Analysis and validation of grid DEM generation based on Gaussian Markov Random Field

Fernando J. Aguilar [a], Manuel A. Aguilar [a], José L. Blanco [a], Abderrahim Nemmaoui [a] and Andrés M. García-Lorca[b]

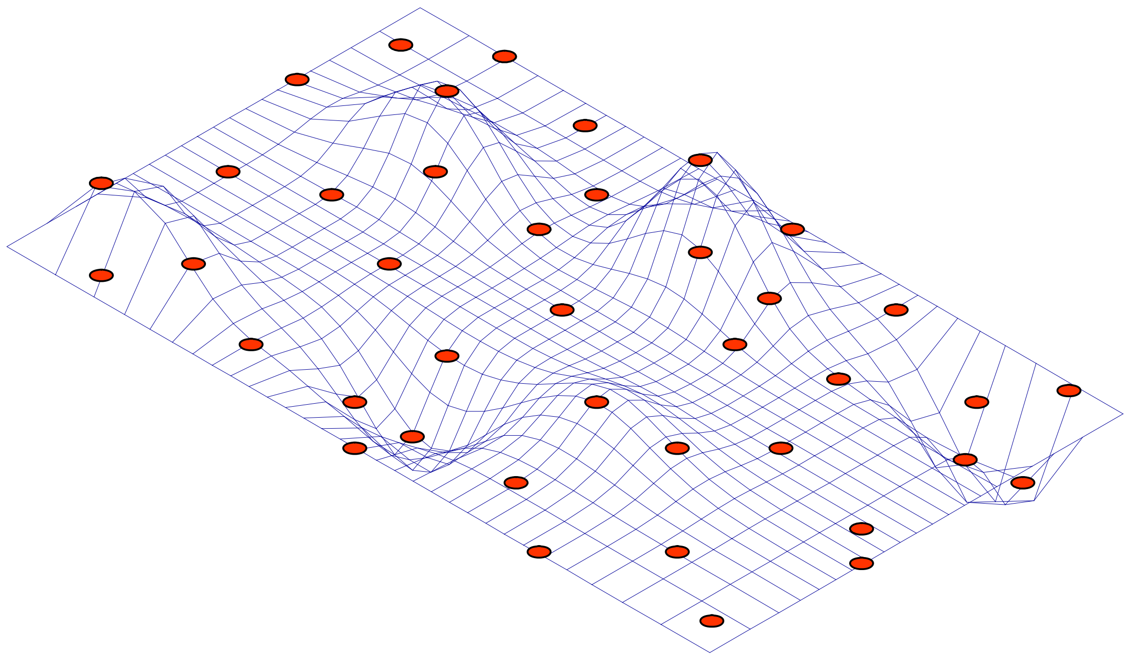
(a) Department of Engineering. University of Almería, Spain.
(b) Department of Geography, History and Humanities. University of Almería, Spain.

Funded by the Research Projects **AGL2014-56017-R** and **DPI2014-56364-C2-1-R**

Introduction

Goal:

Efficient generation of accurate Grid Digital Elevation Models from scattered elevation data including grid elevations uncertainty estimate



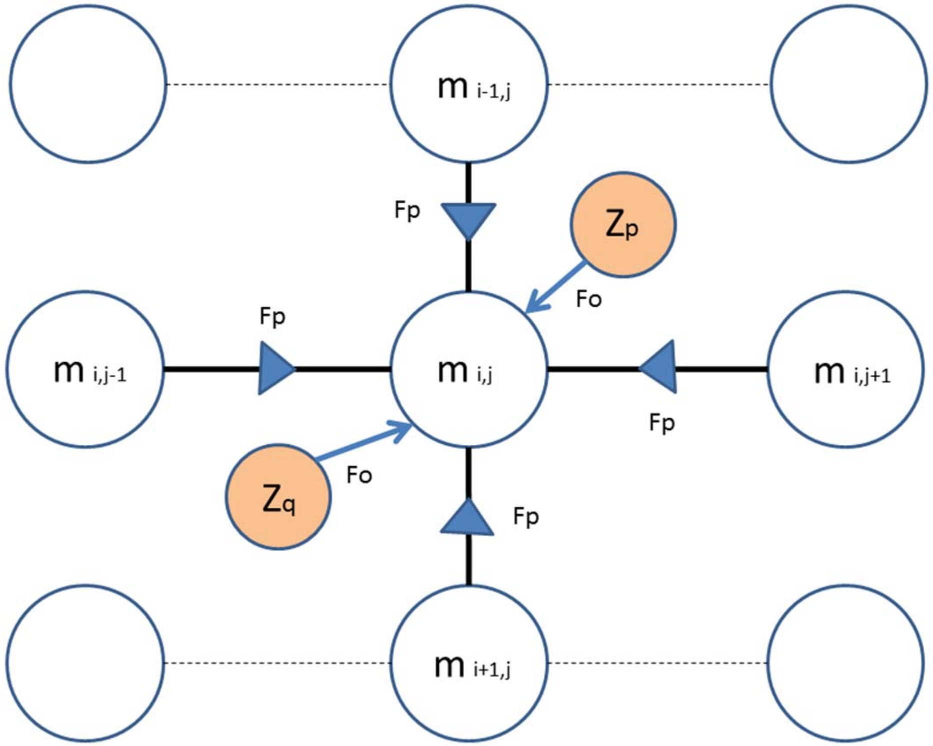
Introduction: Mathematical Framework

Gaussian Markov Random Field (GMRF) to estimate the maximum a posteriori (MAP) grid elevations and their vertical uncertainty

Graphical model for involved Factors:

Observation Factors (Fo)

Prior Factors (Fp)



GreenhouseSat

Introduction: Mathematical Framework

The joint probability distribution to be maximised would the following one:

$$p(m,z) \propto e^{\left(-\sum_{C_o} E_o(n_{c_o}) - \sum_{C_p} E_p(n_{c_p})\right)} \left\{ \begin{array}{l} E_p = \sum_{C_p} E_p(n_{Cp}) = \sum_{k=1}^{L} \frac{(m_{ik} - m_{jk})^2}{\sigma_p^2 / (1 - P(d_{i,j}))^2} \\ E_o = \sum_{C_o} E_o(n_{C_o}) = \sum_{k=1}^{M} \frac{(m_{ik} - z_k)^2}{\sigma_s^2} \end{array} \right.$$

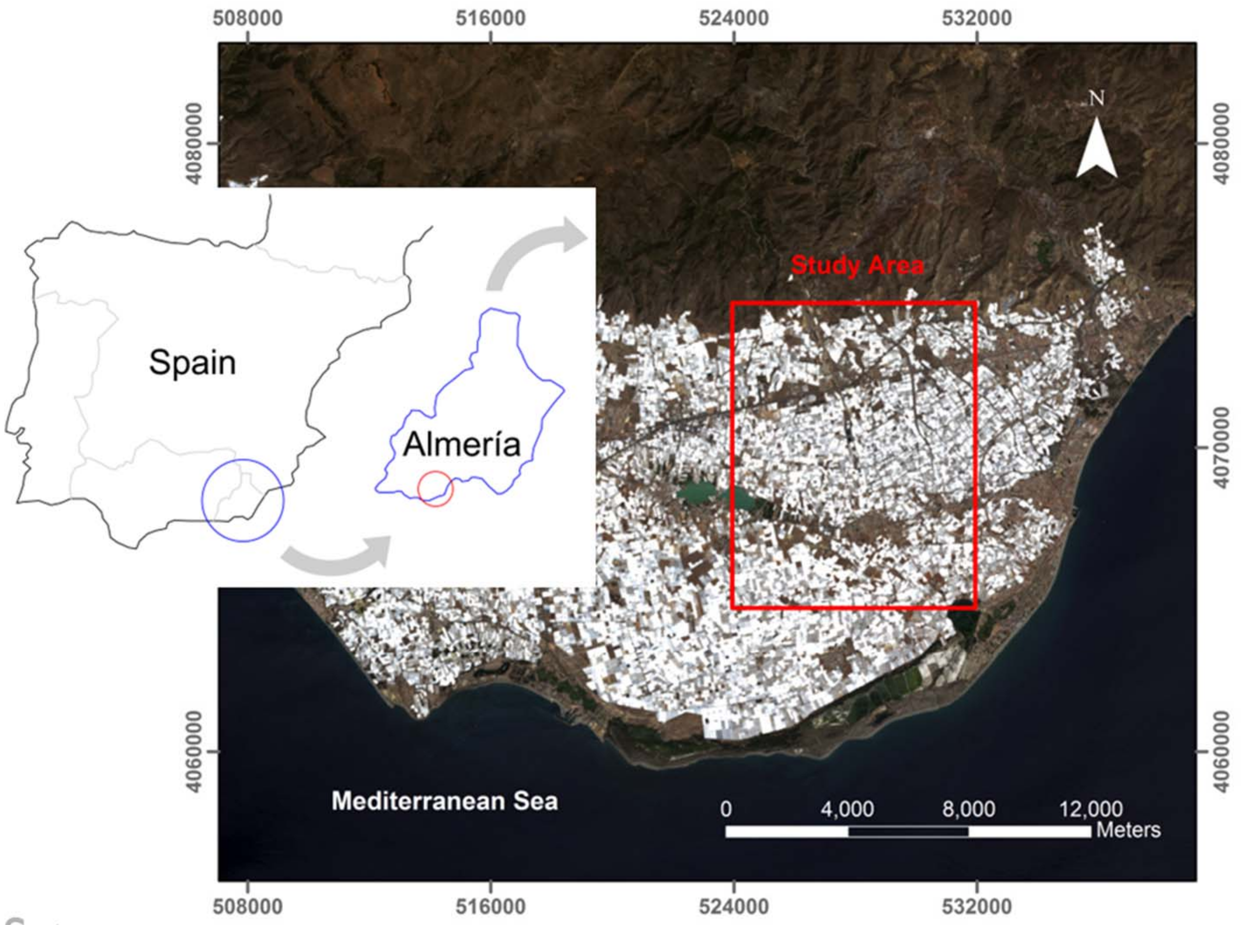
$$\sigma_s = \left(\frac{6}{\sqrt{n}} + 50.\tan\alpha \right) / 100$$

Karel & Kraus (2006)

GreenhouseSat

Study Site and Dataset

Very dense greenhouse covered area located at Almería, southern Spain



GreenhouseSat

Study Site and Dataset

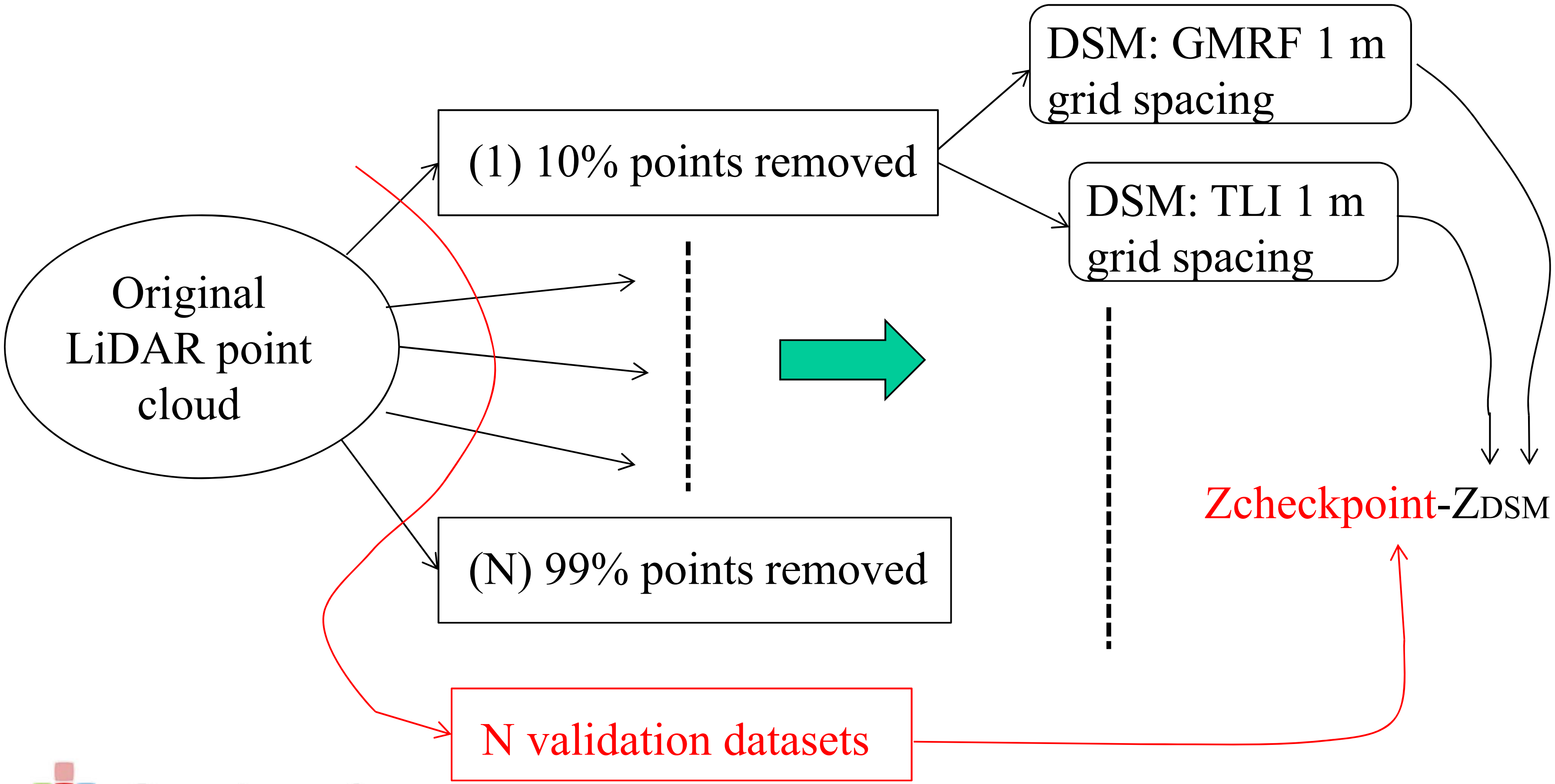
Coloured LiDAR point cloud from PNOA (National Plan of Aerial Orthophotography of Spain).

Sensor: **Leica ALS60**; Flight Height: **2700 m**; Date: September 2015
Point density: **0.87 points/m2**; Single point returns
Reference System: ETRS89 UTM 30N; Orthometric elevations (EGM08-REDNAP)
Vertical error (at open terrain GPS-RTK derived Check Points): **0.14 m**

GreenhouseSat

Methods

DSM accuracy assessment



GreenhouseSat

Results: Sensitivity analysis for σ_p

The lower the tolerance parameter, the higher the smoothing GMRF derived DSM

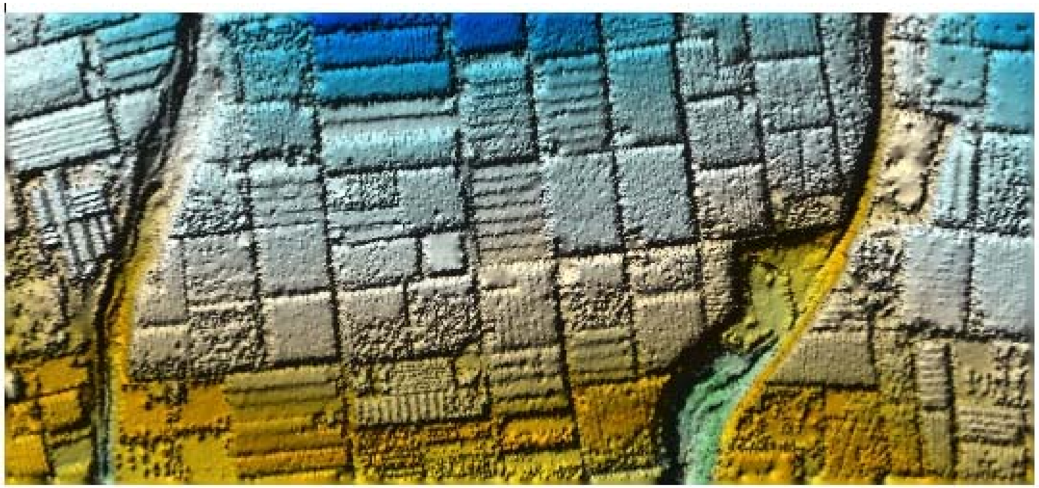
Observed points: 10% of the original dataset[1]			Observed points: 1% of the original dataset[2]		
σ_p (m)	$rmse_z$ (m)	mean error (m)	σ_p (m)	$rmse_z$ (m)	mean error (m)
0.2	0.803	0.008	0.2	1.274	0.011
0.6	0.765	0.013	0.6	1.186	0.002
1	0.765	0.002	1	1.148	0.011
1.4	0.761	0.007	1.4	1.146	0.029
1.8	0.758	0.008	1.8	1.141	-0.0018
2.2	0.760	0.003	2.2	1.143	0.010
2.6	0.761	0.002	2.6	1.158	-0.001
3	0.762	0.008	3	1.140	0.000
4	0.761	0.004	4	1.153	0.008
10	0.761	0.007	10	1.162	0.031

EGS (1) = 10.74 m; EGS (2) = 33.97 m

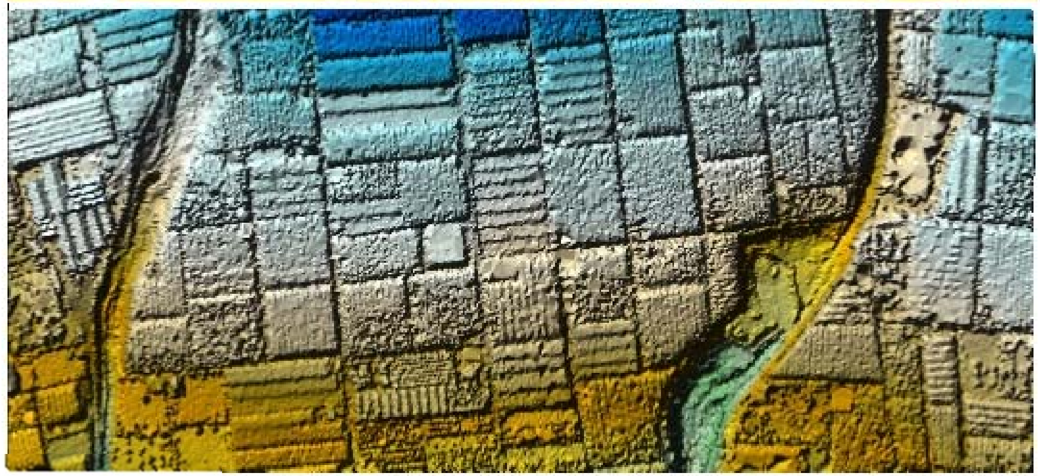
GreenhouseSat

Results: GMRF vs TLI

Qualitative comparison (case 10% observed points; EGS = 10.74 m)



1 m GMRF DSM



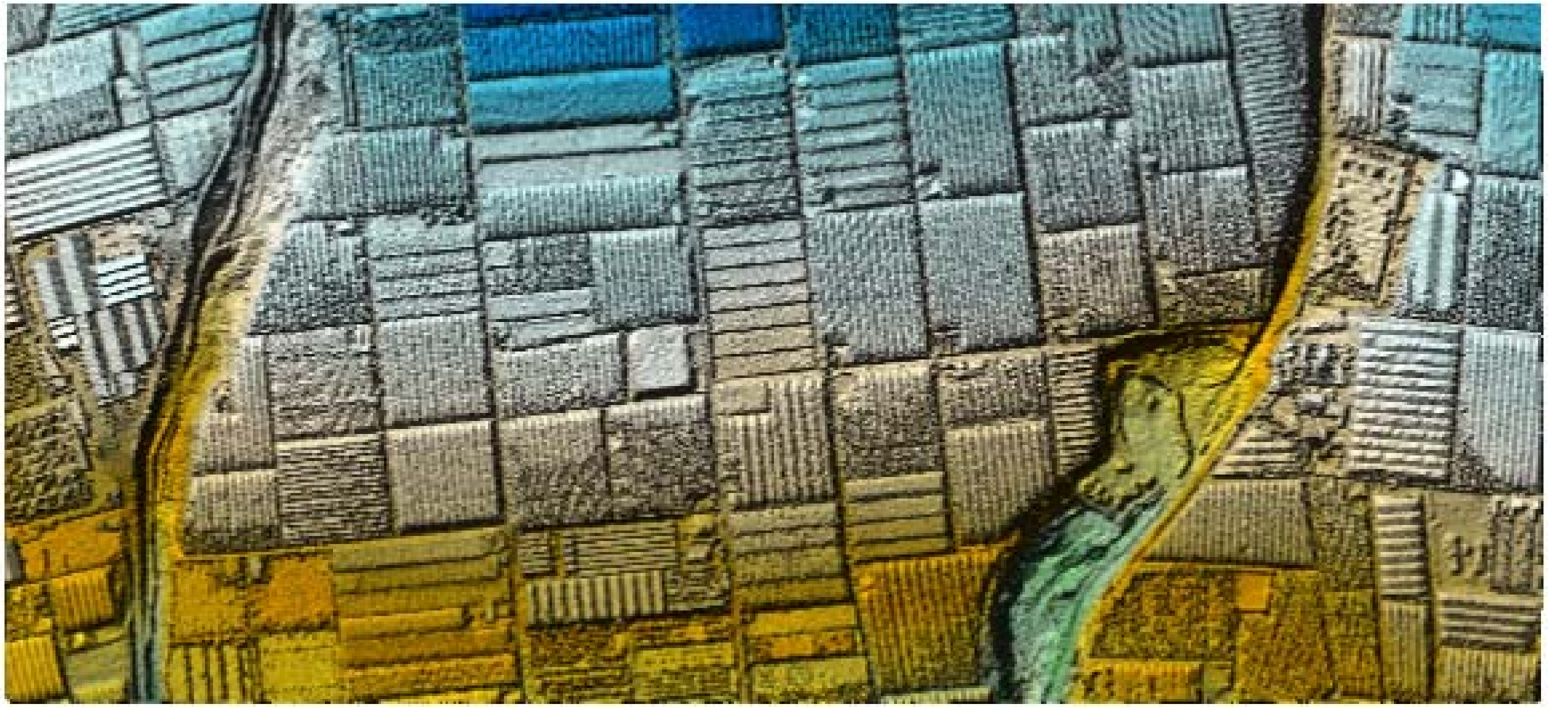
1 m TLI DSM

GreenhouseSat

Results: GMRF vs TLI

Qualitative comparison (case 90% observed points; EGS = 1.13 m)

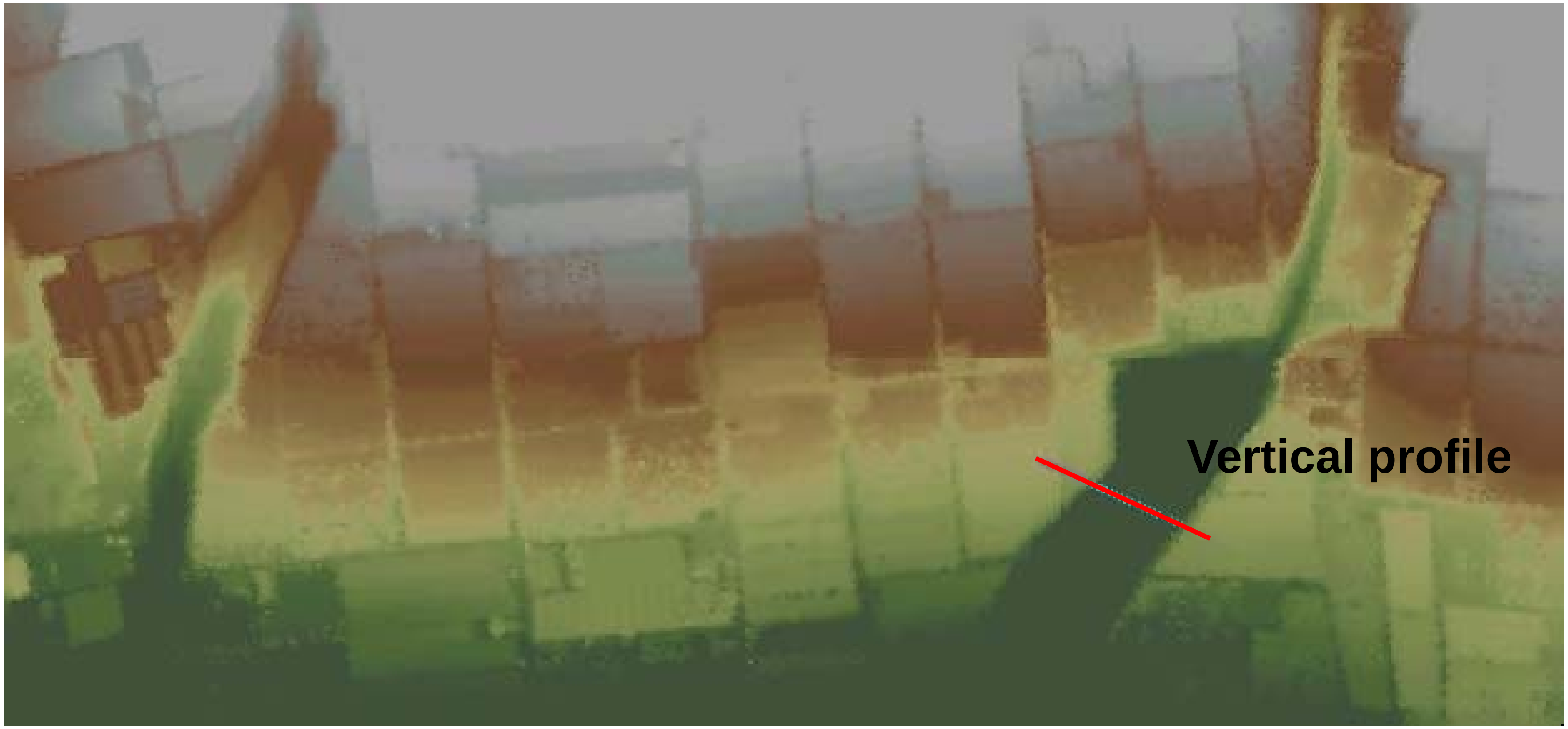
1 m GMRF DSM



GreenhouseSat

Results: GMRF vs TLI

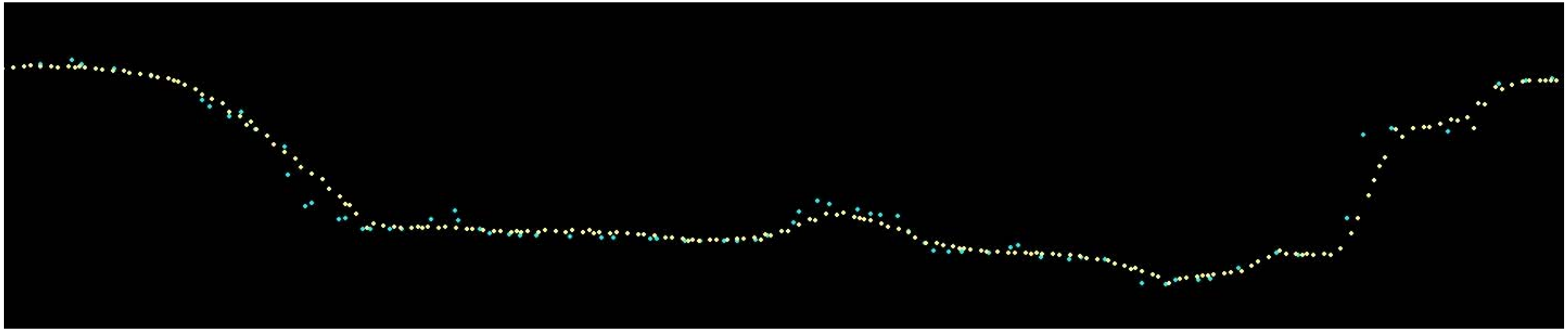
Qualitative results



GreenhouseSat

Results: GMRF vs TLI

Qualitative results (10% observed points; EGS = 10.74 m)

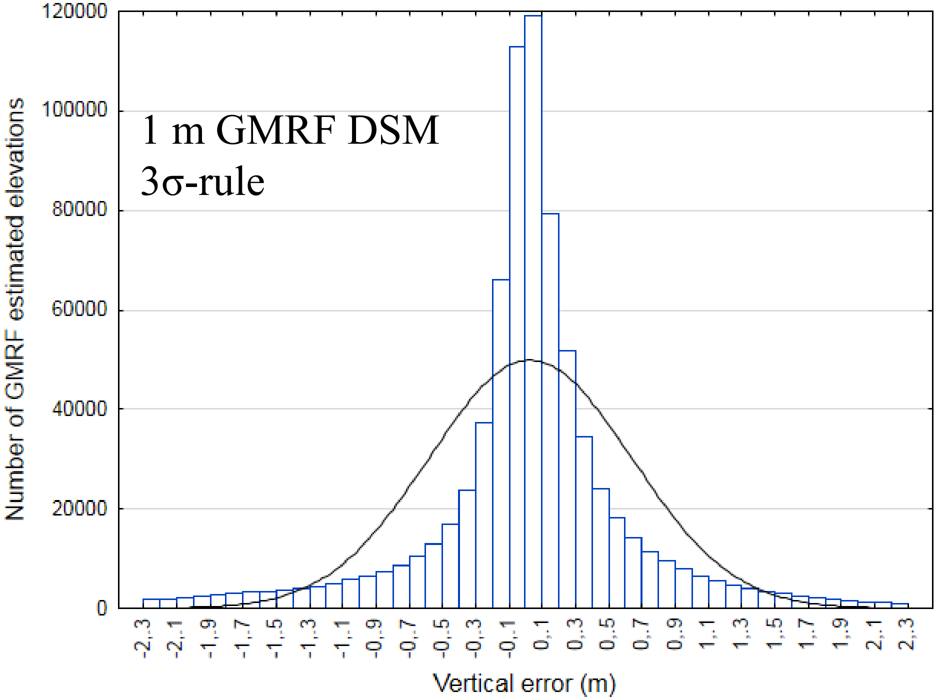


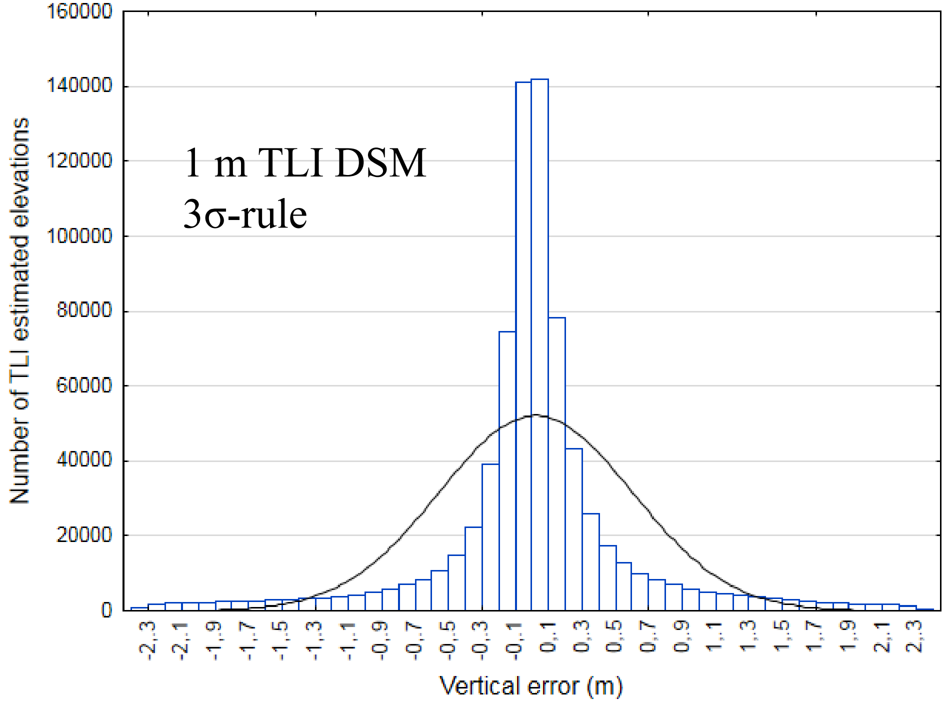
- 1 m GMRF DSM
- LiDAR points

GreenhouseSat

Results: GMRF vs TLI

Quantitative results (10% observed points; EGS = 10.74 m)



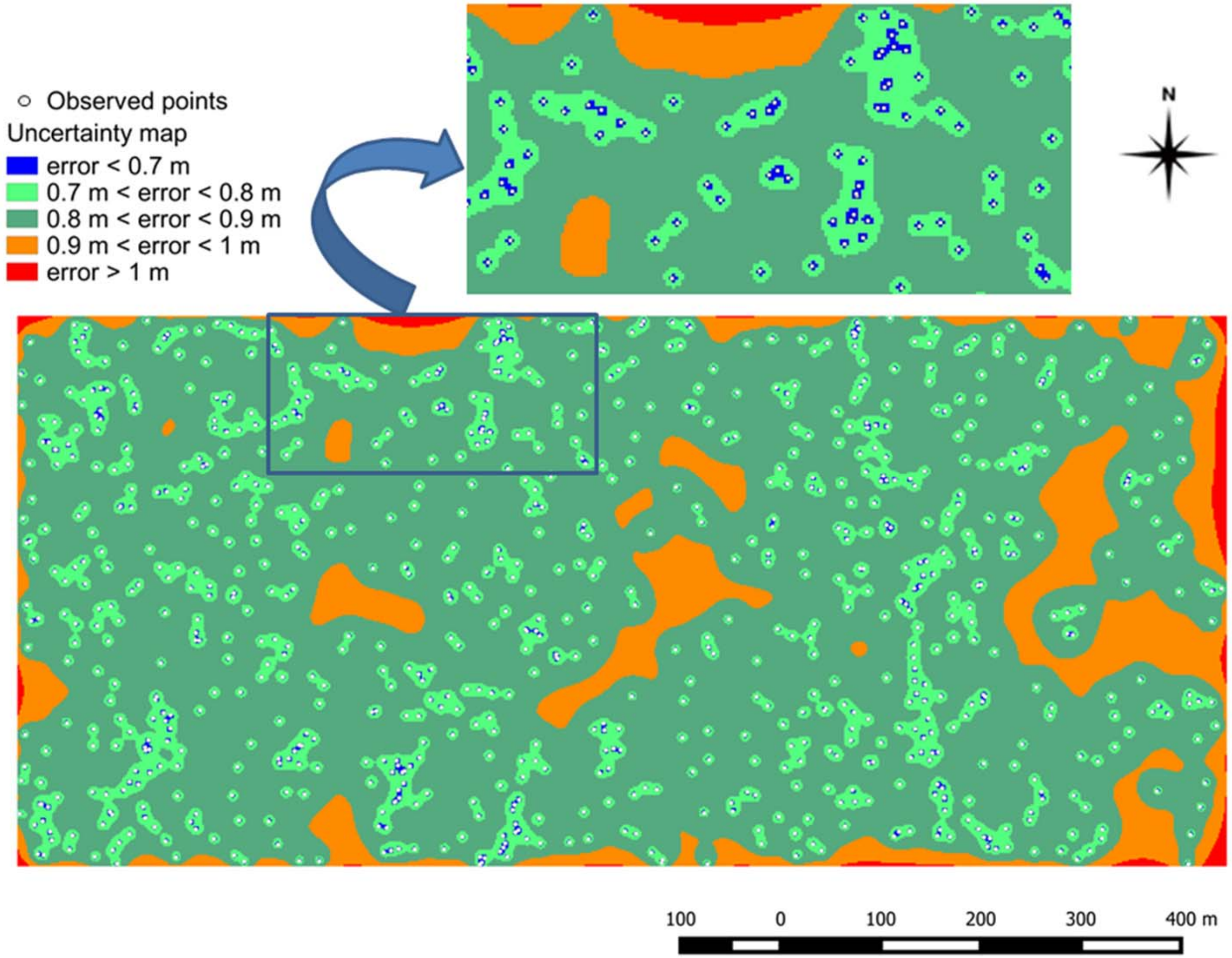


Leptokurtic and unbiased residual distributions

GreenhouseSat

Results: DSM vertical uncertainty

2 m GMRF DSM



GreenhouseSat

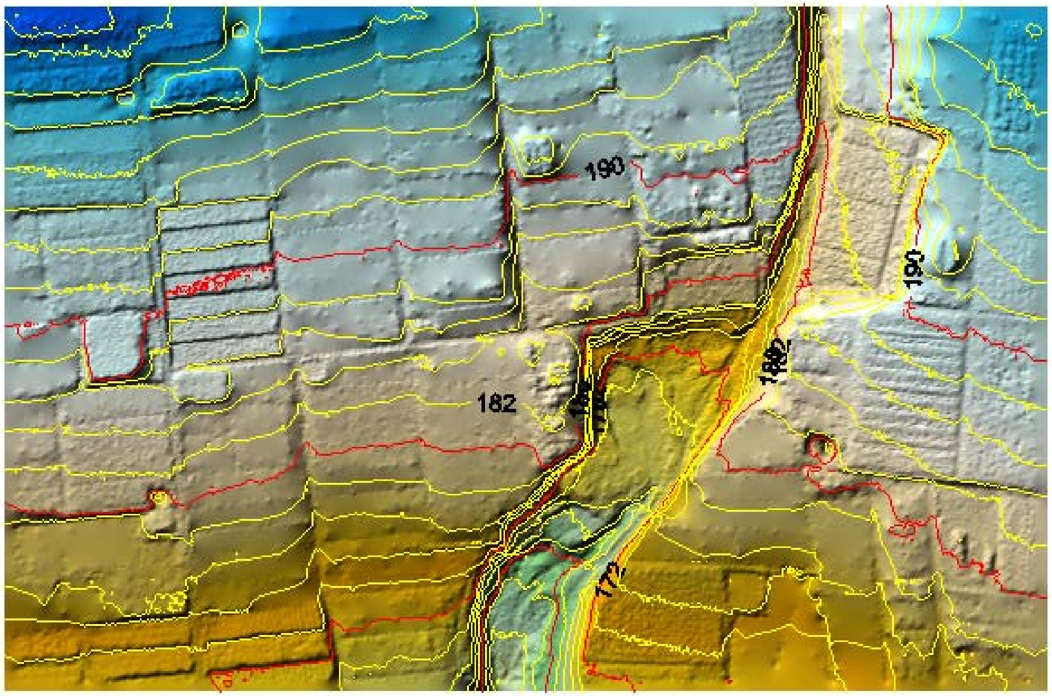
Results: Real-world application

LiDAR ground points filtering applying Lastools and a subsequent manual edition

227084 ground points

1141 check points

1 m GMRF DTM



RMSEz = 28 cm
Mean error = 0.3 cm

Conclusions

The results provided by the proposed GMRF interpolation method may be deemed as very promising, producing visually pleasing and accurate digital elevation models.

GMRF yielded similar qualitative and quantitative results as compared to TLI method. Both methods do not require to specify the local support or kernel.

As a bonus, the mathematical framework implemented through GMRF algorithm makes possible to easily retrieve the maximum a posteriori estimation of every interpolated elevation point (mapping vertical uncertainty) and also include break lines, at least theoretically, to obtain high quality DTMs.

Thank you very much for your kind attention

GreenhouseSat

Open code available at:
https://github.com/3DLAB-UAL/dem-gmrf