Simulations of Seasonal Lake Processes for the Great Lakes using a WRF-Lake model

Baoqing Zhang, Jiming Jin, and Hongping Gu
Departments of Watershed Sciences and Plants , Soils, and Climate, Utah State University, Logan, Utah

Abstract

Lake-atmosphere interactions are vital to weather and climate predictions over lakes and nearby regions. To dynamically simulate seasonal lake processes and lake-atmosphere interactions, a one-dimensional, physically based lake model was coupled with the Weather Research and Forecasting (WRF) model to improve predictions of Lake Surface Temperature (LST) and lake-effect precipitation over lakes and surrounding area. The results show that the simulated LSTs for the Great Lakes with WRF-Lake agree very well with observations and have a better quality than those from the North American Regional Reanalysis (NARR) system that shows strong warm biases. The coupled model also reasonably reproduces the seasonal sensible and latent heat flux in the Great Lakes over the period of 2003-2008 . The warm biases in the NARR LST generate stronger surface water and heat fluxes to the atmosphere in WRF and reduce the stability in the lower atmosphere, resulting in overestimated precipitation. Lake-effect precipitation is more realistically simulated with WRF-Lake than with WRF driven by the NARR LST, indicating that the LST plays a very important role in the precipitation processes over the Great Lakes region. The coupled WRF-Lake adds to a strong capacity in dynamically predicting lake processes and lake-atmosphere interactions.

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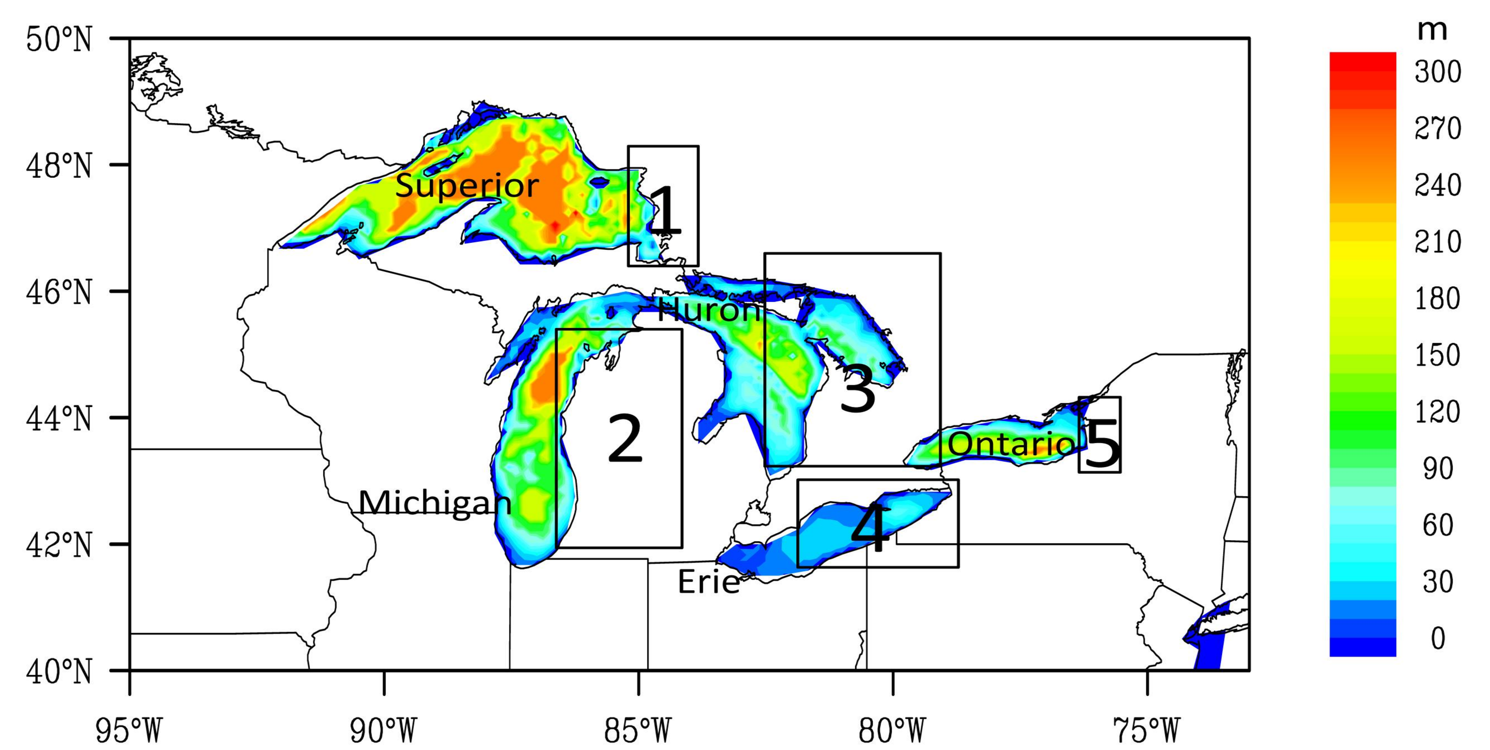

Figure 1. The above figure is for Great Lakes bathymetry observations (unit: m). Boxes 1-5 represent areas with significant lake-effect precipitation for each of the Great Lakes.

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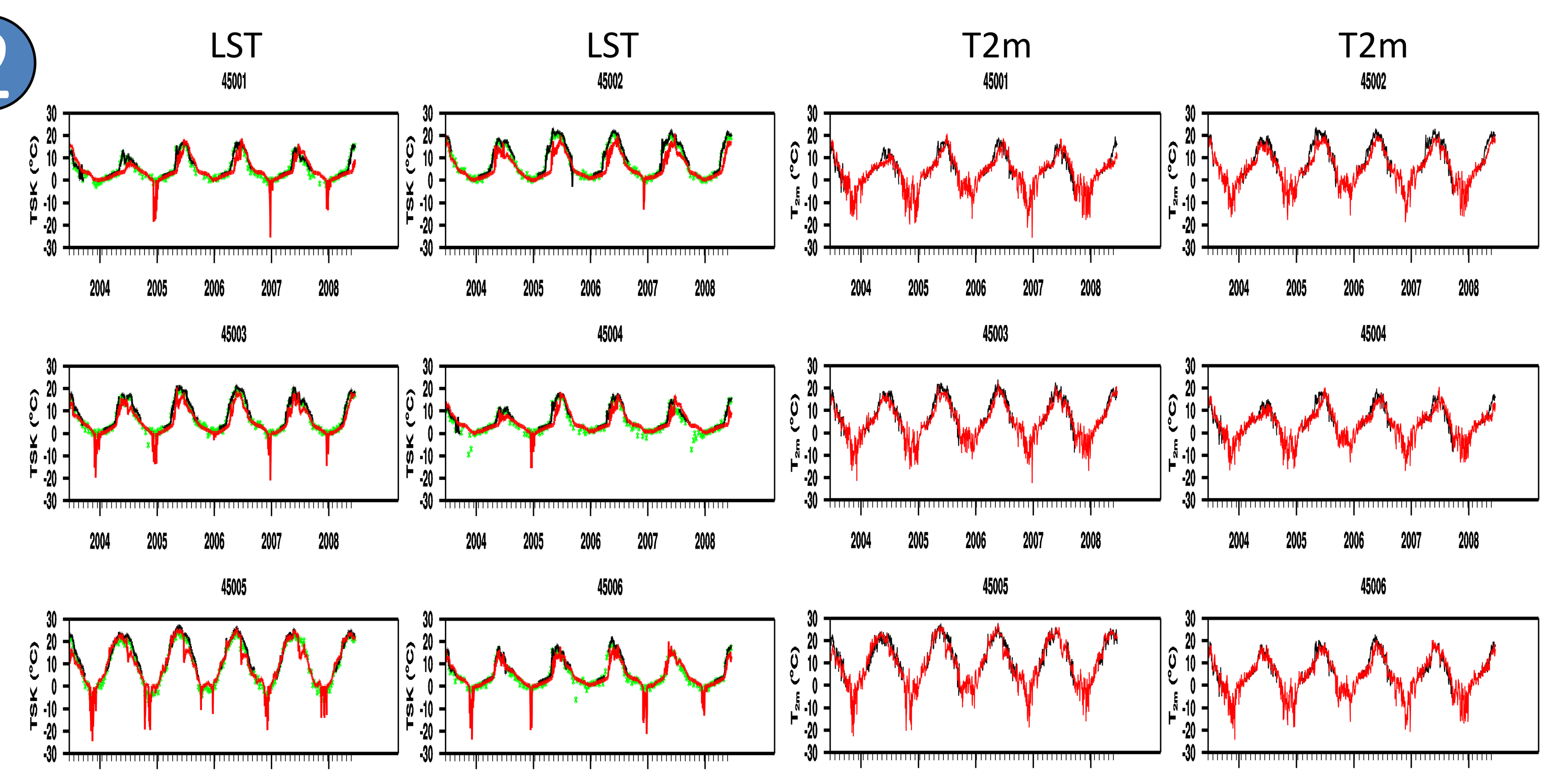

Figure 2. The above figure shows LSTs and T2m for eight buoy observation stations located in Great Lakes over 2003-2008 (Unit: ºC). Black line: observed data; green line: MODIS data; red line: WRF-Lake simulations. The LST and T2m simulated by WRF-Lake model agree well with the observations for the Great Lakes.

3

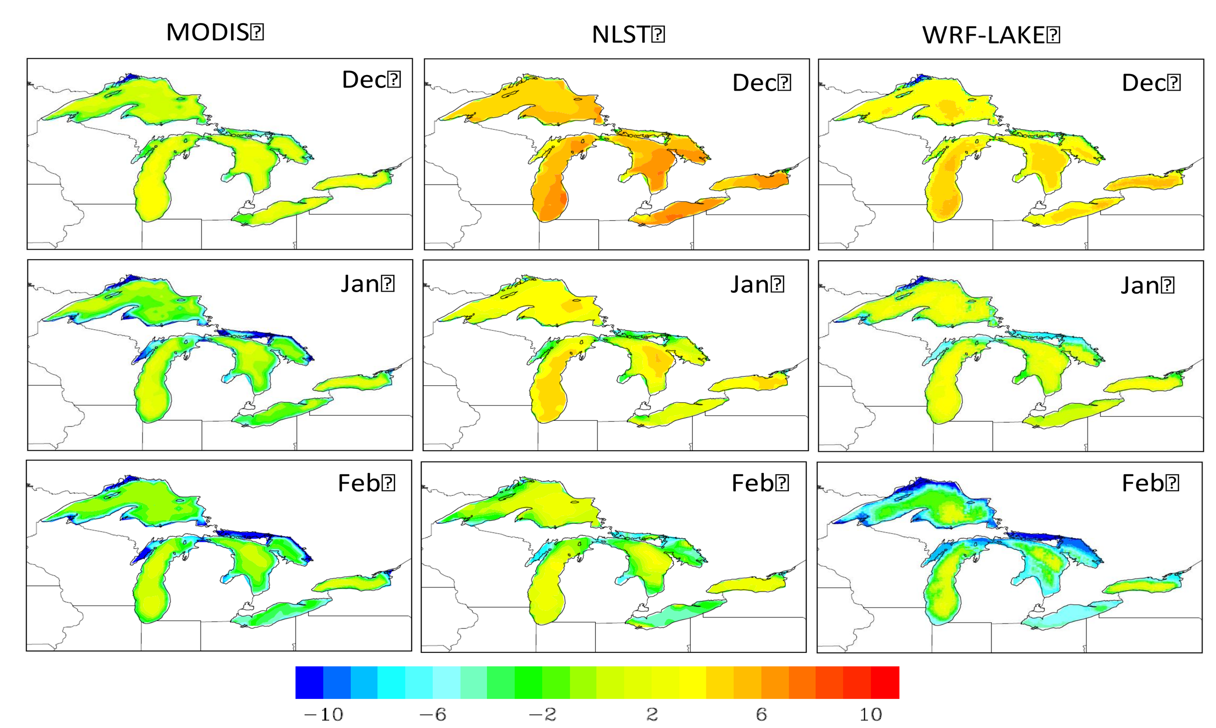

Figure 3. LSTs for the Great Lakes averaged over winter months in 2003-2008 (Unit: ºC). Warm biases are clearly seen in the NARR LST (NLST) data for the entire winter compared against the MODIS data, and WRF-Lake produced substantially better LST data for the Great Lakes.

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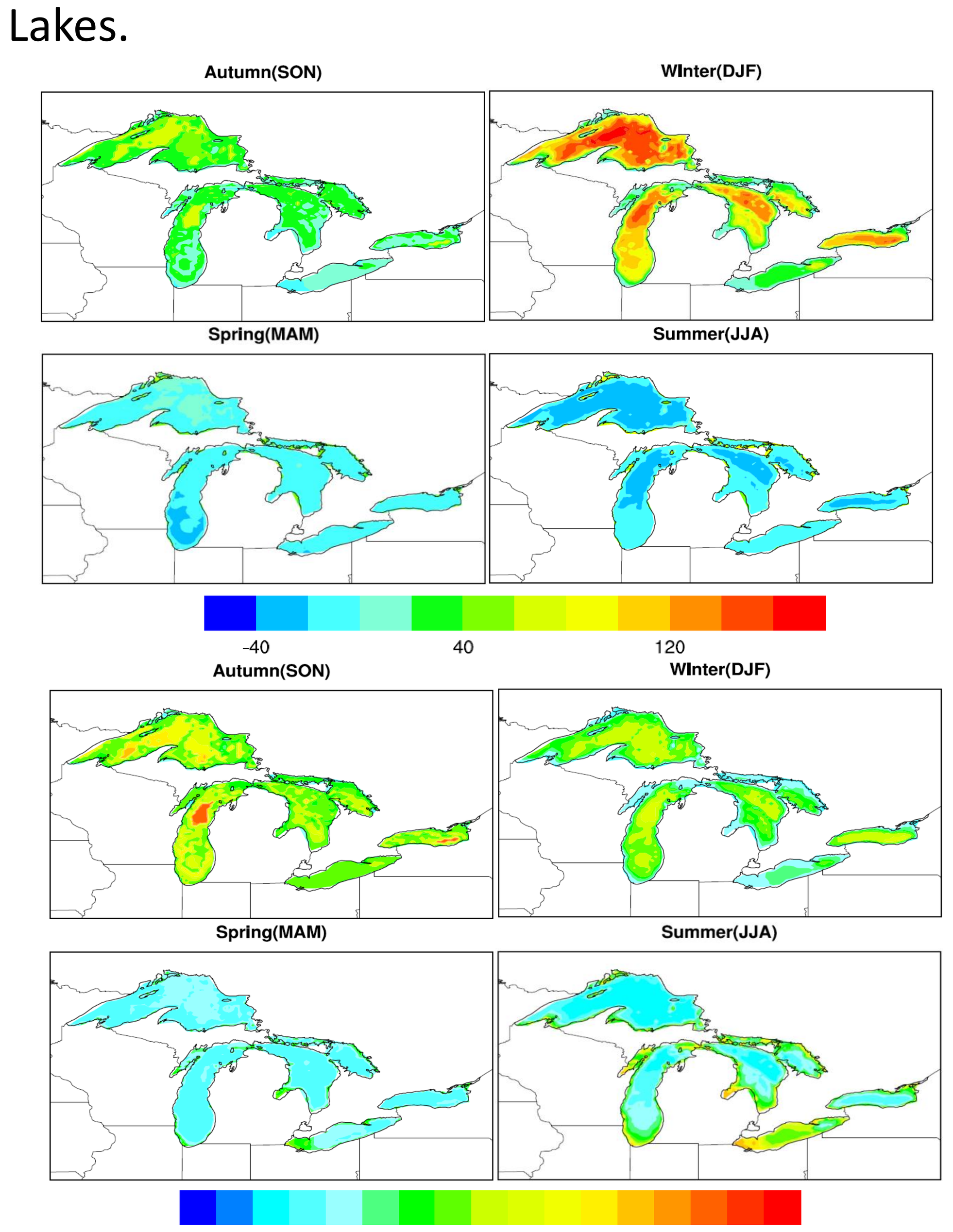

Figure 4. The left figure is for averaged seasonal sensible and latent heat flux simulated by WRF-Lake in the Great Lakes over the period of 2003-2008 (unit: W/m²). Both sensible and Latent heat flux are larger in winter, which could reduce the stability in the lower atmosphere and supplies more moisture to the atmosphere, strengthening in lake-effect winter storms.

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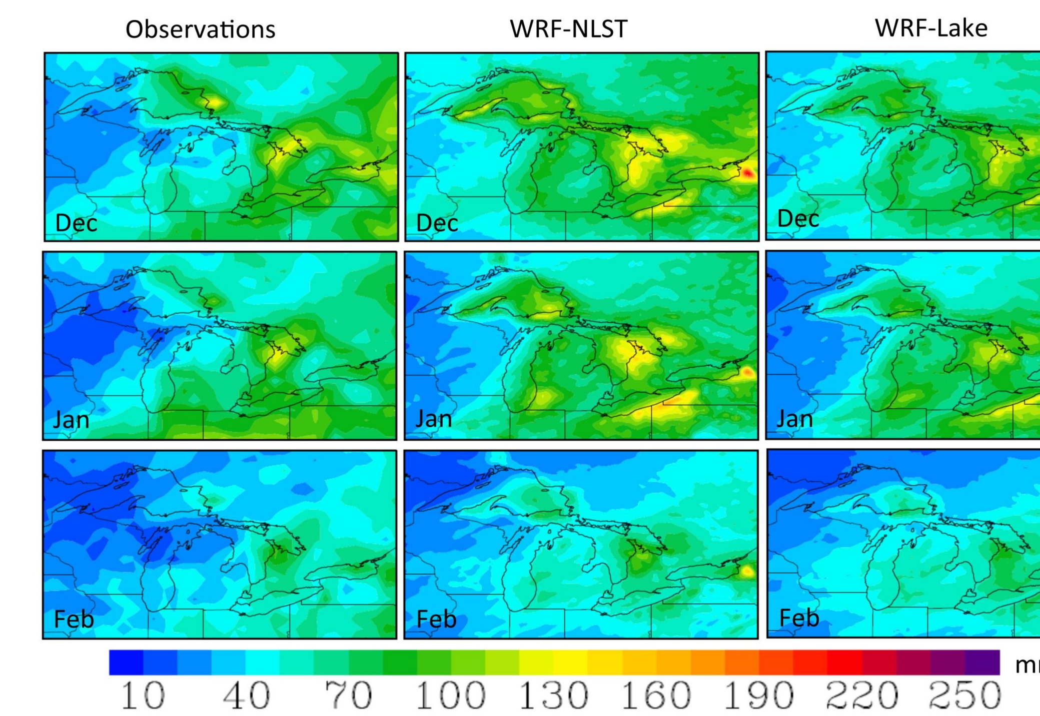

Figure 5. The left figure is for observed and simulated precipitation over the Great Lakes region averaged over 2003-2007 for December and 2004-2008 for January and February (Unit: mm/month). The warm LST bias in WRF-NLST generate stronger surface water and heat fluxes and reduce the stability in the lower atmosphere, resulting in overestimated precipitation.

When compared to observations, the simulated winter precipitation with WRF-Lake even has better quality than the high-resolution NARR data that are often used for weather and climate model evaluation.

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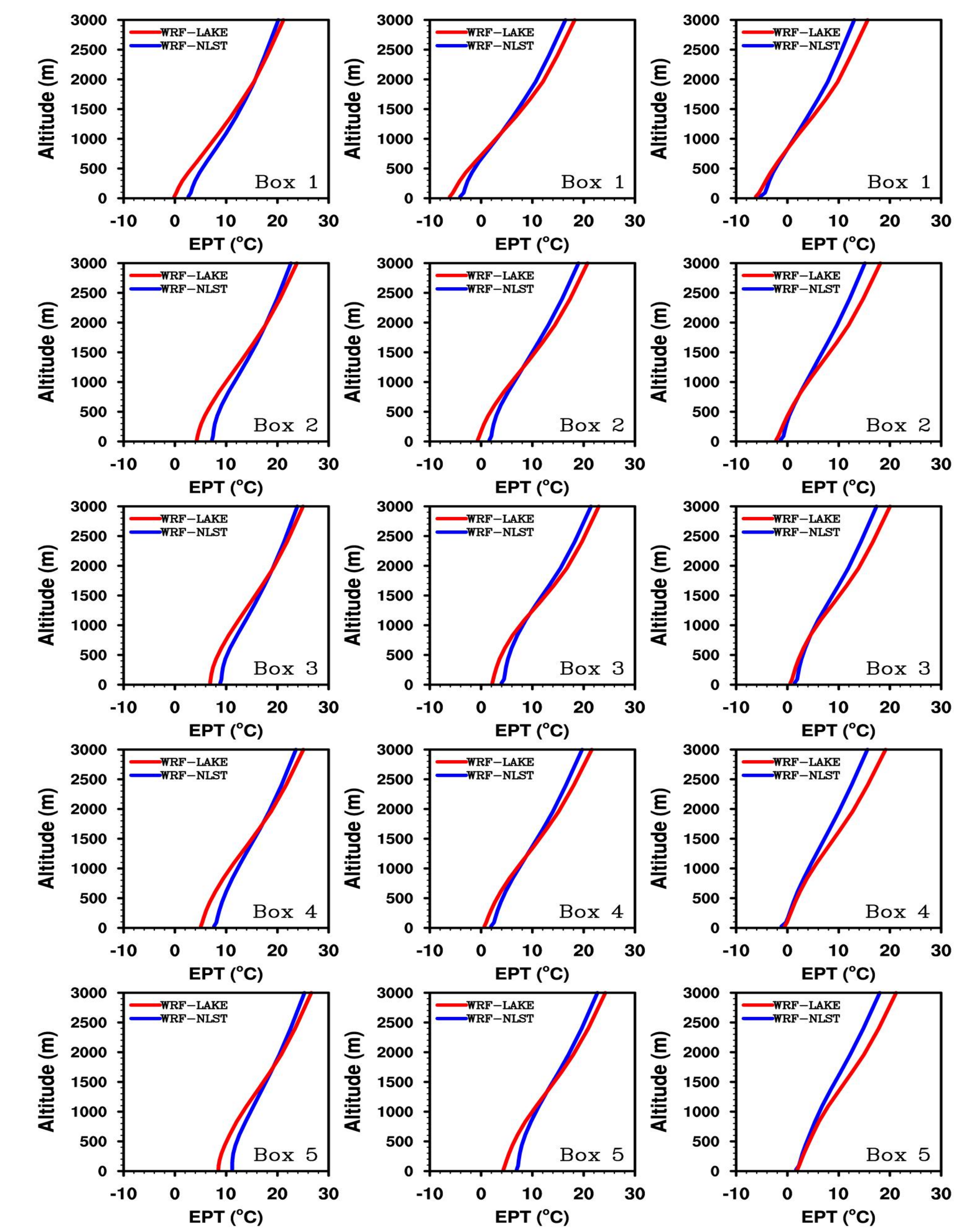

Figure 6. Mean equivalent potential temperature (EPT, unit: ºC) versus altitude above the surface (unit: m) for the significant lake effect domains averaged over winter months (Dec, Jan, and Feb) for the period of 2003-2008. Boxes 1-5 represent the five boxes in Figure 1 for the lake-effect domains. The red profile is for WRF-Lake, and the blue profile is for WRF-NLST. The EPT increases in WRF-NLST from the surface up at a rate of ~5-6ºC/km over the five lake-effect areas, while it increases in WRF-Lake at a rate of ~6-7ºC/km over the same areas. The lower and more realistic LST in WRF-Lake decreases both sensible and latent heat fluxes, increasing the stability of the lower atmosphere, reducing the surface evaporation, and thus, suppressing the overestimated precipitation mostly over the lake-effect areas as seen in WRF-NLST.

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