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Reply to the comment on “Rainfall erosivity in Europe” by Auerswald et al.

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HIGHLIGHTS

- Rainfall erosivity in Europe attended a great scientific interest.
- R-factor of Europe is a great improvement compared to past studies in the same scale.
- Effective calibration procedure minimized the problem of different time resolutions.
- REDES is developed with high resolution rainfall data (mean time series of 17.1 years).
- Shorter time series rainfall data are used in countries with low R-factor variability.

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ABSTRACT

Recently, in the Auerswald et al. (2015) comment on “Rainfall erosivity in Europe”, 5 criticisms were addressed: i) the neglect of seasonal erosion indices, ii) the neglect of published studies and data, iii) the low temporal resolution of the data, especially of the maximum rain intensity, iv) the use of precipitation data instead of rain data and the subsequent deviation of the R-factor in Germany and Austria compared with previous studies, and v) the differences in considered time periods between countries. We reply as follows:

(i) An evaluation of the seasonal erosion index at the European scale is, to our knowledge, not achievable at present with the available data but would be a future goal. Synchronous publication of the seasonal erosion index is not mandatory, specifically because seasonal soil loss ratios are not available at this scale to date. We are looking forward to the appropriate study by the authors of the comment, who assert that they have access to the required data.

(ii) We discuss and evaluate relevant studies in our original work and in this reply; however, we cannot consider what is not available to the scientific community.

(iii) The third point of critique was based on a misunderstanding by Auerswald et al. (2015), as we did indeed calculate the maximum intensity with the highest resolution of data available.

(iv) The low R-factor values in Germany and the higher values in Austria compared with previous studies are not due to the involvement of snow but are rather due to a Pan-European interpolation. We argue that an interpolation across the borders of Austria creates a more reliable data set.

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(v) We agree that the use of a short time series or time series from different periods is generally a problem in all large-scale studies and requires improvement in the future. However, because this affects countries with a rather low variability of the R-factor in our study, we are confident that the overall results of the map are not biased.

In conclusion, the Pan-European rainfall data compilation (REDES) was a great success and yielded data from 1541 stations with an average length of 17.1 years and a temporal resolution of <60 min. However, a Pan-European data collection will never be complete without the help and supply of data from its users. Thus, we invite the authors of the comment to share their data in the open REDES to help build even better rainfall-erosivity maps at regional or European scales.

1. Introduction

We appreciate the in-depth evaluation of our recently published European rainfall erosivity map by Auerswald et al. (2015). The immediate reaction highlights the great scientific interest in our R-factor map. As we sufficiently address in Panagos et al. (2015), we are fully aware that more work can be done at the European scale to improve datasets such as the presented R-factor map. Nonetheless, the rainfall erosivity map is far superior to previous products at this scale, and it represents a major step forward in modeling soil erosion and its triggering factors at the European scale. We agree with Auerswald et al. (2015) that data mining must be adapted to the considered scale and that national and regional maps should be considered for national and regional studies, as we recommended in our original contribution (page 807). However, we would like to note that even if Auerswald et al. (2015) emphasized the availability of regional and national data, many of these studies are published in the so-called “gray literature” and are not available to the scientific community, nor are the data on which these studies are based (please see below for details). Overall, we are surprised with their arguments, and we would like to note that there are serious scientific misunderstandings. As such, we would like to separately address each of the five arguments raised by Auerswald et al. (2015).

2. Seasonal erosion index

The first argument raised by Auerswald et al. (2015) is that we failed to provide a seasonal erosion index that could be matched with a seasonal development of soil loss ratios. The choice to publish the first results (annual R-factor) is, in our opinion, not an argument that can be raised against us. The regionalization of EI30 on a monthly basis is not a task that can be easily completed because the different seasons and regions within Europe require different spatial predictors. Indeed, an evaluation of the seasonal erosion index in combination with seasonal soil loss ratios is our next goal. We are excited to learn that Auerswald et al. (2015) considers this an easy task to accomplish, and we look forward to seeing their work in the near future. However, we would like to note that the mentioned seasonal soil loss ratios, which are required to create an unbiased C-factor map, are not yet available at the European scale, which will limit the added value of the seasonal erosion index for soil erosion risk assessments.

The regional and national studies cited by Auerswald et al. (2015) that were published in international scientific journals did not provide seasonal erosivity values, only annual totals (e.g., Ferro et al., 1991; Aronica and Ferro, 1997; Goovaerts, 1999; Janeček et al., 2013; Strauss et al., 1997). Only Verstraeten et al. (2006) analyzed the monthly distribution of rainfall erosivity, whereas Fiener et al. (2013) only gave monthly values for the period between April and November. Moreover, other cited articles (i.e., Bollinne et al., 1979; Bader and Schwertmann, 1980; Sauerborn, 1994; Rogler and Schwertmann, 1981; Auerswald, 1996; Strauss et al., 1995; Hartmann, 1988) are gray literature. They were all published in journals that are not accessible to the international scientific community. Needless to say, the data on which those studies are based are not publicly available.

We would like to respond further to Auerswald et al. (2015) that Wischmeier (1959) defined a “Rainfall Erosion Index” (not an Erosion Index, as Auerswald et al. refer to) as a product of storm energy and its maximum 30-minute intensity (EI). In the same publication, Wischmeier (1959) proposed a “Rainfall Erosion Index” on a seasonal or annual basis and concluded that the average losses over an extended time period may be estimated within relatively narrow confidence limits based on the EI values.

Panagos et al. (2015) (page 807) already acknowledged the need for data on the remaining USLE factors at the European level. The calculation of monthly R-factor values needs to be combined with the computation of the C-factor on a European scale: “The development of the remaining factors (topography, support practices, land use and management practices) will contribute to the perfecting of soil erosion modelling at the European scale. Furthermore, the calculation of monthly R-factor values in REDES will contribute to the seasonal estimation of rainfall erosivity in Europe”. This extension of REDES is under development, and the monthly rainfall erosivity maps will be presented to the scientific community in the near future. In addition, the monthly rainfall distribution has been accounted for in the interpolation model.

3. Additional rainfall erosivity studies based on high resolution data

Auerswald et al. (2015) criticized our statement “Only few studies in Europe have determined the R-factor directly from high-resolution data…” and noted that we did not cite several additional earlier studies.

It was not our intention to disregard earlier works on rainfall erosivity in Europe. We agree that we might refine our statement to “only a few studies at a national scale used high resolution …”. However, our study was not intended as a review, and as noted above, many of the studies referenced by Auerswald et al. (2015) are not widely available to the scientific community. Consequently, we focused on the most recent and available studies.

Additionally, many of the studies that Auerswald et al. (2015) cited were difficult to trace because they are local or regional studies that did not have an international diffusion due to non-accessibility. Fiener and Auerswald (2009) used a modified version of the original USLE R-factor formulation. Gabriels (2006) mentioned a Fournier index and based his assessment on a Modified Fournier Index (MFI) and monthly precipitation data. Goovaerts (1999) derived an empirical equation based on 2.5 years of 1-minute records. In Ferro et al. (1991), low resolution data were used, and a local equation was developed. Aronica and Ferro (1997) (not Arinica, as in Auerswald's comment) also used monthly data and the Fournier index. Loureiro and Coutinho (1995) and Posch and Rekolainen (1993) used low temporal resolution data (monthly) and extracted equations. The remaining citations provided by Auerswald et al. (2015) are not accessible to the scientific community. The only study that Panagos et al. (2015) (having the same source of data as REDES) may have neglected was performed by Janeček et al. (2013). Further, the study and data of Banasik et al. (1992) included 3 stations, which are a subset of the 9 stations (Banasik et al., 2001) that are included in REDES (Panagos et al., 2015). Therefore, we are convinced that we did not disregard the work done by pioneers in the field. We further disagree with Auerswald et al. (2015) that the four cited studies, which cover Switzerland, Slovenia, northeast Spain and North Rhine Westphalia (Germany), are "small areas".

In the list proposed by Auerswald et al. (2015), most of the European countries are missing (United Kingdom, Ireland, France, Latvia, Lithuania, Estonia, Sweden, Denmark, Luxembourg, Slovakia, Bulgaria, Romania, Slovenia, Croatia, Greece, Cyprus, Spain, Italy (Ferro refers to Sicily only), and Switzerland). Our comprehensive data collection and the setup of the REDES database, in addition to the creation of the R-factor map, are the main achievements of Panagos et al. (2015). Pan-European data collection is a great challenge as demonstrated in the soil erosion data collection from EU member states though the EIONET network (Panagos et al., 2014). Rainfall erosivity dataset is available (REDES will be available in the future) for download in the European Soil Data Centre (Panagos et al., 2012); therefore, users have an opportunity to add their own data and produce better maps with local spatial covariates. The main objective of Panagos et al. (2015) was to estimate rainfall erosivity based on the high temporal resolution data rainfall data in Europe (page 802) by applying a common methodology. On page 807, Panagos et al. (2015) stated that "At regional or local scale, it is recommended to modellers to use REDES plus local high resolution data for making their interpolations". It is obvious that neither our map on a European level nor REDES is intended to be a substitute for any local/regional R-factor database with higher-resolution data (or a longer time-series).

With the data proposed by Auerswald et al. (2015), it would be very difficult (if not impossible) to produce an R-factor map of Europe. The studies mentioned are limited to a few countries or regions and are highly heterogeneous in terms of the time scales and periods, data resolution, and even calculation methods (several of the mentioned studies used monthly data, or modified versions of the USLE R-factor). However, users and Auerswald et al. (2015) are invited to enlarge the REDES database in the future.

4. Calculation of R-factor (Imax30, not maxI30) and conversion of data with different temporal resolution

It is well known that averaging data over longer time steps will smooth the data and consequently lower the observed maximum rainfall intensities. To account for this problem, Panagos et al. (2015) suggested a normalization procedure.

Auerswald et al. (2015) further criticized our approach of estimating the maximum 30-minute intensity; in their opinion, we used the maximum half-hourly rainfall intensity (maxI30) rather than the maximum intensity in 30 min (Imax30). Related to this point, they also claimed that the presented conversion factors are ineffective. In their Fig. 1a, they presented an analysis to demonstrate that using maxI30 yields an underestimation of Imax30 and, therefore, of EImax30, even when our conversion factors were applied.

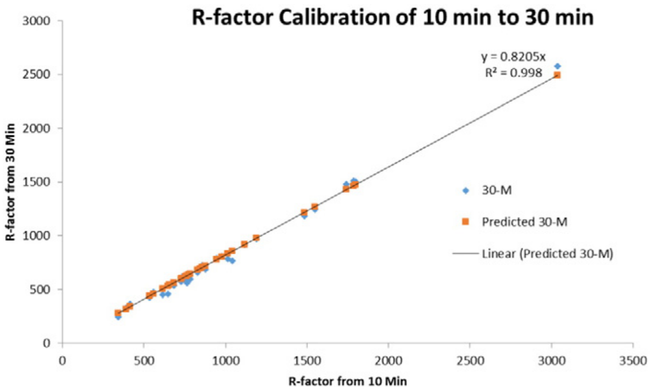

Fig. 1. Calibration used to scale the 10-minute-based R-factor to a 30-minute-based R-factor.

Unfortunately, the logic of Auerswald et al. (2015) is based on an incorrect assumption. We welcome the opportunity to clarify our approach. We did not use the maximum half-hourly intensity (maxI30). The Imax30 computation was based on the highest-resolution data available at each station, and EI30 was computed again based on progressively coarser data by aggregating, for example, the 10-minute data into 30- and then 60-minute data. Using this approach, we were able to fit a linear relationship between the EI30 values computed using the same data at different time resolutions (Fig. 1). Because it was necessary to choose a time resolution to use as a common denominator for all stations, we decided to use the 30-minute time resolution as a compromise. Because the conversion factors are presented for all time resolutions between 5 and 60 min (Panagos et al., 2015), it is possible to translate their EI30 values to other time resolutions, if needed. The applied normalization procedure (calibration) is based on a large pool of stations (82 stations for 60-minute calibration, 31 stations for 15-minute calibration, 31 station for 10-minute calibration, and 12 stations for 5-minute calibration) from many countries covering large portions of Europe. The results are comparable to those obtained by Yin et al. (2007), who performed the calibration of R-factor at the same resolutions.

In areas where 30 min or even 60 min was the rainfall recording time step, we agree with Auerswald et al. (2015) that the calculation of Imax30 in the original sense of Wischmeier (1959) is not possible and will result in an underestimation of Imax30. Pluviograph records, rather than digital data, would be necessary to accomplish this task. Moreover, the availability of data with a record time step of <30 min would not have increased much by including even fee paid data. However, in our study, we proved that the extensive normalization procedure was effective in minimizing this problem.

A proof of the effectiveness of the calibration is that the country borders, where we have a transition of different temporal resolutions, are not visible in the rainfall erosivity map of Europe (Panagos et al., 2015). For instance, Italy provided the data at 30-minute resolution and Slovenia at 5-minute and the borders between those countries are hardly visible in the Rainfall erosivity map.

5. Bias compared with studies conducted for Germany and Austria

The next point of criticism refers to the deviation between the European rainfall erosivity map and the evaluations of Sauerborn (1994) for Germany and of Strauss et al. (1995) for Austria. Panagos et al. (2015) estimated the R-factor for the 148 stations in Germany for the period from 1996 to 2013 with the best available data provided by Deutscher Wetterdienst (DWD). The resulting R-factors are lower than those presented by Sauerborn (1994), which Auerswald et al. (2015) interpreted as proof of a general underestimating effect of the 60-minute data resolution. However, they did not consider that the data used by Sauerborn (1994) are from a different time period (prior to 1993) and that Sauerborn applied a different equation. Furthermore, these data are not accessible, and it is possible they do not refer to the same stations used by Panagos et al. (2015). Auerswald et al. (2015) was incorrect in assuming the stations and time periods to be identical.

For Austria, the maximum R-factor of 4350 MJ mm ha^{-1} h^{-1} yr^{-1} was questioned by Auerswald et al. (2015). They even stated that this value is highly unlikely for Austria and that the use of total precipitation instead of rainfall is the most likely cause. The majority of Austrian stations are in the Eastern part of the country, but there are also a number of stations in the Alps (REDES). Of the 31 stations employed in Austria, 4 are located above 995 m a.s.l. (Flachau, Saalbach, Kogelberg, Alt Aussee). The highest calculated R-factor is in Alt Aussee (1957.2 MJ mm ha^{-1} h^{-1} yr^{-1}, 996 m a.s.l.), followed by Frankenfels (1748.6 MJ mm ha^{-1} h^{-1} yr^{-1}, 468 m a.s.l.). Panagos et al. (2015) reported that 106 stations (6.5% of total amount in REDES) are at an altitude of more than 1000 m a.s.l. (page 805).

Strauss et al. (1995) estimated a maximum value of 1380 MJ mm ha^{-1} h^{-1} yr^{-1}, and Auerswald predicted, based on the results of Strauss et al. (1995), that the maximum erosivity might be as high as 1840 MJ mm ha^{-1} h^{-1} yr^{-1}. We do consider the deviation between 1840 and 1957 (our study) MJ mm ha^{-1} h^{-1} yr^{-1} to be minor because again, different time periods were involved. The high value of 4350 MJ mm ha^{-1} h^{-1} yr^{-1} is not the result of over-prediction due to snowfall, but rather to interpolation.

Auerswald et al. (2015) ignored important aspects of regression principles in geo-statistics. Regression-based interpolation can result in more extreme values, such as those they report. Those extreme values, which can be 1 pixel of 500 m, are due to extrapolation because a few pixels might fall outside the observed range of environmental conditions that constitutes the sample on which the regression model was fit (Hastie et al., 2009, pp. 144–198). However, these extreme values represent less than 0.06% of the predicted values, and the vast majority of the pixels are thus within the range of observed values. Those extrapolated pixels are also visible in the uncertainty analysis where the standard error is presented. However, we recognize that it would have been better if we had proposed the 95th percentile R-factor value instead of the maximum one in the initial study.

In Austria, 5% of the total amount of pixels have R-factors with values 2000–3000 MJ mm ha^{-1} h^{-1} yr^{-1}, 1.2% of the pixels have R-factors with values 3000–4000 MJ mm ha^{-1} h^{-1} yr^{-1} and only 0.06% of the pixels have values higher than 4000 MJ mm ha^{-1} h^{-1} yr^{-1}. All of those areas with elevated R-factors due to interpolation are located near the borders with Italy, Slovenia (Carinthia region) and Switzerland. The influence of Slovenian stations with measured R-factors at the borders between Slovenia and Carinthia (station Javornisju Rovt: 3457 MJ mm ha^{-1} h^{-1} yr^{-1}, station Kamniska Bistrica: 3607 MJ mm ha^{-1} h^{-1} yr^{-1} and station NaRatee-Planica: 2270 MJ mm ha^{-1} h^{-1} yr^{-1}) and at the border between Italy and Carinthia (station Pramolo: 3631 MJ mm ha^{-1} h^{-1} yr^{-1}), will obviously influence geostatistical interpolation across the borders to Austria. We are surprised that Auerswald et al. (2015) expected significantly different values for the north-western Alpine range in Austria (as low as 1380 MJ mm ha^{-1} h^{-1} yr^{-1}) compared with a similar topographic situation on the other side of the border in Switzerland (Meusburger et al., 2012) (note that although precipitation data were used for Switzerland, Meusburger et al. (2012) explicitly subtracted precipitation that might have fallen as snow).

Another misunderstanding of Auerswald et al. (2015) was a confusion between rainfall and snowmelt. Deutscher Wetterdienst (DWD), which kindly provided the data from Germany, distinguishes between the two and provides both precipitation data with (mm/h) and snow depth data (in cm). In Panagos et al. (2015), there was an overuse of the term ‘precipitation’ mainly due to editing (‘precipitation’ was used interchangeably with ‘rainfall’), but this does not explain the confusion between rainfall and snow depth data.

Strauss et al. (1995) estimated R-factors in different stations than Panagos et al. (2015), who also included stations in other parts of Austria. Again, Auerswald et al. (2015) referred to a study that covers a different time period for erosivity analysis. Strauss et al. (1995) used data prior to 1995, whereas Panagos et al. (2015) used the period of 1995 to 2010. This misunderstanding is surprising because Auerswald et al. (2015) stated that the use of “different time periods can modify rain erosivity by more than 50%”.

A comparison of the European R-factor map (Panagos et al., 2015) with a more recent study in Austrian presented by Klik and Konecny (2013) shows very good comparability.

6. Short time series — different periods covered

The use of the time series, which covered different periods for the R-factor calculation, is the last point that is addressed in the comment. The problem that temporal variation can translate into a spatial pattern is mainly caused by i) high internal variation of R-factor and ii) trends in rainfall patterns. Trends are often superimposed by high internal variation, and only very long time series (such as in the two studies of Verstraeten et al. (2006) or Fiener et al. (2013)) identified trends. The time series of 22 years that was used for the R-factor calculation in Switzerland did not show any trends for single stations (Meusburger et al., 2012), even if the Alps is one of the regions where the highest impacts of climate change are expected in Europe (IPCC, 2013). Therefore, we consider the suggested de-trending by Auerswald et al. (2015) to be impossible. Panagos et al. (2015) outlined the problem of the time discrepancies in their original contribution and reported that 5 countries lacked data during the first decade of the 21th century. The meteorological services of Poland, Bulgaria, Greece, and Slovakia requested substantial funds in exchange for data, which were not available to this project. Alternatively, Panagos et al. (2015) used long time series data (over 25 years) for those countries (originating from other scientific resources and databases), even if the period from 2001 to 2010 was not covered.

The lack of a long time series mainly concerned regions with low rainfall erosivity such as Latvia, Finland and Estonia. These regions are also characterized by a very low internal variation, which led to the decision to include these data in the analysis. As the main objective of Panagos et al. (2015) was to create an R-factor map of Europe, it is more advantageous to have the maximum possible number of observations (in geographical and feature space) for the interpolation (even if this results in higher uncertainty) than to have fewer stations available for interpolation. Moreover, the Gaussian Process Regression model smoothness estimation reduces the risk of short length time series by acting as data outliers (Rasmussen and Williams, 2006).

The minimum period of data in REDES is 7 years. This was correctly displayed in Table 1 of Panagos et al. (2015); however, this was incorrectly stated in the abstract, as reported by Auerswald et al. (2015). Nonetheless, to demonstrate their argument, Auerswald et al. (2015) used the assumption of a 5-year period to demonstrate deviations in the R-factor between a 5- and a 17-year period (Fig. 2). Their calculation was primarily based on 10 stations of Fiener et al. (2013) with rainfall data from April to November, not yearly values. This will likely increase the internal variation because R-factors are most variable in the summer months due to the more frequent thunderstorms.

Wischmeier and Smith (1978) and Renard et al. (1997) recommended a minimum period of 22 years for calculating a long term R-factor. The REDES database of Panagos et al. (2015) met this recommendation in 35% of the stations in 11 countries. The study of Verstraeten et al. (2006), cited by Auerswald et al. (2015), stated that, “The analysis based on data from Ukkel thus confirms that a 22-year erosivity record should be sufficient for calculating R-factor” (Page D22109). Verstraeten et al. (2006) presented the 9-year running average of R-factors (Fig. 2 and page D22109) and depicted a decadal variability ranging approximately 30% over the last 3 decades and approximately 40% over the whole century. Based on Verstraeten et al. (2006), the highest variation (approximately 40%) between the moving 9-year average of the year 1938 and the moving 9-year average of 1997 has a $\frac{1}{4560}\left(\frac{2}{96*(96-1)}\right)$ probability of occurrence, according to basic statistical probability theories (Hogg et al., 2010). Even if we express serious doubts regarding Fig. 2 presented by Auerswald et al. (2015), the 17-year average in 1940 showed a variance of less than 40% with the 17-year average in 1998 at a probability of $\frac{1}{2016}\left(\frac{2}{64*(64-1)}\right)$. In conclusion, the analysis presented by Auerswald et al. (2015) is inaccurate because it does not include any probability terms.

In general, we agree with Auerswald et al. (2015) that the short time series for different periods may cause a bias due to the temporal variation of R-factor and that this risk, even if we are convinced that the bias is limited, should be considered. As such, and as mentioned above, there is room for improvement of the presented R-factor map of Europe; however, we are convinced that we have presented a first crucial step that might be used and improved by future studies.

7. Concluding remarks

We would like to conclude that four of the five points of critique raised by Auerswald et al. (2015) originated from misunderstandings or misinterpretations. Regarding the short time series and different periods included in the R-factor map, we agree that there is room for improvement, and we hope that future studies will provide the required data. We are convinced that in 10 years' time, the uncertainty due to the short time series in some countries will be considerably reduced and that the methodology proposed by Panagos et al. (2015) can achieve even better results. Compared with the R-factor developed by Van der Knijff et al. (2000), which was based on a simplistic multiplication of rainfall ($R = 1.3 * \text{precipitation}$), the rainfall erosivity map of Europe (Panagos et al., 2015) is, without a doubt, a considerable improvement. Because rainfall erosivity data on a European scale are seriously lacking, we consider the presented map to be a major step forward.

Panagos et al. (2015) used MJ mm ha^{-1} h^{-1} yr^{-1}, which is in accordance with well-known international literature (Renard and Freimund, 1994; Renard et al., 1997).

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