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April 30, 2015

The Board of Commissioners of Public Utilities
Prince Charles Building
120 Torbay Road, P.O. Box 21040
St. John's, Newfoundland & Labrador
A1A 5B2

Attention: Ms. Cheryl Blundon
Director Corporate Services & Board Secretary

Dear Ms. Blundon:

Re: Newfoundland and Labrador Hydro - the Board's Investigation and Hearing into Supply Issues and Power Outages on the Island Interconnected System – Nostradamus Report

In accordance with item 2.2 of the Liberty Report Recommendations dated December 17, 2014, wherein Hydro is required to "By April 30, 2015, provide the Board an assessment of the effectiveness of Nostradamus during the 2014-15 winter and the sufficiency of the model for continued future use", please find enclosed the original plus 12 copies of Hydro's report entitled *Accuracy of Nostradamus Load Forecasting at Newfoundland and Labrador Hydro Winter 2014/2015.*

We trust the foregoing is satisfactory. If you have any questions or comments, please contact the undersigned.

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

Geoffrey P. Young
Senior Legal Counsel

GPY/jc

cc: Gerard Hayes – Newfoundland Power
Paul Coxworthy – Stewart McKelvey Stirling Scales
Sheryl Nisenbaum – Praxair Canada Inc.
Thomas Johnson – Consumer Advocate
Thomas O' Reilly – Cox & Palmer
Danny Dumaresque

ecc: Roberta Frampton Benefiel – Grand Riverkeeper Labrador

Investigation and Hearing into Supply Issues and Power Outages on the Island Interconnected System

Accuracy of Nostradamus Load Forecasting at Newfoundland and Labrador Hydro

Winter 2014/2015

Newfoundland and Labrador Hydro

April 30, 2015

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EXECUTIVE SUMMARY

Newfoundland and Labrador Hydro (Hydro) uses a short-term load forecast, with a time frame of seven days, to ensure that sufficient generation resources are available to meet the system load. The forecasts are produced using software called Nostradamus, which uses real time weather and load data and weather forecasts to predict future load.

Hydro made significant improvements to the load forecasting process during 2014 to address concerns identified during reviews of the January 2014 supply disruptions. Once those changes were made, Hydro was confident in Nostradamus's ability to provide reliable forecasts through the winter of 2014/2015.

Monthly reviews of the accuracy of the forecasts reported in the daily Supply and Demand Status reports through the winter of 2014/2015 confirmed that the changes made to the forecasting process improved the reliability of Nostradamus and the accuracy of the forecast. No erratic behaviour was observed at high loads and the average difference between forecast and actual peaks was less than 2.5%.

Statistical analyses of the accuracy of the weather forecasts provided by Amec Foster Wheeler established a baseline with which to compare future forecasts and identified several opportunities for improvement in the forecasts of the weather parameters used in the load forecasting.

Hydro is confident that with regular planned training and development of the model, Nostradamus will continue to provide Hydro with the information it needs to manage the system.

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1.0 INTRODUCTION

1.1 Short-term Load Forecasting

Newfoundland and Labrador Hydro (Hydro) uses a short-term load forecast, with a time frame of seven days, to ensure that sufficient generation resources are available to meet the system load. The availability of reserve and spinning capacity is tracked by the Energy Control Centre operators 24 hours a day and compared to the forecast load on a regular basis to aid in decisions about when to start or stop generating units. In addition, the forecast enables Hydro to keep its utility, industrial, and residential customers informed about the status of the Island capability.

1.2 Nostradamus

Hydro uses software called Nostradamus, by Ventyx (an ABB Company), for short-term load forecasting. "The Nostradamus Neural Network Forecasting system is a flexible neural network based forecasting tool developed specifically for utility demand forecasting. Unlike conventional computing processes, which are programmed, neural networks use sophisticated mathematical techniques to train a network of inputs and outputs. Neural networks recognize and learn the joint relationships (linear or non-linear) between the ranges of variables considered. Once the network learns these intricate relationships, this knowledge can then easily be extended to produce accurate forecasts." (Ventyx, 2014).

The Nostradamus model is trained using a sequence of continuous historic periods of hourly weather and demand data, then forecasts system demand using predictions of those same weather parameters for the next seven days.

1.3 Load Forecast Reporting

Internal and external reviews of the circumstances leading to the supply disruptions experienced in the Island system in January, 2014 found that issues with the short-term load forecasting did not contribute to the disruption, but, had the model been working more reliably, communications with stakeholders prior to, and during, the disruptions period could have improved. The Liberty report to Board of Commissioners of Public Utilities (the Board) of December 2014 recommended:

2.1. Provide the Board with monthly updates on the status of Nostradamus upgrades until the production model is fully in-service and shaken down (Conclusion No. 2.1 and 2.2); and

2.2. By April 30, 2015, provide the Board an assessment of the effectiveness of Nostradamus during the 2014-15 winter and continued future use (Conclusion No. 2.1 and 2.2).

Hydro made significant improvements to the load forecasting process during 2014, including updating the model version, changing how the loads are defined, and adding forecasting parameters. The model was retrained using data up to and including 2013/2014 which would have improved the model at low temperatures. Once those changes were made, Hydro was confident in Nostradamus's ability to function adequately through the winter of 2014/2015. A progress report on the changes to Hydro's short and long-term load forecasting processes was submitted to the Board on October 31, 2014.

Hydro made a presentation to Board staff on January 23, 2015 outlining the updates to Nostradamus that were implemented on or before November 30, 2014 and the preliminary results to that time.

Monthly reports were submitted to the Board on the accuracy of the Nostradamus forecasting in December 2014 through March 2015.

This report fulfils the second Liberty recommendation – to report on the accuracy over the whole winter and comment on the model's suitability for ongoing use.

2.0 SHORT-TERM LOAD FORECASTING

2.1 Utility Load

Hydro contracts Amec Foster Wheeler to provide the weather parameters in the form of hourly weather forecasts for a seven-day period. At the same time as the weather forecast data is provided, Amec also provides observed data at the same locations for the previous 24 hours (calendar day). The forecast and actual data are automatically retrieved from Amec and input to the Nostradamus database.

Nostradamus can use a variety of weather parameters for forecasting as long as a historical record is available for training; Hydro uses air temperature, wind speed, and cloud cover. Nostradamus can use each variable more than once, for example both the current and forecast air temperatures are used in forecasting load. Wind chill is not used explicitly as the neural network function of Nostradamus will form its own relationships between load, wind and temperature, which should be superior to the formula used by Environment Canada to derive wind chill. In addition to the weather and demand data, Nostradamus uses a parameter that indicates the number of daylight hours each day.

Weather data for four locations are used in Nostradamus: St. John's, Gander, Deer Lake, and Port aux Basques. Data from January 1, 2012 to October 31, 2014 are being used for training and verification purposes. The training and verification periods are selected to provide a sufficiently long period to ensure that a range of weather parameters are included, e.g., high and low temperatures, but short enough that the historic load is still representative of loads that can be expected in the future.

Demand data for the Avalon Peninsula and for the Island Interconnected System as a whole are input to Nostradamus automatically each hour. Only total utility load (conforming), Newfoundland Power's and Hydro's, is input in the Nostradamus model. Industrial load (non-conforming), which is not a function of weather, is forecast outside the Nostradamus program and added to the forecasts from Nostradamus to derive the total Island load forecast.

During the process of training the Nostradamus model, it creates separate submodels for weekdays, weekends, and holidays to account for the variation in customer use of electricity. Nostradamus has separate holiday groups for statutory holidays and also for days that are known to have unusual loads, for instance the days between Christmas and New Year's and the school Easter break.

2.2 Industrial Load

Industrial load tends to be almost constant, as industrial processes are independent of weather. Under the current procedure, the power-on-order for each Industrial Customer, plus the expected owned generation from Corner Brook Pulp and Paper (CBPP), is used as the industrial load forecasts unless System Operations engineers modify the forecast based on some knowledge of customer loads, for instance a decrease due to reduced production at CBPP or a ramp up in the load expected at Vale. Engineers can change the expected load in one or more cells of a seven by 24-hour grid, or can change the default value to be used indefinitely.

2.3 Supply and Demand Status Reporting

The forecast peak reported to the Board on the daily Supply and Demand Status Report is the forecast peak as of 7:20 am. The weather forecast for the next seven days and the observed weather data for the previous day are input to Nostradamus at approximately 5:00 am. Nostradamus is then run every hour of the day and the most recent forecast is available for reference by System Operations engineers and the Energy Control Centre operators for monitoring and managing available spinning reserves. The within day forecast updates are used by operators to decide if additional spinning reserve is required in advance of forecast system peaks.

2.4 Load Forecasting Improvements

Hydro implemented the following changes to the load forecasting process prior to November 30, 2014:

- Additional training for staff;
- Updating to the most recent Nostradamus software version;
- Revised training and verification periods and additional quality control of the weather data, including the data from January 2014;
- Adding weather parameters for cloud cover and daylight hours;
- Modifying actual demand data used in Nostradamus training to remove unusual system conditions such as significant outages;
- Changing forecasting processes so that Nostradamus forecasts only utility load, with industrial forecasts done separately;
- Increased frequency of forecasting to hourly for the 'today' forecast;
- Changing forecasting process to allow adjustments to the generated forecast to account for unusual system conditions (e.g., to account for an abnormal system configuration that may result in more or less system losses); and
- Creation of new plots and tables showing the load forecast, spinning reserve, and available reserve, which are available on demand to System Operations staff for managing the system.

These model improvements were made on Hydro's Development environment[1] between June and November 2014, and resulted in a gradual improvement of the reliability of the load forecast, as measured by the training and verification statistics produced by the Nostradamus model, and through observation of the real time forecasts. Once Hydro was satisfied that the Development model was functioning well, it was implemented on the Production system at the end of November 2014.

These changes to the model eliminated the erratic load shapes that were present in the forecasts at loads in excess of 1600 MW in January 2014 and improved the reliability of the peak forecast over the full range of expected loads. Hydro was pleased with the

[1] Hydro runs Nostradamus (and other key software) on two servers: Development and Production. Changes are made in Development environment first and then are implemented in the Production environment once testing is complete.

improvements that had been made and was confident that the model would function as required through the winter of 2014/2015.

Additional changes made during the winter of 2014/2015 were as follows:

- A second daily weather forecast is now received at approximately 12:45 pm (1:45 pm during Daylight Savings Time) each day;
- A midday update of observed climate values, with values up to 11:00 am for the current day forecast is also received at approximately 12:45 pm each day;
- The 'tomorrow' forecast is run five times during the day to make use of the current day's load information and the new forecast and observed data received midday; and
- Accuracy reporting on the weather forecasts from Amec.

2.5 Potential Sources of Variance

Improvements made to the Nostradamus forecasting model and to Hydro's processes for load forecasting have improved the reliability and accuracy of the load forecasts. As with any forecasting, however, there will be ongoing discrepancies between the forecast and the actual values. Typical sources of variance in the load forecasting are as follows:

- Differences in the industrial load forecast due to unexpected changes in customer loads;
- Inaccuracies in the weather forecast, particularly temperature, wind speed or cloud cover; and
- Non-uniform customer behaviour which results in unpredictability of load.

3.0 WEATHER FORECAST ACCURACY

Utility load in Newfoundland and Labrador is dominated by the heating load which is highly dependent on weather, including temperature, wind, and cloud cover. The accuracy of load forecasting is, therefore, a function of the accuracy of the weather forecast.

Hydro's new contract for weather forecasting services with Amec Foster Wheeler, which came into effect on January 1, 2015, included a requirement for regular accuracy analysis and reporting. Appendix A is Amec's report for the first quarter of 2015, the first report received during this new contract period.

Amec reported on the accuracy of five weather forecast parameters, compared to observed data at Environment Canada weather stations:

- Temperature;
- Relative humidity;
- Wind speed;
- Wind direction; and
- Cloud cover.

Currently, Hydro uses only three of these parameters: temperature, wind speed and cloud cover for load forecasting. Advice from the vendor and prior testing suggest that use of the other parameters would not likely improve the load forecasts.

The relationship between load and weather is complex, so there can be no direct correlation between the accuracy of the load forecast and the accuracy of any one or more weather forecast parameters.

Temperature has the largest effect on the Island load, due to the dominance of electrical heat. Amec found that, for the first quarter of 2015, the mean absolute error of the St. John's temperature forecast with a lead time of 1 to 24 hours was 0.88°C. The correlation coefficient for that same data set was 0.97. For the St. John's wind speed forecast, with a lead time of 1 to 24 hours, the mean absolute error was 1.48 m/s (5.43 km/hr), and the correlation coefficient was 0.90. For cloud cover, the mean absolute error was 1.77 (on a scale of 0 to 10, where 10 is equivalent to 100% cloud cover) and the correlation coefficient was 0.66. Cloud cover is more difficult to forecast than temperature and wind speed.

Amec's review of the data identified some areas for potential improvement, for instance:

- The accuracy of several of the parameters is generally better at some times of the day than at others;
- Air temperature forecasts were noticeably more accurate at some sites than others, perhaps due to the locations relative to the coast;
- The accuracies of the three global climate models used to produce the seven-day forecast differed, especially for wind speed;
- As expected, accuracy diminishes as lead time increases.

Amec will continue to monitor the accuracy of the forecasts and will investigate techniques which may lead to improvements. More detail is included in the full Amec report, in Appendix A.

4.0 LOAD FORECAST ACCURACY

4.1 Description of Forecast

Table 1 presents the daily forecast peak, the observed peak, and the available system capacity, as included in Hydro's daily Supply and Demand Status Reports submitted to the Board for December 1, 2014 to March 31, 2015. These are the values of forecast and capacity as available at 7:20 am. The data are also presented in Figure 1. The load forecast updates hourly throughout the day, and it is the hourly updates that are used by System Operations engineers and the Energy Control Centre operators for monitoring and managing available spinning reserves.

On March 4 the Island system experienced a supply disruption resulting from unanticipated generation issues on the Avalon Peninsula, causing voltages to decline in the region. March 4, 2015 is omitted from all the analyses because the disruption means that the actual data cannot be compared to the forecast.

The minimum forecast load during the winter was 1050 MW on December 12 and 14, 2014. The maximum load forecast during the winter was 1660 MW on January 14, 2015. The actual peak loads varied from a minimum of 1086 MW on December 14, 2014 to 1683 MW on March 13, 2015.

The difference between the available system capacity and the daily forecast peak at 7:20 am provides a forecast of the available reserves for the day. Throughout the day, as the load forecast updates each hour, the forecast of available reserves updates and System Operations engineers and the Energy Control Centre operators adjust the spinning reserves, if required.

With the exception of March 4, spinning and available reserves were sufficient throughout the winter of 2014/2015.

4.2 Forecast Analysis

4.2.1 Forecast Statistics

Table 2 presents error statistics for the peak forecasts during the winter of 2014/2015. Figure 2 is a plot of the forecast and actual peaks, as shown in Figure 1, but with the addition of a bar chart showing the difference between the two data series. In both the tables and the figures, a positive error is an overestimate; a negative error is an underestimate. Points on the accuracy plot indicate days that were analyzed in more detail in the monthly accuracy reports.

The forecast peak over the winter period was in a range between 8.6% below the actual peak and 7.7% above the actual peak. The forecast peak was within 2% of the actual peak 60% of the time. On average, the forecast peak was 33 MW different than the actual peak, or 2.3%. Tables 1 and 2; and Figures 1 and 2 are based on the 7:20 am forecast. The accuracy of the forecast typically improves during the day as it updates hourly, so the decisions made to manage reserves are made on forecasts with error of less than 2%.

Some error is inherent to the model because Nostradamus uses hourly data only; loads are input on the hour, and forecasts are made hourly. Peak loads can be quite 'spikey', so if a peak occurs at, say, 30 minutes after the hour, it could be significantly different than the values input to Nostradamus on the hours before and after.

4.2.2 Accuracy During High Peaks

The erratic behaviour experienced with the load forecast in January 2014 occurred when the load was above 1600 MW. In the winter of 2014/2015, the peak load was above 1600 MW on 20 days. Table 3 shows an analysis of the accuracy of the forecast peaks on those days only. No erratic behaviour was observed in the winter of 2014/2015.

The peaks above 1600 MW were overestimated on four days, by an average of 13 MW, and underestimated on 15 days, by an average of 57 MW. On average, the forecast high peak was underestimated by 2.5% (46 MW), which is similar to the discrepancy between forecast and actual peak over the full range of loads, confirming that the changes made to Nostradamus before the winter of 2014/2015 addressed the concerns with the performance of Nostradamus at high peaks.

4.2.3 Accuracy Over Time

The load for any hour of any particular day is first forecast seven days in advance. It is then updated once per day for the next four days. On the day before any particular day, the forecast is now run five times (since February 2015). The forecast on the day is updated hourly. For example, 5:00 pm on April 30 would be forecast as follows:

- April 24 through April 28 at 5:20 am;
- April 29 at 5:20 am, 10:20 am, 2:20 pm, 5:20 pm, 9:20 pm; and

- April 30 at 1:20 am, 2:20 am, 3:20 am, 4:20 am, 5:20 am, 6:20 am, 7:20 am, 8:20 am, 9:20 am, 10:20 am, 11:20 am, 12:20 pm, 1:20 pm, 2:20 pm, 3:20 pm, and 4:20 pm.

The peak load forecast reported to the Board each morning is from the 7:20 am load forecast. All the forecasts, from seven days to one hour in advance, are used in monitoring generation reserves.

Figures 3 through 8 demonstrate how the forecast changes as time progresses on two sample days, February 2 and March 13, 2015. February 2 is an example of a day when the 7:20 am forecast was relatively poor; March 13 experienced the highest peak load of the winter of 2014/2015.

February 2, 2015

The accuracy of the peak load forecast as reported for February 2, 2015 was analyzed in the February accuracy report because the forecast at 7:20 am underestimated the peak by 6.7%; the peak of the forecast was 1480 MW, the actual peak was 1587 MW. The forecast time of peak was also incorrect, the forecast indicated a morning peak (9:00 am), whereas the peak actually occurred at 5:00 pm.

The analysis was unable to ascertain with certainty why Nostradamus underestimated the load for the afternoon and evening of February 2. Errors in the weather forecast likely contributed somewhat to the underestimate but other factors, not modelled by Nostradamus, may also have increased the load that day, for instance wind direction, precipitation, or human behaviour.

Figures 3a through 3f show the load forecast for February 2 seven days through one day in advance. In all forecasts the overall load shape is quite accurate though most predicted the morning peak to be higher than the afternoon peak. A forecast that far in advance is strongly influenced by the temperature forecast input. The forecast magnitude of the afternoon peak load on January 29 through 31 was very close to the actual peak.

Figures 3g through 3j show selected hourly load forecast updates from the morning of February 2. Figure 3h shows the forecast at 5:20 am, which is the first time the current day's weather forecast is available. Subsequent hourly forecasts use the same weather forecast but have actual load data up to that hour. The forecasts for the morning peak were quite accurate, but mostly predicted that the afternoon peak would be similar or slightly lower.

Figures 3k through 3n show selected hourly load forecast updates from the afternoon of February 2, up to and including the hour of the actual day's peak. By the time of the 12:20 pm forecast, Nostradamus was correctly forecasting that the afternoon peak would be higher than the morning peak. System Operations engineers and the Energy Control Centre operators use the midday and early afternoon forecast updates to plan which generation resources are required to meet the afternoon peak.

Figure 4 is an excerpt from the daily Supply and Demand Status Report issued for February 2. The plot shows the demand and the available capacity at five-minute intervals through the day, a finer resolution than is used in Nostradamus. It is apparent that the available capacity was well above the load throughout the day. Figure 5 shows in more detail the available and spinning reserves for February 2. The available reserves varied between approximately 400 MW and 1025 MW; the spinning reserves between 150 MW and 525 MW.

March 13, 2015

The load at the time of the peak on March 13, 2015 was 1683 MW, the maximum peak for the winter of 2014/2015. The maximum peak occurred at 8:35 am. The peak forecast by Nostradamus as reported to the Board was 1645 MW at 9:00 am; the actual load at 9:00 am was 1646 MW, so the forecast was accurate. The apparent error between the forecast and actual was due to the timing of the peak compared to the on hour values in Nostradamus.

Figures 6a through 6e show the load forecast for March 13 seven days through two days in advance. In all forecasts the magnitude of both the morning and afternoon peaks was accurate. The forecast predicted the load to be higher in the early hours of the morning, and dip lower during the middle of the day, than actually occurred.

Figures 6f through 6j show the five forecasts produced on March 12, one day before the day in question. The load shape had improved significantly from earlier forecasts. The morning forecast is accurate; the afternoon forecasts under predict the load by about 50 MW.

Figures 6k through 6o show selected hourly load forecasts from the morning of March 13, up to and including the hour of the actual day's peak. The forecast magnitude of the morning peak was accurate but the load shape was not as good as the forecast of the previous day, and the afternoon peak was somewhat under forecast. Overall the forecast model performed well considering the database still has relatively few data points at high loads on which to base the forecast. When Nostradamus is next retrained, data from the winter of 2014/2015 will be included in the database to improve the forecasting for 2015/2016.

Figure 7 is an excerpt from the daily Supply and Demand Status Report issued for March 13. The plot shows the demand and the available capacity at five-minute intervals through the day, a finer resolution than is used in Nostradamus. It is apparent that the available capacity was well above the load throughout the day. Figure 8 shows in more detail the available and spinning reserves for March 13. The available reserves varied between approximately 425 MW and 825 MW; the spinning reserves between 200 and 550 MW.

5.0 CONCLUSION

Nostradamus has long provided Hydro System Operations with short-term load forecasts acceptable for use in managing supply to meet the Island demand. Changes made since the supply disruptions in January 2014 improved the reliability and accuracy of the model, especially at high loads.

Work completed prior to December 1, 2014 improved the model sufficiently that Hydro was confident that the erratic behaviour of the forecast in January 2014 would not be repeated in the winter of 2014/2015. Monthly reviews of the model accuracy have confirmed this.

No erratic behaviour was observed in the forecasts through the winter of 2014/2015, even at the highest loads. Spinning reserve was sufficient throughout. Hydro is confident that with routine training and development of the model, Nostradamus will continue to provide Hydro with the short-term load forecasting that it needs to manage the system.

Hydro's Environmental Management System and its goal of operational excellence require continuous improvement in all processes that affect optimization of hydro resources to minimize the use of thermal resources. Hydro will continue to work towards improving the accuracy of the Nostradamus forecasts, for instance through the transition to two weather forecasts per day.

TABLES AND FIGURES

Table 1 Winter 2014/2015 Load Forecasting Data

Date	Forecast Peak, MW	Actual Peak, MW	Available Island Supply, MW	Forecast Reserve, MW
1-Dec-14	1225	1217	1500	350
2-Dec-14	1325	1387	1660	410
3-Dec-14	1410	1409	1645	310
4-Dec-14	1250	1174	1750	575
5-Dec-14	1350	1386	1775	500
6-Dec-14	1350	1368	1785	510
7-Dec-14	1275	1275	1680	480
8-Dec-14	1500	1638	1880	460
9-Dec-14	1525	1528	1845	400
10-Dec-14	1350	1379	1870	595
11-Dec-14	1300	1361	1910	685
12-Dec-14	1050	1149	1880	900
13-Dec-14	1075	1094	1880	880
14-Dec-14	1050	1086	1850	870
15-Dec-14	1225	1209	1845	695
16-Dec-14	1325	1417	1840	590
17-Dec-14	1360	1417	1800	515
18-Dec-14	1300	1317	1805	580
19-Dec-14	1260	1287	1850	665
20-Dec-14	1275	1373	1665	465
21-Dec-14	1300	1391	1805	580
22-Dec-14	1450	1455	1855	480
23-Dec-14	1375	1435	1845	545
24-Dec-14	1400	1383	1845	540
25-Dec-14	1325	1339	1865	635
26-Dec-14	1250	1199	1860	705
27-Dec-14	1325	1329	1700	470
28-Dec-14	1325	1344	1870	640
29-Dec-14	1325	1413	1860	630
30-Dec-14	1525	1621	1915	490
31-Dec-14	1600	1664	1850	350
1-Jan-15	1575	1537	1770	295
2-Jan-15	1475	1389	1875	495
3-Jan-15	1650	1639	1885	335
4-Jan-15	1575	1639	1860	385
5-Jan-15	1400	1374	1900	595
6-Jan-15	1525	1641	1900	475

Table 1 Winter 2014/2015 Load Forecasting Data, Continued

Date	Forecast Peak, MW	Actual Peak, MW	Available Island Supply, MW	Forecast Reserve, MW
7-Jan-15	1550	1579	1875	425
8-Jan-15	1550	1608	1875	425
9-Jan-15	1625	1636	1875	350
10-Jan-15	1495	1471	1730	330
11-Jan-15	1520	1566	1890	470
12-Jan-15	1600	1606	1865	365
13-Jan-15	1575	1589	1895	420
14-Jan-15	1660	1660	1860	300
15-Jan-15	1515	1501	1845	430
16-Jan-15	1405	1423	1865	555
17-Jan-15	1450	1428	1870	515
18-Jan-15	1460	1515	1875	510
19-Jan-15	1415	1434	1855	535
20-Jan-15	1365	1325	1905	635
21-Jan-15	1375	1416	1885	605
22-Jan-15	1425	1419	1860	530
23-Jan-15	1465	1460	1890	520
24-Jan-15	1460	1470	1855	490
25-Jan-15	1335	1362	1865	625
26-Jan-15	1470	1543	1905	530
27-Jan-15	1565	1640	1865	400
28-Jan-15	1340	1311	1900	655
29-Jan-15	1335	1290	1905	665
30-Jan-15	1390	1424	1930	635
31-Jan-15	1380	1369	1900	615
1-Feb-15	1225	1220	1910	780
2-Feb-15	1480	1587	1930	545
3-Feb-15	1495	1475	1895	495
4-Feb-15	1585	1552	1895	410
5-Feb-15	1625	1608	1895	370
6-Feb-15	1390	1389	1900	605
7-Feb-15	1465	1511	1905	535
8-Feb-15	1490	1537	1915	520
9-Feb-15	1630	1661	1870	340
10-Feb-15	1640	1652	1920	380
11-Feb-15	1615	1499	1910	395
12-Feb-15	1605	1642	1940	435

Table 1 Winter 2014/2015 Load Forecasting Data, Continued

Date	Forecast Peak, MW	Actual Peak, MW	Available Island Supply, MW	Forecast Reserve, MW
13-Feb-15	1500	1504	1890	490
14-Feb-15	1470	1452	1925	550
15-Feb-15	1455	1435	1900	540
16-Feb-15	1460	1449	1905	540
17-Feb-15	1510	1531	1935	525
18-Feb-15	1520	1502	1885	465
19-Feb-15	1405	1413	1900	590
20-Feb-15	1370	1285	1925	650
21-Feb-15	1470	1490	1935	560
22-Feb-15	1445	1436	1905	555
23-Feb-15	1330	1312	1915	680
24-Feb-15	1510	1607	1945	535
25-Feb-15	1655	1640	1890	335
26-Feb-15	1420	1416	1940	615
27-Feb-15	1440	1432	1845	500
28-Feb-15	1550	1528	1865	415
1-Mar-15	1460	1412	1865	500
2-Mar-15	1515	1539	1795	380
3-Mar-15	1490	1570	1810	415
4-Mar-15	1630	*	*	*
5-Mar-15	1460	1472	1995	630
6-Mar-15	1620	1611	2020	500
7-Mar-15	1550	1500	1990	540
8-Mar-15	1385	1385	2015	725
9-Mar-15	1490	1493	2015	620
10-Mar-15	1625	1650	1990	465
11-Mar-15	1565	1578	2000	535
12-Mar-15	1485	1497	1880	490
13-Mar-15	1645	1683	2035	490
14-Mar-15	1610	1569	2020	510
15-Mar-15	1515	1527	2000	585
16-Mar-15	1535	1561	2010	575
17-Mar-15	1365	1368	2000	730
18-Mar-15	1345	1354	1990	740
19-Mar-15	1345	1332	2025	775
20-Mar-15	1405	1410	2035	725
21-Mar-15	1355	1328	2010	750

Table 1 Winter 2014/2015 Load Forecasting Data, Continued

Date	Forecast Peak, MW	Actual Peak, MW	Available Island Supply, MW	Forecast Reserve, MW
22-Mar-15	1375	1411	2020	740
23-Mar-15	1440	1498	1940	595
24-Mar-15	1455	1465	2005	645
25-Mar-15	1440	1431	1990	645
26-Mar-15	1415	1407	1990	670
27-Mar-15	1235	1231	1860	720
28-Mar-15	1200	1210	1870	765
29-Mar-15	1280	1265	1840	655
30-Mar-15	1385	1382	1845	555
31-Mar-15	1355	1344	1825	485
Minimum	1050	1086	1500	295
Average	1435	1446	1884	543
Maximum	1660	1683	2035	900

Notes:

Forecast peak, available capacity and forecast reserve are rounded to the nearest 5 MW.

Forecast peak and available capacity presented is as reported to the Board. The forecast is updated hourly throughout the day for use in maintaining adequate generation reserves.

Forecast Reserve = Available Island Supply - (Forecast Peak - CBPP Interruptible Load (when applicable) - the impact of voltage reduction).

*The supply disruption of March 4 prevents analysis of the accuracy of the forecast.

Table 2 Winter 2014/2015 Analysis of Forecast Error

Date	Actual Peak, MW	Forecast Peak, MW	Error, MW	Absolute Error, MW	Percent Error	Absolute Percent Error	Actual/ Forecast
1-Dec-14	1217	1225	8	8	0.7%	0.7%	0.7%
2-Dec-14	1387	1325	-62	62	-4.5%	4.5%	-4.7%
3-Dec-14	1409	1410	1	1	0.1%	0.1%	0.1%
4-Dec-14	1174	1250	76	76	6.5%	6.5%	6.1%
5-Dec-14	1386	1350	-36	36	-2.6%	2.6%	-2.7%
6-Dec-14	1368	1350	-18	18	-1.3%	1.3%	-1.3%
7-Dec-14	1275	1275	0	0	0.0%	0.0%	0.0%
8-Dec-14	1638	1500	-138	138	-8.4%	8.4%	-9.2%
9-Dec-14	1528	1525	-3	3	-0.2%	0.2%	-0.2%
10-Dec-14	1379	1350	-29	29	-2.1%	2.1%	-2.1%
11-Dec-14	1361	1300	-61	61	-4.5%	4.5%	-4.7%
12-Dec-14	1149	1050	-99	99	-8.6%	8.6%	-9.4%
13-Dec-14	1094	1075	-19	19	-1.7%	1.7%	-1.8%
14-Dec-14	1086	1050	-36	36	-3.3%	3.3%	-3.4%
15-Dec-14	1209	1225	16	16	1.3%	1.3%	1.3%
16-Dec-14	1417	1325	-92	92	-6.5%	6.5%	-6.9%
17-Dec-14	1417	1360	-57	57	-4.0%	4.0%	-4.2%
18-Dec-14	1317	1300	-17	17	-1.3%	1.3%	-1.3%
19-Dec-14	1287	1260	-27	27	-2.1%	2.1%	-2.1%
20-Dec-14	1373	1275	-98	98	-7.1%	7.1%	-7.7%
21-Dec-14	1391	1300	-91	91	-6.5%	6.5%	-7.0%
22-Dec-14	1455	1450	-5	5	-0.3%	0.3%	-0.3%
23-Dec-14	1435	1375	-60	60	-4.2%	4.2%	-4.4%
24-Dec-14	1383	1400	17	17	1.2%	1.2%	1.2%
25-Dec-14	1339	1325	-14	14	-1.0%	1.0%	-1.1%
26-Dec-14	1199	1250	51	51	4.3%	4.3%	4.1%
27-Dec-14	1329	1325	-4	4	-0.3%	0.3%	-0.3%
28-Dec-14	1344	1325	-19	19	-1.4%	1.4%	-1.4%
29-Dec-14	1413	1325	-88	88	-6.2%	6.2%	-6.6%
30-Dec-14	1621	1525	-96	96	-5.9%	5.9%	-6.3%
31-Dec-14	1664	1600	-64	64	-3.8%	3.8%	-4.0%
1-Jan-15	1537	1575	38	38	2.5%	2.5%	2.4%
2-Jan-15	1389	1475	86	86	6.2%	6.2%	5.8%
3-Jan-15	1639	1650	11	11	0.7%	0.7%	0.7%
4-Jan-15	1639	1575	-64	64	-3.9%	3.9%	-4.1%
5-Jan-15	1374	1400	26	26	1.9%	1.9%	1.9%
6-Jan-15	1641	1525	-116	116	-7.1%	7.1%	-7.6%

Table 2 Winter 2014/2015 Analysis of Forecast Error, Continued

Date	Actual Peak, MW	Forecast Peak, MW	Error, MW	Absolute Error, MW	Percent Error	Absolute Percent Error	Actual/ Forecast
7-Jan-15	1579	1550	-29	29	-1.8%	1.8%	-1.9%
8-Jan-15	1608	1550	-58	58	-3.6%	3.6%	-3.7%
9-Jan-15	1636	1625	-11	11	-0.7%	0.7%	-0.7%
10-Jan-15	1471	1495	24	24	1.6%	1.6%	1.6%
11-Jan-15	1566	1520	-46	46	-2.9%	2.9%	-3.0%
12-Jan-15	1606	1600	-6	6	-0.4%	0.4%	-0.4%
13-Jan-15	1589	1575	-14	14	-0.9%	0.9%	-0.9%
14-Jan-15	1660	1660	0	0	0.0%	0.0%	0.0%
15-Jan-15	1501	1515	14	14	0.9%	0.9%	0.9%
16-Jan-15	1423	1405	-18	18	-1.3%	1.3%	-1.3%
17-Jan-15	1428	1450	22	22	1.5%	1.5%	1.5%
18-Jan-15	1515	1460	-55	55	-3.6%	3.6%	-3.8%
19-Jan-15	1434	1415	-19	19	-1.3%	1.3%	-1.3%
20-Jan-15	1325	1365	40	40	3.0%	3.0%	2.9%
21-Jan-15	1416	1375	-41	41	-2.9%	2.9%	-3.0%
22-Jan-15	1419	1425	6	6	0.4%	0.4%	0.4%
23-Jan-15	1460	1465	5	5	0.3%	0.3%	0.3%
24-Jan-15	1470	1460	-10	10	-0.7%	0.7%	-0.7%
25-Jan-15	1362	1335	-27	27	-2.0%	2.0%	-2.0%
26-Jan-15	1543	1470	-73	73	-4.7%	4.7%	-5.0%
27-Jan-15	1640	1565	-75	75	-4.6%	4.6%	-4.8%
28-Jan-15	1311	1340	29	29	2.2%	2.2%	2.2%
29-Jan-15	1290	1335	45	45	3.5%	3.5%	3.4%
30-Jan-15	1424	1390	-34	34	-2.4%	2.4%	-2.4%
31-Jan-15	1369	1380	11	11	0.8%	0.8%	0.8%
1-Feb-15	1220	1225	5	5	0.4%	0.4%	0.4%
2-Feb-15	1587	1480	-107	107	-6.7%	6.7%	-7.2%
3-Feb-15	1475	1495	20	20	1.4%	1.4%	1.3%
4-Feb-15	1552	1585	33	33	2.1%	2.1%	2.1%
5-Feb-15	1608	1625	17	17	1.1%	1.1%	1.0%
6-Feb-15	1389	1390	1	1	0.1%	0.1%	0.1%
7-Feb-15	1511	1465	-46	46	-3.0%	3.0%	-3.1%
8-Feb-15	1537	1490	-47	47	-3.1%	3.1%	-3.2%
9-Feb-15	1661	1630	-31	31	-1.9%	1.9%	-1.9%
10-Feb-15	1652	1640	-12	12	-0.7%	0.7%	-0.7%
11-Feb-15	1499	1615	116	116	7.7%	7.7%	7.2%
12-Feb-15	1642	1605	-37	37	-2.3%	2.3%	-2.3%

Table 2 Winter 2014/2015 Analysis of Forecast Error, Continued

Date	Actual Peak, MW	Forecast Peak, MW	Error, MW	Absolute Error, MW	Percent Error	Absolute Percent Error	Actual/ Forecast
13-Feb-15	1504	1500	-4	4	-0.3%	0.3%	-0.3%
14-Feb-15	1452	1470	18	18	1.2%	1.2%	1.2%
15-Feb-15	1435	1455	20	20	1.4%	1.4%	1.4%
16-Feb-15	1449	1460	11	11	0.8%	0.8%	0.8%
17-Feb-15	1531	1510	-21	21	-1.4%	1.4%	-1.4%
18-Feb-15	1502	1520	18	18	1.2%	1.2%	1.2%
19-Feb-15	1413	1405	-8	8	-0.6%	0.6%	-0.6%
20-Feb-15	1285	1370	85	85	6.6%	6.6%	6.2%
21-Feb-15	1490	1470	-20	20	-1.3%	1.3%	-1.4%
22-Feb-15	1436	1445	9	9	0.6%	0.6%	0.6%
23-Feb-15	1312	1330	18	18	1.4%	1.4%	1.4%
24-Feb-15	1607	1510	-97	97	-6.0%	6.0%	-6.4%
25-Feb-15	1640	1655	15	15	0.9%	0.9%	0.9%
26-Feb-15	1416	1420	4	4	0.3%	0.3%	0.3%
27-Feb-15	1432	1440	8	8	0.6%	0.6%	0.6%
28-Feb-15	1528	1550	22	22	1.4%	1.4%	1.4%
1-Mar-15	1412	1460	48	48	3.4%	3.4%	3.3%
2-Mar-15	1539	1515	-24	24	-1.6%	1.6%	-1.6%
3-Mar-15	1570	1490	-80	80	-5.1%	5.1%	-5.4%
4-Mar-15	*	1630	*	*	*	*	*
5-Mar-15	1472	1460	-12	12	-0.8%	0.8%	-0.8%
6-Mar-15	1611	1620	9	9	0.6%	0.6%	0.6%
7-Mar-15	1500	1550	50	50	3.3%	3.3%	3.2%
8-Mar-15	1385	1385	0	0	0.0%	0.0%	0.0%
9-Mar-15	1493	1490	-3	3	-0.2%	0.2%	-0.2%
10-Mar-15	1650	1625	-25	25	-1.5%	1.5%	-1.5%
11-Mar-15	1578	1565	-13	13	-0.8%	0.8%	-0.8%
12-Mar-15	1497	1485	-12	12	-0.8%	0.8%	-0.8%
13-Mar-15	1683	1645	-38	38	-2.3%	2.3%	-2.3%
14-Mar-15	1569	1610	41	41	2.6%	2.6%	2.5%
15-Mar-15	1527	1515	-12	12	-0.8%	0.8%	-0.8%
16-Mar-15	1561	1535	-26	26	-1.7%	1.7%	-1.7%
17-Mar-15	1368	1365	-3	3	-0.2%	0.2%	-0.2%
18-Mar-15	1354	1345	-9	9	-0.7%	0.7%	-0.7%
19-Mar-15	1332	1345	13	13	1.0%	1.0%	1.0%
20-Mar-15	1410	1405	-5	5	-0.4%	0.4%	-0.4%
21-Mar-15	1328	1355	27	27	2.0%	2.0%	2.0%

Table 2 Winter 2014/2015 Analysis of Forecast Error, continued

Date	Actual Peak, MW	Forecast Peak, MW	Error, MW	Absolute Error, MW	Percent Error	Absolute Percent Error	Actual/ Forecast
22-Mar-15	1411	1375	-36	36	-2.6%	2.6%	-2.6%
23-Mar-15	1498	1440	-58	58	-3.9%	3.9%	-4.0%
24-Mar-15	1465	1455	-10	10	-0.7%	0.7%	-0.7%
25-Mar-15	1431	1440	9	9	0.6%	0.6%	0.6%
26-Mar-15	1407	1415	8	8	0.6%	0.6%	0.6%
27-Mar-15	1231	1235	4	4	0.3%	0.3%	0.3%
28-Mar-15	1210	1200	-10	10	-0.8%	0.8%	-0.8%
29-Mar-15	1265	1280	15	15	1.2%	1.2%	1.2%
30-Mar-15	1382	1385	3	3	0.2%	0.2%	0.2%
31-Mar-15	1344	1355	11	11	0.8%	0.8%	0.8%
Minimum	1086	1050	-138	0	-8.6%	0.0%	-9.4%
Average	1446	1435	-13	33	-0.8%	2.3%	-0.9%
Maximum	1683	1660	116	138	7.7%	8.6%	7.2%

Notes:

Forecast peak is rounded to the nearest 5 MW.

Forecast peak presented is as reported to the Board. The forecast is updated hourly throughout the day for use in maintaining adequate generation reserves.

*The supply disruption of March 4 prevents analysis of the accuracy of the forecast.

Table 3 Winter 2014/2015 Analysis of Forecast Error at High Loads

Date	Actual Peak, MW	Forecast Peak, MW	Error, MW	Absolute Error, MW	Percent Error	Absolute Percent Error	Actual/ Forecast
13-Mar-15	1683	1645	-38	38	-2.3%	2.3%	-2.3%
31-Dec-14	1664	1600	-64	64	-3.8%	3.8%	-4.0%
9-Feb-15	1661	1630	-31	31	-1.9%	1.9%	-1.9%
14-Jan-15	1660	1660	0	0	0.0%	0.0%	0.0%
10-Feb-15	1652	1640	-12	12	-0.7%	0.7%	-0.7%
10-Mar-15	1650	1625	-25	25	-1.5%	1.5%	-1.5%
12-Feb-15	1642	1605	-37	37	-2.3%	2.3%	-2.3%
6-Jan-15	1641	1525	-116	116	-7.1%	7.1%	-7.6%
27-Jan-15	1640	1565	-75	75	-4.6%	4.6%	-4.8%
25-Feb-15	1640	1655	15	15	0.9%	0.9%	0.9%
3-Jan-15	1639	1650	11	11	0.7%	0.7%	0.7%
4-Jan-15	1639	1575	-64	64	-3.9%	3.9%	-4.1%
8-Dec-14	1638	1500	-138	138	-8.4%	8.4%	-9.2%
9-Jan-15	1636	1625	-11	11	-0.7%	0.7%	-0.7%
30-Dec-14	1621	1525	-96	96	-5.9%	5.9%	-6.3%
6-Mar-15	1611	1620	9	9	0.6%	0.6%	0.6%
8-Jan-15	1608	1550	-58	58	-3.6%	3.6%	-3.7%
5-Feb-15	1608	1625	17	17	1.1%	1.1%	1.0%
24-Feb-15	1607	1510	-97	97	-6.0%	6.0%	-6.4%
12-Jan-15	1606	1600	-6	6	-0.4%	0.4%	-0.4%
Minimum	1606	1500	-138	0	-8.4%	0.0%	-9.2%
Average	1637	1597	-41	46	-2.5%	2.8%	-2.6%
Maximum	1683	1660	17	138	1.1%	8.4%	1.0%

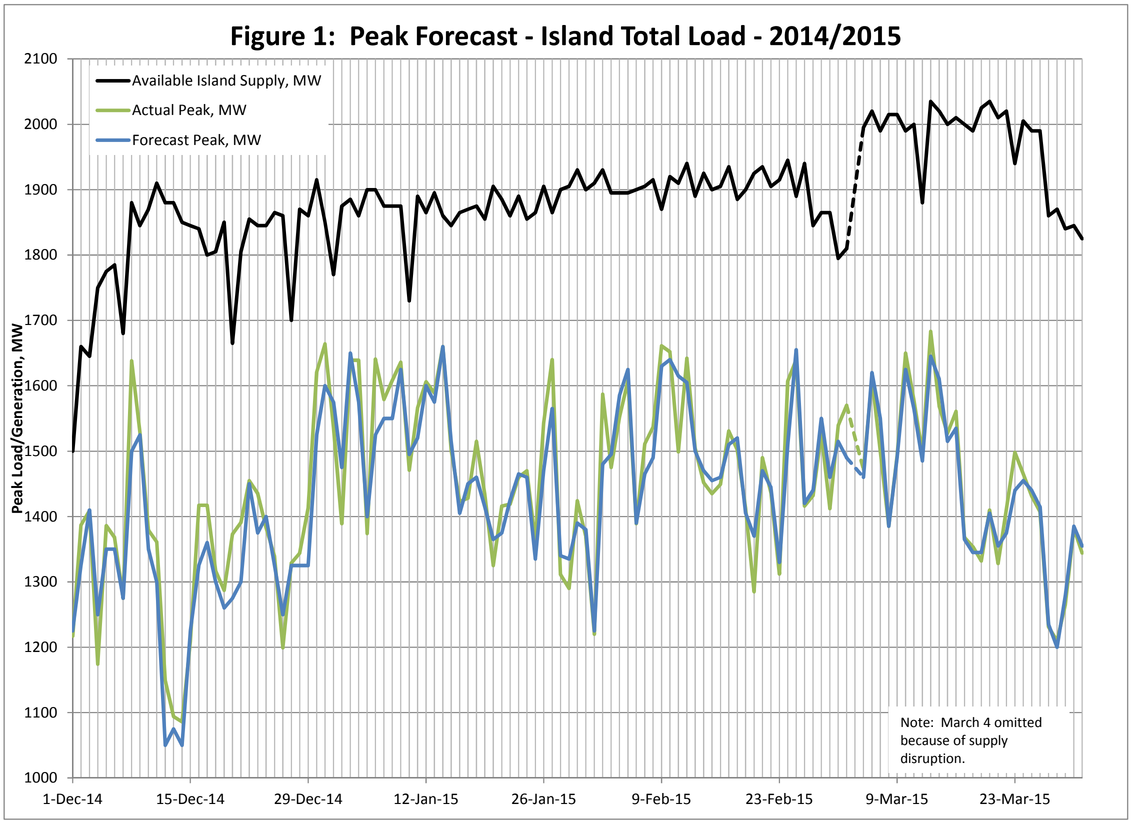

Figure 1: Peak Forecast - Island Total Load - 2014/2015
Available Island Supply, MW
Actual Peak, MW
Forecast Peak, MW
Peak Load/Generation, MW
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
1-Dec-14
15-Dec-14
29-Dec-14
12-Jan-15
26-Jan-15
9-Feb-15
23-Feb-15
9-Mar-15
23-Mar-15
Note: March 4 omitted because of supply disruption.

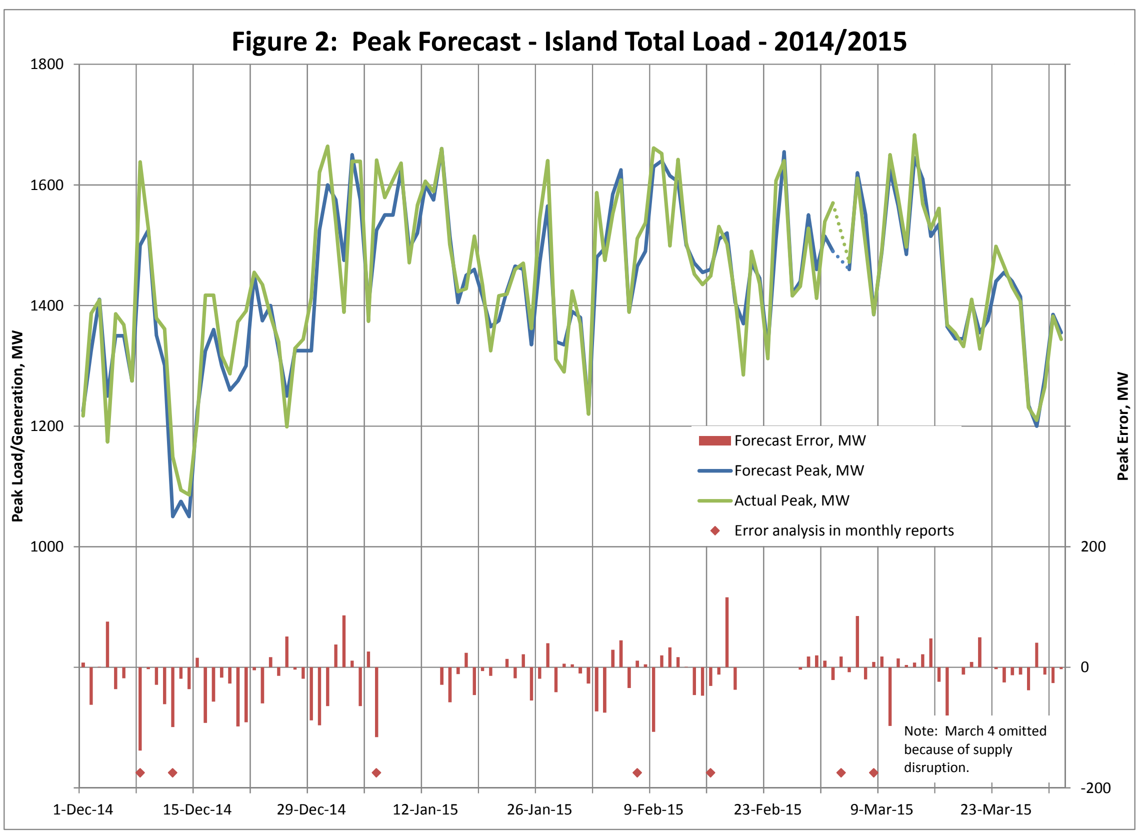

Figure 2: Peak Forecast - Island Total Load - 2014/2015
Peak Load/Generation, MW
Peak Error, MW
1800
1600
1400
1200
1000
200
0
-200
Forecast Error, MW
Forecast Peak, MW
Actual Peak, MW
Error analysis in monthly reports
Note: March 4 omitted because of supply disruption.
1-Dec-14
15-Dec-14
29-Dec-14
12-Jan-15
26-Jan-15
9-Feb-15
23-Feb-15
9-Mar-15
23-Mar-15

Figure 3 Forecast Comparison February 2, 2015 (1 of 3)

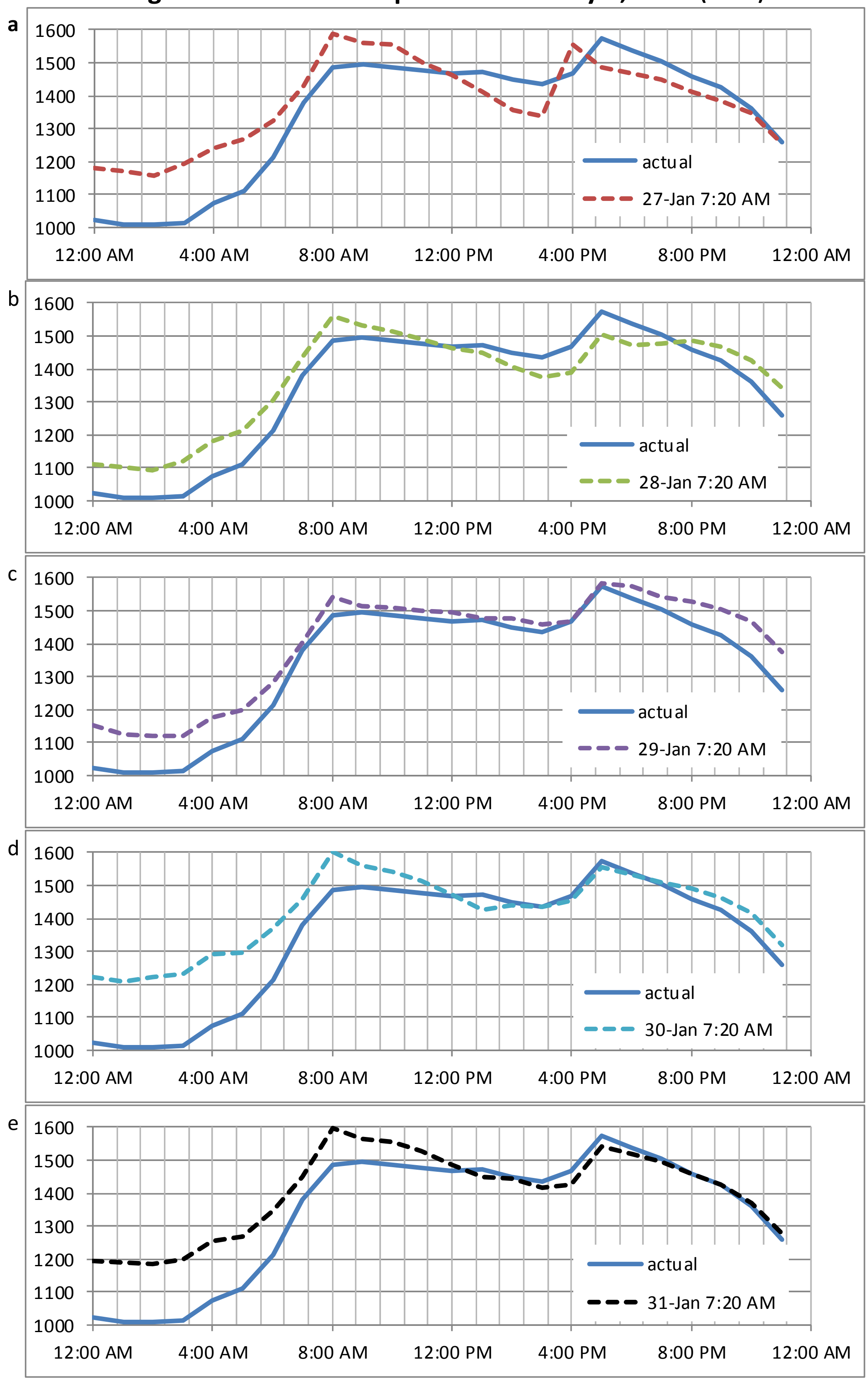

Figure 3 Forecast Comparison February 2, 2015 (2 of 3)

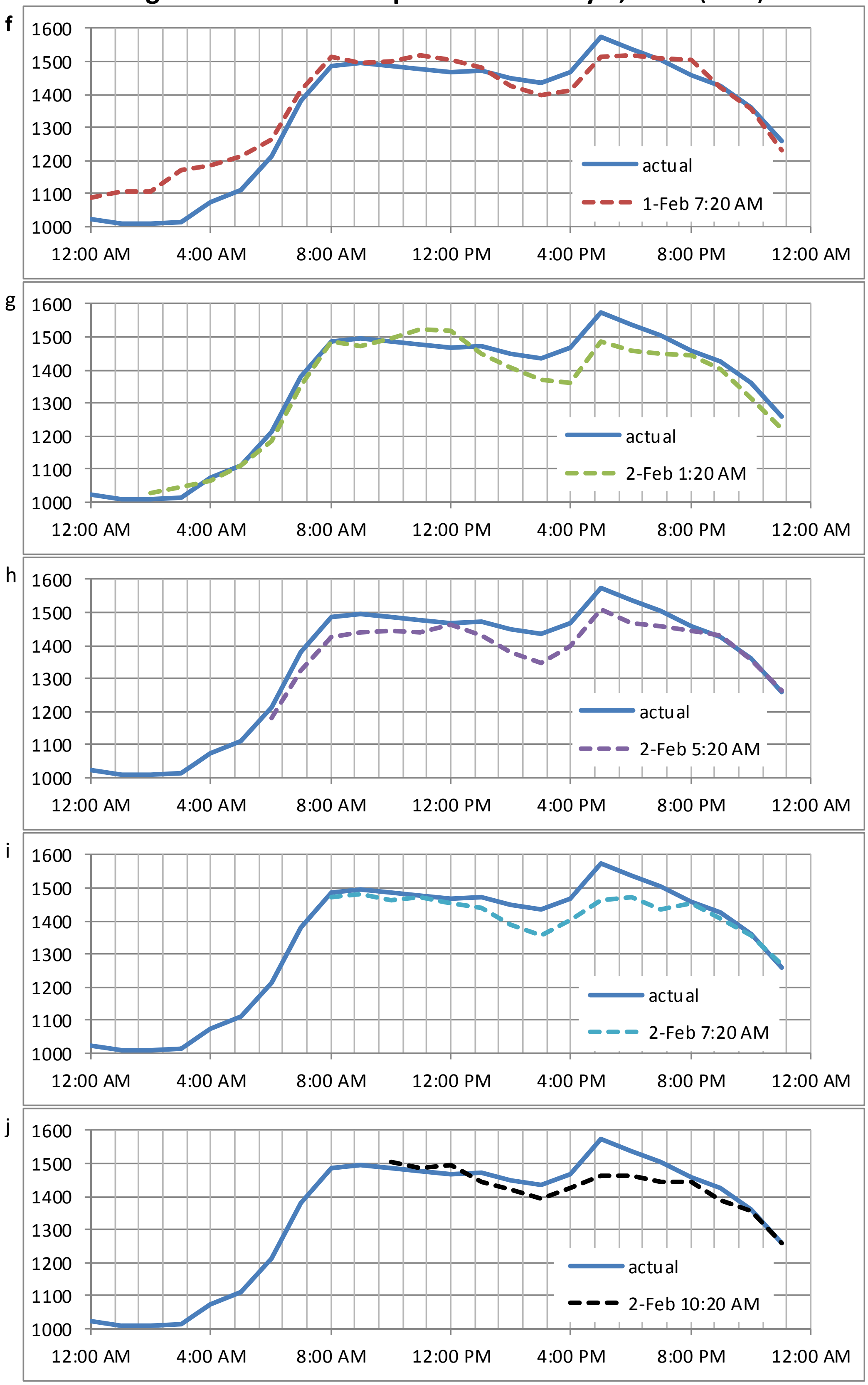

Figure 3 Forecast Comparison February 2, 2015 (3 of 3)

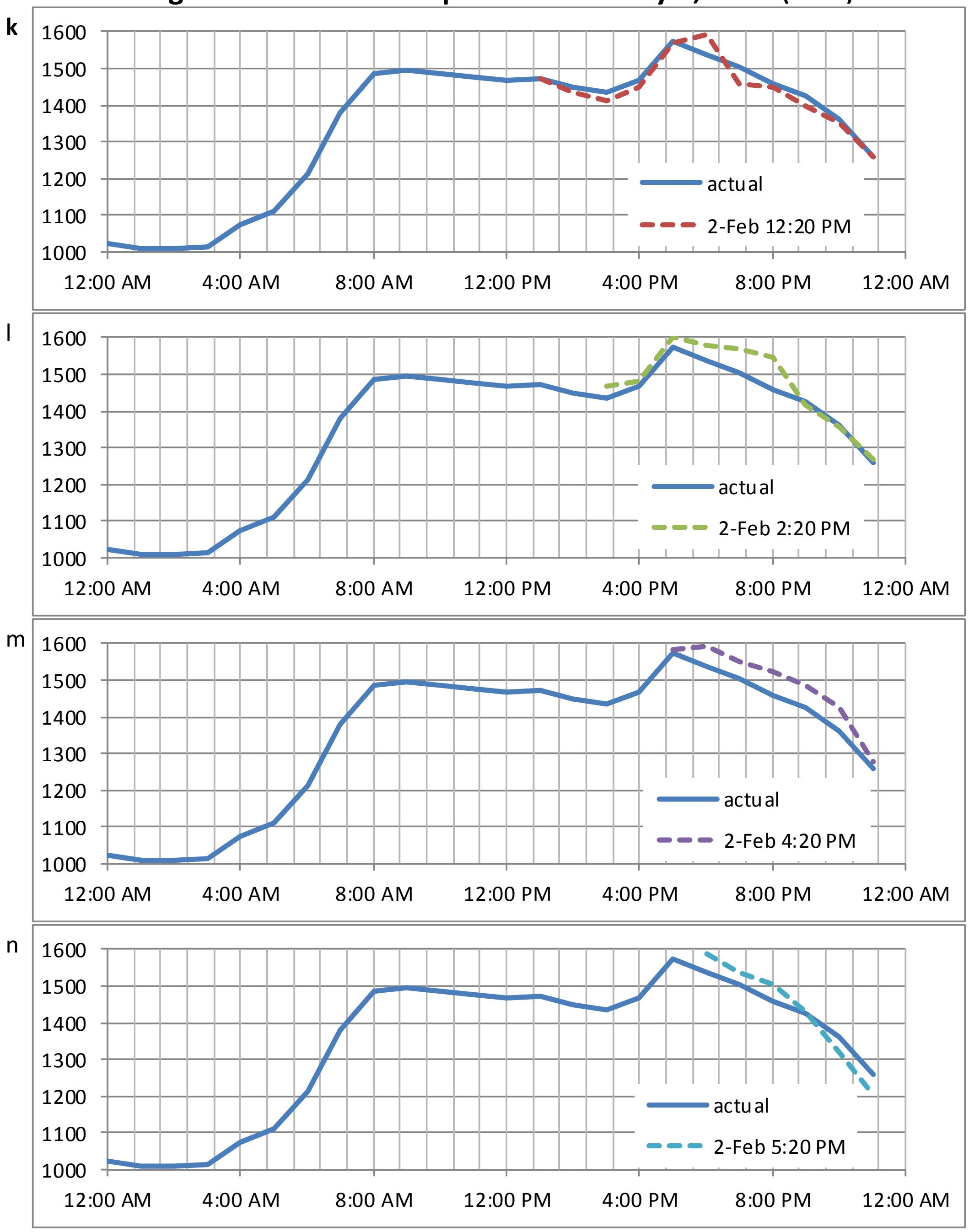

Figure 4 Actual 24 Hour System Performance For Monday, February 2, 2015

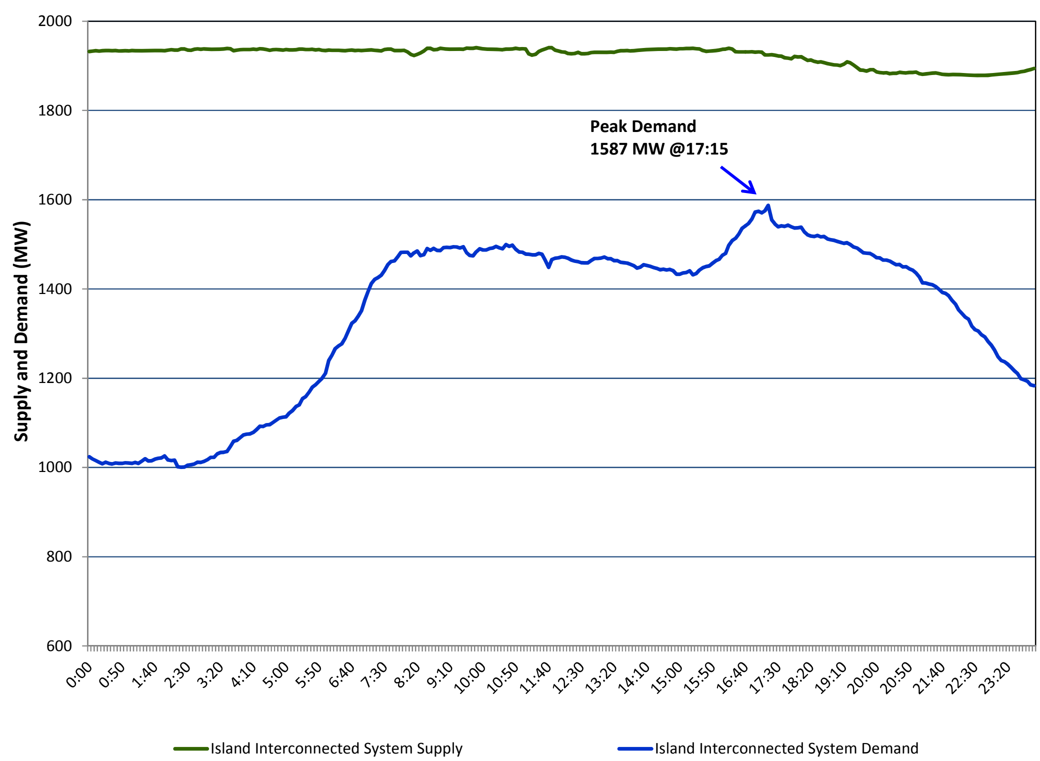

Figure 5 Available and Spinning Reserve, February 2, 2015

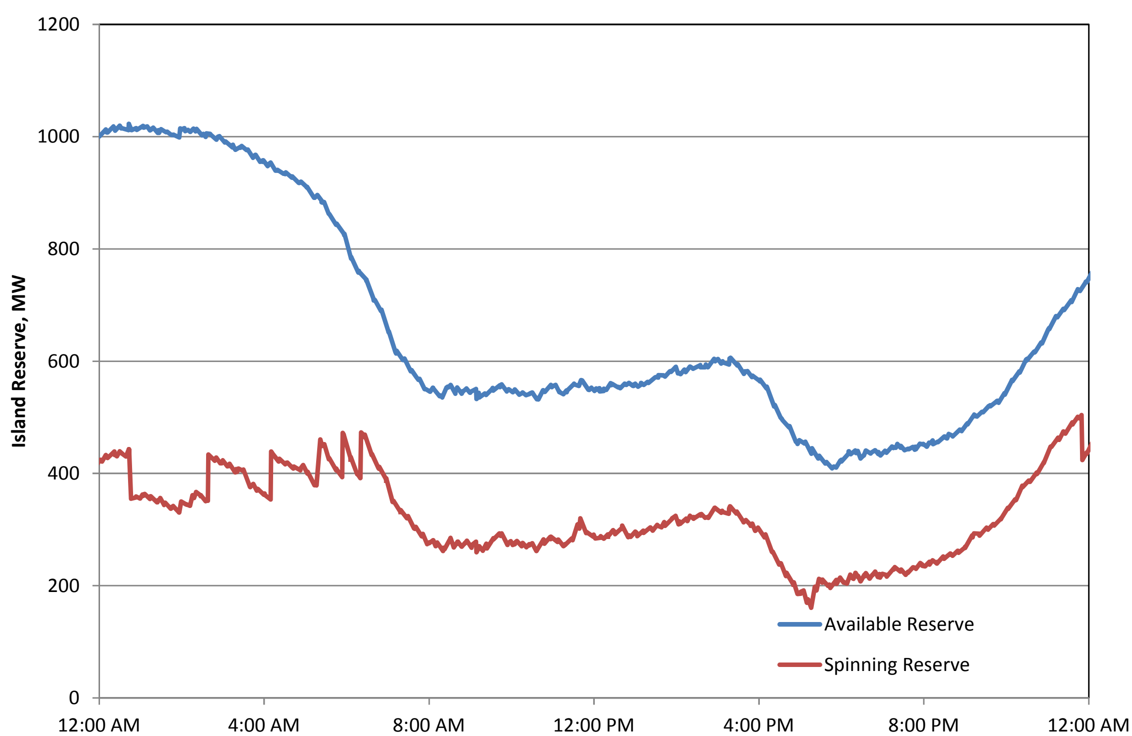

Figure 6 Forecast Comparison March 13, 2015 (1 of 3)

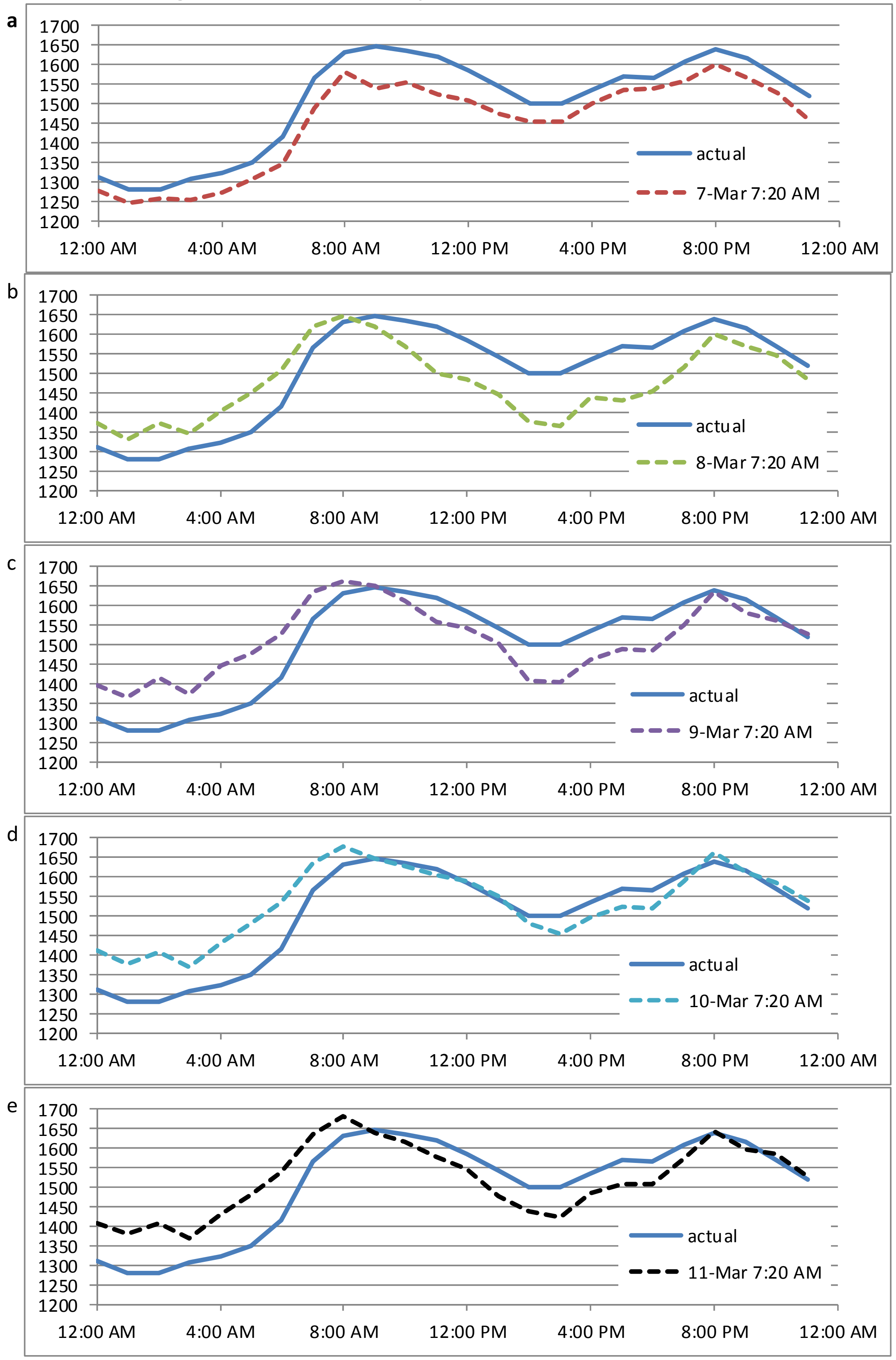

Figure 6 Forecast Comparison March 13, 2015 (2 of 3)

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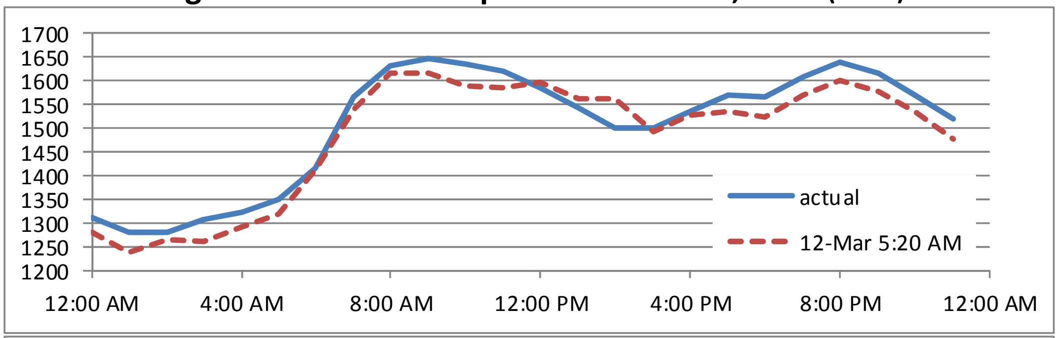

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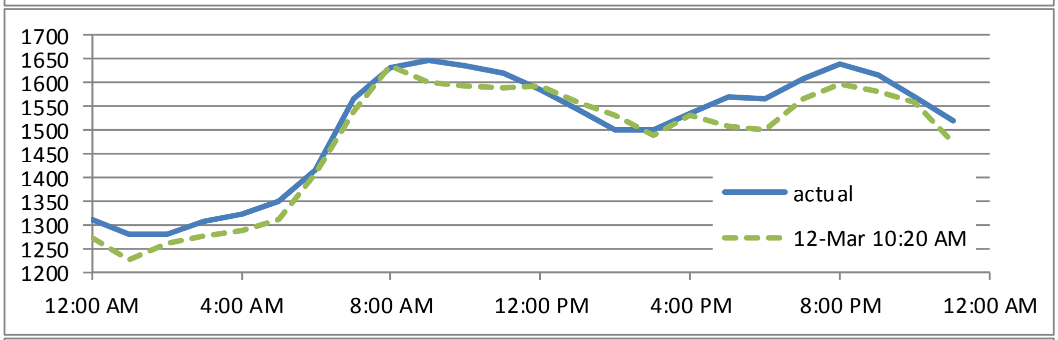

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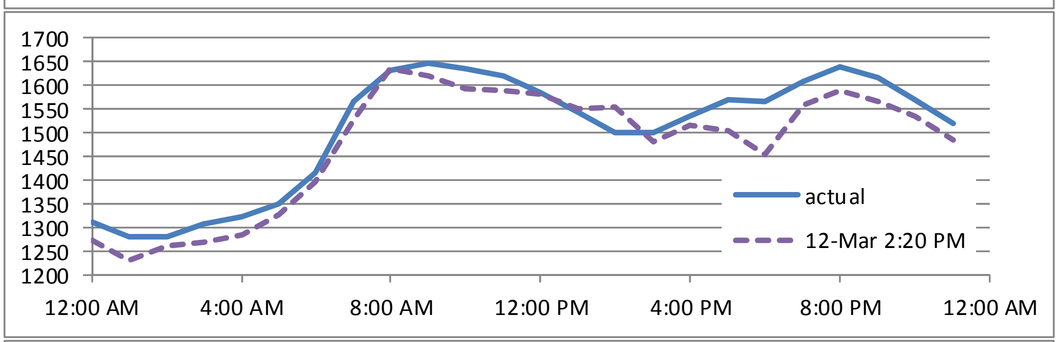

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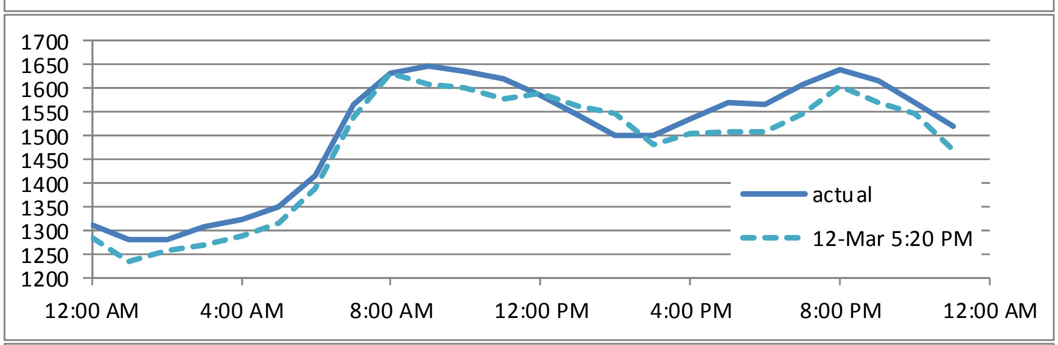

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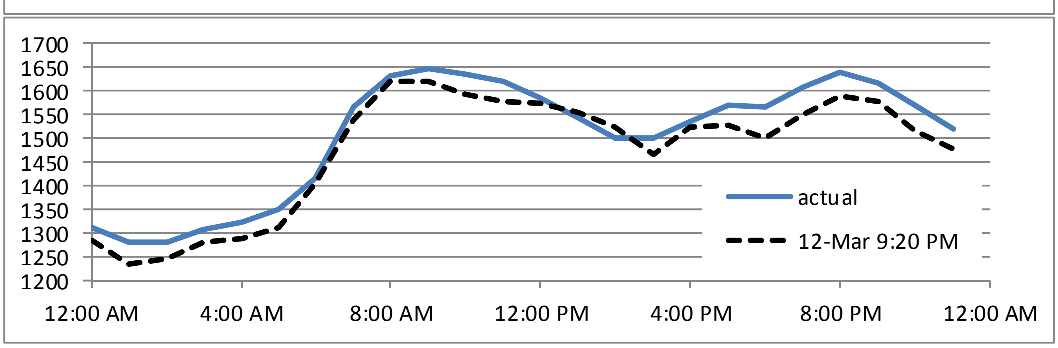


Figure 6 Forecast Comparison March 13, 2015 **(3 of 3)**

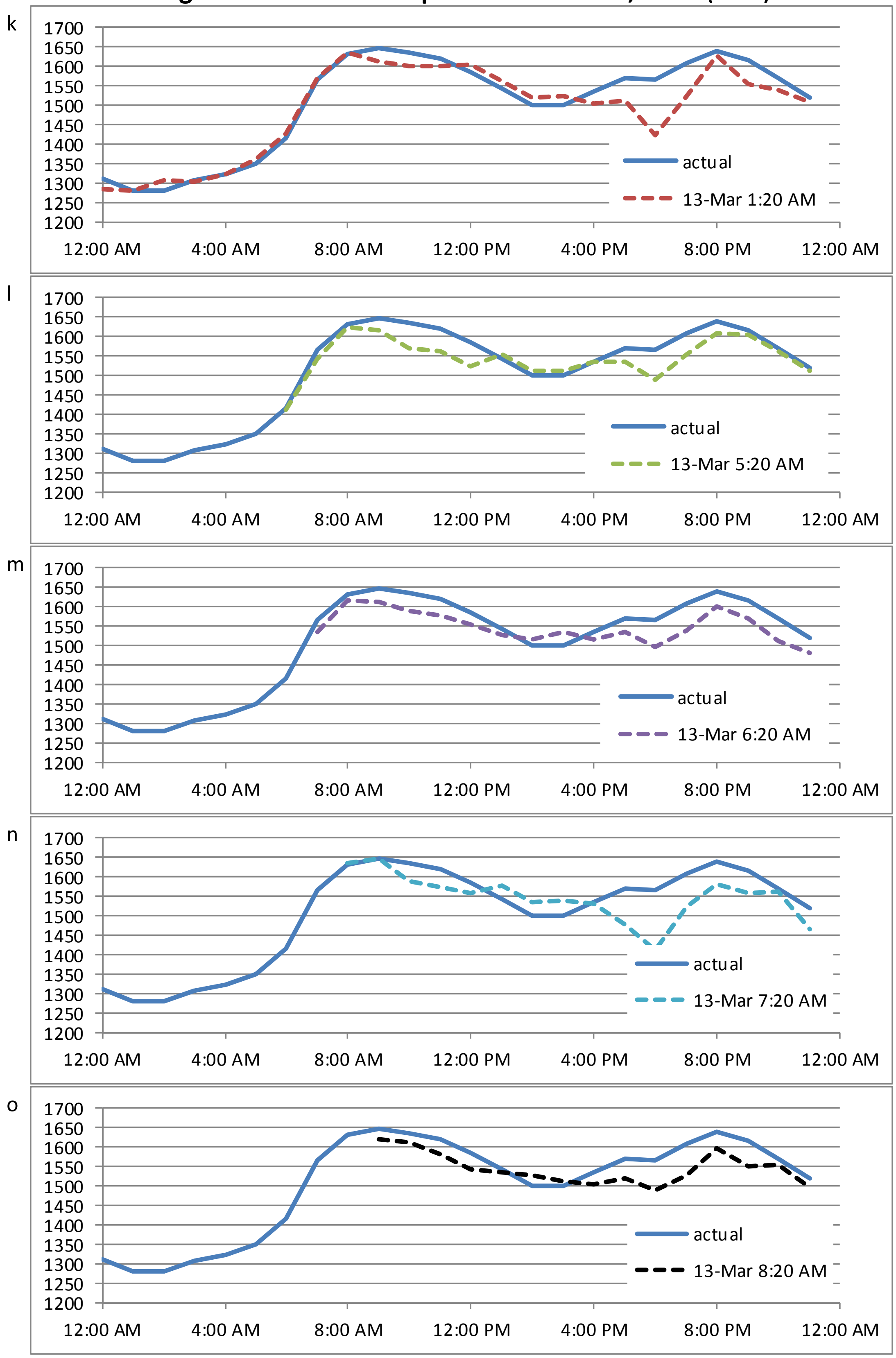


Figure 7 Actual 24 Hour System Performance For Friday, March 13, 2015

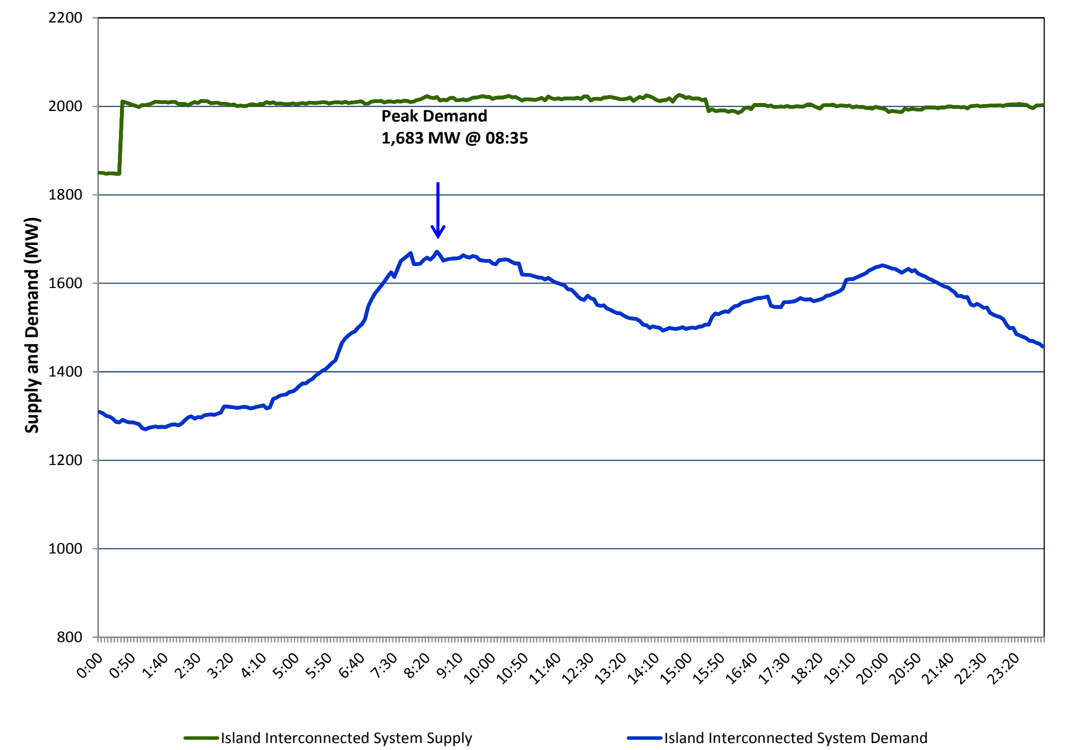
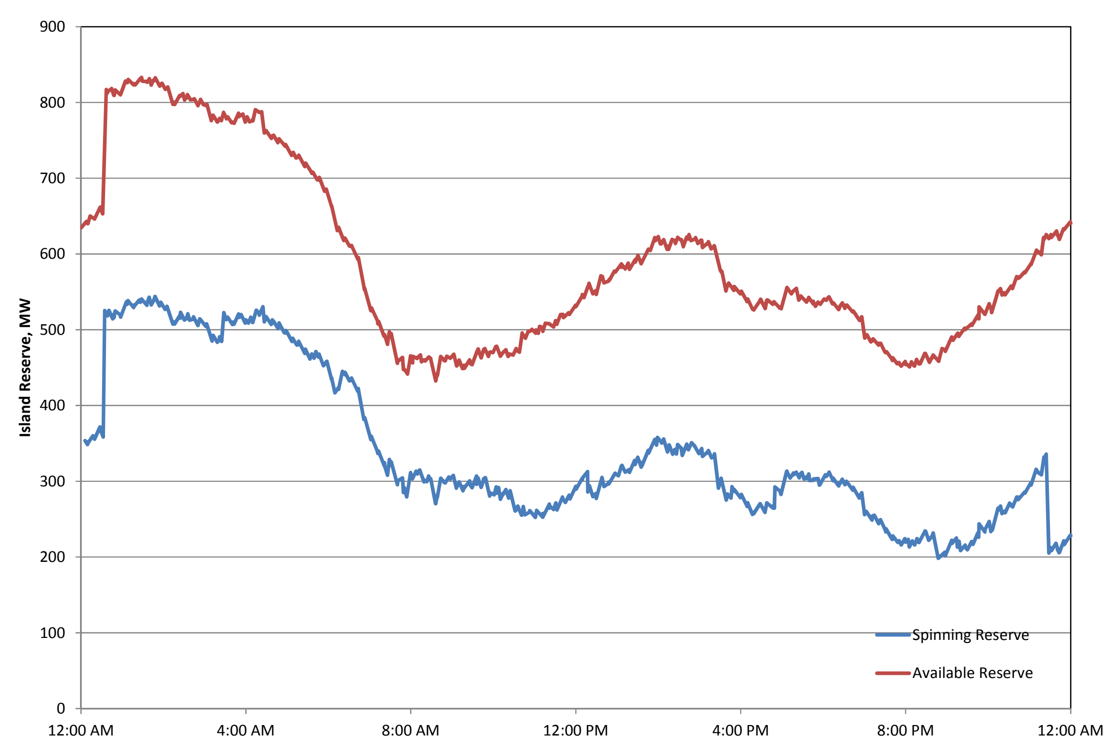


Figure 8 Available and Spinning Reserve, March 13, 2015



REFERENCES

Ventyx, an ABB Company, *Nostradamus User Guide, Release 8.2*, May 2014.

Liberty Consulting Group*, Executive Summary of Repot on Island Interconnected System to Interconnection with Muskrat Falls*, December 17, 2014.

Newfoundland and Labrador Hydro, *A Report to the Board of Commissioners of Public Utilities Progress Report on Load Forecasting Improvements*, October 31, 2014.

Newfoundland and Labrador Hydro, *Accuracy of Nostradamus Load Forecasting at Newfoundland and Labrador Hydro, Monthly Report: December 2015*, February 2, 2015.

Newfoundland and Labrador Hydro*, Accuracy of Nostradamus Load Forecasting at Newfoundland and Labrador Hydro, Monthly Report: January 2015*, February 10, 2015.

Newfoundland and Labrador Hydro, *Accuracy of Nostradamus Load Forecasting at Newfoundland and Labrador Hydro, Monthly Report: February 2015*, March 13, 2015.

Newfoundland and Labrador Hydro, *Accuracy of Nostradamus Load Forecasting at Newfoundland and Labrador Hydro, Monthly Report: March 2015*, April 10, 2015.

APPENDIX A

Verification of NL Hydro Weather Forecast
1 January 2015 to 31 March 2015
Amec Foster Wheeler Environment & Infrastructure
28 April 2015

FINAL

Verification of NL Hydro Weather Forecast
1 January 2015 to 31 March 2015

Submitted to:

Newfoundland and Labrador Hydro

Attn: Joanna Barnard
Hydro Place
500 Columbus Drive
St. John's, NL

Submitted by:

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28 April 2015

Amec Foster Wheeler Project #: TA1510436

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EXECUTIVE SUMMARY

Amec Foster Wheeler Environment & Infrastructure, a Division of Amec Foster Wheeler Americas Limited (Amec Foster Wheeler) is providing this report to Newfoundland and Labrador Hydro (NL Hydro) in support of the weather forecast service and NL Hydro reporting requirements. Amec Foster Wheeler has provided a daily regional weather forecast service since 2002 complemented by daily reservoir weather forecasts and wind farm weather forecasts which began in 2009. This is the first quarterly verification report submitted to NL Hydro. It is intended that this, and subsequent reports in 2015, will establish a baseline with which to compare future reports.

In this report, Amec Foster Wheeler has verified weather forecast data for the first three months of 2015 at the regional forecast locations and verified them against Environment Canada (EC) observation data at nearby sites. Various statistical analyses were evaluated for each set of comparison data for the following parameters: air temperature, relative humidity, wind direction, wind speed, precipitation, and cloud cover. Conclusions are drawn from the statistical analysis, and are summarized below.

Air temperatures at Port aux Basques, Gander and St. John's were noticeably more accurate, and showed less of a diurnal cycle, than those at Wabush, Deer Lake, and to a lesser extent Goose Bay. At times near the daily peak in error values, mean absolute errors for the latter three sites were of a magnitude 2 or 3 times those of the former. This may be caused by the greater range of temperatures experienced at inland sites versus those with coastal climates. The diurnal pattern was also observed to a lesser extent in the errors for relative humidity at some sites.

The relative humidity verification also revealed some suspected model biases at Goose Bay, Deer Lake and Wabush. Model biases were evident at Deer Lake and Wabush as well through examination of the wind speed verification.

Amongst the verification of many parameters there was an indication of changes in model accuracy when source model data changed. This was particularly evident for wind speed. The three model outputs used to produce the regional forecast are UMOS GEM Regional, UMOS GEM Global and XGFS. Switching between the component models occurs at 45 hours and 141 hours. For some parameters and locations the error was greatest for the period of the forecast drawn from UMOS GEM Global, improving with the switch to XGFS in the latter part of the forecast. For others the error increased significantly with the switch from UMOS GEM Global to XGFS.

A second pattern observed between verification of all parameters was diminishing accuracy as lead time increased. In general this is a common attribute of numerical weather prediction models, and is an expected result.

The precipitation verification produced variable errors for all locations. It is difficult to determine any underlying model bias, however the increase in error with lead time was quite evident for this parameter. It is generally recognized that verification of precipitation forecasts is difficult under the best conditions and particularly difficult during winter months. The methodology for precipitation verification will be re-visited to determine whether any improvements can be made.

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1.0 INTRODUCTION

This report presents an analysis of the weather forecast data provided by Amec Foster Wheeler, a division of Amec Foster Wheeler Americas Limited (Amec Foster Wheeler) to Newfoundland and Labrador Hydro (NL Hydro). The data are evaluated, using a number of standard statistical measures, to assess the accuracy of the weather forecasts during the period of analysis.

The purpose of these periodic reports is to document the accuracy and other skill measures for weather forecasts issued to NL Hydro. Amec Foster Wheeler provides NL Hydro with weather forecasts on a daily basis, which fall into three categories:

1. Regional weather forecasts – Forecasts at specific locations throughout the province that are representative of the main population areas. These forecasts are primarily used to estimate the load that will be experienced on the electrical network.
2. Reservoir weather forecasts – Forecasts that represent the reservoirs for the main hydro-electric generating stations. These forecasts are primarily used to estimate the generating capacity and the potential over-supply or under-supply of water available in the reservoirs.
3. Wind farm weather forecasts – Forecasts that predict the wind conditions at the two wind farm locations. These forecasts are primarily used to estimate the potential generating capacity provided by the wind farms.

To determine the accuracy, the weather forecasts are compared to observation data (where available). The verification metrics presented herein were selected based on standard meteorological practice.

The data presented within this report establishes the first part of a baseline of performance data to which future analyses will be compared. This will support ongoing evaluation of weather forecast skill and continuous improvements to the modeling methodology.

2.0 VERIFICATION METHODOLOGY

To determine the accuracy of the weather forecasts, the forecasted values are compared to the actual observations, using the statistical measures defined in Equations 1 to 6. Site-specific forecasts and observations are assumed to be available at the same location and time, and are represented by the notation (F_k,O_k; k=1,…,N). In most cases, the forecast and observation values are not exactly temporally aligned. To overcome this, the forecasts and observations are synchronized temporally using a linear interpolation of the forecast values to coincide with the observations.

The forecast and observation values can be parameters such as wind speed, wind direction, temperature, atmospheric pressure, relative humidity, etc. The forecast data is generated by combining the predictions of three different numerical weather prediction models. The three models have different ranges of validity. When the first model ends at 45 hours, the forecast switches to the second model. When the second model ends at 141 hours, the forecast switches to the third model. The resulting forecast provides predictions of values for parameters, at one-hour intervals, for a total forecast duration of 168 hours (7 days). The observation data, to which the forecasts are compared, are obtained from Environment Canada weather stations and from NL Hydro observation stations.

Most of the statistical metrics discussed in this report are presented as a function of “lead time”. Lead time, also referred to as the “forecast horizon”, is the number of hours into the future for which a forecast value is valid. For example, if a forecast is issued at 0600, the forecast value for 0900 is at a lead-time of 3 hours.

For each of the metrics described in Equations 1 to 6, the interpolated forecast value is compared with the observed value at the corresponding time. During the period of analysis, forecasts were provided once per day, from January 1 to March 31, for a total of 90 forecasts (January – 31, February – 28, March 31).

Each metric is aggregated for all of the forecasts based on lead time. This is generally the most meaningful way to represent error in a situation where there are overlapping forecasts which are issued on different dates. The error for a particular lead time from one forecast, is summed with errors for the same lead-time from the other 89 forecasts. Errors are only compared or aggregated if they are for the same lead-time. For example, the calculated error values at a lead–time of 3 hours, for all 90 of the forecasts, are combined to produce the mean value for lead-time of 3 hours. The aggregation is done because the error of any one individual forecast is not statistically significant or meaningful.

Each error metric, for each parameter, is calculated for each hourly interval of lead time (except precipitation which is aggregated in 6-hourly intervals). Rather than present 168 hourly values for each error metric, the data are summarized in the tables displayed in Section 3.0. The data are summarized as daily averages (the first 24 hourly values are averaged to produce the Day 1 Mean value). This is repeated for each of the seven days in the forecast and then a mean is calculated for the entire seven-day period.

Mean Error (ME) represents the arithmetic average of all of the calculated errors, for each lead-time. This gives a measure of the additive bias, which indicates whether, on average, the forecasts tend to over-predict or under-predict when compared to the observations. The units of this metric are the same as the parameter being measured. The ideal value of Mean Error is 0.

$$\mathrm{ME} = \frac{1}{N}\sum_{k=0}^{N}(F_k - O_k)$$

Equation 1: Mean Error or Additive Bias

Mean Absolute Error (MAE) represents the average of all of the calculated absolute errors, for each lead-time. This gives a measure of how inaccurate the average forecast is, by ensuring that errors do not cancel each other out (as can be the case when using ME). It is especially useful in datasets where the error data tends to be uniformly distributed. The ideal value of MAE is 0.

$$\mathrm{MAE} = \frac{1}{N}\sum_{k=0}^{N}|F_k - O_k|$$

Equation 2: Mean Absolute Error

Mean Square Error (MSE) represents the average of all of the calculated square of the errors, for each lead-time. This statistic incorporates representation of both the variance and its bias. Squaring the error removes the opportunity for errors to cancel each other. One characteristic of MSE is that because of the squaring function, it places more weight on outliers or large errors. This metric is sometimes useful to highlight situations where large errors are significantly worse than small errors, or when a large variance in the error data is significantly less desirable than consistent error. A minimal MSE often indicates a minimum variance. The ideal value of MSE is 0.

$$\mathrm{MSE} = \frac{1}{\mathrm{N}}\sum_{k=0}^{N}(F_k - O_k)^2$$

Equation 3: Mean Square Error

Root Mean Square Error (RMSE) is the square root of the MSE. It is a useful measure of accuracy and features the same characteristics of MSE. An advantage of RMSE over MSE is that its units are the same as the parameter being measured. Similar to MSE, the ideal value of RMSE is 0.

$$\mathrm{RMSE} = \sqrt{\frac{1}{\mathrm{N}}\sum_{k=0}^{N}(F_k - O_k)^2} = \sqrt{\mathrm{MSE}}$$

Equation 4: Root Mean Square Error

Multiplicative Bias is a metric that indicates whether the aggregated forecast values tend to over-predict or under-predict the parameter, when compared to the observations. Multiplicative Bias is expressed as a ratio, whereas the Additive Bias is expressed in the same units as the parameter being measured. Because Multiplicative Bias is expressed as a ratio (or percentage) it is independent of the parameter units and is useful for comparing the performance of different parameters (which may be in different units). An ideal value of Multiplicative Bias is 1.

$$\mathrm{BIAS} = \frac{\frac{1}{\mathrm{N}}\sum_{k=0}^{N} F_k}{\frac{1}{\mathrm{N}}\sum_{k=0}^{N} O_k}$$

Equation 5: Multiplicative Bias

Correlation Coefficient (r) is a measure of the strength of the linear relationship between the forecasted and observed values. The ideal value of Correlation Coefficient is 1.

$$\mathrm{r} = \frac{\sum_{k=0}^{N}(F_k - \bar{F})(O_k - \bar{O})}{\sqrt{\sum_{k=0}^{N}(F_k - \bar{F})^2}\sqrt{\sum_{k=0}^{N}(O_k - \bar{O})^2}}$$

Equation 6: Correlation Coefficient

2.1 Definitions and Abbreviations

Table 2-1: List of definitions and abbreviations used in report

Variable	Description
F	Forecast value (may be a model forecast value)
O	Observed value
N	Number of values used in the calculation
N	Count of the number of values within a category bin
ME	Mean error or additive bias (< 0 under-forecasting on average, > 0 over- forecasting on average, = 0 is an unbiased forecast)
MAE	Mean absolute error
RMSE	Root mean square error
MSE	Mean square error
r	Correlation coefficient (range -1 to 1, 1 is a perfect correlation)
BIAS	Multiplicative bias (< 1 under-forecasting on average, > 1 over- forecasting on average, = 1 is an unbiased forecast)

3.0 FORECAST VERIFICATION

3.1 Regional Forecasts

Regional forecasts are provided once per day for each of the following locations:

1. St. John's
2. Gander
3. Deer Lake
4. Port aux Basques
5. Goose Bay
6. Wabush

All observations for these locations are taken from a corresponding Environment Canada weather station.

The following forecast parameters are provided in the daily forecast, at hourly intervals. Parameters that are not available for verification, or that are modified for verification, are noted in the table:

Table 3-1: Regional forecast verification parameters

Parameter	Notes
Dry-bulb temperature	
Relative humidity	
Cloud cover	
Precipitation amount	Hourly observation data is not available. Verification is determined for a 6-hour period which corresponds with the observation period.
Wind speed	
Wind direction	

3.1.1 Dry-bulb Temperature

Mean Error (ME)

Table 3-2 summarizes the results of the ME calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the ME calculation, for each of the regional forecasts, are also displayed in Figure 3-1 on an hourly basis.

Table 3-2: Regional Forecast - Temperature Mean Error

	Regional Forecast Verification - Temperature					
	Mean Error (°C)					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	-0.04	0.10	0.24	-0.38	0.28	0.72
Mean - Day 2	-0.10	0.01	0.52	-0.36	0.62	0.97
Mean - Day 3	0.27	0.16	0.83	-0.16	1.07	0.69
Mean - Day 4	0.02	-0.03	0.68	-0.14	1.21	0.45
Mean - Day 5	0.05	0.07	0.99	-0.31	1.35	0.85
Mean - Day 6	0.11	0.12	0.80	0.08	1.16	0.55
Mean - Day 7	0.12	-0.70	-1.23	0.70	-1.51	-2.82
Mean Value:	0.06	-0.04	0.40	-0.08	0.60	0.20

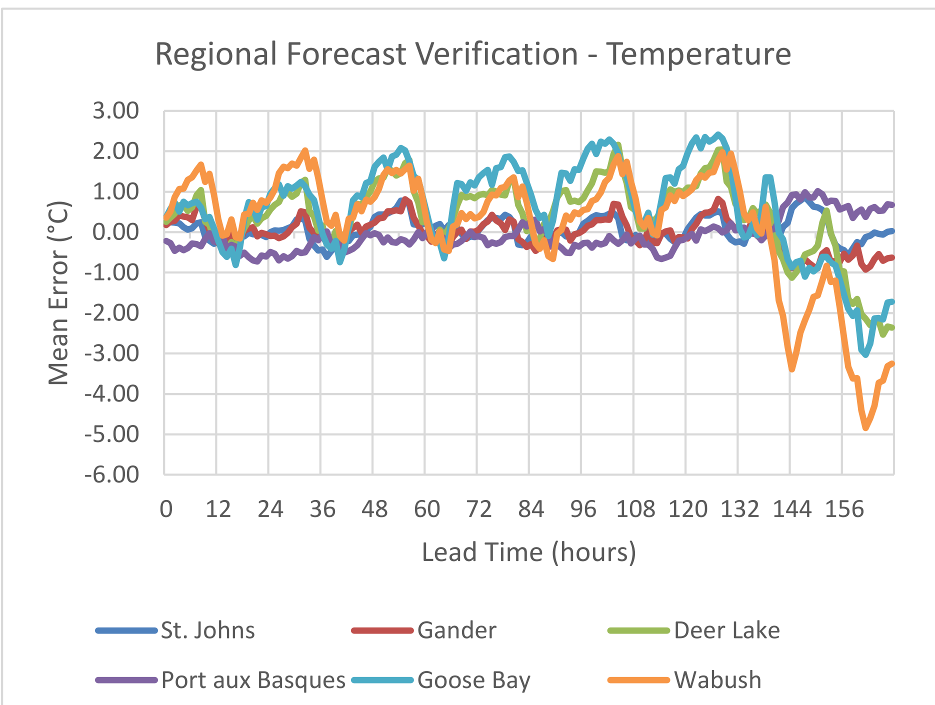

Figure 3-1: Regional Forecast - Temperature Mean Error

Mean Absolute Error (MAE)

Table 3-3 summarizes the results of the MAE calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the MAE calculation, for each of the regional forecasts, are also displayed in Figure 3-2, on an hourly basis.

Table 3-3: Regional Forecast - Temperature Mean Absolute Error

	Regional Forecast Verification - Temperature					
	Mean Absolute Error (°C)					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	0.88	1.15	1.86	1.10	1.75	2.17
Mean - Day 2	1.19	1.47	2.15	1.37	2.08	2.45
Mean - Day 3	1.48	1.84	2.51	1.50	2.57	2.84
Mean - Day 4	1.64	2.00	2.81	1.84	2.95	3.29
Mean - Day 5	2.03	2.45	3.07	2.04	3.40	4.01
Mean - Day 6	2.56	2.82	3.71	2.49	4.09	4.54
Mean - Day 7	3.39	3.95	5.04	2.96	5.09	6.45
Mean Value:	1.88	2.24	3.02	1.90	3.13	3.68

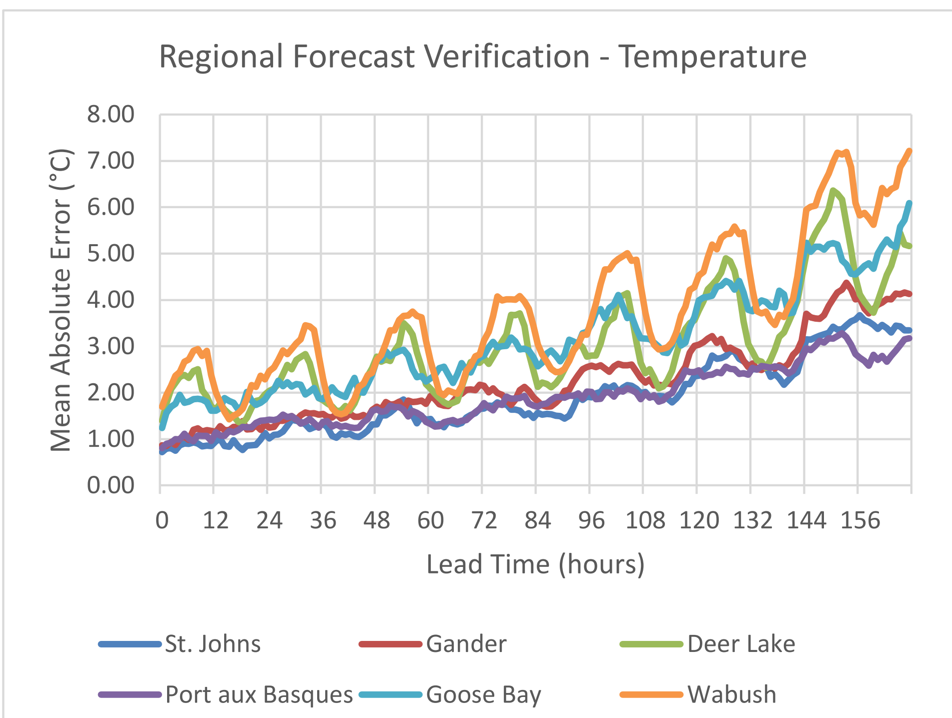

Figure 3-2: Regional Forecast - Temperature Mean Absolute Error

Mean Square Error (MSE)

Table 3-4 summarizes the results of the MSE calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the MSE calculation, for each of the regional forecasts, are also displayed in Figure 3-3, on an hourly basis.

Table 3-4: Regional Forecast - Temperature Mean Square Error

	Regional Forecast Verification - Temperature					
	Mean Square Error					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	1.33	2.22	6.79	2.15	4.97	8.57
Mean - Day 2	2.50	3.86	9.76	3.17	6.74	11.60
Mean - Day 3	3.84	6.00	13.37	3.76	9.89	14.08
Mean - Day 4	4.58	7.00	15.41	5.72	13.85	18.26
Mean - Day 5	7.08	10.09	18.35	7.63	19.75	26.78
Mean - Day 6	12.15	13.70	25.91	10.38	26.41	35.40
Mean - Day 7	18.76	26.86	42.74	14.72	44.04	64.87
Mean Value:	7.18	9.96	18.91	6.79	17.95	25.65

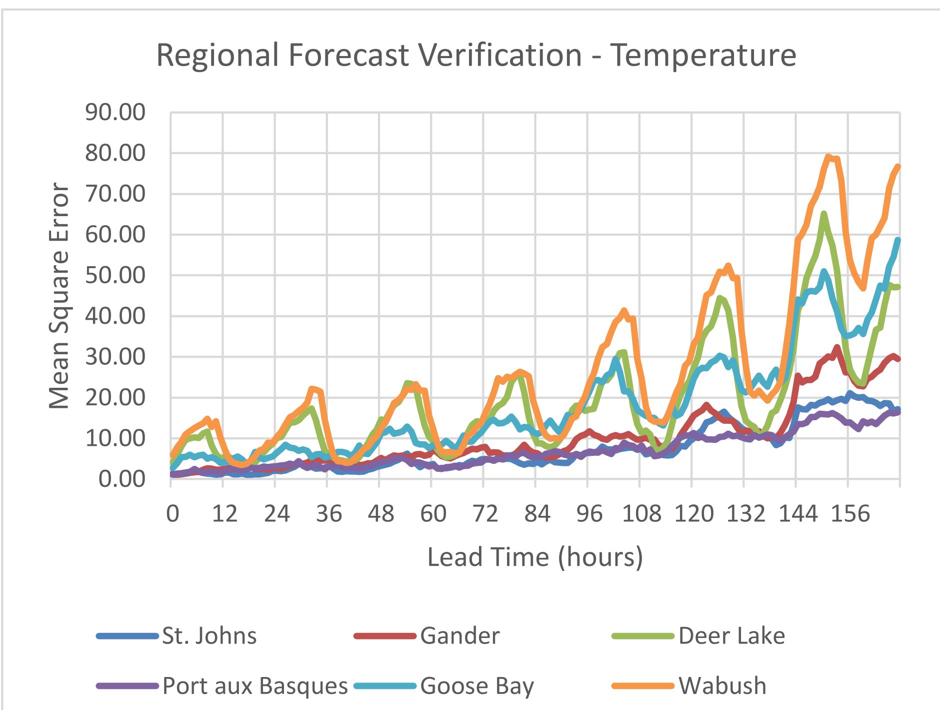

Figure 3-3: Regional Forecast - Temperature Mean Square Error

Root Mean Square Error (RMSE)

Table 3-5 summarizes the results of the RMSE calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the RMSE calculation, for each of the regional forecasts, are also displayed in Figure 3-4, on an hourly basis.

Table 3-5: Regional Forecast - Temperature Root Mean Square Error

	Regional Forecast Verification - Temperature					
	Root Mean Square Error					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	1.14	1.47	2.55	1.45	2.22	2.85
Mean - Day 2	1.56	1.95	3.02	1.77	2.58	3.28
Mean - Day 3	1.94	2.44	3.54	1.92	3.13	3.66
Mean - Day 4	2.12	2.62	3.84	2.38	3.71	4.20
Mean - Day 5	2.64	3.15	4.16	2.73	4.40	5.07
Mean - Day 6	3.45	3.66	4.95	3.21	5.12	5.84
Mean - Day 7	4.31	5.16	6.44	3.83	6.60	8.00
Mean Value:	2.45	2.92	4.07	2.47	3.96	4.70

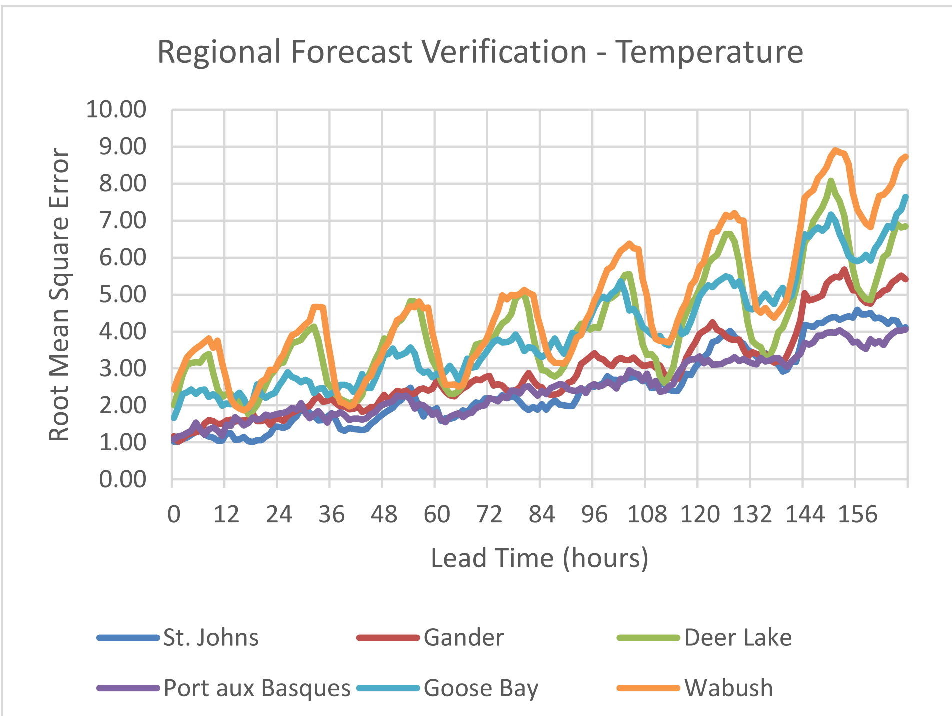

Figure 3-4: Regional Forecast - Temperature Root Mean Square Error

Correlation Coefficient

Table 3-6 summarizes the results of the Correlation Coefficient calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Correlation Coefficient calculation, for each of the regional forecasts, are also displayed in Figure 3-5, on an hourly basis.

Table 3-6: Regional Forecast - Temperature Correlation Coefficient

	Regional Forecast Verification - Temperature					
	Correlation Coefficient					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	0.97	0.96	0.91	0.94	0.96	0.95
Mean - Day 2	0.95	0.93	0.88	0.92	0.95	0.94
Mean - Day 3	0.92	0.89	0.83	0.90	0.92	0.91
Mean - Day 4	0.89	0.87	0.79	0.83	0.88	0.88
Mean - Day 5	0.82	0.80	0.76	0.76	0.83	0.82
Mean - Day 6	0.69	0.73	0.64	0.64	0.75	0.74
Mean - Day 7	0.58	0.55	0.48	0.55	0.60	0.60
Mean Value:	0.83	0.82	0.75	0.79	0.84	0.83

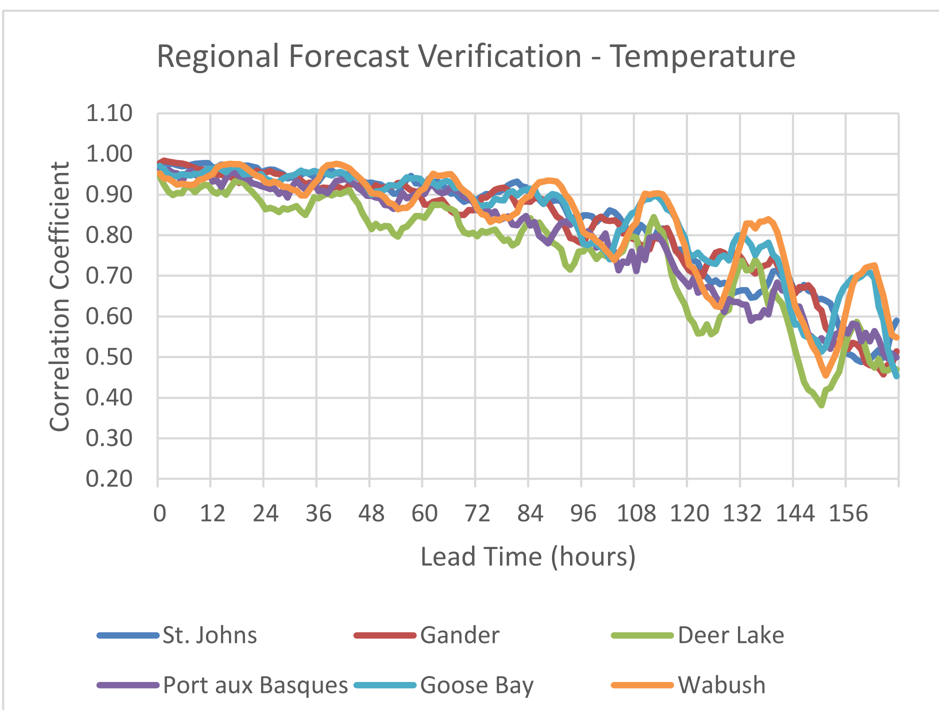

Figure 3-5: Regional Forecast - Temperature Correlation Coefficient

Discussion of Results – Air Temperature

As can be seen in the results, in particular in figures showing ME, MAE, MSE and RMSE, Wabush, Deer Lake and Goose Bay exhibit a strong diurnal cycle in the magnitude of the error. The stronger diurnal cycle in error at these locations may be because they are inland and the daily variability in temperature is generally greater for inland locations as compared to coastal locations. Amec Foster Wheeler will continue to monitor this outcome to see if this cycle remains consistent and if so, endeavour to improve the forecast by reducing the diurnal effect.

Another possible source of error is the hourly interpretation of 3- and 6-hourly data output from the numerical prediction models used to produce the forecasts. Currently, a linear interpolation of the 3-hourly model data is used, which may miss the peak temperature. Improvements can be made to the interpolation which we would expect would reduce the error during these periods. The greatest errors occur at Wabush, Deer Lake and Goose Bay, where the peak errors are 2 to 3 times those for the other three locations.

Generally forecasts are less accurate as lead time increases. This can be attributed to the general characteristic of numerical weather prediction models, which tend to under-forecast temperature at long lead times. As well, lower resolution models are used for the Regional Forecasts past a 45-hour lead time.

3.1.2 Relative Humidity

Mean Error (ME)

Table 3-7 summarizes the results of the Mean Error calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Mean Error calculation, for each of the regional forecasts, are also displayed in Figure 3-6, on an hourly basis.

Table 3-7: Regional Forecast – Relative Humidity Mean Error

	Regional Forecast Verification - Relative Humidity					
	Mean Error (%)					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	-3.06	-0.74	1.37	-2.89	3.80	-1.90
Mean - Day 2	-3.64	-1.58	-0.37	-3.72	6.67	-2.37
Mean - Day 3	-5.48	-1.96	-0.71	-5.94	15.41	3.65
Mean - Day 4	-5.88	-2.41	-0.96	-5.87	15.21	3.66
Mean - Day 5	-5.77	-2.20	-0.88	-6.39	14.73	3.24
Mean - Day 6	-5.33	-0.89	0.76	-6.04	17.04	5.11
Mean - Day 7	-1.69	7.80	17.03	-2.25	38.02	27.20
Mean Value:	-4.41	-0.28	2.32	-4.73	15.84	5.51

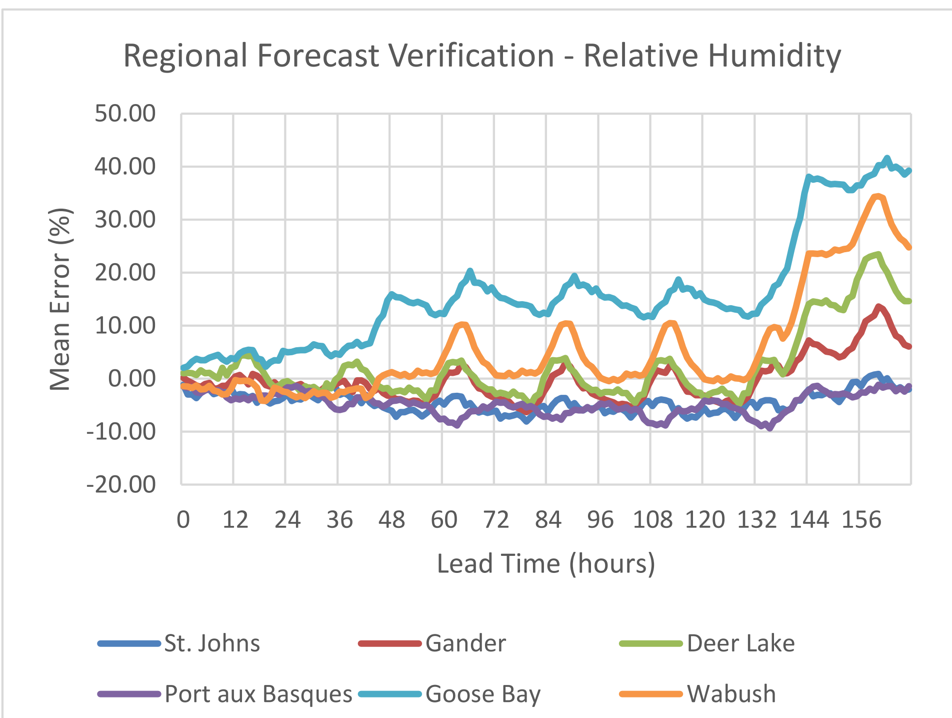

Figure 3-6: Regional Forecast – Relative Humidity Mean Error

Mean Absolute Error (MAE)

Table 3-8 summarizes the results of the Mean Absolute Error calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Mean Absolute Error calculation, for each of the regional forecasts, are also displayed in Figure 3-7, on an hourly basis.

Table 3-8: Regional Forecast – Relative Humidity Mean Absolute Error

	Regional Forecast Verification - Relative Humidity					
	Mean Absolute Error (%)					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	6.29	6.33	7.08	6.86	6.23	6.82
Mean - Day 2	7.08	6.64	6.70	7.23	8.70	6.64
Mean - Day 3	7.82	8.31	7.22	8.83	15.52	6.98
Mean - Day 4	8.52	8.96	7.80	9.15	15.31	7.17
Mean - Day 5	9.14	9.12	7.92	9.52	15.19	7.87
Mean - Day 6	10.22	10.24	8.85	10.14	17.69	9.61
Mean - Day 7	10.52	13.47	17.24	9.95	38.03	27.21
Mean Value:	8.51	9.01	8.97	8.81	16.67	10.33

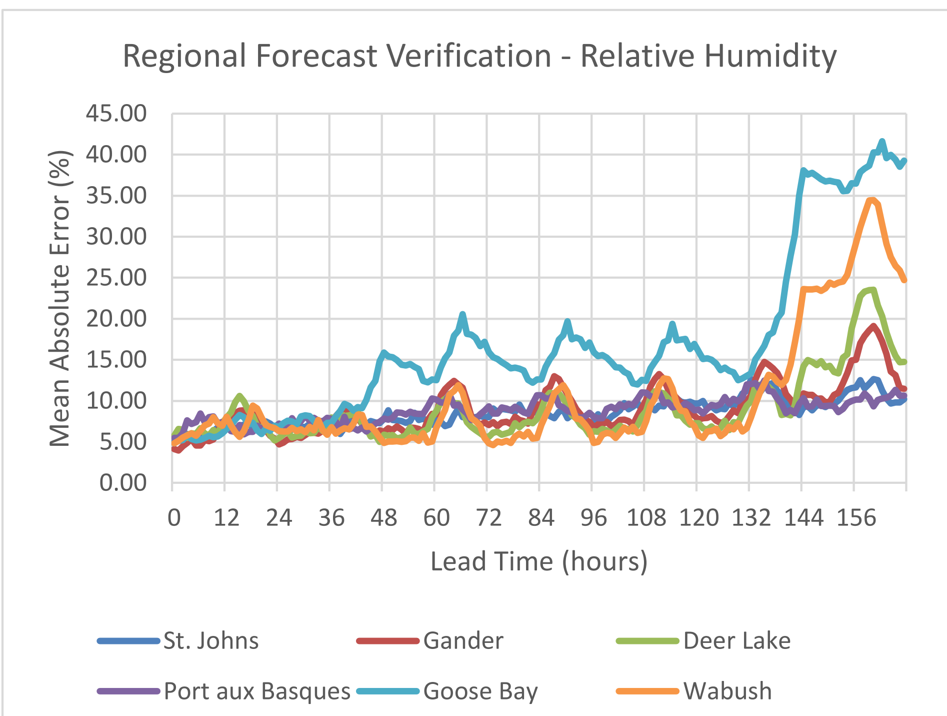

Figure 3-7: Regional Forecast – Relative Humidity Mean Absolute Error

Mean Square Error (MSE)

Table 3-9 summarizes the results of the Mean Square Error calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Mean Square Error calculation, for each of the regional forecasts, are also displayed in Figure 3-8, on an hourly basis.

Table 3-9: Regional Forecast – Relative Humidity Mean Square Error

	Regional Forecast Verification - Relative Humidity					
	Mean Square Error (%^2)					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	65.40	72.02	88.81	78.45	64.34	81.53
Mean - Day 2	78.94	76.19	77.47	83.42	124.40	75.94
Mean - Day 3	99.55	121.44	92.42	123.43	311.79	106.82
Mean - Day 4	118.71	136.96	105.58	133.53	301.45	114.22
Mean - Day 5	136.62	140.29	107.72	147.28	301.23	121.21
Mean - Day 6	172.44	177.29	130.93	170.24	422.35	167.32
Mean - Day 7	184.92	309.19	416.00	157.27	1539.28	853.25
Mean Value:	122.37	147.62	145.56	127.66	437.84	217.18

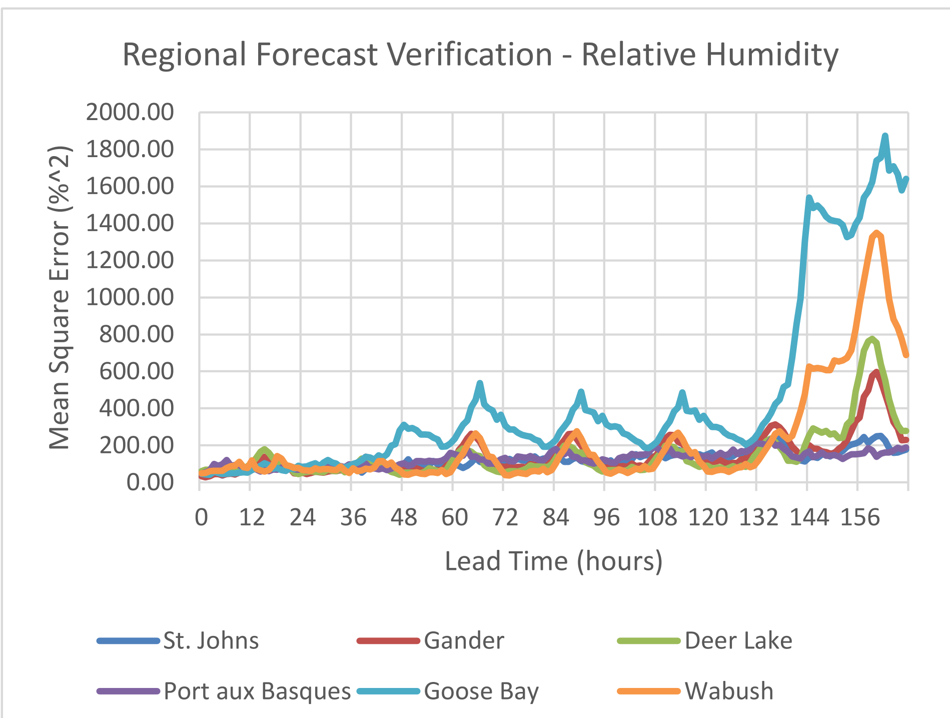

Figure 3-8: Regional Forecast – Relative Humidity Mean Square Error

Root Mean Square Error (RMSE)

Table 3-10 summarizes the results of the Root Mean Square Error calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Root Mean Square Error calculation, for each of the regional forecasts, are also displayed in Figure 3-9, on an hourly basis.

Table 3-10: Regional Forecast – Relative Humidity Root Mean Square Error

	Regional Forecast Verification - Relative Humidity					
	Root Mean Square Error (%)					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	8.00	8.21	9.21	8.78	7.93	8.92
Mean - Day 2	8.85	8.59	8.64	9.09	10.96	8.64
Mean - Day 3	9.93	10.63	9.32	11.04	17.46	9.79
Mean - Day 4	10.85	11.42	10.02	11.47	17.19	10.09
Mean - Day 5	11.61	11.55	10.12	12.06	17.20	10.55
Mean - Day 6	13.00	13.01	11.18	12.97	19.75	12.17
Mean - Day 7	13.50	17.09	19.90	12.49	39.18	28.88
Mean Value:	10.82	11.50	11.20	11.13	18.53	12.72

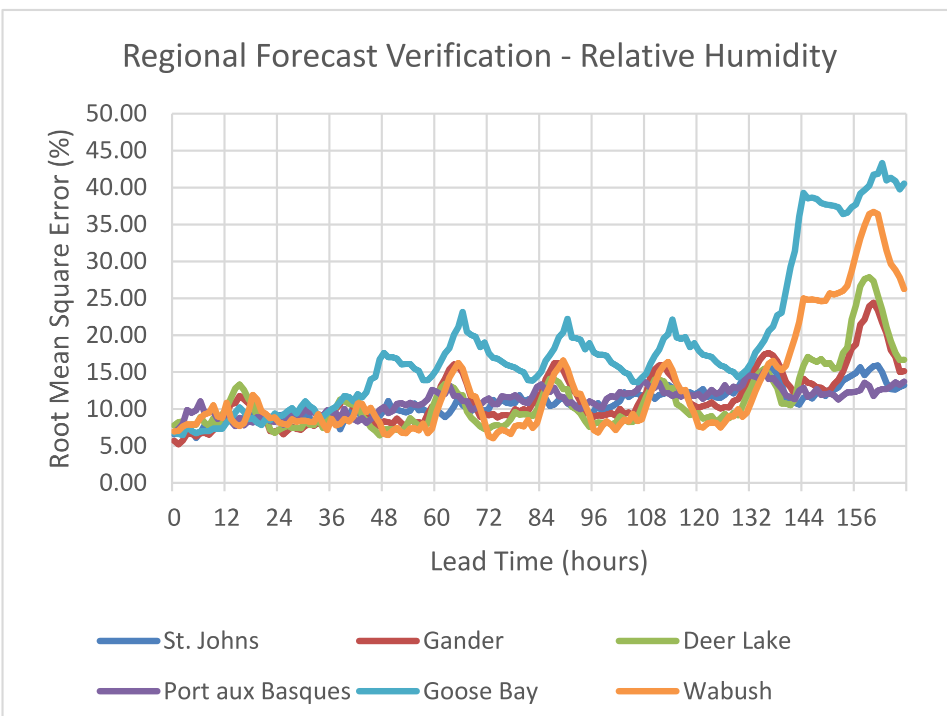

Figure 3-9: Regional Forecast – Relative Humidity Root Mean Square Error

Multiplicative Bias (BIAS)

Table 3-11 summarizes the results of the Multiplicative Bias calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Multiplicative Bias calculation, for each of the regional forecasts, are also displayed in Figure 3-10, on an hourly basis.

Table 3-11: Regional Forecast – Relative Humidity Multiplicative Bias

	Regional Forecast Verification - Relative Humidity					
	Multiplicative Bias					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	0.96	0.99	1.02	0.96	1.07	0.97
Mean - Day 2	0.96	0.98	1.00	0.95	1.12	0.97
Mean - Day 3	0.93	0.98	0.99	0.93	1.27	1.05
Mean - Day 4	0.93	0.97	0.99	0.93	1.27	1.06
Mean - Day 5	0.93	0.97	0.99	0.92	1.26	1.05
Mean - Day 6	0.94	0.99	1.01	0.93	1.30	1.08
Mean - Day 7	0.98	1.10	1.22	0.97	1.67	1.39
Mean Value:	0.95	1.00	1.03	0.94	1.28	1.08

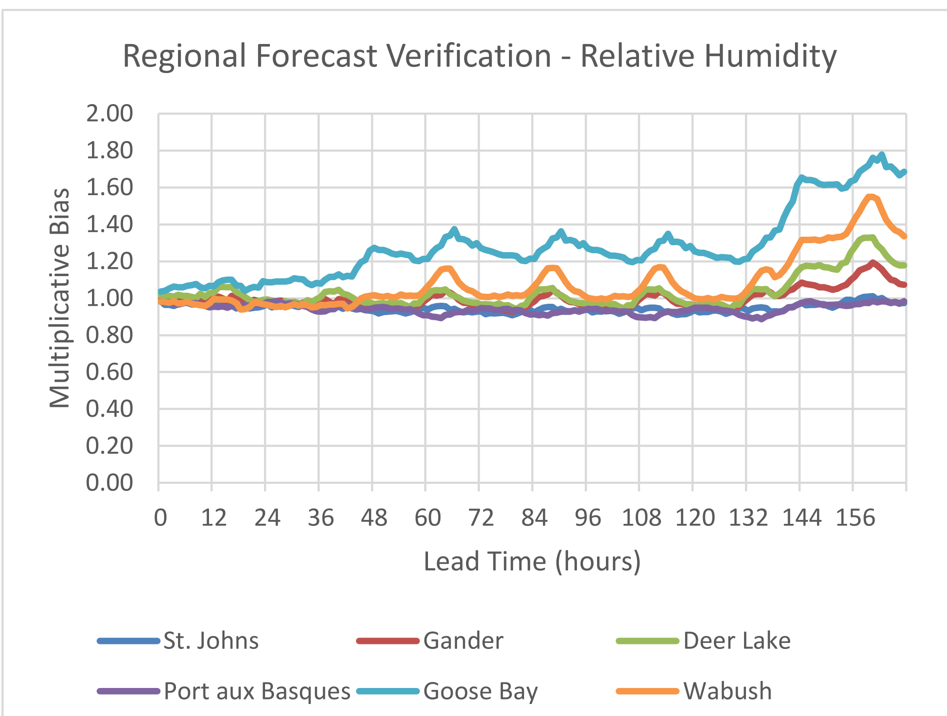

Figure 3-10: Regional Forecast – Relative Humidity Multiplicative Bias

Correlation Coefficient (r)

Table 3-12 summarizes the results of the Correlation Coefficient calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Correlation Coefficient calculation, for each of the regional forecasts, are also displayed in Figure 3-11, on an hourly basis.

Table 3-12: Regional Forecast – Relative Humidity Correlation Coefficient

	Regional Forecast Verification - Relative Humidity					
	Correlation Coefficient					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	0.81	0.79	0.49	0.67	0.73	0.57
Mean - Day 2	0.77	0.76	0.50	0.66	0.57	0.60
Mean - Day 3	0.78	0.65	0.49	0.63	0.56	0.44
Mean - Day 4	0.72	0.60	0.42	0.56	0.57	0.40
Mean - Day 5	0.65	0.58	0.40	0.51	0.44	0.30
Mean - Day 6	0.50	0.40	0.28	0.38	0.31	0.24
Mean - Day 7	0.31	0.23	-0.01	0.18	0.13	0.04
Mean Value:	0.65	0.57	0.37	0.51	0.47	0.37

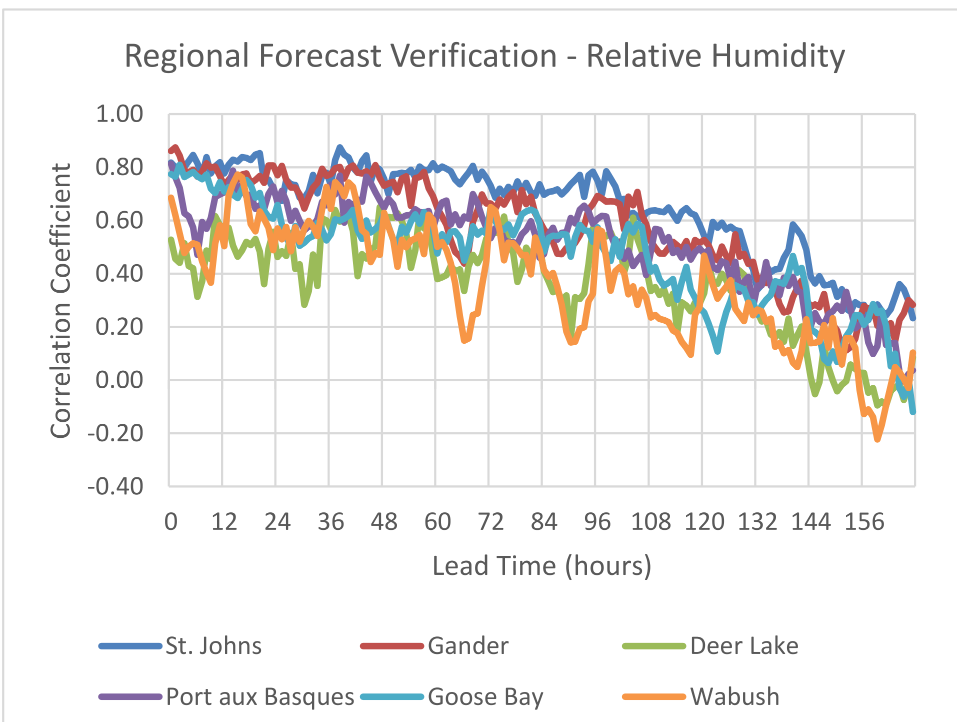

Figure 3-11: Regional Forecast – Relative Humidity Correlation Coefficient

Discussion of Results – Relative Humidity

The diurnal pattern discussed in the previous section is also apparent in verification results for relative humidity. The cause is also likely the variation between characteristic relative humidity ranges at inland versus coastal location. Again, with improvements to the interpolation of the data from 3- or 6-hourly to hourly, we would expect that these errors would be reduced.

The verification data indicates a significant increase in error as lead times increase. This is also possibly a result of reduced skill inherent to the numerical prediction models used in the long-term forecast.

The multiplicative bias figure (Figure 3-10) indicates poor verification for Goose Bay in particular, and for Wabush and Deer Lake to a lesser degree. This appears to be due to model bias at that particular location. Amec Foster Wheeler will take a closer look to see if the correlation between forecast and observed values can be improved.

3.1.3 Wind Speed

Environment Canada observations are generally reported hourly, but occasionally report more frequently. In cases where there are multiple observations per hour, Amec Foster Wheeler calculates the mean value to represent the hourly value.

Mean Error (ME)

Table 3-13 summarizes the results of the Mean Error calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Mean Error calculation, for each of the regional forecasts, are also displayed in Figure 3-12, on an hourly basis.

Table 3-13: Regional Forecast – Wind Speed Mean Error

	Regional Forecast Verification - Wind Speed					
	Mean Error (m/s)					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	0.38	0.90	0.16	0.68	1.01	0.82
Mean - Day 2	0.55	0.74	0.00	0.37	0.94	0.98
Mean - Day 3	0.54	-0.05	-2.12	-1.07	0.17	1.95
Mean - Day 4	0.75	0.23	-2.03	-1.16	0.08	2.14
Mean - Day 5	0.70	0.11	-1.98	-0.87	0.41	2.15
Mean - Day 6	0.56	-0.17	-1.92	-0.62	0.17	1.86
Mean - Day 7	0.35	-2.05	-0.46	-0.08	-0.57	-0.05
Mean Value:	0.55	-0.04	-1.19	-0.39	0.31	1.41

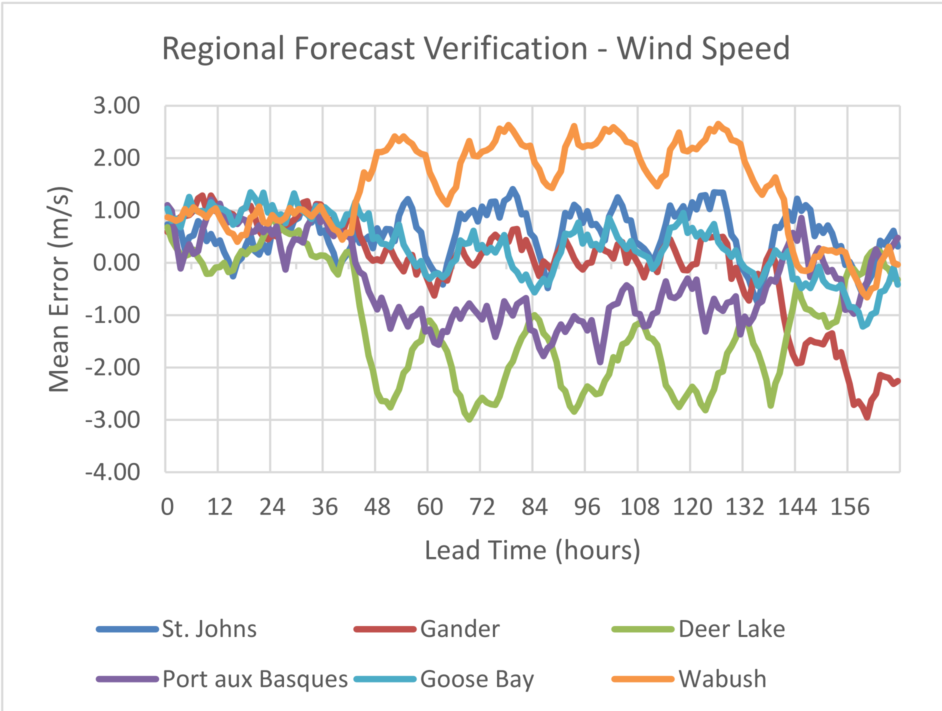

Figure 3-12: Regional Forecast – Wind Speed Mean Error

Mean Absolute Error (MAE)

Table 3-14 summarizes the results of the Mean Absolute Error calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Mean Absolute Error calculation, for each of the regional forecasts, are also displayed in Figure 3-13, on an hourly basis.

Table 3-14: Regional Forecast – Wind Speed Mean Absolute Error

	Regional Forecast Verification - Wind Speed					
	Mean Absolute Error (m/s)					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	1.48	1.52	1.45	2.06	1.64	1.34
Mean - Day 2	1.74	1.67	1.55	2.22	1.72	1.45
Mean - Day 3	2.25	1.96	2.61	2.81	1.75	2.24
Mean - Day 4	2.69	2.09	2.61	3.15	1.94	2.47
Mean - Day 5	3.11	2.54	2.69	3.69	2.18	2.57
Mean - Day 6	3.48	2.85	2.84	4.13	2.30	2.64
Mean - Day 7	3.87	3.26	2.37	4.57	2.31	1.95
Mean Value:	2.66	2.27	2.31	3.23	1.98	2.09

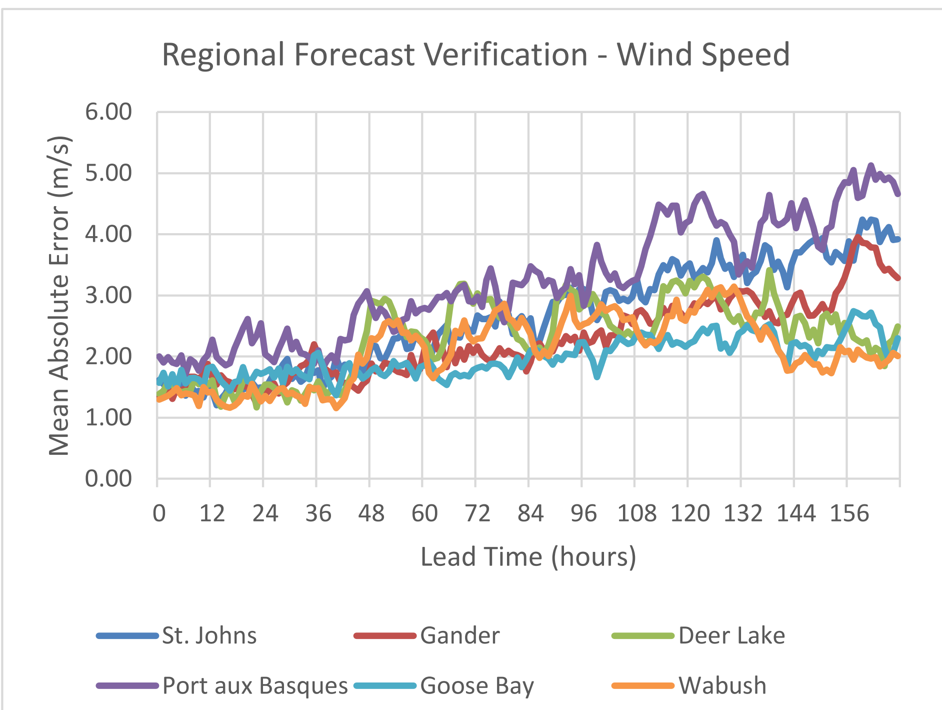

Figure 3-13: Regional Forecast – Wind Speed Mean Absolute Error

Mean Square Error (MSE)

Table 3-15 summarizes the results of the Mean Square Error calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Mean Square Error calculation, for each of the regional forecasts, are also displayed in Figure 3-14, on an hourly basis.

Table 3-15: Regional Forecast – Wind Speed Mean Square Error

	Regional Forecast Verification - Wind Speed					
	Mean Square Error ((m/s)^2)					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	3.52	3.64	6.29	7.19	4.27	2.82
Mean - Day 2	4.86	4.57	6.76	8.11	4.64	3.32
Mean - Day 3	8.59	6.47	13.35	12.72	5.05	8.03
Mean - Day 4	11.97	7.61	13.12	16.71	6.37	9.97
Mean - Day 5	16.39	11.67	14.09	24.16	8.46	10.72
Mean - Day 6	19.16	14.60	14.64	28.14	9.41	11.13
Mean - Day 7	25.05	18.31	12.25	33.65	8.84	6.36
Mean Value:	12.79	9.55	11.50	18.67	6.72	7.48

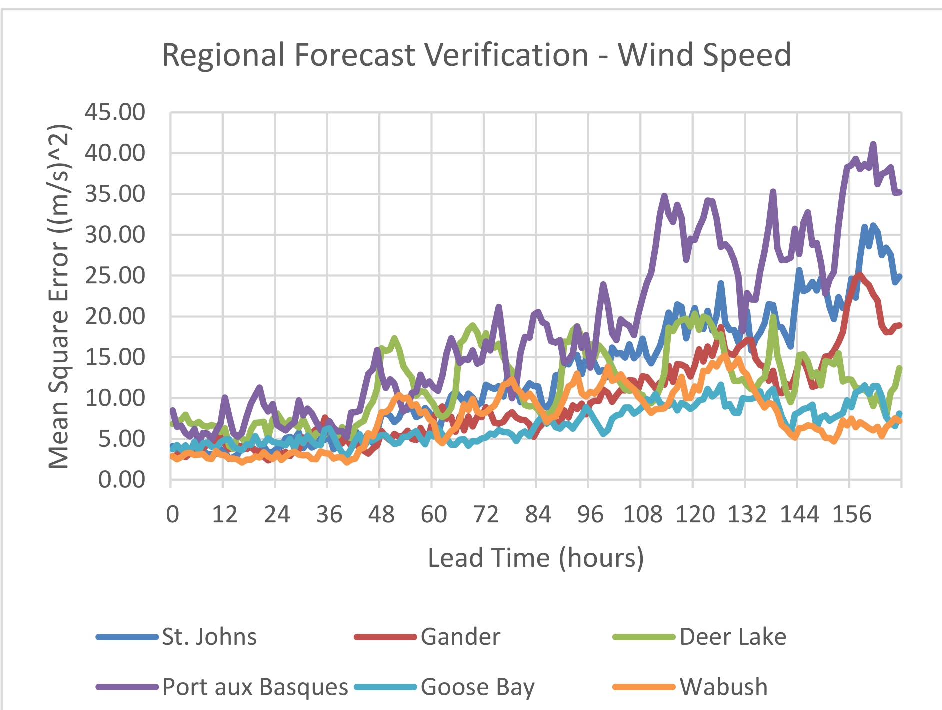

Figure 3-14: Regional Forecast – Wind Speed Mean Square Error

Root Mean Square Error (RMSE)

Table 3-16 summarizes the results of the Root Mean Square Error calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Root Mean Square Error calculation, for each of the regional forecasts, are also displayed in Figure 3-15, on an hourly basis.

Table 3-16: Regional Forecast – Wind Speed Root Mean Square Error

	Regional Forecast Verification - Wind Speed					
	Root Mean Square Error (m/s)					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	1.87	1.90	2.50	2.66	2.06	1.67
Mean - Day 2	2.20	2.12	2.59	2.82	2.15	1.80
Mean - Day 3	2.92	2.53	3.62	3.55	2.24	2.82
Mean - Day 4	3.45	2.75	3.58	4.07	2.52	3.15
Mean - Day 5	4.04	3.41	3.72	4.87	2.90	3.27
Mean - Day 6	4.37	3.81	3.80	5.29	3.06	3.30
Mean - Day 7	5.00	4.25	3.49	5.78	2.96	2.52
Mean Value:	3.41	2.97	3.33	4.15	2.56	2.65

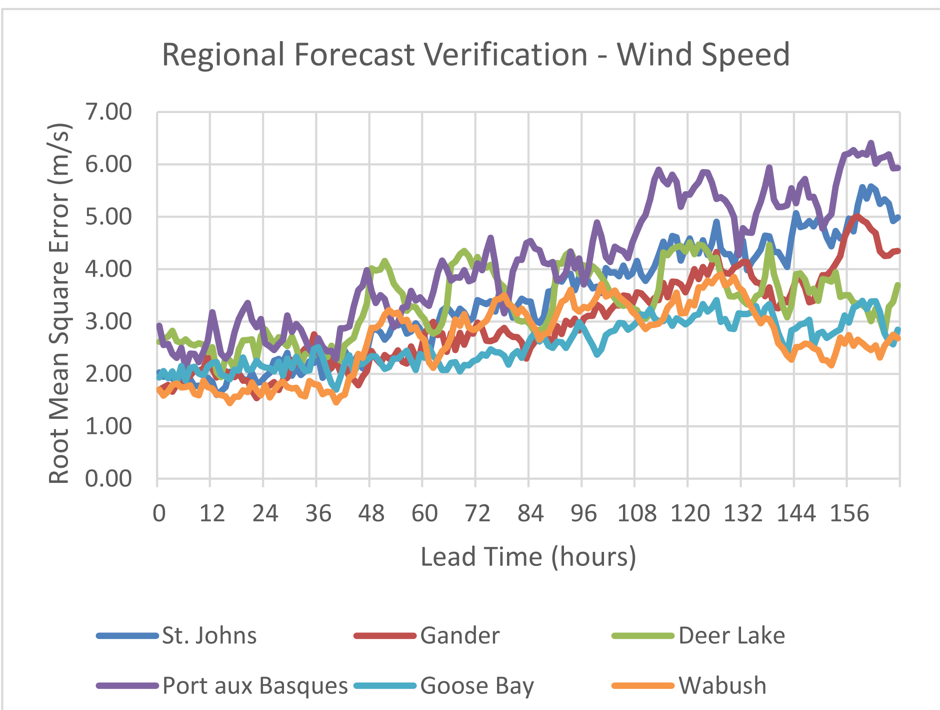

Figure 3-15: Regional Forecast – Wind Speed Root Mean Square Error

Multiplicative Bias (BIAS)

Table 3-17 summarizes the results of the Multiplicative Bias calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Multiplicative Bias calculation, for each of the regional forecasts, are also displayed in Figure 3-16, on an hourly basis.

Table 3-17: Regional Forecast – Wind Speed Multiplicative Bias

	Regional Forecast Verification - Wind Speed					
	Multiplicative Bias					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	1.05	1.14	1.02	1.06	1.23	1.22
Mean - Day 2	1.07	1.11	1.00	1.03	1.21	1.26
Mean - Day 3	1.07	0.99	0.74	0.90	1.05	1.53
Mean - Day 4	1.10	1.04	0.75	0.89	1.03	1.57
Mean - Day 5	1.09	1.02	0.76	0.92	1.10	1.58
Mean - Day 6	1.08	0.98	0.77	0.94	1.05	1.51
Mean - Day 7	1.05	0.70	0.94	0.99	0.87	0.99
Mean Value:	1.07	1.00	0.86	0.96	1.08	1.38

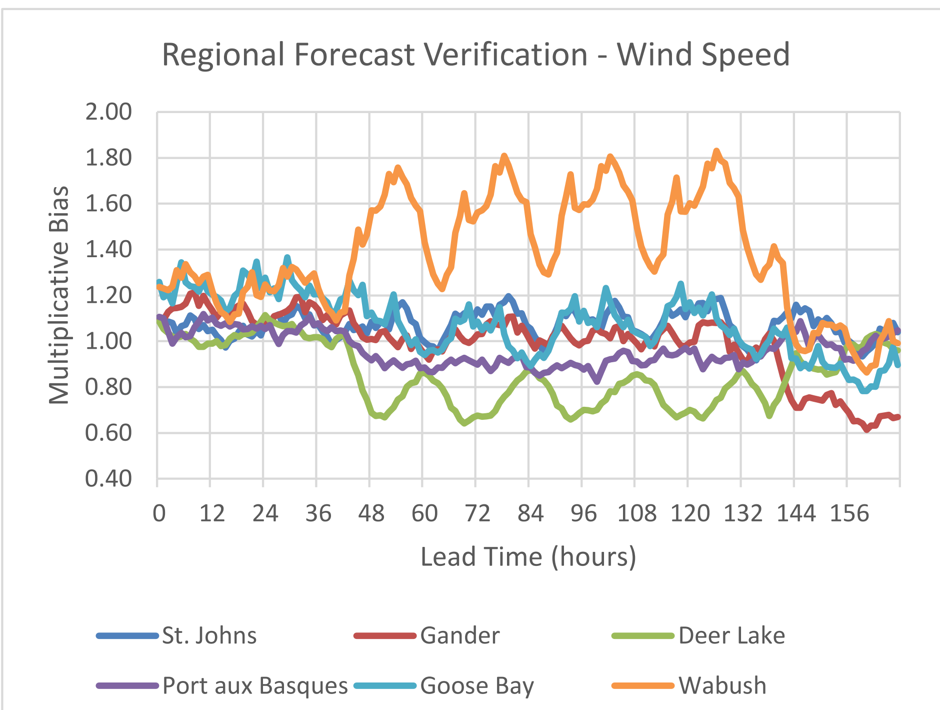

Figure 3-16: Regional Forecast – Wind Speed Multiplicative Bias

Correlation Coefficient (r)

Table 3-18 summarizes the results of the Correlation Coefficient calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Correlation Coefficient calculation, for each of the regional forecasts, are also displayed in Figure 3-17, on an hourly basis.

Table 3-18: Regional Forecast – Wind Speed Correlation Coefficient

	Regional Forecast Verification - Wind Speed					
	Correlation Coefficient					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	0.90	0.87	0.55	0.88	0.79	0.81
Mean - Day 2	0.86	0.82	0.54	0.86	0.75	0.80
Mean - Day 3	0.76	0.76	0.53	0.78	0.67	0.73
Mean - Day 4	0.68	0.70	0.51	0.70	0.61	0.67
Mean - Day 5	0.53	0.52	0.46	0.48	0.48	0.59
Mean - Day 6	0.44	0.40	0.35	0.39	0.37	0.43
Mean - Day 7	0.22	0.19	0.20	0.25	0.29	0.28
Mean Value:	0.63	0.61	0.45	0.62	0.56	0.61

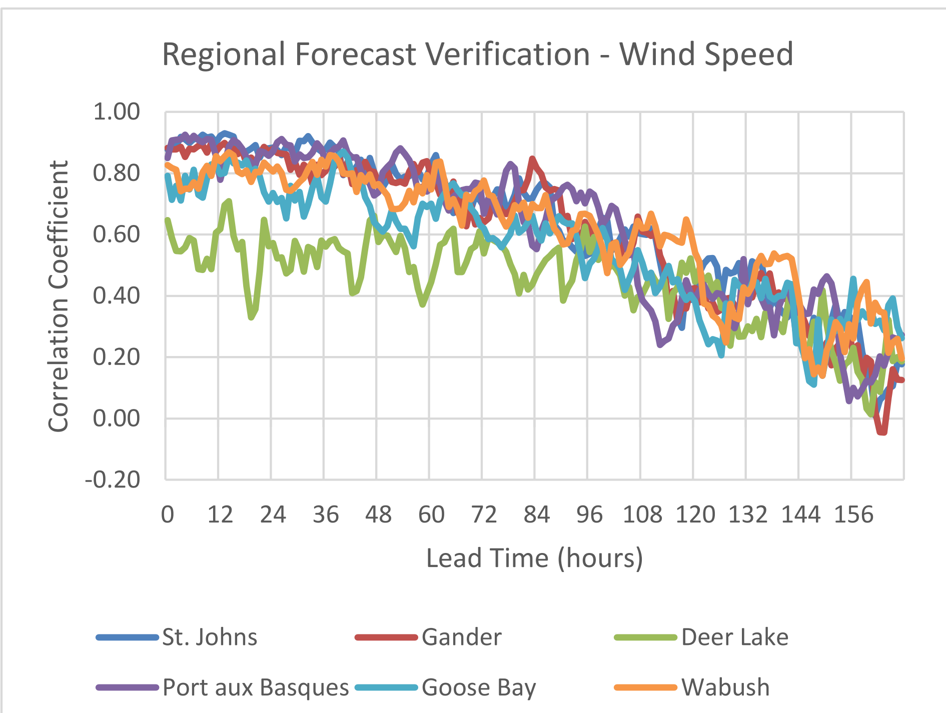

Figure 3-17: Regional Forecast – Wind Speed Correlation Coefficient

Discussion of Results – Wind Speed

A marked increase in the magnitude of error is noted in the Mean Error and other statistics, beginning at approximately day 2 and continuing until approximately day 6. This time range corresponds with one of the component weather models (UMOS GEM Global) that is used to generate the forecast. This indicates that the UMOS GEM Global model is less skilled at predicting wind speed. Amec Foster Wheeler will look at what improvements can be made in the forecast to minimize the error for this time period. Conversely, the ME and MAE clearly show that the error for Gander is greatest after 140 hours, which corresponds with another component weather model (XGFS). The differences observed in accuracy between the models can be attributed to lower resolution and how well a model grid point corresponds with the observation location.

Figure 3-16 shows that wind speeds are over-predicted for Wabush and under-predicated for Deer Lake. Amec Foster Wheeler will investigate further to see what improvements can be made for these sites in particular.

The verification data indicates a significant increase in error as lead times increase. This is also possibly a result of reduced skill inherent to the numerical prediction models used in the long-term forecast.

3.1.4 Wind Direction

Environment Canada observations are generally reported hourly, but occasionally report more frequently. In cases where there are multiple observations per hour, Amec Foster Wheeler calculates the mean value to represent the hourly value.

When comparing the forecast and observation wind direction values, each data pair is pre-processed to ensure that both values are in the same half of the wind compass. For example, if the forecast wind direction is 355° and the observed wind direction is 5°, then the simple error calculation would determine an error of: 355° - 5° = 350°, when in reality the two values differ by only 10°. To avoid this miscalculation, when the absolute difference between the two values is greater than 180°, the lower value is transformed by adding 360° to ensure both values are in the same half of the wind compass. This results in an error calculation of: 355° - 365° = -10°

Mean Error (ME)

Table 3-19 summarizes the results of the Mean Error calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Mean Error calculation, for each of the regional forecasts, are also displayed in Figure 3-18, on an hourly basis.

Table 3-19: Regional Forecast – Wind Direction Mean Error

	Regional Forecast Verification - Wind Direction					
	Mean Error (°)					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	1.64	4.11	-1.71	6.90	-5.50	11.31
Mean - Day 2	2.51	3.04	1.45	8.60	-2.89	9.98
Mean - Day 3	0.82	4.28	19.76	9.09	4.77	14.55
Mean - Day 4	1.38	4.55	18.49	6.92	2.96	9.17
Mean - Day 5	-0.04	3.61	14.43	3.34	3.20	6.68
Mean - Day 6	2.30	3.64	6.89	1.32	-4.30	5.11
Mean - Day 7	-1.94	-1.57	-5.90	-0.33	-5.13	-3.08
Mean Value:	0.95	3.09	7.63	5.12	-0.98	7.67

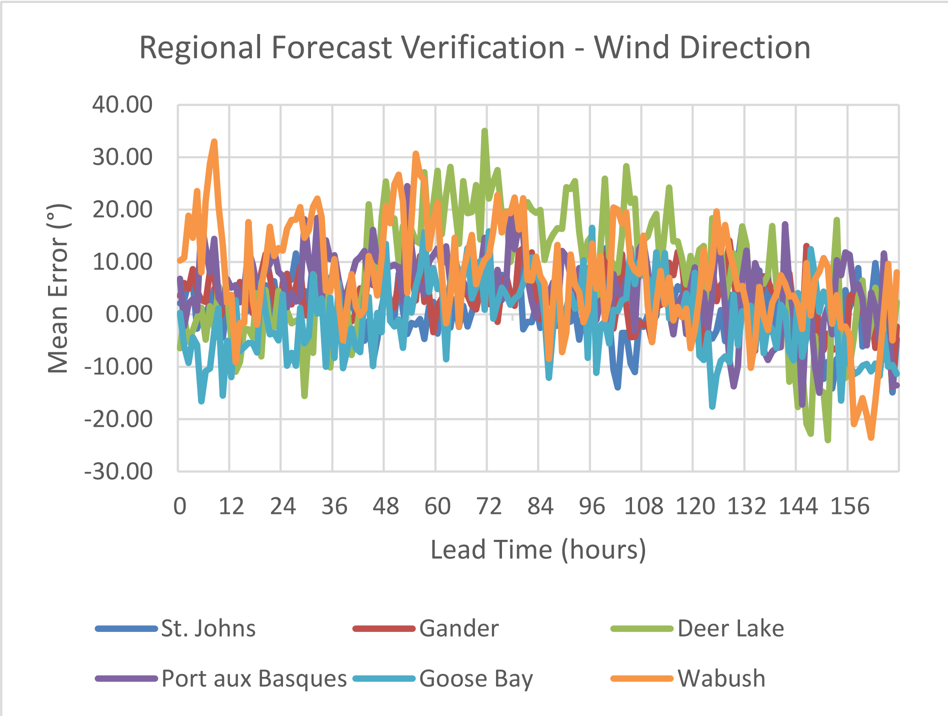

Figure 3-18: Regional Forecast – Wind Direction Mean Error

Mean Absolute Error (MAE)

Table 3-20 summarizes the results of the Mean Absolute Error calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Mean Absolute Error calculation, for each of the regional forecasts, are also displayed in Figure 3-19 on an hourly basis.

Table 3-20: Regional Forecast – Wind Direction Mean Absolute Error

	Regional Forecast Verification - Wind Direction					
	Mean Absolute Error (°)					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	17.35	20.00	39.23	21.11	33.12	38.35
Mean - Day 2	23.09	24.34	40.49	25.51	34.76	39.16
Mean - Day 3	25.40	28.59	53.26	30.04	42.87	42.50
Mean - Day 4	31.07	31.59	54.57	36.05	44.05	44.13
Mean - Day 5	39.12	41.12	57.12	39.81	46.24	49.71
Mean - Day 6	46.78	50.33	67.17	50.12	52.58	54.36
Mean - Day 7	54.74	53.93	69.00	53.39	54.16	56.12
Mean Value:	33.94	35.70	54.40	36.57	43.97	46.33

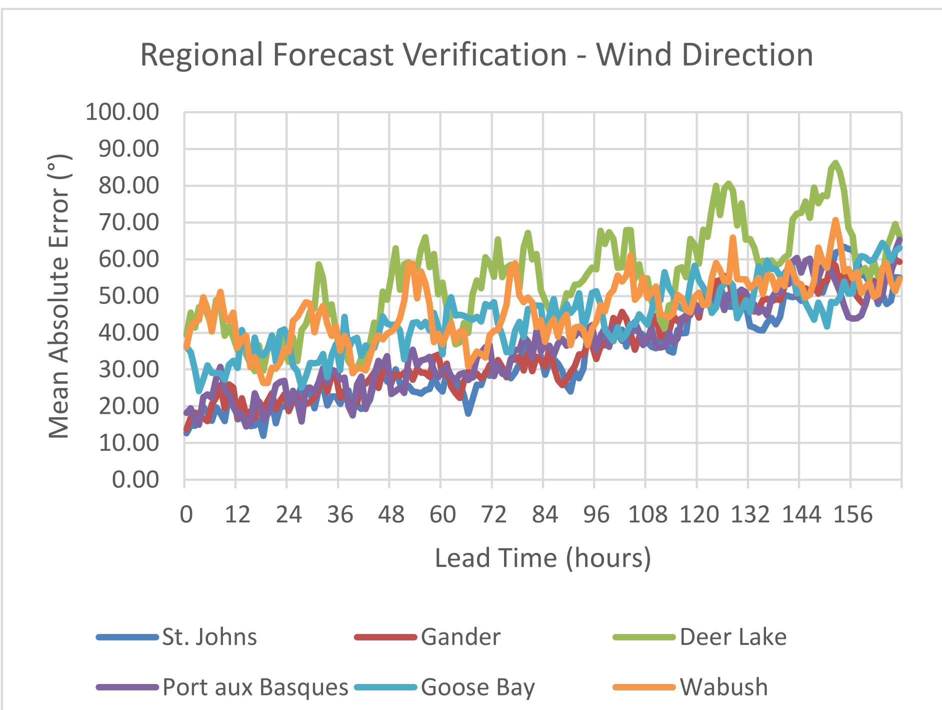

Figure 3-19: Regional Forecast – Wind Direction Mean Absolute Error

Mean Square Error (MSE)

Table 3-21 summarizes the results of the Mean Square Error calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Mean Square Error calculation, for each of the regional forecasts, are also displayed in Figure 3-20, on an hourly basis.

Table 3-21: Regional Forecast – Wind Direction Mean Square Error

	Regional Forecast Verification - Wind Direction					
	Mean Square Error (°^2)					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	945.08	1141.73	3996.47	1306.21	2774.10	3510.71
Mean - Day 2	1580.60	1644.75	3991.72	1808.58	2951.70	3527.82
Mean - Day 3	1667.51	1978.39	5065.04	2252.88	3814.16	3801.46
Mean - Day 4	2153.15	2149.46	5196.18	2946.59	4019.29	3887.57
Mean - Day 5	3170.50	3430.25	5582.27	3355.14	4198.98	4546.14
Mean - Day 6	4166.32	4614.71	7145.49	4716.76	5143.82	4979.34
Mean - Day 7	5321.13	5184.27	8134.35	5228.64	5177.17	5332.76
Mean Value:	2714.90	2877.65	5587.36	3087.83	4011.32	4226.54

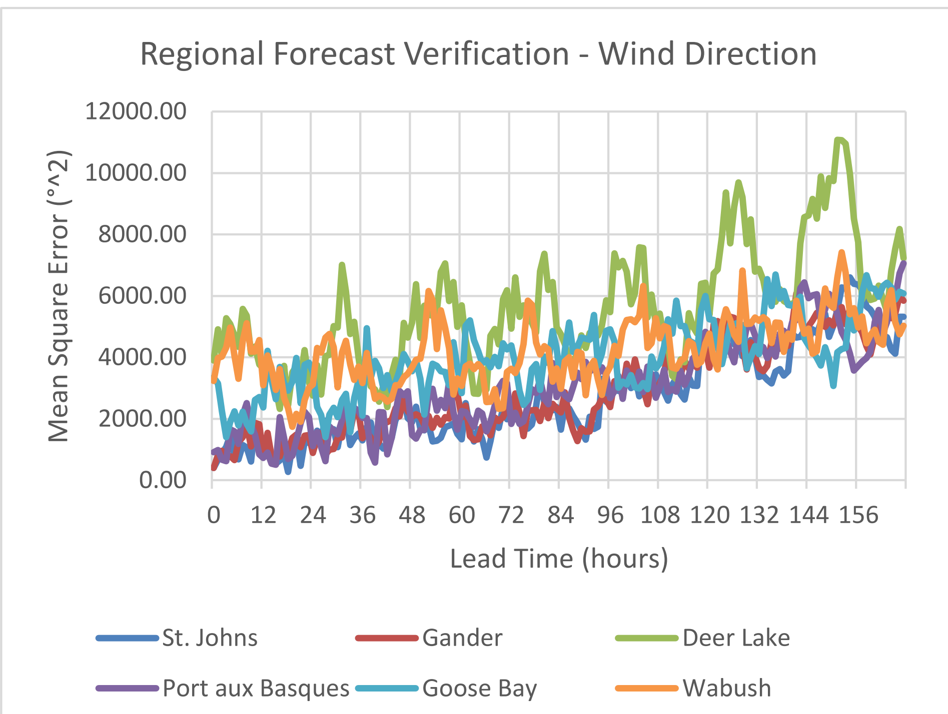

Figure 3-20: Regional Forecast – Wind Direction Mean Square Error

Root Mean Square Error (RMSE)

Table 3-22 summarizes the results of the Root Mean Square Error calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Root Mean Square Error calculation, for each of the regional forecasts, are also displayed in Figure 3-21, on an hourly basis.

Table 3-22: Regional Forecast – Wind Direction Root Mean Square Error

	Regional Forecast Verification - Wind Direction					
	Root Mean Square Error (°)					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	30.06	33.25	62.85	35.16	52.13	58.69
Mean - Day 2	39.42	40.04	62.56	41.64	53.76	59.12
Mean - Day 3	40.53	44.26	70.64	47.09	61.51	61.11
Mean - Day 4	46.13	46.12	71.82	53.98	63.09	62.08
Mean - Day 5	56.17	58.40	74.21	57.73	64.39	67.25
Mean - Day 6	64.36	67.74	84.19	68.54	71.48	70.43
Mean - Day 7	72.79	71.94	89.64	72.00	71.56	72.81
Mean Value:	49.92	51.68	73.70	53.73	62.56	64.50

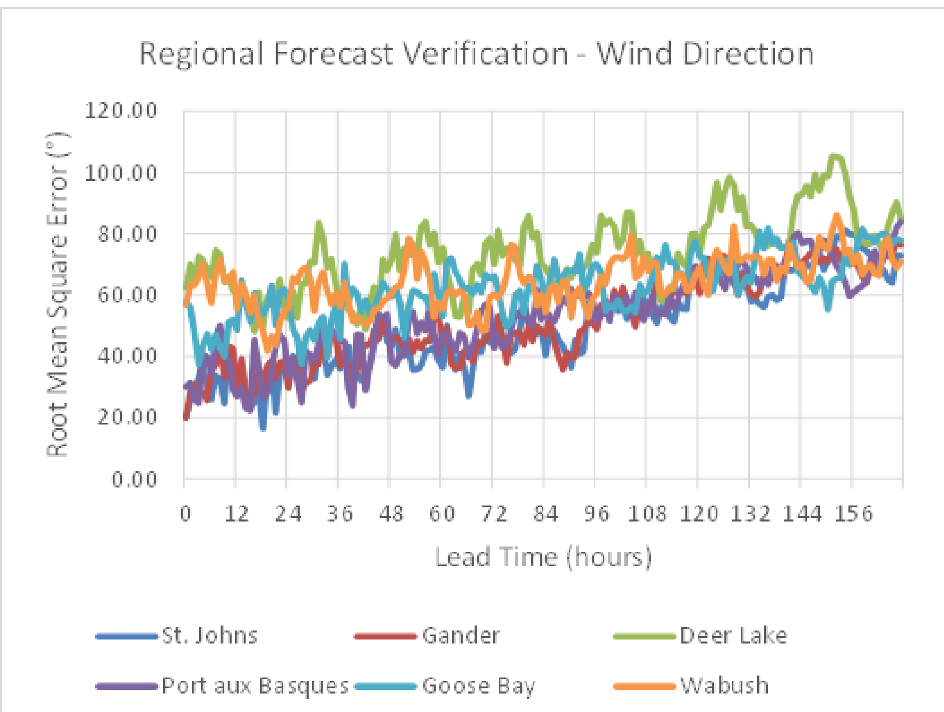

Figure 3-21: Regional Forecast – Wind Direction Root Mean Square Error

Multiplicative Bias (BIAS)

Table 3-23 summarizes the results of the Multiplicative Bias calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Multiplicative Bias calculation, for each of the regional forecasts, are also displayed in Figure 3-22, on an hourly basis.

Table 3-23: Regional Forecast – Wind Direction Multiplicative Bias

	Regional Forecast Verification - Wind Direction					
	Multiplicative Bias					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	1.01	1.02	0.99	1.03	0.98	1.06
Mean - Day 2	1.01	1.01	1.01	1.04	0.99	1.05
Mean - Day 3	1.00	1.02	1.10	1.04	1.02	1.07
Mean - Day 4	1.01	1.02	1.09	1.03	1.01	1.04
Mean - Day 5	1.00	1.02	1.07	1.02	1.01	1.03
Mean - Day 6	1.01	1.02	1.03	1.01	0.98	1.02
Mean - Day 7	0.99	0.99	0.98	1.00	0.98	0.99
Mean Value:	1.00	1.01	1.04	1.02	1.00	1.04

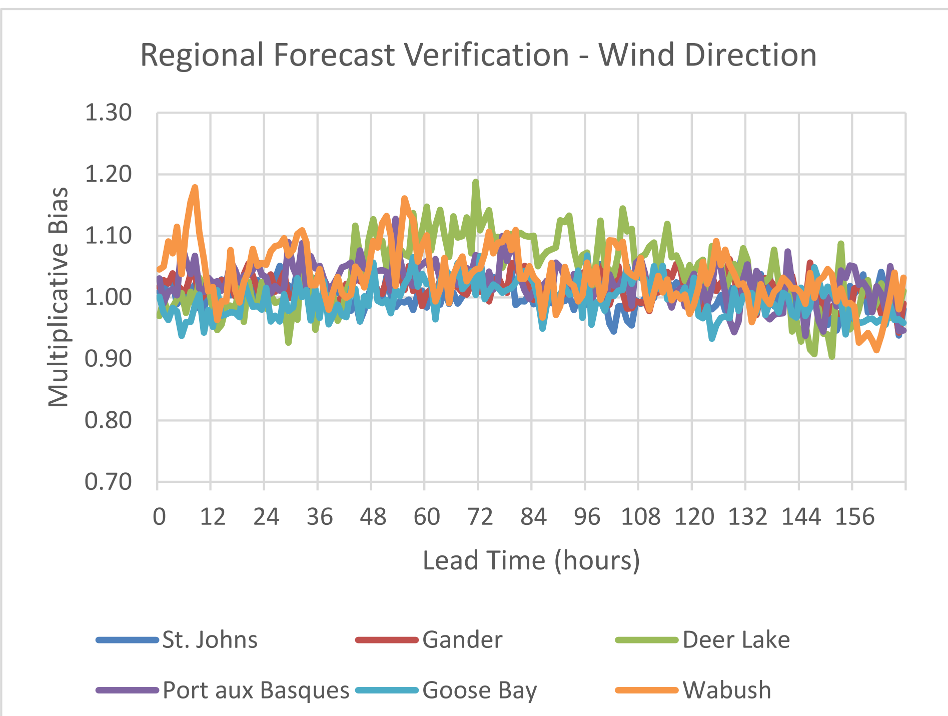

Figure 3-22: Regional Forecast – Wind Direction Multiplicative Bias

Correlation Coefficient (r)

Table 3-24 summarizes the results of the Correlation Coefficient calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Correlation Coefficient calculation, for each of the regional forecasts, are also displayed in Figure 3-23, on an hourly basis.

Table 3-24: Regional Forecast – Wind Direction Correlation Coefficient

	Regional Forecast Verification - Wind Direction					
	Correlation Coefficient					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	0.93	0.92	0.82	0.94	0.83	0.85
Mean - Day 2	0.89	0.89	0.82	0.91	0.83	0.85
Mean - Day 3	0.89	0.87	0.79	0.89	0.79	0.85
Mean - Day 4	0.86	0.86	0.78	0.85	0.79	0.83
Mean - Day 5	0.78	0.77	0.76	0.84	0.74	0.79
Mean - Day 6	0.71	0.68	0.67	0.76	0.66	0.74
Mean - Day 7	0.58	0.59	0.61	0.72	0.62	0.69
Mean Value:	0.80	0.80	0.75	0.84	0.75	0.80

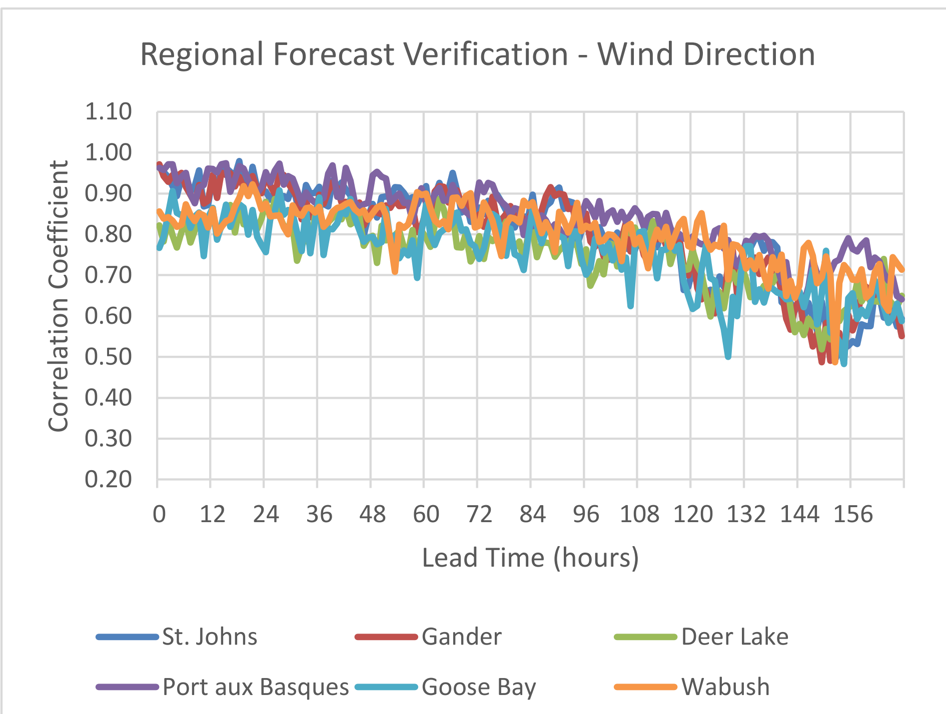

Figure 3-23: Regional Forecast – Wind Direction Correlation Coefficient

Discussion of Results – Wind Direction

The error observed is largely dependent on the site location, local effects at the observation site and proximity of forecast data point to observation point. Where there are minimal local effects and the forecast and observation points are close together correlation would be increased. Where there are local effects which influence wind direction, and where forecast and observation points are further apart, the correlation would be reduced.

The observed errors illustrate an increase with lead time, e.g. MAE increases from 20° to approximately 55° error at the end of the forecast period. This is also possibly a result of reduced skill inherent to the numerical prediction models used in the long-term forecast.

3.1.5 Precipitation

Precipitation observation data are available from Environment Canada as accumulated 6-hourly data. To allow for a direct comparison, Amec Foster Wheeler sums the forecasted values for the corresponding 6-hourly period.

When calculating the metrics for precipitation, only data pairs where at least the forecast or the observation has a non-zero value, are included in the calculation. This causes an overall increase in the error metrics because all of the zero values (which represent a significant portion of the data) are eliminated from the calculation.

A significant portion of the data pairs have only one non-zero value. Generally, in these cases, the value is small; including these data pairs tends to make the correlation coefficient poor.

Comparing accuracy of precipitation forecasts with observed precipitation is a challenging exercise. Many variables affect the accuracy and reliability of measurements from precipitation sensing devices. This is especially true during the winter months, particularly in northern climates where snow is the predominant precipitation for the season.

In the analysis presented within this section, the precipitation data for Wabush has been omitted. A preliminary assessment of the Wabush precipitation data indicated that it was unreliable. This will be monitored and reviewed again in the next quarterly report.

Mean Error (ME)

Table 3-25 summarizes the results of the Mean Error calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Mean Error calculation, for each of the regional forecasts, are also displayed in Figure 3-24, on a 6-hourly basis.

Table 3-25: Regional Forecast – Precipitation Mean Error

	Regional Forecast Verification - Precipitation				
	Mean Error (mm/6hr)				
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay
Mean - Day 1	0.21	0.08	0.02	1.72	0.14
Mean - Day 2	0.44	0.21	0.01	1.66	0.19
Mean - Day 3	0.28	0.10	-0.05	1.19	0.42
Mean - Day 4	0.43	0.51	-0.16	1.12	0.64
Mean - Day 5	0.92	0.17	-0.24	0.93	0.48
Mean - Day 6	0.16	0.29	-0.07	0.77	0.59
Mean - Day 7	0.09	0.09	-0.19	0.99	0.09
Mean Value:	0.36	0.21	-0.10	1.20	0.36

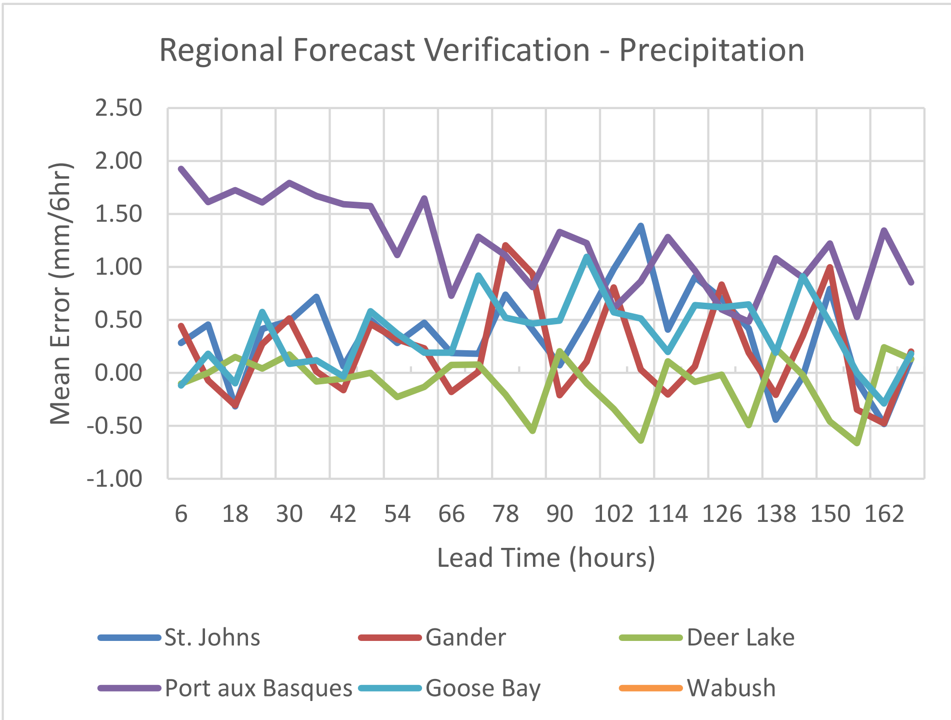

Figure 3-24: Regional Forecast – Precipitation Mean Error

Mean Absolute Error (MAE)

Table 3-26 summarizes the results of the Mean Absolute Error calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Mean Absolute Error calculation, for each of the regional forecasts, are also displayed in Figure 3-25, on a 6-hourly basis.

Table 3-26: Regional Forecast – Precipitation Mean Absolute Error

	Regional Forecast Verification - Precipitation				
	Mean Absolute Error (mm/6hr)				
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay
Mean - Day 1	1.32	1.13	1.20	2.00	0.95
Mean - Day 2	1.41	1.19	1.18	1.97	0.96
Mean - Day 3	1.65	1.29	1.23	1.68	1.54
Mean - Day 4	1.90	1.90	1.33	1.81	1.47
Mean - Day 5	2.77	2.02	1.71	2.17	1.73
Mean - Day 6	2.55	2.40	1.87	1.97	1.80
Mean - Day 7	2.32	2.22	1.74	2.30	1.66
Mean Value:	1.99	1.74	1.47	1.99	1.44

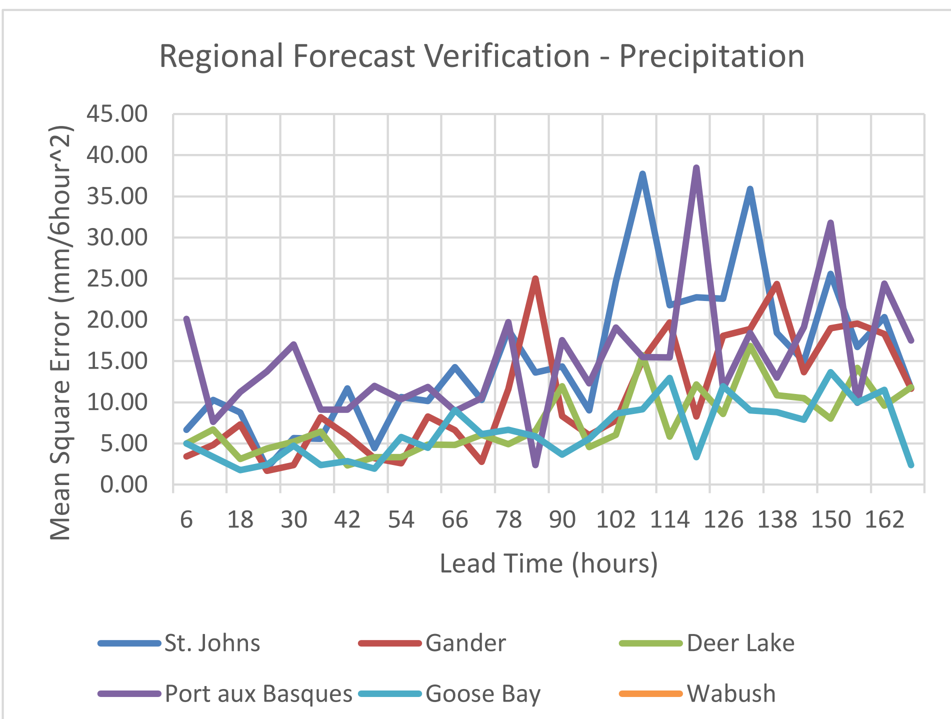

Figure 3-25: Regional Forecast – Precipitation Mean Absolute Error

Mean Square Error (MSE)

Table 3-27 summarizes the results of the Mean Square Error calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Mean Square Error calculation, for each of the regional forecasts, are also displayed in Figure 3-26, on a 6-hourly basis.

Table 3-27: Regional Forecast – Precipitation Mean Square Error

	Regional Forecast Verification - Precipitation				
	Mean Square Error (mm/6hour^2)				
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay
Mean - Day 1	6.93	4.31	4.80	13.19	3.14
Mean - Day 2	6.83	4.92	4.33	11.81	2.97
Mean - Day 3	11.34	5.07	4.77	10.43	6.35
Mean - Day 4	13.95	12.74	6.97	12.99	5.42
Mean - Day 5	26.74	12.72	9.94	22.12	8.52
Mean - Day 6	22.96	18.74	11.70	15.55	9.41
Mean - Day 7	18.59	17.11	10.90	20.90	9.38
Mean Value:	15.33	10.80	7.63	15.28	6.46

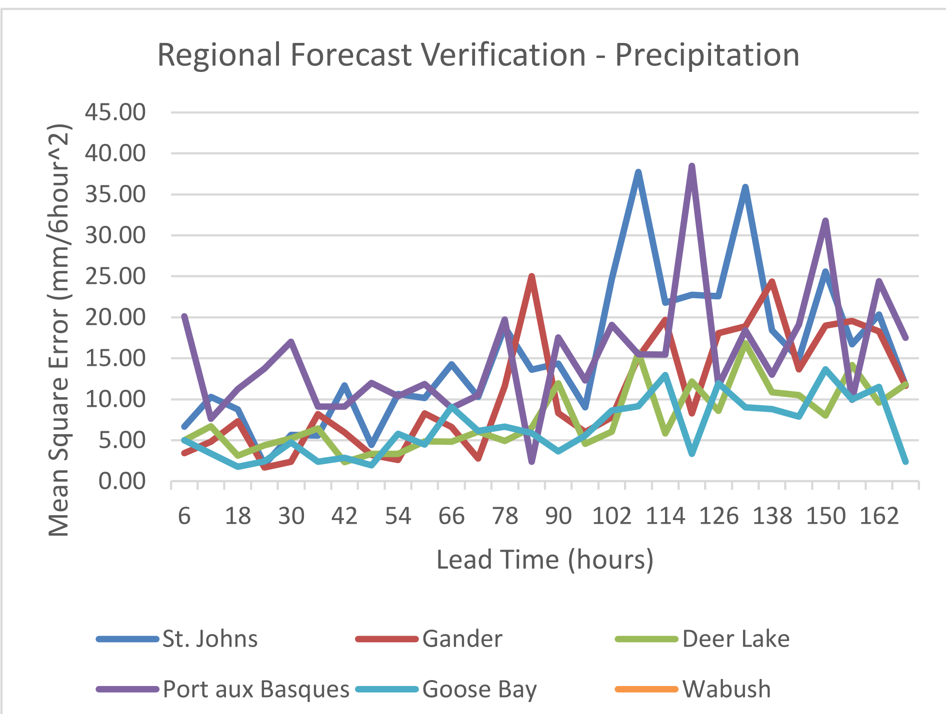

Figure 3-26: Regional Forecast – Precipitation Mean Square Error

Root Mean Square Error (RMSE)

Table 3-28 summarizes the results of the Root Mean Square Error calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Root Mean Square Error calculation, for each of the regional forecasts, are also displayed in Figure 3-27, on a 6-hourly basis.

Table 3-28: Regional Forecast – Precipitation Root Mean Square Error

	Regional Forecast Verification - Precipitation				
	Root Mean Square Error (mm/6hr)				
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay
Mean - Day 1	2.54	2.01	2.17	3.58	1.74
Mean - Day 2	2.56	2.16	2.04	3.41	1.70
Mean - Day 3	3.36	2.18	2.17	3.23	2.50
Mean - Day 4	3.70	3.44	2.59	3.42	2.31
Mean - Day 5	5.14	3.50	3.08	4.61	2.85
Mean - Day 6	4.73	4.31	3.39	3.92	3.06
Mean - Day 7	4.27	4.12	3.28	4.48	2.95
Mean Value:	3.76	3.10	2.68	3.81	2.44

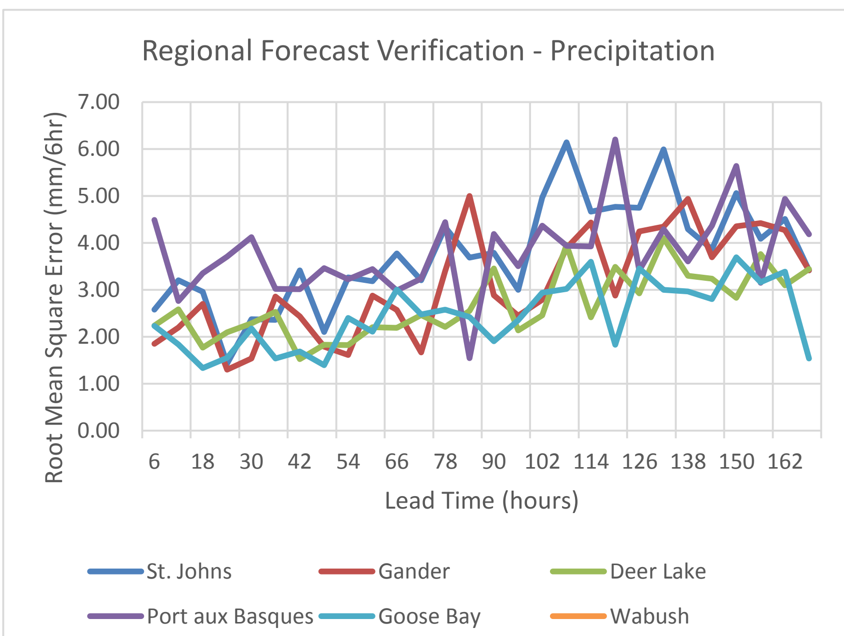

Figure 3-27: Regional Forecast – Precipitation Root Mean Square Error

Multiplicative Bias (BIAS)

Table 3-29 summarizes the results of the Multiplicative Bias calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Multiplicative Bias calculation, for each of the regional forecasts, are also displayed in Figure 3-28, on a 6-hourly basis.

Table 3-29: Regional Forecast – Precipitation Multiplicative Bias

	Regional Forecast Verification - Precipitation				
	Multiplicative Bias				
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay
Mean - Day 1	1.13	1.09	1.03	2.64	1.13
Mean - Day 2	1.27	1.15	1.00	2.53	1.16
Mean - Day 3	1.16	1.07	0.98	2.03	1.34
Mean - Day 4	1.27	1.37	0.93	2.11	1.59
Mean - Day 5	1.56	1.16	0.87	1.94	1.46
Mean - Day 6	1.09	1.22	0.98	1.85	1.65
Mean - Day 7	1.08	1.13	0.92	2.10	1.12
Mean Value:	1.22	1.17	0.96	2.17	1.35

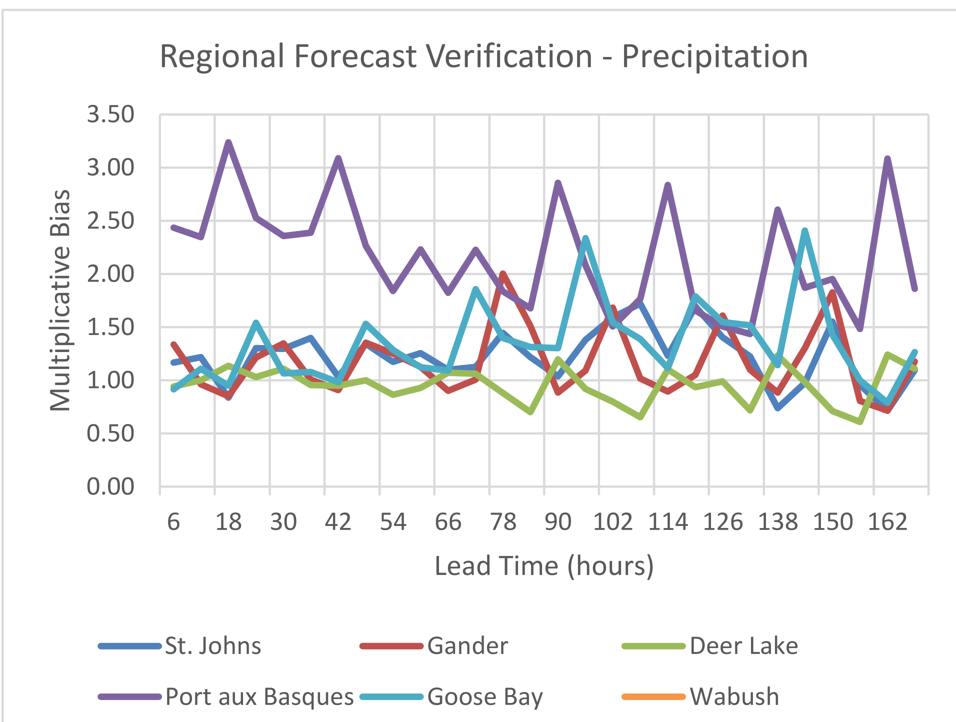

Figure 3-28: Regional Forecast – Precipitation Multiplicative Bias

Correlation Coefficient (r)

Table 3-30 summarizes the results of the Correlation Coefficient calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Correlation Coefficient calculation, for each of the regional forecasts, are also displayed in Figure 3-29, on a 6-hourly basis.

Table 3-30: Regional Forecast – Precipitation Correlation Coefficient

	Regional Forecast Verification - Precipitation				
	Correlation Coefficient				
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay
Mean - Day 1	0.73	0.77	0.70	0.76	0.83
Mean - Day 2	0.73	0.75	0.71	0.78	0.84
Mean - Day 3	0.52	0.69	0.58	0.60	0.68
Mean - Day 4	0.43	0.47	0.51	0.47	0.67
Mean - Day 5	0.16	0.24	0.22	0.19	0.42
Mean - Day 6	0.11	0.12	0.11	0.18	0.41
Mean - Day 7	0.13	0.08	0.12	0.12	0.17
Mean Value:	0.40	0.45	0.42	0.44	0.57

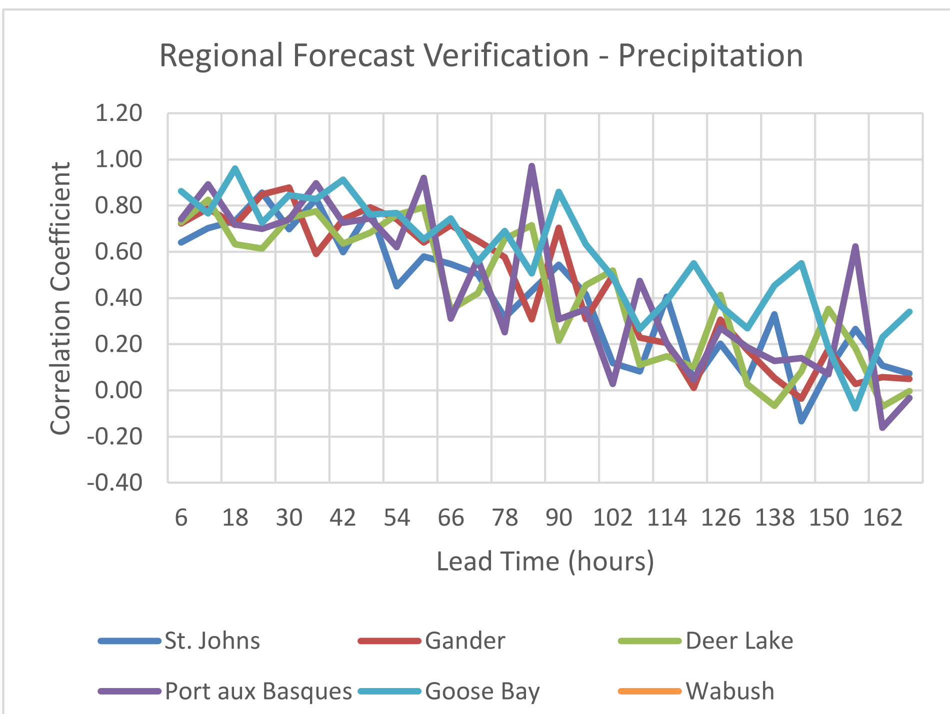

Figure 3-29: Regional Forecast – Precipitation Correlation Coefficient

Discussion of Results – Precipitation

Variable results are observed using these standard statistical techniques for precipitation verification and conclusions cannot be made at this time. As stated earlier, comparing accuracy of precipitation forecasts with observed precipitation is a challenging exercise, and particularly problematic during winter months. Amec Foster Wheeler will review methodologies for data analysis and verification specific to precipitation in order to obtain a more consistent and reliable result.

3.1.6 Cloud Cover

Cloud Cover is indicated on a scale of 0 to 10, representing in tenths, the amount of the whole sky that is observed to be covered.

Mean Error (ME)

Table 3-31 summarizes the results of the Mean Error calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Mean Error calculation, for each of the regional forecasts, are also displayed in Figure 3-30, on an hourly basis.

Figure 3-30 indicates that, in general, the forecasts under-predict the amount of cloud cover.

Table 3-31: Regional Forecast – Cloud Cover Mean Error

	Regional Forecast Verification - Cloud Cover					
	Mean Error ()					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	-0.56	-0.55	0.16	-0.55	-1.40	-0.82
Mean - Day 2	-0.33	-0.72	0.00	-0.72	-1.38	-1.02
Mean - Day 3	-0.42	-1.66	-2.12	-1.66	-2.40	-2.29
Mean - Day 4	-0.49	-1.81	-2.03	-1.81	-2.41	-2.22
Mean - Day 5	-0.54	-1.65	-1.98	-1.65	-2.63	-2.61
Mean - Day 6	-0.72	-1.78	-1.92	-1.78	-2.22	-1.84
Mean - Day 7	-0.35	-1.20	-0.46	-1.20	0.89	2.73
Mean Value:	-0.49	-1.34	-1.19	-1.34	-1.65	-1.15

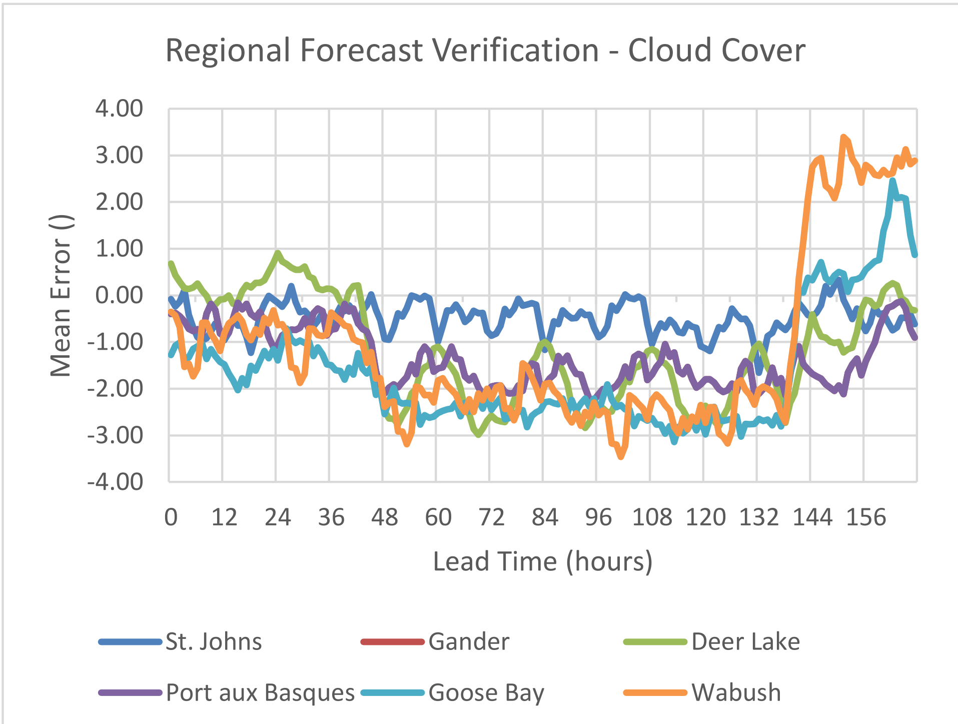

Figure 3-30: Regional Forecast – Cloud Cover Mean Error

Mean Absolute Error (MAE)

Table 3-32 summarizes the results of the Mean Absolute Error calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Mean Absolute Error calculation, for each of the regional forecasts, are also displayed in Figure 3-31, on an hourly basis.

Table 3-32: Regional Forecast – Cloud Cover Mean Absolute Error

	Regional Forecast Verification - Cloud Cover					
	Mean Absolute Error ()					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	1.77	1.74	1.45	1.74	2.12	2.00
Mean - Day 2	1.79	1.84	1.55	1.84	2.17	2.18
Mean - Day 3	1.91	2.40	2.61	2.40	2.91	2.95
Mean - Day 4	1.96	2.65	2.61	2.65	2.88	3.02
Mean - Day 5	2.27	2.76	2.69	2.76	3.38	3.60
Mean - Day 6	2.57	3.10	2.84	3.10	3.63	3.78
Mean - Day 7	2.99	3.34	2.37	3.34	3.61	4.01
Mean Value:	2.18	2.55	2.31	2.55	2.96	3.08

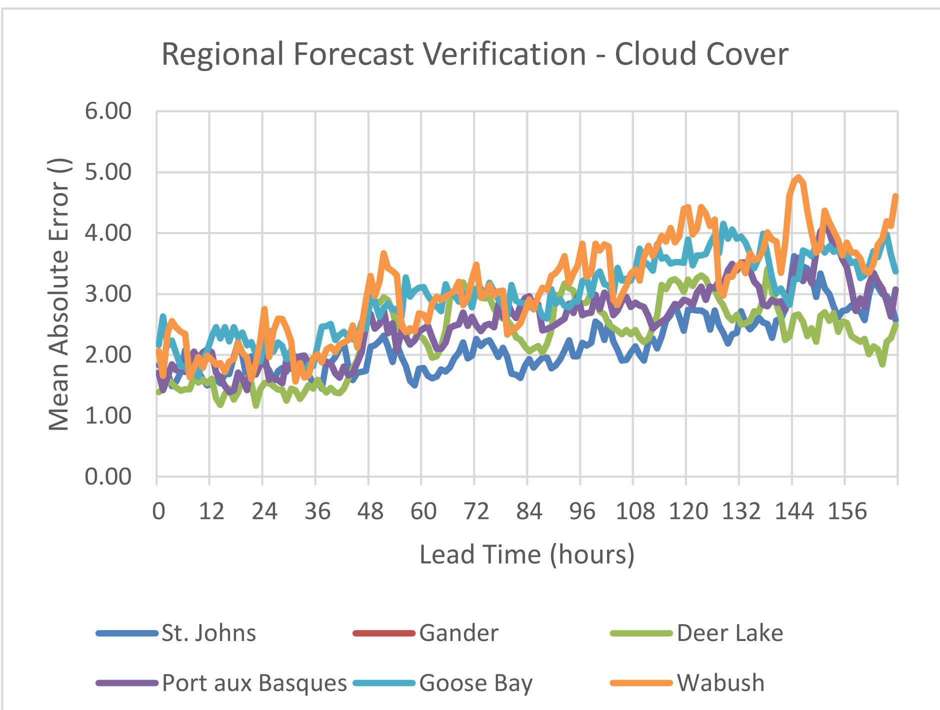

Figure 3-31: Regional Forecast – Cloud Cover Mean Absolute Error

Mean Square Error (MSE)

Table 3-33 summarizes the results of the Mean Square Error calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Mean Square Error calculation, for each of the regional forecasts, are also displayed in Figure 3-32, on an hourly basis.

Table 3-33: Regional Forecast – Cloud Cover Mean Square Error

	Regional Forecast Verification - Cloud Cover					
	Mean Square Error ()					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	7.94	6.97	6.29	6.97	11.56	10.70
Mean - Day 2	7.92	7.53	6.76	7.53	11.92	11.29
Mean - Day 3	7.45	11.15	13.35	11.15	17.42	17.70
Mean - Day 4	7.49	13.02	13.12	13.02	16.74	18.45
Mean - Day 5	10.01	14.46	14.09	14.46	21.37	24.07
Mean - Day 6	11.91	17.08	14.64	17.08	23.46	25.07
Mean - Day 7	17.35	19.86	12.25	19.86	23.70	29.34
Mean Value:	10.01	12.87	11.50	12.87	18.02	19.52

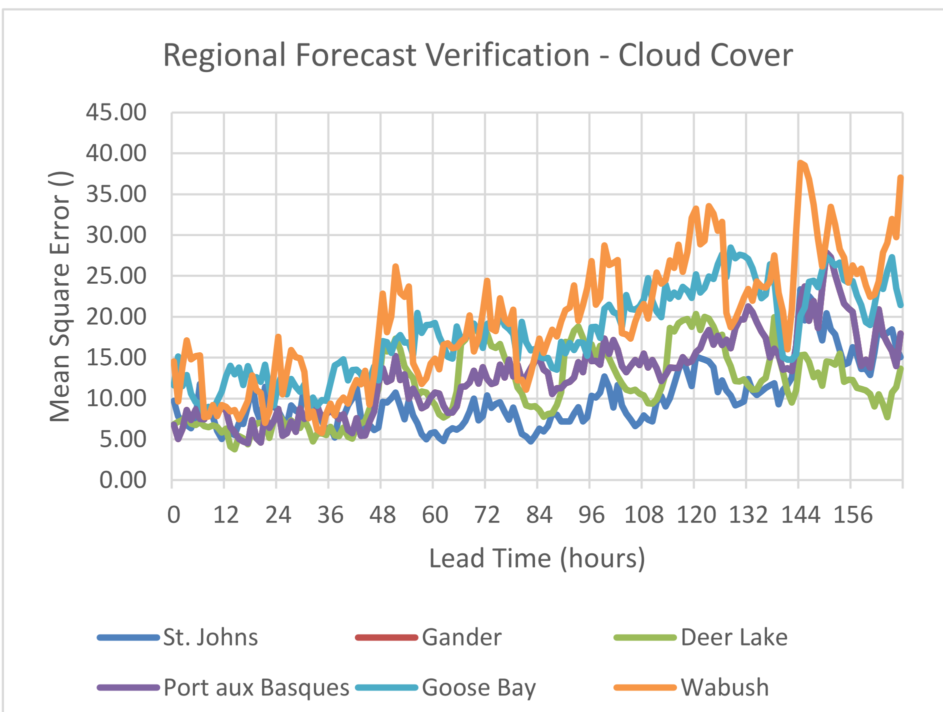

Figure 3-32: Regional Forecast – Cloud Cover Mean Square Error

Root Mean Square Error (RMSE)

Table 3-34 summarizes the results of the Root Mean Square Error calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Root Mean Square Error calculation, for each of the regional forecasts, are also displayed in Figure 3-33, on an hourly basis.

Table 3-34: Regional Forecast – Cloud Cover Root Mean Square Error

	Regional Forecast Verification - Cloud Cover					
	Root Mean Square Error ()					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	2.80	2.62	2.50	2.62	3.39	3.24
Mean - Day 2	2.80	2.73	2.59	2.73	3.44	3.32
Mean - Day 3	2.71	3.33	3.62	3.33	4.17	4.18
Mean - Day 4	2.72	3.60	3.58	3.60	4.09	4.27
Mean - Day 5	3.15	3.80	3.72	3.80	4.62	4.89
Mean - Day 6	3.44	4.13	3.80	4.13	4.82	4.98
Mean - Day 7	4.15	4.43	3.49	4.43	4.86	5.40
Mean Value:	3.11	3.52	3.33	3.52	4.20	4.33

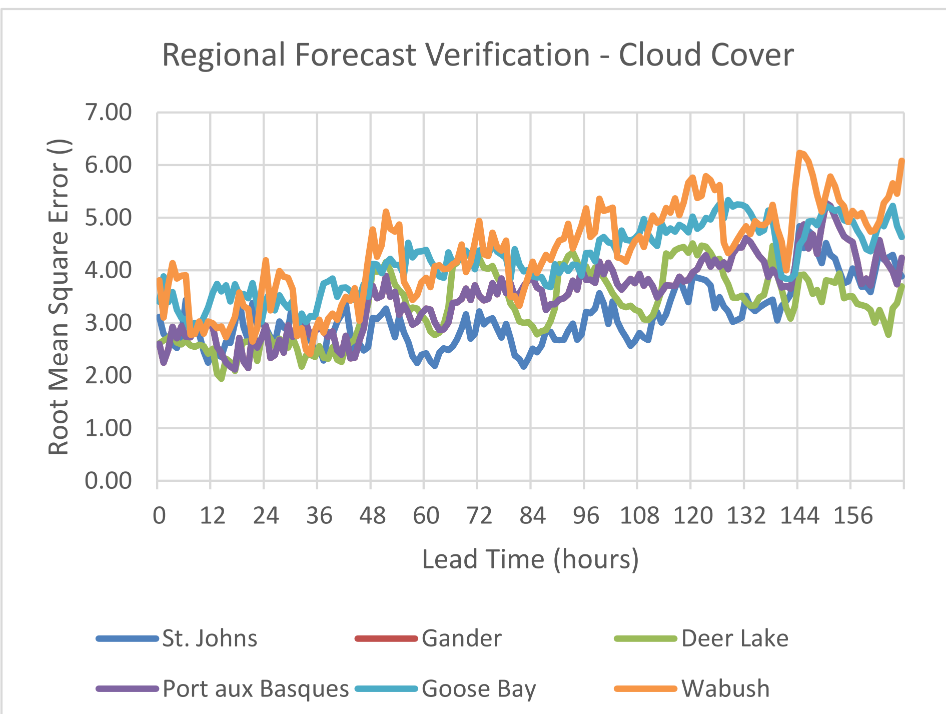

Figure 3-33: Regional Forecast – Cloud Cover Root Mean Square Error

Multiplicative Bias (BIAS)

Table 3-35 summarizes the results of the Multiplicative Bias calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Multiplicative Bias calculation, for each of the regional forecasts, are also displayed in Figure 3-34, on an hourly basis.

Table 3-35: Regional Forecast – Cloud Cover Multiplicative Bias

	Regional Forecast Verification - Cloud Cover					
	Multiplicative Bias					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	0.93	0.92	1.02	0.92	0.77	0.86
Mean - Day 2	0.96	0.90	1.00	0.90	0.77	0.82
Mean - Day 3	0.94	0.76	0.74	0.76	0.60	0.61
Mean - Day 4	0.94	0.74	0.75	0.74	0.60	0.62
Mean - Day 5	0.93	0.76	0.76	0.76	0.56	0.54
Mean - Day 6	0.91	0.74	0.77	0.74	0.63	0.68
Mean - Day 7	0.95	0.83	0.94	0.83	1.15	1.47
Mean Value:	0.94	0.81	0.86	0.81	0.73	0.80

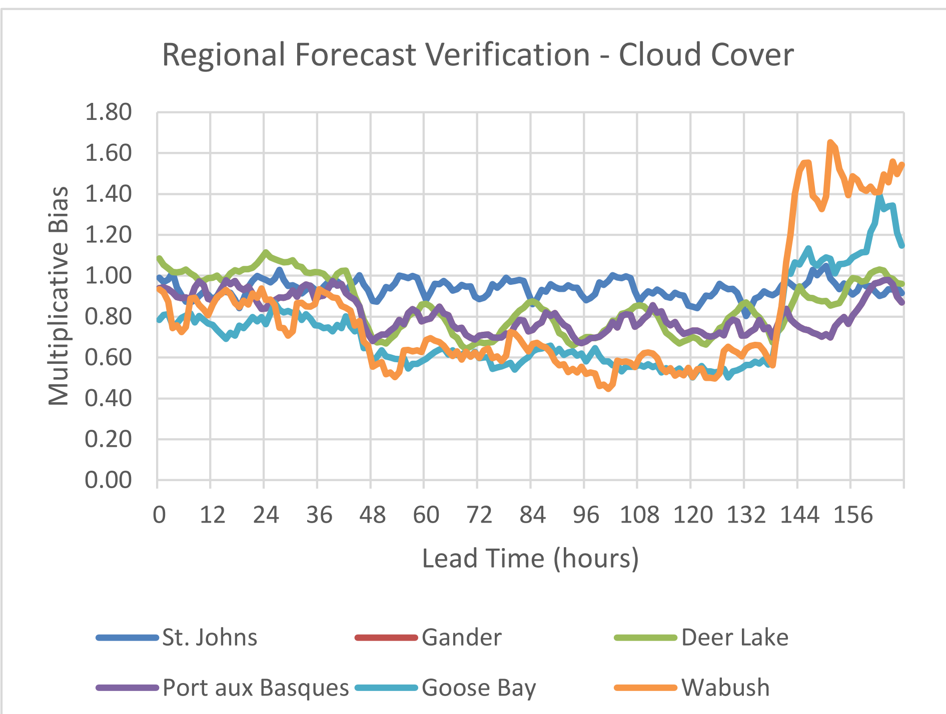

Figure 3-34: Regional Forecast – Cloud Cover Multiplicative Bias

Correlation Coefficient (r)

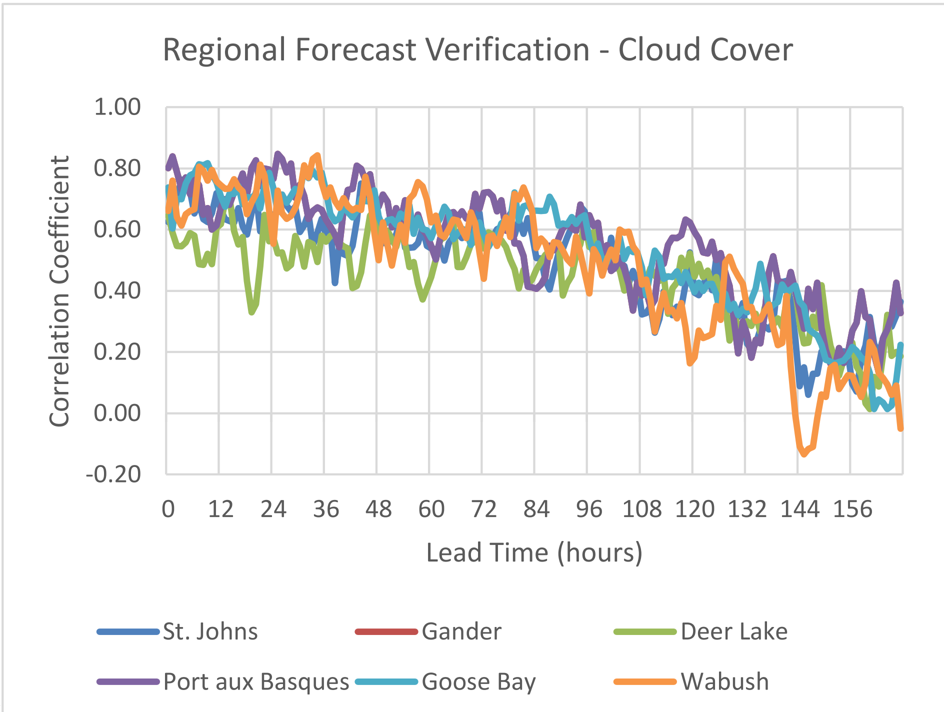

Table 3-36 summarizes the results of the Correlation Coefficient calculation for each of the regional forecasts. The values are averaged for each day of the 7-day forecast. The average for the entire 7-day period is also indicated. The results of the Correlation Coefficient calculation, for each of the regional forecasts, are also displayed in Figure 3-35, on an hourly basis.

Table 3-36: Regional Forecast – Cloud Cover Correlation Coefficient Error

	Regional Forecast Verification - Cloud Cover					
	Correlation Coefficient					
	St. Johns	Gander	Deer Lake	Port aux Basques	Goose Bay	Wabush
Mean - Day 1	0.66	0.74	0.55	0.74	0.73	0.72
Mean - Day 2	0.62	0.72	0.54	0.72	0.71	0.70
Mean - Day 3	0.57	0.63	0.53	0.63	0.62	0.61
Mean - Day 4	0.57	0.58	0.51	0.58	0.64	0.58
Mean - Day 5	0.43	0.50	0.46	0.50	0.49	0.43
Mean - Day 6	0.35	0.41	0.35	0.41	0.38	0.31
Mean - Day 7	0.19	0.28	0.20	0.28	0.17	0.06
Mean Value:	0.48	0.55	0.45	0.55	0.53	0.49

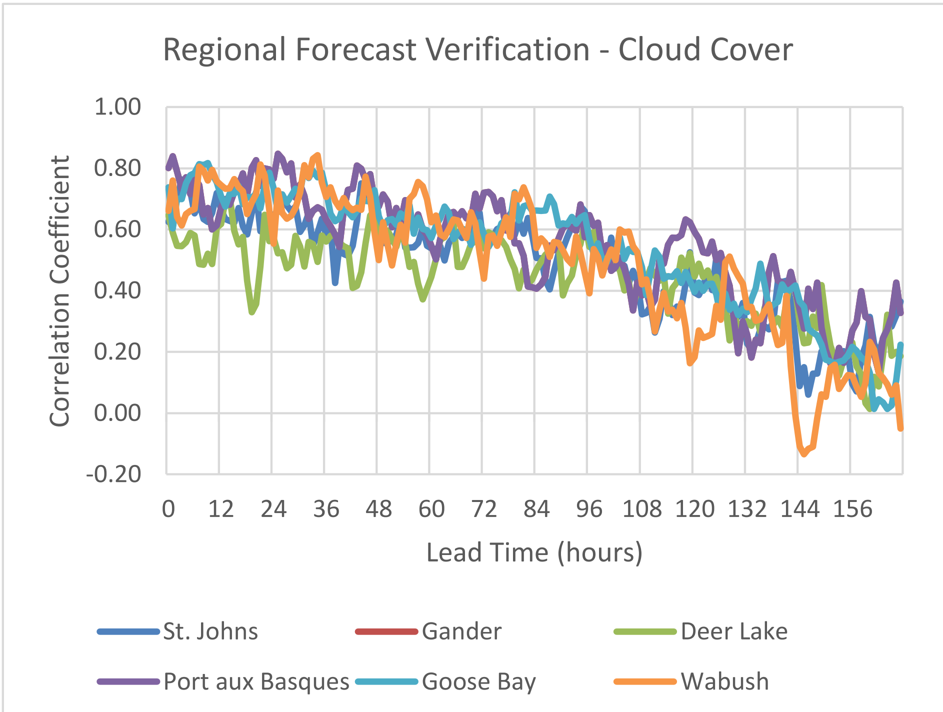

Figure 3-35: Regional Forecast – Cloud Cover Correlation Coefficient

Discussion of Results – Cloud Cover

In addition, error values correspond strongly with changes from one component model to the next. This can be seen especially in the hourly data figures for ME and BIAS. The differences observed in accuracy between the models can be attributed to lower resolution and how well a model grid point corresponds with the observation location. As well, error may be introduced by the precision of cloud cover values from both the forecast data and observations. Overall, cloud cover is under-forecast

The verification data indicates a significant increase in error as lead times increase. This is also possibly a result of reduced skill inherent to the numerical weather prediction models used in the long-term forecast.

3.2 Reservoir Forecasts

Reservoir forecasts are provided to NL Hydro once per day for five reservoir locations.
Preliminary analysis of the weather forecast accuracy provided inconclusive results due to gaps in the data and uncertainty in data interpretation during the analysis. Amec Foster Wheeler will review the methodology and the available data in greater depth and provide updated information for the current period during the next report.

Table 3-37 provides the location names and corresponding observation data that is available to Amec Foster Wheeler for comparison with the forecasts:

Table 3-37: Reservoir Forecast Observation Sites

#	Location	Observation Data Parameters
1.	Long Pond	Temperature, Precipitation
2.	Meelpaeg	No data available
3.	Victoria	No data available
4.	Cat Arm	Temperature, Precipitation values indicate 0.0 precipitation
5.	Hinds Lake	Temperature (some data points missing at end of forecast), Precipitation (no observations prior to January 13)

Preliminary analysis of the weather forecast accuracy provided inconclusive results due to gaps in the data and uncertainty in data interpretation during the analysis. Amec Foster Wheeler will review the methodology and the available data in greater depth and provide updated information for the current period during the next report.

3.3 Wind Farm Forecasts

Wind farm forecasts are provided to NL Hydro once per day for each of the following locations:

1. St. Lawrence
2. Fermeuse

The forecasts include the following parameters:

1. Dry-bulb temperature;
2. 80 meter wind speed;
3. 80 meter wind direction;
4. Air density

At this time, no observation data is available from either St. Lawrence or Fermeuse. Therefore, no verification analysis can be performed in the present report.

4.0 CLOSURE

The purpose of this report is to evaluate the performance of the forecasts that have been provided during the assessment period. Amec Foster Wheeler and NL Hydro will collectively monitor the performance metrics and use this information to determine how to continuously improve the forecasting skill.

If you have any questions or concerns regarding this report, please contact the undersigned.

Yours sincerely,

Amec Foster Wheeler Environment & Infrastructure,
a Division of Amec Foster Wheeler Americas Limited

Prepared by:	Reviewed by:
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