A SLAM-based high-resolution full-character debris-flow channel morphological mapping system

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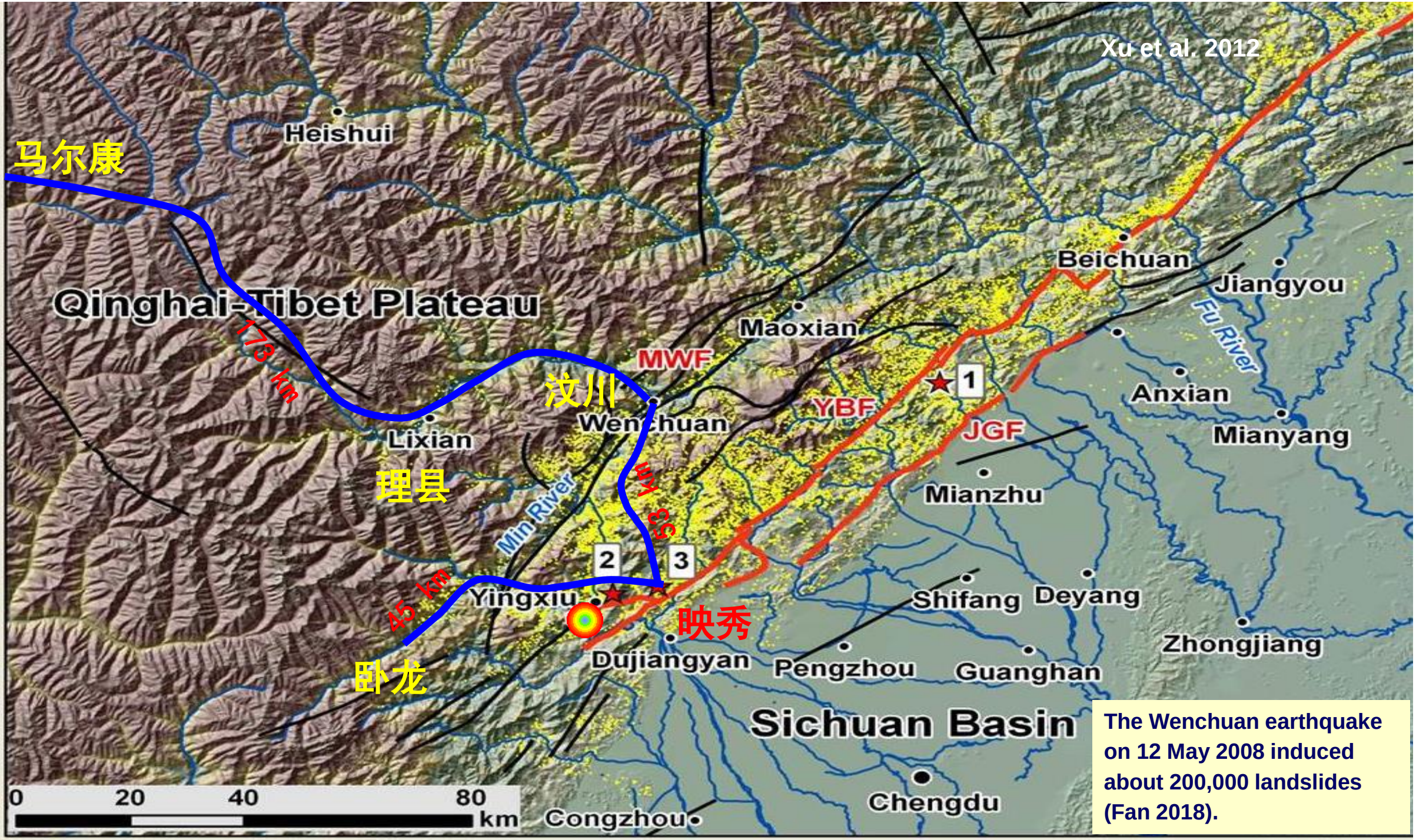
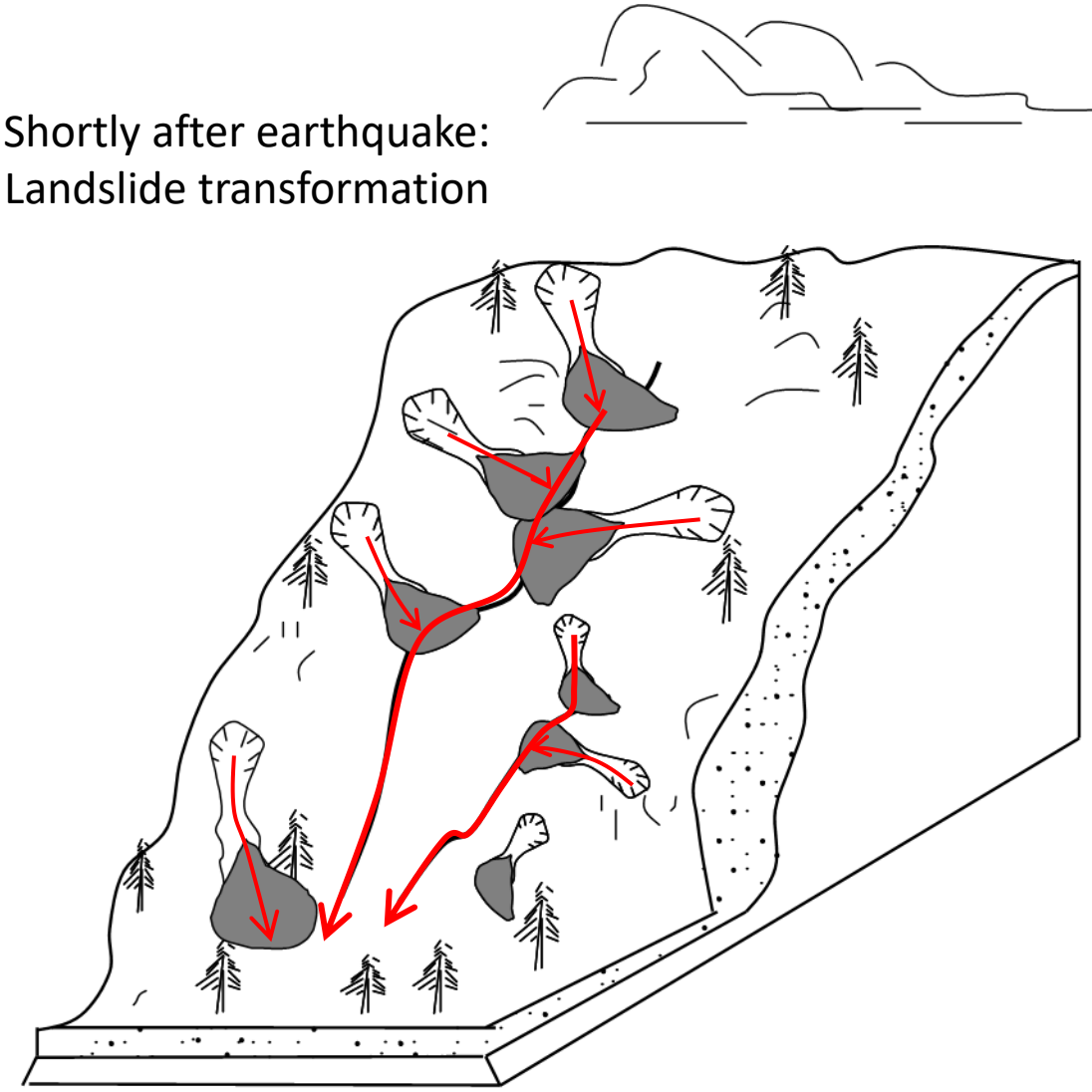


The Wenchuan earthquake on 12 May 2008 induced about 200,000 landslides (Fan 2018).

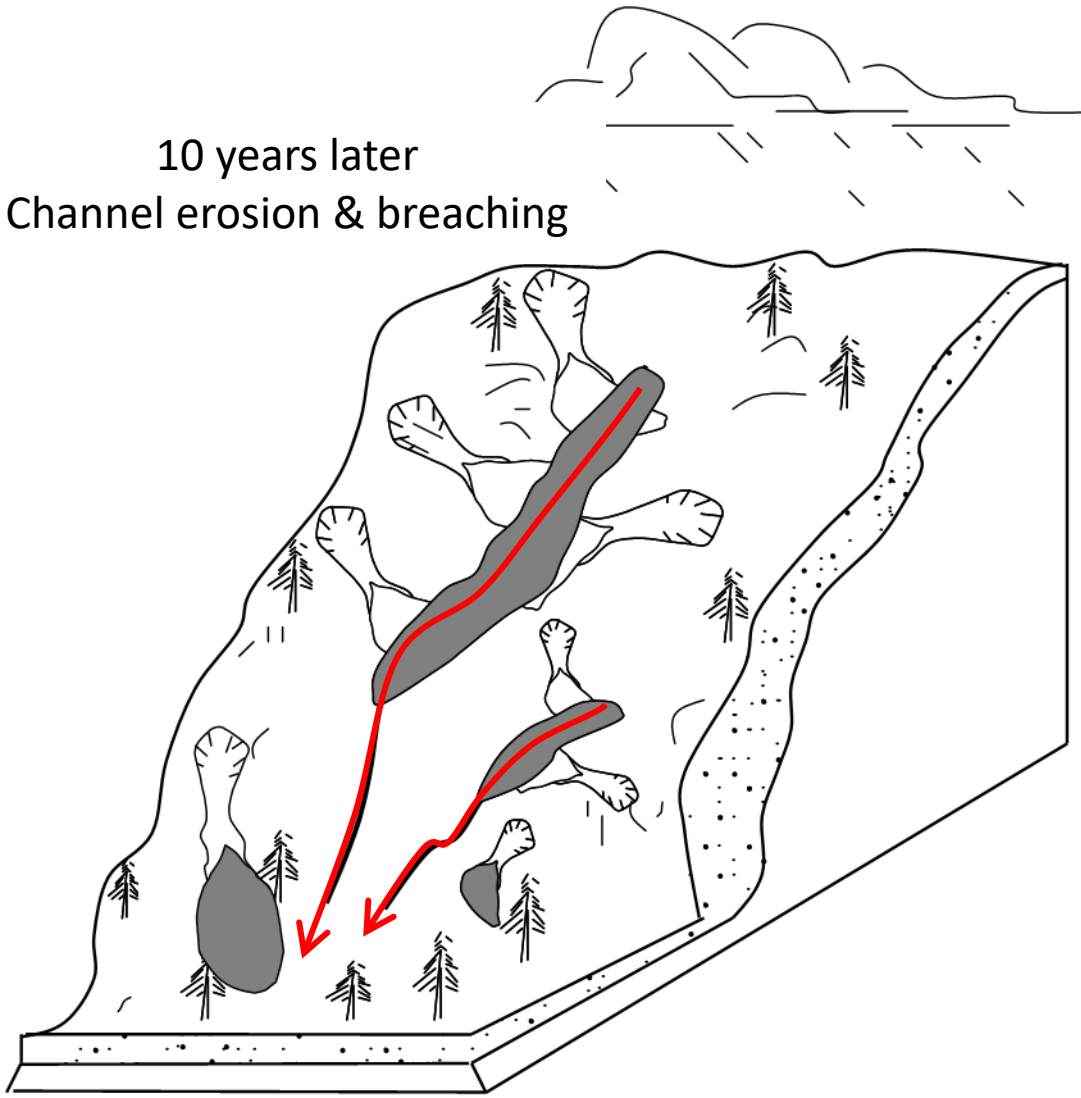
Long-term evolution of debris flow initiation mechanism

Knowing channel interior conditions is imperative for debris flow research and mitigation!

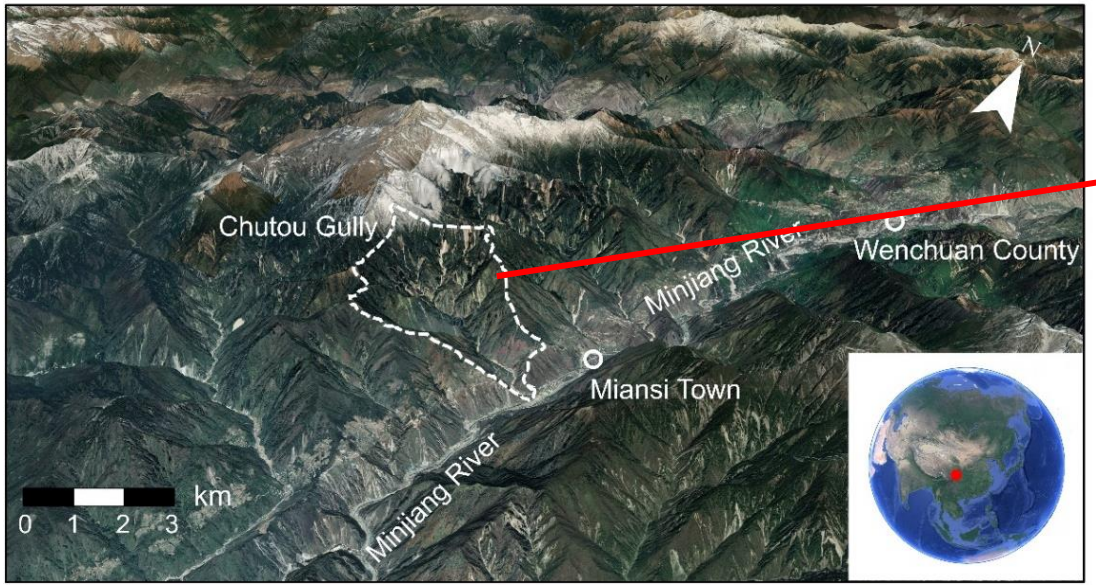
Shortly after earthquake:
Landslide transformation

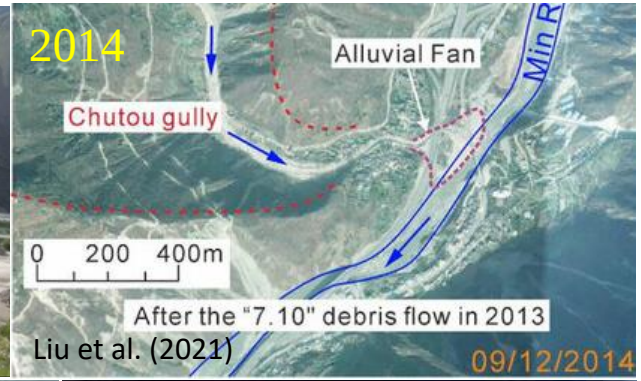


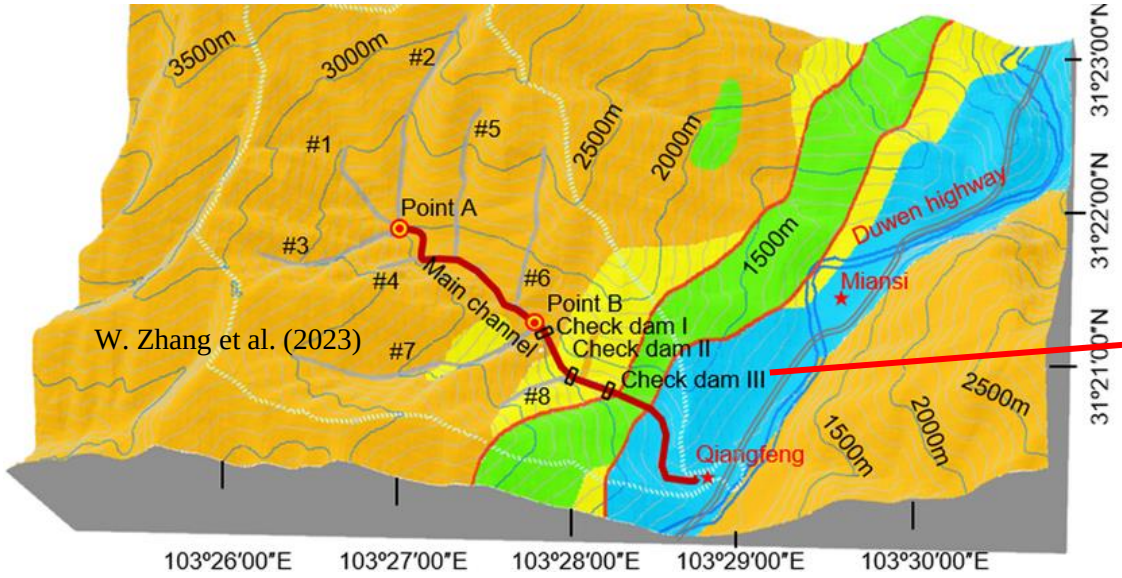
10 years later
Channel erosion & breaching

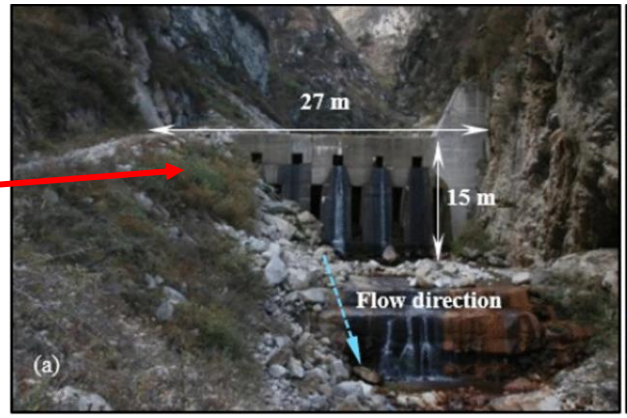


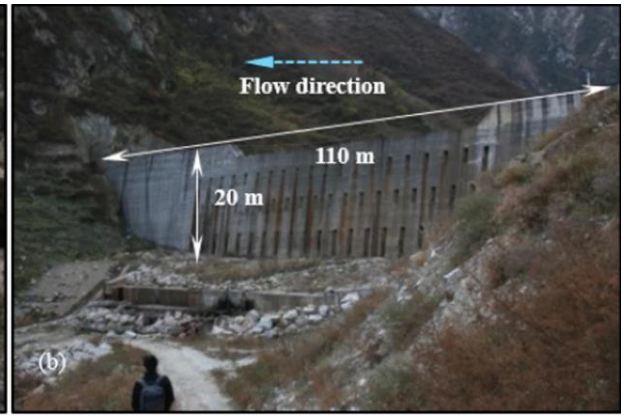
Channelized debris flows in Chutou Gully



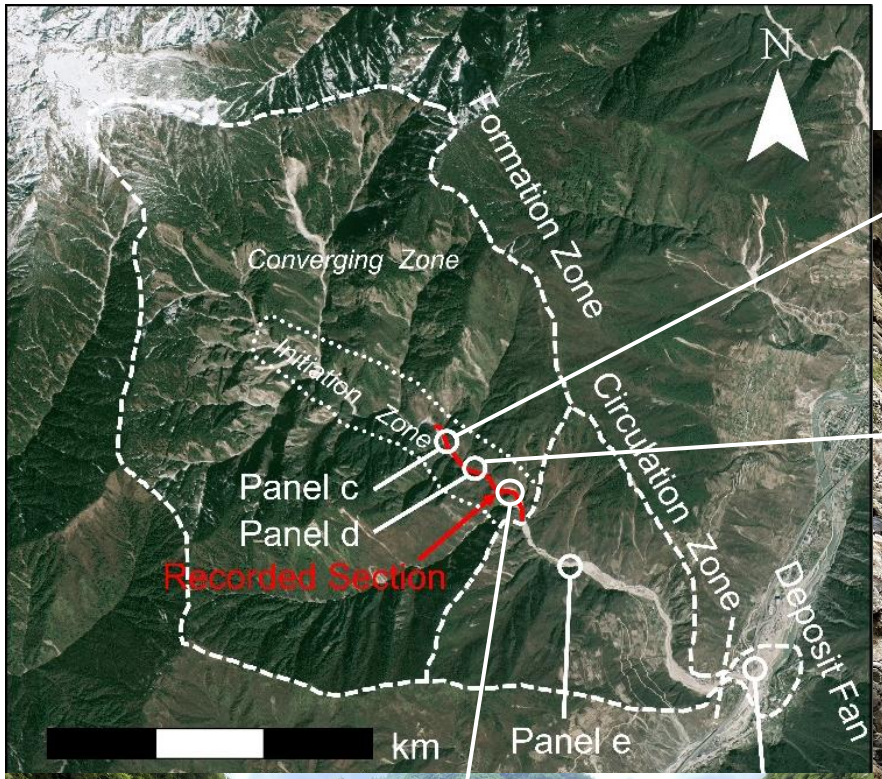


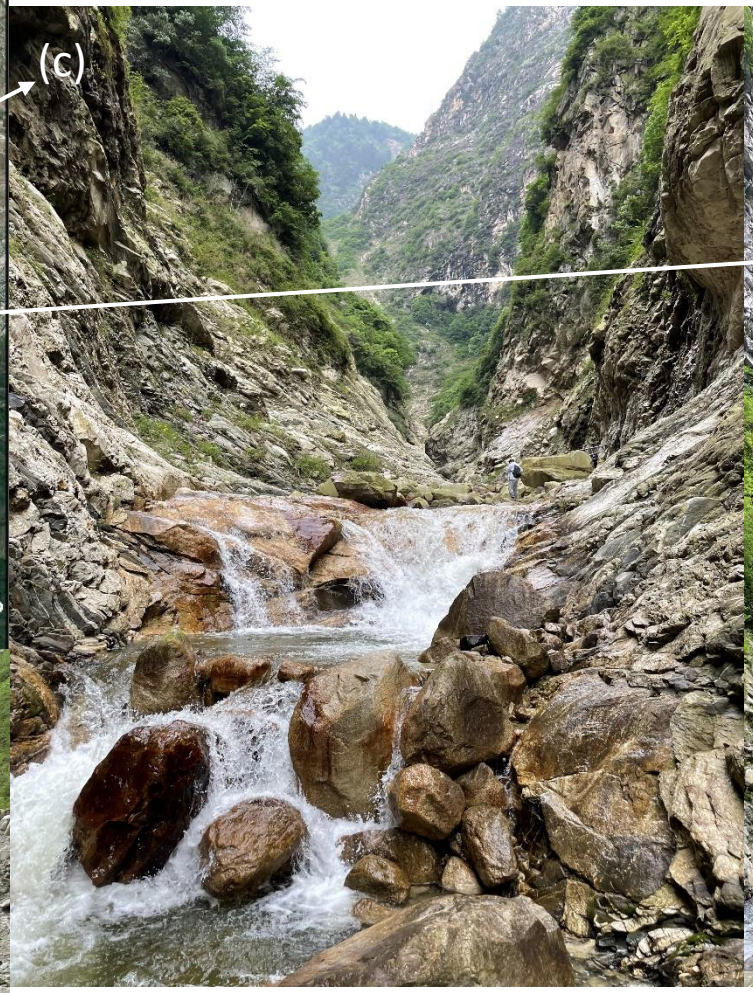






Channel conditions in Chutou Gully





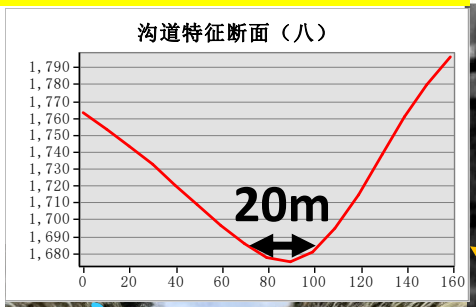
Current challenges

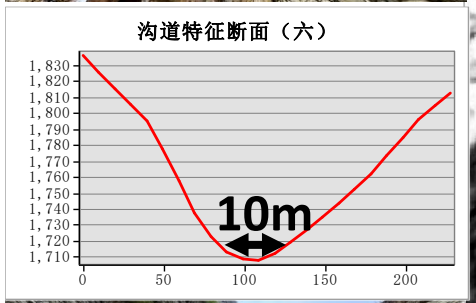
Channel morphology: Overhanging cliff and Narrow channel bed——Large ERRORs in satellite data

Deposits: Distribution, volume, erosion pattern——UNKNOWN

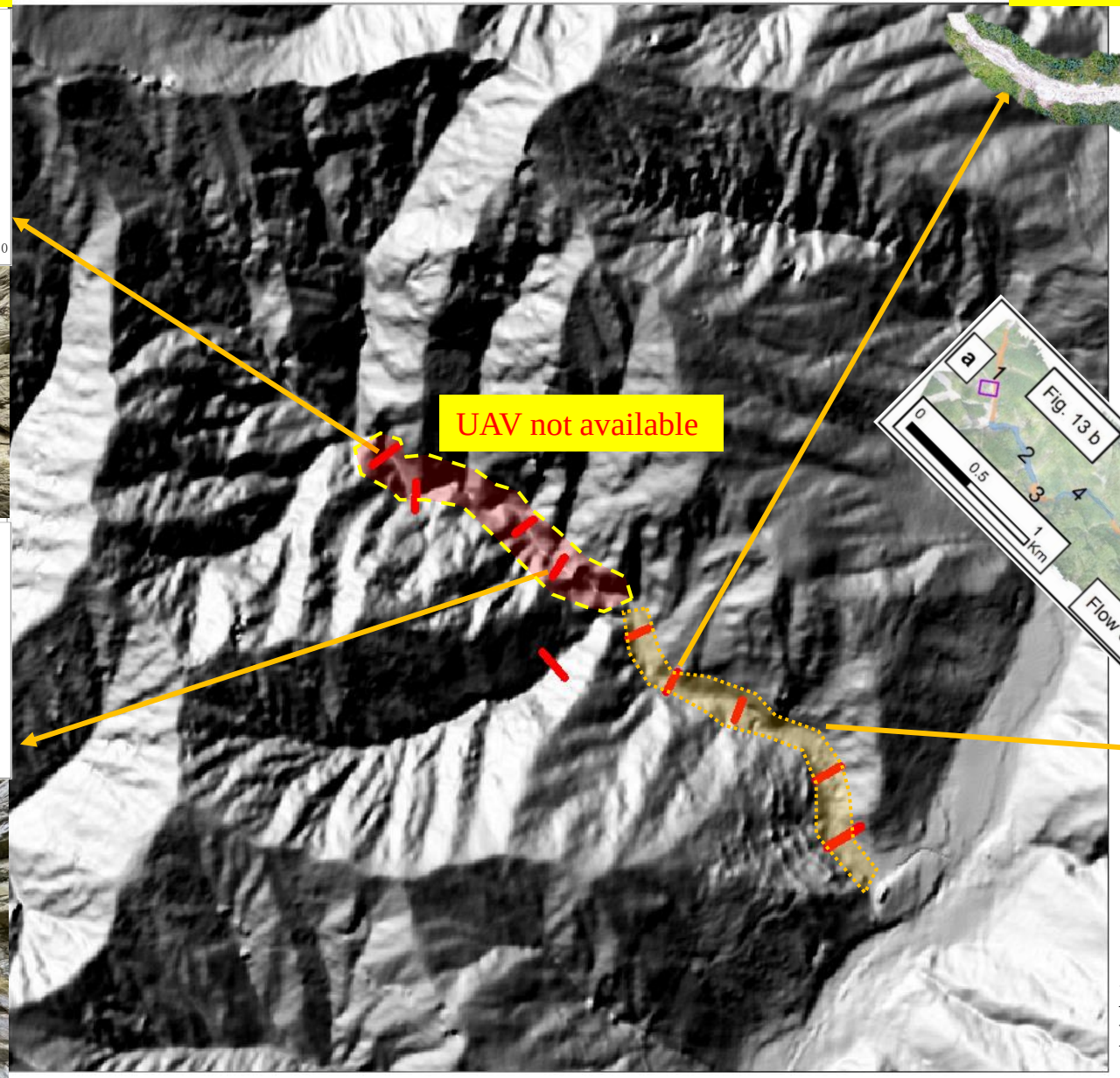
Bottleneck: How to accurately detect this type of channel?

Satellite-derived rough DEM





UAV-based accurate DEM



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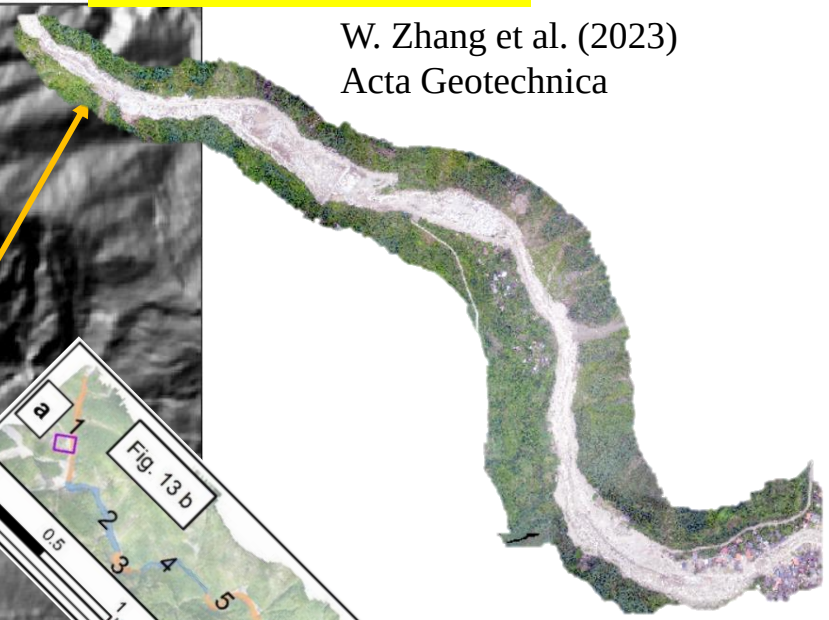

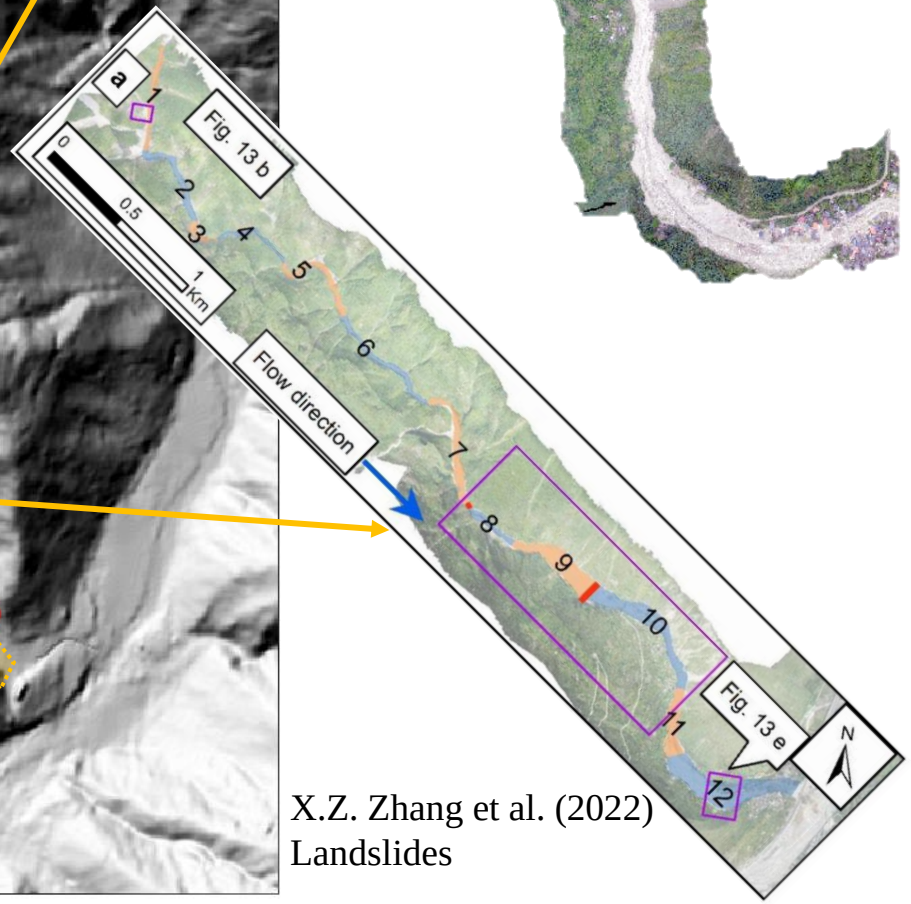

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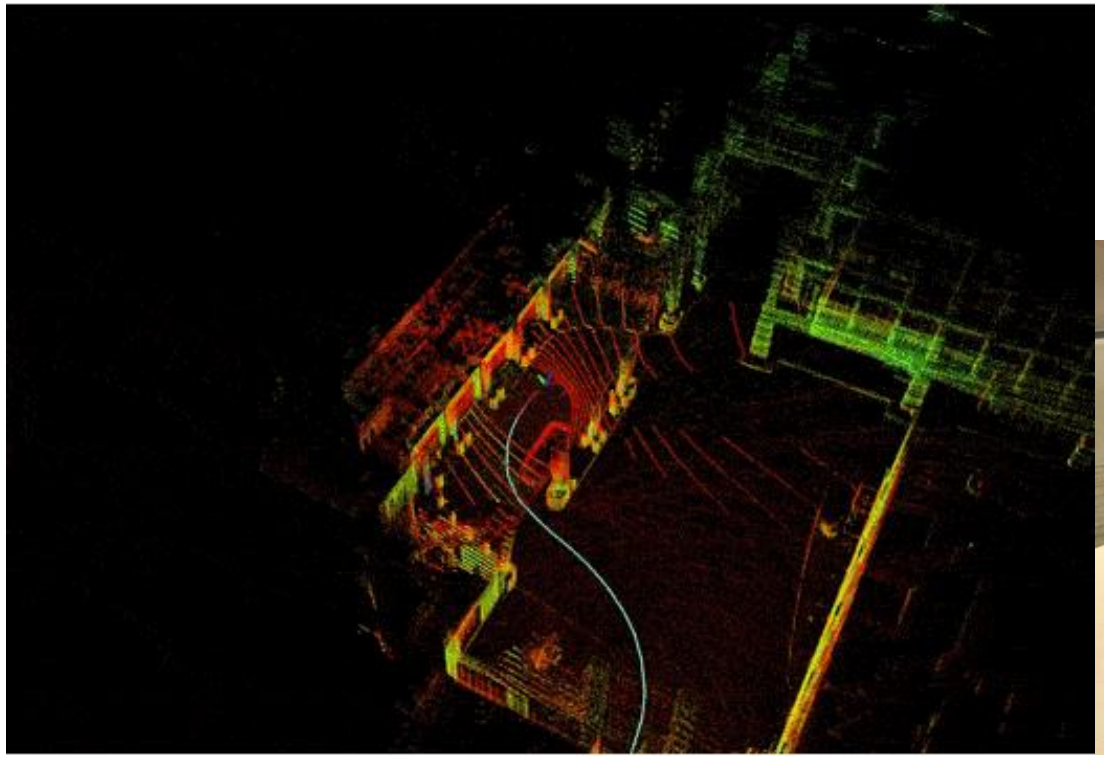
Proposed solution – based on SLAM technology

- Simultaneous Localization And Mapping
- LIOSAM (Shan et al. 2020): LIOSAM is based on LOAM (J. Zhang and S. Singh. LOAM: Lidar Odometry and Mapping in Real-time)



Suitable for flat, smooth environment such as urbanized area

Technical challenges in EQ-region channels:
Rugged ground, unstable pose – jittering, rotating, jumping

Hardware

LIDAR
Leishen C16

IMU
(Built-in barometer)
Xsens Mti-G-710

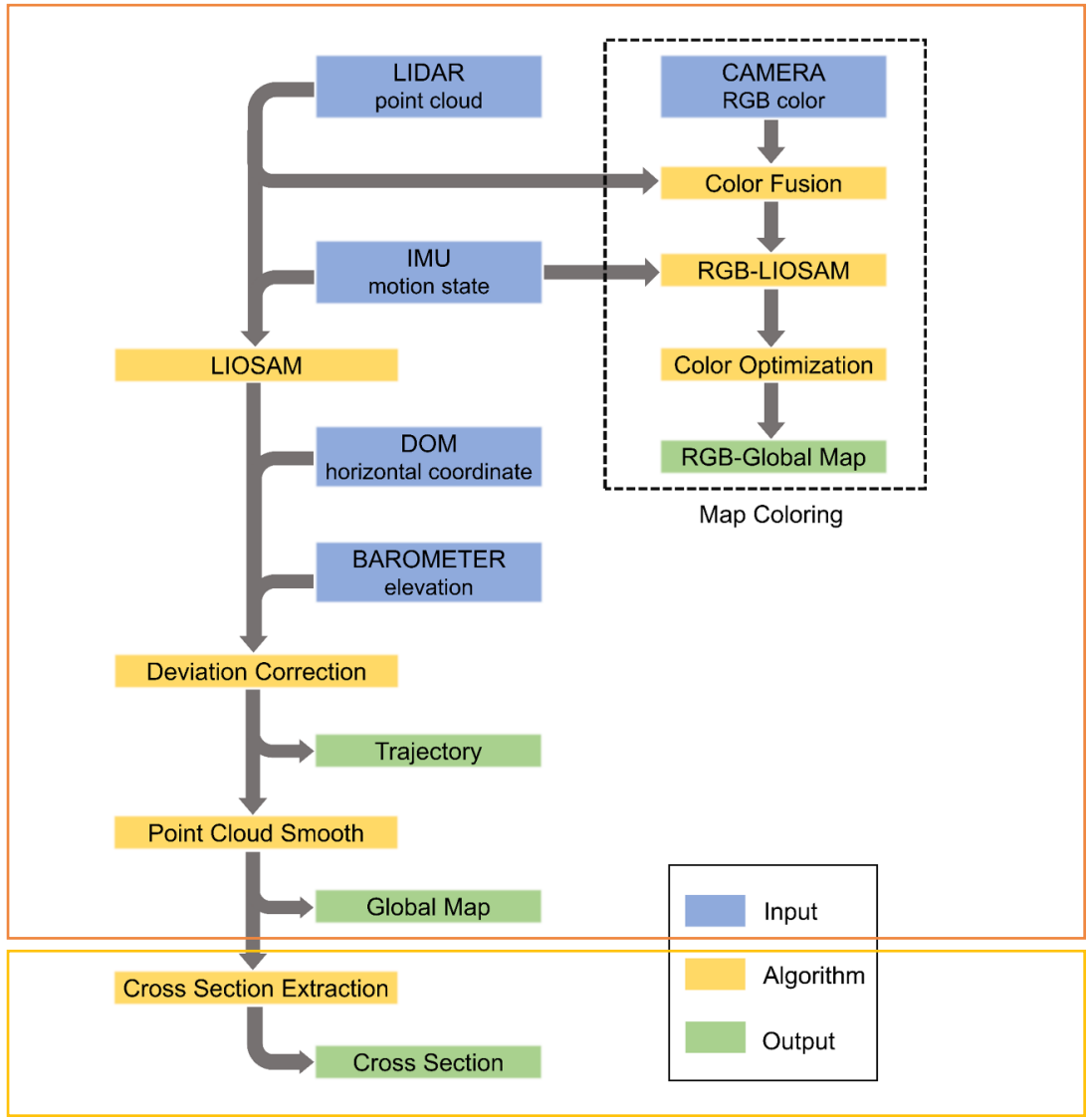
CAMERA
Intel RealSense D415

COMPUTER
Intel NUC10FNH

Algorithm

Debris flow channel mapping

Channel information extraction



Algorithm

Debris flow channel mapping

Deviation correction

$$f_h = L_h/\Delta L_h \quad (1)$$

$$f_e = L_e/\Delta L_e \quad (2)$$

$$T' = \hat{L}\left(\hat{f}[T]\right) \quad (3)$$

$$t''_j = t'_j \cdot \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad (4)$$

$$\check{t}_i = t_i \cdot \begin{bmatrix} f_h & 0 & 0 \\ 0 & f_h & 0 \\ 0 & 0 & f_e \end{bmatrix} \quad (5)$$

$$\check{t}'_j = t'_j \cdot \begin{bmatrix} f_h & 0 & 0 \\ 0 & f_h & 0 \\ 0 & 0 & f_e \end{bmatrix} \quad (6)$$

$$\check{t}''_j = t''_j \cdot \begin{bmatrix} f_h & 0 & 0 \\ 0 & f_h & 0 \\ 0 & 0 & f_e \end{bmatrix} \quad (7)$$

$$\boldsymbol{A_j} = \check{t}'_j - t'_j \quad (8)$$

$$\check{u}_{jm} = u_{jm} - \boldsymbol{A_j} \quad (9)$$

$$\check{G} = \{\check{U}_1, \check{U}_2, \check{U}_3, \cdots, \check{U}_j, \cdots, \check{U}_J\} \quad (10)$$

Point cloud smoothing

$$\rho_k = 1/V_k = 1/\left\{(4/3)\pi \bar{r}_k{}^3\right\} = 3/\left(4\pi \bar{r}_k{}^3\right) \quad (1)$$

$$p_k = \left(\sum_{l=k-N}^{k+N} \rho_l \check{g}_l\right) \Big/ \left(\sum_{l=k-N}^{k+N} \rho_l\right) \quad (2)$$

$$\check{G}' = \{\check{g}'_1, \check{g}'_2, \check{g}'_3, \cdots, \check{g}'_k, \cdots, \check{g}'_K\} = \{p_1, p_2, p_3, \cdots, p_k, \cdots, p_K\} = \hat{w}[\check{G}] \quad (3)$$

Color optimization

If $\boldsymbol{color|c_i| = blank\ value}$

  Find the nearest neighbor of $\boldsymbol{c_i}$ on $\boldsymbol{K_3}$

  If $\boldsymbol{distance\ between\ c_i\ and\ its\ neighbor \leq value\ near\ enough}$

    $\boldsymbol{color|c_i| \leftarrow color\ value\ of\ the\ neighbor}$

    Add $\boldsymbol{c_i}$ to $\boldsymbol{C''}$

  End if

Else

  Add $\boldsymbol{c_i}$ to $\boldsymbol{C''}$

End if

Channel information extraction

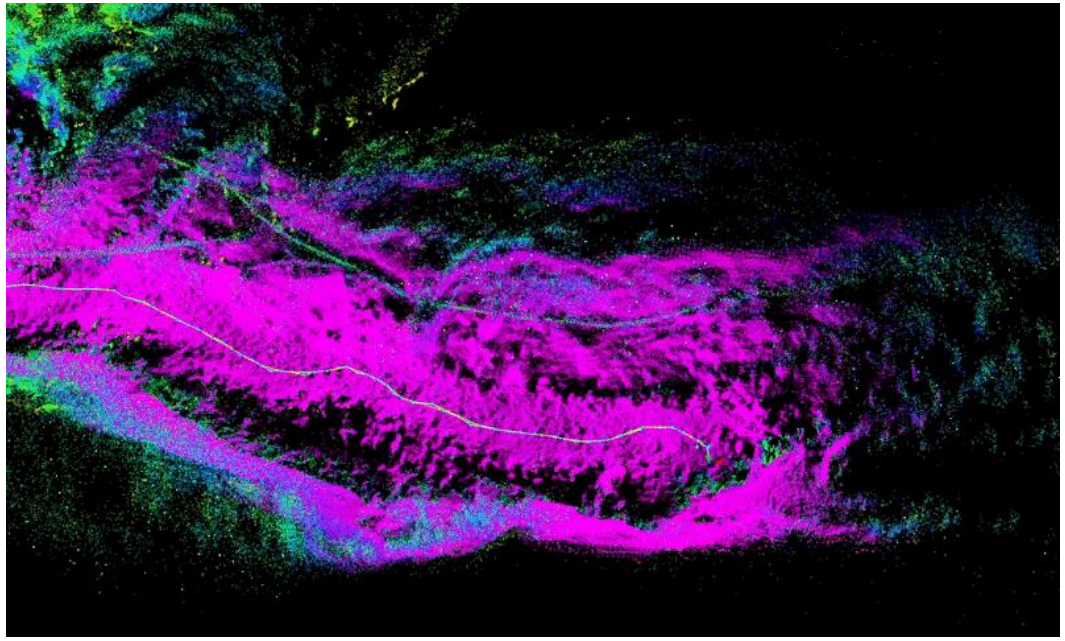
Terrain extraction

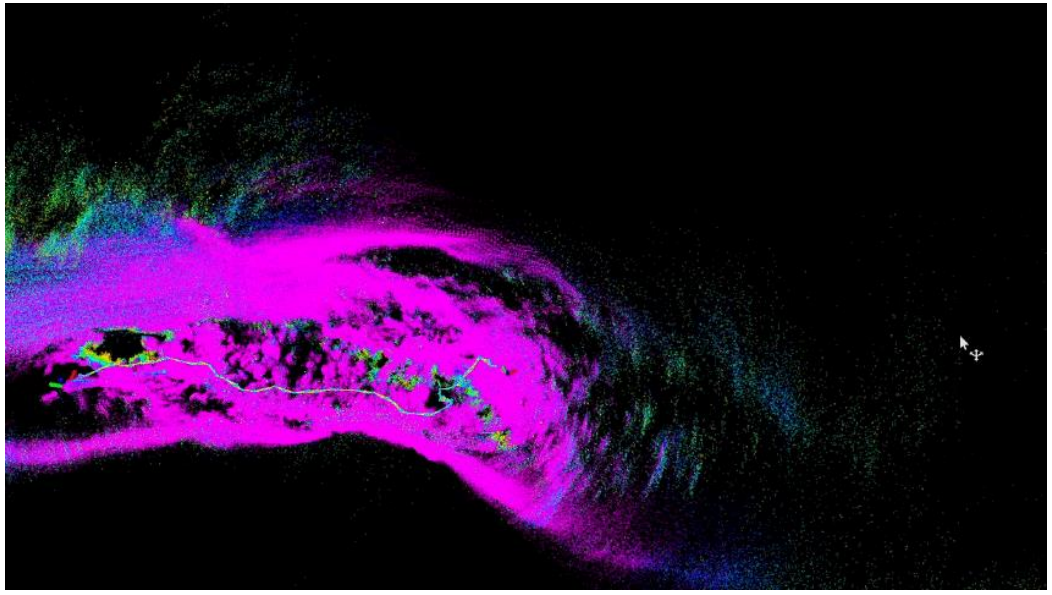
$$\check{u}''_{jm} = \check{u}'_{jm} - \alpha\left(\check{t}''_{j+a} - \check{t}''_{j-a}\right) \quad (1)$$

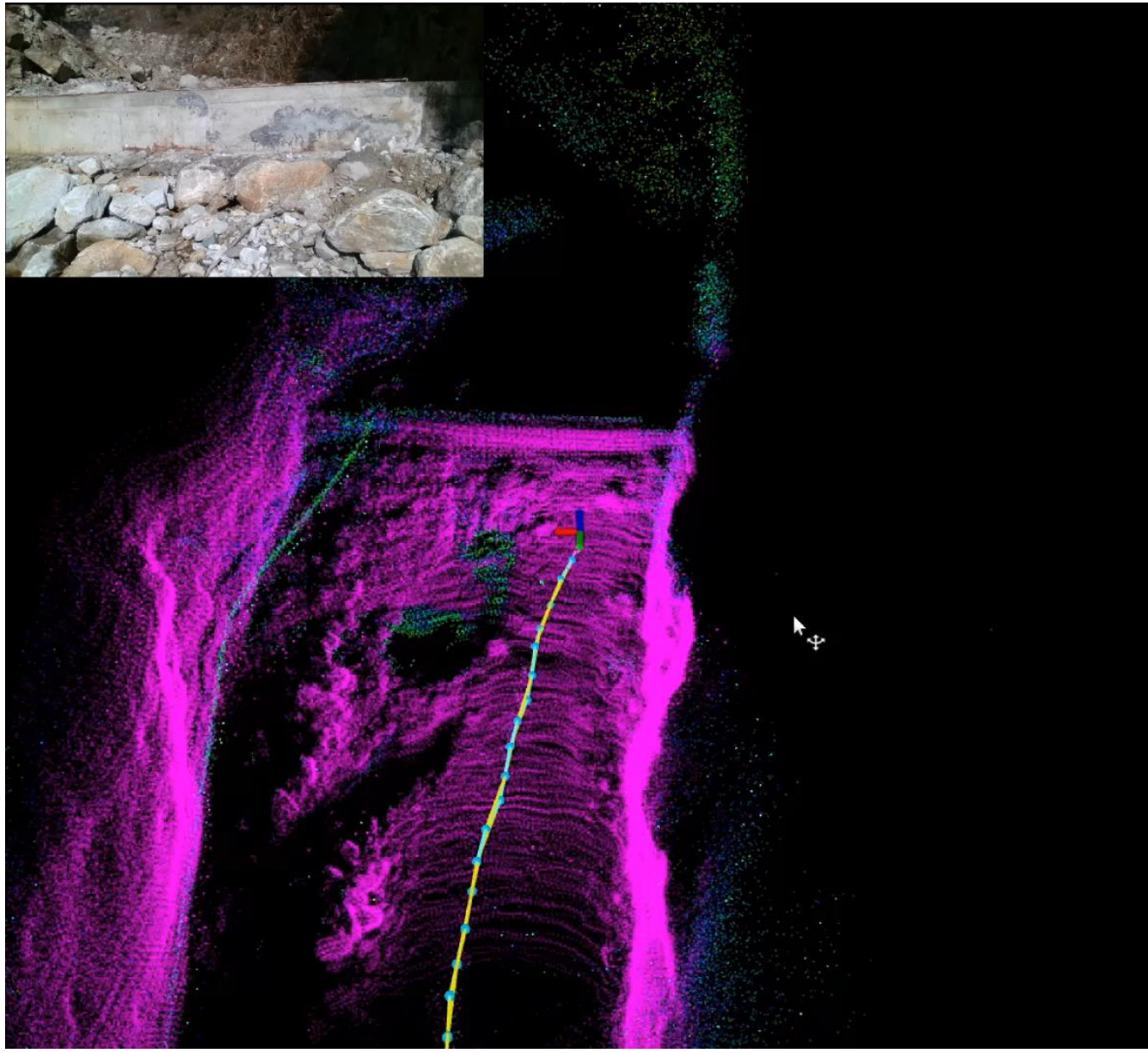
$$\alpha = \left(\check{u}'_{jm} - \check{t}''_j\right)\left(\check{t}''_{j+a} - \check{t}''_{j-a}\right)^T / \left\|\check{t}''_{j+a} - \check{t}''_{j-a}\right\| \quad (2)$$

$$\check{U}'''_j = \hat{L}\left(sort\left|\hat{w}\left[\check{U}''_j\right]\right|\right) \quad (3)$$

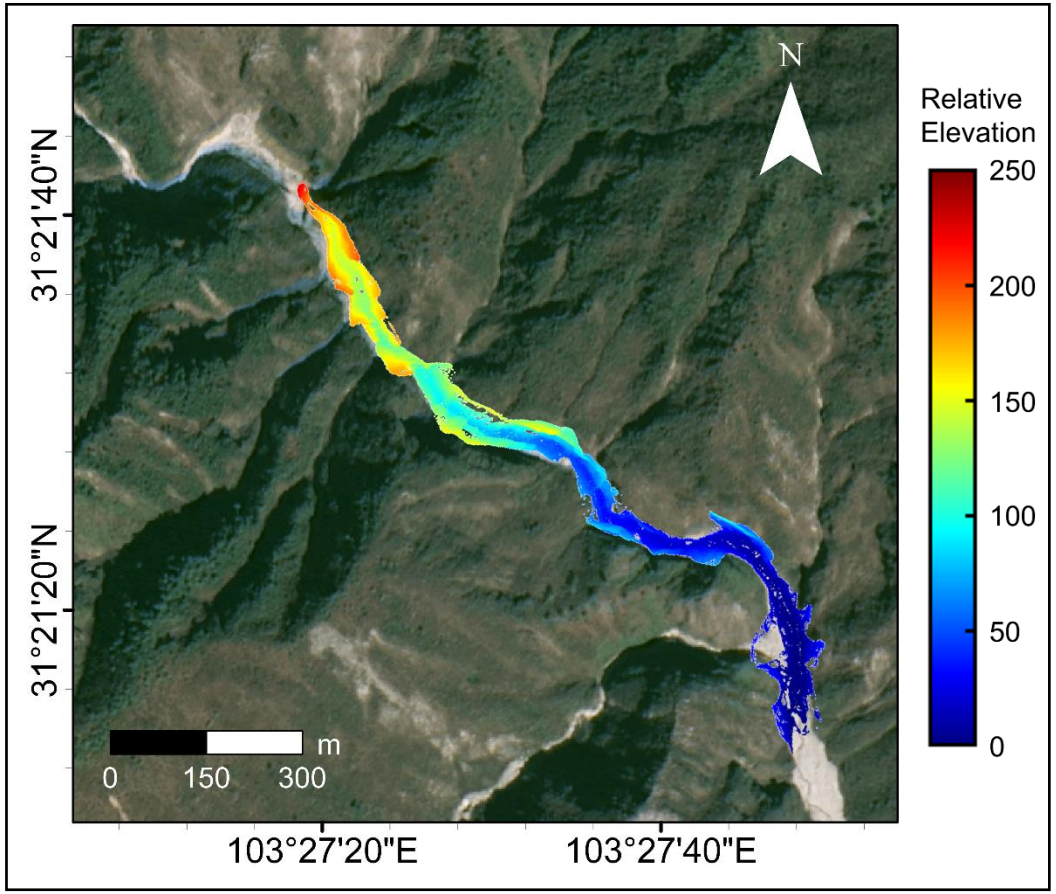
Calculation process



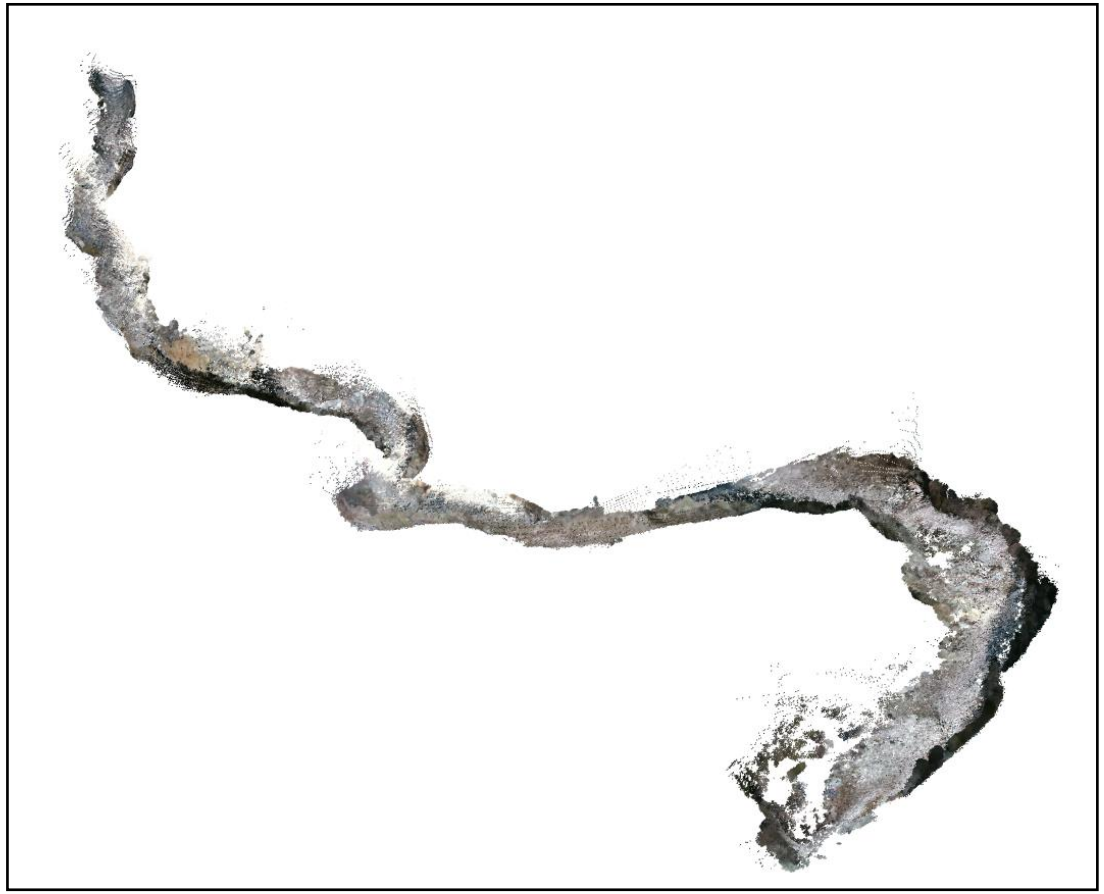




Results

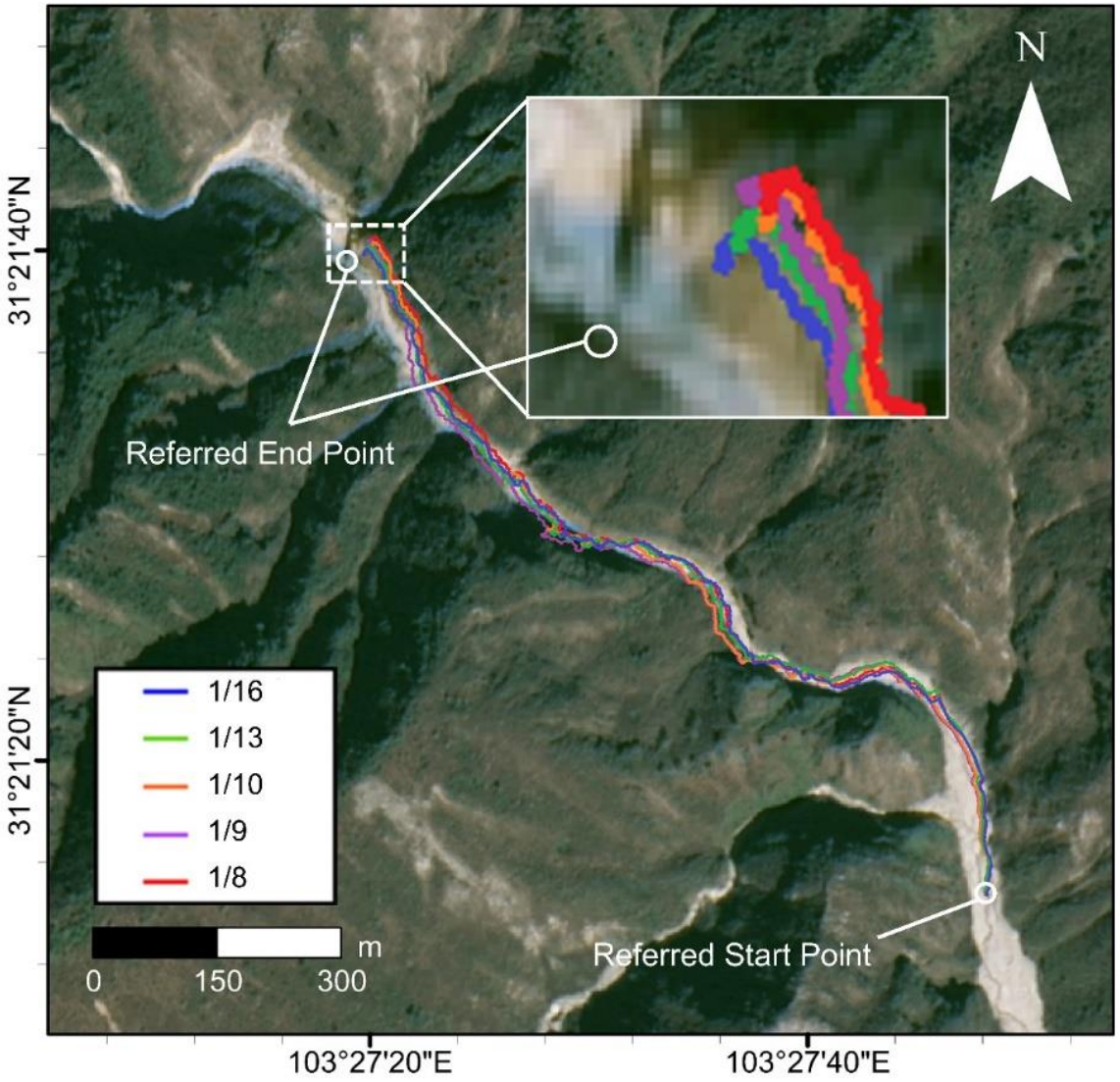


Projection on DOM



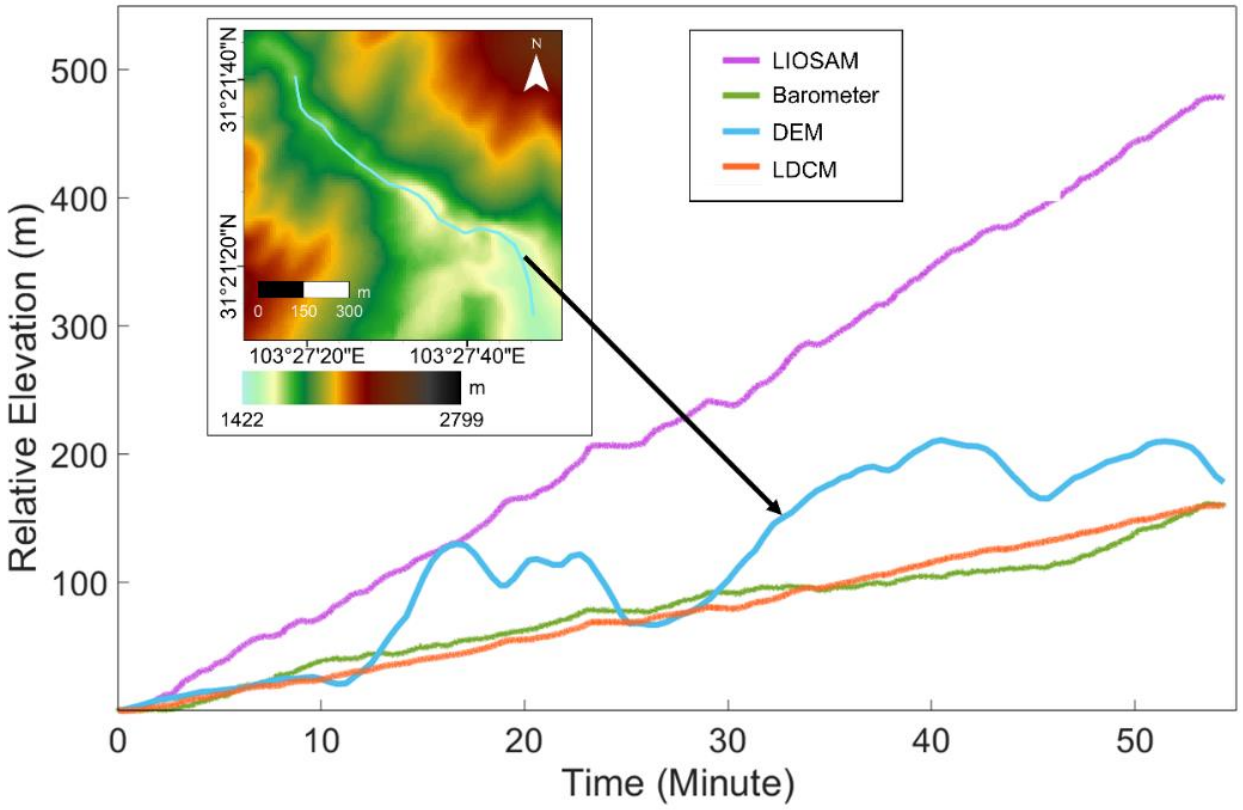
RGB Global Map

Horizontal error



Down-sample Rate	End-point Bias (m)	Displacement Error (%)	Distance Error (%)
1/16	28.66	2.63	2.43
1/13	39.97	3.67	3.39
1/10	41.89	3.84	3.55
1/9	50.91	4.67	4.31
1/8	50.54	4.64	4.28

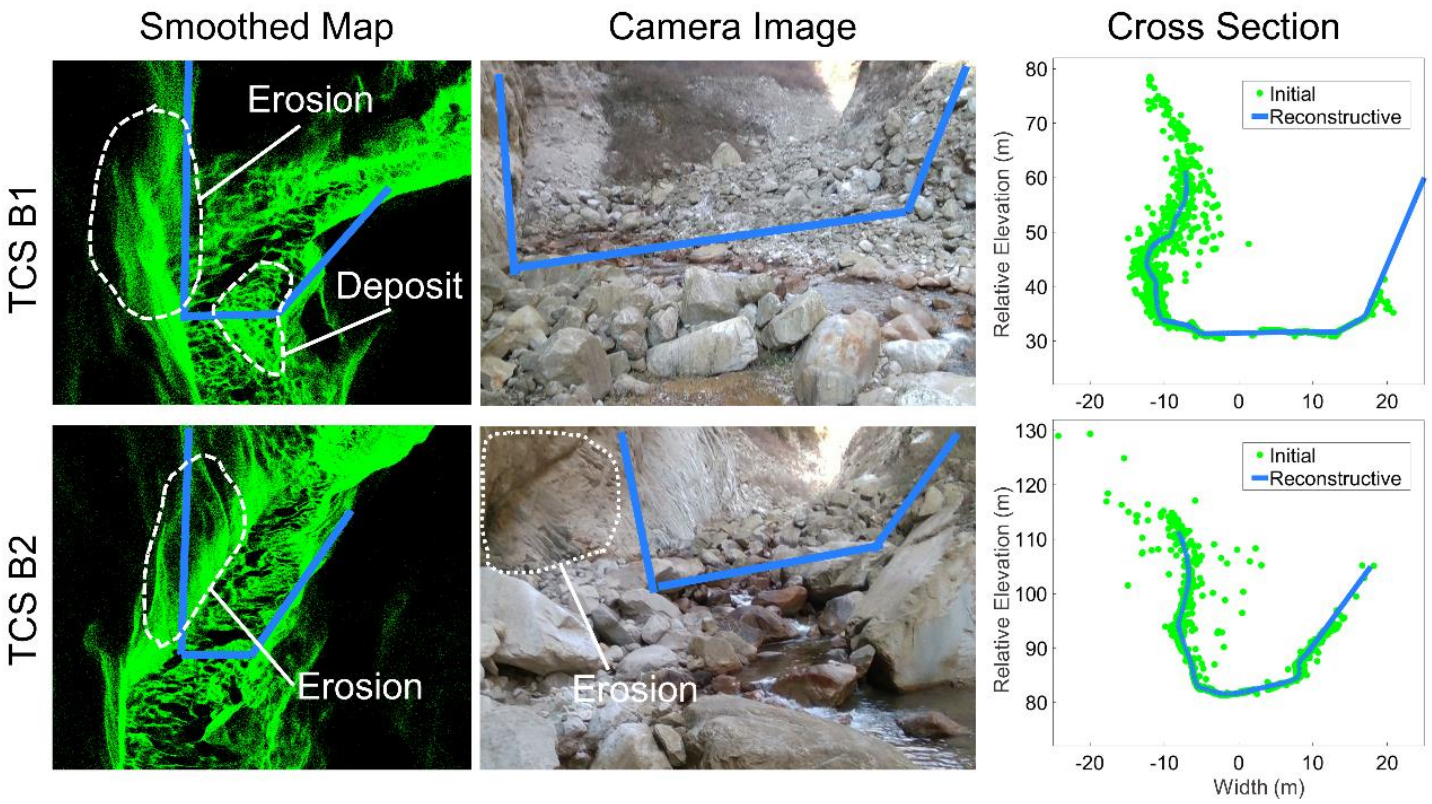
Elevation error



Benchmark: Barometer	LIOSAM	Proposed (LDCM)	DEM (Satellite)
Average Bias (m)	152.76	-0.48	39.25
RMSE (m)	182.43	8.65	46.91

Note: Barometer is taken as benchmark

Channel interior: Morphological characteristics



Challenges solved:

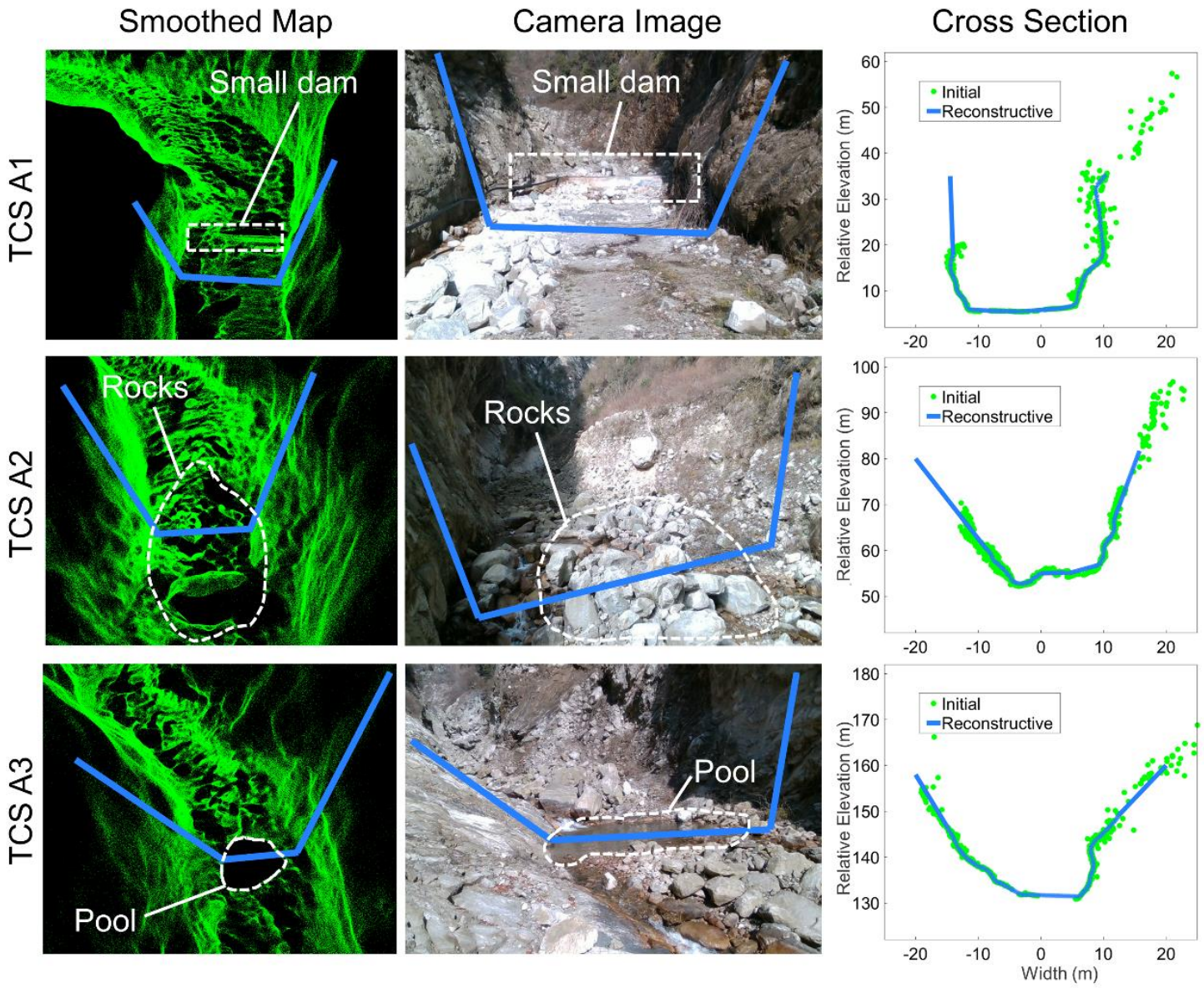
Overhanging cliff ✓

Narrow channel bed

Deposit distribution

Lateral erosion

Channel interior: Morphological characteristics



Challenges solved:

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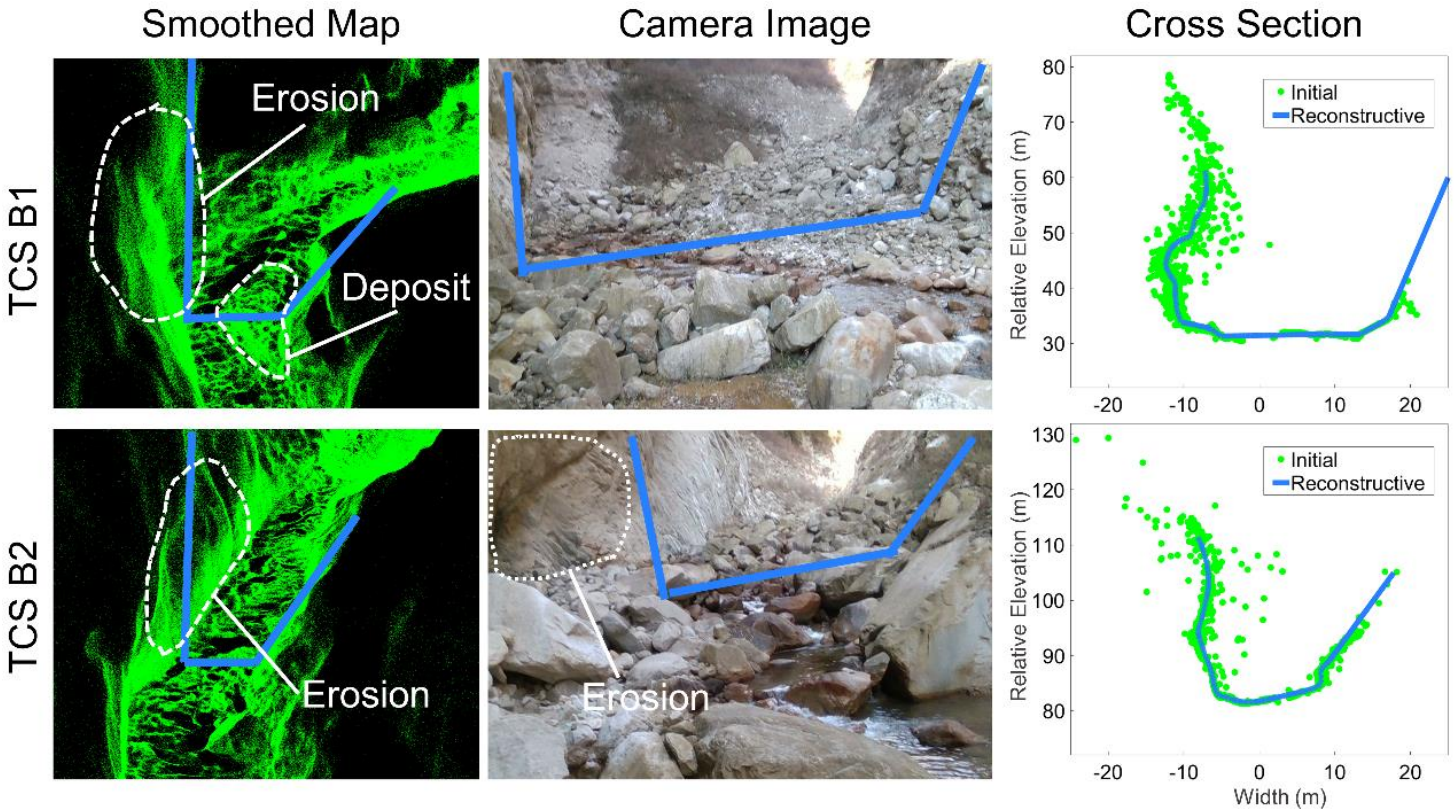
Deposit distribution

Lateral erosion

Channel interior: Deposit characterization



Challenges solved:

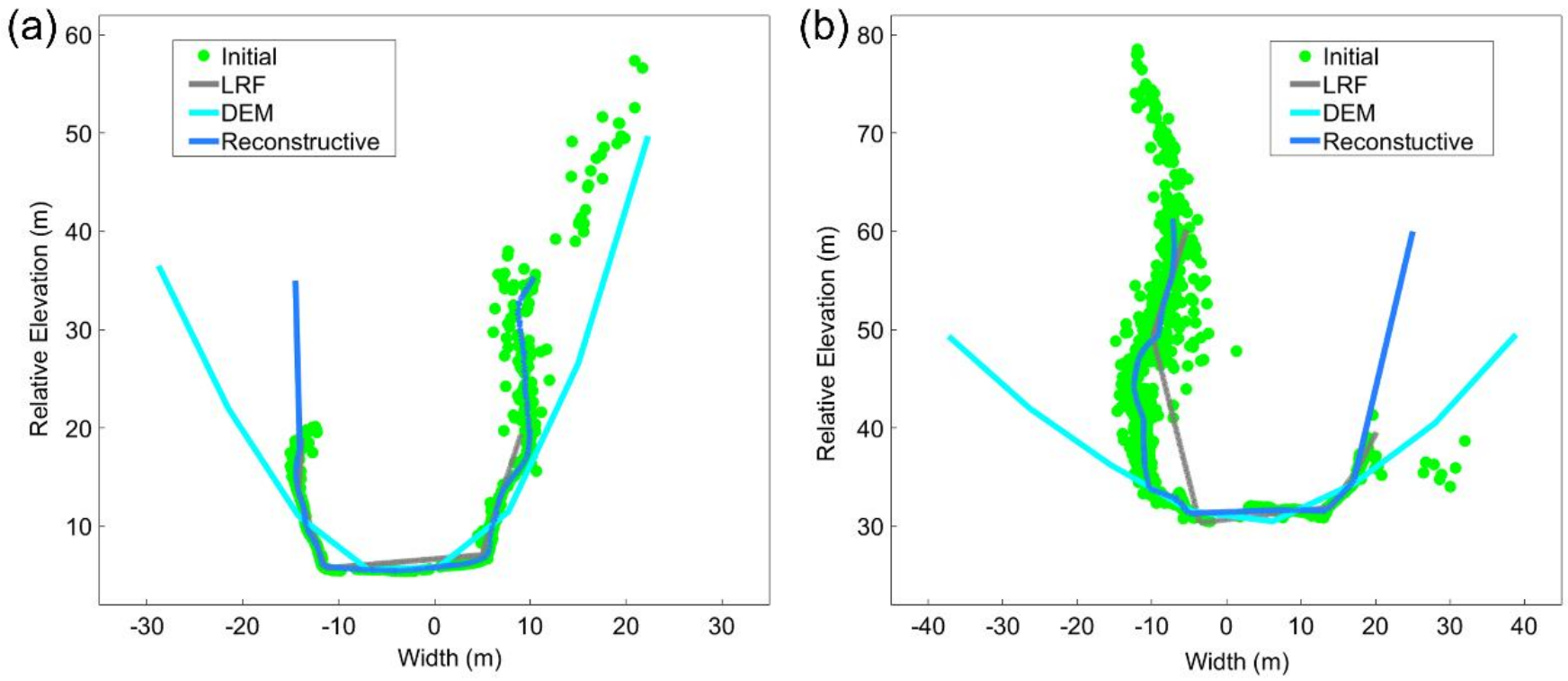
Overhanging cliff ✓

Narrow channel bed ✓

Deposit distribution ✓

Lateral erosion ✓

Channel interior: Comparison of cross section data



Note

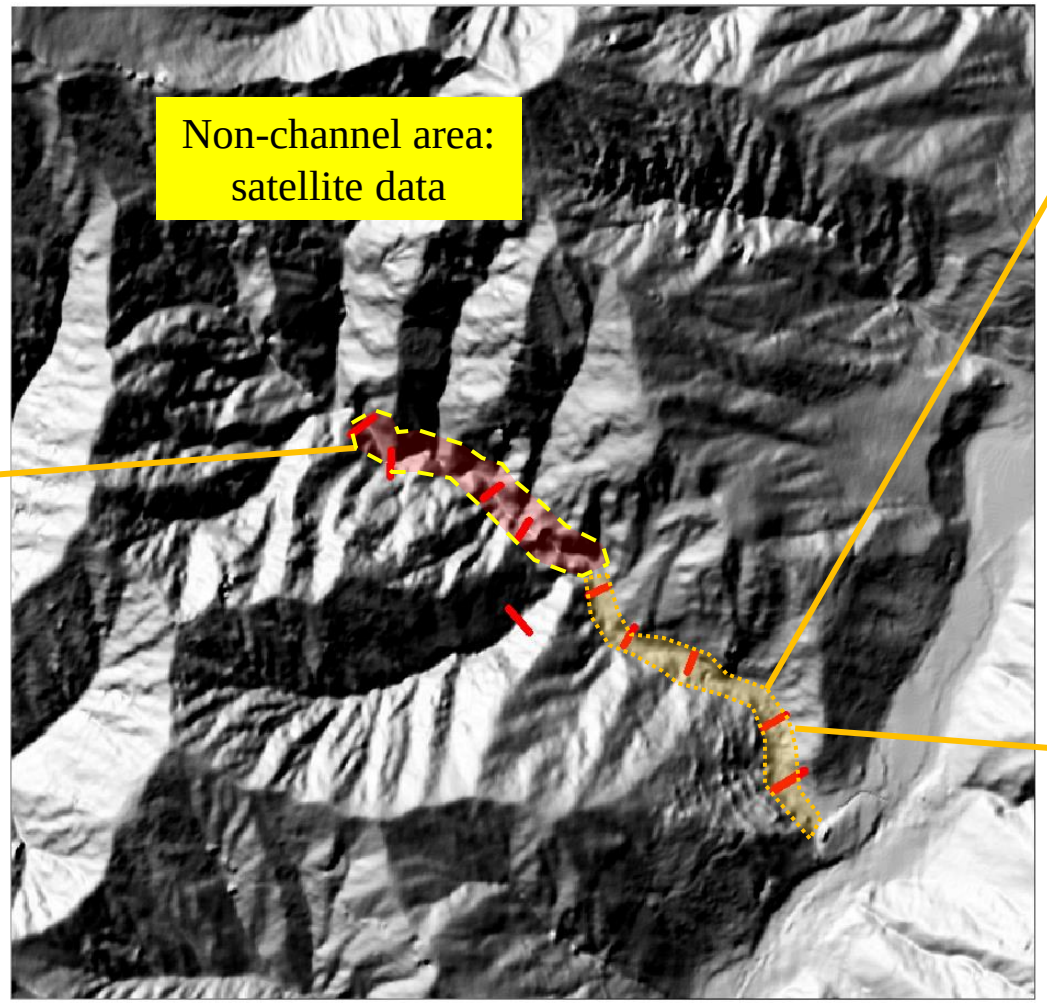
DEM: Satellite-derived DEM

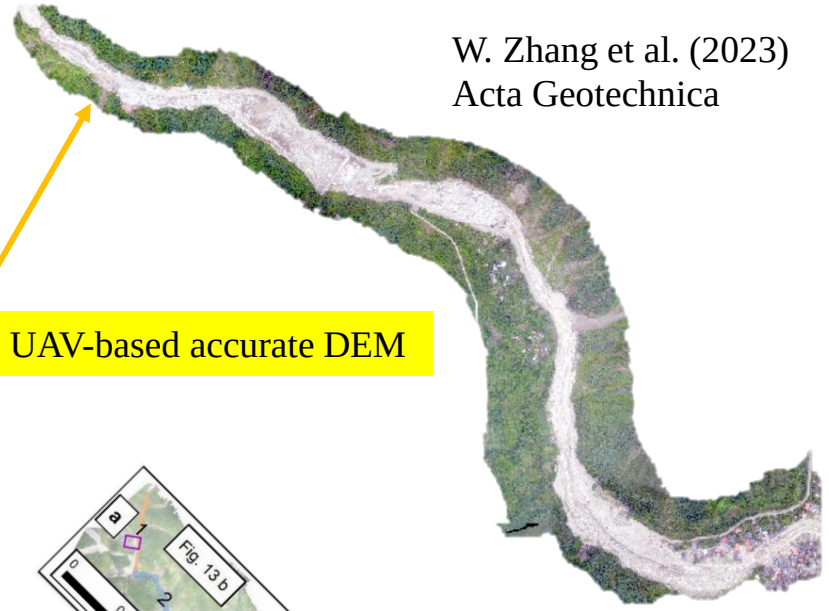
Initial: LIOSAM

LRF: Laser Range Finder on foot

Imperative supplement for existing techniques

LDCM-derived accurate map





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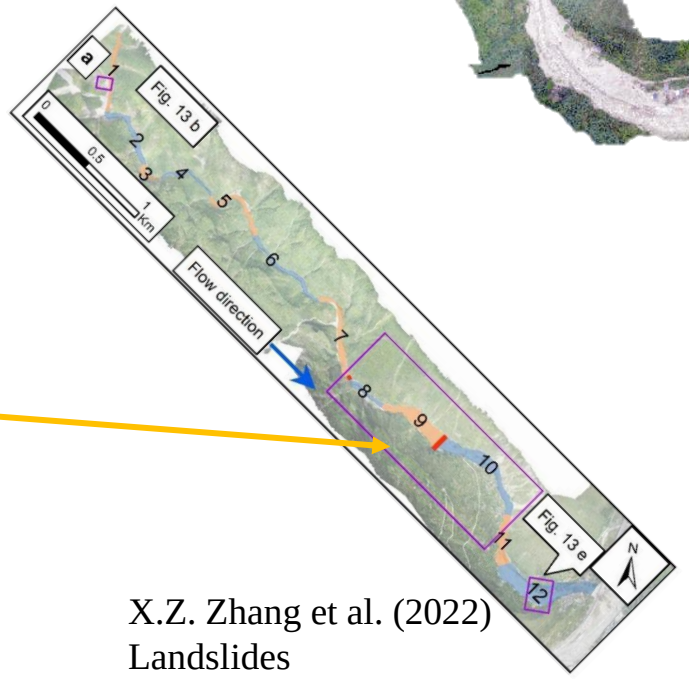
UAV-based accurate DEM



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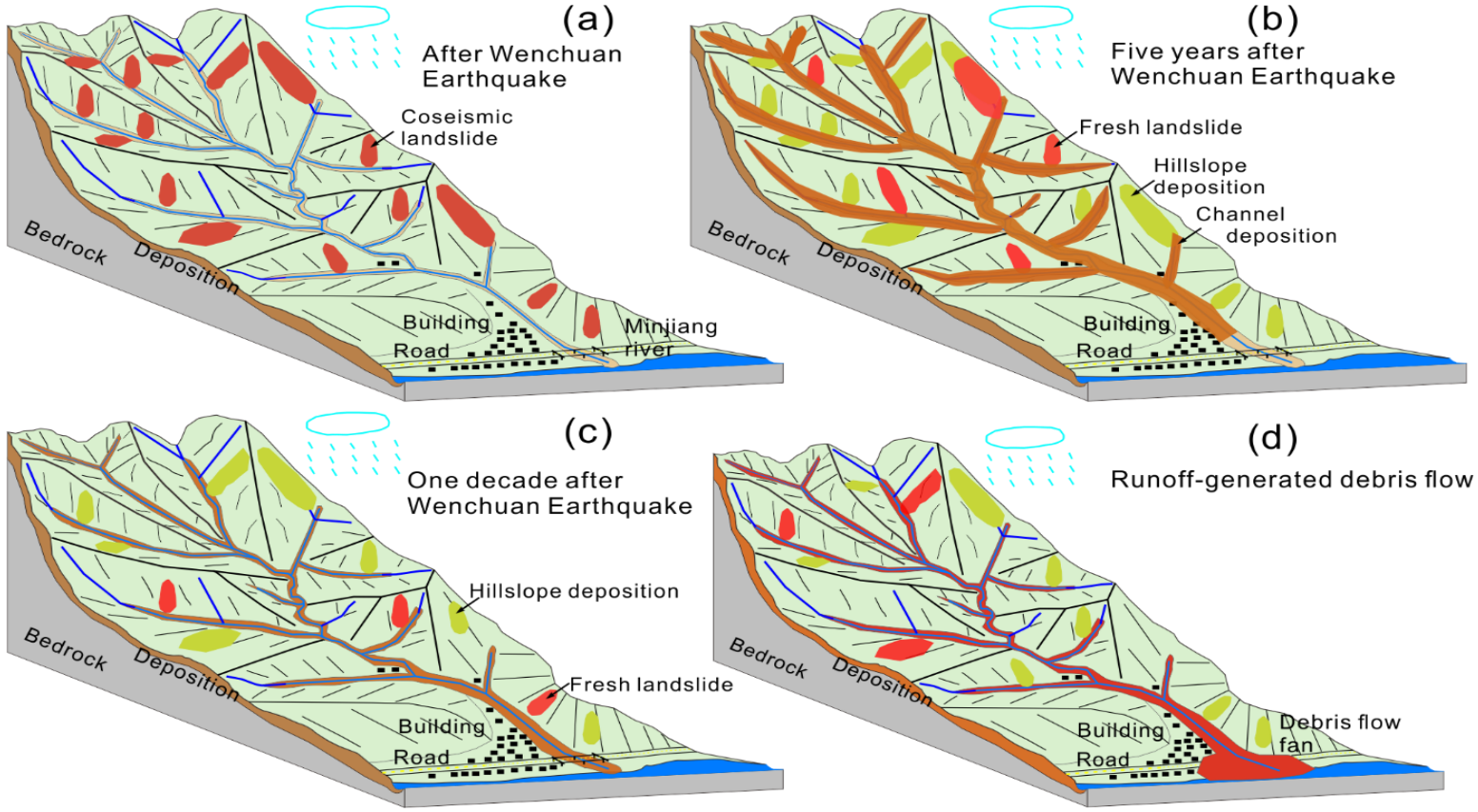
Significance for channelized debris flow research

- Post-seismic evolution
- Initiation mechanisms
- Numerical modelling
- Precise risk assessment
- Precise risk mitigation



Limitations

- Reach of manpower
- More data for correction

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Welcome to any discussion and collaboration!