Biomass estimation combining field data and remote sensing: A Case Study in a Forest Area of Northern Portugal

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Contents

Motivation

- The goal is the estimation of the volume of biomass in a forest area of the northern region of Portugal, combining:
  - Field data collected in 2006
  - Spatial interpolation
  - Remote sensing data, including a vegetation index (VI)

Field Sampled Data

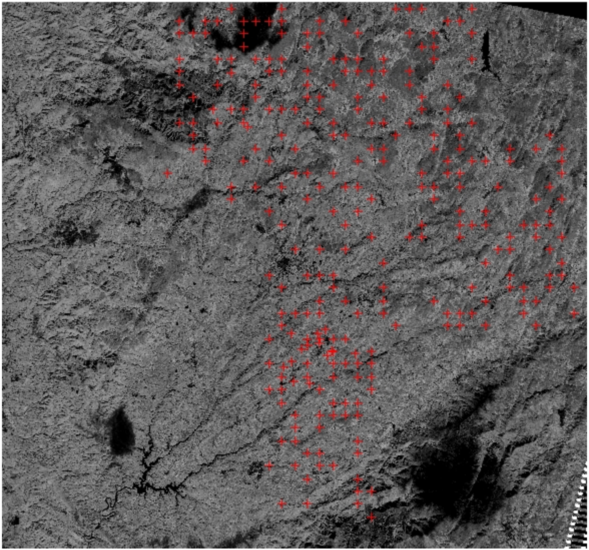
- Biomass volume information collected on the field during 2006 in 280 sample land plots in the study area:
  - Position (x, y)
    - Projected coordinate system: *Lisboa_Hayford_Gauss_IGeoE*
    - Geographic coordinate system: *GCS_Datum_Lisboa_Hayford*
    - Map Projection: *Transverse Mercator*
  - Vegetation type: Scrub forest and trees (*Pinus Pinaster*, oak, *Eucalyptus* and mixed).
  - Weight of green and dry scrub forest (**v** and **s**) by hectare (ton/ha).
  - Cubic meters (**m3**) of biomass by hectare (m^3/ha).

LandSat Image

- The image was acquired on day 12 December 2006.
- The LandSat 5 TM image had been orthorectified and to ensure compatibility between image and the ground data, the image was rectified and georeferenced to the Lisboa_Hayford_Gauss_IGeoE, GCS_Datum_Lisboa_Hayford Map and map projection Transverse Mercator.

Field Data distribution on the Landsat image

Study Area



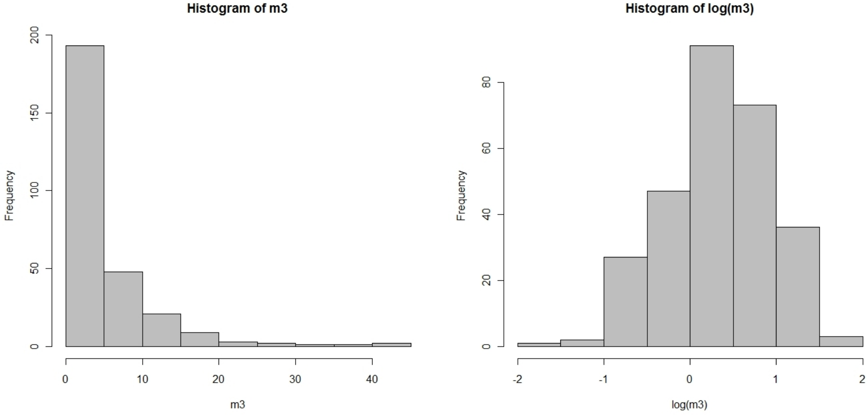
Field Sampled Data

- Statistics of the field sampled data:
  - Descriptive statistics of data:

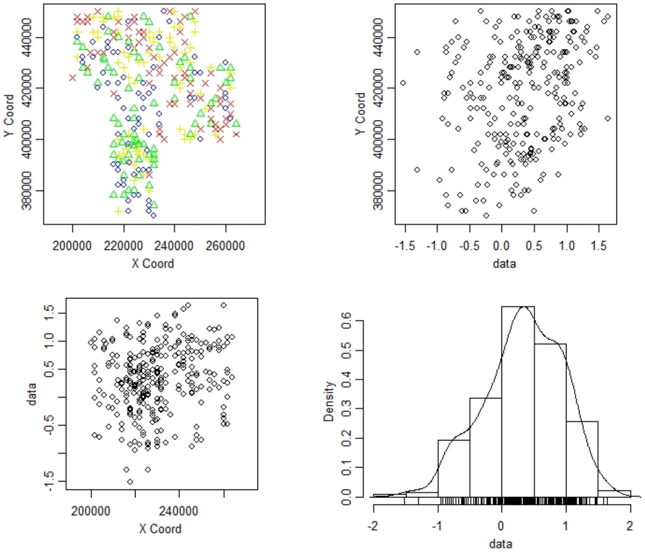
	Min	1Qu.	Median	Mean	3Qu.	Max	SD
m3	2.21	194.8	685.9	2375	2638	35100	4602.48
logm3	0.34	2.29	2.84	2.79	3.42	4.54	0.82

  - Histograms

Field Data: Histograms



Field Data



Y Coord
X Coord
200000 220000 240000 260000
380000 400000 420000 440000
data
-1.5 -1.0 -0.5 0.0 0.5 1.0 1.5
-1.5 -0.5 0.5 1.0 1.5
200000 240000
Density
0.0 0.1 0.2 0.3 0.4 0.5 0.6
-2 -1 0 1 2

NDVI Vegetation Index from the Landsat Image

Definition

Normalized Difference Vegetation Index (NDVI) is the normalized rate:

$$NDVI = \frac{NIR - R}{NIR + R}$$

where R and NIR stand for the spectral reflectance measurements acquired in the red and near-infrared regions, respectively.

Spatial Interpolation Methods

- Methods of spatial interpolation:
  1. Non geostatistics methods (deterministics methods): *Inverse Distance Weighted* (IDW) and *Radial Basis Functions* (RBF)
  2. Geostatistics methods: *Ordinary Kriging* (OK), *Universal Kriging* (UK) and *External Drift Kriging* (EDK)

Inverse Distance Weighted (IDW)

- Linear interpolation on the basis of the spatial distance to the field sample points:
- The IDW estimator is (Flores, 2001):

$$\hat{Z}\left(s_0\right) = \sum_{i=1}^{n} \frac{w_i\left(s_0\right)}{\sum_{k=1}^{n} w_k\left(s_0\right)} \cdot Z\left(s_i\right)$$

with

$$w_i\left(s_j\right) = \frac{1}{d\left(s_i, s_j\right)^p}$$

where p is the power parameter and $d\left(s_i, s_j\right)$ is the distance between s_i and s_j localizations.

Kriging: basic definitions

- The goal of kriging is to estimate the value of a random function $Z(s)$ in some non-sampled positions of a region D from a set of observed data $\{Z(s_1), \ldots, Z(s_n)\}$ in positions $s_1, \ldots, s_n$.
- Kriging predictor, $\hat{Z}(s_0)$, is a linear combination of the observed values:

$$\hat{Z}(s_0) = \sum_{i=1}^{n} \lambda_i \cdot Z(s_i)$$

Kriging: OK, UK and EDK

- Some kriging methods work under asumptions of the structure of the model expectation :

$$E\left[Z\left(s\right)\right]=\mu\left(s\right)$$

  - *Ordinary Kriging* (OK): The mean is constant but unknown and must be estimated.
  - *Universal Kriging* (UK): The mean is unknown but it is a linear combination of known functions .
  - *External Drift Kriging* (EDK): This method uses exogenous variables, i.e. the vegetation index NDVI.

Ordinary Kriging (OK)

- It can be used when the process is second order stationary or intrinsically stationary.
- Ordinary Kriging Estimator (OK) (Isaaks, 1989):

$$Z^*_{OK}(s_0) = \sum_{i=1}^{n} \lambda_i^{OK}(s_0) \cdot Z(s_i) \qquad \text{with} \sum_{i=1}^{n} \lambda_i^{OK}(s_0) = 1$$

where s_0 is an interest localization.

- Ordinary Kriging variance :

$$\sigma^2_{OK}(s_0) = C(0) - \sum_{i=1}^{n} \lambda_i^{OK} \cdot C(s_i - s_0) - \mu_{OK}(s_0)$$

with $C(0) = var[Z(s)]$. It is greater than the Simple Kriging variance.

Universal Kriging (UK)

- Universal Kriging Estimator (UK) is:

$$Z^*_{UK}(s_0) = \sum_{i=1}^{n} \lambda_i^{UK}(s_0) \cdot Z(s_i)$$

where

$$\mu_{UK}(s_0) = \sum_{i=1}^{n} \lambda_i^{UK}(s_0) \cdot m(s_i) = \sum_{k=1}^{p} a_k \cdot \sum_{i=1}^{n} \lambda_i^{UK}(s_0) \cdot f_k(s_i)$$

subject to the condition:

$$\sum_{i=1}^{n} \lambda_i^{UK}(s_0) \cdot f_k(s_i) = f_k(s_0) \qquad k = 0, \ldots p$$

where f_k are the known position functions and a_k are unknown parameters to estimate.

Universal Kriging (UK)

- Universal Kriging Variance is:

$$\sigma^2_{UK}(s_0) = C_R(0) + \sum_{i,j=1}^{n} \lambda_i^{UK} \cdot \lambda_j^{UK} \cdot C_R(s_i - s_j) -$$

$$-2 \sum_{i=1}^{n} \lambda_i^{UK} \cdot C_R(s_i - s_0)$$

being $C_R(.)$ residual covariance.

- In this case, the mean is the polynomial function:

$$\mu_{UK}(s_0) = m(x, y) = a_0 + a_1 x + a_2 y$$

External Drift Kriging (EDK)

- *External Drift Kriging* (EDK) allows the use of an external variable to guide the interpolation of the variable to predict (Goovaerts, 1997).
  - If the variable of interest, i.e. Z, is accurate but sparsely sampled, while the secondary variable, i.e. q, is less accurate but densely sampled, we can combine both:

$$\mu_{EDK}(s_0) = a + b \cdot q(s)$$

External Drift Kriging (EDK)

- External Drift Kriging Estimator (EDK) is:

$$Z^*_{EDK}(s_0) = \sum_{i=1}^{n} \lambda_i^{EDK}(s_0) \cdot Z(s_i)$$

with

$$\sum_{i=1}^{n} \lambda_i^{EDK}(s_0) \cdot q_k(s_i) = q_k(s_0) \qquad k = 1, \ldots, p$$

where Z are spatial data (values of first variable), q_k are p predictor variables and

$$\mu_{EDK}(s_0) = \sum_{k=0}^{p} \mu_k(s_0) \cdot q_k(s_0)$$

being $\mu_k(s_0)$ Lagrange parameters.

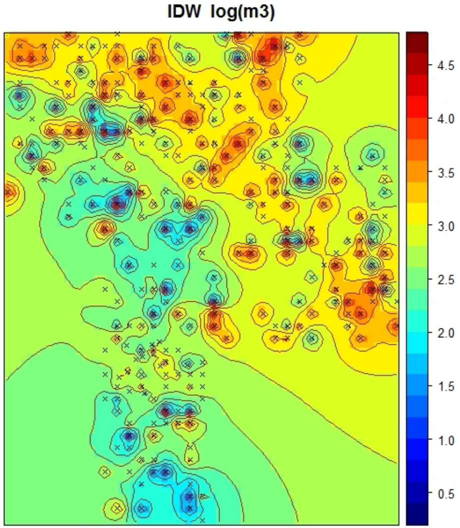
External Drift Kriging (EDK)

- External Drift Kriging Variance is:

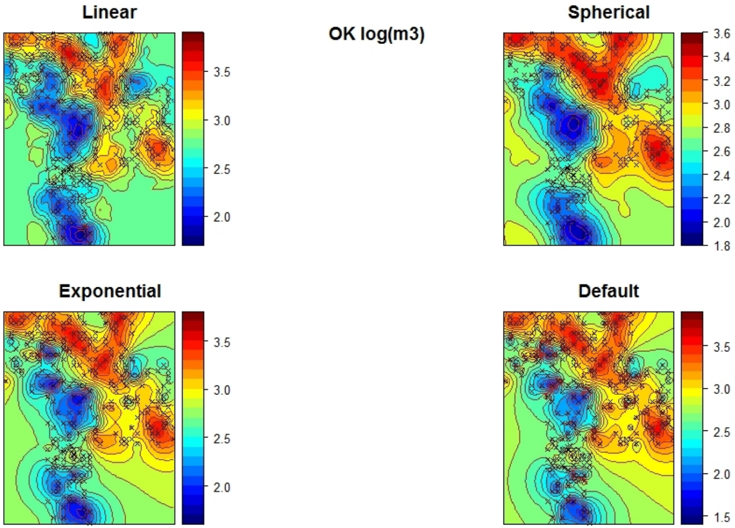
$$\sigma^2_{EDK}(s_0) = C(0) - \sum_{i=1}^{n} \lambda_i^{EDK}(s_0) \cdot C(s_i - s_0) + \sum_{k=0}^{p} \mu_k(s_0) \cdot q_k(s_0)$$

where $C(0)$ is residual stationary covariance, $\mu_k(s_0)$ are Lagrange parameters and $q_k(s_0)$ are tendency functions.

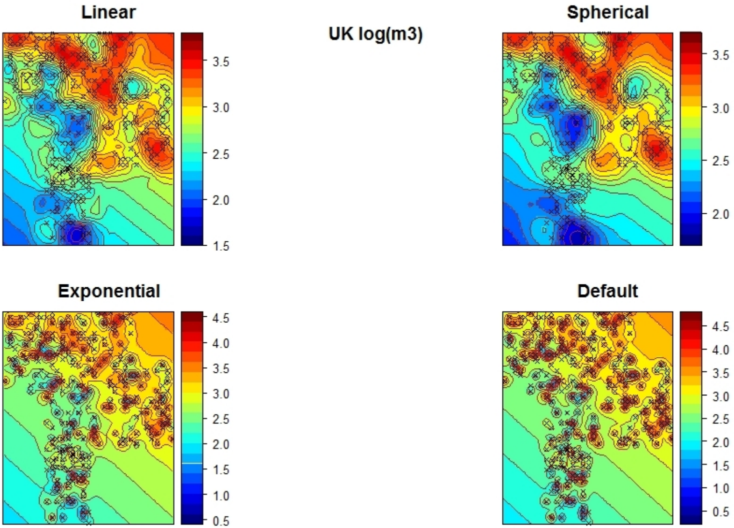
Inverse Distance Weighted (IDW)



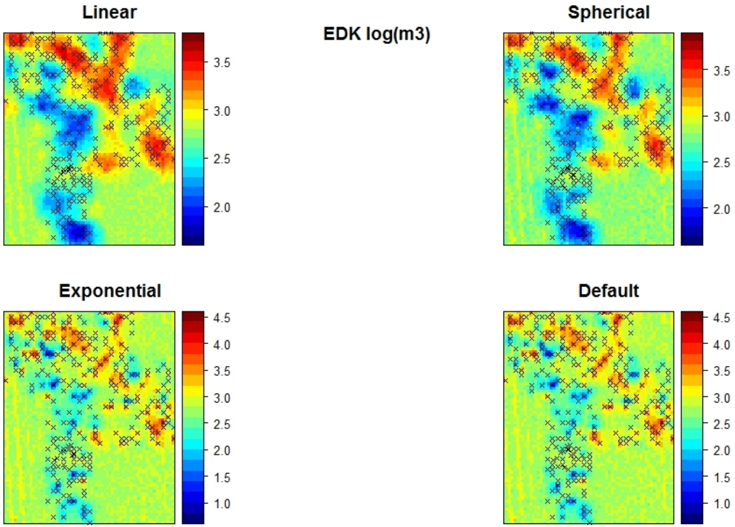
Ordinary Kriging (OK)



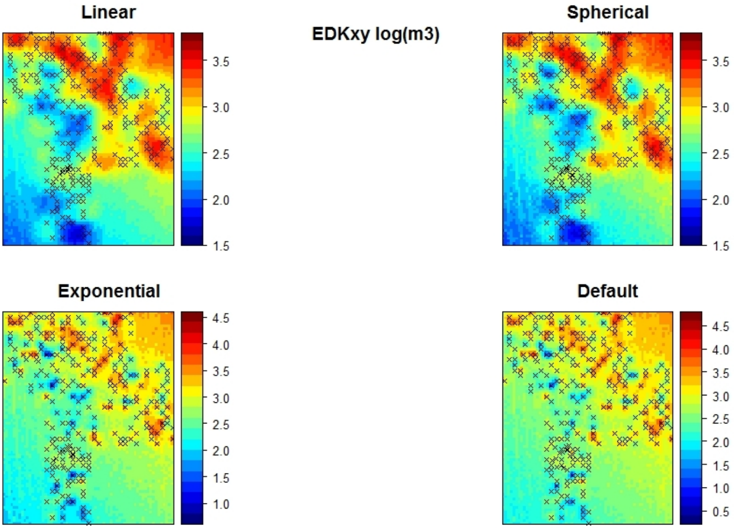
Universal Kriging (UK)



External Drift Kriging (EDK NDVI)



External Drift Kriging (EDK NDVI+x+y)



Cross-Validation Kriging

- The cross validation compares the effectiveness and accuracy of assessment methods and assess the model behavior.
- We have used *Cross-validation Kriging* (Goovaerts, 1997) with 1 folder (*Leave-One-Out*, LOO), 5 and 10 *folders*.
- This type of validation involves:
  - The estimate for all sampling locations
  - The comparison of estimates to the values observed in these locations

Cross-Validation Kriging: OK

OK	ME	MAE	MSE	RMSE	MSRE	RVar	EF	E
Linear 1	0,004	0,603	0,577	0,76	1,103	0,239	0,134	13,412
Linear 5	0,006	0,601	0,563	0,75	1,056	0,227	0,155	15,513
Linear 10	0,008	0,605	0,58	0,761	1,097	0,237	0,13	13,025
Exponential 1	0,003	0,603	0,571	0,756	1,076	0,221	0,143	14,277
Exponential 5	0,005	0,599	0,564	0,751	1,042	0,207	0,154	15,411
Exponential 10	0,006	0,601	0,568	0,754	1,061	0,218	0,147	14,744
Spherical 1	0,004	0,602	0,57	0,755	1,087	0,214	0,145	14,478
Spherical 5	0,009	0,607	0,579	0,761	1,09	0,208	0,131	13,139
Spherical 10	-0,004	0,602	0,575	0,758	1,088	0,209	0,138	13,792
Default 1	0,003	0,602	0,571	0,755	1,07	0,22	0,144	14,379
Default 5	-0,001	0,605	0,582	0,763	1,072	0,226	0,127	12,686
Default 10	0,006	0,603	0,578	0,761	1,076	0,224	0,132	13,22

OK	MSNE	RMNSE	MDE	COP1	COP2	CPR1	CPR2	EV
Linear 1	1,103	1,05	2,836	0,382	0,382	-0,115	-0,115	0,134
Linear 5	1,056	1,028	2,836	0,401	0,401	-0,082	-0,082	0,155
Linear 10	1,097	1,047	2,836	0,377	0,377	-0,118	-0,118	0,13
Exponential 1	1,076	1,037	2,836	0,387	0,387	-0,09	-0,09	0,143
Exponential 5	1,042	1,021	2,836	0,397	0,397	-0,063	-0,063	0,154
Exponential 10	1,061	1,03	2,836	0,391	0,391	-0,082	-0,082	0,147
Spherical 1	1,087	1,043	2,836	0,388	0,388	-0,081	-0,081	0,145
Spherical 5	1,09	1,044	2,836	0,372	0,372	-0,09	-0,09	0,132
Spherical 10	1,088	1,043	2,836	0,38	0,38	-0,084	-0,084	0,138
Default 1	1,07	1,035	2,836	0,388	0,388	-0,088	-0,088	0,144
Default 5	1,072	1,035	2,836	0,371	0,371	-0,111	-0,111	0,127
Default 10	1,076	1,037	2,836	0,376	0,376	-0,104	-0,104	0,132

Cross-Validation Kriging: UK

UK	ME	MAE	MSE	RMSE	MSRE	RVar	EF	E
Linear 1	-0,003	0,602	0,576	0,759	1,086	0,251	0,136	13,556
Linear 5	0,002	0,606	0,595	0,771	1,095	0,261	0,108	10,75
Linear 10	-0,003	0,61	0,592	0,769	1,103	0,272	0,113	11,251
Exponential 1	-0,013	0,607	0,577	0,76	1,039	0,228	0,134	13,396
Exponential 5	-0,014	0,603	0,568	0,754	1,006	0,226	0,148	14,819
Exponential 10	-0,01	0,61	0,588	0,767	1,049	0,221	0,118	11,844
Spherical 1	-0,001	0,604	0,577	0,76	1,087	0,24	0,134	13,395
Spherical 5	-0,003	0,619	0,61	0,781	1,126	0,24	0,085	8,497
Spherical 10	0,002	0,608	0,574	0,757	1,071	0,243	0,139	13,933
Default 1	-0,016	0,608	0,579	0,761	1,068	0,219	0,132	13,163
Default 5	-0,006	0,617	0,593	0,77	1,081	0,199	0,11	10,978
Default 10	-0,016	0,605	0,577	0,76	1,061	0,213	0,134	13,386

UK	MSNE	RMNSE	MDE	COP1	COP2	CPR1	CPR2	EV
Linear 1	1,086	1,042	2,836	0,386	0,386	-0,124	-0,124	0,136
Linear 5	1,095	1,046	2,836	0,361	0,361	-0,159	-0,159	0,108
Linear 10	1,103	1,05	2,836	0,369	0,369	-0,163	-0,163	0,113
Exponential 1	1,039	1,019	2,836	0,379	0,379	-0,106	-0,106	0,134
Exponential 5	1,006	1,003	2,836	0,394	0,394	-0,088	-0,088	0,148
Exponential 10	1,049	1,024	2,836	0,361	0,361	-0,116	-0,116	0,119
Spherical 1	1,087	1,043	2,836	0,382	0,382	-0,116	-0,116	0,134
Spherical 5	1,126	1,061	2,836	0,332	0,332	-0,165	-0,165	0,085
Spherical 10	1,071	1,035	2,836	0,388	0,388	-0,113	-0,113	0,139
Default 1	1,068	1,033	2,836	0,375	0,375	-0,1	-0,1	0,132
Default 5	1,081	1,04	2,836	0,346	0,346	-0,106	-0,106	0,11
Default 10	1,061	1,03	2,836	0,376	0,376	-0,092	-0,092	0,134

Cross-Validation Kriging: EDK NDVI

EDK	ME	MAE	MSE	RMSE	MSRE	RVar	EF	E
Linear 1	0,001	0,586	0,552	0,743	1,019	0,293	0,172	17,189
Linear 5	0,015	0,588	0,556	0,746	1,002	0,271	0,166	16,616
Linear 10	-0,006	0,591	0,552	0,743	1,008	0,283	0,172	17,198
Exponential 1	-0,002	0,591	0,554	0,744	0,983	0,255	0,169	16,926
Exponential 5	-6,71E-005	0,595	0,561	0,749	0,977	0,218	0,158	15,786
Exponential 10	0,01	0,597	0,555	0,745	0,974	0,242	0,168	16,751
Spherical 1	0,001	0,591	0,557	0,747	1,012	0,285	0,164	16,395
Spherical 5	-0,02	0,592	0,557	0,747	0,992	0,275	0,164	16,376
Spherical 10	-0,004	0,595	0,565	0,752	1,016	0,291	0,152	15,167
Default 1	-0,002	0,591	0,554	0,744	0,983	0,255	0,169	16,926
Default 5	-0,006	0,582	0,534	0,731	0,931	0,238	0,199	19,861
Default 10	-0,003	0,591	0,548	0,74	0,964	0,246	0,178	17,839

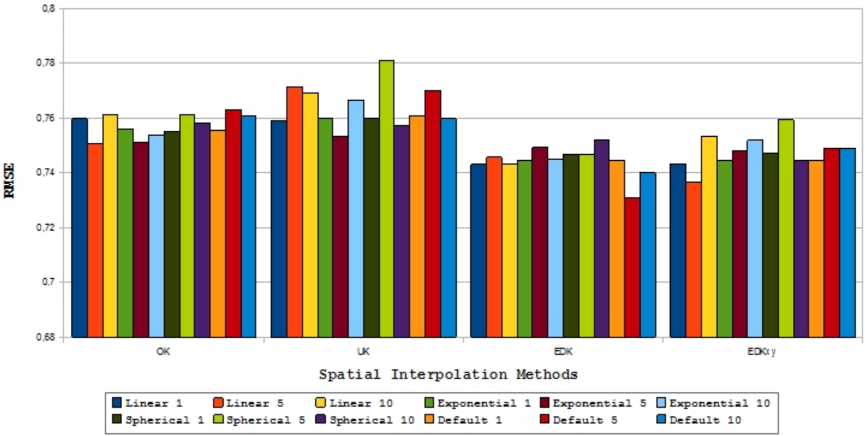
EDK	MSNE	RMNSE	MDE	COP1	COP2	CPR1	CPR2	EV
Linear 1	1,019	1,009	2,836	0,429	0,429	-0,123	-0,123	0,172
Linear 5	1,002	1,001	2,836	0,42	0,42	-0,11	-0,11	0,167
Linear 10	1,008	1,004	2,836	0,428	0,428	-0,115	-0,115	0,172
Exponential 1	0,983	0,992	2,836	0,42	0,42	-0,093	-0,093	0,169
Exponential 5	0,977	0,988	2,836	0,402	0,402	-0,07	-0,07	0,158
Exponential 10	0,974	0,987	2,836	0,416	0,416	-0,082	-0,082	0,168
Spherical 1	1,012	1,006	2,836	0,42	0,42	-0,124	-0,124	0,164
Spherical 5	0,992	0,996	2,836	0,419	0,419	-0,116	-0,116	0,164
Spherical 10	1,016	1,008	2,836	0,41	0,41	-0,14	-0,14	0,152
Default 1	0,983	0,992	2,836	0,42	0,42	-0,093	-0,093	0,169
Default 5	0,931	0,965	2,836	0,448	0,448	-0,045	-0,045	0,199
Default 10	0,964	0,982	2,836	0,428	0,428	-0,075	-0,075	0,178

Cross-Validation Kriging: EDK NDVI+x+y

EDKxy	ME	MAE	MSE	RMSE	MSRE	RVar	EF	E
Linear 1	-0,007	0,585	0,553	0,743	1,017	0,318	0,171	17,116
Linear 5	-0,008	0,584	0,543	0,737	0,977	0,304	0,186	18,577
Linear 10	-0,013	0,591	0,568	0,753	1,032	0,317	0,149	14,86
Exponential 1	-0,014	0,589	0,554	0,745	0,979	0,297	0,168	16,828
Exponential 5	-0,001	0,594	0,559	0,748	0,968	0,288	0,161	16,092
Exponential 10	-0,012	0,596	0,565	0,752	0,985	0,296	0,152	15,172
Spherical 1	-0,008	0,589	0,558	0,747	1,013	0,316	0,163	16,334
Spherical 5	-0,001	0,603	0,577	0,759	1,017	0,304	0,135	13,486
Spherical 10	0	0,588	0,555	0,745	1,001	0,312	0,168	16,795
Default 1	-0,017	0,59	0,554	0,745	0,998	0,291	0,168	16,846
Default 5	0,008	0,595	0,561	0,749	0,994	0,282	0,158	15,835
Default 10	-0,011	0,595	0,561	0,749	1,004	0,292	0,159	15,869

EDKxy	MSNE	RMNSE	MDE	COP1	COP2	CPR1	CPR2	EV
Linear 1	1,017	1,009	2,836	0,434	0,434	-0,143	-0,143	0,171
Linear 5	0,977	0,988	2,836	0,444	0,444	-0,119	-0,119	0,186
Linear 10	1,032	1,016	2,836	0,414	0,414	-0,162	-0,162	0,149
Exponential 1	0,979	0,989	2,836	0,427	0,427	-0,129	-0,129	0,169
Exponential 5	0,968	0,984	2,836	0,418	0,418	-0,129	-0,129	0,161
Exponential 10	0,985	0,992	2,836	0,412	0,412	-0,144	-0,144	0,152
Spherical 1	1,013	1,006	2,836	0,426	0,426	-0,148	-0,148	0,163
Spherical 5	1,017	1,009	2,836	0,398	0,398	-0,165	-0,165	0,135
Spherical 10	1,001	1	2,836	0,43	0,43	-0,142	-0,142	0,168
Default 1	0,998	0,999	2,836	0,426	0,426	-0,124	-0,124	0,169
Default 5	0,994	0,997	2,836	0,415	0,415	-0,127	-0,127	0,158
Default 10	1,004	1,002	2,836	0,417	0,417	-0,135	-0,135	0,159

Cross-Validation Kriging: RMSE



Conclusions and Future Work

- The results showed that kriging methods are useful in estimation tasks forest area data such as biomass, forest fuels, etc.
- The use of the remote sensing information provided by the Landsat image improved the estimation quality.

Conclusions and Future Work

- Futher work will be addressed to asses the usefulness of new external variables in the EDK approaches.
  - Leaf Area Index (LAI)
  - Field data plot altitude
  - Type of vegetation in the study area.
- Applicability of other spatial interpolation approaches.

Acknowledgments

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Thanks for your attention

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