NoeTALUS
Methods for producing rock fall hazard maps of different scales in Lower Austria

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Introduction

The assessment of hazard caused by rockfall is becoming increasingly important. Provinces, such as **Lower Austria** are required to take this into account in their spatial planning. The aim of the **research project "NoeTALUS"**, funded by Lower Austria, is to evaluate methods, applicable to different scales, which will enable the production of reliable rock fall hazard maps at a justifiable amount of human and financial resources.

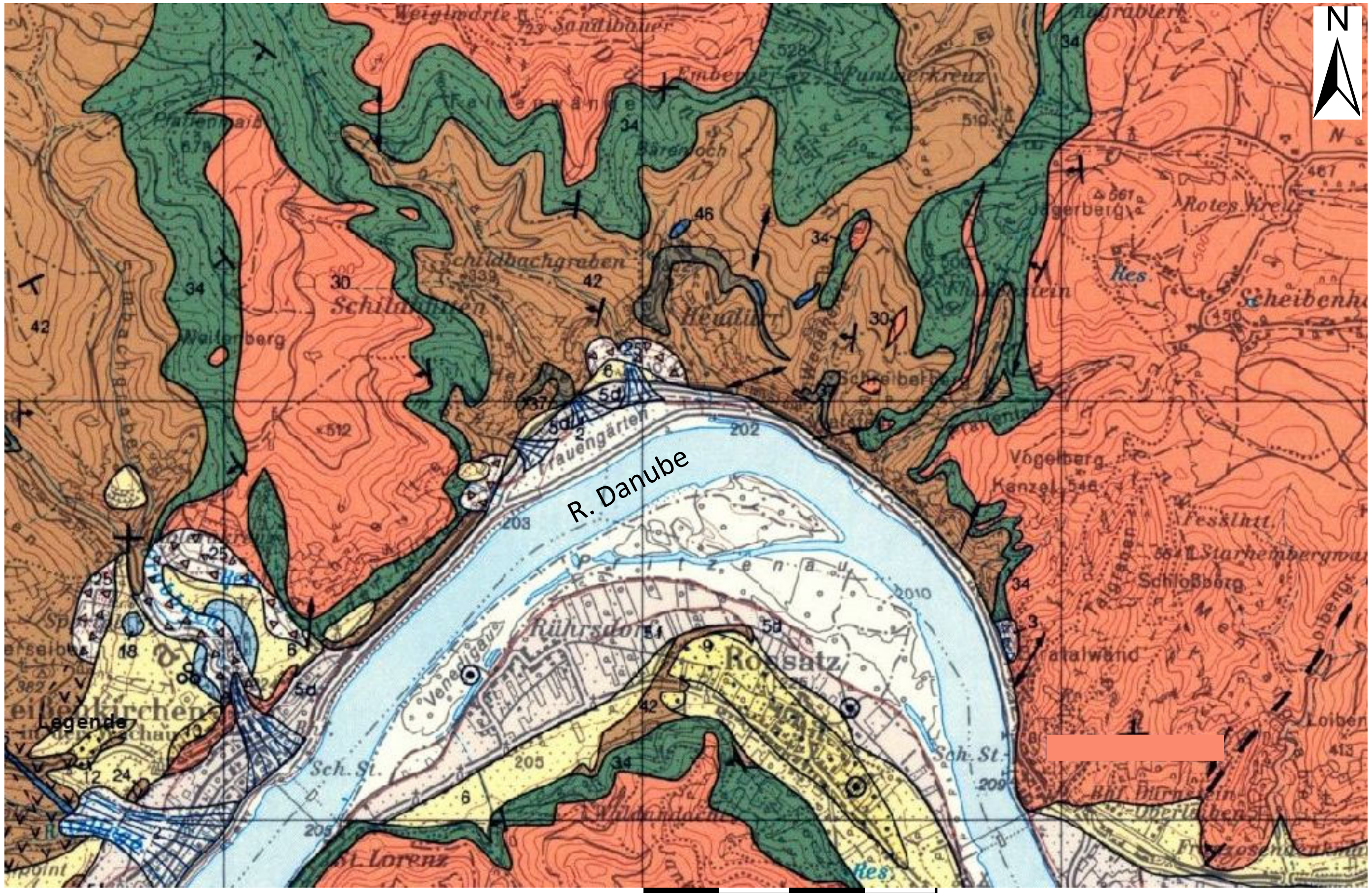
Rock fall hazard maps are being prepared for **two pilot areas** in Lower Austria: one area in the Wachau region along the Danube River west of Vienna, the other area in Waidhofen/Ybbs.

Method comparison: Identifying those methods that can contribute to the creation of reliable rock fall hazard maps, at a reasonable cost.

Recommendations for action: With regard to the preparation of rockfall hazard maps, recommendations for action should be given on the basis of the comparison of methods carried out.

Updateable maps: A common characteristic of maps is, that they change through time. Updateability of a map and how this could be enhanced, deserves some attention. In NoeTALUS project we are trying to address this issue by designing an interface, which will allow authorities and researchers to validate and improve the produced hazard maps with time.

Geological map of the Wachau study area 1:50.000



(Source: Matura et al., 1989, GBA)

0 500 1,000 Meters

Gföhler Gneiss | Migmatitamphibolite | Paragneiss

Potential rock fall source areas in paragneiss

The Wachau study area is located in the South-eastern part of the Moldanubian Zone of the Bohemian Massif. From an geomorphological point of view the study area is characterized by gently ascending slopes and soft hills.

The characteristic hard rock are the Gföhl gneiss (magmatic ortho-gneiss), granulite, ultramafic rocks as well as migmatic paragneiss and amphibolite. Tertiary sediments of the Molasse zone and quaternary sediments occur primarily in the large valley system of the Danube river.

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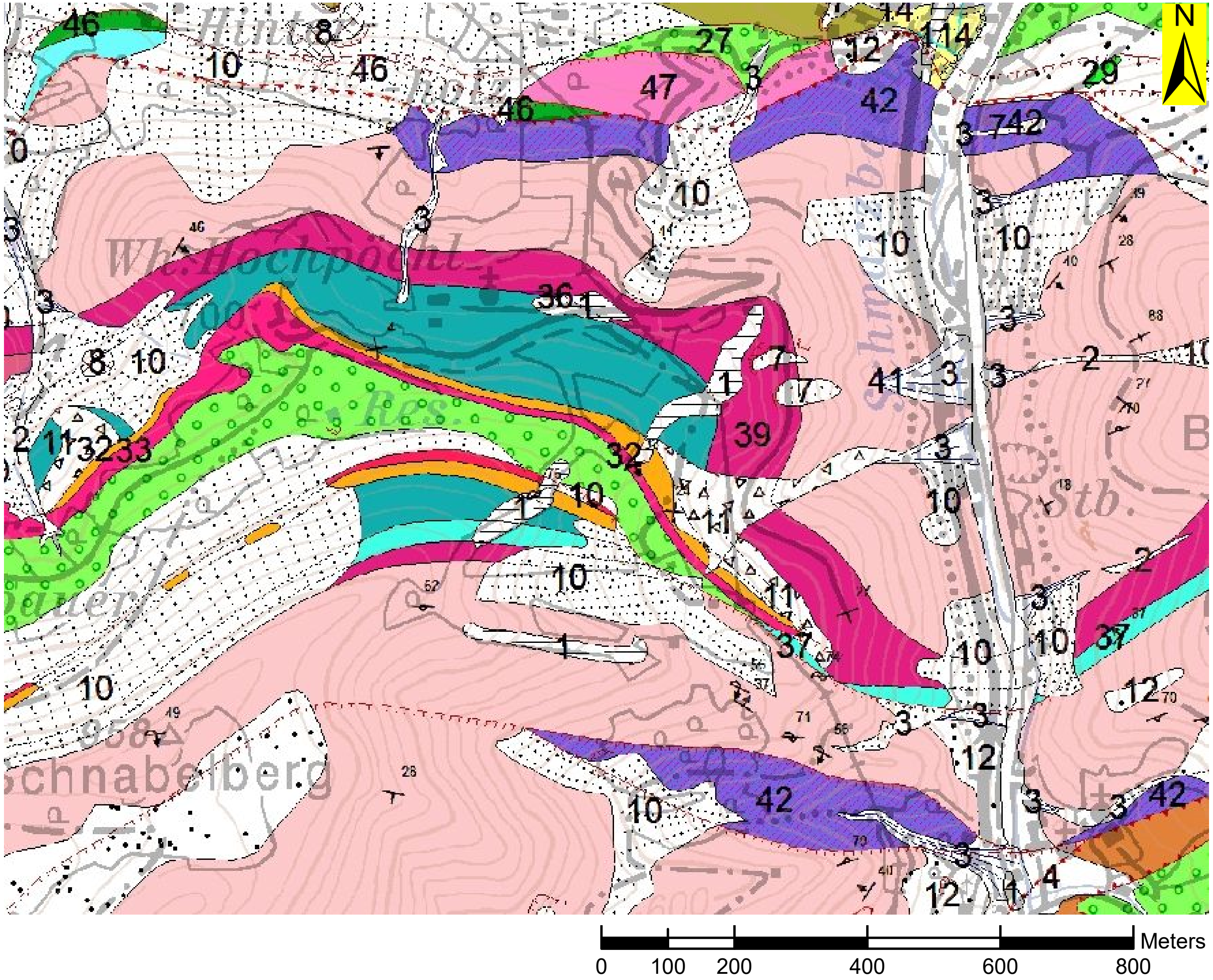
Section from the geological map of pilot area Waidhofen

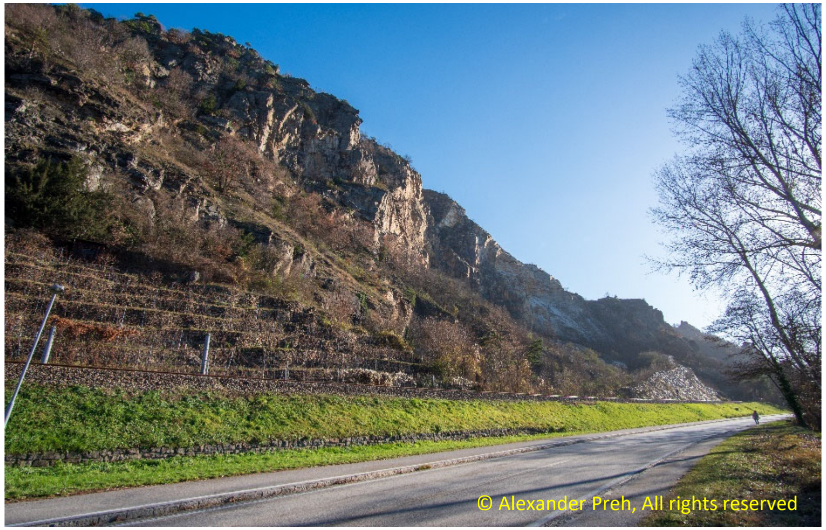


Legend

- 10, 11 — Talus, Talus slope
- 27 — Losenstein Formation (marl, Sandstone)
- 29 — Schrambach Formation
- 32 — Micritc ooidal limestone
- 33 — Vilser limestone & red limestone
- 35 — Allgäu Formation (mottled limestone
- 36 — Schattwald Formation (Mudstone)
- 37 — Puchenstubener Schichten
- 39 — Kössen Formation (marly limestone)
- 41 — Hauptdolomit (mostly dolomitic)
- 42 — Opponitzer Schichten (Rauhwackes)
- 47 — Light grey, grey-beige limestone

The North-western part is predominantly characterized by gentle hills and soft morphological forms, which reflect the dominant character of the soft, siliciclastic dominated flysch sediments.

In the South-eastern part of the study area, the relief changes to higher and steeper, but still relatively moderate, pre-Alpine terrain, which is due to the change to the carbonate-dominated rocks of the eastern Northern Limestone Alps.



The picture on the left shows a typical situation in the Wachau area. Steep rock faces are a risk to the main road, the cycle path and the local railway.

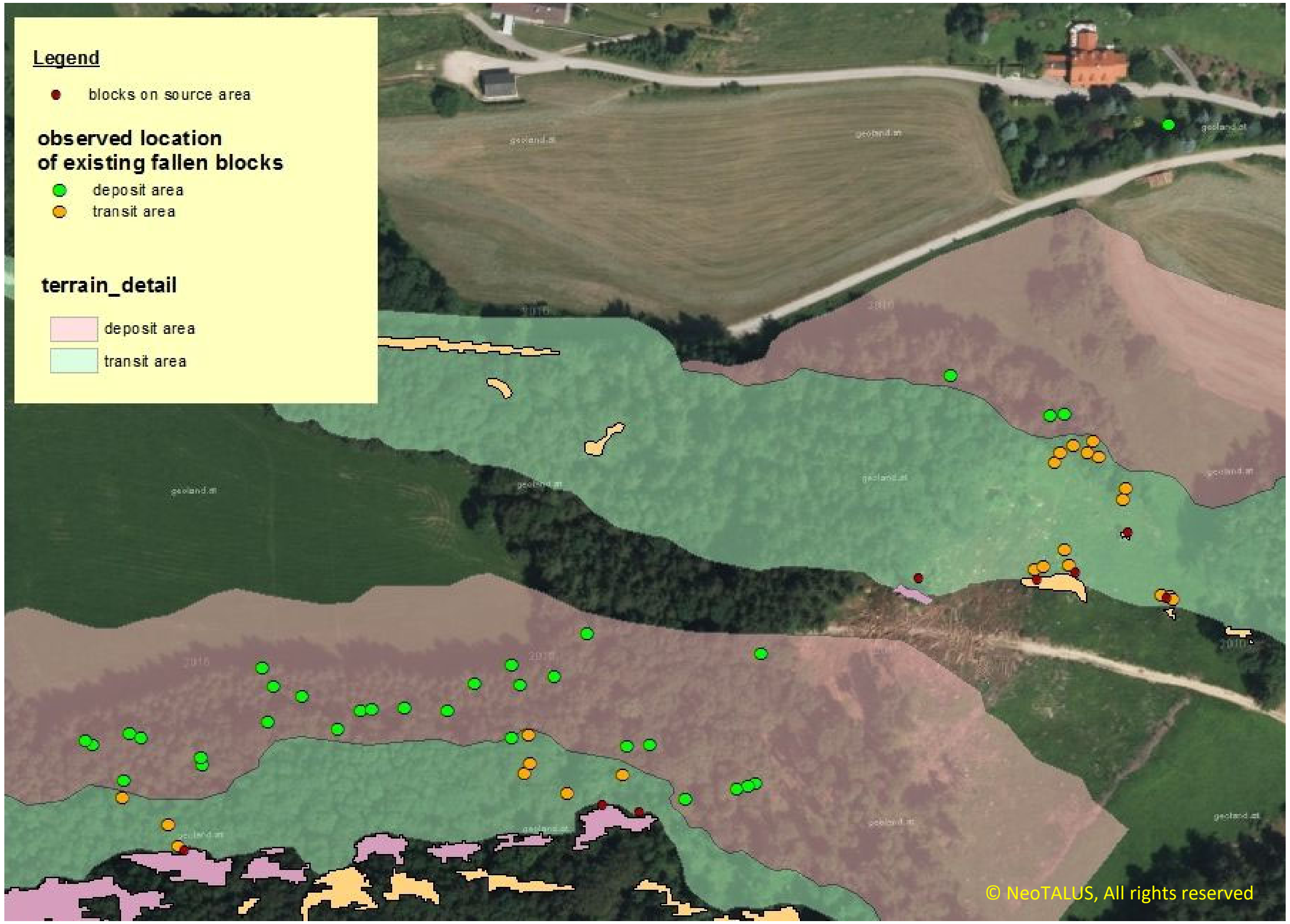
The pictures on the right show a rockfall event in the area of Waidhofen. A single block detached itself from an outcropping rock formation and moved about 100m along a slightly inclined slope until it was stopped by a single row of trees.

In order to answer questions regarding the required quality and effort in collecting data relevant to numerical modelling, investigations under two topographic scales are being conducted. **The entire project area is processed at a regional scale (M ≤ 1:10.000).** Additionally, **ten selected domains** within the project area are investigated **at a slope scale (M ≥ 1:5.000).**

Two different simulation models, Rockyfor3D and WURF (Fleris & Preh 2016), are used to model rock fall spreading and magnitude. Both models differ in their calculation approach with regard to surface-roughness, energy-damping and rock-fragmentation.

Collected data through **field mapping**, through **NÖ ATLAS GIS** infrastructure but also from a number of newly acquired **TLS, UAV-LS** and **photogrammetric** sets, consist the backbone of the project.

Methods: Example of Field Mapping in Waidhofen



Mapped blocks in the source, transit and in the deposit area

Block on source area

Blocks on deposit area

Strategy for conducting numerical experiments

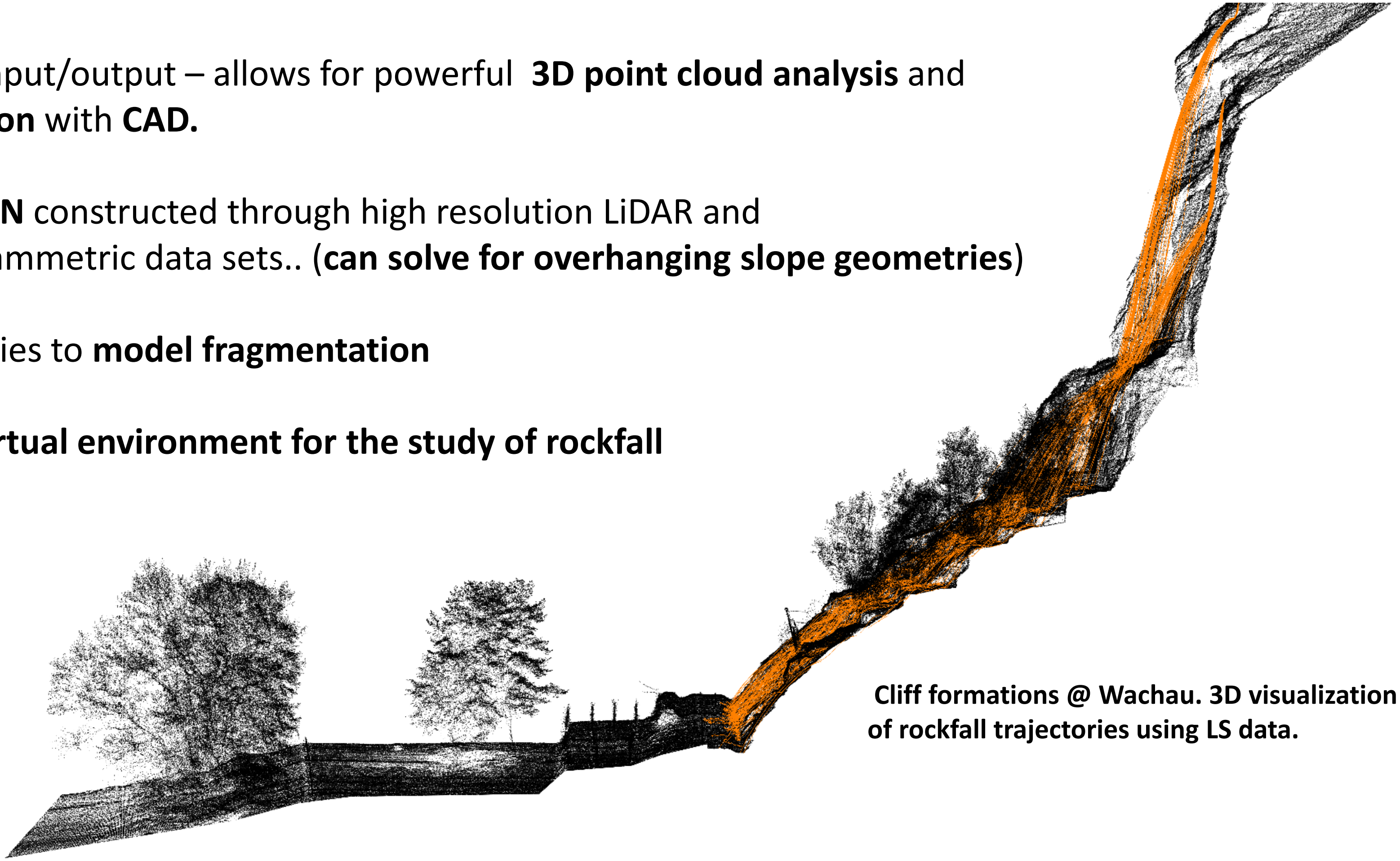
We **model rockfall in 3D** using two different **hybrid lumped mass codes with stochastic elements** in the following sense: Use of **Rockyfor3D** for 'exploration-regional' models since it is an established rockfall code, backed up by a certain methodology for data collection and interpretation of model parameter space. Finally, it is **fast and light (raster)** with the possibility to model **forest interaction.**

Then we can focus on areas of particular interest and follow more rigorous modelling approaches using **WURF**. The later is a **vector based**, **full 3D rockfall code,** exploiting the ideas of **stochastic surface-roughness** and the use of **hyperbolic restitution factors**. **Fragmentation** can also be modelled (experimental stage).

A little bit more about WURF (Fleris & Preh 2016)…

- **Vector** input/output – allows for powerful **3D point cloud analysis** and **interaction** with **CAD.**
- Use of **TIN** constructed through high resolution LiDAR and photogrammetric data sets.. (**can solve for overhanging slope geometries**)
- Possibilities to **model fragmentation**

.. **forms a virtual environment for the study of rockfall**



Cliff formations @ Wachau. 3D visualization of rockfall trajectories using LS data.

Design block vs block size distribution: a critical approach to different guidelines.

Guideline **ONR 24810:2017** “Technical Protection against Rock Fall” provides guidance to assess rock fall hazard (at object scale) by determining a so-called **design block size**.

The design block size is derived from a block size distribution and event frequency, both of which are **uncertain**.

Comparing the design approaches of ONR 24810 to Eurocode 7 (EC 7):

- Properties - *Partial safety factors*
- Input parameters
- Characteristic values of actions F_k
- “Representative” values F_{rep}
- Design values F_d, R_d - *Partial safety factors*

The main difference in the design approach of ONR 24810 compared to EC 7 is, that **ONR 24810 reduces properties** (input parameters) at the beginning of the design approach (95th, 96th, 97th or 98th volume percentile of the block size distribution, depending on event frequency).

Reducing properties and disregarding all small blocks results in **unrealistic values of actions**. Valuable information of maximum energy levels and bounce heights is lost. This is why a **block size distribution** is used for our rock fall simulations, rather than a single block size.

$$H(E,x) = \lambda_f \times P_p(E,x)$$

Rockfall hazard (**H(E, x)**) at a point, x, for a given **kinetic energy E,** is given by the product of the **rock-mass-failure mean probability** or **frequency**, $\boldsymbol{\lambda_f}$, and the **probability of propagation** up to x, $\boldsymbol{P_p}$

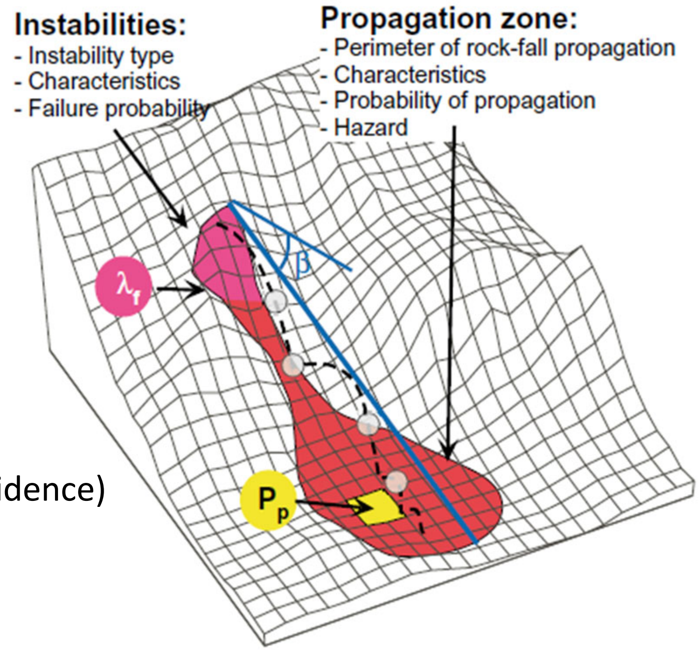
Difficult to derive:

- frequency – magnitude relationships
- possible release positions
- representative block size to be used in simulations

Problematic landforms (*i.e.* wine-terraces @ Wachau)

Model calibration (*i.e.* effects of DTM resolution, limited field evidence)

Experimentation vs Norms/Guidelines



Rockfall hazard definition and supporting figure after Jaboyedoff et al. 2005

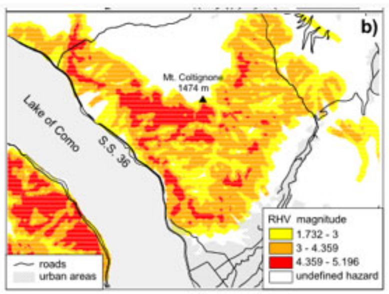
Definition and classification of rockfall hazard – approaches

Rockfall hazard vector (Crosta and Agliardi, 2002)

- Rock fall hazard Index

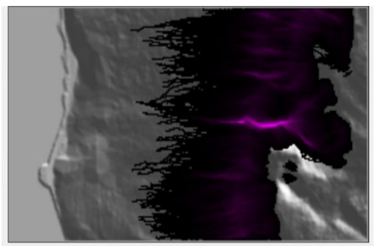
$$RHV = \begin{pmatrix} c \\ k \\ h \end{pmatrix},$$

$$|RHV| = \sqrt{c^2 + k^2 + h^2}.$$



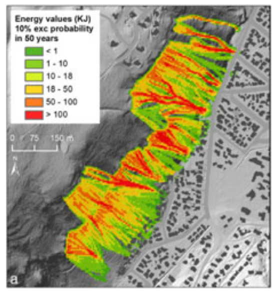
Reach probability and deposit area (Dorren, 2011)

- (Nr_passages*100)/(Nr_simulations_per_source_cell*Nrsourcecells) [%]
- Blocks stopped per cell



A probabilistic approach for landslide hazard analysis (Lari et al., 2014)

- Probability of exceedance
- Run-out frequency
- Intensity



Swiss approach: mean propability-intensity diagram (Raetzo et al., 2016)

- Traffic light scheme

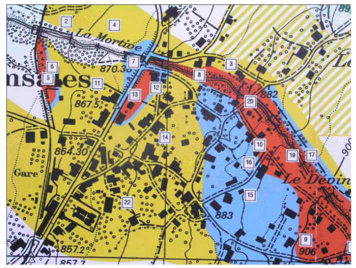
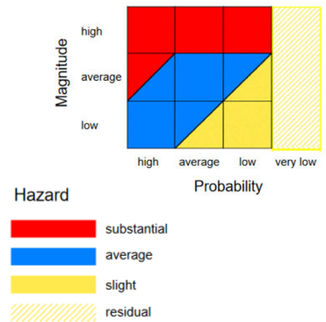
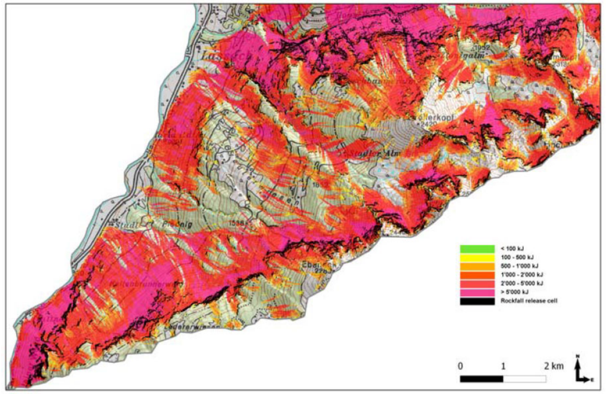


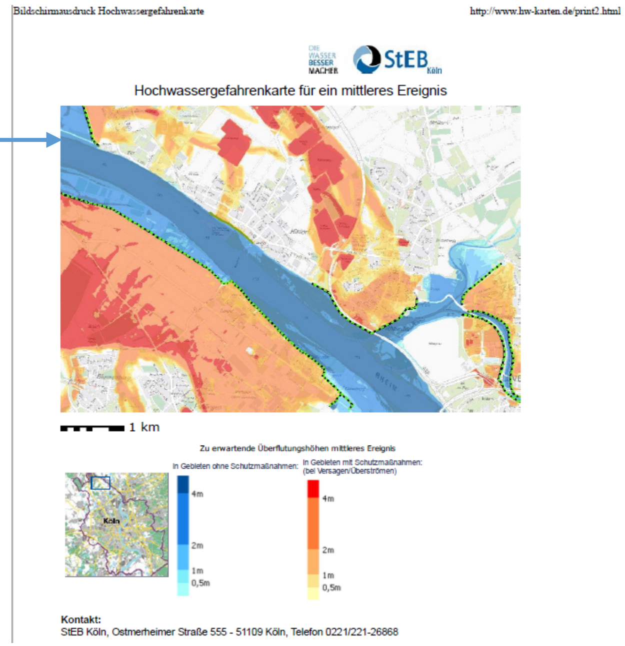
Figure 7: Example cutout of a hazard map for flooding.



- Design
  - Colours → meaning and message
  - Number of classes
- Worst case scenarios
- Consideration of existing protection systems
- Combination of worst case & protection overlay

Dorren L.K.A. et al. 2011





Bell R et al. (2013)

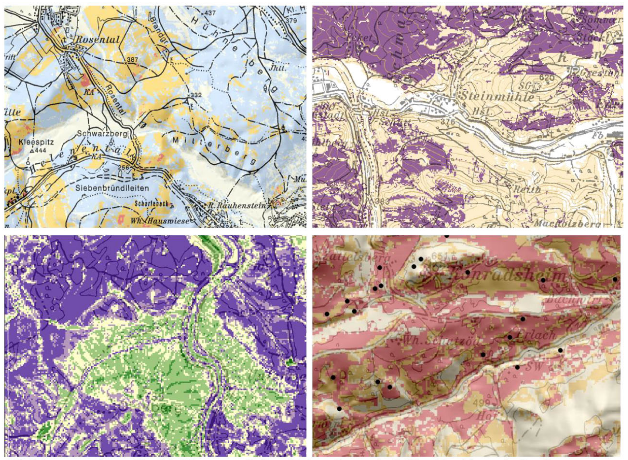
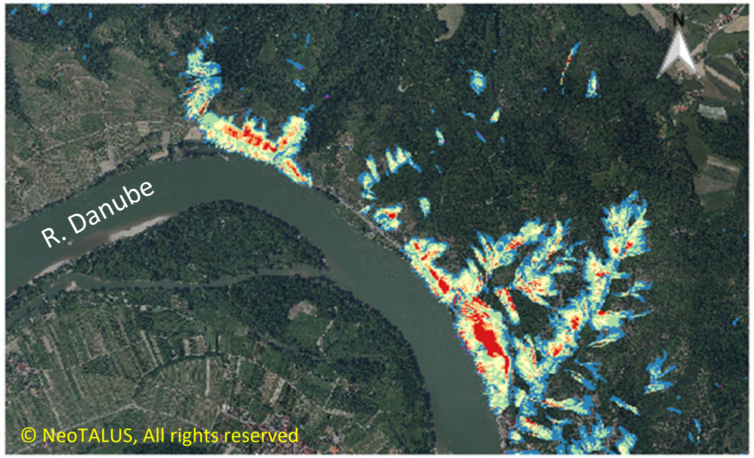


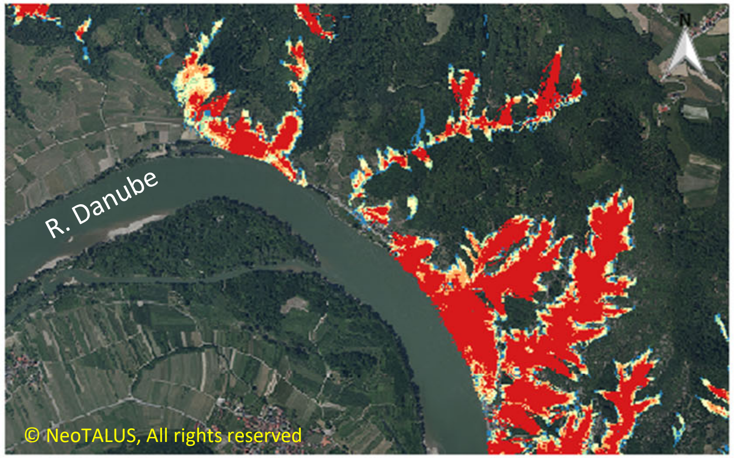
Abb. 9.2: *Ausgewählte Beispiele von verschiedenen Farbgestaltungen der Gefahrenhinweiskarten für Rutschungen (Quelle ÖK und DGM: Land Niederösterreich)*

Example of results: Exploration models at a regional scale @ Wachau

WURF



RF3D

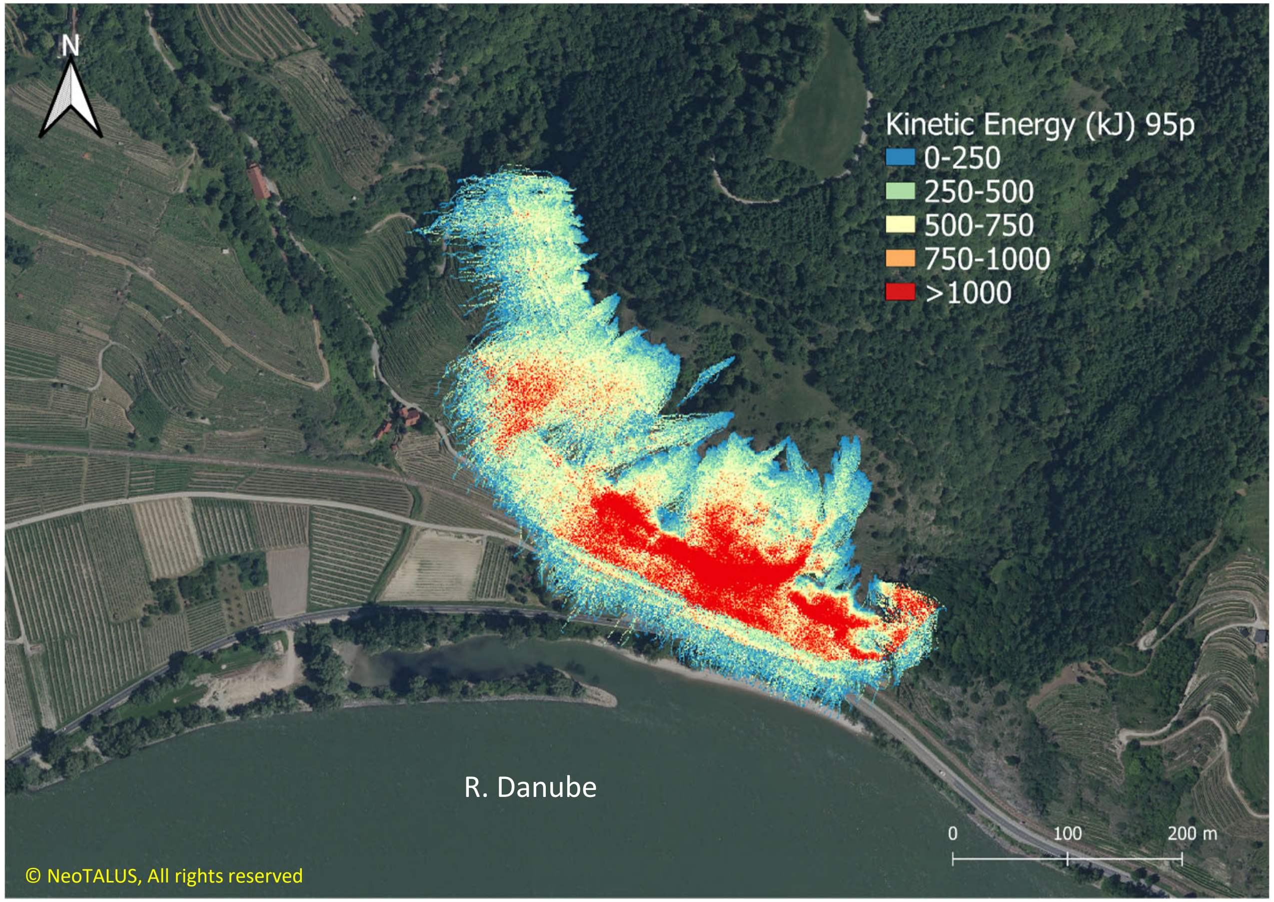


500 0 500 1000 1500 2000 m

Kinetic Energy p98 [kJ]

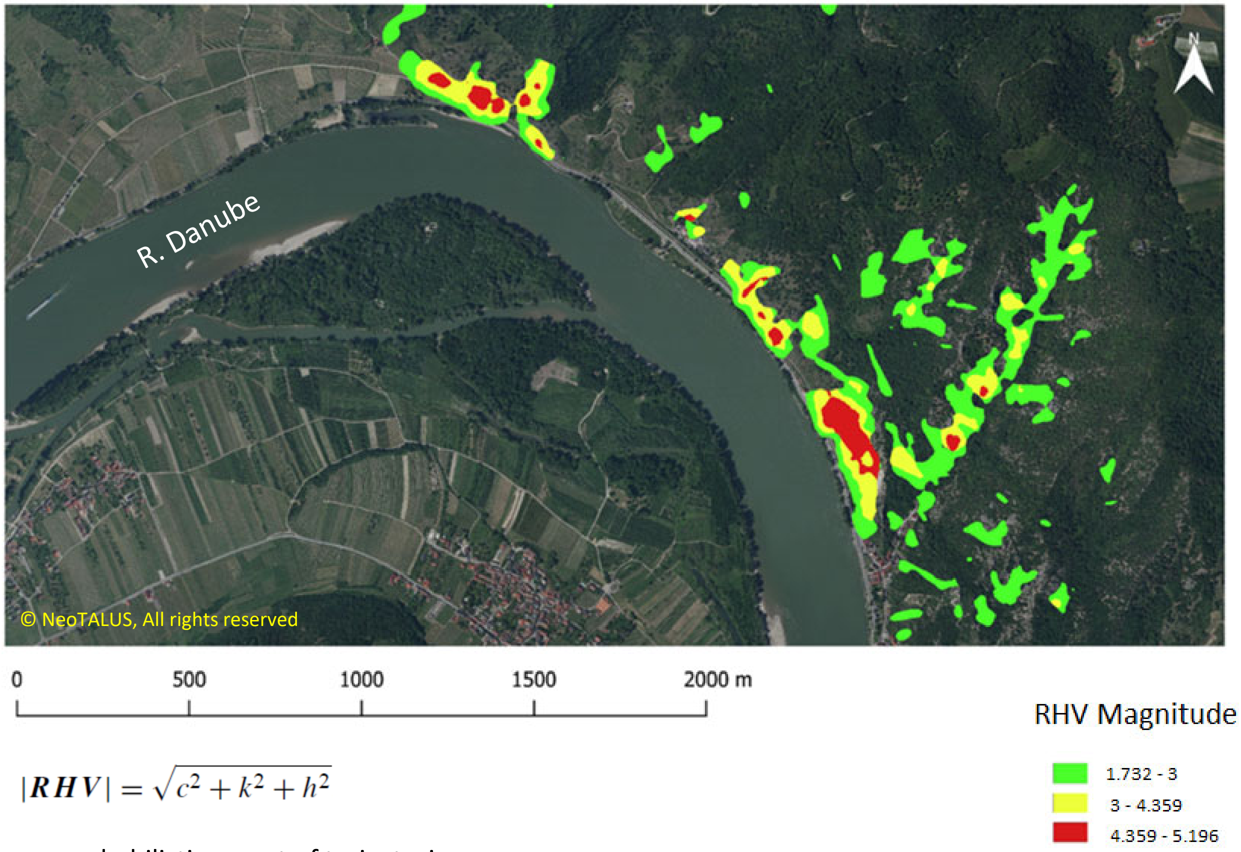
- 0 - 300
- 300 - 600
- 600 - 900
- 900 - 1200
- > 1200

Example of results



Detailed rockfall modelling at a slope scale using WURF. @ Wachau

Example of hazard zonation using Rockfall Hazard Vector (RHV)



$$|\boldsymbol{RHV}| = \sqrt{c^2 + k^2 + h^2}$$

c = probabilistic, count of trajectories
k= total kinetic energy
h = jumping height

NoeTALUS is an ongoing research project.
So far the following conclusions can be given:

- Estimating event frequency is one of the most difficult tasks in the preparation of hazard maps. Even with full support of the Federal State of Lower Austria, it was not possible to determine the probabilities of occurrence on the basis of archive research. Available archives do not keep records with sufficient quality. Therefore, it was decided to create hazard maps based on propagation propabilities and to neglect the propability of occurrence.

- The use of Rockyfor3D for regional models (M ≤ 1:10.000) and of WURF for the models of the slope scale (M ≥ 1:5.000) has proven to be an accepted method, especially for the pilot area in the Wachau with its steep and high rock cliffs.

- Most directives (also the Austrian guideline) and rockfall programs use the concept of a design block to calculate actions (kinetic energy, bouncing height). The choice of a design block requires an estimation of event frequency and detailed mapping. This is particularly difficult at regional scale. Therefore, we have decided to use a block size distribution instead.

NoeTALUS is an ongoing research project.
So far the following conclusions can be given:

- A first recommendation for action derived from this is to record rockfall activity in Lower Austria in a standardised way in the future and to continuously improve the currently still rough hazard maps (in annual intervals) with the help of this new data. For this reason, the procedures for generating hazard maps in the NoeTALUS-project are designed in such a way, that future updates of the maps can be carried out easily using automatized processes.

- Modelling dynamic fragmentation during rockfall remains an extremely difficult task. However, the phenomenon itself can have a dramatic effect on rockfall behaviour. Totally neglecting fragmentation during simulations of rockfall can lead to results of limited value, concerning a realistic calculation of rockfall hazard. Therefore, a module was implemented in WURF to consider fragmentation stochastically. The calibration of this approach is done by means of drop tests.

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