Seasonal variation and climate change impact in Rainfall Erosivity across Europe

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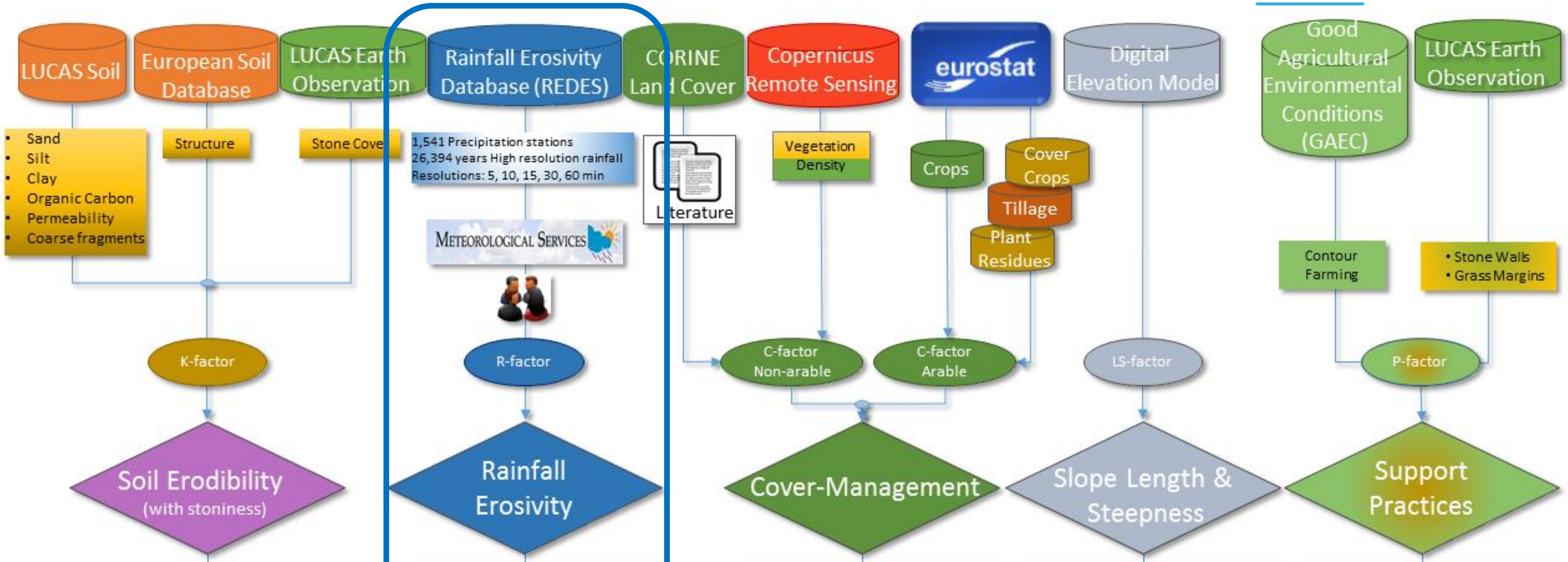
Outline

- Rainfall erosivity and **soil erosion modelling**
- **REDES:** Rainfall Erosivity Database at European Scale
- Mapping **Rainfall erosivity in Europe**
- **Seasonal and Monthly** mapping of erosivity
- **Climate change projections** for Erosivity in 2050

RUSLE2015: New soil erosion model



LUCAS Soil
- Sand
- Silt
- Clay
- Organic Carbon
- Permeability
- Coarse fragments

European Soil Database
- Structure

LUCAS Earth Observation
- Stone Cove

K-factor → **Soil Erodibility** (with stoniness)

Rainfall Erosivity Database (REDES)

1,541 Precipitation stations
26,394 years High resolution rainfall
Resolutions: 5, 10, 15, 30, 60 min

METEOROLOGICAL SERVICES

R-factor → **Rainfall Erosivity**

CORINE Land Cover

Literature

Copernicus Remote Sensing
- Vegetation Density

eurostat
- Crops
- Cover Crops
- Tillage
- Plant Residues

C-factor Non-arable

C-factor Arable

→ **Cover-Management**

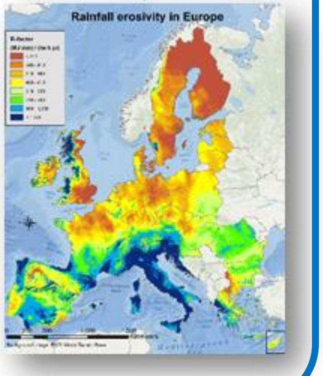
Digital Elevation Model

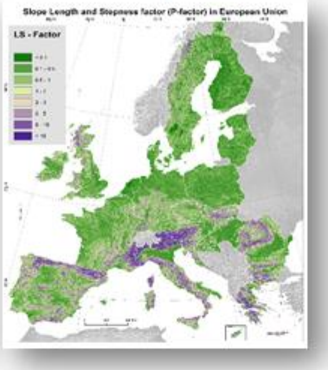
LS-factor → **Slope Length & Steepness**

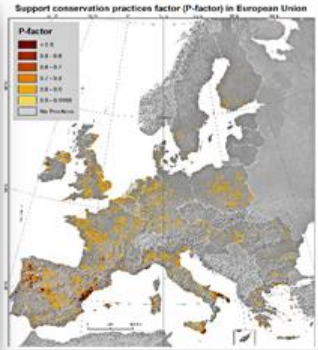
Good Agricultural Environmental Conditions (GAEC)
- Contour Farming

LUCAS Earth Observation
- Stone Walls
- Grass Margins

P-factor → **Support Practices**





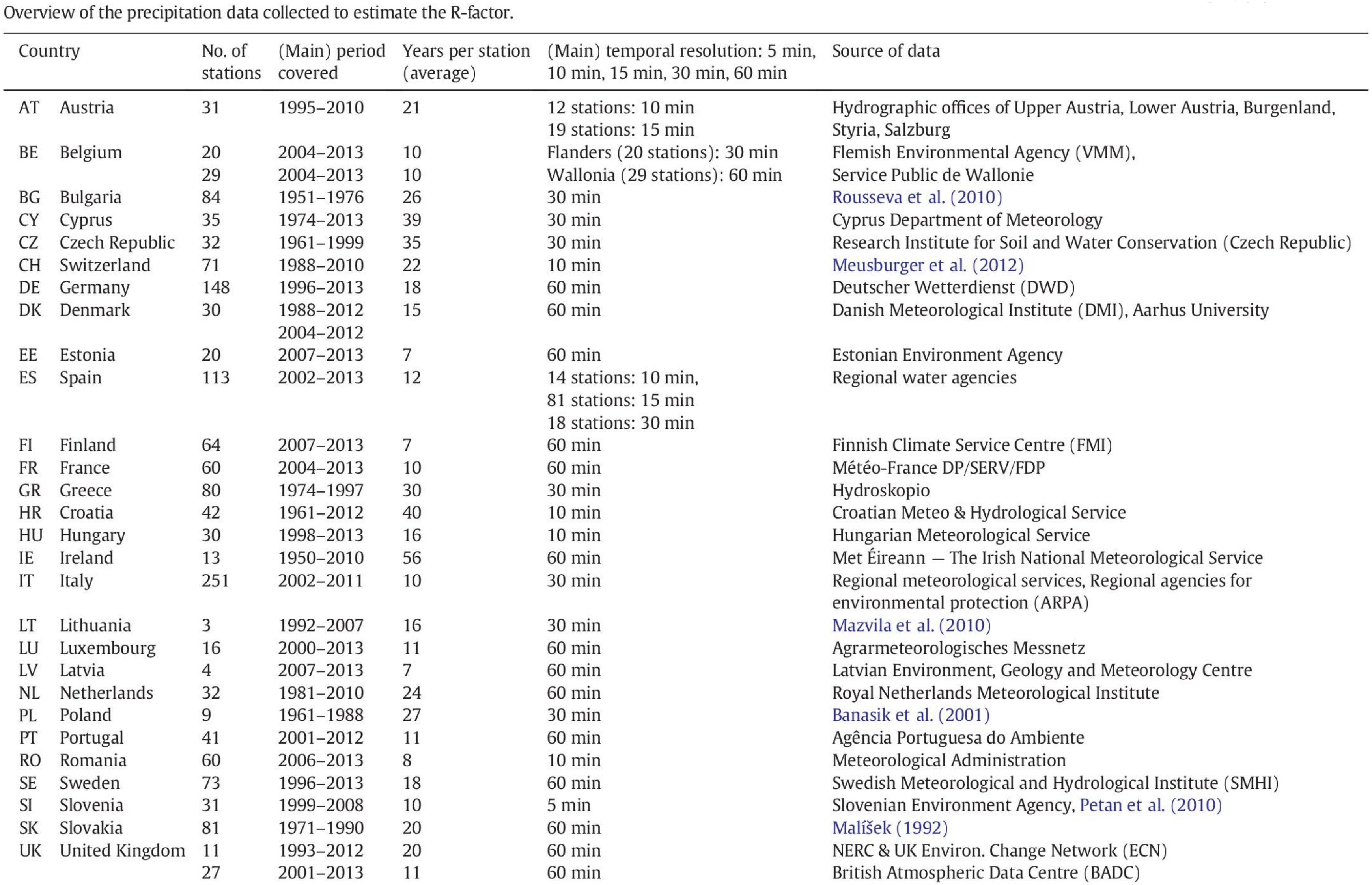


Panagos et al (2015) – Environmental Science & Policy

Objective: Why a European Rainfall Erosivity dataset?

- **Important factor for Soil erosion modelling:** Rainfall erosivity (**R-factor**) is one of the 5 factors for estimating soil erosion using (R)USLE model and is the only seasonally varying (besides crops, but crop are manmade…)
- Spatio-temporal resolution is critical for evaluating **when** and **where** potentially erosive rainfall events occur
- Temporal information is critical for many **erosion prevention measures** as well
- Monthly data allows to create **new indicators** for rainfall erosivity
- **Other applications**:
    - a) Landslide risk assessment;
    - b) flood risk forecasting;
    - c) Post-fire conservation measures;
    - d) agricultural management and design of crop rotation scenarios
    - e) Ecosystem services f) Trends and threats of climate change

Data collection 2013-2015

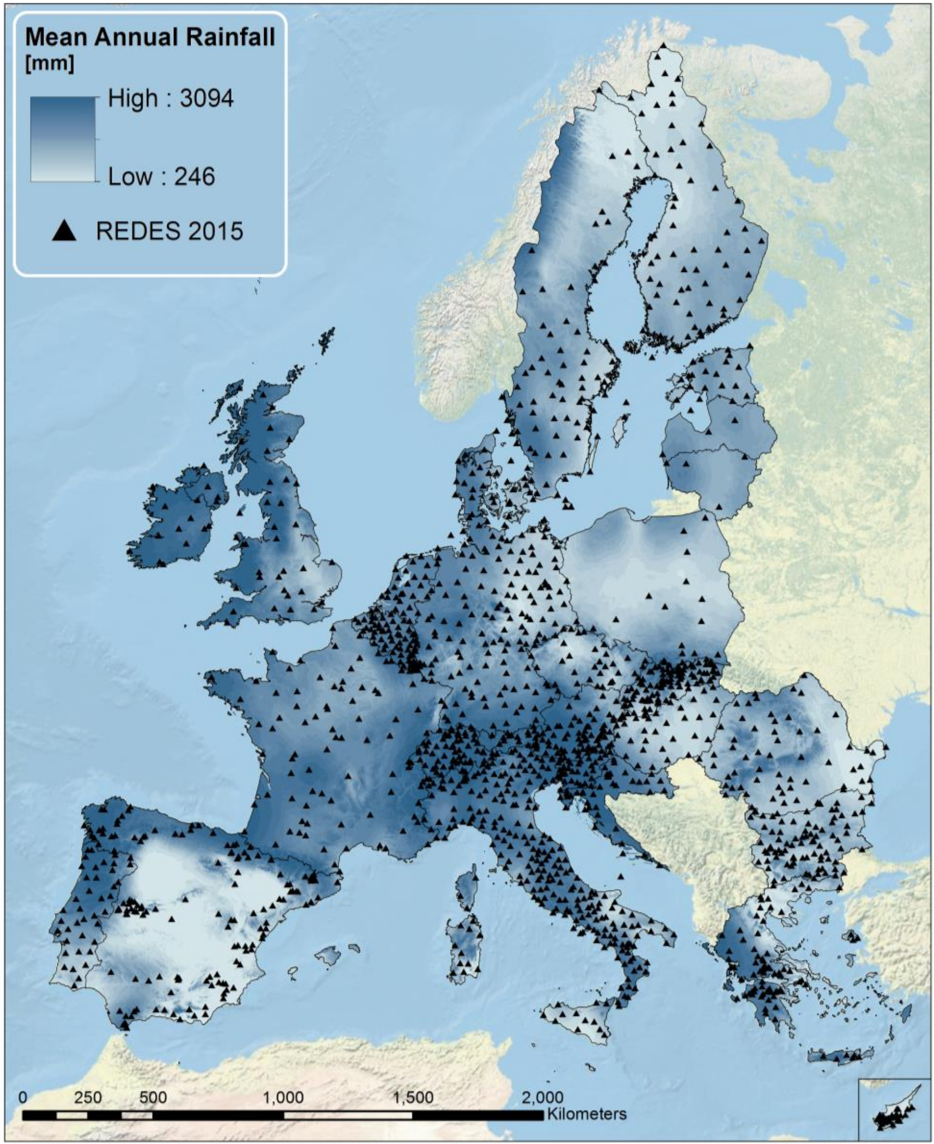


Overview of the precipitation data collected to estimate the R-factor.

Country		No. of stations	(Main) period covered	Years per station (average)	(Main) temporal resolution: 5 min, 10 min, 15 min, 30 min, 60 min	Source of data
AT	Austria	31	1995–2010	21	12 stations: 10 min 19 stations: 15 min	Hydrographic offices of Upper Austria, Lower Austria, Burgenland, Styria, Salzburg
BE	Belgium	20	2004–2013	10	Flanders (20 stations): 30 min	Flemish Environmental Agency (VMM),
		29	2004–2013	10	Wallonia (29 stations): 60 min	Service Public de Wallonie
BG	Bulgaria	84	1951–1976	26	30 min	Rousseva et al. (2010)
CY	Cyprus	35	1974–2013	39	30 min	Cyprus Department of Meteorology
CZ	Czech Republic	32	1961–1999	35	30 min	Research Institute for Soil and Water Conservation (Czech Republic)
CH	Switzerland	71	1988–2010	22	10 min	Meusburger et al. (2012)
DE	Germany	148	1996–2013	18	60 min	Deutscher Wetterdienst (DWD)
DK	Denmark	30	1988–2012 2004–2012	15	60 min	Danish Meteorological Institute (DMI), Aarhus University
EE	Estonia	20	2007–2013	7	60 min	Estonian Environment Agency
ES	Spain	113	2002–2013	12	14 stations: 10 min, 81 stations: 15 min 18 stations: 30 min	Regional water agencies
FI	Finland	64	2007–2013	7	60 min	Finnish Climate Service Centre (FMI)
FR	France	60	2004–2013	10	60 min	Météo-France DP/SERV/FDP
GR	Greece	80	1974–1997	30	30 min	Hydroskopio
HR	Croatia	42	1961–2012	40	10 min	Croatian Meteo & Hydrological Service
HU	Hungary	30	1998–2013	16	10 min	Hungarian Meteorological Service
IE	Ireland	13	1950–2010	56	60 min	Met Éireann — The Irish National Meteorological Service
IT	Italy	251	2002–2011	10	30 min	Regional meteorological services, Regional agencies for environmental protection (ARPA)
LT	Lithuania	3	1992–2007	16	30 min	Mazvila et al. (2010)
LU	Luxembourg	16	2000–2013	11	60 min	Agrarmeteorologisches Messnetz
LV	Latvia	4	2007–2013	7	60 min	Latvian Environment, Geology and Meteorology Centre
NL	Netherlands	32	1981–2010	24	60 min	Royal Netherlands Meteorological Institute
PL	Poland	9	1961–1988	27	30 min	Banasik et al. (2001)
PT	Portugal	41	2001–2012	11	60 min	Agência Portuguesa do Ambiente
RO	Romania	60	2006–2013	8	10 min	Meteorological Administration
SE	Sweden	73	1996–2013	18	60 min	Swedish Meteorological and Hydrological Institute (SMHI)
SI	Slovenia	31	1999–2008	10	5 min	Slovenian Environment Agency, Petan et al. (2010)
SK	Slovakia	81	1971–1990	20	60 min	Malíšek (1992)
UK	United Kingdom	11	1993–2012	20	60 min	NERC & UK Environ. Change Network (ECN)
		27	2001–2013	11	60 min	British Atmospheric Data Centre (BADC)

REDES: Rainfall Erosivity Database at European Scale

European Commission



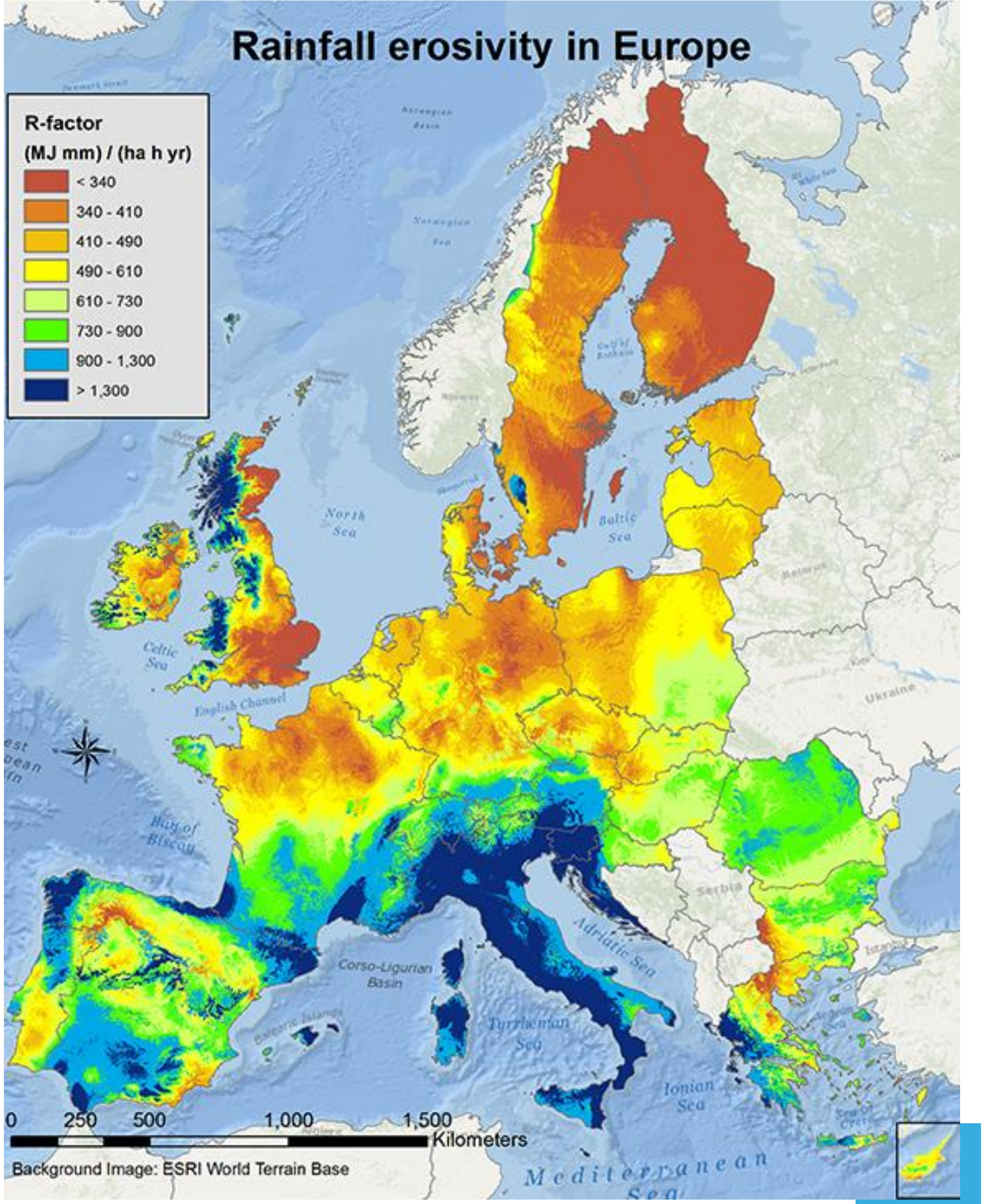
- **Rainfall erosivity** measures rainfall kinetic energy & intensity (MJ mm ha^{-1} h^{-1} y^{-1})
- Combines the influence of **rainfall frequency, duration, amount** and **intensity**

$$R = \frac{\sum_{k=1}^{n}(EI_{30})k}{n}, \; EI_{30} = \left(\sum_{r=1}^{m} e_r v_r\right) \boldsymbol{I_{30}}$$

- **1,541** Precipitation stations with detailed rainfall intensity; **1675 Precipitation Stations** in 2015 update (all countries)
- **Temporal Resolution**: 30-Minutes
- **Time series**: 7 – 56 Years (Mean: 17.1yr; 75% of time series in 2000-2010)
- **Average density:** 1 station per 50km x 50km
- **Stations distribution**: 6.5% of the REDES stations in > 1,000m

Joint Research Centre

Rainfall Erosivity (R-factor)

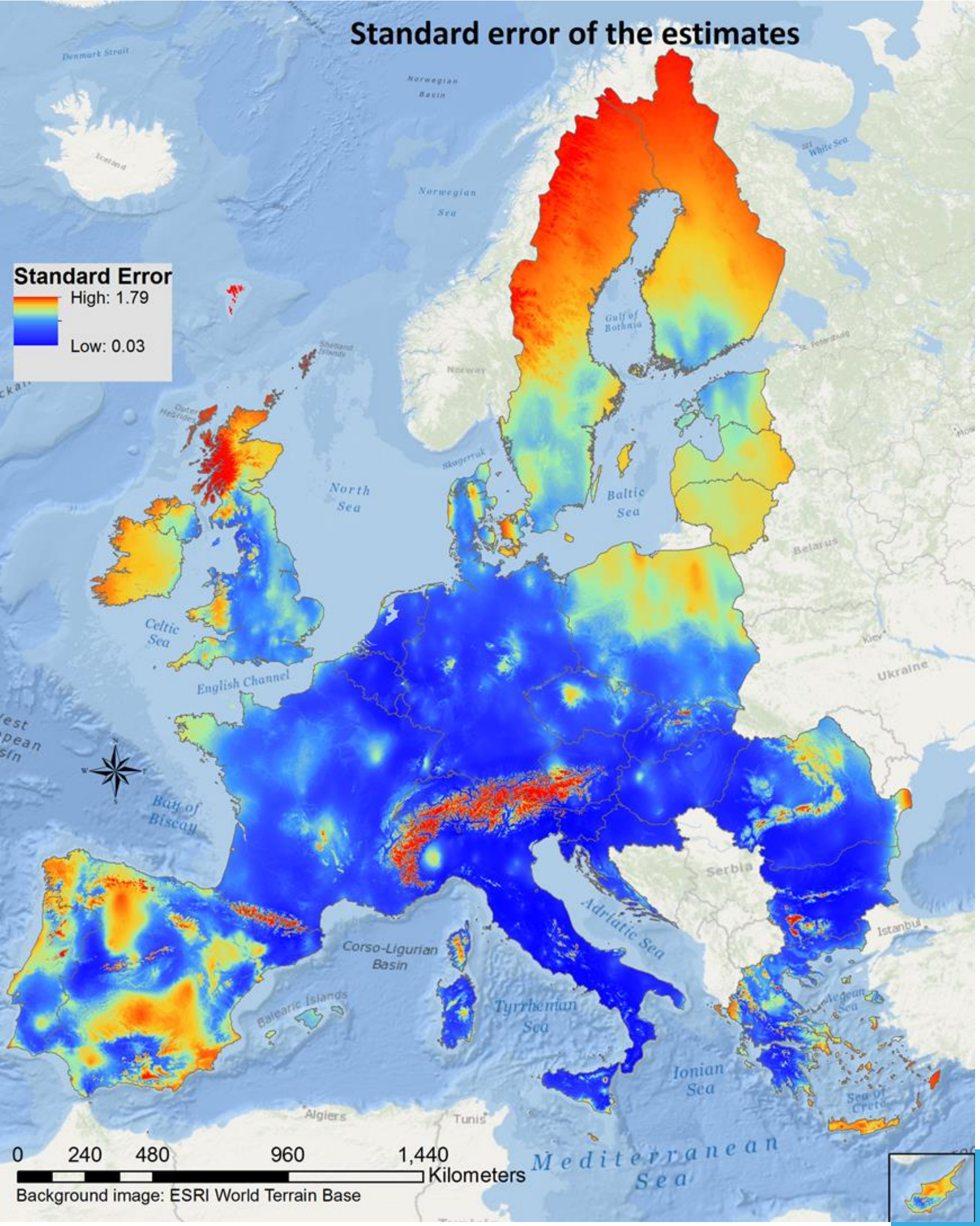

Rainfall erosivity in Europe

Background Image: ESRI World Terrain Base

- **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

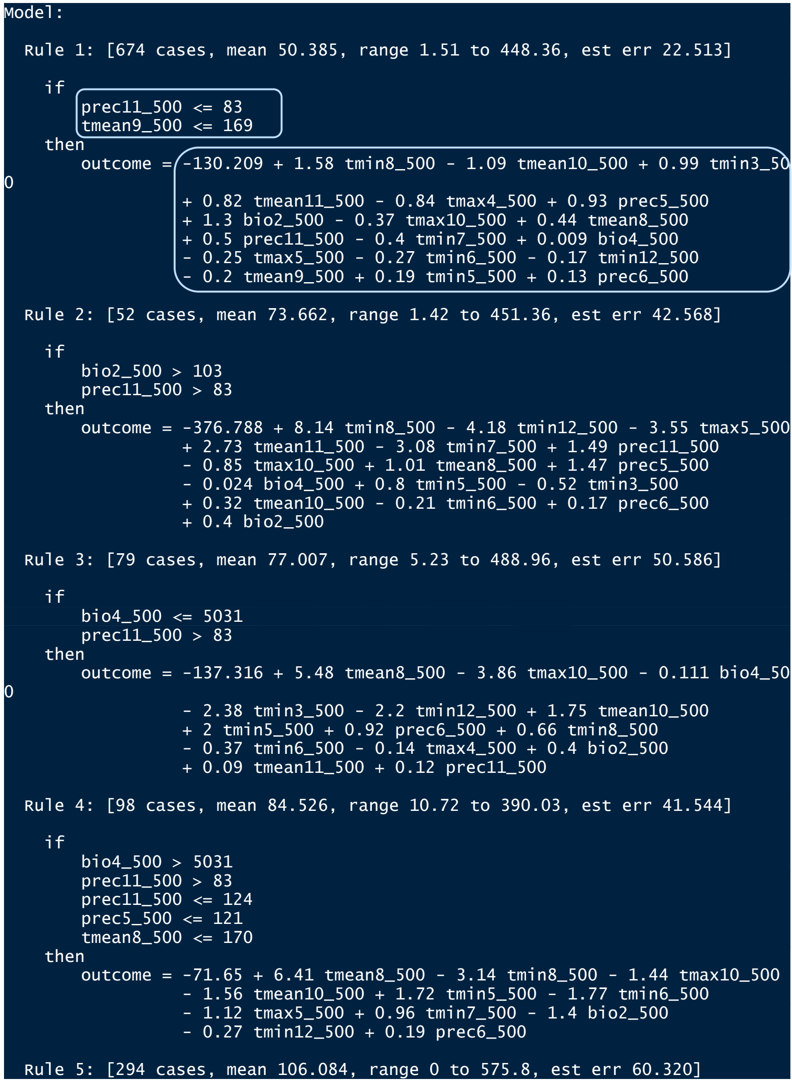
Uncertainty of the prediction model



Standard error of the estimates

- The model had a **good prediction rate** with low standard errors in the majority of the study area
- **High variability of climatic and terrain conditions** in an area of > **4.4 Million km²** resulted in a broad spectrum of rainfall erosivity
- Scotland, north-western Sweden and northern Finland: Relatively **small number of precipitation stations**
- Southern Alps and the Pyrenees**: high diversity of environmental features**

Prediction of Monthly erosivity with Cubist regression



```
Model:

  Rule 1: [674 cases, mean 50.385, range 1.51 to 448.36, est err 22.513]

    if
       prec11_500 <= 83
       tmean9_500 <= 169
    then
       outcome = -130.209 + 1.58 tmin8_500 - 1.09 tmean10_500 + 0.99 tmin3_50
0

                 + 0.82 tmean11_500 - 0.84 tmax4_500 + 0.93 prec5_500
                 + 1.3 bio2_500 - 0.37 tmax10_500 + 0.44 tmean8_500
                 + 0.5 prec11_500 - 0.4 tmin7_500 + 0.009 bio4_500
                 - 0.25 tmax5_500 - 0.27 tmin6_500 - 0.17 tmin12_500
                 - 0.2 tmean9_500 + 0.19 tmin5_500 + 0.13 prec6_500

  Rule 2: [52 cases, mean 73.662, range 1.42 to 451.36, est err 42.568]

    if
       bio2_500 > 103
       prec11_500 > 83
    then
       outcome = -376.788 + 8.14 tmin8_500 - 4.18 tmin12_500 - 3.55 tmax5_500
                 + 2.73 tmean11_500 - 3.08 tmin7_500 + 1.49 prec11_500
                 - 0.85 tmax10_500 + 1.01 tmean8_500 + 1.47 prec5_500
                 - 0.024 bio4_500 + 0.8 tmin5_500 - 0.52 tmin3_500
                 + 0.32 tmean10_500 - 0.21 tmin6_500 + 0.17 prec6_500
                 + 0.4 bio2_500

  Rule 3: [79 cases, mean 77.007, range 5.23 to 488.96, est err 50.586]

    if
       bio4_500 <= 5031
       prec11_500 > 83
    then
       outcome = -137.316 + 5.48 tmean8_500 - 3.86 tmax10_500 - 0.111 bio4_50
0

                 - 2.38 tmin3_500 - 2.2 tmin12_500 + 1.75 tmean10_500
                 + 2 tmin5_500 + 0.92 prec6_500 + 0.66 tmin8_500
                 - 0.37 tmin6_500 - 0.14 tmax4_500 + 0.4 bio2_500
                 + 0.09 tmean11_500 + 0.12 prec11_500

  Rule 4: [98 cases, mean 84.526, range 10.72 to 390.03, est err 41.544]

    if
       bio4_500 > 5031
       prec11_500 > 83
       prec11_500 <= 124
       prec5_500 <= 121
       tmean8_500 <= 170
    then
       outcome = -71.65 + 6.41 tmean8_500 - 3.14 tmin8_500 - 1.44 tmax10_500
                 - 1.56 tmean10_500 + 1.72 tmin5_500 - 1.77 tmin6_500
                 - 1.12 tmax5_500 + 0.96 tmin7_500 - 1.4 bio2_500
                 - 0.27 tmin12_500 + 0.19 prec6_500

  Rule 5: [294 cases, mean 106.084, range 0 to 575.8, est err 60.320]
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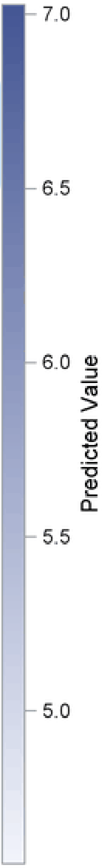
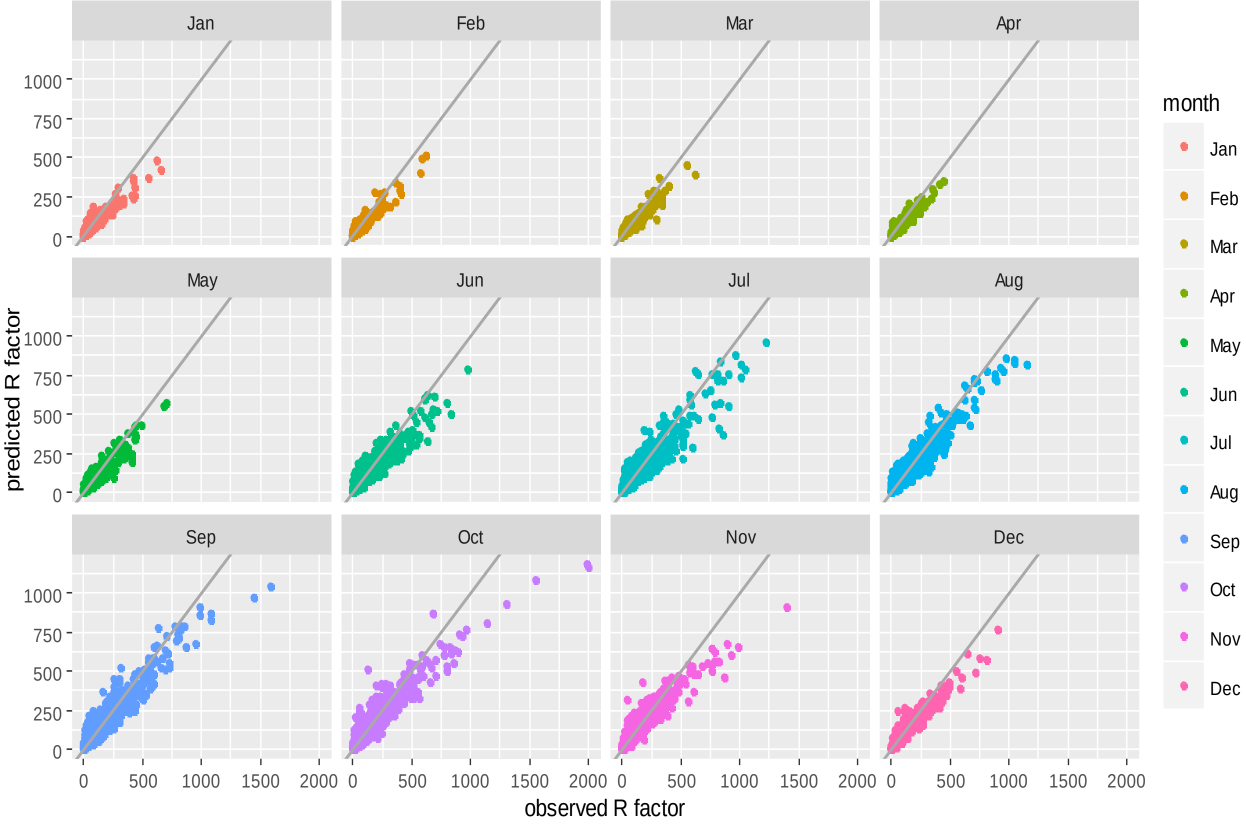


- Estimating the monthly R-factor for the different climatic conditions of Europe requires enough climate information
  - Average Monthly precipitation
  - Average Maximum & Minimum precipitation & temperature
  - Precipitation of wettest / driest month
  - Variation of precipitation over seasons
  - Bioclimatic data
- “Different” parts of the model fit properly on the range of climatic conditions all over Europe
- This calls for the use of models capable of modelling non-linear relations like **Cubist**

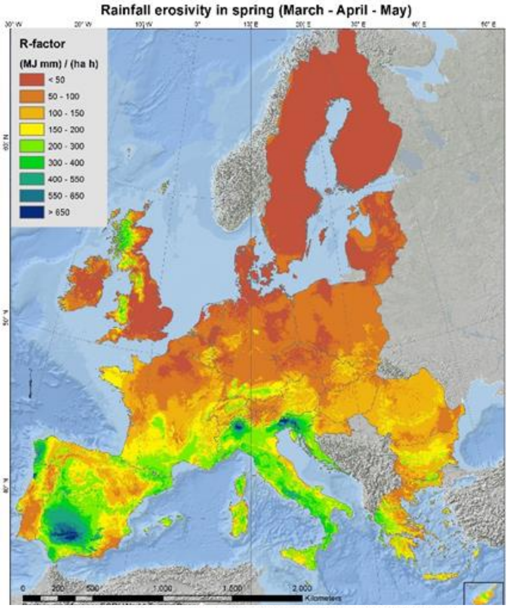
Cubist regression: cross-validation

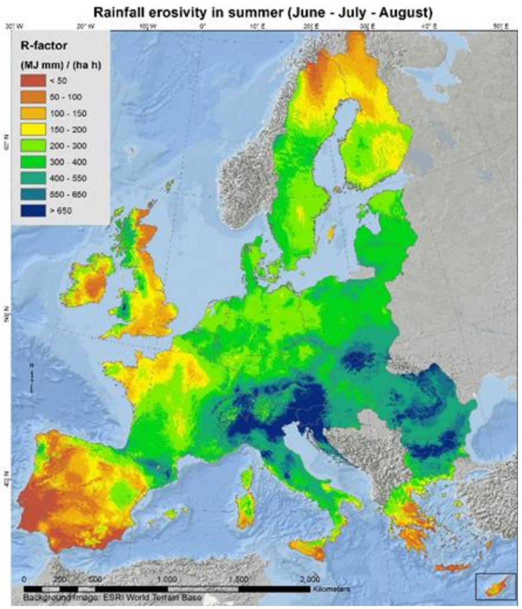


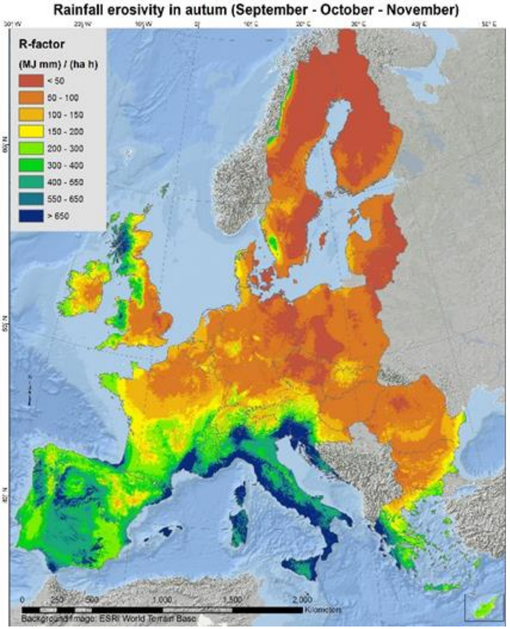
	R^2	RMSE
Jan	0.498	42.07
Feb	0.504	38.09
Mar	0.508	36.12
Apr	0.473	34.19
May	0.462	53.03
Jun	0.494	79.82
Jul	0.519	92.66
Aug	0.590	87.51
Sep	0.613	97.20
Oct	0.475	115.45
Nov	0.536	91.61
Dec	0.607	59.72

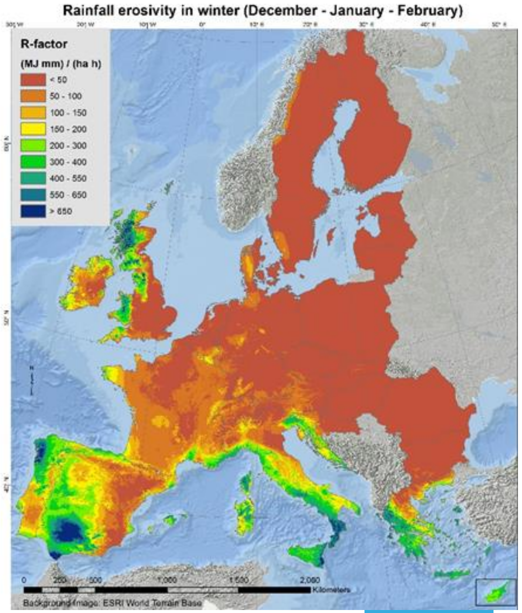
	NRMSE	MBE
Jan	0.064	−0.60
Feb	0.061	−1.71
Mar	0.058	−0.21
Apr	0.077	−0.82
May	0.075	2.76
Jun	0.082	15.14
Jul	0.076	0.92
Aug	0.076	3.05
Sep	0.061	7.52
Oct	0.058	0.45
Nov	0.065	−2.86
Dec	0.066	−1.23

Erosivity Seasonality Maps and Indicators


Rainfall erosivity in spring (March - April - May)


Rainfall erosivity in summer (June - July - August)

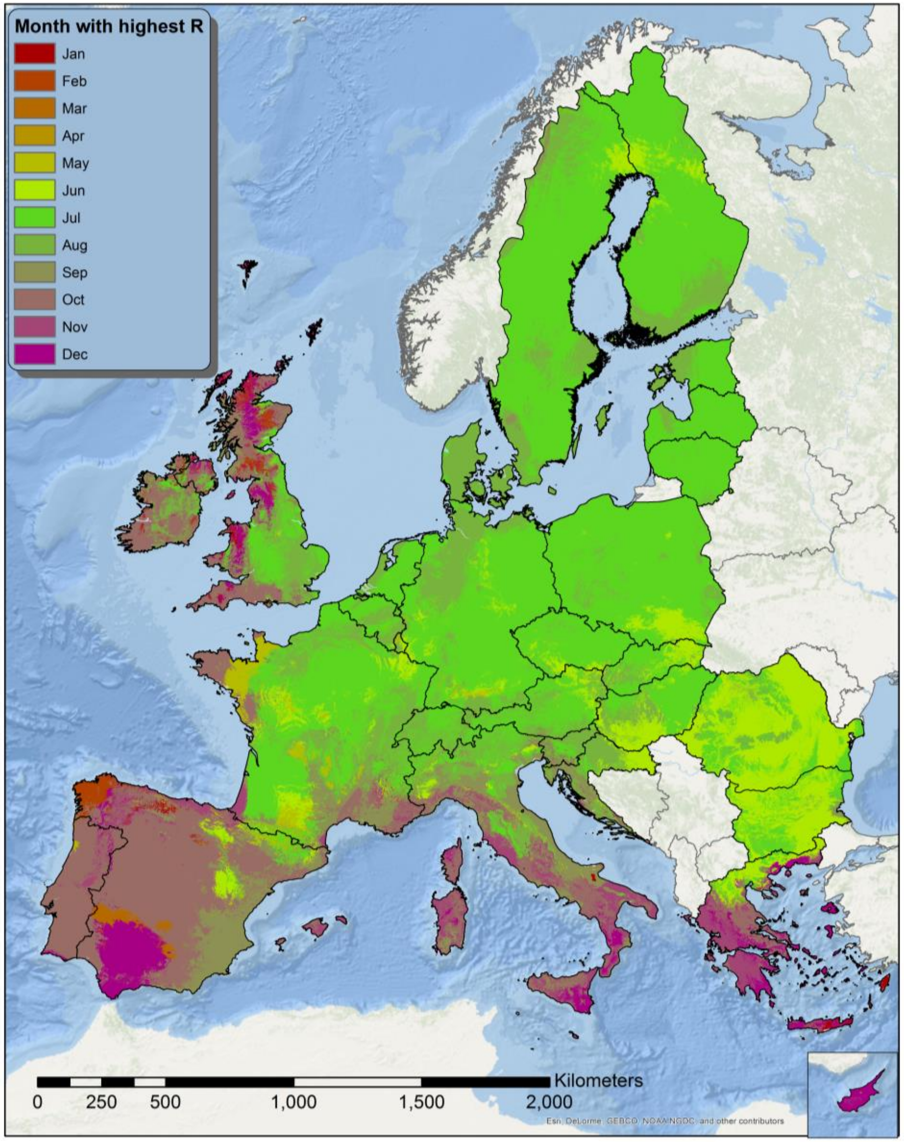

Rainfall erosivity in autum (September - October - November)


Rainfall erosivity in winter (December - January - February)

- Rainfall erosivity is mapped **intra-annually** for the first time at European scale
- **Dynamic Component** in soil erosion model
- Seasonal patterns of erosivity are further analyzed using **clustering techniques**
- Rainfall erosivity can be mapped **continuously in time**
- Further analysis: **Koppen-Geigen climate classification**
- **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.

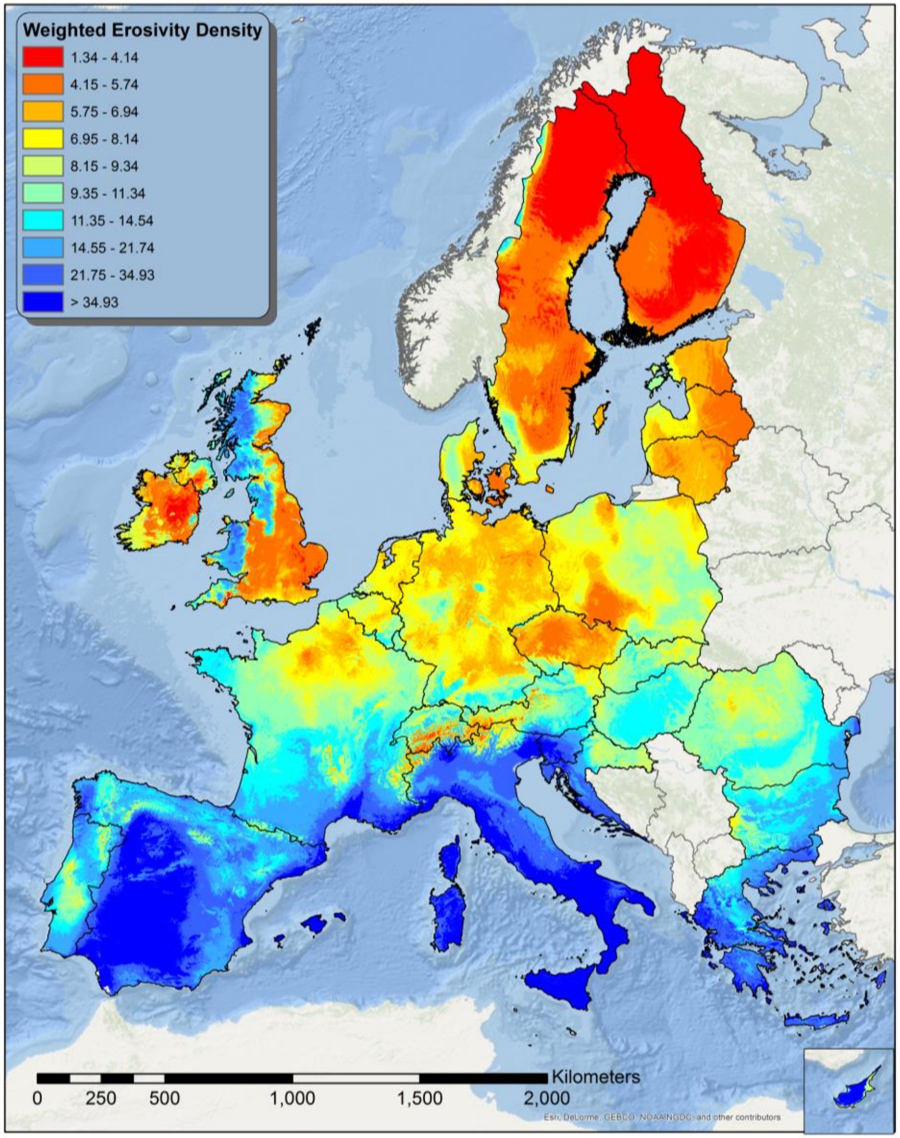
Ballabio et al. STOTEN (2017)

Erosivity Seasonality Maps



- Mapping the R-factor on a monthly basis allows to create maps evidencing the months with the lowest…
- …And highest values of R-factor

Erosivity Seasonality Indicators



- Having R-factor estimates for 12 months allows the development of more complex indicators
- **Weighted monthly Erosivity Density** is an example
  - Given the average annual R (not the sum!)

$$\mu_{MED} = \frac{1}{12}\sum_{i=1}^{12} MED_i$$

  - And its standard deviation

$$\sigma_{MED} = \sqrt{\frac{(\sum_{i=1}^{12} MED_i - \mu_{MED})^2}{12}}$$

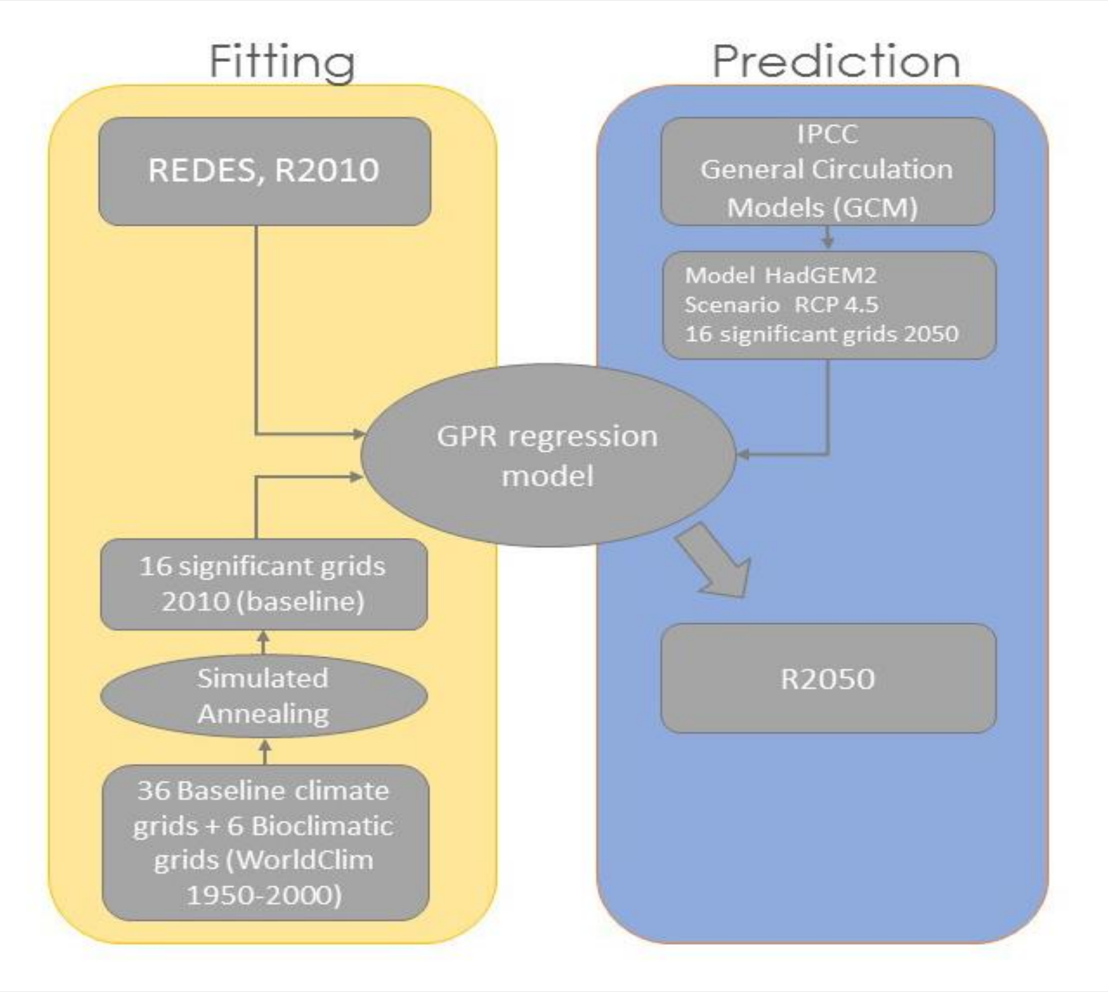
  - $\frac{\sigma_{MED}}{\mu_{MED}}$ is maximized when monthly values of R-factor differ a lot, so multiplying it with the annual R-factor WED is defined as

$$WED = \left(\sum_{i=1}^{12} MED_i\right)\frac{\sigma_{MED}}{\mu_{MED}}$$

WED identifies areas where most of the annual R-factor is given by few month's contribution

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)

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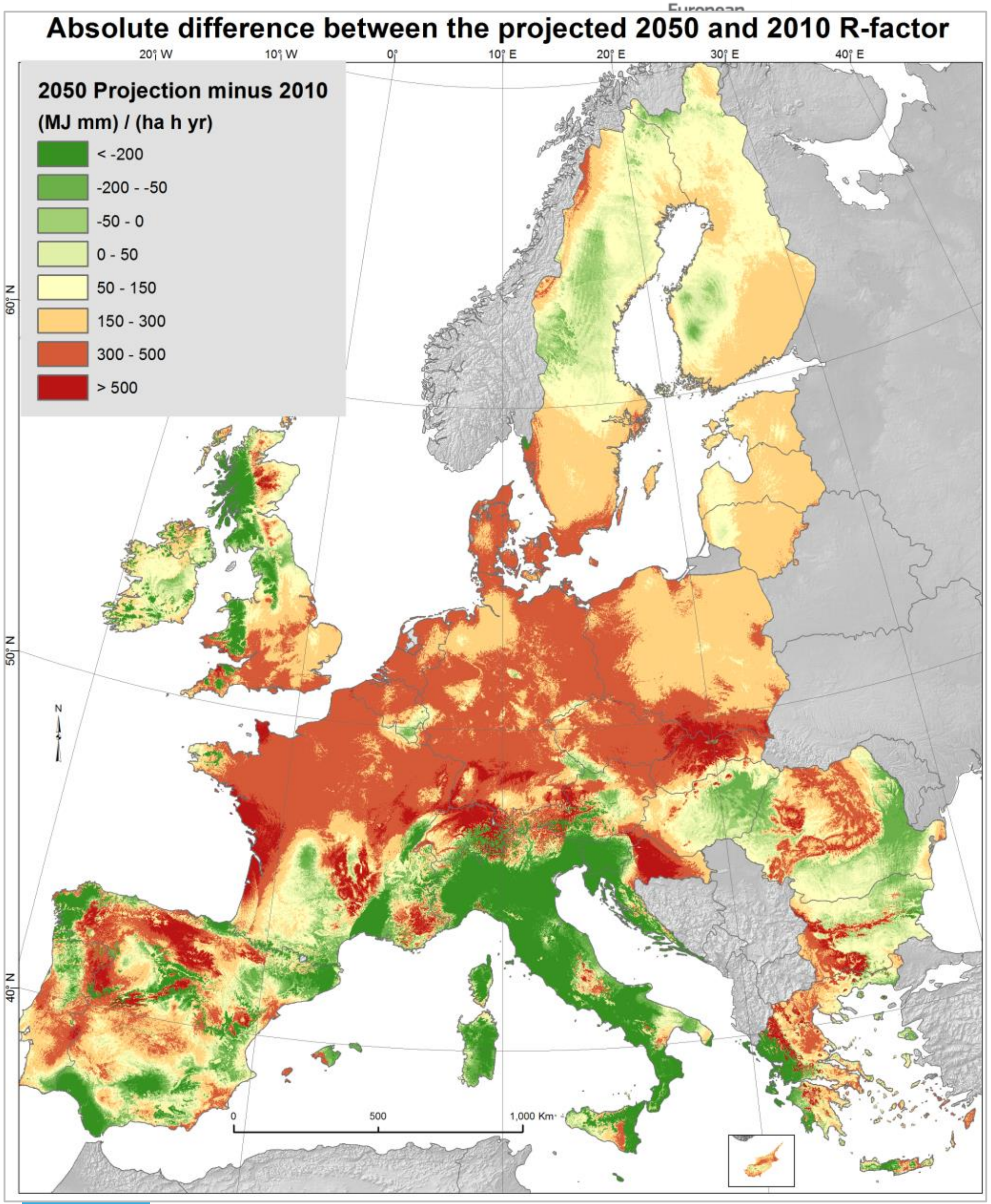
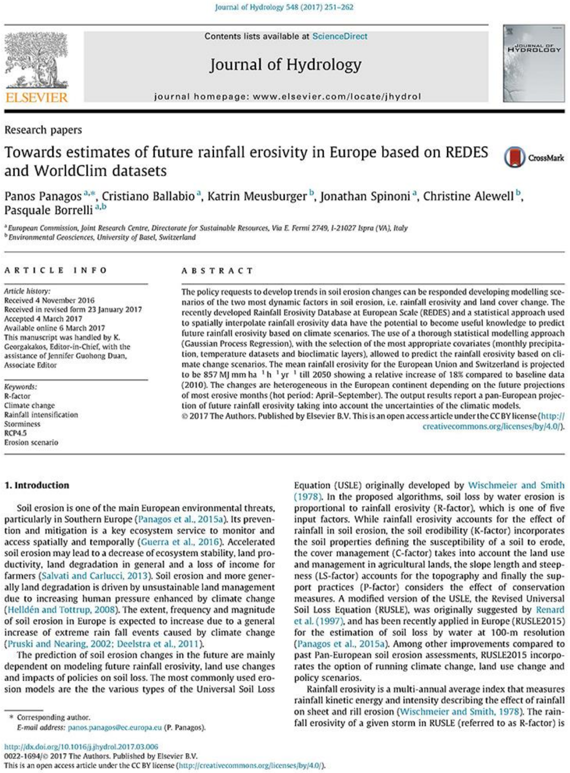


Absolute difference between the projected 2050 and 2010 R-factor

Information and data:



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Research papers

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

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ABSTRACT

The policy requests to develop trends in soil erosion changes can be responded developing modelling scenarios of the two most dynamic factors in soil erosion, i.e. rainfall erosivity and land cover change. The recently developed Rainfall Erosivity Database at European Scale (REDES) and a statistical approach used to spatially interpolate rainfall erosivity data have the potential to become useful knowledge to predict future rainfall erosivity based on climate scenarios. The use of a thorough statistical modelling approach (Gaussian Process Regression), with the selection of the most appropriate covariates (monthly precipitation, temperature datasets and bioclimatic layers), allowed to predict the rainfall erosivity based on climate change scenarios. The mean rainfall erosivity for the European Union and Switzerland is projected to be 857 MJ mm ha $^{-1}$ h $^{-1}$ yr $^{-1}$ till 2050 showing a relative increase of 18% compared to baseline data (2010). The changes are heterogeneous in the European continent depending on the future projections of most erosive months (hot period: April–September). The output results report a pan-European projection of future rainfall erosivity taking into account the uncertainties of the climatic models.

1. Introduction

Soil erosion is one of the main European environmental threats, particularly in Southern Europe (Panagos et al., 2015a). Its prevention and mitigation is a key ecosystem service to monitor and access spatially and temporally (Guerra et al., 2016). Accelerated soil erosion may lead to a decrease of ecosystem stability, land productivity, land degradation in general and a loss of income for farmers (Salvati and Carlucci, 2013). Soil erosion and more generally land degradation is driven by unsustainable land management due to increasing human pressure enhanced by climate change (Helldén and Tottrup, 2008). The extent, frequency and magnitude of soil erosion in Europe is expected to increase due to a general increase of extreme rain fall events caused by climate change (Pruski and Nearing, 2002; Deelstra et al., 2011).

The prediction of soil erosion changes in the future are mainly dependent on modeling future rainfall erosivity, land use changes and impacts of policies on soil loss. The most commonly used erosion models are the the various types of the Universal Soil Loss Equation (USLE) originally developed by Wischmeier and Smith (1978). In the proposed algorithms, soil loss by water erosion is proportional to rainfall erosivity (R-factor), which is one of five input factors. While rainfall erosivity accounts for the effect of rainfall in soil erosion, the soil erodibility (K-factor) incorporates the soil properties defining the susceptibility of a soil to erode, the cover management (C-factor) takes into account the land use and management in agricultural lands, the slope length and steepness (LS-factor) accounts for the topography and finally the support practices (P-factor) considers the effect of conservation measures. A modified version of the USLE, the Revised Universal Soil Loss Equation (RUSLE), was originally suggested by Renard et al. (1997), and has been recently applied in Europe (RUSLE2015) for the estimation of soil loss by water at 100-m resolution (Panagos et al., 2015a). Among other improvements compared to past Pan-European soil erosion assessments, RUSLE2015 incorporates the option of running climate change, land use change and policy scenarios.

Rainfall erosivity is a multi-annual average index that measures rainfall kinetic energy and intensity describing the effect of rainfall on sheet and rill erosion (Wischmeier and Smith, 1978). The rainfall erosivity of a given storm in RUSLE (referred to as R-factor) is

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Mapping monthly rainfall erosivity in Europe

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HIGHLIGHTS

- Rainfall erosivity is mapped intra-annually for the first time at European scale.
- The modelling is based on a developed monthly Rainfall Erosivity Database at European Scale (REDES).
- REDES data is modelled with WorldClim covariates using Cubist regression trees.
- Using Cubist erosivitiy is effectively spatially estimated over Europe for each month.
- Seasonal patterns of erosivity are further analyzed using clustering techniques.

GRAPHICAL ABSTRACT

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ABSTRACT

Rainfall erosivity as a dynamic factor of soil loss by water erosion is modelled in
European scale. The development of Rainfall Erosivity Database at European Sca
with the extension to monthly component allowed to develop monthly and se

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water

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Article

Monthly Rainfall Erosivity: Conversion Factors for Different Time Resolutions and Regional Assessments

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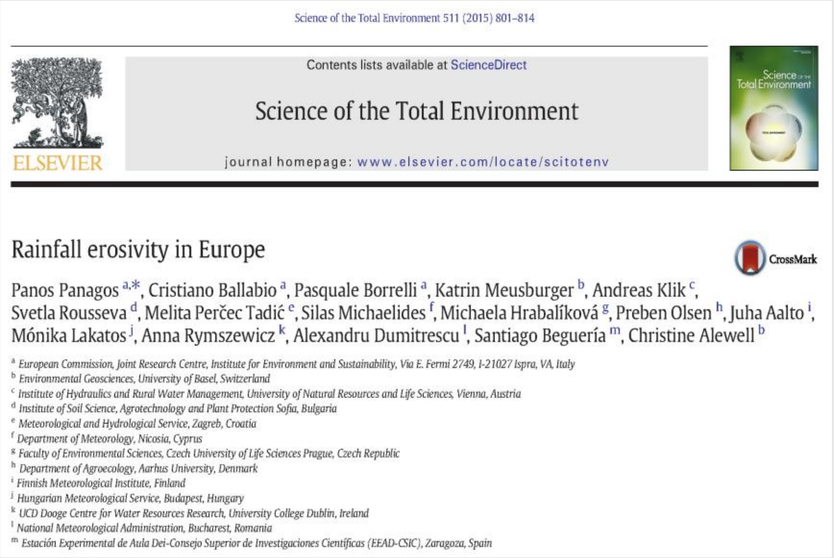

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Rainfall erosivity in Europe

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European Soil Data Centre:
http://esdac.jrc.ec.europa.eu/themes/rainfall-erosivity-europe

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