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Landslide Hazard Assessment

A brief presentation of the SciNetNatHaz adopted approach

Phase 1. Calculation of Factor of Safety

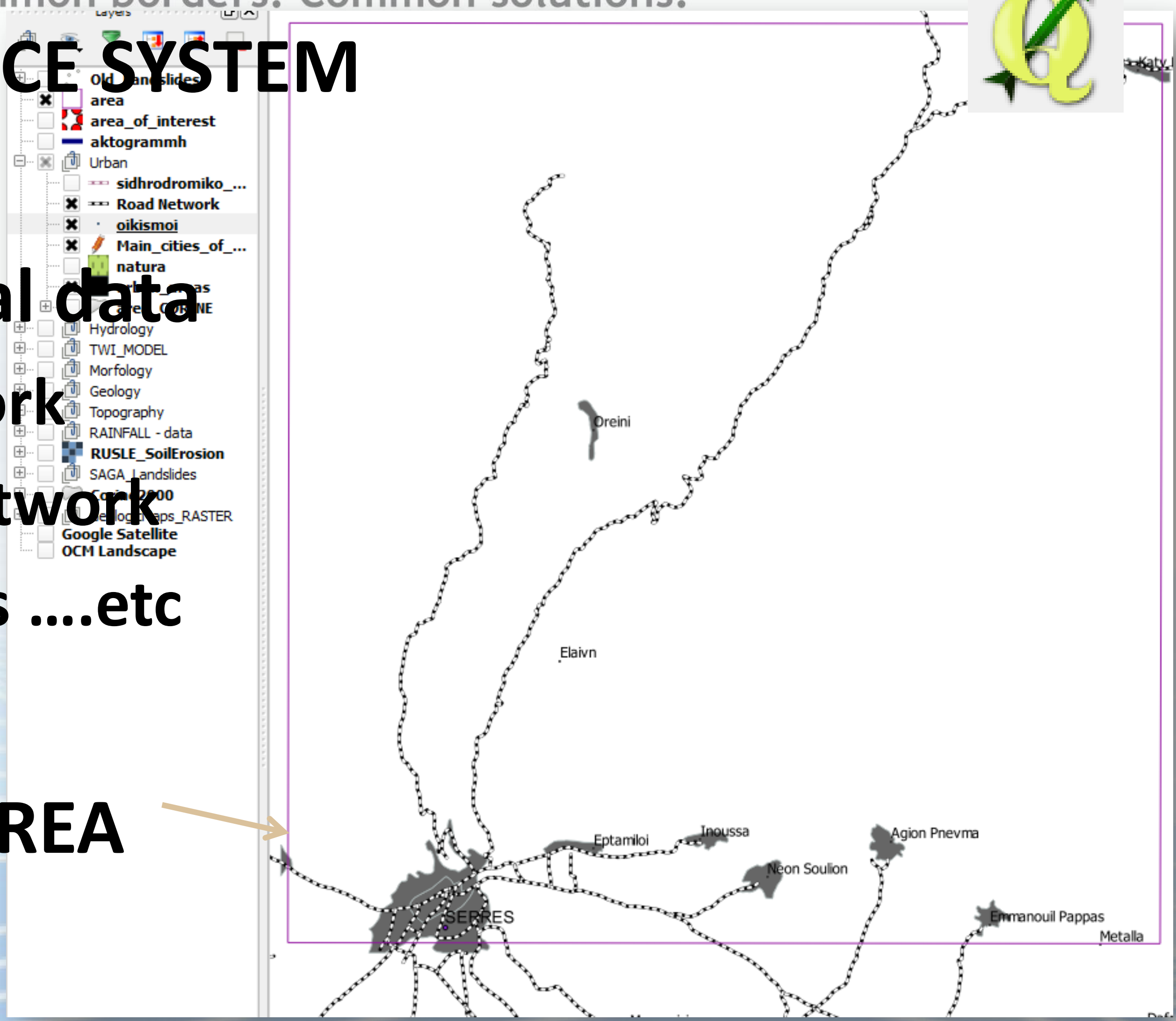
Konstantinos Papatheodorou, Nikolaos Klimis

Basic Info

- **Set REFERENCE SYSTEM**

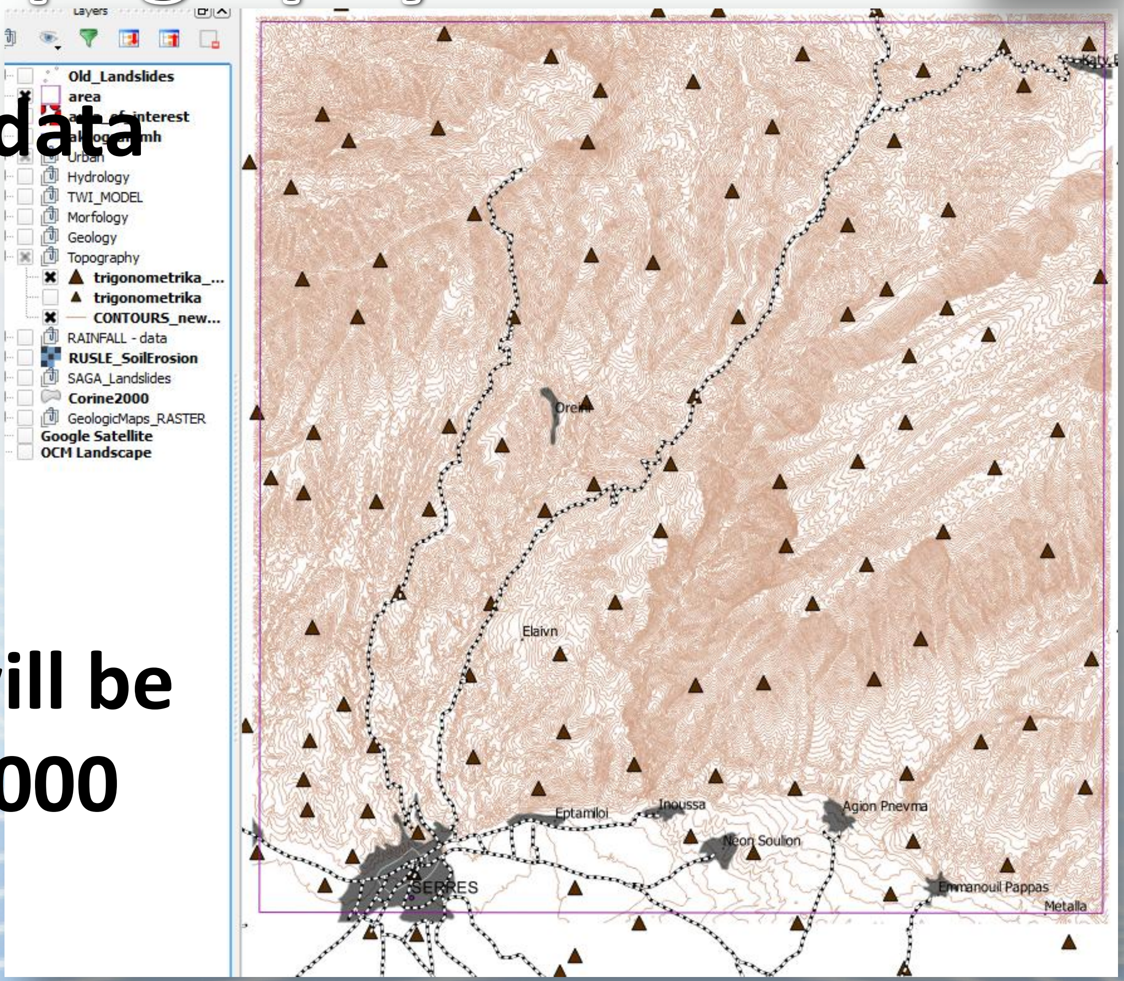
- **Input General data**
  - **Road network**
  - **Railroad network**
  - **Urban areas ….etc**

- **Define the AREA**



Topography

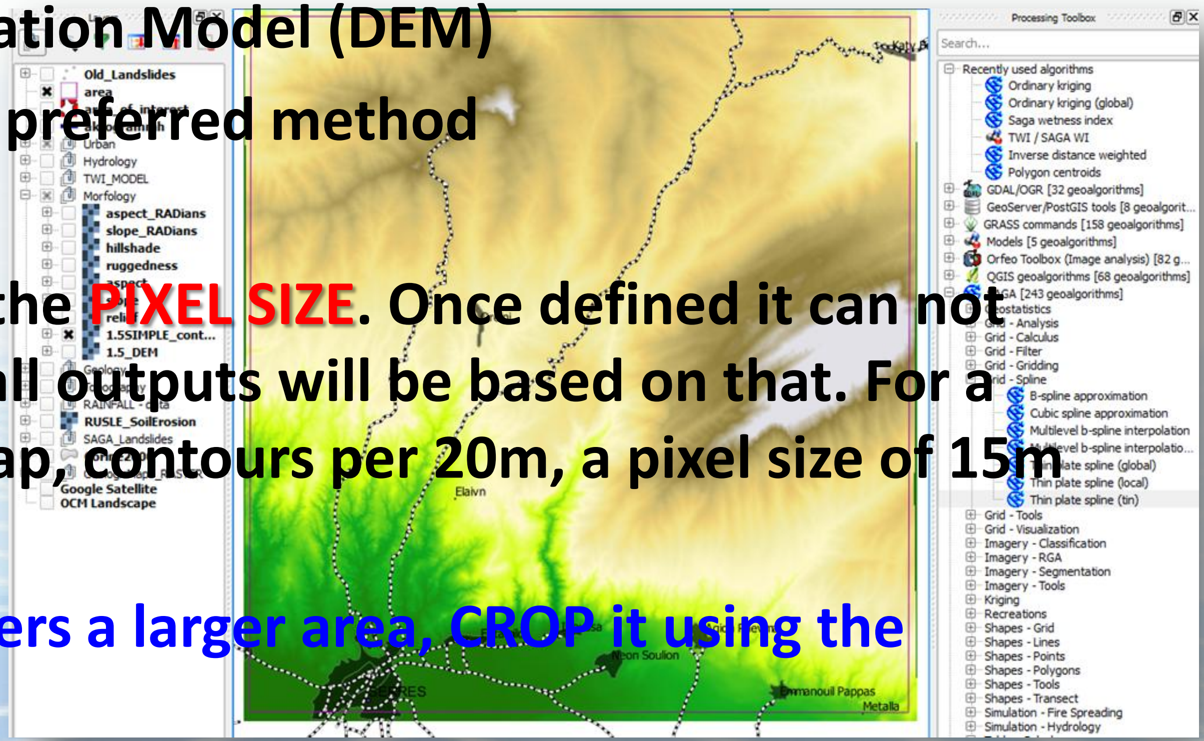
- **Input topographic data**
  - **Contour Lines**
  - **Elevation points**



- **Please Note! We will be working on a 1:50.000 (Regional) scale**

Digital Elevation Model

- **Create a Digital Elevation Model (DEM)**
  - **You can use your preferred method**
  - **….BUT….**
  - **Pay attention to the PIXEL SIZE. Once defined it can not be changed and all outputs will be based on that. For a 1:50.000 scale map, contours per 20m, a pixel size of 15m is fine!**
- **In case the DEM covers a larger area, CROP it using the "AREA" polygon.**



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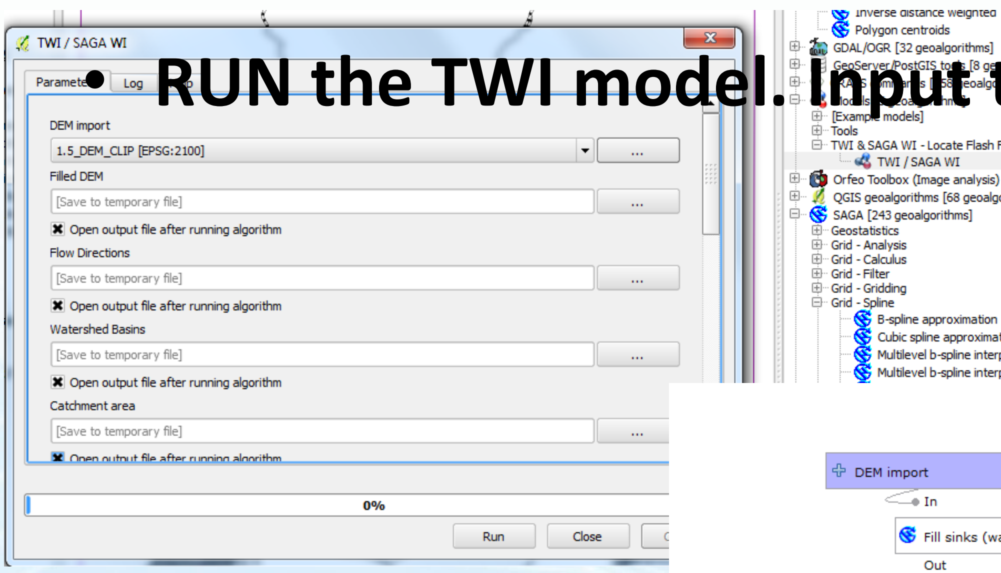
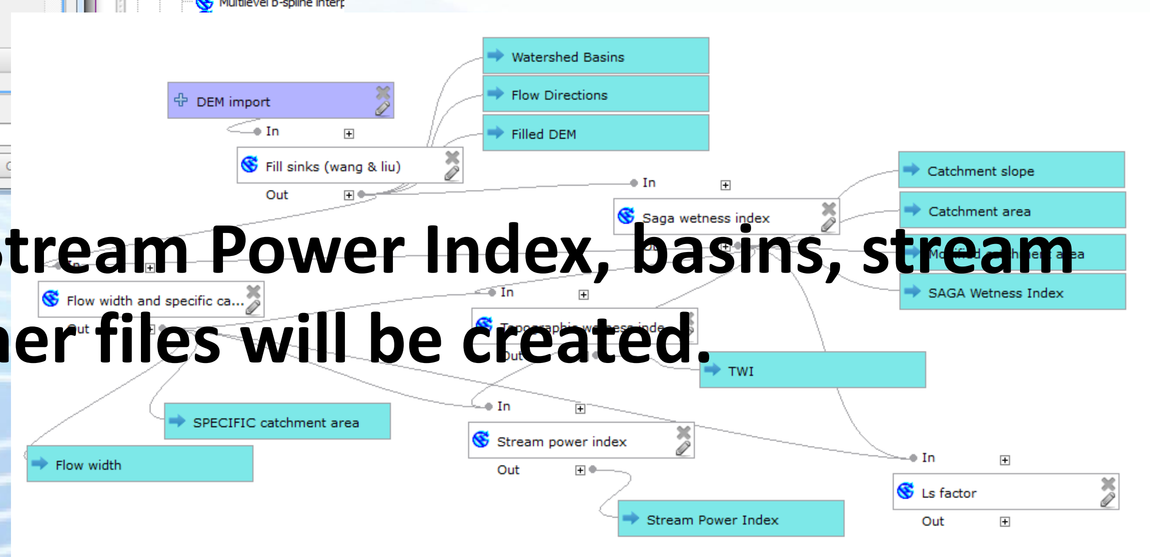
Hydrology- Assessment of Flood prone areas

- RUN the TWI model. Input the DEM file





- TWI, SAGA WI, Stream Power Index, basins, stream network and other files will be created.

  …automatically!

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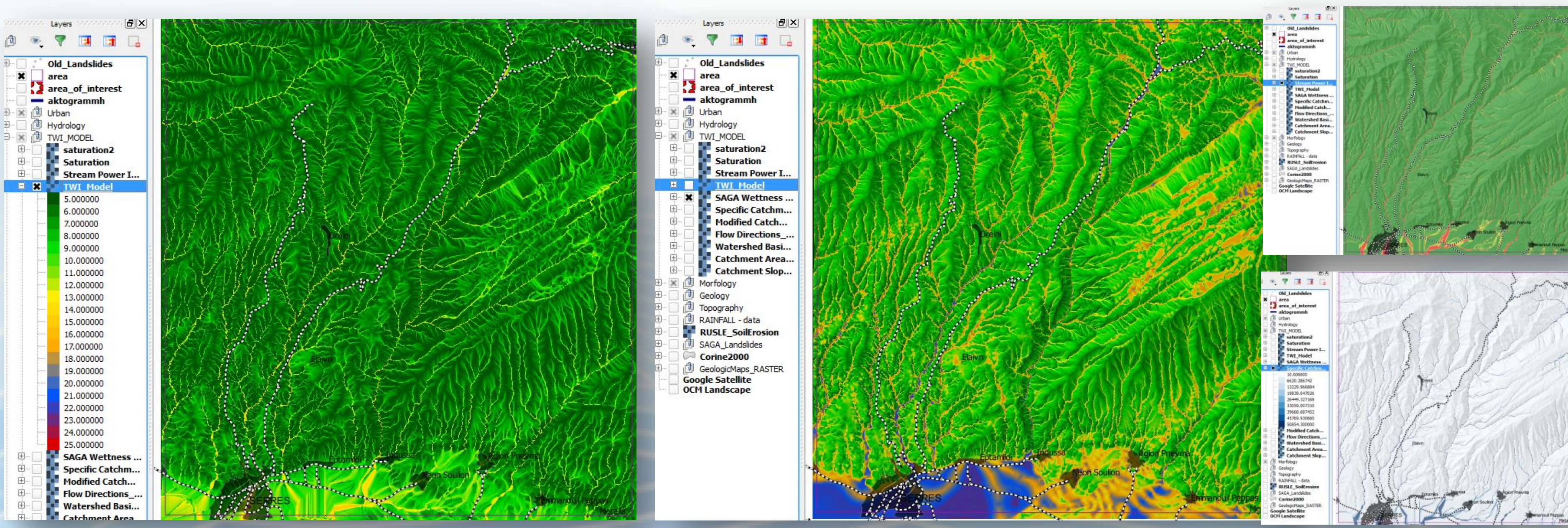
Indices: TWI, SAGA WI etc

- **TWI, SAGA WI, Stream Power Index, basins, stream network and other files created with the model**



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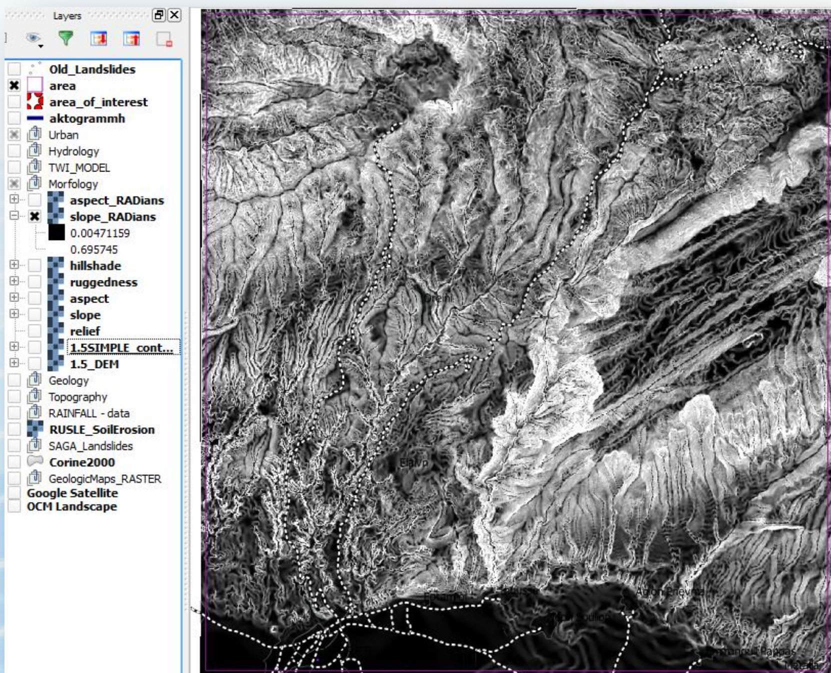
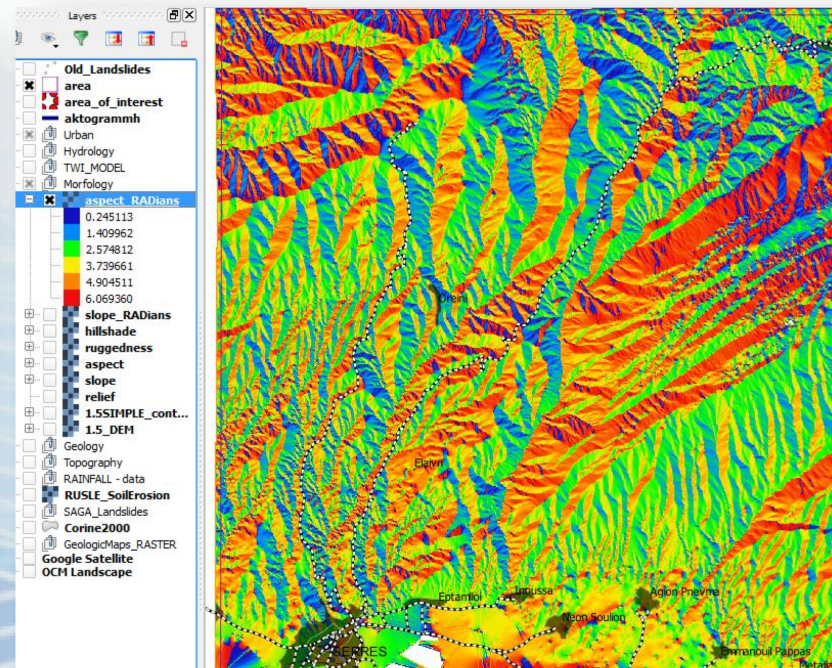
Slope and Aspect maps

- Create SLOPE and ASPECT maps
  - **Please Note!** QGIS uses/calculates angles in RADIANS. Conversions in DEGREES may be needed in the process





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Landslide Hazard Assessment

- **Basic Information comes from topographic data (DEM, Slope, Aspect)**
- **Essential Information comes from the Geologic map**
  - **Geologic formations**
  - **Dip and Dip Direction**
  - **c' (effective cohesion), φ' (effective friction angle), h (hydraulic conductivity), γ (unit weight) etc**

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Geology – Engineering Geology

- **Calculate i) Cohesion (c'); ii) angle of Internal Friction (ϕ); iii) Unit Weight and iv) Hydraulic Conductivity for each of the geologic formations of the area**

	gn,ab			gn,ab,sch			gn,mr			gn-sch			gn-γ			gn-μv			gn1		
Hoek Brown Classification	H=5m	H=50m		H=5m	H=50m		H=5m	H=50m		H=5m	H=50m		H=5m	H=50m		H=5m	H=50m		H=5m	H=50m	
sigci (Mpa)	100	100		100	100		100	100		100	100		120	120		175	175		100	100	
GSI	30	30		31	31		30	30		29	29		31	31		31	31		33	33	
mi	23	23		23	23		12	12		10	10		26	26		26	26		25	25	
D	1	1		1	1		1	1		1	1		1	1		1	1		1	1	
Ei	40000	40000		30000	30000		85000	85000		30000	30000		48000	48000		70000	70000		30000	30000	
MR	400	400		300	300		850	850		300	300		400	400		400	400		300	300	
Hoek Brown Criterion																					
mb	0.15497	0.15497		0.16645	0.16645		0.08086	0.08086		0.06273	0.06273		0.18816	0.18816		0.18816	0.18816		0.20870	0.20870	
s	8.57E-06	8.57E-06		1.01E-05	1.01E-05		8.57E-06	8.57E-06		7.26E-06	7.26E-06		1.01E-05	1.01E-05		1.01E-05	1.01E-05		1.41E-05	1.41E-05	
a	0.52234	0.52234		0.52089	0.52089		0.52234	0.52234		0.52390	0.52390		0.52089	0.52089		0.52089	0.52089		0.51826	0.51826	
Failure Envelope Range																					
Application	Slopes	Slopes		Slopes	Slopes		Slopes	Slopes		Slopes	Slopes		Slopes	Slopes		Slopes	Slopes		Slopes	Slopes	
sig3max (Mpa)	0.12892	1.04787		0.12946	1.05227		0.12066	0.98074		0.12344	1.00331		0.13236	1.07584		0.13693	1.11300		0.13103	1.06504	
Unit Weight (MN/m3)	0.026	0.026		0.026	0.026		0.025	0.025		0.026	0.026		0.026	0.026		0.026	0.026		0.026	0.026	
Slope Height (m)	5	50		5	50		5	50		5	50		5	50		5	50		5	50	
Mohr-Coulomb Fit																					
c (Mpa)	0.0587	0.2299		0.0616	0.2391		0.0530	0.1798		0.0500	0.1653		0.0685	0.2671		0.0827	0.3084		0.0688	0.2651	
phi (degrees)	51.6	35.1		52.3	35.9		46.3	29.9		43.6	27.4		54.4	38.3		56.7	41.1		54.3	38.0	
Rock Mass Parameters																					
sigt (Mpa)	-0.0055	-0.0055		-0.0061	-0.0061		-0.0106	-0.0106		-0.0116	-0.0116		-0.0065	-0.0065		-0.0094	-0.0094		-0.0068	-0.0068	
sigc (Mpa)	0.2256	0.2256		0.2503	0.2503		0.2256	0.2256		0.2031	0.2031		0.3004	0.3004		0.4380	0.4380		0.3067	0.3067	
sigcm (Mpa)	4.5577	4.5577		4.7751	4.7751		3.2471	3.2471		2.8123	2.8123		6.1073	6.1073		8.9065	8.9065		5.4597	5.4597	
Erm (Mpa)	1128.98	1128.98		869.793	869.793		2399.08	2399.08		825.615	825.615		1391.67	1391.67		2029.52	2029.52		922.432	922.432	
Results																					
	H(m)	ϕ	c (kPa)	H(m)	ϕ	c (kPa)	H(m)	ϕ	c (kPa)	H(m)	ϕ	c (kPa)	H(m)	ϕ	c (kPa)	H(m)	ϕ	c (kPa)	H(m)	ϕ	c (kPa)
	5	51.61	58.71	5	52.30	61.65	5	46.31	52.98	5	43.63	50.02	5	54.43	68.54	5	56.70	82.66	5	54.27	68.77
	50	35.14	229.90	50	35.88	239.11	50	29.90	179.85	50	27.39	165.30	50	38.29	267.10	50	41.10	308.41	50	38.04	265.11
Final Values		ϕ	c (kPa)		ϕ	c (kPa)		ϕ	c (kPa)		ϕ	c (kPa)		ϕ	c (kPa)		ϕ	c (kPa)		ϕ	c (kPa)
		35	59		36	62		30	53		27	50		38	69		41	83		38	69

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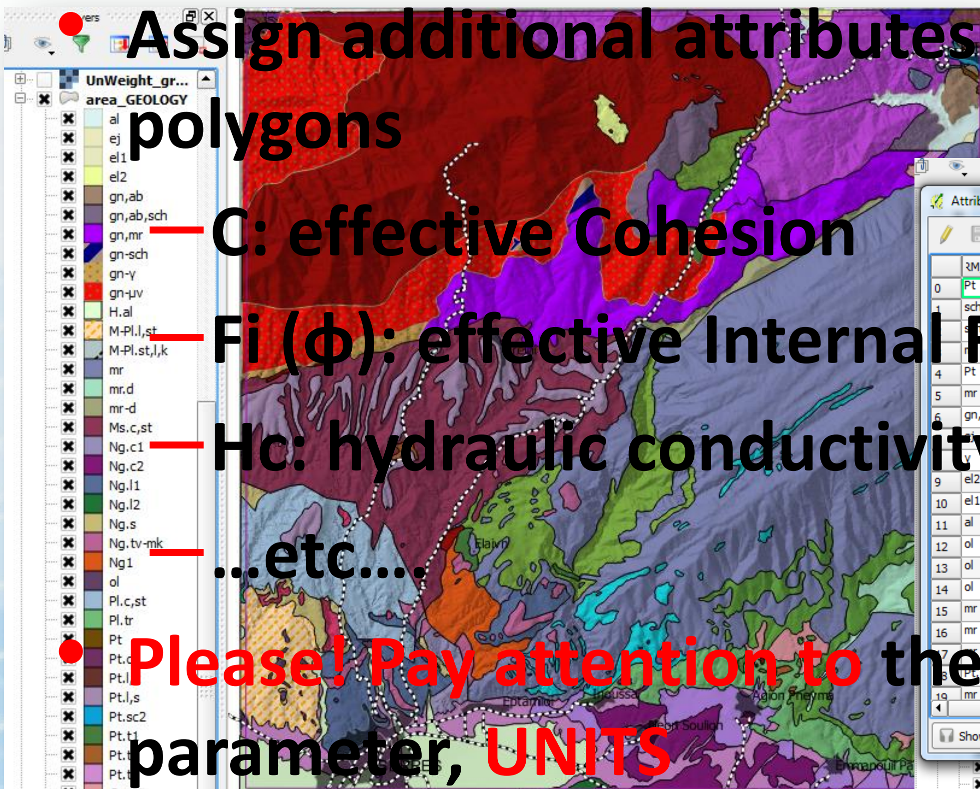
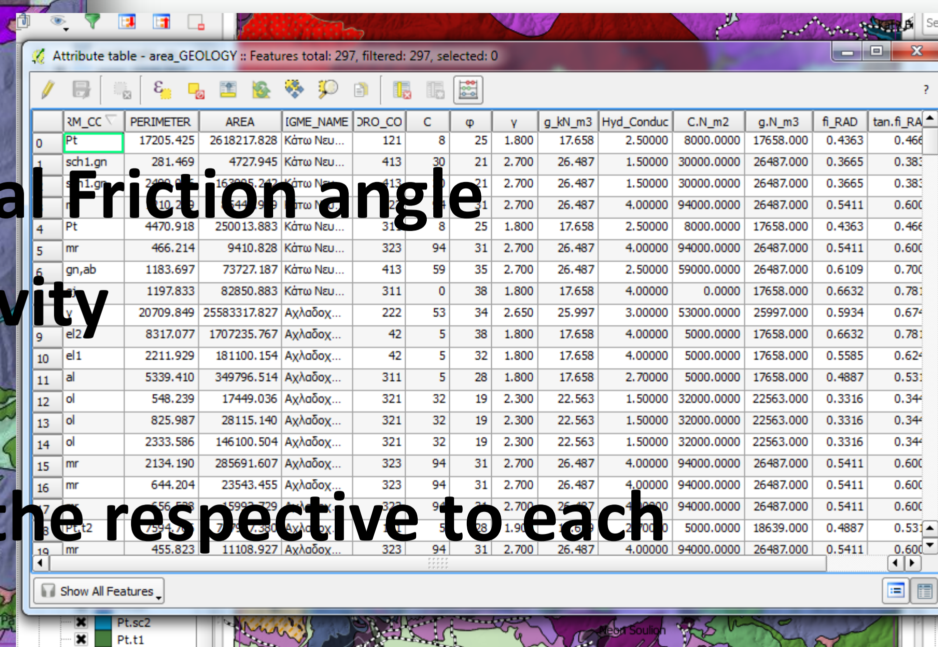
Geology – Engineering Geology

- Digitize the Geologic Map
- Assign additional attributes to geologic formation polygons
  - C: effective Cohesion
  - Fi (φ): effective Internal Friction angle
  - Hc: hydraulic conductivity
  - …etc….
- Please! Pay attention to the respective to each parameter, UNITS





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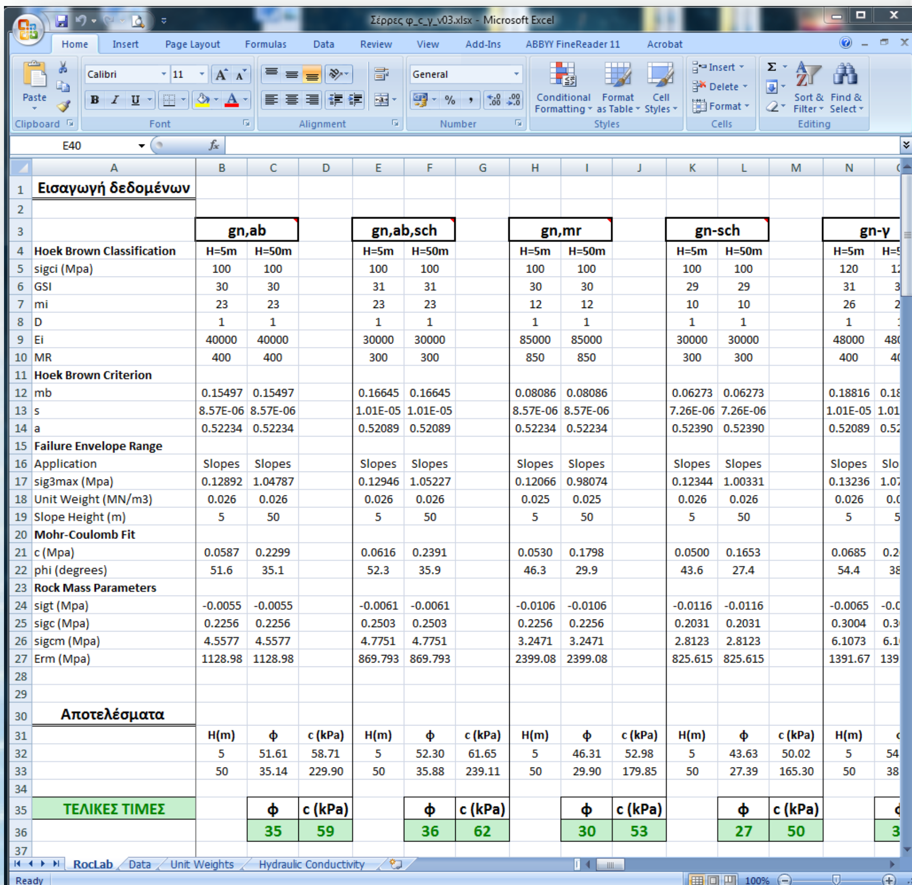
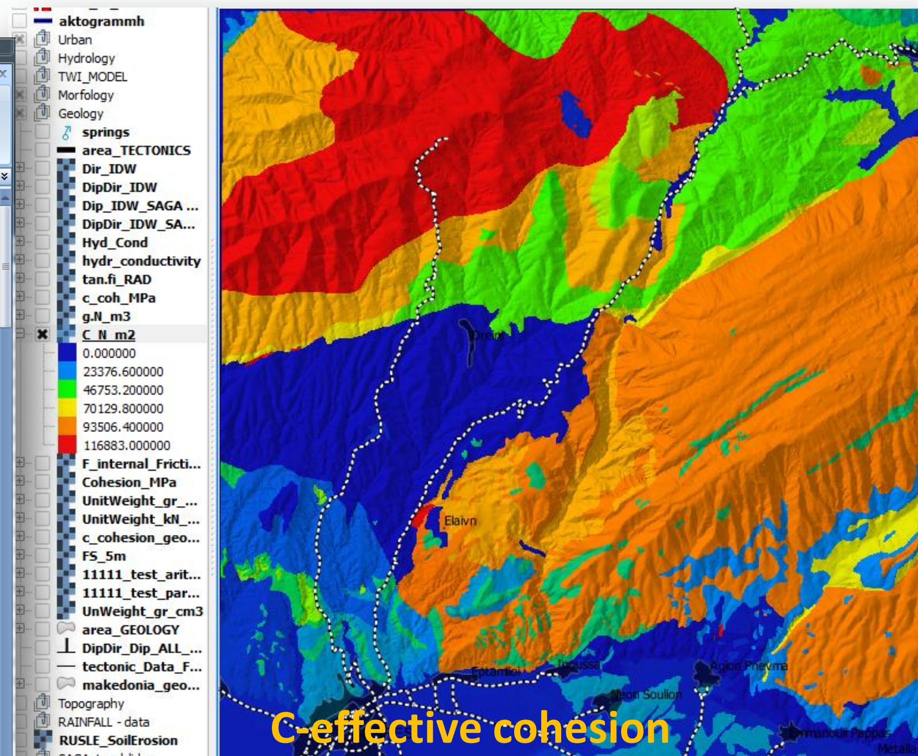
Factor of Safety – Calculate Parameters



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Εισαγωγή δεδομένων													
2														
3		gn,ab			gn,ab,sch			gn,mr			gn-sch			gn-γ
4	Hoek Brown Classification	H=5m	H=50m		H=5m	H=50m		H=5m	H=50m		H=5m	H=50m		H=5m
5	sigci (Mpa)	100	100		100	100		100	100		100	100		120
6	GSI	30	30		31	31		30	30		29	29		31
7	mi	23	23		23	23		12	12		10	10		26
8	D	1	1		1	1		1	1		1	1		1
9	Ei	40000	40000		30000	30000		85000	85000		30000	30000		48000
10	MR	400	400		300	300		850	850		300	300		400
11	Hoek Brown Criterion													
12	mb	0.15497	0.15497		0.16645	0.16645		0.08086	0.08086		0.06273	0.06273		0.18816
13	s	8.57E-06	8.57E-06		1.01E-05	1.01E-05		8.57E-06	8.57E-06		7.26E-06	7.26E-06		1.01E-05
14	a	0.52234	0.52234		0.52089	0.52089		0.52234	0.52234		0.52390	0.52390		0.52089
15	Failure Envelope Range													
16	Application	Slopes	Slopes		Slopes	Slopes		Slopes	Slopes		Slopes	Slopes		Slopes
17	sig3max (Mpa)	0.12892	1.04787		0.12946	1.05227		0.12066	0.98074		0.12344	1.00331		0.13236
18	Unit Weight (MN/m3)	0.026	0.026		0.026	0.026		0.025	0.025		0.026	0.026		0.026
19	Slope Height (m)	5	50		5	50		5	50		5	50		5
20	Mohr-Coulomb Fit													
21	c (Mpa)	0.0587	0.2299		0.0616	0.2391		0.0530	0.1798		0.0500	0.1653		0.0685
22	phi (degrees)	51.6	35.1		52.3	35.9		46.3	29.9		43.6	27.4		54.4
23	Rock Mass Parameters													
24	sigt (Mpa)	-0.0055	-0.0055		-0.0061	-0.0061		-0.0106	-0.0106		-0.0116	-0.0116		-0.0065
25	sigc (Mpa)	0.2256	0.2256		0.2503	0.2503		0.2256	0.2256		0.2031	0.2031		0.3004
26	sigcm (Mpa)	4.5577	4.5577		4.7751	4.7751		3.2471	3.2471		2.8123	2.8123		6.1073
27	Erm (Mpa)	1128.98	1128.98		869.793	869.793		2399.08	2399.08		825.615	825.615		1391.67
28														
29														
30	Αποτελέσματα													
31		H(m)	φ	c (kPa)	H(m)	φ	c (kPa)	H(m)	φ	c (kPa)	H(m)	φ	c (kPa)	H(m)
32		5	51.61	58.71	5	52.30	61.65	5	46.31	52.98	5	43.63	50.02	5
33		50	35.14	229.90	50	35.88	239.11	50	29.90	179.85	50	27.39	165.30	50
34														
35	ΤΕΛΙΚΕΣ ΤΙΜΕΣ		φ	c (kPa)		φ	c (kPa)		φ	c (kPa)		φ	c (kPa)	
36			35	59		36	62		30	53		27	50	



- c' & φ' calculation (left)
- Effective cohesion map (right)

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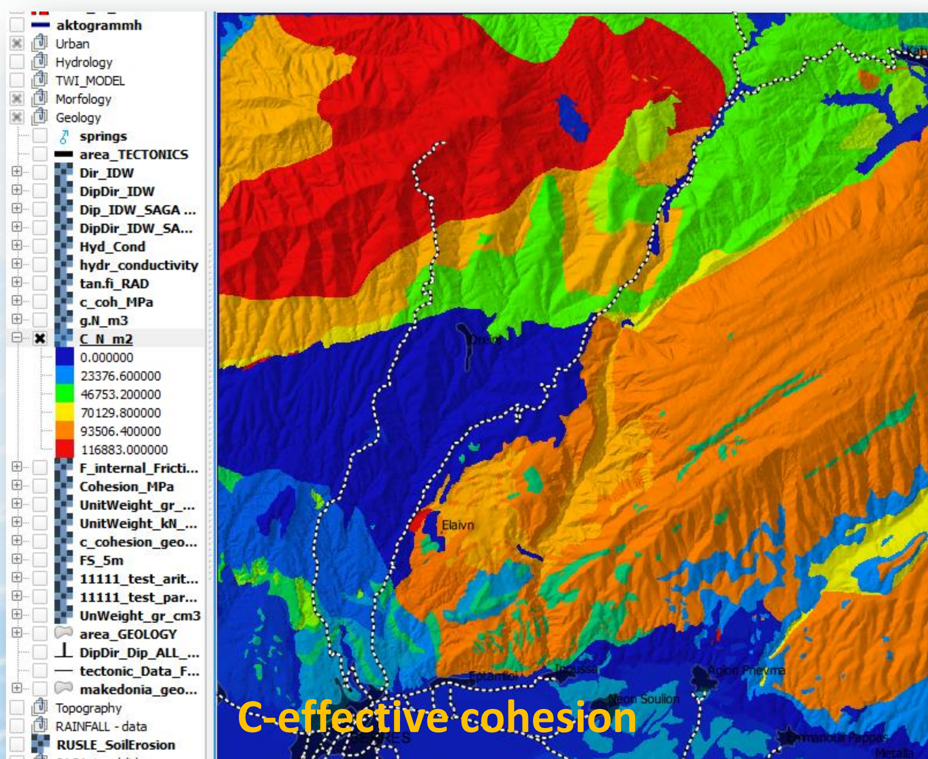
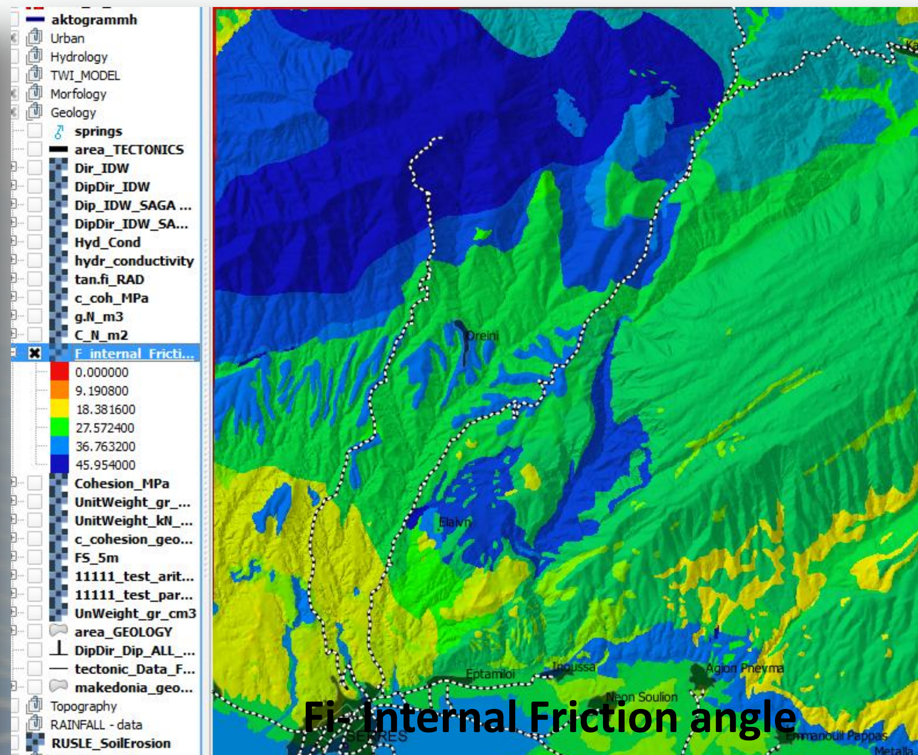
Geology – Engineering Geology





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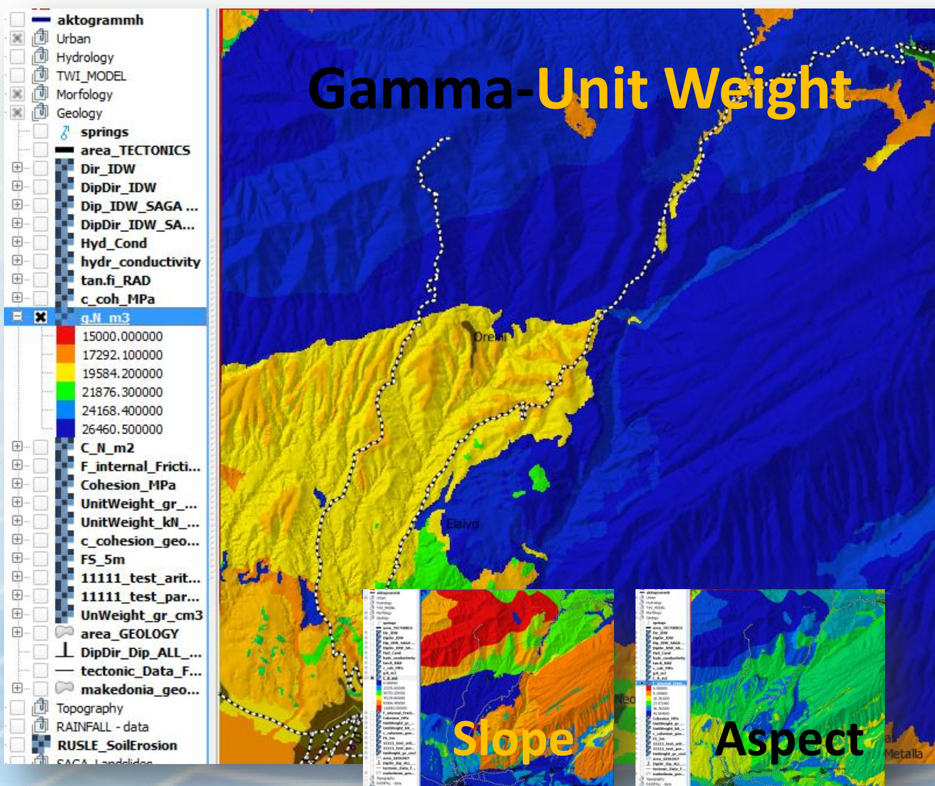

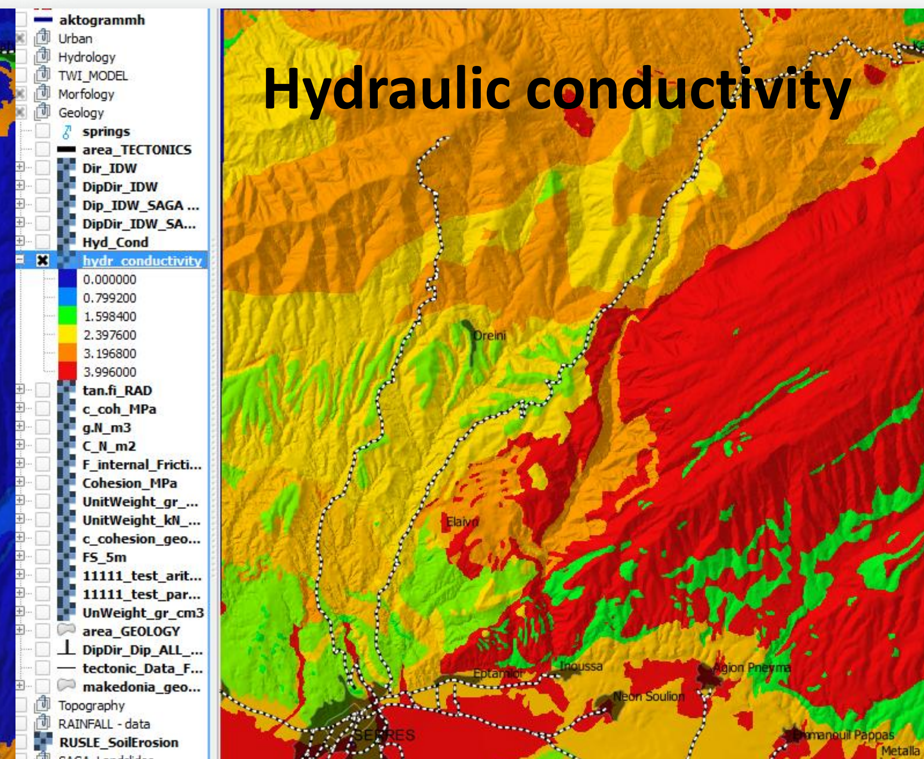

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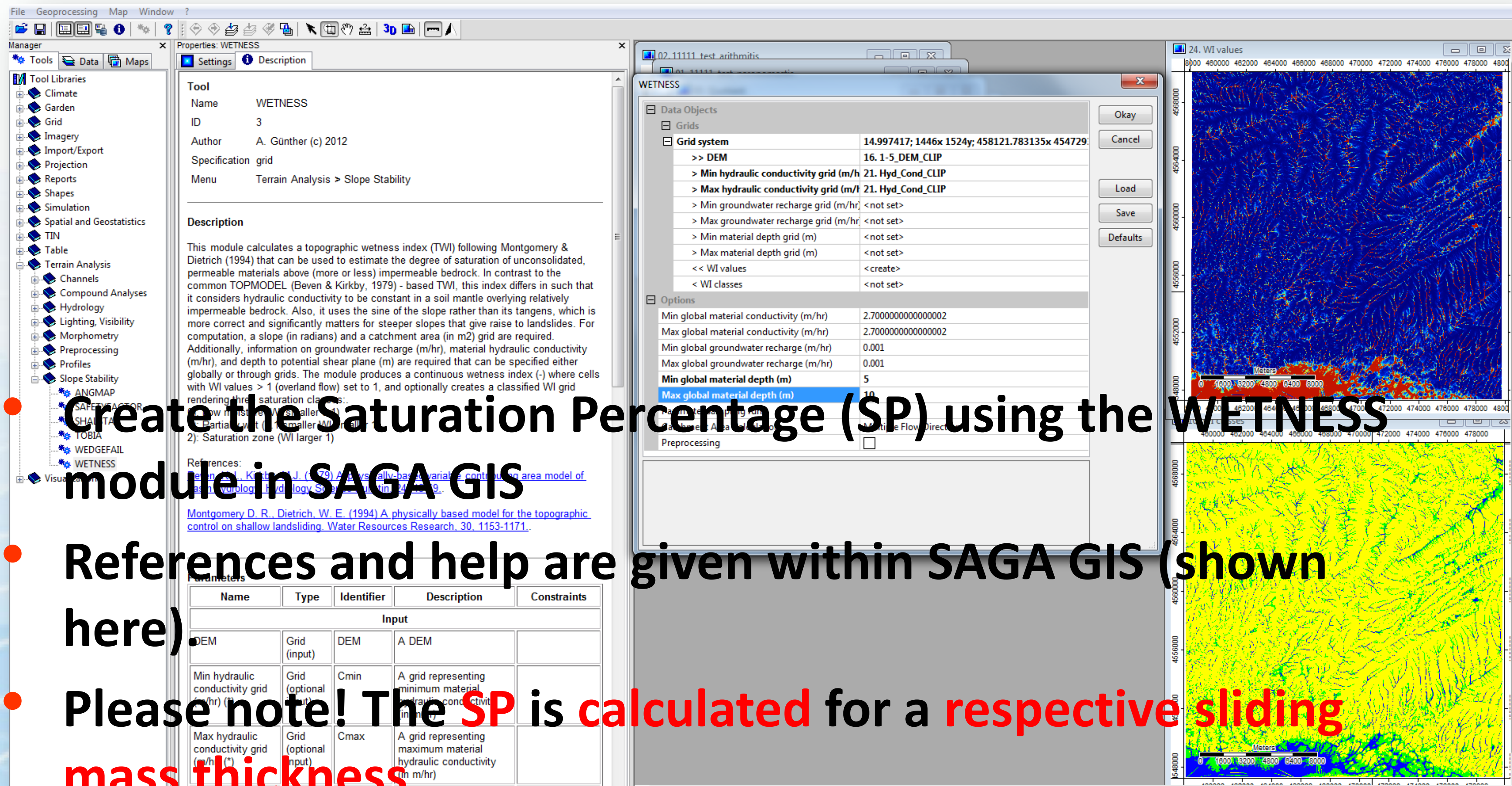
Saturation percentage



- Create the Saturation Percentage (SP) using the WETNESS module in SAGA GIS
- References and help are given within SAGA GIS (shown here).
- Please note! The SP is calculated for a respective sliding mass thickness

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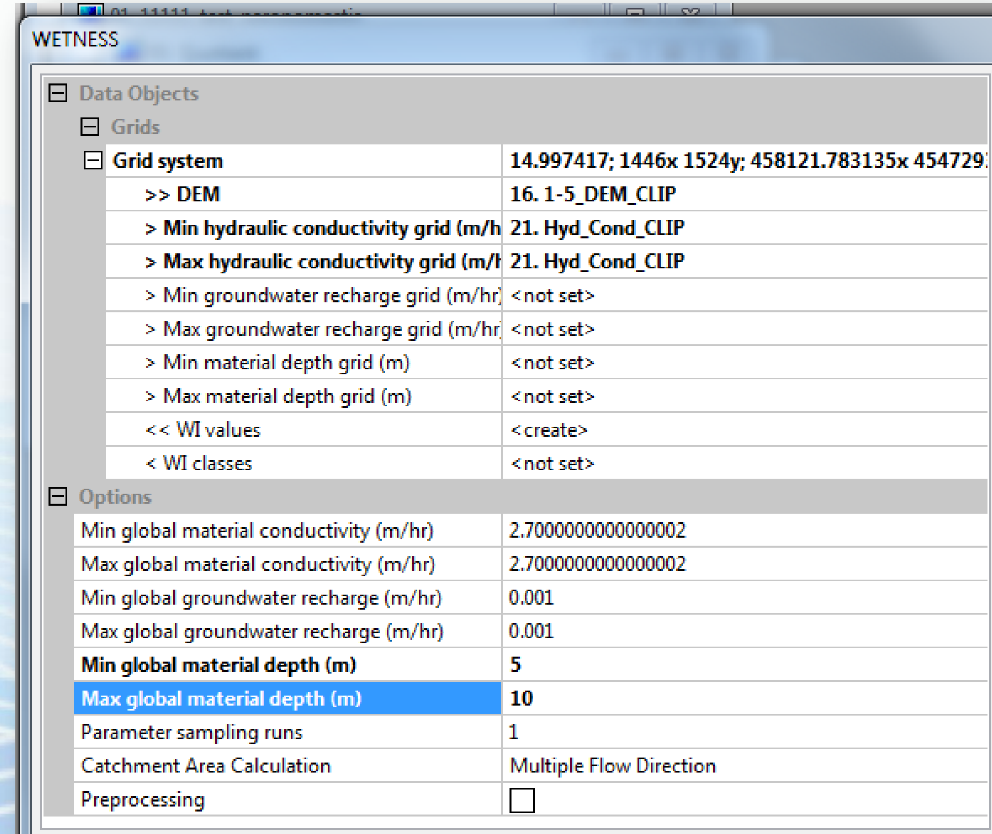
Saturation percentage parameters

Parameters taken into consideration

- Upslope Contribution (flow accumulation)
- Slope
- Hydraulic conductivity
- A combination of Rainfall and effective infiltration (GW recharge)
- Sliding mass thickness



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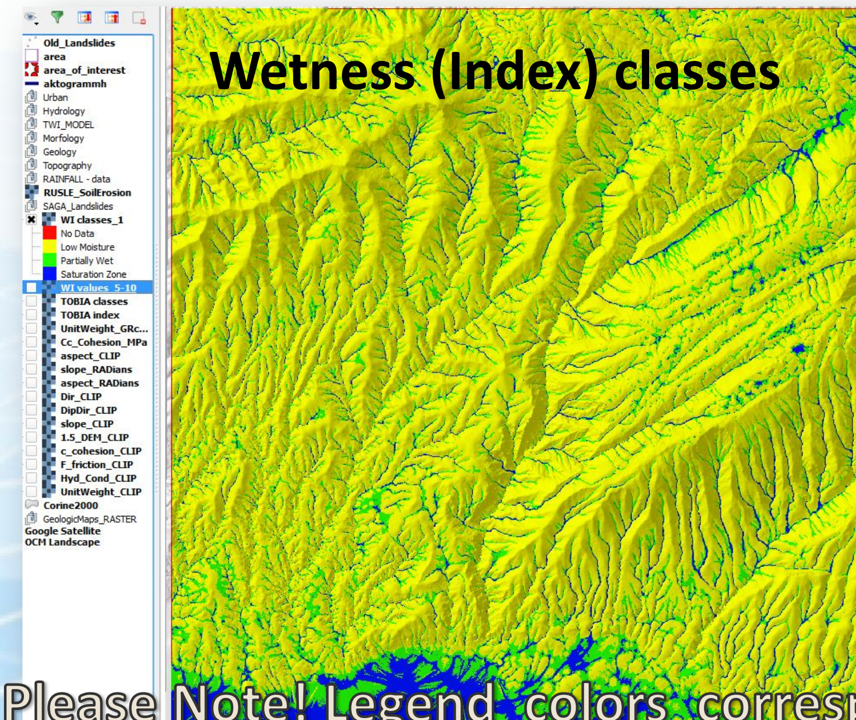
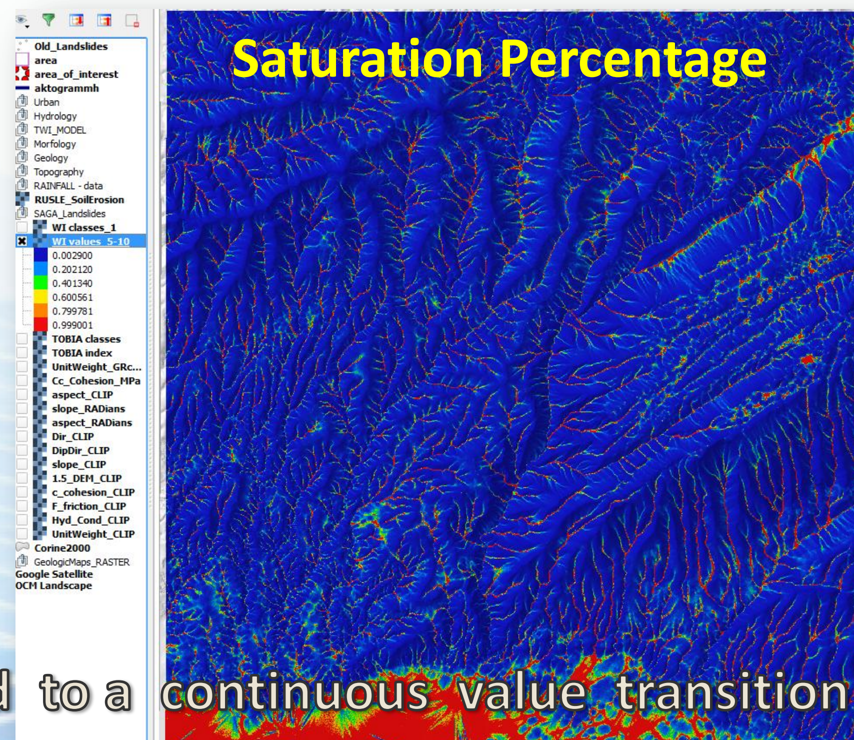
Saturation percentage





Please Note! Legend colors correspond to a continuous value transition

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Landslide HA – Susceptibility mapping

- Create TOBIA index and Classes
- ….Using the respective SAGA GIS module and ….
- …Slope, Aspect, Dip and DipDirection maps

Meentemeyer R. K., Moody A. (2000). Automated mapping of conformity between topographic and geological surfaces. Computers & Geosciences, 26, 815 - 829.

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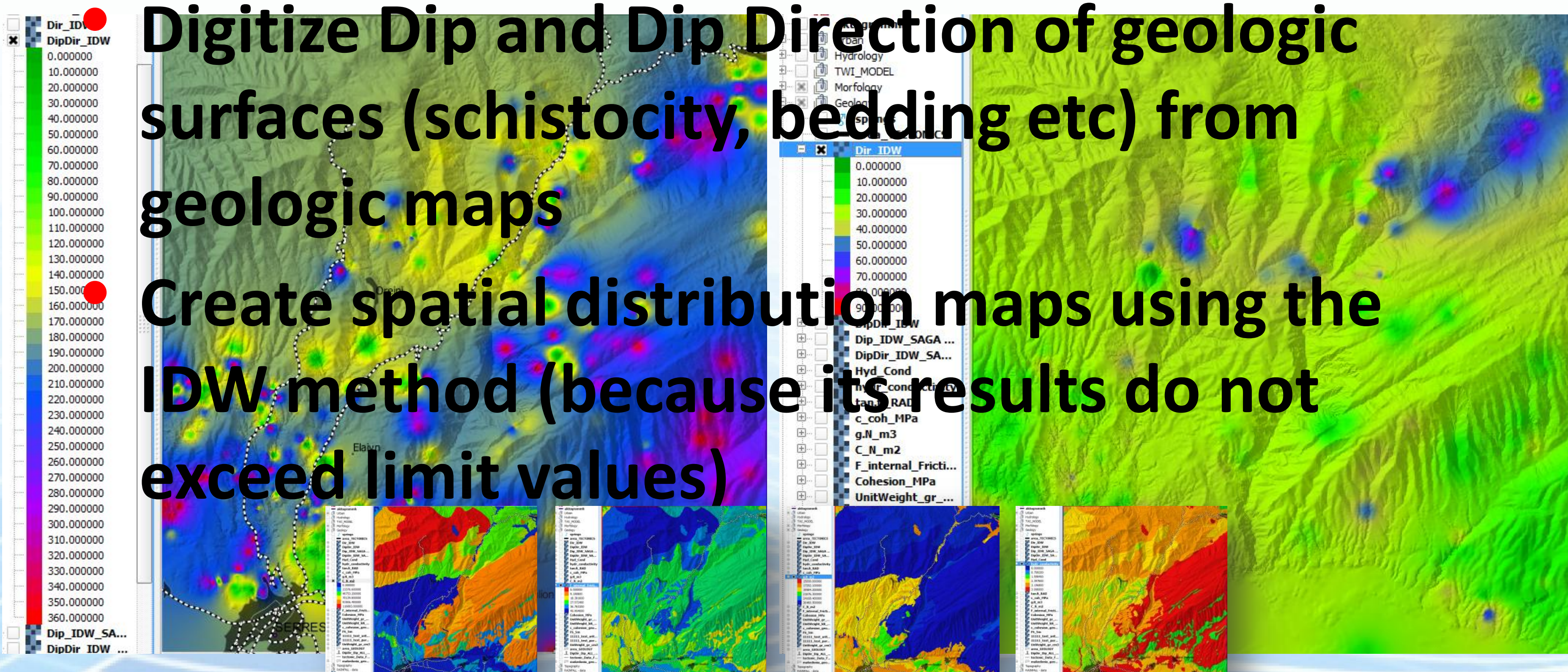
Dip and Dip Direction of geologic surfaces



- **Digitize Dip and Dip Direction of geologic surfaces (schistocity, bedding etc) from geologic maps**
- **Create spatial distribution maps using the IDW method (because its results do not exceed limit values)**

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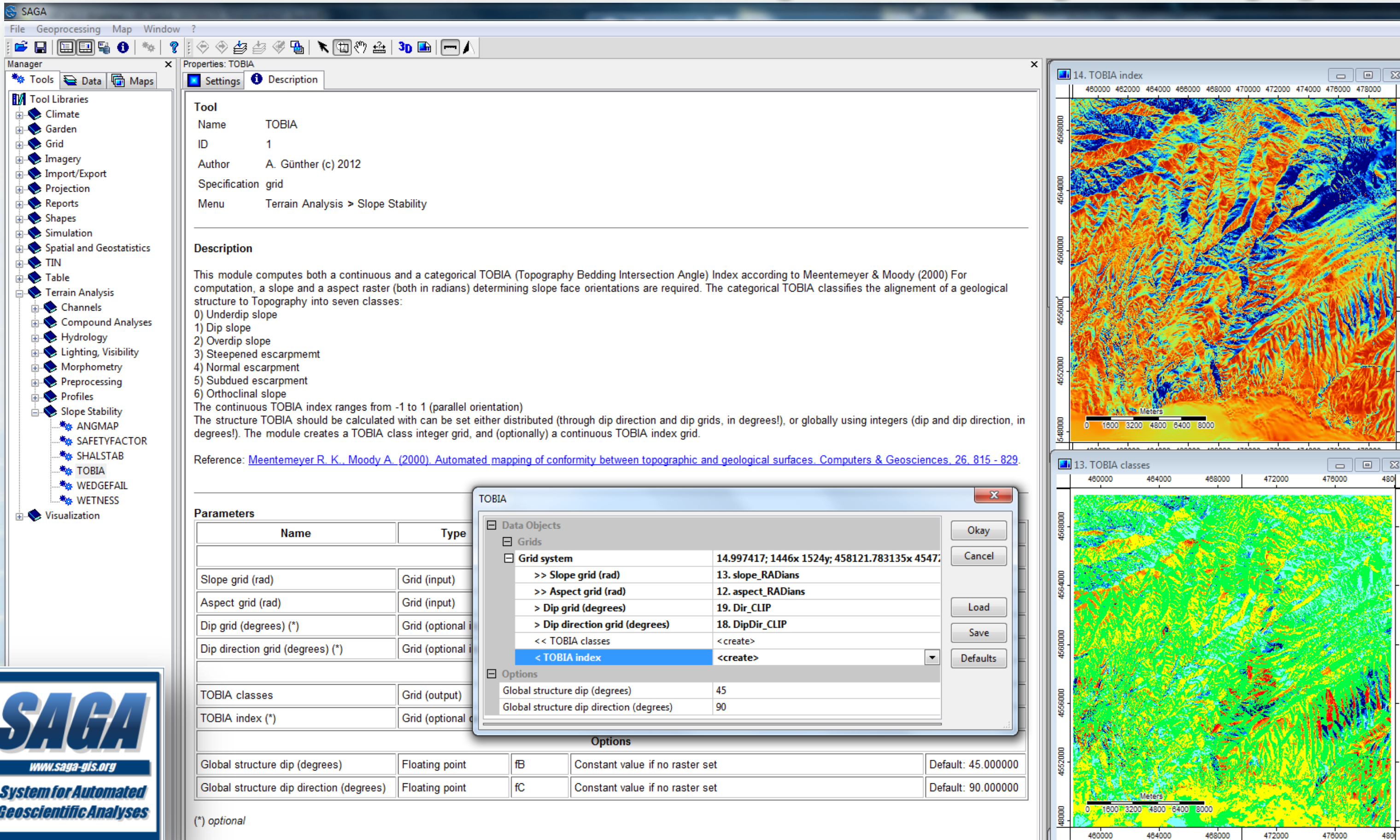
Landslide HA - Susceptibility mapping



SAGA
www.saga-gis.org
System for Automated Geoscientific Analyses

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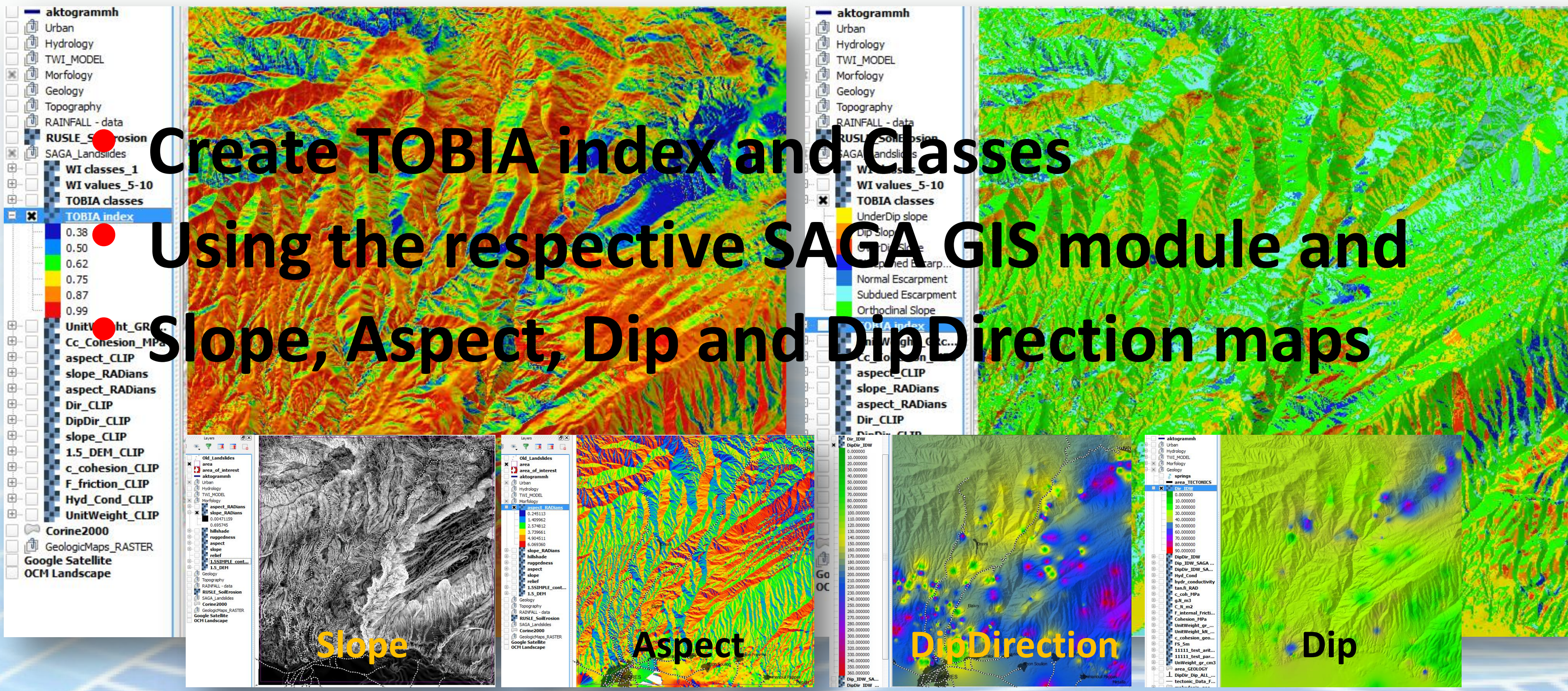
Landslide Susceptibility

- Create TOBIA index and Classes
- Using the respective SAGA GIS module and
- Slope, Aspect, Dip and DipDirection maps



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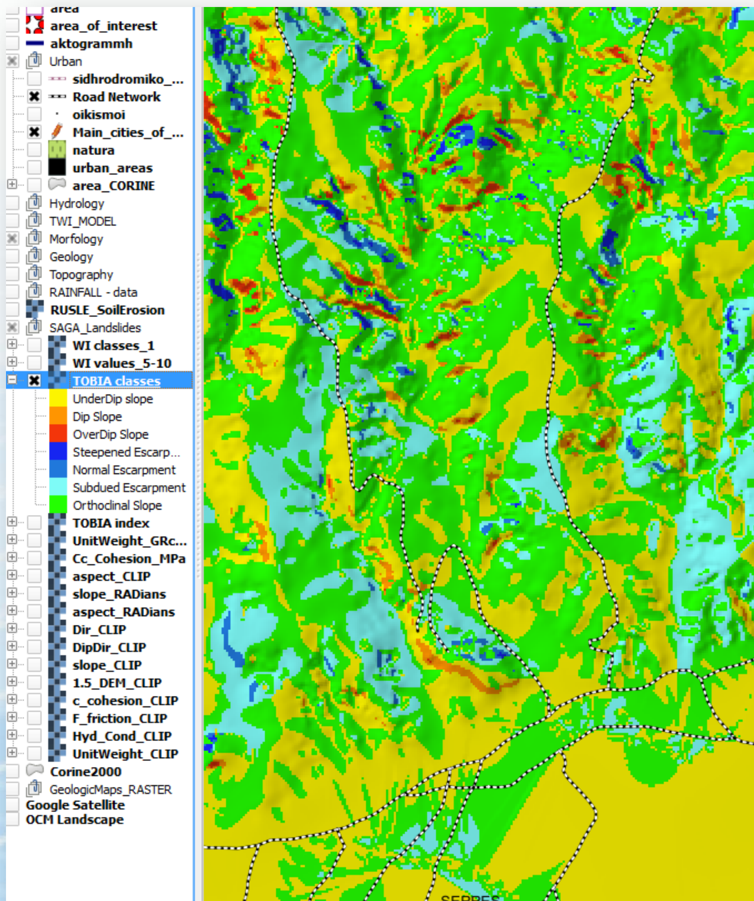
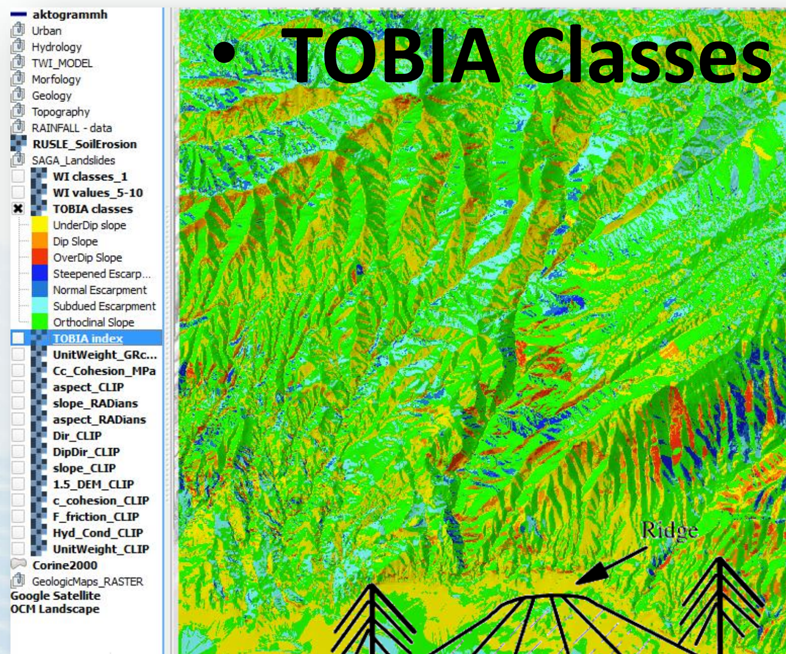
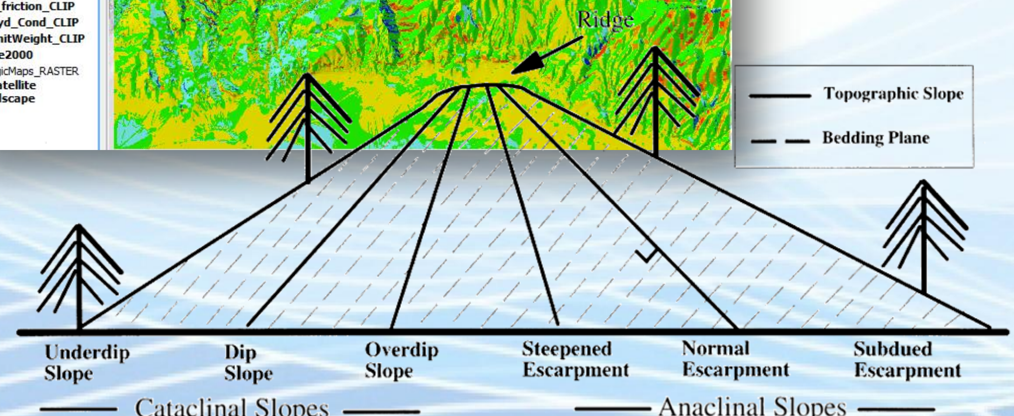
Landslide Susceptibility – TOBIA classes







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Landslide HA – Factor of Safety

- **Calculate Factor of Safety (FS) – water – 5m thick sliding mass***

$$F = \frac{c' + (\gamma - m\gamma_w)\, z \cos^2\beta \tan\phi'}{\gamma z \sin\beta \cos\beta}$$

in which:

c' = effective cohesion (Pa= N/m^2).

γ = unit weight of soil (N/m^3).

m = z_w/z (dimensionless).

γ_w = unit weight of water (N/m^3).

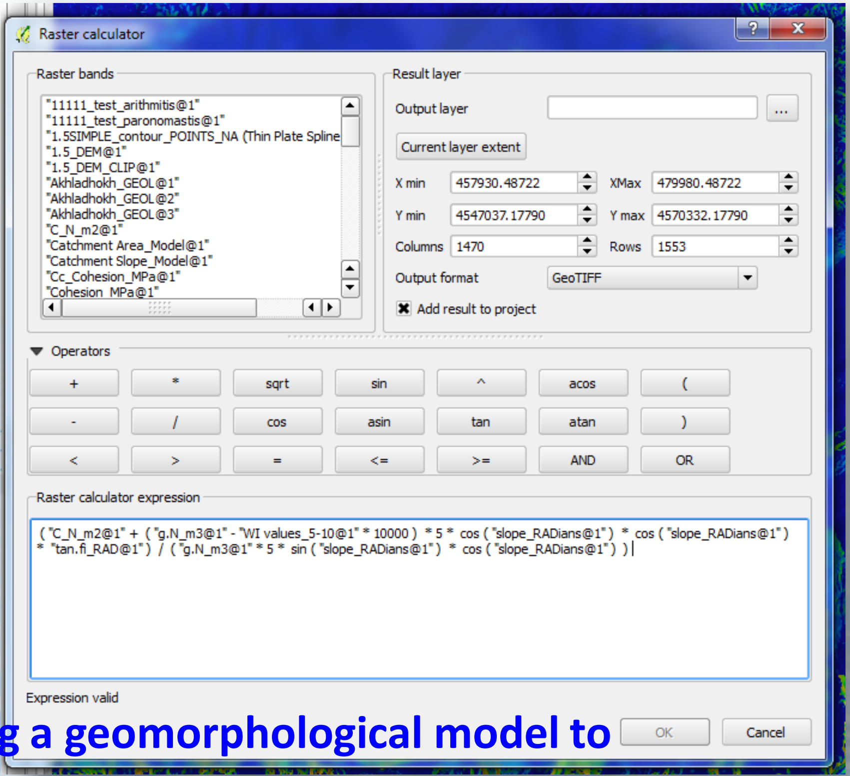
z = depth of failure surface below the surface (m).

z_w = height of watertable above failure surface (m).

β = slope surface inclination (°).

ϕ' = effective angle of shearing resistance (°).

- **…using the information layers created previously and the RASTER CALCULATOR module in QGIS**



*** We are currently working into incorporating a geomorphological model to calculate the soil thickness in the entire area**

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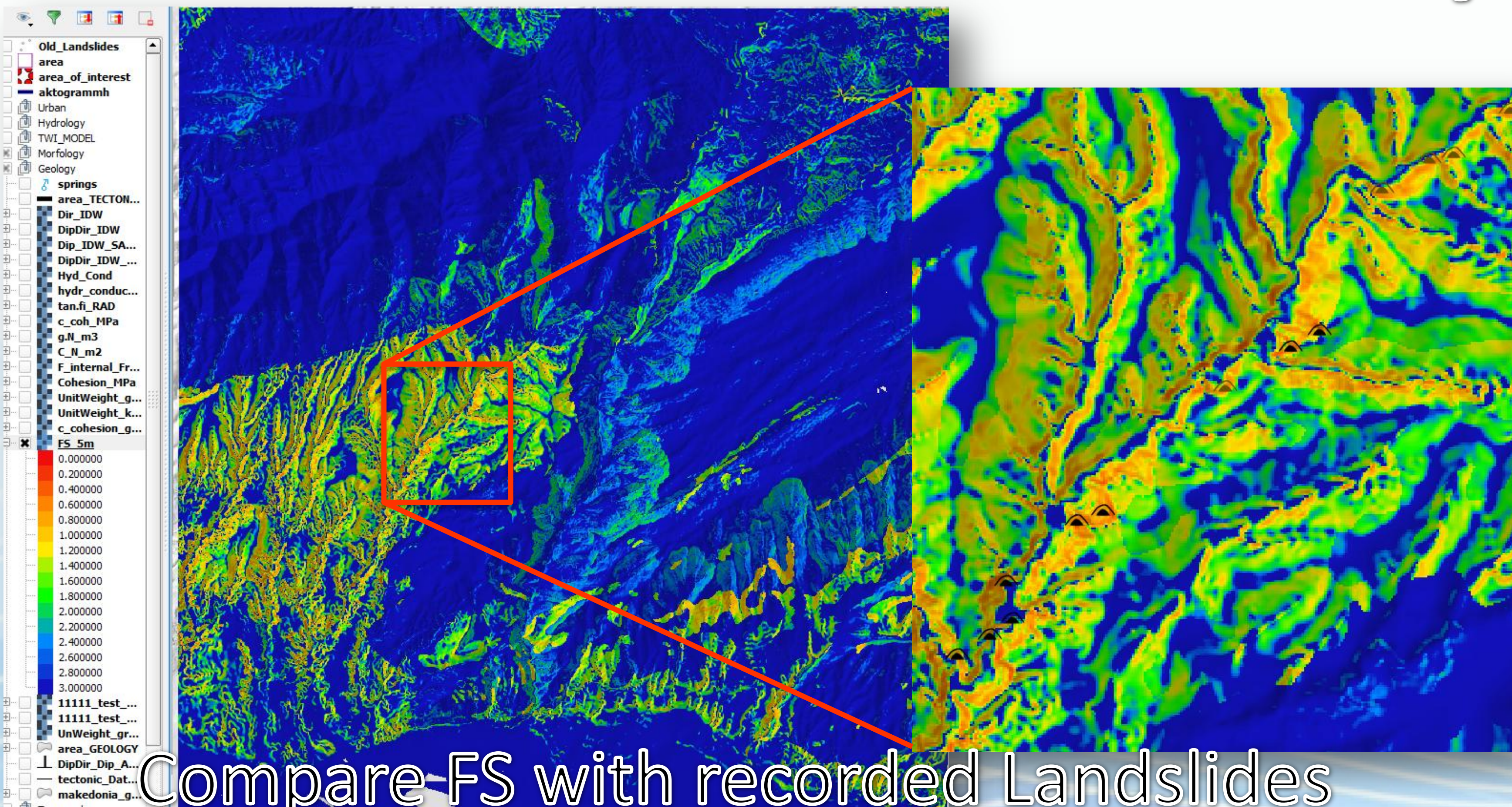
Landslide HA – Factor of Safety



Compare FS with recorded Landslides

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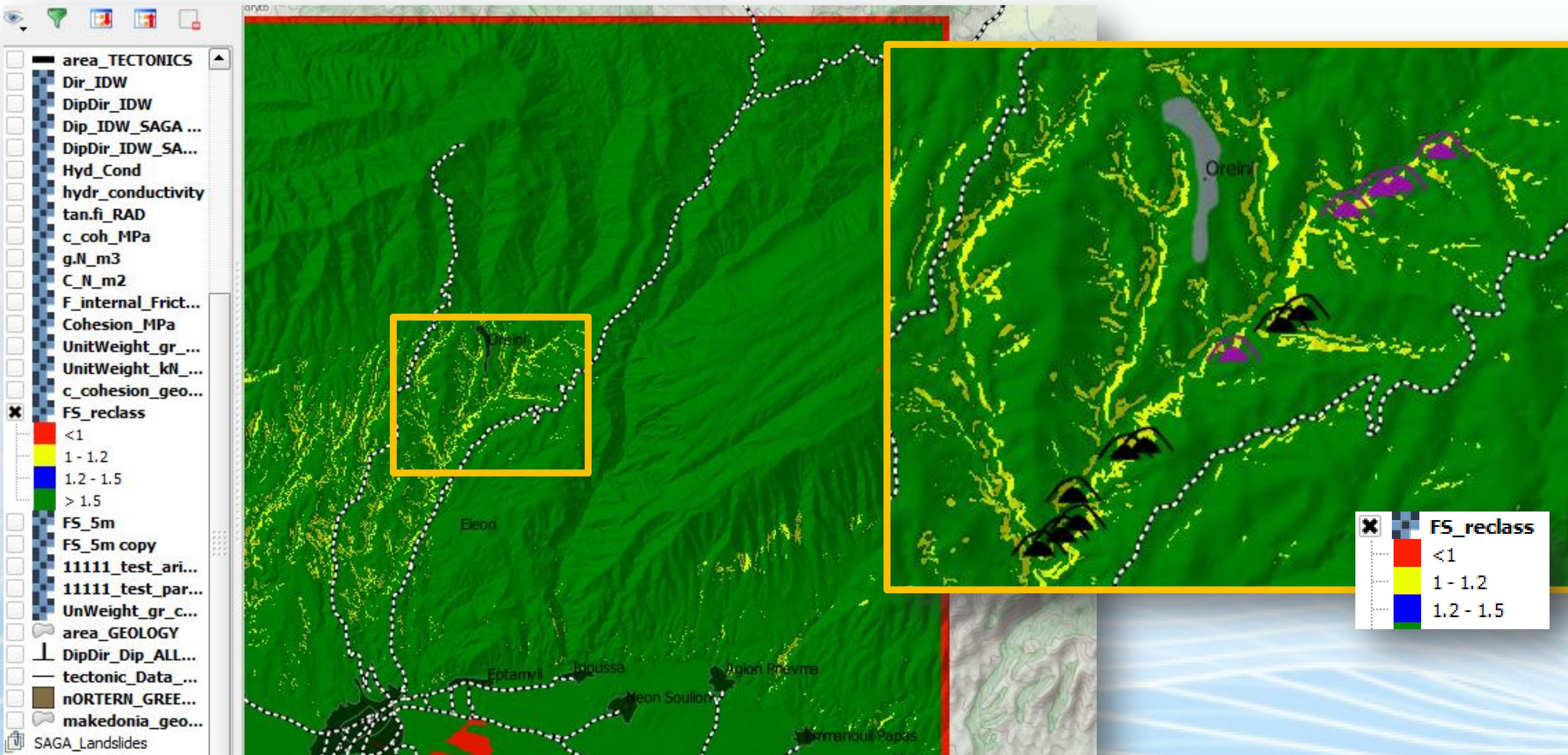
SciNet NatHaz Prevention

Black Sea CROSS BORDER COOPERATION

Common borders. Common solutions.

Landslide Hazard …FS on Regional Scales



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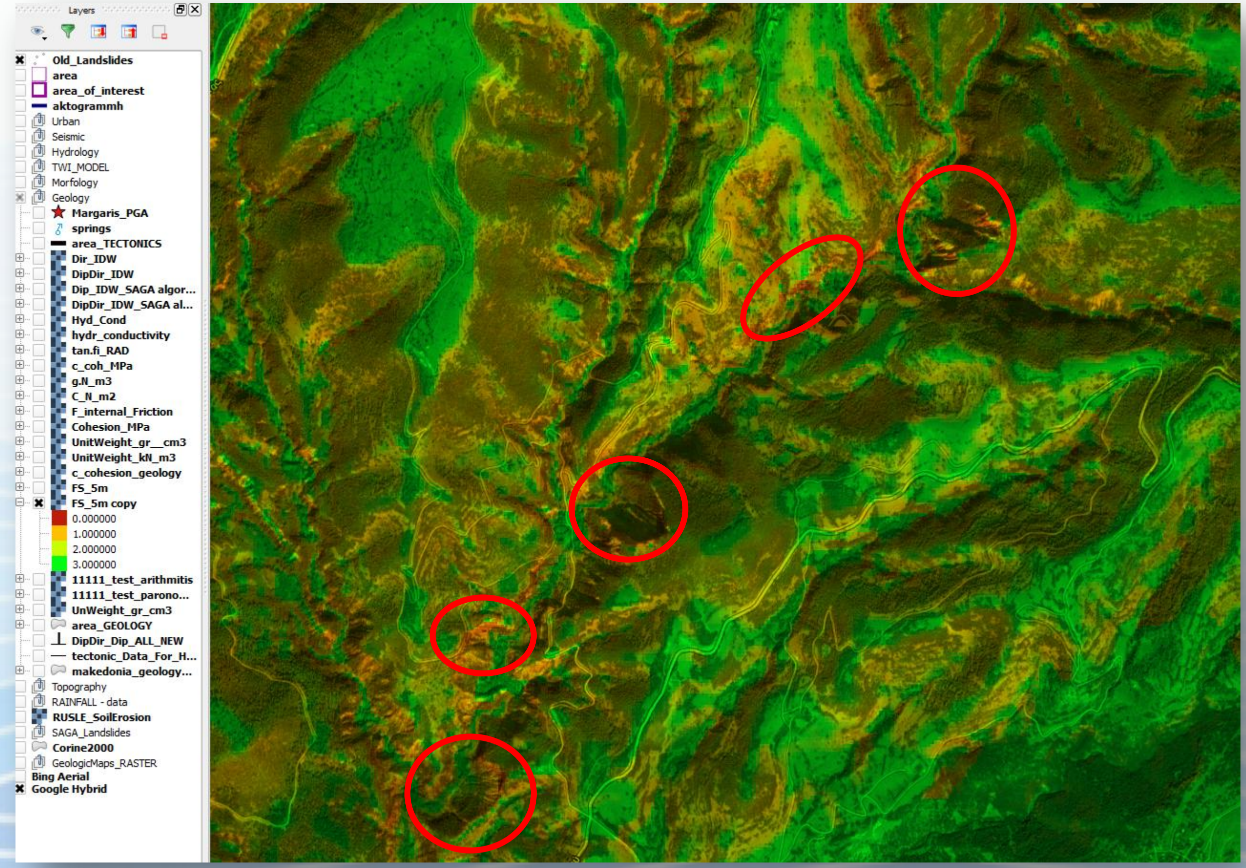
Common borders. Common solutions.

Landslide HA – Factor of Safety



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Common borders. Common solutions.

Thank You All for your Attention!

...to be continued