



POLITECNICO
MILANO 1863

DIPARTIMENTO DI INGEGNERIA
CIVILE E AMBIENTALE

grazie a ...



AGRINATURA

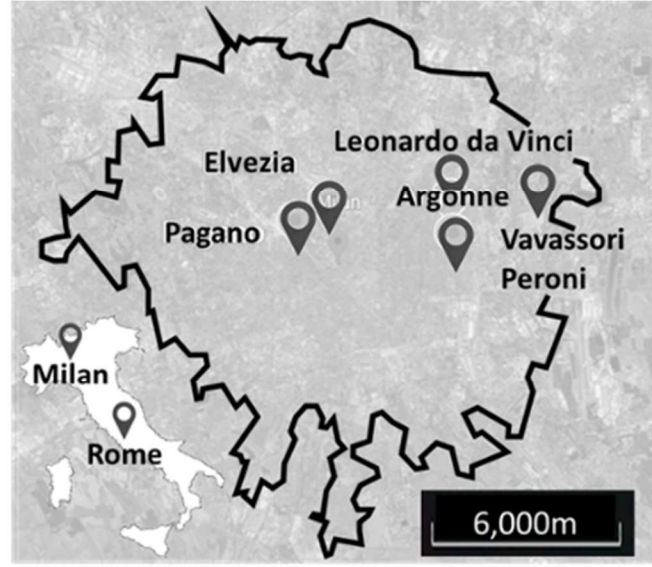


*Ricerca e sviluppo nei metodi per la valutazione della
stabilità di alberi: il contributo dei laboratori universitari*

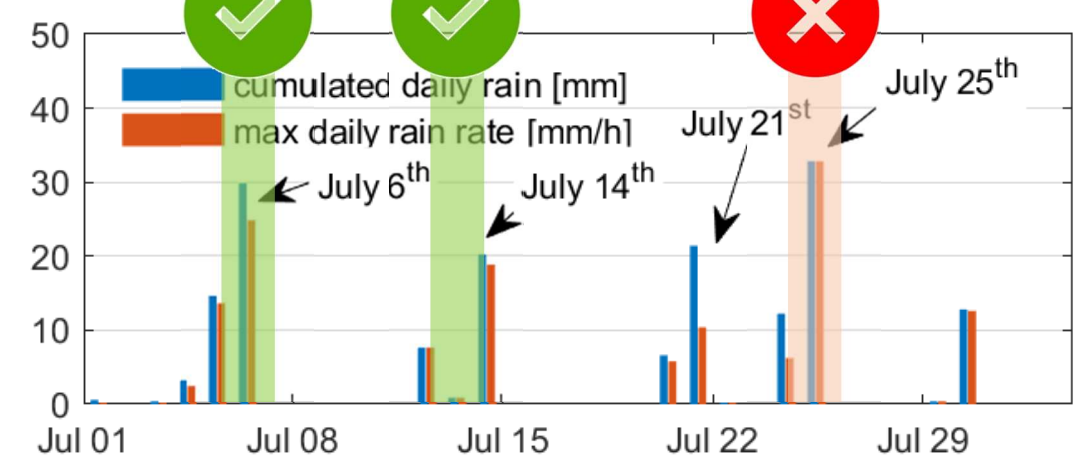
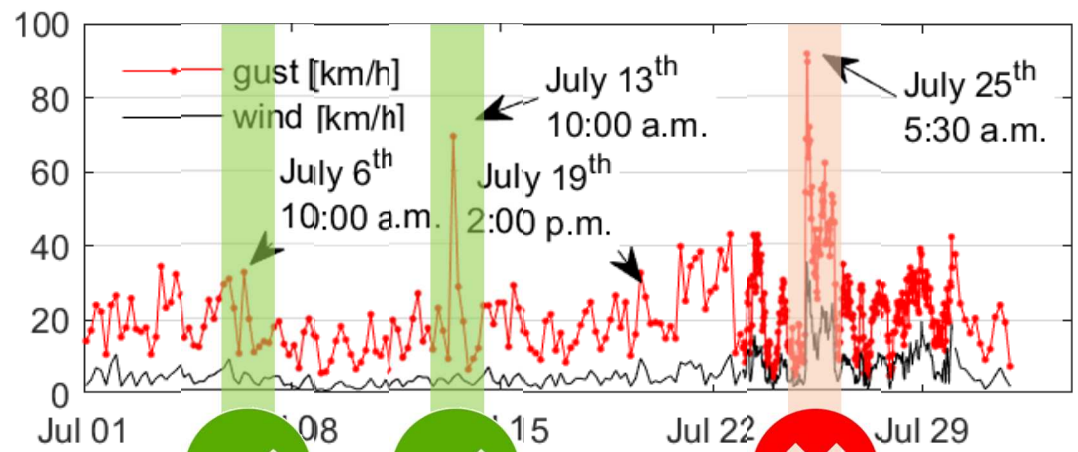
Come ridurre le incertezze?

prof. ing. Andrea Galli
Lariofiere Erba, 1 maggio 2026

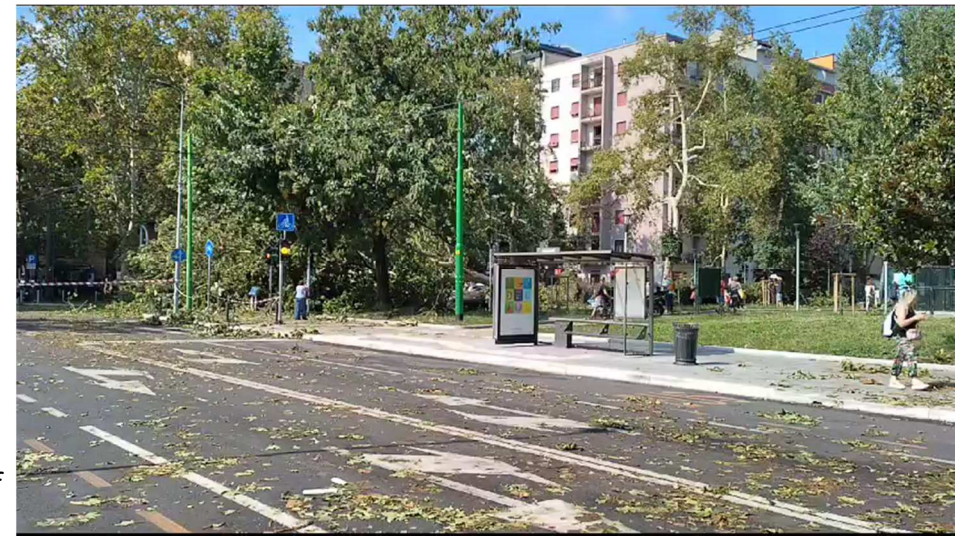
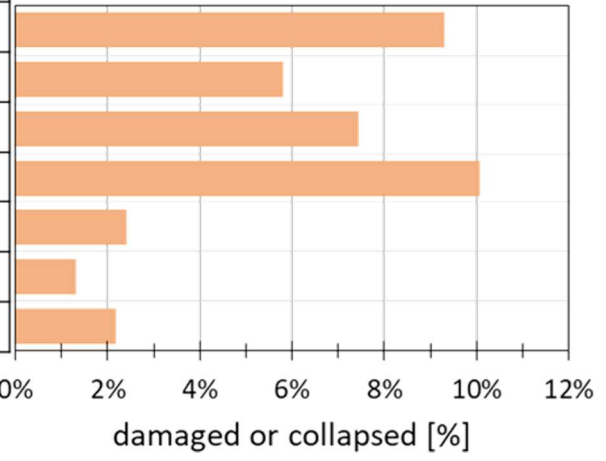
Milano: 25 luglio 2023



Milano: 25 luglio 2023



species	# of exemplars
<i>Carpinus betulus</i>	5577
<i>Acer platanoides</i>	8941
<i>Quercus rubra</i>	5292
<i>Acer saccharinum</i>	3811
<i>Fraxinus excelsior</i>	7942
<i>Platanus x acerifolia</i>	13746
<i>Liquidambar</i>	7330



Galli A., Marrazzo G. (2026) "Geotechnical aspects in tree stability assessment: a state of the art review, with perspective insights", *Rivista Italiana di Geotecnica*, 1/2026, 54-76

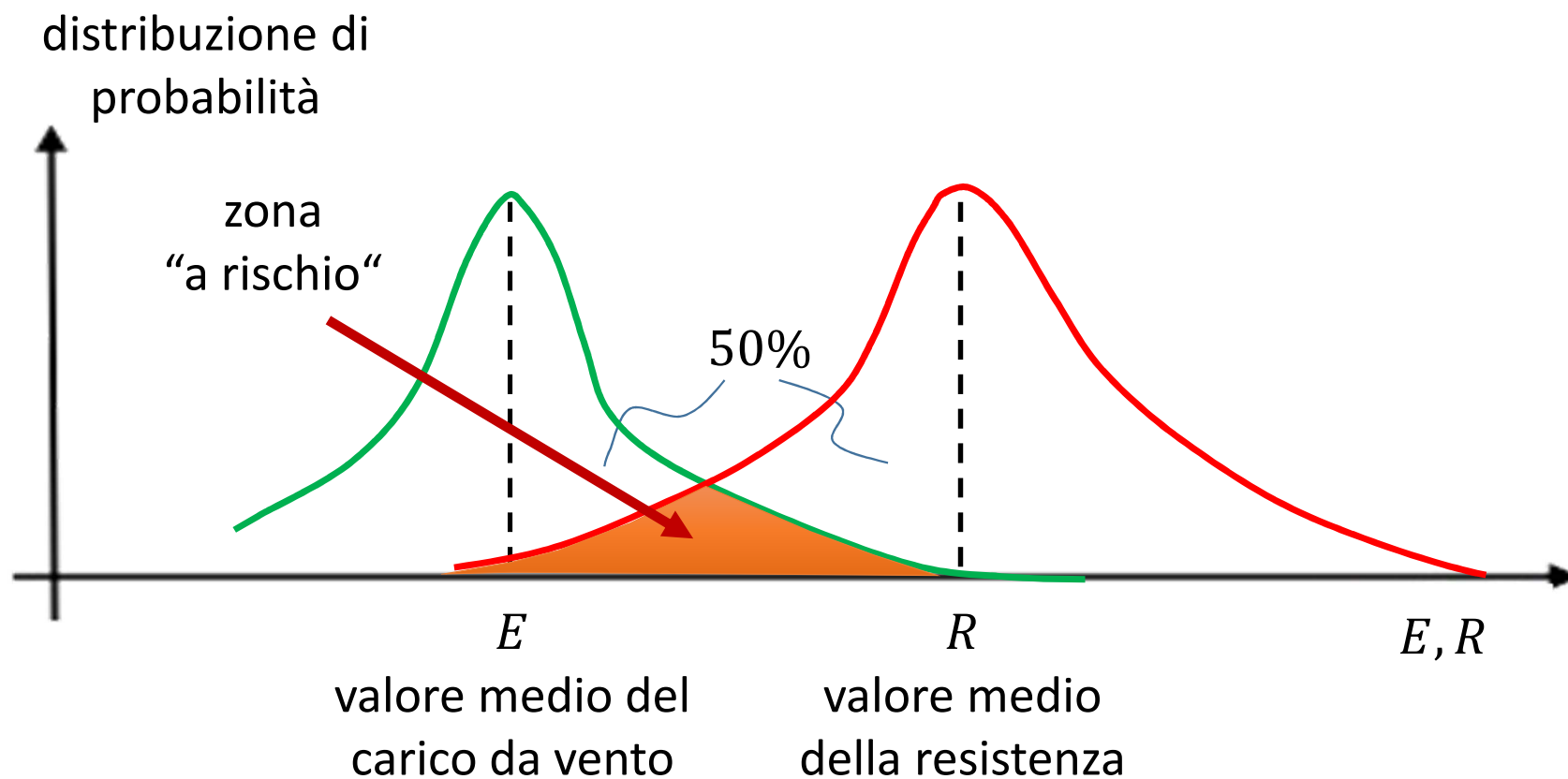
~~rischio e sicurezza~~

pericolosità



condizione di sicurezza: $E < R$

“fattore” di sicurezza: $F_S = R/E$



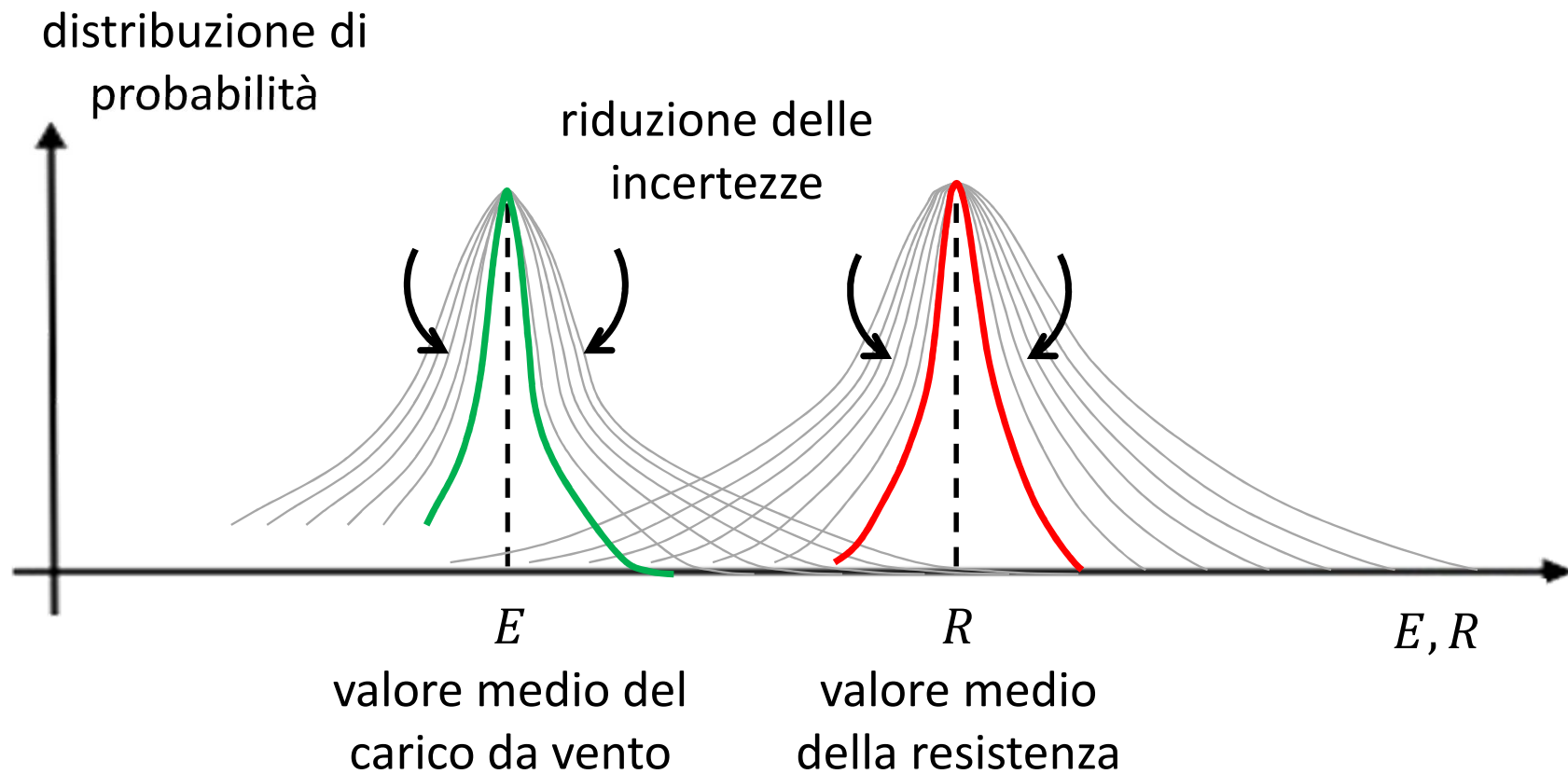
~~rischio e sicurezza~~

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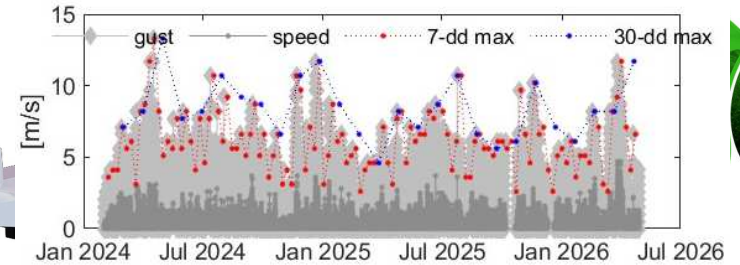


~~rischio e sicurezza~~

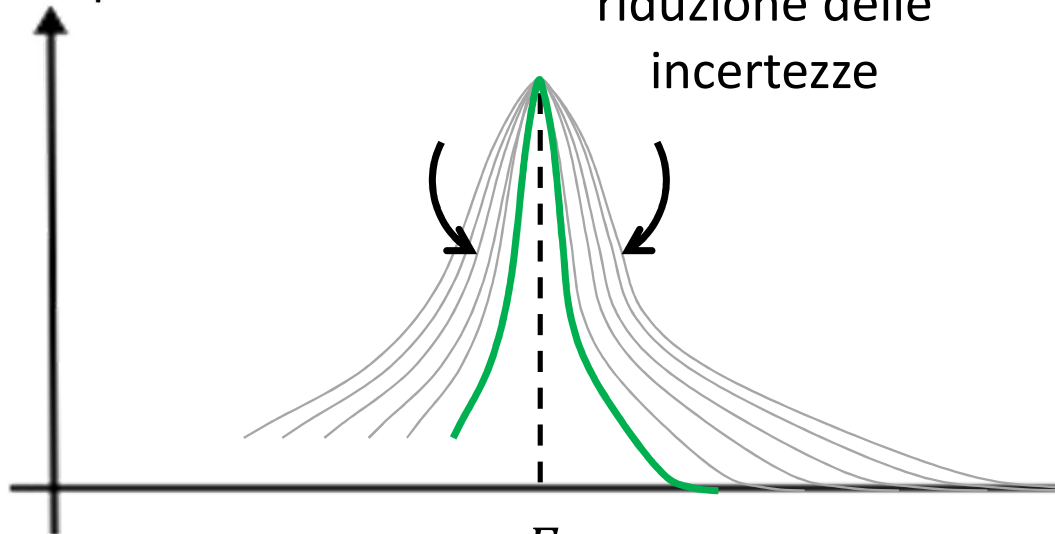
pericolosità

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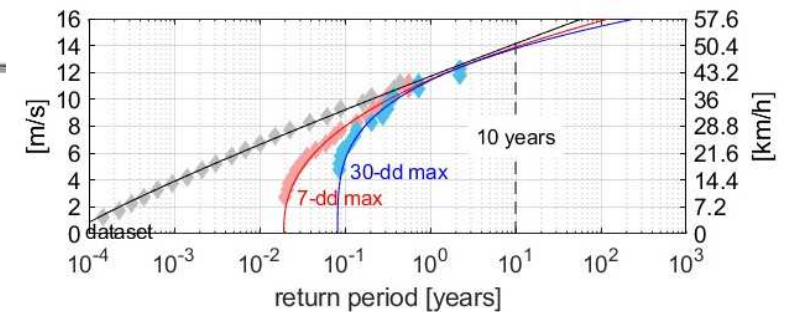
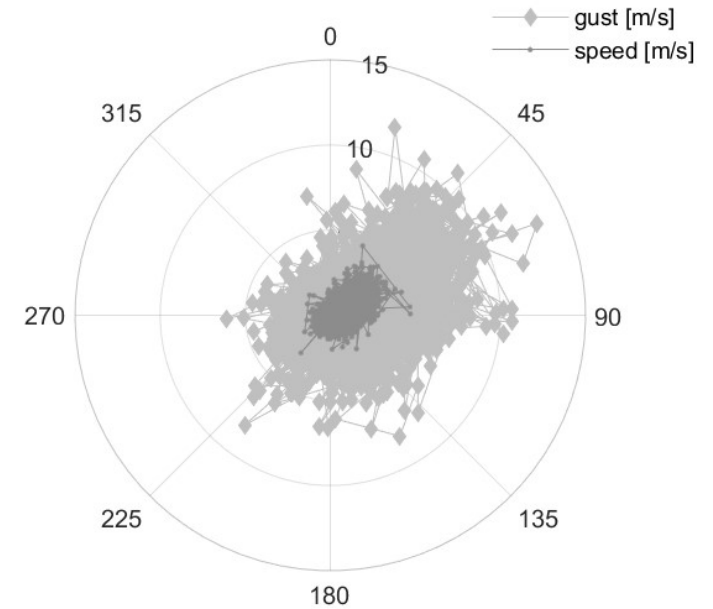


distribuzione di probabilità

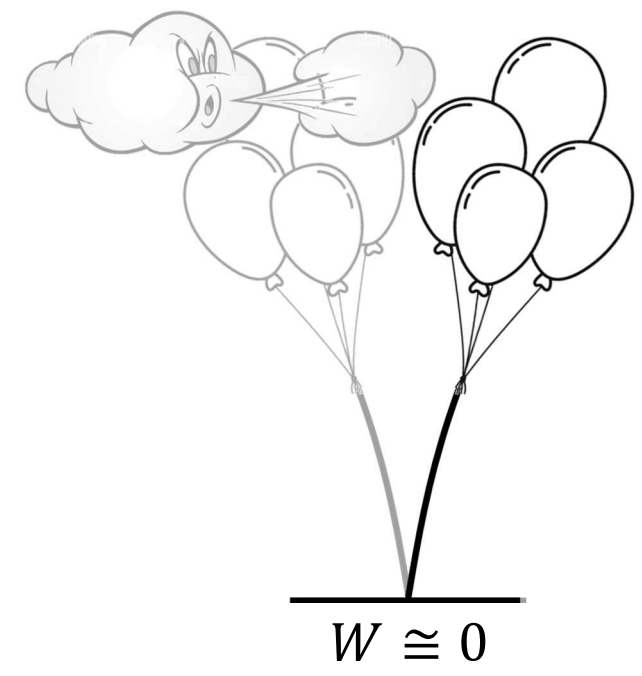
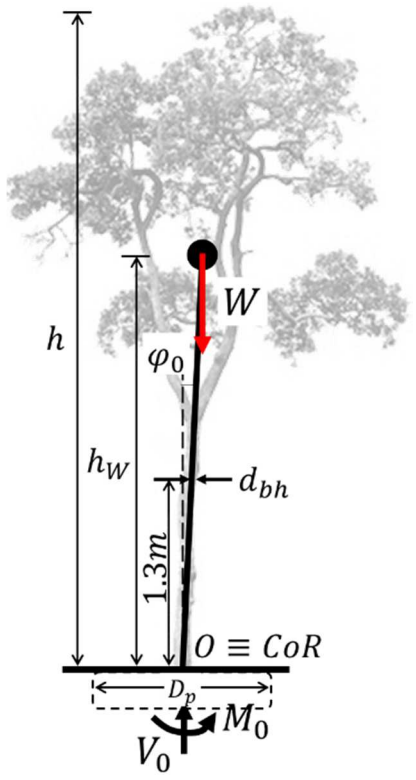


riduzione delle incertezze

valore medio del carico da vento



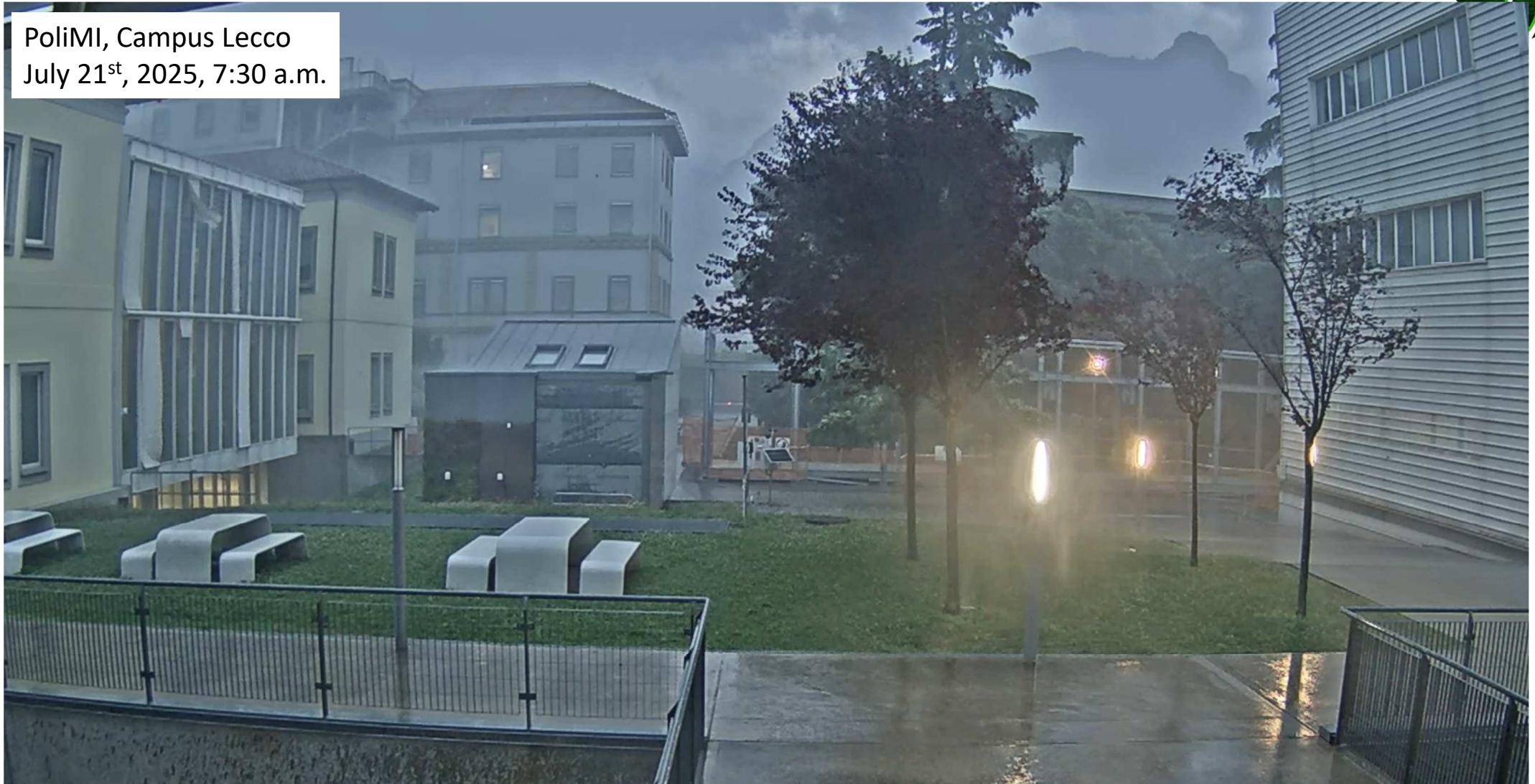
Perché cadono gli alberi?



Perché cadono gli alberi?



PoliMI, Campus Lecco
July 21st, 2025, 7:30 a.m.



Cosa fanno i software (1/2)



Measurement

Name

Rope height on tree (m)	11,5
Anchor-tree level difference (m)	0
Anchor-tree distance (m)	11,5
Drag factor	0,3
Wind speed (m/s)	33
Crown Area (m ²)	378,6
Crown center height (m)	15
Elastic Limit (‰)	2,2

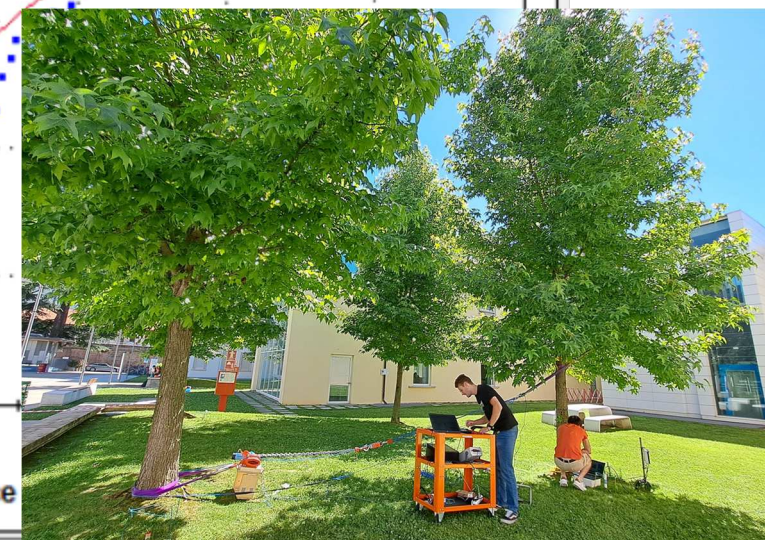
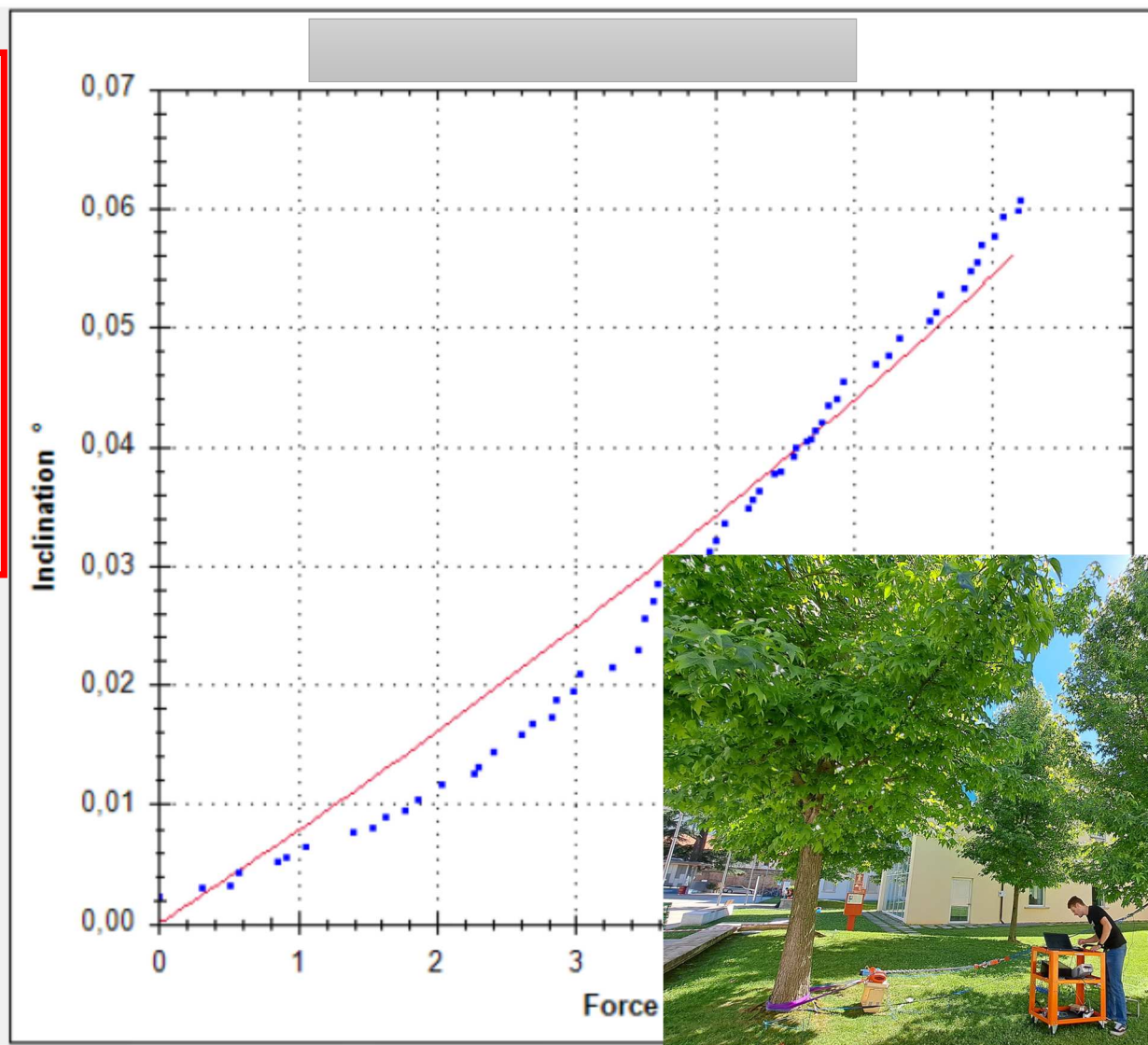
Inclinometer: Elasto2

Alpha (°) = 0,79
F_{max} (N) = 46635,07
M_{max} (Nm) = 379223,72
M_{wind} (Nm) = 1113197,58
SF = 0,34

Filters

- Tare force at first value
- Monotonicity for force
- Monotonicity for inclination

peso??



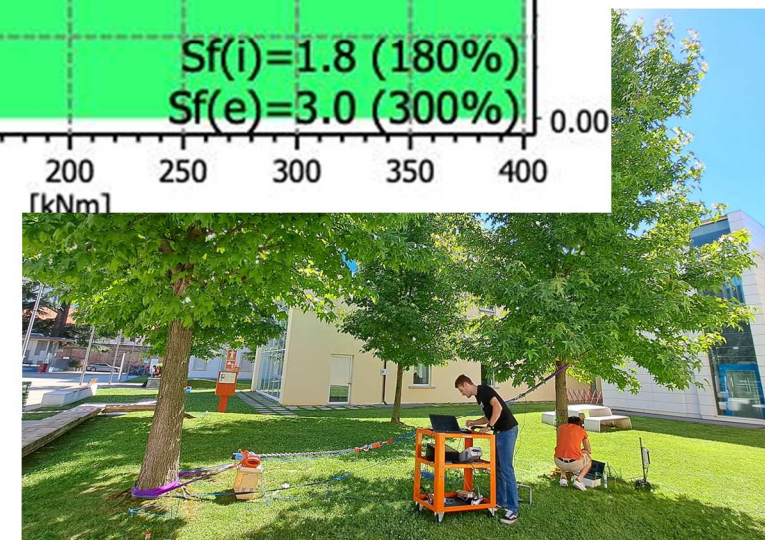
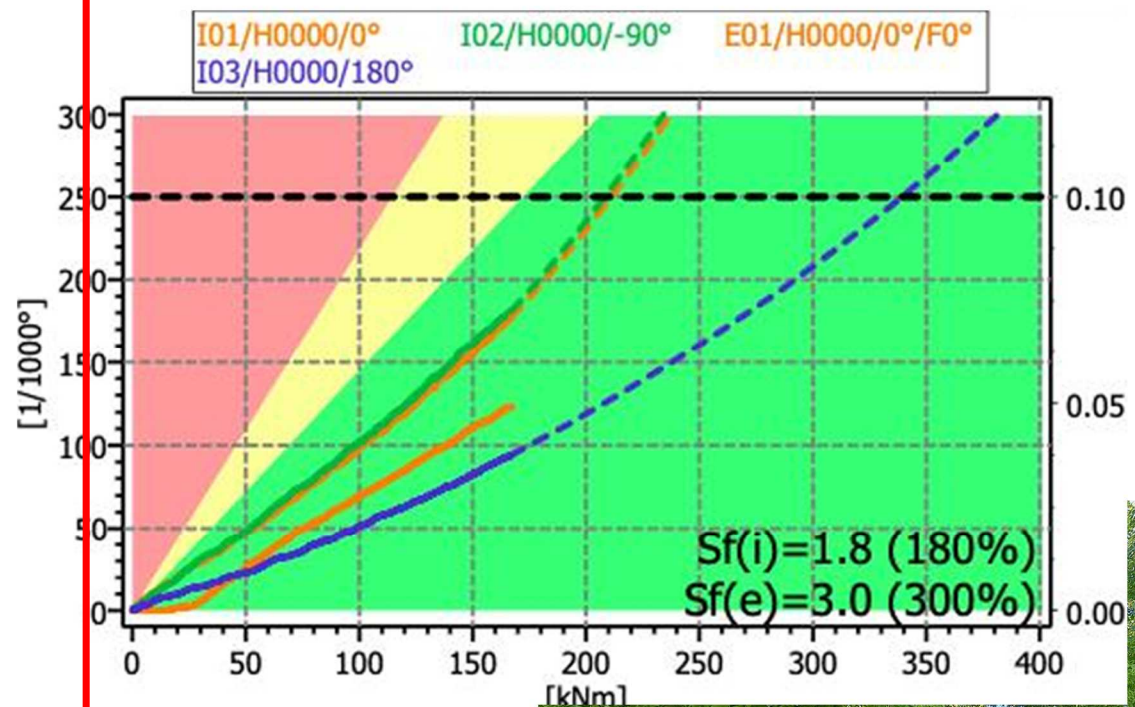
Cosa fanno i software (2/2)



Wind speed V_{ref}	33	[m/s]
=119km/h (74mph) =12 Bft [\approx 33m/s @ H=24m]		
Reference height Z_{ref}	10	[m]
Terrain exponent Z^\wedge	30 Suburb, Parks	[%]
Drag coefficient C_w	20	[%]
Air density d	1250	[g/m ³]
Gust factor g_f (²)	100	[%]
Resonance factor r_f	100	[%]
Tree height = 24 [m]		
Crown area	274	[m ²]
Height of crown area center	\bar{X} 10	[m]
Height of crown force center	\bar{X} 12	[m]
Wind force on crown	25	[kN]
Stembase bending moment	286	[kNm]
Torsion moment	27	[kNm]

Area	CA	HAC	HFC	MF	BM	TM	TH
Crown	274	10.4	12.7	25	286	27	24.0

peso???



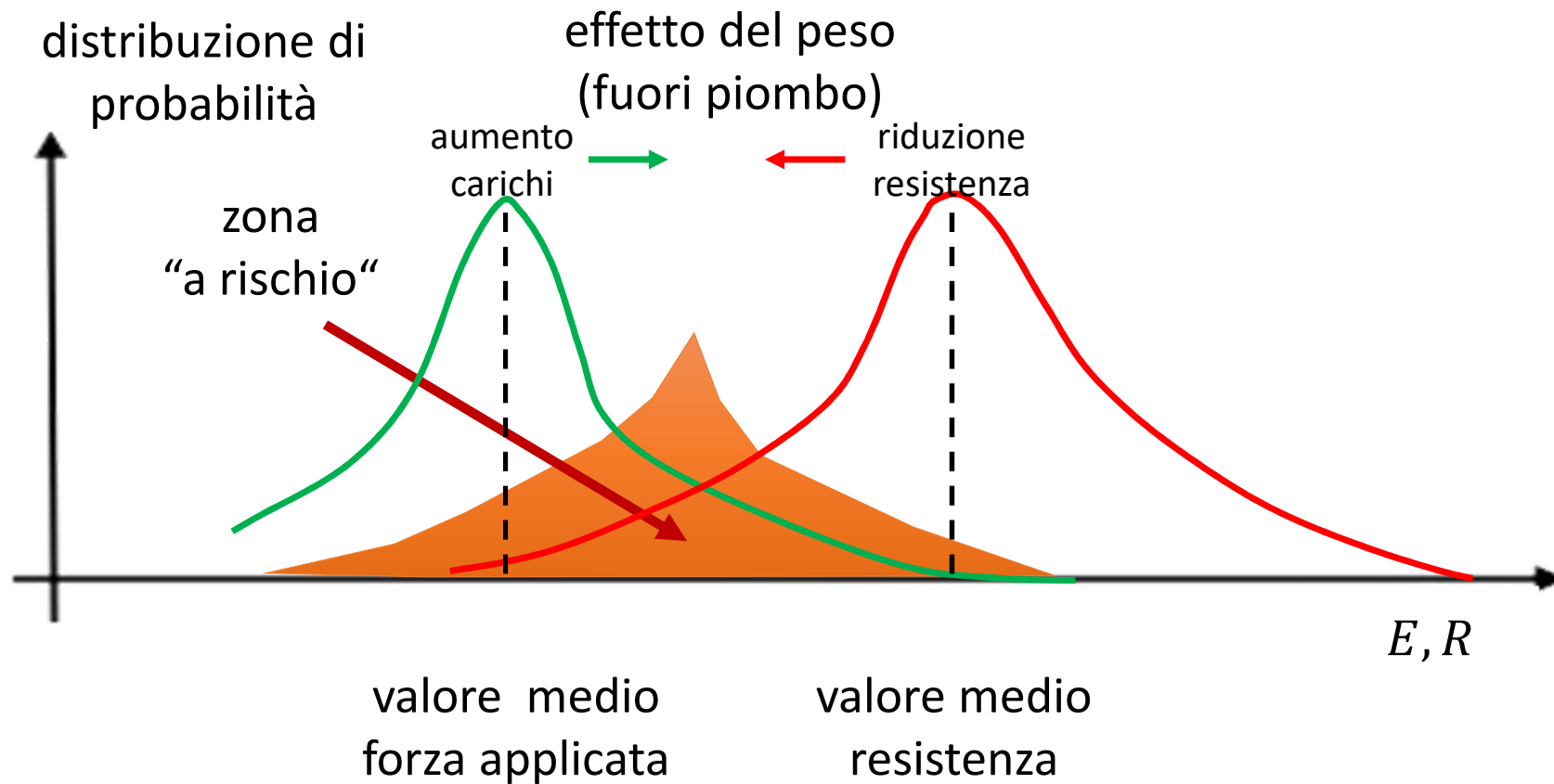
~~rischio e sicurezza~~

pericolosità

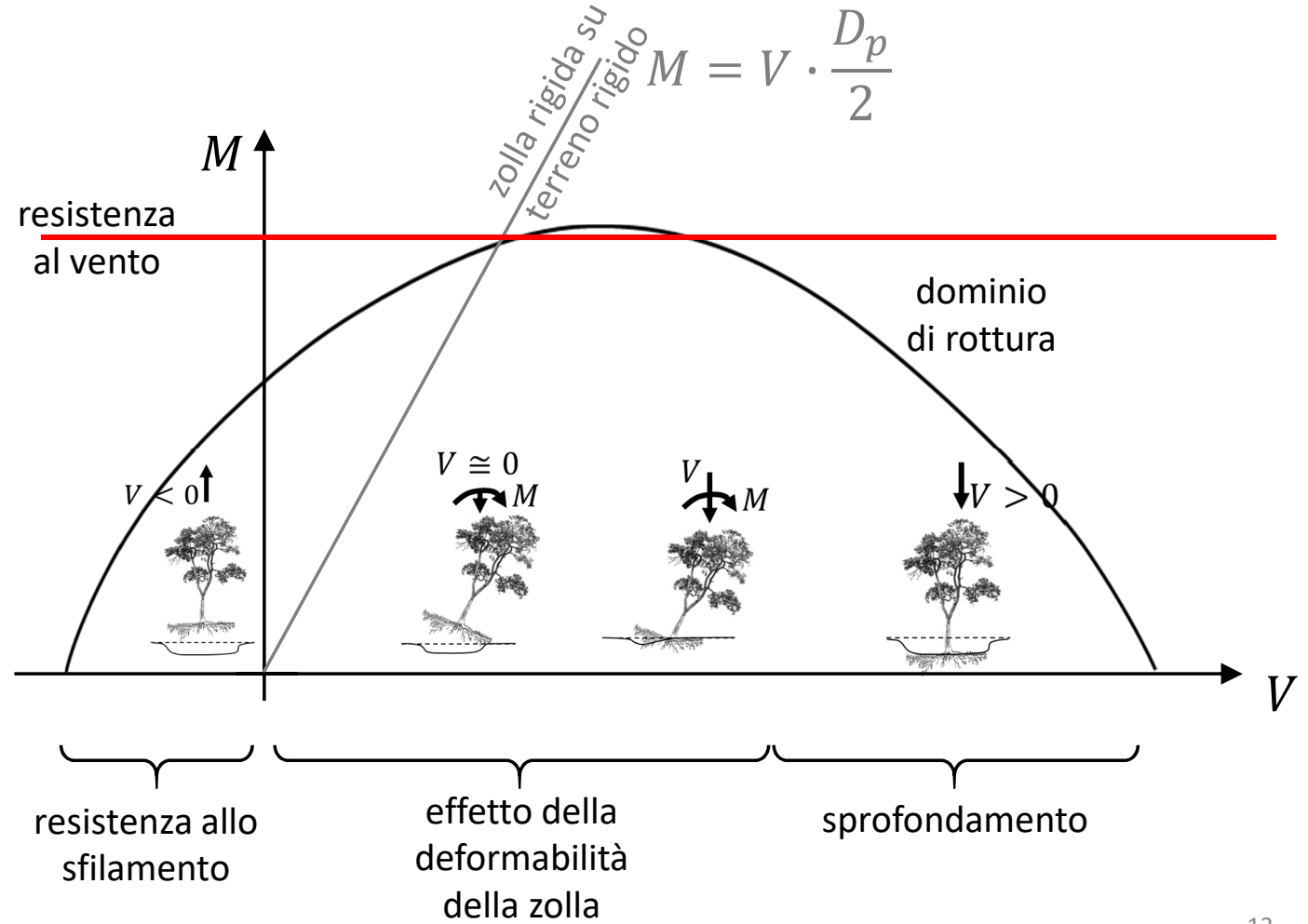
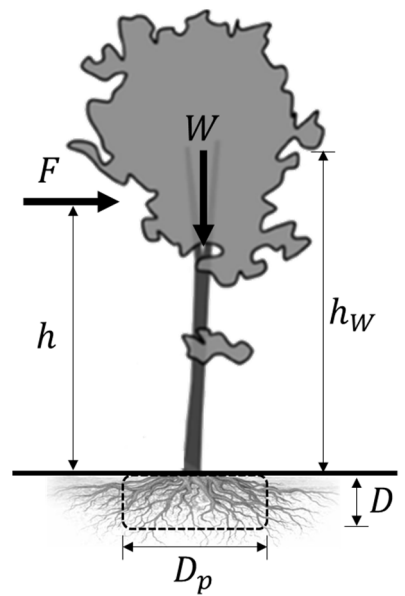
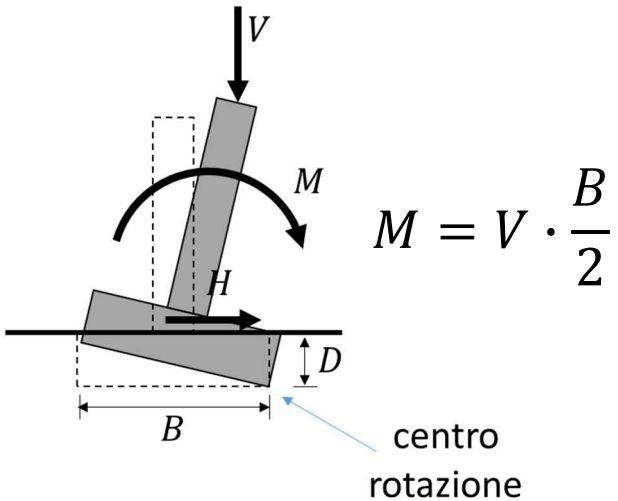


condizione di sicurezza: $E < R$

“fattore” di sicurezza: $F_S = R/E$



Analogia con fondazioni superficiali e **DOMINIO** di rottura





Trees (2024) 38:373–391

<https://doi.org/10.1007/s00468-024-02488-8>

ORIGINAL ARTICLE



A Macroelement Approach for the Stability Assessment of Trees

G. Dattola¹, M. O. Ciantia²✉, A. Galli³, L. Blyth², X. Zhang², J. A. Knappet², R. Castellanza¹, C. Sala⁴, and A. K. Leung⁵

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F. Calvetti et al. (Eds.): CNRIG 2019, LNCE 40, pp. 417–426, 2020.

https://doi.org/10.1007/978-3-030-21359-6_44

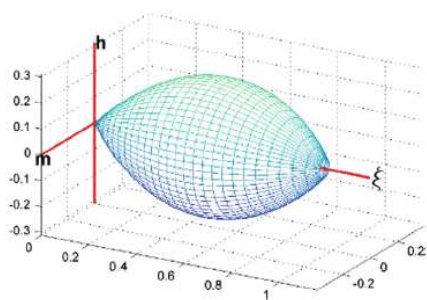


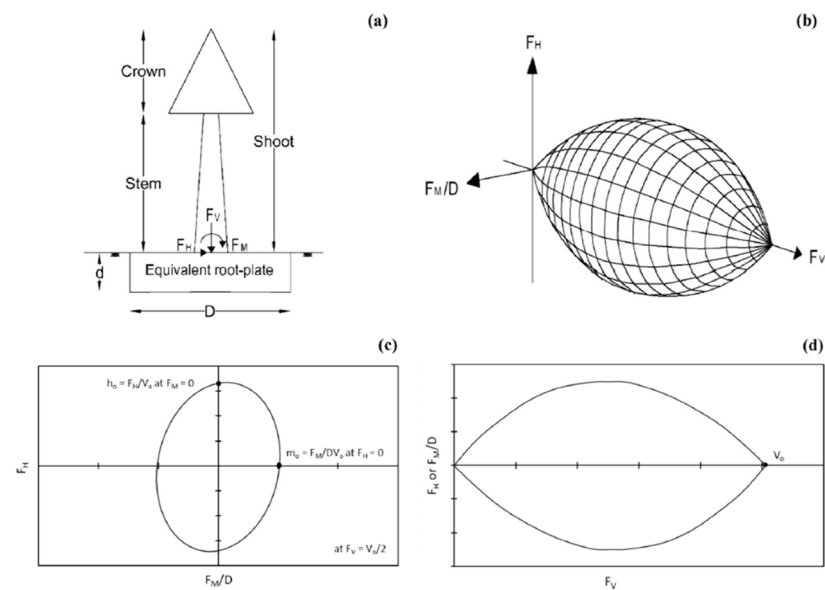
Fig. 4. Plot of the interaction domain at failure in the generalized dimensionless stress space variables.

Windthrow resistance of trees: geotechnical engineering approach

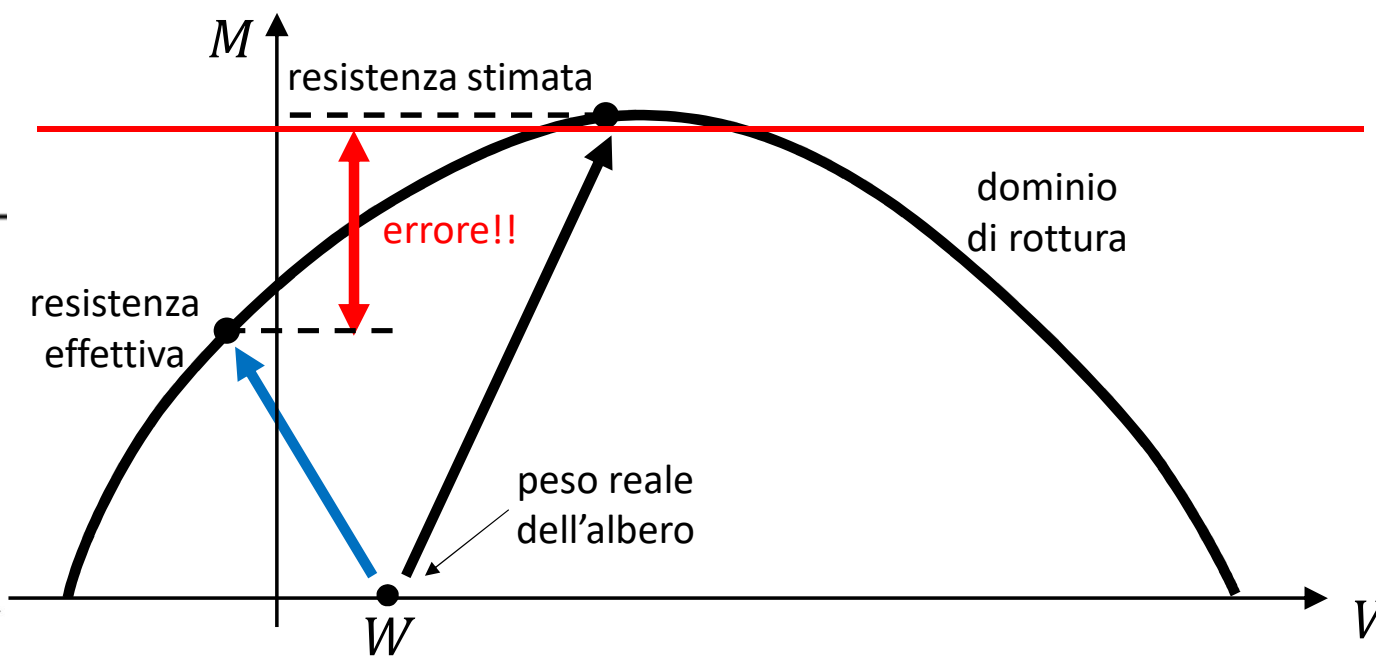
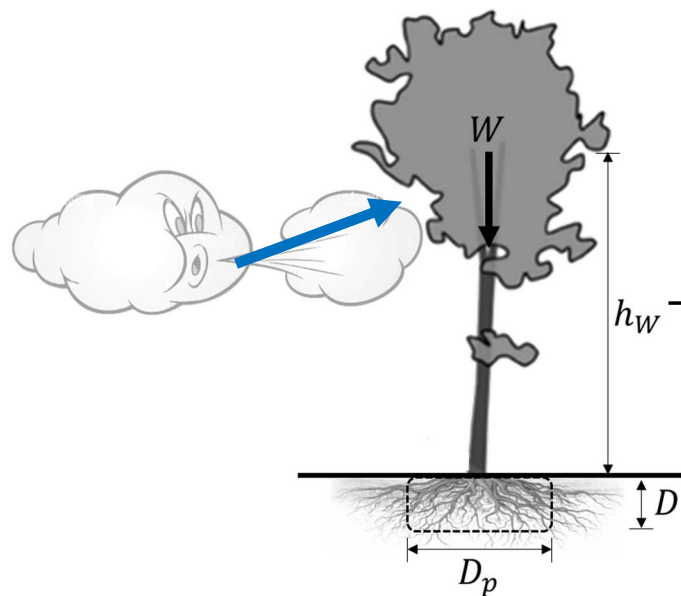
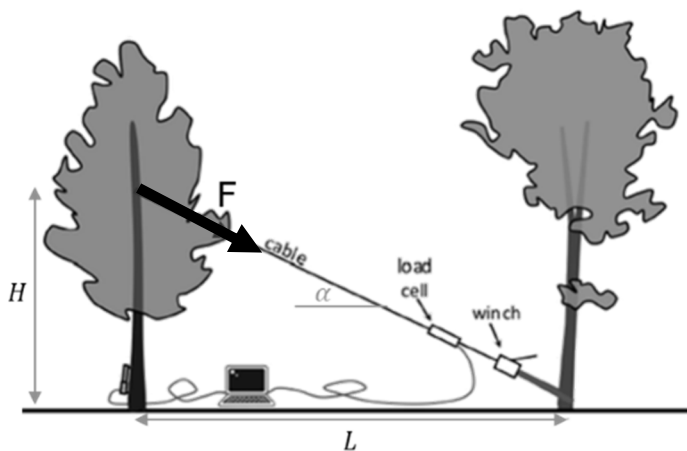
Mohamed A. Mansour¹ · Timothy Newson² · Chris J. Peterson³

Received: 9 August 2023 / Accepted: 29 December 2023 / Published online: 7 March 2024

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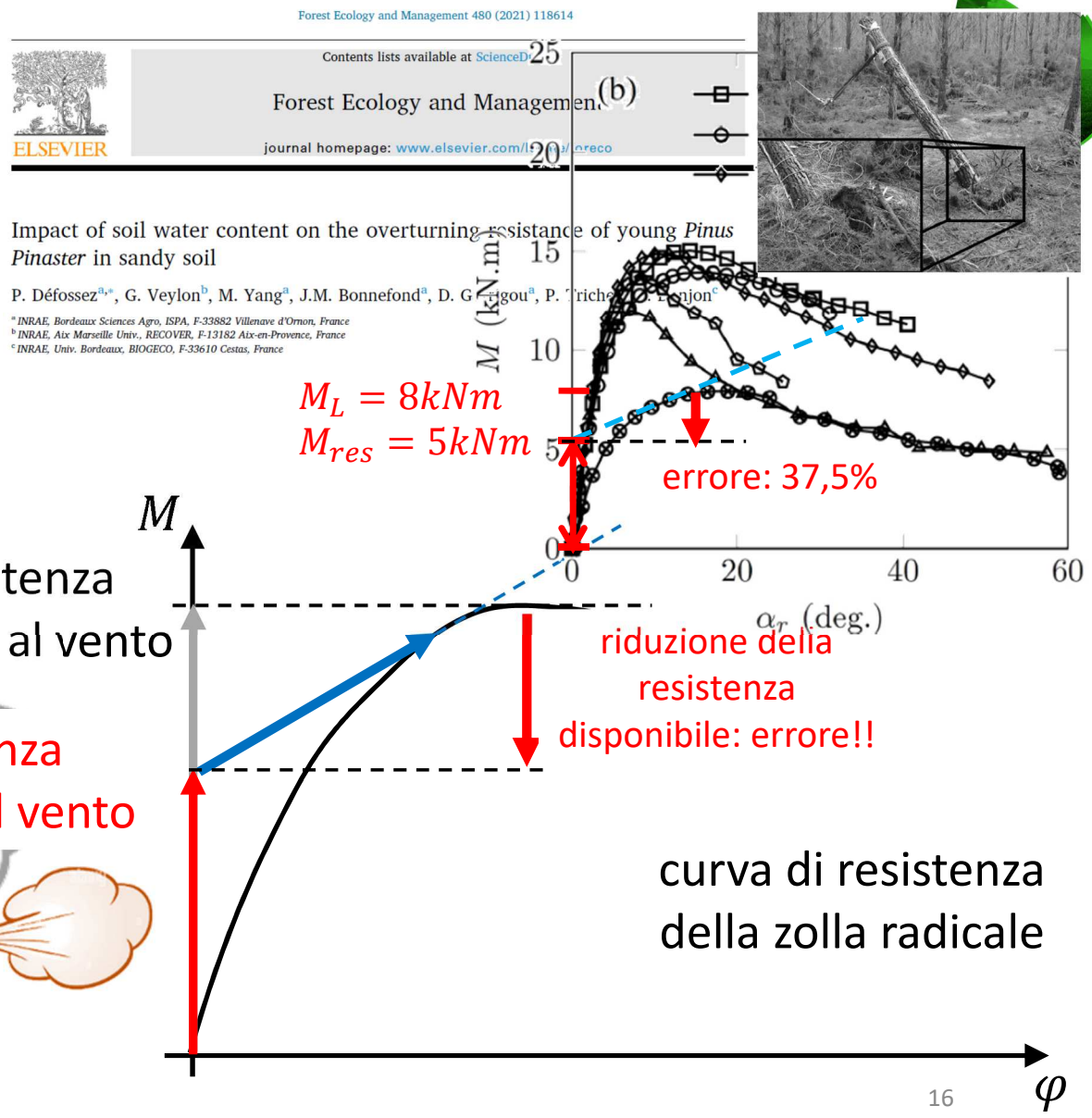


Analogia con fondazioni superficiali e **DOMINIO** di rottura



Il ruolo del peso dell'albero: riduzione della resistenza

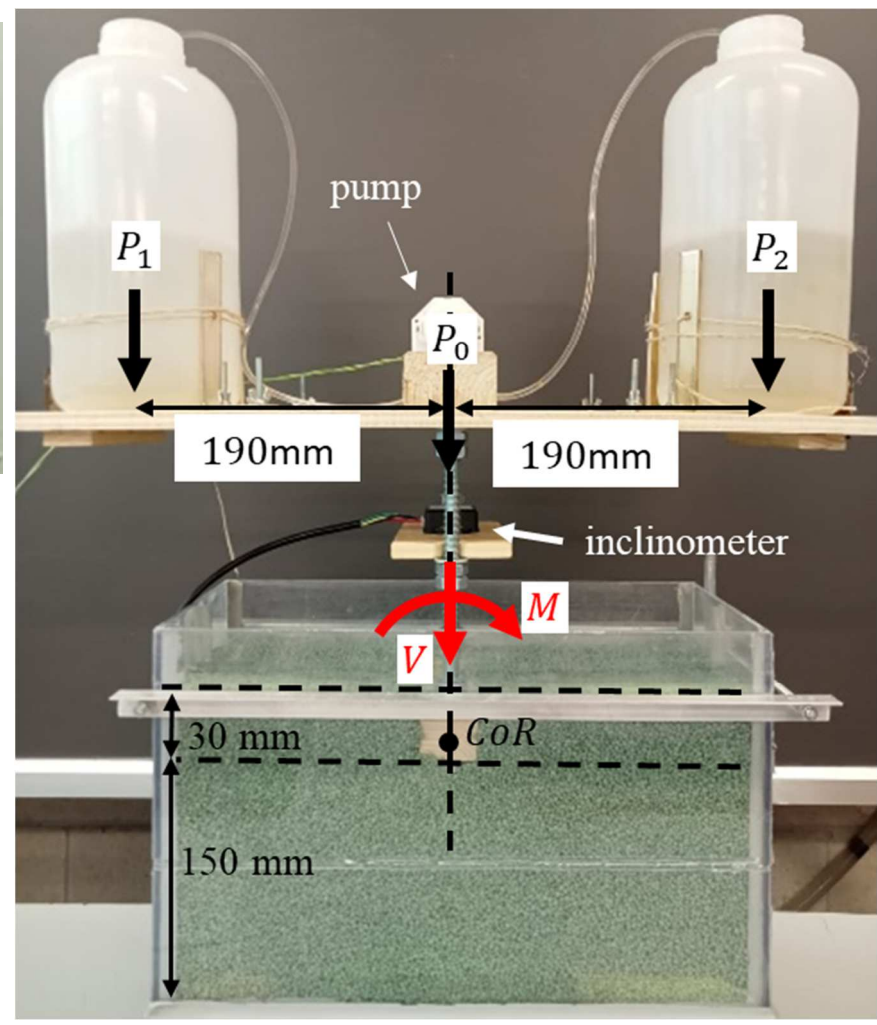
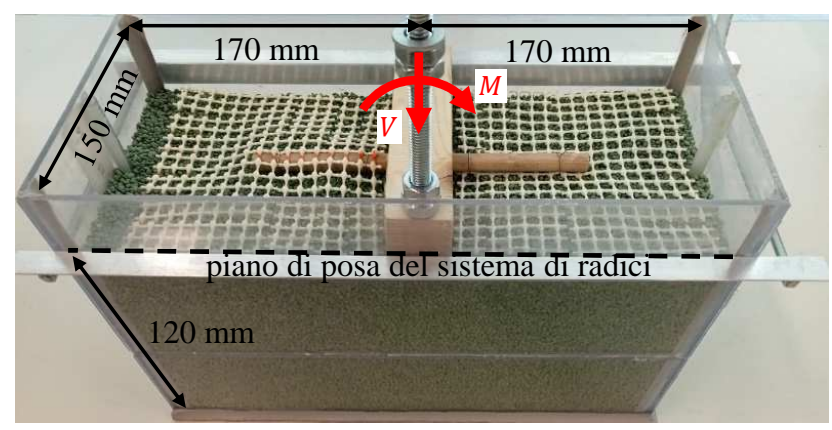
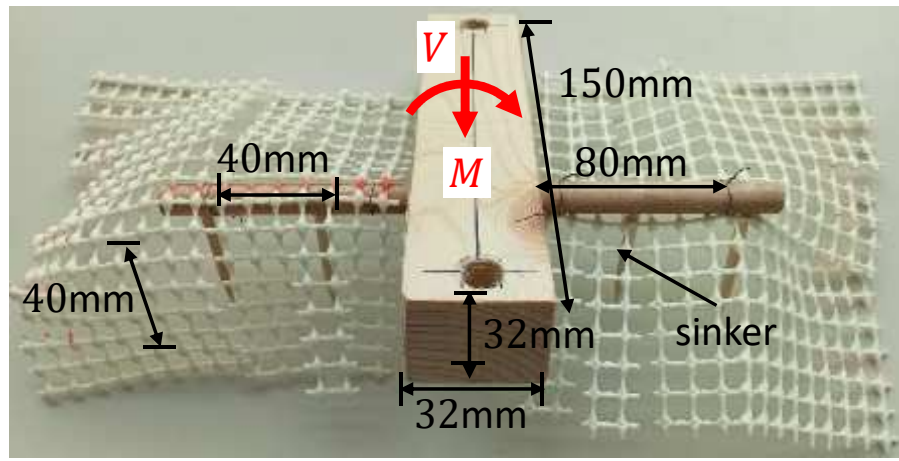
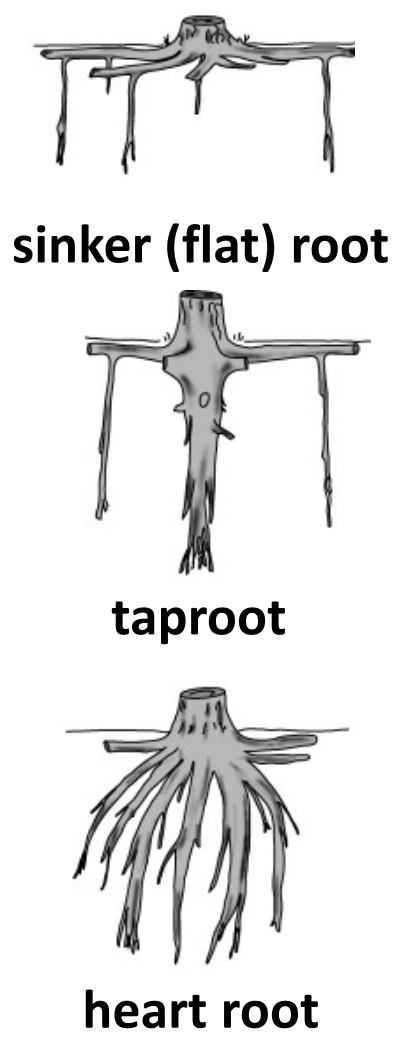
$$M = \underbrace{F \cdot h_F \cdot \cos(\alpha - \varphi)}_{\text{effetto del vento}} + \underbrace{W \cdot h_W \cdot \sin(\varphi_0 + \varphi)}_{\text{effetto del fuori piombo}}$$





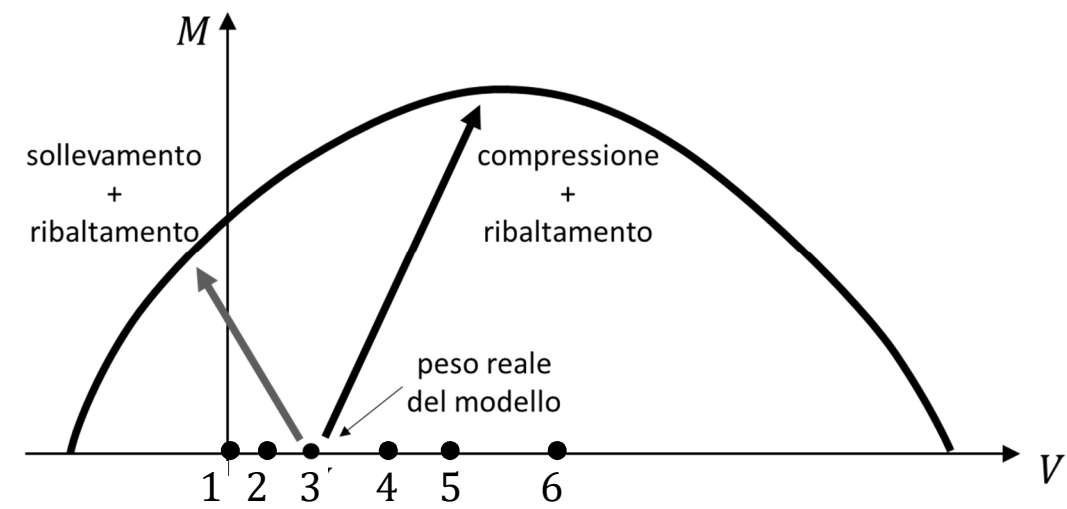
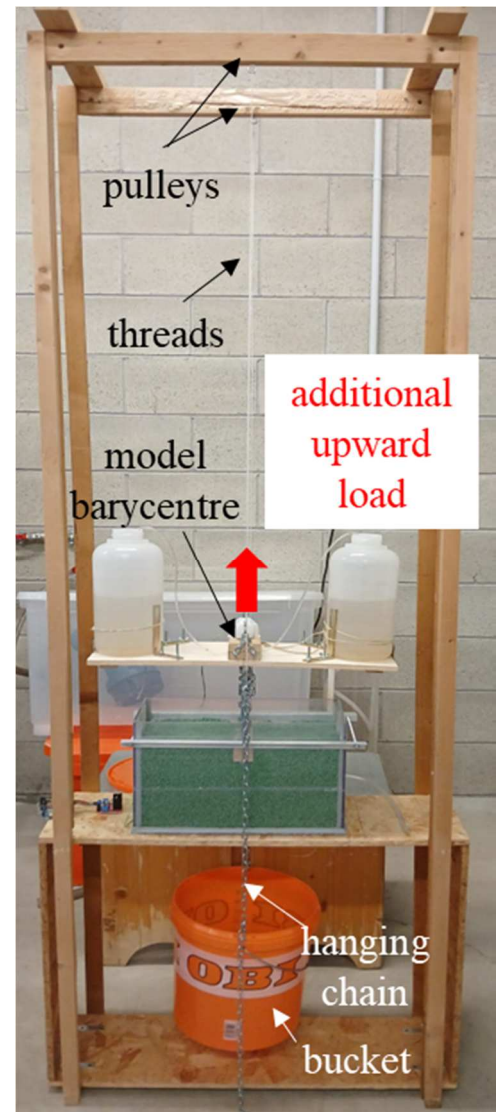
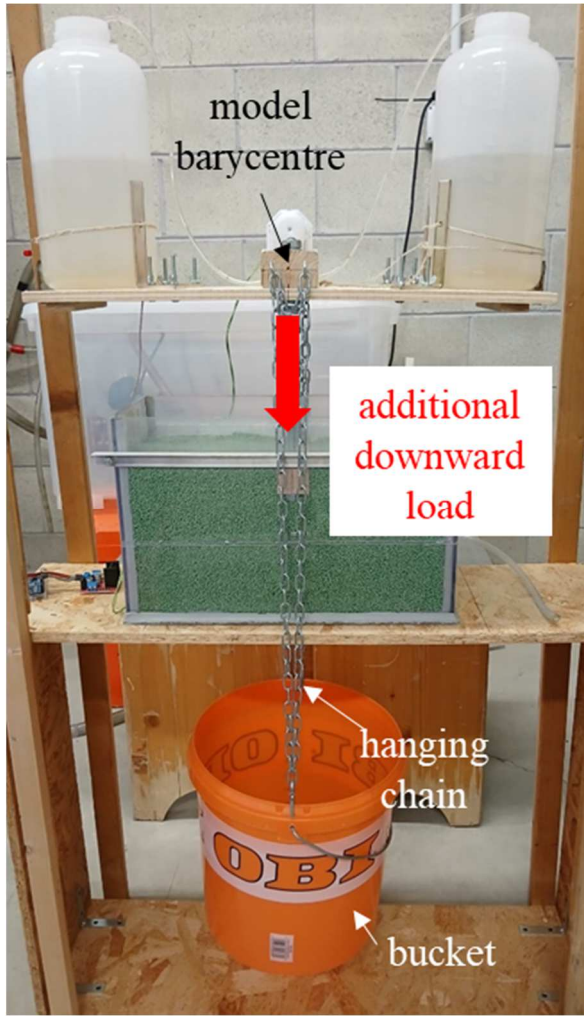
Cosa ci dice il laboratorio?

Galli A., Marrazzo G. (2026) "Geotechnical aspects in tree stability assessment: a state of the art review, with perspective insights", *Rivista Italiana di Geotecnica*, 1/2026, 54-76





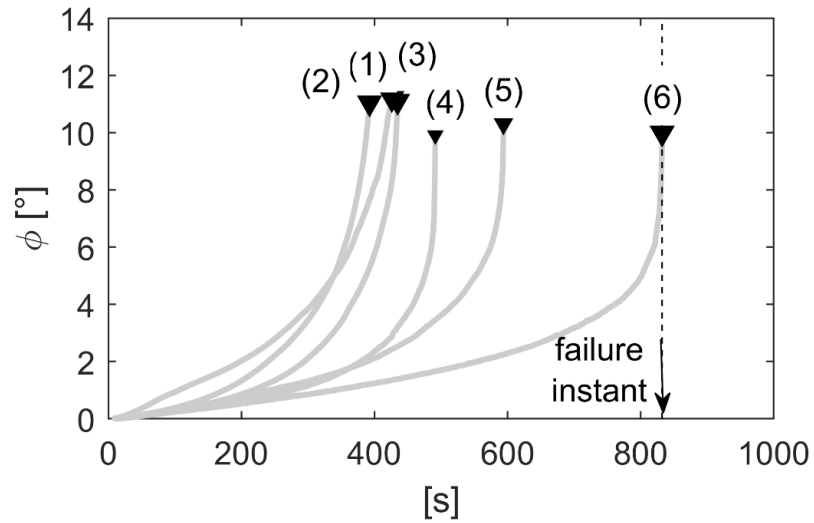
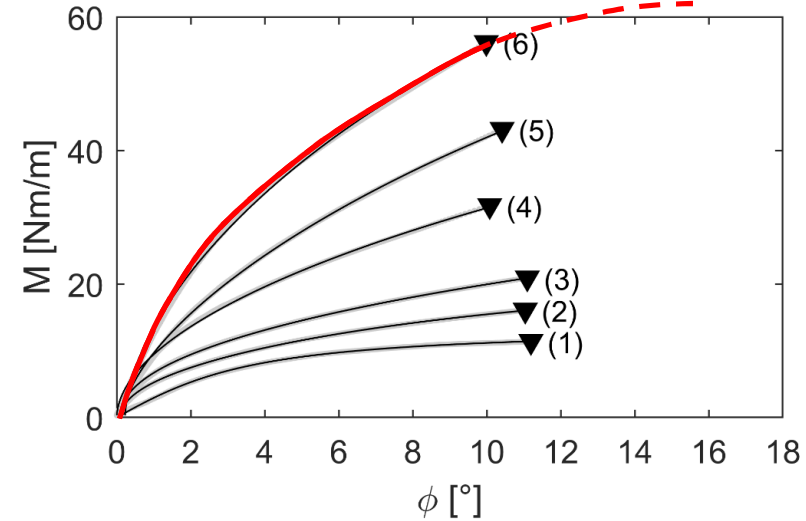
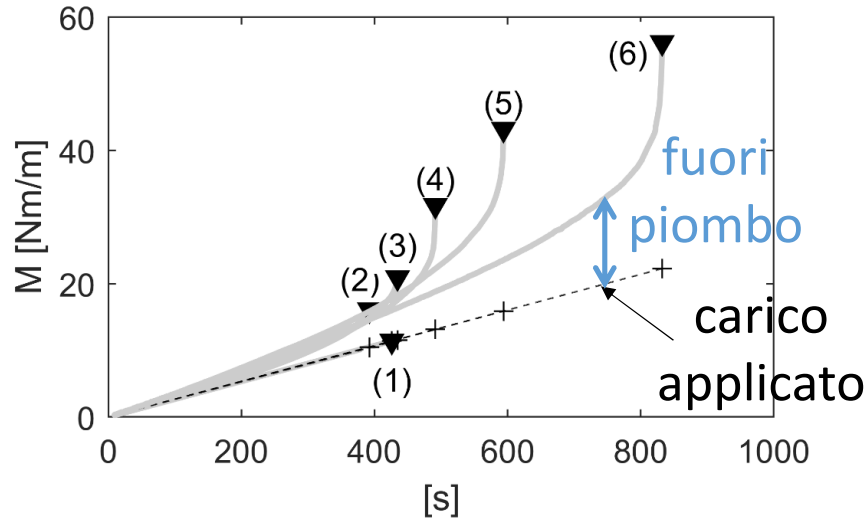
Cosa ci dice il laboratorio?



Prova #	[kg]
1	0
2	1.9
3	3.8 (modello)
4	6.9
5	9.8
6	12.8



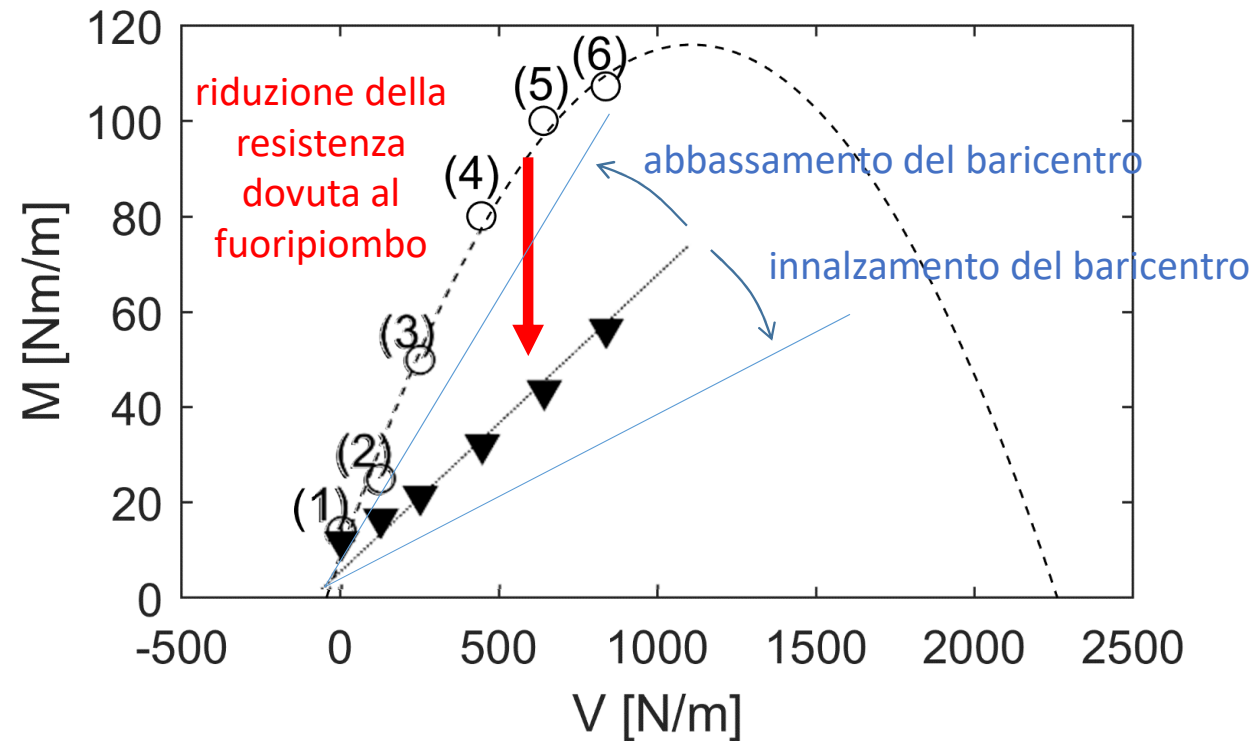
Cosa ci dice il laboratorio?



Galli et al. (2024) $\frac{\varphi}{\varphi_{70}} = a \cdot \tan \left[\frac{\pi}{2} \left(\frac{M}{M_L} \right)^{1/b} \right]$

Wessolly (1998) $\varphi = \frac{1}{3} \tan \left(\frac{100}{73,85} \frac{F}{F_L} \right) + \frac{1}{2} \left(\frac{F}{F_L} \right)^2 - \frac{1}{10} \frac{F}{F_L}$

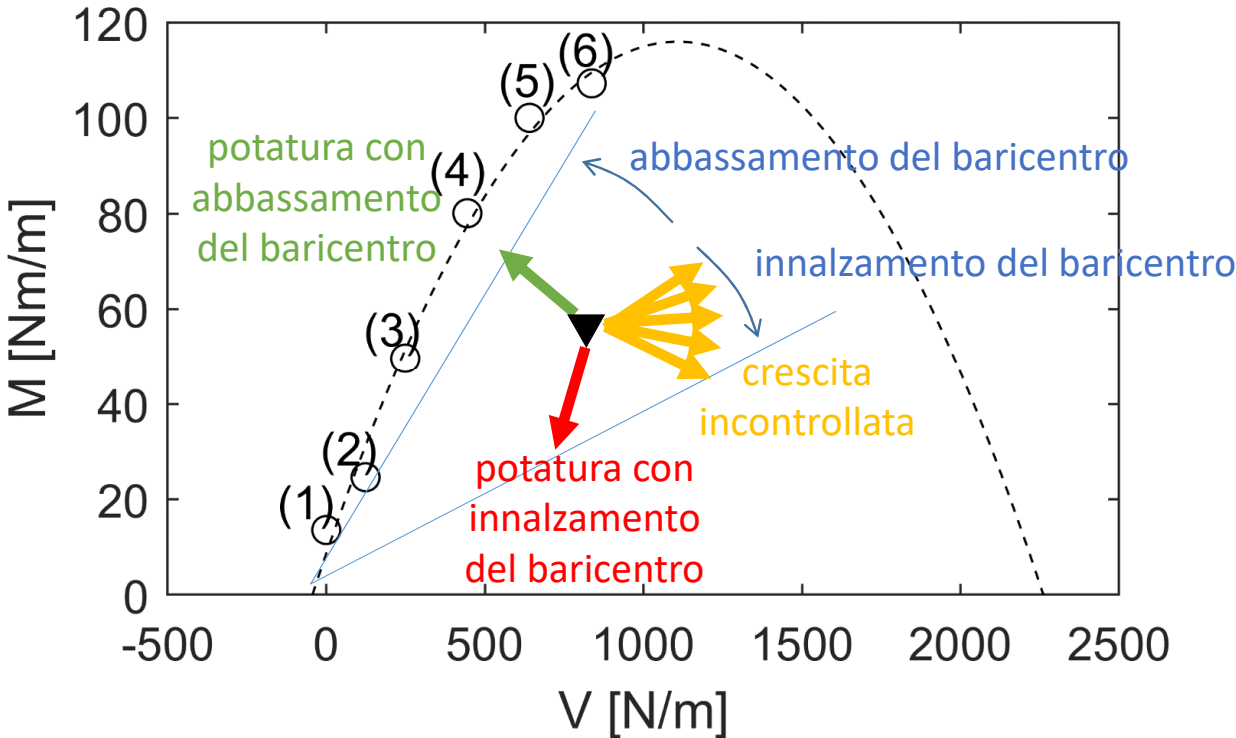
Interpretazione



Marrazzo G., Galli A. (2026) "Investigation of M-V interaction domain for small-scale simplified root system architectures", **11th International Conference on Physical Modelling in Geotechnics**. Zurich, 8-12 June 2026.

Galli A., Marrazzo G. (2026) "Identification of the M-V toppling failure condition of simplified root plates in view of tree stability assessment", **IX Convegno Nazionale dei Ricercatori di Ingegneria Geotecnica**. L'Aquila, 1-3 luglio 2026.

Esempio: gestione e manutenzione del verde



Marrazzo G., Galli A. (2026) "Investigation of M-V interaction domain for small-scale simplified root system architectures", 11th International Conference on Physical Modelling in Geotechnics. Zurich, 8-12 June 2026.

Galli A., Marrazzo G. (2026) "Identification of the M-V toppling failure condition of simplified root plates in view of tree stability assessment", IX Convegno Nazionale dei Ricercatori di Ingegneria Geotecnica. L'Aquila, 1-3 luglio 2026.

Stimare il peso dell'albero:



Wang et al. *Forest Ecosystems* (2021) 8:67
<https://doi.org/10.1186/s40663-021-00340-w>

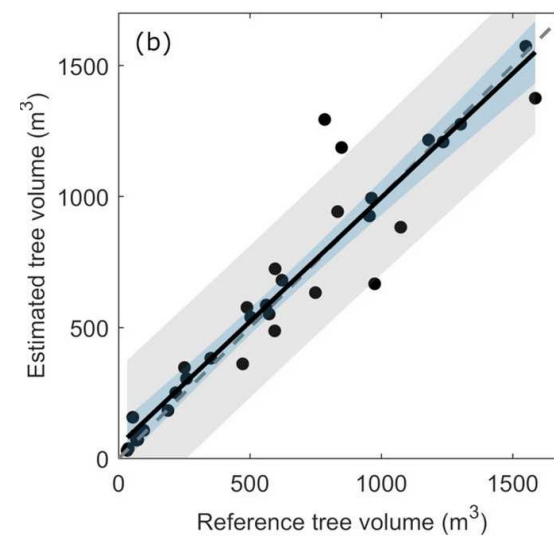
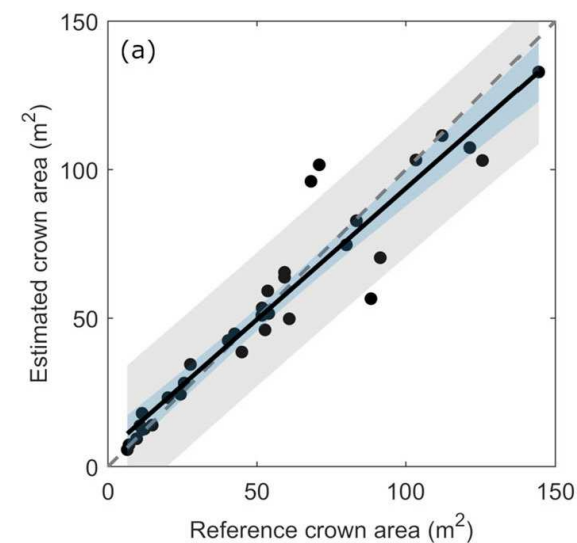
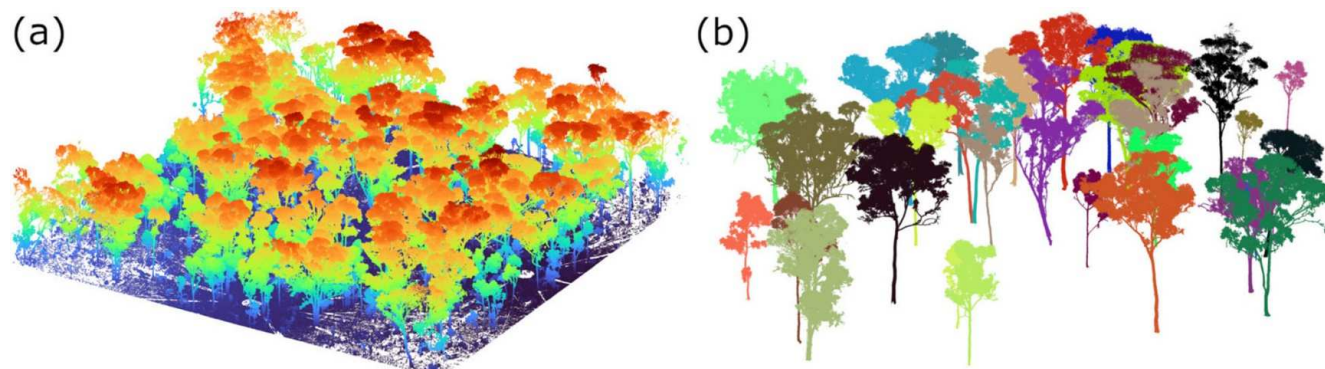
Forest Ecosystems

RESEARCH

Open Access

Individual tree extraction from terrestrial laser scanning data via graph pathing

Di Wang¹, Xinlian Liang^{2,3*}, Gislain Il Mofack⁴ and Olivier Martin-Ducup⁵




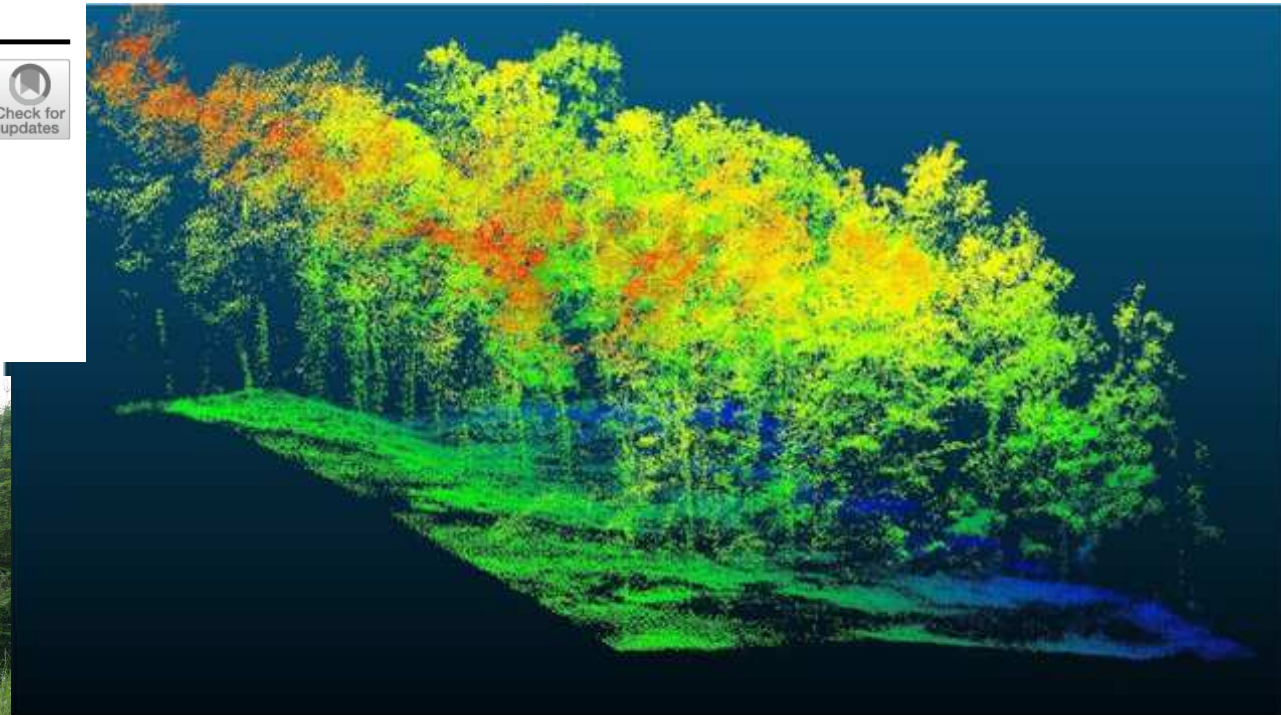
Stimare il peso dell'albero:



Surveys in Geophysics (2019) 40:959–977
<https://doi.org/10.1007/s10712-019-09529-9>

New Opportunities for Forest Remote Sensing Through Ultra-High-Density Drone Lidar

James R. Kellner^{1,2}  · John Armston³ · Markus Birrer⁴ · K. C. Cushman^{1,2} · Laura Duncanson³ · Christoph Eck⁴ · Christoph Falleger⁴ · Benedikt Imbach⁴ · Kamil Král⁵ · Martin Krůček⁵ · Jan Trochta⁵ · Tomáš Vrška⁵ · Carlo Zraggen⁴



Kellner, J.R., Armston, J., Birrer, M. et al. New Opportunities for Forest Remote Sensing Through Ultra-High-Density Drone Lidar. *Surv Geophys* 40, 959–977 (2019).

<https://doi.org/10.1007/s10712-019-09529-9>

Stimare il peso dell'albero:

Forest Ecology and Management 486 (2021) 118945



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Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco



Using terrestrial laser scanning for characterizing tree structural parameters and their changes under different management in a Mediterranean open woodland

Ekaterina Bogdanovich^{a, *}, Oscar Perez-Priego^{a, b}, Tarek S. El-Madany^a, Marcus Guderle^a, Javier Pacheco-Labrador^a, Shaun R. Leveck^c, Gerardo Moreno^d, Arnaud Carrara^e, M. Pilar Martín^f, Mirco Migliavacca^a

^a Max Planck Institute for Biogeochemistry, Hans-Knöll-Str. 10, 07745 Jena, Germany

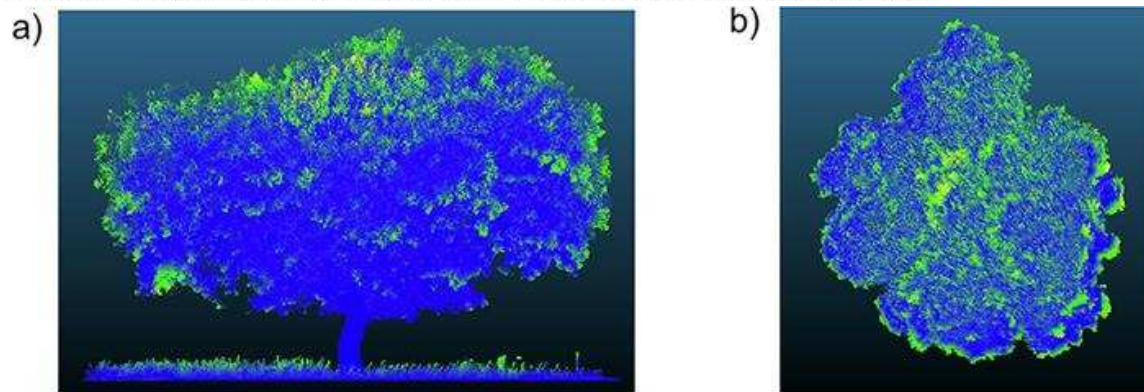
^b Department of Biological Sciences, Macquarie University, 6 Wally's Walk, Sydney, NSW 2109, Australia

^c CSIRO Land and Water, PMB 44, Winnellie, Darwin, NT 0822, Australia

^d Forest Research Group – INDEHESA University of Extremadura, 10600 Plasencia, Spain

^e Fundación Centro de Estudios Ambientales del Mediterráneo (CEAM), Charles Darwin 14, Parc Tecnològic, 46980 Paterna, Spain

^f Environmental Remote Sensing and Spectroscopy Laboratory (SpecLab), Spanish National Research Council (CSIC), Albasanz 26-28, 28037 Madrid, Spain



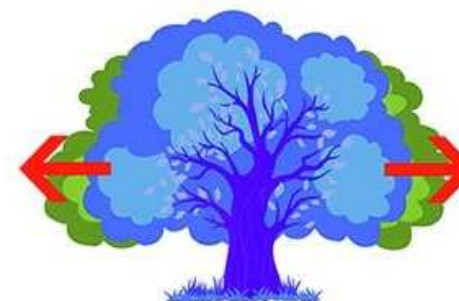
TLS point cloud of holm oak: a) side view; b) top-down view.



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Change in maximum
height Δh_{\max}

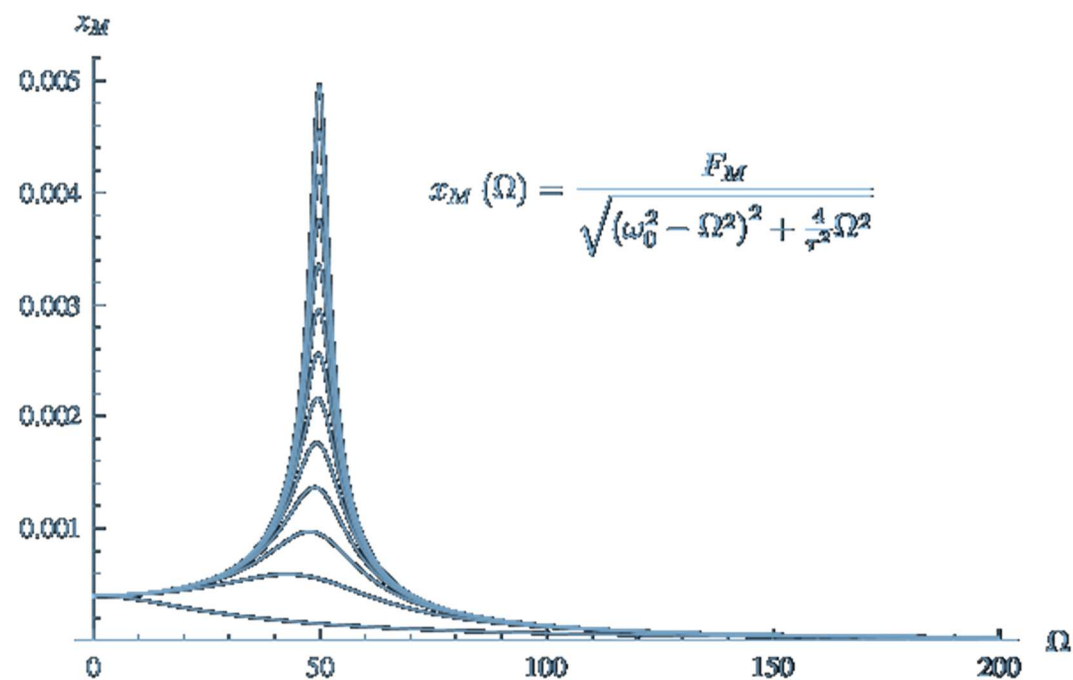
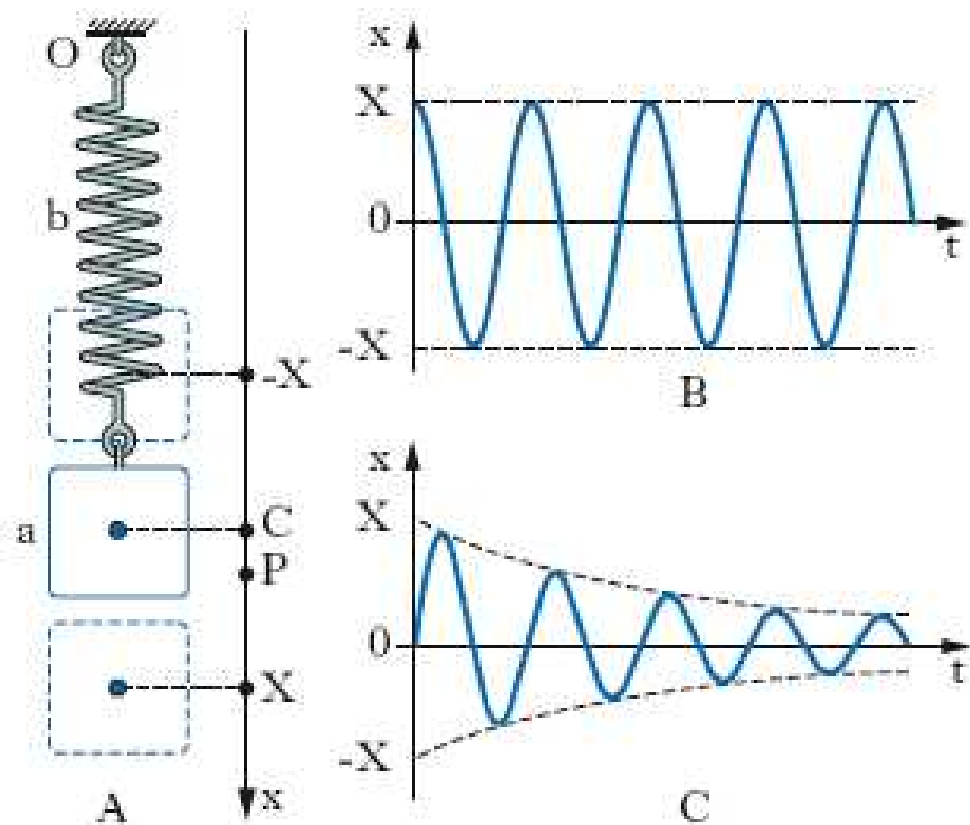


Change in crown
projected area ΔCA

Stimare il peso da prove dinamiche: oscillazioni smorzate



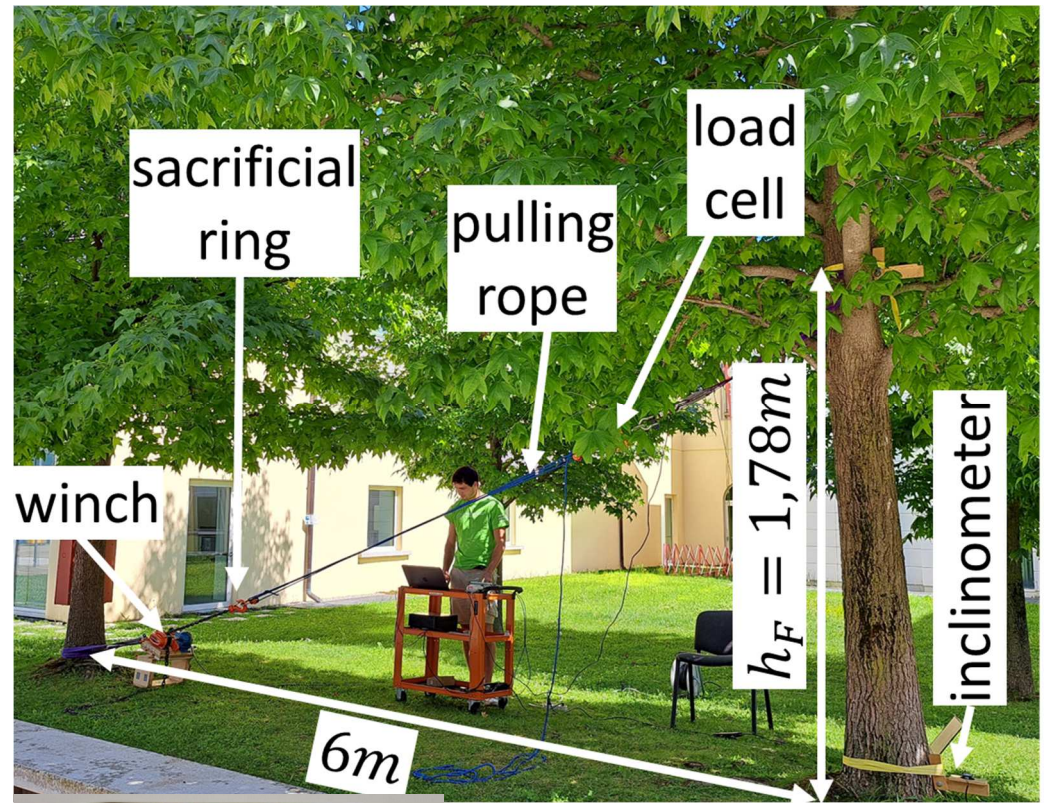
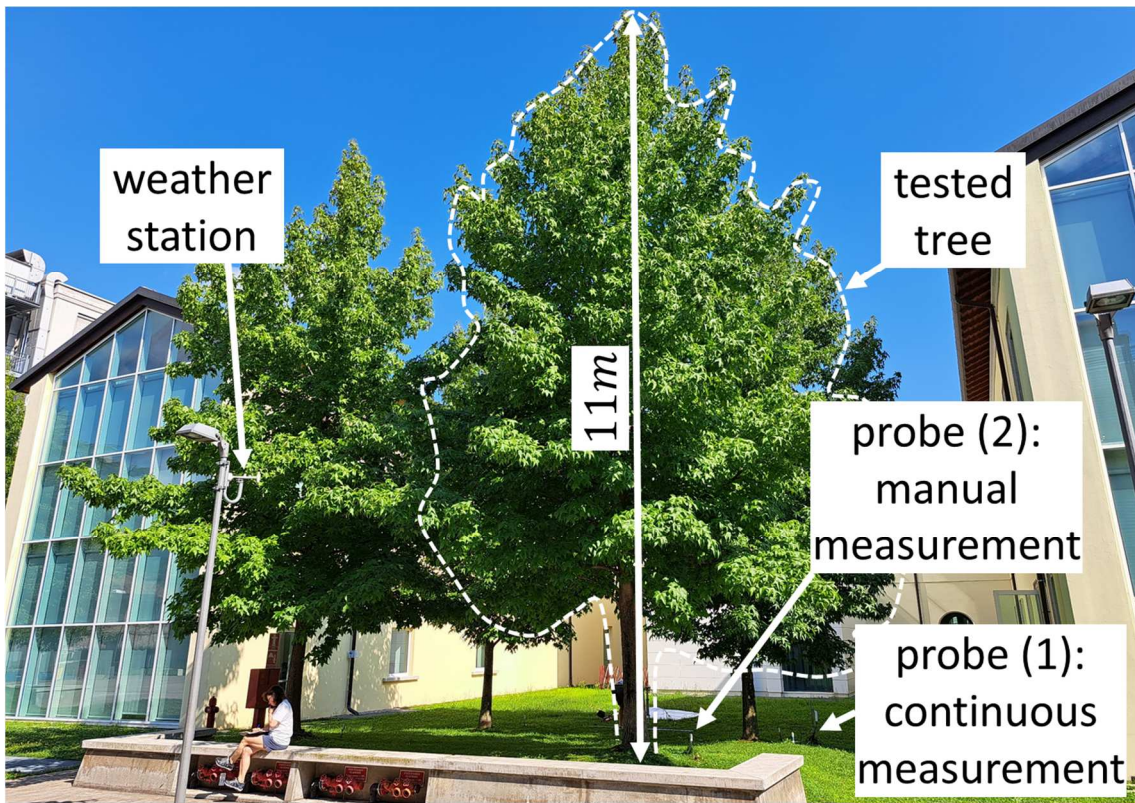
Stimare il peso da prove dinamiche: oscillazioni smorzate



Il campo prova al Polo Territoriale di Lecco



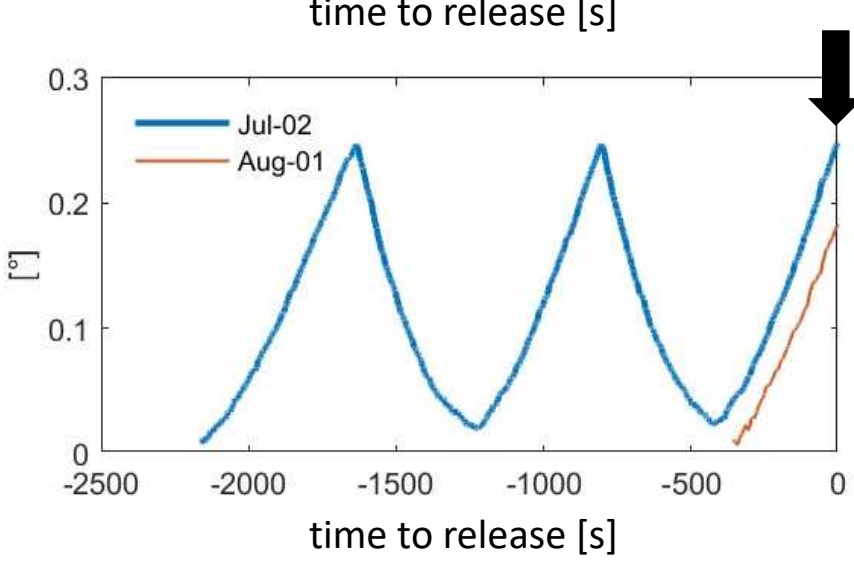
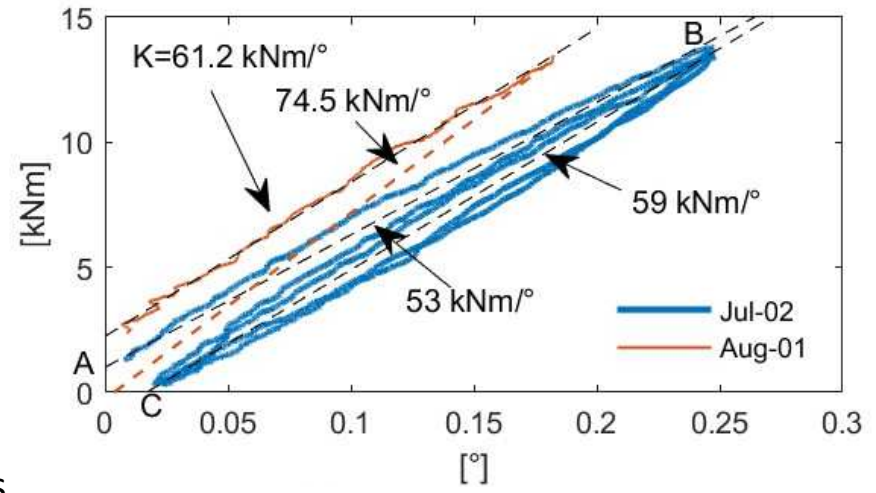
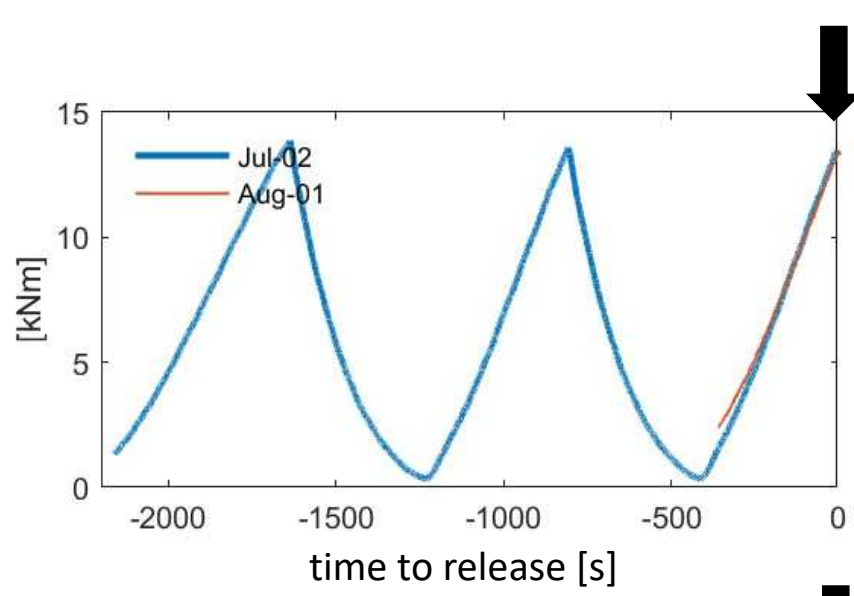
Galli A., Marrazzo G., Scaccabarozzi D. (2026) "IStatic and dynamic pulling tests on a real scale tree: mechanical characterization and simplified preliminary interpretation", 3rd International Symposium RootS25. Bari, 6-7 November 2025.



climbing carabiner (8kN)

(estimated) tree weight: $W = 640kg$
(estimated) baricenter height: $h_W = 7.3m$

Il campo prova al Polo Territoriale di Lecco



rotational stiffness K [kNm/°]	testing session 1	testing session 2
Virgin load	53 +11.3%	61.2 +15.4%
Unload-reload	59 +26.3%	74.5 +21.7%

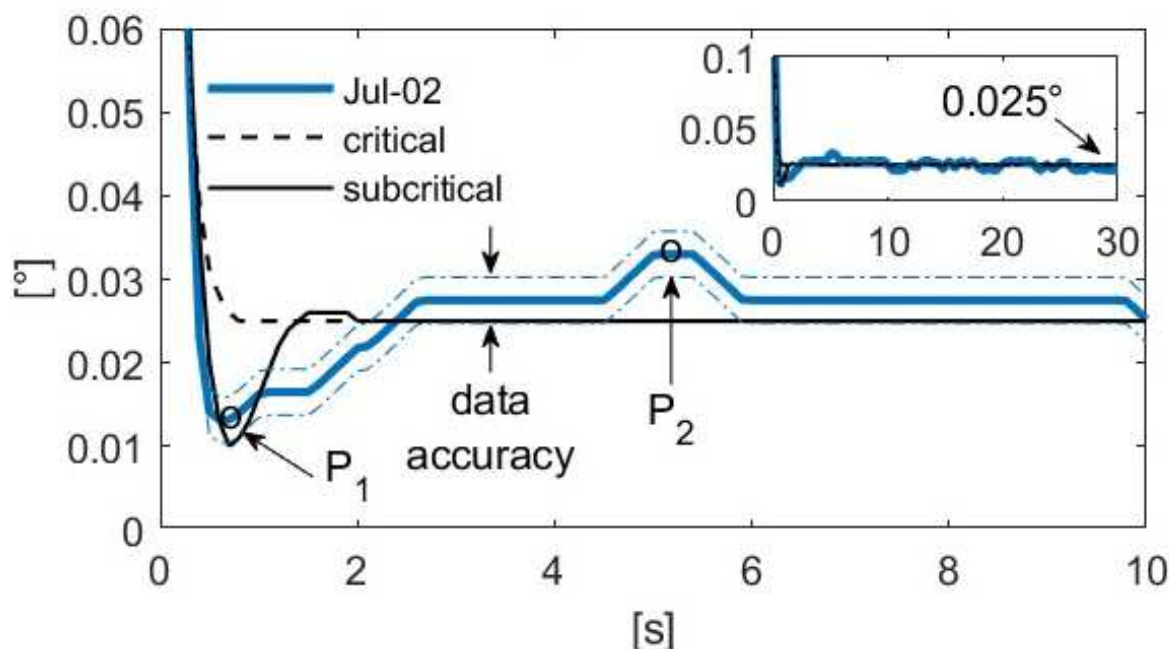
Il campo prova al Polo Territoriale di Lecco: "Pluck test"



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testing session 1



1 d.o.f. rotational oscillator

$$\frac{W \cdot h_W^2}{g} \frac{\pi}{180} \ddot{\varphi}(t) + \eta \cdot \dot{\varphi}(t) + K \cdot \varphi(t) = 0$$

$W \cdot h_W^2, \eta$
(from back-analysis)

$K = 59 \text{ kNm}/^\circ$
(from test 1)

$$\delta = \frac{180 \cdot g \cdot \eta}{2\pi \cdot W \cdot h_G^2}$$

$$\omega^2 = \frac{180 \cdot g \cdot K}{\pi \cdot W \cdot h_G^2}$$

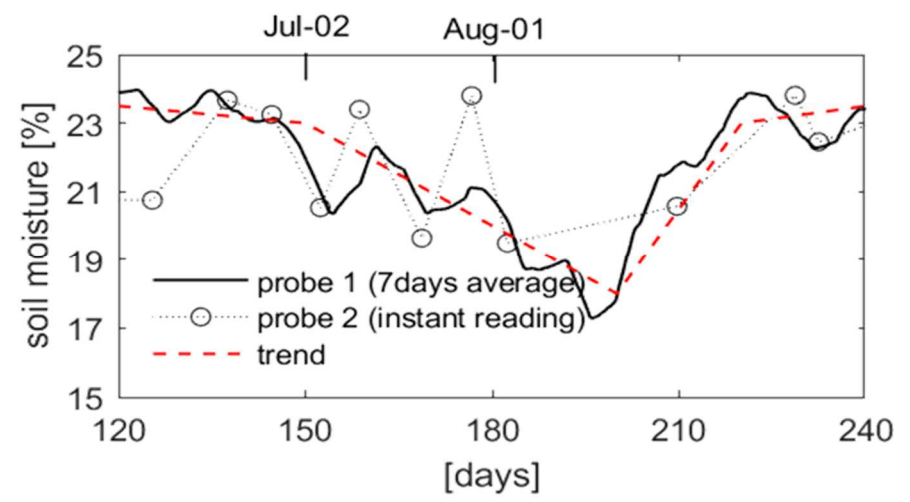
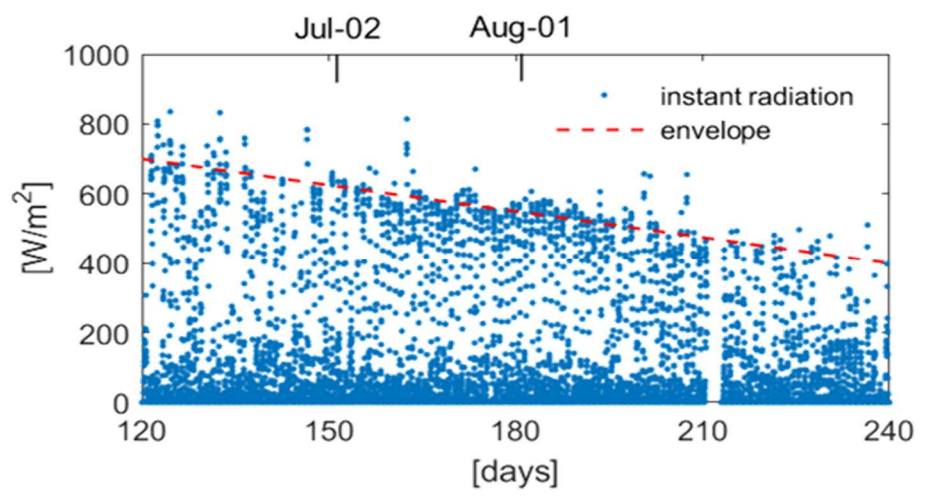
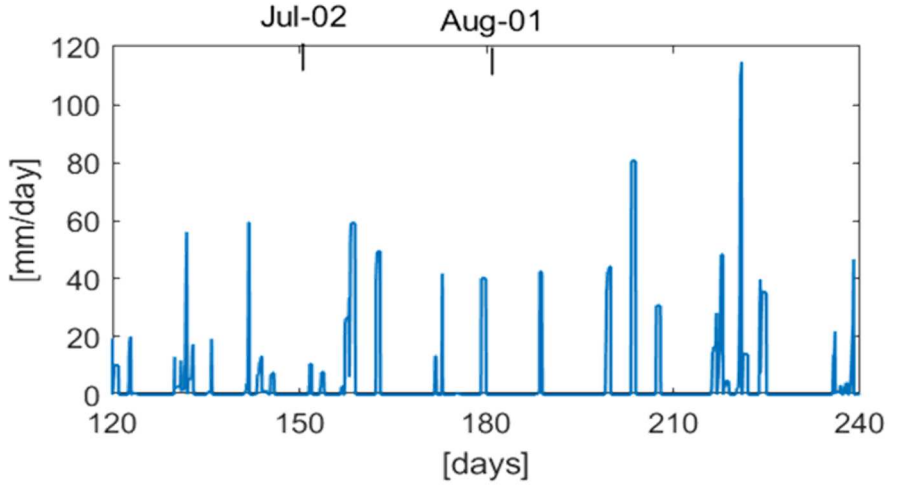
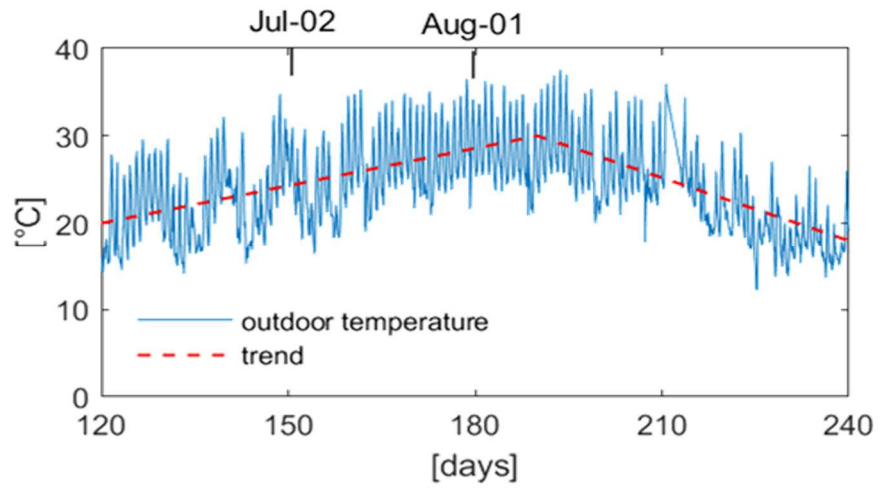
$$\ddot{\varphi}(t) + 2\delta \cdot \dot{\varphi}(t) + \omega^2 \cdot \varphi(t) = 0$$

critical ($\delta = \omega$)	$\omega = 9.39 \text{ rad/s}$ $\delta = 9.39 \text{ rad/s}$	$W = 6.99 \text{ kN} \approx 640 \text{ kg}$ $\eta = 8.41 \text{ kNm} \cdot \text{s}/^\circ$	✓
sub-critical ($\delta < \omega$)	$\omega = 4.40 \text{ rad/s}$ $\delta = \dots$	$W = 31.92 \text{ kN}$ $\eta = \dots$	✗

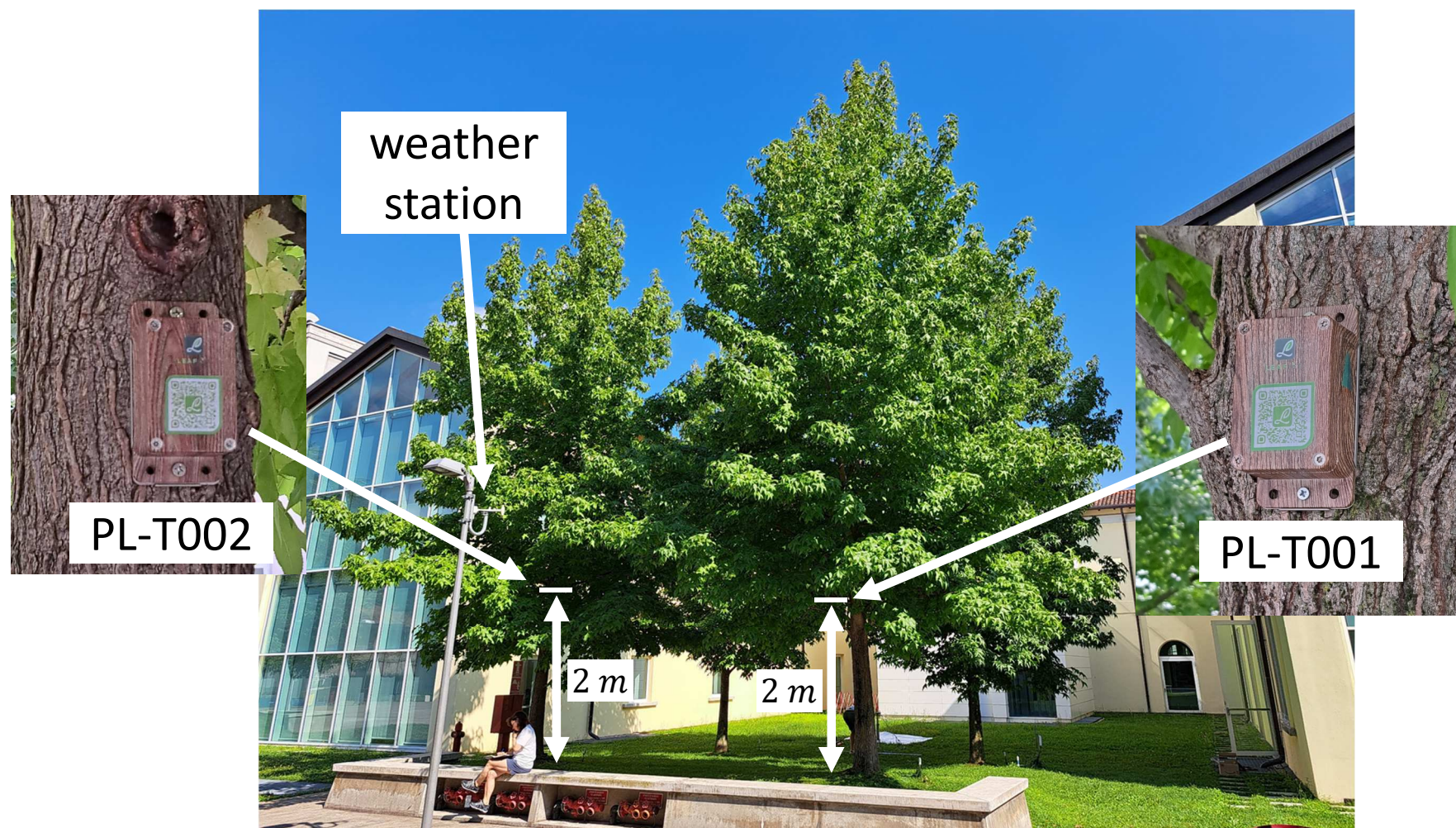
Il campo prova al Polo Territoriale di Lecco



tree testing sessions **1** **2**

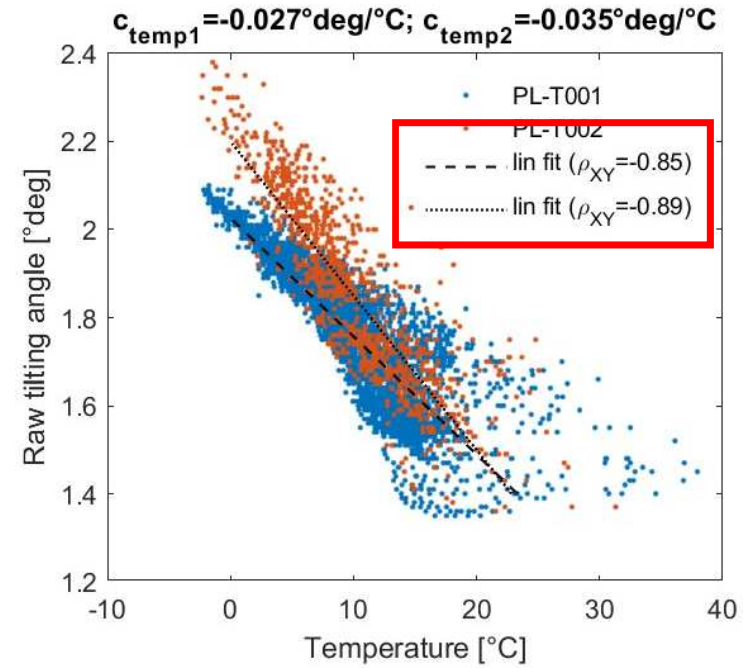
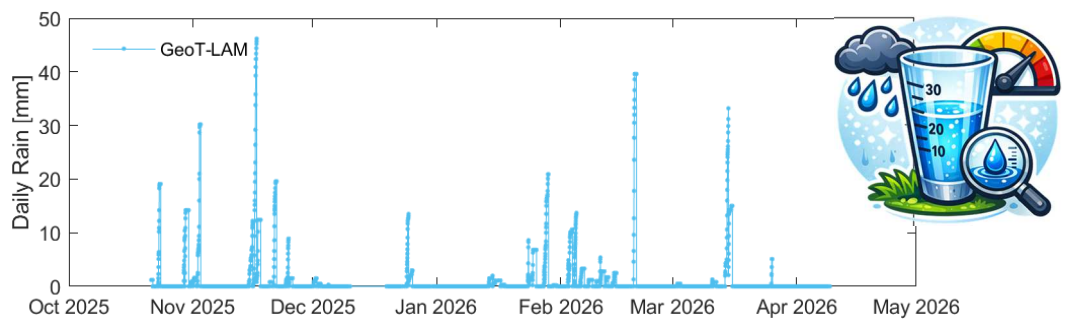
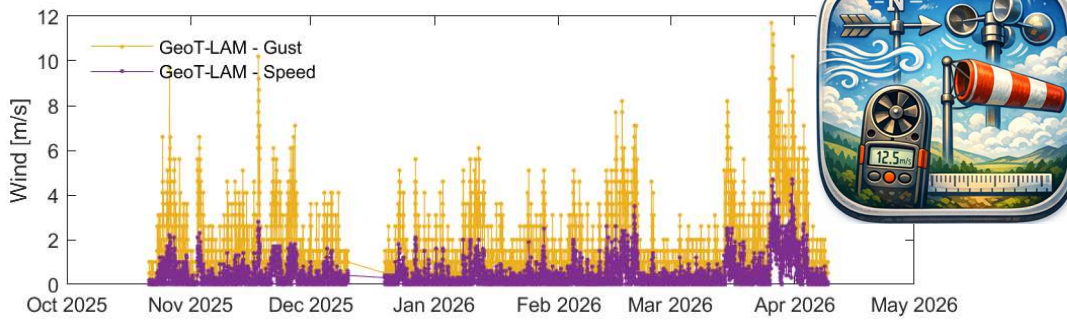
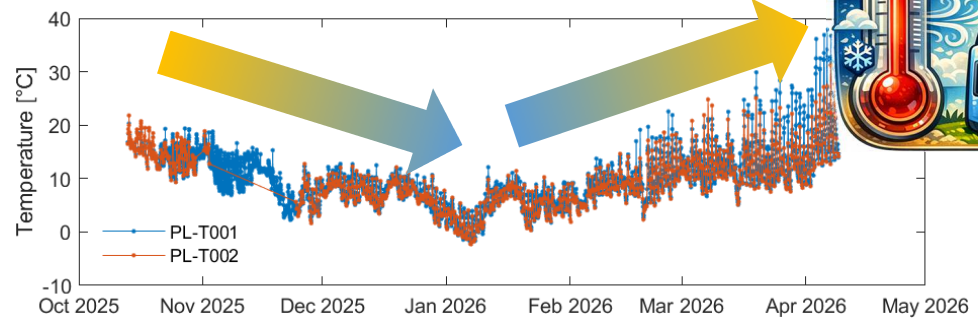
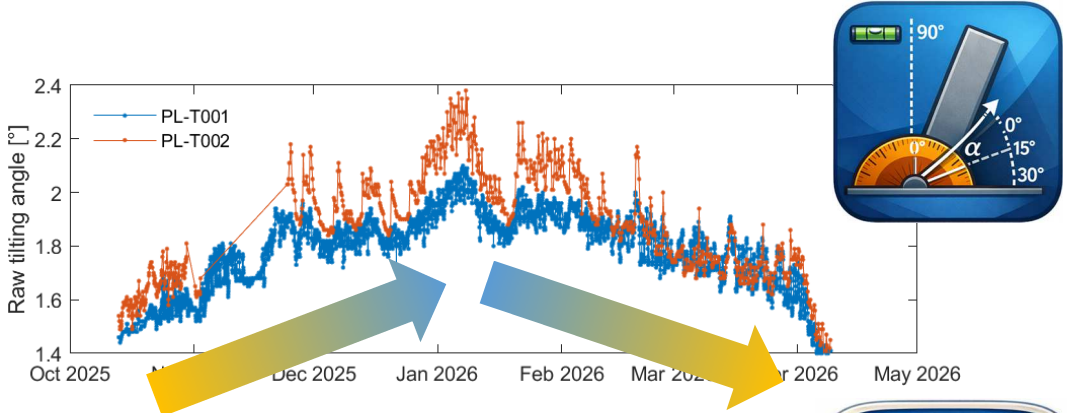


Monitoraggio: l'importanza della comprensione





Monitoraggio: l'importanza della comprensione



In conclusione:



integrazione dei dati



sviluppo modelli di calcolo



