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meteo: package for automated meteorological spatio-temporal mapping

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1. Introduction

The most powerful *R* (R Development Core Team 2012) package available for geostatistical analysis is *gstat*, which was developed for applied geostatistics (Pebesma 2004). Many spatial geostatistics techniques (including ordinary, universal kriging, block kriging, kriging in a local neighborhood, variogram cloud diagnostics, variogram modeling, multivariable variogram modeling, cokriging and simulation) are available to the broad community of geoscientists. The development of the *spacetime* package has already started in 2010 and the *gstat* functions have been adapted for spatio-temporal mapping (Pebesma 2012), including spatio-temporal variogram fitting and implementation of global spatio-temporal ordinary kriging.

Hengl et al. (2012) describe a framework for space-time regression kriging interpolation of daily temperatures that makes use of a time-series of MODIS images, which are presented as a Croatian case study. Kilibarda et al. (2014) made spatio-temporal interpolation for the mean, maximum and minimum temperature using spatio-temporal regression-kriging with a time series of MODIS 8 day images, topographic layers (DEM and TWI) and a geometrical temperature trend as covariates. The model and predictions were built for the year 2011 only, for the global land areas, but the same methodology could be extended for the whole range of the MODIS LST images (2001–today). Global spatio-temporal variograms and regression models described by Kilibarda et al. (2014) are stored in the *meteo R* package for the purpose of automated mapping of daily temperatures at 1 km/ 1 day resolution.

This article describes the *R* package *meteo* that is still under development. The package provides functionalities for the automated mapping of meteorological observations using spatio-temporal regression kriging. The automated spatio-temporal kriging interpolation procedure is a data driven approach designed for mapping with little or no human interaction. Currently, automated mapping with the *meteo* package can be decomposed in chunks:

1. defining input observations and covariates;
2. use of pre-calculated global models;
3. detecting and/or removing outliers;
4. creation of final prediction (and its export to GIS formats);
5. cartographic visualisation of results and/or creation of web maps (e.g. by using *R* package *plotGoogleMaps* (Kilibarda and Bajat 2012) for automatic creation of interactive web maps).

In addition, *meteo* offers the possibility of using user defined covariates, regressions and variograms; thereby giving more flexibility of using the package in a semi-automated approach.

2. Implementation

The *R* is a system for statistical computation and graphics, which provides programming facilities, high-level graphics, interfaces to other languages, and debugging facilities (R Development Core Team 2012). *R* is free and open source software under the terms of the GNU General Public License. *R* is organized as a collection of packages designated for specific tasks.

The package *meteo* has been implemented in the *R* environment for statistical computing. It combines functionalities of the *rgdal* (*GDAL* raster/*OGR* vector data import/export), *raster* packages (raster data loading and analysis), *spacetime* (classes and methods for spatio-temporal data), *gstat* (geostatistics) and *snowfall* package (cluster computing). Spatio-temporal regression kriging prediction and cross validation have been implemented in *meteo*, and presumably it has not been implemented in any other software yet. The set of the so far created functions of *meteo* package is given in Table 1, package *meteo* is available on <https://r-forge.r-project.org/projects/meteo/>, under GPL licence.

Table 1. The functions in *meteo* package.

Function	Description
<i>meteo2STFDF</i>	Creates an object of STFDF (spatio-temporal data with full space-time grid) class from two data frames (observation and stations). The observations data frame contains at least: station ID column, time column (day of observation) and measured variable column. Stations data frame contains at least: station ID column, longitude (or x) and latitude (or y) column.
<i>rm.dupl</i>	This function finds point pairs with equal spatial coordinates from STFDF object and remove locations with fewer observations.
<i>tgeom2STFDF</i>	Calculate geometrical temperature trend for mean, minimum or maximum temperature. (see Kilibarda et al. 2014).
<i>tiling</i>	Tiling raster or Spatila Grid/Pixels object to smaller parts with optional overlap.
<i>pred.strk</i>	Function for spatio-temporal regression kriging prediction based on <i>gstat</i> krigeST function (global spatio-temporal ordinary kriging).

Function for spatio-temporal regression kriging prediction (*pred.strk*) in *meteo* package applies a tiling procedure for prediction. The area is divided into tiles (smaller parts) by the *tiling* function, which is implemented in the *meteo* package. For each tile, the nearest spatio-temporal observations are selected according to distance from tile's centroids. Subsequently, spatio-temporal regression kriging estimates values within each tile on the base of nearest selected observations. Thus, within each tile, all estimates are calculated by using global kriging from previously selected observations. In contrast to traditional kriging in the local neighborhood approach, applied algorithm reduces the number of spatial searching for nearest observations, coming up to one search per tile, instead one per each location.

3. Case study: Automated mapping mean daily temperatures in Serbia

The collection of stations from Global Surface Summary of Day and European Climate Assessment & Dataset data were used for mapping the mean daily temperatures in Serbia from 2011-07-05 to 2011-07-08. Observation data (for July 2011) are stored in the *meteo* package as table data (*data.frame*) for the purpose of demo examples. The corresponding spatial information are stored in the package as the same class.

The covariates for Serbia (2011-07-05 to 2011-07-08) are stored in the package including two dynamic covariates geometrical temperature trend and splined MODIS LST (see Kilibarda et al. 2014), as well as two static covariates DEM and TWI. Figure 1 shows a spatio-temporal plot of the splined MODIS LST over the domain of interpolation.

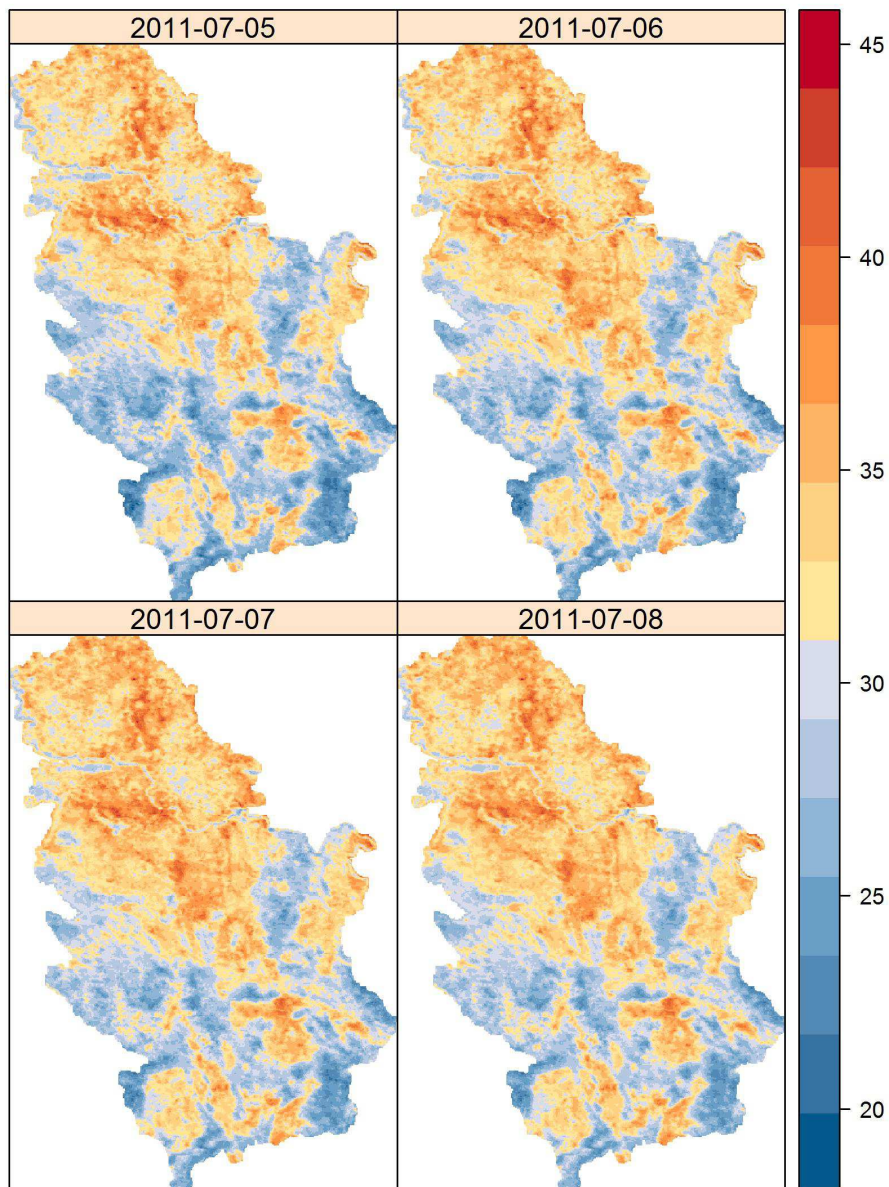


Figure 1. Splined MODIS LST 8-day images in Serbia (2011-07-05 to 2011-07-08).

The prediction of mean daily temperature (Figure 2) was produced based on the observed data of only 27 stations. The trend part was computed by regression model built in the function (methodology is described in detail in Kilibarda et al. 2014) using previously described covariates. MODIS LST images (Figure 1) are significant estimators for mean air

temperatures, despite the evident big difference between land and air temperatures, which is typical during the summer.

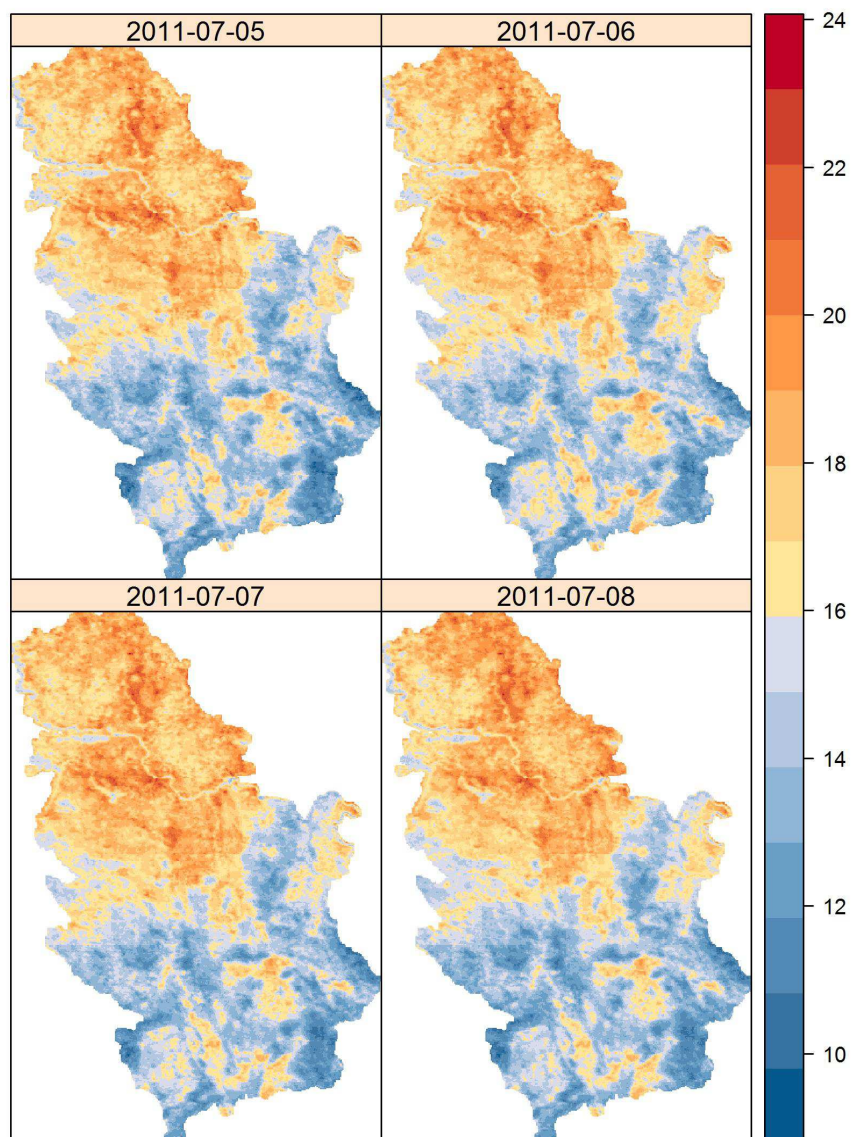


Figure 2. Prediction of mean daily temperature for Serbia (from 2011-07-05 to 2011-07-08) produced by automated mapping.

3. Discussion and conclusion

The illustrated mapping framework enables the use of spatio-temporal regression kriging for meteorological mapping. The implementation of the fast searching algorithm provides an advantage in computing when completing interpolations over a large spatio-temporal grid. The advantage is especially noticeable in case of the grids containing longer time series (e.g. predictions made for the area of interpolation over a year period where each location contains around 365 observations).

The automated mapping framework presented herein is still under development and a lot of functionalities need to be implemented in the future. There are still many open questions related to a) an optimal number of tiles for the domain of interpolation, b) the choice of the

optimal threshold for the automated detection of outliers, and c) incorporating the function for downloading ground station observations from data providers. Likewise, the development of procedures for downloading and mosaicking remote sensing imagery and their organization in an appropriate space-time object would be useful for many meteo/climatic applications.

Filtering missing pixels in MODIS LST 8-day images through the use of spatial splines also needs to be implemented in the package. Similarly, temporal disaggregation from 8-day images to daily images using splines (in the temporal domain) might be offered as an automated procedure.

Automated mapping using a global model incorporated in the mapping framework is a new approach in this field of mapping. The global model should be iteratively improved with increasing availability (and/or quality) of observations both from ground stations and/or from remote sensing data. Therefore, global modelling of processes (modelled with spatio-temporal kriging) could be performed similarly by storing the global model within automated mapping frameworks.

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