Statistica Sinica **35** (2025), 1-21
doi:https://doi.org/10.5705/ss.202022.0064

MODELING AND PREDICTING SPATIO-TEMPORAL DYNAMICS OF $PM_{2.5}$ CONCENTRATIONS THROUGH TIME-EVOLVING COVARIANCE MODELS

Ghulam A. Qadir* and Ying Sun

Heidelberg Institute for Theoretical Studies and
King Abdullah University of Science and Technology

Abstract: Fine particulate matter ($PM_{2.5}$) has become a great concern worldwide due to its adverse health effects. $PM_{2.5}$ concentrations typically exhibit complex spatio-temporal variations. Both the mean and the spatio-temporal dependence evolve with time due to seasonality, which makes the statistical analysis of $PM_{2.5}$ challenging. In geostatistics, Gaussian process is a powerful tool for characterizing and predicting such spatio-temporal dynamics, for which the specification of a spatio-temporal covariance function is the key. While the extant literature offers a wide range of choices for flexible stationary spatio-temporal covariance models, the temporally evolving spatio-temporal dependence has received scant attention only. To this end, we propose a time-varying spatio-temporal covariance model for describing the time-evolving spatio-temporal dependence in $PM_{2.5}$ concentrations. The proposed model is shown to outperform traditionally used models through simulation studies in terms of predictions. We apply our model to analyze the $PM_{2.5}$ data in the state of Oregon, US. Therein, we show that the spatial scale and smoothness exhibit noticeable temporal variation. The proposed model is also shown to be beneficial over traditionally used models on this dataset for predictions.

Key words and phrases: Bernstein functions, Matérn covariance function, nonstationarity, spatio-temporal covariance.

1. Introduction

In the context of air quality control, particulate matter concentrate with diameter $\leq 2.5\mu m$ ($PM_{2.5}$) is a crucial pollutant of concern because of its deleterious effects on human health (Dominici et al., 2006; Pope III and Dockery, 2006). In consequence, $PM_{2.5}$ has been a focal topic in numerous air quality control oriented research where it has been studied for its chemical composition (Zhang et al., 2020), risk assessment (de Oliveira et al., 2012; Amoatey, Omidvarborna and Baawain, 2018), statistical modeling and prediction (Qadir and Sun, 2020; Qadir, Euán and Sun, 2020), etc. $PM_{2.5}$ is closely connected to the meteorology (Dawson, Adams and Pandis, 2007), which causes the seasonality or other time-varying factors to have a strong influence on it. This strong seasonality effect has

*Corresponding author. E-mail: ghulam.qadir@kaust.edu.sa