산사태 위험도 평가모형 (TiVaSS) 및 토석류 모형 (Deb2D) 개발

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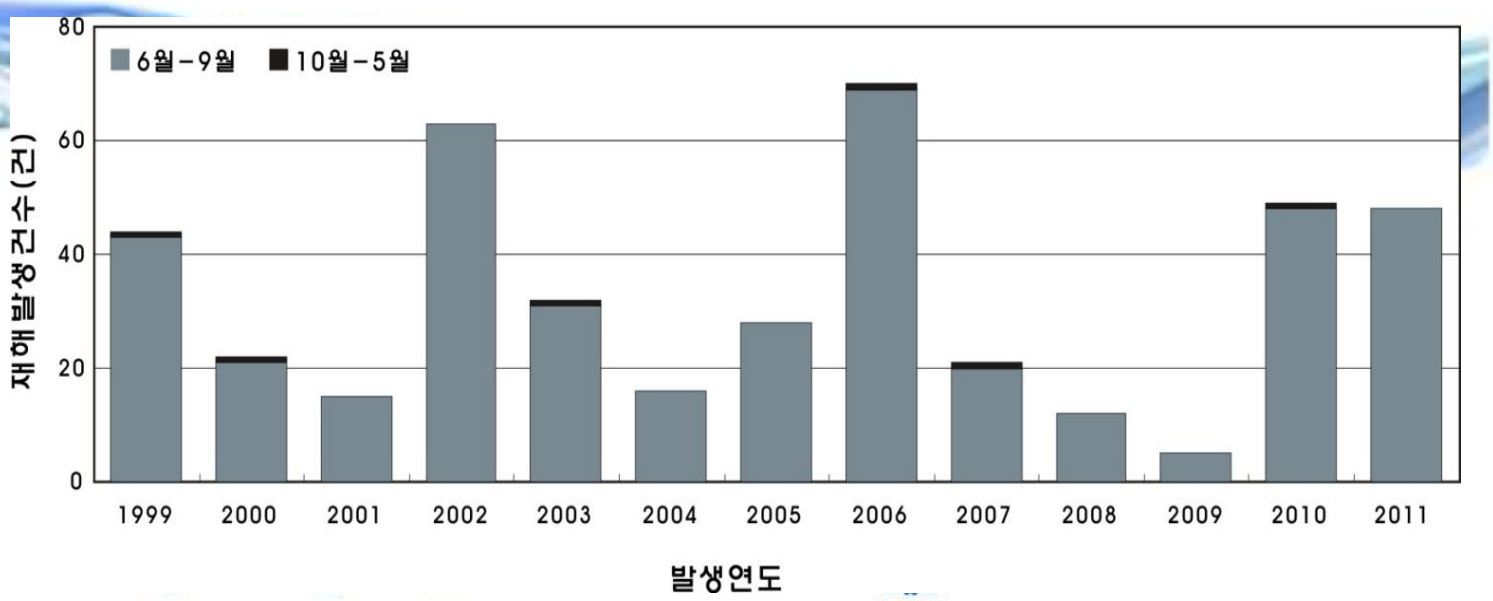
Background




Eearthquake

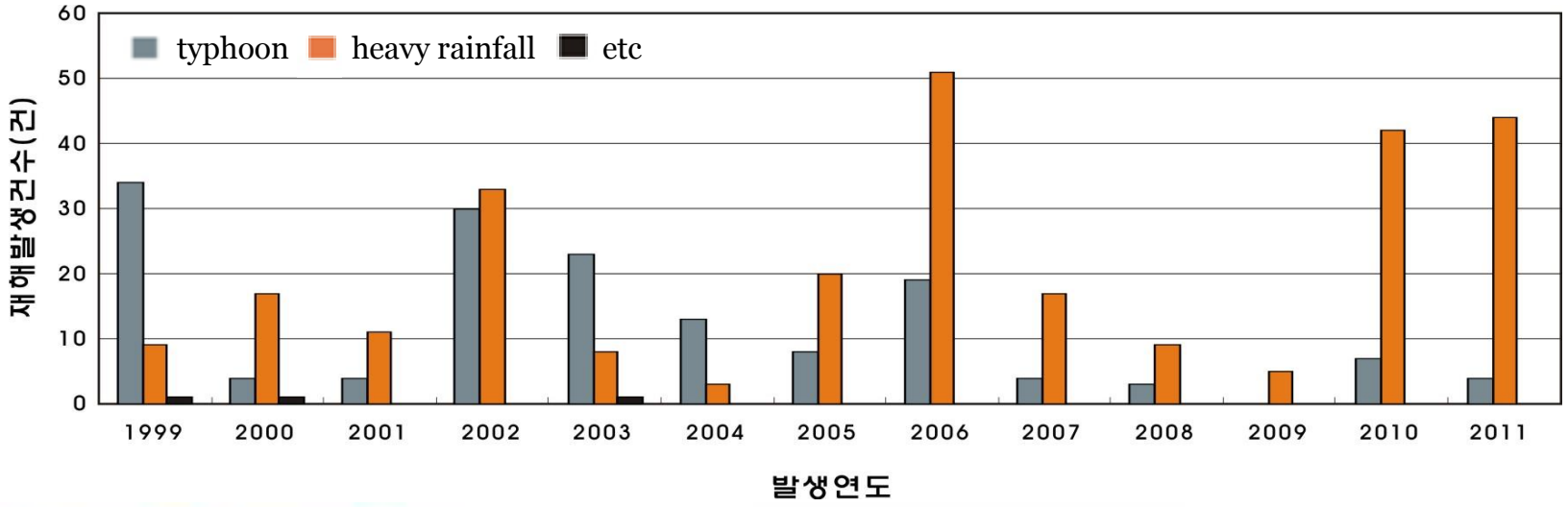
Rainfall



급경사지 재해의 대부분은
6-9월(우기)에 집중됨

출처: 2012년 자연재해저감기술개발사업, 집중호우를 고려한 급경사지 재해위험도 정밀평가기법 및 지반재해위험지도 개발 발표자료

Background



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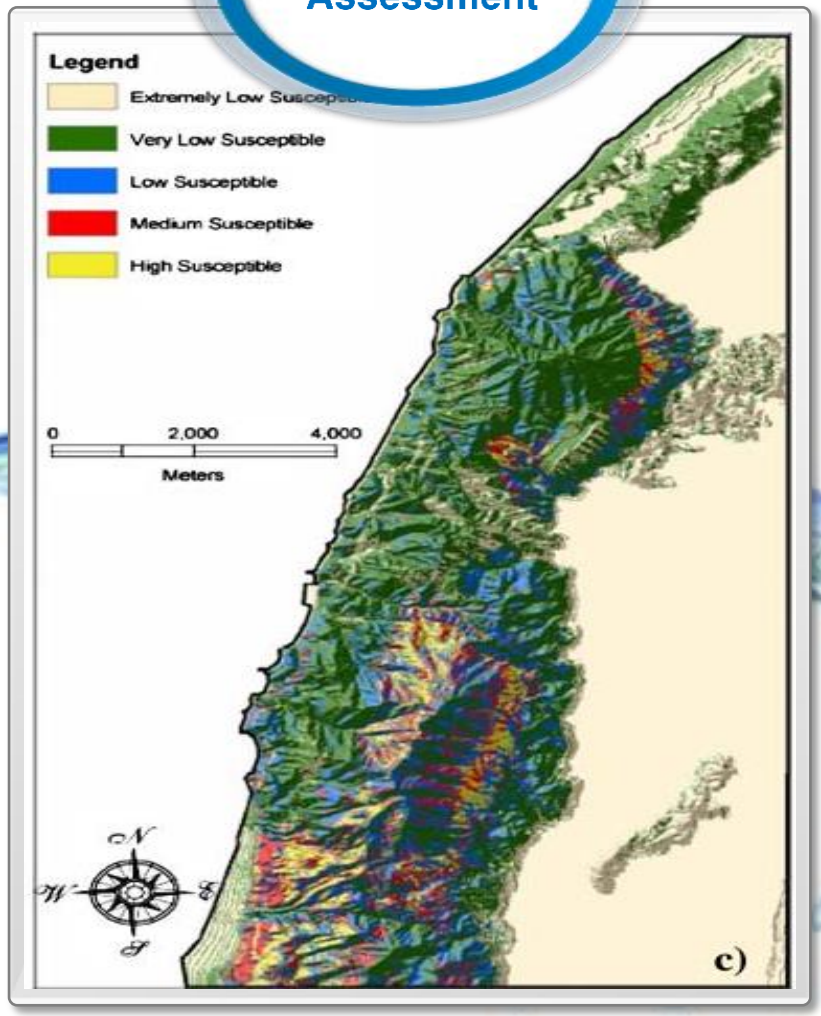
출처: 2012년 자연재해저감기술개발사업, 집중호우를 고려한 급경사지 재해위험도 정밀평가기법 및 지반재해위험지도 개발 발표자료

Topics

Landslide Risk Assessment



Debris Flow Damage

Landslide Risk Assessment method

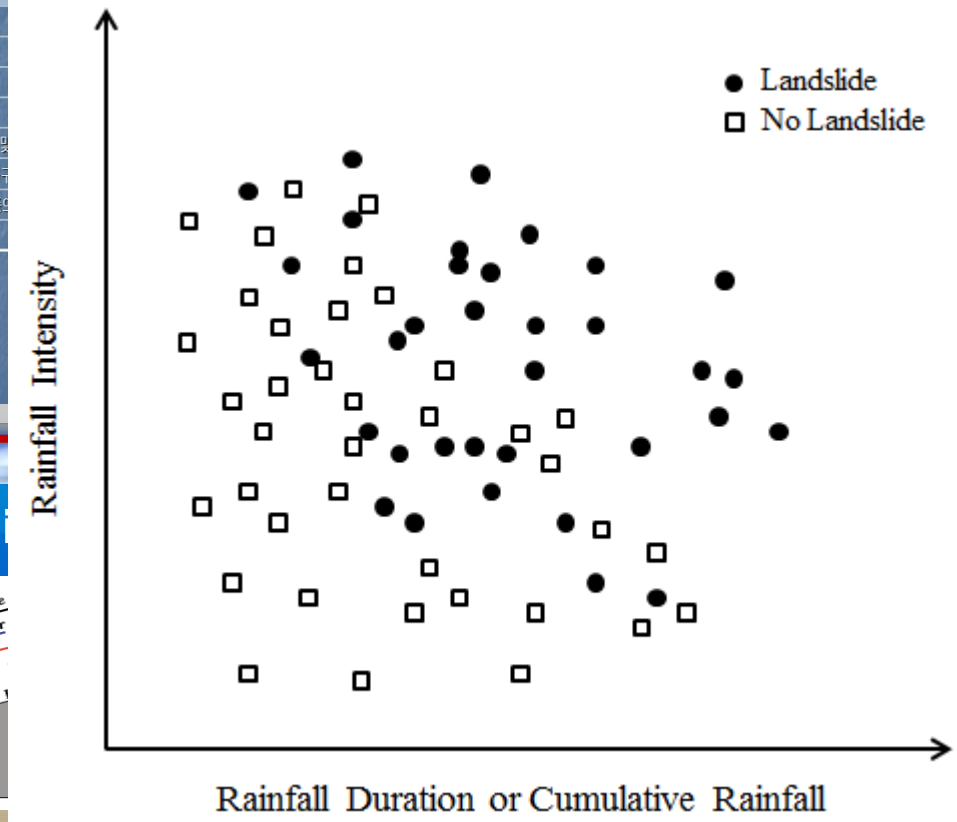
Empirical Method

구분		배점	구분		배점
붕괴위험성	경사길이	20	붕괴위험성	임상	
	사면높이	20		사면형	
	강우강도	20		토심	
	연간강우량	20		경사도	
	지속강우일	20	사회적 영향성	주변환경(구조물및	
	붕괴 이력	20		인가호수(가구	
	모암	20		인가·공공시설 등	
	사면 내 붕괴예상범위	20			

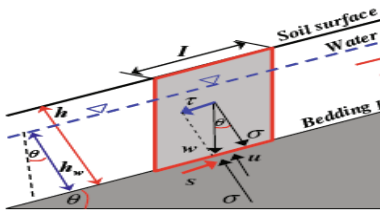
- 붕괴위험도 등급
  - A(0~100) : 붕괴위험성 없음
  - B(101~150) : 붕괴위험성 거의 없음
  - C(151~200) : 붕괴위험성 있음
  - D(201~250) : 붕괴위험성 높음
  - E(251이상) : 붕괴위험성 매우 높음

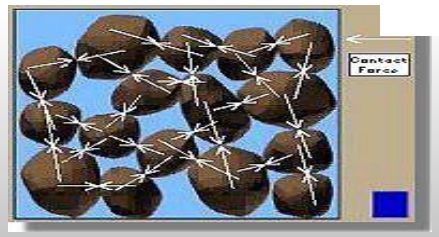
Process-based Method

- 위험요소와 붕괴 사이의 통계적 분석을 통해 위험도를 평가
- 이변량 or 다변량 통계 분석
- logistic regression, ANN, GA, etc



Determini



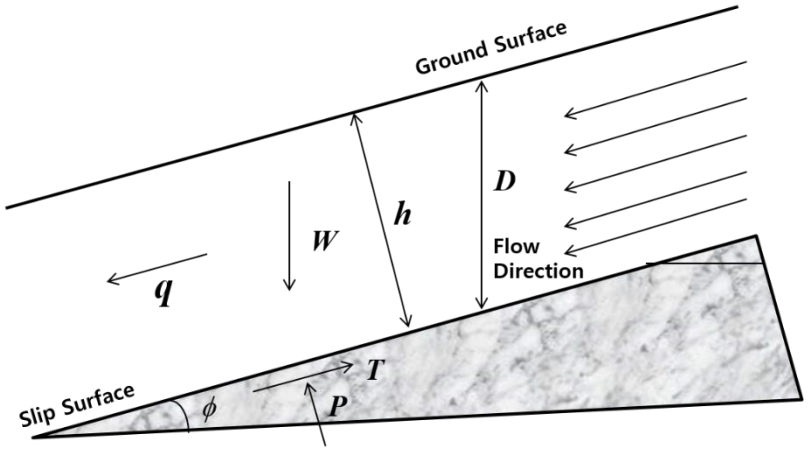


- 사면의 붕괴메커니즘을 고려
- 자료의 불확실성(?)

ence timing

- Decreasing reliability of landslide warming

Deterministic (Physical) Method



Factor of Safety

$$FS = -\frac{\psi S_e \gamma_w \tan\varphi}{\gamma_s D \sin\phi\cos\phi} + \frac{\tan\varphi}{\tan\phi} + \frac{c}{\gamma_s D \sin\phi\cos\phi}$$

ψ : pore water pressure head (m)

Subsurface water movement
- Richards Eq.

$$\frac{\partial\theta}{\partial t} - \nabla\cdot\left(K\nabla\left(\psi + z\right)\right) = 0$$

3D-model

$$\frac{\partial\theta}{\partial t} - \frac{\partial}{\partial z}\left(K\frac{\partial\left(\psi + z\right)}{\partial z}\right) = 0$$

1D-model

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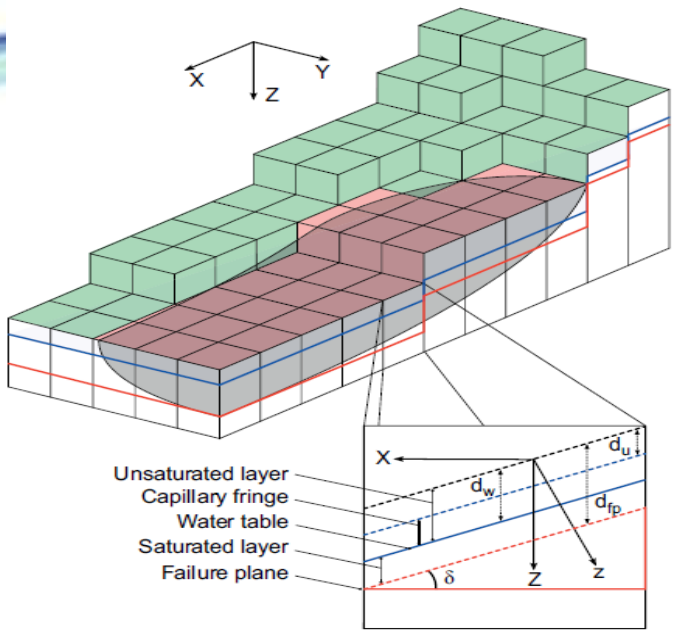
Deterministic (Physical) Method

$$\frac{\partial \theta}{\partial t} - \frac{\partial}{\partial z}\left(K \frac{\partial (\psi + z)}{\partial z} \right) = 0$$

Assumption & linearization

1D analytical solution

TRIGRS
(Iverson, 2000; Baum et al., 2008)

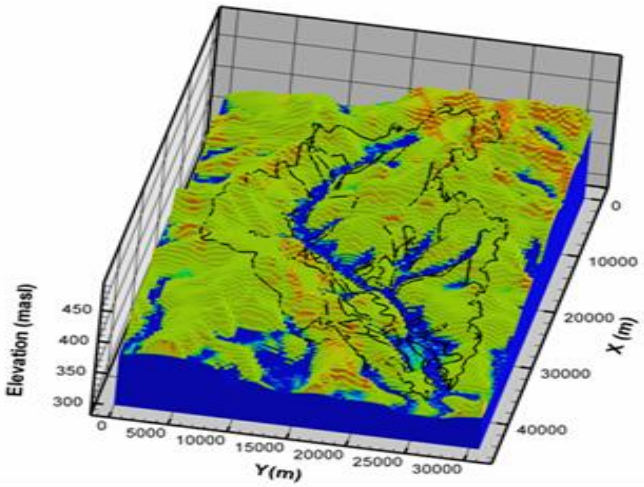


$$\frac{\partial \theta}{\partial t} - \nabla \cdot \left(K \nabla (\psi + z) \right) = 0$$

Numerical method

3D numerical solution

Target



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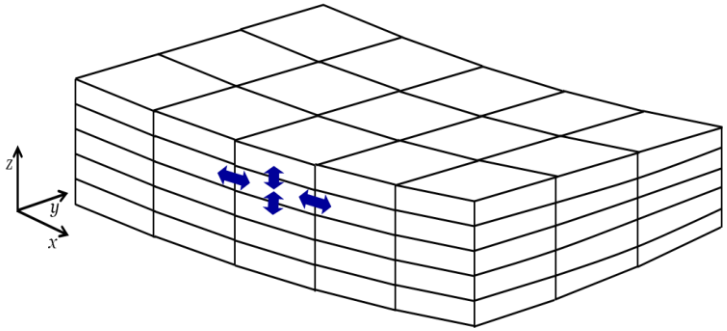
Numerical solver of 3D subsurface flow



Assumtion

- The effect of horizontal flow is not significant as compared with vertical flow

Usual discretization (full implicit, backward Euler)

$$\frac{\theta^{n+1}-\theta^{n}}{\Delta t}-\frac{\partial}{\partial x}\left(K\frac{\partial \psi^{n+1}}{\partial x}\right)-\frac{\partial}{\partial y}\left(K\frac{\partial \psi^{n+1}}{\partial y}\right)-\frac{\partial}{\partial z}\left(K\frac{\partial\left(\psi^{n+1}+z\right)}{\partial z}\right)=0$$

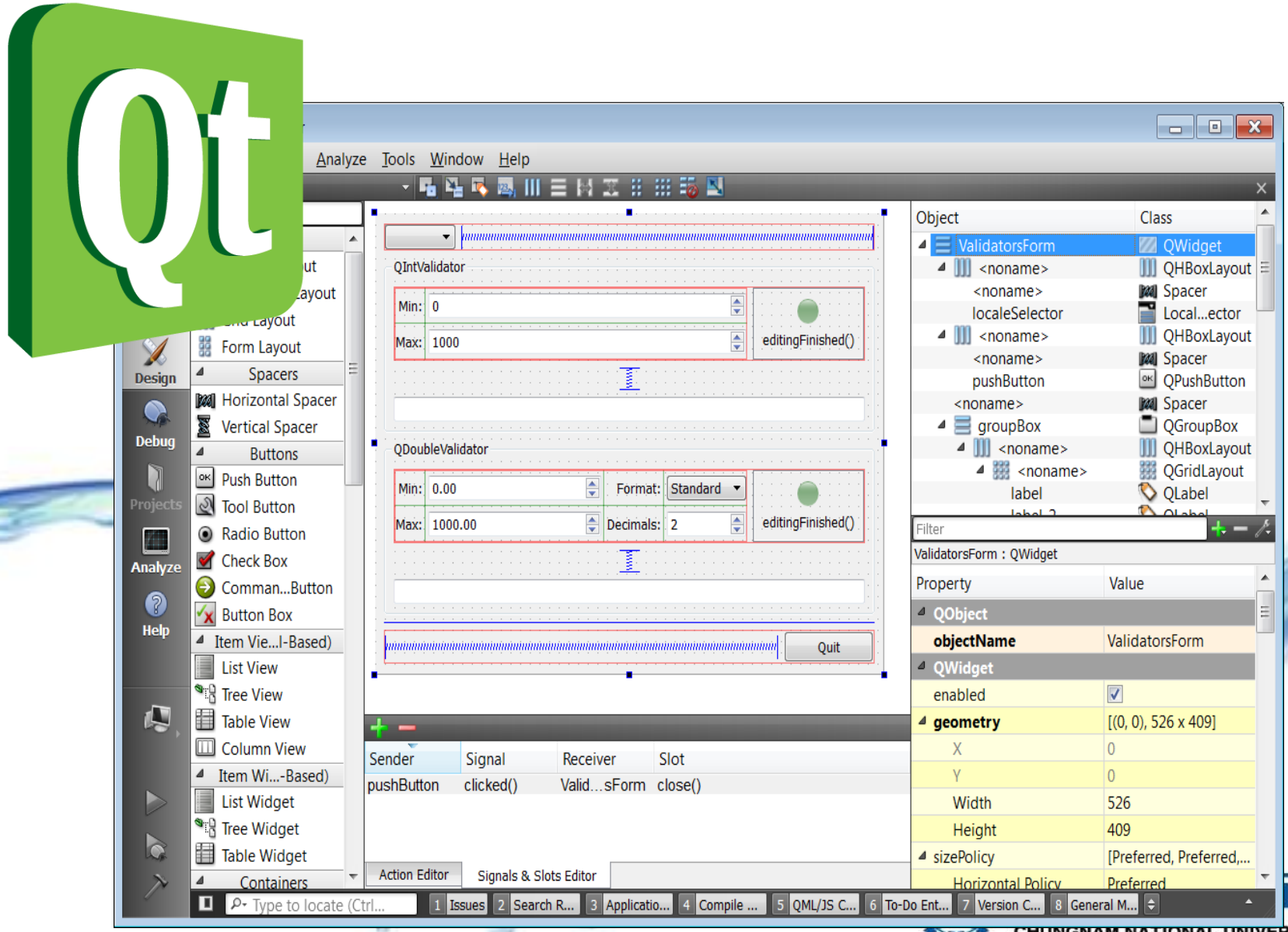
Our approach (partially implicit)

$$\frac{\theta^{n+1}-\theta^{n}}{\Delta t}-\frac{\partial}{\partial x}\left(K\frac{\partial \psi^{n^*}}{\partial x}\right)-\frac{\partial}{\partial y}\left(K\frac{\partial \psi^{n^*}}{\partial y}\right)-\frac{\partial}{\partial z}\left(K\frac{\partial\left(\psi^{n+1}+z\right)}{\partial z}\right)=0$$

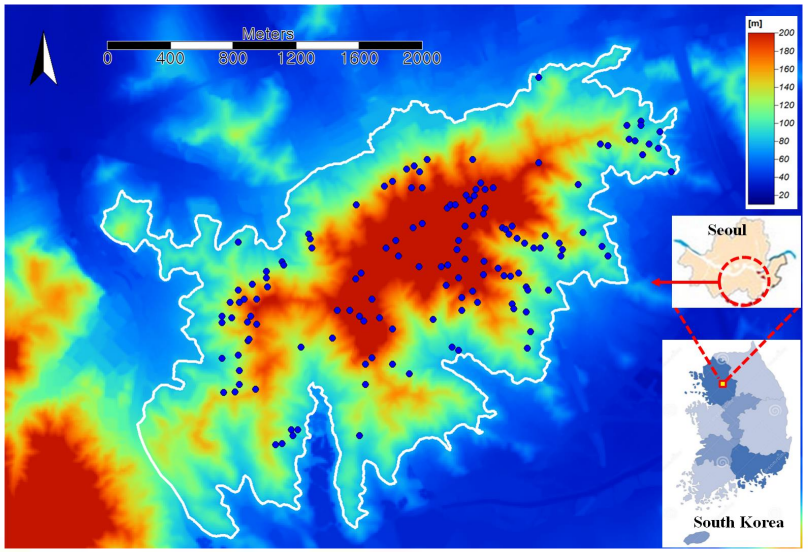
Horizontal flux is computed by pre-determined interval

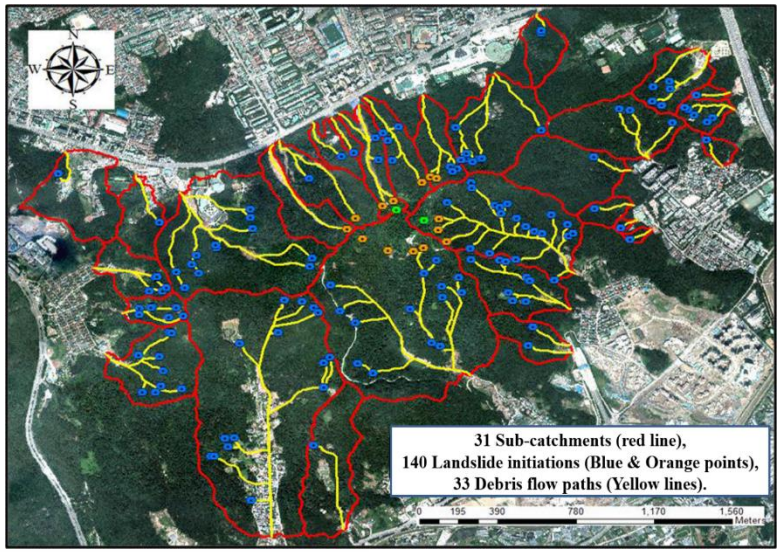
much less CPU time

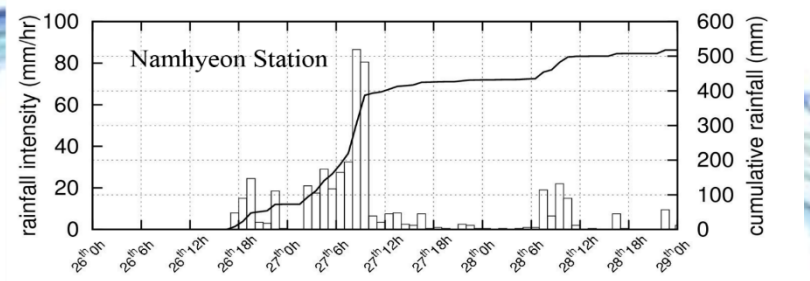
GUI development

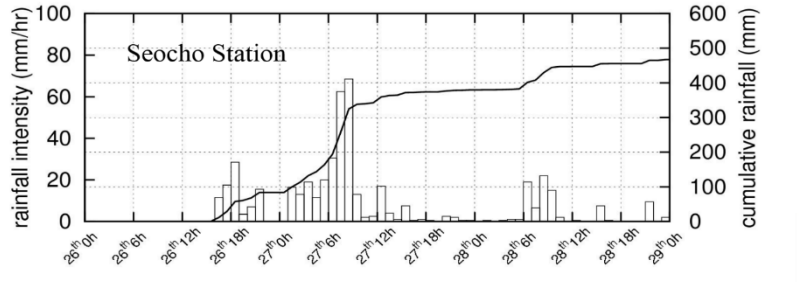


2011 Umyeon Mt. landslide









- 140 occurrence (blue points)
- 31 sub-catchment (yellow lines)

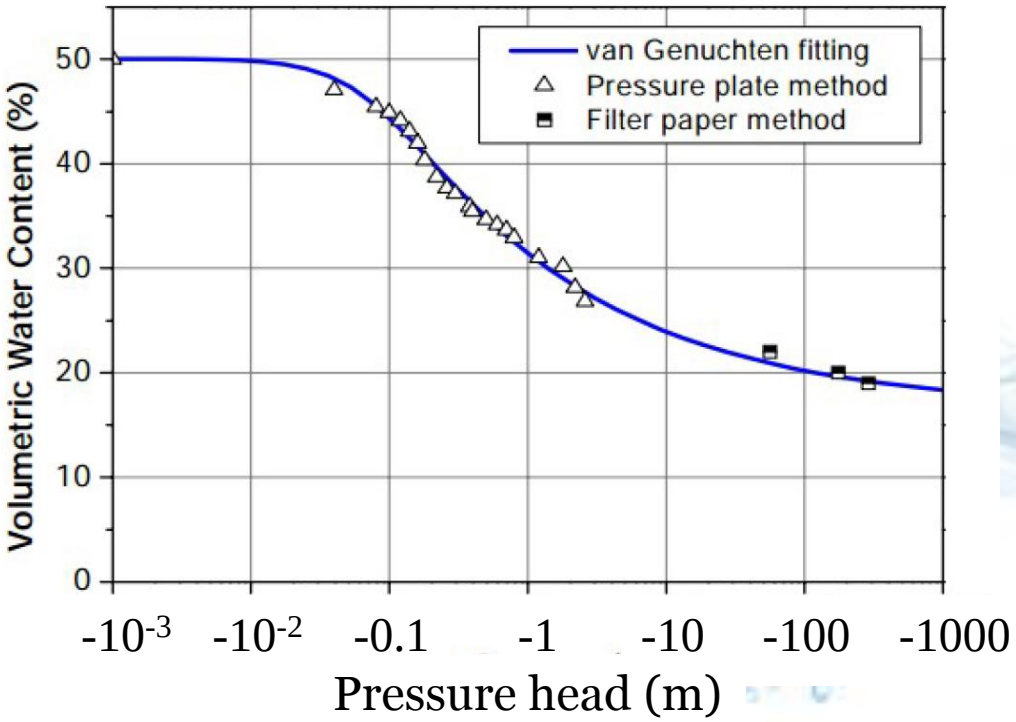
Table 1. Parameter setting

K_s (m/s)	γ_s (kg/m^3)	φ (°)	c_s (kg/m^2)	c_r (kg/m^2)	θ_s (m^3/m^3)	θ_r (m^3/m^3)
1.3E-05	2195	29.63	1838	0	0.5	0.18

Parameters

Table 1. Parameter setting

K_s (m/s)	γ_s (kg/m^3)	φ (°)	c_s (kg/m^2)	c_r (kg/m^2)	θ_s (m^3/m^3)	θ_r (m^3/m^3)
1.3E-05	2195	29.63	1838	0	0.5	0.18



$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \left\{ \frac{1}{1 + \left(\alpha |\psi|^{n_v} \right)} \right\}^{1-1/n_v}$$

$$K = K_s S_e^{1/2} \left\{ 1 - \left(1 - S_e^{n_v/(n_v-1)} \right)^{1-1/n_v} \right\}^2$$

$$\theta_s = 0.5, \quad \theta_r = 0.18,$$

$$\alpha = 1.0\text{m}^{-1}, \quad n_v = 3.0$$

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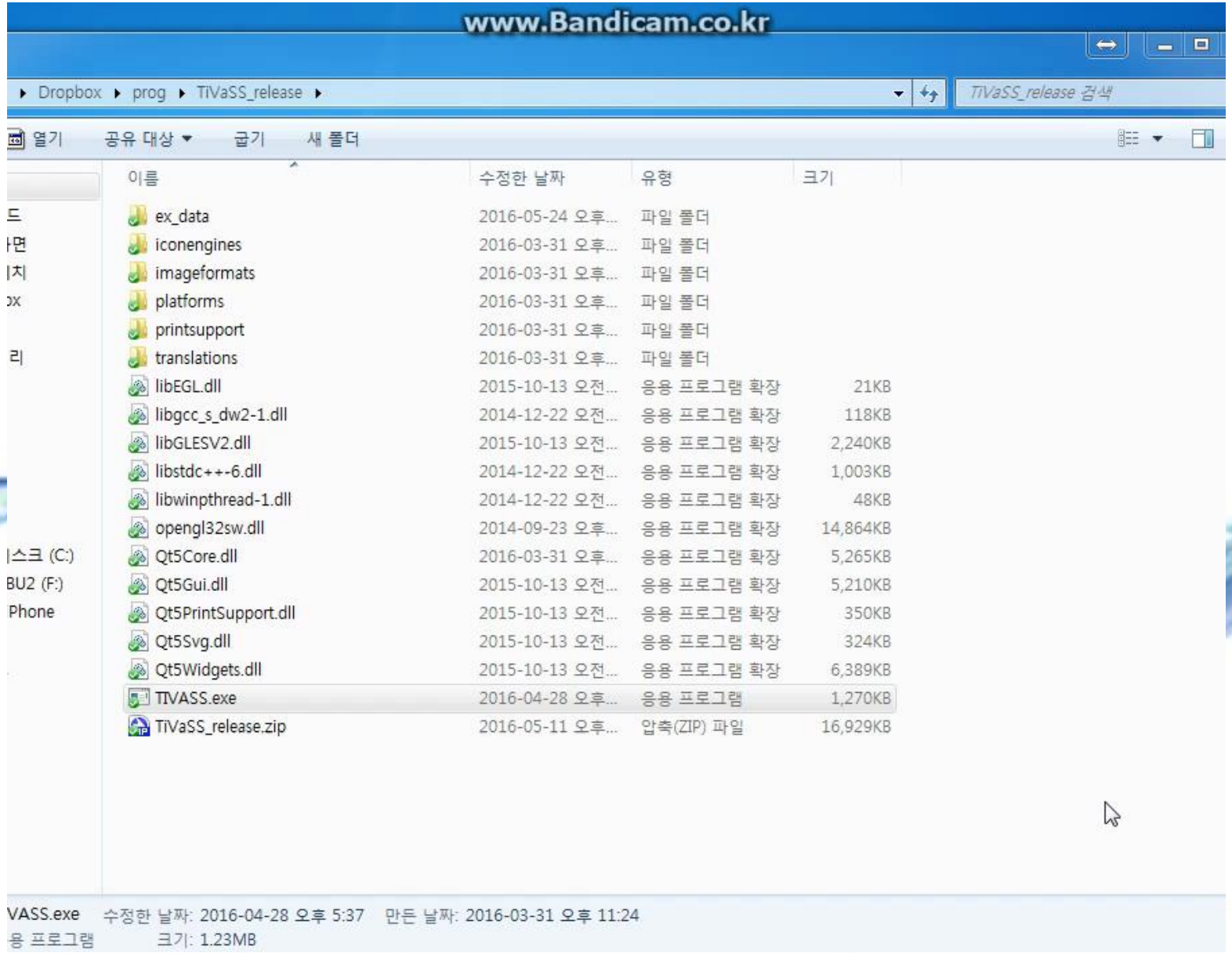
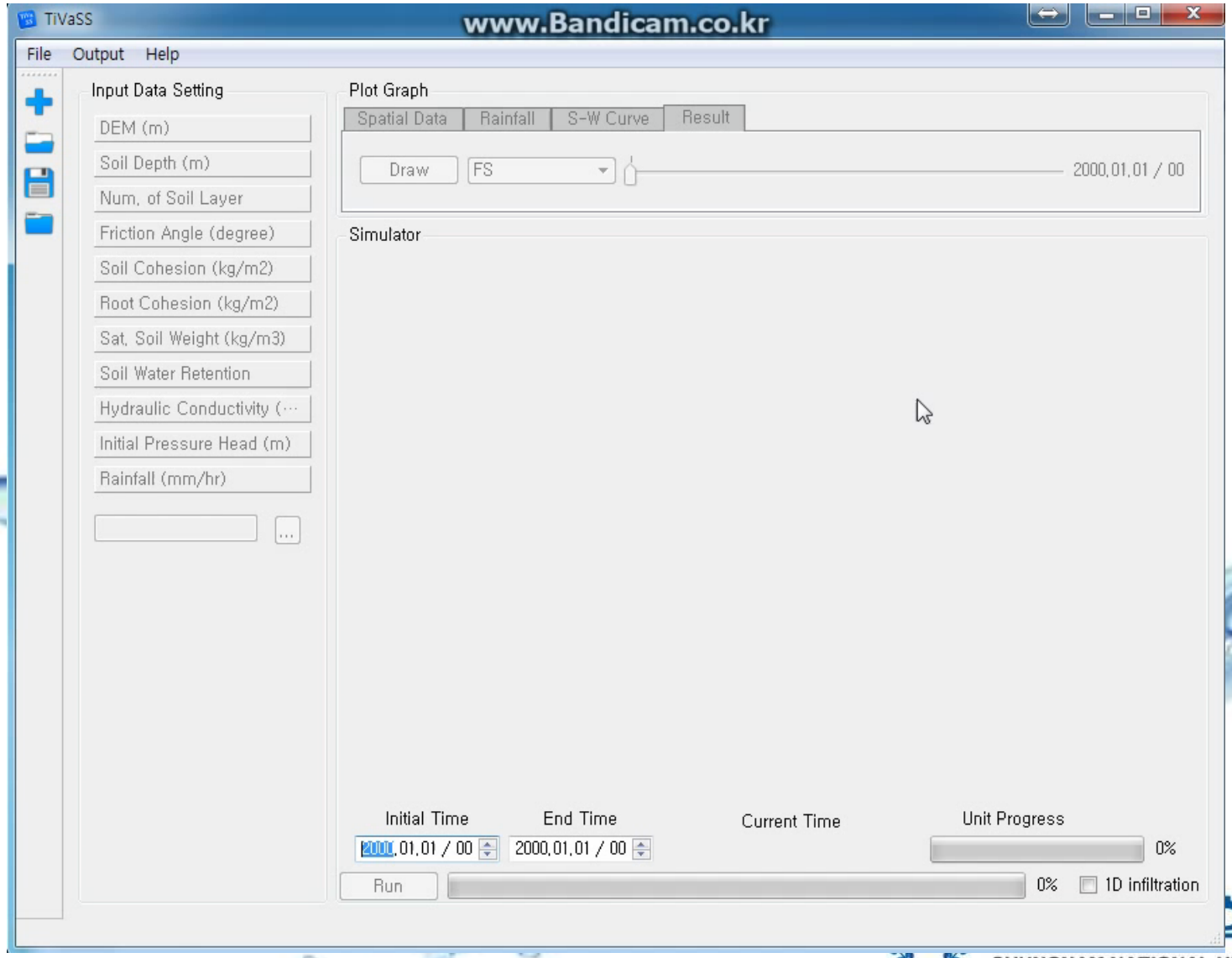
TiVaSS (Time-Variant Slope Stability model)

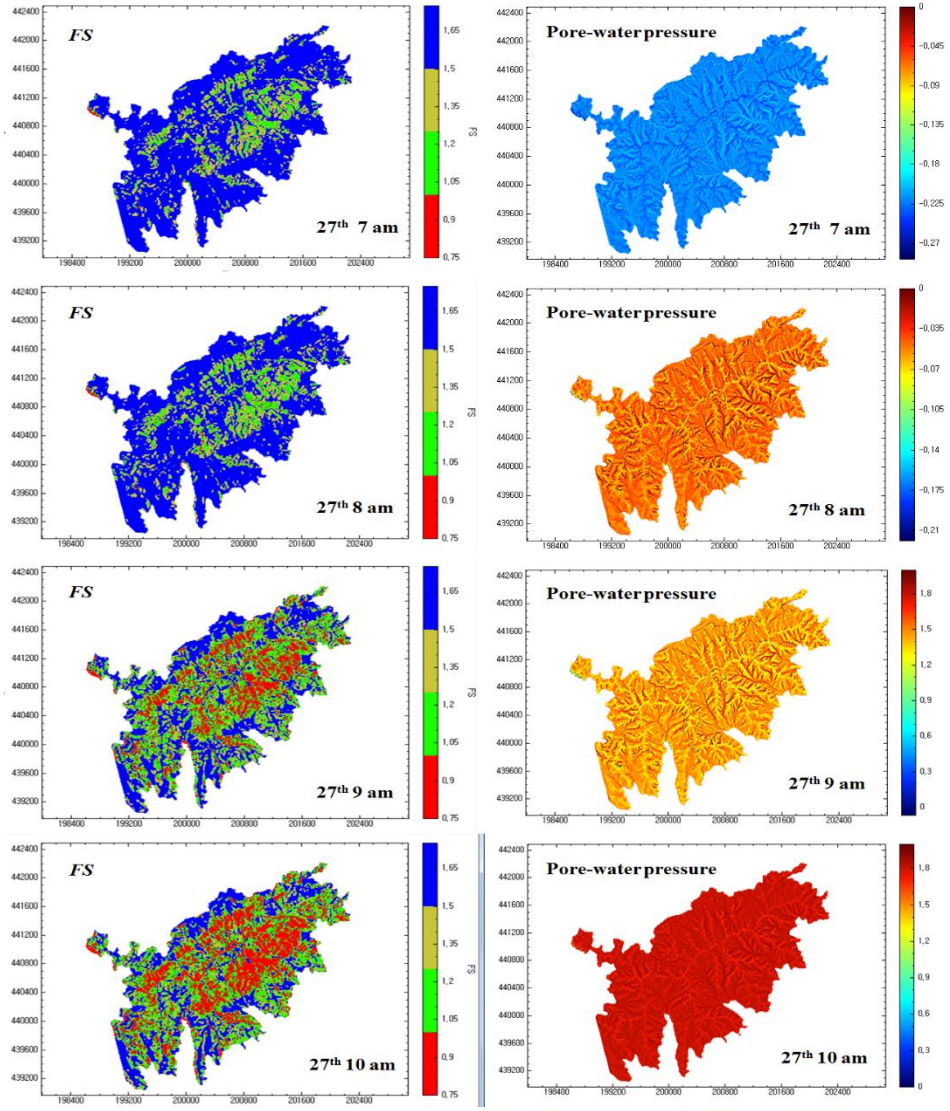


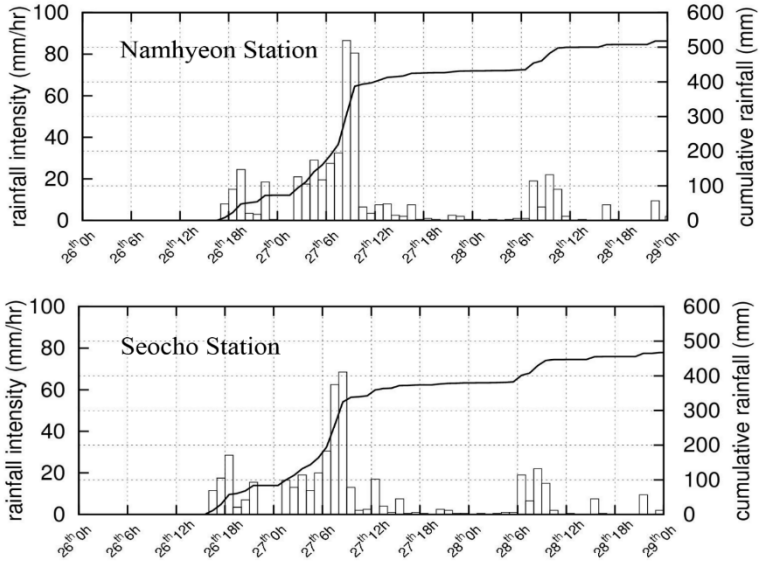
Visualization of Results



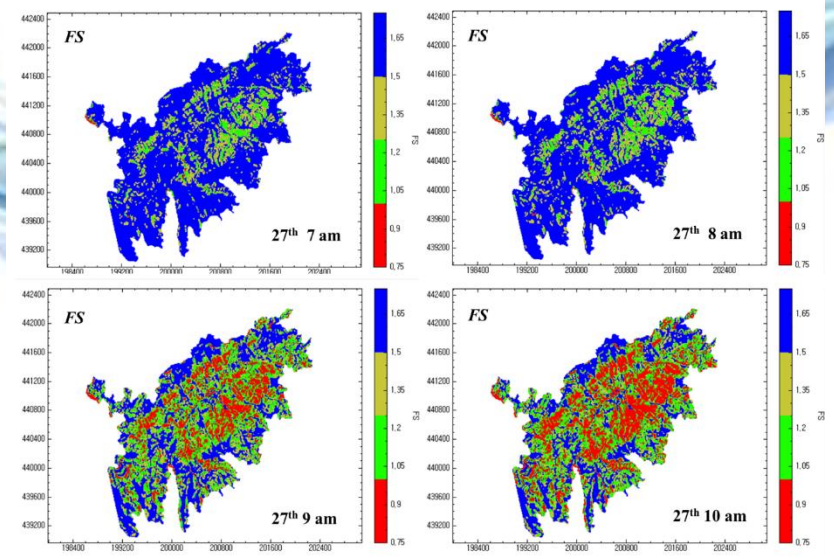
Simulation Results

3D subsurface flow





1D subsurface flow



Accuracy assessment (3D subsurface flow)

- The accuracy index (LR_{class}) is proposed by Park et al. (2013)
- It can be used when the landslide area is unknown.

FS classes	Slope failure location (a)	% of location (c)=a/b	% of predicted area (d)	LR_{class} (e)=c/d	% of LR_{class} =e/f
FS < 1	95	67.86	19.25	3.52	72.54
1 < FS < 1.25	18	12.86	20.81	0.61	12.72
1.25 < FS < 1.5	12	8.57	18.79	0.46	9.39
1.5 < FS	15	10.71	41.15	0.26	5.36
Sum	140 (*b*)	100	100	4.86 (*f*)	100

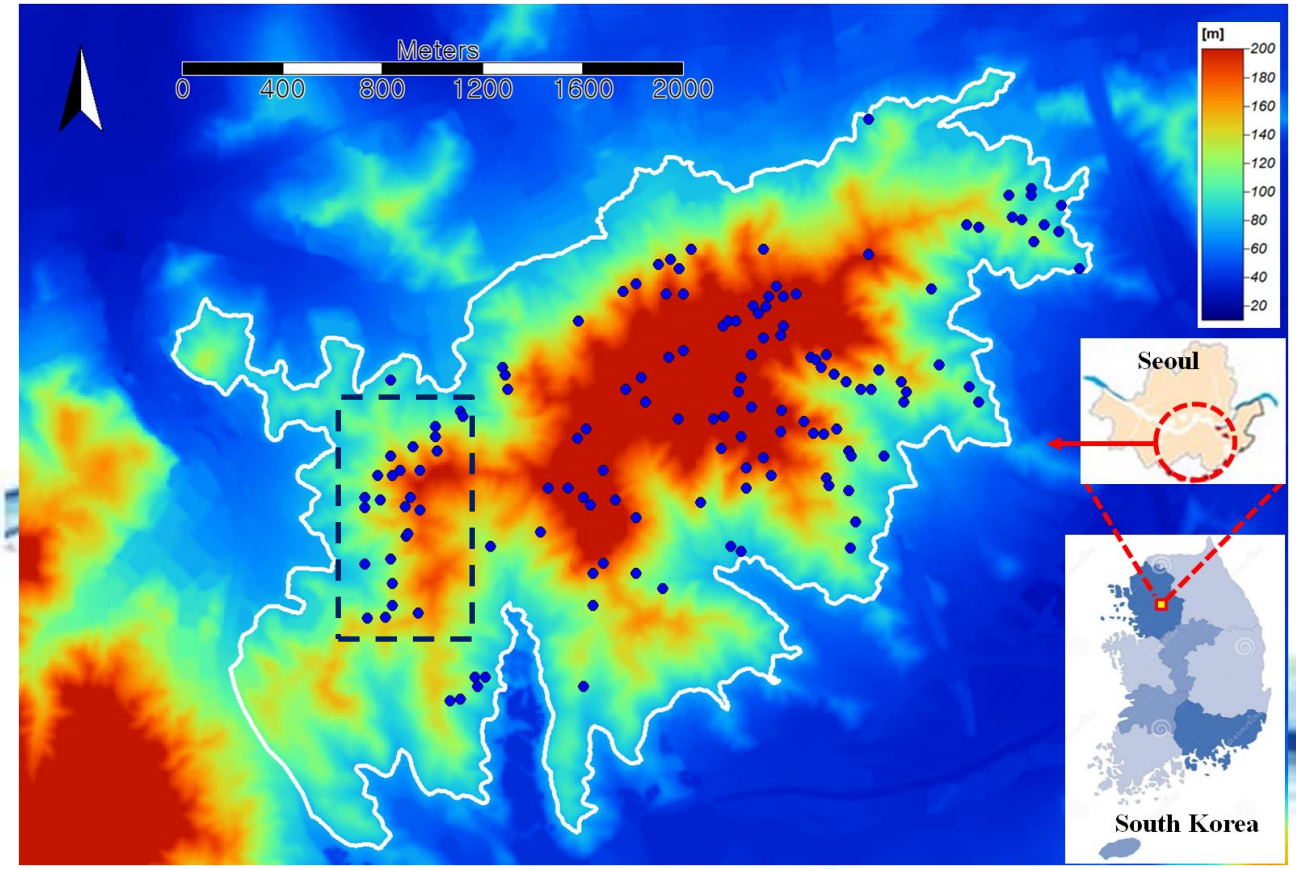
Accuracy assessment (1D subsurface flow)

- The accuracy index (LR_{class}) is proposed by Park et al. (2013)
- It can be used when the landslide area is unknown.

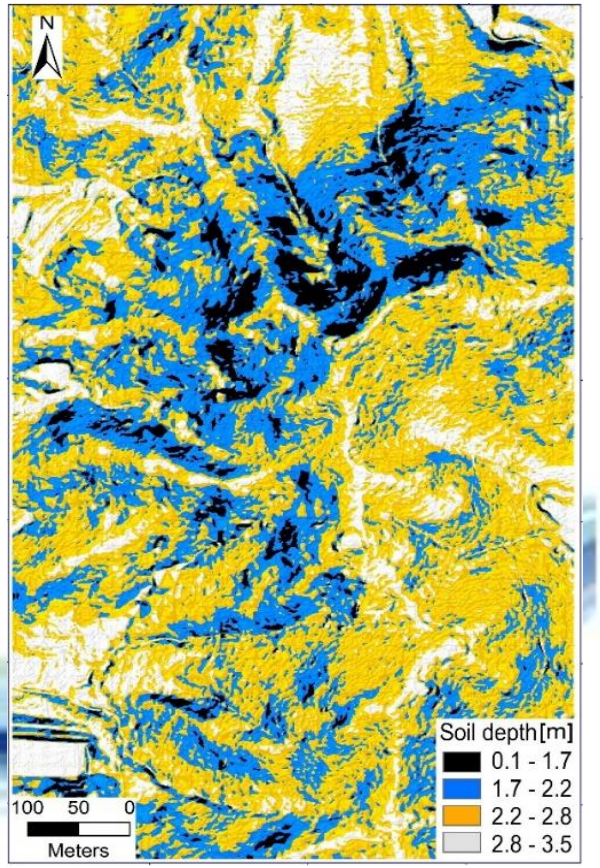
FS classes	Slope failure location (a)	% of location (c)=a/b	% of predicted area (d)	LR_{class} (e)=c/d	% of LR_{class} =e/f
FS < 1	93	66.43	19.26	3.45	70.81
1 < FS < 1.25	20	14.29	20.88	0.68	14.05
1.25 < FS < 1.5	13	9.29	18.81	0.49	10.14
1.5 < FS	14	10.0	40.06	0.24	5.00
Sum	140 (*b*)	100	100	4.87 (*f*)	100

TiVaSS vs TRIGRS

1 X 1 m DEM



Distributed soil depth



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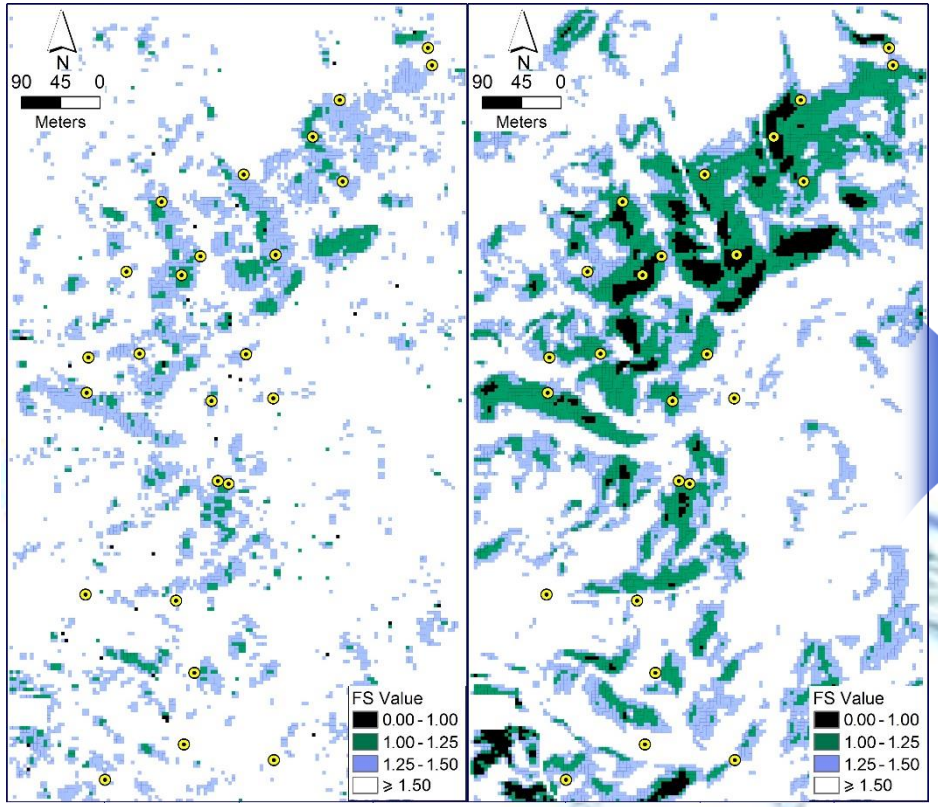
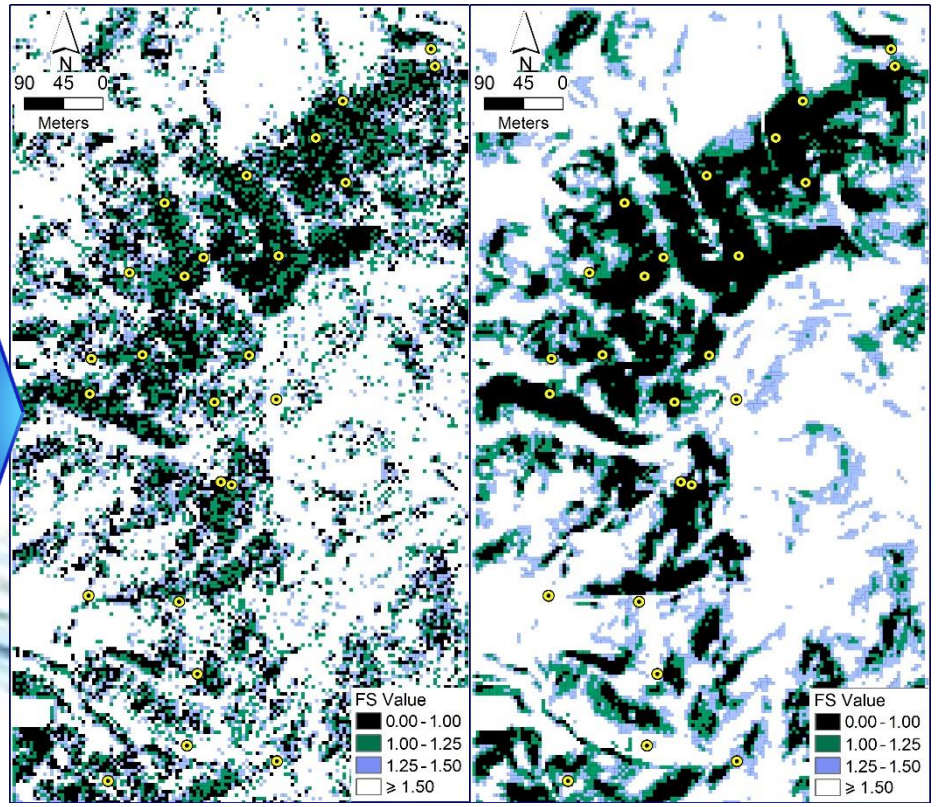
Results, FS

TiVaSS vs TRIGRS



6 am July 27

TiVaSS vs TRIGRS



9 am July 27

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Accuracy assessment TiVaSS vs TRIGRS

9 am July 27

FS Classes	Observed sliding sites		% Observed sliding sites		% of predicted area		LR_{class}		% LR_{class}	
	TRIGRS	TiVaSS	TRIGRS	TiVaSS	TRIGRS	TiVaSS	TRIGRS	TiVaSS	TRIGRS	TiVaSS
FS <1	15	16	60.0	64.0	19.3	20.1	3.11	3.19	64.18	65.75
1-1.25	2	4	8.0	16.0	12.8	15.0	0.63	1.07	12.94	22.01
1.25-1.50	3	1	12.0	4.0	16.7	14.3	0.72	0.28	14.81	5.73
> 1.50	5	4	20.0	16.0	51.2	50.6	0.39	0.31	8.07	6.51
Sum	25	25	100.0	100.0	100.0	100.0	4.85	4.85	100.0	100

Accuracy assessment TiVaSS vs TRIGRS

6 am July 27

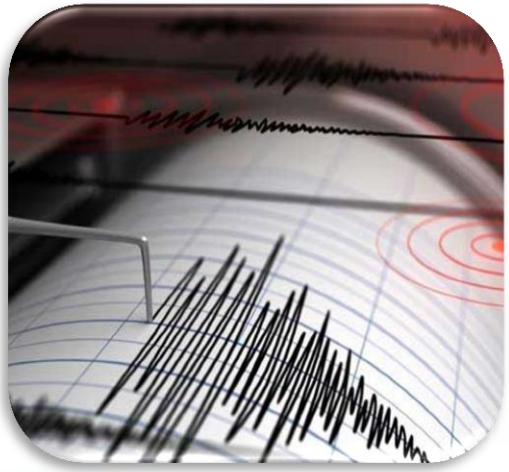
FS Classes	Observed sliding sites		% Observed sliding sites		% of predicted area		LR_{class}		% LR_{class}	
	TRIGRS	TiVaSS	TRIGRS	TiVaSS	TRIGRS	TiVaSS	TRIGRS	TiVaSS	TRIGRS	TiVaSS
FS <1	4	0	16.0	0.0	3.1	0.1	5.16	0.00	56.27	0.0
1-1.25	10	1	40.0	24.0	14.4	3.1	2.79	1.30	30.38	27.60
1.25-1.50	4	11	16.0	32.0	20.7	15.9	0.77	2.77	8.42	58.75
> 1.50	7	13	28.0	44.0	61.8	80.9	0.45	0.64	4.93	13.65
Sum	25	25	100.0	100.0	100.0	100.0	9.17	4.71	100.0	100.0

Summary

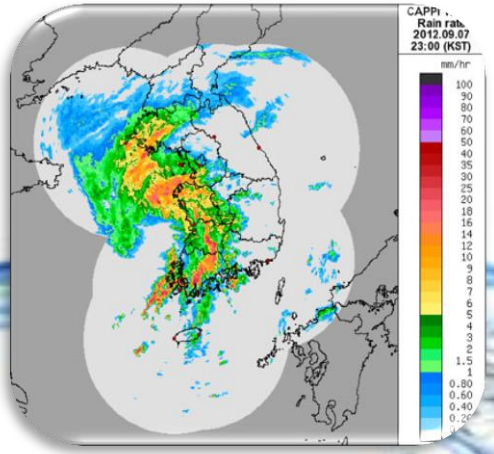
- TiVaSS (Time-Variant Slope Stability model) was developed based on the combination of the infinite slope stability model and the 3D subsurface flow model
- TiVaSS was applied to 2011 Umyeon Mt. landslide event and the performance was satisfactory in overall.
- TiVaSS works on Windows OS, and supports GUI tool and basic 2D data visualization tool.
- Updating and further application is ongoing…
- https://sites.google.com/site/cnuaehelab/software/tivass

Future Plan

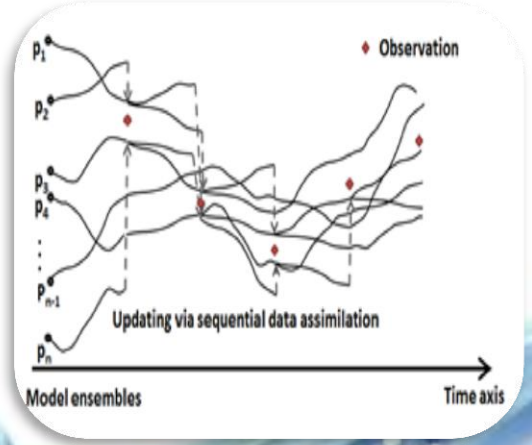
Earthquake



Distributed rainfall gauged by Radar



Data assimilation for forecasting



TiVa SS

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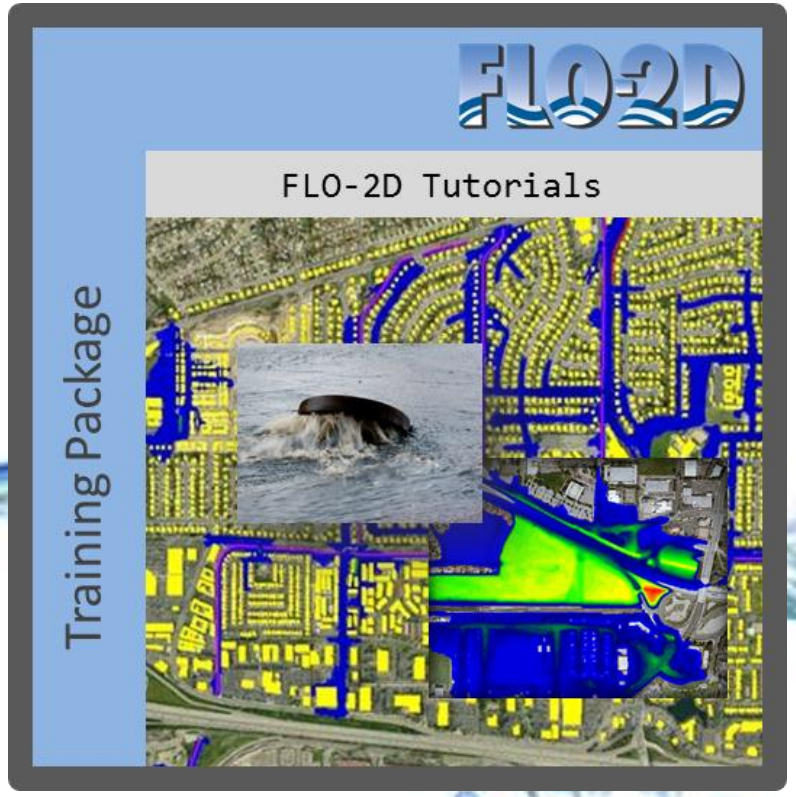
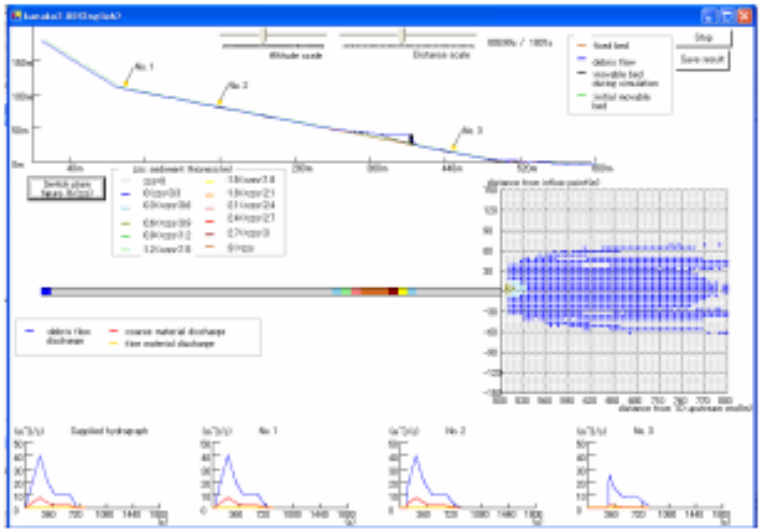
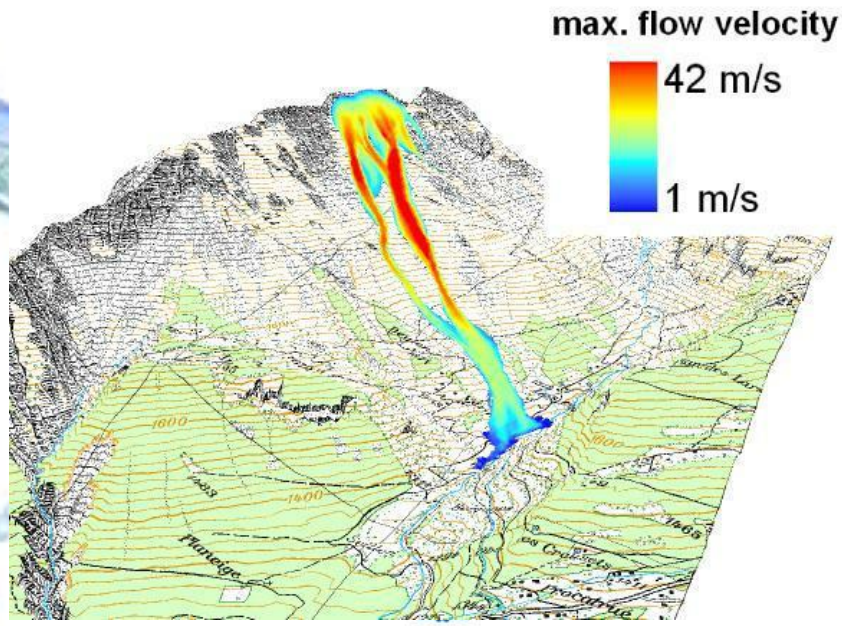
Development of Debris flow model







Governing Equation

$$\frac{\partial \mathbf{q}}{\partial t}+\frac{\partial \mathbf{f}}{\partial x}+\frac{\partial \mathbf{g}}{\partial y}=\mathbf{s},$$

$$\mathbf{q}=\begin{pmatrix} h \\ hu \\ hv \end{pmatrix},\quad \mathbf{f}=\begin{pmatrix} hu \\ hu^2+gh^2/2 \\ huv \end{pmatrix},\quad \mathbf{g}=\begin{pmatrix} hv \\ huv \\ hv^2+gh^2/2 \end{pmatrix},\quad \mathbf{s}=\begin{pmatrix} E \\ -hgz_x-S_{fx} \\ -hgz_y-S_{fy} \end{pmatrix},$$

h : water depth, u, v : velocity,

E : mass source of erisional and deposition effect,

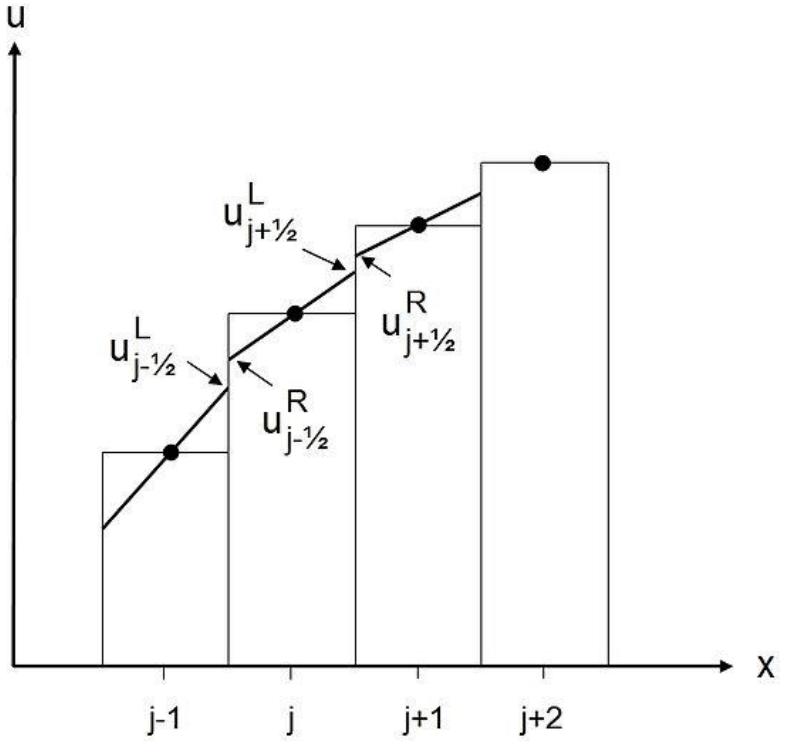
S_{fx}, S_{fy} : friction effect of debris flow mixture,

$$S_{fx}=n_u\left[\mu gh+\frac{g|\vec{u}|^2}{\xi}\right], S_{fy}=n_v\left[\mu gh+\frac{g|\vec{u}|^2}{\xi}\right]$$

$$|\vec{u}|^2=\left|u^2+v^2\right|$$

Voellmy friction model

MUSCL scheme



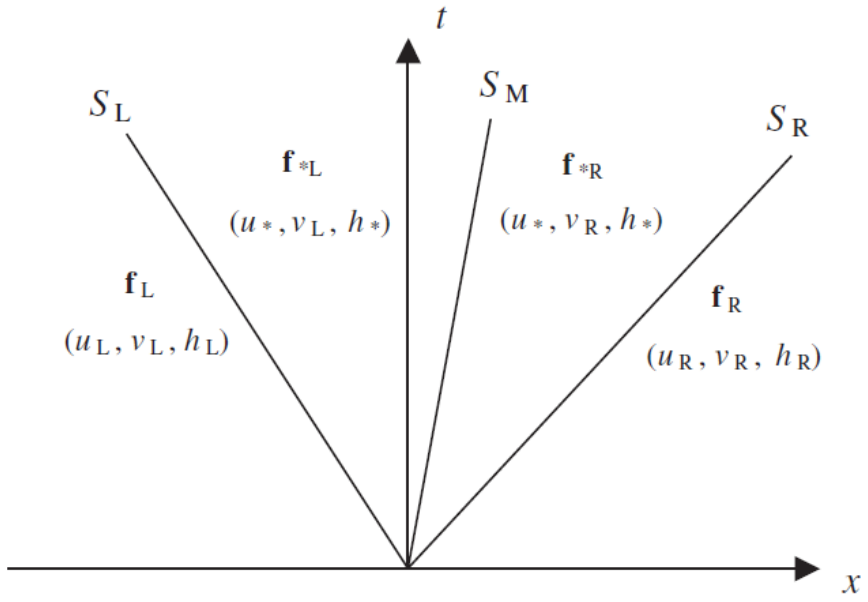
Piecewise linear extrapolation

$$\mathbf{q}_{i,j,f} = \mathbf{q}_{i,j} + \mathbf{r}_f \cdot \nabla \mathbf{q}_{i,j}$$

$$\nabla \mathbf{q}_x = \psi\left(\frac{\mathbf{q}_{j+1} - \mathbf{q}_j}{x_{j+1} - x_j}, \frac{\mathbf{q}_j - \mathbf{q}_{j-1}}{x_j - x_{j-1}}\right)$$

$\psi(a,b)$: limiter function.

HLLC Reimann solver



$$\mathbf{f}_{i+1/2,j} = \begin{cases} \mathbf{f}_L & \text{if } 0 \leqslant S_L \\ \mathbf{f}_{*L} & \text{if } S_L \leqslant 0 \leqslant S_M \\ \mathbf{f}_{*R} & \text{if } S_M \leqslant 0 \leqslant S_R \\ \mathbf{f}_R & \text{if } 0 \geqslant S_R \end{cases}$$

$$S_L = \begin{cases} u_R - 2\sqrt{gh_R} & \text{if } h_L = 0 \\ \min(u_L - \sqrt{gh_L}, u_* - \sqrt{gh_*}) & \text{if } h_L > 0 \end{cases}$$

$$S_R = \begin{cases} u_L + 2\sqrt{gh_L} & \text{if } h_R = 0 \\ \max(u_R + \sqrt{gh_R}, u_* + \sqrt{gh_*}) & \text{if } h_R > 0 \end{cases}$$

$$S_M = \frac{S_L h_R (u_R - S_R) - S_R h_L (u_L - S_L)}{h_R (u_R - S_R) - h_L (u_L - S_L)}$$

$$h_* = \frac{1}{g}\left[\frac{1}{2}(\sqrt{gh_L} + \sqrt{gh_R}) + \frac{1}{4}(u_L - u_R)\right]^2$$

$$u_* = \tfrac{1}{2}(u_L + u_R) + \sqrt{gh_L} - \sqrt{gh_R}$$

Temporal discretisation

$$\frac{\partial \mathbf{q}}{\partial t} + \frac{\partial \mathbf{f}}{\partial x} = \mathbf{s},$$

$$A_{i,j} \left.\frac{\partial \mathbf{q}}{\partial t}\right|_{i,j} + F_{i,j} = \boldsymbol{S}_{i,j}$$

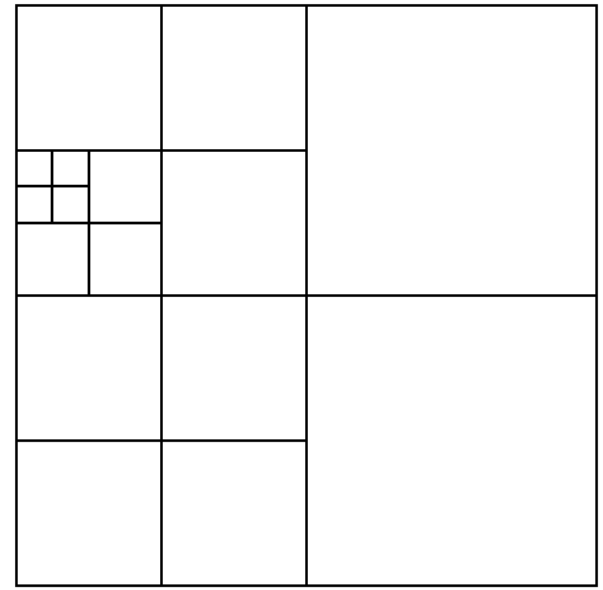
Prediction step

$$A_{i,j}\mathbf{q}_{i,j}^{n+1/2} = A_{i,j}\mathbf{q}_{i,j}^{n} - \frac{\Delta t}{2}(F_{i,j}^{\ n} + \boldsymbol{S}_{i,j}),$$

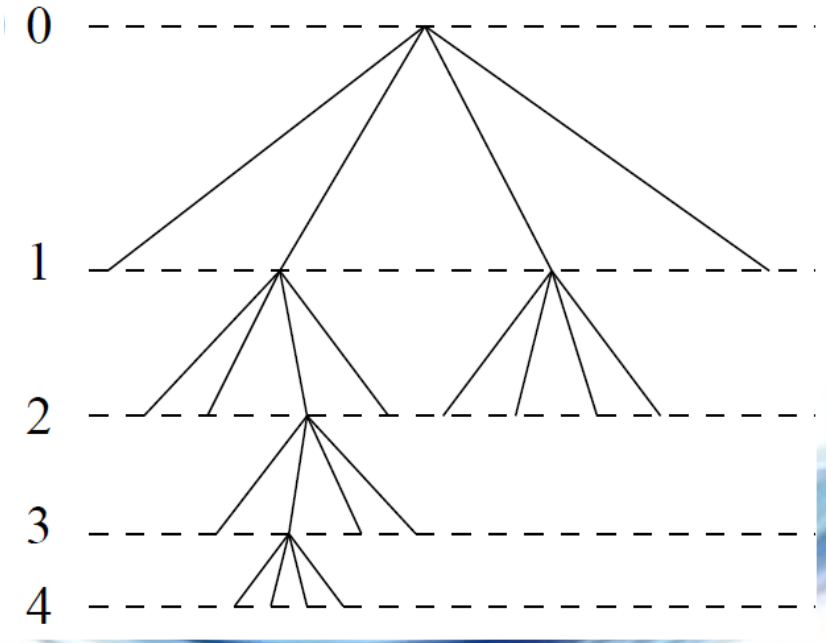
Correction step

$$A_{i,j}\mathbf{q}_{i,j}^{n+1} = A_{i,j}\mathbf{q}_{i,j}^{n} - \Delta t(F_{i,j}^{\ n+1/2} + \boldsymbol{S}_{i,j}).$$

Quadtree grid

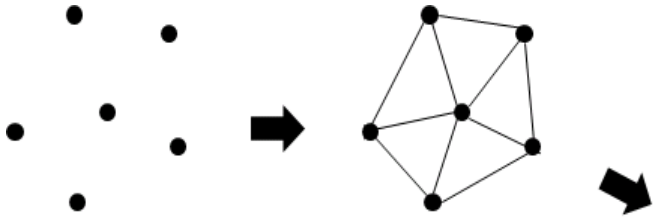


Adaptive mesh



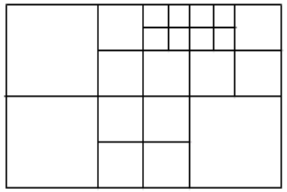
Quadtree grid structure

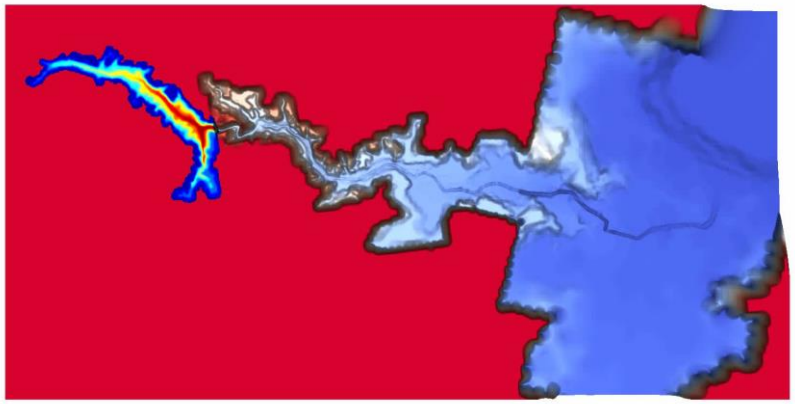
Adaptive Mesh Generation

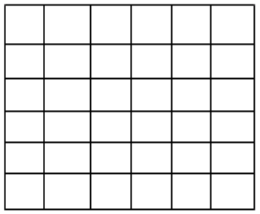


points data

triangular mesh

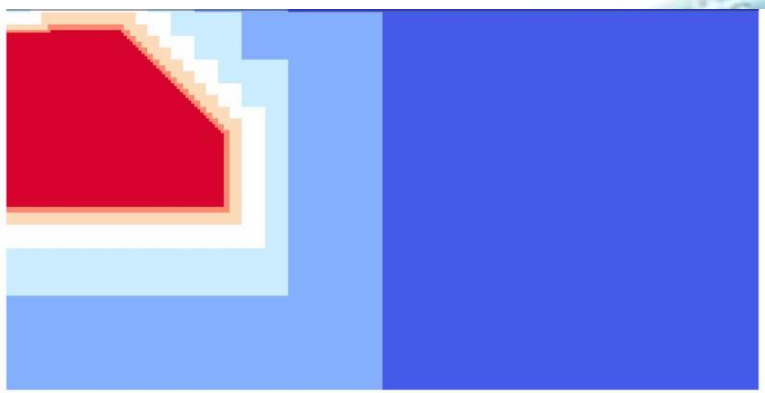






grid data

quadtree
adaptive mesh
generation



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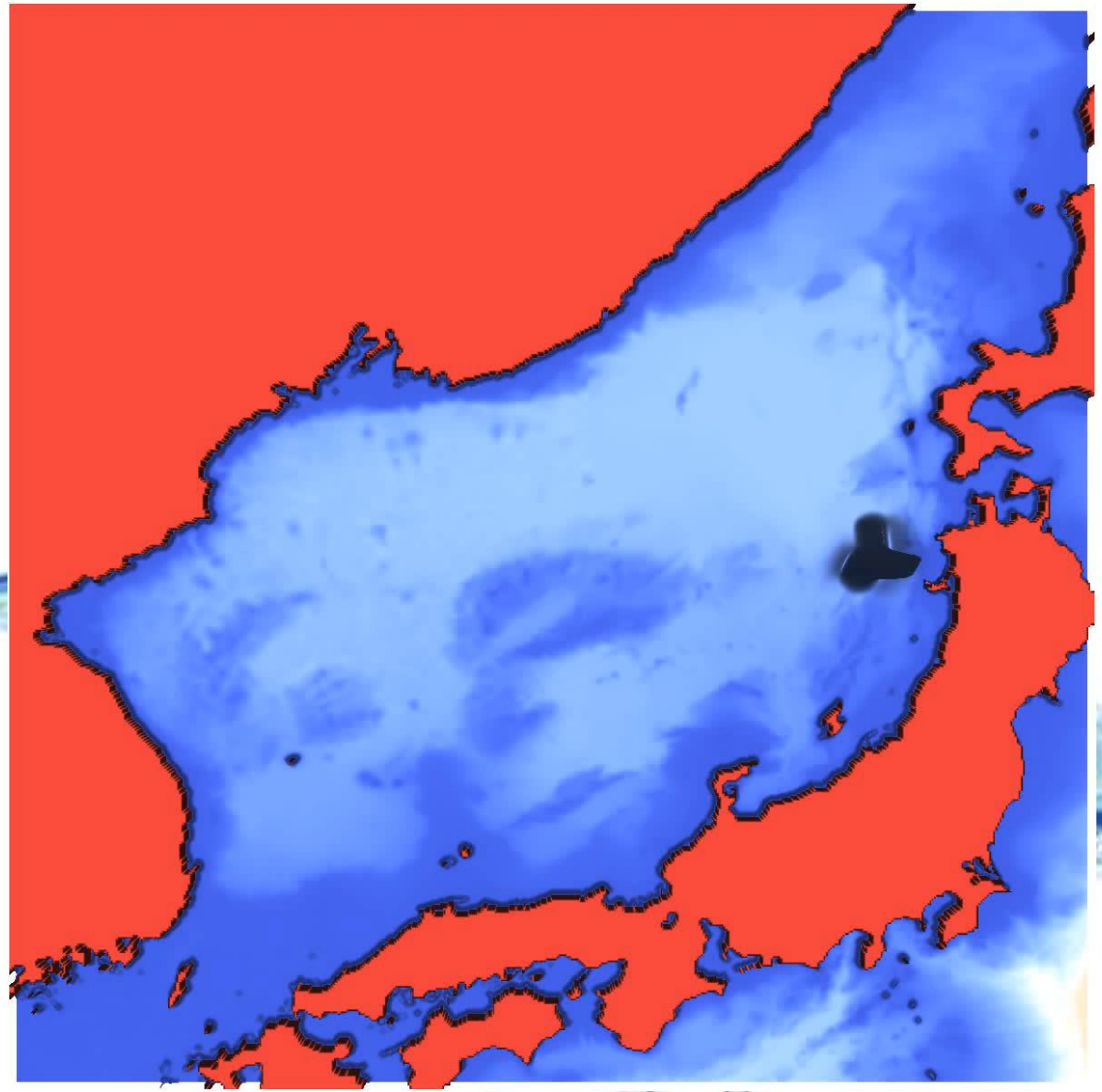
Adaptive Mesh Generation



- 1983 tsunami
- 7.5 m maximum wave height
- 5 dead persons
- More than 400 refugees

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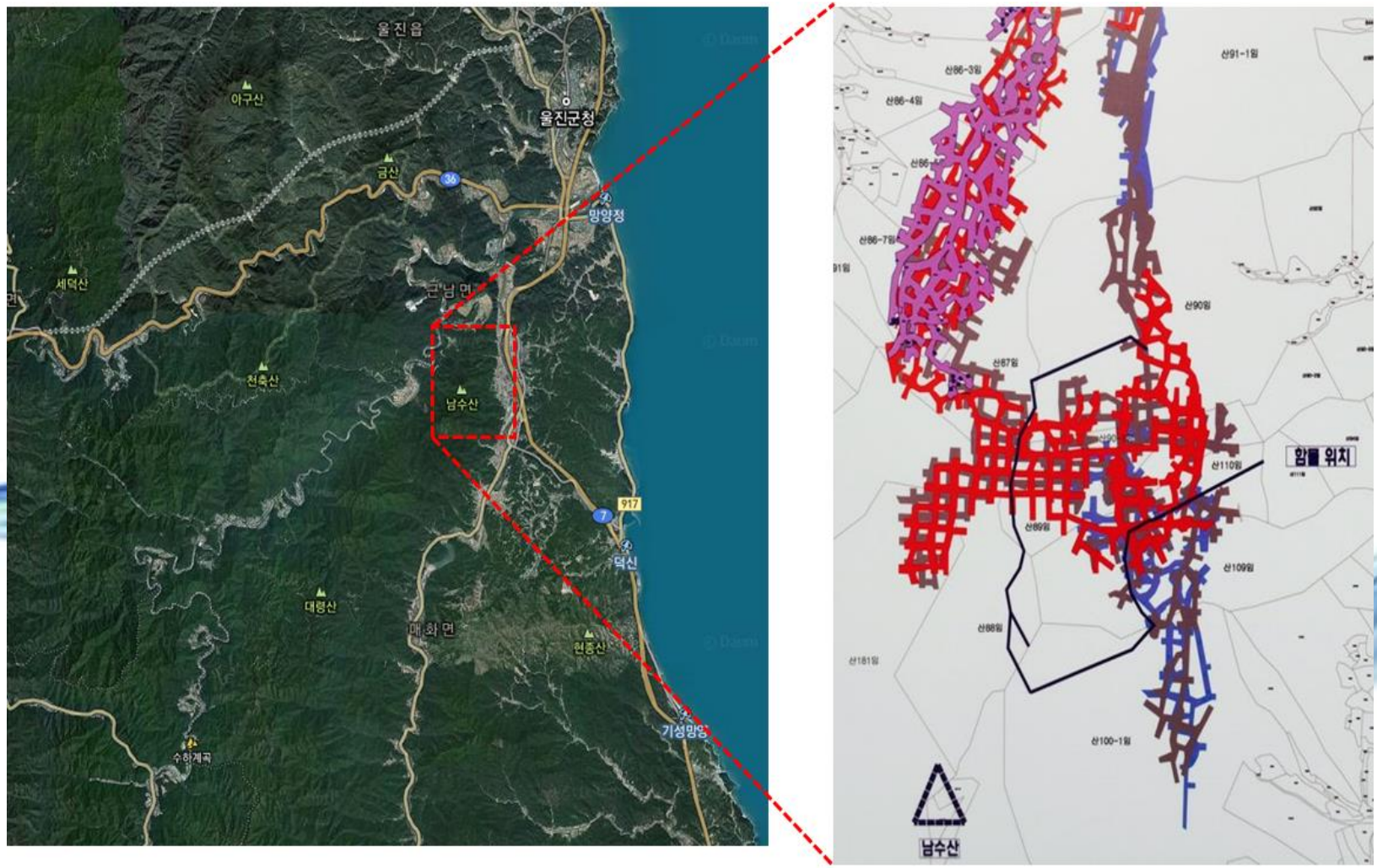
Study Area



- Uljin-goon, Meahwa-myeon

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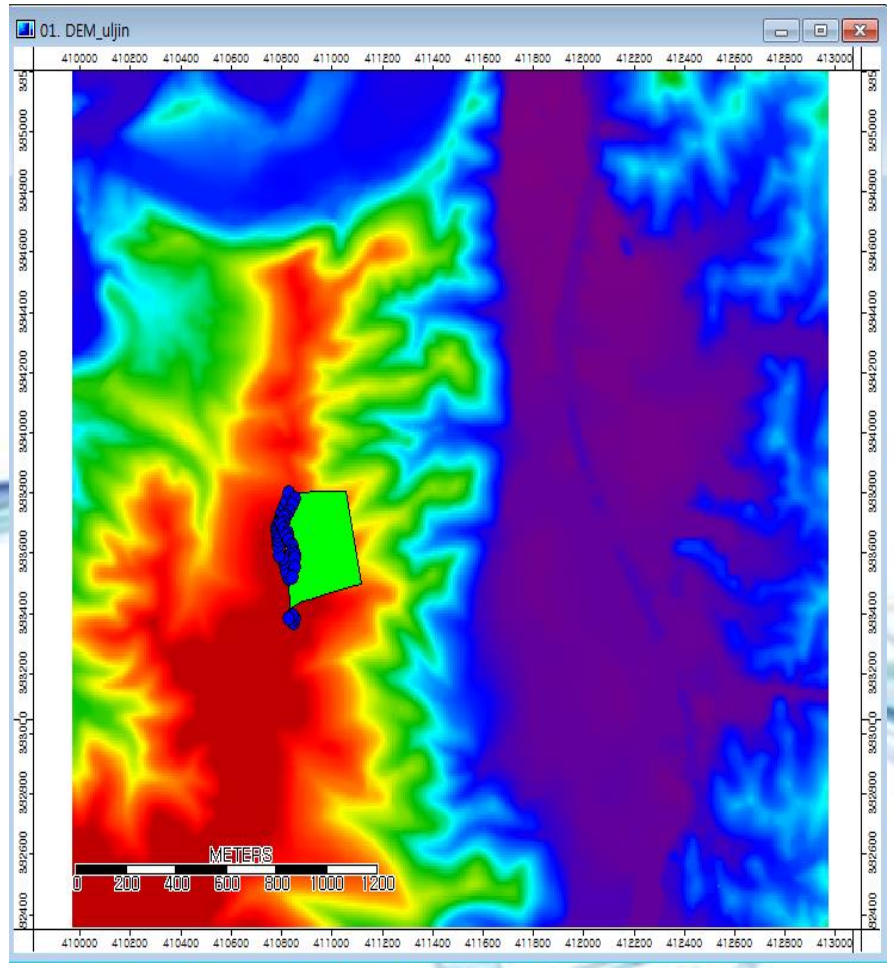
Study Area, Crack

Initial condition



- 3m uniform depth
- 10m uniform depth

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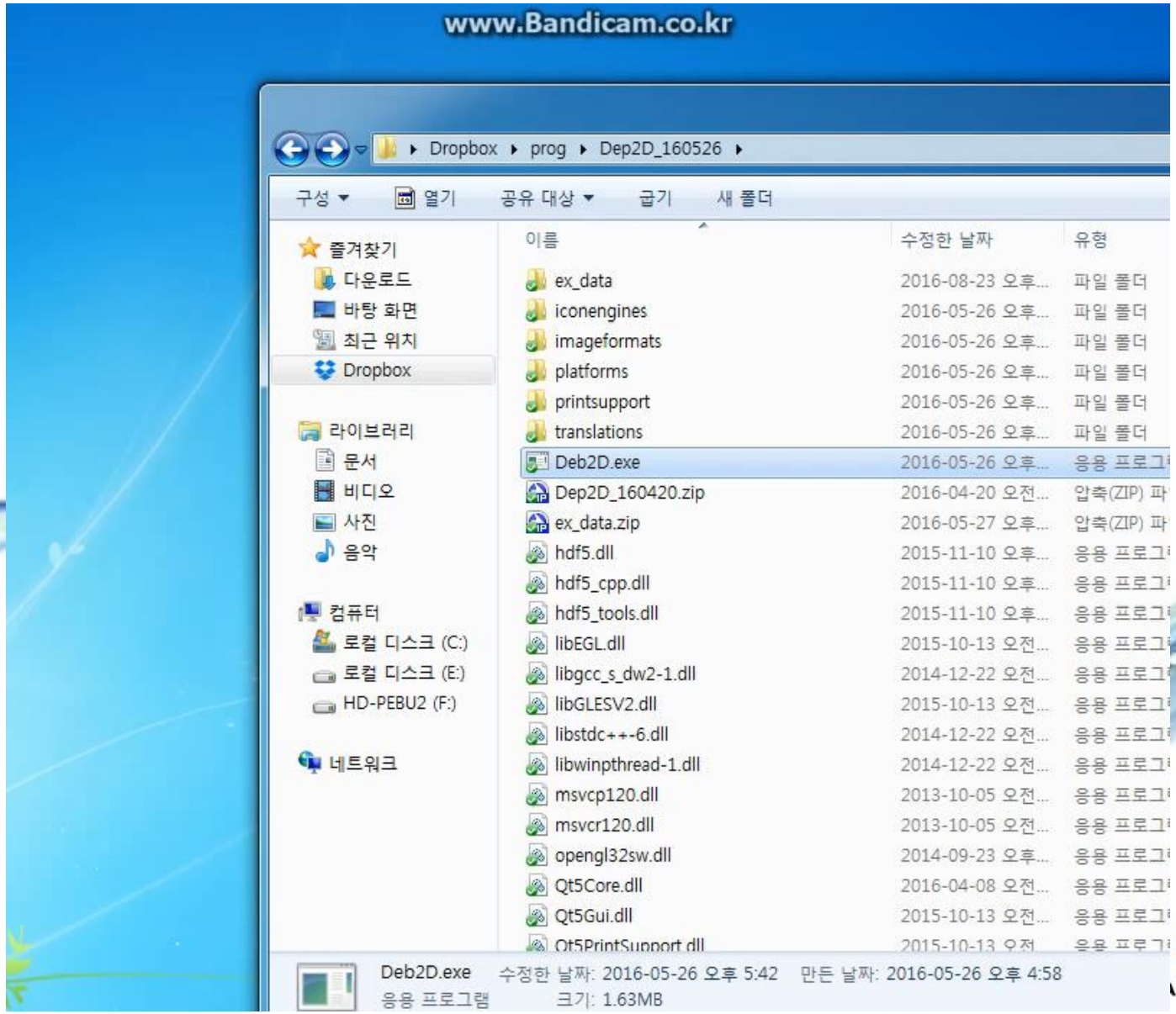
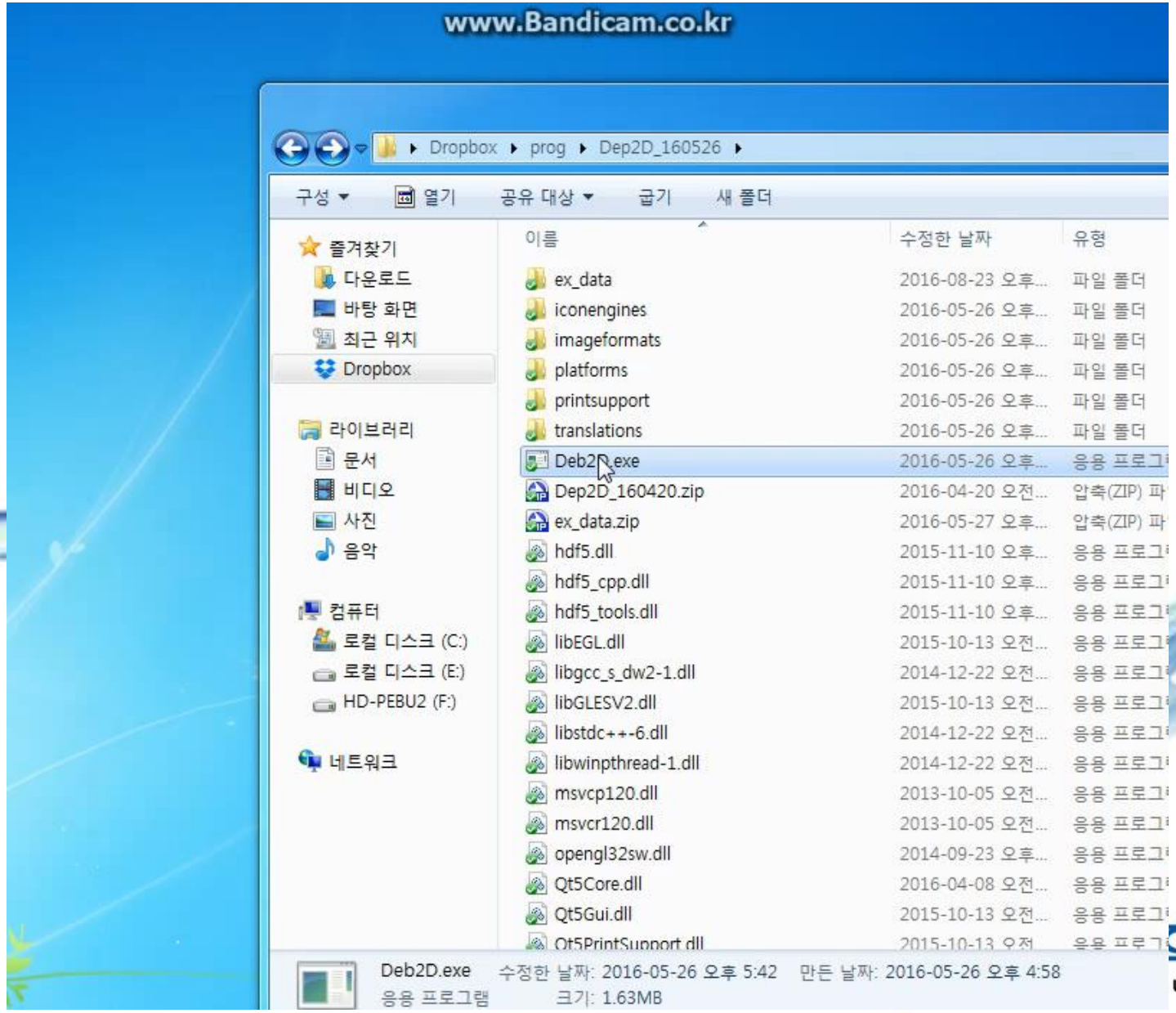
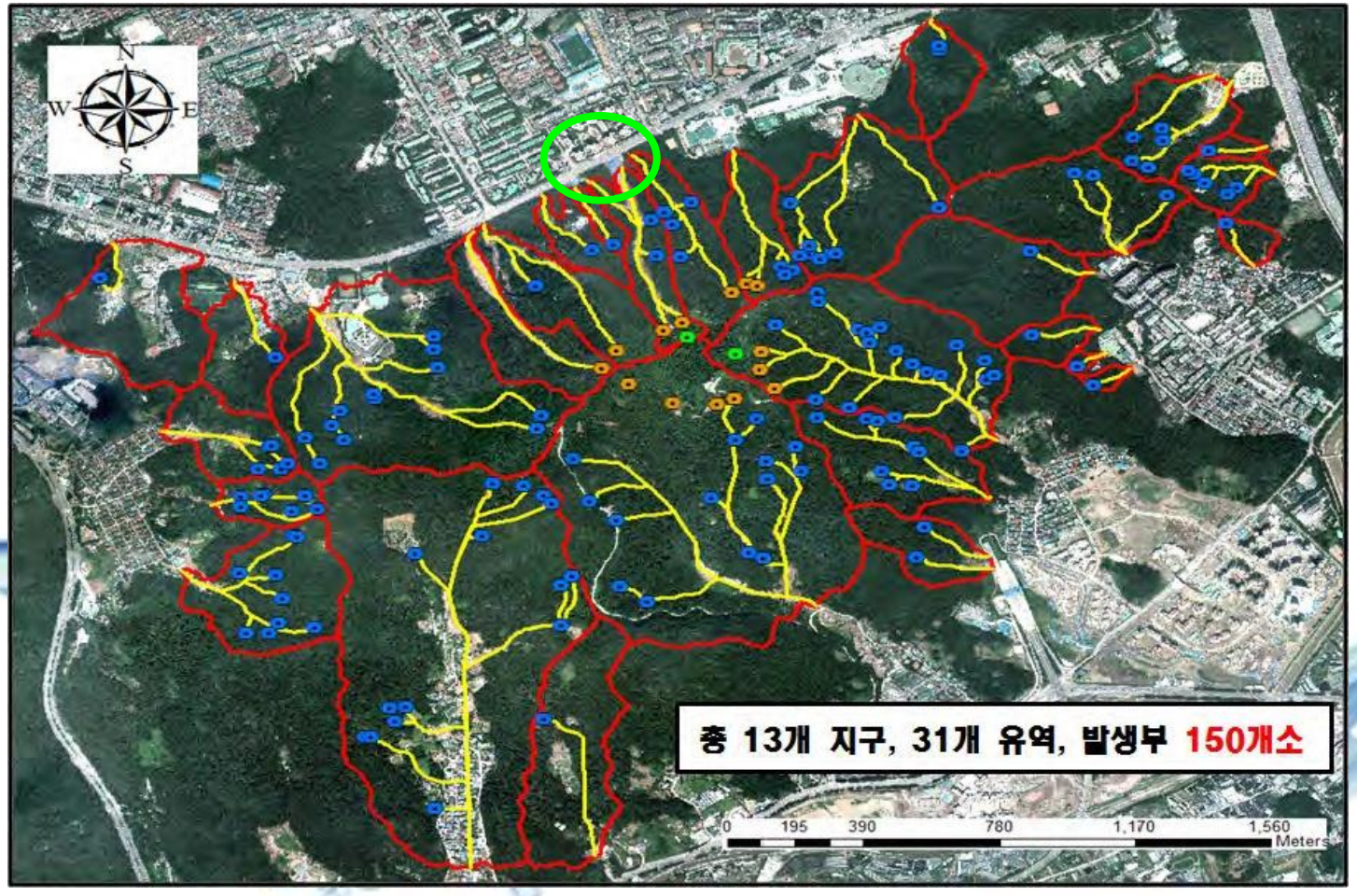
Deb2D (Debris flow model, 2D)



Visualization of Results



Case study: 2011 Umyeon Mt. debris flow



- 150 occurrence (blue points)
- 31 water shed (yellow lines)

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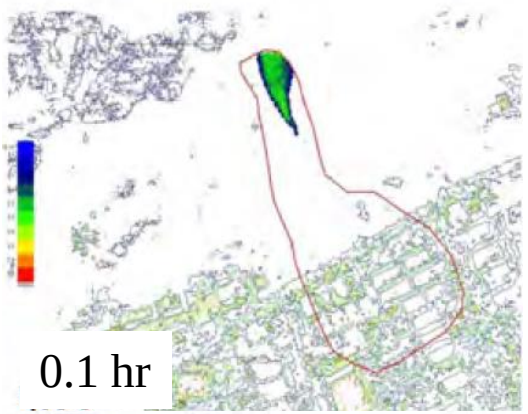
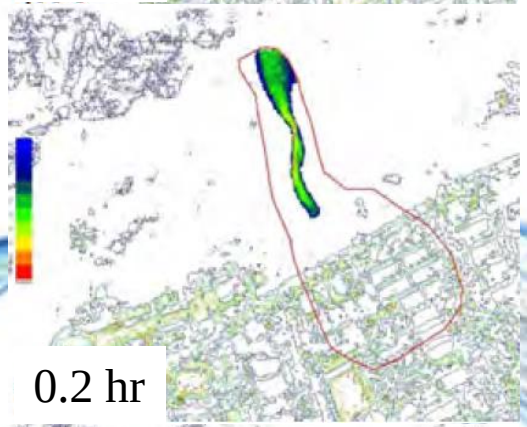
Case study: 2011 Umyeon Mt. debris flow

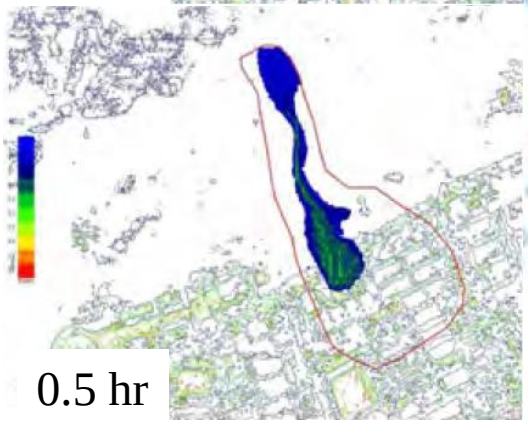
- Average slope : 19 degree
- watershed area : 75600 m²
- 3 fatality
- Reamian APT is damaged up to 3rd floor

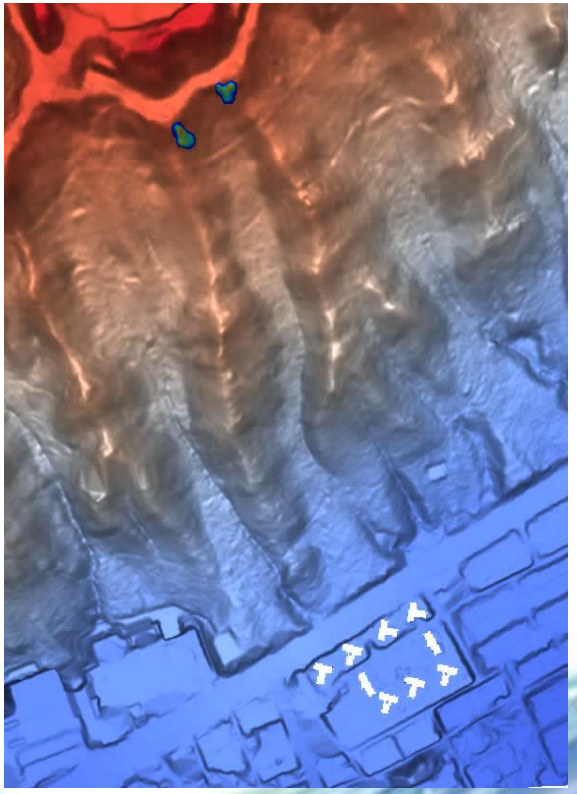
Case study: 2011 Umyeon Mt. debris flow

Simulation Result : comparison with FLO-2D









FLO-2D
erosion (X)
Buildings (X)

Developed model
Erosion (O)
Buildings (O)

Observed data

Black box -> guessed velocity 27 m/s
Flow depth at APT-> 3rd floor
well agreed

Summary

- Adaptive grid based Debris flow model, Deb2D, is developed.
- A simple GUI and visualization tools are supported in Deb2D.
- 2011 Umyeon Mt. debris flow seems to be successfully simulated by the developed model although further verification is required
- Model verification is ongoing.
- https://sites.google.com/site/cnuaehelab/software/dep2d

Thank you !!

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Balance issue

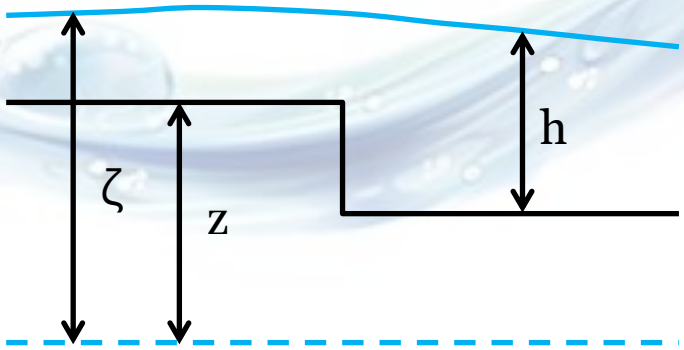
$$\frac{\partial \mathbf{q}}{\partial t} + \frac{\partial \mathbf{f}}{\partial x} = \mathbf{s},$$

$$\mathbf{q} = \begin{pmatrix} h \\ hu \end{pmatrix}, \quad \mathbf{f} = \begin{pmatrix} hu \\ hu^2 + gh^2/2 \end{pmatrix}, \quad \mathbf{s} = \begin{pmatrix} 0 \\ -hgz_x \end{pmatrix},$$

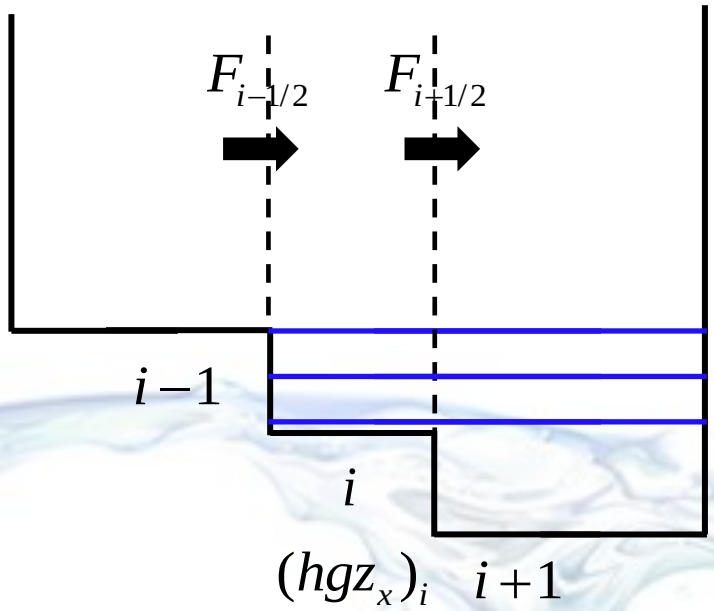
A hydrostatic solution is given as

$$u = 0, \qquad h + z = \text{constant}$$

$$\frac{\partial}{\partial x}\left(gh^2/2\right) + hg\frac{\partial z}{\partial x} = 0$$



Well-balanced scheme



$$\frac{\partial}{\partial x}\left(gh^2/2\right)+hg\frac{\partial z}{\partial x}=0$$

$$\Vert \qquad\qquad \Vert$$

$$(F_{i+1/2}-F_{i-1/2})+hg\left(z_x\right)_i=0$$

const	const	Continuous
non-const	const	Discretized

"hydrostatic reconstruction" technique
(Audusse et al., 2004)

Well-balanced scheme for shallow water equation
(i.e., Rogers et al., 2003; Audusse et al., 2004; Begnudelli & Sanders, 2006; Benkhaldoun et al., 2007; Caleffi et al., 2007; Gallardo et al. 2007; Liange & Borthwick, 2009; Liang & Marche, 2009; etc)

Friction (flow resistance) models

Flow resistance relation	Flow resistance term S_f
Full Bingham	$S_f = \frac{\tau_0}{\rho g h}$ τ_0 can be determined by: $2\tau_0^3 - 3\left(\tau_y + 2\frac{\mu_B q}{h^2}\right)\tau_0^2 + \tau_y^3 = 0$
Simplified Bingham	$S_f = \frac{\tau_0}{\rho g h}$ with $\tau_0 = 1.5\tau_y + 3\frac{\mu_B q}{h^2}$
Voellmy	$S_f = \frac{q\sqrt{q^2}}{h^2 C^2 h_r} + \cos\alpha \tan\delta$
Turbulent & Coulomb	$S_f = \frac{n^2 q\sqrt{q^2}}{h^2 h_r^{4/3}} + \cos\alpha \tan\delta$
Turbulent & Yield	$S_f = \frac{n^2 q\sqrt{q^2}}{h^2 h_r^{4/3}} + \frac{\tau_y}{\rho g h}$
Turbulent, Coulomb & yield	$S_f = \frac{n^2 q\sqrt{q^2}}{h^2 h_r^{4/3}} + \frac{\tau_i}{\rho g h}$ with $\tau_i = \min(\tau_y\,;\ \rho g h \cos\alpha \tan\delta)$
Quadratic	$S_f = \frac{n^2 q\sqrt{q^2}}{h^2 h_r^{4/3}} + \frac{\kappa \eta q}{8h^3 \rho g} + \frac{\tau_y}{\rho g h}$
Coulomb viscous	Full Bingham with $\tau_y = \rho g h \cos\alpha \tan\delta$