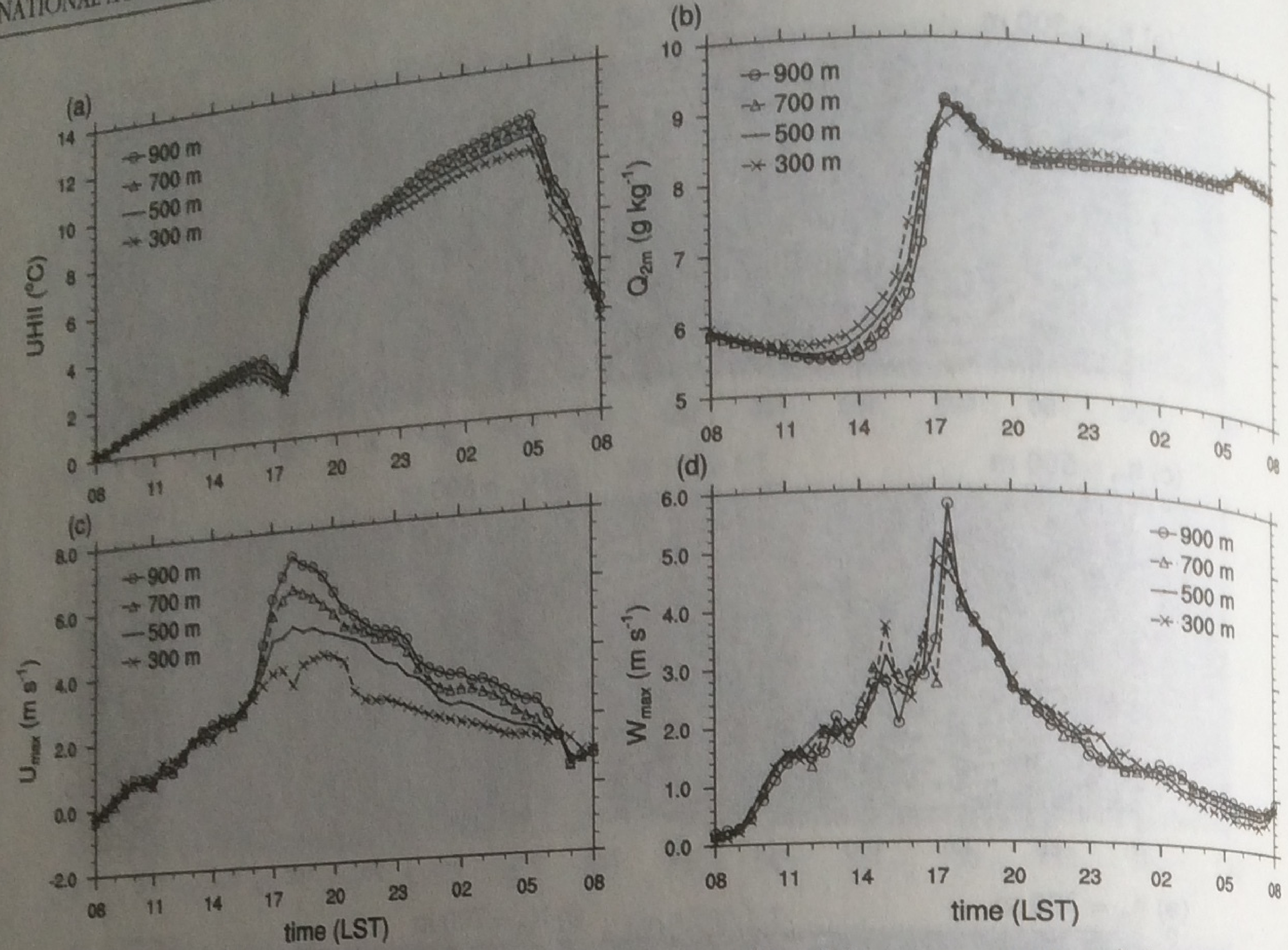

Fig. 4. Time series of (a) urban heat island intensity, (b) water vapor mixing ratio in the valley, (c) maximum horizontal velocity over the valley-side slopes, and (d) maximum vertical velocity over the valley-side slopes and the valley for the simulations with h_m = 300, 500, 700, and 900 m.

IMPACT OF MONGOLIAN GREAT LAKES ON SOME METEOROLOGICAL PARAMETERS

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Abstract

Lakes can alter the thermodynamic characteristics of the regional atmosphere. This study investigates the impact of lakes on the Mongolian Great Lakes region on summertime meteorological parameters using the Weather Research and Forecasting (WRF) model. The model results are evaluated, demonstrating good performance. The effects of the lakes on the surface energy budget include a decrease in sensible heat flux. The influence of the lakes on atmosphere varies diurnally. Greater heat capacity in water bodies compared to grasslands causes slower heating and cooling rates in the lakes. The air temperature amplitude over the lake surfaces is smaller than that over the grasslands. The lakes have profound effects on change in heat flux, as it causes relatively lower surface temperature which leads to shallow boundary layer over the lake surfaces. The winds tend to diverge due to lakes. The lakes tend to stabilize the overlying atmosphere in the summertime.

Introduction

Lakes are important systems in determining local and regional weather and climate. Lakes effectively interact with atmosphere changing heat, water vapor, and momentum fluxes [Kourzeneva et al. 2008]. Through differences in thermal and frictional properties between lake and land surfaces, lakes affect atmospheric circulations in the surrounding region [Mukabana and Pielke 1996].

The effects of lakes on atmosphere have been investigated extensively through numerical models. Unfrozen warmer lake surfaces in autumn or winter due to their large thermal inertia increase the downwind precipitation known as the so-called lake-effect snow [Scott and Huff 1996; Notaro et al. 2013a, b]. On the other hand, frozen lake surfaces reduce precipitation removing water vapor from Overlake evaporation leading to drier atmosphere [Wright et al. 2013]. Notaro et al. [2013a] revealed the influence of the Laurentian Great Lakes on regional climate by comparing the simulations with and without lakes and argued that the presence of lakes decreases (increases) sea level pressure in autumn-winter (summer), weakens cold-season cyclones and increase (decrease) turbulent fluxes during the cold (warm) season. Thiery et al. (2015) have employed the Weather Research and Forecasting (WRF) model to understand the effects of African Great Lakes on regional climate. It was revealed that lakes induce daytime cooling affecting atmospheric dynamics and stability.

The Mongolian Great Lakes region is an important basin in the Central Asia which includes over 300 lakes, among them six large interconnected lakes (saline Uvs, Khyargas, and Dorgon; freshwater Khar-Us, Khar, and Airag). The lakes are shallow and situated generally in a semi-arid land. The lakes in the Great Lakes region are certain to change the atmospheric boundary layer in the surrounding region which leads to significant impact on local and regional weather and climate. Assessment of the impact of lakes on the Mongolian Great Lakes region on the atmospheric boundary layer using the numerical models has not been performed so far. The primary objective of this study is to present the summertime impact of lakes in the Mongolian Great Lakes region on some meteorological parameters including temperature, water vapor mixing ratio, winds, boundary layer height etc.

Data and methods

The impact of Mongolian Great Lakes on the atmosphere are examined using the WRF model version 3.6.1 [Skamarock et al. 2008]. The model has been successfully applied to evaluate the possible impact of lakes on surrounding environment [Klaic and Kvakic 2014; Wen et al. 2015]. The model physics options include the Yonsei University (YSU) planetary boundary layer scheme [Hong et al. 2006], the Rapid Radiative Transfer Model (RRTM) longwave radiation scheme [Mlawer et al. 1997], the Dudhia shortwave radiation scheme [Dudhia 1989], the Kain-Fritsch cumulus scheme (Kain 2004), and the Purdue-Lin cloud microphysics scheme [Chen and Sun 2002]. The lake scheme which is derived from CLM (Oleson et al. 2010) is used.

The model contains three domains with 100×90, 145×127, and 202×172 grid points and horizontal grid spacing of 27, 9, and 3 km, respectively. The innermost domain occupies the Great Lakes region (Fig. 1). The vertical grid contains 51 levels. The initial and 6 h boundary conditions with a horizontal resolution of 1°×1° are obtained from National Center for Environmental Prediction (NCEP) reanalysis data. The innermost domain covers the Great Lakes region. The model is integrated for the period from 0000 UTC 25 June to 0000 UTC 1 August 2015. The simulation results for the one-month period are used for the analysis.

Two simulations are tested – the present state ("LAKE" experiment) and the state without lakes in the Great Lakes region ("NOLAKE" experiment). In the NOLAKE simulation, the lakes are replaced by grasslands, which represent the most common land cover type in the surroundings. A comparison between the simulations reveals the influence of the lakes to the atmosphere.

The performance of the model simulation is assessed by comparing LAKE simulation results to ERA-Interim products for temperature and sea level pressure with a horizontal resolution of 0.75°×0.75°.

Results

Figure 2 shows the surface pressure and temperature at 2 m from the ERA-Interim data and simulation results in the domain 2 averaged for July 2015. The mountainous regions show the relatively lower temperature than the basin area. The simulated patterns of the surface pressure and temperature match well with the ERA-Interim data. The differences in magnitudes are associated with the enhanced resolution of the WRF simulation.

Figure 3 shows the monthly-averaged temperature at 2 m in the LAKE and NOLAKE simulations. The regions with lower altitude or the Great Lakes basin areas show the relatively warmer temperature (~15°C higher) than its surrounding high-altitude regions. The lakes such as Uvs, Khyargas, Har-Us, Har, Uureg, and Dorgon are well captured in the LAKE simulation. The differences in temperature can be seen not only over the lakes but over the areas around the lakes. Thus, the lakes cool peripheral environment.

Figure 4 shows the daily variations of sensible heat flux, the temperature at 2 m, and boundary layer height averaged over the lakes in the Great Lakes basin in the LAKE simulation and the corresponding areas in the NOLAKE simulation. As expected, the sensible heat flux from the grassland in the NOLAKE simulation is greater than that from the lakes in the LAKE simulation. The reduction of sensible heat flux due to lakes are in agreement with Notaro et al. (2013) that the greatest reductions in sensible and latent heat fluxes are found in the summertime. The greater sensible and latent heat fluxes over the grassland surfaces result in the greater temperature at 2 m in the NOLAKE simulation than in the LAKE simulation. The grassland surfaces heat up faster than the lake surface, where the heat is absorbed by thick mixed layer, which in turn leads to the cooler lakes surface, compared to grassland. Grasslands reach the maximum of ~26.7°C while the lakes reach the maximum of ~15.2°C. Also, nocturnal cooling of the lake surfaces is much slower than that of the land surfaces. Moreover, the grassland surfaces produce considerable larger temperature amplitude than the lake surfaces highlighting the absorption of heat by water. The boundary layer in the NOLAKE simulations is convective during the daytime, in contrast, the cool lake surfaces stabilize the overlying atmosphere. The boundary layer height in the LAKE simulation is nearly steady while it varies diurnally reaching ~663 m in average in the NOLAKE simulation.

Figure 5 shows the monthly time series of the sensible heat flux from the surface, the temperature at 2 m, planetary boundary layer height averaged over the lakes in the Great Lakes basin in the LAKE simulation and the corresponding areas in the NOLAKE simulation. The time series in the NOLAKE simulation clearly show the diurnal pattern. The sensible heat flux from the lake surface is lower in the LAKE simulation than in the NOLAKE simulation. For this reason, the air in the LAKE simulation is cooler than that in the NOLAKE simulation. The maximum difference in temperature between the simulations reaches ~15.9°C. It should be noticed that the difference is greater in the daytime than in the nighttime. The sign of negative sensible heat flux in the LAKE simulation implies that the air temperature over the lake is warmer than the lake surfaces. Accordingly, it may accompany the temperature inversion over the lakes which remain worth for further investigation. In response to decreased sensible heat flux and cooler temperature, the boundary layer is suppressed by ~848 m in maximum.

To further explore the horizontal patterns of the influence of lakes on meteorological parameters, we present the mean difference in temperature at 2 m, water vapor mixing ratio vertically averaged within lowest ~100 m layer above the surface, wind fields, and boundary layer height between the LAKE and NOLAKE simulations (Fig. 6). The cooler lakes are horizontally evident with an average difference of ~8.7°C. Drop in water vapor mixing ratio over the lakes in the LAKE simulation is accompanied by suppressed evaporation from the cool water surfaces. The maximum difference in water vapor mixing ratio is ~0.9 g kg^{-1}. This is partly in agreement with the results by Notaro et al. (2013) that revealed the decrease in precipitation and evaporation caused by the presence of the Great Lakes during the warm season. The area with reduced water vapor is seen as far as ~200 km away from the lakes. The winds are altered due to the existence of the lakes, roughly showing diverging direction away from the lakes. The boundary layer height is reduced by ~564 m in average over the lakes associated with the small sensible heat flux, cooler air over the lake surfaces. These features of the changes in summertime temperature and water vapor mixing ratio resemble those found in the Laurentian Great Lakes, USA (Notaro et al. 2013).

Summary

Study on the quantitative impact of the Mongolian Great Lakes on meteorological parameters which is practically and scientifically important for meteorologists, hydrologists, and climatologists is not presently available. The present paper investigates the impact of the Great Lakes within the entire basin of several lakes on several meteorological parameters such as temperature, wind and etc. through numerical simulations using the WRF model. Lake surfaces can alter the meteorological parameters producing the cooler near-surface temperature, lower boundary layer height, diverging winds over the lakes etc. The evidence was found that the lakes cool peripheral environment likely showing potential impact on surroundings. The difference in temperature over the lakes between the LAKE and NOLAKE simulations can be 8.7°C which accompanies the shallower boundary layer. This study is the first investigation on the impact of lakes on the Great lakes basin on atmosphere using the WRF model with full physics, although, the detailed studies on the impact of other lakes in Mongolia on regional climate and the potential change of the lakes in future climate change and its feedback are worth for future studies.

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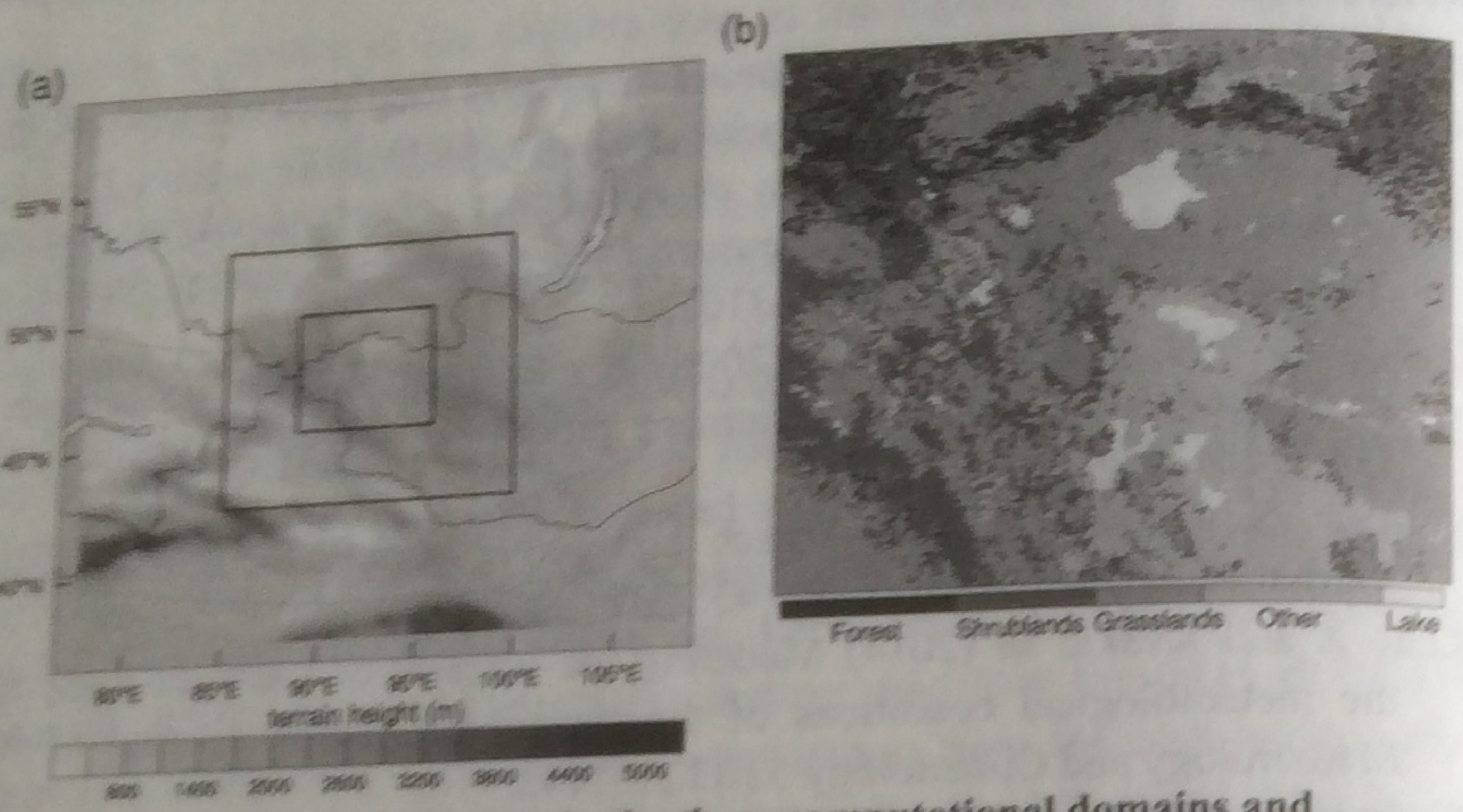

Fig. 1. (a) Terrain height in the three computational domains and (b) land use land cover (LULC) categories in the innermost domain.

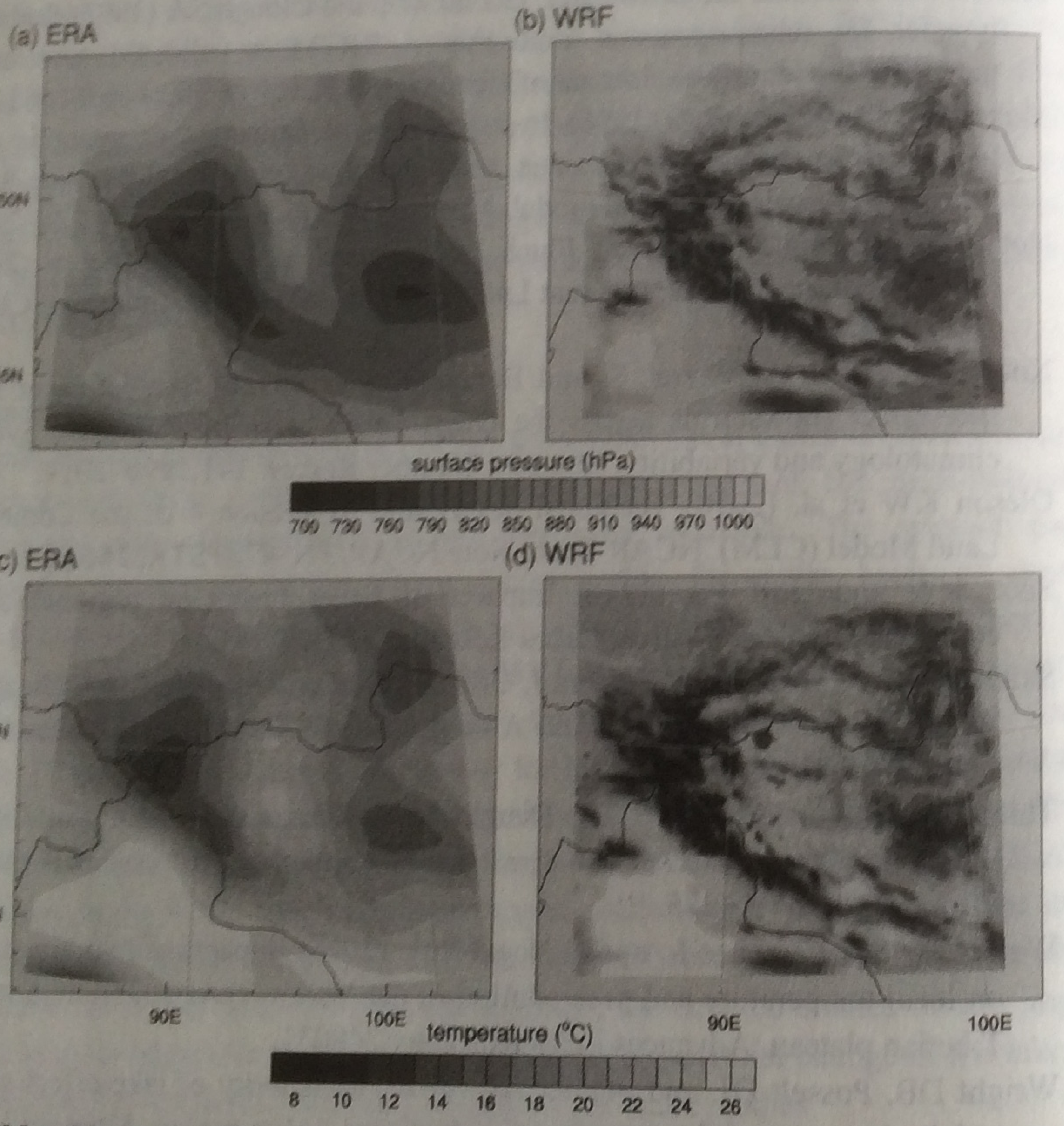

Fig. 2. Monthly averaged surface pressure (upper) and temperature at 2 m (lower) from (a), (c) ERA-Interim products and (b), (d) WRF simulation results in the domain 2.

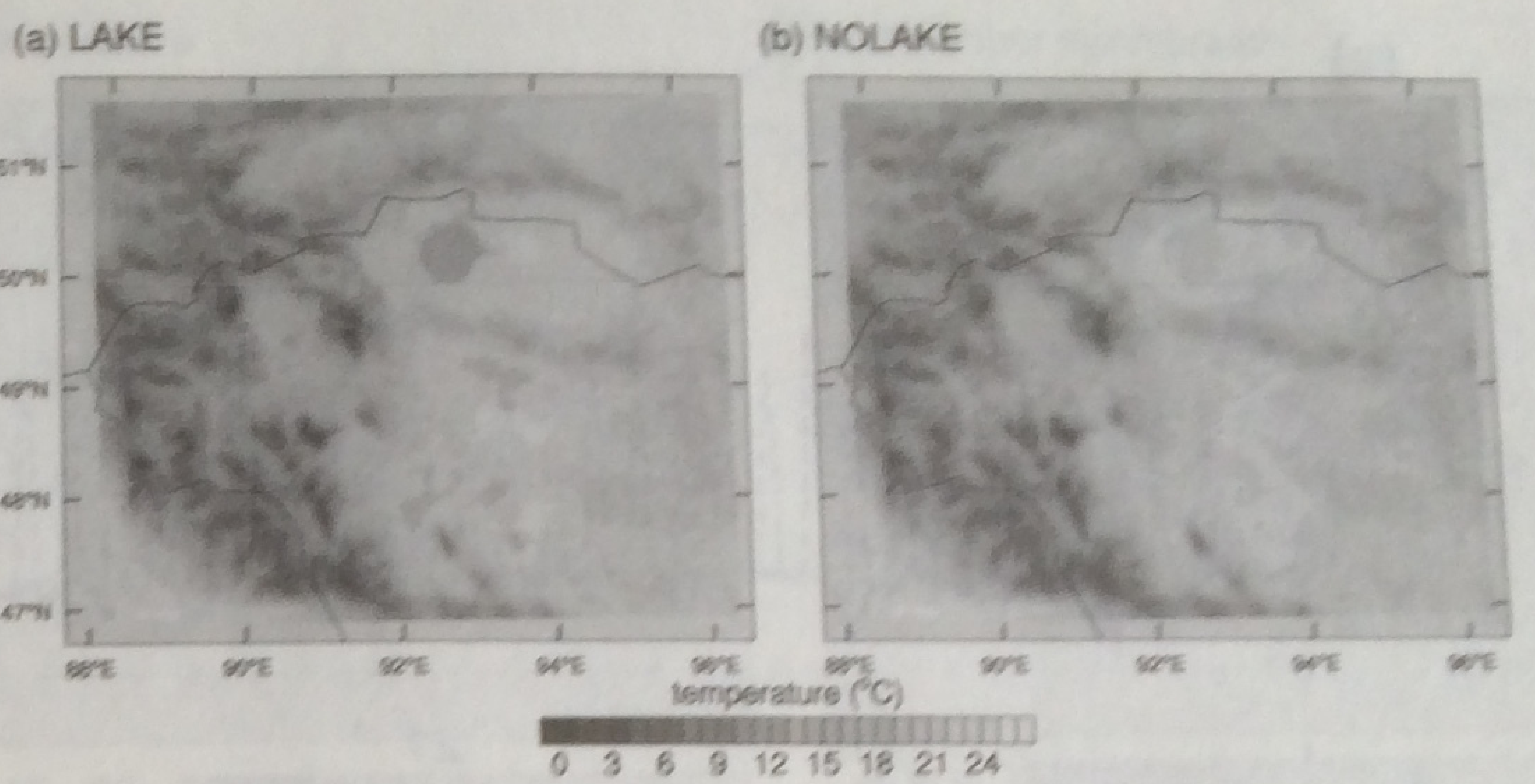

Fig. 3. Monthly averaged temperature at 2 m in the (a) LAKE and (b) NOLAKE simulations.

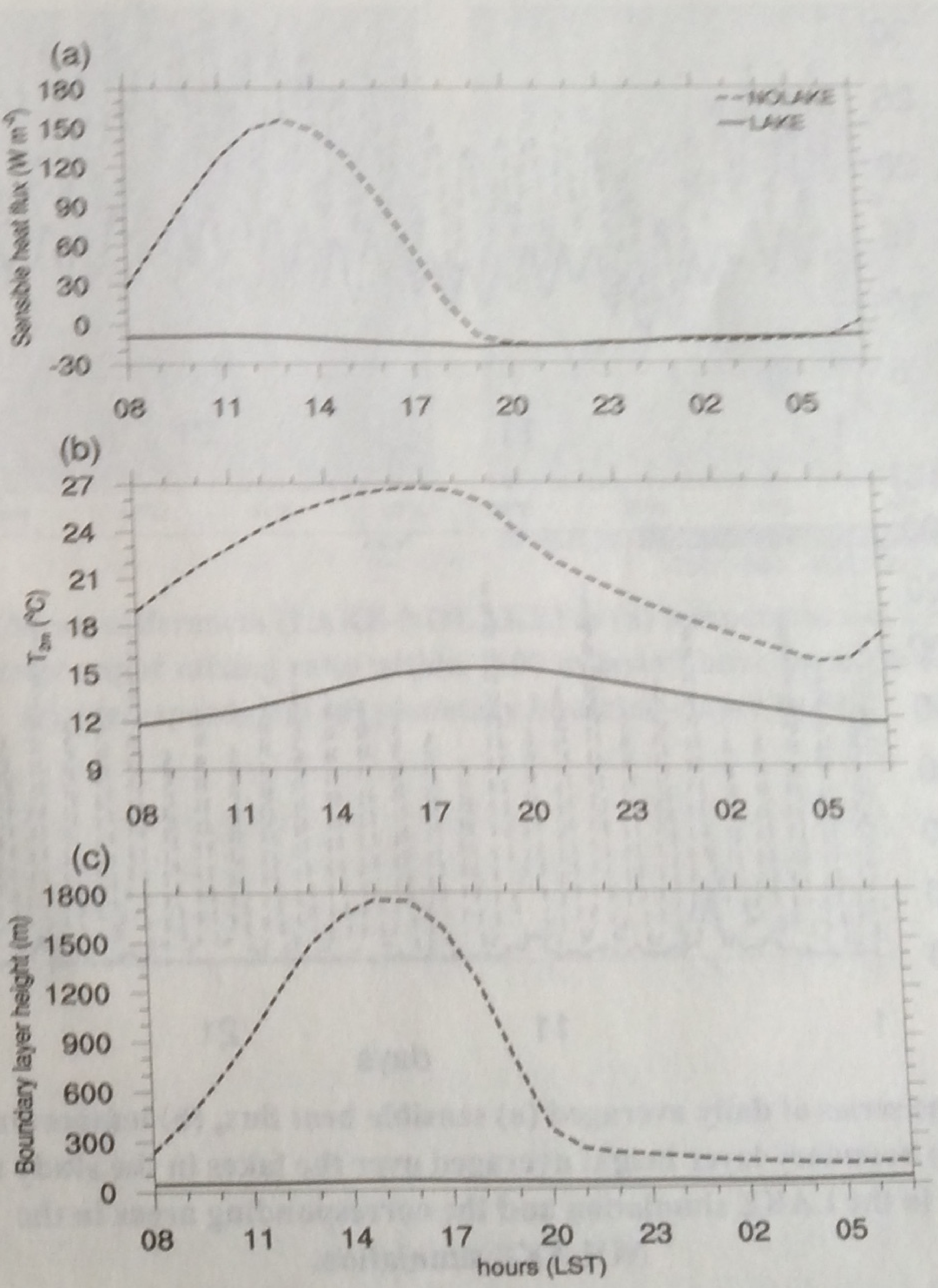

Fig. 4. Daily variations of (a) sensible heat flux, (b) temperature at 2 m, and (c) boundary layer height averaged over the lakes in the LAKE simulation and the corresponding areas in the NOLAKE simulation in the study region.

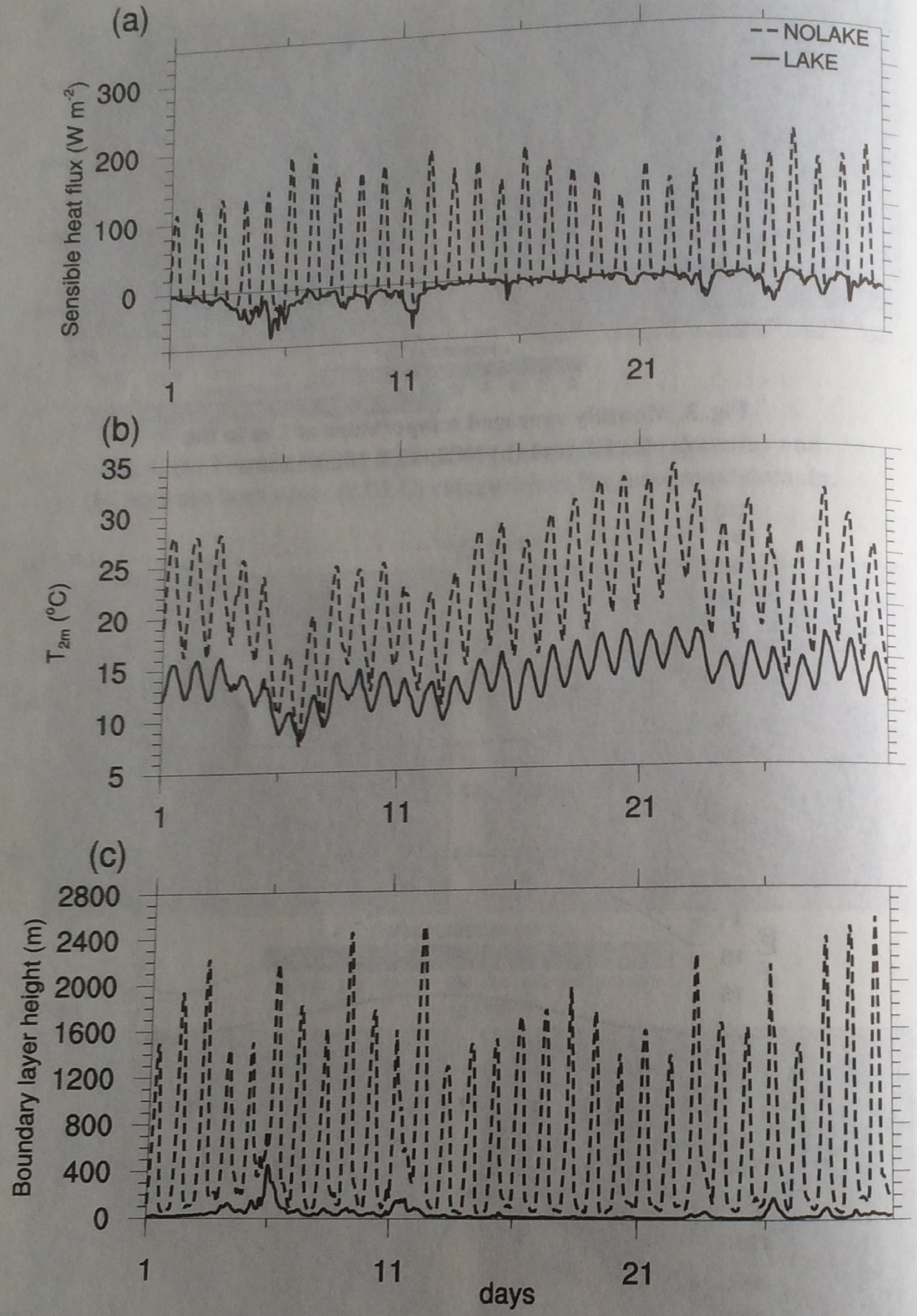

Fig. 5. Time series of daily averaged (a) sensible heat flux, (b) temperature at 2 m, and (c) boundary layer height averaged over the lakes in the study region in the LAKE simulation and the corresponding areas in the NOLAKE simulation.

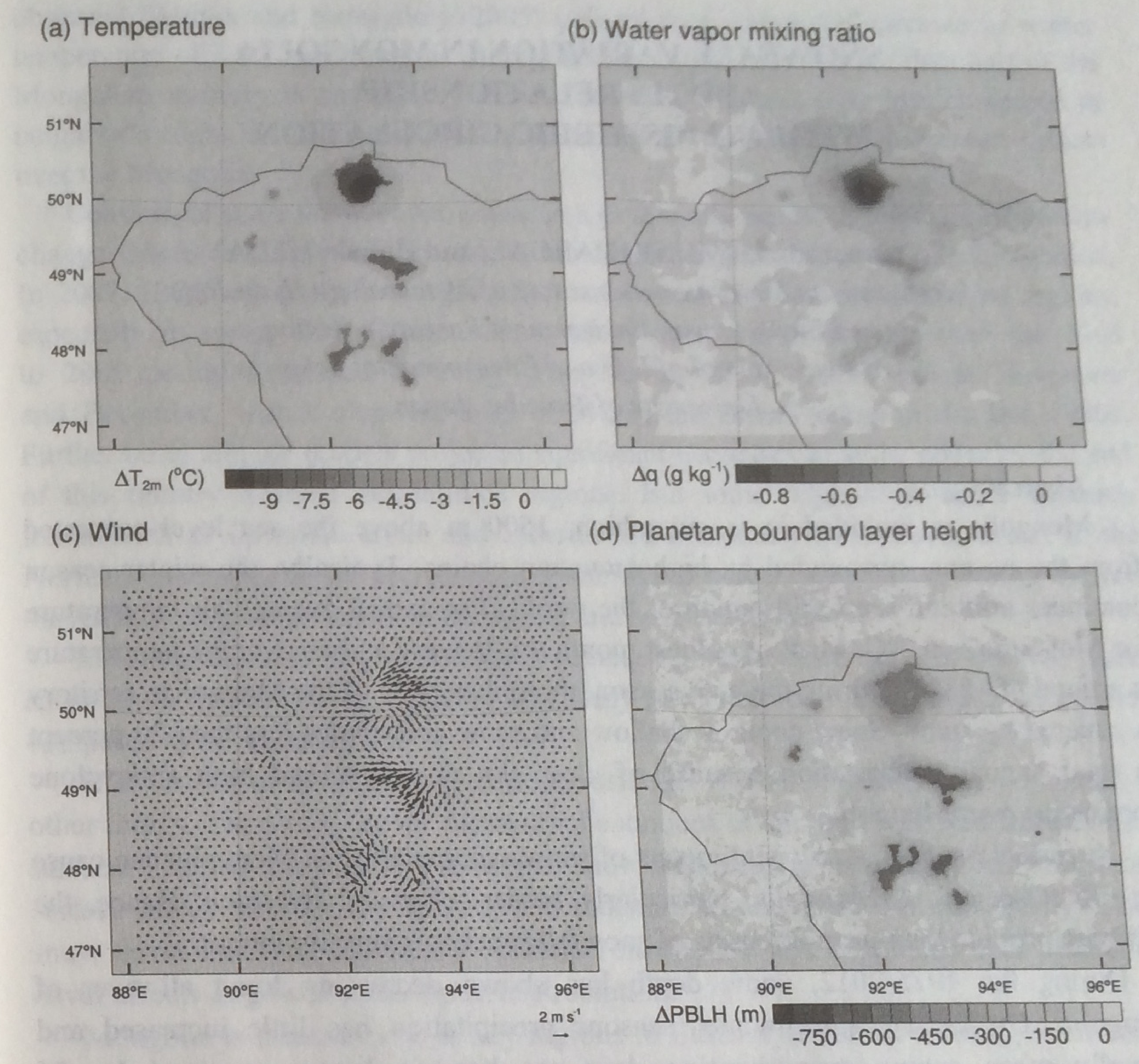

Fig. 6. Mean differences (LAKE-NOLAKE) in (a) temperature at 2 m, (b) water vapor mixing ratio within ~100 m layer above the surface, (c) wind speed, and (d) planetary boundary layer height.