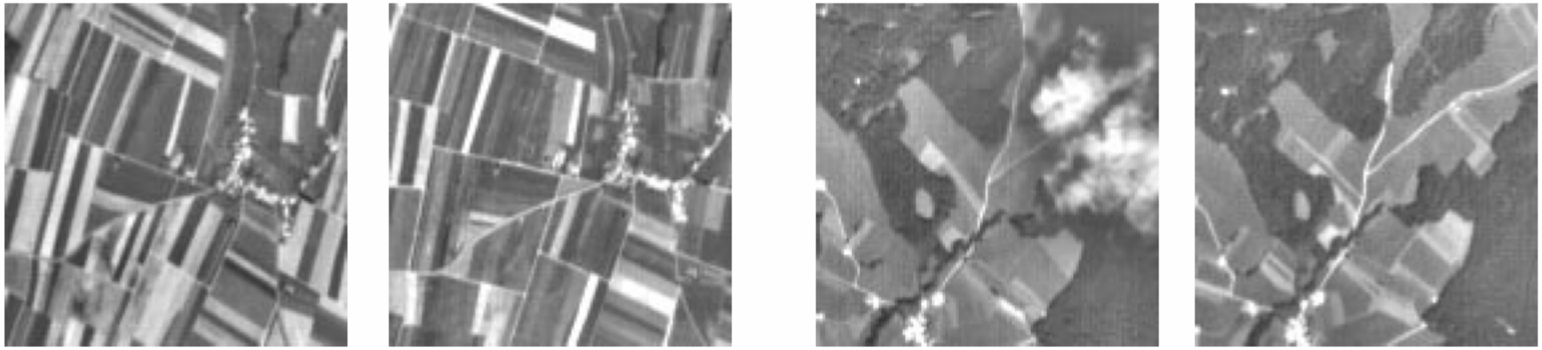
Section 4

Automated DSM generation

Li Zhang , Emmanuel Baltsavias

DSM Generation

- Almost all HR sensors are stereo capable. Some can produce even triplettes within the same strip (facilitating multi-image matching).
- Mostly SPOT (1-5) used for stereo and Ikonos (in spite of high potential of Ikonos for accurate DSM generation, it has been used relatively little)
- High costs of stereo images, initially sold only to governments.
- Almost all HR satellites can acquire stereo images quasi-simultaneously (called wrongly along-track stereo), thus facilitating automatic DSM/DTM generation with image matching, reducing the temporal image differences.



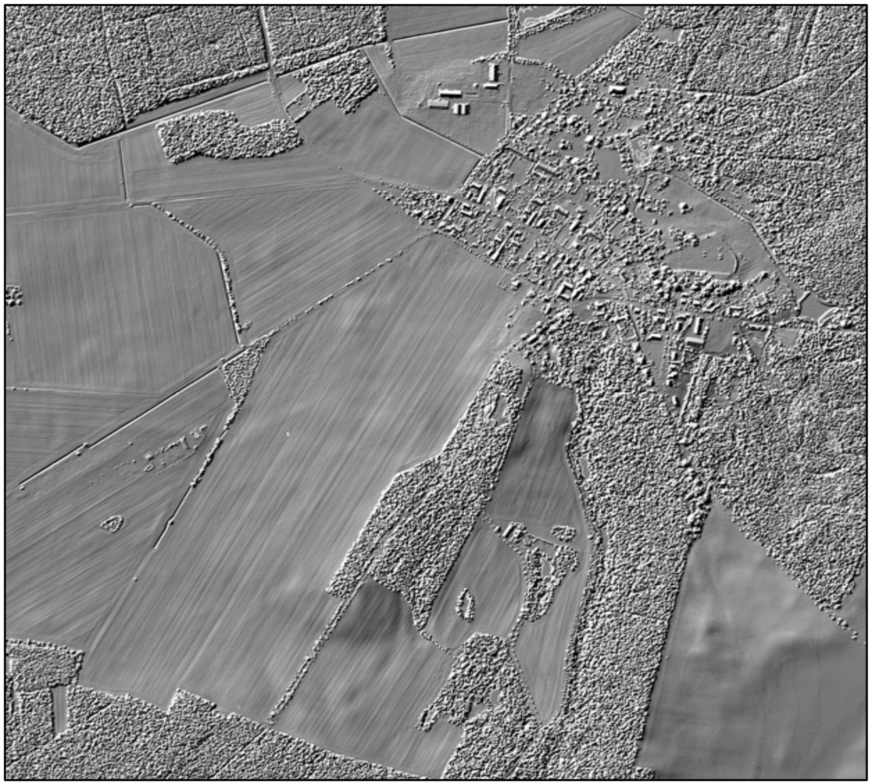
SPOT-1 stereo images taken from different orbits with one month difference

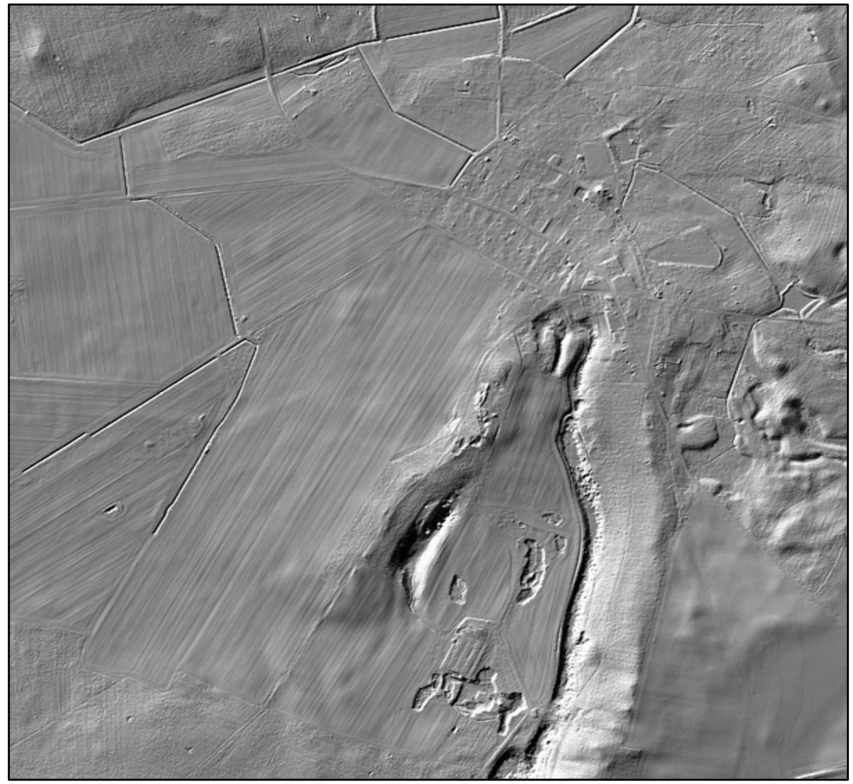
Automatic DSM Generation

- Manual, automatic, semi-automatic measurement modes. Last includes pre- and/or post-editing and is the preferable way.
- Full automation is very difficult.
- For agile satellites, matching methods function better when occluded areas coincide as much as possible with shadow areas, e.g. when the orbit is to the East of the area imaged.
- With automatic mode only DSM can be measured, with the others both DSM and DTM. Reduction of DSM to DTM can rarely be performed fully automatically (e.g. in flat areas with scarce buildings and vegetation).

Digital Surface (DSM) vs Digital Terrain Model (DTM)

Here DSM reduced probably semi-automatically (Lohr, 2001).
Here airborne laser data, where DSM AND DTM generation easier, when laser registers more than one echo per pulse.





Automatic DSM Generation

- Rules of thumb (for matching):

  - DSM / DTM spacing: at min. 2-3 GSD

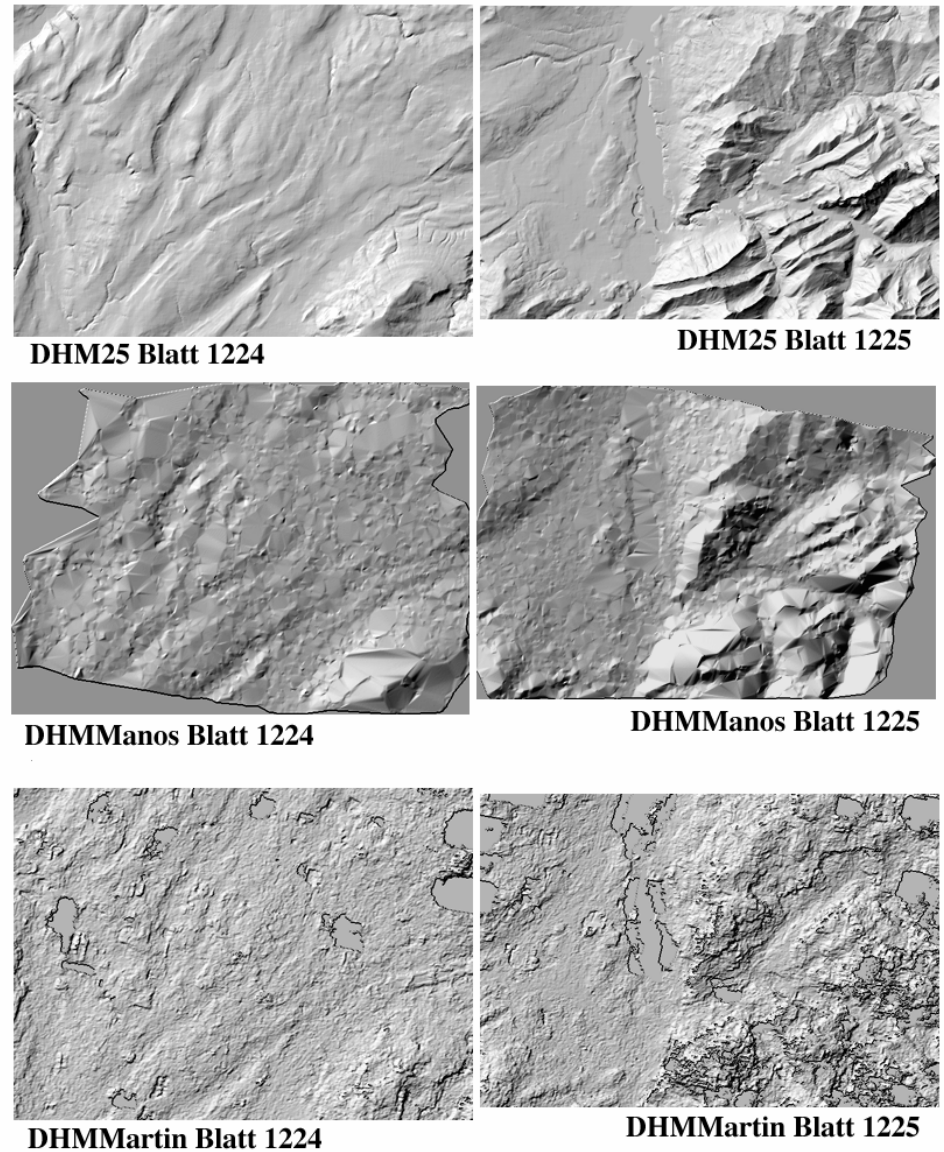
  - Image measurement accuracy (good case): 0.5 to 1.5 pixels

  - Height accuracy: depends mainly on Base / Height ratio but also quality of sensor model and GCP quality; can be in the best case < 1 pixel, average values 1-2 pixels, except difficult areas (dense urban, vegetation).

Automatic DSM Generation

- Matching modules exist in various commercial RS and photogrammetric systems. Methods used are often based on cross-correlation, and match at a regular object or image grid.
- Much better methods exist in research labs. The example from 1991 on the next page, shows for two 1:25,000 scale map sheets, the Swiss national DTM (DHM25) derived from digitising contour lines, fully automated DSM results from SPOT-1 with ETHZ algorithms, and the same using the commercial system PCI. The two SPOT images had large radiometric differences.
- For good quality the breaklines must be well modeled which can be achieved better by using edge-based matching, in combination with other matching methods that provide denser results (see ETHZ method of Zhang Li below).

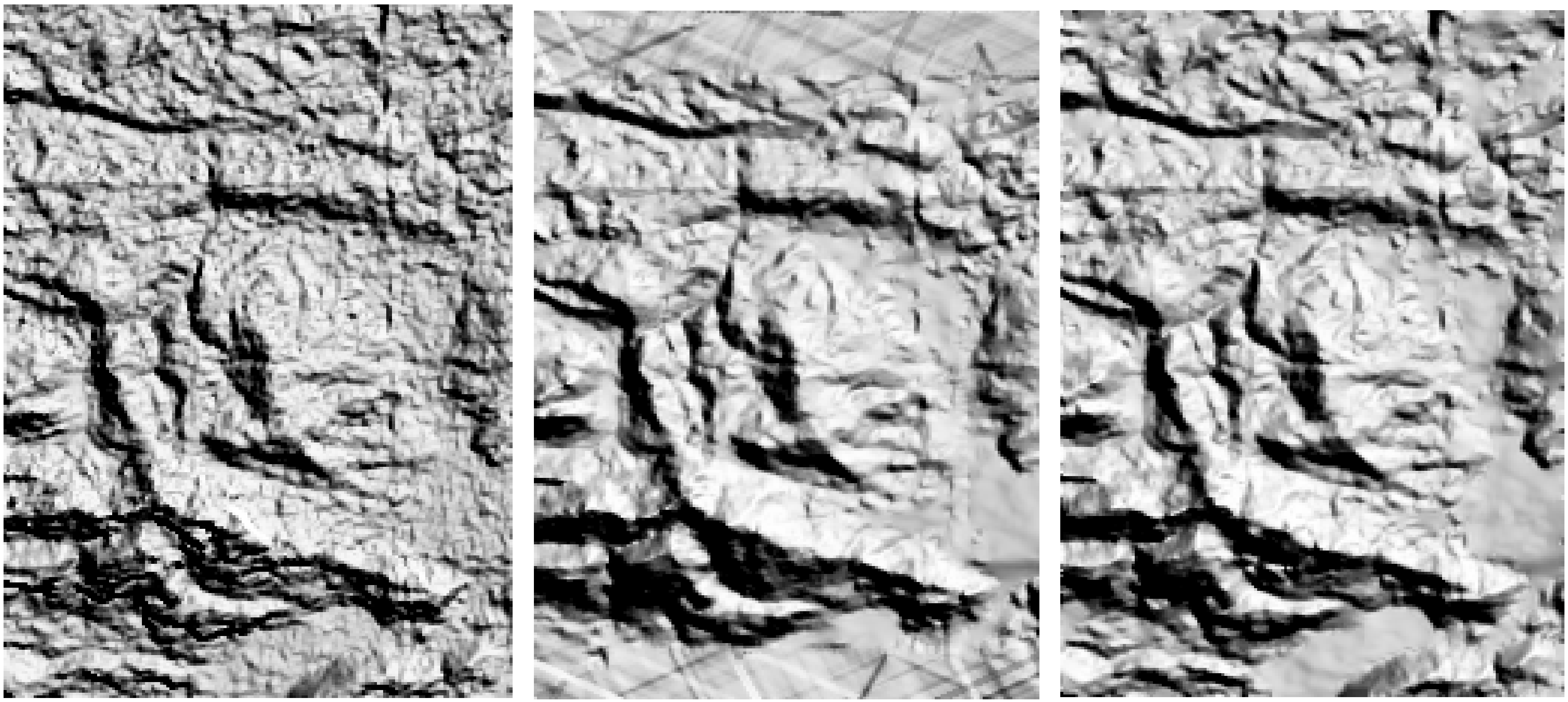
Automatic DSM Generation



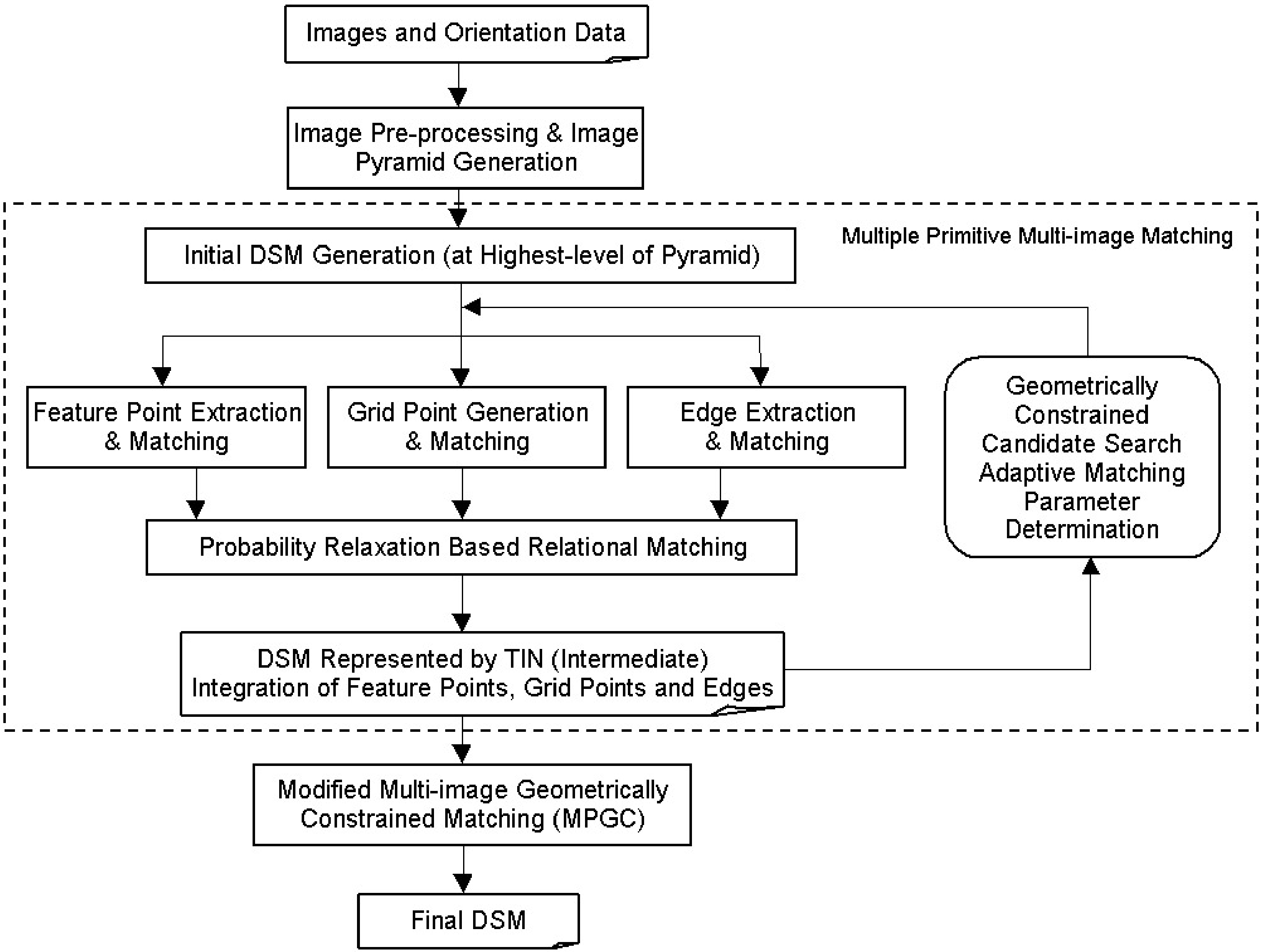
Alle DHM schattiert von Nordwesten mit Sunelevation 30°

Automatic DSM Generation

- Matching results, espec. with commercial systems, can vary a lot depending on the selection of the matching parameters (which have sometimes an unclear definition or at least effect).
- 3 automatically generated DSMs with DPW770, SocetSet. Left and right ATE, middle Adaptive ATE (effect of different matching strategies and matching parameters is clear)



Automatic DSM Generation (one of the methods developed at ETHZ by Zhang Li)



Automatic DSM Generation

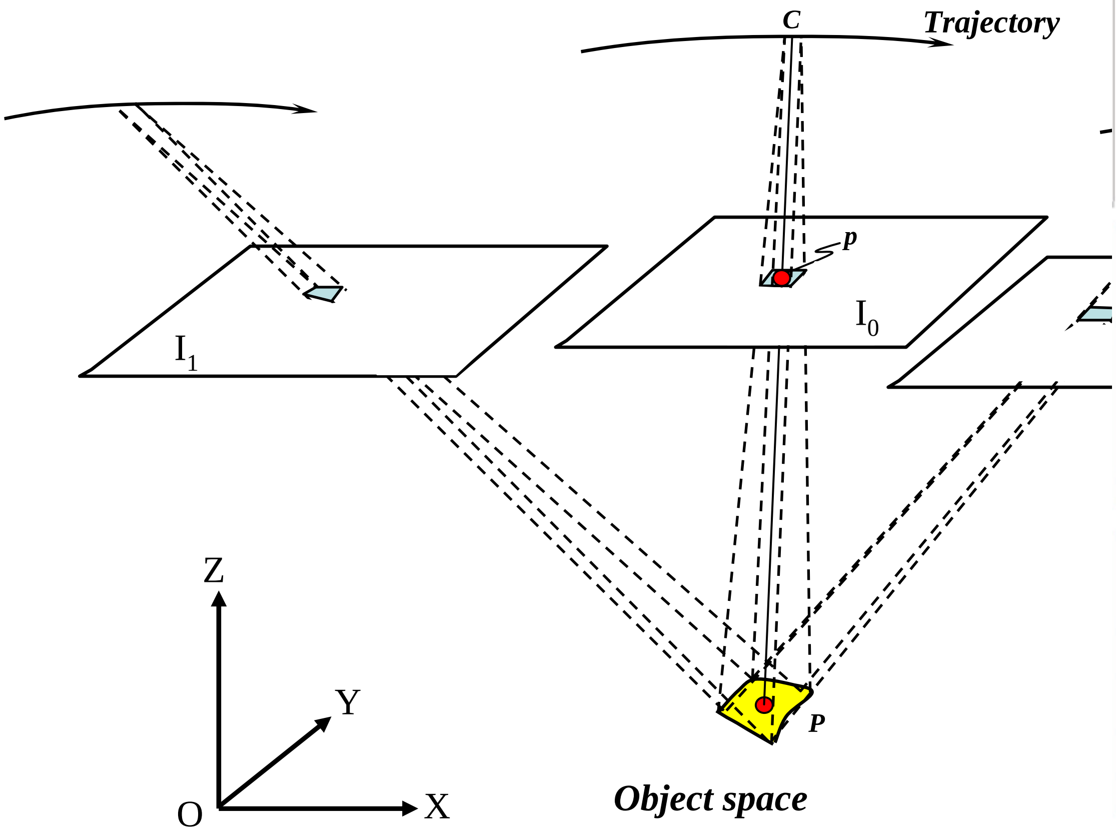
- Multiple image matching
  + Matching guided from object space
  + Simultaneously multiple images (>= 2) with
    Geometrically Constrained Cross-Correlation
- Matching with multiple primitives - points + edges
- Self-tuning matching parameters
- High matching redundancy
- Efficient surface modeling
  + TIN (from a constrained Delauney triangulation method)
- Coarse-to-fine hierarchical strategy

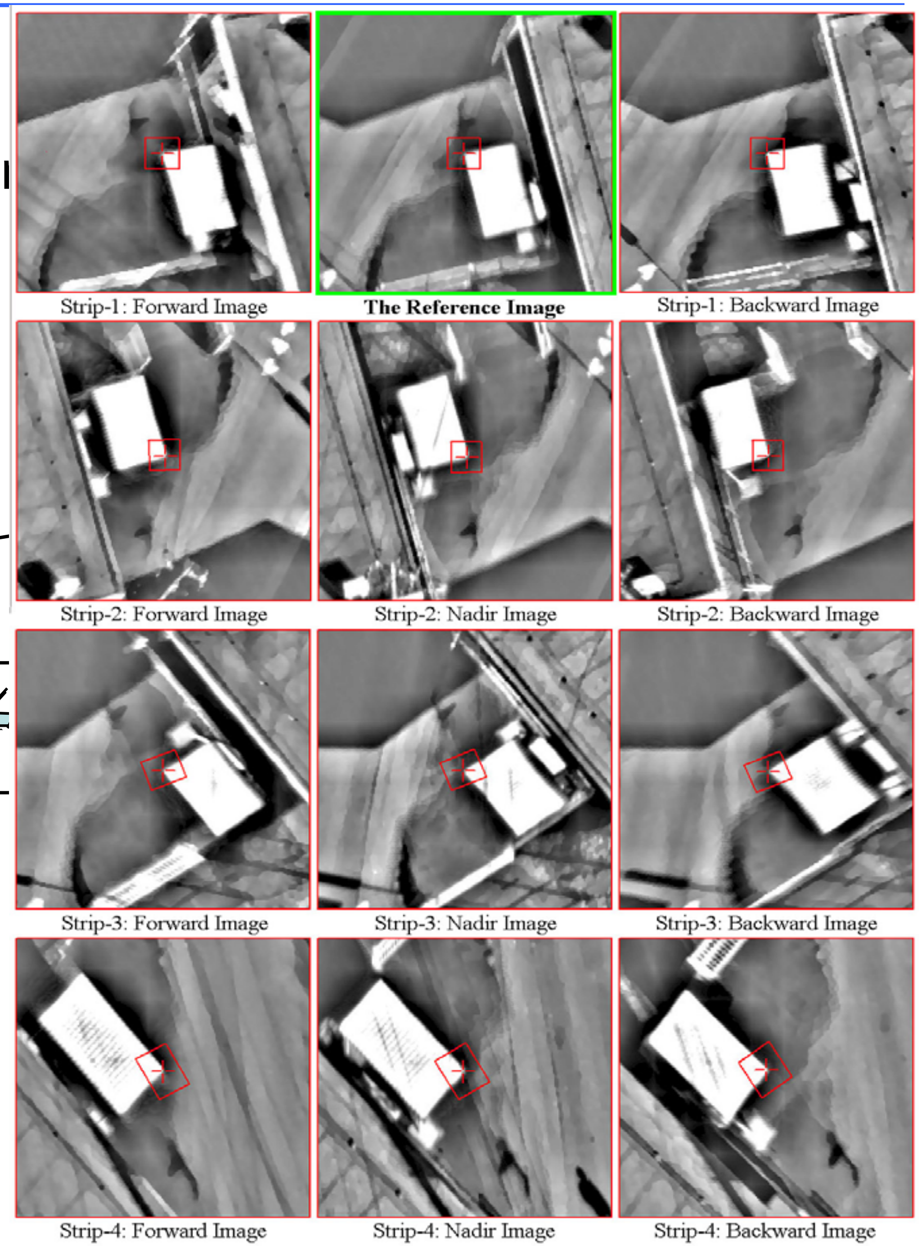
Multiple Image Matching

Geometrically Constrained Cross-Correlatio

+ Extension of traditional cross-correlation method

Step 1: Correlation window warping



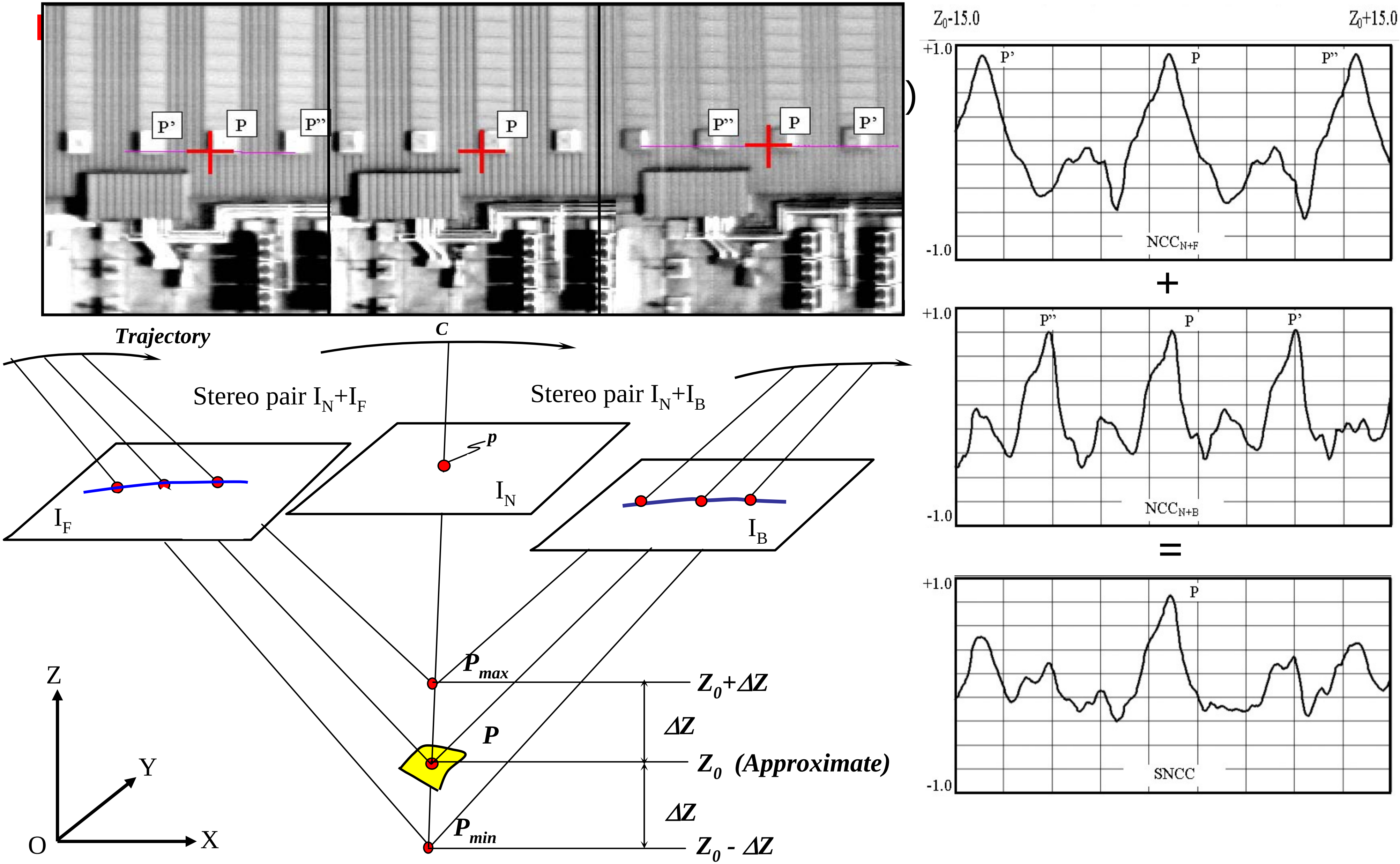


Strip-1: Forward Image | The Reference Image | Strip-1: Backward Image

Strip-2: Forward Image | Strip-2: Nadir Image | Strip-2: Backward Image

Strip-3: Forward Image | Strip-3: Nadir Image | Strip-3: Backward Image

Strip-4: Forward Image | Strip-4: Nadir Image | Strip-4: Backward Image



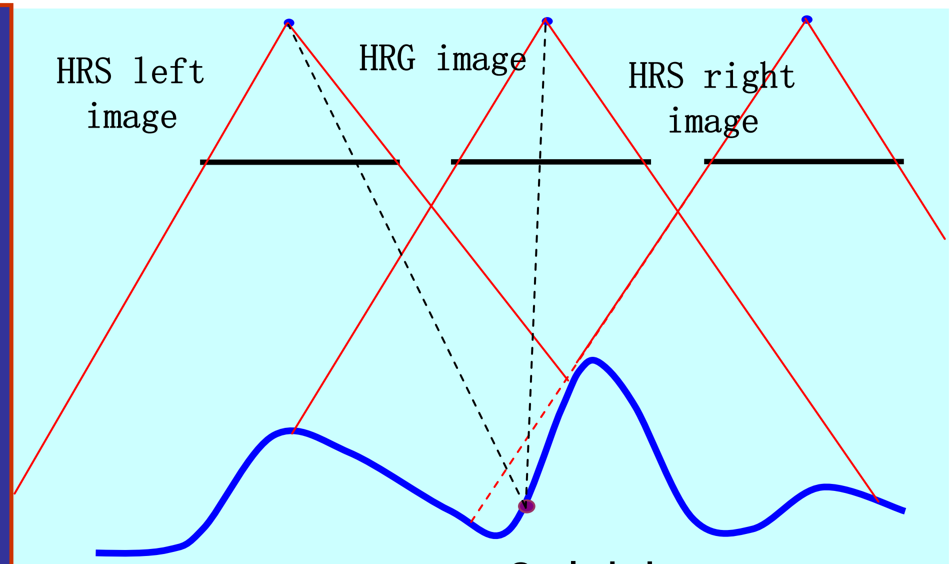
P'
P
P''
Z0-15.0
Z0+15.0
+1.0
-1.0
NCC N+F
NCC N+B
SNCC
Trajectory
C
Stereo pair IN+IF
Stereo pair IN+IB
p
IN
IF
IB
Pmax
P
Pmin
Z0+ΔZ
ΔZ
Z0 (Approximate)
ΔZ
Z0 - ΔZ
Z
Y
O
X

（2）DEM Generation from SPOT5 HRS Stereo images

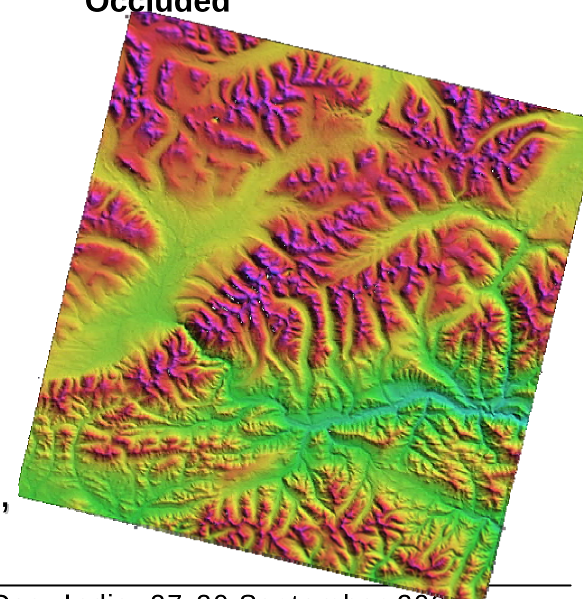
Multi-image, Multi-feature matching procedure was developed in order to generate precise and detailed DEM from satellite imagery

Feature-1: Object-guided multi-image matching, More than 2 images can be simultaneously matched.

Feature-2: Combining multiple matching primitives (feature point matching, grid point matching and edge matching)

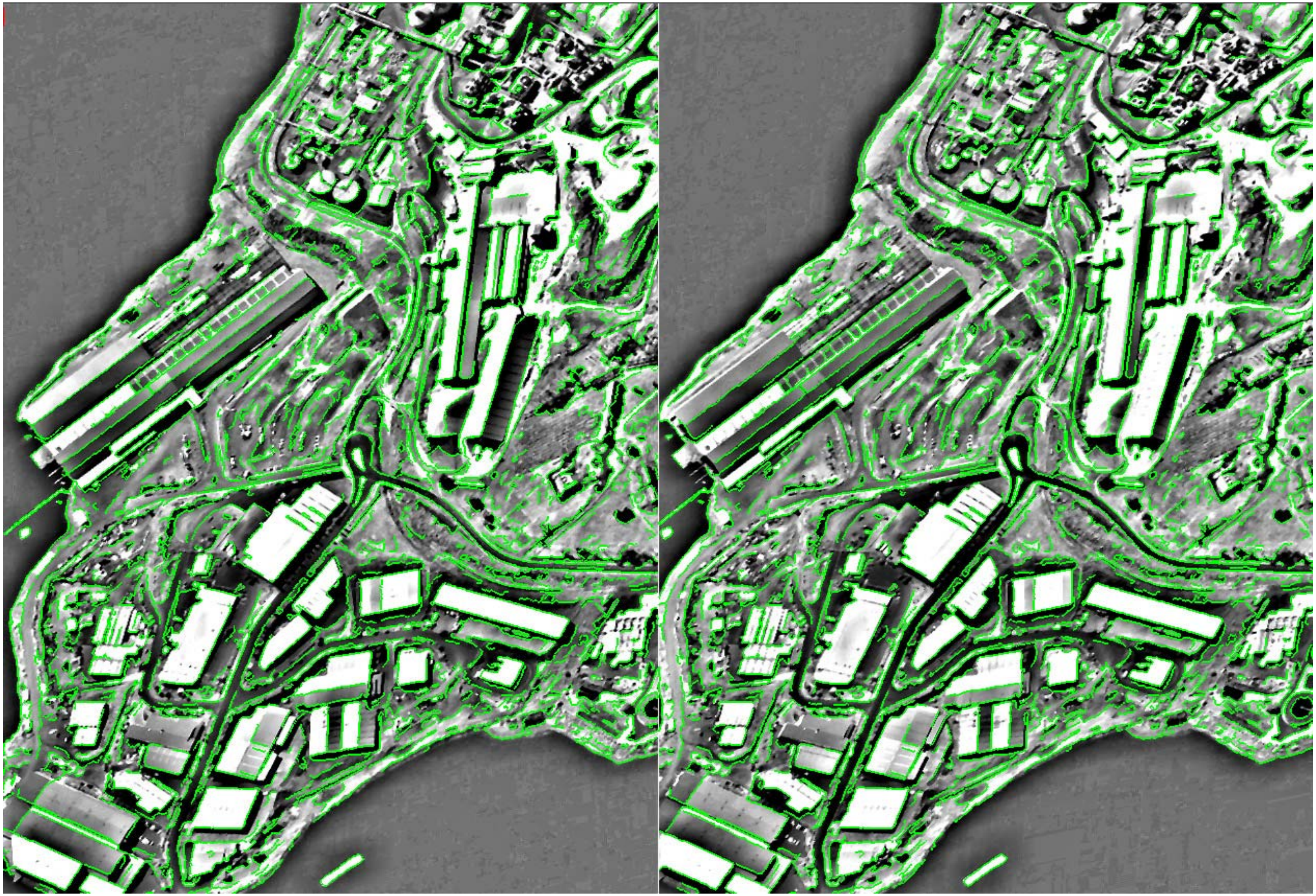


Occluded

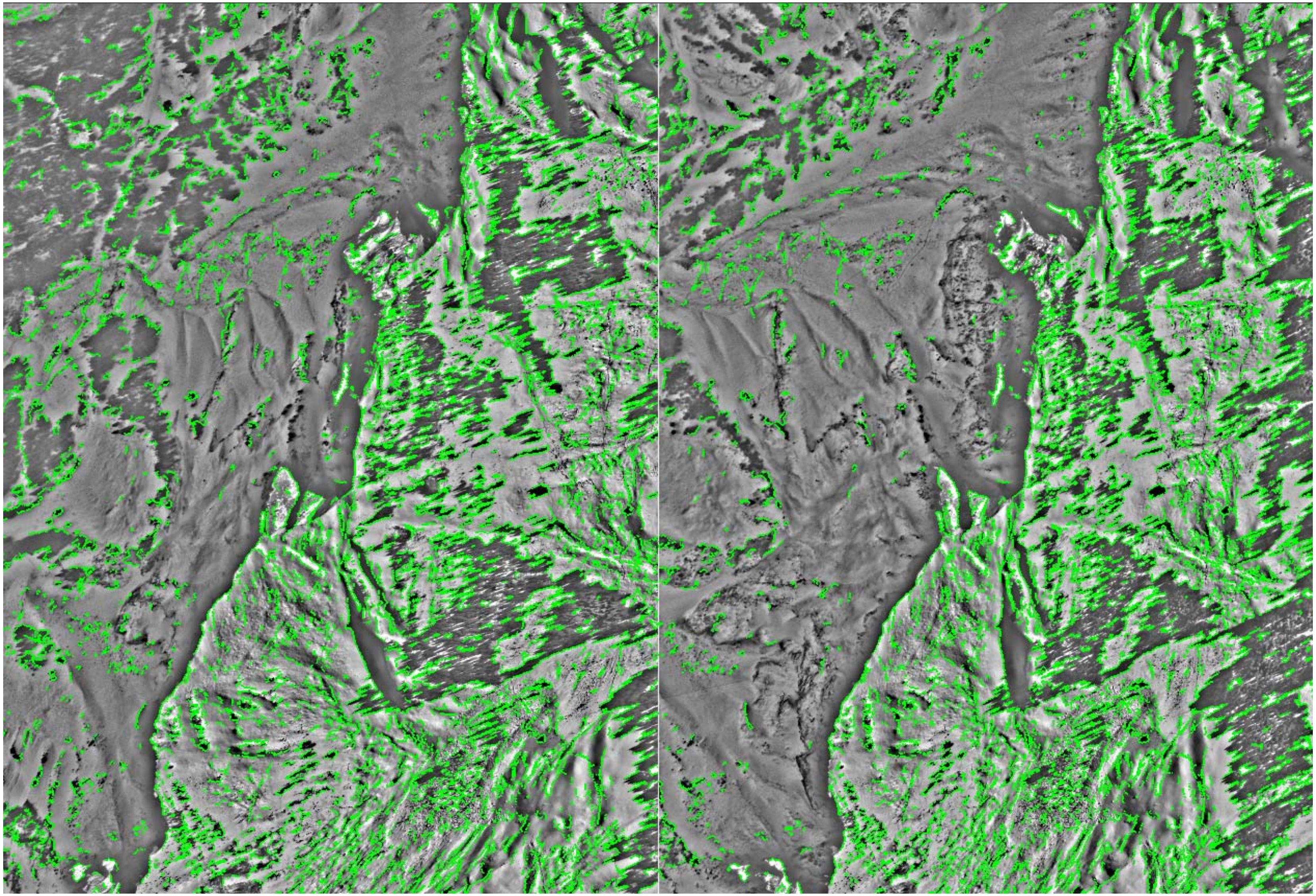


Simultaneously matching SPOT5 HRS/HRG Tristereo, to generate DEM

Automatic DSM Generation (edge matching part)



Automatic DSM Generation (edge matching part)



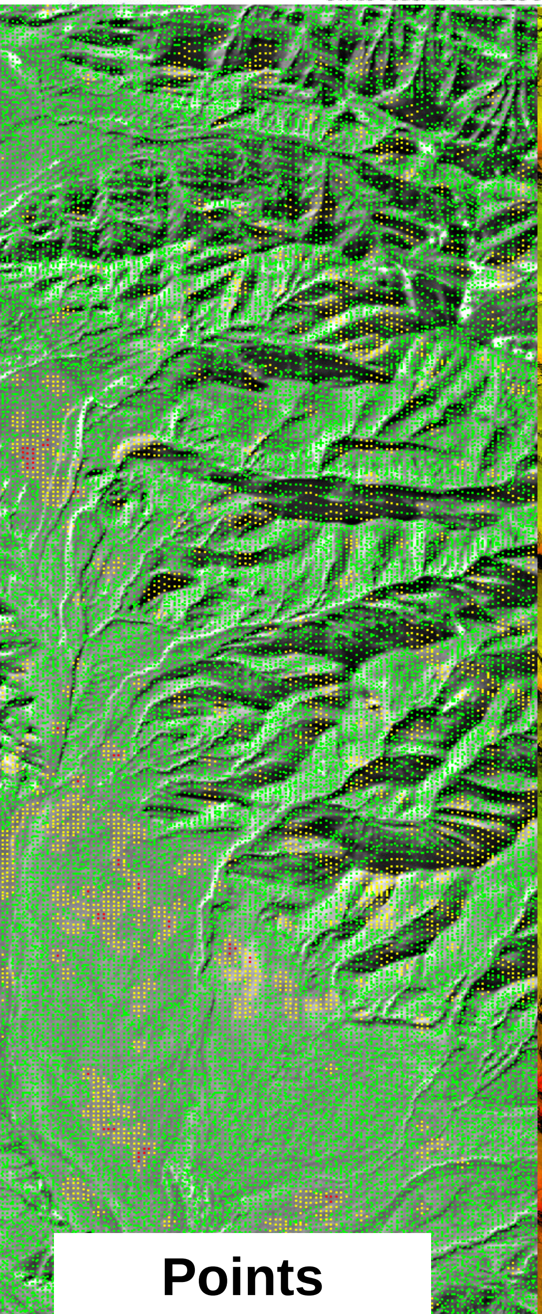
isprs

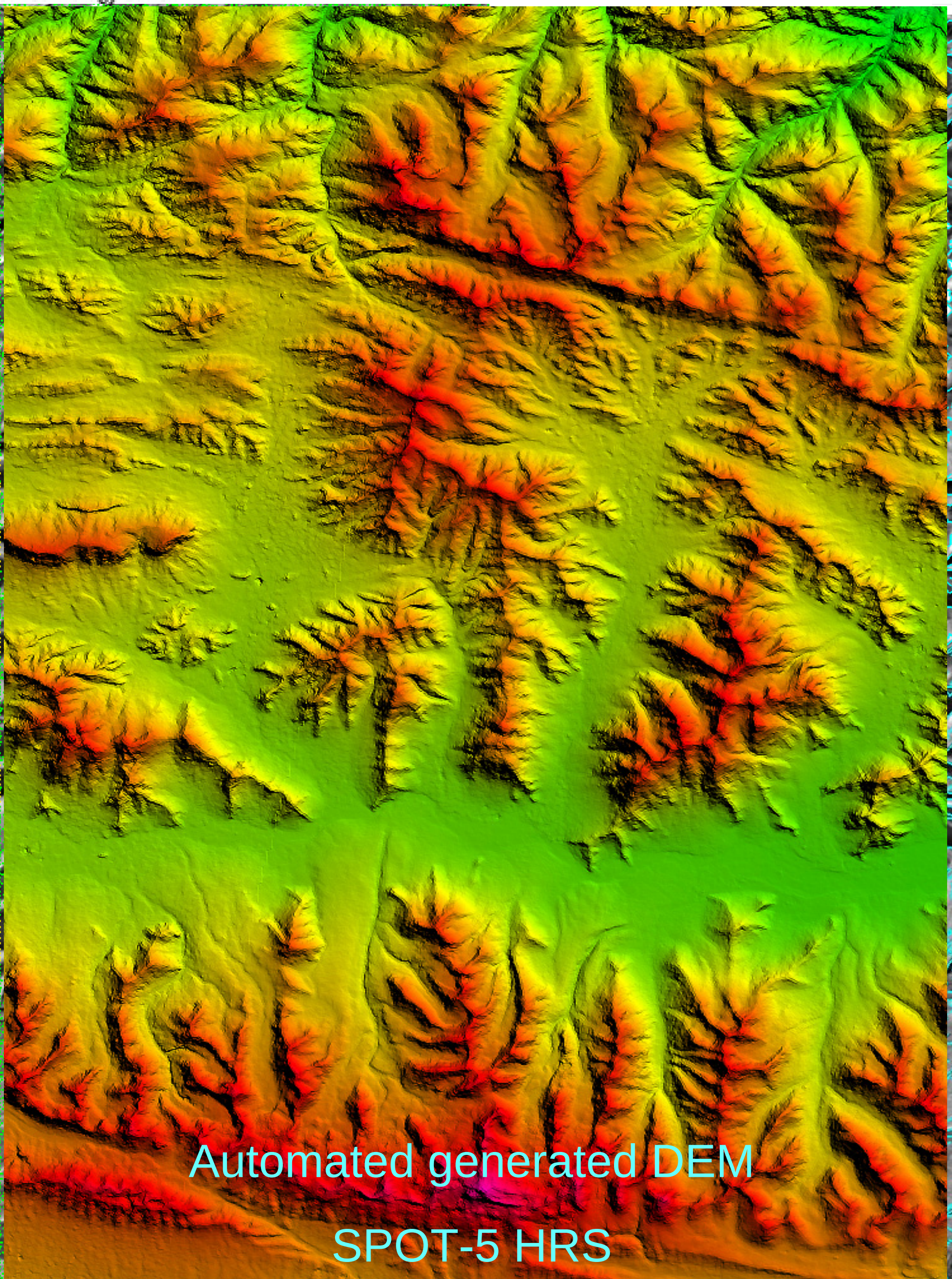
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

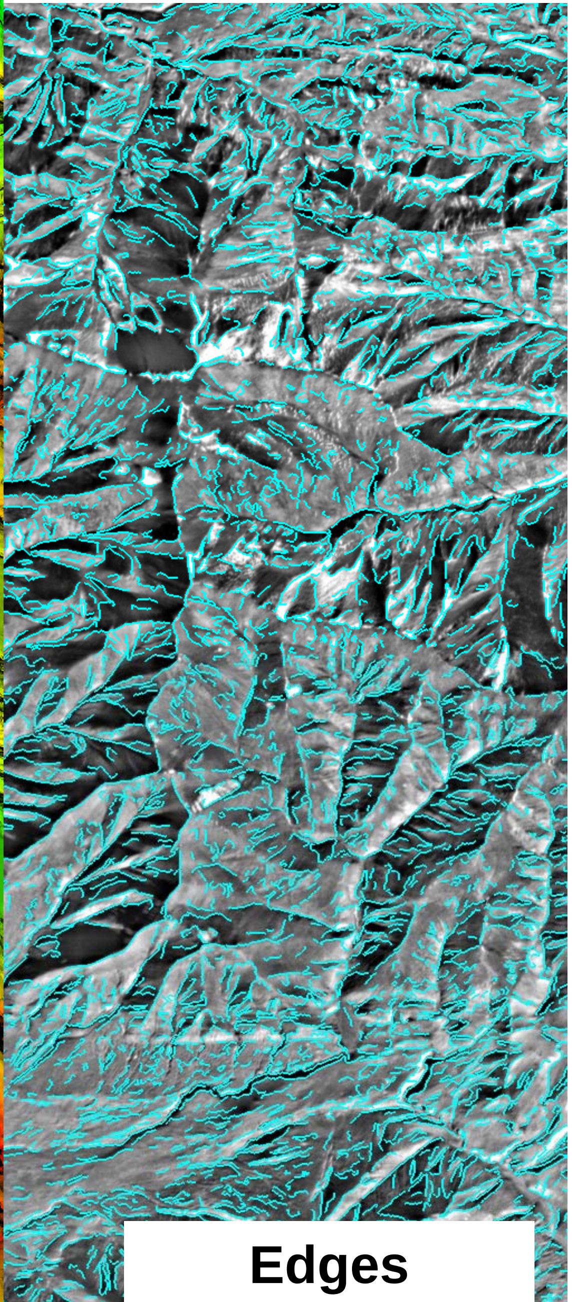
Ordnance Survey

इसरो isro

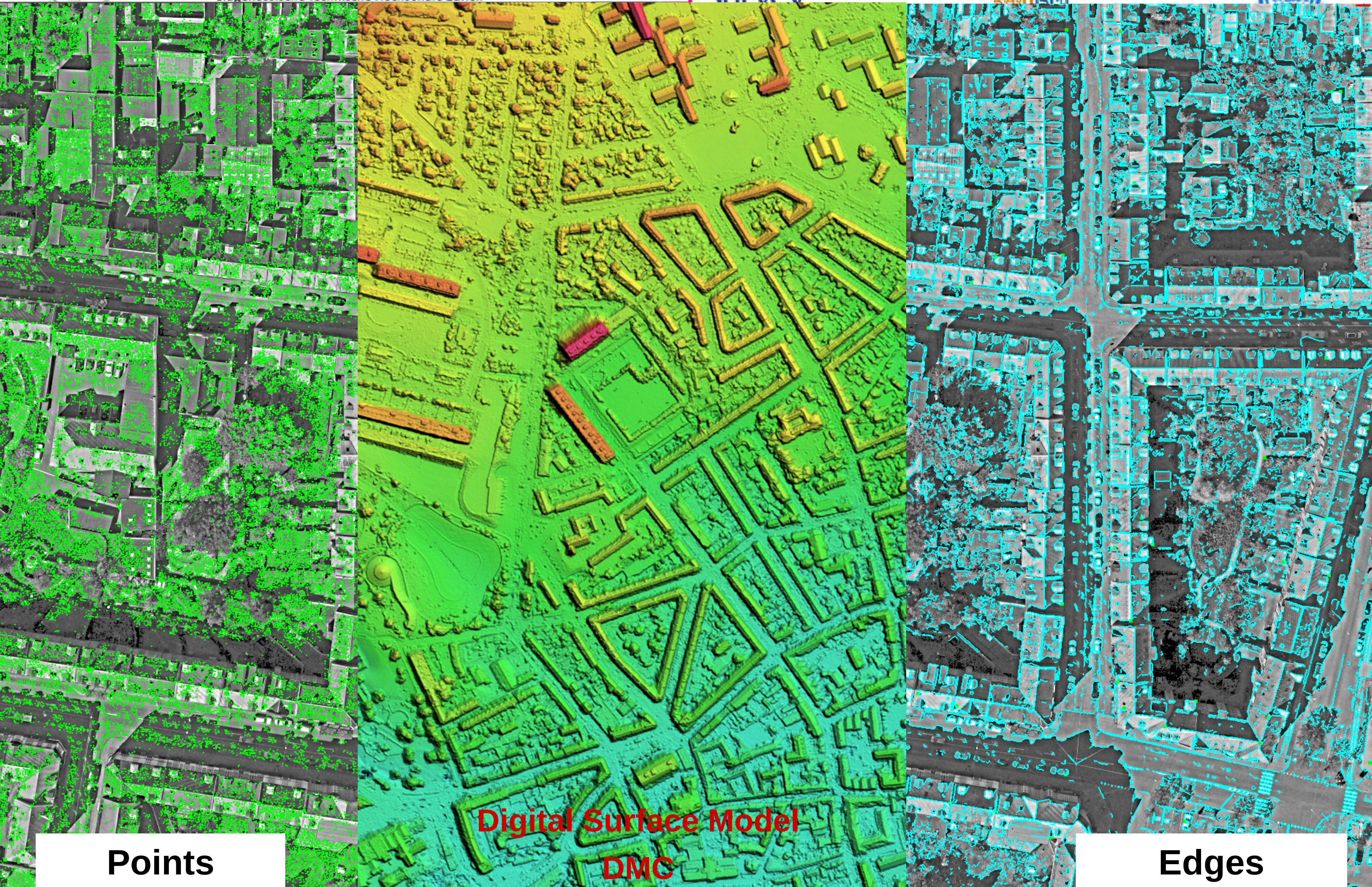
CASM


Points




Edges

isprs ETH Eidgenössische Technische Hochschule Zürich Ordnance Survey



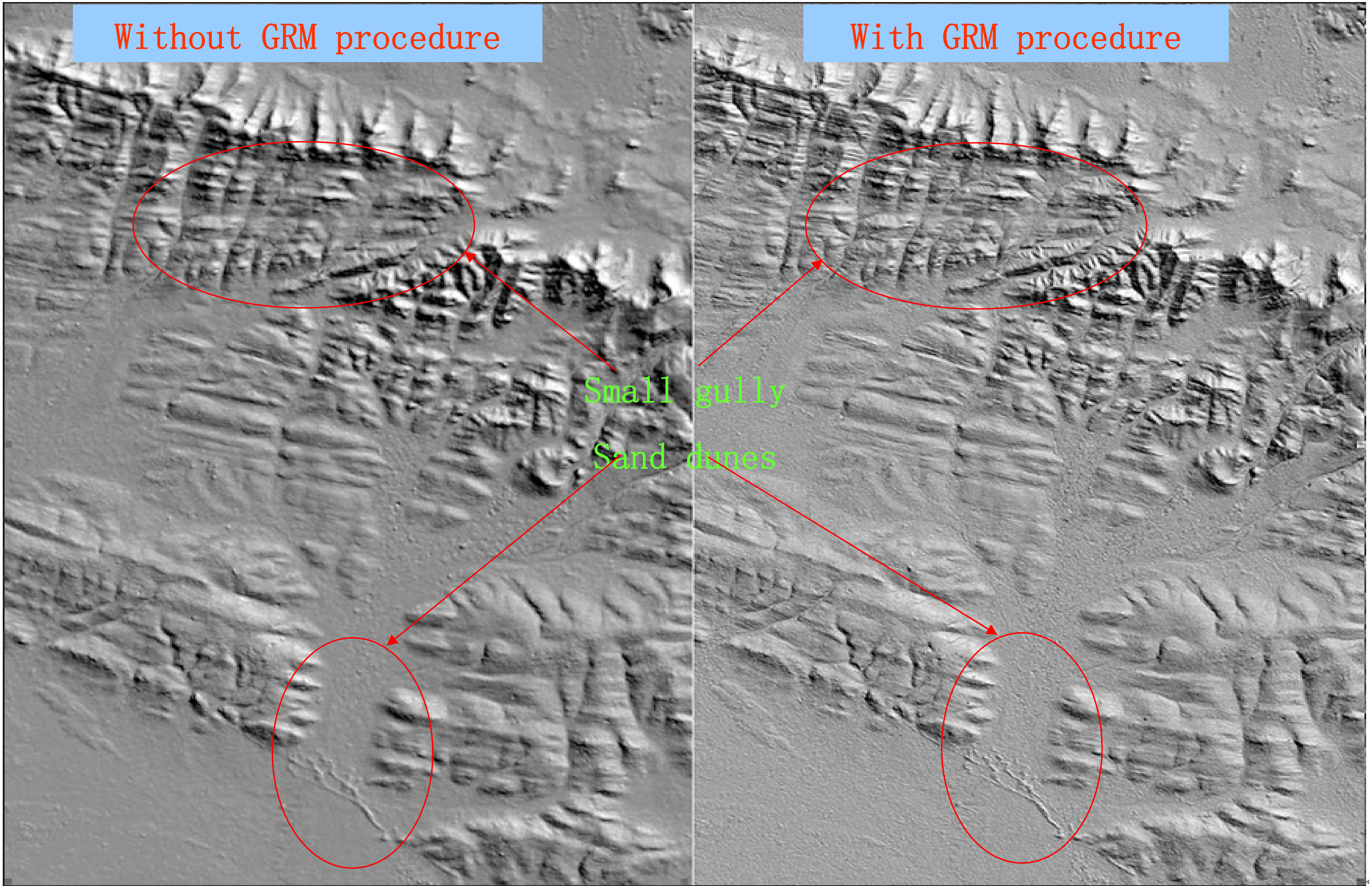
（2）DEM Generation from SPOT5 HRS Stereo images

Feature-3: Self-tuning matching parameters，images from different platforms and different ground resolution can be simultaneously matched；

For example: images of SPOT5 10×5m HRS stereo image and 2.5/5.0m HRG can be simultaneously matched

Feature 4: Combining global- and local-texture information with relaxation-based global matching procedure (combining geometric constraints in object space), poor/non-texture image areas can be smoothly bridge-over；

Feature 5: So-called Geomorphologic details Refinement Matching (GRM) is developed, it well-suitable for detailed geomorphologic feature reconstruction


Without GRM procedure
With GRM procedure
Small gully
Sand dunes

Automatic DSM Generation (IKONOS, Thun, Switzerland)

Study area: Thun, Switzerland

+ Area: 17 × 20 Km^2

+ Height Range: 1600 m

IKONOS Geo Product (O, N below mean with old, new sensor calibration/interior orientation)

Dataset	Image No.	Acquisition Date	Generation date	Sensor-Azimuth	Sensor-Elevation
T_DEC_O	135251_000	2003-12-25	2004-01-19	180.39°	62.95°
	135251_100	2003-12-25	2004-01-19	72.21°	82.15°
	135254_000	2003-12-25	2004-01-19	128.17°	82.62°
T_DEC_N	163001_000	2003-12-25	2005-03-02	180.39°	62.95°
	163001_100	2003-12-25	2005-03-02	72.21°	82.15°
	163003_000	2003-12-25	2005-03-02	128.17°	82.62°
T_OCT	157928_000	2003-10-12	2004-02-11	10.74°	77.85°
	157928_100	2003-10-12	2004-02-11	4.69°	85.26°
	157928_200	2003-10-12	2004-02-11	197.09°	71.95°

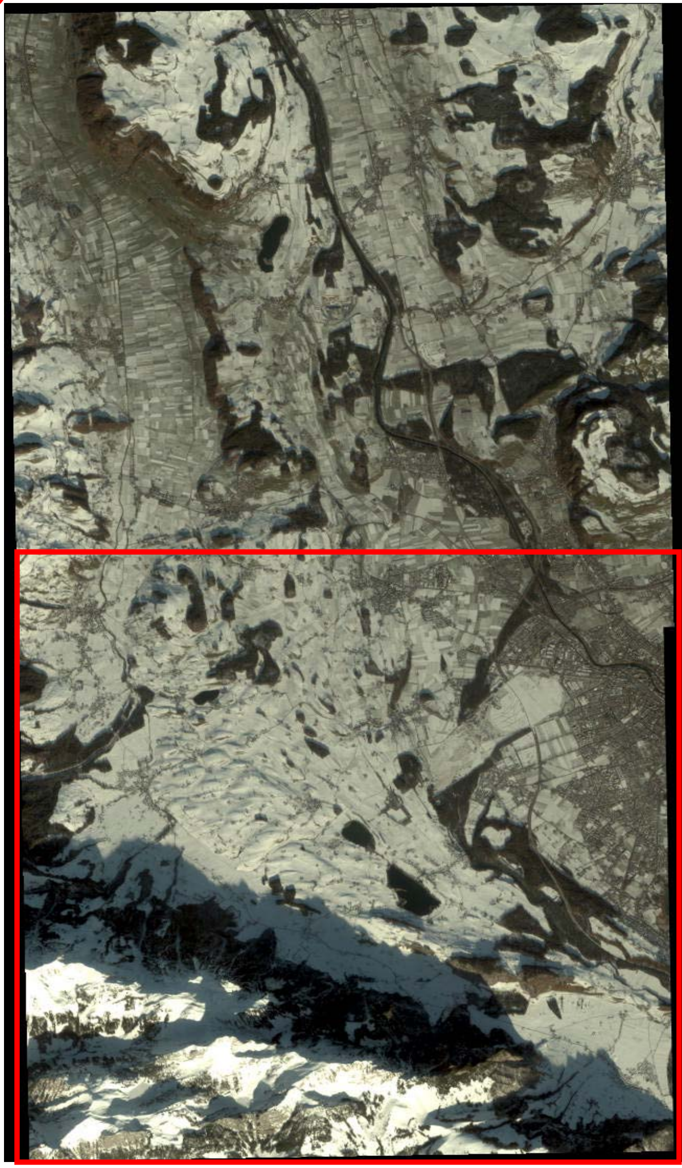
Reference

+ 2m spacing LIDAR DSM as reference

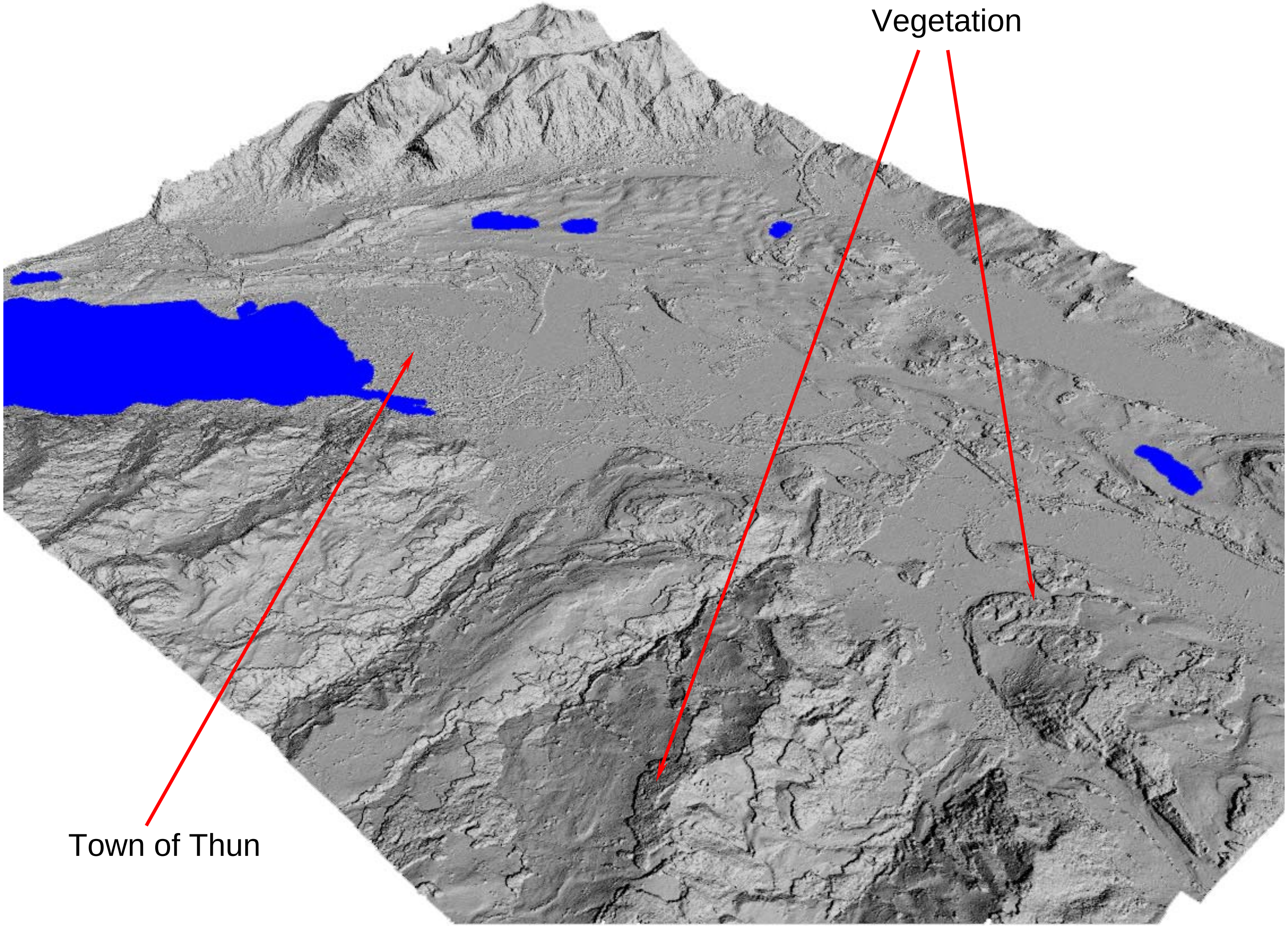
accuracy: 0.5 m (1σ) for open areas;

1.5 m for vegetation areas

+ 50 GPS GCPs (only 39 used)



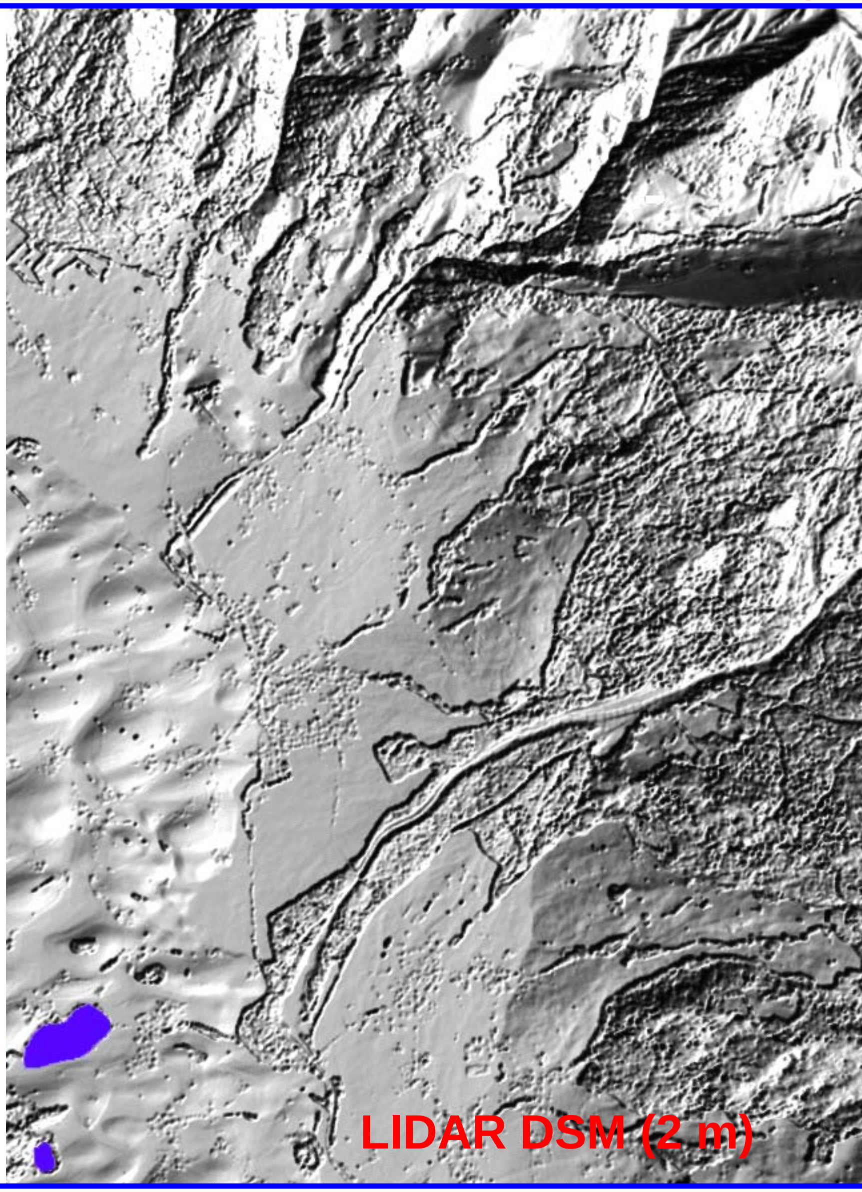
Performance Evaluation: IKONOS, Thun, Switzerland

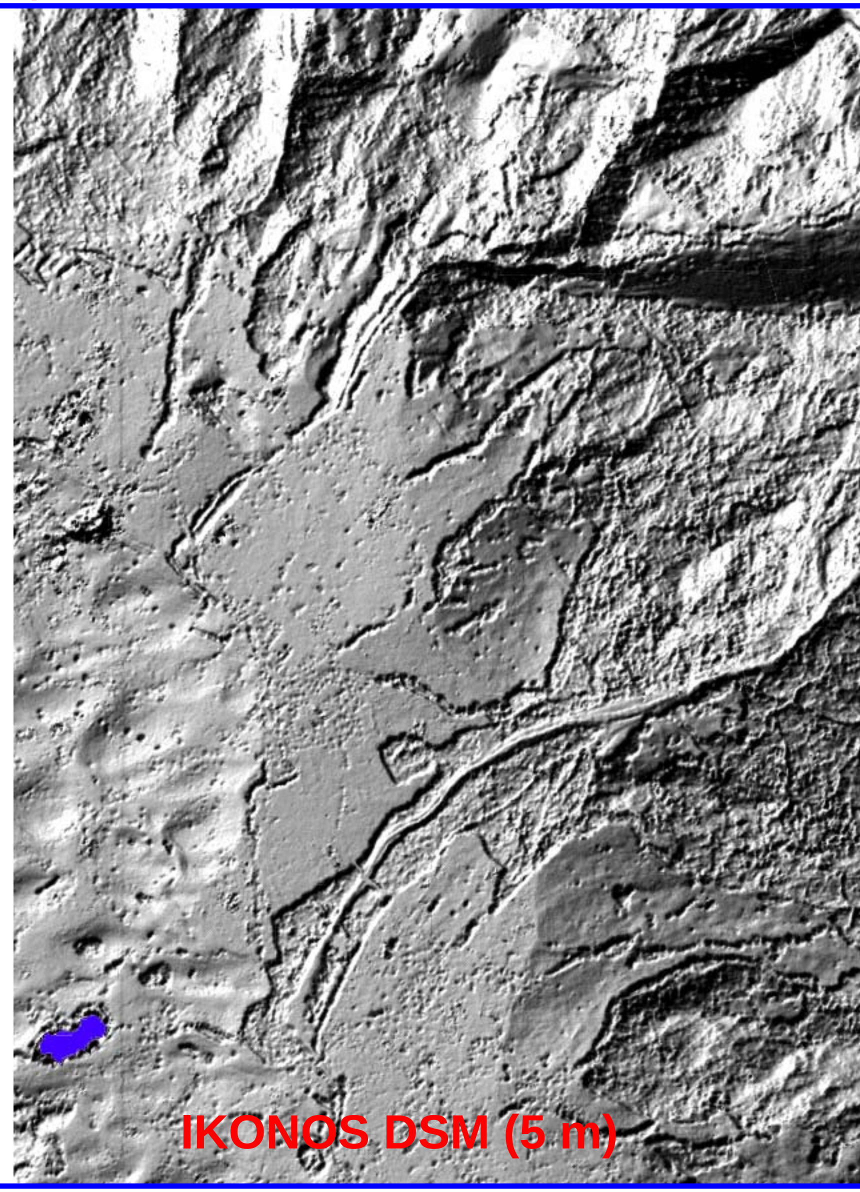


Raster DSM (5 m spacing) generated from IKONOS images (T_DEC_N)

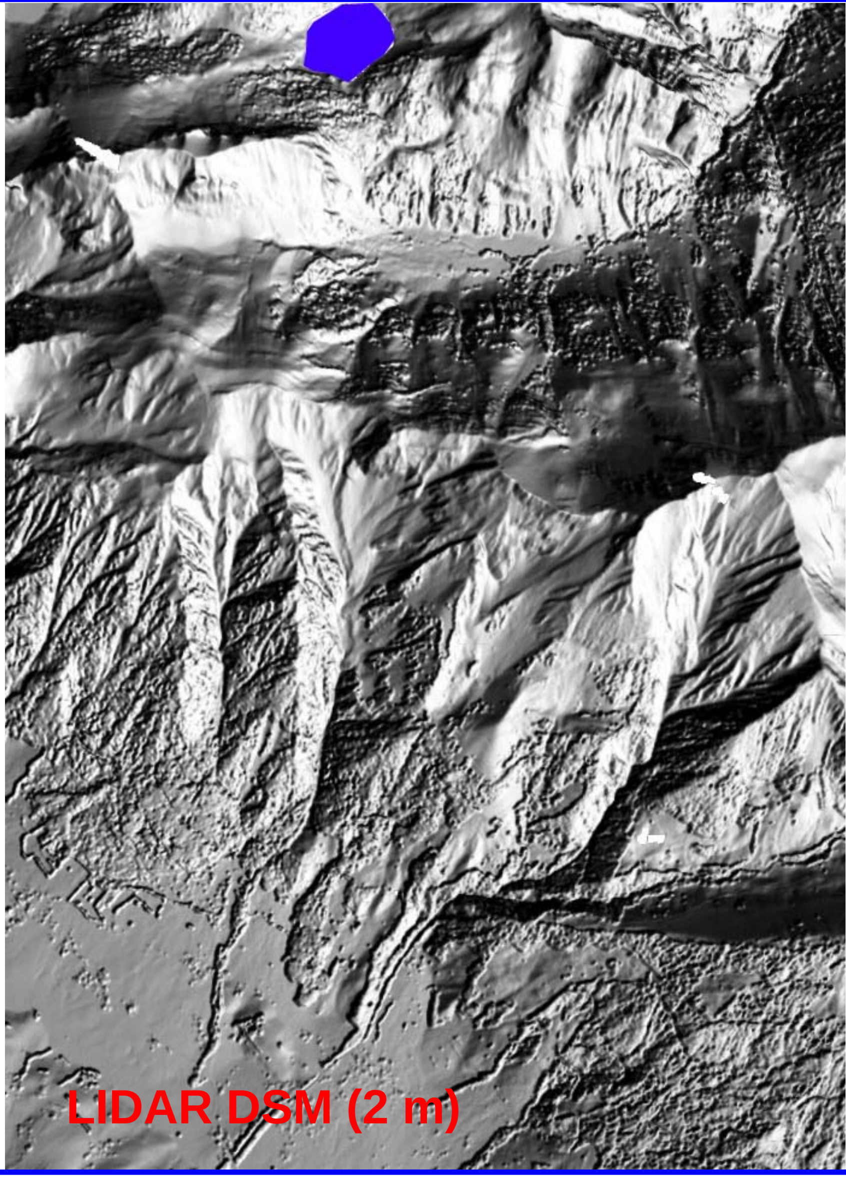
Performance Evaluation: IKONOS, Thun, Switzerland

Performance Evaluation: IKONOS, Thun, Switzerland





Performance Evaluation: IKONOS, Thun, Switzerland



Performance Evaluation: IKONOS, Thun, Switzerland

Lidar DSM - matching (in m) for the triplet **T_DEC_O**

Terrain type	No. of compared points	RMSE	Average	RMSE (95)	Average (95)
B1	7,037,578	**1.27**	0.82	0.93	0.89
B2	7,993,875	**1.84**	0.92	1.04	0.92
B3	9,763,257	**2.11**	0.80	1.20	0.80
C	2,794,389	**3.34**	0.30	2.36	0.30
V	8,689,642	**8.16**	1.68	-	-
W1	28,854,764	**4.93**	1.13	4.24	1.14
W2	18,022,149	**2.74**	0.70	1.45	0.69

B1 – Bare ground; B2 – Bare ground (including mountainous area); B3 – Bare ground (including mountainous and shadow areas)

C – City area only

V – Vegetation area only

W1 – Whole area; W2 – Whole area without vegetation areas.

RMSE (95) and Average (95) are RMS and average after excluding the 5% largest differences

Performance Evaluation: IKONOS, Thun, Switzerland

Lidar DSM - matching (in m) for the triplet **T_DEC_N**

Terrain type	No. of compared points	RMSE	Average	RMSE (95)	Average (95)
B1	7,037,578	**1.15**	0.31	0.73	0.37
B2	7,993,875	**1.90**	0.34	0.93	0.35
B3	9,763,257	**2.14**	0.29	1.19	0.30
C	2,794,389	**3.38**	0.55	2.41	0.55
V	8,689,642	**8.05**	1.58	-	-
W1	28,854,764	**4.90**	0.50	4.23	0.50
W2	18,022,149	**2.54**	0.35	1.41	0.34

Performance Evaluation: IKONOS, Thun, Switzerland

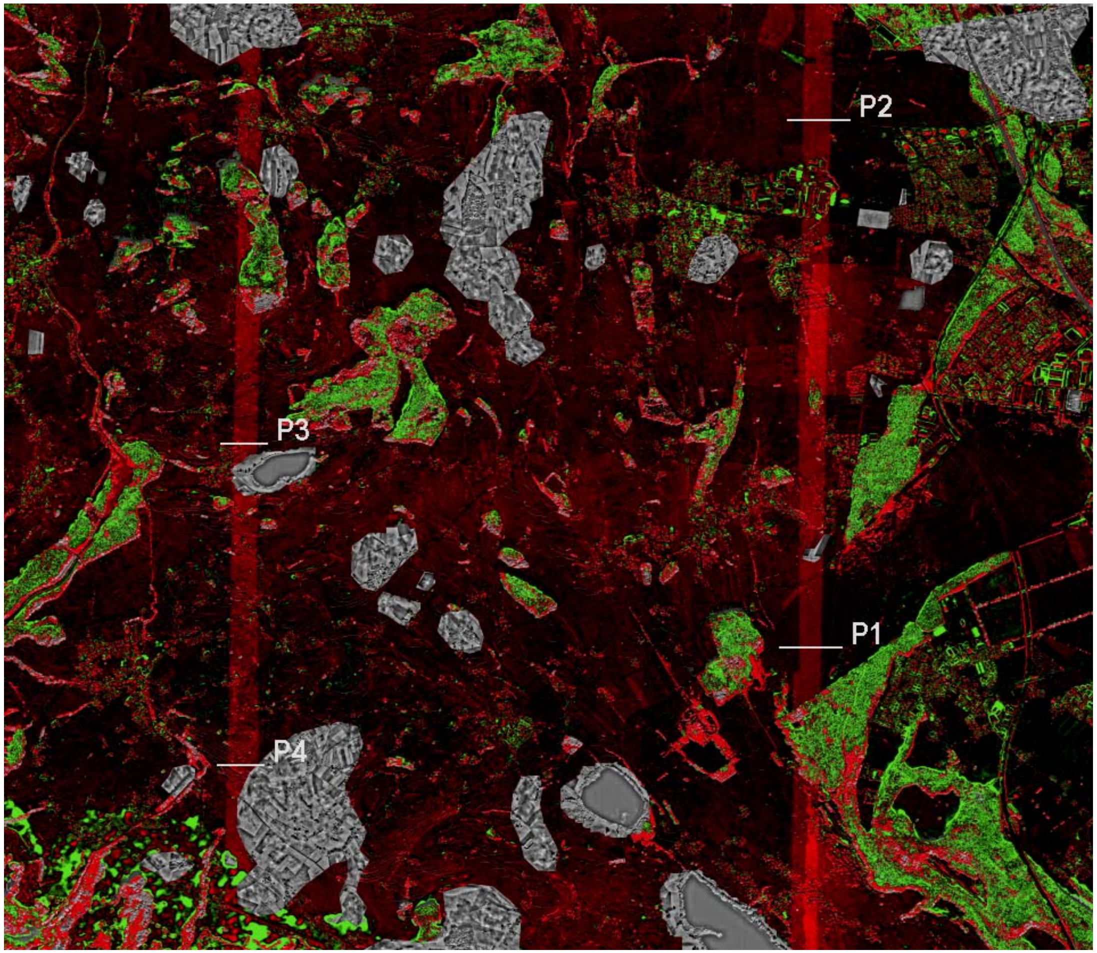
Terrain type	RMSE T_DEC_N	RMSE T_DEC_O	Average T_DEC_N	Average T_DEC_O
B1	1.15	1.27	**0.31**	**0.82**
B2	1.90	1.84	**0.34**	**0.92**
B3	2.14	2.11	**0.29**	**0.80**
C	3.38	3.34	0.55	0.30
V	8.05	8.16	1.58	1.68
W1	4.90	4.93	0.50	1.13
W2	2.54	2.74	0.35	0.70

Performance Evaluation: IKONOS, Thun, Switzerland

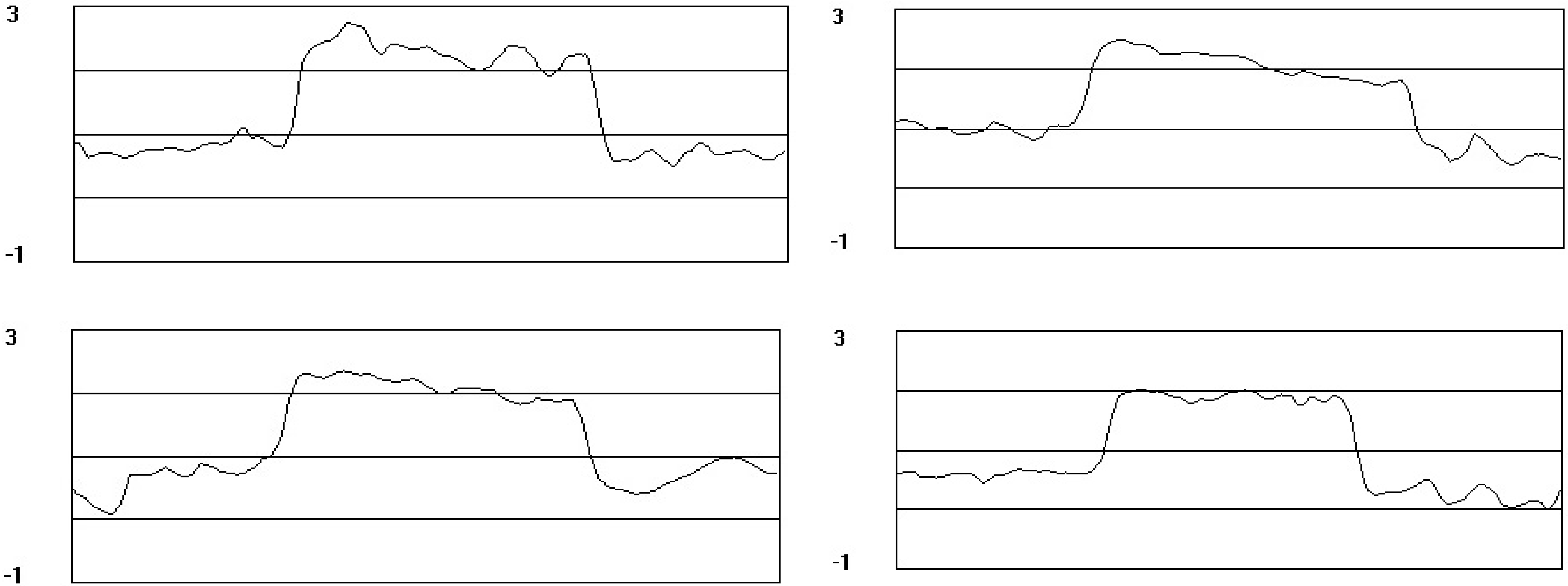
Lidar DSM - matching (in m) for the triplet **T_OCT**

Terrain type	No. of compared points	RMSE	Average	RMSE (95)	Average (95)
B1	7,037,578	**1.41**	0.22	0.95	0.21
B2	7,993,875	**1.77**	0.29	1.09	0.29
B3	9,763,257	**1.75**	0.29	1.07	0.29
C	2,794,389	**2.83**	-0.25	2.08	-0.25
V	8,689,642	**6.61**	-1.97	-	-
W1	28,854,764	**4.25**	-0.40	2.96	-0.39
W2	18,022,149	**2.05**	0.16	1.32	0.16

DSM generation results (Ikonos triplet, Thun, Dec_O)

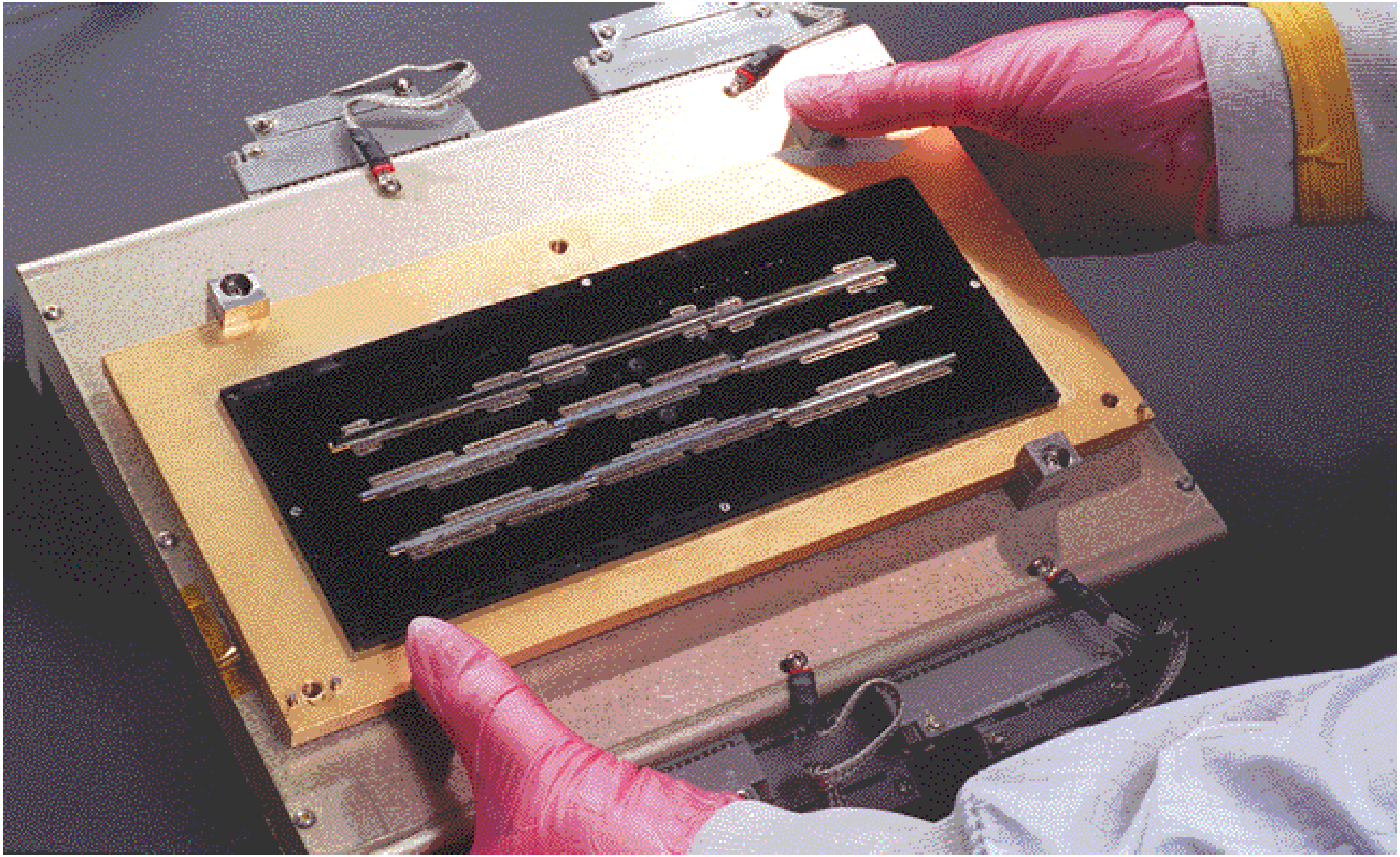


DSM generation results (Ikonos triplet, Thun)

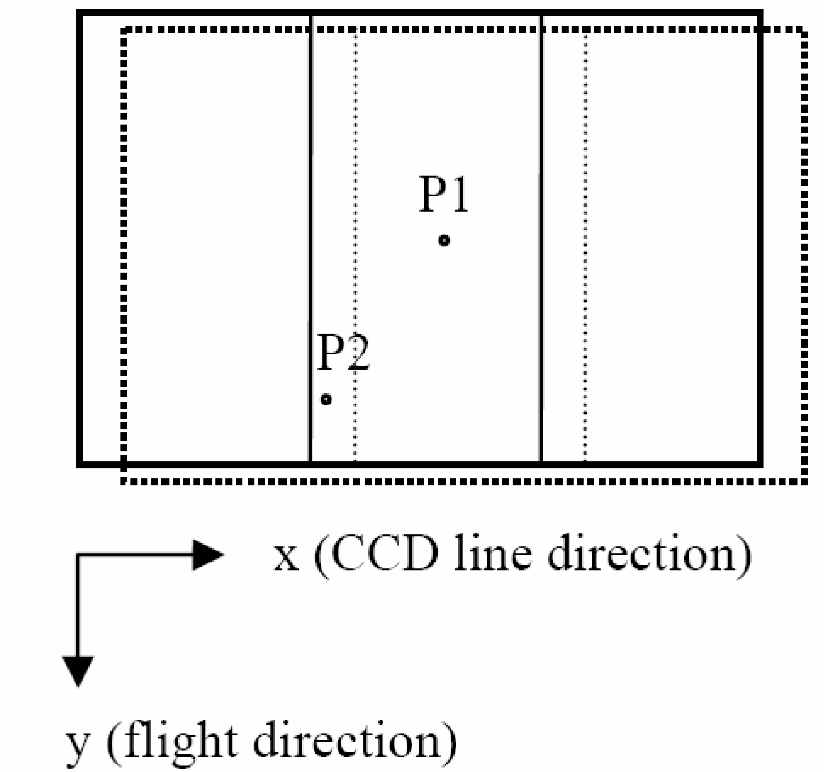


•**Height jump of 1.3-1.5 m corresponds to 0.7-0.8 pixel y-parallax error**

Ikonos focal plane (shift of middle partial PAN CCD caused jump)

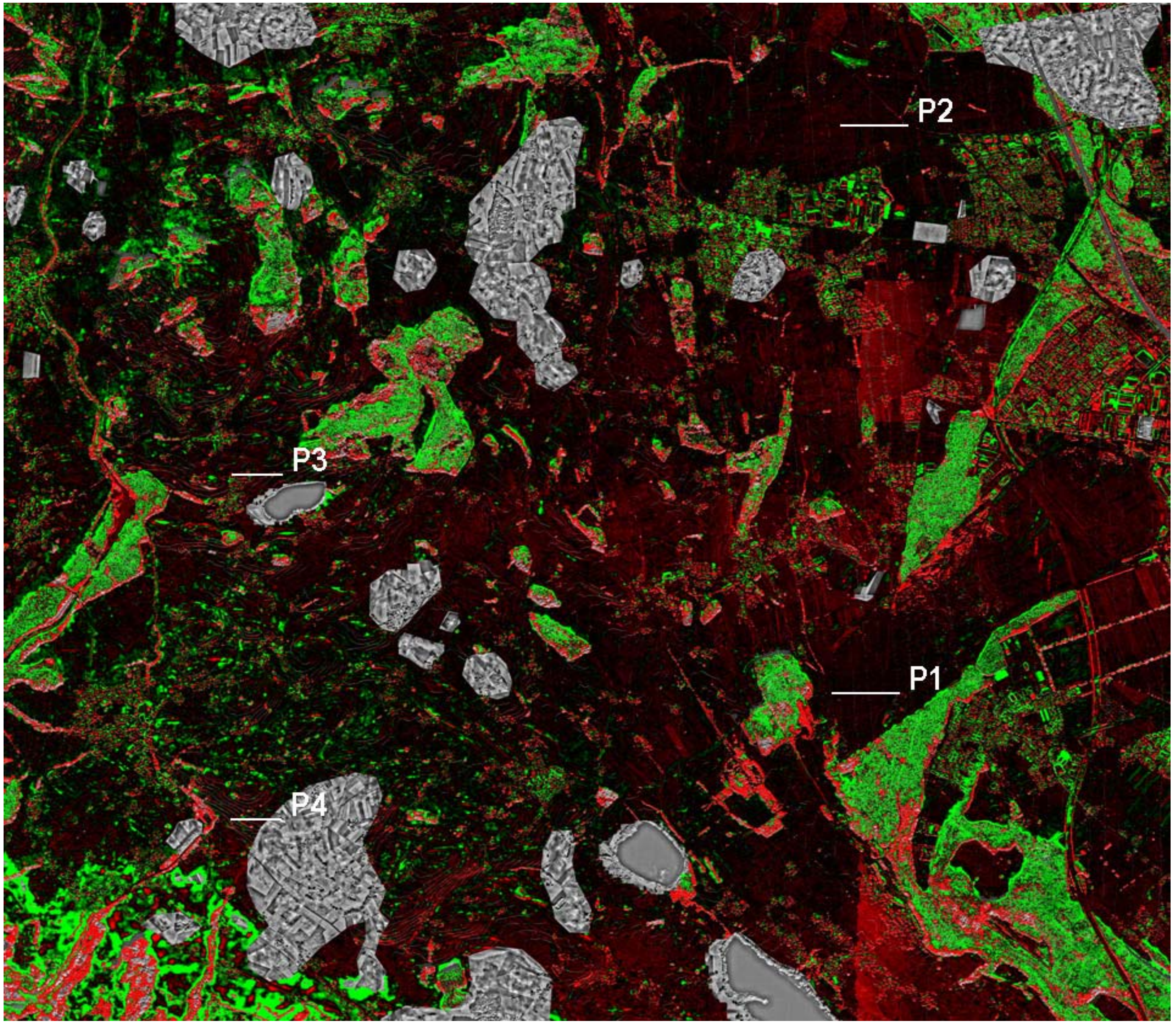


Ikonos interior orientation error

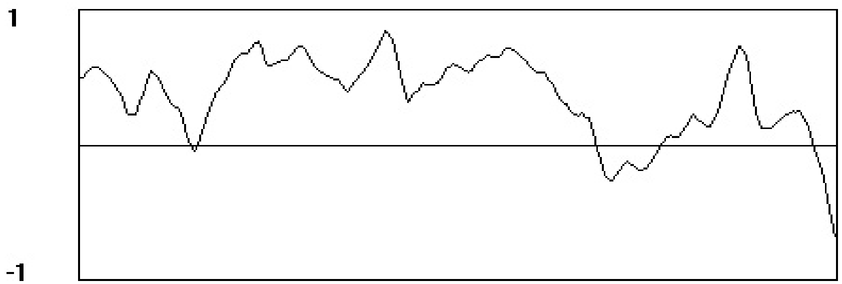


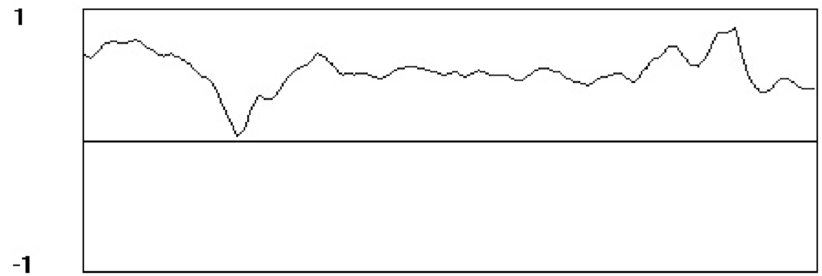
The cause of vertical stripes with larger height error due to inaccurate interior orientation modelling. E.g. a possible shift of the middle CCD relative to the other two will cause the same pixel coordinate error for point P1, but not for point P2, introducing thus a y-parallax (and height) error.

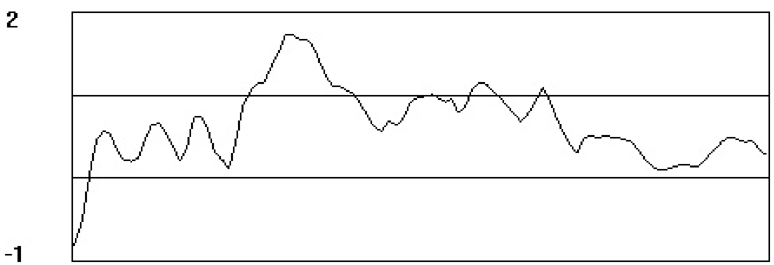
DSM generation results (Ikonos triplet, Thun, Dec_N)

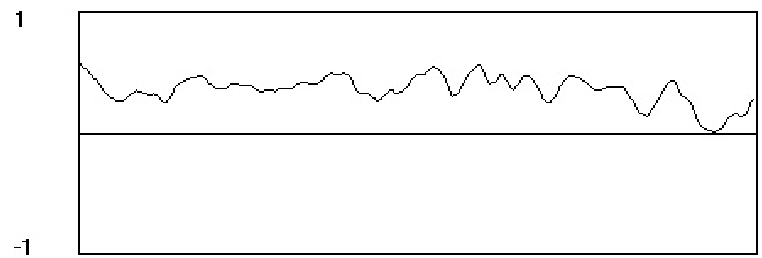


DSM generation results (Ikonos triplet, Thun)

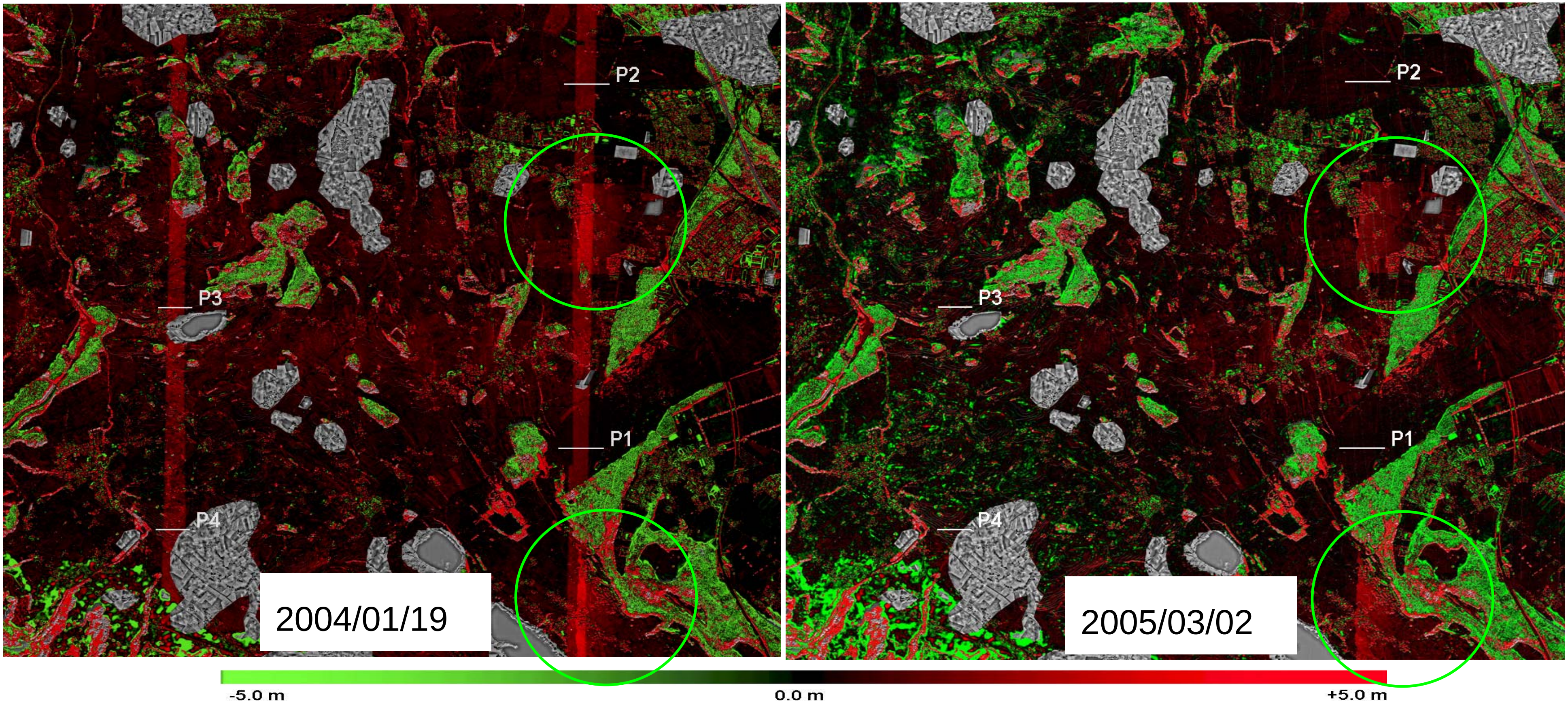








Performance Evaluation: IKONOS, Thun, Switzerland



- Possibility for in-flight calibration of interior orientation errors with good reference DSM and accurate DSM measurement from Ikonos
- Detection of systematic Lidar DSM errors (see marked circles)

Performance Evaluation: SPOT5-HRS, Bavaria, Germany

Study area: Bavaria, Germany

+ Area: 120 × 60 Km^2

+ Height range: ca. 1600 m

SPOT HRS stereo pair

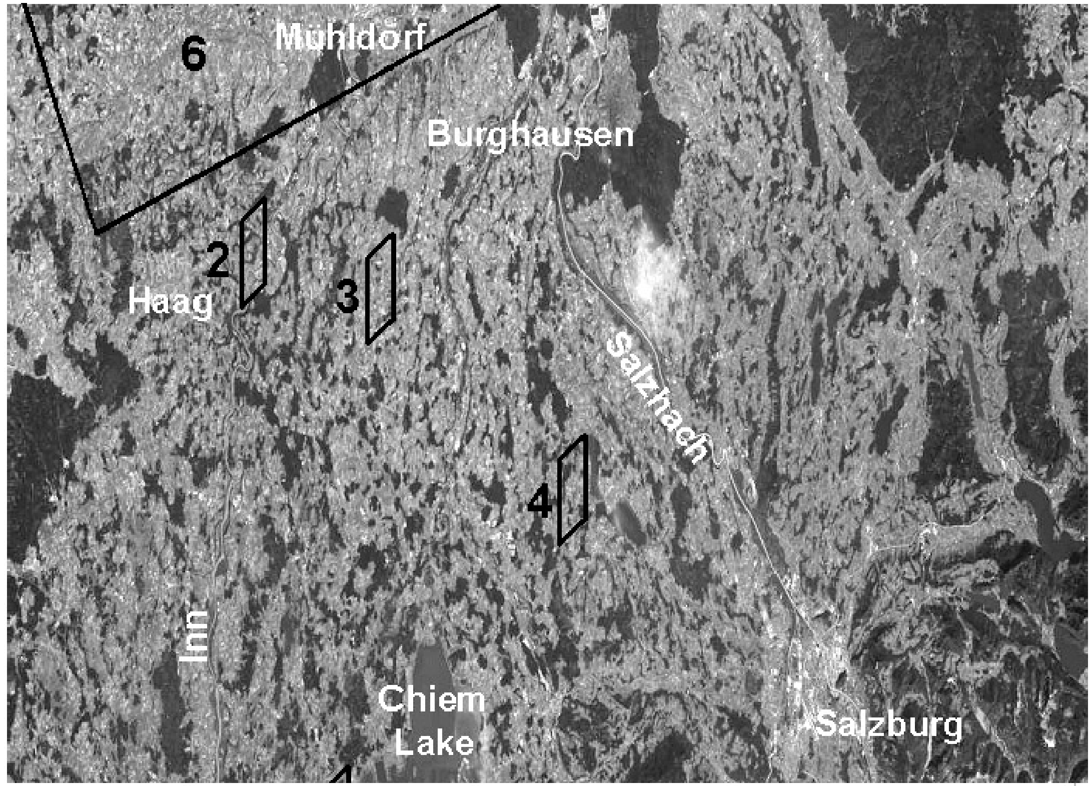
+ Acquisition time: 1st October, 2002

+ 5m / 10m GSD along-/cross-track

Reference data:

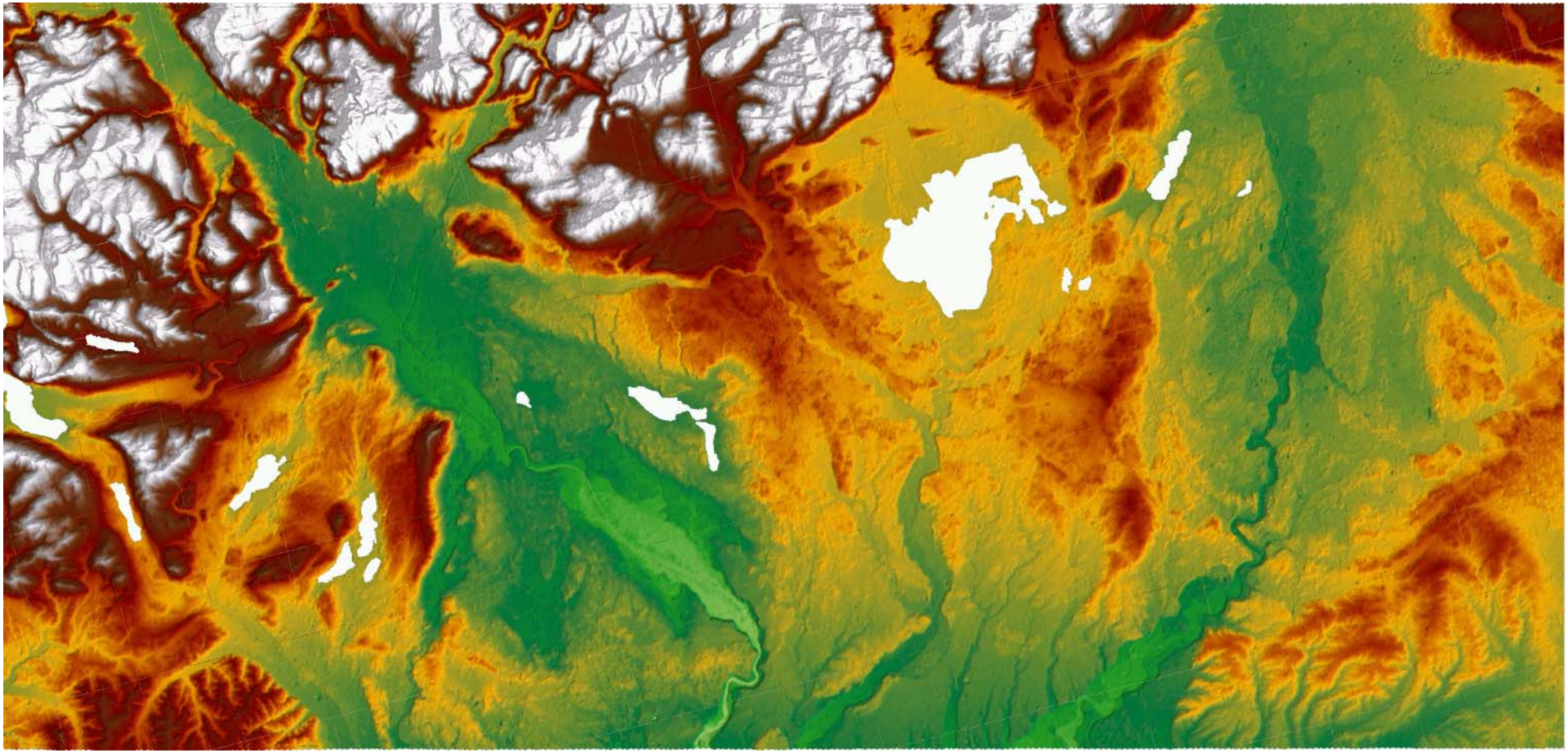
+ 81 GPS GCPs (only 41 used)

+ 6 reference DTMs



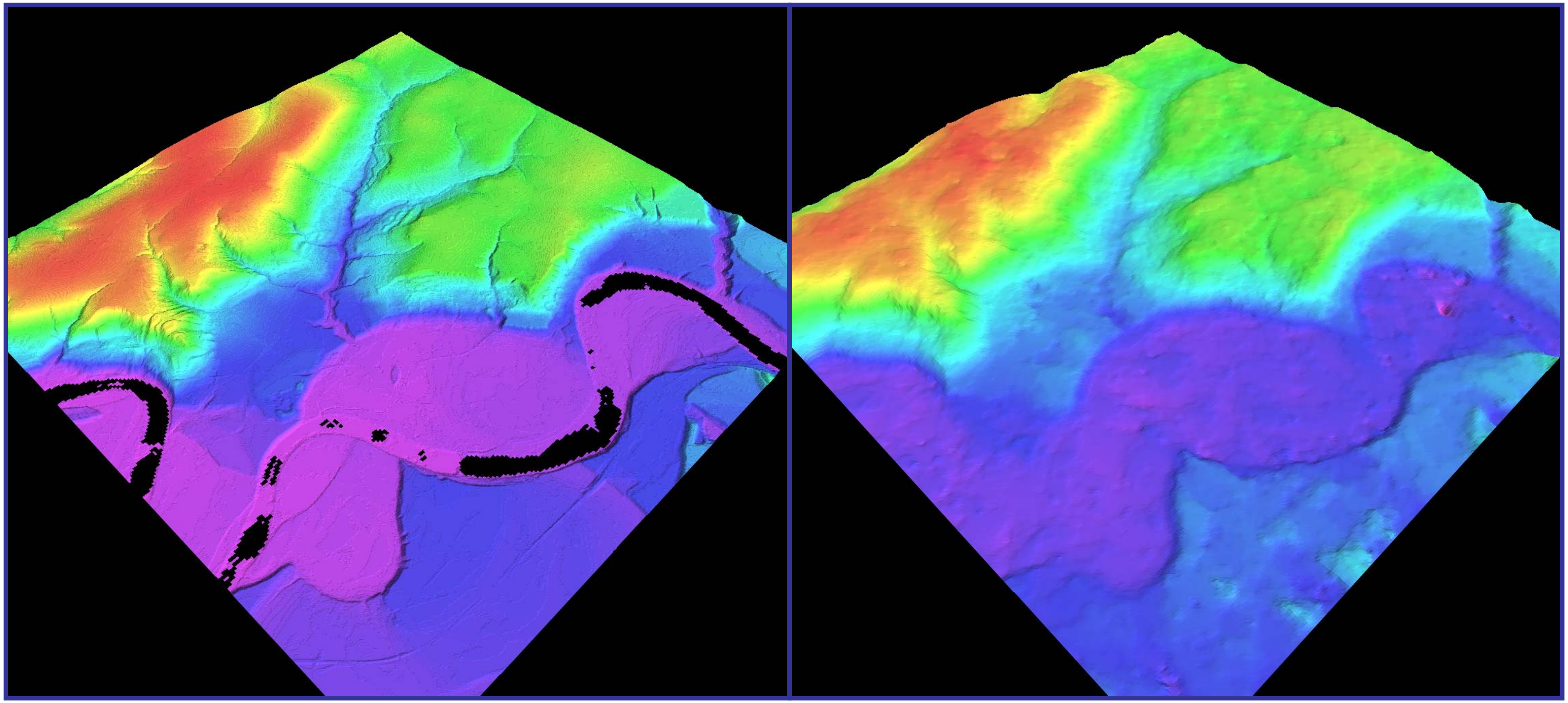
DTM Name	Location	DTM Spacing (m)	Source	DTM Size	Height Accuracy (m)
DTM-1	Prien	5 × 5	Laser Scanner	5km × 5km	0.5
DTM-2	Gars	5 × 5	Laser Scanner	5km × 5km	0.5
DTM-3	Peterskirchen	5 × 5	Laser Scanner	5km × 5km	0.5
DTM-4	Taching	5 × 5	Laser Scanner	5km × 5km	0.5
DTM-5-1	Inzell-North	25 × 25	Laser Scanner	10km × 1.3km	0.5
DTM-5-2	Inzell-Sourth	25 × 25	Contour lines	10km × 7.7km	5.0
DTM-6	Vilsbiburg	50 × 50	Photogrammetry	50km × 30km	2.0

Performance Evaluation: SPOT5-HRS, Bavaria, Germany



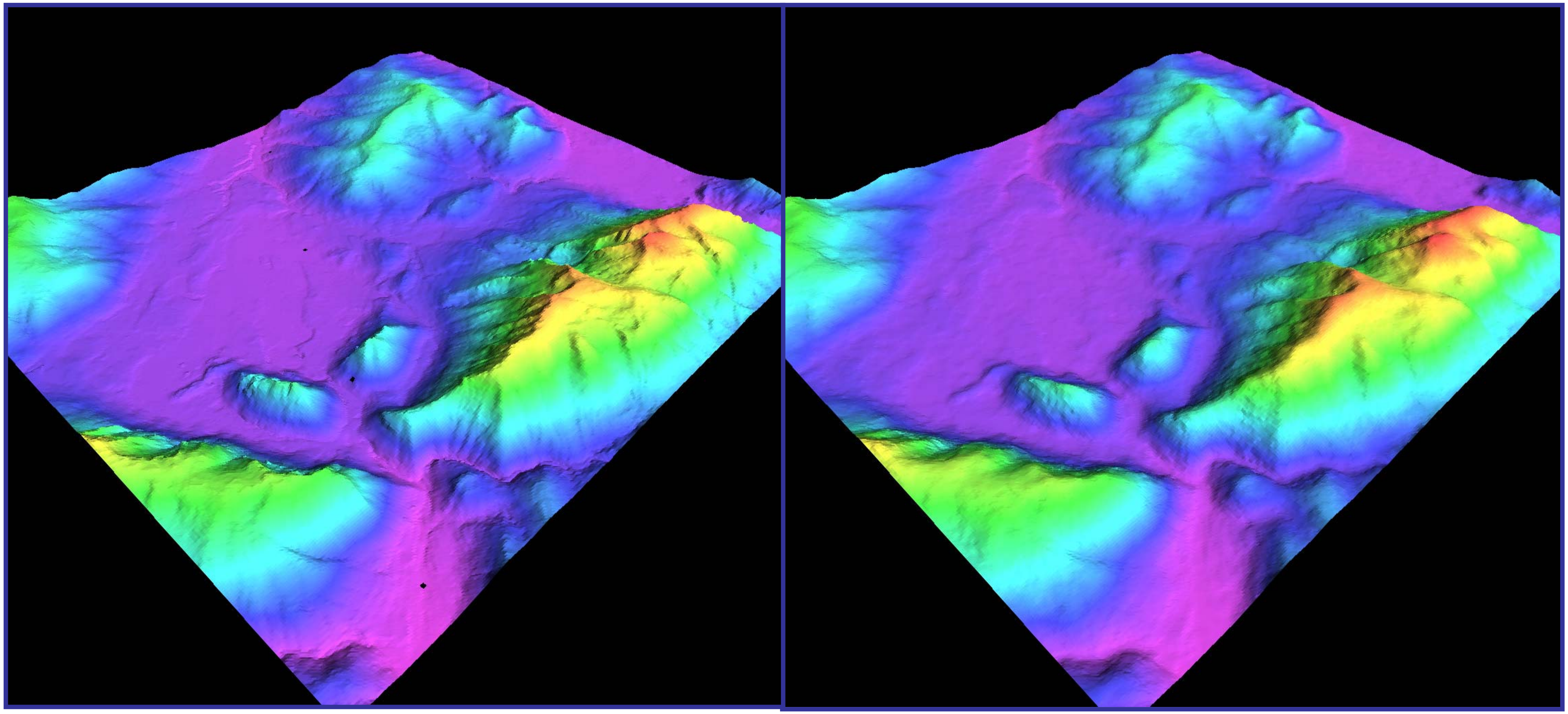
Raster DSM (25 m Spacing,120 × 60 km^2)

Performance Evaluation: SPOT5-HRS, Bavaria, Germany



Reference DSM (5 m) SPOT5 DSM (25 m)

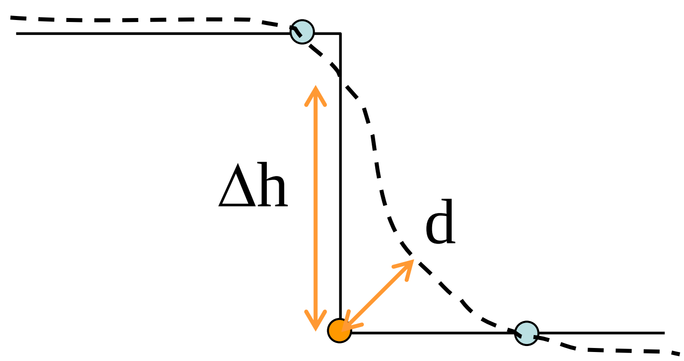
Performance Evaluation: SPOT5-HRS, Bavaria, Germany



Reference DSM (25 m) SPOT5 DSM (25 m)

Accuracy analysis

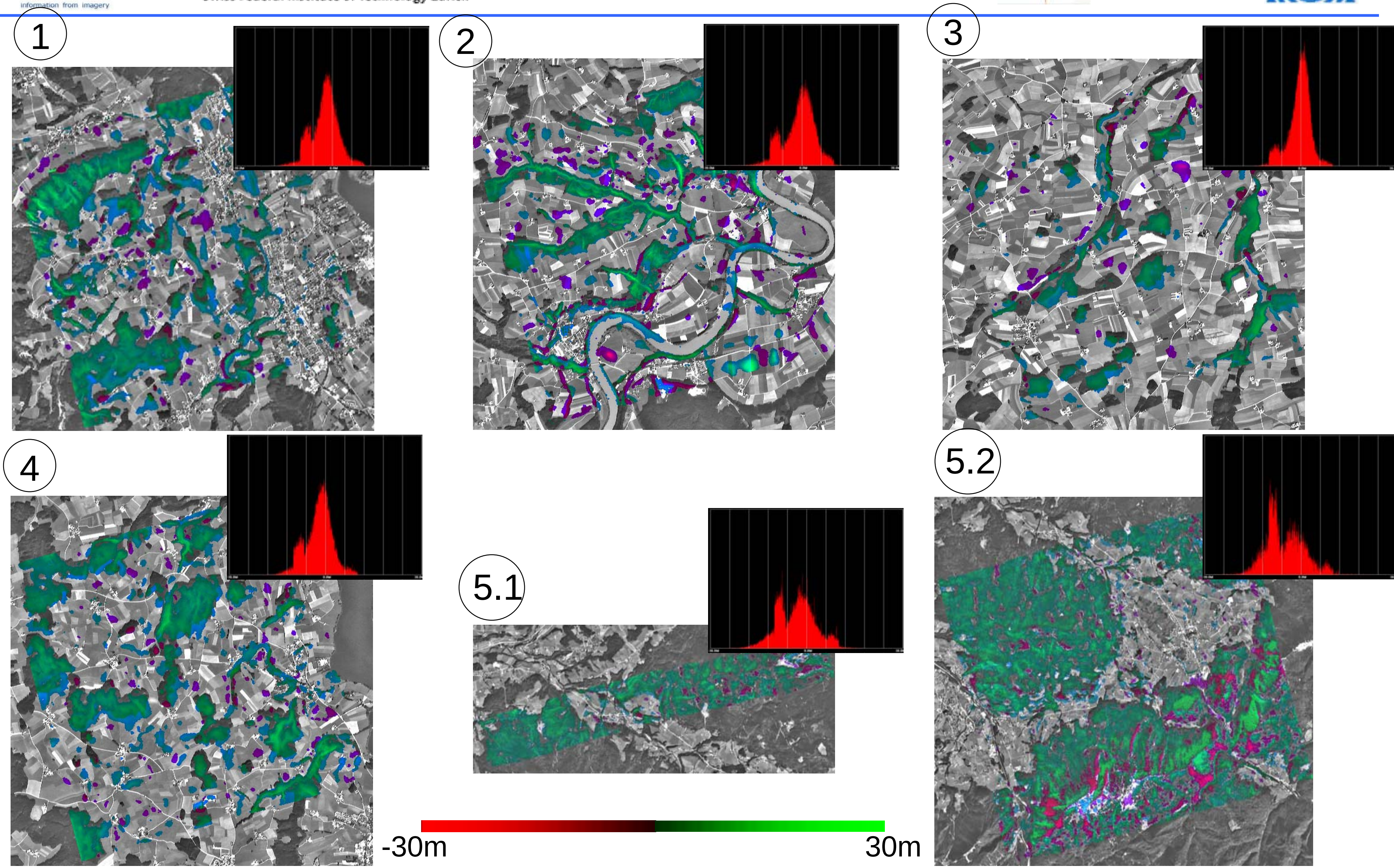
- Quantitative comparison to reference DEMs
- Two comparisons:
  - **Terrain height (2.5D)**: difference between the heights of reference DEMs and the heights interpolated from generated DSMs
  - **Euclidean distance (3D)**: normal distance between the surfaces (Geomatic Studio v4.1 by Raindrop)
- Limit of terrain height comparison: even if the measurement is correct (○), the surface modeling error may cause large height differences (example: step profile)



Accuracy analysis

- Terrain height (2.5D)
  - Original results

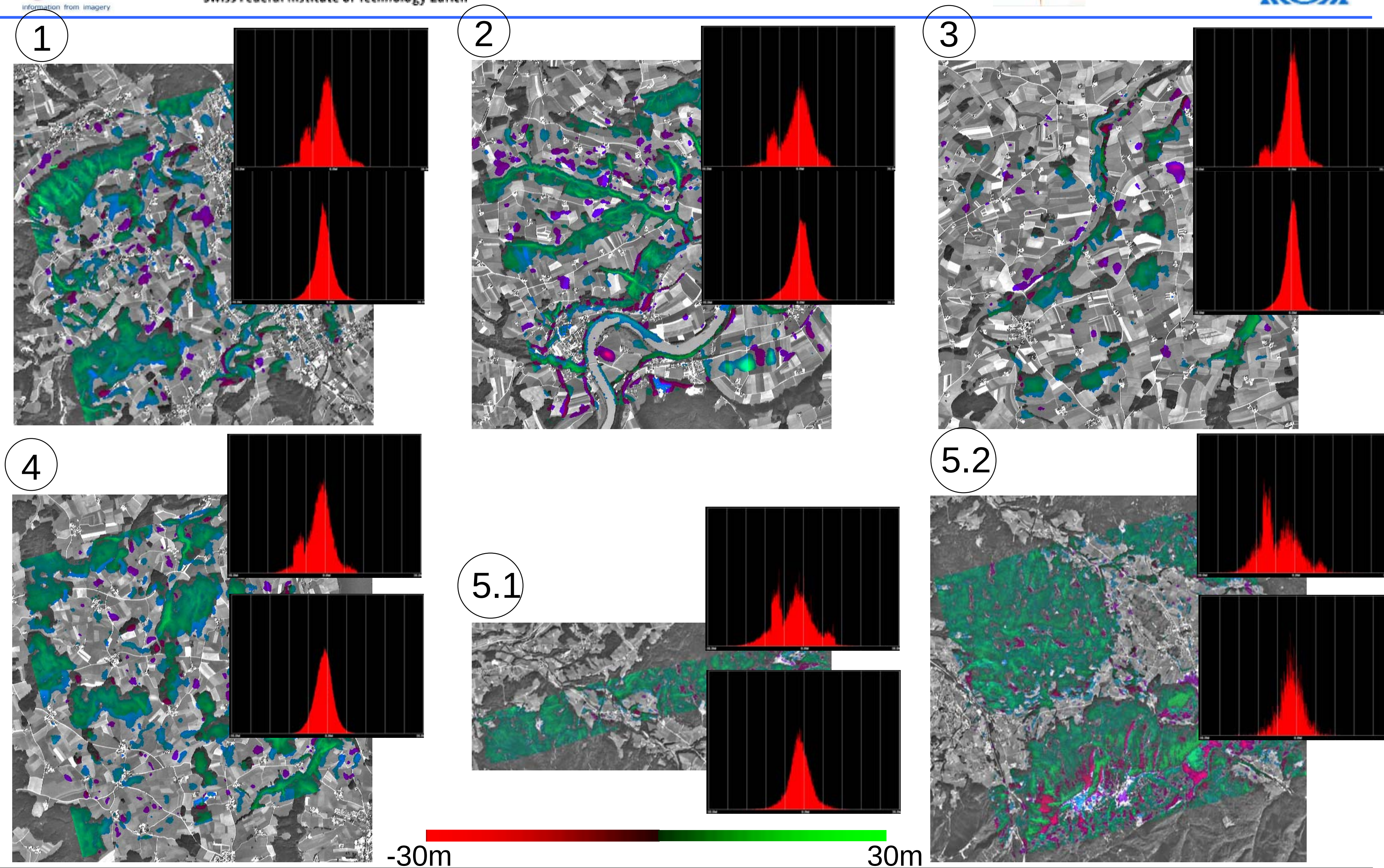
	Number of points		RPC model			
	IGP DEM	Reference DEM	Max Diff.	Min Diff.	Mean	RMSE
1	35448	1000000	25.1	-32.9	-2.6	5.7
2	32932	1000000	29.1	-37.1	-1.2	5.0
3	33450	1000000	20.7	-17.2	-0.5	3.2
4	32067	1000000	13.6	-23.1	-2.5	4.7
5-1	10327	21200	19.2	-33.5	-5.8	8.3
5-2	71795	139200	136.8	-89.3	-4.3	9.5
6	130558	600000	26.8	-27.1	1.5	4.0


1
2
3
4
5.1
5.2
-30m
30m

Accuracy analysis

- Terrain height (2.5D)
  - Removal of areas covered by trees

	RPC model			
	Max Diff.	Min Diff.	Mean	RMSE
1	15.4	-23.7	-1.7	4.6
2	29.1	-31.7	0.2	3.6
3	20.7	-13.6	0.1	2.9
4	10.5	-18.4	-1.2	3.2
5-1	19.1	-13.3	-1.7	4.9
5-2	49.8	-66.8	-1.3	6.7
6	26.8	-25.9	2.1	4.4


1
2
3
4
5.1
5.2
-30m
30m

Accuracy analysis

- Normal distance (3D)

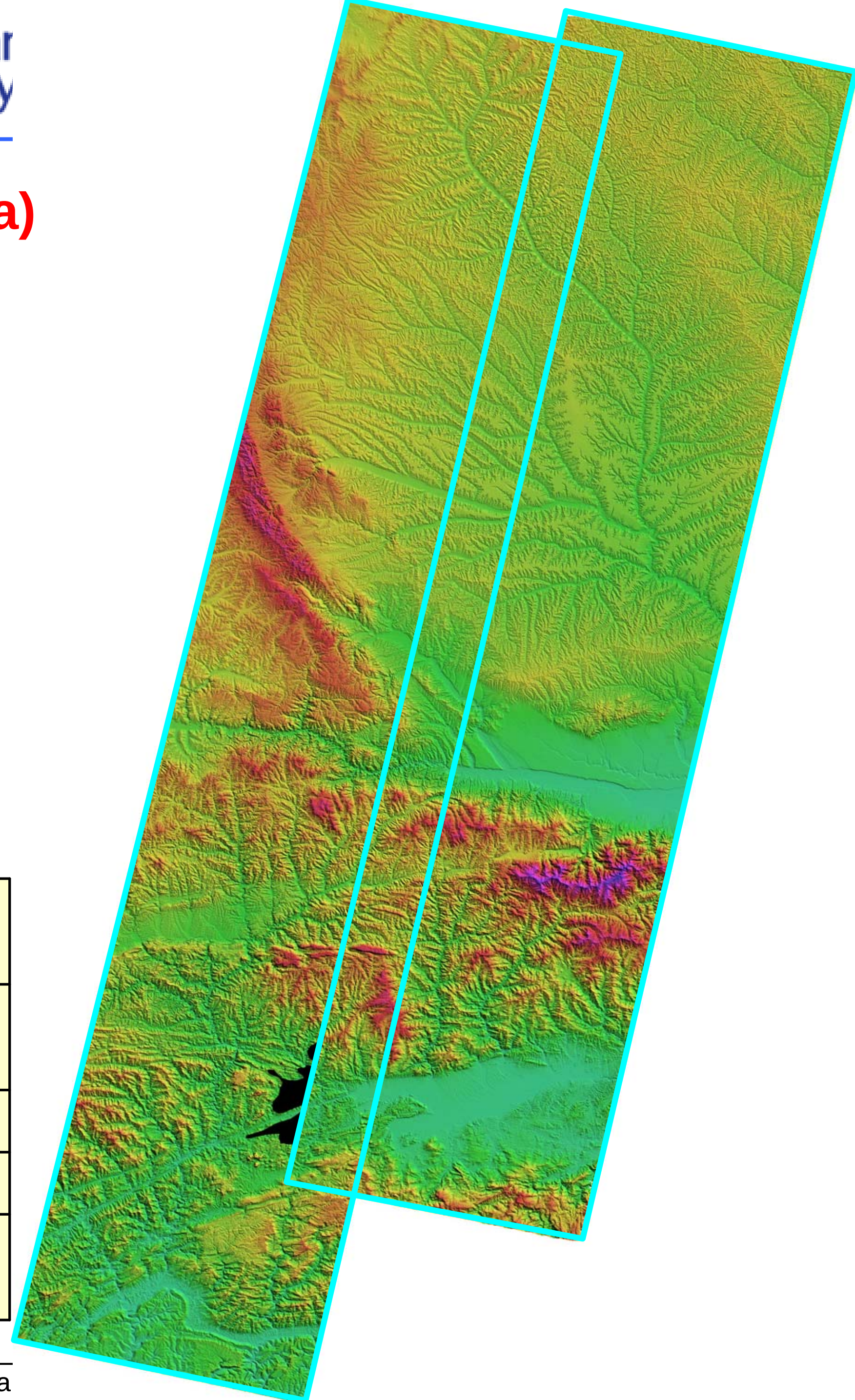
	RPC model			
	Max distance	**Average distance**	**Standard deviation**	**RMSE**
1	18.7	2.2	1.7	2.8
2	37.5	2.7	2.0	3.4
3	21.4	2.7	1.8	3.2
4	20.0	2.2	1.6	2.7
5-1	26.3	6.4	4.4	7.8
5-2	70.1	6.0	5.0	7.8

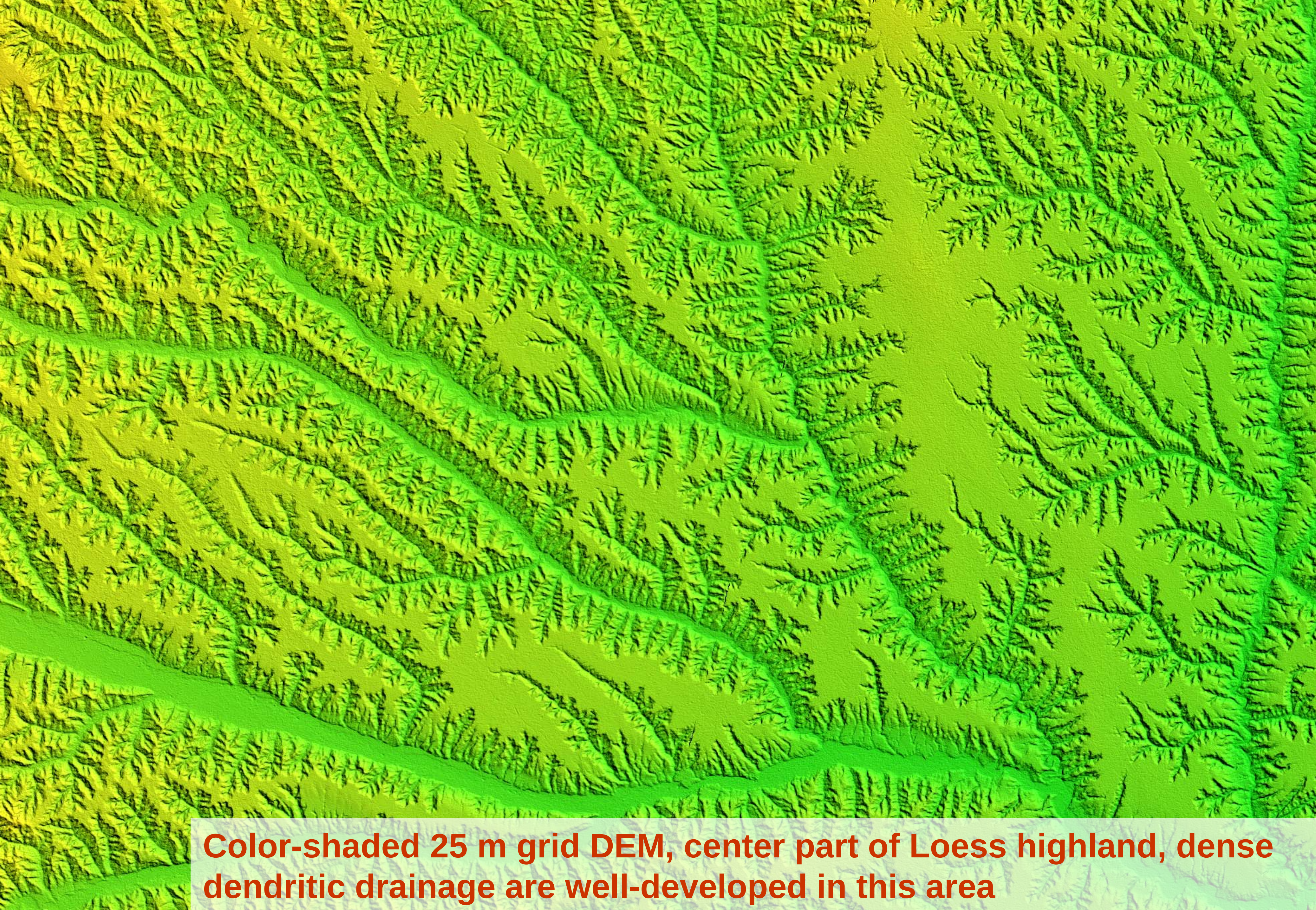
Performance Evaluation: SPOT5-HRS (China)

(Loess highland and Qin-Ling fault block)

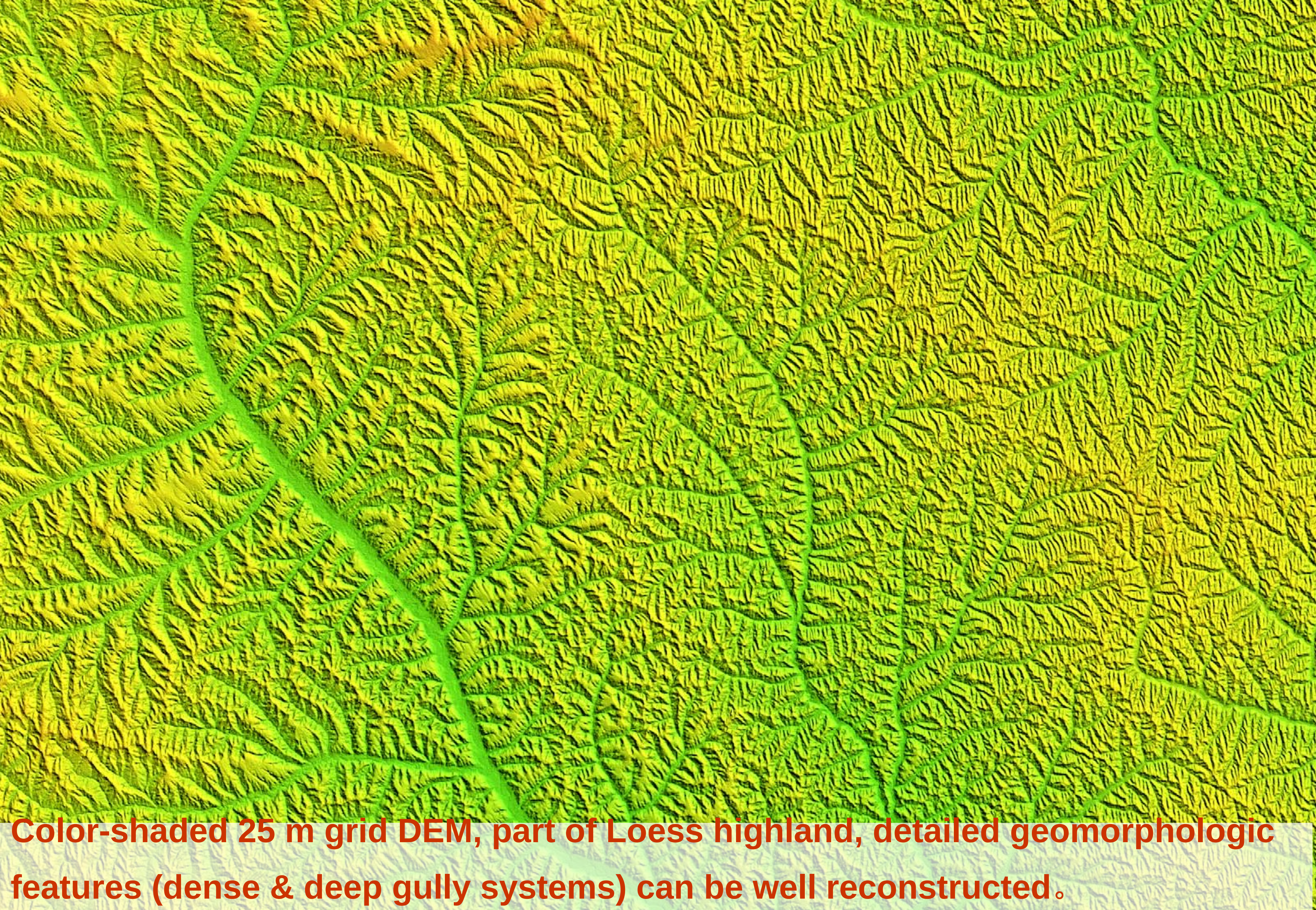
- 2 HRG 10×5m resolution stereo strip, covering about 120,000 Km^2
- 25m grid DEM was generated within 22 hours (feature point matching + edge matching + GRM)

	Strip 126469101/126470101	Strip 126463101/126478101
Region	Longitude/Latitude 92.24/30.96-95.02/36.42	Longitude/Latitude 91.97/33.45-94.05/36.42
Area	120 X 591 Km^2	120 X 310 Km^2
Time	2003-11-23	2003-11-28
Stereo Angle	About 45.0	About 46.0

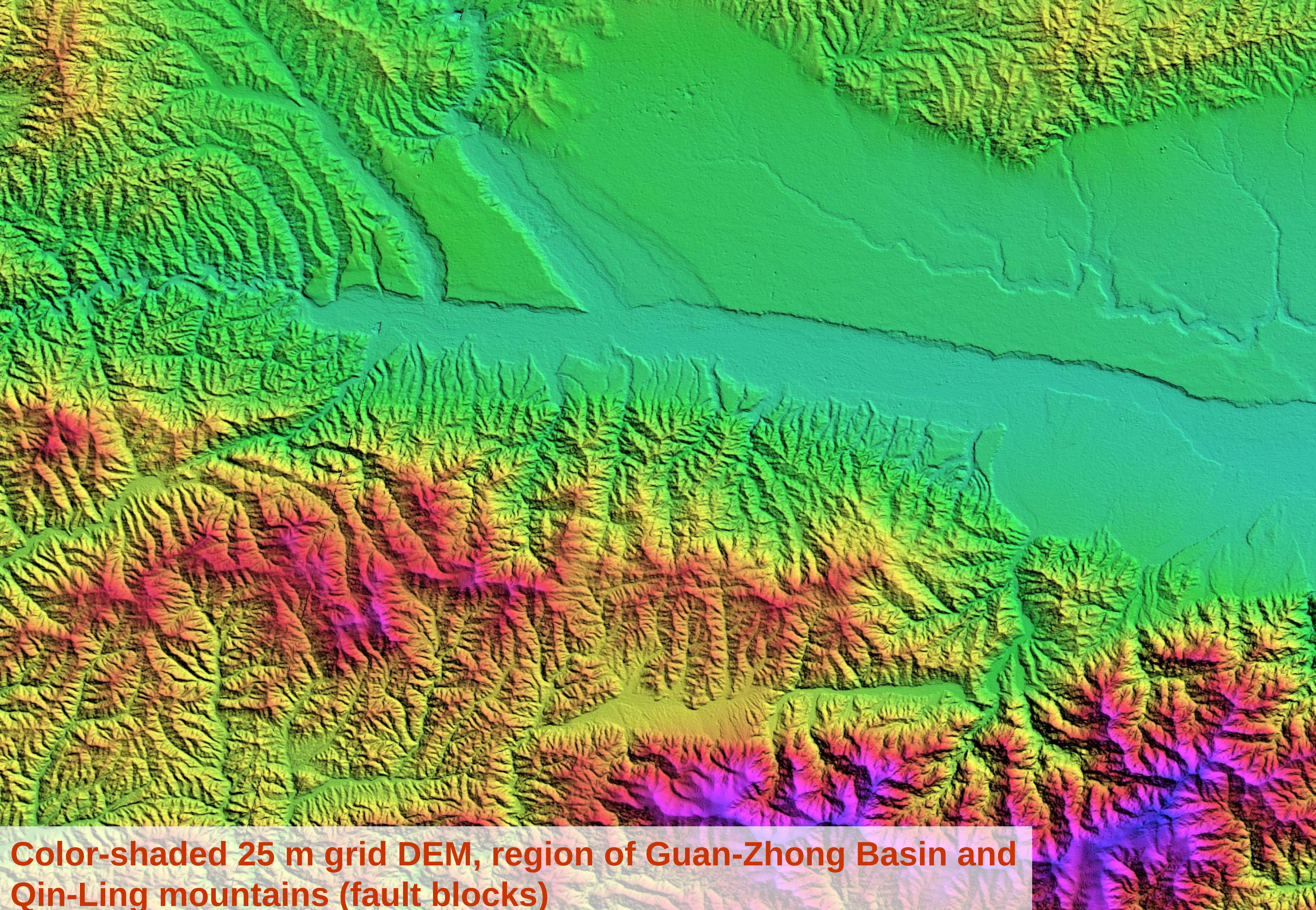




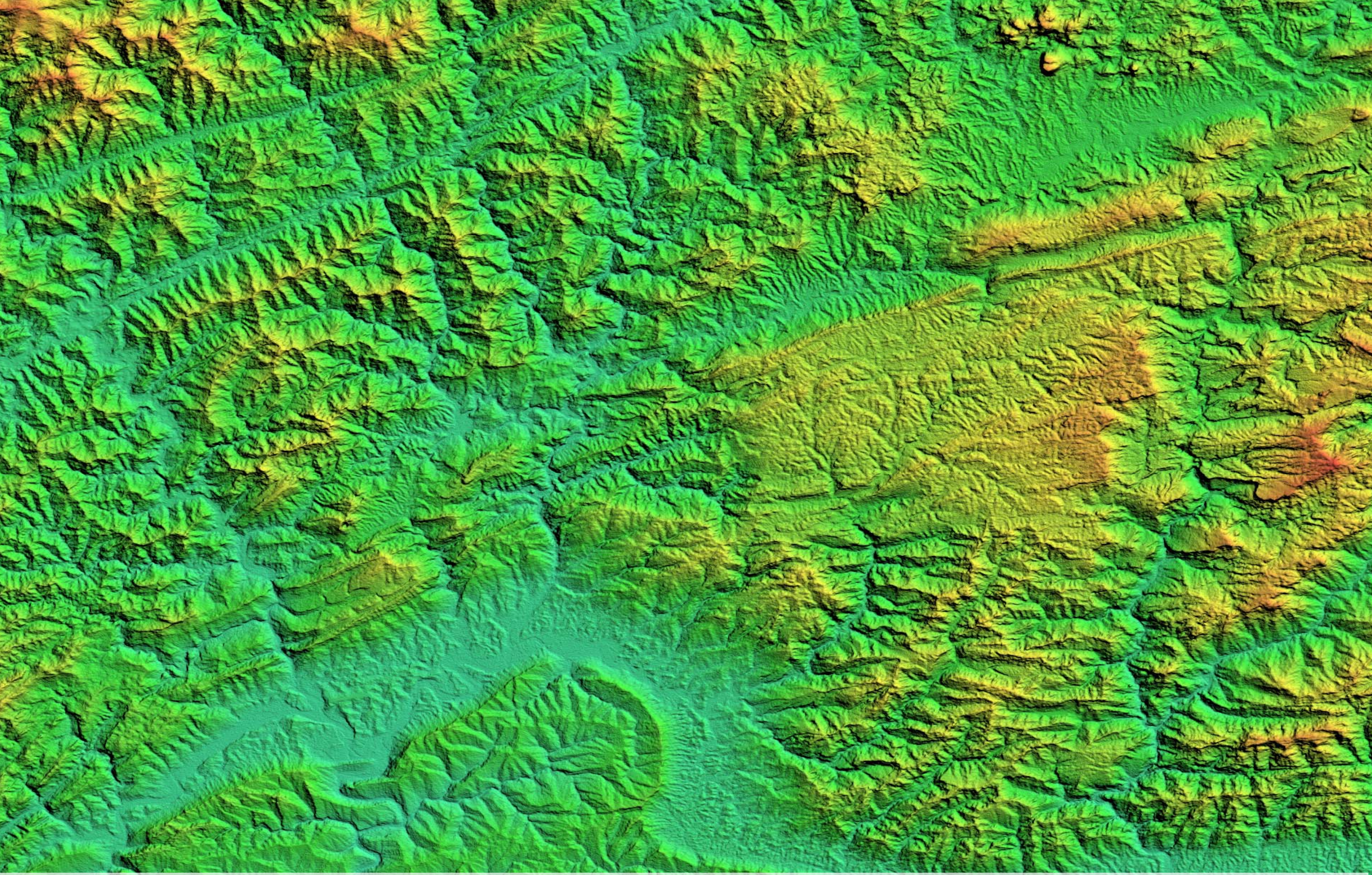
Color-shaded 25 m grid DEM, center part of Loess highland, dense dendritic drainage are well-developed in this area



Color-shaded 25 m grid DEM, part of Loess highland, detailed geomorphologic features (dense & deep gully systems) can be well reconstructed。



Color-shaded 25 m grid DEM, region of Guan-Zhong Basin and Qin-Ling mountains (fault blocks)



Color-shaded 25 m grid DEM, southern part of Qin-Ling mountain, geomorphologic features caused by incised stream systems are well reconstructed

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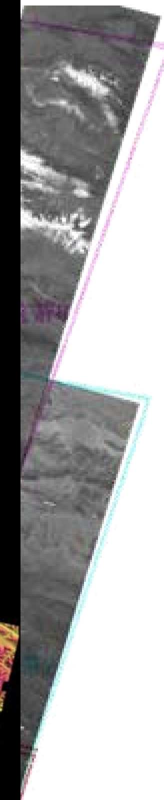
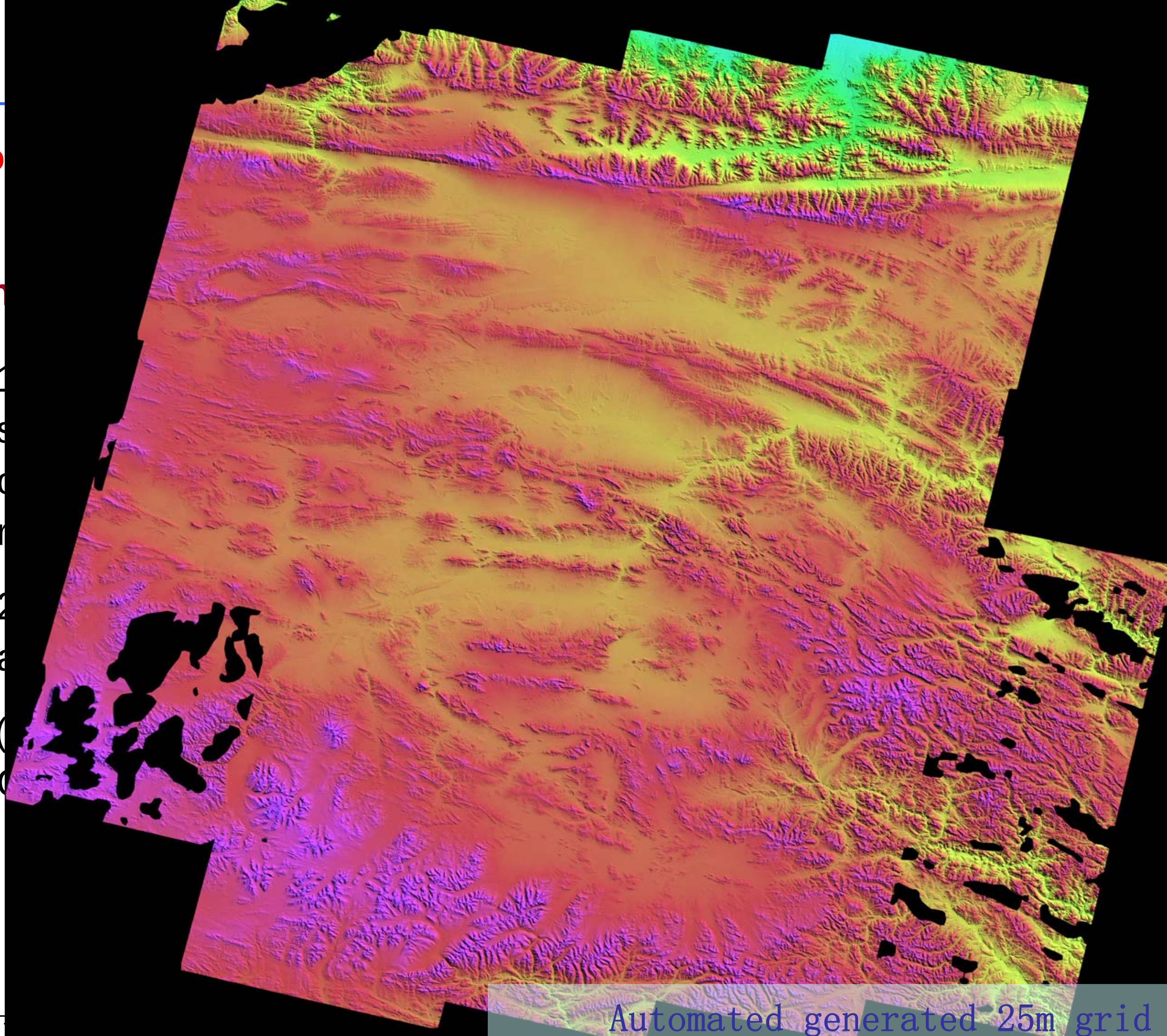
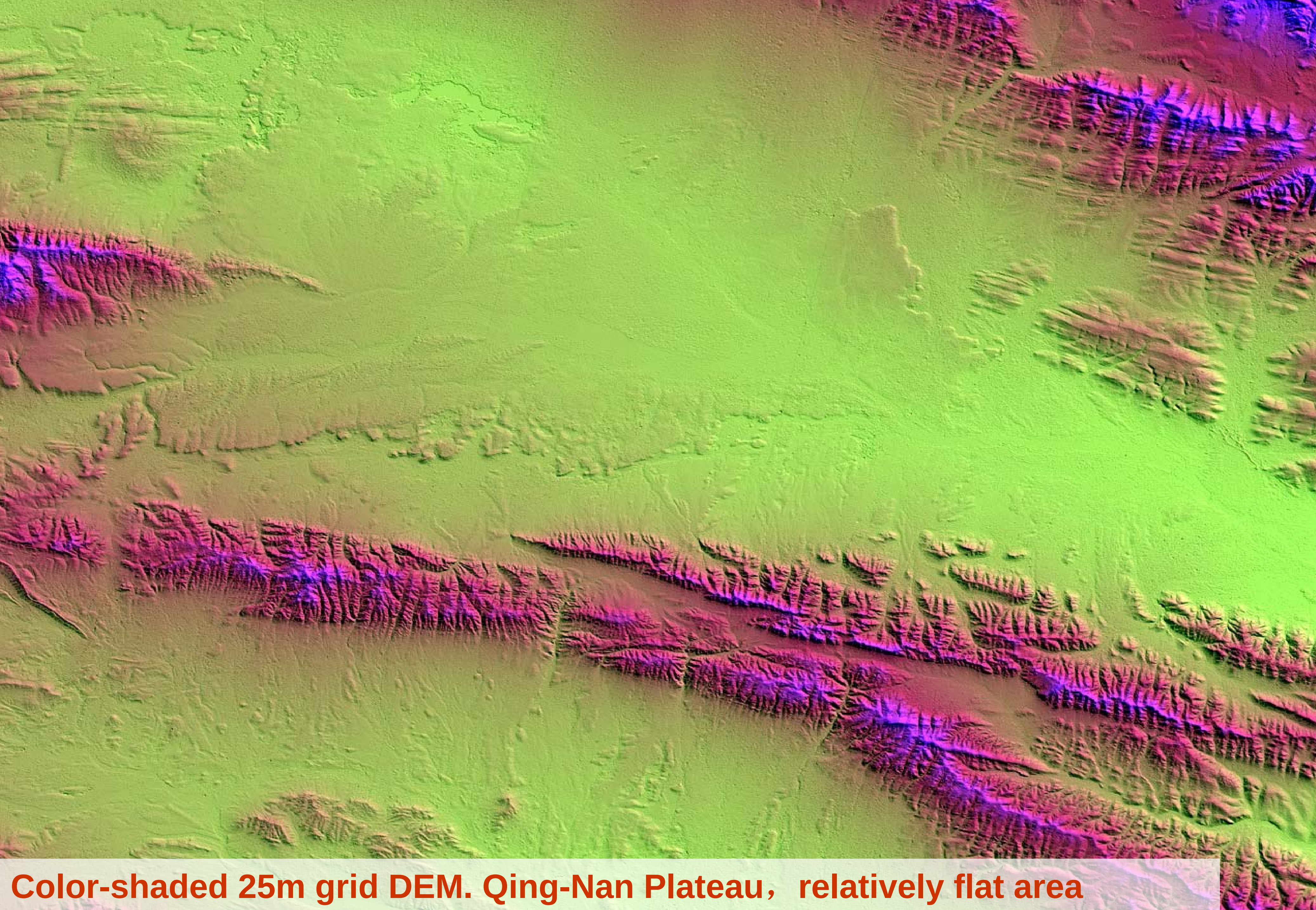
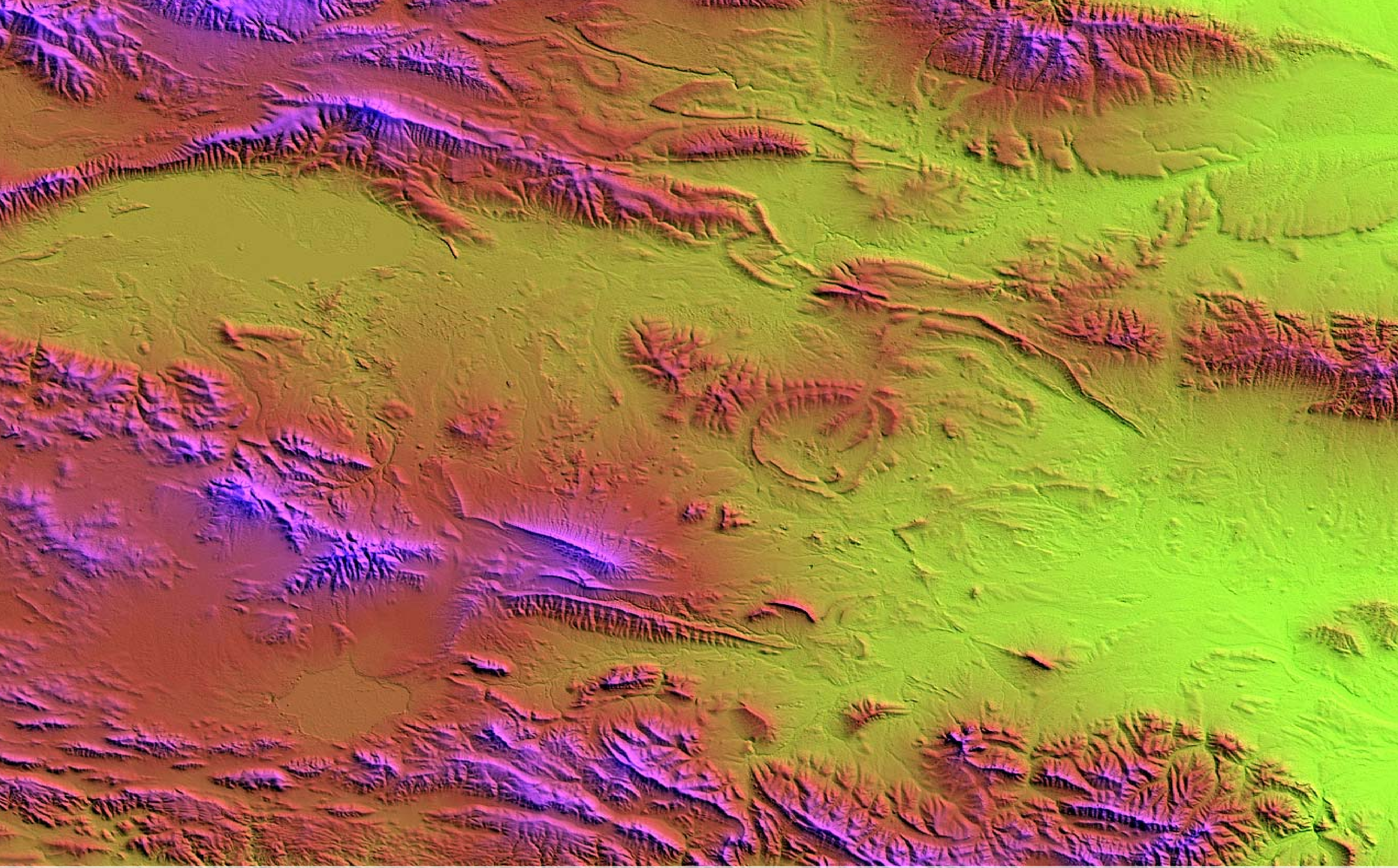


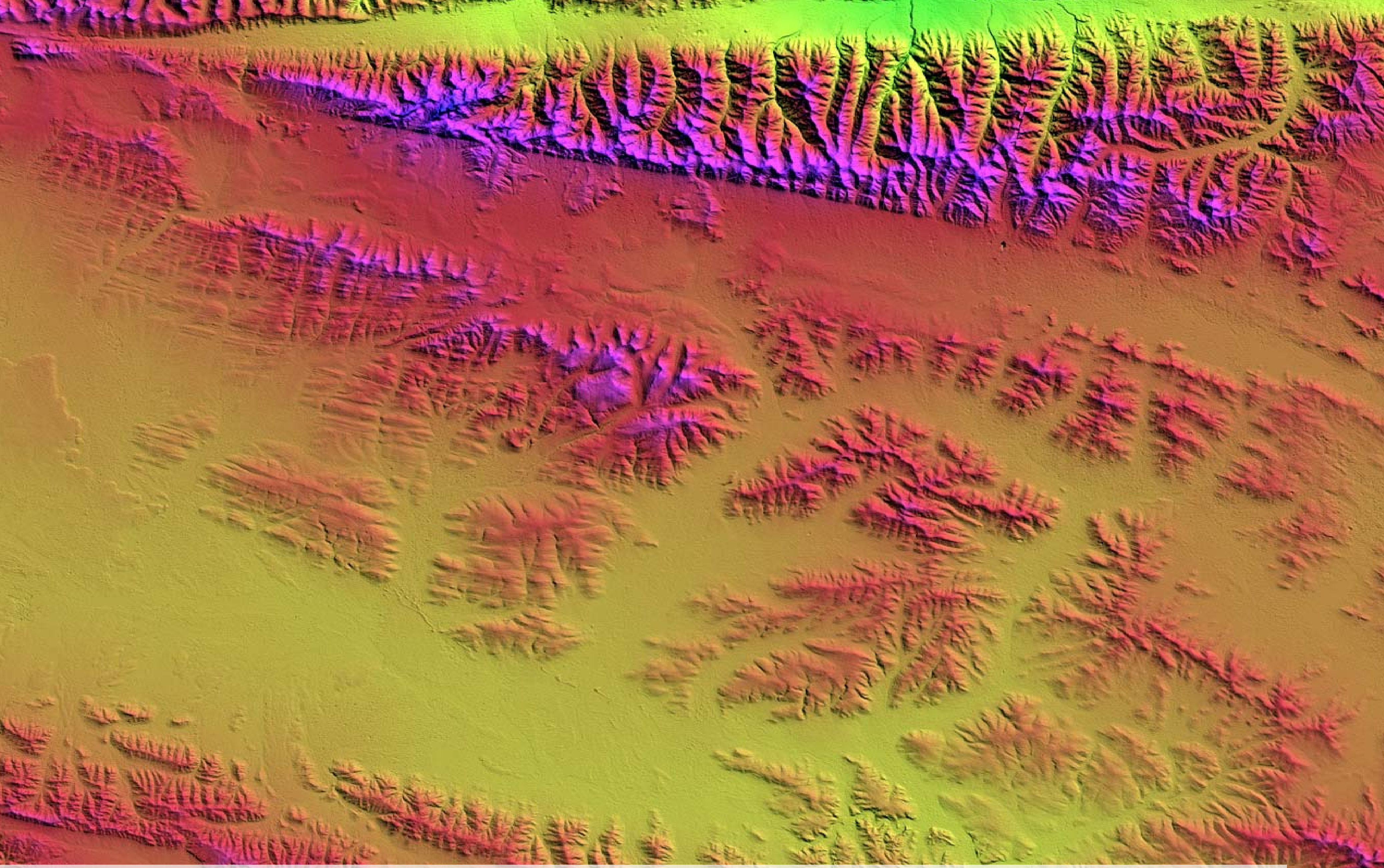




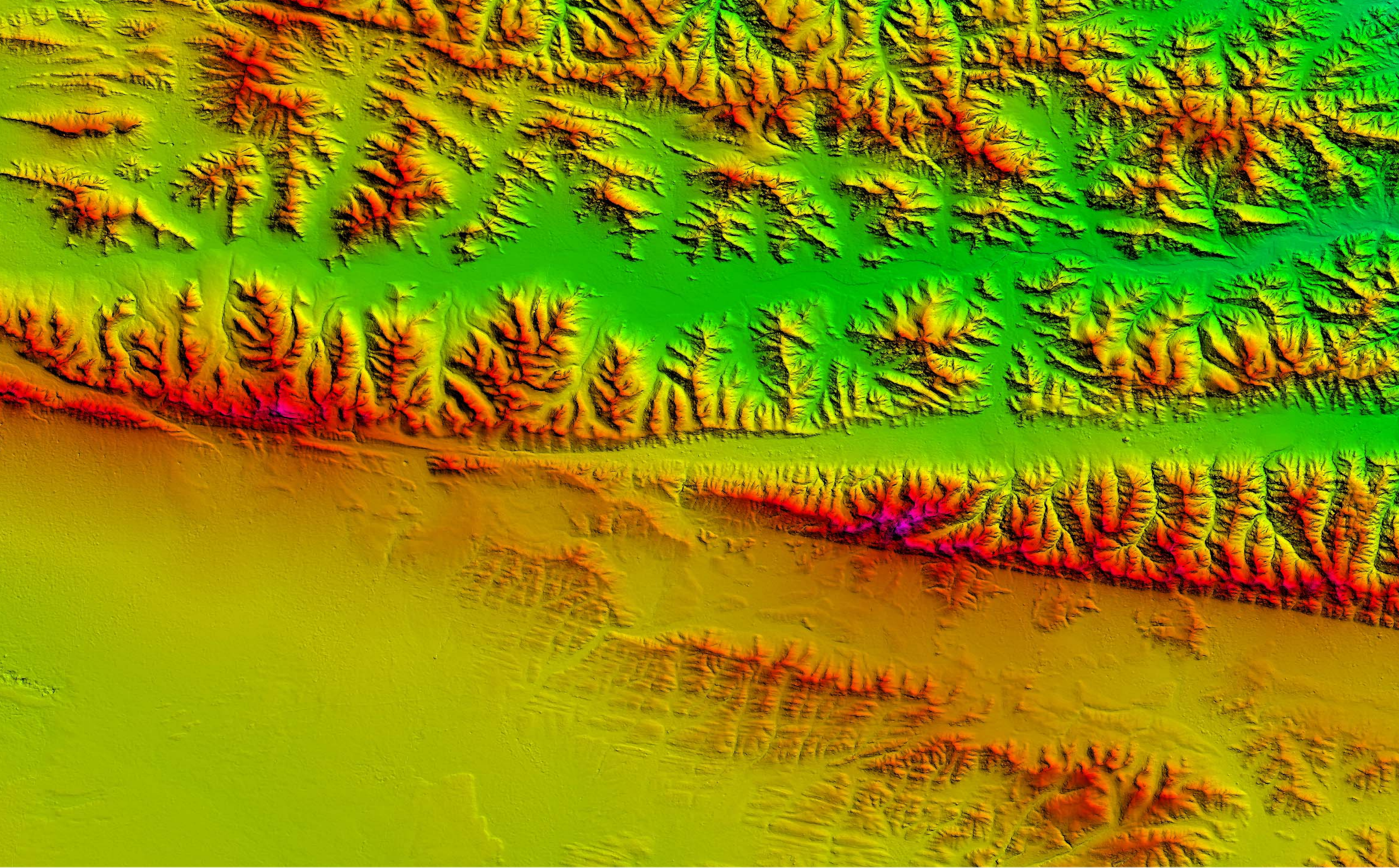
Color-shaded 25m grid DEM. Qing-Nan Plateau， relatively flat area



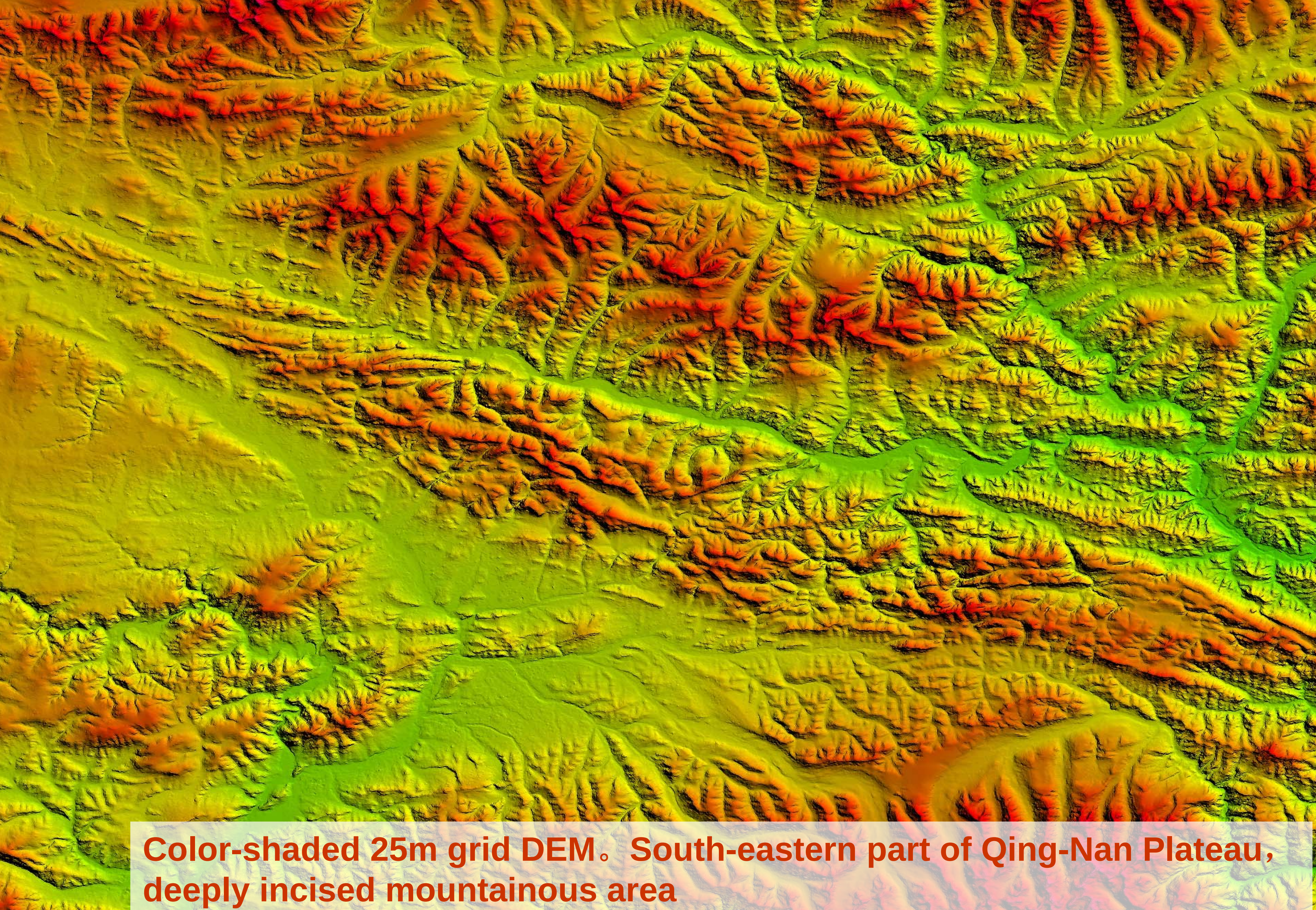
Color-shaded 25m grid DEM. Eastern parts of Qing-Tibet Plateau， mainly folded mountain ranges



Color-shaded 25m grid DEM。Eastern part of Qing-Tibert Plateau，mainly folded and fault-block mountain ranges

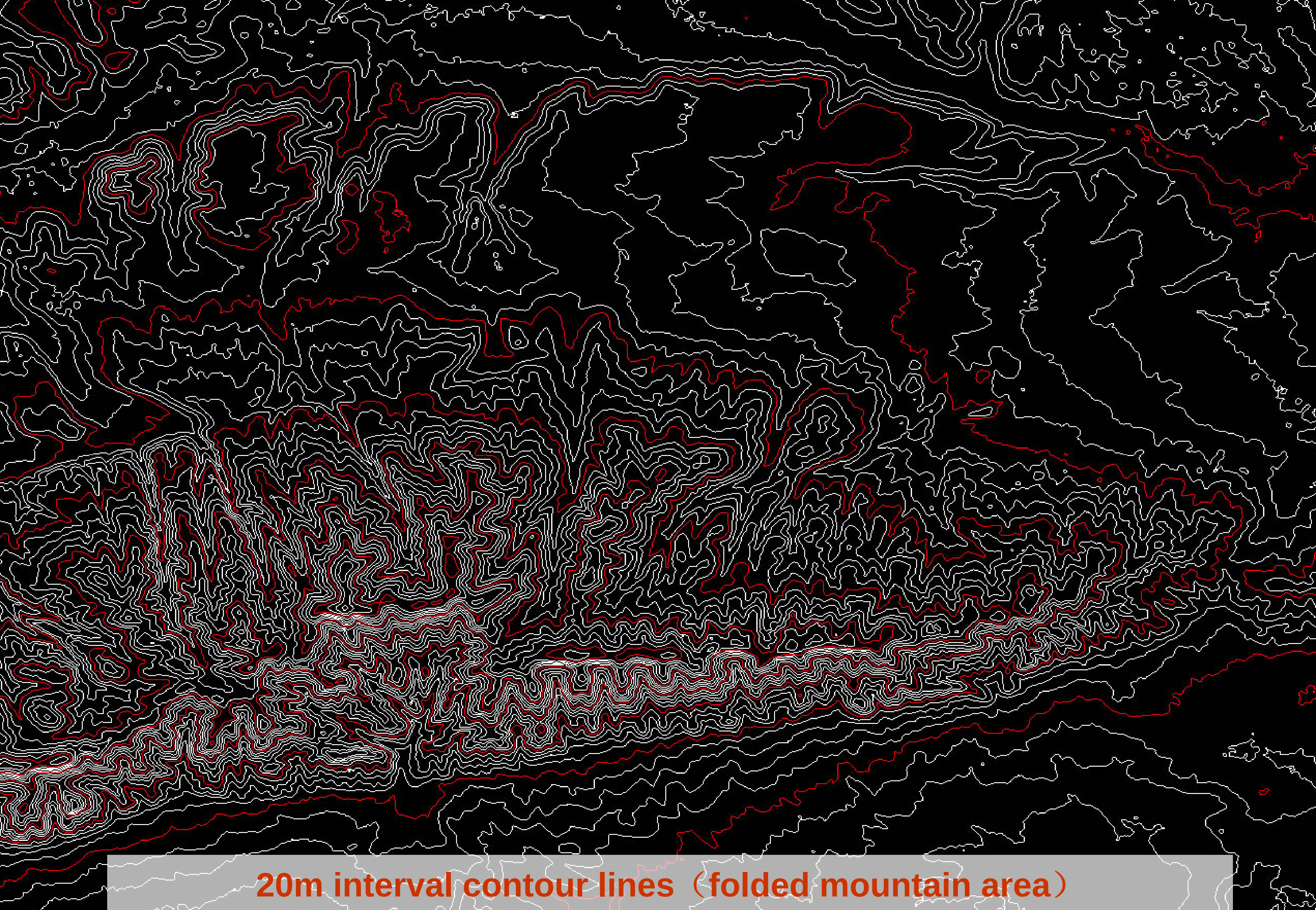


Color-shaded 25m grid DEM。Area of Chai-Da-Mu Basin and Qing-Tibet Plateau, mountainous glaciers are well developed in central part

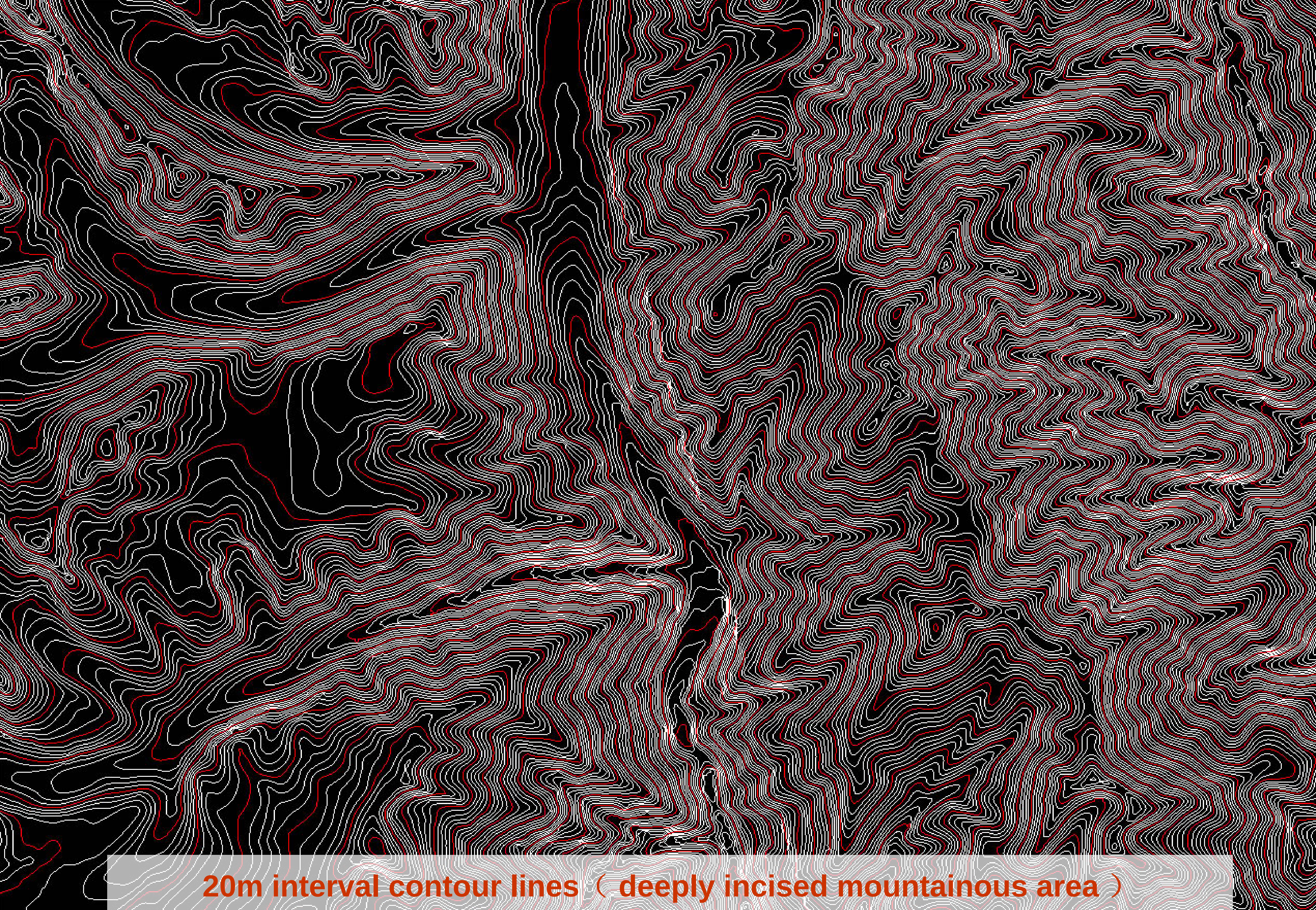


Color-shaded 25m grid DEM。South-eastern part of Qing-Nan Plateau, deeply incised mountainous area

20m interval contour lines（hilly area）

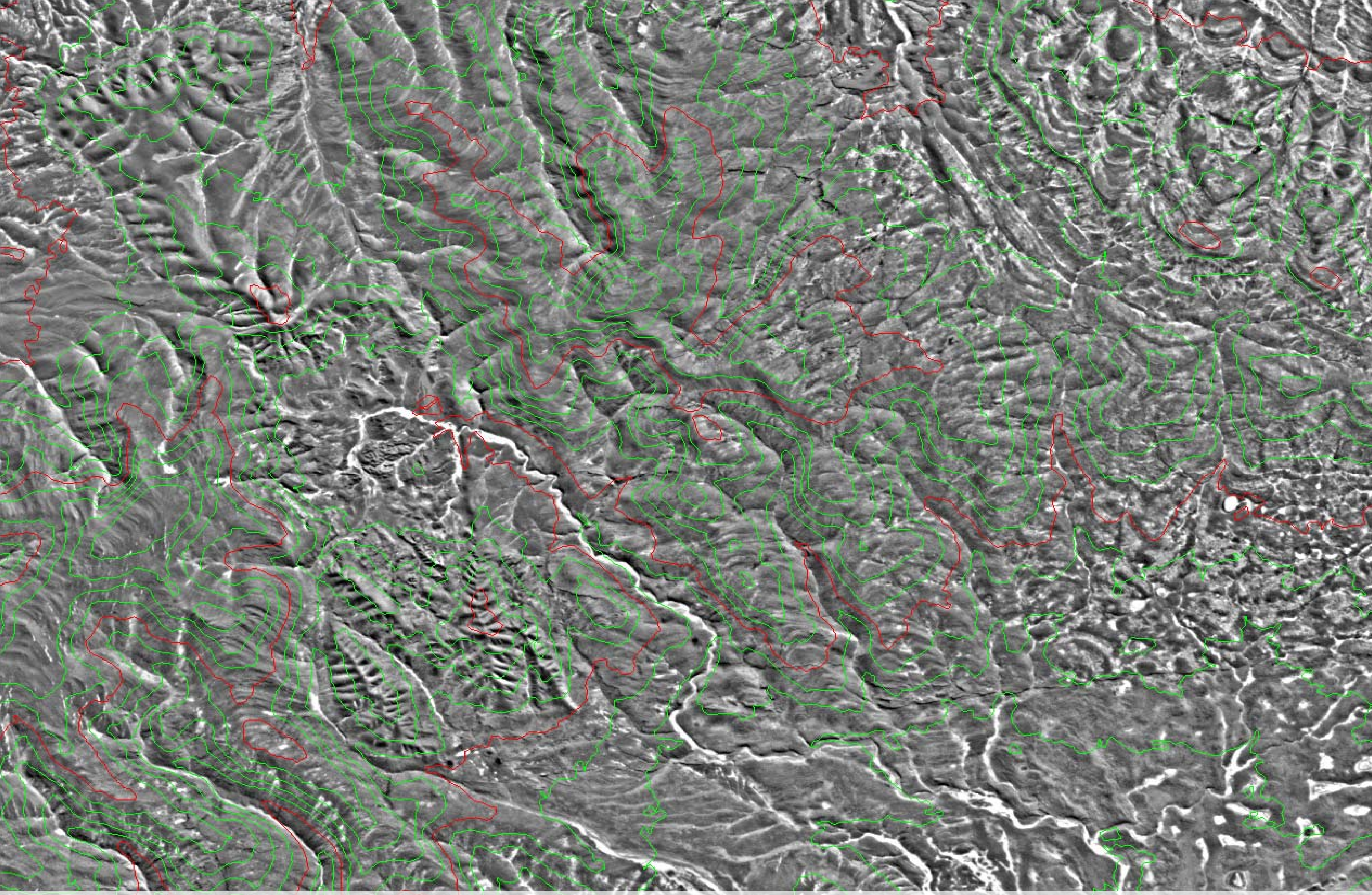


20m interval contour lines（folded mountain area）

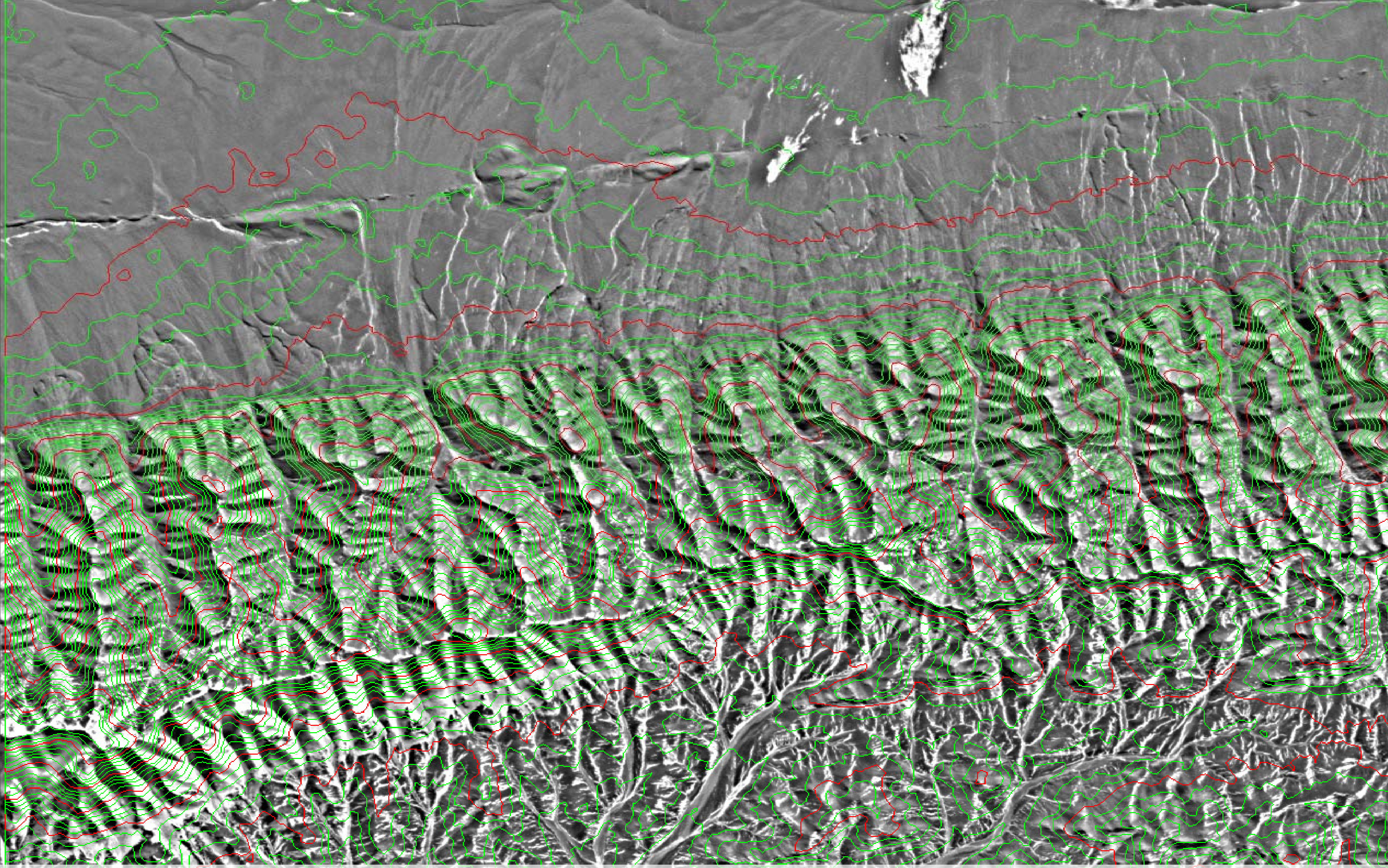


20m interval contour lines（ deeply incised mountainous area ）

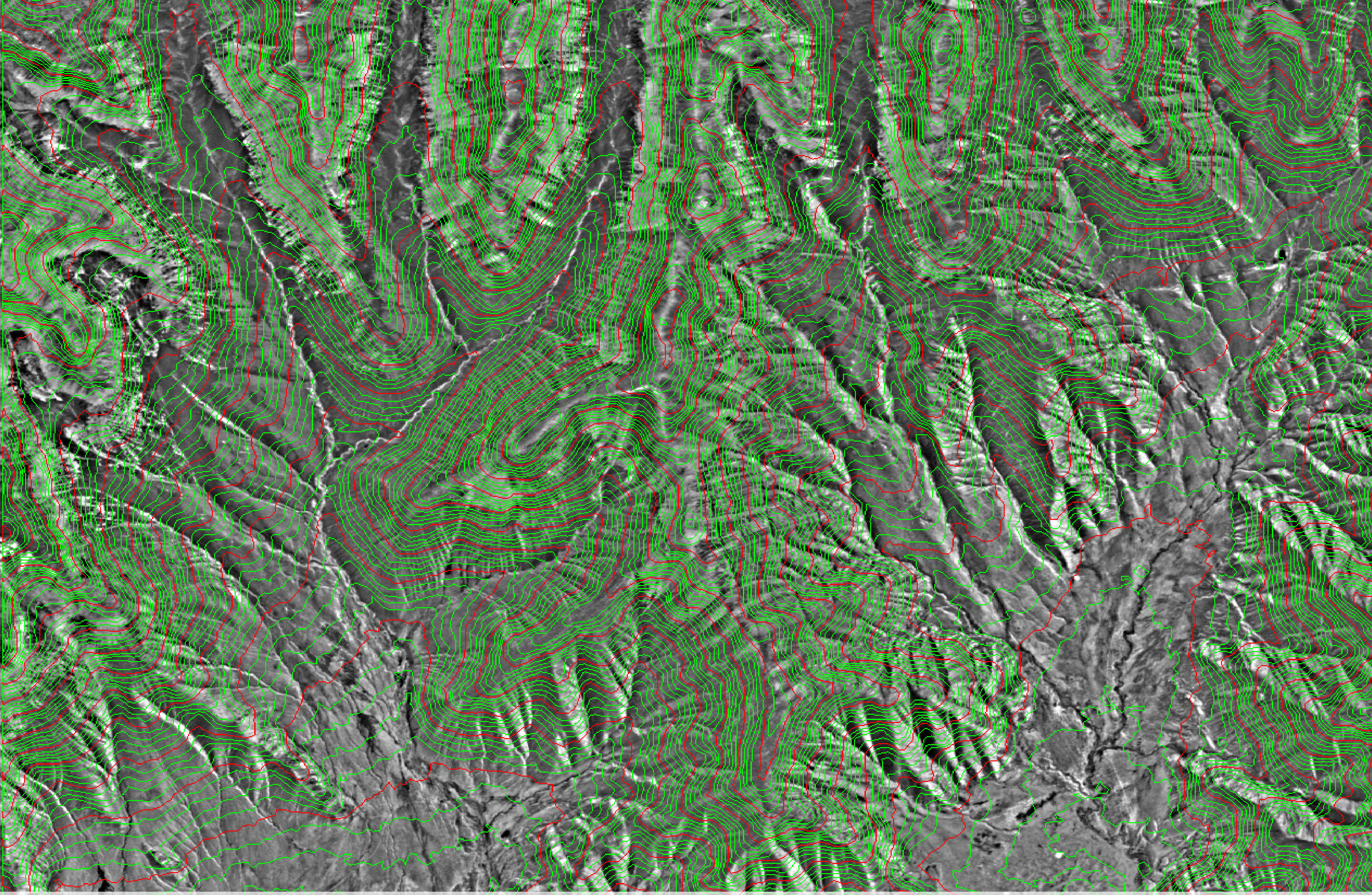
20m interval contour lines（mountainous glaciers）



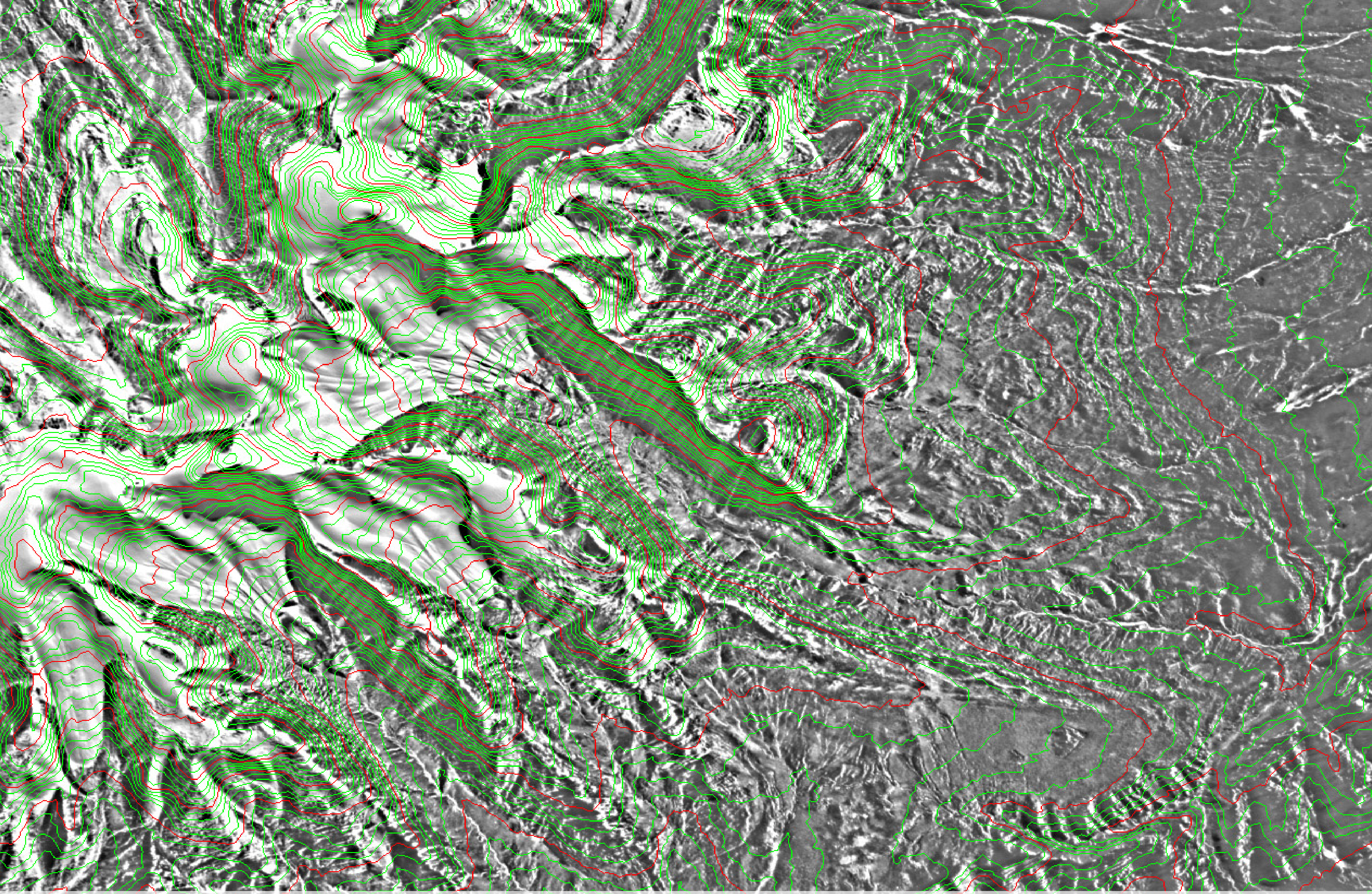
5 m resolution Ortho-image + contour lines（hilly area）



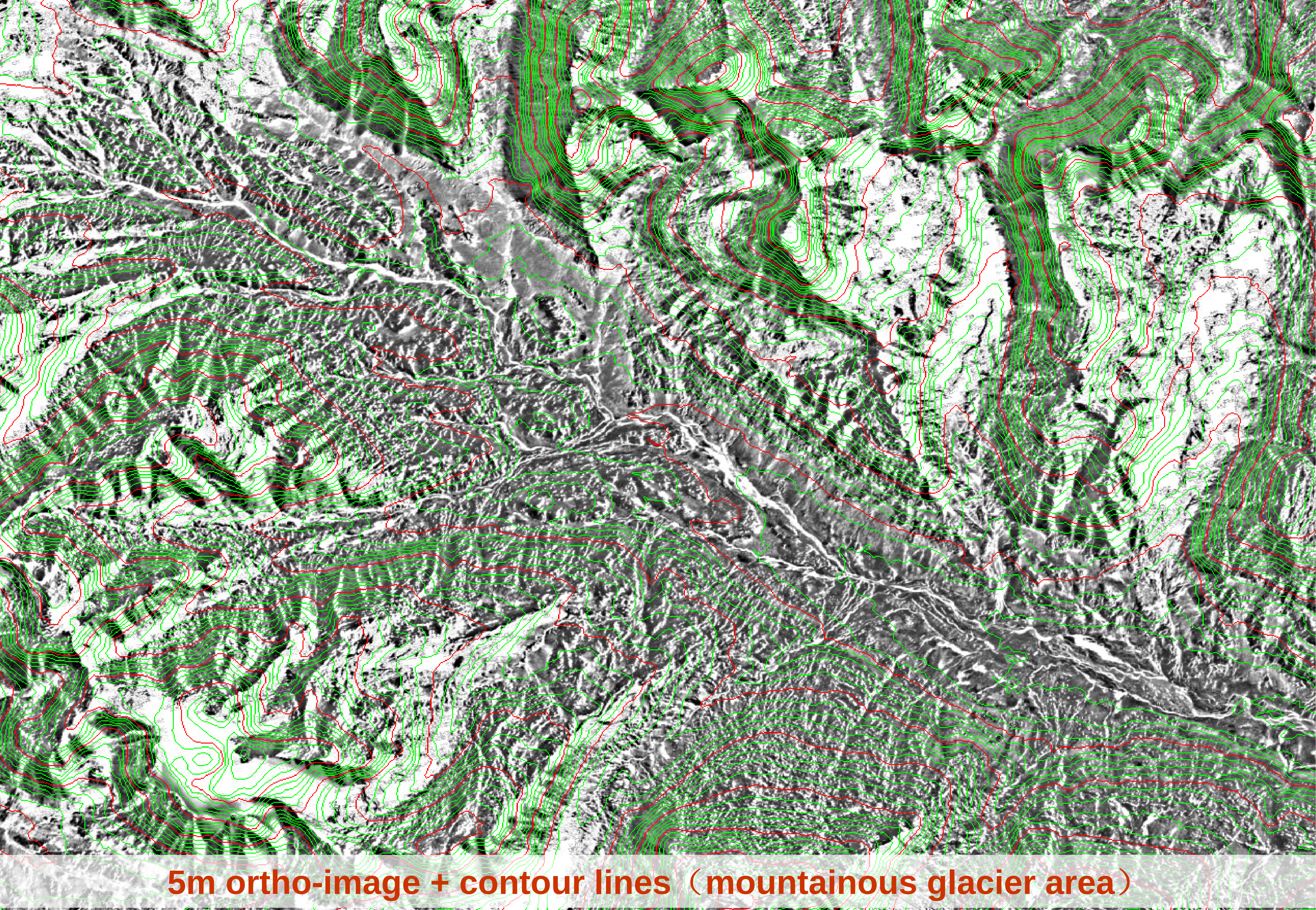
5m ortho-image + 20m interval contour lines（alluvial fans and fault-block mountain ranges）



5m ortho-image + contour lines（deeply incised mountain area）

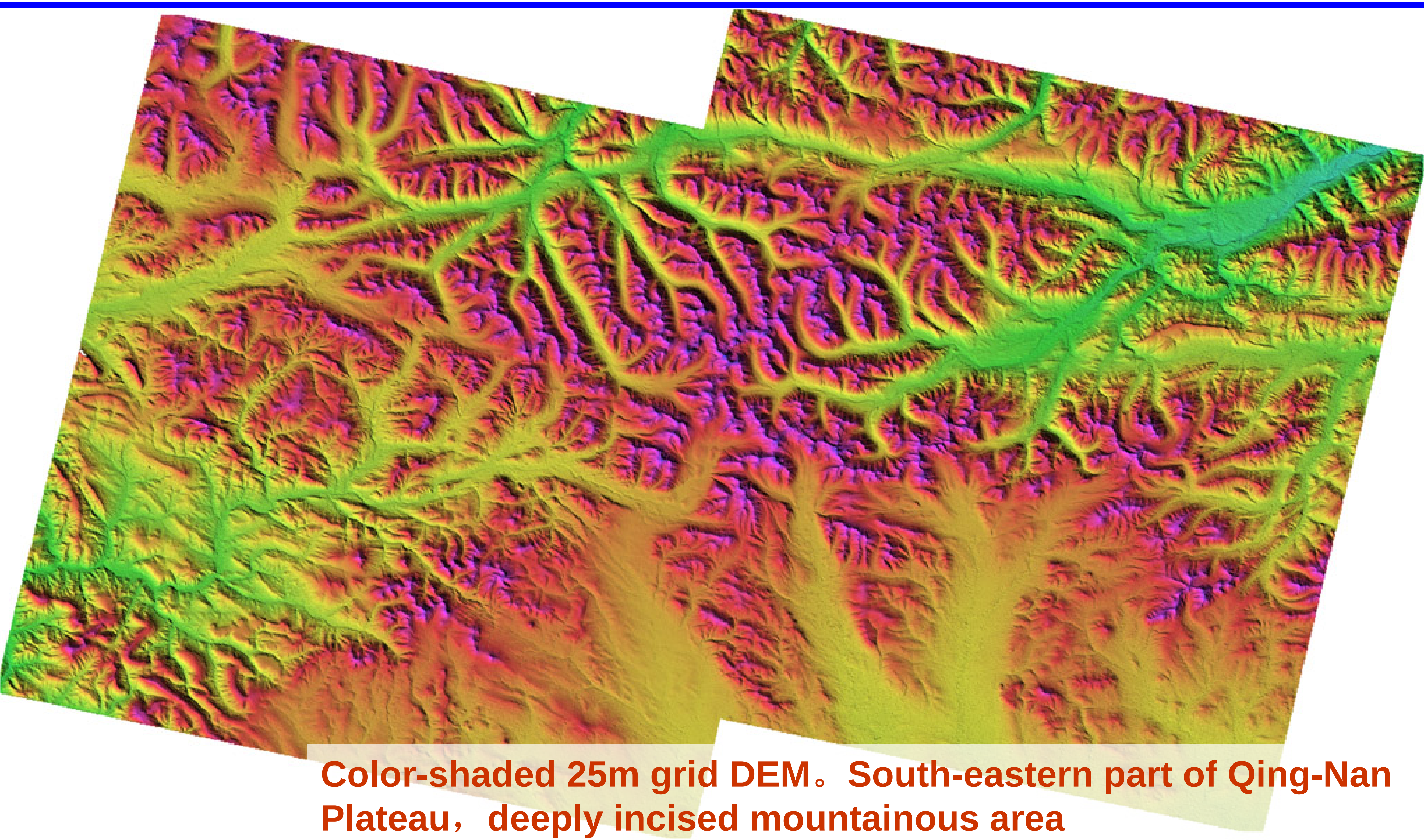


5m ortho-image + contour lines（mountainous glacier area）



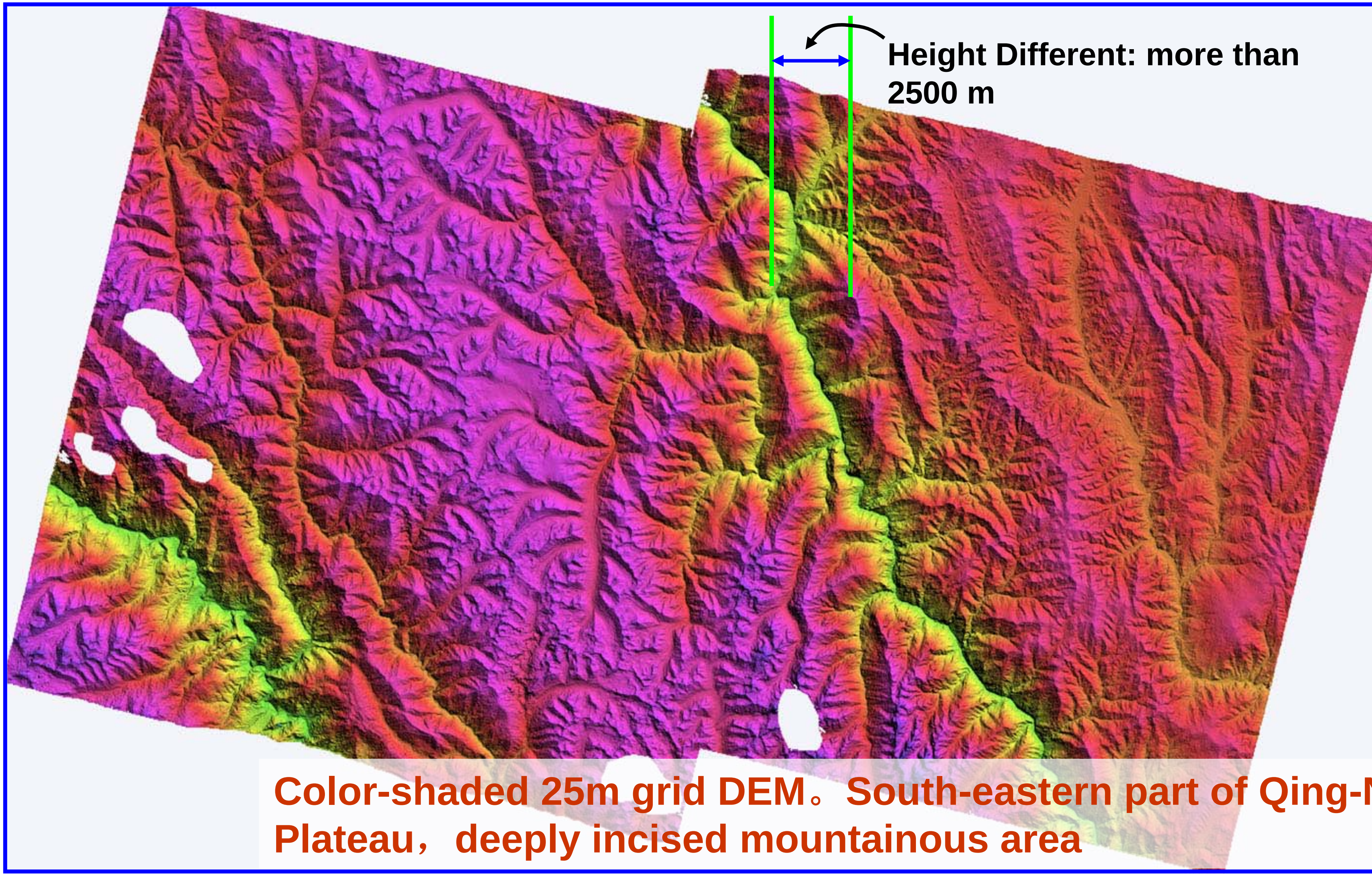
5m ortho-image + contour lines（mountainous glacier area）

Performance Evaluation: SPOT5-HRS/HRG Stereo Triplet (China)



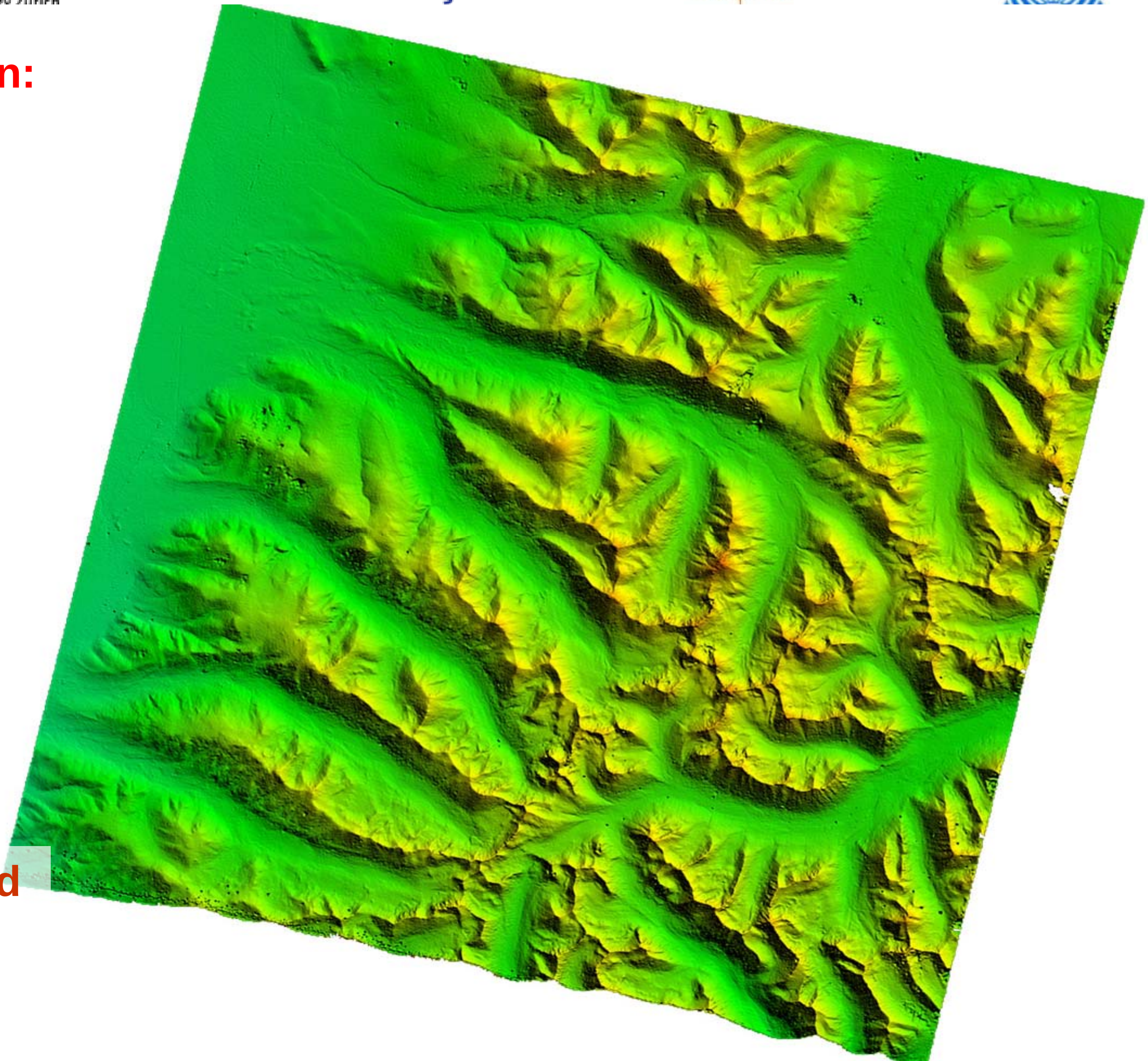
Color-shaded 25m grid DEM。South-eastern part of Qing-Nan Plateau，deeply incised mountainous area

Performance Evaluation: SPOT5-HRS/HRG Stereo Triplet (China)

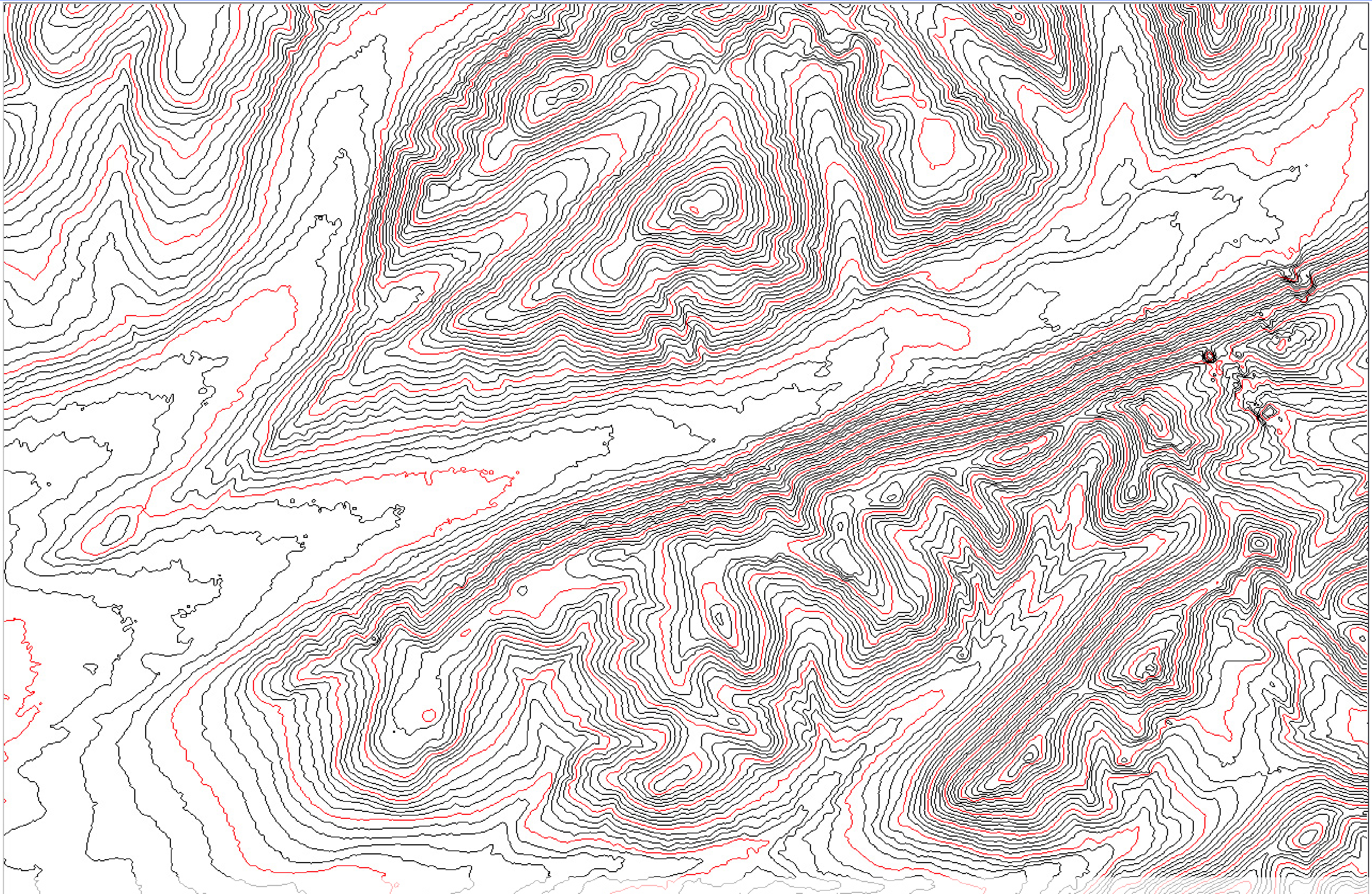


Color-shaded 25m grid DEM。South-eastern part of Qing-Nan Plateau，deeply incised mountainous area

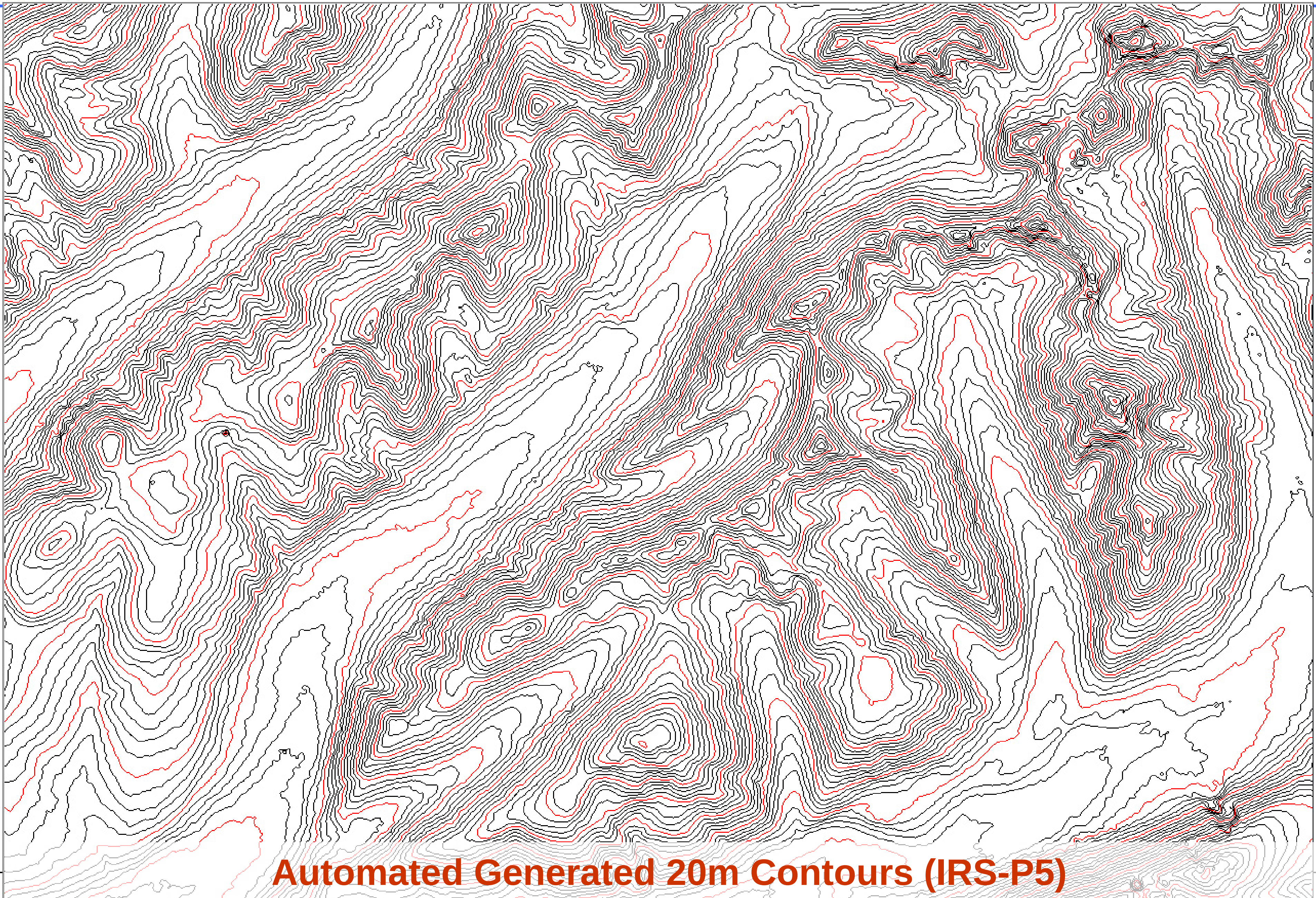
Performance Evaluation: IRS-P5 Stereo (China)



12m Grid DEM generated from IRS-P5 2.5m resolution Stereo Pair



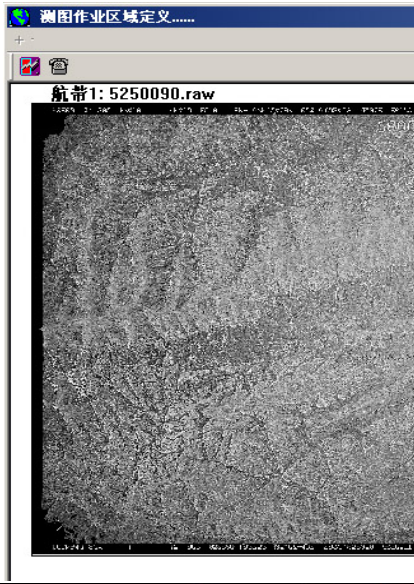
Automated Generated 20m Contours (IRS-P5)

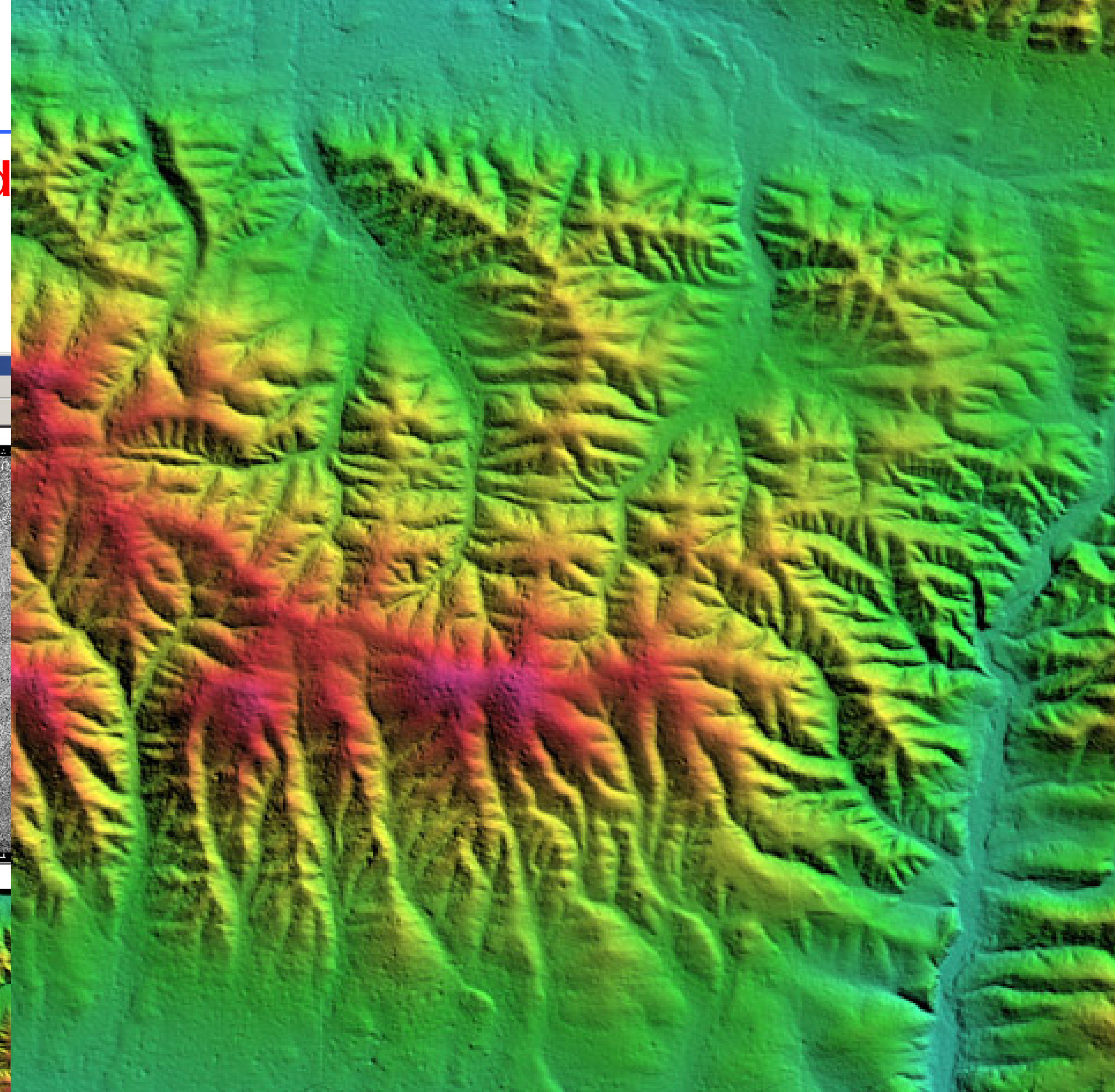


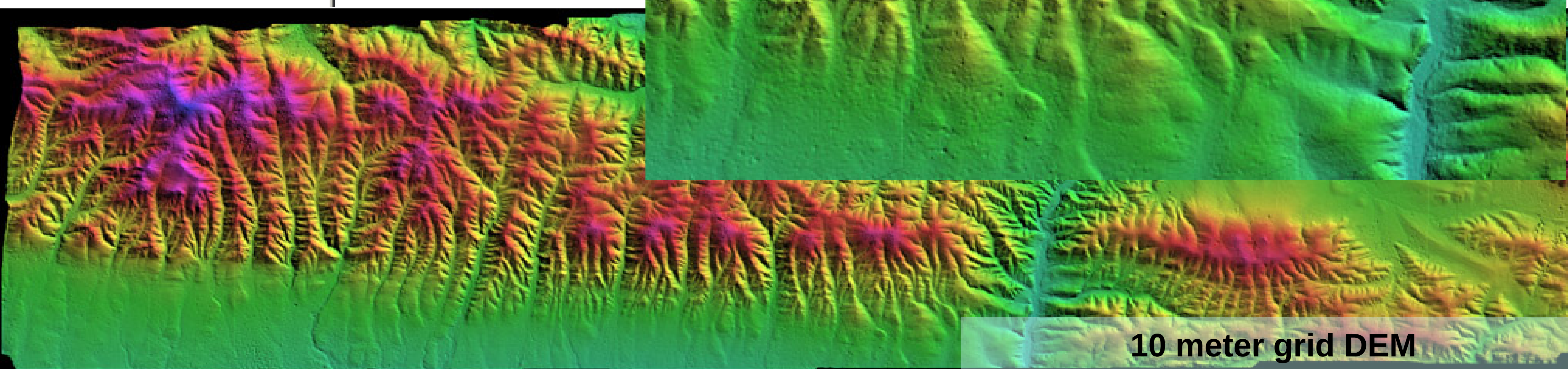
Automated Generated 20m Contours (IRS-P5)

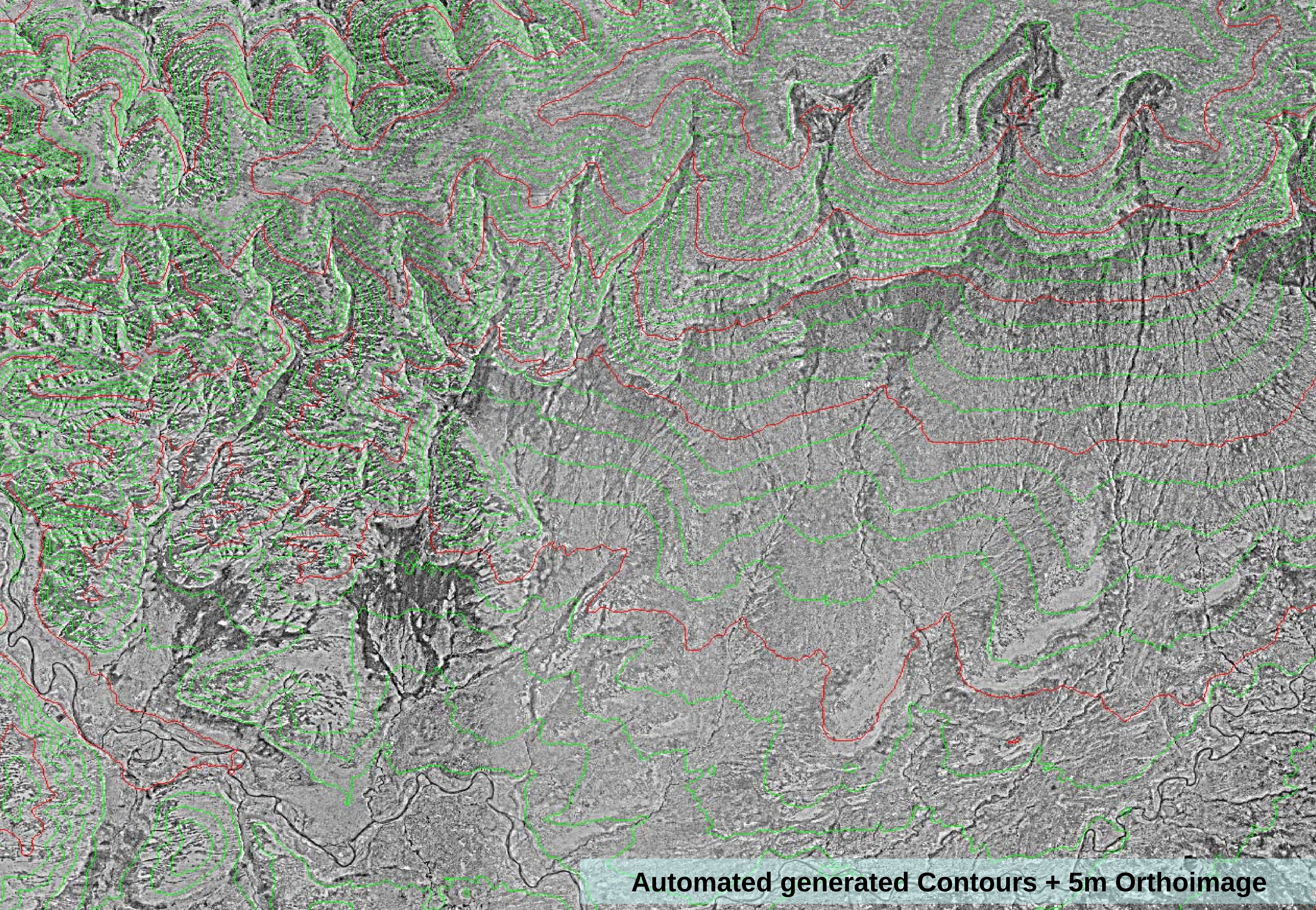
Performance Evaluation: Trad

+ Scale 1：50000
+ Scanned with 25um

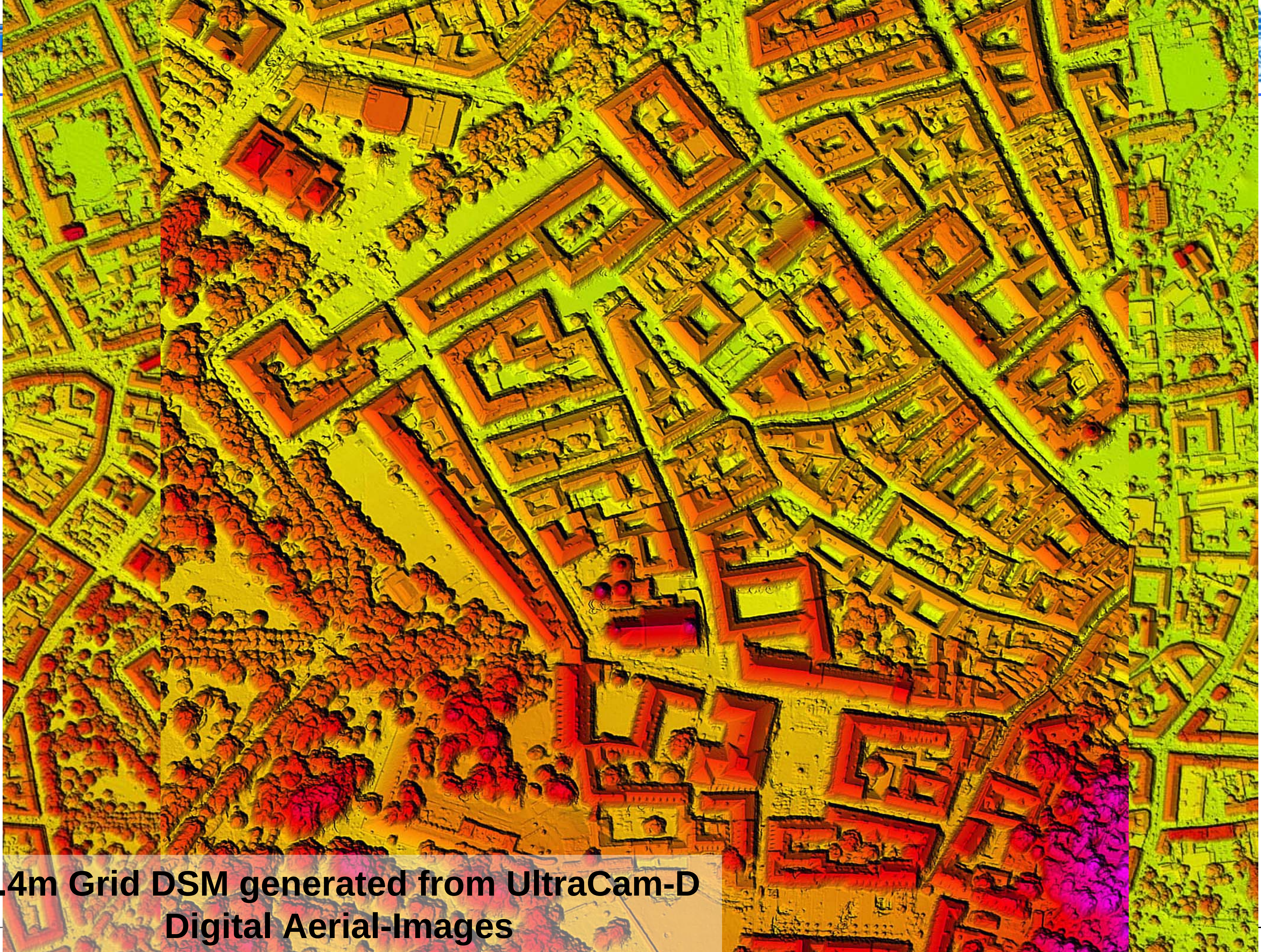








Automated generated Contours + 5m Orthoimage



0.4m Grid DSM generated from UltraCam-D
Digital Aerial-Images

isprs
information from imagery

ETH
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Swiss Federal Institute of Technology Zurich