# Accuracy analysis of height difference models derived from terrestrial laser scanning point clouds

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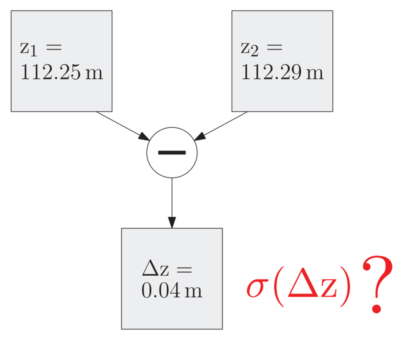
## 1 Aim of this Study

In many research areas the **temporal development of the earth surface** topography is investigated for geomorphological analysis (e.g. landslide monitoring). **Terrestrial laser scanning** (TLS) is often used for this purpose, as it allows a fast and detailed 3d reconstruction.
Earth surface changes are usually investigated on the basis of rasterized data, i.e. **digital terrain models** (DTM). The difference between two DTMs - the **difference model** - should correspond to the occurred terrain height changes between the measurement campaigns. Actually, these height differences can be influenced by **numerous potential error sources**.
In this study a method for the error estimation of the difference model is presented. The result is, besides the difference model itself, an **error map**, which describes the **uncertainity of the estimated height differences**.

Fig.1: Precision estimation for a difference model.




## A Study Area

The study area is situated in the forefield of the **Gepatschferner, Oetztal alps, Austria** which is overtowered by steep moraine slopes of the Little Ice Age glacial maximum (Fig.2). For **multi-epoch georeferencing** of the TLS scans, **8 reflectors** were mounted on immobile bedrock faces. The surveys were carried out in 2011 and 2012.

Fig.2: The study area with highlighted features for the scan orienation.


## 2 Scan Registration

In order to achieve an optimal registration of the two TLS scans, the **orientation process** is divided into **two steps**:

1. Indipendent orientation of the scans using the mounted **reflectors** (Fig.2).
2. Orientation improvement by the **Iterative Closest Point** (ICP) algorithm minimizing the point-to-plane distances $\Delta p$ (Fig.3) within **stable areas** (Fig.2).

Fig.4 shows the final distribution of the point-to-plane distances for the study area.

Fig.3: Minimization of point-to-plane distances

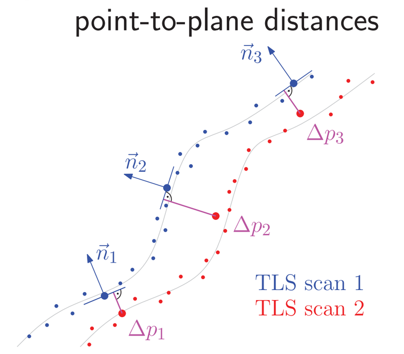
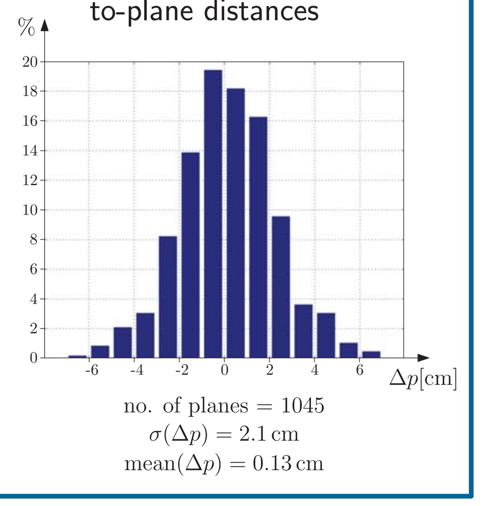


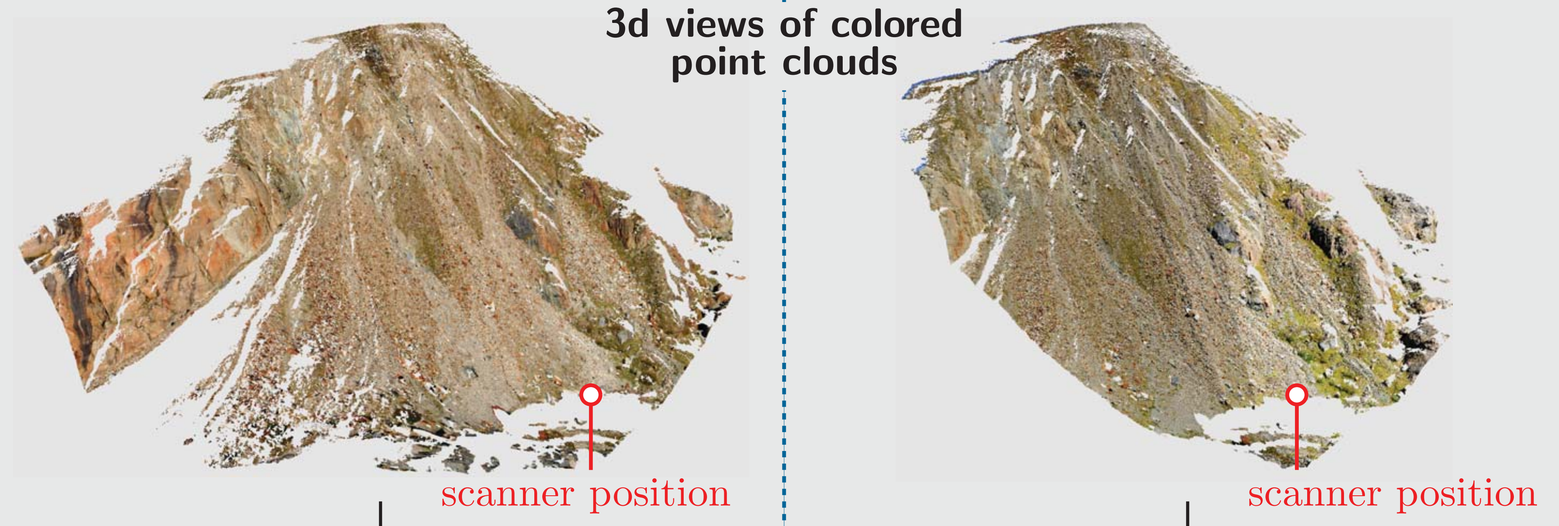

Fig.4: Histogram of all point-to-plane distances

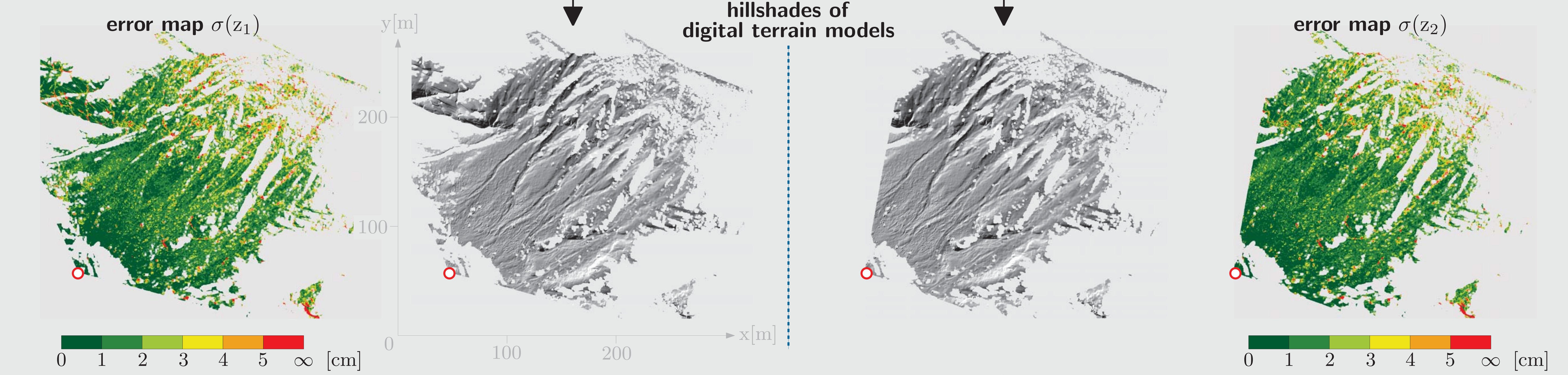



## B Difference Model Derivation

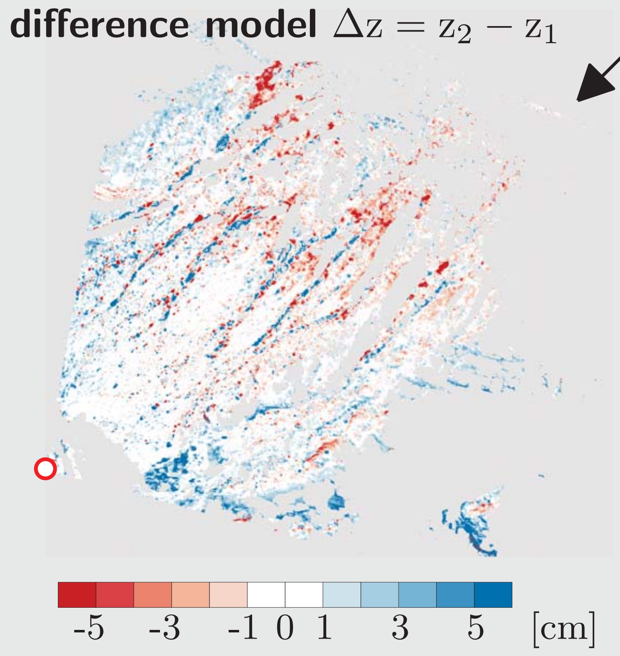
TLS scan 1 (2011/09)

TLS scan 2 (2012/09)

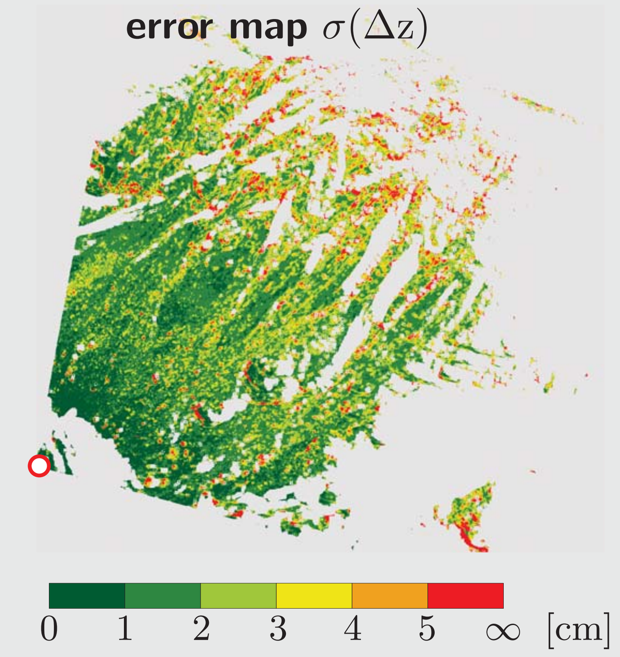



difference model $\Delta z = z_2 - z_1$




error map $\sigma(\Delta z)$




## 3 DTM Interpolation

For the DTM generation the **moving planes interpolation** method is proposed (Fig.5). For each grid cell a best fitting tilted plane (minimizing the vertical distances $\Delta z$ of all points within a specified radius $r$) is estimated.

Fig.5: DTM interpolation

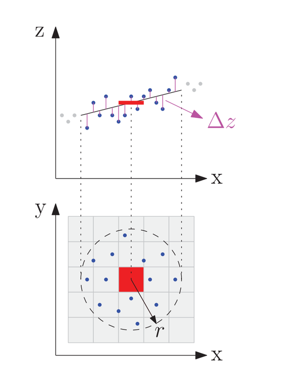
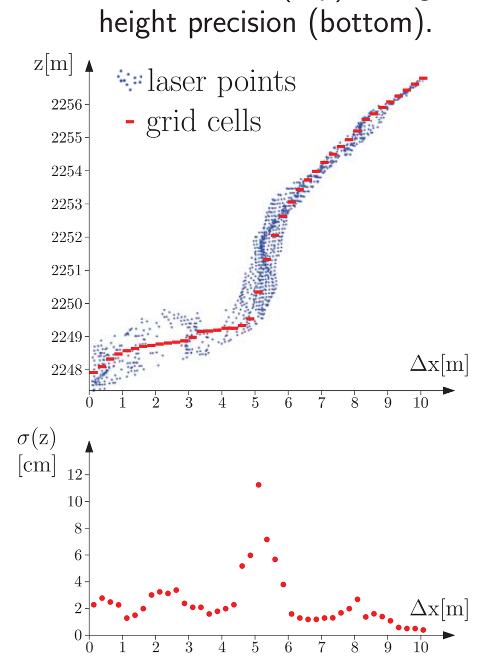



Fig.6: Cross section (top) and grid height precision (bottom).



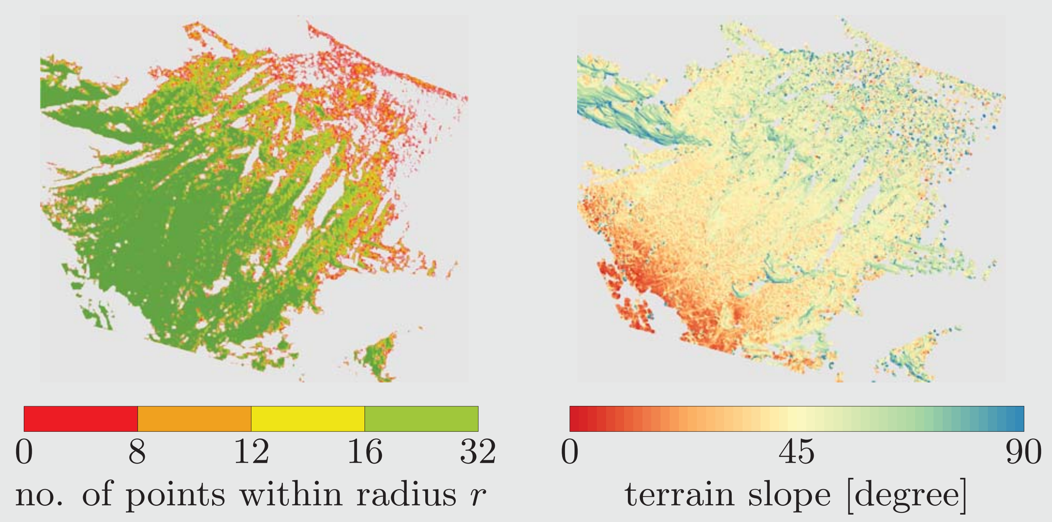

The least squares adjustment performed for the tilted plane interpolator allows the estimation of the **grid height precision** $\sigma(z)$. As can be seen in Fig.6, $\sigma(z)$ mainly depends of:

- the **vertical distribution** of points.
- the number of points within the search radius, i.e. **point density**.
- the **roughness** of the sampled terrain.

## C Parameters for DTM derivation

For the DTM derivation the **moving planes interpolation** was used with a grid size of 25 cm. Within the radius of 1 m a maximum number of 32 points were used for the plane estimation. In order to **avoid extensive extrapolation**, the distance between (1) the grid center and (2) the center of gravity of the points was limited to 0.5 m (excentricity).

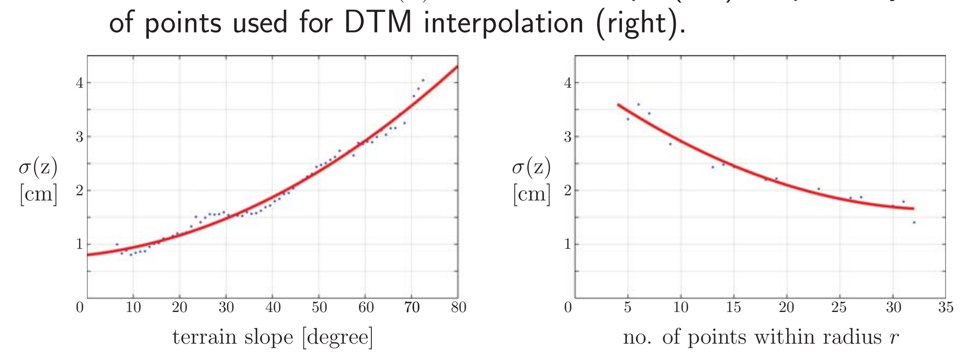
Fig.8: No. of used points for DTM interpolation (left) and terrain slope (right).




## 4 Precision Analysis

The grid height precision $\sigma(z)$ describes the **uncertainty of the estimated grid heights** and is visualized as **error map** for both DTMs in Block B. In Fig.7 the influence of the **terrain slope** (left) and the **point cloud density** (right) on the resulting $\sigma(z)$ is shown.

Fig.7: Correlation between $\sigma(z)$ and terrain slope (left), respectively no. of points used for DTM interpolation (right).




The aim of this study is the derivation of an **error map for the difference model**. This is obtained by propagation of error:

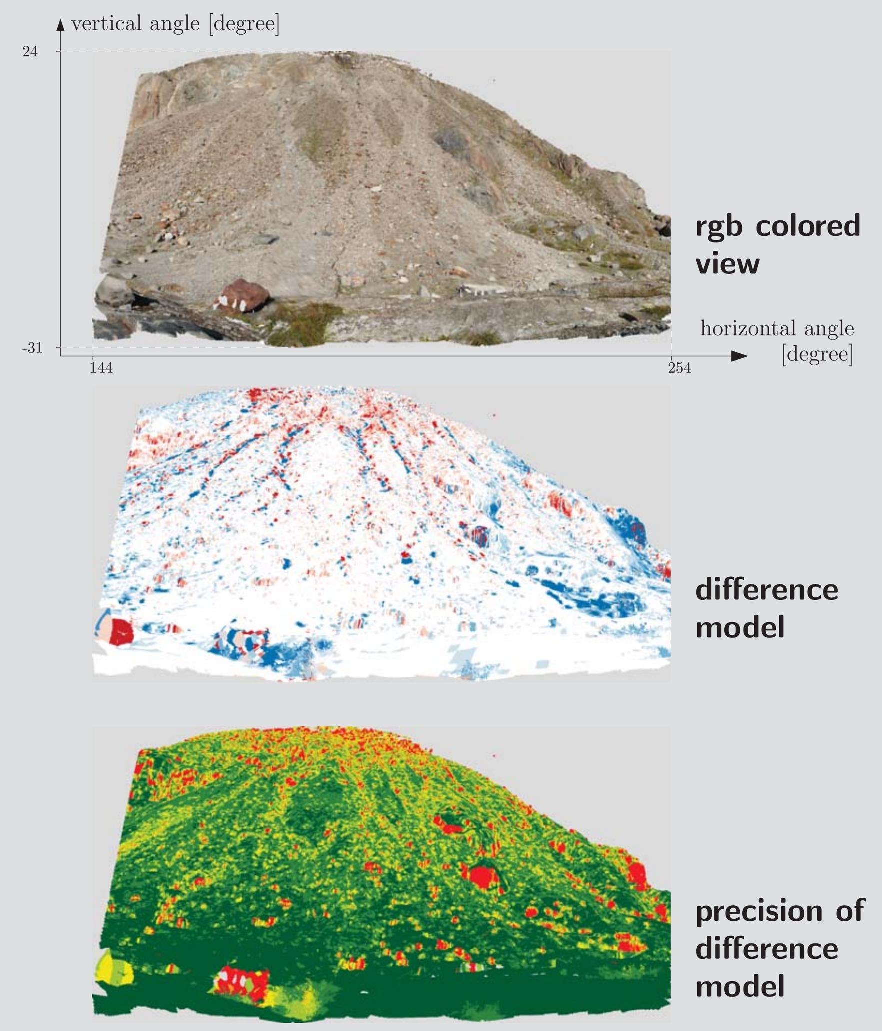
$$\sigma(\Delta z) = \sqrt{\sigma(z_1)^2 + \sigma(z_2)^2}$$

The error map can be used to **judge the reliabilty of the estimated height differences**. In a futher processing step this quality information may be used for **removing erroneous cells** (e.g. all cells with $\sigma(\Delta z) > 5$ cm).

## D Results in Spherical CS

In Fig.5 results are visualized in the spherical coordinate system of scan 1. These visualizations show the data as seen from the scanners center, i.e. without occlusions.

Fig.5: Visualizations in the spherical coordinate system of scan 1.




## 5 Conclusion

Digital terrain models (usually) are **2.5d** representations of the earth surface. Especially in **steep areas** and areas with **low point density** the **grid height estimation is uncertain**. This uncertainity can be estimated within the DTM generation process for each cell.
The main result of this study is the **error map for the difference model**. The error map gives information about the **reliabilty of the estimated height differences**.

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