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January 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 -**

In accordance with the Liberty Report Recommendations dated December 17, 2014, item 2.1 wherein Hydro is required to "provide the Board with monthly updates on the status of Nostradamus upgrades until the production model is fully in-service and shaken down", please find enclosed the original plus 12 copies of Hydro's report entitled *Accuracy of Nostradamus Load Forecasting at Newfoundland and Labrador Hydro Monthly Report: December 2014.*

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

# Accuracy of Nostradamus Load Forecasting at Newfoundland and Labrador Hydro

# Monthly Report: December 2014

Newfoundland and Labrador Hydro

January 30, 2014

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# 1. NOSTRADAMUS LOAD FORECASTING

## 1.1 Nostradamus

Newfoundland and Labrador Hydro (Hydro) uses software called Nostradamus, by Ventyx, for short term load forecasting with a time frame of seven days. "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." (Nostradamus User Guide, Release 8.2, Ventyx, an ABB Company, May 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.

## 1.2 Short Term Load Forecasting

Hydro uses its short term load forecast to manage the power system and ensure adequate generating resources are available to meet customer demand.

### *1.2.1 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 the following weather parameters: 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 one formula used by Environment Canada to derive wind chill.

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.

In addition to the weather and demand data, a parameter that indicates daylight hours each day is input to Nostradamus.

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

### *1.2.2 Industrial Load*

Industrial load (non-conforming) 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 (CBP&P), 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 CBP&P or a ramp up in load expected at Vale. Engineers can change the expected load in one or more cells of a seven by twenty-four grid, or can change the default value to be used indefinitely.

### *1.2.3 Supply and Demand Status Reporting*

The forecast peak reported to the Board of Commissioners of Public Utilities (the Board) on the Daily Supply and Demand Status Report each day 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 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 with-in day forecast updates are used by operators to decide if additional spinning reserve is required in advance of forecast system peaks.

## 1.3 Load Forecasting Improvements

Hydro implemented the following changes to the load forecasting process in 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 which will improve the capability of the model to forecast loads at low temperatures;
- 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;
- 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 losses); and
- Creation of new plots and tables showing the load forecast, spinning reserve, and available reserve, available on demand to System Operations staff for managing the system.

The changes to the Nostradamus model have 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. In addition, improved model performance has allowed an increase to hourly updates of the forecast throughout the day; previously the forecast was updated five times per day.

Additional improvements to the forecasting process are planned for 2015, as follows:

- A further update to the software once it is released by the vendor;
- A move to twice daily weather forecasting and receipt of observed data which will improve forecasting of the afternoon peak and the following day; and
- Monthly accuracy reporting on the weather forecasts from AMEC, which will improve the understanding of any Nostradamus forecast variance.

## 1.4 Potential Sources of Variance

Improvements made to the Nostradamus forecasting model and Hydro's processes for load forecasting have improved the reliability of the load forecasts and it is anticipated that planned revisions will further improve the accuracy.

As with any forecasting, 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 from unexpected changes in customer loads;
- Inaccuracies in the weather forecast, particularly temperature, wind speed or cloud cover; and
- Customer behaviour is not uniform and therefore not completely predictable.

## 2. DECEMBER 2014 FORECAST ACCURACY

Table 1 presents the daily forecast peak, the actual peak observed and the available system capacity, as included in Hydro's Daily Supply and Demand Status Reports submitted to the Board for each day in December 2014. The data are also presented in Figure 1.

There were no days in December when System Operations engineers felt it necessary to make any adjustments to the Nostradamus forecast to account for weather outside the model's ability or for unusual system conditions or events.

**Table 1 December 2014 Load Forecasting Data**

| Date | Forecast Peak, MW | Actual Peak, MW | Available Island Supply, MW | Forecast Reserve, MW |
|---|---|---|---|---|
| 1-Dec-14 | 1075 | 1217 | 1500 | 500 |
| 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 |

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 – CBP&P Interruptible load (when applicable) - impact of voltage reduction)

The observed peaks during December 2014 were between 1086 MW on December 14th and 1664 MW on December 31st. The peaks were above 1600 MW, which would be considered a high demand, on three days: December 8th (1638 MW), December 30th (1621 MW), and December 31st (1664 MW). It was at loads in excess of 1600 MW in January 2014 that the Nostradamus model provided erratic results.

The available capacity during the month was between 1500 MW on December 1st and 1915 MW on December 30th. Reserves were sufficient throughout the period.

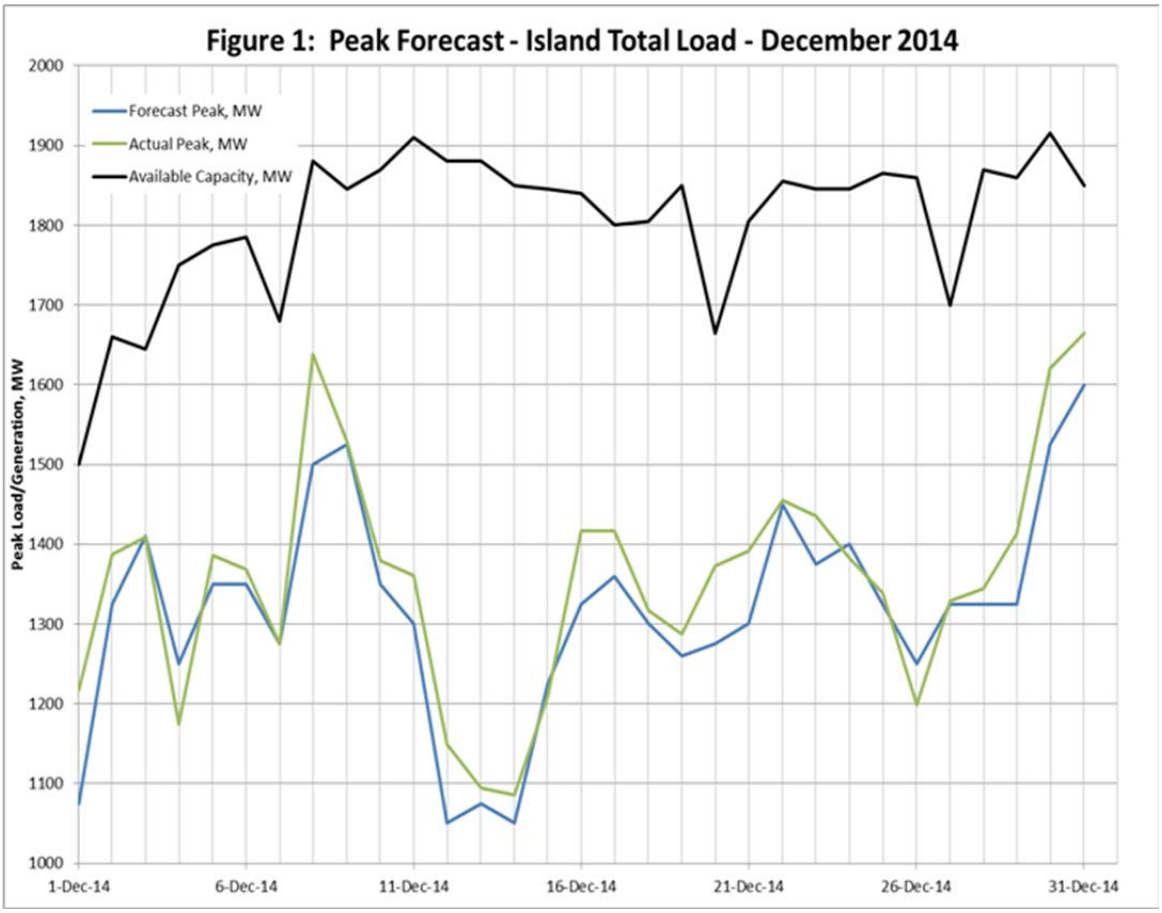



Table 2 presents error statistics for the peak forecasts during the month of December. Figure 2 is a plot of the forecast and actual peaks, as shown in Figure 1, but with the addition of a bar chart showing the forecast errors, the difference between the two data series. In both the tables and the figures, a positive error is an overestimate; a negative error is an underestimate.

**Table 2 Analysis of Forecast Error**

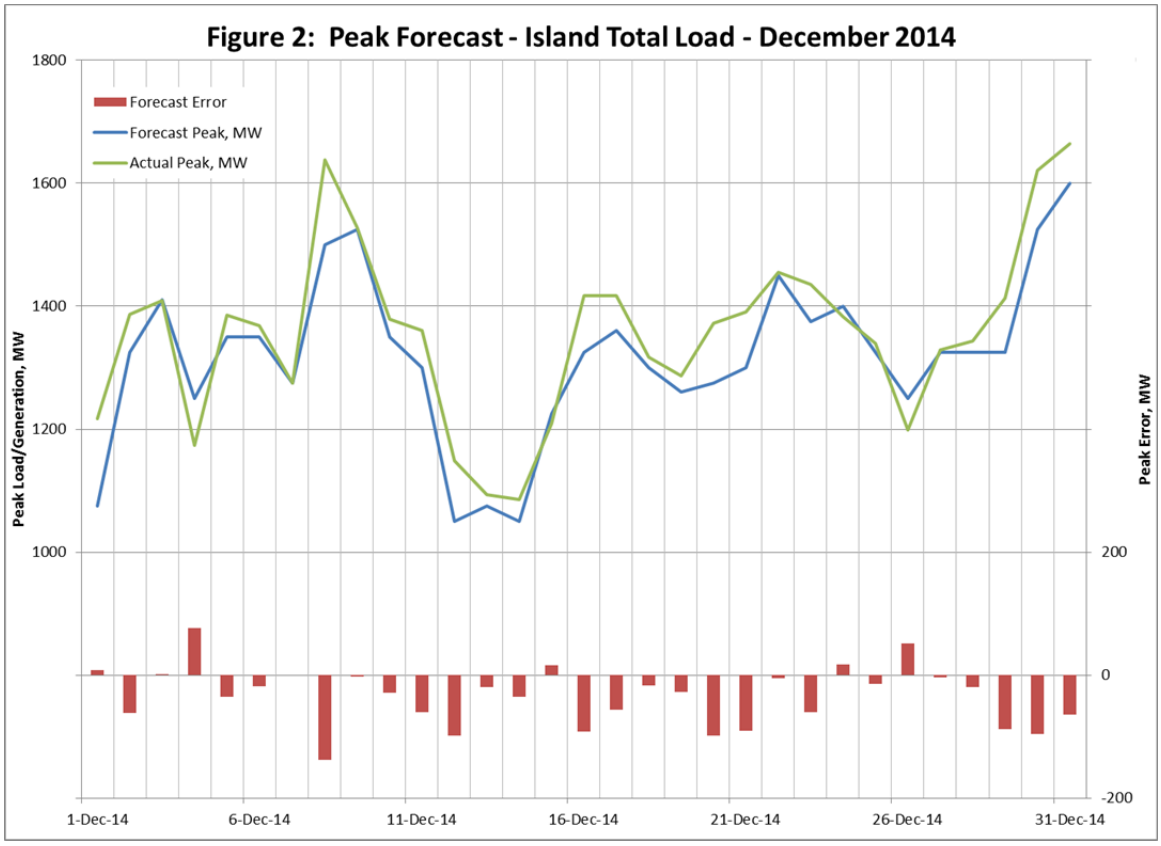
| Date | Actual | Forecast | Error | Absolute Error | Percent Error | Absolute Percent Error | Actual/ Forecast |
|---|---|---|---|---|---|---|---|
| 1-Dec-14 | 1217 | 1225 | 8 | 8 | 0.7% | 0.7% | 0.7% |
| 2-Dec-14 | 1387 | 1325 | -62 | 62 | -4.5% | 4.5% | -4.7% |
| 3-Dec-14 | 1409 | 1410 | 1 | 1 | 0.1% | 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% |
| Minimum | 1086 | 1050 | -138 | 0 | -8.6% | 0.0% | -9.4% |
| Average | 1356 | 1322 | -34 | 45 | -2.4% | 3.3% | -2.6% |
| Maximum | 1664 | 1600 | 76 | 138 | 6.5% | 8.6% | 6.1% |

Notes:

Forecast peak and available capacity are 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.

Through the month of December the forecast peak was between 9% below actual and 7% over the actual peak. On the best day the forecast peak was the same as the actual peak; on the worst day it was 140 MW too low. On average, the forecast peak was 45 MW different than the actual peak, or 3.3%.




In the review of forecast accuracy statistics for December 2014 in Table 2, Hydro offers further detail on the differences found between forecast and actual peak for the days December 8th, when the peak was underestimated by 138 MW, or 8.4%, and December 12th, when the peak was underestimate by 99 MW, or 8.6%.

## 2.1 December 8, 2014

On December 8th, the peak of the 7:20 am forecast was 1500 MW; the actual peak was 1638 MW. The absolute difference was 138 MW, 8.4% of the actual. Figure 3 includes an hourly plot of the load forecast for December 8th as well as several charts which examine components of the load forecast to assist in determining the sources of the differences between actual and forecast loads.

Figure 3(a) shows the hourly distribution of the load forecast compared to the actual load. The forecast predicted a morning peak of 1500 MW. The actual the morning peak was 1526 MW, which was close to the forecast. However, the forecast predicted a lower afternoon peak of 1444 MW but the load actually increased in the afternoon and peaked at 1638 MW at 5:20 pm (the plot shows a peak of 1622 MW as it was created with data from Nostradamus which is input on the hour only).

Figure 3(b) shows the hourly distribution of the utility load forecast only, i.e., the load forecast with the industrial component removed. The difference between the forecast and actual utility loads is similar to that of the total load, so a discrepancy in the industrial forecast does not explain the variance in the peak.

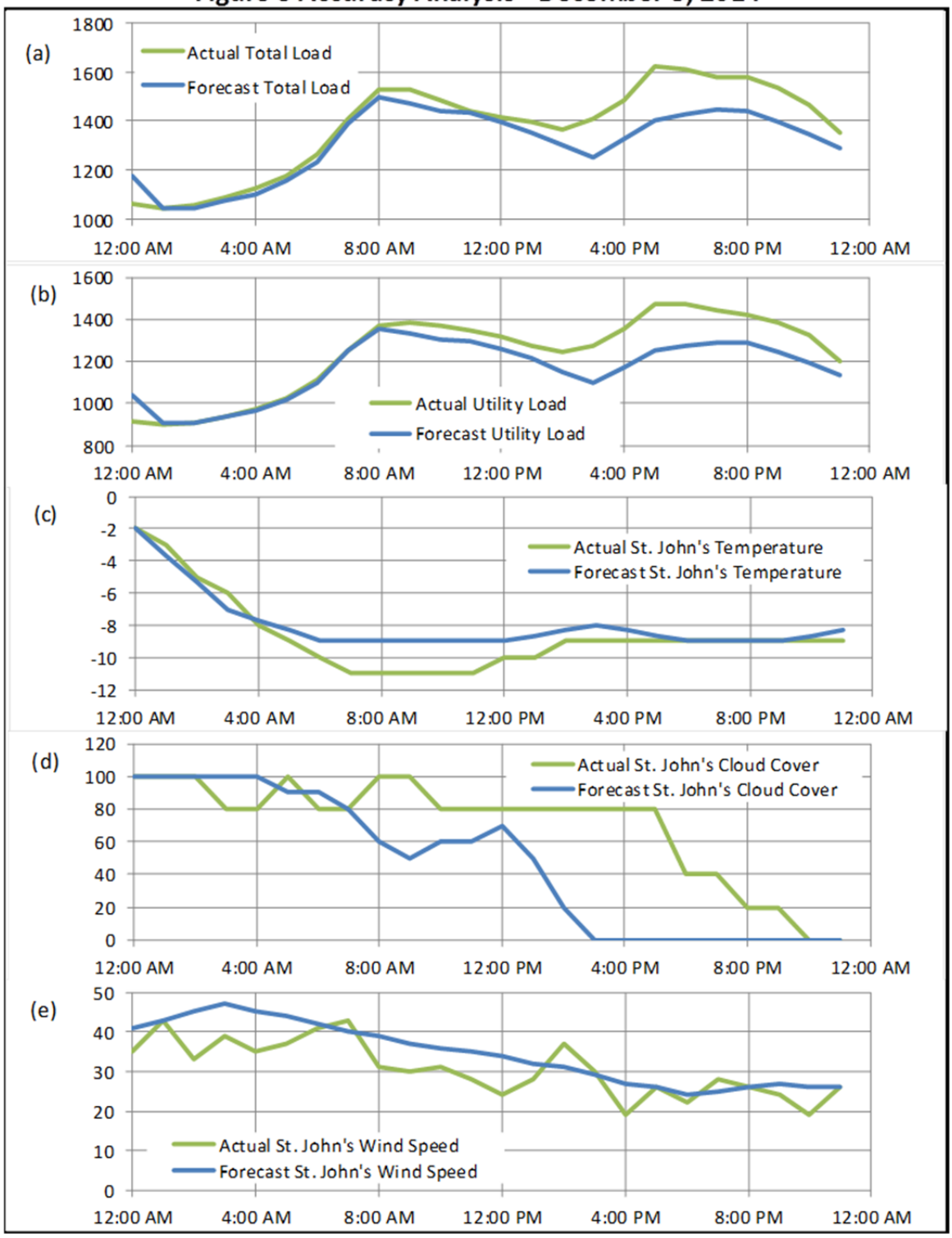
Figure 3(c) shows the actual temperature in St. John's compared to the forecast. Although Nostradamus uses weather data at four sites, the weather in St. John's tends to have the largest effect because of the concentration of customers in St. John's. The temperature was forecast to be approximately two degrees higher during the morning peak than it actually was, but later in the day the temperature forecast was quite good so a variance in the temperature forecast does not explain the difference in the peak.

Figure 3(d) shows the actual cloud cover in St. John's compared to the forecast. For most of the day, the weather was cloudier than forecast. Later in the afternoon, the forecast predicted that skies would be clear (0% cloud) but the cloud cover was recorded at 80%. When the weather is sunny, the solar radiation warms peoples' homes and people tend to feel the cold less, so the absence of the forecast sunshine likely contributed to the discrepancy in the forecast.

Figure 3(e) shows the actual wind speed in St. John's compared to the forecast. For most of the day the actual wind speed was lower than predicted so a variance in the wind speed forecast does not contribute to the difference in the peak.

The Nostradamus model runs every hour to use actual loads experienced that day to improve the estimate for the rest of the day. By the mid-day update, the forecast peak for December 8$^{th}$ was 1590 MW, 32 MW, or 2% below actual. The updates are used by operators to manage spinning reserve.

**Figure 3 Accuracy Analysis - December 8, 2014**



## 2.2 December 12, 2014

On December 12th the peak of the 7:20 am forecast was 1050 MW; the actual peak was 1149 MW. The absolute difference was 99 MW, 8.6% of the actual. Variances in the forecast at lower peaks are generally less of a concern to System Operations because reserves are likely higher during periods of lower peaks.

Figure 4 includes an hourly plot of the load forecast for December 12th as well as several charts which examine components of the load forecast to assist in determining the sources of the differences between actual and forecast loads.

Figure 4(a) shows the hourly distribution of the load forecast compared to the actual load. The shape of the actual load was very similar to the forecast but was consistently approximately 90 MW higher.

Figure 4(b) shows the hourly distribution of the utility load forecast only, i.e., the load forecast with the industrial component removed. The difference between the forecast and actual utility loads is similar to that of the total load, so a variance in the industrial forecast does not explain the difference in the peak.

Figure 4(c) shows the actual temperature in St. John's compared to the forecast. The temperature was forecast to be somewhat higher than it was so the discrepancy in the temperature forecast may contribute somewhat to the variance in the peak.

Figure 4(d) shows the actual cloud cover in St. John's compared to the forecast. The cloud cover forecast was quite accurate so did not contribute to the variance in the load forecast.

Figure 4(e) shows the actual wind speed in St. John's compared to the forecast. The wind speed forecast was quite accurate so did not contribute to the difference in the load forecast.

It is difficult to ascertain why Nostradamus consistently underestimated the load forecast on December 12, 2014. The weather forecast was quite accurate for the parameters that Nostradamus uses and the forecast of industrial load was good. Other factors, not modelled by Nostradamus could have increased the load that day, for instance wind direction, precipitation, or human behaviour.

The Nostradamus model runs every hour to use actual loads experienced that day to improve the estimate for the rest of the day. By the mid-day update, the forecast peak for December 12th was 1098 MW, 51 MW, or 4.5% below actual. The updates are used by operators to manage spinning reserve.

**Figure 4 Accuracy Analysis - December 12, 2014**