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Hydrology and Earth System Sciences Discussions

Interactive comment on "The use of meteorological analogues to account for LAM QPFuncertainty" *by* T. Diomede et al.

T. Diomede et al.

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In response to referee comment RC S1246, 'General, specific and technical Comments' by Maria-Carmen Llasat

We appreciate the constructive comments of the reviewer. All remarks have been considered and the corresponding changes or clarifications have been included in the revised manuscript.
In the following, we respond to each reviewer's note individually (reviewer comments in italic, author replies in normal text).

Specific comments:

Pag. 3068, line 19-21: Authors say that they have tested "several combinations of them *to characterise the atmospheric circulation over Western Europe and East Atlantic". Which are these combinations?*

The different combinations of meteorological variables are: geopotential height at 500 hPa (Z500) combined with geopotential height at 850 hPa (Z850); Z500 combined with vertical velocity at 700 hPa (W); Z500 combined with W and specific humidity at 700 hPa (Q); W combined with Q.

Pag 3068, line 24: you should add a map showing the domain area for the analogues method, the integration region considered by the LAMBO and the Reno basin.

The requested map has been added as Fig. 1a in the revised manuscript.

Pag 3068, line 28: the analyses correspond to 12:00 UTC, for what hourly interval are the rainfall data accumulated?, how many raingauges are available (this figure is only indicated in the Figure)?, has any quality control to rainfall data been applied?

The rainfall data are hourly time series of historical raingauge recordings which are treated as the precipitation forecast without any time aggregation and used as hourly input to run the hydrological model. The first hour of the analogue-based precipitation forecast corresponds to the hourly raingauge measure recorded at 13:00 UTC of the past day selected as analogous; the second forecast hour corresponds to the hourly raingauge measure recorded at 14:00 UTC of the past analogous day and so on up to achieve a 72-hour long time series for each available raingauge.
The number of available raingauges (forty-five) has been added in the text of the revised manuscript.
A quality control has been applied to rainfall measurements to reconstruct data over stations not operating at a certain time interval. Furthermore, wrong values have been corrected: the data validation process consists of the identification of data which do not fall within a predefined range or which show an excessive increase or decrease with respect to the previous value.

HESSD

3, S1716–S1729, 2006

Pag. 3069, lines 1-3: Authors say that "the forecasts obtained via this approach (referred hereafter as scheme A) have been compared with those provided by an alternative implementation of the method (hereafter, scheme B), based on the proposal of Obled et al. (2002)". It seems that if the paragraph above makes reference to scheme A, then in scheme B other fields and similarity criteria should be used. However, the difference between both schemes lies on the procedure to calculate the precipitation forecast for the next 72 h, not on the variables used to characterize the atmosphere, neither on the similarity criteria. This paragraph should be rewritten to make it clear.

The paragraph has been rewritten as follows:
The forecasts obtained via this approach (referred hereafter as scheme A) have been compared with those provided by an alternative implementation of the method (hereafter, scheme B) which follows the proposal of Obled et al. (2002) about the procedure to calculate the precipitation forecast time series for the next 72 hours, using the same variables to characterize the atmosphere and similarity criteria adopted by the scheme A.

Pag. 3069, lines 4-12. The explanation of both schemes is not clear. Authors say "each current day Dc and each past analogue day Dp is characterised by ECMWF analyses at 12:00UTC of day D and day D-1". But, when they are choosing the day Dc-1, are they looking for the n analogous of the day Dc-1 (sample of n analysis Dp -1), or are they choosing the previous day to each analogous Dp (sample of n analysis Dp) to the day Dc? Obviously the analogue of the day Dc-1 can be different of the previous day of the analogue day Dp. The similarity criterion is applied to day Dc, or also to day Dc -1? If you only apply the criterion to day Dc, why do you need to use the day D-1 for the precipitation starting on day D? Is the precipitation forecast obtained for the next 72 h hour by hour? In the scheme B, authors say that "the days Dc and Dp are characterised by ECMWF analyses at 12:00UTC of day D and corresponding model forecasts at +24, +48 and +72 h". They could use the "analysis fields" of the days D+24, D+48 and D+72, or they could use the "forecasted fields", which are they *using?. In the same scheme, authors say that "for each of the three different forecast times, the related precipitation forecast is obtained by the 24 h historical raingauge recordings characterising the corresponding past analogue day", which is the period of time for which precipitation is accumulated: 00-00 UTC, 13:00-13:00 UTC, another?*

For the sake of clarity, in the revised manuscript a new figure (referred as Fig. 2) has been added to help in the understanding of the proposed schemes, whose details are described in the following.
Before to explain the two procedures, it is worth to point out that if the analogy is based on several fields, i.e. different variables, levels or times, this raises the problem of pooling the analogy between each field two by two (Obled et al., 2002). In the present work, the analogue dates are selected by calculating the sum of the individual values of the adopted similarity criterion computed field by field.
In the scheme A, the similarity criterion is applied (considering the ECMWF analysis at 12:00 UTC of the selected meteorological variable or combination of them) distinctly to days Dc and Dc-1, evaluating each day in the past, Dp_i, as analogous of day Dc and the previous day of Dp_i (Dp_i-1) as analogous of day Dc-1; finally, the sum of the individual similarity criterion values is considered to sort the sample of analogues available in the historical archive. In this way, it could happen that it is chosen as member of the N-member subset of analogues a certain pair of days Dp_x and Dp_x-1 whose total analogy degree (conveyed by the sum of the individual similarity criterion values) turns out to be higher with respect to others pairs of days in the data archive, even if the individual analogy degree of day Dp_x or day Dp_x-1 is not among the first N analogues of, respectively, day Dc and day Dc-1. Afterward, in the scheme A, the hourly precipitation forecast is obtained for the next 72 hours by considering the raingauge measurements recorded starting from 12:00 UTC of the selected analogue day Dp_x.
Using different observation times, within the framework of procedure A the analogy involves the change in time of circulation patterns observed in the last 24 hours.
In the scheme B, the ECWMF analyses at 12:00 UTC of each day D available in the archive and the corresponding forecasted fields at +24, +48 and +72 h (the ECMWF

forecasts issued on each day D for the following D+24, D+48 and D+72 forecast range) are used since the analogue search is updated every 24 hours. Also for this scheme different fields (i.e. the same meteorological variable evaluated at two times or different variables evaluated at two times) are evaluated within the analogue search process: therefore, the overall criterion taken to select the analogue dates for each forecast range is just the sum of the individual similarity criterion values computed field by field. In detail, for the current day Dc the analogue search is performed for the first forecast range (+0-24 h) by comparing, distinctly, the ECMWF analysis of day Dc and the ECMWF model forecast at +24 h issued on day Dc with the corresponding field of each past analogue day Dp_i; the hourly precipitation forecast is obtained by considering the raingauge measurements recorded starting from 12:00 UTC of the selected analogue day Dp_1 for the next 24 hours (i.e. the hourly precipitation observed between 12:00 UTC day Dp_1 and 12:00 UTC day Dp_1+1). For the next forecast range, i.e. +24-48 h, the analogy is searched for comparing, distinctly, the ECMWF forecast issued on day Dc for days Dc+1 and Dc+2 with the corresponding field of each past analogue day Dp_i; whenever a certain day Dp_2 is selected as analogous, the hourly precipitation forecast is obtained by considering the raingauge measurements recorded starting from 12:00 UTC of day Dp_2+1 for the next 24 hours (i.e. the hourly precipitation observed between 12:00 UTC day Dp_2+1 and 12:00 UTC day Dp_2+2). Last, for the forecast range +48-72 h the analogy is searched for comparing, distinctly, the ECMWF forecast issued on day Dc for days Dc+2 and Dc+3 with the corresponding field of each past analogue day Dp_i; whenever a certain day Dp_3 is selected as analogous, the hourly precipitation forecast is obtained by considering the raingauge measurements recorded starting from 12:00 UTC of day Dp_3+2 for the next 24 hours (i.e. the hourly precipitation observed between 12:00 UTC day Dp_3+2 and 12:00 UTC day Dp_3+3). Finally, for the scheme B, the hourly precipitation forecast for the next three days is obtained by joining, for each forecast range, the 24-hour long time series of raingauge measurements recorded during the selected subsets of past analogous days, up to achieve the 72-hour long QPF time series.

From the above description, it points out that within the framework of procedure B the analogy involves the change in time of circulation patterns forecasted in the next 24-72 hours, and not observed in the previous 24 hours as in the scheme A.

Pag. 3072, line 13: why fall season takes from 4 September to 29 November?

Due to data availability in the meteo-hydrological historical archive at ARPA-SIM.

Pag. 3072, lines 17-26: you should clarify that you are testing the two criteria of similarity. Figures 2 and 3: are you using the scheme A or the scheme B?, the hour 0 in the abscises axis coincides with the period 12:00-13:00? Please, clarify.

The statistical analysis performed in terms of mean error and root mean-squared error, which results referred to the scheme A are displayed in Figures 2 and 3 (in the revised manuscript, respectively, Fig. 3 and Fig. 4), is addressed not only to test the two criteria of similarity, but also to test the influence of the different meteorological variables, or combination of them, used to determine analogues on the corresponding QPFs.
Figures 2 and 3 refer to the scheme A: this information has been added in the corresponding figure captions as well as in the text of the revised manuscript.
The hour 0 in the x-axis, which is plotted only as reference for the forecast time range, corresponds to 12:00 UTC: this information has been added in the figure captions. The first values of mean error and root mean-squared error are associated with the forecast hour 1 (i.e. 13:00 UTC).

Pag. 3072, lines 20-23: please, introduce in the text the acronyms showed in figure 2; for instance, it is not clear whether ZW would be the vertical velocity at 700 hPa with the geopotential at 500 hPa or with the geopotential at 850 hPa.

For the acronyms showed in Fig. 2 and Fig. 3 (in the revised manuscript, respectively, Fig. 3 and Fig. 4), we mean: with Z the forecast based on the analogues of geopotential height at 500 hPa; with ZZ the combination of the previous variable with the same field at 850 hPa; with W the vertical velocity at 700 hPa; with ZW the combination of geopotential height at 500 and vertical velocity at 700 hPa; with ZWQ the combination of geopotential height at 500, vertical velocity at 700 hPa and specific humidity at 700 hPa; with WQ the combination of vertical velocity and specific humidity, both at 700 hPa. Additionally, the suffix "red" means a domain area reduced (0° E - 20° E; 40° N-50° N) over which the analogy is investigated, while the initials "rnd" indicates random selected analogues.

Pag. 3072, lines 27-28: what procedure are you using to calculate the difference between the forecasted precipitation and the real precipitation? Are you obtaining an average precipitation from all the analogues of day Dc and are you averaging afterwards the error for all the period and each hour? How many analogues are you selecting? Are you giving a weight in terms of the correlation coefficient, for example? Are you calculating the error hour by hour or within 24-h precipitation? Looking at figure 3 it is possible to see the number of analogues tested, but it would be better to introduce it previously in the text.

The difference between the hourly forecasted precipitation and the hourly observed precipitation is calculated for each raingauge and each analogous of day Dc. Then, for each forecast hour, the error is averaged for all the raingauges and analogues considering all days of each fall season.
The analysed results refer to a fifty-element analogue subset.
In the computations, any weighting procedure has been applied to consider the analogy degree of each analogous day.

Pag. 3073, lines 3-4: what do you think is the cause of the trend observed when sorting by ED?

It is not an easy task to explain the cause of the trend observed when sorting by ED since further detailed investigation should be necessary. Therefore, authors try to suppose as follows.
Since the variables W and Q are characterized by a high spatial variability and are more

HESSD

3, S1716–S1729, 2006

Interactive Comment

representative of local conditions characterizing an atmospheric circulation pattern, by a meteorological point of view it could be less significant to calculate their gradient over a large spatial domain and at a coarse resolution with respect to a meteorological variable (such as the geopotential height at 500 hPa) more able to represent the synoptic circulation pattern. Therefore, it is reasonable to believe that the S1 score does not enable to properly recognize the circulation patterns defined in terms of W and/or Q, leading to select poor analogues which do not encompass the local features of vertical velocity and specific humidity. In this way, the fifty-member subsets sorted by S1 considering the aforementioned fields collect analogues whose analogy degree is rather low, resembling the climatology (characterized by a null bias).
Rather, the ED criterion enables to count for in a better way the skill of W and Q to describe patterns, leading to select analogues which are able to trigger the precipitation signal at the beginning of the forecast period, but tend to underestimate the rainfall amount, resulting a negative bias. With increasing lead-times, the skill of such variables decays, so that the spatial-temporal correlation of the precipitation related to selected analogues descends, tending to resemble the climatology (null bias).

Pag. 3073, line 19: what criteria have you used to define the different classes of rainfall? You say that "the number of classes and the class boundaries should be suitably defined counting for the climatology and extension of the area involved, as well as the accumulation period of the precipitation", but you do not explain the methodology followed in your case. The same question will be in relationship with table 2.

The methodology followed to define the different classes of hourly and daily rainfall used in the paper considers all the facets aforementioned at Pag 3073, lines 16-18, conditionally to the regime of precipitation characterizing the Reno river basin.

Pag. 3074, line 6: authors say that "it is preferable to choose the fifty-element subset as it includes more variability", but figure 4 shows that the best results for the RPS correspond to the selection of 30 analogues in ED case. Could you please explain, what is the difference between choosing the fifty-element subset or the selection of 30

HESSD

3, S1716–S1729, 2006

Interactive Comment

analogues? What it depends on?

The results in terms of RPS displayed in Fig. 4 (in the revised manuscript Fig. 5) show that:

- in case of the S1 (Fig. 4b), for both schemes the RPS values related to the fifty-element subsets are always lower, at most equivalent, with respect to the thirty-element subset ones.
- in case of the ED (Fig. 4a), for both schemes the fifty-element subsets related to analogues which consider the variable Z500 are always characterized by lower, at most equivalent, values of RPS with respect to the corresponding thirty-element subsets. Among the analogues not involving Z500, for the solution W the RPS values of the two subsets are substantially equivalent for both schemes; for that solutions involving analogues of W and WQ searched over a restricted domain (labelled with the suffix "red") the thirty-element subset is clearly preferable by both schemes; while, for the solution WQ the thirty-element subset performs better only within the framework of scheme B.

By the light of these results and considering that the analogues which involve Z500 show better performance in terms of QPFs, authors conclude that the fifty-element subset is preferable, in addition a more numerous ensemble enables to count for more variability in the prediction of possible future rainfall scenarios.

Pag 3074, lines 19-22: authors say that "A further test has been carried out to assess the influence of the domain size, extending the area over which the analogy is investigated (20° W - 30° E; 30° N - 60° N)". However, on page 3068 they said that the domain area covers from 10° W to 20° E and from to 30° N to 60° N, meanwhile on page 3072 they introduce a third reduced domain area (0° E - 20° E; 40° N - 50° N) over which the analogy is investigated. Have they used three different domain areas?, why are they comparing the influence of the domain size with the scheme used (in this case, A)?

Among the several facets concerning the analogue method optimization process (Section 2, Pag. 3068, lines 12-15) it is mentioned the size of the spatial domain over which the similarity of atmospheric patterns has to be investigated. Therefore, a further test has been carried out considering an extended area (20° W - 30° E; 30° N - 60° N) over which the analogy is investigated. This test has been performed only for the scheme A. The paragraph at Page 3074, lines 19-22, has been modified counting for this clarification.
Within the framework of both schemes, another (reduced) domain area (0° E - 20° E; 40° N - 50° N) has been considered only for the solutions involving the variable W and the combination of W with Q, as these meteorological variables are characterized by a high spatial variability and are more representative of local conditions characterizing an atmospheric circulation pattern. This clarification has been added at Page 3072, line 26.

Pag 3074, line 26: It is not possible for the reader to do any "visual analysis" because any figure is referred in the text.

The paragraph has been rewritten counting also for the next referee comment and moved at the end of Section 4.

Pag 3074, lines 26-29: Suddenly, you start to compare with the meteorological model LAMBO, but, there is no information about which scheme, selected variables, number of analogues and domain area you are using to do this comparison.

The paragraph has been rewritten as follows and moved at the end of Section 4.
Also the deterministic forecast provided by the meteorological model LAMBO has been used as term of comparison for the daily analogue-based QPFs obtained with the scheme A considering a fifty-member subset. By a subjective analysis (not shown) performed over the autumn seasons of the period 1997-2000 it results that, generally, the temporal forecasting sequences of daily precipitation provided by LAMBO predict better the no-rainy events with respect to any solution of analogue-based QPFs (this

HESSD

3, S1716–S1729, 2006

Interactive Comment

outcome is more evident for the solutions involving Z500), but tend to underestimate the rainfall amount in case of intense events.

Pag 3075, lines 4-7: looking at Figure 4 it is not clear why you propose to work with the fifty-member analogue subset (30-member looks better).

As it is shown in the reply to the comment related to Pag. 3074, line 6, the fifty-member analogue subset performs generally better in terms of QPF accuracy, then it is considered in the comparison proposed at Pag 3075, lines 4-7.

Pag 3076, line 12: Explain the criteria applied to propose 23 classes.

Depending on the streamflow regimes characterizing the Reno river basin, a high number of classes (23) has been defined (Table 3) in order to appreciate a wider range of discharge values (corresponding to streamflow regimes meaningful for stakeholders and basin management authorities) which enable to evaluate the forecast skill in detail.

Pag 3076, line 20: it would be useful to introduce a figure to clarify the sentence "by consensus of both schemes and analogy criteria, the solution of geopotential at 500 hPa combined with vertical velocity at 700 hPa provides a better estimation of future flows". Looking at figure 4, methods S1 and EP point out to different selected variables, and scheme B provides considerable better values of RPS than scheme A.

With the sentence "by consensus of both schemes and analogy criteria" we refer to the sum of RPS values calculated for each solution investigated (i.e. the discharge simulation driven by the QPF provided by analogues selected upon certain meteorological variable or combination of them) considering all scores obtained for each forecast range, scheme and analogy criterion. Following this criterion, the solution of geopotential at 500 hPa combined with vertical velocity at 700 hPa, and also the one with in addition the specific humidity at 700 hPa (not mentioned in the first paper version), provide a better estimation of future flows. Adding this clarification in the text, authors deem that it is not necessary to introduce a new figure displaying the sum of RPS val-

HESSD

3, S1716–S1729, 2006

Interactive Comment

ues since the same information could be deducted, just on a quality level, by Fig. 7 (in the revised manuscript Fig. 8).
Regarding to the results shown in Fig. 4 (in the revised manuscript Fig. 5) on the verification of analogue-based QPFs, it should be considered that at Pag. 3076, lines 16-27, the discharge forecasts are under evaluation, and that the non-linearity in rainfall-runoff processes can strongly modify the outcomes obtained in terms of QPF.
The better performance of the scheme B with respect to scheme A (highlighted in Fig. 4 as well in Fig. 7) does not influence, or contrast, the conclusion drawn in this paragraph of Section 4: this facet does not strongly affect the evaluation process concerning which solution of variables is preferable since the outcomes of scheme B reflect approximately those of the scheme A about the relative performance of different solutions.

Pag 3077, line 25: the three selected case studies, did they exceed the warning threshold?

The maximum water level recorded for each of the three selected case studies (mentioned between the lines 29-35) can be compared to the warning threshold indicated at Pag 3072, lines 7-8. Nonetheless, for the sake of clarity, the information about the exceeding of the warning threshold during the three case studies has been explicitly mentioned in the revised manuscript.

Pag 3081, lines 1-5: there is no conclusion about the application of scheme A or scheme B.

An overall conclusion about the application of schemes A and B for hydrological purposes was hinted at lines 11-13 when authors say that the decay of performance with the lead-time increase can be partially reduced updating the search for analogues every 24 hours of forecast by means of the meteorological variable forecast provided by a numerical model.
To better point out the results concerning the scheme comparison, the following new

HESSD

3, S1716–S1729, 2006

paragraphs have been added in the Section "Conclusions".
Pag. 3080, line 23: Within this framework, two different implementations of the analogue method have been compared: these schemes differ about the procedure to calculate the hourly precipitation forecast for the next 3 days, employing the same variables to characterize the atmospheric pattern and similarity criteria. In the first proposed scheme (referred as scheme A in the paper), the analogy involves the change in time of circulation patterns observed in the last 24 hours, whose evaluation is performed by using the ECMWF analyses at 12:00 UTC; then, the hourly precipitation forecast is obtained by means of the raingauge measurements recorded for the next 72 hours starting from the selected past analogous days. Rather, in the second proposed scheme (referred as scheme B in the paper), the analogy involves the change in time of circulation patterns forecasted for the next 24-72 hours, whose evaluation is performed by using the ECMWF analyses and forecasts at 12:00 UTC and updating the analogue search every 24 hours; then, the hourly precipitation forecast is obtained by joining, for each forecast range, the 24-hour long time series of raingauge measurements recorded during the selected subsets of past analogous days, up to achieve the 72-hour long QPF time series.
Pag. 3081, line 5: The scheme comparison in terms of QPF reveals a performance decay with the lead-time increasing more evident for the scheme A with respect to the scheme B.
Pag. 3081, line 13: Indeed, the scheme comparison reveals that the performance of discharge simulations are substantially equivalent for the first 24 forecast hours, whereas for the next forecast ranges (from +24 to +72 h) it results a performance decay more evident in the scheme A with respect to the scheme B.

Technical Comments:

Pag 3065, line 20: Baur, 1951 is not included in the list of references.

This reference has been included in the revised manuscript.

HESSD

3, S1716–S1729, 2006

Interactive Comment

Pag 3076, line 12: table 3 is not included.

Table 3 has been included in the revised manuscript.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 3, 3061, 2006.