Shallow landslides along the pyroclastic-mantled slopes of mount Partenio (Campania, Italy): the events of 16.12.1999 and 21.12.2019

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Key points

- The mountains of Campania (Italy) are hit by rainfall-induced landslides on slopes mantled by shallow pyroclastic deposits laying on limestone bedrock.
- Triggering is due to reduction of suction caused by the accumulation of infiltrating water within the soil.
- Infiltration and drainage control hydrologic balance of the cover and timing of pore pressure build-up.
- Two landslide events (December 1999 and December 2019) on deeply studied slopes allow checking the validity of developed predictive models.
- The two events are compared in terms of:
  - antecedent and event rainfall;
  - modeling initial conditions and hydrologic response of slopes to precipitations.
- Hydrological conditions predisposing the slopes to failure are identified.

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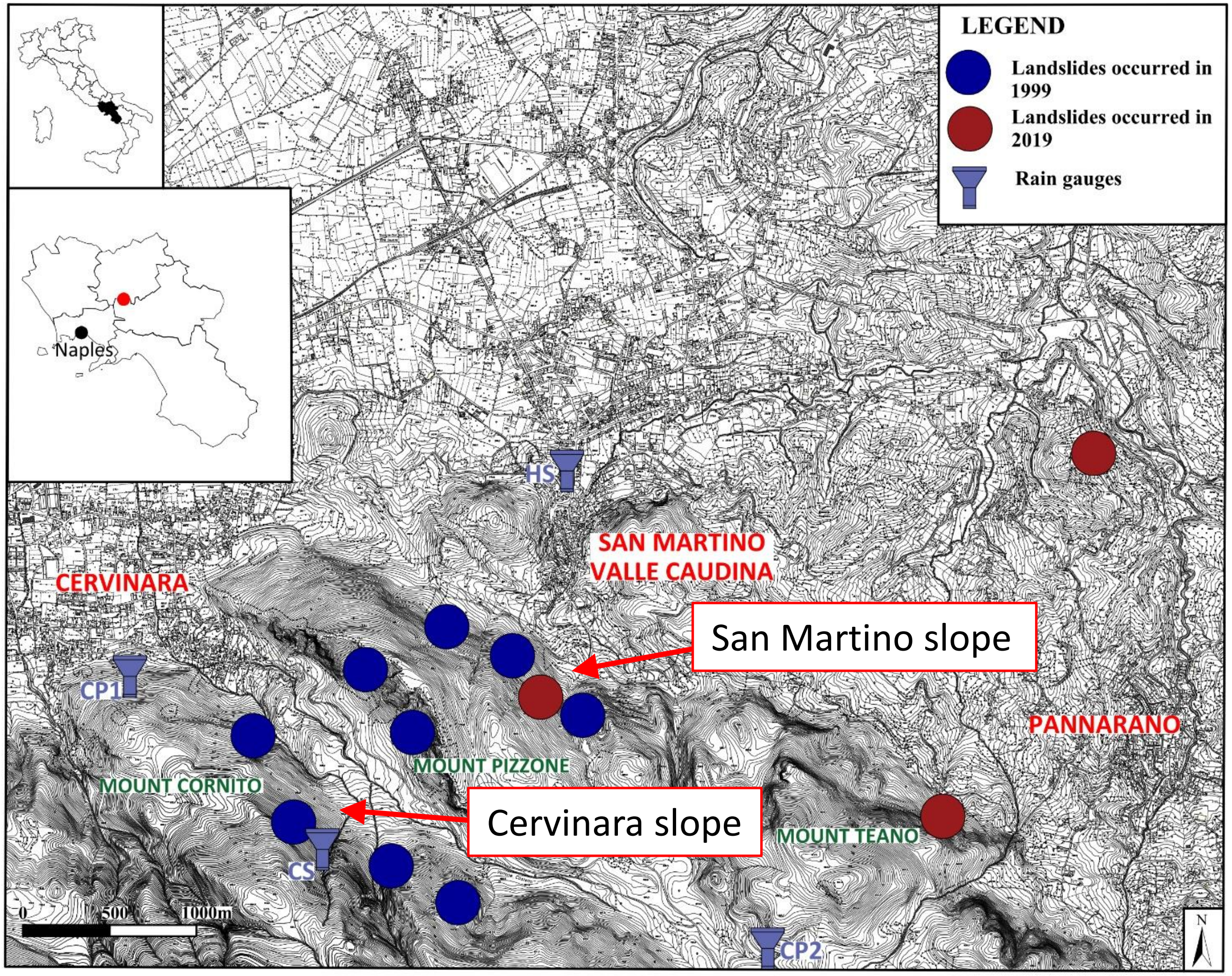
Landslides in 1999 and 2019

Map of the area hit by landslides in 1999 and 2019, with indication of the two studied slopes, the approximate locations of the landslides of the two events, and the rain gauges (CP1 and CP2, Civil Protection Alert Network; HS, Italian Hydrologic Service; CS, monitoring station at Cervinara slope).



Landslides on pyroclastic slopes in Campania (Italy): the events of 1999 and 2019

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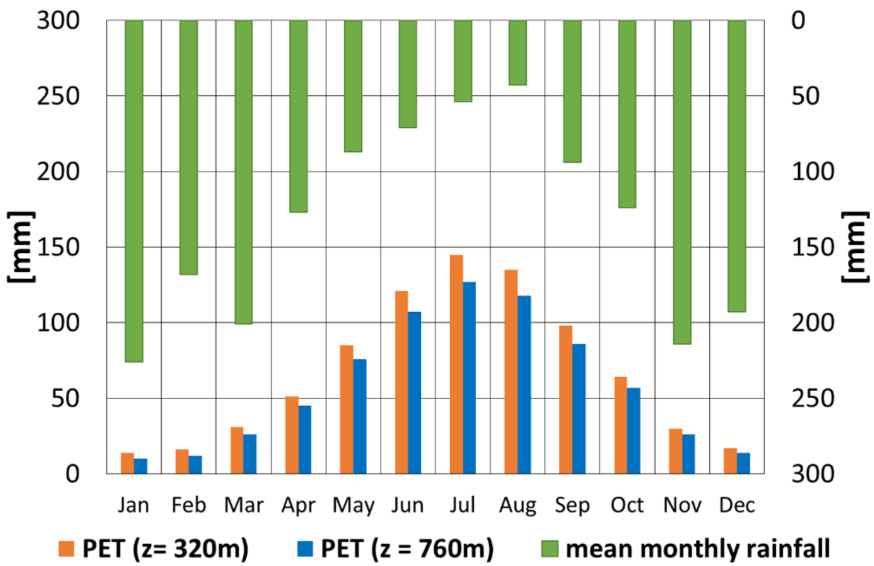
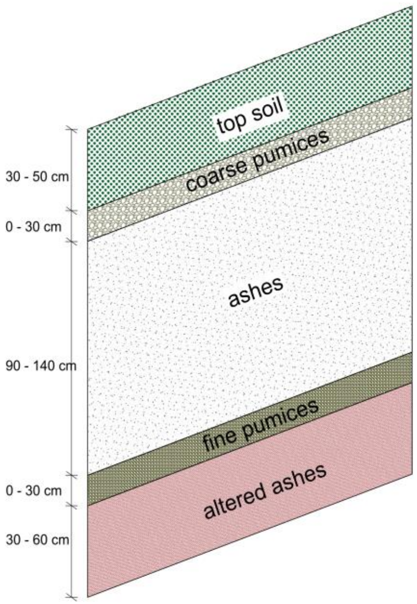
Study area

Mediterranean climate.
Mean annual precipitation about 1400-1600 mm.
Annual potential evapotranspiration 650-800 mm.
Dense woods, chestnuts and oaks, up to 1000 m a.s.l., beeches prevail at higher altitude.
Annual groundwater recharge about 200 mm.





Layered soil profile at Cervinara, and main physical proeperties of the soils

Layer	Thickness (cm)	γ_d (kN/m³)	Porosity (%)	Clay fraction (%)	k_s (m/s)	c' (kPa)	ϕ' (°)
Topsoil	30-50	8.3-11.1	59-69	4-16	-	-	-
Coarse pumices	0-30	11.2	52	0	5×10^{-6}-1×10^{-5}	-	-
Ashes	90-140	6.6-8.7	68-75	2-5	1×10^{-6}-6×10^{-6}	0	38
Fine pumices	0-30	12.0	50	0-4	-	-	-
Altered ashes	30-60	11.5	55	2-10	8×10^{-7}-1×10^{-6}	11	31

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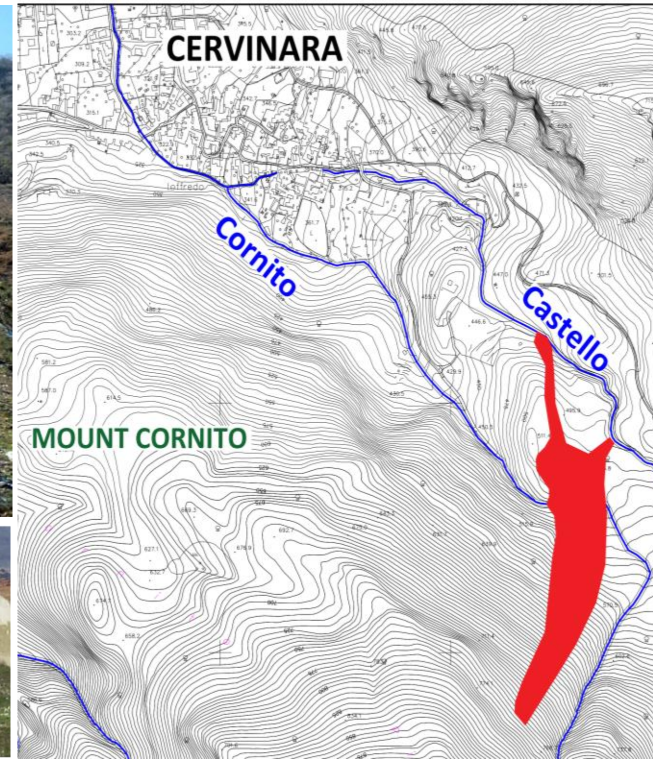
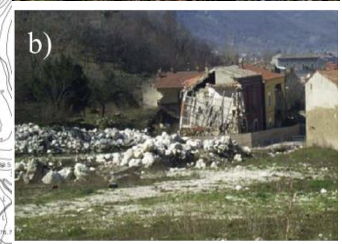
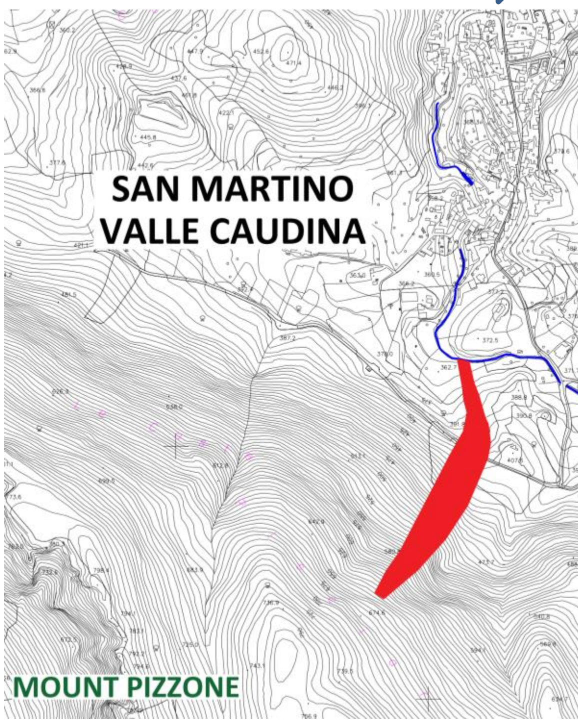
The two landslides

Triggering rainfall 300 mm in 48 hours.
Debris avalanche evolved as channelized debris flow running 2 km in a stream until hitting the town of Cervinara.
Estimated mobilized volume 30000 m^3.







Trigering rainfall 290 mm in 60 hours.
Debris avalanche evolved as channelized debris flow running 1 km in a stream until hitting the town of San Martino Vlle Caudina.
Estimated mobilized volume 10000 m^3.

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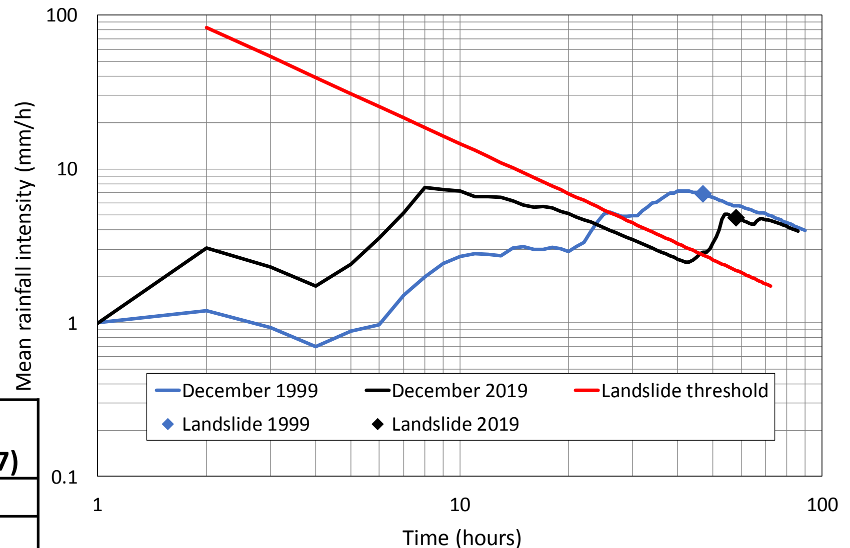
Antecedent and event precipitations

Rainfall of 1999 and 2019 recorded by rain gauges operating in the area (HS, talian Hydrographic Service; CP1 and CP2, Civil Protection; CS, Cervinara slope monitoring station), compared to mean monthly precipitation of 2001-2017.

Period		HS 1999	CP1 2019	CP2 2019	CS 2019*	CP1 (mean 2001-2017)
January		113.4	260.4	302.0	296.1	226
February		103.7	91.2	153.6	127.8	168
March		188.9	61.8	92.6	79.6	201
April		170.2	91.8	138.0	112.7	127
May		112.4	241.8	291.8	281.3	87
June		114.3	19.4	20.8	21.9	71
July		63.7	51.4	69.0	49.7	54
August		31.9	18.6	46.6	17.5	43
September		85.5	36.0	49.8	54.3	94
October		128.8	49.2	79.6	-	124
November		219.5	446.0	708.0	-	214
December	Pre-event	75.5	55.2	90.2	56.9	
	Event rain	309.2	170.2	296.8	279.5	
	Total	474.6	279.2	501.2	397.3	193
Year		1806.9	1646.8	2453.0	-	1602

*Cervinara rain gauge (CS) out of order for 25 days in October and November 2019.



Trend of the mean rainfall intensity during the triggering rainstorms of 15-16 December 1999 (HS rain gauge) and 19-21 December 2019 (CS rain gauge).
The red line indicates a previously developed physically-based rainfall intensity-duration threshold for Cervinara slope (Marino et al., 2020).

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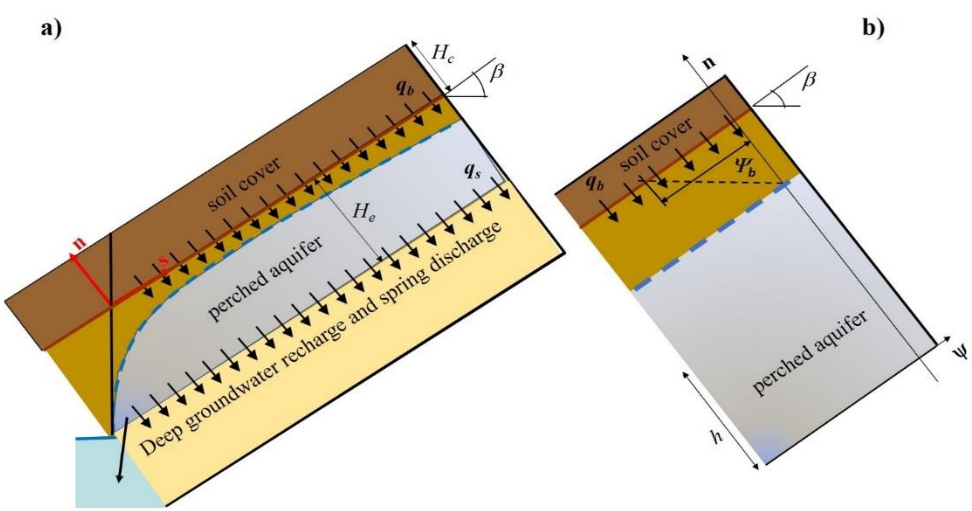
Simulation of slope response by mathematical modeling

Geometrical characteristic	Cervinara slope	San Martino slope
Slope inclination angle, β (°)	40	42
Soil cover thickness, H_c (m)	2.0	1.5
Slope length, L (m)	200	200
Epikarst thickness, H_e (m)	14.0	14.0

Coupled unsaturated and saturated flow domains (Greco et al., 2018).



(a) coupled unsaturated and saturated flow domains;
(b) model of the soil-bedrock interface.

Saturated flow in the perched aquifer in the epikarst:

$$n_e \frac{\partial h}{dt} = \frac{\partial}{ds}\left[K_e h \left(\sin\beta + \frac{\partial h}{ds}\right)\right] + q_b - q_s$$

Unsaturated flow in the soil cover:

$$\frac{d\theta}{d\psi}\frac{\partial\psi}{\partial t} = \frac{\partial}{\partial s}\left[k(\psi)\left(\sin\beta + \frac{\partial\psi}{\partial s}\right)\right] + \frac{\partial}{\partial n}\left[k(\psi)\left(\cos\beta + \frac{\partial\psi}{\partial n}\right)\right] - q_r)$$

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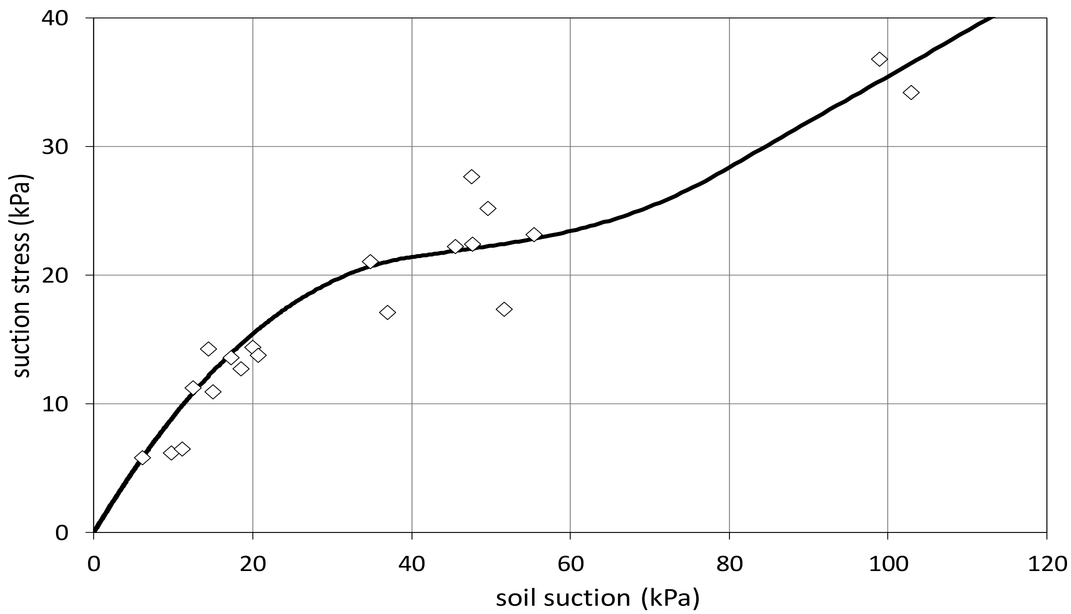
Slope stability analysis

The factor of safety is calculated under the hypothesis of infinite slope:

$$F_s = \frac{\tau_{lim}}{\tau'} = \frac{c' + \gamma d \cos\beta \tan\phi' - \chi(\psi)\gamma_w \psi \tan\phi'}{\gamma d \sin\beta}$$

suction stress



Experimental data of suction stress of Cervinara ashes (Olivares et al., 2019), fitted with the model of Greco and Gargano (2015) and used for the calculation of soil shear strength.

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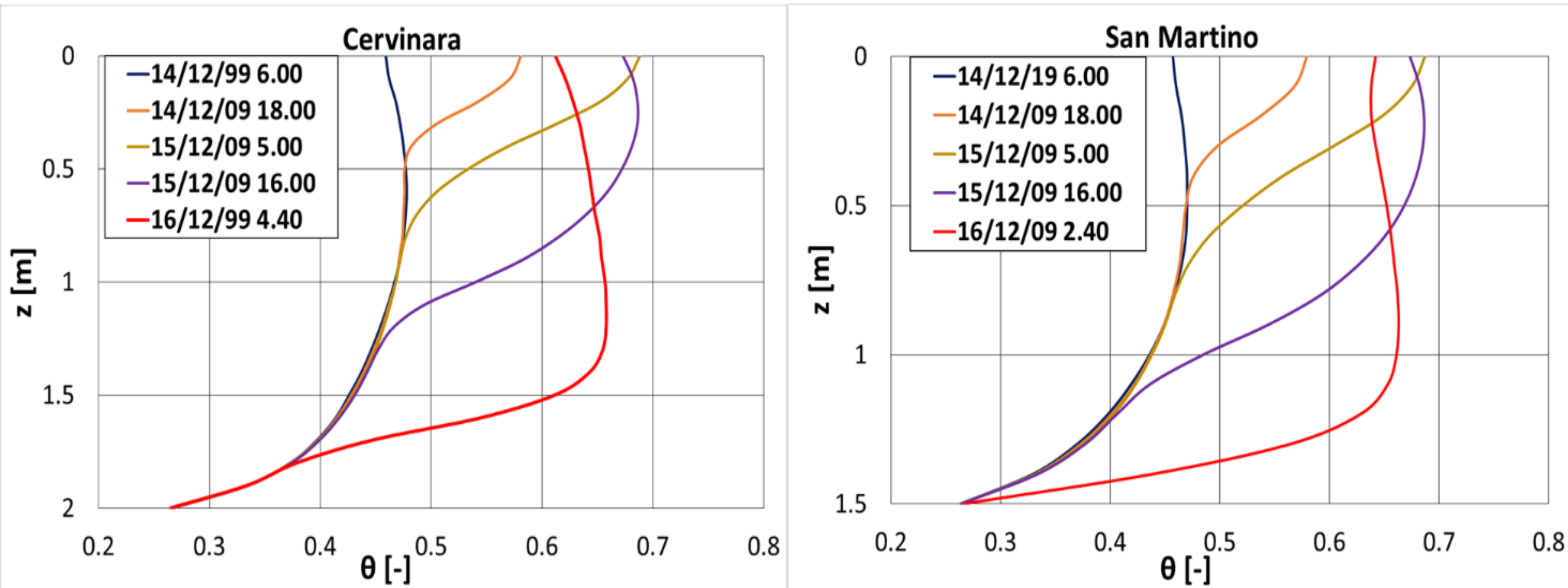
Modeling results

14-16 December 1999
Simulated soil moisture profiles



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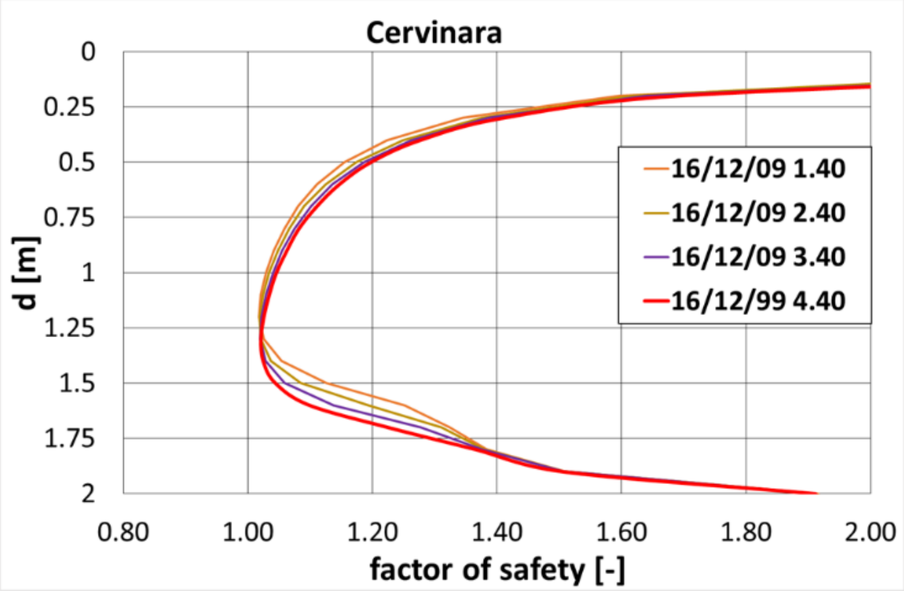
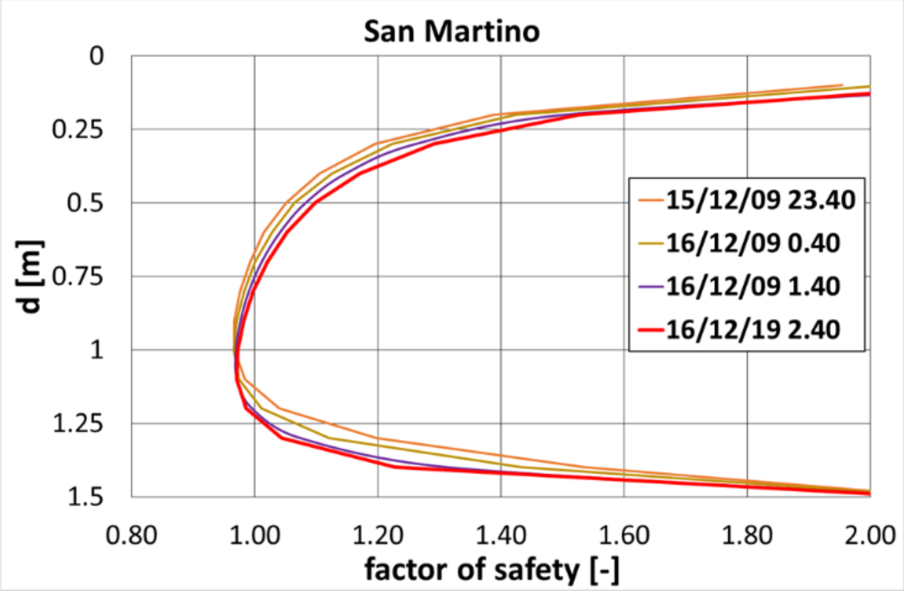
Modeling results

14-16 December 1999
Simulated safety factor profiles





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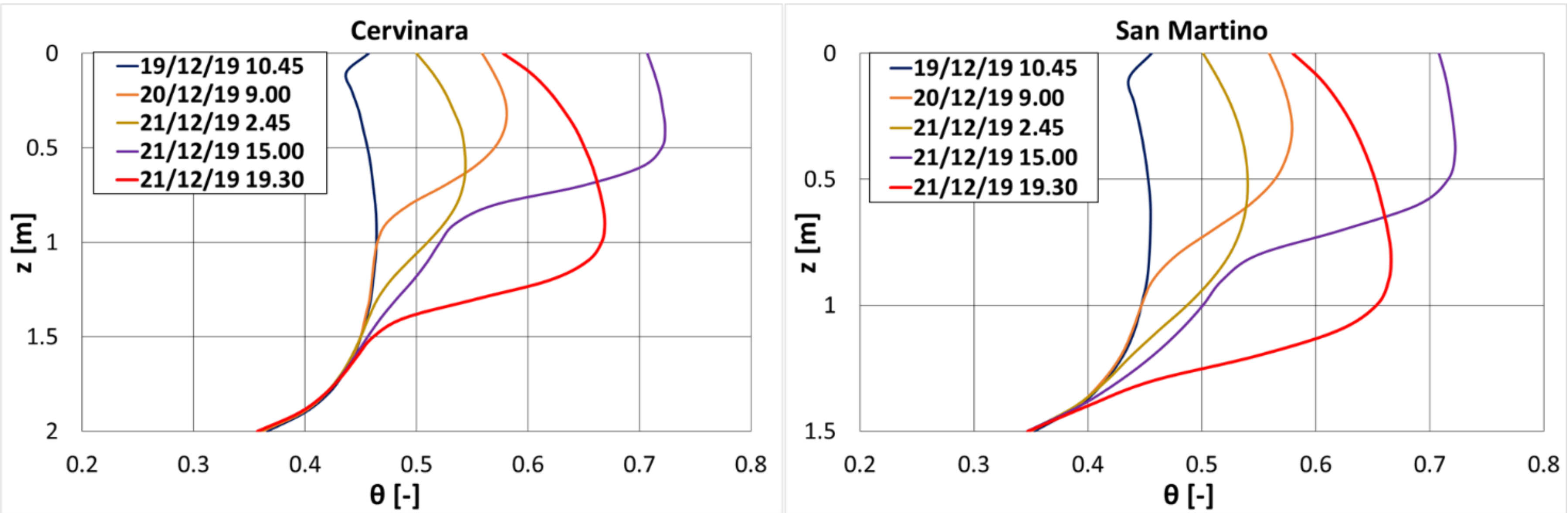
Modeling results

19-21 December 2019
Simulated soil moisture profiles



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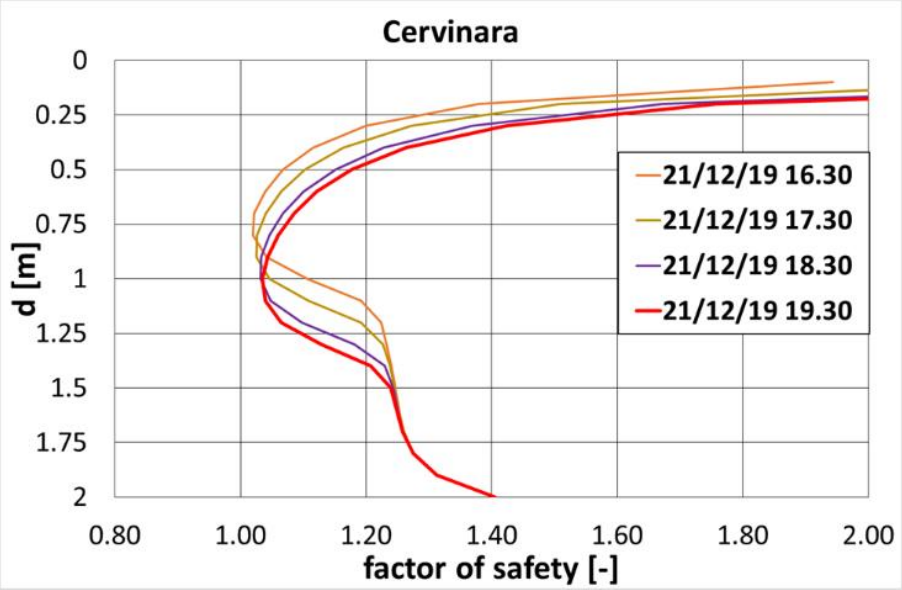
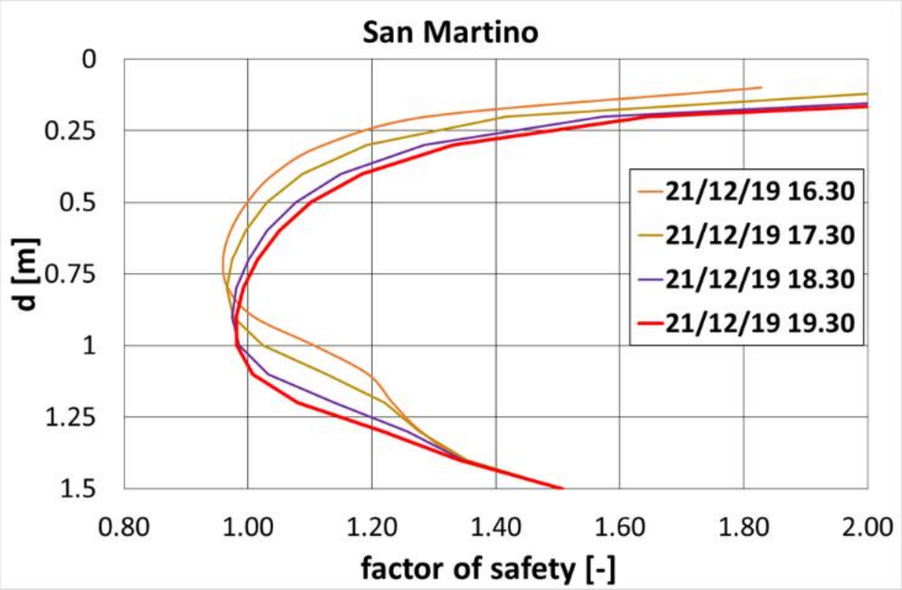
Modeling results

19-21 December 2019
Simulated safety factor profiles





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Conclusions

- The two events had similar rainfall depth (300 mm), but 2019 was longer (60 hours vs. 48 hours).
- Before the rainfall event, in 2019 slopes were wetter.
- Only steep and thin soil covers failed in 2019.
- Dry conditions at the base of the soil cover hampered drainage of infiltrating water in 1999.
- Wet conditions at the base of the soil cover favored drainage of infiltrating water in 2019.
- The interplay between hydrological processes determining initial conditions (**causes**) and rainfall event characteristics (**trigger**) led to slope failure.

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We will be available in chat for any question

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