Evaluation of Height Models

Karsten Jacobsen

Leibniz University Hannover, Germany
Institute of Photogrammetry and Geoinformation

jacobsen@ipi.uni-hannover.de

Introduction

Height models (Digital Elevation Models) are a part of spatial data

Quite simpler by the data structure, but “they shall be correct” – what is correct ?

Quality of DEM: accuracy, morphologic correctness and details

Accuracy: absolute accuracy, relative accuracy, accuracy numbers (RMSE, SZ, NMAD, LE90)

+ accuracy dependencies

Morphologic details: dominated by point spacing, relative accuracy, generalization

Very often morphologic quality is ignored

Source of data specifies the character:

optical images – aerial, from space (+ terrestrial, mobile mapping systems)

LiDAR – aerial (+ terrestrial, mobile mapping)

Radar – **In**terferometric **S**ynthetic **A**perture **R**adar (**InSAR**) (covering large areas)

(Radargrammetry – not for large areas)

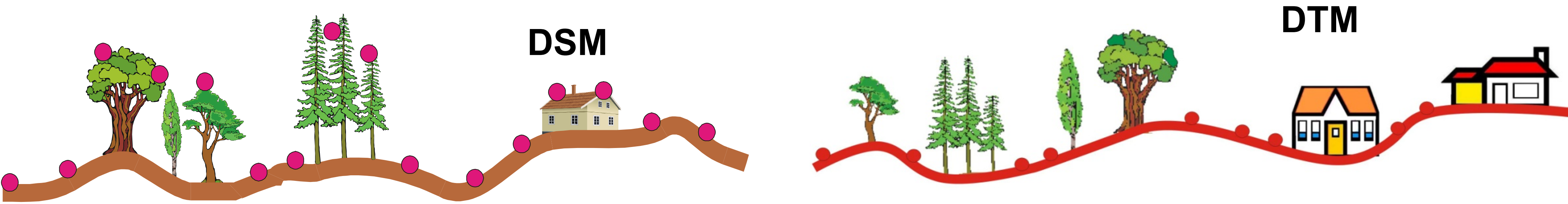
from air and from space

Accuracy determination

Complete accuracy determination of a DEM by comparison with a reference DEM

No complete analysis of a DTM by comparison with check points – check points usually only in flat and open areas, no satisfying density for accuracy function from terrain slope, not enough points for detailed analysis as systematic errors as function of location,
no determination of relative accuracy

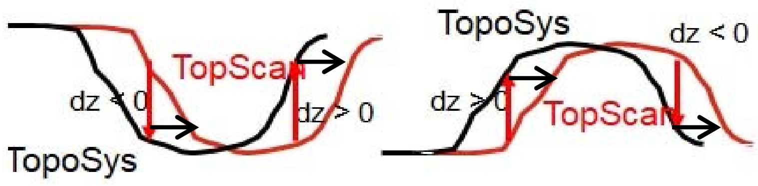
No comparison of a DTM with a DSM – influence of vegetation + buildings
- **question of definition** and not a question of accuracy



Buildings + trees not only location of points on objects, also influence of occlusions

Horizontal fit – shifts; accuracy analysis by comparison of 2 DTMs

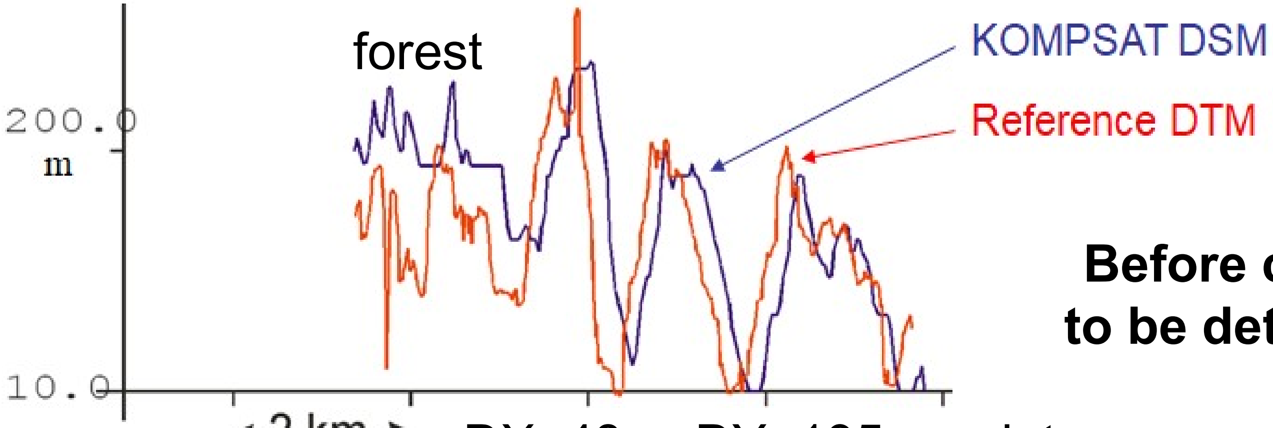
Differences $dz = z_{TopoSys} - z_{TopScan}$
large differences in areas
of large undulations



Horizontal shift 4 – 5m

2m
<-2m
-2m bis -1m
-1m bis -0.5m
+0.5 bis +1m
+1m bis +2m
>+2m
-2m

Comparison of 2 LiDAR
data sets
- horizontal shifts



DX=48m DY=195m – datum errors

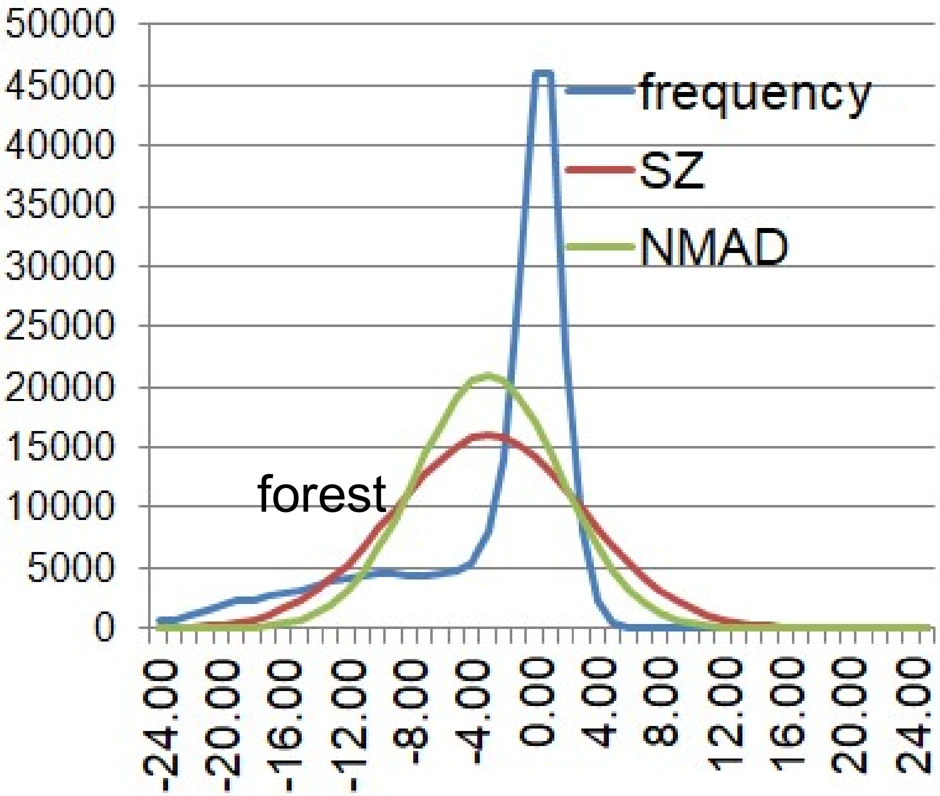
Comparison of aerial DTM
with DSM based on space images
mountainous area, Turkey

Before comparison of 2 DEMs shifts have to be determined + tilts + systematic errors

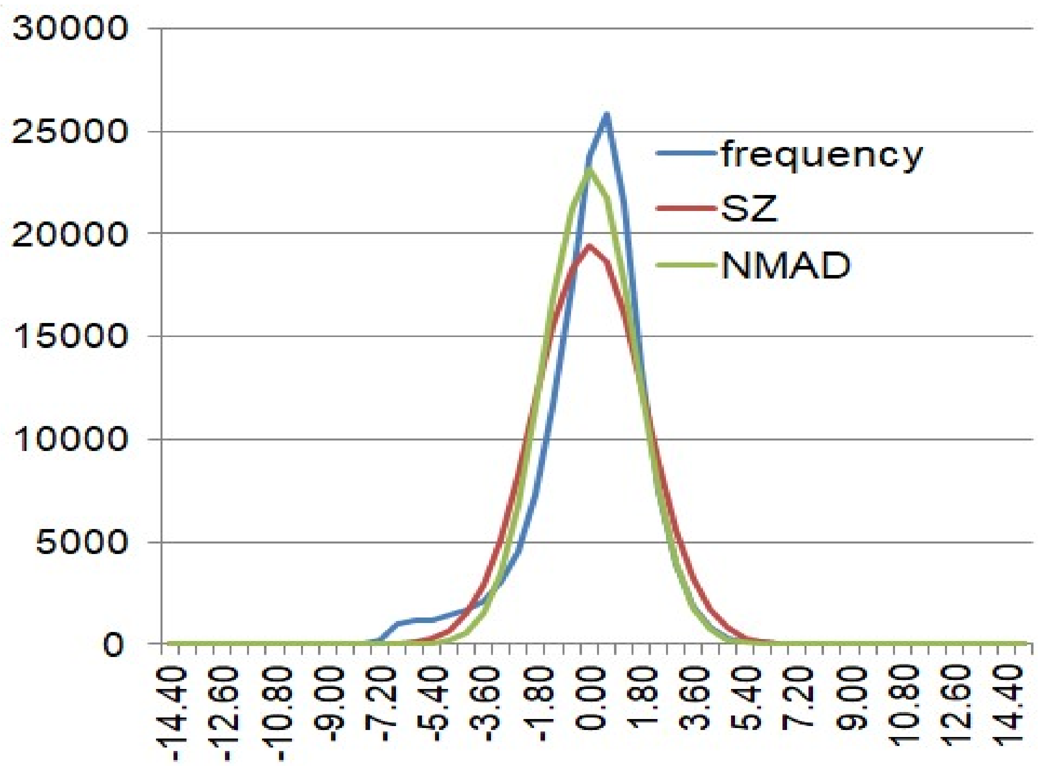
Accuracy figures

Abbreviation	Accuracy figures
RMSZ	Root mean square height differences - square sum + bias
SZ	Standard deviation of height differences (based on discrepancies minus bias), 68% probability square sum influenced by large discrepancies
MAD	Median absolute deviation for height (median value of absolute differences), 50% probability
NMAD	Normalized median absolute deviation for height (MAD × 1.4826), 68% probability in case of normal distributed differences =SZ
LE90	Threshold including 90% of absolute values of discrepancies (90% median), 90% probability determined by 10% largest differences
LE95	Threshold including 95% of absolute values of discrepancies (95% median), 95% probability determined by 5% largest differences

Frequency distribution TDM90 – LiDAR



all differences (DSM against DTM)



only open area

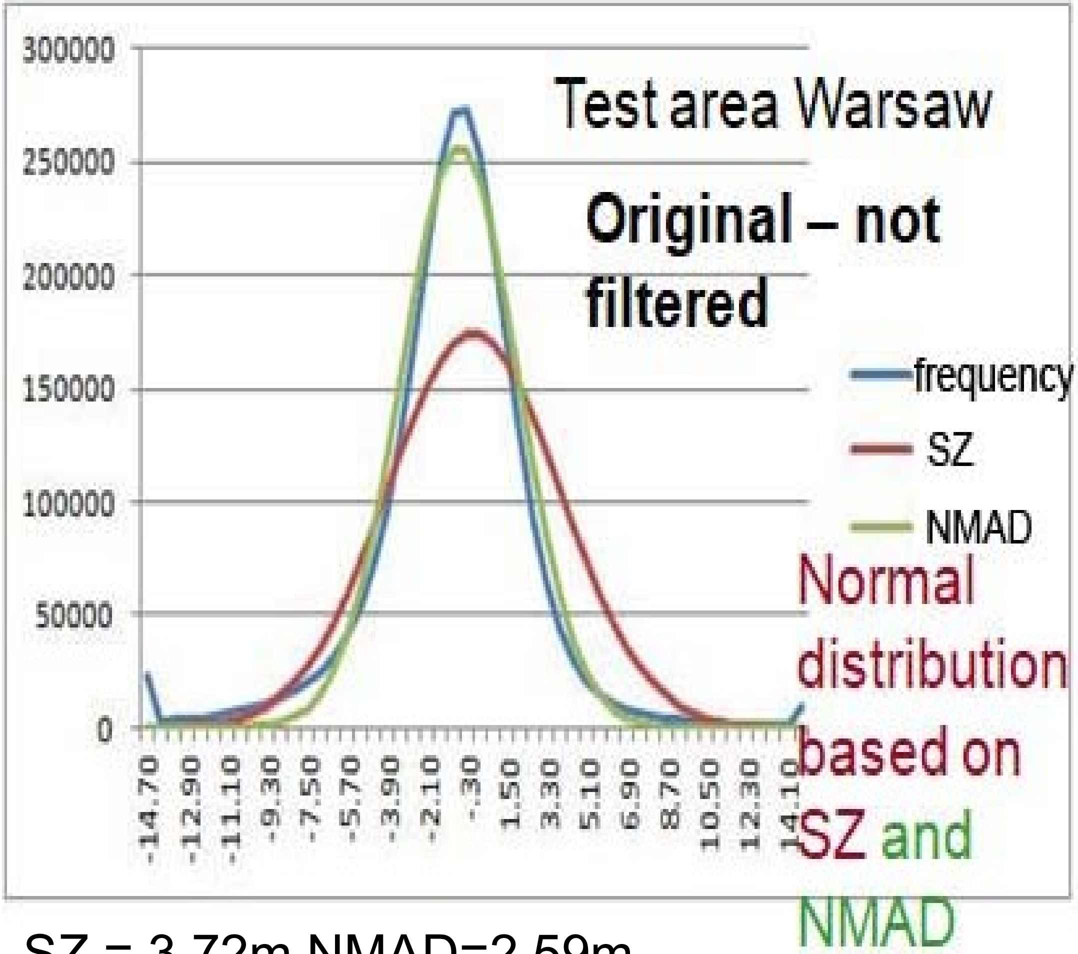
Bias=-2.96m SZ=6.08m
NMAD=5.40m LE90=13.11m
LE90/1.65=7.95m

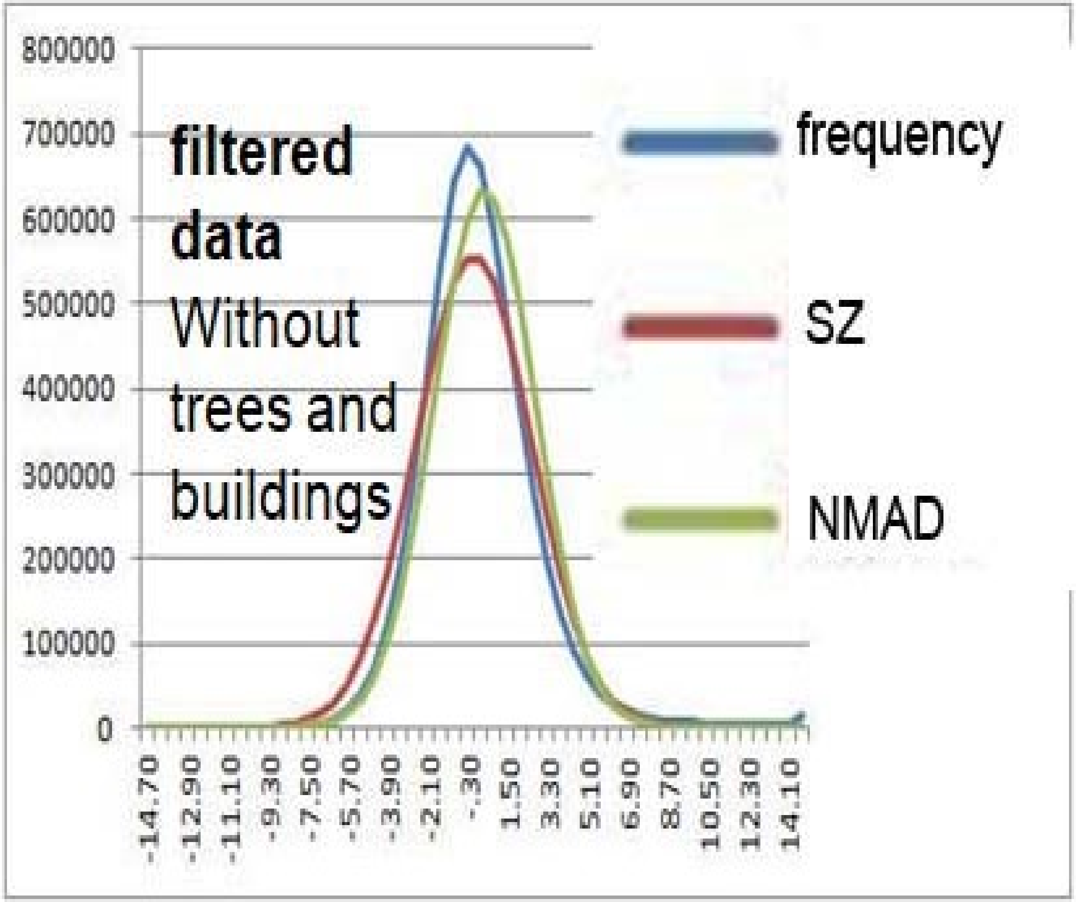
rolling area
Texas

Bias=0.05m SZ=1.87m
NMAD=1.52m LE90=2.97m
LE90/1.65=1.80m

Usually normal distribution based on NMAD closer to frequency distribution as SZ

Frequency distribution of height differences Cartosat-1 DSM - aerial





SZ = 3.72m NMAD=2.59m

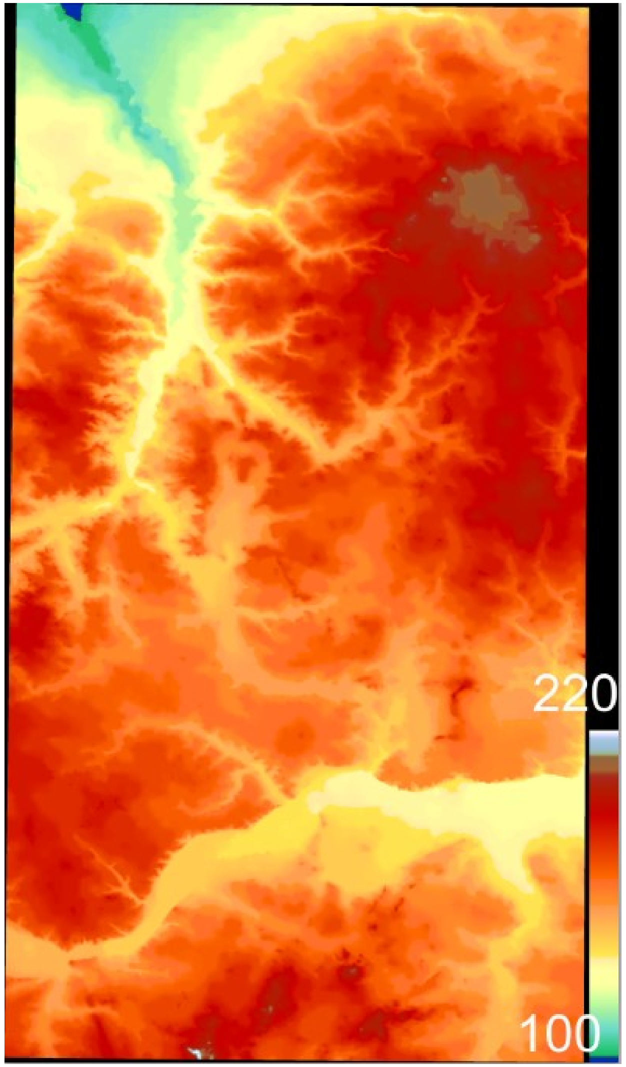
SZ=2.51m NMAD=2.27m

Cartosat-1 DSM – national DTM (Warsaw)

Usually SZ influenced by larger discrepancies – not the case for NMAD

Cartosat-1 DSM – national DTM (close to Warsaw)

	Whole area **not filtered**	Open area **filtered**	Relation not filtered / filtered
RMSZ	3.77m	2.56m	1.47
bias	0.61m	0.50m	
SZ	**3.72m**	**2.51m**	1.48
MAD	1.75m	1.53m	1.14
NMAD	**2.59m**	**2.27m**	1.14
LE90	5.43m (3.29)	4.09m (2.48)	1.33
LE95	7.65m (4.00)	5.21m (2.73)	1.47
	Influence of buildings and trees	Height values on trees and buildings eliminated	

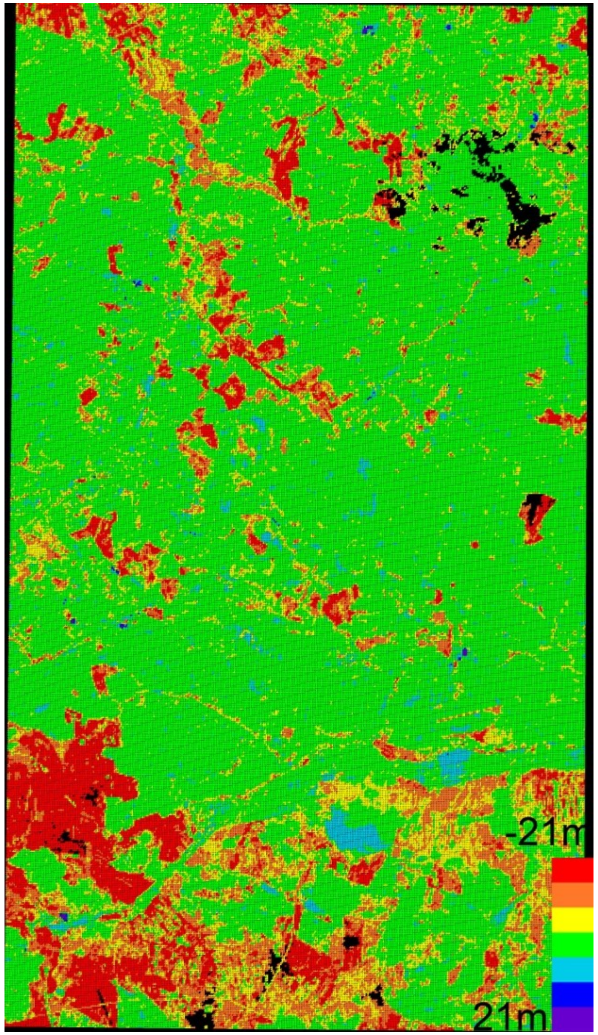


33km x 60km
6 million points
Color coded Reference DTM

In case of normal distribution SZ = LE90/1.65
SZ=LE90/1.91

TDM90 – LiDAR / open area

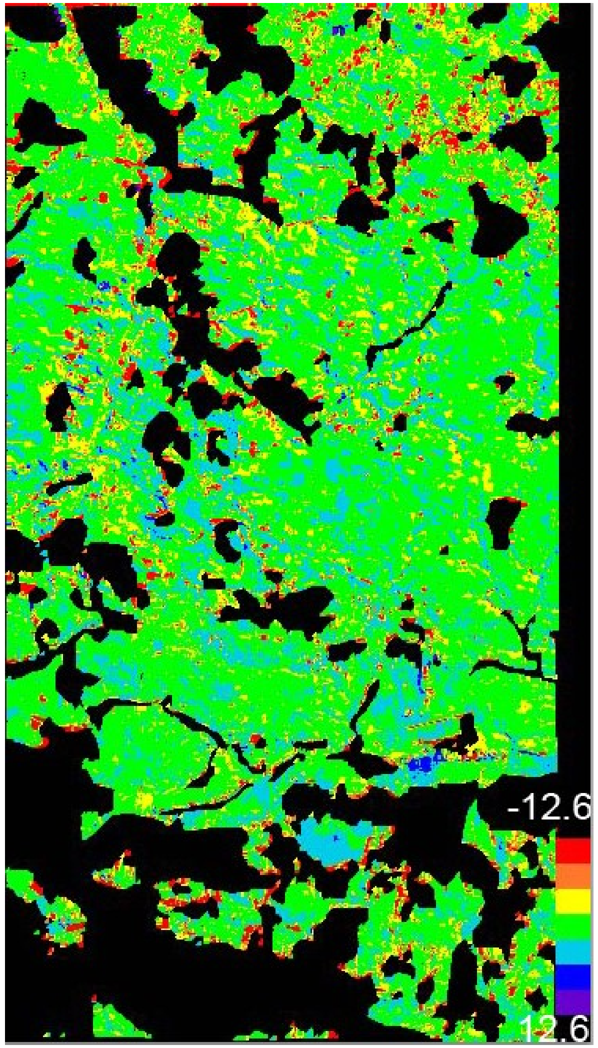
Color coded DZ
max DZ=25m



Bias=-2.96m SZ=6.08m
NMAD=5.40m LE90=13.11m
LE90/1.65=7.95m

Google Earth dark = forest

Color coded DZ



Bias=0.05m SZ=1.87m
NMAD=1.52m LE90=2.97m
LE90/1.65=1.80m

only open area

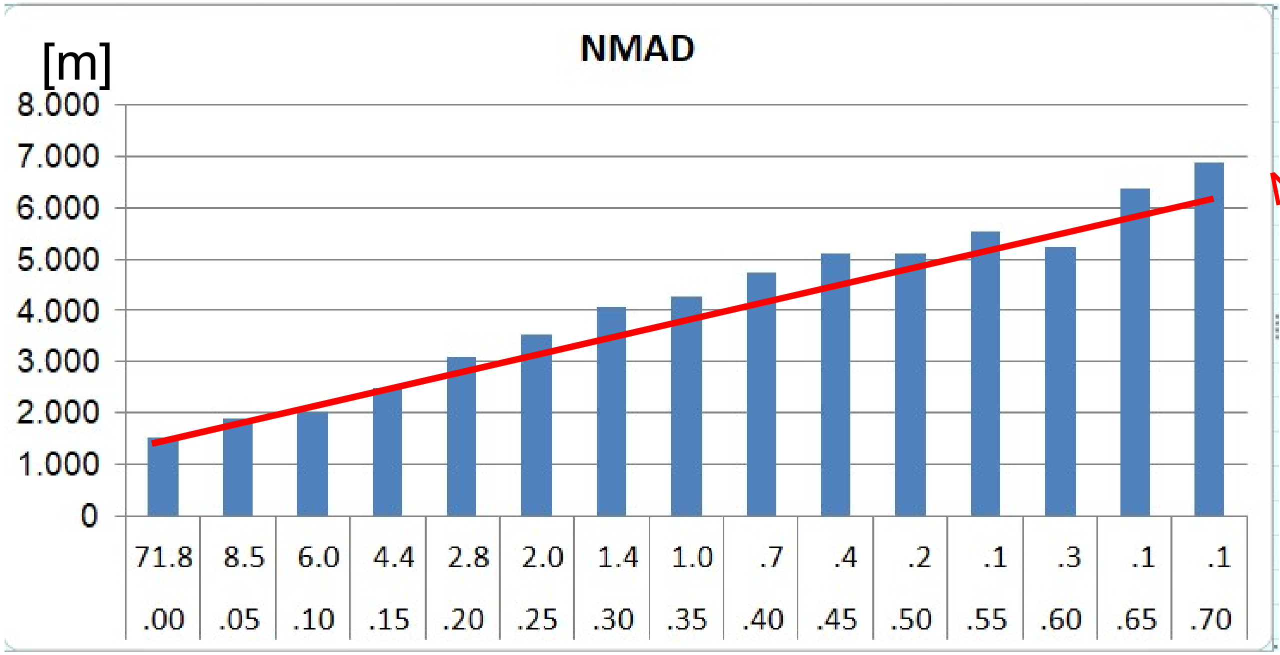
forest layer

rolling area Texas

Accuracy as function of slope

The analyzed DEMs are depending upon the number of InSAR-coverage respectively the number of used stereo models but dominated by **dependency upon terrain inclination**

NMAD = normalized median absolute deviation

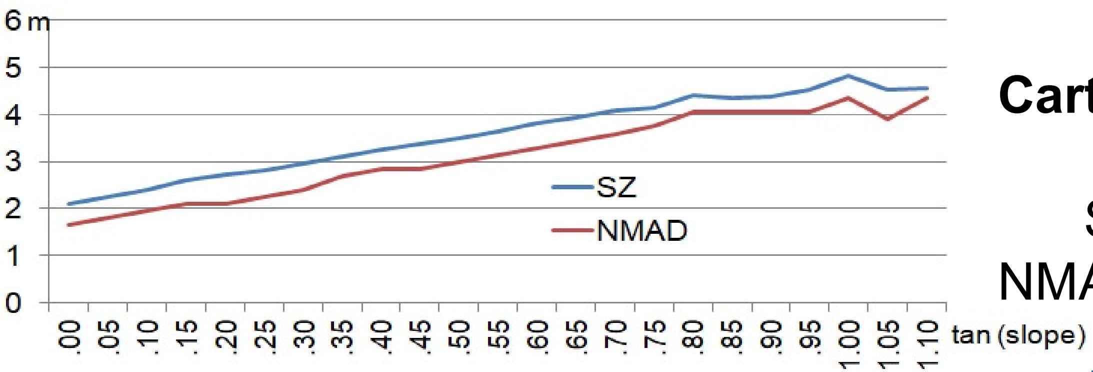


NMAD = 1.50m + 6.6m * tangent (slope)

WorldDEM Dücze against LiDAR reference

InSAR stronger dependency upon slope as DSM from optical images

% in slope group
tangent of slope →

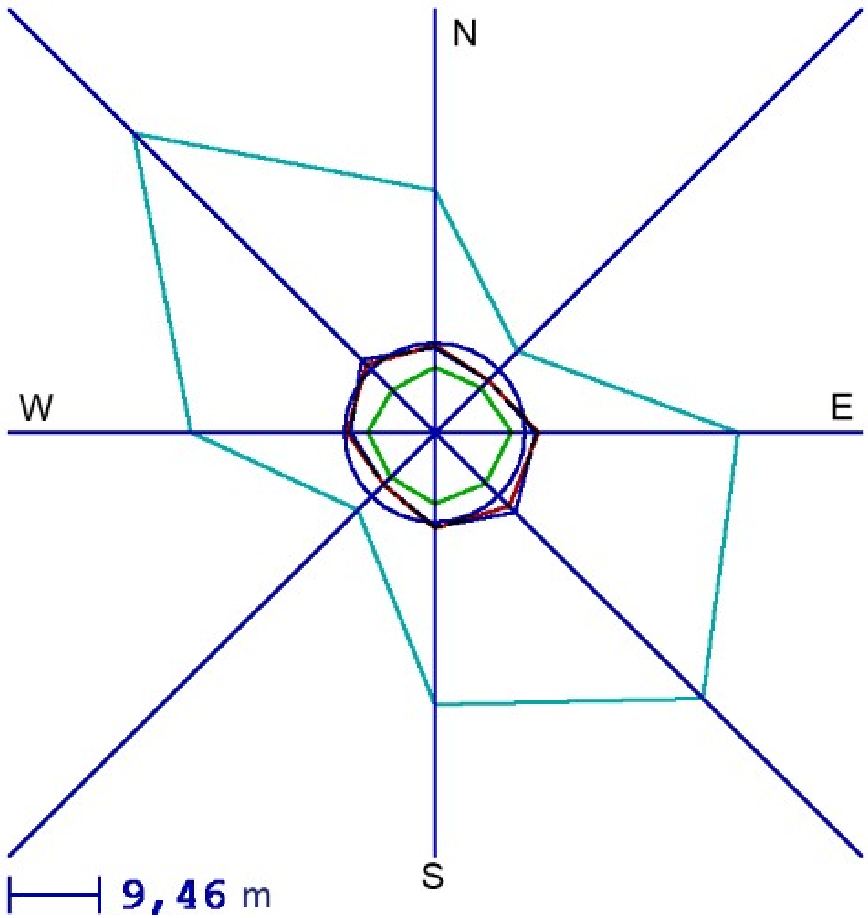


Cartosat-1 against AW3D30

SZ = 2.70m + 1.48m x tan(slope)

NMAD = 2.25m + 1.49m x tan(slope)

Aspects SRTM against LiDAR (Black Sea)



From center to outside
Standard deviation of height:

Green line: for slope = 0.0
Red line: for average inclination
Dark blue line: mean value
Dark blue circle: SZ
Light blue-green line: factor for multiplication with tangent (slope),

Typical result for InSAR in mountainous areas
Perpendicular to orbit radar layover and foreshortening effects reduce accuracy

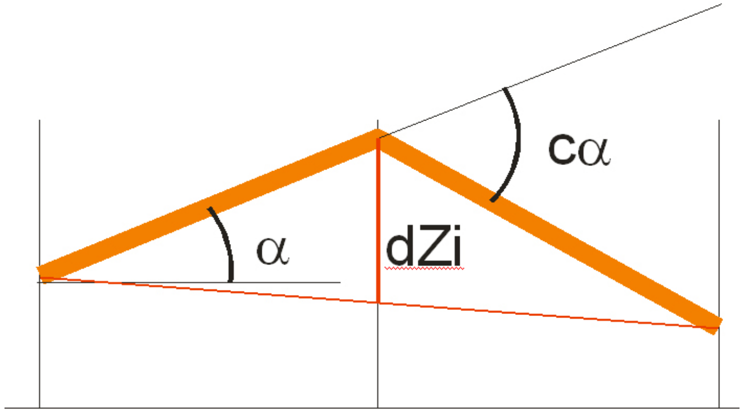
Accuracy as function of slope and slope direction

Interpolation effects depending upon terrain roughness (SRTM)

	spacing	average terrain inclination	average change of terrain inclination	RMSZ
Zonguldak	80m	0.27	0.32	12.0 m
Arizona	90m	0.17	0.09	4.8 m
New Jersey	60m	0.024	0.015	0.45 m
New Jersey	120m	0.024	0.015	1.12 m

SRTM against aerial reference

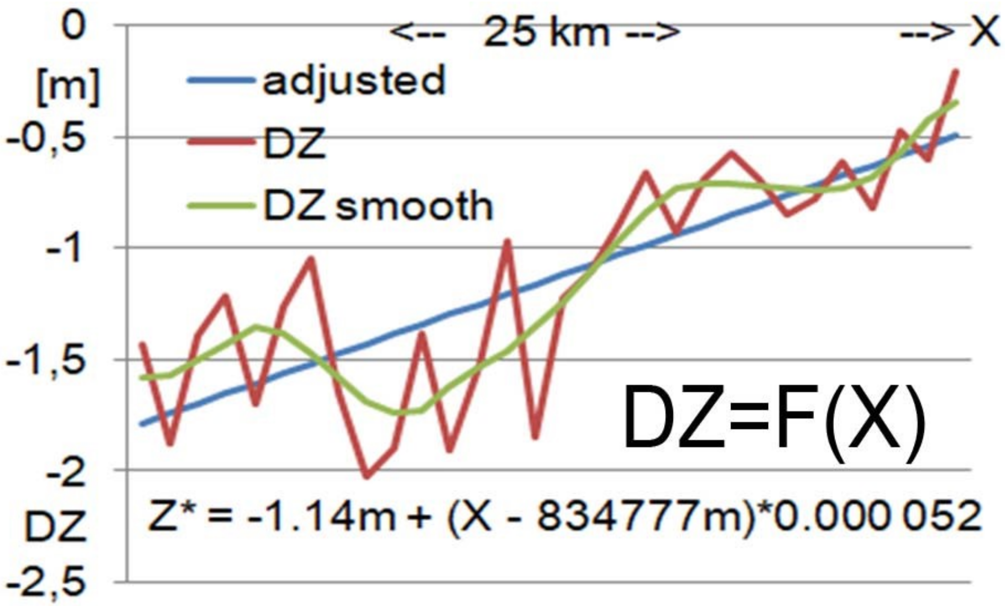
average ($c\alpha$)

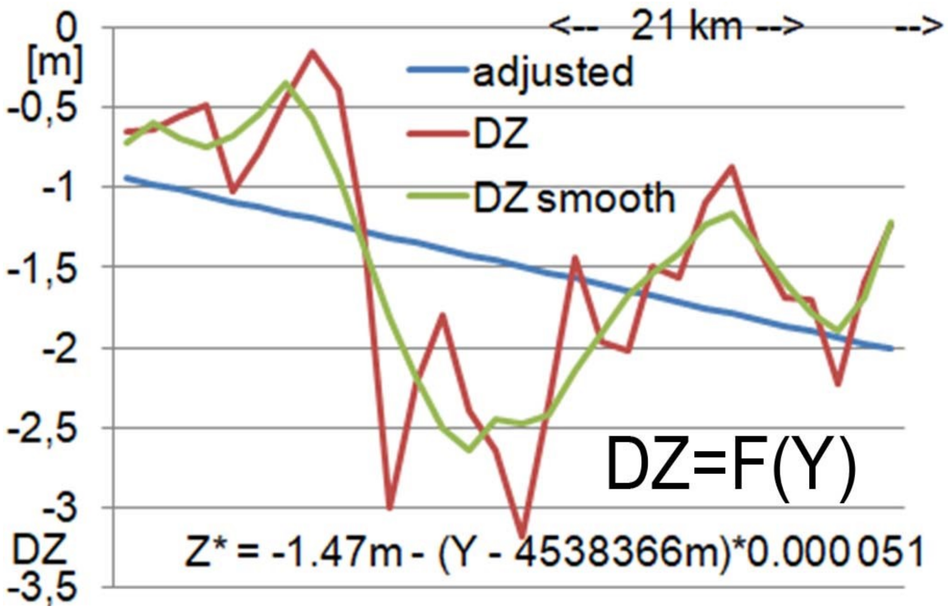


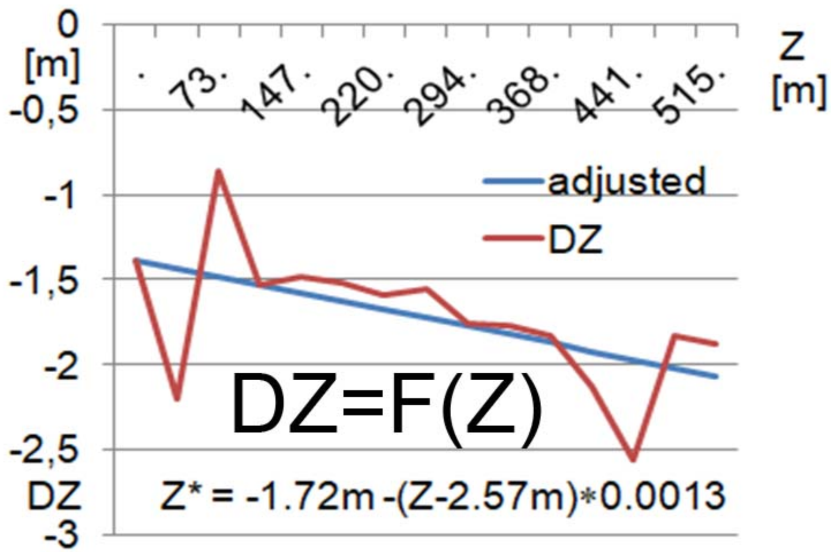
$c\alpha$ = change of inclination of neighbored point spacing - gridded DEM required

Double point spacing → ~ 2² times SZ

Systematic errors of a DEM (WorldDEM – LiDAR)







Systematic errors as F(X) and F(Y) are common – not only linear errors = tilt – also higher degree errors – may be eliminated by program DEMANAL

Linear errors as F(Z) (scale errors of Z) may exist, often caused by errors as F(X), F(Y)

WorldDEM-2 has 10m GSD

Relative accuracy

Distance between points [number of spacing's] ↓

RELATIVE STANDARD DEVIATION OF Z

1	6.56
2	8.33
3	9.18
4	9.58
5	9.78
6	9.93
7	10.05
8	10.17
9	10.24
10	10.27

Relative accuracy →

Absolute accuracy

SPOT-6 DSM against TDM90 DSM Sajama, Bolivia

$$RSZ = \sqrt{\frac{\sum(DZi - DZj)}{2 * nv}}$$

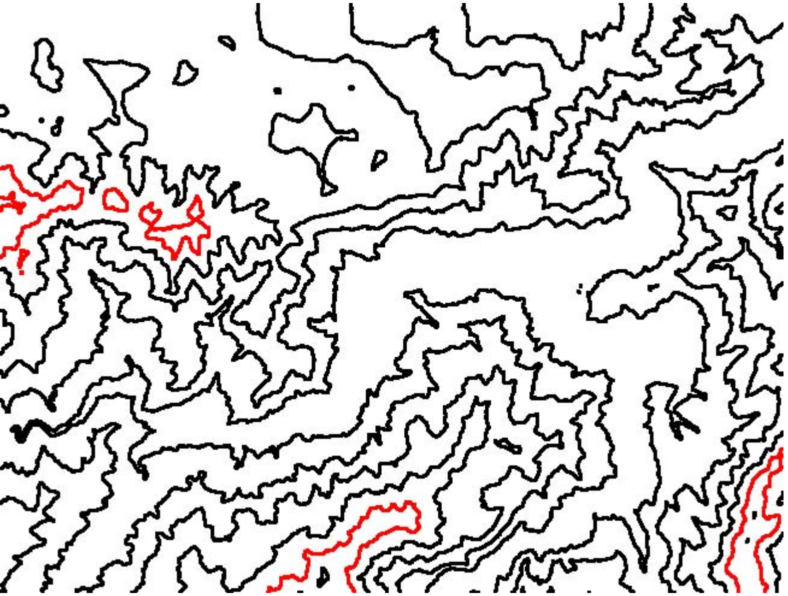
with nv = number of point combinations in the distance group and DZi, DZj = closely neighbored height points

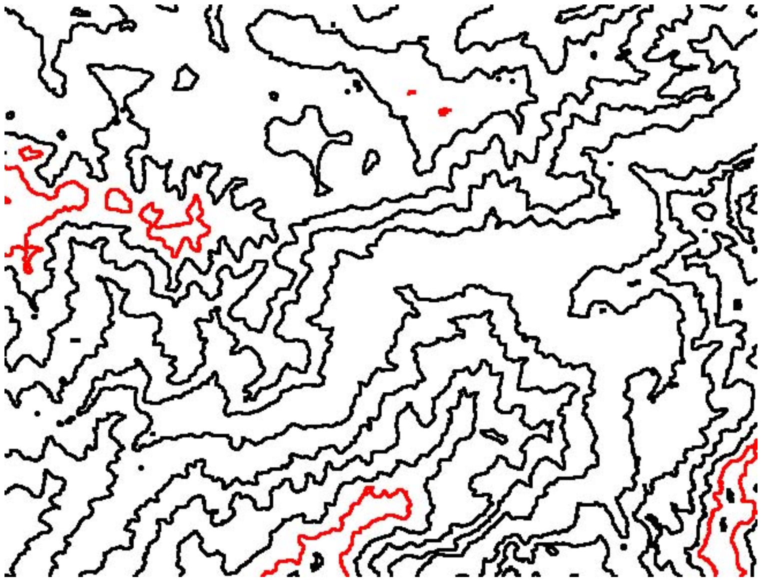
Neighbored points in a DEM are correlated → better relative as absolute accuracy

Relative accuracy important for morphologic quality

Morphologic details (mountainous test area Dücze)

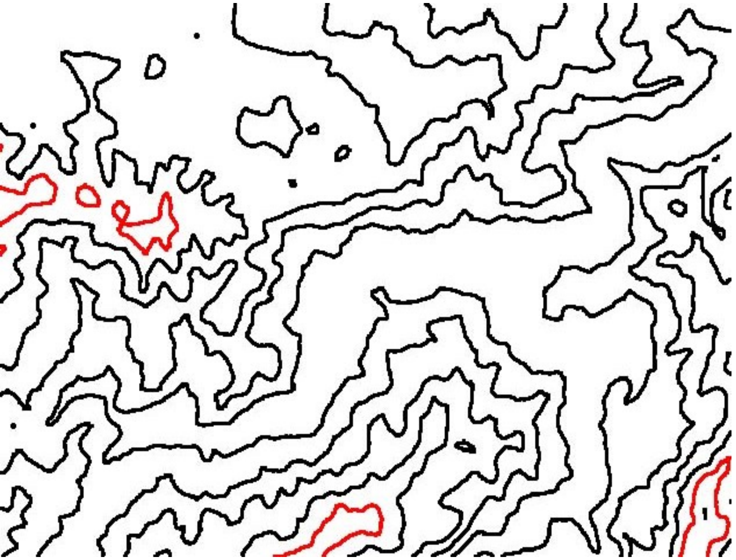
LiDAR 5m



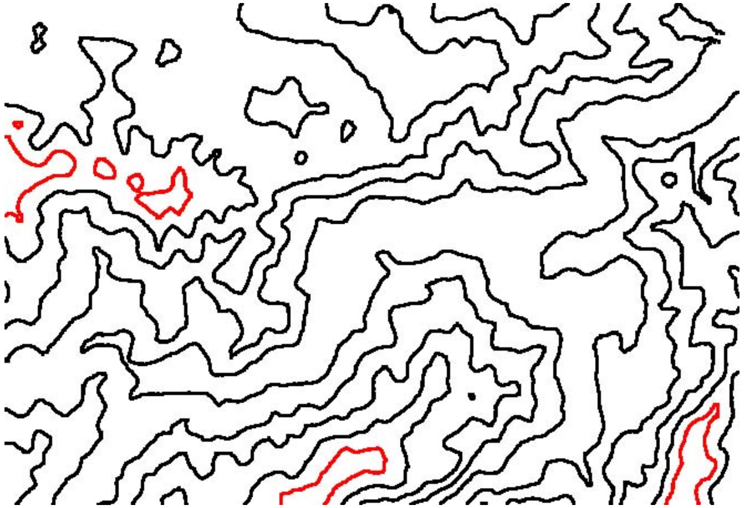


WorldDEM 10m
(TanDEM-X)
open area

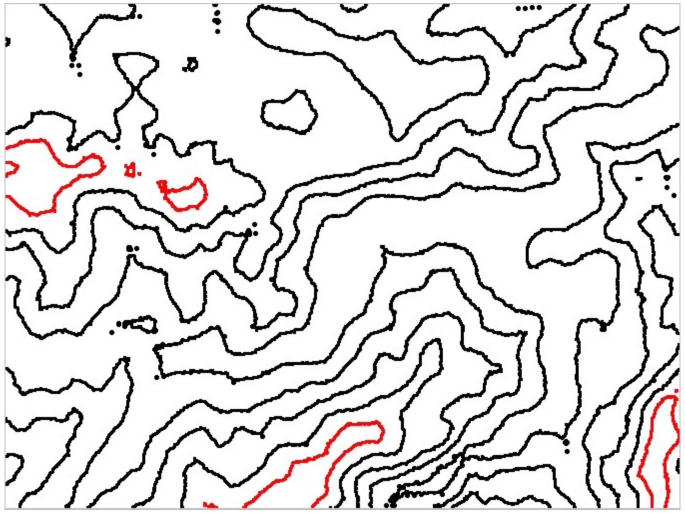
~7km x 6km
50m contour
interval



AW3D30 30m (ALOS-PRISM)



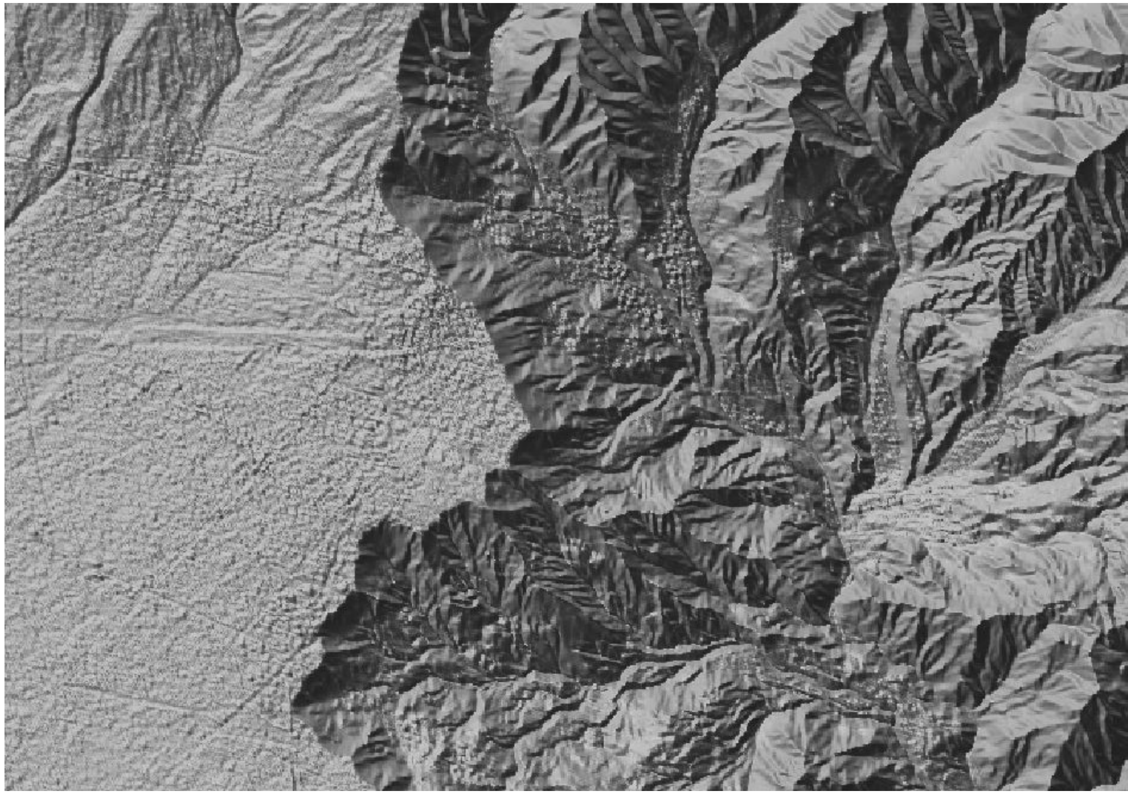
SRTM 30m



TDM90 90m (TanDEM-X)

TDM90 - AW3D30 morphologic details, La Paz

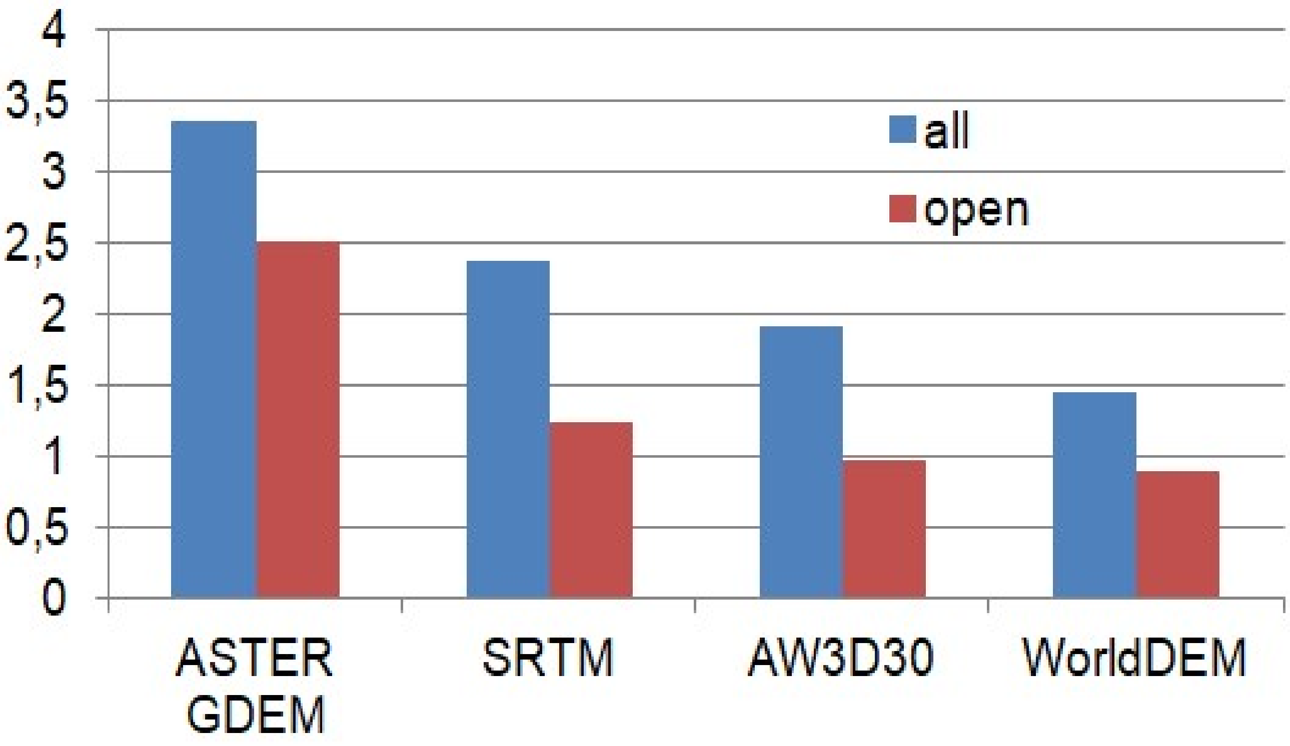
Shaded model TDM90
90m spacing



Shaded model AW3D30
30m spacing

Even if TDM90 is more accurate as AW3D30, with 90m point spacing
not so many morphologic details
→ use of fusion TDM90 with AW3D30

Relative standard deviation test area Dücze



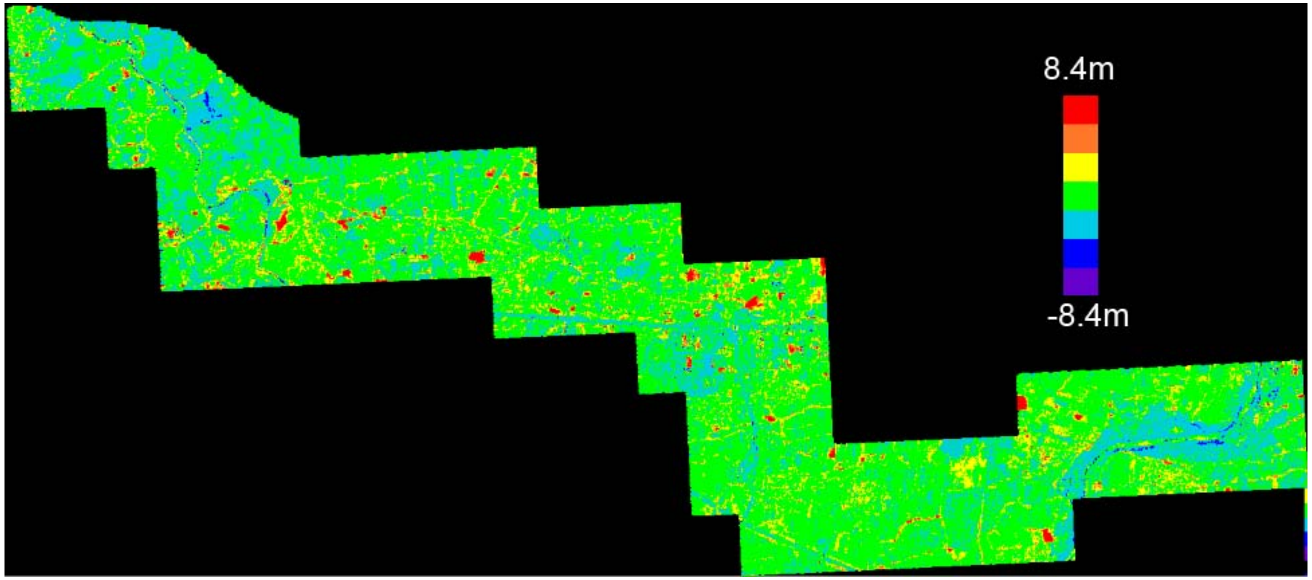
The **relative accuracy** is not influenced by orientation and model deformations – it is an indication for the morphologic accuracy (neighborhood accuracy)

Reference = LiDAR
Point spacing = 30m with exception of WorldDEM = 10m

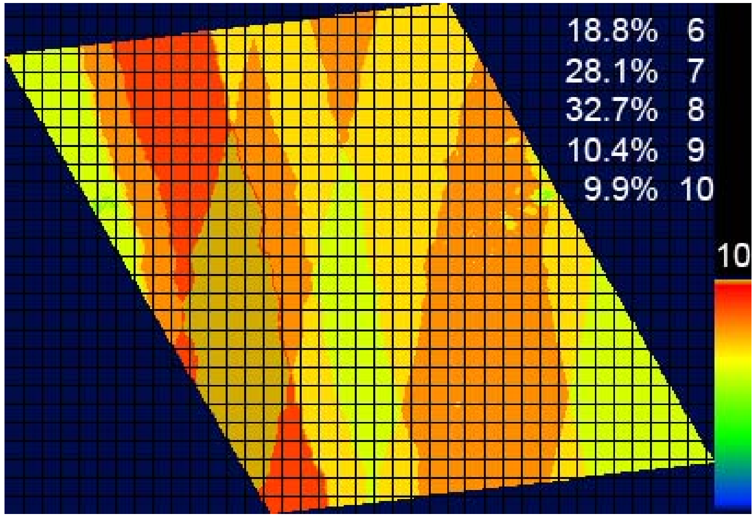
$$RMSZ = \sqrt{\Sigma(DZi - DZj)^2 / (2 \bullet nx)}$$

dl < d < du
dl = lower distance limit
du = upper distance limit
of the distance group

Accuracy as function of repeated determination WorldDEM

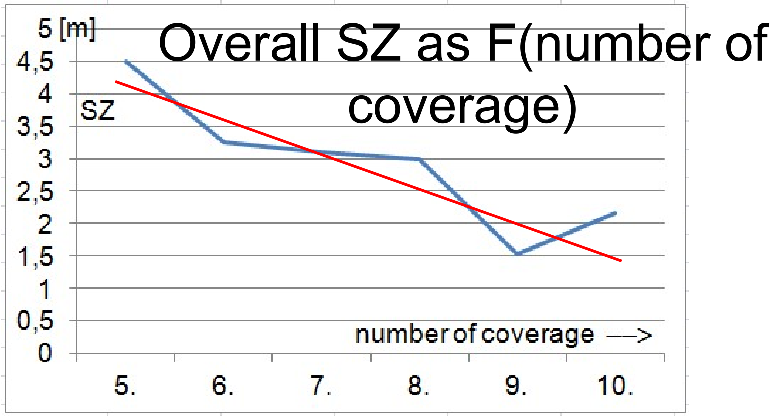


Color coded height differences **WorldDEM against LiDAR**, Dücze, Turkey – mountainous area

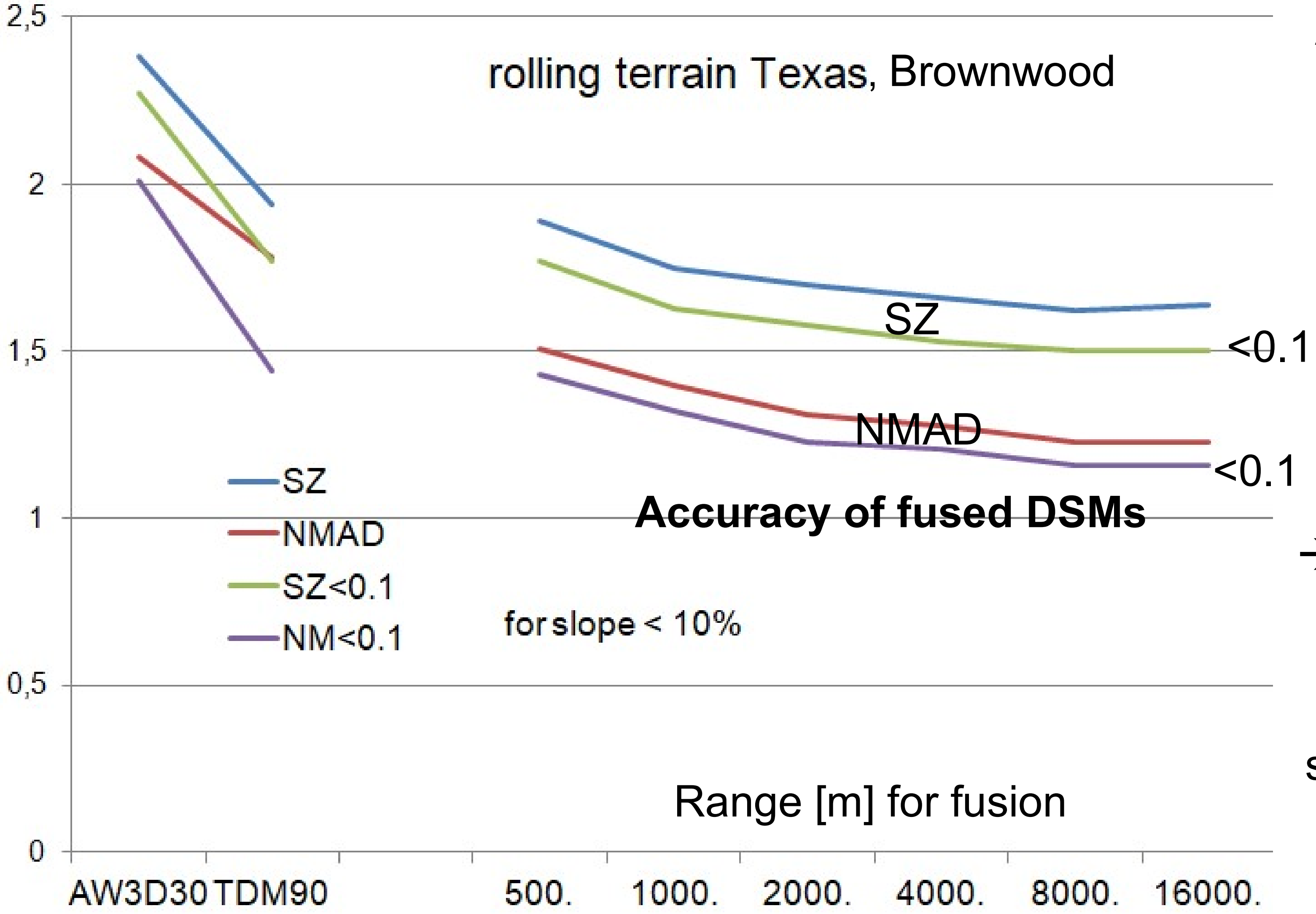


Number of repetitions

Open area including not dense urban area filtered to DTM
with vegetation filter for LiDAR reference
for whole area: SZ = 1.96m NMAD = 1.48m
for slope < 10% SZ = 1.59m NMAD = 0.99m



Accuracy of AW3D30 and TDM90 against LiDAR reference

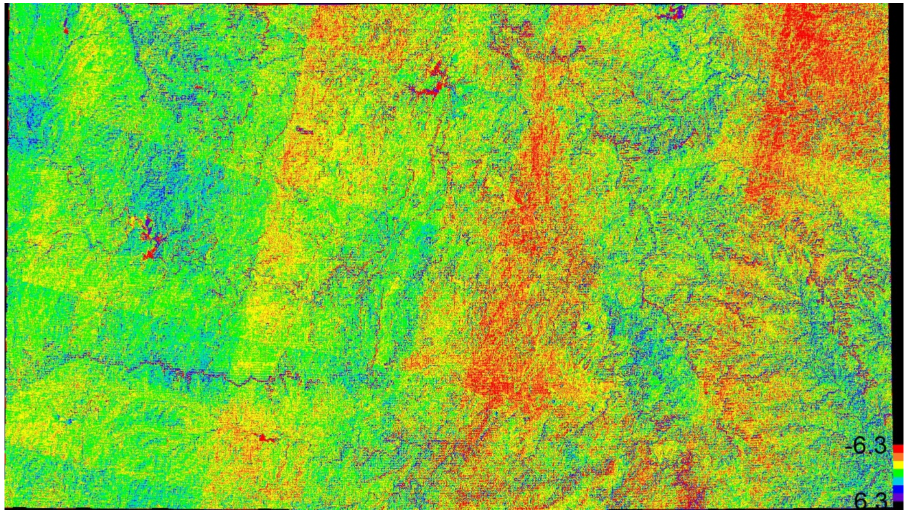


AW3D30 (~ 30m point spacing) not as accurate as TDM90 (~90m point spacing)
-Absolute accuracy of TDM90 better as for AW3D30, but morphologic details of AW3D30 better

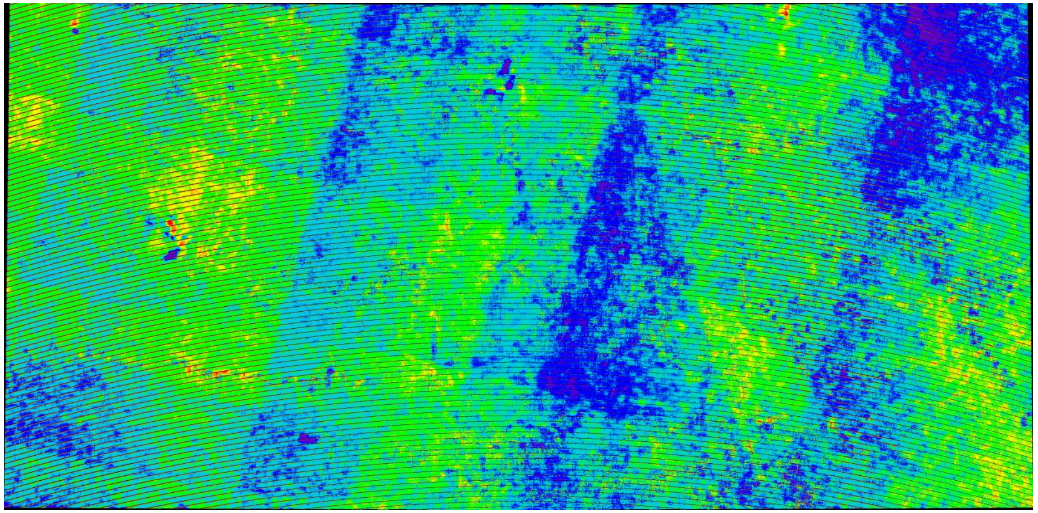
→Fusion of TDM90 with AW3D30 by height change of AW3D30 points by TDM90 in specified moving range

- Fused data better as single DSMs

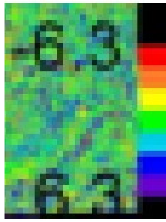
Fusion AW3D30 with TDM90 – color coded height differences



Color coded Z-difference TDM90 – AW3D30

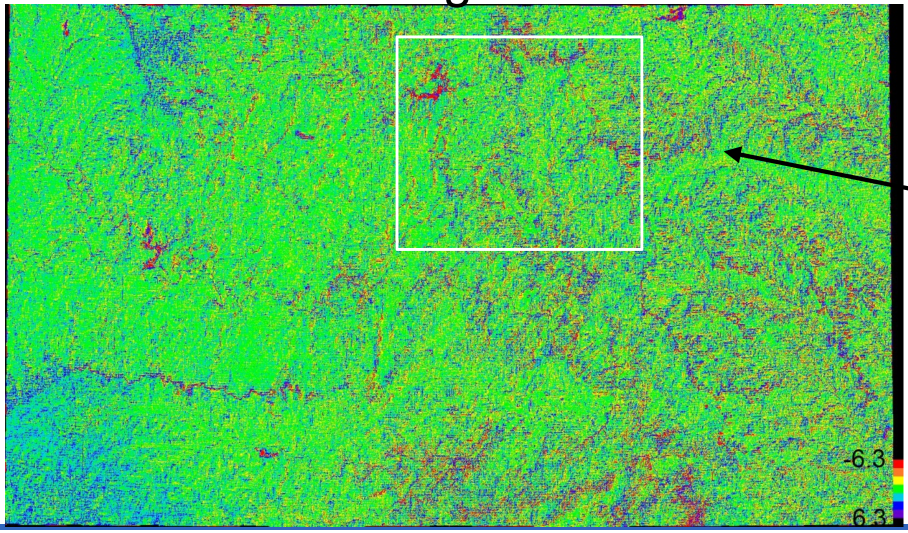


correction of AW3D30 by ZFIT 1000m

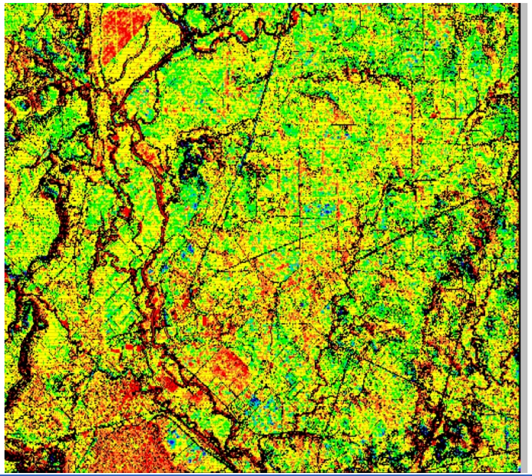


Brownwood, Texas

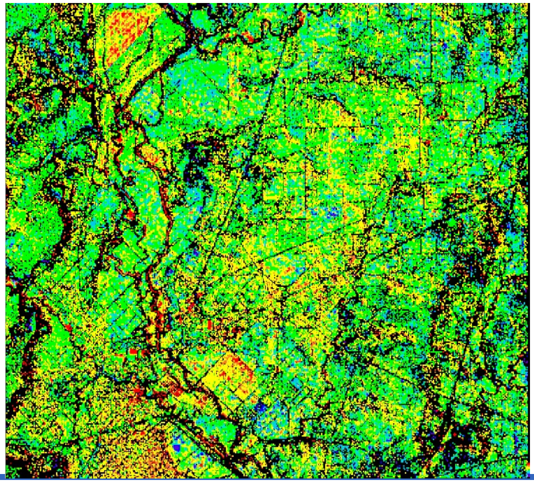
Color coded Z-difference improved AW3D30 against LiDAR



Original AW3D30 - LiDAR



AW3D30 improved by fusion with TDM90 against LiDAR



conclusion

Accuracy of a height model cannot be expressed just by one accuracy figure

Complete analysis requires a reference DEM – not just check points

Horizontal shifts have to be determined and respected

The used accuracy number has to be named

A DSM has to be compared with a reference DSM and a DTM with a reference DTM

The dependency upon the terrain slope is required

If a DEM is based on several determinations, the dependency upon number of repetitions is required

Aspects are important in mountainous terrain especially for InSAR DEMs

The morphologic quality has to be checked – relative accuracy and point spacing

Systematic errors as function of X, Y and Z may occur

Merged height models may combine accuracy from one and morphology from the other