European Commission

Modelling soil erosion at European scale: *the importance of management practices and the future climate and land use scenarios*

Panos Panagos[1], Pasqualle Borrelli[1,2], Katrin Meusburger[2], Cristiano Ballabio[1], Emanuele Lugato[1], Jean Poesen[3], Christine Alewell[2,] Luca Montanarella[1]

[1]European Commision – Joint Research Centre, Ispra, ITALY

[2]University of Basel, Environmental Geosciences, SWITZERLAND

[3]Division of Geography, KU Leuven, BELGIUM

Joint Research Centre

Policy: Soil Thematic Strategy (2006)

Sealing

Soil Biodiversity loss

Erosion

Decline of
Soil Organic Matter

Soil Threats

Salinization

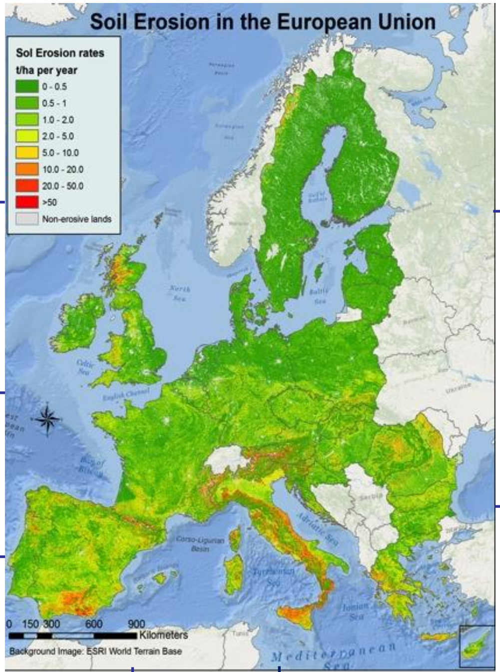
Compaction

Contamination

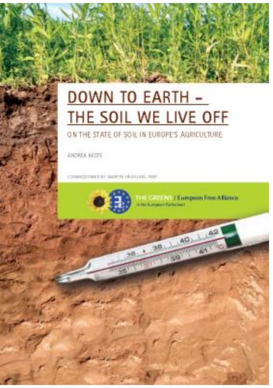
Landslides

Soil erosion indicators & policy support

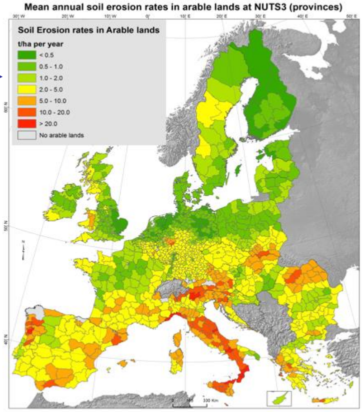
European Commission



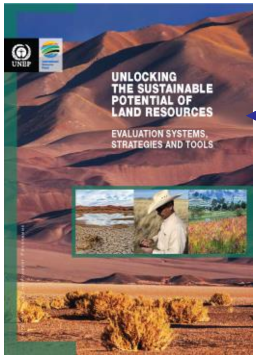
European Parliament - Greens



ESTAT: Agro-Environmental



UNEP



DG AGRI

OECD

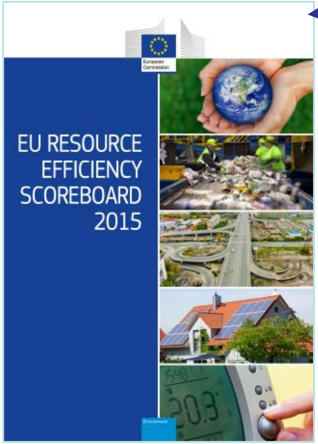
ipbes

GLOBAL SOIL PARTNERSHIP

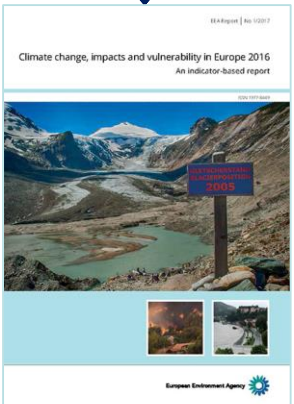
UNCCD

United Nations Convention to Combat Desertification

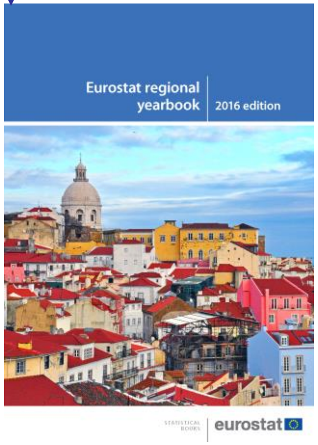
ENV-ESTAT: EUROPE 2020



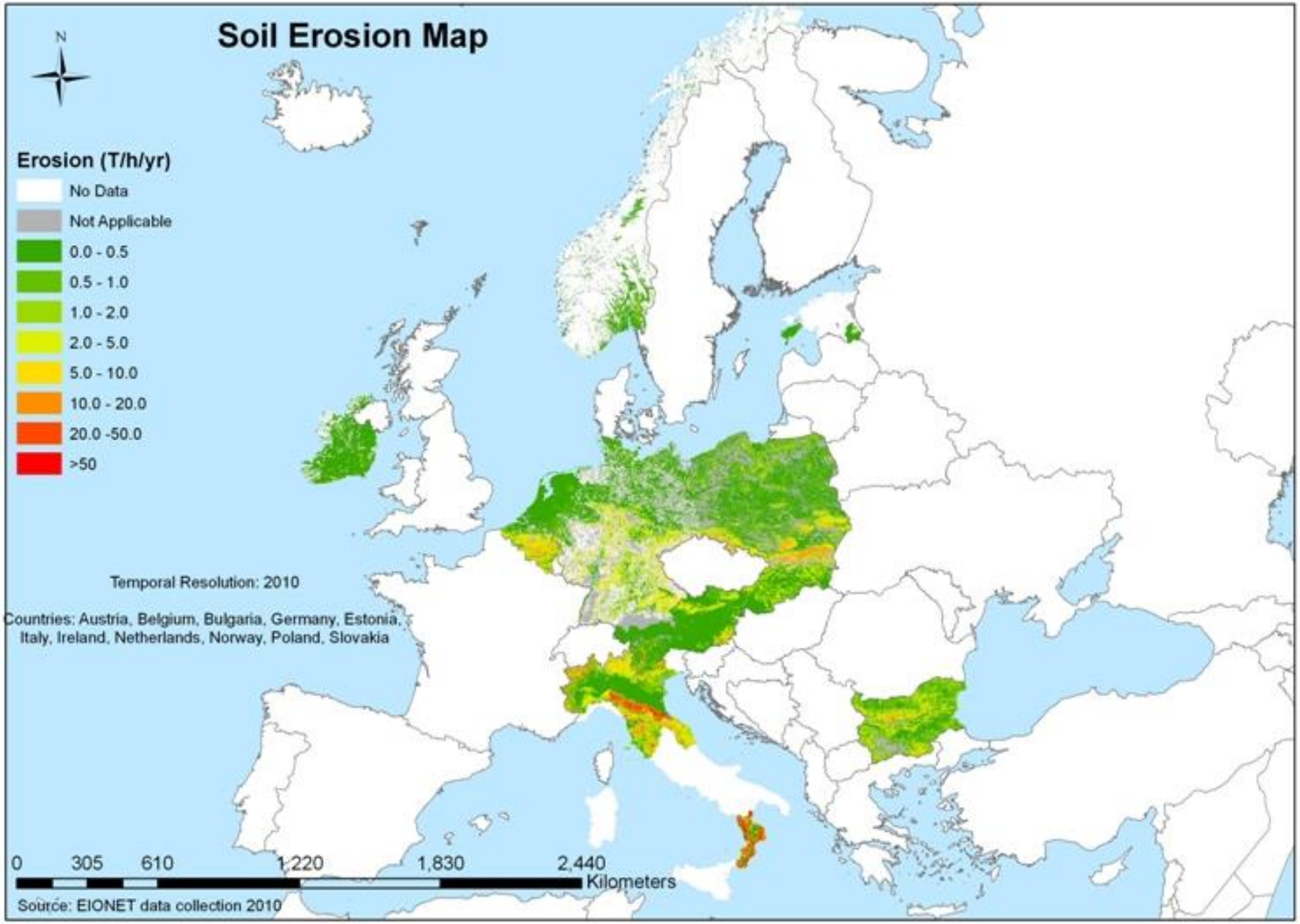
EEA



ESTAT: Regional stats



Soil Erosion after EIONET data collection (2009-2010)

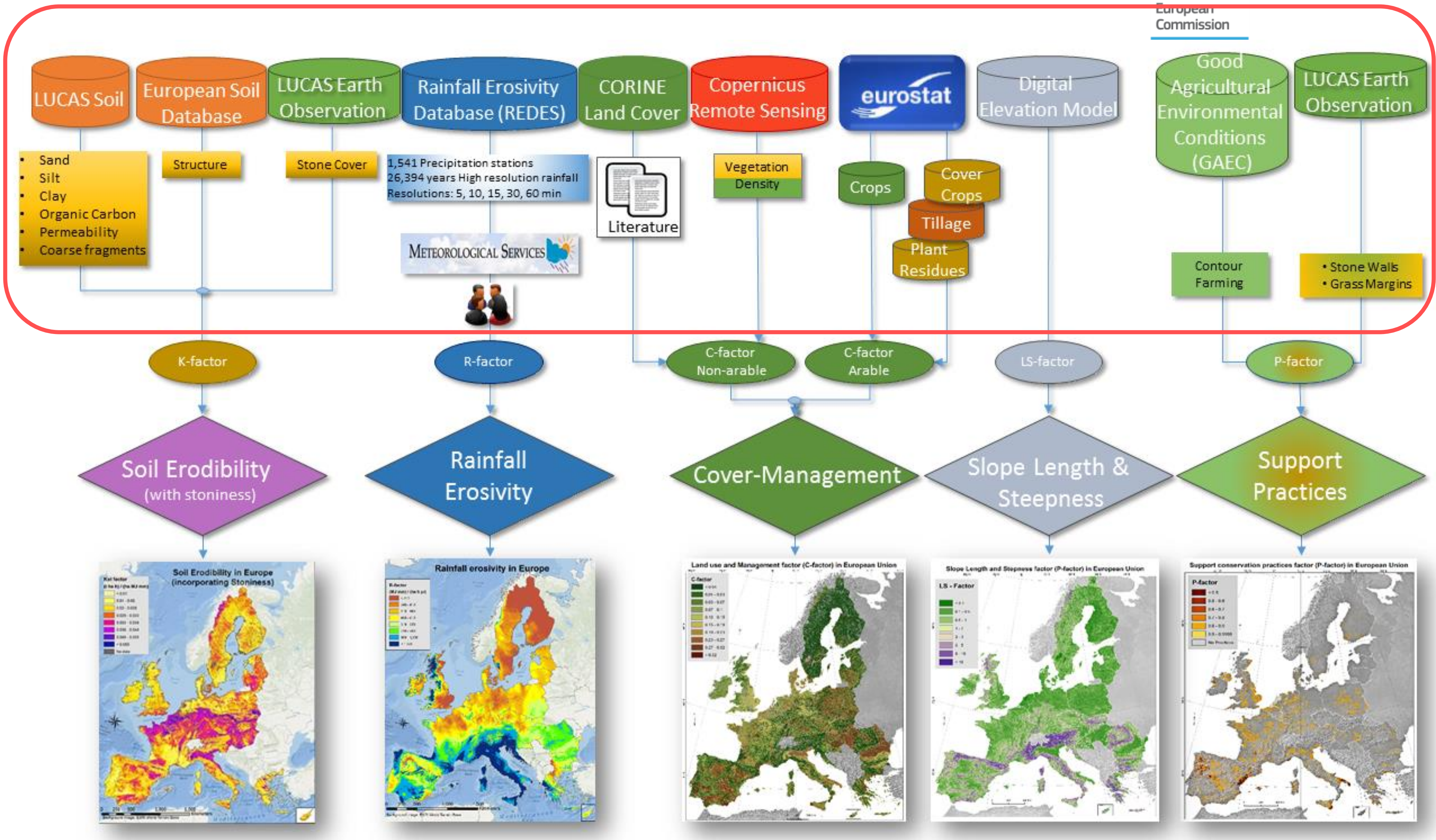


Research Centre

Panagos et al. (2014), Soil Science & Plant Nutrition

RUSLE2015: New soil erosion model

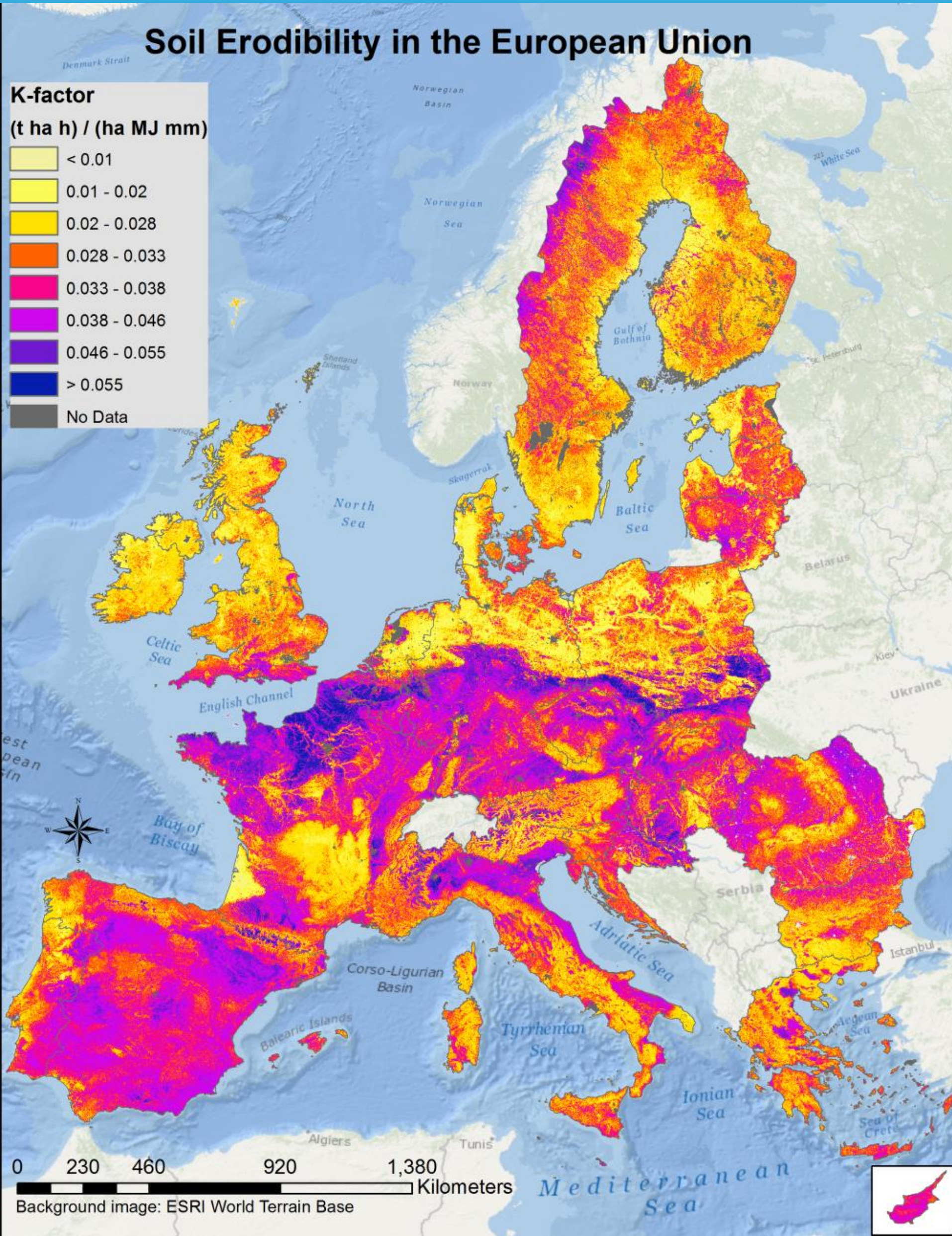
$A = K * R * C * LS * P$



Joint Research Centre

Panagos et al (2015) – Env.Science & Policy

Soil Erodiblity (K-factor)

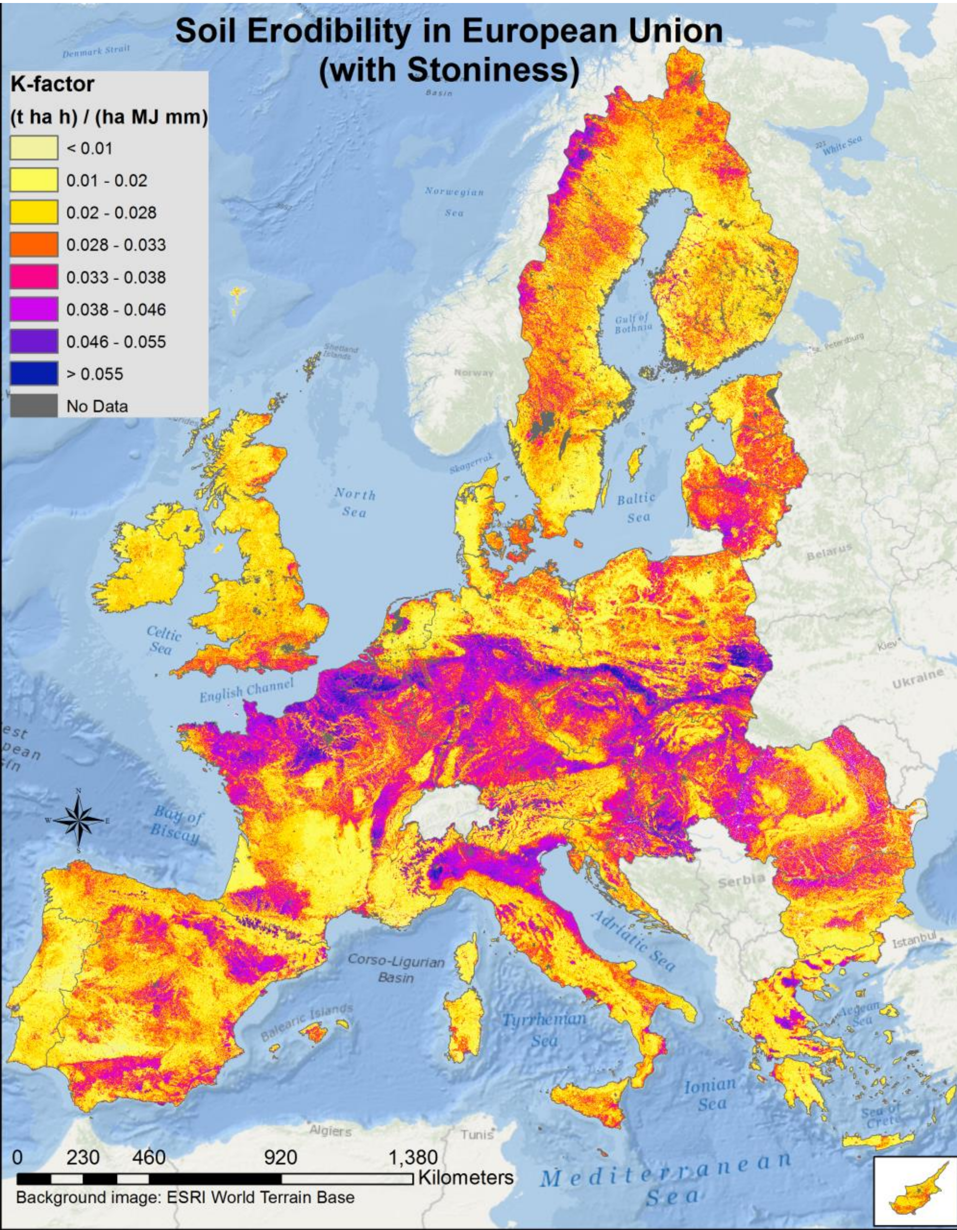


European Commission

- Combines the influence of **Texture, Organic carbon, soil structure, Permeability, coarse fragments and Stone cover**
- **20,000** Land use/cover survey (LUCAS) samples with measured data
- **Regression interpolation** using Terrain features, Lat/Long, vegetation covariates
- **Spatial Resolution**: 500m
- **Verified** against 21 local, regional and national datasets from 13 countries

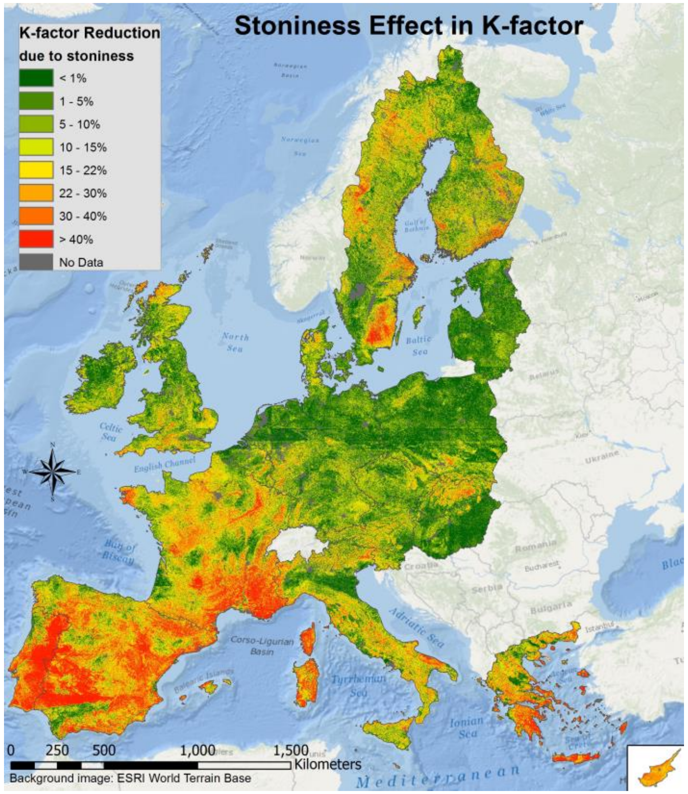
Panagos et al (2014), Science of Tot. Env.

Soil Erodibility (K-Factor) incorporating Stone cover



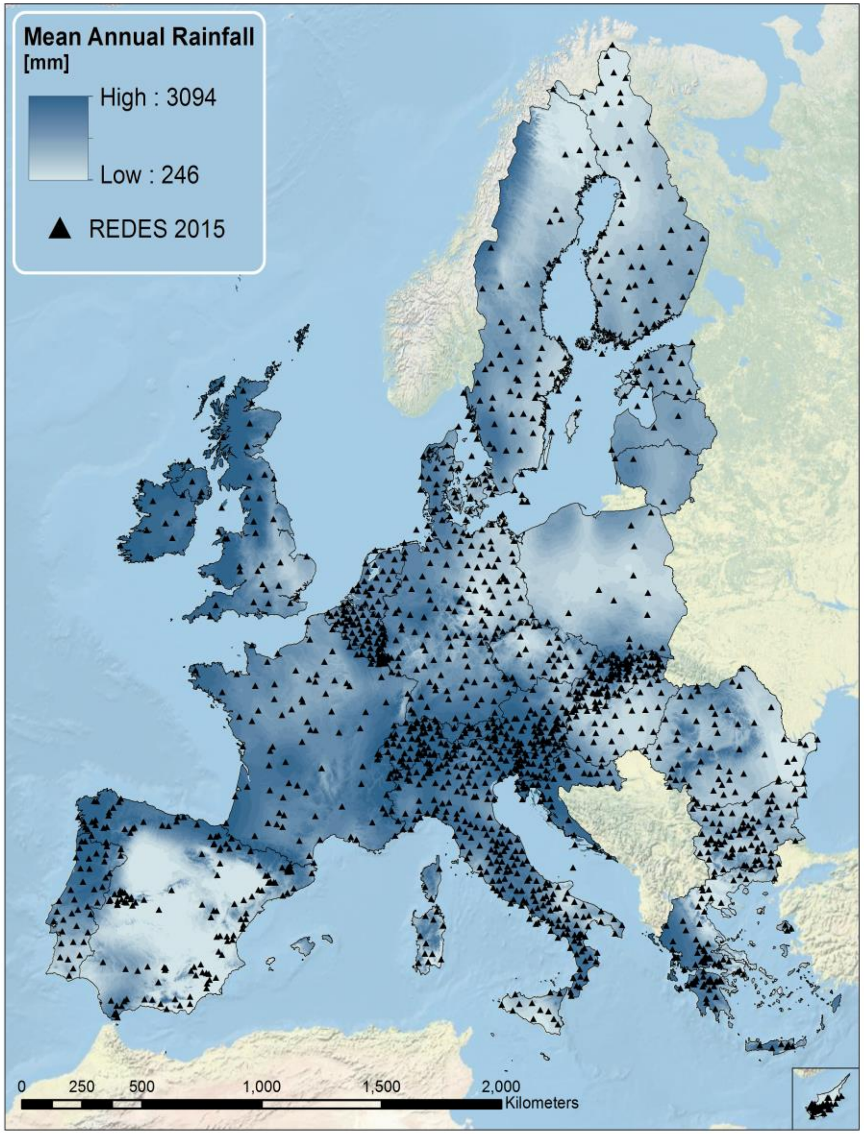
- **Improved version taking into account Stoniness:** 20,000 LUCAS surveyed points

- **Stone cover effect: 15%;**
- Important effect in **Mediterrean**



REDES: Rainfall Erosivity Database at European Scale

European Commission



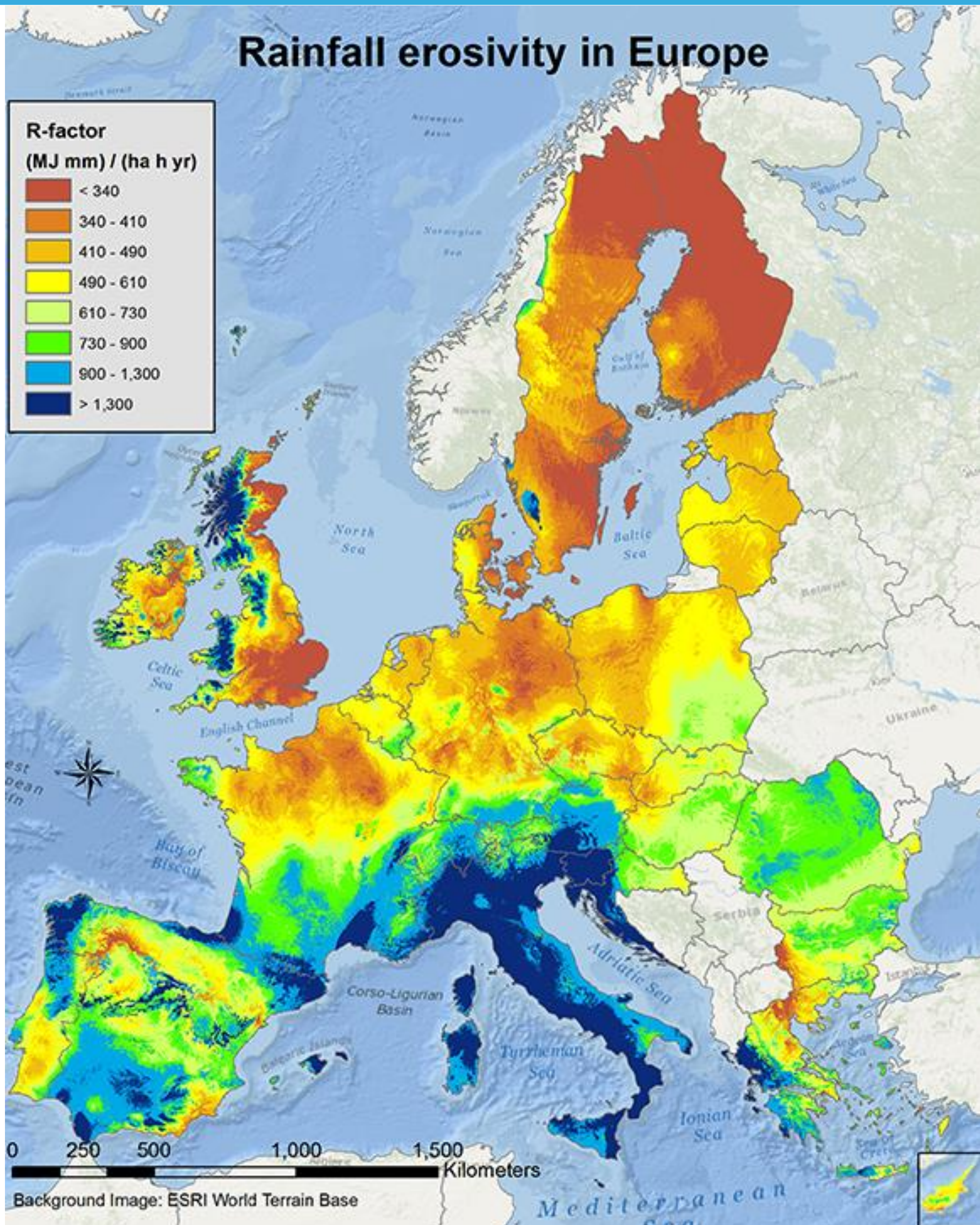
- **Rainfall erosivity** measures rainfall kinetic energy & intensity (MJ mm ha^{-1} h^{-1} y^{-1})
- Combines the influence of **rainfall frequency, duration, amount** and **intensity**
- **Participatory approach**: Environmental & Meteorological Services from all Member States (Mar 2013 – Jun 2014).
- **1,541** Precipitation stations with detailed rainfall intensity; **1675 Precipitation Stations** in 2015 update (all countries)
- Average density: 1 station per 50km x 50km
- **Calibration requested:** 5 min, 10-min, 15 min, 60 min.
- **Temporal Resolution**: 30-Minutes
- **Time series**: 7 – 56 Years (Mean: 17.1yr; 75% of time series in 2000-2010)
- **Data**: 29,000 years of High Temporal resolution precipitation records

Panagos, P., Ballabio, C., Borrelli, P.,.....et 14 others from MS ......(2015). Science of Total Env.

Joint Research

Rainfall Erosivity (R-factor)

European Commission

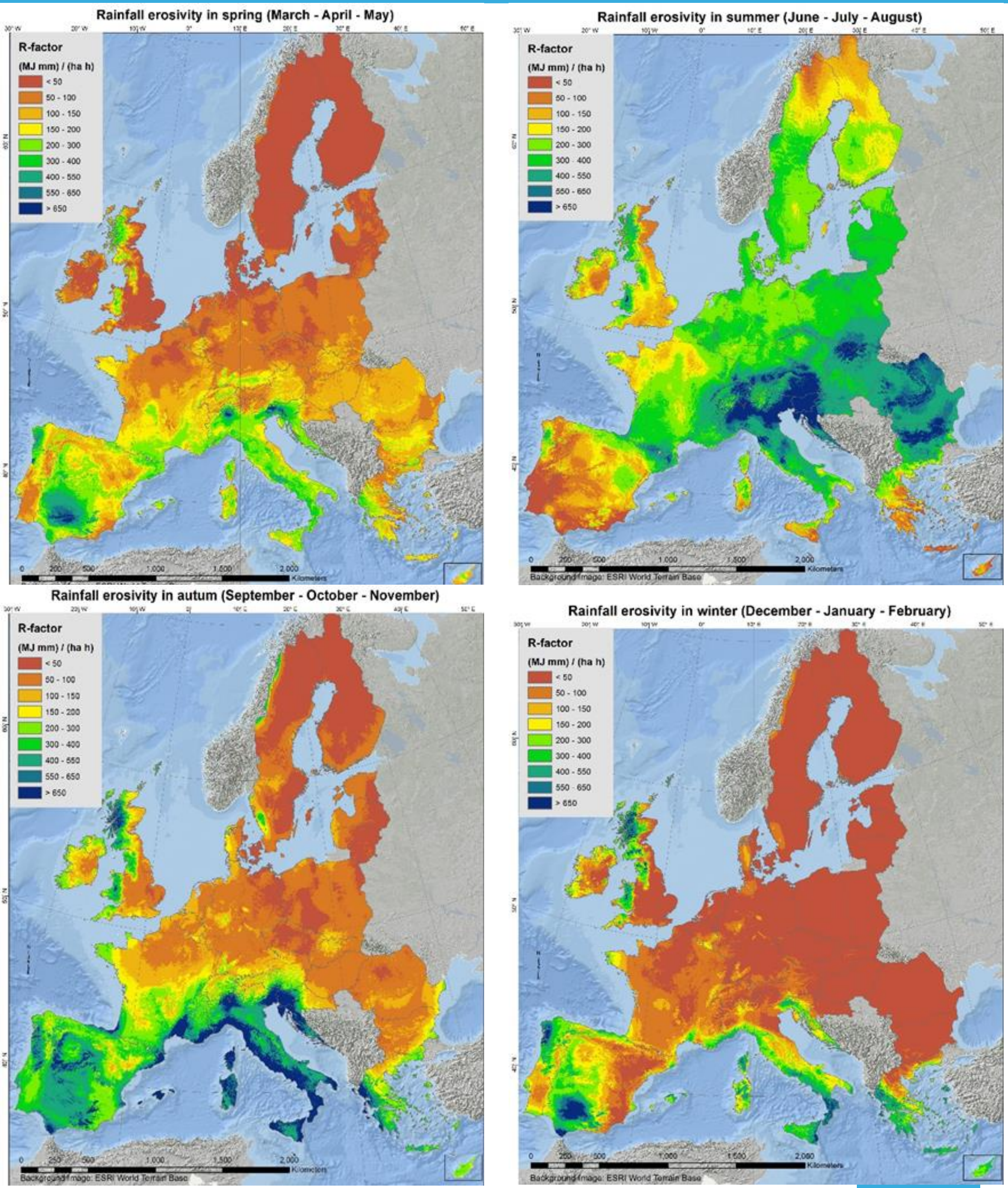


- **Resolution: 500**m
- **Spatial coverage**: European Union (EU-28) plus Switzerland
- **Robust Geo-statistical** model
- **Mean**: 722 MJ mm ha^{-1} h^{-1} yr^{-1}
- Highest R-factor in **Mediterranean & Alpine regions** and lowest in Scandinavia
- **Highest R-factor** levels are in line with the 3 major regions (van Delden, 2001) with **highest frequency of thunderstorms.**
- Erosivity is **not dependent** only from precipitation

Panagos et al. 2015. Science of Total Environment

Monthly Erosivity & additional Indicators

European Commission



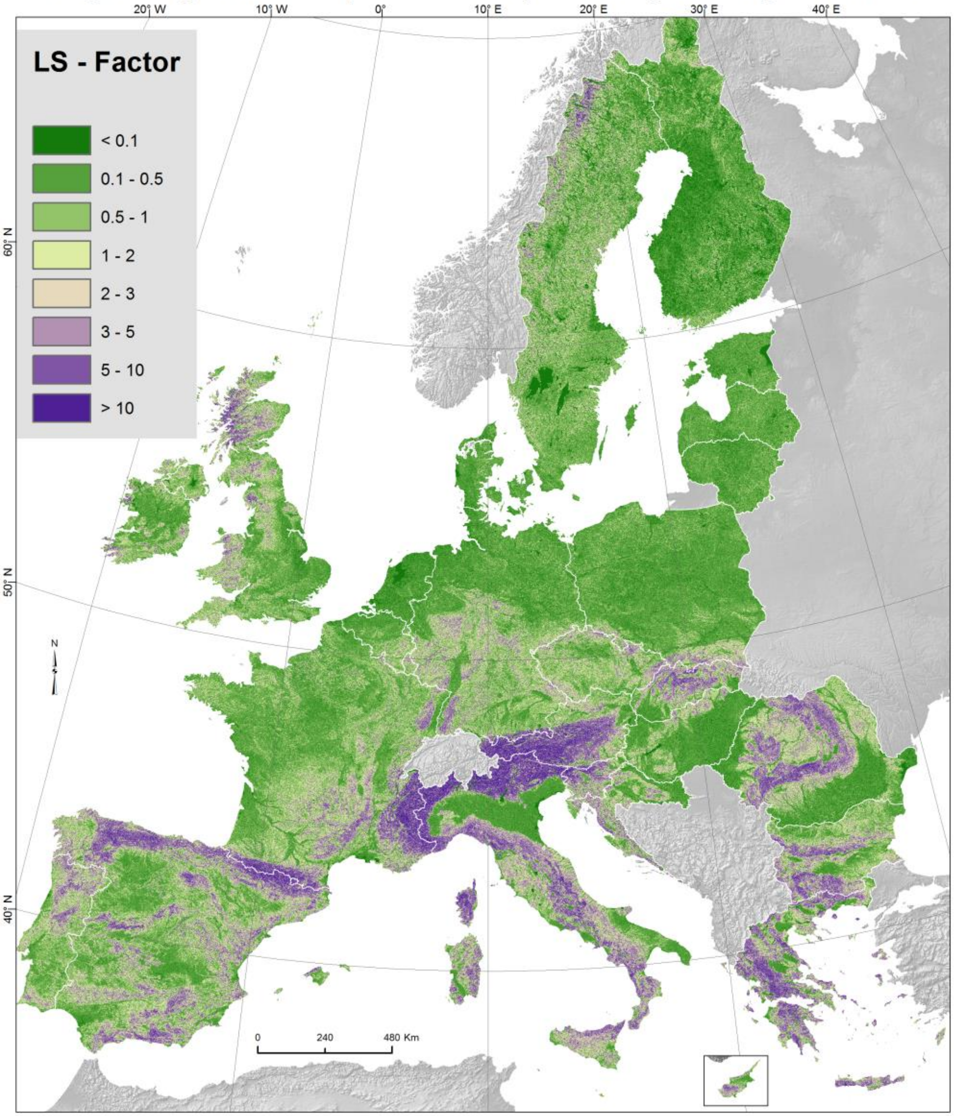
- Rainfall erosivity is mapped **intra-annually** for the first time at European scale
- **53% of the annual rainfall** erosivity in Europe is accounted in **4 months** period (June – September)
- **Northern and Central European** countries exhibit the largest erosivity in **summer**
- **Southern European countries** exhibit the largest erosivity values during **October to January**
- **More indicators developed:**
  - Coefficient of Variation on Monthly Erosivity Density
  - Ratio on pixel basis of erosivity least/most erosive month
  - Weighted monthly Erosivity Density and some others.

Ballabio et al. STOTEN (2017)

Topography (LS-factor)

European Commission

Slope Length and Steepness factor (LS-factor) in European Union



- **25m DEM → resolution 25m LS-factor** (capture geomorphological features compared to 100m DEM)
- Desmet & Govers algorithm (1996)
- Fast process with SAGA software
- **50GB** of dataset available in European Soil Data Centre (ESDAC)
- No arbitrary limitations in slope length

Research Centre

Panagos et al.(2015) , Geosciences, MDPI

Good Agricultural practices against Erosion

Reduced Tillage

Stone Walls

Plant residues

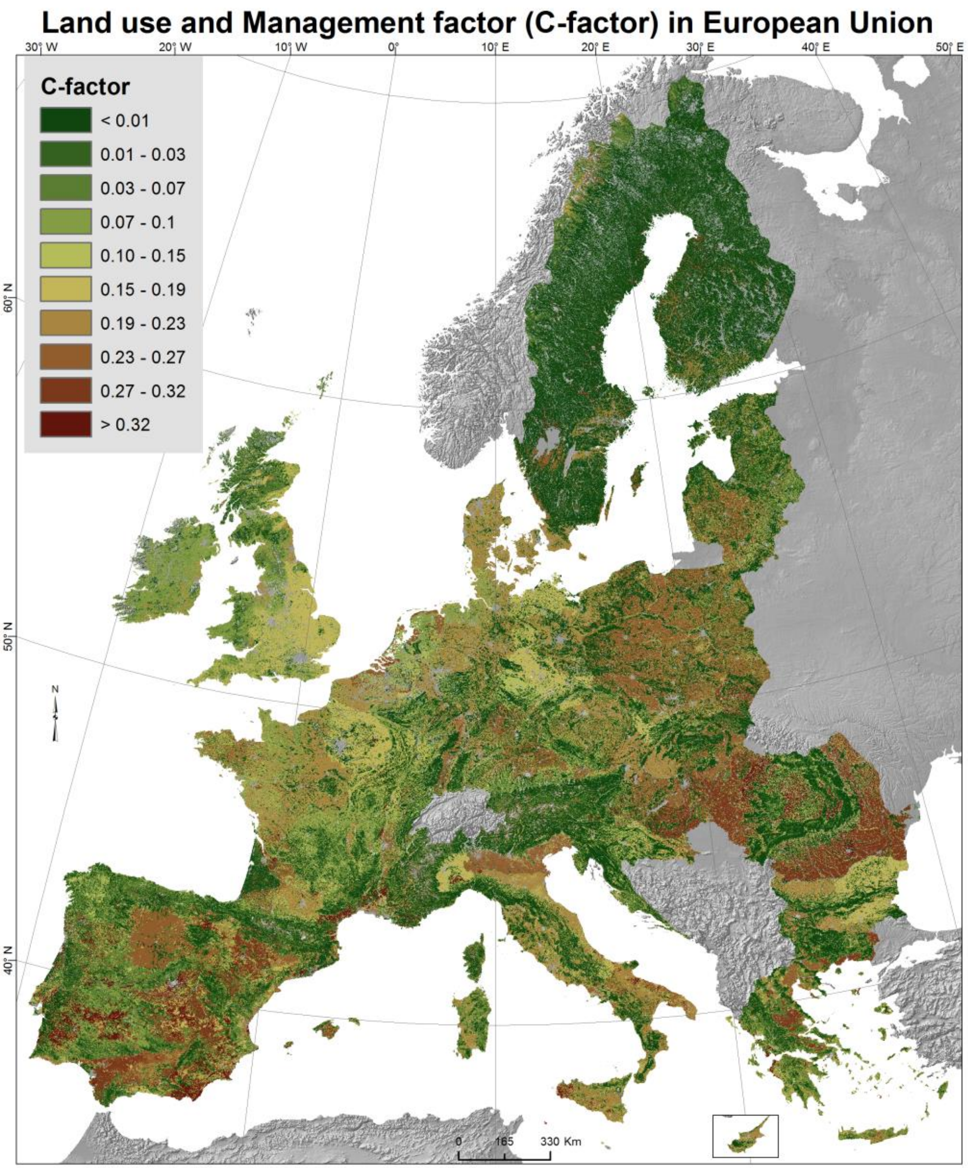
Grass margins

Cover crops

Contour farming

Panagos et al (2015) – Land use policy

Cover – Management (C-factor)



- Differentiate between **Arable lands** & **Non-Arable lands**
- **Non arable:** Forest – Shrub – sparse vegetation – Heterogeneous – Permanent crops - pastures/grasslands
- CORINE Land Cover & Vegetation Density
  - ✓ **Calibrate** the C-factor from literature: 20 major published studies
  - ✓ with **Remote Sensing**(RS) images from Copernicus Programme: Vegetation Density layer: RS every 10 days

Example: Pastures C-factor

- Range from literature: 0.05 – 0.15
- Each pixel gets a value in this range depending on its Vegetation Density (0-100%)
- Pastures (mean) C-factor in Ireland: 0.077
- Pastures (mean) C-factor in Cyprus: 0.125

Panagos et al.(2015) Land Use Policy.

C-factor in arable lands: C_{crop}

European Commission

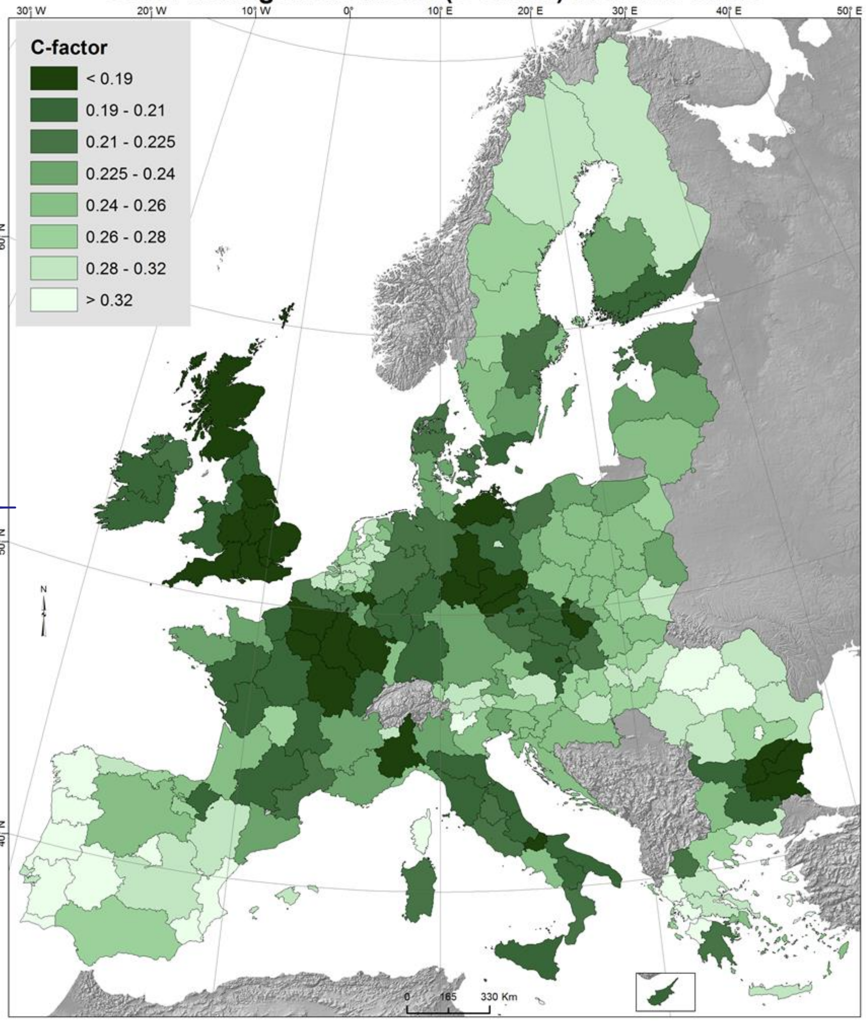
$$C_{arable} = C_{crop} \times C_{management}$$

n	Crop type	Share (%) of the total arable land (EU-28)	C-factor
1	Common wheat and spelt	28.5	0.20
2	Durum wheat	3.2	0.20
3	Rye	3.0	0.20
4	Barley	14.8	0.21
5	Grain maize – corn	12.9	0.38
6	Rice	0.6	0.15
7	Dried pulses (legumes) and protein crop	1.9	0.32
8	Potatoes	2.4	0.34
9	Sugar beet	3.1	0.34
10	Oilseeds	5.8	0.28
11	Rape and turnip rape	8.1	0.30
12	Sunflower seed	4.8	0.32
13	Linseed	0.1	0.25
14	Soya	0.5	0.28
15	Cotton seed	0.4	0.50
16	Tobacco	0.1	0.49
17	Fallow land	9.8	0.50

$$C_{crop} = \sum_{n=1}^{17} C_{crop\,n} * \%NUTS2_{crop\,n}$$

- **NUTS2** (regional) level
- Based on **crop composition** over 5-years (2008-2012)
- **Weighted average of crop composition & their C-factor**
- **Future**: NUTS3 or farm level (LPIS)

Cover-Management factor (C-factor) in arable lands



Joint Research Centre

Panagos et al.(2015) Land Use Policy.

Management factor : $C_{management}$

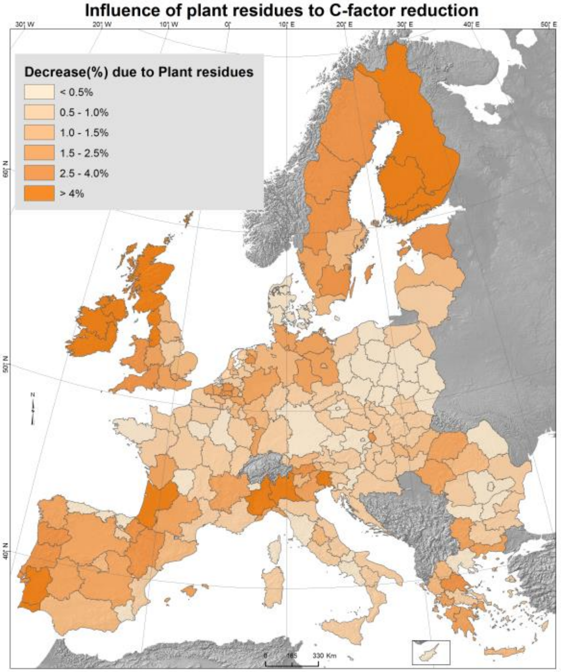
$$C_{arable} = C_{crop} \times C_{management}$$

$$C_{management} = C_{tillage} * C_{residues} * C_{cover}$$

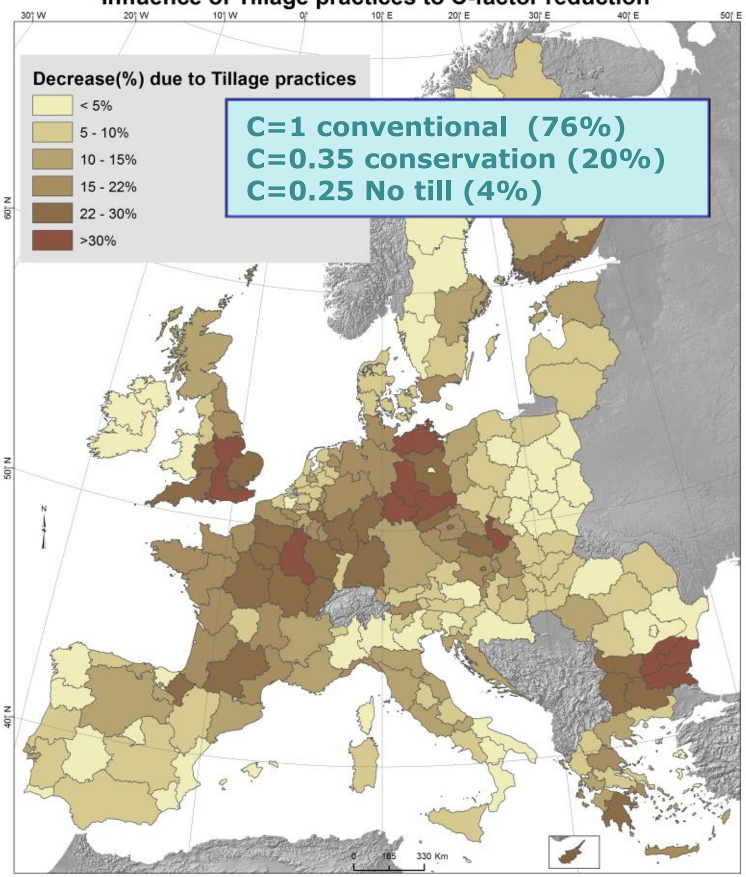
Plant residues applied in 10.6% of EU-28 arable lands

C=0.88

Influence of plant residues to C-factor reduction



Influence of Tillage practices to C-factor reduction

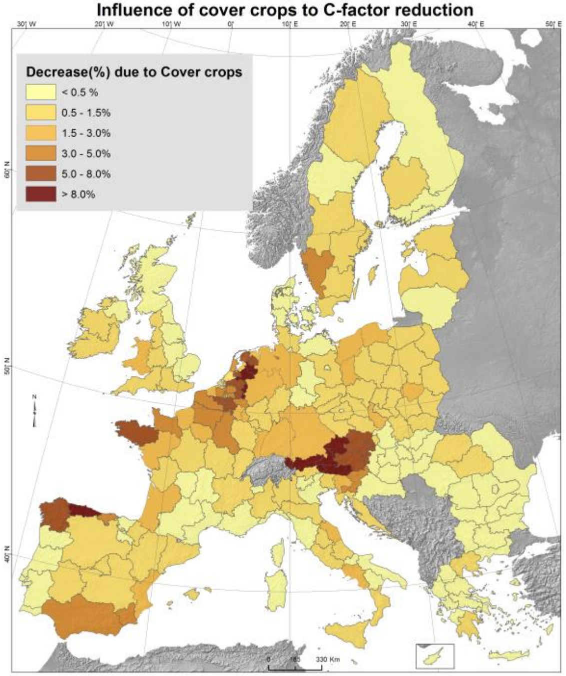


C=1 conventional (76%)
C=0.35 conservation (20%)
C=0.25 No till (4%)

6.5% of the EU-28 arable lands are planted with cover crops

C=0.80

Influence of cover crops to C-factor reduction

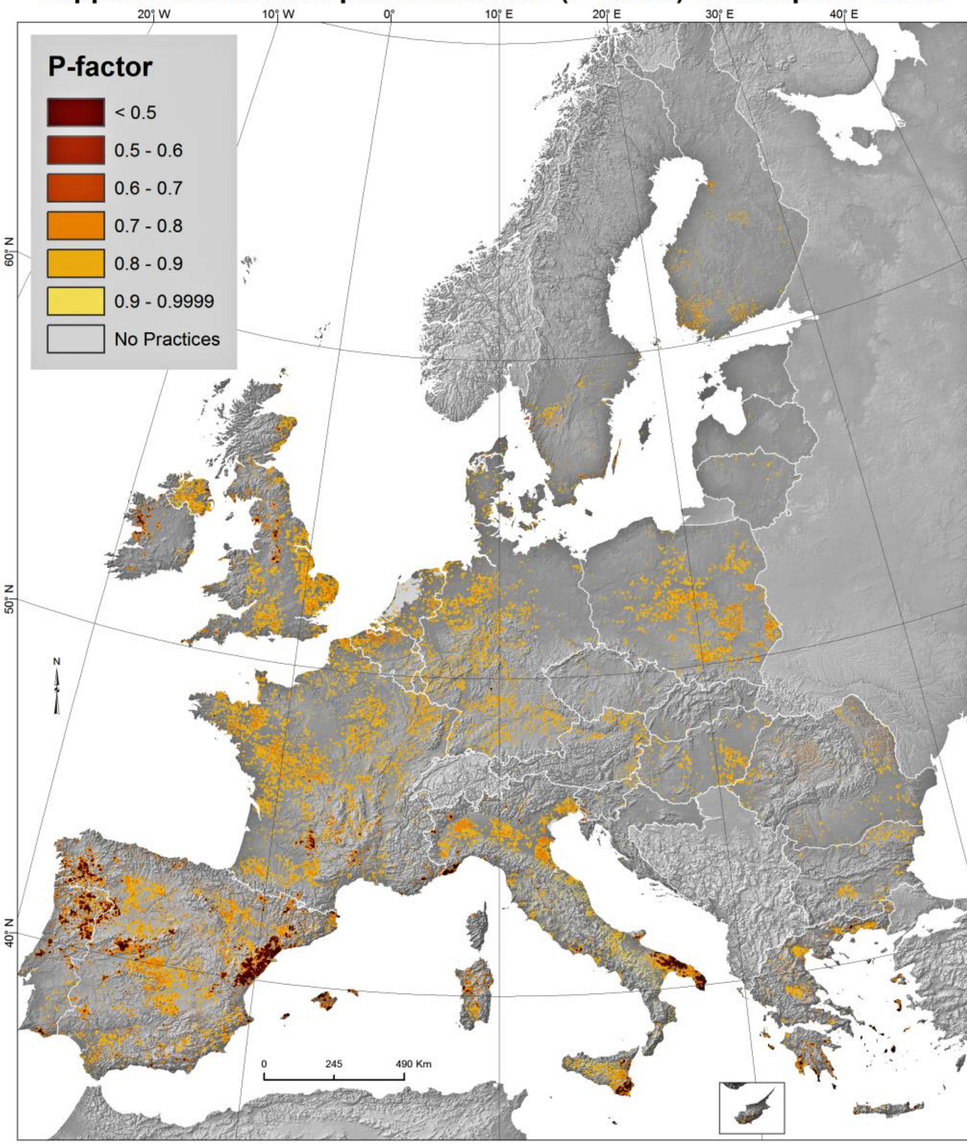


Data input: ESTAT Farm Structure Survey (FSS)

Panagos et al.(2015). Land Use Policy

Support Practices (P-factor)

Support conservation practices factor (P-factor) in European Union



Data input from:

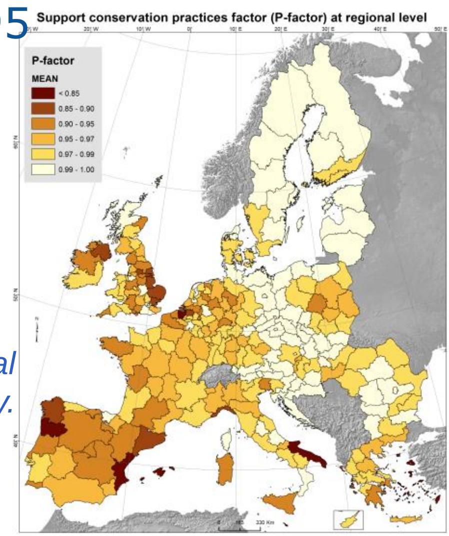
- Good Agricultural Environmental Conditions (GAEC) database plus
- LUCAS **270,000** earth observations

Support practices Impact:

- Contour farming (5%)
- Stone Walls (38%)
- Grass Buffers (57%)

P-factor in EU-28: 0.97

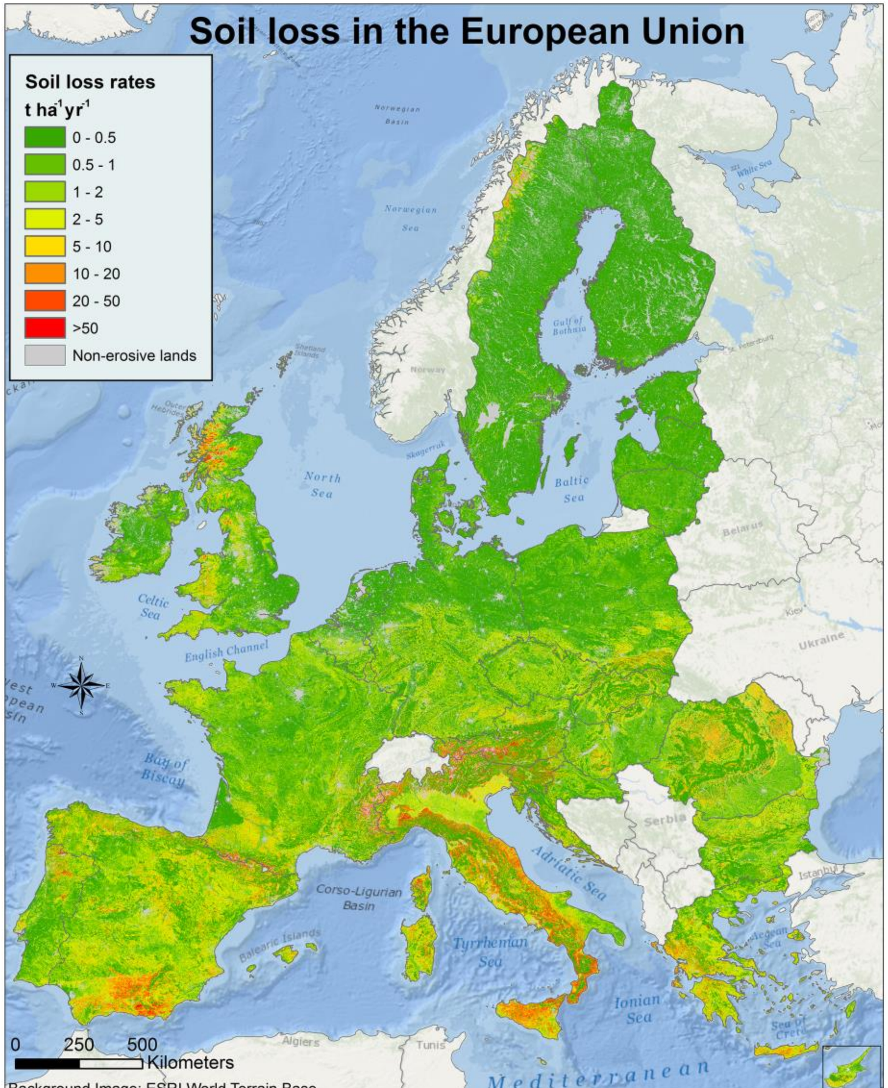
P-factor in **arable**: 0.95



Panagos et al.(2015). Environmental Science and Policy.

Soil loss by water erosion (RUSLE2015)

European Commission



- Average EU-28: **2.46 t ha^{-1} yr^{-1}** (in the erosive prone areas: 91% of EU)
- Total Soil loss: **970 Mt annually**
- Spatial resolution: **100m**
- Reference year: **2010**

- **24%** of EU lands have rates >2 t/ha
- **11% of total area** contributes to almost **70% of total Soil Loss**

"Between 2000 and 2010, intervention measures through the CAP have reduced the rate of soil erosion by an average of 9% in total (20% in arable lands)"

Panagos, Borrelli, Robinson, 2015. NATURE.
Panagos et al (2015) – Environmental Science & Policy

Research Centre

RUSLE2015 & Soil Loss Map:
Concluding remarks

European Commission

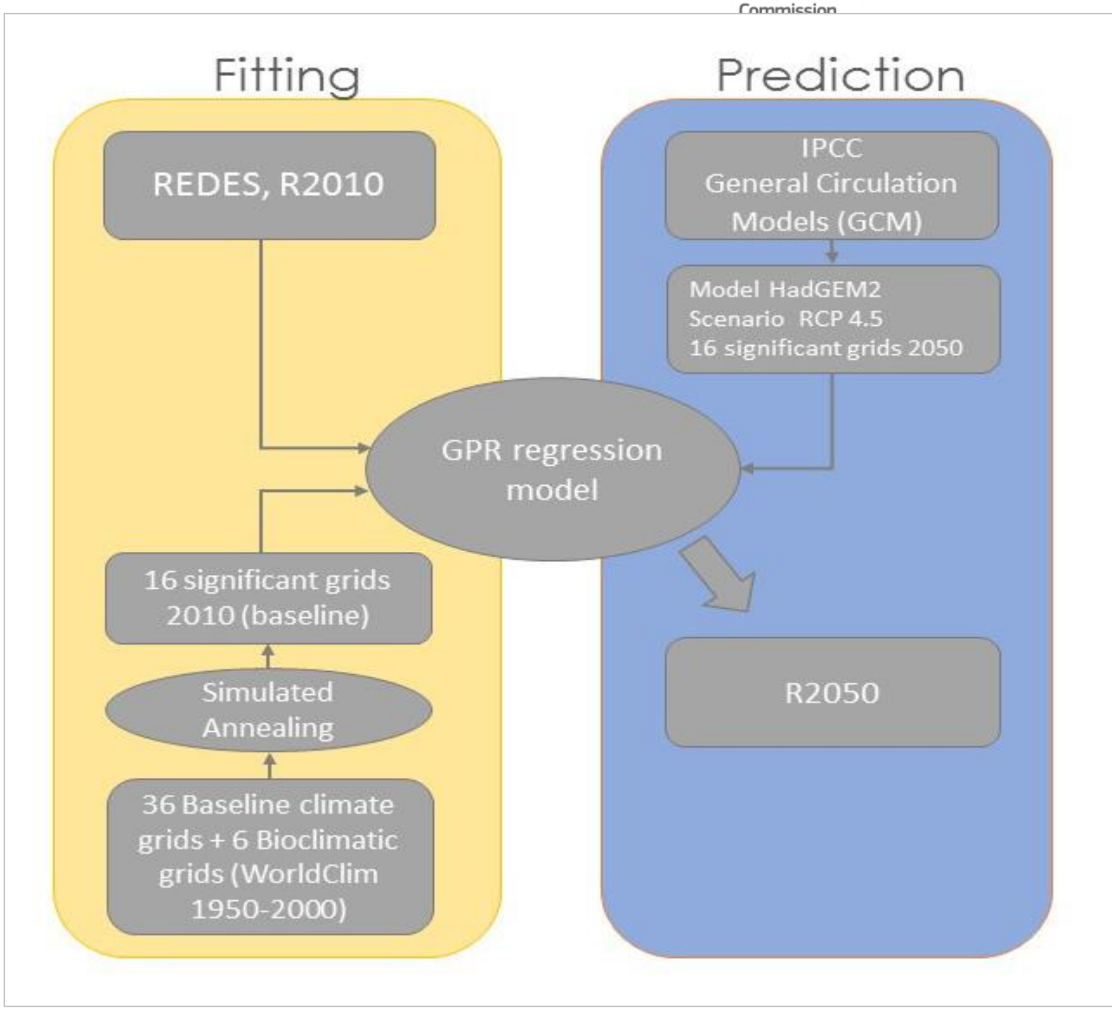
- **Trend**: Decrease of 9% (20% in arable lands) due to impact of Common Agriculture Policy (CAP) and soil protection measures: **reduced tillage, plant residues, cover crop, contour farming, maintenance of stone walls, increase of Buffer strips**.

- Very good correspondence with **EIONET** (7 out of 9 Member States): The European model is as robust as national ones.
- **High resolution** & **best available** input data in EU
- **Transparent way** & **easily parameterization**
- **Peer-reviewed following literature**
- **Replicable & comparable** with national estimates
- **Participatory**: involvement of countries [National meteorological services (*Erosivity*), LUCAS-topsoil (*erodibility*), CORINE/Copernicus (*vegetation*), Statistics – Eurostat (*management*)]
- Incorporates **Scenario analysis**

Panagos et al (2015) – Env.Science & Policy

Model the future erosivity (2050)

- Rainfall erosivity is **strongly correlated with precipitation dynamics** (precipitation seasonality, monthly precipitation) and other bioclimatic variables
- **Simulation Annealing** optimizes the selection of the most appropriate covariates
- Use of future climatic data for the **HadGEM2 scenario 4.5**
- The **regression model** is fitted with covariates of projected future climatic data
- R-factor projections include the **uncertainty of climatic models**



Panagos et al.(2017). Journal of Hydrology

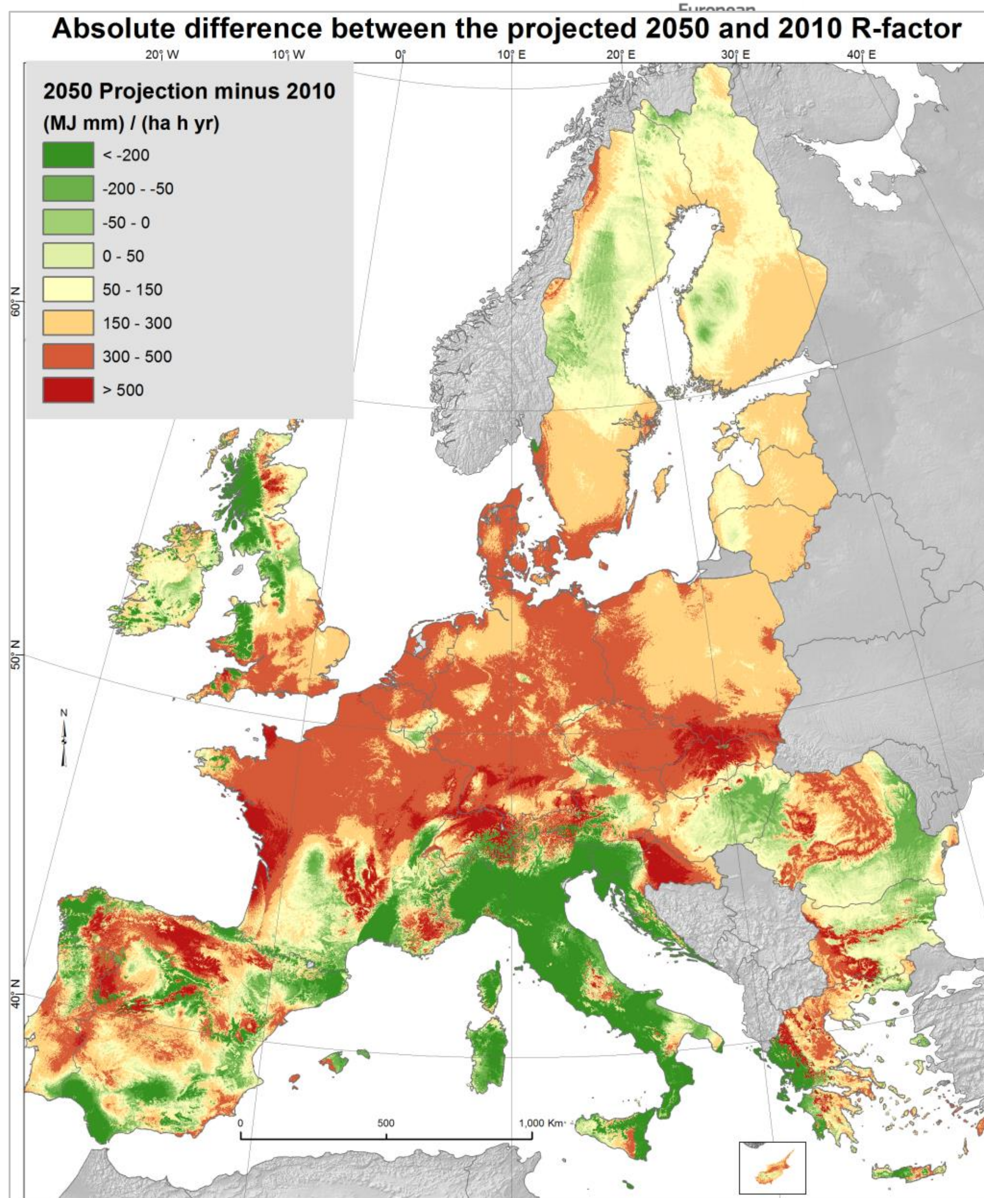
Climate change scenarios and Rainfall Erosivity in 2050

- **Climate change scenarios (2050):** Taking into account IPCC HadGEM2 and REDES we predict 18% increase of R-factor in 2050

- **Highest R-factor increase** is projected in Northern & Central Europe

- Rainfall erosivity will increase in 81% of the study area and decrease in the rest 19%

- Comparison with 3 regional studies in Belgium, Germany and Czech Republic plus other studies which projected trends in erosivity (Italy, Spain, Ireland, Scandinavia)



Panagos et al.(2017). Journal of Hydrology

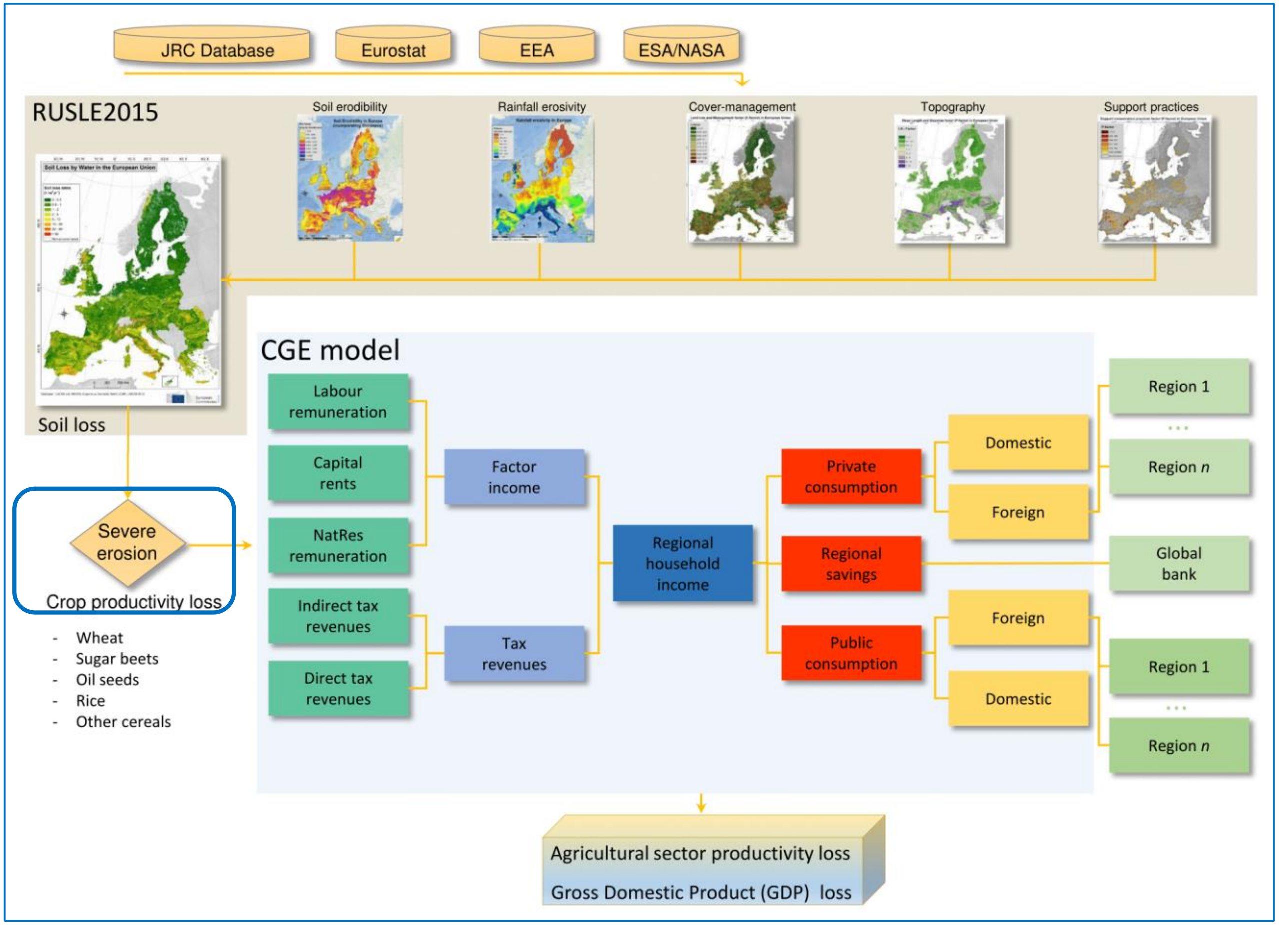
Land use Scenarios & policy developments

European Commission

- **Land use scenarios**: Projections of land use change for the year 2050 based on the pan-European Land Use Modelling Platform (LUISA)
- According to LUISA :
  - All agricultural land uses will be reduced by 2050 (croplands will **decrease** by 1.2%, permanent crops by 0.2% and pastures by 0.6%)
  - Semi-natural areas will also **decrease** by 1%
  - Urban areas will **increase** by 0.7% and forest areas by 2.2%.
- Forest lands, which are the least erosion prone (with mean annual soil loss of 0.065 t/ha), will replace erosion-sensitive land uses (permanent crops, arable, pastures and semi-natural).
- In aggregated soil loss terms, the future land use changes projected by LUISA will result in a **5.8% reduction in soil loss**

- **Policy developments:**
  - Biofuels directive pushes for replacing cereals with energy crops: sugar beet, sunflowers (more erosive). i.e. scenario of 10% conversion to energy crops → increase 3.8% of soil loss in arable lands
  - Hypothetical scenario: Duplicate the grass margins and apply contour farming in arable lands > 5% slope → Reduce soil erosion by 5%

Economic evaluation of agricultural productivity loss



Integration of RUSLE 2015 with **Computable General Equilibrium (CGE)** Macroeconomic model

CGE takes into account the endogenous adjustments in the economic system

CGE employs trading mechanisms: import/export flows, competitiveness, consumer preferences, reallocation of labour and capital between sectors, etc.)

The trading mechanisms mitigate initial crop productivity losses

The annual cost of this loss in agricultural productivity is estimated at around **€1.25 billion**

CGE model estimates the cost in the **agricultural sector** to be close to **€300 million**

Joint Research Centre

In Progress & future

European Commission

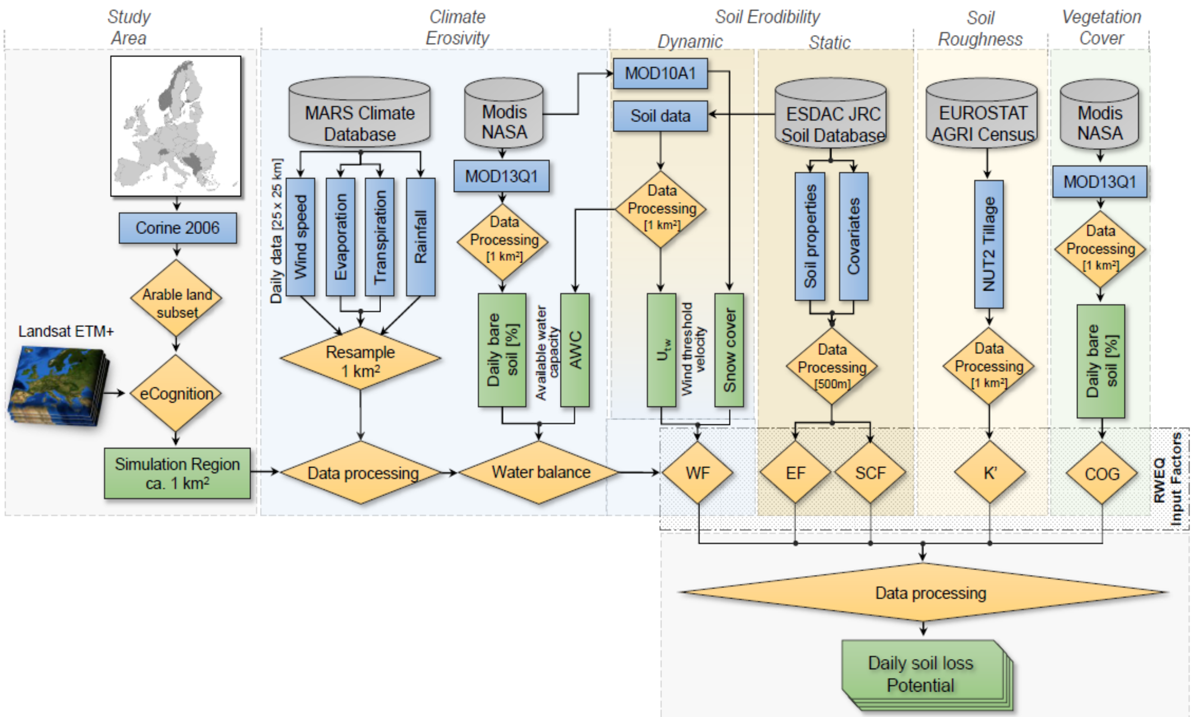
- **Seasonality:** Monthly variability of the erosivity, vegetation and crop management at European scale.
- **Sediment yields predictions from catchment area** (In development with WATEM-SEDEM model)
- **Economic evaluation** of soil loss by water erosion (*Panagos et al., 2015 Nature*) : Impact to agricultural productivity and GDP; Off-site effects

GLOBAL

- Development of the first ever **Global Rainfall Erosivity Database**
  63 countries; >50 scientists; 100 organizations; 3,625 stations; 60,000 yrs HR data
- Comprehensive **Global Land Cover and Management Factor**
- Towards a **Global Soil Erosion dataset** and updated Land Degradation Assessment (supported by FAO, GSP, IPBES).

Wind Erosion Assessment in Europe with GIS-RWEQ model

European Commission



Borrelli et al., 2017. *Land Degradation & Development*, **28:** 335-344

The **first quantitative assessment** at European level.

Main Factors influencing wind erosion (included in the model):

Climate: wind velocity & direction, Rainfall and evapotranspiration

Soil characteristics: sand, silt, clay, Calcium Carbonate(CaCO3), organic matter, water-retention capacity and soil moisture

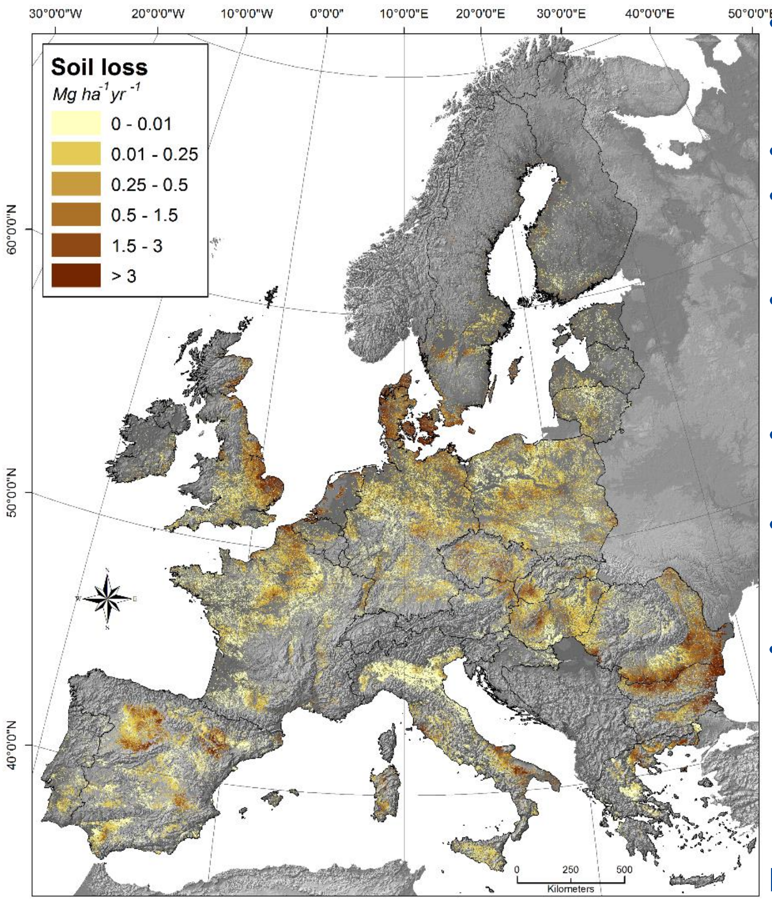
Land use (vegetation cover): land use type, percent of vegetation cover and landscape roughness

Model used: RWEQ

The model scheme is designed to describe the daily soil loss potential at regional or larger scale

Joint Research Centre

Soil loss by wind modelled for the European arable land



- The average annual soil loss predicted by GIS-RWEQ in the EU arable land totalled 0.53 Mg ha^{-1} yr^{-1}

- 2^{nd} quantile equal to 0.3 Mg ha^{-1} yr^{-1}
- 4^{th} quantile equal to 1.9 Mg ha^{-1} yr^{-1}

- Highest wind erosion rates in arable lands: Denmark, Netherlands and Bulgaria

- Peak in winter period (December-February): 57% of total

- Noticeable rates in Eastern UK, North France, Belgium, Czech Republic, Slovakia and Hungary

- In Mediterranean, higher soil loss rates were located in the Spanish regions of Aragón, Castilla y Leon, the Italian regions of Apulia, Tuscany and Sardinia, in the Provence in France and the Greek regions of Central and Eastern Macedonia and Thrace and Aegean islands.

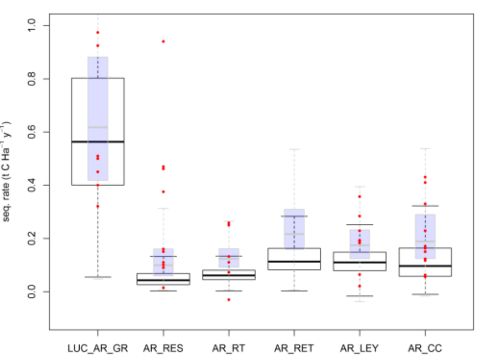
Data available:
http://esdac.jrc.ec.europa.eu/themes/land-susceptibility-wind-erosion

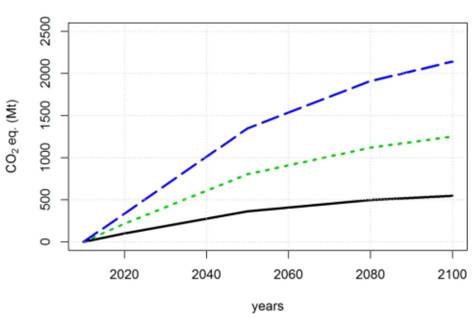
Borrelli et al., 2017. *Land Degradation & Development*, **28:** 335-344

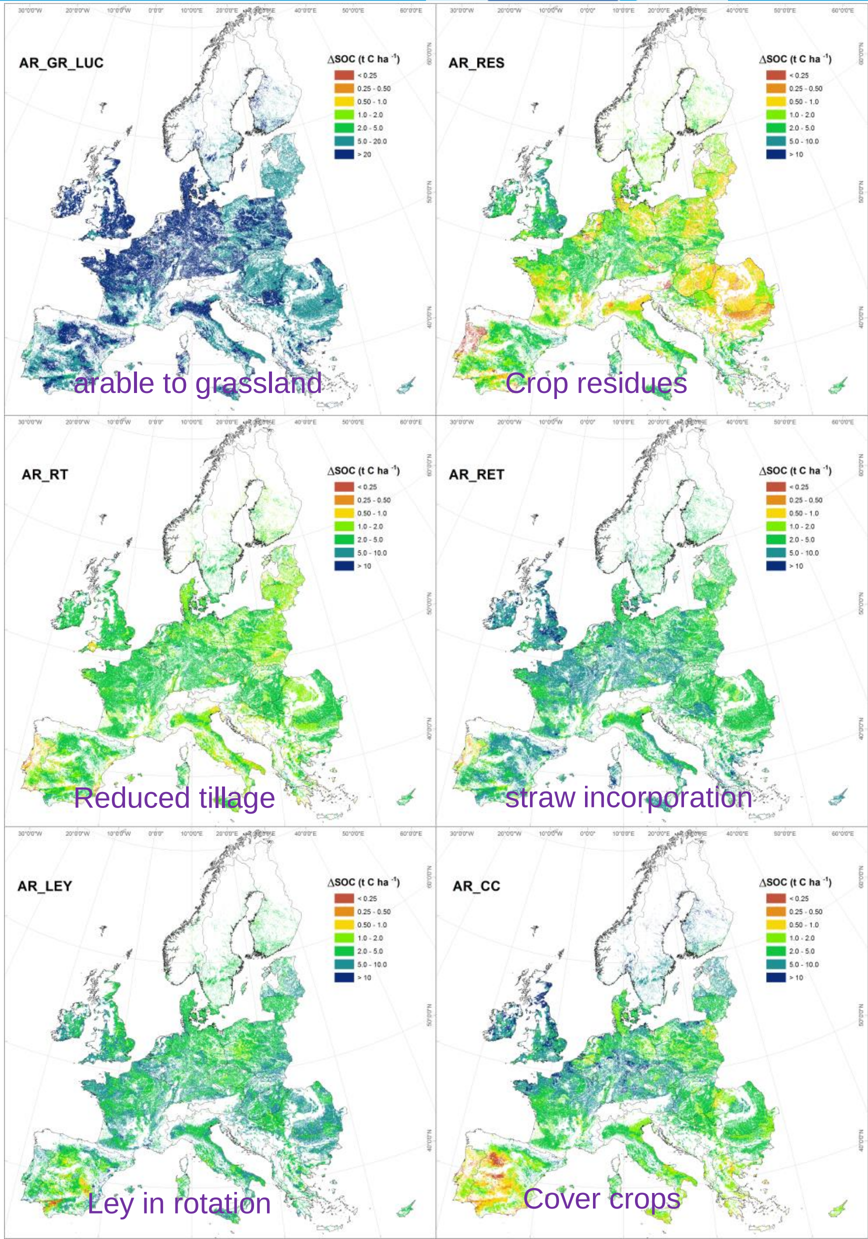
Joint Research Centre

Modelling carbon under agricultural management practices

Modelling tools predicting quantitative effect of different mitigation measures on soil organic carbon in agricultural soils



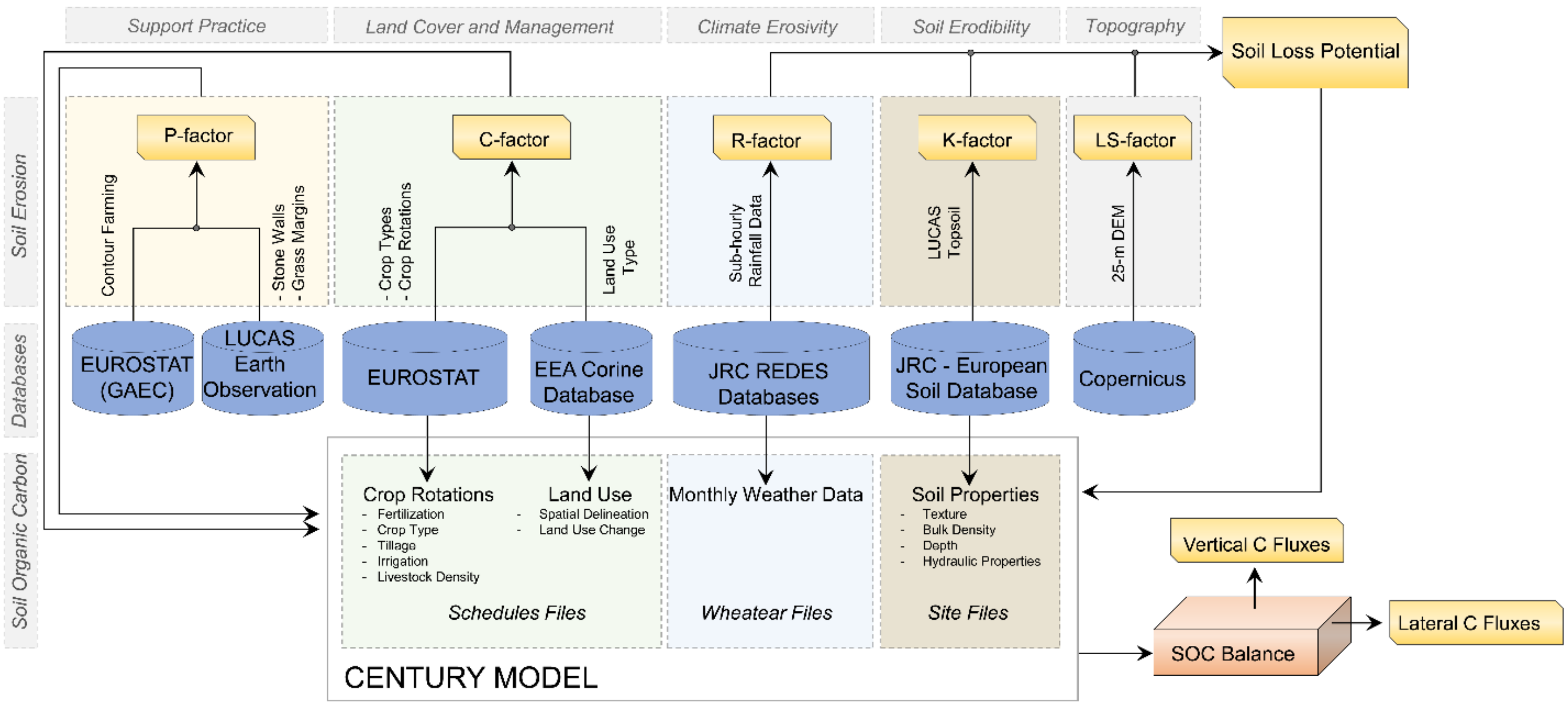




Lugato et al., 2014. Global Change Biology

Joint Research Centre

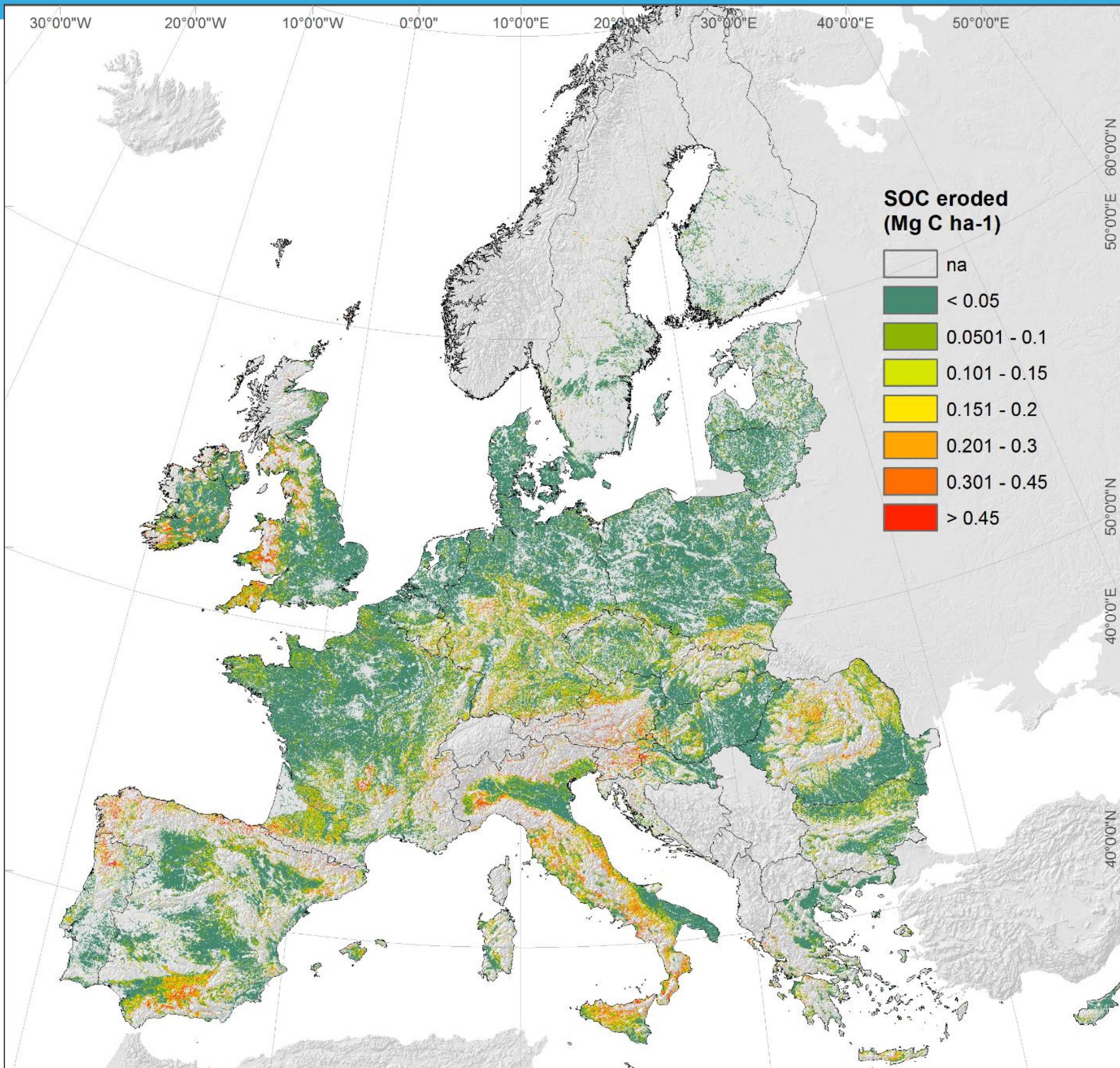
Erosion & SOC modelling (Integration)



- Coupling RUSLE2015 with CENTURY biogeochemical model
- SOC balance and C fluxes at grid cell (1.87 M grid cells of 1Km)
- Part of the C eroded was assumed to move out from grid cell generating CO_2 flux

Lugato et al (2016) – Global Change Biology

Average eroded soil organic carbon



Lugato et al (2016) – Global Change Biology

European Commission

- 76% of agricultural lands **< 0.05 t C ha^{-1} yr^{-1}**
- Hotspots with eroded SOC > **0.45 t C ha^{-1} yr^{-1}**

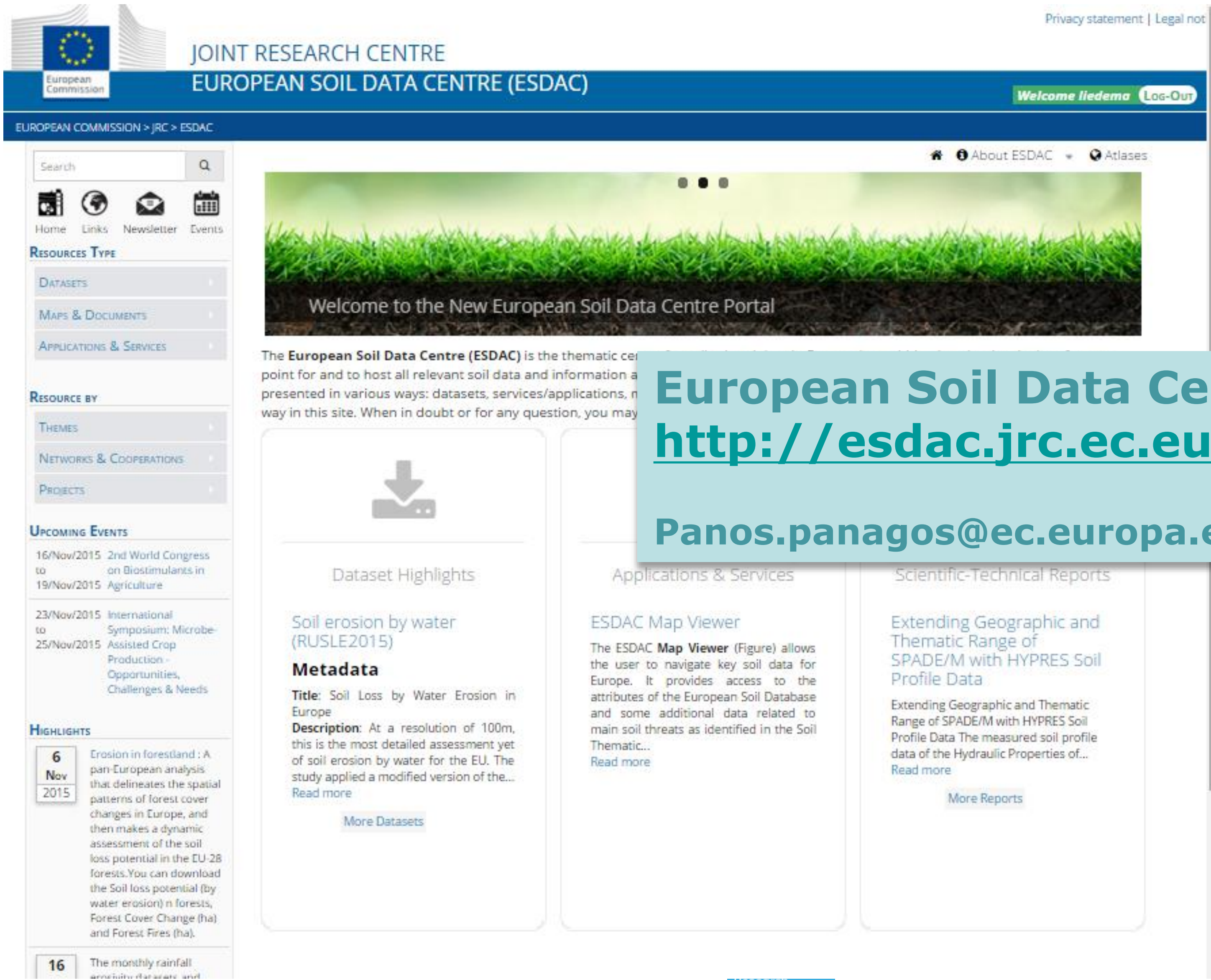
- Erosion across EU agricultural lands contributes **to 2.28 Mt CO_{2eq}**
- Policy oriented scenario estimate to sequester **12.6-42 Mt CO_{2eq}**

"Agricultural practices are needed to prevent or reduce erosion and maintain soil productivity"

Soil erosion modelling workshop

European Commission

Data available:



European Soil Data Centre: http://esdac.jrc.ec.europa.eu/

Panos.panagos@ec.europa.eu

European Commission

Research Centre

Information in peer review publications:

Science of the Total Environment 511 (2015) 801–814
Contents lists available at ScienceDirect
Science of the Total Environment
journal homepage: www.elsevier.com/locate/scitotenv

Rainfall erosivity in Europe

Panos Panagos [a,*], Cristiano Ballabio [a], Pasquale Borrelli [a], Katrin Meusburger [b], Andreas Klik [c], Svetla Rousseva [d], Melita Perčec Tadić [e], Silas Michaelides [f], Michaela Hrabalíková [g], Preben Olsen [h], Juha Aalt... Mónika Lakatos [j], Anna Rymszewicz [k], Alexandru Dumitrescu [l], Santiago Beguería [m], Christine Alewell [b]
[a] European Commission, Joint Research Centre, Institute for Environment and Sustainability, Via E. Fermi 2749, I-21027 Ispra, VA, Italy

Science of the Total Environment 479–480 (2014) 189–200
Contents lists available at ScienceDirect
Science of the Total Environment
journal homepage: www.elsevier.com/locate/scitotenv

Soil erodibility in Europe: A high-resolution dataset based on LUCAS

Panos Panagos [a,*], Katrin Meusburger [b], Cristiano Ballabio [a], Pasqualle Borrelli [a], Christine Alewell [b]

Global Change Biology

Global Change Biology (2016) 22, 1976–1984, doi: 10.1111/gcb.13198

TECHNICAL ADVANCE

Quantifying the erosion effect on current carbon budget of European agricultural soils at high spatial resolution

Land Use Policy 48 (2015) 38–50
Contents lists available at ScienceDirect
Land Use Policy
journal homepage: www.elsevier.com/locate/landusepol

...mating the soil erosion cover-management factor at the European ...e

...s Panagos [a,*], Pasquale Borrelli [a], Katrin Meusburger [b], Christine Alewell [b], ...nuele Lugato [a], Luca Montanarella [a]
...an Commission, Joint Research Centre, Institute for Environment and Sustainability, Via E. Fermi 2749, I-21027 Ispra, VA, Italy
...nmental Geosciences, University of Basel, Switzerland

Journal of Hydrology 548 (2017) 251–262
Contents lists available at ScienceDirect
Journal of Hydrology
journal homepage: www.elsevier.com/locate/jhydrol

Research papers

Towards estimates of future rainfall erosivity in Europe based on REDES and WorldClim datasets

Panos Panagos [a,*], Cristiano Ballabio [a], Katrin Meusburger [b], Jonathan Spinoni [a], Christine Alewell [b], Pasquale Borrelli [a,b]

Modelling the effect of support practices (P-factor) on the reduction of soil erosion by water at European scale

Panos Panagos [a,*], Pasquale Borrelli [a], Katrin Meusburger [b], Emma H. van der Zanden [c], Jean Poesen [d], Christine Alewell [b]

Assessing soil erosion in Europe based on data collected th... European network

Panos PANAGOS[1], Katrin MEUSBURGER[2], Marc VAN LIEDEKERKE[1], ... ALEWELL[2], Roland HIEDERER[1] and Luca MONTANARELLA[1]
[1]European Commission, Joint Research Centre, Institute for Environment and Sustainability, Via E. Fermi 2749, I-21027 Ispra, VA, Italy, [2]Environmental Geosciences, University of Basel, Bernoullistrasse 30, 4056 Basel, Switzerland

Contents lists available at ScienceDirect
Environmental Science & Policy
journal homepage: www.elsevier.com/locate/envsci

Land Degrad. Develop. 27: 1547–1551 (2016)
Published online 29 May 2016 in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/ldr.2538

SOIL CONSERVATION IN EUROPE: WISH OR REALITY?

Panos Panagos[1*], Anton Imeson[2], Katrin Meusburger[3], Pasquale Borrelli[1], Jean Poesen[4], Christine Alewell[3]

The new assessment of soil loss by water erosion in Europe

Panos Panagos [a,*], Pasquale Borrelli [a], Jean Poesen [c], Cristiano Ballabio [a], Emanuele Lugato [a], Katrin Meusburger [b], Luca Montanarella [a], Christine Alewell [b]
[a] European Commission, Joint Research Centre, Institute for Environment and Sustainability, Via E. Fermi 2749, I-21027, Ispra (VA), Italy
[b] Environmental Geosciences, University of Basel, Switzerland
[c] Division of Geography, KU Leuven, Belgium