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Role of the RegCM4 Regional Climate Model in Investigating the Influence of the Initialized Soil Moisture on the Soil Temperature Profile of Egypt

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Abstract. In this study, the sensitivity of the soil temperature (ST) profile of Egypt to different initial soil moisture conditions was investigated using the RegCM4 regional climate model. The RegCM4 was downscaled with the ERA-Interim reanalysis and 25 km grid spacing and it was configured with version 4.5 of the community land model (CLM45). The initial conditions of the soil moisture were defined as ESACCI satellite product (ESA) and Century reanalysis product (CEN). Also, the ST profile was defined as shallow (10 cm), medium (40 cm), and deep (100 cm) depth. Additionally, the added value of the linear scaling (LS) was examined considering the depth 100 cm as an example. The results showed that the ST was sensitive to the initial soil moisture condition. The CEN demonstrated lower ST bias than the one observed in the ESA, particularly for the depth of 100 cm (by 0.5 to 5°C), followed by the 40 cm depth (by 0.5 to 3.5°C), and finally the 10 cm depth (by 0.5 to 1.5°C). Additionally, the LS showed its potential skills in reducing the ST bias in the evaluation/validation periods. Such point was confirmed in simulating the ST climatological annual cycle in different locations (representing different climate zones of Egypt). Quantitatively, the mean bias and standard deviation ratio of the CEN are lower than those of the ESA total locations. In conclusion, our study emphasizes the importance of initializing the RegCM4 with the CEN and applying the LS method for correcting its output to ensure a reliable simulation of the ST profile of Egypt.

Keywords. Egypt, linear scaling, RegCM4, soil moisture, soil temperature

1. Introduction

The earth's life is regulated by many aspects such as soil. Additionally, the heating degree is regulated by the difference between the ground temperature and the 2m air temperature during the day light. From a physiological point of view, the soil controls the plant growth [1]. Soil temperature (ST) is a key variable regulating different hydrological and biogeochemical processes in the terrestrial ecosystems particularly in arid regions [2, 3 and 4]. The authors of [5] highlighted the important role of enhancing

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the potential skills of the regional/global models by merging of the climatological soil temperature as an initial condition. The authors of [6, 7] highlighted the importance of the ST in controlling the microbial activity in the soil ecosystem. Besides, the ST plays a vital role in regulating the energy applications with a particular of interest in the Middle East arid regions such as the Gulf region [2]. Therefore, availability of ST station data is very important to monitor such vital applications. However, availability of long-term records of ST data can be a limiting factor because of the technical difficulties, and maintenance costs [8, 9]. Therefore, there was an urgent need to search for other tools to monitor ST changes.

In efforts to overcome the ST inavailability, neural network models (ANNs) were proposed as an alternative solution as reported by [10]. In the past years, the numerical models became very useful tools to estimate the ST in places where station observations are not available. In the United States of America, the authors of [11] used the fifth generation of the regional CMM climate model. Various kinds of observation were used to provide a full assessment of the CMM model. They found that the CMM has potential skills in reproducing the ST for a hierarchy of time scales. Along with the regional models, the offline land surface models (LSMs) became important tools in simulating the soil temperature of a complicated climate regime [12].

When long-term station data is unavailable, regional climate models can be quite helpful in monitoring ST dynamics in dry locations like Kuwait. As an example, the authors of [2] estimated the ST by means of the RegCM4 regional climate model [13], linear scaling (LS) bias-correction approach and station data. They highlighted the added value of the LS to minimize the ST bias. In Egypt, various attempts were done to constrain the performance of the RegCM4. The authors of [14] showed how the RegCM4 can be sensitive to the choice of the soil temperature status. They found that initialing the RegCM4 (with a spin-up) can ensure a reliable estimation of the ST. Recently, the role of the soil moisture has been investigated. For instance, the authors of [15] observed that inclusion of the satellite (reanalysis) of the soil moisture (temperature) reduces the ST bias. However, a comparison between two kinds of soil moisture (satellite and reanalysis) has not been investigated till today. To accomplish this task, the following points were addressed:

(1) Compare between the ESACCI satellite soil moisture (ESA; [16, 17]) and Century reanalysis (CEN; [18]) with respect to the Century product at three depths (shallow depth of 10 cm, medium depth of 40 cm and deep depth of 100 cm). It should be noted that those depths were selected to match those of the Century reanalysis product [18].

(2) Examine whether the LS can reduce the ST bias in the evaluation/validation periods.

(3) On a point scale, the validity of the LS needs to be further explored concerning the ST climatological annual cycle.

2. Materials and Methods

2.1. Study Area

Our study area is Egypt. Egypt is located in an important place. That is, the Mediterranean Sea surrounds Egypt from the north, and the Red Sea surrounds Egypt from north of Sudan. Besides, Egypt is located between Libya and Gaza, In addition, From a climatic point of view, it is characterized by a mild winter season and a hot dry summer season. Additionally, it receives a precipitation rate on average between 20 and 200 mm year^{-1} ([19, 20]). In the Mediterranean Sea, the dominant wind direction is the northwest. The authors of [21] reported that cooling degree of the nighttime temperature is majorly affected by the topography nature of Saint Catherine Mountain. Additional details (concerning the climatic and geographic nature of Egypt) can be found in [22–24].

2.2. RegCM4 Model Description and Experiment Design

In this study, we used the RegCM regional climate model. Initially, it has been developed at the National Center for Atmospheric Research (NCAR), after that its development has continued in the International Center of Theoretical Physics (ICTP) [25, 26]. That is, the RegCM has undergone a substantial transition from its second version (RegCM2; [27]) to its fourth version (RegCM4 [13]). To further enhance its capability, a new efficient non-hydrostatic core has been implemented in the RegCM model (RegCM5; [28]). The authors of [28] highlighted that RegCM5 has not been fully tested. Instead, version 4.7 of the RegCM (for short; RegCM4) was used. Regarding its performance, the RegCM4 has shown its potential skills in reproducing the regional climate aspects in South America [29], Southeast Asia [30, 31], and Tibetan Plateau [32] and India [33].

Various physical parameterizations have been implemented in the RegCM4 such as the Community Climate Model version 3 CCM3 [34], Rapid Radiation Transfer Model—RRTM [35]), HOLTSLAG (HOLT [36]) and University of Washington (UW [37]), Emanuel (MIT [38]) and land surface (such as Biosphere Atmosphere Transfer Scheme (BATS [39] and community land model version 4.5 (CLM45 [40]). As previously utilized in [21], the radiation scheme of [35], boundary layer scheme of [37], cumulus scheme of [38] and the land surface scheme of [40] were employed in the present study. One of its advantages (with respect to its previous versions) is its ability to reduce the excessive tropical gross primary production (GPP [41]). Following the work of [14, 15], the CLM45 code passed through a series of modifications such as inclusion of an interface facilitating reading the CEN product [42] and a new soil depth.

To achieve the goal of the present study, the RegCM4 was configured following the recommendations of [42]. To this end, the RegCM4 was driven by the ERA-Interim reanalysis of 1.5 degrees (EIN15 [43]). Two simulations were made in the period of 01 January 1979 till 31 December 2015. Following the recommendation of [44], the first two years were omitted from the analysis. Such period was chosen for several reasons such as availability of the EIN (from 1979 to 2018) and the Century reanalysis product (from 1836 to 2015). The two simulations were designated as ESA (as the control simulation [21]) and CEN (as the experiment simulation) to examine how the RegCM4 can be sensitive to the initial condition of the soil moisture. Figure 1 shows the domain topography as well as eight locations. First, a comparison was conducted (between the two simulations) concerning the Century product (OBS). The second step was employing a bias-correction method to possibly reduce the simulated ST bias. The bias correction methods can be categorized as linear scaling (LS), power transformation (PT), local intensity scaling, distribution mapping (DM), variance scaling, quantile mapping (QM), and delta change [46].

In our work, we used the LS because it gives a reliable performance (concerning the available observational dataset [47-49]). Following the work of [21], the time simulation length was divided to two segments. The time segment 1981 – 1996 was considered as the evaluation period, while the time segment 1997 – 2015 was designated as the validation period. As reported by [21], the climatological bias factor was calculated in the evaluation period. The LS added value was tested; by adding this bias factor to the RegCM4's output in the validation period. Concerning the climatological annual cycle, the RegCM performance was quantitatively evaluated using three statistical metric: Pearson correlation coefficient (CORR), standard deviation ratio (STD), and mean bias (MB). The MB, CORR and STD were calculated as follows:

$$MB = \frac{1}{N}\sum_{1}^{N}(S_i - R_i) \quad (1)$$

$$CORR = \frac{N\,(\sum S_i R_i) - (\sum S_i)(\sum R_i)}{\sqrt{[N\sum S_i{}^2 - (\sum S_i)^2][N\sum R_i{}^2 - (\sum R_i)^2]}} \quad (2)$$

$$STD = \frac{SD_{S_i}}{SD_{R_i}}, \quad (3)$$

where N refers to the number of records of the RegCM4 and the observational dataset (OBS). S_i and R_i stand for the RegCM4 and OBS for each climatological month i, respectively. SD is the standard deviation ratio.

2.3. Observational Dataset

In this work, we used the NOAA-CIRES-DOE 20th Century Reanalysis V3 (20CRv3; [45]; for short Century - OBS) to check the RegCM4 performance of every depth on a grid cell and a grid point scales. The Century is available at 1° × 1° global grid and it covers the period of January 1836 to December 2015. Advantages of the OBS can be found in details in [18]. Another advantage of the Century is that it provides a soil temperature/moisture profile for various depths (0 for the surface layer, 10 cm as the shallow depth, 40 cm as the medium depth and 100 cm as the deep depth). To evaluate the simulated ST, the Century was interpolated on the curvilinear grid of the RegCM4 [21].

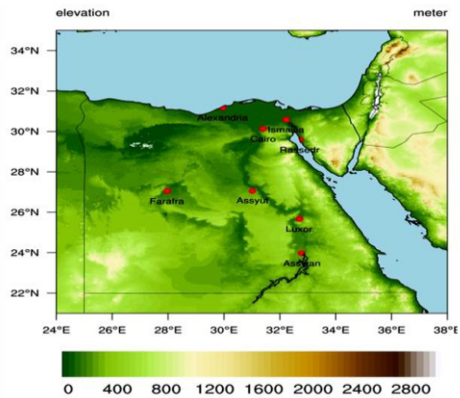

Figure 1. Topography map of Egypt. The red dots refer to eight locations. Note that the topography elevation is in meters.

3. Results

3.1. Seasonal Climatology

Figure 2 shows the simulated soil temperature of depth 10 cm (ST10 for short) in comparison with the Century reanalysis product (OBS) for the seasons: spring (March-April-May; MAM), summer (June-July-August; JJA), autumn (September-October-November; SON) and winter (December-January-February; DJF). From figure 2, it can be observed that the ESA/CEN was able to reproduce the ST10 spatial pattern concerning the OBS. That is the ST10 approached its maximum values in the JJA (figure 2g-i), followed by the SON (figure 2m-o), MAM (figure 2a-c) and eventually the DJF (figure 2s-u). Likewise, the ST10 bias approached its maximum value in the JJA (figure 2j, k) as the ESA showed a bias of 2 – 4ºC in some places and 5 – 8ºC in majority of Egypt. On the other hand, the CEN shows a major bias of 3-5ºC in majority of Egypt and 6-8ºC in some places. In the MAM and SON seasons, the situation was quite different from the one noted in the JJA as both ESA/CEN showed a significant bias of 2 – 6ºC (see figure 2d, e, p, q). However, the ST10 bias spatial pattern of the CEN is shrinked more than one observed in the ESA. The same situation was observed in the DJF except for the fact that the ST10 bias was in the range of 1 – 5ºC (figure 2v, w). Additionally in the MAM, JJA and SON, the CEN was lower than the ESA by 0.5-3.5ºC (figure 2f, l, r) except for the DJF where the CEN was lower than the ESA by 0.5 – 1.5ºC (figure 2x).

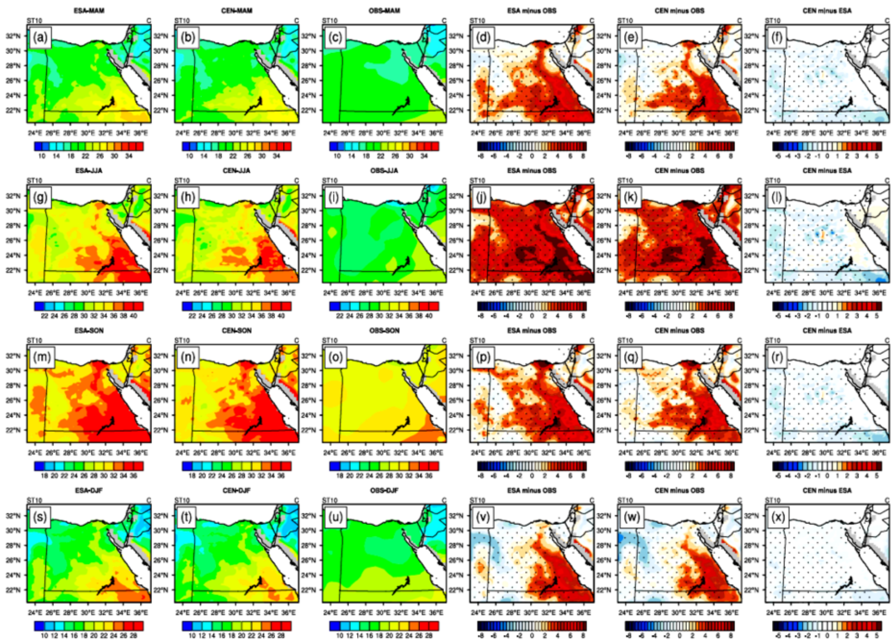

Figure 2. Soil temperature of depth 10 cm over the period of 1981–2015 (ST10; in °C) for the seasons: MAM in the first row (a–f); JJA in the second (g–l); SON in the third (m–r); and DJF in the fourth (s–x). For each row, ESA is on the left, followed by CEN. OBS is the third from left, followed by ESA minus OBS, CEN minus OBS and the difference between CEN and ESA. Significant difference/bias is indicated with black dots using student t-test with alpha equal to 5%.

Similar to the ST10, the RegCM4 was able to capture the spatial pattern of the ST40 concerning the OBS in all seasons (figure 3a-c, g-i, m-o and s-u). However, the difference between the ESA and CEN (concerning the OBS) and between themselves became more noted than the one observed in the ST10. For instance in the MAM season, the ESA showed a ST40 bias of 1 – 6ºC over majority of Egypt (figure 3d), while the CEN showed the same bias order of magnitude but mainly in the region of 22 – 26ºN (figure 3e). Qualitatively, the CEN is lower than the ESA by 0.5 – 2ºC (figure 3f). In the JJA, the difference between the ESA and CEN became clearer (than other seasons) as the ESA showed a bias of 3-8ºC (figure 3j), while the CEN showed a bias of 2 – 6ºC over majority of Egypt and in some places 8ºC (figure 3k). That is it; the CEN had a lower ST40 than the ESA by 1 – 3.5ºC (figure 3l). In the SON, the same behavior was noted but the bias spatial pattern has a lower extent than the one observed in the JJA (see figure 3p, q). Qualitatively, the CEN was lower than the ESA by 1 – 2.5ºC (figure 3r). Finally in the DJF, there was no difference noted between the ESA and CEN either between the OBS or between themselves (see figure 3v, w, x).

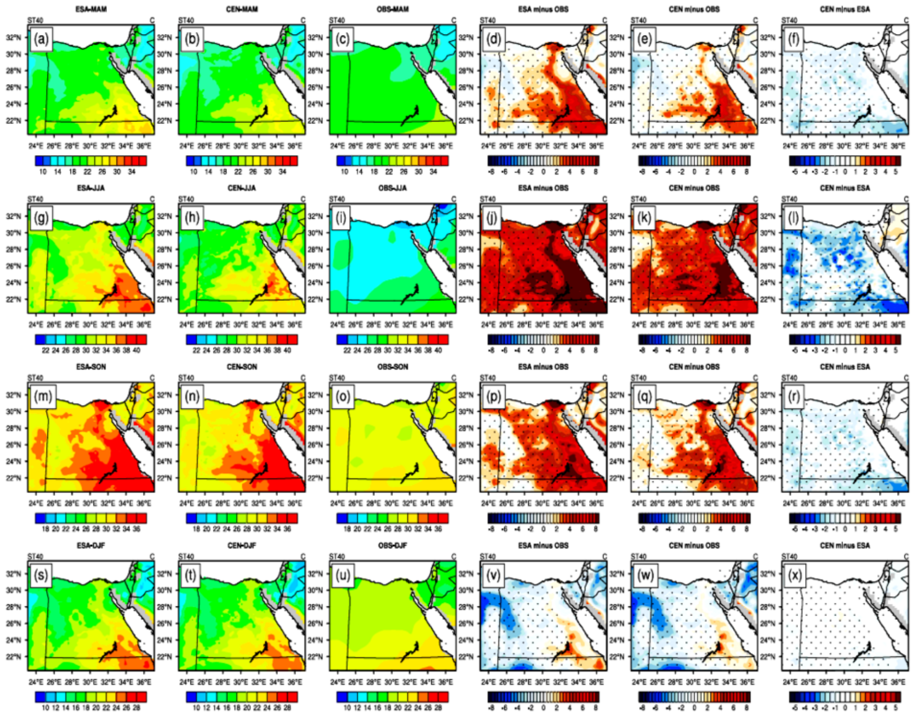

Figure 3. Soil temperature of depth 40 cm over the period of 1981–2015 (ST40; in °C) for the seasons: MAM in the first row (a–f); JJA in the second (g–l); SON in the third (m–r); and DJF in the fourth (s–x). For each row, ESA is on the left, followed by CEN. OBS is the third from left, followed by ESA minus OBS, CEN minus OBS and the difference between CEN and ESA. Significant difference/bias is indicated with black dots using student t-test with alpha equal to 5%.

Figure 4 shows the simulated ST100 in comparison with the OBS. In figure 4, it can be observed that the difference between the ESA and CEN approached its maximum values (compared to the one observed in the ST10 and ST40). For instance in the MAM season, the ESA comprised a bias of ±1-3ºC (figure 4d), while the CEN showed only a negative bias of 1 – 3ºC and the warm bias was reduced to be 1ºC (figure 4e). That is, the CEN had a lower ST100 than the ESA by 0.5-2ºC (figure 4f). In the JJA and SON seasons, the situation was different because the ESA had a warm bias of 3 – 8ºC (figure 4j, p) and CEN showed a warm bias of 2 – 6ºC (figure 4k, q). That is, the CEN had a lower ST100 than the ESA by 1– 4ºC over majority of Egypt and 5ºC in some regions (figure 4l, r). Finally in the DJF season, it can be observed that both the ESA/CEN exhibited a cold bias, yet the ESA had a cold bias of 2 – 5ºC (figure 4v). On the other hand, the CEN showed a cold bias of 1 – 3ºC (figure 4w). From a qualitative point of view, the CEN was warmer than the ESA by 0.5 – 2ºC (figure 4x). From figures 2, 3 and 4 it can be observed that the CEN had a lower ST bias than the ESA in all seasons (except for the ST40 in the DJF season) in agreements with the results reported by [42]. However, the effect was obviously noticed in the ST100 more than the ST40 and ST10 because the ST100 was far from the influences of the surface solar radiation and temperature variability more than the ST40 and ST10. Another reason was that the heat transfer became slow from one layer to another because it occurred in arid region. Therefore, the ST100 received lower heat than the ST40 and ST10.

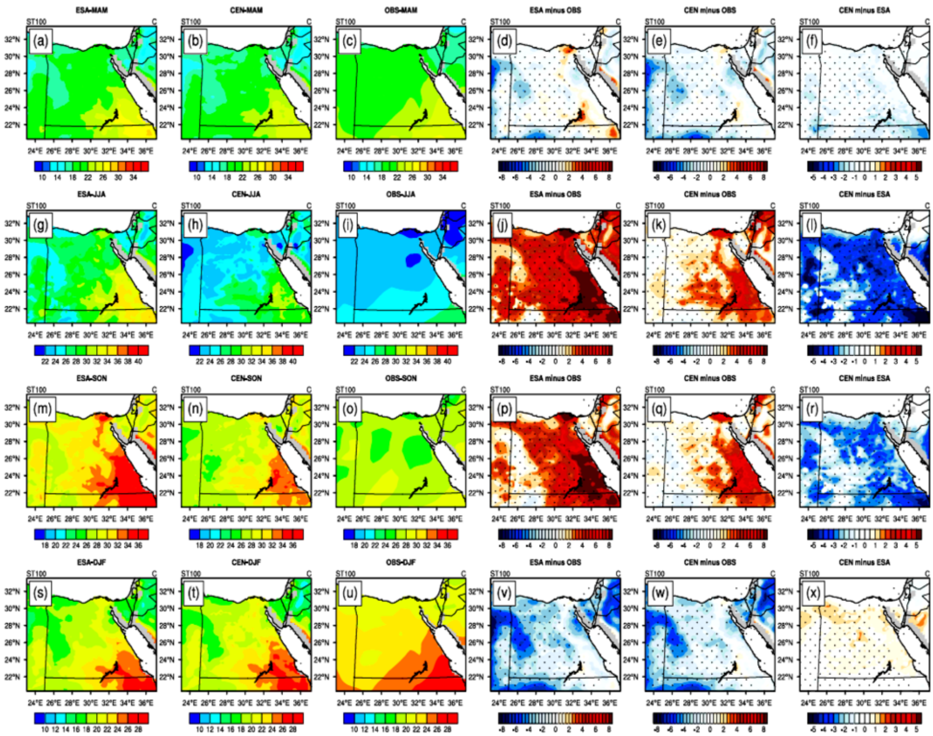

Figure 4. Soil temperature of depth 100 cm over the period of 1981–2015 (ST100; in °C) for the seasons: MAM in the first row (a–f); JJA in the second (g–l); SON in the third (m–r); and DJF in the fourth (s–x). For each row, ESA is on the left, followed by CEN. OBS is the third from left, followed by ESA minus OBS, CEN minus OBS and the difference between CEN and ESA. Significant difference/bias is indicated with black dots using student t-test with alpha equal to 5%.

3.2. Added Value of the LS Method

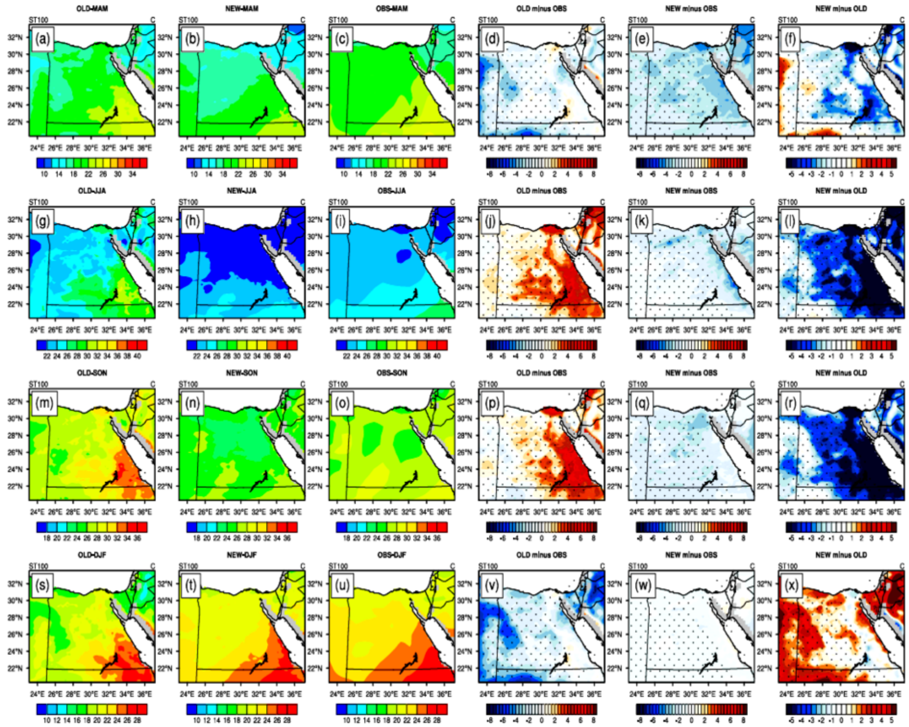

Figure 5. Soil temperature of depth 100 cm over the evaluation period of 1981–1996 (ST100; in °C) for the seasons: MAM in the first row (a–f); JJA in the second (g–l); SON in the third (m–r); and DJF in the fourth (s–x). For each row, OLD is on the left, followed by NEW. OBS is the third from left, followed by OLD minus OBS, NEW minus OBS and the difference between NEW and OLD. Significant difference/bias is indicated with black dots using student t-test with alpha equal to 5%.

Referring to figure 4, it can be noted that the RegCM4 exhibited a high bias particularly in the JJA and SON seasons. Therefore to possibly reduce the ST bias, the LS bias correction method was employed. First, the time segment 1981 – 1996 was considered as the evaluation period, while the time segment 1997 – 2015 was designated as the validation period. Because of the observed effect of the initialized soil moisture on the ST100, the ST100 was chosen to be bias-corrected by means of the LS method. Figure 5 shows the simulated ST100 before applying the LS (OLD) and after applying the LS (NEW) concerning the Century reanalysis product (OBS) for the seasons: MAM, JJA, SON and DJF. From figure 5, it can be observed that the efficiency of the LS depends on the season being applied. For instance in the MAM season, the OLD exhibited a cold bias of 0.5 – 2ºC (figure 5d). On the other hand, the NEW had a cold bias of 1.5 – 3.5ºC (figure 5e). That is, the NEW had a lower ST100 than the OLD by 2.5 - 5ºC (figure 5f). In the JJA and SON seasons, the situation was different because the OLD had a warm bias of 1 – 6ºC depending on the region of study (figure 5j, p). Upon applying the LS method, the NEW showed of around 1.5ºC (figure 5k, q). From a qualitative point of view, the NEW had a lower ST100 than the OLD by 2 – 5ºC (figure 5l, r). Finally in the DJF season, the OLD showed a cold bias of 1 – 4.5ºC (figure 5v). Additionally, the NEW had a cold bias of 0.5 – 1ºC (figure 5w). Qualitatively, the NEW is warmer than the OLD by 1 – 5ºC (figure 5x).

The added value of the LS was explored in the validation period (see figure 6). From figure 6, it can be observed that the NEW had a better capability to reproduce the spatial pattern of the ST100 (than the OLD) concerning the OBS (see figure 6a-c, g-i, m-o and s-u). Furthermore, the ST100 bias was notably reduced when the LS method was applied. For instance in the MAM season, the OLD exhibited a warm bias of 1 – 4ºC (figure 6d), while the NEW had a cold bias of 0.5 – 1.5ºC (figure 6e). That is, the NEW had a lower ST100 than the OLD by 2 - 5ºC (figure 6f). In the JJA and SON seasons, the OLD showed a warm bias of 2 – 8ºC (figure 6j, p). Furthermore, the NEW exhibited a warm bias of 0.5 – 2ºC (figure 6k, q). Qualitatively, the NEW had a lower ST100 than the OLD by 2 - 5ºC (figure 6l, r). Finally in the DJF season, the OLD had a cold bias of 0.5 to 4.5ºC (figure 6v) and the NEW had a cold bias of 0.5ºC (figure 6w). That is, the NEW was warmer than the OLD by around 2 - 5ºC (figure 6x).

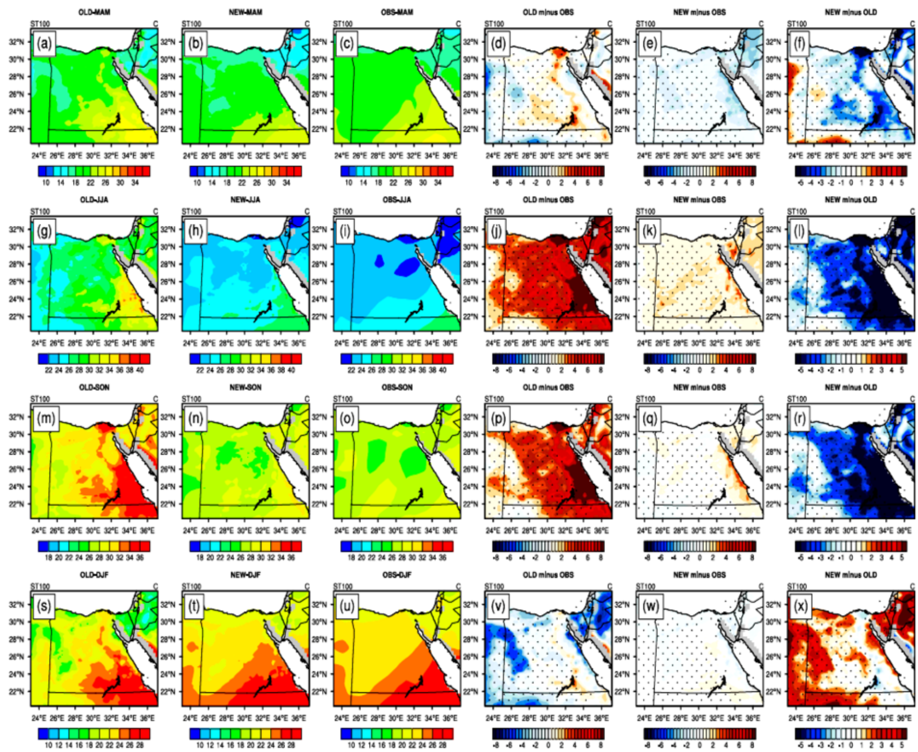

Figure 6. Soil temperature of depth 100 cm over the validation period of 1997–2015 (ST100; in °C) for the seasons: MAM in the first row (a–f); JJA in the second (g–l); SON in the third (m–r); and DJF in the fourth (s–x). For each row, OLD is on the left, followed by NEW. OBS is the third from left, followed by OLD minus OBS, NEW minus OBS and the difference between NEW and OLD. Significant difference/bias is indicated with black dots using student t-test with alpha equal to 5%.

3.3. Climatological Annual Cycle

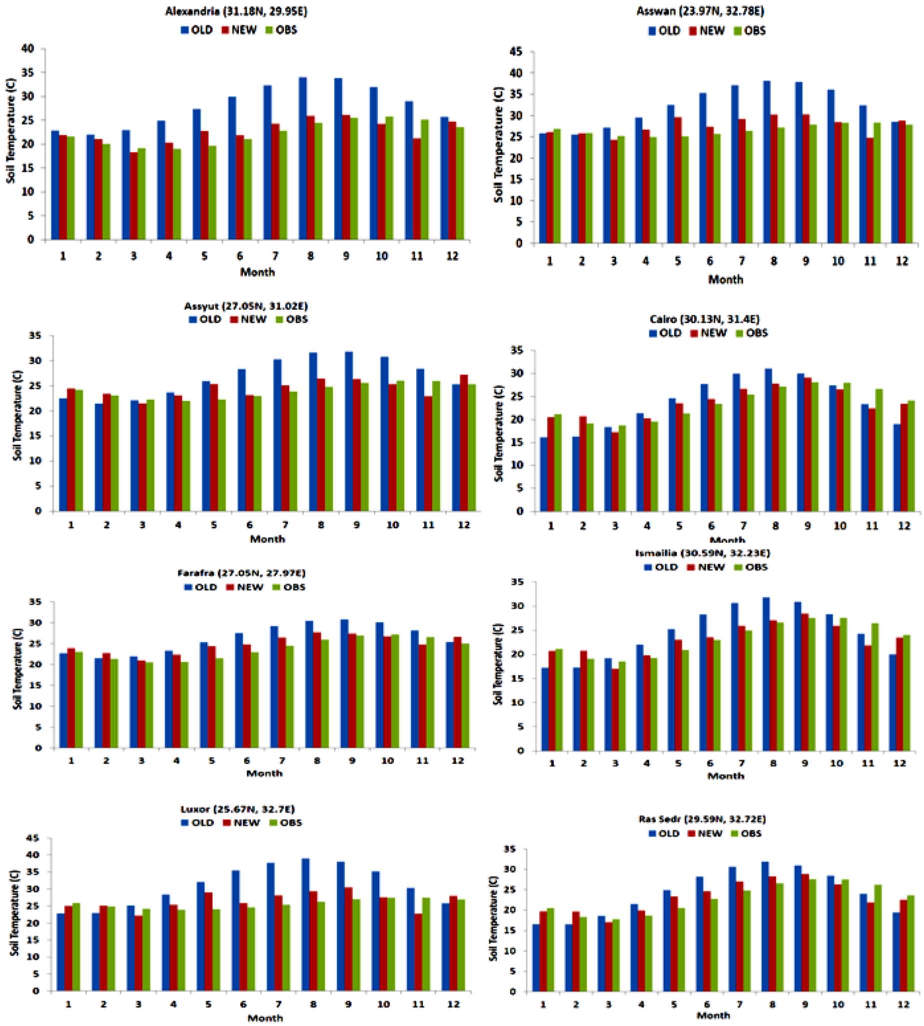

Figure 7. Climatological annual cycle of the simulated ST100 with respect to the OBS over the validation period 1997–2015 (for the locations indicated in figure 1). Note that OLD (in blue) refers to the raw ST100 output before applying the LS bias-correction method, while NEW (in red) refers to the bias-corrected ST100 after applying the LS bias-correction method. OBS is the Century reanalysis product.

To further examine the added value of the LS, the ST climatological annual cycle was plotted (before – OLD and after applying the LS - NEW) for eight locations concerning the OBS (figure 7). From figure 7, it can be shown that the added value of the LS varied with the locations and month. For instance, the NEW was close to the OBS (in Alexandria) for all months. Statistically, the MB_{OLD} was 5.74ºC and the MB_{OLD} was 0.39ºC. Also, the STD_{OLD} was 1.71 and the STD_{NEW} was 0.92. This explored the added value of the LS in terms of reducing the MB and STD. For the CORR, there was no clear difference between the OLD and NEW as the $CORR_{OLD}$ was 0.728 and the

$CORR_{NEW}$ was 0.74. In Asswan, the situation was different because, both the OLD and NEW were close to the OBS in January and February. Also, from month March to November, the NEW was closer to the OBS than the OLD. In December, both the OLD and NEW were close to each other and overestimate the OBS. From a statistical point of view, the MB_{OLD} was 5.53ºC and the MB_{OLD} was 0.99ºC. Additionally, the STD_{OLD} was 3.73 and the STD_{NEW} was 1.64. For the CORR, both the OLD and NEW exhibited low values as the $CORR_{OLD}$ was 0.35 and the $CORR_{NEW}$ was 0.24.

In Assyut, the NEW was closer to the OBS than the OLD in the months January, February, April to November. On the other hand, the OLD was closer to the OBS than the NEW in March and December. In statistical terms, the MB_{OLD} was 2.83ºC and the MB_{OLD} was 0.49ºC; the STD_{OLD} was 2.56 and the STD_{NEW} was 1.15 and the $CORR_{OLD}$ was 0.61 and the $CORR_{NEW}$ was 0.54. For Cairo, behavior of the OLD and NEW was dependent on the month. For instance, the NEW was closer to the OBS (than the OLD) in the months January, February, April to October and December. In month March, the OLD was closer to the OBS than the NEW. Finally in November, both the OLD and NEW underestimated the ST100 concerning the OBS. Statistically, the MB_{OLD} was 0.2ºC and the MB_{OLD} was -0.02ºC. Additionally, the STD_{OLD} was 1.56 and the STD_{NEW} was 1.005; the $CORR_{OLD}$ was 0.76 and the $CORR_{NEW}$ was 0.87. For Farafra, it can be observed that the OLD was closer to the OBS in months January, February, November and December. On the other hand, the NEW had a better performance than the OLD during the months April to October. Quantitatively, the MB_{OLD} was 2.52ºC and the MB_{OLD} was 1.05ºC. Also, the STD_{OLD} was 1.37 and the STD_{NEW} was 0.85. As for the CORR, there was no clear difference between the OLD and NEW.

In Ismailia, the NEW outperformed the OLD in all months except for March, October and November. Such performance was quantitatively confirmed as the MB_{OLD} was 1.33ºC and the MB_{OLD} was -0.13ºC; the STD_{OLD} was 1.58 and the STD_{NEW} was 0.97 and the $CORR_{OLD}$ was 0.75 and the $CORR_{NEW}$ was 0.85. For Luxor, the OLD outperformed the OLD in the months March and November; meanwhile the NEW indicated a better performance (than the OLD) during the rest of months. Statistically, the MB_{OLD} was 5.39ºC and the MB_{OLD} was 0.88ºC; the STD_{OLD} was 4.46 and the STD_{NEW} was 1.94. For the CORR, both the OLD and NEW exhibited low values and there was no clear difference between them as the $CORR_{OLD}$ was 0.26 and the $CORR_{NEW}$ was 0.24. Similar to Ismailia, the NEW outperformed the OLD in all months except for March, October and November. Such performance was quantitatively confirmed as the MB_{OLD} was 1.4ºC and the MB_{OLD} was 0.35ºC; the STD_{OLD} was 1.55 and the STD_{NEW} was 1.04 and the $CORR_{OLD}$ was 0.77 and the $CORR_{NEW}$ was 0.85.

4. Discussion and Conclusion

Soil temperature is an important environmental variable regulating the plant growth as well as it plays an important role in the heat transfer in the climate system. While in-situ observations are a valuable tool for tracking the dynamics of soil temperature, they can also bring up limitations when it comes to addressing such variations. Consequently, it became imperative to look for alternate solutions, such as regional climate models [11], offline land surface models [12], and ANN [10]. RCMs have emerged as one of the promising alternative across the globe for simulating the soil temperature profile, especially in arid environments [2]. In Egypt, the initial condition was found to have a considerable effect on the simulated soil temperature [14, 15]. In this study, the influence of different products of the initialized soil moisture (remote sensing; ESA and reanalysis; CEN) on the soil temperature profile of Egypt was investigated within the framework of the regional climate model RegCM4. The RegCM4 was configured following [15] for the period of 1979 to 2015. The first two years were considered as a spin up [44]. Additionally, performance of the LS bias correction method was explored in the evaluation/validation periods concerning the seasonal climatology. Also, the added value of the LS was explored regarding the climatological annual cycle for several locations.

The results showed that the RegCM4 was able to reproduce the ST spatial pattern concerning the OBS in all seasons. Additionally, the CEN considerably outperformed the ESA in the 100 cm depth followed by the 40 cm depth and finally the 10 cm depth. Such behavior was attributed to the fact that the layer 10 cm was closer to perturbations of the solar radiation and air temperature than the 40 and 100 cm layers. Furthermore, the heat transfer was delayed from one layer to another allowing the clear difference (between the ESA and CEN) in the 100 cm layer more than the 10 and 40 cm depths. The LS showed its added value in reducing the ST bias in the evaluation/validation periods. Additionally, the added value of the LS was explored (concerning the climatological annual cycle) by means of the statistical metric MB, STD and CORR and the outperformance of the NEW (over the OLD) for the majority of the months. Therefore, reliable simulations of the ST profile of Egypt can be ensured by adopting the CEN (as an initial condition) and the LS (as a bias correction method). The output of this work can be useful various sectors in Egypt. Our future work will compare between other bias correction methods such as the power transformation (PT), distribution mapping (DM) and quantile mapping (QM) to check whether the ST bias can be further reduced concerning the OBS.

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