Space-Time Landslide Predictive Modelling

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Assumptions

- Any predictive method can be evaluated by studying the distribution of residuals between the observed data and its modeled estimates.
- This is true for continuous properties but also for discrete data such as landslide presence/absences (susceptibility) and/or landslide counts (intensity).
- If residuals exhibit a spatially-structured or temporally-structured distribution, this may indicate that the covariate set one has chosen may not capture some space-time dependence in the data, acting at the latent level because of some missing covariates.
- These missing covariates and associated effects can then be captured and re-integrated in the predictive method, improving the estimates for each model component and ultimately the overall performance itself.

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Landslide Intensity concept (counts instead of 0/1)

- A general landslide intensity model can be formulated as follows:

$$\log\{\lambda(s)\} = \beta_0 + \sum_{j=1}^{J} \beta_j z_j(s) + f_1 + f_2 + \ldots + f_k \quad (1)$$

- where $\lambda(s)$ is the intensity function (expressed in log scale) estimated at location s, β_0 is the global intercept, the following term is the sum of the products between regression coefficients and the respective linear covariates, and finally the f terms are a number of nonlinear functions one can add to the model.
- being the susceptibility a simpler case of the intensity, we can always convert from the first to the second as follows:

$$Susceptibility = 1 - e^{-\lambda(s)} \quad (2)$$

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Latent spatial effect

- For a study area partitioned into Slope Units, one can compute the residuals over space and use a Besag's classical conditionally autoregressive (CAR; Besag, 1975; Rue & Held, 2005) model to smooth the residuals across adjacent mapping units.

Julian Besag (1975) Statistical analysis of non-lattice data.The statistician, pages 179–195.
Havard Rue and Leonhard Held (2005) Gaussian Markov random fields: theory and applications. CRC Press.

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Latent temporal effect

- For a study area where a multi-temporal landslide inventory is available, one can compute the residuals over time and use a Autoregressive model (AR; Shumway and Stoffer, 2011) typical of time-series analyses to smooth the residuals across subsequent temporal replicates, for each of the available mapping units.

Robert H. Shumway and David S. Stoffer (2011) Time Series Analysis and Its Applications. New York: Springer.

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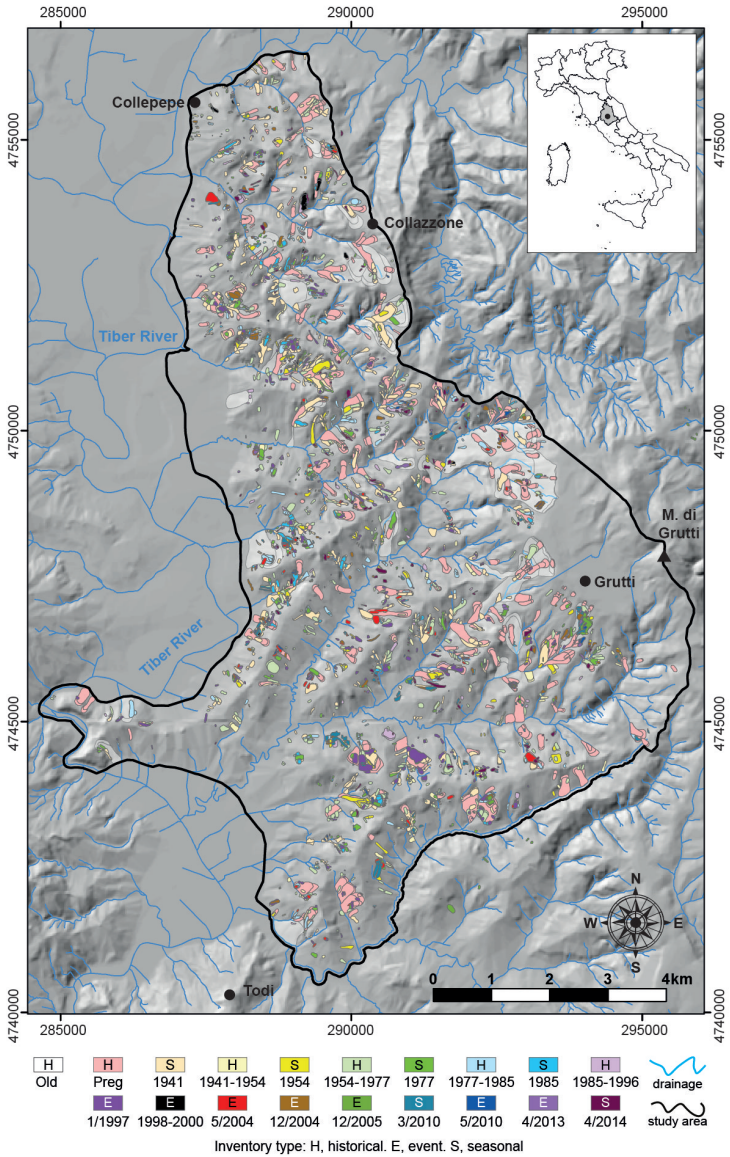
Study area and problem statement



- The area of Collazzone has a centennial history of documented landslides and represents a "gold standard" in the geomorphological literature.
- Can we build proper space-time predictive intensity models?
- To which extent the traditionally disregarded residual components in space and time can improve our prediction and why?

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Baseline and extensions in space, time and space-time

- We opt to model landslide intensity in 5 phases of increasing complexity (for an area partitioned into 889 slope units and 6 time intervals where landslide counts have been aggregated in a 15 years window).
- Mod1: A simple baseline whose structure is typically used in landslide susceptibility studies.
- Mod2: Mod1 + with a multiple intercept per time interval.
- Mod3: Mod2 + latent spatial effects, separately per time interval.
- Mod4: Mod2 + latent temporal effects, separately per slope unit.
- Mod5: Mod2 + latent spatial and temporal effect together.

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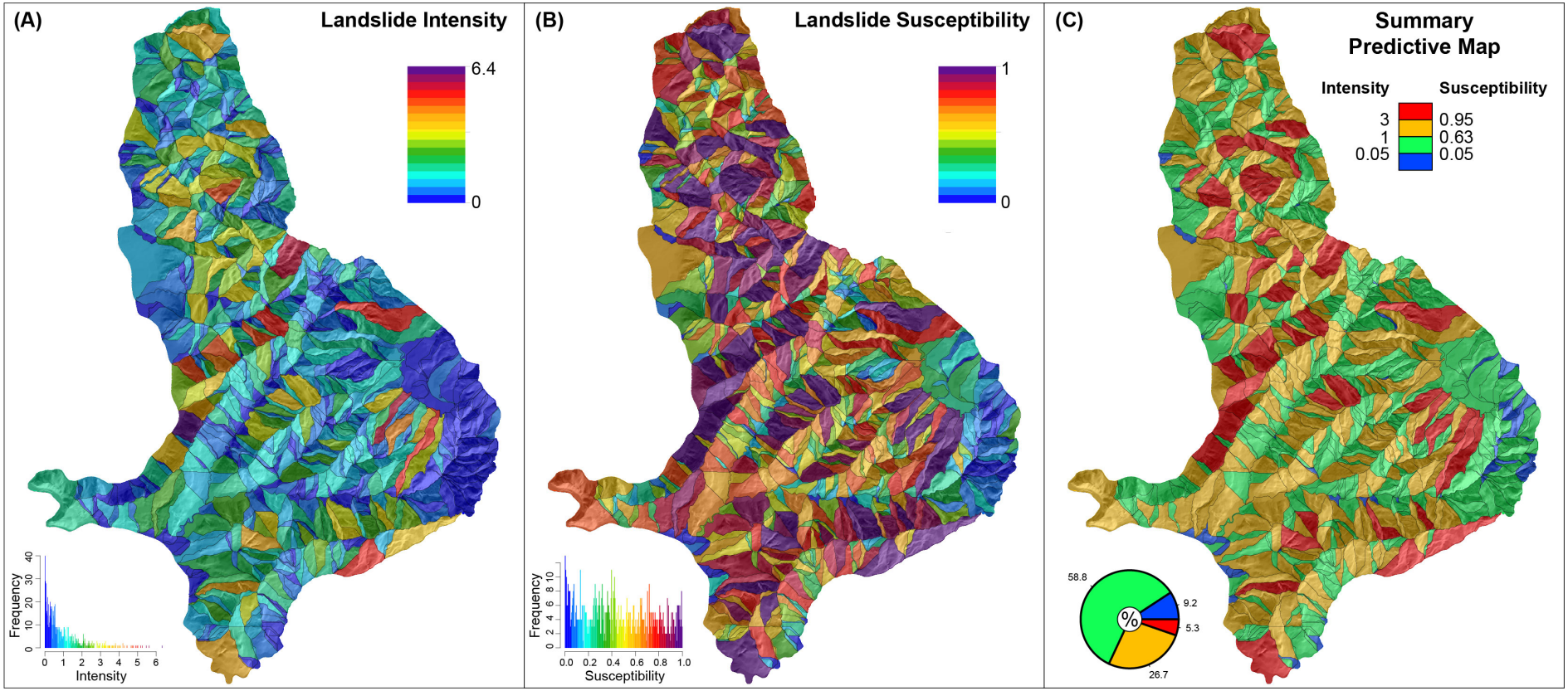
Baseline reference



- Summary of the baseline intensity computed via the common generalized linear model approach used in the geomorphological literature.

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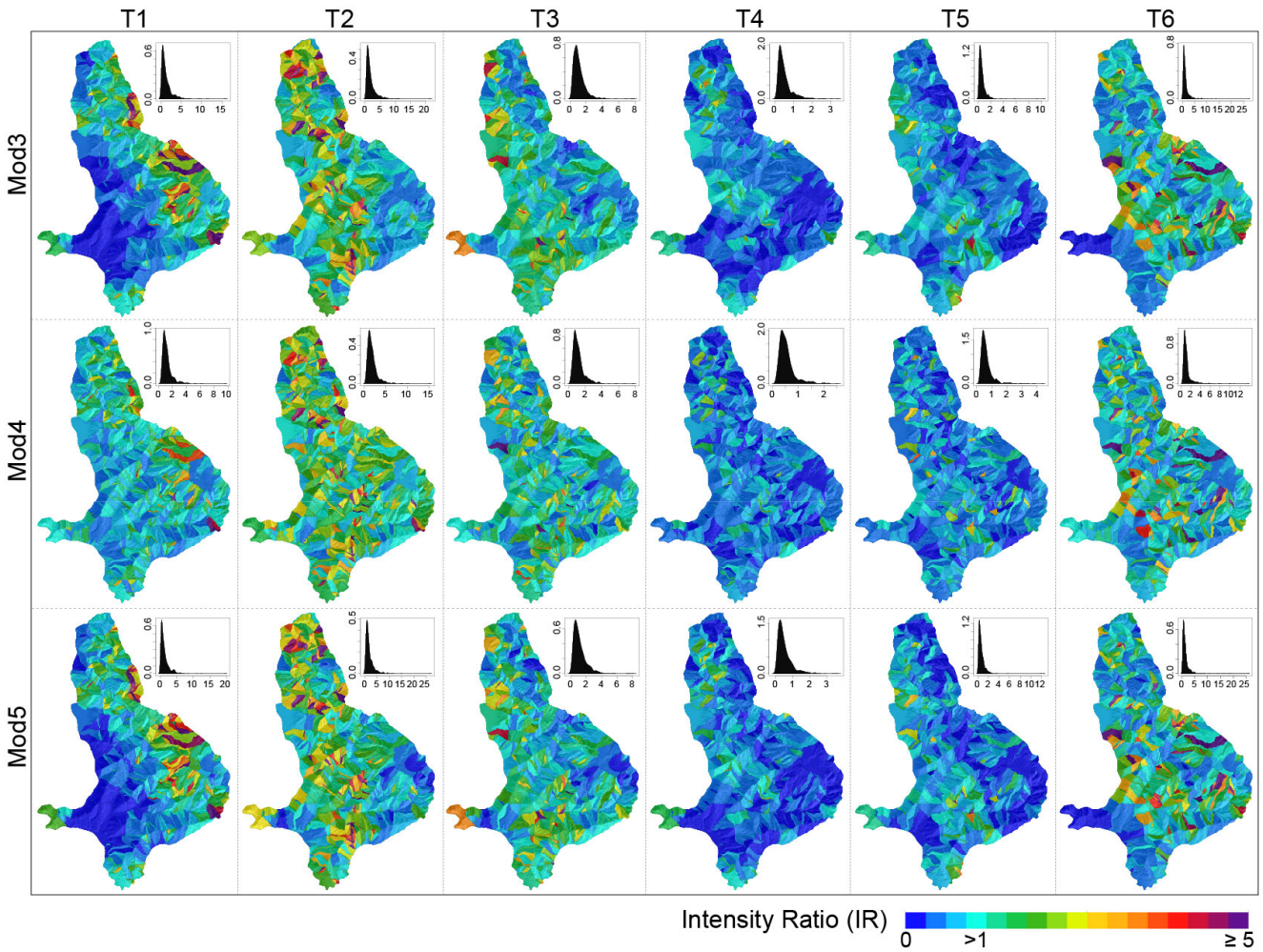
Latent fields for the intensity case



- The IR is the factor by which one should multiply the baseline intensity to properly account for latent space, time and space-time dependencies.

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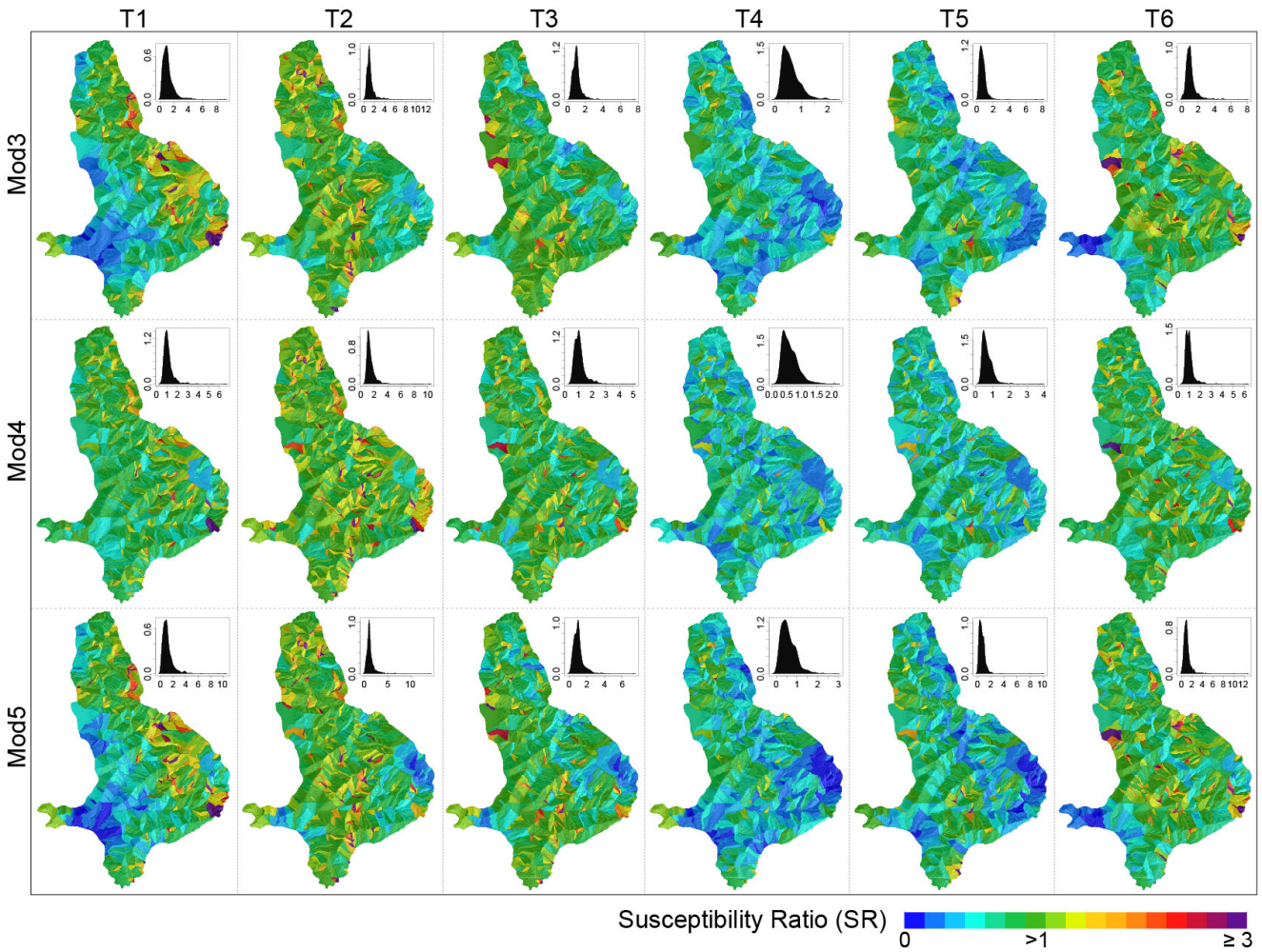
Latent fields for the susceptibility case



- The IR is the factor by which one should multiply the baseline susceptibility to properly account for latent space, time and space-time dependencies.

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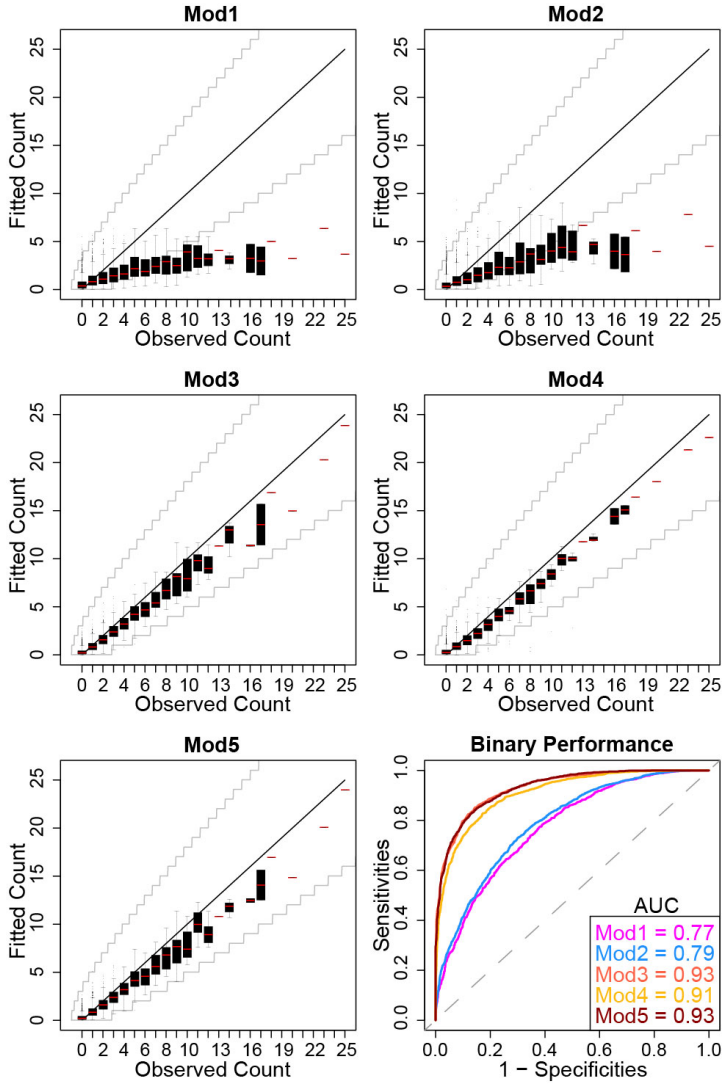
Goodness of fit summary



- The simplicity of the baseline intensity (Mod1) and its extension with a multiple intercept over time (Mod2) is unable to explain the spatio-temporal distribution of the number of landslides per slope units.
- This is possible by capturing unexplained effects acting at the latent level.
- The same consideration is valid for the simpler susceptibility case although the baseline shows more acceptable goodness of fit.

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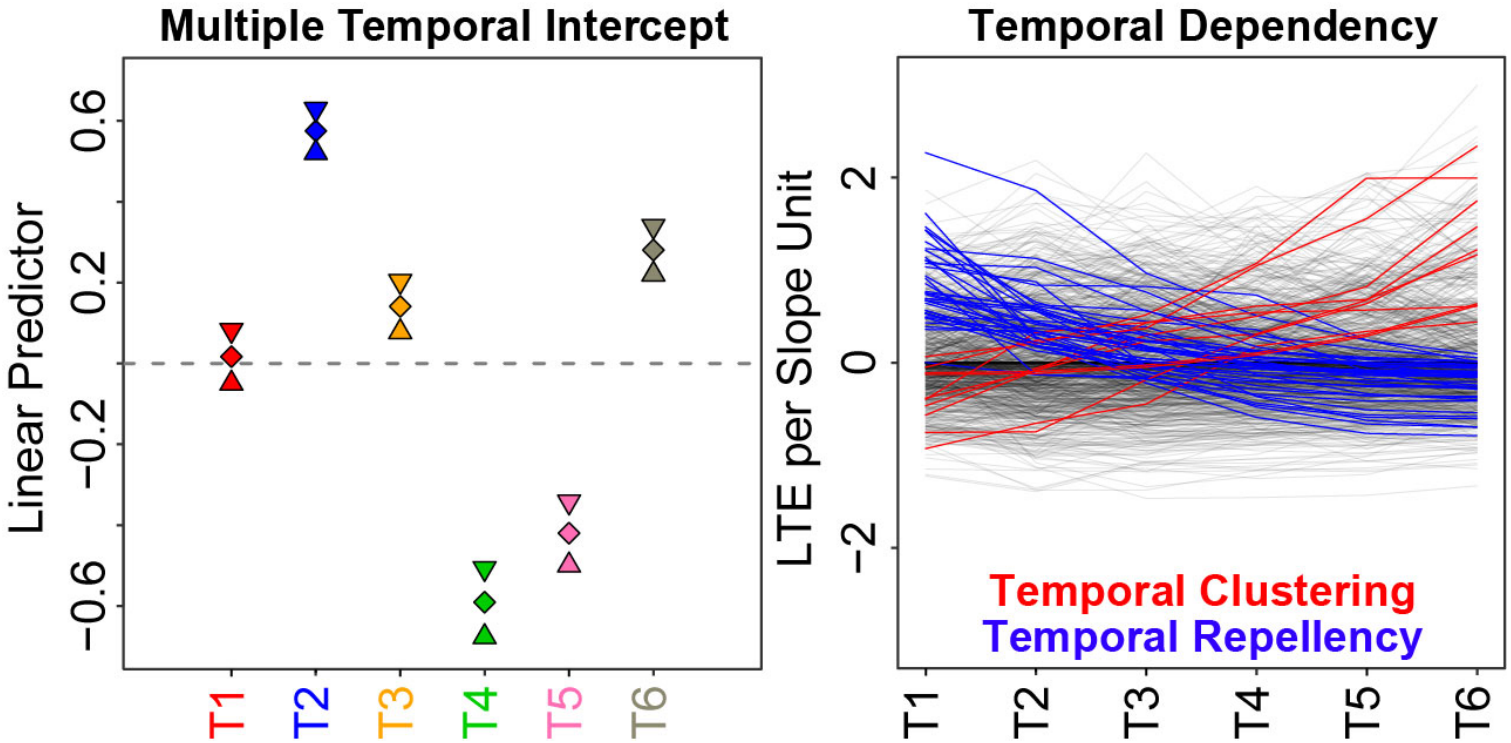
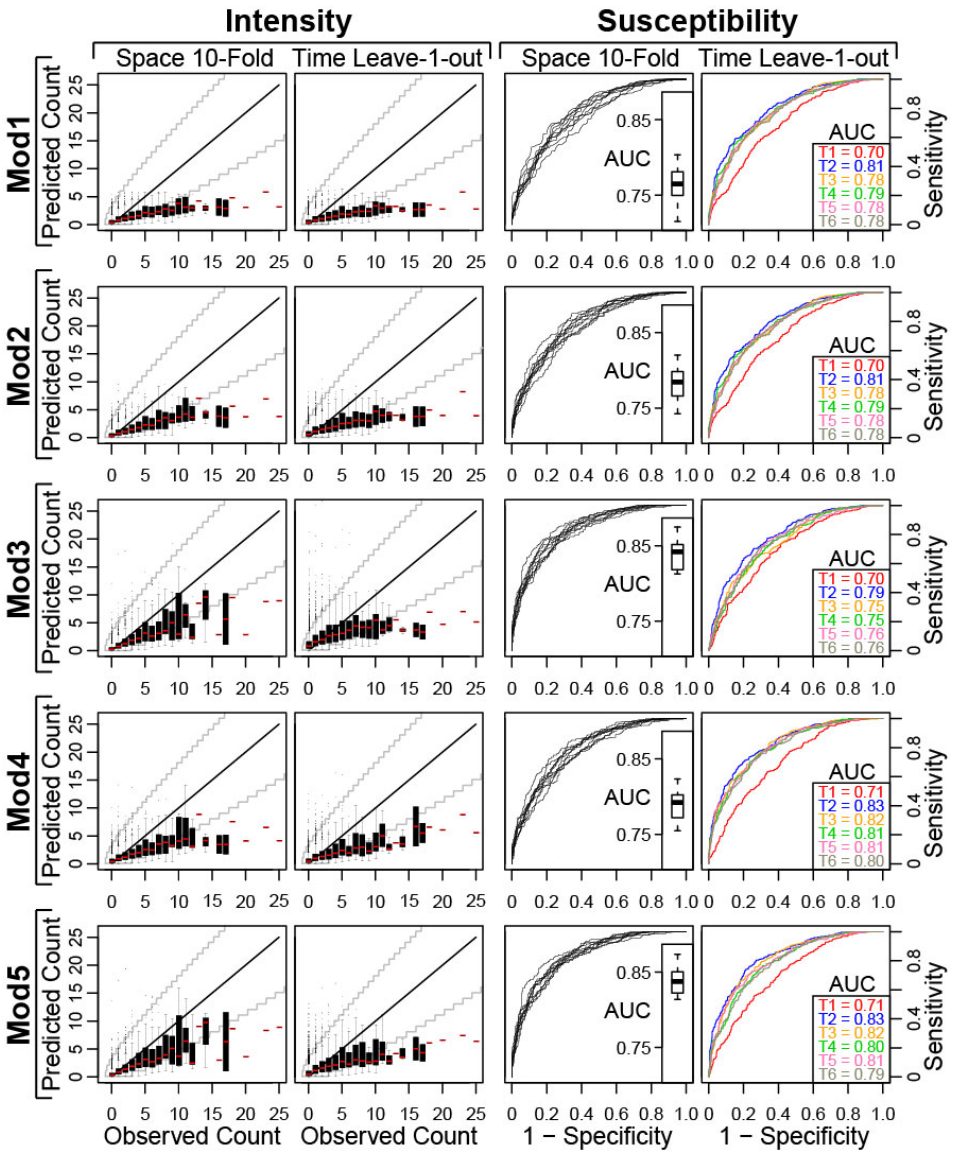
Temporal effect summary



- The latent temporal dimension is dissected in a general signal per time step (left) and a slope unit specific signal per time step (right). Few slope units exhibit a coherent clustering or repellency behavior, whereas the majority of are fluctuating per 15y interval.

Predictive skill summary



- The first two columns report the agreement between observed and predicted landslide counts. The second two columns do the same for the susceptibility case.
- Notably that two validation schemes have been tested.
- The traditional GLM (Mod1) and its simple extension (Mod2) are not sufficient.

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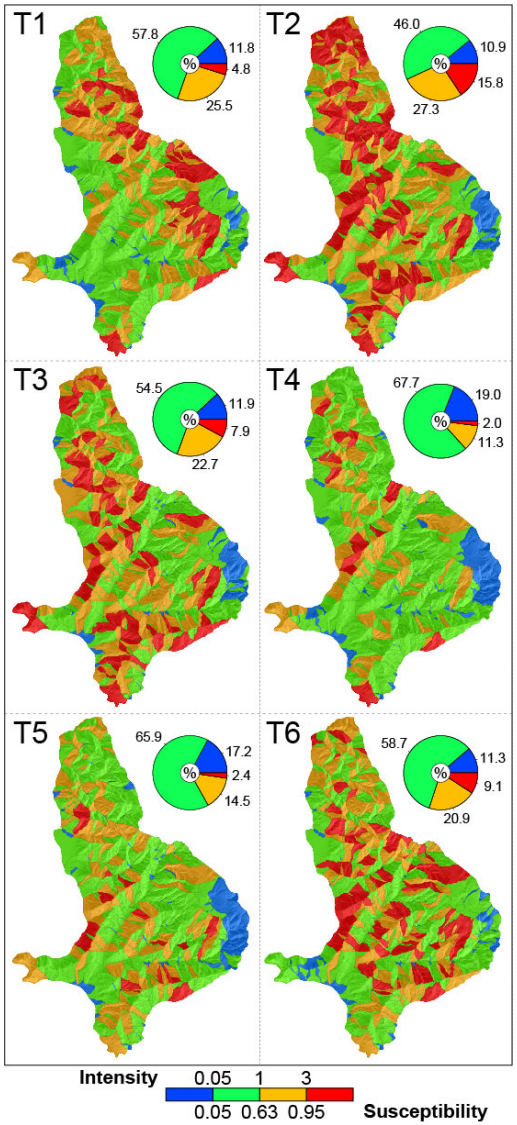
Predictive mapping summary



- The existing link between intensity and susceptibility allows for the creation of a jointly classified map.
- The classification scheme is very different from other proposition in the literature. Here we create two extreme classes where the model is 95% certain of not having or having a landslides. Then two intermediate classes are created where the model estimates less than 1 and more than one landslides on average.
- The spatio-temporal patterns clearly change although each time step is approximately 15y-long.

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Concluding remarks

- Modeling not only where but also how many landslides occur per mapping unit over space and time is possible.
- If one is interested in the susceptibility alone, this can always be computed from the intensity.
- Traditional linear models that disregard space and time dependencies in the data are not equipped to model such complex system.
- The current model predicts where, how many and how frequently landslide occur in the study area, being the first case to satisfy most of the hazard definition in a single model.

THANKS FOR YOUR ATTENTION

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