

Energy Consumption Baseline: Fairchild AFB's Major Boiler Retrofit

2003 ASHRAE Summer Meeting

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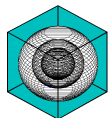
K. Quinn Hart, P.E. – USAF

William Turner – Fairchild AFB

Sylvia Berry-Lewis - Honeywell

June 29th, 2003

Kansas City, Mo.

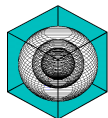


Central Heat Plant Baseline

- FAFB had 4 years of steam plant data
- This was daily data which had the following components
 - Gas Consumed
 - Steam Produced
 - Min / Avg / Max Outside Air Temperatures
- The gas input is the key variable since this is the Energy-In data that will be compared to the total Energy-In data for the post-retrofit

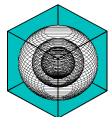
$$\text{Energy-In}_{\text{Pre}} = \text{Energy-In}_{\text{Post}} + \text{Savings}$$

- The Energy-In will be normalized to the Average Outside Air Temperature



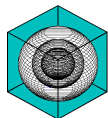
Central Heat Plant Baseline

- With 4 years of steam plant data, the year to year variation could be studied
- This baseline analysis includes
 - Yearly variation from daily consumption analysis
 - Analysis using 2, 3 and 4 Parameter models from the ASHRAE IMT (Inverse Model Toolbox) methods
 - Yearly variation from monthly consumption analysis
 - Analysis using 2, 3 and 4 Parameter models (from the ASHRAE IMT methods)
- Found that the 2-Parameter model (Simple Linear Regression) performed as well as more complicated methods



Central Heat Plant Baseline

- Procedure
 - Create 97, 98, 99, 00 corrected data files
 - Run E-model on daily data (2P, 3P, 4P) on each year - 12 files
 - Create 97, 98, 99, 00 monthly files from corrected data files
 - Run E-model on monthly data (2P, 3P, 4P) on each year - 12 files
 - Extract equations from the data analysis
 - Create predicted files for same year data
 - Determine mean bias error (MBE)
 - Create predicted files using Y2000 parameters and each year's weather.
 - Check variation in models



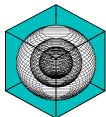
2 Parameter

- Daily Analysis Graphs

Daily Consumption - Nat Gas (1000 cuft/day)

7 Day Week All Year	7 Day Week Summer	7 Day Week Winter
WeekDays All Year	WeekDays Summer	WeekDays Winter
WeekEnds All Year	WeekEnds Summer	WeekEnds Winter

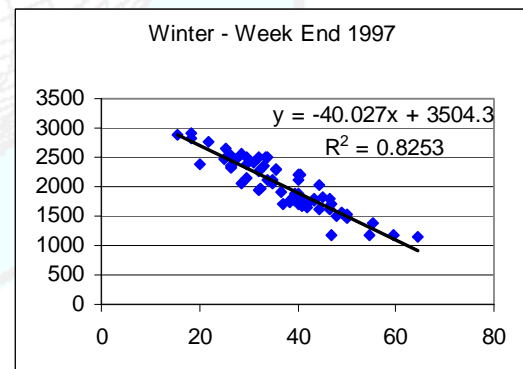
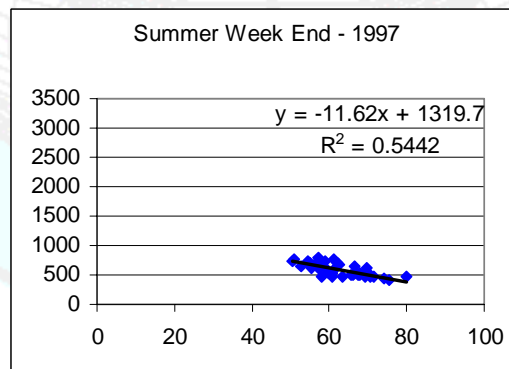
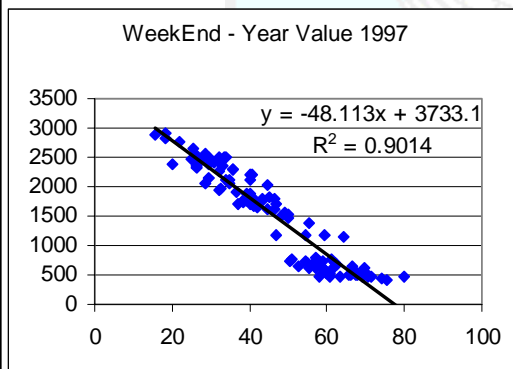
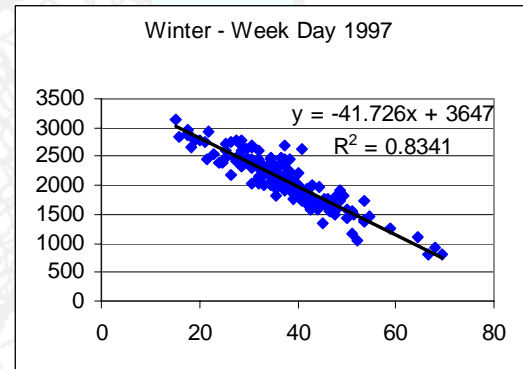
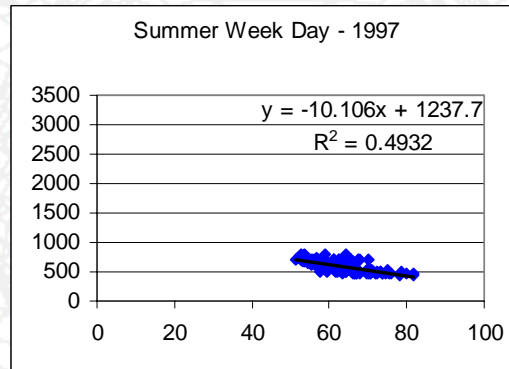
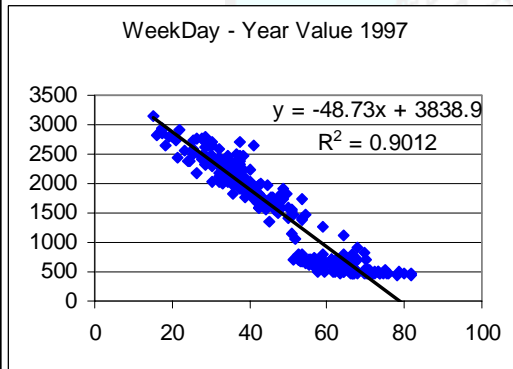
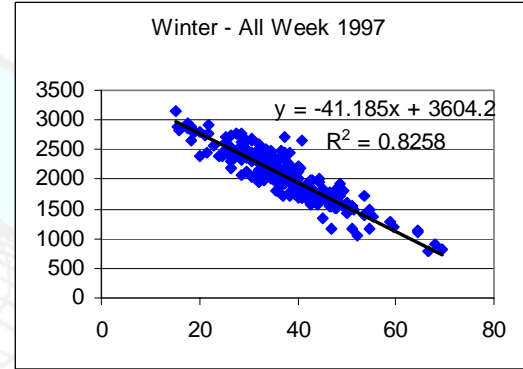
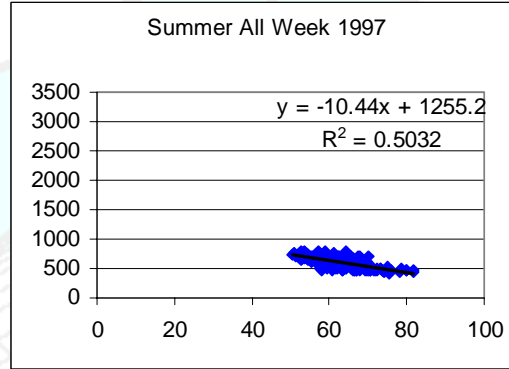
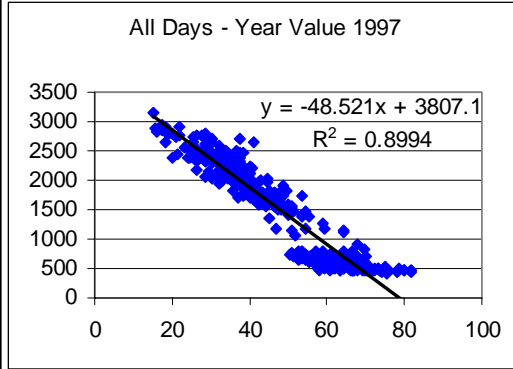
Outside Air Temperature (F)



2 Parameter

Daily Analysis Consumption-1997

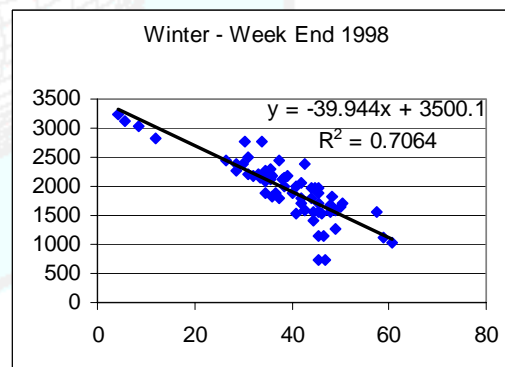
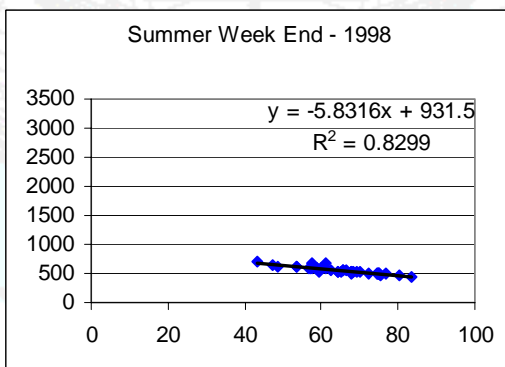
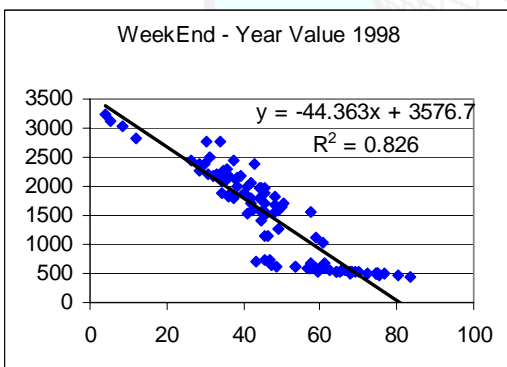
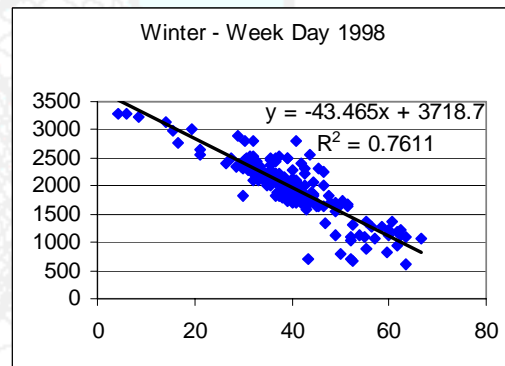
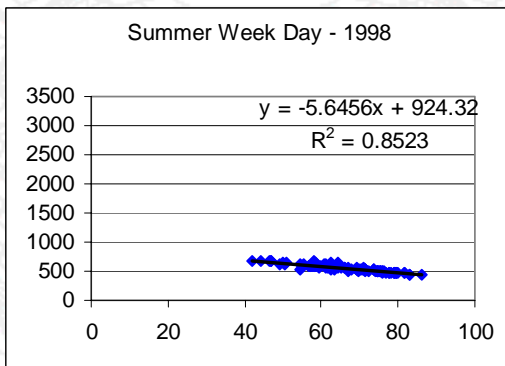
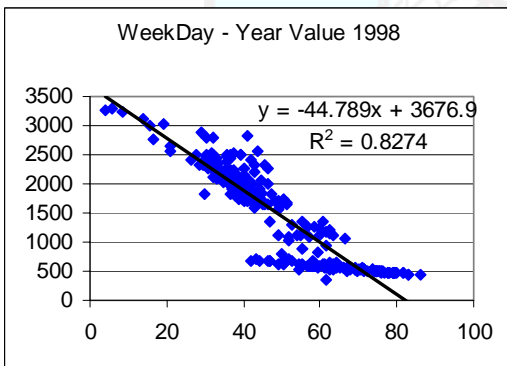
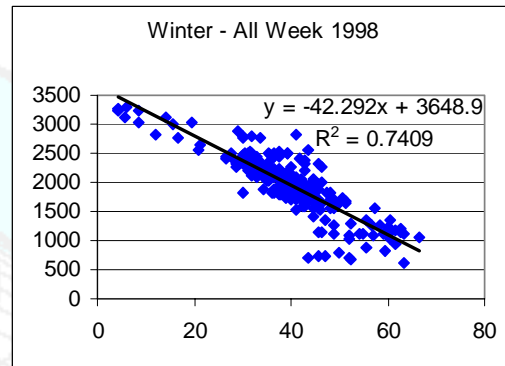
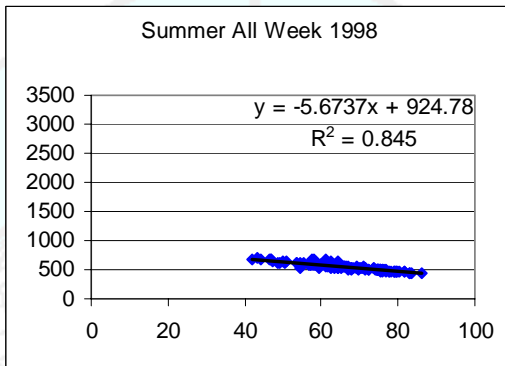
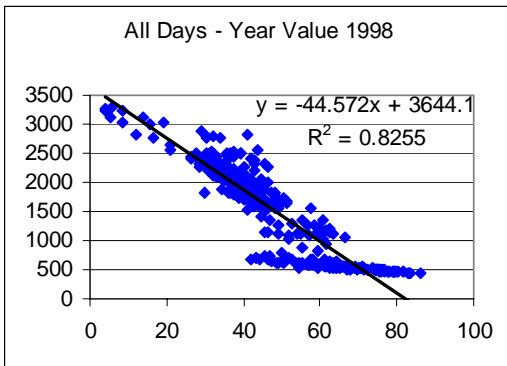
Daily Consumption - Nat Gas (1000 cuft/day)



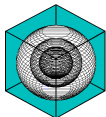
2 Parameter

Daily Analysis Consumption-1998

Daily Consumption - Nat Gas (1000 cuft/day)



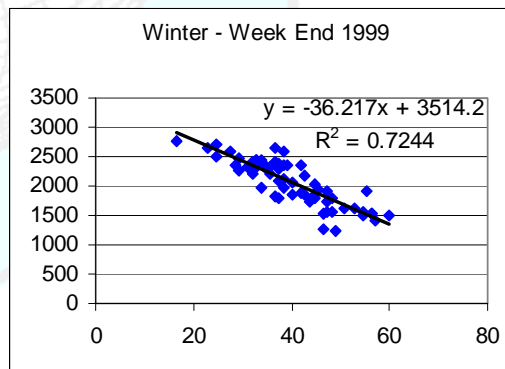
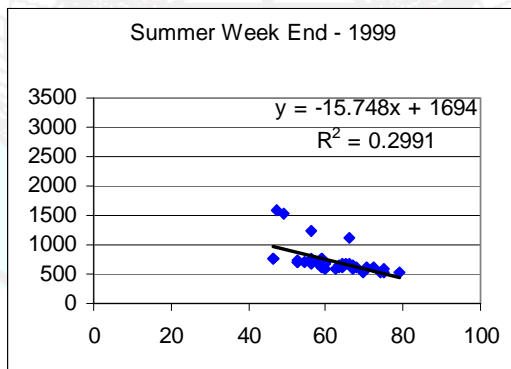
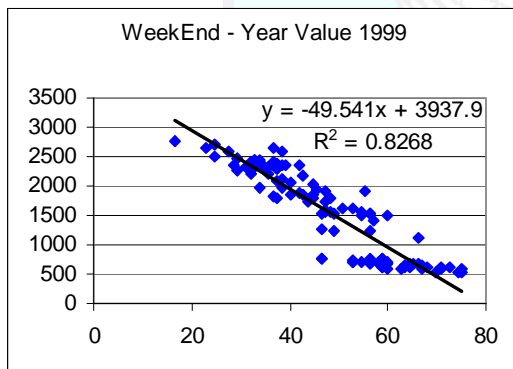
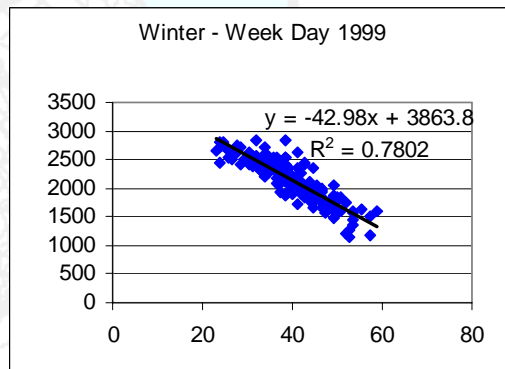
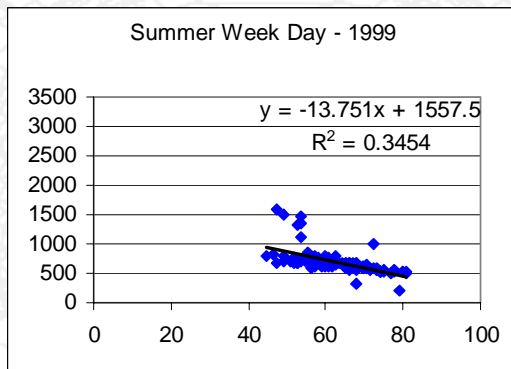
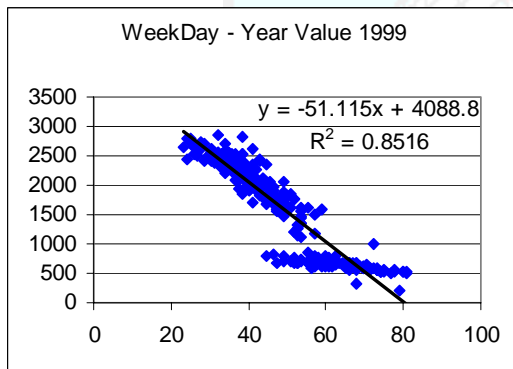
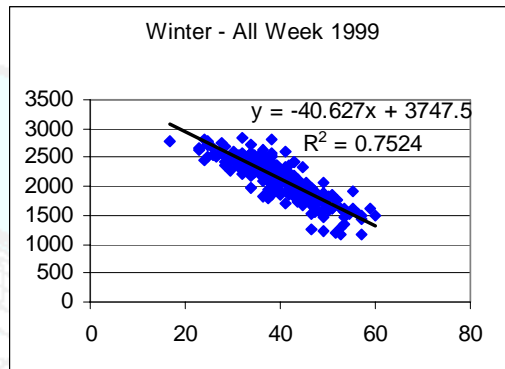
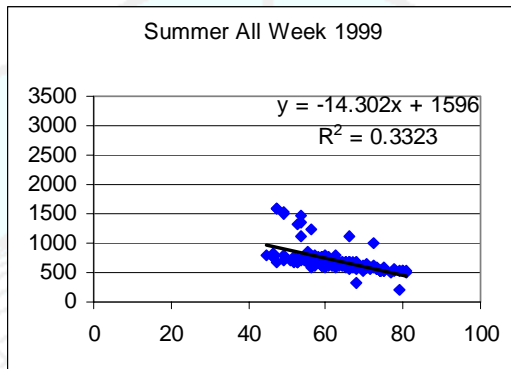
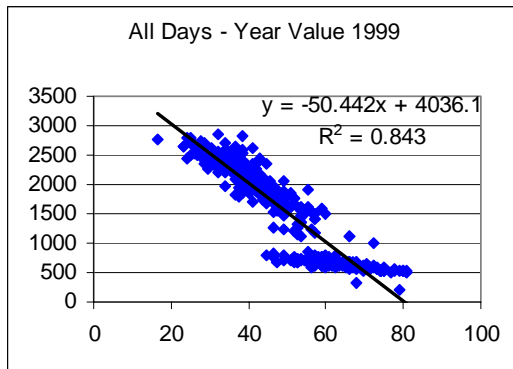
Outside Air Temperature (F)



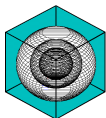
2 Parameter

Daily Analysis Consumption-1999

Daily Consumption - Nat Gas (1000 cuft/day)



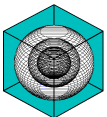
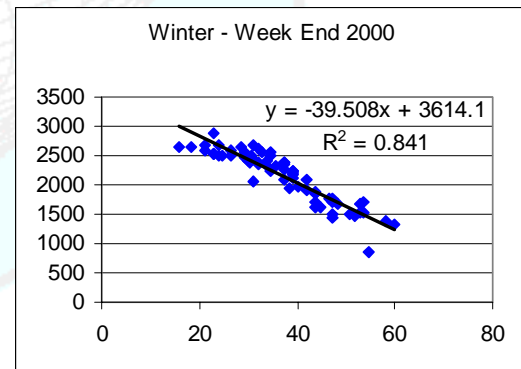
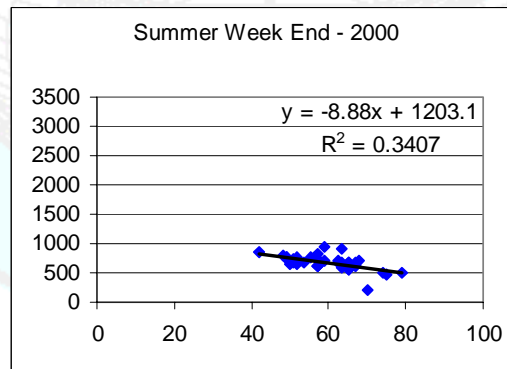
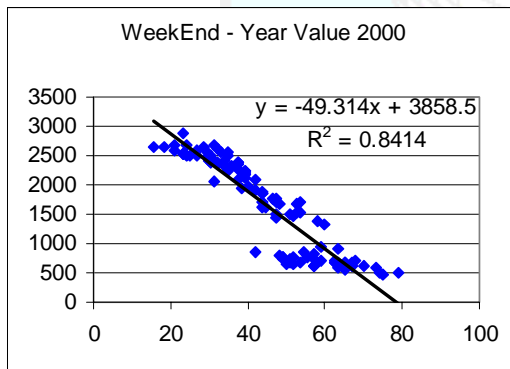
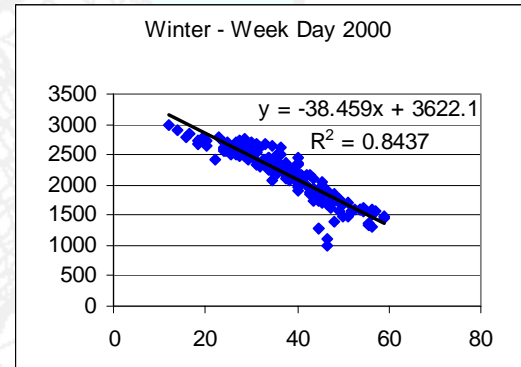
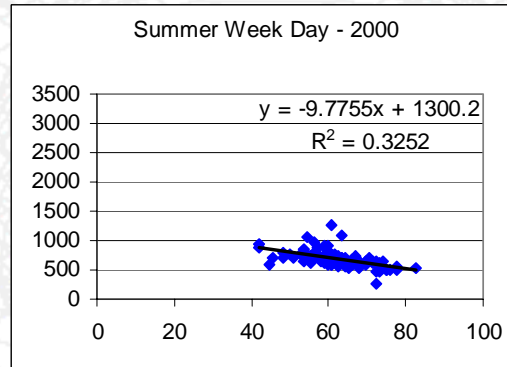
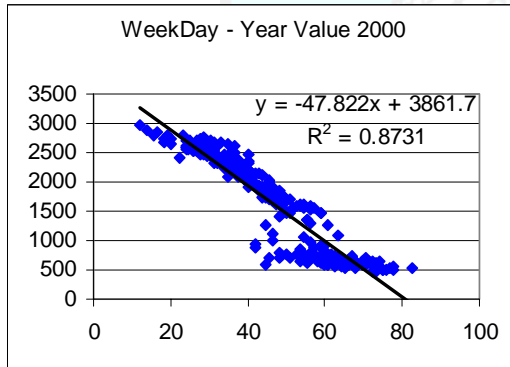
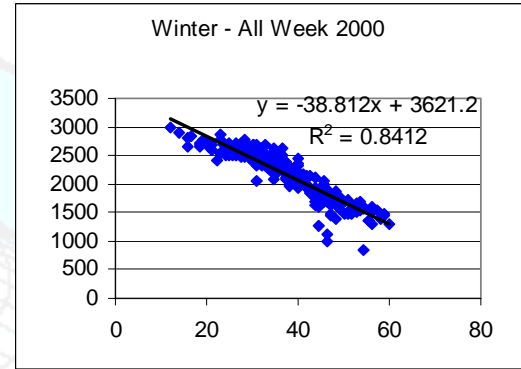
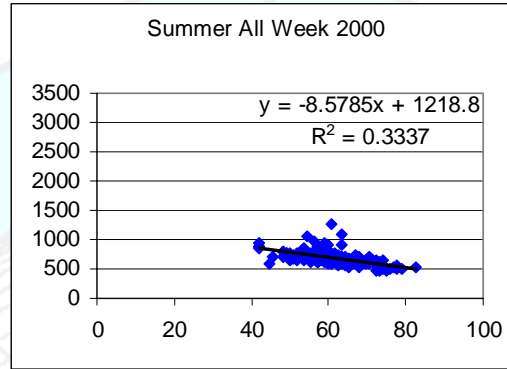
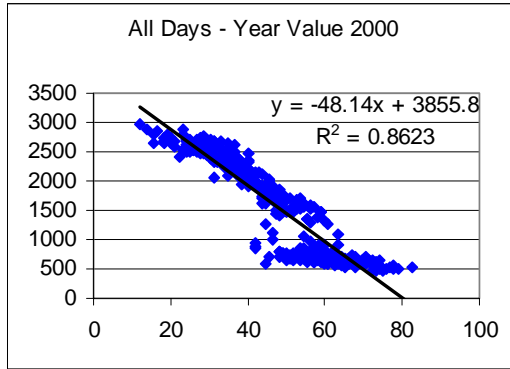
Outside Air Temperature (F)



2 Parameter

Daily Analysis Consumption-2000

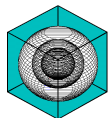
Daily Consumption - Nat Gas (1000 cuft/day)



2 Parameter

- Daily Analysis Consumption Equations ($x = \text{OAT}$)

		All Days	Summer	Winter
All Days	1997	$-48.521x + 3807.1$	$-10.44x + 1255.2$	$-41.185x + 3604.2$
	1998	$-44.572x + 3644.1$	$-5.6737x + 924.78$	$-42.292x + 3648.9$
	1999	$-50.442x + 4036.1$	$-14.302x + 1596.0$	$-40.627x + 3747.5$
	2000	$-48.14x + 3855.8$	$-8.5785x + 1218.8$	$-38.812x + 3621.2$
WeekDays	1997	$-48.73x + 3838.9$	$-10.106x + 1237.7$	$-41.726x + 3647$
	1998	$-44.789x + 3676.9$	$-5.6456x + 924.32$	$-43.465x + 3718.7$
	1999	$-52.254x + 4136.4$	$-13.751x + 1557.5$	$-42.98x + 3863.8$
	2000	$-47.822x + 3861.7$	$-9.7755x + 1300.2$	$-38.459x + 3622.1$
WeekEnds	1997	$-48.113x + 3733.1$	$-11.62x + 1319.7$	$-40.027x + 3504.3$
	1998	$-44.363x + 3576.7$	$-5.8316x + 931.5$	$-39.944x + 3500.1$
	1999	$-49.252x + 3929.6$	$-15.748x + 1694.0$	$-36.217x + 3514.2$
	2000	$-49.314x + 3858.5$	$-8.88x + 1203.1$	$-39.508x + 3614.1$

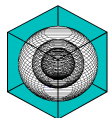


2 Parameter Summer/Winter Data

- Daily Consumption Calculations
 - Using Y2000 Parameters and Selected Year's Weather – Winter / Summer Separated

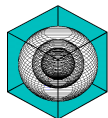
		Actual Year Consumption	Calculated 2-P Year Data	Calculated 2-P Winter / Summer Data
		x(1000 cuft)	x(1000 cuft)	x(1000 cuft)
Totals	1997	546,215	570,586	582,040
	1998	523,565	536,267	563,682
	1999	578,576	553,576	564,948
	2000	593,635	593,635	594,257
Errors	1997		4.27%	6.16%
	1998		2.37%	7.12%
	1999		-4.52%	-2.41%
	2000		0.00%	0.10%

$$\text{Error} = \frac{\text{Calculated} - \text{Actual}}{\text{Calculated}}$$



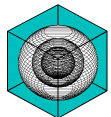
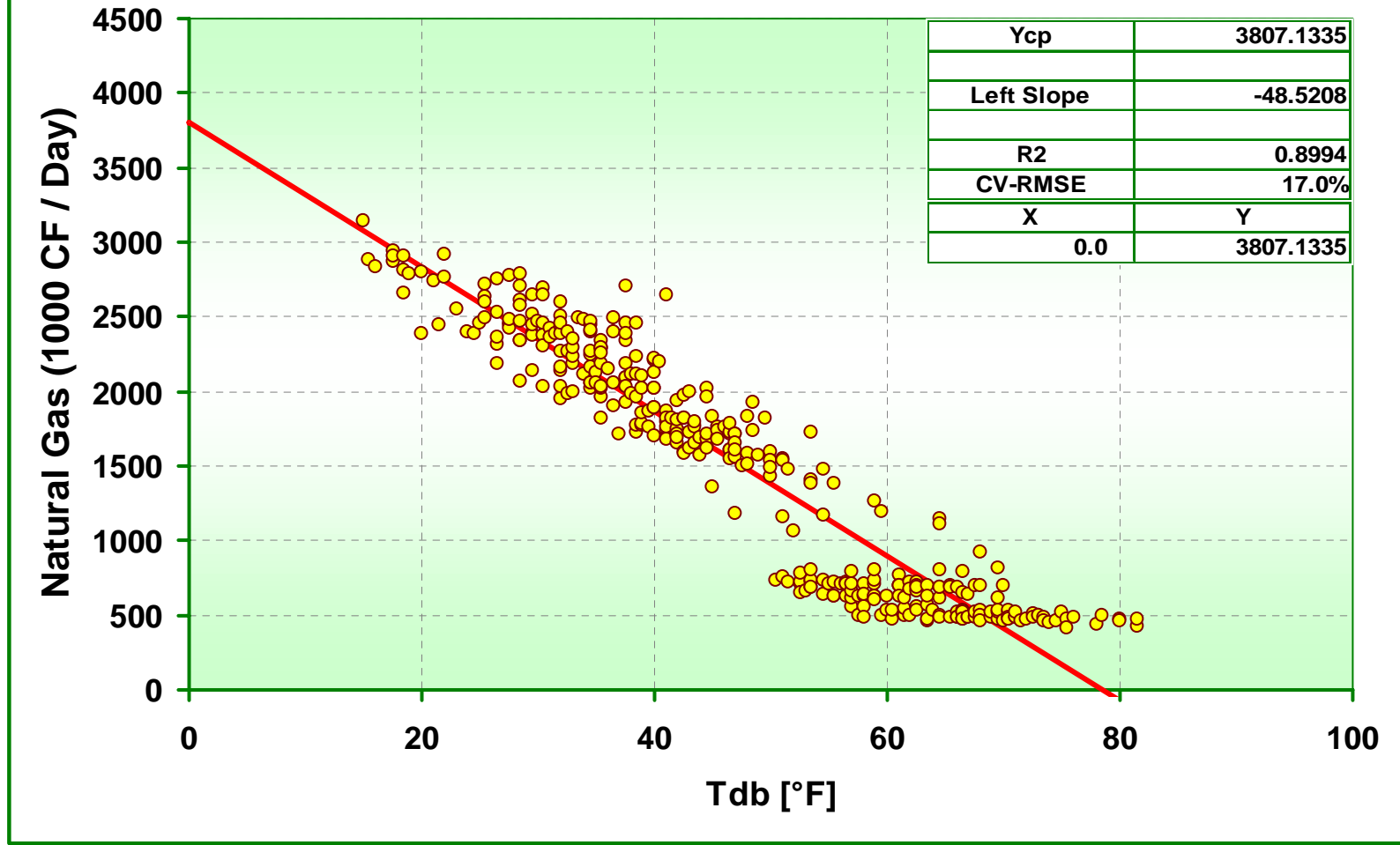
2, 3, 4 Parameter Analysis

- Analyze Mean Bias Error using weather from each year to verify fit
- Analyze using base year weather (Year 2000) to see expected variation
 - The base year weather will be used to weather normalize future years consumption
 - Year 2000 was selected as the base year
 - It is the most recent and it represented an average
 - If weather normalization is used
 - Errors in the range of $\pm 4.5\%$ will be seen between the base year and the other years with this data
 - If weather normalization is not used
 - Errors in the range of $\pm 11\%$ will be seen between the base year and the other years with this data



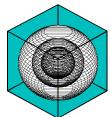
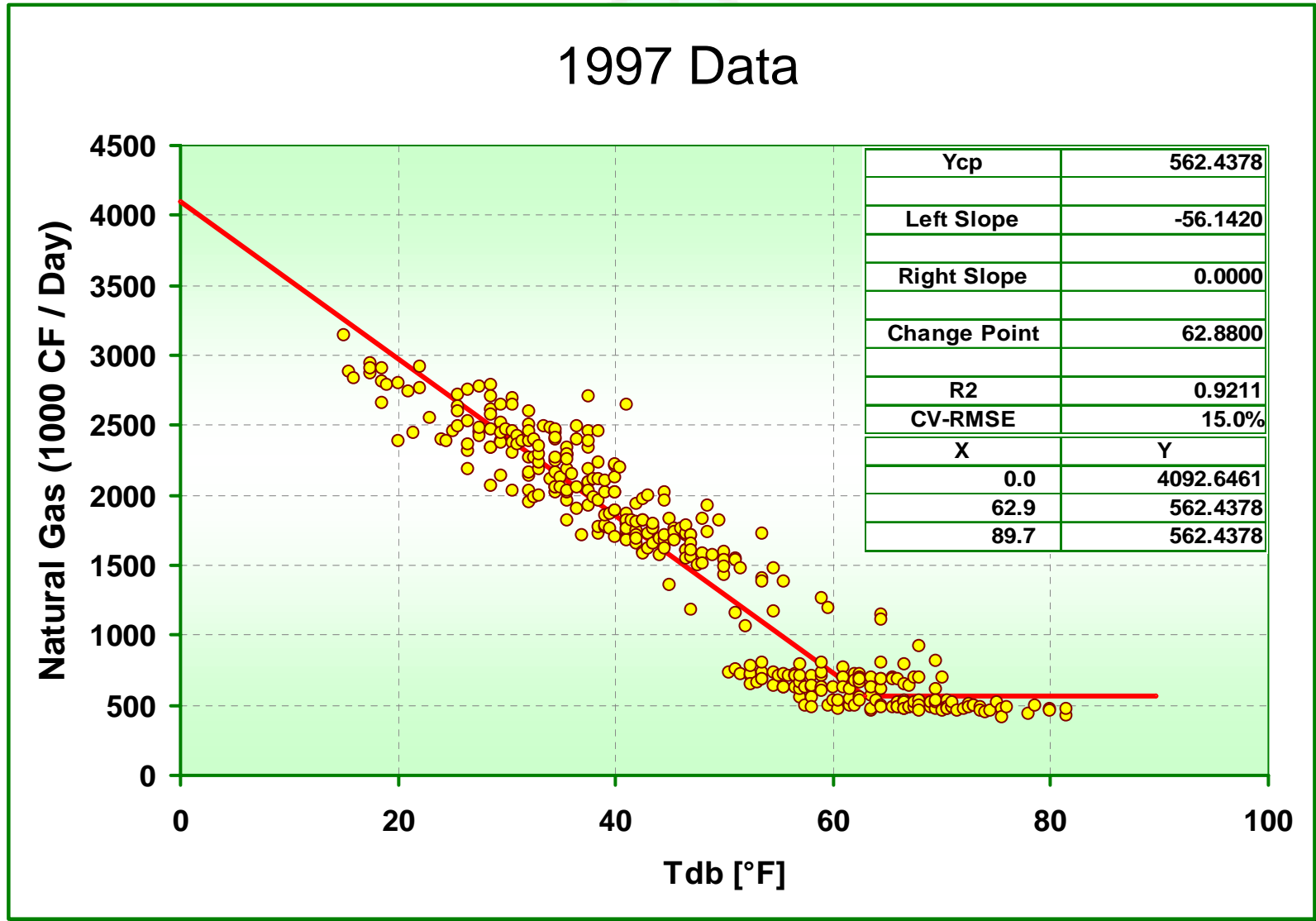
2 Parameter

1997 Data



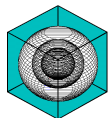
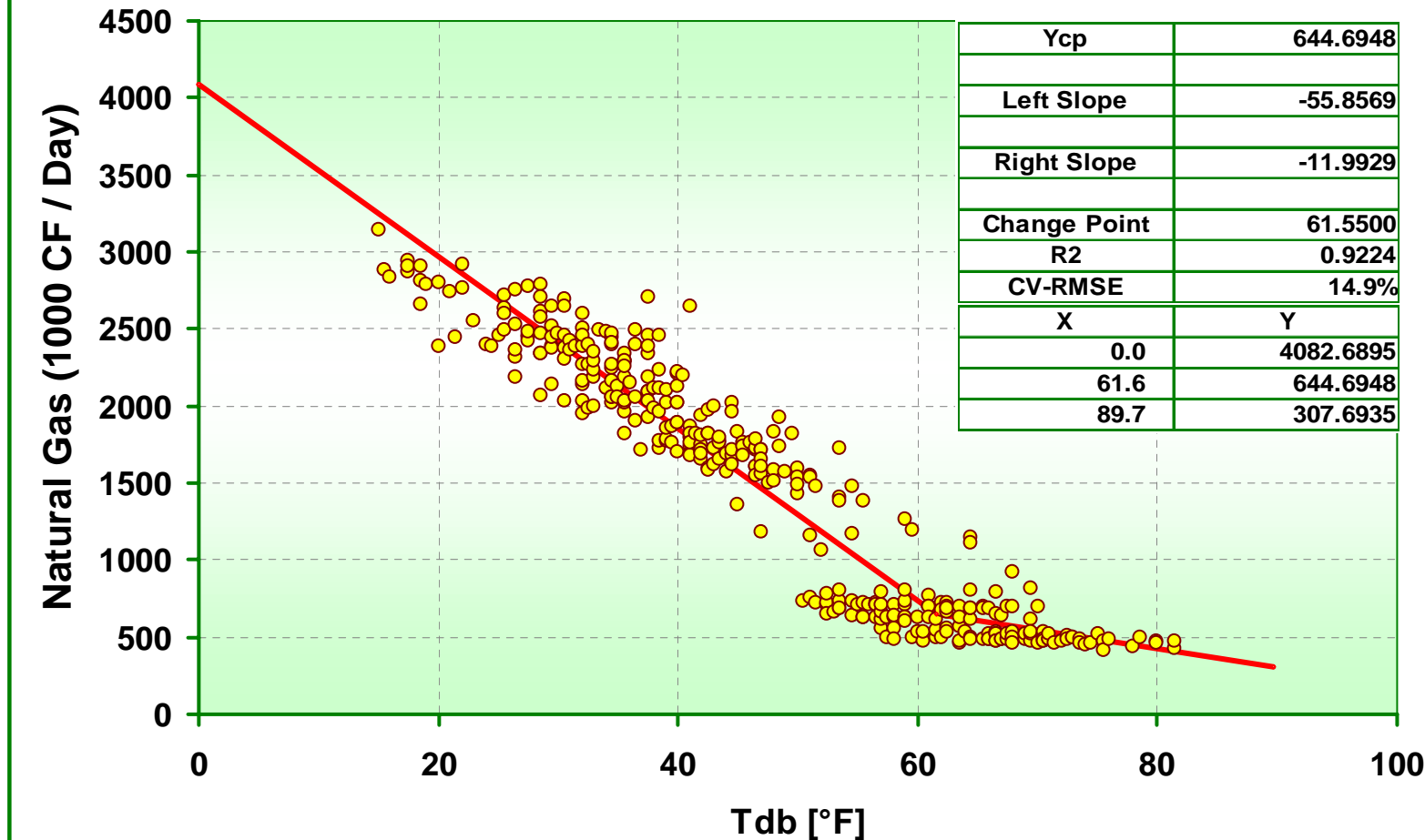
3 Parameter

1997 Data



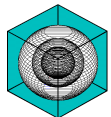
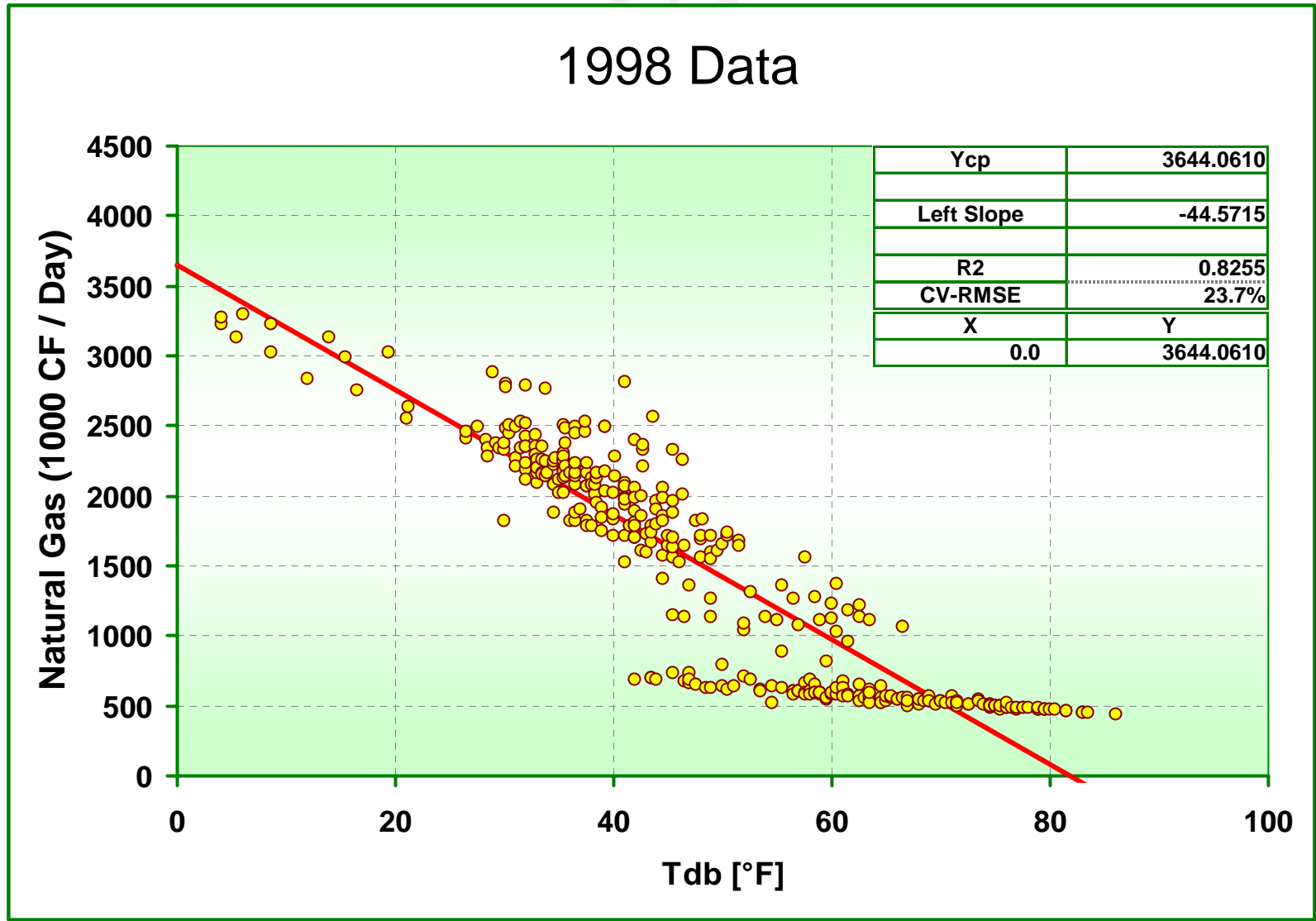
4 Parameter

1997 Data



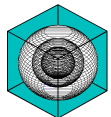
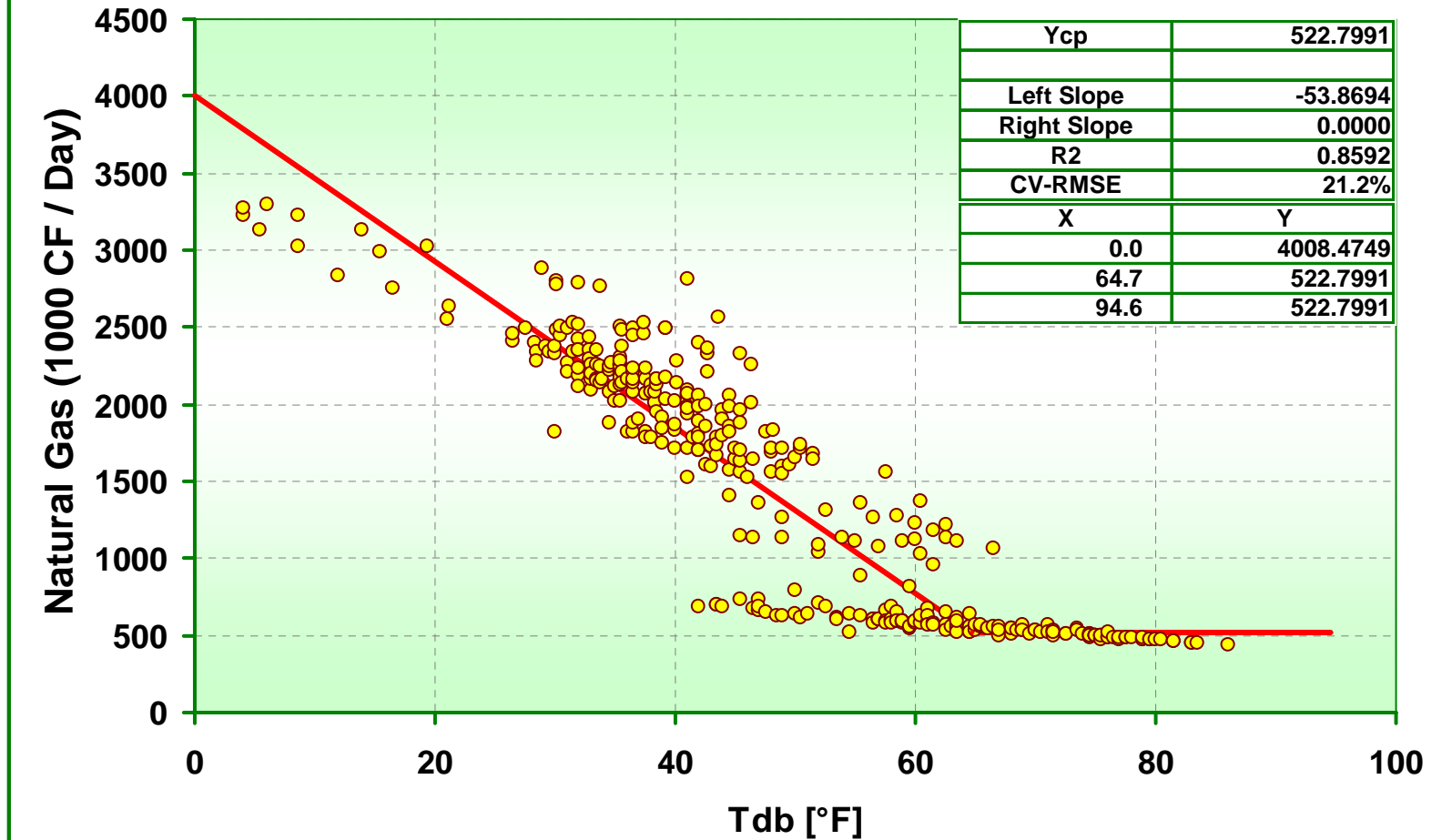
2 Parameter

1998 Data



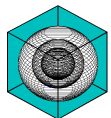
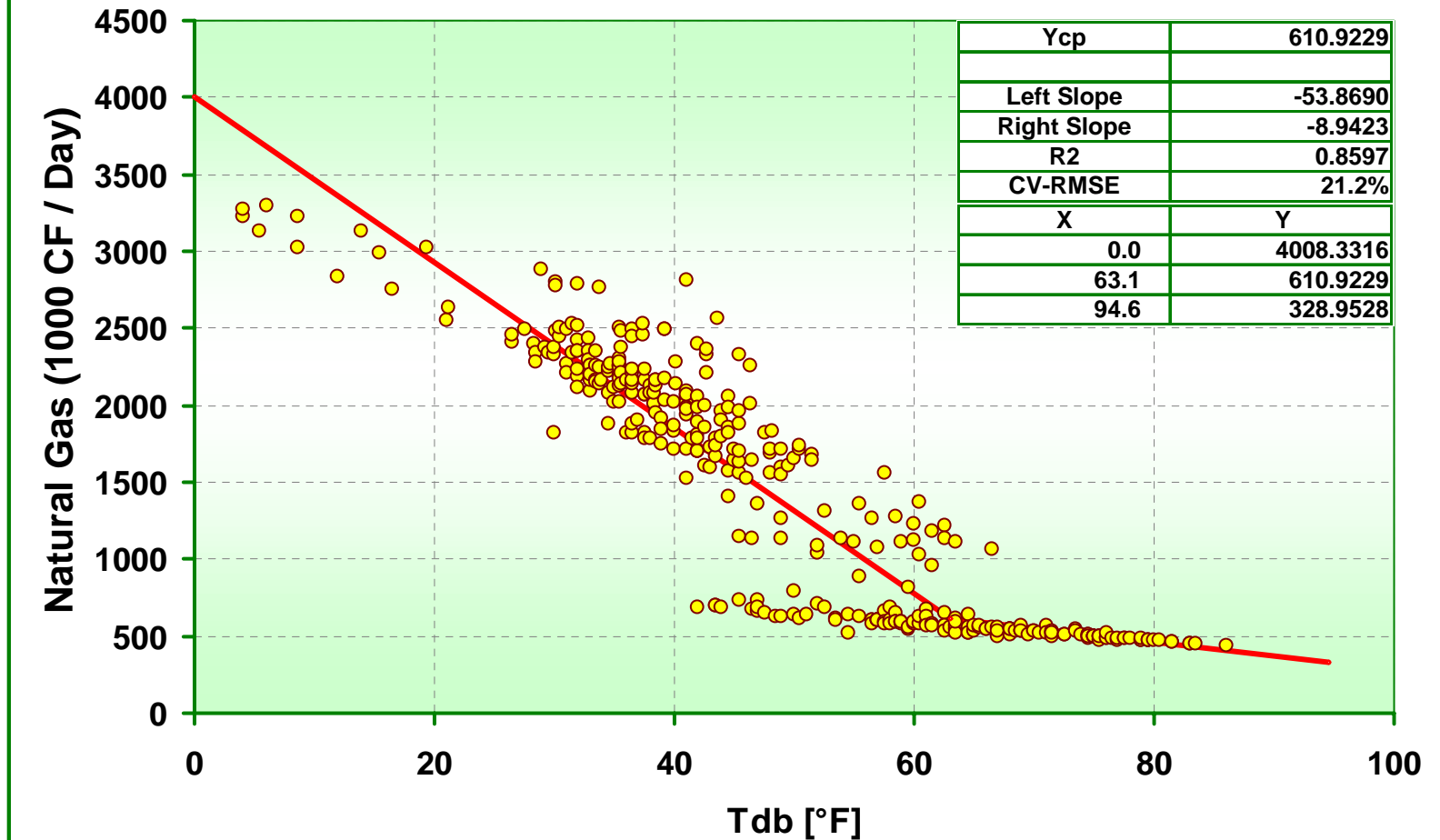
3 Parameter

1998 Data



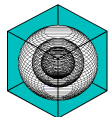
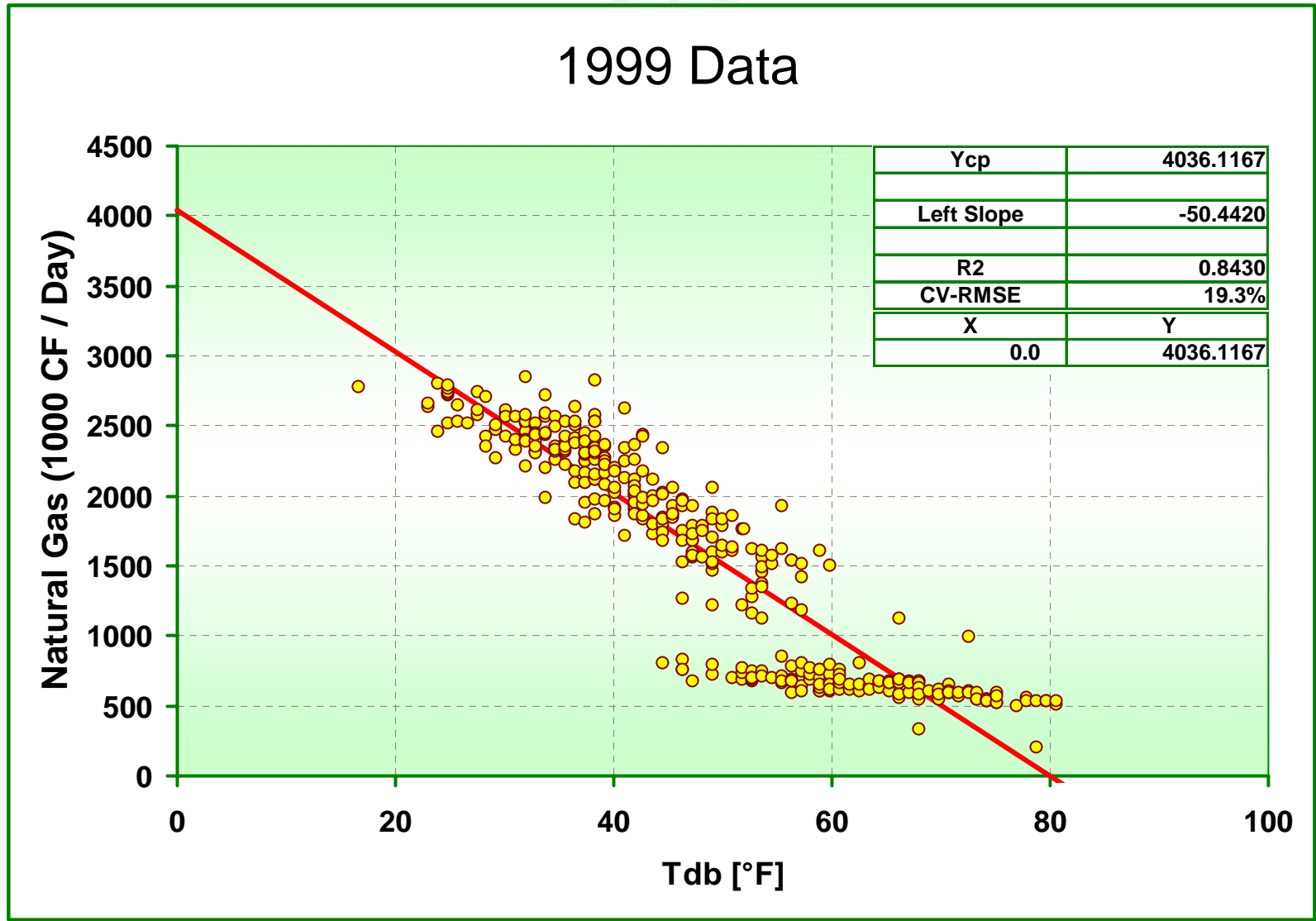
4 Parameter

1998 Data



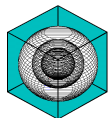
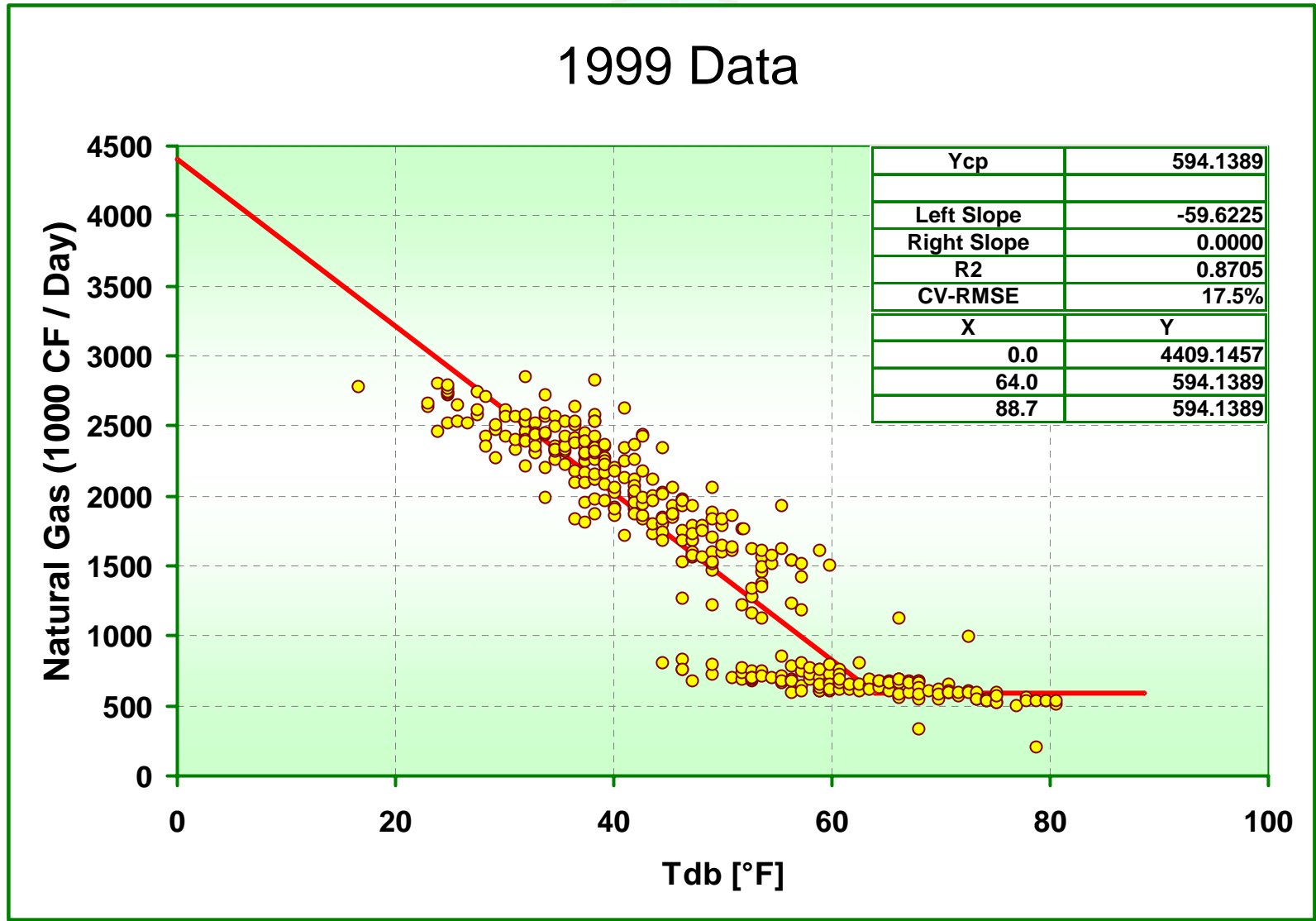
2 Parameter

1999 Data



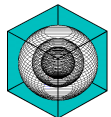
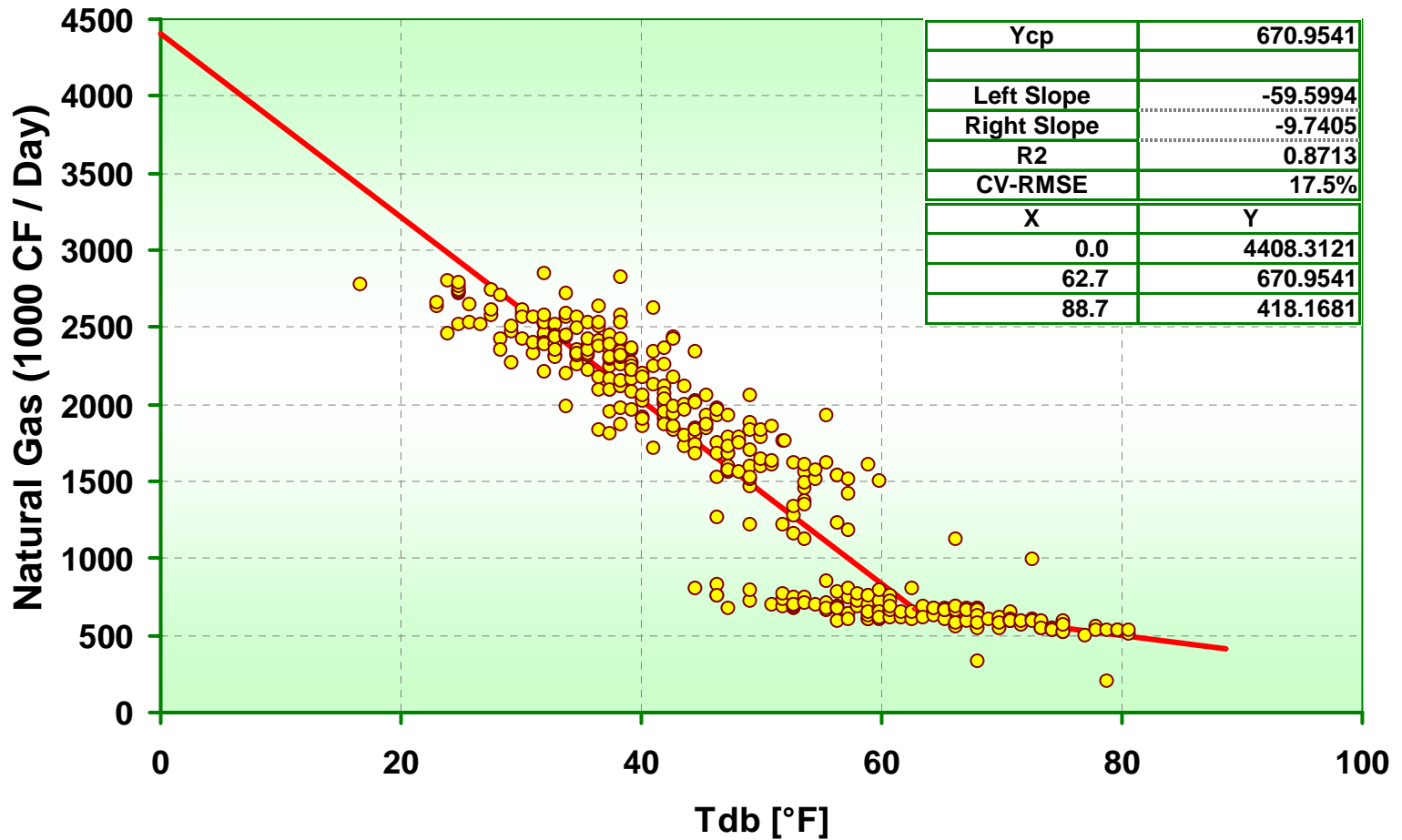
3 Parameter

1999 Data



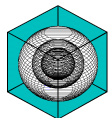
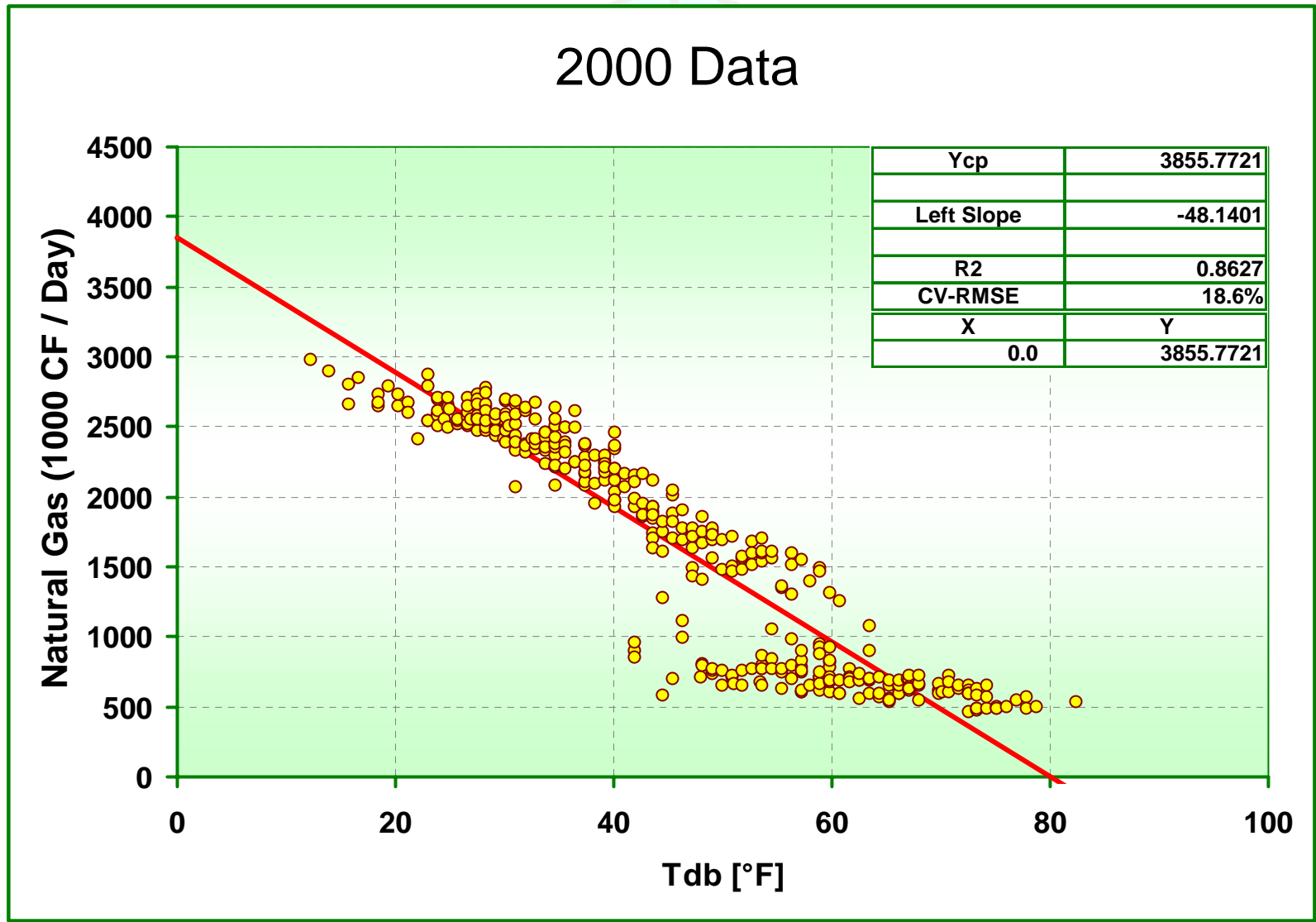
4 Parameter

1999 Data



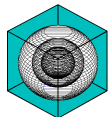
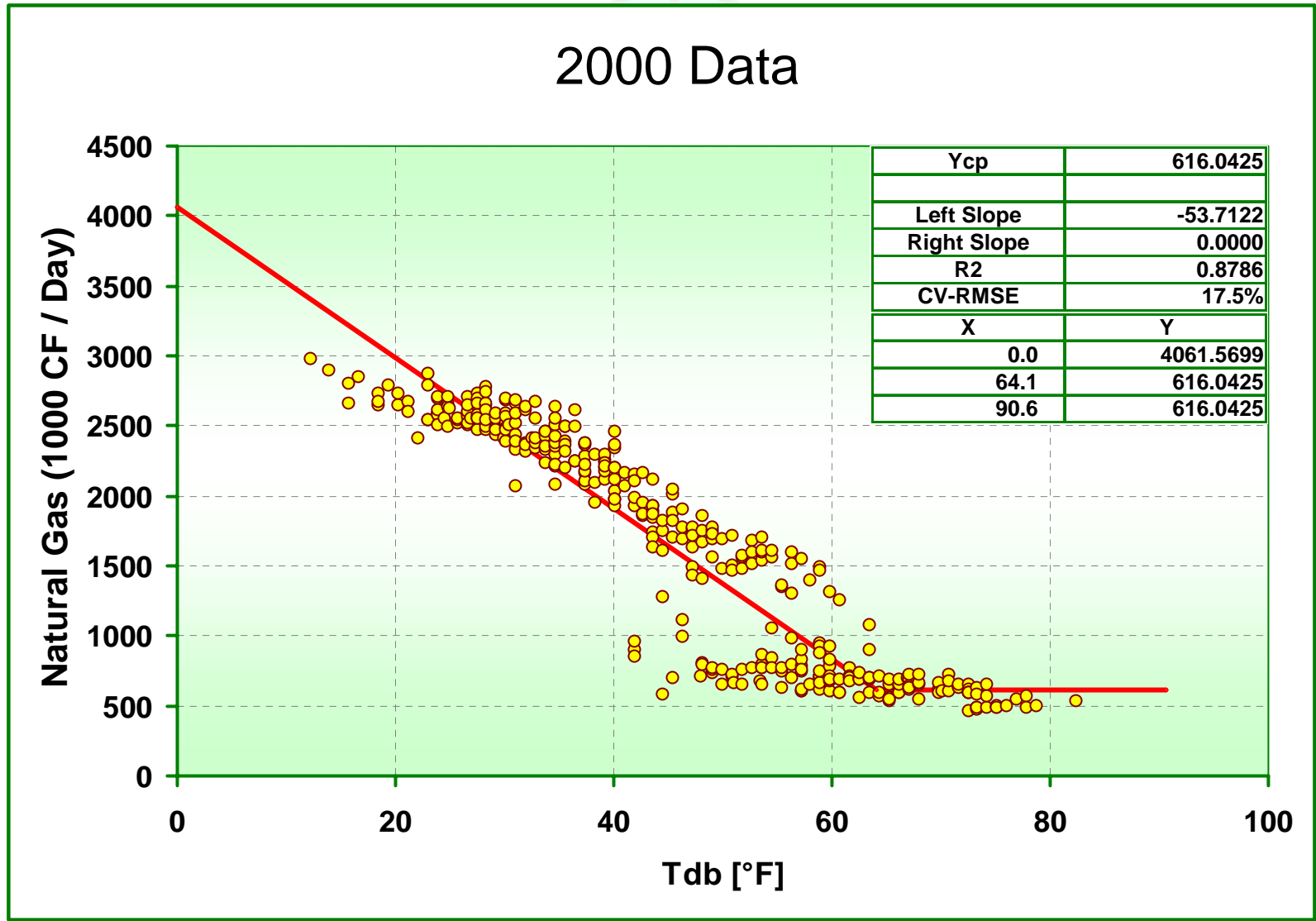
2 Parameter

2000 Data



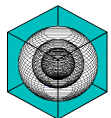
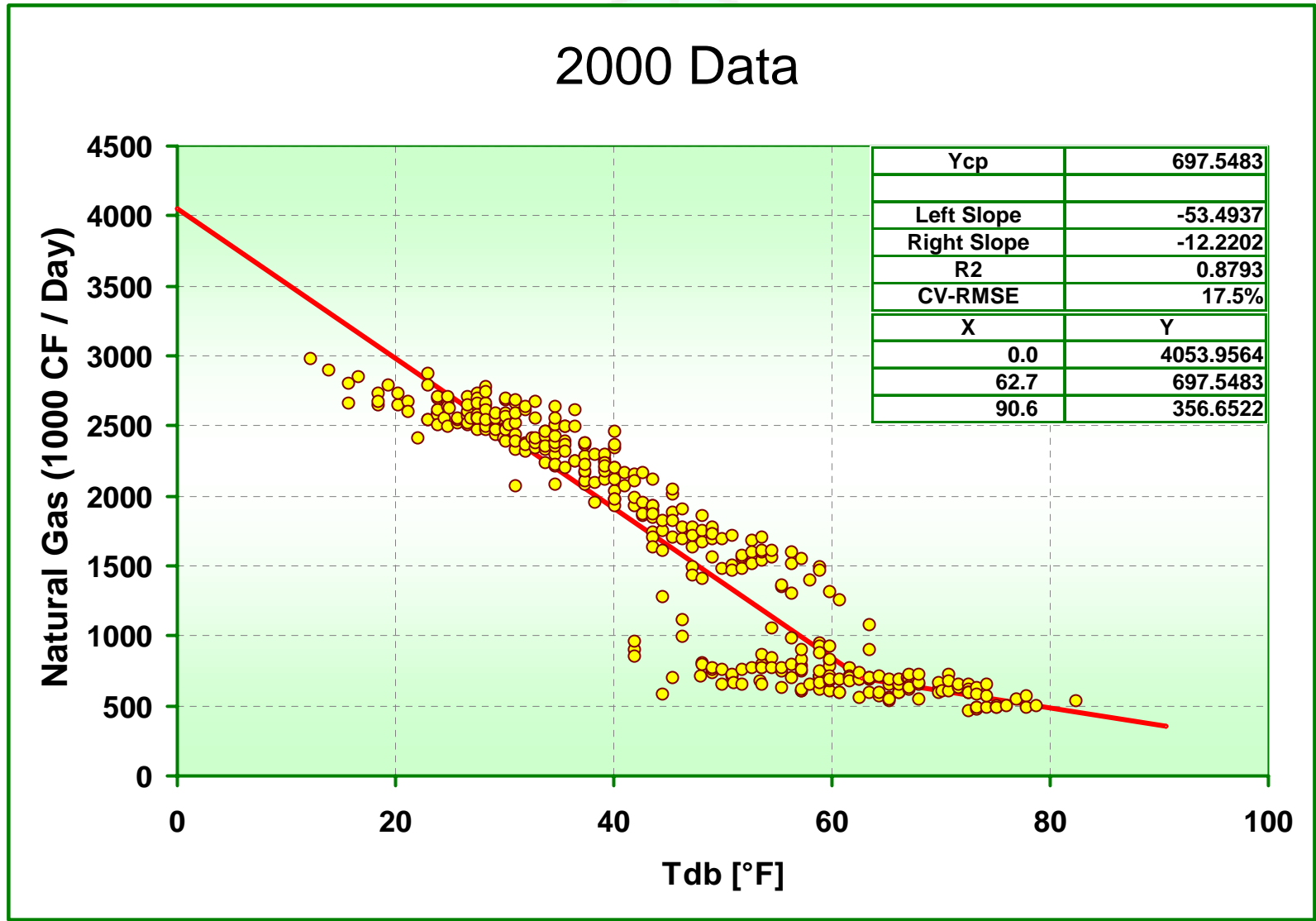
3 Parameter

2000 Data



4 Parameter

2000 Data



No Weather Normalization

- Daily Comparison Calculations

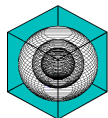
No Weather Normalization
or Data Correction

		Actual
Totals	1997	546,215
	1998	490,530
	1999	566,402
	2000	588,151
Errors	1997	7.13%
	1998	16.60%
	1999	3.70%
	2000	Datum

No Weather Normalization

		Actual
Totals	1997	546,215
	1998	523,565
	1999	578,576
	2000	593,635
Errors	1997	7.99%
	1998	11.80%
	1999	2.54%
	2000	Datum

$$\text{Error} = \frac{\text{Year 2000} - \text{YearYYYY}}{\text{Year 2000}}$$

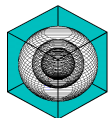


2, 3, 4 Parameter

- Daily Comparison Calculations (Using each years weather)
- Mean Bias Error is ~ 0

		Actual	2Parameter	3Parameter	4Parameter
Totals	1997	546,215	546,215	546,215	546,216
	1998	523,565	523,565	523,565	523,564
	1999	578,576	578,576	578,576	578,576
	2000	593,635	593,635	593,635	593,635
Errors	1997		0.00%	0.00%	0.00%
	1998		0.00%	0.00%	0.00%
	1999		0.00%	0.00%	0.00%
	2000		0.00%	0.00%	0.00%

$$\text{Error} = \frac{(\text{N Parameter} - \text{Actual})_{\text{YearY}}}{(\text{N Parameter})_{\text{YearY}}}$$

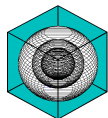


2, 3, 4 Parameter

- Daily Comparison Calculations (Using each years weather)
- Note Agreement Between Methods

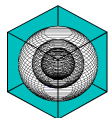
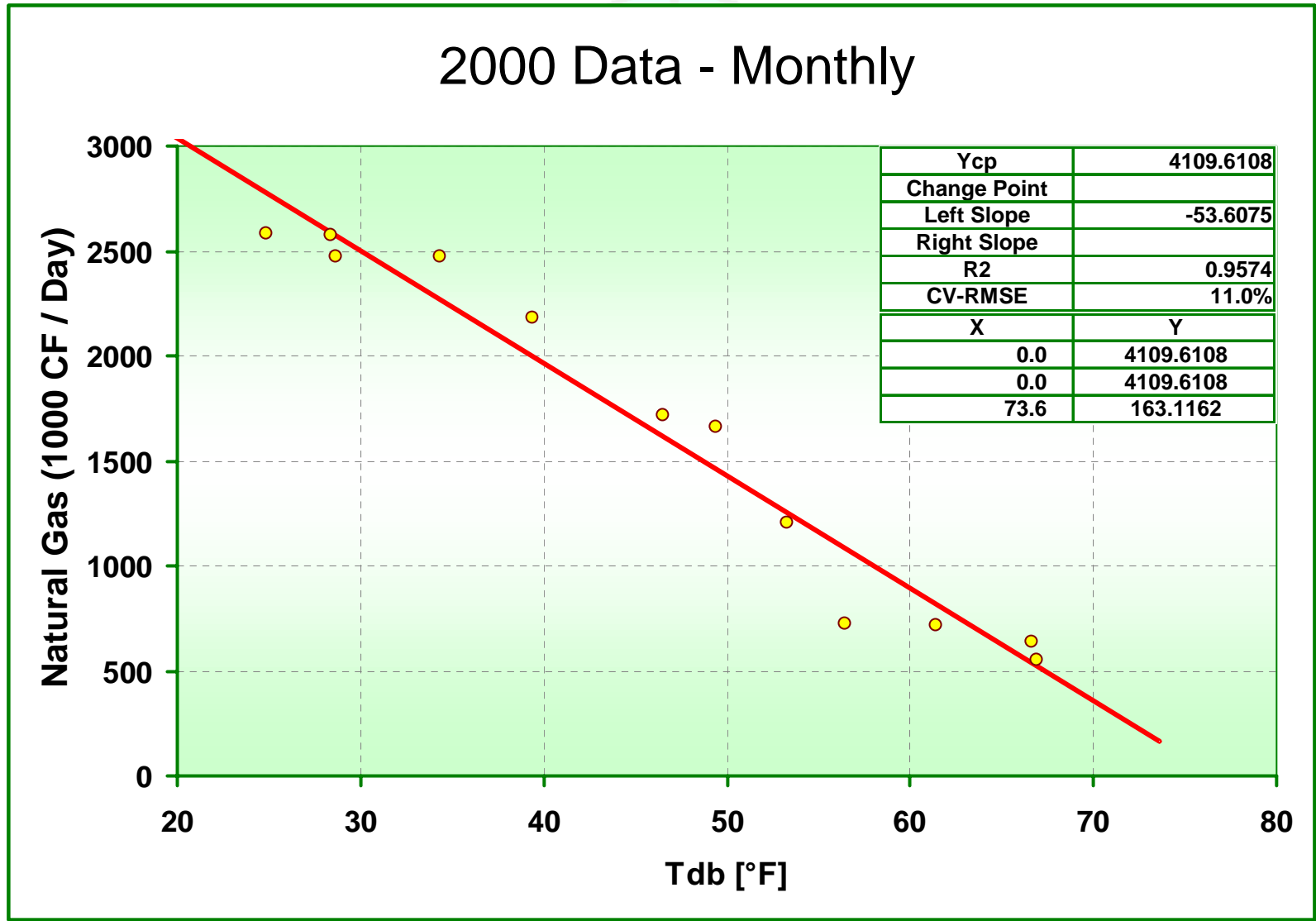
		Actual	2Parameter	3Parameter	4Parameter
Totals	1997	546,215	570,586	570,754	571,080
	1998	523,565	536,267	548,010	545,287
	1999	578,576	553,576	553,324	553,848
	2000	593,635	593,635	593,635	593,635
Errors	1997		4.27%	4.30%	4.35%
	1998		2.37%	4.46%	3.98%
	1999		-4.52%	-4.56%	-4.46%
	2000		0.00%	0.00%	0.00%

$$\text{Error} = \frac{(\text{N Parameter} - \text{Actual})_{\text{YearY}}}{(\text{N Parameter})_{\text{YearY}}}$$



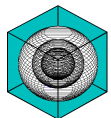
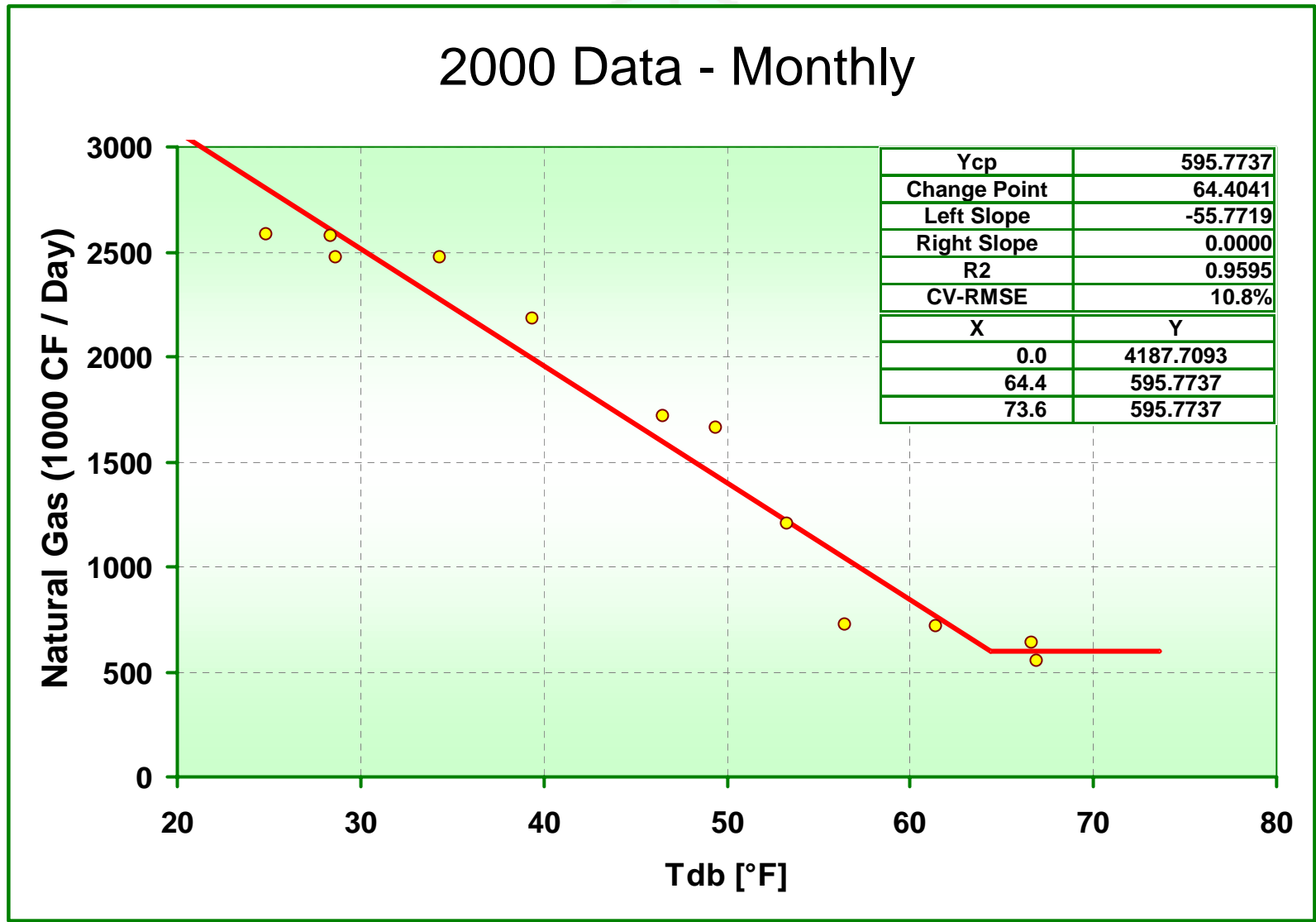
2 Parameter

2000 Data - Monthly



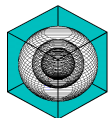
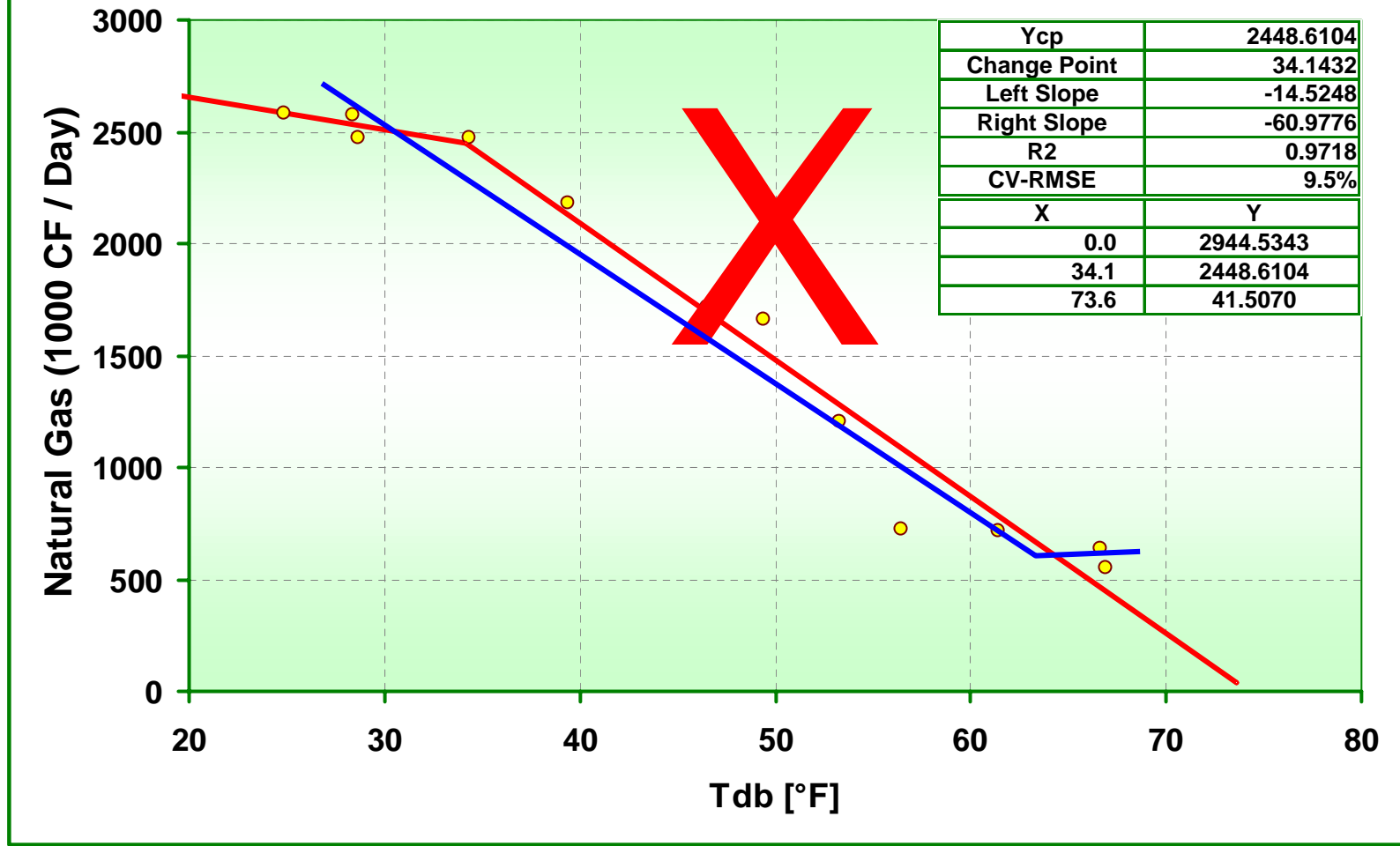
3 Parameter

2000 Data - Monthly



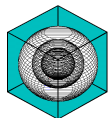
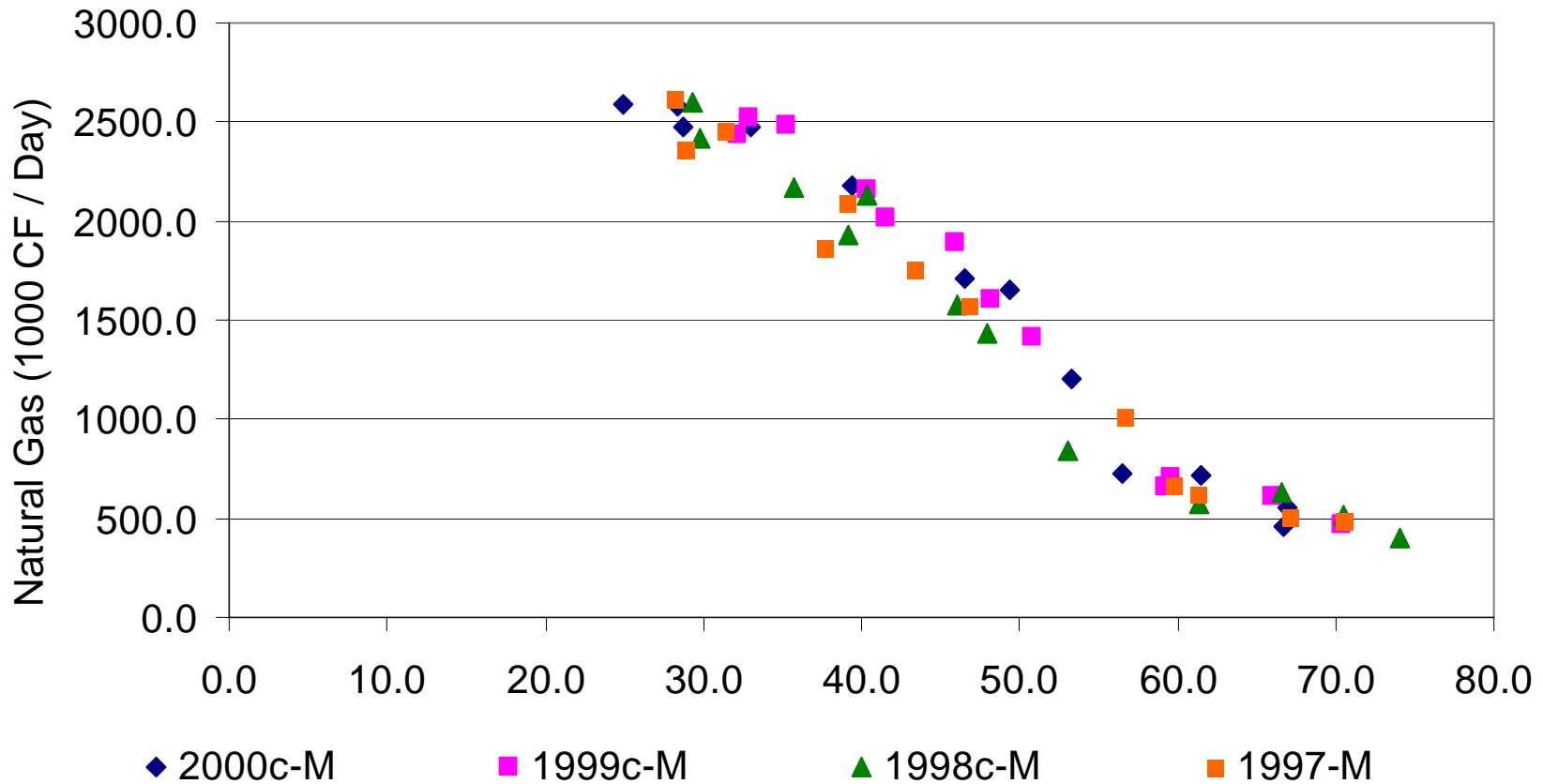
4 Parameter

2000 Data - Monthly



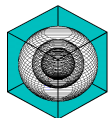
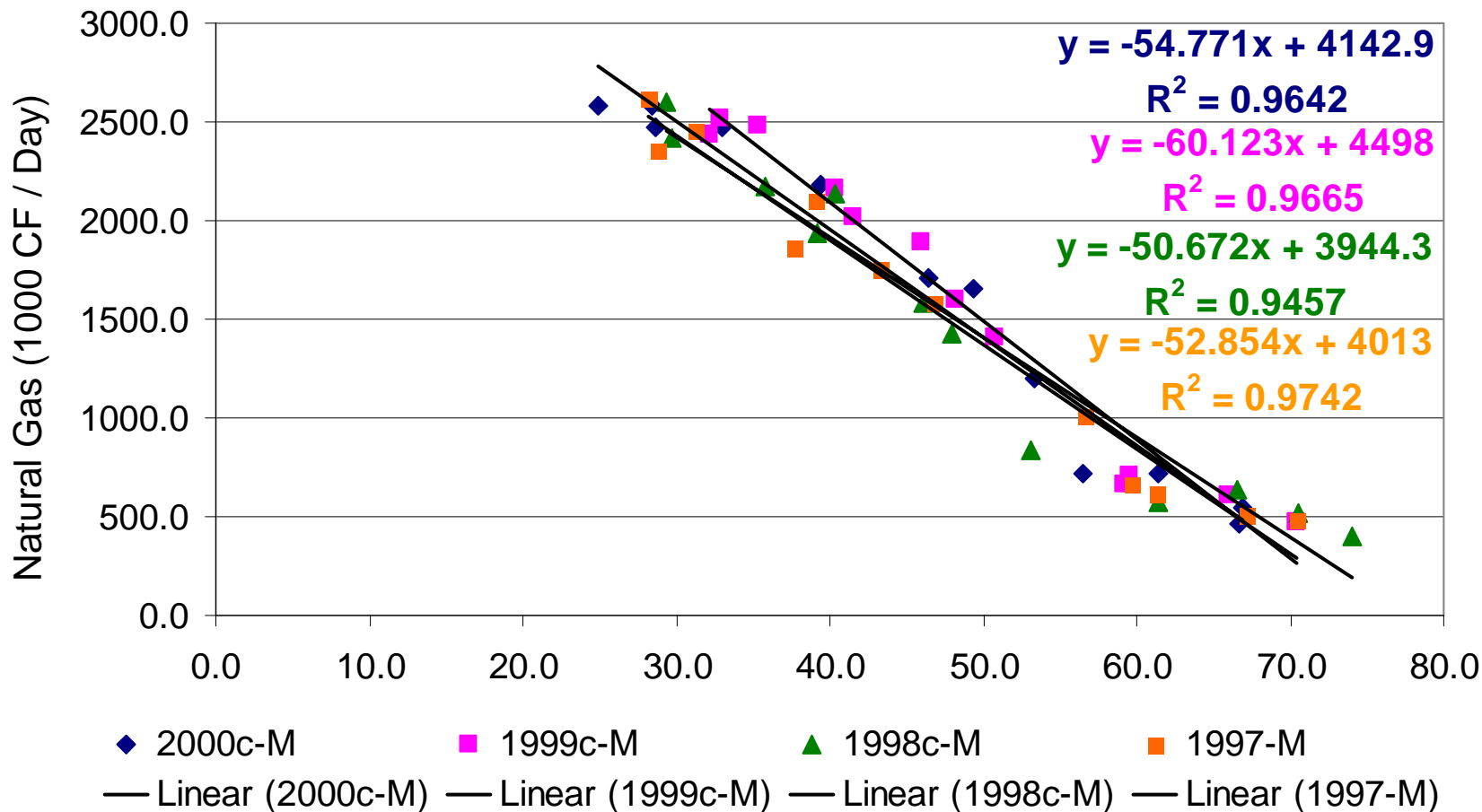
Monthly Data

Monthly Corrected



Monthly Data – 2 Parameter

Monthly Corrected

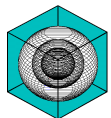


2, 3, 4 Parameter

- Comparison Calculations with Monthly Data (Using each years weather)

		Actual	2Parameter	3Parameter	4Parameter
Totals	1997	546,215	546,199	546,160	546,167
	1998	523,565	523,604	523,925	523,868
	1999	578,576	578,557	578,796	578,782
	2000	593,635	593,352	593,531	591,692
Errors	1997		0.00%	-0.01%	-0.01%
	1998		0.01%	0.07%	0.06%
	1999		0.00%	0.04%	0.04%
	2000		-0.05%	-0.02%	-0.33%

$$\text{Error} = \frac{(\text{N Parameter} - \text{Actual})_{\text{YearY}}}{(\text{N Parameter})_{\text{YearY}}}$$



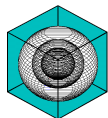
2, 3, 4 Parameter

- Consumption Calculations with Monthly Data (Using Y2000 Weather)

		Actual	2Parameter	3Parameter	4Parameter
Totals	1997	546,215	568,080	567,861	568,510
	1998	523,565	533,291	544,625	541,130
	1999	578,576	550,837	550,901	550,205
	2000	593,635	593,352	593,531	591,692
Errors	1997		3.85%	3.81%	3.92%
	1998		1.82%	3.87%	3.25%
	1999		-5.04%	-5.02%	-5.16%
	2000		-0.05%	-0.02%	-0.33%

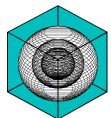
$$\text{Error} = \frac{(\text{N Parameter} - \text{Actual})_{\text{YearY}}}{(\text{N Parameter})_{\text{YearY}}}$$

Not A
Good Model



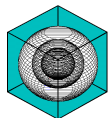
Baseline Equations

- The Final Daily Baseline Equations are:
- 2P **Baseline = -48.1401 * OAT + 3855.7721**
- 3P Baseline =if (OAT <64.148, (-53.7122 * OAT + 4061.5699)
else 616.0425)
- 4P Baseline =if (OAT <62.744, (-53.4937 * OAT + 4053.9564)
else (-12.2202*(OAT - 62.744) + 697.5483))



Summary

- Data exhibits about a 4% to 5% variability
 - Results show little difference in using 2-Parameter, 3-Parameter or 4-Parameter analysis
 - Lowering the resolution of the parameters, increases the bias errors.
 - Using xxx.x in the equations can result in about 0.1% bias error
- Results show that monthly data is as good as daily data
 - Daily data provides better agreement between the 2P, 3P and 4P methods
 - Note that the monthly data model for the Year 2000 – 4 Parameter is suspect



Summary

- $\pm 16\%$ Error Range Without Data Fill and Weather Normalization
- $\pm 12\%$ Error Range Without Weather Normalization
- $\pm 5\%$ Error Range With Fill and Weather Normalization
- Daily Analysis Slightly Better Than Monthly
- Chose **2-Parameter** for simplicity
- Chose **Daily Data Parameters** for slightly improved agreement in the analysis methods
 - Note on this monthly analysis, the “reading date” was known which may not be the case in the field

