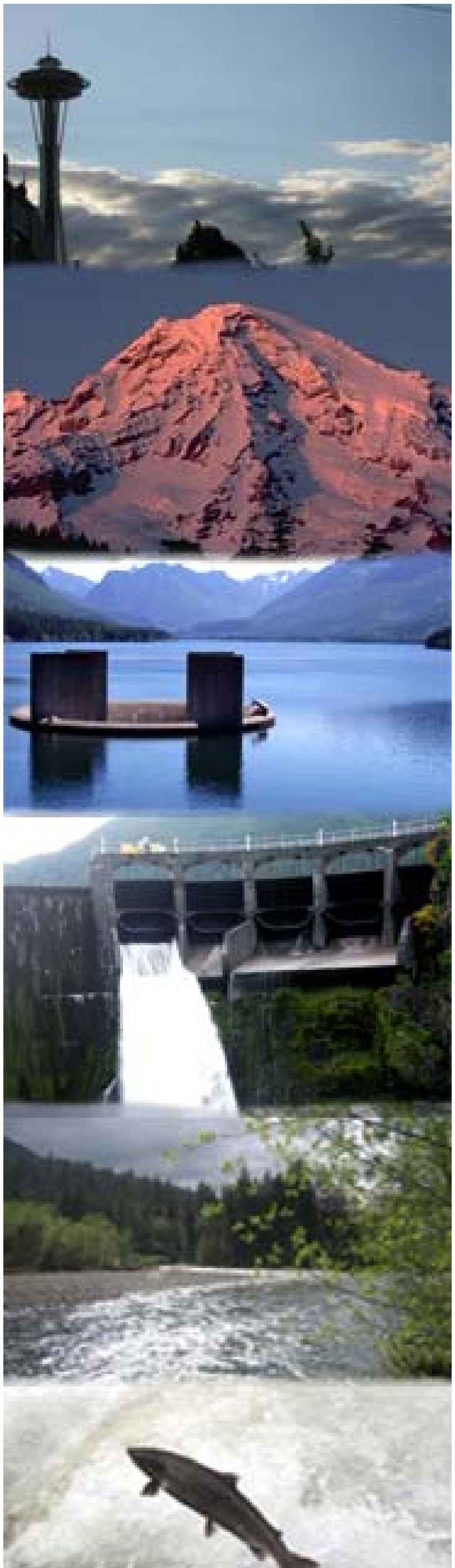

Technical Memorandum #2: Methodology for Downscaling Meteorological Data for Evaluating Climate Change

Prepared for:

Climate Change Technical Committee

12/13/2007

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Technical Memorandum #2:
Methodology for Downscaling Meteorological Data for Evaluating Climate Change

Introduction

The purpose of "downscaling" is to translate global climate signals produced by general circulation models (GCMs) in climate studies into information that is useful in evaluating local hydrological impacts. The information generated by GCMs is produced at a very coarse level from a regional perspective. The meteorological data produced by a GCM may be only for four to six locations for the entire state of Washington; to be useful for regional studies, this information must be translated to sites at a much finer resolution within a watershed.

A challenge in using GCM output is to recognize the transient nature of this information. Climate models are initiated with specific assumptions about future green house gas concentrations which change over time. These assumptions result in changing global precipitation and temperatures, which, in turn, evolve over time. Climate is not assumed to be stationary, but rather, it changes from decade to decade. This paradigm differs significantly from our traditional approach to water resources planning, where past climate is assumed to be stationary; thus the probability of an event is not impacted by when in the time series it occurs.

The downscaling technique used in this study creates climate scenarios that reflect the regional scale climate statistics that are projected by the global scale climate models. To maintain the full range of natural variability that has been observed in the historic record, the downscaling method uses the data and statistical characteristics of the GCMs' outputs, but not the time series of that data directly. This method captures the regional signal described by the climate models, contains local scale phenomenon and patterns as defined by the observed history at a station, and expands the time series to include the entire possible range of variability.

The downscaled impact assessment climate scenarios are developed in three stages:

1. Downscale the climate variables from a GCM scale grid to a regional scale grid,
2. Bias-correct a single regional grid cell to an individual station location, and
3. Expand the station scale transient scenario into multiple, quasi-steady-state time series with full historic variability.

This process allows for a climate change signal to be captured from the GCM by incorporating the shifts in the climate variable's Cumulative Distribution Function (CDF – a CDF fully describes a probability function, it describes the probability that a variable takes on a value less than or equal to a specific number). This process creates longer time series that represents a specific period in the future that also contains all of the extreme events in the observed record. The magnitudes of these events are shifted to correspond with the altered climate signal from the GCM.

The downscaling process uses data from four sources:

1. A GCM, which is in a gridded format at a resolution of approximately 2 degrees (approximately 200 kilometers on a side),
2. Historic meteorological data from specific weather stations, located throughout the region,
3. Historic meteorological data at a 1/8 degree, gridded resolution (12 kilometers on a side), and
4. Historic sea level pressure data from the National Center for Environmental Prediction reanalysis runs.

These data are used as input in the stages described below.

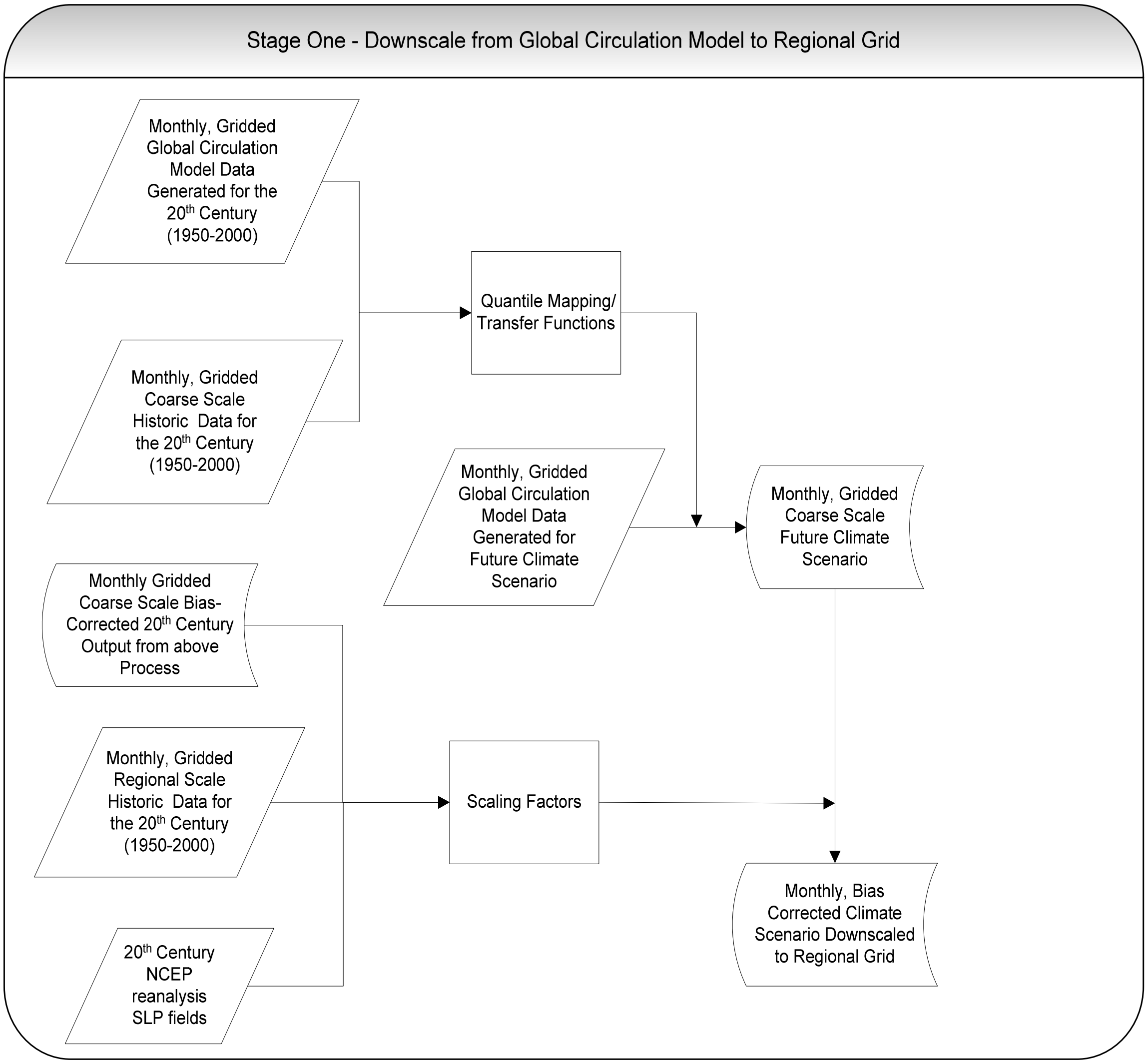
Stage One: Downscale climate variables from the GCMs to a regional scale grid

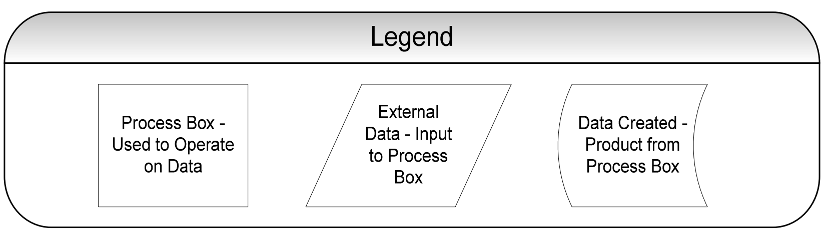
In Stage One, output from a simulation of the 20^{th} century climate using a GCM (monthly, gridded GCM data) and observed historic data (monthly gridded, coarse scale historic data) are employed to develop transfer functions. CDFs for each month of the year are created for both the GCM and the aggregated coarse regional grids. Comparing the values of the CDFs over their full range results in the "transfer functions" that are used to "bias-correct" the projected climate output generated by the GCMs.

The bias-corrected coarse grid is then downscaled to the regional grid (1/8° scale) through scaling factors, which are additive factors for temperature and multiplicative factors for precipitation. This process generates a transient, monthly time-series at the 1/8° scale of GCM simulated climate for average temperature and daily total precipitation variables.

Transfer Functions

Transfer functions utilize the shifts in probability of similar events between two datasets to correct output. For instance, the shift in probability of having a 10 degree C day in the simulated world versus a 10 C degree day in the observed world might not be exact, and so one can correct for this by correcting the probabilities of the biased model to match the observed record. The amount needed to shift the probabilities to their correct values is what is contained in a transfer function. In general, the process which creates a transfer function is known as the quantile mapping process. A transfer function developed from the quantile mapping process can be used to bias-correct additional datasets, i.e. output from a GCM that represent a future time-period can be processed through a transfer function to create a bias-corrected dataset which will have the characteristics of the observed record, but also contain any changes due to anthropogenic activities.


Stage One - Downscale from Global Circulation Model to Regional Grid
Monthly, Gridded Global Circulation Model Data Generated for the 20th Century (1950-2000)
Monthly, Gridded Coarse Scale Historic Data for the 20th Century (1950-2000)
Quantile Mapping/ Transfer Functions
Monthly, Gridded Global Circulation Model Data Generated for Future Climate Scenario
Monthly, Gridded Coarse Scale Future Climate Scenario
Monthly Gridded Coarse Scale Bias-Corrected 20th Century Output from above Process
Monthly, Gridded Regional Scale Historic Data for the 20th Century (1950-2000)
Scaling Factors
20th Century NCEP reanalysis SLP fields
Monthly, Bias Corrected Climate Scenario Downscaled to Regional Grid


Legend
Process Box - Used to Operate on Data
External Data - Input to Process Box
Data Created - Product from Process Box

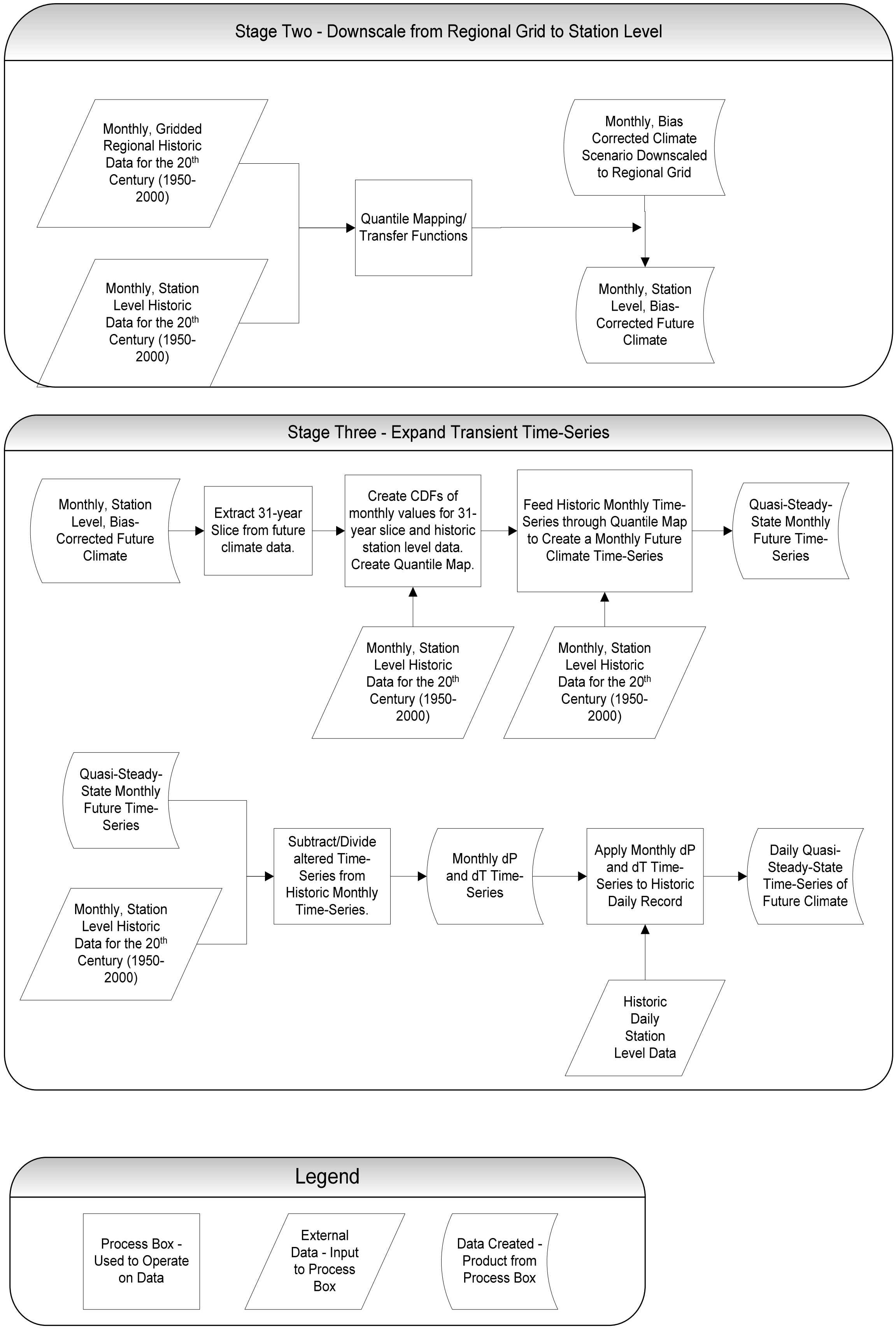
Stage Two: Bias-correct a single regional grid cell to an individual station location

In Stage Two, the 1/8 ° downscaled data generated in Stage 1 is downscaled to specific weather station locations through use of the bias-correcting and downscaling procedure. In Stage Two, the bias is much smaller between the regional grid and the historic station data, though the transfer function is still developed and used to bias-correct. The downscaling process uses additive and multiplicative factors for temperature and precipitation respectively as detailed above. The output from Stage Two of the downscaling process is a transient monthly time-series at the station level that can be disaggregated to a daily time-series or applied to a historic dataset as a perturbation factor as done in the expanded time-series approach.

Stage Three: Creation of Expanded Time Series

In Stage Three, a thirty-one year period of the previously downscaled, future climate data (centered on the year of interest, such as 2050) is selected. The CDFs developed from the thirty-one year climate data are mapped to the historic monthly weather station data, and the monthly difference for each variable is calculated. This monthly difference is then applied onto the original historic daily time-series. The product of Stage Three is a quasi-steady-state daily time-series of a climate variable for a specified location in the projected future. This time series can be used in hydrologic and systems models and preserves the variability of climate seen in the past.

The length of the slice used, thirty-one years, captures decadal variability while still representing the period of interest. A longer slice might add higher resolution to the CDF, and thus more variability and a more complete transfer function, but loses the characteristics of a particular period. A shorter slice length might represent a specified period more accurately, but the CDF becomes coarser, causing the transfer function to have less resolution, and therefore, lose some of the existing variability in the historic data that the future data maps to.


Stage Two - Downscale from Regional Grid to Station Level
Monthly, Gridded Regional Historic Data for the 20th Century (1950-2000)
Monthly, Station Level Historic Data for the 20th Century (1950-2000)
Quantile Mapping/ Transfer Functions
Monthly, Bias Corrected Climate Scenario Downscaled to Regional Grid
Monthly, Station Level, Bias-Corrected Future Climate
Stage Three - Expand Transient Time-Series
Monthly, Station Level, Bias-Corrected Future Climate
Extract 31-year Slice from future climate data.
Create CDFs of monthly values for 31-year slice and historic station level data. Create Quantile Map.
Feed Historic Monthly Time-Series through Quantile Map to Create a Monthly Future Climate Time-Series
Quasi-Steady-State Monthly Future Time-Series
Monthly, Station Level Historic Data for the 20th Century (1950-2000)
Monthly, Station Level Historic Data for the 20th Century (1950-2000)
Quasi-Steady-State Monthly Future Time-Series
Monthly, Station Level Historic Data for the 20th Century (1950-2000)
Subtract/Divide altered Time-Series from Historic Monthly Time-Series.
Monthly dP and dT Time-Series
Apply Monthly dP and dT Time-Series to Historic Daily Record
Daily Quasi-Steady-State Time-Series of Future Climate
Historic Daily Station Level Data
Legend
Process Box - Used to Operate on Data
External Data - Input to Process Box
Data Created - Product from Process Box

Details

Complete details of this process can be found in the following papers:

- Salathé, E.P. (2004). “Methods for selecting and downscaling simulations of future global climate with application to hydrologic modeling.” *International Journal of Climatology*, 25: 419-436
- Widmann, M., Bretherton, C. S., and Salathé, E. P. (2003), “Precipitation downscaling over the Northwestern United States using numerically simulated precipitation as a predictor.” *Journal of Climate*, 16(5): 799-816.
- Wiley, M.W., Palmer, R.N., and Salathe, E.P.(submitted 2006). "The Development of GCM Based Climate Scenarios for use in Water Resource System Impact Evaluations ." submitted to J. Water Resource Planning and Management
- Wood, A.W., Maurer, E.P., Kumar, A. and Lettenmaier, D.P. (2002), “Long range experimental hydrologic forecasting for the eastern U.S.” *Journal of Geophysical Research*, 107(D20): 4429.

Questions

The following list of questions were raised in regards to the downscaling process at the December 13th Meeting. The questions are individually addressed below.

What period of time is used for bias-correction in the GCM to regional grid, and regional grid to station stages of downscaling? Are these periods the same?

The period of time used for the bias-correction process is 1950-2000. This period of time is used to build the transfer functions in both Stage One and Stage Two of the downscaling process. Regionally gridded, historic data prior to 1950 was not available.

What period of time is used for the expanded time-series stage?

The date in which the 31-year slice is centered on determines the period of time that perturbs the historical record in Stage Three. This slice from the transient record is applied to the historic record, which contains daily observations at select stations from 1927-2005. If individual stations have missing records for this time period, an interpolation scheme is used to patch or in some cases extend the original record.

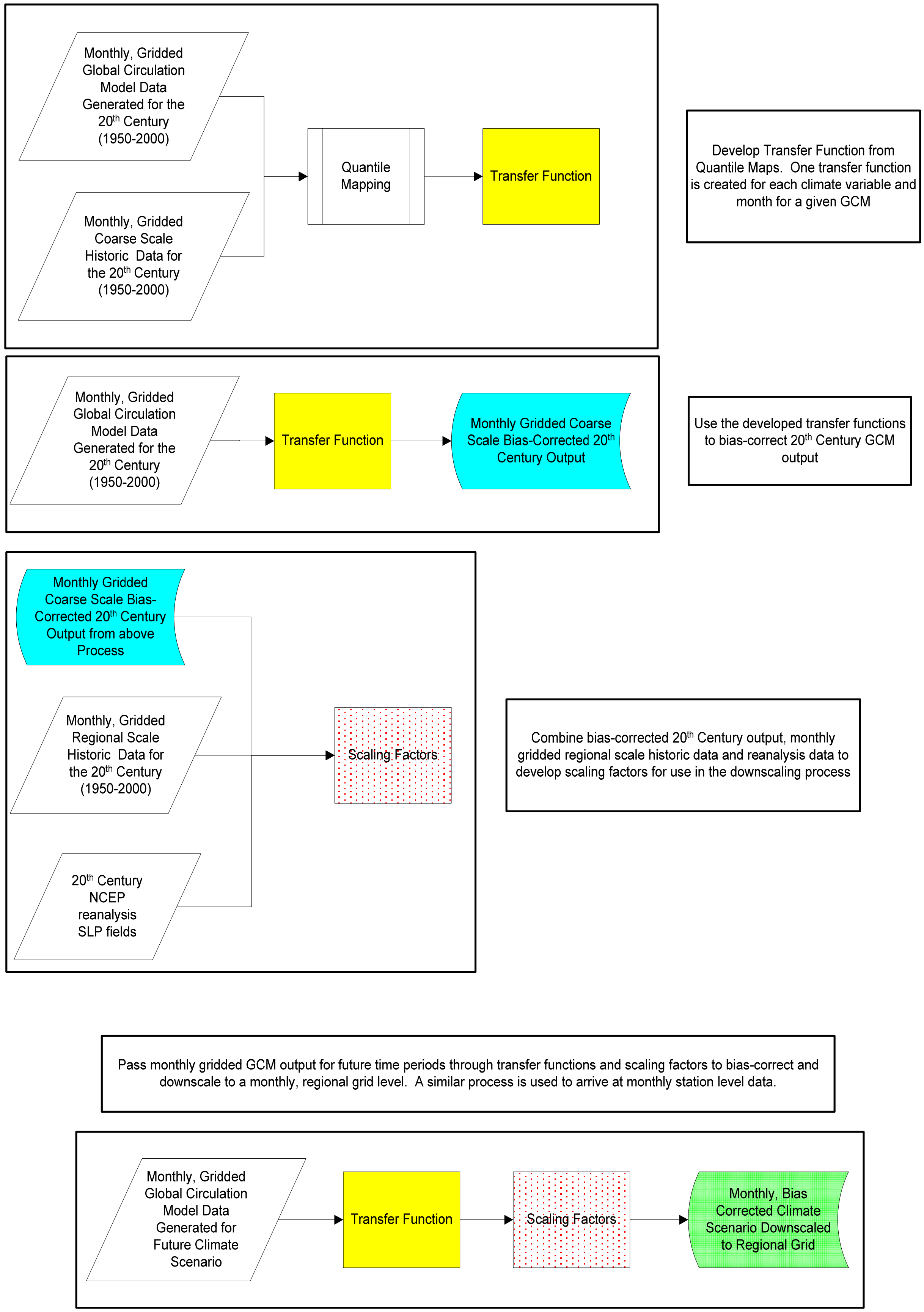
Was a sampling scheme used in generating the future extended time-series?

No. The historic record remains intact, modified by the perturbation factor. A large precipitation event in the historic record will remain an event that is distinguishable in the future but will be modified to fit the corresponding statistics of that future period. This preserves the sequence in which storm events occur and the seasonality of our climate.

A random sampling approach was investigated, but due to minimal differences from the selected method and the difficulty associated in conveying the results, the sampling method was not used. It was also deemed much harder to explain.

How are Tmin and Tmax generated?

Although GCMs do output Tmin and Tmax at a daily time-step, they are not used in the downscaling process due to availability reasons. Instead the average temperature is used from the historic record, and the Tmin and Tmax values are perturbed based on the transfer function value of the future average surface temperature. Because the daily diurnal range is taken directly from the analog month, there is no shifting of the Tmin or Tmax values relative to each other, so the range remains the same, though the Tmin or Tmax values can be translated up or down based on the average surface temperature.


Monthly, Gridded Global Circulation Model Data Generated for the 20th Century (1950-2000)
Monthly, Gridded Coarse Scale Historic Data for the 20th Century (1950-2000)
Quantile Mapping
Transfer Function
Develop Transfer Function from Quantile Maps. One transfer function is created for each climate variable and month for a given GCM
Monthly, Gridded Global Circulation Model Data Generated for the 20th Century (1950-2000)
Transfer Function
Monthly Gridded Coarse Scale Bias-Corrected 20th Century Output
Use the developed transfer functions to bias-correct 20th Century GCM output
Monthly Gridded Coarse Scale Bias-Corrected 20th Century Output from above Process
Monthly, Gridded Regional Scale Historic Data for the 20th Century (1950-2000)
20th Century NCEP reanalysis SLP fields
Scaling Factors
Combine bias-corrected 20th Century output, monthly gridded regional scale historic data and reanalysis data to develop scaling factors for use in the downscaling process
Pass monthly gridded GCM output for future time periods through transfer functions and scaling factors to bias-correct and downscale to a monthly, regional grid level. A similar process is used to arrive at monthly station level data.
Monthly, Gridded Global Circulation Model Data Generated for Future Climate Scenario
Transfer Function
Scaling Factors
Monthly, Bias Corrected Climate Scenario Downscaled to Regional Grid

Downscaling in a Nutshell