Spatial Statistics 13 (2015) 62–75

Contents lists available at ScienceDirect

Spatial Statistics

journal homepage: www.elsevier.com/locate/spasta

Cross-correlation modeling of European windstorms: A cokriging approach for optimizing surface wind estimates

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ARTICLE INFO

Article history:
Received 21 August 2014
Accepted 15 May 2015
Available online 27 May 2015

Keywords:
European windstorms
Cokriging
Land cover
Aspect
Elevation

ABSTRACT

Maximum sustained and peak gust winds from eighteen European windstorms over the last 25 years were analyzed previously to develop surface-level wind predictions across a large and topographically varied landscape based on an anisotropic kriging interpolation methodology for meteorological station data. Results suggested that coastal and mountainous areas experience the highest wind speeds and highest variability over short distances, resulting in the highest errors across concurrent interpolated surfaces. This study utilizes covariates in conjunction with cokriging to investigate the use of cokriging as a method of improvement through the interpolation of five windstorms that impacted both the Alps region and the topographically-varied coastal regions of Western Europe. Results show that cokriging improves isotach interpolation for windstorms in 8 out of 10 models by reducing root mean square error and the total number of high-error stations, primarily in coastal and mountainous areas. Land cover alone contributed to the greatest model improvement in a majority of the models, while aspect

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http://dx.doi.org/10.1016/j.spasta.2015.05.003

and elevation (singularly and collectively) also improved models when compared to original kriging models. Improved surface interpolation is critical for improved understanding of macro-scale windstorm patterns and resulting damage, thus improving risk and vulnerability estimates.

1. Introduction

Improved geospatial analytical modeling of windstorm-induced surface winds is critical to assess wind events for damage correlation, probabilistic studies, and engineering analysis. Interpolation of station-based measurements provides a method for developing a continuous surface of wind speeds, while also incorporating the differences exhibited between stations (Akkala et al., 2010; Luo et al., 2008). Station data depict wind fluctuations at the local scale better than other data types (MacEachren and Davidson, 1987); however, stations often have poor spatial resolution, particularly in topographically and meteorologically complicated terrain. Wind speed measurements between stations can differ drastically based on station placement, topography, and the roughness of the surrounding area (Wieringa, 1986); therefore, interpolated values may vary from observed values, leading to large error between the interpolated surface and measured values at specific locations.

During excessive wind events, wind flows relatively uniformly across flat and smooth terrain, but where terrain changes abruptly (*e.g.*, coastal zones and/or the transition from flat land to hills and mountains), wind velocity and direction change based on the extent and diversity of terrain roughness (Tieleman, 1992). Wind speeds vary greatly in mountainous regions for two reasons: (1) wind is deflected and funneled by varying topography (Wieringa, 1973, 1986); and (2) wind speed changes as winds move upslope and downslope, resulting in local anomalies (Bowen and Lindley, 1977; Hertenstein and Kuettner, 2005). Wind speeds vary greatly in coastal regions for two reasons as well: (1) the land–ocean interface creates turbulence and deflection when the wind moves across a surface discontinuity (Wieringa, 1973, 1986); and (2) wind observation stations rarely exist over water, decreasing station density (MacEachren and Davidson, 1987; Wieringa, 1997). Because elevation, aspect, and land cover significantly affect surface-level wind speeds and are representative of landscape heterogeneity, consideration of these variables may have the potential to improve interpolation results through reduction in high-error stations.

In a previous study (Joyner, 2013), ordinary kriging was used to estimate maximum sustained and peak gust wind speed surfaces for 18 European windstorms over the past 25 years. While kriging proved to be an accurate method of interpolation, high-error stations, defined for this study as modeled values ± 1.96 standard errors from station data (i.e., 2 standard deviations, $p < 0.05$), were observed predominantly in areas of complex terrain. Recent research has noted that cokriging improves the accuracy of wind surface estimates over ordinary kriging (Aznar et al., 2012; Li et al., 2012; Luo et al., 2008, 2011; Odeh et al., 1995; Singh et al., 2011; Wang et al., 2011; Wenxia et al., 2010; Zlatev et al., 2010); however, cokriging wind models focused on the use of elevation as the only covariate, while suggesting that other covariates could be important (Luo et al., 2008; Sliz-Szkliniarz and Vogt, 2011). No research has examined the improvement offered by cokriging with multiple variables in estimating extreme winds. Further, based on station availability and the maximum use of three covariates, model saturation is not expected (Bamber and van Santen, 1985, 2000). To create more accurate surface wind interpolations and to improve understanding of local wind variability in these environments, the present study examines the number of high-error stations produced when interpolating station wind data using ordinary kriging and cokriging with elevation, aspect, and/or land cover covariates. The research questions associated with this study are:

(1) To what extent does cokriging reduce high-error stations, compared to ordinary kriging methods, associated with interpolated wind surfaces for European windstorms?