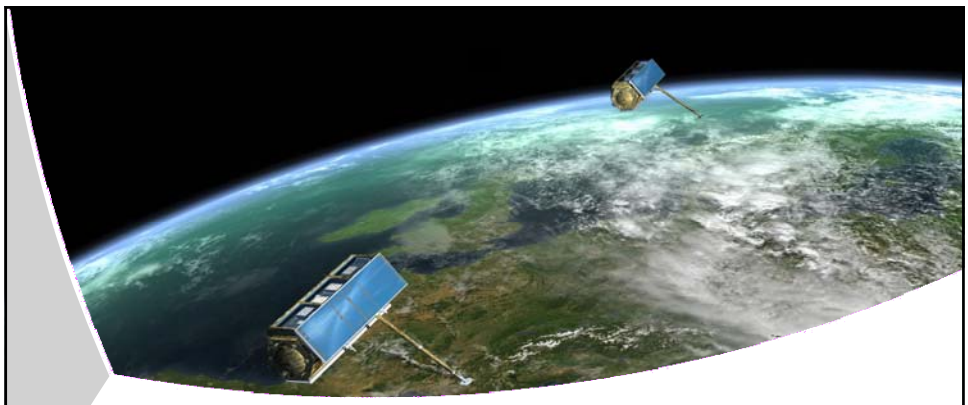

Validation of tie-point concepts by the DEM adjustment approach of TanDEM-X

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TanDEM

July-2010

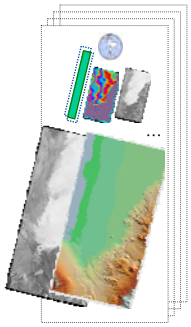
Overview

- Mosaicking and Calibration Processor
- Calibration Point Extraction (ICESat, tie-points)

- Tie-Point Concept
  - Single point approach
  - Area based approach
- DEM Calibration
- Test-site based on SRTM

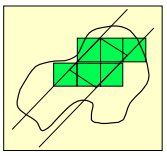
- Results
- Conclusion

Overview of Mosaicking and Calibration Processor (MCP)



Mosaicking and Calibration Processor

Global TanDEM-X DEM

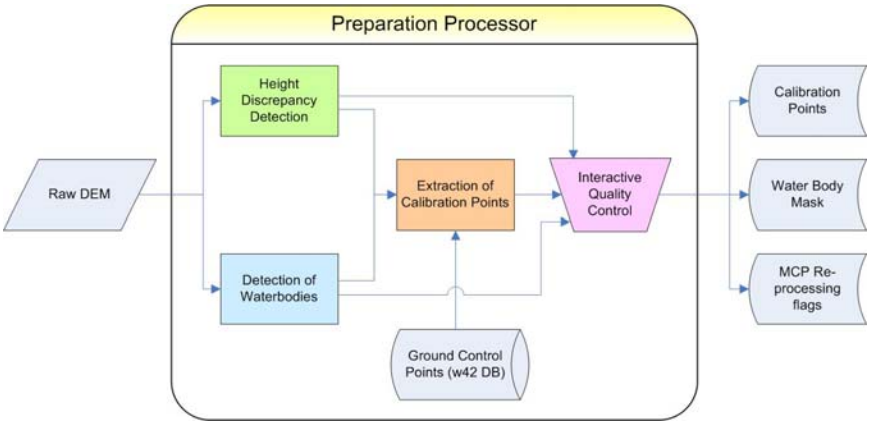


RawDEM:
- Elevation
- Height Error Map
- Amplitude
- Flag Mask

DEM generation:
- Preparation
- Calibration
- Mosaicking
- Validation

mosaicked DEM:
- Elevation
- Height Error Map
- Amplitude Mosaic
- Flag Mask

Preparation Processor



Quality Control - Preparation Processor

- Operator can update reprocessing flags

Product	Acquis. Date Process. Date	status	QC-height	QC-water	QC-tiepoint	Quicklook	Archive
1_1	Acquisition Date: 2009-01-11T13:49:53.013501Z Processing Date: 29-MAR-2010T15:35:10	NOT_APPROVED	NOT_APPROVED	NOT_APPROVED	APPROVED		7 set MCP reprocessing flag Quality Remark Archive
1_1	Acquisition Date: 2009-12-11T23:00:03.937883Z Processing Date: 29-MAR-2010T15:55:16	NOT_APPROVED	NOT_APPROVED	NOT_APPROVED	APPROVED		2 set MCP reprocessing flag Quality Remark Archive
1_1	Acquisition Date: 2009-12-11T22:59:56.888283Z Processing Date: 29-MAR-2010T16:08:02	NOT_APPROVED	NOT_APPROVED	NOT_APPROVED	APPROVED		7 set MCP reprocessing flag Quality Remark Archive

Quality Control – Extraction of Calibration Points

Datatake: 1_1
Coverage: first
Beam: tanDEM_a2_045
Acquis. Date: 2009-12-11T22:59:56.888283Z
Inc. Angle 40.589661 - 37.893799

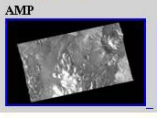
Quality: APPROVED
Proc. Date: 29-MAR-2010T16:08:02

Parameter Pool Pool
CPE Log File
Tiepoint list
Adjustment list
GCP point list

MCP reprocessing flag: 7

APPROVED set Tiepoint status flag

Update tiepoint status

	DEM	AMP	TIEPOINTS
1_1			

Statistic:

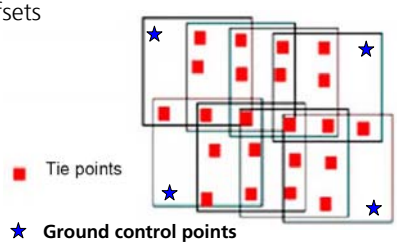
Number of GCPs	181.000000
Number of compared tiepoints	0.000000
Number of extracted tiepoints	31.000000
Coherence threshold for tiepoint calculation	0.600000

Criteria for ICESAT point selection:

Threshold for signal width	15.000000
Threshold for received energy	10.000000
Threshold for clouds	100.000000
Threshold for maximum peak	4.000000

DEM Calibration

- Calibration: Estimation of correction parameters by "**Least-squares adjustment**"
- **Tie Points**: Height differences in overlap areas of RawDEMs
  - Height differences to other acquisitions
  - Estimation of residual errors like slopes
- **Ground Control Points**: Height differences to calibration reference data
  - Estimation of absolute height offsets
  - Use of ICESat data as absolute height references



DEM Calibration: Least-squares adjustment with constraints

- **Constraints: Height differences** of Raw DEMs
  - differences to other acquisitions
  - differences to calibration reference data

  Shall be zero!

CONSTRAINT EQUATIONS

Ground Control Points

$$\hat{H}_{n,GCP} - [\hat{H}_{n,ICP} + \hat{g}_n(x,y)] = 0$$

Tie Points

$$[\hat{H}_{n_{TP2.1}} + \hat{g}_{n_{TP2.1}}(x,y)] - [\hat{H}_{n_{TP2.2}} + \hat{g}_{n_{TP2.2}}(x,y)] = 0$$

$\hat{H}_{n,GCP}$ height of ground control point
$\hat{H}_{n,ICP}$ height of control point in image

$\hat{H}_{n_{TP2.1}}$ height of tie point in image $n_{TP2.1}$
$\hat{H}_{n_{TP2.2}}$ height of tie point in image $n_{TP2.2}$

DEM Calibration

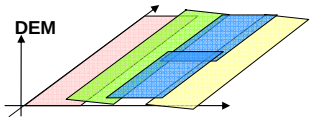
- DEM Calibration: Correction of each data take (not single RawDEM) due to systematic residual errors

HEIGHT ERROR MODEL

$$g_n(x,y) = a_n + b_n x + c_n y + d_n xy + e_n y^2 + f_n y^3$$

n	index of the data take
a_n...f_n	unknown parameter
x,y	range and azimuth

- Main contribution: a-c
  - a: absolute height offset
  - b: slope in range
  - c: slope azimuth



Calibration Point Extraction

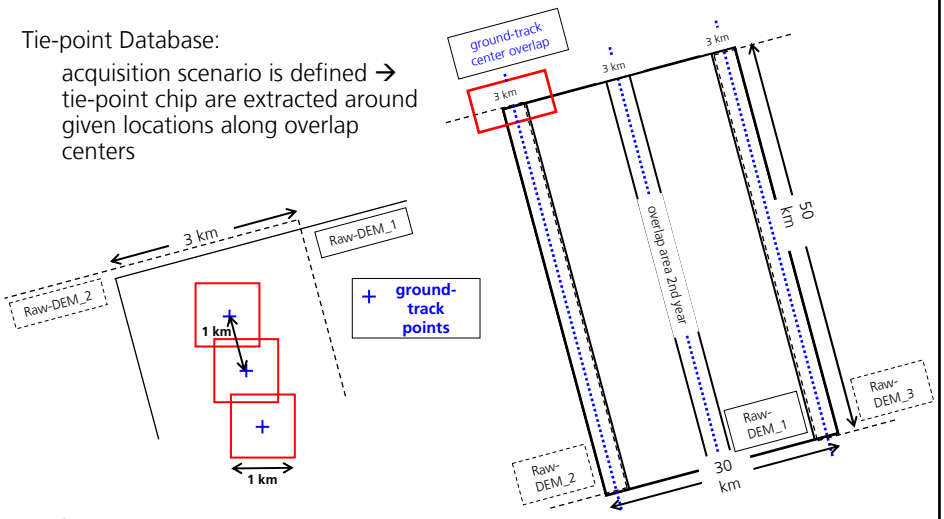
Provides input for Calibration:

- Tie-points between RawDEMs for relative orientation:
  - acquisition scenario is defined
  - best location for tie-points is calculated in advance
  - information is stored in a easy accessible Database
- Ground control points (ICESat) for absolute orientation:
  - global coverage (86°S - 86°N)
  - very large number of points
  - up to 1m height accuracy (adequate selection of points)
  - points are stored in a easy accessible Database

Tie-Point Concept

Tie-point Database:

acquisition scenario is defined → tie-point chip are extracted around given locations along overlap centers



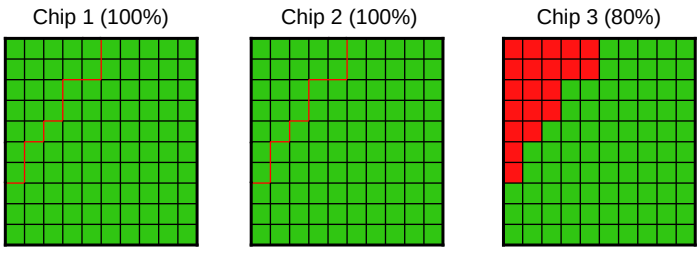
Single Point Approach

- Tie-point is located at the most appropriated location in the chip
- Pixel flagged as shadow, layover, water or having low coherence are not taken into account
- Meanfilter (9x9) identifies most flat area inside the chip
- Height value is averaged over a filtering window (3x3)
- Standard deviation is stored as additional information (quality information)
- Master chip is the extracted chip of the first available DEM
- Master chip identifies tie-point position for all subsequently acquired DEMs

Area Based Approach

- A pair of chips is analyzed to provide one tie-point information
- Pixel flagged as shadow, layover, water or having low coherence are not taken into account
- Histogram is calculated for the height values of the chip
- Median height is used for tie-point instead of mean, reducing the impact of outliers
- Standard deviation is stored as additional information (quality information)

Area Based Approach



Chip1 + Chip2 -> 100%

Chip1 + Chip3 -> 80%

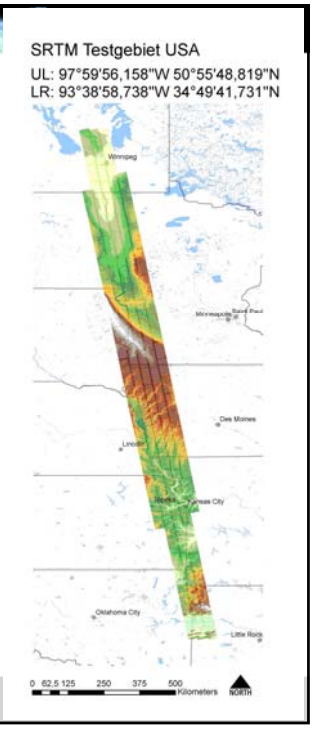
Chip2 + Chip3 -> 80%

Simulated Test Site

- Based on SRTM
- 12 data takes – each divided into 10 RawDEMs

- No absolute height reference available
- Adjustment of SRTM to ICESat

- Initial SRTM heights were distorted
- Random noise of 2m added



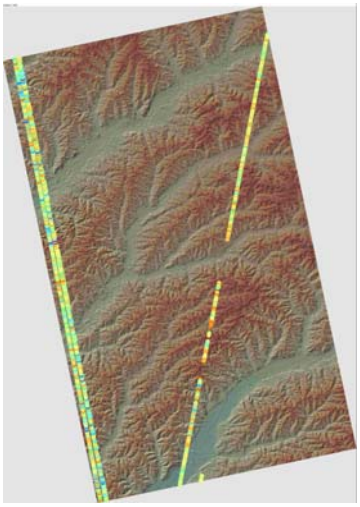
Impact of ICESat points

For whole test site:

- ICESat points available: > 300.000
- Pre-Selected: > 90.000

For each RawDEM:

- Max. number of 200 (most accurate)



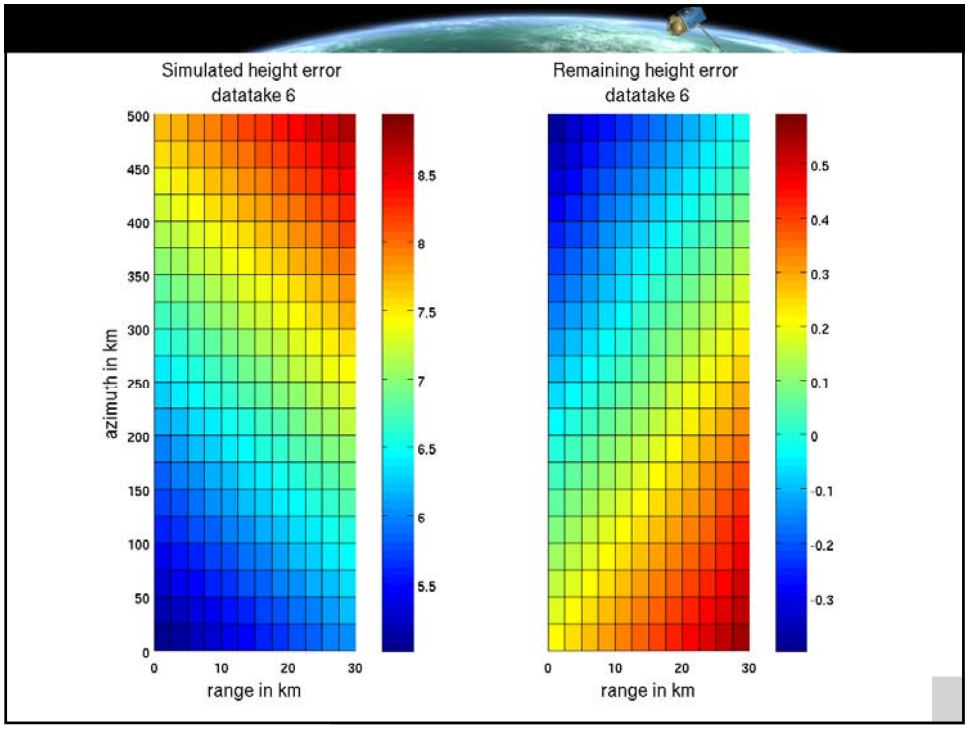
RawDEM with extracted ICESat points

Comparison of single-point and area-based approach

- Detailed comparison of specific chip
  - Determination of best point position
  - Compare only valid pixel

Comparison of single-point and area-based approach

- The estimated height offset and tilt have to be taken into account together
- Maximum height difference between ref. DEM and cal. DEM is evaluated



Comparison of single-point and area-based approach

	200 ICESat, all TPs	
DT Id	Point-based	Area-based
1	-1,60	-1,62
2	-0,47	-0,71
3	0,48	-0,39
4	0,56	0,43
5	-0,99	-0,69
6	0,68	0,59
7	-1,88	-0,78
8	-1,64	-1,11
9	-3,42	-3,47
10	-1,43	-1,37
11	-1,25	-1,29
12	1,41	1,48

Comparison of single-point and area-based approach

	20 ICESat, all TPs	
DT Id	Point-based	Area-based
1	-1,52	-1,46
2	0,77	-0,76
3	1,06	0,71
4	0,34	0,84
5	-1,73	0,97
6	1,55	0,95
7	-2,81	1,30
8	-3,28	-1,87
9	2,57	3,47
10	2,16	1,98
11	-1,81	-1,59
12	2,73	2,25

Impact of number of tie-points

- Maximum height difference to Reference DEM

	Number of tie-points	
DT Id	4178	1044
1	-1,621	-2,005
2	-0,712	-0,658
3	-0,387	-0,438
4	0,43	-1,008
5	-0,688	-0,955
6	0,593	0,868
7	-0,778	-1,118
8	-1,114	-1,281
9	-3,467	-4,043
10	-1,373	-1,437
11	-1,293	-0,922
12	1,482	0,774

Conclusion

- Advantage of the area based approach is the median filter
- Reducing the noise by averaging a larger area
- Results with area-based tie-point approach are better than with the single point approach
- Similar tests will be carried out with real TanDEM-X data