CAPTURING SPATIAL VARIABILITY IN THE INFLUENCE OF TOPOGRAPHY AND VEGETATION ON SNOW DEPTH IN THE TUOLUMNE RIVER BASIN, CA

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EXTENDED ABSTRACT

Understanding spatial nonstationarity in the influence of topography and vegetation on patterns of snow water equivalent (SWE) can improve distributed SWE models and guide investigations of physical processes that generate this variability. In this study, we seek to understand the nature of this nonstationarity and improve upon a basin-scale statistical snow depth model by allowing for spatial patterns within observed relationships. To accomplish these objectives, we apply geographically weighted regression (GWR) (Fotheringham, Brunsdon, and Charlton, 2002) to gridded, 3m-resolution, LiDAR-derived elevation, canopy height, land cover classification, and snow depth products from the Tuolomne River Basin in California. The data are obtained from the Airborne Snow Observatory (ASO) ("ASO | NASA Airborne Snow Observatory" 2015), with snow depth observations from early April flights in 2013, 2014, and 2015 and topographic/vegetation features from 2014. Preliminary results suggest that our approach leads to a ~10% decrease in error relative to a comparable global model and that the spatial patterns in local relationships between snow depth observations and topographic and vegetation features are persistent across seasons. Furthermore, they suggest that the scale of nonstationarity in these relationships may fall between 50-100m, but that there is also a wide range in the magnitude of spatial variation across features.

The statistical model employed in this study consists of two stages. In both stages, we regress snow depth (or residual snow depth) on the following topographic and vegetation features: elevation, slope angle, aspect, curvature, northness ($\cos(aspect) * \sin(slope)$), maximum upwind slope, land cover classification, and canopy height. In Stage 1, we apply a global Mixed Regressive, Spatial Autoregressive (MRSAR) error model to adjust for large-scale heterogeneous processes (e.g. weather) that cause depth observations from nearby pixels to be correlated. In Stage 2, we run a local, stepwise-distance-weighted, multiple regression at each pixel, using the Stage 1 residuals as the predictand. Snow depth, instead of SWE, is analyzed due to the availability of higher-resolution, directly-observed gridded products and to the relative homogeneity of snow density compared with depth (López-Moreno et al., 2013). Cross-validation of 10,000-pixel samples from the 2013 and 2014 datasets gives an optimal Gaussian kernel bandwidth for Stage 2 local models between 50–100m (Figure 1), and 75m is chosen for the full analysis.

This 75m optimal bandwidth is suggestive of the scale of nonstationarity within the observed relationships, of local regression coefficients to that of other features (Figure 2). Local multicollinearity has been demonstrated to affect statistical inference of GWR coefficients (Wheeler and Tiefelsdorf, 2005), so further investigation into this possibility is necessary before a formal interpretation of preliminary results like those seen in Figures 2 and 3. These preliminary results suggest that statistical snow depth predictions can be improved by allowing for spatial

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Paper presented Western Snow Conference 2016

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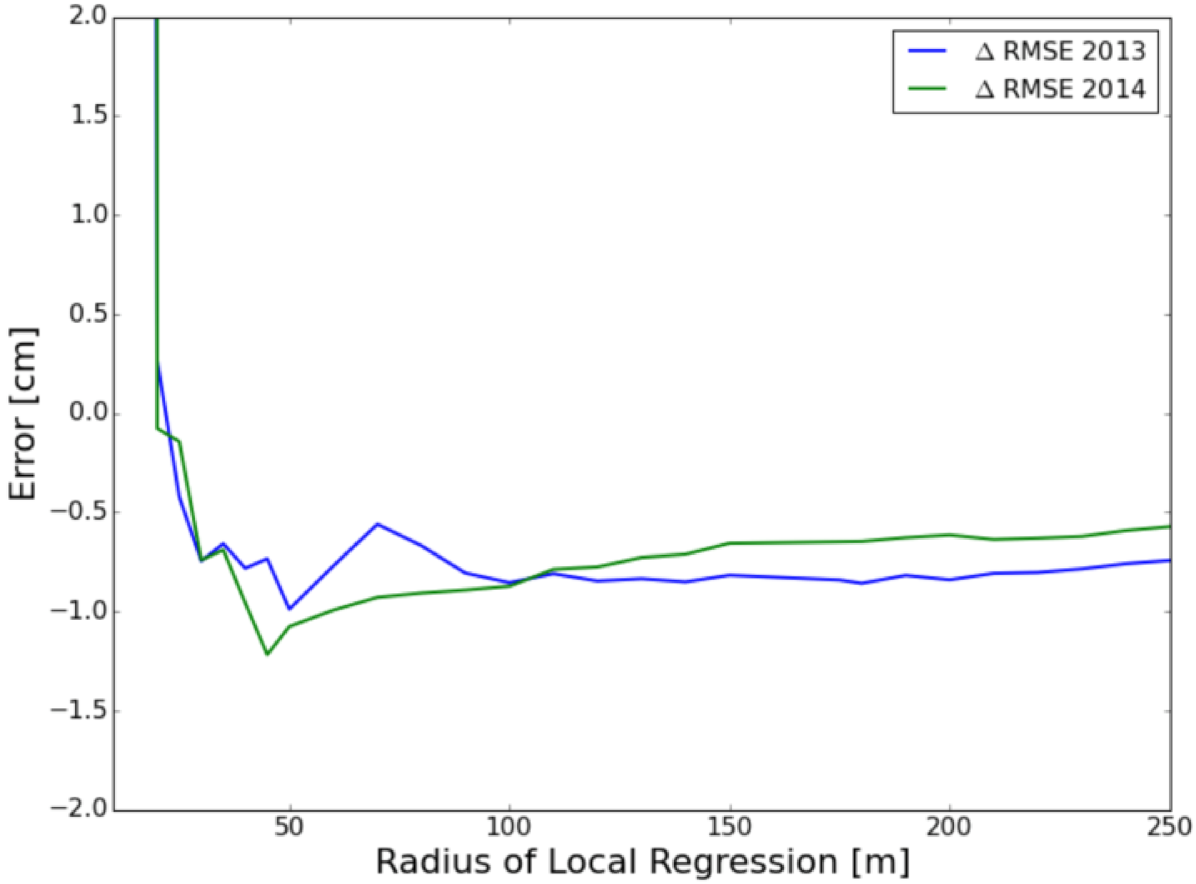

Figure 1. Cross-validated difference in RMSE between Stage 1 (MRSAR error model) and Stage 2 (GWR model) as a function of the kernel bandwidth used in Stage 2, for both 2013 and 2014 snow depth observations.

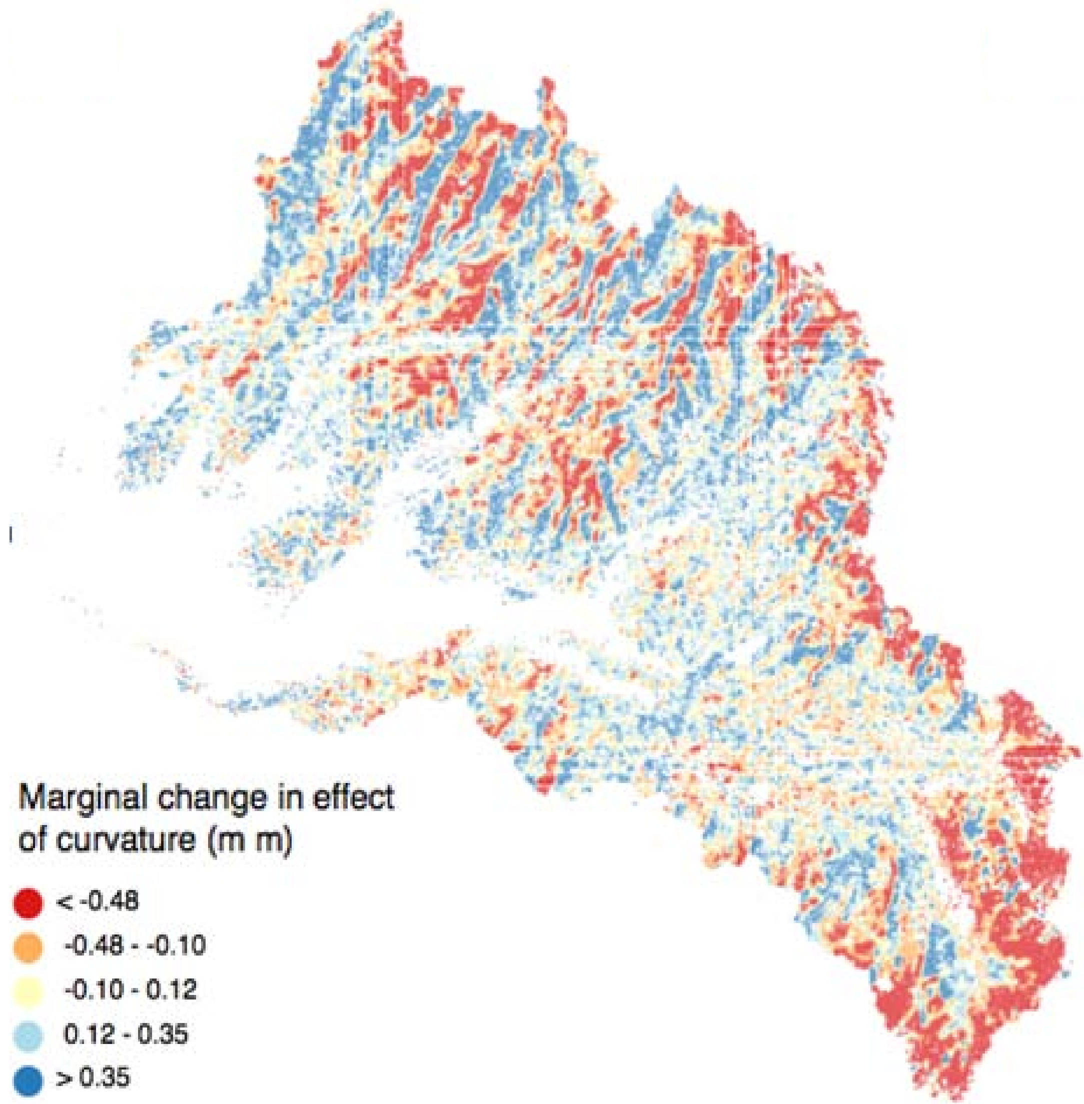

Figure 2. Map of the marginal effect of topographic curvature on snow depth (relative to the global mean effect) within the 2014 model.

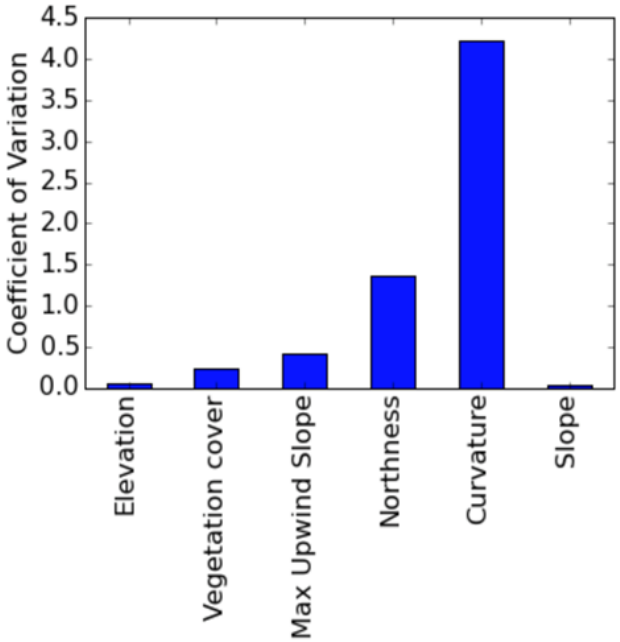

Figure 3. CV of local regression coefficients from the 2014 model for a selection of features.

nonstationarity in linear relationships between topography/vegetation and snow depth. Simultaneously, they imply a need for caution when extrapolating statistical relationships observed in sub-basin scale studies to the entire watershed. While the laws of physics are not varying, it is likely nonlinearities and interactions within these relationships that drive the nonstationarity observed in linear trends. Much additional work remains to be performed. Assessing multicollinearity within the data and the local coefficient estimates will allow for informed interpretation of spatial patterns in these coefficients; comparing GWR results from April and June can provide insight on in-season temporal trends; and aggregating pixels to lower resolution blocks can reveal the impacts of model scale on GWR performance. Statistical SWE/snow depth prediction remains challenging, but understanding spatial patterns of the influence of features can potentially lead to better process knowledge and more accurate prediction. (KEYWORDS: regression, snow depth, topography, vegetation, Tuolumne River)

Note: This research is being conducted with Government support under and awarded by DoD, Air Force Office of Scientific Research, National Defense Science and Engineering Graduate (NDSEG) Fellowship, 32 CFR 168a

REFERENCES

"ASO | NASA Airborne Snow Observatory." 2015. Accessed September 21. http://aso.jpl.nasa.gov/.

Fotheringham, Stewart A., Chris Brunsdon, and Martin Charlton. 2002. *Geographically Weighted Regression: The Analysis of Spatially Varying Relationships*. West Sussex, England: Wiley. http://www.wiley.com/WileyCDA/WileyTitle/productCd-0471496162.html.

López-Moreno, J. I., S. R. Fassnacht, J. T. Heath, K. N. Musselman, J. Revuelto, J. Latron, E. Morán-Tejeda, and T. Jonas. 2013. "Small Scale Spatial Variability of Snow Density and Depth over Complex Alpine Terrain: Implications for Estimating Snow Water Equivalent." *Advances in Water Resources*, Snow–Atmosphere Interactions and Hydrological Consequences, 55 (May): 40–52. doi:10.1016/j.advwatres.2012.08.010.

Wheeler, David, and Michael Tiefelsdorf. 2005. "Multicollinearity and Correlation among Local Regression Coefficients in Geographically Weighted Regression." *Journal of Geographical Systems* 7 (2): 161–87. doi:10.1007/s10109-005-0155-6.