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

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Context and Take-away Message

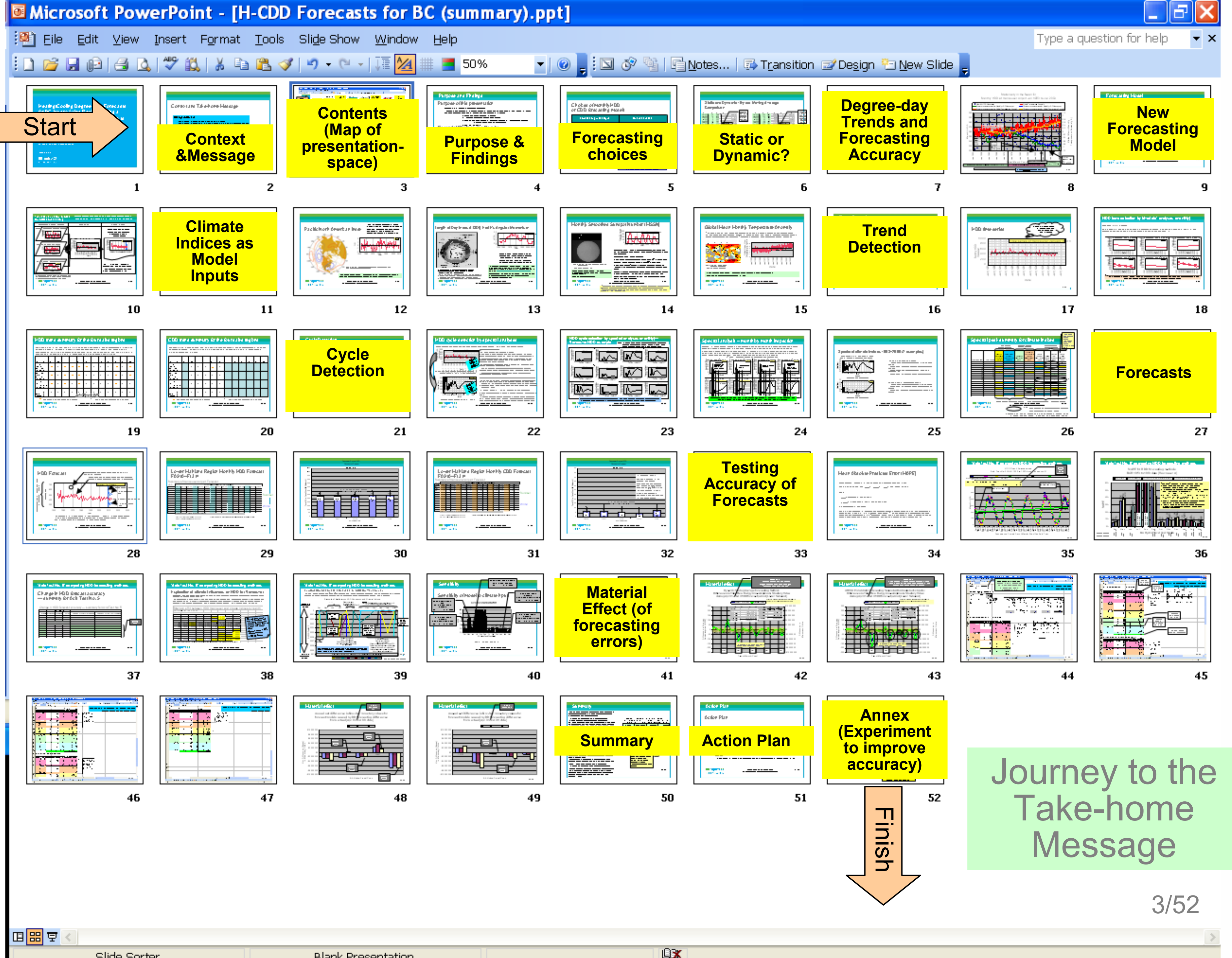
Audience: Managers directing analysts and forecasters implementing degree-day forecasting improvements

BC Hydro Context

- Degree-day forecasting accuracy could be better
- Degree-day forecasting errors have costs in BC Hydro's business model
- More accurate degree-day forecasting is beneficial for BC Hydro

Take-away Message

- Forecasting with moving average methods (as done now) gives acceptable accuracy but inherently offers limited scope for improvement
- Forecasting with new probabilistic model with climate signal inputs has potential for significant accuracy gains
  - Needs further research and development before operational use


Microsoft PowerPoint - [H-CDD Forecasts for BC (summary).ppt]
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Purpose and Findings

Purpose of this presentation

- Summary of a full-length presentation document
- Proposes a new method of forecasting heating or cooling degree days (HDD or CDD, H-CDD, or simply DD) while assessing accuracy of moving average methods of forecasting
  - 5-year (60 unique monthly) forecasts
  - Probabilistic model with climate signal inputs
  - Incorporates understanding of physical processes of regional climate system
    - Climate indices used as model inputs
  - SAS JMP software

Essential Findings and Results

1. Degree-day forecasting methods using static or dynamic moving averages were tested and evaluated and found to be capable of acceptable accuracies (quantified in the full-length document)
2. A forecasting method for degree-days which used a probabilistic model with inputs related to regional climate information was tested and evaluated quantitatively while improving knowledge about climatic factors influencing seasonality of degree-days in BC
3. Developed tools for testing and comparing objectively various forecasting methods
4. Tests and comparisons confirmed that new probabilistic model, by using climate information inputs, has potential for improved accuracy as analysts increase their knowledge about BC's regional climate processes. *This potential was one motivating factor for developing the new model.*

Page or Slide Number references are to the full-length document

Literature references are provided in the "References" section of the full document

Choices of monthly HDD or CDD forecasting models

Forecasting model type	Characteristics
Moving Average (Static)	Each month, although separated by one year, takes on **same predicted** HDD or CDD value for, say, five years of monthly HDD or CDD forecasts. Simple to implement in a spreadsheet; No provisions for dealing with non-stationarity in a Degree Day time series
Moving Average (Dynamic)	Each month, separated by one year, takes on a **new predicted** HDD or CDD value for, say, five years of monthly HDD or CDD forecasts. Simple to implement in a spreadsheet; No provisions for dealing with non-stationarity in a Degree Day time series
Integrated Auto Regressive Moving Average (ARIMA); **Probabilistic Model with Climate Inputs**	More complex than moving average models, but this is compensated for by: (1) the ability to deal with non-stationarity in the Degree Day time series; (2) ease of experimenting with physical process inputs such as climate indices which offers insights into ways of improving forecasting accuracy
Neural Nets (NNs)	Most complex of the four model types; Can be good predictor but NNs are strictly empirical; May obscure insights into physical processes affecting the Degree Day time series and consequent forecasting accuracy

Focus on probabilistic ARIMA model because it has greatest potential for accurate forecasting during an era experiencing global climate change

Static and Dynamic 10-year Moving Average Comparison

	A	B	C	D	E	F
	Apr-1993	255	258.7			0.01451
	May-1993	111	165.9			0.494595
	Jun-1993	72	84.6			0.175
	Jul-1993	53	30.3			0.428302
	Aug-1993	35	26.2			0.251429
	Sep-1993	106	112.1	Forecast year 1		0.057547
	Oct-1993	200	237.2			0.186
	Nov-1993	402	354.6			0.11791
	Dec-1993	412	458.0			0.11165
	Jan-1994	351	441.5			0.257835
	Feb-1994	433	409.3			0.054734
161	Mar-1994	324	336.2			0.037654
	Apr-1994	222	258.7			0.165315
	May-1994	130	165.9			0.276154
	Jun-1994	90	84.6			0.06
	Jul-1994	19	30.3			0.594737
	Aug-1994	8	26.2			2.275
	Sep-1994	74	112.1	Forecast year 2		0.514865
	Oct-1994	235	237.2			0.009362
	Nov-1994	393	354.6			0.09771
	Dec-1994	414	458.0			0.10628
	Jan-1995	413	441.5			0.069007
	Feb-1995	382	409.3			0.071466
173	Mar-1995	335	336.2			0.003582

Mar-1994: Cell C161 =0.1*(B41+B53+B65+B77+B89+B101+B113+B125+B137+B149)

Mar-1995: Cell C173 =C161

Static – forecast copied from year to year. Mar-1995 value remains equal to Mar-1994 value and so on

A	B	C	D	E	F	G
Apr-1993	255	258.7	258.7			0.01451
May-1993	111	165.9	165.9			0.494595
Jun-1993	72	84.6	84.6			0.175
Jul-1993	53	30.3	30.3			0.428302
Aug-1993	35	26.2	26.2			0.251429
Sep-1993	106	112.1	112.1	Forecast year 1		0.057547
Oct-1993	200	237.2	237.2			0.186
Nov-1993	402	354.6	354.6			0.11791
Dec-1993	412	458.0	458.0			0.11165
Jan-1994	351	441.5	441.5			0.257835
Feb-1994	433	409.3	409.3			0.054734
Mar-1994	324	336.2	336.2			0.037654
Apr-1994	222		258.9			0.166081
May-1994	130		168.7			0.297615
Jun-1994	90		84.6			0.060444
Jul-1994	19		28.5			0.501579
Aug-1994	8		26.9			2.365
Sep-1994	74		109.1	Forecast year 2		0.474459
Oct-1994	235		235.3			0.001362
Nov-1994	393		358.6			0.087634
Dec-1994	414		451.0			0.089372
Jan-1995	413		444.3			0.075666
Feb-1995	382		414.0			0.083848
Mar-1995	335		338.9			0.011701

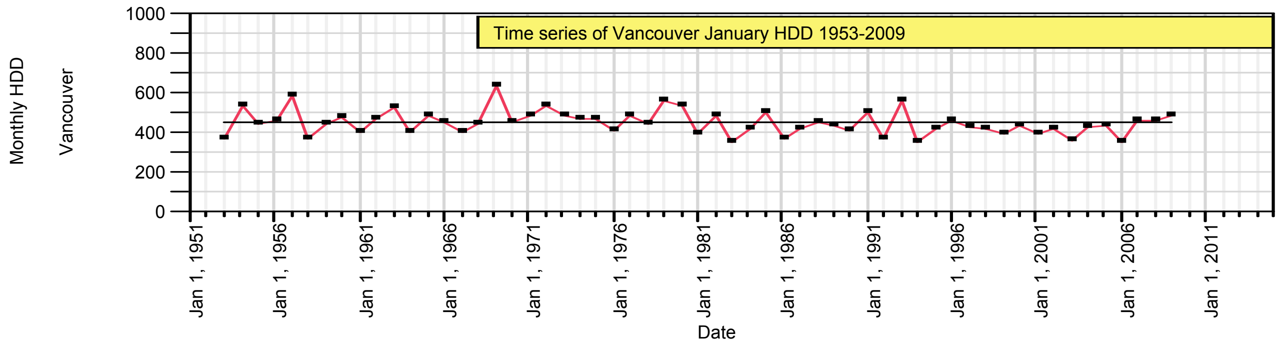
Mar-1994: Cell D161=0.1*(B41+B53+B65+B77+B89+B101+B113+B125+B137+B149)

Mar-1995: Cell D173=0.1*(B53+B65+B77+B89+B101+B113+B125+B137+B149+D161)

Dynamic – first year same as static; calculation of average for month of Mar in following year drops monthly value from “year one” (B41) and includes monthly value from what was previously ”year eleven” (D161). Mar-1995 value is now different from Mar-1994 value

Degree-day Trends and Forecasting Accuracy

Stationarity in the mean for Vancouver HDD

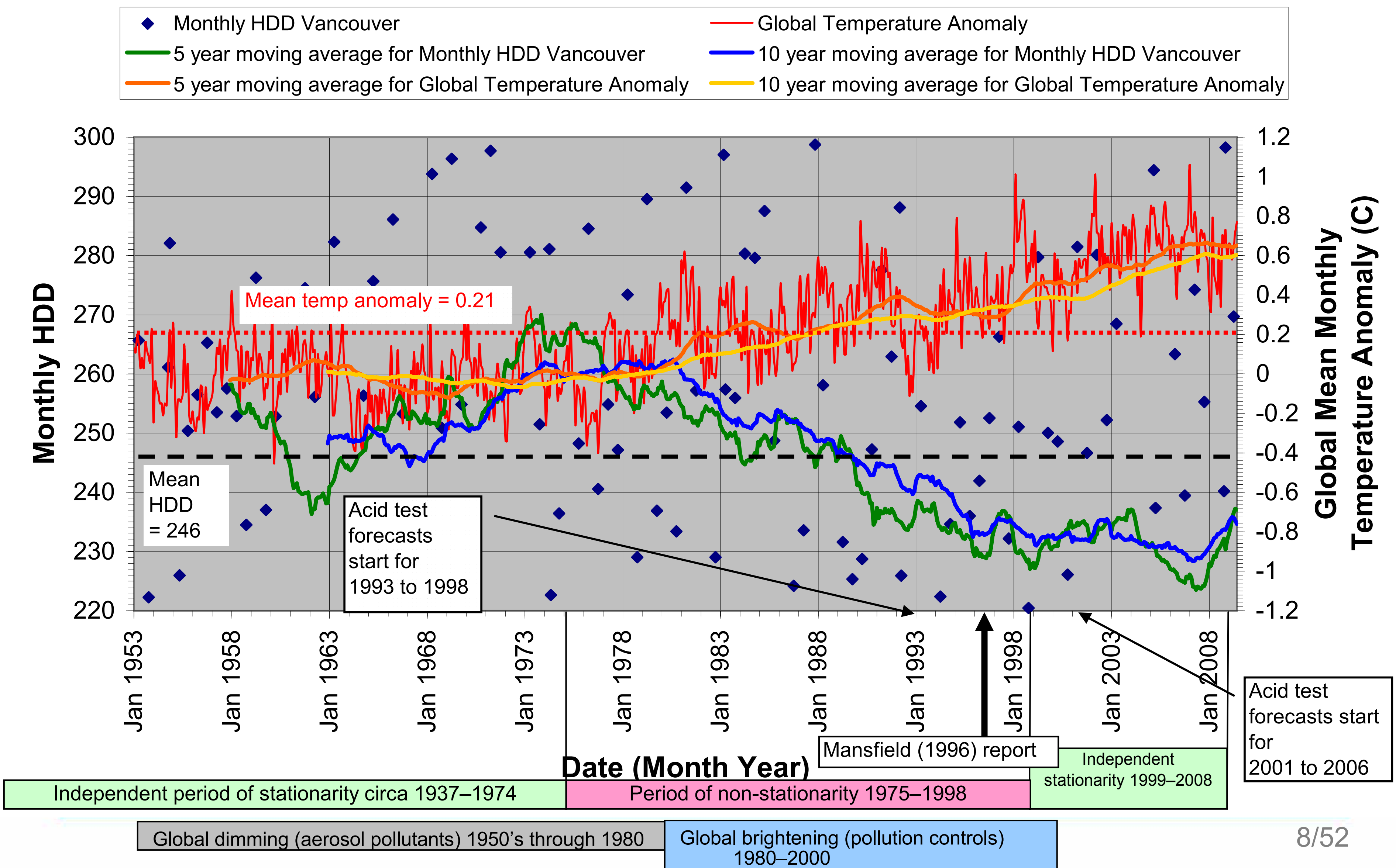


A time series is stationary or exhibits stationarity in the mean if, “the mean, variance, and autocorrelations in the series are constant with time.” (Manly, 2001, page 212)

Autocorrelation refers to the phenomenon of a later time series value, separated by a time lag of defined period from an earlier value, being dependent on the earlier value.

Relevance to DD forecasting: Moving average methods are sufficiently accurate during periods of stationarity but accuracy suffers when DD’s have an increasing or decreasing trend. *This was another motivating reason for research and development of a probabilistic model with climate signal inputs.*

Stationarity in the Mean for Monthly HDD at Vancouver Airport Jan 1953 to Jun 2009



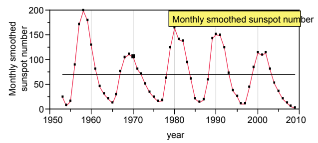
Proposed H-CDD Forecasting Model

Transfer Function Model for HDD Forecasting

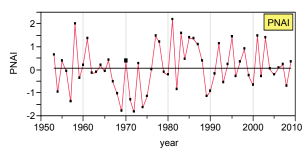
Monthly climate model uses as inputs those climate signals relevant to BC. This example is for January HDD, Vancouver

Inputs Series (Physical Processes)	Noise Series	Output / Forecast

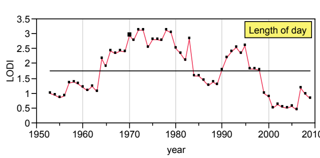
Monthly Smoothed Sunspot Number



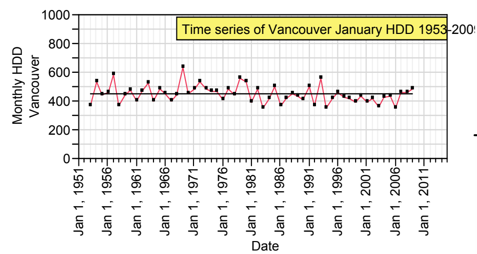
Pacific North American Index



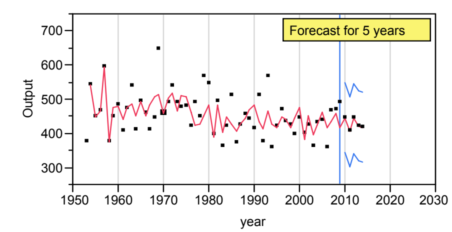
Earth's Angular Momentum Index



HDD Time Series at Station



Integrated autoregressive moving average (ARIMA) probabilistic transfer function model



Result: a five year forecast for monthly HDD, incorporating signals from physical processes operating in the regional climate of BC

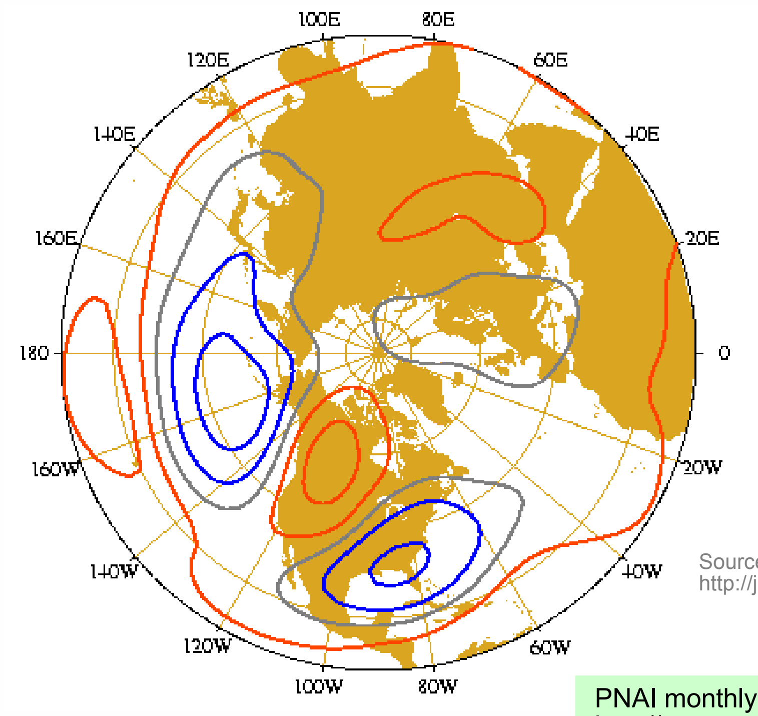
Global Monthly Mean Temperature Anomaly was an additional input for some stations and months. Other climate signal inputs are easily used.

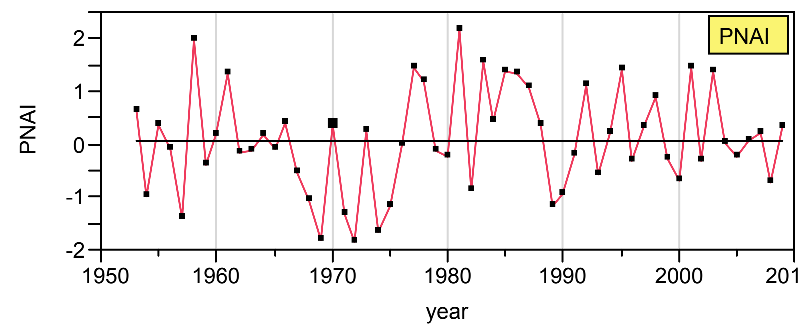
Climate indices as model inputs

- Pacific North American Index
- Earth's Angular Momentum Index
- Monthly Smoothed Sunspot Number
- Global Mean Monthly Temperature Anomaly

Pacific North American Index

PNAI represents intensities of 4 major pressure cells surrounding North America (and BC). Intensities and geographical distribution of cells influences air temperature (therefore H-CDD) in BC

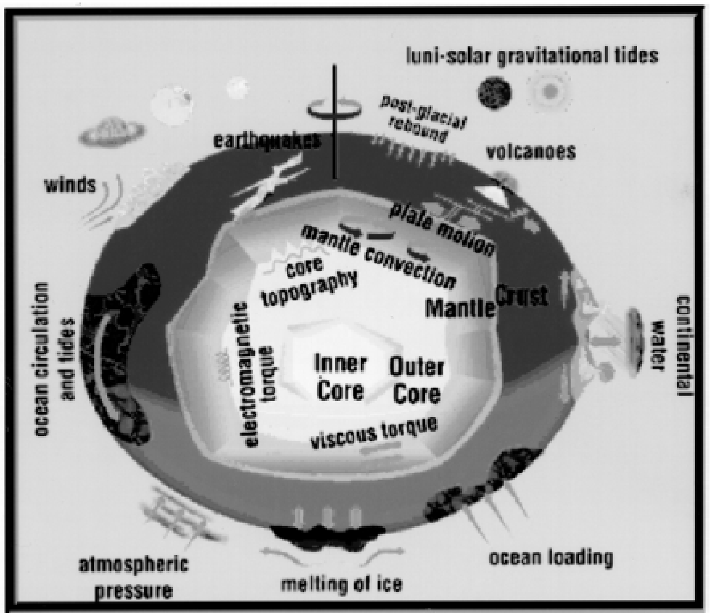




Source for graphic: Joint Institute for the Study of the Atmosphere and Ocean; http://jisao.washington.edu/data_sets/pna/

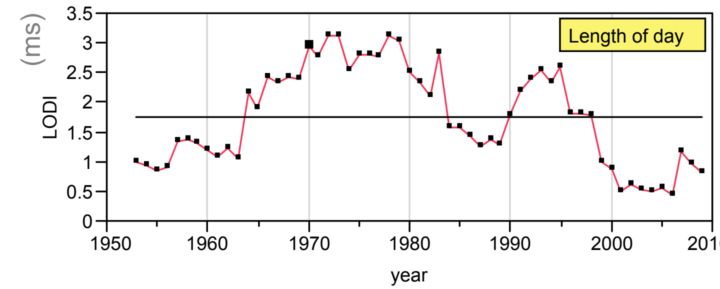
PNAI monthly data is available from the USA's NOAA / National Weather Service at http://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/pna_index.html

Length of Day Index (LODI): Earth's Angular Momentum



Geophysical fluid processes that involve large-scale mass transports and produce variations in Earth's rotation, gravity field, and geocentre.

Figure is from: 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.



Index of major storm activity in Earth system (e.g. related to El Niño events). These events affect sea surface temperatures offshore BC, hence land air temperature and H-CDD across BC

LODI monthly data (starting 1962) is available from ANALYTICAL GRAPHICS, INC. # CENTER FOR SPACE STANDARDS & INNOVATION # EARTH ORIENTATION PARAMETERS (EOP) DATA at http://celestrak.com/SpaceData/eop19620101.txt

Annual values from 1953-1961 are available from Fisheries and Oceans Canada at http://www.pac.dfo-mpo.gc.ca/sci/sa-mfpd/climate/clm_indx_lod.htm

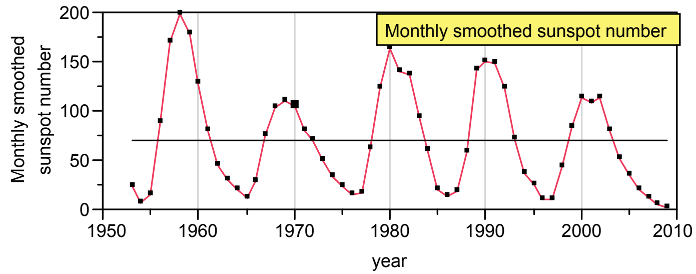
Monthly Smoothed Sunspot Number (MSSN)

Source for graphic: Australian Government IPS Radio and Space Services;

http://www.ips.gov.au/Solar/3/3/1

MSSN monthly data is available from Royal Observatory of Belgium, SIDC – Solar Influences Data Analysis Center at

http://sidc.oma.be/sunspot-data/



Sunspots are cooler regions of concentrated magnetic fields on the Sun's surface. As they increase in number, recent research* suggests the effect on the Earth is that:

-low-altitude cosmic radiation decreases

-Less aerosols (physical mechanism remains unclear) → 4– 5% less clouds

-Sunlight reaching oceans increases by 2 W/m^2 → Oceans warm

Other recent research** invoked stratospheric response of ozone to solar radiation forcing and described an amplifying mechanism reducing low level clouds

Southern Oscillation Index (El Niño/El Niña events) spectral analysis showed a peak related to the 11 year solar cycle of sunspot activity (later slide)

MSSN was used in analyses if a strong 11 year peak appeared in monthly HDD or CDD spectra by month

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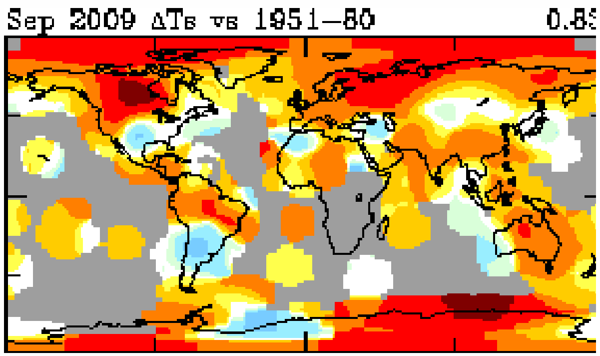
- *Technical University of Denmark (DTU) (2009, Oct 6). Cosmic Ray Decreases Affect Atmospheric Aerosols and Cloud. *ScienceDaily*. Retrieved Oct 7, 2009 from http://www.sciencedaily .com/releases/2009/08/090801095810.htm
- ** Meehl and others (2009) Amplifying the Pacific Climate System Response to a Small 11-Year Solar Cycle Forcing, *Science* **325**, 1114-1118 (28 August 2009)

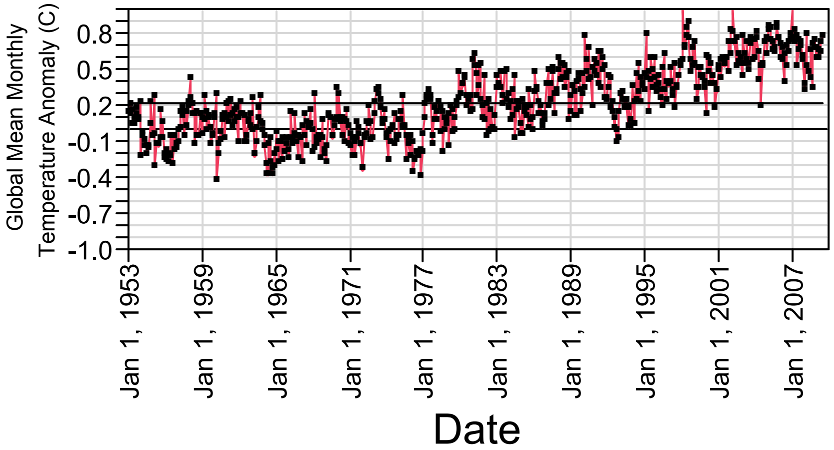
Global Mean Monthly Temperature Anomaly

"The NASA GISS Surface Temperature Analysis (GISTEMP) provides a measure of the changing global surface temperature with monthly resolution for the period since 1880, when a reasonably global distribution of meteorological stations was established." (Summary statement from Global Change Master Directory)



Source for graphic: NASA Goddard Institute for Space Studies;

http://data.giss.nasa.gov/gistemp/



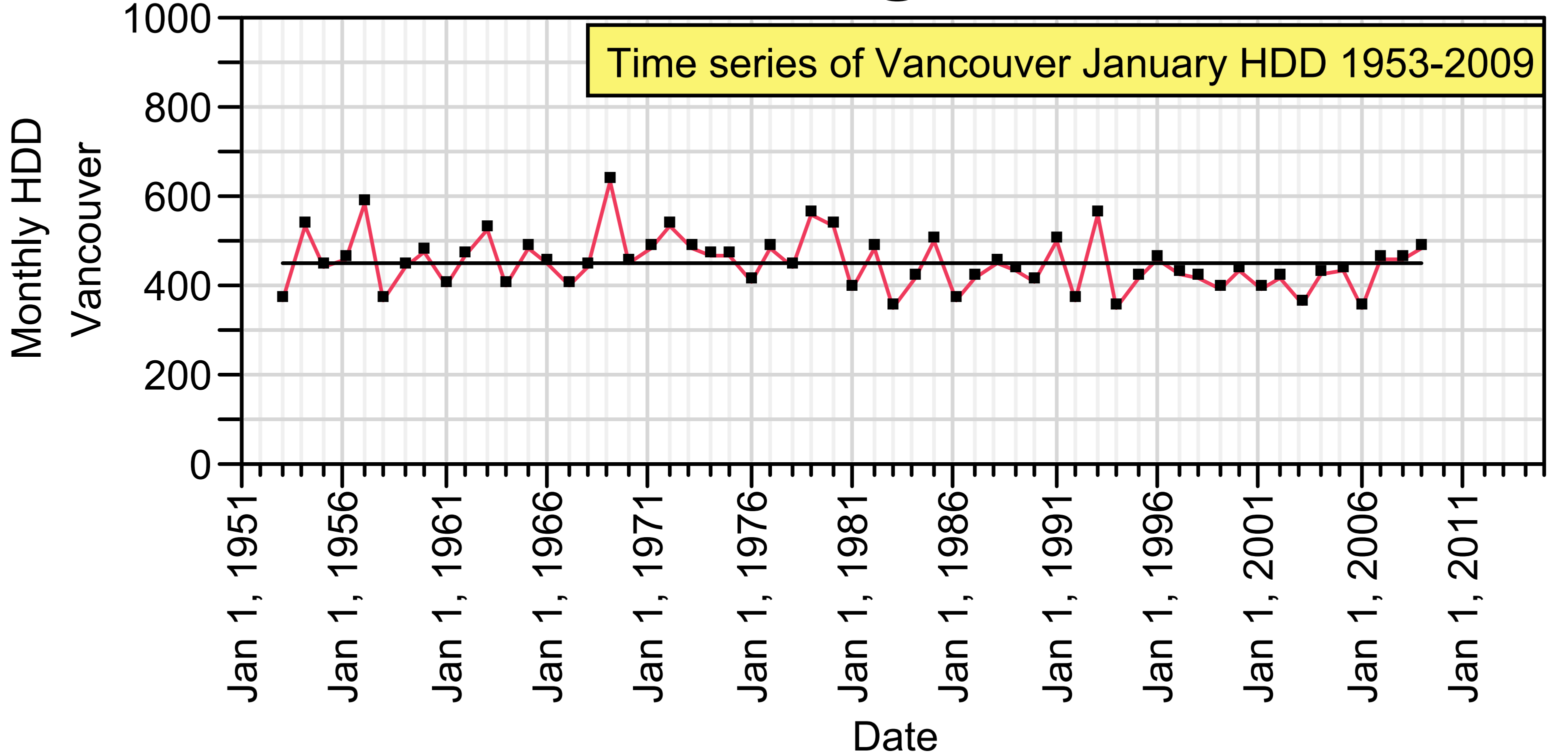
GMMTA monthly data is available from NASA's Goddard Institute for Space Studies (GISS), at http://data.giss.nasa.gov/gistemp/tabledata/GLB.Ts.txt

H-CDD Trend Detection by Bivariate Analyses

Bivariate analysis is a statistical technique for exploring the association between two variables.

HDD time series

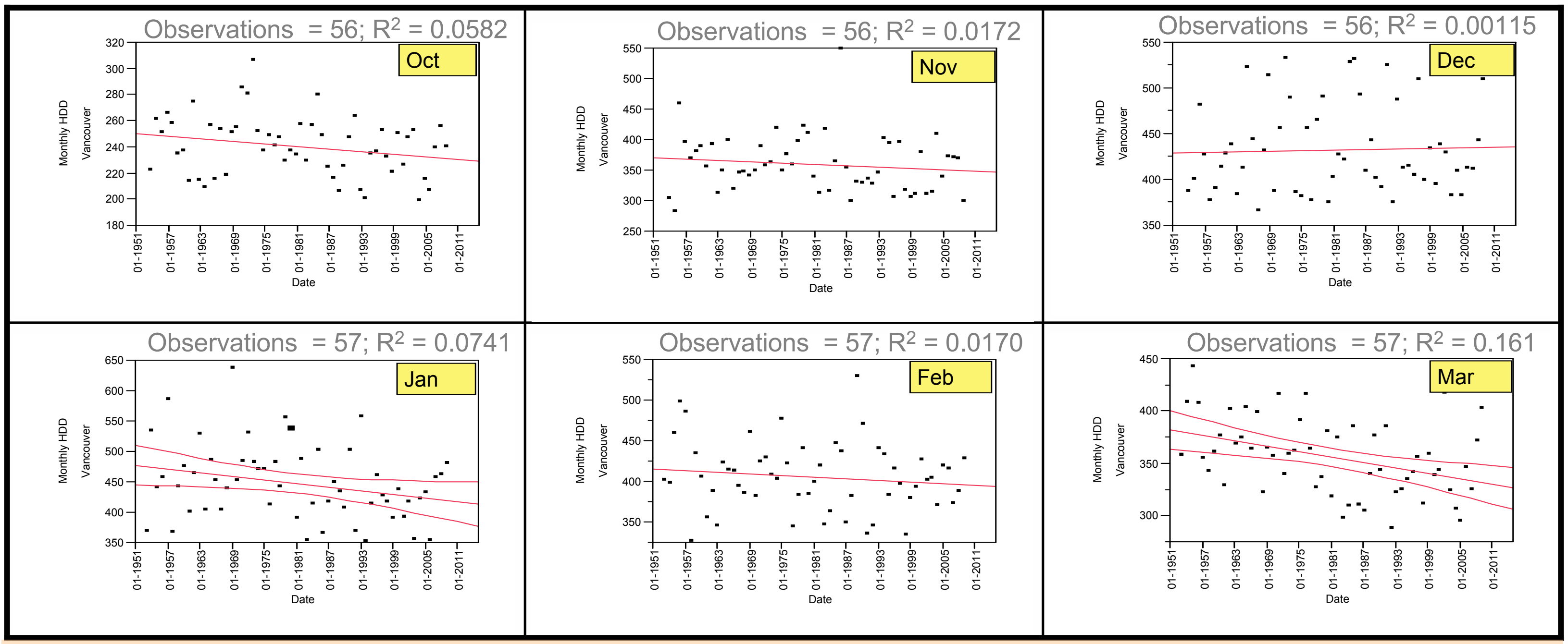
Gather information about ***climate trends and cycles*** to improve HDD forecasts



HDD trend detection by bivariate* analyses (monthly)

Vancouver HDD, Oct–Mar

HDD trends are revealed when data is examined by month. Significant trends were found for the months whose charts have 0.05 confidence curves about the linear fit.



** Bivariate analysis is a statistical technique for exploring the association between two variables. Here, association is based on how monthly HDD varies over time; ANOVA = Analysis of Variance; F-test is an index of model significance*

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HDD trend summary for the four sales regions

Decreasing HDD in Jan, Mar and Apr are likely to have the most effect on consumption of electricity by electric heaters. The lack of trends in Kamloops data may be a result of the relatively short observation period (16 years) compared to the other three regions (57 years). ***Decreasing HDD are consistent with observed global climate change warming temperature trends***

Month/Station	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Lower Mainland: Vancouver 1953-2009	▼	▬	▼	▼	▼	▼	▬	▬	▬	▼	▬	▼
Vancouver Island: Victoria 1953-2009	▼	▬	▼	▼	▼	▬	▬	▬	▬	▼	▬	▼
Northern Region: Prince George 1953-2009	▼	▬	▼	▬	▼	▬	▬	▬	▬	▼	▬	▬
South Interior: Kamloops 1994-2009	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬

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

▼ Decreasing HDD significant at 0.05 level

▬ Trend in HDD not significant at 0.05 level

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CDD trend summary for the four sales regions

Increasing CDD in May through Sep were likely to have the most effect on consumption of electricity by cooling systems. ***Increasing CDD were consistent with observed global climate change warming temperature trends***

Month/Station	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Lower Mainland: Vancouver 1953-2009		▬	▬	▬	▲	▬						
Vancouver Island: Victoria 1953-2009		▬	▬	▬	▬	▬						
Northern Region: Prince George 1953-2009		▬	▬	▬	▬	▬						
South Interior: Kamloops 1994-2009		▬	▬	▬	▬	▬						

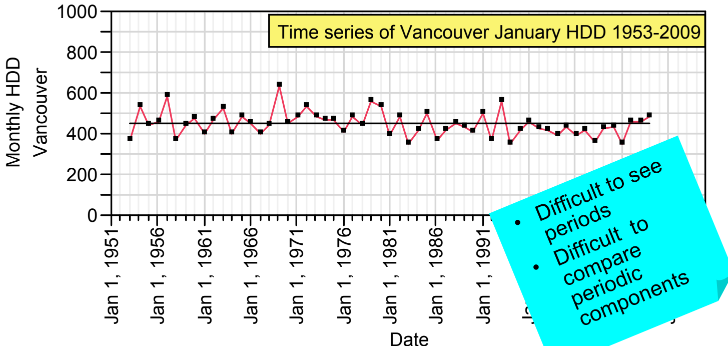
▲ Increasing CDD significant at 0.05 level

▬ Trend in CDD not significant at 0.05 level

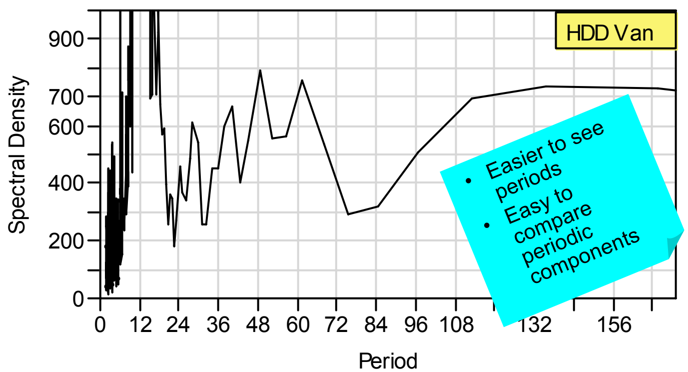
H-CDD Cycle Detection by Spectral Analyses

HDD cycle detection by spectral analyses

Plotting monthly HDD values against time (date) is natural and intuitive. This is called *time domain analysis*.



Software transforms time domain to frequency domain (using a Fourier transform method)



Months (each vertical grid- line is 1 year)

Time domain view of data

The formula, Monthly HDD Vancouver = f (date),

is the *function* or *signal* describing how HDD varied with time. This signal is shown in the time series chart (left). Periods are difficult to see and compare.

A signal can be the sum of several other signals or components. The HDD signal at a climate station was the result of energy gains or losses by the atmosphere surrounding the station.

The local atmosphere at a station gained or lost energy in response to various climatic components, each with their signal:

- Energy from sun or human-caused climate change (Monthly Smoothed Sunspot Number signal or Global Monthly Mean Temperature Anomaly signal)
- Movement and distribution of cyclones (low pressure systems) and air masses (various climate index signals)

Frequency domain view of data (spectral density vs. period or frequency)

The purpose of transforming from time to frequency domain was to quantify the portion of a signal's power (energy per unit time or density) falling within given frequency bins. Bins showed up as peaks and valleys according to the distribution of the signal's power for the duration of the observations (in this case, 1953-2009).

Frequency = 1/period.

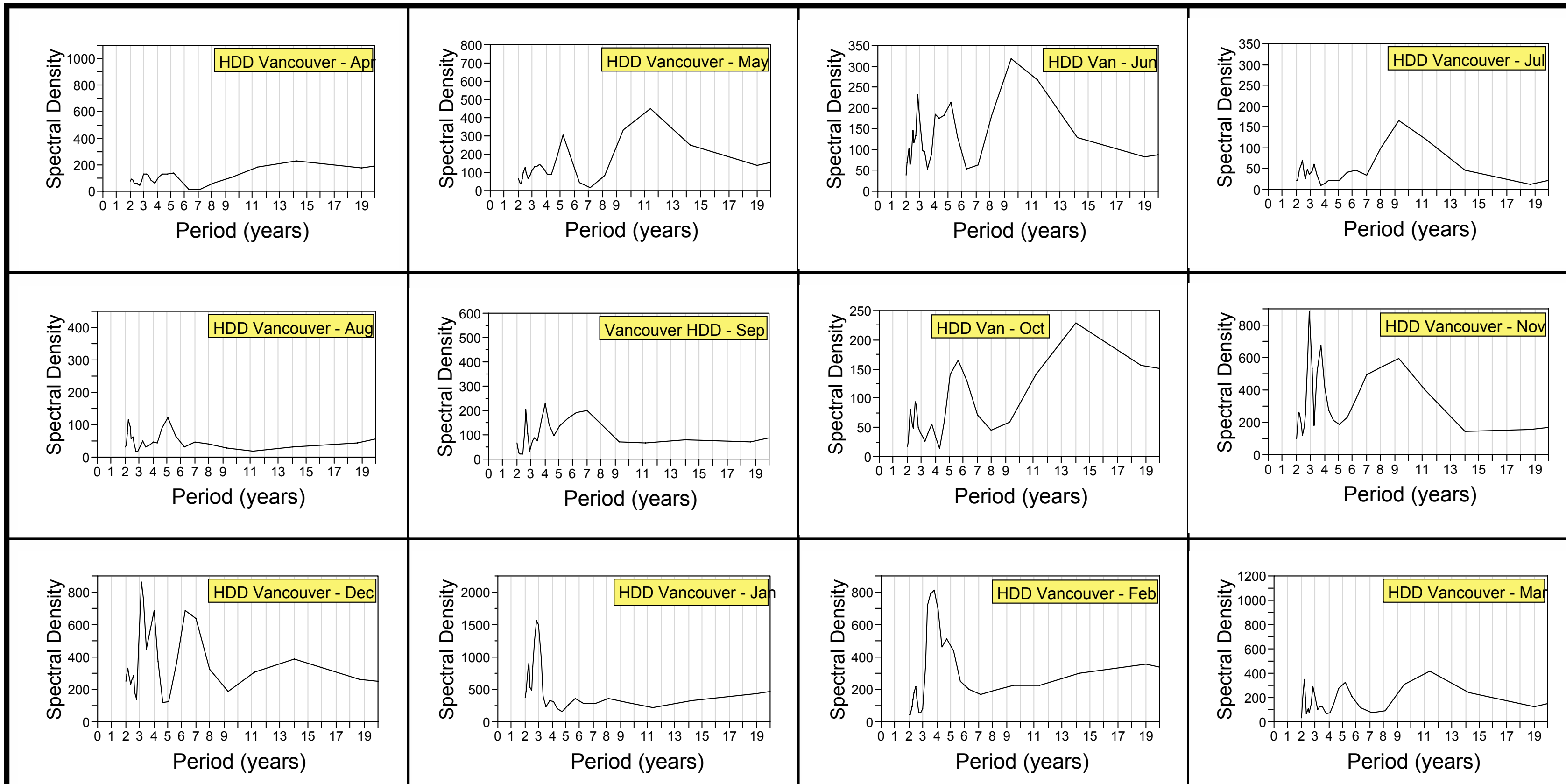
For example, a period of 11 years = 132 months = 0.0076 cycles/month

A peak at 60 months meant a relatively strong HDD signal was repeated every 5 years.

Periodicities (cycles) in the data and relative strengths of periodic components were revealed, making it easier to decide, by visual inspection and comparison, which climate components were influencing the HDD signal at a climate station.

HDD cycle detection by spectral analyses (monthly)—Vancouver HDD example

Note: For ease of viewing peaks, spectral density scale was not kept constant between monthly charts. The scale provides relative values to compare peaks within a single month's chart



Spectral density scale varies between monthly charts: Period is more meaningful than spectral density magnitude for determining which components of regional climate system are influencing monthly HDDs at climate station.

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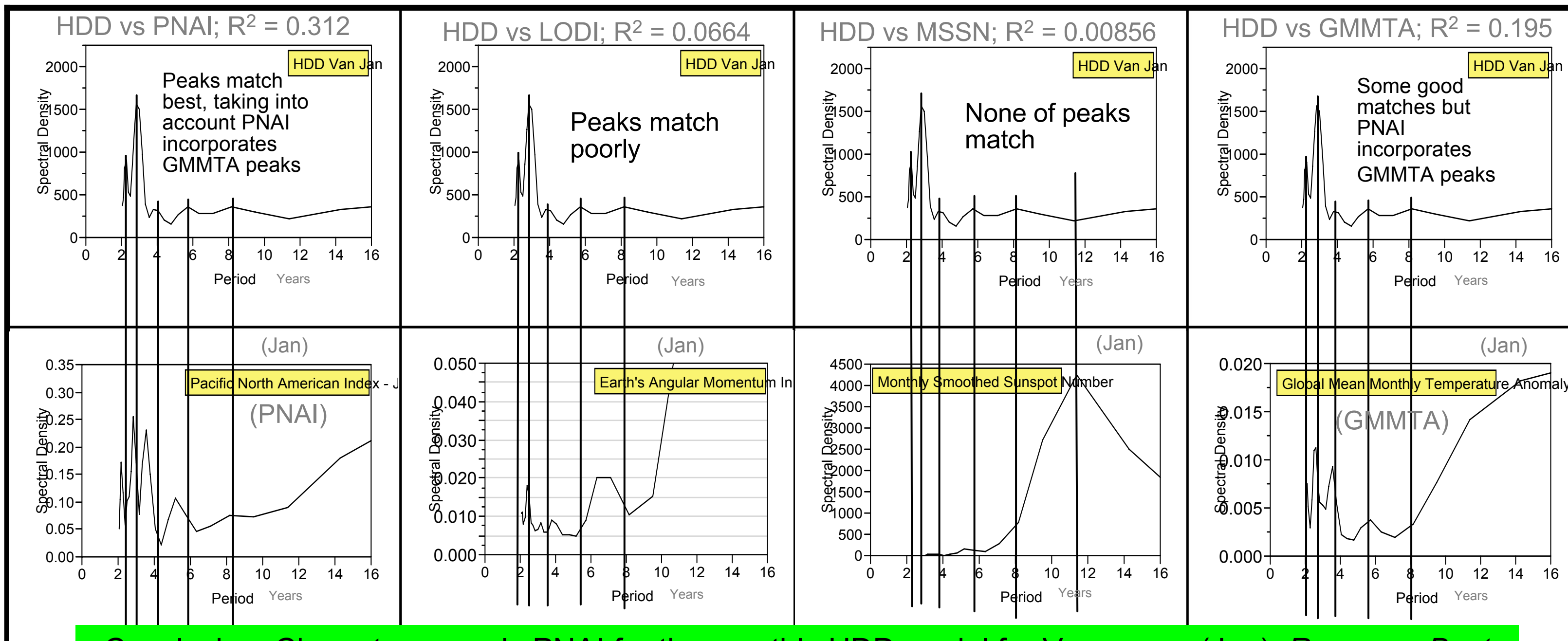
Spectral analysis – month by month inspection

Method: For same month, compare each climate index spectrum to HDD spectrum (visually inspect peaks and check alignments). On this basis, decide which climate indices to use as inputs to probabilistic climate model. Bivariate analyses for station's HDD and climate indices (as discussed earlier) can reinforce decision. Alignments of period values can be checked exactly on periodogram tables which tabulate the data from which spectral density charts are produced

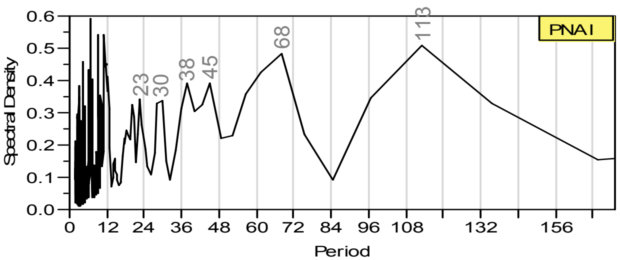
R^2 values from bivariate analyses are shown at top each column (n = 57)



<u>Conclusion:</u> Chose to use only PNAI for the monthly HDD model for Vancouver (Jan). *Reasons: Best match of peaks; reinforced by relatively high R^2 value from earlier bivariate analyses.*

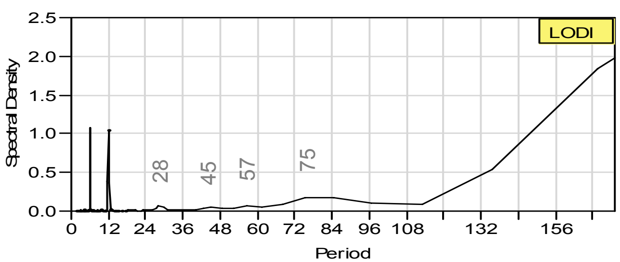
Spectra of climate indices 1953–2009 (2 examples)

These spectra are from full set of data years, these are not spectra by month



Months

Vertical lines are at one year intervals



Months

Vertical lines are at one year intervals

Pacific North American Index

- Periodogram prominent peaks (months): 113, 68, 45, 38, 30, and 23
- Shows peaks from Monthly Smoothed Sunspot Number (68 and 23)
- Shows a peak from Global Mean Monthly Temperature Anomaly (113)
- Shows peaks from Southern Oscillation Index (45 and 30)

Earth's Angular Momentum Index

- Periodogram prominent peaks (months): 75, 57, 45, and 28
- Shows peaks from Southern Oscillation Index at 57 and 45 months
- Shows peak from Monthly Smoothed Sunspot Number at 28 months

Spectral peak summary for climate indices

PNAI is the only index to include peaks representing all three of MSSN, GMMTA, and SOI

Primary global climate processes (Monthly Smoothed Sunspot Number; Global Mean Monthly Temperature Anomaly) — Secondary global climate processes (Southern Oscillation Index; Length of Day (Earth's Angular Momentum) Index) — Continental-scale climate processes (Pacific Decadal Oscillation Index; North Pacific Index; Aleutian Low Pressure Index; Pacific North American Index)

Peak (months)	Peak (years)	Monthly Smoothed Sunspot Number	Global Mean Monthly Temperature Anomaly	Southern Oscillation Index	Length of Day (Earth's Angular Momentum) Index	Pacific Decadal Oscillation Index	North Pacific Index	Aleutian Low Pressure Index	Pacific North American Index
21			X			X			?
22							X	X	
23	1.9	X				X			X
26	2.2		X			X			
27	2.3			X					
28	2.3	X			X		X		
30	2.5			X				X	X
31	2.6		X						
38	3								X
40	3					X	X	X	
42	4	X	X						
45	4			X	X				X
57	5			X	X				
68	6	X	X			X	X	X	X
75	6				X	?			
97	8							X	?
113	9		X			X	X		X
136	11	X		X					

Cycles originate with these processes (Monthly Smoothed Sunspot Number; Global Mean Monthly Temperature Anomaly; Southern Oscillation Index)

These processes embed cycles from global processes (Length of Day Index; Pacific Decadal Oscillation Index; North Pacific Index; Aleutian Low Pressure Index; Pacific North American Index)

Circled peaks (22 months: North Pacific Index and Aleutian Low Pressure Index; 38–40 months: Pacific Decadal Oscillation, North Pacific, Aleutian Low Pressure and Pacific North American indices; 75 months: Length of Day Index; 97 months: Aleutian Low Pressure Index)

(oval) ? = cycles apparently unrelated to global climate processes; further investigation in literature is required

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GMMTA + SOI together accounted for greatest number of peaks in this set of indices; This was relevant to Acid Test No. 6 experiment, Slide 112.

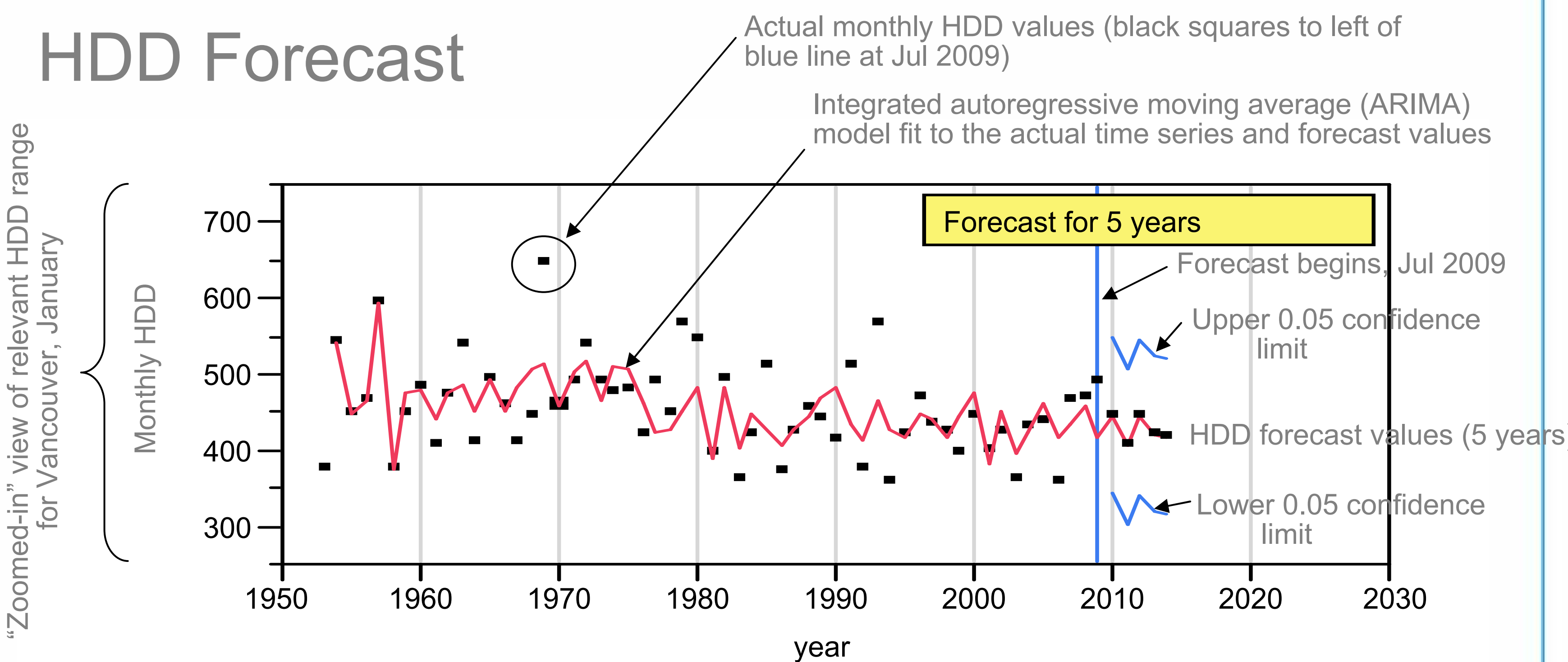
H-CDD Forecasts
for F0910 through F1314

Classification of months into Summer, Winter, and Shoulder seasons, according to number of heating degree days, was done using the hierarchical clustering tool in the JMP software. A separate classification was done for each fiscal year, yielding a five-year forecast for the seasons.

Done for all sales regions but only Lower Mainland results are shown in this summary.

Please see the full-length report for forecasts for all four sales regions.

HDD Forecast



This example of a forecast chart is for HDD Vancouver, January. For each climate station, 12 different forecast models were produced, one for each month. A total of 60 monthly HDD forecast values were calculated for each climate station.

Lower Mainland Region Monthly HDD Forecast F0910–F1314

Summary of Vancouver Airport Forecast

HDD	ARIMA-based forecast for five fiscal years														
Month	**F0910**	***Up CL***	***Lo CL***	**F1011**	***Up CL***	***Lo CL***	**F1112**	***Up CL***	***Lo CL***	**F1213**	***Up CL***	***Lo CL***	**F1314**	***Up CL***	***Lo CL***
Apr	265	*313*	*217*	261	*309*	*213*	240	*290*	*190*	261	*315*	*207*	288	*344*	*232*
May	170	*218*	*122*	220	*268*	*172*	221	*271*	*171*	187	*239*	*135*	175	*227*	*123*
Jun	54	*100*	*8*	35	*81*	*-11*	53	*99*	*7*	81	*127*	*35*	65	*111*	*19*
Jul	24	*58*	*-10*	18	*52*	*-16*	23	*59*	*-13*	24	*60*	*-12*	23	*61*	*-15*
Aug	37	*69*	*5*	0	*34*	*-34*	9	*43*	*-25*	26	*60*	*-8*	32	*72*	*-8*
Sep	79	*133*	*25*	93	*151*	*35*	101	*161*	*41*	102	*162*	*42*	117	*179*	*55*
Oct	244	*280*	*208*	242	*282*	*202*	241	*281*	*201*	240	*280*	*200*	240	*280*	*200*
Nov	359	*437*	*281*	359	*437*	*281*	359	*437*	*281*	359	*437*	*281*	359	*437*	*281*
Dec	410	*486*	*334*	421	*497*	*345*	435	*511*	*359*	426	*502*	*350*	423	*499*	*347*
Jan	440	*550*	*330*	442	*552*	*332*	438	*548*	*328*	459	*571*	*347*	430	*542*	*318*
Feb	431	*481*	*381*	413	*463*	*363*	381	*431*	*331*	408	*464*	*352*	411	*471*	*351*
Mar	358	*394*	*322*	339	*379*	*299*	326	*366*	*286*	315	*355*	*275*	345	*387*	*303*
Total	**2871**	***3519***	***2223***	**2843**	***3505***	***2181***	**2827**	***3497***	***2157***	**2888**	***3572***	***2204***	**2908**	***3610***	***2206***

Summer

Winter

Shading denotes month in shoulder season

Up CL = Upper confidence limit (5%)
Lo CL = Lower confidence limit (5%)

Negative degree day values are interpreted as a forecast of zero

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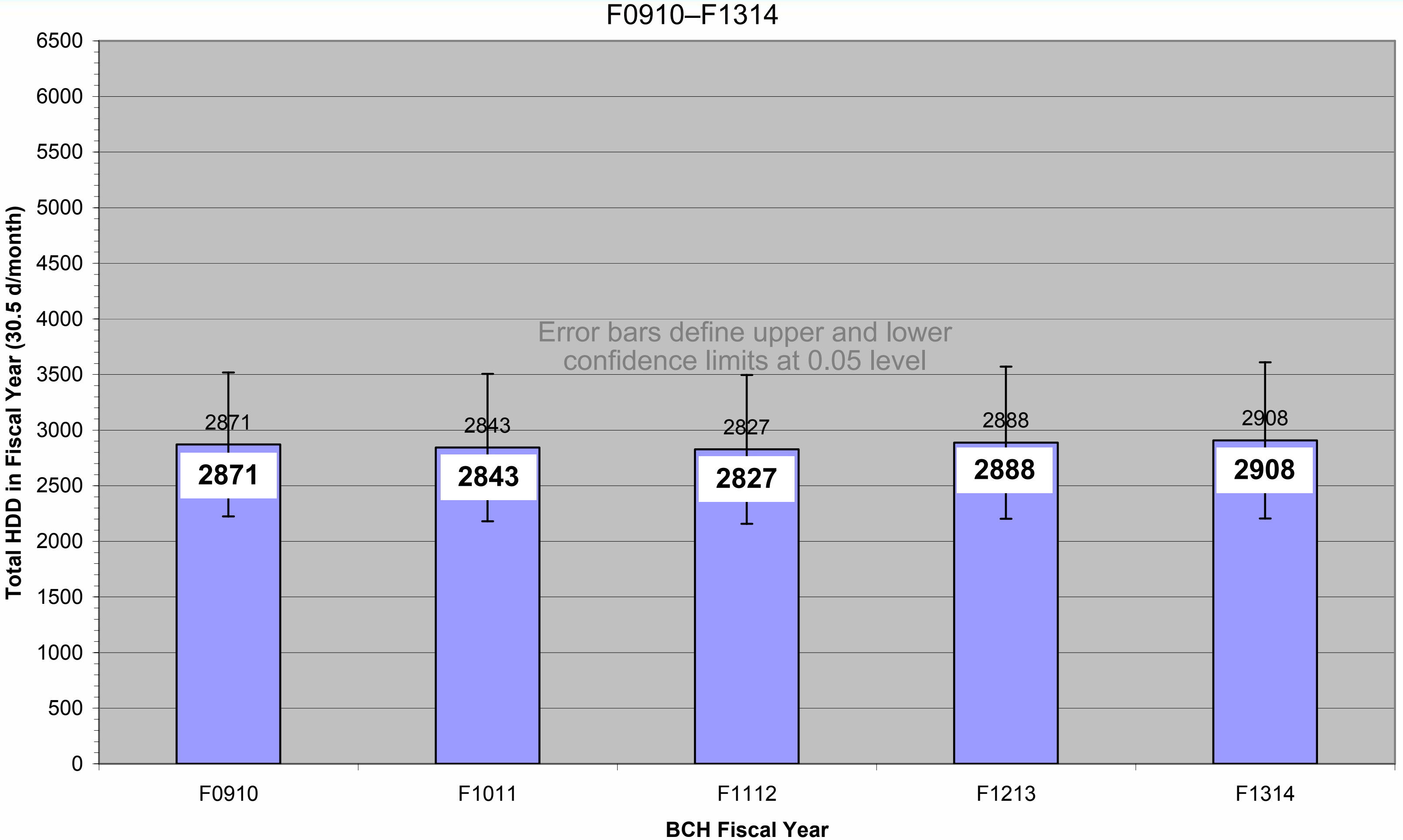
Forecast Annual HDD
Vancouver Airport



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Lower Mainland Region Monthly CDD Forecast F0910–F1314

Summary of Vancouver Airport Forecast

CDD	ARIMA-based forecast for five fiscal years														
Month	**F0910**	***Up CL***	***Lo CL***	**F1011**	***Up CL***	***Lo CL***	**F1112**	***Up CL***	***Lo CL***	**F1213**	***Up CL***	***Lo CL***	**F1314**	***Up CL***	***Lo CL***
Apr	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*
May	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*
Jun	9	*9*	*9*	7	*21*	*-7*	7	*21*	*-7*	7	*21*	*-7*	7	*21*	*-7*
Jul	34	*60*	*8*	36	*62*	*10*	28	*54*	*2*	12	*36*	*-12*	45	*71*	*19*
Aug	19	*49*	*-11*	25	*55*	*-5*	24	*54*	*-6*	23	*53*	*-7*	26	*56*	*-4*
Sep	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*
Oct	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*
Nov	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*
Dec	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*
Jan	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*
Feb	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*
Mar	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*	0	*0*	*0*
Total	**62**	***118***	***6***	**68**	***138***	***-2***	**59**	***129***	***-11***	**42**	***110***	***-26***	**78**	***148***	***8***

Summer

Winter

Shading denotes month in shoulder season

Up CL = Upper confidence limit (5%)
Lo CL = Lower confidence limit (5%)

Negative degree day values are interpreted as a forecast of zero

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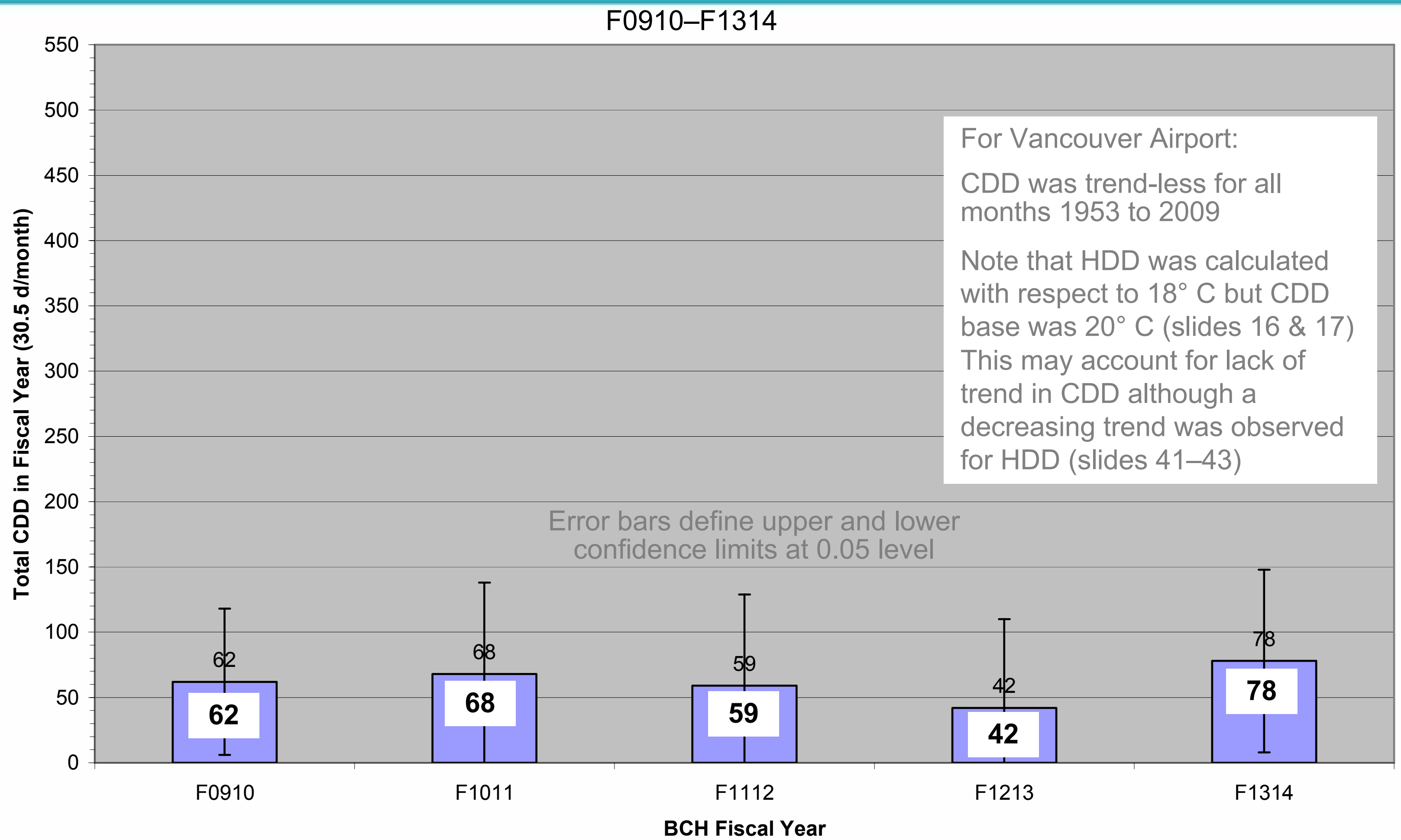
Forecast Annual CDD
Vancouver Airport



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Testing Accuracy of Forecasts

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

Test predicted against actual HDD

- Residuals (not in summary; see full report)
- Correlation coefficient, R (not in summary; see full report)
- Mean Absolute Percentage Error (MAPE)
- "Acid Test" (selected tests; see full report for all tests)

Mean Absolute Predicted Error (MAPE)

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

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

where

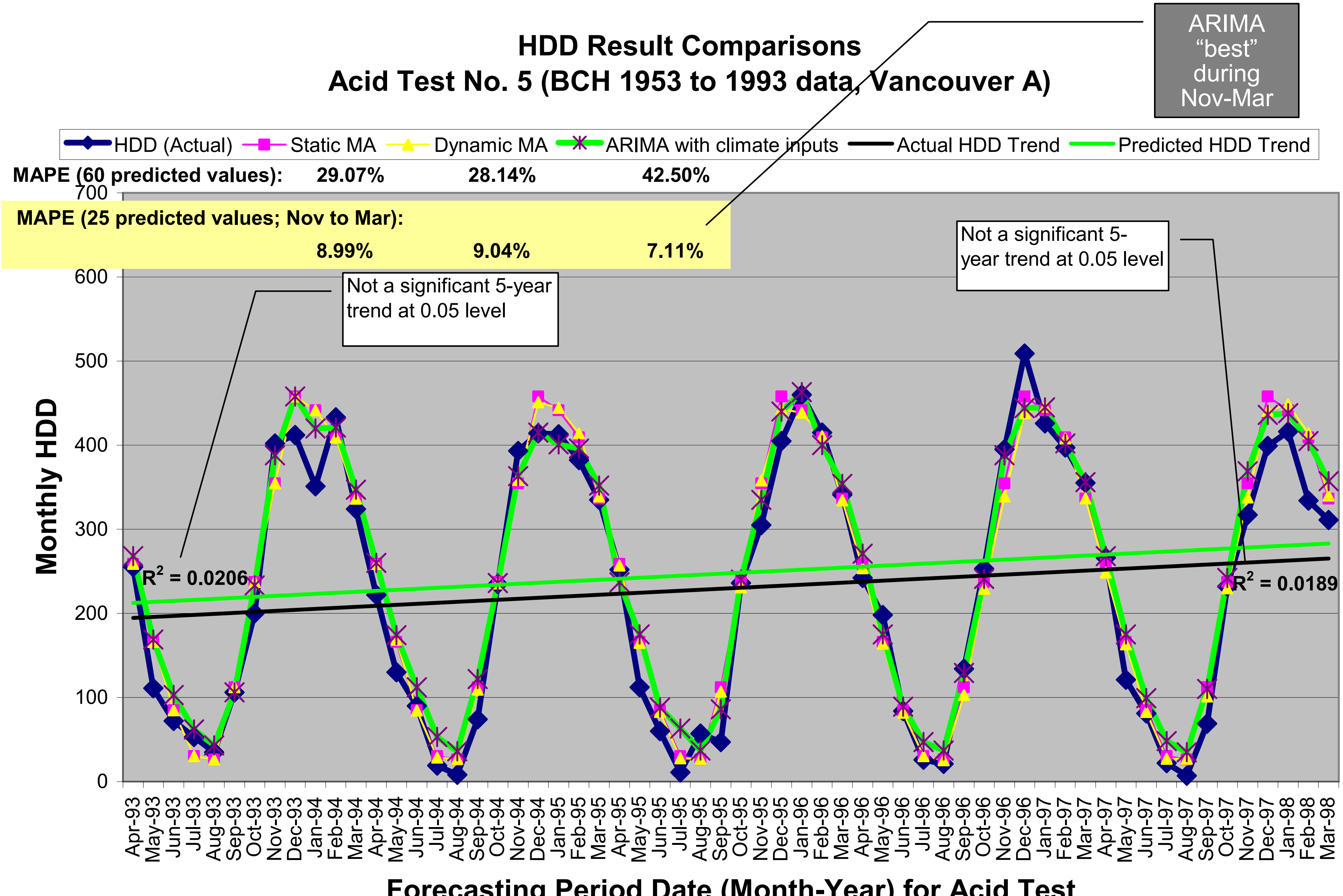
$P_{actual\ i}$ = actual HDD or CDD on day i,

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

N = total number of data points.

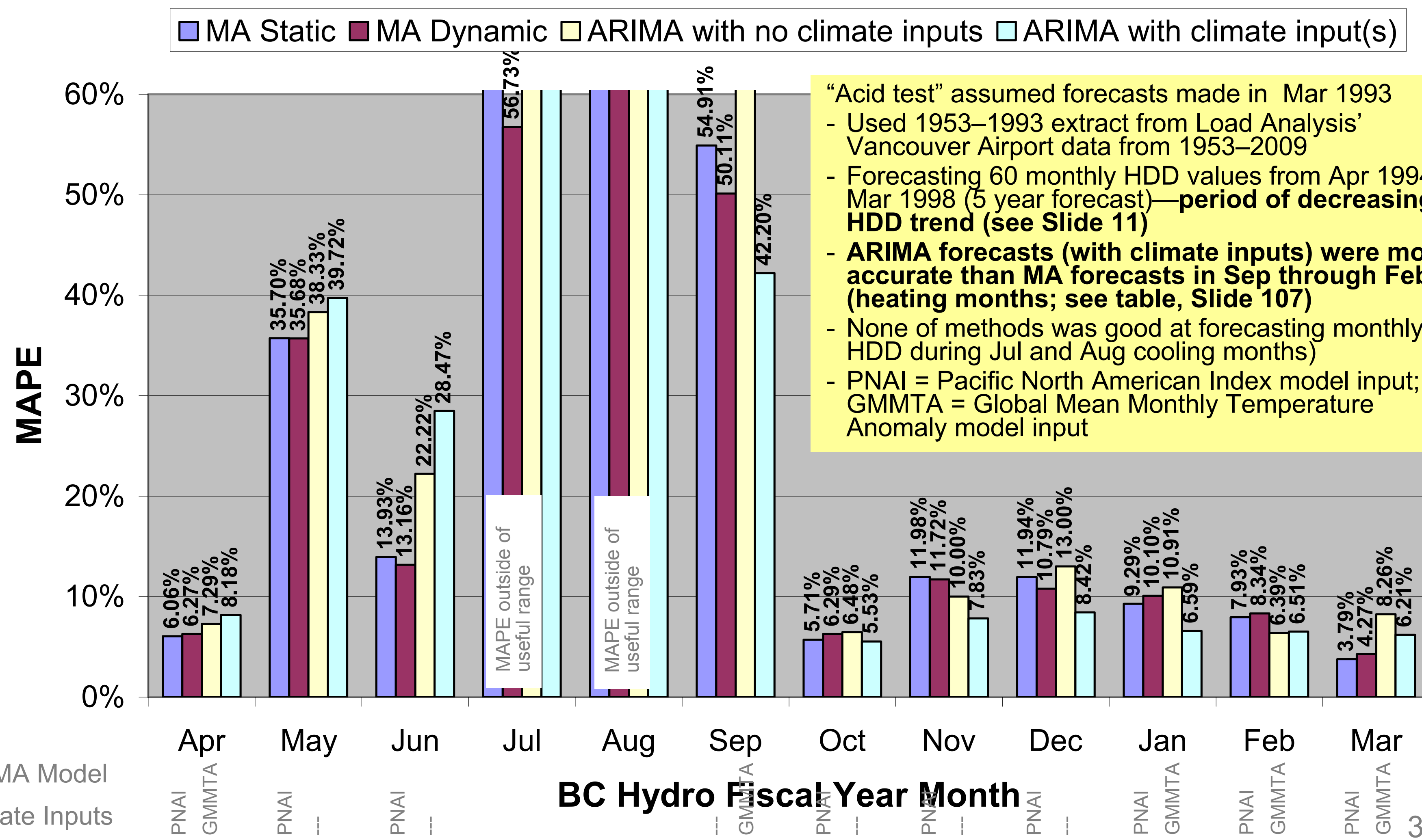
MAPE is a useful statistic for quantifying the amounts by which predicted values differed from actual values of some variable. A MAPE of 19%, for example, would tell us, "…on average the difference between the fitted values and the actual values is 19%." (Stellwagen, 2006). MAPE is the standard for load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

“Acid Test No. 5” comparing HDD forecasting methods



“Acid Test No. 5” 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 (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" (Sep–Feb)

"Acid Test No. 5" comparing HDD forecasting methods

Exploration of climate influences on HDD for Vancouver

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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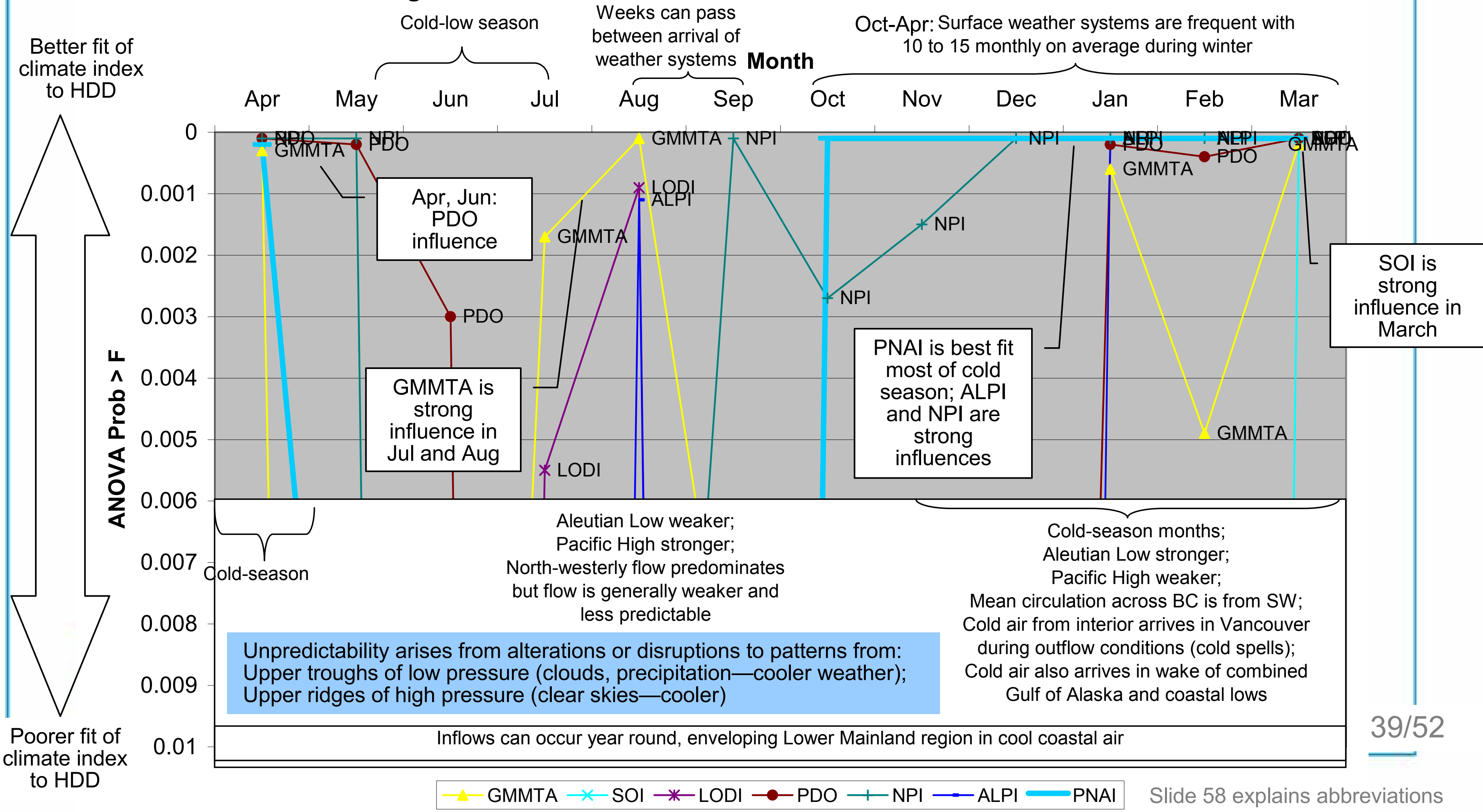
“Acid Test No. 5” comparing HDD forecasting methods

Exploration of climate influences on HDD for Vancouver

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.

Strength of fits between HDD Vancouver and Climate Indices



Slide 58 explains abbreviations

Sensitivity

Sensitivity of model to climate inputs

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

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

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

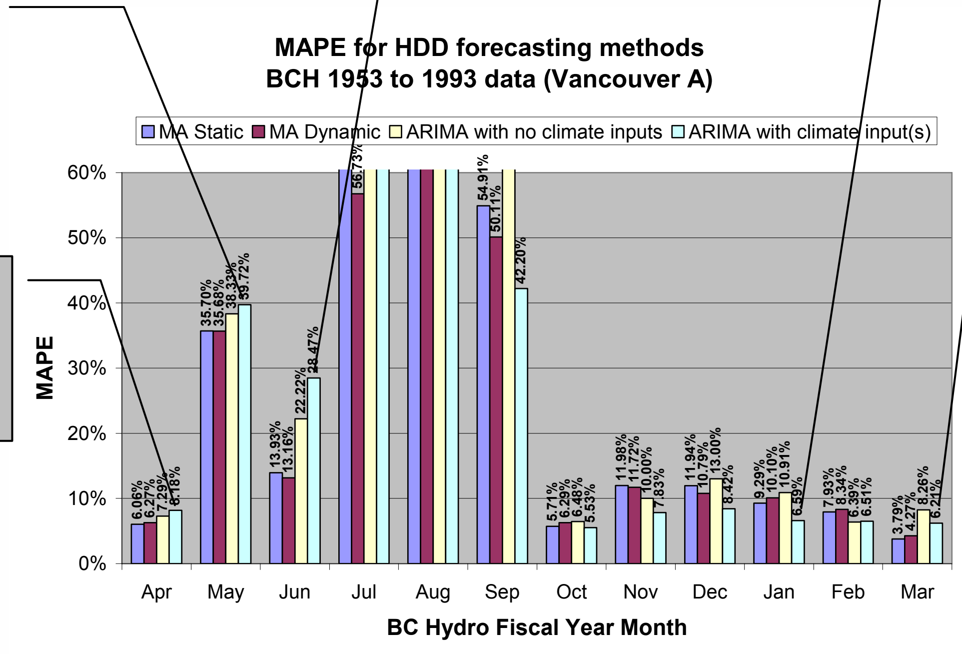
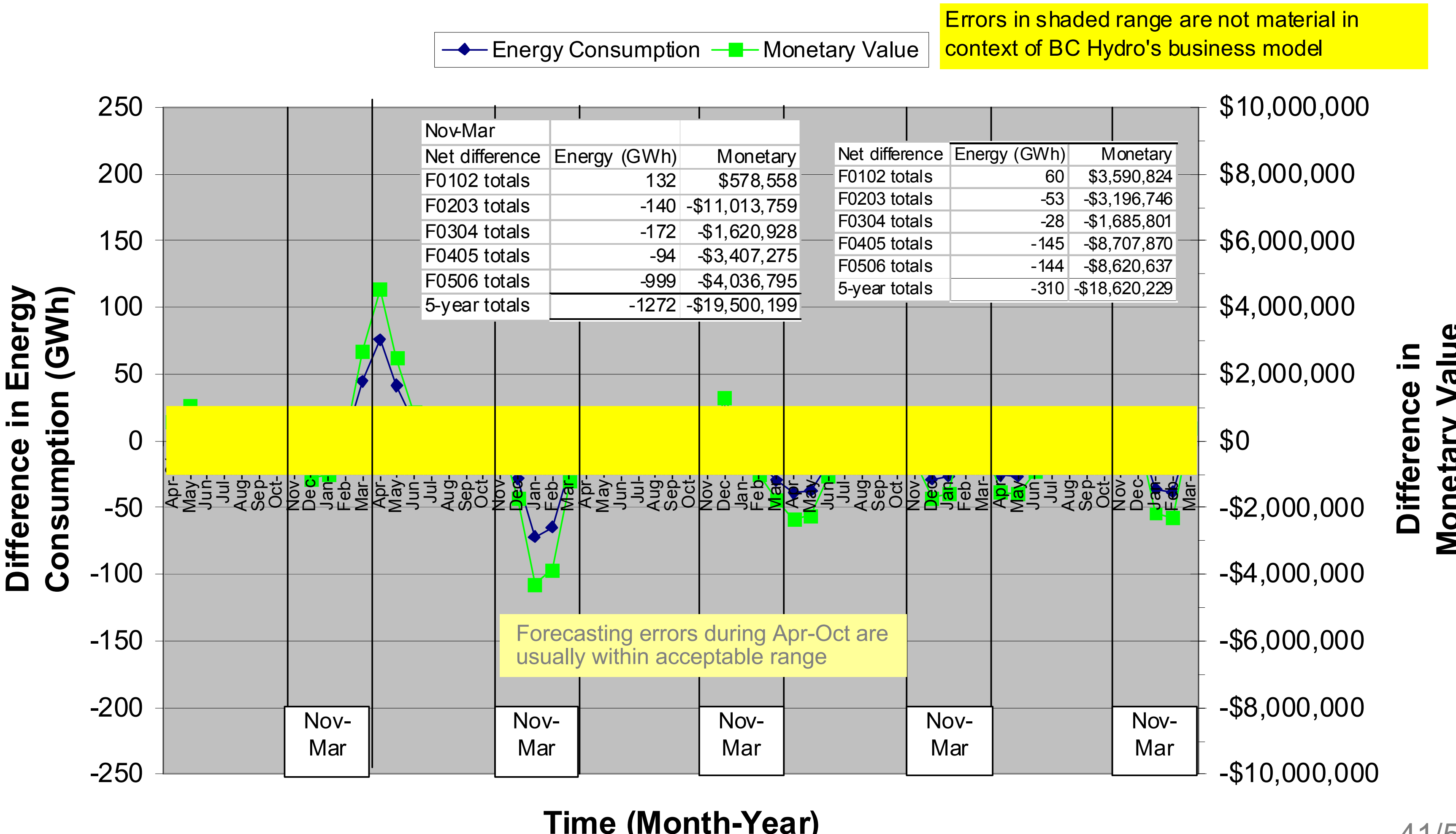


Chart from Acid Test No. 5

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)



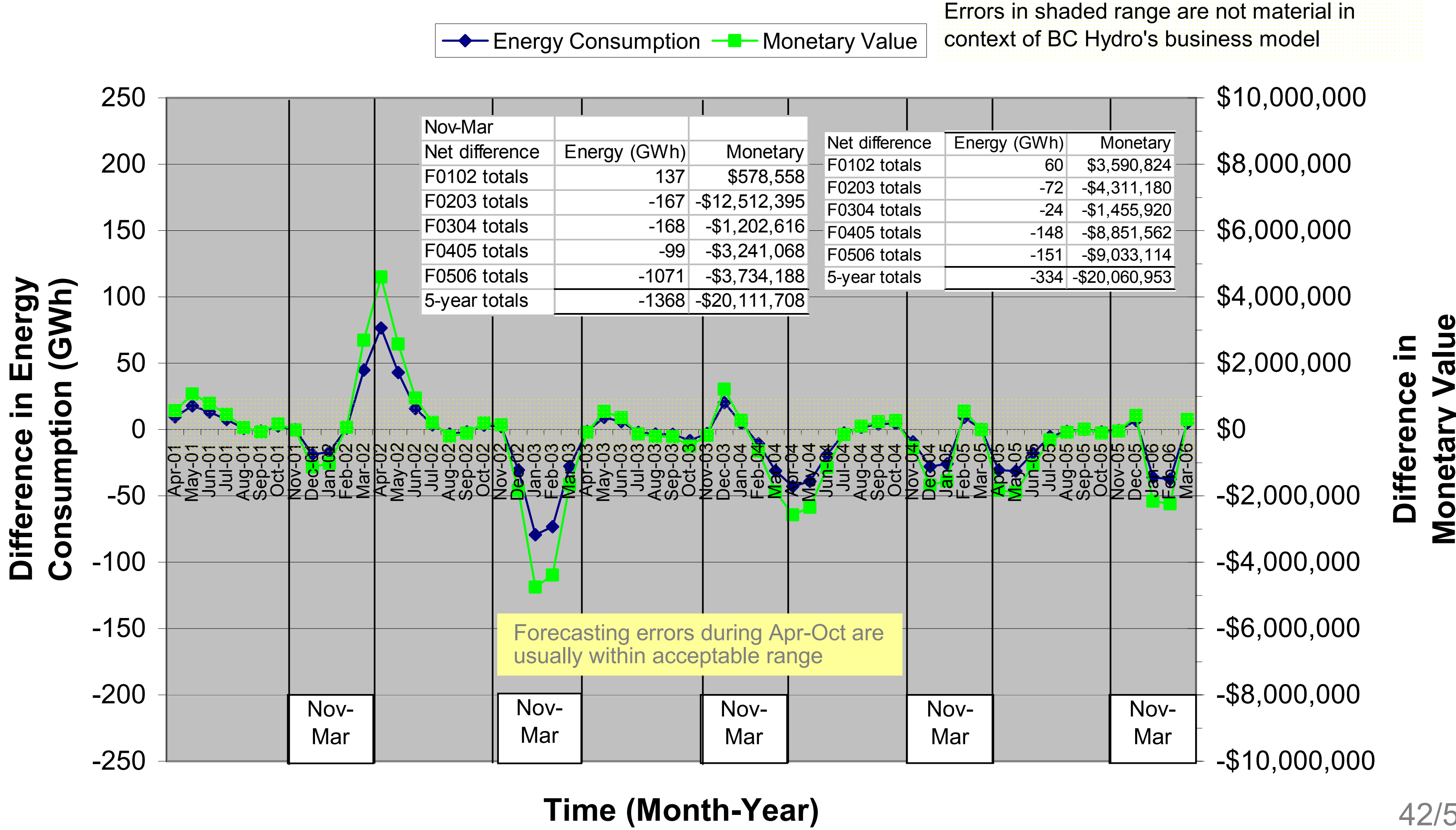
Nov-Mar		
Net difference	Energy (GWh)	Monetary
F0102 totals	132	$578,558
F0203 totals	-140	-$11,013,759
F0304 totals	-172	-$1,620,928
F0405 totals	-94	-$3,407,275
F0506 totals	-999	-$4,036,795
5-year totals	-1272	-$19,500,199

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

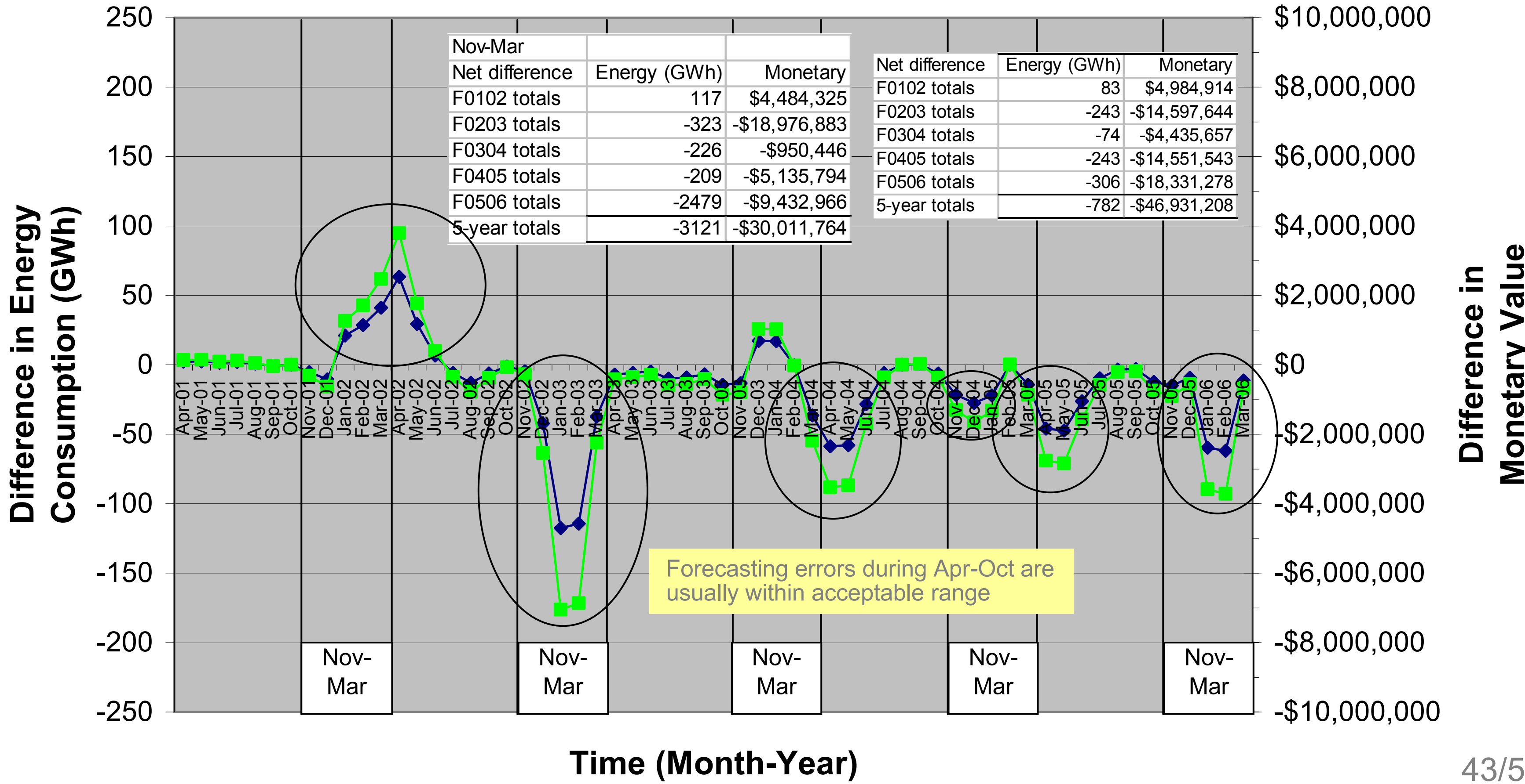
Net difference	Energy (GWh)	Monetary
F0102 totals	60	$3,590,824
F0203 totals	-72	-$4,311,180
F0304 totals	-24	-$1,455,920
F0405 totals	-148	-$8,851,562
F0506 totals	-151	-$9,033,114
5-year totals	-334	-$20,060,953

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)

Errors in shaded range are not material in context of BC Hydro's business model



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

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

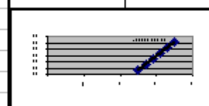
Linear equations relating HDD differences (errors) to Energy Consumption differences

Artifical data used to generate curves

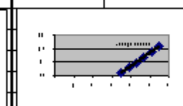
Energy unit is MWh

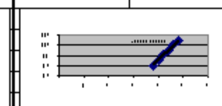
		Energy/HDD (MWh/kelvin day) slope, m	intercept, b
Nov	y = m*x + b	444.56351	626091.9
Dec		547.3067	602989.1
Jan		488.11685	788875
Feb		492.64408	893555
Mar		508.07644	802404.9

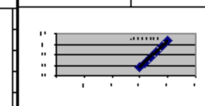
Experimental Data		Experimental Data		Experimental Data		Experimental Data		Experimental Data	
Nov HDD	Nov Energy	Dec HDD	Dec Energy	Jan HDD	Jan Energy	Feb HDD	Feb Energy	Mar HDD	Mar Energy
250	737,538	300	768,326	350	959,258	380	1,080,634	300	954,789
270	746,060	340	788,837	390	979,296	400	1,090,634	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

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

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)

Energy Difference (error)

Monetary Difference (error)

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 / Ch

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

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

G24 =$G$22*F24

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

ARIMA Model results

Spreadsheet enabling 5 years of input - ARIMA Model

one GWh = $60,000

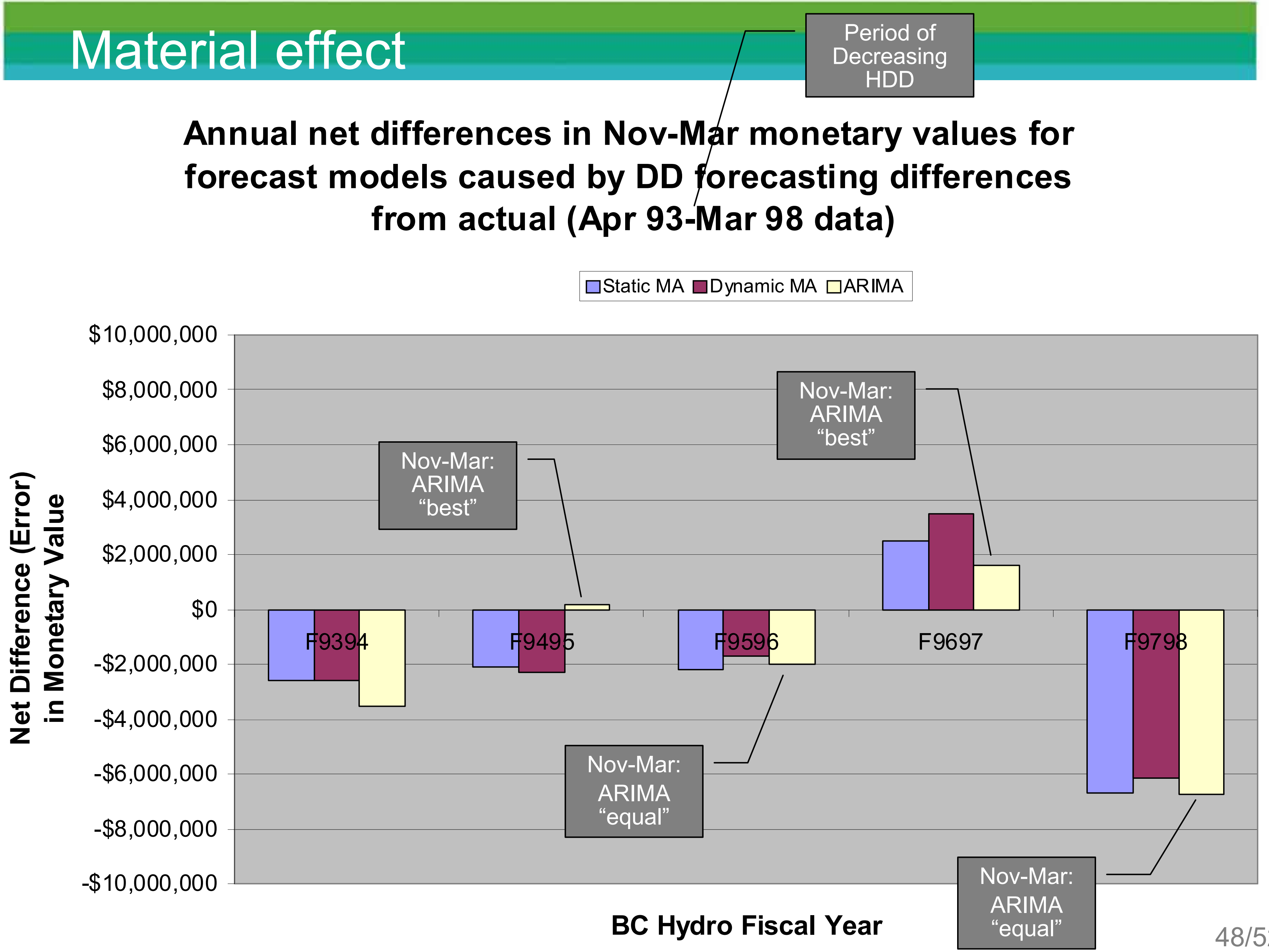
Row	Month	Fiscal Year	Actual HDD	Pred HDD	HDD Diff	Energy Diff (GWh)	Monetary Diff
94	Nov	F9394 1	402	388	14	6	$373,433
95	Dec	1	412	458	-46	-25	-$1,510,567
96	Jan	1	351	420	-69	-34	-$2,020,804
97	Feb	1	433	421	12	6	$354,704
98	Mar	1	324	347	-23	-12	-$701,145
99	Annual Totals		1922	2034	-112	-58	-$3,504,379
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)

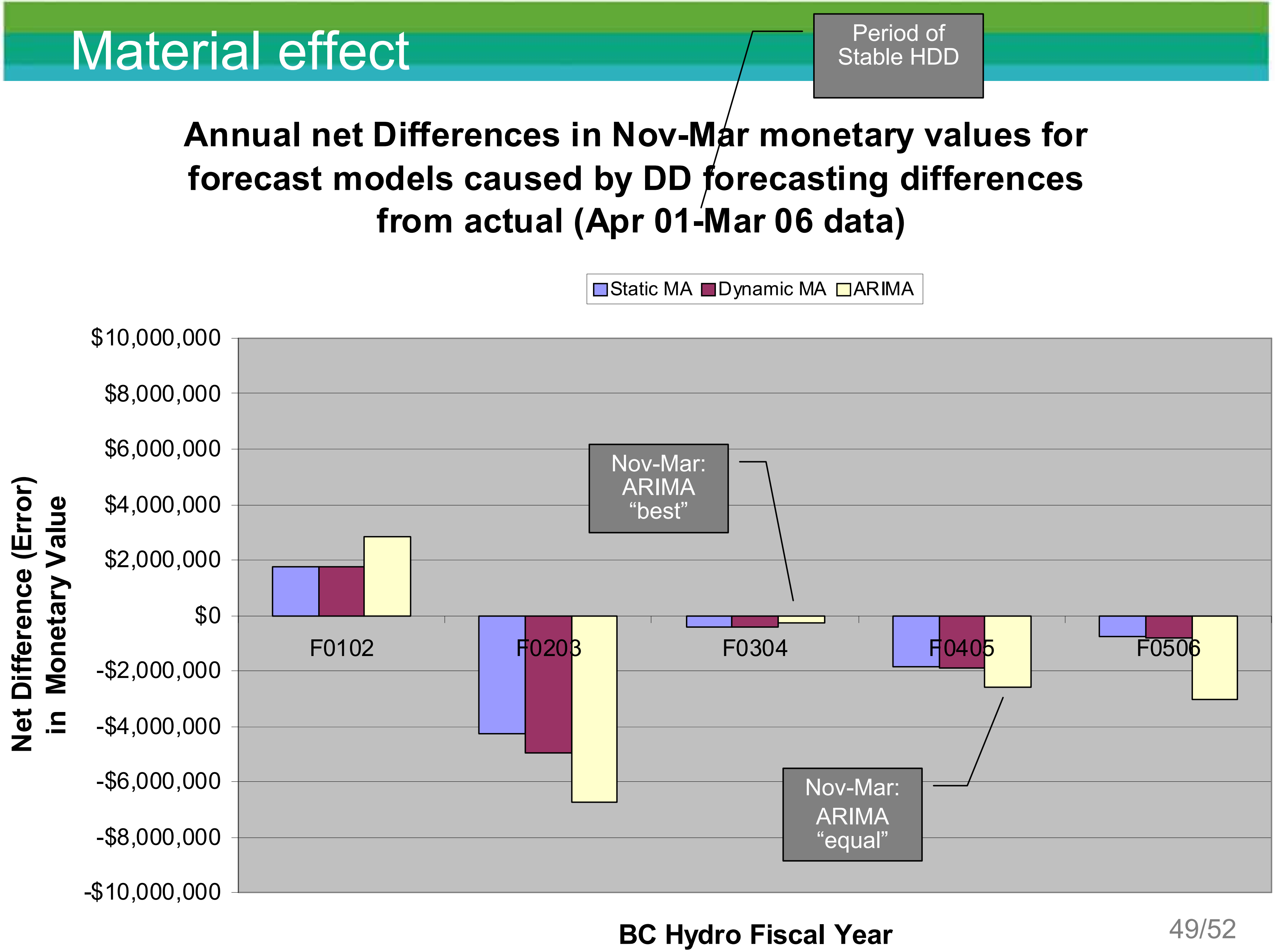
Interactive Spreadsheet 93-98 / Chart-IS 93-98 / Interactive Spreadsheet 01-06 / Chart-IS 01-06 / Ch

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)



Material effect



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

(Circled:) 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

    - See Annex for results of an experiment with different combinations of climate inputs for Jan

Annex — Experiments with various climate input combinations to reduce forecasting errors

Goal: Reduce monetary values of HDD forecasting errors for each month; Results for Jan are shown.

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

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

Annex 1 Tables

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

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.