Evidence for increasing rainfall extremes remains elusive at large spatial scales: the case of Italy

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Key Points:

- A reconciled dataset in Italy allows for a full-scale trend assessment of rainfall extremes.
- A record-breaking analysis suggests that in the last decades the frequency of extremes is slowly, but not significantly, increasing.
- Intensity of extremes displays only local significant trend patterns, compatible with previous studies.

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Abstract

The widespread perception of an increase in the severity of extreme rainstorms has not found yet clear confirmation in the scientific literature, often showing vastly different results. Especially for short-duration extremes, spatial heterogeneities can affect the outcomes of large-scale trend analyses, providing misleading results dependent on the adopted spatial domain. Based on the availability of a renewed and comprehensive database, the present work assesses the presence of regional trends in the magnitude and frequency of annual rainfall maxima for sub-daily durations in Italy. Versions of the Mann-Kendall test and a record-breaking analysis, that considers the spatial correlation, have been adopted for the scope. Significant trends do not appear at the whole-country scale, but distinct patterns of change emerge in smaller domains having homogeneous geographical characteristics. Results of the study underline the importance of a multi-scale approach to regional trend analysis and the need of more advanced explanations of localized trends.

1 Introduction

Climate change and its impact on the frequency and intensity of extreme rainfall is a debated topic in hydrology. Basically, atmospheric temperature is expected to strongly influence the intensity of extreme rainfall, as warmer air is capable of holding more water than cooler air, following the Clausius-Clapeyron equation (Westra et al., 2014). This theoretical argument seems to suggest a relatively easy framework for understanding empirical studies that have found a strong correlations between the increase of the atmospheric temperature and the intensification of extreme rainfall (Westra et al., 2014), even exceeding the increase foreseen by the Clausius-Clapeyron relation (Lenderink & Van Meijgaard, 2008). On the other hand, other outcomes from observational-based studies seem to suggest a more complex nexus, depending on multiple factors, e.g., the considered climatic zone, the local orographic features and the nature of the considered events (e.g., convective or stratiform) (Westra et al. (2013, 2014)). In particular, the latter has been identified by some authors as one of the main characteristics to take into account when analysing the connection between rainfall intensity and temperature, as it is capable of generating significant artifacts in the outcomes of the studies (Molnar et al., 2015). In fact, the sensitivity of the temperature-intensity relationship has proved to be variable even with the evolving dynamic of the single storm (Wasko & Sharma, 2015). With the aim of setting an empirical baseline, many studies have been published in the last decade focusing on the detection of trends in extreme rainfall intensities. Most studies are focused on the daily time scale, with either a regional (e.g., P. Y. Groisman et al. (2012); van den Besselaar et al. (2012); Skansi et al. (2013) for the United States, Southern America and Europe, respectively) or a global spatial extent (e.g., P. Groisman et al. (2005); Alexander et al. (2006); Donat et al. (2013b); Westra et al. (2013)). A few studies explore sub-daily rainfall extremes, being often limited to individual sites or to small regions (e.g., Jakob et al. (2011); Lenderink et al. (2011); Fujibe (2013) for Sydney urban area, Hong Kong and the Netherlands, and Japan respectively). Westra et al. (2014) review a number of studies on the regional assessment of observed trends in sub-daily rainfall underlying that, despite the variability of the outcomes, on the whole they report an increase in the intensity of short-duration events for most of the continental macro-regions.

Westra et al. (2014) also discuss the scarcity in the literature of large-scale studies on sub-daily extremes, stressing the role of the general shortage of long, high-quality sub-daily rain gauge records. Not many countries across the world sistematically record and freely distribute these data (Page et al., 2004). Sub-daily rainfall records are in fact often subjected to restricted-access by the national authorities and, when available, they are often interspersed, fragmented and unevenly distributed (Teegavarapu, 2012). Some gridded interpolated rainfall products are indeed available for free (e.g., Donat et al. (2013a, 2013b)); however, various authors warn on the validity of results obtained using these products for analysing extreme rainfall amounts, especially in areas with complex orography (King et al., 2013; Libertino et al., 2016). The shortage of studies on the short-duration extremes is then a remarkable issue, considering that it is not possible to directly downscale conclusions from daily data analyses, due do the different generating mechanisms of extreme rainfall at different time scales (Barbero et al., 2017; Guerreiro et al., 2018).

In Italy, a new comprehensive dataset of annual maxima for sub-daily durations named *I-RED* (i.e., Italian Extreme Rainfall Dataset) has been recently compiled (Libertino et al., 2018). Annual extremes are easier to collect compared to continuous sub-daily data, and are generally subjected to strict quality control procedures by the national authorities, as they are frequently used as inputs in flood risk applications (e.g., Reed (1999); Coles (2001)). *I-RED* is one of the most complete and temporally extended catalogue of annual maxima of rainfall extremes for short durations. It includes rain gauge stations that have been in operation since the beginning of the twentieth century. Compared to the continental scale the geographical extent of Italy (i.e., about 300000 km^2) could appear limited. However, the country is an ideal climatic bridge between the Mediterranean and the inland Europe climate, as the country present a highly variable morpho-climatic setting and is subjected both to large alluvional flood and to devastating flash floods (Amponsah et al., 2018).

Various works on trend analysis in Italy published in the last decades have targeted limited spatial scales (e.g., within administrative regional borders) and sometimes have used older datasets. Conflicting outcomes then arise from these past studies. More specifically, Crisci et al. (2002); Arnone et al. (2013); Saidi et al. (2015); Uboldi and Lussana (2018) have found general increasing trends for short-duration rainfall respectively in Tuscany, Sicily, Piedmont and Lombardy regions, while Caloiero et al. (2011) have found decreasing trends in Calabria. Finally, Cifrodelli et al. (2015) and Gallus et al. (2018) have found that trends are not significant in Umbria and Liguria regions, respectively. As no more than 9% of the Italian area was considered in the above studies, it is no wonder that the limited spatial scale could justify the lack of uniformity of the outcomes.

This new and comprehensive database now enables analyses of the influence of the spatial scale on observed trends. This has been done by considering rainfall extremes of 5 different durations, varying from 1 to 24 hours. Both the magnitude of the recorded intensities and the frequency of the largest events (i.e., record-breaking) are considered for providing a complete check for their possible non-stationarity both at the country scale and on more limited and geographically homogeneous areas.

2 Data and methods

The possible trends in annual extreme precipitation have been examined with two different approaches, with methods which do not require any prior assumptions on the statistical proprieties of the data other than the independence of the recorded observations in time. The first approach is more focused on the stability of the frequency of the higher extremes while the second one allows at exploring the presence of non-stationarities in the extreme annual maxima of rainfall records.

The *I-RED* database (Libertino et al., 2018) includes the annual maximum rainfall depths for 1-,3-,6-,12- and 24-hours durations recorded from 1915 to 2015 in a net-work of about 5000 rain gauges distributed across Italy. The station density is of about 1 gauge per 70 km^2. In this work, only time series with at least 30 years of either continuous or non-continuous data have been selected, resulting in 1346 stations with records having median length of 47 years (Figure 1). Considering series with less than 30 years of data records has proven not to produce significant changes in the outcomes of the study. To ensure the spatial representativeness of the evaluated statistics the analysis has been further limited to the period 1928-2014, where at least 50 stations are simultaneously active each year (see Figure S1). Consequently, all the data related to years out of the selected range have been excluded. In that period, the records do not deviate significantly from the hypothesis of serial independence in time.

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Figure 1. Rain gauges and regions considered in the analysis.

As a first approach, the presence of trend in the frequency of occurrence of record-breaking events is explored, through the theory of Record-Breaking analysis (RB) (Glick, 1978). Considering that a certain value is defined record-breaking if it exceeds all the previous values in its time series, the RB analysis aims at assessing the increase/decrease in time of the frequency of occurrence of these values. RB analyses have been used by some authors in the recent years for assessing the presence of trends in temperature series (e.g., Benestad (2003); Wergen and Krug (2010); Wergen et al. (2014)) but, to our knowledge, it has not yet been considered with reference to rainfall extremes of short durations. The RB analysis considers each single station separately, and this feature needs to be overcome to investigate changes at a regional scale.

Operatively, a matrix M_g sized $n_g \times Y$ is set up with the recorded annual maxima for each considered duration, n_g being the number of rain gauges and Y the number of years. For each row, if a value of M_g is a RB value, i.e., it exceeds all the previously recorded annual maxima at the considered station, the corresponding value in a new M_{RB} matrix is set to 1; otherwise it is set to 0. M_{RB} has the same size of M_g and missing and null values are preserved. The sum along the columns of M_{RB} for each year generates the vector of the number of observed annual RBs, named R_{obs}, that is compared with the vector R_{exp} containing the number of expected RBs in a stationary climate. R_{exp} is obtained by summing along the columns of the M_{exp} matrix, generated with the same size of M_g by assigning to each non-null time step of each series the expected RB probability value under independent and identically distributed (*iid*) conditions. By doing so, the null-hypothesis of a stationary climate accounts for the same spatial and temporal inhomogeneity found in the observations. The annual RB anomaly is then evaluated as the normalized difference between R_{obs} and R_{exp} (i.e., by using Equation S1, reported in the Supporting Information).

A "field significance" bootstrap-based procedure has then been applied (von Storch & Zwiers, 1999; Marshall, 2007) for testing the significance of the observed trends in the regional anomalies. The testing approach is based on the null hypothesis that in a stationary climate the time series can be described by *iid* values. The validity of this hypothesis has been assessed in Lehmann et al. (2015), that adopted a similar approach while investigating the presence of trend with gridded global precipitation products at the daily time scale. In essence, the test statistic (i.e., the regional normalized annual record-breaking anomaly) is estimated considering both the observed time series and 1000 replicates, that are obtained by bootstrapping along the time axis. The spatial correlation across the stations is preserved while bootstrapping (Hirsch & Ryberg, 2012). The observed statistic is considered compatible with the *iid* hypotesis if it falls inside the domain delimited by the 95% confidence bounds of the bootstrapped distribution.

As a second approach, the presence of trends in the average extreme recorded amount of rainfall is evaluated, using the Mann-Kendall test (MK) (Mann, 1945; Kendall & Gibbons, 1990). The MK is a non-parametric test and does not require any assumption on the distribution of the observations, since it uses the relative magnitudes of the data to one another rather than their absolute values. For this reason, it is often considered in the scientific literature for the evaluation the presence of monotonic trends in environmental series (Hipel & McLeod, 1994). When working in a regional framework the MK trend test is first applied separately to each station, while its regional extension, the Regional Kendall Test (RKT) (Helsel & Frans, 2006) then corrects the site specific MK results to account for the cross-correlation between the series, which results in one test statistic for the region. Considering that spatial correlation among the stations can be significant, especially for nearby sites, the correlation correction proposed in Hirsch and Slack (1984) is adopted in this work. As suggested in Gilbert (1987), for assessing the reliability of the RKT outcomes, the Belle and Hughes (1984) test is applied. The test aims at assessing the homogeneity among the trends detected at the different stations that make up a region. In essence, if different stations have different trend directions, the RKT slope estimate is not meaningful and can be misleading (Gilbert, 1987). If the Belle and Hughes (1984) test fails, Gilbert (1987) suggests to refer to the MK test result and Sen's slope estimator for each individual site, as the outcomes of the RKT can be misleading. When this situation arise, the MK test is thus applied at each station site, and the percentage of stations showing increasing/decreasing statistically significant trends on the total is evaluated. These percentages are compared with the ones expected in the *iid* case with a field significance procedure, analogous to the one adopted for the RB analysis, as suggested in Westra et al. (2013).

The full procedure (RB+RKT) has been applied at first considering the whole area of Italy as a unique region (ITA region) for detecting the presence of trends at the country level. Then, for assessing the role of the spatial inhomogeneities, five pilot sub-regions have been considered with more detail (see Figure 1). These smaller areas have been identified as being representative of different morphological and climatological features of the country, starting from criteria of geographic homogeneity. In detail, with reference to Figure 1, the UP_PO (60 rain gauges), DOL (55 rain gauges), LIG (61 rain gauges), CAL (69 rain gauges) and SAR (55 rain gauges) can be considered representative of flat, alpine, coastal, peninsular and insular environments, respectively. The last 3 regions are also particularly interesting, because they include sites where national record-breaking events (i.e., absolute maxima at the country level) have been recorded in the last 60 years. The full list of the considered national record-breaking events can be found in Section S1 of the Supporting Information.

Details on the application of the procedures and additional details of the results are provided in Sections S2 and S3 of the Supporting Information.

3 Full-scale trend analysis

3.1 Record-breaking analysis

The main outcomes of the application of the RB analysis to the ITA region are reported in this section. The first row of Figure 2 shows the anomalies in the frequency of RB at the country scale and the 95% confidence bounds. The latter are derived with the field significance procedure described in the previous Section, by bootstrapping 1000 resamples of the M_g matrix (with replacement) and considering the annual quantiles related to the 0.025 and 0.975 probabilities. To facilitate the identification of non-linear trends, the RB anomaly and the bounds are filtered with a 10-years moving average window. The most prominent evidence from the graphs is that for all the durations, an oscillating behaviour exists until the 1980s, with periods prior to 1980 characterized by negative anomalies (decreasing events) alternating with periods of positive ones (increasing events). After the '80s increasing anomalies become apparent for the extremes of shorter durations, overcoming the magnitudes of all the previously recorded positive anomalies, and keep growing until the end of the observed period. Similar behaviour can be recognised for the longer durations after the beginning of the 21th century. However, summarizing results at the country level, the frequency of RB does not show evidence of a significant non-stationarity, despite a continuous increasing trend in the last decade for all the durations.

3.2 Regional Kendall test

In order to assess the presence of a unique significant trend in the recorded intensities at the country scale, the Regional Kendall Test is applied at first to the whole dataset, considering the country as a region with a possibly homogeneous behaviour. The resulting overall Kendall-Theil slopes (Theil, 1950; Sen, 1968) are again reported in Figure 2 in terms of numeric values of slopes. Additional results can be found in Table S2. In the row ITA one can notice that all the obtained slopes are not significant under a 5% significance level. Lack of trend evidence may result from two different conditions: there may be no actual trend in most, or all, the series, or some locations may show trends, but not in the same direction. Considering the spatial configuration of Italy, with pronounced North-South elongation, and its climatic variability, going from Alpine to semi-arid climate, the second hypothesis has as reasonable ground. The inhomogeneity in the

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Figure 2. Results of the RB-RKT analysis. Rows refer to the considered regions: ITA (i.e., the whole country), UP_PO, DOL, LIG, CAL and SAR, respectively, while columns refer to the 1-,3-,6-,12- and 24-hours durations, respectively. The plots refer to the RB analysis; the annual RB anomalies (the cyan histograms) are smoothed with a 10-years moving average filter for showing the long-term non linear RB anomaly trends (the blue lines). The black dashed lines represent the 95% confidence interval for the *iid*-model. The coloured numbers refer to the RKT analysis; red/blue values represent the increasing/decreasing Kendall slope, yellow values indicates a null slope. Significant trend under a 5% significance level are reported in bold and underlined. * indicates that the trends in the region are not homogeneous according to a Belle and Hughes (1984) test.

behaviour of the series is confirmed by the trend homogeneity test, proposed in Belle and Hughes (1984), as suggested in Gilbert (1987). Under this condition, the outcomes of the RKT can be misleading and a supporting use of the MK test is thus invoked. Therefore for each duration, the MK test statistic is applied individually on each series, and the significance of the at-site trend is evaluated under a two-sided 5% significance level. The results of the single-site analyses need then to be summarized in a regional perspective for assessing the presence of significant regional trends. To this aim, the percentages of stations showing respectively significant increasing and decreasing trend are counted and compared with the ones expected in the stationary case. The observed values range from ∼4% to ∼7% for the decreasing and from ∼5% to ∼7% for the increasing case, both exceeding the theoretical value of 2.5% under the *iid* condition. However, the spatial dependence across the stations makes the identification of a reference value untrivial (Westra et al., 2013). For avoiding the problem, the field significance resampling-based approach described in Section 2 is used here to assess the compatibility of the percentages obtained from the observed time series with the distributions of the ones obtained by bootstrapping 1000 replicates. The farther the observed values are from the average of these distributions, the larger is the anomaly compared to the *iid* case. In the Italian case, for all the durations the observed values fall in the right tail of the bootstrapped distributions, as emerging from Figure S3. This highlights, for all the durations, the presence of several stations with significant trend, either decreasing or increasing, slightly and systematically larger than the expected one.

Consistently with what emerges from the RB analysis, the MK test gives some hints on the existence of local significant trends, that become non-significant when the wide uneven domain is considered. Consequently, the spatial coherence of the stations with significant at-site trend of the same sign is further explored, in order to highlight the presence of areas with homogeneous behaviour as regards the rainfall regime change. Results are shown in Figure 3 (panels (a)-(e)), where different symbols are adopted for representing the rain gauges according to the outcome of the at-site MK test. Some spatial clusters of significant increasing/decreasing trends emerge, but the sparseness of the stations showing significant trends prevents the identification of clear patterns. Different behaviour for neighbouring stations could derive from the characteristics of the records (fragmentation of the data, actual length of the record, etc.). To understand if local trend patterns are relevant, the MK test statistic (Equation S5) calculated at each site is spatially smoothed by using Ordinary Kriging. As opposed to other commonly used quantities, (e.g., the Sen's slope) the kriging on the MK test statistic allows to take into account both the magnitude of the trend and the length of the series, avoiding excessive weight on steep slopes estimated on short series. The rationale of the procedure is to abandon the binary outcome "test passed"-"test not passed" to accommodate for the existence of different magnitudes of trends of the same sign. A positive/negative value of the test statistic implies a positive/negative trend in the series. The trend significance is proportional to the absolute value of the test statistic, that depends both on the magnitude of the trend and on the length of the series. By interpolating the test statistic with the ESRI ArcGIS Desktop Spatial Analyst Toolbox (ESRI, 2018), using a spherical variogram, we obtained a surface represented in the background of the maps in Figure 3 (panels (a)-(e)).

The visual analysis of Figure 3 underlines an increase of rainfall severity for all the durations in the north-eastern part of the country, while a decreasing trend is evident in the southern extreme of the peninsula (e.g., in the Calabria region, consistently with the findings of Caloiero et al. (2011)). Other duration-dependent patterns can be pointed out: a general decreasing trend for short-duration extremes is apparent in the north-west of the country, turning to an increasing trend when longer durations are considered. The opposite is shown in Sicily. Duration-dependent patterns can suggest sensitivity of the regional trends to the type of rainfall events considered: short duration extremes are related to convective storms, while maxima for the longer durations are mostly recorded during frontal and stratiform rainfall events. The obtained results underline once again the influence of the geographic configuration on the regional trends.

4 Limited-scale trend analysis

To assess the influence of the spatial scale on the trend assessment outcomes and to rigorously test whether the local (sub-regional) trends described in the previous Section are significant, the same procedure applied above has been carried out on the aforementioned set of five pilot-areas. The outcomes are compared with those obtained at the full country scale. Results of the analyses are resumed in Figure 2 (rows from 2 to 6) and in detail reported in Table S2. Concerning the RB analysis, the considered time period varies for the different domains because of the different data availability in the areas under investigation. The main results obtained are summarized as follows:

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Figure 3. Rain gauges showing significant trend at a 5% significance level for (a) 1-, (b) 3-, (c) 6-, (d) 12- and (e) 24-hours durations. The background color represents the spatial distribution of the Mann-Kendall test statistic, interpolated using Ordinary Kriging with spherical variogram.

- the UP_PO region, located in the upper Po valley, is a plain/hilly area in North-Western Italy. Concerning the frequency of RB there is no systematic trend for all the durations, despite some annual positive anomalies going out of the confidence bounds in the last years for longer-duration events. The fact that the analysis is limited to the period 1950-1994 (for the lack of a sufficient number of annual maxima out of this range) could partially prevent the understanding of the evolution of the local trends in the recent years. As expected from the visual analysis of Figure 3, the UP_PO region shows a significant decreasing trend in the intensities for shorter-duration events. The negative slope of the trend line decreases when larger durations are considered, reaching a non-significant positive slope for the 24-hours duration.

- the DOL region is located in the Dolomites area, a mountain area in North-Eastern Italy. The RB anomaly systematically increases with time for the shorter durations and show a less uniform behaviour for the longer ones. The increasing RKT trend in the rainfall intensities is always significant, with the slope of the trend showing to increase with the duration.
- the LIG region is a coastal area between the Ligurian sea and the Appennine mountains, characterized by a complex orography (elevation varies from 0 m a.s.l. to about 2000 m a.s.l) where many national record-breaking amounts have been recorded for various durations. Despite during many years in the last decade the anomaly overcomes the positive confidence bounds for all the durations, the smoothed trend line falls constantly inside the confidence bounds. However, one can notice a consistent increasing trend in the last 20 years only for the shorter durations. The RKT does not detect significant regional trends, probably because of the inhomogeneities in the behaviour among the stations, that emerge from the visual analysis of Figure 3. In fact, the area shows both increasing and decreasing trends, varying both in space and with the duration.
- the CAL area refers to the aforementioned Calabria region, a peninsular area in Southern Italy, characterized by significant relief in the central part and wide flat coastal plains. Two national record-breaking events have been recorded in that area in 1959 and 1964. The RB anomaly is almost consistently negative, and shows a decreasing (but not significant) trend for the longer durations. The RKT confirms the consistent decreasing trend in the intensities that emerges from the visual analysis. Despite this, the regional trend turns out to be non-significant for all the durations, except that of 24 hours. The trend homogeneity test identifies inhomogeneities in the area for the 1- and 12-hours durations.
- the SAR area refers to the Sardinia region, the second-largest island in the Mediterranean sea, where a national record-breaking evnt for the 3-hours duration has been recorded in 2008. No visual evidences of trend in the RB anomaly seems to emerge here. Despite the region is homogeneous according to the trend homogeneity test,

except for the 1- and 12-hours durations, no significant trends are detected from the RKT.

The site-dependent outcomes obtained from the small-scale analysis underline the importance of exploring different spatial scales when performing extreme rainfall trend analyses. While no statistically significant trend can be identified at the country scale, significant regional trends arise when smaller scales are considered, apparently related with the local morpho-climatic setting. The Italian example shows how the spatial variability of the rainfall regime can hide the presence of significant local trends when a too wide domain is considered. Even when the considered domain is apparently homogeneous, as in the case of the CAL and LIG regions, the localized variability can significantly influence the trend detection. This stresses the importance of the definition of a suitable spatial domain when regional trend analyses are performed.

5 Conclusions

A spatial analysis of the trends in extreme rainfall for different sub-daily durations has been carried out in Italy, as a wide and morphologically complex domain with significant features for the Mediterranean region. The analysis takes into account both the frequency of occurrence of large events and the recorded intensities, aiming to give a comprehensive overview of the evolution of the extreme rainfall regime.

Concerning the frequency, the outcomes show that all the observed trends are non-significant, i.e., are compatible with the hypothesis of stationary climate. Despite this, a continuous increase in the positive record-breaking anomalies in the last decade emerges. This outcome stresses the importance of deepening the analysis of the "extremes of the extremes" component, to assess if the increased record-breaking anomaly is the hint of a real variation in the extreme rainfall regime or if the test result are partially biased by other external factors (e.g., increases in the accuracy of the measurements, etc.).

With regards to the intensities of the events, a clear trend in extreme rainfall magnitude can not be detected at the country-scale. However, local trends in some specific areas are significant for certain durations. These spatial-dependent outcomes underline the importance of exploring different spatio-temporal scales when performing extreme rainfall trend analyses. The importance of considering different temporal scales of the rainfall extremes also emerges from the variability that the regional trends show with the durations. Working at the sub-daily scale, different durations are often related to different type of rainfall systems, that can answer in differential way to changes in the climatic setting (e.g., increase in the temperature, etc.).

Considering the relevance of the problem of identifying the consequences of climate change on the extreme rainfall regime, the outcomes of this study stress the need of developing more systematic and localized approaches for a consistent large-scale trend detection at the large scale, capable of effectively merging the results that can be observed with more local analyses.

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Original data supporting the analysis and conclusions of the paper are accessible directly from the Italian regional monitoring institutions. The full list of institutions and the related instructions for obtaining the data are published (Open Access) in Libertino et al. (2018).

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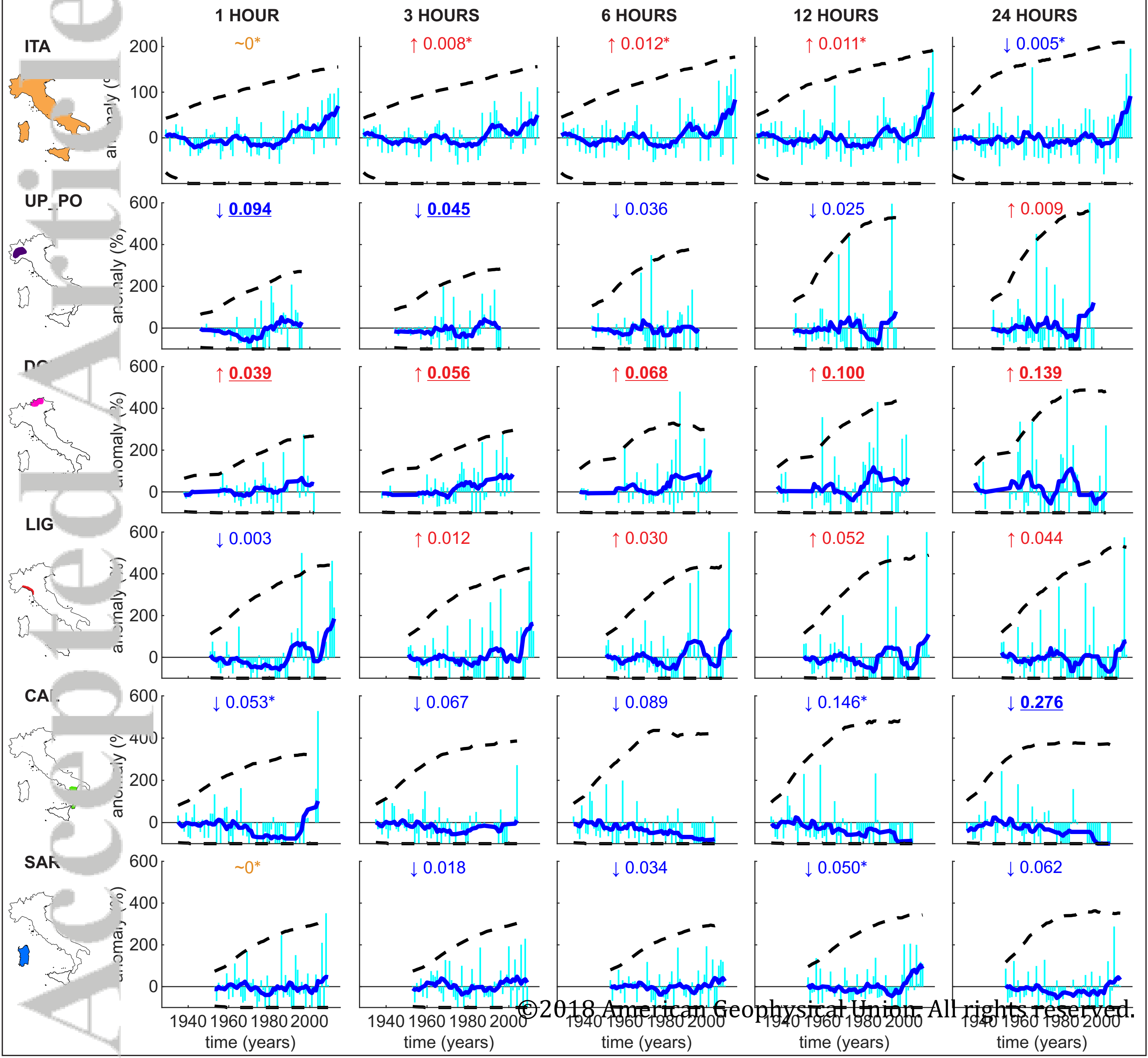
Figure 1.

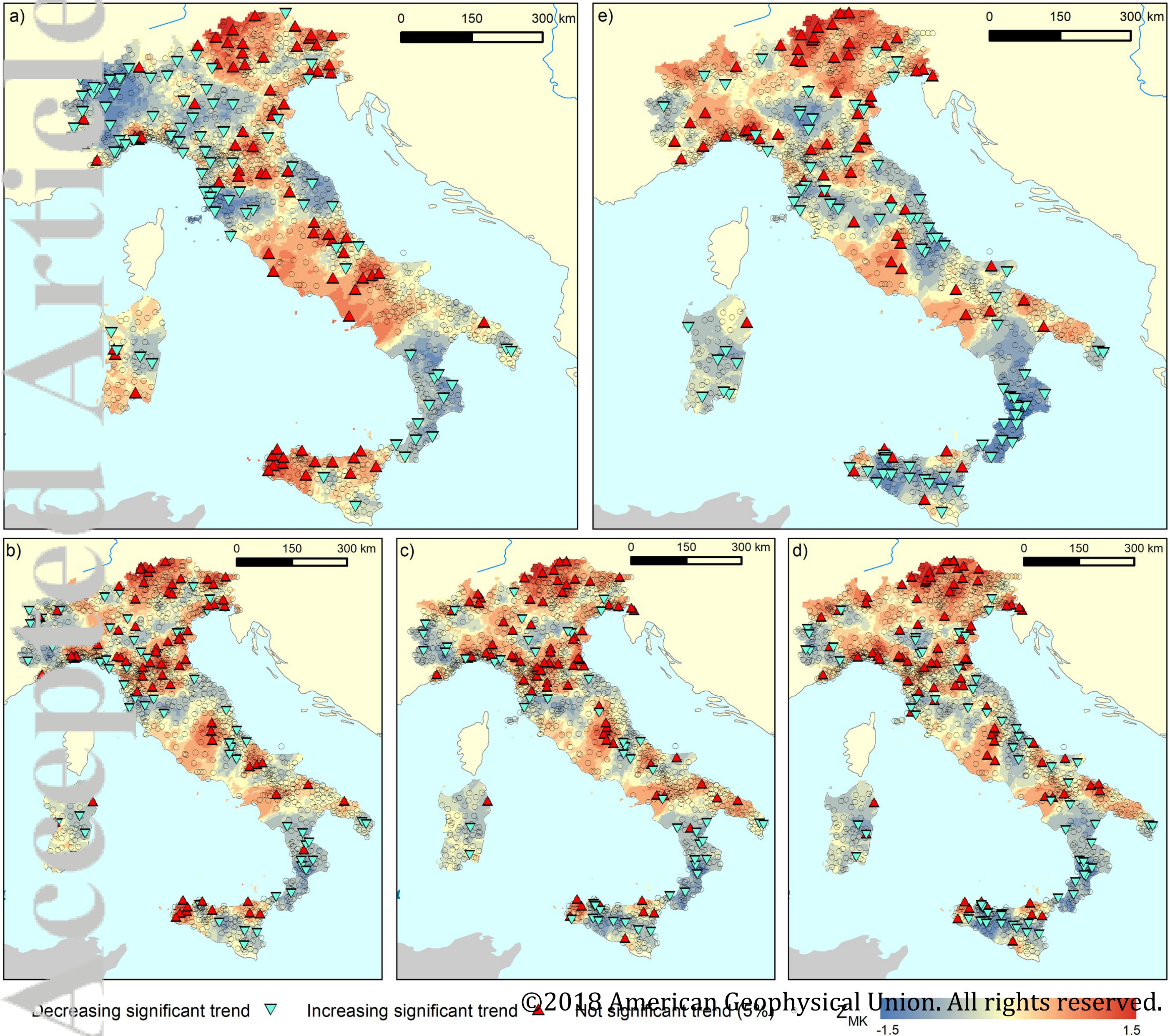

10°
15°
45°
40°
10°
15°
0 100 200 km
Rain gauge
Elevation (m asl):
0
4810
Regions:
ITA
UP_PO
DOL
LIG
CAL
SAR

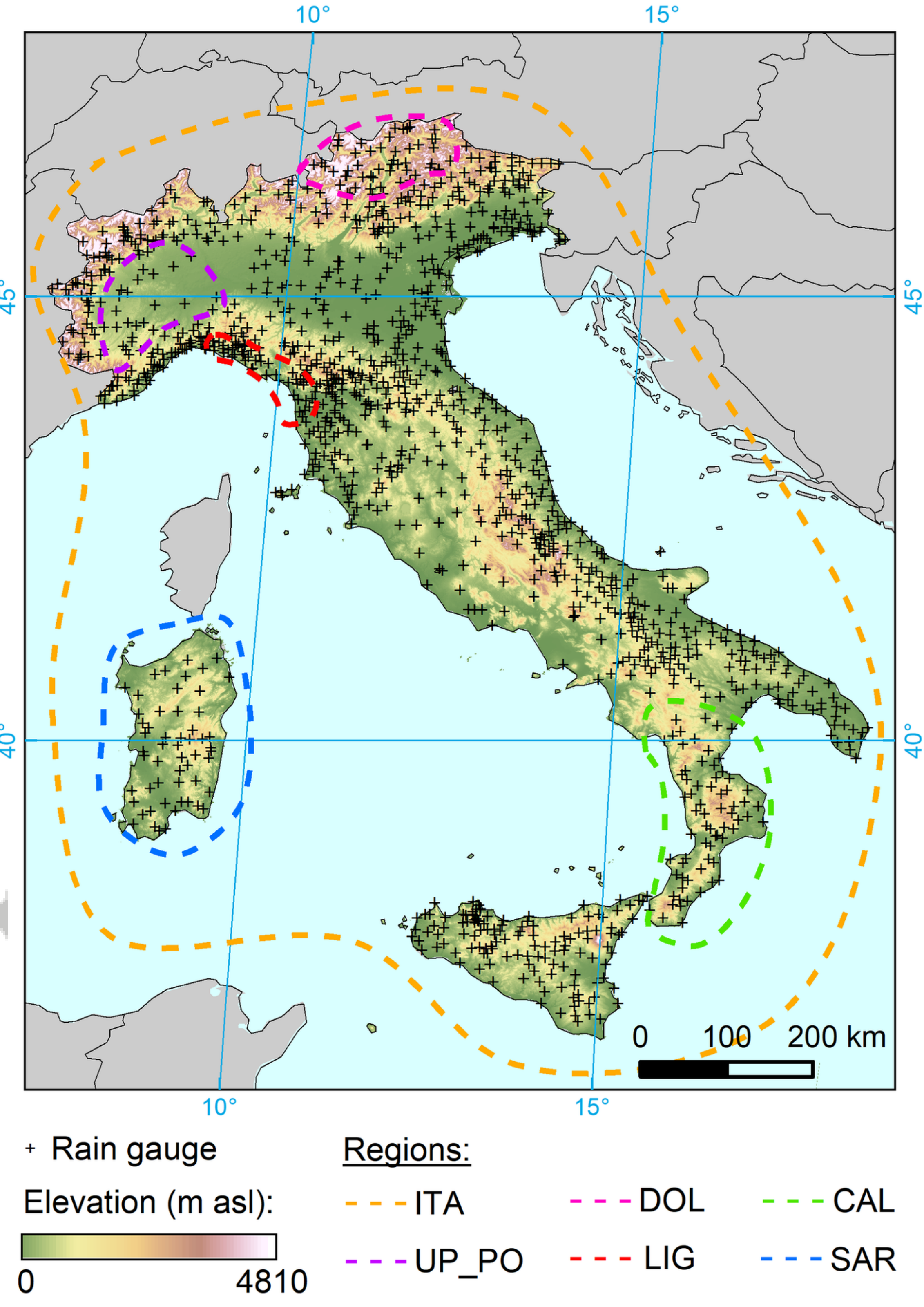
Figure 2.



1 HOUR
3 HOURS
6 HOURS
12 HOURS
24 HOURS
ITA
UP_PO
LIG
~0*
↑ 0.008*
↑ 0.012*
↑ 0.011*
↓ 0.005*
↓ 0.094
↓ 0.045
↓ 0.036
↓ 0.025
↑ 0.009
↑ 0.039
↑ 0.056
↑ 0.068
↑ 0.100
↑ 0.139
↓ 0.003
↑ 0.012
↑ 0.030
↑ 0.052
↑ 0.044
↓ 0.053*
↓ 0.067
↓ 0.089
↓ 0.146*
↓ 0.276
~0*
↓ 0.018
↓ 0.034
↓ 0.050*
↓ 0.062
time (years)

Figure 3.


a)
0
150
300 km
e)
0
150
300 km
b)
0
150
300 km
c)
0
150
300 km
d)
0
150
300 km
Decreasing significant trend
Increasing significant trend
Not significant trend (5%)
Z_{MK}
-1.5
1.5



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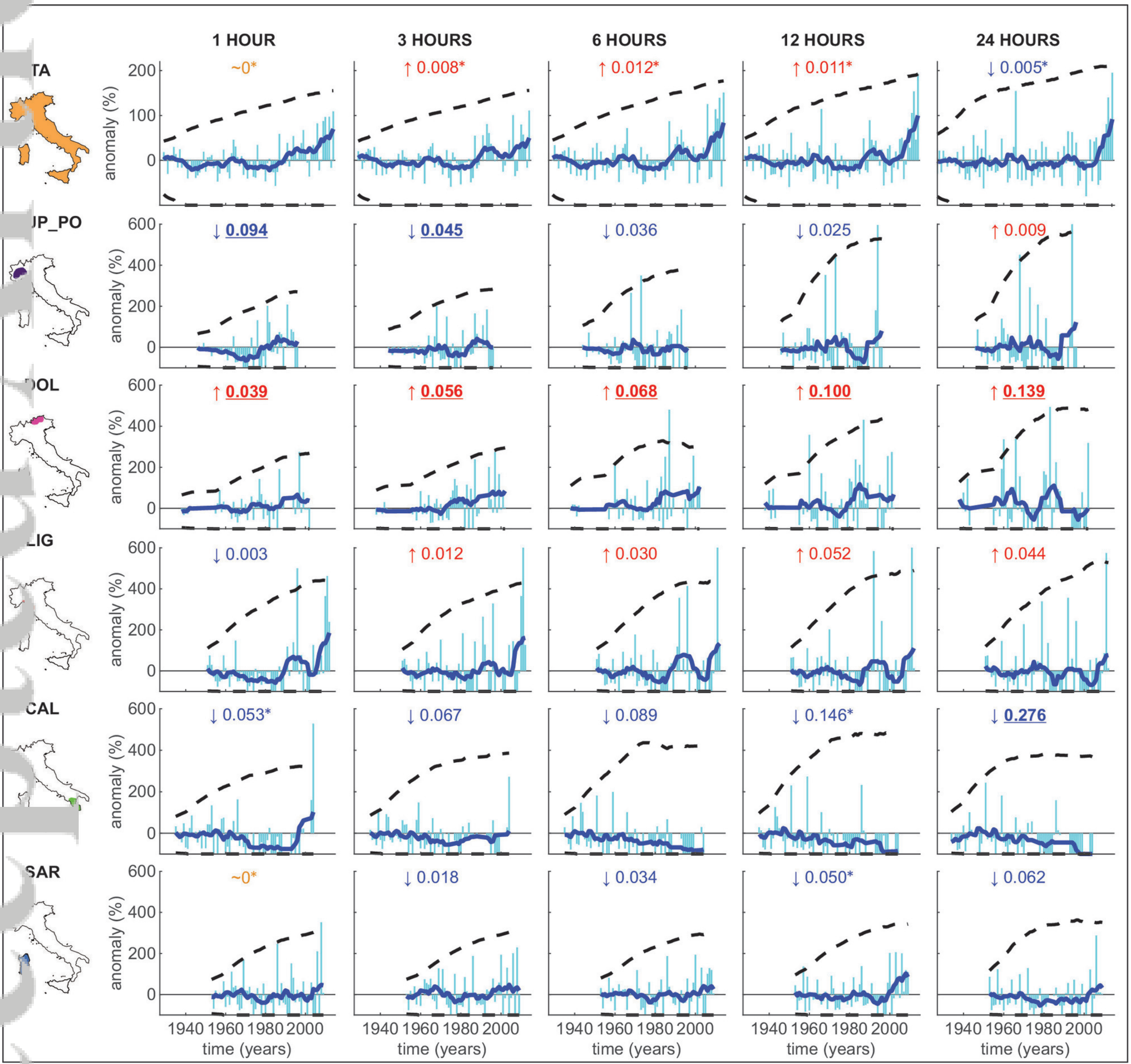

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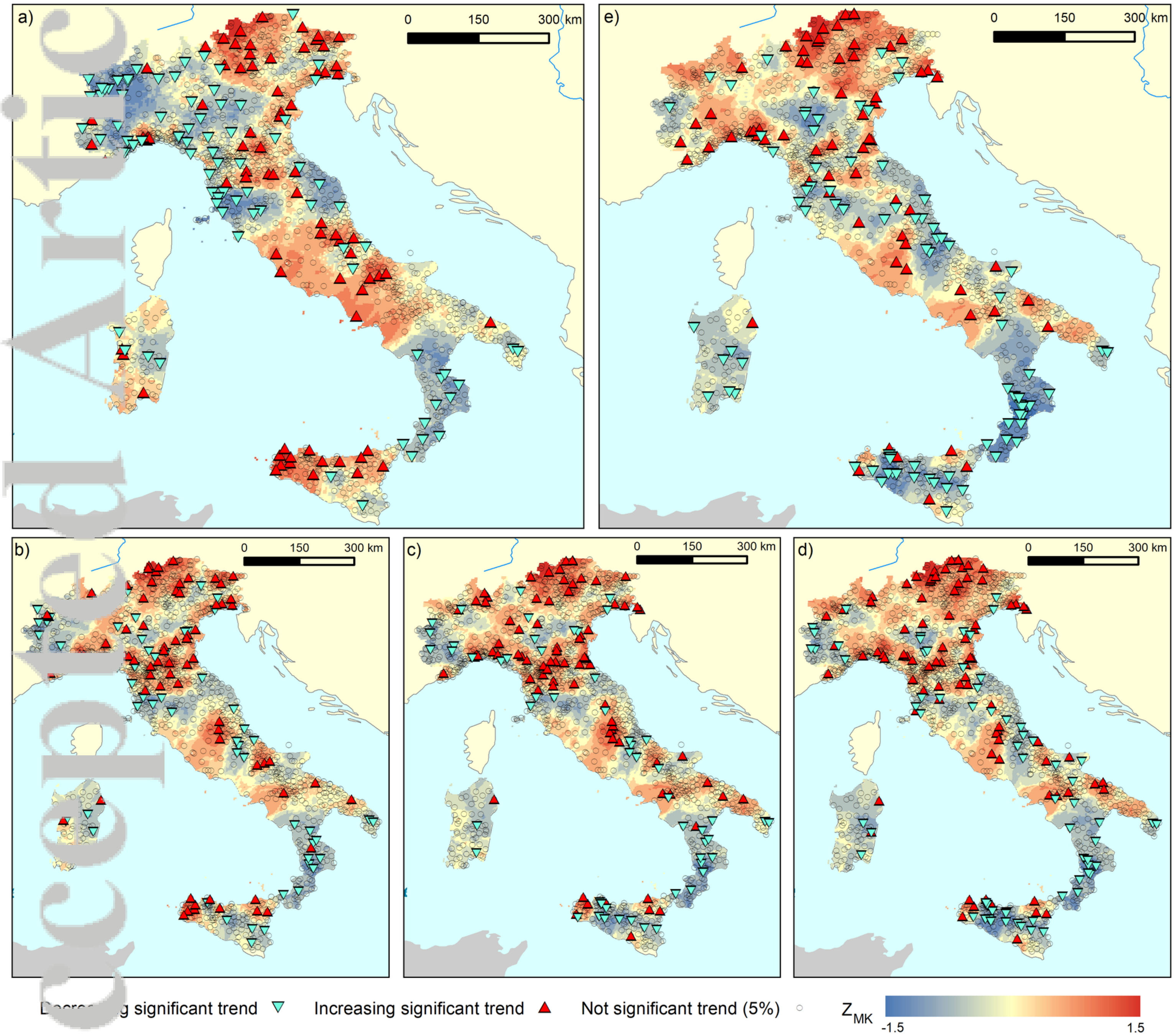

2019GL083371-f03-z-.png