Heating/Cooling Degree Day Forecasts for BC Hydro Sales Regions Using a Probabilistic Model with Climate Inputs

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Roland V Wahlgren, BSc MA
Load Research Analyst
BC Hydro Customer Information Management—Load Analysis
BC Hydro, Burnaby, British Columbia

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Not done for CDD because uncertainties often exceeded CDD values (see previous section of presentation)

Test predicted against actual HDD

- Residuals
- Correlation coefficient, R
- Mean Absolute Percentage Error (MAPE)
- "Acid Test"

Mean Absolute Predicted Error (MAPE)

Mean Absolute Predicted Error (MAPE) values were calculated using the formula:

MAPE [%] = (100/N) $\times$ Σ | ($P_{\text{actual } i}$ – $P_{\text{predicted } i}$) / $P_{\text{actual } i}$ |; sum from i = 1 to i = N

where

$P_{\text{actual } i}$ = actual HDD or CDD on day i,

$P_{\text{predicted } i}$ = forecast value of HDD or CDD on day i, and

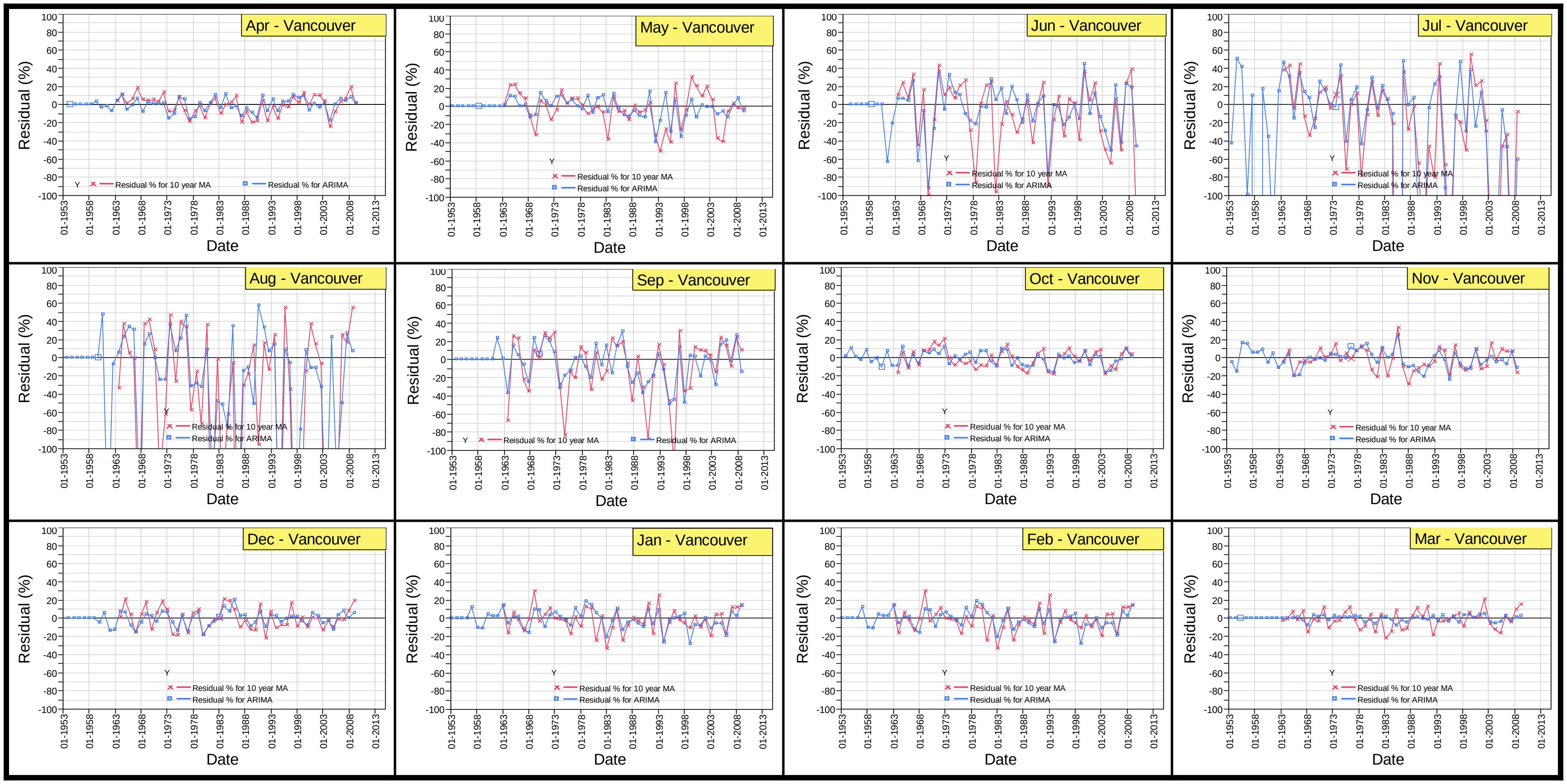
N = total number of data points.

MAPE is a useful statistic for quantifying the amounts by which predicted values differed from actual values of some variable. A MAPE of 19%, for example, would tell us, "…on average the difference between the fitted values and the actual values is 19%." (Stellwagen, 2006). MAPE is the standard for load forecasts by energy utilities (Yazdi, 2009) and is one of the statistics reported by forecasting software such as SAS JMP.

HDD Forecast Quality for Vancouver — Residuals (% of actual HDD) by Month for backcast

Residual (%) for 10 year moving average method

Residual (%) for ARIMA method (proposed forecast model)



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Roland V Wahlgren, Load Research Analyst
BC Hydro Customer Information Management—Load Analysis

Forecast Quality – Lower Mainland Region Monthly HDD

Data was from 1953 to 2008 but 10-year Moving Average (MA) Process discarded first ten years of data

Test predicted HDD against actual HDD for 1963–2008

HDD for Lower Mainland Region (Correlation coefficient r and MAPE were for predicted HDD against actual HDD)

Month	ARIMA predictions (proposed new method), r	r significant	Mean Absolute Percentage Error	10 y MA predictions (used by BC Hydro), r	r significant	Mean Absolute Percentage Error
Apr	0.71	Yes	6.67%	0.37	Yes	8.29%
May	0.76		9.43%	0.19	No	14.31%
Jun	0.67		20.67%	0.22	No	30.62%
Jul	0.51		67.50%	0.49	Yes	74.75%
Aug	0.75		49.68%	0.41	Yes	75.99%
Sep	0.68		17.40%	0.22	No	25.44%
Oct	0.61		6.50%	0.05		8.74%
Nov	0.54		7.83%	-0.01		10.39%
Dec	0.73		6.42%	-0.20		9.99%
Jan	0.64		8.31%	0.19		10.44%
Feb	0.85		3.98%	-0.22		7.97%
Mar	0.94		2.69%	0.25		7.96%

Shading denotes month in shoulder season

critical absolute value of r (5%) = 0.288

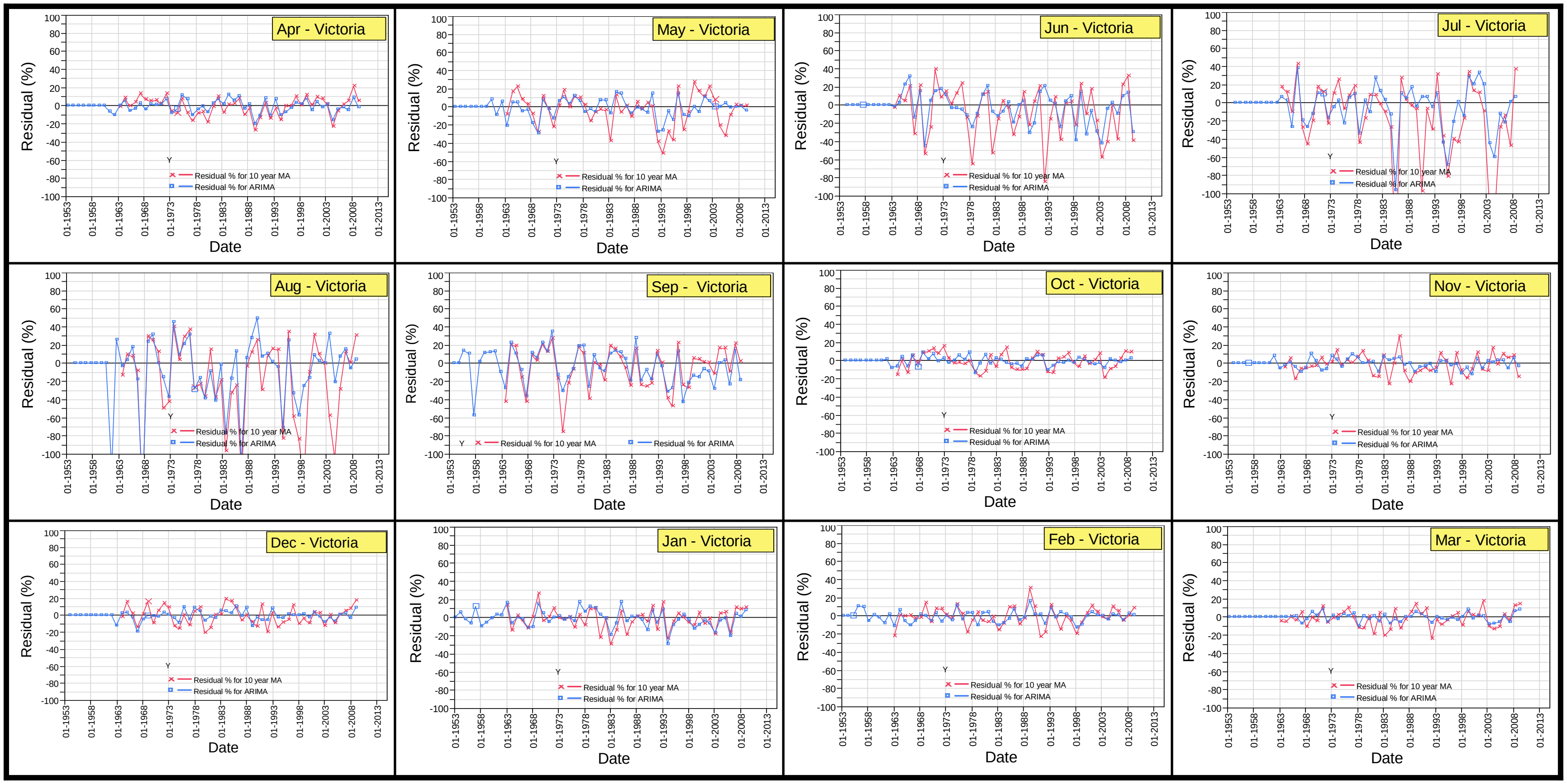
Summer (Jun–Sep)

Winter (Nov–Mar)

HDD Forecast Quality for Victoria — Residuals (% of actual HDD) by Month for backcast

Residual (%) for 10 year moving average method

Residual (%) for ARIMA method (proposed forecast model)



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Forecast Quality – Vancouver Island Region Monthly HDD

Test predicted HDD against actual HDD for 1963–2008

HDD for Vancouver Island Region (Correlation coefficient r and MAPE were for predicted HDD against actual HDD)

Month	ARIMA predictions (proposed new method), r	r significant	Mean Absolute Percentage Error	10 y MA predictions (used by BC Hydro), r	r significant	Mean Absolute Percentage Error
Apr	0.73	Yes	5.76%	0.34	Yes	7.78%
May	0.76	↓	8.28%	0.15	No	13.68%
Jun	0.74	↓	14.63%	0.28	No	22.17%
Jul	0.63	↓	25.74%	0.51	Yes	31.19%
Aug	0.57	↓	26.12%	0.35	Yes	36.96%
Sep	0.34	↓	16.52%	0.11	No	18.38%
Oct	0.81	↓	3.91%	-0.05	↓	7.72%
Nov	0.86	↓	4.85%	-0.04	↓	9.06%
Dec	0.81	↓	4.53%	-0.12	↓	8.94%
Jan	0.54	↓	7.32%	0.23	↓	8.84%
Feb	0.76	↓	4.93%	-0.31	↓	7.94%
Mar	0.86	↓	3.45%	0.19	↓	7.56%

Summer (Jun–Sep)

Winter (Nov–Mar)

Shading denotes month in shoulder season

critical absolute value of r (5%) = 0.288

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Roland V Wahlgren, Load Research Analyst
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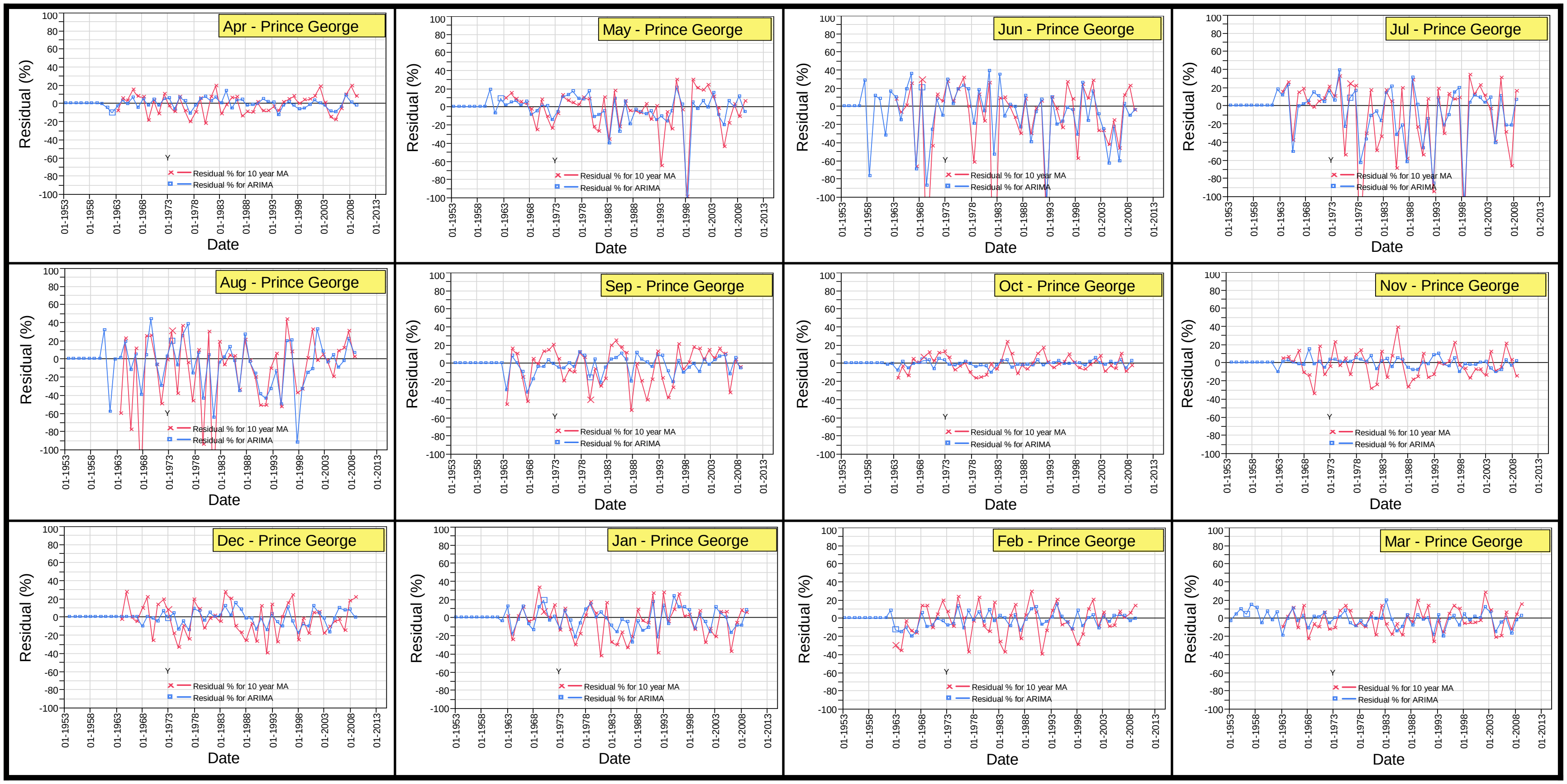
HDD Forecast Quality for Prince George— Residuals (% of actual HDD) by Month for backcast

Residual (%) for 10 year moving average method

Residual (%) for ARIMA method (proposed forecast model)



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Forecast Quality – Northern Region Monthly HDD

Test predicted HDD against actual HDD for 1963-2008

HDD for Northern Region

(Correlation coefficient r and MAPE were for predicted HDD against actual HDD)

Month	ARIMA predictions (proposed new method), r	r significant	Mean Absolute Percentage Error	10 y MA predictions (used by BC Hydro), r	r significant	Mean Absolute Percentage Error
Apr	0.86	Yes	4.34%	0.16	No	8.84%
May	0.64		11.41%	0.02		16.08%
Jun	0.45		23.57%	0.08		29.48%
Jul	0.64		22.17%	0.15		31.34%
Aug	0.63		20.75%	0.04		30.10%
Sep	0.84		8.26%	-0.04		16.98%
Oct	0.92		2.51%	-0.21		7.19%
Nov	0.95		4.04%	-0.16		12.19%
Dec	0.88		6.35%	-0.13		14.86%
Jan	0.74		10.20%	0.14		14.82%
Feb	0.85		6.72%	-0.31		14.65%
Mar	0.76		5.96%	0.00		10.73%

Summer (Jun–Aug)

Winter (Nov–Mar)

Shading denotes month in shoulder season

critical absolute value of r (5%) = 0.288; n = 47

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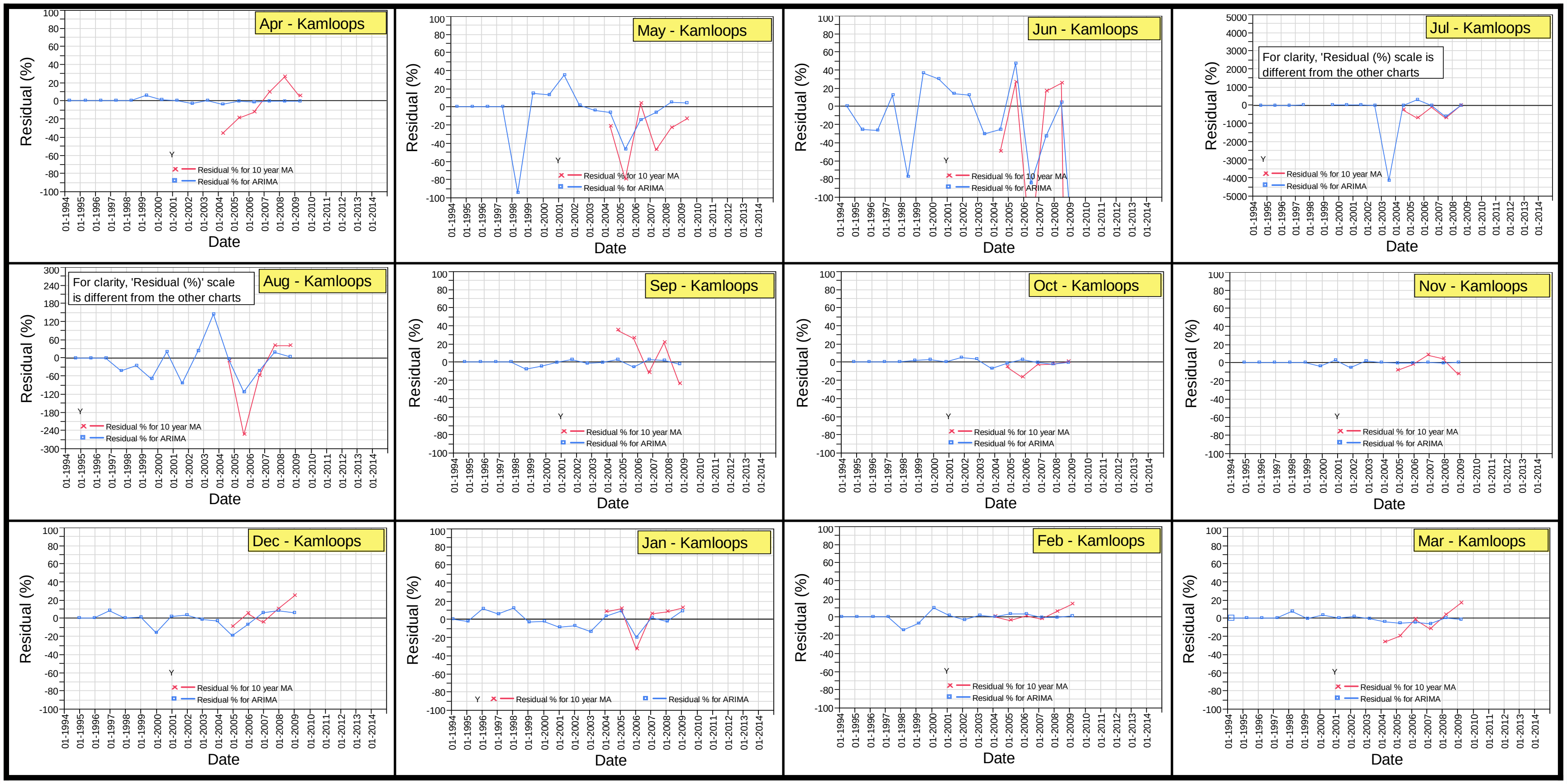
Roland V Wahlgren, Load Research Analyst
BC Hydro Customer Information Management—Load Analysis

HDD Forecast Quality for Kamloops — Residuals (% of actual HDD) by Month for backcast

Residual (%) for 10 year moving average method

Residual (%) for ARIMA method (proposed forecast model)



Roland V Wahlgren, Load Research Analyst
BC Hydro Customer Information Management—Load Analysis

Caution - Missing data from July 1998 limits quality of analyses for Kamloops

Forecast Quality – South Interior Region Monthly HDD

Test predicted HDD against actual HDD for 2004-2008

HDD for South Interior Region

(Correlation coefficient r and MAPE were for predicted HDD against actual HDD)

Month	ARIMA predictions (proposed new method), r	r significant	Mean Absolute Percentage Error	10 y MA predictions (used by BC Hydro), r	r significant	Mean Absolute Percentage Error
Apr	1.00	Yes	1.19%	-0.79	No	18.11%
May	0.76	No	14.06%	0.13		31.47%
Jun	0.71	No	69.33%	-0.93		207.05%
Jul	0.42	No	216.10%	-0.56		421.13%
Aug	0.93	Yes	30.27%	-0.45		68.37%
Sep	0.98	Yes	3.14%	-0.81		23.76%
Oct	0.99	Yes	1.33%	-0.55		5.42%
Nov	1.00	Yes	0.28%	-0.13		7.20%
Dec	0.65	No	9.42%	-0.53		10.62%
Jan	0.81	Yes	7.61%	-0.64		13.53%
Feb	0.97	Yes	1.58%	0.15		4.43%
Mar	0.99	Yes	3.50%	-0.76		13.27%

Summer (Jun–Sep)

Winter (Nov–Mar)

Shading denotes month in shoulder season

critical absolute value of r (5%) = 0.811 for Jan-Jun; n = 6

critical absolute value of r (5%) = 0.878 for Jul-Dec; n = 5

Caution - Missing data from July 1998 limits quality of analyses for Kamloops

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Acid Tests

So far, so good—backcasts appear to have confirmed superiority of the new probabilistic model with climate inputs over the static and dynamic moving average models. MAPEs were always lowest for the new probabilistic model. But, what about stepping back in time and forecasting forward for five years? Compare (using MAPE, slide 86) the forecasts to the actual degree day values observed during these five years. Will the new model stand up to such "acid tests"?

Initial experiments with the first four acid tests gave disappointing results for the new model. These tests were based on the Vancouver Airport HDD time series from 1981–2009 used by BC Hydro's Load Forecasting division or the 1953-2009 series from Load Analysis. Monthly HDD forecasts were made for Apr 2001 to Mar 2006. The new model performed no better than either static or dynamic moving average models. Through a chance re-reading of an article about climate change in *Science*, I realized that this forecast period occurred within periods of stationarity of the time series for the Global Mean Monthly Temperature Anomalies (Kerr, 2009) and Vancouver Airport HDDs. Therefore, it was not surprising that the moving average forecasts performed nicely. The relatively short (30 year) duration of the 1981–2001 observations further handicapped functioning of the new model which depended on incorporating into its algorithms cycles revealed over longer time periods.

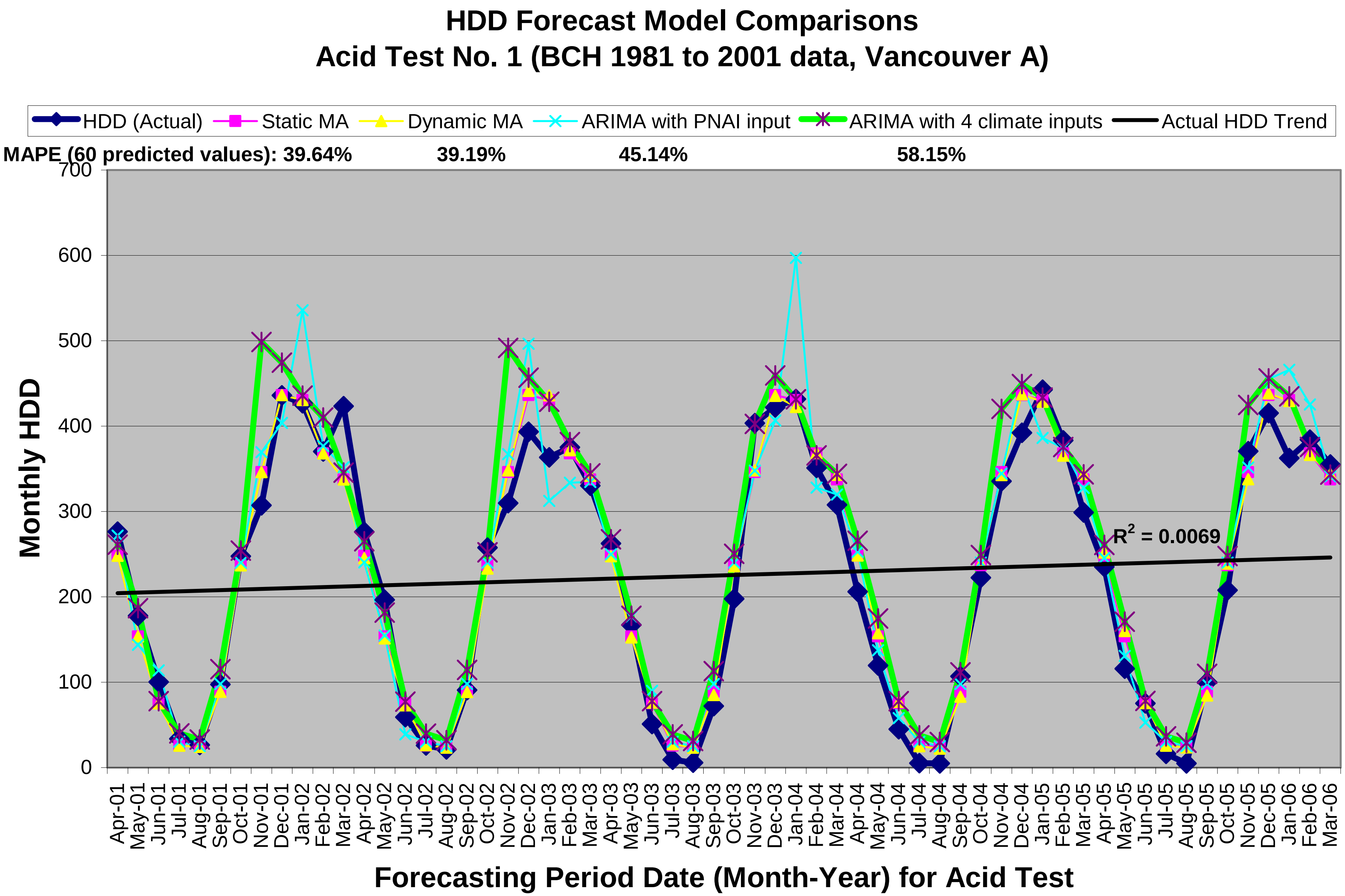
Disappointment was tempered further when it was discovered researchers working on short-term weather forecasting models for model predictive control of commercial buildings, which would not usually be experiencing noticeable trends, found that, "the results show that even the most complicated nonlinear autoregressive neural network with exogenous input does not appear to warrant the additional efforts in forecasting model development and training in comparison to the simpler MA [moving average] models" (Florita and Henze, 2009, p. 835).

To ensure a fair comparison between forecasting methods, Acid Test No. 5 was done using the 1953–2009 time series used for all the other analyses in this project. These acid tests began **forecasts in Apr 1993** (within a **period of non-stationarity** with a decreasing HDD trend). **Now the probability model out-performed the moving average models** for the crucial heating months of Sep through Feb. Accuracy in Mar and Apr was acceptable, although not quite as good as the moving average models. Experimentation showed that the probabilistic model was sensitive to the correct application of climate inputs. If the bivariate analyses done earlier had significant correlations between HDD and a certain climate index, MAPE decreased when all appropriate inputs were applied. If a significant climate index input was omitted, MAPE increased. Finally, Acid Test No. 6 checked thoroughly whether using as ARIMA model inputs climate indices such as SOI, PDO, NPI, or ALPI would improve forecasting accuracy.

Guide to the Acid Tests

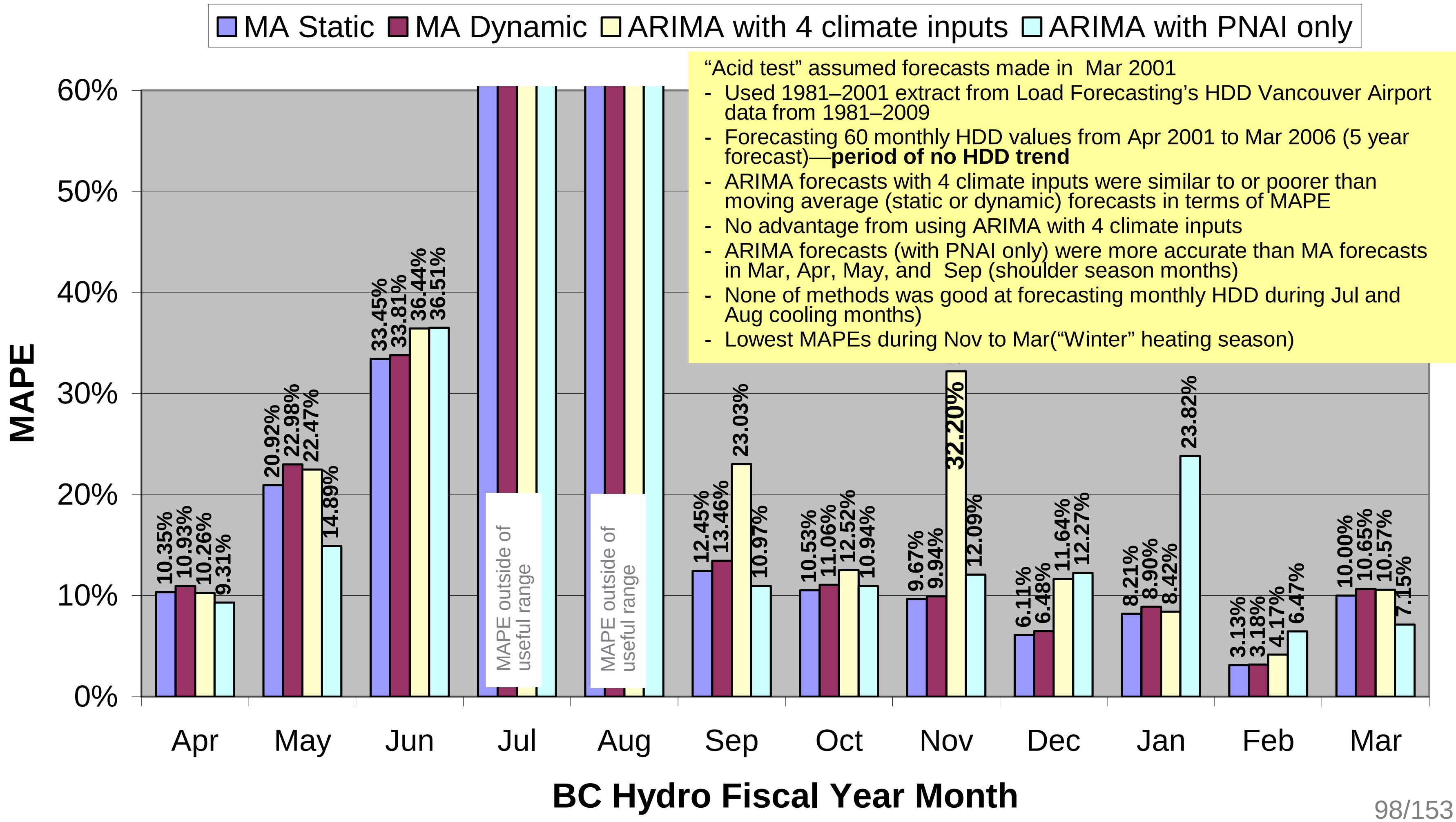
Acid Test No.	**Experiment's focus** **(in addition to comparing results with static and dynamic moving average model results)**
1	Load Forecast's 1981-2009 HDD data set Forecasts from Apr 2001 to Mar 2006—period of HDD stationarity Compared ARIMA with 4 climate inputs to ARIMA with PNAI only
2	Load Forecast's 1981-2009 HDD data set Forecasts from Apr 2001 to Mar 2006—period of HDD stationarity Compared ARIMA with no climate inputs to ARIMA with PNAI only
3	Load Analysis' 1953-2009 HDD data set Forecasts from Apr 2001 to Mar 2006—period of HDD stationarity Compared ARIMA with no climate inputs to ARIMA with PNAI only
4	Load Analysis' 1953-2009 HDD data set **Forecasts from Apr 2001 to Mar 2006—period of HDD stationarity; Contrast with Acid Test No. 5** Compared ARIMA with no climate inputs to ARIMA with multiple inputs
5	Load Analysis' 1953-2009 HDD data set **Forecasts from Apr 1993 to Mar 1998—period of HDD non-stationarity; Contrast with Acid Test No. 4** Compared ARIMA with no climate inputs to ARIMA with multiple inputs; Summarized change in forecast accuracy from using ARIMA; Observed variability in forecast accuracy during forecast period; Explored climate influences on HDD for Vancouver
6	Load Analysis' 1953-2009 HDD data set Forecasts from Apr 1993 to Mar 1998—period of HDD non-stationarity Compared ARIMA with climate inputs (decided by strength of fit) with static and dynamic moving average models

"Acid Test No. 1" comparing HDD forecasting methods



“Acid Test No. 1” comparing HDD forecasting methods

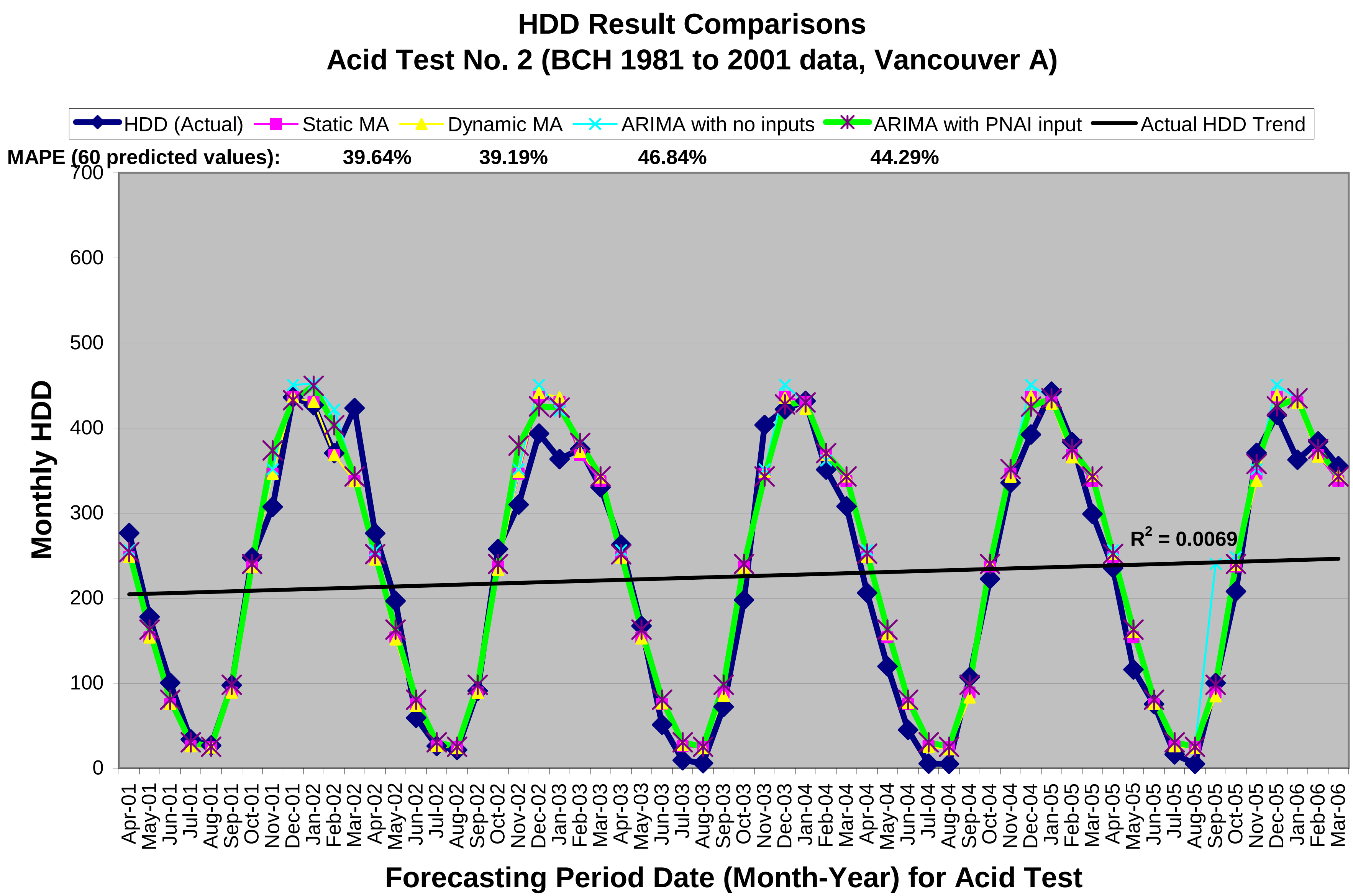
MAPE for HDD forecasting methods
BCH 1981 to 2001 data (Vancouver A)



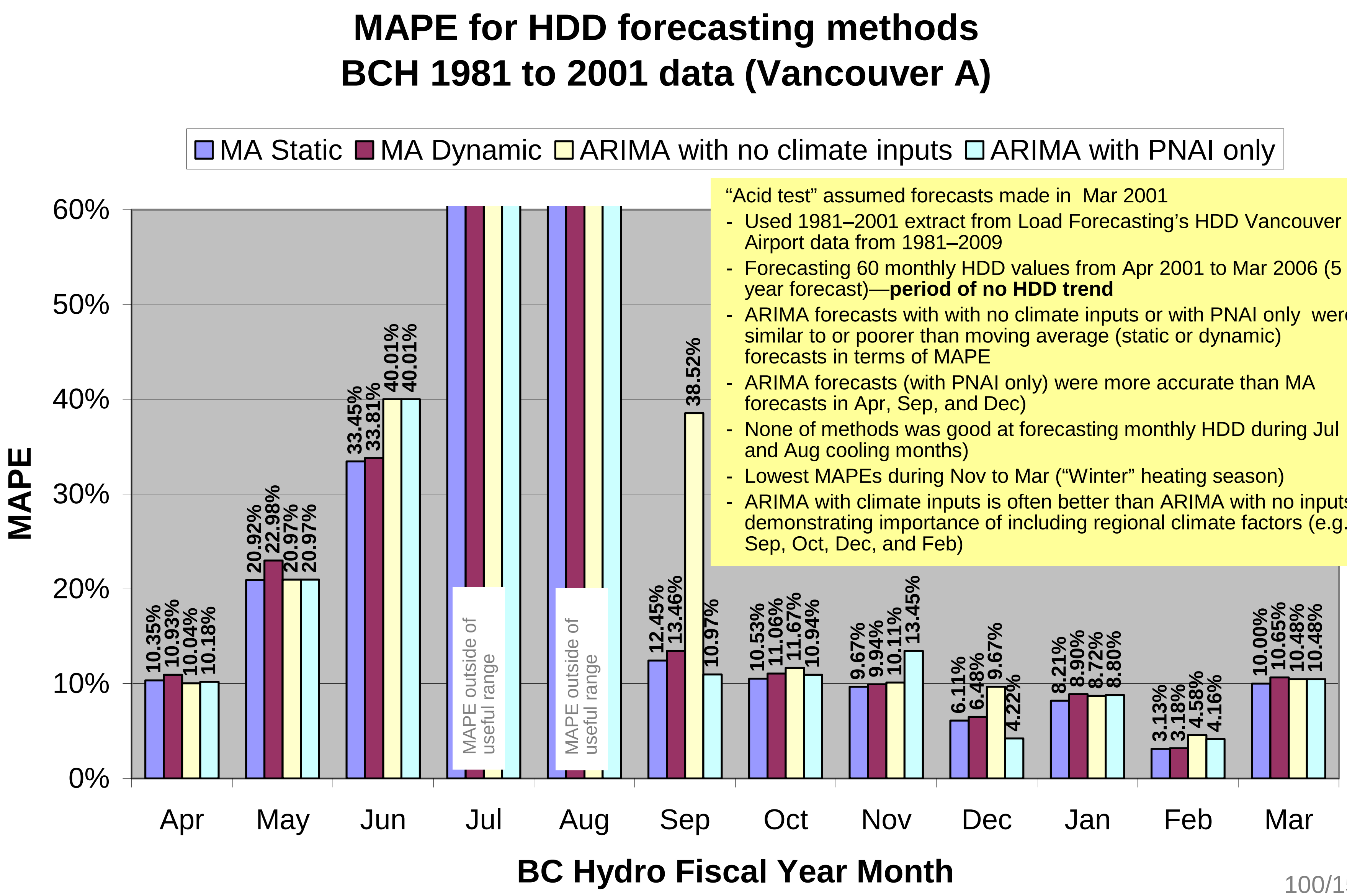
“Acid test” assumed forecasts made in Mar 2001

- Used 1981–2001 extract from Load Forecasting’s HDD Vancouver Airport data from 1981–2009
- Forecasting 60 monthly HDD values from Apr 2001 to Mar 2006 (5 year forecast)—**period of no HDD trend**
- ARIMA forecasts with 4 climate inputs were similar to or poorer than moving average (static or dynamic) forecasts in terms of MAPE
- No advantage from using ARIMA with 4 climate inputs
- ARIMA forecasts (with PNAI only) were more accurate than MA forecasts in Mar, Apr, May, and Sep (shoulder season months)
- None of methods was good at forecasting monthly HDD during Jul and Aug cooling months)
- Lowest MAPEs during Nov to Mar(“Winter” heating season)

"Acid Test No. 2" comparing HDD forecasting methods



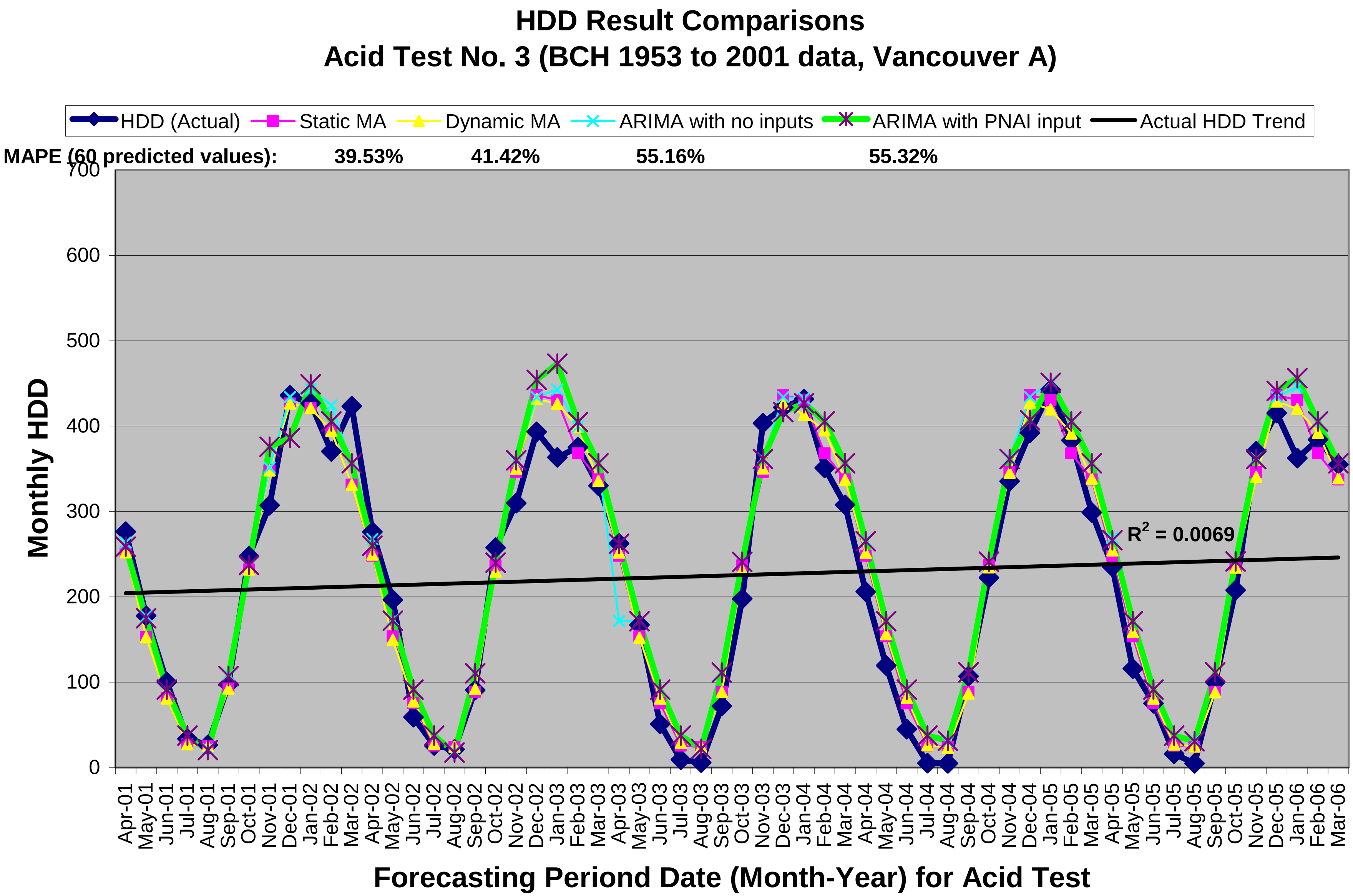
"Acid Test No. 2" comparing HDD forecasting methods



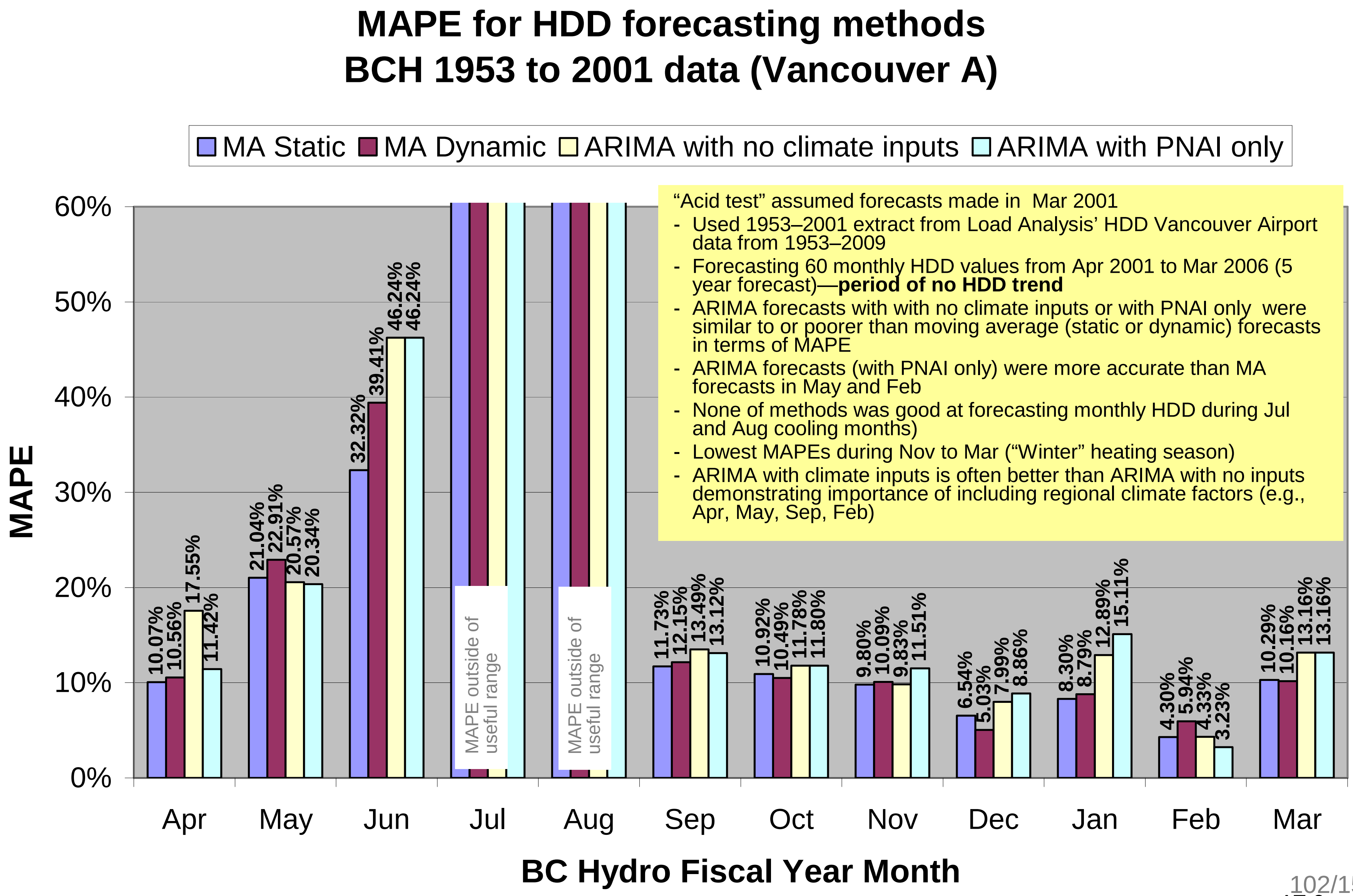
"Acid test" assumed forecasts made in Mar 2001

- Used 1981–2001 extract from Load Forecasting's HDD Vancouver Airport data from 1981–2009
- Forecasting 60 monthly HDD values from Apr 2001 to Mar 2006 (5 year forecast)—**period of no HDD trend**
- ARIMA forecasts with with no climate inputs or with PNAI only were similar to or poorer than moving average (static or dynamic) forecasts in terms of MAPE
- ARIMA forecasts (with PNAI only) were more accurate than MA forecasts in Apr, Sep, and Dec)
- None of methods was good at forecasting monthly HDD during Jul and Aug cooling months)
- Lowest MAPEs during Nov to Mar ("Winter" heating season)
- ARIMA with climate inputs is often better than ARIMA with no inputs demonstrating importance of including regional climate factors (e.g., Sep, Oct, Dec, and Feb)

“Acid Test No. 3” comparing HDD forecasting methods



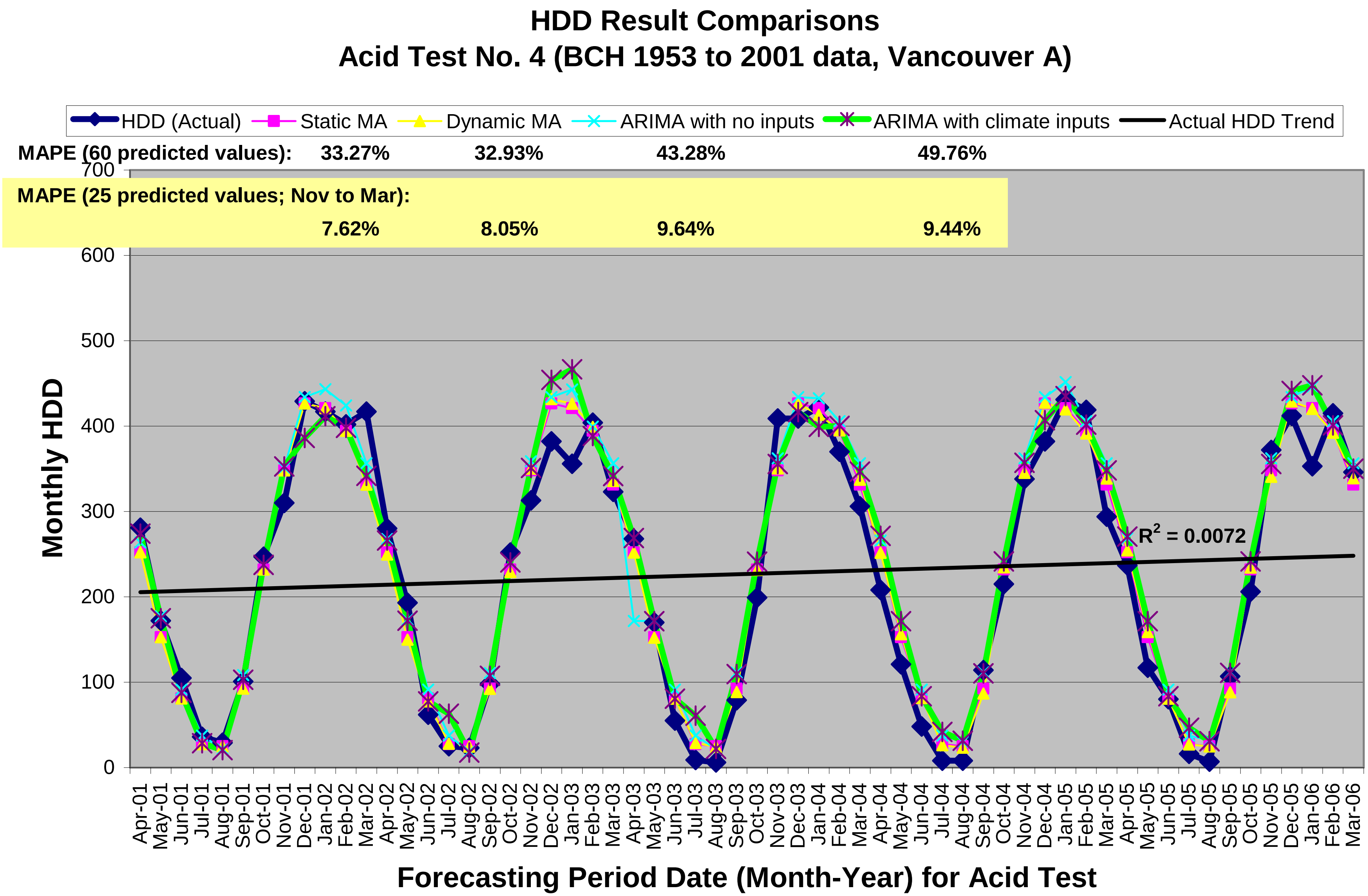
"Acid Test No. 3" comparing HDD forecasting methods



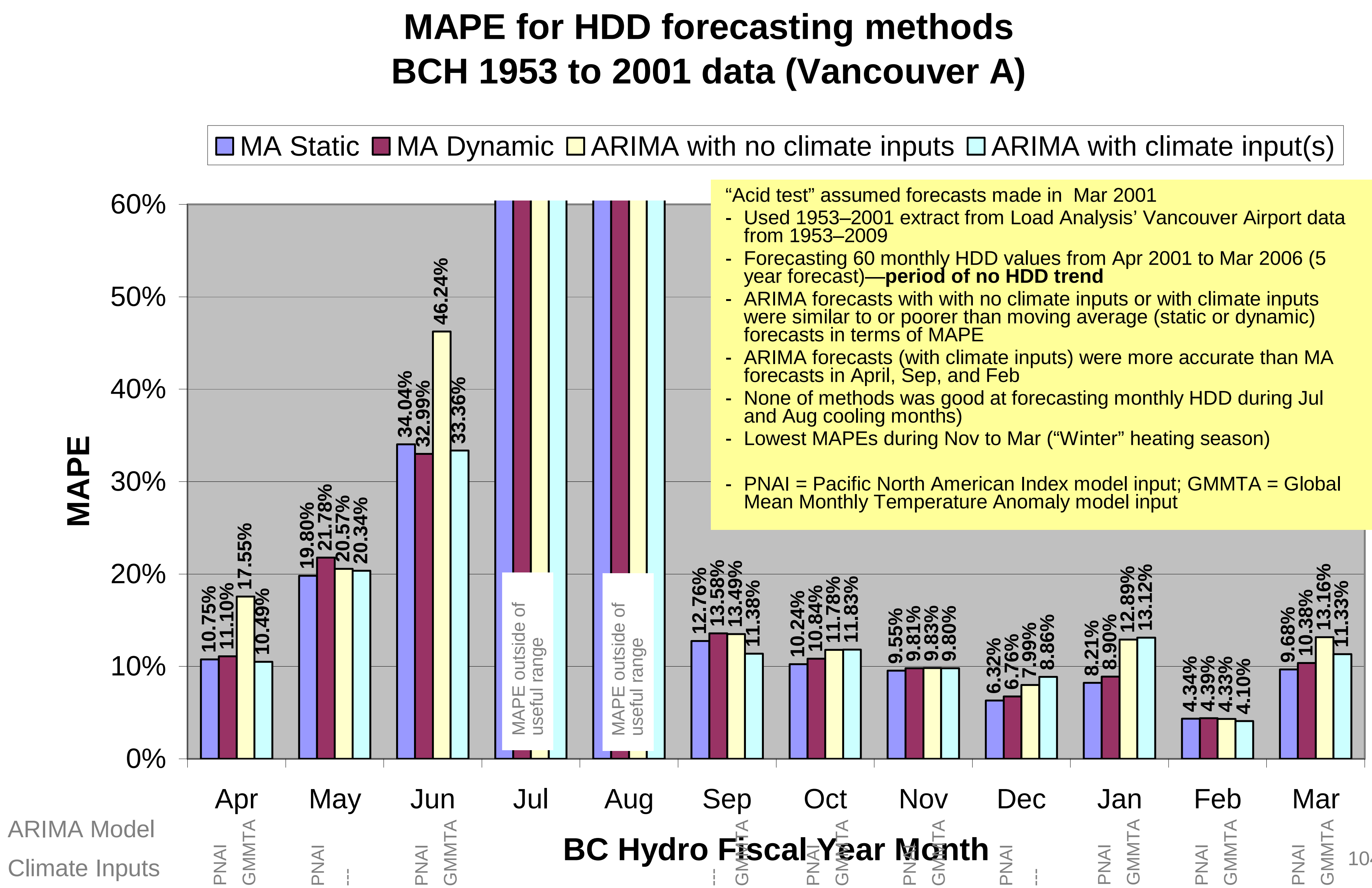
"Acid test" assumed forecasts made in Mar 2001

- Used 1953–2001 extract from Load Analysis' HDD Vancouver Airport data from 1953–2009
- Forecasting 60 monthly HDD values from Apr 2001 to Mar 2006 (5 year forecast)—**period of no HDD trend**
- ARIMA forecasts with with no climate inputs or with PNAI only were similar to or poorer than moving average (static or dynamic) forecasts in terms of MAPE
- ARIMA forecasts (with PNAI only) were more accurate than MA forecasts in May and Feb
- None of methods was good at forecasting monthly HDD during Jul and Aug cooling months)
- Lowest MAPEs during Nov to Mar ("Winter" heating season)
- ARIMA with climate inputs is often better than ARIMA with no inputs demonstrating importance of including regional climate factors (e.g., Apr, May, Sep, Feb)

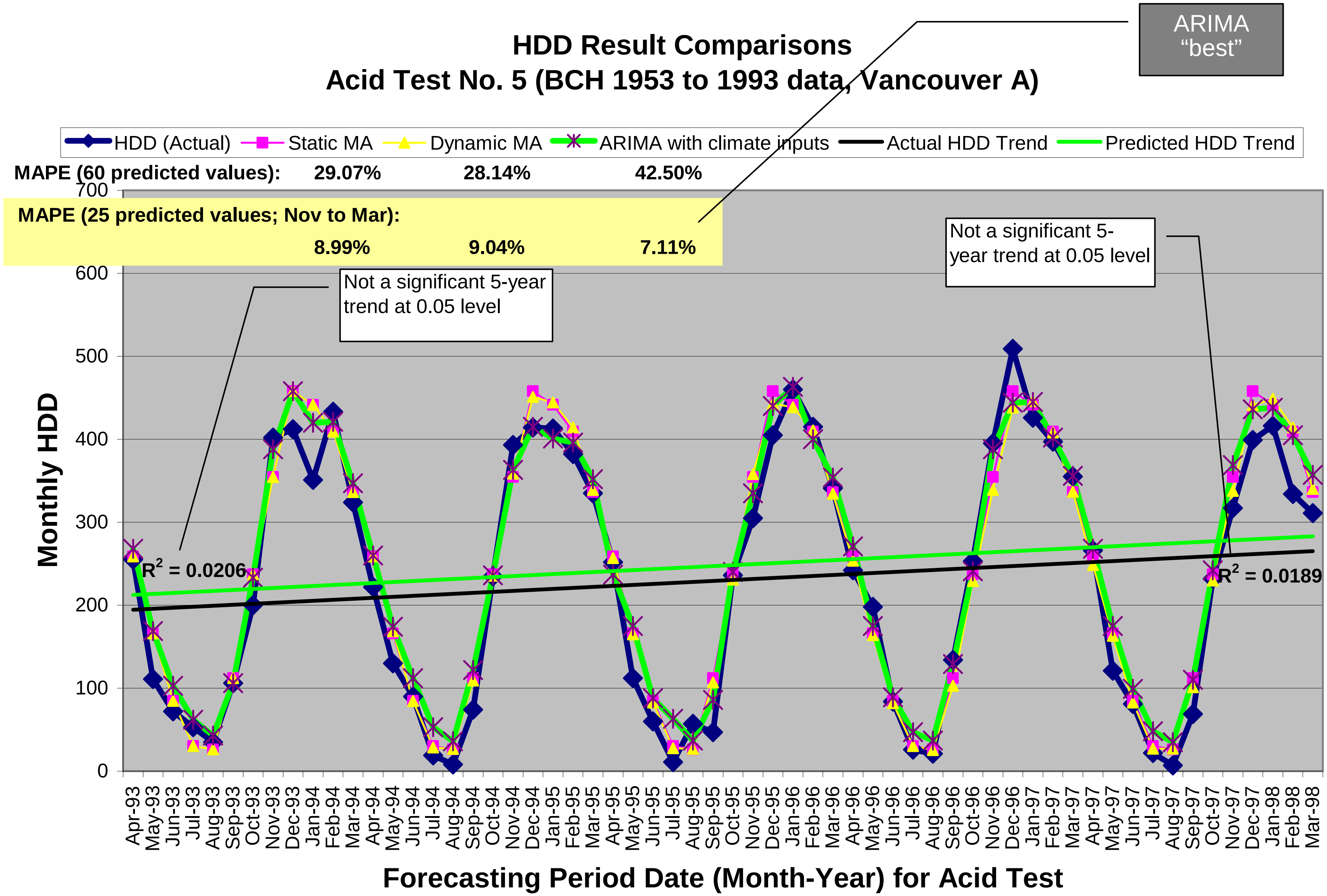
"Acid Test No. 4" comparing HDD forecasting methods



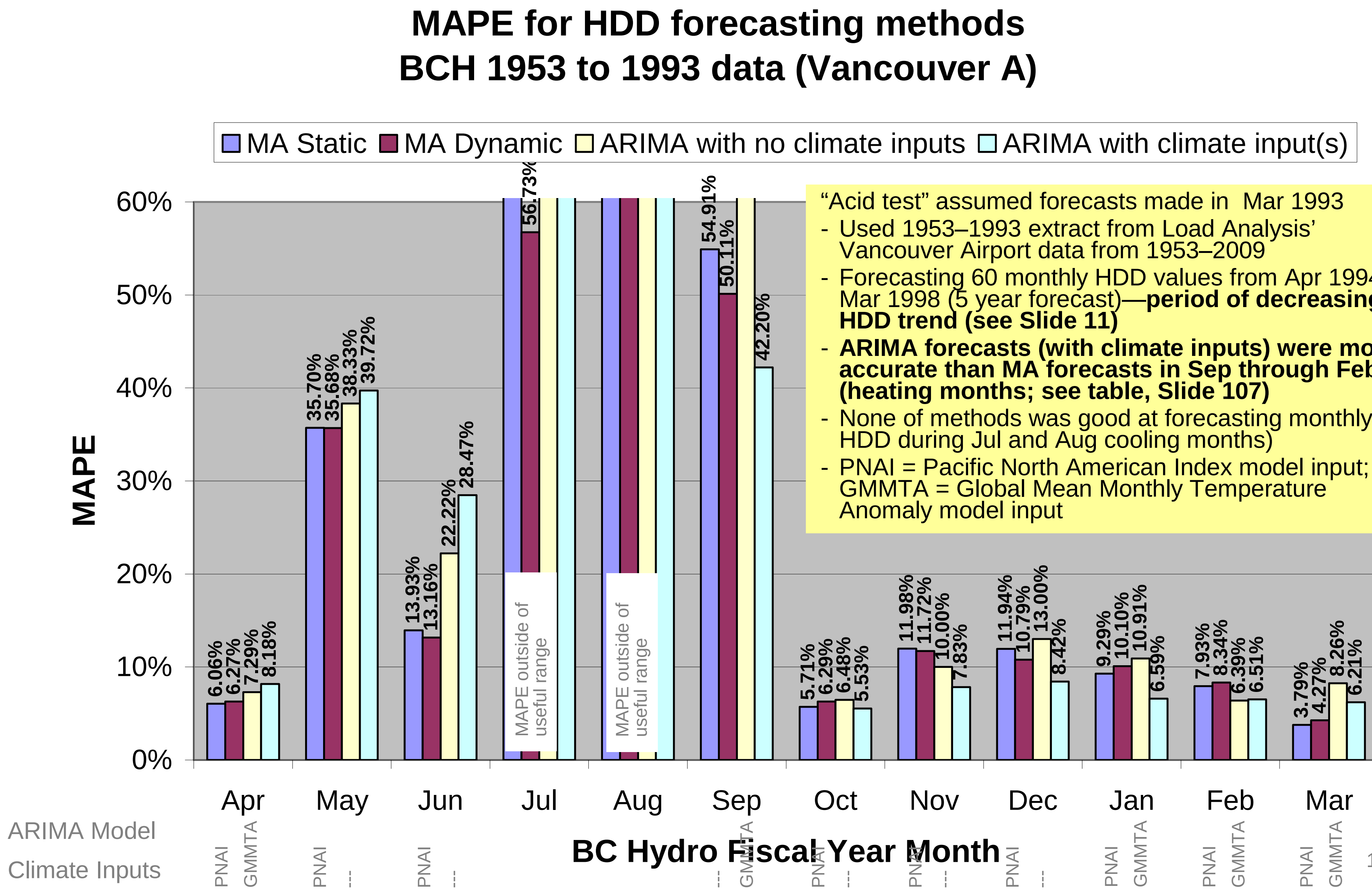
“Acid Test No. 4” comparing HDD forecasting methods



"Acid Test No. 5" comparing HDD forecasting methods



“Acid Test No. 5” comparing HDD forecasting methods



“Acid test” assumed forecasts made in Mar 1993

- Used 1953–1993 extract from Load Analysis’ Vancouver Airport data from 1953–2009
- Forecasting 60 monthly HDD values from Apr 1994 to Mar 1998 (5 year forecast)—**period of decreasing HDD trend (see Slide 11)**
- **ARIMA forecasts (with climate inputs) were more accurate than MA forecasts in Sep through Feb (heating months; see table, Slide 107)**
- None of methods was good at forecasting monthly HDD during Jul and Aug cooling months)
- PNAI = Pacific North American Index model input; GMMTA = Global Mean Monthly Temperature Anomaly model input

Change in HDD forecast accuracy — summary for Acid Test No. 5

Change in HDD forecast accuracy — summary for Acid Test No. 5

	MAPE values			Change in MAPE	
Month	MA Static	MA Dynamic	ARIMA	Change = (ARIMA - MA Static)	Change = (ARIMA - MA Dynamic)
Apr	6.06%	6.27%	8.18%	2.12%	1.91%
May	35.70%	35.68%	39.72%	4.01%	4.04%
Jun	13.93%	13.16%	28.47%	14.54%	15.30%
Jul	MAPE outside of useful range				
Aug	MAPE outside of useful range				
Sep	54.91%	50.11%	42.20%	-12.71%	-7.91%
Oct	5.71%	6.29%	5.53%	-0.17%	-0.76%
Nov	11.98%	11.72%	7.83%	-4.16%	-3.90%
Dec	11.94%	10.79%	8.42%	-3.52%	-2.37%
Jan	9.29%	10.10%	6.59%	-2.70%	-3.51%
Feb	7.93%	8.34%	6.51%	-1.41%	-1.83%
Mar	3.79%	4.27%	6.21%	2.43%	1.94%

ARIMA “best”

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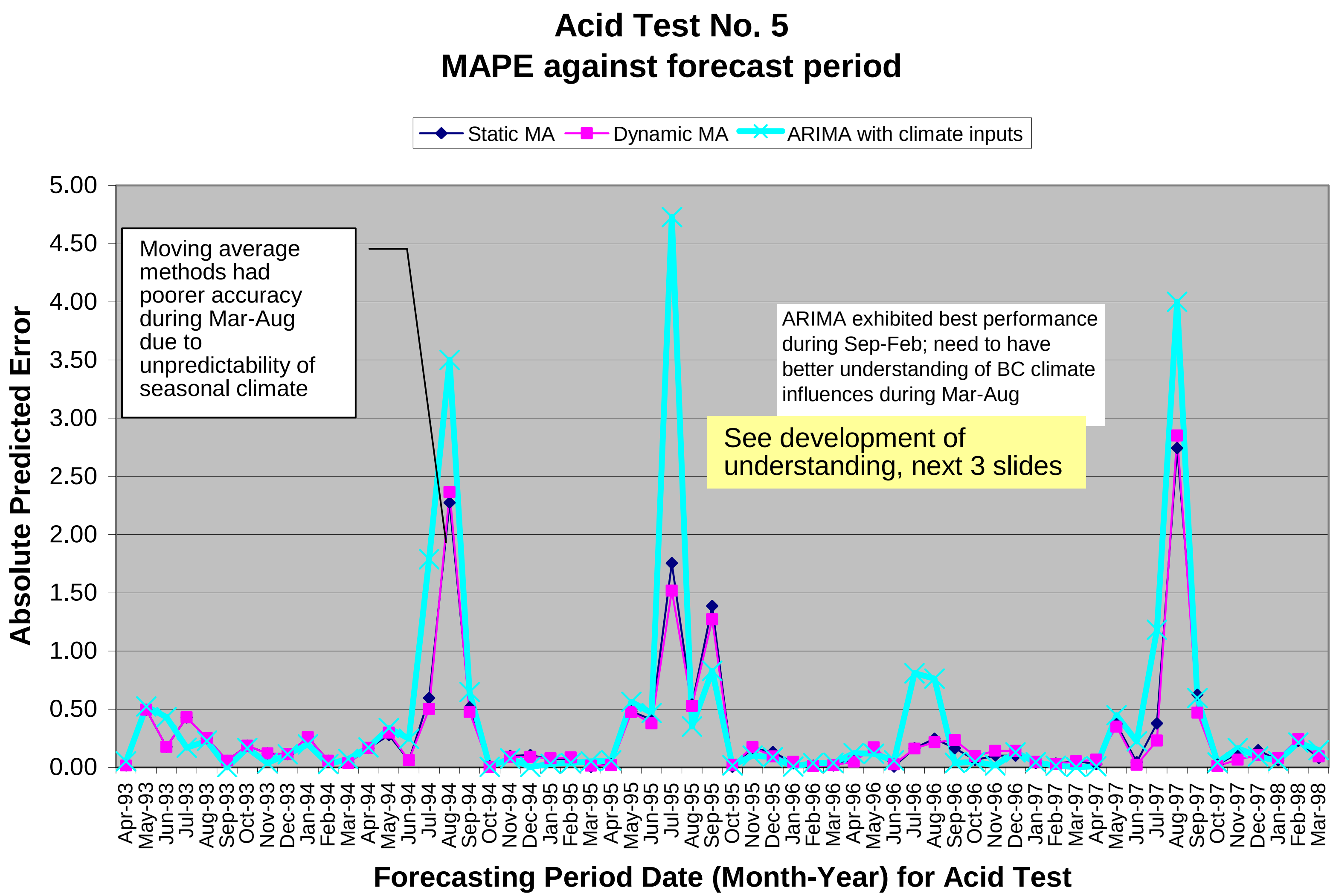
“Acid Test No. 5” comparing HDD forecasting methods

Variability in forecast accuracy during forecast period



"Acid Test No. 5" comparing HDD forecasting methods

Exploration of climate influences on HDD for Vancouver (1 of 3)

Hypothesis: Best fitting indices (coloured cells) were likely to be the best inputs for maximizing climate input information to ARIMA model for increased forecasting accuracy.

The data collected for the strength of fit table below used bivariate analyses similar to the monthly analyses for HDD against PNAI illustrated on Slide 28. Strength of fit was quantified by the value giving the Analysis of Variance (ANOVA) probability that the F-statistic is greater than the critical statistic. Lower probabilities indicate better fits. Table is charted in Slides 110 and 111.

Strength of fit between HDD Vancouver and climate indices by month

HDD data for 1953-2009

	ANOVA Prob > F							
Month	**MSSN**	**GMMTA**	**SOI**	**LODI**	**PDO**	**NPI**	**ALPI**	**PNAI**
Apr	0.2364	0.0003	0.027	0.0768	0.0001	0.0001	0.0407	0.0002
May	0.2175	0.083	0.0138	0.162	0.0002	0.0001	0.5862	0.0165
Jun	0.3675	0.0338	0.0127	0.0856	0.003	0.1437	0.0523	0.0108
Jul	0.5708	0.0017	0.8259	0.0055	0.164	0.1291	0.3396	0.0486
Aug	0.9341	0.0001	0.0456	0.0009	0.047	0.022	0.0011	0.5412
Sep	0.6987	0.0099	0.16	0.1705	0.0881	0.0001	0.4403	0.7963
Oct	0.547	0.0251	0.2499	0.0568	0.2143	0.0027	0.1751	0.0001
Nov	0.9692	0.0205	0.8835	0.551	0.0479	0.0015	0.0472	0.0001
Dec	0.2038	0.106	0.1632	0.2203	0.0563	0.0001	0.7625	0.0001
Jan	0.4936	0.0006	0.5112	0.0529	0.0002	0.0001	0.0001	0.0001
Feb	0.5609	0.0049	0.1296	0.8037	0.0004	0.0001	0.0001	0.0001
Mar	0.5594	0.0002	0.0001	0.7747	0.0001	0.0001	0.0001	0.0001

Note: Decision for which of tied values to use was made by choosing fit with highest R^2 (bolded cells)

We now have three ways of identifying and quantifying relationships between degree days at a station and climate indices:
- Bivariate analysis (R^2)
- Spectral analysis
- ANOVA F-test

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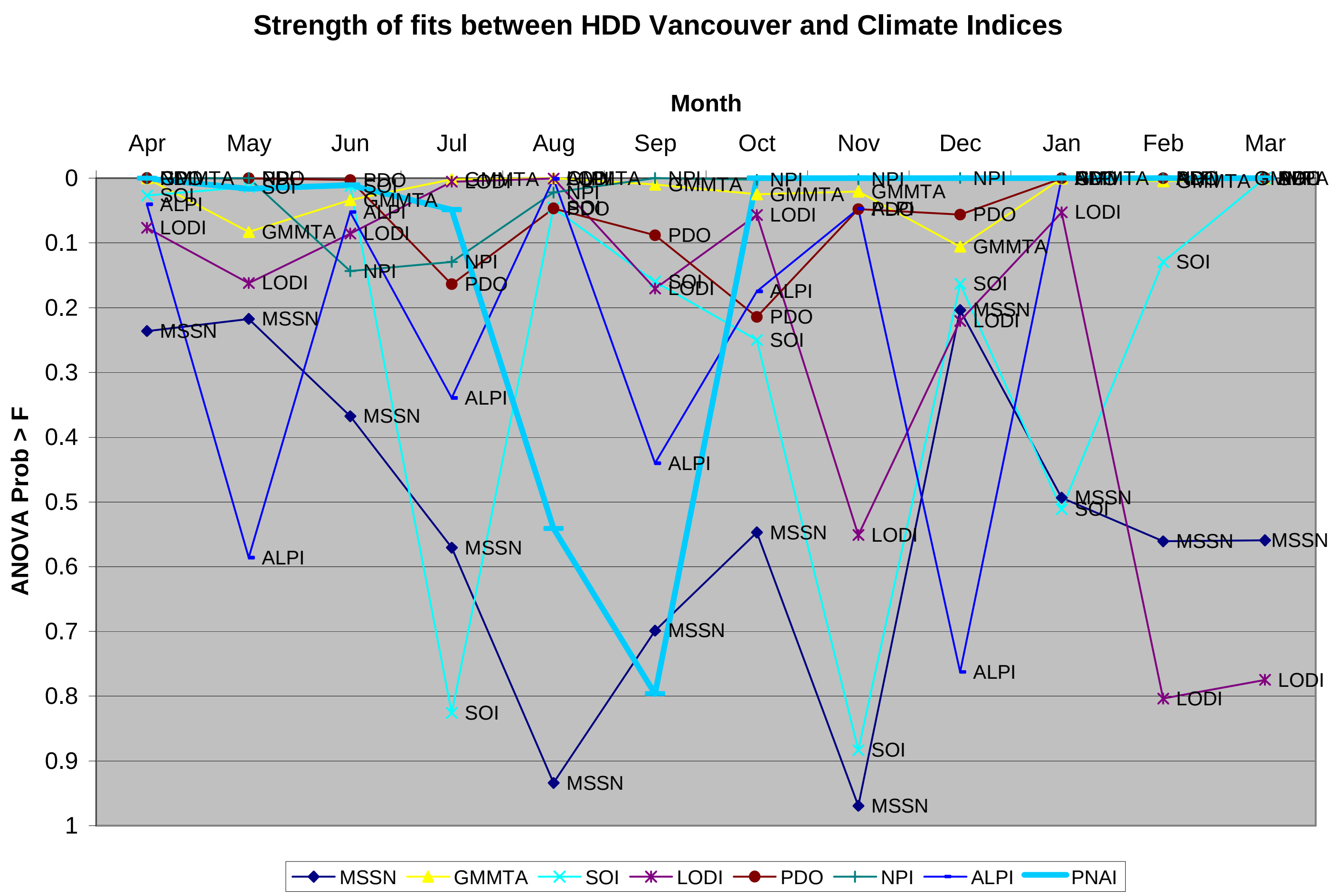
Roland V Wahlgren, Load Research Analyst
BC Hydro Customer Information Management—Load Analysis

“Acid Test No. 5” comparing HDD forecasting methods

Exploration of climate influences on HDD for Vancouver (2 of 3)

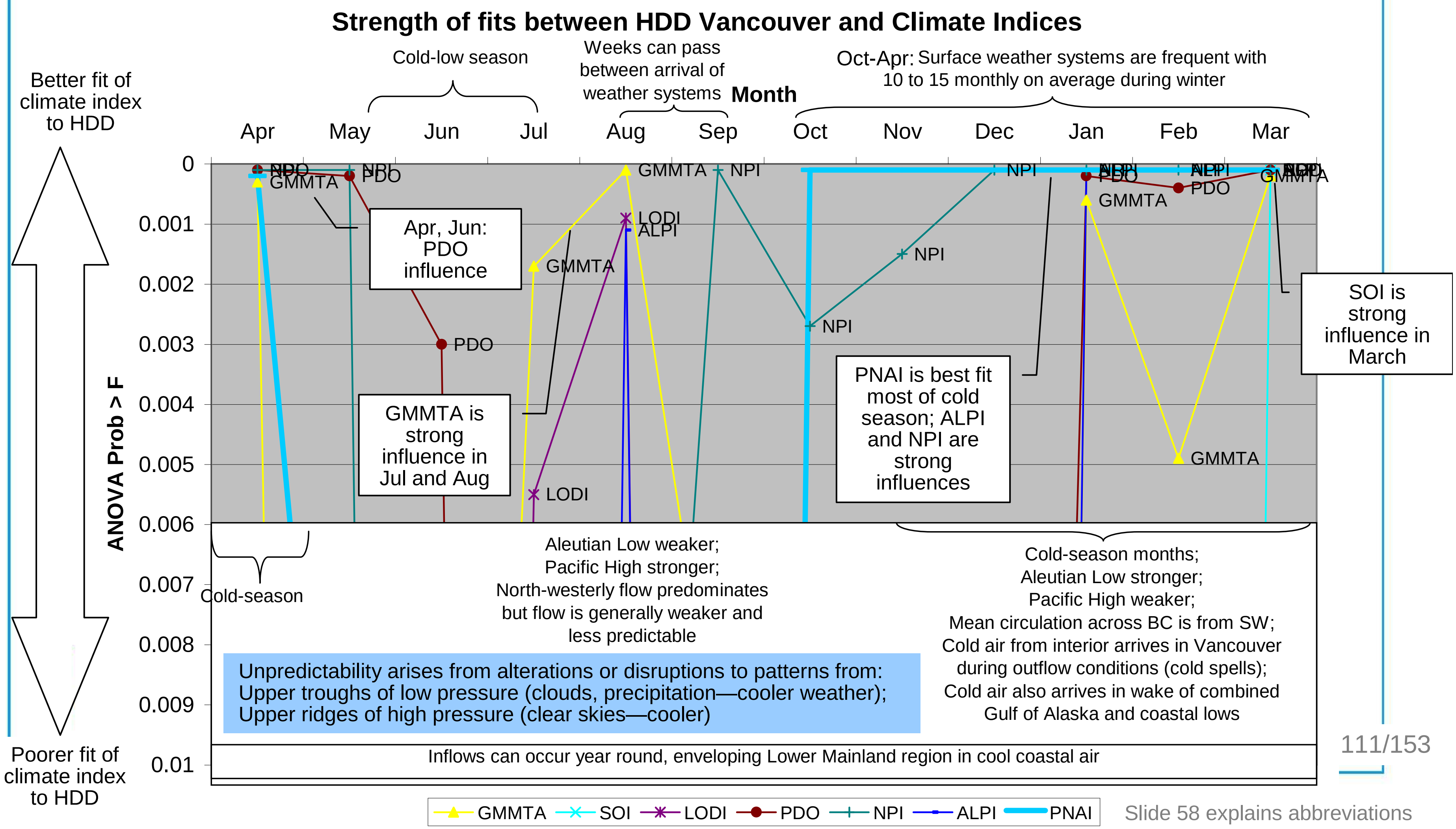
Here is an overview of the strength of fits. This is far “too busy” to comprehend easily, so zoom in, next slide, filtering out all probabilities greater than 0.01. The y-axis was reversed in these charts, so that better fits would be grouped near the top of the chart.



“Acid Test No. 5” comparing HDD forecasting methods

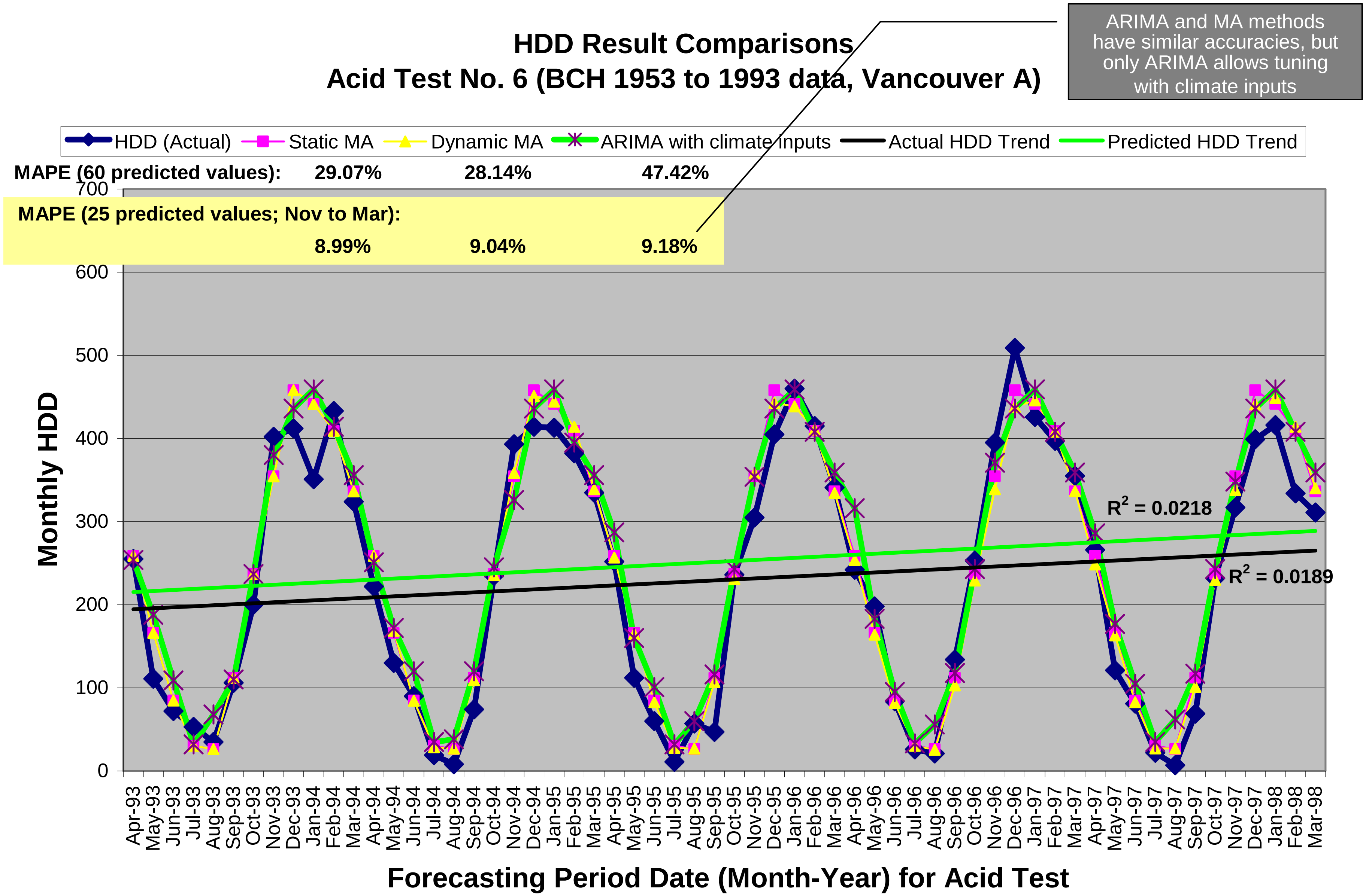
Exploration of climate influences on HDD for Vancouver (3 of 3)

This view focused on indices with “good fits” to Vancouver HDD. Climate notes (Klock and Mullock, 2001, ch. 3) highlight: (1) differences between cold and warm seasons, (2) events which increase heating needs, and (3) difficulty of making reliable predictions.



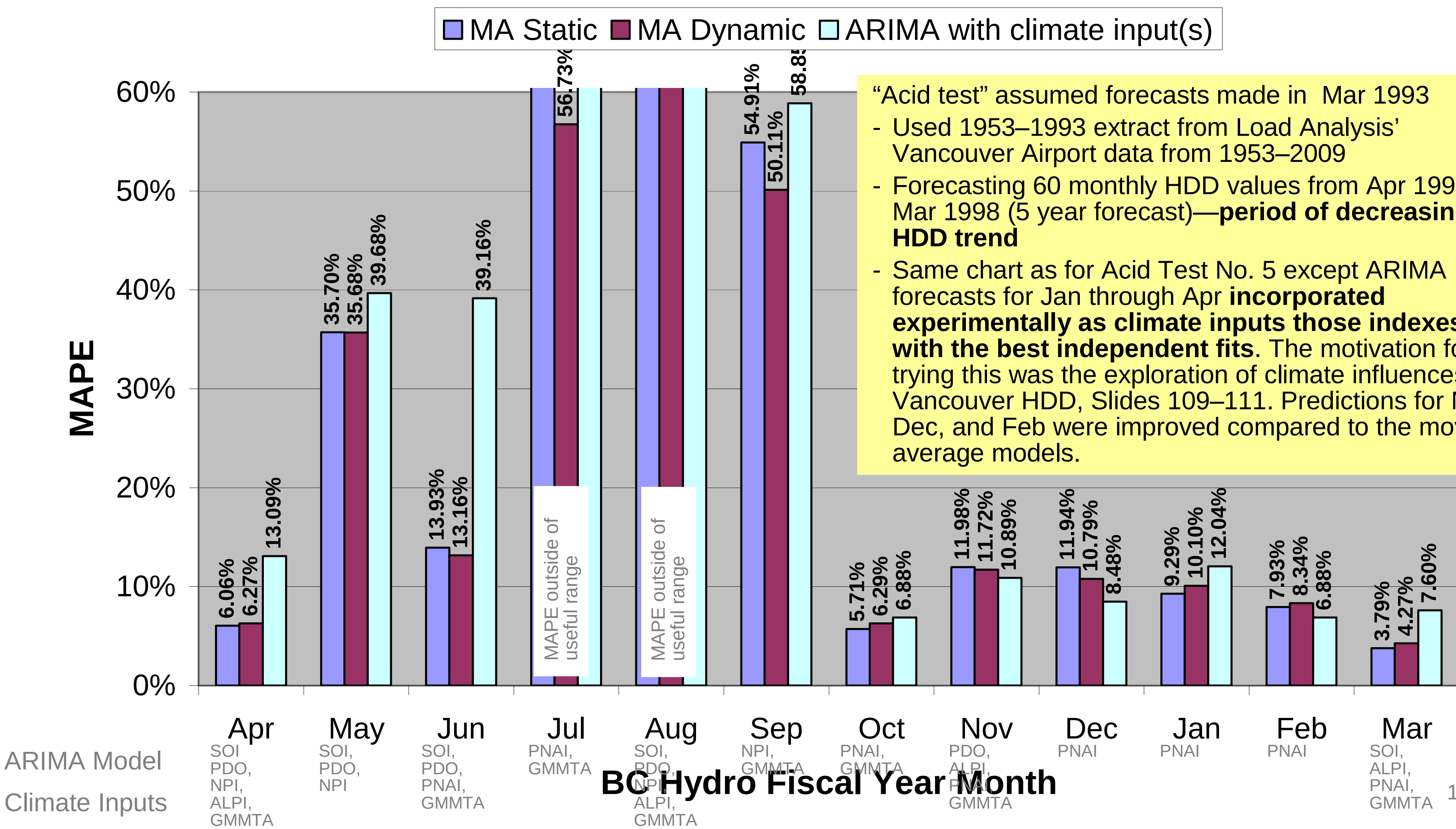
Slide 58 explains abbreviations

"Acid Test No. 6" comparing HDD forecasting methods



“Acid Test No. 6” comparing HDD forecasting methods

MAPE for HDD forecasting methods
BCH 1953 to 1993 data (Vancouver A)



“Acid test” assumed forecasts made in Mar 1993

- Used 1953–1993 extract from Load Analysis’ Vancouver Airport data from 1953–2009
- Forecasting 60 monthly HDD values from Apr 1994 to Mar 1998 (5 year forecast)—**period of decreasing HDD trend**
- Same chart as for Acid Test No. 5 except ARIMA forecasts for Jan through Apr **incorporated experimentally as climate inputs those indexes with the best independent fits**. The motivation for trying this was the exploration of climate influences on Vancouver HDD, Slides 109–111. Predictions for Nov, Dec, and Feb were improved compared to the moving average models.

Knowledge gained from “Acid Tests”

- Backcasting alone is not a sufficient test of forecasting accuracy
- Best test of forecast accuracy is an “Acid Test”, meaning to step back in time, make forecasts, and compare forecast values from alternative methods to actual values using Mean Absolute Predicted Error (MAPE)
- Acid tests should select historical data representing periods of stationarity and non-stationarity for separate tests
- Backcasting period covered periods of stationarity ***and*** non-stationarity; Therefore, this performance test for forecasting accuracy favoured the probabilistic model with climate inputs over the empirical moving average techniques
- Acid test technique is useful for testing various combinations of climate inputs and even new previously unused inputs (such as Southern Oscillation Index) to see if MAPE can be minimized. Better understanding develops of monthly regional climate influences. This experience can later be used in producing new forecasts
- Avoid forecasting HDD for Jul and Aug, Both moving average models as well as ARIMA model yield such high MAPEs that the predicted values are practically useless
- Avoid using unnecessary, extra inputs because over-fitting is likely (NIST/SEMATECH, 2009). Best results were obtained when using one or two climate inputs at a time, not all four at once.
  - Over-fitting (e.g., using all inputs all the time) increases likelihood that noise will be interpreted as the actual signal

Sensitivity

Sensitivity of model to climate inputs

39.72% with GMMTA only;
38.14% with PNAI + GMMTA
MAPE: 1.58% decrease

8.18% with PNAI + GMMTA;
6.00% with GMMTA only
MAPE: 2.18% decrease

28.47% with PNAI + GMMTA;
22.61% with PNAI only
MAPE: 5.86% decrease

6.59% with PNAI + GMMTA;
5.64% with GMMTA + SOI
MAPE: 0.95% decrease

6.21% with PNAI + GMMTA;
3.98% with GMMTA + SOI
MAPE: 2.23% decrease

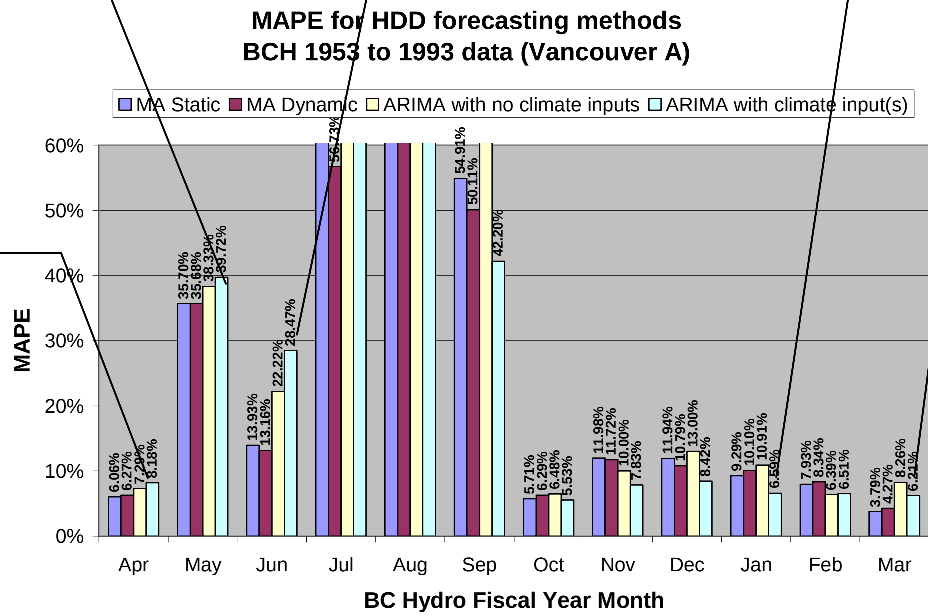


Chart from Acid Test No. 5

More questions than answers?

- Why did 1999 through 2008 Global Mean Monthly Temperature Anomaly time series from NASA GISS reveal a significant trend while the Met Office Hadley Centre's HadCRUT3 temperature record showed no trend?
- Why did bivariate analyses by month show no significant fits between (Vancouver, Victoria, and Prince George) HDDs and the Pacific North American Index during Aug and Sep when the NASA Goddard Space Flight Center Global Change Master Directory claimed that the PNA pattern is weakest in Jun/Jul?
- What is explanation for cycles, apparently unrelated to global climate processes, observed in spectra of the continental-scale climate indices?
- Why did adding SOI as a climate input decrease MAPE in Jan for Acid Test No. 6 even though bivariate analysis showed no significant correlation between HDD and SOI in Jan?

Material effect

Practical effect of degree day model choice on energy consumption and monetary value calculations

What would be the practical effect on BC Hydro Load Forecasting energy consumption calculations (for residential customers) of the choice of HDD/CDD forecasting model? The model choices were: Static Moving Average, Dynamic Moving Average, or probabilistic model with climate index inputs.

The material effect was revealed by translating changes in degree day units into changes in energy units (GWh) and corresponding changes in monetary values. One way of accomplishing the translation was by using BC Hydro Load Forecasting's Weather Normalization Methodology (explained on the next slide) which was embedded in their ResHist spreadsheet model.

A sensitivity analysis was the clearest way to show how HDD uncertainties would propagate into energy consumption and monetary value uncertainties. Dec and Jul represent the typical annual range of values for monthly HDD.

The next three slides illustrate how the ResHist spreadsheet was used for the sensitivity analyses.

Degree Day to Energy Consumption Translation within Load Forecasting's ResHist Model

Translating degree days into residential energy consumption was accomplished by BC Hydro Load Forecasting using an empirical polynomial. The explanation concluding at the bottom of this slide was by BC Hydro Load Analyst Scott Albrechtsen (personal communication).

Blended Degree Day Measurement

The weather variable used is … a "blended" Total Degree Day measurement (BTDD). This a weighted 3 month moving average summation of HDDs and CDDs where the lagged month's weather is weighted the heaviest (@50%) and the current and 2 months lagged weather are weighted also (each @25%). [Load Forecasting] uses the square (BTDD2) and cubic (BTDD3) as variables in [their] weather regressions also.

$$BTDD_t = .5 * \left[\sum (HDD_{t-1}, CDD_{t-1})\right] + .25 * \left[\sum HDD_t, CDD_t, HDD_{t-2}, CDD_{t-2}\right]$$

Weather Normalization Methodology

[Load Forecasting] does 36 month-moving monthly weather regressions during [their] monthly weather normalizations. Each month every segment consists of one regression that consists of 36 observations based on the last 3 years of billing data.

Weather Normalization Regression Structure

[Load Forecasting's] weather normalization is essentially a "weather adjustment" where[by] the weather effect is [eliminated] from the actual billed figures.

$$Actual\_kWh_t = \beta_0 + \beta_1 * BTDD_t + \beta_2 * BTDD_t^{\,2} + \beta_3 * BTDD_t^{\,3} + \varepsilon_t$$

This equation was used in the following "material effect analyses" to convert degree days to energy consumption (GWh). A unique vector of coefficients, (β_0, β_1, β_2, β_3) existed for each point-in-time (month-year) calculation related to prevailing characteristics of the grid and aggregate customer demand for (consumption of) electrical power (electrical energy).

Microsoft Excel - ResHist (modified by RVW re HDD to Energy analysis).xls

Lower Mainland Region

BCH Load Forecasting's ResHist Model Columns A to O

S328

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Lower Mainland					Non-heating					Heating			Total Residential	
2		Actual	Normal	Actual	Normal	Ending		KWh	Gross	E Plus	Ending		KWh	Gross	
3		Heat Deg	Heat Deg	Cool Deg	Cool Deg	No. of	Actual	per	No. of	No. of	No. of	Actual	per	No. of	Actual
4	Date	Days	Days	Days	Days	Accounts	Sales	acct	Accounts	Accts	Accounts	Sales	acct	Accounts	Sales
322	Aug-2007	17.7	15.4	12.3	25.7	776,760	501,590,996	646			122,976	73,949.306	602	899,736	575,540.302
323	Sep-2007	114.1	88.0	0.0	2.8	777,708	512				123,380	71,098.888	577	901,088	583,134.283
324	Oct-2007	259.9	232.9	0.0	0.0	778,675	554				123,979	95,479.903	772	902,654	649,586.134
325	Nov-2007	363.6	339.8	0.0	0.0	779,839	638				124,342	123,147.433	992	904,181	762,075.560
326	Dec-2007	457.8	418.7	0.0	0.0	780,963	709				124,516	163,388.670	1,313	905,479	873,252.304
327	Jan-2008	470.7	416.3	0.0	0.0	782,334	817							067	1,004,865.743
328	Feb-2008	362.5	363.1	0.0	0.0	783,544	798							390	998,019.102
329	Mar-2008	375.2	375.2	0.0	0.0	784,817	734							451	902,147.920
330	Apr-2008	313.2	313.2	0.0	0.0	785,468	690							435	847,476.097
331	May-2008	160.8	160.8	3.5	0.5	786,114	624							293	746,259.402
332	Jun-2008	116.0	116.0	8.3	8.2	786,869	544,580.774	692						003	642,925.544
333	Jul-2008	19.5	45.0	12.8	30.5	788,279	520,714.741	661						060	598,521.680
334	Aug-2008	35.2	35.2	28.3	22.9	789,577	503,243.702	638			128,767	75,657.592	590	918,344	578,901.294
335	Sep-2008	103.3	103.3	0.0	2.6	790,536	518,969.259	657			129,270	75,984.914	589	919,806	594,954.173
336	Oct-2008	247.7	247.7	0.0	0.0	791,671	542,859.139	686			130,486				516
337	Nov-2008	296.4	296.4	0.0	0.0	793,095	624,614.279	788			131,192				52
338	Dec-2008	529.6	529.6	0.0	0.0	794,240	692,676.825	873			131,658				737
339	Jan-2009	491.5	491.5	0.0	0.0	794,825	842,687.050	1,061			133,120				10
340	Feb-2009	393.2	393.2	0.0	0.0	797,586	839,370.568	1,054			134,924				392
341	Mar-2009	406.0	406.0	0.0	0.0	797,691	754,972.260	947			135,980	177,815.658	1,313	933,671	932,787.918
342	Apr-2009		262.8		0.0										
343	May-2009		166.7		0.9										
344	Jun-2009		77.4		8.6										
345	Jul-2009		21.2		26.3										
346	Aug-2009		19.3		21.7										
347	Sep-2009		96.4		1.3										
348	Oct-2009		238.1		0.0										
349	Nov-2009		343.7		0.0										
350	Dec-2009		432.2		0.0										
351	Jan-2010		430.4		0.0										
352	Feb-2010		373.2		0.0										
353	Mar-2010		351.8		0.0										
354															
355	Total 2008														
356	Energy	Non-heat	7,709,623	MWh	7,709,623										
357		Heat	1,560,759	MWh	1,560,759										
358		Total	9,270,382	MWh	9,270,382	Check 0:	0								

	C	D	E	F
3	3,001.04			
3	2,994.28			
3	2,975.40			
3	2,944.14	5,299.45	39.40	70.92
3	2,924.79	5,264.62	38.84	69.91
3	2,909.40	5,236.92	37.51	67.52
3	2,920.36	5,256.65	45.09	81.16
3	2,884.97	5,192.95	43.82	78.88

"Normal" (Running Mean) HDD are set same as Actual except for one monthly value during F0809

For BC Hydro, approx. monetary value of one GWh is $60,000

"2008" meant BCH F0809

Results for Energy, Energy Absolute Predicted Error, GWh difference, and Monetary value difference

Experiment: Jul HDD changed from 19.5 to 45.0; all else held constant

Experiment table Dec HDD	APE for HDD	Total 2008 Energy	Energy (GWh)	APE for Energy	GWh difference	Money value difference in millions		
529.6		9,259,029	9,259					
450	15.03%	9,142,249	9,142	1.26%	117	7.0	Gwh =	$60,000
470	11.25%	9,171,562	9,172	0.94%	87	5.2		
490	7.48%	9,200,911	9,201	0.63%	58	3.5		
510	3.70%	9,230,270	9,230	0.31%	29	1.7		
530	0.08%	9,259,616	9,260	0.01%	-1	0.0		
550	3.85%	9,288,924	9,289	0.32%	-30	-1.8		
570	7.63%	9,318,170	9,318	0.64%	-59	-3.5		
590	11.40%	9,347,330	9,347	0.95%	-88	-5.3		
610	15.18%	9,376,380	9,376	1.27%	-117	-7.0		

Experiment table Jul HDD		Total 2008 Energy				
19.5		9,259,029	9,259			
5	74.36%	9,253,205	9,253	0.06%	6	0.3
10	48.72%	9,255,161	9,255	0.04%	4	0.2
15	23.08%	9,257,172	9,257	0.02%	2	0.1
20	2.56%	9,259,238	9,259	0.00%	0	0.0
25	28.21%	9,261,359	9,261	0.03%	-2	-0.1
30	53.85%	9,263,534	9,264	0.05%	-5	-0.3
35	79.49%	9,265,763	9,266	0.07%	-7	-0.4
40	105.13%	9,268,046	9,268	0.10%	-9	-0.5
45	130.77%	9,270,382	9,270	0.12%	-11	-0.7

This is total energy consumption value resulting from Jul HDD change

The value 9,270,382 was copied to Experiment table

Chart4-Energy vs Dec HDD MAPE / Chart5-Energy vs Jul HDD MAPE / Chart6-Money vs Dec HDD MAPE / Chart7-Money vs Jul HDD MAPE / LwrMl / North

Microsoft Excel - ResHist (modified by RVW re HDD to Energy analysis).xls

Lower Mainland Region

BCH Load Forecasting's ResHist Model Columns CW to DL

Billed Energy Consumption Units are MWh

This is F0809 total billed energy consumption resulting from changing Jul HDD from 19.5 to 45

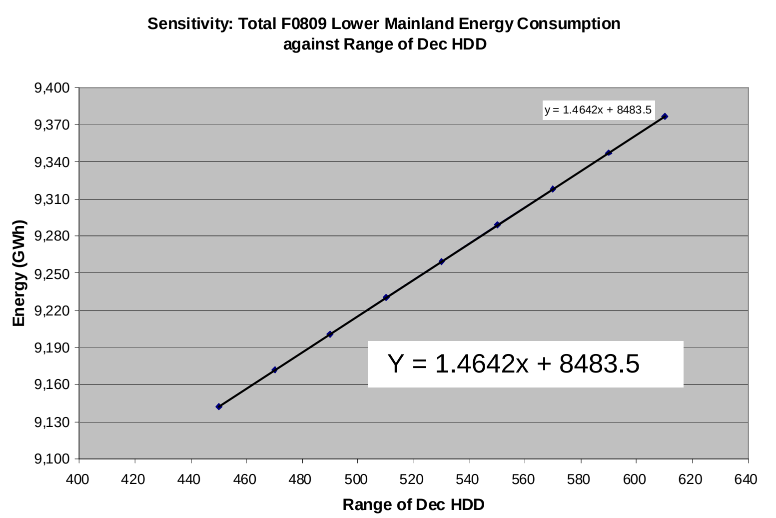
DG370 =SUM(DG358:DG369)

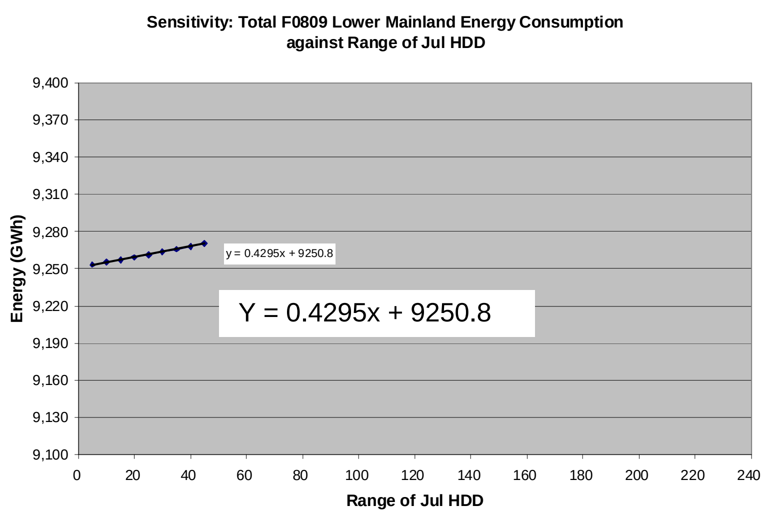
	A	DA	DB	DC	DD	DE	DF	DG	DH	DI	DJ	DK	DL	DM
1	Lower Mainla	Total												
2		Lower Mainland				Monthly								
3			Actual	Normal	Ending	Actual		Normalised		Difference			Actual	
4	Date		Heat Deg	Heat Deg	No. of	Billed	Use	Billed	Use	Billed	Use		Billed	Use
321	Jul-2007	Jun-2005	75.1	70.9	863,890	581,934	674	601,548	697	19,614	23	3.3%	8,383,813	9,802
322	Aug-2007	Jul-2005	16.1	22.7	864,683	588,209	681	593,335	687	5,126	6	0.9%	8,429,341	9,839
323	Sep-2007	Aug-2005	5.0	20.1	866,379	566,288	654	567,741	656	1,453	2	0.3%	8,456,008	9,855
324	Oct-2007	Sep-2005	100.1	86.5	867,911	571,196	659	571,378	659	182	0	0.0%	8,452,312	9,835
325	Nov-2007	Oct-2005	207.9	236.8	870,093	614,998	708	618,531	712	3,532	4	0.6%	8,459,805	9,827
326	Dec-2007	Nov-2005	370.6	334.9	871,850	731,321	840	731,570	840	249	0	0.0%	8,483,238	9,837
327	Jan-2008	Dec-2005	415.3	427.8	873,118	875,355	1,003	863,829	990	-11,526	-13	-1.3%	8,517,983	9,861
328	Feb-2008	Jan-2006	362.6	424.2	874,762	958,570	1,097	988,242	1,131	29,673	34	3.0%	8,518,751	9,844
329	Mar-2008	Feb-2006	384.2	366.9	875,527	898,110	1,026	933,480	1,067	35,369	40	3.8%	8,548,296	9,861
330	Apr-2008	Mar-2006	355.1	343.6	876,018	840,544	960	836,041	955	-4,503	-5	-0.5%	8,637,212	9,948
331	May-2008													
332	Jun-2008	Apr-2006	260.7	253.1	877,895	803,466	916	789,315	900	-14,152	-16	-1.8%	8,687,433	9,989
333	Jul-2008	May-2006	156.6	164.3	879,410	685,123	780	680,993	775	-4,131	-5	-0.6%	8,715,116	10,005
334	Aug-2008	Jun-2006	49.9	72.7	880,469	614,189	698	620,733	705	6,544	7	1.1%	8,747,371	10,026
335	Sep-2008	Jul-2006	16.0	23.1	881,312	584,900	664	588,720	668	3,821	4	0.6%	8,744,062	10,006
336	Oct-2008	Aug-2006	21.3	15.3	883,879	567,787	643	569,130	645	1,343	2	0.2%	8,745,560	9,992
337	Nov-2008	Sep-2006	84.1	92.3	885,526	581,563	657	584,253	660	2,690	3	0.5%	8,755,927	9,987
338	Dec-2008	Oct-2006	246.8	234.1	886,391	612,033	691	613,531	693	1,497	2	0.2%	8,752,962	9,967
339	Jan-2009	Nov-2006	368.1	342.0	887,167	733,900	828	716,634	808	-17,267	-19	-2.4%	8,755,541	9,955
340	Feb-2009	Dec-2006	419.4	428.1	888,239	867,558	977	850,956	959	-16,602	-19	-2.0%	8,747,744	9,932
341	Mar-2009	Jan-2007	464.8	413.6	889,850	992,147	1,116	963,064	1,083	-29,083	-33	-3.0%	8,781,322	9,956
342	Apr-2009	Feb-2007	340.1	365.6	891,393	964,537	1,083	940,031	1,055	-24,506	-28	-2.6%	8,847,748	10,017
343	May-2009	Mar-2007	329.8	344.3	893,849	871,341	976	886,922	994	15,580	17	1.8%	8,878,545	10,036
344	Jun-2009													
345	Jul-2009	Apr-2007	271.2	256.5	895,852	832,015	930	840,197	939	8,182	9	1.0%	8,907,094	10,051
346	Aug-2009	May-2007	165.2	160.6	897,261	720,949	804	713,478	796	-7,471	-8	-1.0%	8,942,920	10,074
347	Sep-2009	Jun-2007	88.4	69.1	898,071	631,467	703	624,133	695	-7,334	-8	-1.2%	8,960,198	10,077
348	Oct-2009	Jul-2007	7.4	22.1	899,145	588,848	655	586,638	653	-2,209	-2	-0.4%	8,964,146	10,065
349	Nov-2009	Aug-2007	17.7	15.4	899,736	575,540	640	577,396	642	1,855	2	0.3%	8,971,899	10,058
350	Dec-2009	Sep-2007	114.1	88.0	901,088	583,134	648	582,682	647	-452	-1	-0.1%	8,973,471	10,045
351	Jan-2010	Oct-2007	259.9	232.9	902,654	649,586	720	635,301	704	-14,286	-16	-2.2%	9,011,024	10,072
352	Feb-2010	Nov-2007	363.6	339.8	904,181	762,076	844	731,400	810	-30,675	-34	-4.2%	9,039,199	10,088
353	Mar-2010	Dec-2007	457.8	418.7	905,479	873,252	965	825,455	912	-47,797	-53	-5.8%	9,044,893	10,078
354		Jan-2008	470.7	416.3	907,067	1,004,866	1,109	938,037	1,035	-66,829	-74	-7.1%	9,057,612	10,076
355	**Total 2008**	Feb-2008	362.5	363.1	908,890	998,019	1,099	943,611	1,039	-54,409	-60	-5.8%	9,091,094	10,097
356	**Energy**	Mar-2008	375.2	375.2	910,451	902,148	992	890,257	979	-11,891	-13	-1.3%	9,121,901	10,115
357														
358		Apr-2008	313.2	313.2	911,435	847,476	930	847,612	930	136	0	0.0%	9,137,362	10,117
359		May-2008	160.8	160.8	912,293	746,259	818	744,968	817	-1,291	-1	-0.2%	9,162,672	10,131
360		Jun-2008	116.0	116.0	914,003	642,926	704	641,642	703	-1,284	-1	-0.2%	9,174,130	10,129
361		Jul-2008	19.5	45.0	916,060	598,522	654	606,287	663	7,765	8	1.3%	9,183,804	10,125
362		Aug-2008	35.2	35.2	918,344	578,901	631	586,005	639	7,103	8	1.2%	9,187,165	10,112
363		Sep-2008	103.3	103.3	919,806	594,954	647	596,945	650	1,991	2	0.3%	9,198,985	10,108
364		Oct-2008	247.7	247.7	922,157	635,118	690	635,499	690	381	0	0.1%	9,184,516	10,074
365	1985/86	Nov-2008	296.4	296.4	924,287	740,800	802	741,270	803	470	1	0.1%	9,163,241	10,033
366	1986/87	Dec-2008	529.6	529.6	925,898	847,549	916	847,549	916	0	0	0.0%	9,137,537	9,986
367	1987/88	Jan-2009	491.5	491.5	927,945	1,038,343	1,120	1,038,343	1,120	0	0	0.0%	9,171,015	10,004
368	1988/89	Feb-2009	393.2	393.2	932,510	1,051,476	1,130	1,051,476	1,130	0	0	0.0%	9,224,471	10,042
369	1989/90	Mar-2009	406.0	406.0	933,671	932,788	1,000	932,788	1,000	0	0	0.0%	9,255,111	10,054
370	1990/91					Total		9,270,382						
371	1991/92													

Chart6-Money vs Dec HDD MAPE / Chart7-Money vs Jul HDD MAPE / LwrMl / North / South / VanIs / Total / AcctGrowth / Regression Worksheet

Ready

Results of sensitivity analyses (1 of 4)

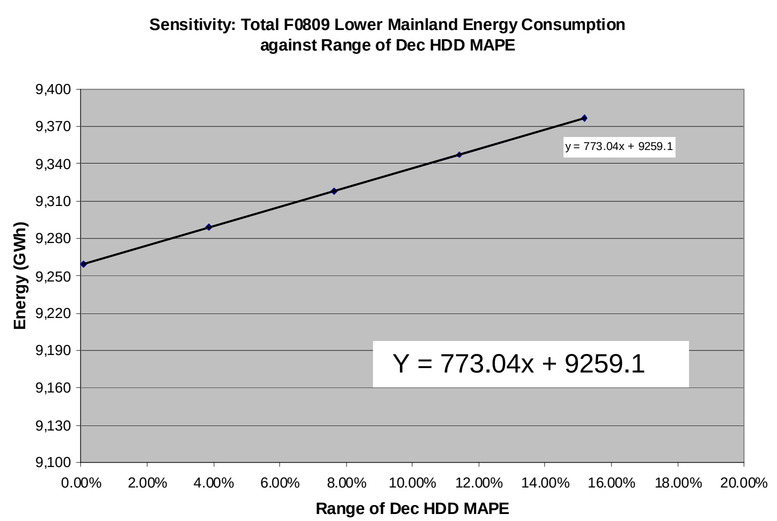


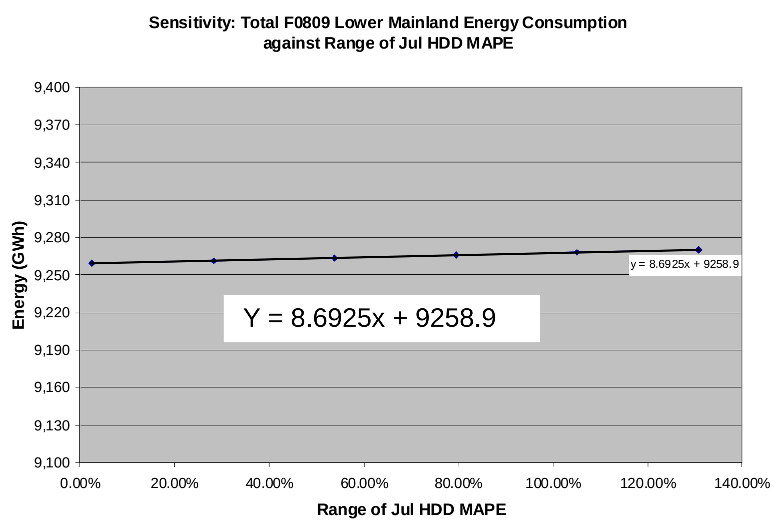


Sensitivity of Energy Consumption to HDD was (1.46/0.430) = 3.4 times greater in Dec 2008 than in Jul 2008

Material effect

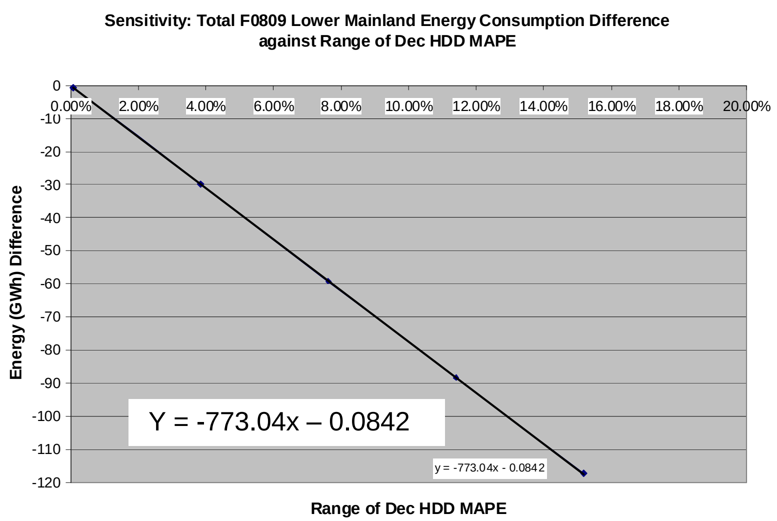
Results of sensitivity analyses (2 of 4)

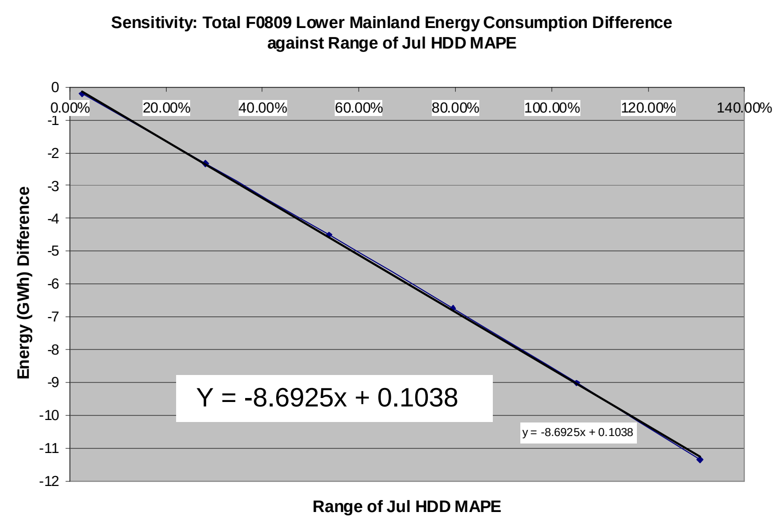




Sensitivity of Energy Consumption to HDD MAPE was (773/8.69) = 89 times greater in Dec than in Jul (2008)

Results of sensitivity analyses (3 of 4)

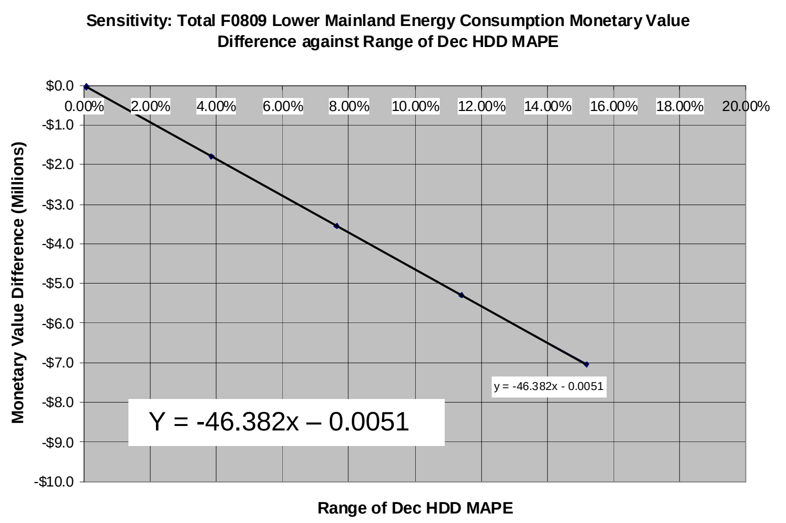


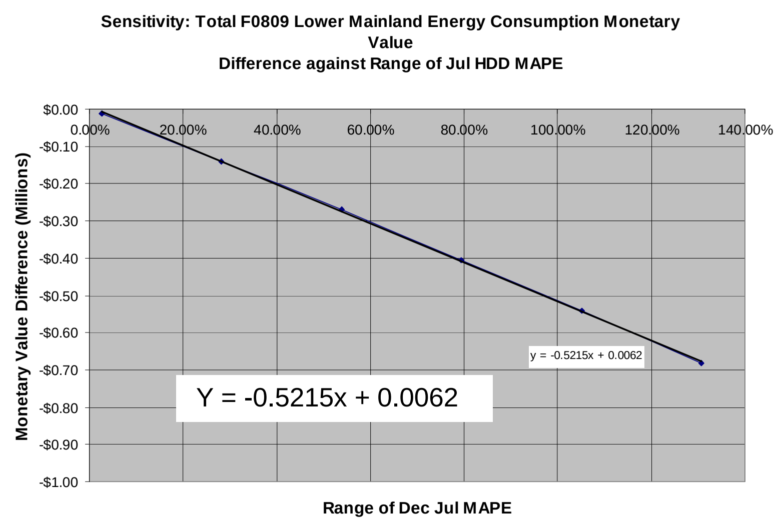


Sensitivity of Energy Consumption Difference to HDD MAPE was (773/8.69) = 89 times greater in Dec 2008 than in Jul 2008

BC hydro FOR GENERATIONS

Results of sensitivity analyses (4 of 4)





Sensitivity of Energy Consumption Monetary Value Difference to HDD MAPE was (46.4/0.522) = 89 times greater in Dec than in Jul 2008

BC hydro FOR GENERATIONS

Summary of sensitivity analyses

- The sensitivity analyses apply to any HDD forecasting method
- Uncertainties and errors have a much greater effect on energy consumption and monetary value estimates in Dec than in Jul
  - Sensitivity of Energy Consumption to HDD was 3.4 times greater in Dec than in Jul (2008)
  - Sensitivity of Energy Consumption to HDD MAPE was 89 times greater in Dec than in Jul (2008)
  - Sensitivity of Energy Consumption Difference to HDD MAPE was 89 times greater in Dec than in Jul
  - Sensitivity of Energy Consumption Monetary Value Difference to HDD MAPE was 89 times greater in Dec than in Jul (2008)
  - Other months would have lower sensitivities compared to the Dec/Jul relationship
- Examples of the effect of forecasting errors:
  - An error of 11 HDD in Dec 2008 created an annual energy consumption error of 16 GWh worth about $1 million
  - An error of 11 HDD in Jul 2008 created an annual energy consumption error of 4.7 GWh worth about $294,000
- Examples of the effect of forecasting improvements:
  - An improvement of Dec 2008 HDD MAPE of 2.1% corresponded to an annual energy consumption difference of 16 GWh worth about $1 million
  - An improvement of Jul 2008 HDD MAPE of 2.1% corresponded to an annual energy consumption difference of 0.18 GWh worth about $11,000
- Return of investment in Degree Day forecasting research can be maximized by focusing on improving HDD forecasts for heating season months—the new probabilistic model could improve Dec HDD by 2% to 3% (see table, Slide 107)—annual improvements worth at least $1 million in monetary value

Material effect

Compare material effect of degree-day forecasting errors for a period of decreasing monthly HDD and another of stable monthly HDD

Method

•Considered the periods Apr 1993–Mar 1998 (decreasing monthly HDD, Slide 11) and Apr 2001–Mar 2006 (stable monthly HDD, Slide 11)

•Material effects that count for BC Hydro include errors in predicting energy consumption and associated monetary value (16 GWh ≈ $1 million)

•Load Forecasting's ResHist model contained values for the coefficients, (β_0, β_1, β_2, β_3), used in the HDD to energy consumption conversion equation (Slide 118)

$$Actual\_kWh_t = \beta_0 + \beta_1 * BTDD_t + \beta_2 * BTDD_t^{\ 2} + \beta_3 * BTDD_t^{\ 3} + \varepsilon_t$$

•Because the coefficients were unique to each point-in-time (month-year), substitution of HDD and CDD into the ResHist model (Slides 119–120) was made only at the 60 points-in-time corresponding to Apr 1993–Mar 1998 and Apr 2001–Mar 2006. Only this one change affecting the "Normal Heat Deg Days" and "Normal Cool Deg Days" pair of columns was made to the ResHist model

•Results were collected in a Model Comparison Table (Slide 127) and charts (Slides 128 to 137) were produced

Results

•The charts revealed opportunities for tuning ARIMA performance. In contrast, Moving Average models cannot be tuned

•The charts show that the ARIMA model can outperform moving average models during periods of HDD non-stationarity

Microsoft Excel - ResHist (modified by RVW re HDD to Energy analysis).xls

Model Comparison Table

Non-stationary case

one GWh = $60,000

Apr 1993 to March 1998

Date (Month-Year)	Actual HDD	Actual CDD	Actual Energy Consumption (MWh)	Actual Energy Consumption (GWh)	Static MA Predicted HDD	Static MA Predicted CDD	Static MA Predicted Energy Consumption (MWh)	Static MA Predicted Energy Consumption (GWh)	Static MA Predicted Diff Energy Consumption (GWh)	Static MA Predicted Diff Monetary Value	Dynamic MA Predicted HDD	Dynamic MA Predicted CDD	Dynamic MA Predicted Energy Consumption (MWh)	Dynamic MA Predicted Energy Consumption (GWh)	Dynamic MA Predicted Diff Energy Consumption (GWh)
Apr-1993	255	0	584,688	585	259	0	585,618	586	-1	-$55,826	259	0	585,618	586	-1
May-1993	111	1	539,048	539	166	1	552,944	553	-14	-$833,780	166	1	552,944	553	-14
Jun-1993	72	1	452,603	453	85	5	472,905	473	-20	-$1,218,101	85	5	472,905	473	-20
Jul-1993	53	0	414,149	414	30	18	421,296	421	-7	-$428,805	30	18	421,296	421	-7
Aug-1993	35	19	400,550	401	26	17	400,439	400	0	$6,656	26	17	400,439	400	0
Sep-1993	106	5	402,020	402	112	2	400,744	401	1	$76,591	112	2	400,744	401	1
Oct-1993	200	0	427,436	427	237	0	431,756	432	-4	-$259,228	237	0	431,756	432	-4
Nov-1993	402	0	512,275	512	355	0	518,938	519	-7	-$399,758	355	0	518,938	519	-7
Dec-1993	412	0	594,874	595	458	0	591,947	592	3	$175,623	458	0	591,947	592	3
Jan-1994	351	0	720,925	721	442	0	757,474	757	-37	-$2,192,936	442	0	757,474	757	-37
Feb-1994	433	0	705,012	705	409	0	756,527	757	-52	-$3,090,881	409	0	756,527	757	-52
Mar-1994	324	0	665,540	666	336	0	679,957	680	-14	-$864,968	336	0	679,957	680	-14
Apr-1994	222	0	592,109	592	259	0	601,894	602	-10	-$587,092	259	0	601,939	602	-10
May-1994	130	0	509,304	509	166	1	537,548	538	-28	-$1,694,676	169	0	538,168	538	-29
Jun-1994	90	1	429,351	429	85	5	447,521	448	-18	-$1,090,205	85	6	448,452	448	-19
Jul-1994	19	35	428,434	428	30	18	431,198	431	-3	-$165,833	29	20	431,487	431	-3
Aug-1994	8	25	418,752	419	26	17	418,737	419	0	$927	27	18	418,797	419	0
Sep-1994	74	0	413,756	414	112	2	415,773	416	-2	-$120,996	109	2	415,785	416	-2
Oct-1994	235	0	421,996	422	237	0	433,254	433	-11	-$675,449	235	0	432,475	432	-10
Nov-1994	393	0	565,584	566	355	0	566,992	567	-1	-$84,454	359	0	566,393	566	-1
Dec-1994	414	0	669,290	669	458	0	661,353	661	8	$476,211	451	0	661,104	661	8
Jan-1995	413	0	784,052	784	442	0	804,518	805	-20	-$1,227,972	444	0	802,620	803	-19
Feb-1995	382	0	707,316	707	409	0	741,356	741	-34	-$2,042,390	414	0	742,207	742	-35
Mar-1995	335	0	664,922	665	336	0	687,190	687	-22	-$1,336,065	339	0	691,119	691	-26
Apr-1995	252	0	588,152	588	259	0	597,602	598	-9	-$567,000	257	0	599,746	600	-12
May-1995	112	0	528,480	528	166	1	544,706	545	-16	-$973,596	165	0	544,055	544	-16
Jun-1995	60	18	458,368	458	85	5	480,616	481	-22	-$1,334,895	83	6	479,475	479	-21
Jul-1995	11	22	438,423	438	30	18	448,510	449	-10	-$605,248	28	20	447,983	448	-10
Aug-1995	57	5	432,070	432	26	17	433,634	434	-2	-$93,810	27	19	433,626	434	-2
Sep-1995	47	0	441,205	441	112	2	443,880	444	-3	-$160,510	107	2	443,825	444	-3
Oct-1995	236	0	482,655	483	237	0	497,631	498	-15	-$898,525	231	0	495,661	496	-13
Nov-1995	305	0	564,099	564	355	0	590,099	590	-26	-$1,559,947	358	0	586,877	587	-23
Dec-1995	405	0	661,551	662	458	0	702,255	702	-41	-$2,442,288	443	0	698,384	698	-37
Jan-1996	460	0	716,331	716	442	0	752,817	753	-36	-$2,189,192	438	0	745,012	745	-29
Feb-1996	415	0	764,108	764	409	0	767,432	767	-3	-$199,432	411	0	761,111	761	3
Mar-1996	341	0	722,165	722	336	0	709,741	710	12	$745,422	334	0	709,018	709	13
Apr-1996	242	0	627,637	628	259	0	628,045	628	0	-$24,480	254	0	625,920	626	2
May-1996	198	0	607,949	608	166	1	607,336	607	1	$36,786	164	0	604,196	604	4
Jun-1996	84	1	481,818	482	85	5	474,509	475	7	$438,512	82	7	472,593	473	9
Jul-1996	26	30	469,288	469	30	18	465,373	465	4	$234,865	30	17	464,587	465	5

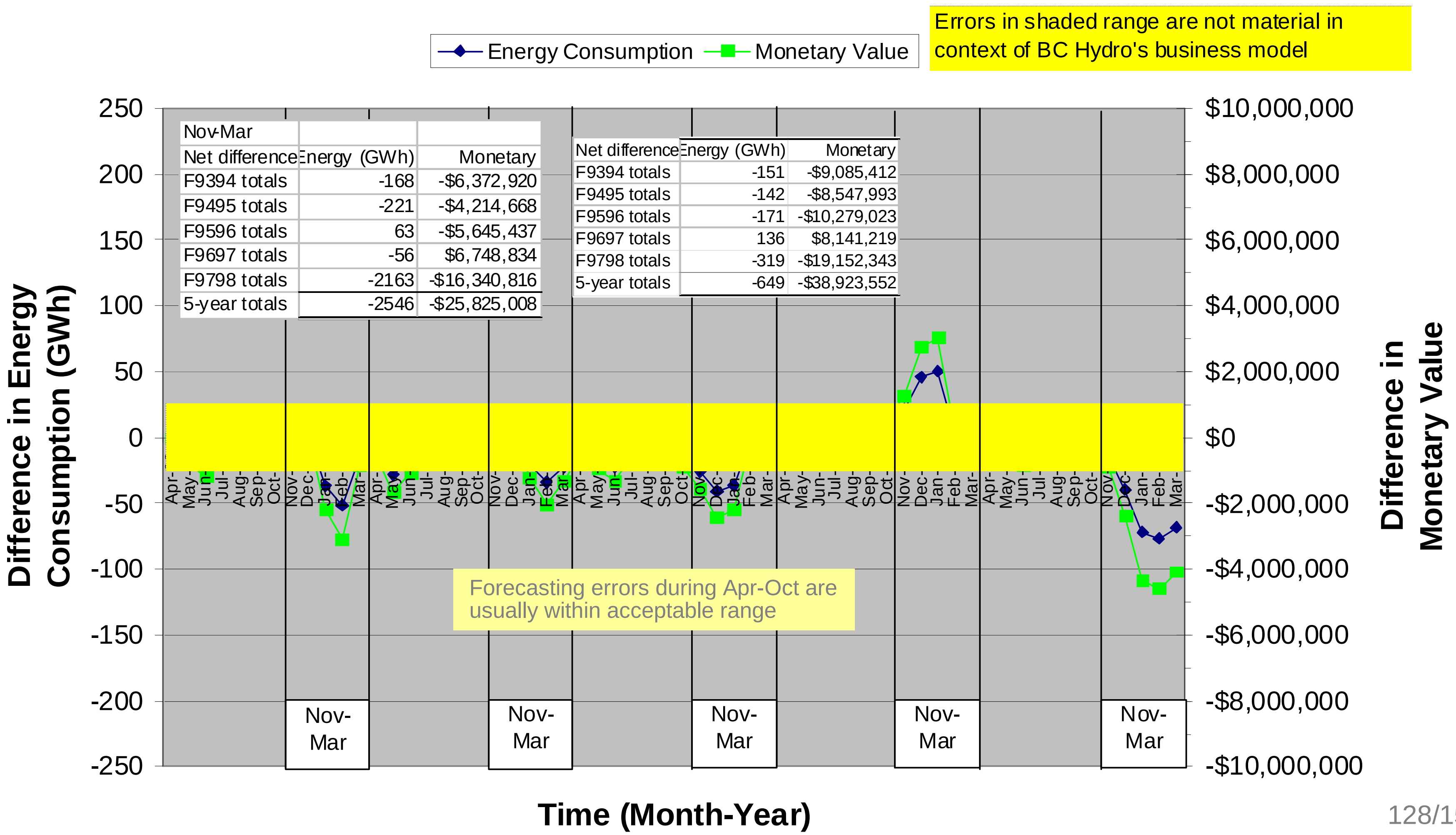
Model Cf Table 93-98 | Ch-Static MA E and $ time 01-06 | Ch-Dyn MA E and $ time 01-06 | Ch-ARIMA E a

Ready

Material effect

Decreasing HDD:
Static Moving Average Model
cannot be tuned to increase accuracy.
“What you see is what you get”.

Static Moving Average Forecasting Method: Differences in Total Res. Energy Consumption & Monetary Value during Apr 93 - Mar 98 DD forecast period (Lower Mainland)



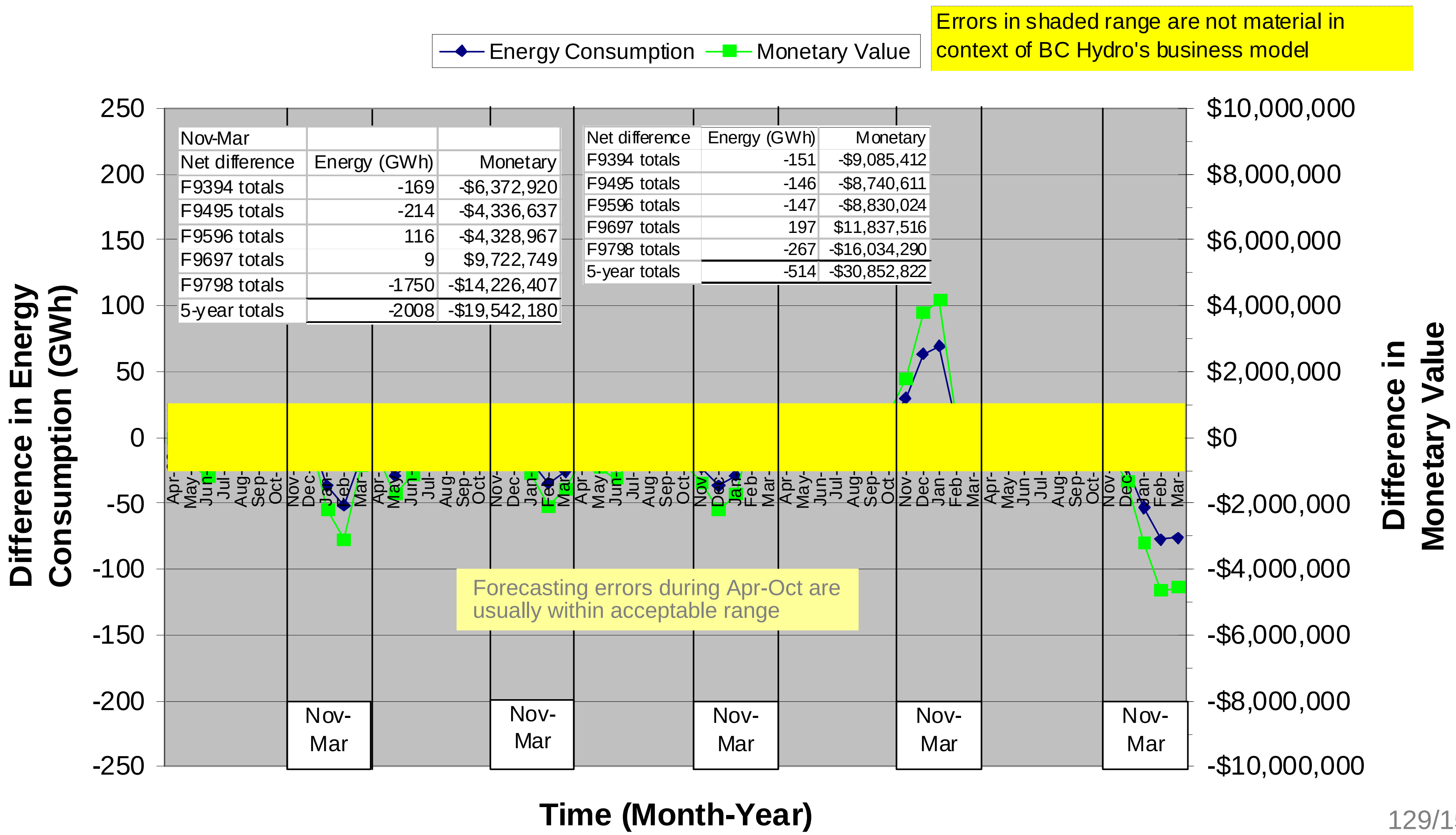
Nov-Mar		
Net difference	Energy (GWh)	Monetary
F9394 totals	-168	-$6,372,920
F9495 totals	-221	-$4,214,668
F9596 totals	63	-$5,645,437
F9697 totals	-56	$6,748,834
F9798 totals	-2163	-$16,340,816
5-year totals	-2546	-$25,825,008

Net difference	Energy (GWh)	Monetary
F9394 totals	-151	-$9,085,412
F9495 totals	-142	-$8,547,993
F9596 totals	-171	-$10,279,023
F9697 totals	136	$8,141,219
F9798 totals	-319	-$19,152,343
5-year totals	-649	-$38,923,552

Material effect

Decreasing HDD:
Dynamic Moving Average Model
cannot be tuned to increase accuracy.
“What you see is what you get”.

Dynamic Moving Average Forecasting Method:
Differences in Total Res. Energy Consumption & Monetary Value
during Apr 93 - Mar 98 DD forecast period (Lower Mainland)



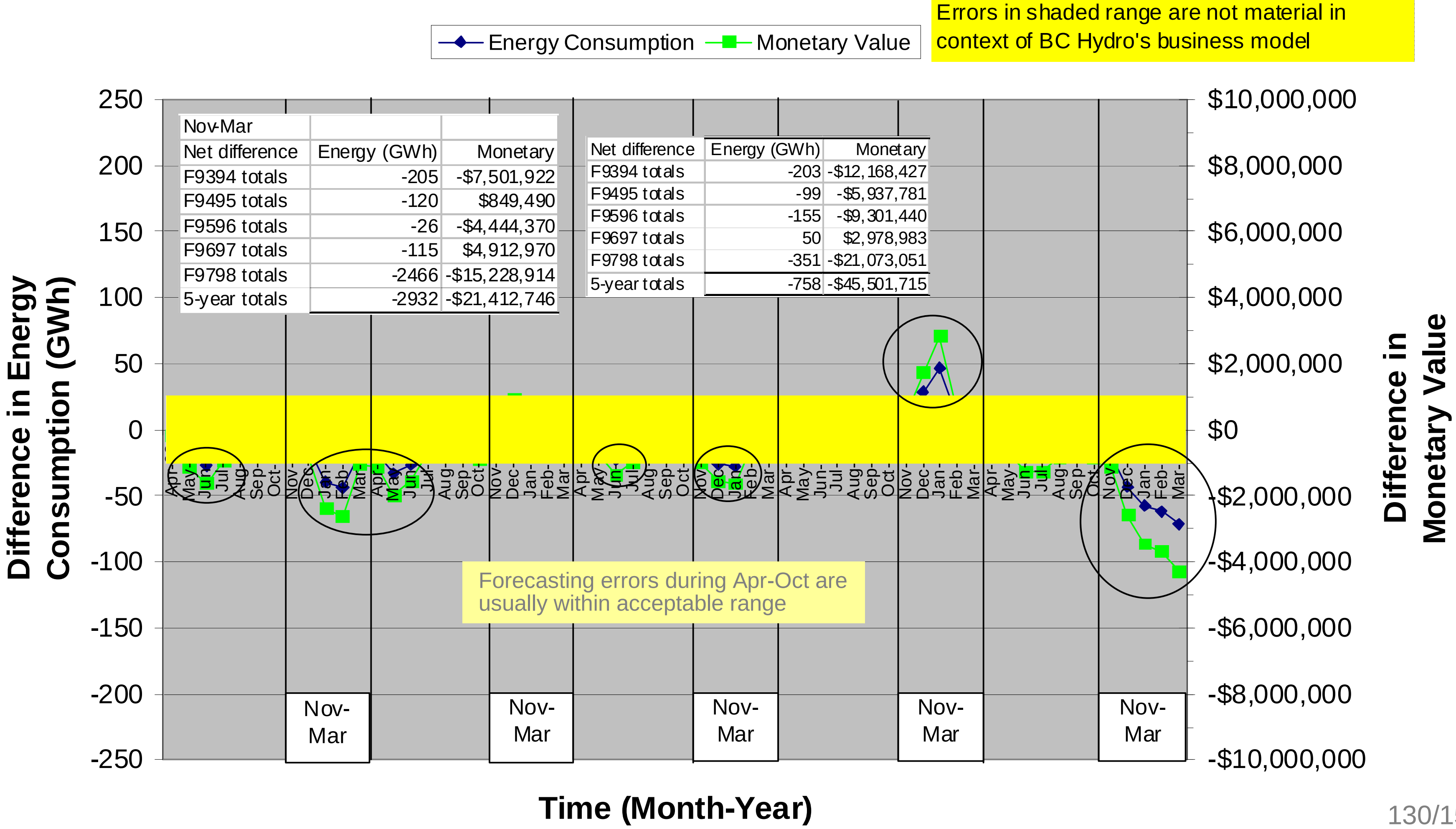
Nov-Mar		
Net difference	Energy (GWh)	Monetary
F9394 totals	-169	-$6,372,920
F9495 totals	-214	-$4,336,637
F9596 totals	116	-$4,328,967
F9697 totals	9	$9,722,749
F9798 totals	-1750	-$14,226,407
5-year totals	-2008	-$19,542,180

Net difference	Energy (GWh)	Monetary
F9394 totals	-151	-$9,085,412
F9495 totals	-146	-$8,740,611
F9596 totals	-147	-$8,830,024
F9697 totals	197	$11,837,516
F9798 totals	-267	-$16,034,290
5-year totals	-514	-$30,852,822

Material effect

Decreasing HDD:
Opportunities for tuning ARIMA model are circled. Tuning is done by improving understanding of how climate index inputs should be applied.

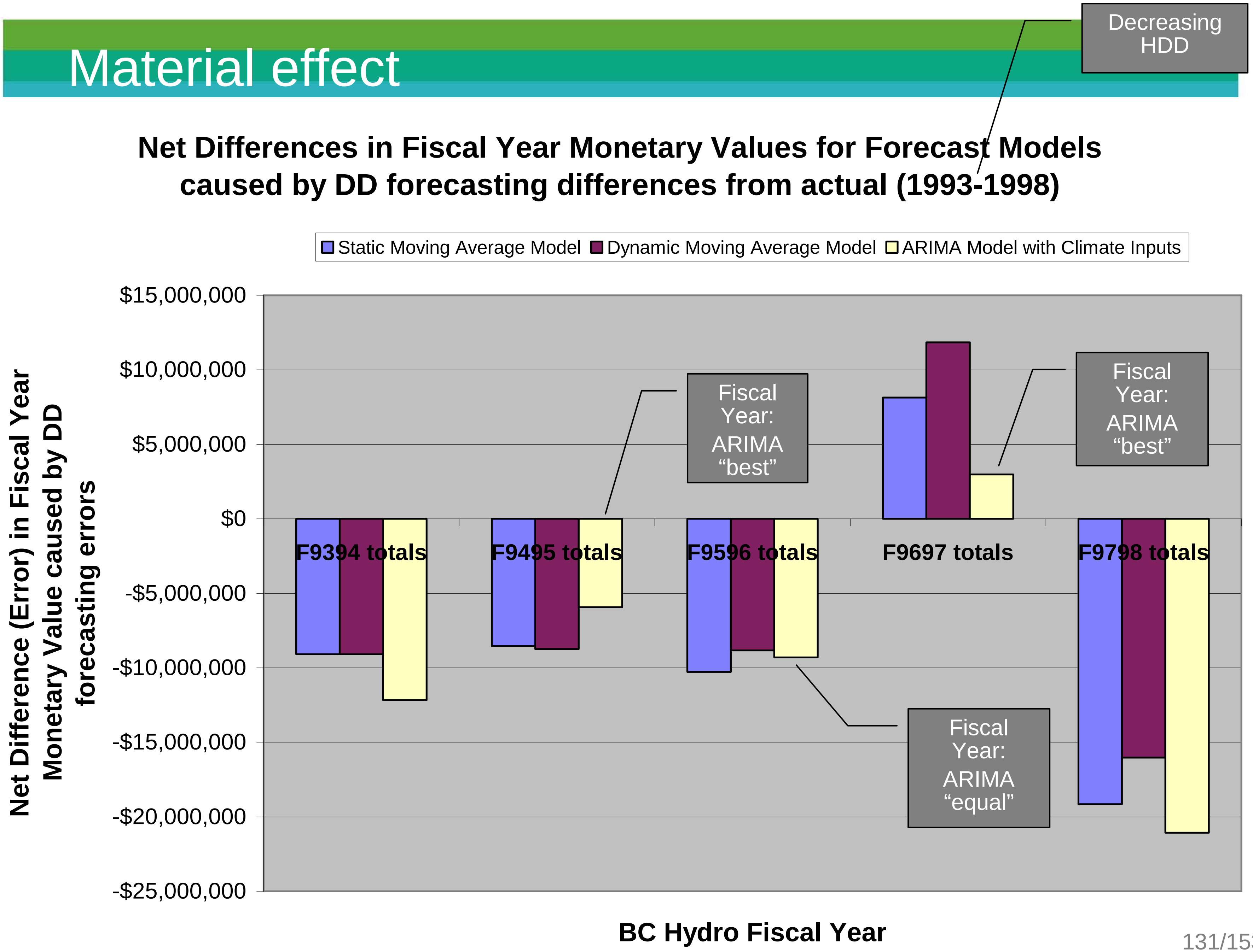
ARIMA Probabilistic Forecasting Method with Climate Index Inputs: Differences in Total Res. Energy Consumption & Monetary Value during Apr 93 - Mar 98 DD forecast period (Lower Mainland)



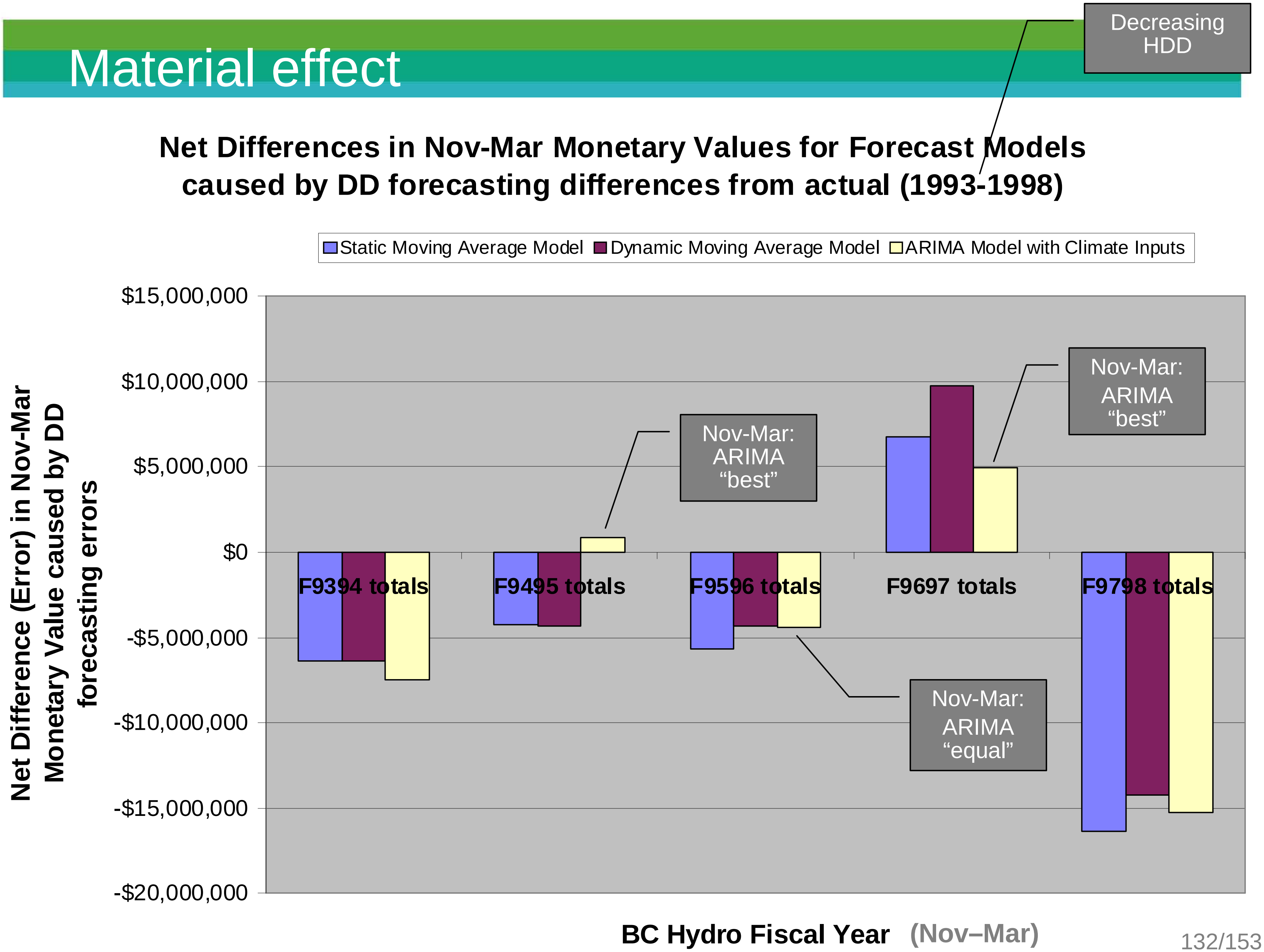
Nov-Mar		
Net difference	Energy (GWh)	Monetary
F9394 totals	-205	-$7,501,922
F9495 totals	-120	$849,490
F9596 totals	-26	-$4,444,370
F9697 totals	-115	$4,912,970
F9798 totals	-2466	-$15,228,914
5-year totals	-2932	-$21,412,746

Net difference	Energy (GWh)	Monetary
F9394 totals	-203	-$12,168,427
F9495 totals	-99	-$5,937,781
F9596 totals	-155	-$9,301,440
F9697 totals	50	$2,978,983
F9798 totals	-351	-$21,073,051
5-year totals	-758	-$45,501,715

Material effect



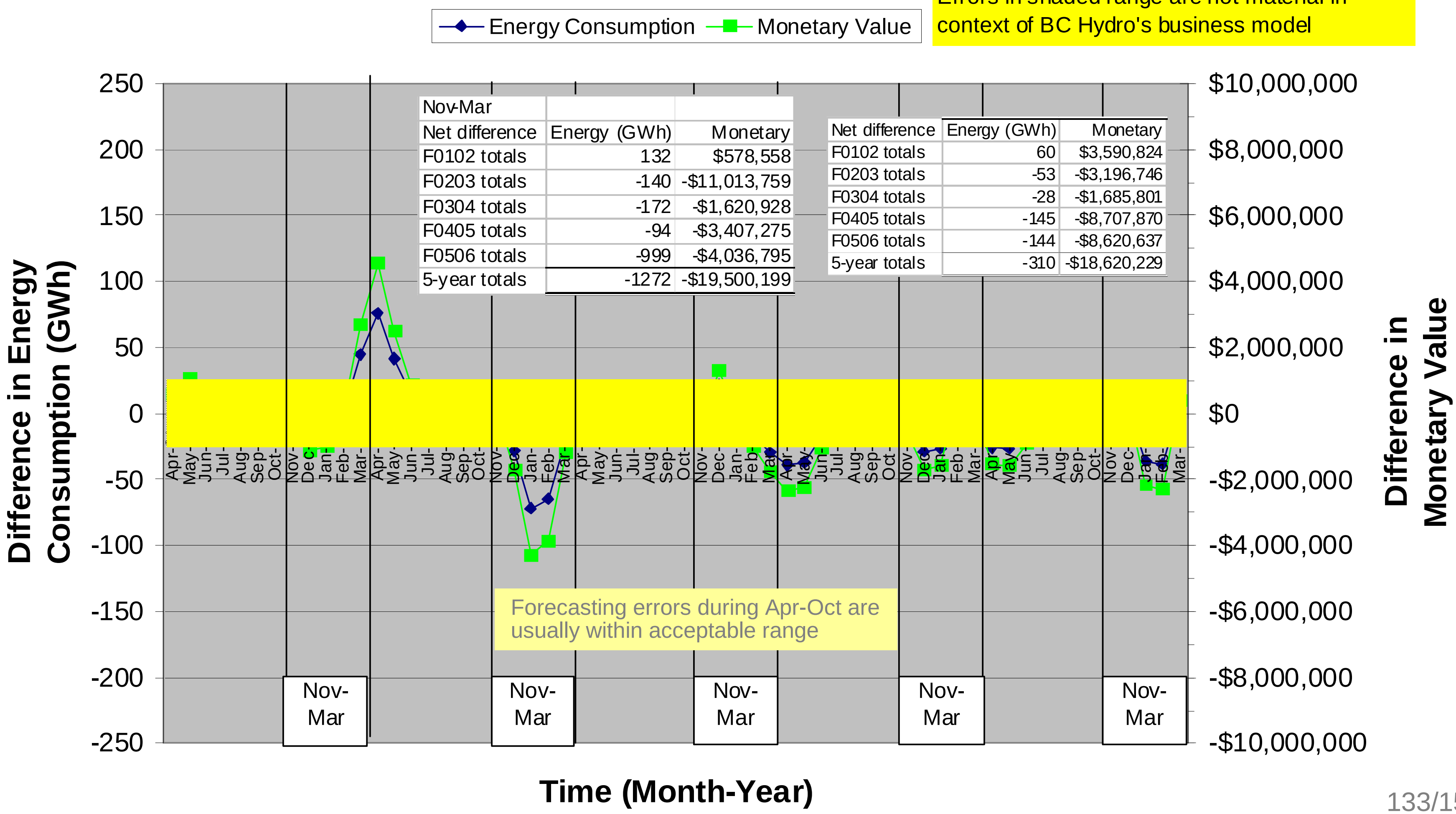
Material effect



Material effect

Stable HDD:
Static Moving Average Model
cannot be tuned to increase accuracy.
“What you see is what you get”.

Static Moving Average Forecasting Method: Differences in Total Res. Energy Consumption & Monetary Value during Apr 01 - Mar 06 DD forecast period (Lower Mainland)



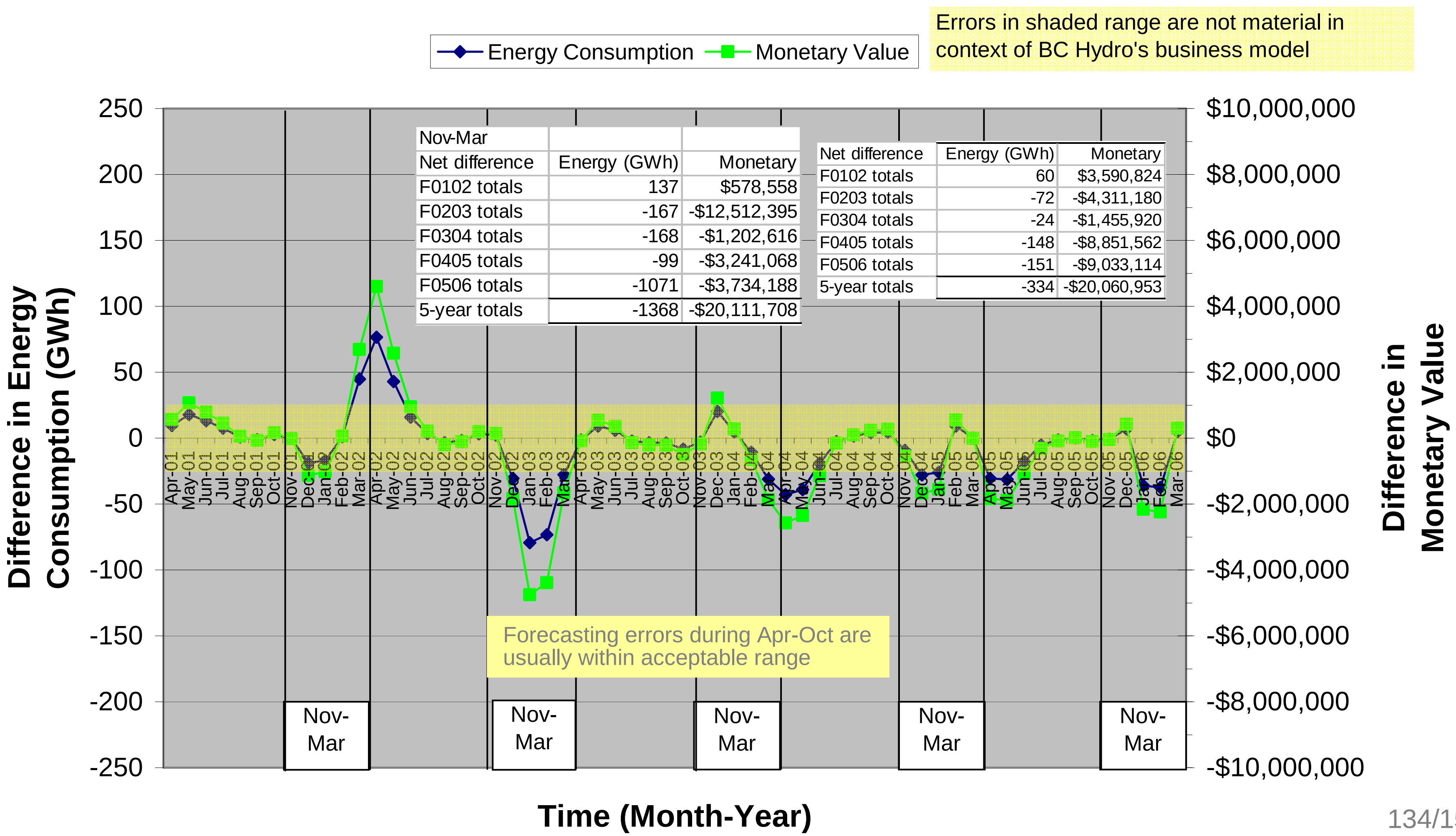
Nov-Mar		
Net difference	Energy (GWh)	Monetary
F0102 totals	132	$578,558
F0203 totals	-140	-$11,013,759
F0304 totals	-172	-$1,620,928
F0405 totals	-94	-$3,407,275
F0506 totals	-999	-$4,036,795
5-year totals	-1272	-$19,500,199

Net difference	Energy (GWh)	Monetary
F0102 totals	60	$3,590,824
F0203 totals	-53	-$3,196,746
F0304 totals	-28	-$1,685,801
F0405 totals	-145	-$8,707,870
F0506 totals	-144	-$8,620,637
5-year totals	-310	-$18,620,229

Material effect

Stable HDD:
Dynamic Moving Average Model
cannot be tuned to increase accuracy.
"What you see is what you get".

Dynamic Moving Average Forecasting Method: Differences in Total Res. Energy Consumption & Monetary Value during Apr 01 - Mar 06 DD forecast period (Lower Mainland)



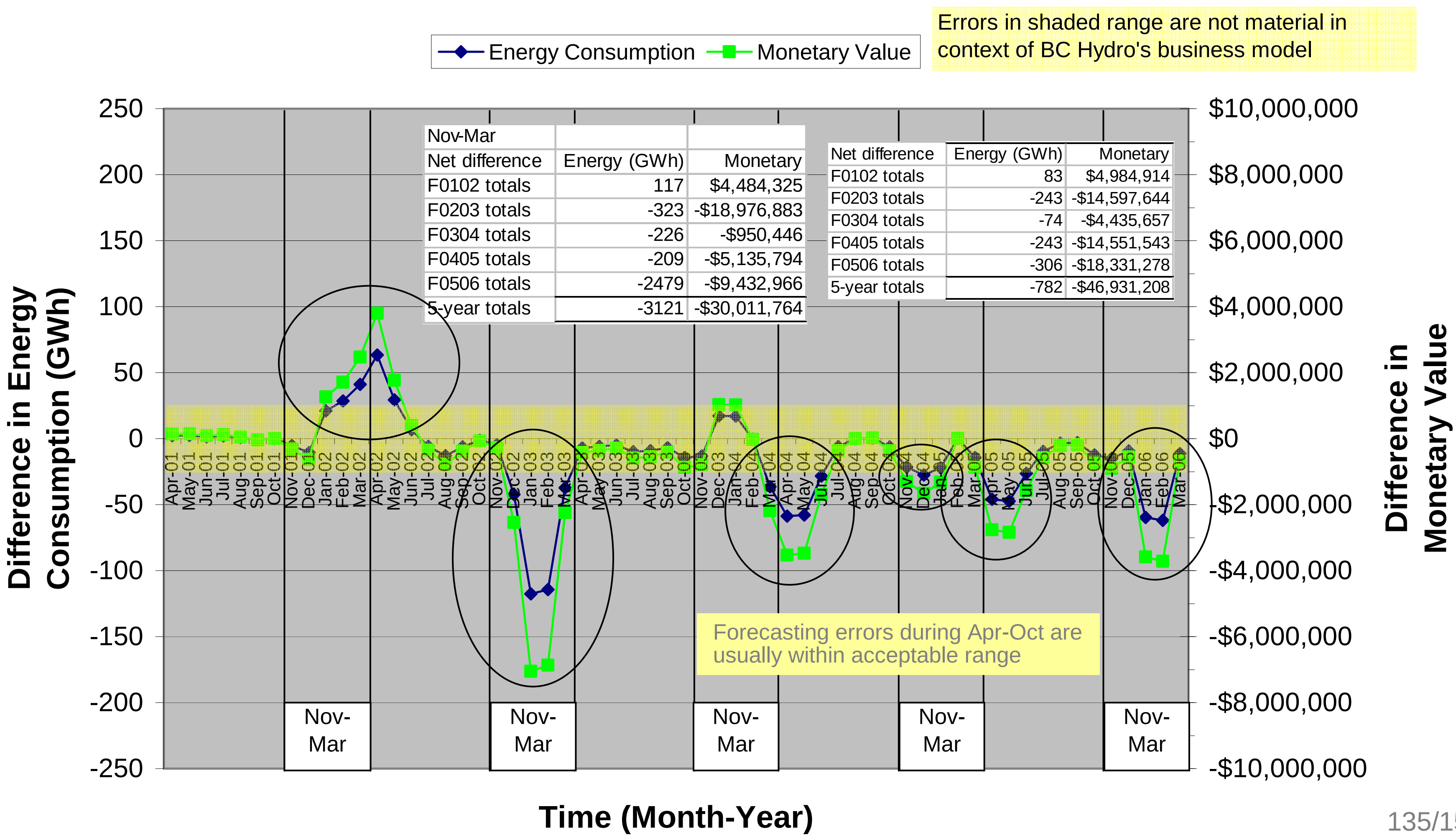
Nov-Mar Net difference	Energy (GWh)	Monetary
F0102 totals	137	$578,558
F0203 totals	-167	-$12,512,395
F0304 totals	-168	-$1,202,616
F0405 totals	-99	-$3,241,068
F0506 totals	-1071	-$3,734,188
5-year totals	-1368	-$20,111,708

Net difference	Energy (GWh)	Monetary
F0102 totals	60	$3,590,824
F0203 totals	-72	-$4,311,180
F0304 totals	-24	-$1,455,920
F0405 totals	-148	-$8,851,562
F0506 totals	-151	-$9,033,114
5-year totals	-334	-$20,060,953

Material effect

Stable HDD:
Opportunities for tuning ARIMA model are circled. Tuning is done by improving understanding of how climate index inputs should be applied.

ARIMA Probabilistic Forecasting Method with Climate Index Inputs: Differences in Total Res. Energy Consumption & Monetary Value during Apr 01 - Mar 06 DD forecast period (Lower Mainland)

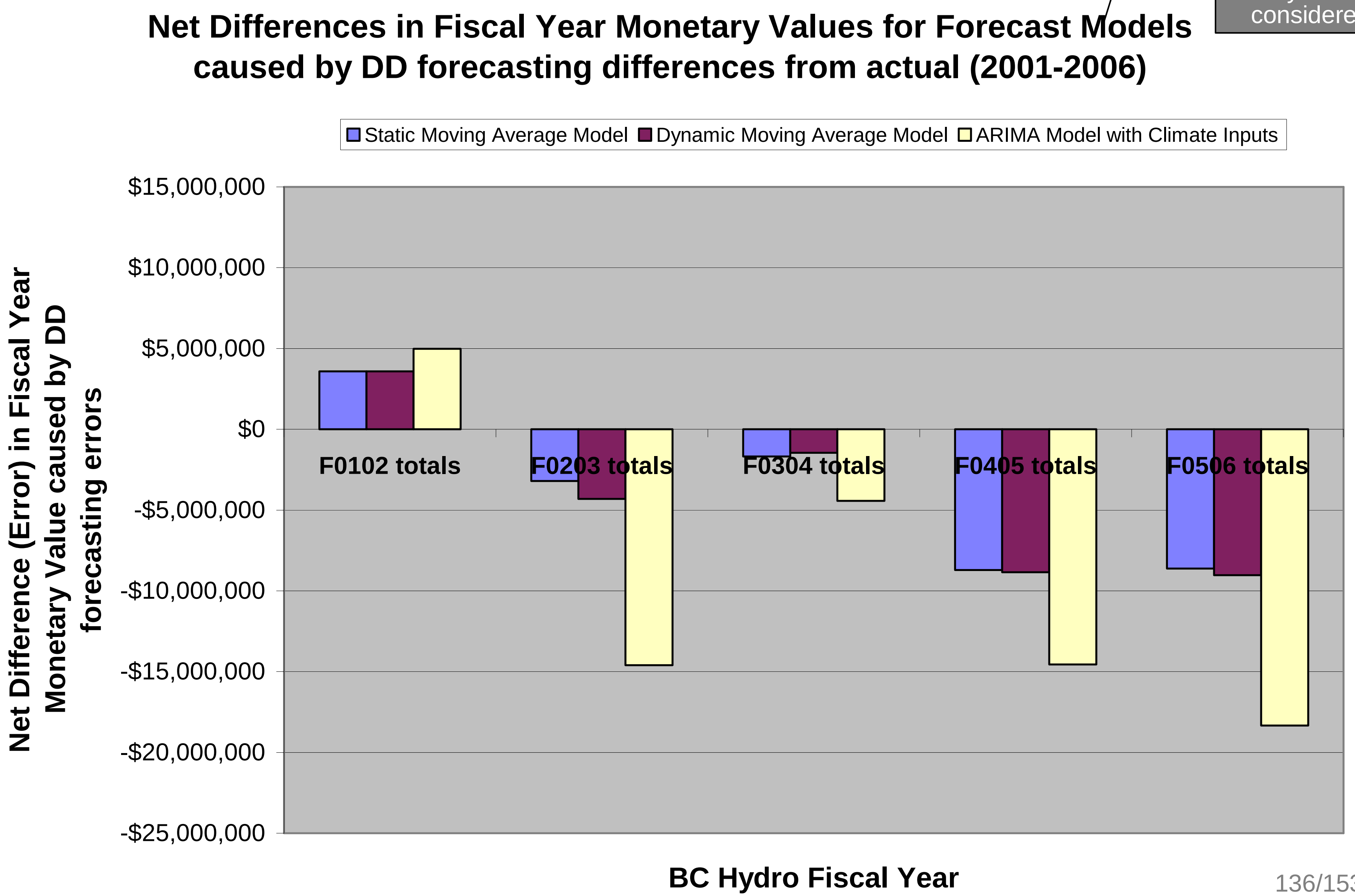


Nov-Mar		
Net difference	Energy (GWh)	Monetary
F0102 totals	117	$4,484,325
F0203 totals	-323	-$18,976,883
F0304 totals	-226	-$950,446
F0405 totals	-209	-$5,135,794
F0506 totals	-2479	-$9,432,966
5-year totals	-3121	-$30,011,764

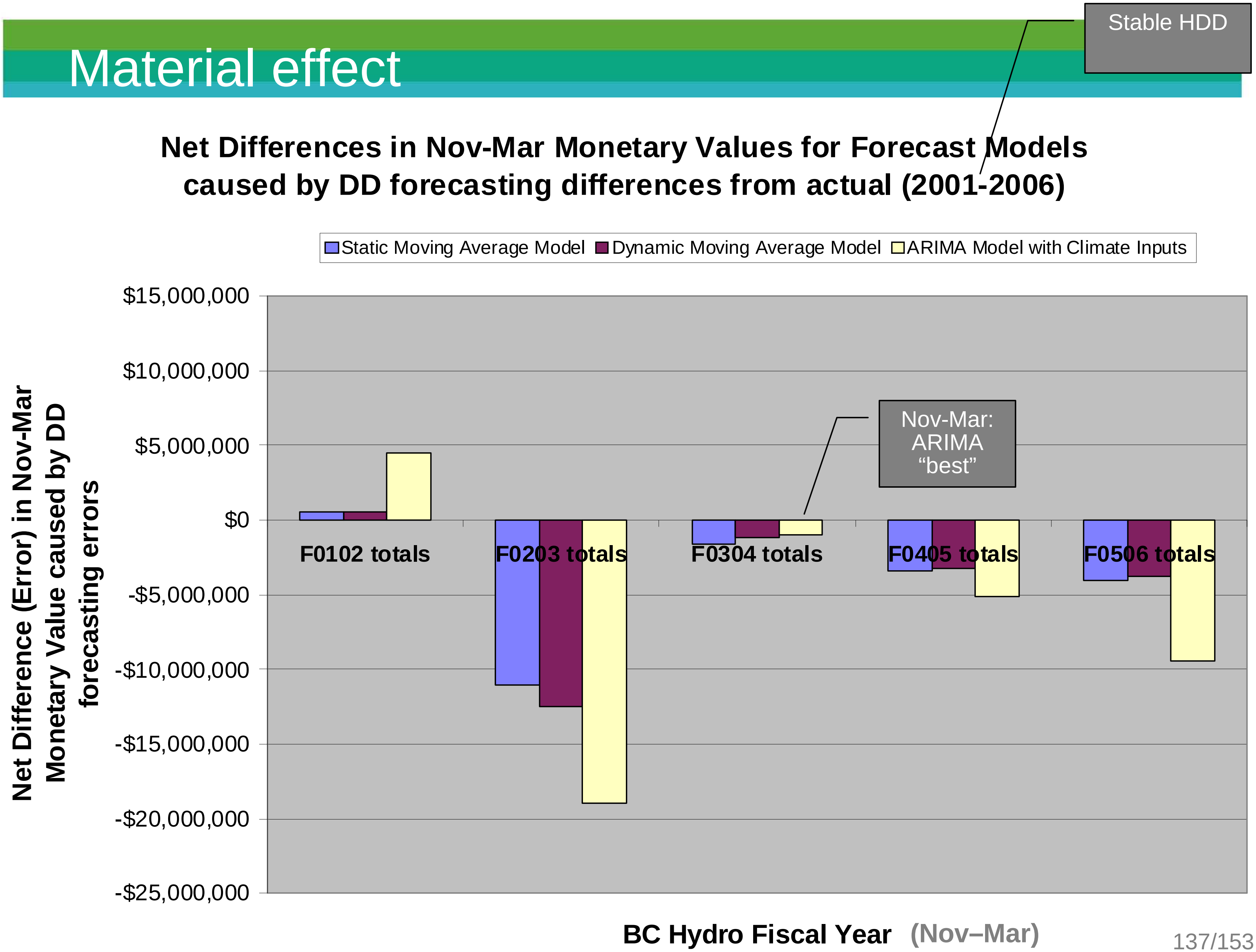
Net difference	Energy (GWh)	Monetary
F0102 totals	83	$4,984,914
F0203 totals	-243	-$14,597,644
F0304 totals	-74	-$4,435,657
F0405 totals	-243	-$14,551,543
F0506 totals	-306	-$18,331,278
5-year totals	-782	-$46,931,208

Material effect

Stable HDD; ARIMA offered no advantage when entire year considered



Material effect

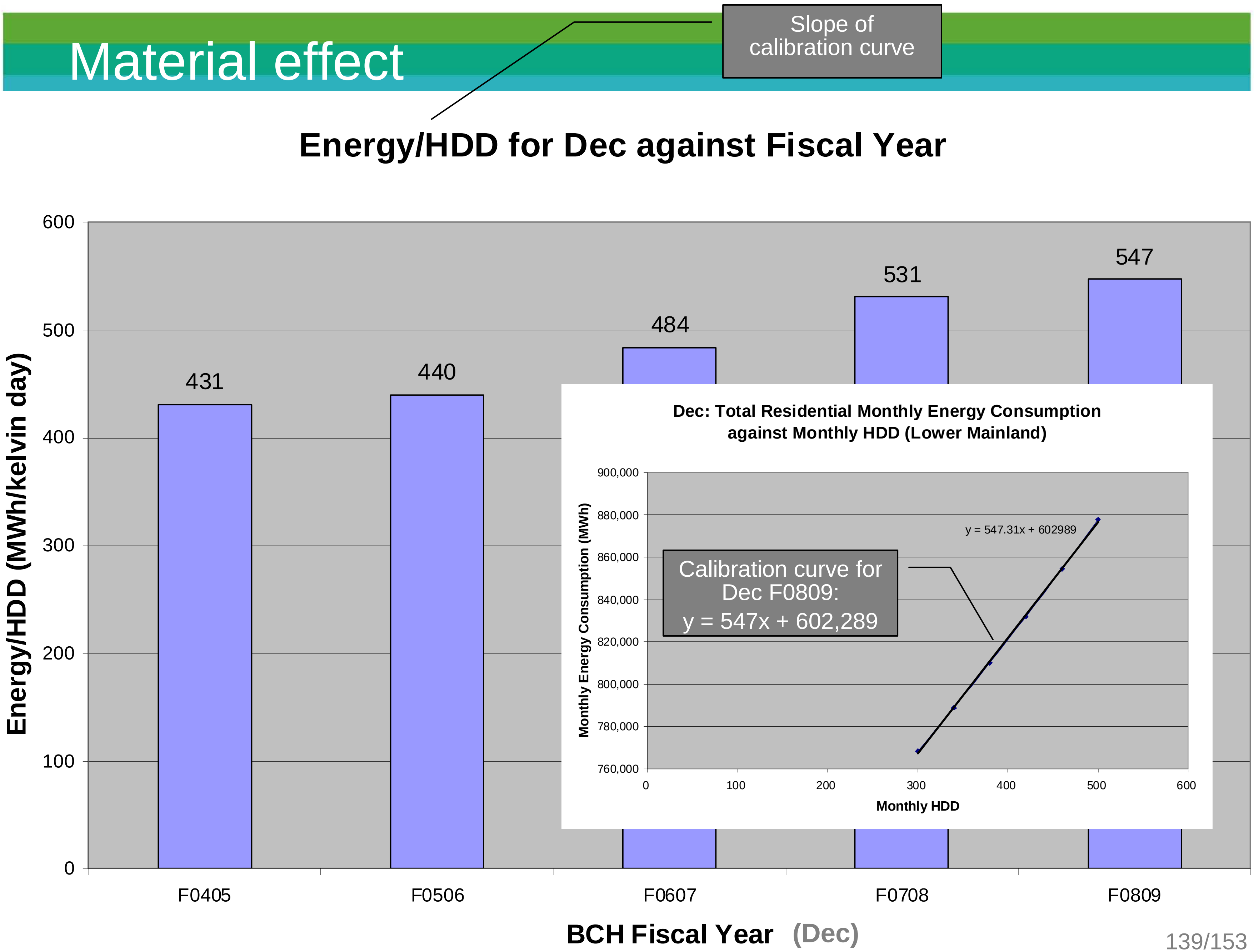


Material effect

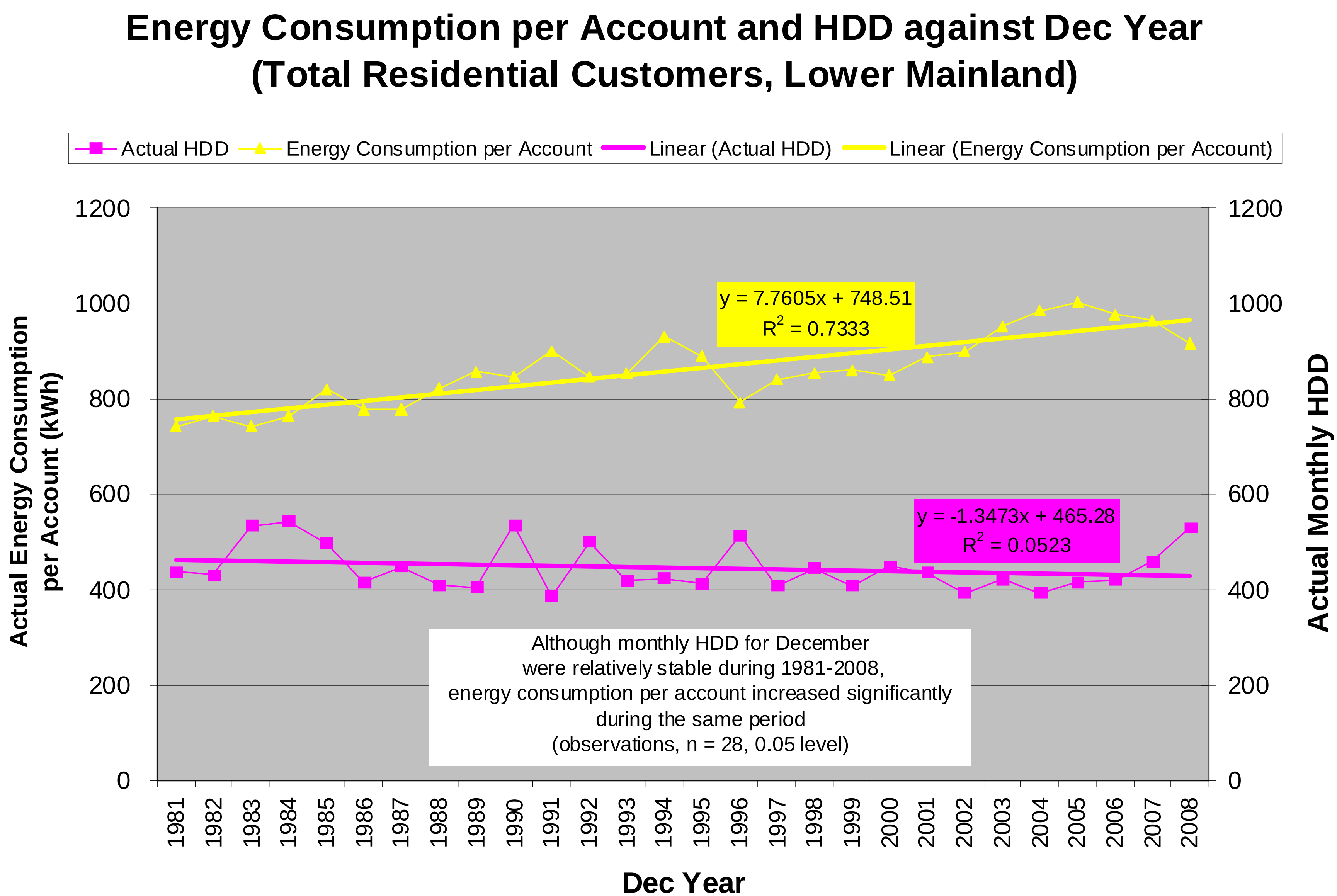
Interactive Spreadsheet

- Screen shots of spreadsheets are in the following slides
- Material effect of errors in HDD was illustrated quantitatively for the Lower Mainland winter (Nov–Mar)
- Designed to accept 5 years of data from any region as an interactive demonstration tool
  - Warning No. 1: Slope of calibration curves changes noticeably from year to year, even over 5 years; see example of month of Dec, Slide 139)
  - Warning No. 2: Calibrations may be affected by various factors, including the fact that consumption of electrical energy per account has been increasing In the Lower Mainland Region during the period Apr 1981 to Mar 2009 (Slide 140)
  - Theoretically, it should have been possible to construct calibration curves ("performance lines" in the nomenclature of Day, 2006) using "total monthly energy consumption for Lower Mainland" (normalized for increasing number of accounts) or "monthly energy consumption per account" against "monthly HDD" but these attempts were unsuccessful. The reason was likely to be that stated above in the second warning. The calibration curves used in the spreadsheet were generated by feeding artificial HDD data into the Load Forecasting ResHist Model for the months Nov–Mar of F0809 (Lower Mainland). Calibration curves are specific to each BC Hydro sales region.
- Test data (actual and predicted HDD) was from the two periods examined earlier in this document
  - Data Apr 1993 to Mar 1998 represented forecast results from a period of decreasing monthly HDD
  - Data Apr 2001 to Mar 2006 represented forecast results from a period of stable monthly HDD
- Result: View monthly, annual, and 5-year cumulative value of errors in terms of:
  - Energy Consumption (GWh)
  - Monetary Value

Material effect



Material effect



Microsoft Excel - HDD to Energy Interactive Model (Nov-Mar) final.xls

Interactive Spreadsheet: Another way of comparing DD forecasting methods for material effect of forecasting errors

Rows 1-46 of spreadsheet; Apr 1993-Mar 1998 data

Calibration curves

Interactive Spreadsheet

Based on ResHist Model for F0809

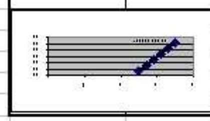
Linear equations relating HDD differences (errors) to Energy Consumption differences

Energy unit is MWh

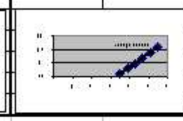
Artifical data used to generate curves

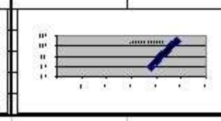
		Energy/HDD (MWh/kelvin day)	
		slope, m	intercept, b
Nov	y = m*x + b	444.56351	626091.9
Dec		547.3067	602989.1
Jan		488.11685	788875
Feb		492.64408	893555
Mar		508.07644	802404.9

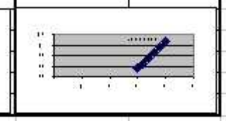
Experimental Data		Experimental Data		Experimental Data		Experimental Data		Experimental Data	
Nov HDD	Nov Energy	Dec HDD	Dec Energy	Jan HDD	Jan Energy	Feb HDD	Feb Energy	Mar HDD	Mar Energy
250	737,538	300	768,326	350	959,258	380	1,080,634	300	954,789
270	746,060	340	788,837	390	979,296	400	1,090,634	320	964,993
290	754,771	380	810,050	430	999,131	420	1,100,566	340	975,182
310	763,666	420	831,951	470	1,018,705	440	1,110,424	360	985,349
330	772,741	460	854,531	510	1,037,955	460	1,120,202	380	995,487
350	781,990	500	877,775	550	1,056,821	480	1,129,892	400	1,005,590



See enlarged calibration chart for Dec on accompanying slide







Spreadsheet enabling 5 years of input - Static Moving Average Model

one GWh = $60,000

Month	Fiscal Year		Actual HDD	Pred HDD	HDD Diff	Energy Diff (GWh)	Monetary Diff
Nov	F9394	1	402	355	47	21	$1,264,339
Dec		1	412	458	-46	-25	-$1,510,567
Jan		1	351	442	-91	-44	-$2,650,474
Feb		1	433	409	24	12	$700,540
Mar		1	324	336	-12	-6	-$371,912
	Annual Totals		1922	2000	-78	-43	-$2,568,074
Nov	F9495	2	393	355	38	17	$1,024,274
Dec		2	414	458	-44	-24	-$1,444,890
Jan		2	413	442	-29	-14	-$834,680
Feb		2	382	409	-27	-13	-$806,951
Mar		2	335	336	-1	-1	-$36,582
	Annual Totals		1937	2000	-63	-35	-$2,098,828
Nov	F9596	3	305	355	-50	-22	-$1,323,021
Dec		3	405	458	-53	-29	-$1,740,435
Jan		3	460	442	19	9	$541,810
Feb		3	415	409	6	3	$168,484
Mar		3	341	336	5	2	$146,326
	Annual Totals		1926	2000	-74	-37	-$2,206,836
Nov	F9697	4	395	355	40	18	$1,077,622
Dec		4	509	458	51	28	$1,674,759
Jan		4	426	442	-16	-8	-$453,949
Feb		4	397	409	-12	-6	-$363,571
Mar		4	355	336	19	10	$573,110

If weather pattern from Apr 93 to March 98 was repeated, these would be values of errors from static moving average model in energy consumption and monetary value (based on BCH grid characteristics of F0809)

Compare methods according to monetary value error

FY Forecast	Static MA	Dynamic MA	ARIMA
F9394	-2,568,074	-2,568,074	-3,504,379
F9495	-2,098,828	-2,277,857	186,761
F9596	-2,206,836	-1,685,630	-1,990,339
F9697	2,507,971	3,469,202	1,586,482
F9798	-6,681,197	-6,137,172	-6,747,328
Five year Nov-Mar totals	**-$11,046,965**	**-$9,199,532**	**-$10,468,803**

Interactive Spreadsheet 93-98 / Chart-IS 93-98 / Interactive Spreadsheet 01-06 / Chart-IS 01-06 / Ch

Ready

Microsoft Excel - HDD to Energy Interactive Model (Nov-Mar) final.xls

Rows 20-69 of spreadsheet; Apr 1993-Mar 1998 data

Static Moving Average Model results

Energy Difference (error)

Monetary Difference (error)

Spreadsheet enabling 5 years of input - Static Moving Average Model

one GWh = $60,000

Month	Fiscal Year		Actual HDD	Pred HDD	HDD Diff	Energy Diff (GWh)	Monetary Diff
Nov	F9394	1	402	355	47	21	$1,264,339
Dec		1	412	458	-46	-25	-$1,510,567
Jan		1	351	442	-91	-44	-$2,650,474
Feb		1	433	409	24	12	$700,540
Mar		1	324	336	-12	-6	-$371,912
Annual Totals			1922	2000	-78	-43	-$2,568,074
Nov	F9495	2	393	355	38	17	$1,024,274
Dec		2	414	458	-44	-24	-$1,444,890
Jan		2	413	442	-29	-14	-$834,680
Feb		2	382	409	-27	-13	-$806,951
Mar		2	335	336	-1	-1	-$36,582
Annual Totals			1937	2000	-63	-35	-$2,098,828
Nov	F9596	3	305	355	-50	-22	-$1,323,021
Dec		3	405	458	-53	-29	-$1,740,435
Jan		3	460	442	19	9	$541,810
Feb		3	415	409	6	3	$168,484
Mar		3	341	336	5	2	$146,326
Annual Totals			1926	2000	-74	-37	-$2,206,836
Nov	F9697	4	395	355	40	18	$1,077,622
Dec		4	509	458	51	28	$1,674,759
Jan		4	426	442	-16	-8	-$453,949
Feb		4	397	409	-12	-6	-$363,571
Mar		4	355	336	19	10	$573,110
Annual Totals			2082	2000	82	42	$2,507,971
Nov	F9798	5	317	355	-38	-17	-$1,002,935
Dec		5	399	458	-59	-32	-$1,937,466
Jan		5	416	442	-26	-12	-$746,819
Feb		5	334	409	-75	-37	-$2,225,766
Mar		5	311	336	-25	-13	-$768,212
Annual Totals			1777	2000	-222.6	-111	-$6,681,197
			Five-year Totals			-184	-$11,046,965

If weather pattern from Apr 93 to March 98 was repeated, these would be values of errors from static moving average model in energy consumption and monetary value (based on BCH grid characteristics of F0809)

Monthly Differences (errors)

Annual Totals of Differences (errors)

Five year totals (Energy, Monetary)

Compare methods according to monetary value error

FY Forecast	Static MA	Dynamic MA	ARIMA
F9394	-2,568,074	-2,568,074	-3,504,379
F9495	-2,098,828	-2,277,857	186,761
F9596	-2,206,836	-1,685,630	-1,990,339
F9697	2,507,971	3,469,202	1,586,482
F9798	-6,681,197	-6,137,172	-6,747,328
Five year Nov-Mar totals	**-$11,046,965**	**-$9,199,532**	**-$10,468,803**

Spreadsheet enabling 5 years of input - Dynamic Moving Average Model

one GWh = $60,000

Month	Fiscal Year		Actual HDD	Pred HDD	HDD Diff	Energy Diff (GWh)	Monetary Diff
Nov	F9394	1	402	355	47	21	$1,264,339
Dec		1	412	458	-46	-25	-$1,510,567
Jan		1	351	442	-91	-44	-$2,650,474
Feb		1	433	409	24	12	$700,540
Mar		1	324	336	-12	-6	-$371,912
Annual Totals			1922	2000	-78	-43	-$2,568,074
Nov	F9495	2	393	359	34	15	$918,646
Dec		2	414	451	-37	-20	-$1,215,021
Jan		2	413	444	-31	-15	-$915,219
Feb		2	382	414	-32	-16	-$946,763
Mar		2	335	339	-4	-2	-$119,500

If weather pattern from Apr 93 to Mar 98 was repeated, these would be values of errors from dynamic moving average model in energy consumption and monetary value (based on BCH grid characteristics of F0809)

Interactive Spreadsheet 93-98 / Chart-IS 93-98 / Interactive Spreadsheet 01-06 / Chart-IS 01-06

Microsoft Excel - HDD to Energy Interactive Model (Nov-Mar) final.xls

G24 =$G$22*F24

Rows 56-108 of spreadsheet; Apr 1993-Mar 1998 data

Dynamic Moving Average Model results

Spreadsheet enabling 5 years of input - Dynamic Moving Average Model

one GWh = $60,000

Row	Month	Fiscal Year		Actual HDD	Pred HDD	HDD Diff	Energy Diff (GWh)	Monetary Diff
59	Nov	F9394	1	402	355	47	21	$1,264,339
60	Dec		1	412	458	-46	-25	-$1,510,567
61	Jan		1	351	442	-91	-44	-$2,650,474
62	Feb		1	433	409	24	12	$700,540
63	Mar		1	324	336	-12	-6	-$371,912
64	Annual Totals			1922	2000	-78	-43	-$2,568,074
65	Nov	F9495	2	393	359	34	15	$918,646
66	Dec		2	414	451	-37	-20	-$1,215,021
67	Jan		2	413	444	-31	-15	-$915,219
68	Feb		2	382	414	-32	-16	-$946,763
69	Mar		2	335	339	-4	-2	-$119,500
70	Annual Totals			1937	2007	-70	-38	-$2,277,857
71	Nov	F9596	3	305	358	-53	-24	-$1,413,712
72	Dec		3	405	443	-38	-21	-$1,247,859
73	Jan		3	460	438	22	11	$644,314
74	Feb		3	415	411	4	2	$118,235
75	Mar		3	341	334	7	4	$213,392
76	Annual Totals			1926	1984	-58	-28	-$1,685,630
77	Nov	F9697	4	395	339	56	25	$1,493,264
78	Dec		4	509	438	71	39	$2,328,243
79	Jan		4	426	446	-20	-10	-$577,613
80	Feb		4	397	408	-11	-6	-$331,243
81	Mar		4	355	337	18	9	$556,551
82	Annual Totals			2082	1968	114	58	$3,469,202
83	Nov	F9798	5	317	338	-21	-9	-$549,997
84	Dec		5	399	441	-42	-23	-$1,379,541
85	Jan		5	416	449	-33	-16	-$954,603
86	Feb		5	334	414	-80	-39	-$2,368,443
87	Mar		5	311	340	-29	-15	-$884,587
88	Annual Totals			1777	1981	-204.369	-102	-$6,137,172
89				Five-year Totals			-153	-$9,199,532

If weather pattern from Apr 93 to Mar 98 was repeated, these would be values of errors from dynamic moving average model in energy consumption and monetary value (based on BCH grid characteristics of F0809)

Spreadsheet enabling 5 years of input - ARIMA Model

one GWh = $60,000

Row	Month	Fiscal Year		Actual HDD	Pred HDD	HDD Diff	Energy Diff (GWh)	Monetary Diff
94	Nov	F9394	1	402	388	14	6	$373,433
95	Dec		1	412	458	-46	-25	-$1,510,567
96	Jan		1	351	420	-69	-34	-$2,020,804
97	Feb		1	433	421	12	6	$354,704
98	Mar		1	324	347	-23	-12	-$701,145
99	Annual Totals			1922	2034	-112	-58	-$3,504,379
100	Nov	F9495	2	393	363	30	13	$800,214
101	Dec		2	414	415	-1	-1	-$32,838
102	Jan		2	413	401	12	6	$351,444
103	Feb		2	382	396	-14	-7	-$413,821
104	Mar		2	335	352	-17	-9	-$518,238
105	Annual Totals			1937	1927	10	3	$186,761
106	Nov	F9596	3	305	335	-30	-13	-$800,214
107	Dec		3	405	440	-35	-19	-$1,149,344
108	Jan		3	460	463	-3	-1	-$87,861

If weather pattern from Apr 93 to Mar 98 was repeated, these would be values of errors from ARIMA model in energy consumption and monetary value (based on BCH grid characteristics of F0809)

Interactive Spreadsheet 93-98 / Chart-IS 93-98 / Interactive Spreadsheet 01-06 / Chart-IS 01-06 / Ch

Rows 91-144 of spreadsheet; Apr 1993-Mar 1998 data

ARIMA Model results

Microsoft Excel - HDD to Energy Interactive Model (Nov-Mar) final.xls

G24 =$G$22*F24

Spreadsheet enabling 5 years of input - ARIMA Model

one GWh = $60,000

Row	Month	Fiscal Year	Actual HDD	Pred HDD	HDD Diff	Energy Diff (GWh)	Monetary Diff
94	Nov	F9394 1	402	388	14	6	$373,433
95	Dec	1	412	458	-46	-25	-$1,510,567
96	Jan	1	351	420	-69	-34	-$2,020,804
97	Feb	1	433	421	12	6	$354,704
98	Mar	1	324	347	-23	-12	-$701,145
99	Annual Totals		1922	2034	-112	-58	-$3,504,379
100	Nov	F9495 2	393	363	30	13	$800,214
101	Dec	2	414	415	-1	-1	-$32,838
102	Jan	2	413	401	12	6	$351,444
103	Feb	2	382	396	-14	-7	-$413,821
104	Mar	2	335	352	-17	-9	-$518,238
105	Annual Totals		1937	1927	10	3	$186,761
106	Nov	F9596 3	305	335	-30	-13	-$800,214
107	Dec	3	405	440	-35	-19	-$1,149,344
108	Jan	3	460	463	-3	-1	-$87,861
109	Feb	3	415	400	15	7	$443,380
110	Mar	3	341	354	-13	-7	-$396,300
111	Annual Totals		1926	1992	-66	-33	-$1,990,339
112	Nov	F9697 4	395	388	7	3	$186,717
113	Dec	4	509	444	65	36	$2,134,496
114	Jan	4	426	445	-19	-9	-$556,453
115	Feb	4	397	402	-5	-2	-$147,793
116	Mar	4	355	356	-1	-1	-$30,485
117	Annual Totals		2082	2035	47	26	$1,586,482
118	Nov	F9798 5	317	369	-52	-23	-$1,387,038
119	Dec	5	399	436	-37	-20	-$1,215,021
120	Jan	5	416	438	-22	-11	-$644,314
121	Feb	5	334	405	-71	-35	-$2,098,664
122	Mar	5	311	357	-46	-23	-$1,402,291
123	Annual Totals		1777	2005	-228	-112	-$6,747,328
124			Five-year Totals			-174	-$10,468,803

If weather pattern from Apr 93 to Mar 98 was repeated, these would be values of errors from ARIMA model in energy consumption and monetary value (based on BCH grid characteristics of F0809)

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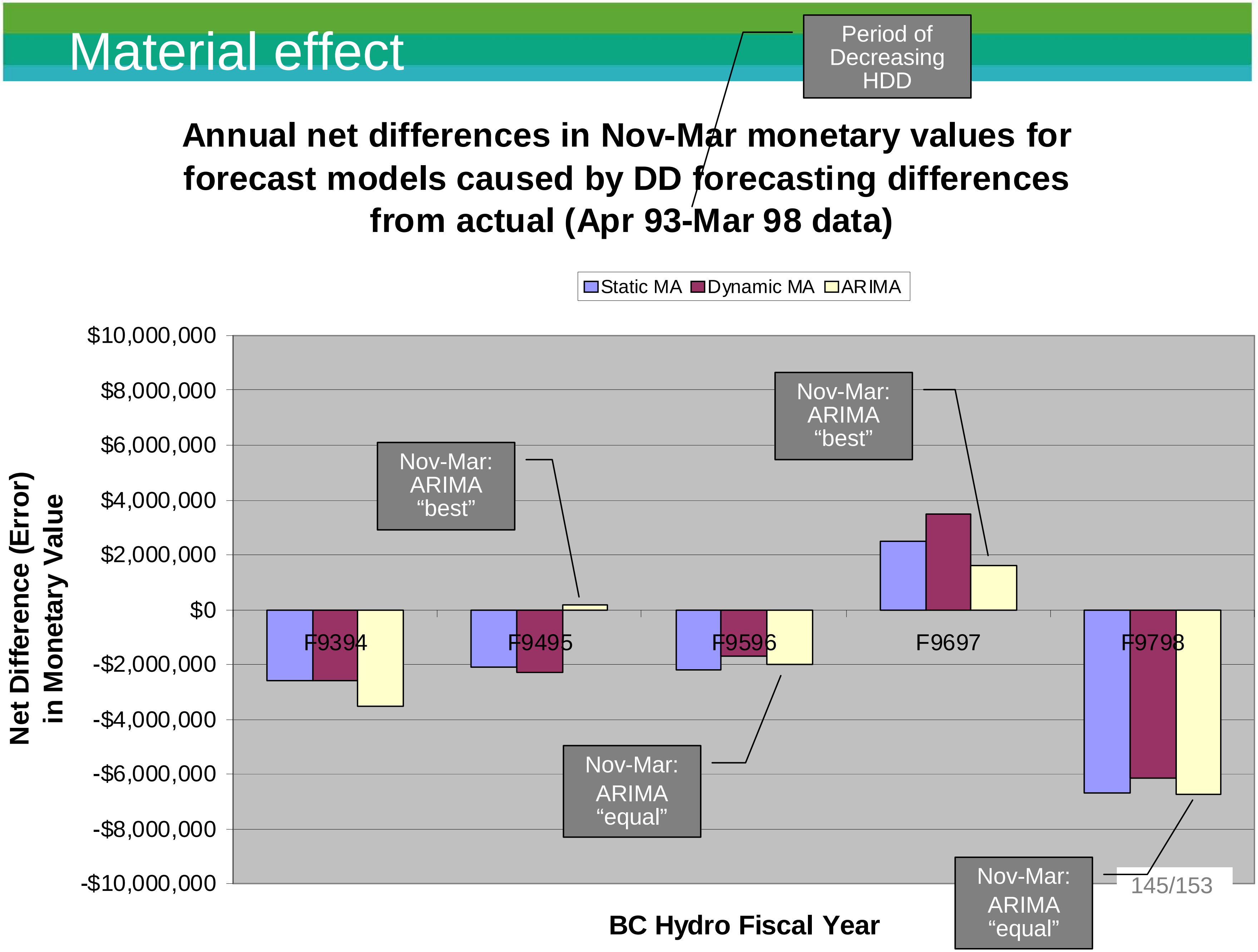
Material effect

Annual net differences in Nov-Mar monetary values for forecast models caused by DD forecasting differences from actual (Apr 93-Mar 98 data)



Microsoft Excel - HDD to Energy Interactive Model (Nov-Mar) final.xls

Rows 1-43 of spreadsheet; Apr 2001-Mar 2006 data

Calibration curves

Interactive Spreadsheet

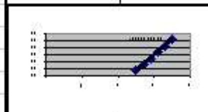
Based on ResHist Model for F0809

Linear equations relating HDD differences (errors) to Energy Consumption differences

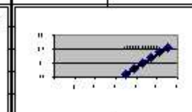
Energy unit is MWh

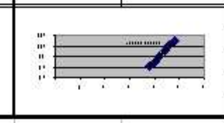
Month	Equation	Energy/HDD (MWh/kelvin day) slope, m	intercept, b
Nov	y = m*x + b	444.563511	626091.9
Dec		547.306704	602989.1
Jan		488.116847	788875
Feb		492.644078	893555
Mar		508.076444	802404.9

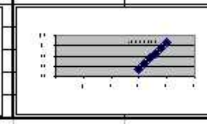
Nov HDD	Nov Energy	Dec HDD	Dec Energy	Jan HDD	Jan Energy	Feb HDD	Feb Energy	Mar HDD	Mar Energy
Experimental Data		Experimental Data		Experimental Data		Experimental Data		Experimental Data	
250	737,538	300	768,326	350	959,258	380	1,080,634	300	954,789
270	746,060	340	788,837	390	979,296	400	1,090,634	320	964,993
290	754,771	380	810,050	430	999,131	420	1,100,566	340	975,182
310	763,666	420	831,951	470	1,018,705	440	1,110,424	360	985,349
330	772,741	460	854,531	510	1,037,955	460	1,120,202	380	995,487
350	781,990	500	877,775	550	1,056,821	480	1,129,892	400	1,005,590



See enlarged calibration chart for Dec on accompanying slide







Spreadsheet enabling 5 years of input

one GWh = $60,000

Month	Fiscal Year		Actual HDD	Pred HDD	HDD Diff	Energy Diff (GWh)	Monetary Diff
Nov	F0102	1	310	348	-38	-17	-$1,013,605
Dec		1	429	426	3	1	$85,380
Jan		1	417	421	-4	-2	-$120,077
Feb		1	402	394	8	4	$224,646
Mar		1	417	332	86	43	$2,606,432
Annual Totals			1975	1921	54	30	$1,782,776
Nov	F0203	2	313	348	-35	-16	-$933,583
Dec		2	382	426	-44	-24	-$1,458,025
Jan		2	356	421	-65	-32	-$1,906,584
Feb		2	404	394	10	5	$283,763
Mar		2	323	332	-9	-4	-$259,119
Annual Totals			1778	1921	-143	-71	-$4,273,549
Nov	F0304	3	409	348	61	27	$1,627,102
Dec		3	409	426	-17	-10	-$571,388
Jan		3	422	421	1	0	$26,358
Feb		3	370	394	-24	-12	-$721,231
Mar		3	306	332	-26	-13	-$777,357
Annual Totals			1916	1921	-5	-7	-$416,515
Nov	F0405	4	338	348	-10	-4	-$266,738
Dec		4	382	426	-44	-24	-$1,458,025

If weather pattern from Apr 01 to March 06 was repeated, these would be values of errors from static moving average model in energy consumption and monetary value (based on BCH grid characteristics of F0809)

Compare methods according to monetary value error

FY Forecast	Static MA	Dynamic MA	ARIMA
F0102	$1,782,776	$1,782,776	$2,826,666
F0203	-$4,273,549	-$4,929,894	-$6,726,464
F0304	-$416,515	-$440,992	-$284,011
F0405	-$1,850,851	-$1,895,093	-$2,594,243
F0506	-$776,212	-$795,271	-$3,009,165
Five year Nov-Mar totals	**-$5,534,351**	**-$6,278,474**	**-$9,787,217**

Interactive Spreadsheet 93-98 | Chart-IS 93-98 | Interactive Spreadsheet 01-06 | Chart-IS 01-06 | Ch

Microsoft Excel - HDD to Energy Interactive Model (Nov-Mar) final.xls

Rows 20-65 of spreadsheet; Apr 2001-Mar 2006 data

Static Moving Average Model results

Spreadsheet enabling 5 years of input

one GWh = $60,000

Month	Fiscal Year		Actual HDD	Pred HDD	HDD Diff	Energy Diff (GWh)	Monetary Diff
Nov	F0102	1	310	348	-38	-17	-$1,013,605
Dec		1	429	426	3	1	$85,380
Jan		1	417	421	-4	-2	-$120,077
Feb		1	402	394	8	4	$224,646
Mar		1	417	332	86	43	$2,606,432
Annual Totals			1975	1921	54	30	$1,782,776
Nov	F0203	2	313	348	-35	-16	-$933,583
Dec		2	382	426	-44	-24	-$1,458,025
Jan		2	356	421	-65	-32	-$1,906,584
Feb		2	404	394	10	5	$283,763
Mar		2	323	332	-9	-4	-$259,119
Annual Totals			1778	1921	-143	-71	-$4,273,549
Nov	F0304	3	409	348	61	27	$1,627,102
Dec		3	409	426	-17	-10	-$571,388
Jan		3	422	421	1	0	$26,358
Feb		3	370	394	-24	-12	-$721,231
Mar		3	306	332	-26	-13	-$777,357
Annual Totals			1916	1921	-5	-7	-$416,515
Nov	F0405	4	338	348	-10	-4	-$266,738
Dec		4	382	426	-44	-24	-$1,458,025
Jan		4	431	421	10	5	$289,941
Feb		4	419	394	25	12	$727,143
Mar		4	294	332	-38	-19	-$1,143,172
Annual Totals			1864	1921	-57	-31	-$1,850,851
Nov	F0506	5	372	348	24	11	$640,171
Dec		5	412	426	-14	-8	-$472,873
Jan		5	353	421	-68	-33	-$1,994,445
Feb		5	415	394	21	10	$608,908
Mar		5	346	332	15	7	$442,027
Annual Totals			1898	1921	-23.4	-13	-$776,212
				Five-year Totals		-92	-$5,534,351

If weather pattern from Apr 01 to March 06 was repeated, these would be values of errors from static moving average model in energy consumption and monetary value (based on BCH grid characteristics of F0809)

FY Forecast	Compare methods according to monetary value error: Static MA	Dynamic MA	ARIMA
F0102	$1,782,776	$1,782,776	$2,826,666
F0203	-$4,273,549	-$4,929,894	-$6,726,464
F0304	-$416,515	-$440,992	-$284,011
F0405	-$1,850,851	-$1,895,093	-$2,594,243
F0506	-$776,212	-$795,271	-$3,009,165
Five year Nov-Mar totals	-$5,534,351	-$6,278,474	-$9,787,217

Spreadsheet enabling 5 years of input

one GWh = $60,000

Month	Fiscal Year		Actual HDD	Dyn MA Pred HDD	HDD Diff	Energy Diff (GWh)	Monetary Diff
Nov	F9394	1	310	348	-38	-17	-$1,013,605
Dec		1	429	426	3	1	$85,380
Jan		1	417	421	-4	-2	-$120,077
Feb		1	402	394	8	4	$224,646
Mar		1	417	332	86	43	$2,606,432
Annual Totals			1975	1921	54	30	$1,782,776
Nov	F9495	2	313	350	-37	-16	-$989,598

If weather pattern from Apr 01 to March 06 was repeated, these would be values of errors from dynamic moving average model in energy consumption and

Interactive Spreadsheet 93-98 | Chart-IS 93-98 | Interactive Spreadsheet 01-06 | Chart-IS 01-06 | Ch

Microsoft Excel - HDD to Energy Interactive Model (Nov-Mar) final.xls

Rows 56-104 of spreadsheet; Apr 2001-Mar 2006 data

Dynamic Moving Average Model results

Spreadsheet enabling 5 years of input

one GWh = $60,000

Month	Fiscal Year		Actual HDD	Dyn MA Pred HDD	HDD Diff	Energy Diff (GWh)	Monetary Diff
Nov	F9394	1	310	348	-38	-17	-$1,013,605
Dec		1	429	426	3	1	$85,380
Jan		1	417	421	-4	-2	-$120,077
Feb		1	402	394	8	4	$224,646
Mar		1	417	332	86	43	$2,606,432
Annual Totals			1975	1921	54	30	$1,782,776
Nov	F9495	2	313	350	-37	-16	-$989,598
Dec		2	382	432	-50	-27	-$1,630,098
Jan		2	356	426	-70	-34	-$2,059,170
Feb		2	404	399	5	2	$140,699
Mar		2	323	336	-13	-7	-$391,727
Annual Totals			1778	1943	-165	-82	-$4,929,894
Nov	F9596	3	409	351	58	26	$1,560,151
Dec		3	409	426	-17	-9	-$561,668
Jan		3	422	413	9	4	$256,525
Feb		3	370	395	-25	-12	-$743,814
Mar		3	306	337	-31	-16	-$952,186
Annual Totals			1916	1922	-6	-7	-$440,992
Nov	F9697	4	338	345	-7	-3	-$196,346
Dec		4	382	428	-46	-25	-$1,494,620
Jan		4	431	419	12	6	$337,823
Feb		4	419	391	28	14	$816,398
Mar		4	294	339	-45	-23	-$1,358,347
Annual Totals			1864	1922	-58	-32	-$1,895,093
Nov	F9798	5	372	341	31	14	$837,635
Dec		5	412	429	-17	-9	-$553,847
Jan		5	353	420	-67	-33	-$1,965,498
Feb		5	415	392	23	11	$670,436
Mar		5	346	339	7	4	$216,003
Annual Totals			1898	1921	-23	-13	-$795,271
				Five-year Totals		-105	-$6,278,474

If weather pattern from Apr 01 to March 06 was repeated, these would be values of errors from dynamic moving average model in energy consumption and monetary value (based on BCH grid characteristics of F0809)

Spreadsheet enabling 5 years of input

one GWh = $60,000

Month	Fiscal Year		Actual HDD	ARIMA Pred HDD	HDD Diff	Energy Diff (GWh)	Monetary Diff
Nov	F9394	1	310	353	-43	-19	-$1,141,639
Dec		1	429	386	43	23	$1,405,484
Jan		1	417	412	5	3	$158,150
Feb		1	402	398	4	2	$115,279
Mar		1	417	342	75	38	$2,289,392
Annual Totals			1975	1891	84	47	$2,826,666
Nov	F9495	2	313	351	-38	-17	-$1,010,937
Dec		2	382	454	-72	-39	-$2,367,649
Jan		2	356	467	-111	-54	-$3,242,072
Feb		2	404	389	16	8	$458,159
Mar		2	323	342	-19	-9	-$563,965

If weather pattern from Apr 01 to March 06 was repeated, these would be values of errors from ARIMA model in energy consumption and monetary value (based on BCH grid characteristics of F0809)

Chart-IS 93-98 | Interactive Spreadsheet 01-06 | Chart-IS 01-06 | Chart1-April HDD | Chart2-Dec HDD

Microsoft Excel - HDD to Energy Interactive Model (Nov-Mar) final.xls

G94 =$G$22*F94

Rows 91-140 of spreadsheet; Apr 2001-Mar 2006 data

ARIMA Model results

Spreadsheet enabling 5 years of input

one GWh = $60,000

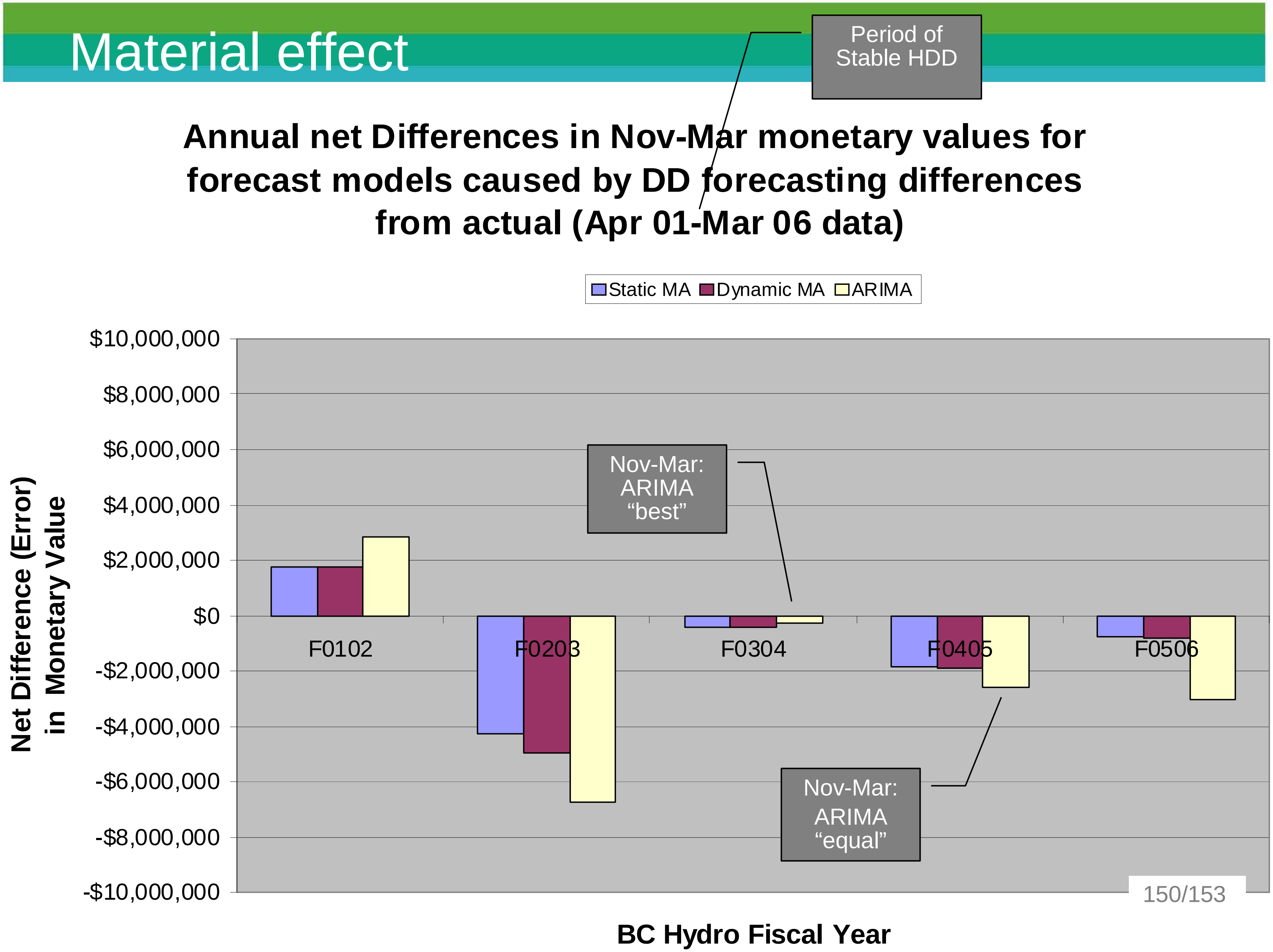
Month	Fiscal Year	Actual HDD	ARIMA Pred HDD	HDD Diff	Energy Diff (GWh)	Monetary Diff
Nov	F9394 1	310	353	-43	-19	-$1,141,639
Dec	1	429	386	43	23	$1,405,484
Jan	1	417	412	5	3	$158,150
Feb	1	402	398	4	2	$115,279
Mar	1	417	342	75	38	$2,289,392
Annual Totals		1975	1891	84	47	$2,826,666
Nov	F9495 2	313	351	-38	-17	-$1,010,937
Dec	2	382	454	-72	-39	-$2,367,649
Jan	2	356	467	-111	-54	-$3,242,072
Feb	2	404	389	16	8	$458,159
Mar	2	323	342	-19	-9	-$563,965
Annual Totals		1778	2002	-224	-112	-$6,726,464
Nov	F9596 3	409	356	53	24	$1,421,714
Dec	3	409	416	-7	-4	-$243,004
Jan	3	422	399	23	11	$670,673
Feb	3	370	400	-30	-15	-$892,671
Mar	3	306	347	-41	-21	-$1,240,723
Annual Totals		1916	1918	-2	-5	-$284,011
Nov	F9697 4	338	357	-19	-8	-$509,470
Dec	4	382	407	-25	-14	-$820,960
Jan	4	431	435	-4	-2	-$123,005
Feb	4	419	402	17	8	$508,409
Mar	4	294	348	-54	-27	-$1,649,216
Annual Totals		1864	1949	-85	-43	-$2,594,243
Nov	F9798 5	372	356	16	7	$434,783
Dec	5	412	441	-29	-16	-$962,165
Jan	5	353	448	-95	-46	-$2,773,480
Feb	5	415	401	14	7	$419,733
Mar	5	346	350	-4	-2	-$128,035
Annual Totals		1898	1996	-97.7	-50	-$3,009,165
			Five-year Totals		-163	-$9,787,217

If weather pattern from Apr 01 to March 06 was repeated, these would be values of errors from ARIMA model in energy consumption and monetary value (based on BCH grid characteristics of F0809)

Chart-IS 93-98 | **Interactive Spreadsheet 01-06** | Chart-IS 01-06 | Chart1-April HDD | Chart2-Dec HDD

Material effect

Annual net Differences in Nov-Mar monetary values for forecast models caused by DD forecasting differences from actual (Apr 01-Mar 06 data)



Summary

- Degree day forecasts with ARIMA can be based on meaningful climatological inputs; more information content about physical processes than purely empirical methods
- Forecasts can be quantified with 5% confidence limits
- Quality of ARIMA forecasts was tested by back-casting, correlating actual HDD values with predicted values. Quality varied by month and by region with tested predictions always significant for Vancouver, Victoria, and Prince George (46 year test; 1963–2008). Kamloops ARIMA forecast quality was affected by the short period of observations (5 year test; 2004–2008). In all four regions, ARIMA backcasts had "mean absolute percentage error" (MAPE) always less than the MAPE for the 10-year moving average backcasts
- Six separate "acid tests" assumed forecasts were made in Mar 1993 (decreasing HDD trend) or Mar 2001 (no HDD trend); Forecasts could be compared to actual monthly HDD for the next 60 months; Results were: (1) ARIMA model outperformed (Nov-Mar) moving average models during period with trend; (2) ARIMA model was no better than moving average models during period with no trend (3) ARIMA model climate input decisions changed with duration of time series record
- Material effect (on improved accuracy of energy consumption calculations) of using the ARIMA model sometimes exceeded $1 million in monetary value
- ARIMA models are used widely in the physical and social sciences; Software such as SAS JMP offers relative ease of use
- Similar results will be obtained by different analysts
- Forecasts can be updated following documented methods
- ARIMA probabilistic model with climate index inputs has lowest risk of unknowingly embarking on a period of over or under-estimating HDDs or CDDs compared to moving average models [such as happened to BC Hydro in the 1980's and 1990's (Mansfield, 1996)]

Five-year (Nov-Mar) total monetary values of errors experienced by forecasting methods when compared using interactive spreadsheet model

Forecast period (Nov-Mar)	Static Moving Average	Dynamic Moving Average	ARIMA
F9394 to F9798 (decreasing HDD trend)	-$11,046,965	-$9,199,532	$10,468,803
F0102 to F0506 (stable HDD)	-$5,534,351	-$6,278,474	-$9,787,217

(Circle) Best 5-year performance during period

Improve ARIMA results, even in stable HDD period, by increasing knowledge about regional climatology (see Annex)

Action Plan

- Introduce new Degree Day Forecasting Model to BC Hydro Load Forecasters and Meteorologists
- Train two BC Hydro employees (e.g., Load Research Analysts or Load Forecasters) to use the model
- Implement model for Degree Day Forecasting
  - Monitor performance month by month so that feedback from MAPE results helps develop expertise with appropriate use of climate index inputs
  - Monitor the climatology literature for new climate indices, applicable to the regional climate of BC, that may make the new model more powerful
  - Budget time and resources for regular experimentation with model to improve accuracy. According to Mansfield (1996; pages 4–6), HDD forecasting inaccuracies can result in large errors estimating electricity consumption and revenue. The sensitivity analyses and experiments with material effect confirmed Mansfield's statement. Diligent, scheduled experimentation with the proposed new forecasting model is likely to result in worthwhile improvements in HDD and CDD forecasting accuracy

References

AGU-American Geophysical Union (2009) *Eos*, Transactions, American Geophysical Union, Vol. 90, No. 23, Jun 9, 2009, Page 202

ASHRAE (2005, 2009) AHRAE Handbook—Fundamentals (SI). American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Chao, B. F.; Dehant, V.; Gross, R. S.; Ray, R. D.; Salstein, D. A.; Watkins, M.M.; and Wilson, C. R. (2000) Space Geodesy Monitors Mass Transports in Global Geophysical Fluids. *Eos*, Transactions, American Geophysical Union, Vol. 81, No. 22, May 30, 2000, Pages 247, 249 – 250

Day, Tony. (2006) *Degree-days: theory and application.* Technical Memorandum TM41: 2006. Chartered Institution of Building Services Engineers, London, UK

Florita, A. R. and Henze, G. P. (2009) Comparison of Short-Term Weather Forecasting Models for Model Predictive Control. *HVAC&R Research* **15** (5): 835–853

Kerr, R. A. (2009) What Happened to Global Warming? Scientists Say Just Wait A Bit. *Science* **326**: 28–29 (2 October 2009)

Manly, B. F. J. (2001) *Statistics for Environmental Science and Management*. Chapman & Hall / CRC

Mansfield Consulting Inc. (1996). *B.C. Hydro Evaluation of Alternative Projection Methods for Five Year Forecasts of Monthly Heating Degree Days*. Mansfield Consulting Inc., Suite 1700, 1111 West Georgia Street, Vancouver, BC, V6E 4M3 (May, 1996)

Meehl G. A.; Arblaster, J. M.; Matthes, K.; Sassi, F.; and van Loon, H. (2009) Amplifying the Pacific Climate System Response to a Small 11-Year Solar Cycle Forcing, *Science* **325**, 1114-1118 (28 August 2009)

Klock, R. and Mullock, J. (2001) *The Weather of British Columbia: Graphic Area Forecast 31*. Nav Canada. Retrieved Dec 11, 2009 from http://www.navcanada.ca/ContentDefinitionFiles/publications/lak/bc/3-BC31E.PDF

NIST/SEMATECH (2009). *NIST/SEMATECH e-Handbook of Statistical Methods*, http://www.itl.nist.gov/div898/handbook/, Accessed November 8, 2009

Rodionov, S. N.; Overland, J. E.; and Bond, N. A. (2005). The Aleutian Low and Winter Climatic Conditions in the Bering Sea. Part I: Classification. *Journal of Climate* **18**, 160–177.

Stellwagen, E. (2006) Forecasting 101: The MAPE, the MAD and the BIC. ForecastPRO. Business Forecast Systems, Inc. Retrieved Dec 10, 2009 from http://www.sistemasypronosticos.com/Trends/pdf/TrendsMay2006.pdf

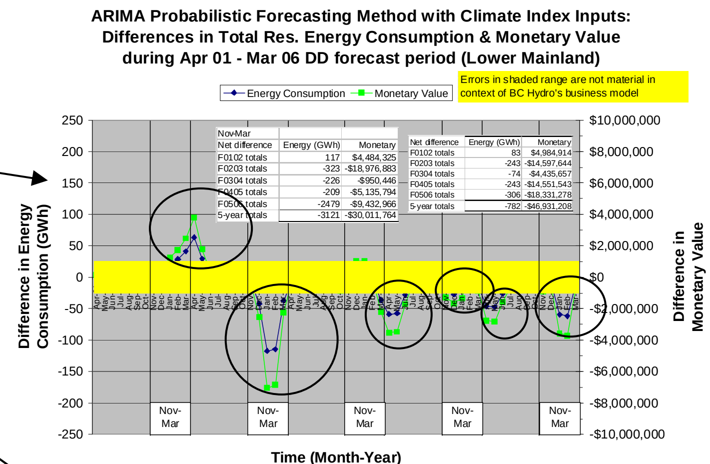
Technical University of Denmark (DTU) (2009, Oct 6). Cosmic Ray Decreases Affect Atmospheric Aerosols and Cloud. *ScienceDaily*. Retrieved Oct 7, 2009 from http://www.sciencedaily .com/releases/2009/08/090801095810.htm

Yazdi, F. M. (2009) Application of Neural Networks for 24-Hour-Ahead Load Forecasting. Proceedings of World Academy of Science, Engineering, and Technology 38: 593–596. Retrieved May 27, 2009 from http://www.waset.org/pwaset/v38/v38-101.pdf

Annex 1 (1 of 2) — Experiments with various climate input combinations to reduce forecasting errors

Test effect on forecasting accuracy of changing ARIMA climate inputs:

- Focus on Apr 01 to Mar 06 forecast errors
- Errors > $1 million revealed on Slide 135 (copy shown here; errors with material effect were circled)
- Forecast for Jan used climate indices PNAI and GMMTA
- Jan forecasts errors resulted in errors exceeding $1 million, each forecast year
- Revised forecast #1 used climate indices NPI, ALPI, and PNAI (based on chart, slide 109 showing ANOVA Prob > F was 0.0001 for these 3 indices)
- Revised forecast #2 used climate indices PNAI and LODI; rule #1 – [ANOVA Prob > F] < 0.05; rule #2 – correlation coefficient relating indices , r < 0.5
- Results of revised forecasts are tabulated on the next slide
- Discovering proper combination of climate indices to use for a month is crucial for accurate forecasting with ARIMA method
- Once best combination for a month is found, use it for all new forecasts involving that month
- This method recognizes regional climate processes
- Improved understanding of BC's climate in each BCH sales region can improve forecasting accuracy — refer to slide 152 "Action Plan"



Strength of fit between HDD Vancouver and climate indices by month

HDD data for 1953-2009

	ANOVA Prob > F							
Month	**MSSN**	**GMMTA**	**SOI**	**LODI**	**PDO**	**NPI**	**ALPI**	**PNAI**
Apr	0.2364	0.0003	0.027	0.0768	0.0001	0.0001	0.0407	0.0002
May	0.2175	0.083	0.0138	0.162	0.0002	0.0001	0.5862	0.0165
Jun	0.3675	0.0338	0.0127	0.0856	0.003	0.1437	0.0523	0.0108
Jul	0.5708	0.0017	0.8259	0.0055	0.164	0.1291	0.3396	0.0486
Aug	0.9341	0.0001	0.0456	0.0009	0.047	0.022	0.0011	0.5412
Sep	0.6987	0.0099	0.16	0.1705	0.0881	0.0001	0.4403	0.7963
Oct	0.547	0.0251	0.2499	0.0568	0.2143	0.0027	0.1751	0.0001
Nov	0.9692	0.0205	0.8835	0.551	0.0479	0.0015	0.0472	0.0001
Dec	0.2038	0.106	0.1632	0.2203	0.0563	0.0001	0.7625	0.0001
Jan	0.4936	0.0006	0.5112	0.0529	0.0002	0.0001	0.0001	0.0001
Feb	0.5609	0.0049	0.1296	0.8037	0.0004	0.0001	0.0001	0.0001
Mar	0.5594	0.0002	0.0001	0.7747	0.0001	0.0001	0.0001	0.0001

Note: Decision for which of tied values to use was made by choosing fit with highest R^2 (bolded cells)

BC hydro FOR GENERATIONS

Annex

Annex 1 (2 of 2)

Annex 1 Tables

3 climate patterns with significant relationships to Vancouver HDD; but correlation coefficients high between them

Rev No. 1: NPI, ALPI, PNAI

Jan Year	Old error as monetary value (PNAI and GMMTA)	New error as monetary value	Change in error value = |new value| - |old value|	Change in error value trend
2002	$1,260,859	$447,984	-$812,875	Decrease
2003	$7,055,327	$7,055,327	$0	No change
2004	$1,019,316	$7,939	-$1,011,377	Decrease
2005	$1,322,049	-$5,251,258	$3,929,209	Increase
2006	-$3,584,093	-$6,066,937	$2,482,844	Increase
Five-year totals	**$7,073,458**	**-$3,806,945**	**-$3,266,513**	**Decrease**

2 climate patterns with significant relationships to Vancouver HDD; but correlation coefficients low between them

Rev No. 2: PNAI and LODI

Jan Year	Old error as monetary value (PNAI and GMMTA)	New error as monetary value	Change in error value = |new value| - |old value|	Change in error value trend
2002	$1,260,859	$447,984	-$812,875	Decrease
2003	$7,055,327	$6,185,981	-$869,346	Decrease
2004	$1,019,316	-$167,826	-$851,490	Decrease
2005	$1,322,049	-$5,042,767	$3,720,718	Increase
2006	-$3,584,093	$2,296,911	-$1,287,182	Decrease
Five-year totals	**$7,073,458**	**$3,720,283**	**-$3,353,175**	**Decrease**

Improvements in ARIMA forecasting quality, resulting from changing climate index input combinations, are highlighted in green

Results make it appear worthwhile to continue experiments but need to consider cost and benefits.