Digital soil mapping as a tool for soil protection

II. DSM: examples of application

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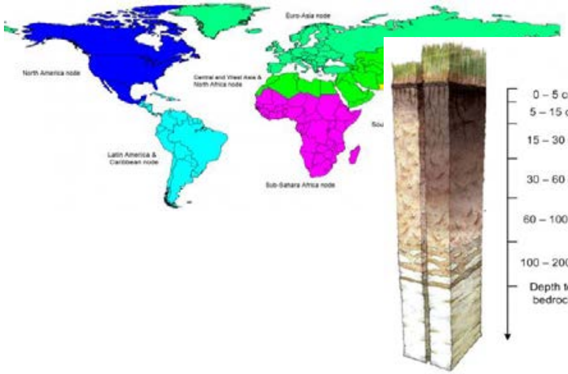
DSM examples of application

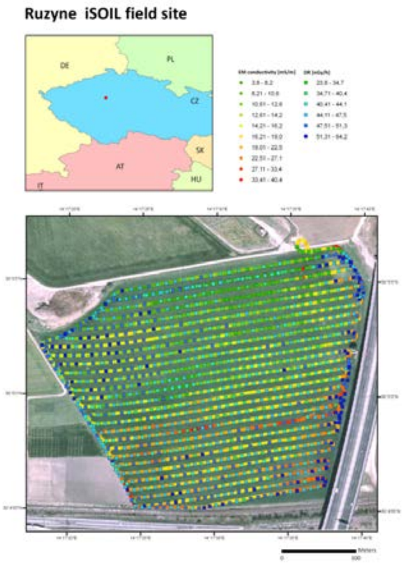
1. **Global mapping projects**
   A. SoilGrids
   B. Global soil map
   C. eSOTER
   D. iSOIL
   E. SoLIM

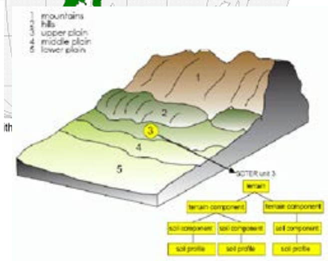
2. **Update of soil spatial information**
   A. Regional/continental level (LUCAS)
   B. Description of soil degradation intensity

3. **Improvement of new data collection**
   A. Rationalization of soil sampling scheme

4. **Tools for soil protection at policy level**
   A. Anti-erosional calculator
   B. Soil sealing

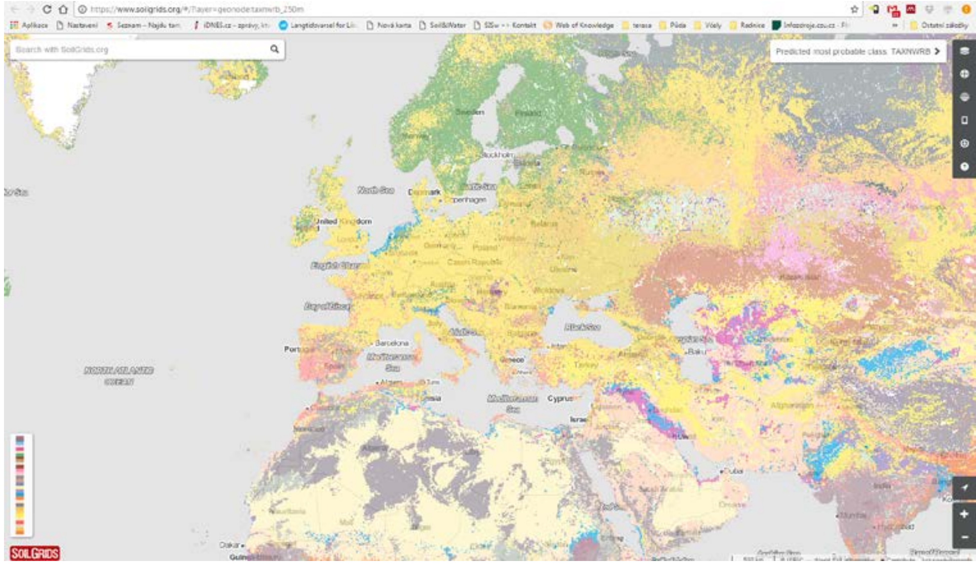






Map products: SoilGrids

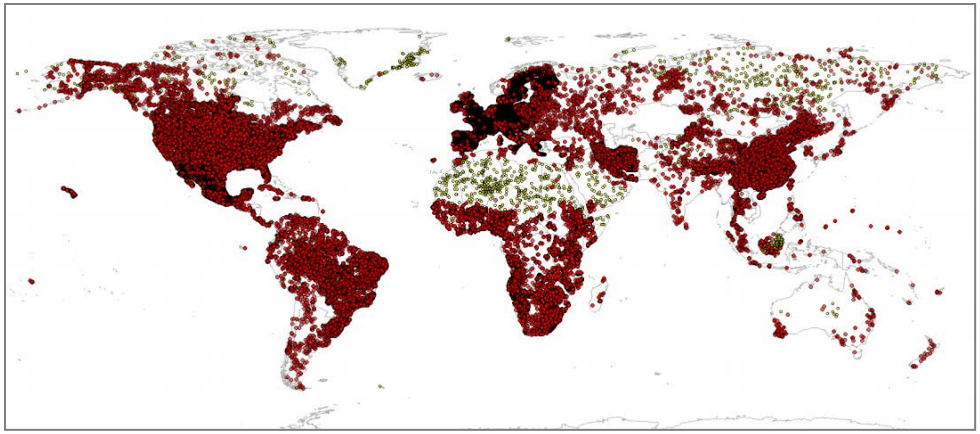
- Produced by ISRIC
- SoilGrids1km and SoilGrids250m
- a system for automated global soil mapping
- https://www.soilgrids.org/#/?layer=geonode:taxnwrb_250m



- prediction of soil units
- predictions for standard numeric soil properties:
  - organic carbon,
  - bulk density,
  - Cation Exchange Capacity (CEC),
  - pH,
  - soil texture fractions and
  - coarse fragments

- Depth intervals
  - 0, 5, 15, 30, 60, 100 and 200 cm

- Predictions were based on ca. 150,000 soil profiles
  - harmonisation
- 158 remote sensing-based soil covariates
  - MODIS
  - SRTM DEM derivatives
  - climatic images
  - global landform
  - lithology maps



- DEM:
  - slope, profile curvature, Multiresolution Index of Valley Bottom Flatness (VBF), deviation from Mean Value, valley depth, negative and positive Topographic Openness and SAGA Wetness Index
- MODIS Enhanced Vegetation Index (EVI)
- surface reflectances for MODIS
- MODIS land surface temperature
- Snow cover occurrence
- MODIS Flood Water
- Land cover classes - GlobCover30
- Monthly precipitation - WorldClim
- Lithologic units - n Global Lithological 195 Map GLiM
- Landform classes - Map of Global Ecological Land Units
- Average soil and sedimentary-deposit thickness in meters
- Global Water Table Depth in meters; after Fan et al.

DEM

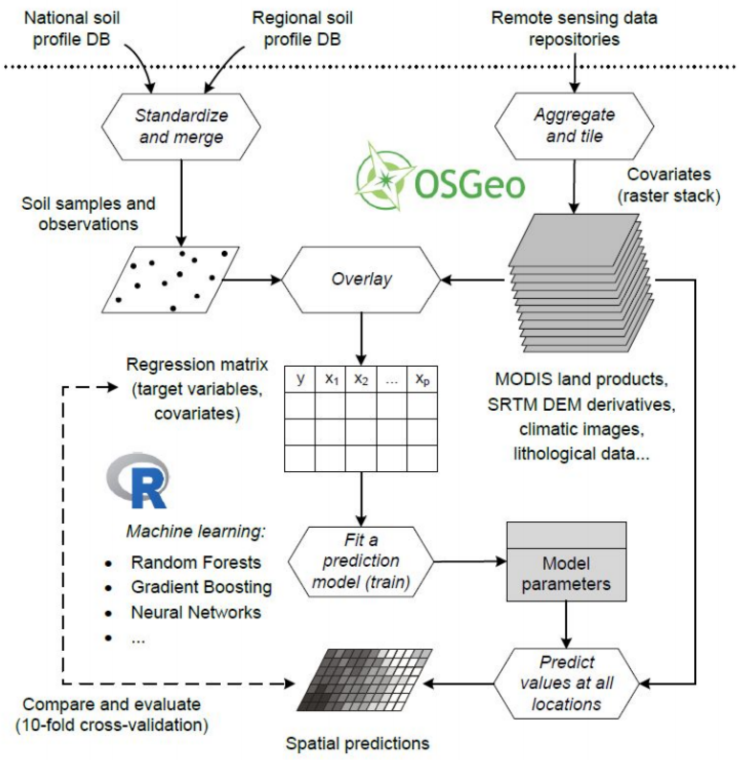
Remote Sensing

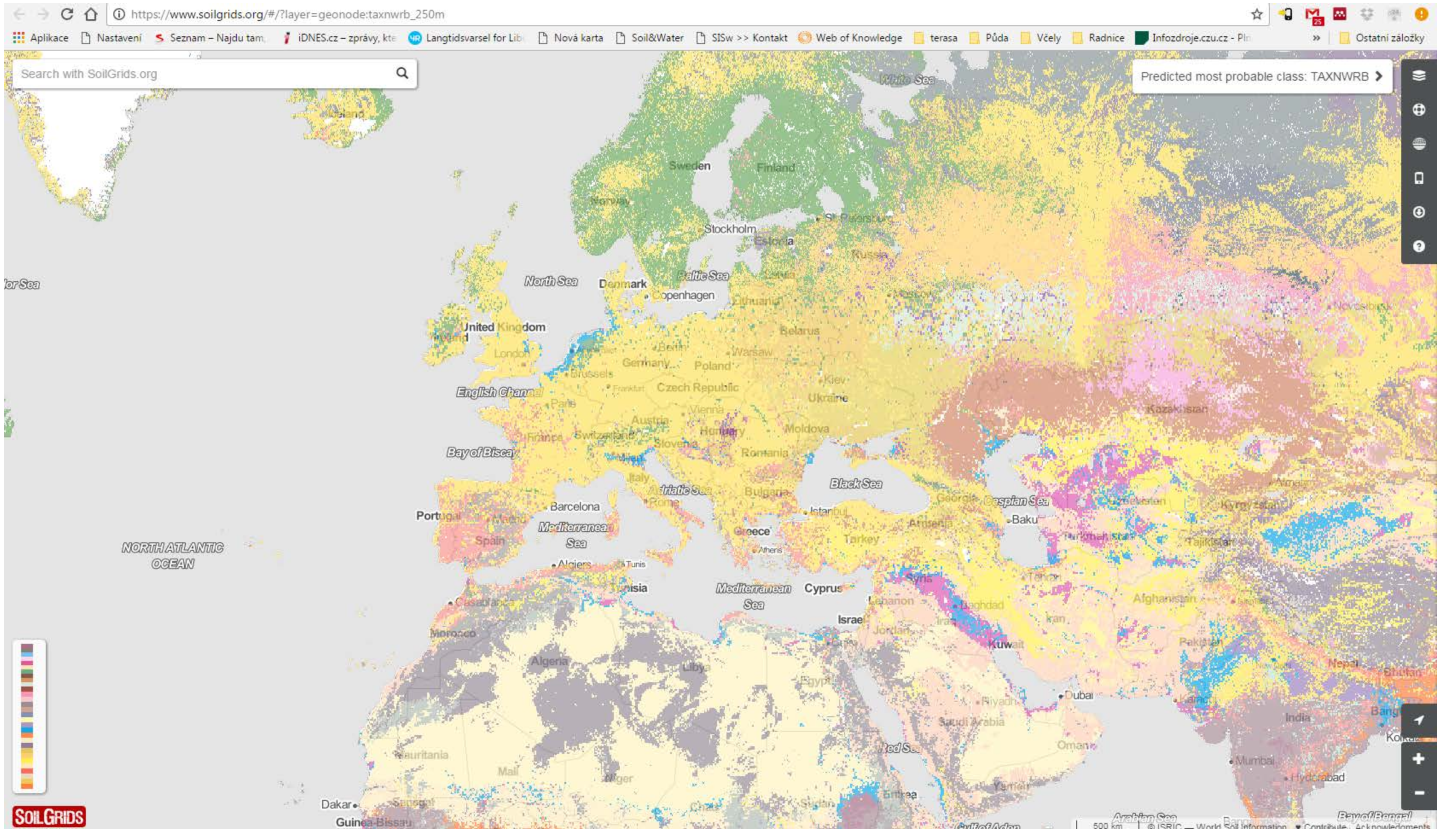
Interpolated measurements

Other sources – digital mapping products

- machine learning methods
  - random forest and gradient boosting
  - multinomial logistic regression

- Software used
  - SAGA
  - R raster package
  - GDAL
  - …

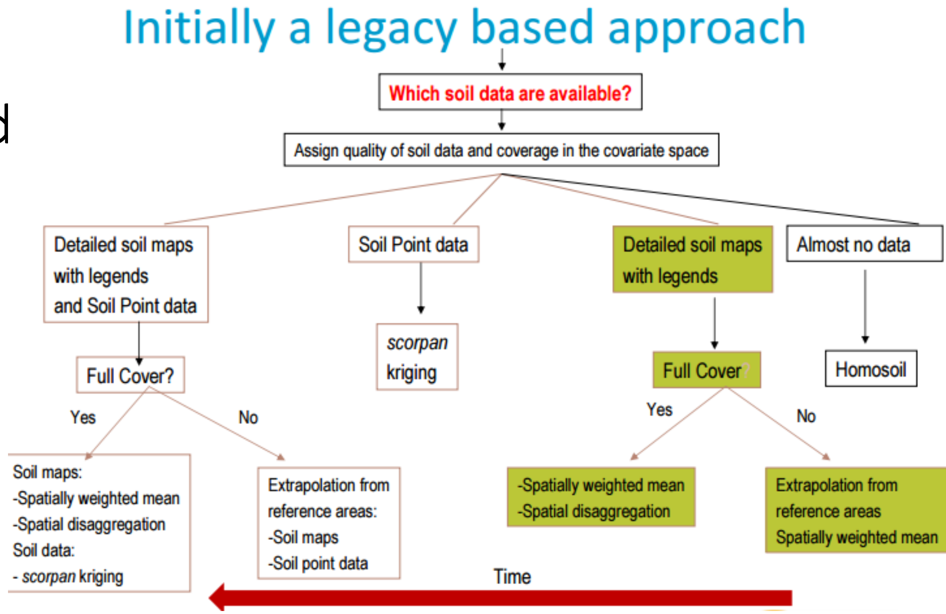




https://www.soilgrids.org/#/?layer=geonode:taxnwrb_250m

Map products: Glogalsoilmap

- Aim: digital soil map of the world using state-of-the-art and emerging technologies for **soil mapping and predicting soil properties at fine resolution**
- aim to assist better decisions in a range of global issues such as food production and hunger eradication, climate change, and environmental degradation
- soil properties at a grid resolution of **90 by 90 meters**
- **freely available**, web-accessible



- Twelve soil properties will be predicted
  - (1) total profile depth (cm)
  - (2) plant exploitable (effective) soil depth (cm)
  - (3) organic carbon (g/kg)
  - (4) pH (x10)
  - (5) sand (g/kg)
  - (6) silt (g/kg)
  - (7) clay (g/kg)
  - (8) gravel (m3 m-3)
  - (9) ECEC (cmolc/kg)
  - (10) bulk density of the fine earth (< 2 mm) fraction (excludes gravel) (Mg/m3)
  - (11) bulk density of the whole soil in situ (includes gravel) (Mg/m3) and
  - (12) available water capacity (mm).

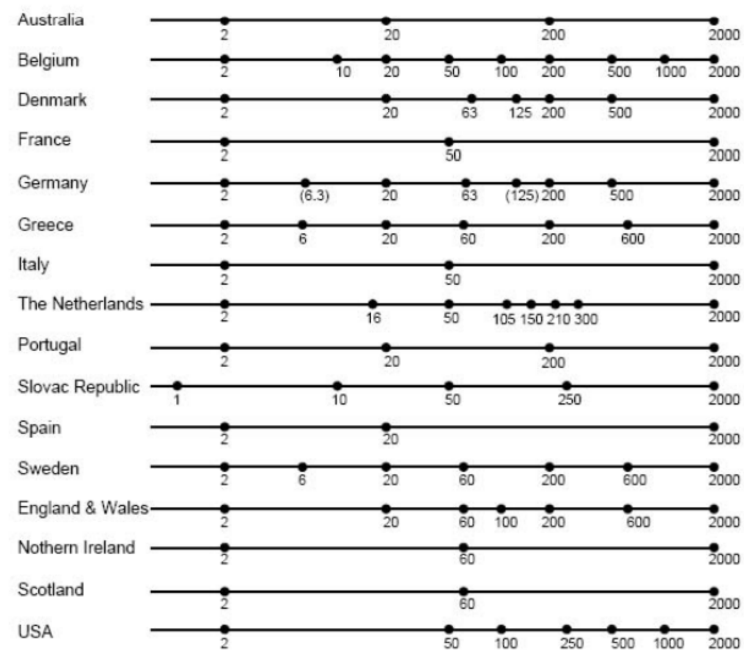
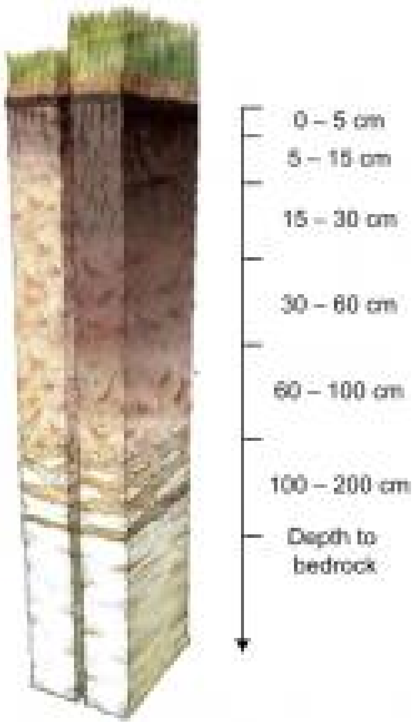


Table 10. Regression equations for converting values of pH between different methods

No.	Target Method (Y)	Source Method (X)	Equation	R2	Reference
1	pH (1:1 0.01 m CaCl2)	pH (1:1 water)	$y = 1.08(x) - 0.973$	0.98	Miller and Kissel (2010)
2	pH (1:1 0.01 m CaCl2)	pH (saturated paste)	$y = 1.10 (x) - 0.923$	0.98	Miller and Kissel (2010)
3	pH (1:1 0.01 m CaCl2)	pH (1:2 water)	$y = 1.05 (x) - 0.950$	0.97	Miller and Kissel (2010)
4	pH (1:1 water)	pH (1:1 0.01 m CaCl2)	$y = x + 0.267 (\text{EC 1:1 water})^{-0.445}$	0.99	Miller and Kissel (2010)
5	pH (1:2 water)	pH (1:1 0.01 m CaCl2)	$y = x + 0.239 (\text{EC 1:1 water})^{-0.505}$	0.98	Miller and Kissel (2010)
6	pH (1:5 0.01 m CaCl2)	pH (1:5 water)	$y = 1.012 (x) - 0.76$	0.99	Conyers and Davey (1988)
7	pH (1:5 0.01 m CaCl2)	pH (1:5 water)	$y = 0.979 (x) - 0.71$	0.68	Bruce et al., (1989)
8	pH (1:5 0.01 m CaCl2)	pH (1:5 water)	$y = 0.887 (x) - 0.199$	0.88	Aitken and Moody (1991)
9	pH (1:5 0.01 m CaCl2)	pH (1:5 water)	$y = 0.197 (x)^2 - 1.21 (x) + 5.78$	0.92	Aitken and Moody (1991)

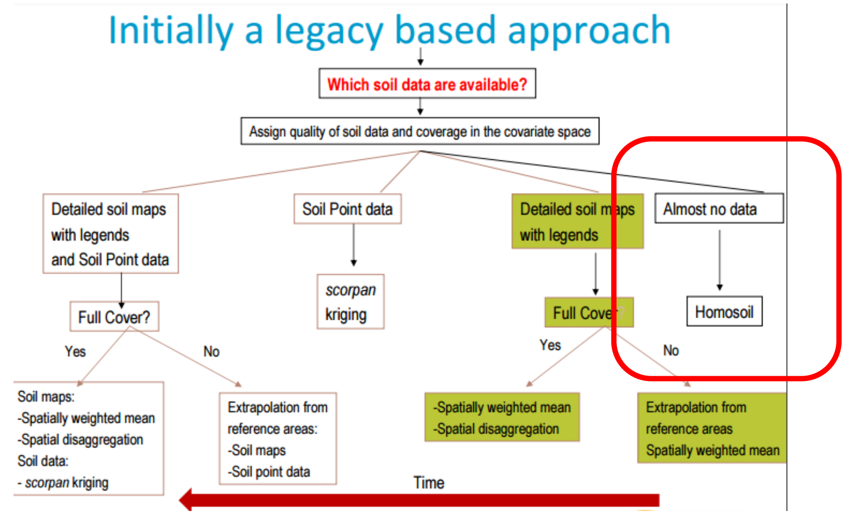
- 6 standard depth intervals:
  - 0-5 cm,
  - 5-15 cm,
  - 15-30 cm,
  - 30-60 cm,
  - 60-100 cm and
  - 100-200 cm

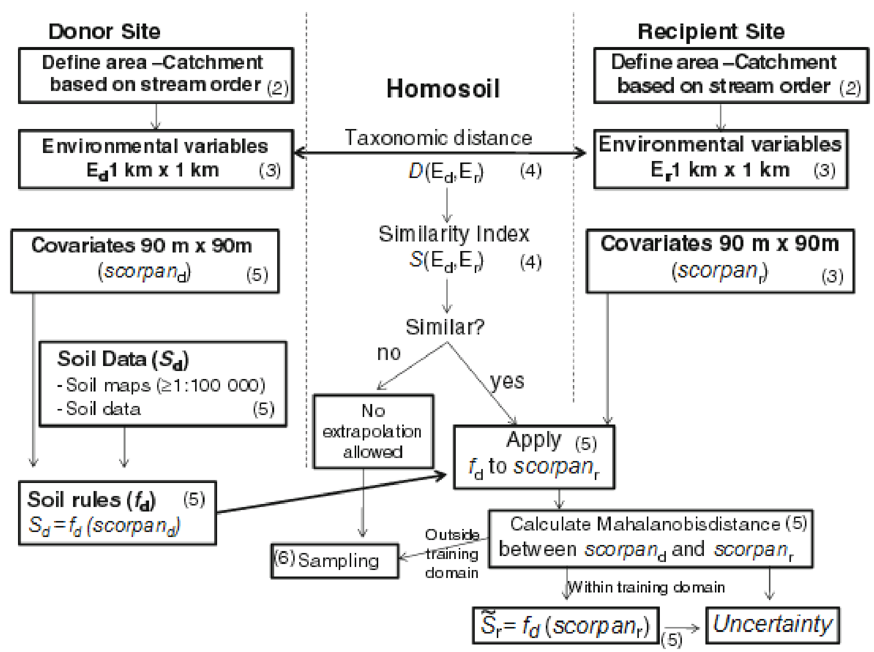
- Uncertainty Definition
  - 90% Prediction Interval (PI)



Applications: Homosoils

- Assumes homology of soil-forming factors between reference area and area of interest
  - Climate
  - Physiography
  - Parent materials
- Seeking smalest taxonomical distance of scorpan factors





- Climate data
  - Climate research unit / CRU
  - Solar radiation, rainfall, temperature, evapotranspiration
- Terrain
  - HYDRO1k
  - Elevation, slope, compound topographic index
- Geology
  - Lithology of the world
  - 0.5x.05° grid

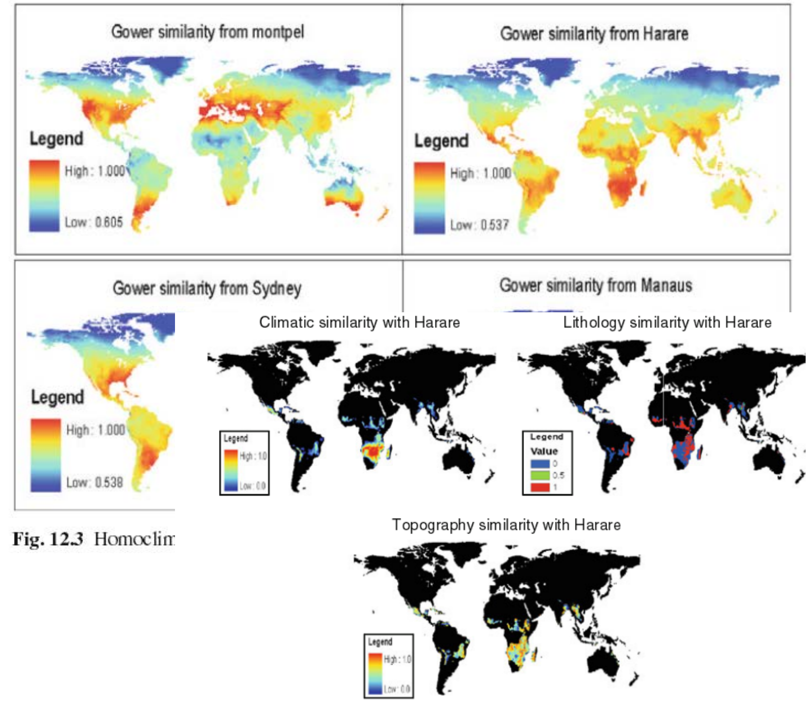
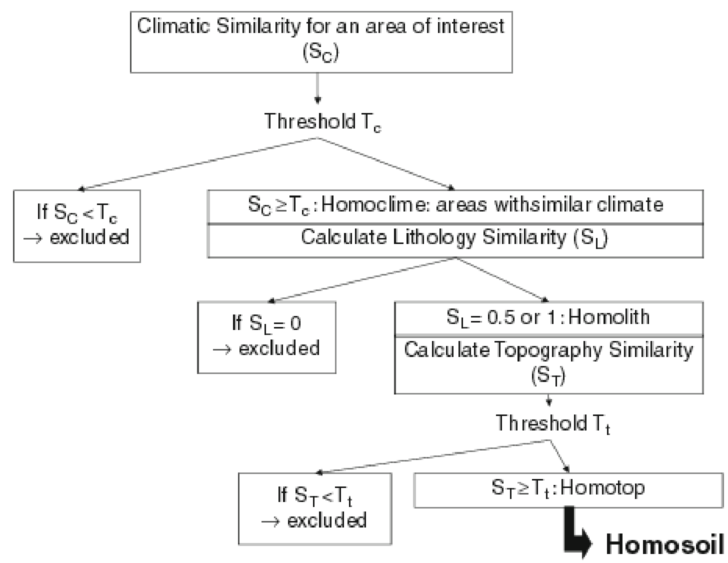


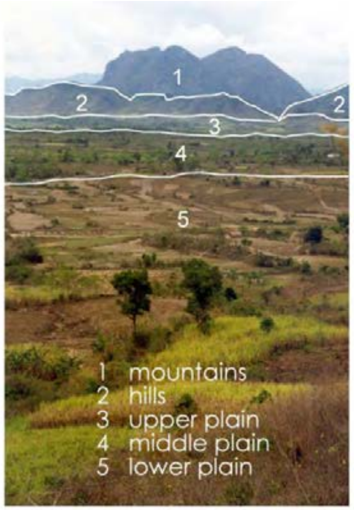
Fig. 12.3 Homoclim

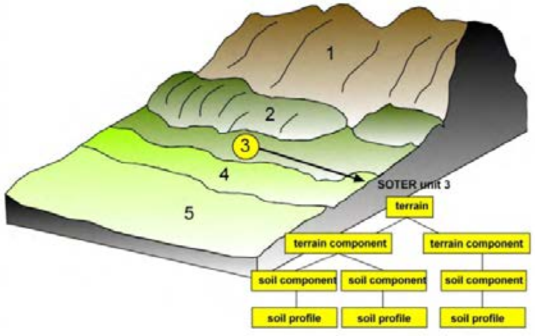
Fig. 12.4 Homoclime, homotop, and homolith for Harare

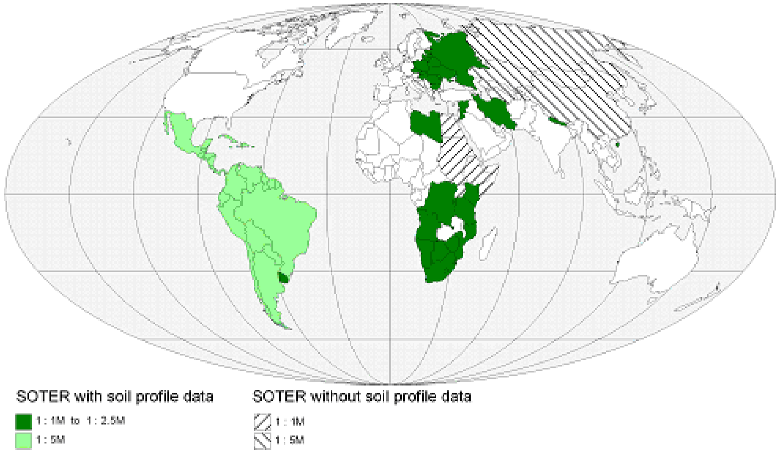


Map product: eSOTER

- SOTER (SOil and TERrain database)
  - scale 1:5 000 000
  - implemented by FAO, UNEP and ISRIC
  - Aim to to establish geodatabase containing digidized map units (area class maps) and their **attribute data**
  - <u>Main principle: </u>delineation of areas with distinctive, often repetetive, pattern of **landform**, **lithology**, surface form, slope and **soil**







Map product: eSOTER

- A comprehensive soil observing system consists of five components:
  - data collection
  - transformation
  - data management
  - interpretations
  - delivery

- …but: present system cannot fulfill the requirement for immediately accessible, interoperable, digital information on specific soil and terrain attributes, and global coverage is incomplete

- ….eSOTER project

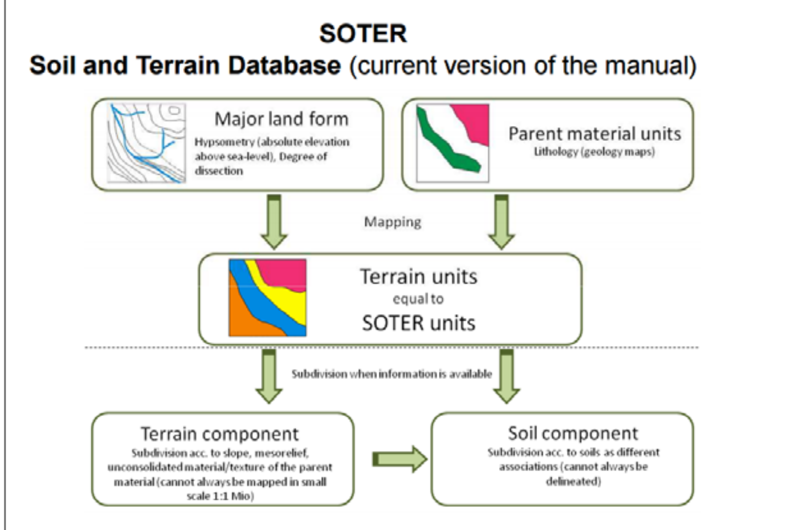


Figure: Bock et al. (in preparation)

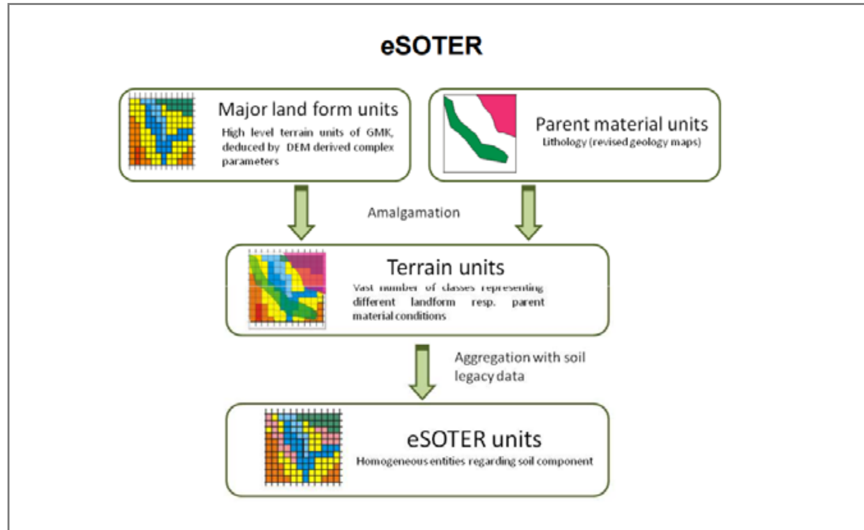
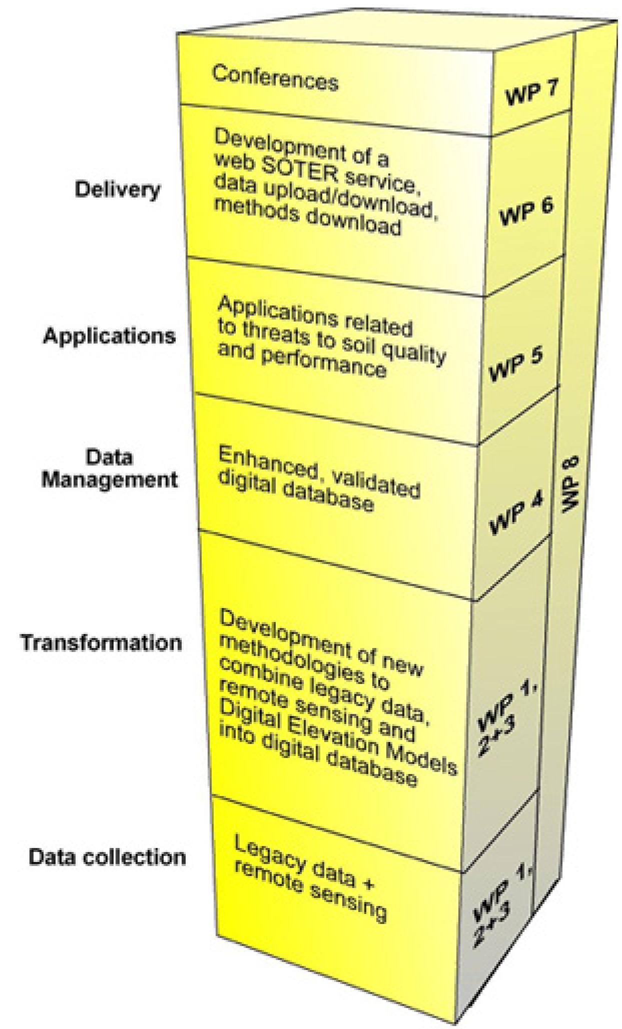


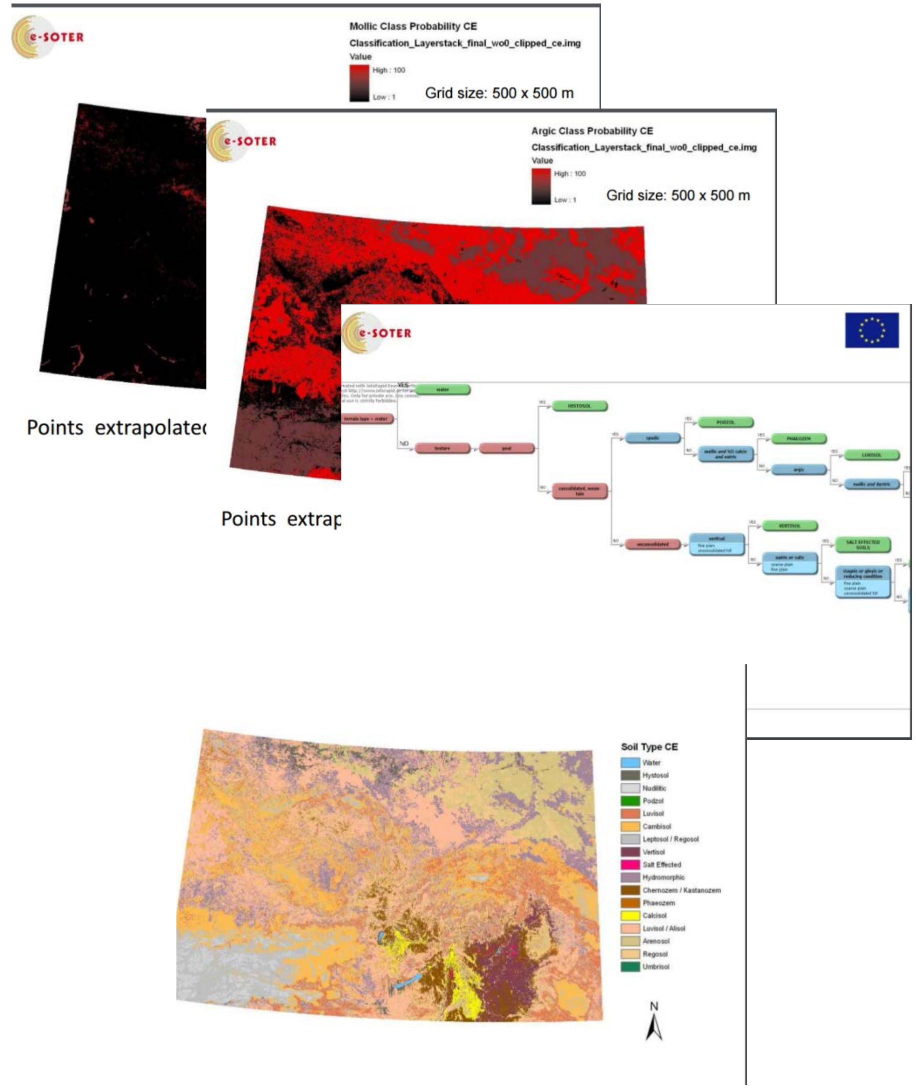
Figure: Bock et al. (in preparation)

Mapping projects: eSOTER

- e-SOTER adds value by:
  - using remotely-sensed data both to validate and correct existing survey data
  - generating new data surfaces
  - improving the quality of results of applications previously based on legacy data alone
  - providing a freely accessible web service that delivers both selected data in an easy-to-use format and procedures to compile e-SOTER databases locally and upload these data to the European database if they meet prescribed quality standards.

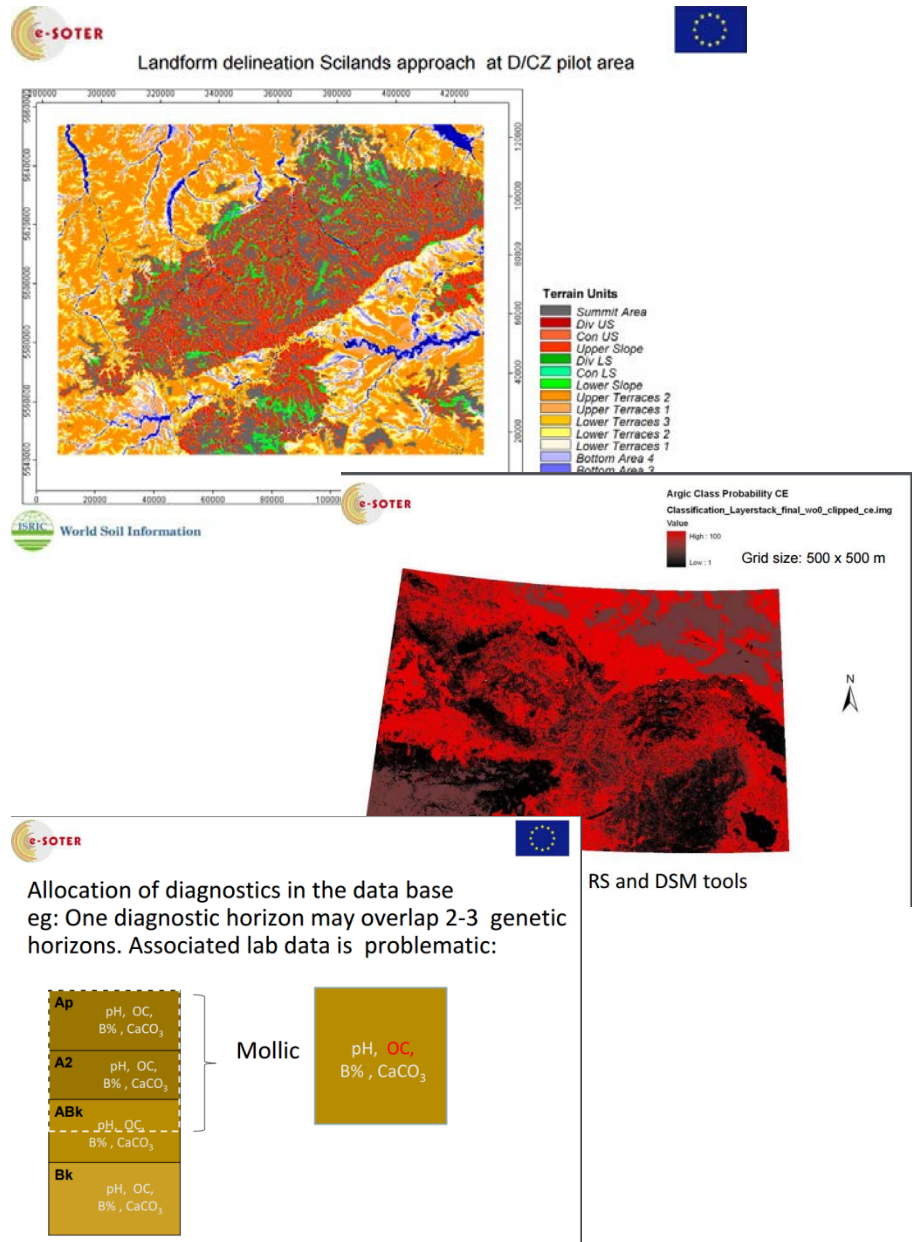


- The project addresses four major barriers to a comprehensive soil observing system:
  - Morphometric descriptions (quantitative mapping of landforms)
  - Soil parent material characterization by remote sensing
  - Soil pattern recognition by remote sensing;
  - Standardization of methods and measures of soil attributes to convert legacy data to a common standard (harmonisation)



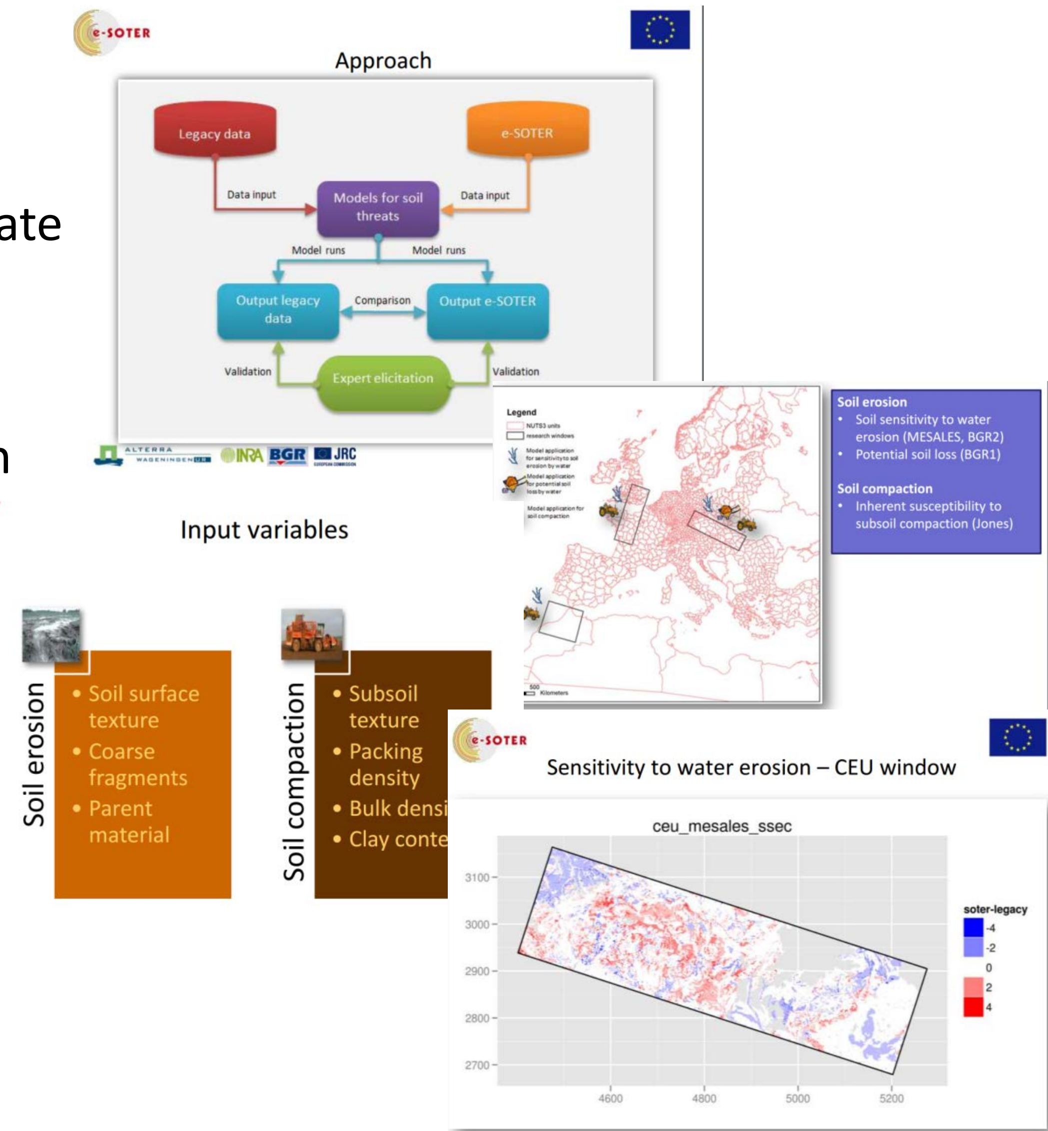
- Morphometric descriptions of landforms
  - Automated, based on the SRTM DEM
  - 1:1M, 1:250k scale
- Soil parent material by RS
  - new hierarchical classification system of soil PM
- Soil by RS
  - Multitemporal MODIS data

- legacy data conversion
  - Converting soil legacy profile data into WRB



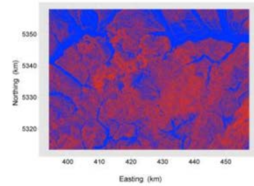
eSOTER: Applications of e-SOTER related to major soil threats

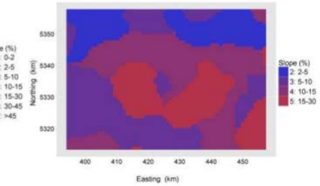
- Objectives:
  - provide examples of how e-SOTER can be used to evaluate threats to soils
- Targed threats
  - Soil compaction and erosion

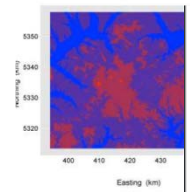


eSOTER: validation and accuracy

- Landform validation
  - More precize DEM

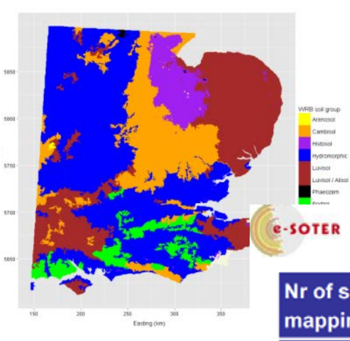


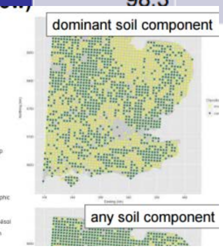




Landform attribute	Western European window		Central European window	
	strict purity	'one-off' purity	strict purity	'one-off' purity
Elevation	81.1	99.4	87.8	99.8
Relief intensity	92.0	99.7	81.1	98.5
Slope	44.6	94.8	50.6	86.6
Flatness	98.3		98.1	

- Soil validation
  - independent existing soil data





e-SOTER

Results soil validation

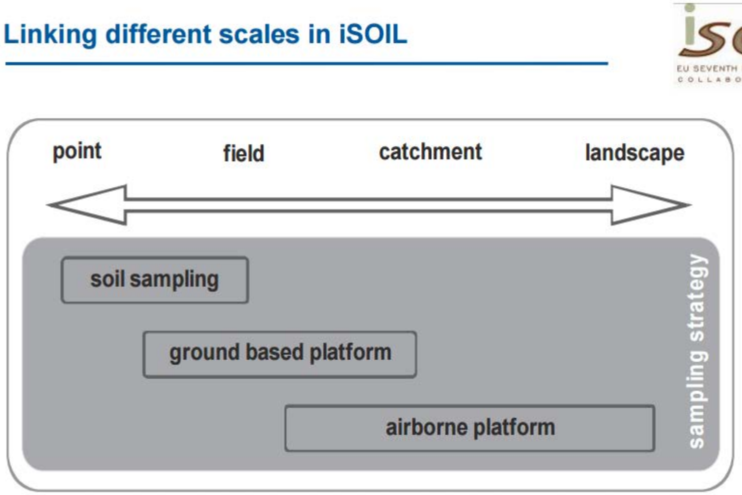
Nr of soil components in mapping unit	UK part Western European window	G/CZ part Central European window
1	51.0	31.2
2	65.4	
3	76.8	
4	83.7	
5	87.6	
Any soil component (in the association)	91.6	86.0

eSOTER

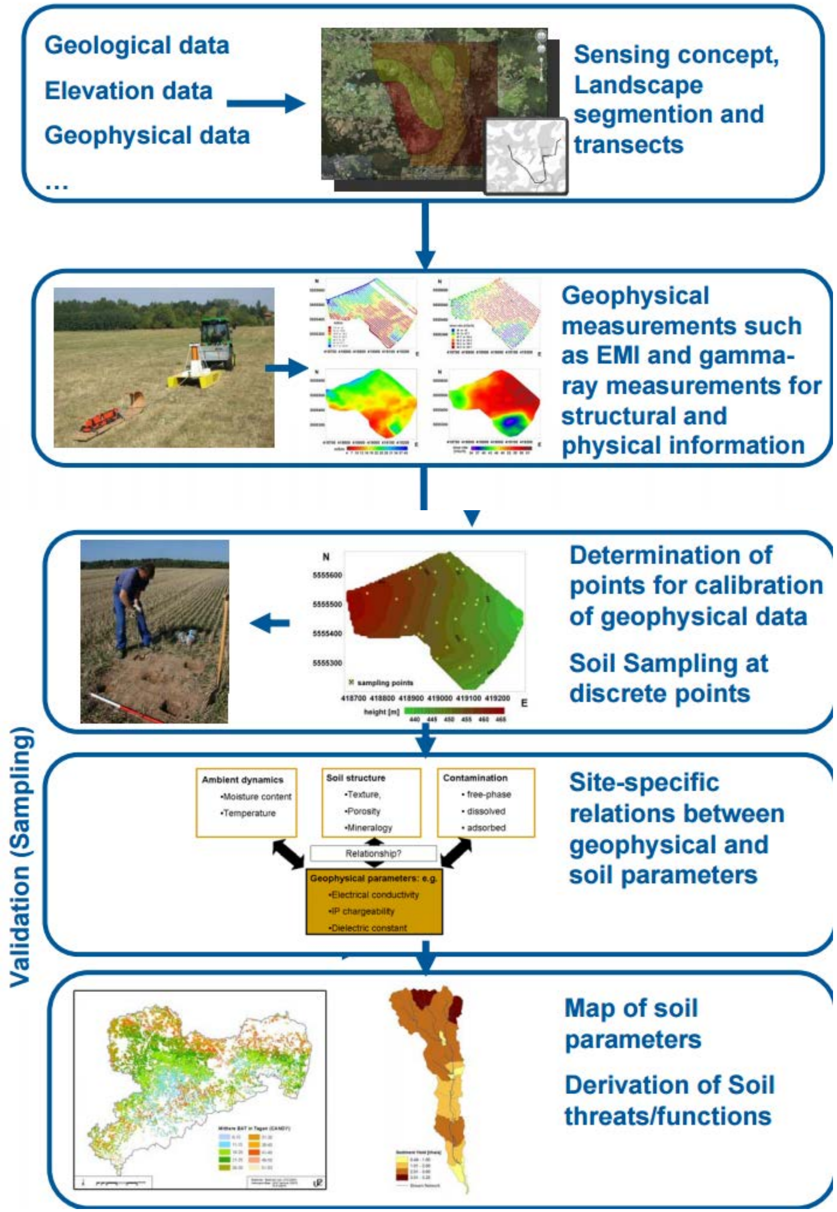
- Updated SOTER methodology enables more precise spatial description of soil cover
- New approaches to WEB dissemination
- Methodology
  - no global product (depend on users)
  - Applications:
    - eSOTER Danube – updated soil database 1:250 000
    - Burkina Faso

Mapping projects: iSOIL

- Interactions between soil related sciences - Linking geophysics, soil science and digital soil mapping
- AIM:
  - application of new technologies for assessing soil properties along depth accurately and with high resolution
  - The focus of the iSOIL project is on improving fast and reliable mapping of soil properties, soil functions and soil degradation threats.
  - Mainly geophysical methods



- **Objectives:**
  - Development of new and the improvement of existing methods that include geophysical, spectroscopic and monitoring techniques
  - Development, validation and evaluation of necessary concepts and strategies for the transfer of measured physical parameter distributions into soil maps
  - Development of guidelines for target-oriented soil mapping realistic for end-users
  - Dissemination of the technologies and concepts developed



Application: SoLIM

- SoLIM = Soil Land Inference Model
- a new technology for soil mapping based on recent developments in geographic information science (GISc), artificial intelligence (AI), and information representation theory
- designed to improve the methods, efficiency and accuracy of the soil survey
- used in USA for as supporting tool for soil mapping

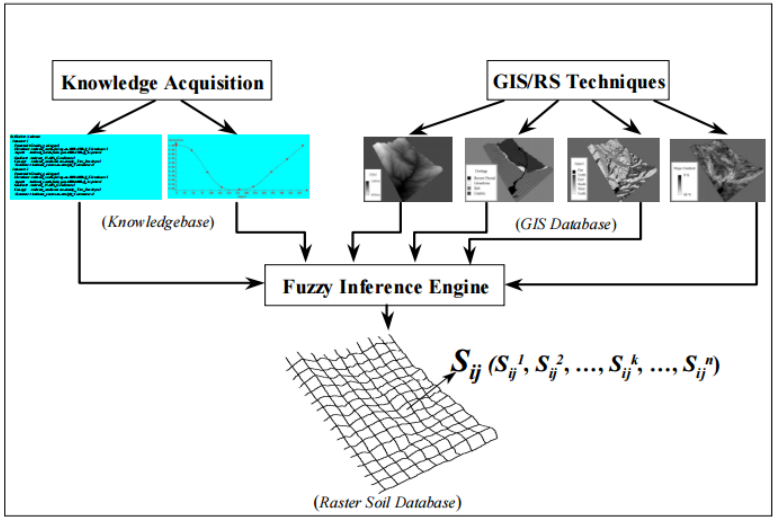
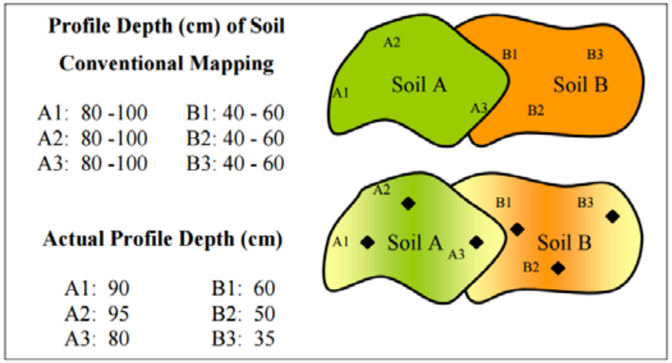


Figure 6.1: The inference process



- Based on fuzzy logic
  - the soil at a given pixel can be assigned to more than one soil class with varying degrees of class assignment
  - These degrees of class assignment are referred to as fuzzy memberships
  - Each fuzzy membership is regarded as a similarity measure between the local soil and the typical case of the given class

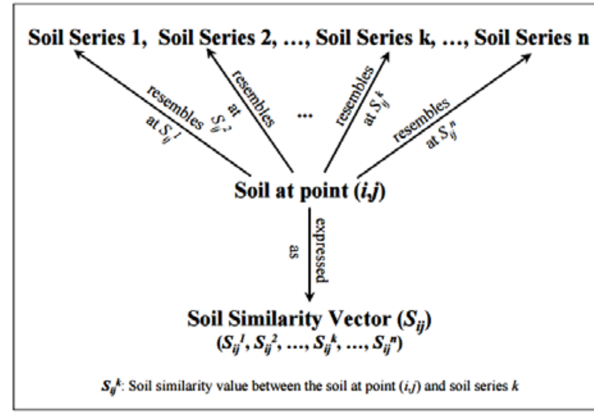


Figure 3.1: Fuzzy representation of soil information using soil similarity vector

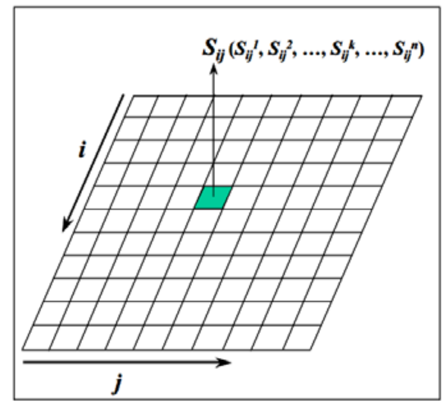


Figure 3.2: The similarity model for representing detailed soil spatial information

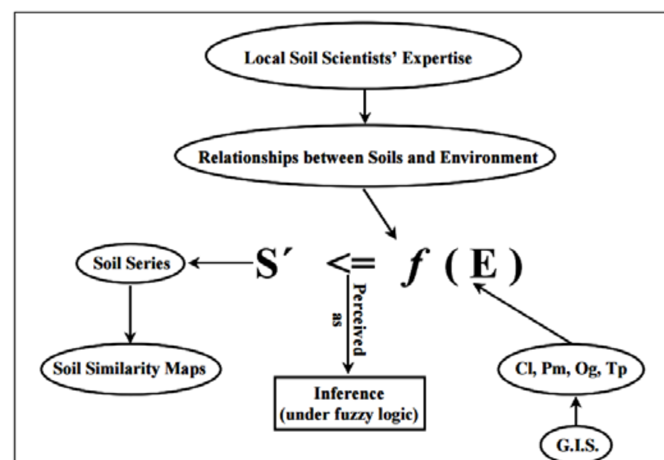
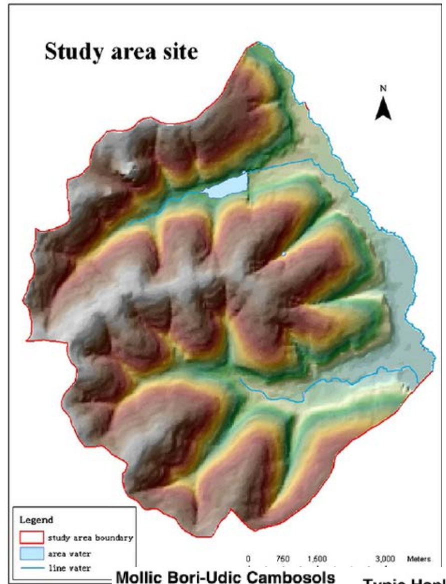
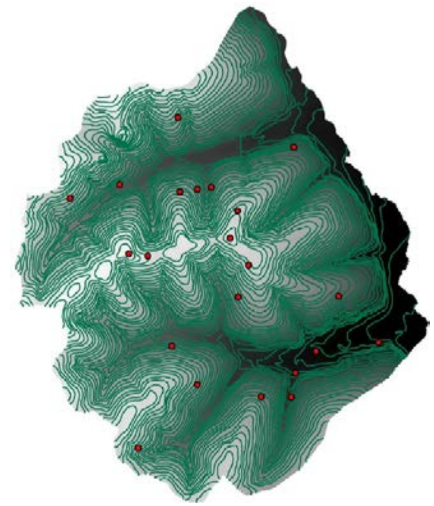


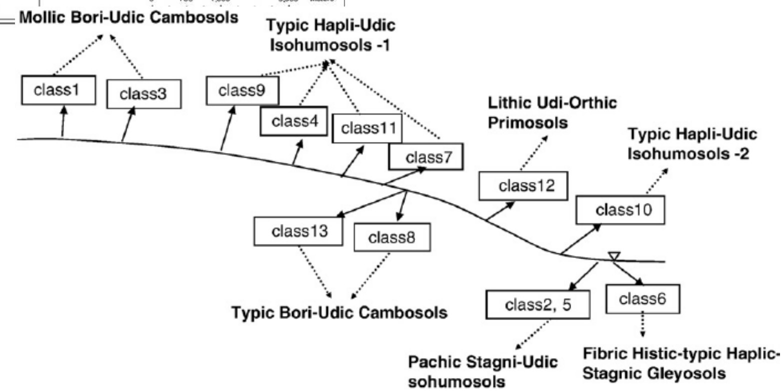
Figure 4.1: Implementation of SoLIM

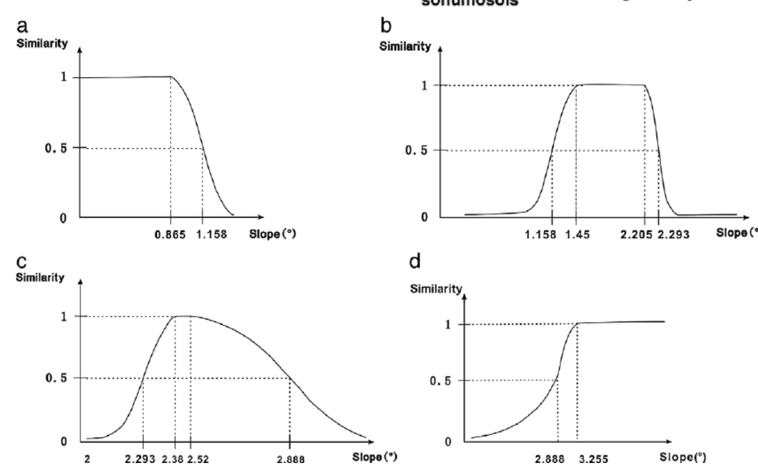
- Typical auxiliary data:
  - Topography:
    - elevation,
    - slope aspect,
    - slope gradient,
    - profile and planar curvatures,
    - upstream drainage area,
    - wetness index,
    - distance to streams,
    - distance to ridges.
  - Bedrock and/or surficial geology
  - Landuse/vegetation

- characterizes soils for pixels using a similarity model
- represents the soil at each pixel as a collection of fuzzy membership values
- Each membership value provides the similarity of the pixel's soil to a known soil type
- raster/similarity representation allows portrayal of soil as a spatial continuum









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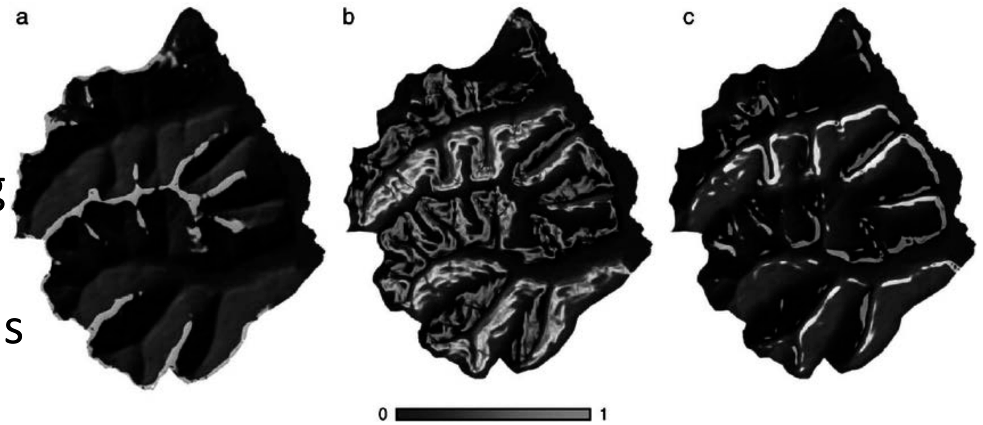
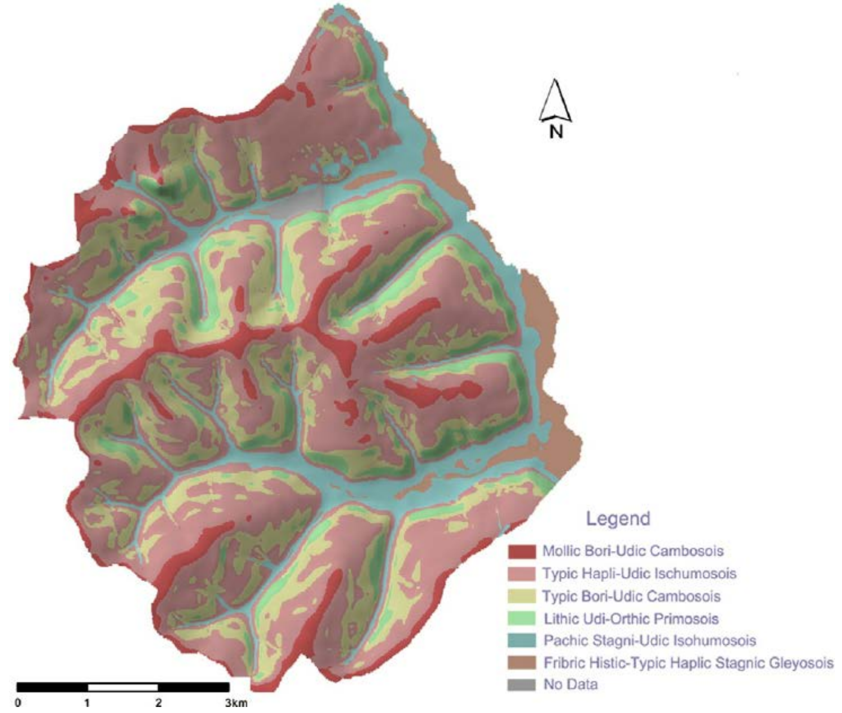




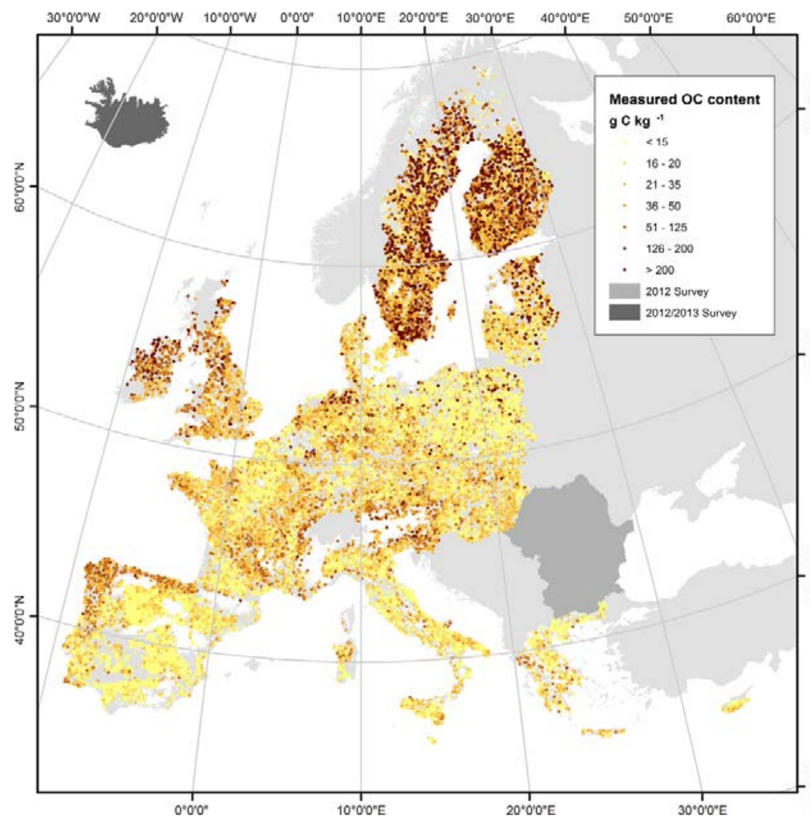
- map products:
  - fuzzy membership maps - membership of soils for a given soil type
  - detailed raster soil categorical maps - soil bodies as small as a single pixel
  - conventional soil maps - filtering out the small soil bodies from the detailed raster soil categorical maps

- Advantages:
  - Consistency
  - Accuracy
  - higher spatial resolution
  - time and cost savings compared to traditional soil surveys
  - Explicit documentation of soil-landscape relationships

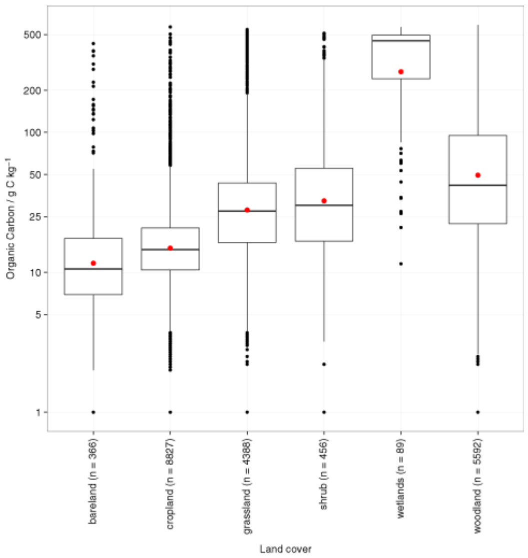
- Disavantages:
  - Depends on the quality of the input data
  - extracting information from local soil experts
  - Methods such as fuzzy c-means clustering and data mining need to be further explored

Case study: Regional data harmonisation - LUCAS

- attempt to build a consistent spatial database of the soil cover across the EU based on standard sampling and analytical procedures
- 19,967 topsoil samples with unique geo-referenced locations were collected in 23 Member States
- dispatched to a central laboratory

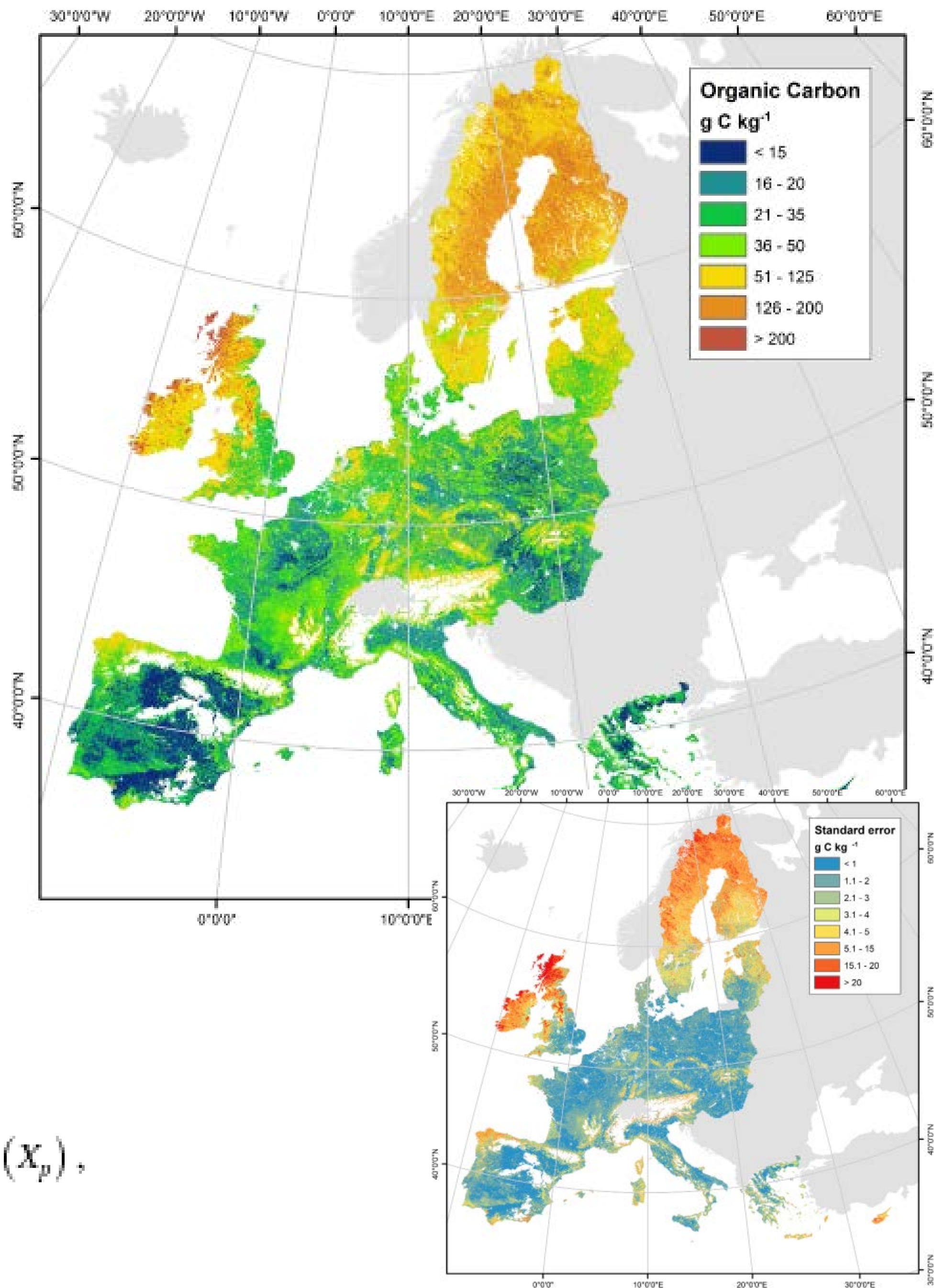


- Soil samples have been analysed for:
  - particle size distribution,
  - pH,
  - organic carbon, carbonates,
  - NPK,
  - cation exchange capacity (CEC) and
  - multispectral signatures



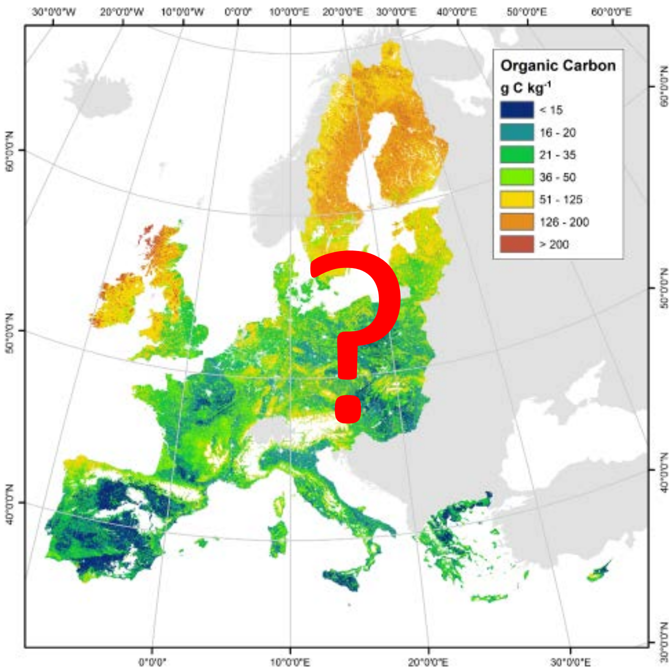
- dataset was split into a calibration (85%) and a validation (15%)
- Auxiliary data
  - elevation, slope, net primary productivity, temperature, PP_0, latitude, longitude, measured OC content and CORINE land cover
- Model
  - Generalized linear regression model (GAM)

$$E\left(Y|X_1, X_2, \ldots, X_p\right) = \alpha + f_1\left(X_1\right) + f_2\left(X_2\right) + \ldots\ f_p\left(X_p\right),$$

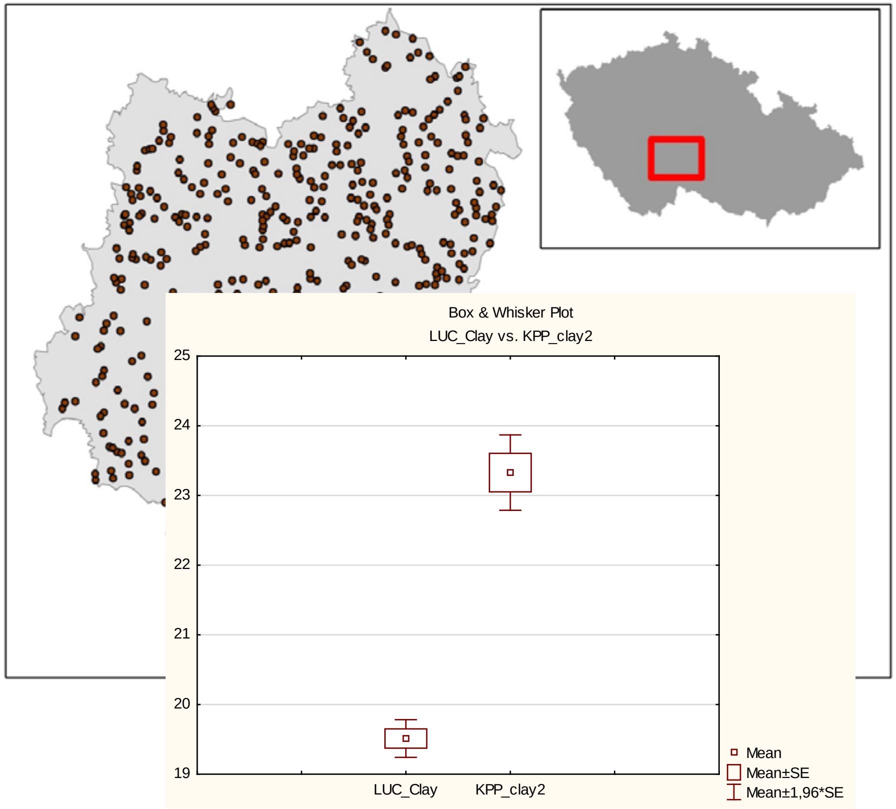


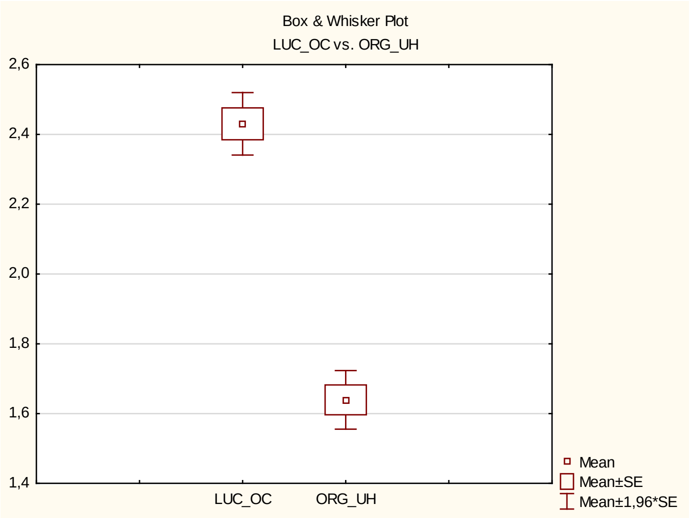
LUCAS validation

- Aim:
  - to compare data extracted from the predicted maps based on LUCAS dataset
  - Comparison to values originated from a soil survey



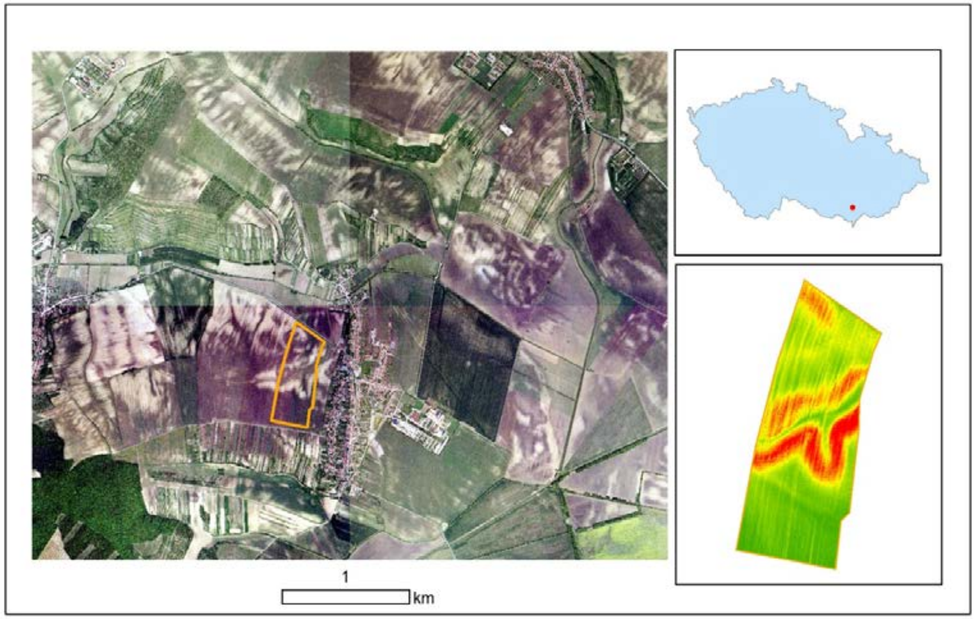
- Validation dataset originates from the Lange-scale mapping of agriculture soil of Czechoslovakia
  - proceeded in 1961-1971
  - Different analytical limits (clay 0.001 mm)
  - Different analytical methodds (organic matter was measured by wet combustion by dichromium solution)

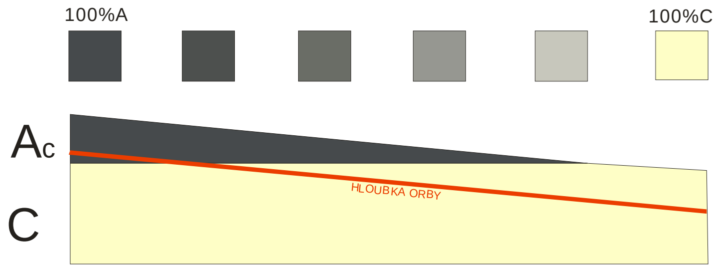


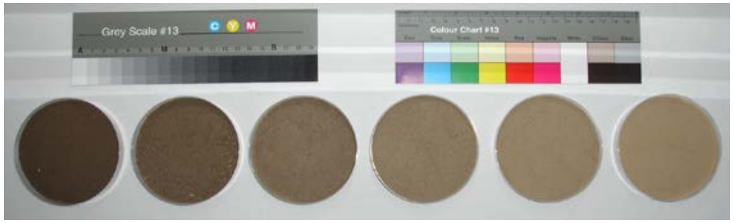


Case study: Assessment of soil degradation due to water erosion

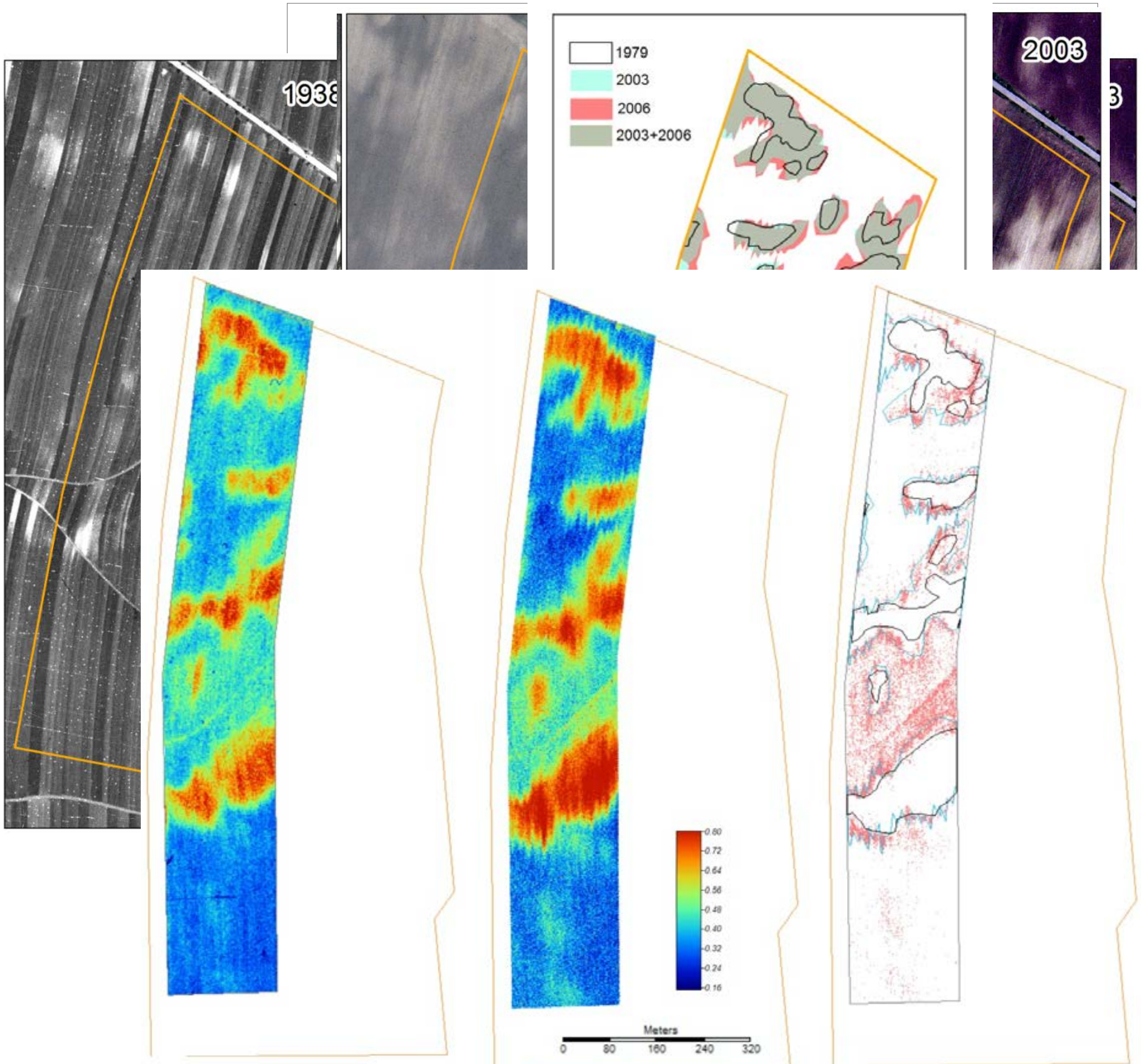
- Aim:
  - To assess soil cover change given by soil degradation due to water erosion between 1930th – 2010th
- Methodology:
  - Loess region in SE Czechia
  - 1. soil color x Cox relationship definition
  - 2. analysis of aerial photographs from given time period
  - 3.delineation of eroded areas
    - Images pre/processing
    - classification





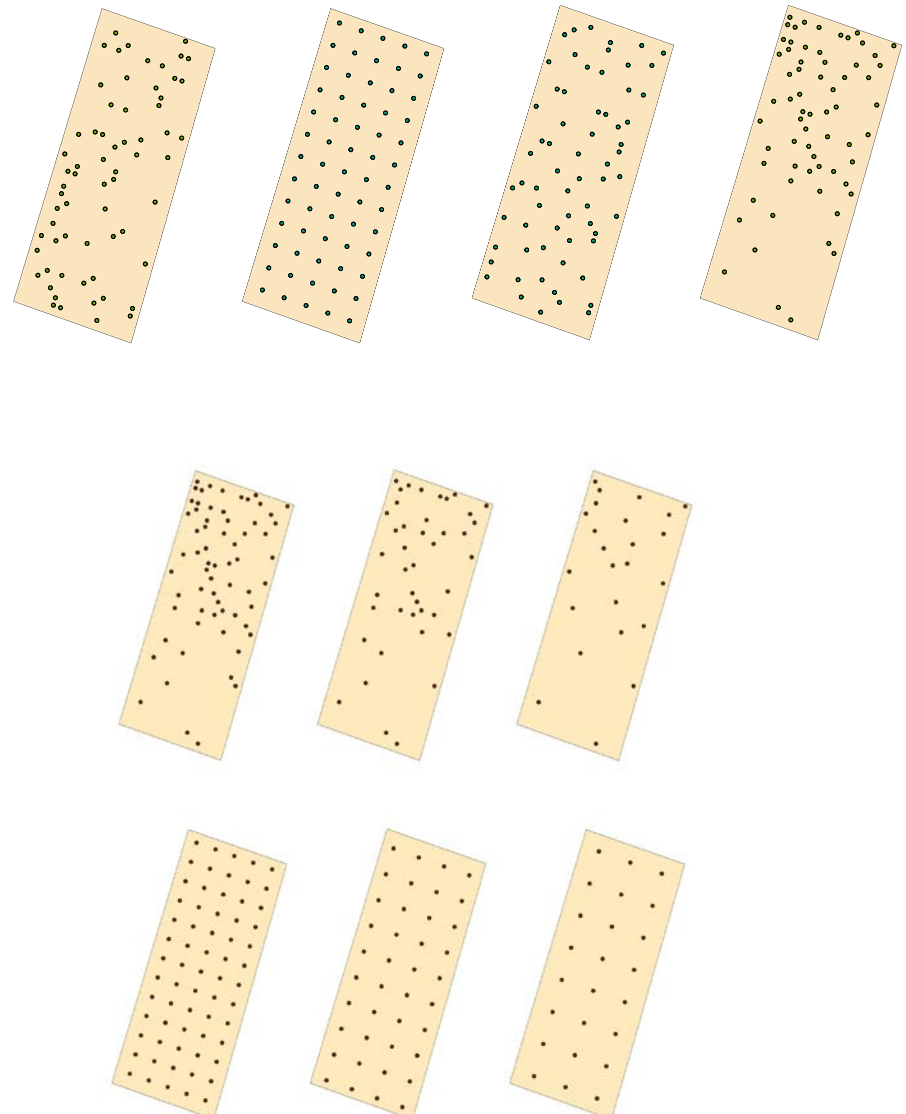


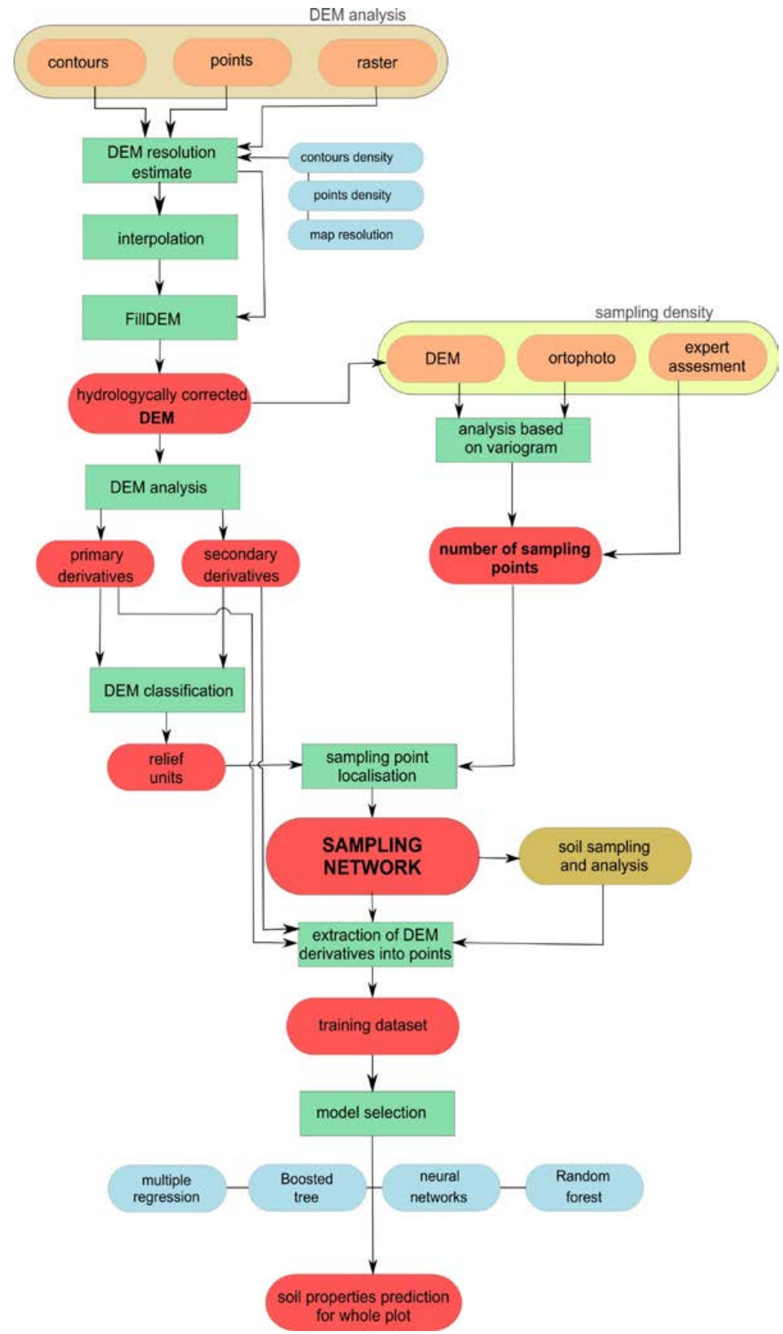
- Results:
  - Quantitative relationship between soil color and Cox
  - Limited area with bare soil exploitable for the analysis (0 – 15 %)
  - Erosion development 1979 - 2003(2006) increased from 18 % to 26,7-30,7 %



Case study: Sampling optimalization in degradated areas

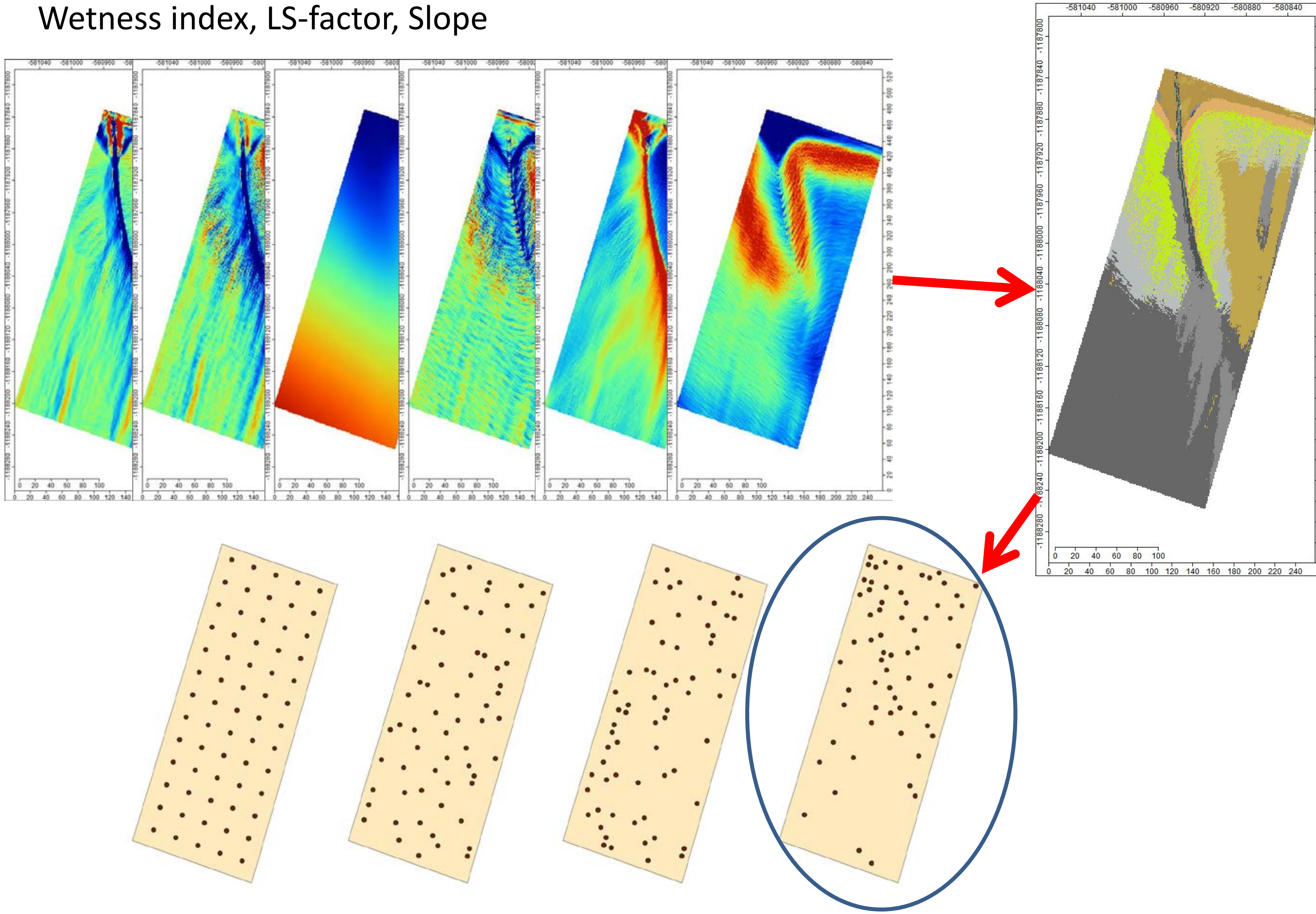
- Aim:
  - To develop optimal sampling scheme for soil assessment in eroded areas
  - Produce map of soil depth
- Methodology:
  - Agriculture plot (6 ha)
  - Comparison:
    - 4 sampling networks
      - Random
      - Regular
      - systematic unaligned
      - Stratified by DEM
    - 3 sampling densities
      - 24
      - 40
      - 60



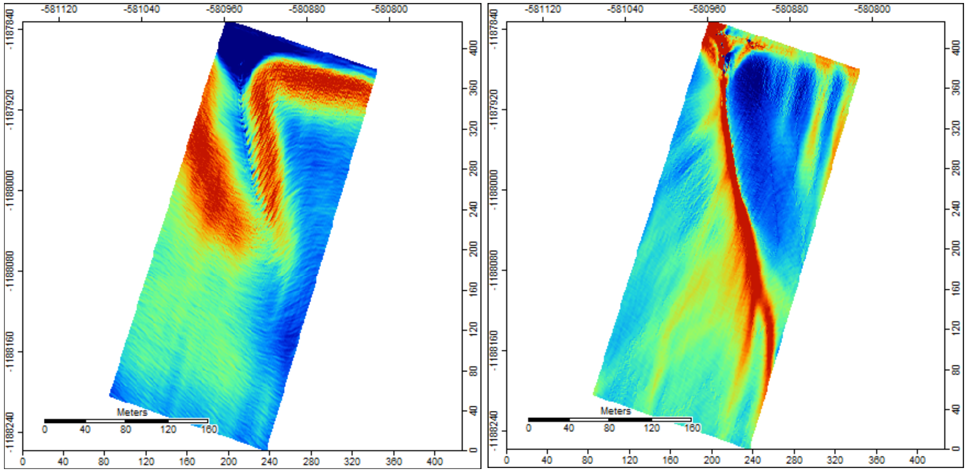


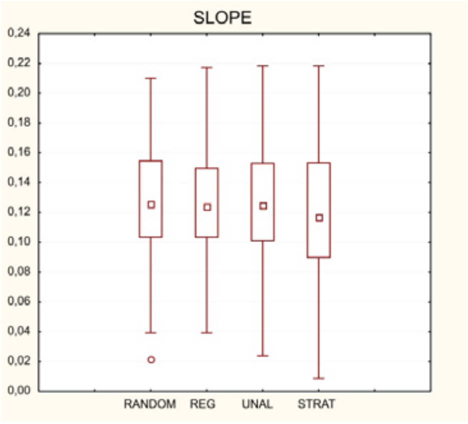
DEM analysis
contours
points
raster
DEM resolution estimate
contours density
points density
map resolution
interpolation
FillDEM
hydrologycally corrected DEM
sampling density
DEM
ortophoto
expert assesment
analysis based on variogram
DEM analysis
primary derivatives
secondary derivatives
number of sampling points
DEM classification
relief units
sampling point localisation
SAMPLING NETWORK
soil sampling and analysis
extraction of DEM derivatives into points
training dataset
model selection
multiple regression
Boosted tree
neural networks
Random forest
soil properties prediction for whole plot

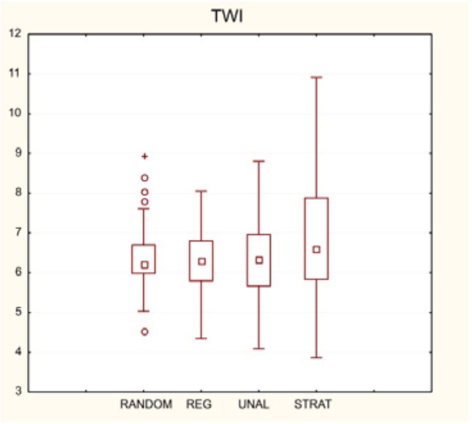
- DEM derivatives: Plan Curvature, Profile Curvature, Vertical Distance To Chanel Network, Convergence Index, Wetness index, LS-factor, Slope



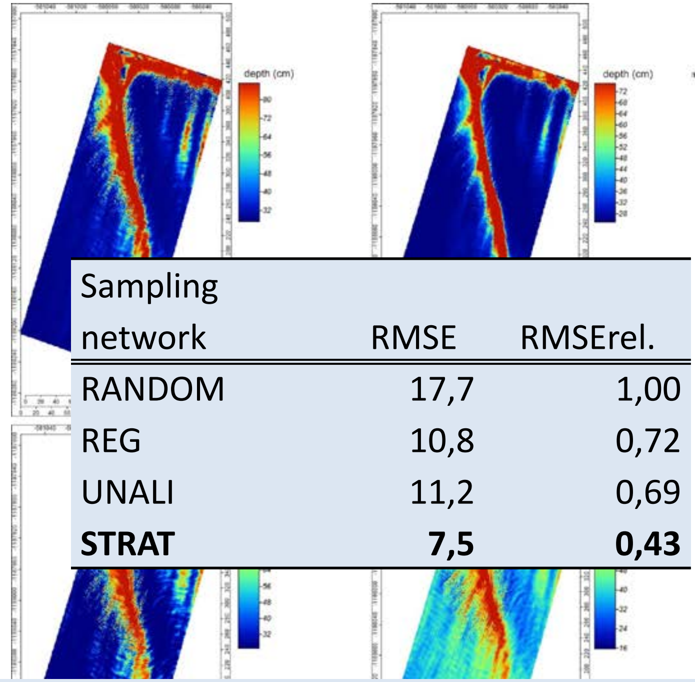
- Results
  - Sampling networks influence sifnificantly the depicted range of terrain properties (main covariates for soil stratification)
  - Stratified sampling network provides best results - lowest RMSE



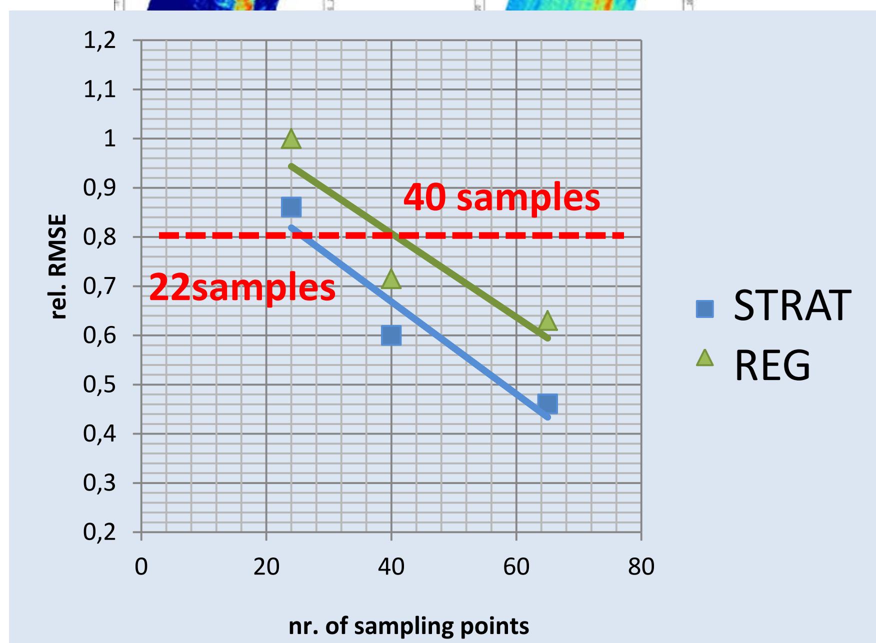




- Results
  - Sampling networks influence sifnificantly the depicted range of terrain properties (main covariates for soil stratification)
  - Stratified sampling network provides best results - lowest RMSE

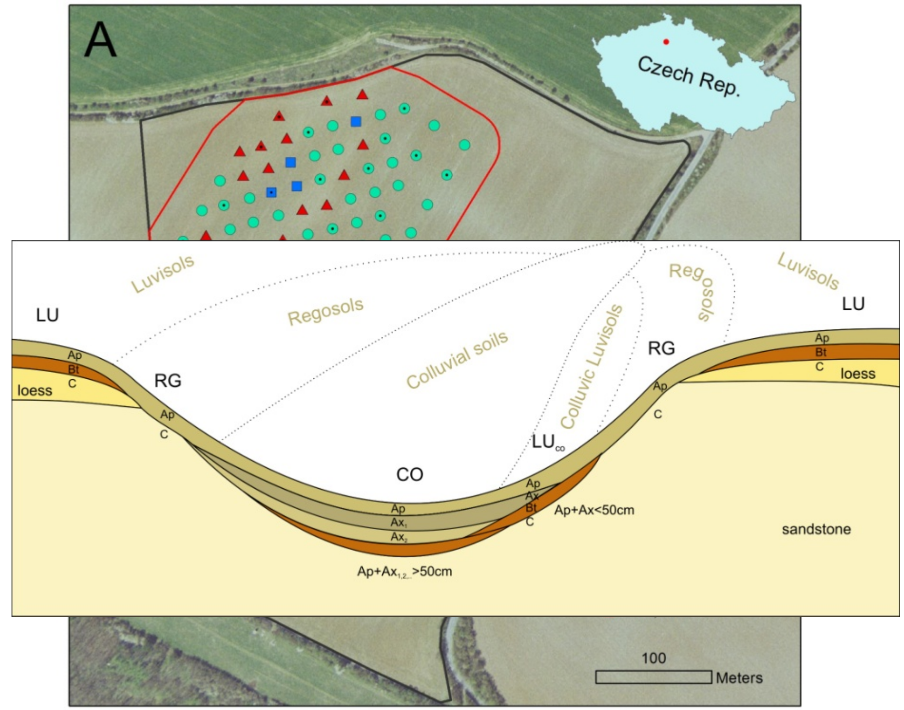


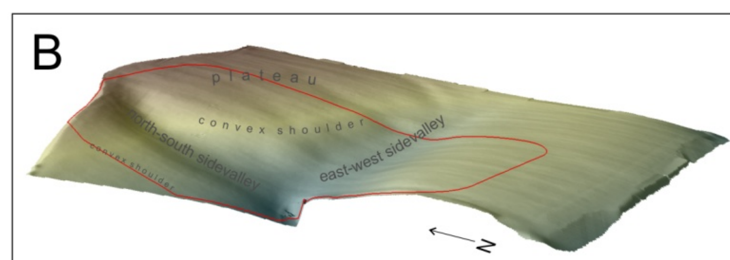
Sampling network	RMSE	RMSErel.
RANDOM	17,7	1,00
REG	10,8	0,72
UNALI	11,2	0,69
STRAT	**7,5**	**0,43**

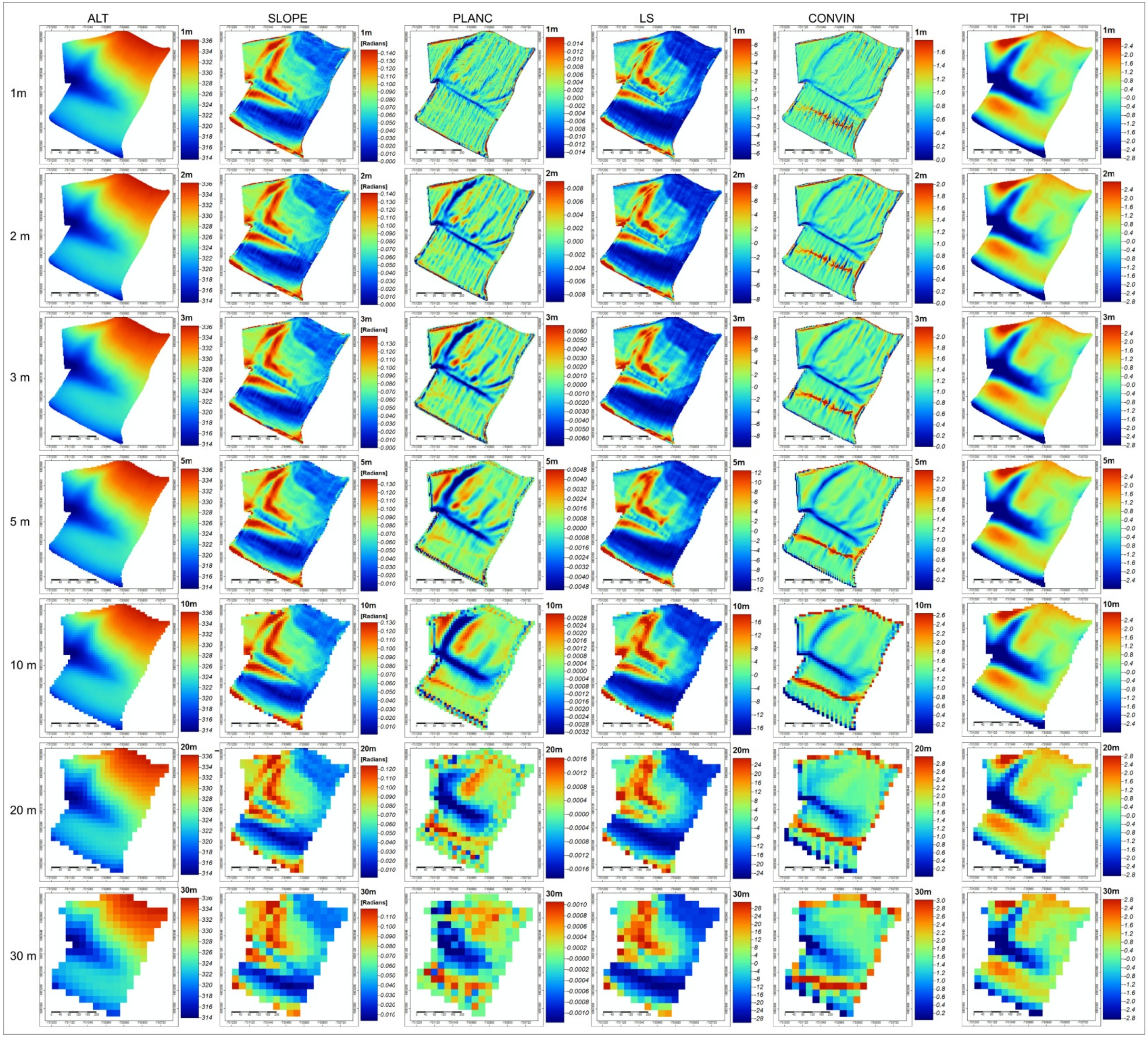


Case study: Influence of auxiliary data resolution on soil mapping

- Aim:
  - Assessment of DTM resolution on delineation of soils
- Methodology:
  - Raster resolution: 1, 2, 3, 5, 10, 20 and 30 meters
  - 6 terrain derivatives + 4 models
  - Set of 111 soil profiles

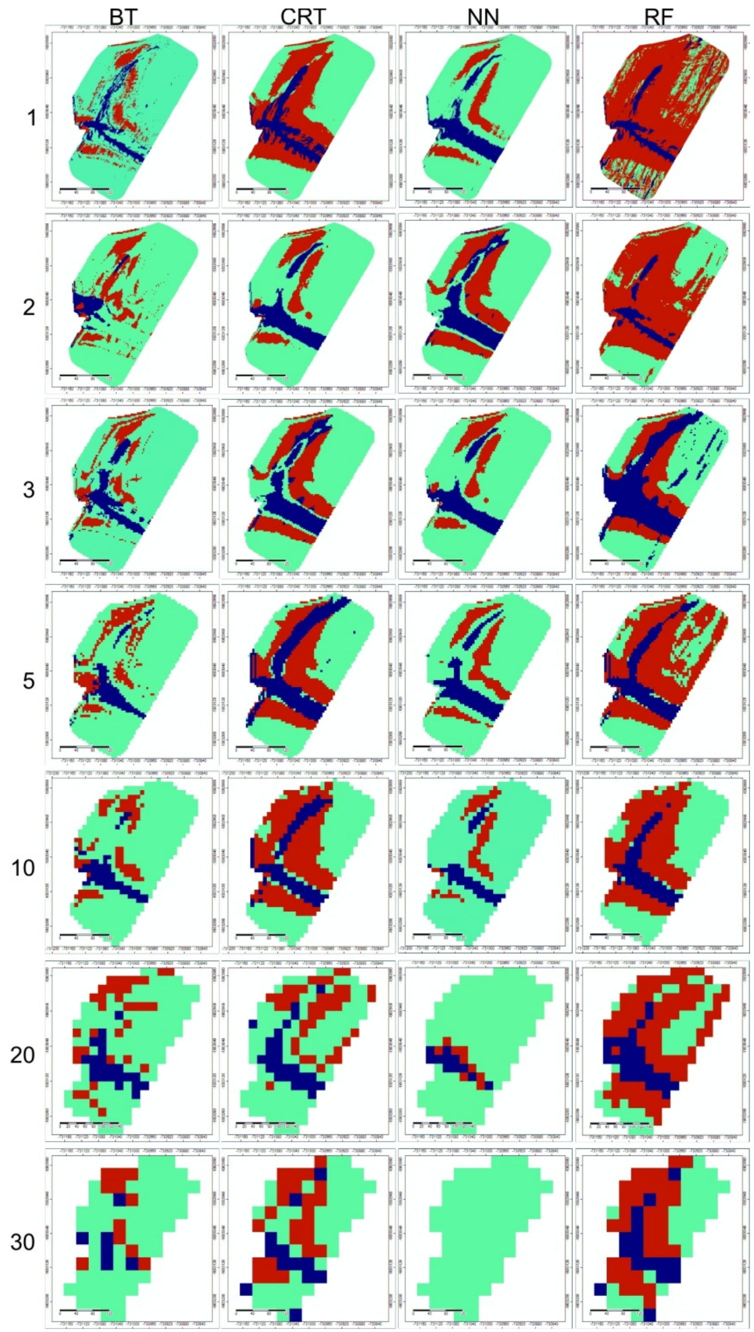


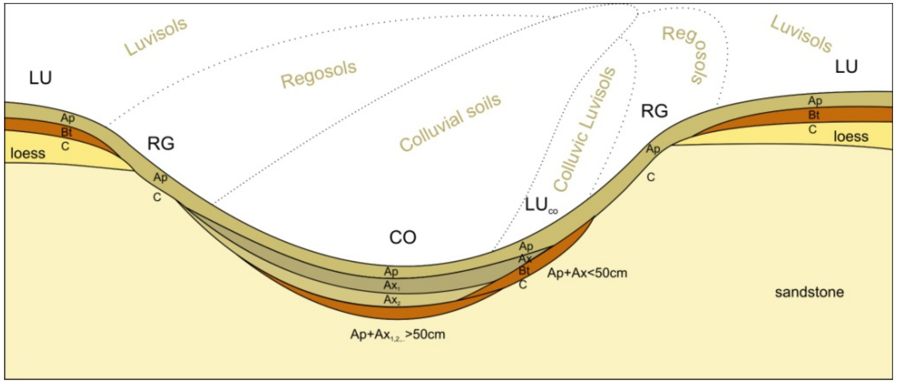




ALT
SLOPE
PLANC
LS
CONVIN
TPI
1m
2 m
3 m
5 m
10 m
20 m
30 m
[Radians]

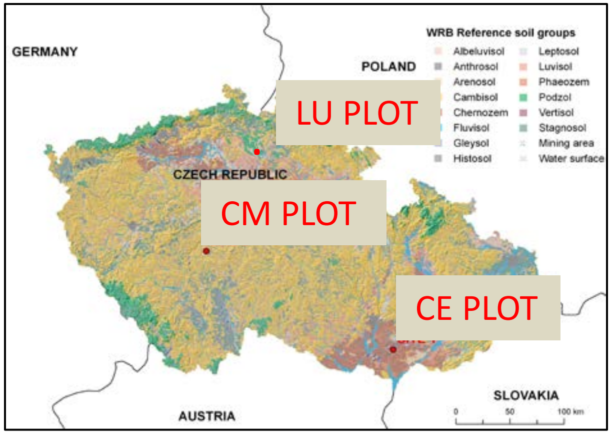
- Results:
  - Resolution significantly influences the range of the DTM derivatives
  - Model accuracy > 70% for all resolutions
  - No direct connection between DTM resolution and prediction accuracy

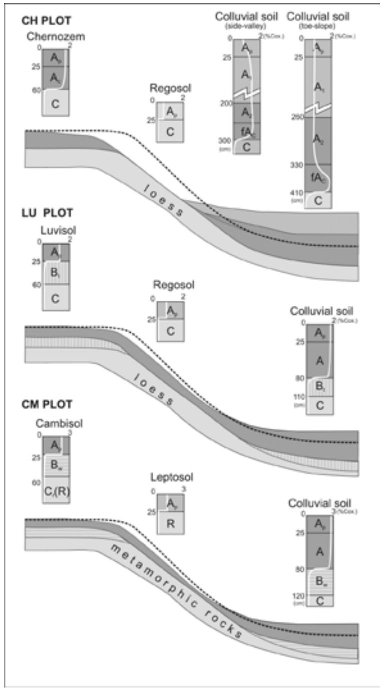




Case study: Delineation of colluvial soils in different soil regions

- Aim:
  - Delineation of colluvial soils
  - Important sink of SOC
- Methodology
  - 558 samplings at a plot scale
  - stereo-photogrammetry based DEM (1 x 1 m grid)
    - Terrain attributes include: altitude (ALT), slope (SLP), plane curvature (PLANC), profile curvature (PROFC), catchment area (CA), topographic wetness index (TWI), topographic position index (TPI), LS factor (LS), convergence index (CONVIN), and altitude above channel network (ALTCHN).

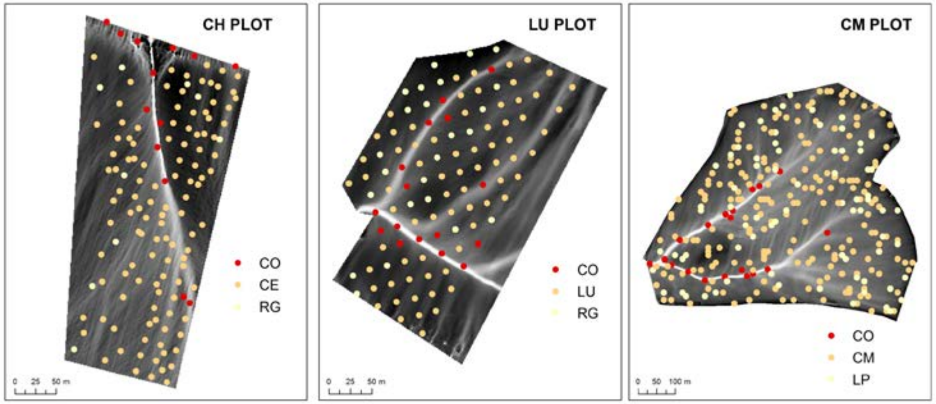




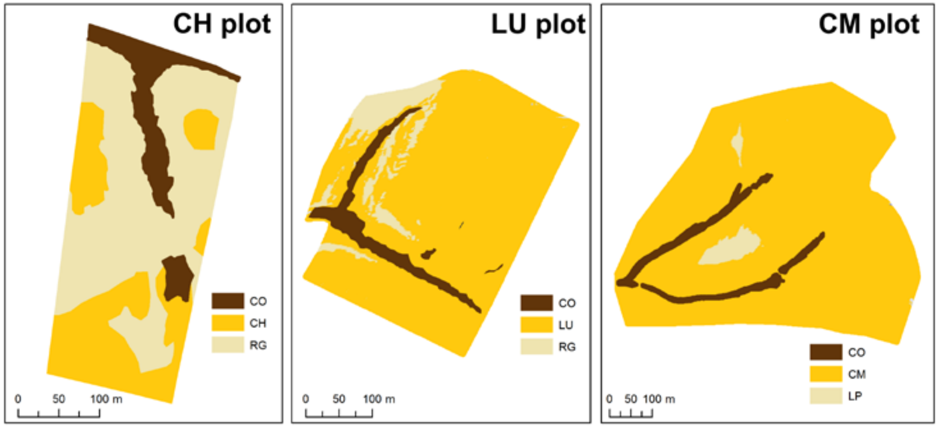
- support vector machine (SVM)
- To choose the most appropriate predictor variables (terrain attributes), we performed the best subset selection (fitting SVM models for each possible combination of predictors, and selecting a single best model using 5-fold cross-validation).

- To test set validation involves randomly dividing the available set of observations into two parts: a training set and a test set, in a 3:2 ratio.

- The prediction accuracy of the final model is expressed as the overall probability (%) and as Cohen's kappa coefficient (κ).

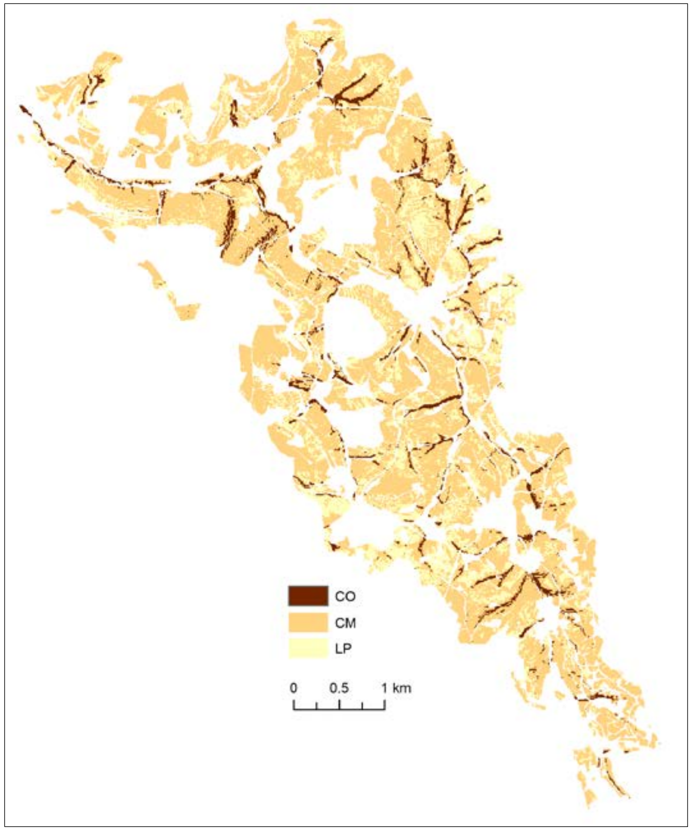


Plot	Predictors	Prediction accuracy		CO (% of total area)
		Overall accuracy	κ	
CH	ALTCHN+CONVIN+ALT+LS+PROFC+TPI	0.88	0.80	13.45
LU	CONVIN+ALT+LS+PLANC+SLP+TPI	0.84	0.66	8.78
CM	ALTCHN+LS+SLP+PI	0.77	0.27	3.03



- The model trained at the plot scale was applied to the catchment in CM region and validated by 100 testing points.

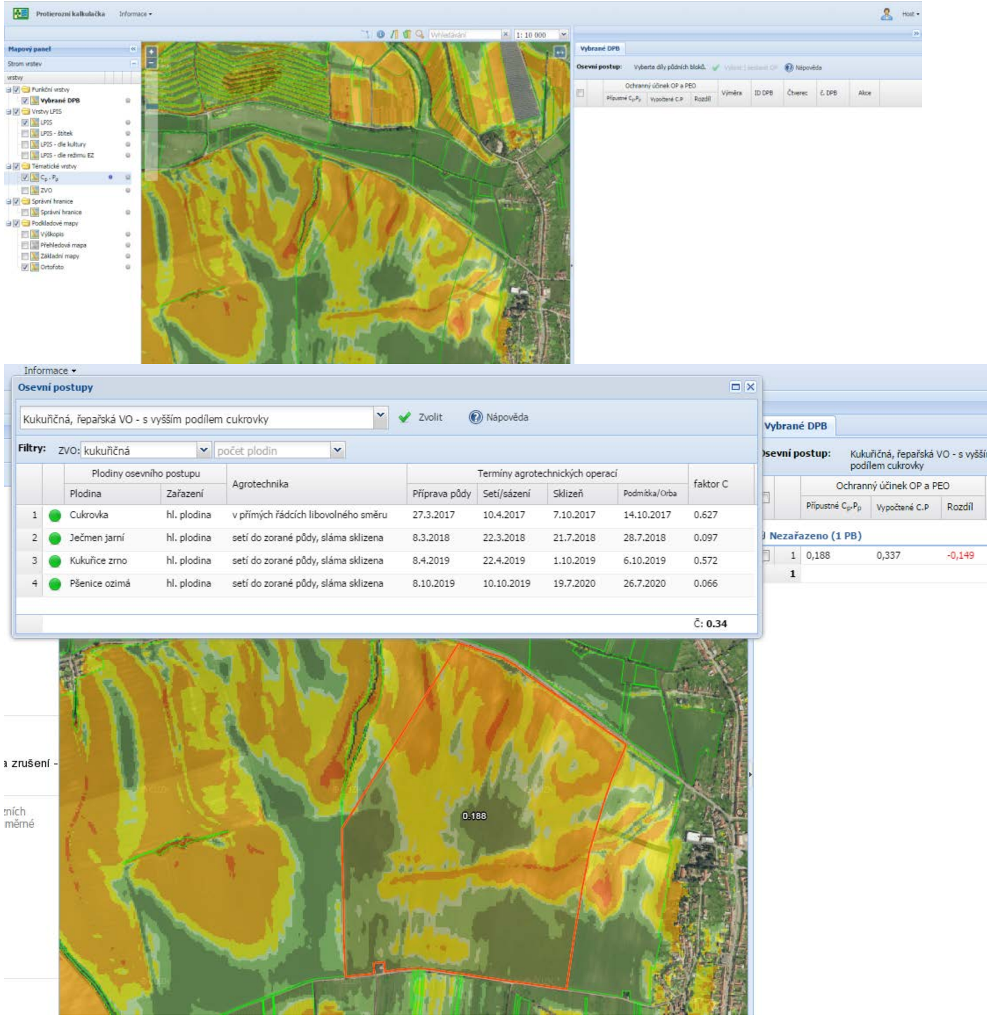
- more samples for the catchment level needed to refine the model parameters and improve its performance.



Catchment	Predictors	Prediction accuracy		CO (% of total area)
		Overall accuracy	κ	
CM	ALTCHN+LS+SLP+TPI	0.45	0.14	5.96

Application: Policy tools for soil erosion protection

- Soil erosion is main degradation process
- EU legislation force farmers to protect the soil
- Precise terrain analysis are used to delineate potentially endangered areas



- Good Agricultural and Environmental Conditions (GAEC)
  - Maintainance of land (soil) in good agricultural and environmental conditions
  - Member States shall define minimum requirements
  - **Cross Compliance** (tool of Common Agricultural Policy (CAP))

- Control of soil erosion
  - **GAEC 4:** Minimum soil cover
  - **GAEC 5:** Minimum land management reflecting site specific conditions to limit erosion

- **Soil erosion**

  USLE equation:

  G = R × K × L × S × C × P

  G - long-term average annual soil loss,

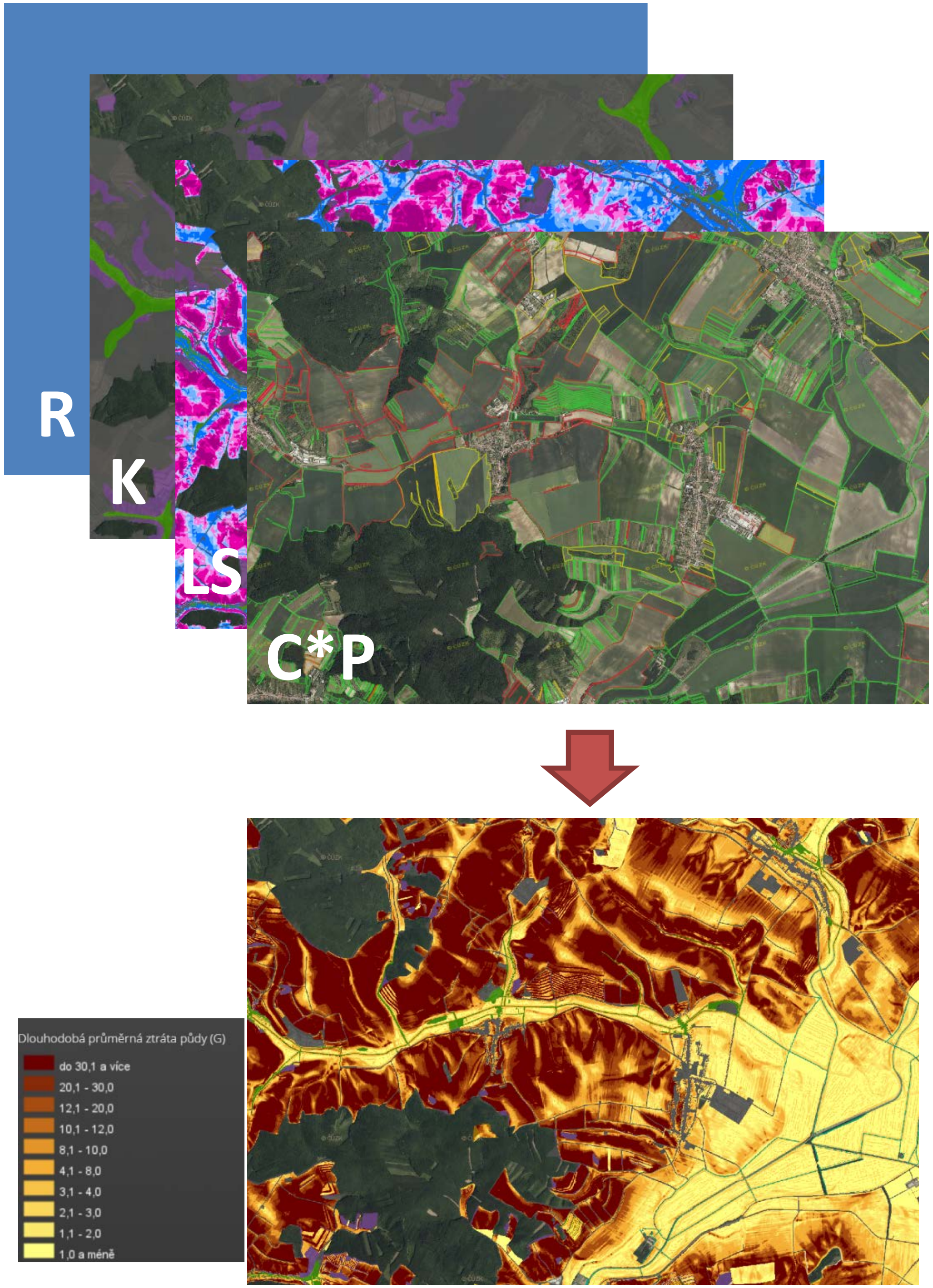
  R - rainfall erosivity factor,

  K - soil erodibility factor,

  LS - topographic factor,

  C - cropping management factor,

  P - conservation practices factor



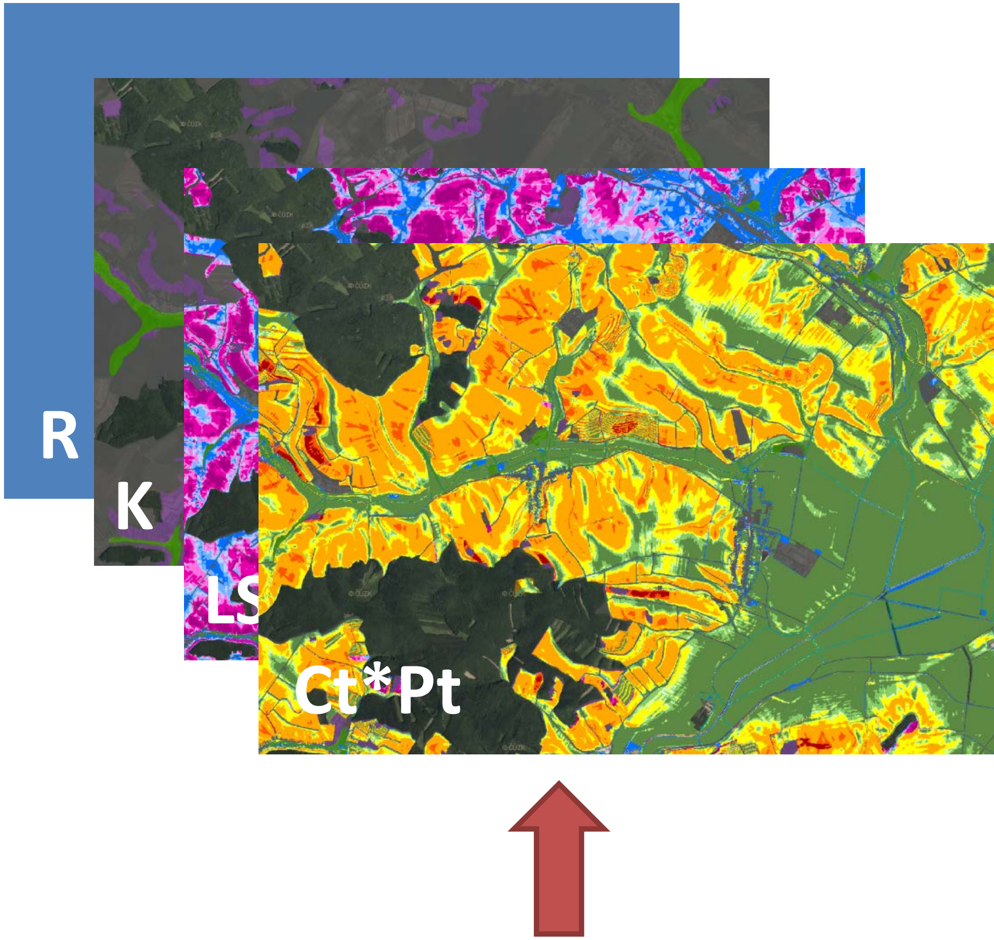
Web application

- Data:
  - LPIS database

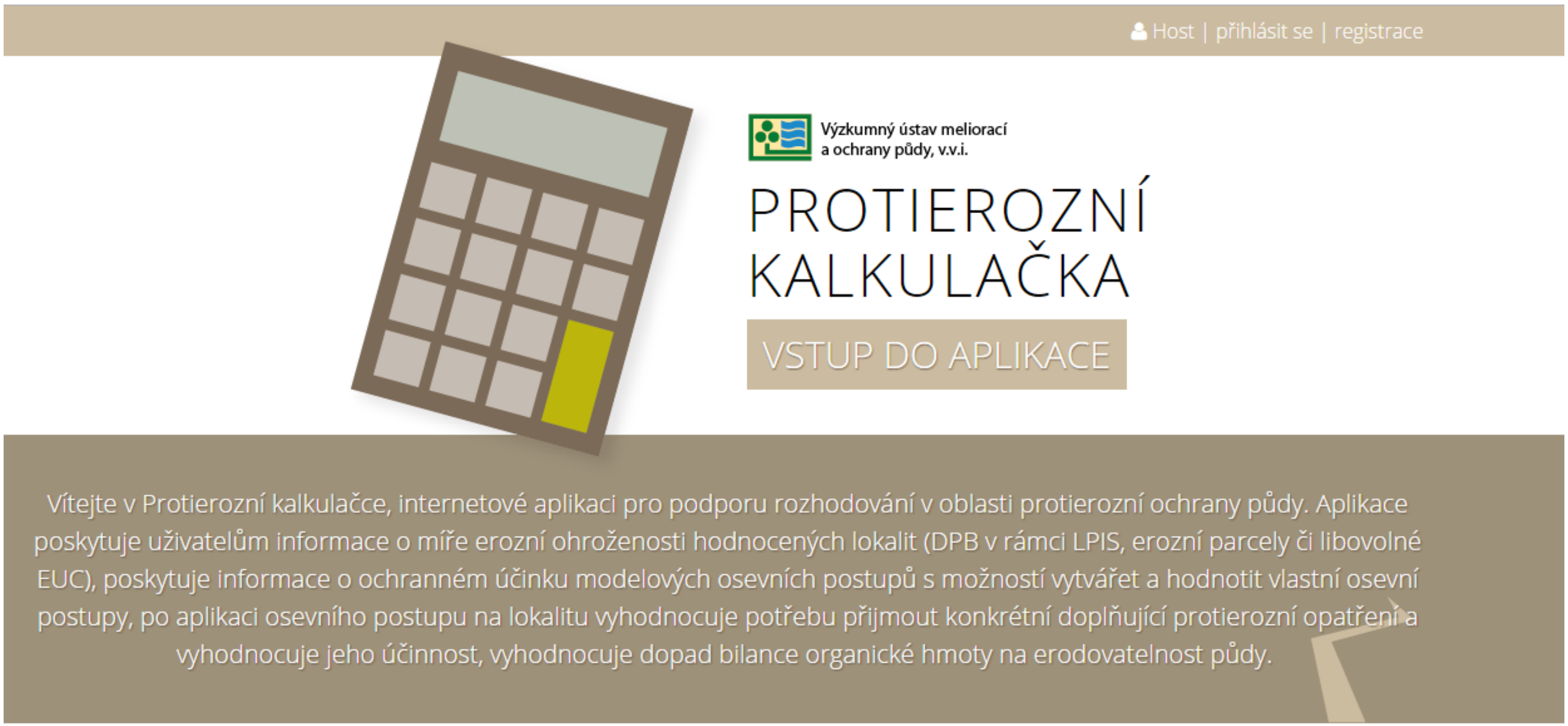
  ii) Minimal requested cropping and management factor (Cp . Pp),
  - iii) factor of soil erodibility (K)
  - iv) slope + slope lenght (LS)
  - v) tolerable soil loss (Gp)

- **Tolerable** soil erosion
  - ...when torelable soil loss (**Gt**) is set, than the only factor that can be optimized is **C*P**....:
  - **Gt = R × K × L × S × Ct × Pt**

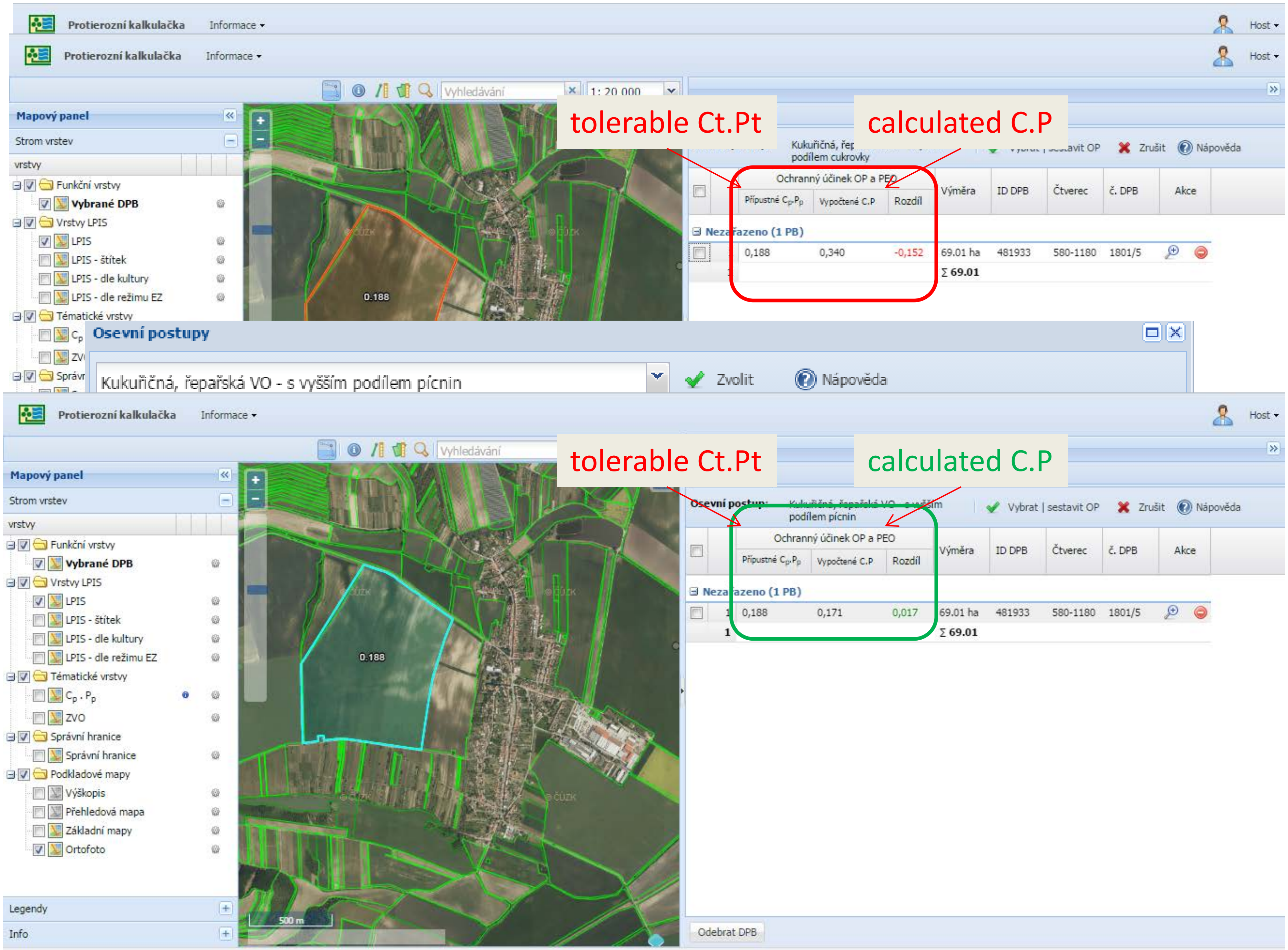
  - **Ct – crop rotation**
  - **Pt – management practices (minimal tillage, ...)**



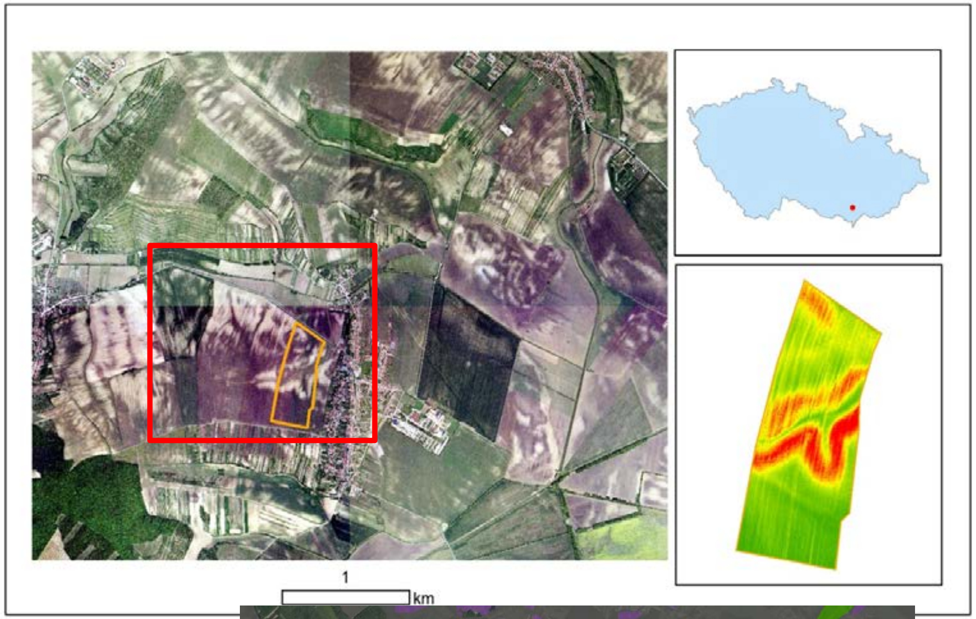
Gt <= X $t.ha^{-1}.a^{-1}$

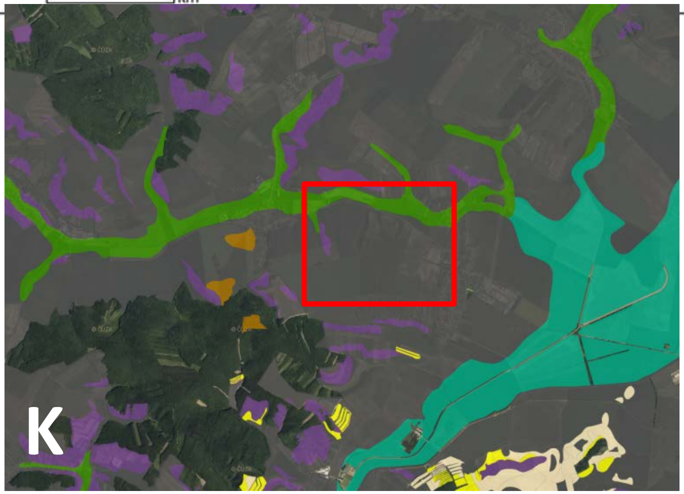


- http://kalkulacka.vumop.cz


Protierozní kalkulačka
Informace
Host
Mapový panel
Strom vrstev
vrstvy
Funkční vrstvy
Vybrané DPB
Vrstvy LPIS
LPIS
LPIS - štítek
LPIS - dle kultury
LPIS - dle režimu EZ
Tématické vrstvy
Správní hranice
Podkladové mapy
Výškopis
Přehledová mapa
Základní mapy
Ortofoto
Legendy
Info
Vyhledávání
1: 20 000
0.188
tolerable Ct.Pt
calculated C.P
Kukuřičná, řepařská VO - s vyšším podílem cukrovky
Vybrat | sestavit OP
Zrušit
Nápověda
Ochranný účinek OP a PEO
Přípustné $C_p.P_p$
Vypočtené C.P
Rozdíl
Výměra
ID DPB
Čtverec
č. DPB
Akce
Nezařazeno (1 PB)
0,188
0,340
-0,152
69.01 ha
481933
580-1180
1801/5
Σ 69.01
Osevní postupy
Kukuřičná, řepařská VO - s vyšším podílem pícnin
Zvolit
Osevní postup:
0,171
0,017
500 m
Odebrat DPB

- Possible further improvements:
  - Regionalized climatic factor
  - More detail soil information



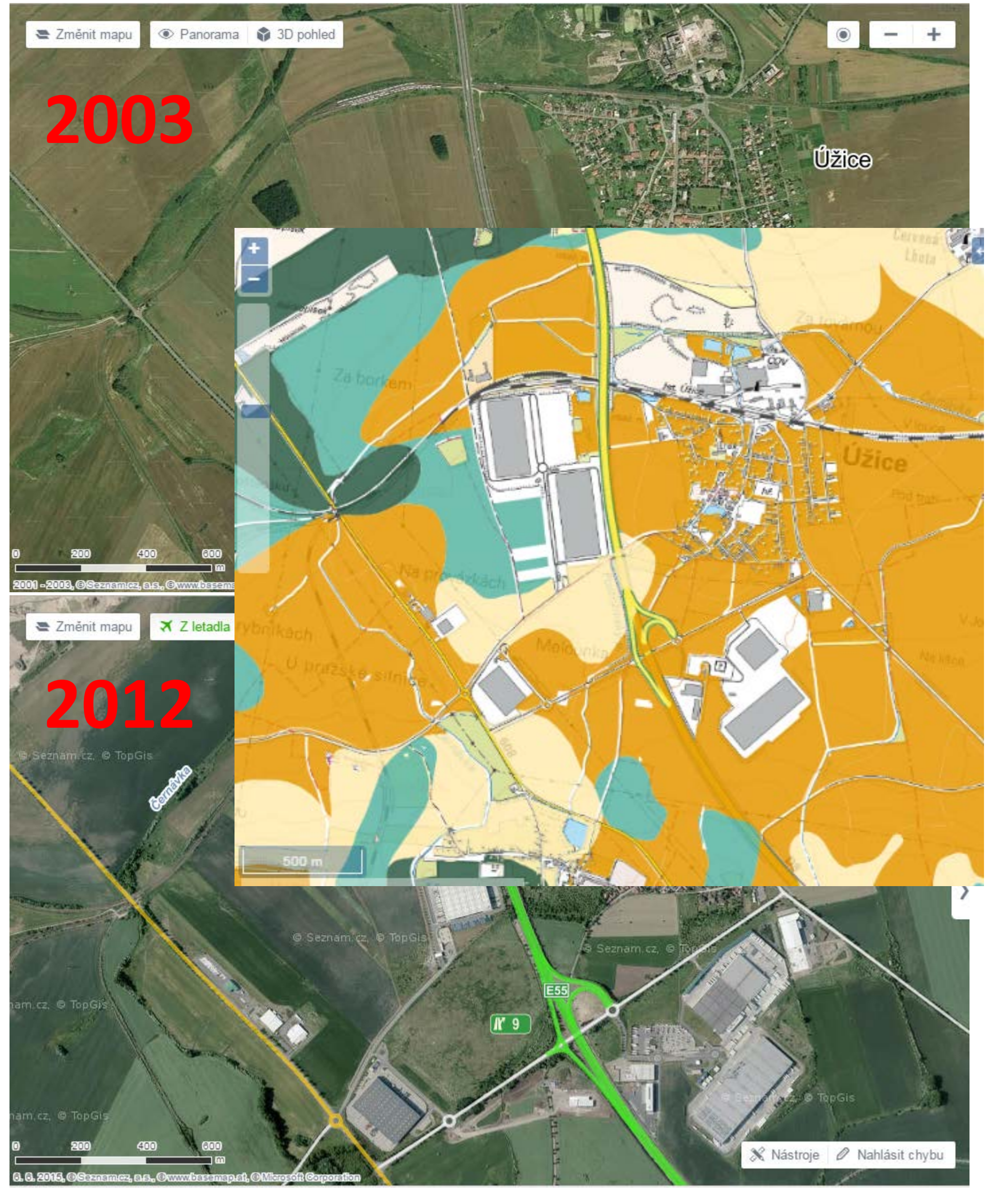


Monitoriong of erosion

http://me.vumop.cz/mapserv/monitor/

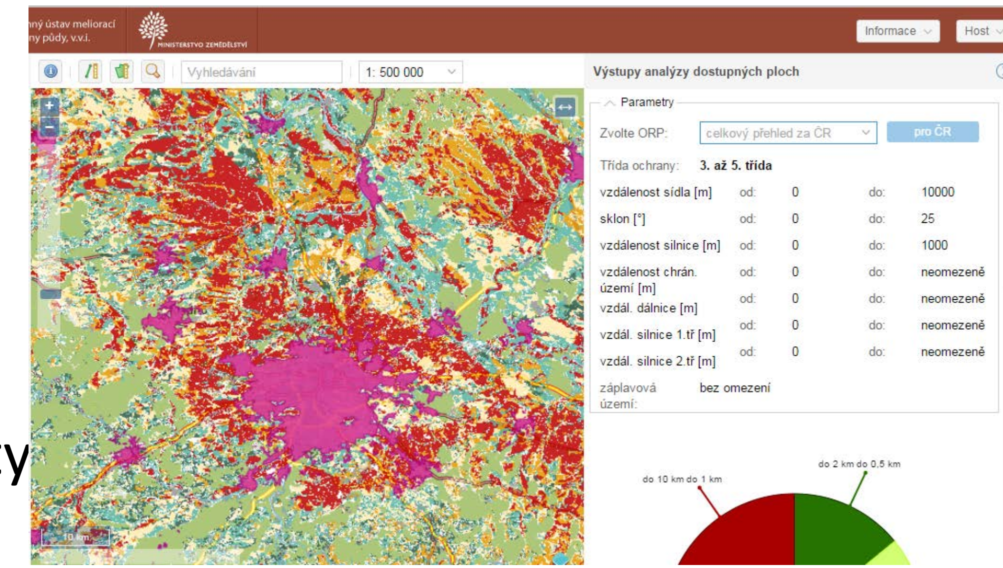
Application: Soil sealing protection

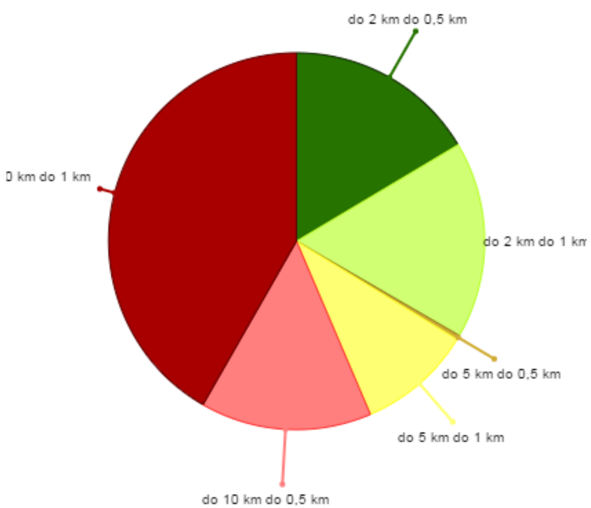
- Soil sealing is one of the main degradation factor of soils in Europe
- Most of the GDP is connected with land take
- There is a need to protect the most fertile soils

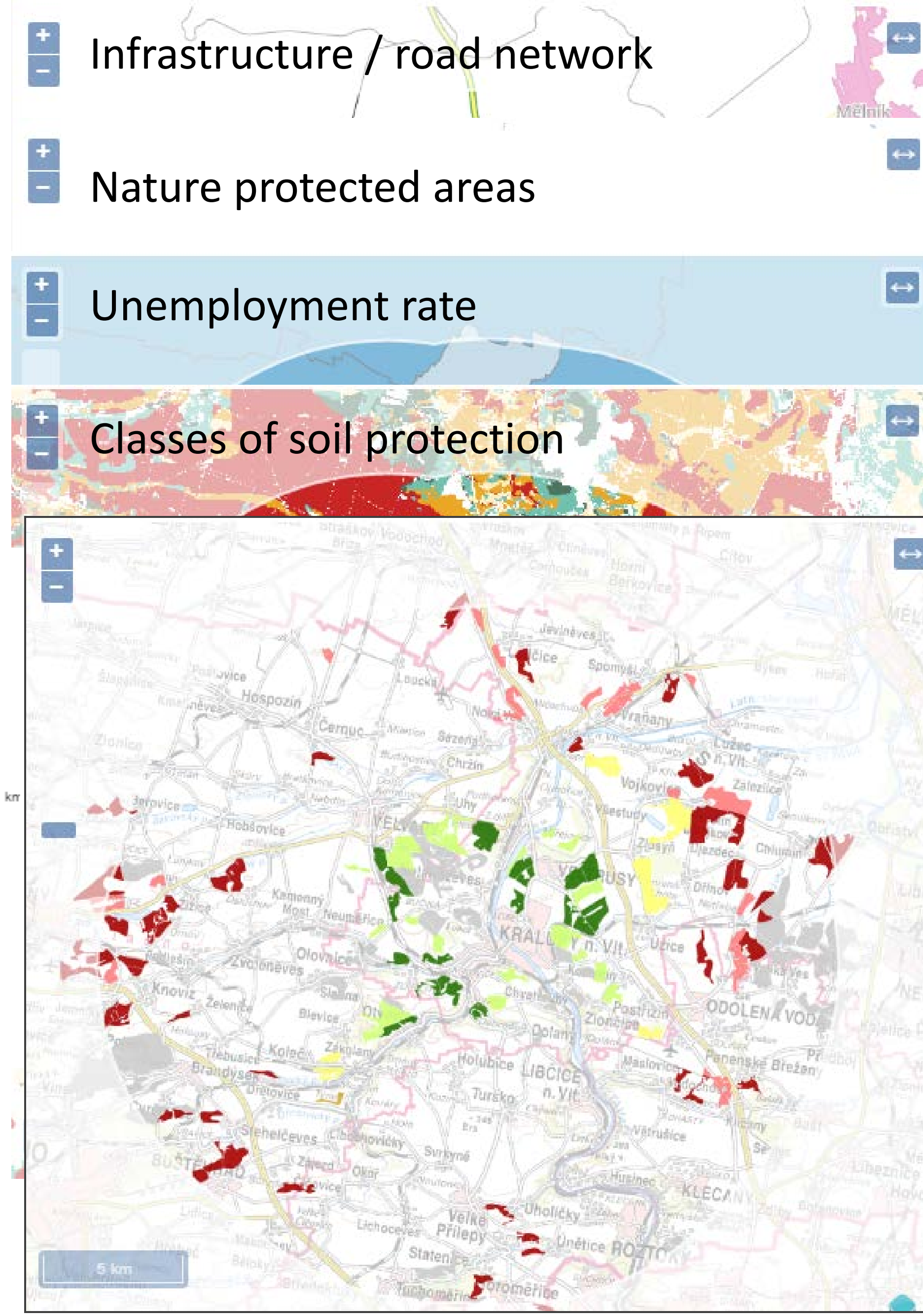


- Act nr. 334/92 - **protection** of the **agricultural** land
  - 5 classes of soil quality
  - Limits of changing the landuse
  - Payments (1 500- 60 000 EUR/ha)

- Web application enables to investors to see availability of lower quality soil in regions
- Data layers
  - Soil quality classes
  - infrastructure availability
  - Flooding zones
  - Natural protected areas
  - Socio/economical data
  - ....




do 2 km do 0,5 km
0 km do 1 km
do 2 km do 1 km
do 5 km do 0,5 km
do 5 km do 1 km
do 10 km do 0,5 km


Infrastructure / road network
Nature protected areas
Unemployment rate
Classes of soil protection
5 km

Conclusions

- The DSM turned from theory development into real applications
  - Global to local level
- The methods are suitable in both
  - areas with limited data
  - areas rich in legacy data
  -
- Important tool in increasing knowledge level about soil resources