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an e-GEOS (ASI / Telespazio) Company

Euro-Maps 3D

DSM Generation and Procedures for Validation and Product Finalisation

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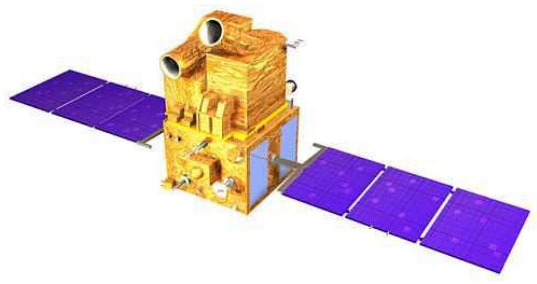
Euro-Maps 3D

- Part of GAF AG's multi-stereo elevation suite (0.3 m – 10 m)
- DSM with 5 m post spacing
- Based on 2.5 m optical in-flight stereo data from IRS-P5 Cartosat-1

	PAN-Fore	PAN-Aft
Tilt Along Track	+26 deg	-5 deg
Spatial Resolution	2.5 m	2.5 m
Swath-width	30 km	27 km
Radiometric Resolution, Quantisation	10 bit	10 bit
Spectral Coverage	500-850 nm	500-850 nm
Focal Length	1945 mm	1945 mm
CCD Arrays	1 * 12000	1 * 12000
(no. of arrays * no. of elements)		
CCD Size	7 µm x 7 µm	7 µm x 7 µm
Integration Time	0.336 ms	0.336 ms



(Image Copyright © ISRO)

- Systematic acquisitions at Neustrelitz ground station (2008-2016) and worldwide Indian archive (2005-2019)
- DSM processing in dedicated Cartosat-1 processing chain developed in cooperation with DLR
- Automated validation steps inside the processing chain are complemented by external QA & QC workflows

Stereo Data Availability

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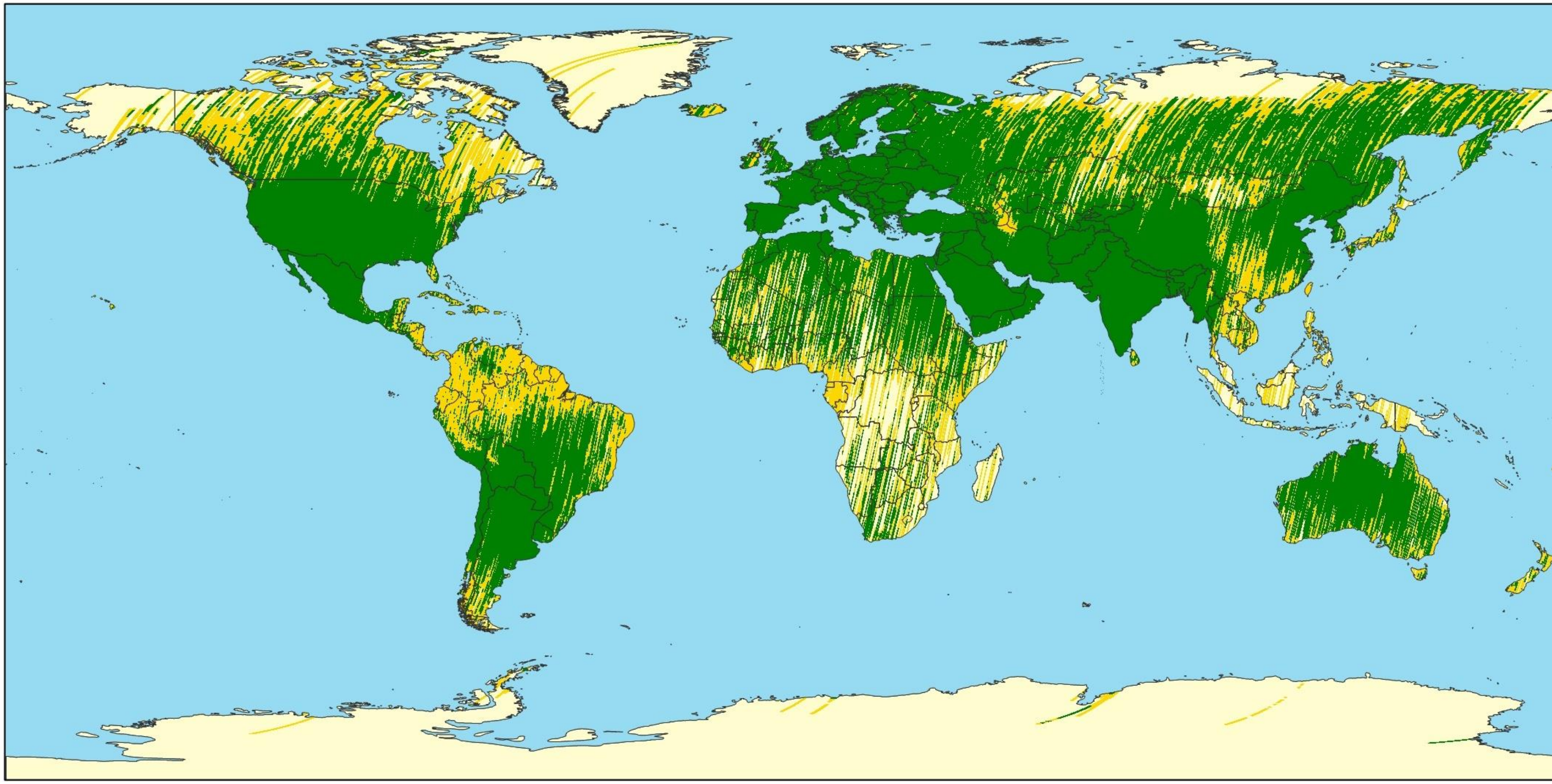


Legend:

- Cloud Cover <= 10%
- Cloud Cover > 10%
- no IRS-P5 Stereo Data available

Data archive: GAF AG / NRSC

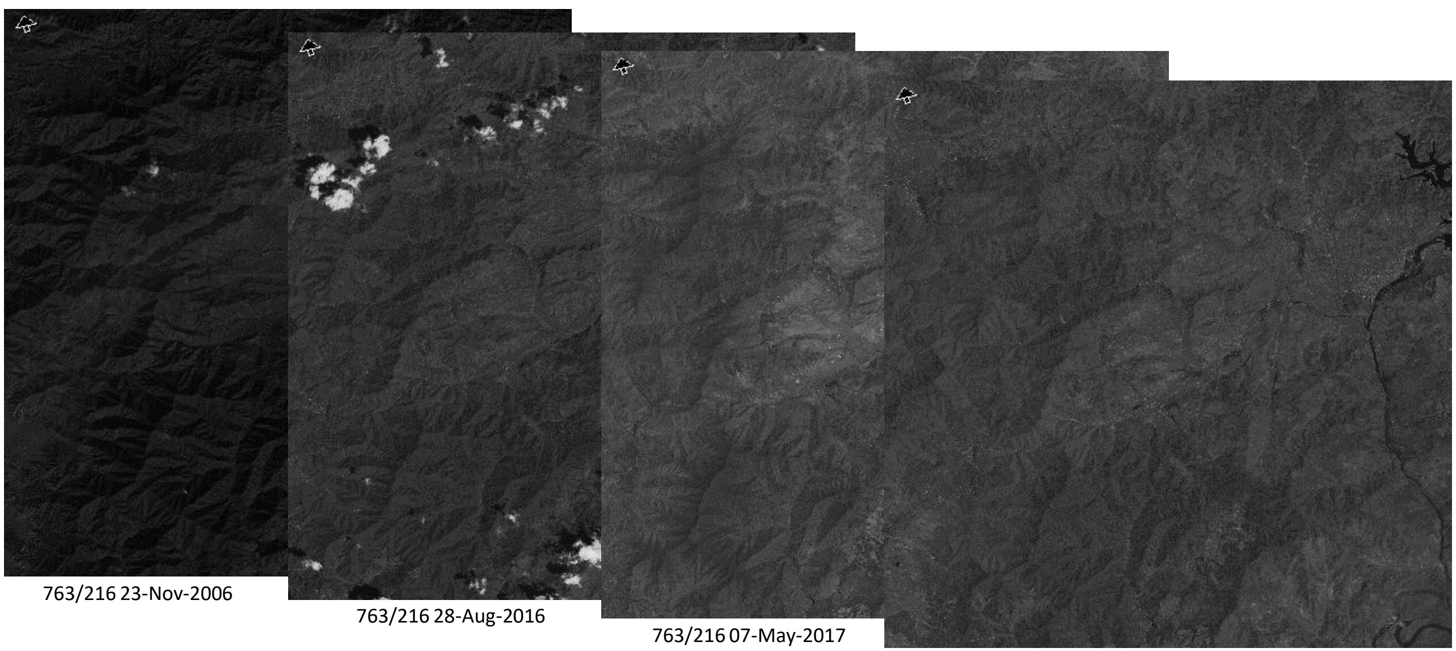
Scene Selection
- Acquisition: 09-May-2005 to 19-May-2018
- Sun Elevation: >= 20°
- Roll Bias: -15° to 15°

N

0 km 2500 km 5000 km

Quality of Input Stereo Data

- Semi-automated assessment of input data:
  - Cloud cover
  - Sun elevation
  - Roll & pitch (2 different stereo configurations flown)
  - Season
- NSG reception cone: maximal archive usage (~20% of all collected stereo data)
- Worldwide: nominal quadruple stereo coverage (increased if necessary)



763/216 23-Nov-2006

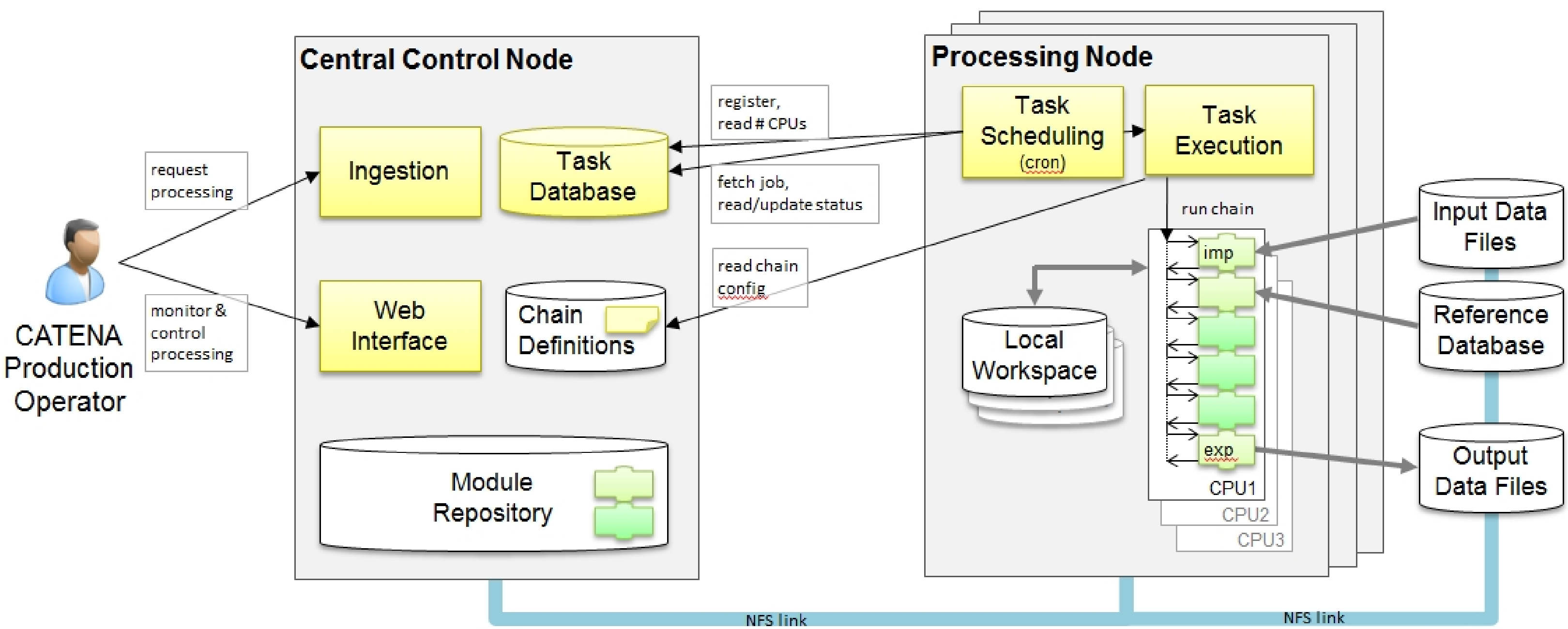
763/216 28-Aug-2016

763/216 07-May-2017

763/216 22-Jul-2018

DSM Processing

- Fully automated processing chain based on CATENA infrastructure, developed at Remote Sensing Technology Institute (IMF) of the German Aerospace Center (DLR)
- Scene based stereo matching (> 200 in parallel)
- Blockwise DSM generation using bundle block adjustment (> 10 blocks, 5000 stereo pairs in parallel)



https://www.dlr.de/eoc/Portaldata/60/Resources/images/5_tech_datproz/Catena_at_work.jpg

DSM Processing Output

- Processing chain output: mosaicked DSM plus visual and thematic layers
- Accompanied by detailed bundle reports for manual quality assessment:
  - Number and quality of GCPs
  - Number and quality of tie points
  - RPC correction parameters
  - Difference to reference DSM
  - Statistics

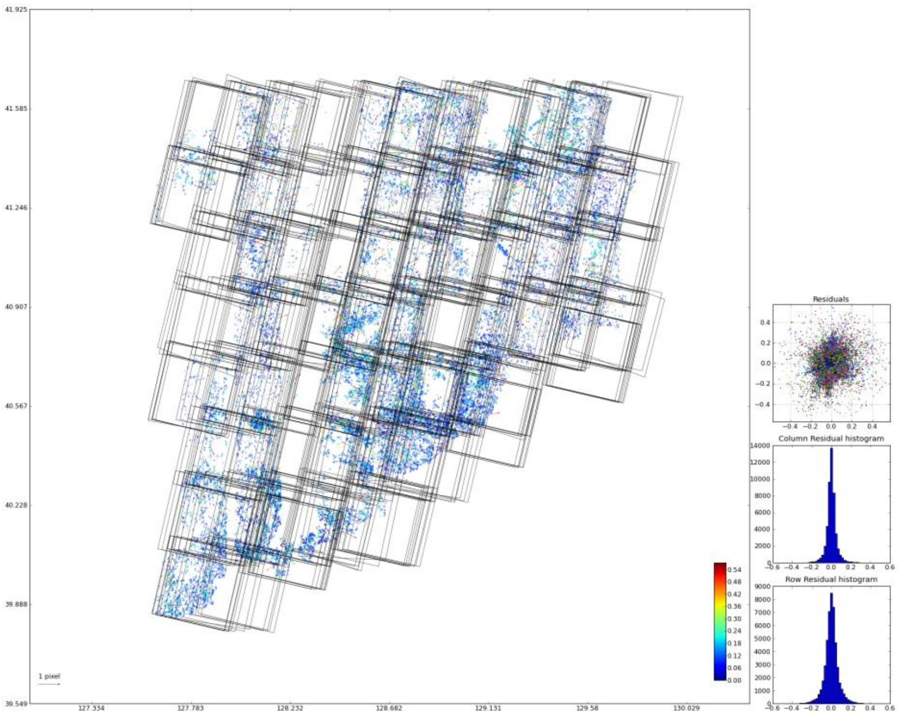
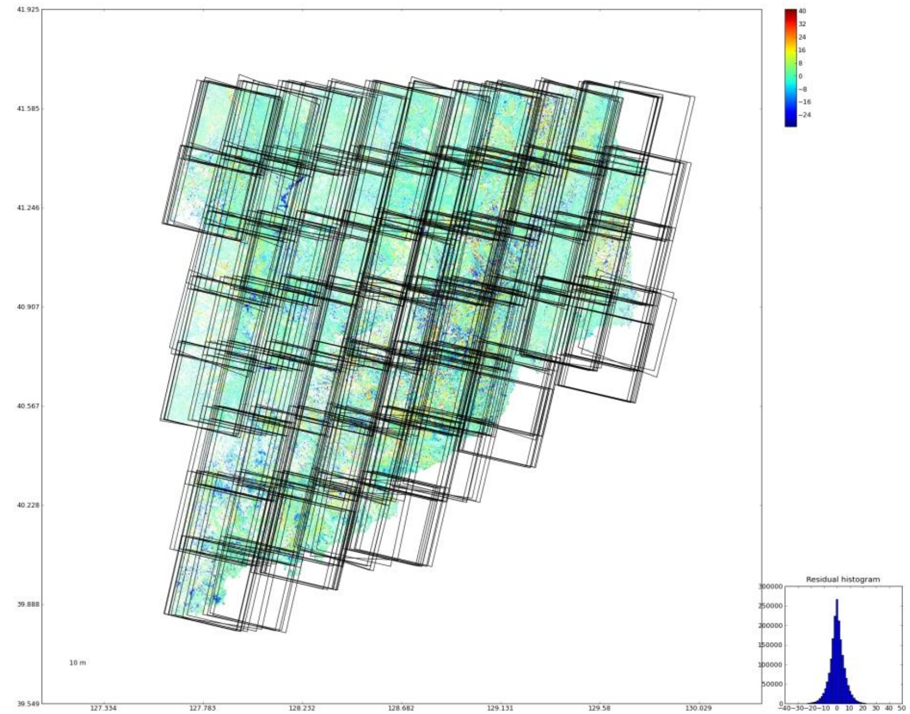


Image residuals for GCPs



DEM difference (DEM – Reference DEM)

DSM Validation – ICESat

- ICESat GLA14 r34 data (land surface altimetry) used as reference dataset
- Appropriate filter methods developed based on
  - Publications:
    - Huber, M., Wessel, B., Kosmann, D., et al, 2009. Ensuring globally the TanDEM-X height accuracy: Analysis of the reference datasets ICESat, SRTM, and KGPS-Tracks. In: Proceedings of IGARSS 2009, Cape Town, South Africa, 2009
    - Gonzalez, J.H., Bachmann, M., Scheiber, R., et al, 2010. Definition of ICESat selection criteria for their use as height references for TanDEM-X. IEEE Trans. Geosci. Remote Sens. 48(6), 2750–2757
    - Pagnutti, M. and R. E. Ryan, 2009, "Automated DEM Validation Using ICESAT GLASS DATA," in Proceedings of the ASPRS/MAPPS Fall Conference , San Antonio, Texas, November 16-19
  - Tests:
    - Northern Italy: Euro-Maps 3D DSM 5 m & Aerial Survey DSM 5 m
    - Northern Iraq: Euro-Maps 3D DSM 5 m
    - Oberstdorf: Lidar DSM 10 cm
    - Euskirchen: Lidar DSM 10 cm

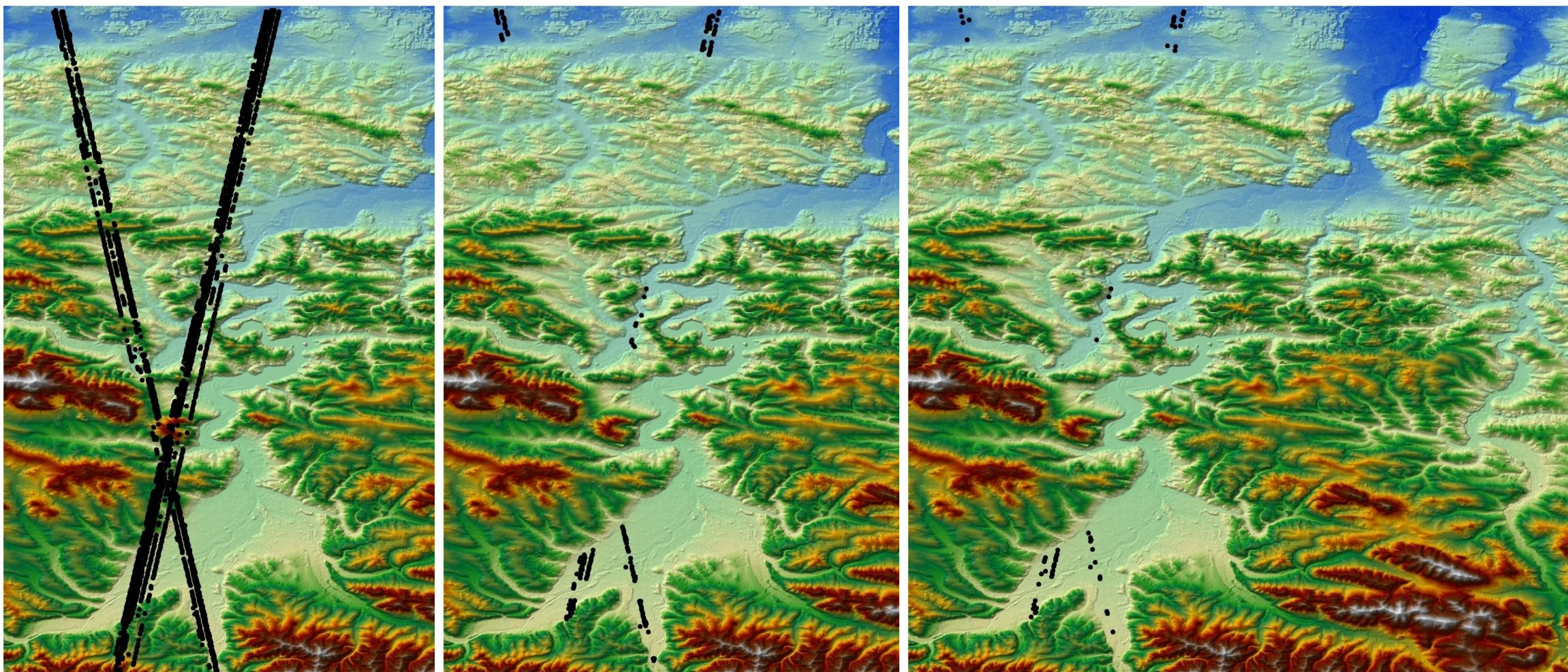
DSM Validation – ICESat

- Considered ICESat parameters:
  - elev_use_flg, elv_cloud_flg, d_elev, d_DEM_elv, d_deltaEllip, d_satElevCorr, d_RecNrgAll, d_satNrgCo, sat_corr_f, i_numPk, i_Gsigma1, i_nPeaks, d_RecNrgAI, Laser, d_beamCoelv, …
- Suitable ICESat attribute values grouped and mapped to four single attributes
- Different and/or combinations of these four attributes define three ICESat filtering methods of different strengths
  - [F_Gonz_3] = 1 OR [F_Gonz_5] = 1 OR [F_Huber] = 1 OR [F_Cloud] = 1
  - [F_Gonz_5] = 1 AND [F_Huber] = 1 AND [F_Cloud] = 1
  - [F_Gonz_3] = 1 AND [F_Huber] = 1 AND [F_Cloud] = 1
- Additional filtering using LandCover data and slope classes

- Filtered ICESat points are input for GAFmap DEMCheckTool

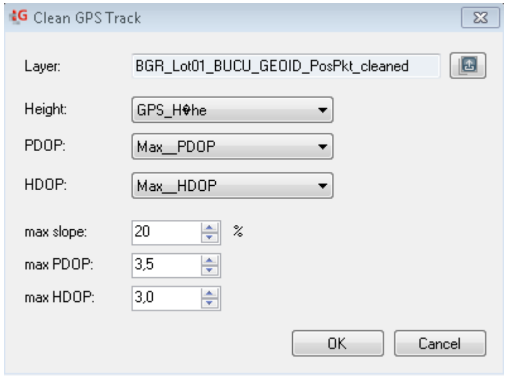
DSM Validation – ICESat

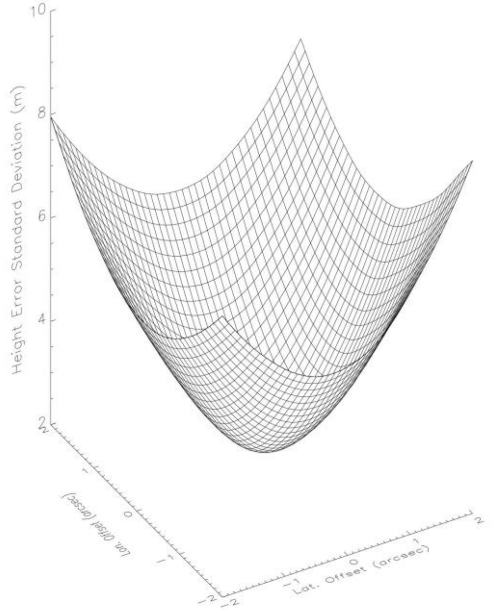
- Example: Euro-Maps 3D tile 093758P5020E049NPB___G4
  - Covered by 4835 unfiltered GLA14 points
  - Weak filter combination (left): 2743 points; calculated LE90: 6.87 m
  - Medium filter combination (middle): 169 points; calculated LE90: 5.49 m
  - Strong filter combination (right): 56 points; calculated LE90: 5.93 m

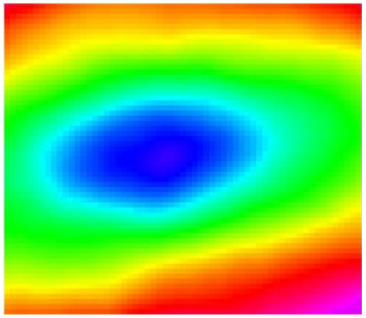


DSM Validation – GPS Transects

- Filtering of input GPS data based on position dilution of precision (PDOP), horizontal dilution of precision (HDOP), slope values, land cover and visual inspection
- DSM is shifted in x- and y-direction against GPS reference dataset
- Minimum standard deviation of height differences sought
- Shift image with clearly visible minimum indicates reliable result



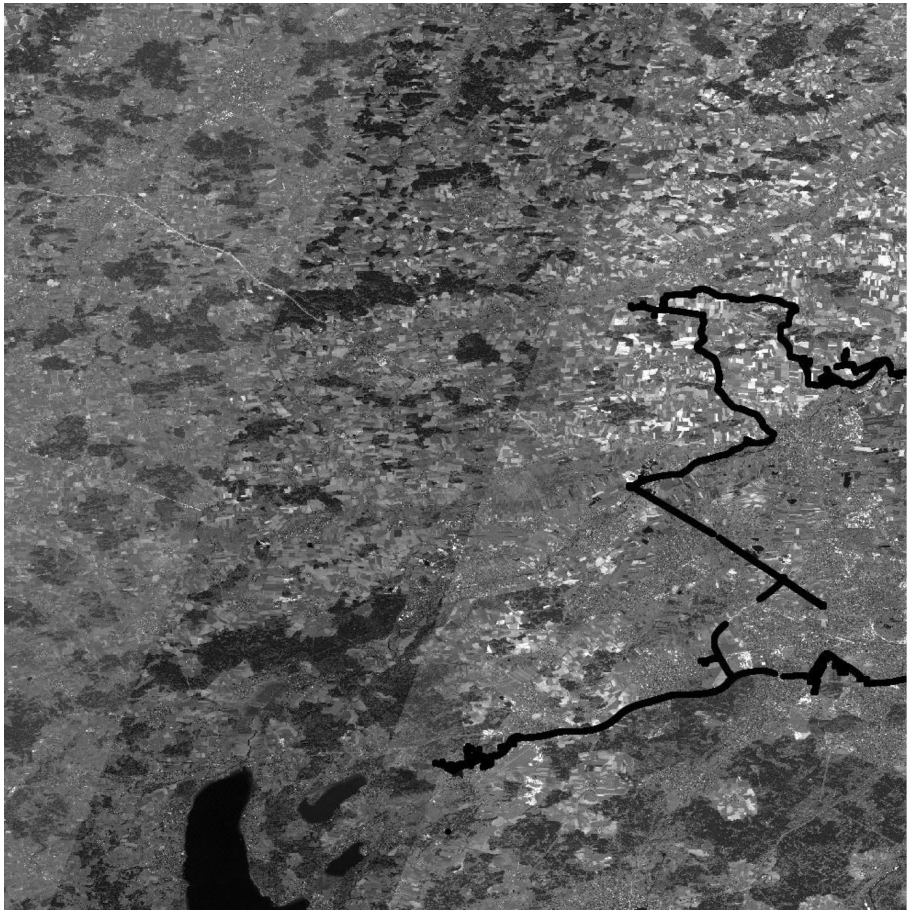




Rodriguez, E., Morris, C. S., Belz, J. E., Chapin, E. C., Martin, J. M., Daffer, W., et al. (2005). An assessment of the SRTM topographic products, Technical Report JPL D-31639.Pasadena, California: Jet Propulsion Laboratory 143 pp

DSM Validation – GPS Transects

- Example: Euro-Maps 3D tile 109683P5011E048NPC___G4
  - Horizontal: CE90: 5.34 m
  - Vertical: LE90: 5.42 m



DSM Validation – Optical Reference

- Where available, high quality optical datasets are the reference of choice
- WMS layers of national ortho/aerial imagery or VHR chips
- Correlation of the Euro-Maps 3D ortho layer against 2D reference
- Example: Euro-Maps 3D tile 114181P5012E042NPB___G4
  - WMS: GEOPORTALE NAZIONALE
  - Points found: 1576; CE90: 3.48 m

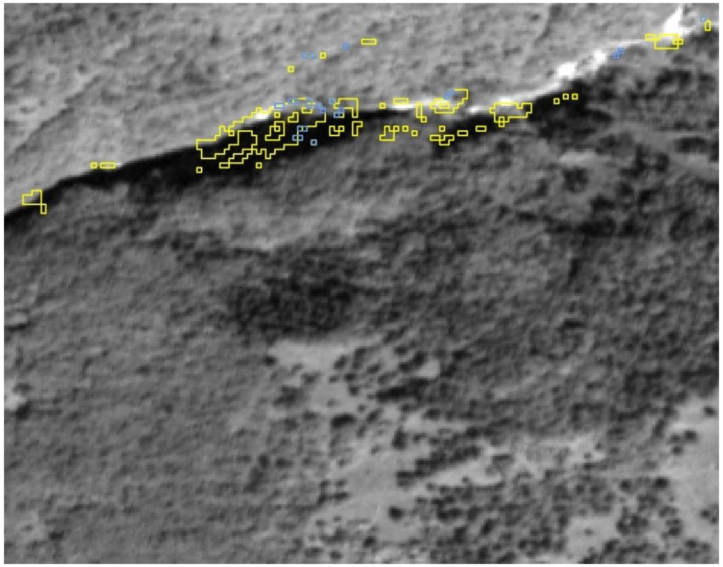
http://wms.pcn.minambiente.it/ogc?map=/ms_ogc/WMS_v1.3/raster/ortofoto_colore_06.map

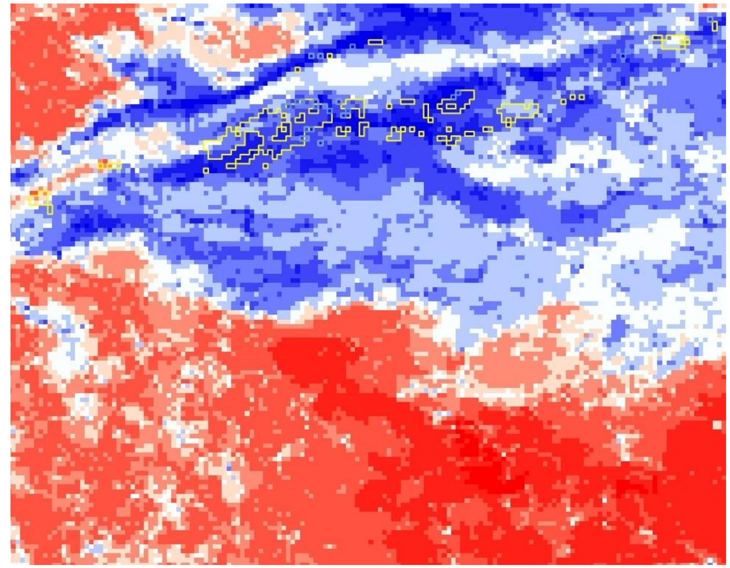
DSM Preparation – Automated Outlier Detection

- In addition to the outlier detection inside the processing chain, two different fully automated artefact detection algorithms are used
- Software used: GDAL, python, bash
- Spike&Well: detects jumps in elevation values between adjacent pixels
- Num_Δh_std: detects large height differences between DSM and reference DSM, utilising the processing chain's thematic auxiliary layers NUM and STD
- Detection thresholds defined according to product specification:
  - 5 meters for slopes < 20 %
  - 7 meters for slopes 20 % - 40 %
  - 10 meters for slopes > 40 %
- Different detection thresholds over forest, water and urban areas are used to minimize false positive detections

DSM Preparation – Automated Outlier Detection

Ortho

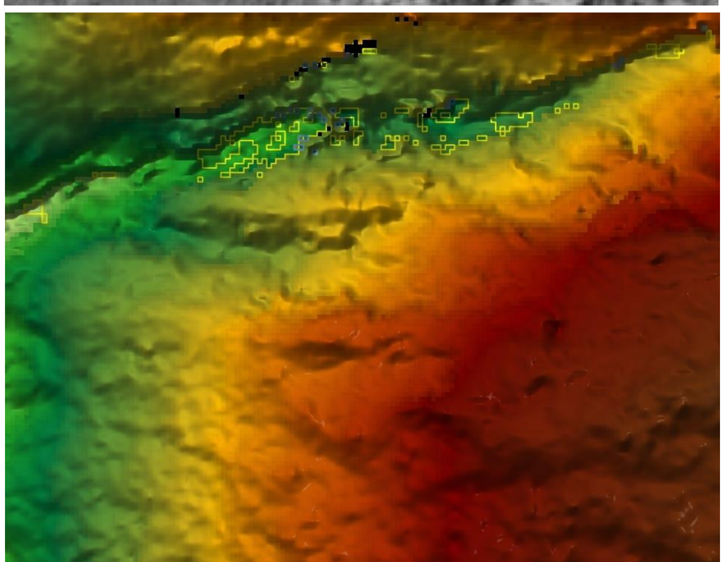


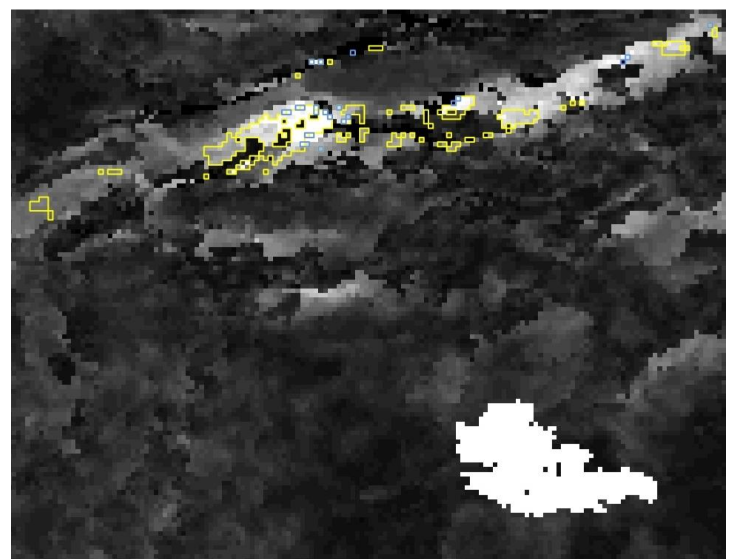


1.2 11
Min: 0
Max: 11

NUM

DSM

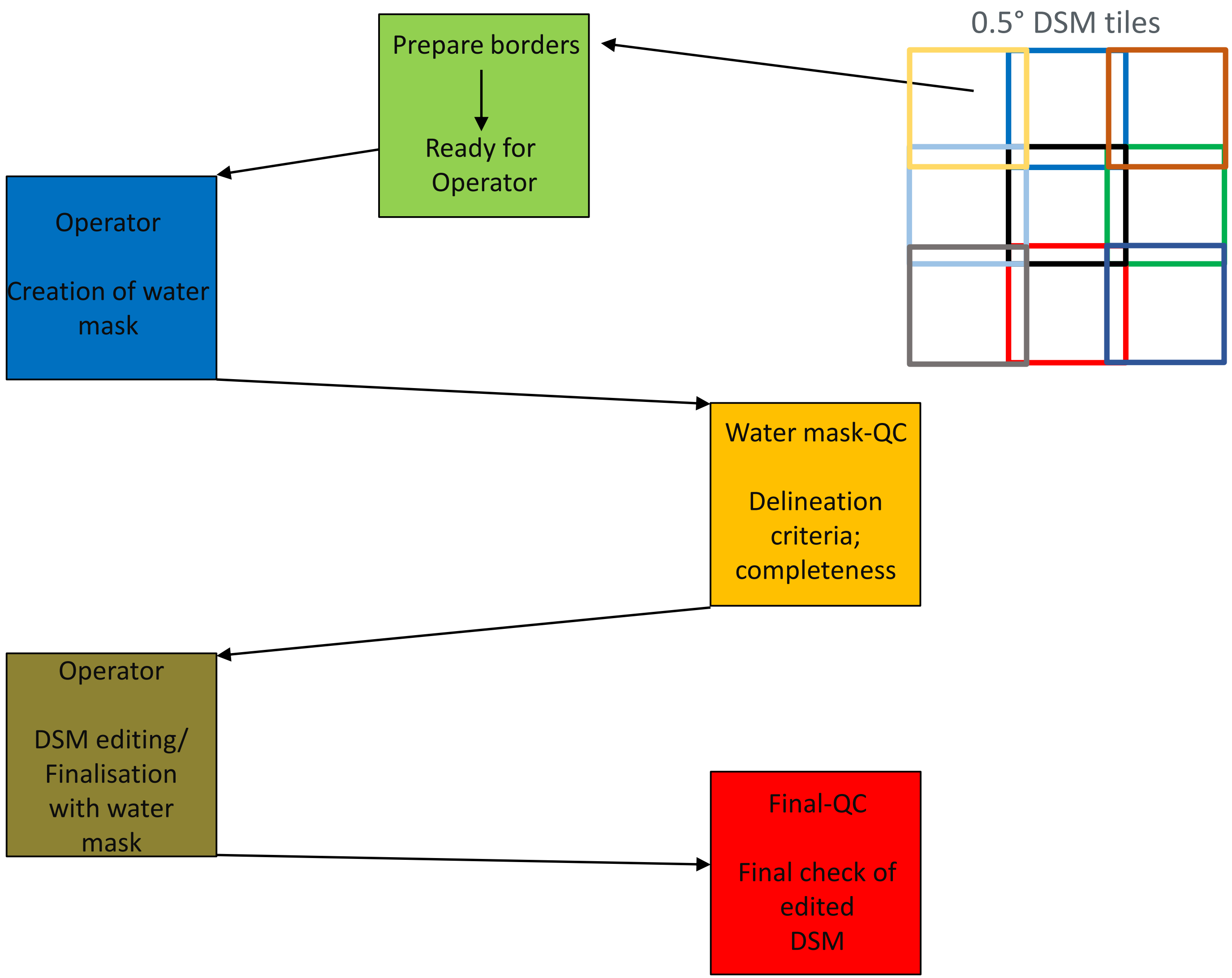




Min: ~-1
Max: ~1926

STD

DSM Preparation – Editing Workflow

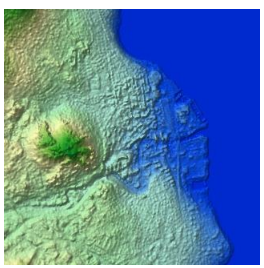


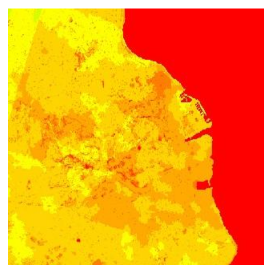
DSM Preparation – Editing Workflow

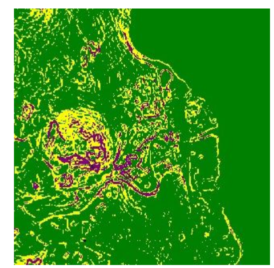
- A standardized editing workflow for the tile-based DSM product has been implemented using a wide range of editing tools within the GAFmap GIS software
- Defined Workspace settings, defined editing scales
- Water bodies collected manually on the visual ortho layer according to defined detection criteria (minimum size, minimum width, etc.)
- Individual manual water mask QC
- False positives check of automatically detected DSM errors
- Manual edits for remaining artefacts
- Elevation values of water bodies are derived from edited DSM
- Overlap consistency checks for geometries and raster
- Backup of intermediate files for traceability and quality control
- Individual manual final QC regarding filling, editing and hydro-enforcement
- Final, script-based checks for completeness and consistency, to ensure seamless product accuracy across tiles

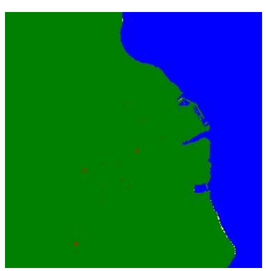
DSM Finalisation

- Edited DSM data is then ready for final formatting
- Pixel-level quality and traceability layers provide information from processing step, through editing step up to final product:
  - DSM layer contains the elevation heights
  - SRC layer contains the data source for each pixel
  - NUM layer contains the number of stereo matches used for DSM generation
  - QC layer is set to 1 for each validated pixel derived from IRS-P5 Cartosat-1
  - ACV layer contains a value corresponding to the absolute vertical accuracy
  - Ortho layer contains the nadir-near images, orthorectified with the unedited DSM


DSM


NUM


ACV


SRC


QC


Ortho

DEM for Ortho

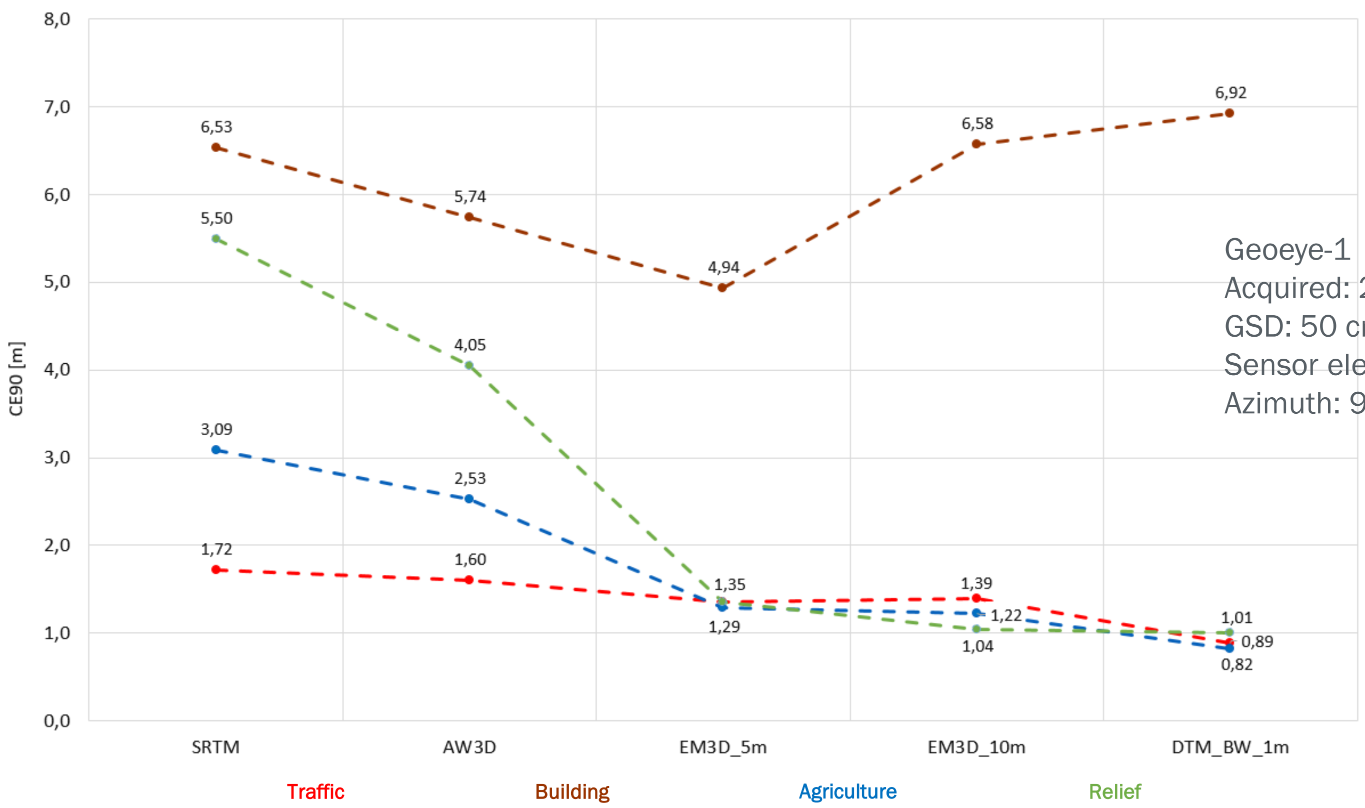
- Euro-Maps 3D for Ortho: a blend of DTM for urban areas and DSM elsewhere
- Automatically detected errors were removed from the 5 m DSM
- Semi-automatically generated water mask based on co-registered Sentinel-2 imagery applied to 5 m DSM
- Filtering plus resampling to 10 m resolution
- Optimized for orthorectification purposes

VHR data orthorectified with Euro-Maps 3D 5 m DSM

VHR data orthorectified with Euro-Maps 3D for Ortho

DEM for Ortho – Orthorectification of VHR Data

- „Comparative analysis of the impact of different terrain models on the quality of orthorectification of high-resolution satellite imagery” (Vogl, 2019)
- Euro-Maps 3D for Ortho (EM3D_10m), Euro-Maps 3D (EM3D_5m), ALOS World 3D - 30 m (AW3D) and SRTM - 30 m (SRTM) compared against national elevation model Baden-Württemberg, Germany



Geoeye-1
Acquired: 21-Apr-2017
GSD: 50 cm
Sensor elevation: 60.6°
Azimuth: 95.5°

DEM for Ortho – Orthorectification of VHR Data

Geoeye-1 acquired on 21-Apr-2017; GSD 50 cm; Sensor elevation 60.6°; Azimuth 95.5°											
Traffic											
	# CP	MW_X [m]	MW_Y [m]	$RMSE_X$ [m]	$RMSE_Y$ [m]	MW_R [m]	$RMSE_R$ [m]	CE90 [m]	a [m]	b [m]	Θ [°]
SRTM	66	-0,41	0,18	1,23	0,38	0,44	1,28	1,72	2,53	0,63	98,16
AW3D	66	-0,48	0,19	1,11	0,38	0,52	1,18	1,60	2,19	0,65	97,80
EM3D_5m	66	-0,52	0,19	0,89	0,37	0,55	0,96	1,35	1,59	0,64	99,62
EM3D_10m	66	-0,70	0,19	0,93	0,36	0,72	1,00	1,39	1,36	0,63	100,59
DTM_BW_1m	66	-0,44	0,18	0,50	0,33	0,47	0,60	0,89	0,68	0,40	35,12
Building											
	# CP	MW_X [m]	MW_Y [m]	$RMSE_X$ [m]	$RMSE_Y$ [m]	MW_R [m]	$RMSE_R$ [m]	CE90 [m]	a [m]	b [m]	Θ [°]
SRTM	33	-4,27	0,30	4,55	1,54	4,28	4,80	6,53	3,52	3,15	52,05
AW3D	33	-3,53	0,22	3,79	1,56	3,54	4,10	5,74	3,41	2,92	15,65
EM3D_5m	33	-2,65	0,10	3,08	1,52	2,65	3,43	4,94	3,59	3,14	52,35
EM3D_10m	33	-4,37	0,32	4,59	1,53	4,38	4,84	6,58	3,56	2,77	39,03
DTM_BW_1m	33	-4,64	0,37	4,89	1,56	4,66	5,13	6,92	3,47	3,15	47,31
Agriculture											
	# CP	MW_X [m]	MW_Y [m]	$RMSE_X$ [m]	$RMSE_Y$ [m]	MW_R [m]	$RMSE_R$ [m]	CE90 [m]	a [m]	b [m]	Θ [°]
SRTM	43	1,29	-0,18	2,48	0,40	1,30	2,51	3,09	4,61	0,71	94,26
AW3D	43	0,95	-0,14	1,95	0,41	0,96	1,99	2,53	3,71	0,76	95,22
EM3D_5m	43	-0,32	-0,03	0,85	0,35	0,32	0,92	1,29	1,71	0,74	97,20
EM3D_10m	43	-0,42	-0,01	0,80	0,33	0,42	0,87	1,22	1,49	0,72	92,50
DTM_BW_1m	43	-0,17	-0,04	0,44	0,32	0,17	0,55	0,82	0,88	0,70	93,49
Forest											
	# CP	MW_X [m]	MW_Y [m]	$RMSE_X$ [m]	$RMSE_Y$ [m]	MW_R [m]	$RMSE_R$ [m]	CE90 [m]	a [m]	b [m]	Θ [°]
SRTM	43	-5,70	2,32	6,38	3,98	6,15	7,52	11,12	7,89	5,08	143,58
AW3D	43	-4,39	2,10	5,52	3,89	4,86	6,75	10,10	8,61	5,43	133,71
EM3D_5m	43	-2,08	1,71	3,37	3,51	2,70	4,86	7,38	6,73	5,66	163,92
EM3D_10m	43	-2,42	1,77	3,72	3,56	3,00	5,15	7,82	6,98	5,85	150,30
DTM_BW_1m	43	-12,72	3,51	13,13	4,80	13,20	13,97	19,23	8,24	5,62	136,01
Relief											
	# CP	MW_X [m]	MW_Y [m]	$RMSE_X$ [m]	$RMSE_Y$ [m]	MW_R [m]	$RMSE_R$ [m]	CE90 [m]	a [m]	b [m]	Θ [°]
SRTM	36	3,12	-0,36	4,41	0,72	3,14	4,47	5,50	6,88	0,67	99,86
AW3D	36	2,55	-0,27	3,24	0,54	2,56	3,28	4,05	4,39	0,81	98,25
EM3D_5m	36	-0,25	0,11	0,92	0,35	0,27	0,98	1,35	1,92	0,71	92,53
EM3D_10m	36	-0,20	0,09	0,66	0,31	0,22	0,73	1,04	1,39	0,64	86,54
DTM_BW_1m	36	-0,33	0,11	0,61	0,33	0,35	0,70	1,01	1,12	0,78	89,90

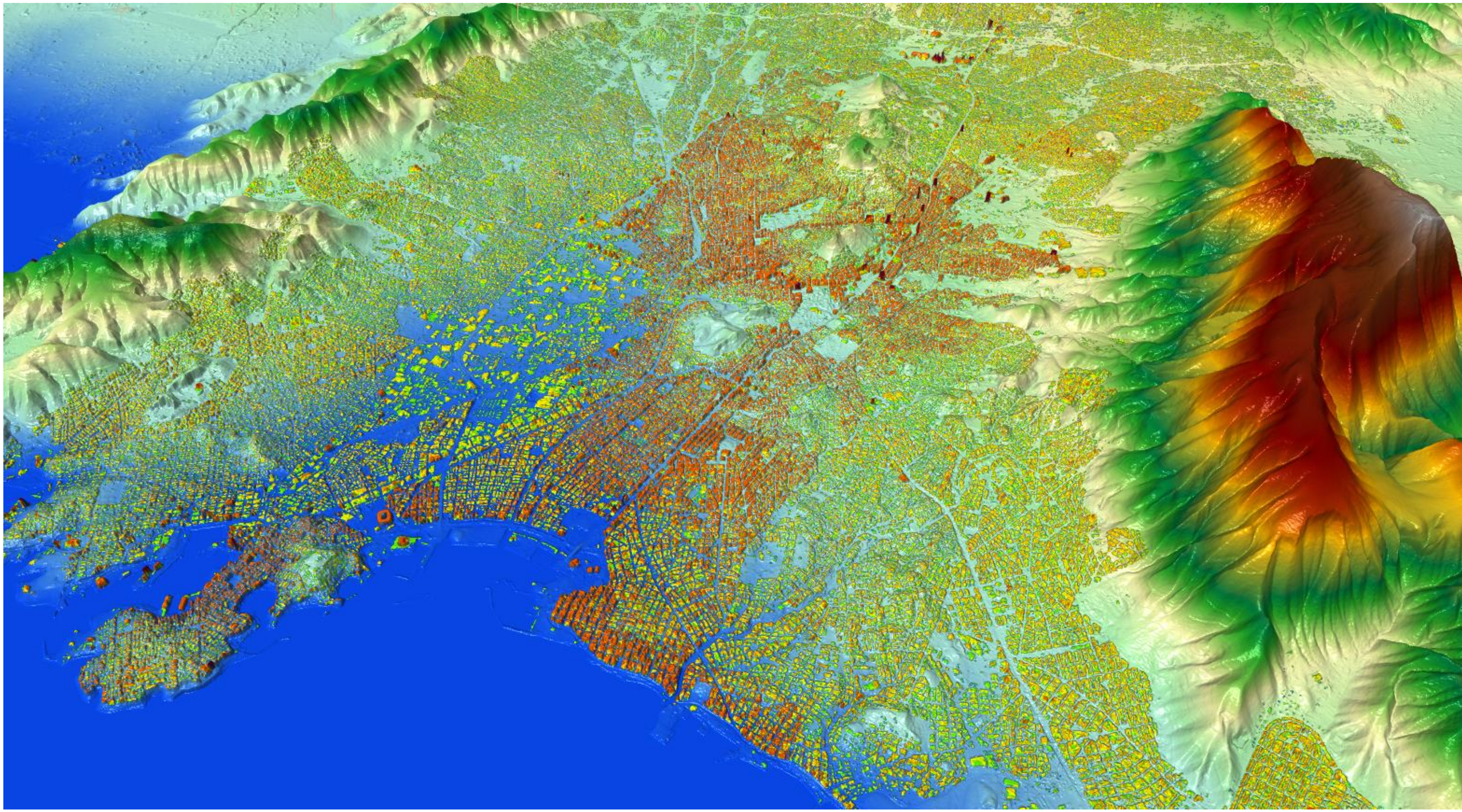
Building Block Heights

- 2.5 m stereo-matched Cartosat-1 base data is also used for additional projects
- Example: Urban Atlas Building Height 2012 product
  - Base data from reference period processed to 3 m DSM
  - DSM editing, followed by DTM generation and normalized DSM (nDSM) calculation
  - Final editing of derived building block heights
  - Final height accuracy of better than 3 m achieved for all 28 datasets
  - Warsaw dataset: „Accuracy assessment of the Copernicus Buildings Height 2012 layer based on the city of Warsaw” (Kaluski, Hoscilo, Gurdak; Geoinformation Issues 10 (1 (10)), 2018)

    “In general, data from both datasets are compatible, however the overestimation of the height was observed. The comparison carried out in two ways produced similar results. On average, the overestimation of the satellite-based building height for the study area reached 1.08 m.“

    (http://bc.igik.edu.pl/Content/872/GI_Vol.+10+z.+1%2810%29_6.pdf)

- Common project of European Commission, EEA and ESA https://land.copernicus.eu/local/urban-atlas



Urban Atlas 3D Athens, Greece; Processed by GAF. Includes material © Antrix, distributed by GAF AG

Conclusion

- The 2.5 m stereo data of Cartosat-1 has been a success story for GAF
- High quality input data combined with extensive elevation data expertise
- A high quality transnational 5 m DSM for Europe and other areas worldwide
- Additional products were derived and projects successfully completed
- Follow-on missions Resourcesat-3S/3SA to provide stereo data continuity with improved parameters: pan stereo 1.25 m, swath 60 km, multispectral 2.5 m