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The Analogue Method for Precipitation Forecasting: Finding Better Analogue Situations at a Sub-Daily Time Step

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Abstract. The Analogue Method (AM) aims at forecasting local weather variables (predictands), such as precipitations, by means of a statistical relationship with predictors at a synoptic scale. The analogy is generally assessed in the first place on the geopotential field by mean of a comparison of the gradients, in order to sample the days with a similar atmospheric circulation.

The search for candidate situations, for a given target day, is usually undertaken by comparing the state of the atmosphere at fixed hours of the day, for both the target day and the candidate analogues. The constraint being the use of daily time series, due to the length of available archives they provide, and the unavailability of equivalent archives at a finer time step. However, it is unlikely that the best analogy happens at the very same hour, but it may occur at a different time of the day. In order to assess the potential of finding better analogues at a different hour, a moving time window (MTW) has been introduced on a reduced archive of hourly precipitation totals.

The MTW resulted in a better analogy in terms of the atmospheric circulation, with improved values of the analogy criteria on the whole distribution of analogue dates. The improvement was found to grow with the analogue ranks due to an accumulation of more similar situations in the selection. Moreover, the improvement is even more important for days with heavy precipitation events, which are generally related to more dynamic atmospheric situations, where timing is more specific.

A seasonal effect has also been identified, with larger improvements in winter than in summer, supposedly due to the stronger effect of the diurnal cycle in summer, which favors predictors at the same hour for target and analogues.

The impact of the MTW on the prediction performance has been assessed by means of a sub-daily precipitation series transformed into moving 24 h-totals at a 6-hourly time step. This resulted in an improvement of the prediction skills, which were even larger after recalibrating the AM parameters.

However, attempts to reconstruct longer precipitation series of running 24 h-totals by means of simple methods failed. It emphasized the need to use time series with an appropriate chronology.

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These should be available in a near future, either by means of growing observed archives, or by the establishment of precipitation reanalyses through regional modeling. Then, the use of a MTW in the AM should be considered for any application, especially when the prediction quality of extreme events is important.

1 Introduction

The Analogue Method (AM) is based on the principle that two relatively similar synoptic situations may produce relatively similar local effects (Lorenz, 1956, 1969). Multiple variations of the methods exist and listings can be found in Horton et al. (2016) or Ben Daoud et al. (2015). The versions that will be considered here are often used as references or benchmarks for various improvements.

The first method is based on the analogy of the atmospheric circulation only (Table 1, Obled et al., 2002; Bontron and Obled, 2005; Marty et al., 2012). Searching analogue situations for a target day starts by a preselection step of the potential candidate for analogy. Here, it has been limited to the 4 months centered around the target date for every year of the archive, in order to cope with seasonal effects. Then, the similarity of the atmospheric circulation of the target date with every day of the preselection is assessed by processing the Teweles and Wobus (1954) score (S_{TW}), which is a comparison of gradients, over a certain spatial window and at certain hours. The smaller the S_{TW} values, the more similar the pressure fields.

The predictand, here a 24 h precipitation total, results from meteorological situations that are continuous transitions between changing circulation patterns. Thus, the observed predictors fields, extracted from reanalysis datasets, are considered at different time of the day and at different heights. In our case, the geopotential height is considered at 1000 hPa (Z1000) at 12 h UTC and 500 hPa (Z500) at 24 h UTC. The selection of the observation time of the predictor was found by Bontron (2004) to have a significant influence.

Then, N_1 dates with the lowest values of S_{TW} are considered as analogues to the target day, N_1 being a parameter to calibrate. Then, the daily observed precipitation amount of the corresponding dates provide the empirical conditional distribution considered as the probabilistic forecast for the target day. Following the nomenclature proposed by Horton et al. (2016), this method will be named 2Z.

The second reference method adds a subsequent level of analogy on moisture variables, compared by means of the root-mean-square error (E_{RMS}) (method 2Z-2MI, Table 2). This second predictor is a moisture index made of the product of the total precipitable water (TPW) with the relative humidity at 850 hPa (RH850) (Bontron, 2004). When adding a second level of analogy, N_2 dates are subsampled in the N_1 analogues on the atmospheric circulation, to end up with a smaller number of analogue situations. When a second level of analogy is added, a higher number of N_1 analogues is kept on the first level.

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To calibrate the method, the commonly used technique is a semi-automatic sequential procedure elaborated by Bontron (2004). AtmoSwing (Horton et al., 2016), which implements this technique, was used in order to calibrate the parameters in the present study. The score that is most often considered to assess an AM performance is the Continuous Ranked Probability Score (S_{CRP}, Brown, 1974; Matheson and Winkler, 1976; Hersbach, 2000). It allows evaluating the predicted cumulative distribution functions $F(y)$, for example of the precipitation values y from analogue situations, compared to the observed value y^0. The better the forecast, the smaller the score. It is defined as follows:

$$S_{\text{CRP}} = \int_{-\infty}^{+\infty} \left[F(y) - \text{H}(y - y^0)\right]^2 \text{d}y, \tag{1}$$

where $\text{H}(y - y^0)$ is the Heaviside function that is null when $y - y^0 < 0$, and has the value 1 otherwise. Bontron (2004) proposed a decomposition of this score interpreted into a sharpness and an accuracy terms.

In order to compare the value of the score in regard to a reference, one often considers its skill score expression, and use the climatological distribution as the reference. The Continuous Ranked Probability Skill Score (S_{SCRP}) is thus defined as following:

$$S_{\text{SCRP}} = \frac{S_{\text{CRP}} - S_{\text{CRP}}^r}{S_{\text{CRP}}^p - S_{\text{CRP}}^r} = 1 - \frac{S_{\text{CRP}}}{S_{\text{CRP}}^r} \tag{2}$$

where S_{CRP}^r is the S_{CRP} value for the reference (climatological distribution) and S_{CRP}^p would be the one for a perfect forecast (which implies $S_{\text{CRP}}^p = 0$). A better forecast is characterized by an increase in S_{SCRP}.

The AM is usually implemented with a daily time step, due to the availability of long precipitation archives that have no equivalent at a finer resolution. Therefore, the analogue situations are assessed on the basis of a daily time step, by comparing predictors at fixed hours of the day, otherwise one would not know what precipitation values to assign to them. However, it can be expected that the analogy of the synoptic situations does not occur systematically at the same time of the day, and that better candidates can be found by shifting to a different hour. On this assumption, a moving time window (MTW) was introduced to allow searching for candidates at different hours of the day.

Previous tests showed the benefit, in terms of analogy criteria values, of searching for analogue synoptic situations at a finer time step, but without assessing the impact on the forecast skills (Finet et al., 2008). In order to assess this potential improvement of the prediction, precipitation data with a resolution of 10 minutes, on a respectable archive length, was used (Sect. 2.1). It was then aggregated in the form of 24 h-totals, but starting at different 6-hourly time step, by means of a moving total (Sect. 2.2).

One can question the interest of using daily totals when a 6-hourly precipitation series can be used. The first reason is that the 6-hourly time series generated by the AM may not represent well the

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dynamic of the accurate precipitation (results not shown), due to a smoothed signal. Then, sometimes one just does not need finer resolution than the daily time step. Finally, when using a reconstructed precipitation archive, the errors in intra-day precipitation distributions have a lesser impact over 24 h daily totals.

The MTW is explained in Sect. 2.2. As this method requires sub-daily time series, the available archive length is reduced compared to more common daily measurements, which has some consequences on the performance score (Sect. 2.3). The benefit of introducing a MTW was assessed first in regards to the analogy criteria improvement (Sect. 3.1), and then in terms of precipitation prediction skill (Sect. 3.2). Finally, attempts were made to reconstruct longer 24 h-total precipitations series (Sect. 4).

2 Data and method

2.1 Study area and data

The study area is the upper Rhône catchment in Switzerland (see also Horton, 2012). Due to the low density of weather stations with high temporal resolution and long archives, no spatially aggregated rainfall was processed. The time series (on the period 1982–2007) come from 6 automatic weather stations, namely Ulrichen, Zermatt, Visp, Montana, Sion and Aigle (Fig. 1), which are subject to various meteorological influences (Horton et al., 2012). The results will thereafter be presented arbitrarily for the Ulrichen station, but they are equivalent for all stations. The precipitation time series were then aggregated by means of a moving 24 h-total (see next section).

Predictors are extracted from the NCEP/NCAR reanalysis I (Kalnay et al., 1996) dataset with a 6-hourly temporal resolution, 17 pressure levels, and a spatial resolution of 2.5°.

2.2 The moving time window (MTW) approach

In order to assess the benefit of searching analogue situations at a sub-daily time step, an appropriate precipitation series is required. On the basis of high resolution time series (Sect. 2.1), 24 h-totals were processed, but at a 6-hourly time step (temporal resolution of the reanalysis dataset), by means of a moving 24 h-total.

The target situations and their corresponding observed precipitation values (used for validation) do not change, because the forecast is always established for a fixed period of the target day (6–30 h), as before. The difference is that the candidates are 4 times more numerous (Fig. 2).

Based on some preliminary tests (not shown), no constraint was added in order to restrict the selection of multiple analogues within the same candidate dates.

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2.3 Consequences of the archive reduction

As sub-daily precipitation time series are usually available on a shorter period than traditional daily time steps, the first assessment consists in assessing the loss of performance resulting from a reduction of a 47 years archive (1961 to 2008) to 25 years (1982 to 2007). This change is assessed with the original method, without MTW.

Both 2Z (Table 1) and 2Z-2MI (Table 2) methods were considered. The AM parameters were calibrated using AtmoSwing (Horton et al., 2016) on the original archive (Tables 3 and 4) and will be used thereafter.

The impact of the change in the archive length is summarized in Table 5 for both 2Z and 2Z-2MI methods. As expected, a loss of performance can be observed for each station, except for that of Aigle, which seems relatively indifferent to this change. This loss is globally significant, with up to -1.89 points for Visp and the 2Z method.

3 Results and discussion

3.1 Influence on the analogy criteria

3.1.1 Changes in the atmospheric circulation analogy

When searching for analogues on the geopotential heights, as in the 2Z method, there are now 4 times more candidates than before, which obviously allows to find better matches.

Figure 3 presents the changes in the distributions of the S_{TW} criterion for the 1^{st}, 5^{th}, 20^{th} and 40^{th} analogues for the Ulrichen station on the whole calibration period, due to introduction of the MTW. The precipitation target remains as before, that is centered on 18 h UTC (6 h UTC to 6 h UTC the next day). The shapes of the distributions of the conventional approach and the MTW are similar, but the values of the analogy criteria are now reduced (shifted to the left), and therefore better. An increase in the difference between a fixed window and a moving window is identifiable, which means that the last analogues are further improved. The latter effect is due to the accumulation of improvements brought by the new analogue situations in the selection.

The improvements of the S_{TW} criteria are summarized in Fig. 4, which shows (top) quantiles of the S_{TW} criteria according to the analogue rank for the conventional method and the MTW, and (bottom) quantiles of the relative reduction. This confirms that all quantile seem similarly reduced (S_{TW} distributions keep their shape), and that this improvement is constantly increasing from the first to the last analogue (Fig. 4 bottom).

The median of the S_{TW} values reduction (Fig. 4 bottom) starts approximately at 5 % for the first analogue and reaches more than 10 % for the last one. This increasing trend with the analogue rank can be explained by the accumulation of better analogues in the distribution. The minimum improvement starts from 0 and reaches 2–3%, meaning that the criteria have been improved on most

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analogues for every day of the calibration period. All other stations have a similar improvement of the S_{TW} criteria, both in terms of distribution shape and amplitude.

3.1.2 Influence of the weather situation

It can be assumed that the atmospheric conditions with a low dynamism, such as the frequent anticyclonic situations, will not be radically improved by the introduction of the MTW. Conversely, dynamic situations, such as weather disturbances, have a well marked temporal evolution. Indeed, the position of the driving elements such as the low-pressure center and the fronts change significantly during a day. We can therefore expect to improve more significantly these situations with a higher dynamism when introducing a MTW, as better matches to the target situation may be found.

The dynamism of a given atmospheric condition cannot be easily quantified. A basic assumption is considered here, which stipulates that the more a day is rainy, the more dynamic the situation is. The results of this analysis are summarized in Fig. 5 by the median reduction of S_{TW} for days with precipitation (organized into classes) between two thresholds. The number of cases per class being reduced, the curves are not as smooth as in previous analyzes. It is nevertheless clear that the improvement tends to increase on days with higher precipitation. This is true for all our stations and confirms our intuition.

3.1.3 Seasonal effect

Atmospheric dynamics varies greatly from one season to another, which reflects on the performance of the AM that is generally lower between June and August (Bliefernicht, 2010). It therefore makes sense to verify the effect of the MTW separately per season.

A seasonal effect can be observed on the reduction of the S_{TW} criteria due to the MTW (Fig. 6). The improvements are greater for winter than summer. One hypothesis is that the diurnal effects of the summer months have an influence on the atmospheric circulation, at least in the lower layers. This effect is based on the daily cycle and good analogues are essentially found for the same hours or time windows.

An analysis of the selected hours for the geopotential predictor seems to confirm this assumption (Fig. 7). It was found that the new choice of the temporal window in winter, when using the MTW approach, is well balanced between the 4 options. This means a change of 75% of the analogues selection compared to the conventional approach, which improves the circulation analogy.

On the contrary, the summer months have a preference for the initial temporal window (Z500 24 h & Z1000 12 h), due to more pronounced diurnal effects which reduces the potential for improvement of the criteria. Other seasons are between these two extremes, which is consistent with their respective improvements. This seasonal effect was observed for each station in a very similar way, and generally even with a slightly larger amplitude than for Ulrichen (see example of the Visp station in Fig. 8).

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3.1.4 Changes in the moisture analogy

When considering the second level of analogy of the 2Z-2MI method (Table 2), the number of candidates situations did not increase, as they are subsampled in the previously N_1 selected analogues, but their dates have changed. In contrast to earlier, both a reduction or an increase of the E_{RMS} analogy criterion values are possible. Indeed, Fig. 9 shows an almost insignificant improvement of the E_{RMS} values. Unlike for the first level of analogy, the relative improvement of the E_{RMS} values are distributed relatively symmetrically around zero, with improvements and losses of the same amplitude. Once again, the results for the other stations are similar.

This result of a globally null improvement of the E_{RMS} values does not mean that the 2Z-2MI method cannot be improved by the MTW. It means that after the selection of the analogues situations in terms of the synoptic circulation, the new candidate dates do not allow to find better analogues in terms of moisture. However, the selected dates have changed in the first level of analogy, and thus also in the final selection, which can potentially improve the performance scores on the predictand.

3.2 Impact on performance scores

A systematic improvement of the S_{TW} values was previously observed. However, finding better analogue situations does not obligatory imply better skills to predict the precipitation. Therefore, the impact of the MTW introduction, and thus the selection of other analogue dates, has to be assessed on the performance scores. In order to perform this assessment, the 24 h-totals (moving average) at a 6-hourly time step were used (see Sect. 2.1). The target dates remain unchanged, since the original time slot (6 h UTC – 6 h UTC the next day) is kept, and thus the performance scores can be directly compared with the former ones.

The new performance scores are provided in Table 6, along with the differences regarding the conventional method with the same archive length. The differences ranges from 0.57 to 2.14 points for the 2Z method and from 1.53 to 2.20 points for the 2Z-2MI method. The introduction of the MTW brings an improvement of the performance that is not very large, but that is nevertheless significant. Moreover, it requires no additional predictor. No relationship was found between the improvement of the score and the reduction of the S_{TW} criteria, neither with the season.

3.2.1 Improvement by precipitation classes

The S_{TW} criteria was previously found to be improved to a greater extent for the most dynamic situations related with higher precipitation values (Sect. 3.1.2). The changes in terms of performance scores will now be assessed regarding precipitation thresholds. Fig. 10 synthesizes these differences for the Ulrichen station, other stations having the same behavior.

The increasing positive trend of skill improvements regarding the precipitation threshold is significant and shows that the prediction of higher precipitation totals is further improved. Thus, both the

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analogy criteria and the performance scores are improved to a greater extent for heavier precipitation events. On the contrary, the non-rainy days and small accumulations are not improved.

3.2.2 Effect of recalibrating the parameters

The previous assessment of the performance improvement was established with the original parameters optimized with a fixed time window. However, one can assume that the introduction of the MTW may change the optimum of some parameters. The calibration has then been reprocessed.

After recalibrating, some changes in the optimal parameters can be observed for both 2Z (Table 7) and 2Z-2MI methods (Table 8). Among these, the east-west dimension of the spatial windows of the circulation analogy tends to decrease. More significantly, the optimal number of analogues increases after introducing the MTW, of a significant order of magnitude: 25 % to 83 % for the 2Z method and 20 % 67 % for the 2Z-2MI method. The number of analogues of the first analogy level of the 2Z-2MI method even reached three times its previous value for the Visp station. It seems as if the method perceive the increase in the archive length and diversity by allowing to extract more analogues. As we saw in Fig. 4, the improvement of the S_{TW} criteria grows along with the rank of the analogue, which shows an accumulation of better analogue situations in the distributions. It seems thus profitable to widen the selection of analogues in order to keep also some whose rank has increased, as they appear to be also relevant to predict precipitation values. The number of good analogues is thus globally increased.

This increase in number of analogues has a slight effect on the performance of the different precipitation classes. The same analysis as in Sect. 3.2.1 has been performed again on the basis of the newly calibrated parameters. The results are generally very similar, but a slight performance increase of small precipitation values can be observed at the expense of higher amounts. The change in the analogues numbers is likely to be responsible for this difference in the performance distributions.

The values of the S_{SCRP} scores for both methods (Table 9) have significantly increased after recalibration. With the introduction of the MTW, the performance loss related to the reduction of the archive length is compensated.

3.2.3 Changes in sharpness and accuracy

The S_{CRP} score can be decomposed into two components, namely sharpness and accuracy (see Bontron, 2004). The impact of the MTW has been analyzed on these components and the results can be found in Table 10 for the original parameters and in Table 11 for the re-calibrated methods. The changes are expressed relative to the total S_{CRP}. Both components do not have the same value ranges: accuracy is in our case almost twice the sharpness values. Since the S_{CRP} is considered here and not the S_{SCRP}, improved prediction capacity results in a lower score. A decrease of the score is thus desirable.

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It appears that the sharpness is a bit inferior with the MTW in favor of accuracy (Table 10). When using the recalibrated parameters, the components are a bit more balanced, but still the accuracy prevails on the sharpness (Table 11). Fig. 11 illustrates the changes (relative to the total S_{CRP}) in sharpness and accuracy for different precipitation thresholds at the Ulrichen station. Be it for the 2Z or 2Z-2MI method, the original or the recalibrated parameters, the changes are similar: the improvements concern the accuracy over the sharpness, and this to a greater extent for significant precipitation events. The MTW does not allow to improve the sharpness, but the improvement in accuracy is significant, and this especially for the days with heavy precipitation. In terms of the predicted precipitation distribution, it means that the median of the prediction is closer to the observed values, while the distribution is not more condensed than previously.

4 Application attempts on the full archive

The improvement provided by the MTW is interesting, mainly for heavy precipitation events, and thus it would be profitable to be able to apply it to the complete archive. Unfortunately, there is no long precipitation time series available with a sub-daily time step. In order to reconstruct a longer archive of moving 24 h-totals, different disaggregation approaches of the daily time series were assessed and are presented in the following sections.

4.1 Proportional distribution

A proportional distribution is certainly the simplest approach that can be performed. It consists in allocating proportional parts of the original daily time series into a new moving average of 24 h-totals (Fig. 12). When using this reconstructed time series on the shorter period, the method performance was degraded (Table 12 to compare to Table 6) and was even below the conventional method without MTW (Table 5). The benefit of a better selection of the analogue situations is lost due to a precipitation archive of poor quality.

4.2 Use of a proxy variable

As demonstrated in the previous section, the performance improvement brought by the MTW is lost when using a simplistic precipitation time series. In order to get closer to the chronology of the actual precipitation, the reconstruction procedure must rely on some informative variable. Data from the NCEP/NCAR reanalysis 1 (Sect. 2.1) was used in this perspective, despite their rough resolution.

The first step consisted in determining which variables from the precipitable water or the relative humidity (at 1000 hPa, 925 hPa or 850 hPa) produces the precipitation chronology that is the most correlated (on non-zero values) with the accurate 6-hourly precipitation time series on the period 1982-2007. The location of the most predictive point from the reanalysis grid had to be assessed (closest points: 5–7.5° E and 45–47.5° N), as well an eventual time lapse between both series, due

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to the significant distance separating the weather stations and the reanalysis grid point. The most relevant point will probably not be the same for all stations, since one can expect to find the optimum in the direction of the main moisture inflows for the station. This assessment must be carried out for each station.

The results of the correlation analyses (on non-zero values) between the new series reconstituted using the proxy and the actual series are illustrated in Table 13 for Zermatt (on the short period, 1982–2007). The best proxy is the precipitable water at 45° N and 7.5° E, with a time offset of -6 h. The determination coefficient of 0.721 is higher than that of the series from the proportional distribution (0.698), which confirms that a little information was added to the series of precipitation.

Table 14 presents the S_{SCRP} scores obtained by the reconstituted series using the proxy of precipitable water at the optimal point (Table 13). A slight improvement can be obtained compared to the proportional distribution method, but it is still relatively small, and most of the benefit of the MTW is again lost.

These attempts to transpose the MTW on the total archive highlight the importance of the actual rainfall chronology. The MTW is profitable, provided that the precipitation series are close to the observed one. Without precipitation series with an accurate sub-daily chronology, the introduction of a MTW remains fruitless.

5 Conclusions

The AM is most often based on a daily time step, due to the availability of long precipitation archives. However, it is unlikely that two analogue synoptic situations, that evolve relatively quickly, would correspond optimally at the same hour of the day. It is thus more likely that a better match can be found at another time, which can change the selection of the analogues dates.

As Finet et al. (2008) had previously shown, the introduction of a MTW allows finding better analogue situations in terms of the atmospheric circulation. It has been here demonstrated that the improvement of the S_{TW} criteria values is growing with the rank of the analogue. This is due to the accumulation of better analogues within the predicted distributions.

The improvement of the circulation analogy was found to be more important for heavy precipitation events, which are generally related to more dynamic atmospheric situations. This dynamism implies more specific circulation patterns that are evolving more rapidly. Thus, a MTW is found to be of particular interest in this kind of situation, and benefits the prediction of extreme precipitation events.

A seasonal effect has been highlighted, as the MTW is more profitable for winter months than summer. The reason is likely that the diurnal cycle has a bigger effect in summer than in winter, which results in better analogues at the same time of the day. The preference for the same hours in

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summer has been demonstrated, whereas 75% of the analogue situations are selected at a different time in winter.

The impact of the MTW on the prediction performance has never been assessed before, due to the shortcoming of long precipitation series at a sub-daily time step. The impact of the MTW approach could be assessed on a 25 years time series with a high temporal resolution. After the introduction of the MTW, the performance scores increased of the same order of magnitude as if the length of the archive doubled, in this case study.

The parameters were then calibrated again, using the MTW. Some parameters changed, the main difference being the number of analogues, which systematically and significantly increased compared to the original set. A wider selection of analogue situations, containing those whose rank decreased, seemed profitable for the prediction performance. The number of good analogues is thus globally increased. This change seems to benefit mainly the prediction of days with small precipitation totals.

The importance of the quality of the precipitation archive was also demonstrated, as too simplistic reconstructions of 6-hourly time series lead to a loss of all the improvement brought by better analogue situations identified by the MTW. The precipitation prediction is improved only when the precipitation chronology is close to the accurate one. Attempts to reconstruct longer time series based on a simplistic proportional distribution or using meteorological variables from the NCEP reanalysis 1 dataset as proxy did not succeed. Other reanalysis datasets could eventually preform better.

Perspectives of using the MTW rely on the availability of long precipitation series at a sub-daily time step and with high accuracy. The first source of such data is the simple fact that with time, these archives of high temporal resolution precipitation data are getting longer. The second source is the establishment of precipitation reanalysis at a country scale, or the use of reanalysis-driven RCMs (Regional Climate Models) or LAMs (Limited Area Models) on a long period. When such precipitation data will be available, the use of a MTW in the AM should be considered for any application, especially when the prediction quality of extreme events is important.

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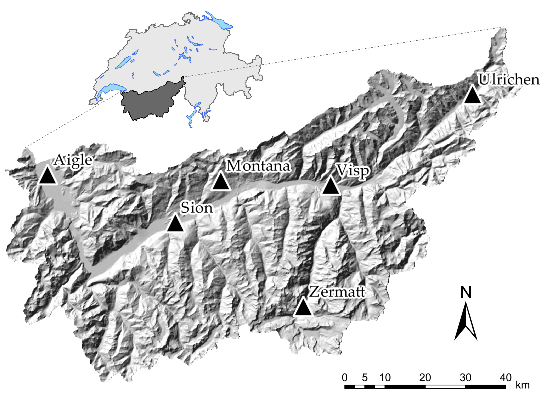

Figure 1. Position of the 6 weather stations of interest (Ulrichen, Zermatt, Visp, Montana, Sion and Aigle) in the study area.

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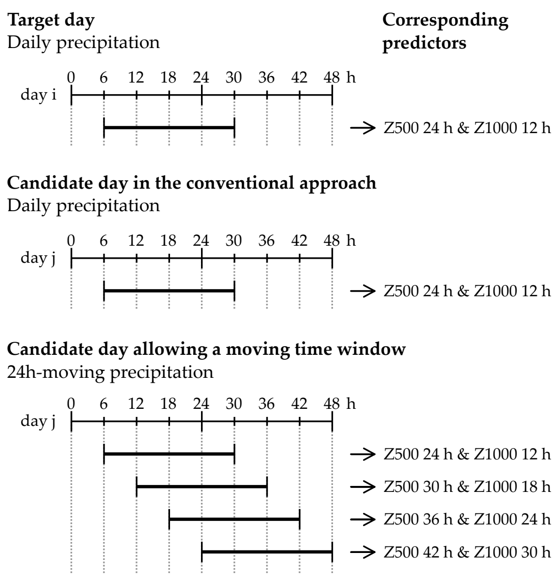

Figure 2. Illustration of the principle of a moving time window. The larger horizontal bars represent the 24 h precipitation totals.

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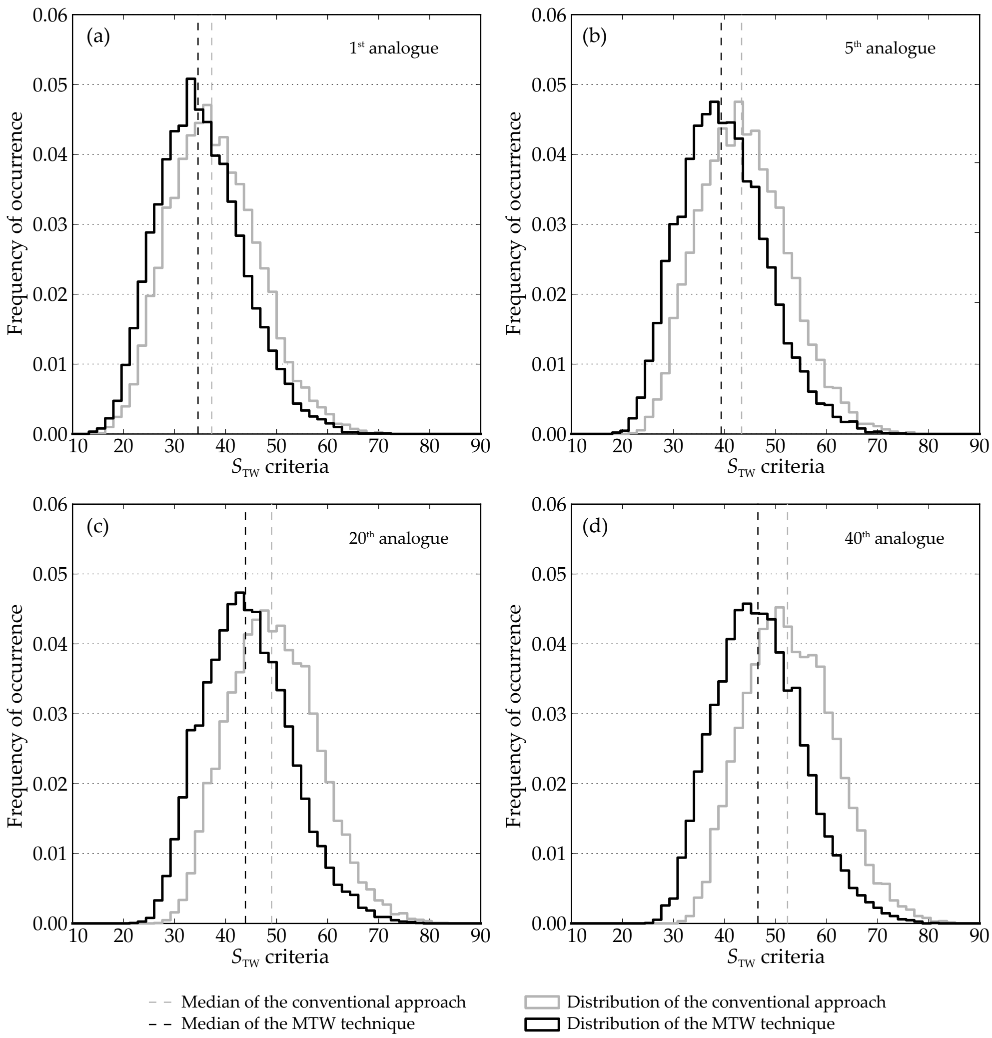

Figure 3. Changes in the S_{TW} criteria distributions of (a) the 1^{st}, (b) 5^{th}, (c) 20^{th} and (d) 40^{th} analogue ranks for the Ulrichen station, due to the MTW.

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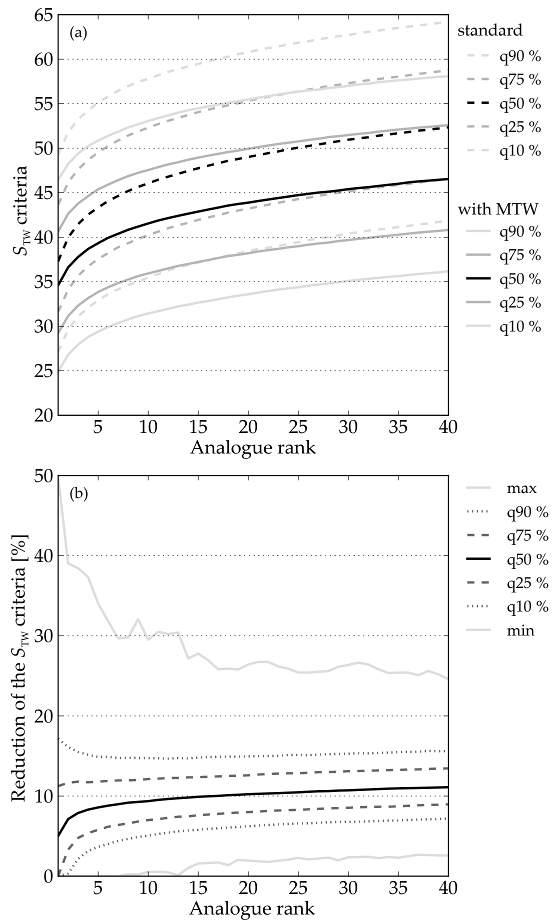

Figure 4. Synthesis of the changes in the S_{TW} criteria, due to the MTW, for the Ulrichen station, depending on the ranks of the analogue. (a) Quantiles of the S_{TW} distributions with and without the MTW. (b) Quantiles of the relative improvements of the S1 criteria when using the MTW.

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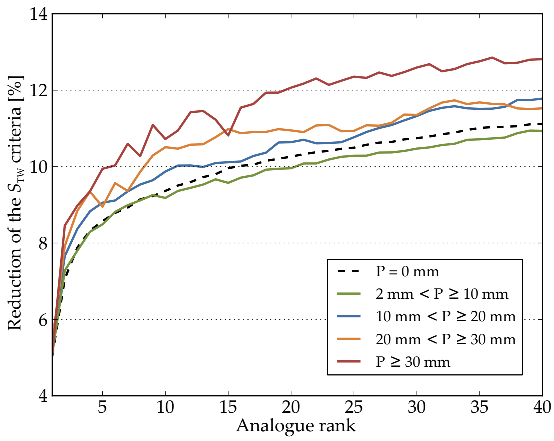

Figure 5. Distribution of the median improvements of the S_{TW} criteria, due to the MTW, depending on precipitation thresholds at the Ulrichen station.

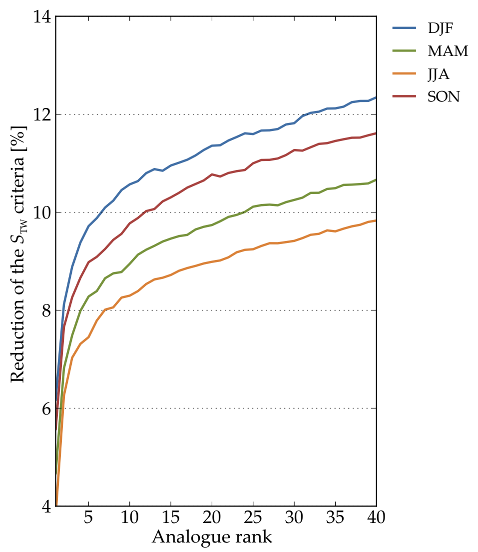

Figure 6. Seasonal effect on the median reduction of the S_{TW} criteria for the Ulrichen station due to the MTW. DJF: winter, MAM: spring, JJA: summer SON: fall.

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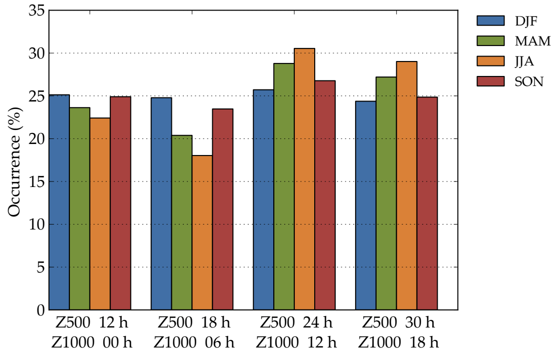

Figure 7. Distribution of the predictors hours in the selected analogue dates depending on the season, for the Ulrichen station.

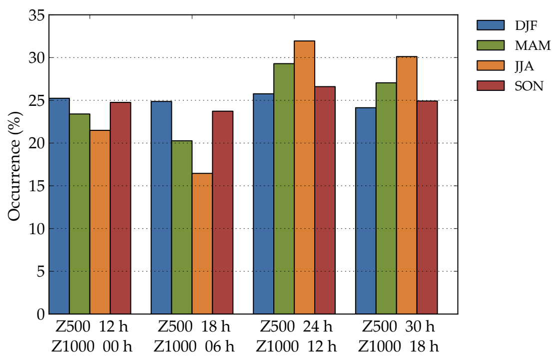

Figure 8. Distribution of the predictors hours in the selected analogue dates depending on the season, for the Visp station.

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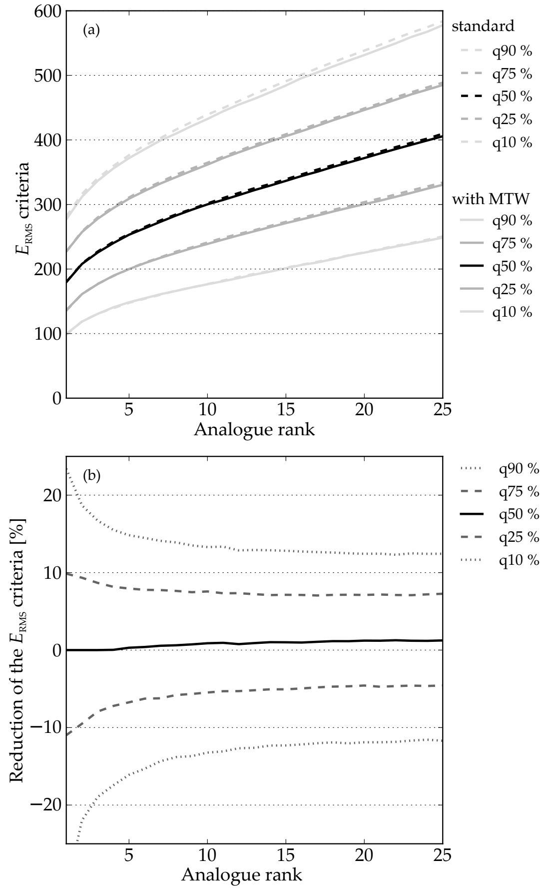

Figure 9. Synthesis of the changes in the E_{RMS} criteria, due to the MTW, for the Ulrichen station, depending on the ranks of the analogue. (a) Quantiles of the E_{RMS} distributions with and without the MTW. (b) Quantiles of the relative improvements of the E_{RMS} criteria when using the MTW.

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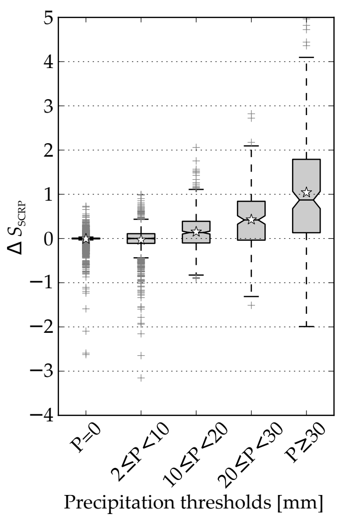

Figure 10. Differences of the S_{SCRP} performance score, due to the introduction of the MTW, as a function of precipitation thresholds at the Ulrichen station. The stars represent averages.

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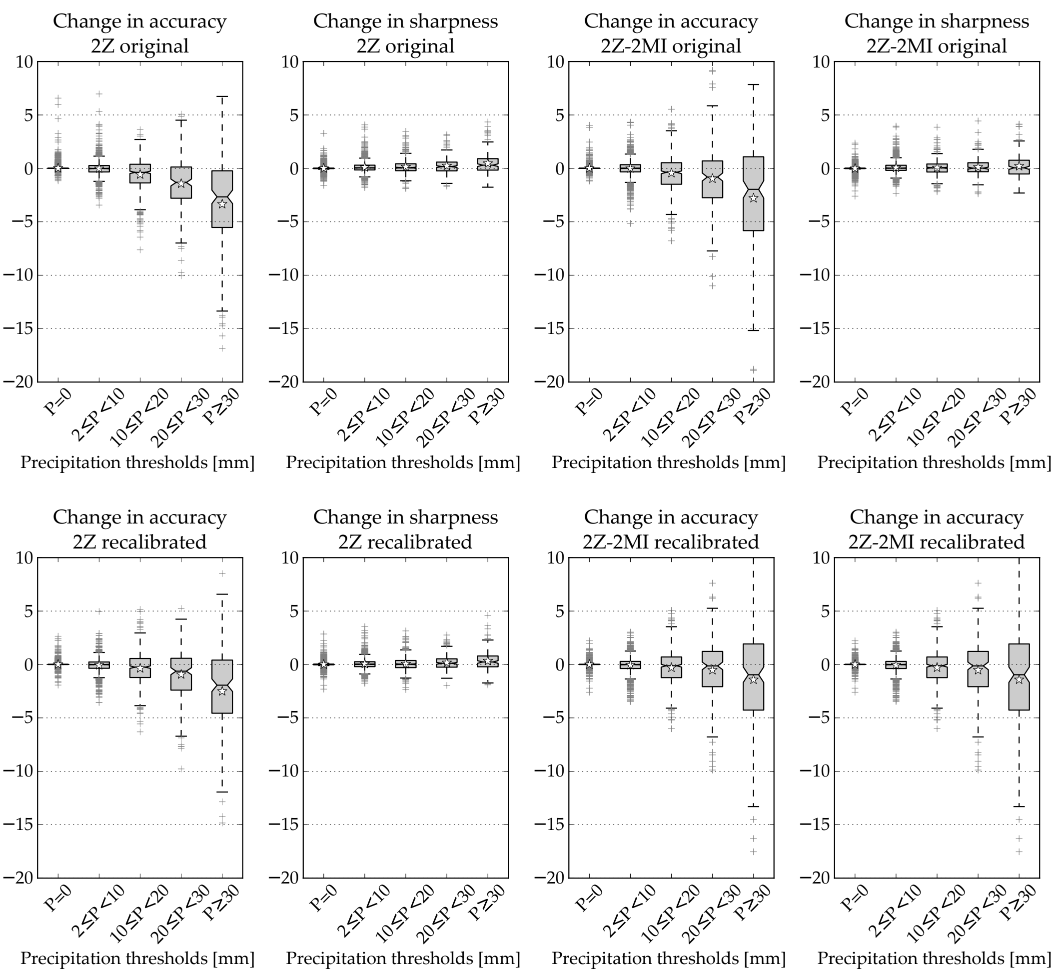

Figure 11. Influence (%) of the MTW on the S_{CRP} components (accuracy and sharpness) relatively to the total S_{CRP}, for the 2Z and 2Z-2MI methods, according to different precipitation thresholds. The results are presented for (top) the original parameters, and (bottom) the recalibrated parameters. Improved prediction results in a lower score.

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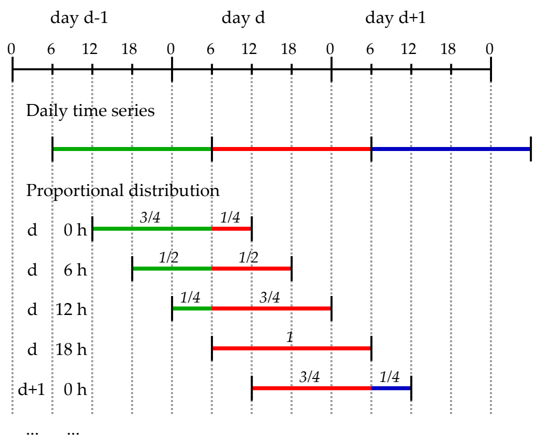

Figure 12. Illustration of the generation of 24 h-totals moving averages by means of a proportional distribution. The colours refer to the corresponding day of the daily time series.

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Table 1. Parameters of the reference method on the atmospheric circulation (2Z). The first column is the level of analogy (0 for preselection), then comes the meteorological variable and its hour of observation (temporal window). The criteria used for the current level of analogy is then provided, as well the number of analogues.

Level	Variable	Hour	Criteria	Nb
0	±60 days around the target date			
1	Z1000	12 h	S_{TW}	N_1
	Z500	24 h		

Table 2. Parameters of the reference method with moisture variables (2Z-2MI). Same conventions as Table 1

Level	Variable	Hour	Criteria	Nb
0	±60 days around the target date			
1	Z1000	12 h	S_{TW}	N_1
	Z500	24 h		
2	TPW * RH850	12 h	E_{RMS}	N_2
	TPW * RH850	24 h		

Table 3. Calibrated parameters (spatial windows and number of analogues) for the analogy on the geopotential at 500 hPa and 1000 hPa (method 2Z) and skill score (%) of the method on the full archive.

Station	Long (° E)	Lat (° N)	N_1	S_{SCRP}
Ulrichen	0 → 17.5	42.5 → 47.5	40	30.73
Zermatt	0 → 20	37.5 → 50	35	23.87
Visp	-2.5 → 20	40 → 47.5	30	25.11
Montana	-2.5 → 17.5	40 → 47.5	40	32.55
Sion	-2.5 → 17.5	40 → 47.5	40	26.23
Aigle	-5 → 17.5	40 → 50	50	30.59

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Table 4. Parameters of the moisture variables from the 2Z-2MI method and the corresponding skill score (%) on the complete archive. The parameters for the atmospheric circulation are the same as in Table 3, except the number of analogues of the first analogy level (N_1), which are here different. The 5^{th} column is the number of analogues for the second level (N_2).

Station	Long (° E)	Lat (° N)	N_1	N_2	S_{SCRP}
Ulrichen	5 → 10	45 → 47.5	60	25	34.31
Zermatt	5 → 10	45 → 47.5	55	25	28.28
Visp	5 → 10	45 → 47.5	45	25	28.85
Montana	5 → 7.5	45 → 47.5	55	30	36.11
Sion	5 → 10	45 → 47.5	90	30	31.16
Aigle	7.5	45 → 47.5	100	35	35.82

Table 5. Influence of the archive reduction on the S_{SCRP}. S_{SCRP} values are provided for both considered methods and the differences are expressed in absolute value.

Station	2Z		2Z-2MI	
	82-07	Δ	82-07	Δ
Ulrichen	29.37	-1.36	33.24	-1.08
Zermatt	22.20	-1.67	26.95	-1.32
Visp	23.23	-1.89	27.77	-1.08
Montana	30.79	-1.76	34.77	-1.34
Sion	24.78	-1.45	29.36	-1.80
Aigle	30.57	-0.01	35.95	0.13

Table 6. New S_{SCRP} performance scores for both 2Z and 2Z-2MI methods obtained by the MTW approach. The differences are expressed regarding the conventional method with the same archive length.

Station	2Z		2Z-2MI	
	MTW	Δ	MTW	Δ
Ulrichen	31.12	1.74	35.44	2.20
Zermatt	24.34	2.14	28.92	1.97
Visp	24.39	1.16	29.42	1.64
Montana	31.59	0.80	36.30	1.53
Sion	25.35	0.57	31.07	1.71
Aigle	31.78	1.21	38.11	2.16

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Table 7. Calibrated parameters (spatial windows and number of analogues) for the analogy on the geopotential at 500 hPa and 1000 hPa (method 2Z) with the MTW approach.

Station	Long (° E)	Lat (° N)	N_1
Ulrichen	0 → 17.5	42.5 → 50	50
Zermatt	0 → 17.5	40 → 50	55
Visp	-2.5 → 20	40 → 50	55
Montana	-2.5 → 15	42.5 → 47.5	55
Sion	-2.5 → 15	37.5 → 50	55
Aigle	-2.5 → 15	40 → 50	75

Table 8. Parameters of the moisture variables from the 2Z-2MI method with the MTW approach. The parameters for the atmospheric circulation are the same as in Table 7, except the number of analogues of the first analogy level (N_1), which are here different. The 5^{th} column is the number of analogues for the second level (N_2).

Station	Long (° E)	Lat (° N)	N_1	N_2
Ulrichen	5 → 10	45 → 47.5	110	35
Zermatt	7.5	45 → 47.5	80	30
Visp	7.5	45 → 47.5	135	35
Montana	5 → 7.5	45	110	40
Sion	5 → 10	45 → 47.5	140	50
Aigle	5 → 7.5	45	135	45

Table 9. Values of the S_{SCRP} (%) skill score for the newly calibrated parameters using the MTW approach. The differences are expressed regarding the conventional method with the same archive length.

Station	2Z		2Z-2MI	
	MTW	Δ	MTW	Δ
Ulrichen	31.58	2.20	35.72	2.48
Zermatt	24.71	2.51	29.63	2.68
Visp	25.08	1.85	30.29	2.52
Montana	32.22	1.43	37.15	2.38
Sion	26.07	1.29	31.68	2.32
Aigle	32.21	1.64	38.50	2.55

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Table 10. Changes in sharpness and accuracy relatively to the total S_{CRP}, due to the introduction of the MTW. The changes are presented for both 2Z and 2Z-2MI methods with the original parameters. A decrease of the score is desirable.

Station	2Z		2Z-2MI	
	Sharpness	Accuracy	Sharpness	Accuracy
Ulrichen	2.82	-5.29	1.00	-4.30
Zermatt	2.26	-5.01	0.88	-3.58
Visp	3.66	-5.18	2.67	-4.94
Montana	1.62	-2.78	0.57	-2.91
Sion	2.02	-2.78	0.33	-2.75
Aigle	0.52	-2.26	-1.20	-2.17

Table 11. Same as Table 10 but with the re-calibrated parameters.

Station	2Z		2Z-2MI	
	Sharpness	Accuracy	Sharpness	Accuracy
Ulrichen	1.44	-4.56	-0.37	-3.34
Zermatt	0.80	-4.03	0.75	-4.42
Visp	1.53	-3.94	1.47	-4.96
Montana	-0.27	-1.80	0.06	-3.71
Sion	0.95	-2.66	-0.10	-3.19
Aigle	-0.35	-2.01	-2.08	-1.90

Table 12. Values of the S_{SCRP} (%) skill score for the original and the recalibrated parameters (with the sequential method, as described in Sect. 1) using the MTW approach on the disaggregated precipitation time series (short period) by means of the proportional distribution.

Station	2Z		2Z-2MI	
	original	recalib.	original	recalib.
Ulrichen	29.13	29.61	33.15	33.45
Zermatt	22.17	22.80	26.72	27.43
Visp	22.32	22.89	27.01	28.04
Montana	29.41	30.24	33.83	34.55
Sion	22.98	23.41	28.57	29.15
Aigle	29.07	29.46	34.66	35.09

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Table 13. Value of the coefficient of determination between the reconstructed 6-hourly precipitation time series using the listed variables, and the accurate time series on the period 1982-2007. The grid points are the following: 1) 5° E, 47.5° N, 2) 5° E, 45° N, 3) 7.5° E, 47.5° N, 4) 7.5° E, 45° N. The highest coefficient of determination is indicated in bold.

Variable	Point	Time lapse				
		-12 h	-6 h	0 h	+6 h	+12 h
RH1000	1	0.668	0.669	0.684	0.683	0.670
	2	0.669	0.669	0.683	0.681	0.669
	3	0.662	0.673	0.691	0.682	0.673
	4	0.666	0.671	0.688	0.681	0.668
RH925	1	0.672	0.673	0.684	0.684	0.675
	2	0.674	0.674	0.683	0.682	0.672
	3	0.662	0.673	0.691	0.682	0.673
	4	0.666	0.671	0.689	0.681	0.668
RH850	1	0.675	0.675	0.679	0.678	0.671
	2	0.681	0.690	0.691	0.677	0.664
	3	0.665	0.680	0.693	0.683	0.675
	4	0.675	0.694	0.706	0.681	0.659
TCW	1	0.688	0.687	0.667	0.655	0.652
	2	0.697	0.699	0.669	0.644	0.644
	3	0.686	0.708	0.689	0.655	0.648
	4	0.696	**0.721**	0.696	0.643	0.636

Table 14. Values of the S_{SCRP} (%) skill score for Zermatt, for the original and the recalibrated parameters (with the sequential method, as described in Sect. 1) using the MTW approach on the disaggregated precipitation time series (short and long periods) by means of variables from the reanalysis.

Period	2Z		2Z-2MI	
	original	recalib.	original	recalib.
1982–2007	22.57	23.14	27.11	27.71
1961–2008	23.81	24.38	28.42	28.86