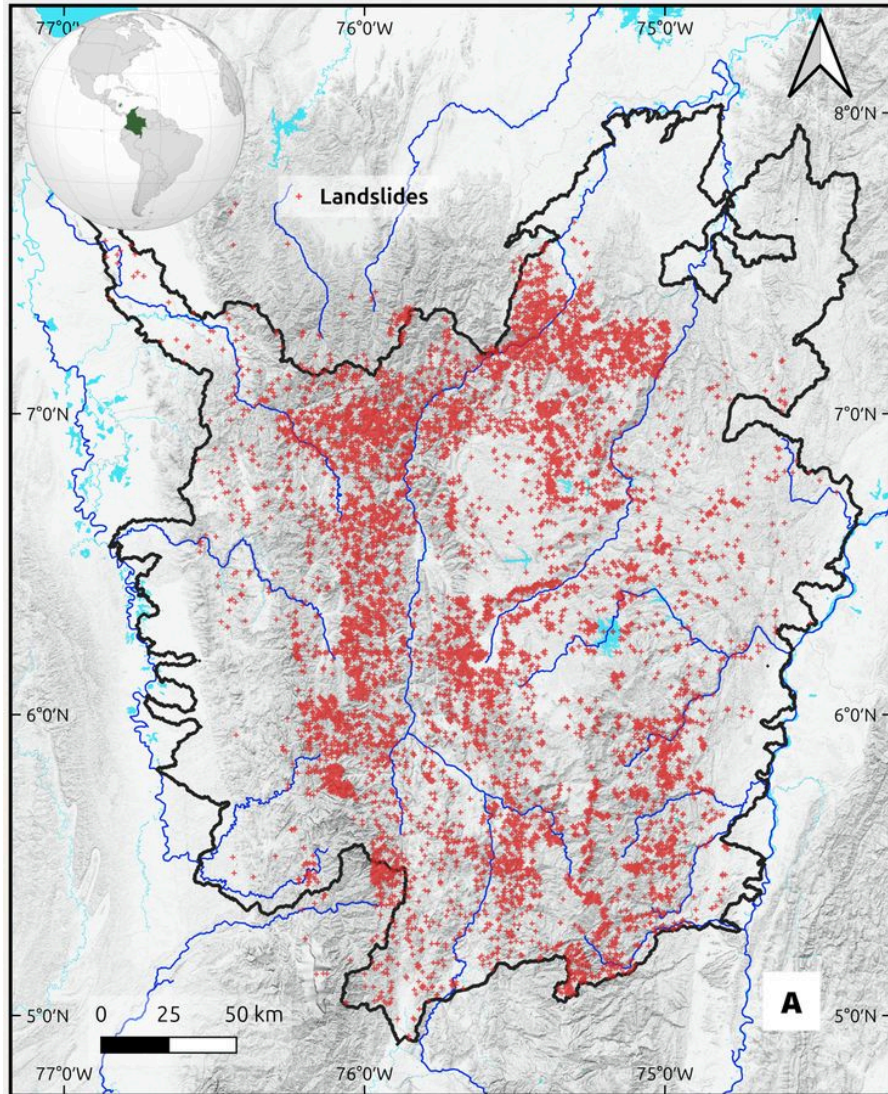# Accounting for spatial dependence and heterogeneity in landslide susceptibility assessment

Edier Aristizábal, Luigi Lombardo, Oliver Korup

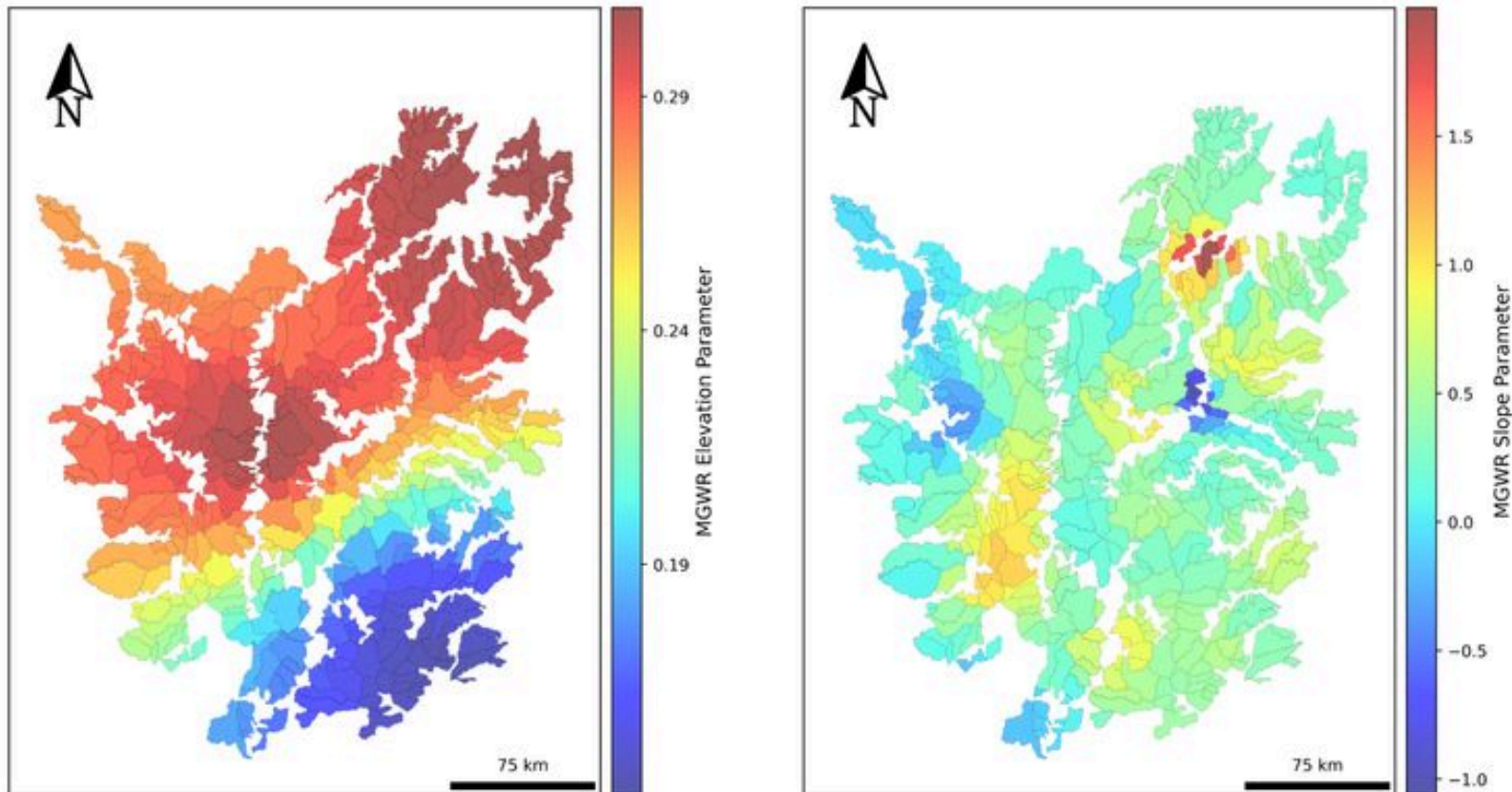Universidad Nacional de Colombia | University of Twente | University of Potsdam

Study Area: Northern Colombian Andes

- Tectonically active, tropical rainfall.

- **10,837 Landslides** mapped (1970-2023).

- **Unit:** 533 Catchments (The Terrain Mapping Unit).

- **Susceptibility proxy:** Number of landslides

- **Predictors:** Rainfall, Slope, Elevation, Relief, etc.
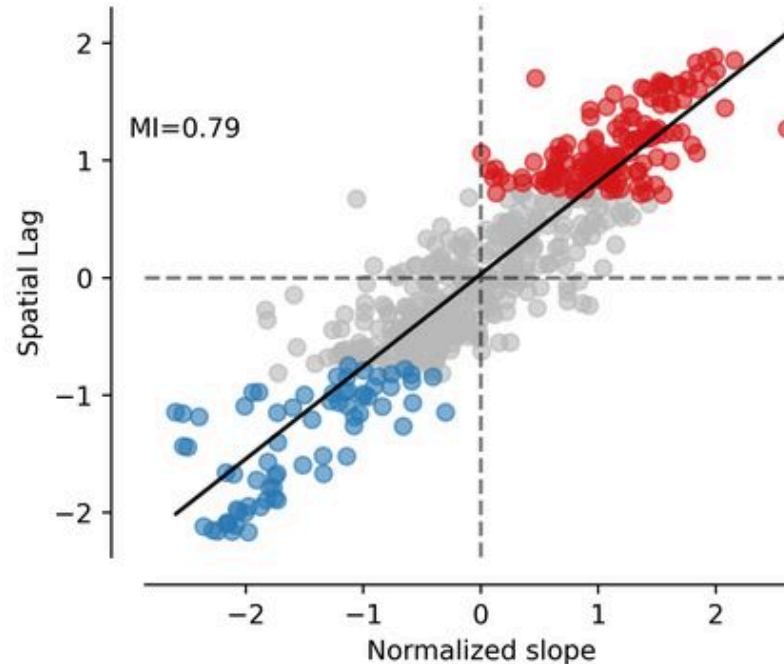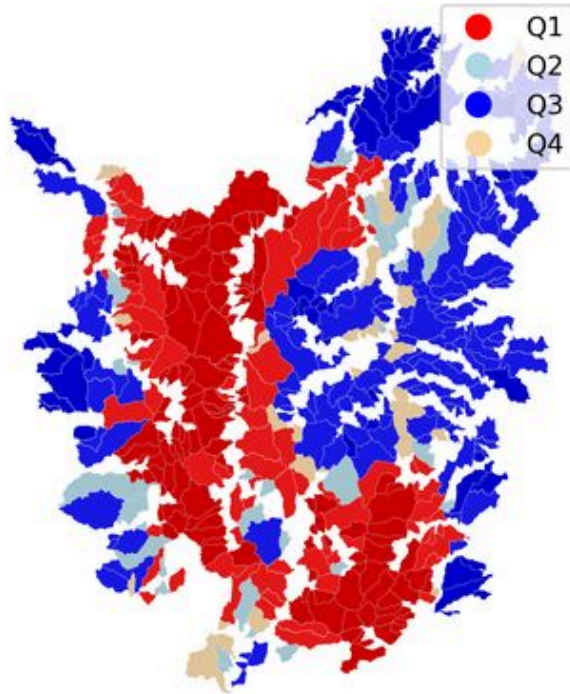
Spatial Heterogeneity

The relationship between predictors (e.g., slope) and landslides is not universal; it varies locally.

A global model "averages" these effects, failing to identify local drivers.
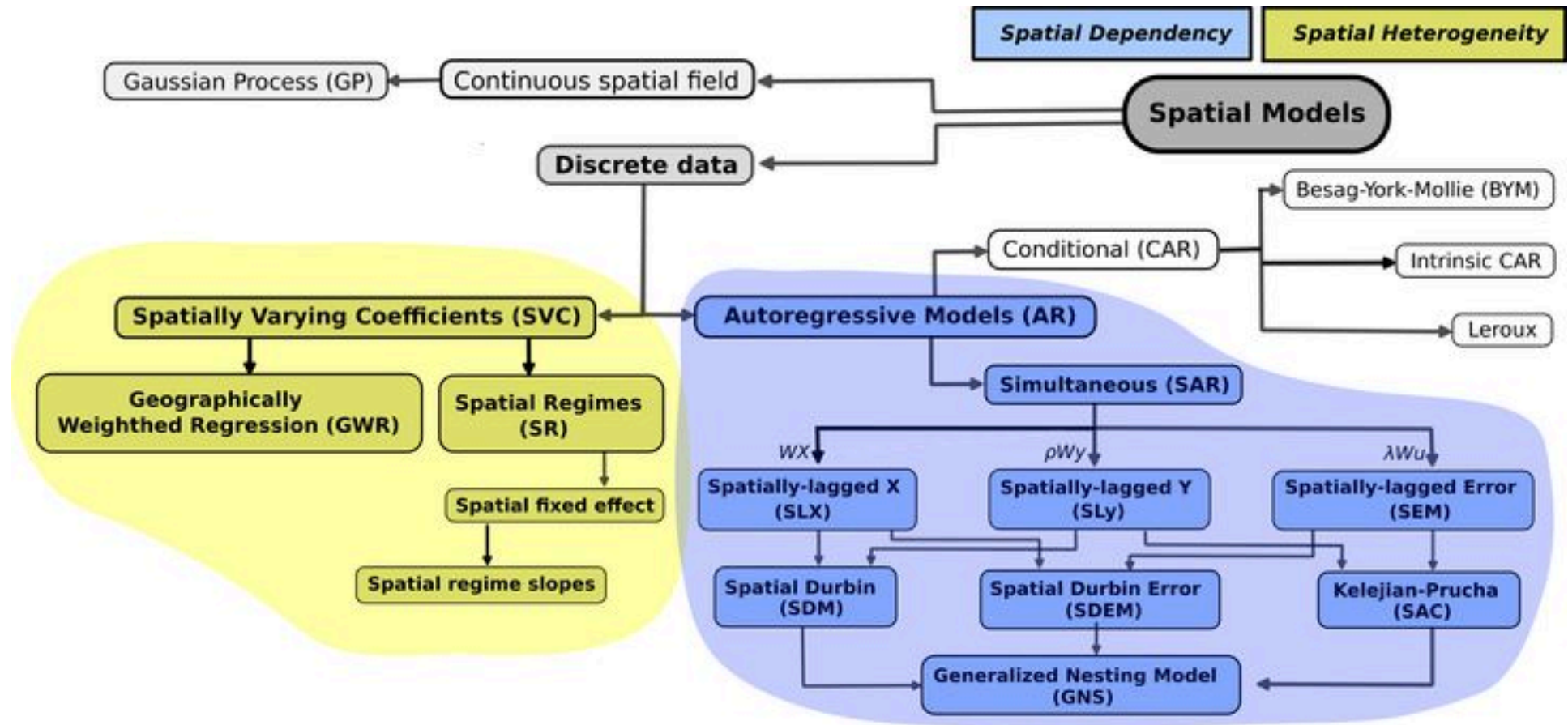
Spatial Dependence

The propensity for landslides in one unit is influenced by its neighbors.

Latent Drivers: It acts as a proxy for unobserved, spatially continuous factors. Ignoring this leads to underestimated variance and overconfident p-values.

Spatial models

Two Frameworks

We tested the spatial hypothesis using two statistical approaches:

Gaussian Framework

Modeling continuous **(Log-transformed)**

$$y = \mathbf{X}\beta + \rho\mathbf{W}y + \lambda\mathbf{W}\mu + \epsilon$$

- Heterogeneity: **GWR, Spatial Regimes**
- Dependence: **SAR, SEM**

Bayesian Framework
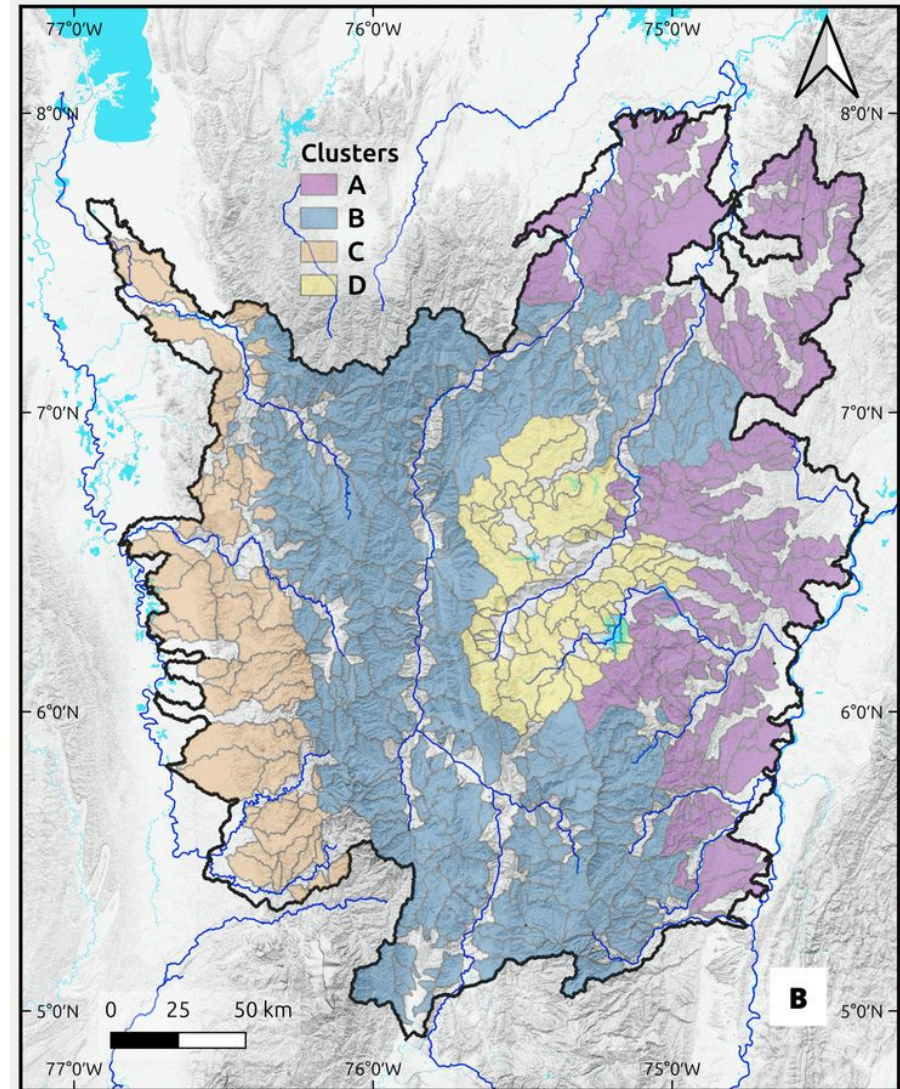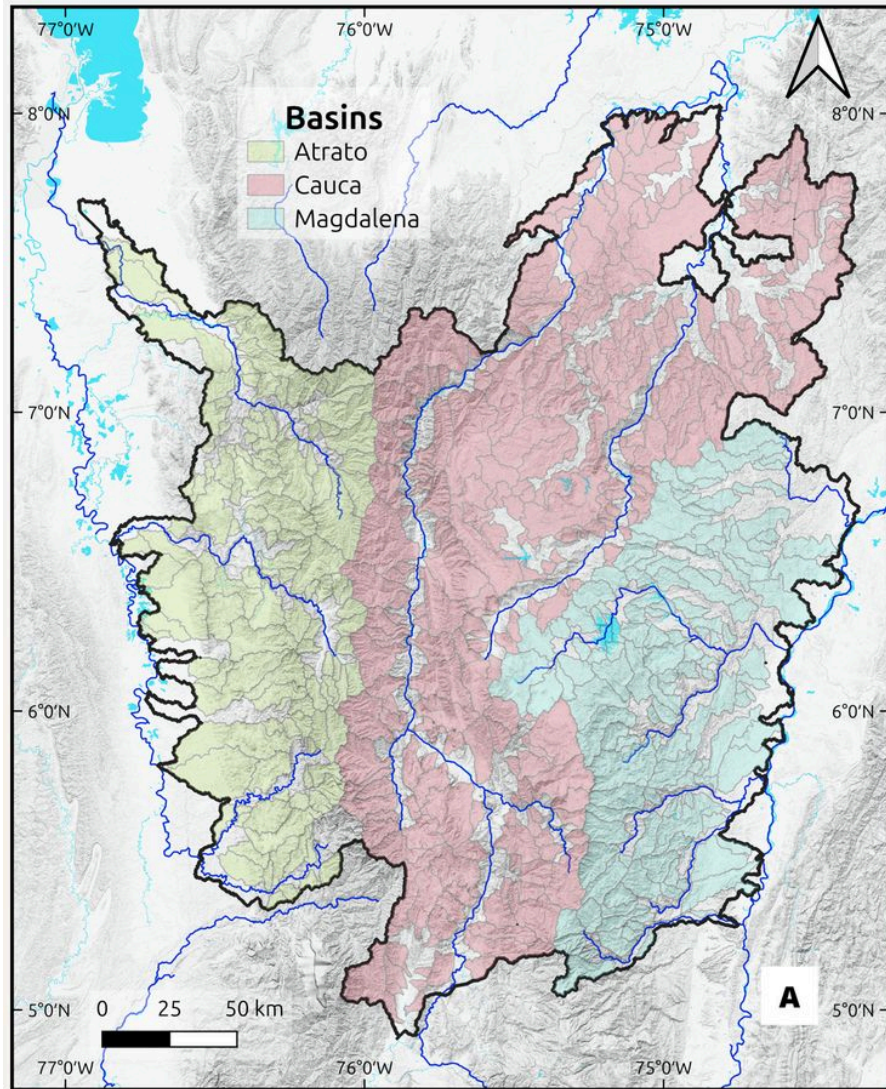
Modeling Counts **(Hierarchical Poisson)**

$$Y_{ij} \sim Poisson(\lambda_{ij})$$

$$\log(\lambda_{ij}) = \mathbf{X}_{ij}\beta + \underbrace{u_{basin(j)}}_{Regional} + \underbrace{v_{spatial(i)}}_{Local}$$
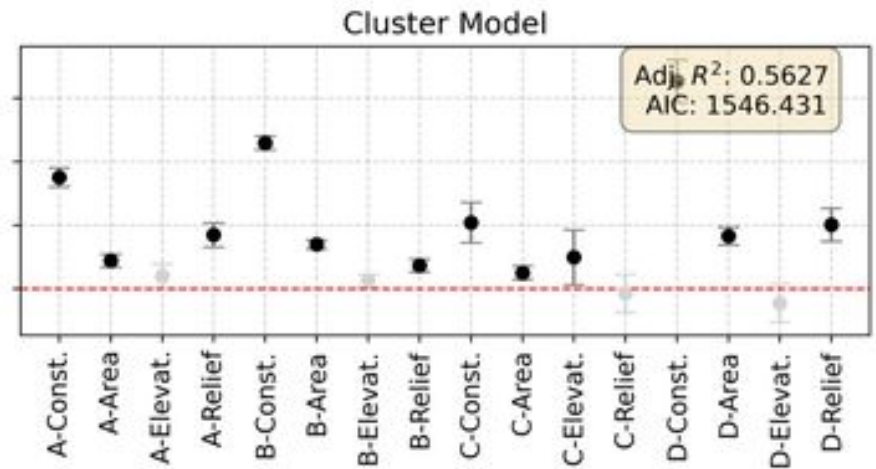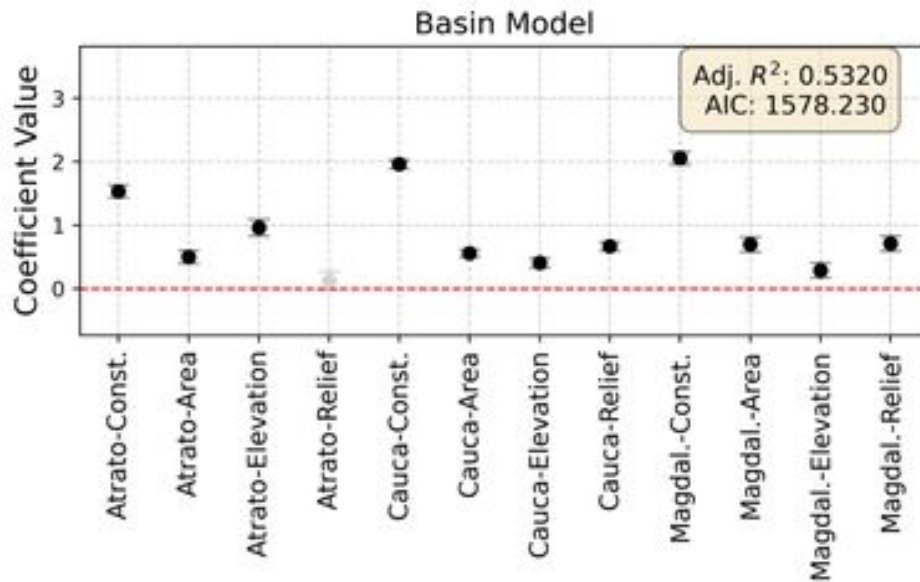
- **Heterogeneity (Level 1-Region):** Random Intercepts
- **Dependence: (Level 2-Local):** ICAR, BYM, Leroux
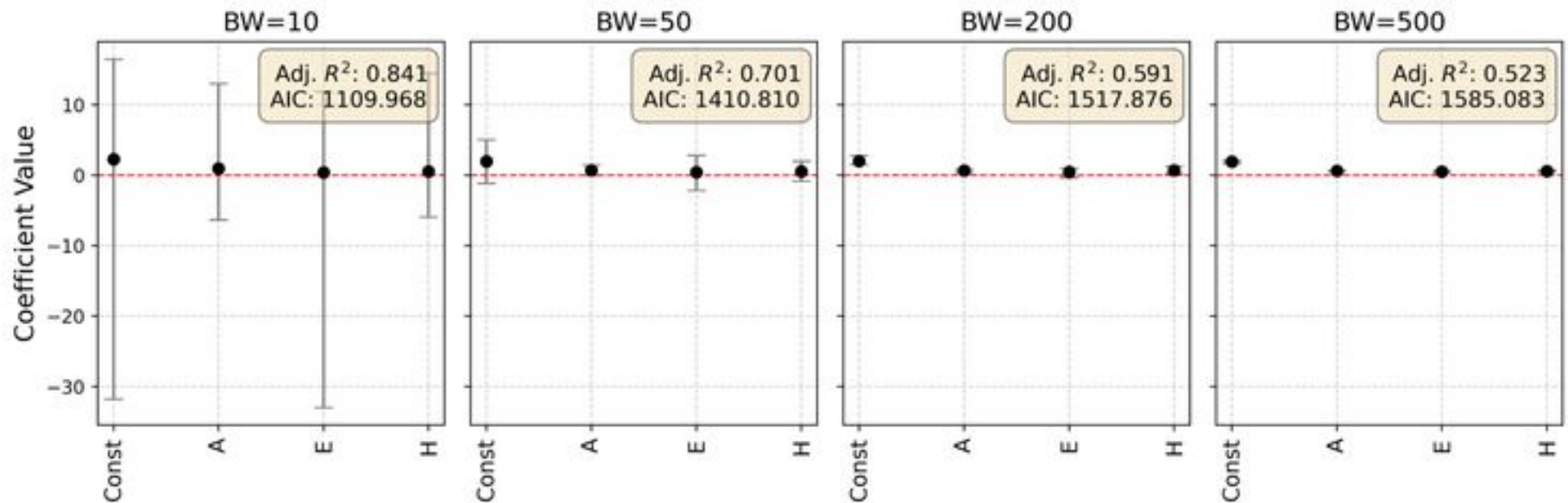
Spatial regimes (Heterogeneity)
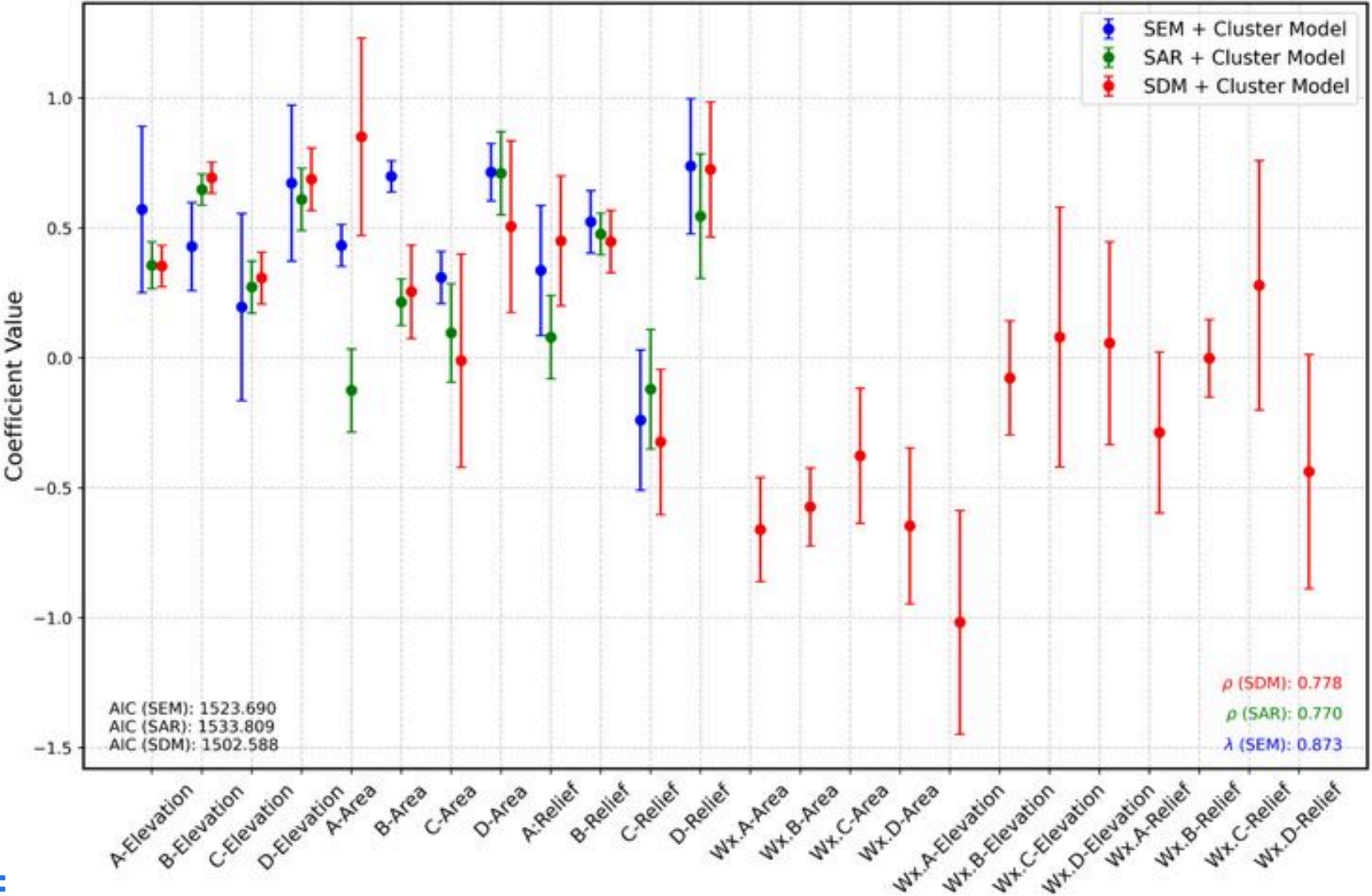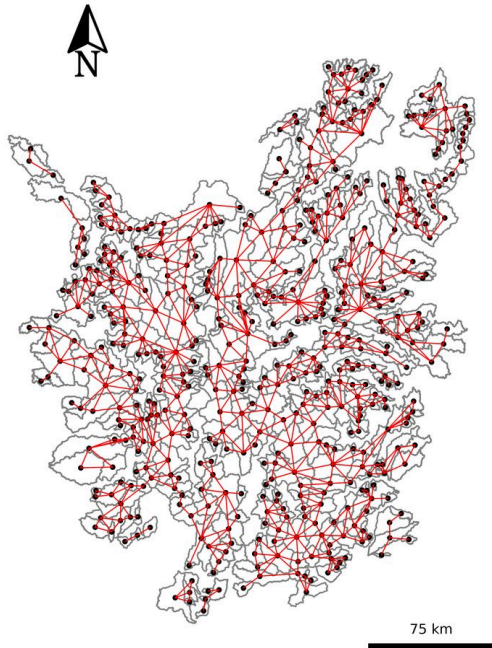
Spatial regimes (Heterogeneity)

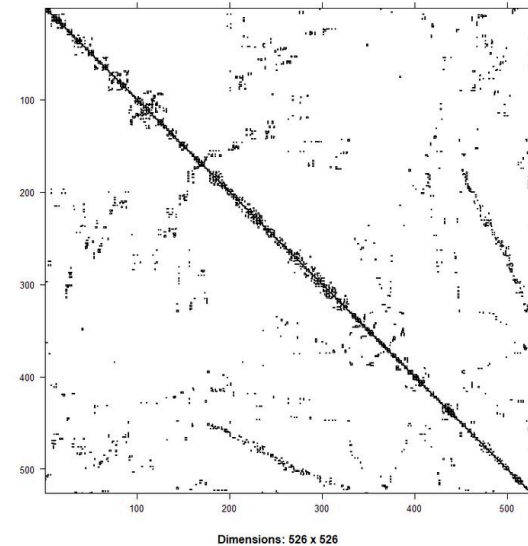# MGWR (Heterogeneity)

SAR (Dependence)

Neighborhood Matrices (Dependence)

75 km

Dimensions: 526 x 526

SAR Model
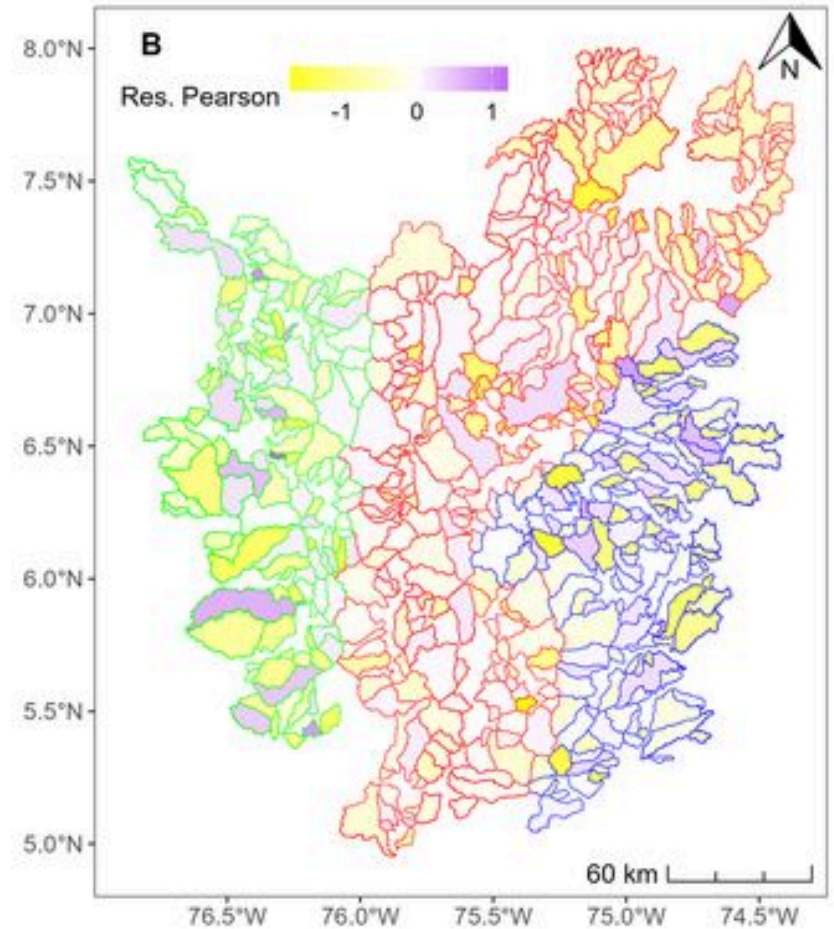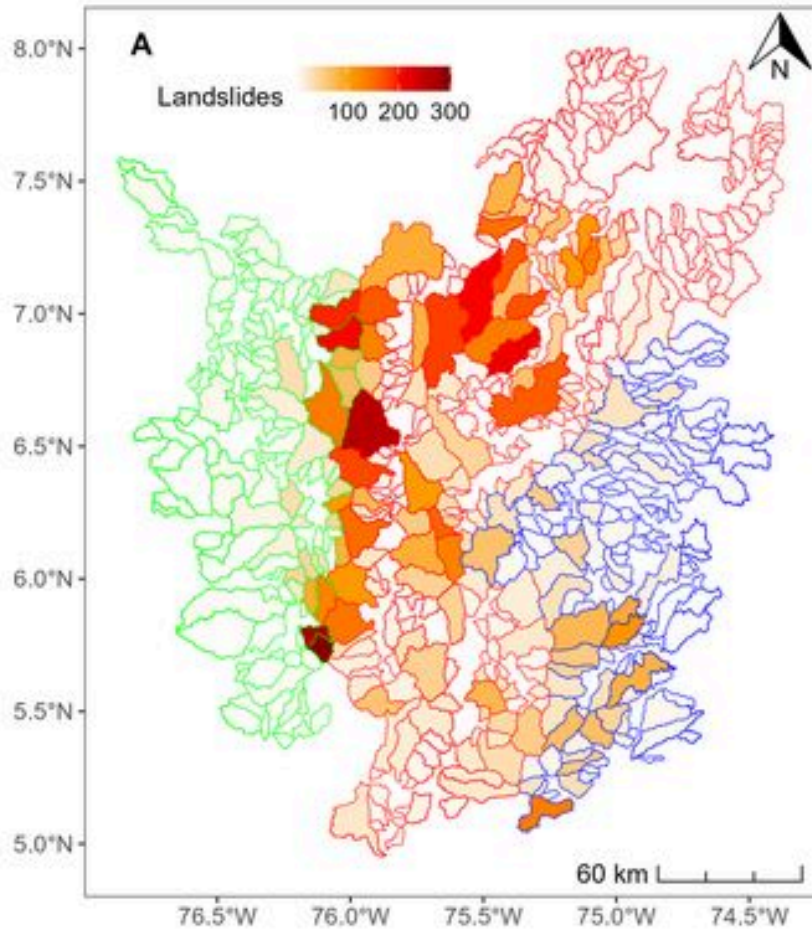(Simultaneous Autoregressive)

Global Spillover Effect

CAR Model
(Conditional Autoregressive)

Local Conditional Impact

CAR (Heterogeneity & Dependence)

Take-Home Messages

- Landslide susceptibility is inherently a **spatial process**. Ignoring this leads to misspecification.

- **Latent factors dominate:** Up to 87% of unexplained variance is spatially structured.

- By handling spatial autocorrelation, we "purify" the fixed effects (Slope, Rain), making them **less biased**.

- Allows stratification by **geomorphological domain** (e.g., Canyon vs. Plateau).

- Spatial models create **smoother**, geologically realistic high-susceptibility zones, rather than "patchy".

¡Gracias!

https://edieraristizabal.github.io/Presentaciones/AGU2025_spatial.html

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