IMPACTS OF LAKE ABAYA AND CHAMO ON THE AIR TEMPERATURE OF ARBA MINCH, SOUTHERN ETHIOPIA REGION, ETHIOPIA

ABSTRACT

Lakes play an important role in the water cycle by storing surface water from precipitation, snowmelt, and glacier melt. However, their interactions with land and water surfaces have been disregarded or explored in a basic manner. The high thermal inertia of lakes has the potential to have a considerable impact on regional climate. The purpose of this study was to examine the effect of Abaya and Chamo Lakes on the temperature of Arba Minch using WRF-Chemistry model simulation results, both with and without lakes. The result was analyzed based on temperature data from 10/1/2020 to 11/11/2020. WRF-Chemistry model was utilized to simulate the temperature of the study area. WRF-Chemistry models performed strongly in terms of r (0.88) with control, r (0.89) with simulated without Lake, and r (0.77) with flat topography condition. The study showed that the presence of Lake Abaya and Lake Chamo significantly affects local weather condition in Arba Minch, with lower temperatures in highlands. The lake's energy absorption and release during the wet and dry seasons contribute to the Arba Minch's temperature anomaly.

Keywords: Temperature, Climate, Lake, WRF-Chemistry

1. INTRODUCTION

1.1 Background

Lakes have an impact on the air temperature in a particular region. It is possible to explore and quantify the effects of the Abaya and Chamo lakes by simulating their presence and absence. Lakes play a vital role in the water cycle because they store a lot of surface water from precipitation, snowmelt, and glacier melting (Abdi and Gebrekristos 2022). The interaction of the atmosphere with land and sea surfaces has received a lot of attention, but lakes have been either ignored or studied in a very basic style (Zhang et al. 2020). The reason for this is that land and sea dominate the earth's surface, while lakes are only regionally significant (Elias 2017). In regions where lakes represent a non-negligible fraction of the surface their large thermal inertia, as compared to the land surface, may cause them to have a significant impact on the regional climate (Minallah and Steiner 2021).

A mesoscale anticyclone develops above the lake when the air density increases due to lake freezing. During the day, heating of adjacent land areas creates a pressure gradient of two or more mb, causing air to move from the higher pressure of the lake to the lower pressure of the land.

The Weather Research and Forecasting (WRF) model is a community non-hydrostatic and fully compressible atmospheric model, maintained by the National Center for Atmospheric Research (NCAR) (Powers et al. 2017). This model was important to simulate temperature data for studying influence of lakes on the surrounding region.

In climate change studies, temperature anomalies are more important than absolute temperature. A temperature anomaly is the difference from an average, or baseline, temperature. Baseline temperature is calculated by averaging 30+ years of data. Positive anomalies indicate warmer temperatures, while negative anomalies indicate cooler ones (Moore et al. 2019). Station location and elevation affect absolute temperatures, but anomalies are less critical. For example, a summer month may be cooler than average at different locations (Moore et al. 2019).

The overall objective of this study is to analyses and quantifies the impact of Lake Abaya and Chamo on the surface temperature of Arba Minch town as well as to quantify the WRF-Chemistry model performance by simulating temperature data using the WRF-Chemistry model with and without the two lakes. We explore the role of lakes as an important component of town weather, as well as their impact on the town, from 10/1/2020 3:00:00 AM to 11/11/2020 6:00:00 PM (1000 observations).

2. DATA AND METHODOLOGY

2.1 Description of the study area

Arba Minch is a town in Southern Ethiopia at 6°04'N latitude and 36°40'E longitude, at an elevation of 1,285 meters above mean sea level. The name Arba Minch is derived from the term "forty springs," which refers to a group of more than forty springs located within the Arba Minch natural forest. It is 505 km from the capital city of Addis Ababa. It consisted of four administrative sub-cities. Secha, Sikella, Abaya, and Nechsar, which are further divided into eleven Kebeles.

2.2 Data source

2.2.1 Observed data

Observational data is important in many domains of research, particularly in studies of climate and weather in detail (Kumar et al. 2012). Hourly weather data used in this study was obtained from Arba Minch University Automatic weather station from 10/1/2020 to 11/11/2020 (1000 observations).

2.2.2 Model data

The numerical experiment is determined by subtracting the simulated value with lake from control value. In order to quantify the lake effect on local climate, another numerical experiment, nolake (simulation without lake), is performed for comparison with the control. no-lake is based on control, but the two lakes (Abaya Lake and Chamo Lake) are filled with nearby land use cover (forest). For this study hourly simulated model data of temperature parameters was analyzed by using WRF-Chemistry model from time 10/1/2020 3:00:00 AM to 11/11/2020 6:00:00 PM.

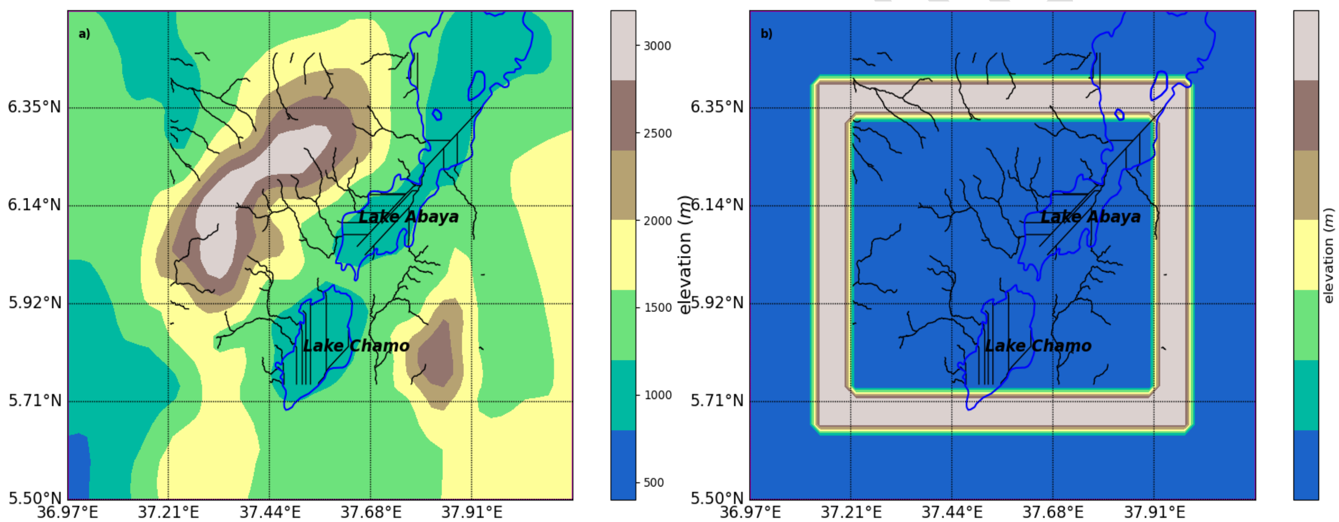
2.3 Methods

Numerical modelling has given us the ability to better comprehend the atmosphere and its processes (Randall et al. 2007). The model is largely created by the National Centre for Atmospheric Research (NCAR), in partnership with other agencies such as the National Oceanic and Atmospheric Administration (NOAA), the National Centre for Environmental Prediction (NCEP), and others. It is a non-hydrostatic, basic equation model with limited area and several physical parameterization techniques (Skamarock and Klemp 2008).

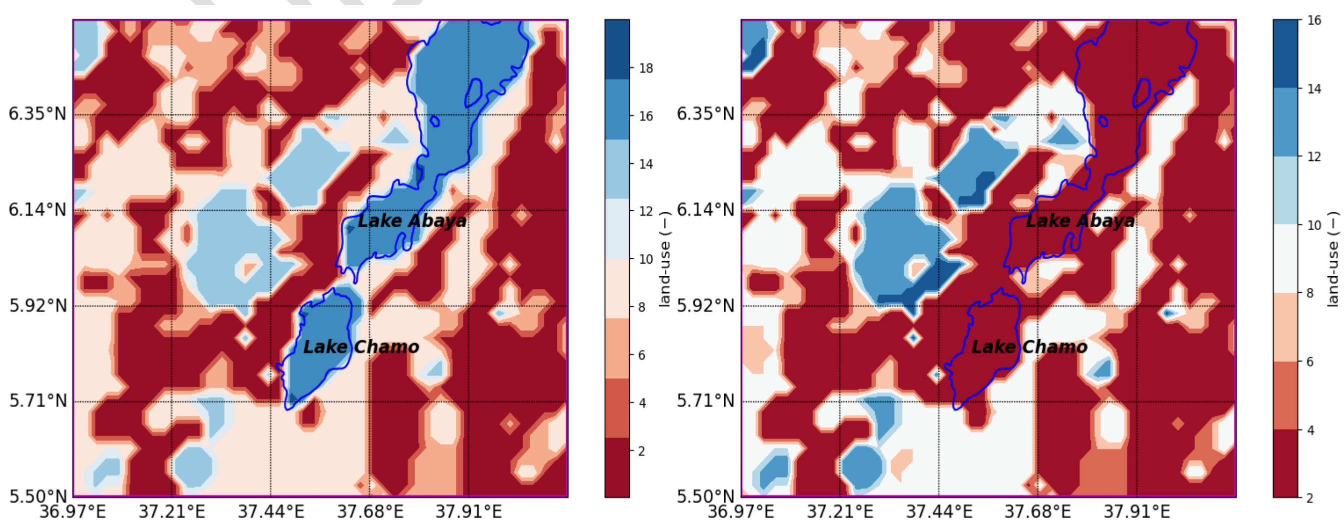
WRF-Chem is a Weather Research and Forecasting (WRF) model combined with Chemistry. The model models the emission, transport, mixing, and chemical change of trace gases and aerosols while also accounting for meteorology. The model is used to investigate regional scale air quality, field program analysis, and cloud-scale interactions with chemistry (Kumar et al. 2012).

The numerical experiment is computed by subtracting the simulated value with lake and the control value. To assess the lake effect on local climate, another numerical experiment, no-lake (simulation without lake), is run in comparison to the control. No-lake is centered on control, yet the two lakes (Abaya Lake and Chamo Lake) are surrounded by forested terrain. In this study, hourly simulated model data of temperature was analyzed using the WRF-Chem model from 10/1/2020 3:00:00 AM to 11/11/2020 6:00:00 PM (1000 observations).

The research area's elevation and land use were described in terms of control variables, flat topography, and lake presence or absence. The hourly temperature data was simulated at a scale of 1km x 1km in control, flat topography, with and without the Lake.



Elevation map a. Control b. Flat topography



Land use map a. With lake   b. Without lake

Figure 1: Elevation map of (a) control and (b) flat topography and land use map of (a) with Lake and (b) without Lake

2.4 Model Evaluation Statistics

Statistical analyses were conducted to evaluate the performance of the WRF model. The accuracy of observed and simulated data is quantitatively analyzed using four statistical indicators of correlation coefficient (CC), Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and Index of Agreement (IOA). The correlation coefficient (CC) is a measure of the linear relationship between the model and the observed data. The mean absolute error (MAE) and root mean square error (RMSE) summarize how near the predicted values are to the measured values, while the Index of Agreement (IOA) indicates how well the model depicts the pattern of perturbation around a mean value. These statistical metrics will choose to evaluate the performance of simulated models and formulas are depicted in table 1

Table 1: Description of quantitative statistical measurement

Statistics	Formula	Range	Perfect Score
Root Mean Square Error	$RMSE = \sqrt{\frac{\sum_{t=1}^{N}(S_i - O_i)^2}{N}}$	0-∞	0
Correlation Coefficient	$r = \frac{\sum_{t=1}^{N}(S_o - \bar{S}_s)\,(O_i - \bar{O}_i)}{\sqrt{\sum_{t=1}^{N}(S_i - \bar{S}_i)(O_i - \bar{O}_i)}}$	-1 to +1	+1
Mean Absolute Error	$\mathrm{MAE} = \frac{1}{n}\sum_{i=0}^{n} \lvert \mathrm{Oi} - \mathrm{Si} \rvert$	0 to ∞	0
Index of Agreement	$\mathrm{IOA}=1-\frac{\sum_{i=1}^{n}(Oi-Si)^2}{\sum_{i=1}^{n}\lvert Si-\bar{O}\rvert \lvert Si-\bar{O}\rvert^2}$	0 to 1	1

3. RESULT AND DISCUSSION

3.1 Evaluation of WRF-Chemistry Model Performance

Simulated results in simulated with lake, without lake, and flat topography are evaluated against observed daily temperature with automatic station data. WRF-Chem models performed strongly in terms of correlation coefficient r (0.88) for simulated with lake, r (0.89) for without lake, and r (0.77) for flat topography. The index of agreement value between simulated temperature with and without lake is 0.75, indicating a nearly perfect match. Temperature with lake simulation is nearly same to temperature without lake simulation. Nonetheless, the RMSE and MAE between simulated and observed statistical values in temperature with lake are slightly less than in temperature without lake, and the temperature with lake simulation is more accurate than the temperature without lake.

Table 2 explains how the WRF Model simulated values relate to observed values using four statistical metrics: correlation coefficients (r), root-mean-square error (RMSE), mean absolute error (MAE), and index of agreement (IOA).

Table 1: The efficiency of WRF-Chem model simulation

Observed and modeled simulations	**Avg. hourly temp**	**MAE**	**RMSE**	**IOA**	**R**
Tavg (observed)	22.37	-	-	-	-
Temp_Control (S_ Lake)	20.23	2.40	2.88	0.75	0.88
Temp_noLake (S_without Lake)	20.24	2.41	2.90	0.75	0.89
Temp flat Topography	21.56	1.80	2.24	0.71	0.77

3.2 Statistical Description

The following table shows the descriptive statistics for the hourly temperature time series. The lower and upper quartiles of observed temperature, simulated with lake temperature and simulated without lake are 19.1 °C and 25.8 °C, 17.6 °C and 22.8 °C, and 17.6 °C and 22.8 °C, respectively.

Table 3: Descriptive statistics for the hourly temperature time series

Column	Observed temperature	Simulated temperature with Lake	Simulated temperature without Lake	Unit
No. of observations	1000	1000	1000	

Minimum	15.1	15.0	13.8	℃
Maximum	31.2	26.3	26.4	℃
Mean	22.4	20.2	20.2	℃
Std. deviation	3.9	2.9	3.1	℃
Median	21.7	20.1	20.0	℃
Geometric mean	22.0	20.0	20.0	℃
Lower Quartile	19.1	17.6	17.6	℃
Upper Quartile	25.8	22.8	22.8	℃
Quartile Deviation	3.4	2.6	2.6	℃
Std. Error of Mean	0.1	0.1	0.1	℃
Coefficient of variation	17.4	14.3	15.1	%
Mean Deviation	3.4	2.5	2.6	℃

3.3 Effect of Lakes on Local Temperature

3.3.1 Hourly Temperature Temporal Variation

During the wet season, the lake absorbs energy, while the land reradiates it into the atmosphere. As a result, air over land is warmer than that over the surface of lakes. During the dry season, the energy collected by the lake water is gradually released into the atmosphere, making the air over the water warmer than the air over the land.

Hourly temperature time series give good indications of typical climate patterns and expected conditions. The simulated hourly weather data have been analysis 1km by 1 km. The hourly temperature anomaly for flat topography simulations is positive. This suggested that the simulated flat topography temperature was warmer than the simulated with lake, although the simulated without lake was slightly higher than the simulated with lake.

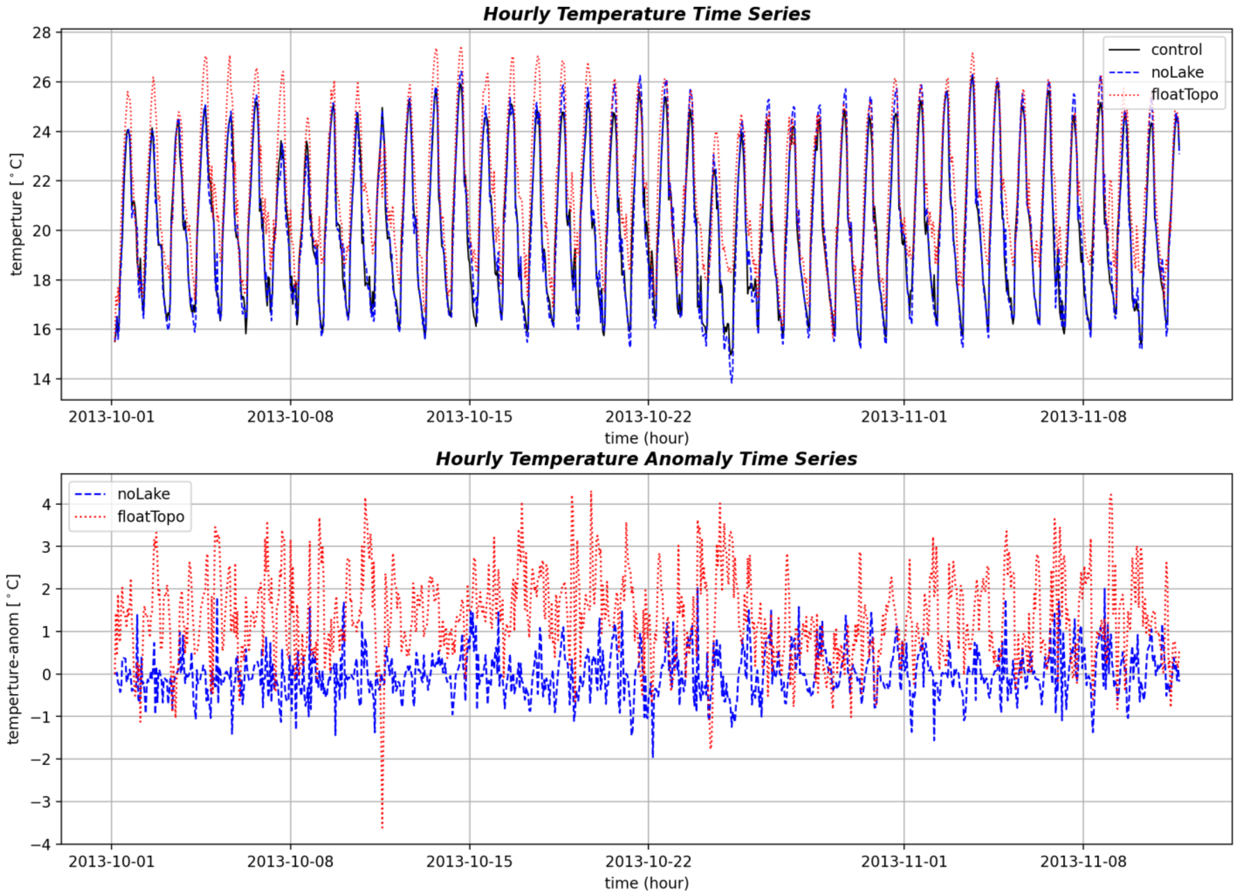


Figure 2: Hourly temperature time series and hourly temperature anomaly

3.3.2 Hourly average Temperature Spatial variation

The effect of temperature (S-without Lake minus S-with Lake) was more evident in the northern, southeast, and south-west parts of Lake Abaya, as well as the southern section of Lake Chamo. The highlands of Arba Minch have colder temperatures than the lowlands. The temperature in lake areas ranges from 20 to 25 °C. If there are no lakes around Arba Minch, the temperature drops in a narrow area. Wen et al. 2015 reported that lakes have a considerable impact on local climate, with varying effects throughout space and time. The spatial temperature distribution with and without Lake were displayed in Figure 4 and 5.

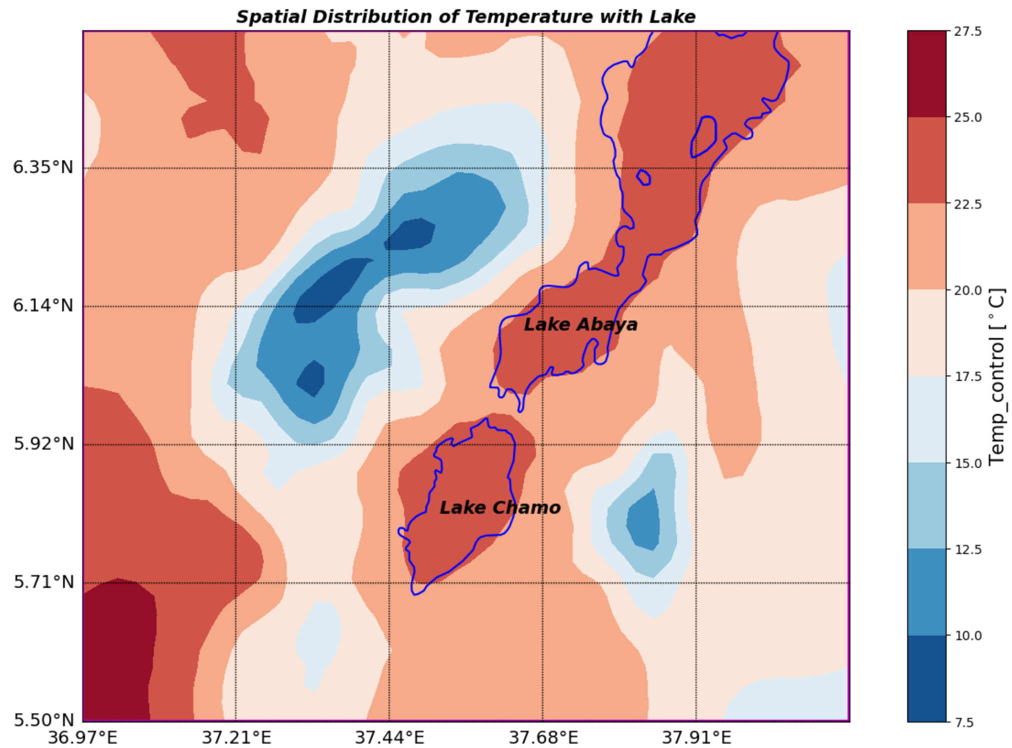


Figure 3: Spatial analysis of temperature with Lake

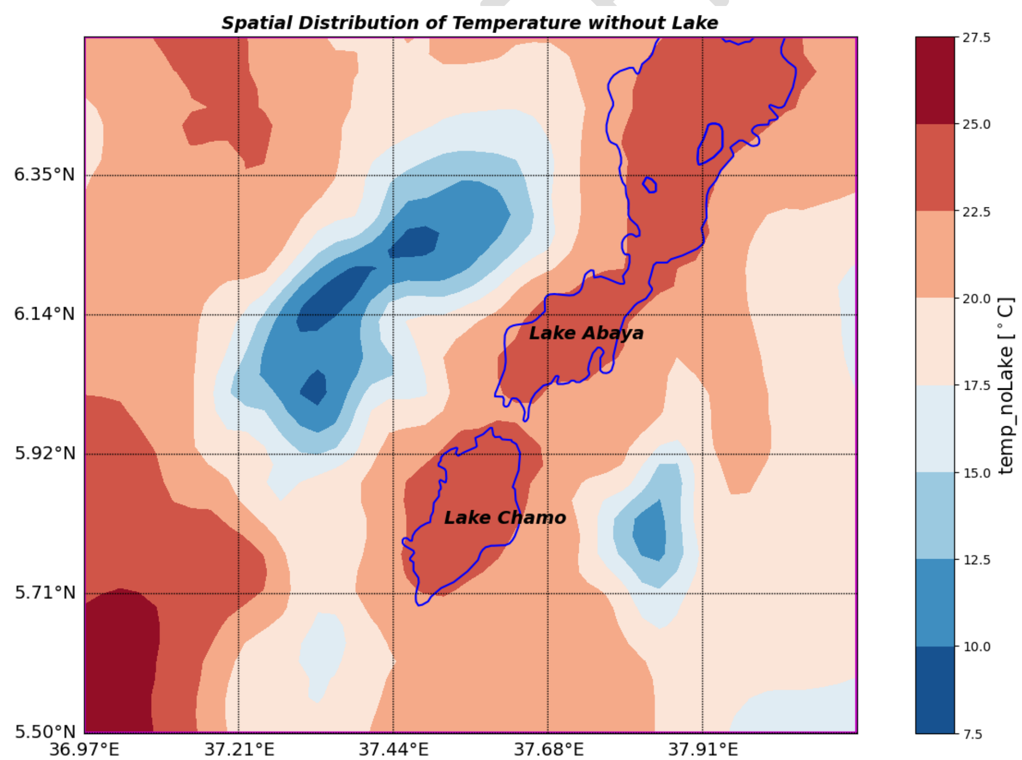


Figure 4: Spatial analysis of temperature without Lake

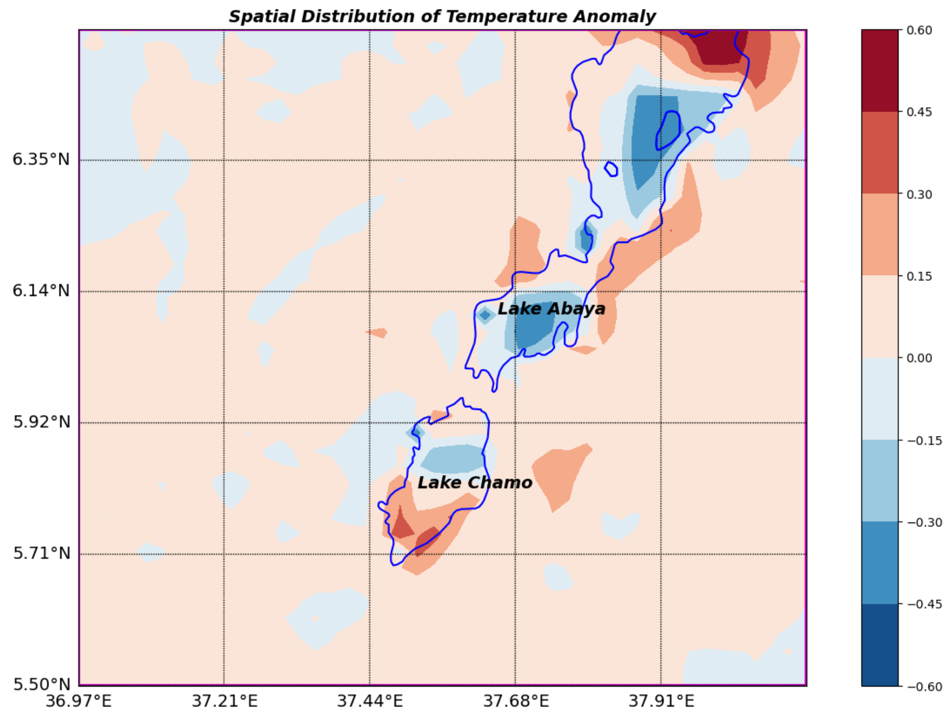


Figure 5: Spatial distribution of temperature anomaly (Temperature without Lake minus Temperature with Lake)

3.3.2 Average Diurnal Temperature Variation

Figure 7 indicates that the average diurnal temperature of Arba Minch start to rise at 7:00 AM and continue to increases up to 1:00 PM then it decreases rapidly in all cases. The average diurnal temperature reaches peak during mid-day time between 1:00 PM and 4:00 PM. Night Time is cooler than daytime. The diurnal simulated without lake temperature was greater than simulated with lake temperature from 11:00 AM to 3:00 AM.

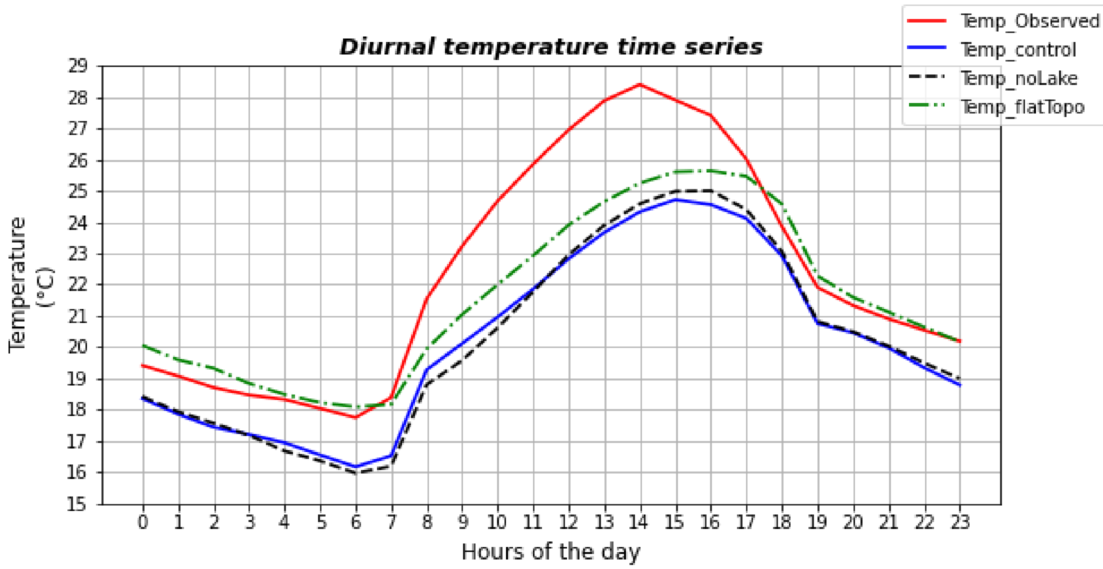


Figure 6: Diurnal temperature time series of Arba Minch town

3.3.3 Daily Temperature Time Series

The daily average temperature between simulated with and without Lake did not differ significantly, however simulated with flat topography did. In most cases, the observed daily temperature exceeded the two simulated values.

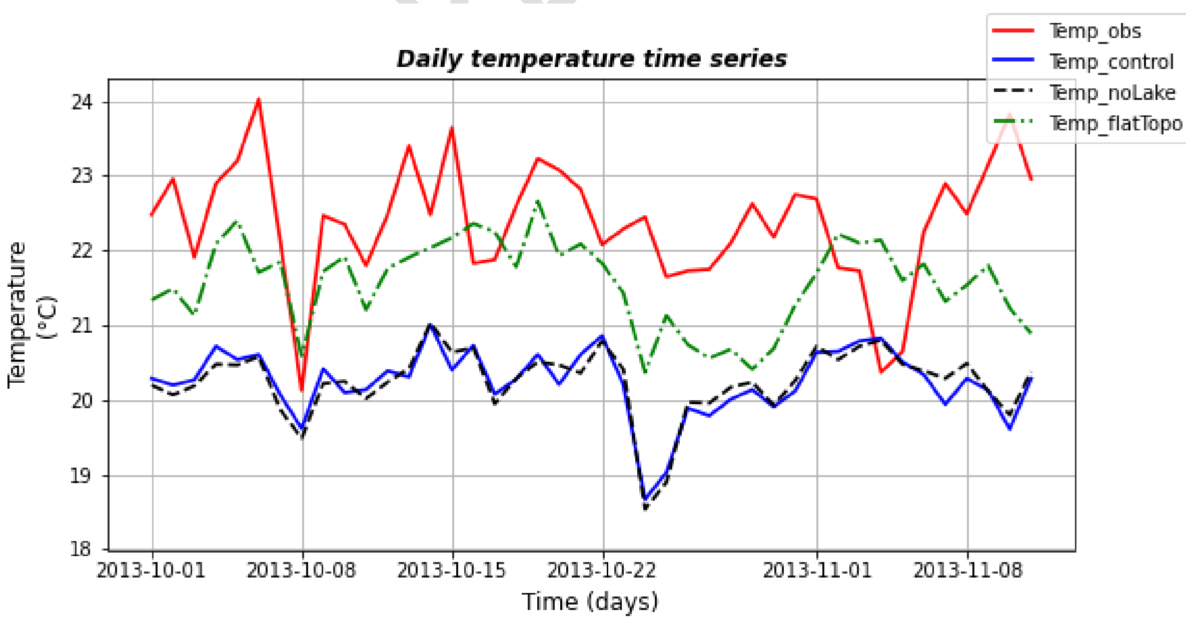


Figure 7: Daily temperature time series

The daily temperature anomaly was computed by subtracting the control value from without Lake and flat topography simulation results. The lowest daily temperature differences between simulated without lake and simulate with lake value were -0.25 ℃ and the highest difference were 0.35℃.

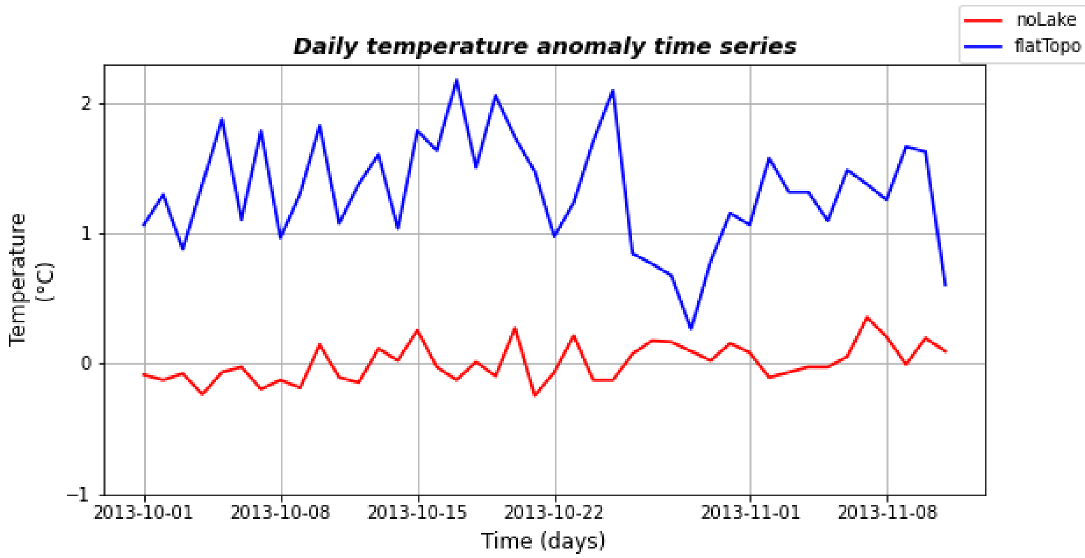


Figure 8: Daily temperature anomaly of the study area

4. CONCLUSION

The results suggest that WRF-Chem can simulate Abaya and Chamo Lakes well, both with and without lakes. The WRF-Chem model performs well for hourly temperature data. The average diurnal temperature peaked near the middle of the day. The WRF-Chem model performed well both with and without a lake, with temperatures that were virtually identical to those observed and simulated. However, the RMSE and MAE between simulated and actual statistical indices did not increase with lake temperature, indicating that it was more accurate.

During the wet season, the lake absorbs energy, warming the land more than the sea. During the dry season, lake water releases energy, making the air above it warmer. Hourly temperature data from 1km by 1km simulations demonstrate that simulated flat topography temperatures are higher than those with a Lake. The temperature anomaly is positive (Simulated without Lake minus Simulated with Lake) across the majority of Arba Minch. As a result, the presence of the two lakes is critical in lowering the temperature in Arba Minch for the majority of residents. The study demonstrates that temperature influences local climate in Lake Abaya and Lake Chamo, with lower temperatures in highlands and narrow areas devoid of Lakes.

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