

**Advances in Lake-Effect Process Prediction within NOAA's Climate Forecast
System for North America**
Project Number: **NA14OAR4310191**

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Progress Report for the Fourth Year: 1 August 2014 to 31 July 2018.

Results and Accomplishments

For this project, we focused on improving the forecasts of lake-related processes in the Climate Forecast System (CFS) by coupling it with a physically based lake model. Over the four-year period of the project, we have finished (1) incorporating Freshwater Lake (Flake) into the CFS model; (2) performing ensemble forecasts with our coupled CFS-Flake model; (3) performing extensive calibration and validation for the coupled CFS-Flake model with observations; and (4) quantifying the role of lakes in the climate system over North America. For this project, we have published four peer-reviewed papers and submitted three manuscripts for peer-reviewed journals (in review). We have also given 13 project-related presentations and seminars at both domestic and international conferences and institutions.

For this project, we have conducted ensemble retrospective forecasts with the original CFS version 2 and the coupled CFS-Flake for the period of 1997 through 2016 with nine leads on our local computing platforms. We performed a total of 1,440 runs, and each run was a 9-month integration. These runs were equivalent to about 115-year simulations with each version of the CFS model. We initialized the model at 0000UTC on the 1st, 6th, 11th, 16th, 21st, and 26th of each month, with a total of 9 lead forecasts for every month. To ensure that every month had 9 lead forecasts, our model runs actually started in April 1996. A total of about 200 terabytes of data have been generated. Our model evaluations were focused primarily on the winter months, since we did not see significant simulation differences between CFS and CFS-Flake over the summer months.

1) Lake fraction and depth data

In the original version of CFS, lake points were prescribed as ocean (large lakes) or land (small lakes) (left figure in Figure 1). For this project, two sets of lake data have been developed for the coupled CFS-Flake model: lake fraction and lake depth. The lake fraction dataset is based on the U.S. Department of Agriculture-Global Land Cover Characteristics (GLCC) data at 1 km resolution. A lake fraction is considered in a CFS model grid only if it is greater than 0.1%. The lake depth dataset at 1 km resolution is based on a global dataset produced by Kourzeneva (2010), and the lake depth is set to a fixed value of 25 m if it is missing. The 1-km resolution depth data are aggregated into one fixed value for a 100-km resolution CFS grid with lake coverage. These two datasets are used as input to the coupled CFS-Flake model.

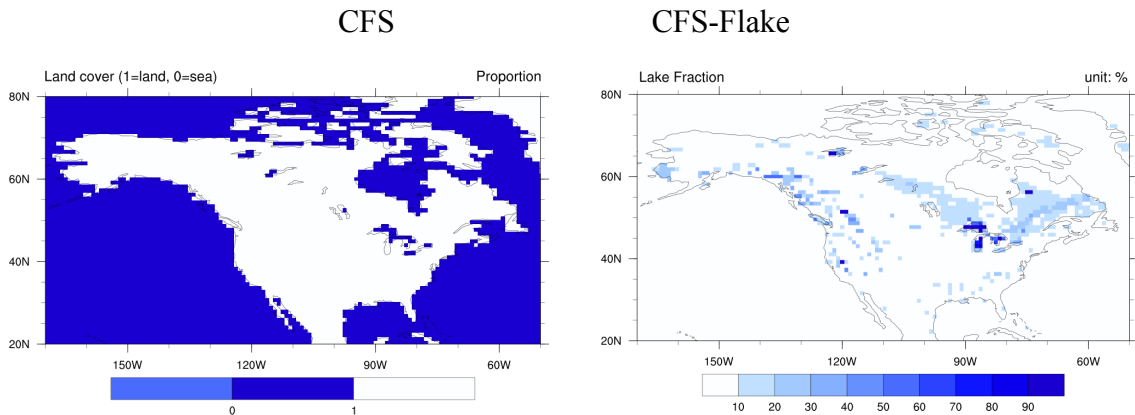


Figure 1 Lake fractions for North America for the original CFS (left) and coupled CFS-Flake (right). CFS-Flake includes the global lake fraction data. Since this project focuses on North America, we show data only for North America.

2) Surface skin temperature forecasts for North America

We first analyzed the surface skin temperature forecasts with the original CFS and the coupled CFS-Flake for North America. We can see that the simulated root-mean-square errors (RMSEs) are reduced quite significantly with the coupled CFS-Flake, when compared to those with the original CFS where the lake points are prescribed as either ocean (e.g., Great Lakes) or land (e.g., small lakes) points (Figure 2). The most significant RMSE reduction is seen in northern Canada and the Great Lakes, where lake-effect snowstorms often occur. In addition, it is seen that the averaged RMSEs of surface skin temperature simulated by CFS-Flake with different leads for North America are systematically reduced compared with those by the original CFS (Figure 3).

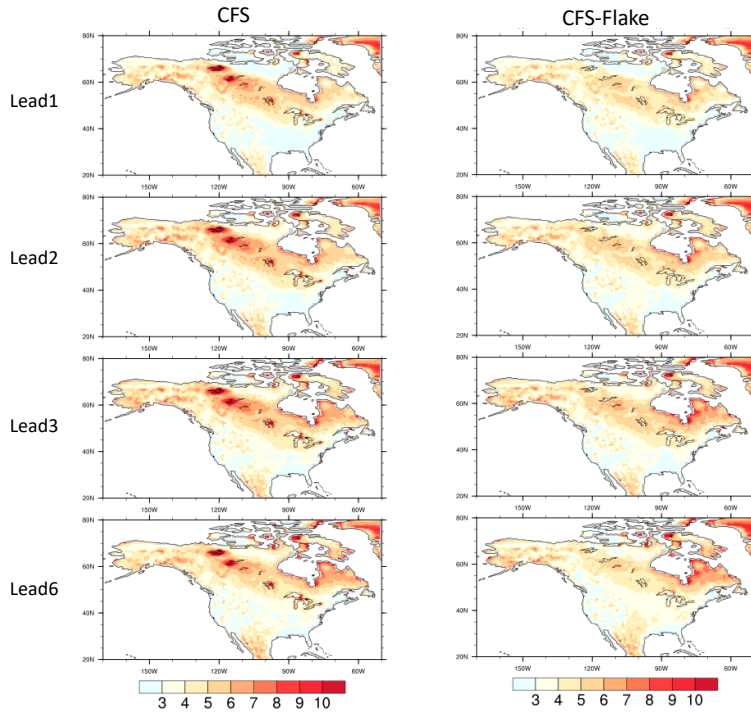


Figure 2. Surface skin temperature forecasts with CFS and CFS-Flake averaged over the winter months (December, January, and February) for the period of 2003-2016. Rows 1, 2, 3, and 4 are for lead forecasts 1, 2, 3, and 6, respectively. Columns 1 and 2 are accordingly the RMSEs of surface skin temperature for CFS and CFS-Flake. Observations are MODIS data.

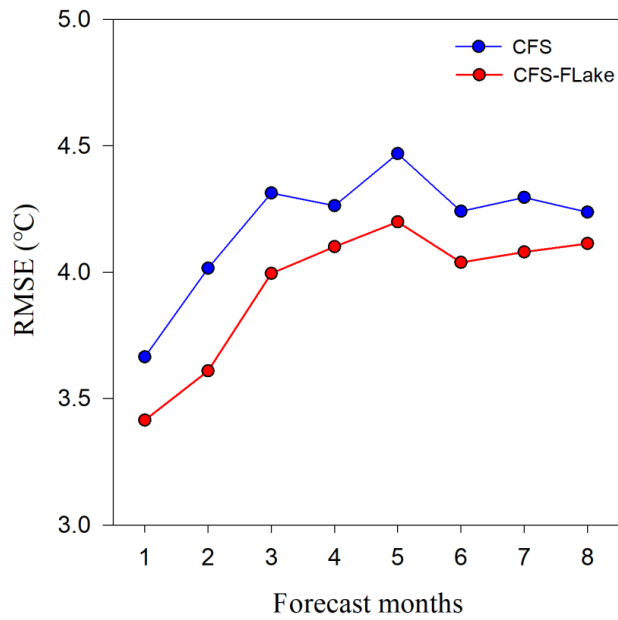


Figure 3. Averaged RMSEs of surface skin temperature over North America for the period of 2003-2016. Observations are MODIS data.

2) Precipitation forecasts for North America

We evaluated the precipitation forecasts generated with both CFS and CFS-Flake with the mean absolute percentage error (MAPE) for the winter over the same period mentioned above. The MAPE is formulated as follows:

$$\text{MAPE} = \frac{100}{n} \sum_{t=1}^n \left| \frac{A_t - F_t}{A_t} \right|$$

where t is time, A_t is the actual value, and F_t is the forecast value. The model evaluation focuses on the wintertime, when frequent lake-effect snowstorms occur in the Great Lakes area. Although the two versions of CFS do not seem to accurately capture the spatial distribution of winter precipitation (Figures not shown), the forecast skill with CFS-Flake is higher with reduced MAPE than that with CFS (Figure 4). Figure 5 also shows that the MAPEs with CFS-Flake with eight lead months are systemically lower than those with CFS.

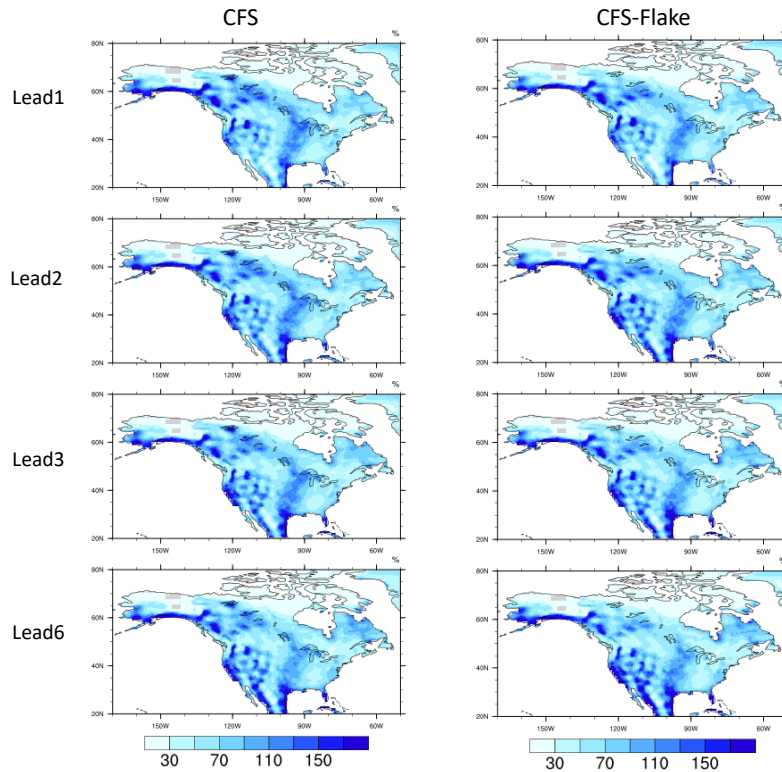


Figure 4. Precipitation forecasts with CFS and CFS-Flake averaged over the winter months (December, January, and February) for the period of 1997-2016. Rows 1, 2, 3, and 4 are for lead forecasts 1, 2, 3, and 6, respectively. Columns 1 and 2 are the MAPEs of precipitation for CFS and CFS-Flake, respectively. Observations are Climate Research Unit data.

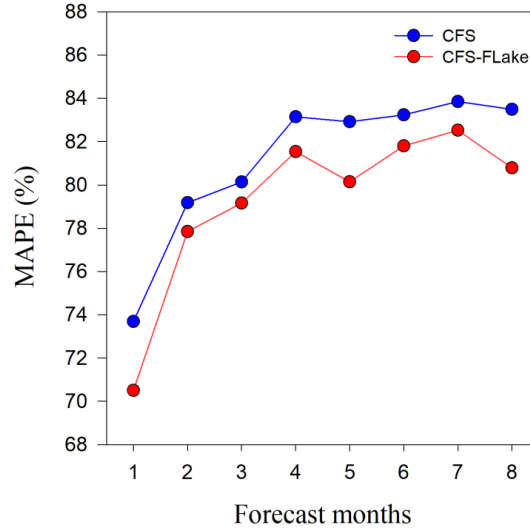


Figure 5. Averaged MAPEs of precipitation over North America for the winter months (December, January, and February) over the period of 1997-2016. Observations are Climate Research Unit data.

3) Lake ice forecasts for the Great Lakes

For this project, we focus on the evaluation of lake ice forecasts only for the Great Lakes, since observed ice coverage data are publicly available for those lakes. Here, we show the model forecasts with Lead 1 averaged over the period of 1997-2015 (the results from the other leads look similar). Based on observations, we can see that lake ice in the Great Lakes starts in December and reaches the highest level in March. The original CFS is almost unable to simulate the lake ice over the cold season due to the lake points being prescribed as either ocean or land as discussed previously, resulting in large errors in predicting the geographic distribution of lake ice. With our coupled CFS-Flake model, we have significantly improved lake ice forecasts for the Great Lakes. The main reason for this improvement is the reasonable configuration of lake points and realistic parameterization of lake ice processes in the coupled CFS-Flake model.

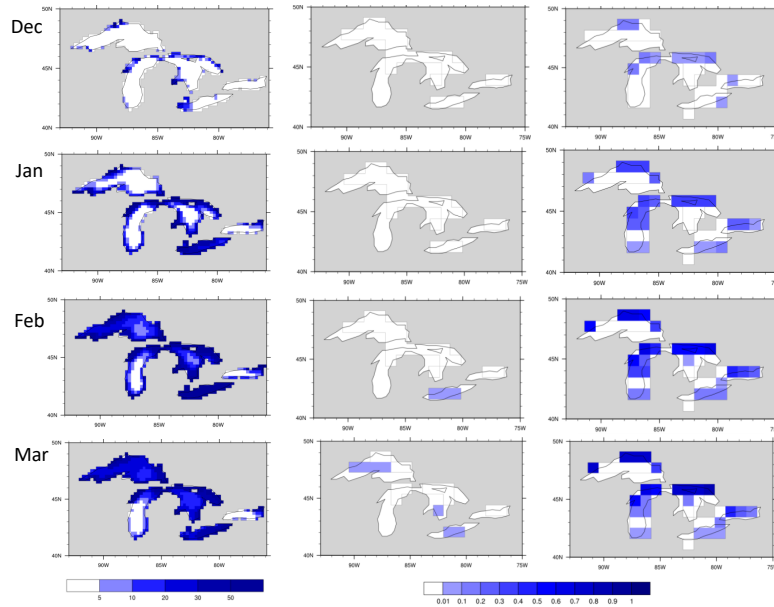


Figure 3. Lake ice fraction observations (Column 1, unit: %) and Lead 1 lake ice thickness (unit: m) forecasts with CFS (Column 2) and CFS-Flake (Column 3) for the Great Lakes for December (Row 1), January (Row 2), February (Row 3), and March (Row 4) over the period of 1997-2015.

Accomplishment Highlights

- The Flake model was incorporated into CFS.
- 20-year retrospective forecasts with nine leads were performed with CFS and CFS-Flake.
- These forecasts for North America were quantitatively analyzed with different metrics.
- Surface skin temperature, precipitation, and lake ice spatial distribution predicted by the coupled CFS-Flake over the winter months were significantly improved when compared with those predicted by the original CFS.

Publications related to this project

Jin, J., S. Zhang, M. B. Ek, and Y. Wu, 2018: Improvement of Flake simulations for deep lakes. Submitted to *Journal of Hydrometeorology*.

Lv, Z., J. Jin, S. Zhang, M. B. Ek, and Y. Wu, 2018: Improved climate forecasts with the coupled CFS-Flake model for the Great Lakes region. Submitted to *Climate Dynamics*.

Jin, J., H. Gu, M. B. Ek, and Y. Wu, 2018: Simulations of winter lake surface temperature and its effects on precipitation for the Great Lakes using a regional climate model. Submitted to *Climatic Change*.

Zhang, Q., J. Jin, and L. Zhu, 2018: Modelling of water surface temperature of three lakes on the Tibetan Plateau using a physically based lake model. *Atmosphere-Ocean*, <https://doi.org/10.1080/07055900.2018.1474085>.

- Zhu, L., J. Jin, and L. Tian, 2017: Simulations of the impact of lakes on local and regional climate over the Tibetan Plateau. *Atmosphere-Ocean*, doi:10.1080/07055900.2017.1401524.
- Dhungel, S., D. G. Tarboton, J. Jin, and C. P. Hawkins, 2016: Potential effects of climate change on ecologically relevant streamflow regimes. *River Research and Applications*, dx.doi.org/10.1002/rra.3029.
- Guo, J., X. Su, V. P. Singh, and J. Jin, 2016: Impacts of climate and land use/cover change on streamflow using SWAT and a separation method for the Xiyang River Basin in northwestern China. *Water*, 8, 192, doi:10.3390/w8050192.

Presentations related or partially related to the project since its beginning

- Jin, J., 2018: Regional climate simulations and projections. Invited Seminar, Xinjiang Meteorological Bureau, Urumqi, China, July 26, 2018 (invited).
- Jin, J., 2018: Modeling of lake processes and their role in the global climate system. Invited Seminar, Qinghai Meteorological Bureau, Xining, China, July 10, 2018 (invited).
- Balkcom, T., J. Jin, and S. Null, 2018: Modeling of the effects of climate change on Arctic lake temperature. Spring Runoff Conference, Logan, UT, March 27, 2018.
- Balkcom, T., J. Jin, and S. Null, 2018: Arctic lake temperature modeling with a physically based lake model. Annual Arctic LTER Meeting, Woods Hole, MA, February 12-15, 2018.
- Balkcom, T., J. Jin, and S. Null, 2017: Anticipating the effects of climate change on Arctic lake temperature. WATS Graduate Student Symposium, Logan, UT, April 7, 2017.
- Jin, J., 2017: Improving lake process prediction within the Climate Forecast System for North America. The NGGPS/MAPP Principal Investigators Meeting, August 2-3, 2017 (invited).
- Jin, J., 2017: Modeling of regional climate and hydrological processes. Lanzhou University, May 27, 2017 (invited).
- Zhu, L., and J. Jin, 2016: Impacts of horizontal resolution and physical parameterization on modeling precipitation over the Tibetan Plateau with WRF. The American Geophysical Union Meeting. December 12-16, 2016.
- Jin, J., 2016: The role of Tibetan Plateau lakes in regional climate systems. The Workshop for Land-Atmosphere Interactions over the Tibetan Plateau. Kunming, China, November 22-24, 2016 (invited).
- Jin, J., 2016: Simulations of lake processes and their effects on the atmosphere over the Tibetan Plateau. The International Workshop on Land Surface Multi-spheres Processes of Tibetan Plateau and their Environmental and Climate Effects Assessment, Xining, China, August 8-10, 2016 (invited).
- Jin, J., S. Zhang, M. Ek, and Y. Wu, 2015: Advances in lake-effect process prediction within CFS for North America. The NOAA Climate Testbed Meeting, College Park, MD, November 9-10, 2015.
- Jin, J., H. Gu, M. B. Ek, and Y. Wu, 2014: Lake process simulations with a coupled regional climate model. Sun-Yat Sen University, Guangzhou, China, December 2, 2014 (invited).

Jin, J., T. Crawford, M. B. Ek, and Y. Wu, 2014: Transition plan: Advances in lake-effect process prediction within NOAA's climate forecast system for North America. The NOAA MAPP-CTB project meeting, St. Louis, MO, October 21, 2014.

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