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Physiographic Parameters as Indicators of Snowpack State for the Colorado River Basin

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EXTENDED ABSTRACT

The majority of the streamflow in the southwestern United States is derived from snowmelt. This makes an adequate assessment of the volume of snow in the alpine snowpack crucial to water management. River runoff volumes are often forecasted using point data that are deemed indicative of a watershed's snowpack and have a correlation with streamflow. To assist the forecasting efforts, the Southwest Regional Earth Science Applications Center is developing snowpack maps of the Colorado River Basin. This snowpack mapping is the merging of satellite derived snow-covered area (SCA) and interpolated snow water equivalent (SWE) maps. The SCA images are generated using broad-banded measurements from Advanced Very High Resolution Radiometer (AVHRR) scanners. The procedure is summarized in Daly *et al.* (2000) and Fassnacht *et al.* (2001).

Mapping of SWE using point measurements has typically focused on small alpine watersheds where intense surveys have been undertaken (see Balk and Elder, 2000 for a review). Dressler *et al.* (2000) suggested that the use of a multivariate regression with physiographic parameters would improve large scale SWE mapping for the Colorado River Basin. Physiographic parameters were used by Solomon *et al.* (1968) to develop maps of precipitation, temperature and runoff for the Island of Newfoundland, Canada. The methodology was modified to grid monthly climate normals for all of Canada (Seglenieks *et al.*, 1999). Daly *et al.* (1997) illustrated the use of the Parameter-elevation Regressions on Independent Slopes Model (PRISM) to map monthly and annual precipitation and temperature for the United States. Atkinson (2000) used spatial modelling techniques to improve the spatial resolution of irregularly spaced and sparsely populated data elements for the Canadian arctic archipelago. While physiographic parameters have been used to develop areal distributions of climatological variables, their use for gridding hydrologically based variables has been limited to the runoff generation by Solomon *et al.* (1968).

This research is working towards using physiographic parameters for developing gridded SWE maps to cover large watersheds, especially for alpine regions with large variations in topography. The importance of the parameters is being investigated in terms of the order of inclusion in the regression with respect to increases in the correlation coefficient and decreases in the standard error of the estimate. The degree of importance is being assessed by examining the magnitude of the normalized coefficients in the regression. The evolution of the inclusion of parameters is being examined as a function of both time of year and compared on an inter-annual basis.

Nineteen physiographic parameters and one forest parameter were used in the analysis. These parameters can be considered as station based, derived and forest-related. The station based and derived parameters were computed for a 1 km pixel based on a 100 m digital elevation model (DEM). A resolution of 1 km was used in the analyses.

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The station-based parameters are the 3 location coordinates (X and Y position, elevation), the slope and the aspect. The slope and aspect have been integrated to yield a directional slope, i.e., the change in the x, y and z directions. Specifically these are Δz (computed by the *sine* of slope), Δx (computed by the *sine* of aspect), and Δy (computed by the *cosine* of aspect). Four different scales of directional slope have been chosen. These are the local slope at 1 km, two footprint slopes, and a regional slope. The footprints were considered from the west (5 columns by 3 rows with the pixel of interest in the 4^{th} column from west and 2^{nd} row north) and from the south (3 columns by 4 rows with the pixel of interest in the 2^{nd} column from the west and 2^{nd} row from north). These footprints are used to determine on which side of the mountain that a station or grid block is located. This is an indicator of windward versus leeward side, as this is very important for orographic-type precipitation. The regional slope is a 9 km swath around each 1 km pixel.

Three derived parameters are the same as those generated by Solomon *et al.* (1968). The distance to ocean is a measure of the proximity to ocean, which represents the relation to the major source of moisture; the barrier height is a measure of the difference in height from the highest point between the ocean and the station/grid block to the station/grid block; and the shield height is the accumulation of elevation rise from the ocean to the station/grid block. The barrier distance was added for this analysis. It is the distance from the station/grid block to the highest point between the ocean and the station/grid block. Seglenieks *et al.* (1999) considered the eight main compass directions for the derived parameters. These represent the station/grid block location with respect to sources of moisture. Since the snowpack is an accumulatory memory of precipitation under predominantly colder than freezing/snow conditions, only the direction to the nearest ocean, in this case the Pacific, was considered.

The nature of vegetation present in a location is in part indicative of the local climate. In the southwestern US, the presence of snow-cover is often complemented by a coniferous forest, except above the timberline. However, this is correlated in part by elevation and “side of the mountain” (the 5 by 3 footprints). Thus to avoid the use of a logit-type regression for canopy type, canopy density was used. The canopy density is the percent canopy coverage. Vegetation density products were available from the 1km AVHRR imagery, as produced by the US Forest Service. These products are derived from the normalized difference vegetation index (NDVI).

To match the AVHRR-derived fractional SCA, maps of daily SWE were required for multiple years. Daily SWE measurements are recorded at 125 snow telemetry (SNOTEL) sites within the Colorado River basin. Measurements are also taken around the basin at 115 SNOTEL sites. Snow water equivalent is measured at the SNOTEL sites using snow pillows. The data used for this study were scrutinized by Serreze *et al.* (1999) to ensure consistency.

After an initial investigation, the most important parameters appear to be location (x, y and z), distance to the ocean, barrier height and shield height. Some of the slopes and aspect were moderately important, but this often varied from year to year.

An inverse relationship was found between the X location and the distance to the ocean. Where either one of these parameters was found to be important, in terms of having a large coefficient, the other parameter was of equal magnitude but in the opposite direction, thus essentially cancelling each other out. This occurs due to the nature of the regression method whereby only one parameter was added at a time.

To characterize the western United States snowpack, Serreze *et al.* (1999) divided the western US into 8 regions. The Colorado River Basin was divided into Northwest Wyoming, Utah, Colorado, and Arizona-New Mexico. Since the Colorado basin is large enough, the variations in the characteristics of the snowpack from north to south can be separated by using the 4 Colorado sub-regions defined by Serreze *et al.* (1999). However, the specific parameters of importance must be identified for the Arizona-New Mexico region as the station data are limiting.

The use of a linear multi-variate regression also generates problems in transitional areas where stations are reporting no snow. The regression techniques used by Daly *et al.* (1997) and Seglenieks *et al.* (1999) are for monthly and annual climate normals; all stations have observations that are greater than zero. However, this binary problem exists for snow data where the snowpack has yet to accumulate or has completed ablated at a particular station. The use of physiographic parameters or any geostatistical method must distinguish between snow and no snow areas.

Considering a simple regression between SWE and elevation, multiple stations with no snow below the snowline will skew the slope of the regression. Therefore, it is recommended that all stations should be removed, or assigned values of no data, once it is well established that snow is and will no longer be present for the remainder of the season.

Keywords: snow water equivalent, SWE mapping, SWE interpolation, SNOTEL, physiography

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