Spatial interpolation of daily snow depth over Romania

Alexandru Dumitrescu • Marius-Victor Birsan
Department of Climatology
Meteo Romania (National Meteorological Administration)
Bucharest, Romania
marius.birsan@gmail.com

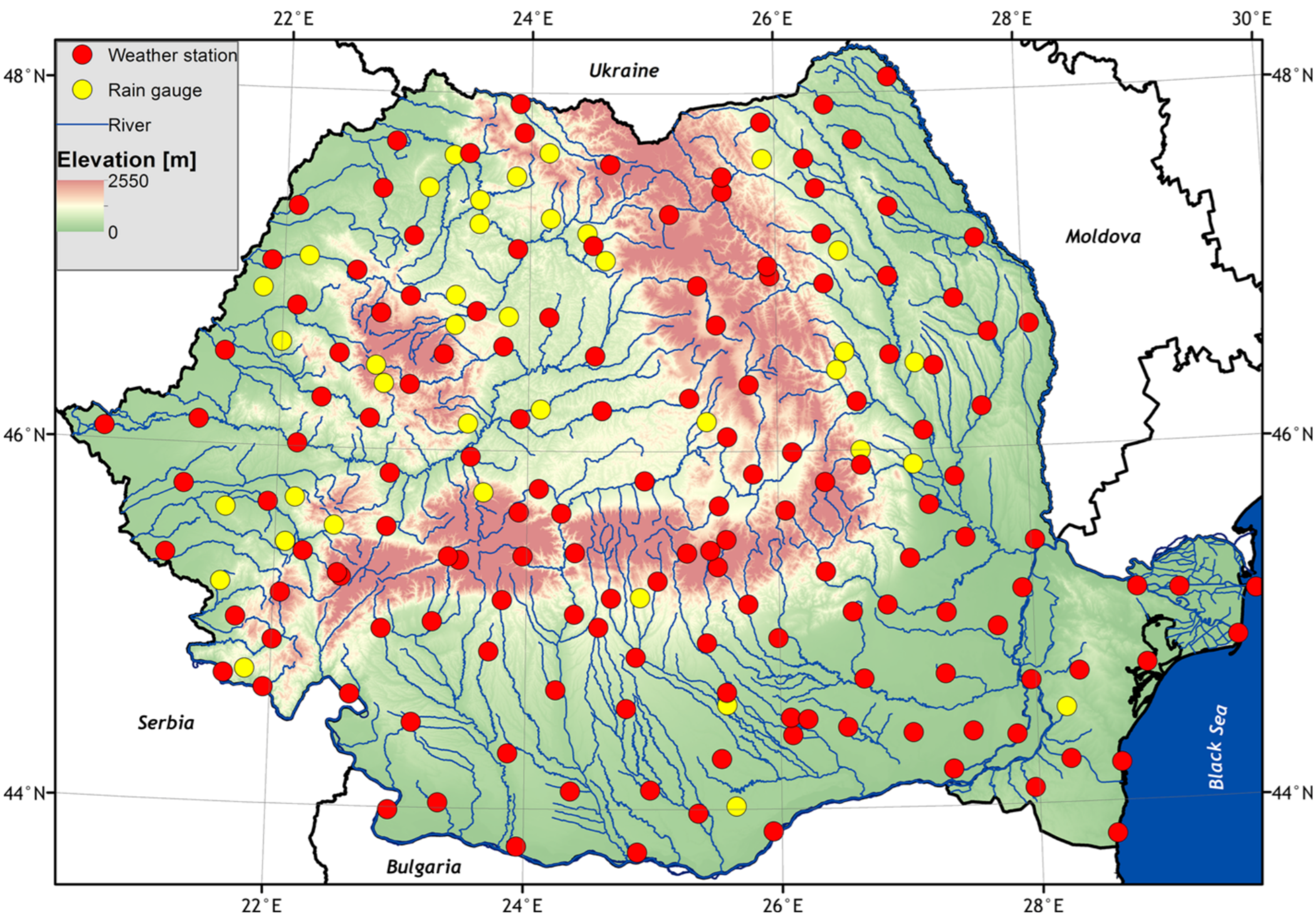
Importance

- Snow cover has major effects on surface albedo and energy balance, and represents a major storage of water.
- The snowpack strongly influences the overlying air, the underlying ground and the atmosphere downstream.
- Snow cover duration influences the growing season of the vegetation at high altitudes.
- Tourism, hydropower planning.

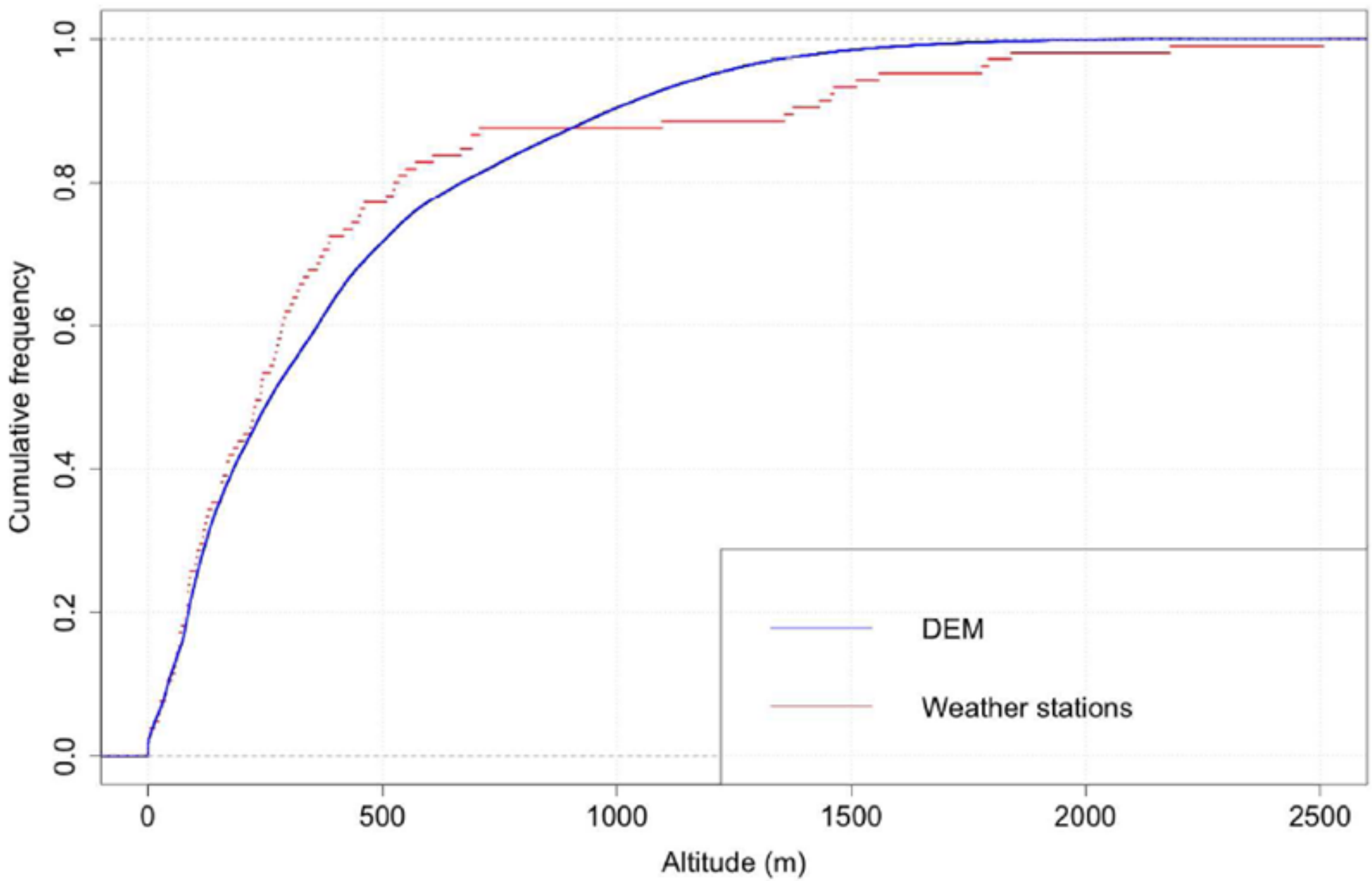
Romania

- Area: 238’391 km^2 (largest country in SE Europe).
- The terrain is fairly equally distributed between mountainous (Carpathians), hilly and lowland areas.
- Elevation varies between zero and 2544 m.a.s.l.
- The climate is continental-temperate with various influences: oceanic (West), Mediterranean (South-West), Baltic (North), semi-arid (East), Pontic (South-East).

Weather stations – spatial distribution



Vertical distribution: stations and 1km DEM



Data

Time series: daily snow depth measurements at 159 weather stations (Dec-Mar, 2005-2015).

Auxiliary data derived from the Digital Elevation Model (DEM) was taken for interpolating the multiannual values:

- altitude;
- mean altitude in a 20-km radius;
- latitude;
- distance to the Black Sea;
- distance to the Adriatic Sea.

Methodology: 3-step interpolation procedure

1. Spatial interpolation at 1 km × 1 km resolution of the mean multiannual values (2005-2015) corresponding to each month, computed from the data extracted from the climatological database;

2. Computation of the daily deviations against the multiannual monthly mean for every day and year over 2005-2015 and their spatial interpolation;

3. Spatio-temporal dataset were obtained through merging the two surfaces made in stages 1 and 2.

The anomalies were considered to be the ratio between the daily snow depth values and the climatology.

The spatial variability of the data used in the first stage was taken into account by using a series of predictors derived from the digital elevation model (DEM) and the CORINE Land Cover product.

Methods

To interpolate the maps with the climatological normals (multiannual means), the Regression-Kriging (RK) spatial interpolation method was used.

In order to choose the optimum gridding of the deviations, four interpolation methods were tested through the cross-validation procedure:

- Multiquadratic (MQ);
- Ordinary Kriging with separate semivariograms (sepOK);
- Ordinary Kriging with pooled semivariograms (pvOK);
- 3D Kriging (K3d).

RK

– a multivariate method that can take into account one or more variables with a spatially continuous distribution (e.g., digital elevation model, satellite images, etc.);

– it results from summing the surface determined through the least squares method (applied to multiple regression) and the surface obtained by spatially interpolating the regression residuals, with Kriging.

Selection of the best regression method: by stepwise regression.

The matrix of the multiple regression grid points represents the large-scale variability of the analysed parameter, function of the explanatory variables, the interpolated residuals representing the local peculiarities of the target variable, modeled with the help of the semivariogram.

4 interpolation approaches

MQ: belongs to the class of exact interpolation methods called Radial Bases Functions, which resembles much to the Kriging family class, but they do not benefit from the contribution of the spatial data structure analysis through the semivariogram;

OK: computes the weights on the basis of the functions that also take for computation the spatial configuration of data;

> (1) sepOK: OK with daily estimation of the variograms (separated fitted daily semivariograms);
>
> (2) pvOK: OK with pooled semivariograms (a single variogram is constructed relying on all data, treating each day as a copy of the same spatial dependence structure.

K3d: an extension of the 2-d Kriging method, which considers time to be the third orthogonal dimension. The predictions from the space–time cube are based only on one semivariogram model for the period of analysis.

Validation

To choose the optimum method for interpolating the deviations, the leave-one-out cross-validation was applied. This implies the elimination one by one of the values from the set of observed values and determining the value of the point excluded on the basis of the other observed data. The difference between the P estimated data and the O measured ones represents the ε experimental value:

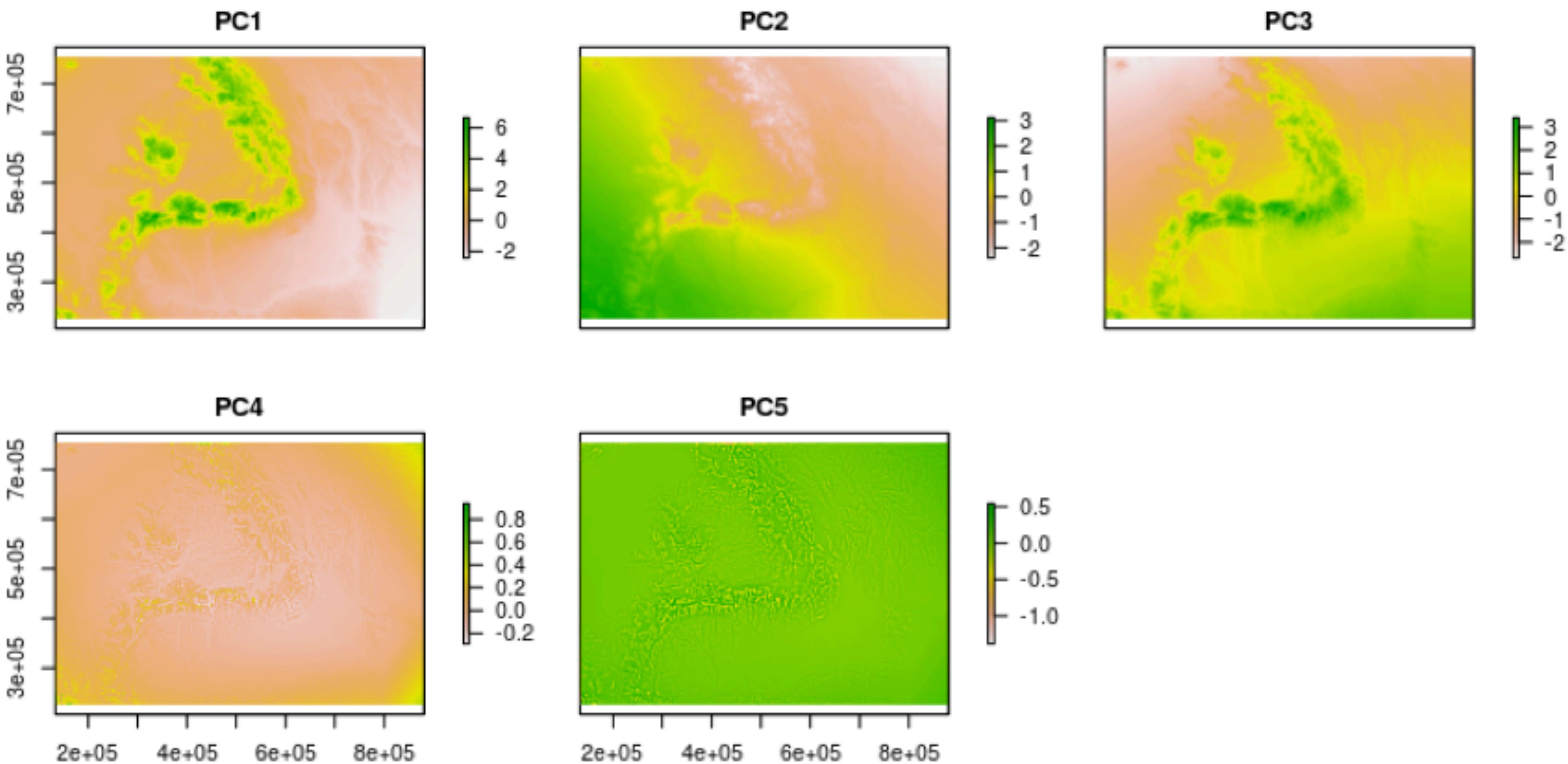
$$\varepsilon_i = P(s_i) - O(s_i)$$

Results: climatological maps

For achieving the gridded climatology, we used as main data the mean multiannual monthly snow depth (December – March from 2005 to 2015). Maps representing the climatological normals were obtained with the RK method.

Due to the existence of the collinearity effect, the predictors derived from the DEM were subject to filtering process through the principal component analysis (PCA) – by transforming the initial variables into a new set of variables, uncorrelated and of a smaller size. The new obtained data set retains (most of) the variability the original dataset.

PCA transformed predictors



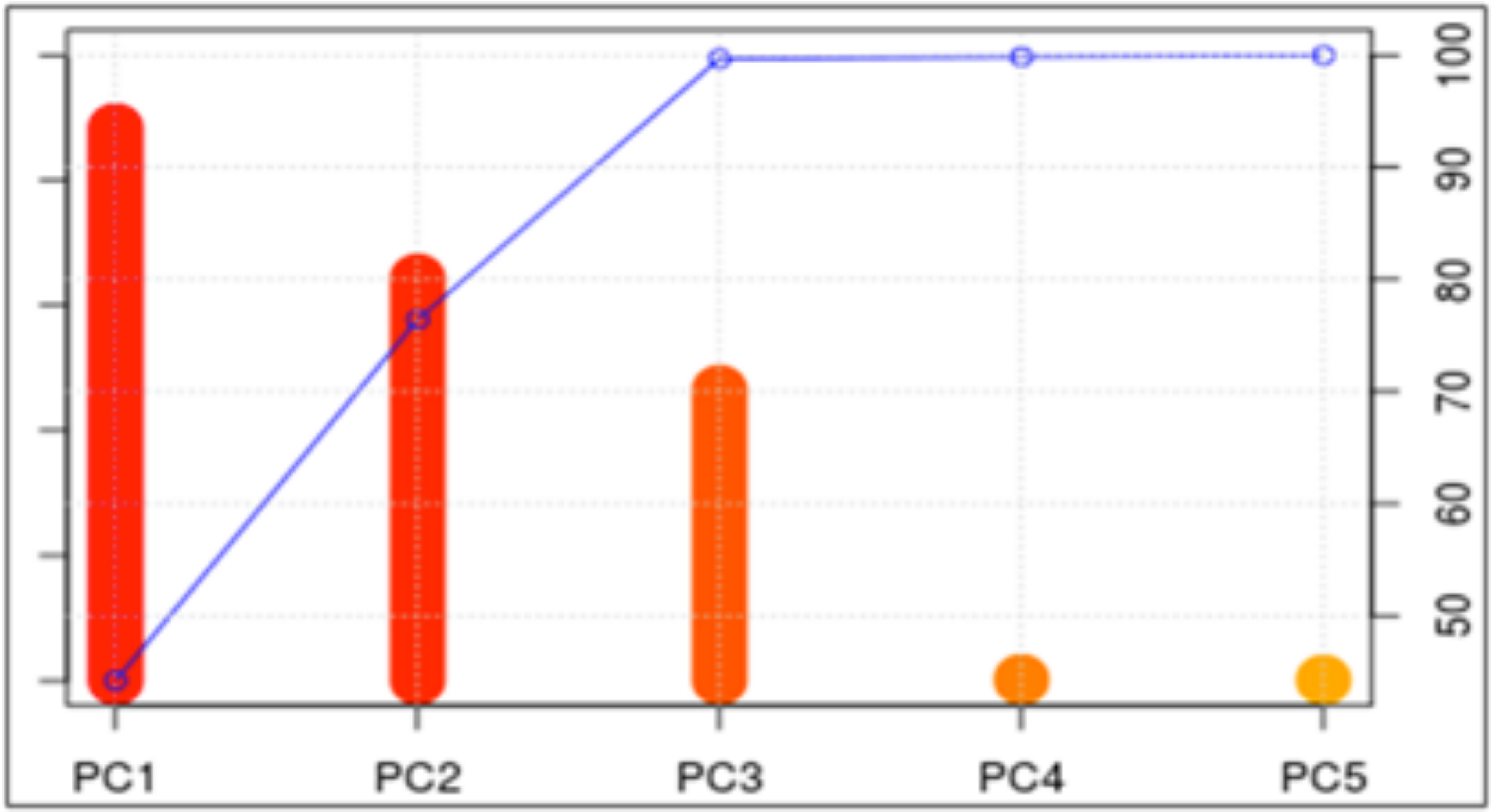
Results: climatological maps

Prior to applying the RK method, we identified statistical relationships between the snow depth values and the auxiliary variables (PCA predictors) for every winter month. By applying the retrograde type stepwise regression, they can be selected for each case (month) taken apart the statistically significant predictors.

Analyzing the frequency distributions, it was noted that the target variables have a positive skewed distribution, hence they were transformed to a close normal distribution by applying the natural logarithm function. The log1p() function from R language was used, which can also be applied to data series with zero values.

The estimations were back-transformed to real values with a help of expm1() function (https://stat.ethz.ch/R-manual/R-devel/library/base/html/Log.html).

Results



Variance explained by the principal components (PCA) computed from the set of predictors obtained from the numerical altimetric model.

Results: climatological maps

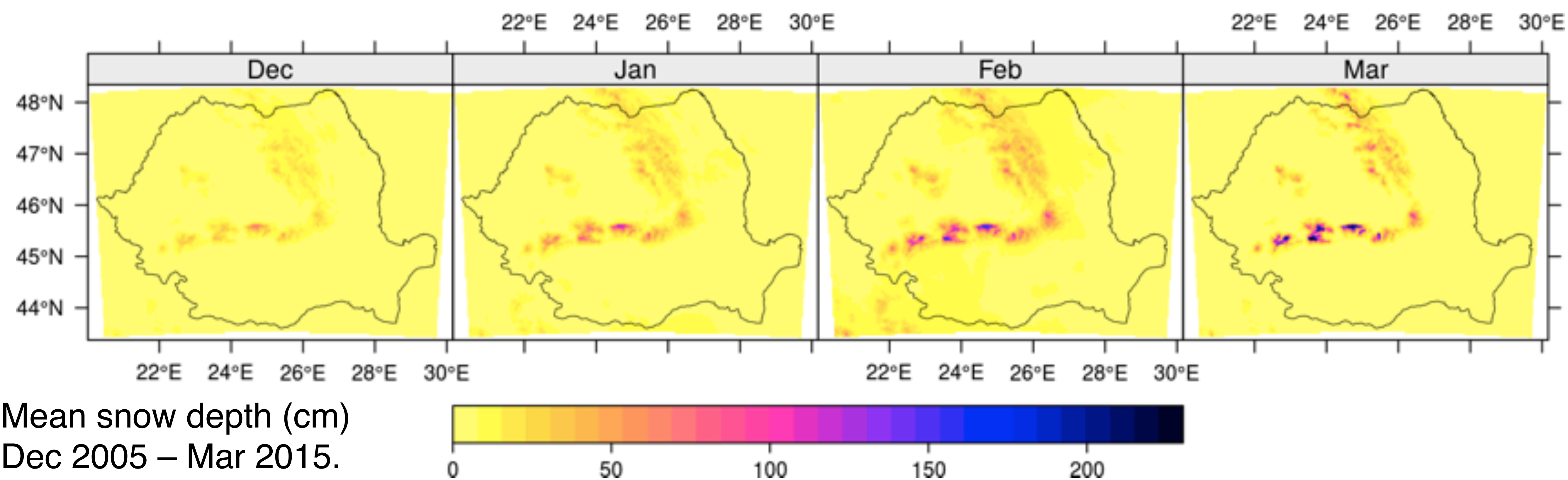
Snow depth: predictors selected by stepwise regression and R^2 determination coefficients

Month	***Predictors***	***R^2***
log1p(Dec)	PC1 + PC2 + PC3	749
log1p(Jan)	PC1 + PC2 + PC3	733
log1p(Feb)	PC1 + I(PC1^2) + PC3	736
log1p(Mar)	PC1 + I(PC1^2) + PC2 + PC3	844

Results: climatological maps

The predictive power of the regression models varies from month to month, with smallest R-squared value in January, and the largest value in March. For all months, more than 70% of the spatial variability of snow depth is explained by the predictors.

The highest values are recorded in the closing month of the cold season, being generated by persisting below zero temperatures at high altitudes, which favors constant accretion of snow.



Mean snow depth (cm)
Dec 2005 – Mar 2015.

Results: daily gridded dataset

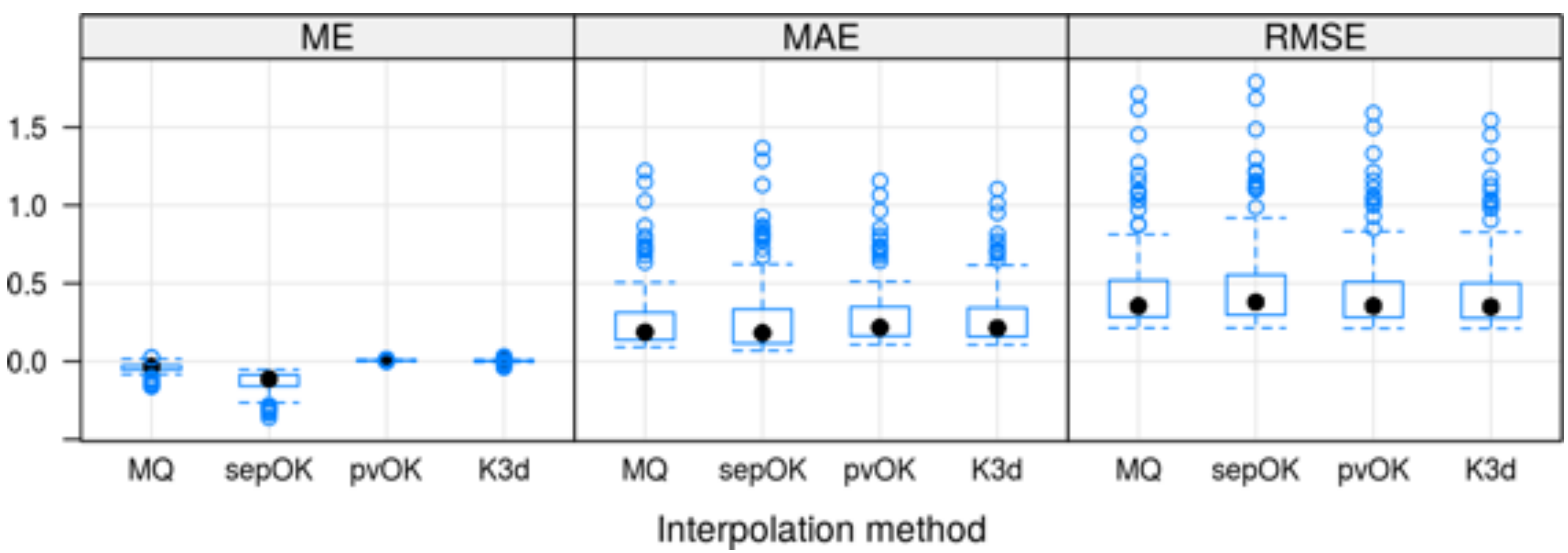
Here, four interpolation methods were tested in order to choose the optimum interpolation method of daily anomalies: Multiquadratic (MQ), Ordinary Kriging - separate (sepOK) and pooled variograms (pvOK)- and 3D Kriging (K3d). For the sepOK method the semivariograms were automatically estimated through the use of the automap R package.

Since there are regions where the mean multiannual snow depth is equal to zero, at the stations located on lower altitudes, a 1 cm value was added to the multiannual means prior to computing the daily anomalies.

The cross validation procedure was applied to the anomalies computed over the period 1 Dec 2014 – 31 Mar 2015.

Results: daily gridded dataset

The estimations performed with the four methods are very similar, a difference being apparent with the help of RMSE indicators, and ME that points out the superior estimations performed with K3d method.



Box-plot diagrams of daily anomalies (Dec 2014 – Mar 2015), computed through using the original datasets against those estimated through the cross validation procedure using MQ, sepOK , pvOK and K3d interpolation methods.

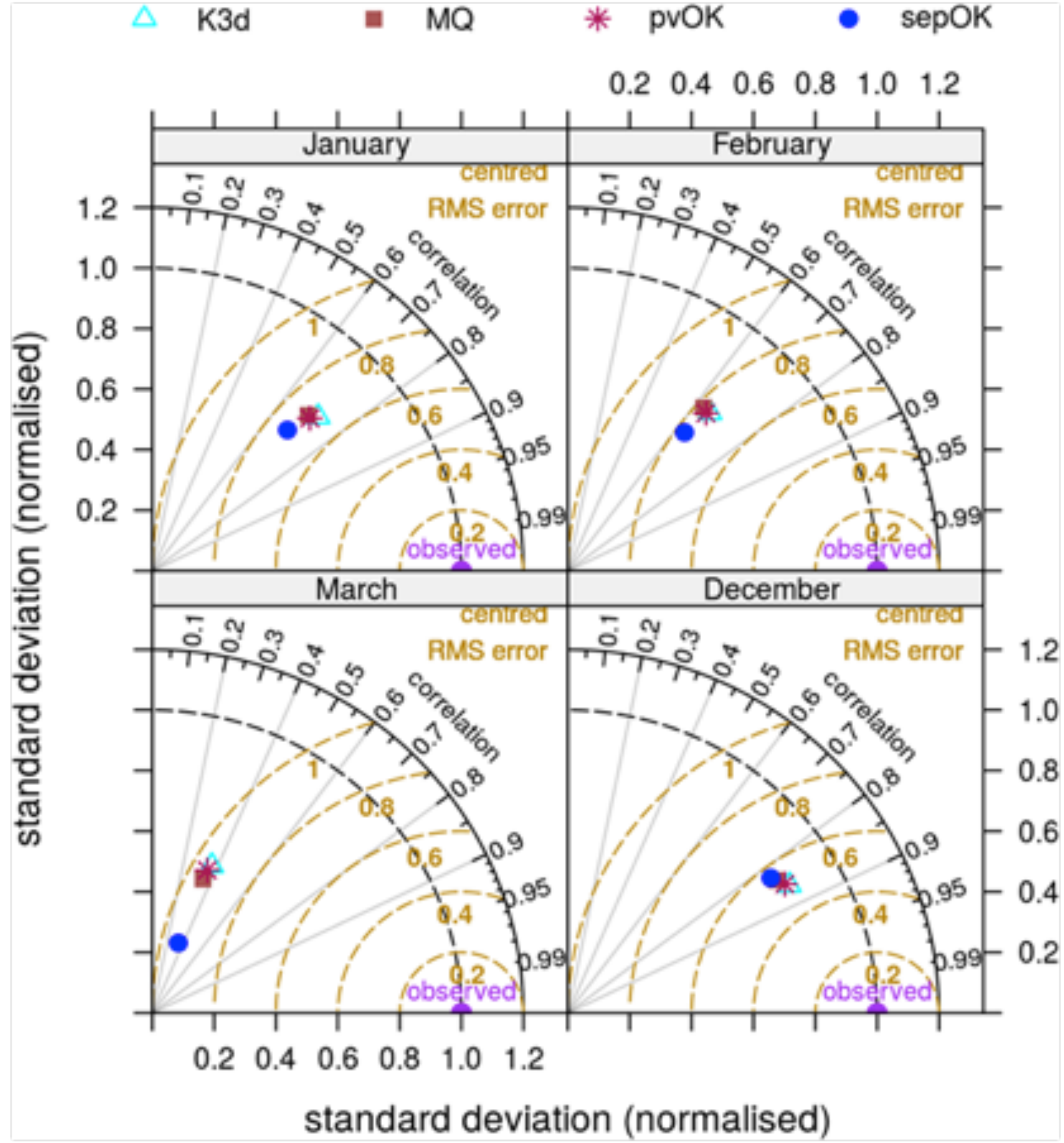
Results: daily gridded dataset

The Taylor diagrams confirm that the best estimates are provided by K3d method, regardless the month analyzed.

pvOK obtains comparable results, with nearly the same computed values for Pearson’s correlation coefficient and slightly larger standard deviation values.

sepOK has the poorest accuracy in terms of the three computed indicators.

NB: all methods underestimate the variability of the observed data, the poorest performance being computed for the March month, when the snow depth is >0 only in the mountain regions.



Taylor-type diagram of daily deviations obtained through the cross-validation procedure for the four methods.

Results: daily gridded dataset

Selected method to generate daily anomaly maps: **K3d**

– good results in interpolating ratios;

– fewer steps required for producing the maps.

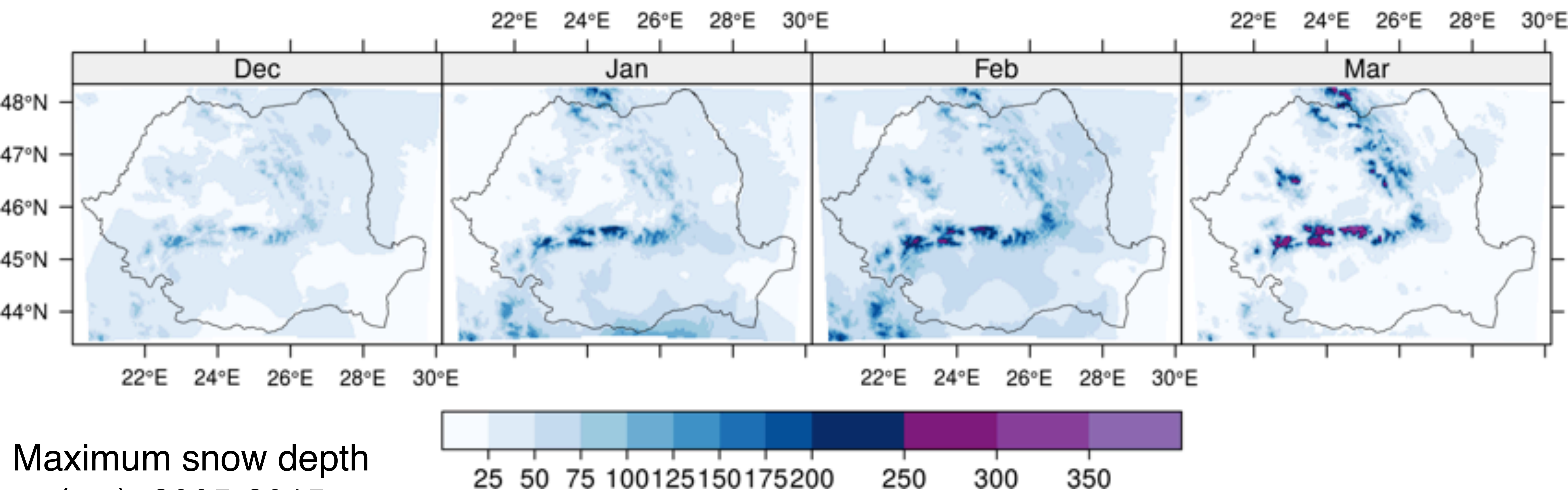
The final daily snow depth maps were generated by multiplying the ratio maps with those representing the monthly climatology.

From the daily grids, the monthly maximum snow depth was computed in every grid point.

Results: monthly maximum snow depth

Highest values correspond to the high mountainous areas (>200 cm starting from January), persisting till March;

Considerable snow depth (> 50 cm) can also be found in the extra-Carpathian areas as a consequence of blizzard episodes specific to January and February.



Maximum snow depth (cm), 2005-2015

Acknowledgement

SnowBall

Remote sensing, model and in-situ data fusion for snowpack parameters and related hazards in a climate change perspective

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