Morphohydraulics
Research Group

Forward and inverse computational morphology of debris and alluvial fans

Yuan-Hung Chiu[1], Tzu-Yin Kasha Chen[2], Chi-Yao Hung[3] and Hervé Capart[1]

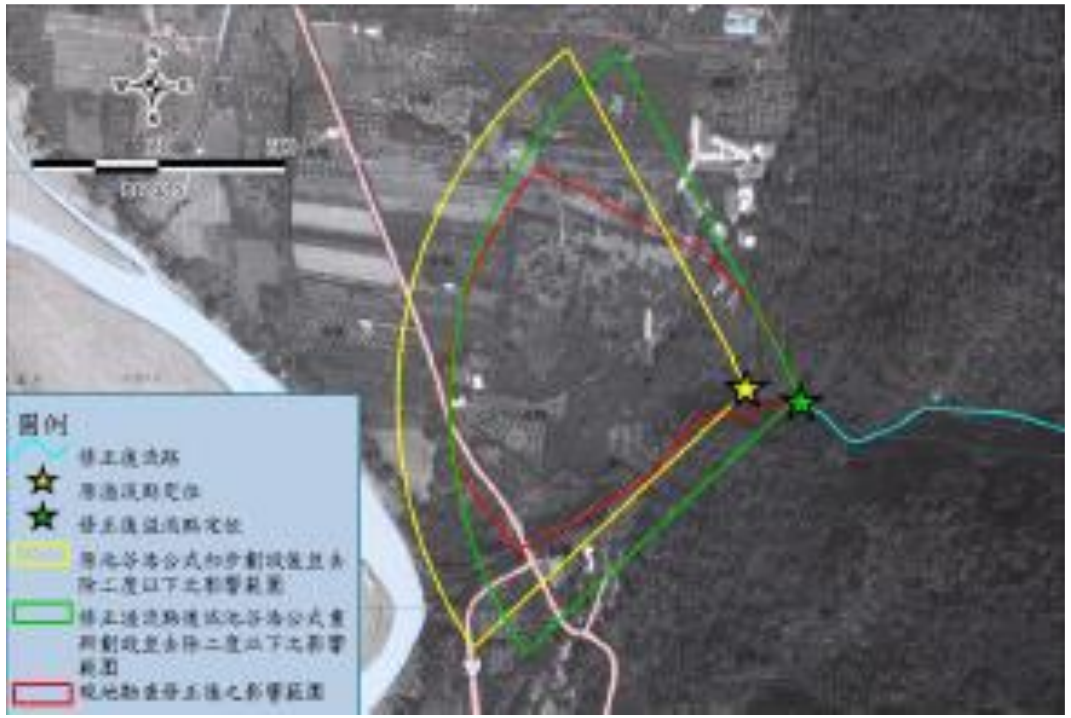
1 Dept of Civil Engineering and Hydrotech Research Institute, National Taiwan University

2 School of Environmental Science & Geography, Simon Fraser University

3 Dept of Soil and Water Conservation, National Chung Hsing University

土石流潛勢溪流影響範圍劃設





資料來源：土石流潛勢溪流劃設作業手冊(2013)

六龜新發村土石流（2009）



資料來源：齊柏林

土石流潛勢溪流影響範圍劃設－FLO-2D, Debris-2D

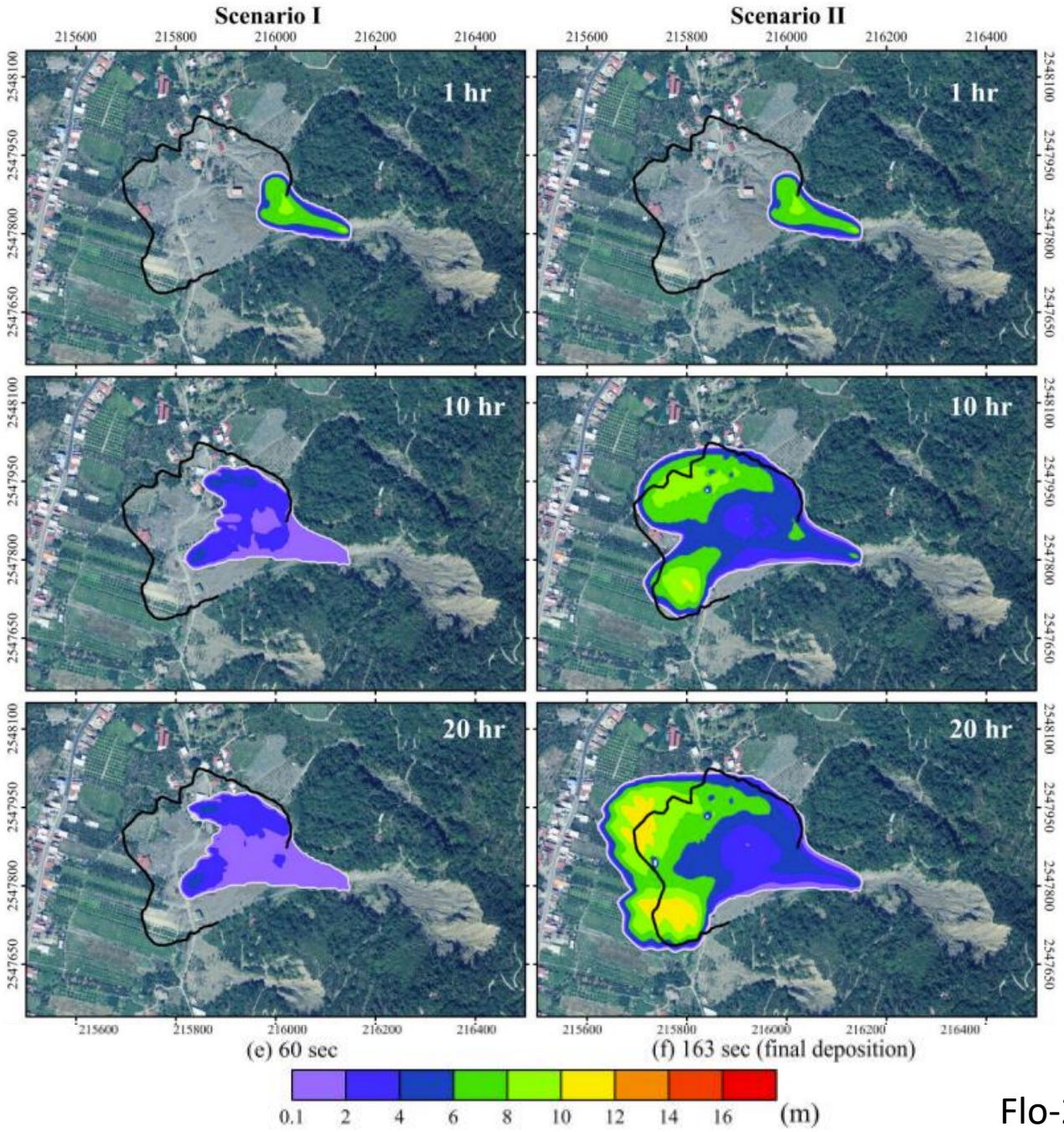
Table 2 Input data of FLO-2D and Debris-2D for Xinfa village case study

Attribute		FLO-2D	Debris-2D
Category	Item		
Topography	DEM resolution	5m × 5m	
	Manning's n value†	n=0.03 for riverbed n=0.1 for farm land n=0.04 for road & artificial surfaces	Not required
Parameters input	C_v	0.603	
	Yield stress (Pa)	α_2=0.0723 and β_2=20 for Equation (7)	τ_0=1,250
	Viscosity	α_1=0.05 and β_1=20 for Equation (8)	Not required
	Resistance parameter K	2,000	Not required
	Specific weight (kg/m^3)	2,650	
	Simulation time	40 hours	Not required
Debris flow input	Initial mass distribution	Not required	Figure 6a
	Water discharge hydrograph	see Scenario I and II in Figure 5	Not required

Note: DEM=digital elevation model; C_v=Volume concentration (%); †reference: FLO-2D Software, Inc. 2006

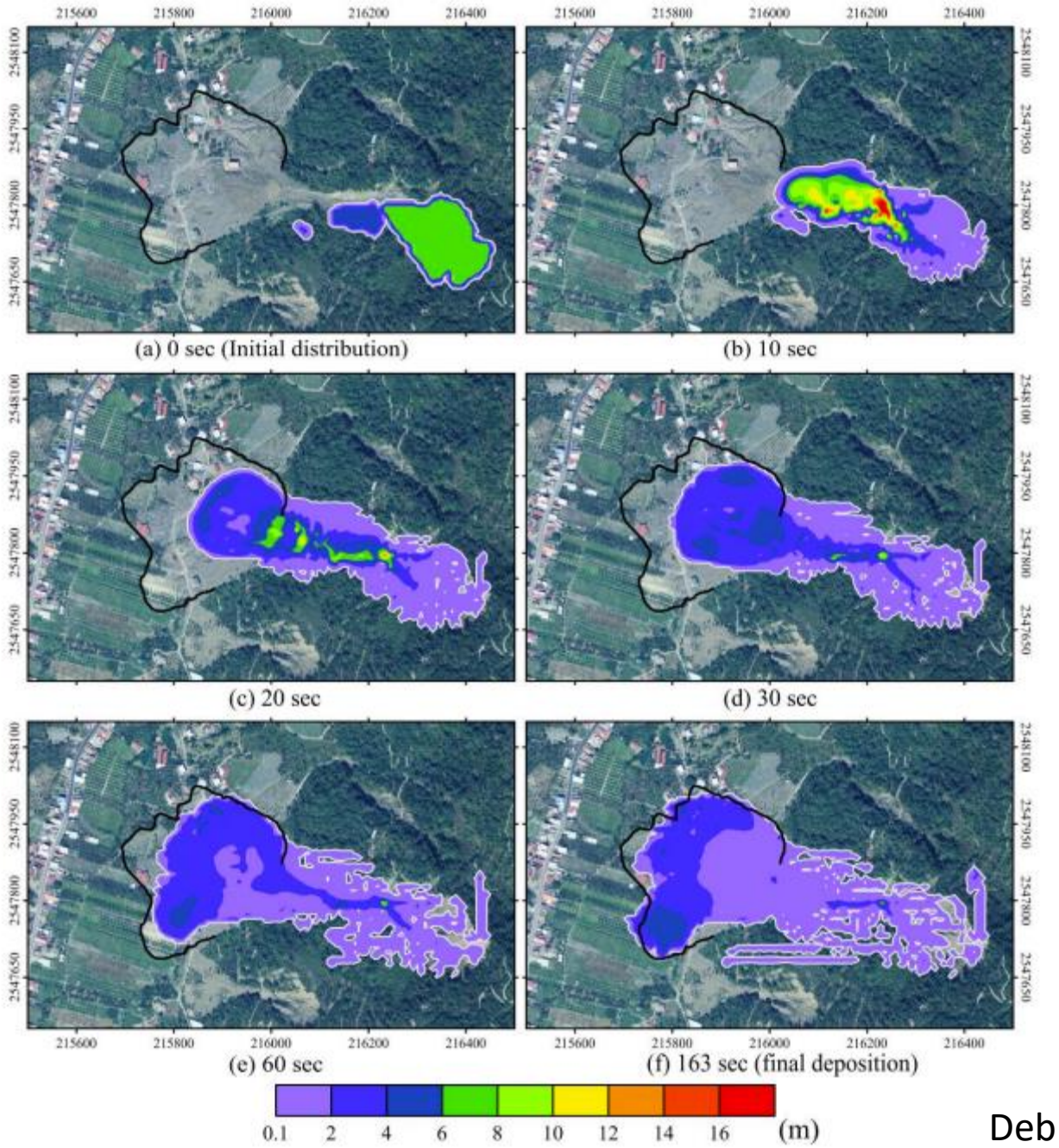
Flo-2D and Debris-2D models (Wu et al. 2012)

FLO-2D



Flo-2D model (Wu et al. 2012)

Debris-2D



Debris 2D model (Wu et al. 2012)

Hyper KANAKO 2D

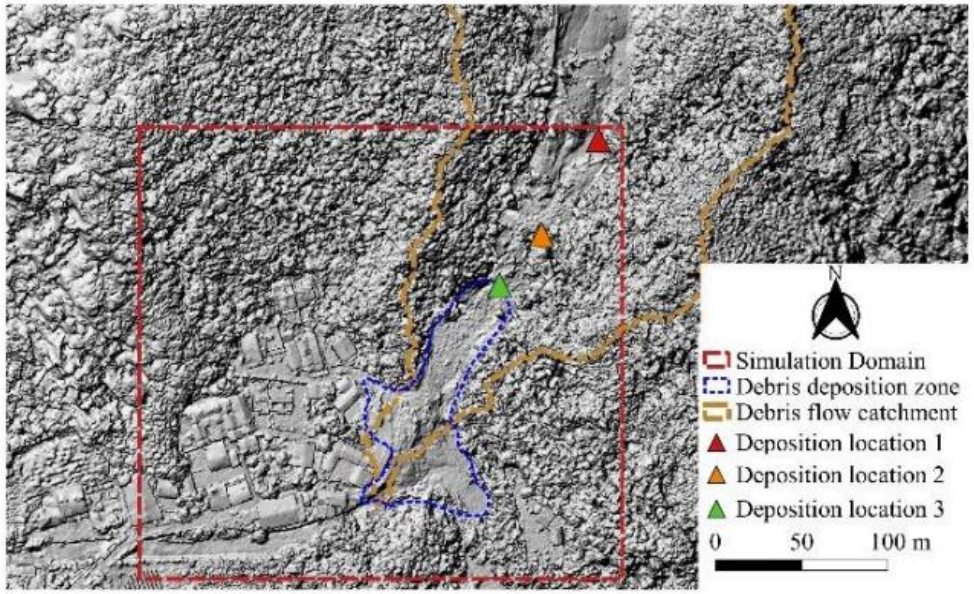
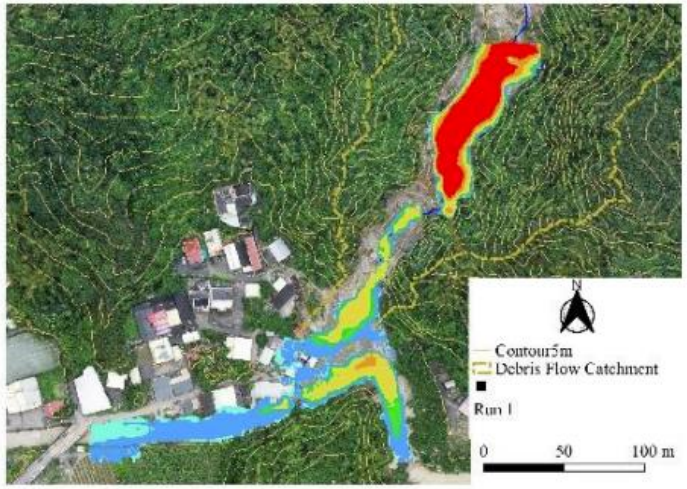
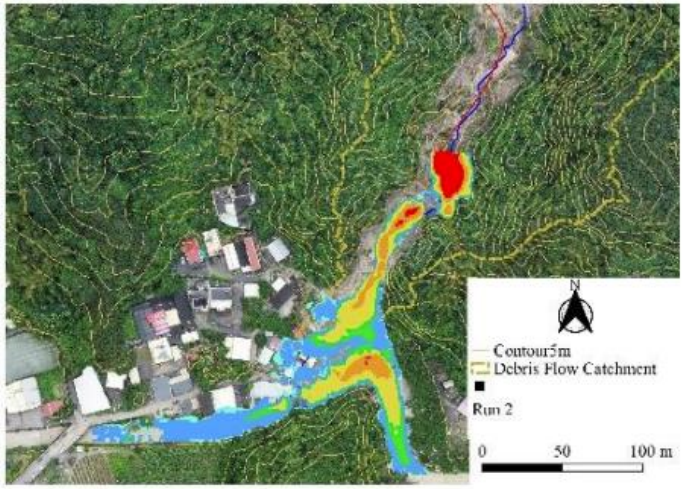
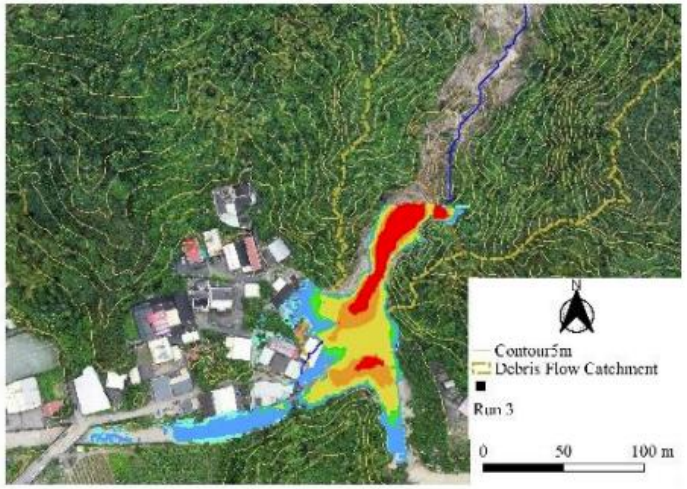


Table 1 Parameters of the simulation

Case Number	Deposition location	Water supply discharge	Model parameter		
		Q_p (m^3/s)	n	d	C
Run 1	Location 1	10	0.03	0.001	0.2
Run 2	Location 2	10	0.03	0.001	0.2
Run 3	Location 3	10	0.03	0.001	0.2
Note	Q_p: Peak discharge; d: Diameter of material(m); C: Concentration (-); n: Manning's roughness coefficient ($s/m^{1/3}$)				







Hyper KANAKO 2D model (Lin et al. 2020)

玉穗溪沖積扇－明霸克露橋(台20線94K+144)

Before
2021/08/07

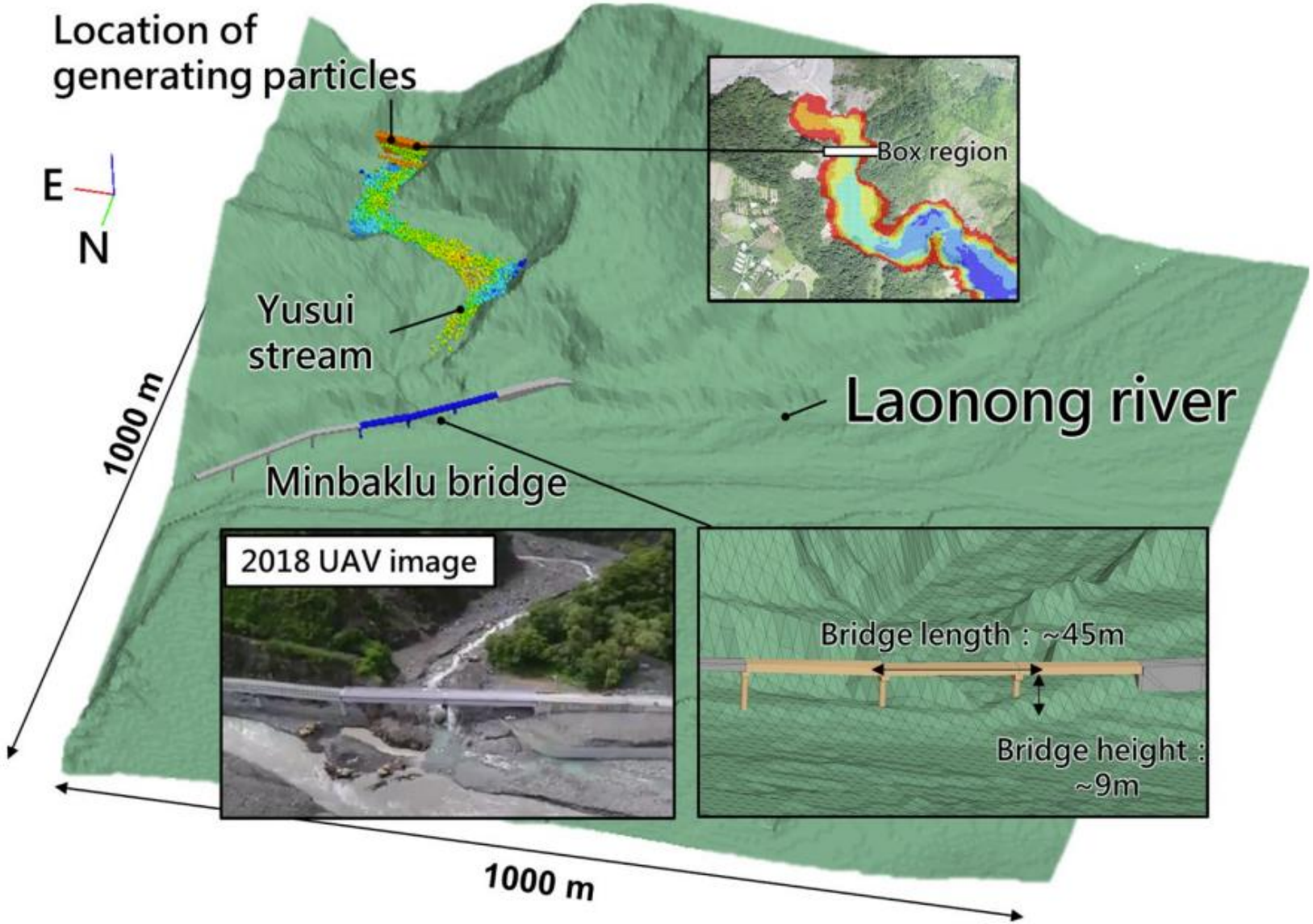


After
2021/08/07



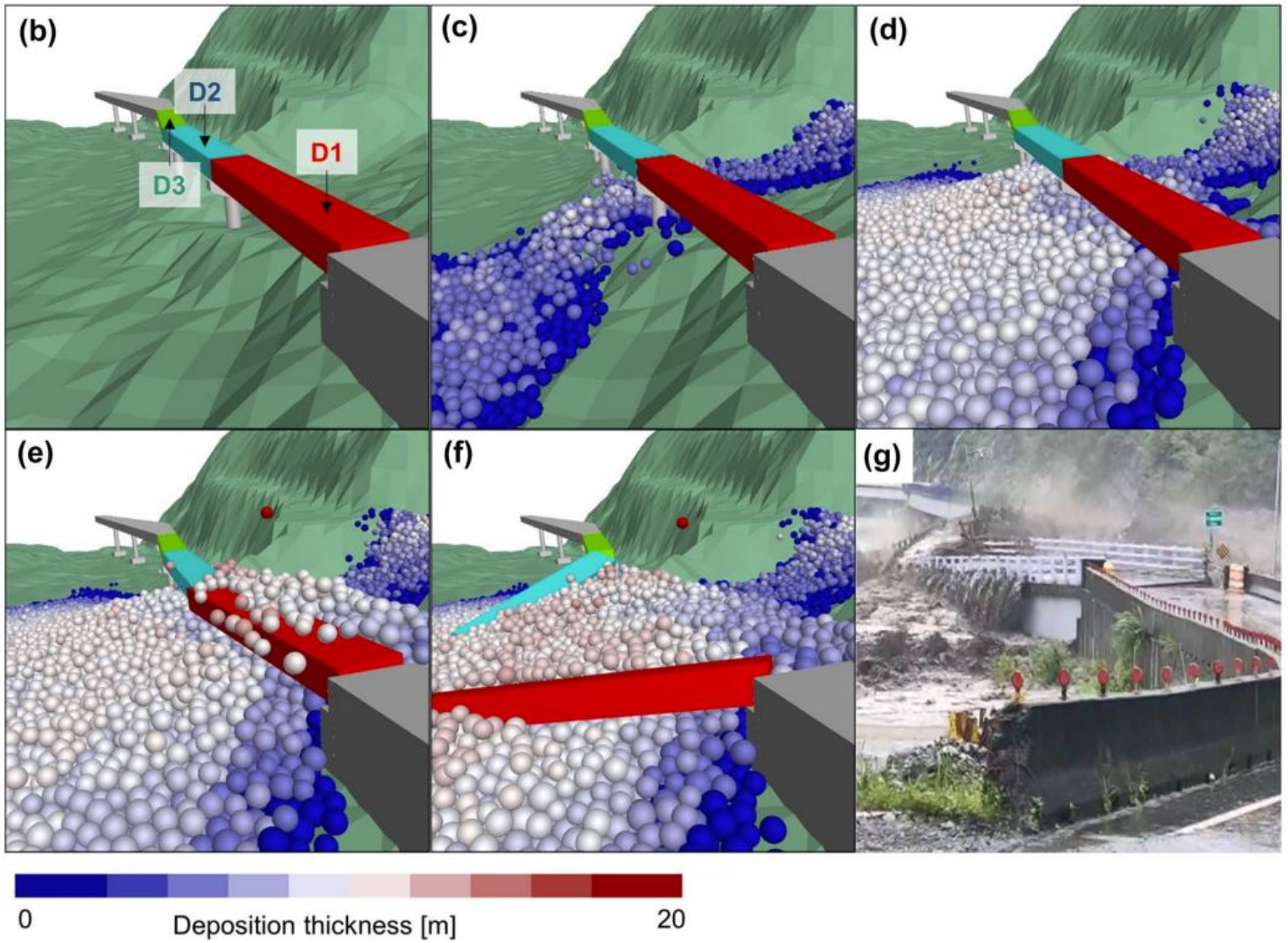
資料來源：公路總局／ 台灣世曦

Hybrid RAMMS-PFC



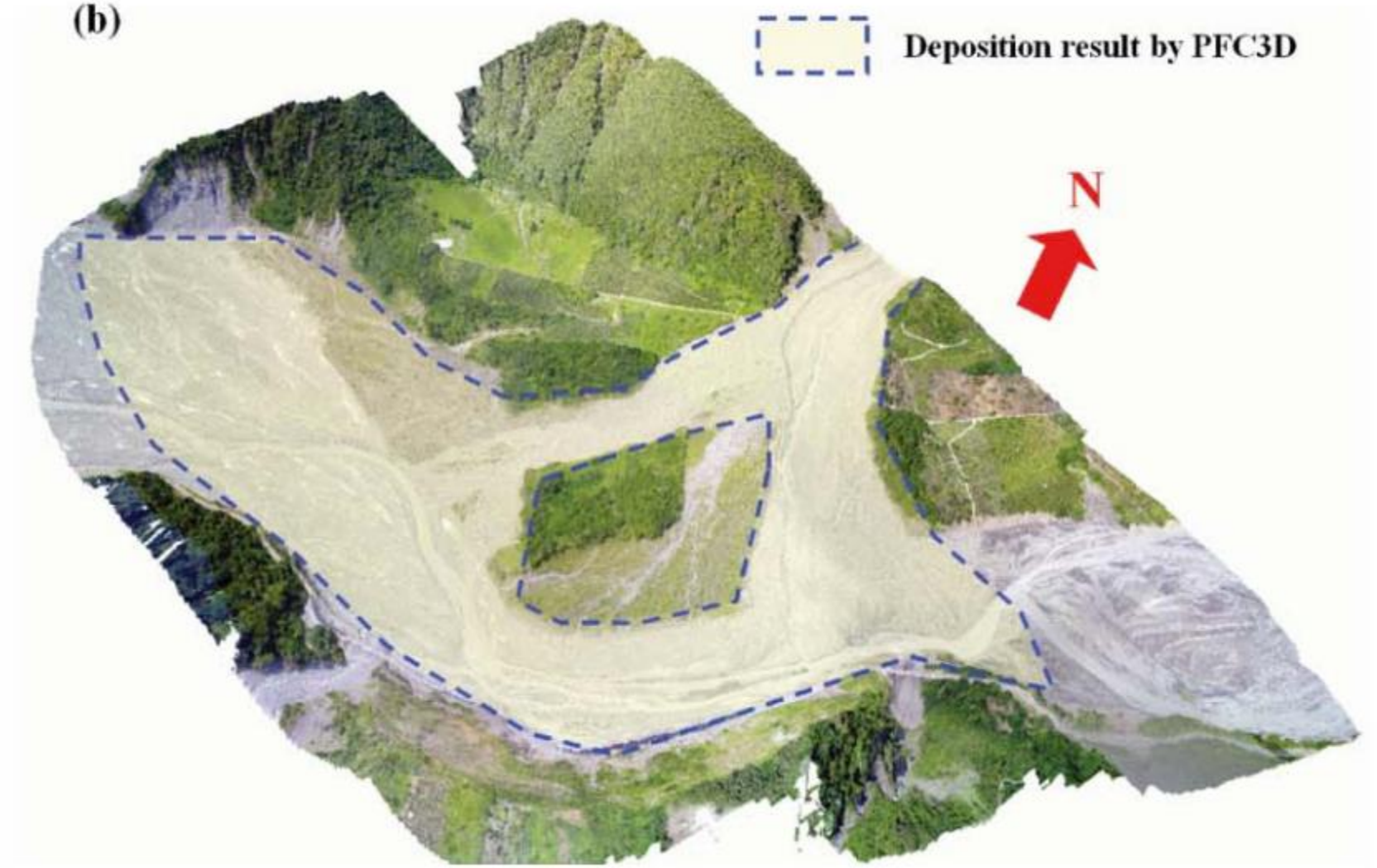
Hybrid RAMMS-PFC model (Shiu et al. 2023)

Hybrid RAMMS-PFC model



Hybrid RAMMS-PFC model (Shiu et al. 2023)

PFC3D model



PFC3D model (Lo et al. 2018)

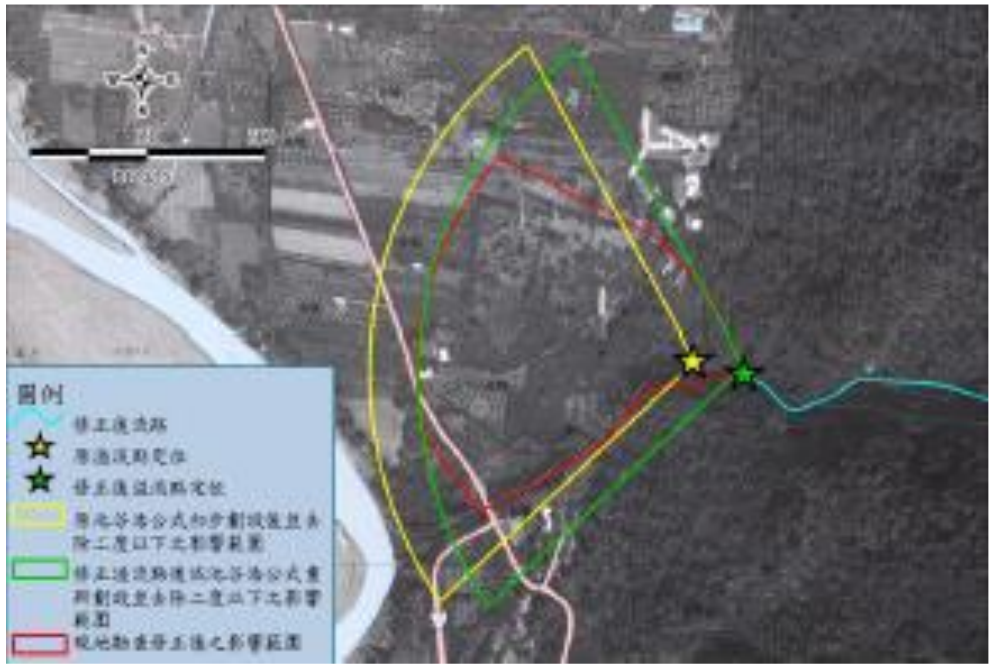
Geometric cone models of debris and alluvial fans

Advantages:

- Rapid delineation of at-risk area
- Simple empirical relations for the fan slope

Drawbacks:

- Poor use of detailed topographic data
- Poor accuracy



資料來源：土石流潛勢溪流劃設作業手冊(2013)

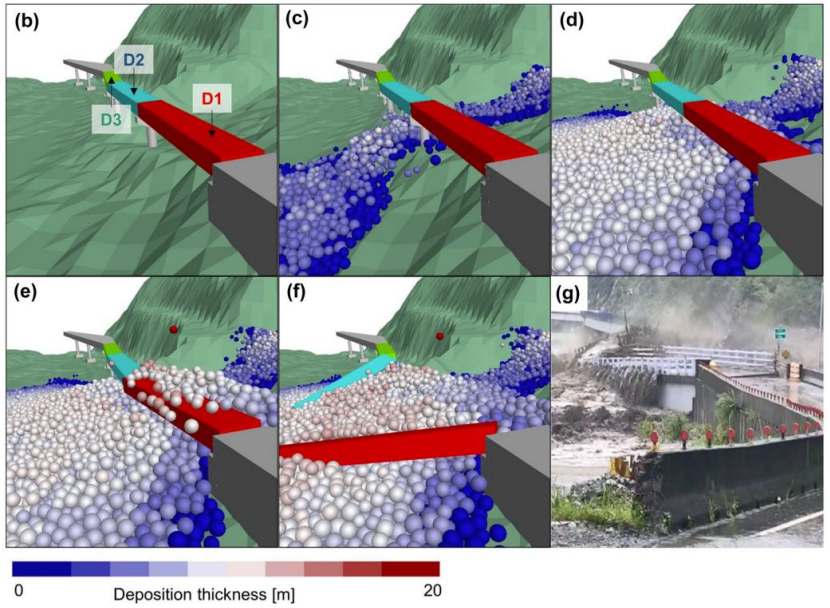
Flow models based on fluid and particle mechanics

Advantages:

- Detailed flow processes and material properties can be represented
- Good use of detailed topographic data

Drawbacks:

- Model parameters difficult to calibrate
- Long computation times



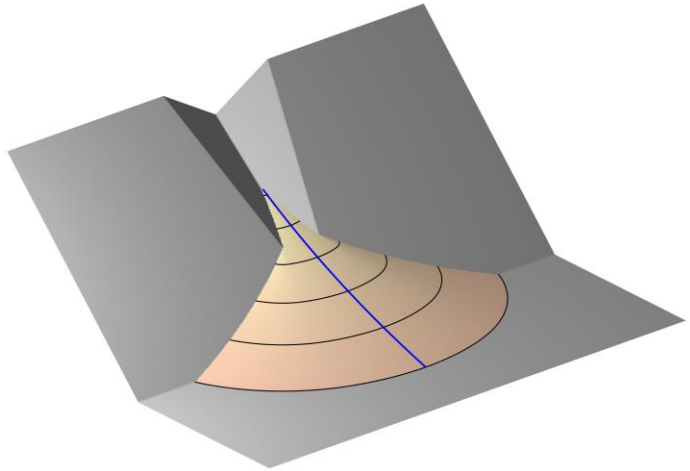
Hybrid RAMMS-PFC model (Shiu et al. 2023)

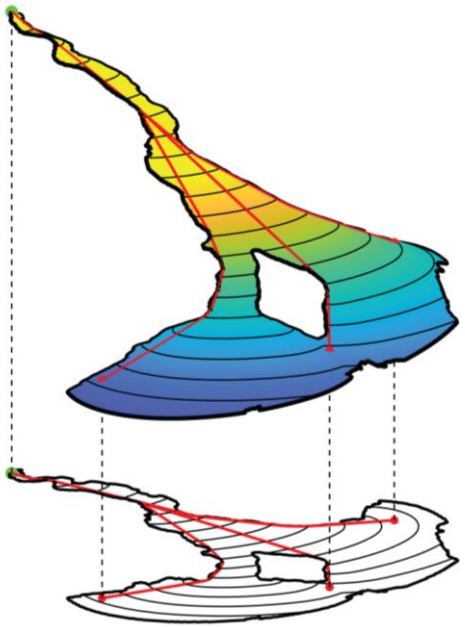
Goals of this research

- Develop a more accurate geometric model
- Easy to calibrate and apply using topographic data
- Fast computation of multiple scenarios

Outline

- Introduction
- Forward method
- Inverse method
- Application
- Conclusion and future work





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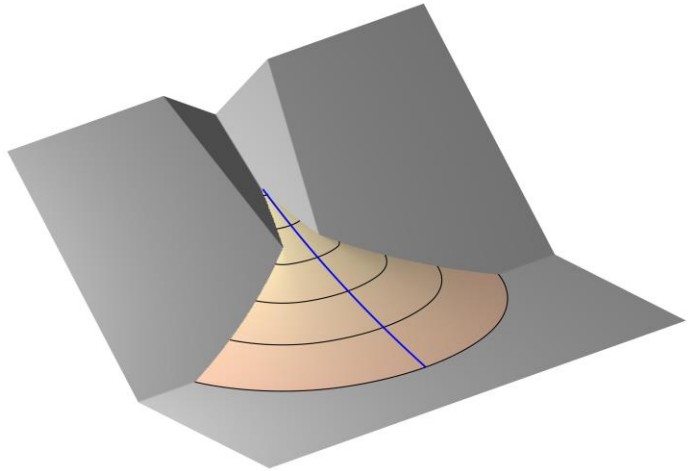
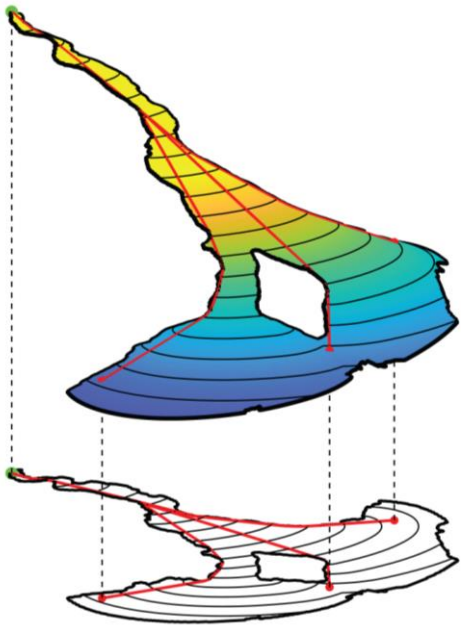
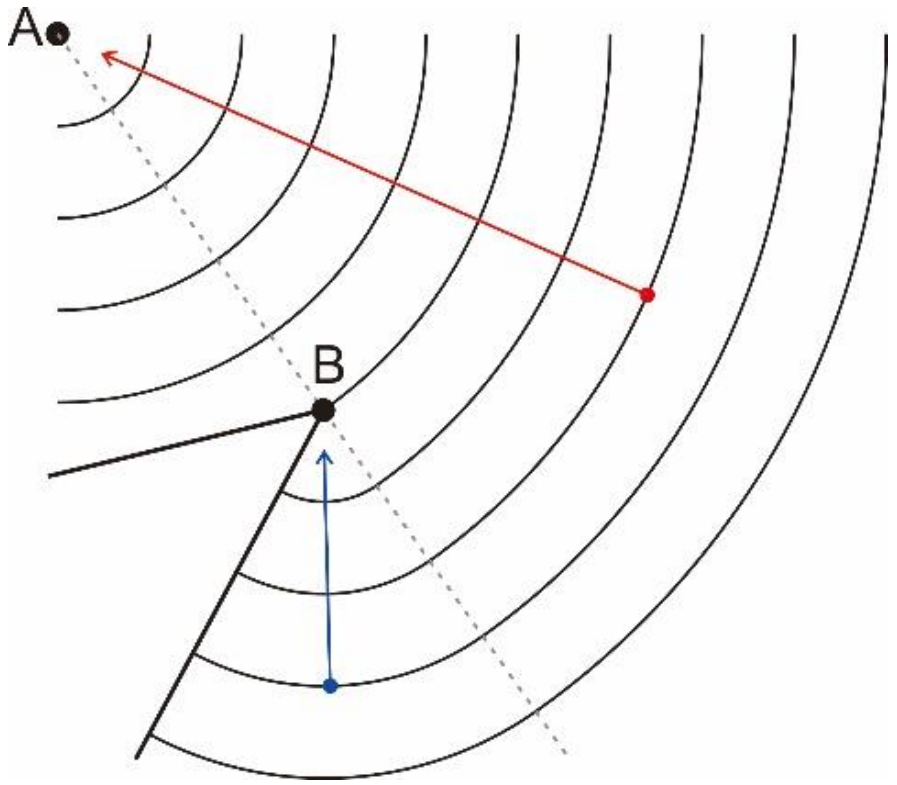




Constant-slope fan

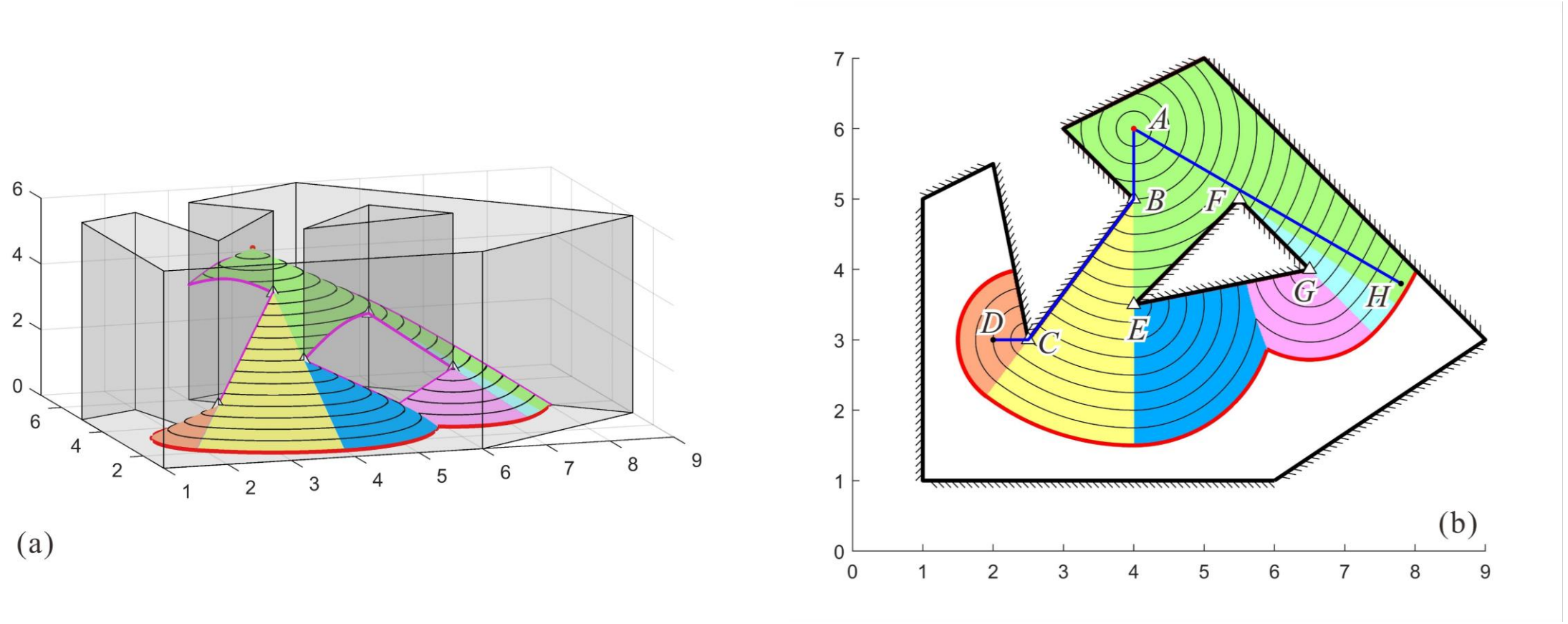
Governing equation

$$\|\nabla z\| = S, \quad \nabla z = (\frac{\partial z}{\partial x}, \frac{\partial z}{\partial y}),$$
$$(S = \tan\alpha)$$



Chen, T. Y. K., and Capart, H. (2022)

Method - Visibility polygon

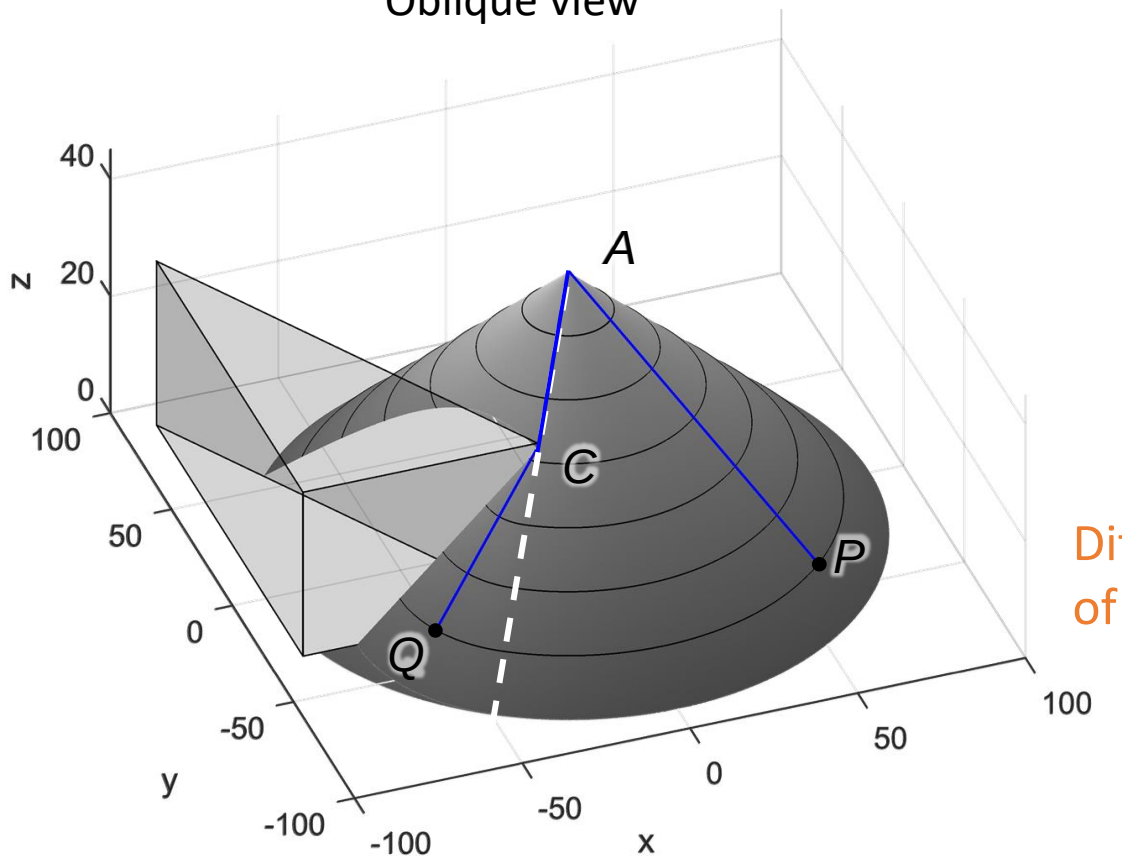


Chen, T. Y. K., and Capart, H. (2022). Computational morphology of debris and alluvial fans on irregular terrain using the visibility polygon. *Computers and Geosciences,* 105228. DOI:doi.org/10.1016/j.cageo.2022.105228.

Modeling constant slope fans

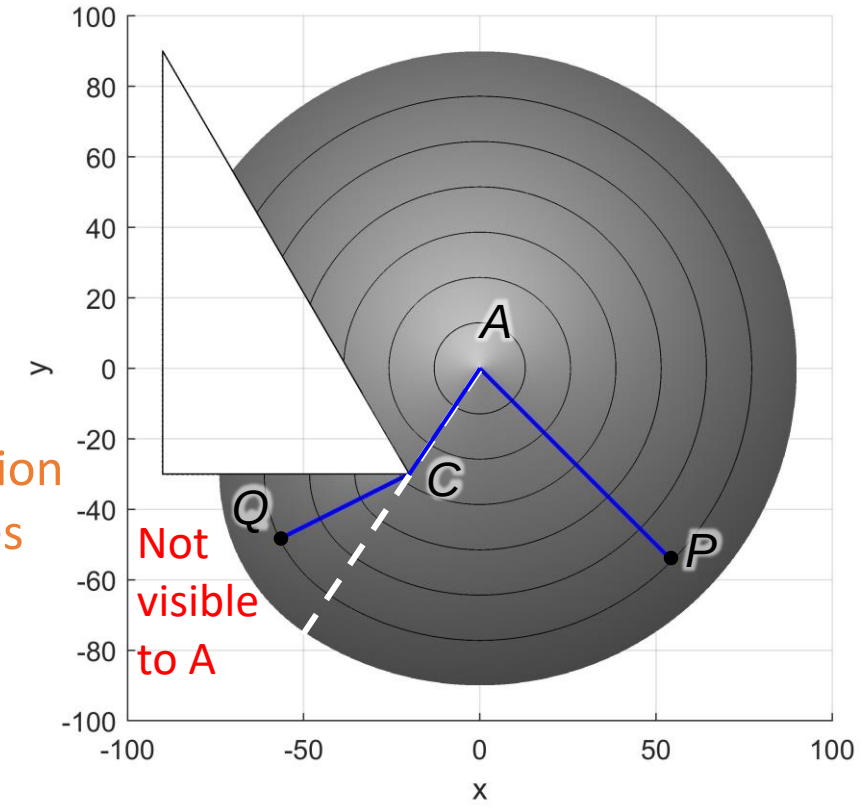
Slope = constant

Oblique view



Diffraction of waves

Top view



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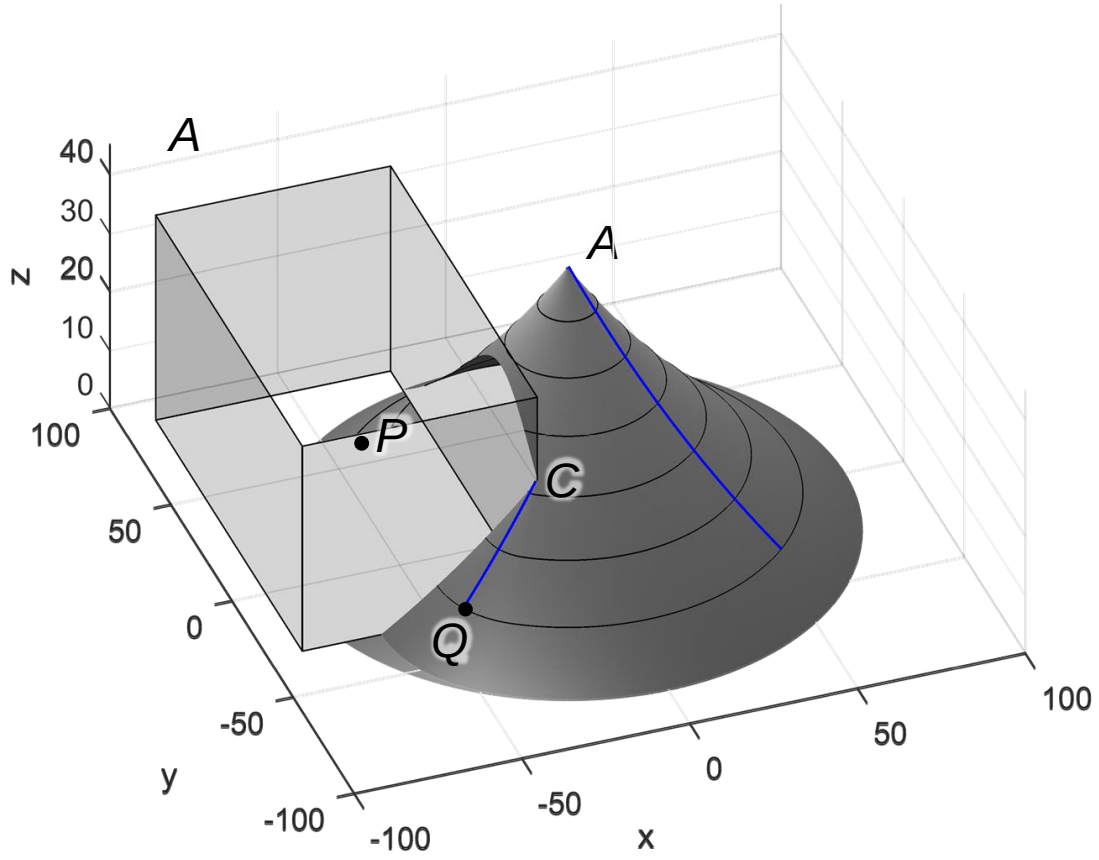
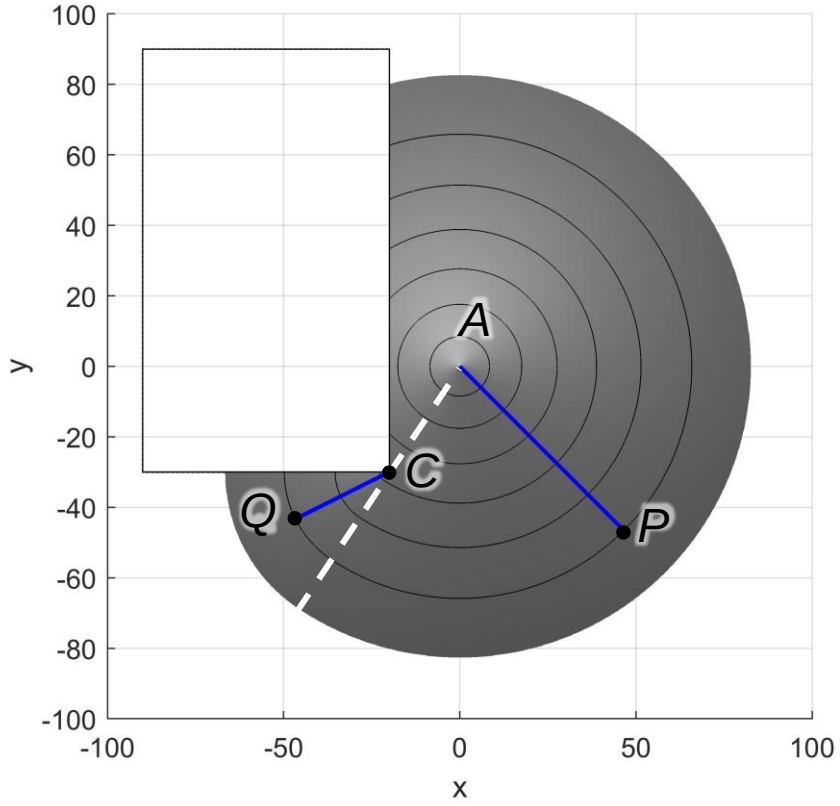
Modeling concave fan

$$\text{Slope} = f(\text{distance})$$





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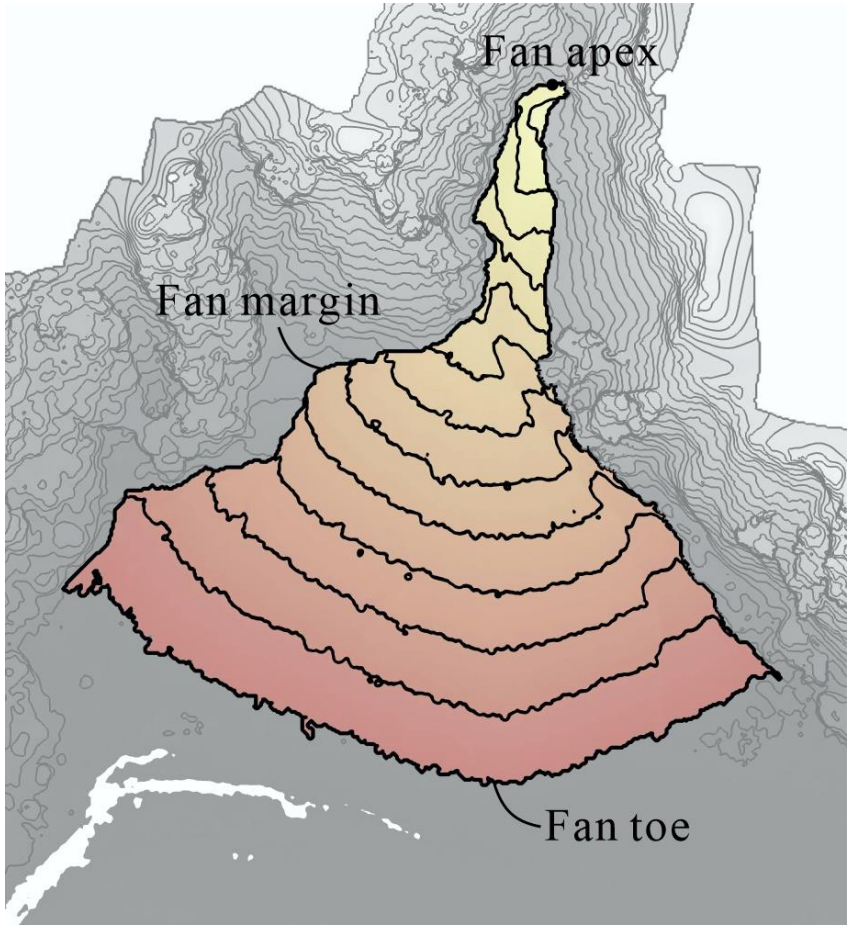
Validation with field cases





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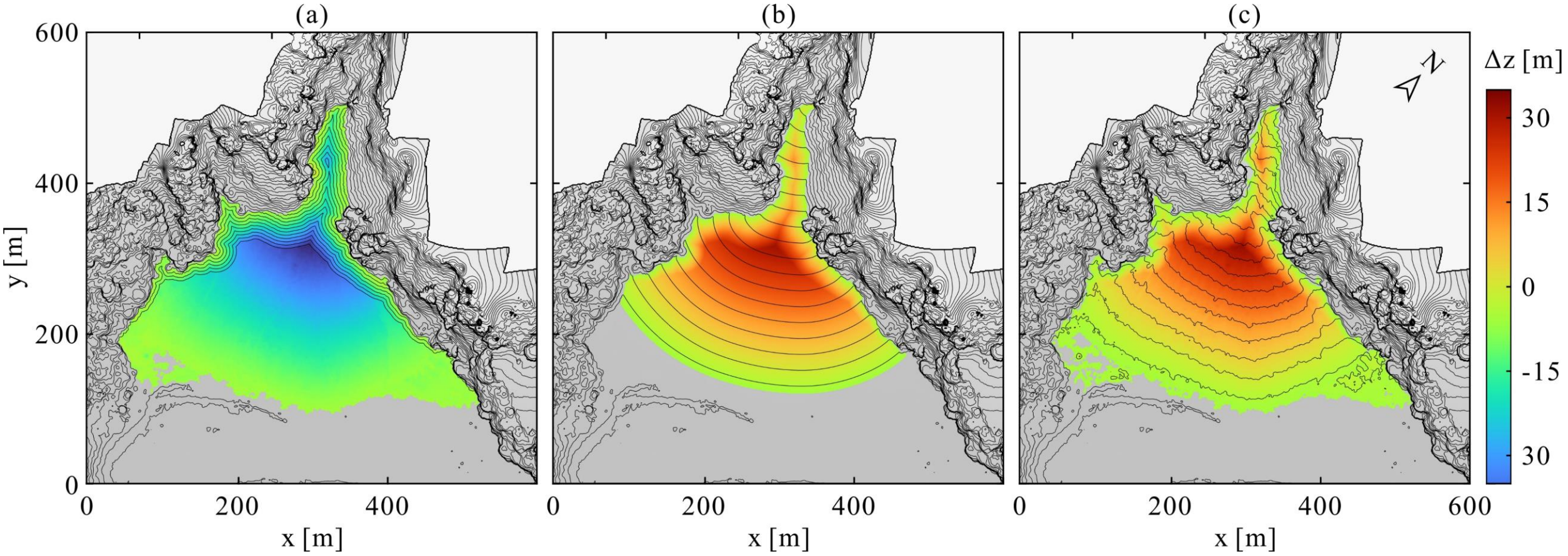

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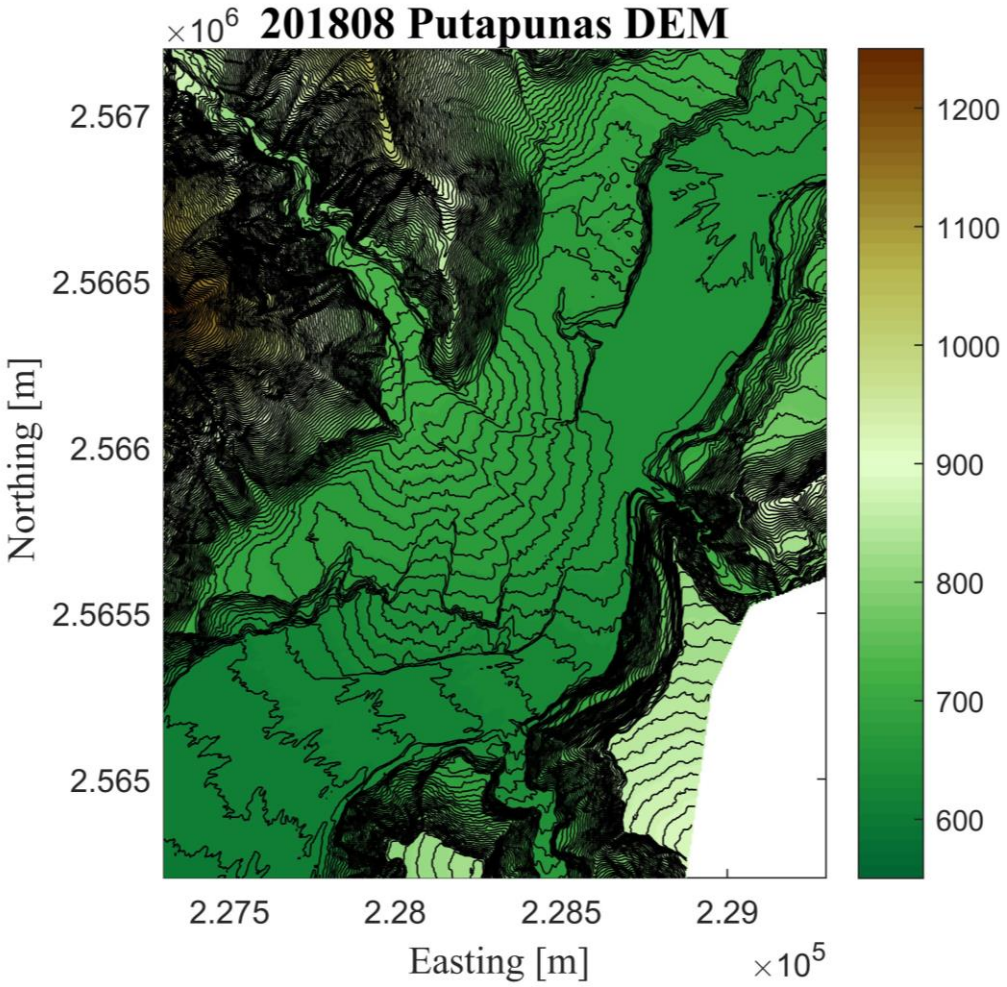

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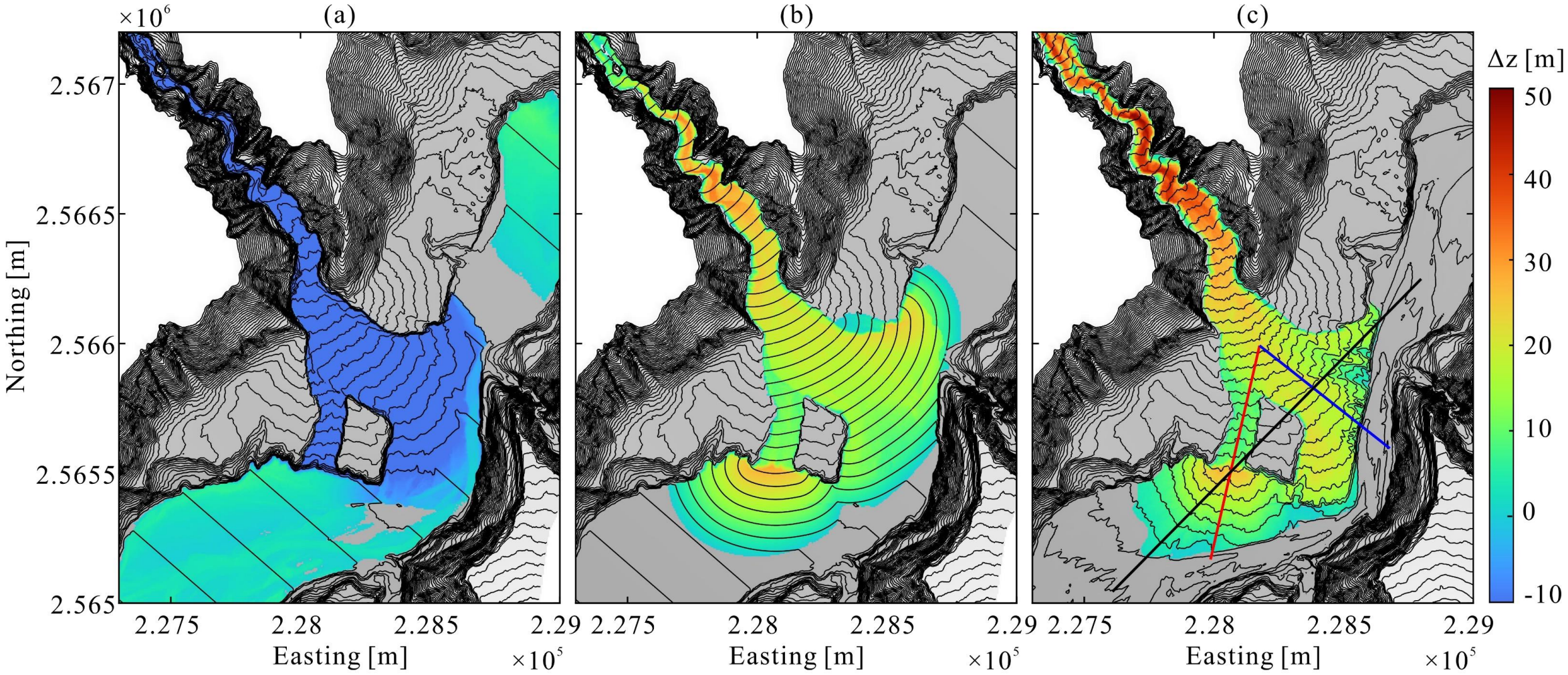

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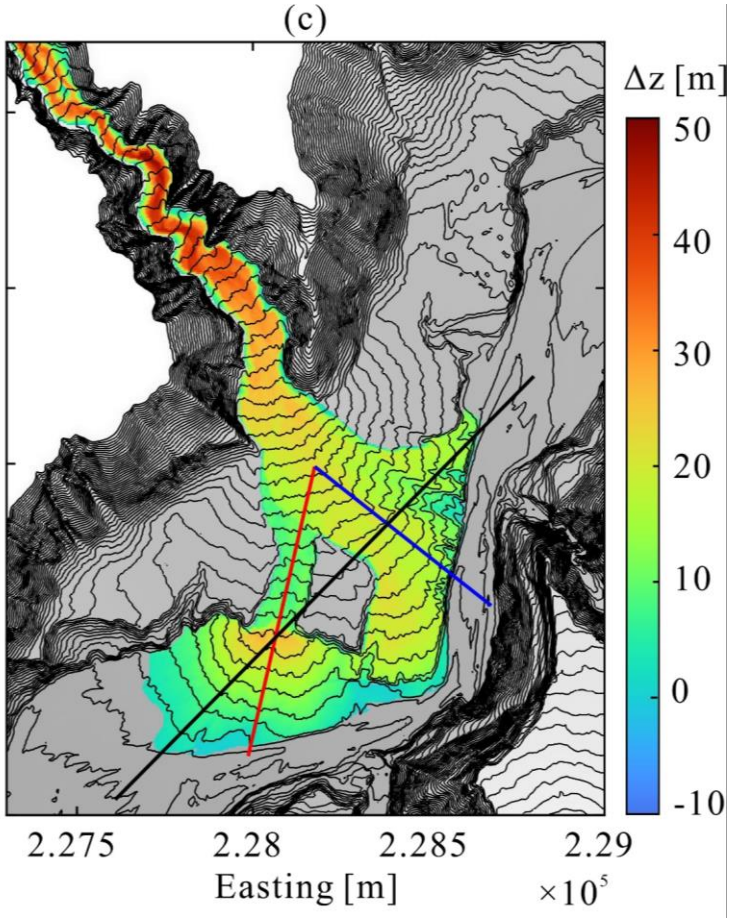
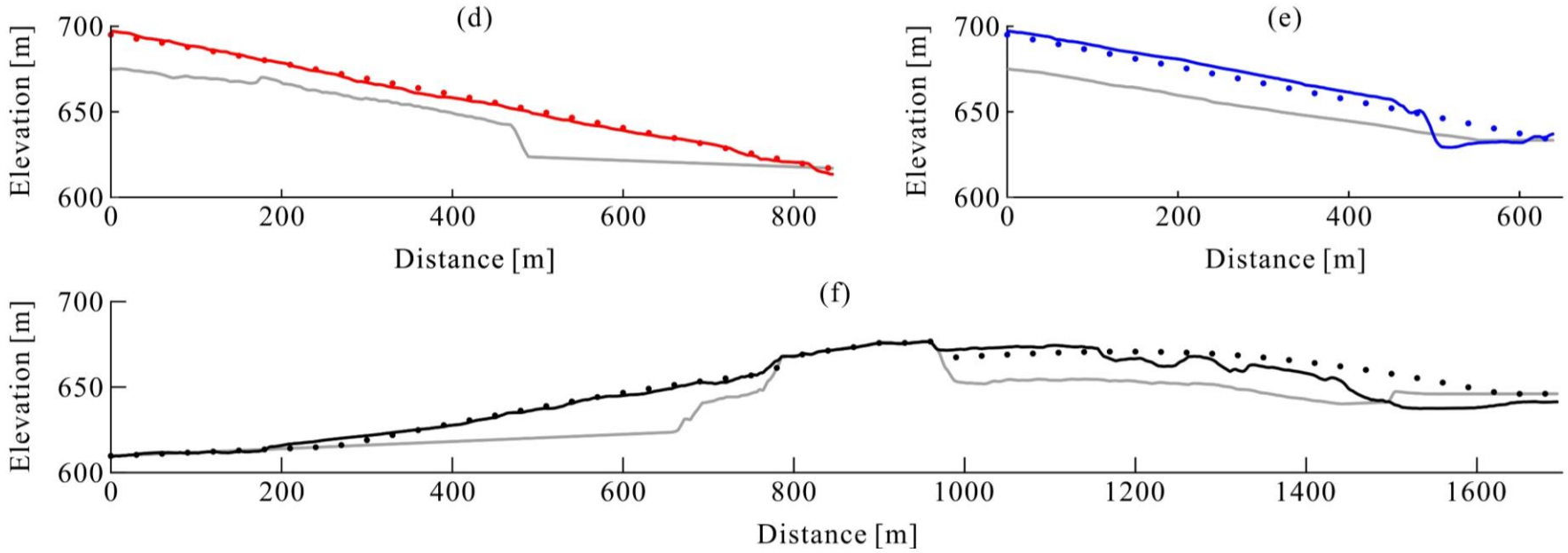
Validation with field cases

dots: simulation data
Solid line: field data
Gray line: initial topography





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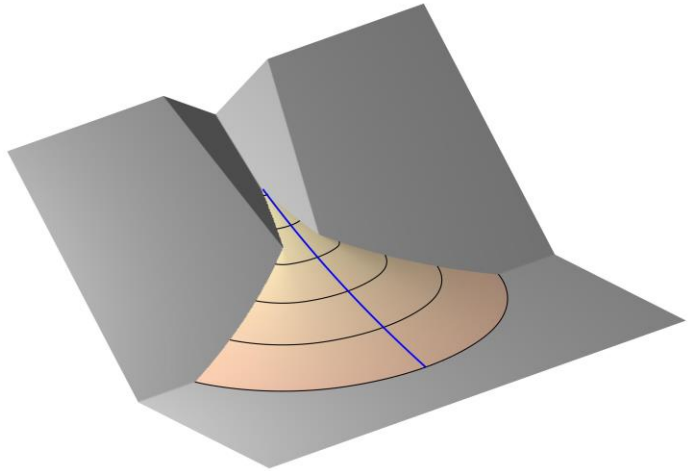
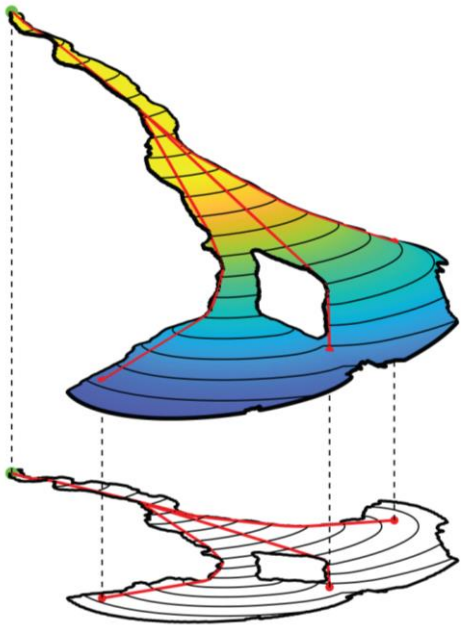
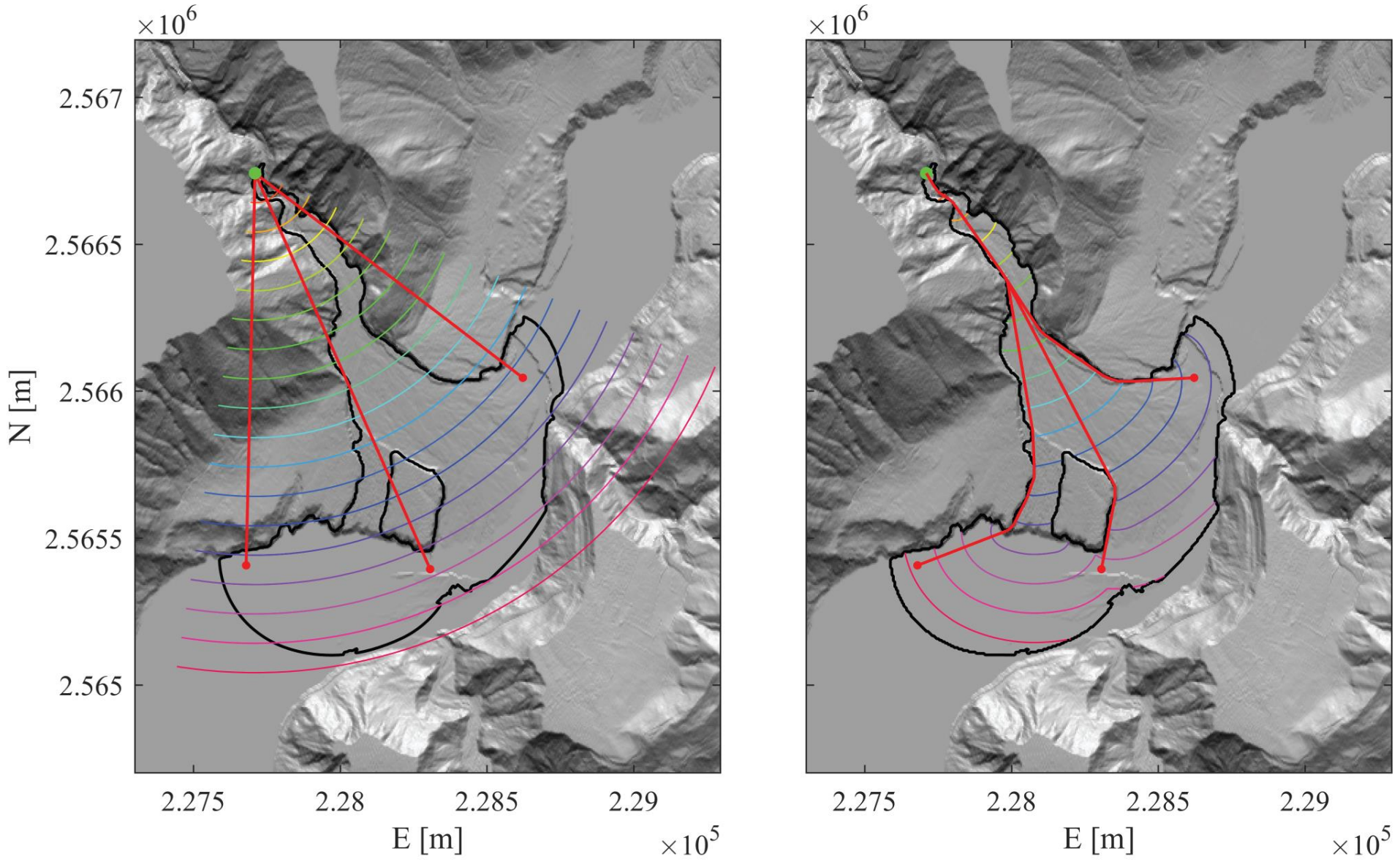
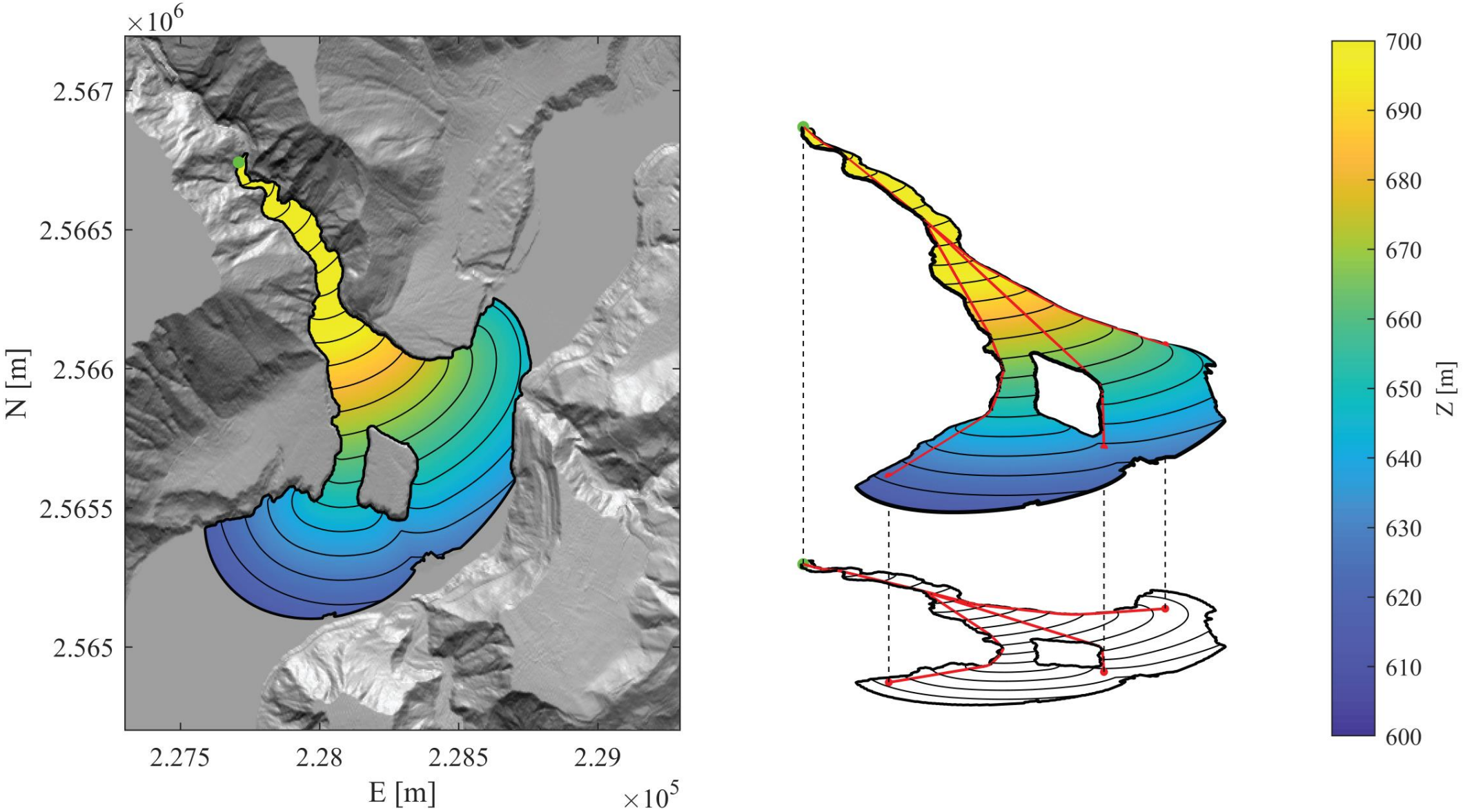




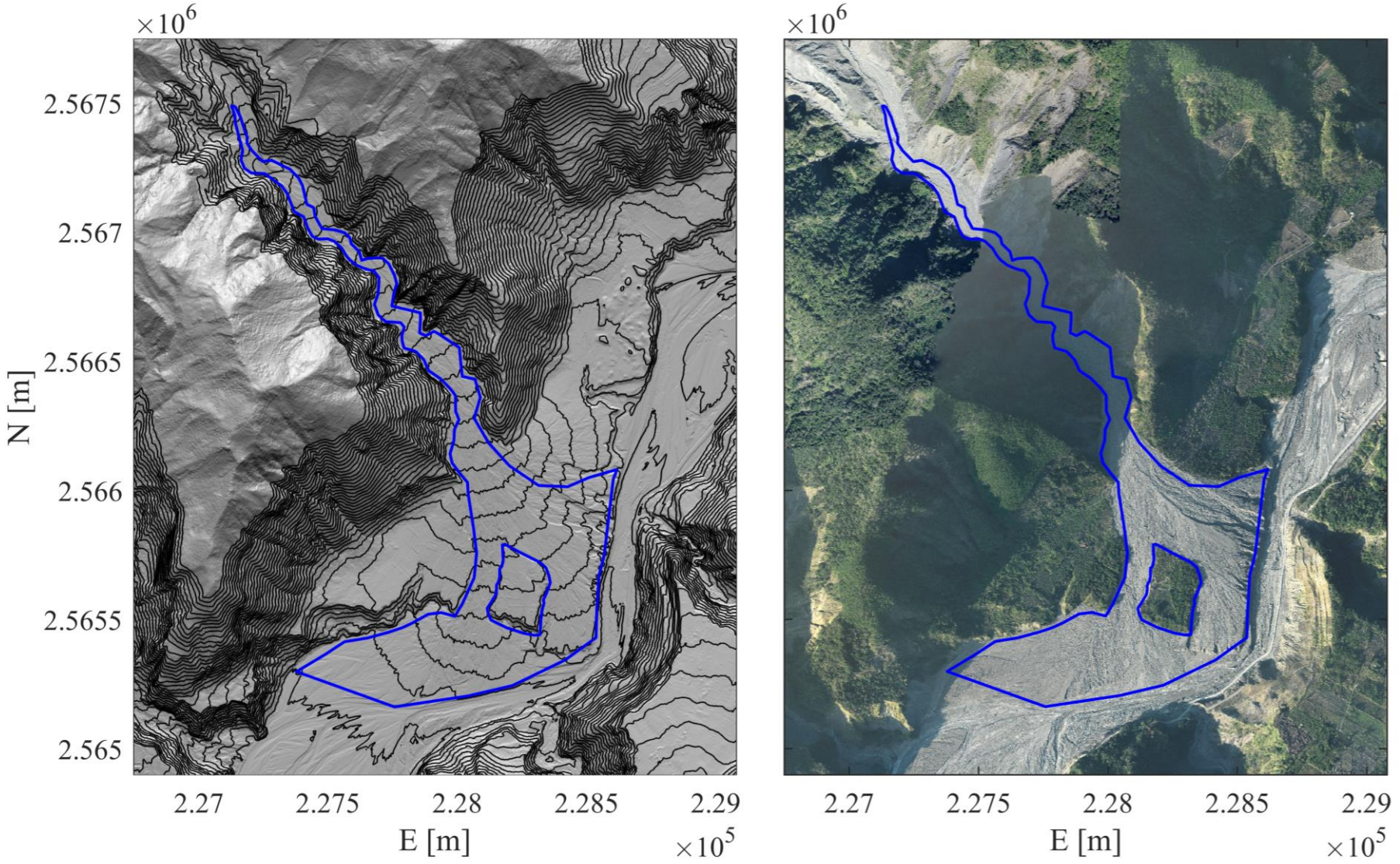
Meaning of distance *d* and *s*



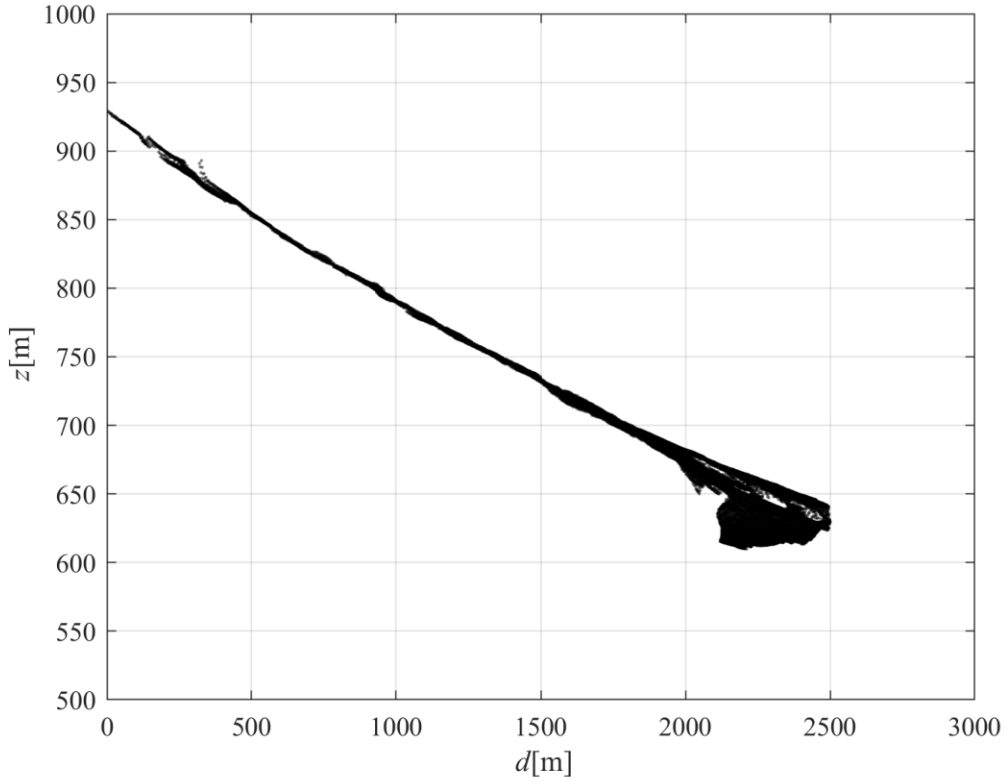
Corresponding *z* and *s*



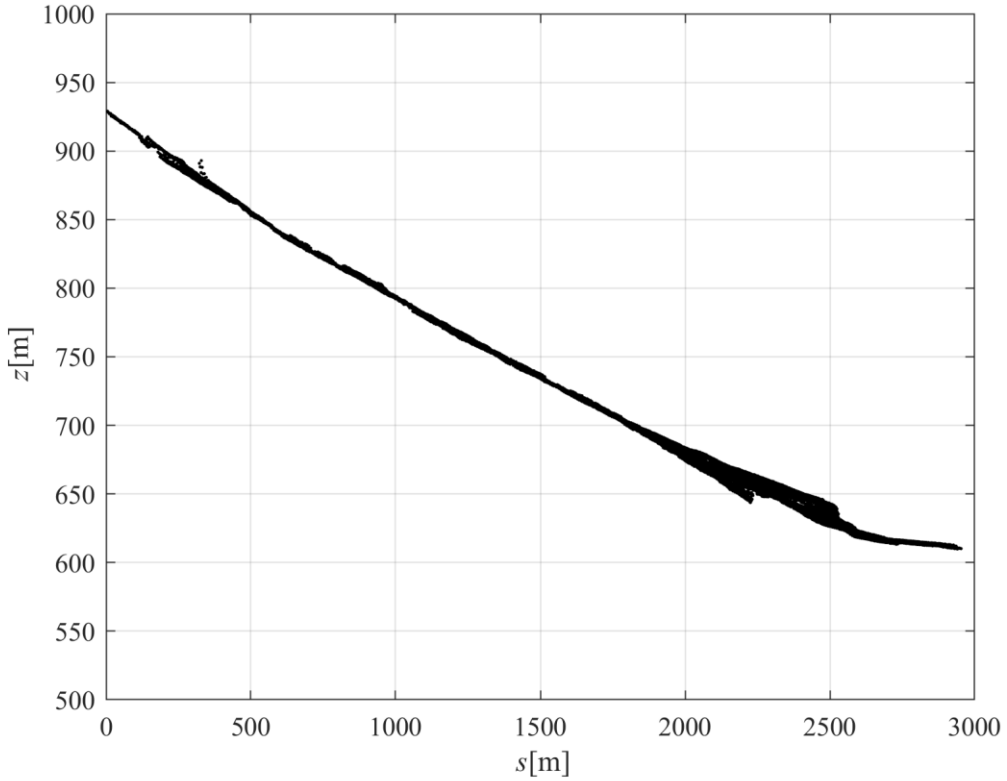
Delineate the outline of debris fan



Comparison of distance *d* and *s*

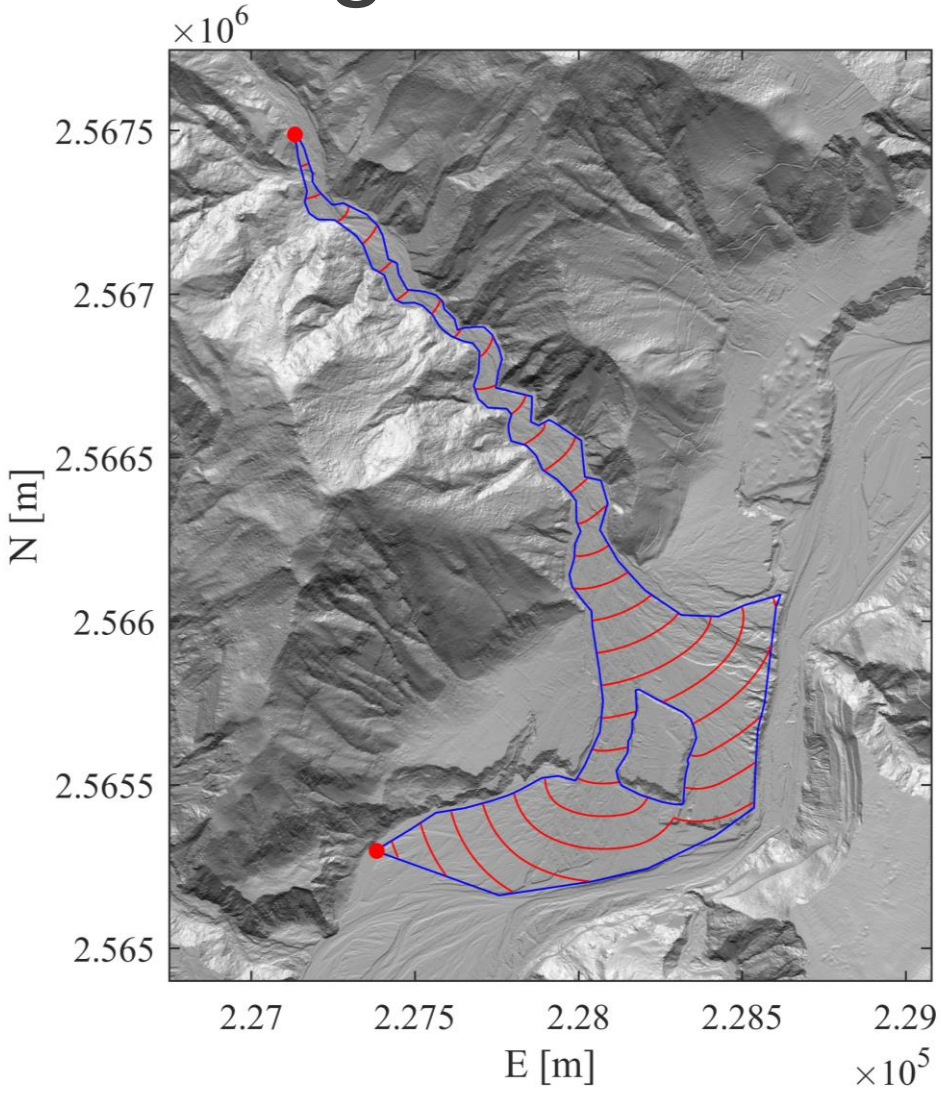


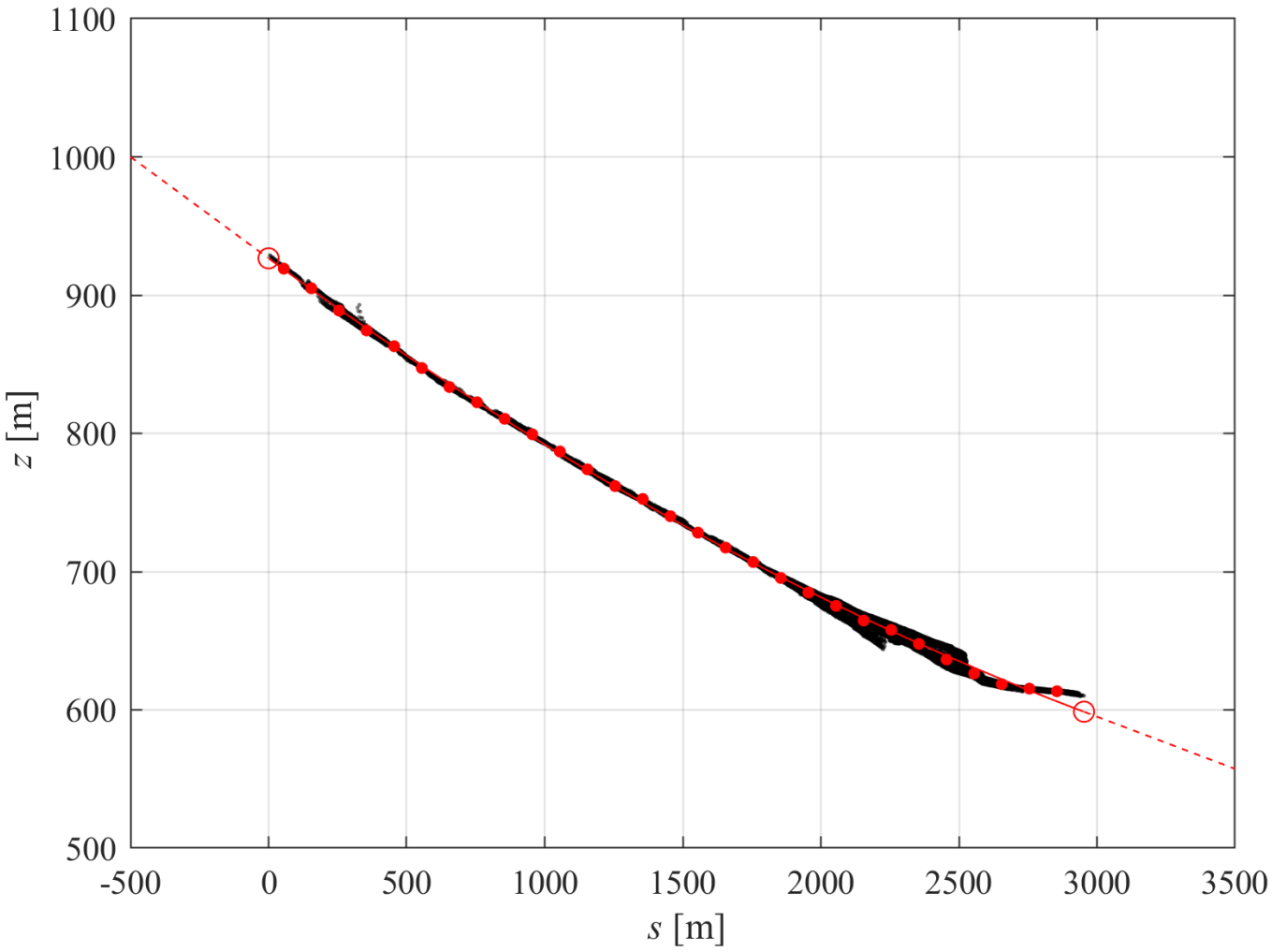
Distance *d*



Distance *s*

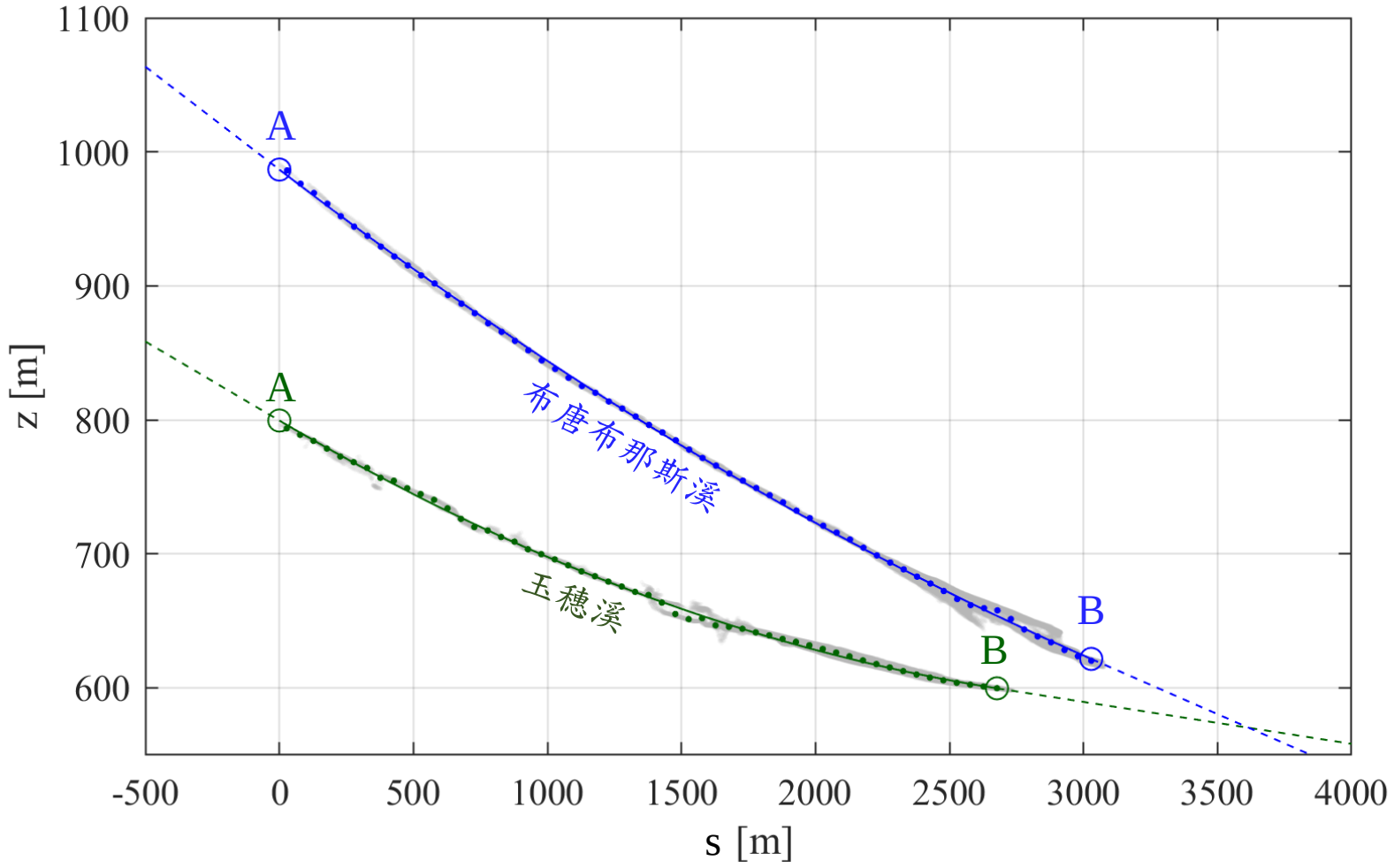
Fitting with second polynomial function



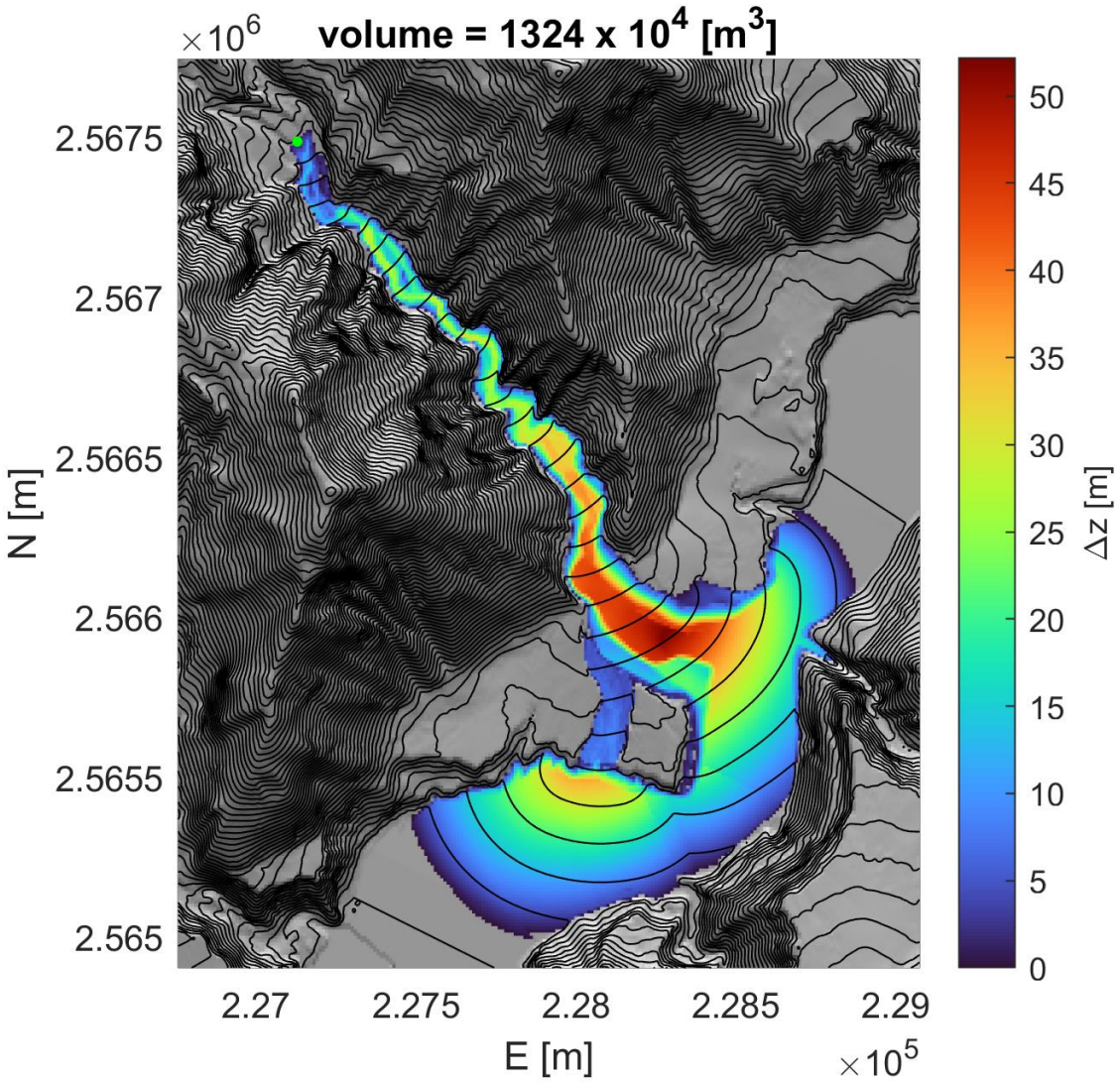


二次迴歸曲線沖積扇剖面

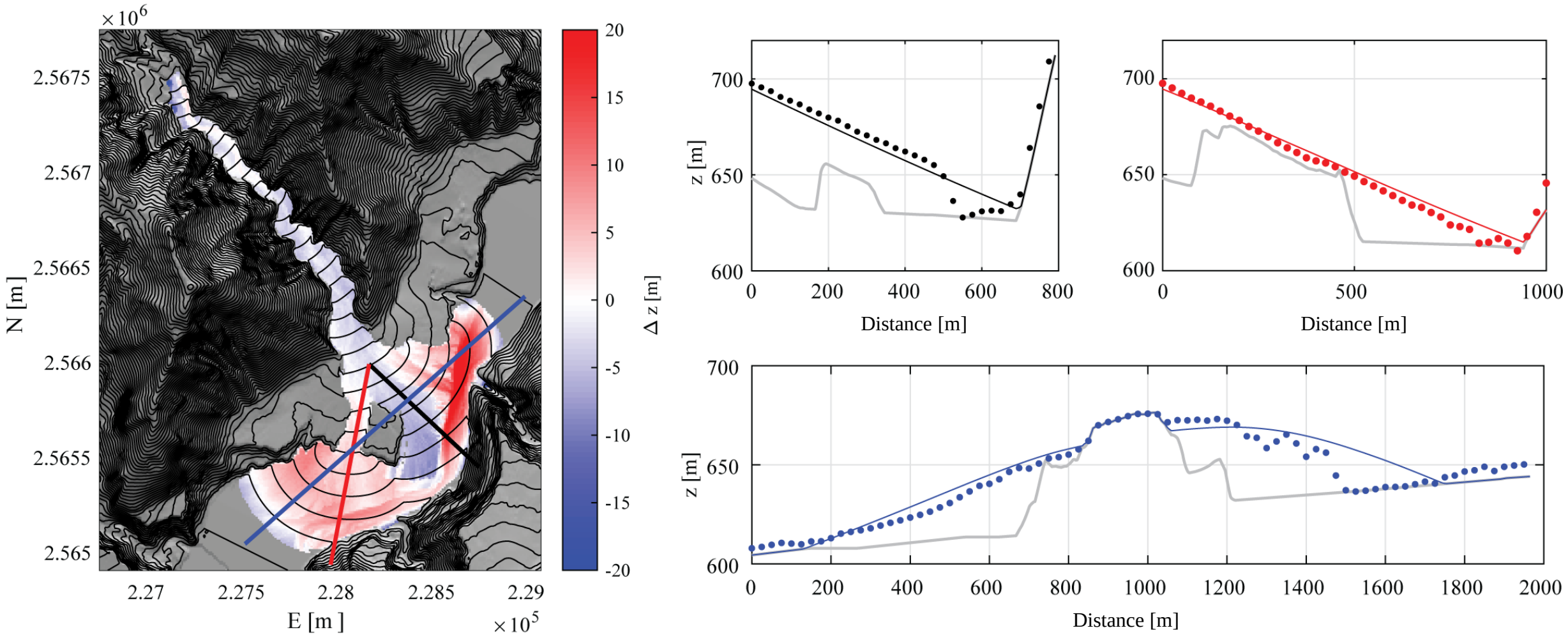
$$z(s) = \begin{cases} (2as_{\mathrm{A}} + b)s - as_{\mathrm{A}}^2 + c & , s \leq s_{\mathrm{A}} \\ as^2 + bs + c & , s_{\mathrm{A}} < s < s_{\mathrm{B}} \\ (2as_{\mathrm{B}} + b)sa - as_{\mathrm{B}}^2 + c & , s_{\mathrm{B}} \leq s \end{cases}$$



Geometric model simulation result



Validation with field cases



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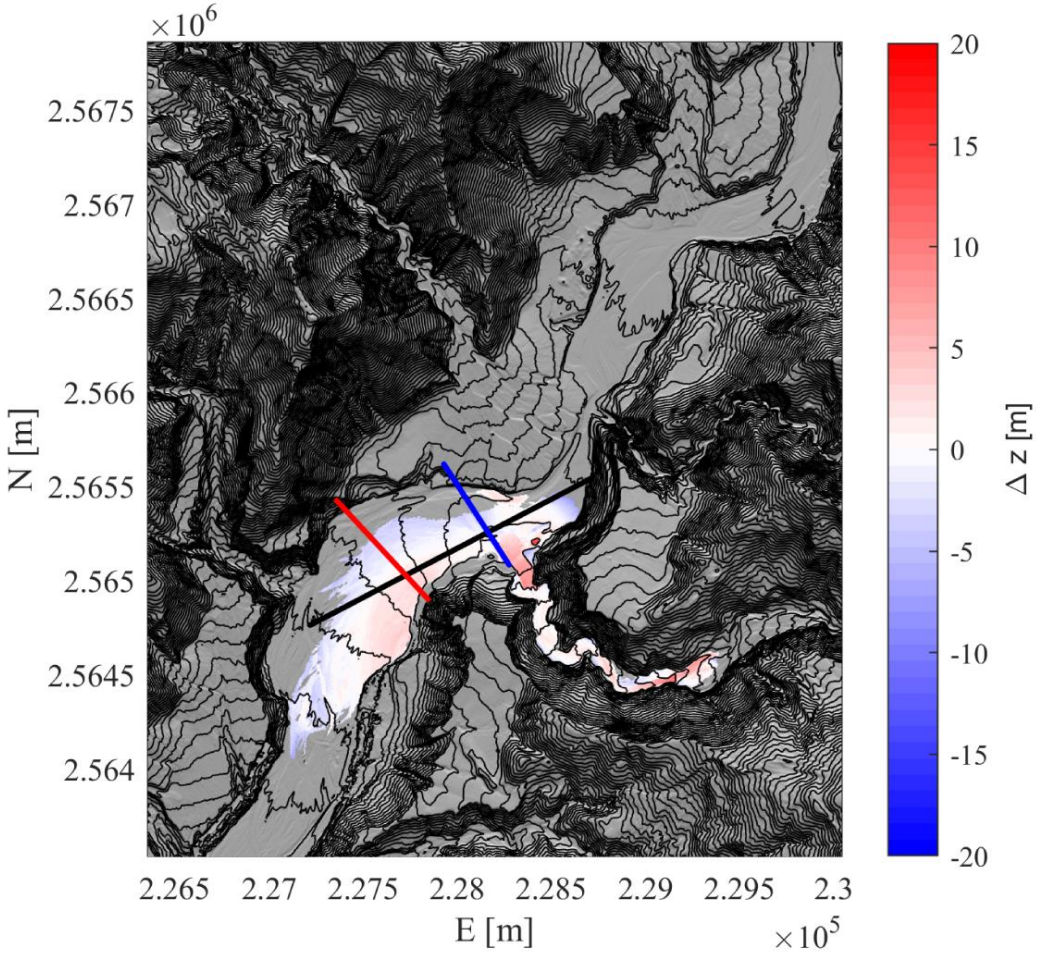
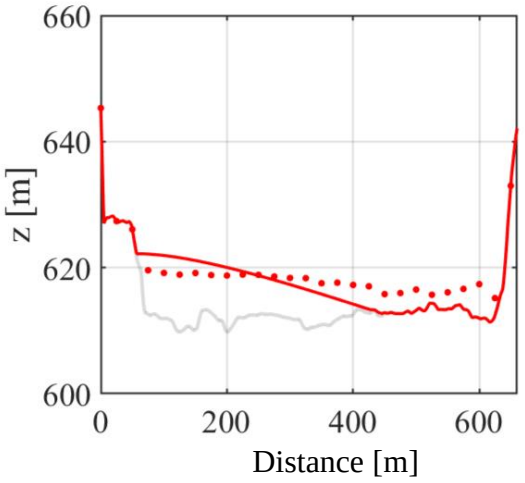
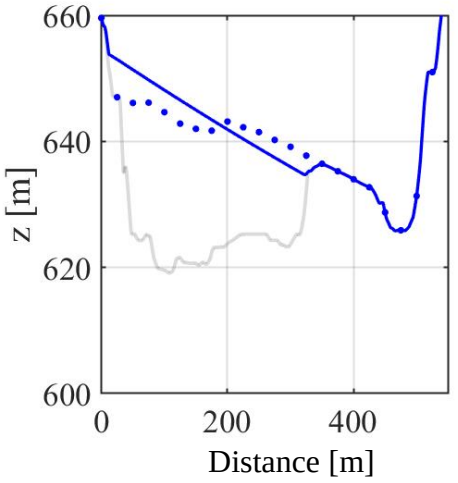
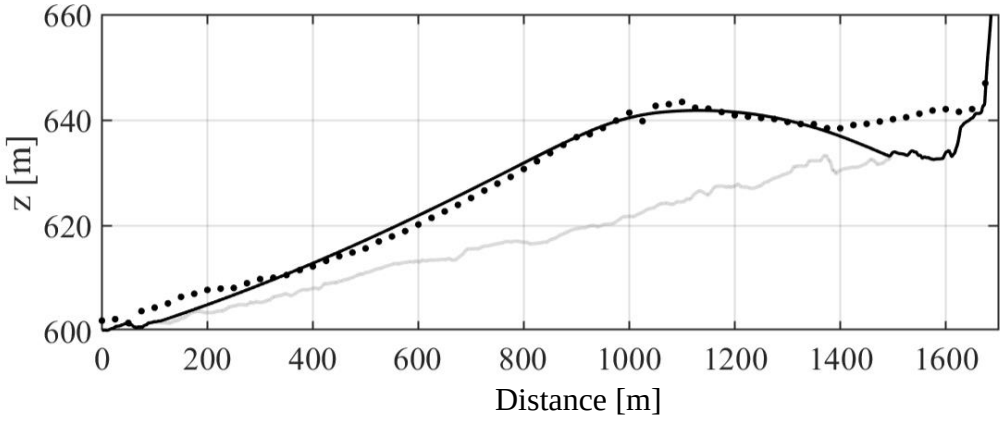
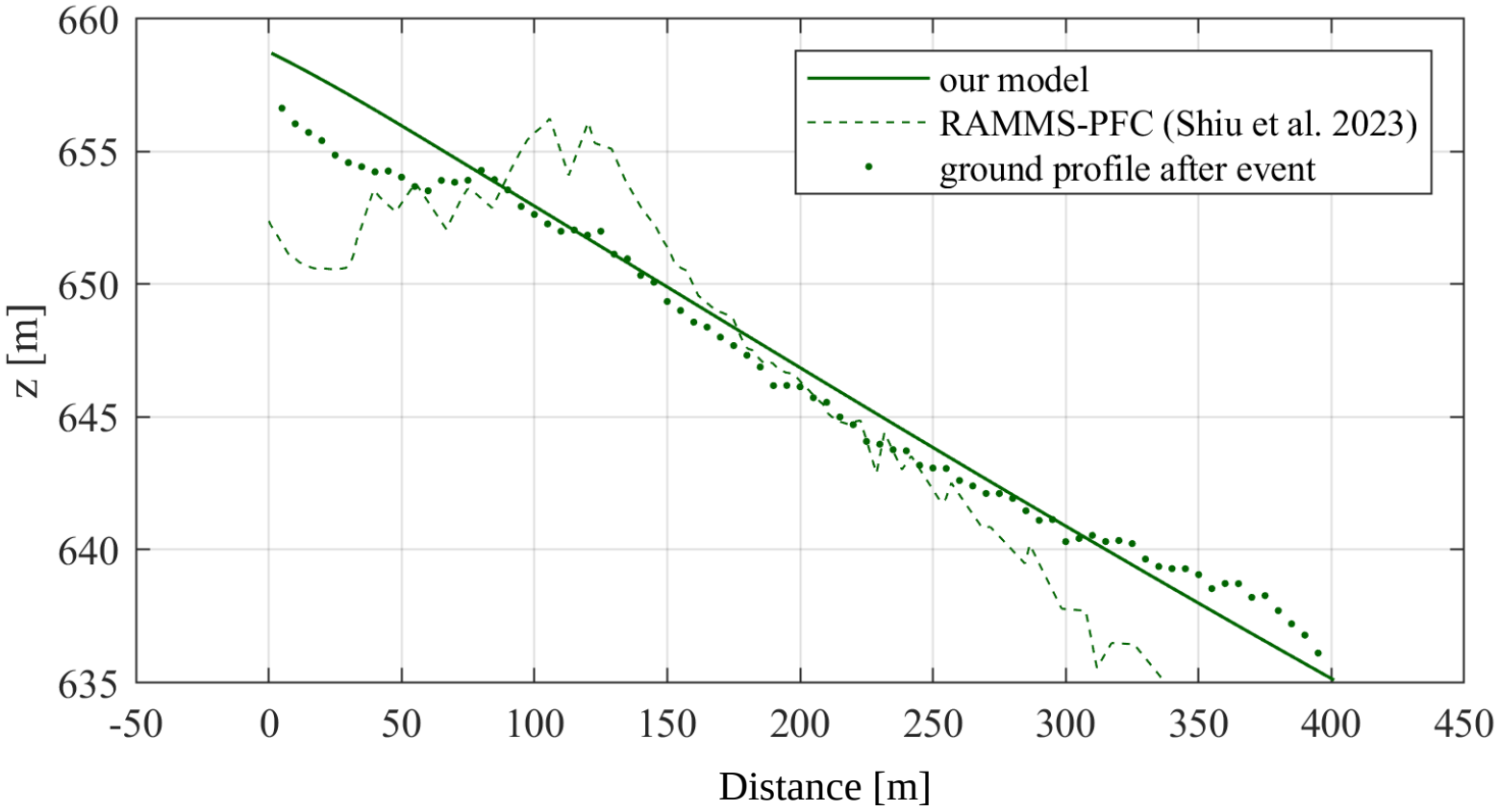




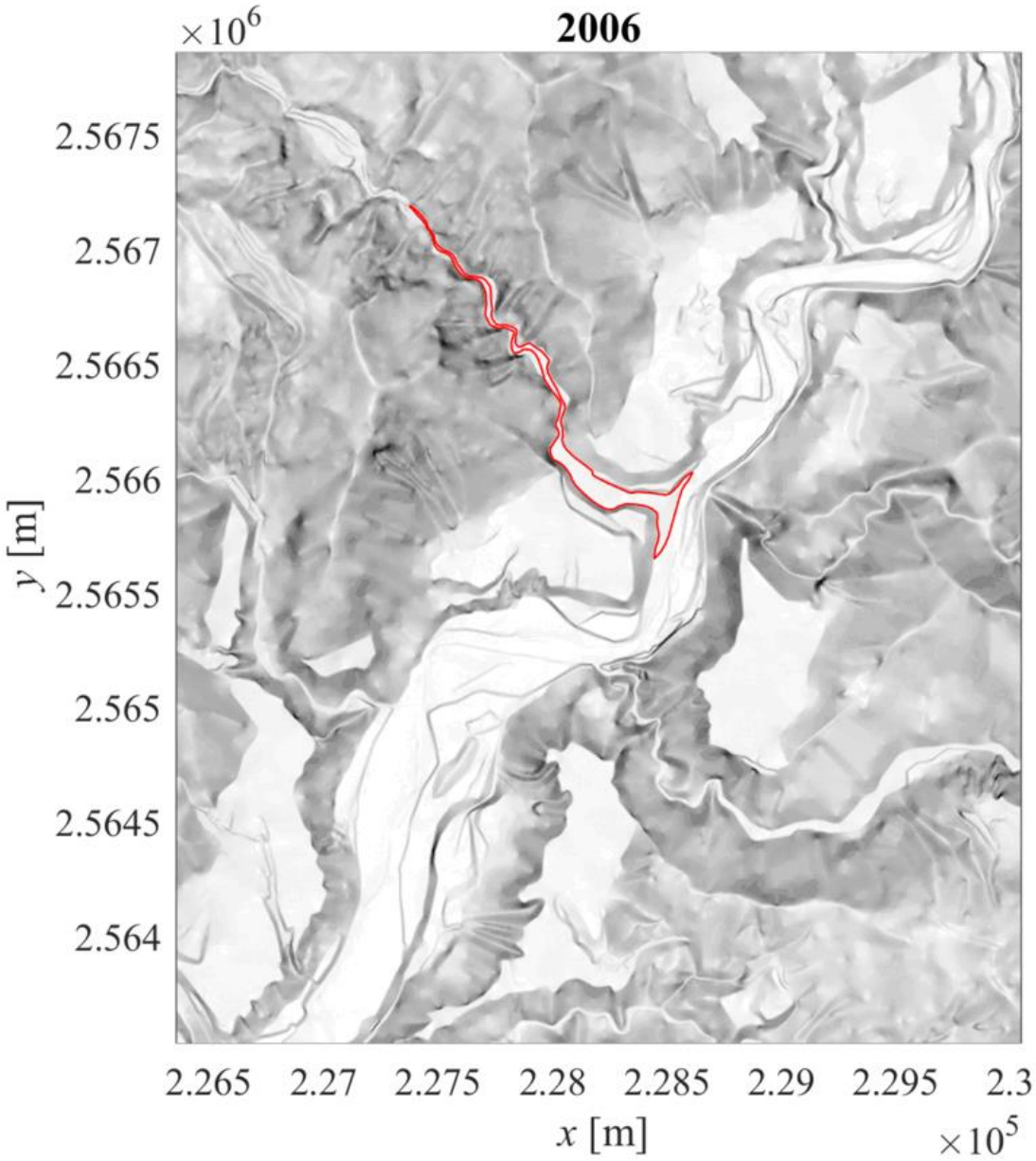


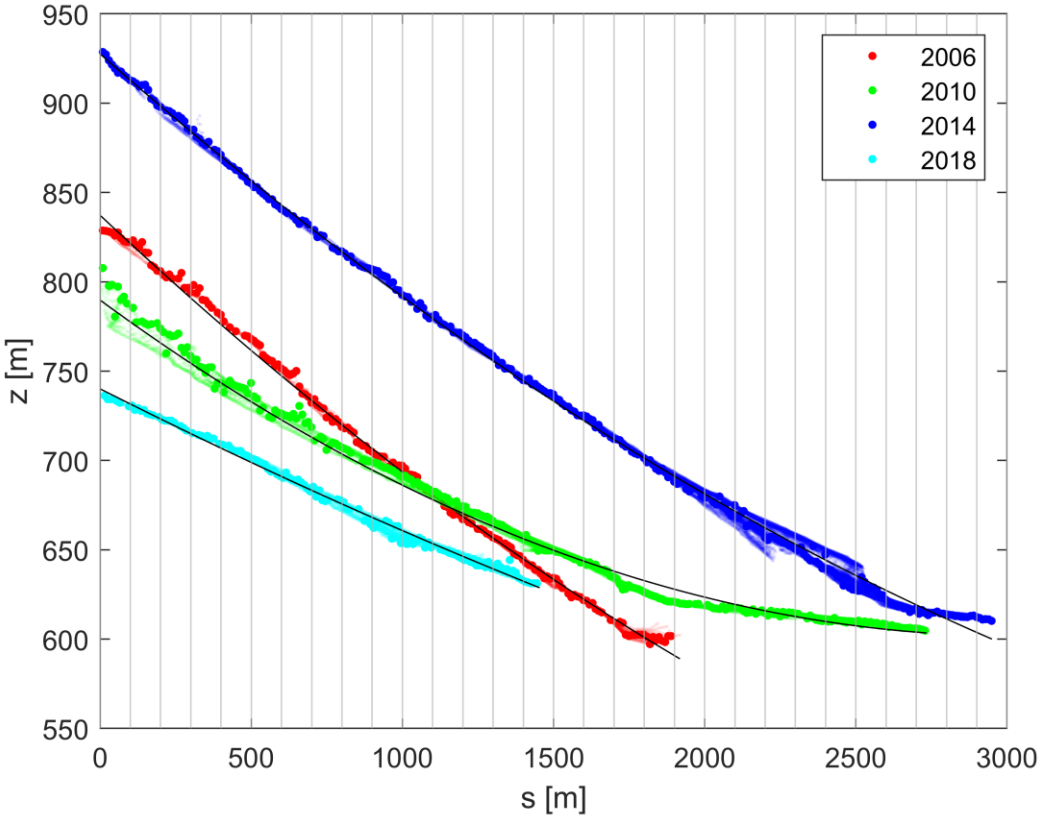


Validation with RAMMS-PFC

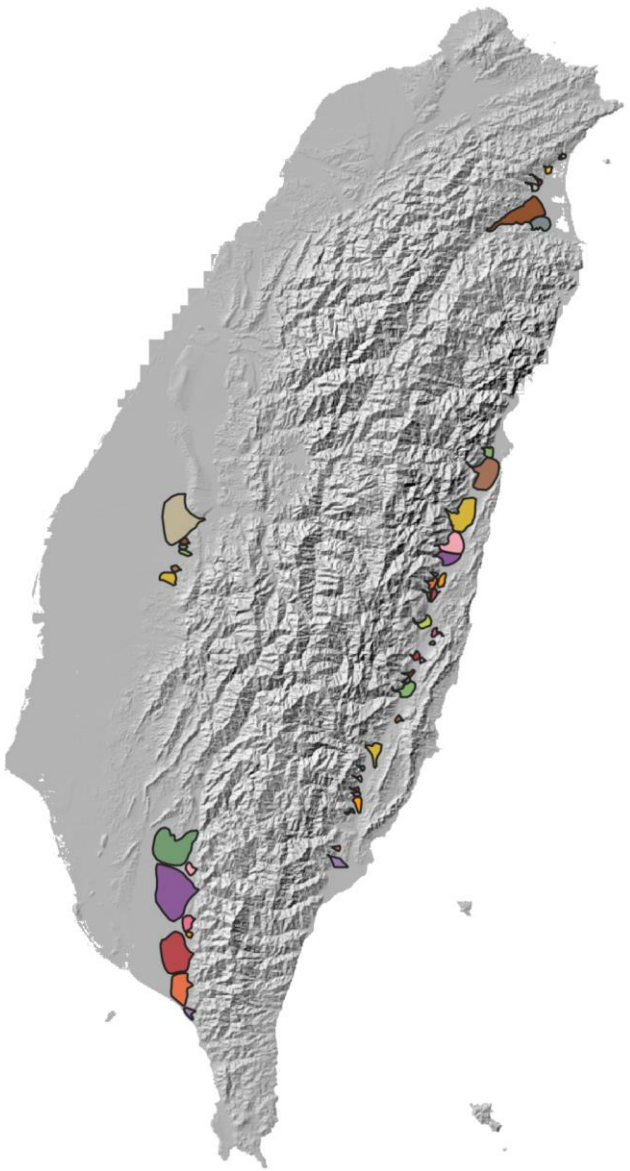


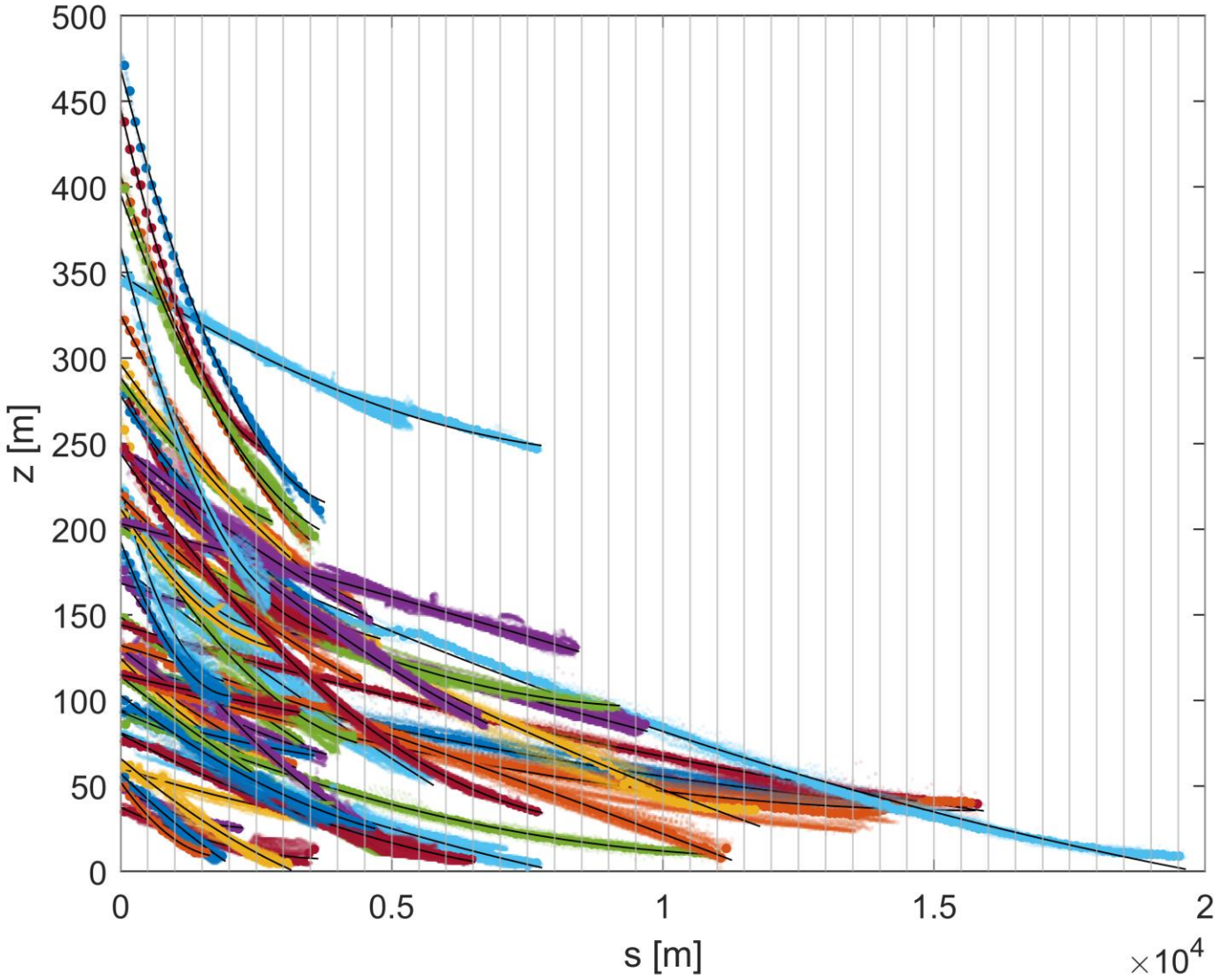
Comparison of Debris Fans Over Time



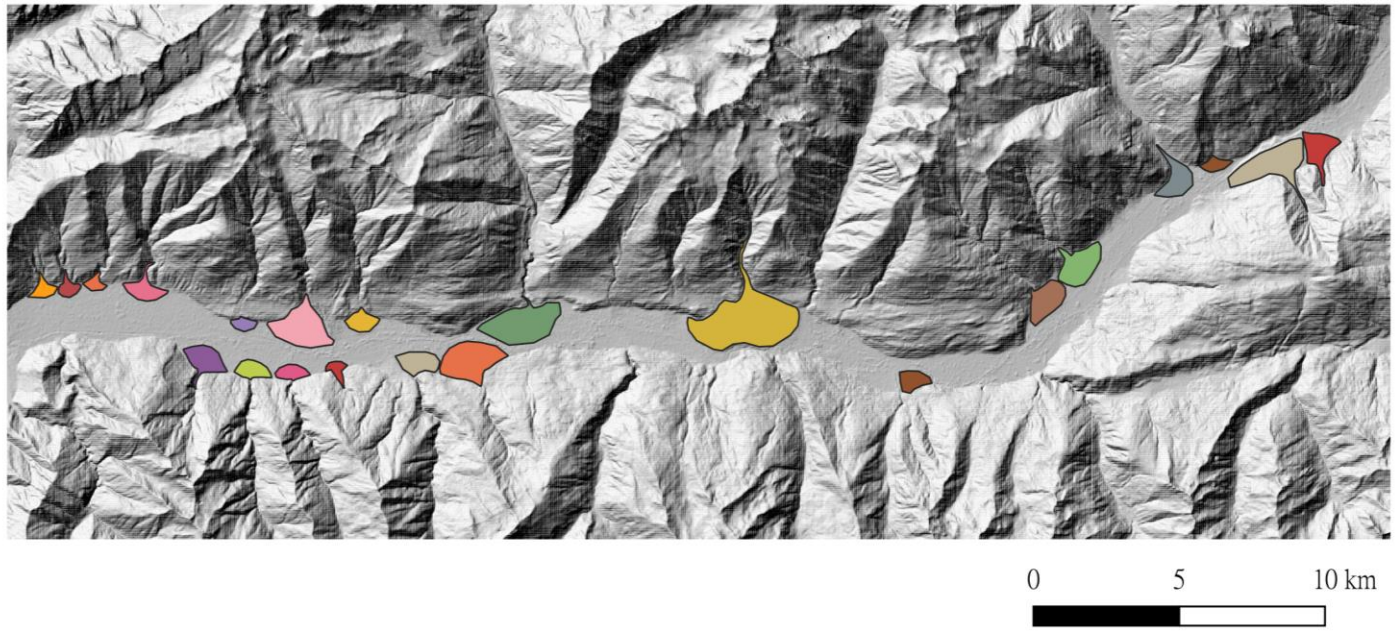


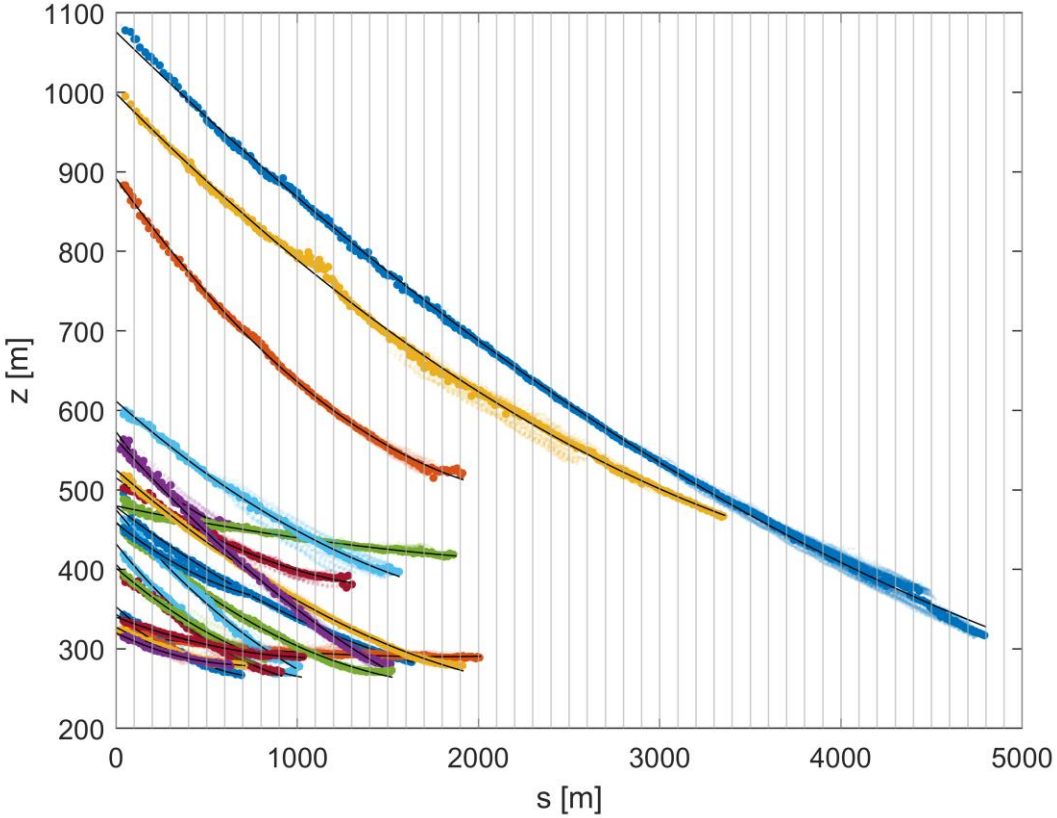
Comparison of Different Debris Fans in Taiwan





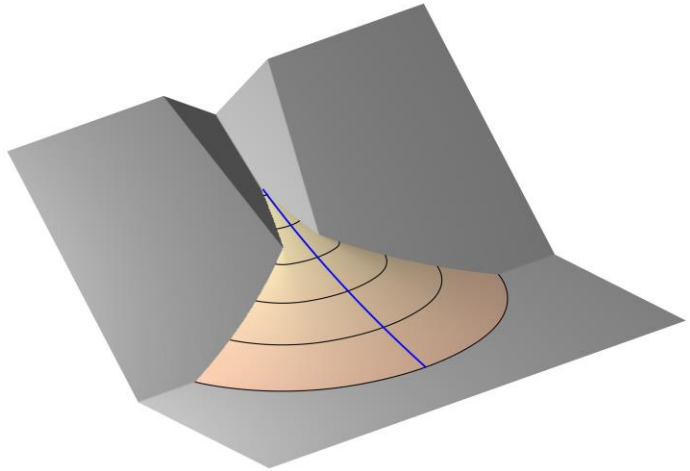
Comparison of Different Debris Fans in Italy

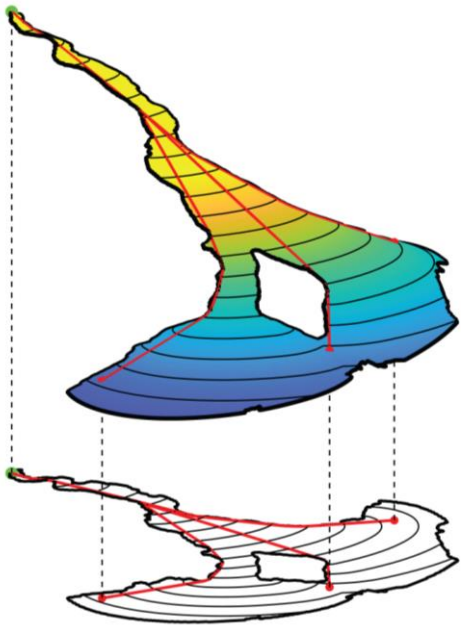




Outline

- Introduction
- Forward method
- Inverse method
- Application
- Conclusion and future work





玉穗溪沖積扇－明霸克露橋(台20線94K+144)

Before
2021/08/07

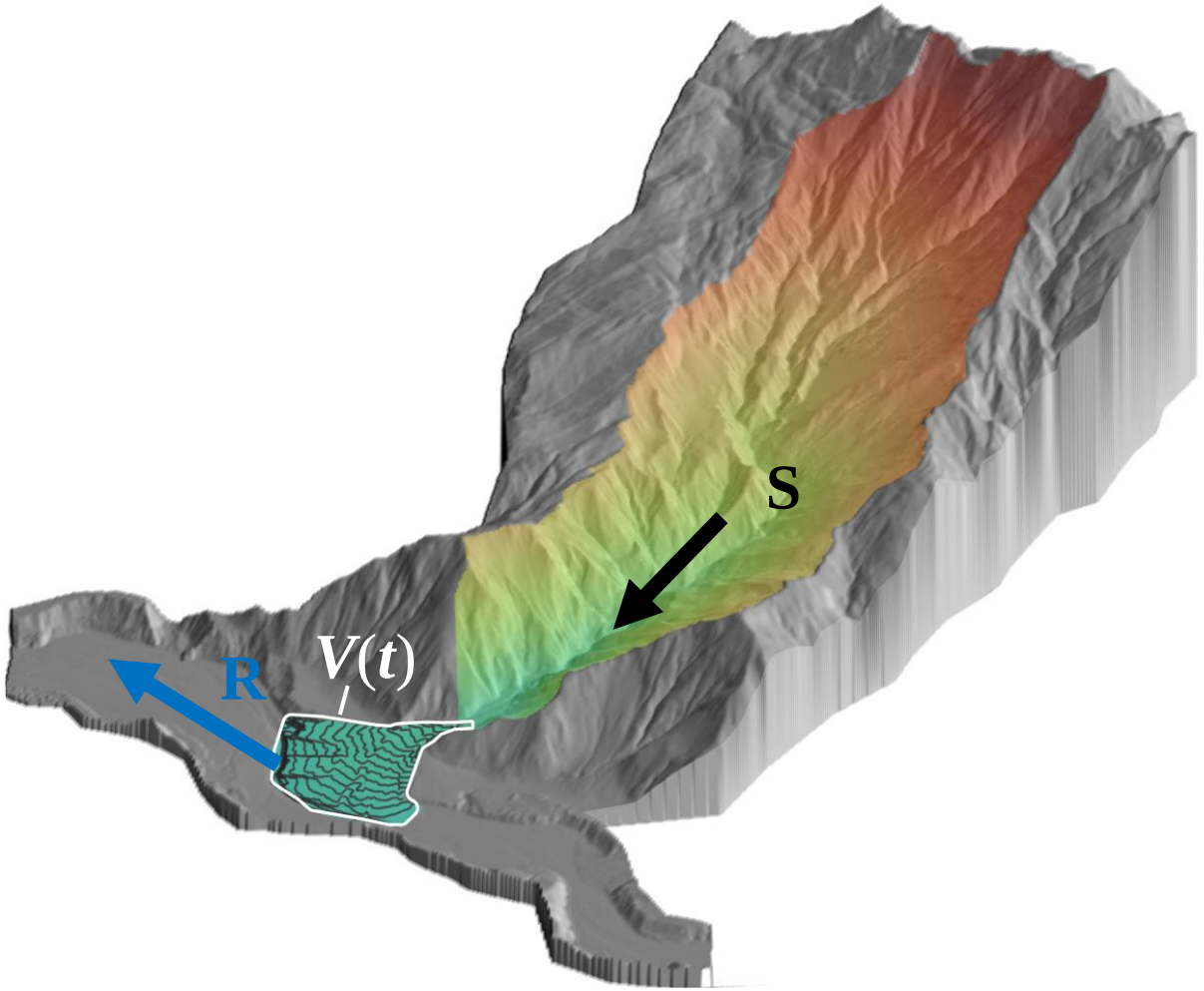


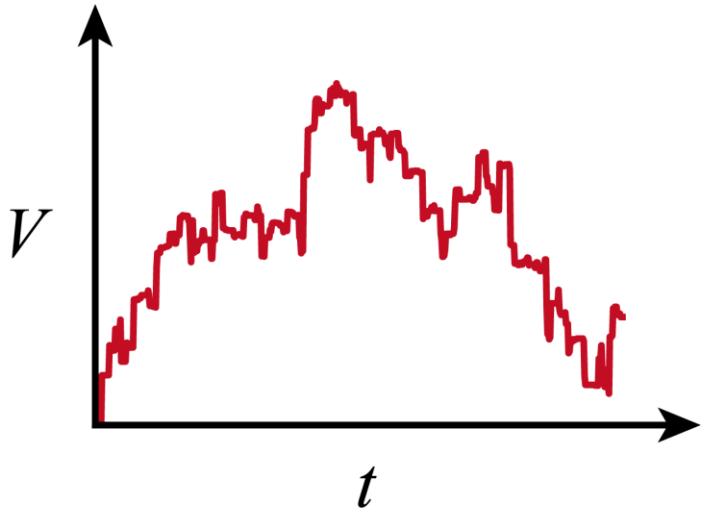
After
2021/08/07



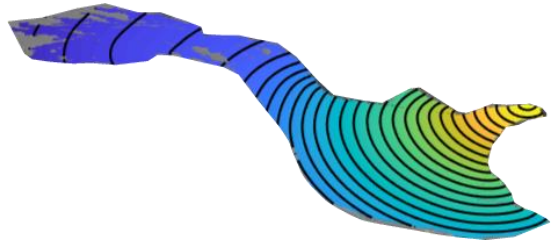
資料來源：公路總局／ 台灣世曦

Application





1 Geometric model for $z(x,y,t)$



2 Stochastic model for $V(t)$

Variance gamma 隨機過程

由長期資料率定

$$dV = \sigma dW(\tau(t))$$

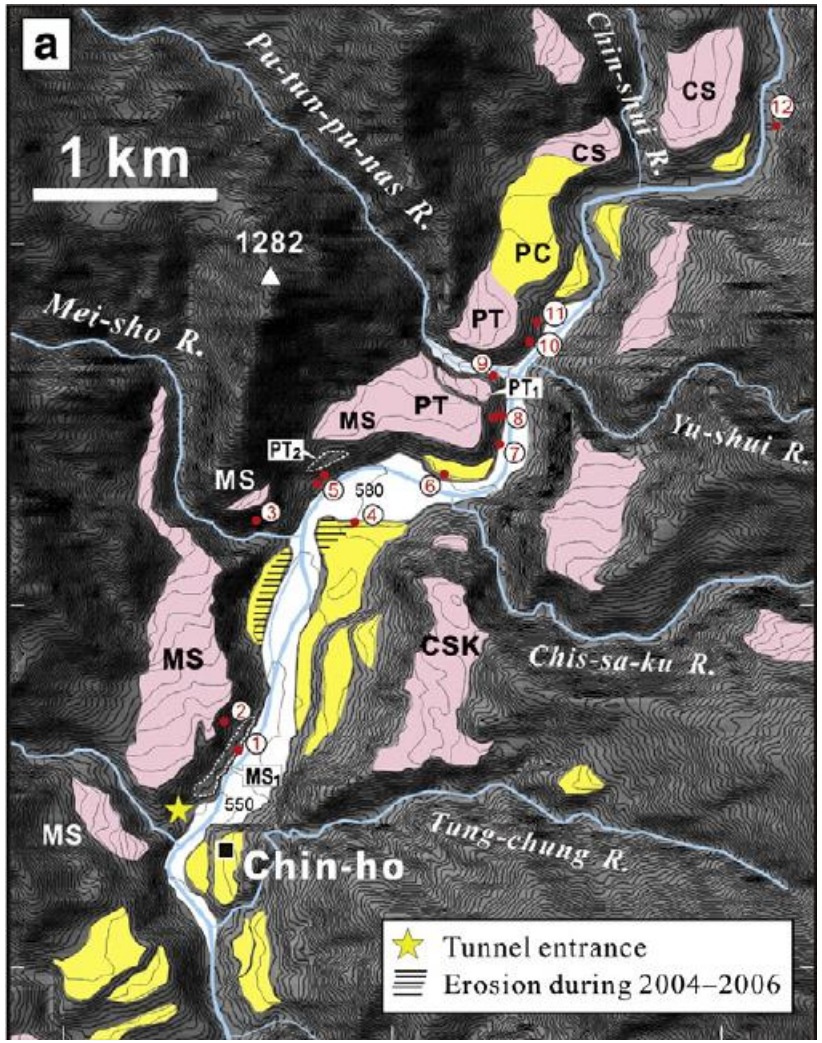
V 為沖積扇的體積$[m^3]$，σ 為波動率(volatility)，$W(\tau(t))$ 為 Wiener 過程$[yr^{1/2}]$，$\tau(t)$ 為地質時間。此方程式可看作是波動率為$\sigma\left[m^3/\sqrt{yr}\right]$的 Wiener 過程 $W(\tau(t))$，其中 Wiener 過程也稱作布朗運動(Brownian motion)，其時間項為地質時間$\tau(t)$，其來自 Gamma 隨機過程，可用來描述沖積扇體積變動的快慢。Gamma 隨機過程的變動量$\Delta\tau(t)$為來自 Gamma 分佈的隨機變數

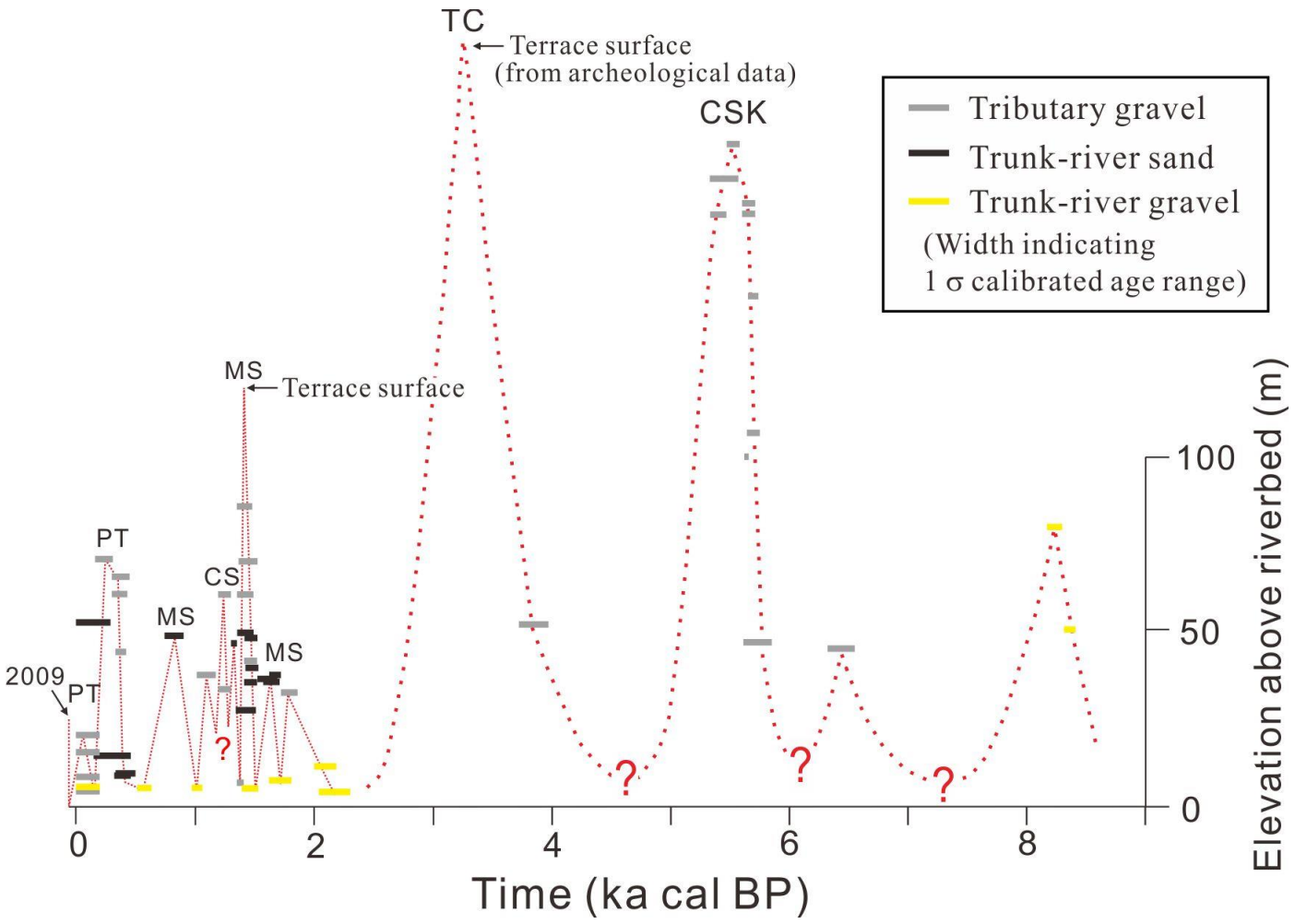
由短期資料率定

$$\Delta\tau \sim \Gamma\left(\frac{\Delta t}{\nu}, \nu\right)$$

$\frac{\Delta t}{\nu}[-]$和$\nu[yr]$為 Gamma 分佈中的形狀參數(shape parameter)和尺度參數(scale parameter)，就長時間平均來說$\Delta\tau$會和Δt相等，然就短時間體積發展的間歇性會隨機的受ν影響。

沖積扇及河床資料彙整－碳14定年法





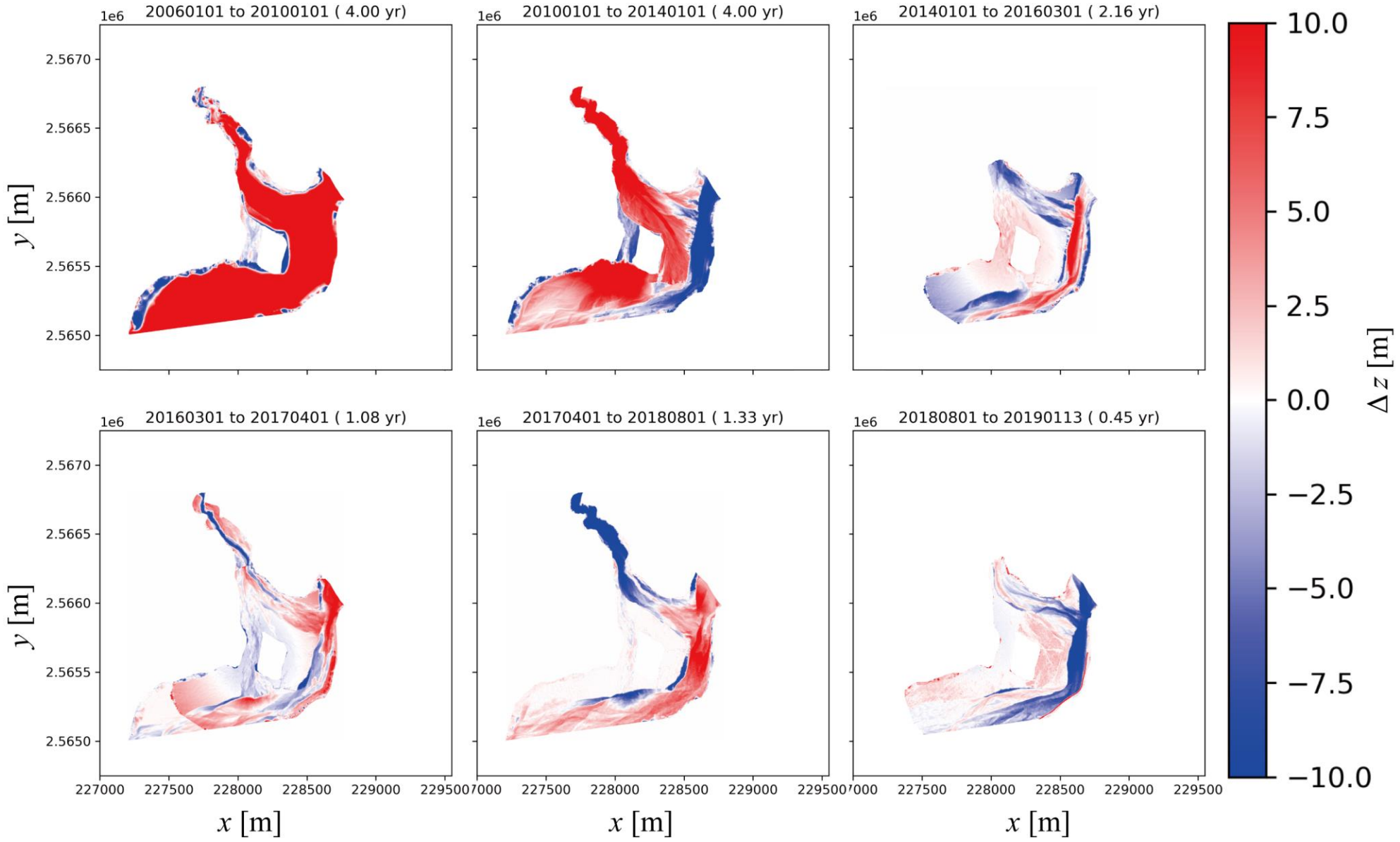
資料來源：Hsieh and Capart, 2013

資料來源：謝孟龍

沖積扇長期率定資料彙整表

名稱	起始時間	結束時間	最大值發生時間	體積［$\times 10^4$ ㎥］
布唐布那斯溪	2006	2009	2007	205
布唐布那斯溪	2006	2023	20170401	2591
玉穗溪(0807)	2006	2023	2021	304
清水溪	2006	2023	2014	754
美秀溪	2006	2023	2009	207
布唐布那斯溪(PT)	BC 0	-	BC 250	1883
清水溪－清水臺與薩巴阿爾臺(CS)	BC 0	-	BC 1250	3278
美秀溪(MS)	BC 0	-	BC 1500	12909
玉穗溪(CSK)	BC 0	-	BC 5800	29084
清水溪(CS higher)	BC 0	-	BC 12300	18479

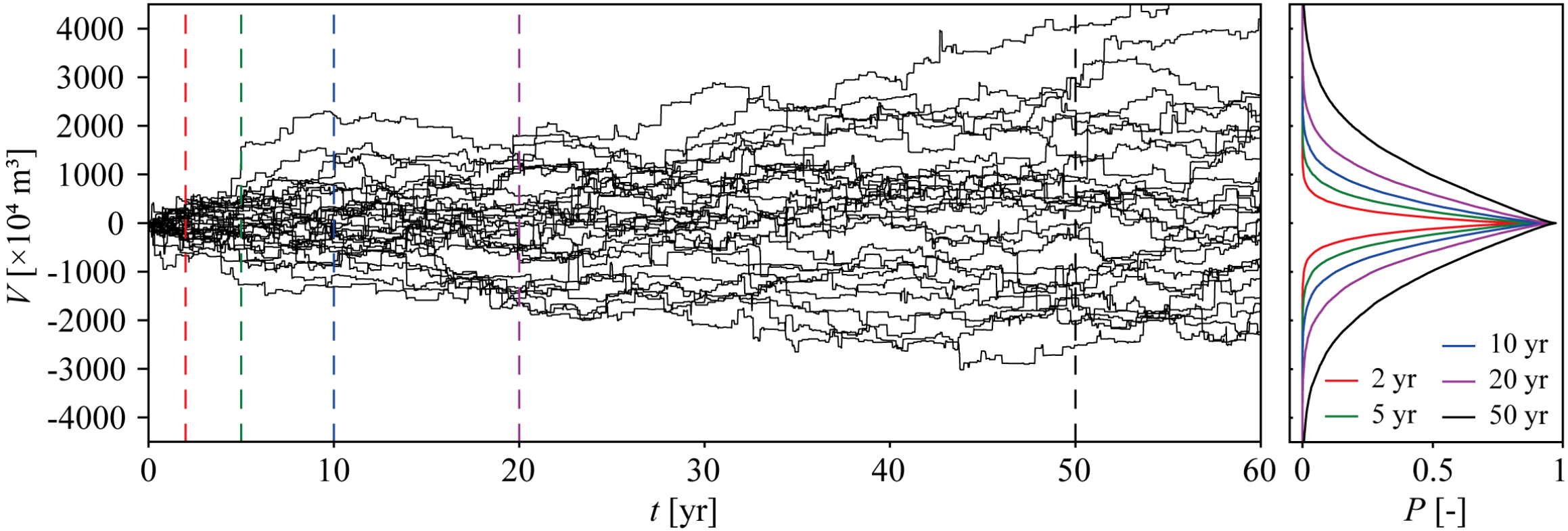
沖積扇短期率定資料


1e6
20060101 to 20100101 (4.00 yr)
20100101 to 20140101 (4.00 yr)
20140101 to 20160301 (2.16 yr)
20160301 to 20170401 (1.08 yr)
20170401 to 20180801 (1.33 yr)
20180801 to 20190113 (0.45 yr)
y [m]
2.5670
2.5665
2.5660
2.5655
2.5650
x [m]
227000
227500
228000
228500
229000
229500
Δz [m]
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0

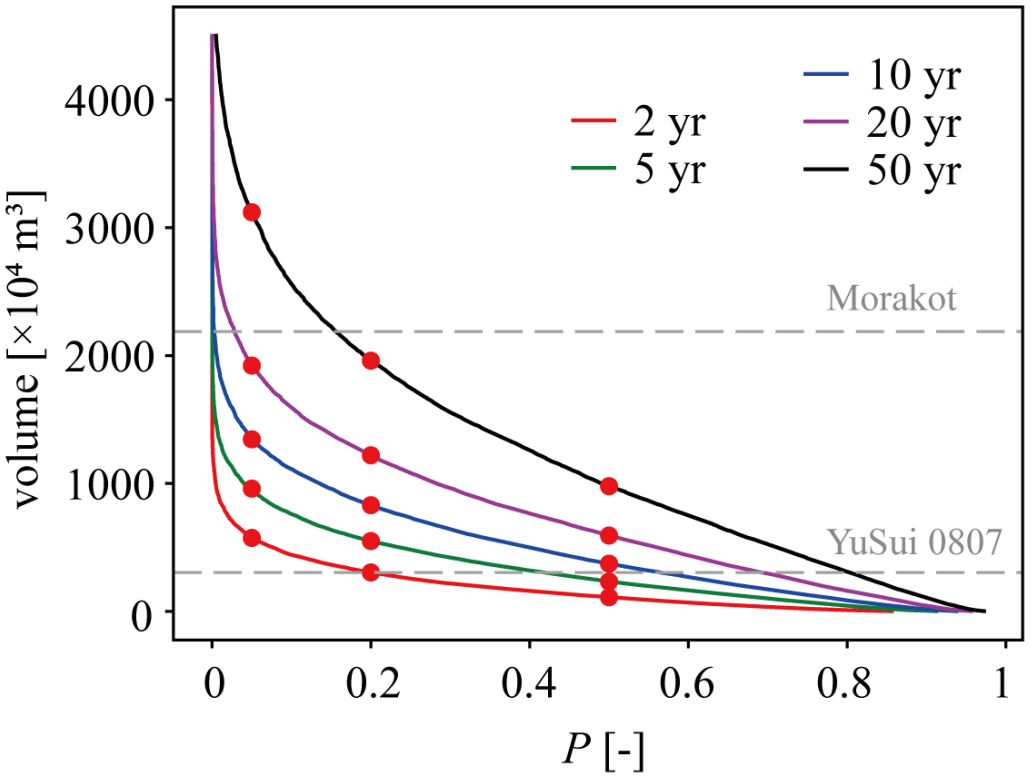
沖積扇短期率定資料彙整表

量測日期	量測日期	時間間格 [year]	淤積體積 [$\times 10^4 m^3$]	沖蝕體積 [$\times 10^4 m^3$]	淨體積 [$\times 10^4 m^3$]
20060101	20100101	4.00	2264	-77	2187
20100101	20140101	4.00	553	-195	357
20140101	20160301	2.16	94	-117	-23
20160301	20170401	1.08	145	-75	70
20170401	20180801	1.33	157	-181	-24
20180801	20190113	0.45	49	-149	-100
20190113	20190717	0.51	14	-25	-11
20190717	20190903	0.13	31	-96	-65
20190903	20191004	0.08	22	-4	18
20191004	20200120	0.30	40	-37	2
20200120	20200308	0.13	31	-12	20
20200308	20200330	0.06	4	-9	-5
20200330	20200629	0.25	10	-14	-3
20200629	20210312	0.70	23	-11	12
20210312	20210528	0.21	3	-8	-5
20210528	20210704	0.10	11	-9	3
20210704	20220123	0.56	169	-103	66

經過率定之沖積扇累積體積時間序列

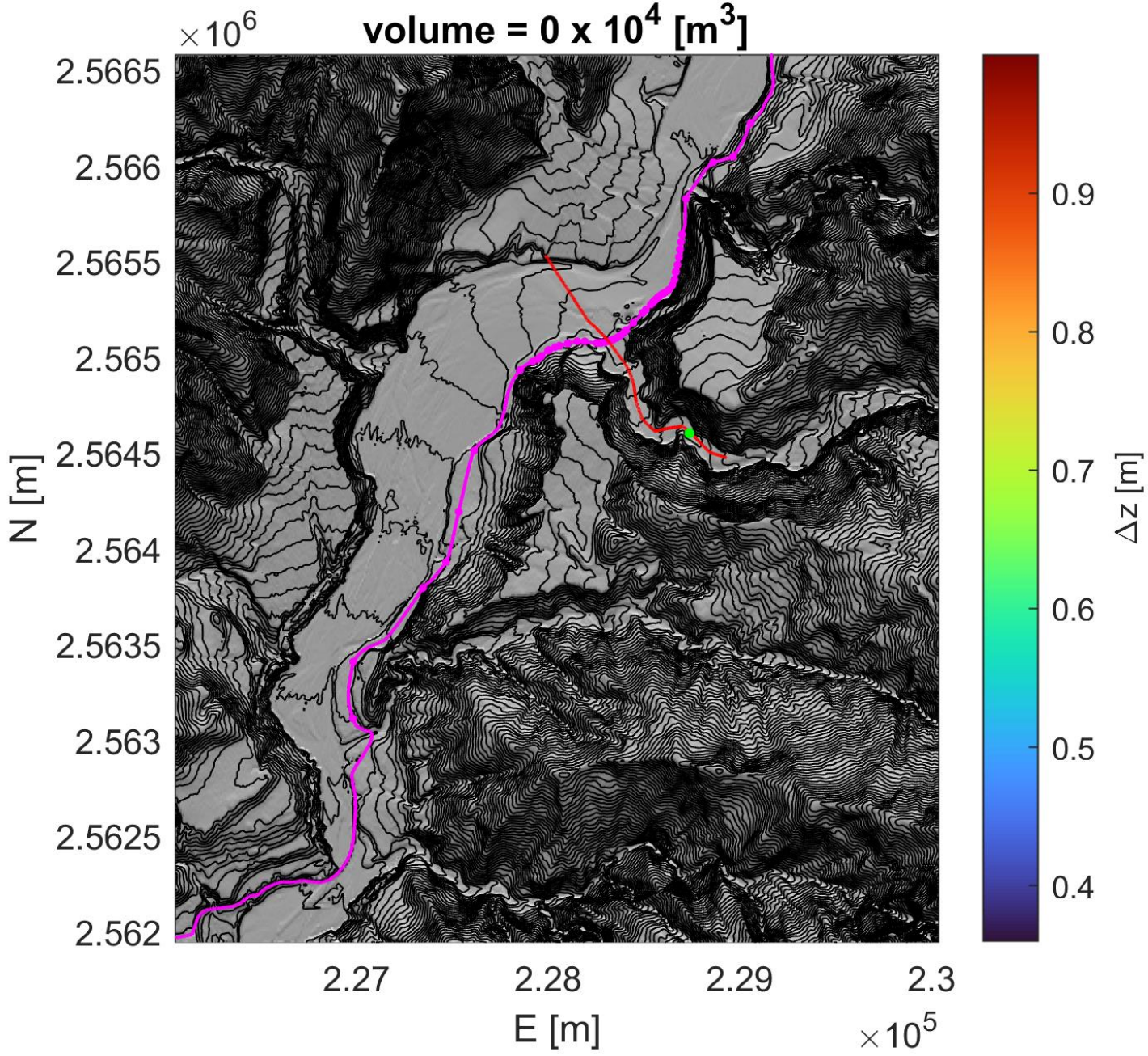


不同時間尺度和破壞機率之累積量體

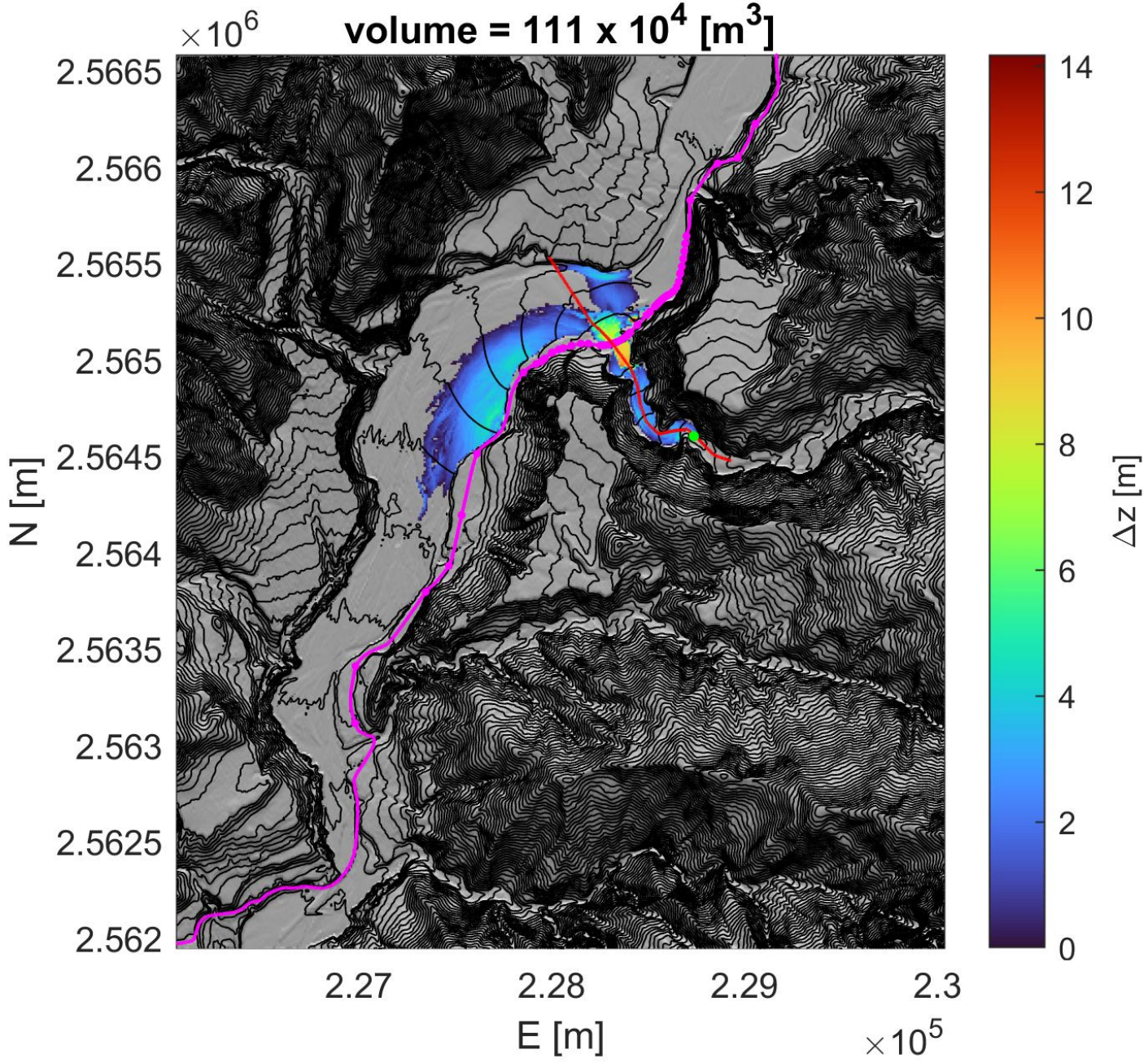


破壞機率[-]	時間尺度 [yr]	沖積扇體積 [× 10^4 m^3]
0.05	2	582
	5	937
	10	1349
	20	1924
	50	3067
0.2	2	305
	5	546
	10	824
	20	1222
	50	1966
0.5	2	110
	5	233
	10	380
	20	583
	50	978

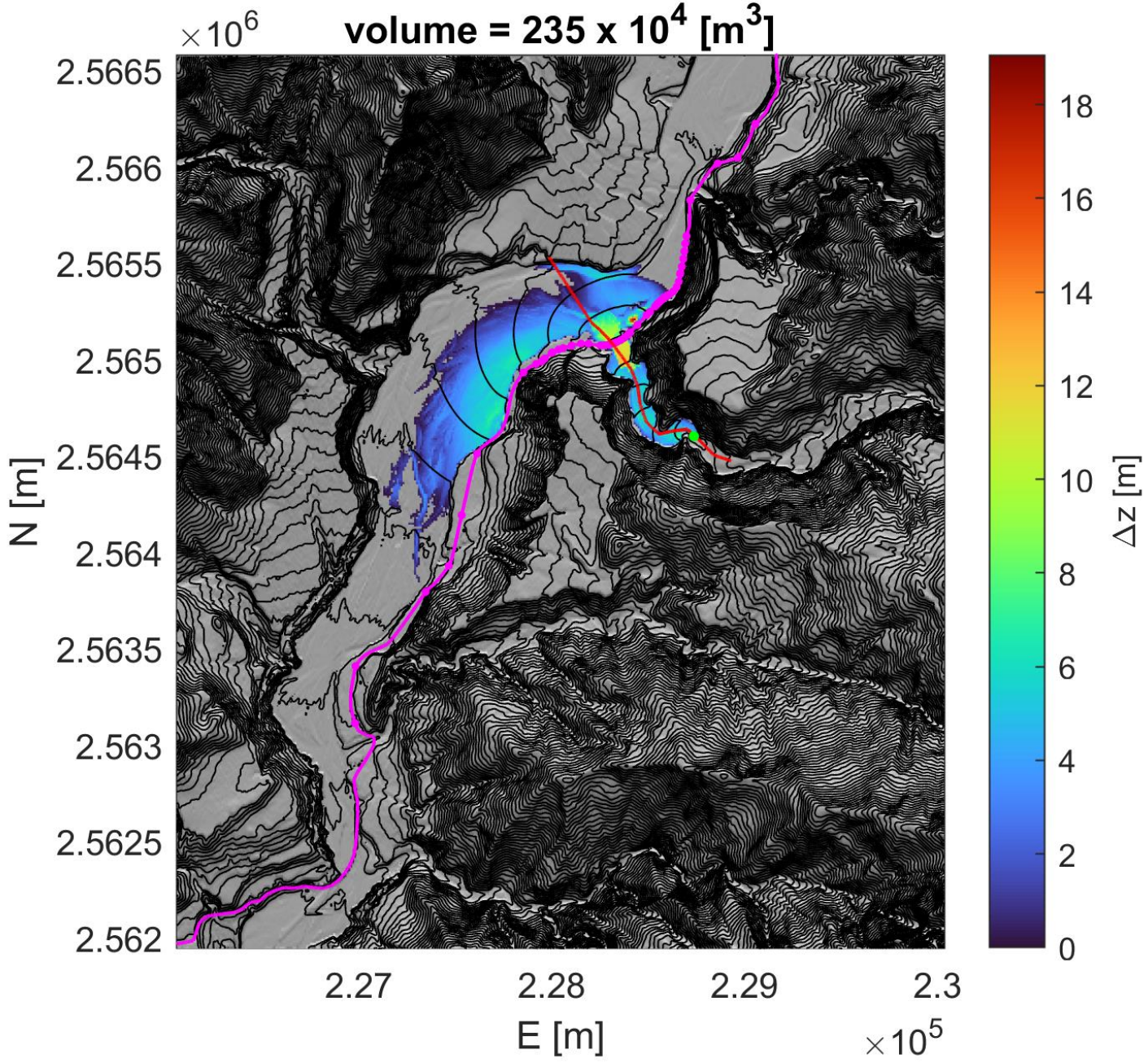
Fan aggradation risk analysis



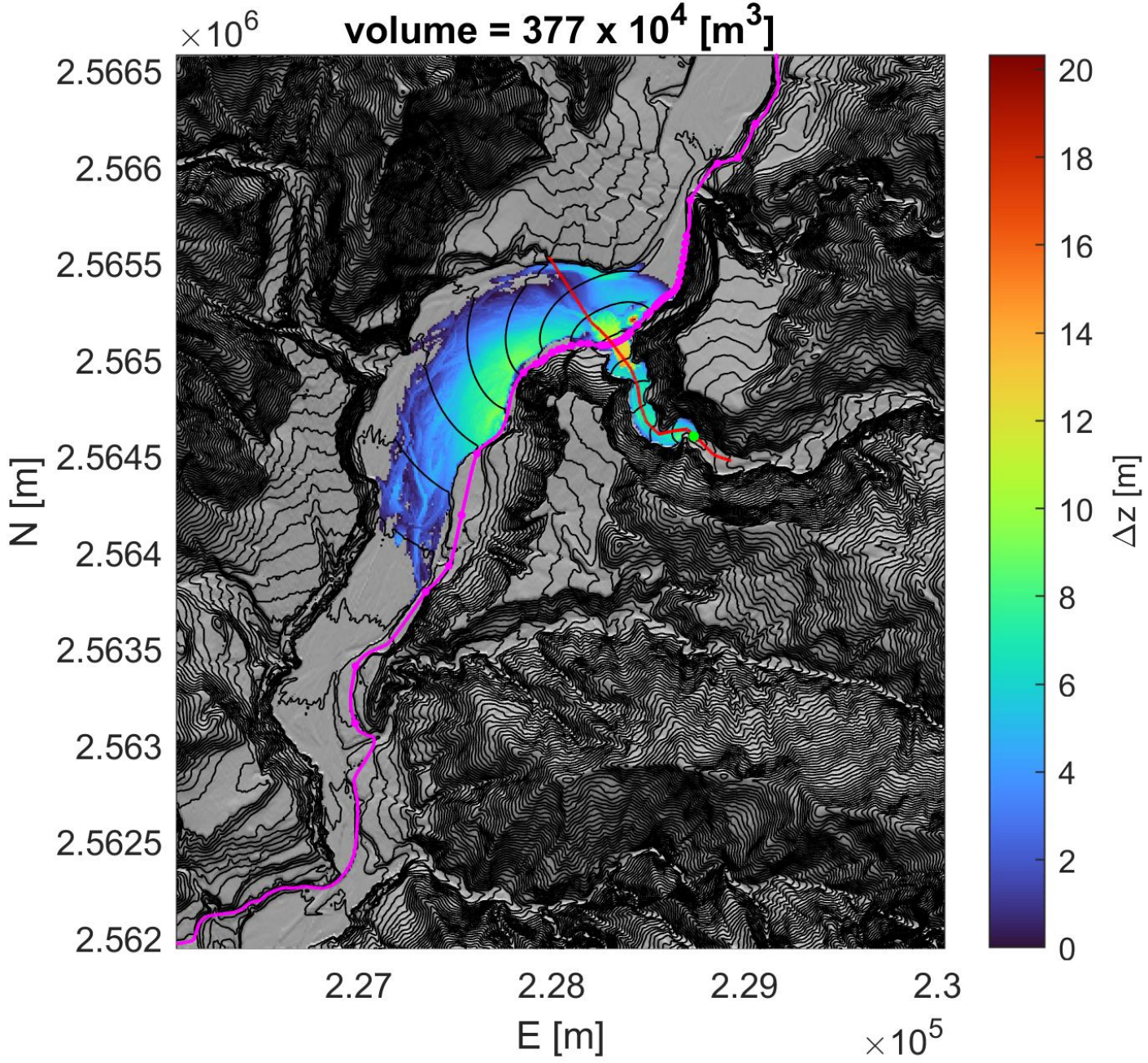
P = 0.5 [-], time = 2 [yr]


volume = 111 x 10^4 [m^3]
×10^6
2.5665
2.566
2.5655
2.565
2.5645
2.564
2.5635
2.563
2.5625
2.562
N [m]
2.27
2.28
2.29
2.3
E [m]
×10^5
14
12
10
8
6
4
2
0
Δz [m]

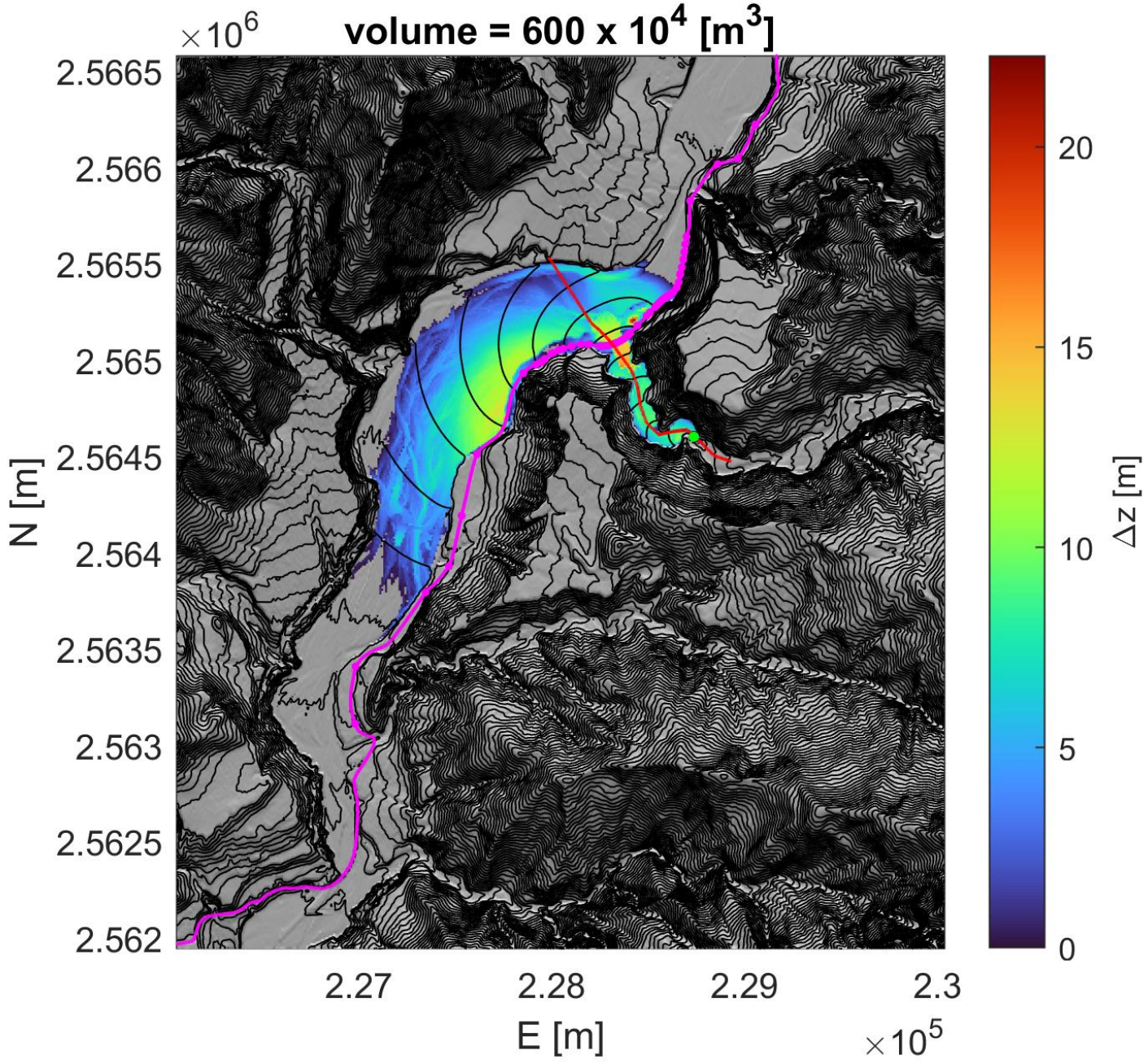
P = 0.5 [-], time = 5 [yr]


volume = 235 x 10^4 [m^3]
×10^6
2.5665
2.566
2.5655
2.565
2.5645
2.564
2.5635
2.563
2.5625
2.562
N [m]
2.27
2.28
2.29
2.3
E [m]
×10^5
18
16
14
12
10
8
6
4
2
0
Δz [m]

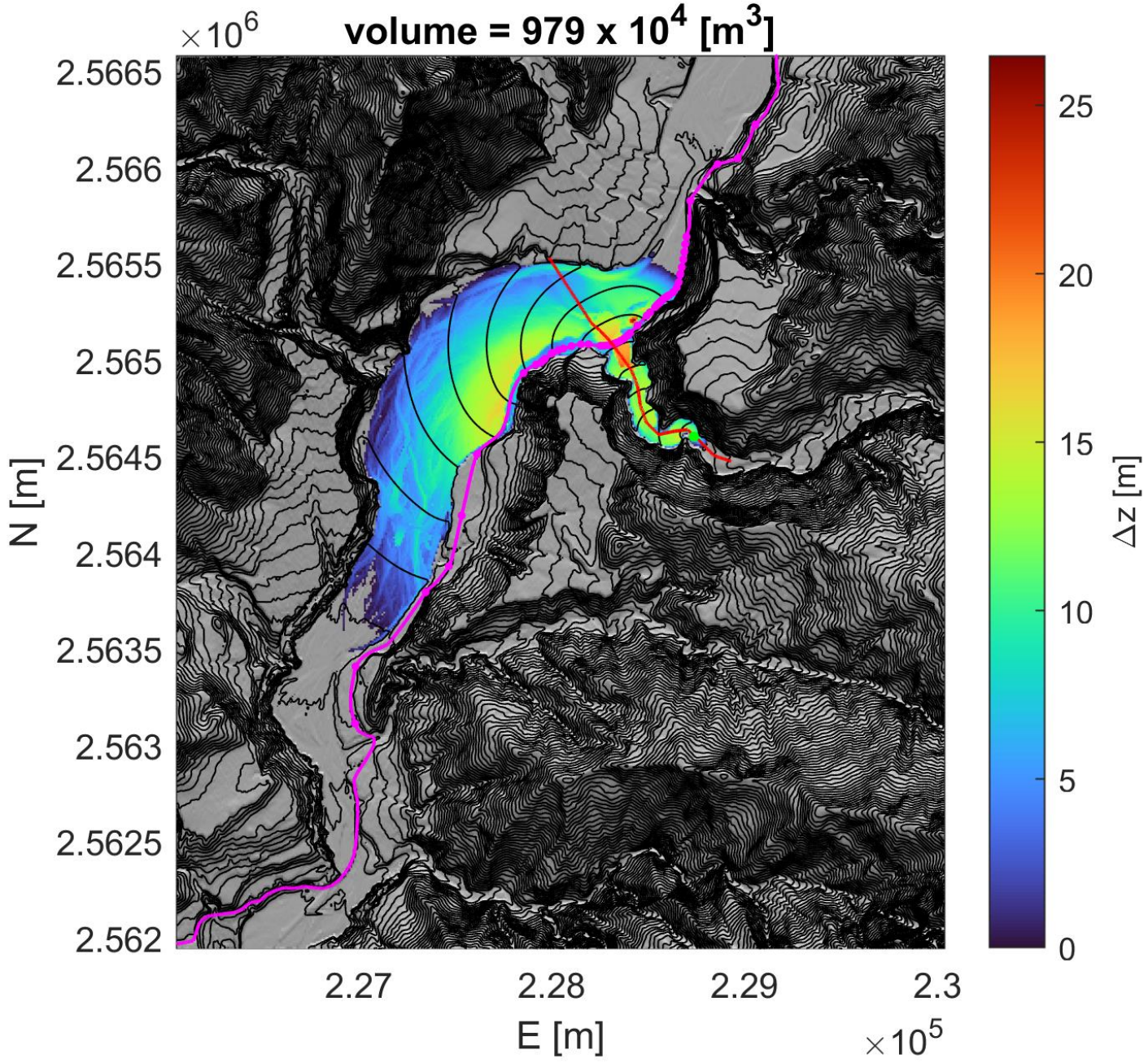
P = 0.5 [-], time = 10 [yr]

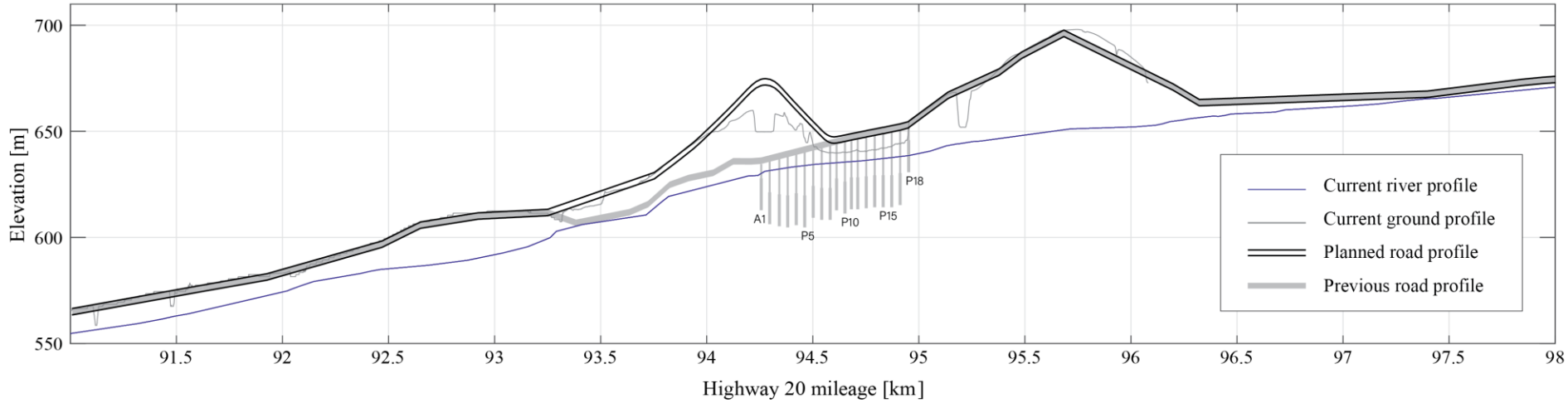


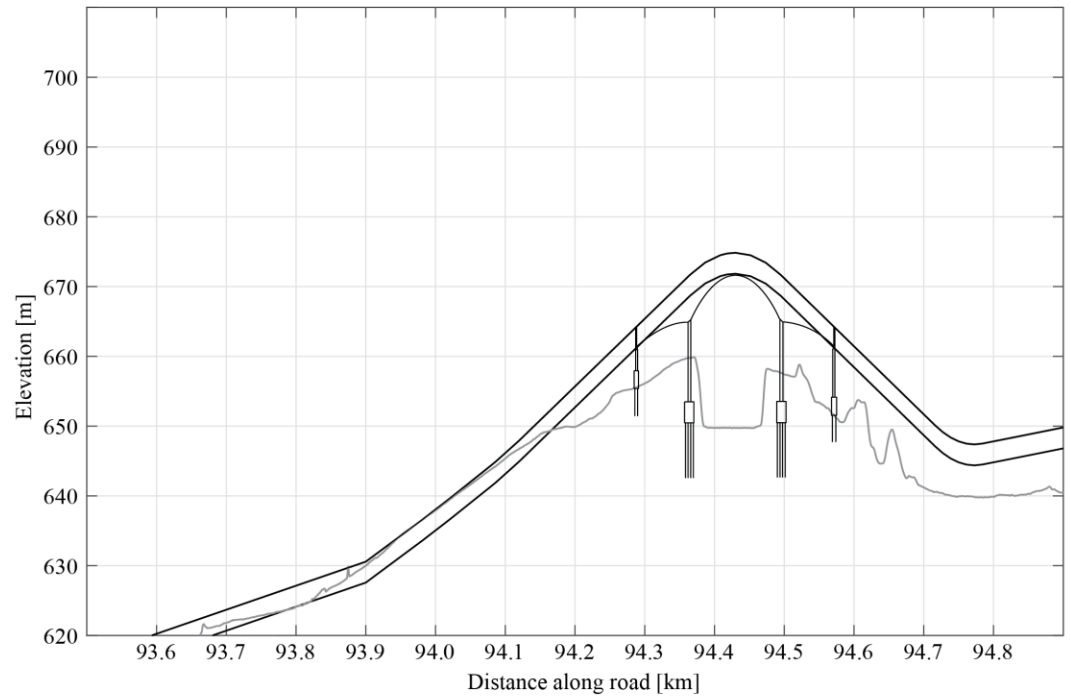
P = 0.5 [-], time = 20 [yr]

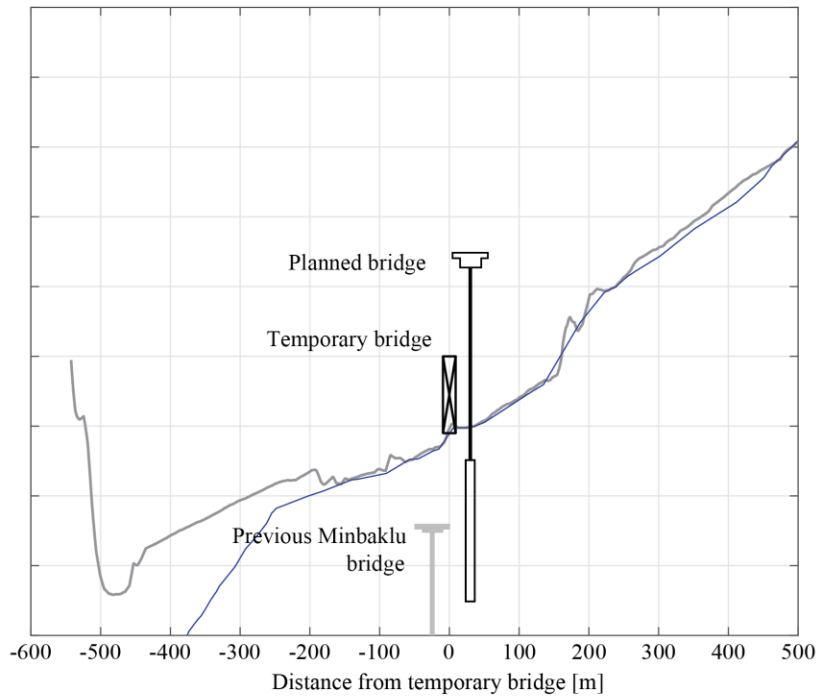


P = 0.5 [-], time = 50 [yr]

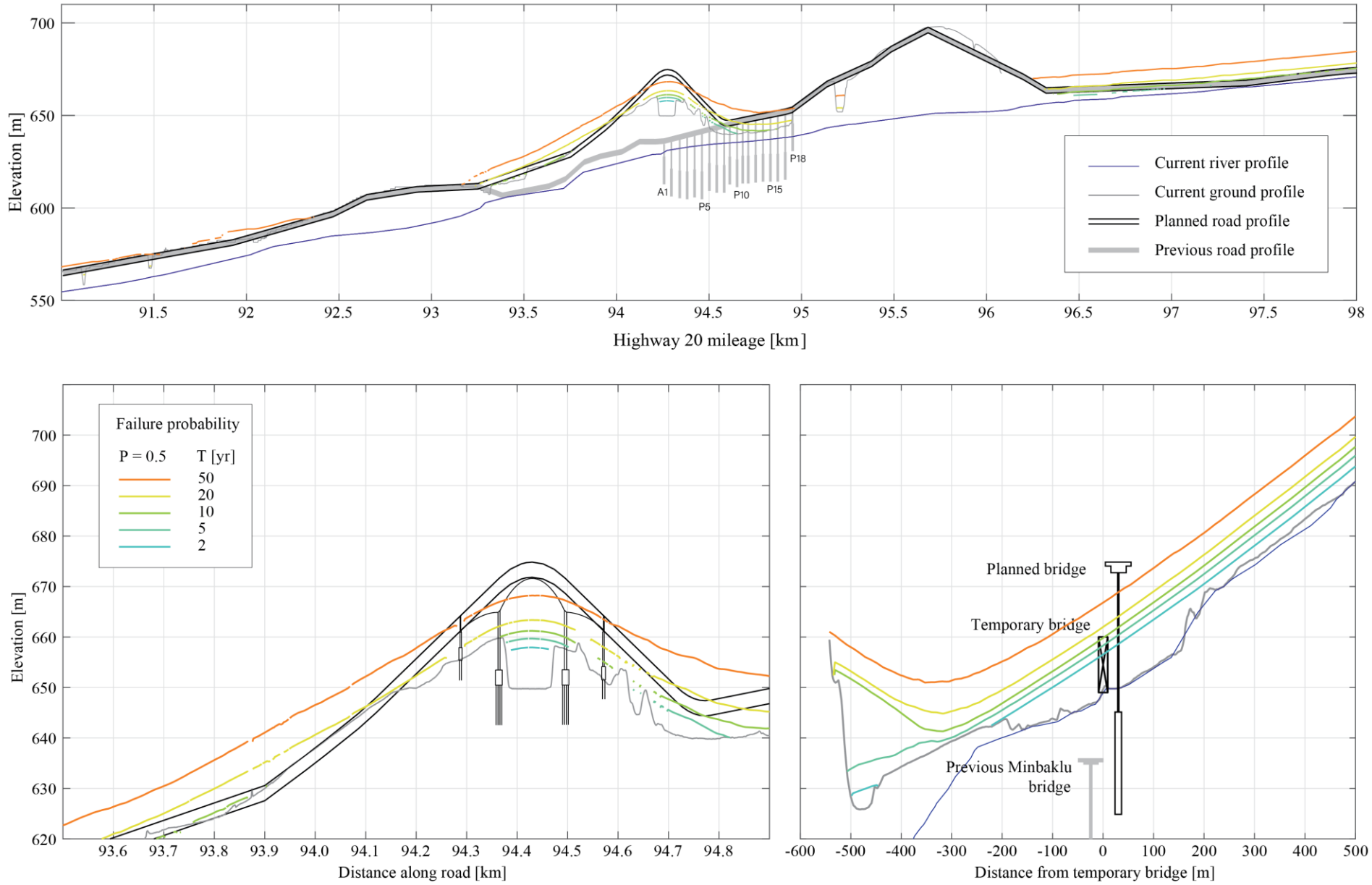



Elevation [m]
700
650
600
550
91.5
92
92.5
93
93.5
94
94.5
95
95.5
96
96.5
97
97.5
98
Highway 20 mileage [km]
A1
P5
P10
P15
P18
Current river profile
Current ground profile
Planned road profile
Previous road profile


Elevation [m]
700
690
680
670
660
650
640
630
620
93.6
93.7
93.8
93.9
94.0
94.1
94.2
94.3
94.4
94.5
94.6
94.7
94.8
Distance along road [km]

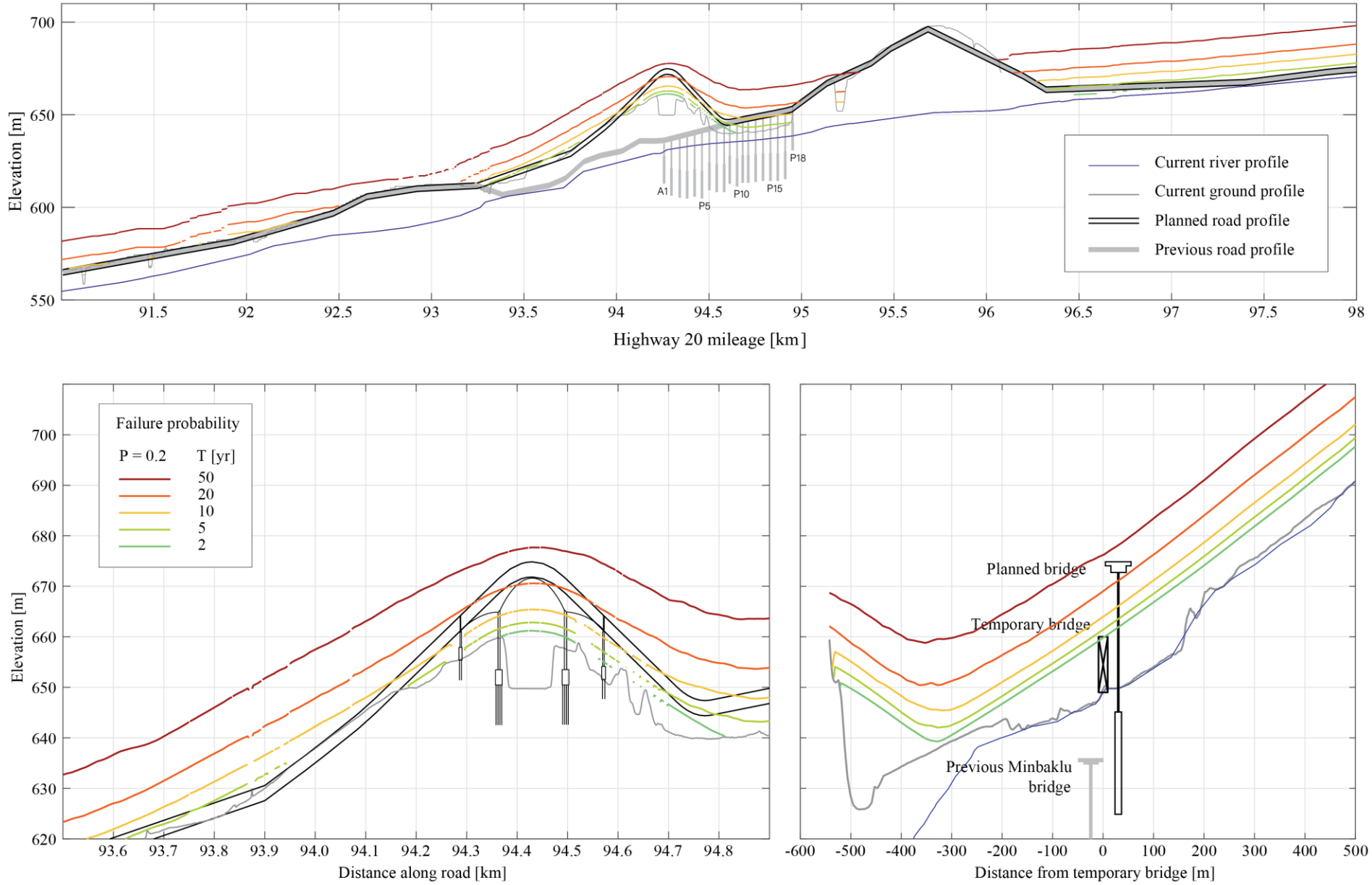

Planned bridge
Temporary bridge
Previous Minbaklu bridge
-600
-500
-400
-300
-200
-100
0
100
200
300
400
500
Distance from temporary bridge [m]

資料來源：台灣世曦



多沖積扇與主流淤高, P = 0.5

資料來源：台灣世曦



多沖積扇與主流淤高, P = 0.2

資料來源：台灣世曦

Outline

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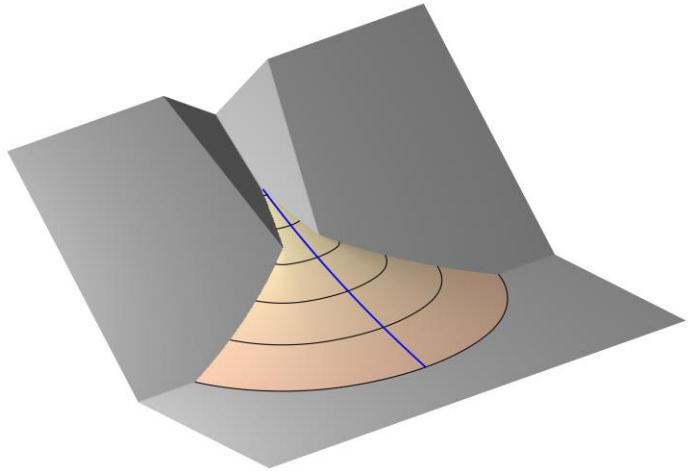
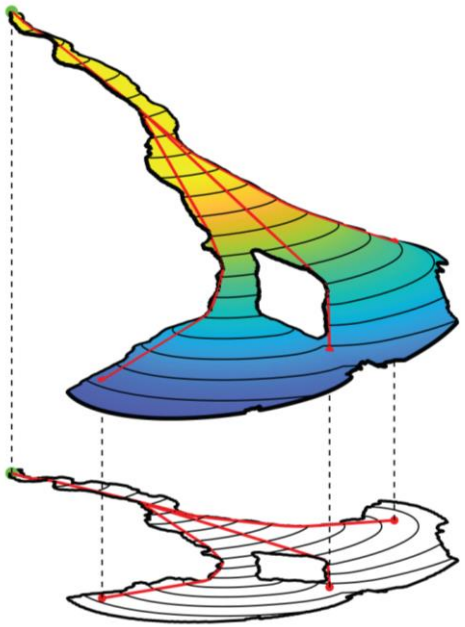
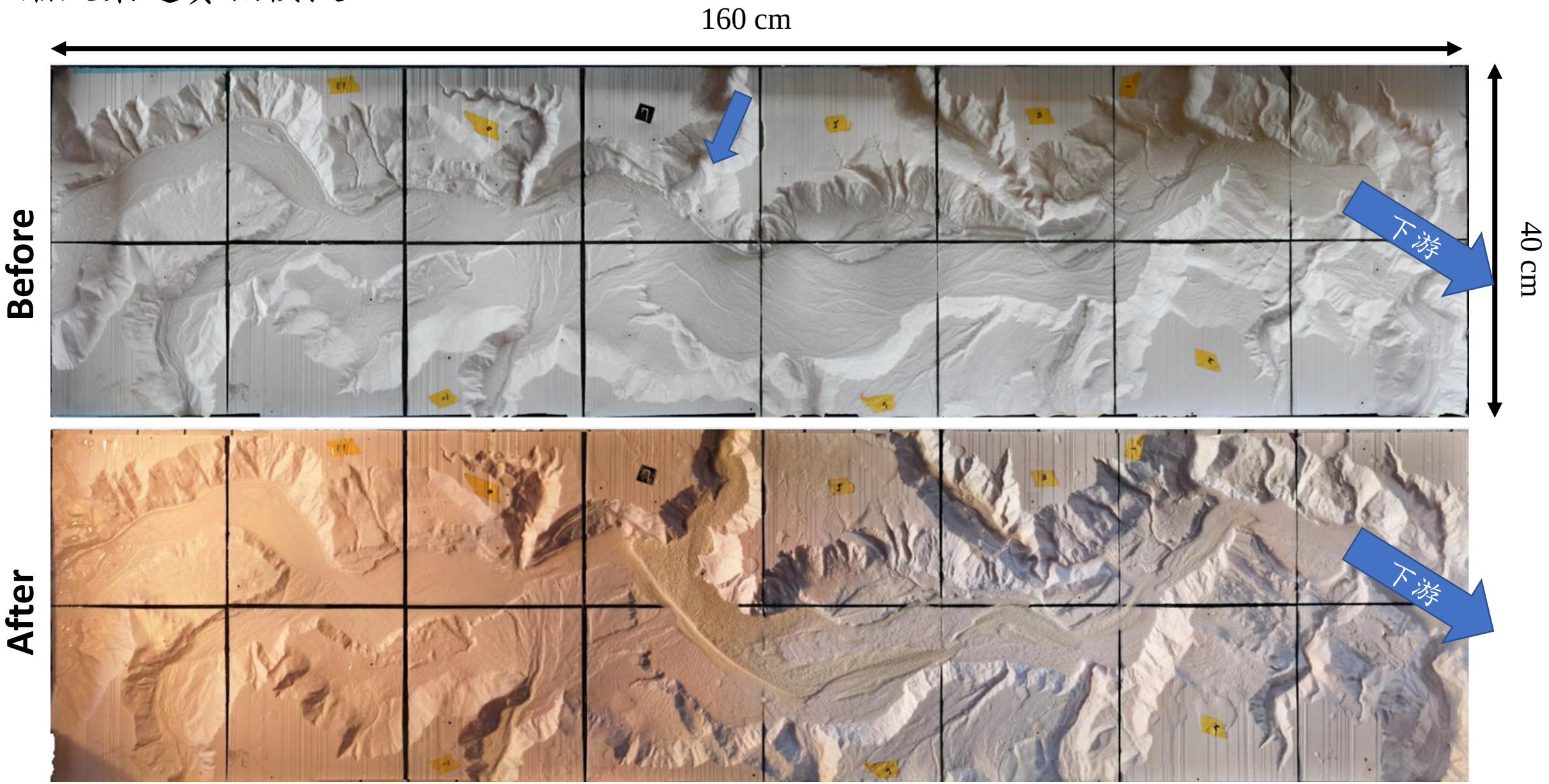




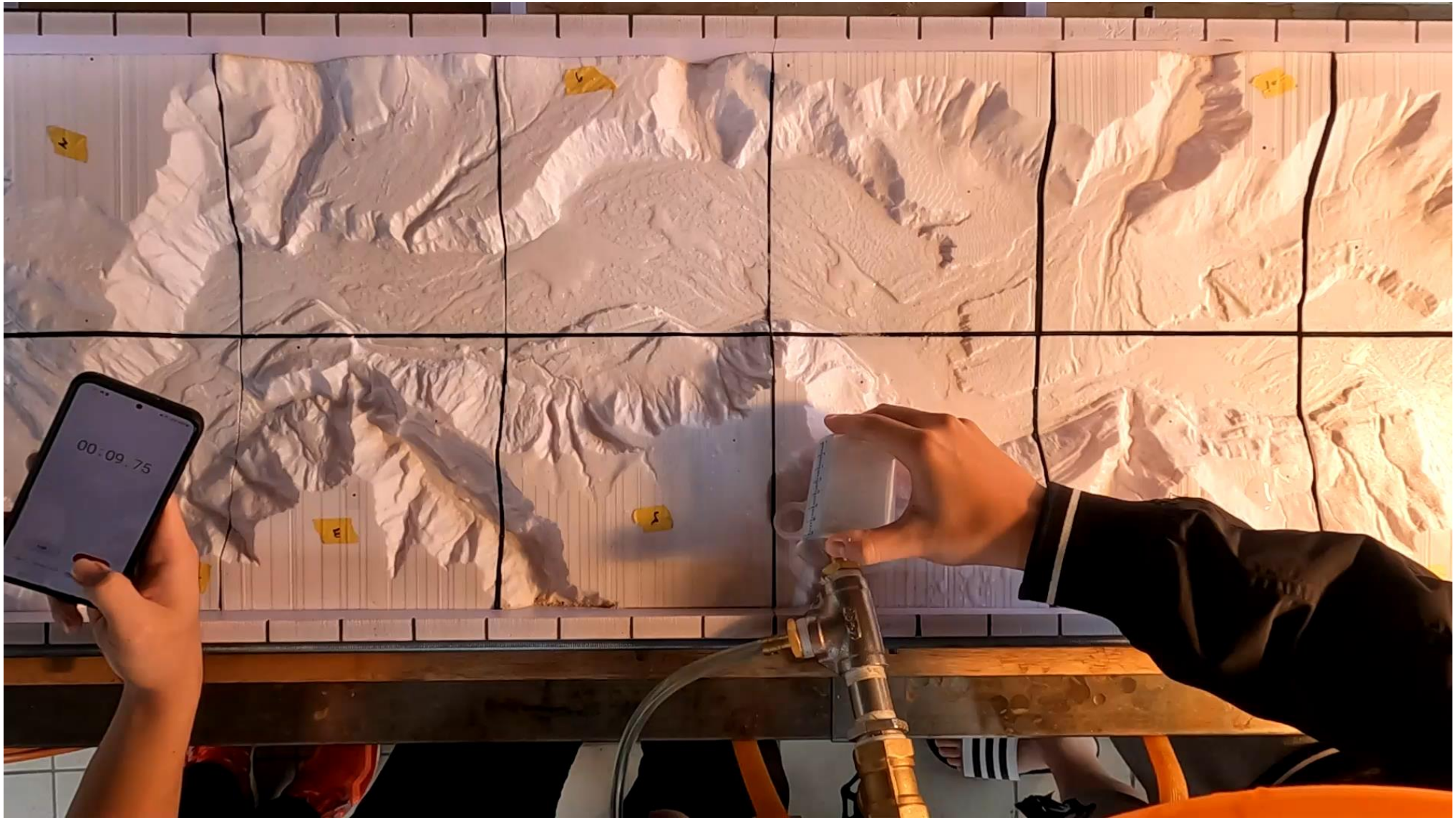
縮尺渠道實驗模擬



資料來源：112-1 Capstone 學生團隊 李怡萱、張晟祐、林植杰、陳迪耀、江翰霖

模型尺度：1:5000

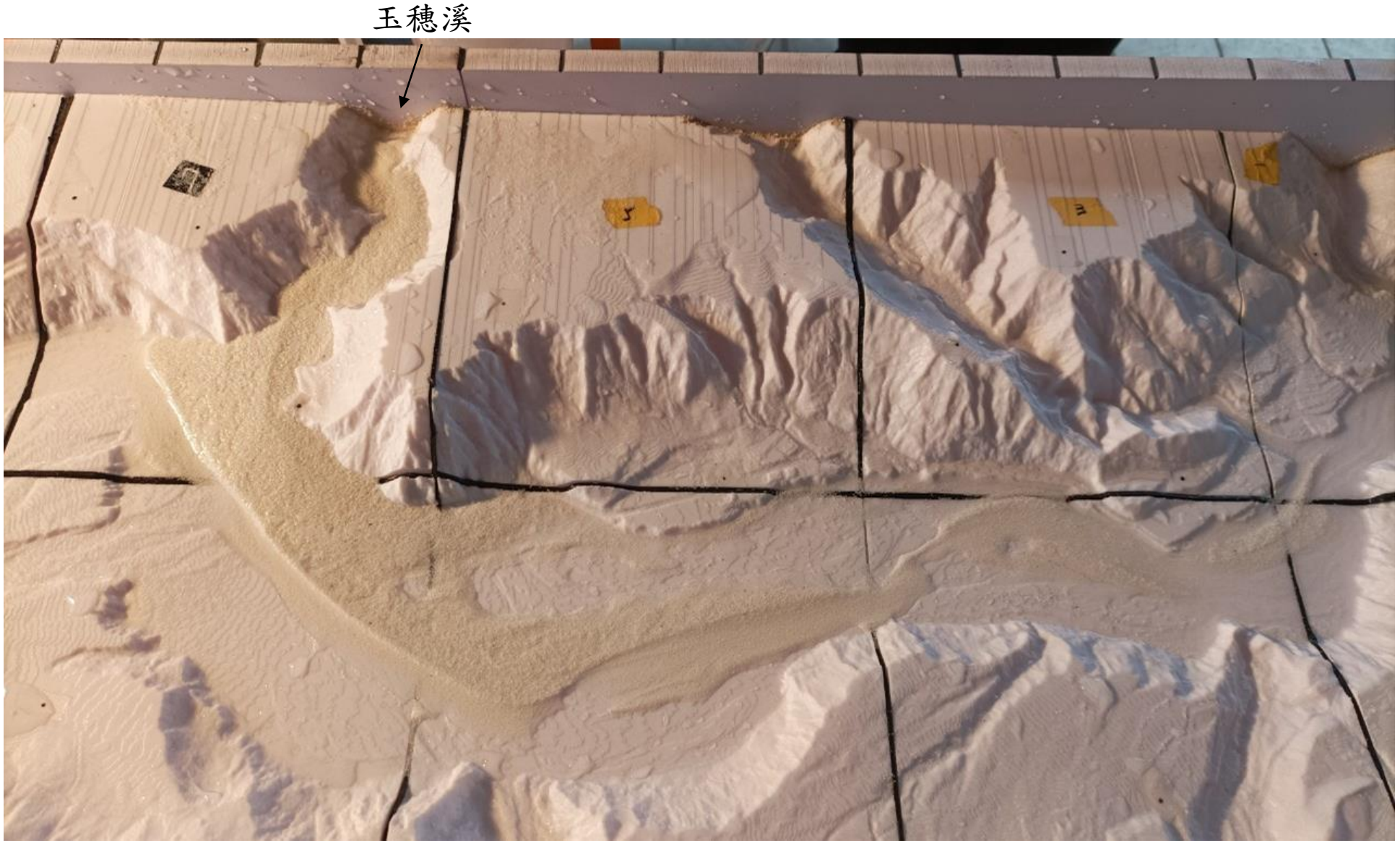
實驗影片



資料來源：112-1 Capstone 學生團隊 李怡萱、張晟祐、林植杰、陳迪耀、江翰霖

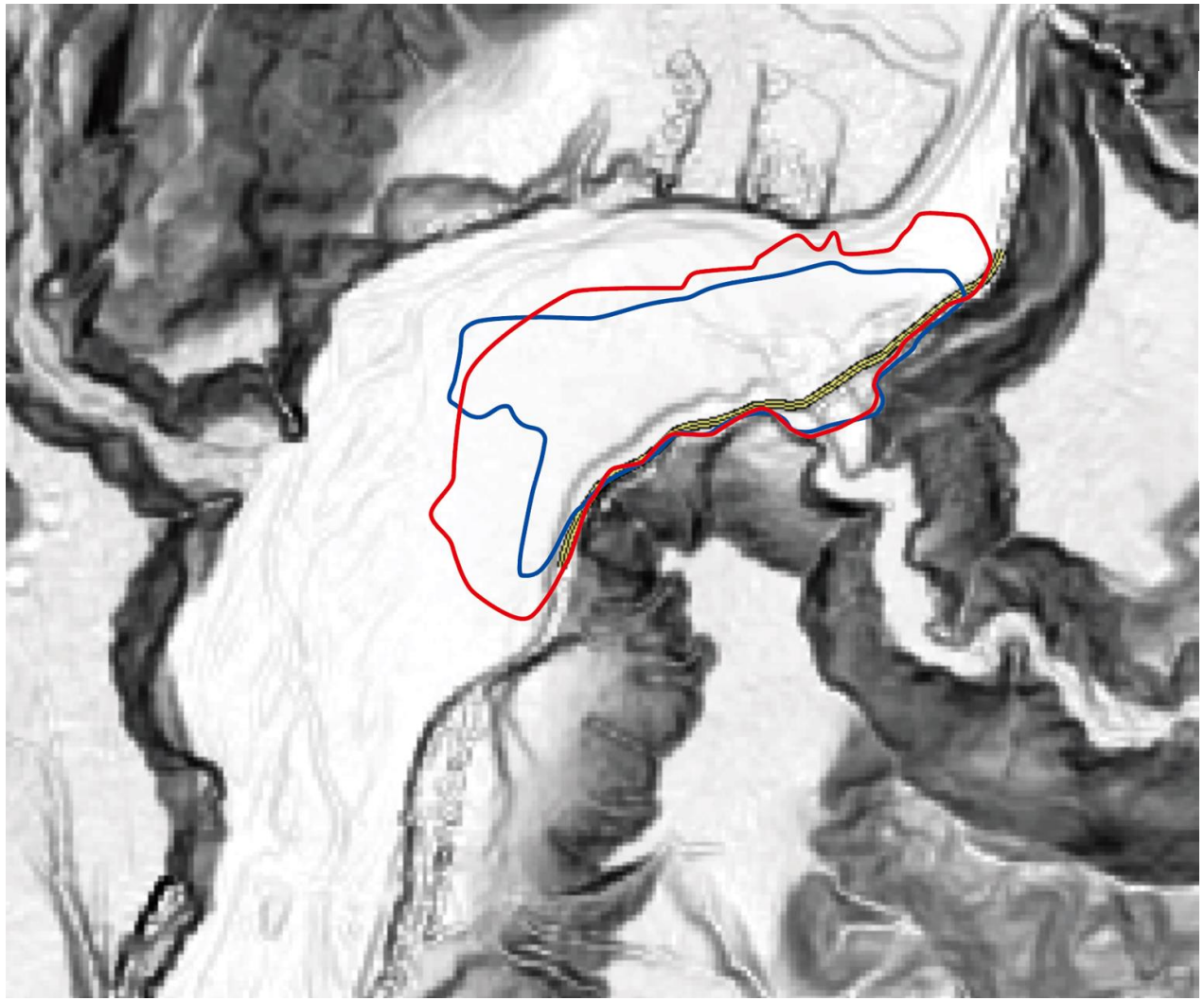


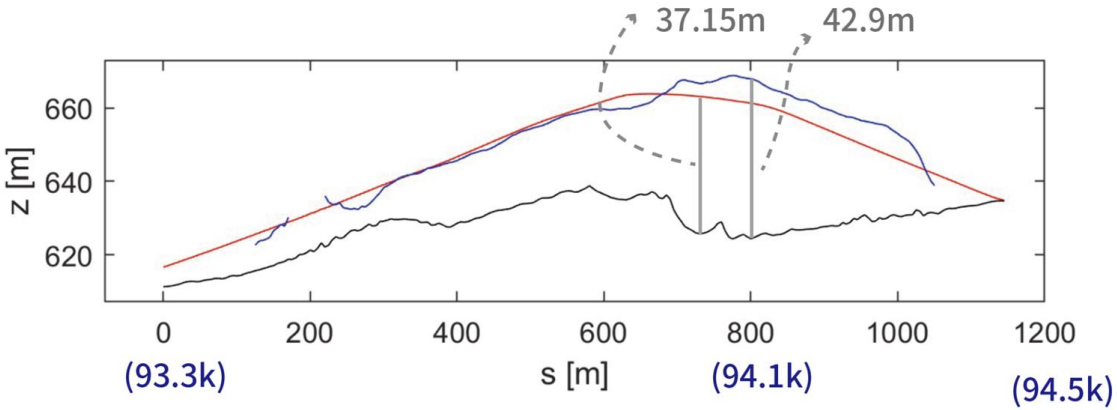
實驗模擬結果



資料來源：112-1 Capstone 學生團隊 李怡萱、張晟祐、林植杰、陳迪耀、江翰霖

實驗結果與模擬結果比較





Visibility Polygan Method

實驗

highway20 (2017)

資料來源：112-1 Capstone 學生團隊 李怡萱、張晟祐、林植杰、陳迪耀、江翰霖





資料來源：林倍辰 碩士論文

Thank you!

Reference

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