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Proceeding Paper

Simulating the Daily Soil Temperature of Egypt Using a High-Resolution Regional Climate Model: Sensitivity to Soil Moisture and Temperature Initial Conditions †

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Abstract: In this study, a high-resolution regional climate model (RegCM4) was used to forecast the daily soil temperature of depth 40 cm (hereafter ST40). The RegCM4 was downscaled by the Global Forecast System (GFS of one degree horizontal resolution) to 25 km grid spacing. **To examine the sensitivity of the ST40** to different initial conditions of the soil moisture and temperature, four experiments were conducted and grouped to two cases. The first case considered the comparison between initialing the RegCM4 from bare soil and from the global satellite soil moisture product (ESACCI). On the other hand, the second case examined the influence of initializing the soil temperature from the Century reanalysis product (Century) versus initializing from zero values. The results showed that initializing the RegCM4 with the ESACCI has a notable impact on the simulated ST40 with respect to the bare soil. **Additionally**, when the RegCM4 is initialized with the Century product, the simulated ST40 is improved in the sense that the ST40 trend becomes smoother than when the RegCM4 is initialized with zero values. **In comparison with a reanalysis product, the RegCM4 shows a good performance when it is initialized with the ESACCI and Century products. In conclusion, the RegCM4 can give a reliable forecast of the ST40 when it is initialized with the ESACCI satellite soil moisture and Century reanalysis soil temperature products especially in scarce-data regions.**

Keywords: Egypt; ESACCI; RegCM4; satellite; soil moisture

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1. Introduction

Soil temperature is an important variable in the climate system because it modulates the surface energy balance components (sensible and latent heat fluxes) and therefore **it controls** the water and energy fluxes exchanged between the land surface and the atmosphere as well as the mesoscale circulations [1]. Additionally, the soil temperature controls the physical and biological activities beneath the earth surface and eventually the **agricultural productivity** [2]. In arid regions (e.g., Kuwait), the authors of [3] found that there is a strong correlation between soil temperature of shallow depths (up to 20 cm) and air temperature and **a** weak correlation between soil temperature of deep depths (50–100 cm) and the air temperature. They concluded that air temperature can be used as **a** predictor to estimate the soil temperature when station observation is not available **either** spatially or temporary.

Because of limited availability of **the** soil temperature records, regional climate models **or** offline land surface models can be alternative **useful** tools to estimate the soil temperature **of** a particular depth. For instance, the authors of [4] examined the potential skills of the fifth-generation PSU-NCAR Mesoscale Model (MM5)-based regional climate model (CMM5) concerning the annual cycle and interannual variability of the United States soil temperature and moisture. They found that the CMM5 bias can be attributed to the inconsistencies between measurements taken under short grass versus model representations beneath other land cover types. Regarding the offline land surface model, the authors of [5] found that version 3.5 of the community land model (CLM3.5) gave satisfactory performance in simulating the soil temperature over a range of time scales (hours to monthly) with respect to the in-situ observations. Also, they reported that the CLM3.5 is a useful tool to understand the regional and vertical characteristics of the soil temperature in Xinjiang.

In Egypt, the authors of [6] used the regional climate model (RegCM4; [7]) to simulate the soil temperature profile with respect to the in-situ observations. They found that the RegCM4 is able to reproduce the daily variability despite of notable biases between the RegCM4 and the observations. Additionally, they reported that the RegCM4 gives satisfactory results when it is initialized by a long-term spin-up file rather than initializing from a bare soil. However in the aforementioned studies, the sensitivity of the regional climate model (e.g., CMM5 or RegCM4) or the offline land surface model (e.g., CLM3.5) to different initial conditions of the soil temperature/moisture has not been examined. Therefore, the present study aims to address this issue in Egypt using the RegCM4 model for **five** days forecast. The study is organized as: Section 2 describes the study area and experiment design; Section 3 shows the results of the study and finally Section 4 provides the discussion and conclusion.

2. Materials and Methods

2.1. Experiment Design

In the present study, the International Center of Theoretical Physics (ICTP) regional climate model (RegCM4; [7]) was used. The **RegCM4's** domain **was** centered at 27° latitude and 30° longitude with 60 grid points in zonal and meridional directions and 25 km horizontal grid spacing following [8, 9 and 10]. **This study** adopted the physical configuration of [10]. **To provide the lateral boundary condition and sea surface temperature (SST)**, the Global Forecast System of one degree grid spacing (GFS; [5]) was used. The reader can find more details of the GFS in [5] as well as the website: https://www.emc.ncep.noaa.gov/emc/pages/numerical_forecast_systems/gfs.php. To simulate the soil temperature of depth 40 cm (ST40), the RegCM4 was configured with version 4.5 of the community land model (CLM45; [12]) following the procedure adopted in [6].

To examine the sensitivity of the simulated ST40 to different initial conditions of the soil moisture and temperature, four experiments were conducted and grouped to two cases. The first case considers **the initialization** the RegCM4 from the bare soil and ESACCI global satellite soil moisture product ([13,14]). The ESACCI is based on integrating of different microwave sensors and it is available at 0.25 degree grid spacing. The reader can refer to [13,14] for more details of the ESACCI. Figure 1 shows the interpolated ESACCI on the curvilinear grid of the RegCM4. The second case examines the sensitivity of the simulated ST40 to two initial conditions: bare soil and version 3 of the Century reanalysis product [15]. The Century product is available from year 1836 till 2015.

For the purpose of the present study, the long-term average of the Century was calculated. In the first case, the RegCM4 started at 18-05-2023 and ended at 23-05-2023. For the second case, the RegCM4 started at 20-05-2023 and ended at 25-05-2023. Note that, the first day (in each case) was discarded from the analysis to bring the atmosphere to the equilibrium state. Also in the first case, both simulations began with zero values of the ST40. On the other hand, the second case considered initializing the soil moisture from the ESACCI. Please note that initializing the RegCM4 with a long-term spin-up of the soil temperature following [6] was not feasible in the present study, because it was found that the RegCM4 is not stable in generating the daily restart files needed for acquiring the equilibrium state from the long-term spin-up file. Instead, the RegCM4 was initialized **by means of** the long-term average of the Century to overcome this **point**.

2.2. Observational Dataset

The authors of [6] reported that the soil temperature profile is defined by the depths of 2, 5, 10, 20, 50, 100 and 200 cm. However during the time of the simulations, there was no in-situ observation of the soil temperature of depth 40 cm. Instead, the daily climatology of the Century product was used to evaluate the RegCM4 performance in each case. The mean bias (MB) was used as a statistical metrics to quantitatively assess the RegCM4's performance. Concerning the Century reanalysis product, the authors of [16] reported that this product has two advantages: 1–it is available for a long time (spanning from 1836 to 2015) and 2–it provides good estimates of the atmospheric variables.

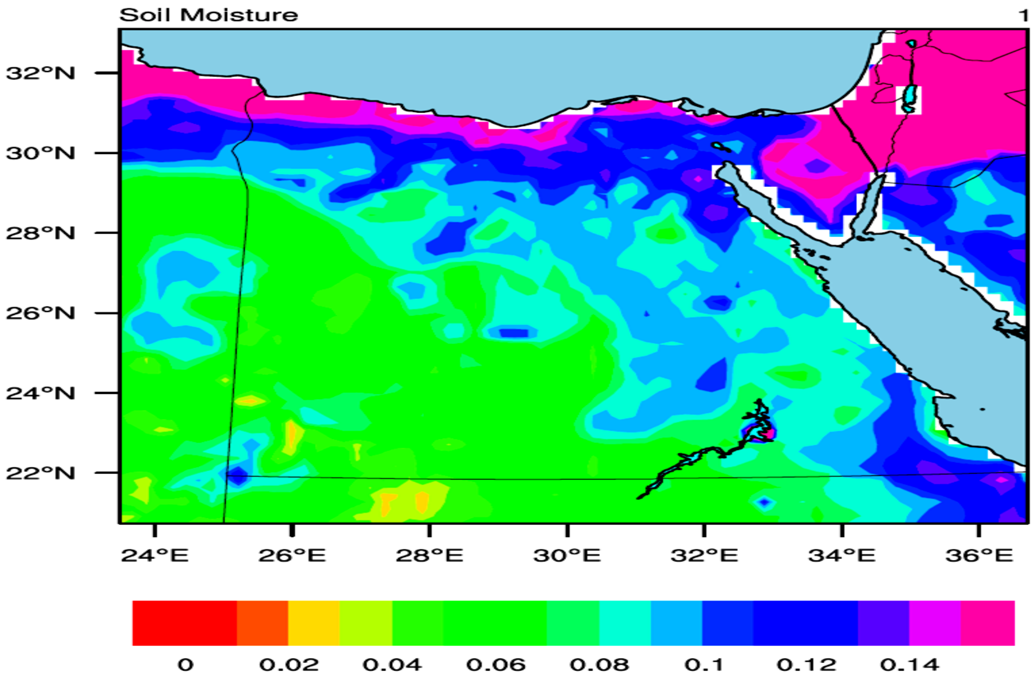

Figure 1. The figure shows the interpolated ESACCI satellite soil moisture product on the RegCM4 curvilinear grid. Note that soil moisture is expressed in percentage (%).

3. Results

3.1. Qualitative Assessment

Figure 2 shows the simulated ST40 (in degree Celsius) initialized with bare soil (No-moisture) and ESACCI (Moisture). From Figure 2, it can be noted that both simulations exhibit an obvious trend which can be attributed to the fact that the ST40 (in the two simulations) begins with zero values. Also, initializing the RegCM4 with the ESACCI has a considerable impact on the simulated ST40 as the Moisture is warmer than No-moisture by 1.4 to 1.9 °C (depending on forecast day; see Table 1). One can note from Figure 1 that despite of small values of the soil moisture (ranging from 0.01 to 0.14), but the simulated ST40 showed a good sensitivity to the ESACCI compared to initialization with bare soil. A possible explanation for the physical effects (associated with the ESACCI) is indicated by a flow chart (see Figure 3).

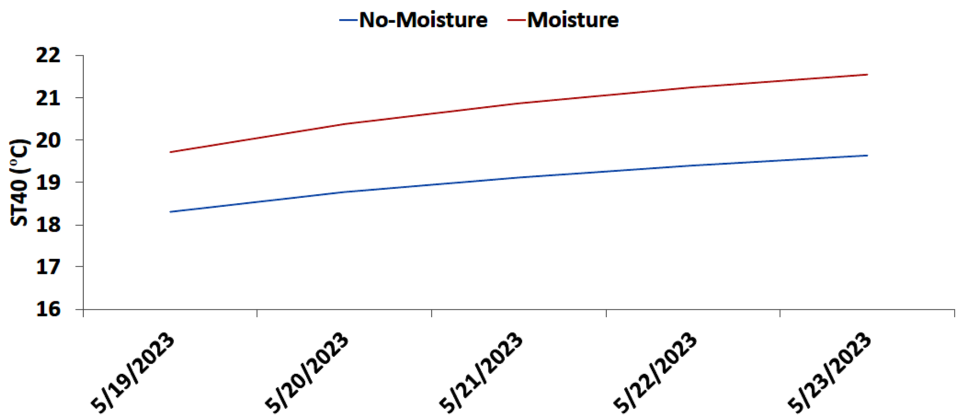

Figure 2. The figure shows the simulated ST40 (in °C) over the period 19-05-2023 till 23-05-2023. Initializing from bare soil (No-Moisture) is shown in blue color, while from the ESACCI is presented in red color.

Table 1. The table shows the simulated ST40 (in °C) initialized by bare soil (No-Moisture), with the ESACCI (Moisture) and the difference between them.

Day	No-Moisture	Moisture	Diff
19 May 2023	18.3043	19.7198	1.4155
20 May 2023	18.7751	20.3834	1.6083
21 May 2023	19.1178	20.8762	1.7584
22 May 2023	19.4009	21.2561	1.8552
23 May 2023	19.6374	21.5524	1.915

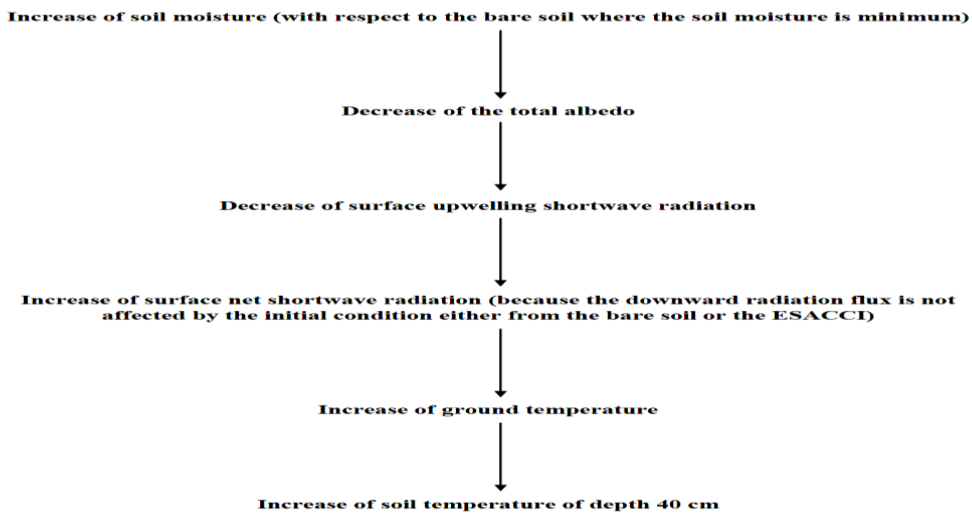

Figure 3. The figure shows the ESACCI mechanism of action on the simulated soil temperature of depth 40 cm (ST40).

Figure 4 shows the simulated ST40 initialized from zero values and from the Century. From Figure 4, it can be noted that initializing from zero values (Without-Century) indicates an obvious trend and the simulated ST40 ranges between 20.5 and 24.5 °C in the five day forecast (see Table 2). On the other hand, when the RegCM4 was initialized by the Century (Century), the trend becomes smooth and the ST40's range became narrow (starts at 22.7 °C and ends at 23.8 °C). This noted behavior is quantitatively confirmed as the difference between Century and Without-Century decreases with time (see Figure 5).

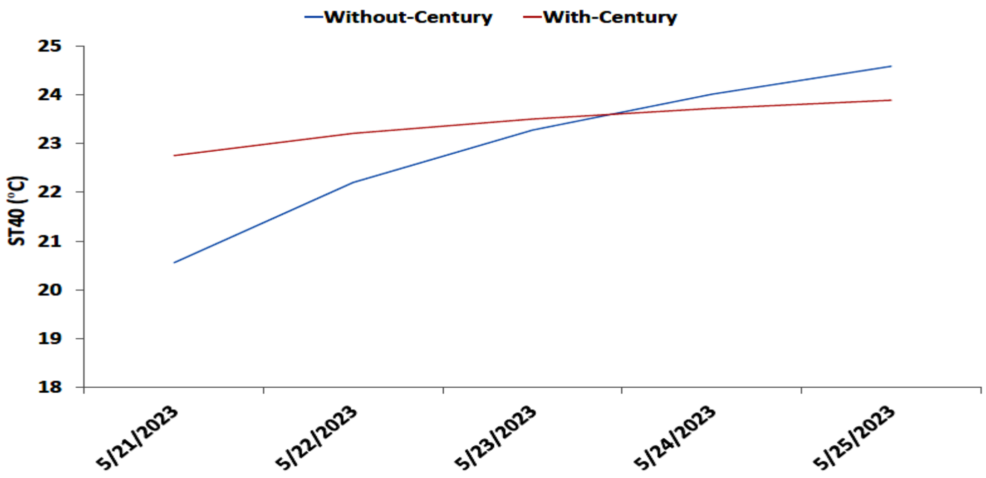

Figure 4. The figure shows the simulated ST40 (in °C) over the period 21-05-2023 till 25-05-2023. Initializing from zero values (Without-Century) is shown in blue color; while from the Century (With-Century) is presented in red color.

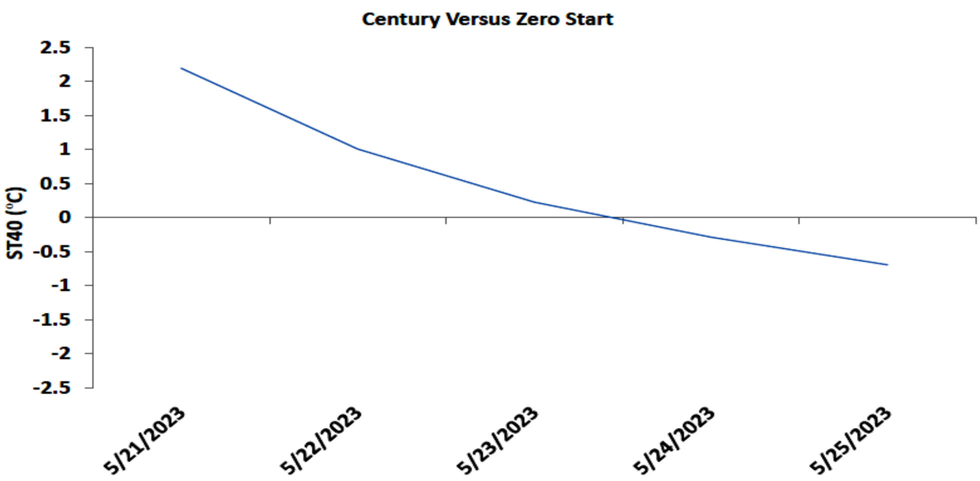

Figure 5. The figure shows the difference between (in °C) Century and Without-Century over the period 21 May 2023 till 25 May 2023.

Table 2. The table shows the simulated ST40 (in °C) initialized by zero values (Without-Century), with the Century (With-Century) and the difference between them.

Day	Without-Century	With-Century	Diff
5/21/2023	20.5555	22.7506	2.1951
5/22/2023	22.2006	23.207	1.0064
5/23/2023	23.2726	23.4991	0.2265
5/24/2023	24.0068	23.7183	−0.2885
5/25/2023	24.5794	23.8854	−0.694

3.2. Evaluating the RegCM4 with the Century Reanalysis Product

In Section 3.1, a qualitative assessment has been conducted between initialization from bare soil and ESACCI/Century products (by calculating the difference between the two simulations in each case). To determine which configuration is suitable for initializing the RegCM4, the two simulations (of each case) have been compared with the Century reanalysis dataset (hereafter OBS). Figure 6 shows the comparison between NoMoisture and Moisture with respect to the OBS. From Figure 6, it can be observed that both simulations underestimate the ST40 compared with the OBS. However, the Moisture is closer to the OBS than the NoMoisture.

Such behavior has been quantified as NoMoisture has MB of −5.05 °C, while Moisture has MB of −3.3 °C. Concerning the initializing the RegCM4 with bare soil/Century product, it can be noted from Figure 7 that there is a considerable difference between Without-Century and OBS (MB = −1.34 °C) because the RegCM4 shows a notable trend compared to the OBS. On the other hand, when the RegCM4 was initialized with the Century, the RegCM4 shows a smooth trend similar to the one noted in the OBS. Also, the RegCM4 has MB of −0.85 °C in this case.

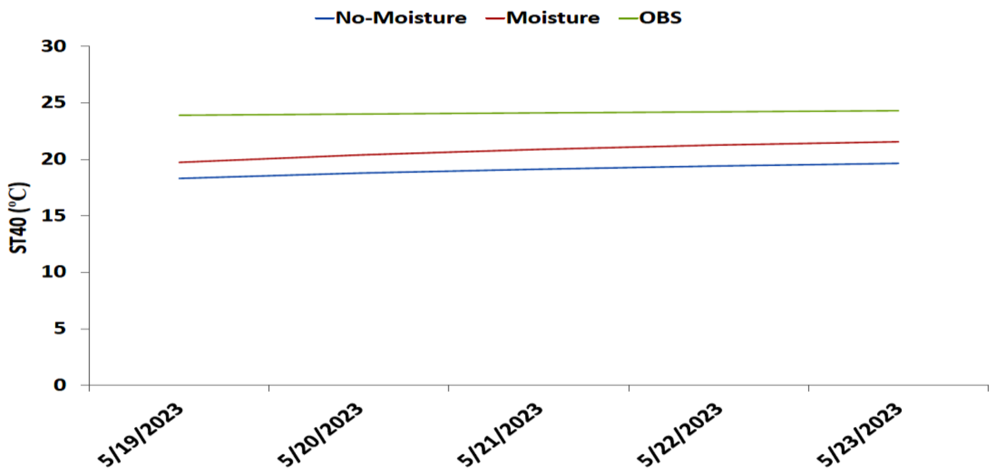

Figure 6. The figure shows the comparison between the NoMoisture (in blue) and Moisture (in red) with respect to the Century reanalysis product (OBS; in green).

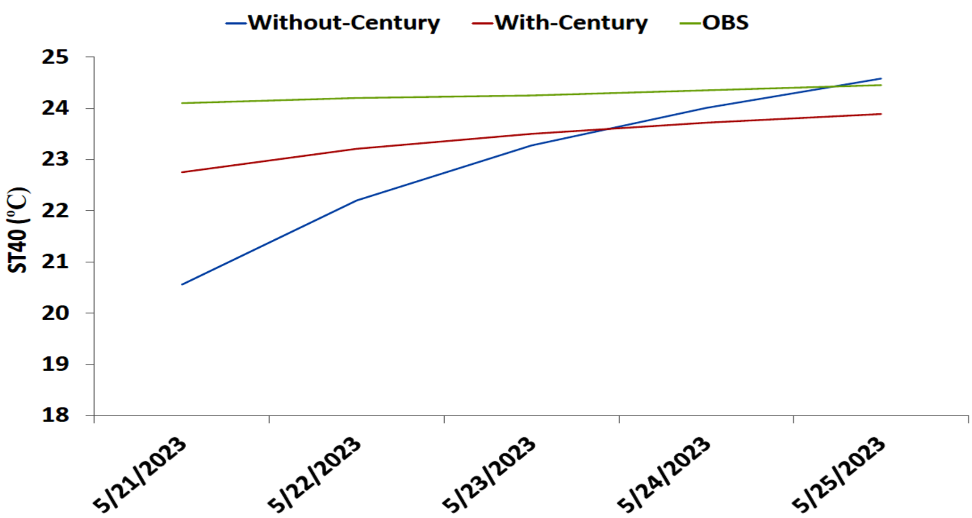

Figure 7. The figure shows the comparison between Without-Century (in blue) and With-Century (in red) with respect to the Century reanalysis product (OBS; in green).

4. Discussion and Conclusions

Soil temperature is important in monitoring **the** daily agricultural activities as well as controlling the status of the land surface. When station observation is limited or not available, regional climate models (e.g., RegCM4) are valuable tools to simulate the soil temperature with high-resolution at any grid point. Hence, it was necessary to examine the RegCM4's performance as reported by [6]. **Moreover**, in arid regions (as in the present study), the RegCM4 **is** sensitive to different initial conditions of the soil temperature and moisture. To handle this issue, it was necessary to initialize the RegCM4 (with different initial conditions) to ensure a reasonable accuracy of the simulated ST40.

In the present study, the sensitivity of the simulated ST40 (to different initial conditions of the soil moisture and temperature) was investigated using a high-resolution **grid-spacing** of the RegCM4. To this end, four simulations were conducted and grouped to two cases. **The RegCM4 model output was evaluated with respect to the Century reanalysis product (OBS).** The results showed that the simulated ST40 is considerably sensitive to the soil moisture initial conditions. This can be clearly seen as Moisture is warmer than No-Moisture. Furthermore, initializing the RegCM4 with the Century product showed a smoother trend and a narrower range of the simulated ST40 than initializing from zero values. **In comparison with the Century reanalysis product (OBS), the RegCM4 gives a good performance when it is initialized with the ESACCI/Century products**.

In conclusion, the RegCM4 can give a reliable forecast (of the simulated ST40) when it is initialized with the ESACCI satellite soil moisture and a long-term Century reanalysis products. **Additionally, a future study will consider the following points:**

1. Using a long-term spin-up soil temperature file (as an initial condition following [6]) and check its added value with respect to the results reported in the present study.
2. Addressing the sensitivity of the simulated ST40 to different global reanalysis products of the soil moisture such as Climate Prediction Center (CPC; [17]) and ECMWF's atmospheric reanalysis of the 20th century (ERA-20C; [18]).

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