Application of the North American Multi-Model Ensemble to seasonal water supply forecasting

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Background on Great Lakes Water Level Forecasting:

Official coordinated seasonal water level forecasts are produced monthly through a collaboration between the U.S. Army Corps of Engineers Detroit District Office (USACE-Detroit) and Environment and Climate Change Canada's Great Lakes-St. Lawrence Regulation office (ECCC). These forecasts, issued during the first week of each month, are the result of coordination of 1- to 6-month forecasts of water levels produced independently by each organization. The USACE contribution to this forecast is described in **Figure 1**.

Water level forecasts are driven by forecasts of net basin supply (NBS), which represents an estimate of the supply of water to a lake, excluding flows through connecting channels and diversions (**Figure 1**). NBS is then translated to changes in water levels through the use of a regulation and routing model that incorporates regulation rules and relationships required to estimate flow through the connecting channels.

USACE Regression Model:

A simple multiple linear regression model, described by Noorbakhsh and Wilshaw (1990), relates a forecasted month's NBS to recent precipitation, temperature, and NBS, as well as forecasted precipitation and temperature. This is one of several models that USACE uses to predict NBS.

$$NBS_0 = \sum_{i=0}^{6} a_i P_i + \sum_{j=0}^{1} b_j T_j + \sum_{k=1}^{3} c_k NBS_k$$

NBS = monthly net basin supply
a, b, c = coefficients of regression
P = monthly total precipitation
T = monthly average temperature
i, j, k = month from the forecast (i.e. i=0 is the forecast month, i=1 is one month previous to the forecast month)

NMME in Great Lakes:

The Great Lakes Seasonal Climate Forecast Tool (**Figure 2**) summarizes precipitation and temperature forecasts from the North American Multi-Model Ensemble for each of the Great Lakes basins. Since 2015, USACE has used the NMME median precipitation and temperature to drive the Regression Model.

Objective:

Recent enhancements in USACE's operational procedures allow ensemble forecasting. This study investigates the potential for applying the full ensemble of NMME-derived temperature and precipitation to the USACE Regression Model for Great Lakes NBS.

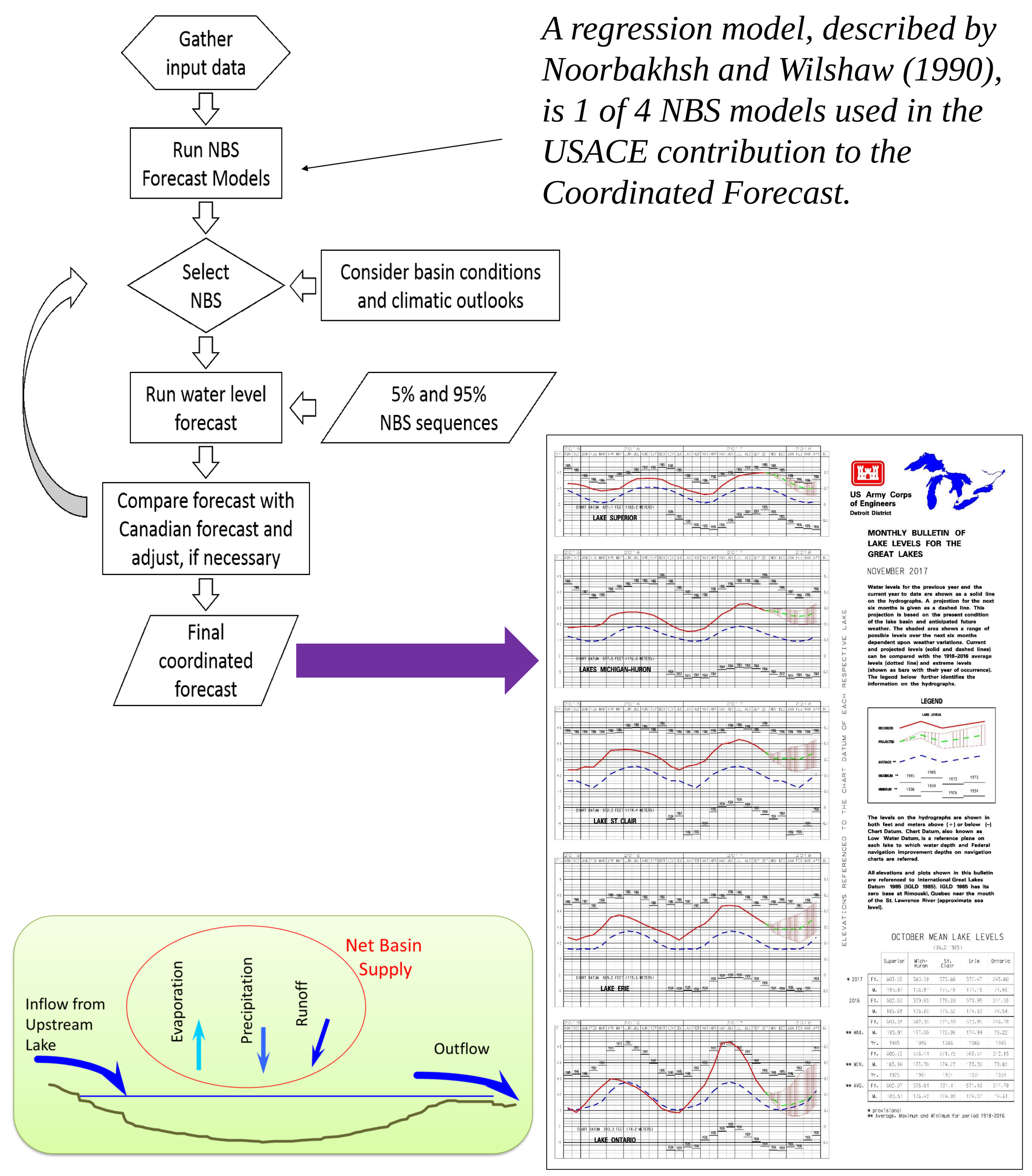

Figure 1. Great Lakes Water Level Forecasting. Water level forecasts are driven by predictions of net basin supply (NBS). One NBS model employed in the USACE contribution to the coordinated forecast is a regression model, relating forecasted months' NBS to recent observed precipitation, temperature, and NBS, as well as forecasted precipitation and temperature.

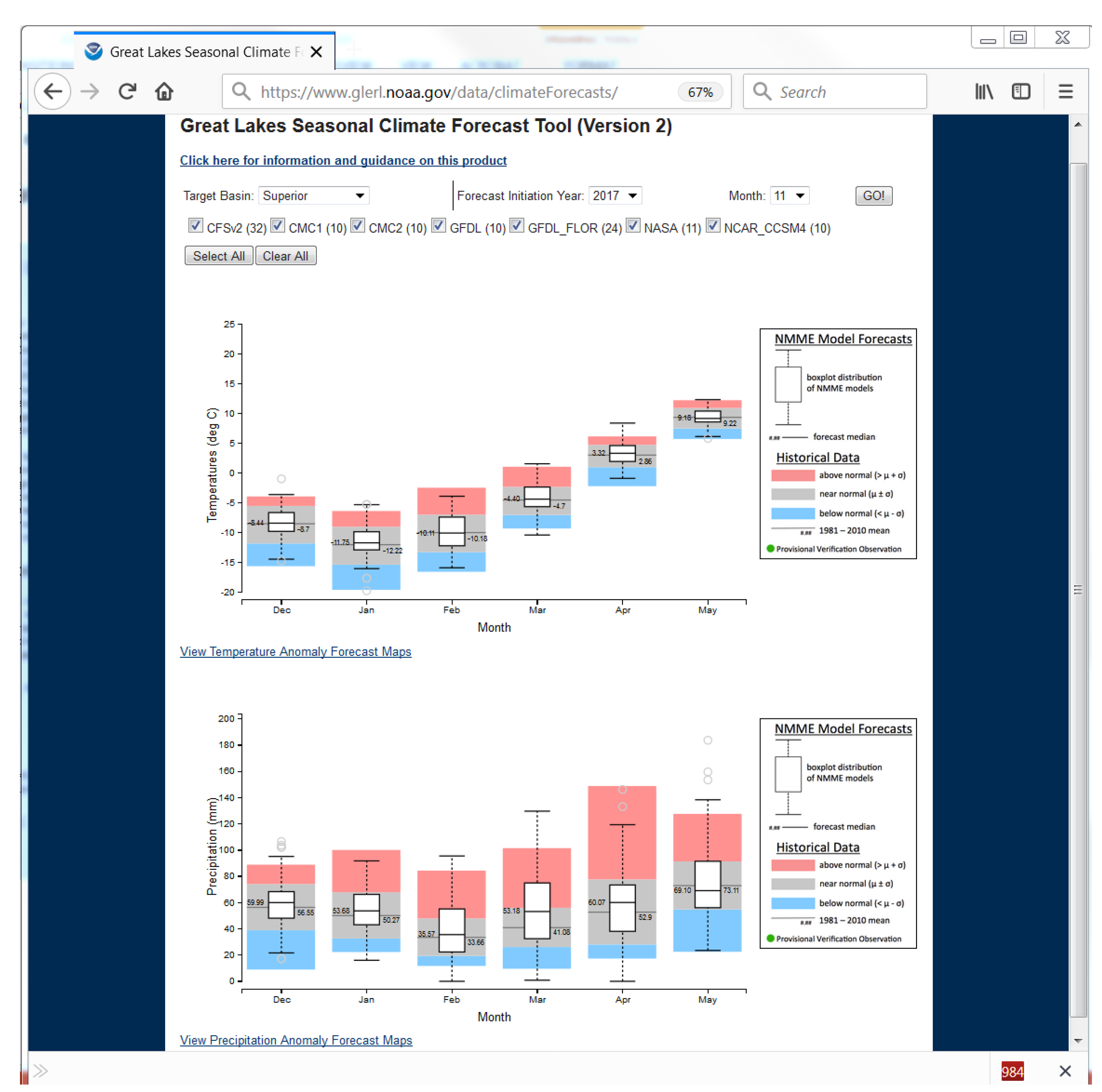

Figure 2. The Great Lakes Seasonal Climate Forecast Tool. The ensemble forecast is displayed as a box-and-whisker plot. The box contains the middle 50% range of all the members in the ensemble. Open circles show forecast outliers. The forecast median value is displayed to the left of the box-plot. The climatology is displayed as color shading, with the gray shading representing the normal range of values in the 1895 - 2015 time period. The red shading goes up to the highest value for the period of record, and the blue shading goes down to the lowest value for the period of record. This tool is described in detail by Bolinger et al. (2017).

Results:

Temperature and precipitation forecasts

1-month precipitation and temperature forecasts from the NMME model members are shown in **Figure 3** for Lake Erie in 2016, as an example.

- The variability in model member performance in each month indicates that no model(s) can be singled out for exclusion in NBS forecasts.
- Precipitation forecast uncertainty is large, and is likely to be a major factor in the expression of uncertainty in NBS forecasts.

NBS forecasts from the Regression Model

1-month forecasts of NBS for all lakes from January 2016 to October 2017 are shown in **Figure 4**.

- Representation of the variability of precipitation and temperature forecasts offers an improvement over the median forecast.
- Several extreme NBS values were within the prediction limits, with the notable exception of the May 2017 NBS on Lake Ontario, which was a record high.

Categorical skill assessment of ensemble NBS forecasts

The proportion of NBS forecast ensemble members that fall within the above normal, normal, and below normal terciles are illustrated in the stacked bar plot in **Figure 5** for Lake Ontario, as an example.

- This plot provides a forecaster with the categorical skill of previous forecasts, and is useful in the decision-making process when forecasting for the coming month.
- In the Lake Ontario example, two time periods stand out: the very dry spring/summer of 2016 and the exceptionally wet spring of 2017. Overall, during these time periods, the ensemble forecasts based on NMME model members were generally successful at predicting these dry and wet climate conditions.

Conclusions / Recommendations:

- Implementation of the regression model in an ensemble framework offers an improvement over the existing practice of selecting the NMME median for a deterministic forecast.
- Future efforts should focus on evaluating the potential for developing the ensemble regression model for application to the full 6-month forecast horizon.

References:

Bolinger, R. A., Gronewold, A. D., Kompoltowicz, K., & Fry, L. M. (2017). Application of the NMME in the Development of a New Regional Seasonal Climate Forecast Tool. Bulletin of the American Meteorological Society, (2017).

Kirtman, B. P., Min, D., Infanti, J. M., Kinter III, J. L., Paolino, D. A., Zhang, Q., ... & Peng, P. (2014). The North American multimodel ensemble: phase-1 seasonal-to-interannual prediction; phase-2 toward developing intraseasonal prediction. Bulletin of the American Meteorological Society, 95(4), 585-601.

Noorbakhsh and Wilshaw (1990). Forecasting Water Levels in the Great Lakes Using Multiple Linear Regression and Time Series Analysis of Net Basin Supplies. In Proceedings of the Great Lakes Water Level Forecasting and Statistics Symposium.

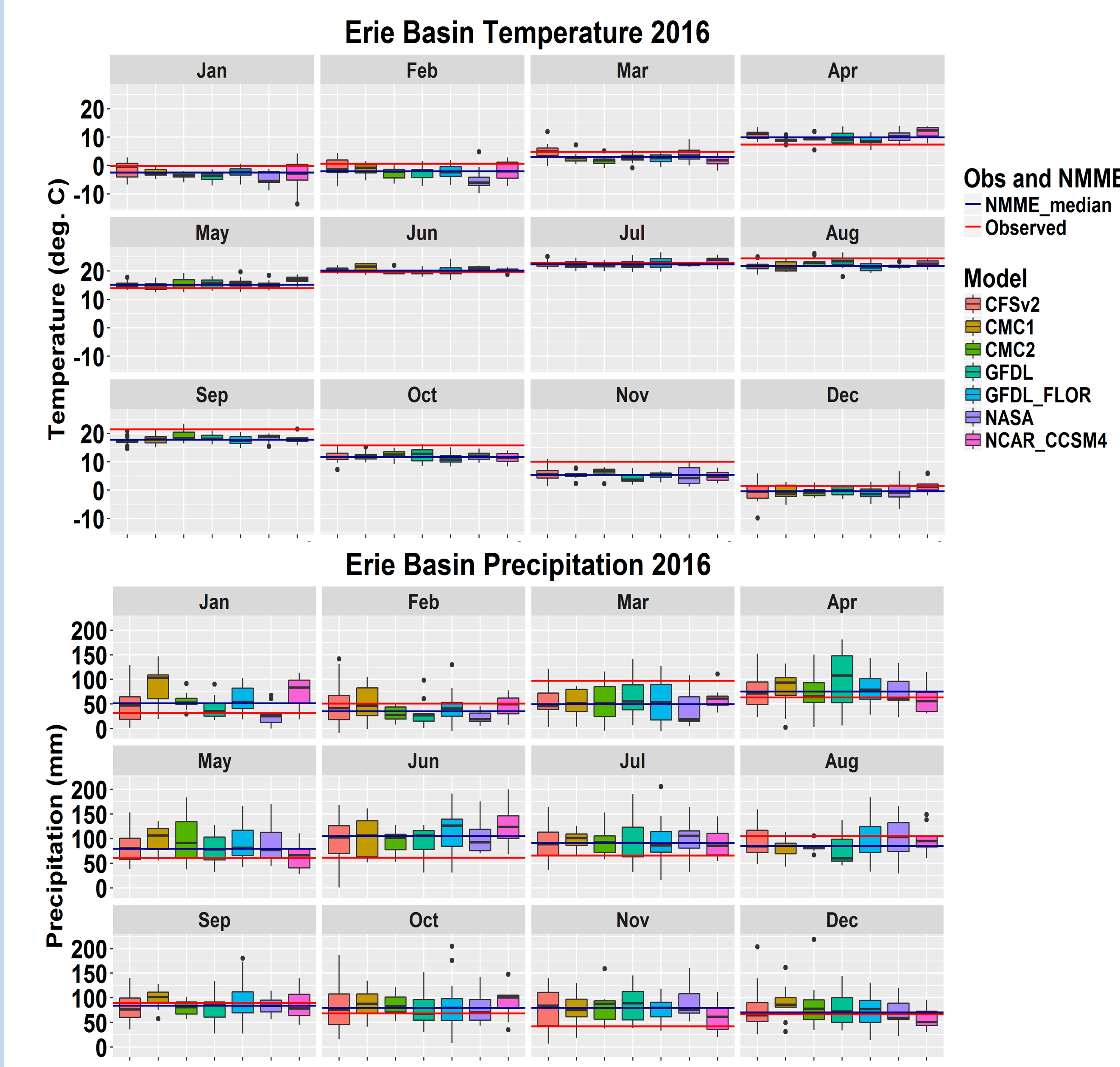

Figure 3. Temperature and precipitation forecasts from the NMME model members. The observed values are shown as a red horizontal line. The ensemble median is shown as a blue horizontal line.

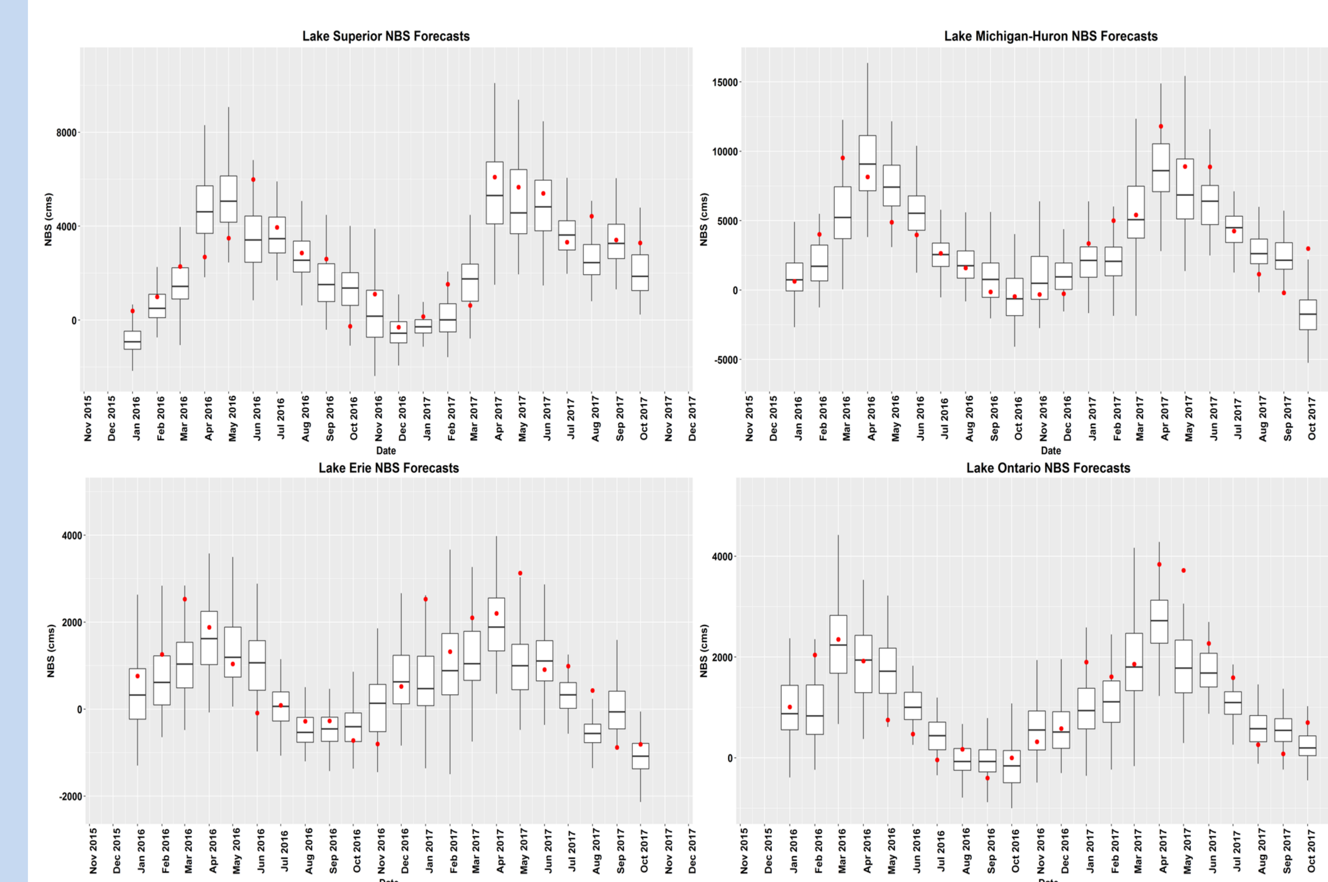

Figure 4. Retrospective ensemble regression model forecasts produced using NMME precipitation and temperature. Each boxplot represents the one-month forecast for the given month. The red dots depict observed NBS.

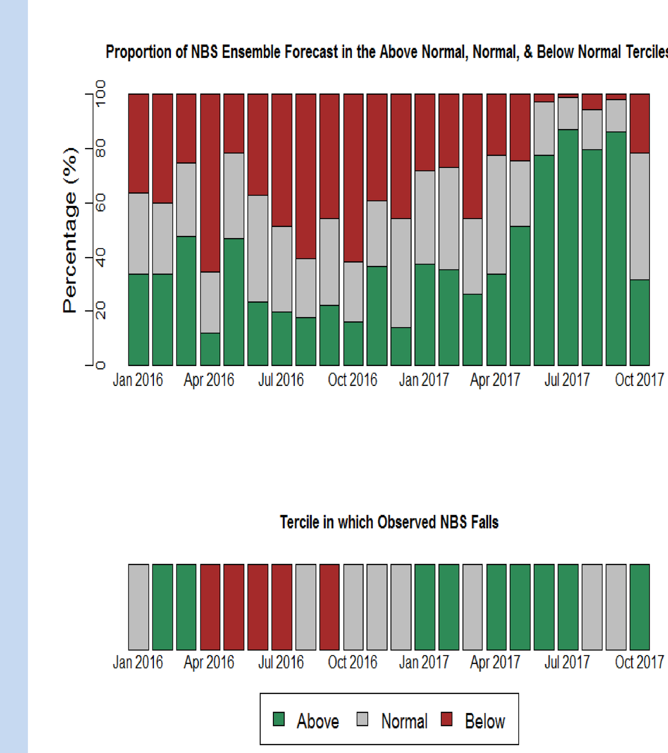

Figure 5. Categorical evaluation of the ensemble NBS forecasts for Lake Ontario. The top bar plot illustrates the proportion of ensemble members predicting NBS in the above normal, normal, and below normal terciles based on the historical period. The bottom plot represents the tercile that the observed NBS falls into.