Electronic supplementary material

A workflow for the rapid assessment of the landslide-tsunami hazard in perialpine lakes

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1. Forecasted peak ground accelerations for Switzerland

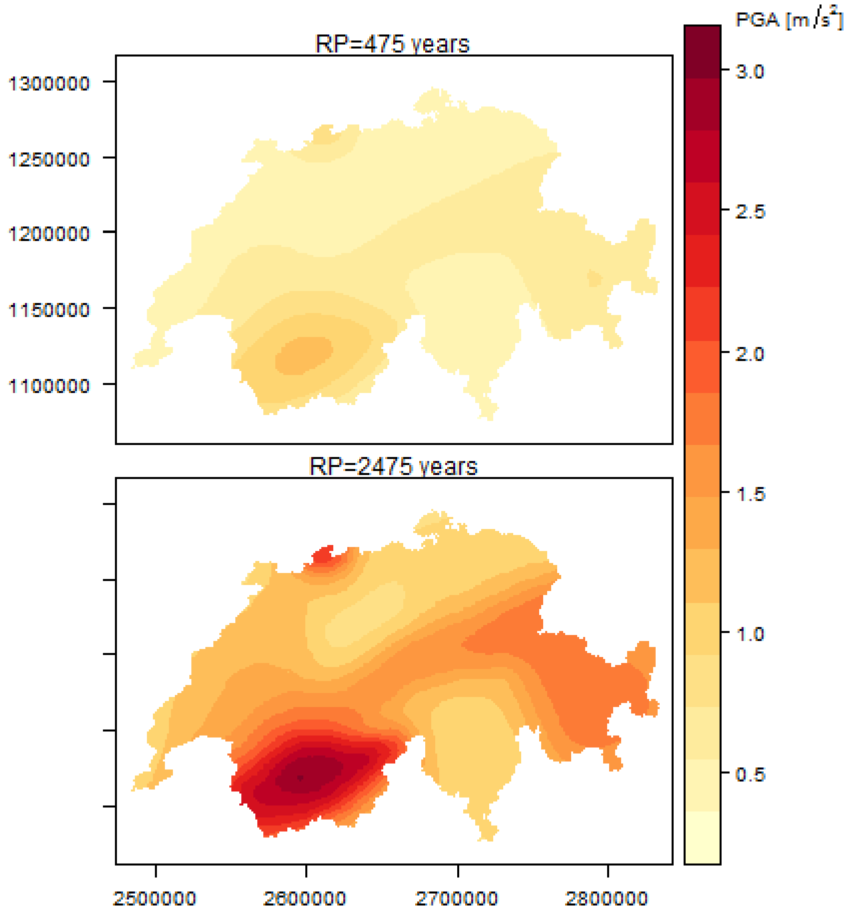

Fig. ESM.1. Interpolated median PGAs expected for mean return periods of 475 (top) and 2475 years (bottom) in Switzerland. PGA values are in m/s^2. Coordinate Reference System: CH1903+. Data from Wiemer et al. (2016)

2. Sedimentation model

T_{PMS}(i,j) is calculated as function of its water depth and slope gradient with the following linear regression (Equation ESM.1; Strupler et al. 2018):

$$T_{PMS}(i,j) = \sum_{unit=SMU3}^{unit=SMU4} unit\ age\ interval\ [yr] \times 0.01 \times (a(i,j)) + b \times wd(i,j) - c \times \alpha(i,j) \qquad (1)$$

For the Holocene drape in Lake Zurich, two different units (termed “SMU3” and “SMU4” in Strupler et al. (2018b)) with different sedimentation rates can be identified: a stratigraphically lower/older lying Holocene sedimentary unit that spans ~ 5000 years and an upper/younger Holocene unit that spans ~7000 years (Strasser 2008; Strupler et al. 2018). The potentially mobile sediment results from the summation of the two unit thicknesses at each pixel (i,j). Used coefficients are shown in Table ESM.1.

Table ESM.1. *Coefficients used in Equation ESM.1*

Unit	Age interval (years)	a	b	c
SMU3	5000	0.047	0.000175	0.001305
SMU4	7000	0.021	0.000104	0.000654

3. Lake Lucerne

Comparison of T_{PMS} (this study) to measured Holocene thickness (Strasser et al. 2007)

Holocene sedimentation rates (i.e. < 11500 cal yr B.P.) at three slope locations in Lake Lucerne are ~22 cm/ka (Weggis site), ~36 cm/ka (St.Niklausen site), and ~42 cm/ka (Chrütztrichter site), which would correspond to a drape thickness of ~2.5, ~4., and ~4.8 m at their investigated sites (Strasser et al. 2007). In comparison, the potentially mobile sediment modelled with the approach of Strupler et al. (2018b) does not show a systematic over- or underestimation. However, there are differences between ~20 and ~50 %.

Table ESM.2. *Location, measured and modelled Holocene drape of long cores from Strasser et al. (2007) that show an undisturbed Holocene sediment drape. Water depth (WD) and slope were sampled from the bathymetry based on the core location. Core coordinates from Strasser (2008) with Coordinate Reference System CH1903 were converted to CH 1903+.* $T_{Strasser2007}$ *= measured thickness by Strasser et al. (2007),* T_{PMS} *= Thickness of the potentially mobile sediment calculated in this study.*

Core Name	X	Y	WD	Slope	$T_{Strasser2007}$	T_{PMS}	Diff. [%]
4WS05-K1	2668474	1208744	35.2	6.1	2.5	3.7	48
4WS05-K4	2672225	1209150	57.2	14.6	4.1	3.1	-24
4WS05-K6	2675025	1208983	32.2	5.2	4.8	3.8	-21

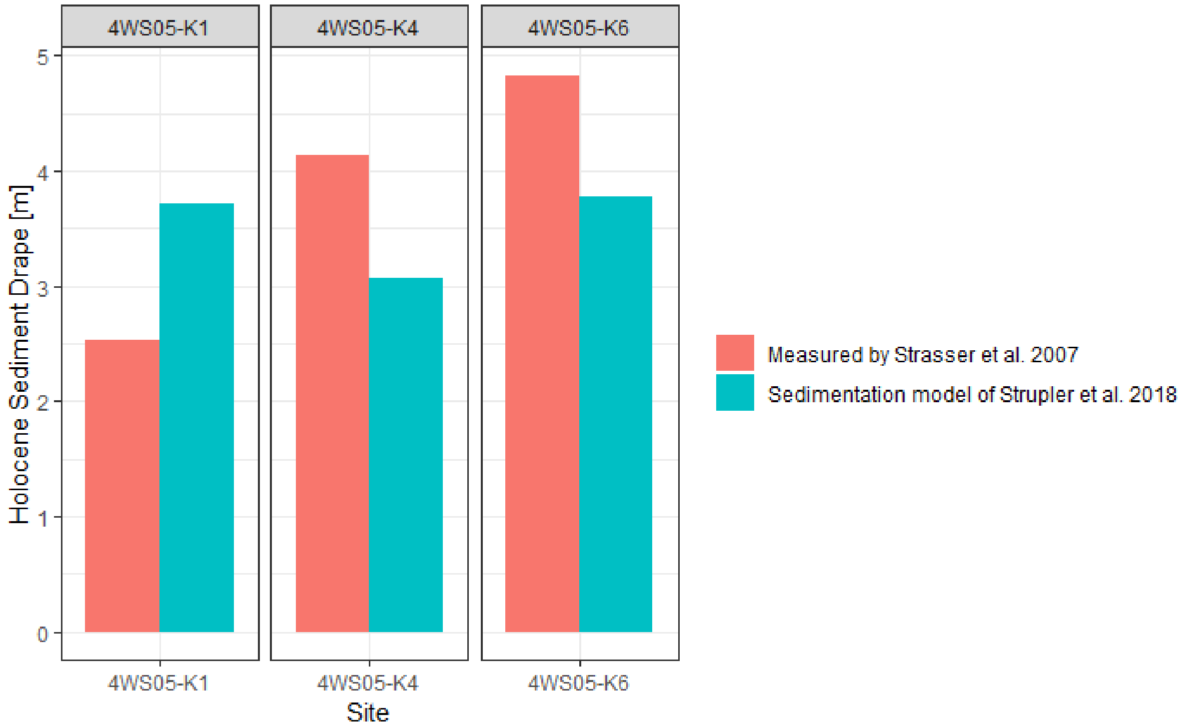

Fig. ESM.2. Comparison of T_{PMS} to measured Holocene thickness from Strasser et al. (2007)

Plots of landslide volumes

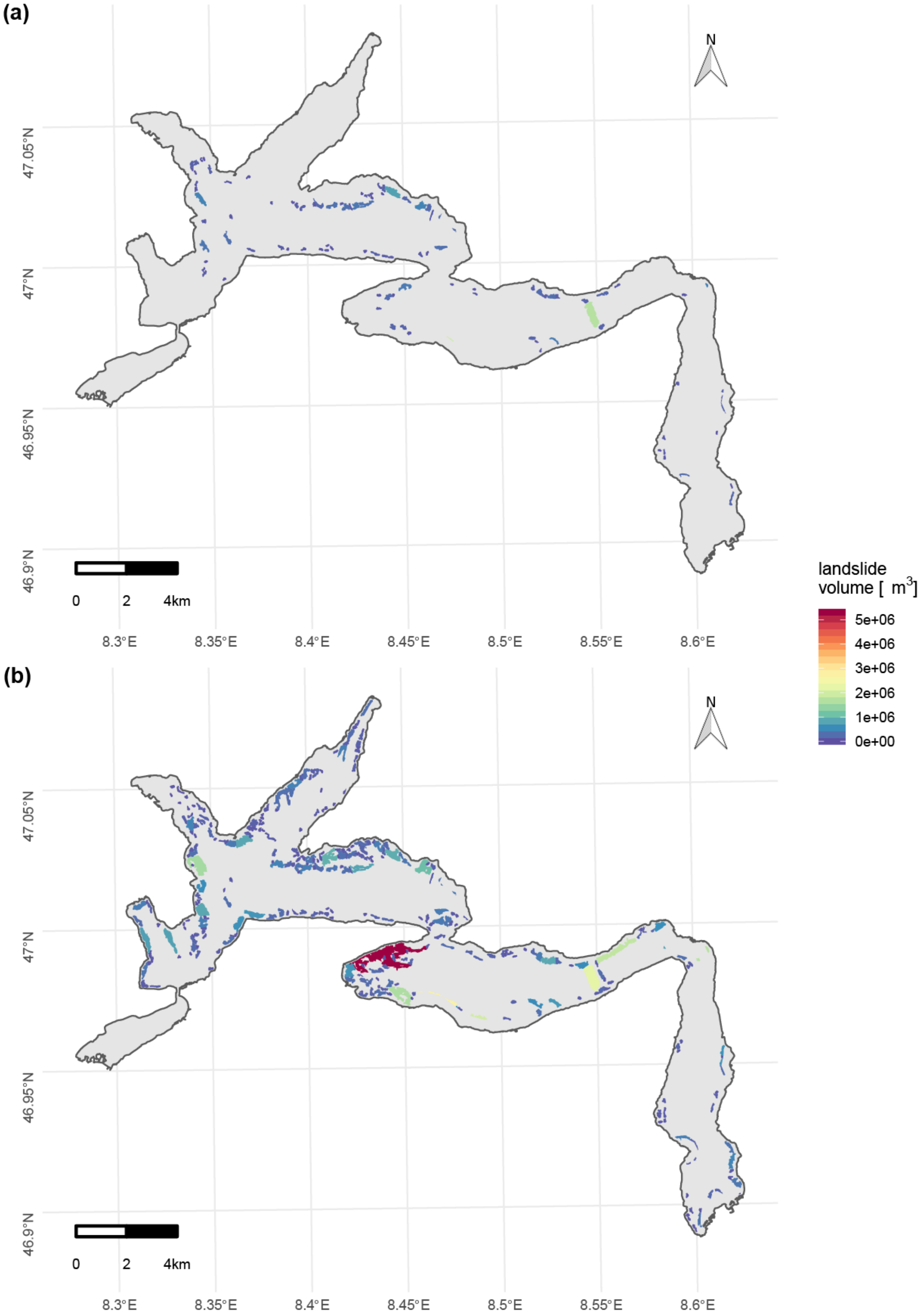

Fig. ESM.3. Potential landslides in Lake Lucerne for a mean RP of 475 (a) and 2475 years (b)

4. Lake Zug

Bathymetry

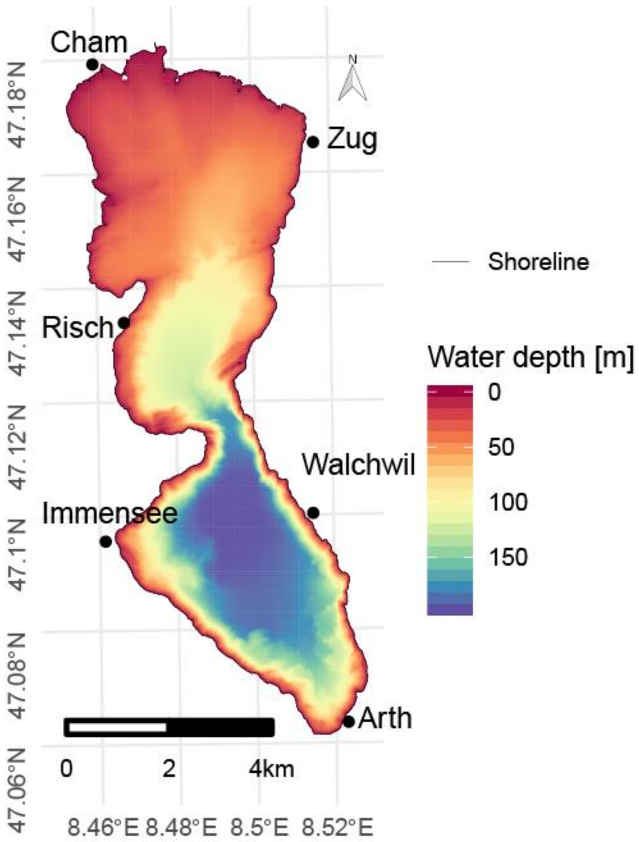

Fig. ESM.4. Bathymetry of Lake Zug

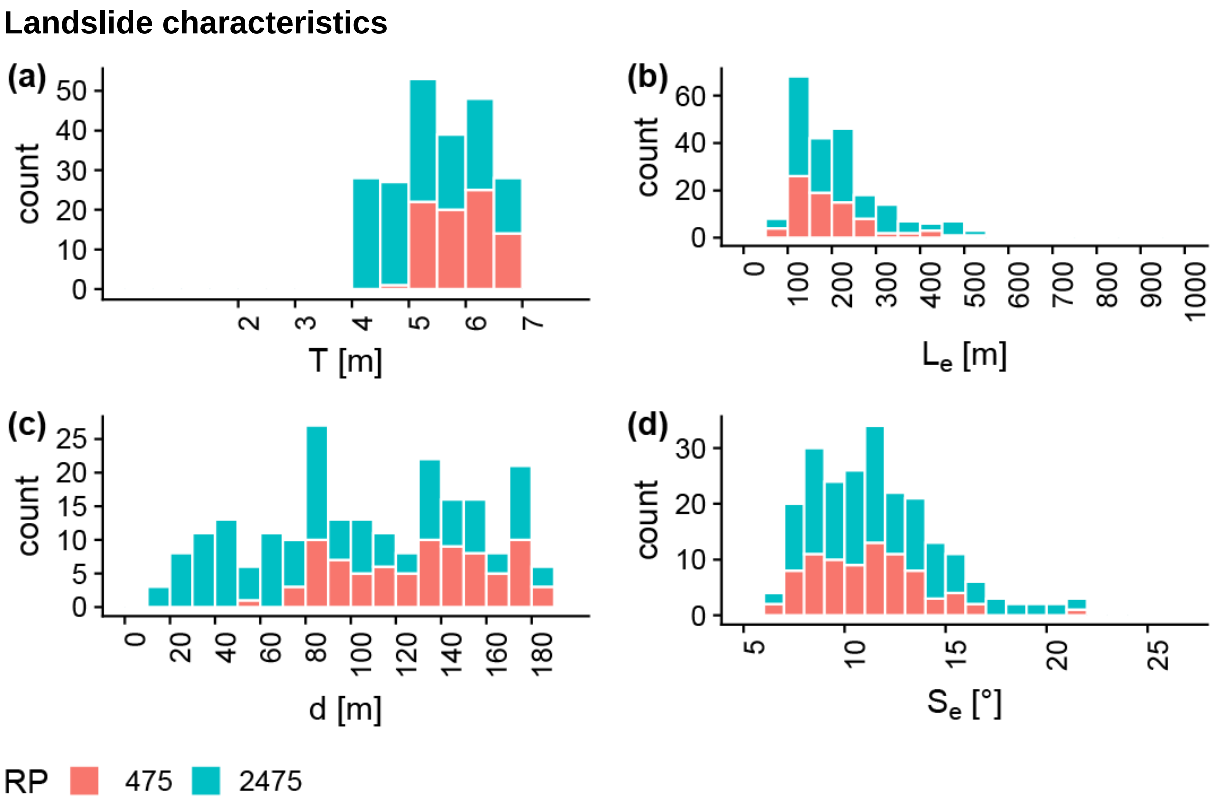

Fig. ESM.5. Characteristics of potential landslides forecasted for Lake Zug for RP=475 (red) and 2475 years (cyan).

Location of forecasted landslides and $\eta0_{2D}$

(a)

(b)

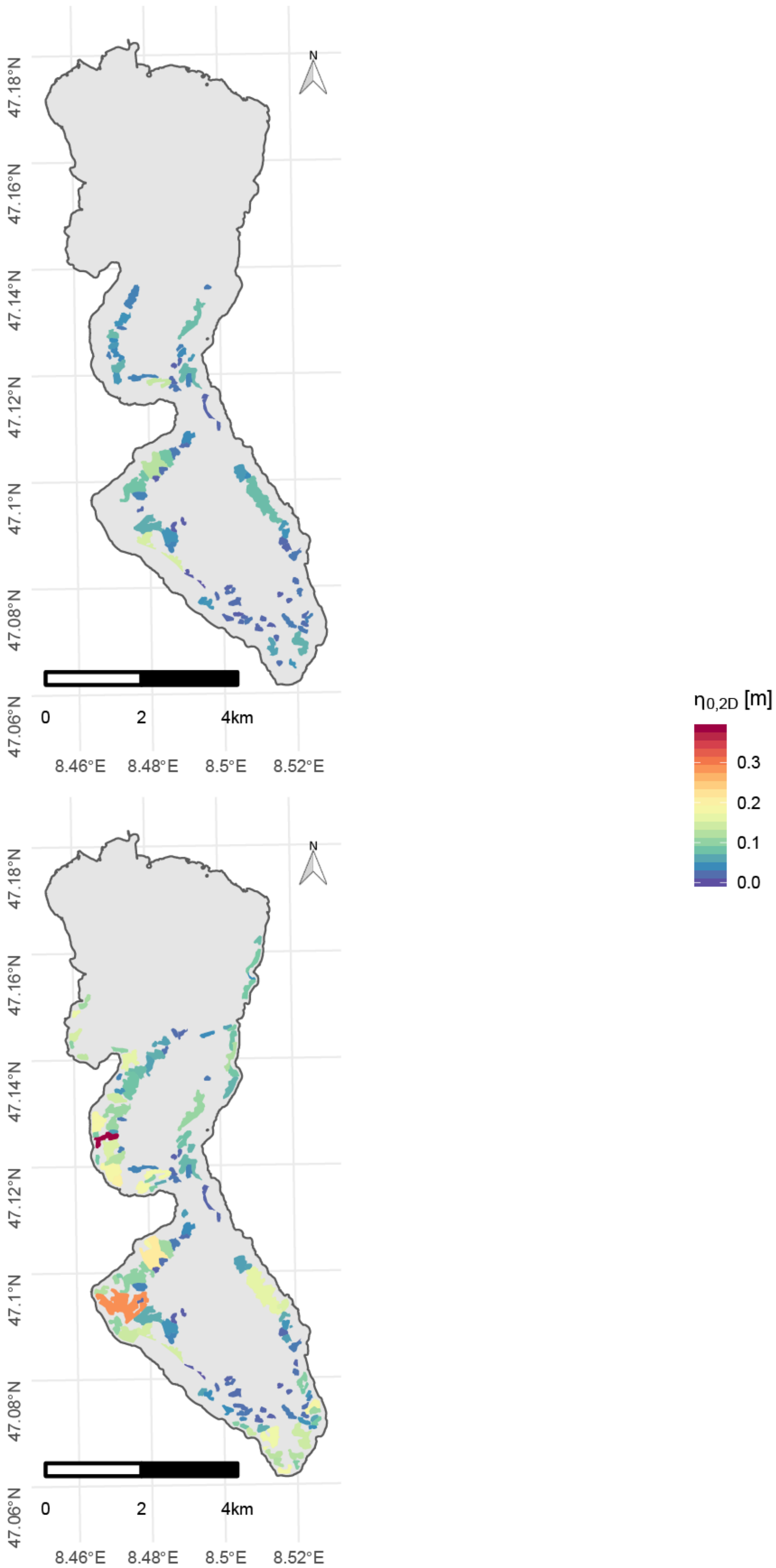

Fig. ESM.6. Location of forecasted landslides and characteristic tsunami amplitudes in Lake Zug for PGAs with RP=475 (a) and 2475 years (b)

5. Lake Walensee

Bathymetry

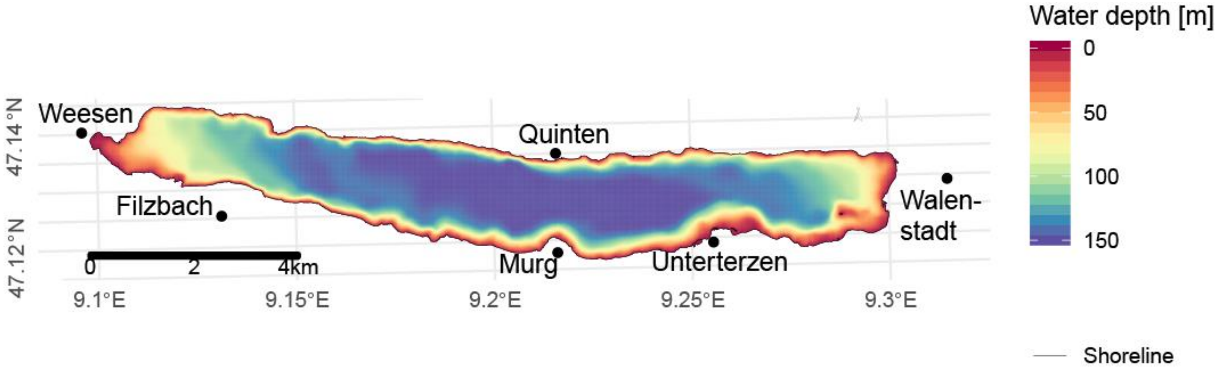

Fig. ESM.7. Bathymetry of Lake Walensee

Landslide characteristics

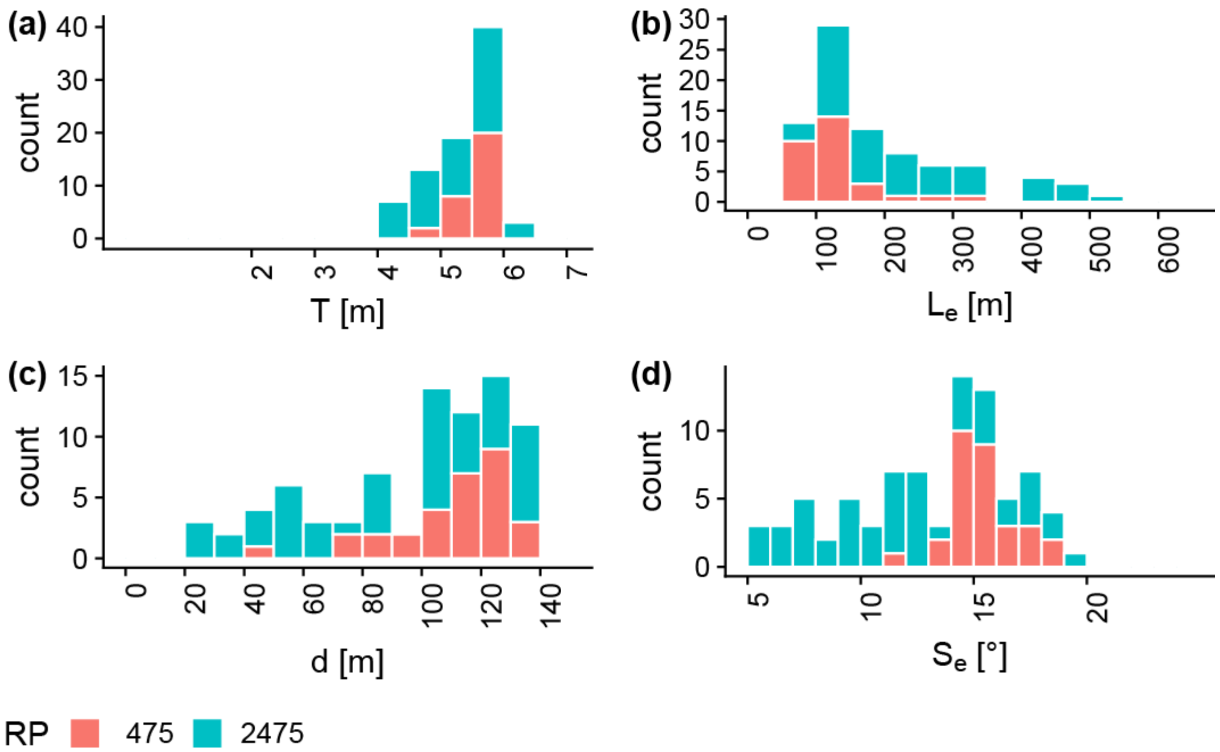

Fig. ESM.8. Characteristics of potential landslides forecasted for Lake Walensee for RP=475 (red) and 2475 years (cyan).

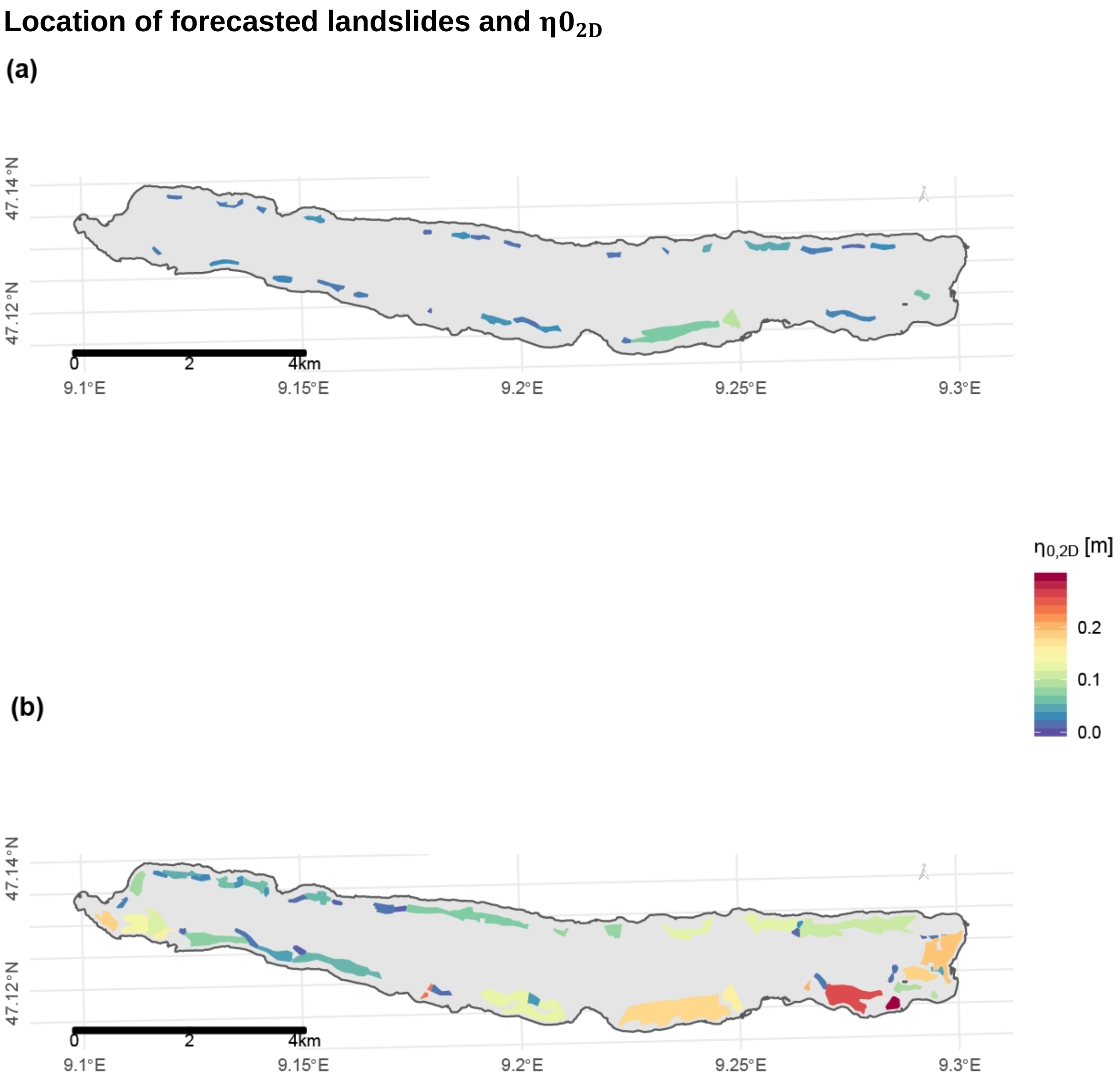

Fig. ESM.9. Location of forecasted landslides and characteristic tsunami amplitudes in Lake Walensee for PGAs with RP=475 (a) and 2475 years (b).

6. List of used R Libraries

Table ESM.3. *R libraries used in the workflow*

Library	Reference
cowplot	Wilke 2019
ggpubr	Kassambara 2019
ggrepel	Slowikowski 2019
ggsn	Santos Baquero 2019
knitr	Xie 2019
lwgeom	Pebesma 2019b
pracma	Borchers 2019
raster	Hijmans 2019
RColorBrewer	Neuwirth 2014
rgdal	Bivand et al. 2019
rgeos	Bivand and Rundel 2019
rmapshaper	Teucher and Russell 2018
RPyGeo	Brenning et al. 2018
scales	Wickham 2018
sf	Pebesma 2019a
Smoothr	Strimas-Mackey 2018
stringr	Wickham 2019
tidyverse	Wickham 2017
units	Pebesma et al. 2019

7. References

Bivand R, Keitt T, Rowlingson B (2019) Rgdal: Bindings for the 'geospatial' data abstraction library

Bivand R, Rundel C (2019) Rgeos: Interface to geometry engine - open source ('geos')

Borchers HW (2019) Pracma: Practical numerical math functions

Brenning A, Polakowski F, Becker M (2018) RPyGeo: ArcGIS geoprocessing via python

Hijmans RJ (2019) Raster: Geographic data analysis and modeling

Kassambara A (2019) Ggpubr: 'Ggplot2' based publication ready plots

Neuwirth E (2014) RColorBrewer: ColorBrewer palettes

Pebesma E (2019a) Sf: Simple features for r

Pebesma E (2019b) Lwgeom: Bindings to selected 'liblwgeom' functions for simple features

Pebesma E, Mailund T, Kalinowski T (2019) Units: Measurement units for r vectors

Santos Baquero O (2019) Ggsn: North symbols and scale bars for maps created with 'ggplot2' or 'ggmap'

Slowikowski K (2019) Ggrepel: Automatically position non-overlapping text labels with 'ggplot2'

Strasser M (2008) Quantifying Late Quaternary Natural Hazards in Swiss Lakes - Subaquatic Landslides, Slope Stability Assessments , Paleoseismic Reconstructions and Lake Outbursts. ETH Zurich; Schweizerische Geotechnische Kommision, Dissertation ETH Zurich

Strasser M, Stegmann S, Bussmann F et al (2007) Quantifying subaqueous slope stability during seismic shaking: Lake Lucerne as model for ocean margins. Marine Geology 240:77–97. doi: 10.1016/j.margeo.2007.02.016

Strimas-Mackey M (2018) Smoothr: Smooth and tidy spatial features

Strupler M, Danciu L, Hilbe M et al (2018) A subaqueous hazard map for earthquake-triggered landslides in Lake Zurich, Switzerland. Natural Hazards 90:51–78. doi: 10.1007/s11069-017-3032-y

Teucher A, Russell K (2018) Rmapshaper: Client for 'mapshaper' for 'geospatial' operations

Wickham H (2017) Tidyverse: Easily install and load the 'tidyverse'

Wickham H (2019) Stringr: Simple, consistent wrappers for common string operations

Wickham H (2018) Scales: Scale functions for visualization

Wiemer S, Danciu L, Edwards B et al (2016) Seismic Hazard Model 2015 for Switzerland. Swiss Seismological Service (SED) at ETH Zurich. 1–163. doi: 10.12686/a2

Wilke CO (2019) Cowplot: Streamlined plot theme and plot annotations for 'ggplot2'

Xie Y (2019) Knitr: A general-purpose package for dynamic report generation in r