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Hydrology and Earth System Sciences
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Discussions



# *Interactive comment on* "Building long-term and high spatio-temporal resolution precipitation and air temperature reanalyses by mixing local observations and global atmospheric reanalyses: the ANATEM method" *by* A. Kuentz et al.

**A. Kuentz et al.**

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The authors are grateful to Referee #3 for his positive evaluation, his interesting comments and detailed corrections. The answers to the general and specific comments, as well as for a selection of technical comments are detailed below.

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**General comments**

**I am writing with some advantage, as two earlier reviews have already been made. Disagreeing with them on one point, I did not find the manuscript particularly well written. Some effort should be placed in order to make it so. Future contributions would benefit enormously from the review of a native speaker.**

The revised version of the manuscript will be reviewed by a native speaker.

**The presented results are encouraging. Nonetheless, in many examples there is relatively little improvement from the application of a simple linear regression and ANATEM. I believe the biggest advantage of applying ANATEM is not the improved accuracy of mean estimates, but rather the representation of uncertainty it produces. This is not sufficiently emphasized in the text.**

We agree with reviewer #3 that there might be a limited improvement of ANATEM, compared to linear regression. However, in our opinion, the other improvement is to give a better spatial robustness of the results. We also agree that another interest of ANATEM is to produce a representation of uncertainties, which is rather difficult concerning precipitation with a linear model (Wu et al., 2011). Another improvement of the modelling of precipitation uncertainty is that it is conditioned by atmospheric circulation patterns.

The following paragraph (p. 323 l.13-15) :
*"The originality and the strength of the ANATEM method introduced here is to combine the two previous models and to consequently take advantage of both local and large*



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*scale information."*

has been modified as :
*"The originality and strength of the ANATEM model introduced here lies in an approach that combines the two previous models. In this way, it can take advantage of both local and large scale information and produce an original representation of uncertainties, conditioned by atmospheric circulation patterns."*

This sentence has also been added to the conclusion (after p338 l.2):
*"Besides these results in terms of performances, the ANATEM model provides an original representation of uncertainties, which are conditioned by atmospheric circulation patterns through the use of an ensemble of analogue days."*

**The introduction is interesting and provides a nice overview of the scientific relevance of the work and the challenges associated with it. I would have benefited, however, from a deeper overview of mathematical models and approaches employed to similar ends. ANATEM is solely compared with linear regression (a very simple model) and the analog method (developed in 1969). Ideally, it should be compared with more recent and potentially more performing alternatives (one that instantly comes to mind is non-linear regression). Understanding that this could require a large amount of work, I believe the authors should introduce at least a list of "competing" models.**

We agree with reviewer #3 and ANATEM has only been compared to rather simple and classical models (analog method and linear regression).

This paragraph has been added in the introduction (after p.315 l.27):
*"A classical reconstruction is obtained using external data (proxy data) from long-term series of observations available from one or several neighbouring stations. The most*



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*popular reconstruction approach is based on linear (multiple-)regression models but a variety of other approaches have been proposed, including non-linear multiple regression (e.g. neural networks), kriging methods and copula based methods (Coulibaly and Evora, 2007; Teegavarapu, 2012; Bárdossy and Pegram, 2014)."*

**Although straightforward in hindsight, I found the goals of the work hard to precise at the first stages of the reading. I recommend that a graphical scheme is added to the manuscript in order to facilitate its reading. Also, I believe a simple scheme covering what periods and stations are used in order to calibrate the models, as well as what periods and stations are used in their evaluation would be worthwhile.**

As suggested, a graphical scheme (Fig. 1) representing the three methods compared in the study has been added.

The complete caption of this figure is the following:
*Schemes of the 3 reconstruction models : local model (LM – top scheme), analogue model (ANA – middle scheme), combined local+analogue model (ANATEM – bottom scheme). Predictors are either (1) local scale meteorological predictors (LM model), (2) mesoscale atmospheric predictors (ANA model) or both (1)+(2) (ANATEM model). Local scale predictors are daily observations of the variable at one (possibly several) neighbouring precipitation or temperature station (for the present work, Gap rain gauge, Marseille temperature station for precipitation / temperature reconstruction respectively). Mesoscale predictors are fields of atmospheric variables (700 and 1000hPa geopotential heights over a mesoscale European domain). Local and mesoscale predictors cover the whole period (observation + reconstruction). The three reconstruction models are first developed and evaluated based on their reconstruction skill for the observation period where concomitant observations of the target variable are available*



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*(dots of series 3 in the scheme, period 1948-2010 in the present work). Models are next applied for the reconstruction of each day of the reconstruction period (period 1883-2010 in the present work). Note : The reconstruction period can also include the observation period (this is the case in the present work).*

**Finally, from the introduction and conclusion sections, one is inclined to think the manuscript is focused on the analysis of "long-term" climate records. From the remaining sections it appears the focus is on the proposal and evaluation of the novel ANATEM model that aims at reconstructing (not analyzing) long-term series. I consider the introduction of ANATEM a worthy objective and find the introduction and conclusion sections a bit misleading. Perhaps they could be adapted in order to increase the value of the paper.**

Some changes have been made in the introduction, we hope that the focus of the paper is now easier to understand from it.

**Specific comments**

**As mentioned before, the manuscript could probably benefit from a number of writing corrections. One prevalent issue is the use of the word "we", which I believe should be avoided. In the technical corrections, below, the authors will find some suggestions.**

As suggested, the revised version of the manuscript has been reviewed by a native speaker.



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**There is a fair amount of text which, in essence, is explaining how a simple linear regression works and how it is applied to the problem at hand. This occurs in §3.1 and, again, in §3.3.1. I hope readers will be mostly familiar with such concepts. If the sections could be made shorter, particularly, 3.3.1, it would add to the clarity and flow of the text. (and technical comment "4.13 Page 324 l. 10-25. + page 325 l.1-5 : Review this section. This is too long in order to explain something as well established as a simple linear regression. The equations are also a bit redundant in my opinion.")**

We have reduced both paragraphs 3.1 and 3.3.1.

The paragraph 3.1 (p319 l.9-26) has been replaced with :
*"A classical method used for climatic reconstructions is based on regression-like models, where predictors should be well correlated with the data to be reconstructed. This model is calibrated against observations during the observation period. In the following, the principle of the local model (LM) is to reconstruct the target series (referred to as Tg) from a local neighbour series (referred to as Ne) using a classical linear regression model."*

The paragraph 3.3.1 (p324 l.2 to p325 l.8) has been replaced with :

*"The probabilistic air temperature prediction from the ANATEM model for day* $d$ *has the following expression:* $\left[\widehat{T}^k_{ANATEM}(d)\right]_{k=1...n} = \widehat{T}_{LM}(d) + \left[T(d_k) - \widehat{T}_{LM}(d_k)\right]_{k=1...n}$ *where* $\left[\widehat{T}^k_{ANATEM}(d)\right]_{k=1...n}$ *is the ensemble of reconstructed values for the target day* $d$ *(*$ANATEM$ *stands for "Combined Model" and refers to the ANATEM model),* $\widehat{T}_{LM}(d)$ *the air temperature estimate obtained with* $LM$ *for target day* $d$*,* $d_k$ *the* $k^{th}$ *analogue day selected for target day* $d$*,* $T(d_k)$ *the observed air temperature for this* $k^{th}$ *analogue day*



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*and $\widehat{T}_{LM}(d_k)$ the air temperature estimate obtained with the local model ($LM$) for the same day $d_k$.*

*In this expression, $\left[T(d_k) - \widehat{T}_{LM}(d_k)\right]$ is the error obtained with the LM model when it is applied to estimate the temperature of the $k^{th}$ analogue day $d_k$.*

*The statistical dressing of the LM prediction for the target day $d$ can be simply represented on a graph in a ($T_{LM}$,$T$) space, as shown in Fig. 3 (right). In this figure, the green point is the value obtained for the target day with the LM model. The different blue crosses in the y direction around this estimate define the distribution of the $n$ errors obtained with the LM model respectively applied to the $n$ analogue days. Each cross is simply the intercept of two lines: the vertical line at the $\widehat{T}_{LM}(d)$ value on the x axis and the 1:1 line passing through the point ($\widehat{T}_{LM}(d_k)$, $T(d_k)$). This is illustrated for a given analogue day in Fig. 3 (left)."*

**The methods are applied using only one neighbouring station. Why not to use more? If more were available a range of interpolation techniques would become available (e.g. Kriging with covariates: KED, co-Kriging, universal Kriging).**

We agree with reviewer #3 that more sophisticated interpolation techniques could be interesting when multiple stations were available. In this case study on the Durance watershed, only one station for precipitation and one station for temperature have been found with data available on the whole reconstruction period (1883-2010). This is the reason why the model has been developed with only one neighbouring station. As mentioned in the conclusion (p339 l.2-4), it would be worth to use more if more were available. This was however not the case for our study. The following sentences of the conclusion were probably misleading with this respect.



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Extract from the discussion version (p339 l.1-4):
*"A thorough sensitivity analysis to the selection of the reference time-series should be carried out. Considering the importance of local information, an extension of the method should also consider the possibility to make use of all historical stations available in the close or farer neighbourhood of the region under construction."*

We thus modified it. It now reads:
*"A thorough analysis of the sensitivity to the choice of the reference time series should be carried out. Considering the importance of local information, an extension of the method should also consider the possibility of making use of other historical stations, if available, in the neighbourhood of the region of reconstruction. Cases with multiple historical stations available would open the door to other alternative reconstruction approaches (as stated in the introduction)."*

**Notation could be revised. Estimates are denoted with a circumflex accent in some parts of the manuscript, yet not throughout. They should be. An example is §3.3.1, line 11 "$\ldots T_{LM,d}$ is the air temperature estimate ..."**

According to this suggestion and to the editor comment, mathematical notations of the whole paper have been revised in the final version.

**Figures 12 and 13 are too small and hard to read. Also, there is some spelling in French (besides the location names, evidently).**

These figures have been modified in the revised version, the two figures have been split into three figures (see new figures attached to this comment).



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**In the analysis sections, the authors refer the stations by their name, but this can become confusing. To some extent they could make use of the numbers put forward in Figure 1.**

That is true, the numbers used in Fig. 1 and Tab. 1 have been added in the text when a reference is made to a station name.

**Personally, I find the claims based on the correlation metric are taken too far. For instants, why does a high correlation show that a model captures well both short and long-term variability?**

The correlation coefficients have been computed comparing the observed and reconstructed time-series at different aggregation time-steps. The correlation estimated on the daily (resp. annual) series gives information on the capacity of the model to reproduce the high-frequency (resp. low-frequency) variability.

For more clarity, the terms “short-term variability” and “long-term variability” have been replaced by “high-frequency variability” and “low-frequency variability” respectively (e.g. p. 332 l.6).

**More importantly, I have doubts regarding the interpretation of figures 12 and 13. Low differences in terms of correlation should hint that the models are very similar. For instants, a low correlation difference between ANATEM and LM, should mean that most of the information contained in ANATEM comes from LM. I am**



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**not sure the analyses of the figure's results – particularly regarding spatial patterns – go in that sense.**

The reviewer is right. This is the first result to highlight. We wanted also nevertheless to highlight the noticeable spatial pattern of these contributions, which are highly dependent on the distance to the reference station. We have modified the text accordingly :

Extract from the discussion version (p. 334 l.11-16) :
*"The contribution of LM model (Fig. 12d) to the performance of ANATEM, decreases from south-west to north-east, ranging from 0.06 to 0.04. Conversely, the contribution of ANA model (Fig. 12e) to the performance of ANATEM, slightly increases from south-west to north-east, ranging from 0.0 to 0.02. The contribution of large scale information 15 (through ANA model) is stronger when LM model (local information) is less efficient, that is, when the location at reconstruction is far from the reference temperature station."*

Modified paragraph :
*"The contribution of the LM (resp. ANA) model to the performance of the ANATEM model is presented in Fig. 11d (resp. 11e). It is estimated by the difference between the performance of the ANATEM and ANA (resp. LM) models. The contribution of the LM model is much higher than that of ANA, whatever the location, meaning that most of the information provided by ANATEM comes from LM. Note however that for both the LM and ANA models, the contribution of the model presents a clear south-west to north-east gradient, which decreases for LM (from 0.06 to 0.04) and increases for ANA (from 0.0 to 0.02). The contribution of large-scale information (through the ANA model) is stronger when the LM model (local information) is less effective, that is, when the location to be reconstructed is far from the reference temperature station."*

A similar clarification has been added in the paragraph 4.4.2 about precipitation reconstructions.



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Extract from the discussion version (p.335 l.1-5) :
*"ANATEM increases the global reconstruction performance but it also notably smooths local contrasts. The contribution of LM to the performance of ANATEM decreases as the distance to Gap increases, ranging from 0.22 to 0.02 (Fig. 13d). Conversely, the contribution of ANA to the performance of ANATEM slightly increases from south-west to 5 north-east, ranging from 0.0 to 0.07 (Fig. 13e)."*

Modified paragraph:
*"ANATEM slightly increases the overall reconstruction performance but at the same time notably smoothes local contrasts. The contribution of LM to the performance of ANATEM is generally higher than that of ANA, but decreases as the distance from Gap increases, ranging from 0.22 to 0.02 (Fig. 12d). On the other hand, the contribution of ANA to the performance of ANATEM is close to 0 for the stations closest to Gap and slightly increases (up to 0.07) with the distance from Gap (Fig. 12e)."*

**Also, the references to plots d) and e) might be switched.**

The references are not switched but we agree that the legend was perhaps confusing. It has been changed to:
*"Spatial patterns of (d) the contribution of the LM model to ANATEM performance (estimated by the difference between the performance of the ANATEM and ANA models) and of (e) the contribution of the ANA model to ANATEM performance (estimated by the difference between the performance of the ANATEM and LM models)"*



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**The conclusion ends with the mention of an application of the ANATEM results to the reconstruction of hydrological long-term series. I can imagine why the authors – having conducted the work – felt inclined to add this to the manuscript. I also believe that, however interesting the topic is, it requires a number of additional considerations which have not, nor should be, addressed in the present contribution. The paper is already valuable due to the introduction of ANATEM – particularly its uncertainty estimation feature. I see no need to close it with a 15-line long reference to another work.**

We have drastically reduced this 15-lines reference to this natural extension of the work (see new version in the technical comments). We expect actually to publish it in a fully dedicated publication.

**Technical corrections**

Most of the technical corrections suggested by referee #3 have been made in the revised version. We answer below to a selection of them that doesn't imply only phrasing or spelling but could also impact understanding.

**4.11 Page 322. 24. Please clarify what a moving seasonal filter is. What was the window size, etc.**

The clarification is given in the following sentence. The point has been replaced by a



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column to evidence the link between the two sentences. We also replaced “a moving seasonal filter” by “a moving calendar filter”.

**4.12 Page 323. 16-25. An overall confusing paragraph. Should be rephrased with an emphasis on clarity.**

Paragraph from the discussion version:
*“The principle of ANATEM is the following: the local variable reconstructed for the target day $d$ is the local variable estimate obtained by the local model, corrected by the errors of the Local Model identified when it is applied for the prediction of the local variable on the $n$ analogs days. In other words, for any target day, the Analog Model ANA allows the identification of $n$ analog days in terms of atmospheric circulation (see Sect. 3.2). The $n$ prediction errors respectively obtained when the Local Model LM is used for predicting the local observed value for each of these n days are used to define the error distribution associated to the prediction obtained with the Local Model for the target day $d$. The prediction obtained with ANATEM for the target day is therefore probabilistic.”*

New modified paragraph:
*“The principle of ANATEM is the following: for any target day, the analogue model allows the identification of $n$ analogue days in terms of atmospheric circulation (see Section 3.2). The local model is then used to obtain an estimate of the variable to be reconstructed (precipitation or air temperature at the target site) for each of the selected analogue days. These $n$ estimates are respectively compared with the corresponding observed values for these $n$ days, allowing the calculation of $n$ predictions errors. These $n$ error values are finally used to define the error distribution associated with the prediction obtained with the local model for the target day $d$. The prediction obtained with ANATEM for the target day is therefore probabilistic.”*



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**4.20 Page 331. 1-12. Please rephrase the section.**

Paragraph from the discussion version:
*"For the sake of conciseness, we consider here for the evaluation only one reference time-series for each model. For the Local Model, this is simply the reconstruction obtained with the model. For the probabilistic reconstruction models ANA and ANATEM, this is the mean time-series derived from the ensemble of 50 time-series reconstructions (the daily value for a given day is the mean of the probabilistic reconstruction for this day). As it will be noticed later, these mean time series obviously present a much lower variability than each time series of the reconstruction ensemble. For the sake of simplicity, these mean time series will be also referred to as reconstructed time series. In the following, the performance of a given model will be presented with the distributions of r, $\alpha$, $\beta$ and KGE criteria obtained for the 22 watersheds at the daily, monthly and annual time-steps."*

New modified paragraph:
*"For the sake of readability, only one time series is considered for each model. ANA and ANATEM probabilistic reconstructions are represented by the mean time series derived from the ensemble (the daily reconstructed value for a given day is the mean of the 50 probabilistic reconstructions for this day). For the sake of simplicity, these mean time series will be referred to as the reconstructed time series in the following. As will be illustrated later, note that these ensemble mean time series logically present a much lower temporal variability than each individual component of the reconstruction ensemble. In the following, the performance of a given model will be presented with the distributions of r, $\alpha$, $\beta$ and KGE criteria obtained for the 22 watersheds at the daily, monthly and annual time steps."*



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**4.23 Page 334. 24-25 Rephrase.**

Paragraph from the discussion version:
*"However, the similarity in terms of large scale forcing influences probably influences the performance. Hence, two watersheds at the same distance to the Gap station have rather different performances (i.e. Buech watershed have a very good correlation of 0.88 and the Durance at Briançon a moderate correlation of 0.77)."*

New proposed paragraph:
*"However, the distance from the local reference station is probably not the only factor influencing performance, as two watersheds at the same distance from the Gap station displayed somewhat different performance (i.e. the reconstructions for the Buech watershed – #10 in Fig. 1 – have a very good correlation of 0.88 and the reconstructions for the Durance at Briançon watershed – #3 in Fig. 1 – a moderate correlation of 0.77). This could be due to large-scale climatic influences that give some watersheds a higher proximity to Gap in terms of the precipitation pattern."*

**4.24 Page 335. 18-20. What does the sentence inform the reader about really? The variability is even larger from year to year... By the other hand, the periods referred to are not related to long-term trends...**

Sentence in the discussion version:
*"This series (red curve in Fig. 14) highlights a relatively strong variability: mean air temperature can vary of nearly 1 °C in less than 10 years (e.g.: 1890–1900, 1940–1950)."*

This sentence has been removed.



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**4.25 Page 336. 18-20. Please clarify what is meant, give values, and check phrasing.**

Paragraph in the discussion version:
*"ANATEM series present a very homogeneous temporal behaviour when compared to the high dispersion observed between the five HISTALP series. This may be partly explained by the fact that ANATEM series are reconstructed for all watersheds based on a same reference series (Gap). The main reason is however probably the high spatial variability of precipitation and the fact that HISTALP series cover a much wider spatial domain than ANATEM series. The low dispersion between the reconstructed series is otherwise coherent with the limited dispersion obtained between time-series observed for the same 22 watersheds on the observation period (not shown here)."*

New modified paragraph:
*"The dispersion between the 22 ANATEM reconstructed time series is relatively low. It is actually similar to the dispersion obtained between the time series of observations available for the same 22 watersheds over the 1960-2010 period (not shown here). The dispersion observed between the five HISTALP series is comparatively much higher. This may be partly explained by the fact that the ANATEM series are reconstructed for all watersheds based on a same reference series (Gap). The main reason is however probably that the HISTALP series cover a much wider spatial domain with a high spatial variability of atmospheric influences and thus precipitation regimes and times series."*

**4.28 Page 339. 7-10. Could be improved. Please rephrase.**

Paragraph in the discussion version:



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*"The region we have considered covers a rather narrow domain. However, we can expect that the interest of the reference station is much lower if we would do reconstructions for much more distant locations. We can expect conversely that the relative interest of the large scale information would be much larger for distant sites."*

New proposed paragraph:
*"The region considered in the present study is relatively small. The importance of the reference station would be expected to decrease for reconstructions concerning larger regions. At the same time, in such cases, the contribution of the large-scale information would be expected to be higher."*

**20-end. Too long and, in my opinion, off topic and not needed to value the paper.**

Paragraph in the discussion version:
*"A major application of such reconstructions will be obviously the possibility to reconstruct long term variations for a number of climate driven variables. As an illustration, the long-term climatic time-series produced in the present work have been used for reconstructing long-term hydrological time-series at multiple hydrometric stations of the Durance basin (Kuentz, 2013; Mathevet et al., 2013).*
*(line 20) An outstanding result of this reconstruction is that the time series obtained for the whole 20th century present a very high correlation level with historical discharges time series obtained from rescued hydrometric archives for the catchment. In our case, the availability of historical streamflow time series allowed us to demonstrate the overall quality of the meteorological reconstruction. This independent hydrological validation is not expected to be feasible everywhere but it gives high confidence in this hydrometeorological reconstruction approach. Even when such an independent validation cannot be carried out, the reconstructed time series definitively produce a high-value information for researchers or water resources managers. Further works for other hydrocli-*



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*matic contexts are therefore also worth to better identify the potential of the method and the possibility for improving it."*

The end from (line 20) has been replaced by:
*"Thanks to the availability of long observed discharge series, this study provided an independent hydrological validation of the climatic reconstructions over the entire 20th century."*

## References


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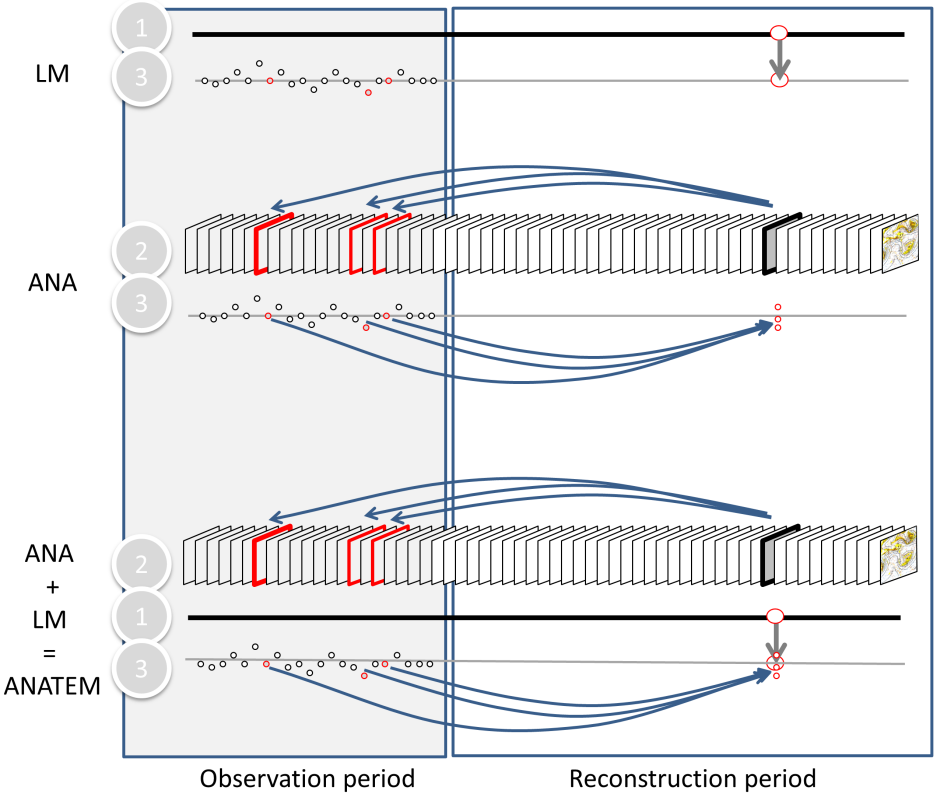


**Fig. 1.** New figure 1 : Schemes of the 3 reconstruction models : local model (LM – top), analogue model (ANA – middle), combined local+analogue model (ANATEM – bottom). More detailed caption in the paper.



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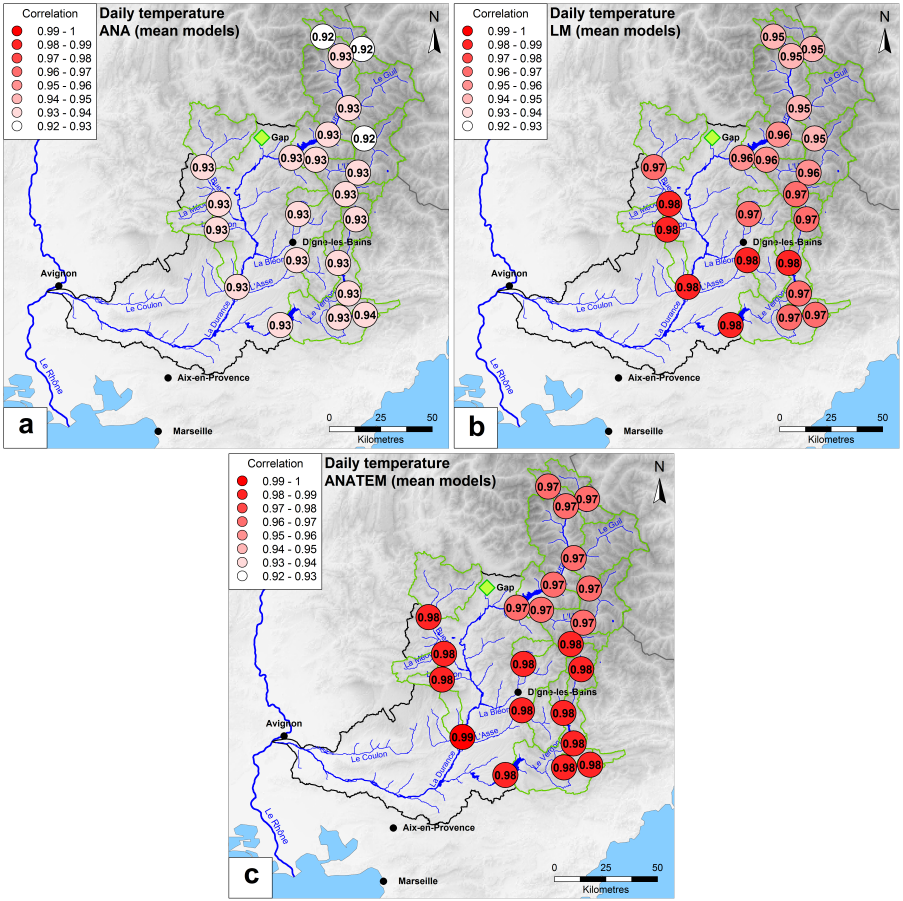


**Fig. 2.** New figure 12 : Regional correlation patterns of air temperature mean reconstructions by the (a) analogue model (ANA), (b) local model (LM) and (c) ANATEM model.



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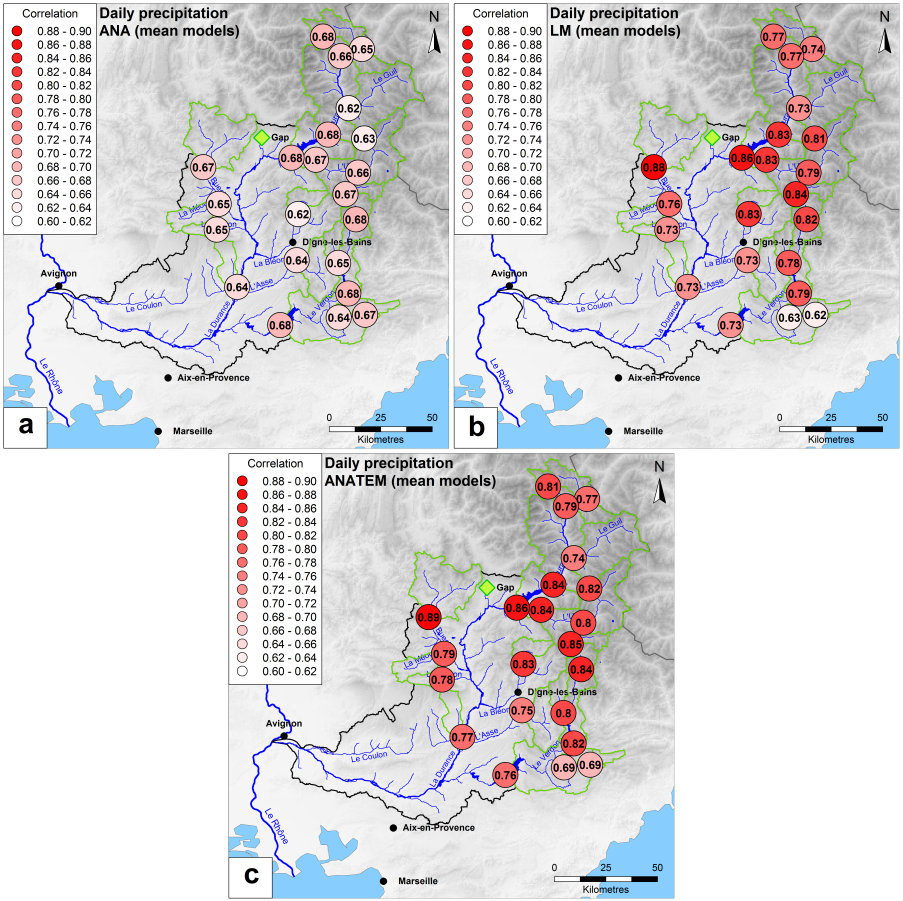


**Fig. 3.** New figure 13 : Regional correlation patterns of precipitation mean reconstructions by the (a) analogue model (ANA), (b) local model (LM) and (c) ANATEM model.



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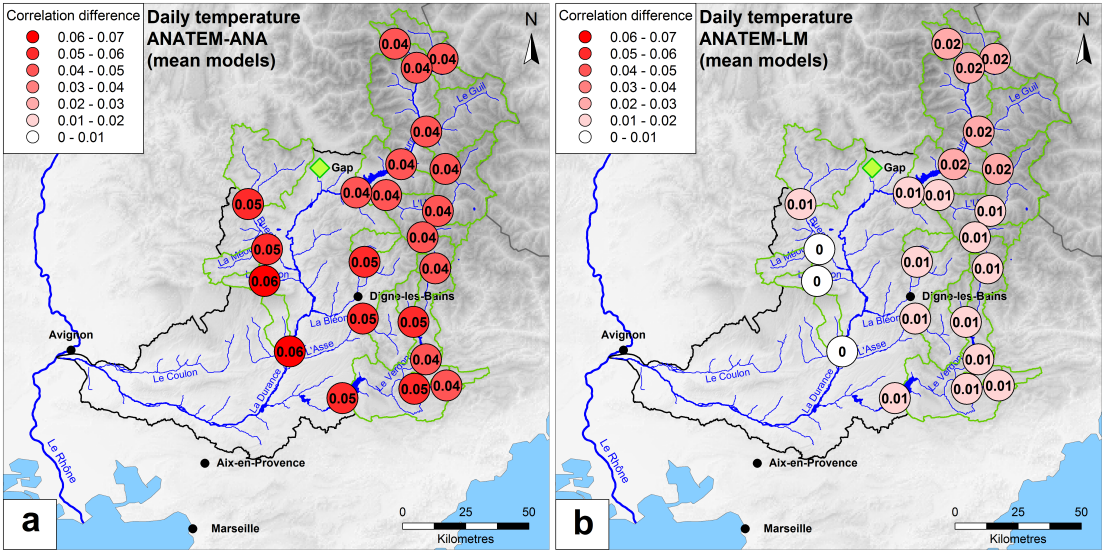


**Fig. 4.** New figure 14 (top) : Spatial patterns of (a) the contribution of the LM model to ANATEM and (b) the contribution of the ANA model to ANATEM (air temperatures)



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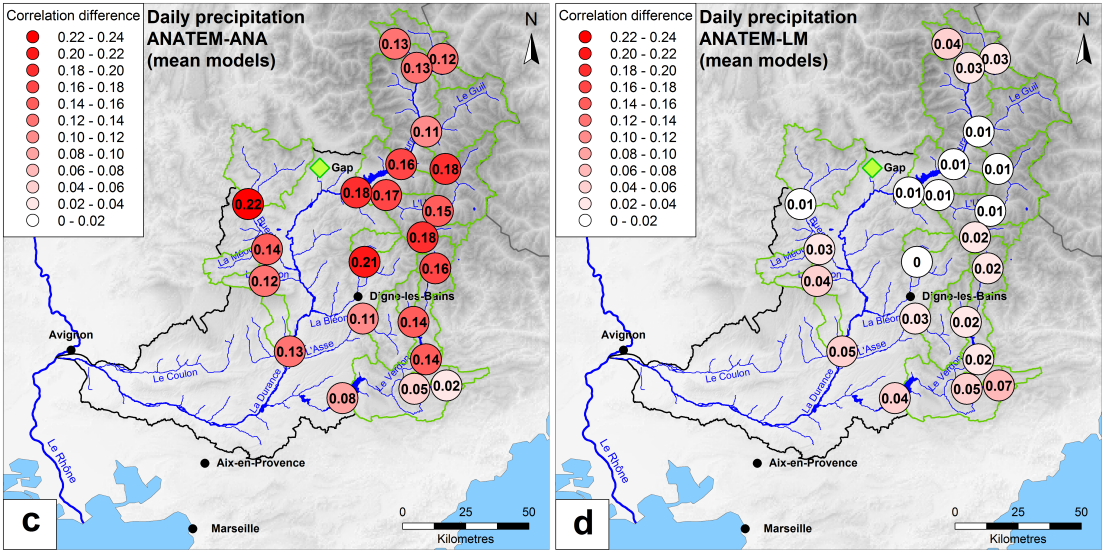


**Fig. 5.** New figure 14 (bottom) : Spatial patterns of (c) the contribution of the LM model to ANATEM and (d) the contribution of the ANA model to ANATEM (precipitations)



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