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Seasonality and Weather Effects on Electricity Loads: Modeling and Forecasting

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Seasonality and Weather Effects on Electricity Loads: Modeling and Forecasting

Preliminary Results – Comments Welcome

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Objectives

- Examine the temperature effects on electricity loads within the PJM ISO
- Develop parsimonious specifications for hourly load models
- Test one and two day ahead forecasting capability of models
- Simulate the response to a 2°F increase in mean temperature

Objectives

- The research project focuses on short-term and long-term responses to changing temperature, its impact on generation and consumption technologies, and public health.
- Our focus today is only on short-run hourly consumption during the summer months.
- Our work is preliminary – we have a lot to learn and expect to benefit from the MetrixND User Meeting hosts and participants.

Progress and Learning

- Collected hourly load data for the control regions
- Collected hourly weather station data from NOAA
- Developed approach for correcting missing observations and outliers in weather data
- Developed a general-to-specific approach for modeling hourly demand

Progress and Learning

- Focus today is only on BG&E, Baltimore's load region within PJM
- Data problems specifically with weather

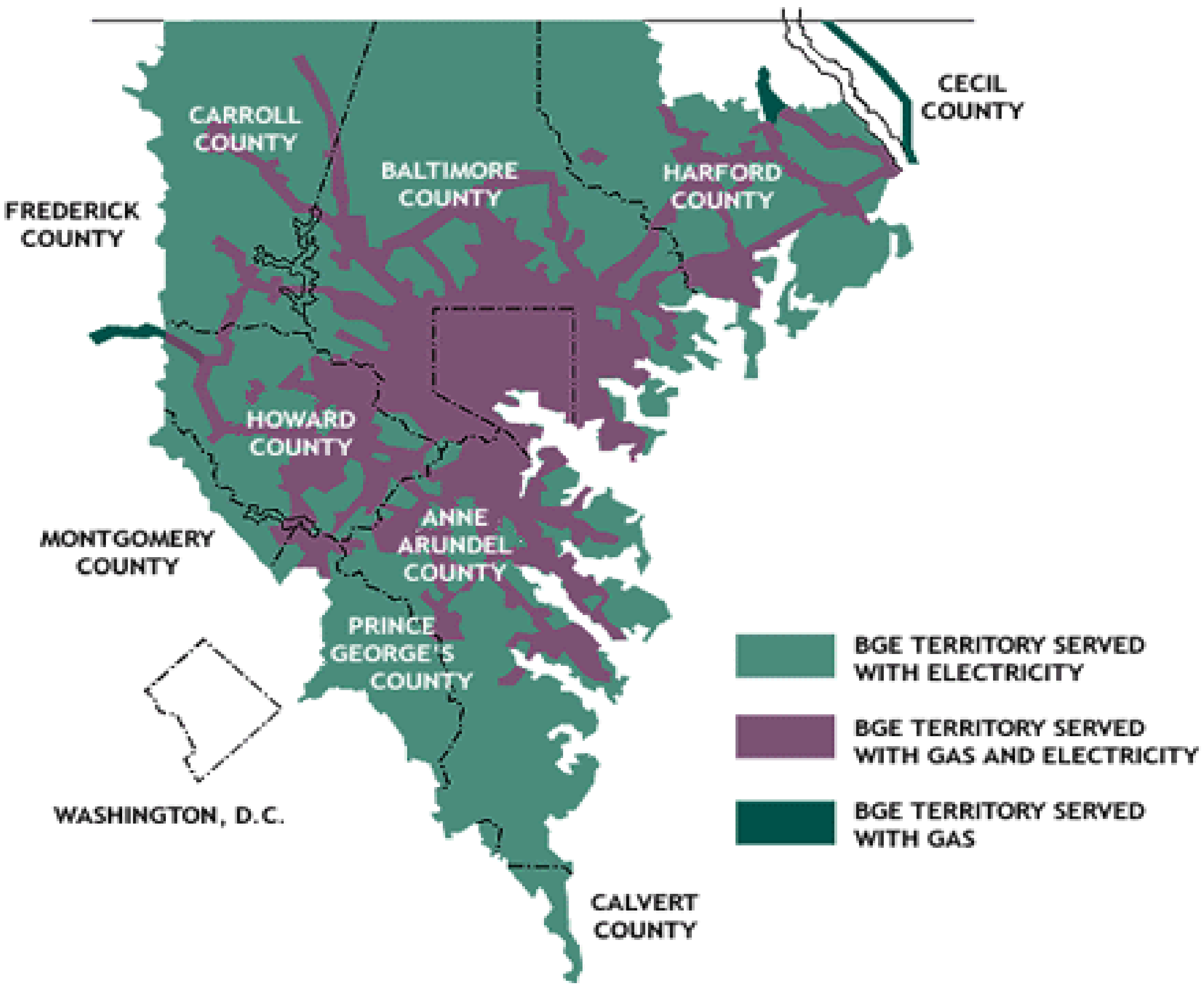
Progress and Learning

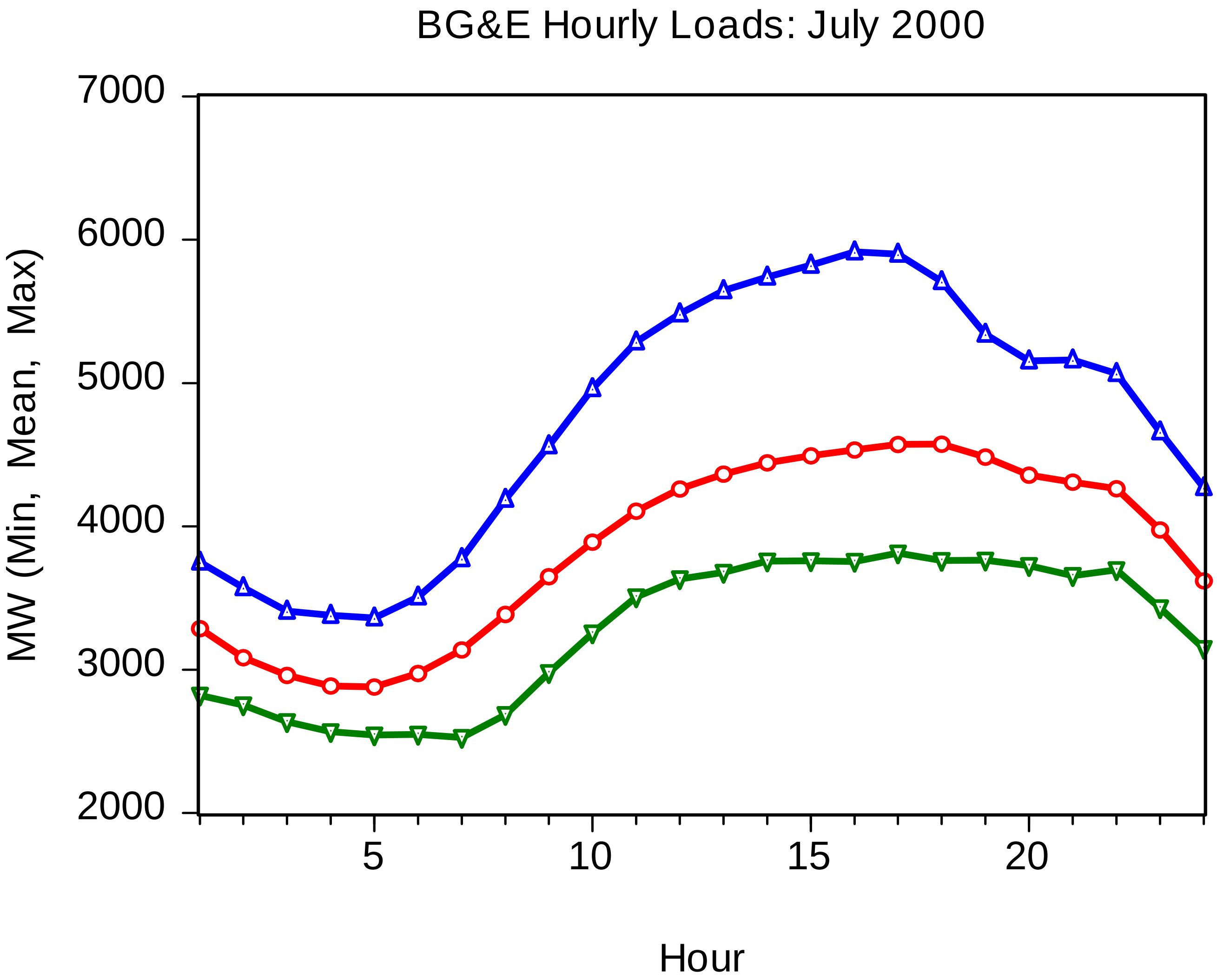
- The Hourly Demand Model depends on:
  - Autoregressive components
  - Daily and Monthly Effects
  - Temperature and Temperature Squared
- We have estimated “cooling effect” elasticities
- We have performed forecast evaluations
- We have run a higher temperature simulation

BG&E Load Region

- In operation for over 100 years
- 1.1 million electricity customers
- 580,000 natural gas customers
- 2,300 square miles
- 1,200 miles of transmission lines
- 21,000 miles of overhead & ground distribution lines
- Traditional vertically integrated utility until July 1st, 2000
- A subsidiary of the holding company, Constellation Energy Group.

BG&E Load Region





Refer to Table 2 of Handouts

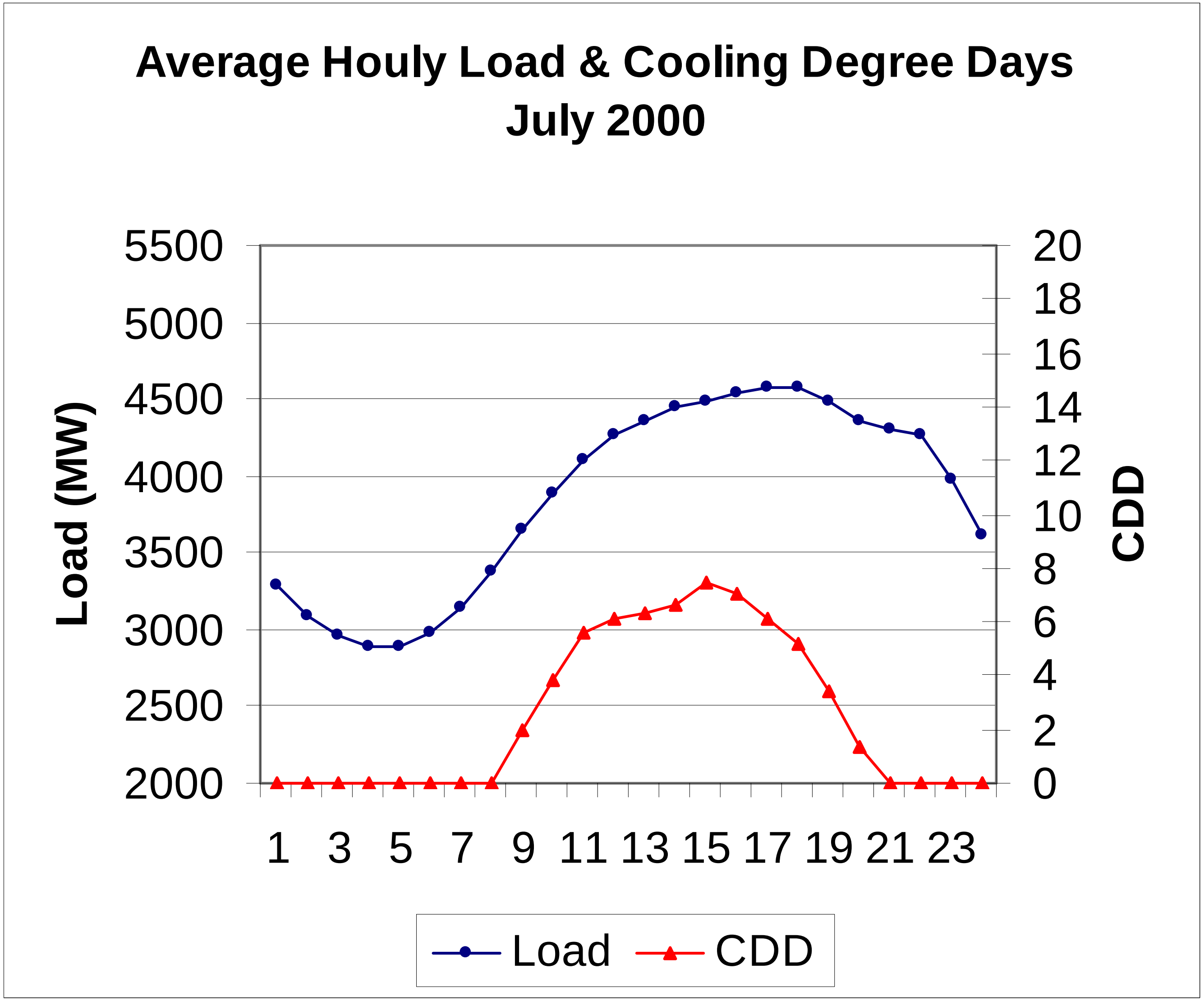
Weather Data

- Hourly weather station data from Baltimore-Washington International Airport, WBAN#724060
- 29,184 total observations
- 868 missing observations (3% of total)
- 8,784 observations for June, July, August, and September in 1998, 1999 and 2000
- There are 155 missing observations (1.8%)

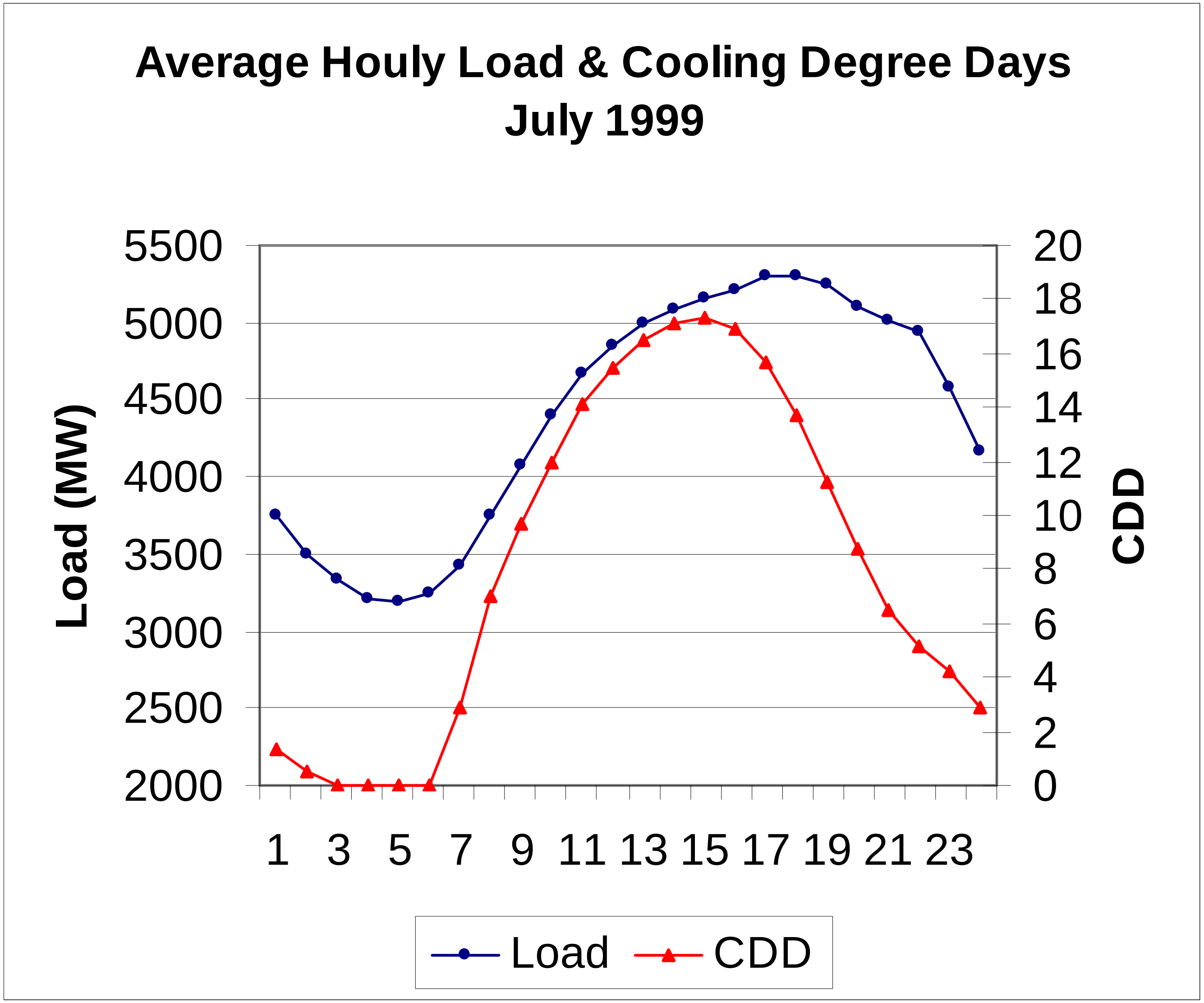
Temperature Sensitivity Variables

We constructed Cooling Degree Day variables for modeling purposes:

$$CDD = \begin{cases} \text{Hourly Temperature} - 72 \\ 0 \text{ for Temperatures below } 72°F \end{cases}$$



Refer to Table 2, 3, and 4 in Handouts



Refer to Table 2, 3, and 4 in Handouts

The General Load Model

$$\log(Load_{ht}) = \beta_0 + \sum_{i=1}^{7} \beta_i Day_{iht} + \sum_{i=1}^{3} \delta_i Month_{iht}$$

$$+$$

$$\sum_{i=1}^{4} \alpha_i Month_{iht} \cdot CDD_{iht} + \sum_{i=1}^{4} \gamma_i Month_{iht} \cdot CDD_{iht}^2 + \phi(L) \cdot \log(Load_{ht}) + e_{ht}$$

The autoregressive component includes the previous three hours and the same hour from the previous day:

$$\phi(\mathrm{L}) = \varphi_1 \mathrm{L} + \varphi_2 \mathrm{L}^2 + \varphi_3 \mathrm{L}^3 + \varphi_{24} \mathrm{L}^{24}$$

Interpreting the Coefficients

- The electricity load in hour h on Fridays in July is captured by the expression

  $$\beta_0 + \beta_5 + \delta_1 + \alpha_2 * CDD + \gamma_2 * CDD^2$$

- The Friday effect comes from the β_5 parameter and the δ_1 parameter captures the difference between July and June.

- The effect for a Tuesday in June is given by

  $$\beta_0 + \beta_1 + \alpha_1 * CDD + \gamma_1 * CDD^2$$

- The parameter β_1 represents the difference from Monday in June.

General to Specific Modeling Approach

- Goal is to explain a lot with a little
- The general model has 23 parameters to estimate
- We test 40 hypotheses on the deterministic variables on the temperature sensitivities, and both jointly – total 960 hypotheses
- Refer to Handout Table 8 for Description
- Refer to Handout Table 9 for Selection

General to Specific Modeling Approach

- Model Evaluation is based on:
  - Likelihood Ratio Statistics
  - Akaike Information Criteria
  - Schwartz Criteria
- Removal of deterministic effects for days and months reduces explanatory power.
- Level and Quadratic terms for CDD are important, but different on an individual monthly basis
- Symmetry found across months as well as for June/September and July/August

MStat Comparison – Hour 10

Model	Coefs	Err DF	Std Err	AIC	BIC	Log-L
Model0_10	23.00	1191.00	0.01	-8.62	-8.52	3536.52
Model40_10	19.00	1195.00	0.01	-8.63	-8.54	3533.29
Model41_10	17.00	1197.00	0.01	-8.62	-8.55	3529.84

- Version 3.0 of MetrixND allows the modeler to conduct the general-to-specific hypotheis tests that we did "by hand"
- The first line shows results for our General Model
- Other lines compare results for our Restricted Models 40 and 41

The Final Load Model

$$\log(Load_{ht}) = \beta_0 + \sum_{i=1}^{6} \beta_i \, Day_{iht} + \beta_7 Holiday_t + \sum_{j=1}^{3} \delta_j Month_{jht}$$

$$+ \alpha \, \mathrm{CDD}_{\mathrm{ht}} + \gamma \, \mathrm{CDD}_{\mathrm{ht}}^{2} + \phi(\mathrm{L}) \cdot \log(Load_{ht}) + \mathrm{e}_{\mathrm{ht}}$$

•The intercept captures Mondays in June

•Imposing symmetry across monthly CDD effects does not reduce the model's explanatory power

•A close alternative suggested that there is a distinction between the June/September and July/August combinations

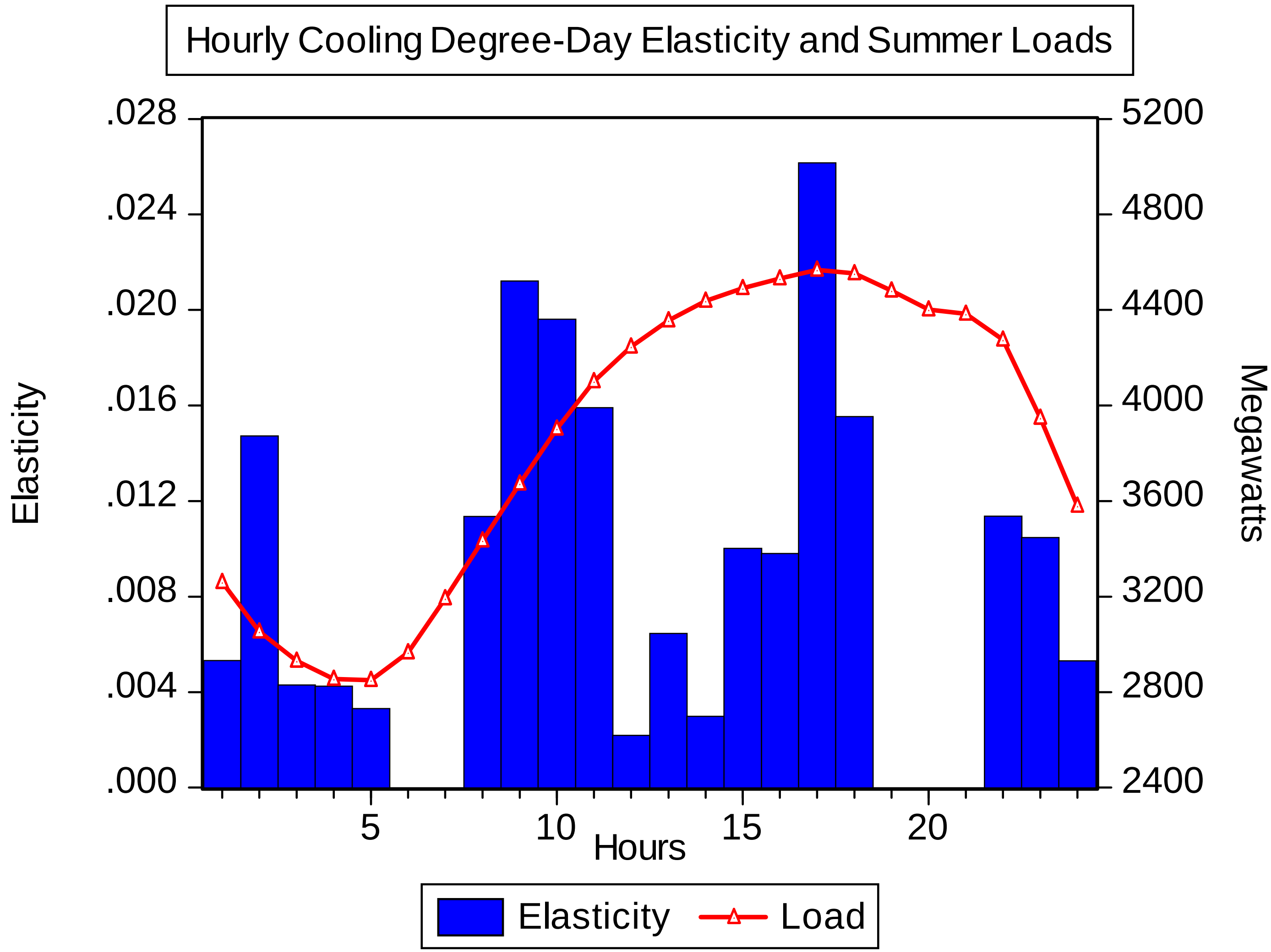
•Exmaple: Hour 14 Model in Handout Table 11

Temperature or CDD Elasticities

- The hourly cooling degree day elasticity in month/season j is defined as

$$E_{Chj} = (\alpha_{hj} + \gamma_{hj} * 2 * MCDD_{hj}) * MCDD_{hj} .$$

- Subscripts C, h, and j refer to cooling, hour, and month/season respectively
- The M in front of MCDD terms indicates that degree day measures are evaluated at their mean values
- Refer to Table 15 in Handouts



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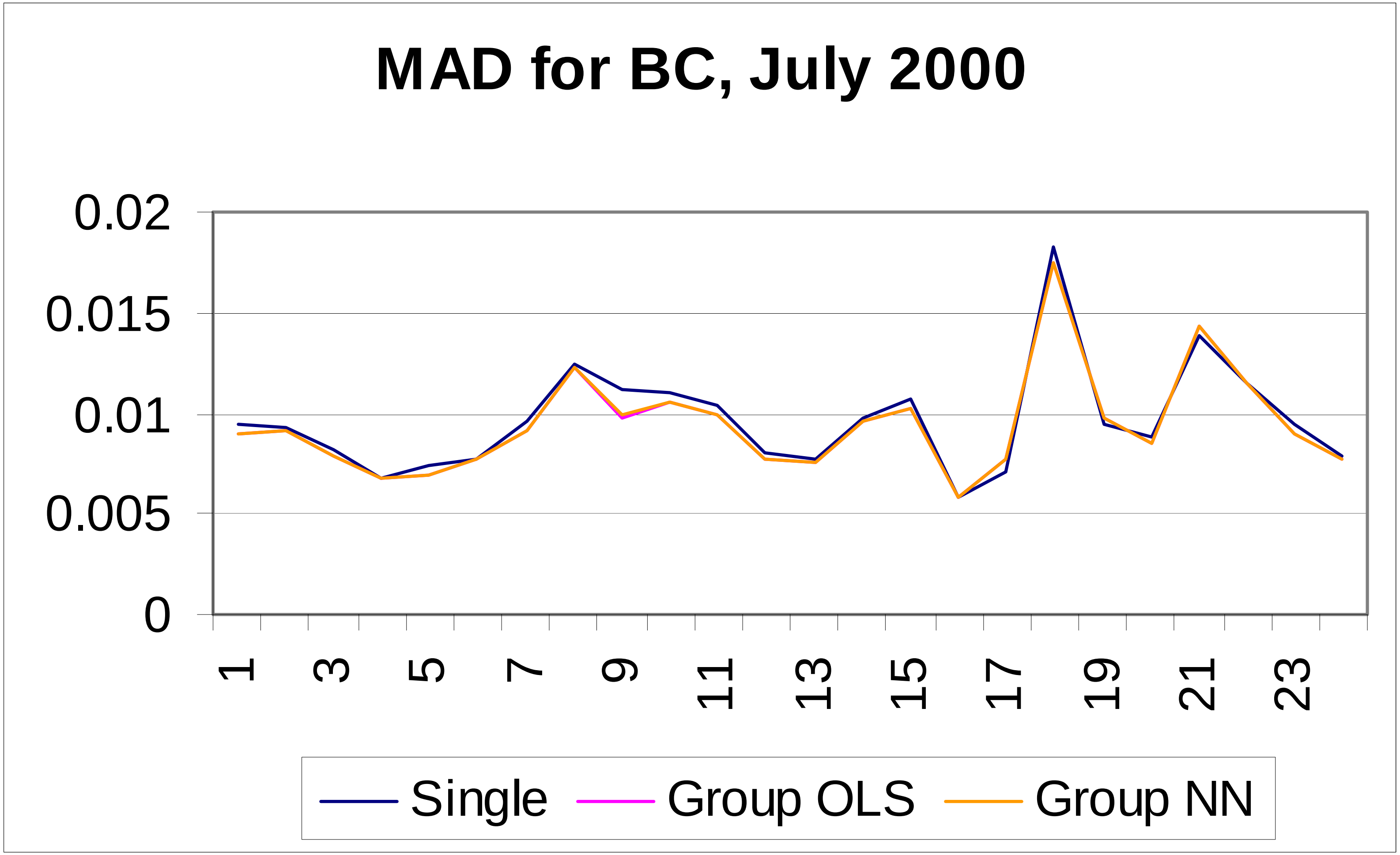
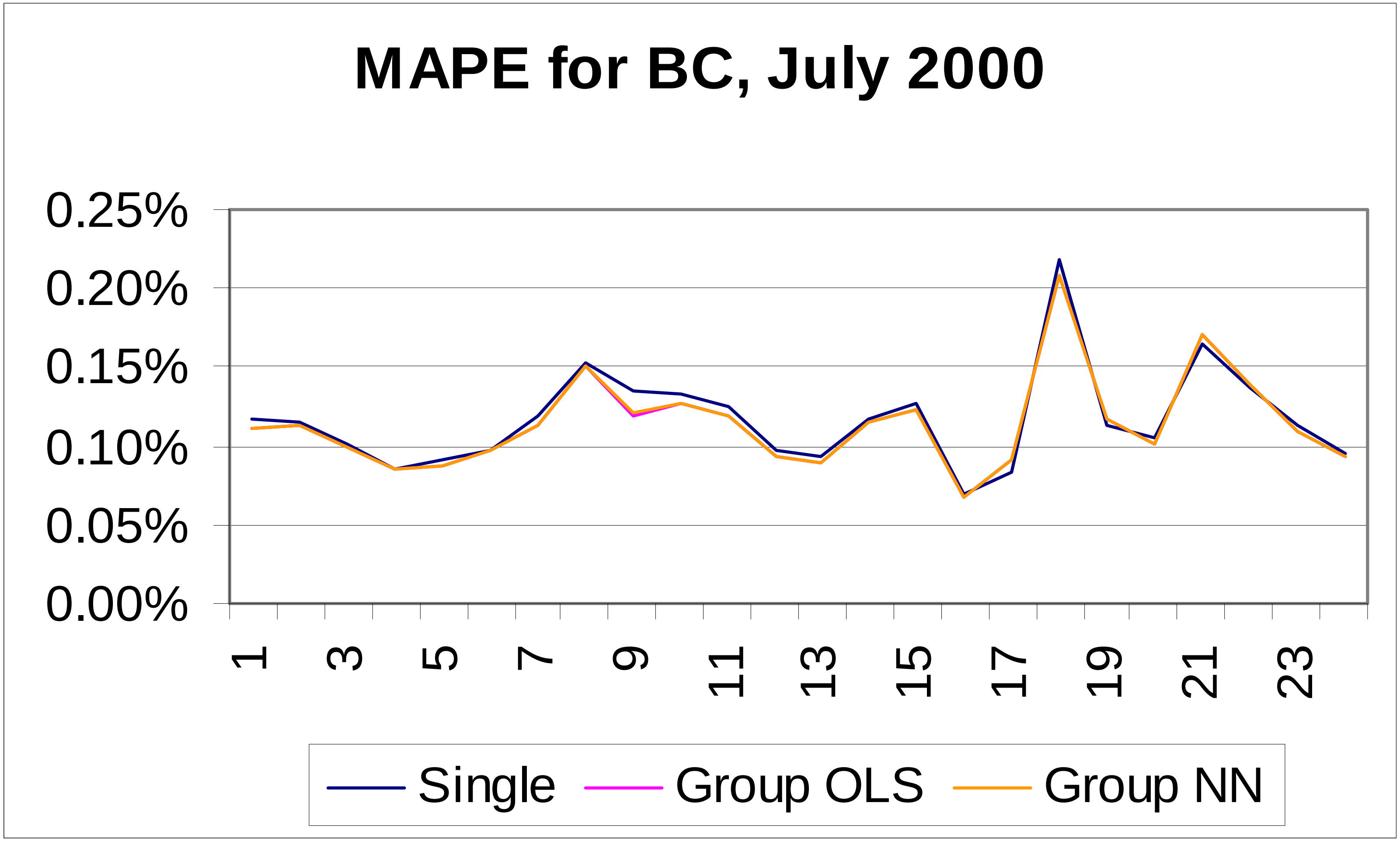
Forecast Comparison

- Compare Three Approaches:
  - Individual Hourly OLS Model Forecasts
  - Group OLS Forecasts
  - (Group) Neural Net Forecasts
- Estimate models from June-September 1998-1999 and June 2000
- Forecast July 2000 (31 one day ahead forecasts)

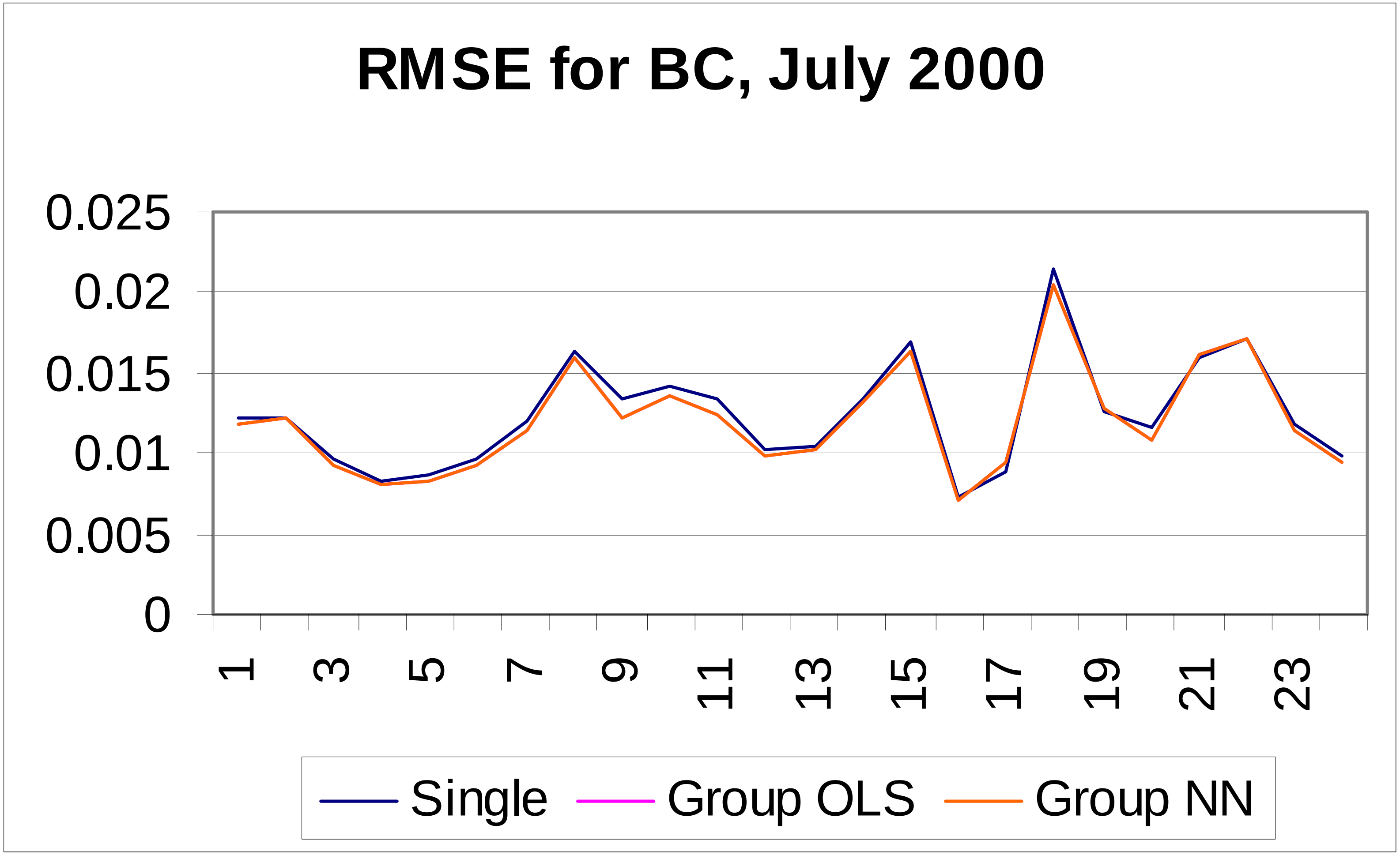
Comparison of MAD



Comparison of MAPE

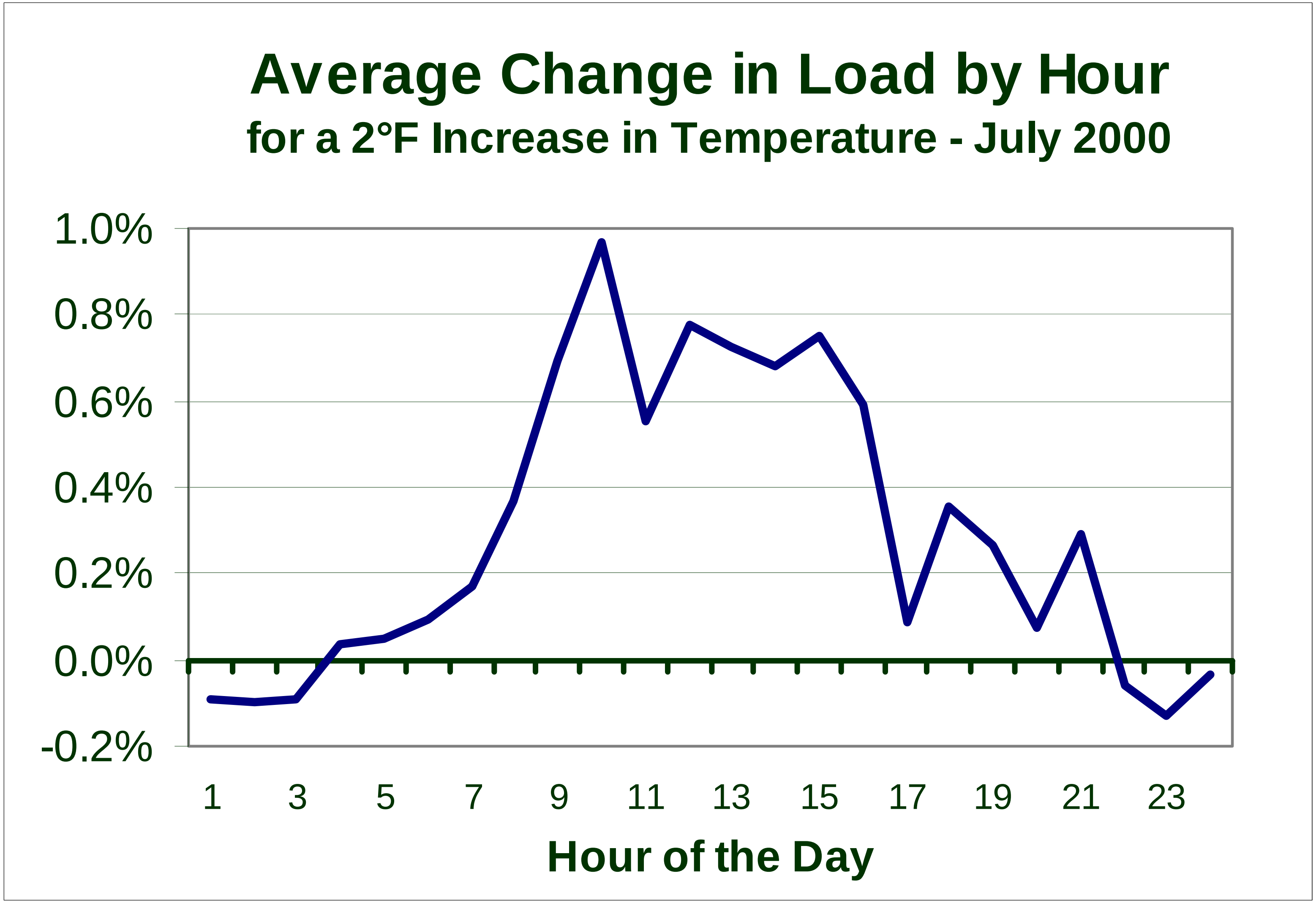


Comparison of RMSE



Simulation

- Compare the effect of a 2°F increase on loads
- Focus on July 2000
- Predicted values calculated using actual temperature data
- Simulated values using actual temperature plus 2 degrees.



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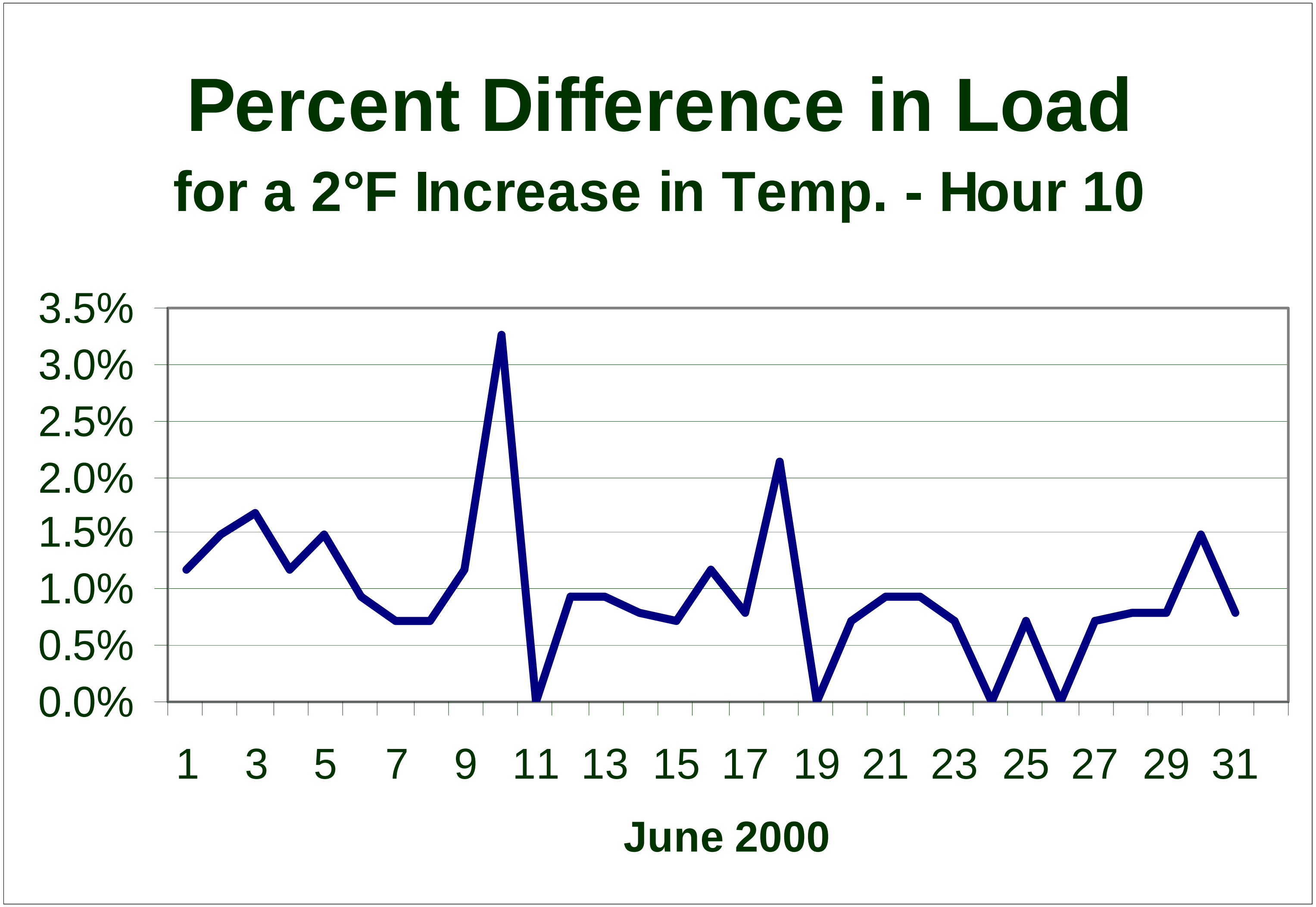
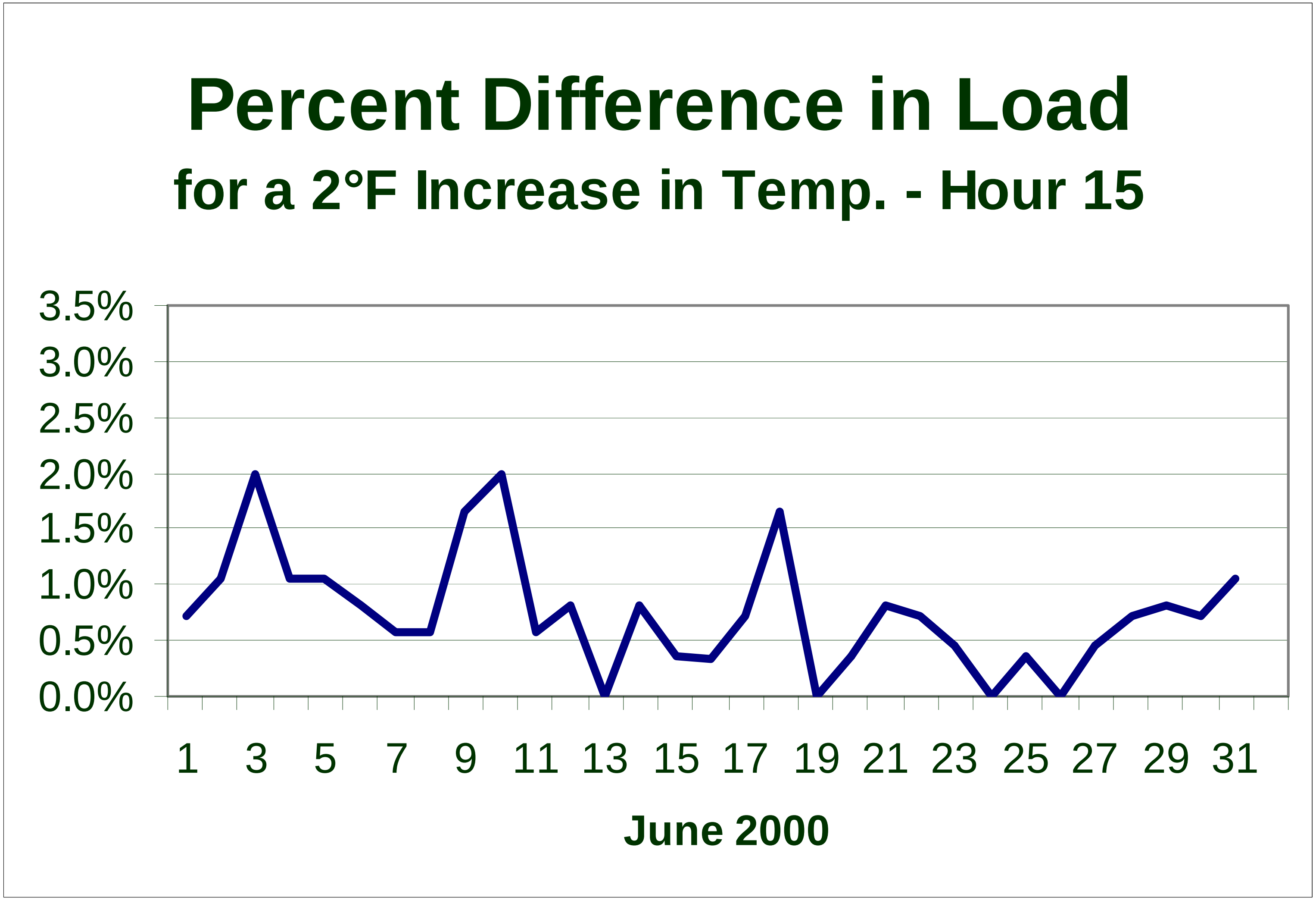


Percent Difference in Load
for a 2°F Increase in Temp. - Hour 10
3.5%
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
June 2000



Percent Difference in Load
for a 2°F Increase in Temp. - Hour 15
3.5%
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
June 2000

Conclusion

- Base-line study for estimating hourly impacts of cooling needs for one load region in PJM
- Forecast comparison – we could not distinguish between the different models
- CDD Elasticities were most pronounced in the late morning and late afternoon

Conclusion

- Simulation with temperature increased by 2°F in July 2000
- Biggest average hourly effect is 1% at Hour 10
- Between Hour 9 and Hour 15 the average effect 0.75% or more
- The Hour 10 effects range to 3.25%

Further Research

- Model Specification
  - Are Quadratic Temperature Effects Enough?
  - Cubic Temperature Effects?
  - Convert from natural logarithms to levels?
- Clean Weather Data from Weatherbank
- Other Weather Variables
  - Cloud Cover
  - Precipitation
  - Wind Speed
  - Other Seasonal differences
- Extend modeling efforts to other PJM load regions

Further Research

- MetrixND issues and ideas:
  - Version 3.0 is big improvement over 2.6
  - We relied on econometric package Eviews for many specification tests, because of programming requirements
  - Specification tests – compare with MSTAT
  - Elasticity estimates
  - Conversion from transformations to original series
  - Understand how to construct recursive group forecasts in MetrixND
  - Visual Basic for programming and testing large groups of models