On the nature of rainfall intermittency as revealed by different metrics and sampling approaches

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Comments to Authors

Paper summary

The reviewed manuscript presents a systematic analysis of rainfall intermittency properties in time, using high-resolution rainfall data (1-min) from a network of 201 raingauges in Sardinia (Italy).

The authors apply different statistical analysis techniques (i.e. spectral and scale invariance analysis, and calculation of clustering and intermittency exponents) to study how the lacunar character of the rainfall support (i.e. the alternation of dry and wet periods), and the amplitude of rainfall fluctuations, contribute to the variability of the rainfall process at different temporal scales.

Similar to previous studies, the authors find that temporal rainfall variability is characterized by three scaling regimes, in the range from 1 min to 45 days, associated with single storms, frontal systems, and larger scale atmospheric circulation patterns. In addition, their analysis shows that the lacunar character of the rainfall support is geographically constant over the island of Sardinia (hence not significantly affected by the topography and local climate), and that the spatial heterogeneity of rainfall is mostly related to the effect of the local climate and topography on the amplitude of rainfall fluctuations.

In a comparative analysis, the authors demonstrate that different sampling approaches for the rainfall signal produce different results concerning rainfall intermittency, and conclude that multifractal scale invariance techniques are insensitive to the sampling approach used for data retrieval.

Contribution and audience

The reviewed manuscript presents a systematic analysis of rainfall intermittency properties in time using different statistical analysis techniques, applied to a dense network of high-resolution raingauges over the island of Sardinia, Italy. The authors find that while the lacunar character of the rainfall support is fairly unique over the island of Sardinia, the amplitude of rainfall fluctuations is affected significantly by topographic features and the local climate. In addition they conclude that multifractal scale invariance analysis produces rainfall intermittency estimates that are insensitive to the sampling approach used for data collection. Evidently, the subject is of interest to a wide audience of hydrologists and, definitely, within the scope of this Special Issue of HESS.

Technical soundness, organization and style

The manuscript is technically sound and well written. In addition, all Figures and Tables are necessary. My only concern is the use of the gradient amplitude method (introduced by Tessier et al., 1993), used in Section 4.2 to obtain an intermittency exponent. Several studies (Veneziano and Iacobellis, 1999; Veneziano and Langousis, 2010; Neuman 2010a,b; 2012; Guadagnini and Neuman, 2011) have shown that the ratio in equation (6) does not scale and, therefore, the exponent μ_2 in equation (6) depends on the temporal scale τ. Since the authors do not use μ_2 to study the scaling properties of rainfall, but rather to infer how the variance of the temporal process depends on the amplitude of rainfall fluctuations [i.e. by comparing results obtained for the binary (BS) and full (FS) series at the same scale of averaging], their analysis, results and conclusions are not affected by lack of scaling of the ratio in equation (6). However, I find it important that the authors mention the lack of scaling introduced by the gradient amplitude method, refer to the aforementioned studies, and explain that the validity of their results is not affected by lack of scaling of the measure, since they do not compare results from different temporal scales. Alternatively, the authors may eliminate the gradient amplitude method from their analysis. The final decision is left to them, and the editor in charge.

Prior publication

To my knowledge, neither the same nor very similar work has been published elsewhere.

Recommendation

For the reasons mentioned above, it is recommended that the paper is published in *HESS* after minor revisions. A list of comments and suggestions is presented below.

<u>General comment 1 (page: 9981; lines: 1-6):</u>

I do not understand why smaller values of spectral exponents indicate longer memory; lines 2-3. Actually, for Gaussian processes, larger spectral exponents indicate longer memory. Since the authors do not consider such processes, my opinion is that spectral exponents indicate how the overall variability of the process is distributed to different scales. That said, starting from the smallest scale, high spectral exponents indicate fast decrease of the variability of the process with increasing scale, whereas smaller values indicate a less intense decrease. I suggest the authors avoid relating the memory of the process with its spectrum, and stay with more profound arguments on how the variability of the process decreases with increasing temporal scale. This applies, also, to other parts of the manuscript where spectral exponents are linked to the memory of the process (e.g. page 9983, lines: 21-23; page 9986, lines: 9-19).

Specific comment 1 (page: 9968; line: 2):

Change: referred to

To: attributed to

Specific comment 2 (page: 9968; lines: 3-4):

Change: the fragmentation of the wet-dry rainfall support, the strength of intensity fluctuations and of rainfall bursts

To: the fragmentation of the rainfall support (i.e. the alternation of wet and dry intervals), the strength of intensity fluctuations and bursts

Specific comment 3 (page: 9968; lines: 10-14):

Change: quantify the contribution to the overall intermittency due to the alternation of dry and wet periods (i.e. the rainfall support fragmentation), and to the fluctuations of intensity amplitudes. The presence of three ranges of scaling regimes in the time interval from 1 min to ~45 days is first demonstrated.

To: quantify the contribution of the alternation of dry and wet intervals (i.e. the rainfall support fragmentation), and the fluctuation of intensity amplitudes, to the overall intermittency of the rainfall process. The presence of three ranges of scaling regimes between 1 min to ~45 days is first demonstrated.

Specific comment 4 (page: 9968; line: 17):

Change: the considered technique, suggesting that such tools explain different aspects

To: the applied technique, suggesting that different tools explain different aspects

Specific comment 5 (page: 9968; line: 21):

Change: effect on the fluctuations of the rainfall amplitudes and minimal influence

To: effect on the amplitude of rainfall fluctuations and minimal influence

Specific comment 6 (page: 9968; lines: 22-23):

Change: Next, evidence is shown of spatial patterns of the scaling exponents computed, for each analysis tool, in the range of frontal systems.

To: In addition, for each analysis tool, evidence is shown of spatial patterns of the scaling exponents computed, in the range of frontal systems.

Specific comment 7 (page: 9968; line: 26):

Change: it is demonstrated

To: we demonstrate

Specific comment 8 (page: 9969; line: 17):

Change: of intensity

To: of the rainfall intensity

Specific comment 9 (page: 9969; line: 20):

Change: be thought as due

To: attributed

Specific comment 10 (page: 9970; line: 5):

Change: across the scales

To: across scales

Specific comment 11 (page: 9970; line: 6):

Change: has been often

To: has often been

Specific comment 12 (page: 9970; line: 7):

Change: ranges of duration typical of weather phenomena

To: typical durations of weather phenomena

Specific comment 13 (page: 9970; line: 10):

Change: with the aim of weighting the contribution owed to the alternation

To: aiming at weighting the contribution of the alternation

Specific comment 14 (page: 9970; line: 11):

Change: phases on

To: phases to

Specific comment 15 (page: 9970; line: 13):

Change: across the gages

To: across gages (i.e. climatic conditions)

Specific comment 16 (page: 9971; lines: 4-11):

Change: tipping-bucket gages, which recorded the tipping instants corresponding to 0.2mm rainfall depth with 1-s time precision. Specifically, we pursue the following main objectives. First, we apply several techniques to investigate the intermittency properties of the rainfall time series recorded at each station with the aim to: (a) show how each technique is able to characterize diverse aspects of the intermittency; (b) identify the presence of multiple scaling regimes and compute, for each of them, a number of metrics that permit quantifying the intermittency behavior related to the fluctuations of rainfall intensity and to the fragmentation or clusterization of its support

To: tipping-bucket gages, with tipping accuracy of 0.2mm of rainfall depth at time precision of 1-s. Specifically, we pursue the following main objectives. First, we apply several techniques to investigate the intermittency properties of the rainfall time series recorded at each station aiming at: (a) assessing the effectiveness of each technique to characterize diverse aspects of rainfall intermittency; (b) identify the presence of multiple scaling regimes and compute, for each of them, a number of metrics that permit intermittency quantification related to the fluctuations of rainfall intensity and the fragmentation or clusterization of its support

Specific comment 17 (page: 9971; line: 16):

Change: with the

To: the

Specific comment 18 (page: 9971; lines: 17-18):

Change: Finally, we focus on a third objective related to the effect on the intermittency analysis due to the sampling methodology used to build the rainfall intensity signal.

To: Finally, we focus on a third objective related to the effect of the sampling methodology (used to build the rainfall intensity signal) on the intermittency analysis.

Specific comment 19 (page: 9971; line: 25):

Add reference to Veneziano and Furcolo (2008).

Specific comment 20 (page: 9972; line: 1):

Change: sistematically

To: systematically

Specific comment 21 (page: 9972; lines: 16-20):

Change: distribution of the annual rainfall is reported in the map of Fig. 1b, obtained by applying the kriging technique to averages of about 70 yr of annual rainfall records collected by ~200 rain gages operating at daily resolution. Comparison with Fig. 1a clearly reveals a strong relation between the annual rainfall and elevation: in areas at lower heights, the total rainfall is about 500mm per year, while it reaches 1160mm in the highest

To: distribution of annual rainfalls is shown in Fig. 1b, obtained by applying the kriging technique to annual rainfall averages obtained from 70 yr – long rainfall records collected by 201 rain gages operating at daily resolution. Comparison with Fig. 1a clearly reveals a strong relation between annual rainfall depth and elevation: in areas of lower elevation, the total rainfall is about 500mm per year, reaching 1160mm at the highest

Specific comment 22 (page: 9972; lines: 16-20):

Change: distribution of the annual rainfall is reported in the map of Fig. 1b, obtained by applying the kriging technique to averages of about 70 yr of annual rainfall records collected by ~200 rain gages operating at daily resolution. Comparison with Fig. 1a clearly reveals a strong relation between the annual rainfall and elevation: in areas at lower heights, the total rainfall is about 500mm per year, while it reaches 1160mm in the highest

To: distribution of annual rainfalls is shown in Fig. 1b, obtained by applying the kriging technique to annual rainfall averages obtained from 70 yr – long rainfall records collected by 201 rain gages operating at daily resolution. Comparison with Fig. 1a clearly reveals a strong relation between annual rainfall depth and elevation: in areas of lower elevation, the total rainfall is about 500mm per year, reaching 1160mm at the highest

Specific comment 23 (page: 9972; line: 24):

Change: circulation using daily rainfall depth

To: circulation. The analysis was performed using daily rainfall depths

Specific comment 24 (page: 9972; line: 26):

Change: reported in Fig. 2, and the associated dominant synoptic conditions

To: reported in Fig. 2, associated with different dominant synoptic conditions

Specific comment 25 (page: 9973; line: 1):

Change: The clusters

To: Clusters

Specific comment 26 (page: 9973; line: 6):

Change: The cluster

To: Cluster

Specific comment 27 (page: 9973; line: 7):

Change: with a synoptic situation

To: with synoptic circulation

Specific comment 28 (page: 9973; line: 9):

Change: In this condition

To: Under these conditions

Specific comment 29 (page: 9973; line: 13):

Change: condition, precipitation events with

To: conditions, precipitation events of

Specific comment 30 (page: 9973; line: 14):

Change: of the order of

To: on the order of

Specific comment 31 (page: 9973; line: 23):

Change: circles

To: dots

Specific comment 32 (page: 9973; line: 26):

Change: Our high-resolution dataset spans eleven

To: the high-resolution dataset spans over eleven

Specific comment 33 (page: 9974; line: 1):

Change: length

To: lengths

Specific comment 34 (page: 9974; line: 27):

Change: fashion

To: manner

Specific comment 35 (page: 9976; line: 18):

Change: with

To: to

Specific comment 36 (page: 9979; line: 5):

Change: Eq.

To: in Eqs

Specific comment 37 (page: 9979; line: 7):

Change: whose

To: with

Specific comment 38 (page: 9979; line: 7):

Change: were determined

To: determined

Specific comment 39 (page: 9979; lines: 8-9):

Change: with more details

To: in more detail

Specific comment 40 (page: 9979; line: 25):

Change: the diverse

To: diverse

Specific comment 41 (page: 9979; lines: 17, 28):

Please indicate the stations with IDs 1, 42, 6 and 319 (e.g. with arrows) in Figure 1.

Specific comment 42 (page: 9980; line: 10):

Change: we also indicated

To: we indicated

Specific comment 43 (page: 9980; line: 17):

Change: The exam

To: Examination

Specific comment 44 (page: 9980; line: 23):

Change: have

To: has

Specific comment 45 (page: 9981; line: 2):

Change: more

To: longer

Specific comment 46 (page: 9981; line: 10):

Change: the smaller

To: smaller

Specific comment 47 (page: 9981; line: 14):

Change: it assumes

To: it receives

Specific comment 48 (page: 9981; lines: 25-28):

A probable reason for the observed inconsistency is that, at scales larger than several days, the rainfall process does not exhibit a multiplicative structure.

Specific comment 49 (page: 9982; line: 27):

Change: in subplot

To: in the subplot

Specific comment 50 (page: 9983; line: 13):

Change: of the gage locations. For this purpose, we calculated slope, aspect

To: at the gage locations. For this purpose, we calculated the slope, aspect

Specific comment 51 (page: 9983; lines: 21-23):

I think that the increase of a^{BS} with elevation is very small and within the range of statistical variability. The increase of a^{FS} is statistically significant and, according to my opinion, it shows faster decrease of the variability of the rainfall process with increasing scale, as the elevation increases. I suggest the authors avoid referring to the memory of the process; see General comment 1.

Specific comment 52 (page: 9985; lines: 21-23):

Change: the fluctuations of the amplitudes of rainfall intensity

To: the fluctuations of rainfall intensity amplitudes

Specific comment 53 (page: 9986; line: 8):

Change: considerations

To: conclusions

Specific comment 54 (page: 9986; lines: 9-19):

See General Comment 1.

Specific comment 55 (page: 9988; lines: 1-2):

Change: by a tipping-bucket rain gage whose bucket volume corresponds to 0.2mm rainfall depth

To: by a tipping-bucket rain gage with bucket volume that corresponds to 0.2mm of rainfall

Specific comment 56 (page: 9989; line: 10):

Please specify how the obtained results depend on Δt^*. Also, please include a brief description of your findings (no figure is required).

Specific comment 57 (page: 9990; lines: 5-6):

Change: The steps

To: Steps

Specific comment 58 (page: 9990; line: 7):

Change: basing

To: based

Specific comment 59 (page: 9996; Table caption):

Change: Mean and standard deviation (in parenthesis) across the 201 gages of the metrics in the different scaling regimes, separated by square brackets. The breaking points of the timeranges for each metric are reported in the header, where we also indicated the characteristics of the weather phenomena used to interpret the spectra scaling regimes by Fraedrich and Larnder (1993). The metrics have been calculated on FS and/or BS signals constructed with the CC method.

To: Mean and standard deviation (in parenthesis) across the 201 gages of the metrics in different scaling regimes (separated by square brackets). The breaking points of the timeranges for each metric are reported in the header, where we also indicate the characteristics of the weather phenomena used to interpret the spectra scaling regimes by Fraedrich and Larnder (1993). The metrics have been calculated on FS and/or BS signals constructed with the DC method.

(Note the change from CC to DC. Is it correct?)

Specific comment 60 (page: 9997; Figure 1):

Please add contour lines, and indicate stations with IDs 1, 42, 6 and 319 (e.g. with arrows).

Specific comment 61 (page: 9997; Caption of Figure 1):

Change: inlet

To: inset

Specific comment 62 (page: 9998; legend caption):

Change: Rainfall normalized on a daily basis (mm)

To: Daily rainfall depth (mm)

Specific comment 63 (page: 9998; Caption of Figure 2):

Change: Centroids of the three dominant clusters of rainfall data normalized on a daily basis, as found by Chessa et al. (1999) (with permission of Springer-Verlag).

To: Main classes of rainfall spatial patterns in the Sardinian region; adapted from Chessa et al. (1999) (with permission of Springer-Verlag); see main text for details.

Specific comment 64 (page: 9999; Caption of Figure 3):

Change: Example of scaling regimes emerged through the spectral analysis for gages with ID 42, 6 and 319, for (a) the FS and (b) the BS series. The slopes of the lines are estimates of the spectral exponents a^{FS} and a^{BS} in Eq. (1). Arbitrary units in the y-axis are used in order to display results from different gages in the same graph.

To: Example of scaling regimes obtained through spectral analysis for gages with IDs 42, 6 and 319, for (a) the FS and (b) the BS series. The slopes of the lines are estimates of the spectral exponents a^{FS} and a^{BS} in Eq. (1). Arbitrary units in the y-axis are used in order to display results from different gages in the same graph.

Also refer to Figure 1 for the stations with IDs 42, 6 and 319.

Specific comment 65 (page: 10000; Caption of Figure 4):

Change: ID

To: IDs

Also refer to Figure 1 for the stations with IDs 42, 6 and 1.

Specific comment 66 (page: 10001; Caption of Figure 5):

Change: Example of scaling regimes revealed by the computation of the clustering exponent φ for gages with ID 42, 6, and 319. The slopes of the lines are estimates of φ in Eq. (4).

To: Example of scaling regimes using the clustering exponent φ for gages with IDs 42, 6, and 319. The slopes of the lines are estimates of φ in Eq. (4).

Also refer to Figure 1 for the stations with IDs 42, 6 and 319.

Specific comment 67 (page: 10002; Caption of Figure 6):

Change: Example of scaling regimes revealed by the computation of the intermittency exponent μ_2 for gages with ID 42, 6, and 319,

To: Example of scaling regimes obtained by computing the intermittency exponent μ_2 for gages with IDs 42, 6, and 319,

Also refer to Figure 1 for the stations with IDs 42, 6 and 319.

Specific comment 68 (page: 10003; Caption of Figure 7):

Change: kriging technique on the 201 gages

To: kriging technique for the 201 gages

Specific comment 69 (page: 10004; Caption of Figure 8):

Change: Relation between the metrics in the range of frontal systems and the elevation. See the text for the illustration of the derivation of the bars shown in each panel.

To: Relation between the metrics in the range of frontal systems and the elevation; see main text for details.

Specific comment 70 (page: 10005; Caption of Figure 9):

Change: from the signal

To: for the signals

Specific comment 71 (page: 10005; Caption of Figure 9):

Change: in the three

To: for the three

Specific comment 72 (page: 10006; Caption of Figure 10):

Change: from the signal

To: for the signals

Specific comment 73 (page: 10006; Caption of Figure 10):

Change: in the three

To: for the three

Specific comment 74 (page: 10007; Caption of Figure 11):

Change: from the signal

To: for the signals

Specific comment 75 (page: 10008; Caption of Figure 12):

Change: from the signal

To: for the signals

Specific comment 76 (page: 10009; Caption of Figure 13):

Change: with DC and CC method

To: with the DC and CC methods

Specific comment 77 (page: 10009; Caption of Figure 13):

Change: build with the DC method

To: built with the DC method

References

Guadagnini, A. and S.P. Neuman (2011) Extended power-law scaling of self-affine signals exhibiting apparent multifractality, *Geophys. Res. Lett.*, **38**, L13403, doi:10.1029/2011GL047727.

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Tessier, Y., S. Lovejoy and D. Schertzer (1993) Universal multifractals in rain and clouds: Theory and observations, *J. Appl. Meteor.*, **32**, 223-250.

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Veneziano, D. and V. Iacobellis (1999) Self-similarity and multifractality of topographic surfaces at basin and sub-basin scales, *J. Geophys. Res.,* **104**(B6), 12,797-12,812.

Veneziano, D. and Furcolo, P. (2009) Improved moment scaling estimation for multifractal signals, *Nonlin. Processes Geophys.*, **16**, 641-653, doi:10.5194/npg-16-641-2009.