Comparison of object-based and object-oriented physically-based land-surface segmentation

Example of the Western Carpathians and the Alps regions

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Introduction

- Land surface of mountain systems is formed by smaller features – these need to be individually delineated to perform a successful analysis of morphotectonic development
- Traditionally done by manual mapping resulting in geomorphological regions
- Demand for automated processes in geomorphology -> use of object-based image analysis (OBIA)

- **Goals of the study:**
  - To challenge the automatic replication of traditional manually-made geomorphological regions
    - Two approaches – object-based and object-oriented were applied to determine their performance and usability
  - To formulate, test and compare hypotheses of morphotectonic development of the two study areas
    - Our novel Index of steady state (ISS) is used as example

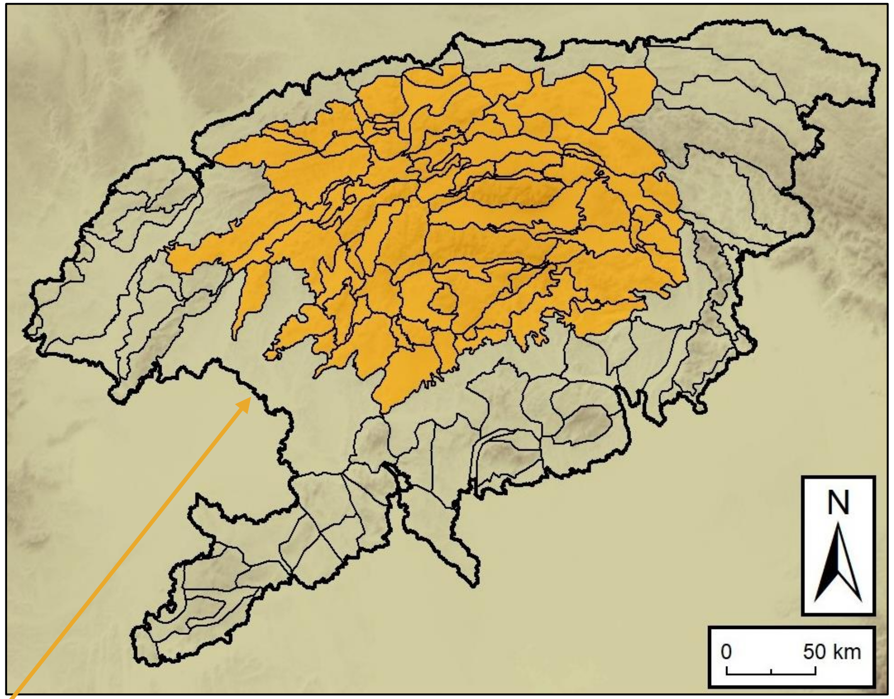
- **Physically-based land surface segmentation is used**
  - characterized by using physically interpretable input variables instead of traditional geomorphometric variables
  - a concept of mapped landforms is reflected directly in the input data

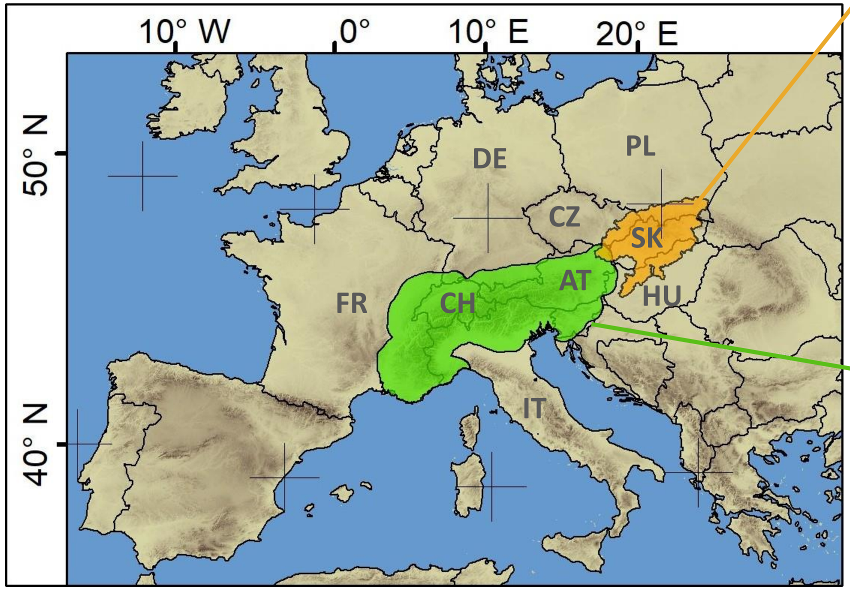
Study areas

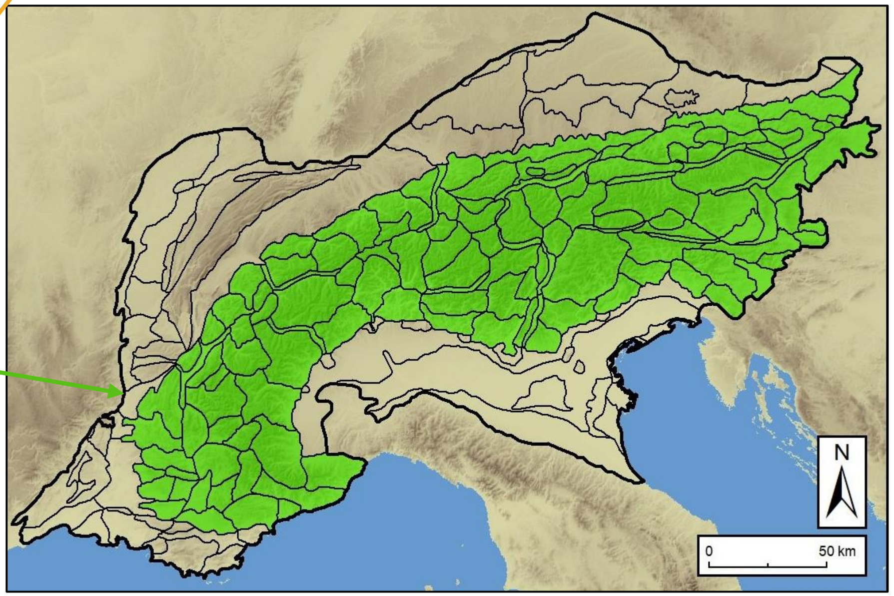
- both are part of Alpine-Himalayan orogenic belt
- until the Miocene similar orogenesis as a collisional mountain belt

- **Western Carpathians**
  - complex neotectonic development led to
    - more contrasting composition of terrain
    - so-called mosaic of mountains and intramontane basins

- **Alps**
  - remained as a compact mountain belt – typical for collision mountain
    - less contrasting terrain
    - more homogenous terrain with narrow valleys







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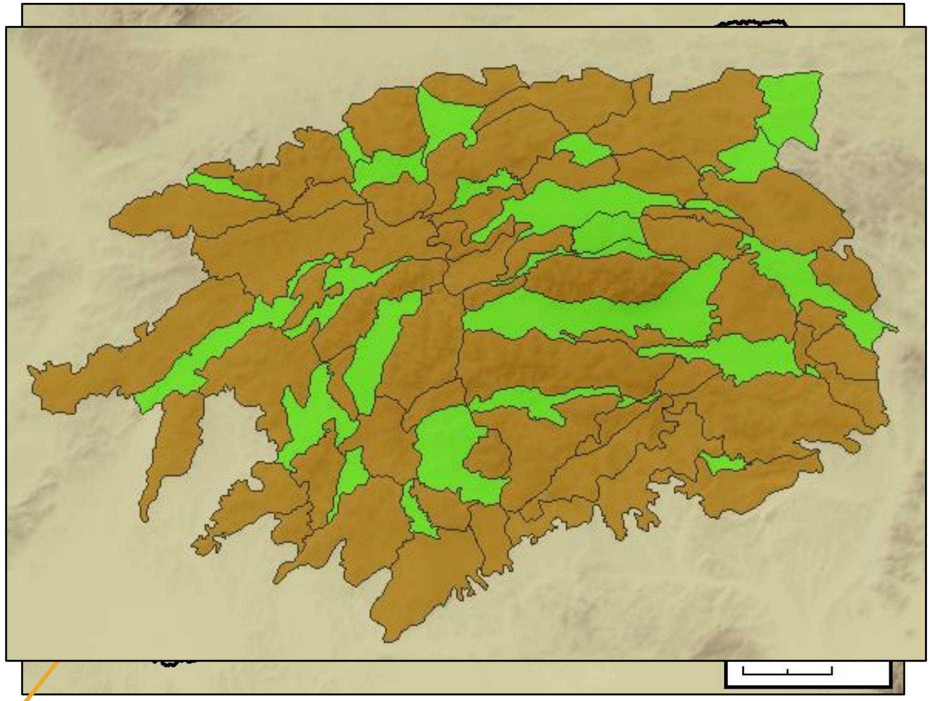
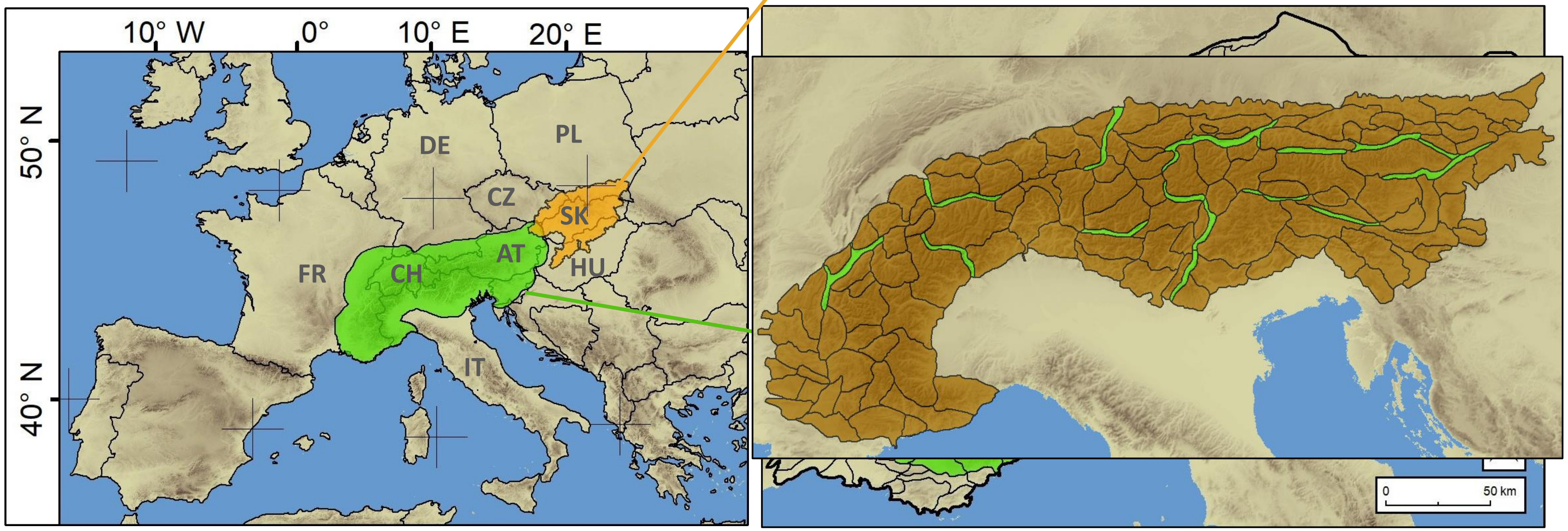




Input data

Primary input data:

- SRTM V4 dataset as input DEM
- Geological map as spatial basis for representation of the rock density

Physical component of the layers:

- rock density (σ) and gravity acceleration (g)

Geomorphometric component of the layers:

- max, mean and range of elevation (*Focal Statistics*, d = 1800 m ≈ Topographic grain
- distance to morphologically-based stream network (*r.stream module*)

Prior to segmentation (to make layers equal):

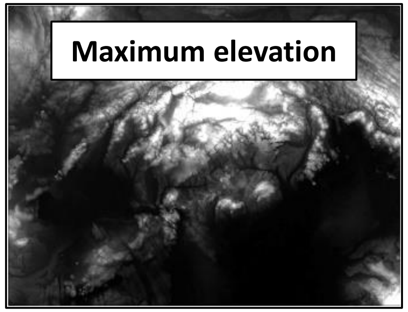
- normalization of distribution – square root
- normalization to range – interval 0-255

Replacement of:

Layer 1

EnW – Endogenous work = max elev. × σ × g/2

elevation



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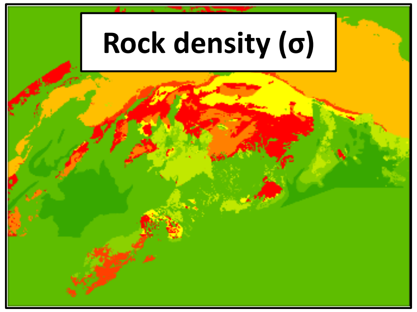
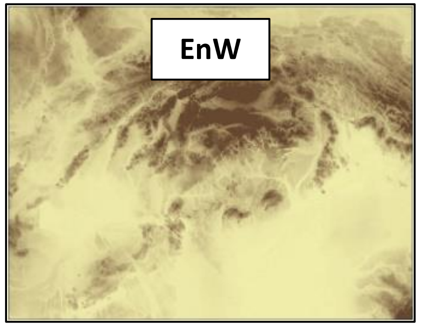


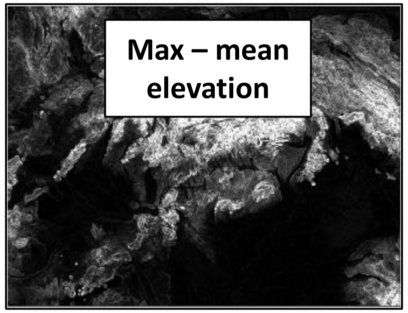
× 4.9 =



Layer 2

ExW – Exogenous work = (max - mean elev.) × σ × g/2

vertical dissection



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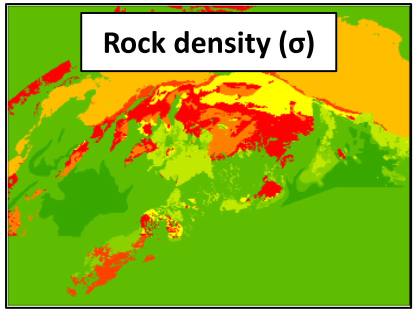

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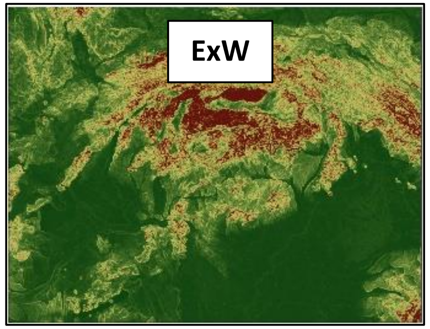
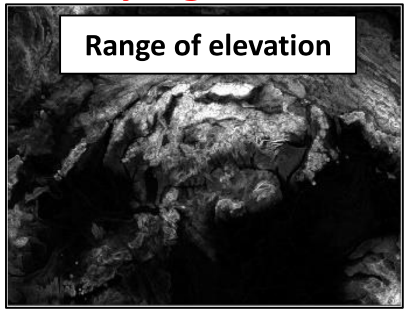


Layer 3

RBF – Relief brake force = range of elevation – (2 × mean d. to str.) × g

slope gradient



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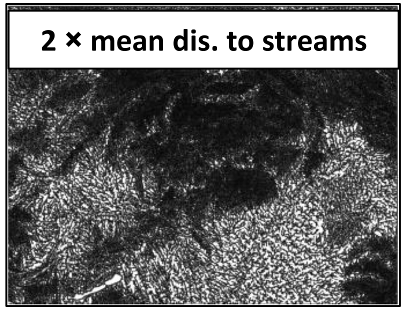
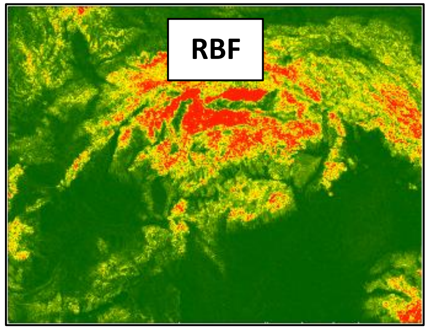


× 9.8 =



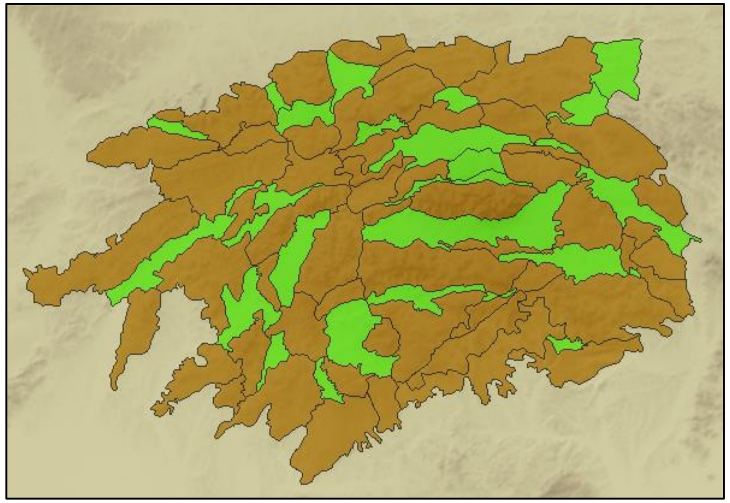
Physically-based segmentation

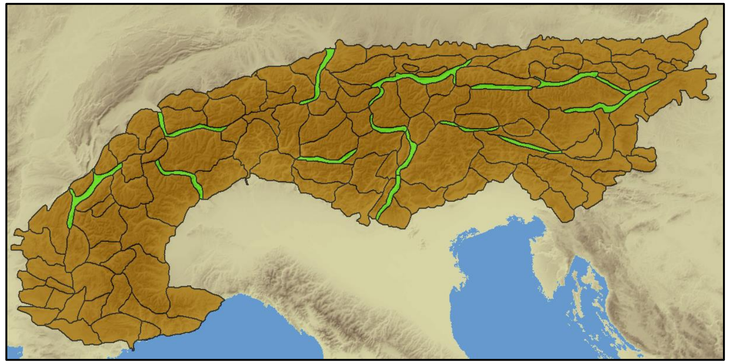
Western Carpathians

- complex object-oriented approach consisting of:
  - **segmentation** (3 x)
    - Estimation of scale parameter 2 tool (ESP2) – automated tool utilizing multiresolution segmentation algorithm in the eCognition Developer
      - optimisation of segmentation scale – through SP step size (value of increment of SP increase)
      - decreasing step size: 100 ≈ super-regional, 10 ≈ regional scale
      - equal layer weights (1)
      - shape and compactness = 0.5 and 0.7, production of more compact objects ≈ tectonic blocks
  - **two types of nested classification**
    - differentation of objects into High and Low domain based on median of elevation (2 x)
    - selection and removal of distinct individuals based on object´s difference to its neighbours in elevation (1 x)
  - **complemented with** (1 x)
    - Removal of wrongly delineated (elongated) objects – based on their re-segmentation and merging with neighbours based on shape

Alps

- the same complex approach evaluated as not necessary
- **simple segmentation – object-based approach –** using only the ESP2 tool proved to be sufficient



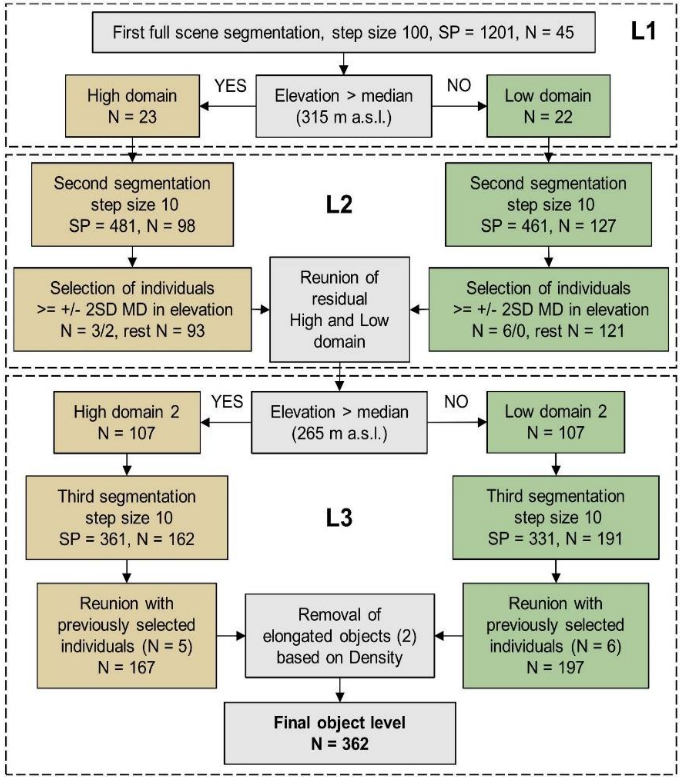


Physically-based segmentation

Western Carpathians

- 3 segmentations – 1 × step size 100, 2 × step size 10
- 2 differentiations of objects into High and Low domain
- 1 selection and removal of distinct individuals

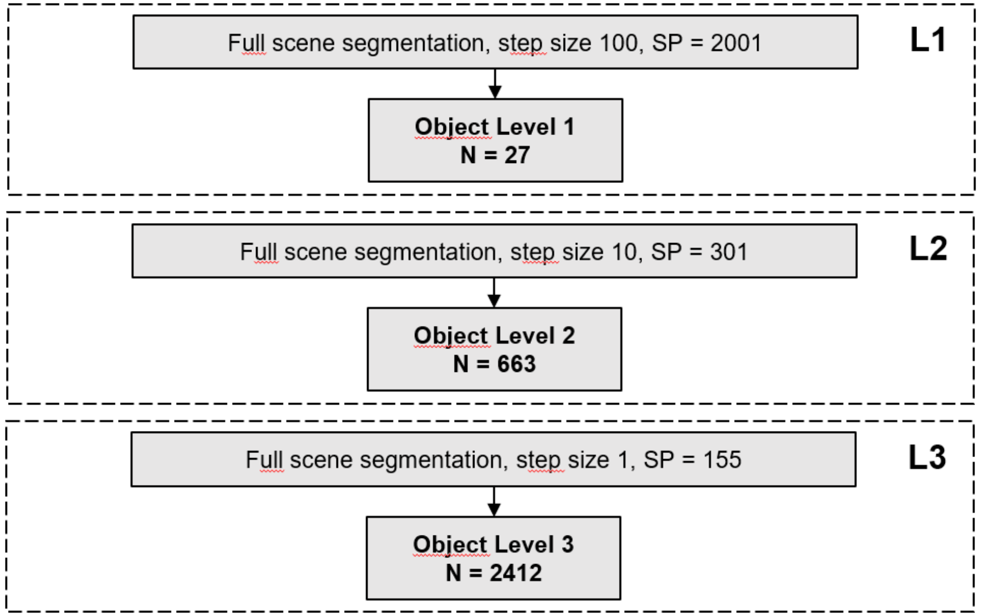
- resulting in three hierarchically-structured object levels with systematically increasing number of objects



Alps

- 3 segmentations
  - 1 × step size 100
  - 1 × step size 10
  - 1 x step size 1

- resulting in three hierarchically-structured object levels with systematically increasing number of objects

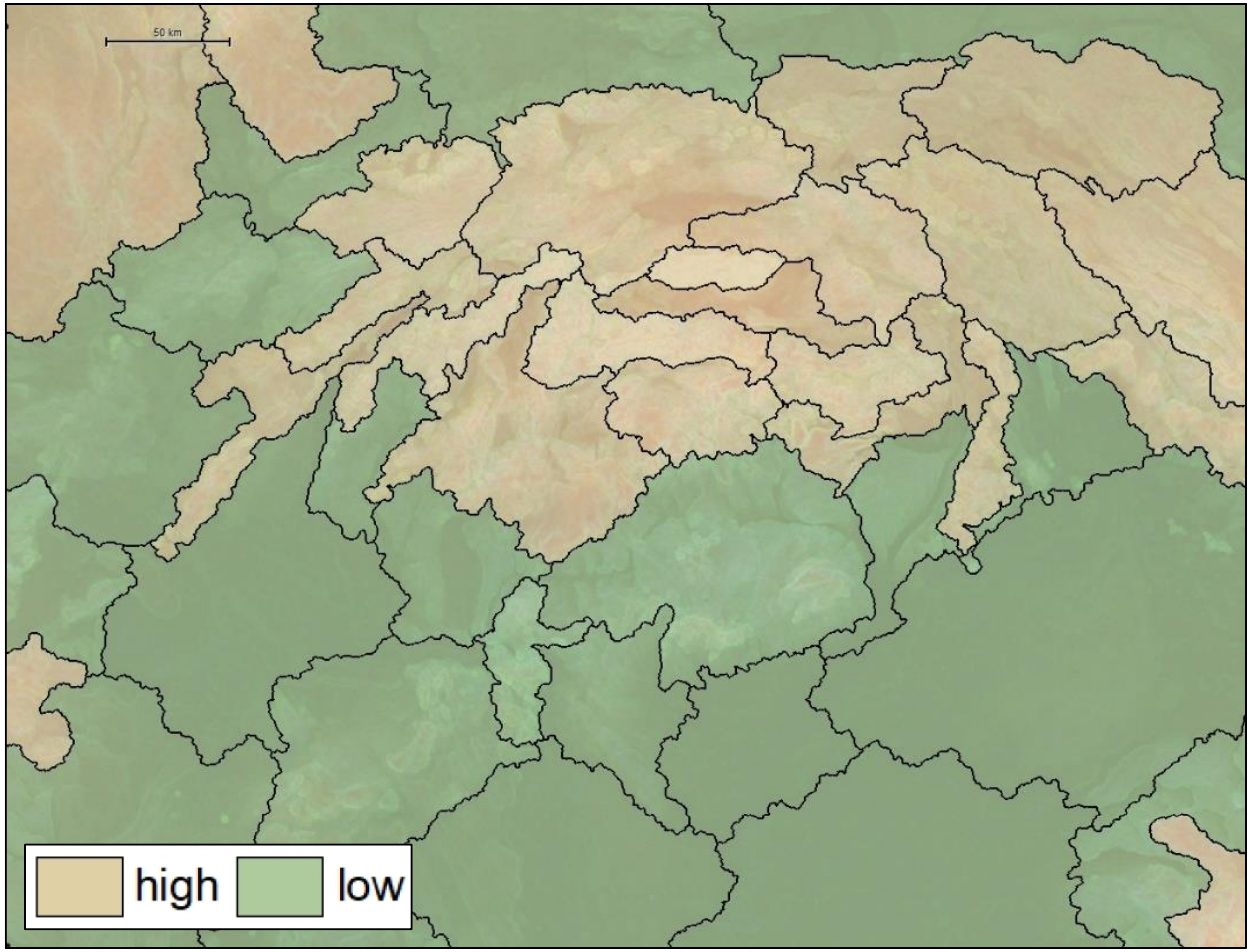


Results – segmentation

Western Carpathians

Level 1

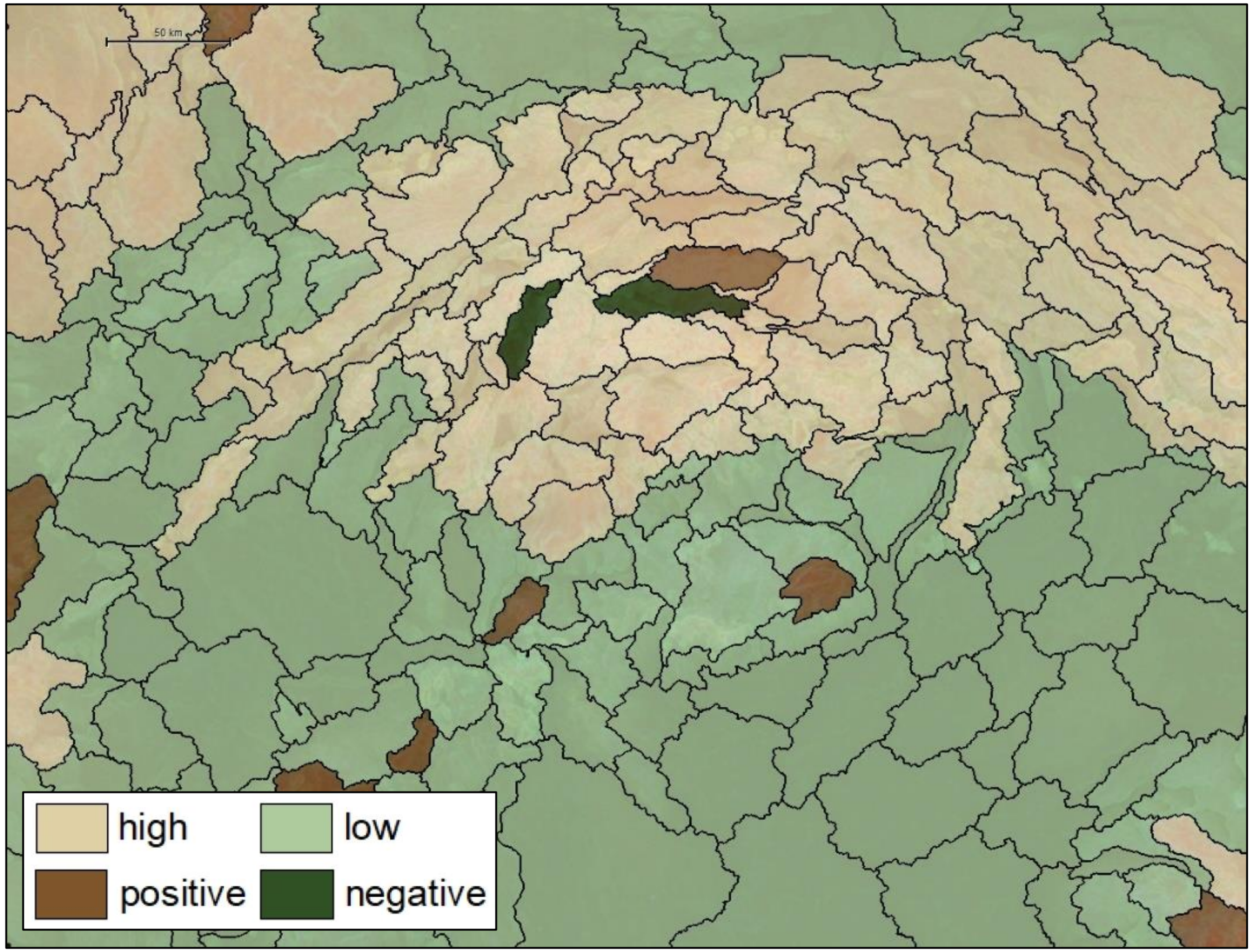
Full scene segmentation – SP 1201 (step size 100), N = 45
Classfication based on median elevation (315 m a.s.l.)



- Delineation of main super-regional features
- Coarsest object level, highly generalised and under-segmented
- pre-processing of the full scene

Level 2

First segmentation of separated domains (step size 10)
High – SP 481, N = 98; Low – SP 461, N = 127; **N = 225**

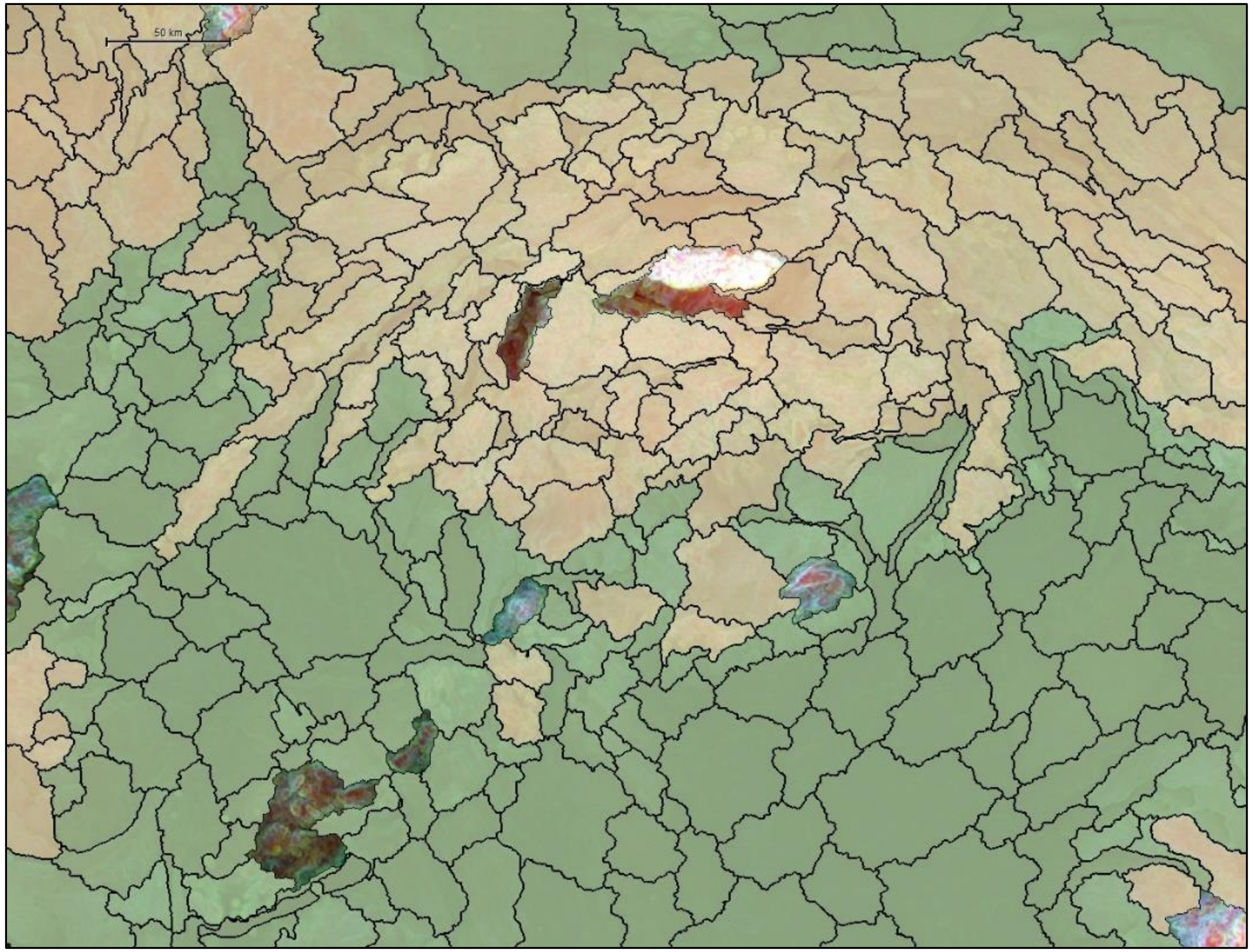


- Delineation of main regional features, 11 individuals selected
- signs of under-segmentation are still visible, mainly in the less rough areas

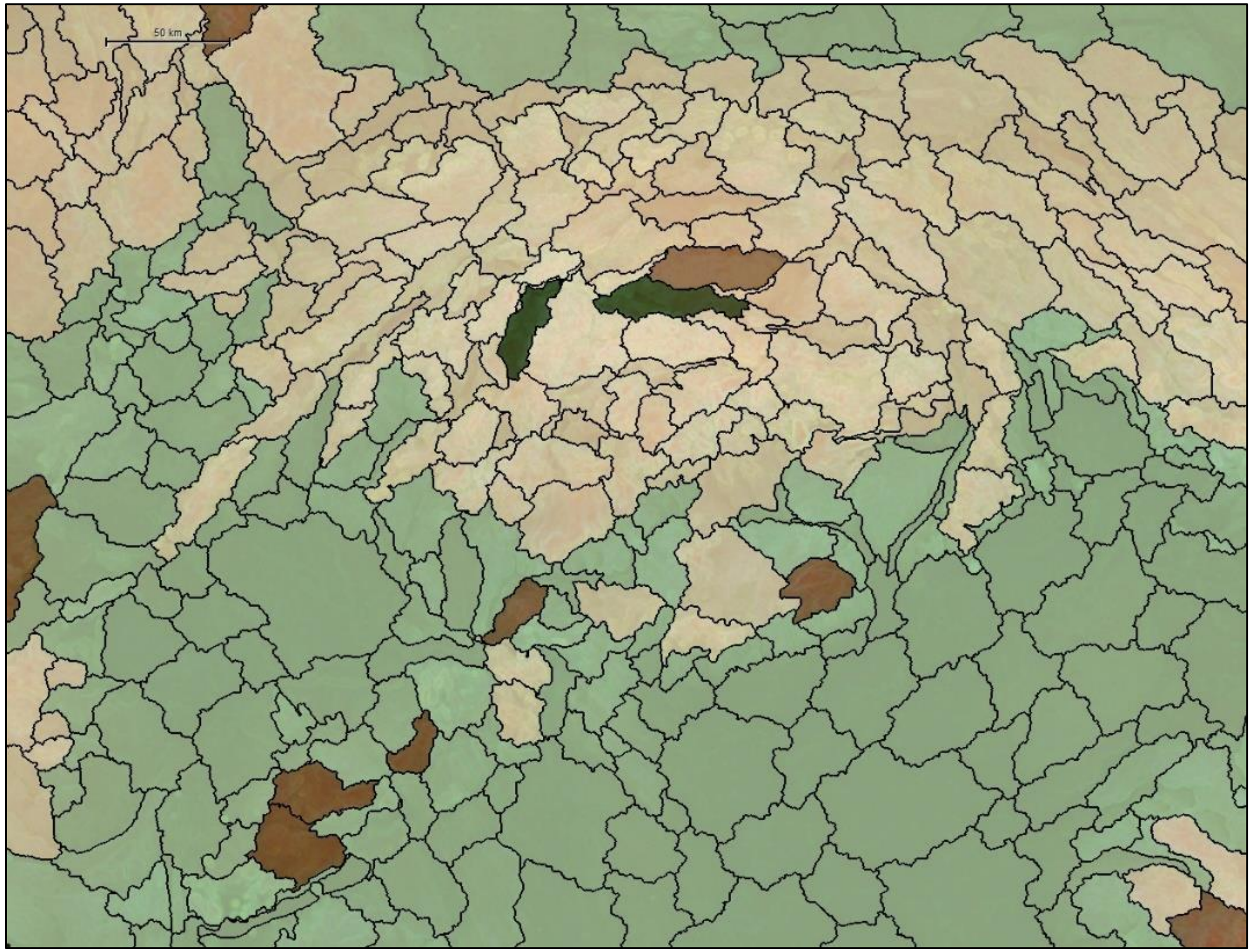
Western Carpathians

Level 3

Second segmentation of separated domains (step size 10)
High – SP 361, N = 162; Low – SP 331, N = 191; **N = 353**



Union with previously removed individuals (N = 11)
N = 364



- additional regional features were delineated and some of the previous were re-shaped

Western Carpathians

Level 3

Final level

after removal of elongated objects and selection of objects covering only the Western Carpathians (N = 209)

Traditional geomorphological regions

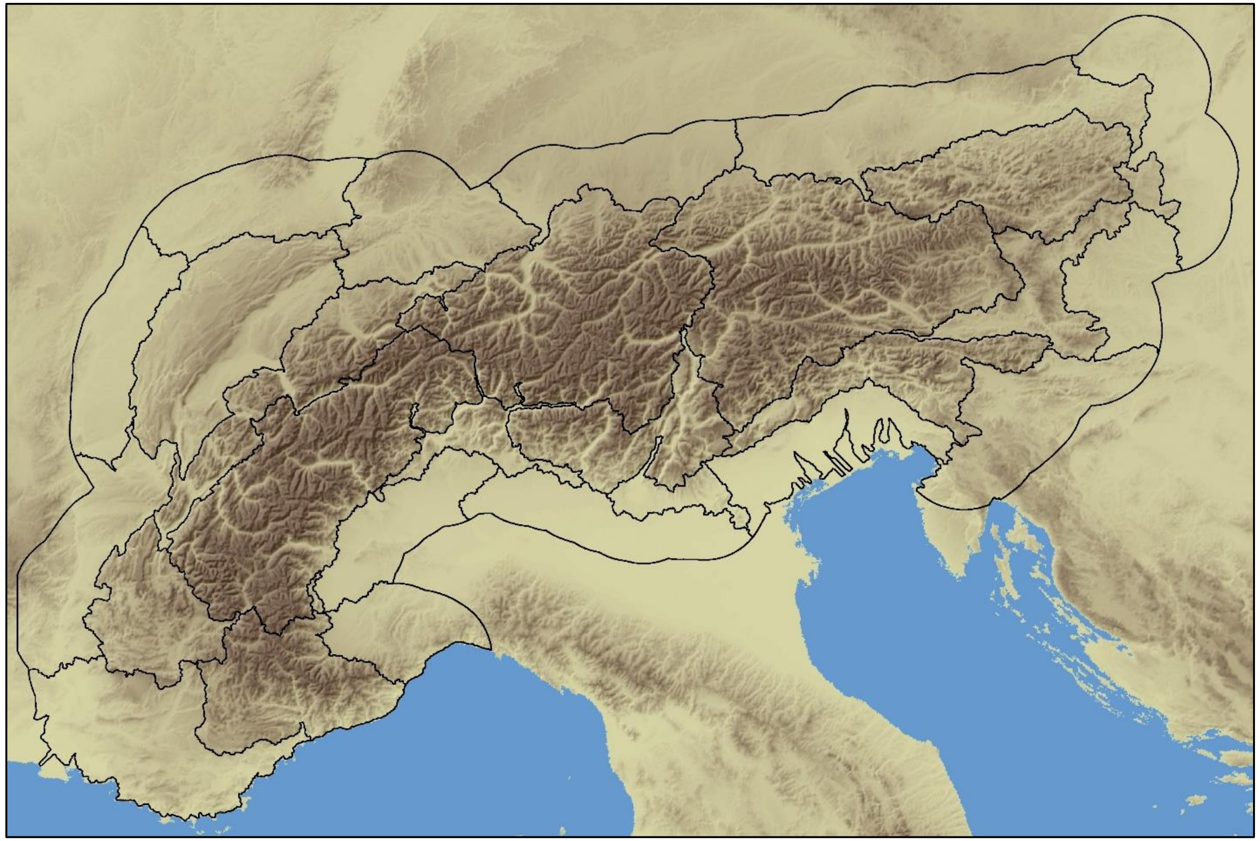
made by Balatka et al. (1971), Kondracki (1978), Mazúr & Lukniš (1978), Pécsi & Somogyi (1969); N = 145

- generally well-delineated objects, good visual compatibility with the traditional regions (209 vs. 145 objects)
- differentiation between mountains and intramontane basins is clearly intercepted, higher success in more contrast areas

Alps

Level 1

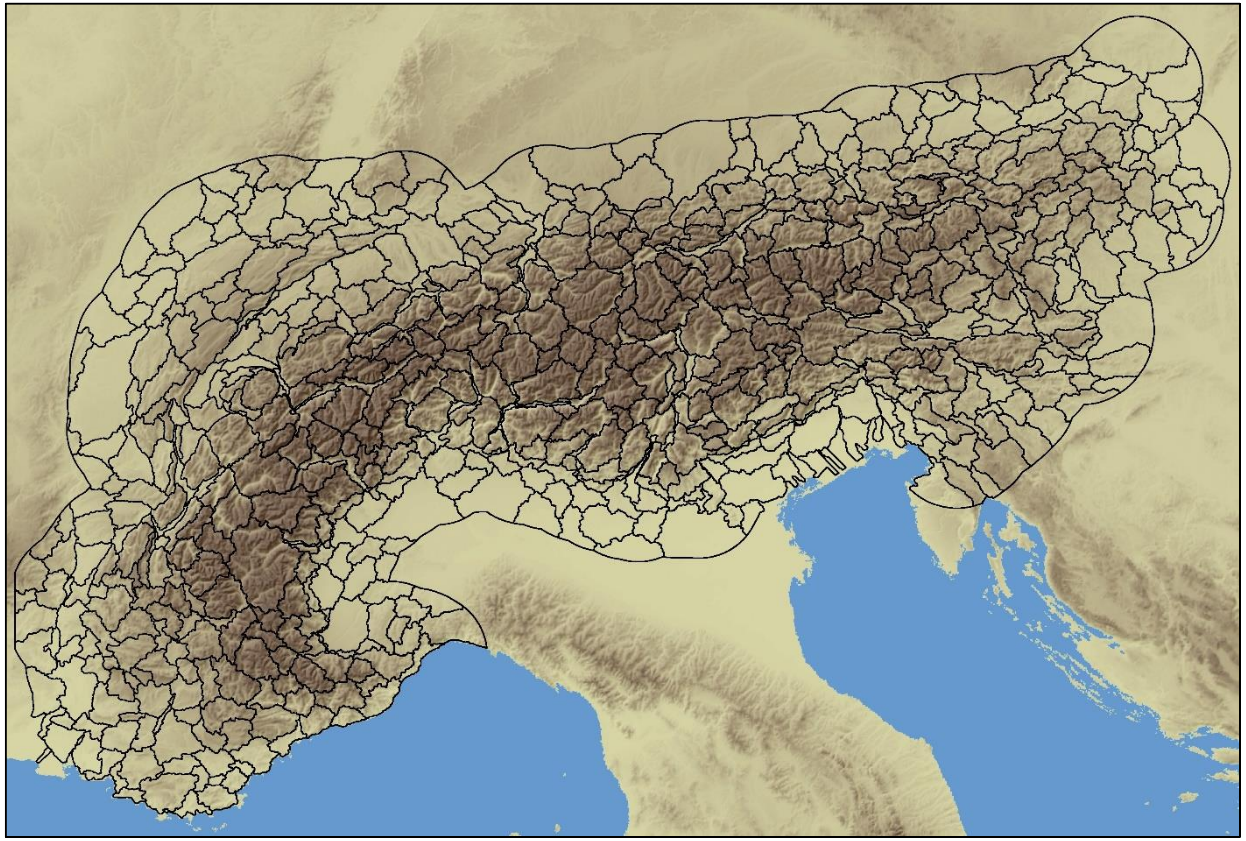
Full scene segmentation SP 2001 (step size 100), N = 27



- Delineation of large super-regional features
- Coarsest object level, highly generalised and under-segmented

Level 2

Full scene segmentation – SP 301 (step size 10), N = 663



- Delineation of regional and sub-regional features
- middle object level, but desired level of detail

Alps

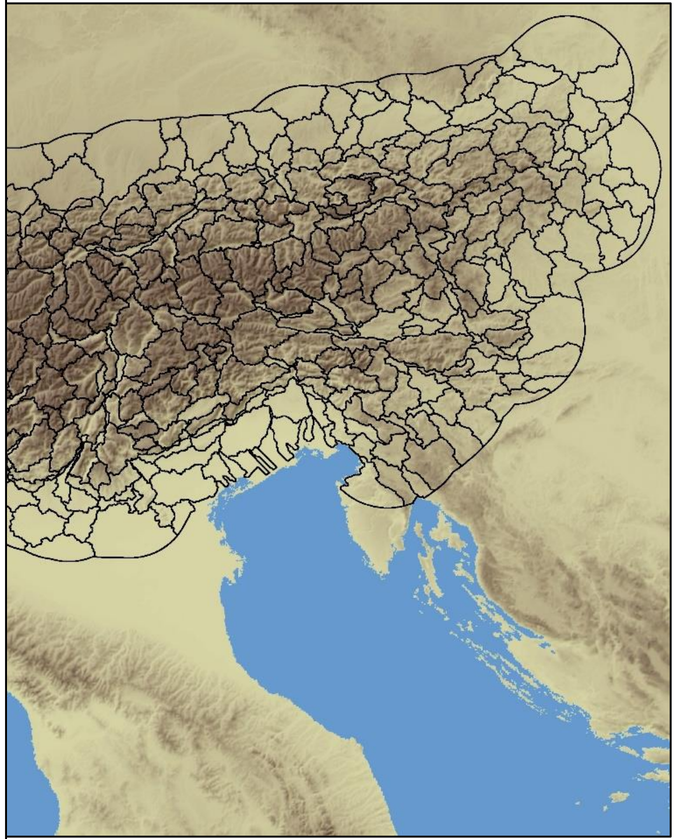
Level 1

Full scene segmentatior

- Delineation of large supe
- Coarsest object level, segmented

Level 2

- SP 301 (step size 10), N = 663

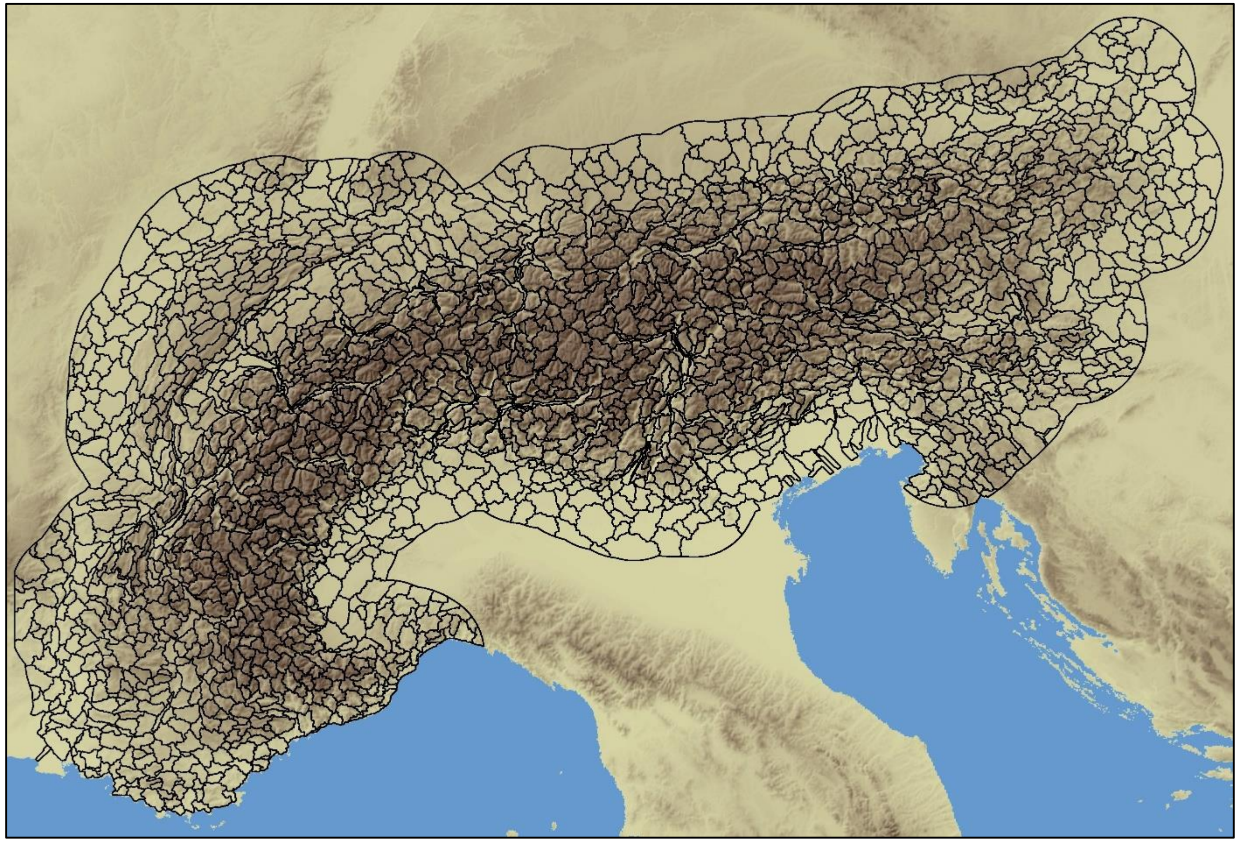


d sub-regional features

esired level of detail

Level 3

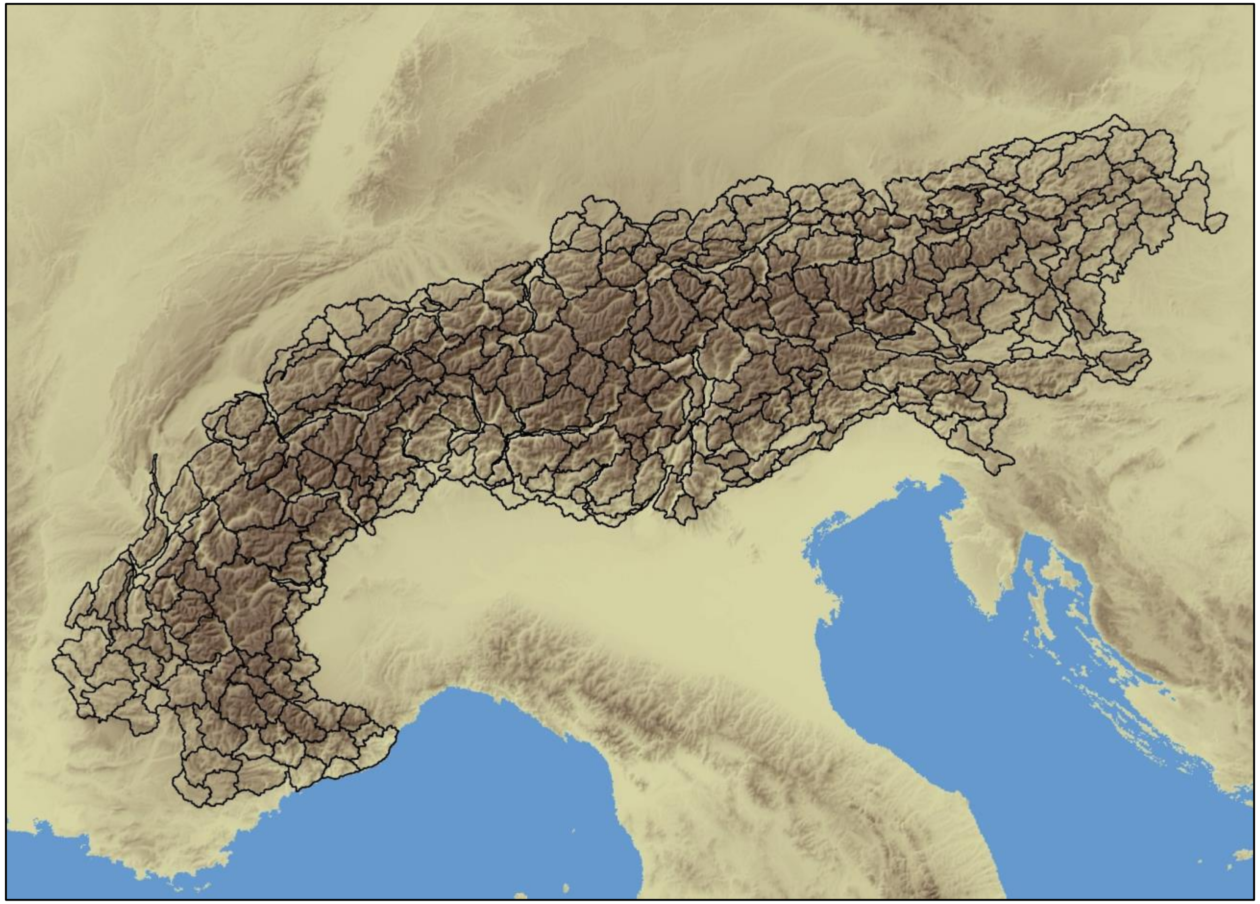
Full scene segmentation – SP 155 (step size 1), N = 2412



- Delineation of small regional and local features
- most detailed object level, visible over-segmentation not suitable for a regional study

Alps

Final level
after selection of objects covering only the Alps (N = 364)



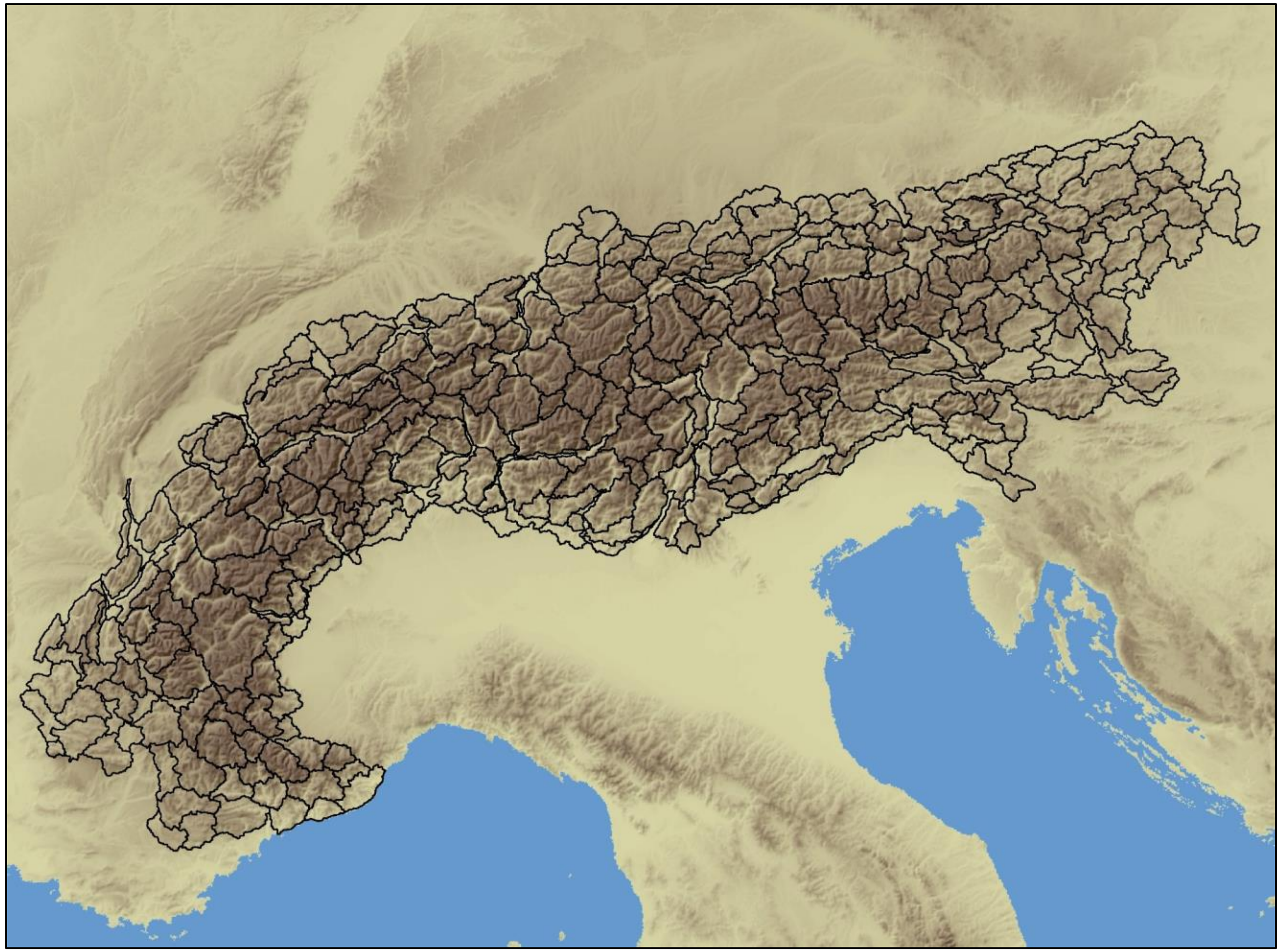
Traditional geomorphological regions
made by Král (1999)
N = 129

- generally well-delineated objects, less visual compatibility with the traditional regions due to depiction of larger scale
- differentiation between separate smaller parts of mountains and narrow valleys is clearly intercepted

Western Carpathians vs. Alps

Object-oriented approach

Object-based approach



- different approaches for both study areas – comparable results with similar interpretational value
- heterogenous terrain as in the Western Carpathians – object-oriented approach is needed to avoid over-/under-segmentation
- more homogeneous terrain as in the Alps – simpler object-based approach is sufficient

Results
example of interpretations

ISS index computation and evaluation

Index of Steady state

- compares the ratio of the endogenous and exogenous geomorphic work preserved in the recent terrain
- reflects similarities and differences in the geological structure and geodynamic development of the two mountain ranges
- it is reflected in relatively stable topography

$$ISS = \frac{EnW}{ExW} \cdot \left(\frac{R_{BF}}{ExW} \cdot \frac{ExW_{mean}}{R_{BF_{mean}}} \right)$$

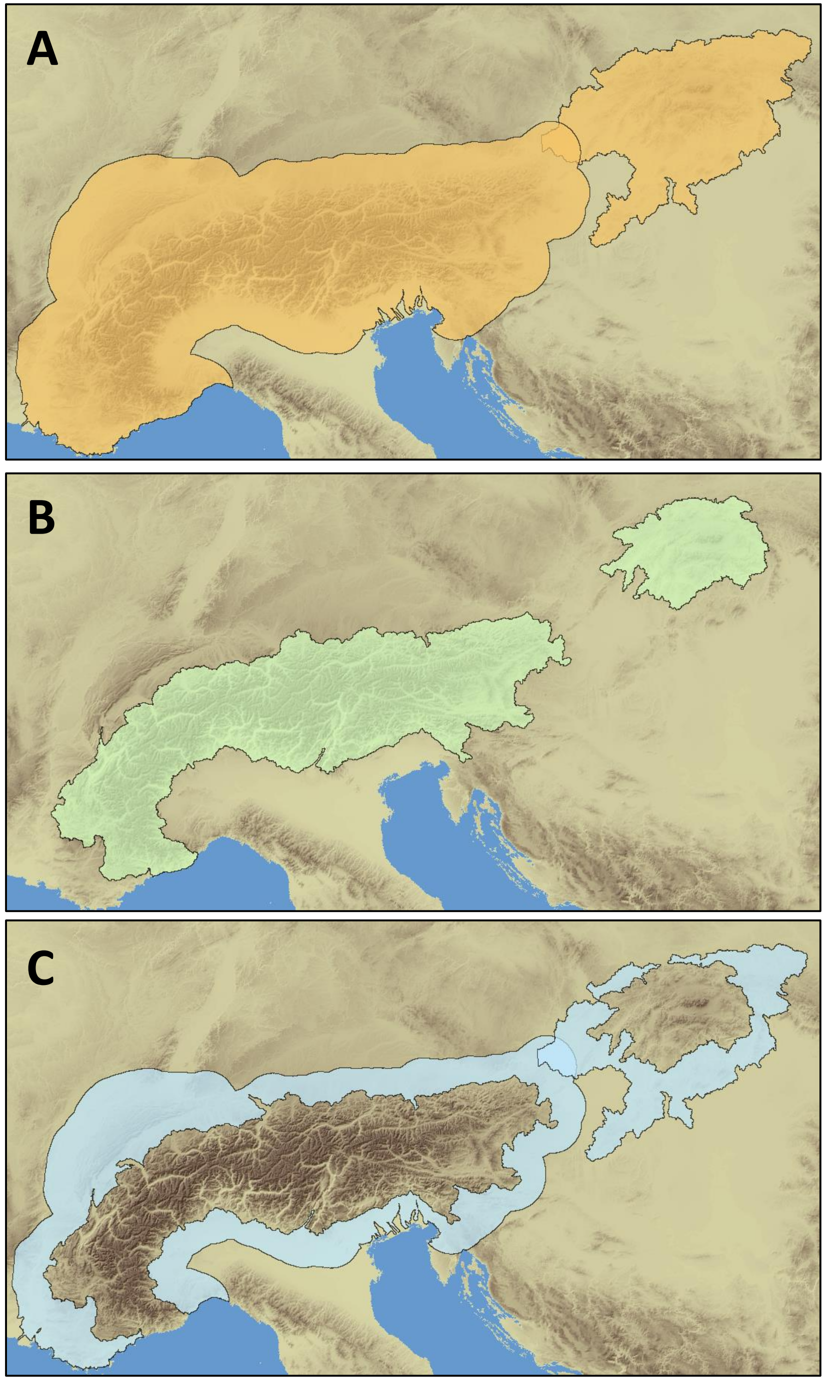
- EnW – Endogenous work (altitudes)
- ExW – Exogenous work – (available relief)
- RBF – Relief brake force – (slope)

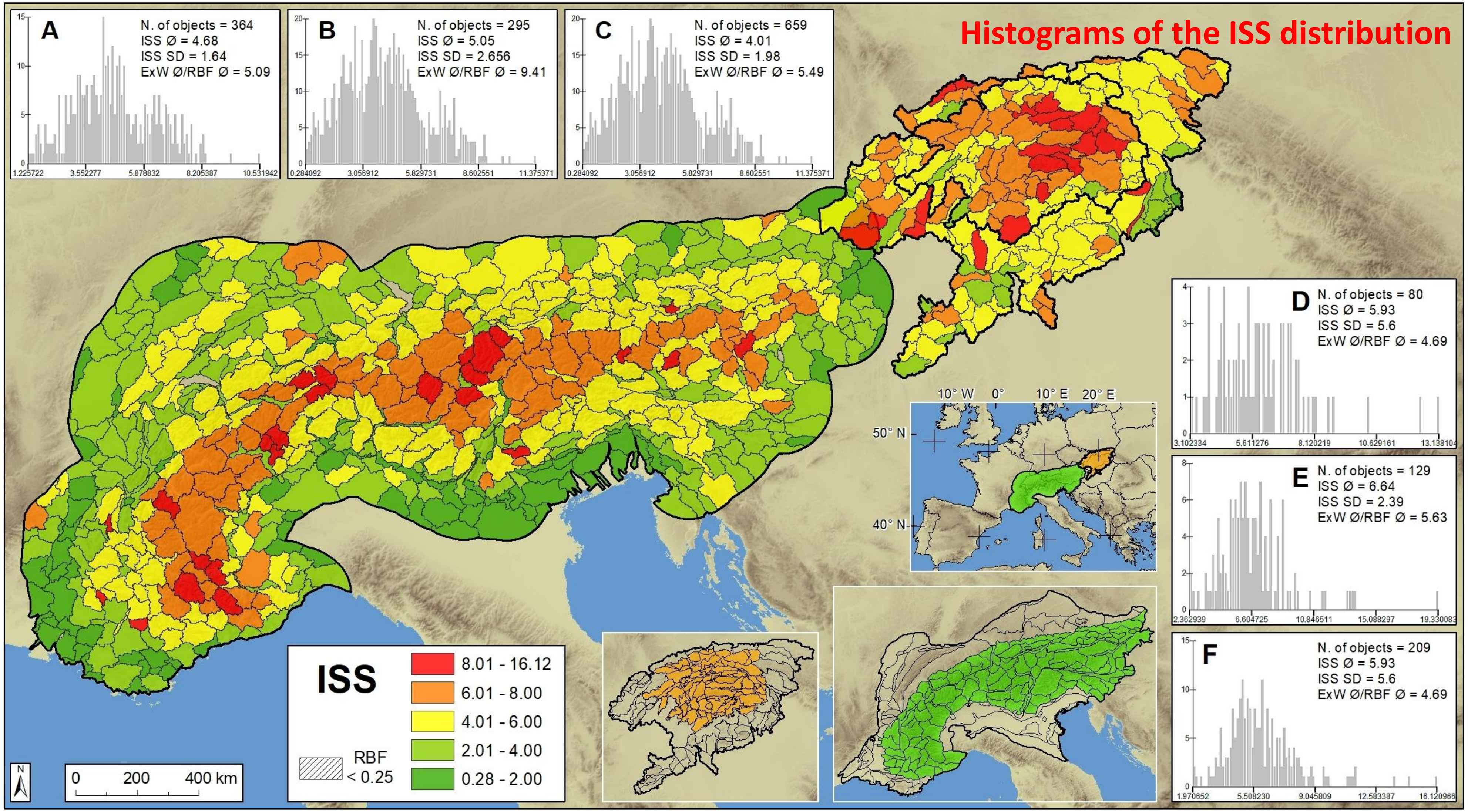
- because the second part of equation is dependent on the study area delimitation, the evaluation of ISS can be done for:

  A. entire study areas

  B. Alps without foreland; core area of Western Carpathians

  C. Alpine foreland; transitional area of Western Carpathians





A – Alps
B – Alpine foreland
C – Alps with foreland
D – W. Carp. core area
E – W. Carp. trans. area
F – W. Carp. core & trans.

1. Alps are much larger but appear more homogeneous than the Western Carpathians (based on maps and histograms).
2. points to different geodynamic development in these regions (ongoing collision vs. complex geodynamic history).

Highest ISS values

- in the Western Carpathians are in lower mountains with later uplift and delayed erosion and remnants of planation surfaces
- in the Alps are in the central parts with highest elevations, which were mostly glaciated in the Pleistocene. It could be due to the protection from intense denudation by a conservation effect of the glaciers

Conclusions

- according to the results, our concept of physically-based segmentation can be used not only in area of the Western Carpathians, where it was developed, but also in other areas
  - given by the complexity of the terrain, object-oriented or object-based aproach can be applied
- convenience of the physically-based layers used even as input for the segmentation is confirmed by more straightforward subsequent interpretations
  - ISS index was used as example for evaluation of the development of study areas individually as well as for their mutual comparison and can provide non-trivial morphotectonic interpretations

Thank you for your attention

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